DEPARTMENT OF PHYSICS / UNIVERSITY OF JYVÄSKYLÄ / ANNUAL REPORT 2012

JYFL

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ANNUAL REPORT 2012

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UNIVERSITY OF JYVÄSKYLÄ

P.O. BOX 35
FI–40014 UNIVERSITY OF JYVÄSKYLÄ
FINLAND
Tel: +358 40 805 4356
Fax: +358 14 617 411
www.jyu.fi/physics

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DEPARTMENT OF PHYSICS UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT

2012

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Department of Physics 2012

Department of Physics

Jukka Maalampi, Head of the Department

The Department has published annual reports regularly since 1976. This annual report describes the research and teaching carried out in the Department in 2012. All research groups have contributed to this report, presenting their activities and achievements. The report also lists all refereed publications, thesis works and relevant statistical information of the year.

Research

In recent years, a great number of research evaluations have been carried out by different parties. In these evaluations, the assessments concerning the Department of Physics have always been very positive. It was hence in line with our expectations that the Department of Physics also performed well in the evaluation *Physics Research in Finland 2007–2011* arranged by the Academy of Finland in 2012. Obviously, the Department of Physics has succeeded in achieving the goal of producing high-quality international research in all its chosen fields.

The international panel of the evaluation was extremely appreciative of the research carried out by the staff of the Accelerator Laboratory, Finland's largest and only truly international research infrastructure. The standard of research

Photo Juho Jäppinen

was classed as being exceptionally high and the activities as being well-organised and efficient.

The panel also appreciated the Nanoscience Centre, with its multidisciplinary activities and impressive collection of quality research equipment. It was also noted that the "trident" of experimental, theoretical and numerical research directions formed a balanced and effective whole.

As far as Particle Physics was concerned, the panel focused its attention on the research into ultrarelativistic heavy ion collisions, which has a high international visibility and is held in high regard (to which the panel did not do the justice it deserves). In 2012, the Department decided to strengthen its activity in the ultrarelativistic heavy ion physics by establishing a professorship in experimental particle physics focused on this field.

The panel also voiced strong support for the neutrino physics laboratory, planned to be situated in the Pyhäsalmi mine. This pan-European LAGUNA project was viewed as being an excellent opportunity for the Finnish particle physics community to open a new and positive development route. Our Department, in a close collaboration with physicists from Helsinki and Oulu Universities, is an active player in the EU-funded LAGUNA design study.

According to the recently published citation analyses our Department is in a league of its own when compared to other Physics Departments in Finland as far as the international impact of its research is concerned (see the histogram on the next page), and was also at the sharp end of things when all fields of research were considered. One would have hoped that this bias-free measurement would have been visible in the Academy evaluation whose one aim was to assess the quality of physics research in Finland as compared to international standards.

The co-operation with the Helsinki Institute of Physics (HIP) in particle and nuclear physics research has continued to be close and productive. The contribution of the Department's researchers to the scientific output of HIP has been quite substantial in many common programs and projects.

Education

The number of MSc degrees awarded (37) was at our usual level but slightly short of the goal set for us. The number of PhD degrees (11) was quite satisfactory. As a Centre of Excellence in University Education, the Department has continued its efforts to improve and develop teaching and the instruction of students, and furthermore to develop the Department as an inspiring and motivating learning environment. A gradual move from traditional lecturing to interactive teaching methods has continued. Encouraging improvement in learning has been achieved by the new teaching practices. The internal audit of the University, carried out in 2012, concentrated on educational matters. Particular strengths of the Department were identified as being the good working and studying atmosphere and the lightness of bureaucracy, employment prospects for graduates of the Department, and the functional feedback system. The practices surrounding supervision of thesis works was found to be the most urgent target for development.

Funding

The total funding of the Department in 2012 was 17.4 M€, with an 8.8 % increase compared with that of the previous year. The increase was mainly due to external funding which grew from 6.9 M€ to 8.0 M€. In 2012, 46% of the total funding came from external sources. This clearly exceeds the corresponding number of 34% for the University of Jyväskylä as a whole. The most important source of external funding in 2012 was the Academy of Finland (3.9 M€). The total number of outside-funded projects was about 100. In spite of the substantial increase of general costs and rents, the budget return was clearly on the positive side, thanks to occasional savings in salary costs.

Commercial services are an essential source of income for the Department. The planned commercial production of medical radioisotopes for positron emission tomography (PET) at the new MCC30 cyclotron has had some difficulties in its inception. It is hoped that these difficulties will soon disappear.

Personnel

In 2012 three of the Professors of the Department moved on to other challenges. Juha Äystö started as the director of the Helsinki Institute of Physics in the beginning of the year, Matti Manninen started his five-year period as the Rector of the University in August, and Harry Whitlow left his position and moved to continue his career in Switzerland. Kimmo Kainulainen started as a Professor of theoretical physics in the beginning of the year, and Paul Greenlees was appointed as Professor of experimental nuclear physics, starting from September 2013 when the period of his ERC starting grant ends. A most delightful piece of news was also the funding of a second

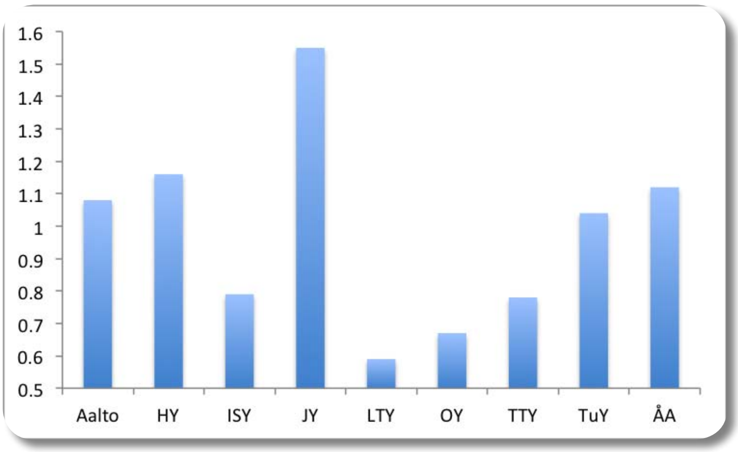


Fig. 1. The relative citation indices of the physics and astronomy publications in 2006–2008 of the Finnish universities (the world average = 1). Source: Sitaatioindeksityöryhmä II:n raportti, OKM:n julk. 2011:34.

Some statistical data from 2012

Personnel	187
- professors incl. research professors	17
- university lecturers and researchers	30
- postdoctoral researchers	25
- MSc researchers (incl. graduate students)	86
- technicians	25
- administration	4
+ several research assistants (MSc students)	
Undergraduate students	520
of which new students	110
Graduate students	85
BSc	30
MSc degrees	37
PhLic degrees	2
PhD degrees	11
Credits (all)	14450
Median time to complete MSc (years)	6,1
Number of foreign visitors	~245
- in visits	~355
Visits abroad	~360
Peer reviewed publications	~225
Conference proceedings	~30
Others	~30
Conference and workshop contributions	
- Invited talks	~170
- Other talks	~135
- Posters	~85
Funding (million €)	17,4
* University budget (incl. premises)	9,4
* External funding	8,0
- Academy of Finland	3,9
- EAKR	0,2
- Technology Development Centre, T&E Centres	0,2
- International programmes	0,8
- HIP	0,6
- Contract research	1,8
- Others	0,5

five-year period for FiDiPro Professor Jacek Dobaczewski.

The Secretariat of the Department, which has suffered with a continually growing workload, got more capacity through the hiring of Minttu Haapaniemi as a departmental secretary with her main responsibilities in educational matters.

Outlook

It is reasonably safe to assume that the coming years will witness a considerable worsening of the budget funding. This will unavoidably have effects on the activities of the Department. Nevertheless, the staff and the students of the Department have fulfilled their tasks in research, in education, and in social interaction outstandingly well, so we all have reason to look optimistically to the future.

Centre of Excellence in Nuclear and Accelerator-based Physics

Rauno Julin

In 2012, the JYFL Centre of Excellence (CoE) in Nuclear and Accelerator-Based Physics began its third consecutive six-year term with this status granted by the Academy of Finland.

Part of the CoE, the JYFL Accelerator Laboratory (JYFL-ACCLAB) continued to act as an EU-FP7-IA-ENSAR-access infrastructure and as an accredited test laboratory of the European Space Agency (ESA). In spite of the development work still going on at IGISOL4 and the new MCC30/15 cyclotron, the number of beam time hours at the K130 cyclotron used for basic research and industrial applications totalled 6441 hours. Among them were 18 experiments supported by the ENSAR initiative. The number of peer reviewed publications in 2012 was 110. A highlight was an article from the study of ^{256}Rf by the Nuclear Spectroscopy team, which was published in Physical Review Letters and which also generated a Viewpoint article of the American Physical Society (*Putting a Spin on Superheavy Elements*).

Professor Juha Äystö, one of the pioneers of accelerator-based research at JYFL and the leader of the IGISOL team, started as the new Director of the Helsinki Institute of Physics (HIP) on 1st April 2012. The JYFL-CoE activities at CERN-ISOLDE and in the FAIR project are coordinated and funded via the Nuclear Matter Programme of HIP. The new leader of the IGISOL team is professor Ari Jokinen. The world-leading research work carried out at IGISOL since 1980 has now been published in the form of an "IGISOL Portrait", which was partially published

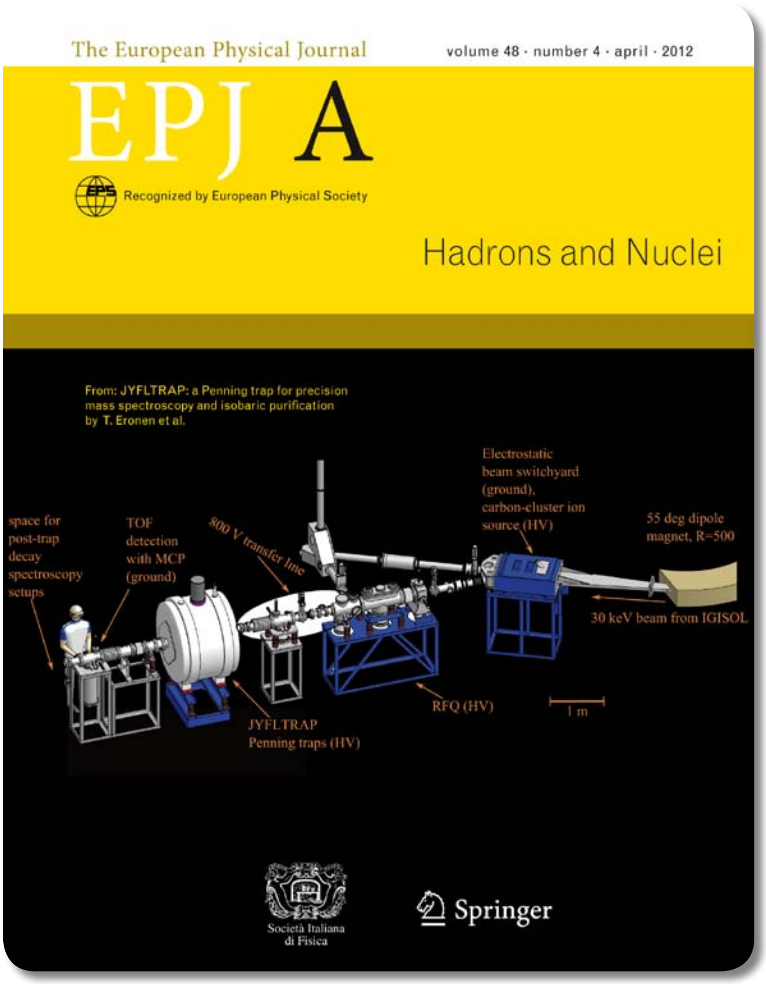


Fig. 1 Topical issue of European Physical Journal A 48, Number 4, which is a part of the IGISOL Portrait. With kind permission of the authors and the European Physical Journal (EPJ).

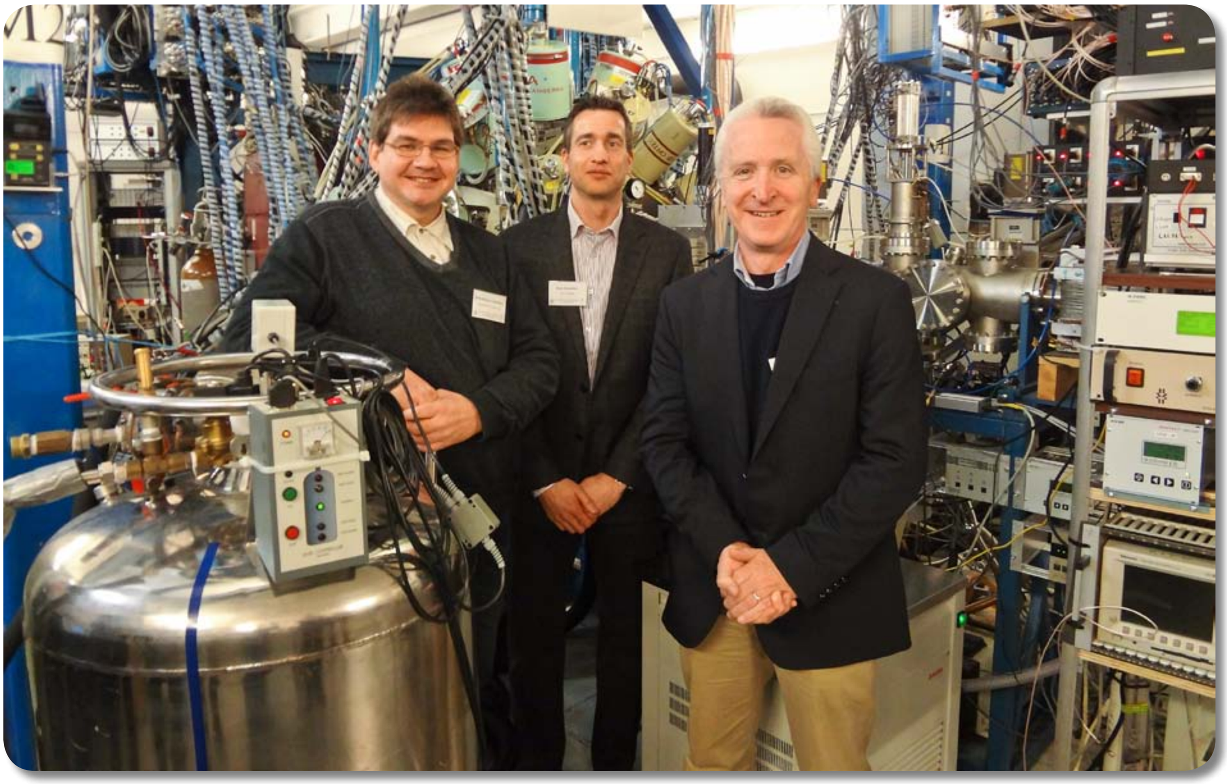


Fig. 2 Tony Medland, the Head of Particle and Nuclear Physics from the Science Programmes Office of the STFC touring through JYFL-ACCLAB under guidance of Professors Rolf-Dietmar Herzberg (University of Liverpool) and Paul Greenlees (JYFL).

as a series of articles in a Topical Issue of the European Physical Journal A 48, Number 4.

In April 2012, Professor Harry J. Whitlow moved to Switzerland and became the leader of a research group forming part of the Applied Microtechnologies Institute (IMA) of the University of Applied Sciences Arc. Harry was the leader of the accelerator-based materials physics group of the CoE for almost eight years, a period during which the group grew rapidly. Leadership of the group has now been taken over by Docent Timo Sajavaara.

Professor Jacek Dobaczewski was appointed for a second term (2013–2017) as a Finland Distinguished Professor (FiDiPro) at JYFL. The FiDiPro project is funded jointly by the Academy of Finland and the University of Jyväskylä. It aims to provide a substantial boost in the description of global properties of nuclei by construction of next-generation energy-density functionals.

Dr. Janne Pakarinen was appointed as a Research Fellow of the Academy of Finland for five years and awarded a Marie Curie Career Integration Grant for his project to develop in-beam conversion electron and gamma-ray spectroscopic methods for stable and radioactive ion-beams at JYFL and CERN-ISOLDE, respectively.

The Annual Users Meeting of JYFL-ACCLAB was dedicated to the celebration of two decades of extremely fruitful UK-Finland collaboration. In his key talk, professor Peter Butler said “the science output from Jyväskylä has been phenomenal, being one of the most productive of all the overseas laboratories for the UK programme in the last 15 years”. The meeting was honoured to host Tony Medland, the Head of Particle and Nuclear

Scientific Advisory Board of the Centre of Excellence in Nuclear and Accelerator Based Physics
Witold Nazarewicz, professor, University of Tennessee, USA
Reiner Krücken, Head of the Science Division at TRIUMF, Canada
Pekka Koskela, professor, University of Jyväskylä
Riitta Kyrki-Rajamäki, professor, Academy of Finland
Antti Väihkönen, science adviser. Academy of Finland

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory
Michael Block, GSI, Germany
Thomas Duguet, CEA, Saclay, France
Sean Freeman, University of Manchester, UK (chair)
Wolfram Korten, CEA, Saclay, France
Thomas Nilsson, Chalmers University of Technology, Sweden
Marek Pfützner, Warsaw University, Poland

Physics from the Science Programmes Office of the UK funding agency the STFC (Science and Technology Facilities Council).

Third International Symposium on Negative Ions, Beams and Sources (NIBS2012) was organized by the ion source group of JYFL-ACCLAB. With the ITER fusion reactor nearing its construction phase, the most numerous contributions in terms of submitted manuscripts came from the fusion community. The number of registered participants was 76 from a total of 15 countries.

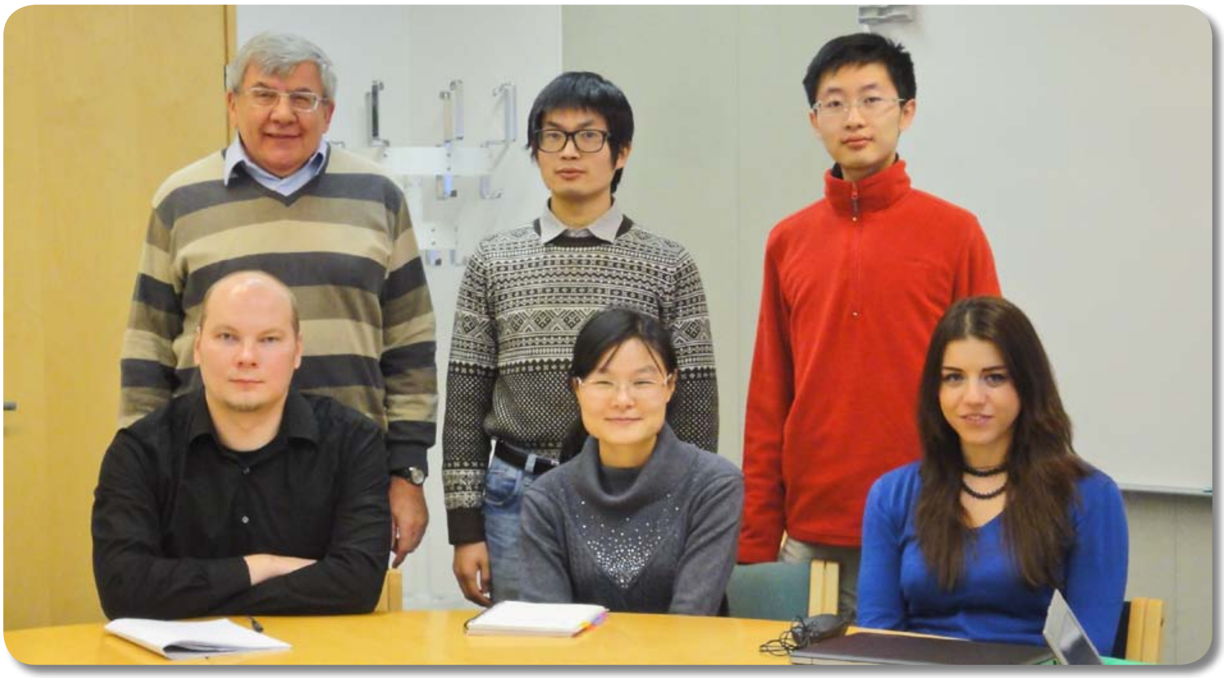
Department of Physics 2012

The FIDIPRO

In 2012, the FIDIPRO project has been funded by a one-year bridge grant awarded in 2011 by the Academy of Finland, and in years 2013 – 2017, it will continue its activity within the second FIDIPRO grant awarded by the Academy of Finland and matched by the University of Jyväskylä. The FIDIPRO team includes now six researchers working together on common project goals. All detailed information on the FIDIPRO project, and on its achievements, publications, and meetings, is available on the project web page at: http://www.jyu.fi/accelerator/fidipro/.

In 2012, the main focus of the project was on studying collective excitations within the energy density functionals (EDFs) in nuclear self-consistent theory. Based on principles of the effective theory, we have also proposed a new type of functionals to be used in nuclear-structure calculations.

Jacek Dobaczewski, professor, team leader
Jussi Toivanen, university researcher
Markus Kortelainen, postdoctoral researcher
Vaia Prassa, postdoctoral researcher, 1.3 –
Xiaobao Wang, postdoctoral researcher, 1.9 –
Francesco Raimondi, graduate student, – 31.3
Yuan Gao, graduate student
Lingfei Yu, graduate student, 19.11 –



Standing, from left: Jacek Dobaczewski, Xiaobao Wang, Yuan Gao, Seated, from left: Markus Kortelainen, Lingfei Yu, Vaia Prassa.

The limits of the nuclear landscape

Last year we published in Nature 486, 509 (2012) [in collaboration with the nuclear theory group at University of Tennessee/ORNL], a study about the limits of the nuclear landscape. It was found that with six well-calibrated Skyrme EDF models, the prediction for two-neutron drip line is rather robust and systematic error among the models is smaller than initially anticipated. Also, the statistical model error was found to be similar in magnitude compared to the systematic one. As expected, systematic and statistical model errors for the neutron drip line position increased towards heavier elements. For two-proton drip line, the consistency among the models was very good, with uncertainty usually not exceeding $\Delta Z=2$. It was predicted that within the region of $Z\leq120$, there exists a total of $6900\pm500_{syst}$ different isotopes.

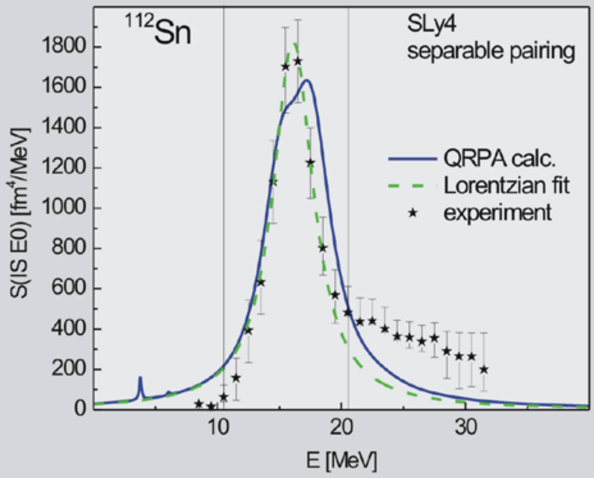


Fig. 1. The QRPA monopole strength function in ^{112}Sn (solid line) compared to raw experimental data and Lorentzian fit to data (dashed line) performed in the region of energies of 10.5–20.5 MeV.

Giant monopole resonances and nuclear incompressibility

Following the 2007 precise measurements of monopole strengths in tin isotopes, there has been a continuous theoretical effort to obtain a precise description of the experimental results. Up to now, there is no satisfactory explanation of why the tin nuclei appear to be significantly softer than ^{208}Pb. In our work, we determined the influence of finite-range and separable pairing interactions on monopole strength functions in semimagic nuclei; see Fig. 1. We employed self-consistently the quasiparticle random phase approximation (QRPA) on top of spherical Hartree-Fock-Bogoliubov solutions. We used the Arnoldi method to solve the linear-response problem with pairing. We found that the difference between centroids of giant monopole resonances measured in lead and tin (about 1 MeV) always turns out to be overestimated by about 100%. We also found that the volume incompressibility, obtained by adjusting the liquid-drop expression to microscopic results, is significantly larger than the infinite-matter incompressibility. In conclusion, the zero-range and separable pairing forces cannot induce modifications of monopole strength functions in tin to match experimental data.

Low-lying collective excitations of semimagic nuclei

We have applied the implicitly restarted Arnoldi method (IRAM) to the quasiparticle random-phase approximation equations, using Skyrme effective interactions. Our method is a generalization of our earlier iterative method developed for nuclear strength functions. The IRAM does not need to explicitly use the matrix whose eigenstates are calculated, and it calculates only the most important lowest QRPA eigenstates. We used the IRAM QRPA to calculate the low-lying excitations of semimagic nuclei, see Fig. 2. In particular, we studied the lowest 2^+ states of Lead isotopes below N=122 and N=126 isotones around the Z=82 shell closure, as new experiments to measure the low-lying states of these nuclei are being planned. Calculations performed for four different isotope chains show that the Skyrme interactions, which have effective mass close to one, for example SkX, describe the low-lying excited states better than those with a small effective mass.

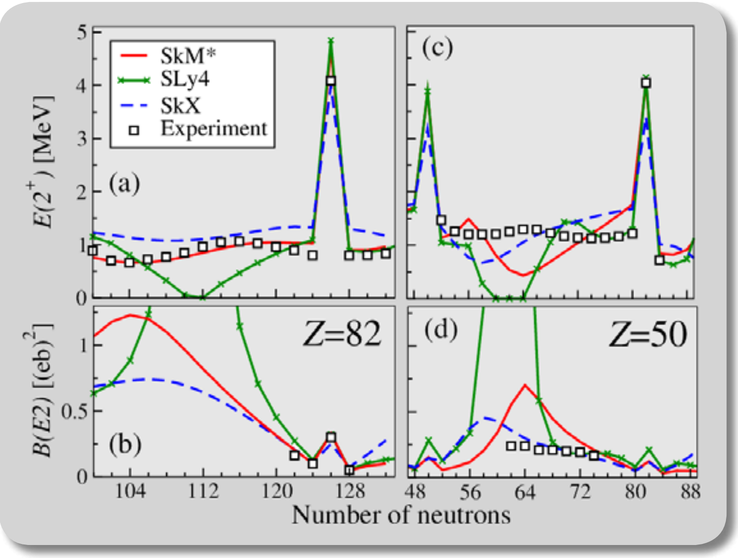


Fig. 2. Excitation energies and reduced transition probabilities [B(E2; $0^+ \rightarrow 2^+$)] for Pb and Sn isotopes. Results are shown for three different Skyrme parametrizations.

New energy density functionals based on effective theory

We introduced a new class of effective interactions to be used within the energy-density-functional approaches. They are based on regularized zero-range interactions and constitute a consistent application of the effective-theory methodology to low-energy phenomena in nuclei. They allow the definition of the order of expansion in terms of the order of derivatives acting on the finite-range potential. Numerical calculations show a rapid convergence of the expansion, see Fig. 3, and independence of results of the regularization scale.

