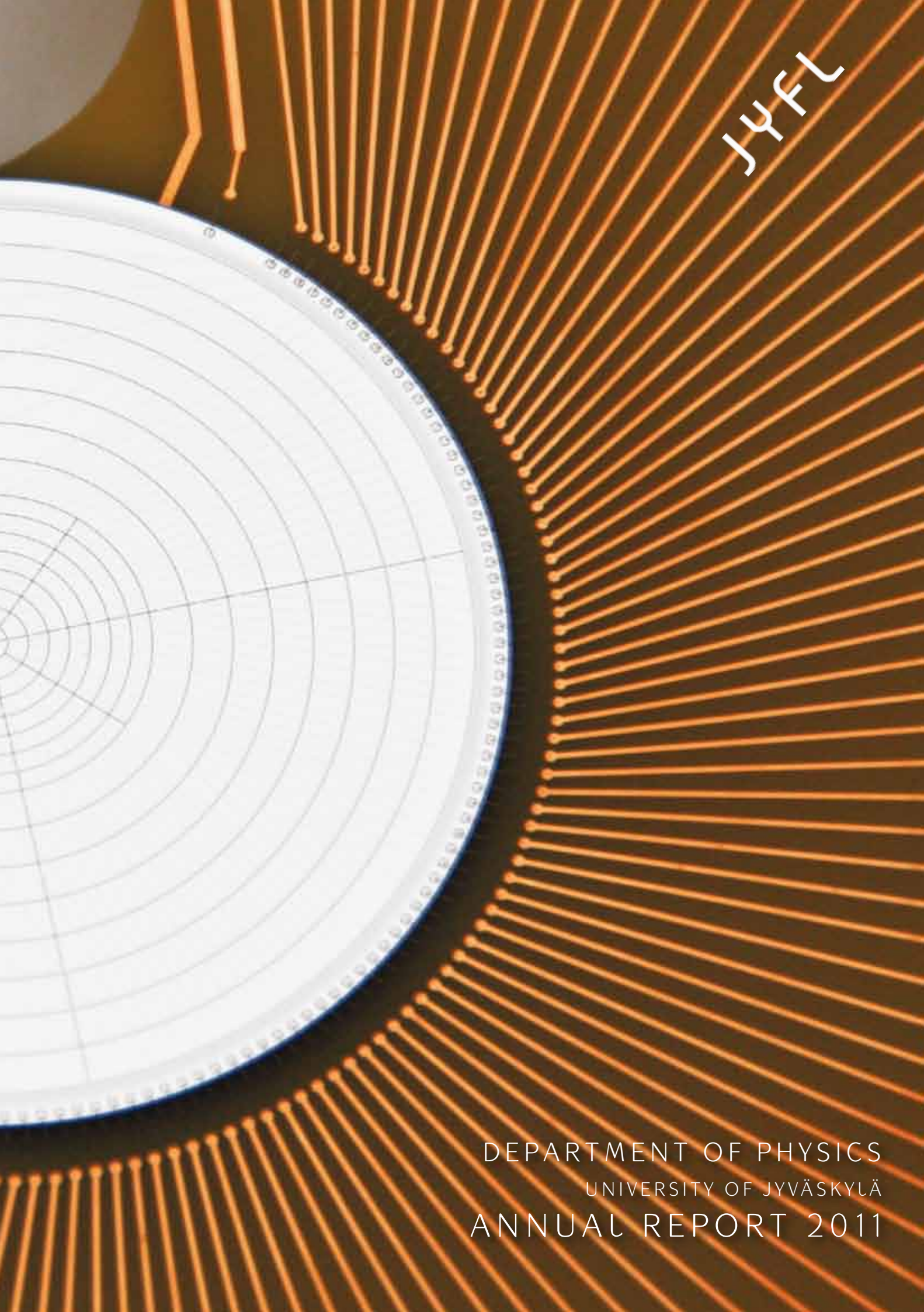

JYFL

DEPARTMENT OF PHYSICS

UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT 2011

Photo Mikko Palosaari

JYFL

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ANNUAL REPORT 2011

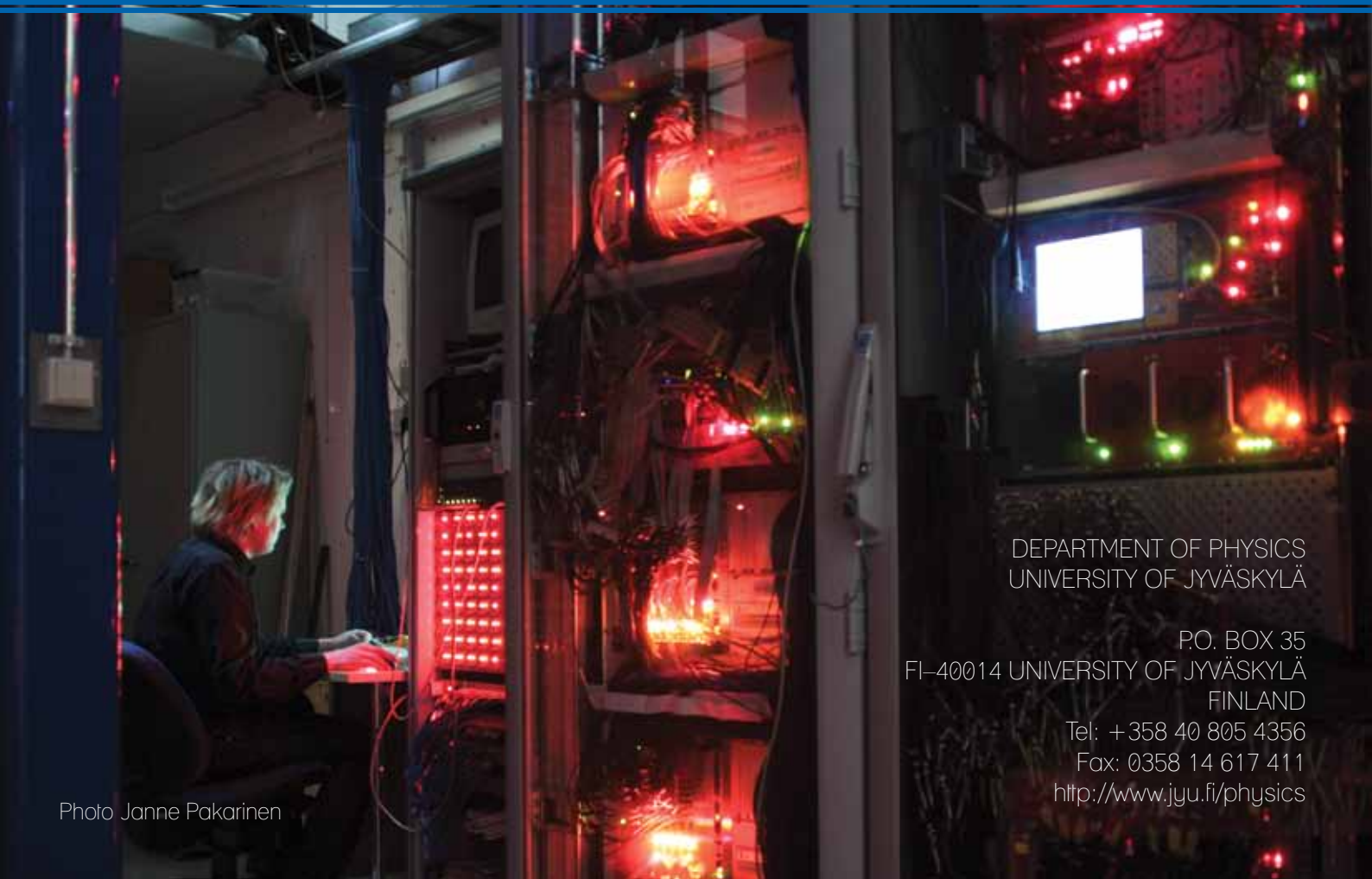

Photo Janne Pakarinen

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JYFL

DEPARTMENT OF PHYSICS UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT 2011

Graphic design Juho Jäppinen
Photo Mikko Palosaari

Contents

Department of Physics

Jukka Maalampi, Head of the Department

Preface

The research and teaching carried out in the Department in 2011 is described in this annual report. Statistical information about the Department and its activities are also given, and noteworthy events that took place during the year are recalled.

Research

In terms of publications the Department maintained the level attained in recent years, with about 200 peer-reviewed original articles in international journals. The publication activity has been good in all three of the main research areas, nuclear and accelerator-based physics (94 publications), materials physics (53), and particle physics (51). In the research evaluation of our University, carried out in 2011, the international panel presented a very positive assessment of our research achievements of the years 2006–2010. Nordforsk, a Nordic organization promoting research and research collaboration, published a citation analysis in 2011, which concerns science publications from 2004–2008 in the Nordic countries. The scientific impact of our research was found to be very high in this analysis. The common score of physics and mathematics research exceeded the world average by 43 % and was found to be the highest of all sciences in Finland and among the highest in all the Nordic countries. Our share of highly cited (top 10 %) physics and

Photo Juho Jäppinen

mathematics publications was overwhelmingly the highest in Finland.

The Center of Excellence in Nuclear and Accelerator-based Physics started a new six-year period in 2012. The implementation of the new MCC30/15 cyclotron and extended experimental hall has continued and will soon be completed allowing the research program to begin. Plans to use the new accelerator for production of radioactive tracers for positron emission tomography (PET) have been developed, which could have significant socio-economic impact.

The Helsinki Institute of Physics (HIP), which our University operates together with four other universities, is the most important partner for our Department in the field of subatomic physics. Finnish participation in the ALICE heavy-ion collision experiment at CERN is a fine example of the fruitful collaboration between the two institutions. HIP coordinates Finnish activity in the FAIR facility in Darmstadt, Germany, which will form an important part of our nuclear physics research in the future. In theoretical particle physics and cosmology, HIP has an important role in offering a framework for active cooperation between the research groups in Helsinki and Jyväskylä that work in these fields.

Teaching

Our Department holds the status of a Center of Excellence in University Education. The status is recognition for the efforts we have made in developing teaching and learning, but it also obliges us to pay constant attention to the quality of our results in education. A major theme in our development of teaching in the forthcoming years will be a gradual move from traditional lecturing to interactive teaching methods. Pekka Koskinen, along with some other teachers from our younger generation, has done valuable pioneering work in this direction. With respect to the teaching atmosphere and assessment of the grades obtained, the results are quite encouraging. Many new research results and ideas concerning the education of physics were presented in the international GIREP-EPEC 2011 conference, which our Department was honoured to host and organize together with the Department of Teacher Education.

In the number of doctoral degrees, the total of 14 exceeded the official goal (13) by one graduation. The trend has been positive for a long time, the three-year average having increased from 9 in 2005 to 13 in 2011. The number of MSc degrees in 2011 was 39. In contrast with doctoral degrees, the long-term trend has here

been slightly negative. This development has not been intentional but it is in accord with the objectives of the state educational authorities to slightly decrease education in our field. The employment uptake of students who have graduated from the Department bears witness to the good quality and relevance for labour market of the instruction we provide, being close to the one-hundred percent level.

Personnel

In 2011, the total number of people working in the Department was 190, practically the same as in the previous year.

In 2011, after an international call, two new professors where nominated, Ari Jokinen as a professor of nuclear physics and Kimmo Kainulainen as a professor of theoretical particle physics and cosmology. These nominations started a substantial - and also a welcomed – renewal of our professoriate that will be witnessed in the forthcoming years as a consequence of many retirements. In 2012 other important changes will also happen in the Department's professoriate. Professor Matti Manninen will start as the rector of the University in June. We all are very proud of Matti's selection for this eminent position, and we wish him all success in the important and challenging job ahead. Similarly, we wish success to professor Juha Äystö in the prominent position of the director of the Helsinki Institute of Physics, in which he will start in April.

The Department strengthened its technical resources by employing new personnel to work in the Department's workshops and to help the experimental groups in the accelerator laboratory in assembling and maintaining the research equipment. The aim of this is to lighten the workload of graduate students many of who have used a significant part of their time in technical work that has not been directly connected with their own thesis work. One of the most long-standing members of our technical personnel Veikko Nieminen retired in 2011 after 30 years of devoted service.

The administrative personnel of the Department is also on the threshold of a new era as its key members are approaching retirement. The change started smoothly in 2011 when Nina Kaari was employed to succeed Ritva Väyrynen as a departmental secretary. Ritva moved to well-earned retirement in February 2012 after 36 years of dedicated and highly valued service.

At the end of the year, we heard the sad news of the death of emeritus professor of theoretical physics Vesa Ruuskanen. Over many decades, Vesa had a great influence on the development of the Department, both in research and teaching, and to the Department's unique spirit.

Administration

Financially the year turned out to be less successful than the previous year when measured in terms of returns as we moved from a substantial surplus in 2010 to a minor deficit in 2011 when both the budget and outside funding were taken into account. The total funding of the Department in 2011 was 15.9 M€, about 7 % more than in the previous year. The growth is all due to external funding, which increased from 5.7 M€ to 6.9 M€. The proportion of external funding in 2011 was 43 %, compared to 37 % in 2010. The Academy of Finland was our most important source of outside funding in 2011.

Some statistical data from 2011

Personnel	190
- professors incl. research professors	16
- university lecturers and researchers	35
-postdoctoral researchers	25
- MSc researchers (incl. graduate students)	87
- technicians	23
- administration	4
+ several research assistants (MSc students)	
Undergraduate students	540
of which new students	105
Graduate students	84
BSc degrees	35
MSc degrees	39
PhLic degrees	1
PhD degrees	14
Credits (all)	15167
Median time to complete MSc (years)	6,0
Number of foreign visitors	~240
- in visits	~330
Visits abroad	~320
Peer reviewed publications	~200
Conference proceedings	~70
Others (articles in books etc.)	~20
Conference and workshop contributions	
- Invited talks	~150
- Other talks	~95
- Posters	~75
Funding (million €)	15,9
* University budget (incl. premises)	9,0
* External funding	6,9
- Academy of Finland	3,3
- EAKR	0,1
- Technology Development Centre, T&E Centres	0,2
- International programmes	0,7
- HIP	0,6
- Contract research	1,4
- Others	0,6

Events

The Department organized a great number of international conferences, workshops and schools during 2011. In addition to the GIREP-EPEC conference mentioned above, the following quite impressive list of events can be presented:

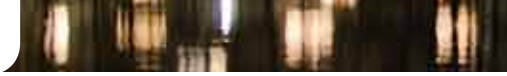
In particle physics, the Department hosted the Annual ALICE Week in September where scientists of the ALICE collaboration gathered to discuss the physics emerging from the data collected in heavy ion and proton collisions at the LHC collider at CERN.

Neutrino detection technology based on particle tracking in liquid argon was discussed in the GLA2011 workshop organized in the Department in June. Liquid argon is one of the detection technologies proposed for the LAGUNA neutrino observatory, which is now in a design study phase. The Pyhäsalmi mine, some 160 km north of Jyväskylä, is a strong candidate to be the host site of the observatory.

An international group of cosmologists were gathered in August to discuss inhomogeneous cosmologies, the question of whether inhomogeneity could solve the conundrum of dark energy in the Universe and how the large-scale structures affect observations.

Physicists and chemists working in the field of nanoscience gathered in August to discuss the recent developments, current challenges and future perspectives in experimental and theoretical research of monolayer-protected nanoclusters.

The production and use of energetic radioactive beams is a rapidly developing new field in nuclear physics, especially in Europe. The Euroschool on Exotic Beams brought students and young postdocs of 20 different nationalities to Jyväskylä in August to receive instruction on many topics related to this field.



Centre of Excellence in Nuclear and Accelerator Based Physics

Rauno Julin

The year 2011 was the last one of the six year period of the present Finnish Centre of Excellence (CoE) in Nuclear and Accelerator Based Physics. According to the report of its Scientific Advisory Board, the research produced by the CoE was outstanding, with a number of spectacular discoveries. During the CoE period JYFL has strengthened its leadership position in the worldwide nuclear physics community and built strong foundations for the future programmes.

The success was endorced by the approval of the proposal for a renewed CoE in Nuclear and Accelerator-Based Physics 2012–2017 by the Academy of Finland. In total, proposals from nearly 140 Finnish research units were submitted, from which 15 were finally awarded the CoE status. This status is extremely important for JYFL as it will provide stability in funding of both the experimental and theoretical nuclear physics programmes at JYFL.

The first beams from the new MCC30/15 have been delivered and the new IGISOL4 site will soon be ready for experiments. In spite of the reconstruction work, the number of beam time hours at the K130 cyclotron, used by the CoE teams for experiments of basic research and industrial applications summed up to 5946 hours during 2011. Among them were 13 experiments supported by the EU-FP7-IA-ENSAR project. A highlight was the first observation excited states of the Z = 104 nucleus ^{256}Rf. It is the heaviest nucleus so far probed via in-beam gamma-ray spectroscopy. In addition, many experiments and developments at the Pelletron accelerator were carried out.

In total, 36 proposals for experiments were evaluated by the Programme Advisory Committee (PAC) of the JYFL Accelerator Laboratory in the meetings on the 15th April and 14th October, 2011.

The JYFL-CoE activities at CERN, including ISOLDE and ALICE, as well as the FAIR project in Darmstadt form the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP). ALICE runs at the LHC have already resulted in interesting physics. Heavy neutron-deficient radioactive beams available at ISOLDE have been used in Coulomb excitation experiments led by JYFL researchers.

The year 2011 was also the last one of the very successful FiDiPro project led by Jacek Dobaczewski. The European nuclear physics community has been fascinated by this project and recommended it as a flagship model to be followed by other Large Scale Facilities for integration of nuclear theory with experiments. An extension of the project by one year has been funded by the Academy of Finland. Also, a proposal for a renewed FiDiPro project has been submitted.

Left: Ari Jokinen, the new professor in nuclear physics

Right: Director of the Accelerator Laboratory Applications Activities, Ari Virtanen, after the Academic Entrepreneurship Competition.

Ari Jokinen, the co-leader of the IGISOL and JYFLTRAP groups, was appointed as a full professor. Ari has been involved in several international activities in the field and is currently the Finnish representative in NuPECC. He is also the vice director of the new CoE in Nuclear and Accelerator Based Physics.

First prize was awarded to the commercial activities of the JYFL Accelerator Laboratory, which was the representative project for the University of Jyväskylä, in the 2011 Academic Entrepreneurship Competition for Finnish Universities. The competition was organized by the Finland Chamber of Commerce, Confederation of Finnish Industries and Federation of Finnish Enterprises.

The 18th Euroschool on Exotic Beams was organized at JYFL on 20th–26th August. Altogether 53 students representing 20 nationalities and some local researchers followed excellent lectures on different nuclear physics related topics.

SCIENTIFIC ADVISORY BOARD OF THE CENTRE OF EXCELLENCE IN NUCLEAR AND ACCELERATOR BASED PHYSICS
Witold Nazarewicz, professor, University of Tennessee, USA
William Gelletly, professor, University of Surrey, UK
Jaana Bamford, 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
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Lorenzo Corradi, INFN-LNL, Legnaro, Italy
Günther Dollinger, Universität der Bundeswehr München, Germany
Thomas Duguet, DSM/IRFU/SPhN, France
Sean Freeman, University of Manchester, UK
Mark Huyse, Katholieke Universiteit Leuven, Belgium.

