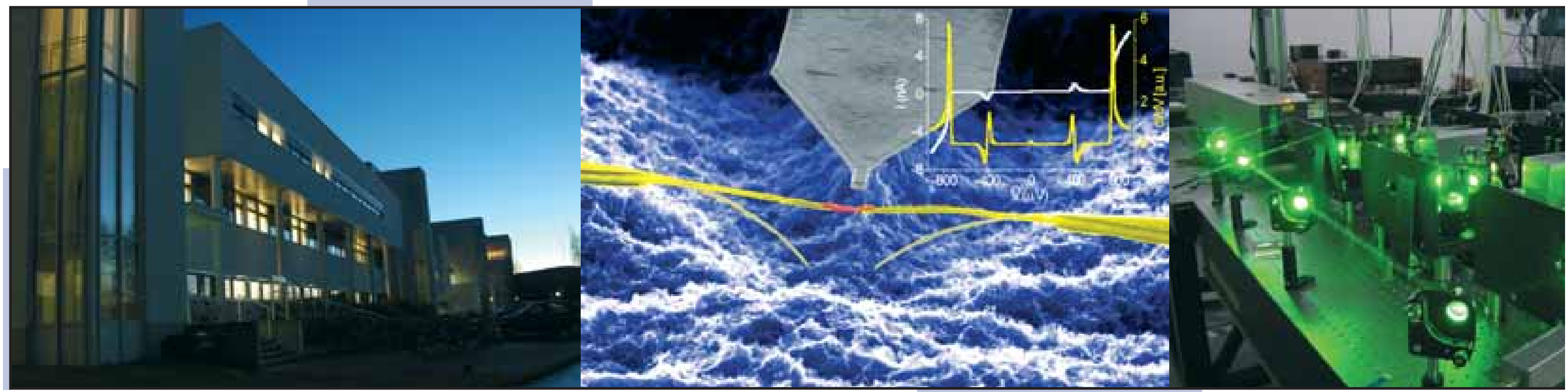
JYFL

DEPARTMENT OF PHYSICS • UNIVERSITY OF JYVÄSKYLÄ



2004 ANNUAL REPORT

DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

JYFL

annual report 2004

DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

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Contents

Department

Department of Physics

Matti Leino

The beginning of the year 2005 is a remarkably suitable moment for contemplating the past and the future of our Department. The last years have been a period of fairly rapid expansion both in breadth of research activities and in the number of staff members. This has not happened at the expense of quality. The very latest information concerning the productivity of research in Finland shows that the natural sciences at the University of Jyväskylä are ranked first among all the Finnish universities. Our Department is to a great degree responsible for this.

How is this fact reflected in our funding and what are our prospects concerning the future? To start on a positive note, in 2004, the Academy of Finland distributed funds for the purpose of developing the infrastructure in science. The total amount granted to our Department was about 1 M€, which was quite significant and allowed some crucial investments in for example nuclear physics and nanophysics research. The money coming through the University budget, however, has not increased during the past few years. This fact is presently causing some alarm, as it seems difficult to go on in 2005 with projects started in 2004, or even to keep the facilities running at normal level of activity.

The year 2004 was the first one when the new system for distributing the money within the university was effective. The main principle is that external funding is completely under the control of each department but rent (including e.g. electricity) as well as overheads used for funding the libraries etc. must be paid for by the department using partly budget funds and partly external funds. It seems that presently the system may be somewhat unfavourable for those departments with extensive external funding such as Physics. The system will be reviewed in 2006 when hopefully some corrections will be made but it would be important to keep the budget funding of our Department at an adequate level also during the intervening time.

In August 2004, and within schedule, the new Nanoscience Center (NSC) building was ready to accommodate some 35 physicists together with another 30 people from the Department of Biology and Environmental Sciences as well as from the Department of Chemistry. This made it somewhat easier for us to find office space in the main Physics building for the staff, which has increased from about 100 to almost 160 since the inauguration of the building in 1996. The NSC inauguration ceremony took place on the 19th of October.

The NSC building will have facilities such as clean rooms and measurement laboratories. The Nanophysics and Nanoelectronics laboratories have electrically shielded measurement rooms for extreme low signal measurements. The Cryolaboratories have electrically shielded rooms equipped for cryogenic measurements at low temperatures. NSC has also special laboratories such as the AFM microscopy laboratory and the nanoelectronics laboratory.

Extra funding was provided via our faculty for the start-up of the operations in 2004-5 but it is presently not clear how the funding will be organised in the following years. The employees in the Nanoscience building remain staff members of the corresponding Departments. To deal with those scientific and administrative questions not under the control of the individual Departments, a steering committee has been set up. The committee was chaired in 2004 by Prof. Päivi Törmä from the Physics Department.

Three inauguration lectures were given last year. Professor Päivi Törmä moved from a temporary to a permanent position. Her field is nanoelectronics. She joined our staff already in 2001. Markus Ahlskog moved to Jyväskylä from the Helsinki University of Technology. His field is nanophysics with emphasis on for example nanotubes. Professor Harry Whitlow's chair is in Materials Physics applications using accelerator-based methods in nanomaterials technology. Prior to Jyväskylä, he held positions in Malmö and Uppsala, Sweden.

Two staff members with a long career in Jyväskylä behind them retired in 2004. Lecturer Seppo Sohlo was for many years responsible for teaching several Physics courses, mainly in theory. Laboratory technician Alpo Lyhty, head of our mechanical workshop, was with us since 1969 and was known for a very high level of quality in his work.

A special event took place during June 17-18, 2004 when the 10+30 Anniversary symposium on Cyclotron Research at JYFL was held. This coincided with the meeting of NuPECC in Jyväskylä. Talks were given on the history and the present of the Accelerator Laboratory by Dr. Jonathan Billowes, Prof. Peter Butler, Prof. Gottfried Münzenberg, Dr. Jaana Kumpulainen, Dr. Reno Harboe-Sørensen, and Prof. Juha Äystö. Prof. Muhsin Harakeh reviewed the prospects of Nuclear Physics research on the basis of the NuPECC Long Range Plan. Greetings from the University and from the City of Jyväskylä were heard from Rector Aino Sallinen and from acting Mayor of Jyväskylä, Mr. Olli Heikkilä, respectively.

The Nanoscience Center organised its first major international event, a workshop entitled "Electronic structure simulations of nanostructures" (ESSN-2004) June 18-21. The scope of the workshop was to explore the current status of the research in the area of electronic structure simulations of nanoclusters, nanoparticles and nanostructures in various fields of physics, chemistry and biology.

ESSN-2004 gathered about 70 participants from 17 countries, including several leading experimentalists and theorists working in cross-disciplinary fields in chemistry and physics.

Teaching

In teaching the year was moderately successful. The numbers of MSc and PhD degrees awarded in physics were 40 and 8, respectively. The Department started its second year as one of the high-quality education units in Finland. JYFL participates in several national graduate schools and coordinates the Graduate School in Particle and Nuclear Physics. Four foreign students from three to twelve months visited the Accelerator Laboratory under the programme of a Marie Curie Host Training Site. The importance of developing and improving the quality of teaching is fully recognised and more resources have been devoted to this area.

The employment rate of the newly graduated students has been very good. According to a survey done by the Department, the employment among the graduates of the years 2000-2004 is 98% being the same as in our earlier survey of the years 1995-1999.

Some statistical data in 2004

Personnel	155	(58)
- professors	12	(11)
- lecturers	4	(4)
- senior assistants	9	(8)
- assistants	4	(5)
- researchers and research assistants	97	(5)
- technicians	25	(21)
- administration	4	(4)

( ) = permanent posts

Undergraduate students	570
of which new students	95
Graduate students	60
MSc degrees	40
PhD degrees	8
Credits (national)	7109
Median time to complete MSc (years)	5,3
Number of foreign visitors	~270
- in visits	~360
Visits abroad	~210
Peer reviewed publications	132
Invited talks	42
Other talks	75
Posters	78
Funding (million €)	11,1
* University budget (incl. premises)	5,9
* External funding	5,2
- Academy of Finland	2,7
- Technology Development Centre	0,2
- International programmes	1,0
- HIP, HUT etc.	0,5
- Contract research	0,5
- Others	0,3

Research

The year 2004 was for most of the department the fifth year as the Finnish Centre of Excellence in Nuclear and Materials Physics. The Accelerator Laboratory continued as an EU Major Research Infrastructure in the EU-FP5-IHP programme. From January 2005, it will have a similar status within the EU-FP6-I3-Infrastructure project EURONS. JYFL groups participate in about 15 international research projects, in three of them as a coordinator. The Department was very successfully evaluated in the second application process for the Finnish Centres of Excellence.

In 2004, the total operating time of the JYFL cyclotron was again nearly 7000 hours. A total of 2400 hours of beam time were devoted to the second joint-European JUROGAM campaign. The JUROGAM array combined with the RITU separator and the GREAT focal plane spectrometer forms the most efficient spectrometer system in the world for structure studies of exotic heavy nuclei. The IGISOL upgrade was completed by installing a new dipole magnet from GSI and a new laser system FURIOS to be used for selective ionization of rare isotopes. The JYFLTRAP facility at IGISOL was used to measure masses of nearly 30 neutron-rich isotopes from fission.

In the semiconductor industry and nanotechnology there is an increasing interest in the use of ion beams. The goal of accelerator based applied research is to improve the understanding of mechanisms in ion beam modification of materials and microelectronics. These studies have direct impact on the development of radiation hard components and solar cells, e.g. for space technology, and on new processing methods for micro- and nanotechnology. A new contract with ESA, concerning the upgrade and utilisation of the RADEF

irradiation station for SEE tests with protons and heavy ions, has been signed.

The JYFL activities in the CERN-ALICE and CERN-ISOLDE projects are carried out within the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP). The theoretical research on ultrarelativistic heavy ion collisions at JYFL is a part of the Theoretical Physics Programme of HIP.

In nuclear theory the main activity has been directed towards calculation of nuclear matrix elements in the context of neutrino and dark-matter physics. In this way one can use the atomic nuclei as test laboratories of the absolute mass scale of the neutrinos, their fundamental properties and the composition of the cold dark matter of the Universe.

In nanophysics and nanotechnology, the research focuses on experiments and theory of the electronic and thermal properties of micron and submicron size structures. Thermal properties of insulating nanostructures and the coupling between electronic and lattice (phonons) degrees of freedom is one key field, as is one-dimensional superconductivity. Quantum coherence in small Josephson junctions is investigated for finding out whether these systems can be used as elements of a quantum computer. Recently, the physical properties of single carbon nanotubes have become a focus of interest.

In nanoelectronics and nanotechnology, the focus is on multidisciplinary nanoscience projects, for instance research on electrical conductivity and nanoscale manipulation of macromolecules such as DNA. Nanosensors are developed in collaboration with industry and other groups at the Nanoscience Center. The theory research focuses on ultracold atomic Fermi gases; in 2004, a significant contribution was made to interpreting breakthrough observations of the superfluid pairing gap in these gases.

Research in soft condensed matter and statistical physics deals with problems like fracture of brittle materials, fluid flow in porous structures, dynamics of liquid-particle suspensions, properties of stochastic systems and applications in areas like bone research and paper technology. This research includes experiments as well as extensive ab initio numerical simulations. Recently much effort has been given to modern tomographic methods for gaining accurate structural information in three dimensions.

Theory of atomic clusters and semiconductor nanostructures is studied in collaboration with the experimental research groups in nanotechnology. The main research areas are electronic and magnetic properties of metal clusters on surfaces, catalytic reactions on clusters, and many-particle physics of quantum dots and nanowires.

The research in theoretical high energy physics is carried out in two interconnected groups. In the group for ultrarelativistic heavy ion collisions, the topics studied range from applications of perturbative QCD and hydrodynamics in nuclear collisions to effective field theories for understanding the properties of QCD matter. In the group for theoretical particle physics and cosmology, the focus is in neutrino astrophysics, the phenomenology of the minimal supersymmetric extension of the Standard Model, baryogenesis, and the cosmological problem of dark matter and dark energy, particularly the quintessence hypothesis.

Excellence

Center of Excellence in Nuclear and Condensed Matter Physics

Juha Äystö

The Centre of Excellence in Nuclear and Condensed Matter Physics carries out research on several subject areas which form a compact programme focusing on different aspects of the basic structure of matter and its constituents. About 80 % of the research effort of the Department of Physics (JYFL) is funded under the CoE contract. The present funding period extends until the end of 2005.

One part of research comprises of nuclear physics where the experimental part is carried out at the JYFL Accelerator Laboratory. The second part consists of applied research accompanied by a research programme on accelerator-based materials physics and industrial applications. The third part concerns condensed matter physics where the experimental part is mainly carried out at the JYFL Laboratory for Nanotechnology. More detailed descriptions of recent scientific activities of the CoE are given in appropriate sections of this annual report.

In general, the programme proposed originally for the CoE has been realized in an excellent way. This is true both for the quality of the scientific output as well as for the statistics on publication activities and education of young scientists. In 2004 the number of refereed publications was 117 and the number of invited talks in international conferences was 41. The graduate and undergraduate students of the CoE form an important fraction of its work force. This is exemplified by 8 PhD degrees awarded in 2004.

The CoE has had an important impact on the improved situation for new post doctoral fellow and graduate student recruiting at the Physics Department. The most important benefit from the CoE funding programme has been its long-term duration allowing for concentration on actual work as well as for making possible easier opening of new projects and areas of research.

Research areas and project leaders

Nuclear physics and particle accelerators
(Prof. Rauno Julin, Prof. Matti Leino, Doc. Pauli Heikkinen, Prof. Jouni Suhonen, Prof. Juha Äystö)

Accelerator based materials physics and industrial applications
(Prof. Harry J. Whitlow and Doc. Ari Virtanen)

Condensed matter physics and nanotechnology
(Prof. Markus Ahlskog, Prof. Matti Manninen, Prof. Jussi Timonen)

Scientific Board of the Centre of Excellence at JYFL
(2004 annual meeting was held on 29th April)

Niels E. Christensen, professor (chairman), University of Århus
Paul Kienle, professor, Technical University of Munich
Timo Tiihonen, vice-rector, University of Jyväskylä
Kari Rissanen, professor, Academy of Finland
Anu Huovinen, secretary general, Academy of Finland

Research

Nuclear and accelerator based physics

Summary of the Accelerator Laboratory activities

Rauno Julin

In 2004, the total operating time of the cyclotron was 6997 hours, beam being on the target for a total of 5744 hours. A total of 37 scheduled experiments were performed and the number of foreign collaborators visiting the laboratory was 169.

In order to deliver higher beam intensities and heavier ion beams from the cyclotron, a new modified plasma chamber for the 6.4 GHz ECRIS was designed and constructed. Following the development of a new instrument for plasma potential measurements, new research was carried out and interesting information obtained concerning the behaviour of the plasma and formation of the beam in the ECR ion source.

The IGISOL upgrade was completed with the installation of a new dipole magnet from GSI and the new laser system FURIOS to be used for selective ionization of rare isotopes. The JYFLTRAP facility at IGISOL was used to measure masses of nearly 30 neutron-rich isotopes produced through fission. A series of experiments conducted at IGISOL and ISOLDE have led to a revision of the knowledge on the excited states of the ^{12}C nucleus relevant for the triple-alpha process leading to the formation of carbon in stars. This work has been published in Nature.

Along with development work for the CERN-ALICE project at JYFL, experiments at the CERN-ISOLDE facilities have been carried out as a part of the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP).

A total of 100 days of beam time were devoted to the tagging experiments of the second JUROGAM campaign carried out in collaboration between the JYFL gamma- and RITU groups and groups from a number of foreign institutes. The JUROGAM+RITU+GREAT facility now forms the most efficient spectrometer system in the world for structure studies of heavy proton drip-line nuclei and transfermium nuclei. A total of 11 experiments were performed, including the first plunger lifetime measurements using the Recoil-Decay Tagging technique.

A new contract has been signed with the European Space Agency (ESA), concerning the upgrade and utilisation of the RADEF irradiation station. To obtain higher energy heavy ions for the space electronics tests, the 14 GHz ECR ion source was equipped with a new TWT Amplifier. Both heavy ion and proton tests can now be performed at the new RADEF beam line.

The research in the JYFL Accelerator Laboratory is a part of the Centre of Excellence in Nuclear and Materials Physics programme of JYFL. Until the end of January 2004 the JYFL accelerator operated as one of the European Research Infrastructures in the IHP programme of the EU. The JYFL Accelerator Laboratory is a partner of the FINUPHY activity of the IHP Infrastructures task and coordinates the IHP-RTD project EXOTAG.

A new Integrated Infrastructure Initiative for Nuclear Structure Physics (EURONS) in the 6th framework programme of the EU commences on January 1, 2005. In

NuPECC board in Jyväskylä on June 18, 2004

addition to the Transnational Access Activity (TNA) of EURONS, the JYFL Accelerator Laboratory will be a partner in 6 different Join Research Activities (JRA) of EURONS. They are: INTAG for further development of tagging methods, AGATA for development of a gamma-ray tracking array, DLEP for low-energy particle detection, ISIBHI for development of an advanced ECR ion source, LASER for development of resonance ionisation laser ion sources and TRAPSPEC for development of spectroscopic methods at ion traps.

JYFL coordinates the National Graduate School in Particle and Nuclear Physics (GRASPANP) and the Accelerator Laboratory has the status of a Marie Curie Host Training Site of the EU.

Harry J. Whitlow was appointed as professor of materials physics from 1 August 2004. He will direct his activities towards the application of accelerator methods in nanomaterials technology.

An Anniversary Symposium to celebrate 10 years of operation of the new Accelerator Laboratory and 30 years of cyclotron physics in Jyväskylä was held on June 18, 2004. The celebration was honoured by the presence of NuPECC that held its 50th board meeting in Jyväskylä.

Research

Accelerator facilities

Pauli Heikkinen and Hannu Koivisto

By the end of 2004 the cyclotron has been operated for over 71 000 hours since 1992. In 2004 the total operating time was 6 997 hours, out of which the beam-on-target time was 5 744 hours. The rest of the total time consisted of stand by time due to the user, beam tuning and developing. The maintenance period was somewhat longer than usual due to extensive maintenance and upgrading work of the water-cooling system. New pumps were installed and the water circuit was connected to the heating of the new parking hall, which is a part of the newly finished nanoscience building.

Proton is still the most used ion, and it counts for almost 40% of the total. The beam was mostly used for ^{123}I production and for proton induced fission at IGISOL. The second most used beam was ^{83}Kr (10 %). Beam cocktails for radiation defects measurements (space electronics) used 8 % of the beam time. Altogether 27 different isotopes from protons to ^{132}Xe were accelerated for experiments and applications in 2004.

During 2004 a new modified plasma chamber for the 6.4 GHz ECRIS was designed and built. Due to the stronger hexapole field the performance of the source is expected

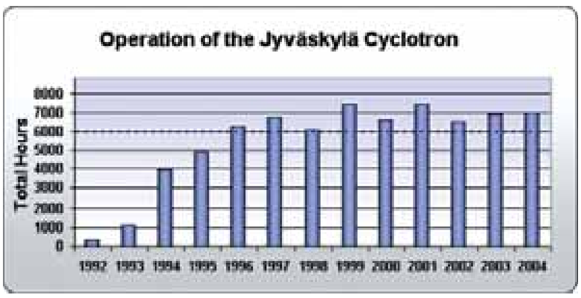

Fig. 1. Operation of the Jyväskylä cyclotron

Pauli Heikkinen, chief engineer
Hannu Koivisto, senior assistant
Pekka Suominen, graduate student
Olli Tarvainen, graduate student
Pentti Frondelius, MSc student
Tommi Ropponen, MSc student
Arto Lassila, laboratory engineer
Veikko Nieminen, laboratory engineer
Teuvo Poikolainen, laboratory engineer
Juha Ärje, laboratory engineer
Jani Hyvönen, operator
Anssi Ikonen, operator
Hannu Leinonen, technician
Raimo Seppälä, technician

to improve for highly charged ions. The first tests were carried out in January 2005.

A Traveling Wave Tube Amplifier (TWTA) arrived in the fall of 2004. The new device has been tested with the JYFL 14 GHz ECRIS and a remarkable improvement was achieved when it was used together with the 14 GHz klystron. For example the intensity of Xe^{31+} ion beam increased by a factor of about 5, which means that the TWTA plays a key role in the radiation tests for European Space Agency. The TWTA made also possible the first 1 GeV beam ($^{132}Xe^{33+}$) from the cyclotron.

Numerous experiments with the plasma potential measurement device developed at JYFL have been performed. New interesting information about the plasma behavior and beam formation of the ECR ion source has been achieved.

http://www.phys.jyu.fi/research/accelerator/index.html

Research

Exotic nuclei and beams

Ari Jokinen, Heikki Penttilä and Juha Äystö

http://www.phys.jyu.fi/research/igisol/index.html

Our activity in 2004 has continued along the well established path consisting of numerous experiments and R&D on instrumentation at JYFL and ISOLDE, CERN. The work at ISOLDE is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics. Major achievements have been the finishing of the IGISOL upgrade by introducing a new dipole magnet from GSI and the completion of the new laser system FURIOS to be used for selective ionization of rare isotopes at IGISOL. In early 2004 the ISOLDE Si-ball was shipped to JYFL, where it was applied in four different spectroscopic studies, namely beta decay studies of ^{13}O, ^{31}Cl and ^{58}Zn and in the study of triple-alpha states in ^{12}C.

The highlights of the experiments performed at IGISOL include the first accurate mass measurement of nearly 30 neutron-rich isotopes from fission [1], decay spectroscopy of isobarically purified n-rich Zr isotopes [2], the study of molecular structures of light nuclei via beta-delayed particle emission [3] and measurement of charge radii and hyperfine structure of some radioactive yttrium isotopes [4]. At ISOLDE our team has been involved in several experiments, including structure studies of n-rich Mg isotopes near the island of inversion and n-rich Cd isotopes near ^{132}Sn as well as in the mass measurement of the rp-process waiting point nucleus ^{72}Kr. Finally, a series of experiments conducted at IGISOL and ISOLDE have led to a revision of the knowledge on the excited states of ^{12}C relevant for the triple-alpha process leading to formation of carbon in stars. This work was published in early 2005 in NATURE.

Juha Äystö, professor
Heikki Penttilä, academy researcher
Ari Jokinen, senior assistant
Stefan Kopecky, senior researcher -31.7.
Iain Moore, postdoctoral researcher
Jussi Huikari, postdoctoral researcher
Youbao Wang, postdoctoral researcher -31.8.
Tetsu Sonoda, postdoctoral researcher 1.10.-
Tommi Eronen, graduate student
Ulrike Hager, graduate student
Jani Hakala, graduate student
Anu Kankainen, graduate student
Pasi Karvonen, graduate student
Thomas Kessler, graduate student 11.10.-
Sami Rinta-Antila, graduate student
Bruce Marsh, Marie Curie Training Site student -12.3.
Benjamin Tordoff, Marie Curie Training Site student 1.9.-
Viki-Veikko Elomaa, MSc student
Janne Ronkainen, MSc student
Antti Saastamoinen, MSc student

Experimental studies for new neutrino detector nuclides, such as ^{100}Mo, have been initiated at IGISOL [5]. In another intriguing project radioactive isotopes produced at IGISOL were used as probe atoms in studying diffusion properties of impurities in solids [6]. Some decay studies of neutron-rich fission products were performed for producing data for the nuclear reactor heat calculations [7].

Our team has been benefiting significantly from collaborations with several groups from Europe and the US as well as EU-funded RTD projects NIPNET, Ion Catcher and EURISOL. See the list of collaborators at the end of this section.

Technical development

Upgrade to IGISOL 3

In 2004 the performance of the new IGISOL facility was tested in connection with the nuclear physics program that was launched as soon as the mass separator became operational. The observed gain factors in yield for different reactions vary between 2 and 8. The cumulative yield of ^{112}Rh in the 30 MeV proton induced fission of ^{238}U reached the 10^5 ions/second level in June. The improvement in efficiency appears to be due to a better transmission through the extraction electrode, afforded by the increased pumping efficiency. The mass resolving power is sufficient to focus the IGISOL beam properly to the de-acceleration stage of the RF cooler. For A = 112 fission fragments a transmission through the cooler as high as 70 % has been measured.

Ion guide development

A novel kind of ion guide was developed in collaboration with Lawrence Berkeley National Laboratory to mass separate the reaction products from the quasi- and deep-inelastic reactions. Production of ion beams utilizing these reactions that allow the neutron rich side of the valley of stability to be probed has been found to be extremely difficult, in particular for refractory elements. The new ion guide was tested under on-line conditions with ^{197}Au(^{65}Cu,X)Y reactions [8].

FURIOS project

In order to address the issues of a lack of selectivity and efficiency inherent in the IGISOL technique, a new laser ion source project commenced in January 2004

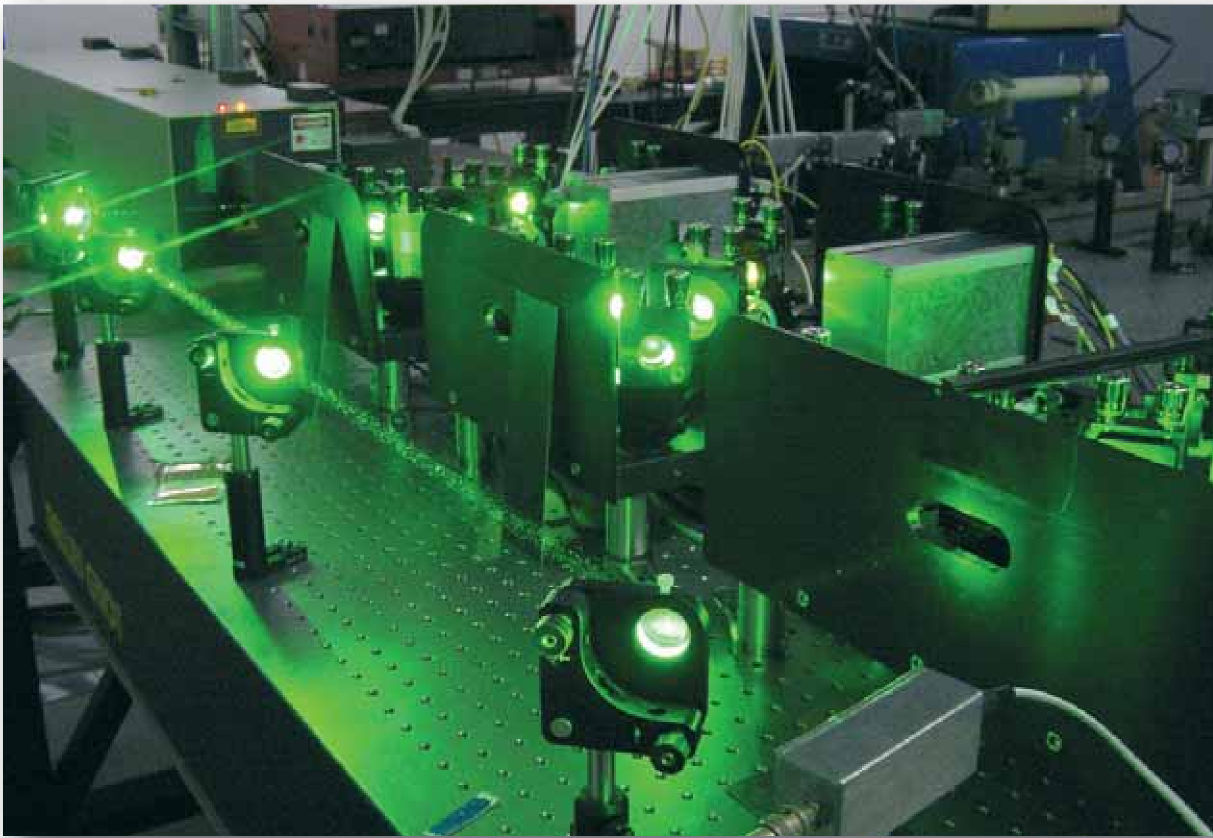

Fig. 1. View to the lasers in the FURIOS cabin.

– the Fast Universal Resonant laser IOn Source, FURIOS. A laser cabin housing two separate pulsed laser systems was installed on the roof of the IGISOL cave. The first, an all solid state system comprises of a high repetition rate Nd:YAG laser (10 kHz) pumping three Titanium Sapphire lasers developed and built in collaboration with the University of Mainz. A second system, built in the manner of the highly successful ISOLDE RILIS ion source consists of a high repetition rate Copper Vapour laser (10 kHz) pumping two pulsed dye lasers. This twin laser facility will provide a universal coverage of ionization schemes throughout the periodic table. Two forms of ion source development are being undertaken. The first is the well-developed laser ionization of elements within the gas volume of the ion guide. In a series of off-line tests on rubidium, the first laser ions were observed from an oven-ion guide. The second direction of development is towards the high selectivity production achievable with a LIST (Laser Ion Source Trap).

JYFLTRAP

At the end of 2003, the JYFLTRAP facility was commissioned. In 2004 a series of improvements were made to further improve the setup. The possibility of using the purification trap alone as an isobaric selector was tested for ^{100,102,104}Zr decays [2]. The isotope of interest was selected in the purification trap and then shot through the precision trap directly to a beta-gamma spectroscopy setup. The overall transmission efficiency in an isobaric purification mode is typically 10 %, but losses in transmission are often balanced by the selectivity gained.

Experimental highlights

Precision mass measurements of refractory fission products with JYFLTRAP were performed for neutron-rich Sr, Zr and Mo isotopes [1]. Overall uncertainties of extracted masses were about 10 keV. This level of accuracy of direct mass measurements leads to two conclusions: firstly, existing mass data in the studied region is clearly in error for many of the nuclei. Secondly, by expressing the data as two-neutron separation energies, one can identify a remarkable discontinuity at N=58-60. This effect is strongest for the Zr isotopes and smoothens out in the Sr and Mo isotopes. By combining this data with charge radii measurements and modern theories, this effect can be attributed to sudden changes of deformation.

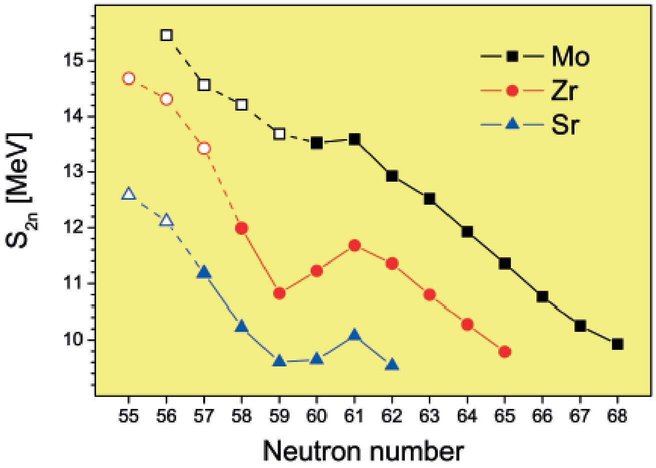

Fig. 2. The two-neutron separation energies for neutron-rich Sr, Zr and Mo isotopes. The discontinuity at N=58-60 is clearly visible. See text for details.

Molecular alpha structures of ^{12}C fed in the beta decay of ^{12}N [3]

Our first study on states in ^{12}C was reported in the JYFL Annual Report 2001. In 2004 we have reinvestigated the decay of ^{12}N, feeding states in ^{12}C, using an improved detection setup for low-energy charged particles. In these measurements we have tried to resolve long-standing questions about the triple alpha process that creates carbon nuclei. By precisely measuring the timing and energies of alpha particles, it was possible to infer the energy, spin, and parity of the carbon nuclei just before decay. Such information is used to determine the rate of the triple alpha process in stars over a wide range of temperatures, from 10^7 to 10^{10} K.

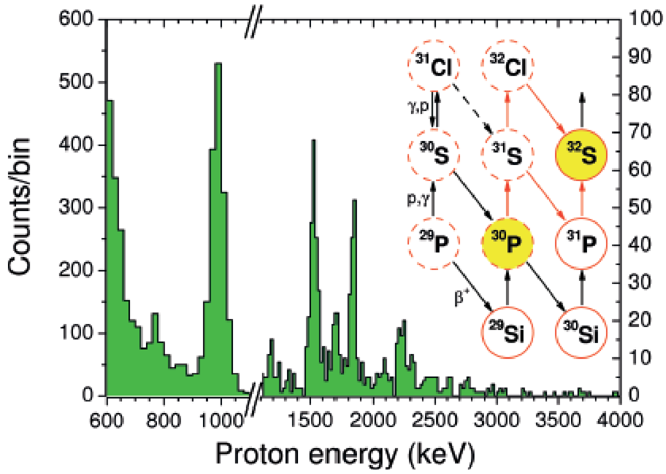

Fig. 3. Beta-delayed protons from mass-separated ^{31}Cl. The proton spectrum gives information on the rate of ^{30}P(p,γ) which plays a key role in the synthesis of heavier nuclei in novae. The insert shows the main nuclear paths from ^{30}P to ^{32}S in novae [see J. José et al., Astrophys. Journal 560, 897-906 (2001)].

Beta decay of ^{13}O [3]

The existence of molecular states consisting of neutrons occupying molecular-like orbits around α-particle clusters has thus far been most successfully demonstrated in the Be-isotopes. The ISOLDE Si ball and the DSSSD detectors were employed in the study of the beta decay of ^{13}O via beta delayed proton emission. This was the first time when ^{13}O decays were observed from a small, mass separated source, thus the quality of the data leads to an improved level scheme with more precise relative intensities than before.

Beta decay of ^{31}Cl [9]

This beta decay is important for astrophysical studies because it delivers a way to inversely determine the rate of the ^{30}P(p,γ)^{31}S reaction which is crucial for the studies on nucleosynthesis of elements heavier than phosphorus in massive ONe novae. The ^{31}Cl ions were produced by a 40-MeV proton beam on a ZnS target, mass separated with the IGISOL and implanted into a thin carbon foil. Their beta decay was studied with a set-up that consisted of three double-sided silicon strip detectors (DSSSDs) backed with thick silicon detectors, the ISOLDE Si-ball and a 70% HPGe detector.

Laser spectroscopy [4]

During 2004 the scope of the laser spectroscopic research programme at the IGISOL was substantially boosted by the development of new laser wavelengths.

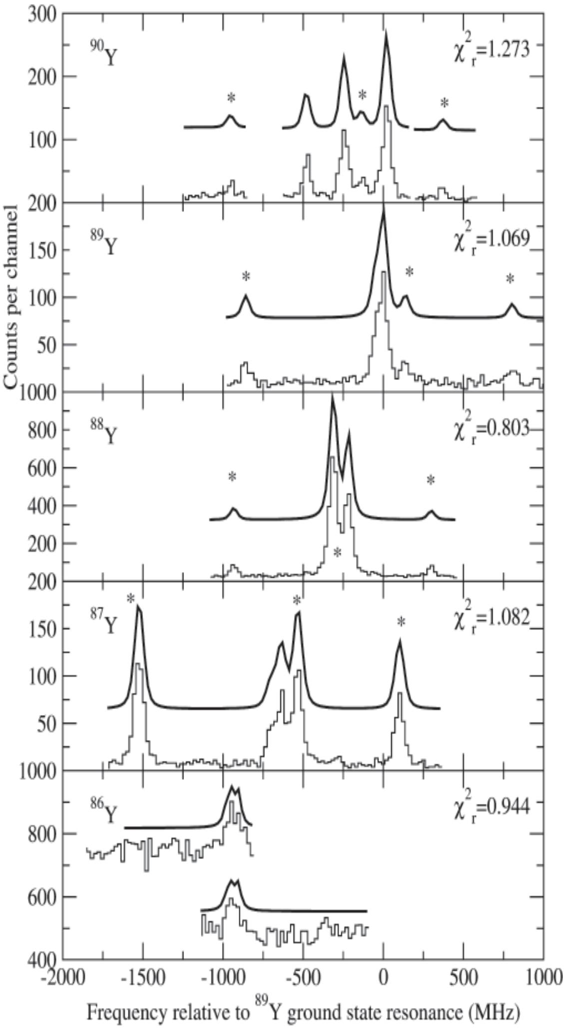

Fig. 4. Optical resonances observed in near-stability yttrium isotopes and isomers. Fits to the observed profiles are displaced for clarity and structure arising from isomeric configurations is marked by asterisks.