In our opinion, future prospects for using the proposed regularized (pseudo)potentials are high. First, they may present better convergence properties than similar expansions based on the zero-range interactions. Second, they allow for convergent summations of contributions from high single-particle momenta, which is not the case for zero-range interactions. And third, they allow for formulating a consistent expansion in terms of the orders of derivatives, with the convergence properties gauged against the regularization scale. This last feature is unique among all the EDF approaches based on zero-range and finite-range interactions developed so far, and gives us the potential to build an order-by-order correctible theory.

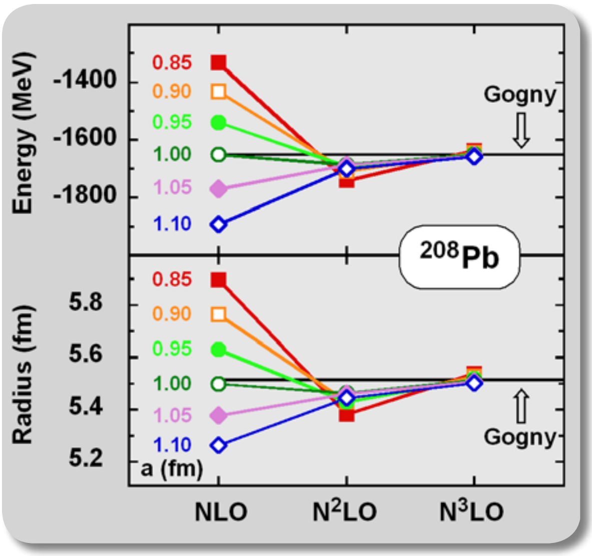


Fig. 3. Convergence of the total energy (upper panel) and proton rms radius (lower panel) to the results obtained for the Gogny interaction in ^{208}Pb.

Department of Physics 2012

Accelerator Facilities

Pauli Heikkinen and Hannu Koivisto

Cyclotrons

The use of the K130 cyclotron in 2012 operations was rather normal. The total use of the cyclotron in 2012 was 6441 hours out of which 4610 hours on target. Since the first beam in 1992 the total run time for the K130 cyclotron at the end of 2012 was 124’138 hours. The largest share of the beam time was for JUROGAM experiments (29 %) the second being industrial applications at RADEF (26 %). Altogether over 20 different isotopes were accelerated in 2012. Beam cocktails for space electronics testing were the

Pauli Heikkinen, chief engineer
Hannu Koivisto, university lecturer
Olli Tarvainen, postdoctoral researcher
Taneli Kalvas, graduate student
Jani Komppula, graduate student
Ville Toivanen, graduate student
Jaana Kumpulainen, laboratory engineer
Arto Lassila, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Tuunanen, laboratory engineer
Juha Ärje, laboratory engineer
Jani Hyvönen, operator
Anssi Ikonen, operator
Jukka Paatola, technician
Raimo Seppälä, technician

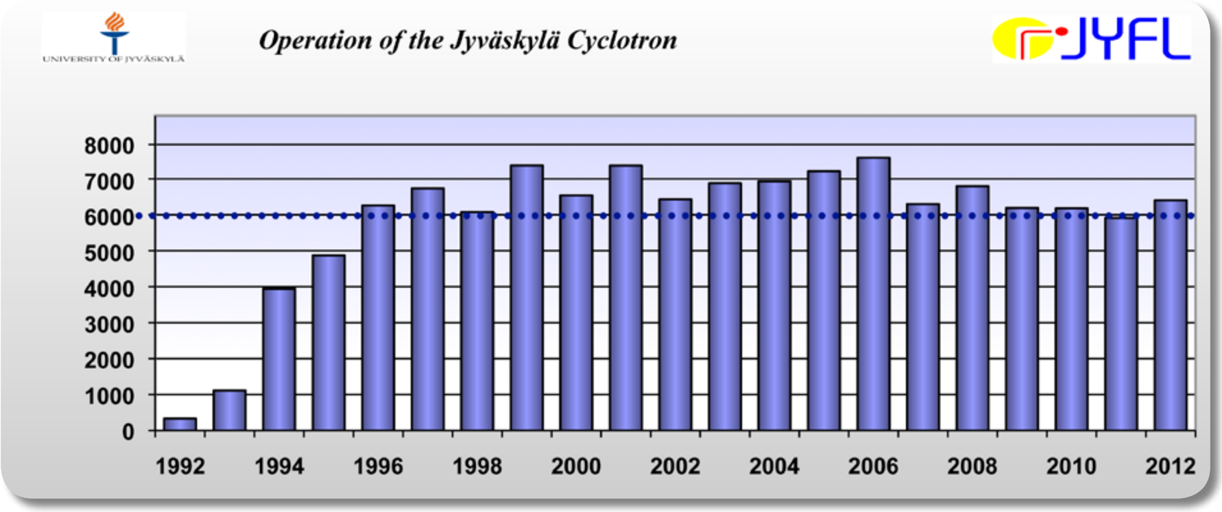


Fig 1. Operation of the Jyväskylä K130 cyclotron in 1992 – 2012.

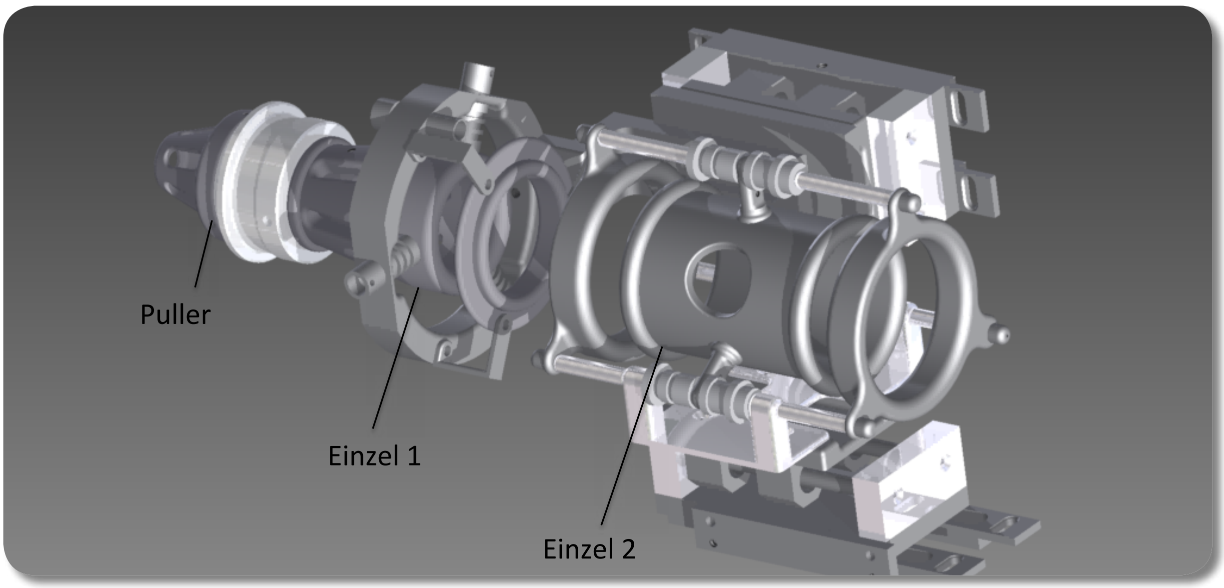
most commonly used beams (26 %). The most used single ion beam was ^{48}Ca (13 %).

The MCC30/15 cyclotron will deliver proton and deuteron beams for IGISOL-4 and for isotope production. The IGISOL set-up was mainly under construction and we had only one beam test from the MCC30/15 cyclotron to IGISOL target area. Isotope production with the MCC30/15 cyclotron has suffered from severe administrative delays. Finally in December 2012 a preliminary budget study for a GMP laboratory for FDG production (^{18}F) was done. Decisions on the radiopharmaceuticals production at JYFL will hopefully be done during 2013.

New extraction for the JYFL 14 GHz ECRIS

A new extraction system has been designed and constructed for the JYFL 14 GHz ECRIS

Fig. 2. New extraction geometry of the JYFL 14 GHz ECRIS resulting in improved beam transport. Two accelerating Einzel lenses are used requiring the operation voltages of about -13 kV and -8 kV for the first and second lens, respectively.



(see Fig. 2). The goal of the new design is to improve the performance of the ion source and increase the transmission efficiency of the low energy beam transport and the accelerator. The new extraction system is designed to be able to handle higher beam currents, yield better beam quality and offer more tuning flexibility. The design was made with the aid of simulations performed with the IBSimu code. The suitability of the code for this task was verified by simulating the old extraction system where good agreement between simulations and measurements was achieved. The new extraction system has been constructed, installed and tested. The first experiments showed that the beam intensities after the K130 cyclotron increased even by a factor of 2.

VUV diagnostics

The VUV-emission of different hydrogen plasmas has been studied extensively using the experimental setup developed and constructed at JYFL. One of the main interests has been to measure the VUV-light power emitted from the plasma using different bandpass filters to select different energy windows of the VUV-spectrum (Fig 3). This work has revealed new and important information about the hot electron densities, reaction rate densities and heating

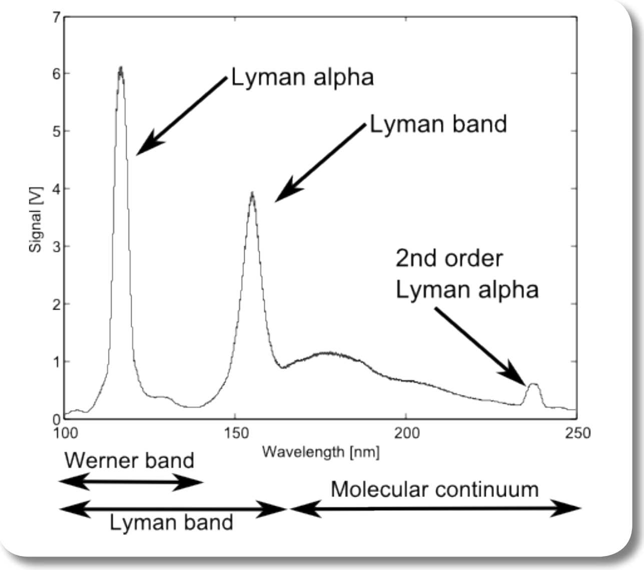
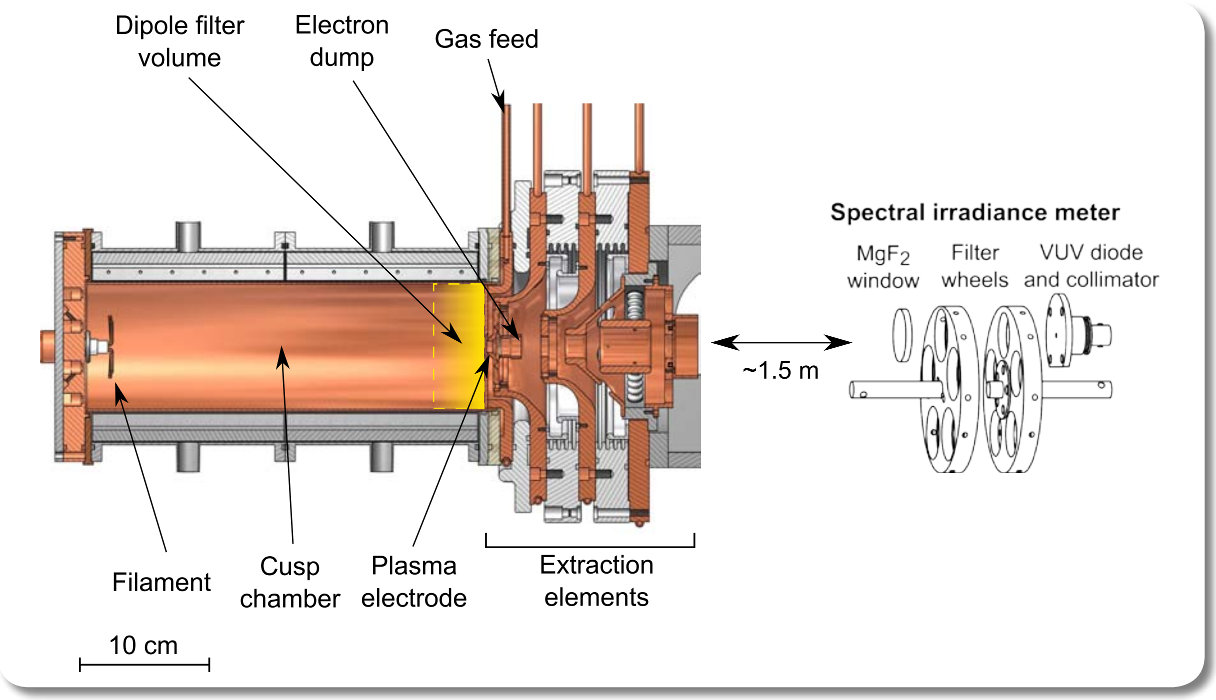


Fig. 3. Typical VUV spectrum emitted by hydrogen plasma.

Fig. 4. Experimental setup for measuring the VUV emission power of hydrogen and deuterium plasmas. In the figure the filament driven multicusp ion source LIISA is shown.



power dissipation of plasma in light ion sources. The power of VUV-emission has been measured with the developed irradiance meter presented in Fig. 4. The wavelength band is selected with a proper filter and the corresponding irradiance is measured with a photodiode. The irradiance meter is isolated from the plasma using a MgF_2 window. The average VUV-emission density and the total VUV-emission power of the plasma have been calculated from the measured signals. The measurements using the microwave and filament driven hydrogen plasmas have shown that up to 20–35% of the total plasma heating power dissipates via light emission in VUV-range.

Third International Symposium on Negative Ions, Beams and Sources (NIBS2012)

The symposium was organized by the JYFL ion source group. The symposium topics covered fundamental processes and modeling, H^-/D^- ion sources for neutral beam injection and accelerators, heavy negative ions and their applications, beam formation and transport, acceleration and neutralization of negative ions and descriptions of existing and future facilities. With the ITER fusion reactor nearing its construction phase, the most numerous contributions in terms of submitted manuscripts came from the fusion community. The number of registered participants was 76 from 15 countries.

Department of Physics 2012

Exotic Nuclei and Beams

Ari Jokinen, Iain Moore, Heikki Penttilä and Juha Äystö

Activity 2012

The year 2012 was the second year in a row without extensive experimental nuclear physics research in our home laboratory. This was due to the on-going construction of the new IGISOL-4 facility and the related technical development. The nuclear physics program could however be carried out at ISOLDE, CERN, and in GSI/FAIR, Darmstadt, within the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). Regarding the international collaboration, we have also benefited from participation in the EU FP7 programs ENSAR, ANDES and ERINDA.

In 2012, a record-high number of reviewed research papers authored and co-authored by the members of our research group was published. This is partly due to the "IGISOL Portrait", a collection of articles reviewing the research at IGISOL since the 1980's. The complete Portrait will be out in early 2013.

Ari Jokinen, professor
Juha Äystö, professor (Helsinki Institute of Physics, Helsinki, 1.4.–)
Iain Moore, senior researcher
Heikki Penttilä, senior researcher
Valery Rubchenya, senior researcher (Khlopin Radium Institute, St. Petersburg)
Anu Kankainen, postdoctoral researcher -31.12.
Veli Kolhinen, postdoctoral researcher
Sami Rinta-Antila, postdoctoral researcher
Juho Rissanen, postdoctoral researcher -30.4.
Antti Saastamoinen, postdoctoral researcher - 31.3.
Mikael Reponen, graduate student -31.10., postdoc researcher (U. of Manchester) 1.11 -
Dmitry Gorelov, graduate student
Jani Hakala, graduate student
Jukka Koponen, graduate student
Ilkka Pohjalainen, graduate student
Volker Sonnenschein, graduate student
Jani Turunen, graduate student (STUK)
Kari Rytkönen, MSc student (LUT, Lappeenranta)
Kaisa Jokiranta, summer trainee 11.6.-10.9.
Mikko Koikkalainen, summer trainee, 21.5.-20.8.
Henri Kulmala, summer trainee, 1.6-31.8.
Tomi Pikkarainen, summer trainee, 1.6-31.8
Juha-Matti Ojanperä, summer trainee, 1.5.-31.8.
Thibault Chevret, ENSICAEN exchange student, 1.5.-31.7.
Céline Duchemin, ENSICAEN exchange student, 1.5.-31.7.

Technical developments

Construction of the IGISOL-4 facility. The ion beam transportation from the front end to the newly built switchyard was commissioned both off-line and on-line. The RFQ transmission at its new location was found to be similar to that at the old laboratory. The beam lines behind the RFQ were constructed; the ion beam delivery to the collinear laser spectroscopy station and to JYFLTRAP is still in progress.

Laser ion source development. The FURIOS laser system was re-commissioned, housed in two new laser cabins and boasting an optimized laser transport path for both in-source and in-jet laser ionization. In anticipation of first on-line experiments, the performance of the dual chamber gas cell was characterized with an alpha-recoil source. In on-line tests, resonance ionization of silver was performed, comparing the selectivity in helium and argon buffer gases as a function of primary beam intensity.

The application of high-resolution and high-sensitivity laser spectroscopy studies, combined with the production of purified isomeric beams, has become of topical interest at several facilities worldwide. In 2012, we were able to reduce the laser linewidth of the Ti:sapphire based laser system by introducing a second etalon in the cavity. Via synchronized movement of the two etalons, wide range wavelength tuning was demonstrated with a linewidth reduction from 5 GHz to below 1 GHz. Experiments with this newly developed system have been performed on copper isotopes. Fig. 2 illustrates the spectral resolution obtained using a collimated atomic beam reference cell, a gas cell and a gas jet (in counter-propagating geometry). An even greater reduction of the laser linewidth is possible using the technique of injection-locking. For this purpose, a continuous wave Ti:sapphire laser has been ordered and a pulsed bow-tie ring cavity is under construction.

Neutron target project. The intense proton beam available from the MCC-30 cyclotron can be

Fig. 1. The IGISOL group in front of JYFLTRAP in January 2013. In the back from left to right: Ilkka Pohjalainen, Volker Sonnenschein, Dmitry Gorelov, Mikael Reponen, Jukka Koponen, Veli Kolhinen, Sami Rinta-Antila. In the front: Iain Moore, Heikki Penttilä, Ari Jokinen.

utilised by a proton/neutron converter target, in particular for fission studies. Beryllium was chosen as a converter material based on simulations performed in collaboration with the University of Uppsala. In June 2012, an experiment was conducted at the The Svedberg Laboratory in Uppsala to experimentally verify the neutron yield and angular distribution from 30 MeV protons on a thick beryllium target. The results are used in the design of the prototype of the converter, which is expected to be ready for first tests by the summer 2013.

Yield of ^{100}Pd [I158]. ^{100}Pd would be a suitable probe for perturbed angular correlation measurements of internal magnetic fields in possible dilute magnetic semiconductors such as GaN or ZnO. Currently, the ion guide technique is the only means to produce a beam of ^{100}Pd to be implanted into such a sample. A yield test as a feasibility study for ^{100}Pd implantation was performed at IGISOL-4 in November 2012, which also served as a first on-line performance test. ^{100}Pd was produced via ^{103}Ru(p,4n) ^{100}Pd with 40 MeV protons. Since ^{100}Pd has a 3.7 day half-life, the mass-separated A = 100 samples implanted in aluminium foil for 1 - 4 hours were measured with a Ge detector inside a low background counting station. Fig. 3 shows one of the obtained gamma ray spectra. The deduced yields were found to be comparable to those for similar reactions at IGISOL 3.

Highlights at ISOLDE

Laser spectroscopy. Away from stability, single-particle levels migrate resulting in a weakening of shell or sub-shell closures, while new candidates emerge. One such candidate at N = 40 has received much attention. A series of optical measurements was performed on the manganese isotope chain in order to provide unambiguous measurements of nuclear spins, moments and

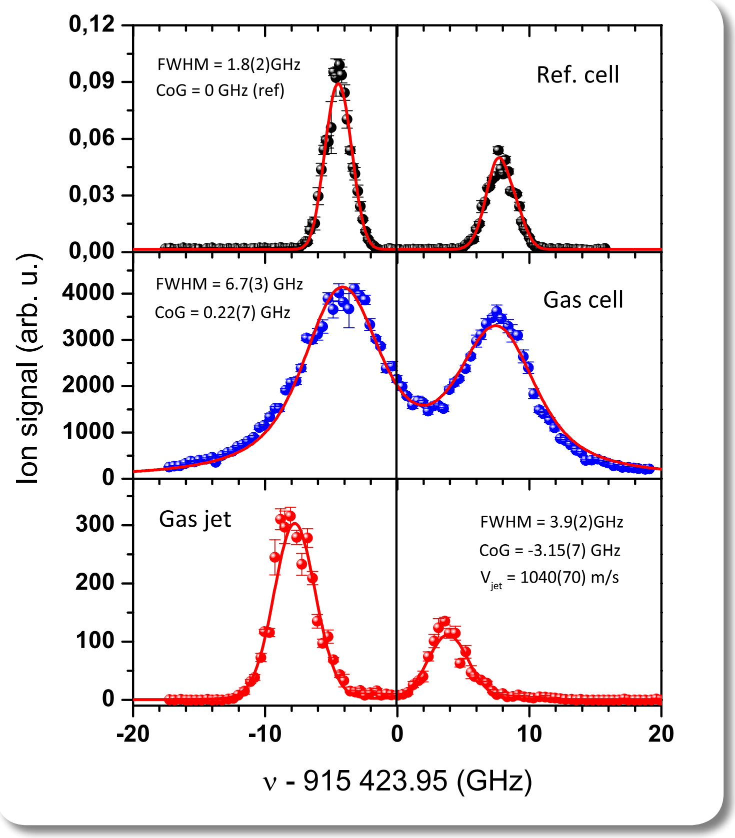


Fig. 2. Ti:sa frequency scans of a first step transition in copper obtained in 3 locations; reference cell, gas cell and gas jet. The vertical line indicates the center of gravity of the reference cell structure.

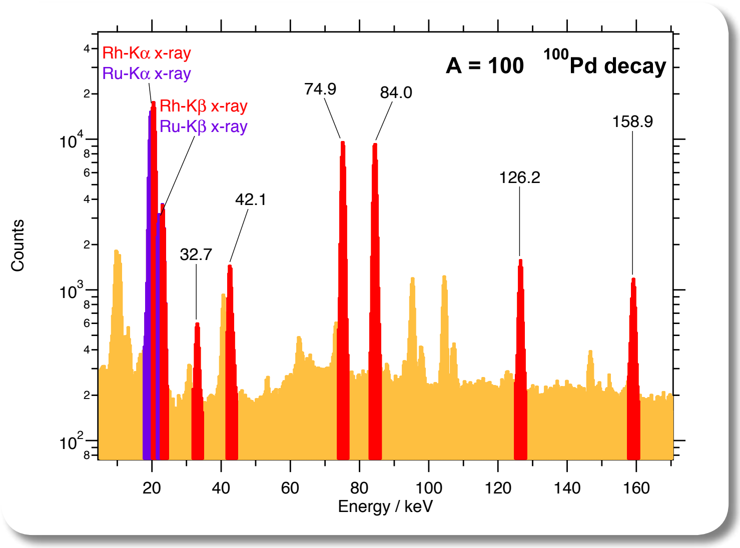


Fig. 3. Gamma ray spectrum from a mass separated A = 100 sample. Radiations following the decay of ^{100}Pd are marked in red. Ru x-rays marked in purple are due to the decay of ^{100}Rh, which is mostly produced via the decay of ^{100}Pd. Gamma radiations from the decay of ^{100}Rh are at much higher energy.

changes in mean-square charge radii across the N = 40 shell closure candidate, ^{65}Mn. Full hyperfine structures of ^{51}Mn and $^{53-64}Mn$ were measured. This work considerably expands the range of earlier IGISOL data and provide a useful consistency check of future atomic factor calculations. The results are currently under analysis.

Nuclear astrophysics. In order to better understand the explosion mechanism in core-collapse supernovae, an experiment (IS543) was performed to measure the cross-section for the reaction $^{44}Ti(\alpha,p)^{47}V$ at low energies. This cross section has an effect on the amount of ^{44}Ti produced in supernovae. Beta decay of ^{44}Ti results in the emission of a gamma ray with a very specific energy which could be detected by satellites, allowing comparison to the model predictions. The material for the ^{44}Ti beam was collected from recycled radioactive waste at PSI, Switzerland. The $^{44}Ti^{13+}$ beam from REX-ISOLDE was impinged into a helium gas cell and the reaction products were detected with a ΔE-E telescope and with a Ge detector. During the experiment, data at two different energies were collected and the analysis is in progress.

Highlights at GSI/FAIR

A prototype of the cryogenic stopping cell (CSC) and a multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) for the Low-Energy Branch (LEB) of FAIR have been commissioned at the FRS in a collaboration of Justus-Liebig-Universität Gieβen, KVI-University of Groningen, JYFL and GSI. The CSC is the first helium-filled stopping cell that is operated on-line at cryogenic temperatures. In the tests, a variety of projectile fragments produced at 1 A•GeV were thermalized using a gas density almost twice as high as ever reached previously for a stopping cell operating with RF ion repelling structures. High extraction efficiencies were achieved with extraction times on the order of a few tens of milliseconds. The MR-TOF-MS was operated as a high-precision mass spectrometer, which allowed direct mass measurements of short-lived nuclei, including ^{213}Rn with a half-life of 20 ms only.

Experiment spokespersons
and collaborating institutes 2012:
[I158] Ferromagnetism in GaN, ZnO and AlN studied by perturbed angular correlation. Spokeperson: Reiner Vianden
Collaborating institutes: Universität Bonn, Germany; University of Helsinki, Finland

Department of Physics 2012

Nuclear Spectroscopy

Janne Pakarinen, Tuomas Grahn, Paul Greenlees, Panu Ruotsalainen and Juha Uusitalo

As in previous years, the Nuclear Spectroscopy group has been kept busy with the experimental campaign. In 2012, the JYFL nuclear structure group recorded 132 days of in-beam spectroscopy experiments, the highest number since the beginning of the JUROGAM campaigns. The first series of experiments in 2012 was dedicated to the second SAGE campaign. The SAGE spectrometer was employed in five experiments, mainly focusing on single-particle structures in odd-mass superheavy nuclei. Involvement of the group in the continuous development of ancillary devices was demonstrated in a test-experiment on beta-tagging, followed by the first DPUNS campaign. The DPUNS plunger device allowed the collectivity in proton-rich nuclei to be probed in four experiments. During the autumn, three in-beam gamma-ray recoil-decay tagging experiments explored exotic structures in nuclei around the Z=82 shell closure. The end of the year was dedicated to preparations for the first full LISA campaign in early 2013. This year, group members have co-authored 22 peer-reviewed journal manuscripts, 15 of them based on data obtained at JYFL. These include the first measurement of a rotational band in the superheavy nucleus ^{256}Rf, whose stability is entirely derived from the shell-correction energy. Janne Pakarinen was appointed as an Academy Research Fellow. His proposal will strengthen the activities of the group at ISOLDE – CERN, and cement the position of the group at the forefront of simultaneous in-beam gamma-ray and conversion electron spectroscopy.