Finland Distinguished Professor – FIDIPRO – Programme

Jacek Dobaczewski

In 2011, the FIDIPRO project has reached its final year and now it is being continued based on funds of a one-year grant awarded in 2011 by the Academy of Finland. The FIDIPRO team comprised on average six researchers working together on common project goals. All detailed information on the FIDIPRO project, and on its achievements and publications, is available on the project web page at http://www.jyu.fi/accelerator/fidipro/

In 2011, the main focus of the project was on studying higher-order energy density functionals (EDFs) in nuclear self-consistent theory, which has become the subject of Francesco Raimondi's thesis, defended on December 14, 2011. We

Jacek Dobaczewski, research professor
Jussi Toivanen, university researcher
Nicolas Michel, university researcher – 10.9
Markus Kortelainen, postdoctoral researcher 1.11.–
Petr Veselý, postdoctoral researcher – 6.9
Francesco Raimondi, graduate student
Yuan Gao, graduate student 21.11–
Pekka Toivanen, graduate student
Yue Shi, visiting graduate student 22.9 – 21.12

The FIDIPRO team on January 10, 2012. Standing, from left: Markus Kortelainen, Jacek Dobaczewski, Seated, from left: Francesco Raimondi, Jussi Toivanen, Yuan Gao.

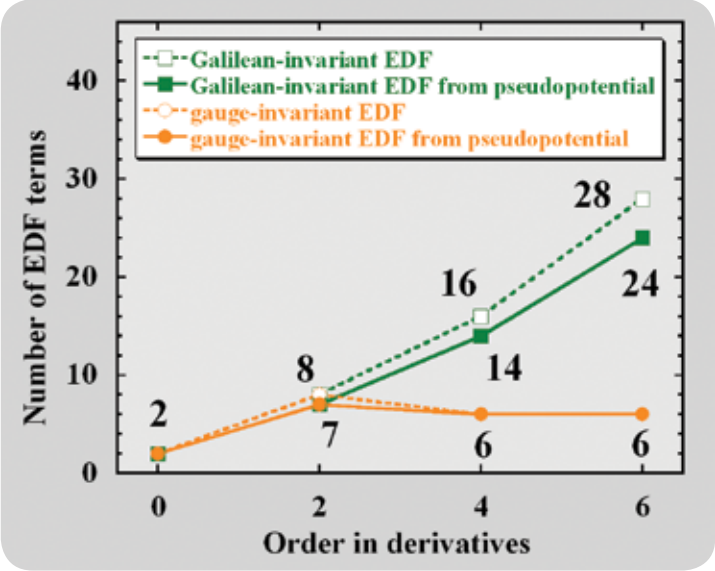


Fig. 1. Number of terms of the spherical EDF that is related to pseudopotential (solid lines). Full squares and circles show results for the Galilean and gauge invariance, respectively. For reference, dashed lines with open squares and circles show the corresponding results for the general spherical EDF.

have also performed first fully microscopic calculations of the isospin-breaking corrections to superallowed beta decays.

Pseudopotential and continuity equation for EDFs with higher-order derivatives

We derived a zero-range pseudopotential that includes all possible terms up to sixth order in derivatives, that is, up to next-to-next-to-next-to-leading order (N^3LO). Within the Hartree-Fock approximation, it gives the average energy that corresponds to a quasilocal nuclear EDF built of derivatives of the one-body density matrix up to N^3LO. The direct reference of the EDF to the pseudopotential acts as a constraint that, in the general case, divides the number of independent coupling constants of the EDF by two. This allows, e.g., for expressing the isovector part of the functional in terms of the isoscalar part, or vice versa. We also derived the analogous set of constraints for the coupling constants of the EDF that is restricted by spherical, space-inversion, and time-reversal symmetries, see

Our work generalized the standard Skyrme force up to sixth order and allowed us to make a link with the general N^3LO EDF. The complete higher-order EDFs or pseudopotentials have never yet been applied in practical calculations. Work toward this goal is now in progress, with basic derivations like the ones in the present work coming first, the construction of numerical codes coming next, and the full adjustments of coupling constants that will follow. In this respect, at present, we are in a similar phase of studies to that before the chiral N^3LO potentials for two-nucleon systems were adjusted and after the tools for calculating the corresponding N^3LO diagrams were developed

A rigorous power counting scheme, analogous to what has been introduced in the chiral perturbation theory, would have to use derivatives of regularized zero-range interactions. Such regularization would provide a proper cut-off scale, against which the powers of derivatives could be estimated. A good model of the regularized delta force is the Gaussian interaction, which, however, leads (through the exchange term) to nonlocal functionals. Within the EDF methodology, an effective theory based on derivatives of a finite-range force is, in principle, possible, but has not yet been tried because of the degree of numerical complications involved. Nevertheless, we may attempt taking this avenue of research in our future investigations.

We also determined to what extent the presence of higher-order derivatives in the functional can be compatible with the continuity equation. In particular, we studied the relations between the validity of the continuity equation and the invariance of the functional under gauge

transformations. We obtained four sets of constraints on the coupling constants of the N^{3}LO EDF that guarantee the validity of the continuity equation in all spin-isospin channels. In particular, for the scalar-isoscalar channel, the constraints are the same as those resulting from imposing the standard U(1) local-gauge-invariance conditions. For vector and isovector channels, such validity requires the invariance of the functional under local rotations in the spin and isospin spaces.

Microscopic calculations of isospin-breaking corrections to superallowed beta decay

Nuclear structure effects through isospin-breaking corrections affect the superallowed beta-decay rates that provide stringent constraints on physics beyond the standard model of particle physics. In our work, we used for the first time the self-consistent isospin- and angular-momentum-projected nuclear density functional theory to compute those corrections for a number of Fermi transitions in nuclei from A = 10 to A = 74. The resulting leading element of the Cabibbo-Kobayashi-Maskawa matrix, $|V_{ud}|$ = 0:97447(23), agrees well with the recent result of Towner and Hardy.

While our value of $|V_{ud}|$ is consistent with both Towner and Hardy and neutron-decay results, a question arises about its confidence level, especially in light of poor spectroscopic properties of the Skyrme force SV, which we must have used in our calculations. To check this, we carried out the confidence-level (C.L.) test including uncertainties on experimental values. The test is based on the assumption that the

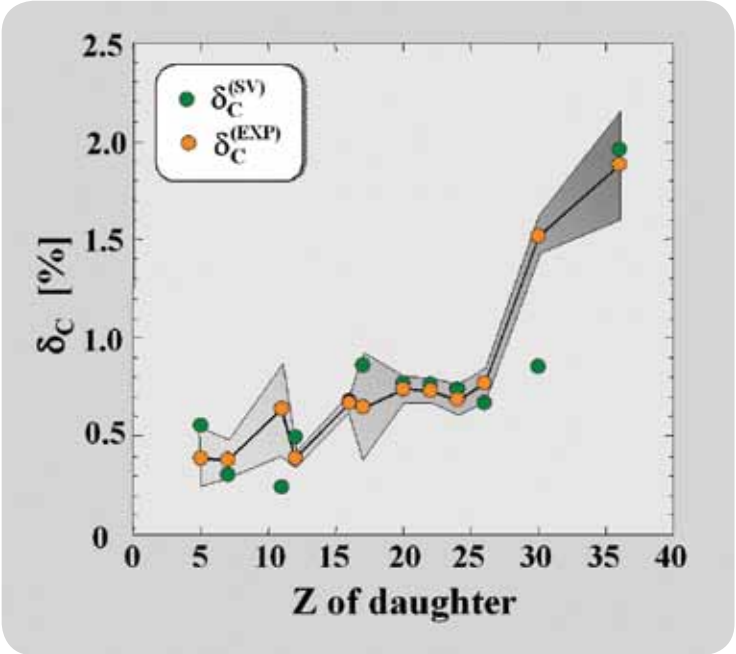


Fig. 2. Calculated (green dots) and empirical (orange dots) values of the isospin-breaking correction δ_C (in percent) in function of the proton number in the daughter nuclei. Shaded band illustrates the values of experimental error bars.

conserved vector current hypothesis is valid to at least ±0.03% precision, implying that a set of structure-dependent corrections should produce a statistically consistent set of Ft values. The C.L. can be assessed by minimizing the root-mean-square deviation between predicted and empirical values of δ_C with respect to values of reduced Ft. The final result corresponding to Ft=3070.0 s is shown in Fig. 2. Our value of reduced χ^2 per degree of freedom is 5.2. This is considerably higher than the values reported for the Damgaard model (1.7), SM with Woods-Saxon radial wave functions (0.4), SM with Hartree-Fock radial wave functions (2.2), and the relativistic Hartree plus RPA model (2.1). The low C.L. of our model results primarily from the single point at Z = 31, see Fig. 2.

Accelerator Facilities

Pauli Heikkinen and Hannu Koivisto

The year 2011 in K130 cyclotron operations had some longer breaks in January and July for beam line magnet installations and for cyclotron testing. This was the first year since 1995 when we did not reach 6000 hours/year but 5946 hours with 4486 hours on target. The largest share of the beam time was for JUROGAM experiments (45 %) where the two main beams were ^{48}Ca (10.5 %) and ^{50}Ti (9.1 %). Industrial applications used 28 % of the beam time using mostly beam cocktails. Altogether over 20 different isotopes were accelerated in 2011.

The MCC30/15 cyclotron will deliver proton and deuteron beams for IGISOL-4 and for isotope production but it was not used for experiments in 2011 since the IGISOL-4 installations were not finished. However, we made short beam tests to get a beam to the IGISOL target position both from the K130 cyclotron (200 MeV ^{40}Ar) and from the MCC30/15 cyclotron (30 MeV p). The construction of the isotope production site will start during 2012.

The ion source group has done several experiments during 2011 in order to develop titanium ion beams. As an example, more than 20 μA of Ti^{11+} ion beam was obtained with the sputter technique and the JYFL 14 GHz ECRIS. However, excessive heating of the sputter sample damaged one of the sextupole magnets. This strongly affected the performance of the ion source, and the damaged plasma chamber

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

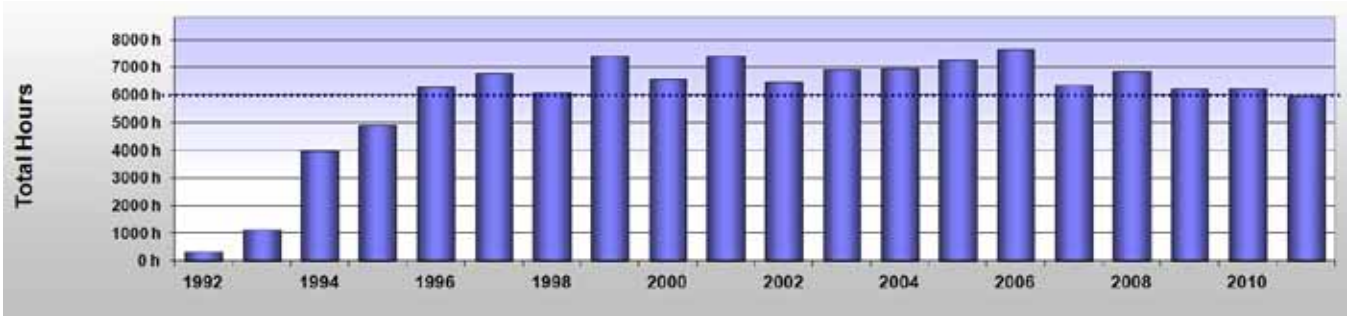


Fig. 1. Operation of the Jyväskylä K130 cyclotron in 1992 – 2011.

was replaced by a spare unit. A new plasma chamber with a stronger multipole field was immediately constructed in order to secure and guarantee the cyclotron operation. The cooling of the permanent magnets will be improved in order to further develop the sputter technique. In addition to the sputter development, the Strasbourg research group succeeded in synthesizing a titanium compound needed for the production of titanium ion beams with the MIVOC method. As a result, an intensive (≈ 20 μA) $^{50}Ti^{10+}$ ion beam was produced for a nuclear physics experiment.

Experiments targeting the space charge compensation and its effects on ion beam quality in the ECRIS beam line were continued. A positively biased grid was installed and tested in the beam line, both upstream and downstream from the analyzing magnet, in order to probe the space charge compensation degree. The experiment showed that even a small disturbance in the density of compensating electrons between the ion source and the analyzing magnet results in severe deterioration of the beam properties. Downstream from the analysing magnet the effect was negligible.

Comprehensive collar structure experiments with the 14 GHz ECRIS plasma electrode were carried out in 2011. Different geometries and materials were studied in order to understand the effect of the technique on the beam properties. According to the preliminary analysis, the collar seems to give a positive effect on the beam intensity and the beam emittance.

The experimental setup for the VUV-measurements was completed and new information about the plasma of different H^- -ion sources was obtained (CERN sLHC-plasma generator, LIISA filament ion source, 2.45 GHz microwave ion source). The next objective is to define the absolute VUV power emitted by hydrogen plasmas in different types of ion sources.

The plasma breakdown process of the JYFL 14 GHz ECRIS was studied in collaboration with the ion source group of Institute of Applied Physics, Russian Academy of Sciences. New information about the time evolution and energy distribution of electrons was obtained. The results can be used for validation of theories and simulations predicting and explaining the behavior of highly charged plasmas.

A project for developing an RF-driven negative ion source (H^-/D^-) for the new MCC30/15 cyclotron was initiated in the fall of 2011. The motivation for the project is to extend the time between services of H- ion sources at JYFL. The RF-system and the power supplies were assembled on the stand of LIISA ion source and the first RF-driven plasma was ignited in the beginning of 2012.

A low power, small size electron gun based on field emission was successfully developed and tested in 2011. The electron gun is capable of producing up to 2 mA of electron beam at the power level of about 1 W. These specifications are required by miniature satellites (for example ESTCube-1) having limited power available.

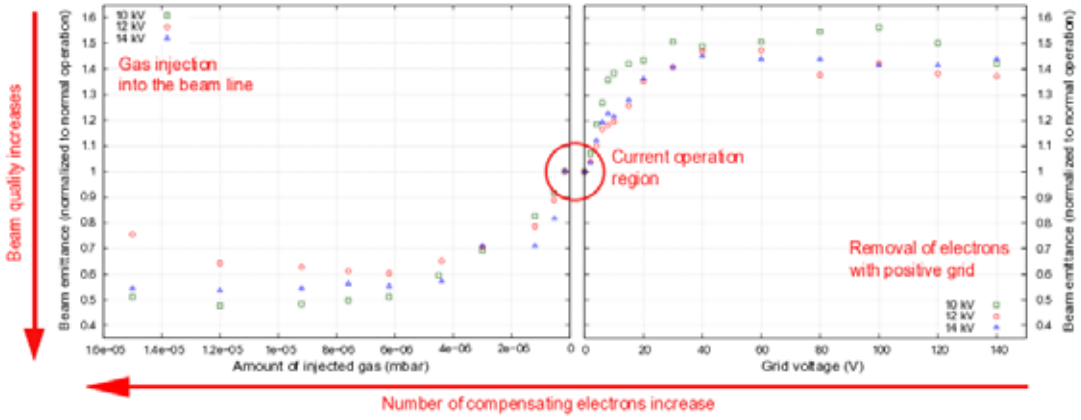


Fig. 2. The link between space charge compensation and beam quality has been studied by altering the number of compensating electrons in the beam line with two different approaches. Results show that ion beams are not fully compensated and the beam quality has clear dependence on the degree of compensation.

Exotic Nuclei and Beams

Ari Jokinen, Iain Moore, Heikki Penttilä and Juha Äystö

Juha Äystö, professor
Ari Jokinen, university lecturer -31.7., professor 1.8.-
Veli Kolhinen, university researcher
Iain Moore, university lecturer
Heikki Penttilä, university researcher
Valery Rubchenya, senior researcher (Khlopin Radium Institute, St. Petersburg)
Anu Kankainen, academy postdoctoral researcher
Tommi Eronen, postdoctoral researcher – 31.7.
Pasi Karvonen, postdoctoral researcher – 30.6.
Sami Rinta-Antila, postdoctoral researcher 1.10.–
Dmitry Gorelov, graduate student
Jani Hakala, graduate student
Ilkka Pohjalainen, graduate student
Mikael Reponen, graduate student
Juho Rissanen, graduate student
Antti Saastamoinen, graduate student
Volker Sonnenschein, graduate student
Jani Turunen, graduate student (STUK)
Heli Hoilijoki, MSc student
Henri Kulmala, MSc student
Joni Parkkonen, MSc student -31.5.
Toni Pikkarainen, MSc student
Kari Rytkönen, MSc student (LUT, Lappeenranta)
Laura Vainio, MSc student

Activity 2011

The year 2011 was exceptional for the IGISOL group. Due to the on-going construction of the new IGISOL-4 facility and related technical development, no nuclear physics experiments could be carried out in our home laboratory. Traditionally, our team has benefited from collaborations with several groups from Europe and the US in particular in experiments performed in Jyväskylä. This year, experiments were run at ISOLDE, CERN,

The IGISOL group in the IGISOL-4 experimental area. From the left: Ari Jokinen, Iain Moore, Anu Kankainen, Dmitry Gorelov, Jukka Paatola, Mikael Reponen, Sami Rinta-Antila, Kari Rytkönen, Ilkka Pohjalainen, Juho Rissanen, Volker Sonnenschein, Jani Hakala, Jukka Koponen, Antti Saastamoinen, Veli Kolhinen, Camino Rodriguez, Heikki Penttilä and Juha Äystö.

The 7-T superconducting solenoid of JYFL-TRAP was moved into the new laboratory and re-energized already in the summer of 2011. The magnetic field was shimmed so that the field homogeneity at the trap regions is 1.57 and 0.28 ppm (purification trap and precision trap), respectively.

The commissioned MCC30 cyclotron beam was delivered to the IGISOL target position for the first time on November 23. A view of the MCC30 control area.

and in GSI, Darmstadt, which work was carried out within the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). In addition, we have benefited from participation in the EU FP7 programs ANDES, ENSAR and ERINDA.

During the year, a significant amount of previously collected data was analysed and the members of our research group authored and co-authored more reviewed papers in 2011 than in 2010 or 2009. A collection of articles related to the three decades of research at IGISOL was also prepared for the "IGISOL Portrait" which will be published in 2012.

Technical developments

Construction of the new IGISOL facility. Ion beams from both the K130 cyclotron and the commissioned MCC30 will be delivered to the new IGISOL facility. During 2011, beam from both cyclotrons was provided to the IGISOL-4 target position. The target area is also accessible to laser beams from the front and from the back of the ion guide. There are no major modifications in the target area as compared to IGISOL-3; however, space has been reserved for future developments such as the neutron production target for fission studies.

Laser ion source development. Members of the IGISOL group joined researchers from Mainz, GANIL and RIKEN, at the Leuven laser ion source facility, in an important study comparing two distinctly different laser systems - a 200 Hz dye laser system and a 10 kHz Ti:sapphire system. Repetition rate, pulse energy and spectroscopic resolution were compared under off- and on-line conditions. Using ^{59}Cu ($t_{1/2}$ = 59 s), a comparable yield was achieved for in-cell laser ionization however a considerable advantage for in-jet laser ionization was obtained using the high-repetition rate system.

Experimental highlights

Trap assisted spectroscopy. Utilizing a Penning trap as a mass selective filter considerably reduces the background radiation emitted from neighboring nuclei. Therefore, it is a very powerful tool for nuclear decay spectroscopy measurements. This method was used to produce pure samples for decay studies of very neutron-rich fission products around A=110, where an oblate ground state deformation has been predicted to take place. A successful campaign of measurements resulted in three publications in 2011, giving new information about the shape evolution in the studied area. The resolution of the mass selection can be further improved via utilization of the Ramsey technique for mass purification. In a proof-of-principle experiment in collaboration with the University of Brighton, the particular case of the two states of ^{100}Nb was studied. These states are separated in energy by 313 keV (a mass difference of 3 ppm) and both beta decay into ^{100}Mo. The resolution of the trap system was sufficient to isolate the two nuclear states and allowed the separate study of the gamma-ray spectrum arising from each β-decay path. The technique will now be extended to other nuclei in the A~100 region, famous for shape coexistence and rapidly changing nuclear shapes.