The new laser capabilities, which enable the production of laser light in the near-UV region around 370 nm, were immediately applied to the study of near-stability ground states and isomers in yttrium and will shortly facilitate the first optical studies of cerium and yttrium fission fragments.

Figure 4 shows the optical resonances, and hyperfine structures, observed in 5 ground states and 4 isomers in the yttrium chain near N=50 ($^{86-90}Y$). The measurement of these near-stability systems was both a vital prerequisite for the study of yttrium fission fragments and the first opportunity to study the developing deformation of the low-lying $\pi\, g_{9/2}$ isomers.

Work at ISOLDE

Advanced timing measurements on Mg-isotopes

Among light neutron-rich nuclei we have studied excited states in $^{30,31,32}Mg$-isotopes close to the “island of inversion” by applying the advanced time delayed $\beta\gamma\gamma(t)$ method. It provides complementary information on transition strengths, which to date have only been extracted from Coulomb excitation (Coulex) measurements with radioactive ion beams at GANIL, MSU, RIKEN, and CERN. This project will continue in 2005 with possible extension to E0-measurements.

Level structure of neutron-rich Cd isotopes

We have carried out a dedicated experiment at ISOLDE to systematically study collective (vibrational, quasi-particle) states of Cd isotopes in order to understand the influence of neutron excess on these excitation modes. In 2004 we studied at ISOLDE excitation schemes of $^{122,124,126}Cd$ as a continuation to our studies at JYFL for $^{116,118,120}Cd$.

Mass measurement of ^{72}Kr

A direct high precision mass measurement was performed on the waiting point in the astrophysical rp-process, ^{72}Kr, with the Penning trap mass spectrometer ISOLTRAP. The measurement yielded a relative mass accuracy of $\delta m/m = 1.2 \times 10^{-8}$. With new mass data, one can conclude that the effective lifetime of ^{72}Kr remains within 80% of its beta decay half-life and thus ^{72}Kr remains a strong waiting point nucleus in the rp-process during X-ray bursts.

Collaborators

Manchester University collaboration

Jonathan Billowes, head
Paul Campbell
Arto Nieminen, postdoctoral researcher
Malamatenia Avgoulea, graduate student
Ben W. Tordoff, graduate student
Bruce A. Marsh, graduate student

Birmingham University collaboration

Garry Tungate, head
David Forest
Bradley Cheal, graduate student
Matthew Gardner, graduate student
Mark Bissell, graduate student

Mainz University collaboration

Klaus Wendt
Christopher Geppert

ISOLTRAP and SHIPTRAP groups

Experiment spokespersons and collaborating institutes in 2004:

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Ludvig Maximilian University, Munich, Germany.
[2] S. Rinta-Antila
[3] H.O.U. Fynbo, L. Fraile
University of Aarhus, Denmark; CSIC, IEM, Madrid, Spain; CERN, Switzerland; KVI, Groningen, The Netherlands; University of York, UK; Chalmers University of Technology, Göteborg, Sweden; Technische Universitet, Darmstadt, Germany.
[4] P. Campbell
University of Manchester, UK; Univeristy of Birmingham, UK.
[5] A. Garcia
University of Washington, Seattle, USA; ANL, Argonne, USA.
[6] H. Whitlow; J. Räisänen
Malmö högskola, Sweden; Lund University, Sweden; University College Dublin, Ireland; Helsinki University.
[7] A. Algora
University of Valencia, Spain; University of Surrey, UK; NPI, St. Petersburg, Russia; V.G.Khlopin Radium Institute, St. Petersburg, Russia ; Mushashi Institute of Technology, Japan; CEA, France; IAEA, Vienna, Austria; INFN, Legnaro, Italy; CIEMAT, Madrid, Spain; CSIC, IEM, Madrid, Spain; IRES, Strasbourg, France; INR, Debrecen, Hungary.
[8] K. Peräjärvi
LBNL, Berkeley, USA.
[9] A. Jokinen, D.G. Jenkins
University of York, UK; ANL, Argonne, USA; University of Edinburgh, UK; Universitat Politecnica de Catalunya, Barcelona, Spain.

Research

In-beam spectroscopy

Paul Greenlees, Pete Jones, Rauno Julin and Sakari Juutinen

http://www.phys.jyu.fi/research/gamma/index.html

Fig. 1. The Gamma and RITU groups in January 2005

Rauno Julin, professor
Sakari Juutinen, senior assistant
Pete Jones, senior scientist
Paul Greenlees, senior scientist
Matti Piiparinen, lecturer
Päivi Nieminen, postdoctoral researcher -30.6.
Tuomas Grahn, graduate student
Markus Nyman, graduate student
Janne Pakarinen, graduate student
Panu Rahkila, graduate student
Mikael Sandzelius, Marie Curie student 16.4.-
Tatjana Faul, visiting student 1.3.-11.6.
Jenni Andersin, MSc student
Juha Sorri, MSc student

Continued success with JUROGAM

As in 2003, a significant part (100 days) of the JYFL beam time was devoted to the in-beam gamma-ray spectroscopy experiments of the second JUROGAM campaign. The majority of the measurements employed the Recoil-Decay Tagging (RDT) technique whereby the JUROGAM array is coupled to the RITU gas-filled recoil separator and reaction products are identified with the aid of the GREAT focal-plane spectrometer. The campaign was therefore carried out in close collaboration with the RITU group. A photo of the two groups can be found in Figure 1.

JUROGAM is an array of 43 EUROGAM Phase I-type Compton-suppressed Ge detectors supplied from the EUROBALL and UK-France detector pools which surrounds the target of the RITU separator. The photo-peak efficiency of the array for the detection of 1.3 MeV gamma rays is approximately 4.2 %. Combined with the RITU separator and the U.K. funded focal plane GREAT spectrometer and associated Total Data Readout (TDR) acquisition system, it forms the world's most powerful spectrometer system for studies of the structure of heavy proton drip-line nuclei and transfermium nuclei. The triggerless TDR system collects data in a "free-running" mode, each channel being independent. The use of time-stamping (with a resolution of 10 ns) alleviates the common dead-time problems of conventional systems used in RDT measurements. The TDR system is important especially when using the RDT method, where delayed decay events are correlated with prompt gamma-ray events. The GRAIN event construction and software package was used in all of the experiments of the JUROGAM campaign.

The GREAT spectrometer, composed of a transmission MWPC gas detector, high-granularity double-sided silicon strip detectors (DSSSD's), a "box" of 28 Si-PIN-diodes and a highly segmented planar Ge detector, was completed in 2004 with the addition a large volume Ge- Clover detector. Further details can be found in the RITU group report.

A new target chamber for JUROGAM was designed and installed by the IReS group from Strasbourg. The chamber, based on a design used earlier in EUROGAM II, incorporates a rotating target wheel which can be used for both in-beam and focal plane experiments with high intensity beams. A measurement of the rotation speed, target current and motor temperature is available. The system can be removed in order to use standard stationary targets in experiments with lower beam intensities. A photograph of the rotating wheel system is shown in Figure 2.

Fig. 2. The IReS Strasbourg rotating target wheel system installed at JYFL.

Details of the second JUROGAM Campaign

The second JUROGAM campaign involved 45 foreign collaborators. The spokespersons and collaborating institutes are listed at the end of the present report. After initial commissioning experiments (3 days) in April, 3 test experiments (4 days) and a total of 11 production experiments (93 days) were carried out:

[1] Spectroscopy of the deformed ground-state proton emitter ^{113}Cs

[2] Two-photon alternated-parity decay: 0^- to 0^+ 2-gamma transitions in ^{14}N excited via the ^{13}C(p,gamma) reaction

[3] Ground state and excited bands in ^{250}Fm

[4] Search for triple shape coexistence in ^{190}Po

[5] Gamma-ray spectroscopy of ^{192}Po with JUROGAM

[6] Detailed spectroscopy of ^{191}Bi

[7] A recoil-decay tagged plunger lifetime measurement for the yrast levels of ^{186}Pb

[8] A plunger lifetime measurement of low-lying yrast states in ^{194}Po

[9] Gamma-ray spectroscopy of the very neutron-deficient nucleus ^{188}Po

[10] High Spin-States in the N=84 Isotones ^{156}Hf, ^{157}Ta, ^{158}W

[11] Spectroscopy of ^{176}Hg: shape coexistence at the extremes

Analysis of the new data from these experiments is still in progress. The following sections report preliminary data from the latest experiments along with more detailed analysis of some experiments from the first JUROGAM campaign.

An oblate non-yrast band in ^{186}Pb

The efficiency of the JUROGAM+RITU+GREAT system enables RDT gamma-gamma coincidence measurements to be performed even when the production cross section is very low. Such an experiment from the 1st JUROGAM campaign was the study of ^{186}Pb, where a low-lying non-yrast quadrupole band was identified. The analysis of these data is now completed. The observation of strong I→I and weak I→I-2 interband transitions to the prolate yrast band (together with IBM calculations) indicate an oblate shape for this new band. This band can be associated with an oblate intruder 0^+ state, which is the first excited state in ^{186}Pb [see A.N. Andreyev et al. Nature Vol. 405, (2000), 430]. The kinematic moment of inertia, J^1, extracted from the gamma-ray energies of this new band is plotted in Figure 3, along with similar plots for known oblate and prolate yrast bands of nuclei in this region. The behavior of the new band is in contrast to that of the other bands. At lower rotational frequencies (gamma-ray energies) the J^1 values are similar to those for the known oblate bands, whilst at higher frequencies the values are similar to those in the known prolate bands. This behaviour may be due to a shape change towards a more deformed oblate structure.

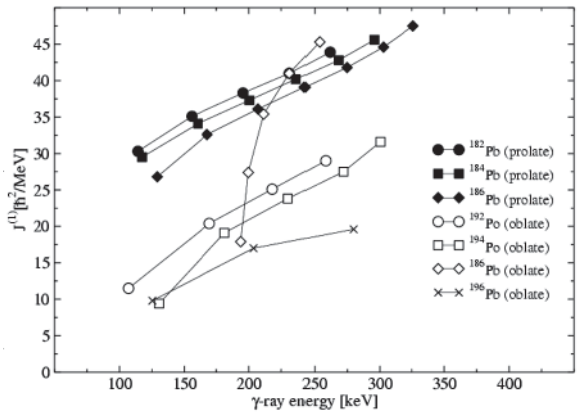

Fig. 3. Kinematic moment of inertia as a function of gamma-ray energy for the new non-yrast band in ^{186}Pb together with similar plots for known oblate and prolate intruder yrast bands in nuclei of this region.

Collectivity of the yrast line of ^{188}Pb

In order to probe the collectivity of yrast states in ^{188}Pb a plunger lifetime measurement was performed during the 1st JUROGAM campaign, employing the Köln plunger device in combination with RITU and JUROGAM (spokesperson A. Dewald). This was the first time that a gas-filled separator was combined with a plunger device. The ^{108}Pd(^{83}Kr,3n) ^{188}Pb reaction was used at a beam energy of 340 MeV and the standard stopper foil of the plunger was replaced by a 2.5 mg/cm^2 gold degrader foil. In this manner, the recoiling fusion products can be identified with the focal plane detectors and the fully Doppler-shifted component of the gamma-ray peaks can be separated from the degraded components. Recoil-gated gamma-ray spectra were collected at 10 selected distances between the target and the degrader foil. Decay curves extracted from the intensities of the two components of the gamma-ray peaks originating from the yrast transitions up to the 10^+ state in ^{188}Pb are shown in Figure 4.

The yrast band above the yrast 2^+ state in ^{188}Pb is assumed to be based on a prolate minimum originating from multi-particle multi-hole intruder configurations. The lifetimes derived from the decay curves result in an average transition quadrupole moment of 8.8(5) eb for the $8^+ \rightarrow 6^+$ and $6^+ \rightarrow 4^+$ transitions. The 8^+, 6^+ and 4^+ states are considered to be rather pure prolate states and therefore a deformation parameter β = 0.286(14) for this band can be derived from this value. The quadrupole moment extracted from the measured transition rate for the $4^+ \rightarrow 2^+$ transition is 6.0(2) eb, revealing that the 2^+ state is mixed with a prolate component of 40%.

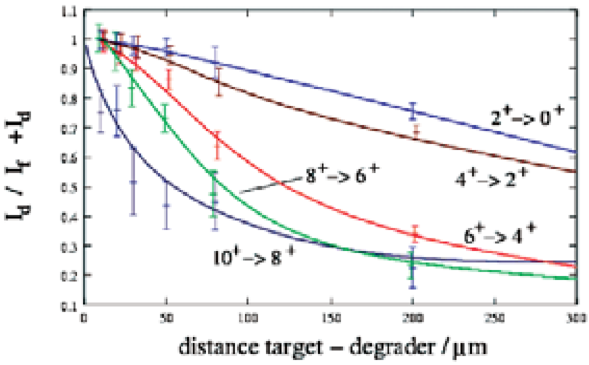

Fig. 4. Experimental decay curves of transitions in the yrast band of ^{188}Pb. I_d and I_f denote the intensities of the degraded and the fully shifted component, respectively.

First excited state of ^{107}Te

One of the highlights of the 1st JUROGAM campaign was the first identification of gamma rays from ^{107}Te in an RDT experiment, produced using the symmetric ^{58}Ni(^{52}Cr,3n)^{107}Te reaction (spokesperson B. Cederwall). On the basis of the collected data an excited state at 90 keV, tentatively of $g_{7/2}$ character, is proposed. This low excitation energy may have implications for the reaction rates in the closed Sn-Sb-Te cycle, recently predicted to form the end point of the astrophysical rp- process. Moreover, the opposing trends of the excitation energy of the 7/2$^+$ states in the very neutron-deficient Sn and Te nuclei point to the importance of np correlations in the structures of these N ≈ Z nuclei.

RDT plunger lifetime measurement of the prolate yrast levels in ^{186}Pb

Following the success of measurements in the first campaign, an attempt to employ the Köln plunger in an RDT measurement was made in the second JUROGAM campaign. Degrader foils of 2.2mg/cm^2 Au, 1.0mg/cm^2 Al and 1.0mg/cm^2 Mg were used and gamma-ray spectra with 11 different target-to-degrader foil distances (from 10 to 1600 µm) were collected. The ^{186}Pb nuclei were produced using the ^{106}Pd(^{83}Kr,3n)^{186}Pb reaction and gamma-ray spectra corresponding to ^{186}Pb were extracted by tagging with the ^{186}Pb alpha decay. The sample RDT gamma-ray singles spectra of Figure 5 are very clean and show that it will be possible to determine level lifetimes in ^{186}Pb up to the yrast 8$^+$ state. This measurement represents the first time that the RDDS lifetime measurement method has been combined with the RDT technique.

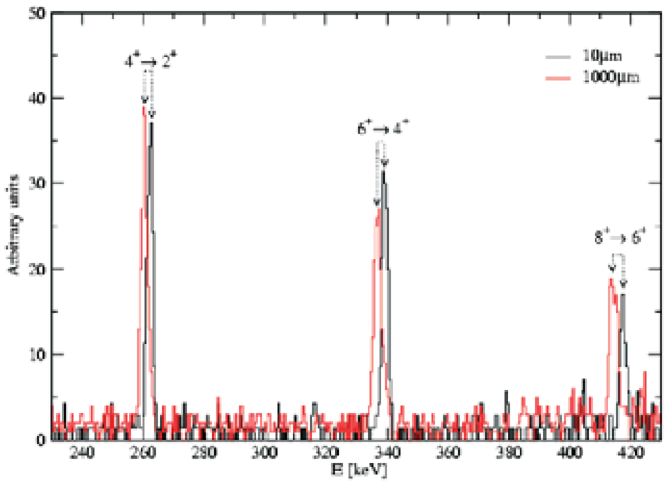

Fig. 5. Singles recoil-decay tagged spectra of ^{186}Pb from the 134 degree detector ring at target-to-degrader distances of 10 and 1000 µm. The fully Doppler-shifted and degraded components of γ-rays de-exciting the yrast band of ^{186}Pb are clearly visible. The spectra have been normalised such that the intensity of the 4$^+$ → 2$^+$ peak is the same for both distances.

RDT plunger lifetime measurement of the oblate yrast levels in ^{194}Po

In addition to lifetime measurements of the prolate intruder states in ^{186}Pb and ^{188}Pb, it is also important to probe the collectivity of the oblate intruder states found in this region of shape coexistence. So far, the comparison of the prolate and oblate bands has been based only on the energy level spacing and level systematics. Therefore, an RDDS lifetime measurement was performed for the low-lying states in ^{194}Po, again using the Köln plunger device in an RDT experiment with JUROGAM+RITU+GREAT. Data from earlier standard experiments indicate that the yrast band of ^{194}Po has an oblate character. The ^{114}Cd(^{83}Kr,3n)^{194}Po reaction and a Mg degrader foil of thickness 1.0mg/cm^2 were used.

Gamma-ray spectra tagged with ^{194}Po alpha decays were collected at 13 different target-to-degrader foil distances ranging from 5 to 3000 µm. Analysis of the data is in progress.

Spokespersons and collaborating institutes outside Jyväskylä of the second JUROGAM campaign

[1] J. F. Smith
University of Manchester, U.K.; University of Liverpool, U.K.; University of York, U.K.
[2] T. Lönnroth
Åbo Akademi, Finland
[3] R.-D. Herzberg
University of Liverpool, U.K.; DAPNIA/SPhN CEA Saclay, France; CERN-ISOLDE, Switzerland; IReS Strasbourg, France; IFJ PAN, Krakow, Poland
[4] A. N. Andreyev
TRIUMF, Canada; University of Liverpool, U.K.
[5] P. Rahkila
TRIUMF, Canada; University of Liverpool, U.K.
[6] S. Juutinen
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[8] T. Grahn
University of Köln, Germany; University of Liverpool, U.K.; University of Helsinki, Finland
[9] P.T. Greenlees, S. Juutinen and A. N. Andreyev
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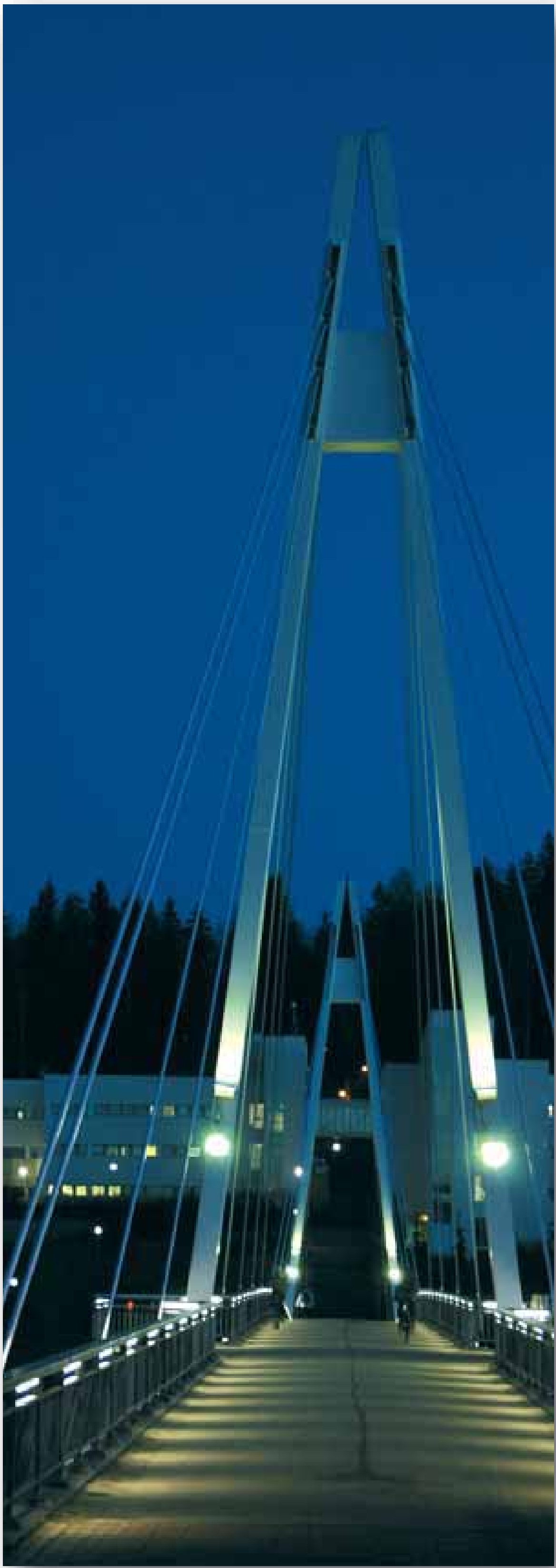
[10] D. T. Joss and J. Uusitalo
CCLRC Daresbury, UK; University of Liverpool, UK; KTH Stockholm, Sweden; University of York, UK; Argonne National Laboratory, U.S.A.
[11] J. Simpson and R. Julin
CCLRC Daresbury, UK; University of Liverpool, UK; University of York, UK



Research

The JYFL gas-filled recoil separator RITU

Matti Leino and Juha Uusitalo

Matti Leino, professor
Juha Uusitalo, senior researcher
Catherine Scholey, postdoctoral researcher
Sarah Eeckhaudt, graduate student
Ari-Pekka Leppänen, graduate student
Jan Sarén, graduate student 1.8.2004-
Iain Darby, Marie Curie Ph. D. student 1.4.-
Timo Kosonen, MSc
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http://www.phys.jyu.fi/research/ritu/index.html

The activity of the RITU group in 2004 focused on recoil decay tagging in-beam γ-ray spectroscopy (JUROGAM campaign) studies. The RITU separator was successfully used in a large variety of experiments. The heavy element in-beam experiment of ^{250}Fm [1] was repeated with very low background conditions. In the lead region many nuclei were studied using both asymmetric and symmetric reactions. The isotope ^{113}Cs [2] was produced using the symmetric reaction of a ^{58}Ni beam impinged on a ^{58}Ni target and was successfully separated from the primary beam and studied.

Again, an attempt was made to investigate whether the updated RITU separator could be used below the mass 100 region. In the test an ^{36}Ar beam was used to bombard a ^{48}Ti target at the Coulomb barrier energy (90 MeV). Fusion evaporation products from the mass 80 region were separated from the beam and transported to the focal plane of RITU. With 10 MeV higher bombarding energy the separation became more difficult. We have learned that with the updated version of RITU it is possible to use symmetric reactions to produce nuclei of interest in the mass 100 region and even below, if bombarding energies at the Coulomb barrier are used. This development work will continue.

A new Compton suppressed large volume HPGe Clover detector to measure high-energy γ rays has been added to the GREAT spectrometer. A new frame to firmly support this detector was also installed. The frame has positions for four detectors, so in future it will be possible to simultaneously handle four large cluster or clover Ge-detectors giving a higher γ-ray collection efficiency at the focal plane of RITU.

Two stand-alone studies were also performed at the focal plane of the RITU separator. The updated GREAT spectrometer was used to look for α-γ, α-e and/or e-γ coincidences as well as to search for delayed γ's or/and e's tagged with α decays. The heavy element experiment on ^{255}No [3] was performed using a ^{48}Ca beam on ^{208}Pb targets to look for possible new isomeric decays and fine structures in the α decays. In another experiment the N = 126 isotones ^{217}Pa and ^{215}Ac [4] were studied to search for evidence for octupole correlations by bombarding ^{181}Ta targets with an ^{40}Ar beam.

The RITU separator has been used extensively during the recent years. The large international collaborations have led to a situation where quite often it is necessary to change the detector setups both at the target position and at the focal plane. This and the fact that RITU was

Fig. 1. A high efficiency segmented Germanium CLOVER Detector with Compton suppression installed into the new supporting frame at the focal plane of RITU separator.

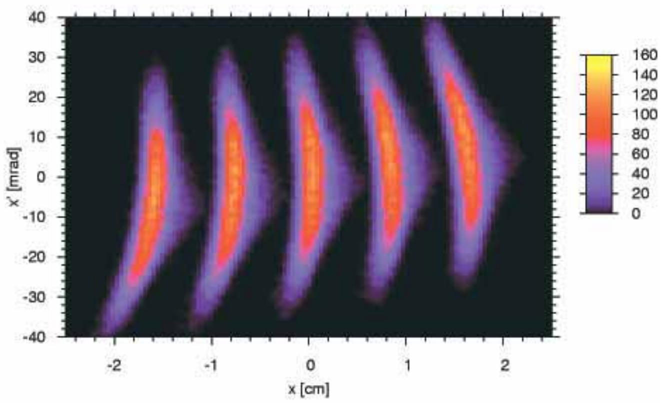

Fig. 2. A simulated mass spectrum at the focal plane of the new vacuum separator. Five different masses in the mass region 100 are shown (1 MeV/n). Input angular cones of ± 30 mrad and ± 40 mrad in the vertical and horizontal directions, respectively, were used. An energy spread of ± 7 % for the products was allowed.

originally constructed for heavy elements studies and there is lot of interest to perform spectroscopy studies also in the lower mass region (^{100}Sn region and beyond) have raised needs for another separator. To diminish the load on RITU and to make performing different experiments more flexible, the design of a new separator has started [5]. The new separator is better suited to the mass region 50-150 for nuclei produced in symmetric or nearly symmetric reactions. An electromagnetic mass separator was chosen to fulfil these requirements. The new separator will be an energy and angle focussing recoil mass spectrometer. The ion optics code GIOS has been used to design the configuration of magnetic and electric elements. Two bending elements are used in an order where the electric dipole (E) is followed by a magnetic dipole (M). The EM structure is augmented with a quadrupole triplet lens, QQQ, system to increase the solid angle and to improve the final angular focus. A maximum angular acceptance better than 10 msr was reached and a mass resolving power better than 1/350 (with 5 msr acceptance) was attained. It is envisaged that the new separator will be in operation in year 2008. Our hope is that the new vacuum separator will make our laboratory even more attractive for the European collaborators to perform experiments here.

Spokespersons and collaboration institutes:

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University of Liverpool
[2] J. F. Smith,
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University of York
[3] R.-D. Herzberg,
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[4] K. Hauschild,
CSNSM Orsay
[5] M. Leino, J. Sarén, J. Uusitalo

Research

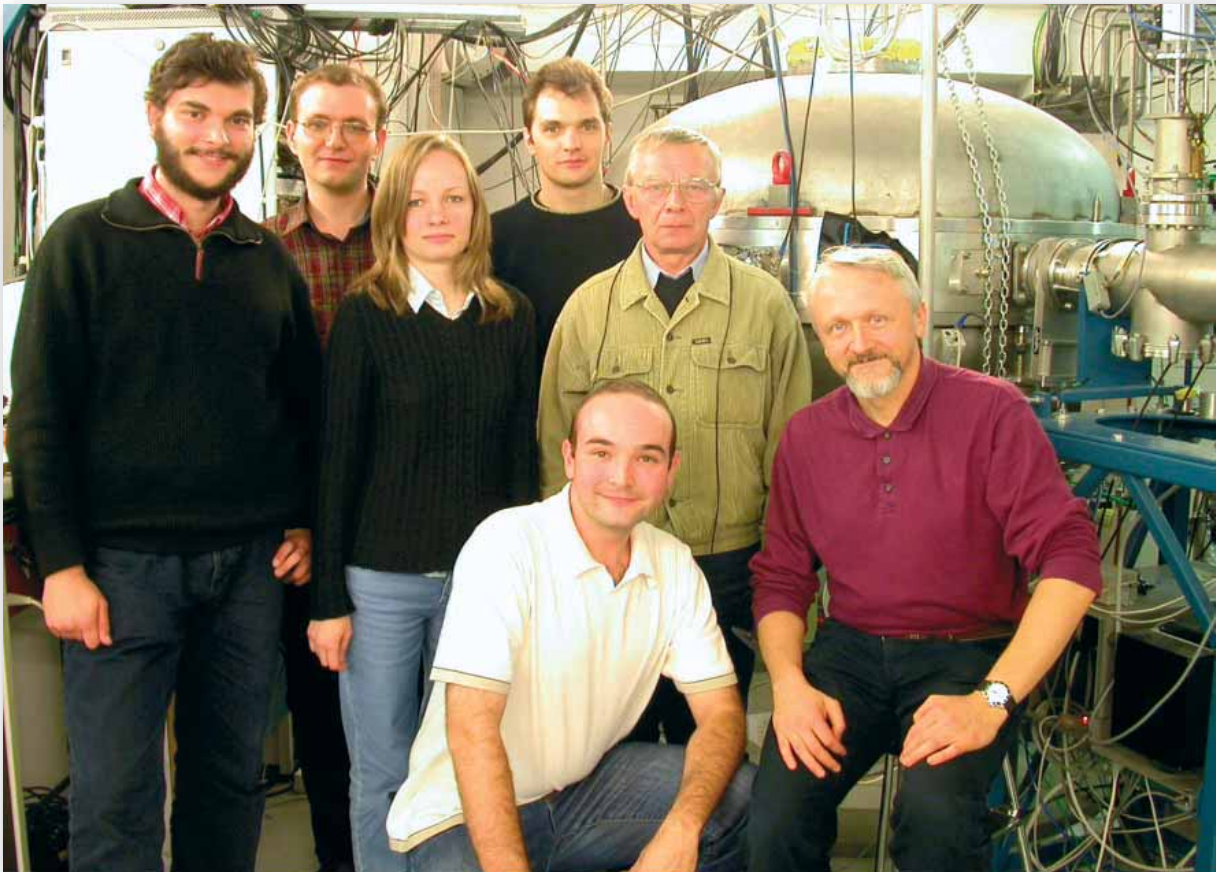
ALICE and nuclear reactions

Wladyslaw Trzaska

The scope of activities of our group is very broad. It reaches into both extremes of available particle energies. At CERN LHC we shall investigate ultra relativistic collisions, whereas at ILL we are measuring thermal neutron induced fission. Naturally, there are some historical reasons for this diversity. The main unifying factors are our broad collaboration links and the accumulated know-how in experimental methods. For instance, years of

Wladyslaw Trzaska, senior researcher
Mariana Bondila, graduate student (HIP/JYFL)
Serguei Iamaletdinov, graduate student
Tomasz Malkiewicz, graduate student
Galina Knyazheva, CIMO scholarship student
Teppo Harju, MSc student
Vladimir Lyapin, engineer (HIP/JYFL)

http://www.phys.jyu.fi/research/alice/index.html



From the left: Tomasz Malkiewicz, Jaroslaw Perkowski, Galina Knyazheva, Serguei Iamaletdinov, Vladimir Lyapin, Angel Munos-Martin and Wladyslaw Trzaska.

R&D to improve HENDES detectors gave us a head start in the work on T0 detector for ALICE because although pre- and post scission neutron emission has not much in common with non-diffractive processes at 7 TeV/c, the signals registered by photomultipliers are very similar. Also the detectors, electronics and computer techniques developed for fission measurements have over the years found their way into other fields and applications.

ALICE

There are only two years left before the first LHC beam is expected to collide inside ALICE but in spite of the growing time pressure the construction of the detector proceeds on schedule. The Finnish team has a significant part in this success. Our group is coordinated and financed in part by Helsinki Institute of Physics within the Nuclear Matter Program. Also the workload is shared between Helsinki (bonding of the tracker components), and Jyväskylä (construction of the T0 detector and development of the track reconstruction software). One of the symbolic highlights of 2004 was publication of the first physics paper by ALICE: Physics Performance Report, Volume I It has appeared in the Journal of Physics G 30 (2004) 1517-1763 and, naturally, we have also contributed to it. The growing importance of physics and data analysis in the work of our ALICE group has been strengthened by the creation of the new research position at the University of Jyväskylä. We are happy to inform that this position was awarded to Dr. Jan Rak (currently working in PHENIX experiment at RHIC) and will be filled starting from the middle of 2005.

ALICE/ITS/SSD module assembly

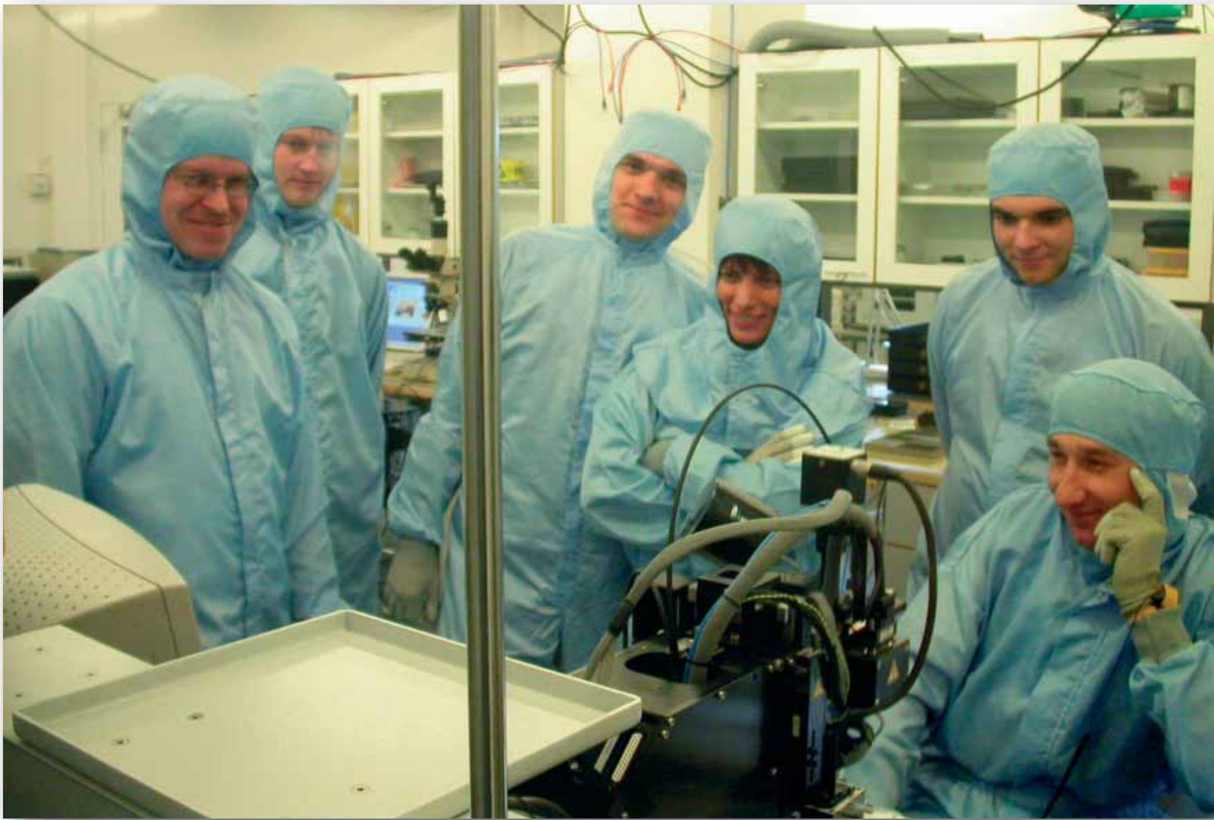
The two largest layers of the ALICE Inner Tracking System (layers 5 & 6) will contain about 2000 Silicon Strip Detector (SSD) modules. The production of these modules is shared between France, Italy and Finland. The assembly of the Finnish share of SSD modules (defined by so-called core funding) is being done in the Detector Laboratory located in Kumpula Campus in Helsinki.