In-beam spectroscopy group members

Rauno Julin, professor
Paul Greenlees, research professor
Sakari Juutinen, university lecturer
Tuomas Grahn, postdoctoral researcher
Päivi Nieminen, postdoctoral researcher - 30.3.2012
Janne Pakarinen, postdoctoral researcher, academy research fellow 1.9.2012 -
Panu Rahkila, postdoctoral researcher
Mikael Sandzelius, postdoctoral researcher
Andrej Herzáň, graduate student
Joonas Konki, graduate student
Pauli Peura, graduate student
Juha Sorri, graduate student
Sanna Stolze, graduate student

Separator group members

Matti Leino, professor
Juha Uusitalo, university researcher
Cath Scholey, university researcher
Jan Sarén, postdoctoral researcher
Kalle Auranen, graduate student
Ulrika Jakobsson, graduate student
Jari Partanen, graduate student
Panu Ruotsalainen, graduate student

Fig. 1 The Nuclear Structure Group.

DPUNS commissioning

The commissioning of the DPUNS plunger device (collaboration led by the University of Manchester, UK) demonstrated the feasibility of plunger operation in the He gas of RITU. The differential pumping system of RITU, located next to the plunger device, did not interfere with the distance stabilization and feedback system of DPUNS, which is driven by piezoelectric crystals (M.J. Taylor, in press, NIMA). The highlight of the DPUNS campaign was the measurement of lifetimes in ^{151}Lu, a proton emitter produced at the ~40 μb level. Reaching such selectivity in a plunger experiment was enabled by the unique proton-decay tag of ^{151}Lu at the focal plane of RITU.

Second SAGE campaign

In early 2012, the second campaign of experiments using the SAGE spectrometer was carried out (in collaboration with the University of Liverpool and Daresbury Laboratory, UK). In the intervening

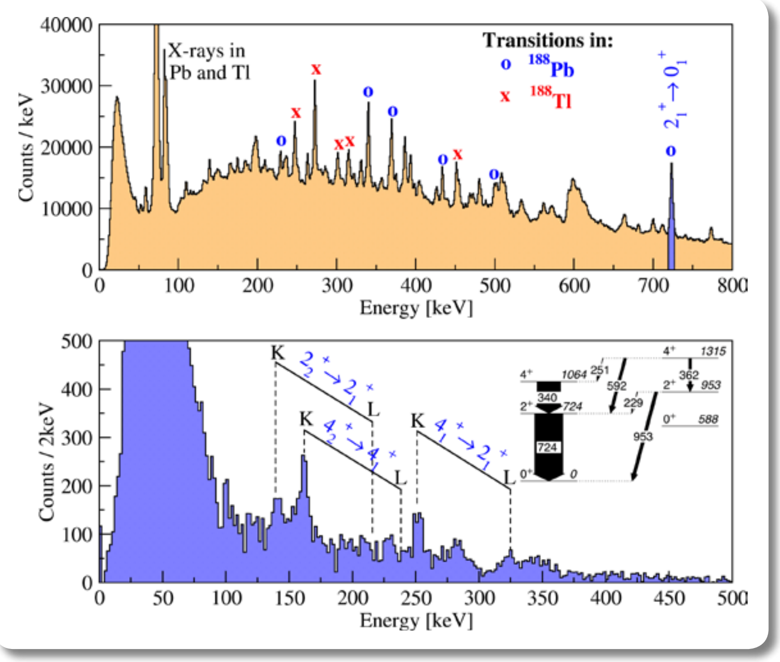


Fig. 2. SAGE data for ^{188}Pb. Top panel: projection of the recoil-gated γe^{-} matrix onto the γ-axis. Bottom panel: conversion electron spectrum obtained by gating on the yrast 2^{+} to 0^{+} transition. A partial level scheme is shown in the inset.

period after the first campaign, problems with the silicon detector and associated electronics were ironed out. SAGE operated reliably in five experiments lasting a total of 48 days of beam time. It was possible to perform simultaneous in-beam gamma-ray and conversion electron spectroscopy with beam intensities of typically 10 pnA and at cross-section levels down to a few hundred nanobarns (in the case of ^{255L}r). The experiments to study the heavy elements ^{251}Md, ^{253}No and ^{255}Lr were very challenging, but preliminary analysis suggests that new data on the rotational bands in these nuclei will be forthcoming. An example of the quality of the data can be seen in the Fig. 2 on the previous page, which shows spectra from electron-gamma coincidences in ^{188}Pb. The aim of the experiment was to determine the magnitude of the E0 components in the I to I transitions between the co-existing prolate and oblate bands. The electron spectrum in coincidence with the first 2^+ to 0^+ 724 keV gamma-ray transition clearly shows strong peaks at 141 keV and 163 keV, corresponding to the 2^+ to 2^+ and 4^+ to 4^+ inter-band transitions, respectively. Further analysis is ongoing, but consideration of the feeding of the second 2^+ state and the observed intensity relative to the 4^+ to 2^+ electron peaks clearly shows that the inter-band transitions have strong E0 components.

During the campaign, further minor issues with the spectrometer were found, which will be addressed before the next campaign. It is hoped that these modifications will lower the spectroscopic limit still further.

MARA developments

Construction of the vacuum-mode recoil separator MARA is making good progress. All the major parts related to the magnets and vacuum system have been procured and installation of plumbing for the cooling water is going on. Delivery of the electrostatic deflector is delayed and it is foreseen to arrive in summer 2013. The Rector of JyU allocated significant funding for 2012 and 2013 to instrument the MARA separator. This will cover, for example, more than 250 channels of digital electronics and new detectors. The new electronics will be merged with the existing total data readout system and will also serve the future needs of the recoil separator RITU. Several pre-amplifiers connected to the new digital electronics have been evaluated with very promising results. For example it was found that electrons (40–400 keV), alpha particles (3–10 MeV) and fission fragments (<160 MeV) incident on a double-sided silicon strip detector can be measured using a single energy range. In addition, very fast decays can be identified from signal traces. The final signal readout system will be fully digital (~600 channels) and can be adapted to RITU experiments.

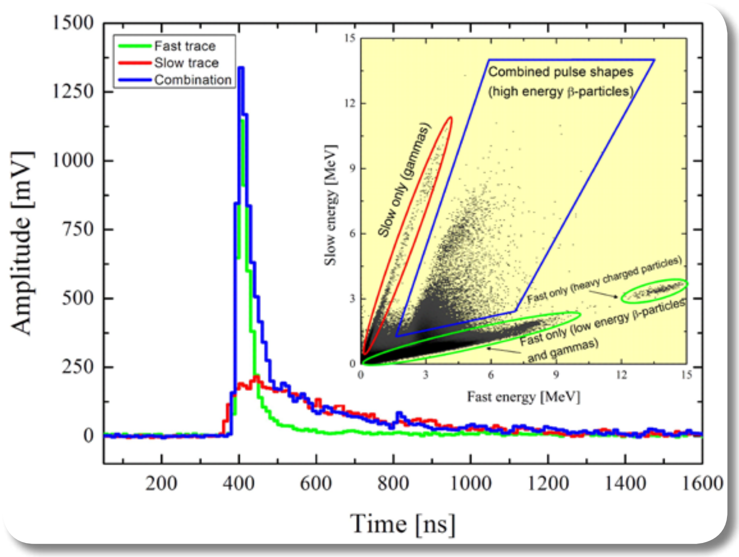


Fig. 3. The phoswich scintillator detector together with digital signal processing enabled an efficient way to identify and discriminate good beta-events to be used as a "tag" from prompt gamma-rays.

Recoil beta-tagging studies and instrumentation development

In recent years, tagging with beta-particles (RBT) has successfully been employed to study several A~70 proton rich nuclei around the N=Z line at JYFL (in collaboration with University of York, UK). In order to gain access to even more exotic cases, an increase in the detection sensitivity is needed. In 2012 new instruments, including a highly pixelated implantation detector, were installed and tested at the focal plane of RITU. A phoswich detector was employed with digital signal processing to discriminate between beta particles and gamma rays (see Fig. 3). These improvements, along with the UoYtube veto detector, have increased the RBT sensitivity to a new level. In the coming years, this will allow further fascinating physics goals to be reached.

Experiment spokespersons and collaborating institutes in 2012

[S06] Exploring nuclear shapes in the transitional region of N~90: Coulomb excitation of ^{152,154}Sm to study E0 transitions with SAGE
P. Davies, University of York, U.K.
C. Barton, University of York, U.K.
JYFL

[S07] Probing E0 transitions in ^{188}Pb using the SAGE spectrometer
P. Papadakis, University of Liverpool, U.K.
J. Pakarinen, JYFL
Katholieke Universiteit Leuven, Belgium
University of Warsaw, Poland

[S10] Spectroscopy of the odd-proton ^{249,251}Md
Ch. Theisen, CEA Saclay, France
R.-D. Herzberg, University of Liverpool, U.K.
P. T. Greenlees, JYFL
CSNSM Orsay, France
IPHC Strasbourg, France

[S08] Simultaneous conversion-electron and gamma-ray spectroscopy using SAGE; An in-beam study of ^{253}No
R.-D. Herzberg, University of Liverpool, U.K.
CSNSM Orsay, France
TRIUMF Vancouver, Canada
JYFL

[S09] Complete Spectroscopy of the Transfermium Nucleus ^{255}Lr
A. Lopez-Martens, CSNSM Orsay, France
K. Hauschild, CSNSM Orsay, France
M. Sandzelius, JYFL
University of Liverpool, U.K.
IPHC Strasbourg, France
CEA Saclay, France
ANL, Argonne, U.S.A.

[JR113] DPUNS Commissioning: Investigation into the low-energy yrast structure of ^{98}Ru via lifetime measurements
M. J. Taylor, University of Manchester, U.K.
University of Liverpool, U.K.
IKP Köln, Germany
JYFL

[JR114] DPUNS: Lifetime Measurements of Proton-Unbound States in ^{151}Lu; Proton Emission from a Spherical or Deformed system?
D. M. Cullen, University of Manchester, U.K.
University of Edinburgh, U.K.
University of York, U.K.
IKP Köln, Germany
University of Liverpool, U.K.
JYFL

[J17] The evolution of collectivity near the N=Z=50 closed shell in the neutron-deficient nuclei ^{111}I and ^{113}I using DPUNS
M. Procter, University of Manchester, U.K.
KTH, Stockholm, Sweden
JYFL

[JR117] Electromagnetic transition strengths in the yrast band and shape coexistence in ^{180}Pt
C. Fransen, IKP Köln, Germany
University of Manchester, U.K.
JYFL

[JR109] Search for non-collective transitions in ^{166}Os
T. Grahn, JYFL
D. O' Donnell, University of Liverpool, U.K.
University of Manchester, U.K.
KTH Stockholm, Sweden
STFC Daresbury, U.K.
IKP Köln, Germany
IKP Darmstadt, Germany

[JR115] Shape co-existence in odd-A isotopes: In-beam spectroscopy of ^{177,179}Au
M. Venhart, Institute of Physics, Slovak Academy of Sciences, Slovakia
D. T. Joss, University of Liverpool, U.K.
iThemba Labs, South-Africa
University of York, U.K.
JYFL

[JR110] Prompt and delayed spectroscopy of ^{199}At and ^{201}At
K. Hauschild, CSNSM Orsay, France
U. Jakobsson, JYFL

[JR107] Configurations and Competing Structures in ^{194}Bi and ^{195}Bi
P. Nieminen, JYFL
K. Hauschild, CSNSM Orsay, France

Department of Physics 2012

Nuclear Reactions

Wladyslaw Trzaska

Our group has carried out 8 major experiments in 2012: 6 using the K130 cyclotron at JYFL, one at Warsaw cyclotron (HIL) and one utilizing neutrons from the ILL reactor in Grenoble. The main highlight of the Jyväskylä measurements was the preliminary result of our studies of exotic cluster states with enhanced radii. Our activity in this field is concentrated around the famous Hoyle state (0^+_2, E* = 7.65 MeV) in ^{12}C. Different modern theories predict this state to be an alpha particle "gas-like" state. A long-standing problem is whether there are excitations based on the Hoyle state and, if so, what is their structure. Our 2012 spectra of inelastic scattering of α particles on ^{12}C at E(α)

Fig. 1. Members of the traditional Christmas experiment at JYFL. Standing from the left: Eduard Kozulin, Konstantin Kuzmenkov, Taras Loktev, Kirill Novikov, Yulia Itkis, Nina Kozulina, Emanuele Vardaci. In the front row: Sophie Heinz, Sergey Khlebnikov, Galina Knyazheva, Wladyslaw Trzaska.

= 65 MeV show a broad (Γ = 1.4 MeV) group corresponding to the excitation energy 13.75 MeV. Angular distributions indicate that the spin-parity assignment of this new state is 4^+. With high probability, together with the recently discovered 2^+_2 state at $E^* \approx 9.8$ MeV this 4^+ level belongs to the new rotational band based on the Hoyle state. The corresponding moment of inertia is about twice that of the ground state rotational band. The radius of the solid rotator extracted from the moment of inertia (R = 2.7 fm) is in good agreement with those of the Hoyle and 2^+_2 states obtained from the scattering analysis. This newly discovered rotational nature of the Hoyle state and the measured radii of the band members contradict the popular model of alpha particle condensation.

Also the measurement at ILL brought an exciting new result. While studying TRI and ROT effects in neutron induced ternary fission of ^{241}Pu we have employed the spin-tilt method instead of the customary spin-flip. The former changes the polarization of neutrons between perpendicular and parallel with respect to the beam direction while the later flips between parallel and anti-parallel orientation. The spin-tilt revealed a new asymmetry in the intensity of ternary particles. The magnitude is of the order of 3 parts per thousand that is about 4 times stronger than the previously reported ROT and TRI. We have named the new asymmetry CET as we think that it might be connected to the additional centrifugal component when the neutrons are polarized perpendicular to the emission direction of the ternary fission fragment.

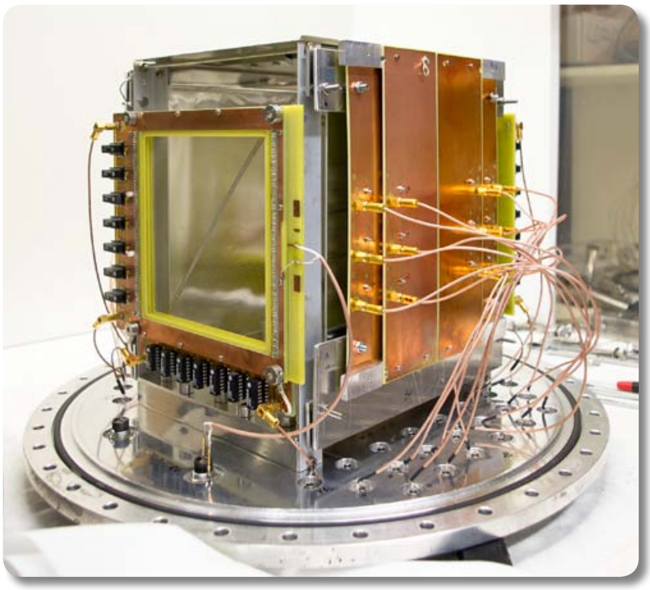


Fig. 2. Detector system used for the discovery of a new asymmetry in ternary fission induced by polarized neutrons.

Fig. 3. Alla Demyanova, Alexey Ogloblin, Nurzhan Saduyev, and Sergey Khlebnikov preparing the hunt for the new rotational band based on the Hoyle state in ^{12}C.

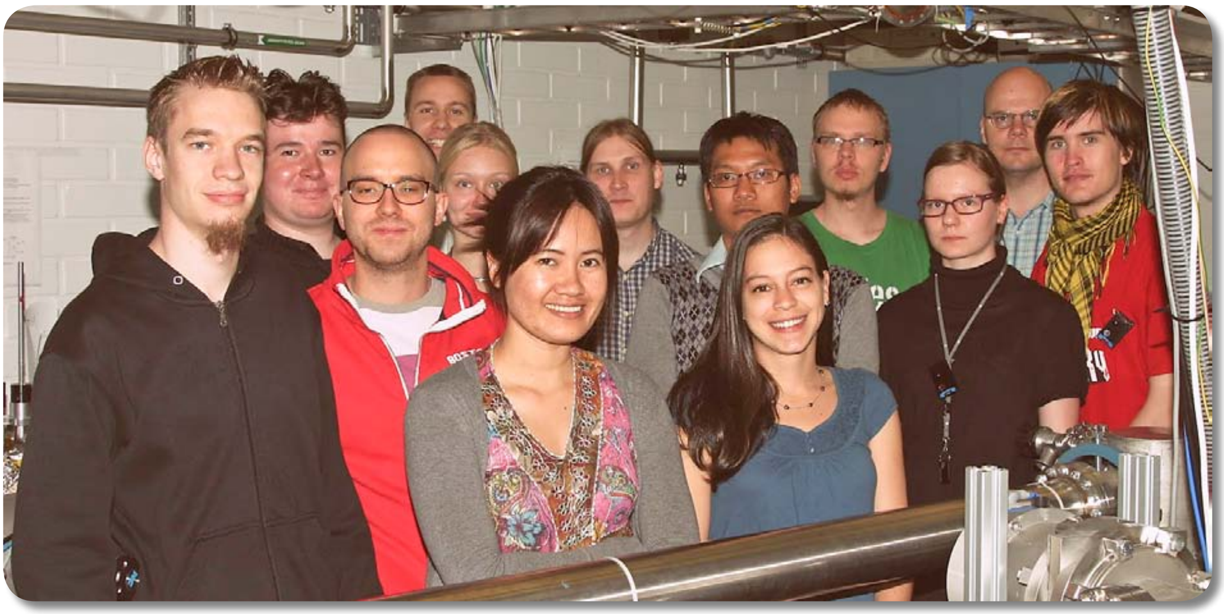
Department of Physics 2012

Accelerator-based Materials Physics

Timo Sajavaara

The Pelletron accelerator has gone through one minor and two major upgrades in 2012. The first major upgrade was the installation of a new multi-cusp H^- ion source (PELLIS). The new ion source has proven to be reliable and is able to produce several microamperes of stable beam through the accelerator and to the target. The second major upgrade was the installation of a new terminal stripper system with a gas circulation by means of a turbo pump. This together with the installation of electrostatic beam steerers to the injector enabled higher beam currents and higher ion charge states through the accelerator. The highest energy used in the measurements has been 17 MeV for $^{79}Br^{9+}$ ions. In 2012 a project to replace an old sputtering ion source by a multicathode SNICS-II ion source

Harry J. Whitlow, professor, -14.4.
Timo Sajavaara, university lecturer
Nitipon Puttaraksa, postdoctoral researcher
Ananda Sagari A.R., postdoctoral researcher -31.3.
Jaakko Julin, graduate student
Mikko Laitinen, graduate student
Laura Mättö, graduate student
Mari Napari, graduate student
Rattanaporn Norarat, graduate student
Henri Kivistö, MSc student
Mikko Konttinen, MSc student
Marko Käyhkö, MSc student
Jarno Parttimaa, MSc student
Laura Rojas, MSc student
Joonas Soininen, MSc student



was started and the new source is planned to be operational in early 2013.

A full microfluidic lab-on-a-chip device aiming for borrelia infection detection was realised in collaboration with the Department of Biological and Environmental Science within the EU-FP7-HILYSENS project. The chip design was based on the ion beam lithography work, which allowed to study the flow in the capillaries and the operation of different components like valves and capillary pumps in detail. The fast prototyping of microfluidic channels was done in the Accelerator Laboratory. Within this project a small series of full prototype chips was externally fabricated for clinical testing using UV embossing, which can also be used for mass production of polymer devices and components.

The main focus in 2012 in ion beam analysis was in the development of gas ionisation detectors and digitizing data acquisition. A new gas ionization detector was constructed and it has replaced the Si-detector in the time-of-flight elastic recoil detection analysis (TOF-ERDA) setup. The new detector with a Si_3N_4 entrance window (thickness 100 nm and area 14x14 mm^2) gives a solid angle comparable to the detector used previously while the energy resolution of the detector is superior compared to a conventional solid state detector for elements heavier than oxygen. In addition, hydrogen can be measured simultaneously with other elements, which was a key design requirement.

The active collaboration in thin film and materials characterisation with both Finnish and international research institutes remained strong also in 2012. Especially useful TOF-ERDA was in the analysis of lithium containing films. Like hydrogen, lithium is also difficult to depth profile quantitatively with common analysis techniques. The two most active ongoing collaborations are with MECHALD-consortium (Technical Research Centre of Finland, Aalto University, JYFL) and Department of Chemistry, University of Oslo.

Energy straggling of 3–10 MeV/u ^{82}Kr ions in He, N_2, Ne, Ar and Kr gases was studied together with RADEF group and researchers from Switzerland, Sweden and Denmark in two campaigns using beams from the K130 cyclotron. The measurement setup consisted of a gas cell, which had 200 nm thick Si_3N_4 windows in both ends, surrounded by two timing gates in front and two after the cell. The experimental results are being compared

Fig. 1. The new stripper channel is being installed to the Pelletron terminal.

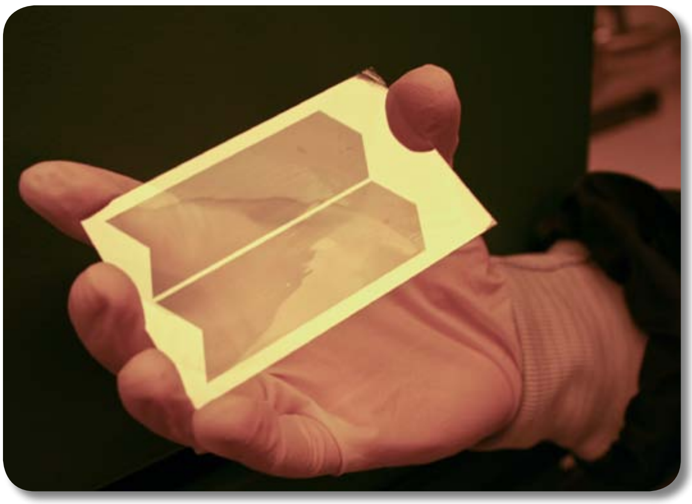


Fig. 2. Microfluidic chip prototype, a result from the HILYSENS project.

to the theoretical predictions including linear straggling, bunching and charge-exchange straggling.

Cytoplasmic endosomes were studied in collaboration with the Centre for Ion Beam Applications using proton-induced fluorescence imaging (PIF) and scanning transmission ion microscopy (STIM) in National University of Singapore. The cells could be imaged at sub-150 nm resolution using the PIF technique, and at 50 nm and 25 nm resolution by using proton- and He-STIM, respectively. The combination of both techniques offers a powerful tool to improve fluorescence imaging beyond optical diffraction limits.

In order to visualise radiation in our everyday life environment, a diffusion cloud chamber was designed, constructed and optimal running parameters studied as an MSc project within the group. The chamber has an active area of 60x60 cm^2, and it makes tracks of beta and alpha radiation as well as energetic cosmic particles visible. This device is now permanently located in the entrance hall of the Physics Department and constantly explored by visitors, students and local staff.

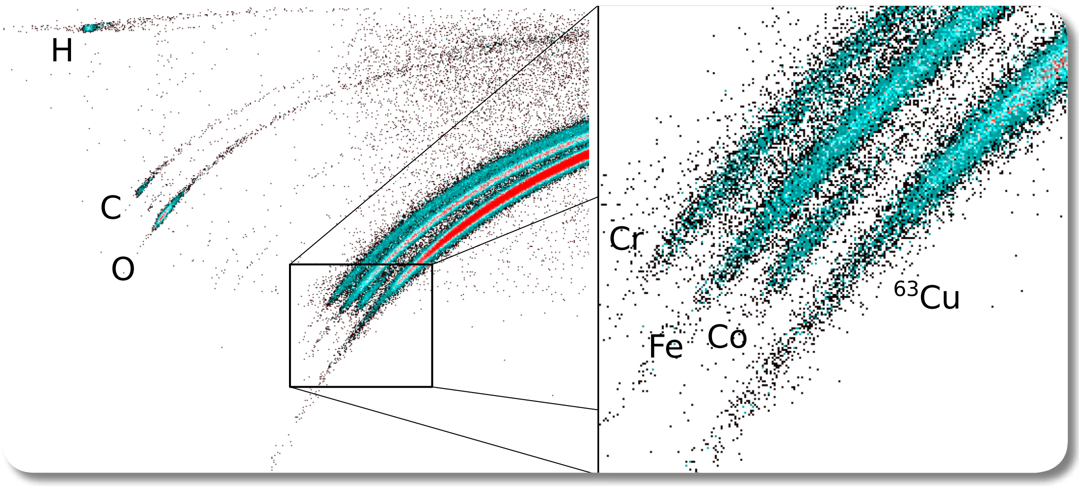


Fig. 3. A time-of-flight-energy histogram from TOF-ERDA measurement of a thin Co_3O_4 film on stainless steel. The superior energy resolution of the gas ionisation detector for heavy elements results in a good mass resolution and enables the separation of adjacent elements even for higher masses. Incident beam was 11.9 MeV $^{63}Cu^{6+}$.

Fig. 4. Evolution of a single α-particle and several β-particle tracks photographed in the JYFL cloud chamber.

Department of Physics 2012

Industrial Applications

Ari Virtanen

Ari Virtanen, research director
Heikki Kettunen, university researcher
Arto Javanainen, graduate student -31.8, postdoctoral researcher 1.9.-
Taneli Kalvas, graduate student
Jukka Jaatinen, laboratory engineer 9.1.-
Mikko Rossi, operator

One of our highlights was Arto Javanainen's thesis defence: "Particle Radiation in Microelectronics". The opponent was Distinguished Professor Kenneth F. Galloway from Vanderbilt University, Tennessee, USA. This was the first PhD work on radiation effects in electronics done in JYU. After graduation Arto continued as a postdoctoral researcher in our group.

We also got a new group member, Jukka Jaatinen, who started in January as a laboratory engineer. Heikki Kettunen and Mikko Rossi were also appointed to office of laboratory engineers starting in January 2013. Heikki continues as the leader of technical issues. Our group in the recent form is presented in Fig. 1.

Fig. 1. Group members from the left: Arto, Mikko, Jukka, Ari, Taneli and Heikki.

The use of the beam time

The usage of the beam time is shown in Fig. 2. The total beam hours used in 2012 were 1208 and we gained a new record in annual revenue, i.e. 757 000 €.

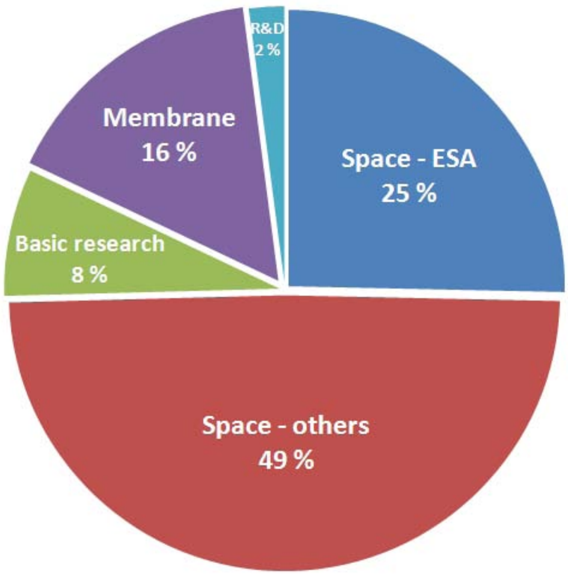


Fig. 2. Beam time distribution; Space-ESA = space component tests for ESA, Space-others = space component tests for satellite industry, Membrane = membrane irradiation, R&D = research & development of RADEF, Basic research = studies based on PAC proposals.