Superallowed beta decays. As the last of several superallowed beta decays studied at IGISOL-3, the improved β-decay half-life and the ground-state–to–ground-state Q_{EC}-value of ^{30}S were published in 2011. The relative precision of 1.4 per mille for the half-life and 0.2 per mille for the Q_{EC}-value is three times and 20 times more precise, respectively, than measured previously. This leaves ^{14}O as the only well-known superallowed beta emitter yet to be studied with JYFLTRAP. The work on superallowed decays will continue at IGISOL-4.

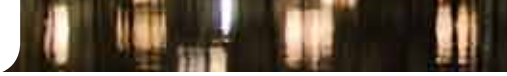
Double beta decay. Q values for double beta decays of ^{116}Cd and ^{130}Te were determined with a precision of 0.13 keV and 0.23 keV, respectively. These isotopes are considered promising candidates for the search of the neutrinoless double-beta decay in the CUORE and COBRA experiments.

Highlights at ISOLDE

In 2011, the campaign of optical measurements on gallium isotopes proceeded towards neutron-deficient nuclei, yielding data on nuclear spins, moments and isotope shifts for $^{63\text{-}71}$Ga. Earlier work at GANIL pointed towards an anomalous behavior of the matter radii which was seen to increase with decreasing neutron number. This was speculated being as evidence for the development of a proton skin. The new laser measurements at ISOLDE, sensitive to changes in mean-square charge radii, showed no such increase.

Highlights at GSI

A milestone was achieved in October 2011 at GSI: the first ever test of a cryogenic ion catcher in realistic experimental conditions. At the FRS, relativistic nuclei were slowed down to a few eV within a cryogenic stopping cell of length 1 m and diameter 25 cm. During the tests, a helium gas density several times larger than achieved with comparable, room temperature, ion catchers was used. Electric fields guide the stopped ions towards a fine-structured RF carpet on the exit side and following extraction the ions were transferred towards a multiple-reflection time-of-flight mass spectrometer for analysis. Efficient stopping and extraction of ^{223}Th was realized. Participation in the gas catcher project forms a part of the Finnish contribution towards the FAIR facility.



Nuclear Spectroscopy

Tuomas Grahn, Paul Greenlees, Rauno Julin, Matti Leino,
Mikael Sandzelius, Cath Scholey and Juha Uusitalo

The experimental programme spanned the nuclear chart from investigations of nuclear structure at extreme neutron deficiency to experiments probing neutron-rich nuclei and nuclei near the closed shells. The first half of 2011 was devoted to RDT experiments with JUROGAM II and RITU focusing on nuclear structure near the proton drip line. A dedicated decay spectroscopy experiment (R44) with the digitised DSSD recording trace data in order to detect fast decays was carried out. After a successful test of the University of York veto detector of prompt charged particles (UoYtube) focus was given to the in-beam spectroscopy of ^{256}Rf and ^{111}Xe. At the end of the year careful preparatory work was carried out in order to optimise the experimental set-up for the next SAGE campaign. The 11 international experiments (see the list below) occupied 142 days of beam time. In addition, the group participated in experiments at REX-ISOLDE and GSI. Group members were authors in 30 peer-reviewed publications, 23 of them based on data obtained at JYFL. The study of excited states in the $N = Z$ nucleus ^{92}Pd carried out at GANIL was published in Nature and rapidly acquired attention as a topic of current interest in the nuclear structure physics community. Jan Sarén successfully defended his PhD thesis entitled “The Ion Optical Design of the MARA Recoil Separator and Absolute Transmission Measurements of the RITU Gas-Filled Recoil Separator”.

IN-BEAM SPECTROSCOPY GROUP MEMBERS
Rauno Julin, professor
Paul Greenlees, research professor
Sakari Juutinen, university lecturer
Pete Jones, university researcher - 30.6.2011
Tuomas Grahn, academy postdoctoral researcher
Steffen Ketelhut, postdoctoral researcher - 31.8.2011
Päivi Nieminen, postdoctoral researcher
Panu Rahkila, postdoctoral researcher
Mikael Sandzelius, postdoctoral researcher
Andrej Herzáň, graduate student
Pauli Peura, graduate student
Juha Sorri, graduate student
Sanna Stolze, graduate student, 1.9.2011 –
Joonas Konki, MSc student
Karl Hauschild, visiting scientist – 30.7.2011
Araceli Lopez-Martens, visiting scientist – 30.7.2011

SEPARATOR GROUP MEMBERS
Matti Leino, professor
Juha Uusitalo, university researcher
Cath Scholey, university researcher
Sami Rinta-Antila, postdoctoral researcher – 30.9.2011
Kalle Auranen, graduate student, 1.9.2011 –
Ulrika Jakobsson, graduate student
Panu Ruotsalainen, graduate student
Jan Sarén, graduate student

^{256}Rf – at the high-Z limit of in-beam spectroscopy

The long-term goal of making an in-beam study of ^{256}Rf was finally crowned with success in 2011

Fig. 1. The Nuclear Spectroscopy Group as of January 2012. From left to right, first row: Paul Greenlees, Juha Sorri, Pauli Peura, Mikael Sandzelius, Jan Sarén, Tuomas Grahn, and second row: Rauno Julin, Päivi Nieminen, Janne Pakarinen, Cath Scholey, Ulrika Jakobsson, Juha Uusitalo, Panu Ruotsalainen, and third row: Joonas Konki, Sakari Juutinen, Panu Rahkila, Andrej Herzáň, Matti Leino, Sanna Stolze and Kalle Auranen.

(experiment JR111). The successful conclusion was made possible by development of a new technique in producing an enriched ^{50}Ti beam at the ECR2 ion source. The collaborative efforts of the group at IPHC Strasbourg and the local ECR team produced the beam, thereby ensuring a stable beam with the average intensity of around 30 pnA throughout the experiment.About 2000 fission events recorded at the focal plane of RITU offered a clean “tag” of the prompt gamma

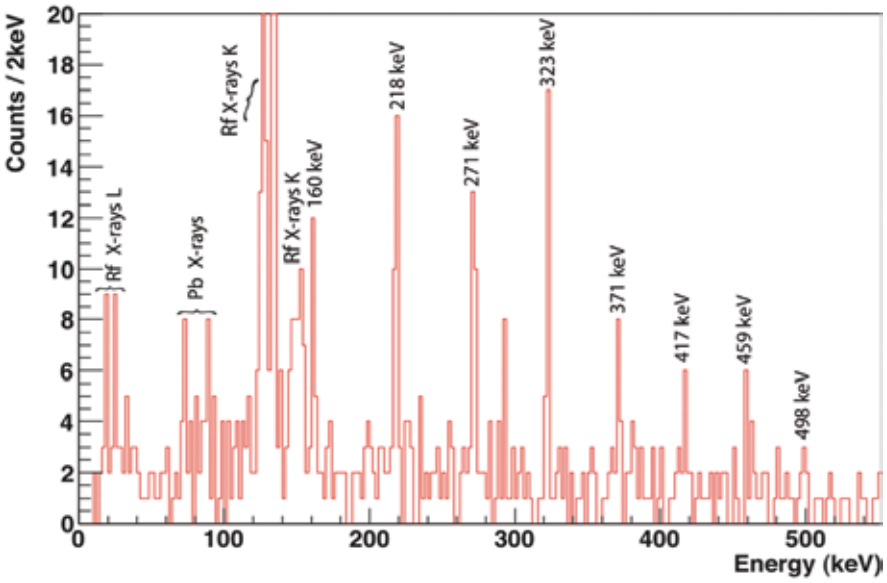


Fig. 2. Prompt singles gamma-ray spectrum tagged with ^{256}Rf fission events.

rays registered in digitised JUROGAM II at the target position. The fission-tagged gamma-ray spectrum in Fig. 2 reveals a rotational band structure in ^{256}Rf, and hence provides evidence of its deformed character. This measurement represents the state-of-the-art in selectivity ^{256}Rf being the heaviest element in which excited states have been established in an in-beam spectroscopy experiment. The results will be of strong current interest, addressing the burning issue of superheavy element stability by shedding light on the single-particle structure above the deformed shell gap at Z =100.

Studies of transition probabilities

In 2011 several high profile publications were published based on the JYFL mean lifetime measurement data acquired with the plunger device (see list of publications). The studies of transition probabilities in ^{109}I and ^{108}Te at JYFL resulted in detailed information of transition matrix elements in neutron-deficient nuclei above Z = 50. The lifetime measurements in ^{109}I represent a forefront of selectivity, being the first ever proton-tagged plunger lifetime measurement. These together with the ^{111}Xe experiment carried out this year will shed more light on the interplay of collectivity and single-particle regime in this region. Another highlight was the study of shape coexistence in the odd-mass nucleus of ^{175}Au, in which the lifetimes of the coexisting configurations were measured addressing the origin of shape coexistence in the odd-mass nuclei near Z = 82.

SAGE developments

The SAGE spectrometer was successfully re-commissioned in 2011. Following intensive work

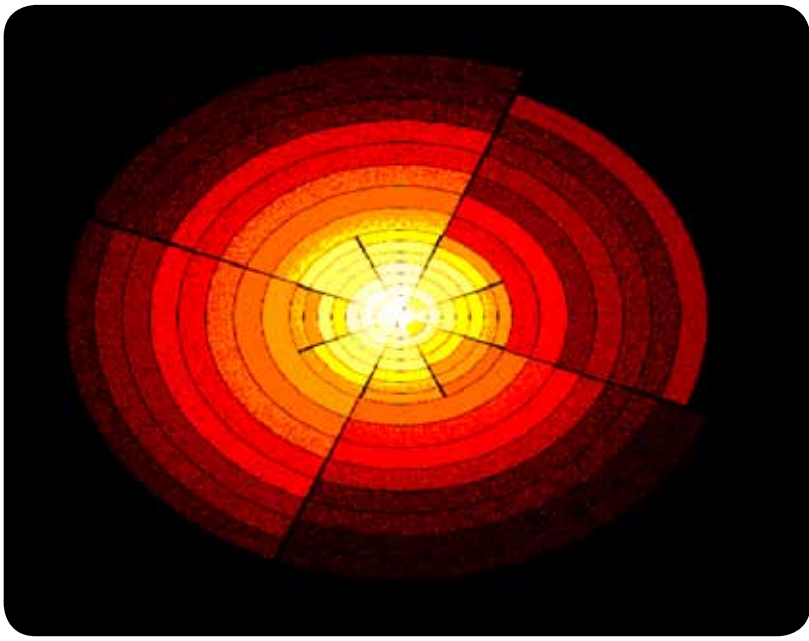


Fig. 3. Centralised hit pattern of prompt conversion electrons. The central part of the detector is more pixelated than the outer parts in order to sustain higher counting rates.

it was possible, for the first time, to centre the distribution of prompt conversion electrons over the detector. This feature represents a milestone for SAGE and enables the spectrometer to operate with higher beam intensities without excessive individual pixel counting rates. Fig. 3 depicts the centralised electron distribution. The stability of the detector and the functionality of the HV barrier were also demonstrated, paving way for a campaign of experiments in early 2012.

MARA separator construction in progress

A big leap forward was made in the realisation of the in-flight recoil mass separator MARA (Mass Analysing Recoil Apparatus), which has been under design since 2004. MARA will be a complementary separator to the existing gas-

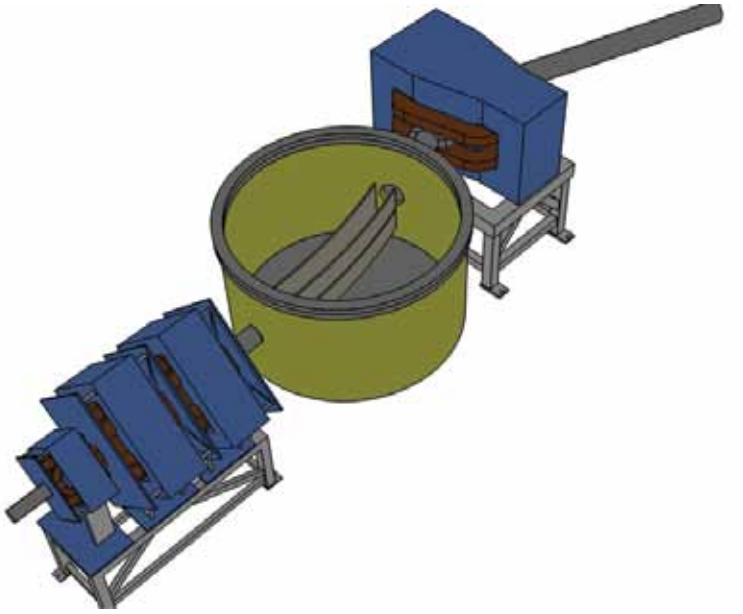


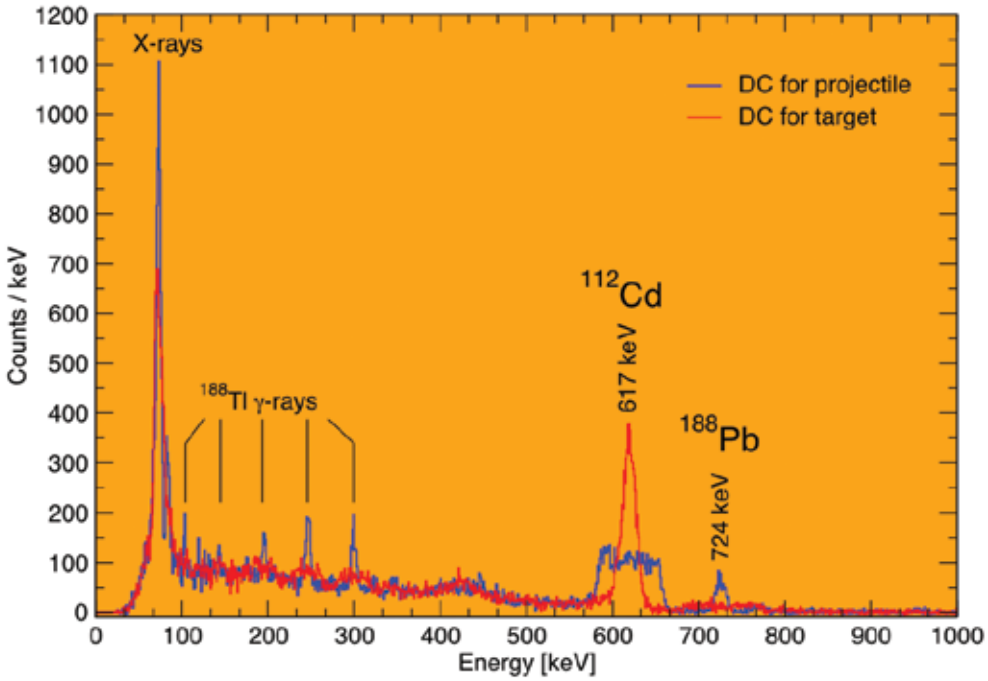
Fig. 4. The MARA separator is a combination of three magnetic quadrupoles, an electrostatic deflector and a magnetic dipole.

filled recoil separator RITU. Components needed for the separator have been purchased annually over the recent years. The most expensive part, the electrostatic deflector, was finally funded through Academy of Finland Infrastructure Funding in 2011, with 465 k€ allocated to the MARA electrostatic deflector. An agreement with the supplier Danfysik A/B was made and the delivery of the deflector is expected to occur in autumn 2012. The construction of the MARA cave, the former IGISOL site, has already begun. The MARA separator is shown in Fig. 4.

Rare isotope studies at ISOLDE

A Coulomb excitation measurement programme with the MINIBALL gamma-ray spectrometer and with heavy Radioactive Ion Beams (RIBs) from REX-ISOLDE was carried out for studies of shape coexistence in the neutron-deficient Pb nuclei down to A=188 (T. Grahn, J. Pakarinen spokespersons). The spectra in Fig. 5 exemplify Coulomb excitation experiments with radioactive Pb beams. The E2 transition rate for the 0^+ to 2^+ transition in ^{188}Pb can be extracted from such spectra. In addition, the development of nuclear structure as a function of nucleon number in going away from the closed-shell at

Fig. 5. Background subtracted gamma-ray spectra in coincidence with particles detected in low centre-of-mass angles in the CD particle detector. The same spectrum is shown with different Doppler corrections; blue for the projectile (^{188}Pb) and red for the target (^{112}Cd) nuclei. The ^{188}Tl gamma-ray lines, resulting from the isobaric impurities in RIB, can also be seen.



magic numbers was addressed by Coulomb excitation of ^{208}Rn (T. Grahn spokesperson).

Our group has also secured more RIB time at REX-ISOLDE for studies of heavy and medium-heavy nuclei. Due to experience with construction of the RITU and new MARA separator at JYFL, our group will participate in the investigations of the scientific and technical requirements of a vacuum-mode recoil separator to be constructed at HIE-ISOLDE.

EXPERIMENT SPOKESPERSONS AND COLLABORATING INSTITUTES IN 2011

[JR96] Search for superdeformation ^{193}Bi
S. Juutinen, JYFL
M. Nyman, University of Helsinki
University of Manchester, U.K.

[J15] Prompt gamma-ray spectroscopy of neutron-rich nuclei in the mass 115-130 and mass 80 regions
G. Simpson, LPSC, Grenoble, France
University of Manchester, U.K.
JYFL

[R44] Decay spectroscopy of ^{164}Ir and the structure of ^{160}Re
R. D. Page, University of Liverpool, U.K.
University of West of Scotland, U.K.
JYFL

[J16] Exploration of the "α-^{208}Pb" structure of ^{212}Po
A. Astier, CSNSM, Orsay, France
IPN Lyon, France
IPHC-Strasbourg, France
INRNE, Bulgaria
JYFL

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

[S03] Competing structures in neutron-deficient heavy nuclei: Character of isomeric state in ^{189}Pb
P. Nieminen, JYFL
D. M. Cullen, University of Manchester, U.K.
G. Dracoulis, ANU, Canberra, Australia

[JR106] Neutron single-particle orbitals and resultant shapes in neutron-deficient A = 173 nuclei
D. O'Donnell, University of Liverpool, U.K.
C. Scholey, JYFL
University of Guelph, Canada

[JR104] Proof-of-principle of double-beta-tagging
D. G. Jenkins, University of York, U.K.
University of Edinburgh, U.K.
IRFU-CEA Saclay, France
JYFL

[JR111] In-beam gamma-ray spectroscopy of heavy elements: ^{256}Rf
P. T. Greenlees, JYFL
B. Gall, IPHC, Strasbourg, France
R.-D- Herzberg, University of Liverpool, U.K.
Ch. Theisen, IRFU-CEA Saclay, France

[JR108] In-beam spectroscopy of N=Z+3: ^{111}Xe
J. F. Smith, University of West of Scotland, U.K.
University of Liverpool, U.K.
STFC, Daresbury, U.K.
University of Manchester, U.K.
University of Guelph, Canada

[S11] Commissioning of the SAGE spectrometer through in-beam investigation of ^{177}Pt
P. Papadakis, University of Liverpool, U.K.
P. T. Greenlees, JYFL
R.-D. Herzberg, University of Liverpool, U. K.

Nuclear Reactions

Wladyslaw Trzaska

In 2011 we have completed 7 experiments including 3 that required the design, construction and testing of entirely new measurement setups. As a contribution to the development of the radioactive beams we have measured neutron yields produced by 40 MeV deuterons on thick carbon target with a new transport system, improved our dE/dx setup by adding a bolometer provided by the Mainz/GSI, and developed a complex gas catcher/purifier/transport system for the investigation of heavy neutron-rich nuclei in the region of N=126. We have closed the year with the traditional Christmas to New Year run studying radii of exotic alpha-cluster states in ^{11}B and investigating neutron halo in He isotopes.

Galina Knjazheva (standing), Kiril Novikov, Oleg Rudakov, and Paul Greenlees (sited from the left) making preparations for the test run.