The SSD assembly has suffered considerable delays in the past: design of the preamplifier chip was changed along with the project and lack of components has made difficult the tuning of the assembly process. This delay created a new opportunity for the Finnish participation in the assembly. Instead of delegating the work to the industry, as it was initially assumed, we were able to convince the collaboration to transfer the entire workload to the Detector Laboratory in Helsinki. The new clean rooms were very suitable for that purpose but the lab had no adequate equipment, personnel, nor know-how for the task. To solve these problems we have persuaded the collaboration to commit part of the core funding into equipping of the lab and into travel compensation for the experts in the production of and bonding to Kapton/Al microcables. These experts are our ALICE colleagues from Ukraine. The scheme was accepted and during 2002-2003 our research group has equipped the laboratory and acquired the needed know-how. The biggest single investment was a new fully automatic bonder (F&K Delvotec 6400). It was installed in June 2003 and already one month later a fully automatic bonding scheme for the ALICE components was successfully demonstrated in Helsinki. This breakthrough in the assembly has put the Helsinki laboratory into the front line of the ALICE SSD assembly project and we have remained there ever since.

More on the work of our Helsinki team can be found in HIP 2004 Annual Report and on the web pages of the Nuclear Matter Program (http://www.hip.fi/research/nucmat/index.html).

T0 detector

T0 is the fast timing and trigger detector for ALICE. It will give the key trigger- and timing signals, measure on-line vertex position and give rough centrality. Among the many technical challenges is the dead time below 25 ns needed to cope with the bunch crossing rate in p-p collisions, sustained count rate of 0.2 MHz, required time resolution below 50 ps, radiation hardness of up to



500 krad, operation in the 0.5 T magnetic field, compact design, high reliability and maintenance-free operation during the entire life-time of ALICE. It must be ready and operational from the day one. Data from T0 will be crucial not only for extraction of the precise interaction time but also for normalization between proton-proton and heavy ion runs.

In 2004 we have completed a major milestone towards the commissioning of the detector by publishing, jointly with FMD and V0, ALICE Technical Design Report (ALICE TDR-011, CERN-LHCC-2004-025, 10 September 2004). In this 150 page document the three forward detectors, their operation, electronics, readout and slow control are described in full detail. Our TDR includes the latest test results from in-beam experiment carried out in June 2004 at CERN with a mixture of 6 GeV/c negative pions and kaons. In that run we have tested the full electronics chain as it will be used in ALICE including the actual length of the signal cables for the final setup. In the measurements we have reached the new record in time resolution with Cherenkov detectors. By reducing the radiator's diameter to match that of the photocathode of the photomultiplier tube we have pushed down the resolution from 37 ps (our 2003 record) to 28 ps. It was achieved without the need of any off-line corrections. This result is better by nearly a factor of 2 from what other such systems were able to achieve. For instance, a very similar detector called Beam-Beam Counter that is part of the PHENIX experiment at RHIC reports only 100 ps on-line resolution and 50 ps after off-line slewing corrections (NIM A 411 (1998) 238).

One of challenges in the electronics design of T0 is the need to provide a wake-up signal to the Transition Radiation Detector (TRD) well in advance of the Level 0 trigger. The maximum acceptable latency of around 100 ns excludes the use of any electronics outside the magnet as the delay on the signal cables alone would be in excess of 250 ns. That means that the functional duplicate of the trigger electronics has to be designed and build for the use in the hostile and congested environment inside of the ALICE magnet. The key element of that arrangement is a fast amplifier unit. Currently we are testing prototype of the 3rd generation of this unit. It has been performing so well that ALICE Technical Board has recommended its use also for the V0 detector.

ALICE Tracking

Study of strange particle production in heavy-ion collisions is one of the main goals of the ALICE experiment. The motivation is based on the prediction that the density of strange quarks in quark-gluon plasma should approach that of light quarks, enhancing production of strange particles. In order to reconstruct hyperons and identify kaons via their decay topologies one has to detect their products in the tracking system and find the decay vertices. To do that, we have developed a method of finding secondary vertices and the kinematical reconstruction of the decay. We detect charged kaons and neutral strange particles using their kink and V0-like decay topologies in the Time Projection Chamber (TPC) of the ALICE setup. The main challenge in this work is a very high multiplicity expected in the Pb-Pb collisions at the LHC energies, resulting in a very high background. Nevertheless, the first results, based on the detailed simulations indicate the possibility of the successful identification of charged kaons and neutral strange particles using the ALICE TPC. The methods are being developed and tested with Monte-Carlo simulations using the ALICE software framework (ALIROOT). The preliminary estimates of the reconstruction efficiency, precision and background conditions are very encouraging.

Nuclear Reactions

In 2004 our team has used 1000 hours of beam time of the JYFL cyclotron. We have also participated in experiments at Dubna, Legnaro, Warsaw, Catania and ILL and made off-beam measurements totaling to about 200 days of data taking. Due to the limited space in this report it is impossible to cover all the aspects of our work so just a few selected highlight are given below.

Fusion-fission

In order to study influence of the entrance channel and deformations of the colliding nuclei on the competition between the fusion-fission and quasi-fission processes the reactions ^{40}Ca + ^{154}Sm and ^{48}Ca + ^{144,154}Sm were used. Our data suggest that the deformation of target nuclei plays an important role in the formation probability of the compound nucleus (CN), especially at energies near and below the Coulomb barrier. For the ^{48}Ca + ^{154}Sm reaction we have observed an asymmetric component in the fission-fragment mass distributions. A contribution of this component into the total mass distribution increases with respect to the symmetric CN-fission as the projectile energy decreases. For the ^{40}Ca + ^{154}Sm system we have found a quasi-fission “shoulder” in mass-energy distributions of fission fragments at energies near and below the Coulomb barrier as observed in ^{48}Ca + ^{154}Sm. In the case of the spherical ^{144}Sm target no quasi-fission manifestation was found at the same excitation energy and angular momentum as in the reactions with ^{154}Sm.

Most of the off-beam measurements were committed to Collinear Cluster Tripartition (CCT). We have shown, for example, that a simple hypothesis assuming central CCT fragment at rest is not correct. Instead, the latest JYFL data indicates that the effect observed initially at FOBOS is consistent with two of the 3 CCT participants flying out at a small relative angle. In this scenario one of the two parallel fragments is lost inside the supporting grids producing the reported missing mass effect. The same effect is seen also in the JYFL data obtained with a different experimental technique (MCP + silicon detector instead of gas-filled detectors). The missing masses coincide with the magic numbers and produce discernable peaks in the diagonal projection (constant missing mass). We are preparing new experiments to solve that puzzle.

Cluster radioactivity

Cluster radioactivity (CR) occupies an intermediate position between alpha-decay and spontaneous fission. More than a dozen of theoretical models were proposed for the explanation of this phenomenon. They describe CR either as an adiabatic "fission-like" or as a sudden two-step "α-decay-like" (cluster) process. Despite this fundamental difference between the two approaches, both models reproduce the measured decay probabilities quite well. The main reason for this paradox is that due to compensation of different factors determining the decay probability, the influence of the difference in the shape of the potential barrier between the "fission-like" and "α -decay-like" models becomes evident only deep below the barrier where the measurements are very difficult and data scarce and inaccurate. Thus, to reveal the real mechanism behind CR one should investigate sub-barrier fusion and get complimentary information on nucleus-nucleus potential. The extracted potential should reproduce both the fusion excitation function and cluster decay probability. At present there are only two available projectile-target combinations leading to the formation of compound nuclei with the measured cluster decay probabilities. These are $^{222}Ra \rightarrow {}^{14}C + {}^{208}Pb$ and $^{230}U \rightarrow {}^{22}Ne + {}^{208}Pb$.

At JYFL we have measured fusion cross section $^{22}Ne + {}^{208}Pb \rightarrow 230U^*$ with an array of solid-state track detectors. The analysis of the data was performed in the framework of the HIVAP code used also in the analysis of the $^{12}C + {}^{204;206;208}Pb$ excitation functions. The shape of the fusion barriers extracted from the data belongs to the family of cluster, or "α-decay-like" potentials,

and can be approximated by the Woods-Saxon form with the diffusenes parameter similar to that obtained in scattering experiments. Successful description of deep sub-barrier fusion in the ^{16}O and ^{22}Ne reactions allows us to propose the study of the $^{28;30}Si + ^{208}Pb \rightarrow ^{236;238}Cm^*$ reactions. The experiment is under preparation. The use of solid state track detectors demonstrated extremely high efficiency of the method (exceeding by 2 -3 orders of magnitude the known measurements of deep sub-barrier fusion), and the natural further step could be its application to studies with the radioactive beams (e.g., $^{34}Si + ^{208}Pb \rightarrow ^{242}Cm^*$, the reaction of large importance for understanding the cluster radioactivity mechanism). Moreover, it is of interest to test applicability of our approach to the analysis of deep sub-barrier cross section data obtained in symmetric combinations, for which some unusual limitations on fusion were recently revealed.

Scattering and nuclear structure

The studies of nuclear rainbow scattering in the ^{16}O + $^{12,14}C$ systems carried out at Jyvaskyla cyclotron resulted in observation of some new effects in nuclear dynamics (e.g., “abnormal nuclear dispersion”) and demonstrated the connection between experimental observables and some general properties of nuclear matter (effective nucleon-nucleon interaction, nuclear incompressibility). For the sake of generality and approaching to the conditions of infinite nuclear matter it was highly desirable to extend these studies to heavier projectile-target combinations. However, nuclear rainbow structures of the differential cross-sections have been never observed for the systems heavier than $^{16}O + ^{16}O$. We performed the exploring experiment with the aim to try to observe the rainbow effects in the $^{16}O + ^{40}Ca$ elastic scattering at ^{16}O energy 214 MeV. The estimates showed that in this case the number of nucleons in the region of nucleon density overlap will be 25 – 30, being three times more than in the former reactions. The angular distribution was measured in the interval 13° – 60° (cm). Two types of detection methods were used: $\Delta E - E$ method and kinematical coincidences. We have reached down to the 10^{-5} mb/sr cross section level and found a typical rainbow signature in the angular interval 45° – 60° (cm). The data are under processing, but it is possible to state already at this stage of analysis that for the first time the nuclear rainbow effect was observed in such a heavy projectile-target system as $^{16}O + ^{40}Ca$.

In the experiment at Warsaw cyclotron we have measured scattering of ^{20}Ne on ^{118}Sn. Contrary to theoretical expectations the data does not confirm presence of a structure in quasi-elastic barrier distribution. Also the suggestion of possible smoothing due to the strong α-transfer channels has to be rejected based on our latest $^{22}Ne + ^{118}Sn$ data.

Measurements with α-beam at JYFL have helped to probe the structure of light nuclei. In a joint effort of groups from Russia, Finland and Kazakhstan, energy dependence of the total reaction cross-sections for the reactions $^{4,6}He + ^{28}Si$ and $^{6,7}Li + ^{28}Si$ at energies E = 5 - 30 MeV/u have been measured. We are trying to find out, for instance, if ^{6}Li behaves the same way as the other light nuclei (4,6He and 7Li). The differences in the cross-sections may be explained by the halo structures of the light nuclei.

Energy loss

The need for precise energy loss data for heavy ions is apparent in many areas of basic and applied research. They require 1% accuracy level, at least in the vicinity of the Bragg peak, for a representative sample of ions and materials. Our 2004 measurements have brought us already close to this goal. The main remaining obstacles are inadequate quality of the stopping foils and lack of reference points for energy calibration. This situation may improve soon when the cyclotron operation in higher harmonic modes will become possible and energies below 2 MeV/u will become available.

Research

Accelerator based materials physics and industrial applications

Vladimir Tuboltsev, Ari Virtanen and Harry J. Whitlow

Accelerator based materials physics

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Industrial applications team:
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Petteri Lappalainen, MSc student
Sasha Pirojenko, MSc student

The experimental materials physics group started in August 2004. The main thrust of the work is directed towards the application of ion beams for Nanoscience and technology. The group thus acts as a bridge between the newly opened Nanoscience Centre and the Cyclotron Laboratory. The main themes of work have been: (i) the development of ion beam lithography on a nanometre scale, (ii) atomic and nanometre scale modification of material with ion beams and (iii) the application of radioactive ion beams from IGISOL for fundamental studies of diffusion. In addition some work on stopping measurements have been carried out.

Nanometre scale lithography using ion beams

The main effort has focused on planning a second generation ion beam lithography system for the Jyväskylä cyclotron. This use of the Jyväskylä cyclotron configured as an ion-on-demand system will enable patterns for e.g. biomedical tissue engineering substrates to be written using single ion tracks that are precisely positioned. In addition an off-line MeV proton ion source will be used to produce proton beams focused to spots of 10

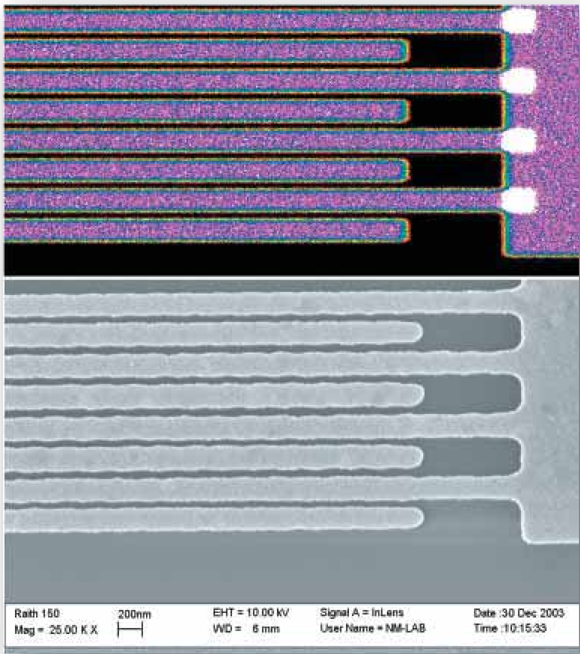

Fig. 1. (top) Simulated pattern dose distribution and (bottom) metal pattern after metal lift-off for lithography with 1 MeV protons.

http://www.phys.jyu.fi/research/ion-matter/index.html nm or so for writing extremely high-spatial density and high- aspect ratio patterns for nanoelectronics. It is noteworthy that such patterns that are needed in making of stamps for mass production by Nano Imprint Lithography are extremely difficult, or impossible to produce by other methods.

Modification of material on a nanometre scale with ion beams

KeV energy ion beams are very powerful tools for modifying nanometre scale materials because of the strong coupling between the ion and individual atoms along the ion path because of the Coulomb interaction between nuclei. We have instigated a collaboration with Pacific Northwest National Laboratory, USA on advanced technological materials. In the first project thin film cobalt silicide phase formation using filtered Metal Vacuum Arc disposition has been studied (Fig.2).

Ultra-narrow nanowires by ion beams

Low-dimension structures exhibit very often properties markedly different when compared to those of a bulk material. In a 1-D superconducting wire so-called

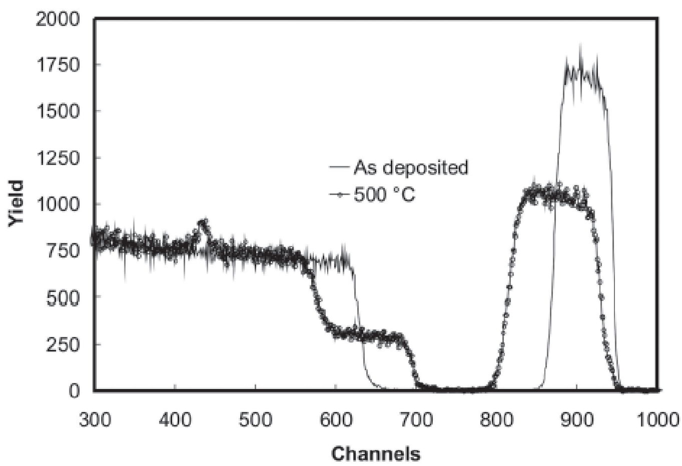

Fig. 2. RBS spectra showing reaction transformation from Co/Si to CoSi/Si structure.

quantum phase slip was theoretically predicted to occur that would manifest itself as breakdown of the superconductivity. Following the general trend of minimization, characteristic dimensions of the functional elements in modern technology constantly decrease on a nanometer scale. This imposes a fundamental limit on minimal size of superconducting components implying more strict compatibility constraints in the downsizing race. Though theoretically predicted, no solid evidences for the quantum phase slip have been reported so far. In our experiments ion beams have been applied to prefabricated Al nanowires for gradual thinning by sputtering. The critical temperature of transition to superconductive state was measured as a function of the wires cross section. Transition to superconductive state was no longer observed in the wires less than ~10 nm in diameter. The project has been carried out in collaboration with NanoScience Centre, University of Jyväskylä.

Fundamental studies of atomistic diffusion using IGISOL

Radioactive ions produced by IGISOL are a particular powerful technique for study of atomistic diffusion because the superior sensitivity implies the diffusion is considerable less sensitive to agglomeration of diffusing atoms to form immobile nanoclusters. Part of the activity of the group has been directed towards study of dopant species in SiGe alloys. In experiment A29 at JYFL, the diffusion of Pb in the surface layers of soda lime glass has been investigated. The diffusion behaviour of Pb isotopes in glass surfaces is of particular interest because the measurement of ^{210}Pb that is recoil implanted into the surface of glass is the basis of a new technique to measure radon exposure in dwellings over a period of 20-30 years. Besides, diffusion of some widely used in microelectronics dopants (Ga, Sn, Be and Er) has been measured in relaxed $Si_{1-x}Ge_x$ epi-layers with x ranging from 0 to 1.

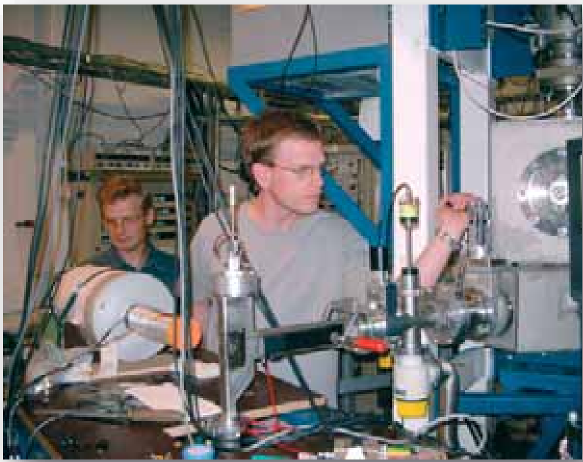

Fig. 3. Jörgen Ekman (Malmö) and Vladimir Tuboltsev loading a glass sample for irradiation at IGISOL during the A29 experiment

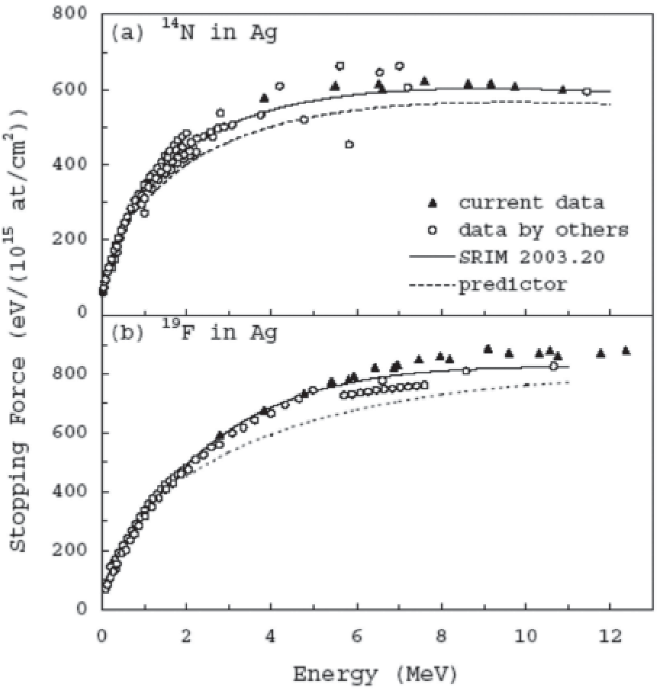

Fig. 4. Stopping data for ^{14}N and ^{19}F ions in Ag measured using the Pelletron accelertors at ANU and Lund.

Measurement of stopping in nanometre materials

In a collaboration that brings together the special competence and facilities of researchers from Australia, Asia and Europe the stopping force (dE/dx) has been studied using the polka-dot technique. This overcomes many of the difficulties associated the need for self-supporting stopping media.

Er implanted SiGe for optoelectronics

At present, there is an urgent requirement for new optical emitters compatible with conventional ultra-large scale integration (ULSI) silicon based technology. Since silicon is known to have an indirect gap, it is fundamentally inefficient light emitter when compared with direct gap semiconductors, e.g. GaAs. However, it is much more expensive to fabricate devices using III-V semiconductors because different processing is required and this is not compatible in general with contemporary silicon based technology. Silicon devices completely dominate the microelectronics market because of their low manufacturing cost. Optical properties of Er doped semiconductors have attracted a lot of attention due to potential application for fabrication of future opto-electronic devices. Virtually independent of the host matrix incorporated erbium in its trivalent state Er^{3+} emits light at a wavelength of 1.54µm that corresponds to the minimum of optical absorption of silica widely used in optoelectronic interconnections. By adding only few percent of germanium, SiGe allows to manipulate with electronic and optical properties. This makes SiGe a promising material for fabrication of next generation optoelectronic devices fully compatible with conventional ULSI silicon technology. Since ion implantation by nature is a non-equilibrium process, it can be used to extend the concentration of optically active Er atoms in SiGe alloys well beyond the terminal equilibrium solid solubility limit. Within the project structural, thermal and diffusion properties of Er implanted SiGe alloys have been studied.

Main Collaborators:
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Dr. T Weijers, Australian National Laboratory, Canberra, Australia
Dr. Heiko Timmers, Australian Defence Force Academy, Canberra Australia
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CERN/ISOLDE collaboration, Geneva, Switzerland

Industrial applications

Space related study

The increasing demands for radiation testing at accelerators attracted ESA and the space community to Jyväskylä some years ago. Initial test campaigns showed capabilities at RADEF that were not present at the Heavy ion Irradiation Facility (HIF) of Centre de Recherches du Cyclotron (CRC) of the Universite Catholique de Louvain (UCL), Louvain-la-Neuve, Belgium.

Higher ion energies resulting in much deeper ion penetration ranges allowed successful reverse side irradiation of thinned IC-components. Recognising that even more energetic ions could be produced, and the need for increased usability of the present setup, ESA placed a contract with JYFL for the development of a"High Energy Heavy Ion Test Facility for Component Radiation Studies". This contract, running for a four-year period, consists of an initial development phase and a later utilisation phase. The development phase started in August 2004, with the commissioning to take place in April 2005.

To draw customers' attention to RADEF, ESA also decided to organise its "QCA Final Presentation Days" in Jyväskylä in May 2005, first time outside ESA. In this connection ESA, CNES and RADECS-association will arrange a Thematic meeting on radiation effects with invited lecturers from among the experts of the community. The official inauguration of RADEF facility will take place on the third day. It is also worth mentioning that in RADECS'04 conference, held in September 2004 in Madrid, it was decided that the biannual 2008 RADECS workshop will be organised in Jyväskylä. All these events give extremely good opportunities to generate co-operation with the leading European space companies, organisations and universities.

Several organisations and companies visited Jyväskylä to carry out irradiation tests in RADEF during the spring. These include EADS Astrium and EADS Space from France and Germany, respectively, as well as the French CNES and ONERA. The last test before the upgrade was performed by Saab Ericsson Space for ESA.

During the upgrade period the biggest single investment has been a Travelling Wave Tube Amplifier (TWTA), which works in conjunction with ECRIS2. With the help of this transmitter a beam over 1 GeV was accelerated for a first time in the laboratory's history in December 2004. The particle spectra measured with a scintillator/PMT are shown in figure 1. The ECR2 with TWTA was used to produce $^{132}Xe^{33+}$ with the defined total energy of 1061 MeV. This way the stripping of 33 electrons was illustrated. Remarkable improvements in intensities of high charge state ions were seen and, e.g. the intensity of Xe^{31+} beam, increased by a factor of five. The improvement factor should be even higher for the higher charge states and the aim is to increase the beam energy over 1200 MeV and reach xenon's penetration of 100 microns in silicon.

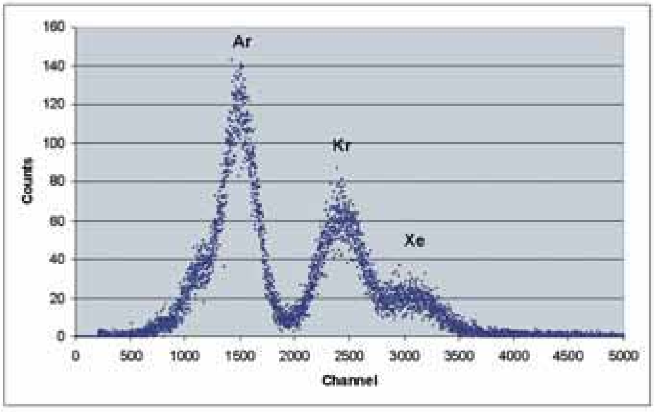

Fig. 1. The spectra taken from the Ar-, Kr- and Xe beams. The flat, but clearly distinguished peak corresponds to Xe with the energy of 1.06 GeV.

The upgrade started with the reconstruction of the RADEF beam line in a new cave. Figure 2 shows the sketch from the old and new cave installations. One can see that a totally new beam line for the proton tests will be constructed. Also, the new shack is shown and the location of the old one will be on top of it. In the photo of figure 3 the transfer of the new dipole magnet to its location is in progress.

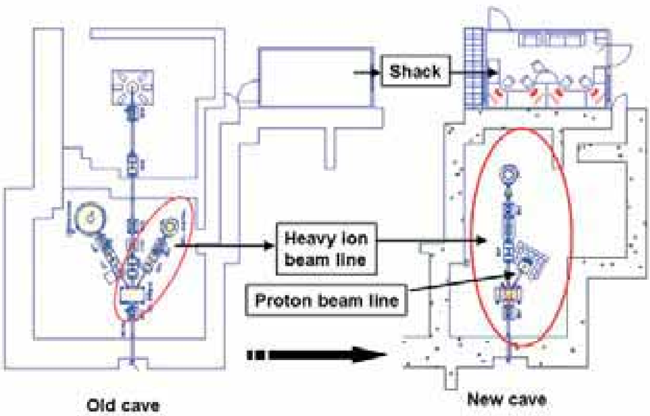

Fig. 2. The floor plan of the old and new test facilities.

The principle of a diagnostic procedure in the new beam line is shown in figure 4. A position sensitive avalanche counter (PSAC) monitors beam homogeneity and intensity. The diagnostic box includes also the four scintillator detectors equipped with the photomultiplier tubes. Their meaning is explained in the figure.

HEP related study

Another use of RADEF is done with the CERN/HIP collaboration, where the purpose is to develop radiation hard silicon detectors. They are widely used for track finding and particle analysis in large High-Energy Physics (HEP) experiments such as CERN LHC project. Radiation hardness of up to 10^{16} n_{eq}/cm^2 is required in the future HEP experiments. Two proton tests were performed last year in this collaboration.

Radio-medicine

The high-intensity proton beams, produced from the LIISA ion source, are used weekly in the production of ^{123}I radioisotope for MAP Medical Technology Ltd (a part of the international Schering group). This production covers the needs of radioactive iodine for the 20 largest hospitals in Finland. The ^{123}I based radio-medicines produced by MAP are mainly used in diagnosing brain-based diseases. They are also delivered for medical research work to many other European countries. Altogether 47 irradiations were performed during the year 2004.

Fig. 3. Graduate student Arto Javanainen and MSc student Mikko Rossi lying down the new dipole magnet into the new cave.

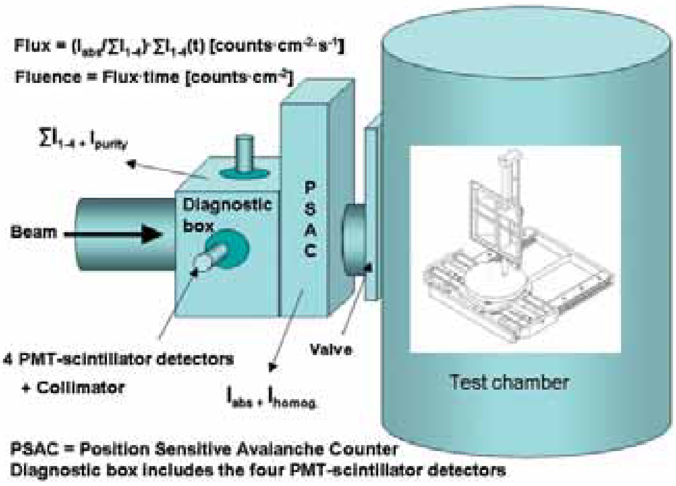

Fig. 4. The tasks of the dosimeter elements: PSAC measures the absolute intensity and homogeneity. The four PMT detectors are used to define the relative flux and the beam purity. A new linear movement apparatus inside the chamber is also illustrated. The fixture can be moved in x-, y- and z directions and can spin around the y-axis for irradiations of tilted components.

Other collaboration

Cooperation with several Finnish companies and organizations also continued. A positive funding decision for a joint project with a new partner, i.e. VTT Processes from Jyväskylä, arrived just before the end of the year. The project starts in February 2005 and is funded by National Technology Agency (Tekes). It contains studies of different radiation based analyzing techniques of biofuels.

Major national collaborators are:

Doseco Ltd.
Gammapro Ltd.
Jyväskylä Science Park Ltd.
MAP Medical Technologies Ltd. (belongs to Schering group)
Metso Paper Co.
Patria New Technologies Ltd.
Radef Research Ltd.
Tekes, National Technology Agency of Finland
VTT Processes, Technical Research Centre of Finland

Major foreign collaborators for industrial applications:

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C. Binois, T. Bouchet, EADS Astrium, France
J. Härkönen, K. Lassila-Perini, E. Tuovinen, Helsinki Institute of Physics/CERN, Geneva, Switzerland
F. Bezerra, Centre National d'Etudes Spatiales, CNES, Toulouse, France
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D. Falguere, T. Nuns, S. Duzellier, The French Aeronautics and Space Research Center, ONERA, Toulouse, France
L. Granholm, Swedish Space Corporation, Sweden
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Research

Nuclear Structure, nuclear decays, rare and exotic processes

Jouni Suhonen

Muon capture as a powerful probe of double beta decay

A reliable theoretical description of double-beta-decay processes needs a possibility to test the involved virtual transitions against experimental data. Unfortunately, only the lowest virtual transition can be probed by the traditional electron-capture or beta-decay experiments. We have recently proposed that calculated amplitudes for many virtual transitions can be probed by experiments measuring muon-capture rates to the relevant intermediate states. This process involves the capture of a negative muon from the atomic s orbital without emission of a gamma quantum.

Recently we have calculated double beta decays and the corresponding muon-capture rates for several light nuclei using the nuclear shell model with realistic effective interactions. According to our calculations the muon capture could be a powerful probe of double beta decays in light nuclei. These calculations predict a significant dependence of the double-beta and muon-capture rates on the structure of the wave functions of the low-lying intermediate states in the A=36, A=46 and A=48 double-beta chains.

Computation of detection rates for supersymmetric dark matter

Recent particle-physics theories seem to favour the lightest supersymmetric particle (LSP), the lightest neutralino, as possible constituent of cold dark matter (CDM) of the Universe. To chart the possible detector nuclei and their sensitivity to the LSP detection we have performed LSP-nucleus cross section calculations for the ^{71}Ga, ^{73}Ge and ^{127}I detectors. The first calculations were done by using the microscopic quasiparticle-phonon model (MQPM), originally developed by our group to study the structure of odd-mass nuclei from a microscopic point of view. Now we have improved both on the nuclear-structure part of the detector nuclei and on the accuracy of calculation of the detection rates for the LSPs.

The recent calculations have been done by using the large-scale shell-model framework for the above-listed nuclei. Since the scattering rate of the LSPs is spin dependent for the used odd-mass nuclei, the description of the magnetic moments of the ground states of these nuclei is extremely important. The shell-model framework has impoved this description considerably over the one of the MQPM. In our recent studies we have been able to parametrize the involved nuclear-structure ingredients in terms of the LSP mass and the detector energy threshold. Our tabulated nuclear-structure coefficients enable evaluation of the LSP detection rates for the above detector nuclei independently of the used

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Jussi Toivanen, senior scientist
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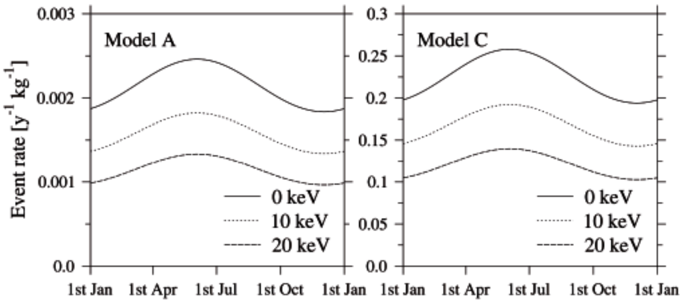
Sami Peltonen, graduate student

http://www.phys.jyu.fi/research/nuclear_theory/index.html parametrizations of the supersymmetric particle-physics models used to produce the LSPs. Hence, studies of detection-rate predictions via scatter plots of supersymmetric parameter spaces are easily accomplished. Study of the inelastic channels of the LSP detection is in progress.



The calculated annual modulation of the event rate in ^{127}I with three different detector threshold energies. The calculation was done by using two supersymmetric parametrizations (models A and C). The mass of the LSP was taken to be 110 GeV.

Systematic calculation of alpha-decay hindrance factors

We have performed a systematic, fully microscopic calculation of hindrance factors of alpha decays to excited 2^+ states in spherical and nearly spherical nuclei. The basic nuclear-structure framework consists of the use of the BCS method to create two-quasiparticle excitations and to use the quasiparticle random-phase approximation (QRPA) to take into account collective degrees of freedom in the alpha-decay daughter nucleus. A realistic G-matrix based effrective two-body interaction has been used in the studies. Several isotopic decay chains have been treated within this framework in order to study the interplay between the isoscalar/isovector part of the interaction and the electromagnetic and alpha-decay rates. A quite good simultaneous prediction of both the electromagnetic decay rates and the alpha-decay hindrance factors has been achieved. Further stadies are planned for scanning the decays to the first excited 0^+ states. These are processes of great experimental interest at the present.

Gamma and beta decays involving two-phonon states

Microscopic description of low-lying two-phonon states in even-even nuclei has been developed. The main bilding blocks are the quasiparticle random-phase approximation (QRPA) phonons. A realistic microscopic nuclear hamiltonian is diagonalized in a basis containing one-phonon and two-phonon components coupled to a given angular momentum and parity. The QRPA equations are directly used in deriving the equations of motion for the two-phonon states. The Pauli principle is taken into account by diagonalizing the metric matrix and discarding the zero-norm states. These methods constitute what is known as the Microscopic Anharmonic-Vibrator Approach (MAVA). In the MAVA the electromagnetic transition matrix elements are derived in terms of the metric matrix.

Recently an extension of the MAVA to describe odd-odd nuclei and their beta decay to the adjacent even-even nuclei has been accomplished. This model, known as the proton-neutron MAVA (pnMAVA), has been applied to describe beta-decay feeding of the low-lying collective states in the ^{106}Pd and ^{108}Pd nuclei.

Nuclear matrix elements for double beta decay from beta-decay data

Recently we have studied the possibility to extract useful information on double beta decays from the data on single beta decays. In particular, it is shown that the matrix elements of the neutrinoless double beta decay are better controlled by the beta decay data than the data on two-neutrino double beta decay. Resorting to data on two-neutrino double beta decays can lead to serious inconsistencies on the level of beta decays indicating that the thus obtained wave functions are not very reliable. At the same time the use of the data on two-neutrino double beta decay half-lives biases strongly the parameters of the calculations. To obtain more information of the flaws of the mentioned method further studies about the decomposition of the matrix elements of the neutrinoless double beta decay are being carried out. Dedicated experiments to measure the relevant properties of these matrix elements are proposed.