Space related study

RADEF continued as ESA's external European Component Irradiation Facility (ECIF) for serving European satellite industry. In total 36 campaigns for 12 companies or institutes were performed. These are summarized in Table 1.

Table 1. Satellite companies and institutes, which performed tests at RADEF

ATMEL, France
DLR, German Aerospace Center
EADS ASTRIUM, France
ESA/ESTEC, The Netherlands
HIREX Engineering, France
IDA, Institute of Computer and Network Engineering, Germany
IMEC, Interuniversity Microelectronics Centre, Belgium
Microtest, Italy
RUAG Sweden
Sandia National Laboratories, NM, USA
Thales Alenia Space, France
TRAD, France

ESA continued its technical assessment project on "Effects of the ion species and energy on the oxide damage and SEGR failure". Some results have already been published. The objective of the study is to determine the worst-case conditions for SEGR testing and use the results in the next ESA's SEE test guidelines.

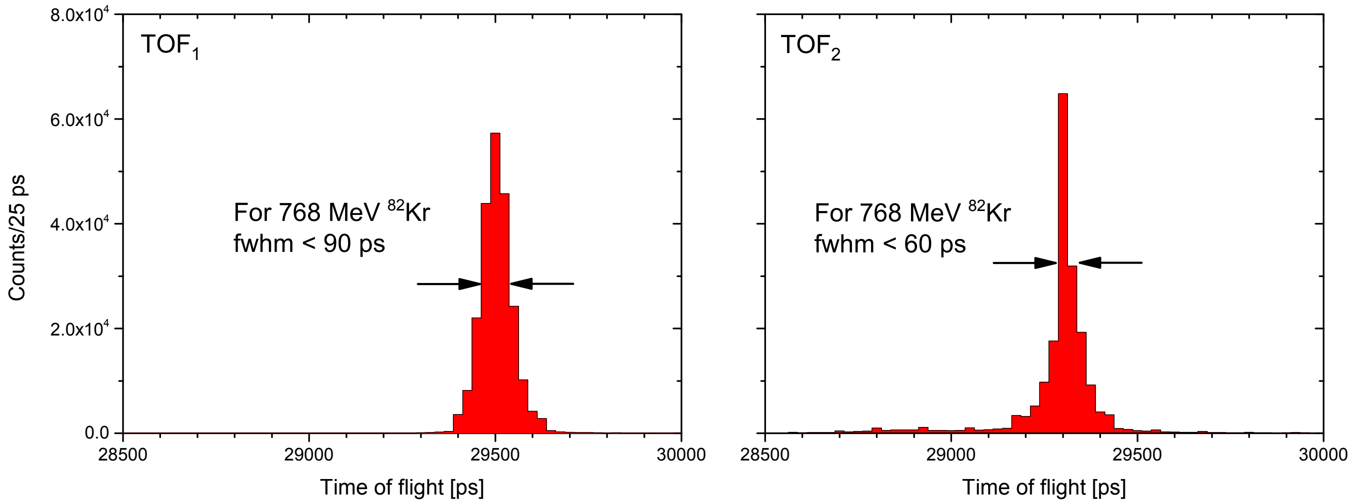
Fig. 3. Valentino Liberali and Arto Javanainen.

SkyFlash (262890 EU-FP7 Project), started in 2011, continued. It aims to develop a RadHard by design (RHBD) methodology for non-volatile flash memories. The methodology focuses on environments affected by radiation due to electrons, protons and heavy ions. Other partners are from Cyprus, Israel, Italy, Spain and Sweden (www.skyflash.eu/). The first heavy ion test was performed in October at RADEF. Fig. 3 shows Professor Valentino Liberali from University of Milano and Arto Javanainen during the test.

Fig. 4. The excellent time resolutions of the TOF-detector systems were obtained in the straggling measurement.

Fundamental research

We also performed a basic research experiment with the world leading stopping power experts. The energy-loss straggling of heavy ions in noble gases was determined by using our TOF setup. Recent predictions indicate that the straggling could be more than an order of magnitude higher than the Bohr straggling at the MeV/u region. Our measurements at energies up to 9.3 MeV/u for Kr ions in He, N_2, Ne and Kr targets confirm this feature. In figure 4. TOF-coincidence spectra for both of the TOF1 and TOF2 systems at full energy direct Kr-beam are shown. The results were presented in the ICACS conference in Japan and will soon be published.



Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Jouni Suhonen

Calculations of weak decay processes in nuclei

We have continued our calculations of various double beta processes by using the quasiparticle random-phase approximation (QRPA) and its higher-RPA extension, the multiple-commutator model (MCM). Special interest has been devoted to theoretical description of various positron-emitting modes of double beta decays, like the various decay channels of ^{96}Ru [1], depicted in Fig. 1. A combined experimental and theoretical work for the various decay channels of ^{106}Cd has been published in [2]. An interesting decay channel is the resonant neutrinoless double electron capture which can be used to explore the absolute mass and mass hierarchy of the neutrino. General nuclear-structure features of this decay mode have been reviewed in [3].

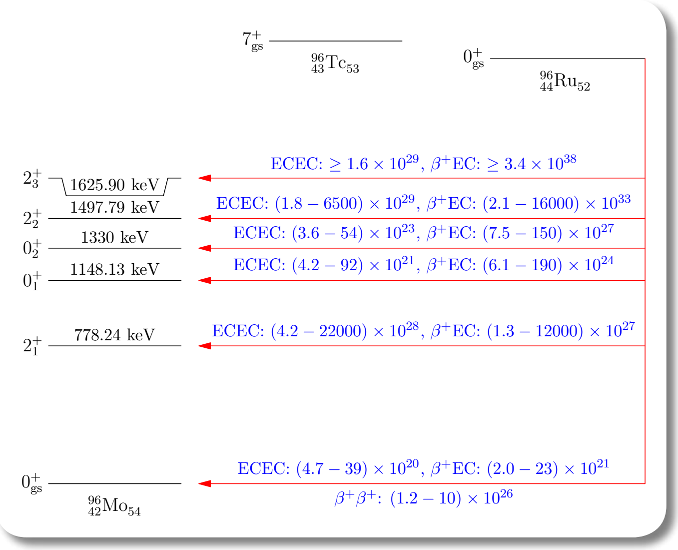


Fig. 1. Computed half-lives (in units of years) of the two-neutrino double beta decays of ^{96}Ru to the various final states in ^{96}Mo. The decay modes are double electron capture (ECEC), double positron emission (β+β+) and combined electron capture and positron emission (β+EC).

Jouni Suhonen, professor
Emanuel Ydrefors, postdoctoral researcher -30.6.
Mikko Haaranen, MSc student
Wafa Almosly, MSc student
Juhani Hyvärinen, MSc student
Teemu Tervo, MSc student

Isovector spin monopole excitations and Gamow-Teller strength functions

Excitation of the isovector spin monopole (IVSM) 1^+ mode can pollute experimental data on Gamow-Teller strength functions in charge-exchange reactions. Since these strength functions can be used in surveys of the contributions to the double-beta nuclear matrix elements false conclusions about these contributions could be drawn due to the IVSM contamination. We have examined theoretically the possible IVSM contamination in the Gamow-Teller strength functions generated by the ^{116}Cd(p,n)^{116}In and ^{116}Sn(n,p)^{116}In charge-exchange reactions [4]. A further study of the (p,n) and (n,p) reactions on other nuclear targets is under way.

General survey of the nuclear matrix elements related to double beta decays

In the review [5] the work of the Jyväskylä-La Plata collaboration on the double-beta-decay nuclear matrix elements has been summarized. There all modes of double beta decays were discussed and related to experimental observables like decay half-lives of single and double beta decays, cross sections of charge-exchange reactions, capture rates of muons from atomic orbitals and strength functions of the IVSM excitations. Another review [6] concerns the analysis of the systematical behaviors of double-beta nuclear matrix elements calculated in several different theory frameworks, like the QRPA, interacting shell model, interacting boson approximation (IBA), deformed Hartree-Fock-Bogoliubov mean-field theory with angular-momentum projection and the energy-density functional (EDF) approach. Interesting conclusions could be drawn based on the systematics of the matrix elements.

Neutrino-nucleus scattering and supernova neutrinos

Accurate estimates of nuclear responses to supernova neutrinos are of great interest both for studies of neutrino properties and for various astrophysical applications, e.g. supernova modeling and nucleosynthesis of heavy elements. This year we have continued our efforts to provide reliable cross sections for the charged-current and neutral-current neutrino scatterings off the stable molybdenum isotopes. Large-scale calculations for the neutral-current scatterings off ^{95}Mo and ^{97}Mo were performed in Ref. [7]. Results for the charged-current neutrino interactions for the stable molybdenum nuclei were also computed and have been published in [8] and [9]. In Fig. 2 the computed charged-current nuclear responses to supernova electron neutrinos are shown for the stable molybdenum isotopes.

We have also recently started to study the ^{116}Cd nucleus which is of interest for double-beta-decay searches. In collaboration with the FIDIPRO group we have developed a framework for calculations of charged-current neutrino-nucleus cross sections based on realistic energy density functionals. Computations will in the near future be performed both with energy density functionals and with the ordinary pnQRPA.

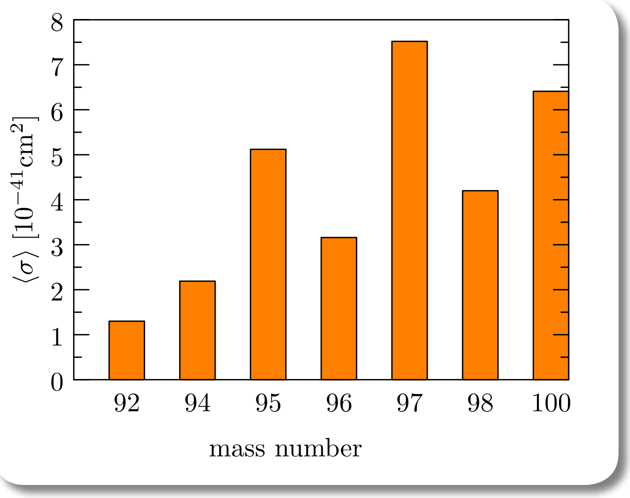


Fig. 2. Computed averaged cross sections for the charged-current neutrino-nucleus scatterings off the stable molybdenum nuclei.

[1] J. Suhonen, Phys. Rev. C 86 (2012) 024301
[2] P. Belli et al., Phys. Rev. C 85 (2012) 044610
[3] J. Suhonen, Eur. Phys. J. A 48 (2012) 51
[4] D. R. Bes, O. Civitarese and J. Suhonen, Phys. Rev. C 86 (2012) 024314
[5] J. Suhonen and O. Civitarese, J. Phys. G: Nucl. Part. Phys 39 (2012) 085105
[6] J. Suhonen and O. Civitarese, J. Phys. G: Nucl. Part. Phys 39 (2012) 124005
[7] E. Ydrefors, K.G. Balasi, T.S. Kosmas and J. Suhonen, Nucl. Phys. A 896 (2012) 1
[8] E. Ydrefors and J. Suhonen, Advances in High Energy Physics: Special issue on Neutrino Physics 2012, Article ID 373946
[9] E. Ydrefors and J. Suhonen, Phys. Rev. C 87 (2013) 034314

Department of Physics 2012

Experimental Nanophysics and Technology

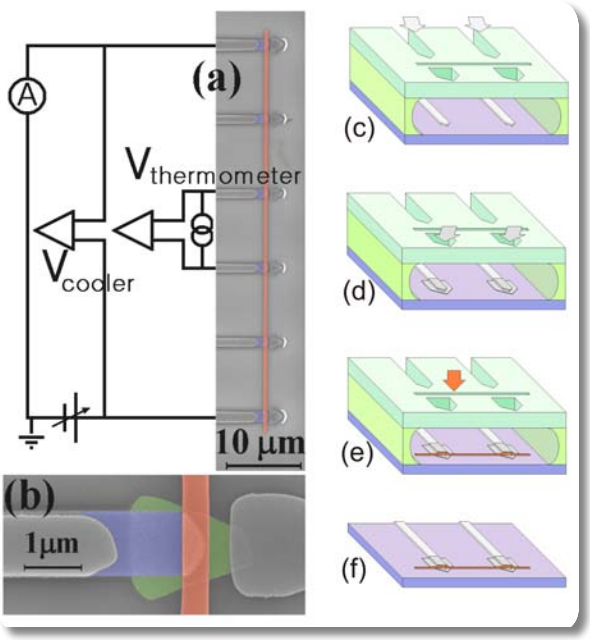
Thermal properties of nanostructures and radiation detector development

Ilari Maasilta

The main research direction of the thermal nanostructure research team is to understand and engineer energy flow mechanisms in low-dimensional geometries, develop thermometric techniques for the study of thermal phenomena and use the obtained physical know-how in the development of ultrasensitive radiation sensors for applications (bolometry). A few highlights of the activity in 2012:

Normal-metal-insulator-superconductor (NIS) tunnel junctions have many interesting properties, for example, they act as sensitive thermometers at low temperatures, and can also be used as microscale electronic refrigerators, where a simple voltage bias across the device can lead to significant cooling. The usual superconducting material for these devices is aluminum, due to the excellent properties of its oxide, which forms the tunnel barrier. However, the operational range for electronic cooling aluminum is limited by its critical temperature ~1.5 K, to temperatures below 0.3 K. We have recently developed [1] also sub-micron scale NIS devices from superconducting Nb instead of Al (Fig. 1), and shown that they work as sensitive thermometers up to 6 K instead of the 1.5 K limit in Al-based devices. We also

Markus Ahlskog, professor
Ilari Maasilta, professor
Konstantin Arutyunov, university lecturer
Jussi Toppari, academy research fellow
Saumyadip Chaudhuri, postdoctoral researcher
Kimmo Kinnunen, postdoctoral researcher
Tuomas Puurtinen, postdoctoral researcher -30.6. 2012
Svitlana Baieva, graduate student
Zhuoran Geng, graduate student
Olli Herranen, graduate student
Matti Hokkanen, graduate student
Tommi Isoniemi, graduate student
Tero Isotalo, graduate student
Juhani Julin, graduate student
Mikko Koponen, graduate student, -31.7. 2012
Jarkko Lievonen, graduate student, -29.2. 2012
Davie Mtsuko, graduate student, -31.7. 2012
Minna Nevala, graduate student, -31.8. 2012
Mikko Palosaari, graduate student
Antti Pennanen, graduate student
Boxuan Shen, graduate student
Yaolan Tian, graduate student
Peerapong Yotprayoonsak, graduate student
Tuomas Hänninen, MSc student
Mikko Konttinen, MSc student
Ilkka Pekkala, MSc student 1.6-31.8 2012
Teemu Parviainen, MSc student
Joonas Saari, MSc student 1.6-31.12 2012
Ville Saunajoki, MSc student 1.6-31.8 2012
Dongkai Shao, MSc student 15.11.2012–
Kosti Tapio, MSc student
Andrii Torgovkin, MSc student
Lasse Vuori, MSc student 1.6-31.8 2012



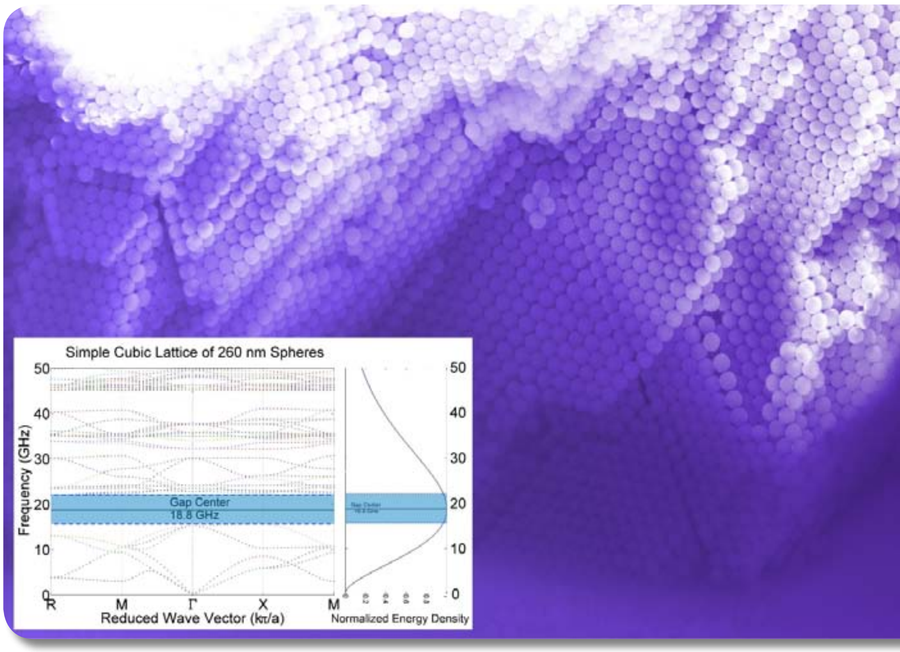


Fig. 1. (a) Scanning electron micrograph (SEM) of a Nb thermometer and cooler sample showing the measurement configuration. The outermost two larger electrodes serve as the cooler junctions, while a pair of inner electrodes act as a NIS thermometer to sense the electron temperature of the Cu wire. (b) High resolution SEM of a single junction showing the tapered Nb edge (blue) covered with Al (green), contacting the Cu (red). (c)-(e) The three different angle evaporation steps needed to fabricate the final device (f): (c) evaporation of niobium (d) evaporation of aluminum+oxidation, (e) evaporation of copper.

FIG. 2. A typical SEM image of a thick phononic crystal, self-assembled from polystyrene nanospheres of diameter 260 nm. Inset: The calculated phononic band structure of a simple cubic nanosphere crystal, exhibiting a full band gap centered at 18.8 GHz. The thermal Debye energy density distribution at 50 mK is also plotted.

demonstrated some limited cooling with the device. Further optimization is in progress with the goal of developing a microscale electronic cooler operating at 1K bath temperature, and reaching a base temperature of 0.1 K, using Nb as the superconductor.

In a related work [2], we also analysed quite extensively the effect of non-idealities in double junction NIS devices (SINIS), both theoretically and experimentally. Specifically, we investigated the effect of asymmetry in the tunnelling resistances of the two junctions, and a series resistance that is not caused by the tunnelling barrier, such as the resistivity of the normal metal region. One of the most interesting discoveries was that junction asymmetry can actually increase the cooling power of a SINIS device, by a factor of two in best cases.

Research in developing novel heat transport “metamaterials”, or phononic crystals, has also moved forward [3]. We have perfected the techniques how to self-assemble polymeric nanospheres (diameter 260 nm) into ordered lattices from aqueous solutions onto lithographically pre-patterned substrates, showing that thick (~ 50 lattice periods) films can be fabricated onto large domains of size up to ~ 400 µm x 400 µm (Fig. 2). We also calculated the phononic band structures of similar type of 3D phononic crystals using the finite element method (FEM), with the exciting result that a wide, full phononic

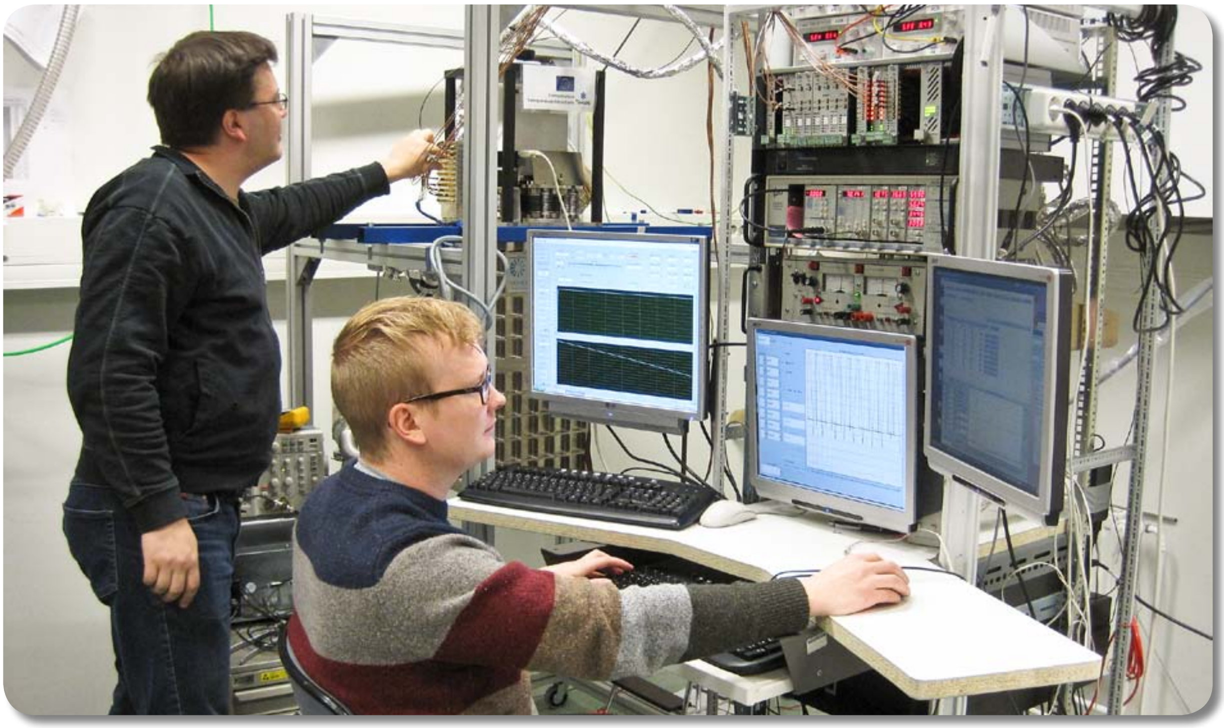


Fig. 3. The new cryogen free ADR ultrasensitive superconducting TES X-ray spectrometer in operation, with Dr. Kimmo Kinnunen (left) and Mikko Palosaari.

gap developed at ~20 GHz, corresponding to the peak in the thermal phonon distribution at 50 mK. Thus, we expect these type of devices to exhibit a very strong reduction of thermal conductivity at low temperatures.

Another focus field has been development of superconducting transition-edge sensor (TES) X-ray detectors. In 2012, significant progress was made in understanding the theoretical foundations as well as noise properties of transition-edge sensors with thermal circuit consisting of more than one heat capacity block [4–6]. In addition, we started a new TEKES funded project in collaboration with VTT Micronova in Espoo, NIST Boulder in USA, and the accelerator-based materials physics group at JyU, where the main goal is to (a) demonstrate a unique new materials analysis tool using accelerator-based excitation of characteristic X-rays from materials, and the subsequent spectral analysis of the emitted X-ray spectra using ultrahigh-resolution superconducting TES detectors. A second goal is to develop the wafer-scale fabrication process for 256 pixel arrays of TES detectors so that commercialization of the technology becomes feasible. The measurements are made possible by a special cryogenic setup (Fig. 3)

[1] M. R. Nevala, S. Chaudhuri, J. Halkosaari, J. T. Karvonen, and I. J. Maasilta,
”Sub-micron normal-metal/insulator/superconductor tunnel junction thermometer and cooler using Nb”, Appl. Phys. Lett. 101, 112601 (2012).
[2] S. Chaudhuri and I. J. Maasilta, ”Cooling, conductance, and thermometric performance of non-ideal normal metal-superconductor tunnel junction pairs”, Phys. Rev. B 85, 014519 (2012).
[3] T. J. Isotalo, Y. L. Tian and I. J. Maasilta, ”Fabrication and modelling of three-dimensional sub-kelvin phononic crystals”, J. Phys.: Conf. Ser. 400, 052007 (2012).
[4] K. M. Kinnunen, M. R. J. Palosaari, and I. J. Maasilta, ” Normal metal - superconductor decoupling as a source of thermal fluctuation noise in transition-edge sensors”, J. Appl. Phys. 112, 034515 (2012).
[5] M. R. J. Palosaari, K. M. Kinnunen, M. L. Ridder, J. van der Kuur, H. F. C. Hoevers and I. J. Maasilta. ”Analysis of impedance and noise data of an X-ray transition-edge sensor using complex thermal models”, J. Low Temp. Phys. 167, 129 (2012).
[6] I. J. Maasilta, “Complex impedance, responsivity and noise of transition-edge sensors: Analytical solutions for two- and three-block thermal models”, AIP Advances 2, 042110 (2012).

developed in a previous TEKES/EAKR project, where X-rays from the lab can be coupled into the 40 mK stage of a cryogen-free adiabatic demagnetization refrigerator (ADR) with a time-division multiplexed multi-stage SQUID readout electronics. The setup was developed in collaboration with NIST Boulder, Lund University and Star Cryoelectronics LLC.

Molecular Technology

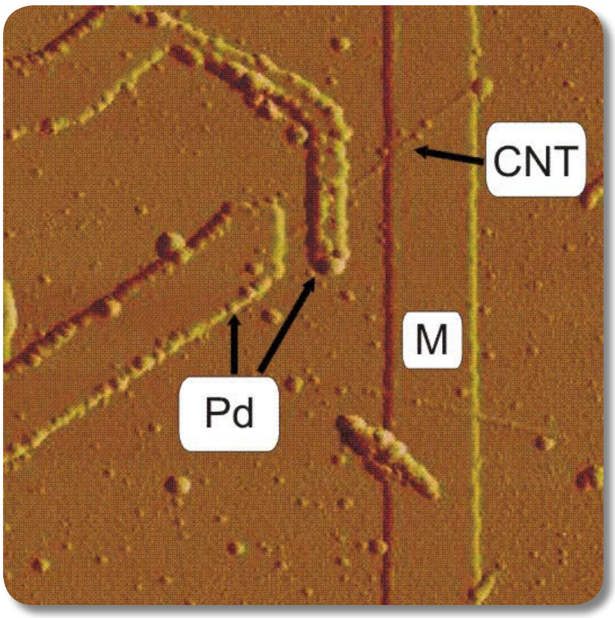
Markus Ahlskog

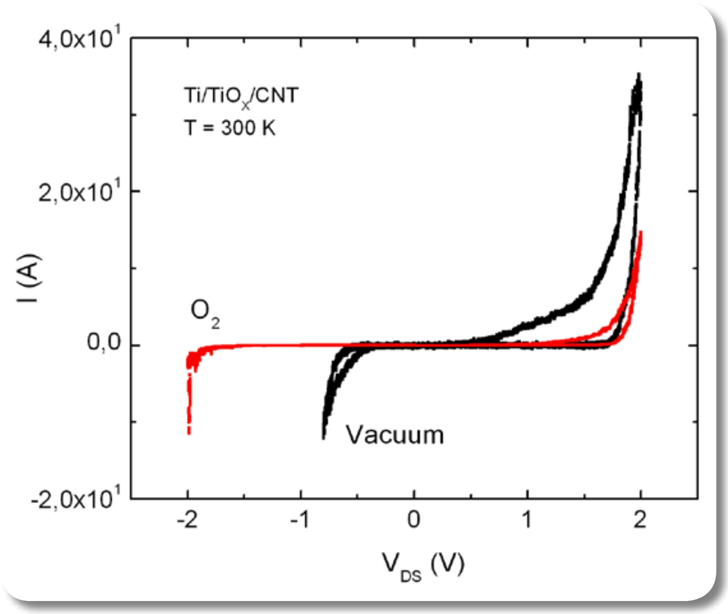
The Molecular Technology group studies electronic and mechanical properties of carbon nanotubes (CNTs) and devices that are based on them. Scanning probe microscopy and biological particles are also investigated.