Accelerator-based Materials Physics

Timo Sajavaara and Harry J. Whitlow

Pelletron Accelerator

The Pelletron has functioned well throughout the year with only minor breaks for ion-source renovation. During the year the construction work on the new multi-cusp H- ion source (PELLIS) had been completed and components have been purchased. This is scheduled for commissioning during the early part of 2012. A new re-circulating gas stripper has been projected and an order placed for delivery in March 2012.

Harry J. Whitlow, professor
Timo Sajavaara, university lecturer
Nitipon Puttaraksa, postdoctoral researcher
Jaakko Julin, graduate student 1.8.–
Mikko Laitinen, graduate student
Laura Mättö, graduate student
Mari Napari, graduate student
Rattanaporn Norarat, graduate student
Ananda Sagari A.R., graduate student
Henri Kivistö, MSc student
Laura Rojas, MSc student

MeV ion beam lithography

The work on MeV ion beam lithography is one of the main research themes in the group. This has focused on developing a fundamental understanding of the basic ion-induced processes in PMMA, the extension of MeV ion beam lithography for direct writing in silica and other glasses, and development of our Programmable proximity aperture lithography technique for rapid prototyping of microfluidic devices. A significant part of this work has been within the EU-FP7-HILYSENS project which has the goal to develop a low-cost microfludic chip for detection of Lyme disease which is transmitted by deer ticks and epidemic in Northern Europe. The capabilities for microfluidic fabrication using e.g. soft lithography have been combined with expertise in chromatography for analytical chemistry to develop microfluidic instruments on a chip.

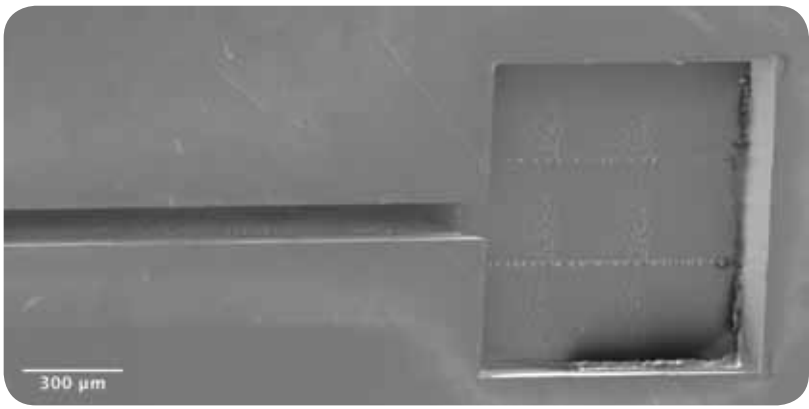


Fig. 1. Direct writing of deep 140 µm channel in PMMA with 3 MeV protons by ion beam lithography.

MeV ion beam microscopy

During the year our work on objective improvement of the visual quality of MeV ion microscopy images has continued. This has been carried out in conjunction with the Centre for Ion Beam

Applications (CIBA) at the National University of Singapore. It was found that the visually disturbing speckle in the images from Poisson statistics could be most effectively supressed, with minimal ringing using a Daubechies- 4th wavelet with a LevelShrink selection of the soft-thresholds. Also in collaboration with CIBA and bioimaging researchers in Jyväskylä we started an investigation of multivesicular endosomes which are implicated in a range of disease processes for optimization of MeV ion fluorescence microscopy to study of biomolecule pathways in cells using fluorescent markers. Construction of the DREAM MeV ion microscope in Jyväskylä is progressing. In particular the data collection and control system has been realised and constructed. Basing this on know-how in JYFL on total data collection methods has enabled a highly compact new system with a data collection rate that is governed by the speed of the ADCs and allows also study of the time evolution of processes such as ionobleaching on a sub-μs scale.

Ion beam analysis

The group also strongly focuses to the development of instrumentation and data analysis tools, and application of different ion beam analysis techniques. In 2011 the activities grew rapidly with several new scientific and industrial collaborations and this increased activity lead to several collaborative articles in high impact factor journals. The main instrumental development in 2011 was the realisation of fully digitised data acquisition for time-of-flight elastic recoil detection analysis (TOF-ERDA) with a performance equal or better in comparison to analog data acquisition. This, as well as the continued development of high energy resolution gas ionization detector are part of project HIUDAKE funded by EU regional funds for period of 7/2011-6/2013. A major TEKES-project ALEBOND ended 6/2011 but was followed by another major TEKES-project MECHALD, in which mechanical properties of atomic layer deposited (ALD) films will be studied. Pelletron group has had a substantial role in both of these projects.

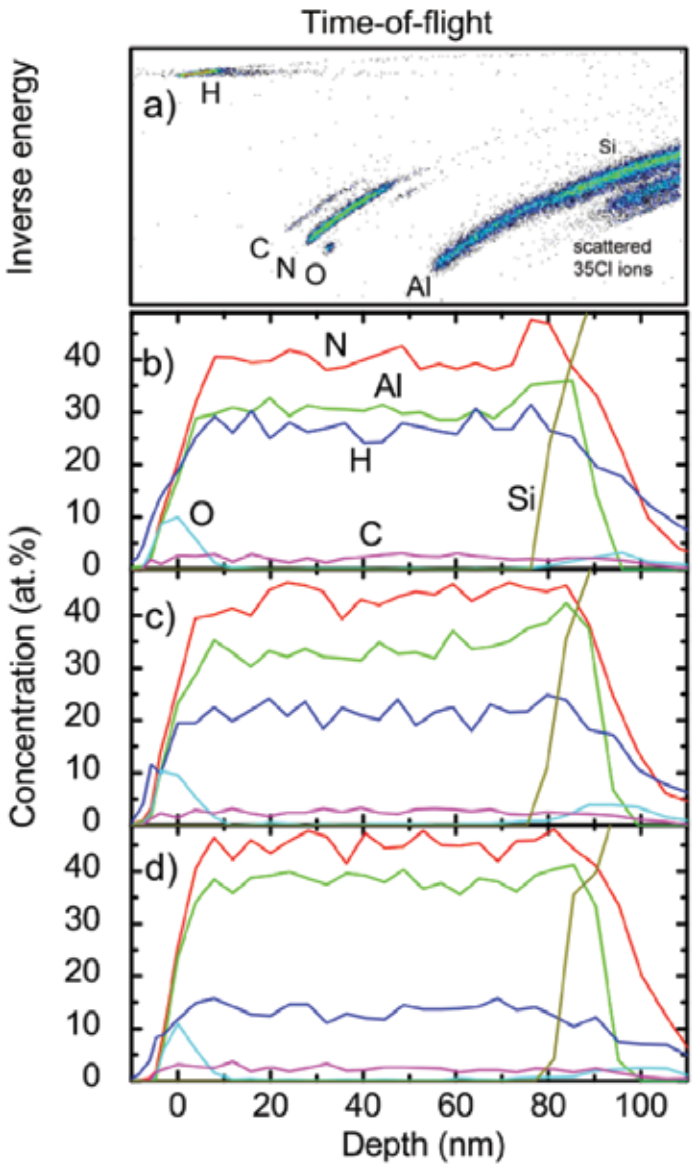


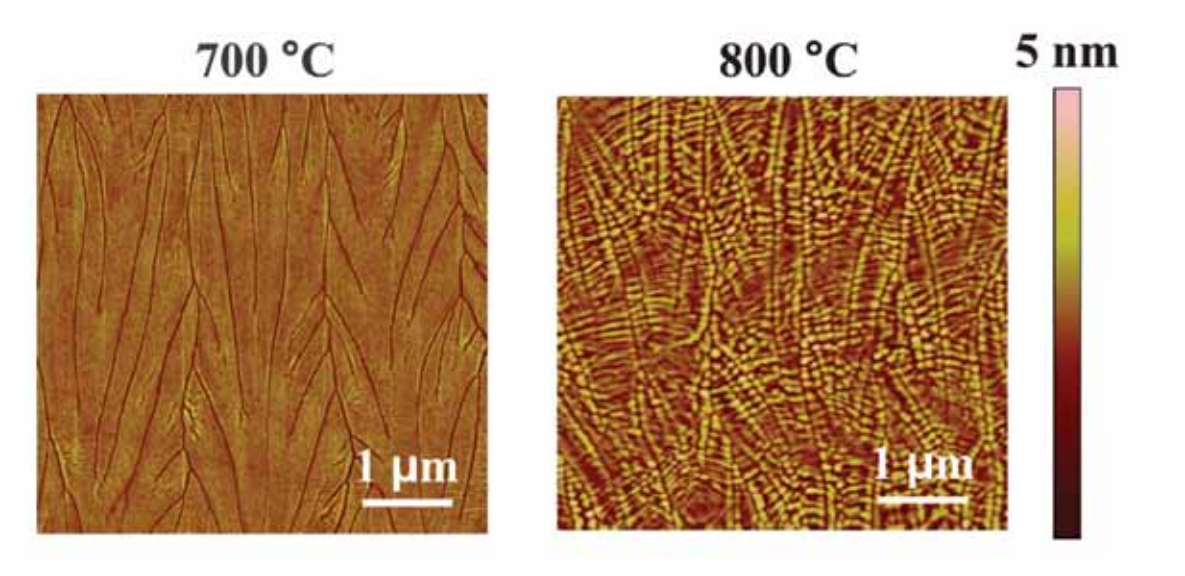
Fig. 2. Raw TOF-energy histogram for a film grown at 1150 °C and concentration depth profiles of the films grown at b) 150, c) 200 and d) 300 °C. Depth profiles were converted from at./cm^2 to nm by using densities determined with X-ray reflectivity. (M. Bosund, T. Sajavaara, M. Laitinen, T. Huhtio, M. Putkonen, V.-M. Airaksinen, and H. Lipsanen, Appl. Surf. Sci. 257 (2011) 7827.

Biomaterials studies

The biomaterials research continued in studies of 50 nm ALD-Ca-P-O films deposited on titanium substrates with different roughness. The surface topography, film composition, crystalline structure, wettability, and pre-osteoblast cell spreading were studied from as-deposited and annealed samples. The main findings were that uniform, good quality films could be deposited on both smooth and rough titanium substrates and Ca-P-O films also crystallise to hydroxyapatite-phase on titanium at 700 °C.

Education

The group has been active in education during the year and has developed two new courses in data aquisition and control that capitalise on our specialist research experience within the group. In addition we organised a Summer School course *"FYSV 412: Fundamentals of Ion–Matter Interaction"* which was lectured by Prof. Peter Sigmund of the University of Southern Denmark.



AFM images (5 µm x 5 µm) of originally amorphous and smooth Ca-P-O films with 208 ALD cycles on Si substrates annealed under humid argon (99.999%) atmosphere for 10 minutes at 700 °C and 800 °C.

Industrial Applications

Ari Virtanen

Industrial applications of the Accelerator Laboratory won first prize and a cheque for 10 000 € in an academic entrepreneurship competition, which is organized every year for Finnish universities. The organizers are the Finland Chamber of Commerce, Confederation of Finnish Industries and Federation of Finnish Enterprises. The aim of our proposal was to show how a high-level research of CoE can also create business. In the evaluation the jury gave special recognition to the strong innovativeness and commercial productivity of our work.

Ari Virtanen, research director
Heikki Kettunen, university researcher
Iiro Riihimäki, postdoctoral researcher -30.6.
Arto Javanainen, graduate student
Taneli Kalvas, graduate student
Mikko Rossi, operator
Kalle Auranen, MSc student
Alex Hedlund, MSc student

The use of the beam time

The usage of the beam time for different purposes is shown in Fig. 1. The total beam hours used in 2011 was 1401.

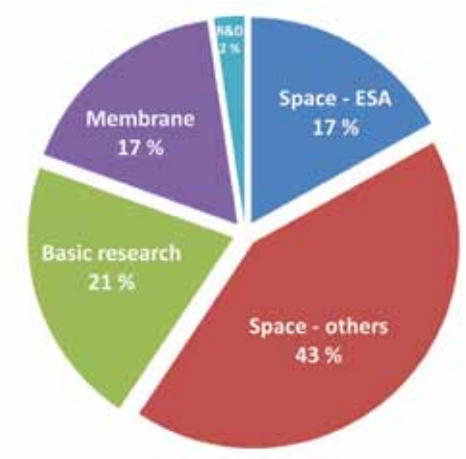


Fig. 1. Beam time distribution; Space-ESA = space component tests for ESA, Space-other = space component tests for satellite industry, Membrane = membrane irradiation, R&D = research and development of RADEF, Basic research = studies based on PAC proposals.

Space related study

RADEF continued as an ESA's external European Component Irradiation Facility (ECIF) for serving European satellite industry. In total 33 campaigns for 13 satellite companies or institutes were performed during 2011. These are summarized in Table 1.

DTU, Denmark
EADS ASTRIUM, France
EFACEC, Portugal
ESA/ESTEC, The Netherland
FUJI Electric, Japan
HIREX Engineering, France
IDA, Germany
JAXA, Japan
NASA/JPL, CA, USA
RUAG Sweden
SOFRADIR, France
Thales Alenia Space, France
TRAD, France

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

Basic mechanisms underlying the Single Event Gate Rupture (SEGR) are not well known. Therefore, ESA performed a specific technical assessment project on “Effects of the ion specie and energy on the oxide damage and SEGR failure”. The objective of this study was to determine the worst-case conditions for SEGR testing and inject the results in ESA’s SEE test guidelines.

RADEF became part of EU FP7-Space-2010-1 program with a SkyFlash project. It started in September 1st and the consortium consists of two European companies (Red Cat Devices, Milan, Italy, being the coordinator) and six universities. The aim is to develop stable and radiation-resistant flash memories for in-space applications. The SEE tests of the project will be performed at RADEF by using our standard high-penetration ion cocktail.

Also NASA has become our regular user by performing the test in RADEF already third time in 2011. Their study focused to the evaluation of mechanisms in SEE susceptibility of single- and multilevel high density flash memories. Japan Aerospace Exploration Agency (JAXA) was also testing electronics for Japanese satellites. The work was performed during the week 10 and the group landed back at Sengen in Japan just before the big earthquake. A photo of JAXA-group members is shown in Fig. 2.

Other industrial activities

Oxyphen GmbH continued the irradiation of their polymer films. Three campaigns were performed in 2011. A new contract for coming six years was negotiated and signed at the end of the year. A photo after the assignment, taken in business premises of Oxyphen located in Wetzikon, Switzerland, is shown in Fig. 3.

Fundamental research

We also participated and RADEF facility was used in several basic research experiments in collaboration with several universities and research institutes. Those included e.g. irradiation for Spiral2 radioprotection benchmark studies, development of the TOF-CLTD method for high-precision energy loss measurements and acquiring response data for solid state detectors.

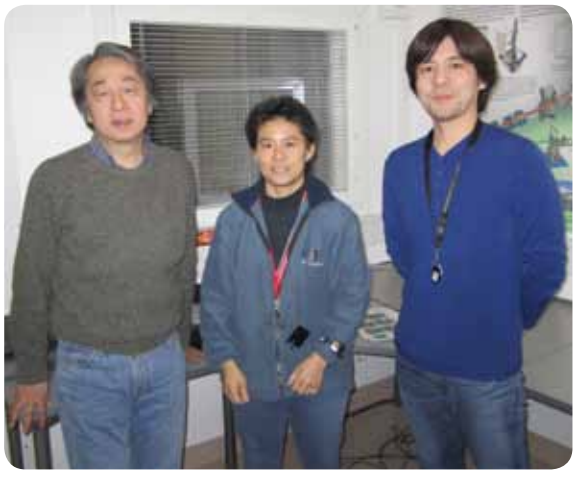


Fig 2. (left) JAXA group from left to right: Satoshi Kuboyama, Naomi Ikeda and Osamu Shimada.

Fig. 3. Annette Heusser-Nieweg, CEO of Oxyphen, and Ari Virtanen after signing the continuation of the service agreement contract.

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Jouni Suhonen

Calculations of weak decay processes in nuclei

We have continued our calculations of double beta decays in various nuclei in order to clarify the role of the orbital occupancies of the single-particle states and the effects coming from the sizes of the single-particle model spaces. This concerns the excited-states transitions in particular. Furthermore, a systematic calculaton of the double beta decays occurring in less studied (with less favourable Q values) nuclei has been carried out. A thorough theoretical analysis of the various double positron decays of ^{106}Cd was performed complemented by the analyses of various other related decays together with the Penning-trap mass measurements of the JYFLTRAP group.

A novel analysis of the possible ultra-low-Q-value decay branch in ^{135}Cs was accomplished. This study is aimed to be an incentive for experiments trying to detect weak decay branches in ^{135}Cs and other potentially interesting nuclei. The fundamental relevance of this study lies in its potential to verify the expected strong atomic effects in nuclear decays with extremely small decay energies.

Jouni Suhonen, professor
Mika Mustonen, postdoctoral researcher -30.6.
Emanuel Ydrefors, graduate student
Mikko Haaranen, MSc student

Calculations of nuclear responses to supernova neutrinos

Detection of supernova neutrinos is essential both for the disentanglement of the currently unknown supernova dynamics and for studies of neutrino properties. The fact that neutrinos interact only weakly with matter implies that they can be detected by terrestrial detectors using

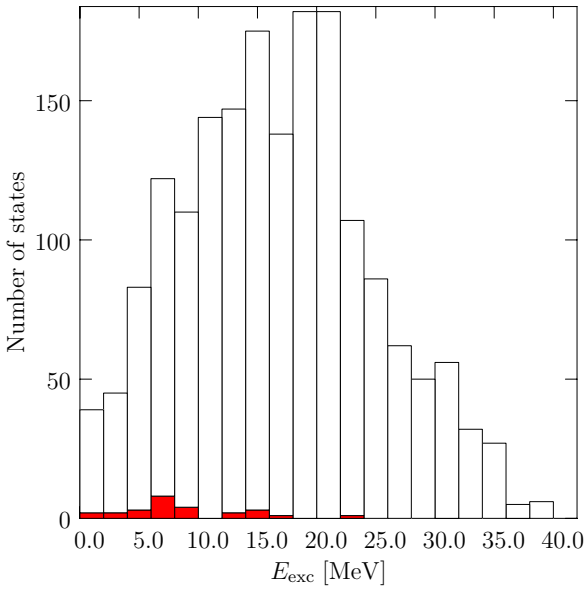


Fig. 1. Distribution of the computed states in ^{116}In. In the figure the fraction of states which are important for the charge-changing neutrino-nucleus cross sections is shown in red.

charged-current and neutral-current neutrino-nucleus reactions. The theoretical estimates of nuclear responses to supernova neutrinos for feasible nuclei are of paramount importance. Our published works have thus far connected to neutral-current neutrino-nucleus reactions on stable molybdenum nuclei.

Lately we have developed a theoretical machinery to attack the charged-current neutrino-nucleus reactions for both even and odd target nuclei. To begin with we have estimated the averaged cross sections for the charged-current supernova-neutrino scattering off ^{116}Cd leading to the ground state and excited states of ^{116}In. The distribution of the calculated states in ^{116}In is shown in Fig. 1. The fraction of states which have important contributions to the cross sections is indicated by red color. As seen this fraction is small. The calculations of nuclear responses require accurate description of the final states up to high excitation energies. In order to improve the nuclear wave functions in ^{116}In we have started to perform large-scale calculations using Skyrme forces in collaboration with the FIDIPRO group.