Recent progress in large-scale shell-model calculations with the EICODE

The shell-model code EICODE has been designed to carry out very large nuclear shell-model calculations. The parallel version of EICODE has become mature. It has been tested and it is now running in the IBM eServer cluster of the CSC (the Finnish IT organisation for Science). The serial version of EICODE has been used to calculate the approximate ground-state wave-functions of the medium-heavy nuclei ^{73}Ge, ^{71}Ga and ^{127}I. In addition to these truncated calculations, large unrestricted shell-model calculations for the accurate ground state and excited-state wave functions of these nuclei are currently being computed in the pfg shell. The results of these calculations will be published in the near future.

Large-scale computation with the MOVA model family

The MOVA (Monster-Vampir) model family is based on solid approximations of the exact many-body problem, potentially applicable on the entire chart of nuclei. Currently, the real mean-field MOVA models are being modified to allow userfriendly calculations globally on the entire chart of nuclei. Nuclear masses and energies of the first excited 2^+ states of all known doubly even nuclei are used as the first experimental data set to be studied. Preliminary results using a G-matrix as a two-body interaction are promising.

Research

Materials physics

Nanoscale physics and nanotechnology

Markus Ahlskog, Konstantin Arutyunov, Ilari Maasilta and Sorin Paraoanu

http://www.phys.jyu.fi/research/nanotech/index.html

The Nanophysics group is mainly dedicated to experimental research in some of the key issues in nanoscale or mesoscopic physics. Main activities are mesoscopic superconductivity, thermal effects in mesoscopic devices, and the fundamentals of solid state quantum computing. In addition, we have during 2004 begun research on the physical properties of single carbon nanotubes.

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Konstantin Arutyunov, senior assistant
Ilari Maasilta, academy researcher
Shadyar Farfanghar, senior researcher 1.7.-
Sorin Paraoanu, Marie Curie Research Fellow
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Jenni Karvonen, graduate student
Kimmo Kinnunen, graduate student
Panu Koppinen, graduate student
Minna Nevala, graduate student
Lasse Taskinen, graduate student
Maciej Zgirski graduate student
Asaf Avnon, MSc student
Chunrok Bae, MSc student
Ari Halvari, MSc student
Mohamed Hassan, MSc student
Jaakko Leppäniemi, MSc student
Jarkko Lievonen, MSc student
Kari-Pekka Riikonen, MSc student
Tarmo Suppula, MSc student
Tuula Walkeajärvi, MSc student
Lasse Väistö, MSc student
Antti Nuottajärvi, laboratory engineer

Thermal properties of nanostructures and radiation detector development

Ilari Maasilta

The main research direction of the thermal nanostructure research team is to (a) understand energy flow mechanisms from electronic to phononic degrees of freedom and within the phonon system in restricted, low-dimensional geometries, and (b) ulitize this knowledge in the development of ultrasensitive thermal and radiation sensors (bolometry).

Electron-phonon interaction in nanostructures

We have continued to utilize normal-metal-superconductor tunnel junctions (NIS) for ultrasensitive thermometry in sub-Kelvin temperature range. NIS-junctions can be used to characterize the electron-phonon (e-p) interaction in metals very accurately. Two main results have been achieved in 2004: (a) Measurements on numerous samples of varying disorder and different materials (Cu, Au) have confirmed our earlier observation of reduced strength of the e-p interaction in thin films. Unexpectedly, our results indicate that the longitudinal phonon modes are dominant, contrary to the theoretical prediction. (b) Novel ac measurement technique has been developed, where the e-p scattering rate can be measured directly without any fitting parameters. Using the new technique, the interaction can be characterized as a function of external parameters such as temperature, or in the case of non-equilibrium shape of the energy distribution. Since the dimensionality of the lattice should also have a strong effect on this interaction, work is in progress to measure the interaction in suspended membrane and wire geometries.

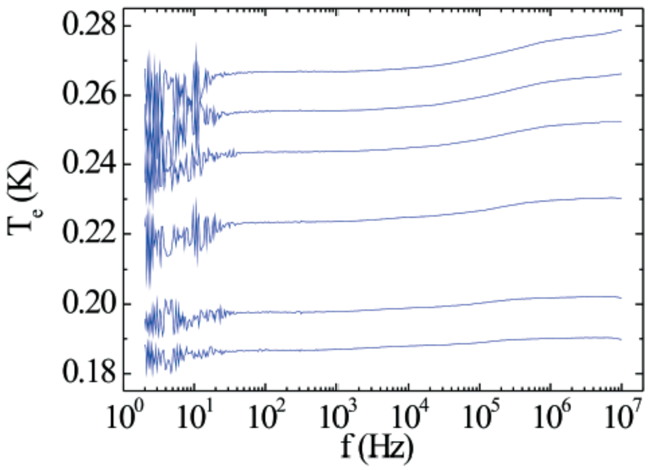


Fig. 1. Measured electron temperature in Cu as a function of ac heating frequency. The rise in temperature around 10 kHz- 1 MHz is caused by the fact that the heating becomes faster than the cooling rate due to e-p scattering. This cut-off frequency is a direct measure of the e-p scattering rate.

Thermal transport in insulating nanostructures

New Academy funded project has started, with a goal to study the quantum limit of thermal transport in insulating low-dimensional nanostructures. So far good progress has been achieved in fabricating narrow beams out of SiN (Fig. 2), and novel materials for this purpose are being developed in collaboration with the Indian Institute of Technology, Kanpur and UC Santa Barbara.

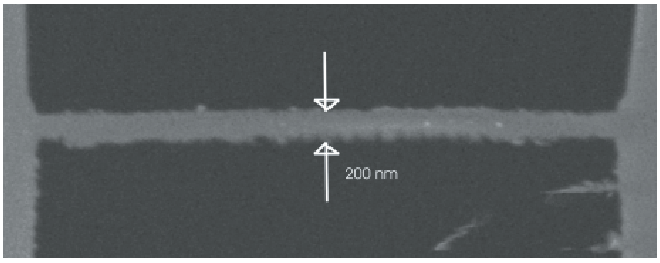


Fig. 2. A suspended SiN nanobridge of width ~200 nm. Note accidentally produced SiN nanowire in the lower right corner.

Novel solid-state cooler development

We have initiated a program to study novel superconductor-normal metal solid-state coolers based on aluminium doped with magnetic impurities (Mn) acting as a normal metal. The material enables one to produce coolers with wide variety of superconducting materials and large junction size. Initial experiments on Al-AlMn coolers have proven the feasibility of the fabrication

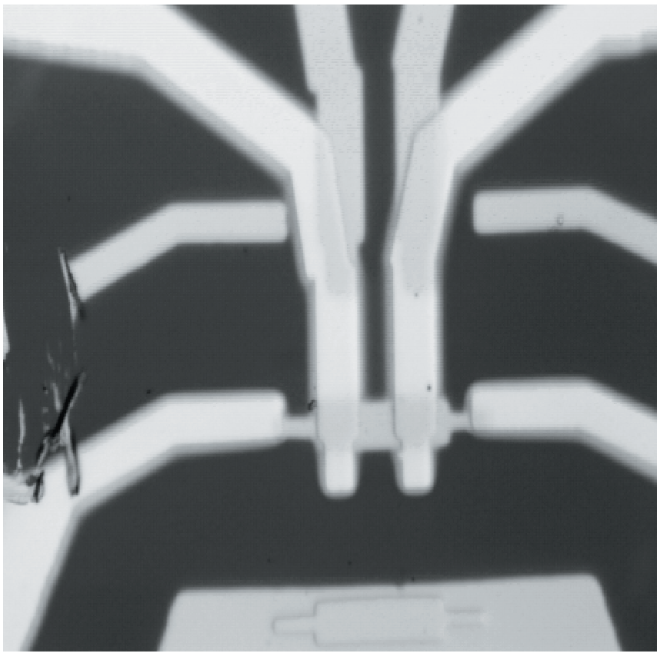


Fig. 3. SEM image of an Al-AlMn cooler. Junction size: 5 x 7 microns.

using evaporated Al-Mn, and reproduced the cooling efficiency of traditional Al-Cu coolers (10 pW cooling power). Using niobium, the temperature range of the cooler will be extended upwards to the technologically and commercially important 1.5 K range.

Superconducting Transition Edge Sensors (TES) for X-ray calorimetry

Superconducting transition edge microcalorimeter development continued with two different European Space Agency funded projects. The first project, in collaboration with Oxford Instruments, aims to optimise the performance of a single pixel in terms of energy resolution and speed. The long term goal for ESA is to develop a cryogenic imaging spectrometer in the 0.1-10 keV band with a few eV resolution, to be installed onboard a satellite (XEUS). Novel detector geometry development has continued, as well as optimisation of the SQUID preamplifier setup (SQUID work in collaboration with the National Institute of Standards and Technology (NIST) in Boulder, Colorado). In addition, a high speed digital data acquisition system has been installed, capable of 10 Msamples/s digitising of the X-ray pulses. New, dedicated software for the acquisition and digital filtering and data analysis has been developed. Theoretical work has concentrated on calculating the ultimate optimal energy resolution of such devices.

The second project is in collaboration with the Space Research Organization Netherlands (SRON), where the low-temperature (detector operating temperature 100 mK) thermal properties of the TES detector arrays are being investigated. The thermal conductance of SiN membranes used for the detector arrays as substrate has been studied. Results indicate that phonons are scattered only at the boundaries (radiative transport), and that the scattering is mostly specular. Work is also in progress to measure the thermal boundary resistance between the SiN film and the Si substrate (Fig. 4).

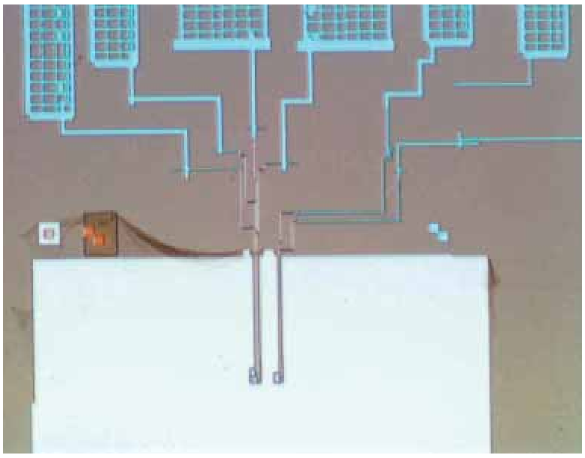


Fig. 4. A Sample for the measurement of thermal boundary resistance. Small blue dots are SINIS thermometers on a micromachined SiN pillar (gray), the light blue area is the exposed substrate (Si).

Superconducting Nb microbridge bolometer

A new TEKES funded project in collaboration with the VTT and Helsinki University started in 2004, whose aim is to develop superconducting sub-mm bolometers. We have succeeded in fabricating high transition temperature (7.5 K) novel microbridge bolometers out of niobium (active element) and gold (antenna), that together with the new ac SQUID readout developed at VTT is capable of reaching the ultimate sensitivity limit of photon shot noise (i.e. measurement noise is not limited by the detector or the readout, as is usually the case). In the future, actual optical measurements will be performed in collaboration with VTT.

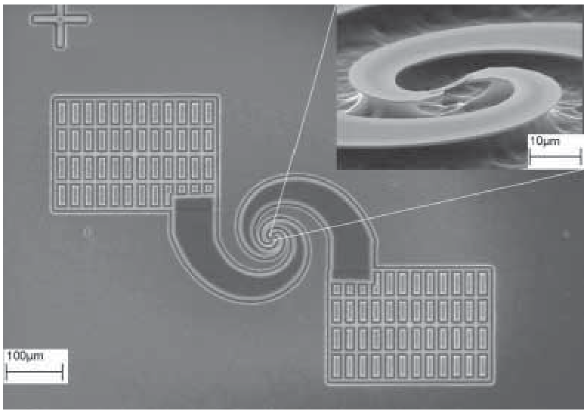


Fig. 5. Sub-mm Nb/Au air-bridge bolometer.

Mesoscopic superconductivity

Konstantin Arutyunov

Size Dependent Breakdown of Superconductivity in Ultranarrow Nanowires

Below a certain temperature T_c (typically cryogenic) some materials lose their electric resistance R entering a superconducting state. With the natural tendency of integration of greater number of electronic components it is desirable to use superconducting elements to minimize heat dissipation. It is expected that this basic property of a superconductor (dissipationless electric current) will be preserved at reduced scales required by modern nanoelectronics. Unfortunately, there are indications that there is a certain limit ~ 10 nm below which a 'superconducting' wire is not any more a superconductor in a sense that it acquires a finite resistance. The team led by Dr. Arutyunov has collected an experimental evidence of such a behavior in ultranarrow aluminum nanowires.

We have applied the method of Ar^+ ion bombardment for progressive reduction of a nanowire effective cross section by, enabling measurements of the same sample between the sputtering sessions . The original aluminum nanowires with typical dimensions 60 nm x 100 nm x 10 µm were fabricated on *Si* substrates using conventional e-beam lithography and e-gun evaporation of 99.995% pure aluminum followed by a lift-off process. An extensive scanning probe microscope (SPM) and scanning electron microscope (SEM) analysis was done to select structures without noticeable geometrical imperfections. Only those samples which showed no obvious artifacts on R(T) dependencies were further processed. The inset in Fig.1 shows the evolution of the wire geometry with sputtering. A remarkable feature of the method is that the low energy (~ 1 keV) Ar^+ ion bombardment provides 'smooth' polishing effect: the initial roughness of a structure is reduced (Fig.6).

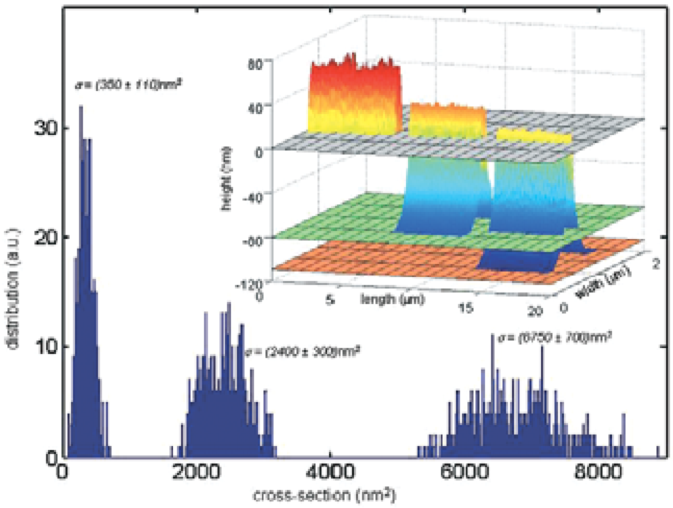


Fig. 6. Histograms showing the distribution of the wire cross section after a sequence of sputtering. To collect statistics about 500 SPM scans were taken across the wire with the step along its axis ~ 12 nm, which is comparable to the radius of curvature of the SPM tip. Narrowing of the histograms is due to the 'polishing' effect of ion sputtering. The inset shows the evolution of the sample shape while sputtering measured by SPM. Bright color above the grey plane corresponds to *Al*, blue one below the plane is *Si*. Planes (grey, green, orange) indicate *Si* substrate base levels after successive sessions of sputtering. As *Si* is sputtered faster then *Al* finally wire is situated at the top of *Si* pedestal. Grey plane (height = 0) separates *Si* from *Al*.

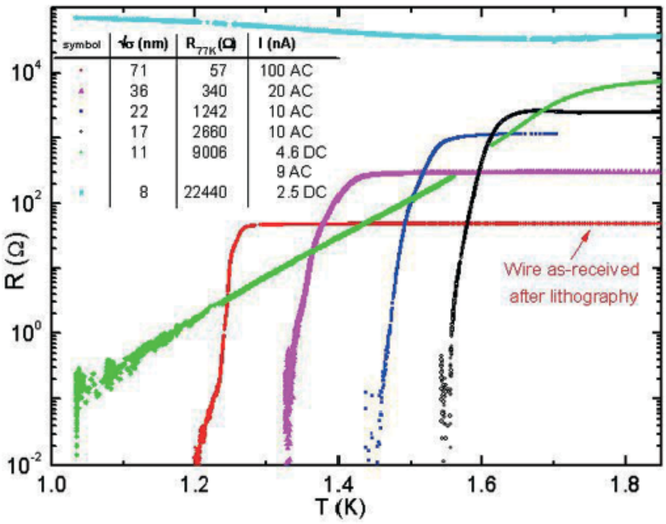


Fig. 7. Resistance vs. temperature for the *same* wire of length L = 10 µm after several sputtering sessions. The sample and the measurement parameters are listed in the table. For low-Ohmic samples lock-in AC measurement with the front-end preamplifier with input impedance 100 kΩ were used, for resistance above ~ 500Ω we used DC nanovolt preamplifier with input impedance ~ 1GΩ. The absence of data for the 11 nm sample at T ~ 1.6 K is due to switching from DC to AC set up. Note the qualitative difference of R(T) dependencies for the two thinnest wires from the thicker ones.

Fig. 7 shows an evolution of the R(T) dependencies of the same 10 μm long nanowire while a sequence of sputtering. It can be easily seen that for larger diameters (from $\sqrt{\sigma} \lesssim 17$ nm) the R(T) dependencies follow the same qualitative behavior: relatively narrow transition with quasi-linear slope in logarithmic scale. These experimental data can be fitted with a reasonable accuracy by theoretical calculations explained in terms of a 'conventional' model of thermally activated phase slips.

When the wire effective diameter reaches ~ 11 nm and the corresponding normal state resistance R_N ~ 9 kΩ, the shape of the R(T) dependence dramatically changes: it suddenly becomes much 'wider' (Fig. 2). Contrary to thicker wires, the shape of the transition cannot be fitted by the model of thermally activated phase slips at any reasonable set of parameters (Fig. 8). This much broader R(T) transition for thinner wires we associate with the quantum phase tunneling effect.

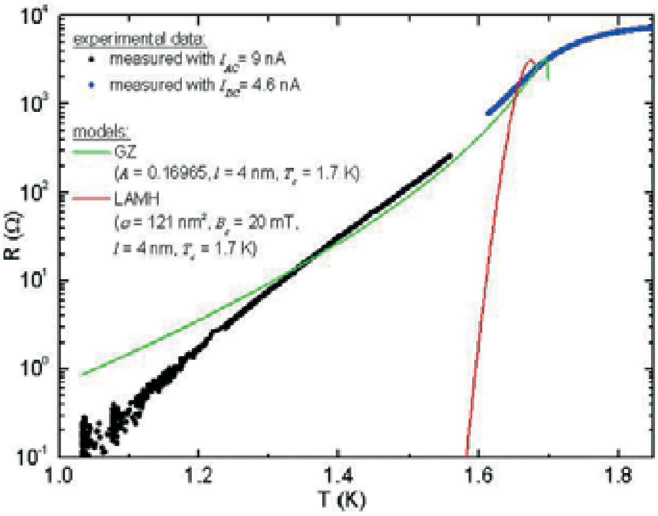


Fig. 8. R(T) dependence for the $\sqrt{\sigma}$ ~ 11 nm sample. Green line shows the result of fitting to renormalization theory with A, l, T_c being fitting parameters. The same set of parameters together with the critical magnetic field B_c measured experimentally is used to show corresponding effect of thermally activated phase slips on wire's R(T) transition (red line). The parameter σ is obtained from normal state resistance value and the known sample geometry. The estimation for σ is in a reasonable agreement with SPM analysis as well as with evolution of σ over all sputtering sessions (see Fig.7).

There have been several approaches for theoretical description of this phenomenon. Here we present a comparison of our data with the renormalization theory. The comparison of the calculations with our data is presented in Fig. 8. Taking into consideration the simplified 'short wire limit' approach, the correspondence between the model and the experiment can be considered as satisfactory.

The effect of quantum phase tunneling should have a universal validity for all superconducting materials. Apart from *Al* other materials (*Sn, In, Pb*) are in the list of our current study. The study of quantum fluctuations phenomenon suppressing superconductivity in ultranarrow wires is of a vital importance for future development of nanoelectronics. It puts a fundamental limitation to utilization of superconducting nanoelements designed to transport a dissipationless electric current.

Normal Metal – Insulator – Superconductor Mesoscopic Interferometery

To some extend one may treat a metal ring with two probes as a solid-state analogue of an optical interferometer. One node can be considered as a beam splitter (bi-prism, for example), and the electric current at the other node as an equivalent to a light intensity of an interference pattern formed at a screen. We observed an interference of nonequilibrium quasiparticles injected into a superconductor. Two types of nanostructures were fabricated. First is a superconducting fork (Al) shorted by a normal metal bar (Cu) through two parallel tunnel barriers (Fig.9).

Second one is a complete aluminium loop with an overlapping copper electrode above the oxide layer (Fig.11, inset). The area of the loop varied from 0.5 to few hundreds of square micrometers. Both structures showed a typical current-voltage characteristic of a normal metal – insulator – superconductor structure. Application of a perpendicular magnetic field B at a

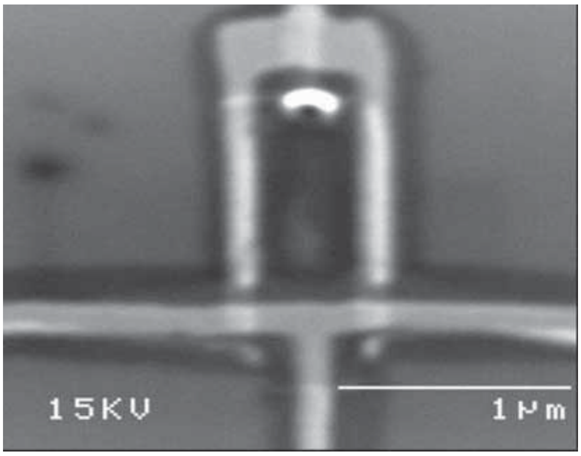


Fig. 9. SEM image of a solid state 'double-slit' interferometer.

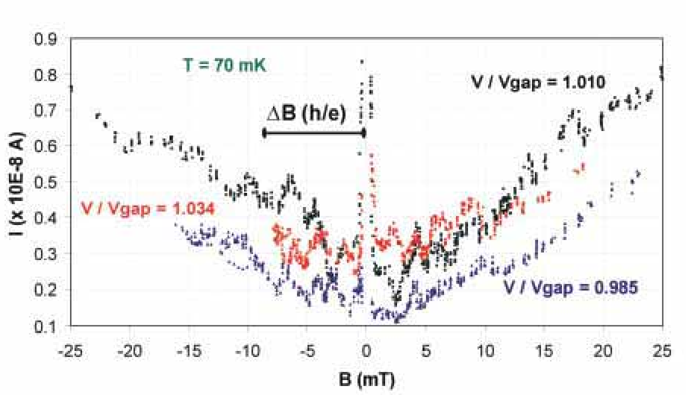


Fig. 10. Fraunhofer-type interference pattern in a 'double slit' system: oscillation of a tunnel current as a function of perpendicular magnetic field .

fixed voltage bias V_b causes periodic modulation of the tunnel current (Fig. 10 and 12). The period of the oscillations does not correspond to one flux quantum enclosed by the area of the loop. The magnitude of the tunnel current oscillations I (B, V_b = const) depends on the bias voltage, showing a non-monotonous behaviour. Maximum current modulation is obtained at bias voltages comparable with the superconducting gap voltage, corresponding to intensive injection of 'hot' quasiparticles into a superconductor. Both structures can be considered as the solid-state analogues of the optical interferometers: double slit and Michelson, correspondingly.

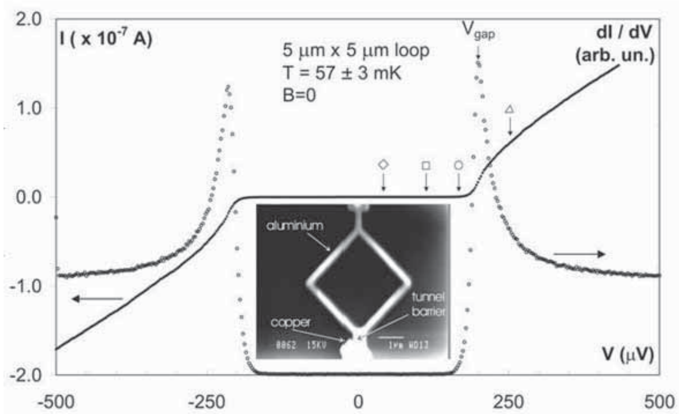


Fig. 11. Typical I(V) and dI/dV(V) characteristics at zero magnetic field. Arrows indicate the bias voltages at which magnetic field sweeps were made. Inset: SEM image of a typical 'beam splitter' interferometer.

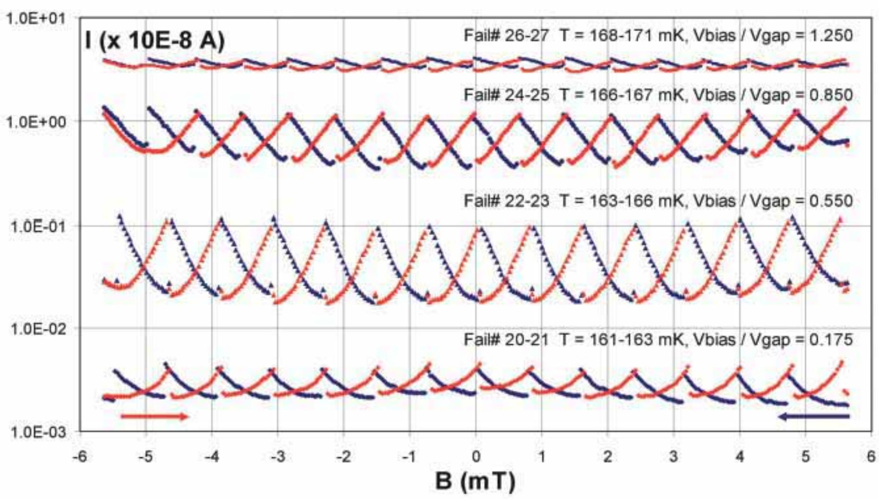


Fig. 12. Example of I(V=const, H) dependencies taken at T = 166 ± 6 mK at various voltage biases, normalized by the gap voltage V / V_{gap}. Arrows show the direction of the field sweep at Fig. 11.

Quantum Engineering

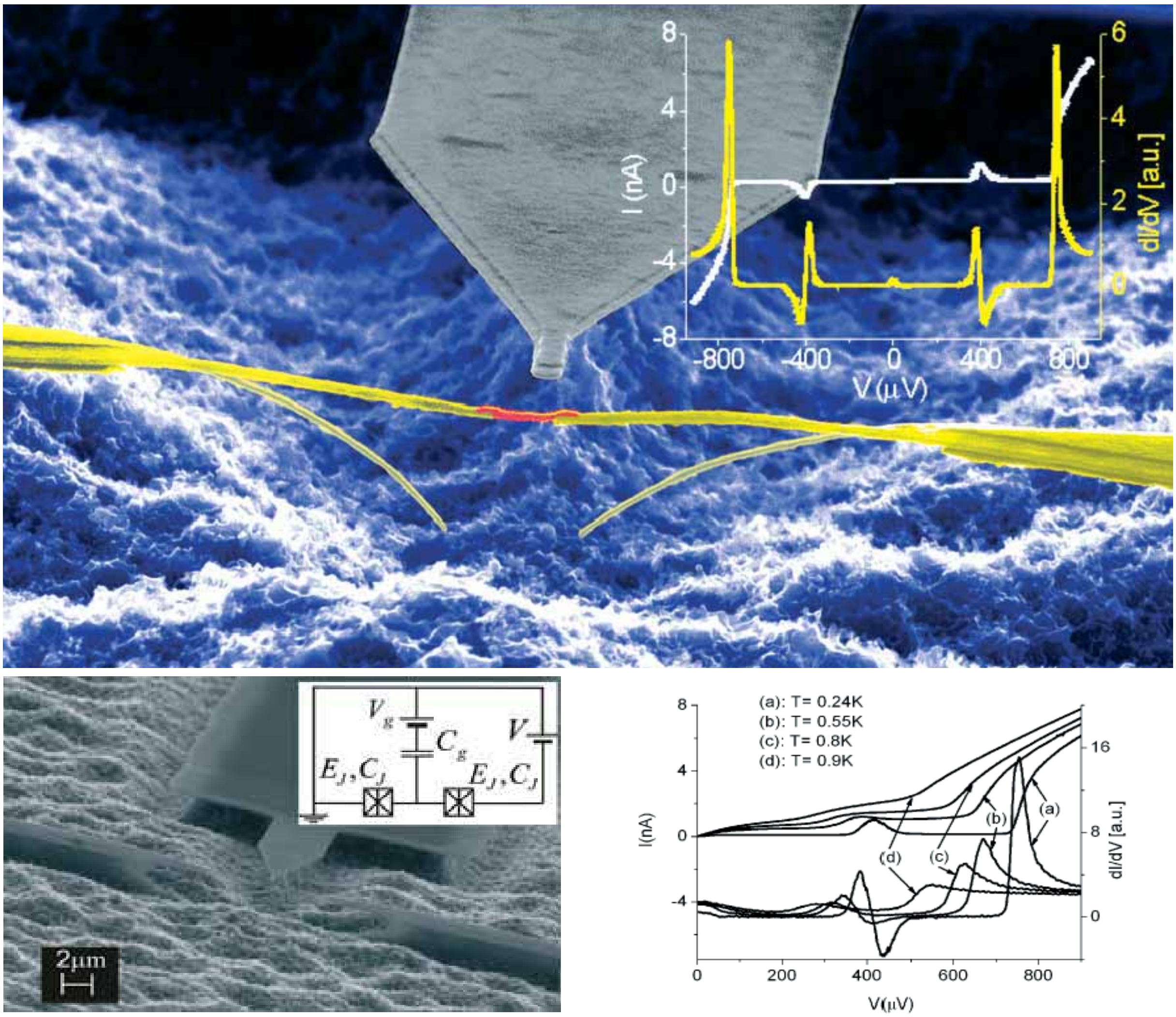
Sorin Paraoanu

The Quantum Engineering (QE) team the Nanophysics group (S. Paraoanu, A. Halvari, and M. Hassan) has been doing research on transport phenomena and quantum coherence effects in superconducting devices based on the Josephson effect.

Suspended nanoelectronics devices

In continuation of our work on suspended SET's (Fig. 13) we have analyzed the behavior of the device at various temperatures. The motivation of this project is to fabricate a very sensitive charge sensor for quantum computing experiments. Nano-electrometers with sensitivities close to the quantum limit have been demonstrated recently: but they have to be operated in the r.f. regime at a frequency higher than the noise coming from the silicon oxide substrate. This introduces a lot of complications and makes the electrometers in

Fig. 13. A suspended superconducting single electron transistor was fabricated for the first time in our team (up). The island in the middle (red), barely visible in this coloured SEM picture as an extremely thin line, is suspended above the substrate and it makes contact with the left and right electrodes (yellow) through two small Josephson junctions. The electrode coming from above (grey) is the gate, which is coupled capacitively to the island. The inset shows the IV and dI/dV of this structure, with perfectly defined Josephson, JQP, and quasiparticle currents. Right-low: larger scale structure and schematic (inset). Left-low: I-V's at various temperatures.



general impractical. If there is no substrate at all, there will be presumably less of the 1/f noise that hampers the functioning of these electrometers at low frequencies.

Reference: G. S. Paraoanu and A. M. Halvari, Applied Physics Letters (in press). Paper selected by the editor for the cover of the 28th Feb. issue.

Andreev tunnelling

A significant experimental problem in Josephson-based quantum bits is the existence of open transport channels in the junction; these are responsible for Andreev-type currents that would produce dephasing and decoherence in a superconducting qubit. In the case of Nb junctions, we have analyzed the resulting density of states associated with these channels in magnetic fields and at various temperatures. A typical sample is shown in Fig. 14. We are also studying the electrical noise in these systems, in collaboration with the NanoElectronics group. (Sample fabrication: A. Halvari; measurements, data analysis: S. Paraoanu).

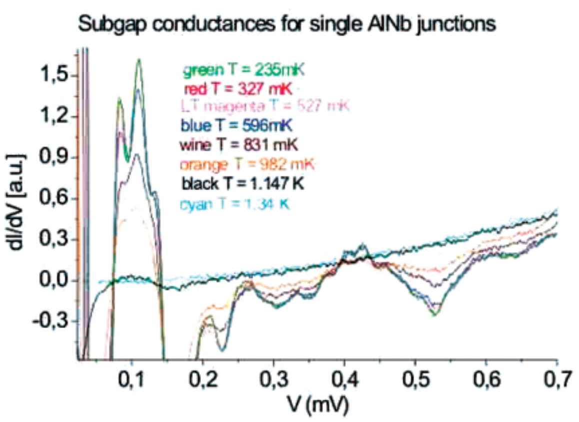


Fig. 14. Conductance versus bias voltage for a single Al-(AlOx)-Nb junction, for subgap bias voltages. The threshold voltages at which each of these transport channels opens changes from sample to sample, but, for a given one, they are temperature-independent.

Fast-pulsed switching current measurements

We have made preliminary measurements of the switching probability of a current-biased Al-Nb-Al SET (Fig. 15) with relatively large Josephson energy. (Sample fabrication: A. Halvari; measurements: S. Paraoanu; data analysis: E. Blair and S. Paraoanu).

Running-phase state

We have studied theoretically the structure of the macroscopic wavepacket resulting from MQT in Josephson washboard potentials. For idealized underdamped junctions, the wavepacket and the average of observables such as voltage can be calculated (Fig. 16). Surprisingly, although the problem looks an analytically complicated

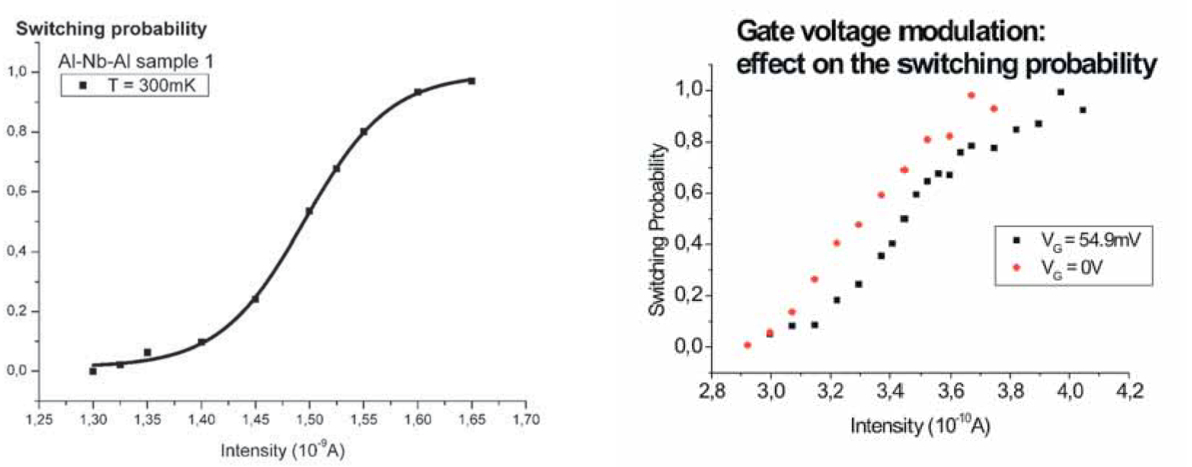
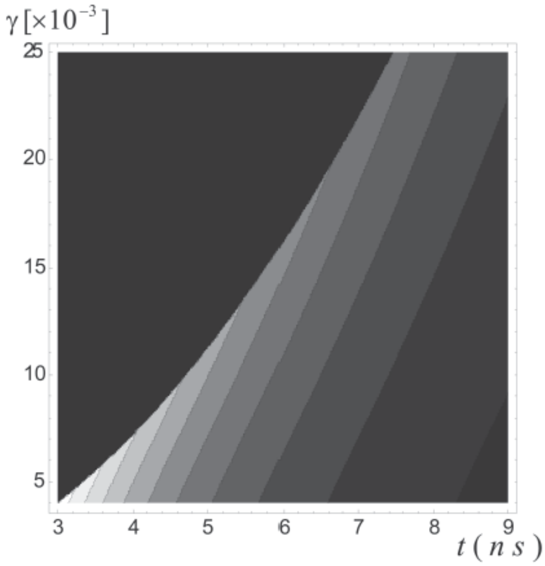


Fig. 15. Measured switching probability of a Nb SET (left) and the effect of the gate on the switching probability (up right).