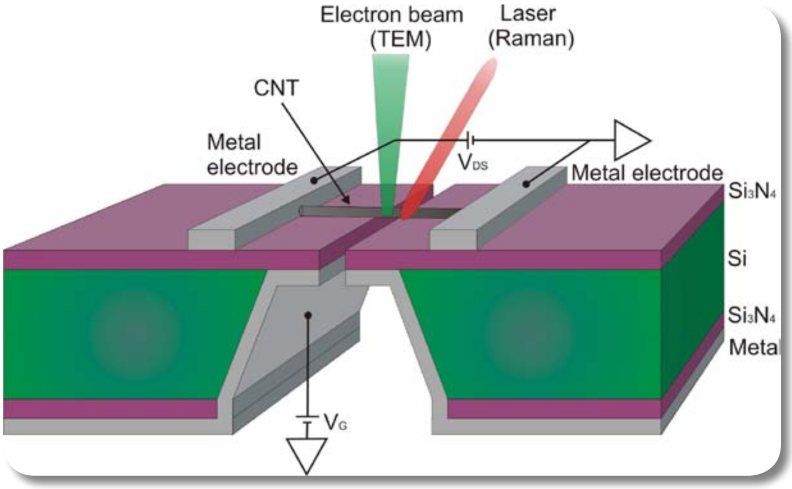
We have measured the conductive properties of junctions between multiwalled carbon nanotubes (CNT) and non-noble metals M (M=Al,Ti,Nb), which are separated by the native oxide (M_{ox}) of the metal, see fig. 4. Reproducible and asymmetric current-voltage characteristics were obtained from Ti/Ti_{ox}/CNT (Fig. 4) and Nb/Nb_{ox}/CNT junctions, while Al/Al_{ox}/CNT exhibited no current until breakdown, which is attributed to the larger bandgap of Al_{ox}. The conduction in the Ti- and Nb-based junctions is not due to direct tunneling since they exhibit a strong temperature dependence. The presence of oxygen is shown to drastically, but reversibly, modify the current-voltage characteristics, and in particular its asymmetry. The observed phenomena are discussed in terms of an elementary model where the different work functions of M and the CNT determine the asymmetric barrier of the junction. These results are complemented with Kelvin probe microscopy measurements (at Katholieke Universiteit Leuven, Belgium) of the work function distribution in the vicinity of the junctions in different gas environments.

Combined techniques for measurement of structural, electron transport, and optical

Fig. 4. Left) AFM image (error signal) of a fabricated metal/insulator/CNT junction where the insulator is the native oxide (M_{ox}) of the 1 mm wide metal line (M).
Right) The room temperature IV characteristics of a representative Ti/Ti_{ox}/CNT junction in vacuum and in oxygen (O_2).







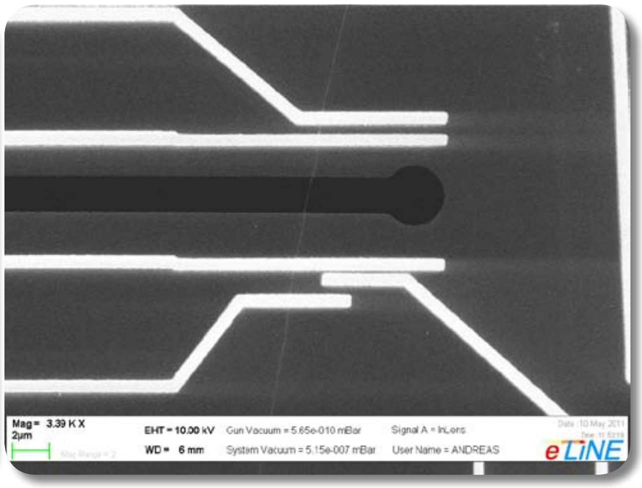
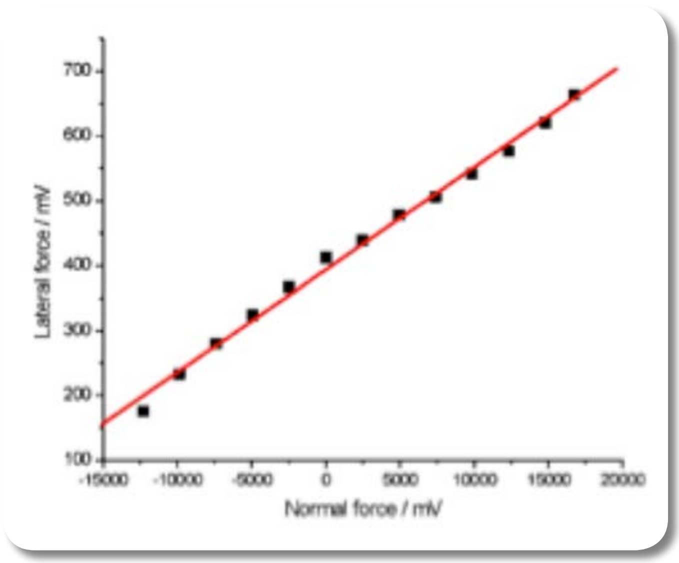


Fig. 5. Left) Schematic of our suspended carbon nanotube samples and the measurement techniques possible in this configuration. Right) SEM image of fabricated nanotube device crossing slit.

properties of individual carbon nanotubes are very important. We are developing methods to suspend nanotubes over narrow slits for this purpose, see Fig. 5. We have established a laminar flow CVD (chemical vapor deposition) furnace system to grow carbon nanotubes directly on top of the substrate. We pattern lithographically metal catalyst (usually Co or Fe) areas to the substrate and then place the substrate to a horizontal tube furnace. The actual growth happens in 900 °C when hydrocarbons (ethanol in our case) is introduced to the tube. Nanotubes start to grow at the sites of metal catalyst particles when the carbon containing gas is broken apart at the surface of the catalyst. With this kind of nanotube synthesis method we have better control of nanotube growth in the right locations, which is especially important for suspended nanotube samples. The studies are done in an interdisciplinary collaboration with the groups of Prof. Mika Pettersson at University of Jyväskylä (Raman spectroscopy, Four wave mixing spectroscopy), Prof. Martti Kauranen at Tampere University of Technology (Second harmonic generation) and Prof. Esko I. Kauppinen at Aalto University (TEM diffraction) [Ref. 8]. First results of the fabricated samples include demonstration of second harmonic generation from carbon nanotubes (submitted) and progress in four wave mixing experiments (unpublished).

Imaging of carbon nanotubes (CNT), and other nanoscale particles, with the atomic force microscope (AFM) is overwhelmingly done in various versions of the non-contact mode. Nevertheless, frictional forces are of interest in AFM and tribology, which are measured in frictional force microscopy or Lateral force

Fig 6. Lateral force (friction) measured with different scanning forces on a MoS_2 surface.



microscopy (LFM), using contact mode. Contact mode operation is also important in various cases where, for example, nanotubes are mechanically measured or manipulated [Ref. 9].

Materials that have a small coefficient of friction are commonly used as a protective film on many surfaces. Such materials are, for example, diamond-like carbon (DLC) and molybdenum disulfide (MoS_2). Their properties in the nanoscale domain are not well understood and will certainly be to some extent different. We have begun the study of these with the AFM, as shown in Fig. 6.

[7] A. Juutilainen, A. Volodin, M. Ahlskog
"Measurements of tunneling conduction to carbon nanotubes and its sensitivity to oxygen gas"
Physical Review B. 86, 045405 (2012)
[8] M.J. Huttunen, O. Herranen, A. Johansson, H. Jiang, P.R. Mudimela, P. Myllyperkiö, G. Bautista, A. G. Nasibulin, E. I. Kauppinen, M. Ahlskog, M. Kauranen, M. Pettersson
"Observation of second-harmonic generation from an individual carbon nanotube"
Submitted
[9] Jarkko Lievonen, Doctoral Thesis, Department of Physics, University of Jyväskylä, Research Report No. 8/2011.

Quantum Nanoelectronics

Konstantin Arutyunov

The activity of Quantum NanoElectronics group can be formally separated into three tightly interlinked domains: (I) quantum size phenomena at nanoscales; (II) interface phenomena at nanoscales; and (III) applied nanotechnology. In 2012 the most intriguing results were obtained related to studies of quantum phase slip (QPS) phenomena. Phase slip is a fluctuation-governed topological singularity leading to dissipation in ultra-narrow superconducting nanostructures. Several breakthrough results were obtained.

For some time it was believed that observation of QPS requires sub-10 nm dimensions. We have demonstrated [10,11] that with proper selection of 'superconducting' material (ultra-low-Tc and high normal state resistivity) the QPSs manifest themselves already at ~ 35 nm scales (Fig. 7b). The extensive microscopic and elemental analyses, made in collaboration with Pelletron lab of JYU, revealed the reasonable homogeneity of the samples without any traces of defects, which can mimic the QPS effect. The observation is very important removing all skepticism related to homogeneity of the structures, where presence of QPS is claimed.

It has been predicted that the electrodynamics of a QPS nanowire is dual to the one of a Josephson junction. Fluctuation-induced QPSs provide the dynamic equivalent of conventional (static in space and time) tunnel junctions, required for operation of Josephson-based devices. For example, a single electron transistor (SET), with Cooper pair charge 2e in case of a superconductor (Fig. 8a), can be substituted by a QPS equivalent (Fig. 8b,c). Fig. 8d demonstrates the counter-intuitive application of a superconductor: with proper selection of parameters the 'superconducting' circuit demonstrates insulating (!) behavior [12]. The device can be considered as a junctionless transistor.

Yet another manifestation of the QPS phenomena can be observed in superconducting loops. The coherent QPSs enable superposition of persistent currents of opposite directions. The QPS leads to dramatic changes in the current-phase relation and the magnitude of the persistent currents of tiny superconducting nanoloops [13]. The effect is of fundamental importance indicating the first-time observation of the impact of quantum fluctuations on the ground state of a quantum system. Following the breakthrough discovery [13], in collaboration with NEC-RIKEN (Japan),

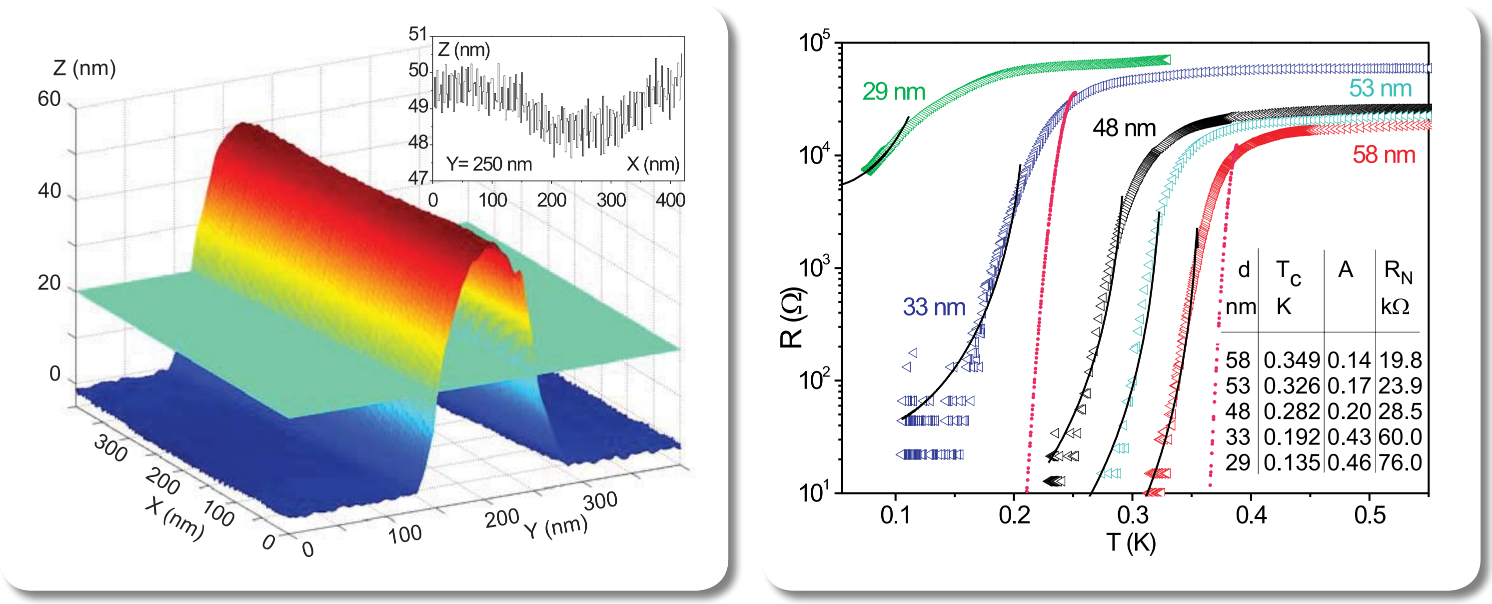
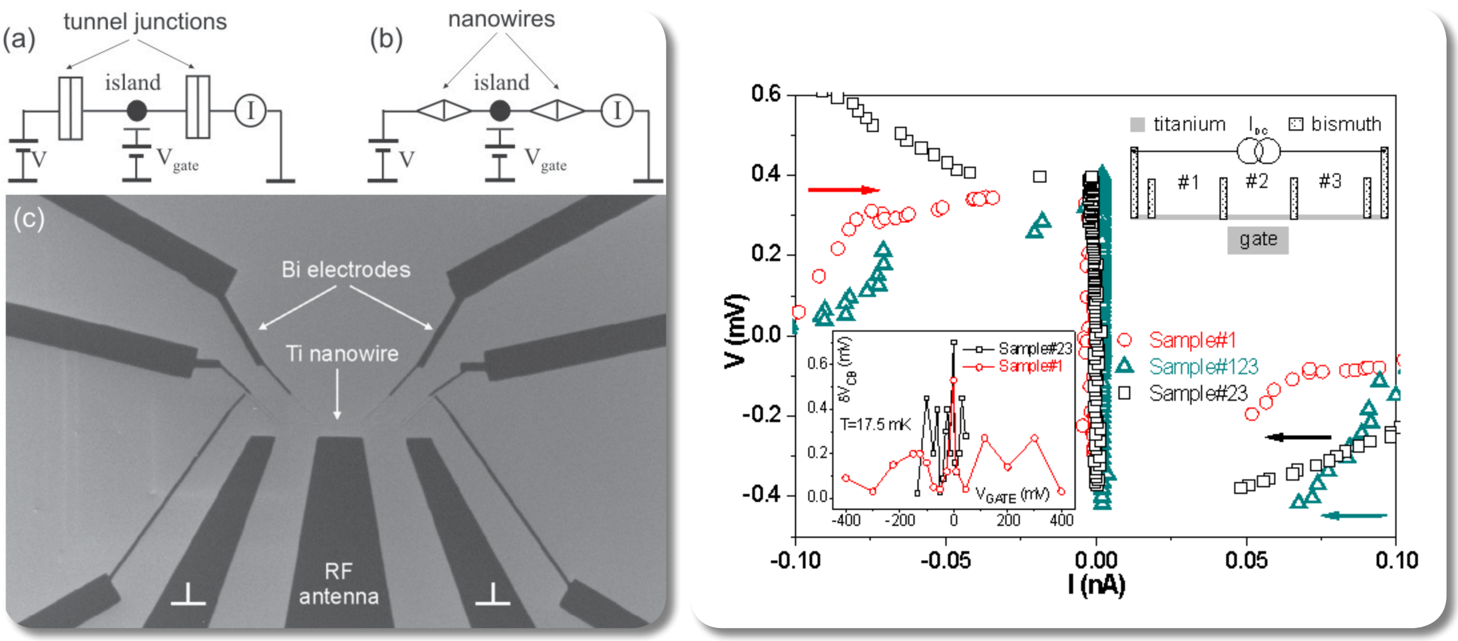


Fig. 7. (Left) AFM image of a typical part of a titanium nanowire. Horizontal plane indicates the interface between the metal and the sputtered Si substrate. Inset: Profile of the top part of the sample. Note the extreme surface smoothness ±1 nm. (Right) Resistance vs. temperature for the same titanium nanowires with length L = 20 μm and progressively reduced effective diameter $\sqrt{\sigma}$ indicated in the plot and specified with accuracy ±2 nm. Fits using the QPS model are shown with solid lines. ‹Conventional› thermal fluctuation model (TAPS) estimates for 33 nm and 58 nm samples are shown with dashed lines [10].

Fig. 8. (a) Schematics of a conventional single electron transistor (SET) with tunnel junctions. (b) Equivalent circuit of an SET with QPS nanowires substituting tunnel junctions. (c) SEM image of the sample. (d) The I-V characteristics demonstrate the Coulomb blockade for all three neighboring parts of the same nanostructure (right inset). Arrows indicate the direction of the current sweep. Application of the gate voltage dV_{CB} periodically modulates the Coulomb gap (left inset) [12].



Rutgers University (USA) and Weismann (Israel) we have demonstrated that such a ring in the regime of quantum fluctuations represents the quantum two level system – qubit (Fig. 9) [14]. The results were published in 2012 in two subsequent Nature papers [13,14].

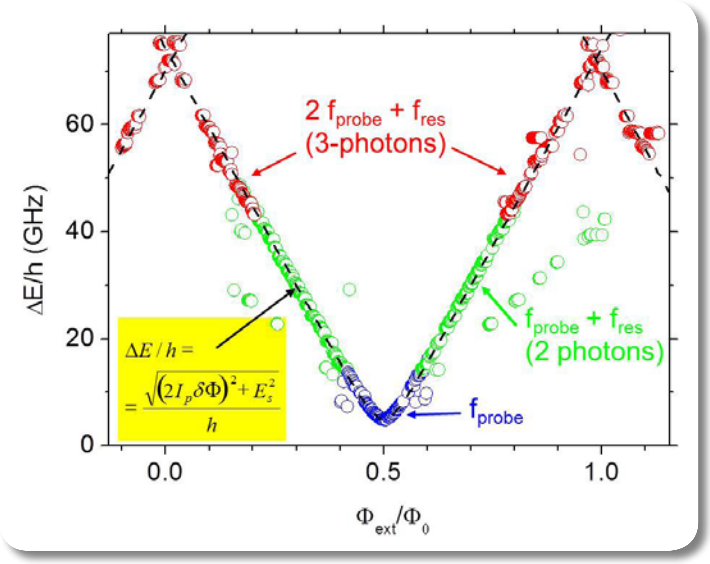


Fig. 9. Spectroscopy of the QPS-based qubit across a wide range of flux and frequency. Perfect agreement of the experimental data with the calculated energy bands supports our interpretation: the quantum states of the system correspond to the superposition of the two adjacent flux states induced by coherent QPS [14].

[10] J. S. Lehtinen, T. Sajavaara, K. Yu. Arutyunov, M. Yu. Presnjakov and A. Vasiliev, "Evidence of quantum phase slip effect in titanium nanowires", Phys. Rev. B 85, 094508 (2012).
[11] J. S., Lehtinen1 and K. Yu., Arutyunov, The quantum phase slip phenomenon in superconducting nanowires with a low-Ohmic environment, (invited topical paper), Supercond. Sci. and Technology, 25 124007 (2012).
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[14] O. V. Astafiev, L. B. Ioffe, S. Kafanov, Yu. A. Pashkin, K. Yu. Arutyunov, D. Shahar, O. Cohen, & J. S. Tsai, Coherent quantum phase slip, Nature 484 (7394), 355 (2012).

Molecular Electronics and Plasmonics

Jussi Toppari

The research of the Molecular Electronics and Plasmonics group can be divided into two main categories: DNA based self-assembly and electrical measurements, and nanoscale plasmonics with emphasis in coupling with optically active molecules. We have studied various DNA-based self-assembled structures, e.g. DNA-origamis, and especially developed a dielectrophoretic trapping method to capture them between nanoscale electrodes to characterize them electrically. Based on these results, we have also developed devices by functionalizing these scaffolds. In addition, we have characterized the electrical conductivity of conjugates of silver nanoparticles and G-wires, i.e., form of DNA consisting of four poly-G strands attached to each other.

On the plasmonics, we have extended our studies of strong coupling of surface plasmon polaritons (SPP) to biomolecules, namely β-carotene, which has outstanding importance due to its functions in photosynthesis [15,16]. Dispersion relations were measured from samples having thin silver film with β-carotene embedded in a polymer on top. In spite of the complex excited state dynamics, the S_2 state of β-carotene is strongly coupled to SPPs with coupling energies up to 130 meV. On the other hand, we did not observe any coupling to the forbidden S_1 state of the carotenes. We also performed molecule excitation by a laser, and analyzed the emission patterns revealing clear surface plasmon coupled emission (SPCE) and Raman signals of β-carotene.

Sun is the only source of energy that is infinite relative to the lifespan of the human species, and plasmonics research may open new pathways towards more efficient solar energy harvesting for a more sustainable future. We have presented the first direct optical measurement of light coupling into a planar waveguide by plasmonic nanoparticles [17]. Also we have shown that in a thin high refractive index waveguide, the interference plays a major role in the plasmon-waveguide coupling. This is of importance when designing, e.g. window integrated, plasmon enhanced transparent solar cells or collectors.

Naturally, combination of these two research branches, i.e. DNA self-assembly and plasmonics,

Fig. 10. Dispersion relations of a “glass|50nm silver|50nm β-carotene” -structure obtained from reflection (red circles) and SPCE (empty circles) measurements, are shown together with the β-carotene absorption (red curve) and fluorescence (black curve) spectra. The inset shows a measured radiative pattern of the same structure excited with two wavelengths (solid and empty circles), together with the calculated one (black curve).

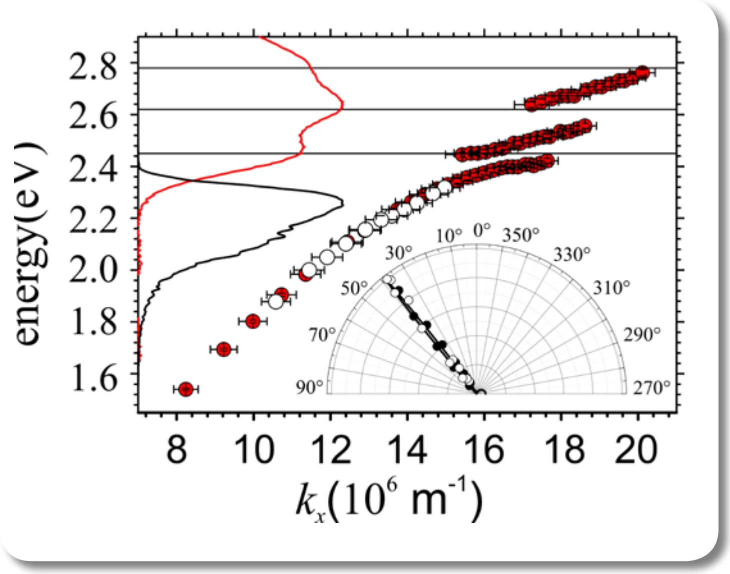
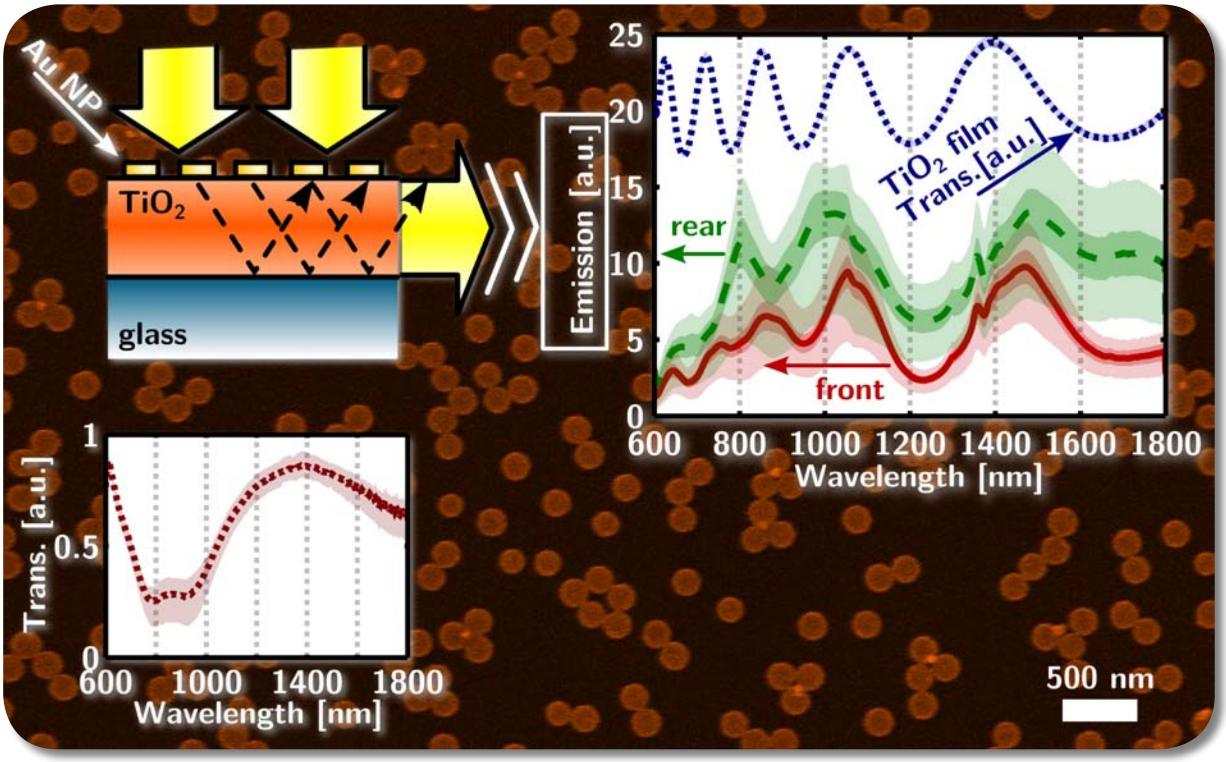


Fig. 11. Optical measurement of plasmon-waveguide coupling is illustrated in the upper left image. The upper right graph shows coupling measurements of a sample with 900 nm TiO_2 film (front and rear illumination). Effect of TiO_2 thin-film interference to the coupling is evident. Transmittance of the Au nanodisks on TiO_2 is presented in the lower left graph, showing plasmon resonance around 850 nm, and suggesting other one over 1800 nm.



is also possible, as demonstrated in a collaborative work with the Nanobiophotonics group from the Institute of Photonic Technology (Jena, Germany) [18]. In this work a plasmonic coupling to a dsDNA nanowire via metallic nanoparticles and a long-range transfer of an excitation along the DNA, was demonstrated.