In Fig 2. we show the number of expected events/kton of ^{116}Cd as function of the distance

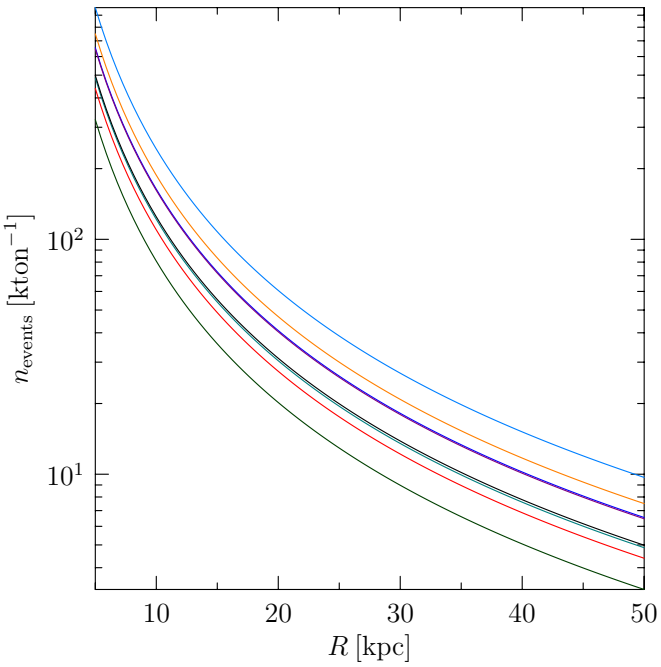


Fig. 2. The number of expected events per kiloton of ^{116}Cd as a function of the distance to the supernova for eight representative supernova models.

to the supernova for 8 different representative supernova models. As is seen in the figure the feasibility of detecting a supernova depends strongly on the distance R to the supernova event. The computed results are also quite sensitive to the adopted supernova models.

Experimental Nanophysics and Nanotechnology

Markus Ahlskog, Konstantin Arutyunov, Ilari Maasilta and Jussi Toppari

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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 2011:

The nature of phononic thermal transport in nanoscale structures is not very well understood. In particular, at low temperatures most bulk phonon scattering mechanisms (phonon-phonon, phonon impurity scattering) die out, leaving the surfaces of structures in a critical role. However, it is experimentally quite difficult to distinguish which scattering mechanisms, if any, are still active. Recently, we have theoretically and experimentally shown [1] that it is clearly possible to distinguish between the diffusive (bulk scattering) and ballistic cases (no scattering) in thin membranes with central heaters, on the basis of the radial temperature profiles alone. Model results were also compared with experimental profiles measured using 40-nm thick free-standing silicon nitride membranes at temperatures below 1 K; tunnel junction (SINIS)

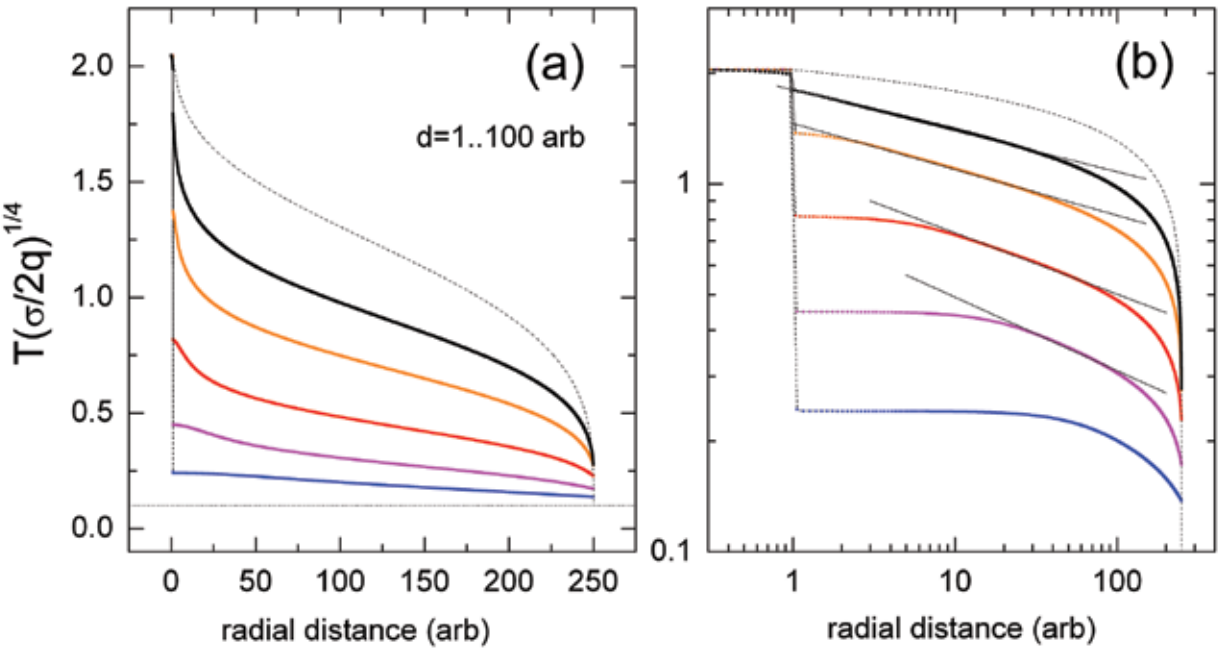

Fig. I. Calculated temperature profiles for 2D Casimir heat conduction (points) for R = 250 and d = 1, 3.16,10, 31.6, 100, where R and d have arbitrary units in (a) linear scale, (b) log-log scale. Higher curves have lower d. Dashed line shows the bulk diffusive result, and dotted line the value of bath temperature used. In (b), the solid lines are power law fits with exponents -1/9, -1/8, -1/6, -1/5 from top to bottom.

thermometers were used for the measurements. Agreement with the ballistic model was seen distances below 50 μm.

In a related theoretical work [2], we also computed for the first time the temperature profiles in thin membranes for the case where there is no bulk scattering, but where the surfaces scatter phonons diffusively; this case is usually known as the Casimir limit. For 2D radial heat flow, the resulting equation for the temperature profile is an integral equation, which has to be solved numerically. The temperature profile does not have a universal solution, as in the 1D Casimir limit (already solved in 1938), but depends on that ratio of the lateral membrane size to its thickness. In addition, the size of the heat source has a direct effect on the profile.

Another focus field has been development of superconducting transition-edge X-ray detectors. In 2011, significant progress was made in understanding the noise properties of transition-edge sensors. We showed that in various different detector geometries [3,4,5] all of the noise can be explained by known noise mechanisms, and the most significant component is due to the fact that the detector cannot be described as a single heat capacity, but that it breaks up into a more complex thermal circuit with several blocks of heat capacities connected by different thermal conductances. In our case, a three-block model always explained the responsivity and noise data. Moreover, based on the value of heat capacities and their change as a function of the bias point, we have evidence that the superconducting device within the transition region separates into a normal and a superconducting region, and that there is a finite thermal conductivity between the regions, so that this normal metal-superconductor thermal decoupling is the origin of two of the three heat capacity blocks.

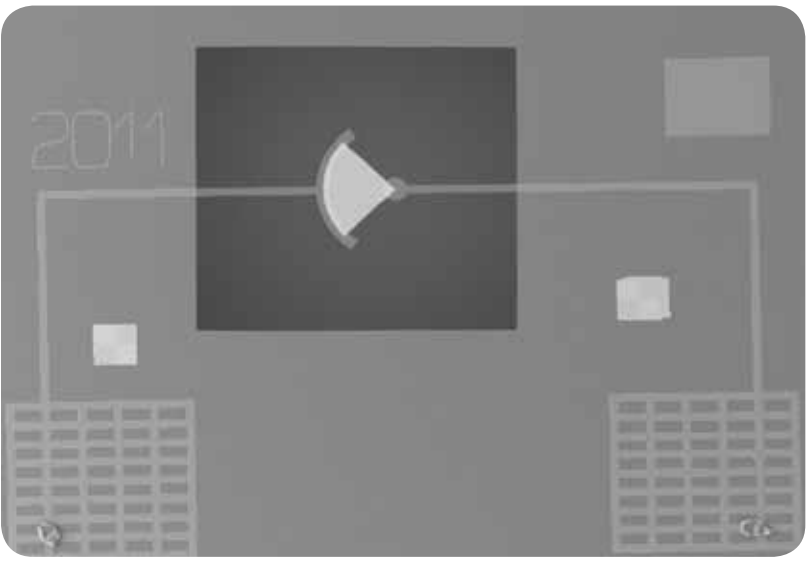

Fig. 2. Scanning electron micrograph of a Ti/Au transition-edge sensor with an unconventional "slice" geometry, leading to the normal-metal-superconductor thermal decoupling. Black area is the SiN membrane.

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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.

Combined techniques for measurement of structural, electron transport, and optical properties of individual carbon nanotubes are very important. We are developing methods to suspend nanotubes over narrow slits for this purpose, see Fig. 3. 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) and Prof. Esko I. Kauppinen at Aalto University (TEM diffraction) [Ref. 6].

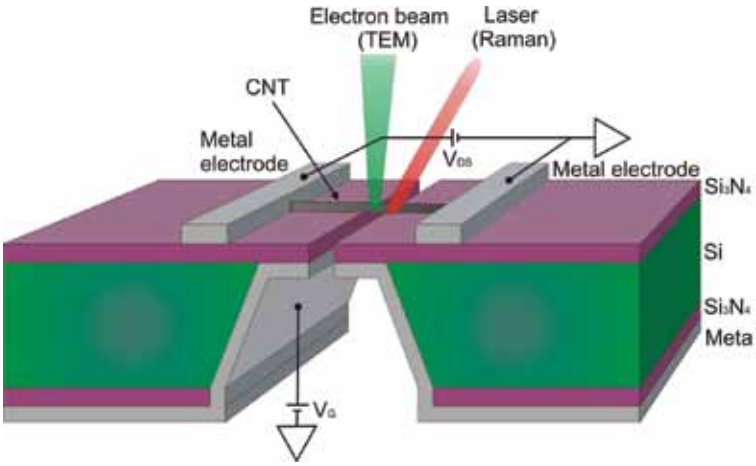

Fig. 3. a) Schematic of our suspended carbon nanotube samples and the measurement techniques possible in this configuration. b) SEM image of fabricated nanotube device crossing slit.

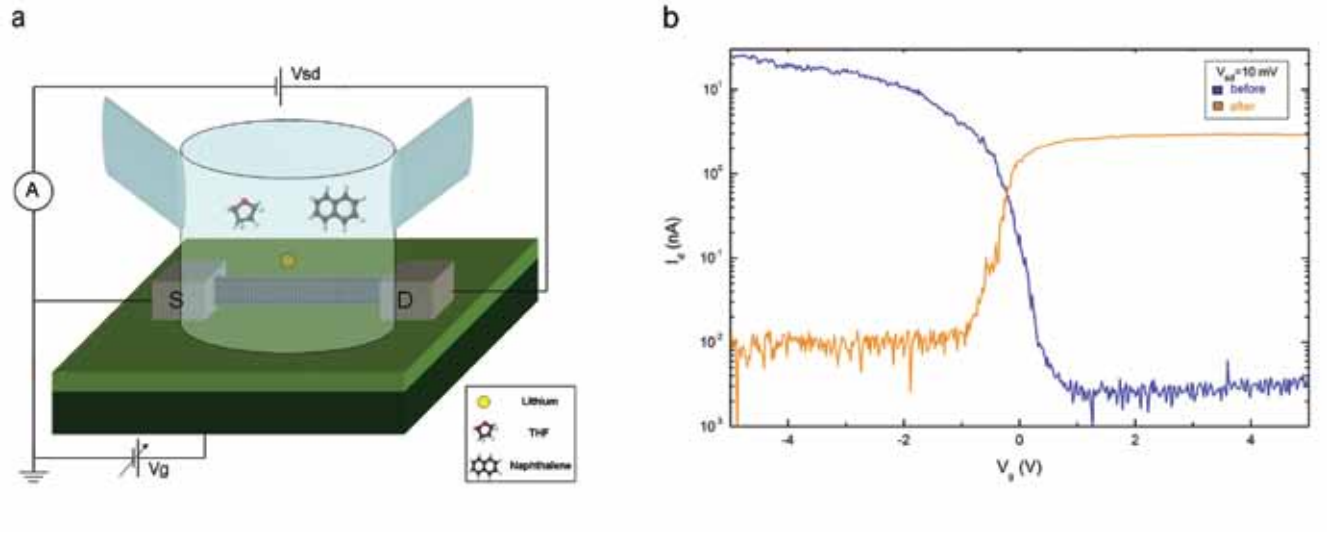

Fig. 4. a) Schematic of CNT FET liquid-phase doping and measurement setup. b) Transfer characteristics from a CNT FET before (blue) and after (orange) liquid-phase n-doping.

In another project we are studying chemical modification of CNT properties. While CNTs are intrinsically undoped, transfer characteristics from CNT field-effect transistors (FETs) typically show p-type behavior, which is due to the common choice of a contact metal with a work function closer to the valance than the conduction band of the CNT. It would however be very beneficial to be able to tailor the doping along different sections of the CNT. We are studying [Ref. 7] a method to n-dope CNTs under liquid phase – by exposing them to a solution of Li cations and naphthalene anions in tetrahydrofuran, as drawn in Fig. 4(a). The exposure has to be done under inert conditions due to high reactivity with oxygen. By measuring electronic transport properties of individual CNT FETs subjected to liquid-phase doping, we have characterized the change from p-type to n-type, see Fig 4(b). The doping consists of a redox interaction with Li acting as the reductant, and is fully reversible upon exposing the CNT to air. The method may have potential as a scalable processing step in CNT device making, in nanoscale sensor applications or by preserving the n-doping with a protective passivation layer. Presumably it is also applicable to other hydrocarbon species, with graphene closest in mind.

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 microscopy (LFM), using contact mode. Contact mode operation is also important in various cases where, for example, nanotubes are mechanically measured or manipulated [Ref. 8].

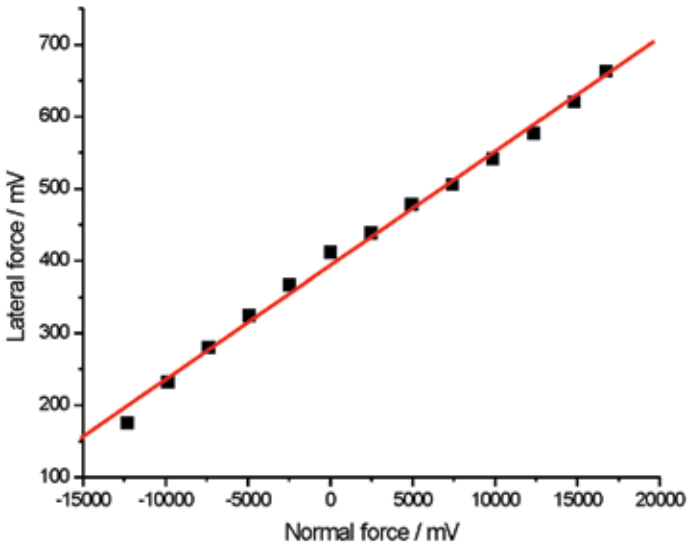

Fig. 5. Lateral force (friction) measured with different scanning forces on a MoS_2 surface.

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. 5.

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"Observation of second-harmonic generation from an individual carbon nanotube" Submitted
[7] P. Yotprayoonsak, K. Hannula, T. Lahtinen, M. Ahlskog, A. Johansson "Liquid-phase alkali-doping of individual carbon nanotube field-effe transistors observed in real-time" Carbon 49, 5283 (2011).
[8] J. Lievonen, T. Parviainen, J. Åström, M. Ahlskog
"AFM Tip Shape estimation Using Carbon Nanotubes and Microfabricated Steps" Submitted

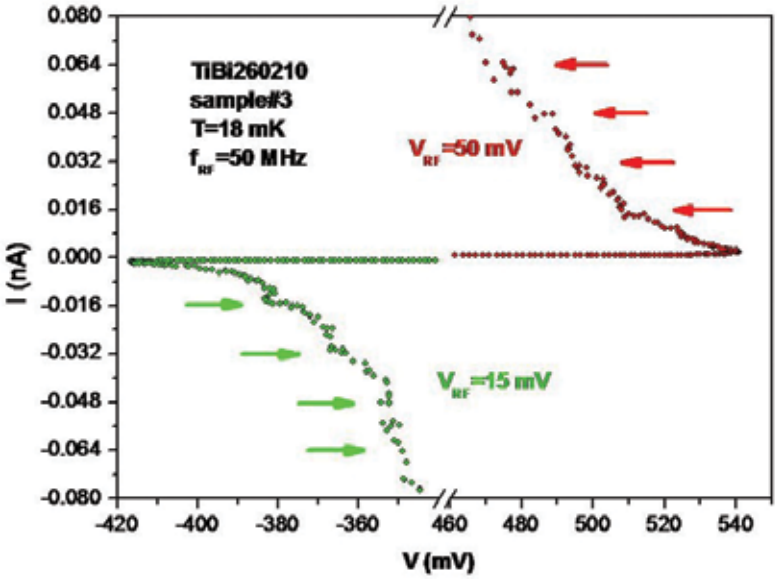

Fig. 6. The representative part of the I-V characteristic of ~18 nm thin titanium nanowire in high-Ohmic environment. Note the Coulomb blockade and the characteristic back-bending ("Bloch nose"). Application of external RF radiation stimulates singularities: the arrows correspond to the expectation $I_n=2e\times f_{RF}\times n$, where n is integer.

Quantum nanolectronics

Konstantin Arutyunov

The activity of *Quantum NanoElectronics group* can be formally separated into three topics: (I) quantum size phenomena at nanoscales; (II) interface phenomena at nanoscales; and (III) applied nanotechnology. In 2011 the most intriguing results were obtained related to the studies of quantum fluctuation phenomena in nanoscale superconductors. Two breakthrough results were obtained.

First, it has been demonstrated that the physics of ultra-thin superconducting channels is dual to the well-know Josephson systems. In particular, such a nanowire in high-Ohmic environment demonstrates insulating (!) behavior – Coulomb blockade (Fig. 6). Being exposed to the external RF radiation, the system demonstrates the dual Shapiro effect: current quantized steps at positions $I_n=2e\times f_{RF}\times n$, where n is integer

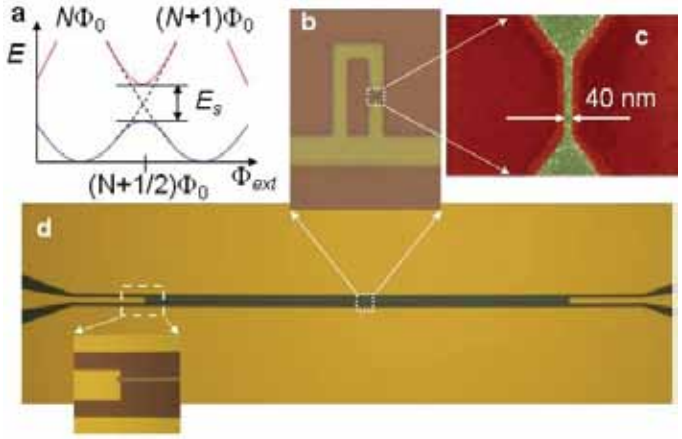

Fig. 7. a, Energies of the loop versus external flux Φ_{ext}. The degeneracy between states with N and N+1 of Φ_0 is lifted due to the phase-slip energy E_S, when $\Phi_{ext} = (N + 1/2)\,\Phi_0$. b InO_x loop with the narrow wire on the right side is attached to the resonator (straight line) at the bottom. c, False colour SEM image of the narrow InO_x segment. d, The step-impedance resonator consisting of the 3 μm wide InO_x strip with wave impedance Z_1 » 1600 W galvanically coupled to the gold Z_0 = 50 W coplanar line. The boundaries of the resonator are defined by the strong impedance mismatch ($Z_1 >> Z_0$)

(Fig. 6). The effect is expected to lead to an important metrological application: the current standard of electric current.

Second, as continuation of the Group's earlier studies on ultra-narrow nanorings, in collaboration with NEC-RIKEN (Japan) , 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. 7). The results will be published in April 2012 issue of Nature.

Päivi Törmä (Aalto Univ.) and Henrik Kunttu (Dept. of Chemistry, JYU).