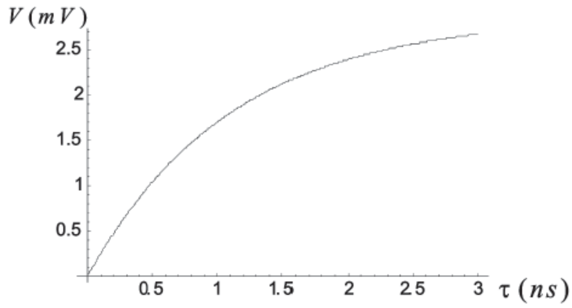


Fig. 16. Left: average voltage in an ideal switching-current experiment with duration τ of the current pulse. Right: Contour plot of the probability in the phase-time coordinates for the running-phase state.

question in scattering theory, closed forms for all expressions involved can be obtained with suitable approximations.

Reference: Gh.-S. Paraoanu, "Running-phase state in a Josephson washboard potential", cond-mat/0501280.

Flux qubits: fabrication issues

Future quantum computers will consist of relatively large number of qubits; in the case of superconducting qubits, scalability implies also the possibility of making identical qubits.

For flux qubits of the 3JJ type we have made some test samples (Fig. 17) to see how identical we can fabricate the qubits: each qubit was imaged with SEM and AFM, with the result that they were all functional (good junctions) and identical enough with respect to the shape and areas of the junctions formed. With a more advanced e-beam lithography system due to be installed at JyU in 2005 we hope we can achieve an even better degree of similarity. (Sample: M. Hassan and A. Halvari).

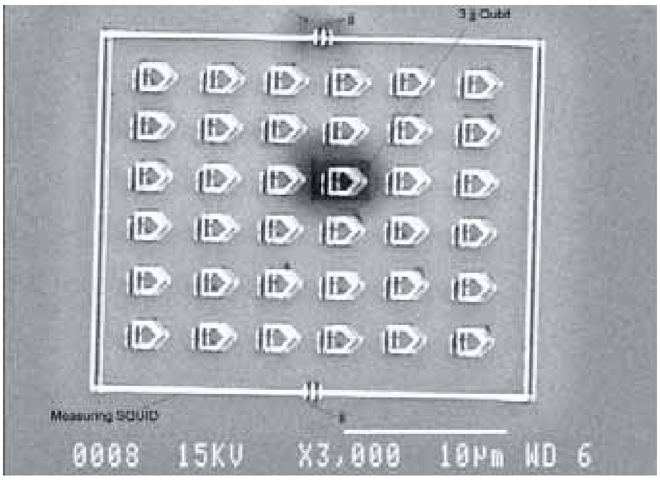


Fig. 17. A system of 36 flux qubits encircled by a dc SQUID loop. Each qubit is a ring interrupted by 3 small junctions.

On-chip qubit initialization

We investigate, in the QE team, a system consisting of two capacitively coupled Josephson junctions, separated by the rest of the measurement setup by on-chip resistors (Fig. 18). Similar circuits have been used as coupled phase qubits and for sensitive noise measurements. We plan to study the possibility of using one junction as a signal generator (when voltage-biased, via the standard Josephson effect, there should be a microwave radiation being generated) and the other as a qubit to be controlled. (Sample: A. Halvari).

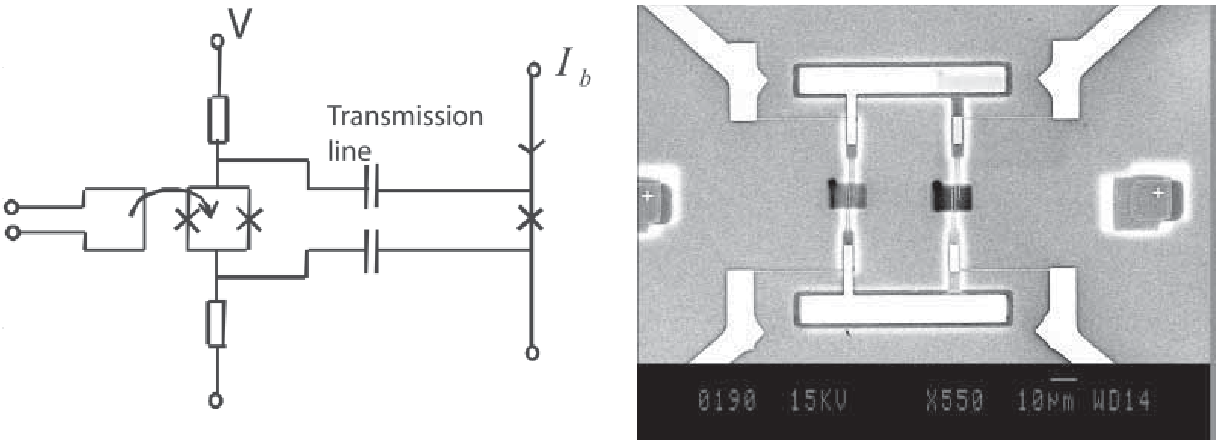


Fig. 18. Left: Schematic of the experiment envisaged: the left SQUID generates a microwave signal which is transmitted to the right junction. Right: SEM picture of the sample. The junctions are in the dark areas in the middle of the picture. The capacitors are the two white rectangles; the Pt resistors are barely visible as thin horizontal lines.

Photonic crystals

In the QE team we have fabricated and measured a microwave photonic crystal that displays a negative index of refraction (Fig. 19). The device can have applications in radar technology (ultra-efficient antennas with resolution above the diffraction limit). In our case, the interest in this system comes from the need to understand and design on-chip microwave resonators.

Reference: S. Ylinen, research report (erikoistyö).

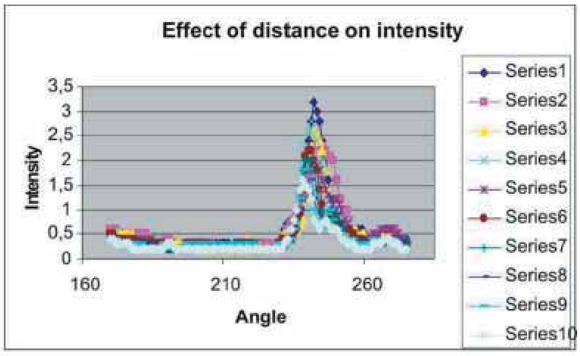


Fig. 19. Data showing the intensity of the emergent beam from a microwave photonic crystal as a function of refraction angle. The peak corresponds to a negative index of refraction. Different colors show the intensity at various distances from the crystal, thus checking that the phenomena is not an accidental interference effect, but indeed a beam is emerging from the structure.

Carbon nanotubes

Markus Ahlskog

The research activity on carbon nanotubes (CNT) was begun during 2004. During 2004 three Master's Theses were begun within this topic. Carbon nanotubes are seen as one of the main components in future nanotechnology and already today as a superb system in which the phenomena of nanoscale physics can be investigated. The carbon nanotube consists of one or multiple concentric shells of seamless graphite sheets. A single wall nanotube (SWNT) has a diameter of 1-3 nm while the multiwalled nanotube (MWNT) may have any diameter in the range of 2-50 nm. Depending on the wrapping angle of the graphite sheet (chirality), an individual nanotube can be either metallic or semiconducting. A fact of fundamental importance is that the charge carriers in nanotubes of all sizes are truly delocalized. Ballistic conduction over μm-sized distances have been measured in carbon nanotubes. The axial Young's modulus of an individual nanotube sheet is approximated by the in-plane modulus of graphite (≅ 1 TPa), which makes the carbon nanotube one of the stiffest material that exists. A single carbon nanotube is thus an excellent freestanding electrical conductor. In the very near future we will concentrate on the carbon nanotube. However, nanotubes and nanowires (with solid core) based on other elements besides carbon have also attracted attention. The research methods to be developed will enable us to study these as well in the future.

The electronic and mechanical properties of CNTs are likely to be significant in micro- and nanoelectromechanical systems (MEMS & NEMS) that are currently being vigorously investigated for advanced technological applications as oscillators, bandpass filters and other components in microelectronic circuits. Nanoelectromechanical systems also have a demonstrated capability for novel measurements and detection methods in fundamental physics and related sciences. NEMS has been pursued by advanced processing techniques within traditional semiconductor technology. More recently, the CNT has been forwarded as the active element in NEMS.

We will concentrate on the study of single carbon nanotubes and therefore the methods for preparing suitable samples of individual tubes are particularly important. This has also been among the themes for the Master's theses. In particular, a variety of methods to produce suspended nanotubes is of interest, since this is the starting point for CNT based NEMS devices. Figure 20 shows an AFM image of a MWNT suspended between two gold lines. Future work will be devoted to develop detection methods for the mechanical vibrations of the suspended tube.

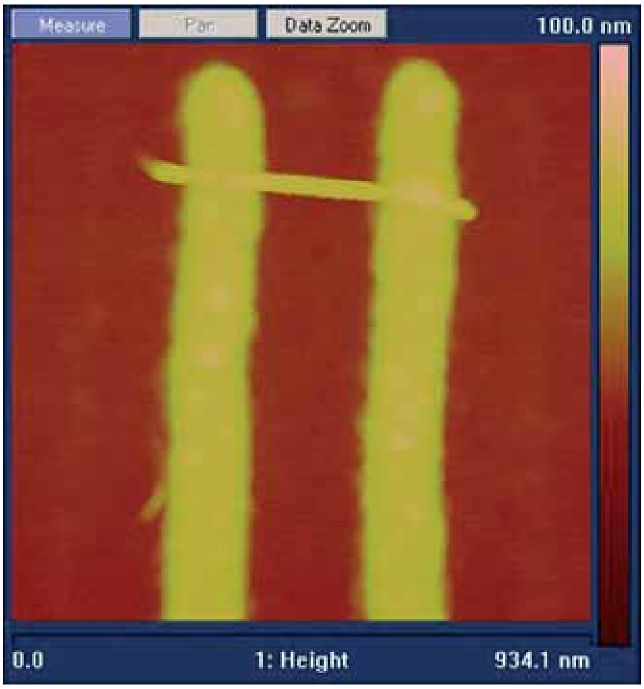


Fig. 20. A short multiwalled carbon nanotube suspended between gold lines.

Research

Nanoelectronics and nanotechnology

Päivi Törmä

Ultracold atomic Fermi gases

The year 2004 witnessed dramatic development in the experiments on ultracold alkali gases of the fermionic isotopes. The Bose-Einstein condensation (BEC) of molecules formed out of fermions was achieved by several groups and strong evidence for the fermionic BCS-condensation was obtained.

We have proposed the use of on- or near-resonant light or RF-fields to probe the energy spectrum, the excitation gap and the order parameter in order to detect the superfluid transition of the atomic Fermi gas. This method was used in an experiment at Innsbruck University and the excellent agreement with our theoretical calculations strongly suggests that BCS-transition was indeed achieved. The experimental results as well as our theory work were published in Science and chosen among the highlights of 2004 by Physics World. Also Science listed the Fermionic condensates among the top ten scientific breakthroughs of the year.

Diluteness and the purity of atomic gases offer ideal tools for studying fundamental quantum statistical and many-body physics. By applying a magnetic field on the atomic cloud, one can study BEC, BCS and the crossover regions, offering an excellent test ground for e.g. theories of high temperature superconductors. We are continuing our work on RF spectroscopy to construct quantitative tests for different versions of BEC-BCS crossover theories relevant for high-T_c physics.

Trapping the cloud of fermions in a periodic optical potential allows one to study several intriguing quantum transport phenomena. We have studied Bloch oscillations for degenerate and superfluid Fermi gases, and the effect of the BCS-BEC crossover on the amplitude of the oscillations. On the other hand, combining the optical lattice with a harmonic trapping potential makes the quantum transport of free Fermi atoms differ crucially from Bloch oscillations, as shown by the reasonably good agreement between our simulations and the experiments.

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Janne Haatanen, MSc student
Lasse Hirviniemi, MSc student
Anton Kuzyk, MSc student
Mikko Leskinen, MSc student
Markus Rinkiö, MSc student

The group belongs to the Nanoscience Center (NSC) of the University of Jyväskylä.

http/:www.phys.jyu.fi/research/electronics/

Fig. 1. The group in its new lab at the Nanoscience Center, opened 2004.

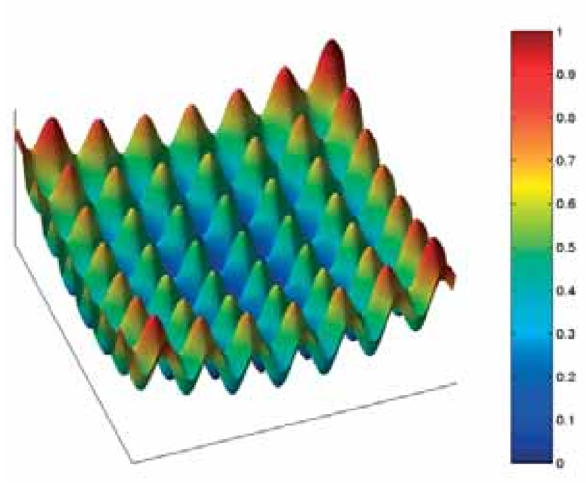

Fig. 3. Optical lattice combined with a harmonic trap.

Fig. 2. Dr. Cheng Chin visiting Jyväskylä. The Innsbruck experiment (Chin et al., Science 2004) on Fermion condensates was chosen among the top ten breakthroughs of 2004 by Science and Physics World. Our work (Kinnunen et al., Science 2004) provided the theoretical framework to understand the experiment.

The use of the optical potential increases the effective mass of the atoms and therefore the critical temperature of the BCS transition. Experiments on such systems are likely to be done in the near future. We are currently studying the density as well as the spin response of the superfluid Fermi gas in an optical lattice, in search for experimental signatures for the expected transition.

Molecular electronics: dielectrophoresis and conductivity measurements of DNA

Considering the sequence-specific DNA recognition applications as well as the potential use of DNA as a self-assembly component in future molecular electronics, the electrical conductivity of double helical DNA is an essential property. The variety of experimental results on DNA conductivity reported in literature may be due to electrical properties of DNA being sensitive to deformations of the double helix structure, caused, e.g., by ambient conditions or interactions with the

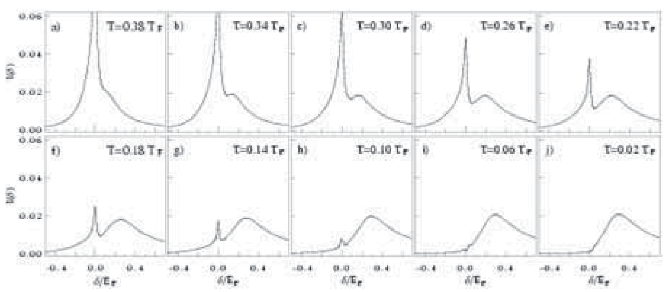

Fig. 4. The spectra of the RF-transition of the trapped atomic Fermi gas. The peak at zero detuning corresponds to free atoms at the borders of the trap and the shifted peak shows the excitation gap of the paired atoms providing signatures of a Fermion condensate.

substrate surface. We are aiming at highly reproducible conductivity measurements, eventually at the single molecule level, to further investigate the effects of varying conditions, role of contacts and potential signatures of single base pair mismatches in conductivity.

Fingertip type nanoscale gold electrodes (Fig. 5) with about 100 nm separation were fabricated using electron beam lithography. We use so-called dielectrophoresis, i.e., the lateral motion of polarisable particle in non-uniform electric field, for trapping of 414 base pairs long (about 140 nm) double-stranded DNA between electrodes, after which conductivity measurements are performed. Thiol-modified natural dsDNA which had a thiol group, i.e., −SH, in both ends was obtained by using 5'-thiol-modified oligonucleotides as primers in the polymerase chain reaction (PCR).

We have succeeded to trap a small amount of DNA molecules between the electrodes (Fig. 6) with several samples. Conductivity measurements so far have shown the insulating behaviour (R_{DNA} ~ TΩ) for DNA on the substrate surface in dry air but low resistance for the same DNA in moist air conditions.

Preliminary studies of using carbon nanotubes in molecular electronics have also been done, with the goal of using nanotubes as nanoscale tweezers for molecular manipulation, e.g. as nanometer-scale electrodes yielding large gradients in the applied electric field and therefore more effective dielectrophoresis.

The research has been done in collaboration with chemists and biologists at NSC.

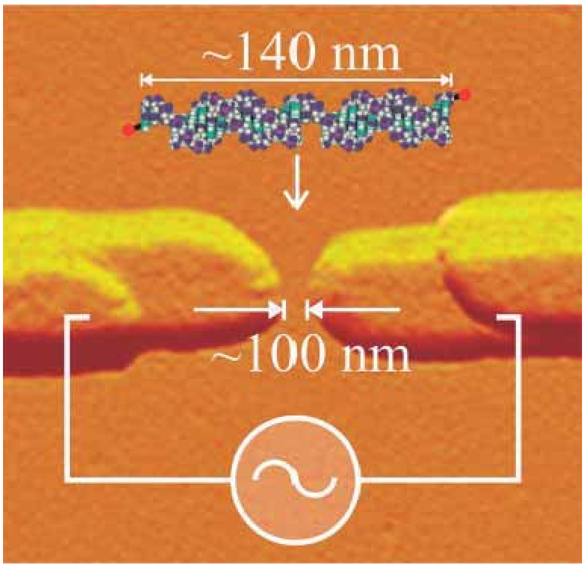

Fig. 5. AFM image of the fingertip type electrode nanostructure and experimental setup for dielectrophoresis of thiol-modified DNA helices. Note that the picture of DNA is not in scale.

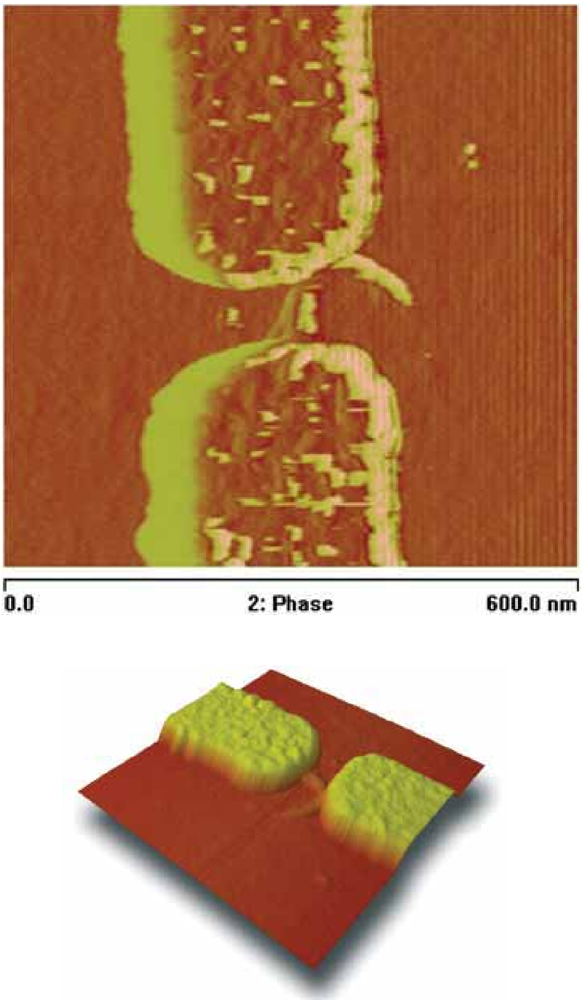

Fig. 6. AFM images of DNA molecules trapped between electrodes.

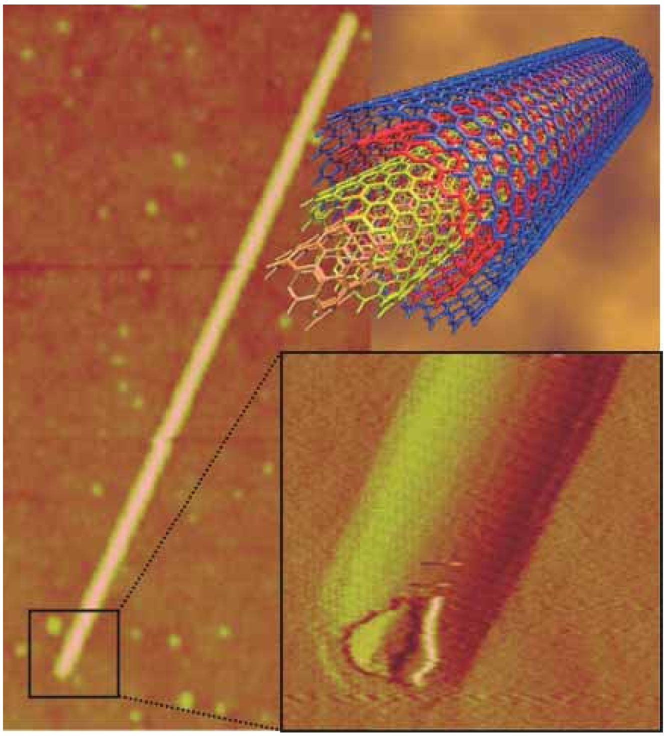

Fig. 7. AFM image of a multi-walled carbon nanotube (MWNT). Open end of the nanotube, displaying multiple layers, can be seen in the image.

Nano- and microsensors

We have developed nano- and microscale sensors for scientific and industrial applications. E-beam lithography, thin film deposition and reactive ion etching methods are used to further scale down the conventional sensor applications for more cost-efficient fabrication and to invent novel sensing techniques based on purely nanoscale phenomena.

The have developed an integrated optical and micromechanically fabricated electrical sensor for monitoring chemical changes in an industry application. Microcontroller-based smart sensor measuring system was designed and engineered to a stand-alone sensor. Field-testing of the prototype sensor is presently under way. The research has been done in cooperation with industry.

Temperature sensors based on metal-insulator-metal junctions and other solutions have been developed for thermometry of biological microsystems. The sensitivities and noise properties of the sensors have been investigated both theoretically and experimentally to compare the applicability of different sensor types for ultrasensitive thermometry. Attempts have been made to minimize the thermal conductivity and mass of the sensor by modifying the substrate. The small thermal mass and conductivity allows the monitoring of very rapid variations of temperature. Also the measurement electronics has been under development in order to minimize the noise contribution of the measurement setup. The research has been done in collaboration with biologists at NSC.

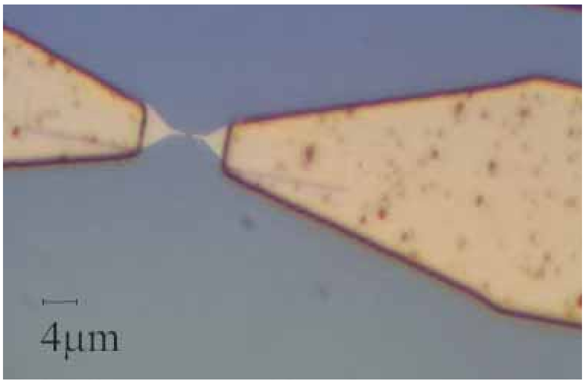

Fig. 8. Optical micrograph of a fabricated sensor. The large wires create the contact between the bonding pads and the sensing junction.

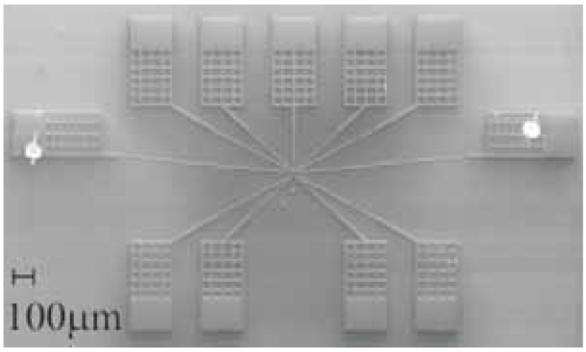

Fig. 9. SEM micrograph of the fabricated metal-insulator-metal sensor array. The contact pads are connected to metal islands between each junction, which enables the measurement of the temperature gradient.

Electron-phonon interaction in silicon at sub-Kelvin temperatures

Our results open the opportunity to modify the electron-phonon thermal conductance in Si by varying the doping level. For comparison, the corresponding value for the electron-phonon thermal conductance in Cu is roughly two orders of magnitude higher. This makes Si-based cryogenic applications, such as hot-electron bolometers or electron refrigerators, very promising.

We have investigated the electron-phonon thermal resistance in silicon-on-insulator films in the heavily doped region. The experiment was carried out by electrically heating up the electron gas in the Si mesa (Fig. 10) and simultaneously measuring the electron and phonon temperatures. For the correct analysis one must take into consideration the local overheating of the lattice in the films and therefore the phonon thermometry is required. From the known applied heating power we can deduce the heat flow and consequently obtain the thermal conductance between electron and phonon systems.

Based on theory, the temperature dependence of the heat flow should demonstrate a T^6-dependence and this has been confirmed in our study. Strength of the electron-phonon thermal resistance in heavily Al-doped Si decreases with the increasing doping level. The research has been done in collaboration with Helsinki University of Technology and VTT Microelectronics.

Photonic band gap materials

Photonic crystals are periodic dielectric structures, where the period is of the order of the wavelength of light. As a result of interference, there exist band gaps for light in photonic crystal materials. Light with frequency in the band gap cannot exist inside a photonic crystal. Two-dimensional photonic crystals embedded with defects can be used e.g. as waveguides for inte-

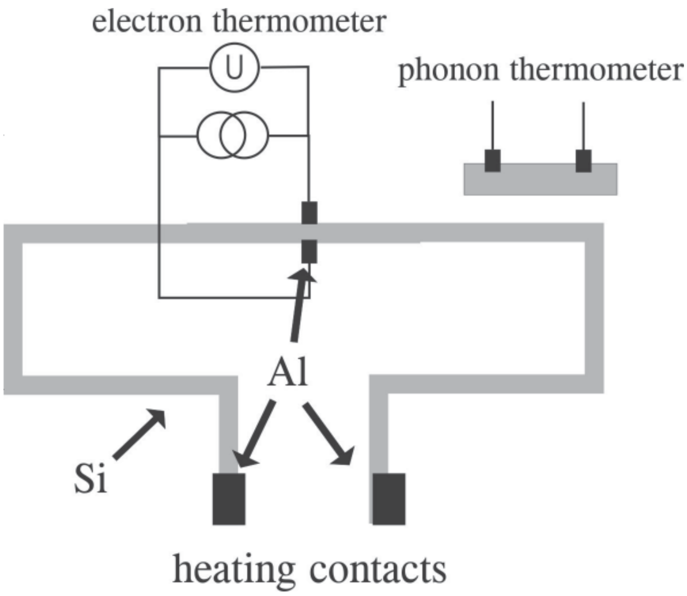

Fig. 10. The simplified sample geometry. Si mesa is the gray area, Al contacts are black. The electron temperature is measured far away from the heating contacts in order to avoid possible interference effects. For a correct analysis the local phonon overheating must be taken into account. The phonon temperature is measured with a similar setup and has been omitted from the figure for clarity. The mesa width is 60 µm.

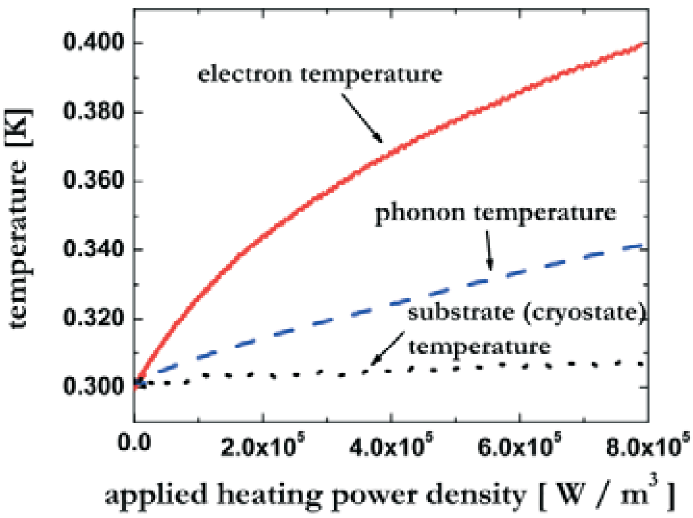

Fig. 11. The electron, phonon and substrate temperatures in a Si sample as a function of the applied heating power to the Si mesa. The heating of the phonon system over the substrate temperature in the Si mesa is remarkable and it must be therefore taken into account in the heat flow analysis.

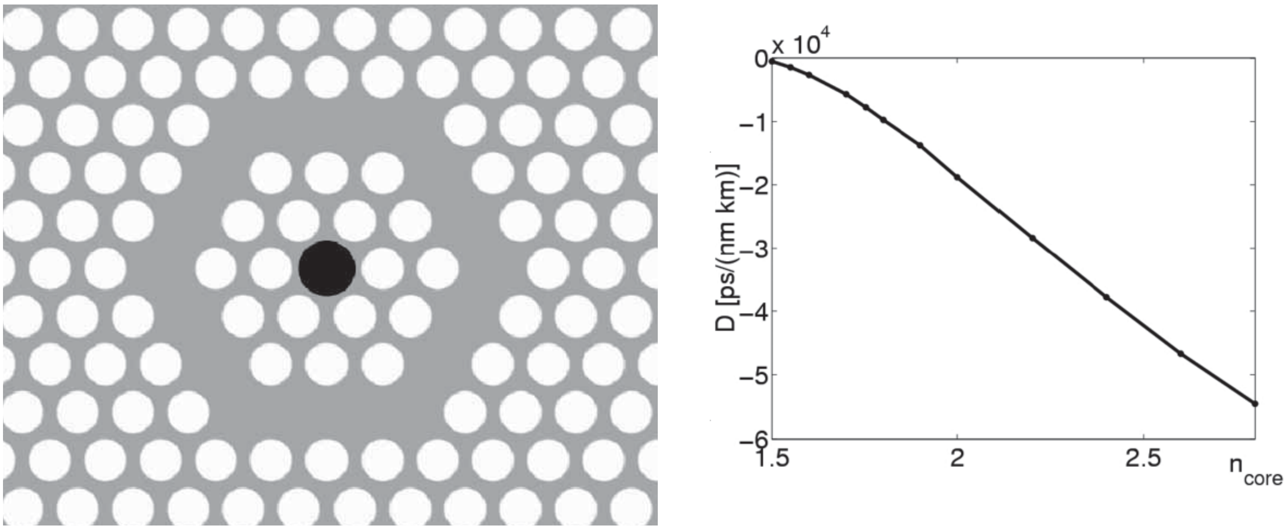

Fig. 12. Geometry and dispersion parameter (D) as a function of the core refractive index (n_{core}) of the dispersion compensating photonic crystal fiber.

grated optics and a defect inside a three-dimensional photonic crystal can act as a microcavity. Photonic crystals are a very attractive option to various applications in telecommunications.

We have studied coupling and decoupling of parallel waveguides in two-dimensional square-lattice photonic crystals. We have found that when there is an odd number of rows between the waveguides, the guides are completely decoupled at a certain wavelength. Decoupling can be used to avoid cross talk between adjacent waveguides.

We have also studied photonic crystal fibers. The cladding layer of photonic crystal fibers is periodic in the plane of the fiber cross-section. We found that a photonic crystal fiber with a dual-core geometry and a high index core exhibits extremely high dispersion, but still a large mode area. It could be used as a dispersion compensating fiber.

Research

Computational nanosciences

Hannu Häkkinen and Matti Manninen

Theory of quantum dots, rings and wires

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Multicomponent density functional theory

Local density approximation is extended for semiconductor nanostructures with several band minima. This allows applications for vertical double dots and for dots with heavy and light holes. The results indicate that the increased internal degree of freedom ("isospin") leads at densities to a generalization of Hund's first rule. At low electron densities the increased number of degrees of freedom helps the electrons to form a Wigner lattice.

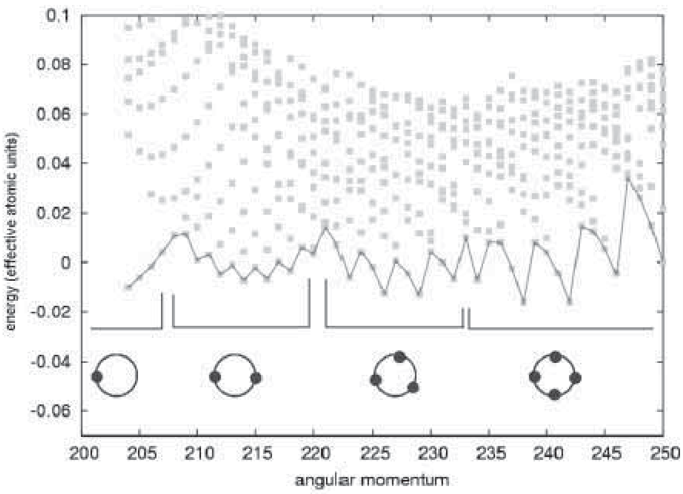
Quantum rings

Exact diagonalization of the Hubbard Hamiltonian is used to study prsistent currents in quntum rings connected with a quantum dot or a stub. In these coupled systems the interest is the charge fluctuation between the ring and the stub. Our preliminary results show that at certain electron numbers the charge of the attached stub or dot can be controlled with the magnetic flux through the ring.

Vortices in quantum dots

When the electrons in an circular trap of the quntum dot is put in rotation with an external magnetic field, vortices will form. We are studying the vortex formation using exact numerical diagonalization of the Hamiltonian of interacting electrons in a harmonic trap. The results show vortex formation which is very similar to that observed on rotating bose condensates. Using models based on the Laughlin wave function for quantum Hall effect we were able to trace the origin of this universal behavior in small systems (Toreblad et al, Phys. Rev. Lett. 993, 90407 (2004)). In fermionic case, like in quntum dots the vortex formation and their localization can be understood as formation of fractional quantum Hall liquid of holes, i.e. Missing electrons in the Fermi see. This leads to formation of vortex lattices and corresponding characteristic oscillations in the energy spectrum of electrons (see Figure below).

http://www.phys.jyu.fi/research/clusters/index.html



Energy spectrum for a quantum dot with 20 electrons. The insets show schematically the localization of vortices in a ring (http://arxiv.org/abs/cond-mat/0410622).

http://www.chem.jyu.fi/nanoscience/index.htmla

ab initio simulations of clusters and nanostructures

Hannu Häkkinen

Symmetry and Electronic Structure of Noble-Metal Nanoparticles and the Role of Relativity

Understanding the energetically most favorable structures that aggregates of metal atoms inherently adopt during their formation process is one of the long-standing issues in the science of clusters and nanoparticles. The atomic structure and its symmetry are intimately related to the electronic structure, which in turn defines the electrical, optical and chemical properties of the particle. Resolving the atomic structures of nanoclusters therefore represents an important preliminary for their controlled use in future nanotechnologies. Noble-metal clusters and nanoparticles have attracted much attention recently as they are considered promising candidates for applications, e.g., in catalysis, labeling, or photonics.

We have studied anionic Cu_N, Ag_N, and Au_N clusters, with n = 53–58, via high-resolution UV-photoelectron spectra and density-functional calculations. The observed electron density of states is not the expected simple electron shell structure, but is strongly influenced by electron-lattice interactions. Only Cu_{55} and Ag_{55} exhibit highly degenerate states. This is a direct consequence of their icosahedral symmetry, as is confirmed by theory. Neighboring sizes exhibit perturbed electronic structures, as they are formed by removal or addition of atoms to the icosahedron and therefore have lower symmetries. Gold clusters in the same size range show completely different spectra with almost no degeneracy, which indicates that they have structures of much lower symmetry. This behavior is related to strong relativistic bonding effects in gold, as demonstrated by ab initio calculations for anionic Au_{55} (see Figure 1).