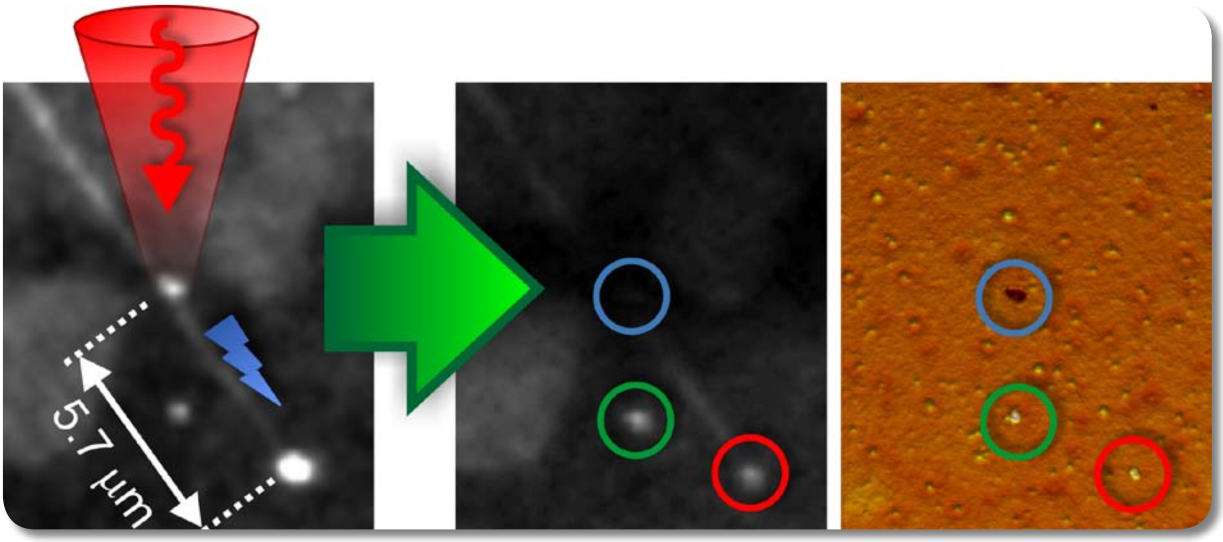


Fig. 12. Plasmonic coupling to a dsDNA nanowire via metallic nanoparticles illuminated by a femtosecond laser, and subsequent transfer of an excitation along the DNA to another nanoparticle. Both DNA and nanoparticles are fluorescently labeled and the transfer is observed as bleaching. The first two images are fluorescent images and the right one is an AFM image of the same area.

International Peer Reviewed Articles

[15] S. V. Baieva, T. K. Hakala and J. J. Toppari
Strong coupling between surface plasmon polaritons and Sulforhodamine 101 dye
Nanoscale Research Letters, 7 (2012) 191

[16] S. V. Baieva, J. A. Ihalainen and J. J. Toppari
Strong coupling between surface plasmon polaritons and β-carotene in nanolayered system
J. Chem. Phys. 138 (2013) 044707

[17] A. M. Pennanen and J. J. Toppari
Direct optical measurement of light coupling into planar waveguide by plasmonic nanoparticles
Opt. Express 21 (2013) A23

[18] J. J. Toppari, J. Wirth, F. Garwe, O. Stranik, A. Csaki, J. Bergmann, W. Paa and W. Fritzsche
Plasmonic Coupling and Long Range Transfer of an Excitation Along a DNA Nanowire
ACS Nano 7 (2013) 1291

Department of Physics 2012

Computational Nanosciences

Matti Manninen, professor (university's rector since 1.8 2012)
Hannu Häkkinen, professor (physics and chemistry)
Robert van Leeuwen, professor
Vesa Apaja, senior researcher
Karoliina Honkala, lecturer (chemistry)
Pekka Koskinen, academy research fellow
Esa Räsänen, academy research fellow (-31.8.2012)
Jenni Andersin, postdoctoral researcher (chemistry)
Xi Chen, postdoctoral researcher (chemistry)
Andre Clayborne, postdoctoral researcher (chemistry)
Klaas Giesbertz, postdoctoral researcher (- 31.8.2012)
Lauri Lehtovaara, postdoctoral researcher (chemistry)
Sami Malola, postdoctoral researcher (chemistry)
Claudia Gomes da Rocha, postdoctoral researcher
Michael Ruggenthaler, postdoctoral researcher (-30.9.2012)
Lars Gell, graduate student (chemistry)
Markku Hyrkäs, graduate student
Janne Kalikka, graduate student
Anna Kausamo, graduate student (chemistry)
Oleg O. Kit, graduate student
Ville Kotimäki, graduate student
Perttu Luukko, graduate student
Topi Korhonen, graduate student
Petri Myöhänen, graduate student (- 8.6.2012)
Ville Mäkinen, graduate student
Lauri Nykänen, graduate student (chemistry)
Antti Putaja, graduate student
Niko Säkkinen, graduate student
Riku Tuovinen, graduate student
Anna-Maija Uimonen, graduate student
Janne Nevalaita, graduate student
Johannes Nokelainen, MSc student
Janne Solanpää, MSc student
Pauli Parkkinen, MSc student (chemistry)
Teemu Peltonen, MSc student
Kirill Pervushyn, MSc student

Redox chemistry of gold with high-valence Doped Calcium Oxide

Hannu Häkkinen and Karoliina Honkala

Oxide-supported metal catalysts play a central role in the field of heterogeneous catalysis. Controlling the size and shape of the active metal phase is of utmost importance since these properties affect the dispersion of the catalytically active metal particles. The metal-support interactions govern the number and the nature of catalytically active sites, consequently, much of the current research in the field is concentrated on gaining understanding and control of this interaction. Doping the oxide material with higher-valence transition metals atoms has turned out to be a useful method to modify the electronic properties of the oxide and to control the morphology of the catalytically active metal.

Gold particles are catalytically active only at the nanometer length-scale, and it has been shown that the active sites e.g. for oxidation reactions are at the interface between the particle edge and the oxide support. According to theoretical calculations and STM experiments, dispersion of gold particles is most effective on supports where transfer of electrons can take part from the support to gold, facilitating growth of two-dimensional nano-islands of the metal with negatively charged edges. It has been generally believed that the main part of the adsorption energy between gold and the support originates

from electrostatic interactions between the charged metal and the oxide. Recently we demonstrated, however, that the energetics of the adsorption process of gold on high-valence doped oxides is much more complicated than generally believed.[1] Analysis of the whole adsorption process as a closed Born-Haber cycle shows that the main contribution is the energy of the reduction-oxidation reaction between the doping transition metal in the oxide and gold. Systematic study with several transition metal dopants in Calcium Oxide revealed a clear correlation between the 3rd ionization energy of the dopant and the adsorption energy of gold. Similar calculations based on the Born-Haber cycle can be employed to analyze adsorption energies of many other electronegative adsorbates on various doped oxide surfaces.

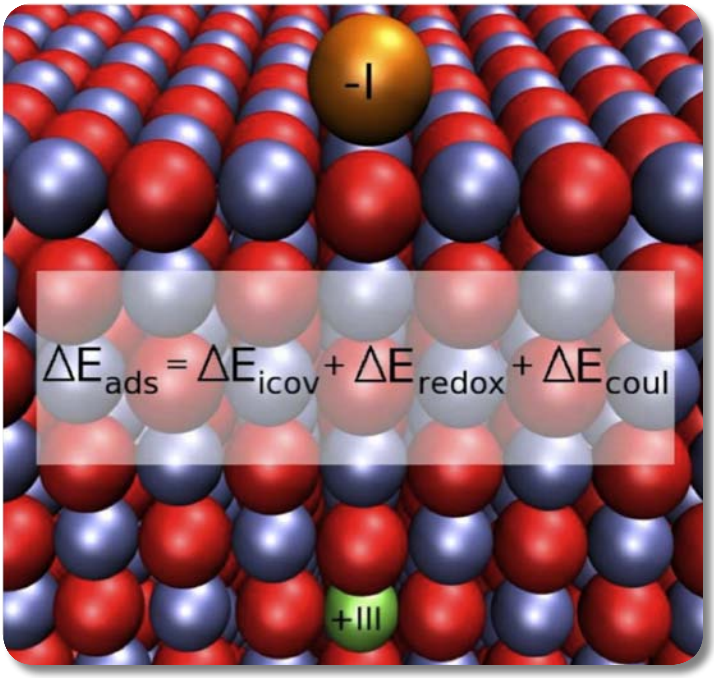


Fig. 1. Visualization of a structure where a negatively charged (charge -1) gold adatom is adsorbed on Molybdenum-doped Calcium Oxide. The Molybdenum dopant has an oxidation state of +3. The adsorption energy consists of ionocovalent, redox and Coulombic contributions. Yellow: gold, green: molybdenum, blue: calcium, red: oxygen.

[1] J. Andersin, J. Nevalaita, K. Honkala and H. Häkkinen, "The redox chemistry of gold with high-valence doped CaO", Angewandte Chemie International Edition (2012) online: http://onlinelibrary.wiley.com/doi/10.1002/anie.201208443/abstract

Time-dependent Quantum Many-body Theory

Robert van Leeuwen

Since the solution of the full many-particle Schrödinger equation is prohibitive, we have explored three approaches to develop a theoretical framework based on reduced quantities. The first approach is based on the hierarchy of density matrices, the so-called Bogoliubov-Born-Green-Kirkwood-Yvon hierarchy, that couples equations of motion of the N-body density matrix to that of the (N+1)-body density matrix. We explored decoupling schemes that express the 3-body matrix in terms of the 1- and 2-body matrix. This can be done in such a way that basic conservation laws for energy and particle number are obeyed. However, we also found that the corresponding nonlinear differential equations can lead to chaotic and divergent behavior.[2]

The second approach is time-dependent density functional theory (TDDFT). Regarding the foundations of TDDFT there are still a number of open questions. The theory is based on a 1-1 mapping between external potentials and particle densities. Existing proofs that establish this connection are based on analyticity of the potential, which is a strong mathematical requirement. We have been able to give generalizations that lift this restriction [3].

The third approach we explored is nonequilibrium Green's function theory. The theory is based on Wick's theorem for decomposition of the N-particle Green's functions in terms of the 1-particle Green's function. This theorem is, however, only applicable to certain initial states. We have been able to find a generalization of the theorem that is valid for general initial states.[4]

Rolling up Graphene

Pekka Koskinen

For the past 20 years carbon nanotubes have been tributed as "rolled-up graphene," though no one ever really did the rolling. By the electronic structure simulation method developed earlier in our group[5], and by continuum elasticity modeling done in collaboration with Jussi Timonen's group at the NanoScience Center, we predicted that, indeed, long and narrow graphene ribbons can be rolled into carbon nanotubes by means of twisting (Fig.2).[6]

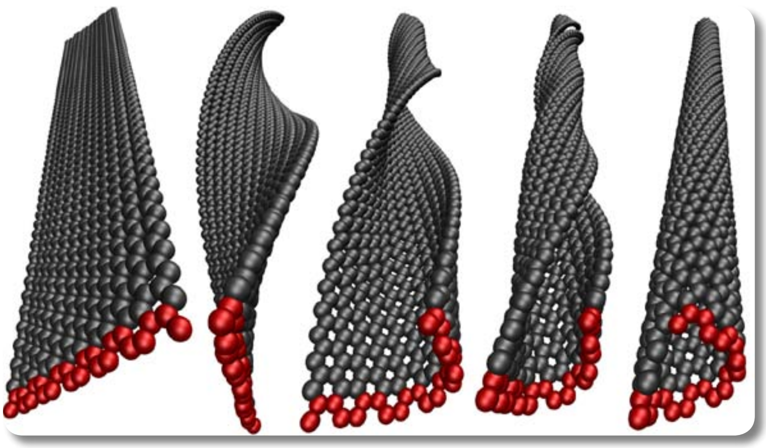


Fig. 2. Pristine graphene nanoribbons can be transformed into pristine carbon nanotubes by means of twisting.

Fig. 3. The transformation of a ribbon into a tube is inherently a classical phenomenon, and can be demonstrated easily by twisting a strap of a backpack.

As today carbon nanotubes, along with many other nanomaterials, are made by atom-by-atom growth, the twisted prediction makes up a fundamentally different nano-fabrication method. The basic idea, however, is simple and easily grasped: just twist the ends of a strap of your backpack and watch the result (Fig.3). Therefore the mechanism, being classical in origin, is robust and valid in macro-, micro-, and nano-scales. Mechanism also enables experimental control of the tube chirality, so it could be used to make carbon nanotubes controllably, to make various kinds of novel carbon nanotubules, to encapsulate molecules inside tubes, and to make tubules from ribbons made of other planar nanomaterials.

[2] A. Akbari, M. J. Hashemi, A. Rubio, R. M. Nieminen, R. van Leeuwen "Challenges in truncating the hierarchy of time-dependent reduced density matrices" Phys. Rev. B 85, 235121 (2012)
[3] M. Ruggenthaler, K. J. H. Giesbertz, M. Penz, R. van Leeuwen "Density potential mappings in quantum dynamics" Phys. Rev. A 85, 052504 (2012)
[4] R. van Leeuwen and G. Stefanucci "Wick theorem for general initial states" Phys. Rev. B 85, 115119 (2012)
[5] P. Koskinen, O. O. Kit "Efficient approach for simulating distorted nanomaterials" Phys. Rev. Lett. 105, 106401 (2010); O. O. Kit, L. Pastewka, P. Koskinen "Revised periodic boundary conditions: fundamentals, electrostatics and the tight-binding approximation" Phys. Rev. B 84, 155431 (2011)
[6] O. O. Kit, T. Tallinen, L. Mahadevan, J. Timonen, P. Koskinen "Twisting graphene nanoribbons into carbon nanotubes" Phys. Rev. B 85, 085428 (2012) (highlighted by Editor's suggestion, APS Physics synopsis, and PRB Kaleidoscope)

Department of Physics 2012

Soft Condensed Matter and Statistical Physics

Markku Kataja and Jussi Timonen

X-ray tomography laboratory

The primary research facility within the X-ray Tomography Laboratory includes three up-to-date tomographic scanners. Together, these devices are capable of non-intrusive three-dimensional imaging of the internal structure of heterogeneous materials with resolution ranging from 40 μm down to 50 nm. In addition to tomographic scanners, the laboratory is equipped with specific devices for measuring various transport properties of materials. In 2012, the sample preparation and manipulation abilities of the laboratory were significantly improved especially by acquisition and implementation of a novel laser system for accurate cutting of small samples, a sample holder that allows mechanical straining of the sample and a device for controlling the humidity and temperature of the sample during imaging. The entire facility had a high operation rate in basic and applied research related e.g. to analysis and development of fibre based materials, and structural properties of minerals and biological materials such as ceramics, bentonite clay and bone.

Examples of research on heterogeneous materials: The effect of heterogeneous structure on diffusion in rock was studied using a number of different methods: X-ray tomography (XCT), the C-14-PMMA method and electron microscopy were

Jussi Timonen, professor
Markku Kataja, professor
Juha Merikoski, university lecturer
Markko Myllys, university lecturer
Pekka Kekäläinen, university researcher
Jouni Takalo, university researcher
Topi Kähärä, postdoctoral researcher
Keijo Mattila, postdoctoral researcher
Lasse Miettinen, postdoctoral researcher -30.6.
Petro Moilanen, postdoctoral researcher
Tuomas Puurtinen, postdoctoral researcher
Tuomas Tallinen, postdoctoral researcher (JYFL and Harvard)
Jukka Toivanen, postdoctoral researcher (Mathematical Information Technology)
Vesa Aho, graduate student
Axel Ekman, graduate student
Aaro Eloranta, graduate student
Antti Juutilainen, graduate student
Janne Kauttonen, graduate student
Vantte Kilappa graduate student
Jukka Kuva, graduate student
Arttu Miettinen, graduate student
Tuomas Turpeinen, graduate student (Mathematical Information Technology)
Mikko Voutilainen, graduate student
Markku Väisänen, graduate student
Roope Lehto, research assistant
Joni Parkkonen, laboratory engineer
Jarno Alaraudanjoki, laboratory engineer
Teemu Isojärvi, MSc student
Tero Harjupatana, MSc student
Jalmari Pirhonen, MSc student

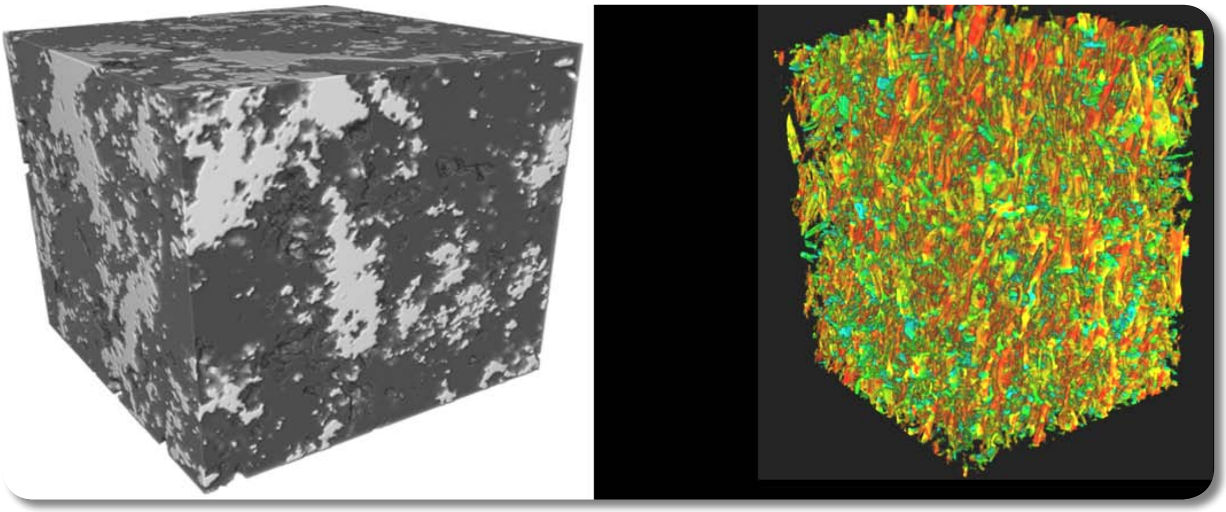
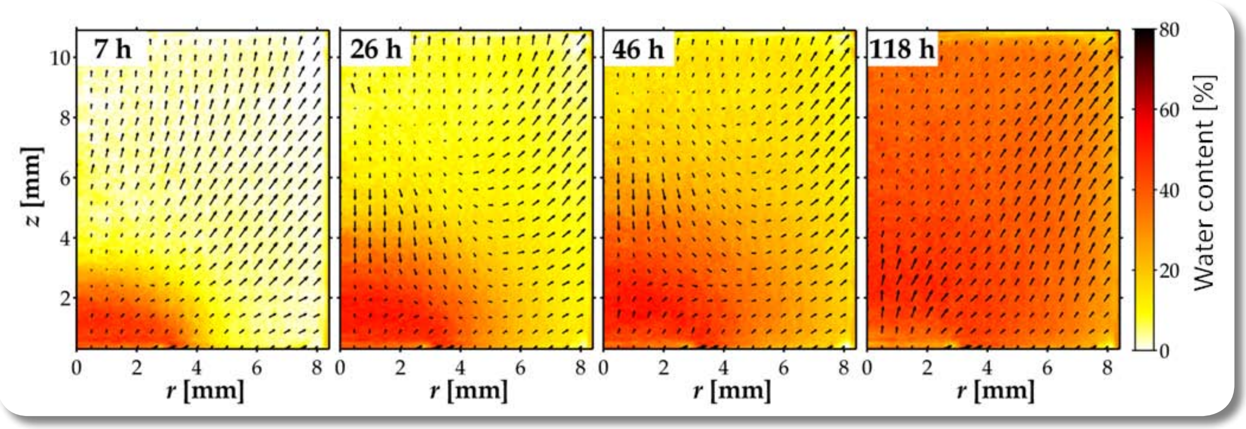


Fig. 1. Left) A 3D porosity map of a tonalite sample: pores (black, porosity 100 %), altered feldspar (dark gray, porosity 4.5 %) and altered mica (light gray, porosity 8.6 %). Right) 3D visualization of fibres in a wood-fibre composite. Fibre orientation is colour coded.

used to characterize the pore structure and porosity of strongly altered Sievi tonalite. Similar methods together with petrography analysis were used to determine 3D distributions of minerals and porosities in rock samples that contained different types of fractures that had been water conducting. Rock properties around these fractures displayed uncorrelated variation, and no clear pattern emerged for a given type of fracture. Combining different results, 3D porosity maps were constructed of samples (see Fig. 1 a) for studying the effect of heterogeneous porosity on their diffusion properties. In the altered tonalite analyzed, inclusion of heterogeneous porosity increased the diffusion coefficient by 16 %.

Structural characterisation of biodegradable wood fibre composites was done using µXCT and 3D image analysis. The focus was on wood fibre-ligning and wood fibre-PLA composites. The analysis methods found to be suitable for these materials included measurement of fibre length using granulometric techniques, fibre orientation distribution using the structure tensor method and the cross-sectional shape of fibres (see Fig.1 b). The results indicate that, e.g. in

Fig. 2. The measured displacement fields and moisture distributions in a bentonite sample at four phases of the wetting-swelling process (averaged over the azimuthal angle).



the injection moulding process, the length of fibres decrease considerably as they are turned into dust particles.

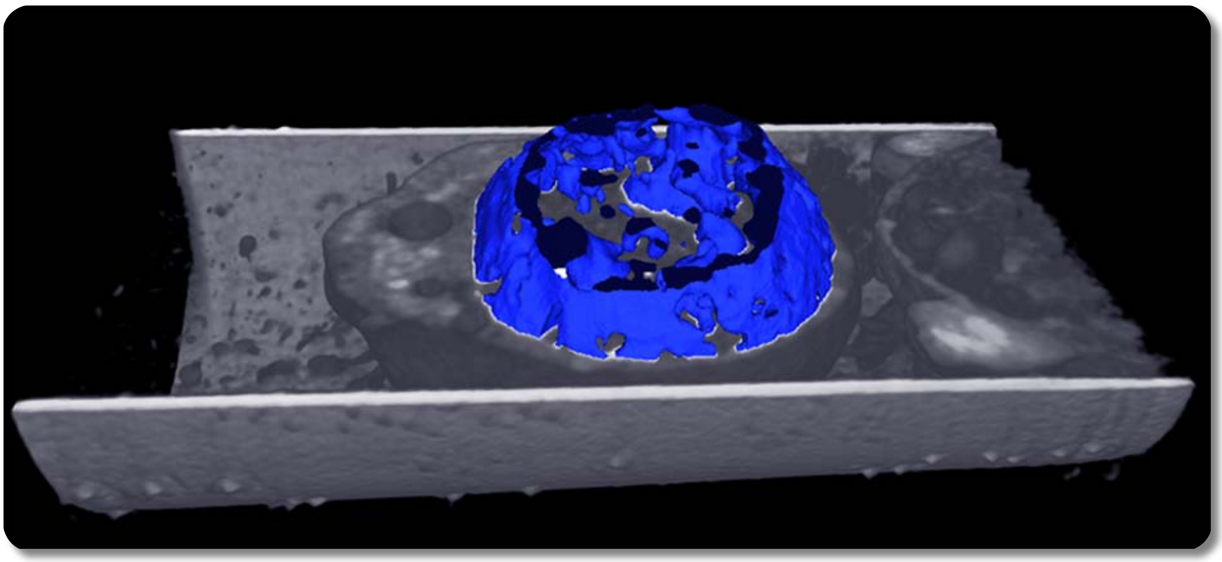
The study of mechanical and transport properties of bentonite clay, planned to be used as a buffer material in the final repository for nuclear waste, was continued. In particular, the µXCT method for simultaneous non-intrusive 3D measurement of water transport and the resulting intrinsic deformations in bentonite samples was further developed so as to gain better signal-to-noise ratio and to measure the swelling stress. The resulting experimental data (see Fig. 2) will be used for validating numerical models for the long-term behaviour of bentonite buffer under repository conditions.

Soft x-ray tomography

Cryogenic soft X-ray Tomography (SXT) at LBNL generates high-contrast 3D images of intact cells with 50 nm resolution. We used SXT to obtain the first high-resolution 3D analysis of an intact interphase nucleus of a mouse primary cell in the native state. SXT generated remarkable 3D views of chromatin topology, revealing that heterochromatin throughout the nucleus is interconnected (see Fig. 3).

DNA contains all the genetic information and is located mostly in the cell nucleus. Nuclear (chromatin) structure is divided into regimes of heterochromatin and euchromatin, which are correlated with silent and active regions of the genome, respectively. Compartmentalization of genes is believed to serve regulatory purposes. Irreversible developmental decisions, such as those made by differentiating neurons or lymphocytes, use diverse epigenetic mechanisms to lock in the status of the cell. Differentiation of olfactory sensory neurons (OSNs) provides an extreme example: OSNs choose one out of ~2800 olfactory receptor alleles, and establish a stable transcription program that assures that axons from like neurons converge to distinct glomeruli. Reorganization of nuclear architecture was found to be LBR-induced, and to govern the monogenic transcription of OSNs.

Fig. 3. 3D visualization of a mouse primary cell in the native state: SXT with 50 nm resolution. Segmented continuous heterochromatin is shown as blue.



Large strain elasticity

We developed a finite element model for elasticity of materials with large strains. Features of the model include contact processing of self-avoiding surfaces and possibility to apply growth of the material with feedback rules. For example, growth rate may depend on the local stress in the material. This model was first applied to cutting of soft solids, resulting in a quantitative explanation of why it is more efficient to cut material by slicing rather than by pressing a cutting tool in the direction of the normal to it. Another application is a surface instability of soft solids in which the initially smooth surface is patterned by sharp cusps, called sulci, if the compressive strain exceeds a critical value. Ongoing work includes the mechanics of a developing tissue, where the model allows numerical experimentation with various hypotheses on how a growing tissue develops a shape.

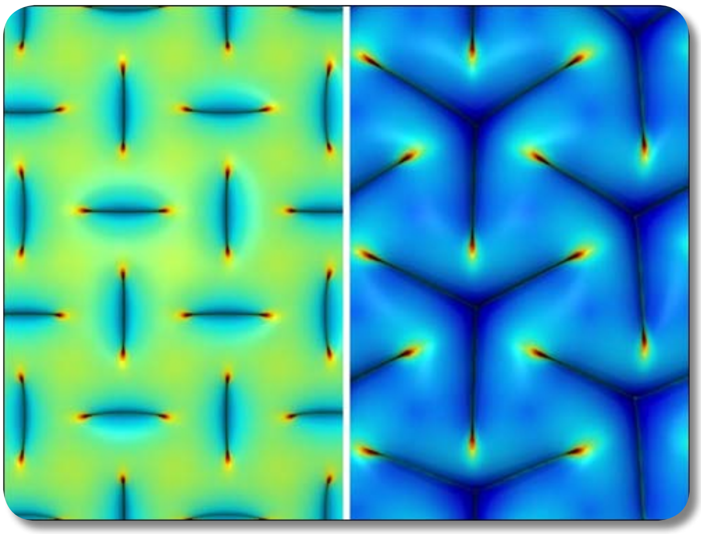


Fig. 4. A squeezed elastic surface displays a pattern of I-shaped sulci near the threshold of instability and Y-shaped sulci far from the threshold.