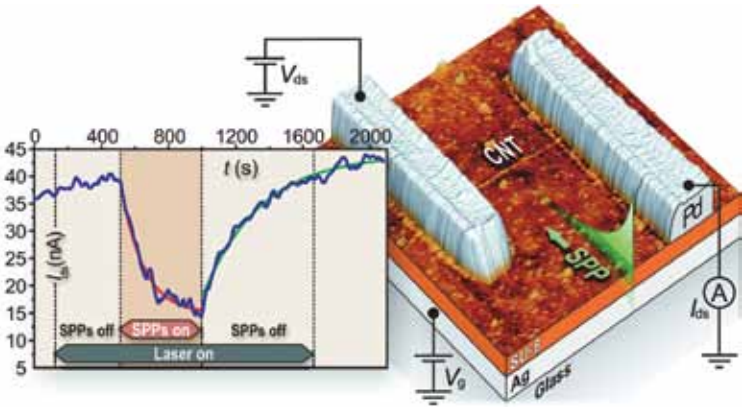

Fig. 8. LEFT: Current response of a CNT FET to SPP and laser excitation. RIGHT: AFM image with a schematic of the device. [Ref. 9.]

Molecular electronics and plasmonics

Jussi Toppari

The exceptional durability, very high thermal conductivity and variable electronic properties depending on the chirality, have made carbon nanotubes (CNTs) a promising material in nanoelectronics. In addition to the regular operation with a gate voltage, the current in a CNT field-effect transistor (FET) can be modulated with several other excitations, making the CNT FET suitable for sensor applications. The device is, e.g., sensitive to its chemical surroundings, and photoexcitation can also be used for gating. We have demonstrated a novel CNT FET (see fig. 8) that can be modulated with surface plasmon polaritons (SPPs), utilizing desorption and subsequent adsorption of physisorbed molecules in ambient conditions to control the current. The SPPs are excited in the Kretschmann configuration on a silver film at a 50 nm distance to the semiconducting CNT. As the field is enhanced on the metal surface by SPPs, lower intensities are needed compared to the far-field photoexcitation. Using nanostructured carbon materials as SPP conductors is also under study. This work has been carried out as collaboration with Profs.

We have also demonstrated a strong coupling between SPPs and Sulforhodamine 101 dye molecules (SR101). SPPs were excited onto a silver layer below a thin polymer film containing the SR101 molecules, and dispersion curves for SPPs were obtained experimentally by reflectometry measurements. The obtained dispersion relations were drastically modified by the strong coupling between SPP and SR101, and clear Rabi splittings were observed (see fig.9). The gaps are opened at the positions of the dye absorbance maxima and the energy separation becomes larger with increasing the dye concentration. Transfer matrix method was used to model the reflection coefficient of the studied multilayer structures. Detection of the scattered radiation on the SR101 film side provides another way to obtain the dispersion relation, and provides insight into dynamics of the SPP-SR101 interaction. We show that the energy gaps were dependent also on the SPP-dye interaction time, as well as the SPP's lifetime. [Ref. 10].

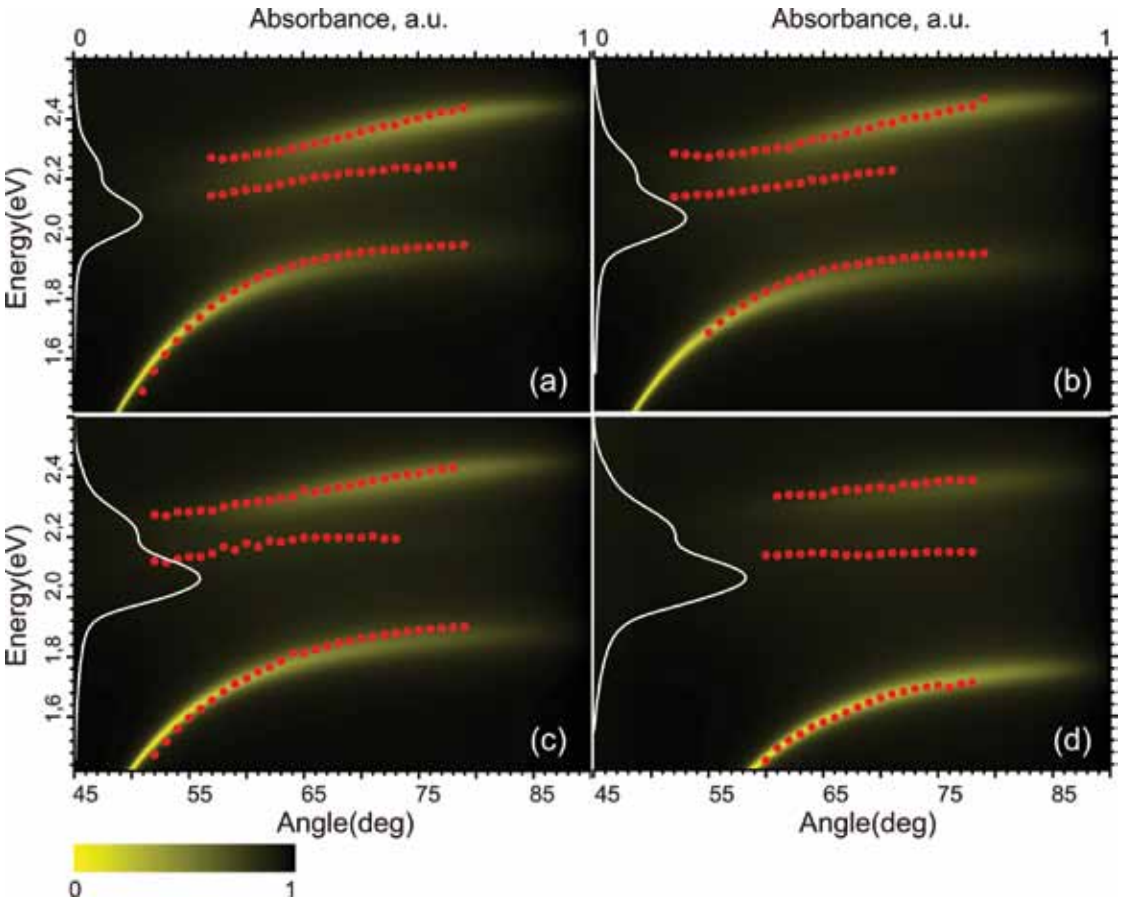

Fig. 9. Dispersion curves: Experimentally observed SPP resonances (red dots) together with the calculated reflectance coefficients (yellow-black background) as a function of the excitation energy and the angle of incidence for samples having 1× (a), 2× (b), 3× (c) and 4× (d) concentrations of SR101. White line is the measured absorbance of the SR101 layer as a function of the excitation energy (scale on the top axis). [Ref.10].

Due to its striking self-assembly properties, DNA is one of the most promising molecules for the bottom-up fabrication of complex nanoelectronic systems or nanodevices. We have studied various DNA-based self-assembled structures, e.g. *DNA-origamis, TX-tiles,* and other structures utilizing them. In addition to the fabrication and functionalization of these structures, we have especially developed a dielectrophoresis based trapping method to capture the structures between nanoscale electrons to further characterize them electrically [Ref. 11]. For example, the electrical conductivity of single trapped TX-tile complexes and origamis were analyzed by AC impedance spectroscopy [Ref. 12]. Based on these results, we have developed devices by functionalizing these scaffolds. Future aim is for self-assembled electrical and plasmonic nanoscale devices.

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Computational Nanosciences

Fingerprints of a gold cluster revealed

Hannu Häkkinen

Nanometre-scale gold particles are currently intensively investigated for possible applications in catalysis, sensing, photonics, biolabelling, drug carriers and molecular electronics. The particles are prepared in a solution from gold salts and their reactive gold cores can be stabilised with various organic ligands. Particularly stable particles can be synthesised by using organothiolate ligands that have a strong chemical interaction to gold. The first definite information of their atomic structure became available in 2007 when the group of Roger Kornberg (Chemistry Nobel Laureate 2006) at Stanford University succeeded in making single crystals for X-ray diffractometry containing only one type of a particle having 102 gold atoms and 44 thiolate ligands, the so called Au_{102}(*p*-MBA)$_{44}$ particle (see Figure 1) [1]. Our group has previously analyzed this and other known atomistic structures of thiolate-stabilized gold clusters and developed a theoretical framework that relates the chemical stability of the particle to its electronic structure [2].

Now, in collaboration with Kornberg group and the spectroscopy group in the Chemistry department, we have reported the first full spectroscopic characterisation of the absorption of electromagnetic radiation by the Au_{102}(*p*-MBA)$_{44}$ particle in solution and solid phases [3]. The spectroscopic study was performed in a large range of electromagnetic spectrum from mid-

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Klaas Giesbertz, postdoctoral researcher
Claudia Gomes da Rocha, postdoctoral researcher, 22.6.–
Julen Larrucea, postdoctoral researcher
Olga Lopez-Acevedo, postdoctoral researcher –30.6.
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Janne Kalikka, graduate student
Oleg O. Kit, graduate student
Ville Kotimäki, graduate student
Perttu Luukko, graduate student
Petri Myöhänen, graduate student
Ville Mäkinen, graduate student
Lauri Nykänen, graduate student (chemistry)
Juho Ojajärvi, graduate student -31.7.
Antti Putaja, graduate student
Niko Säkkinen, graduate student
Riku Tuovinen, graduate student 1.4.-
Anna-Maija Uimonen, graduate student
Gül Bekcioglu, MSc student
Markku Hyrkäs, MSc student
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Anna Kausamo, MSc student (chemistry)
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Janne Solanpää, MSc student

infrared (“heat absorption”) to ultraviolet light and complemented by detailed calculations of the absorption spectrum from linear-response time-dependent density functional theory. As a result, clear “fingerprint” features were found in the absorbance spectrum that can be used in the future to benchmark chemical modifications of this particle for various applications. The work also establishes the molecular nature of the clusters by the observation of a band gap of 0.45 eV, in excellent agreement with theory.

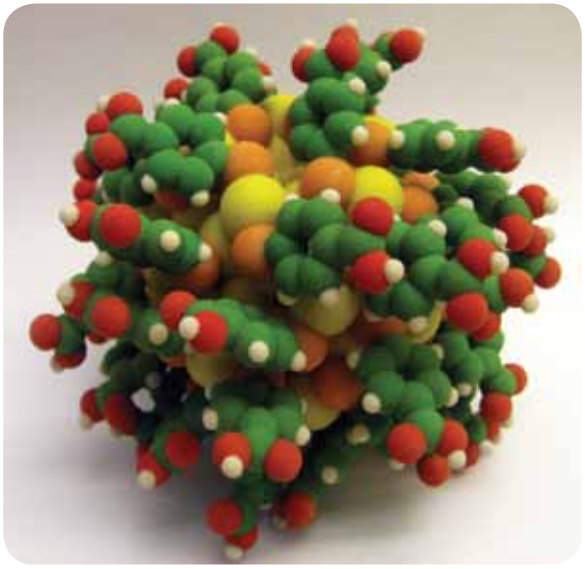

Fig. 1. An atomistic model of the known structure of $Au_{102}(p\text{-MBA})_{44}$ particle. Gold:yellow, sulfur:orange, carbon:green, oxygen:red, hydrogen:white.

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New materials for third-generation solar cells

Esa Räsänen

Development of solar cells has gradually led, at least on the conceptual and prototype level, to the so-called third generation, where single-layer silicon structures (first generation) or multilayer thin-film materials (second generation) have been replaced by, e.g., dye-sensitized, hot-carrier, multijunction, and intermediate-band (IB) solar cells (IBSCs). As originally proposed in 1997 [1], the IB enhances the photogenerated current via a two-step absorption of sub-band-gap photons. The IBSC has an impressive maximum efficiency of 63% for a *single* material.

Chalcopyrite materials lead the current efficiency ranking of solar cells based on thin-film technologies. The practical challenge in using chalcopyrite structures in the IBSC implementation is the finding a suitable semiconductor matrix that has larger band gap than the nanostructured material. In our recent study [2] we have demonstrated clear charge-carrier confinement in the low band gap CuInSe2 layer, which is a prerequisite for an IBSC application [see Figs. 2(a) and (b)]. In addition, we have shown that epitaxial growth of CuInSe2 dots embedded in CuGaS2 matrix leads to distinctive tetrahedral nanostructures [see Figs. 2(c) and (d)], and that they satisfy the known physical constraints to reach the maximum efficiency as an IBSC [3].

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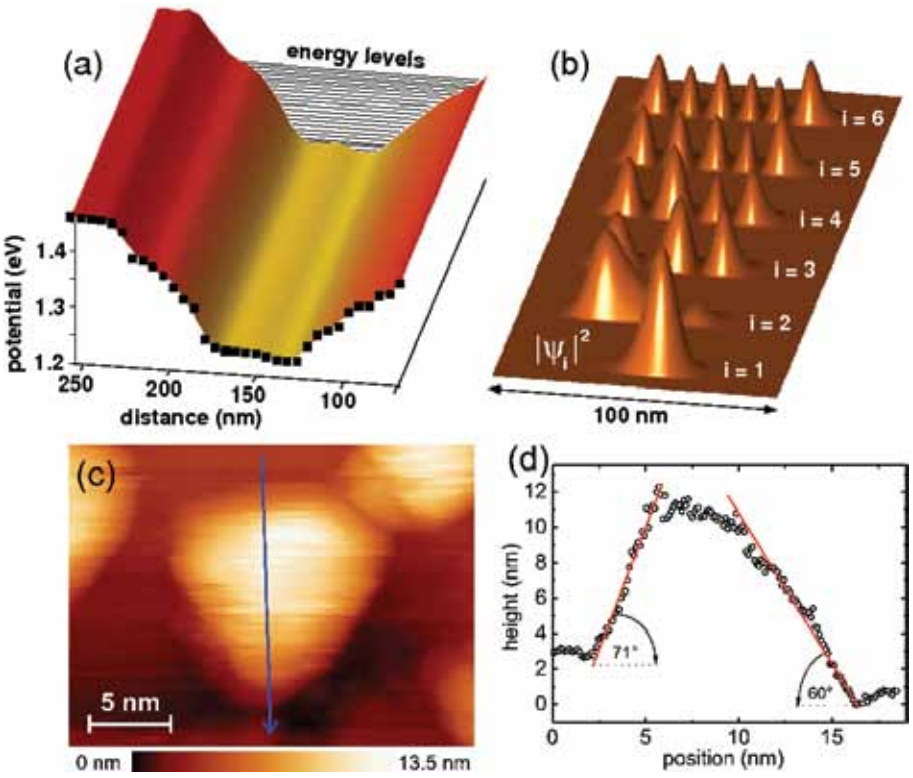


Fig. 2. (a) Quantum-well potential obtained through polynomial fitting to the measured profile (squares) in a chalcopyrite multilayer and the first quantized energy levels (lines). (b) Squares of the first six eigenstates confined in the potential [2]. (c-d) Scanning electron microscopy image of a tetrahedral CuGaSe2 nanodot and its height profile [3].

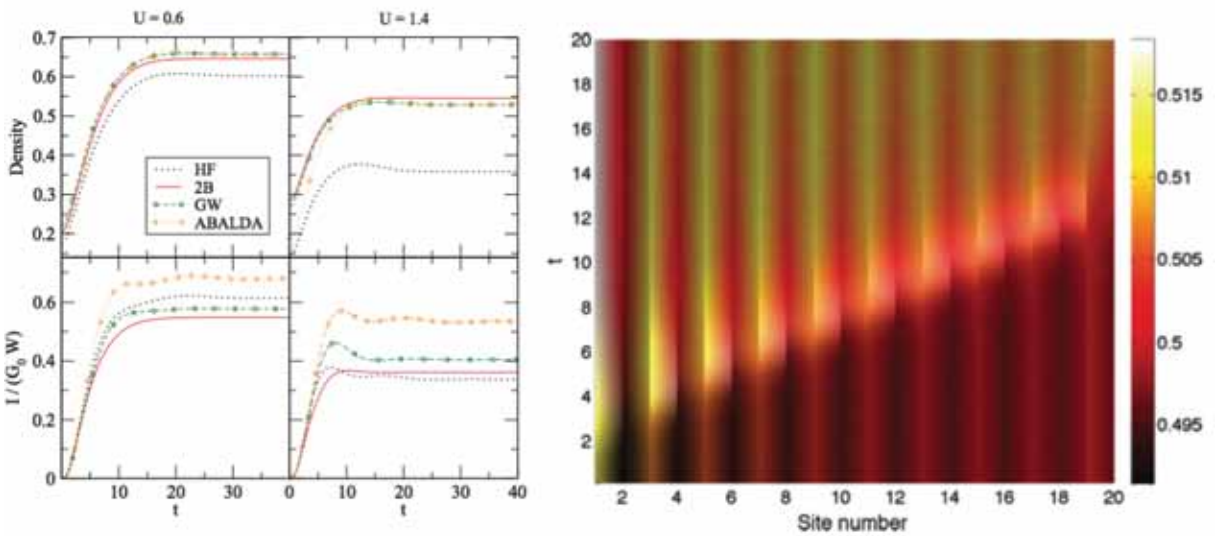
Many-electron effects in time-dependent transport through single molecules

Robert van Leeuwen

We explored the time-dependent phenomena that take place in single molecular junctions consisting of a molecule coupled to metallic macroscopic leads. The theoretical description of the physics of such a system is very challenging as it involves the calculation of out-of-equilibrium observables of an open many-electron quantum system. As many of the fast electronic processes cannot be resolved by experimental techniques many fundamental questions on the processes in such systems have remained unanswered. Since the quantum processes involve time-dependent changes of the electron number in the molecular junction, we have developed [1] a many-body technique for quantum transport based on the time propagation of the particle and hole Green's functions that describe the addition and removal of electrons. Parallel to this development researchers elsewhere advanced an effective, but in principle exact, mean-field like approach based on time-dependent density-functional theory to describe time-dependent quantum transport in which the many-electron interactions are described by a local potential functionally dependent on the density. In an international collaboration we tested and compared [2] both approaches for the out-of-equilibrium Anderson model involving a single correlated atom coupled to one-dimensional leads. This system was chosen due to the availability of accurate benchmark data. It was found that the many-body method that we developed agrees very well with the exact data which gives confidence in the method for more complicated systems. Furthermore it was found that commonly used adiabatic approximations used in density functional theory are insufficient to describe the nonlocal effects introduced by electronic interactions.

Fig. 3. Left: Time-dependent densities at the central atom and currents into the right lead after a sudden switch-on of a voltage (U=strength of two-body interaction). The mean-field (HF) and density-functional (ABALDA) approaches deviate from the more accurate many-body approaches (2B,GW). Right: Density wave entering the right lead as a function of time and atom number (site) in the lead, for the many-body approach in the 2nd Born approximation [2].

[1] P.Myöhänen, A.Stan, G.Stefanucci and R.van Leeuwen, Phys.Rev. B 80, 115107 (2009)
[2] A.-M.Uimonen, E.Khosravi, A.Stan, G.Stefanucci, S.Kurth, R van Leeuwen and E.K.U.Gross, Phys.Rev. B 84, 115103 (2011)



Soft Condensed Matter and Statistical Physics

Markku Kataja, Juha Merikoski and Jussi Timonen

X-ray tomography laboratory

The X-ray Tomography Laboratory operated by the group includes three tomographic devices used for 3D imaging of the internal micro-structure of heterogeneous materials with a resolution ranging from 40 µm down to 50 nm. After completing the major upgrade of the tomographic scanners in 2009, the acquisition program was continued in 2011 by equipping the Laboratory with devices for sample preparation and manipulation. These devices include a laser system for cutting 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. This acquisition phase will be completed by June 2012. In addition to X-ray scanners, the laboratory is equipped with specific devices for measuring various transport properties of materials. The facility was actively used in basic and applied research related e.g. to structural analysis and development of fibre based materials, and structural properties of minerals and biological materials such as ceramics, bentonite clay and bone.