This work was done in collaboration with the groups of Dr. M.Moseler (Fraunhofer Institute for Mechanics of Materials, Freiburg, Germany) and Dr. B.v.Issendorff (University of Freiburg, Germany)

Melting and Electronic Structure of Sodium Clusters

Density functional theory with ab initio pseudopotentials was used to study melting of small cationic sodium clusters. Na_{59}^+ and Na_{93}^+ are found to undergo a phase transition which can be identified as melting by traditional indicators. Melting transition was observed to start at 175 K and at 160 K in the case of Na_{59}^+ and Na_{93}^+, respectively. The simulated melting temperature of Na_{93}^+ is consistent with experiments. Both Na_{59}^+ and Na_{93}^+ stay electronically magic through the melting transition.

The Ab initio simulation method is also used to study the electronic structure of sodium clusters. Positively charged Na_{59}^{+} and negatively charged Na_{57}^{-} have both 58 valence electrons and are a "magic" clusters according to the jellium model. Although the geometries of both clusters are nearly spherical, the results show differences in the electronic shells. Both clusters show clearly the shell structure of the jellium model. However, the energy gaps between the jellium subshells are different. In Na_{57}^{-} the magic number 20 disappears and is replaced with a new magic number 18. Our results for Na_{59}^{+} are in good agreement with the experimental results. The agreement of the electron density of states of liquid Na_{93}^{+} with the experimental photoelectron spectra is also excellent.

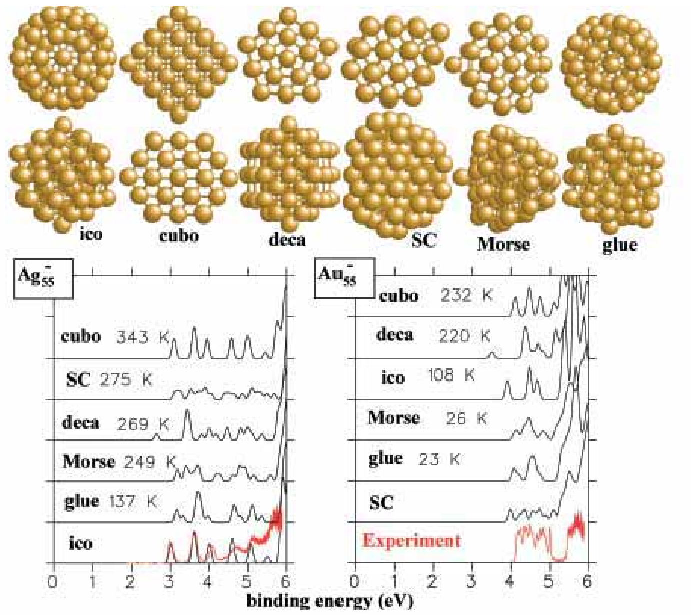


Fig. 1. Structures and density of states (DOS) of Ag and Au clusters obtained via density functional calculations. (a) Six candidate structures for Ag_{55} and Au_{55} representing different structural motifs: closed atomic shell icosahedral (ICO), decahedral (DECA), and cuboctahedral (CUBO) structures, and clusters optimized previously by classical Sutton-Chen (SC), Glue, and short ranged Morse potentials; (b) DOS of the six structures (black curves) compared to the experimental photoelectron spectra (red curves) for Ag (left panel) and Au (right panel). The numbers denote the energy difference to the most stable structure (GS). For more details, see H. Häkkinen et al, Phys. Rev. Lett. 93, 093401 (2004).

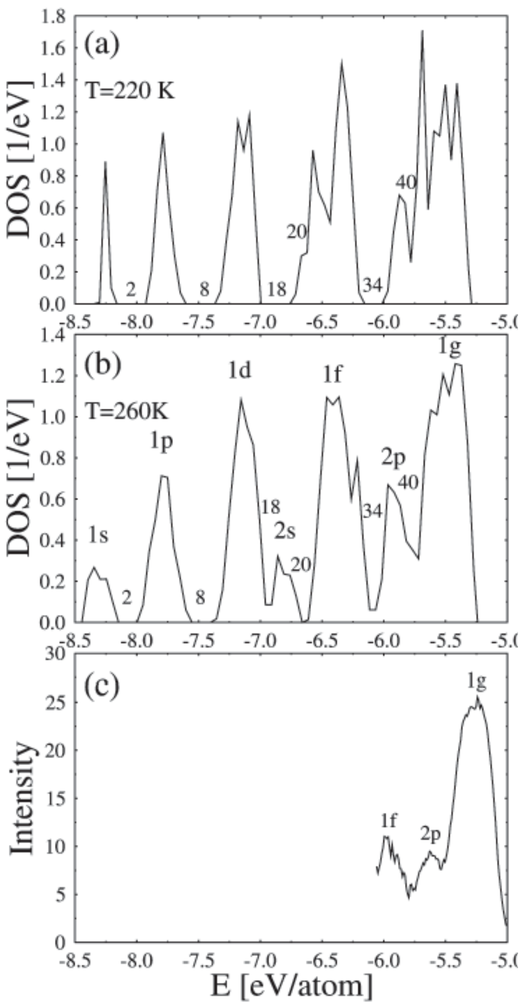


Fig. 2. Density of Kohn-Sham states (in units of 1/eV) for (a) solid and (b) melted Na_{59}^{+} clusters at 110 and 260 K, respectively, and (c) the experimental photoelectron spectrum of Na59+ (G. Wrigge et al, Phys. Rev. A 65, 063201 (2002)). The jellium shell-closing electron numbers are also shown.

Photoionization from Kohn-Sham wave functions

The process of photoionisation can be used as experimentally rather simple tool to study the electronic properties of systems under observations. For extended systems, the electronic structure is most efficiently calculated using DFT in the formulation of Kohn-Sham wave functions. Originating from the atomic description, the current theory for photoionisation is formulated in one-centre angular momentum expansions, whereas very accurate DFT wave functions are often represented on grids in momentum or configuration space. We have shown how the angular momentum expansion can be avoided by using a final state wave function which describes an electron of specific momentum. The continuum electron is described by an analytical wave function and the matrix elements are calculated in both in length and velocity form of the dipole operator. The test case of the water molecule shows excellent agreement between the calculations and experiment in the ionisation energies if a vertical transition is considered. The cross sections agree well with the experiment in particular in case of the velocity form results. Differences to the length form and deviations from the experimental asymmetry parameters indicate the limitations in an analytical description of the continuum.

Anomalous binding sequence of CO ligands to an anionic triplatinum carbonyl complex

A systematic density functional theory study on the structures and binding energies of triplatinum carbonyls $Pt_3(CO)_x^q$, with x=1-6 and q=0,-1, reveals an anomalous trend in binding energies of the CO ligands to the triangular platinum core, with the first three ligands strongly bound at terminal Pt sites, followed by weaker bound ligands at Pt-Pt bridge sites for x=4-6. This work provides a novel explanation to the anomalous CO binding trend reported in mid-1990's from collision-induced-dissociation (TCID) and photodissociation (PD) experiments. The current work has implications regarding design of bimetallic Au-Pt cluster nanocatalysts for CO oxidation.

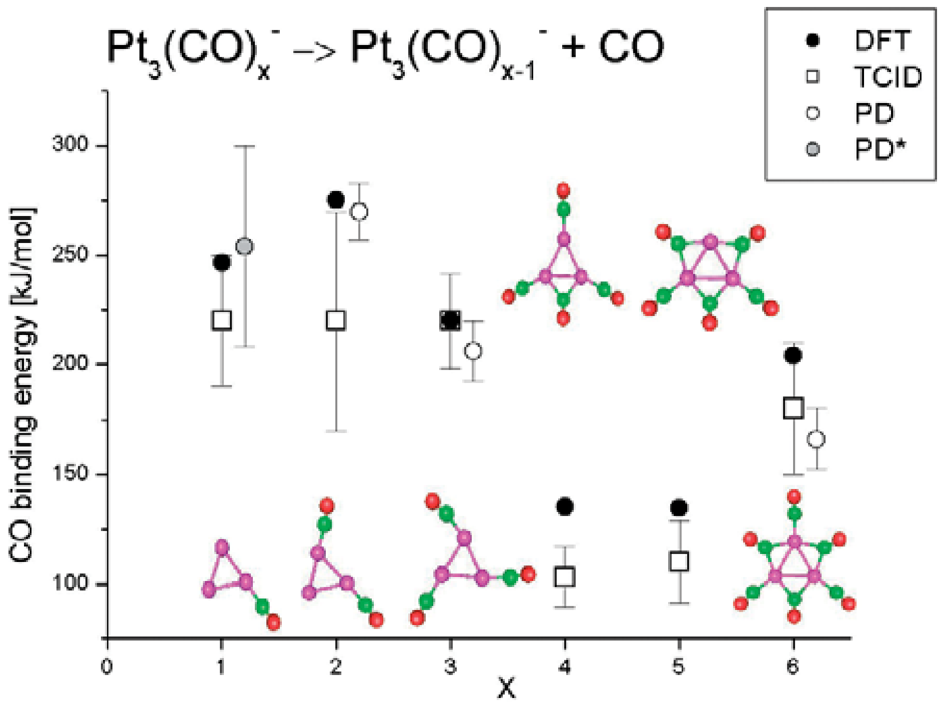


Fig. 3. Sequential binding energy of CO ligands to anionic platinum cluster carbonyls $Pt_3(CO)_x^-$ for x=1-6. The theoretical results of this work are compared to TCID and PD data (see review by K.M. Ervin in Int. Reviews in Physical Chemistry 20, 127 (2001)). For each x we also show the ground state structure of the anionic cluster carbonyl.

Research

Soft condensed matter and statistical physics

Markku Kataja, Juha Merikoski and Jussi Timonen

Statistical physics

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Juha Vinnurva, graduate student

http://www.phys.jyu.fi/research/statphys/index.html

Membrane crumbling

We introduced a first-principles numerical model for crumpling of a stiff tethered membrane. This model displays wrinkles, ridge formation, ridge collapse, and initiation of stiffness divergence. The amplitude and wave length of the wrinkles, and the scaling exponent of the stiffness divergence, were found to be consistent with both theory and experiment. Close to the stiffness divergence further buckling was hindered by the non-zero thickness of the membrane, and its elastic behaviour became similar to that of dry granular media. No change in the distribution of contact forces could be observed at the crossover, implying that the network of ridges was then simultaneously a granular force-chain network.

Fragmentation of brittle matter

We introduced a generic model for brittle fragmentation of D-dimensional objects in D dimensions, and this model was shown to lead to a fragment-size distribution with two distinct components. In the small fragment-size limit a scale-invariant size distribution results from a crack branching-merging process, with a universal scaling exponent 2-1/D. At larger sizes the distribution becomes exponential as a result of a Poisson process, which introduces a large-scale cutoff. Numerical simulations were used to demonstrate the validity of the distribution for D=2. Data from laboratory-scale experiments and large-scale quarry blastings of granitic gneiss confirmed its validity for D=3, over about twelve orders of magnitude in fragment size. In these experiments the non-zero grain size of rock caused deviation from the ideal model distribution in the small-size limit, but this deviation could be explained with a correction of log-normal form. Further support for D=3 was gained from fragmentation of gypsum disks. It became evident from the results of these experiments, however, that some dimensional effects might appear in fragmentation of thin disk-like objects.

We constructed therefore a numerical model for brittle fragmentation of (D-1)-dimensional objects in D-dimensional space. We indeed found that for D=3 a new mechanism appears, in addition to the initial crack branching-merging process, in the later phases of fragmentation. Fragments already formed by the branching-merging process were fragmented further. This second mechanism is also scale invariant as it leads to a power-law fragment-size distribution with a scaling exponent 1.17. This scale invariance means e.g. that the cracks responsible for further fragmentation must be spatially correlated. The scaling exponent is in excellent agreement with earlier experimental results for effectively two-dimensional objects in three-dimensional space.

Stochastic systems

It has been shown recently that in interfaces that belong to the Kardar-Parisi-Zhang universality class, the distribution of the local variations in the position of the interface can assume a number of different forms depending on the global geometry and the initial conditions of the interface. These distributions are related to those of the largest eigenvalue of certain random-matrix ensembles. We demonstrated that in slow-combustion fronts propagating in paper, two of these distributions can be observed, one that describes the transient dynamics and another that describes the stationary-state behaviour of an initially flat interface. To this end a detailed analysis of the large-fluctuation tails of the distributions was required. To confirm the interpretation of the experimental results, necessarily for finite systems, computer simulations were employed on two models in the KPZ universality class with parameters determined from experimental data.

We studied the size of the largest component in a stochastic model of a bipartite graph, whose dynam-

Fig. 1. Optical tomographic device mounted in concentric mixing tube of fibre suspension (dyed blue and discharged axially at the center of the tube) and water (annular flow) for measurement of consistency distribution in the mixing zone. In the actual experiment, unlike shown here, also the water phase is made opague by added latex.

ics is governed by a zero-range process on one set of vertices. Based on our analyses for different types of zero-range interaction, we could construct the possible phase diagrams and determine the related critical exponents. Analytical results supplemented with Monte Carlo simulations show that Landau-type theory is valid for a large class of these models. We also analyzed zero-range processes for interaction functions with long tails. A very distinct crossover in the size of the condensate as a function of system size was observed, related to the behaviour of the effective chemical potential in the system.

Manipulation of optical memory bits

We analyzed propagation of a slow-light soliton in atomic vapours and Bose-Einstein condensates described by the nonlinear Λ-model. The group velocity of the soliton was shown to monotonically decrease with decreasing intensity of the controlling laser field, which decays exponentially after the laser is switched off. The shock wave of the vanishing controlling field overtakes the slow soliton and stops it, while the optical information is recorded in the medium in the form of spatially localized polarization. An explicit solution describing the whole process was found within the approximation of slowly varying amplitude and phase. Our results indicate it is possible to produce spatially localized memory bits and to move such bits in the medium in a controlled fashion.

Soft condensed matter physics

Fluid flow through fibrous porous materials

We combined several advanced numerical and experimental techniques in analyzing flow in fibrous porous materials. The methods used include high-resolution X-ray microtomography together with image analysis, numerical models of fibre webs based on a deposition algorithm, and *ab initio* fluid-flow simulations by the lattice-Boltzmann method. The transverse flow permeability as determined by the lattice-Boltzmann method for fibrous mats generated by the deposition algorithm agreed well with experimental results for various fibrous materials such as filters, non-woven fabrics and stacks of cylindrical rods. 3D X-ray tomographic images of samples of paper were also analyzed for their transverse and in-plane permeability, porosity, specific surface area, and tortuosity, using image analysis as well as simulations. The results obtained by different methods were consistent with each other. The accuracy of the image-analysis and simulation results may still have suffered from the limited resolution of the tomographic techniques now used. For structures with larger pores and fibre dimensions, such as e.g. paper-making fabrics, tomographic imaging combined with numerical simulations and image analysis can already lead to accurate predictions for their fluid-transport properties.

In our analysis of capillary penetration of a wetting liquid in paper, an X-ray tomographic image of paper board was used, and our results were in good agreement with models that describe imbibition, the Lucas-Washburn equation in the case of unidirectional penetration and the Marmur equation in the case of two-dimensional radial penetration. A capillary model constructed for the penetration of small droplets in paper explained well the corresponding simulation results.

In the experiments the absorption kinetics of various liquids penetrating a sample of paper was studied. For this purpose we developed a new measurement device based on a high-speed photo diode that can measure the changes in the optical properties of the sample due to its wetting. We can thus measure the time-dependent local amount of liquid in or on top of the sample even in a fast dynamic process. Oscillations in the droplet after its impact on the surface of the sample were well resolved, as well as the crossover from the initial mechanical phase of spreading into a phase of capillary absorption. The following lateral spreading of the liquid that has absorbed in the sample was well described by a Marmur type of model developed for this case.

In order to facilitate more effective simulations by the lattice-Boltzmann method for fluid flow in porous media, we implemented a versatile software package that includes reading and processing of tomographic images, automatic domain decomposition for parallel computing, and the actual computation and analysis software. For a computationally more efficient implementation for our LBM we developed a new Swap algorithm, and optimized the utilization of modern computer architecture. Better employment of the cache memory hierarchy led in particular to a clear increase in performance. Parallel efficiency of the implementation is a major issue, and this efficiency was improved by balancing the workload among the processors. Balancing can now be realized by conventional three-dimensional cartesian domain decomposition, or alternatively by generalized orthogonal recursive bisection. The overall performance of our LBM implementation was increased by a factor of up to four.

Rheology of liquid-particle suspensions

Rheological properties of model colloidal suspensions were investigated with rotational rheometry for varying particle size, particle concentration and interparticle colloidal forces. The viscosity of the monodisperse suspension was highest for the smallest suspended particles due to the largest relative increase in their effective (hydrodynamic) particle size. However, colloidal forces

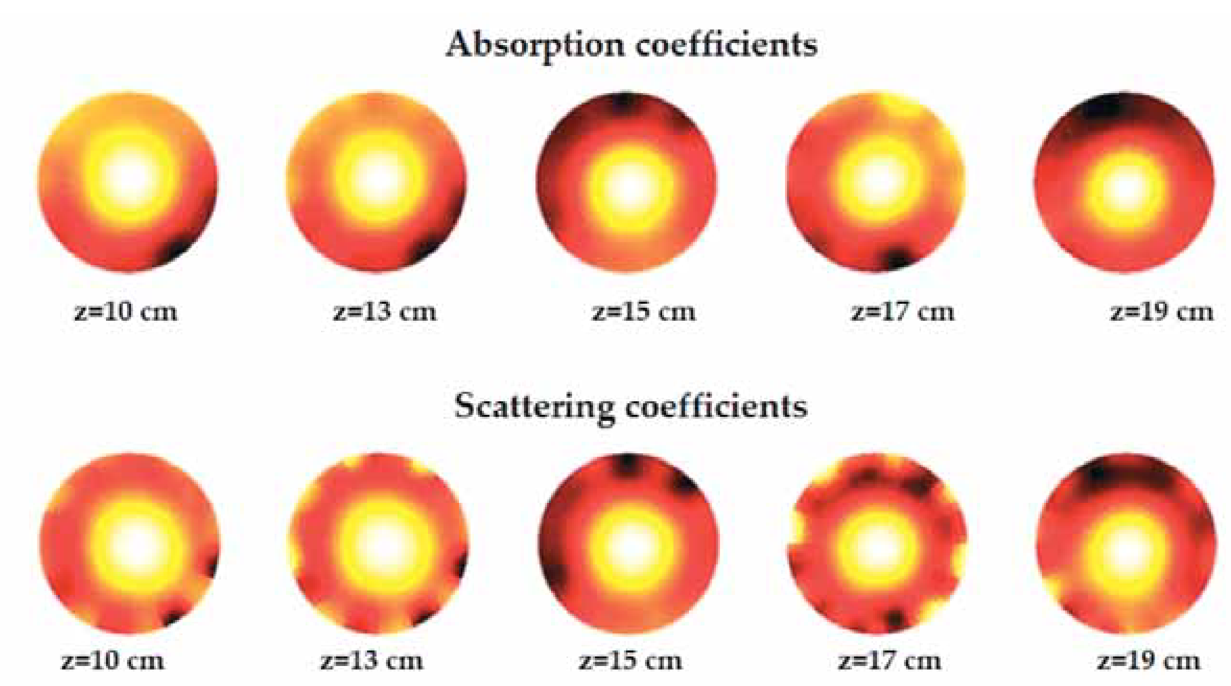

Fig. 2. 3D- reconstructed images based on the distribution of absorption and diffusion coefficients for concentric mixing flow of fibre suspension and latex solution. The labels above individual images indicate distance from the beginning of the mixing zone (end of the central tube).

tended to reduce this particle-size effect. The measured viscosity increased with increasing particle concentration in accordance with the Krieger-Dougherty and Eiler models. The viscosity of the suspension was also found to increase with increasing electrolyte concentration. This effect could be attributed to suppression of the electrostatic double layer on particle surface, which decreases the strength of colloidal forces.

Direct numerical simulations using lattice-Boltzmann and Stokesian simulations were also used to analyze 3D flows of liquid-particle suspensions. These simulations allowed detailed analyses of the behaviour of the suspended particles, and thereby of the basic particle-scale mechanisms underlying the observed rheological behaviour of the suspension. Of particular interest here were flows that occur in various rheometric experiments, such as e.g. Poiseuille flow that is confined between two parallel plates. In this case lubrication layers free from particles were found to form next to the plates due to lateral migration of particles. The inhomogeneous particle concentration thus formed leads to shear-thinning behaviour of the suspension, and is expected to hamper the interpretation of results of rheometric measurements, for which the velocity and concentration profiles are generally unknown. Simulations could thus be used as an advanced data-analysis tool in experimental rheology.

Channel flow of fibre suspensions

Channel flow of paper pulp often exhibits a regime where the pressure loss surprisingly decreases with increasing flow rate. We constructed a laser-optical device by which the boundary layer in a channel flow of fibre suspension can be accurately measured, and performed a large number of measurements. By detailed analyses of the measured data we could confirm that decreasing pressure loss arises from a thin lubrication layer of pure water, which develops between the fibre plug and the channel wall. We also introduced a multi-phase model that reproduces the observed drag reduction. In this model, fibre suspension enters the channel in a fully turbulent state that gradually decays to a state of stationary fibre network. In this process, part of the turbulent energy is captured as the elastic energy of the fibre plug, which manifests itself as a residual structural stress. This stress induces increased loss when fibres are in contact with the channel wall at low flow rates. At moderate flow rates, transverse hydrodynamic lift forces acting on the fibres keep them away from the channel wall. A fibre plug forms thus directly in a state with a lubrication layer, and the pressure loss is reduced. We have confirmed the qualitative behaviour of the lift force by direct numerical simulations by the lattice-Boltzmann method. The thickness of the lubrication layer predicted by the model is in good agreement with the experimental results.

3D imaging of multiphase flows using optical tomography

We have developed a device for optical tomographic imaging of highly diffusive multiphase fluids such as paper pulp. The methods developed include advanced processing techniques for low signal levels together with sophisticated algorithms for the inverse problem. The reconstruction algorithm used was developed at the University of Kuopio. Optical tomography is non-intrusive, relatively fast, and capable of both 2D and 3D constructions of the local density variations in opaque non-homogeneous fluids. It is based on reconstructing the distribution of light absorption and scattering coefficients inside the medium on the basis of light intensity measurements at its surface. The present measurement system (see Fig. 2.) for cylindrically symmetric flow geometries includes two circular collars, each with eight modulated laser diodes and eight avalanche photodiode light detectors mounted evenly around their inner surface.

One measurement cycle (exposure) involves image reconstruction from 64 or 256 light-intensity values in the one-collar (2D imaging) or two-collar (3D imaging) operation mode, respectively. For the present device version, the exposure time is 1/16 s in 2D imaging and 1/8 s in 3D imaging. Each exposure results in two images, one for the distribution of the absorption coefficient and another for the scattering coefficient in the reconstructed volume. An example of results obtained for a concentric mixing flow of a fibre suspension and a latex solution is shown in Fig. 2.

High-resolution computed X-ray tomography

Computer tomography (CT) can be used to obtain a 3D construction of the internal mass distribution of the sample based on the measured attenuation of X-rays. The internal structure of the sample can thus be disclosed due to varying mass density. A couple of hundred 2D images of the sample at different angles are typically required for a reliable 3D structure. We have imaged a fairly large number of paper samples, with both an X-ray micro-CT system with a nominal resolution of 2 μm or 0.9 μm, and with synchrotron radiation at the European Synchrotron Radiation Facility (ESRF) with a nominal resolution of 0.7 μm. Different image-analysis techniques and noise-reduction methods were also developed. 3D tomographic images were used in the analysis of the fluid-transport properties of paper by lattice-Boltzmann simulations as decribed above. Effects of the structure of the fibre network on a coating layer were as well studied (see Fig.3.) Thus far the main emphasis of the work has been on methodological developments.

Assessment of bone by ultrasonic guided waves

As the cortical thickness is a clinically relevant indicator of osteoporosis, we developed signal- analysis methods and an inversion scheme, which now allow us to determine the cortical thickness from ultrasonic guided-wave data. For bone phantoms and human radius-bone specimens, the thickness determined in this way correlated significantly with that measured by a calliper (for phantoms) or by computed tomography (for bone samples). Our inversion scheme is based on an analytical model of guided waves, and it was validated for plates and tubes with a thin wall. For tubes with a thick wall, tubular guided-wave modes must be used. We also discovered that the soft tissue overlying the bone in the in vivo measurements has a noticeable effect on the measured signal, as the ultrasonic guided waves now propagate in a bilayer composed of bone and soft tissue. To solve this soft-tissue problem we started to develop a bilayer model. This model can be used when determining the velocity of the guided waves, and also in the inversion scheme. During 2004 we also made in vivo measurements on more than a hundred subjects with promising results.

Fig. 3. 3D- CT image of the coated paper. The coating layer is segmented from the base paper and visualized with different colors.

Research

High energy physics

Ultrarelativistic heavy ion collisions

Kari J. Eskola and Vesa Ruuskanen

The primary goal of ultrarelativistic heavy ion collisions (URHIC) is to study strongly interacting elementary particle matter, Quark Gluon Plasma (QGP), and its transition to a gas of hadrons. Experimental and theoretical research in this field interact vividly; the success of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven since 2000 and the anticipation of the ALICE experiment at the CERN Large Hadron Collider (LHC) in 2007 have inspired and intensified also the theoretical URHIC research. In the theoretical and phenomenological studies of nuclear collisions we have focused on (1) predicting primary production by using perturbative QCD (pQCD) supplemented with a conjecture of gluon saturation, (2) describing the evolution of produced matter from the calculated initial state to observable final free hadrons by applying hydrodynamics, (3) obtaining hadronic observables from the hydrodynamic calculation, (4) investigating the suppression of high-p_T hadron spectra at RHIC and LHC, (5) calculating thermal emission of electromagnetic signals by combining thermal rates with the hydrodynamical model, (6) studying the deconfinement phase transition by using effective theories for QCD at finite temperature and density, and (7) studying hard pQCD processes and parton distributions in hadronic and nuclear collisions.

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Kari J. Eskola, academy researcher
Kimmo Tuominen, assistant
Pasi Huovinen, postdoctoral researcher (HIP/JYFL)
Vesa Kolhinen, postdoctoral researcher
Heli Honkanen, graduate student (JYFL/HIP)
Harri Niemi, graduate student (HIP/JYFL)
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Suvi Laitinen, MSc student

This research is financially supported by the Academy of Finland (SA). URHIC theory has also been one of the projects in the Theory program of the Helsinki Institute of Physics since 2002, in collaboration with prof. Kajantie's Finite Temperature Field Theory group at the Department of Physical Sciences, University of Helsinki. We are also in a close contact with prof. Rummukainen (Univ. of Oulu and CERN/TH) and with the ALICE group at JYFL. As a joint effort together with the HIP Theory program lead by prof. Enqvist (Helsinki), the JYFL High energy physics group participated in a SA Center of Excellency application. Our international collaborators come from e.g. CERN/TH (Switzerland), Niels Bohr Institute (Denmark), LAPTH (France), SdPT/Saclay (France), Univ. of Frankfurt (Germany) and Univ. of Padova (Italy) in Europe, and from Lawrence Berkeley National Laboratory, Univ. of Minnesota, and Iowa State Univ. in the USA. We also run an active visitor program and participate in URHIC meetings and theory collaborations such as Hard Probes. In 2004, in collaboration with prof. Hoyer (Helsinki), the European Graduate School (Giessen-Copenhagen-Helsinki-Jyväskylä) and the Jyväskylä Summer School, we organized a Lecture week on the

http://www.phys.jyu.fi/research/urhic/index.html

Physics of Hadrons and URHIC. We were also among the organizers of the Strong and Electroweak Matter 2004 meeting in Helsinki. Together with Kajantie's group, we have participated in EU network proposals such as the I3HP Joint research proposal for Hadron Physics approved for 2004-6.

Initial state of the QGP from pQCD and saturation

Gluons and quarks with transverse momenta of a few GeV, minijets, are expected to dominate the QGP formation at collider energies. Production of such quanta can be computed using perturbative Quantum Chromodynamics (pQCD). Infrared safe quantities, like the transverse energy and the net baryon number carried by the minijets above a minimum transverse momentum scale, can be computed to next-to-leading order (NLO) pQCD. A further element needed in estimating the QGP initial densities is gluon saturation: at sufficiently high densities, gluon fusion can be conjectured to inhibit the production of gluons at smaller momenta and a dynamically generated saturation scale of 1...2 GeV govern the initial parton production in AA collisions (A~200) at RHIC and LHC. Based on the saturated minijet initial conditions followed by boost-invariant isentropic evolution of the system, we have predicted correctly the measured charged-particle multiplicities for central Au+Au collisions at several cms energies at RHIC. We have studied the chemical composition of the produced matter in detail: the computed initial net baryon number density leads to final antibaryon-to-baryon ratios which agree well with the RHIC data. Predictions for the LHC can thus be considered plausible. Also chemical equilibration in the QGP at RHIC and LHC has been studied as part of the CERN Hard Probes investigation.

Hydrodynamical evolution of nuclear collisions

Relativistic hydrodynamics provides a method to study the evolution of a locally thermalized expanding system. Even though the hydrodynamic results on a system of nuclear size cannot be pushed too far, strong features in its favour are the implementation of conservation laws and the QCD phase transition through the equation of state. In addition to enabling the calculation of hadron spectra, it also provides a reasonably sound framework to study phenomena during the expansion stage like electromagnetic emission or flavour evolution.

We have computed the final, observable, transverse momentum spectra of different hadrons for central AA collisions within the framework of pQCD + saturation + hydrodynamics, described above. The calculations show that the low-p_T part, $p_T \leq 3$ GeV, of the measured pion, kaon and (anti)proton p_T-spectra at RHIC are correctly reproduced. Since only a small fraction of produced particles and energy is in the spectrum at larger p_T's, this demonstrates the consistency of the assumption that essentially all produced partons become thermalized. It also provides a consistent picture for the study of jet quenching: most of the partons form a thermal matter through which the high-p_T partons traverse loosing part of their energy but remaining more energetic than the partons in the thermal component. We also observe that a single, fairly high, decoupling temperature of about 150 MeV reproduces the spectra of both light and heavy hadrons. This can be taken as an indication that the hadron gas phase is effectively shorter than previously expected. Encouraged by these RHIC results, we next publish the predictions for the LHC. Related to the observed baryon densities at RHIC, rate equation network for baryon-antibaryon production has also been studied in the framework of hydrodynamical evolution. Work in progress includes (i) investigation of how sensitive the observed azimuthal asymmetry in the hadron spectra (elliptic flow) in noncentral collisions is to the order of the phase transition, (ii) studies of more detailed decoupling dynamics, (iii) making predictions for the elliptic flow effects at the LHC, (iv) breaking the longitudinal boost symmetry in our hydro codes to study rapidity dependent observables.

Suppression of large-p_T hadron spectra

One of the most promising probes of the produced QCD matter, and one of the hottest topics in the field currently, is the observed clear suppression of high-p_T hadrons in central Au+Au collisions at RHIC. The absence of such suppression in d+Au collisions supports the interpretation of the phenomenon in Au+Au as energy loss of high-p_T partons in penetrating through a dense medium. By analysing the spectra measured at pp and $p\bar{p}$ collisions at several cms-energies, and by using pQCD cross sections, nuclear parton distributions (see below) and fragmentation functions, we have computed the reference spectra of high-p_T hadrons in *AA* collisions in the no-medium case. Also this calculation strongly suggests that the high-p_T suppression observed at RHIC cannot originate from the nuclear modifications of the parton distributions but is a final state effect. By accounting for parton energy loss probabilities at different in-medium path lengths, computed by our collaborators at CERN/TH, and for a detailed production geometry, we have determined the energy loss strengths at RHIC on the basis of the data, and predicted the suppression for the LHC case. Detailed comparison with the hydrodynamic spectra at RHIC and LHC is to be published soon.

Electromagnetic probes

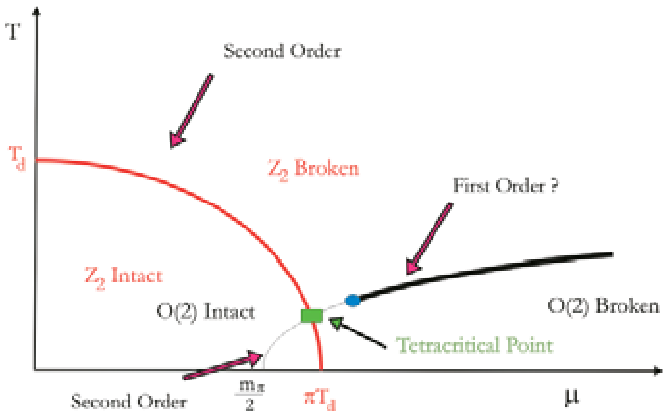
The measured hadron spectra are indispensable constraints in pinning down the space-time evolution of the dense system. Once the hydrodynamic evolution is under control, one may meaningfully compute the signals from secondary collisions, such as thermal photon and dilepton production. Previously, we have computed the spectrum of thermal photons in URHIC at the CERN-SPS and, even though we are not able to differentiate between different equations of state, the results compare well with the experimental spectra if a high temperature initial state is assumed. At collider energies the situation becomes more complicated, since the predicted initial (anti)quark deficit of the QGP and the evolution towards chemical equilibrium need to be considered. Studies on this, launched initially for the CERN Hard Probes collaboration, will be pursued further.

Effective theories for QCD and QCD-like theories at finite temperature and density

Deconfinement and chiral symmetry restoration have always attracted much interest. Using effective theories at finite temperature we have explained why deconfinement and chiral symmetry restoration appear as a single phase transition for matter in the fundamental representation, while there are two phase transitions, well separated in temperature, for matter in the adjoint representation. Our results are applicable also at nonzero baryon chemical potential, and may also be applied to investigate the equation of state used in the hydrodynamical modeling of URHIC.

Studies of QCD are motivated by experimental needs. However, important clues about nonperturbative behaviour of strong interactions may be obtained by considering various other QCD-like theories. The above mentioned strongly interacting theory with adjoint fermions constitutes a relevant example, which is theoretically motivated also by supersymmetry. We have shown that the phase diagram of two-colour adjoint QCD at finite temperature and chemical potential may possess a tetracritical point, see Figure. This critical point is similar to the one which governs the behaviour of anisotropic antiferromagnets in a uniform magnetic field.

Investigations of the dynamics of various strongly interacting theories have far reaching consequences also beyond hadron physics: The electroweak symmetry breaking may be driven by a new kind of strong interaction termed Technicolor. This scenario had severe phenomenological problems regarding the electroweak precision measurements, and was thought already ruled out. Using cutting edge techniques developed in the context of supersymmetric Yang–Mills theories we have shown that the simplest Technicolor theories, when higher fermion representations are used, provide theories which cannot be killed with existing data, but must be confronted with LHC. Careful analysis of the phenomenology of these theories is in progress.



Hard processes and parton distributions of bound and free nucleons

Specific signals of the QGP are examined against the reference cross sections of inclusive hard processes in high energy nuclear collisions. These large momentum scale processes, such as production of direct photons, large-mass dileptons and large-p_T hadrons, are computable in a factorized form. For this, however, the number densities of different parton flavours in the colliding nuclei, the nuclear parton distributions (nPDFs), must be known. Also in the pQCD computation of the QGP initial state the nPDFs are an essential ingredient. One of our specialties has been a global analysis, where the nPDFs depend on the energy-momentum scale as predicted by pQCD (DGLAP evolution) and where they are constrained by experimental data from hard processes in lepton+A and pA collisions and also by conservation laws. In particular, we have predicted a relatively strong gluon excess, antishadowing, supported by the recent RHIC data in d+Au collisions. Our EKS98 parametrization, also implemented in CERN PDFLIB, has been in a worldwide use. As a further improvement, we are now finishing a quantitative statistical error analysis, the results of which are to be published soon. Next, we plan to extend the previous leading-order analysis to NLO pQCD. Our work has been recognized also in the CERN Hard Probes activity.