Ultrasonic guided waves in bone

Methods were developed for improved multi-mode ultrasonic assessment of long bones, such as the radius and tibia. Two ultrasonic guided wave modes, a fast first arriving signal (FAS) and a fundamental flexural guided wave (FFGW) can be measured in bone at low ultrasonic frequencies (f=50-500kHz) for which ultrasonic wavelength is long enough for probing osteoporotic changes deep in the endosteal (inner) cortical bone. An in vivo study of 95 postmenopausal women showed that FAS in the forearm discriminated subjects with a history of osteoporotic fractures from those without fractures: it thus has diagnostic efficiency. While FAS is mainly sensitive to properties like mineral density and elastic modulus, FFGW provides additional sensitivity to e.g. cortical thickness. Simultaneous measurement of these modes would permit better assessment of bone properties. It was demonstrated in collaboration with the University of Paris VI that bone supports propagation of many Lamb modes, whose measurement would further increase the accuracy of bone property assessment, but it is challenging. To this end, methods of signal processing were investigated in collaboration with the Fudan University in Shanghai. A method using dispersion compensation was shown to be promising. Also, methods of tailored ultrasound excitation and detection based on photo-acoustics were developed in collaboration with the Universities of Helsinki and Oulu so as to reduce the present problems in signal detection.

Department of Physics 2012

Experimental Particle Physics

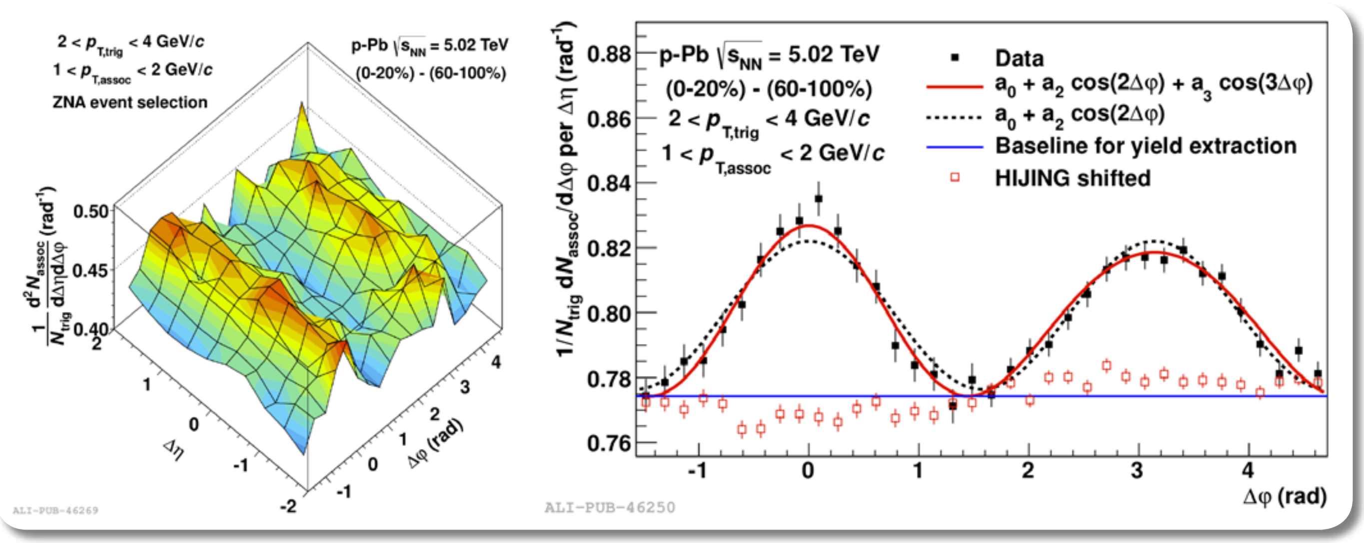
Jan Rak and Wladyslaw Trzaska

ALICE

Most of the LHC running time in 2012 was committed to pp collisions at 8TeV. The total 2012 integrated luminosity at ALICE was 9.96 pb^{-1}. This important parameter was determined with the help of T0 operating as an online luminosity and background monitor with a fast feedback to the accelerator team. The collected data will certainly keep us busy during the LHC shutdown

Jan Rak, university researcher (JYFL/HIP)
Wladyslaw Trzaska, university researcher
DongJo Kim, university researcher (JYFL/HIP)
Filip Krizek, postdoctoral researcher (HIP/JYFL)
Astrid Morreale, postdoctoral researcher (JYFL/HIP)
Sami Räsänen, postdoctoral researcher (HIP/JYFL)
BeomSu Chang, graduate student (JYFL/HIP)
Tuomo Kalliokoski, graduate student
Jiri Kral, graduate student (JYFL/HIP)
Kai Loo, graduate student
Norbert Novitzky, graduate student (HIP/JYFL)
Johannes Hissa, graduate student (CUPP)
Tomi Räihä, graduate student (CUPP)
Juho Sarkamo, graduate student (CUPP)
Maciej Slupecki, MSc student (Warsaw University of Technology)
Tiia Monto, MSc student
Esko Pohjoisaho, MSc student
Jussi Viinikainen, MSc student

Fig. 1. Left panel: the (Δφ,Δη) correlation function after the subtraction of the high- and low-multiplicity classes. The Δφ projection of the correlation function from the right panel. The solid red line represents the Fourier fit with second and third harmonic, coefficients, the dashed line shows the same fit with only the second Fourier coefficient included. The open symbols show the HIJING Monte Carlo simulation.



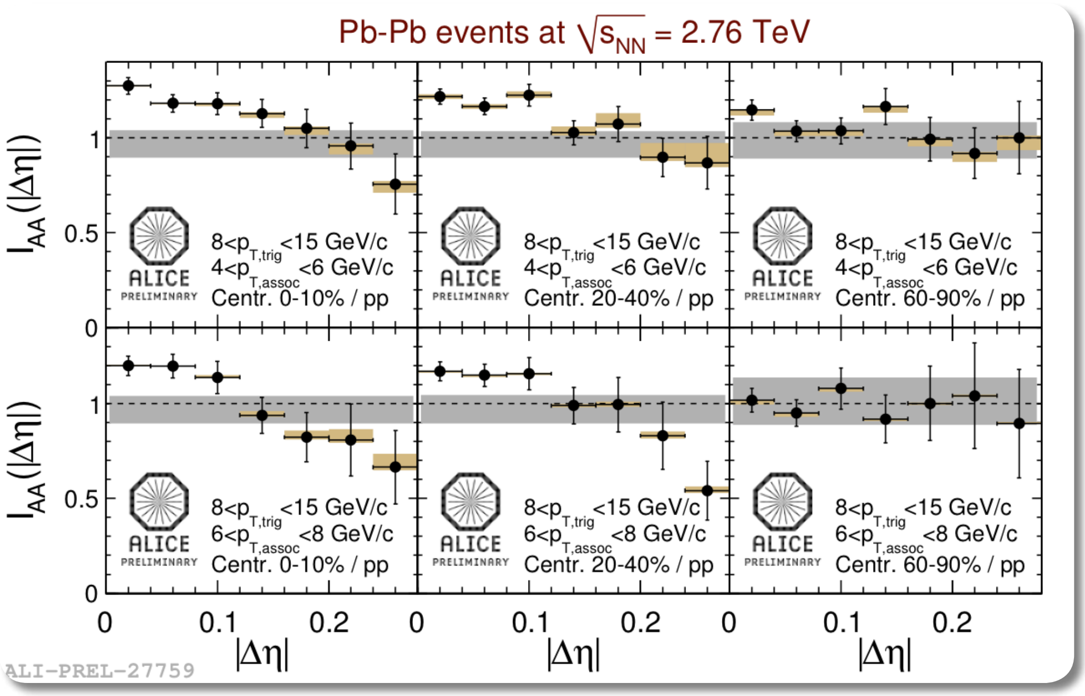


Fig. 2. per trigger normalized yields in Pb-Pb collisions divided by the same quantity in p-p, called I_{AA}, as a function of pseudorapidity difference inside the leading jet. Falling trend implies narrowing of the jet in central heavy ion collisions.

period. Perhaps the most exciting outcome emerged in the fall of 2012 during the pilot p-Pb run. ALICE has observed an unexpected double-ridge structure in two-particle correlations [PLB719 (2013) 29-41]. This phenomenon was later confirmed by ATLAS.

In the lead-lead analysis, we studied the changes in the jet shapes at the heavy ion collisions. The two-particle correlations showed that in the kinematical region where both trigger and associated particles are hard, the jet actually gets narrower. Currently there are several candidate explanations of this interesting new effect that was presented by us at Quark Matter 2012.

Throughout the entire 2012 collision period the T0 detector served as a key component of the ALICE trigger system. It was part of the online physics selection by supplying up to five different trigger inputs. It also provided accurate collision time (time zero) for Time-of-Flight measurements required for particle identification. No aging effects were observed in the detector. It worked flawlessly providing vertex and interaction time even at the highest interaction rates of up to 400 kHz. The efficiency for pp collisions at 8 TeV was ~70% for either T0A or T0C signals while the vertex efficiency was 50%. Throughout the 2012 LHC campaign our team supplied T0 detector experts with on-call duties. We were also directly responsible for inspecting and improving the data quality assurance and for maintaining the official online monitoring tool AMORE. In addition, we have conducted offline studies to further improve the current pp time resolution of ~40ps.

EMMA experiment

In 2012 EMMA experiment has reached several important milestones. Two tracking stations (C and F) got fully instrumented with a calibrated drift chambers. On July 10 these stations started taking cosmic ray data and operated in the continuous running mode till the end of the year. In parallel, the third tracking station (G) was built and equipped with detectors. Now there are three stations connected to the DAQ (C, E and F), and the new tracking station (G) will be added soon. In the fall EMMA received the shipment of limited streamer tube detectors from the decommissioned KASCADE GRANDE experiment. The new detectors will add 180 m^2 to the 250 m^2 of active area provided by the drift chambers from DELPHI. After three years of measurements with cosmic muons all 600 drift chambers are now fully calibrated and ready for deployment. The first, preliminary multiplicity results and the performance plots were presented at the 23rd European Cosmic Ray Symposium in Moscow. On October 30th Tomi Räihä successfully defended his Ph.D. thesis Analysis Tools for the EMMA Experiment.

Three central tracking stations of the EMMA experiment (from left: F, G, and C). Each station is equipped with three double layers of drift chambers and connected to the data acquisition.

EMMA team ready for bowling. Standing from the left: Kai Loo, Johanna Kutuniva, Maciej Slupecki, Pasi Kuusiniemi, Jari Joutsenvaara, Tomi Räihä, Wladyslaw Trzaska, Timo Enqvist, Juho Sarkamo, Marko Aittola, and Eelis Kokko.

Department of Physics 2012

Ultrarelativistic Heavy Ion Collisions – Theory

Kari J. Eskola, Tuomas Lappi and Thorsten Renk

Kari J. Eskola, professor
Thorsten Renk, academy research fellow
Tuomas Lappi, university researcher
Kimmo Tuominen, university lecturer, HIP project leader
Rupa Chatterjee, postdoctoral researcher
Harri Niemi, postdoctoral researcher
Hannu Paukkunen, postdoctoral researcher 1.10.–
Redamy Peréz-Ramos, postdoctoral researcher 1.10.–
Jussi Auvinen, graduate student –30.9.
Ilkka Helenius, graduate student
Risto Paatelainen, graduate student
Heikki Mäntysaari, graduate student
Jarkko Peuron, MSc student

Studies of strongly interacting elementary particle matter, the Quark Gluon Plasma (QGP), in ultrarelativistic heavy ion collisions (URHIC) are among the fundamental tests of the Standard Model. We aim at understanding the QCD matter properties and collision dynamics through various observables measurable in the BNL-RHIC and CERN-LHC experiments. We are funded by the Academy of Finland, PANU and private foundations. We are also part of Tuominen's LNCPMP project at HIP. In 2012 we participated in the physics planning of the possible future electron-ion colliders in CERN and U.S., contributed to the JET theory collaboration and the EU network I3-HP3 TURIC activities, participated with a high profile in the largest international conferences in our field, and organized three lecture series in the international Jyväskylä Summer School. Paukkunen and Peréz-Ramos started as our new postdocs, and Chatterjee got a BARC position at Kolkata. Auvinen reached the PhD degree and is now a postdoc at Frankfurt.

In heavy-ion phenomenology, the LHC Pb+Pb measurements have strengthened the status of relativistic hydrodynamics, a traditional expertise of our group, as a cornerstone of URHIC physics. In computing the produced QGP initial densities for hydrodynamics, we improved our NLO pQCD + saturation (EKRT) theory framework considerably and demonstrated its predictive power against the measured RHIC and LHC multiplicities and p_T spectra. We also investigated how the temperature dependence of the shear viscosity affects the azimuthal asymmetry coefficients (v_n) of the hadron spectra. In our recently developed event-by-event (EbyE) hydro framework, we studied the EbyE fluctuations of v_n which closely reflect the initial conditions of the system. We also charted the centrality and formation-time systematics of thermal photon emission in URHIC, addressing on an EbyE basis the puzzlingly large direct photon v_2 observed at RHIC and LHC. We also presented a new derivation of relativistic dissipative fluid dynamics from the Boltzmann equation using the method of moments, thus improving the consistency between the fluid-dynamical and kinetic-theory solutions.

High-p_T observables are another cornerstone of the experimental URHIC program at RHIC and LHC. With the high-statistics LHC data, the focus has now shifted from single-hadron spectra to a plethora of fully reconstructed jet observables. We develop and maintain Monte Carlo codes to compute such observables in a realistic way, embedding the hard events into constrained hydrodynamical backgrounds and simulating the experimentally relevant biases due to clustering or analysis cuts. Using this framework, our aim is to systematically pin down the QCD dynamics of the parton-medium interaction and the early time medium evolution, and also offer suggestions regarding promising discriminative novel observables to our experimental colleagues.

Nuclear parton distribution functions (nPDFs) are needed for the computation of all collinearly factorizable hard-process cross sections in nuclear collisions. Our pioneering global analysis, EKS98, is a standard reference in the field, and our EPS09 package defines the current state of the art for the nPDFs and their uncertainties. We have now released also the sets EPS09s and EKS98s of spatially dependent nPDFs, which enable the calculation of nuclear hard processes in different centrality classes. The nuclear effects of the hadron spectrum from the first p+Pb run at the LHC agreed nicely with our EPS09s-based NLO predictions for pion production.

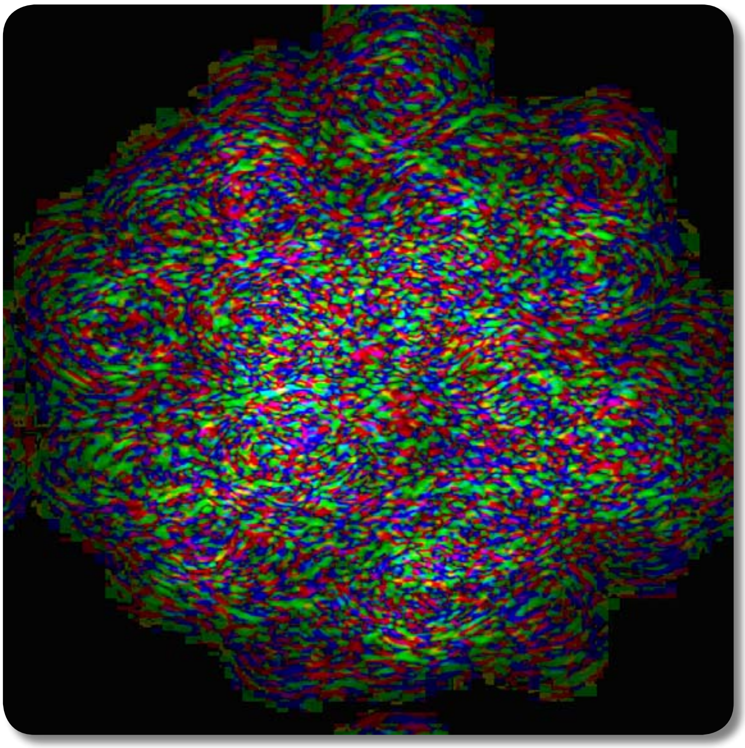


Fig. 1. Classical color fields during the initial stages of a heavy ion collision. The colors indicate different components of a chromoelectric field and the lightness and darkness correspond to the field strength.

In the Color-Glass-Condensate (CGC) framework, we are continuing our studies of high energy QCD, relevant e.g. for the QGP initial state in URHIC (Fig. 1). In 2012 we computed the azimuthal angle dependence of forward dihadron correlations at forward rapidity in d+Au collisions in the RHIC kinematical region. We also proposed a new way to implement the running QCD coupling in the JIMWLK equation, performing a detailed numerical comparison of our proposal to the running coupling BK equation.

Department of Physics 2012

Neutrino Physics and Beyond the Standard Model Physics

Jukka Maalampi, Wladyslaw Trzaska and Kimmo Tuominen

Jukka Maalampi, professor
Wladyslaw Trzaska, university researcher
Kimmo Tuominen, university lecturer, HIP project leader
Hidenori Sakuma (HIP), postdoctoral researcher,
Timo Alho, graduate student
Tuomas Karavirta, graduate student
Topi Kähärä (HIP), postdoctoral researcher
Kai Loo, graduate student
Tuomo Kalliokoski, graduate student
Tero Oravasaari, MSc student
Tiia Monto, MSc student

Neutrino Physics

Jukka Maalampi and Wladyslaw Trzaska

Our activity in neutrino physics covers topics both in neutrino phenomenology and experiments. The focus of the phenomenological studies has been on the hypothetical sterile neutrinos, particles which have no Standard Model interactions except those induced by their mixing with the ordinary neutrinos. We have investigated the effects of ordinary-sterile neutrino mixing on the fluxes of the neutrinos originating in distant astrophysical sources like active galactic nuclei (AGN).

Our group plays a significant role in LAGUNA, an EU-funded Design Study that has teamed up physicists and industrial partners to build a large-scale, underground neutrino detector complex for fundamental research in particle and astroparticle physics. LAGUNA is designed to provide unique scientific data with a great potential for fundamental discoveries. Apart from the neutrinos created in astronomical sources like the Sun and supernovae, as well as in radioactive decays taking place in the Earth's interior, the LAGUNA detectors will detect neutrinos artificially produced at particle accelerators hundreds of kilometers away. The Pyhäsalmi mine located 180 km north from Jyväskylä has emerged as the strongest candidate for the site of the experiment. One of the project's five Work Packages is on the responsibility of our group (Wladyslaw Trzaska). Our group was organizing a workshop and visit of the international LAGUNA technical team and industrial partners in Pyhäsalmi mine in January 2012.

The main LAGUNA milestone in 2012 was the submission in June of the Expression of Interest to the CERN Super Proton Synchrotron (SPS) Committee concerning a long-baseline neutrino oscillation experiment (LBNO). The EoI proposes to use the SPS accelerator at CERN to deliver intense neutrino beams to the Pyhäsalmi mine. The main scientific goals of the experiment are solving the question of neutrino mass hierarchy and determining the value of the leptonic CP violation angle δ. The document was supported by 300 signatories, of whom 28 were from Finland.

The LAGUNA project achieved very positive comments and recommendations from the international panel evaluating the research in physics in Finland (Physics Research in Finland 2007–2011, Academy of Finland, 2012). The panel found it "a very new and positive avenue for future High Energy Physics activities both in Finland and on a greater scale".

There were significant new developments for LENA – the liquid scintillator option for the neutrino detector of the next generation. As a result of improved rock engineering the old value for the maximum span of the cavern at the depth of 1400 m was modified allowing alternative designs to the slim, tall tank that formed the basis of all previous design studies. The most exciting progress was accomplished in the event simulation and reconstruction. Our latest results indicate that a large scintillator performs surprisingly well also as a far detector for long baseline neutrino oscillation studies.

Our group has greatly benefited from a close collaboration with the Oulu Southern Institute, University of Oulu, and the Department of Physics, University of Helsinki, in the context of the LAGUNA project.

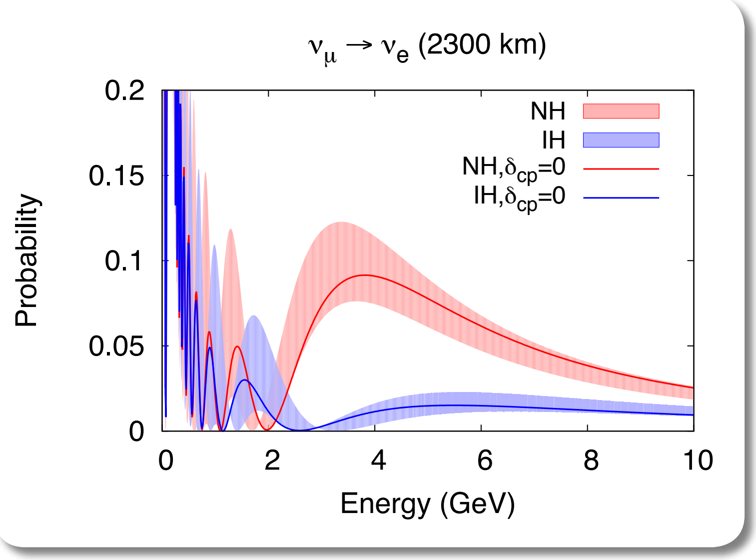


Fig 1. Electron neutrino appearance probability for Cern to Pyhäsalmi baseline with different mass hierarchies and CP-violation phases.

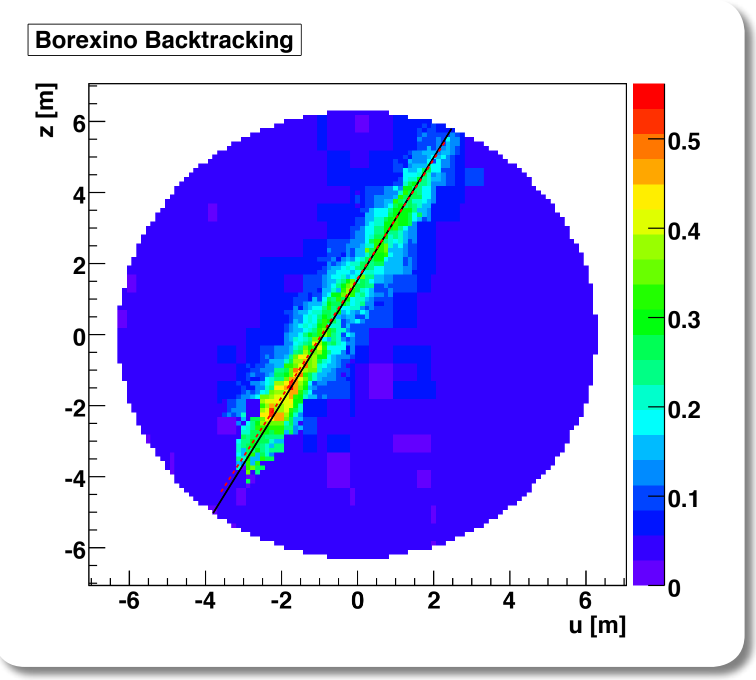


Fig 2. First stage of event reconstruction sequence in LSc detector constructs the probability distribution of origin of scintillation photons. Here method is applied to the muon event recorded by solar neutrino experiment BOREXINO.

Particle Physics beyond the Standard Model

Kimmo Tuominen

The remarkable discovery of a Higgs-like boson with mass around 125 GeV was announced by the experiments at CERN Large Hadron Collider (LHC) in July 2012. Further analyses are hoped to pinpoint the physics responsible for the electroweak symmetry breaking (EWSB) and to a possible theory beyond the Standard Model (BSM). For several years both EWSB and BSM have been our research focus, and several pioneering model studies have been carried out; these have now been augmented also with current LHC data. Our studies constitute an integral part of the activities of the Helsinki Institute of Physics project Laws of Nature and Condensed Matter Phenomenology at the LHC (project leader K. Tuominen). Additional funding sources include the Academy of Finland (SA), private foundations and EU.

Composite Higgs (i.e. Technicolor) and supersymmetric models remain as well motivated candidates for BSM physics. Within both classes (and also combining the two paradigms) we have built models, analysed their collider signatures, established possible dark matter (DM) candidates and studied the nonperturbative properties of Technicolor models on the lattice. In our studies of DM candidates we collaborate with K. Kainulainen's Cosmology group at JYFL and in lattice studies we collaborate with Prof. K. Rummukainen's group in Helsinki.

Our group has established an international leading role in using large scale lattice simulations to gain insight into nonperturbative conformal dynamics of strongly interacting SU(N) gauge theories. While our primary motivation is in the applications for BSM model building, our results are important for understanding the dynamics of strong interactions in general. The lattice calculations with Wilson fermions are subject to large discretization errors, so called lattice artifacts, but there exists a systematic way to diminish these errors by improving the fermion actions. During the past year we have optimized the improved Wilson fermion actions in SU(2) and SU(3) gauge theories with matter fields in the fundamental or higher representations, and our results can be now applied in large scale simulations to obtain reliable results on nonperturbative dynamics of these theories.

A complementary method to obtain nonperturbative information on strong interactions is the application of gauge/gravity correspondence, i.e. holography. During 2012 we studied thermodynamics of QCD in the Veneziano limit in a holographic model. The model incorporates the renormalization group running and chiral symmetry properties of the boundary theory into the gravity dual, and also describes the nonperturbative backreaction of the fermion flavors onto the gravity solution. Analyses within this model will be continued in order to establish a dual representing real QCD as closely as possible.

Department of Physics 2012

Cosmology

Kimmo Kainulainen

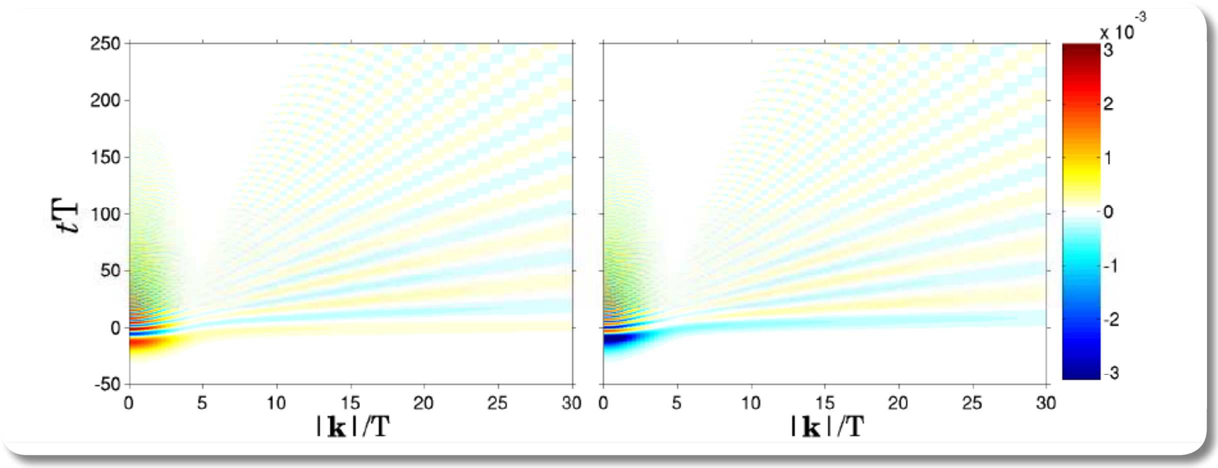
Kimmo Kainulainen, Lecturer
Pyry M. Rahkila, graduate student
Joni Pasanen, graduate student
Mikko Pääkkönen, graduate student
Joonas Ilmavirta, MSc
Henri Jukkala, MSc

The current Standard Cosmological Model is very simple and it succesfully explains almost all existing observational data. On the other hand, it contains several ingredients of unknown origin. We still do not know the nature or origin of the dark matter and the dark energy, which control the evolution of the universe at large scales, and we do not have particle physics models for inflation responsible for the initial density perturbations, nor for the dynamical mechanism that was responsible for the origin of the matter in the Universe.