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Mechanics of highly deformable solids

Large deformations and instabilities of soft solids are important in a variety of biological and physical systems. In particular, strongly compressed, or swelling, elastic layers exhibit an instability that leads to formation of sharp sulci. Previous studies have focused on simulations and theory of two dimensional systems, while so far three dimensional systems have only been studied in experiments. We are now exploring sulcation of a three dimensional medium by the numerical model we have developed for highly deformable solids.

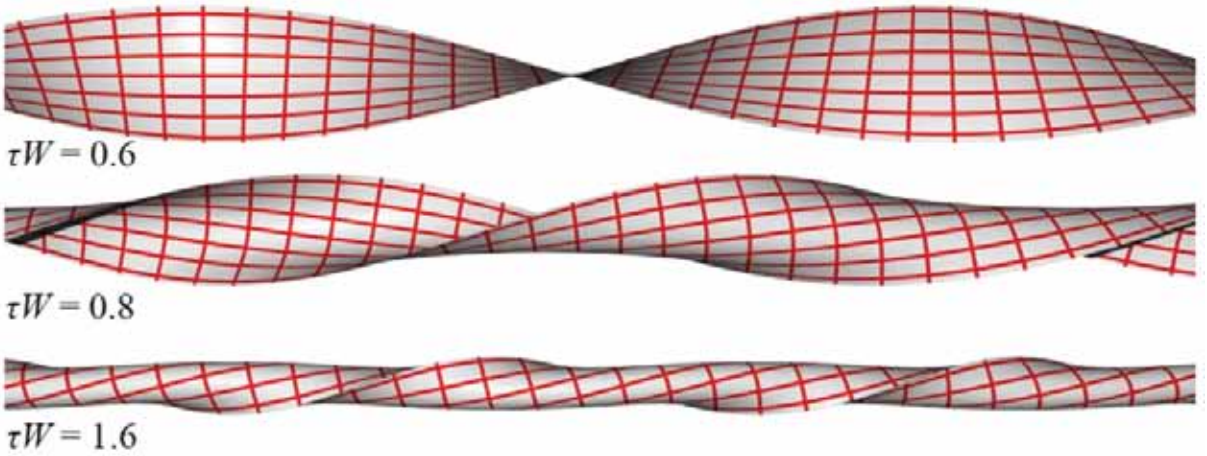
We studied fracture of thin sheets utilizing the previously developed discrete element model of crumpling. This work was stimulated by a variety of complex patterns observed when thin sheets of brittle and ductile materials are torn by blunt objects. These apparently very complex patterns were captured by tuning the elastic and plastic properties and the fracture criterion of the material. We now understand the important role ductility plays in the formation of fracture geometry, and how that role can be explained by fundamental principles of fracture mechanics. For example, purely brittle sheets are characterized by an oscillatory motion of a single crack, which is qualitatively different from wedge formation in the fracture of ductile sheets.

Elasticity theory was formulated for twisting of thin elastic ribbons with or without external longitudinal strain, and buckling of the ribbon as a function of twisting was analyzed. The subsequent formation of a carbon nanotube with well defined chirality in the case of graphene ribbons, upon bond formation between adjacent ribbon edges, was analyzed by Pekka Koskinen's group at the NanoScience Center.

Stochastic systems

We continued our studies of transport of complex objects that experience strong time-dependent driving fields using stochastic models and master equation methods. In addition to one-dimensional polymer-like objects, we extended our method so as to study also two-dimensional objects, with islands on a solid surface as an application. In that case we used a generic bond-counting model and considered different types of time variation of the external field. We showed how pulsed and rotated fields coupled with shape fluctuations can, for a suitably chosen frequency of the field, increase the drift velocity. We also combined our numerically exact master equation method with graph optimization methods such

Fig. 1. An elastic ribbon remains initially flat under twisting, but upon increasing the twist it first buckles, and there after its edges approach each other so as to finally form a tube.



that we could optimize the transport properties with respect to model parameters and identify the dominating transition cycles and transport mechanisms.

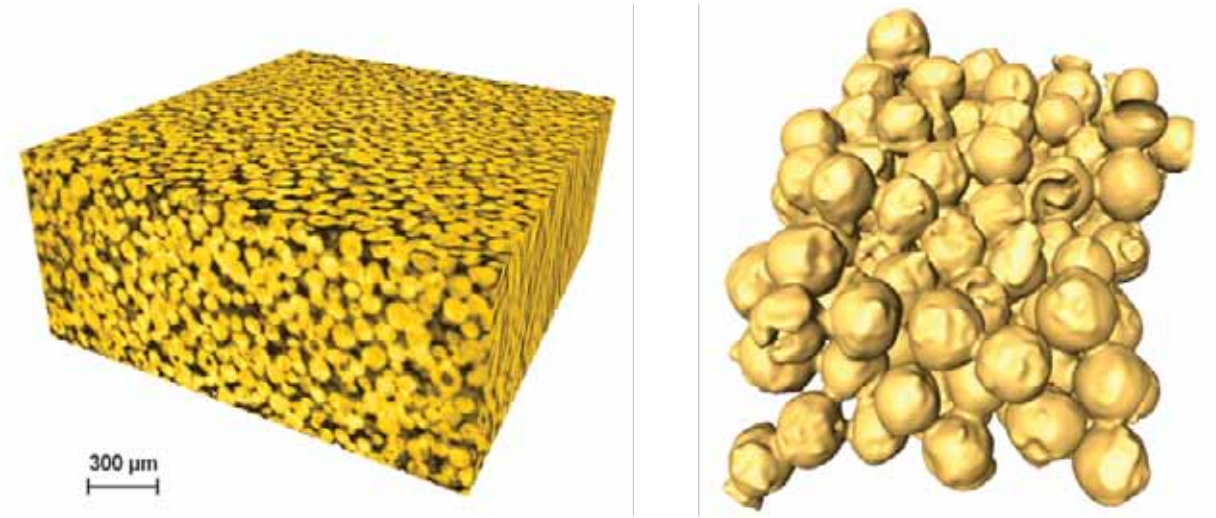
Heat transfer, diffusion and fluid flow in porous media

The in-plane thermal conductivity of porous sintered bronze plates was studied both experimentally and numerically. We developed and validated an experimental setup, where the sample was placed in vacuum and heated while its time-dependent temperature field was measured with an infrared camera. A vacuum chamber was utilized so that the convective heat transfer was completely eliminated. The system was modelled by relevant one-dimensional heat-diffusion equation that was solved numerically. The measured temperature data were fitted by the solution of the heat equation, with thermal conductivity and emissivity as the two fitting parameters.

The porosity and detailed three-dimensional structure of the sintered samples were determined by X-ray microtomography. Lattice-Boltzmann simulations of thermal conductivity in the tomographic reconstructions of the samples were used to correct the contact area between bronze particles as determined by image analysis from the tomographic reconstructions. Small openings in the (apparent) contacts could not be detected with the imaging resolution used, and they caused an apparent thermal contact resistance between particles. With this correction included, the behaviour of the measured thermal conductivity was successfully explained by an analytical expression, originally derived for regular structures, which involved three structural parameters of the porous structure: the contact area per particle and the numbers of particles per unit length and per unit area. All three parameters were determined from tomographic reconstructions of the samples. There was no simple relationship between heat conductivity and porosity.

3D distributions of minerals (X-ray tomography) and porosities (the C-14-PMMA method) were determined for rock samples that included water-conducting fractures. In the analysis of these samples conventional petrography methods and electron microscopy were as well used. It seems that the properties of rock around a water-conducting fracture depend on so many uncorrelated factors that no clear pattern

Fig. 2. 3D visualization of part of a tomographic reconstruction of a sintered bronze plate (left). 3D rendering of bronze particles inside a sintered bronze plate (right). The average diameter of the particles is about 130 µm.

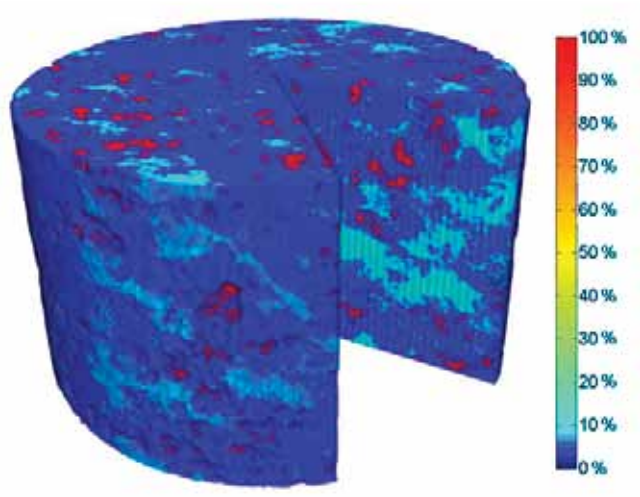


emerged even for rock samples with a given type of fracture. We can conclude, however, that when a combination of different analysis methods is used, novel structural information can be inferred of the alteration zones adjacent to fracture surfaces.

Three-dimensional distribution of porosity was obtained for rock samples by combining distributions of different minerals (X-ray tomography) with mineral specific porosities (the C-14-PMMA method combined with staining of specific minerals). The effect of heterogeneous distribution of porosity on diffusion of tracers could then be analyzed by simulating diffusion in the porosity maps obtained. To this end a simulation method was developed based on random walkers in a Lagrangian formulation with finite volumes and continuous time. The method was found to be especially convenient when dealing with large systems since it was 10–50 faster than the traditional random walker methods. In some types of rock the effect of heterogeneity on the diffusion coefficient was about 10 percent in a centimetre scale, while other types of rock appeared almost homogeneous in that length scale.

In addition, porosities, permeabilities, and diffusion coefficients were measured using He-gas methods of rock samples taken from the nuclear waste repository under construction in Olkiluoto on the west coast of Finland. Comparison will later be made with results of in situ measurements that are being carried out in Olkiluoto, and with those of complementary measurements to be carried out in water phase at the University of Helsinki.

Fig. 3. 3D porosity map of altered Sievi tonalite.



Structural analysis of fibres and fibre networks

The enzyme-cellulose interaction and the effect of different additives were analyzed for three different enzymes using mainly AFM. We developed a method that allowed imaging of individual fibres at same location before and after an enzyme treatment. To this end fibres were attached to a special holder. For high concentrations of enzymes abundant non-specific binding of fibres was observed. Pre-treatment of fibres with a cationic polymer reduced the binding of enzymes, whereas pre-treatment with a cationic surfactant did not have a noticeable effect. Immersion of enzyme treated fibres in a high PH liquid removed the enzymes, but caused also swelling of the fibres. Bound enzymes could also be removed using AFM in contact mode. In this way adhesion forces can as well be estimated.

Spreading and absorption of small (down to pico-litre size) liquid drops in paper were analyzed with an ultrafast camera system and also with confocal microscopy using fluorescent substances in the liquid and the substrate. Related simulations with a lattice-Boltzmann code that included point-like particles suspended in a liquid, developed for this purpose, indicated good agreement between simulated and measured absorption behaviour of the liquid. The camera system was developed further so as to include the possibility to measure also the surface tension of the liquid used.

An important quantity of fibrous materials is the mean segment length between fibre-fibre contacts as it is related to material strength and is a natural ingredient when constructing theoretical models for such structures. A new method to determine this quantity was developed based on theoretical results for 3D deposited networks of fibres. An explicit relation was also derived between the mean segment length and the number density of fibre-fibre contacts. An analytical expression was derived for the mean segment length in terms of the average length of the shortest paths along fibres through the sample. The lengths of such paths could be determined by applying a distance transform to tomographic reconstructions of actual networks. Numerically generated networks were used to validate the method, and the results found for samples of cardboard were in excellent agreement with theory.

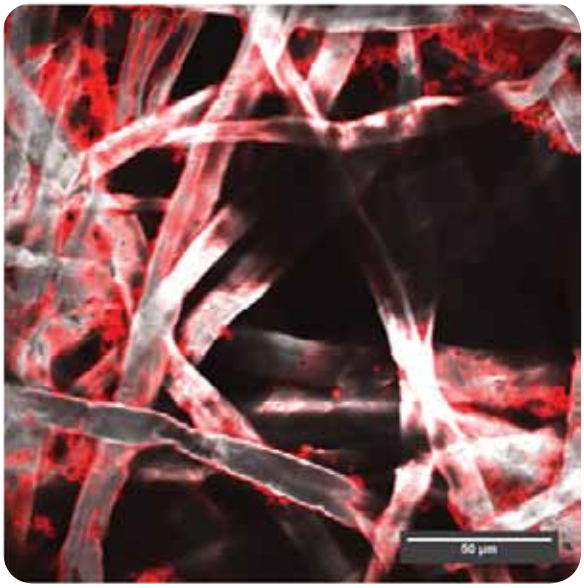
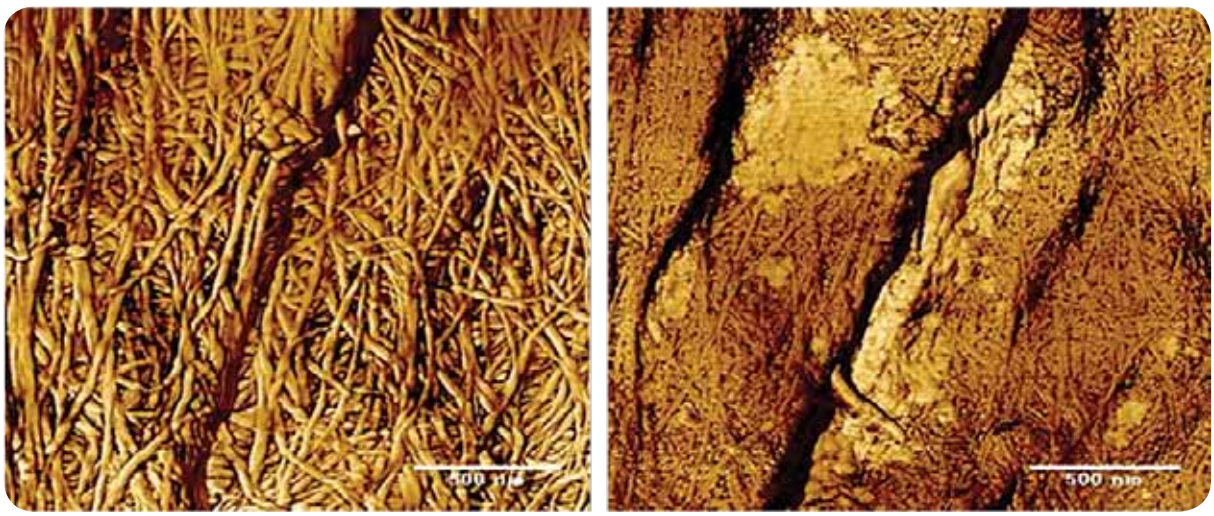


Fig. 5. Spreading of liquid in the surface layer of paper as determined by confocal microscopy with fluorescent labelling.

Inversion based methods were applied to analyzing the structure of paper. A Bayesian inversion framework was used to retrieve approximately the areal mass distribution of paper from its optical transmission image. Optical data were augmented with a priori knowledge of the mass distribution obtained by X-ray microtomography. In this way the optical transmission images of paper could be transformed so that they resembled fairly closely the corresponding X-ray transmission images. In addition, a novel wavelet-based curvelet analysis was introduced for measuring the orientation distribution and orientation anisotropy in paper. Illumination of paper surface for its optical imaging was analyzed so as to determine the conditions under which surface features can reliably be determined.

Fig. 4. Surface structure of a cellulose fibre as determined by AFM (left). Enzymes attached to fibre surface partly removed by washing with alcohol (right).



Material modelling of bentonite clay

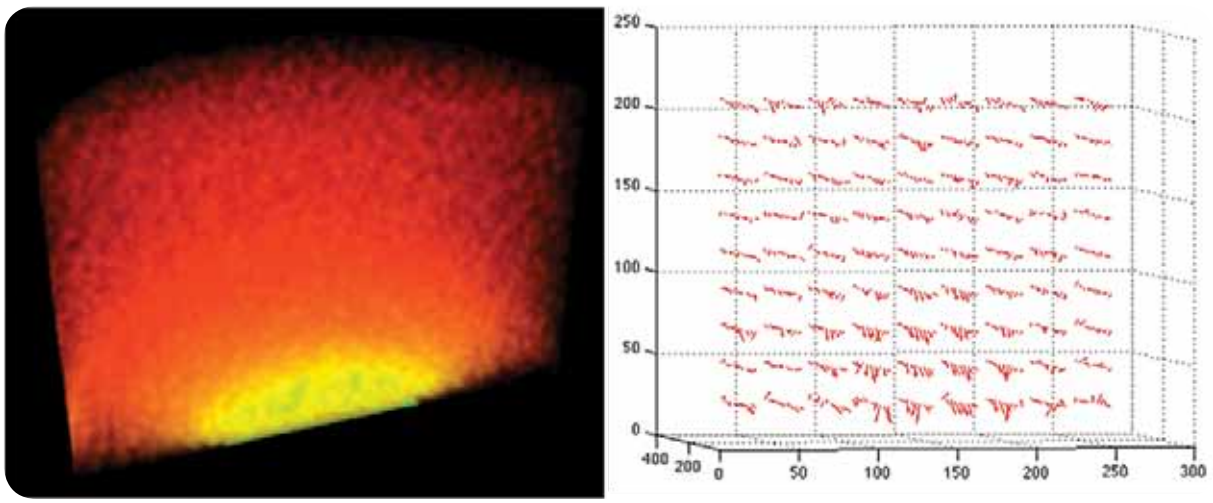
This long-term research is part of methods development for the safety analysis of the final disposal facility of spent nuclear fuel in Finland. The earlier thermo-mechanical model for bentonite clay that is used as a buffer material was previously updated to include large elasto-plastic deformations of the solid. The model is based on a covariant spatial formalism, and it is also possible to include plastic deformations in the model.

In order to find a realistic constitutive model for bentonite clay we developed experimental methods to measure its wetting, swelling and yielding behaviour. During 2011, the first set of systematic experiments was carried out on the elasto-plastic properties of bentonite samples under uniaxial and hydrostatic compression. In addition, transport of water, and 3D deformation of bentonite during wetting, were studied using X-ray tomography which enabled monitoring of the density variation and displacements under varying humidity in compacted bentonite samples (see Fig. NN).

Fig. 6. A cross-section of an X-ray reconstruction of a compacted bentonite sample after one day of wetting with colour-coded density (left). Material displacement field inside the sample caused by wetting and measured by correlating X-ray reconstructions of the dry and wet sample (right).