As a new feature, we have recently studied the effects of adding first nonlinear terms to the DGLAP scale evolution equations of the free proton PDFs. We predict an enhancement of the gluon number densities at small momenta at the few-GeV scales on the basis of the constraints from the recent small-x HERA data in ep collisions. Consequently, we have suggested that charm-quark production at the LHC should be enhanced relative to the expectations based on the standard PDF sets. Possibilities to observe this at ALICE have also been explored. Related to the corresponding nonlinearities in nuclei, we have reported the gluon saturation limits for the CERN Hard Probes. These are of interest e.g. for the studies of the QGP intial densities and also for color-glass condensate studies. Extension to NLO and analysis of nPDF with the nonlinear evolution equations are on our future work list.

Research

Theoretical particle physics and cosmology

Kimmo Kainulainen and Jukka Maalampi

Neutrino physics

Neutrino physics is one of the most vital research areas in particle physics today. Plenty of new experiments are in operation or under planning and much theoretical work going on aiming to clarify and solve the fundamental questions associated with neutrinos and their interactions.

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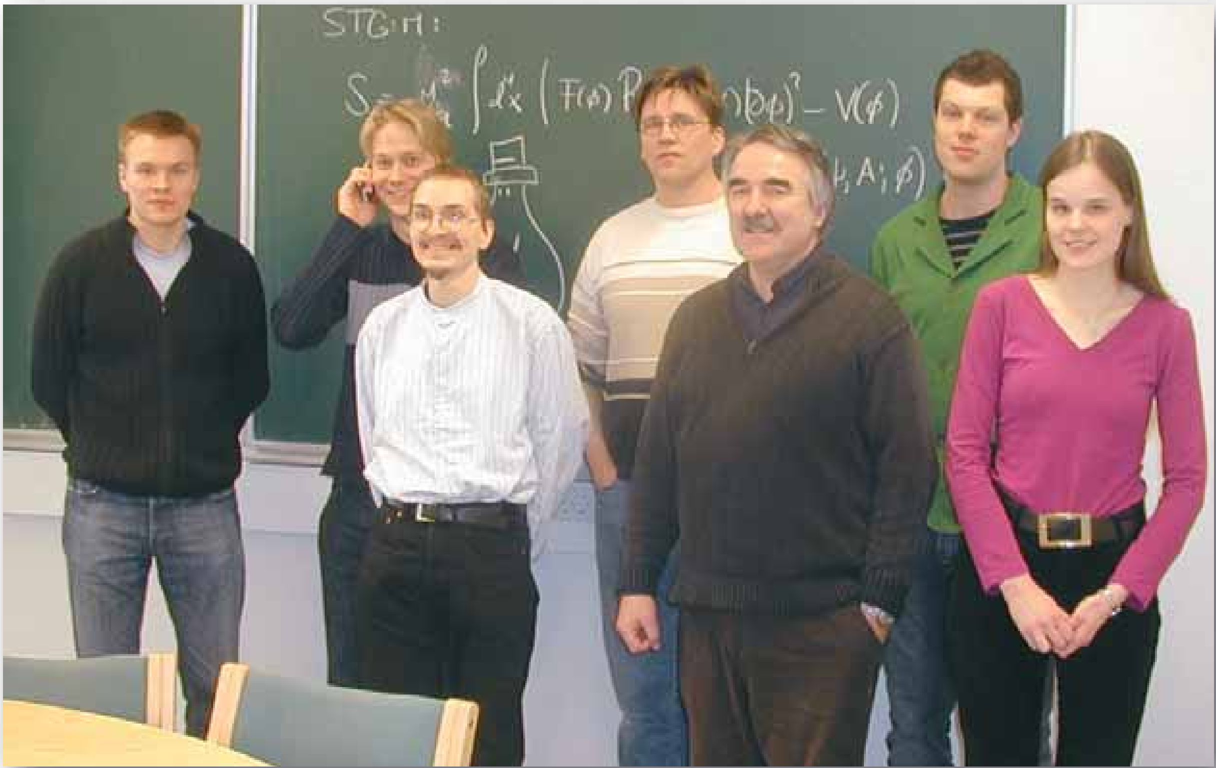


Some members of our Theoretical particle physics and cosmology group in JyU: from left to right Jussi, Matti, Pyry, Kimmo, Jukka, Daniel and Minja. (One of us, Janne – in a truly modern Finnish tradition – participated in the photo session over a cell-phone (talking to Matti).

The recent activity of the group in neutrino physics has mainly concerned astrophysical neutrino phenomena. One topical question in astrophysics is the origin of ultra high-energy cosmic rays (UHECR). Neutrinos, which are created along with other particles in the active centres of galaxies and other cosmic ray sources, will carry direct information about the acceleration processes responsible on the creation of UHECR. We have also investigated the possibility of using these neutrinos to probe the basic properties of neutrinos and their interactions. In particular we have investigated the effects of sterile neutrinos (neutrinos that lack the standard particle interactions) on the fluxes of different flavour components of UHECR neutrinos and neutrinos from supernovae. If such sterile neutrinos were closely degenerate in mass with active neutrinos, this would be the only way to verify their existence.

Physics beyond the Standard Model

Supersymmetry is considered as the most natural extension of the Standard Model, and supersymmetric particles have been searched in particle physics experiments already for two decades. It is probable that first evidences of supersymmetry are not superparticles themselves but rather the indirect radiative effects caused by virtual supersymmetric particles. We have investigated low-energy predictions of the minimal supersymmetric extension of the Standard Model, the MSSM model, applying the so-called effective theory approach. We have studied the MSSM predictions for the electric dipole moments of the neutron and the c quark, investigated the two-loop gluino effects on the radiative decay of the B meson, and analysed the new contributions of the MSSM to the neutrino mass generation in the case of broken R-parity.

Cosmology

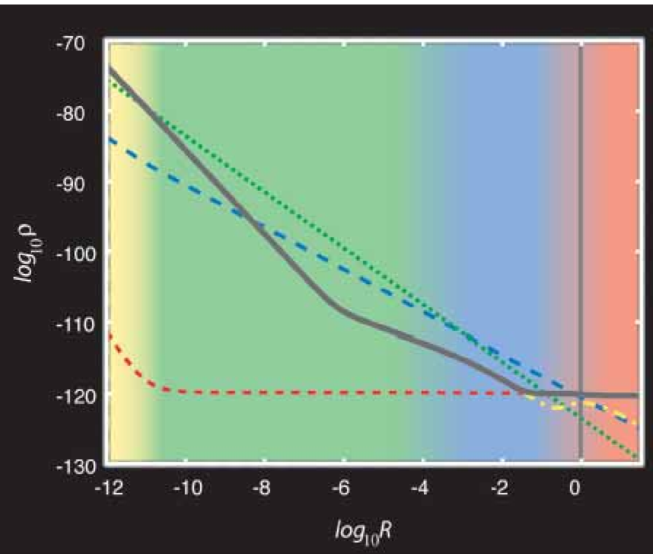
Dark energy

Perhaps the greatest mystery for the present cosmology concerns the origin and the nature of the so-called “dark energy” (DE), which has been recently been confirmed to be dominating the total energy density of the universe. What makes DE strange is its negative pressure equation of state. Our group has studied the DE-problem in the context of a particular class of scalar-tensor gravity models (STGM). These can be viewed as a phenomenological extensions of the usual classical Einstein-Hilbert-action, but they have also been shown to originate naturally in the context of some particular large extra dimensional models. We have demonstrated that our model can lead to cosmologically acceptable solutions with the right amount of DE, which are also in agreement with the present gravity bounds. In particular, we have established some quintessence type solutions, where the present DE at present behaves as a cosmological constant: $p = -\rho$. We also pointed out that the model can also give rise to an even more bizarre type of DE, called phantom energy, which has $p = w\rho$ with $w < -1$. Motivated by some recent observational evidence that the DE equation-of-state may indeed be phantom-like today, we are currently making a thorough investigation of a class of solutions within our model where an originally quintessence-like STGM-DE may be changing its character to a phantom-DE at present epoch.

Matter-antimatter asymmetry

Another intriguing problem in modern cosmology concerns the origin of the baryon asymmetry, the excess of matter over the antimatter, in the Universe (BAU). Our group has studied the creation of BAU in the electroweak phase transition (EWPT).

The quantum transport equations used in the analysis of EWBG were first derived heuristically using the WKB method. Our group has then explored the general problem of fundamental derivation of quantum transport equations for particles in non-equilibrium plasmas in spatially and temporally changing background fields. This is most naturally done by writing the field theory in the Schwinger-Keldysh closed time path (CPT) formalism. In the spatially slowly varying backgrounds and weak interactions, such as is often the case in EWBG problem, one may simplify these equations by a controlled expansion in gradients and in coupling constant. Among our results so far is the proof that the plasma has a single particle (spectral) limit to first order in $\hbar$, which contains the first, and also the dominant CP-violating effects. This result immediately leads to verification of correctness of the WKB picture in the limit of slowly varying backgrounds. We are currently extending the quantum transport formalism to situations where the non-local quantum coherence effects (reflection) are important. Our eventual goal is to explore the full spectrum of CP-violating terms in the quantum transport equations, and compute the resulting baryon asymmetry in the context of the minimal supersymmetric extension of the standard model.



Shown is the energy density of the universe as a function of the scale factor R in a Quintessence-like solution arising from a model with large extra dimensions (thick solid gray line). Other lines indicate separate density components: radiation (green), matter (blue) and the potential (red) and the kinetic energy of the radion (yellow). The present time (R=0) is emphasized by a solid vertical line. The yellow shade indicates the epoch of the kinetic energy dominance (kination). Similarly green shade corres-ponds to the radiation-, bue to the matter- and red to the cosmolgical constant dominance.

Research

Quantum gravity

Markku Lehto

http://www.phys.jyu.fi/research/gr/index.html

Markku Lehto, senior assistant
Diego Meschini, graduate student
Ari Peltola, graduate student
Johanna Piilonen, MSc student

Spacetime and quantum mechanics

It is possible to understand the problem of quantum gravity not as a matter of quantizing general relativity, but as a matter of investigating what quantum theory-so far the only branch of science forced to confront directly the problem of existence-has to say about the still open issue of the physical existence of empty spacetime.

According to our best available understanding provided by general relativity, empty spacetime is void of all fields, including the metric field g(x). This means that empty spacetime is void of all geometric magnitudes, i.e., of all quantitative geometry. After the removal of g(x), the line elements ds^2 must go as well, and empty spacetime is thus tantamount to bare spacetime points. These geometric objects are intrinsic to the notion of field, since physical fields f(P), where P is a point, consist of localized geometric magnitudes. However, according to the diffeomorphism invariance postulate of general relativity, spacetime points are not observable by means of any physical tests.

Einstein advocated thus the view that empty spacetime (i.e., a collection of spacetime points) is not physically real. But because in the above quantum theory was not taken into account, we must challenge the certainty of his conclusion by proposing to search for observables intrinsic to empty spacetime. This search should be carried out (i) guided by quantum theory and some physical principle directly relevant to the existence of empty spacetime, and (ii) via strictly non-geometric methods; i.e., going beyond the intrinsic geometric description of spacetime [1].

The physical insight (i) that we follow is afforded by the principle of diffeomorphism invariance. At face value, it states that a "displacement" of spacetime points does not cause any observable effects and that, in consequence, spacetime points are not physically real. However, an earlier attempt [2] insinuated that when this principle and quantum theory are both taken into account, they lead together to the result that spacetime points display mutual correlations. We hold these to be the key to their possible observation.

Thus, one must not search for the individuality of spacetime points, but rather if and how they "interact" with each other, i.e., what observable correlations they might display. In field-theoretic language, the idea is that a field f(P) at point P dragged onto another point Q, $\phi^*[f(P)]$, and then pulled back again, $\phi_*[f(Q)]$, could carry properties pertaining to Q back with it, so that a comparison of f(P) and $\phi_*[f(Q)]$ could yield that they are not physically the same.

The challenge is to find observables which reveal this possible behaviour of field f(P). If spacetime points had any physical reality of their own, then $f(P) \neq \phi_*[f(Q)]$, in which case there would be some long-range correlations seen in the line element ds^2. The existence of spacetime correlations, however, would point to things beyond geometry or even pregeometry.

Black holes

A black hole is a region of spacetime where the gravitational effects are so strong that not even light can escape from it. The existence of black holes is predicted by general relativity. These peculiar objects are shown to be formed, for instance, as the final states of massive stars. At the classical level, i.e., when quantum-mechanical effects are ignored, black holes shut themselves completely out of their surroundings. The two-dimensional surface of spacetime which separates a black hole from the rest of the universe is known as the event horizon. However, when quantum-mechanical effects are taken into account, it turns out that black holes are not completely black but emit thermal radiation with a spectrum similar to that of a black body.

How can a black hole emit any radiation when it is by definition a “region of no escape”? The answer to this question is that radiation does not come from the interior of the hole but from the instant vicinity of the event horizon. It was shown by Hawking in the beginning of 70’s that when spacetime is treated classically and matter fields quantum-mechanically, there exists a steady flux of particles which seems to come out of the black hole. Since this kind of analysis includes elements both from classical and quantum theories, the Hawking effect is said to be a semiclassical result.

The temperature of a black hole may be inferred from its radiation spectrum. Since the hole has a certain temperature, it also has a certain entropy. The black hole entropy is proportional to the area of its event horizon, and the correct value for the constant of proportionality is, in the units where $G=\hbar = c = k_B=1$, equal to one quarter. According to statistical mechanics, entropy is the natural logarithm of the number of microstates corresponding to a certain macrostate of a physical system.

It can be shown that the macrostate of a black hole can be characterized by only three quantities: mass, electric charge and angular momentum. Therefore there must exist an enormous number of quantum-mechanical degrees of freedom giving rise to the entropy. It is one of the greatest challenges of modern physics to identify these quantum-mechanical degrees of freedom. Black hole radiation gives us one of the few known clues to the search for quantum gravity: the quantum theory of gravity should be able to explain the microscopic origin of black hole entropy.

There are good reasons to believe that the quantum-mechanical degrees of freedom of the black hole are due to the microscopic structure of spacetime at the event horizon. Therefore one is led to probe the microscopic properties of the event horizon. It is possible, for example, to construct the horizon from microscopically small black holes such that the correct (statistical) entropy is produced [3]. This is an encouraging result since it has been proposed that microscopic black holes might have something to do with the structure of spacetime at the Planck-length scale. The concept of entropy may be associated with other horizons of spacetime as well and, at least to some extent, even with any spacelike two-surface of spacetime [4]. An understanding of the nature of black hole radiation may therefore give valuable insights into the microscopic theory of spacetime.

[1] Meschini, D., Lehto, M., Piilonen, J. (2004). arXiv: gr-qc/0411053. Accepted for publication in Studies in History and Philosophy of Modern Physics.
[2] Lehto, M., Nielsen, H. B., Ninomiya, M. (1986). Nuclear Physics B 272, 228-252.
[3] Mäkelä, J., Peltola, A. (2004). Physical Review D 69 124008.
[4] Mäkelä, J., Peltola, A. (2004). arXiv:gr-qc/0406032.

Industry

Industrial collaboration

Jussi Timonen, Päivi Törmä and Ari Virtanen

The Department has numerous contacts with domestic and foreign industry and research laboratories.

In accelerator physics an important part in industry related research was played by radiation tests of space components and contract related issues with ESA. In addition to ESA and CERN, private companies like Saab-Ericsson Space, EADS Astrium and EADS Space Transportation as well as French national space organisations CNES and ONERA performed their component test campaigns at the RADEF facility. ESA placed a contract with JYFL for the development of a "High Energy Heavy Ion Test Facility for Component Radiation Studies". This four years contract consists of an initial development phase and later utilization phase. The development phase started in Q1 2004, with the commissioning to take place in March 2005. This was the final goal of the project carried out within the AVALI technology programme of the National Technology Agency, Tekes.

Another important branch of in industrial collaboration is related to the medical application. The Iodine-123 production for MAP Medical Technologies was continued at a constant level during 2004. A total of 47 production runs were performed, in which the average beam current was 45 µA. Collaboration with Doseco continued in terms of one MSc. project, which included close co-operation with the Central Finland Health Care District. A new type of multielectrode ionisation chamber was under development. This work received funding from Jyväskylä Science Park through their programme for wellness technology. Yet another medical project was done in collaboration with Gammapro and Jyväskylä Radiotherapy Hospital with funding from Tekes and Jyväskylä Science Park Ltd. The aim of this long term project is to develop a new kind of γ-field detector for oncology to operate in the whole accelerator voltage range of 5 to 25 MV commonly used in therapy.

Collaboration with paper and paper machine industry continued actively in terms of projects with Metso Paper and M-real. In these projects radiation was employed for studying formation profiles in paper. The same idea is used in a new project launched at the end of the year in the joint proposal with the Technical Research Centre, VTT, to Tekes. The work will be done in collaboration with VTT Processes and eight private companies. The aim is to study controlling possibilities of biomass flow used in fuel peat power plants.

The nanophysics and nanotechnology group has well established collaboration with a few companies in Finland. For about three years ultrasensitive radiation detectors based on calorimetry and bolometric sensing for x-rays and IR-radiation have been developed in collaboration with Oxford Instruments Analytical company from Espoo (formerly Metorex International). At the first stage the work has been motivated by the need of on-chip integrable ultrasensitive sensors in space research, and collaborative projects are continuing, funded by the European Space Agency. The Nanoway company, a spin-off from the university's nanotechnology group is producing and marketing the nanothermometer invented and initially developed in our physics department. There is well defined niche market for this product and especially along with the discovery of how to extend the operation from cryogenic temperatures up to room temperature, it may well be attractive to even a wider range of customers. Nanoway also provides micro- and nanotechnical services to interested companies and institutes.

The nanoelectronics and nanotechnology group has established contacts with industry. The professorship in electronics has been sponsored by local municipalities and industry. The nanoelectronics group was funded by Tekes within the ELMO ("Miniaturization of Electronics") research programme. The project focused on micro- and nanosensors and was in collaboration with the companies Enermet, Metso Drives, Nanoway and JSP (Jyväskylä Science Park). A patenting process has been started as a result of the project. The industry collaboration will be continued under new projects and including more companies interested in nanotechnology such as Nokia and Vaisala. The Nanoelectronics Education and Investment programme is going on during the years 2002-2004 in collaboration with several companies such as Enermet, Nokia, JSP, Nanoway, Aplicom. The programme is mainly funded by EU via the regional government and partly by companies. The programme allows developing the teaching in electronics and investments to equipment essential for research in nanoelectronics and nanotechnology. The Nanoscience Center research infrastructure programme 2004-2006, also funded by EU via the regional government and partly by companies (now about ten participating), is also an important platform for industry collaboration. Through this programme, companies can have a so called "Window to Nanotechnology" to follow the rapid development of the field.

The soft condensed matter and statistical physics group continued its long-term collaboration with a number of companies in several branches of industry. The research group participated in three large national research consortia funded by Tekes and industry, and in one funded by the Ministry of Trade and Commerce. These projects focussed on developing new experimental and numerical techniques for flow in porous media, on basic and applied research on the rheological properties and dynamics of liquid-particle suspensions, and on tomographic imaging of paper-like materials and minerals. The previously constructed device based on optical tomography was further developed, and tested on mixing flows at VTT Processes. Ultrasound anemometry and optical wall-layer measurements were used to study the basic flow properties of fibre suspensions in a pipe flow. As a new activity, tomographic imaging of various porous materials was initiated as an international collaboration (Norwegian University of Science and Technology, Ecole Française de Papeterie et des Industries Graphiques, and the University of Minnesota), using high-resolution microtomographic devices based on attenuation of X-rays, as well as a measuring site at the European Synchrotron Radiation Facility in Grenoble. For better understanding flow in paper-like materials, numerical simulations based on the lattice-Boltzmann method were carried out on tomographic images of paper and board produced by these two methods.

Several projects involved also direct collaboration with industry. These projects included experimental research, numerical simulation and modelling of processes such as paper forming, small-scale structure of paper, tomographic imaging and related three-dimensional structural analysis of paper and board, sizing of paper, transport of fluid in coated paper surfaces, matrix diffusion, rheological properties of pigment suspensions, and environmental effects of a paper machine during its life span. Many of these projects involved MSc theses carried out in industry. Industrial collaborators in these projects included Metso Paper, Stora-Enso, M-real, UPM Kymmene and Posiva.

Education

Jukka Maalampi and Juha Merikoski

http://www.phys.jyu.fi/teaching/index.html

http://www.phys.jyu.fi/opetus/index2.html (in Finnish)

The Department of Physics offers a wide program of study in all academic levels. In 2004 about 540 undergraduates were working for a master degree, with physics, theoretical physics, applied physics, electronics, or physics teacher education as their specific major. In addition, some 30 students, mainly with a polytechnic engineer's background, studied in the master programs of industrial physics and nanoelectronics. The post-graduate studies are organized in the framework of nationwide graduate schools in condensed matter physics, nuclear and particle physics, pulp and paper science and technology, and teacher education. The number of post-graduate students aiming at the degree of Doctor or Licentiate of Philosophy in 2004 was 60. In addition to its regular teaching program, the Department has organized in co-operation with the Open University a supplementary-education program for teacher qualification, participated in by about 50 mainly engineers and unqualified school teachers. The Department has also been an active part in the Jyväskylä International Summer School, which was organized for the 14th time.

The Finnish Higher Education Evaluation Council elected the Department of Physics as a high-quality education unit for the period 2004-2006, the only such unit in exact natural sciences nationwide.

Student enrolment

In the summer 2004 there were 440 applicants for physics studies, with 290 indicating physics as their first choice. The entrance examination was organized together with the universities of Helsinki, Kuopio, Oulu and Turku. The majority of students were admitted on the basis of their high school record and national maturity test result. The Department enrolled as a whole 95 new students in 2004. About one quarter of the applicants and enrolled students were women.

Graduation

In 2004 40 students took their Master degree in the Department of Physics. The number of degrees of Doctor of Philosophy was 8. The number of Master degrees strengthens the positive trend witnessed in recent years. The number of doctor degrees shows a slight fluctuation downwards as compared with the result of the previous year. The employment of the newly graduated students has been very good. According to a survey done by the Department, the employment among the graduates of the years 2000-2004 is 98%.

Educational co-operation with schools

The Department of Physics has had active co-operation with schools in the Central Finland district. The popular laboratory course for talented high school students, organized now for the fifth time, collected 25 participants. The Department has collaborated with schools also in the framework of their CERN Network by organising training lectures prior to the CERN visits of student groups. The Department has maintained its popularity as an excursion destination for school students.

Teaching development

At the undergraduate level the first-year course *Introduction to modern physics,* also called "Flying start", was given for the fourth time. It is a part of the program to, starting from the very beginning of studies, increase the students' knowledge of the local faculty, awareness of professional opportunities available for physicists and control of the progress of studies. During the course new students learn about the most recent research and applications of physics, get to know the personnel of the Department and each other, and learn to work together in small groups. The course has turned out to be very successful in improving students' communication with the personnel and motivation.

Overall, the Department has devoted significant efforts to develop the teaching to take it closer to the students and to make it better correspond to the requirements of the physics profession in practice. These include promoting teamwork and developing lecture demonstrations, as well as relating teaching to current research and industrial and other practical applications at all stages of studies. To make better use of the summer term and also to diversify the learning and teaching methods, three compulsory M.Sc. level courses were, in addition to giving them as conventional lecture courses, offered during the summer 2004 as guided self-study courses. The Department has also continued its extensive summer student program for familiarizing students with research work.

Research in physics education

The Department participates in the Finnish Graduate School of Mathematics, Physics, and Chemistry Education with five students working on a degree of doctor or licentiate of philosophy in physics education. One of the research projects concerns with the development of laboratory work as a part of physics curriculum. To support the further development of the Flying start and the transfer of its key ideas to other physics courses, a research project was initiated. The Department organized the Winter Seminar of the Graduate School in 2-5 January and the Symposium on Didactics of Modern Physics in 5-6 May.

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Jukka Maalampi (on leave 1.8.-31.12.)
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Matti Manninen, professor
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Mikko Laitinen, student
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Juha Äystö, JYFL
Paul Greenlees, Scientific Secretary, JYFL

http://www.phys.jyu.fi/research/index.html

Peer reviewed articles

Accelerator facilities

O. Tarvainen, P. Suominen, and H. Koivisto
Effect of the gas mixing technique on the production efficiency of ion beams extarcted from an electron cyclotron resonance ion source
Nucl. Instr. Meth. B 217 (2004)136

P. Suominen, O. Tarvainen, and H. Koivisto
3D-simulation studies of the modified magnetic multipole structure for an electron cyclotron resonance ion source
Nucl. Instr. Meth. B 225 (2004) 572

P. Suominen, D. Hitz, O. Tarvainen, and H. Koivisto
Optimization of the Halbach-type magnetic multipole structure for electron cyclotron resonance ion sources
Rev. Sci. Instrum. 75, 1 (2004) 59

H. Koivisto, P. Suominen, O. Tarvainen, and D. Hitz
A modified permanent magnet structure for a stronger multipole magnetic field
Rev. Sci. Instrum. 75, 5 (2004) 1479

P. Suominen, O. Tarvainen, and H. Koivisto
The effects of the gas mixing and plasma electrode position on the emittance of an electron cyclotron resonance ion source
Rev. Sci. Instrum. 75, 5 (2004) 1517

O. Tarvainen, P. Suominen, H. Koivisto, and I. Pitkänen
Reduction of the carbon contamination of an electron cyclotron resonance ion source
Rev. Sci. Instrum. 75, 5 (2004)1523

O. Tarvainen, P. Suominen, and H. Koivisto
A new plasma potential measurement instrument for plasma ion sources
Rev. Sci. Instrum. 75, 10 (2004) 3138

Exotic nuclei and beams

J.C. Wang, P. Dendooven, S. Hankonen, J. Huikari, A. Jokinen, V. S. Kolhinen, G. Lhersonneau, A. Nieminen, K. Peräjärvi, S. Rinta-Antila and J. Äystö
Reinvestigation of the beta-decay of ^{110}Mo
Eur. Phys. J. A 19 (2004) 83

Ph. Dessagne, M.J.G. Borge, J. Giovinazzo, A. Huck, A. Jokinen, A. Knipper, C. Longour, G. Marguier, M. Ramdhane, V. Rauch, O. Tengblad, G. Walter, Ch. Miehe, and the ISOLDE Collaboration
The N = Z nucleus ^{76}Sr: Gamow-Teller strength and nuclear deformation
Eur. Phys. J. A 20 (2004) 405

K. Peräjärvi, J. Cerny, L.M. Fraile, A. Jokinen, A. Kankainen, U. Köster, J. Äystö and the ISOLDE Collaboration
The beta-decay scheme of ^{232}Fr and the K = 0 ground-state band in ^{232}Ra
Eur. Phys. J. A 21 (2004) 7

J.- C. Thomas, L. Achouri, J. Äystö, R. Beraud, B. Blank, G. Canchel, S. Czajkowski, P. Dendooven, A. Emsallem, J. Giovinazzo, N. Guillet, J. Honkanen, A. Jokinen, A. Laird, M. Lewitowicz, C. Longour, F. de Oliveira Santos, K. Peräjärvi, and M. Stanoiu
Beta-decay properties of ^{25}Si and ^{26}P
Eur. Phys. J. A 21 (2004) 419

Yu. P. Gangrsky, K.P. Marinova, S.G. Zemlyanoi, I.D. Moore, J. Billowes, P. Campbell, K.T. Flanagan, D.H. Forest, J.A.R Griffith, J. Huikari, R. Moore, A. Nieminen, H.Thayer, G. Tungate, and J. Äystö
Nuclear charge radii of neutron deficient titanium isotopes ^{44}Ti and ^{45}Ti
J. Phys. G: Nucl. Part. Phys. 30 (2004) 1089

V. Kolhinen, T. Eronen, U. Hager, J. Hakala, A. Jokinen, S. Kopecky, S. Rinta-Antila, J. Szerypo, and J. Äystö
JYFLTRAP: A cylindrical penning trap for isobaric beam purification at IGISOL
Nucl. Instr. Meth. A 528 (2004) 776

S. Heinz, J. Äystö, D. Habs, S. Hegewisch, J. Huikari, A. Nieminen, S. Rinta-Antila, M. Schumann, and J. Szerypo
A radio frequency ring electrode cooler for low-energy ion beams
Nucl. Instr. Meth. A 533 (2004) 239

J. Huikari, P. Dendooven, A. Jokinen, A. Nieminen, H. Penttilä, K. Peräjärvi, A. Popov, S. Rinta-Antila, and J. Äystö
Production of neutron deficient rare isotope beams at IGISOL; on-line and off-line studies
Nucl. Instr. Meth. B 222 (2004) 632

H.O.U. Fynbo, C.Aa. Diget, Y. Prezado, J. Äystö, U.C. Bergmann, J. Cederkall, P. Dendooven, L.M. Fraile, S. Franchoo, B.R. Fulton, W. Huang, J. Huikari, H. Jeppesen, A. Jokinen, B. Jonson, P. Jones, U. Koster, M. Meister, T. Nilsson, G. Nyman, M.J.G. Borge, K. Riisager, S. Rinta-Antila, I.S.Vogelius, O. Tengblad, M. Turrion, Y. Wang, L. Weissman, K. Wilhelmsen, and the ISOLDE Collaboration
News on ^{12}C from beta-decay studies
Nucl. Phys. A 738 (2004) 59

M.J.G. Borge, U.C. Bergmann, R. Boutami, J. Cederkäll, P. Dendooven, L.M. Fraile, H.O.U. Fynbo, W.X. Huang, J. Huikari, Y. Jading, H. Jeppesen, A. Jokinen, B. Jonson, I. Martel, M. Meister, T. Nilsson, G. Nyman, Y. Prezado, K. Riisager, O. Tengblad, L. Weismann, K. Wilhelmsen, and J. Äystö
Beta-delayed multiparticle emission studies at ISOL-type facilities
Nucl. Phys. A 746 (2004) 243

A. Jokinen, T. Eronen, U. Hager, J. Hakala, V. Kolhinen, S. Rinta-Antila, and J. Äystö
First mass measurement at JYFLTRAP
Nucl. Phys. A 746 (2004) 277

A. Kankainen, M. Santana Leitner, L.M. Fraile, A. Jokinen, M. Oinonen, K. Peräjärvi, H. Ravn, J. Äystö, and the ISOLDE Collaboration
Optimization of krypton yields for rp-process studies at ISOLDE(CERN)
Nucl. Phys. A 746 (2004) 433

T. Nilsson, J. Äystö, K. Langanke, K. Riisager, G. Martinez-Pinedo, and E. Kolbe
Muonic radioactive atoms - a unique probe for nuclear structure
Nucl. Phys. A 746 (2004) 513

A. Kellerbauer, G. Audi, D. Beck, K. Blaum, G. Bollen, P. Delahaye, F. Herfurth, H.-J. Kluge, V. Kolhinen, M. Mukherjee D. Rodríguez, and S. Schwarz
Towards high-precision mass measurements on ^{74}Rb for a test of the CVC hypothesis and the unitarity of the CKM matrix
Nucl. Phys. A 746 (2004) 635

I. Podadera, T. Fritioff, T. Giles, A. Jokinen, M. Lindroos, F. Wenander, and the ISOLDE Collaboration
Design of a second generation RFQ ion cooler and buncher (RFQCB) for ISOLDE
Nucl. Phys. A 746 (2004) 647

A. Wojtasiewicz, G. Canchel, A. Emsallem, M. Gierlik, Z. Janas, M. Kisielinski, W. Kurcewicz, J. Kurpeta, H. Lefort, S. Lewandowski, H. Penttilä, A. Plochocki, E. Roeckl, B. Roussière, S. Sidor, and A. Syntfeld
Investigation of a gas catcher/ion guide system at the Warsaw cyclotron
Nucl. Phys. A 746 (2004) 663

S. Rinta-Antila, S. Kopecky, V.S. Kolhinen, J. Hakala, J. Huikari, A. Jokinen, A. Nieminen, J. Äystö, and J. Szerypo
Direct mass measurements of neutron-rich zirconium isotopes up to ^{104}Zr
Phys. Rev. C 70 (2004) 011301 (R)

I.D. Moore, K. Bailey, J. Greene, Z.-T. Lu, P. Müller, T.P. O'Connor, Ch. Geppert, K.D A. Wendt, and L. Young
Counting individual ^{41}Ca atoms with a magneto-optical trap
Phys. Rev. Lett. 92 (2004) 153002

D. Rodriquez, V. Kolhinen, G. Audi, J. Äystö, D. Beck, K. Blaum, G. Bollen, F. Herfurth, A. Jokinen, A. Kellerbauer, H-J. Kluge, M. Oinonen, H. Schatz, E. Sauvan, and S. Schwarz
Mass measurement on the rp-process waiting point ^{72}Kr
Phys. Rev. Lett. 93 (2004) 161104

Juha Äystö
CERN's longest serving experimental facility
Physics Reports 403-404 (2004) 459

In-beam spectroscopy

P.T. Greenlees, A.N. Andreyev, J. Bastin, F. Becker, E. Bouchez, P.A. Butler, J.F.C. Cocks, Y.Le Coz, K. Eskola, J. Gerl, K. Hauschild, K. Helariutta, R.-D. Herzberg, F.P. Hessberger, R.D. Humphreys, A. Hurstel, D.G. Jenkins, G.D. Jones, P. Jones, R. Julin, S. Juutinen, H. Kankaanpaa, A. Keenan, H. Kettunen, T.L. Khoo, W. Korten, P. Kuusiniemi, M. Leino, A.-P. Leppanen, M. Muikku, P. Nieminen, R.D. Page, T. Page, J. Pakarinen, P. Rahkila, P. Reiter, Ch. Schlegel, C. Scholey, Ch. Theisen, J. Uusitalo, K. Van de Vel, R. Wadsworth, and H.-J.Wollersheim
In-beam spectroscopy at the RITU gas-filled recoil separator
Eur. Phys. J. A 20 (2004) 87

Hürstel, Y.Le Coz, E. Bouchez, A. Chatillon, A. Gorgen, P.T. Greenlees, K. Hauschild, S. Juutinen, H. Kettunen, W. Korten, P. Nieminen, M. Rejmund, Ch. Theisen, J. Wilson, A.N. Andreyev, F. Becker, T. Enqvist, P.M. Jones, R. Julin, H. Kankaanpää, A. Keenan, P. Kuusiniemi, M. Leino, A.-P. Leppanen, M. Muikku, J. Pakarinen, P. Rahkila, and J. Uusitalo
Prolate deformation in the $^{187, 189}$Bi isotopes
Eur. Phys. J. A 21 (2004) 365

H. Kankaanpää, P.A. Butler, P.T. Greenlees, J.E. Bastin, R.-D. Herzberg, R.D. Humphreys, G.D. Jones, P. Jones, R. Julin, A. Keenan, H. Kettunen, M. Leino, L. Miettinen, T. Page, P. Rahkila, C. Scholey, and J. Uusitalo
In-beam electron spectrometer used in conjunction with a gas-filled recoil separator
Nucl. Instr. Meth. A 534 (2004) 503

D.Sohler, J.Timar, Zs.Dombradi, J.Cederkall, J.Huijnen, M.Lipoglavsek, M.Palacz, A.Atac, C.Fahlander, H.Grawe, A.Johnson, A.Kerek, W.Klamra, J.Kownacki, A.Likar, L.-O.Norlin, J.Nyberg, J.Persson, D.Seweryniak, G.de Angelis, P.Bednarczyk, D.Foltescu, D.Jerrestam, S.Juutinen, E.Makela, M.de Poli, H.A.Roth, T.Shizuma, O.Skeppstedt, G.Sletten, S.Tormanen, M.Weiszflog
Band-terminating states in ^{101}Ag
Nucl. Phys. A 733 (2004) 37

T.Shizuma, S.Mitarai, G.Sletten, R.A.Bark, N.L.Gjorup, H.J.Jensen, M.Piiparinen, J.Wrzesinski, Y.R.Shimizu
High-spin structure in ^{185}Os
Phys. Rev. C 69 (2004) 024305