In our group we have studied cosmological models with large nonlinear structures such as a local void of radius up to 1 Gpc. Our void model includes several non-comoving fluids with arbitrary equations of state, which makes them useful in studies of a large variety of cosmological and astrophysical problems. In particular we can test to which extent the dark energy could be mimicked by a large local void. We found that observational constraints on the dark energy equation of state strongly depend on the local matter density around the observer. For example, if we live at the center of an inhomogeneity with a density contrast of d=0.1–0.15, the dark energy is not a cosmological constant at 95% confidence level. We have also studied weak gravitational lensing and its impact on cosmological observables. We are extending our stochastic gravitational lensing (sGL) method to include a modeling of observational biases and adapting it for computation of weak lensing distortions to the angular power spectrum in the CMB as well as on analysis of the the angular distribution of quasar double images.

We are also continuing to study dark matter in minimal walking technicolor models. These models may provide a dynamical electroweak symmetry breaking and solve the hierarchy problem and provide a gauge coupling unification, consistently with all precision electroweak constraints. These models also predict a natural candidate for the DM in the universe. Making a comprehensive scan of the parameter space of the model has proven a challenging task, which we haven't quite completed yet. We do already know however, that there are interesting regions of parameters that can provide DM with a full consistency with all observational and laboratory constraints.

We extended our quantum transport formalism to the case of flavor mixing both for scalar and fermion fields. This relativistic out-of equlibrium transport theory includes both flavour- and particle-antiparticle coherences, it is derived from



the first principles of nonequilibrium quantum field theory and it is now complete with explicit propagators and Feynman rules for perturbative calculations. We are currently applying this formalism to the case of neutrino mixing and to compute baryon asymmetry arising from Leptogenesis with two heavy mixing Majorana neutrinos. With a new PhD student (HJ) we are beginning to apply these methods also to the case of Electroweak Baryogenesis. Indeed this formalism is the only known method capable of describing the EWBG in cases where the quantum reflection mechanism is playing an important role.

Fig. 1. Shown are the real (left) and imaginary (right) parts of the flavour-off-diagonal particle-antiparticle coherence correlator for positive helicity states obtained from cQPA analysis. The x-axis shows the absolute value of momentum |k| and the y-axis the time t from the phase transition, both in units of the ambient temperature T.

Electroweak baryoenesis can be already studied to a good accuracy in the limit of quasi-slowly varying background fields by use of a semiclassical method developed earlier in our group. We have used this approach to study the EWBG in inert singlet models whice extend the Higgs sector of the Minimal Standard Model (MSM) by an inert singlet scalar with a Z_2-symmetry. Extending MSM is necessary because EWBG is known not to work quantitatively in the MSM. The singlet model easily provides a strongly first order phase transition and a large enough baryon asymmetry, it is consistent with all laboratory data, and it may also provide an interesting subleading component for the dark matter. We are currently finishing a work in inert doublet models with similar conclusions.

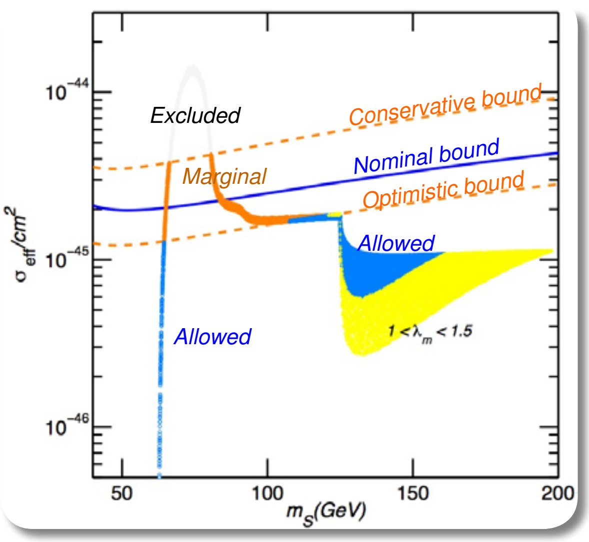


Fig. 2. Scatter plot of the expected cross section in the Xenon experiment against the mass of the DM particle. Solid blue ("nominal bound") line shows the nominal XENON100 bound and the dashed orange lines the more conservative (upper curve) and more optimistic (lower curve) bounds reflecting uncertainties due to local DM distribution. All models shown satisfy all laboratory and precision EW-constraints and provide the correct baryon asymmetry in the universe.

Department of Physics 2012

Industrial Collaboration

Markus Ahlskog, Markku Kataja, Ilari Maasilta, Timo Sajavaara, Jussi Timonen and Ari Virtanen

Again in 2012, the Industrial Applications group of the accelerator laboratory had numerous contacts with domestic and foreign industry and research laboratories. Thirty six irradiation campaigns for 12 international partners were performed at the RADEF facility. In addition to ESA also the institutes like German Aerospace Center (DLR), Institute of Computer and Network Engineering (IDA, Germany) and Sandia National Laboratories (NM, USA) visited the facility. The regular company collaborators, ATMEL, EADS ASTRIUM and Thales Alenia Space were again performing tests at RADEF. Also, the Interuniversity Microelectronics Centre, IMEC, from Belgium performed their first test at RADEF.

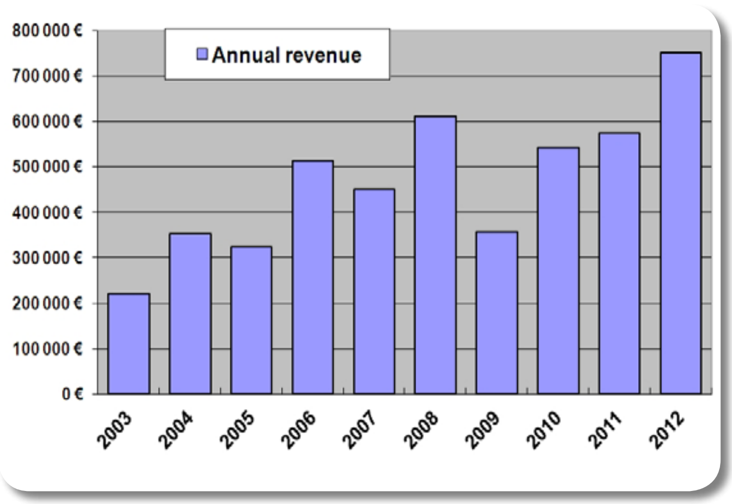
We continued the technical assessment project for ESA on "Effects of the ion species and energy on the oxide damage and SEGR failure". The objective of this study is to determine the worst-case conditions for SEGR testing and use the results in the next ESA's SEE test guidelines. This work has been approved to be continued in 2013 by ESA.

RADEF participates also in EU's FP7-Space-2010-1 project, where the aim is to develop RadHard non-volatile flash memories for space applications. The methodology focuses on environments affected by radiation due to electrons, protons and energetic heavy ions. The first heavy ion test of the project was performed in October at RADEF. Our standard high-penetration ion cocktail was used. The consortium consists of two companies and six universities from Italy, Israel, Cyprus, Spain, Sweden and Finland (www.skyflash.eu/). The total duration of the project is 30 months and the rest of the heavy ion irradiation tests are scheduled for 2013.

The irradiations of the polymer membranes for Oxyphen AG were also continued with two campaigns in the year 2012.

The total beam time used for these activities during the year 2012 was 1208 hours. Out of those 74% was used for space related tests, 16% for membrane irradiations and the rest of

Fig. 1. Annual revenue of industrial applications at the accelerator laboratory since 2003.



the beam time was used for EU projects, basic research and R&D work.

We also obtained a new record in annual revenue in 2012, i.e. 757 000 €. Figure 1 illustrates the development of commercial revenue during the last ten years. The cumulative total amount for this period is 4.7 M€.

The Accelerator Based Materials Physics group within the Accelerator Laboratory has had active industrial collaboration both with international and domestic companies in 2012. The interdisciplinary EU-FP7 project HIghLY- SENSitive low-cost lab-on-a-chip system for Lyme disease diagnosis (HILYSENS) continued in 2012 and the goal of this project is to develop a low-cost disposable biomedical test kit having all the analysis functions integrated into a microfluidics chip. The group is a research partner in a major TEKES project (MECHALD) in which the mechanical properties of atomic layer deposited films are studied within a consortium including groups from Aalto University and VTT. A TEKES/EAKR project HIUDAKE develops new detectors and digitized data acquisition for ion beam analysis, and as a result of this project a new high performance energy detector based on gas ionization has been taken into use. To develop further industrial collaboration a 1.3 M€ NANOPALVA-project was established between several groups within the department. This project is funded by EU through the Regional Council of Central Finland, University of Jyväskylä and local companies, and major part of the funding is directed to new infrastructure, which include an Atomic Layer Deposition tool, a 3D nanolithography tool and a new chamber for sensor testing in variable environments. The Pelletron accelerator and especially ion beam analysis was actively used in solving thin film and material related problems also in 2012.

The Experimental Nanophysics groups have well established collaboration with a few companies in Finland. In the past years, Department of Physics ultrasensitive superconducting radiation detectors for X-rays have been developed in collaboration with Oxford Instruments Analytical Oy, motivated by the need of on-chip integrable ultrasensitive sensors in space research. In 2012 a new TEKES funded project started, where our new ultrasensitive X-ray spectrometer setup developed in a previous TEKES project is going to be used for novel terrestrial materials science applications. In addition, commercial wafer scale superconducting detector fabrication is going to be developed in collaboration with the VTT Micronova micro- and nanofabrication center in Espoo. Our consortium included also Aivon Oy and Star Cryoelectronics Inc. from USA as industrial partners, in addition to a larger unit of Oxford Instruments, Oxford Instruments Nanotechnology Tools Ltd from UK. In addition, the molecular electronics and plasmonics group has a continued collaboration with companies Beneq Oy and Iamit.fi funded by Jyväskylä Innovation and and Suomen Luonnonvarain Tutkimussäätiö, to develop integrable solar energy collection. The Quantum Nanoelectronics group, on the other hand, is currently involved in the large TEKES project DEMAPP, which involves industrial collaboration with several companies such as Metso and Moventas. The technological activity supported by the project forms the basis of the MSc thesis of L. Leino.

The Soft Condensed Matter and Statistical Physics group continued its long-term collaboration with a number of Finnish and European companies in several long-term and short-term applied research projects.

The group runs an extensive x-ray tomographic laboratory that includes three x-ray scanners used in non-invasive three-dimensional imaging and analysis of the internal microstructure of a wide range of heterogeneous materials. The laboratory is also equipped with adequate sample preparation and manipulation devices, a versatile set of instruments for measuring transport properties in porous materials, and with an ultra fast camera system for imaging absorption and spreading properties of liquid droplets of down to picolitre size. All these devices were widely used in applied research with industrial partners, e.g. for the analysis of structural and transport properties of fibre based materials, ceramics and minerals. Experimental work was complemented with material modelling, and here basic research results of the group were taken in immediate practical use. The traditional close collaboration with VTT Technical Research Centre of Finland was continued, involving e.g. 3D structural analysis of various types of materials of industrial relevance.

Individual projects were related e.g. to development of novel bio-based materials, their barrier, strength, deformation, fracture, printing and optical transmission properties, and to the safety analysis of repositories of spent nuclear fuel. The group has a long tradition to develop ultrasound methods for the assessment and monitoring of bone quality, and for diagnosing osteoporosis, including related device development, possibly in collaboration with manufacturers. This work was successfully continued.

Industrial collaborators included Stora Enso, UPM-Kymmene, Metsä-Botnia, Posiva, Metso, Numerola, Paperra, Jyväskylä Innovation, Paroc, Borealis, Oscare Medical, CSC (IT Centre for Science Ltd), Institute for Surface Chemistry (YKI) and Innventia in Stockholm, and Glass and Ceramics in St. Petersburg. Through an EU FP7 project collaboration was also started with Allinea Software (UK), Cray UK Ltd, German Aerospace Centre, The Center for Information Services and High Performance Computing (Germany) and The European Centre for Medium-Range Weather Forecasts.

In addition to industry, funding to applied research was received from Finnish Program for Strategic Centres for Science, Technology and Innovation (SHOK), EAKR/Regional Council of Central Finland, Technology Development Centre of Finland and the Ministry of Employment and the Economy.

Department of Physics 2012

Education

Jukka Maalampi, Jussi Maunuksela and Juha Merikoski

Jukka Maalampi, professor
Jussi Maunuksela, university lecturer
Juha Merikoski, university lecturer
Pekka Koskinen, academy research fellow
Jussi Helaakoski, graduate student
Toni Purontaka, graduate student
Jussi Ahokas, MSc student
Jari Alftan, MSc student
Aaro Eloranta, MSc student
Matti Hakkarainen, MSc student
Konsta Hannula, MSc student
Heidi Ihaksinen, MSc student
Katri Leino, MSc student
Leena Leino, MSc student
Timo Leppänen, MSc student
Mikko Määttänen, MSc student
Esko Pohjoisaho, MSc student
Pauli Repo, MSc student
Aki Saarela, MSc student
Heli Siltanen, MSc student
Sini-Jatta Suonio, MSc student
Anna Vankka, MSc student

The year 2012 was for the Department the third year as one of the ten national High-quality Education Units, nominated by the Finnish Higher Education Evaluation Council under the Ministry of Education and Culture for the years 2010-2012. A key element behind the High-quality Education Unit status of the Department is the way frontline research done at the laboratories is connected with education. Another one is the interactive approach to education by promoting contacts and collaboration among students and between students and the personnel. This is the direction in which teaching at the Department has been further developed during the year.

From teaching to learning

The development of basic level courses has continued at the Department, with the emphasis shifting from teaching to learning. This development has now been extended to subject level teaching where interactive teaching methods have been adopted on quantum mechanics courses. On the first physics courses peer instruction utilizing clickers has become an established method to promote learning. Also development of new ways to organize the homework problem recitals has been continued and extended to several other courses. These developments have further activated the students resulting in considerably better learning outcomes. The new six compulsory courses on mathematical methods have found their place in the curriculum with promising results. Ex tempore exercise sessions with immediate feedback have been used on the courses of the first year. This in part means reduction of the amount of conventional lecture hours and increasing supervised small group work instead. Our next challenge is to

continue adopting interactive teaching methods on higher-level physics courses.

Teacher education

The trilateral co-operation between the Departments of the Faculty, the Department of teacher education and the Teacher training school has continued. Direct enrollment to teacher education, including the possiblity to register during the first weeks of studies, has established itself as the main route to teacher qualifications. The Department participates in the Finnish graduate school of mathematics, physics, and chemistry education, with two students working on a degree of doctor or licentiate of philosophy in physics education.

Other education activities

In addition to its regular teaching program, the Department has continued the co-operation with the Open University supplementary-education program. The Department arranged four courses in the 22nd Jyväskylä International Summer School.

Contacts with schools

To provide high-school students a hands-on experience on research work the Department offered, in summer 2012 for a fourth time, summer jobs for students interested in science. The newspaper advertisement produced about 75 applicants from 20 schools, of whom ten from different high schools were chosen to work in the research groups at the Department. The national training camp for Physics Olympics and training lectures for CERN visits of school students were also arranged at the Department.

The annual open-doors day for student recruitment was very successful, this time with a more attractive set of corridor demonstrations. As personal contacts have proven to be the most effective way of student recruitment, we have been reviving our visit program to schools and advertise the possibility for high-school classes to make visits in the Accelerator laboratory and the Nanoscience center. The contacts of the Departments of the Faculty with schools are being strengthened through the LUMA center of Central Finland, which was officially founded in January 2011.

Statistics

In spring 2012 there were 623 applicants for physics studies, with 381 of them indicating physics as their first choice. As a whole, 99 undergraduate students enrolled in autumn 2012. Additionally 12 undergraduate students enrolled in January 2013. Over 90% of the new BSc students are admitted based on their high school record and national matriculation exam result, the rest via a traditional entrance examination. The total number of undergraduate students is almost 520. Some students with a polytechnic engineering background study in the master programs for industrial physics and renewable energy. At the Department there are 85 post-graduate students aiming at the PhD degree. In 2012 the number of MSc degrees taken at the Department was 37, sixteen of them with teacher qualifications. The number of PhD degrees was 11.

PERSONNEL

HEAD OF THE DEPARTMENT

Jukka Maalampi, prof.

VICE-HEADS OF THE DEPARTMENT

Rauno Julin, prof.
Markku Kataja, prof.

PROFESSORS

Markus Ahlskog
Kari J. Eskola
Hannu Häkkinen
Ari Jokinen
Rauno Julin
Kimmo Kainulainen
Markku Kataja
Matti Leino
Jukka Maalampi
Ilari Maasilta
Matti Manninen, on leave 1.8.-
Jouni Suhonen
Jussi Timonen
Robert van Leeuwen
Harry J. Whitlow -14.4.
Juha Äystö, on leave 1.4.-

RESEARCH PROFESSORS

Jacek Dobaczewski (FidiPro award)
Paul Greenlees (ERC award)

UNIVERSITY LECTURERS

Konstantin Arutyunov
Sakari Juutinen
Hannu Koivisto
Markku Lehto
Kari Loberg
Jussi Maunuksela
Juha Merikoski
Iain Moore
Markko Myllys
Timo Sajavaara
Kimmo Tuominen

ACADEMY RESEARCH FELLOWS

Pekka Koskinen
Janne Pakarinen 1.9.-
Thorsten Renk
Esa Räsänen -31.8.
Jussi Toppari

PHD SCIENTISTS

Vesa Apaja
Rupa Chatterjee
Saumyadip Chaudhuri
Klaas Giesbertz -31.8.
Tuomas Grahn
Claudia Gomes da Rocha
Pauli Heikkinen
Arto Javanainen 1.9.-
Anu Kankainen
Pekka Kekäkäinen
Heikki Kettunen
DongJo Kim
Kimmo Kinnunen -30.11.
Veli Kolhinen
Markus Kortelainen
Topi Kähärä
Tuomas Lappi
Julen Larrucea -31.1.
Petro Moilanen
Astrid Morreale
Davie Mtsuko 1.6.-31.8.
Harri Niemi
Päivi Nieminen -31.3.
Heikki Penttilä
Janne Pakarinen -31.8.
Vaia Prassa 1.3.-
Tuomas Puurtinen
Panu Rahkila
Jan Rak (JYFL/HIP)
Redamy Perez-Ramos 1.10.-
Sami Rinta-Antila
Juho Rissanen.-30.4.
Valery Rubchenya
Michael Ruggenthaler -31.8.
Sami Räsänen(HIP/JYFL)
Hidenori Sakuma (HIP/JYFL)
Mikael Sandzelius
Jan Sarén
Catherine Scholey
Adrian Stan
Jouni Takalo
Tuomas Tallinen
Olli Tarvainen
Jussi Toivanen
Wladyslaw Trzaska
Juha Uusitalo
Ari Virtanen
Emanuel Ydrefors 1.7.-

MSC SCIENTISTS

Vesa Aho
Tommi Alanne
Timo Alho
Kalle Auranen
Jussi Auvinen -30.9.
Svitlana Baieva
Beomsu Chang (JYFL/HIP)
Axel Ekman
Ville Föhr -31.3.
Yan Gao
Zhuoran Geng
Dmitry Gorelov
Jani Hakala
Ilkka Helenius
Olli Herranen
Andrej Herzan
Matti Hokkanen
Markku Hyrkäs
Tommi Isoniemi
Tero Isotalo

Ulrika Jakobsson
Arto Javanainen -31.8.
Henri Jukkala
Jaakko Julin
Juhani Julin
Antti Juutilainen -
Janne Kalikka
Tuomo Kalliokoski
Taneli Kalvas
Tuomas Karavirta
Janne Kauttonen
Vantte Kilappa
Oleg Kit
Rudolf Klemetti
Jani Komppula
Joonas Konki
Jukka Koponen
Mikko Koponen -31.8.
Ville Kotimäki
Jiri Kral (JYFL/HIP)
Jukka Kuva
Mikko Laitinen
Janne Lehtinen
Roope Lehto
Jarkko Lievonen -29.2.
Kai Loo
Perttu Luukko
Arttu Miettinen
Lasse Miettinen - 30.6.
Davie Mtsuko -31.5
Petri Myöhänen -31.7.
Ville Mäkinen
Heikki Mäntysaari
Laura Mättö
Mari Napari
Minna Nevala -31.5.
Janne Nevalaita
Rattanaporn Norarat
Norbert Novitzky (HIP/JYFL)
Risto Paatelainen
Mikko Palosaari
Jari Partanen 1.9.–
Joni Pasanen (HIP/JYFL)
Antti Pennanen
Pauli Peura
Ilkka Pohjalainen
Esko Pohjoisaho (HIP/JYFL) 1.12.-
Antti Putaja
Mikko Pääkkönen
Pyry Rahkila (HIP/JYFL)
Francesco Raimondi -31.3.
Mikael Reponen
Timo Riikilä 1.12.-
Panu Ruotsalainen
Antti Saastamoinen -31.3.
Ananda Sagari A.R. -31.3.
Boxuen Shen 1.7.-
Volker Sonnenschein
Juha Sorri
Sanna Stolze
Niko Säkkinen
Kosti Tapio 1.9.-
Yolan Tian
Ville Toivanen
Andrii Torgovkin 1.10.-
Riku Tuovinen
Tuomas Turpeinen
Anna-Maija Uimonen
Jussi Viinikainen -
Mikko Voutilainen -
Markku Väisänen
Emanuel Ydrefors -30.6.
Lingfei Yu -
Peerapong Yotprayoonsak

MSc students are listed in research reports.

LABORATORY ENGINEERS

Jarno Alaraudanjoki
Väinö Hänninen
Jukka Jaatinen
Kimmo Kinnunen 1.12.-
Jaana Kumpulainen
Arto Lassila
Antti Nuottajärvi -31.7.
Joni Parkkonen
Einari Periainen
Aki Puurunen -29.2.
Kimmo Ranttila
Tarmo Suppula
Juha Tuunanen 2.2.-
Juha Ärje

OPERATORS

Jani Hyvönen
Anssi Ikonen
Mikko Rossi

OTHER TECHNICIAL STAFF

Martti Hytönen
Atte Kauppinen
Juha Kulmala
Esa Liimatainen
Markus Liimatainen
Jukka Paatola 30.1.-
Tuomas Pietikäinen
Hannu Pohjanheimo
Kai Porras
Marko Puskala
Raimo Seppälä
Markku Särkkä

ADMINISTRATION

Anna-Liisa Blå
Minttu Haapaniemi 12.11.-
Marjut Hilska
Nina Kaari
Soili Leskinen
Ritva Väyrynen -30.6.

PEER REVIEWED ARTICLES

ACCELERATOR FACILITIES

V. Skalyga, I. Izotov, A. Sidorov, S. Razin, V. Zorin, O. Tarvainen, H. Koivisto and T. Kalvas
High current proton source based on ECR discharge sustained by 37.5 GHz gyrotron radiation
JINST 7 (2012) P10010

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Nucl. Instr. and Meth. B 276 (2012) 33

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Plasma instability in the afterglow of ECR discharge sustained in a mirror trap
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Prospects for advanced electron cyclotron resonance and electron beam ion source charge breeding methods for EURISOL
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B. X. Han, T. Kalvas, O. Tarvainen, R. F. Welton, S.N. Murray, T. R. Pennisi, M. Santana and M. P. Stockli
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Towards the island of stability with relativistic energy density functionals
AIP Conf. Proc. 1491 (2012) 238

N. Schunck, J. Dobaczewski, J. McDonnell, W. Satuła, J. A. Sheikh, A. Staszczak, M. Stoitsov and P. Toivanen
Solution of the Skyrme-Hartree-Fock-Bogolyubov equations in the Cartesian deformed harmonic-oscillator basis. (VII) HFODD (v2.49t): a new version of the program
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THESES AND DEGREES

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Jussi Ahokas, *Kestävä kehitys lukion opetussuunnitelmassa ja oppikirjoissa*

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JYFL Laboratory Report 2/2012

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DEGREES

BSc DEGREES
(main subject is physics)

Aho, Kaisa
Ahokas, Jussi
Alftan, Jari
Hakkarainen, Matti
Hallikainen, Pertti
Hovila, Hannu
Hämäläinen, Joni
Hämäläinen, Joonas
Hänninen, Juho
Isojärvi, Teemu
Kakko, Miika
Kemppainen, Jussi
Kervinen, Mikko
Korhonen, Topi
Lehtinen, Antti
Leino, Katri
Leino, Leena
Määttänen, Mikko

Ojala, Mikko-Ilari
Parttimaa, Jarno
Parviainen, Teemu
Pekkala, Ilkka
Pikkarainen, Toni
Saikko, Juuso
Soininen, Joonas
Solanpää, Janne
Suonio, Sini-Jatta
Tervo, Teemu
Vaskonen, Ville
Yliselä, Eero

MSc DEGREES
(main subject)
*=MSc includes teacher's pedagogical studies

Ahokas, Jussi (physics)*
Alftan, Jari (physics)*
Eloranta, Aaro (physics)*
Filippovych, Kateryna (physics)
Hakala, Petri (physics)
Hakkarainen, Matti (physics)*
Hannula, Konsta (physics)*
Harjupatana, Tero (appl. physics)
Ihaksinen, Heidi (physics)*
Ilmavirta, Joonas (theor. physics)
Jukkala, Henri (theor. physics)
Kakko, Miika (appl. physics)
Kervinen, Mikko (theor. physics)
Korhonen, Topi (theor. physics)
Leino, Katri (physics)*
Leino, Leena (physics)*
Leppänen, Timo (physics)*
Määttänen, Mikko (physics)*
Nykänen, Anne (appl. physics)
Partanen, Jari (physics)
Pirhonen, Matti (appl. physics)
Pohjoisaho, Esko (physics)*
Repo, Pauli (physics)*
Riikilä, Timo (physics)
Rojas Rojas, Laura (physics)
Ruonala, Verneri (physics)
Saarela, Aki (physics)*
Shen, Boxuan (physics)
Siltanen, Heli (physics)*
Suonio, Sini-Jatta (physics)*
Tapio, Kosti (physics)
Toikka, Tauno (physics)
Torgovkin, Andrii (physics)
Vainio, Laura (physics)
Valve, Assi (physics)
Vankka, Anna (physics)*
Viinikainen, Jussi (theor. physics)

Phil.Lic. DEGREES
Koponen, Mikko (physics)
Kärnä, Aarno (appl. physics)

PhD DEGREES
Auvinen, Jussi (theor. physics)
Föhr, Ville (physics)
Javanainen, Arto (physics)
Kauttonen, Janne (physics)
Mtsuko, Davie (physics)
Myöhänen, Petri (physics)
Nevala, Minna (physics)
Oksanen, Antti (appl. physics)
Reponen, Mikael (physics)
Voutilainen, Mikko (physics)
Ydrefors, Emanuel (theor. physics)

JYFL
DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

P.O. Box 35
FI-40014 UNIVERSITY OF JYVÄSKYLÄ
FINLAND

Tel: +358 40 805 4356
Fax: +358 14 617 411
http://www.jyu.fi/physics

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