R.D. Humphreys, P.A. Butler, J.E. Bastin, P.T. Greenlees, N.J. Hammond, R.-D. Herzberg, D.G. Jenkins, G.D. Jones, H. Kankaanpää, H. Kettunen, A. Keenan, T. Page, P. Rahkila, C. Scholey, J. Uusitalo, N. Amzal, P.M.T. Brew, K. Eskola, J. Gerl, K. Hauschild, K. Helariutta, F.-P. Heßberger, A. Hürstel, P.M. Jones, R. Julin, S. Juutinen, T.-L. Khoo, W. Korten, P. Kuusiniemi, Y. Le Coz, M. Leino, A.-P. Leppänen, M. Muikku, P. Nieminen, S.W. Ødegård, J. Pakarinen, P. Reiter, G. Sletten, Ch. Theisen, and H.-J. Wollersheim
In-Beam electron spectroscopy of ^{226}U and ^{254}No
Phys.Rev. C 69 (2004) 064324

P. Nieminen, S. Juutinen, A.N. Andreyev, J.F.C. Cocks, O. Dorvaux, K. Eskola, P.T. Greenlees, K. Hauschild, K. Helariutta, M. Huyse, P.M. Jones, R. Julin, H. Kankaanpää, H. Kettunen, P. Kuusiniemi, Y. Le Coz, M. Leino, T. Lönnroth, M. Muikku, P. Rahkila, A. Savelius, J. Uusitalo, N. Amzal, N.J. Hammond, C. Scholey, and R. Wyss
Gamma -ray spectroscopy of ^{191,193}Bi
Phys. Rev. C 69 (2004) 064326

D.T. Joss, K. Lagergren, D.E. Appelbe, C.J. Barton, J. Simpson, B.Cederwall, B. Hadinia, R.Wyss, S. Eeckhaudt, T. Grahn, P.Greenlees, A. Johnson, P.M. Jones, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, C. Scholey, and J. Uusitalo
Recoil decay tagging of gamma rays in the extremely neutron-deficient nucleus ^{162}Os
Phys. Rev. C 70 (2004) 017302

P.M. Raddon, D.G. Jenkins, C.D. O'Leary, A.J. Simons, R. Wadsworth, A.N. Andreyev, R.D. Page, M.P. Carpenter, F.G. Kondev, T. Enqvist, P.T. Greenlees, P. M. Jones, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, J. Uusitalo, and D.T. Joss
Gamma-decay and recoil-decay tagging studies of ^{183}Tl
Phys. Rev. C 70 (2004) 064308

Hadinia, B. Cederwall, K. Lagergren, J. Blomqvist, T. Bäck, S. Eeckhaudt, T. Grahn, P. Greenlees, A. Johnson, D.T. Joss, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A.-P. Leppänen, R.J. Liotta, P. Nieminen, M. Nyman, J. Pakarinen, E.S. Paul, P. Rahkila, C. Scholey, J. Uusitalo, R. Wadsworth, and D. R. Wiseman
First identification of gamma-ray transitions in ^{107}Te
Phys. Rev. C 70 (2004) 064314

R. Julin
Gamma-ray and conversion-electron spectroscopy of exotic heavy nuclei
Lecture notes in physics: The euroschool lectures on physics with exotic beams, Vol.1, Springer, Editors: J. Al-Khalili and E. Roeckl (2004) 263

The JYFL gas-filled recoil separator RITU

M. Leino, and F.P. Heßberger
The nuclear Structure of heavy-actinide and transactinide nuclei
Annu. Rev. Nucl. Part. Sci. 54 (2004) 175

F.P. Heßberger, S. Hofmann, D. Ackermann, R.-D. Herzberg, I. Kojouharov, P. Kuusiniemi, M. Leino, and R. Mann
Alpha-gamma decay studies of ^{251,253}No and their daughter products ^{247,249}Fm
Eur. Phys. J. A 22 (2004) 417

S. Hofmann, F.P. Heßberger, D. Ackermann, S. Antalic, P. Cagarda, B. Kindler, P. Kuusiniemi, M. Leino, B. Lommel, O.N. Malyshev, R. Mann, G. Münzenberg, A.G. Popeko, S. aro, B. Streicher, and A.V. Yeremin
Properties of heavy nuclei measured at the GSI SHIP
Nucl. Phys. A 734 (2004) 93

H. Kettunen, T. Enqvist, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, A. Keenan, P. Kuusiniemi, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, and J. Uusitalo
Decay studies of ^{170,171}Au, $^{171-173}$Hg, and ^{176}Tl
Phys. Rev. C 69 (2004) 054323

W.F. Mueller, W. Reviol, M.P. Carpenter, R.V.F. Janssens, F.G. Kondev, K. Abu Salem, I. Ahmad, H. Amro, C.R. Bingham, J. Caggiano, C.N. Davids, D. Hartley, A. Heinz, B. Herskind, D. Jenkins, T.L. Khoo, T. Lauritsen, W.C. Ma, J. Ressler, L.L. Riedinger, D.G. Sarantites, D. Seweryniak, S. Siem, A.A. Sonzogni, J. Uusitalo, P.G. Varmette, I. Wiedenhöver, and R. Wadsworth
High-spin States in ^{179}Au – spectroscopy of shape-driving orbitals beyond the neutron midshell
Phys. Rev. C 69 (2004) 064315

ALICE and nuclear reactions

L. Swiderski, P. Czosnyka, M. Kowalczyk, E. Piasecki, K. Piasecki, M. Witecki, J. Jastrzebski, A. Kordyasz, M. Kisielinski, T. Krogulski, N. Rowley, C. Marchetta, A. Pagano, M. Mutterer, W.H. Trzaska, and K. Hagino
How many fusion barriers?
Int. J. Mod. Phys. E 13, 1 (2004) 315

Yu.V. Pyatkov, V.V. Pashkevich, W.H. Trzaska, G.G. Adamian, N.V. Antonenko, D.V. Kamanin, V.A. Maslov, V.G. Tishchenko, and A.V. Unzhakova
Nontrivial manifestation of clustering in fission of heavy nuclei at low and middle excitiation
Jad. Phys. 67 (2004) 1

ALICE Collaboration
ALICE physics performance report
J. Phys. G 30, 1 (2004) 1517

M. G. Itkis, J. Äystö, S. Beghini, A.A. Bogatchev, L. Corradi, O. Dorvaux, A. Gadea, G. Giardina, F. Hanappe, I.M. Itkis, M. Jandel, J. Kliman, S.V.Khlebnikov, G.N. Kniajeva, N.A. Kondratiev, E.M. Kozulin, L. Krupa, L. Latina, T. Materna, G. Montagnoli, Yu. Ts. Oganessian, I.V. Pokrovsky, E.V. Prokhorova, N. Rowley, V.A. Rubchenya, A. Ya. Rusanov, R.N.Sagaidak, F. Scarlassara, A.M. Stefanini, L. Stuttge, S. Szilner, M. Trotta, W.H. Trzaska, D.N. Vakhtin, A.M. Vinodkumar, V.M. Voskresenski, and V.I.Zagrebaev
Shell effects in fission and quasi-fission of heavy and superheavy nuclei
Nucl. Phys. A 734 (2004) 136

V.A. Rubchenya, W.H. Trzaska, I.M. Itkis, M.G. Itkis, J. Kliman, N. Kniajeva, N.A. Kondratiev, E.M. Kozulin, L. Krupa, V. Pokrovski V.M. Voskressenski, F. Hanappe, T. Materna, O. Dorvaux, L. Stuttge, G. Chubarian, S.V. Khlebnikov, D.N. Vakhtin, and V.G.Lyapin
Fission dynamics in the proton induced fission of heavy nuclei
Nucl. Phys. A 734 (2004) 253

G.N. Kniajeva, L. Krupa, A.A. Bogachev, G.G. Chubarian, O. Dourvaux, I.M. Itkis, M.G. Itkis, J. Kliman, S. Khlebnikov, N.A. Kondratiev, E.M. Kozulin, V. Lyapin, T. Materna, I.V. Pokrovsky, V.A. Rubchenya, W.H. Trzaska, D. Vakhtin, and V.M. Voskressenski
Neutron and gamma-ray emission in the proton induced fission of ^{238}U and ^{242}Pu
Nucl. Phys. A 734 (2004) E25

S.P. Tretyakova, A.A. Ogloblin, M.V. Rozhkov, R.N. Sagaidak, W.H. Trzaska, and S.V. Khlebnikov
Study of nucleus-nucleus potential by combined measurement of deep sub-barrier fusion and cluster decay
Nucl. Phys. A 734 (2004) E33

M. Mutterer, Yu.N. Kopatch, P. Jesinger, A.M. Gagarski, F. Gönnenwein, J. von Kalben, S.G. Khlebnikov, I. Kojouharov, E. Lubkiewicz, Z. Mezentseva, V. Nesvishevsky, P.G. Petrov, H. Schaffner, H. Scharma, D. Schwalm, P. Thirolf, W.H. Trzaska, G.P. Tyurin, and H.-J. Wollensheim
Recent experimental studies on particle-accompanied fission
Nucl. Phys. A 738 (2004) 122

S.P. Tretyakova, A.A. Ogloblin, R.N. Sagaidak, W.H. Trzaska, S.V. Khlebnikov, R. Julin, and J. Perkovski
Study of extremely deep subbarrier ^{22}Ne+^{208}Pb fusion-fission and evidence for alpha-decay-like mechanism of ^{230}U cluster radioactivity
Nucl. Phys. A 738 (2004) 487

V.Yu. Ugryumov, I.V. Kuznetsov, E. Byalkovski, A. Kugler, K.A. Kuterbekov, I.N. Kukhtina, V.F. Kushniruk, V.G. Lyapin, V.A. Maslov, Yu.E. Penionzhkevich, Yu.G. Sobolev, W. Trzaska, G.P. Tyurin, S.V. Khlebnikov, and S.R. Yamaletdinov
Energy dependence of the total reaction cross section of silicon induced by ^{4}He ions with silicon nuclei
Phys. Atomic Nuc. 68 (2005) 16

V.Z. Goldberg, G.V. Rogachev, W.H. Trzaska, J.J. Kolata, A.Andreyev, C. Angulo, M.J.G. Borge, S. Cherubini, G. Chubarian, G. Crowley, P. Van Duppen, M. Gorska, M. Gulino, M. Huyse, K.-M. Källman, M. Lattauda, T. Lönnroth, M. Mutterer, R. Raabe, S. Romano, M.V. Rozhkov, B.B. Skorodumov, C. Spitaleri, O. Tengblad, and A.Tumino
Investigation of the alpha-cluster structure of ^{22}Ne and ^{22}Mg
Phys. Rev. C 69 (2004) 024602

I. Tsekhanovich, N. Varapai, V.A. Rubchenya, D. Rochman, G.S. Simpson, V. Sokolov, G. Fioni, and I. Al Mahamid
Fission-product formation in the thermal-neutron-induced fission of odd Cm isotopes
Phys. Rev. C 70 (2004) 044610

Accelerator based materials physics and industrial applications

H.J. Whitlow, M.L. Ng, V. Auželyté, I.A. Maximov, J.A. van Kan, A. Bettiol and F. Watt
Lithography of high spatial-density biosensor structures with sub-100 nm spacing by MeV proton beam writing with a minimal proximity effect
Nanotechnology 15 (2004) 223

P. Golubev, B. Jakobsson, P. Marciniewski, A. Siwek, E.J. van Veldhuizen, L. Westerberg, H.J. Whitlow, J.M. Østby V. Avdeichikov, and G. Førre
CHICSi a compact ultra-high vacuum compatible detector system for nuclear reaction experiments at storage rings.III. Readout system, L. Carlén),
Nucl. Instr.Meth. A 516 (2004) 327

J. Härkönen, E. Tuovinen, P. Luukka, E. Tuominen, K. Lassila-Perini, P. Mehtälä, S. Nummela, J. Nysten, A. Zibellini, Z. Li, E. Fretwurst, G. Lindström, J. Stahl, F. Honniger, V. Eremin, A. Ivanov, E. Verbitskaya, P. Heikkilä, V. Ovchinnikov, M. Yli-Koski, P. Laitinen, A. Pirojenko, I. Riihimäki, and A. Virtanen
Radiation hardness of czochralski silicon, float zone silicon and oxygenated float zone silicon studied by low energy protons
Nucl. Instr. Meth. A 518, 1-2 (2004) 346

P. Luukka, J. Härkonen, E. Tuovinen, E. Tuominen, K. Lassila-Perini, P. Mehtälä, S. Nummela, J. Nysten, D. Ungaro, A. Zibellini, P. Laitinen, I. Riihimäki, A. Virtanen, A. Furgeri, and F. Hartmann
Results of proton irradiations of large area strip detectors made on high-resistivity Czochralski silicon
Nucl. Instr. Meth. A 530, 1-2 (2004) 117

Y. Zhang, W.J. Weber and H.J. Whitlow
Electronic stopping powers for heavy ions in silicon
Nucl. Instr. Meth. B 215 (2004) 48

H. Timmers, K. Stenström, M. Graczyk, and H. J. Whitlow
Energy loss measurements for mass-14 ions using a pattered stopping medium on a PIN diode
Nucl. Instr. Meth. B 219 (2004) 263

P. Laitinen, M. Nevala, A. Pirojenko, K. Ranttila, R. Seppälä, I. Riihimäki, J. Räisänen, and A. Virtanen
Utilisation of JYFL sputtering device for targetry and diffusion studies
Nucl. Instr. Meth. B 226, 3 (2004) 441

J. Härkönen, E. Tuovinen, P. Luukka, E. Tuominen, K. Lassila-Perini, J. Nysten, Z. Li, E. V. Eremin, A. Ivanov, E. Verbitskaya, P. Heikkilä, V. Ovchinnikov, M. Yli-Koski, P. Laitinen, I. Riihimäki, and A. Virtanen
Particle detectors made of high resistivity Czochralski grown silicon
Physica Scripta T114 (2004) 88

Nuclear structure, nuclear decays, rare and exotic processes

J. Suhonen, and E. Holmlund
Nuclear-structure calculations for neutrino physics and dark-matter physics
Czech. J. Phys. 54 (2004) B281

R. Arnold, C. Augier, J. Baker, A.S. Barabash, V. Brudanin, J. Caffrey, V. Egorov, J. L. Guyonnet, F. Hubert, Ph. Hubert, L. Jenner, C. Jollet, S. Jullian, A. Klimenko, O. Kochetov, S. Konovalov, V. Kovalenko, D. Lalanne, F. Leccia, I. Linck, C. Longuemare, G. Lutter, Ch. Marquet, F. Mauger, H. W. Nicholson, H. Ohsumi, F. Piquemal, J.-L. Reyss, R. Saakyan, X. Sarazin, F. Scheibling, Yu. Shitov, L. Simard, A. Smolnikov, I. \v Stekl, J. Suhonen, C.S. Sutton, G. Szklarz, V. Timkin, J. Thomas, V. Tretyak, V. Umatov, L. V\'ala, I. Vanyushin, S. Vasiliev, V. Vasilyev, V. Vorobel, and Ts. Vylov
Study of two-neutrino double beta decay of ^{100}Mo and ^{82}Se using the NEMO3 detector
Jetp. Lett. 80 (2004) 377

M. Kortelainen, and J. Suhonen
Nuclear muon capture as a powerful probe of double-beta decays in light nuclei
J. Phys. G 30 (2004) 2003

E. Holmlund, M. Kortelainen, T.S. Kosmas, J. Suhonen, and J. Toivanen
Theoretical LSP detection rates for the ^{71}Ga, ^{73}Ge and ^{127}I dark-matter detectors
Phys. Atom. Nucl. 67 (2004) 1198

M. Kortelainen, and J. Suhonen
Analysis of the $2\nu\beta\beta$ decay and muon-capture reactions for the mass A=46 and A=48 nuclei using the nuclear shell model
Phys. Atom. Nucl. 67 (2004) 1202

O. Civitarese, and J. Suhonen
Neutrino masses, nuclear matrix elements, and the $0\nu\beta\beta$ decay of ^{76}Ge
Phys. Atom. Nucl. 67 (2004) 1206

I.N. Izosimov, A.A. Kazimov, V.G. Kalinnikov, A. Solnyshkin, and J. Suhonen
Beta-decay strength measurement, total beta-decay energy determination, and decay-scheme completeness testing by total absorption γ-ray spectroscopy
Phys. Atom. Nucl. 67 (2004) 1876

E. Holmlund, M. Kortelainen, T.S. Kosmas, J. Suhonen, and J. Toivanen
Microscopic calculation of the LSP detection rates for the ^{71}Ga, ^{73}Ge and ^{127}I dark-matter detectors
Phys. Lett. B 584 (2004) 31

M. Kortelainen, and J. Suhonen
Probing double beta decay by the nuclear muon capture, in MUONS -2004 (New Research), Ed. J. Caparthy, NOVA Publishers, 2004 (Invited Monograph) ISBN: 1-59454-175-2

Nanoscale PHYSICS and nanotechnology

M. Savolainen, V. Touboltsev, P. Koppinen, K.-P. Riikonen, and K.Yu. Arutyunov
Ion beam sputtering for progressive reduction of nanostructures dimensions
Appl. Phys. A 79 (2004) 1769

S. Chakraborty, I.J. Maasilta, S.H. Tessmer, and M.R. Melloch
Imaging a two-dimensional electron system with a scanning charged probe
Phys. Rev. B 69 (2004) 073308

K.Yu. Arutyunov, and T.T. Hongisto
Normal metal – insulator – superconductor interferometer
Phys. Rev. B 70 (2004) 064514

J.T. Karvonen, L.J. Taskinen, and I.J. Maasilta
Electron-phonon interaction in thin copper and gold films
Phys. Stat. Sol. (c) 1 (2004) 2799

L.J. Taskinen, J.M. Kivioja, J.T. Karvonen, and I.J. Maasilta
Direct measurement of the electron-phonon relaxation rate in thin copper films
Phys. Stat. Sol. (c) 1 (2004) 2856

I. Kuljanishvili, S. Chakraborty, I.J. Maasilta, S.H. Tessmer and M.R. Melloch
Modeling electric field sensitive scanning probe measurements for a tip of arbitary shape
Ultramicroscopy 102 (2004) 7

K.Yu. Arutyunov, T.T. Hongisto, and J.P. Pekola
Solid state analogue of an optical interferometer
Quantum computing and quantum bits in mesoscopic systems edited by A. Leggett, B. Ruggiero and P. Silvestrini, Kluvert Academic Plenum Publishers (2004) 247

Nanoelectronics and nanotechnology

J. Kinnunen, M. Rodríguez, and P. Törmä
Pairing gap and in-gap excitations in trapped fermionic superfluids
Science 305 (2004) 1131
Published also online in ScienceExpress 22 July 2004, 10.1126/science.1100782

J. Vanhanen, M. Rinkiö, J. Aumanen, J. Korppi-Tommola, E. Kolehmainen, T. Kerkkänen, and P. Törmä
Characterization of used mineral oil condition by spectroscopic techniques
Appl. Optics 43 (2004) 4718

T. Koponen, A. Huttunen, and P. Törmä
Conditions for waveguide decoupling in square-lattice photonic crystals
J. Appl. Phys. 96, (2004) 4039

J.J. Toppari, J.M. Kivioja, J.P. Pekola and M.T. Savolainen
Turnstile behaviour of the Cooper pair pump
J. Low Temp. Phys. 136 (2004) 57

V. Ruuska, and P. Törmä
Quantum transport of non-interacting fermi gas in an optical lattice combined with harmonic trapping
New J. Phys. 6 (2004) 59

M. Rodríguez, and P. Törmä
Bloch oscillations in Fermi gases
Phys. Rev. A 69 (2004) 014602(R)

M. Rodríguez, P. Pedri, P. Törmä, and L. Santos
Scissors modes of two-component degenerate gases: Bose-Bose and Bose-Fermi mixtures
Phys. Rev. A 69 (2004) 023617

J.-P. Martikainen, and H.T.C. Stoof
Quantum theory of a vortex line in an optical lattice
Phys. Rev. A 69 (2004) 053617

J.-P. Martikainen, and H.T.C. Stoof
Longitudinal sound mode of a Bose-Einstein condensate in an optical lattice
Phys. Rev. A 69 (2004) 023608

J.-P. Martikainen and H.T.C. Stoof
Spontaneous squeezing of a vortex in an optical lattice
Phys. Rev. A 70 (2004) 013604

J.-P. Martikainen and H. T. C. Stoof
Quantum fluctuations of a vortex in an optical lattice
Phys. Rev. Lett. 91 (2004) 240403

J. Kinnunen, M. Rodríguez, and P. Törmä
Signatures of superfluidity for Feshbach-resonant Fermi gases
Phys. Rev. Lett. 92 (2004) 230403

J.-P. Martikainen and H. T. C. Stoof
Vortex-line solitons in a periodically modulated Bose gas
Phys. Rev. Lett. 93 (2004) 070402

A. Savin, J. Pekola, M. Prunnila, J. Ahopelto, and P. Kivinen
Electronic cooling and hot electron effects in heavily doped silicon-on-insulator film
Phys. Scripta T114 (2004) 57

P. Kivinen, M. Prunnila, A. Savin, P. Törmä, J. Pekola, and J. Ahopelto
Electron-phonon heat transport in degenerate Si at low temperatures
Phys. Stat. Sol. (c) 1 (2004) 2848

Computational nanosciences

K. Manninen, A. Rytkönen, and M. Manninen
Influence of electronic and geometric properties on melting of sodium clusters
Eur. Phys. J. D 29 (2004) 39

R.N. Barnett, H. Häkkinen, A.G. Scherbakov, and U. Landman
Hydrogen welding and hydrogen switches in a mono-atomic gold nanowire
Nano Lett. 4 (2004) 1845

S. Viefers, P. Koskinen, P. Singha Deo, and M. Manninen
Quantum rings for beginners: Energy spectra and persistent currents
Physica E 21 (2004) 1

K. Manninen, H. Häkkinen, and M. Manninen
The electronic structure and the melting of magic Na59
Phys. Rev. A 70 (2004) 023203

K. Rytkönen, J. Akola, and M. Manninen
Sodium atoms and clusters on graphite: a density functional study
Phys. Rev. B 69 (2004) 205404

T. Kühn, D.V. Anghel, J.P. Pekola, M. Manninen, and Y.M. Galperin
Heat transport in ultra-thin dielectric membranes and bridges
Phys. Rev. B 70 (2004) 125425

K. Kärkkäinen, M. Koskinen, S.M. Reimann, and M. Manninen
Density functional theory of multicomponent quantum dots
Phys. Rev. B 70 (2004) 195310

M. Toreblad, M. Borgh, M. Manninen, M. Koskinen, and S.M. Reimann
Universal vortex formation in rotating traps with bosons and fermions
Phys. Rev. Lett. 93 (2004) 090407

H. Häkkinen, M. Moseler, O. Kostko, N. Morgner, M.A. Hoffman, and B. v. Issendorff
Symmetry and electronic structure of noble metal nanoparticles and the role of relativity
Phys. Rev. Lett. 93 (2004) 093401

K. Kärkkäinen, M. Koskinen, M. Manninen, and S.M. Reimann
Electron-hole bilayer quantum dots: Phase diagram and exciton localization
Solid State Commun. 130 (2004) 187

Soft condensed matter and statistical physics

S. Ramaswamy, M. Gupta, A. Goel, U. Aaltosalmi, M. Kataja, A. Koponen, and B.V. Ramarao
The 3D structure of fabric and its relationship to liquid and vapor transport
Coll. and Surf. A. 241(1) (2004) 323

R.P. Linna, J.A. Åström, and J. Timonen
Unconstrained periodic boundary conditions for solid state elasticity
Comp. Phys. Comm. 158 (2004) 26

J. Hyväluoma, P. Raiskinmäki, A. Jäsberg, A. Koponen, M. Kataja, and J. Timonen
Evaluation of a lattice- Boltzmann method for mercury intrusion porosimetry simulations
Future Gen. Comp. Syst. 20 (2004) 1003

A.V. Rybin, and I.P. Vadeiko
Manipulation of optical solitons in Bose-Einstein condensates
J. Optics B: Quantum and Semiclass. Optics 6 (2004) 416

V. Rybin, G.G. Varzugin, and J. Timonen
Collapse in the symmetric Gross-Pitaevskii equation
J. Optics B: Quantum and Semiclass. Optics 6 (2004) S392

J.B. Parkinson, R.J. Elliot, and J. Timonen
Small clusters with anisotropic antiferromagnetic exchange in a magnetic field
J. Phys.: Condens. Matter 16 (2004) 2407

U. Aaltosalmi, M. Kataja, A. Koponen, J. Timonen, A. Goel, G. Lee, and S. Ramaswamy
Numerical analysis of fluid flow through fibrous porous materials
J. Pulp and Paper Sc. 30 (2004) 251

A.V. Rybin, I.P. Vadeiko, G.G. Varzugin, and J. Timonen
Singularity formation in the Gross-Pitaevskii equation and collapse in BEC
Phys. Rev. A 69 (2004) 13677

N.M. Bogoliubov, C. Malyshev, R.K. Bullough, and J. Timonen
Finite-temperature correlations in the one-dimensional trapped and untrapped Bose gases
Phys. Rev. A 69 (2004) 23619

J. A. Åström, R. P. Linna, J. Timonen, P. F. Møller and L. Oddershede
Exponential and power-law mass distributions in brittle fragmentation
Phys. Rev. E 70 (2004) 26104

J.A. Åström, F. Ouchterlony, R.P. Linna, and J. Timonen
Universal dynamic fragmentation in D dimensions
Phys. Rev. Lett. 92 (2004) 245506

J.A. Åström, J. Timonen and M. Karttunen
Crumpling of a stiff tethered membrane
Phys. Rev. Lett. 93 (2004) 244301

P. Moilanen, V. Kilappa, P.H.F. Nicholson, J. Timonen, and S. Cheng
Thickness sensitivity of ultrasound velocity in long bone phantoms
Ultrasound in Med. and Biol. 30 (2004) 1517

Ultrarelativistic heavy ion collisions

Several articles in CERN Yellow Report on Hard Probes in Heavy Ion Collisions at the LHC, Eds. M. Mangano, H. Satz, U. Wiedemann CERN-2004-009, ISSN 0007-8328, ISBN 92-9083-234-7

A. Dainese, R. Vogt, M. Bondila, K.J. Eskola, and V.J. Kolhinen
D-meson enhancement in pp collisions at the LHC due to nonlinear gluon evolution
J. Phys. G 30 (2004) 1787

F. Gelis, H. Niemi, P.V. Ruuskanen, and S.S. Räsänen
Photon production from non-equilibrium QGP in heavy ion collisions
J. Phys. G 30 (2004) S1031

K.J. Eskola, V.J. Kolhinen, and R. Vogt
Enhanced charm hadroproduction due to nonlinear corrections to the DGLAP equations,
J. Phys. G 30 (2004) S1171

A. Mocsy, F. Sannino, and K. Tuominen
Deconfinement and chiral symmetry restoration
J. Phys. G 30 (2004) S1255

P. Huovinen, and J.I. Kapusta
Rate equation network for baryon production in high energy nuclear collisions
Phys. Rev. C 69 (2004) 014902

J. Randrup, and P.V. Ruuskanen,
Thermodynamic consistency of the equation of state of strongly interacting matter,
Phys. Rev. C 69 (2004) 047901

P. Hoyer, J.T. Lenaghan, K. Tuominen, and C. Vogt
Subprocess size in hard exclusive scattering
Phys. Rev. D 70 (2004) 014001

F. Sannino and K. Tuominen
Tetracritical behavior in strongly interacting theories
Phys. Rev. D 70, (2004) 034019.

J. Randrup
Spinodal decomposition during the hadronization stage at RHIC?
Phys. Rev. Lett. 92 (2004) 122301

K.J. Eskola, V.J. Kolhinen, and R. Vogt
Enhancement of charm quark production due to nonlinear corrections to the DGLAP equations
Phys. Lett. B 582 (2004) 157

Theoretical particle physics and cosmology

Tai-Fu Feng, X.-Qian Li, and J. Maalampi
Anomalous Higgs-top-quark couplings in the MSSM
Phys. Rev. D 69 **(**2004**)** 115007 **(**1-24**)**

Tai-fu Feng
The two-loop gluino's corrections on the inclusive b ---> x(s) gamma decay in the CP violation MSSM with large tan beta
Phys. Rev. D 70 (2004) 096012

P. Keränen, J. Maalampi, M. Myyryläinen and J. Riittinen
Effects of degenerate neutrinos on the supernova neutrino flux
Phys. Lett. B597 (2004) 374

Quantum gravity

J. Mäkelä, and A. Peltola
Spacetime foam model of the Schwarzschild horizon
Phys. Rev. D 69 (2004) 124008

Theses and degrees

Theses and degrees

Theses

MSc theseS (chronological order)

Eveliina Lammentausta, Metalli-ionisuihkujen tuottaminen ECR-ionilähteellä sputterointimenetelmän avulla

Sami Mäki, Tutkimus todennäköisyydestä kvanttimekaniikan opiskelijoille

Jussi Jääskeläinen, Tärkkelysliuoksen paineavusteinen tunkeutuminen paperirainaan

Anne Heikkilä, Auringon neutriinot

Antti Rovasalo, Hiertämön lämmöntalteenotto

Timo Santa-Nokki, Karbonyyliryhmän sitoutuminen kolmiatomiseen palladiumklusteriin

Sanna Haavisto, Kuitususpension suotautumismittaukset ultraäänidoppler-anemometriaan perustuvalla menetelmällä

Aki Grekula, Peruskoululaisten käsityksiä energiasta

Juha Pakarinen, Rainan syntymekanismeihin vaikuttavat fysikaaliset ilmiöt kitaformerin muodostuselementin alueella

Ilkka Malinen, Elektroniikan perusteita lukiossa

Helena Heikkilä, Paperikoneteknologia kouluopetuksessa

Sakari Pasanen, Lyhytkuitulajin ja täyteainemäärän vaikutus hienopaperin ajettavuuteen ja kalanteroitavuuteen

Tuomo Rinne, Kuitujen muodonmuutos märän paperin kokoonpuristuvuuden avulla

Mikko Aikio, Suurten molekyylien diffuusio

Harri Niemi, Ultrarelativististen raskasionitörmäysten hydrodynaaminen mallintaminen ja elliptinen virtaus

Heidi Parviainen, Raskaiden ionien energiajättö kohtiossa

Jan Sarén, RITUn kehittäminen ja kaasutäytteisiin separaattoreihin liittyvää ionioptiikkaa

Teemu Turunen, Menetelmä paperikoneen elinkaaren aikaisen ympäristövaikutuksen laskemiseen

Terhi Hongisto, Normal metal –insulator –superconductor structures as solid state interferometers

Viivi Koivu, Paperin permeabiliteetin mittaamismenetelmä

Virve Karjalainen, Mittauskarttojen kohdistaminen paperin analyysimenetelmänä

Tiina Hälikkä, Paperin lokaalin deformaation mittaaminen

Pasi Karvonen, IVACS-IGISOL massaerottimen tyhjiönohjausjärjestelmä

Tommi Hakala, On-chip thermometer for bioapplications

Turkka Salminen, Avaruussäteilyn aiheuttamista virheistä elektroniikkakomponenteissa

Janne Juntunen, ZRP-mallin ominaisuuksia hitaasti vaimenevilla siirtymätaajuusfunktioilla

Jarno Stranden, SIMON kammioon liitettävän optisen etäisyysmittauslaitteiston suunnittelu ja toteutus

Einari Periainen, Metallien muokkausjäljen paljastaminen sputterointimenetelmällä

Inkeri Halkosaari, Lentävä lähtö

Teemu Linjama, Fysiikkaa ja kemiaa jo viidennellä luokalla – uusien oppikirjojen sisällöt

Jenni Andersin, Superraskaan ^{250}Fm ytimen in-beam spektroskooppinen tutkimus

Marcus Rinkiö, Kapasitiivinen mikroanturi

Juha Leppävuori, Kuvausparametrien vaikutukset CCD-kameralla otetuista kuvista laskettuun kuitususpension flokkikokoon

Antti Saastamoinen, Erittäin ohuet kaksipuoleiset piinauhailmaisimet

Johanna Piilonen, Kvanttimekaniikasta, ajasta ja todellisuudesta

PhD theses

Pauli Laitinen, Self and impurity diffusion in intrinsic relaxed silicon-germanium
JYFL Research Report 1/2004

Kirsi Manninen, Studies of structures and melting of small metal clusters
JYFL Research Report 2/2004

Riku Linna, Dynamic aspects in brittle fragmentation
JYFL Research Report 3/2004

Juhani Hämäläinen, Partitioning of parameter spaces of physical models
JYFL Research Report 4/2004

Marko Savolainen, Size sensitive phenomena in superconducting wires and single charge devices
JYFL Research Report 5/2004

Eero Holmlund, Microscopic nuclear-structure calculations for the neutrino- and LSP-scattering processes
JYFL Research Report 6/2004

Pasi Raiskinmäki, Dynamics of multiphase flows: Liquid-particle suspensions and droplet spreading
JYFL Research Report 7/2004

Petro Moilanen, Ultrasonic guided wave measurements in bone
JYFL Research Report 8/2004

Degrees
(alphabetical order)

BSc degrees
(main subject)

Hakala, Tommi (electronics)
Walkeajärvi, Tuula (physics)

MSc degrees
(main subject)

*=MSc includes teachers pedagocigal studies

Agar, David (appl. physics)
Aikio, Mikko (theor. physics)
Andersin, Jenni (physics)*
Haavisto, Sanna (appl. physics)
Hakala, Tommi (electronics)
Halkosaari, Inkeri (physics)*
Heikkilä, Anne (physics)*
Heikkilä, Helena (appl. physics)
Hongisto, Terhi (appl. physics)
Hälikkä, Tiina (appl. physics)
Joutsi, Jaakko (physics)*
Juntunen, Janne (physics)
Jääskeläinen, Jussi (appl. physics)
Kalvas, Taneli (physics)
Karjalainen, Virve (appl. physics)
Karvonen, Pasi (physics)
Koivu, Viivi (appl. physics)
Lammentausta, Eveliina (physics)
Leppävuori, Juha (physics)
Linjama, Teemu (physics)*
Malinen, Ilkka (physics)*
Moilanen, Hannu (physics)*
Mäki, Sami (physics)*
Niemi, Harri (theor. physics)
Pakarinen, Juha (appl. physics)
Parviainen, Heidi (physics)*
Pasanen, Sakari (appl. physics)
Periainen, Einari (electronics)
Piilonen, Johanna (theor. physics)
Rinkiö, Marcus (electronics)*
Rinne, Tuomo (appl. physics)
Rovasalo, Antti (appl. physics)
Saastamoinen, Antti (physics)
Salminen, Turkka (appl. physics)
Santa-Nokki, Timo (physics)
Sarén, Jan (physics)
Somppi, Tero (physics)*
Stranden, Jarno (physics)
Turunen, Teemu (appl. physics)
Välitalo, Minna (physics)*

PhD degrees

Holmlund, Eero (theor. physics)
Hämäläinen, Juhani (theor. physics)
Laitinen, Pauli (physics)
Linna, Riku (appl. physics)
Manninen, Kirsi (physics)
Moilanen, Petro (appl. physics)
Raiskinmäki, Pasi (appl. physics)
Savolainen, Marko (appl. physics)

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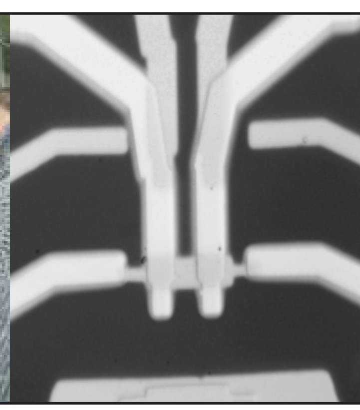


Juho Jäppinen/Jussi Jäppinen Ky Kopijyvä Oy 2005