Assessment of bone by ultrasonic methods

Methods are being developed for improved multi-modal ultrasonic assessment of long bones, such as the radius and tibia. Two ultrasonic guided wave modes, a fast first arriving signal (FAS) and a slow guided wave (SGW) can be measured in bone at low ultrasonic frequencies (f=50-500kHz). At such frequencies, ultrasonic wavelength in bone is long enough for probing osteoporotic changes deep in the endosteal (inner) cortical bone. In an in vivo study on 254 voluntary subjects (age 20-88 y) it was shown that an array ultrasonic transducer, developed and optimized by the group for the FAS mode, indeed probed well bone treats such as subcortical bone mineral density and cortical thickness (r=0.7-0.8; p<0.001). In a further clinical study it was shown that the FAS can discriminate subjects with a history of osteoporotic fractures from those without fractures, which indicates the diagnostic efficiency of this wave mode. The other mode, SGW, is consistent with Lamb A0 mode and shows excellent sensitivity to cortical bone thickness. It is challenging, however, to excite and detect the SGW through the overlying soft tissue by means of traditional contact ultrasound transducers. To this end, a new technique based on photo-acoustic excitation and detection is being developed in collaboration with the Department of Physics at the University of Helsinki and the Department



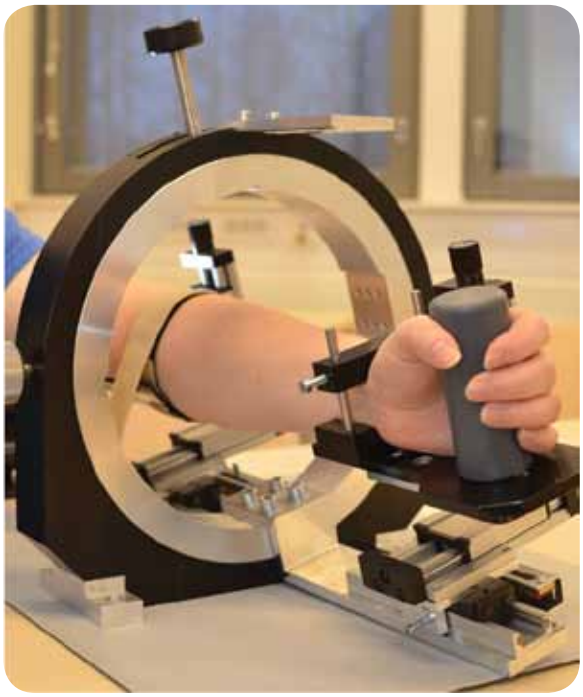


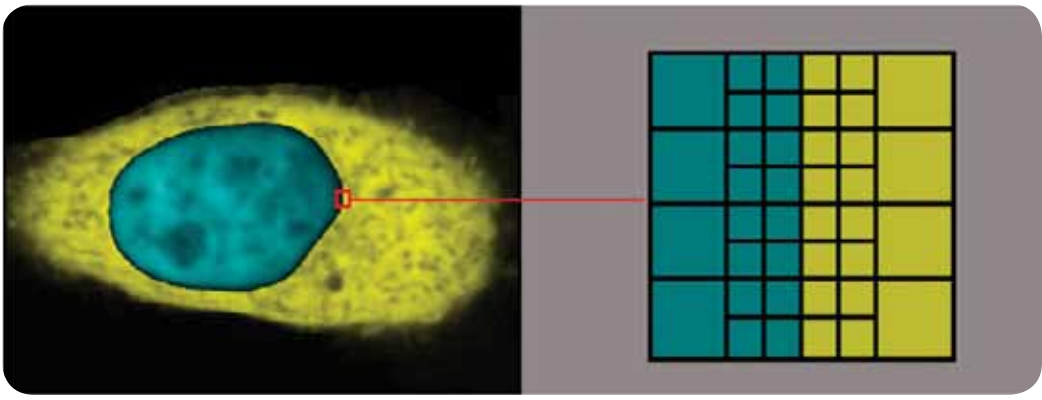
Fig. 7. A forearm holder designed and constructed for photo-acoustic ultrasound measurements on the radius.

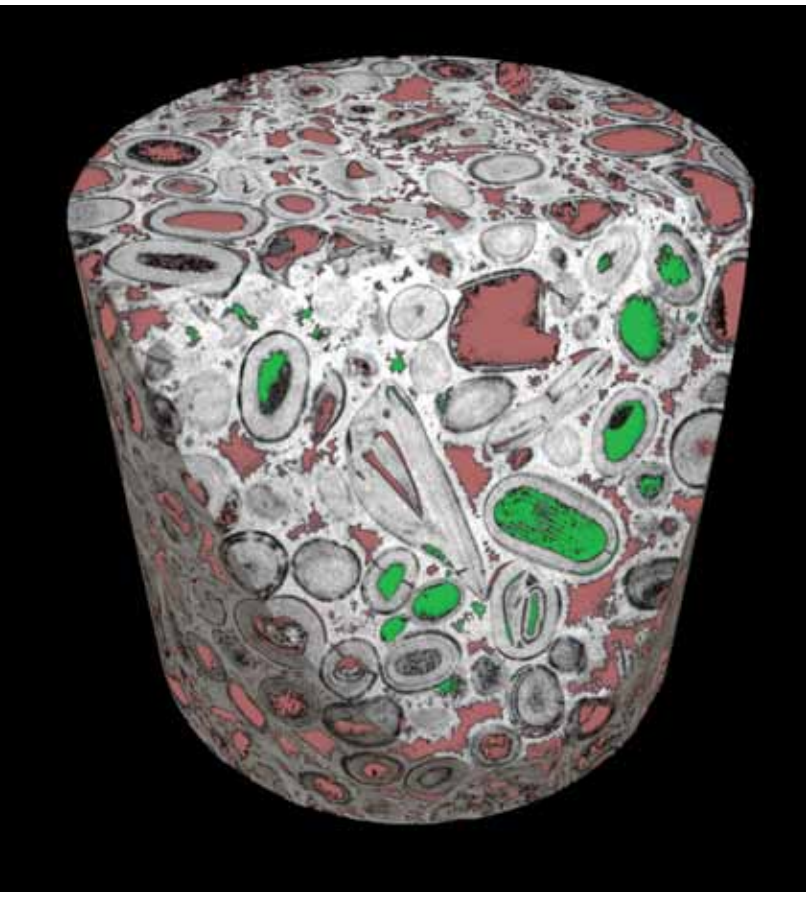
of Electrical and Information Engineering at the University of Oulu. Initial results from experiments on bone phantoms were positive, suggesting that photo-acoustics enables measurement of the SGW through a thin coating layer. In particular, photo-acoustics enabled tailoring of the excited ultrasound mode which is useful for reducing the impact of interferences caused by the soft tissue coating. A new device setup was designed and assembled to enable reproducible photo-acoustic in vivo measurements on the human forearm. A patent application was filed on the newly developed approach of photo-acoustic bone assessment.

Structure of and protein transport in Eucaryotic cells

Nanometre-scale resolution in three-dimensional tomographic imaging of individual cells has opened a completely new view into biological imaging. Using soft X-rays (517 eV) the inner cellular structures can be observed with a resolution of 30 nm for sample sizes of up to 15 µm. Imaging of nuclear architecture of mouse olfactory neurons was done using the XM-2 X-ray microscope in the Advanced Light Source facility at Lawrence Berkeley National Laboratory (LBNL) in the National Center for X-ray Tomography. Gene expression is thought to be regulated by gene positioning and nuclear architecture. We developed noise-reduction methods and image-analysis techniques so as to determine the structural features of euchromatin and heterochromatin regions inside the cell nucleus. Based on our results it indeed seems that nuclear architecture and compartmentalization have an instructive role in gene regulation.

Fig. 8. A model cell constructed on the basis of confocal microscopy imaging. The cytoplasm was labelled with a yellow fluorescent protein, and the structure of the cell nucleus and the location of the nuclear envelope were determined with a simultaneous use of a chromatin-binding cyan fluorescent protein. A grid refinement algorithm was implemented around the nuclear envelope represented by a two-pixel thick layer between the cytoplasm and nucleoplasm.





3D characterization of porosity of Savonniéres Limestone using X-ray tomography. Pores connected to the boundaries are marked red and those unconnected to the boundaries are marked green. The height and diameter of the sample are 4.3 mm and 4.8 mm, respectively. The voxel size is 2.53 µm.

In collaboration with the Department of Biological and Environmental Science a new method was developed to analyze protein dynamics in living cells. This method combines construction of a realistic 3D model cell based on confocal microscopy imaging of the cell containing suitable fluorophores with numerical modelling of protein transport using the lattice-Boltzmann method. With this method we could mimic in detail photobleaching (FRAP) experiments carried out on the same cells for which the model cells were constructed. Comparison of measured and simulated FRAP data was used to determine the diffusion coefficient (only diffusion at this initial stage) in the cytoplasm of the protein used. We distinguished diffusion in the liquid phase (cytosol) from that in the complicated cellular environment (cytoplasm), and could in this way resolve an old problem of widely varying diffusion coefficients depending on measuring techniques. This method is being extended to the cell nucleus and nuclear translocation.

Experimental Particle Physics

Jan Rak and Wladyslaw Trzaska

ALICE

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After completing an excellent proton-proton period that concluded in the end of October 2011 at the verge of discovery of the still elusive Higgs boson, CERN LHC ended the year with an extraordinary Heavy Ion run – the focus of ALICE physics interests. The peak luminosity was five times higher than expected and even exceeded by a factor of two the design value for this energy. The integrated luminosity was fifteen times higher than in 2010 and the collected statistics have grown by over an order of magnitude.

T0 has played a visible role in this success constituting an integral part of the ALICE trigger and providing vertex identification with nearly 100% efficiency and timing resolution of better than 30ps. Furthermore, our group is responsible for the level-0 single-photon trigger electronics which has been successfully commissioned together with the new EMCAL super-modules installation. The 2011 *Pb+Pb* run was very important to ALICE because, most likely, it was the last heavy-ion run before the long shutdown scheduled for 2013 – 2014.

The focus of our data analysis was on high-p_T sector and the jet transverse fragmentation function. These phenomena are related to the quantum coherence effects and their modification in nuclear collisions and serve us as the tools to study the details of parton interaction with the deconfined medium. For instance, we have contributed to the reconstruction of the transverse momentum component of the associated particle with respect to the jet axis ($k_\perp$).

During 28 August – 2 September 2011 we have hosted ALICE Physics Week 2011 – the key scientific event of the year of our collaboration. It was the first physics meeting when ALICE discussed the analysis of the *Pb+Pb* run and the large data sample taken in 2010. With 138 participants and 83 talks it is the largest ALICE Physics Week on record.

From the left: Andre Rubbia, Dave Wark and Takashi Kobayashi inspecting EMMA construction site during the visit to the Pyhäsalmi mine at the start of GLA2011.

Transportation of EMMA detectors underground.

Astroparticle Physics

2011 has marked the completion of the LAGUNA Design Study and the start of LAGUNA–LBNO (Long Baseline Neutrino Oscillations) – the second and the final Design Study for LAGUNA supported in part by the FP7 Research Infrastructure Grant. This project has teamed up 300 physicists and industrial partners from 14 countries to plan a large-scale, underground neutrino detector complex for fundamental research in particle and astroparticle physics. Pyhäsalmi – the deepest mine in Europe and the location of CUPP and EMMA experiment – has emerged as the strongest contender for the site of the proposed giant detector. Our group has on its responsibility one of the project's five Work Packages.

LAGUNA is being 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 Earth's interior, the LAGUNA detectors will detect neutrinos artificially produced at particle accelerators hundreds of kilometers away. The same accelerator complex at CERN

Participants of the 2011 ALICE Physics Week on the way to the conference dinner in Savutuvan Apaja.

that injects particles into the Large Hadron Collider could be used for producing a neutrino beam sent through the Earth's crust to the Pyhäsalmi mine. The distance between CERN and Pyhäsalmi mine, 2300 km, is optimal for such long baseline experiments, which will help to reveal extraordinary properties of neutrinos, such as determination of the mass hierarchy and the possible violation of the CP symmetry and probe the stability of matter.

If sterile neutrinos exist, although they lack fundamental gauge interactions, nevertheless they should manifest themselves by modulating the known (three-flavour) neutrino oscillation pattern. Our calculations indicate that with a proper detector such subtle effects would be measureable. For instance, using the source similar to the one used for GALLEX experiment and placed close to a liquid scintillator detector one should observe, in addition to the smooth slope governed by the θ_{13} mixing parameter, an additional, high frequency component with period length of about 1 m. With a sufficiently long detector (e.g. LENA) to cover many of such fluctuations, a proper fitting procedure should be able to revile the existence of the sterile neutrino pattern and perhaps distinguish between the (3+1) and the (3+2) scenario. Our results were presented and discussed at the NNN11 conference in Zurich.

On June 5 – 10, 2012 we have hosted GLA2011 – the 2nd International Workshop towards the Giant Liquid Argon Charge Imaging Experiment. This event has attracted 60 scientists interested in realizing a giant neutrino observatory based on the liquid Argon time projection chamber technology, combining next-generation searches for proton decay and neutrino physics with natural and artificial sources. The workshop included a visit to the Pyhäsalmi Mine.

Ultrarelativistic heavy ion collisions – theory

Kari J. Eskola, Tuomas Lappi, Thorsten Renk and Kimmo Tuominen

Kari J. Eskola, professor
Kimmo Tuominen, university lecturer, HIP project leader
Thorsten Renk, academy research fellow
Tuomas Lappi, academy postdoctoral researcher
Rupa Chatterjee, postdoctoral researcher
Heli Honkanen, postdoctoral researcher 1.2.–
Topi Kähärä, postdoctoral researcher (HIP/JYFL)
Harri Niemi, postdoctoral researcher 1.10.–
Hannu Holopainen, graduate student –16.10.
Jussi Auvinen, graduate student
Ilkka Helenius, graduate student
Risto Paatelainen, graduate student
Heikki Mäntysaari, MSc student

Studies of strongly interacting elementary particle matter, the Quark Gluon Plasma (QGP), and its transition to a hadron gas in ultrarelativistic heavy ion collisions (URHIC) are among the basic 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 (SA), GRASPANP, private foundations and EU, and our studies are also part of K. Tuominen's *LNCPMP* HIP project activities. We have an extensive network of foreign research collaborators. We participate actively in international meetings, graduate school networks and EU networks, and interact closely also with the local experimental group. In 2011 Drs. Honkanen, Kähärä and Niemi were our new postdocs, H. Holopainen reached the PhD degree and moved on to a postdoctoral position in Frankfurt.

In heavy-ion phenomenology, the year 2011 with the big *Quark Matter 2011* meeting in Annecy, offered various exciting new results from Pb+Pb collisions at the LHC. Remarkably, these results are now confirming the validity of the hydrodynamical picture in describing the spacetime evolution of the produced QCD matter. In the hydrodynamical modelling, using our pQCD&saturation-based initial states, we have charted the hadron production systematics from RHIC to LHC against the LHC measurements. We have developed a Monte Carlo (MC) -based event-by-event hydro framework, which accounts for the initial QCD-matter density fluctuations – a framework crucial for extracting the QCD matter viscosity from the measurements. Related to this, Holopainen received the 2011 Nuclear Physics A *Young Scientist Award* for the best theory talk in *QM2011*. We have also studied production of thermal photons, focusing especially on their elliptic flow for which some very exciting RHIC measurements were published. Also the importance of the density fluctuations in enhancing the thermal photon yields has now been pointed out by us.

High-p_T observables, ranging from single-hadron spectra and few-particle correlations to hadronic jets, are important QCD-matter probes in URHIC at RHIC and LHC. We are

conducting systematic studies of various hard-parton interaction models within hydrodynamical medium evolution scenarios and developing MC codes, such as YaJEM, for in-medium jet physics. We have established that the data is consistent with perturbative medium-induced radiation combined with a small component of elastic energy loss. This suggests further constrains for the hydrodynamical evolution, the initial state fluctuations (Fig. 1) and the constituents of the medium, while on the other hand we have found non-perturbative strong coupling scenarios disfavoured by the data.

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 of nPDFs, the set *EKS98*, is a standard reference in the field, and our *EPS09* package defines the state of the art for the nPDFs and their uncertainties. We have applied *EPS09* in the NLO pQCD computation of prompt photon production in nuclear collisions, and now also in the QGP initial-state studies mentioned above. We have participated in the planning of the possible future LHeC collider and LHC p+Pb runs. Studies of the spatial dependence of the nPDFs have been launched.

In the Color-Glass-Condensate (CGC) framework, we are continuing our studies of high energy QCD. We have now published the first results from our new numerical code for solving the JIMWLK renormalization group equation that describes the energy dependence of QCD cross sections. It has been applied both to single inclusive gluon production in URHIC and to multigluon correlations.

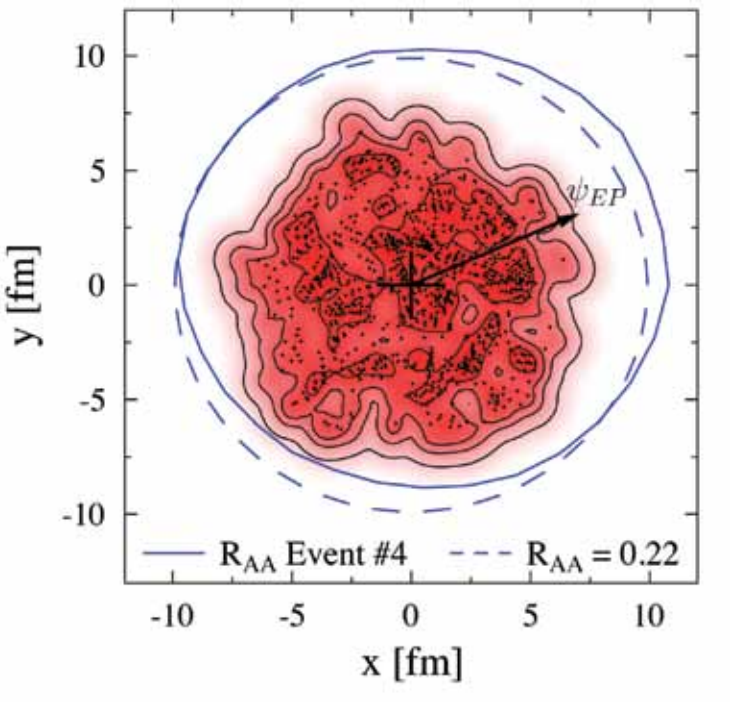


Fig. 1. Initial-state temperature profile in the transverse-coordinate plane, constant-T contours for T = 160, 300, 400, 500 MeV; binary collision points; the event plane direction; and a polar plot of the nuclear modification ratio $R_{AA}(\phi)$ at p_T=10 GeV, for a selected event in 200 GeV Au+Au collisions.

In effective theories of QCD, we have continued our studies on phase diagrams of two-flavor QCD using effective models of chiral fields and the Polyakov loop. As a new direction, we have extended these models to study theories with two flavors in the adjoint or sextet representations of the SU(3) color group.

Neutrinos and Beyond the Standard Model Physics

Jukka Maalampi and Kimmo Tuominen

Jukka Maalampi, professor
Kimmo Tuominen, university lecturer, HIP project leader
Hidenori Sakuma, postdoctoral researcher (HIP/JYFL)
Timo Alho, graduate student
Tuomas Karavirta, graduate student
Topi Kähärä, postdoctoral researcher (JYFL/HIP)
Janne Riiltinen, graduate student
Tommi Alanne, MSc student
Henri Jukkala, MSc student
Ilkka Mäkinen, MSc student
Tero Oravasaari, MSc student

Neutrino physics

Jukka Maalampi

Our activity in neutrino physics covers topics both in neutrino phenomenology and experiments. Our phenomenological studies are concentrated on the neutrino oscillation phenomena and neutrino cosmology. The focus has been on the hypothetical sterile neutrinos, particles that lack fundamental interactions except gravity. We have investigated the possibilities for the so-called leptogenesis in particular a class of models defined in five-dimensional spacetime. The leptogenesis is the mechanism for the creation of the baryon asymmetry of the universe through neutrino physics phenomena violating the conservation of CP symmetry.

Our neutrino theory group participates in the LAGUNA-LBNO project (see the previous Section), having at this stage of the project contributed mainly to administrative and promotional matters. The main physics aims of the project, such as determining the neutrino mass hierarchy and the leptonic CP violation angle, are crucially important for the development of neutrino physics theory. The intriguing observation recently made in T2K, MINOS and Daya Bay experiments that the value of the so far unknown mixing angle θ_{13} is higher than expected, around 8 degrees, stengthens the reliance on that these aims could be reached with a conventional long-baseline neutrino beam from CERN to Pyhäsalmi mine.

Particle physics beyond the Standard Model

Kimmo Tuominen

The successful running of the CERN Large Hadron Collider (LHC) during 2011 culminated with a glimpse of a possible experimental evidence of the Higgs boson. The efforts to improve the experimental verification of the mechanism for the electroweak symmetry breaking will be the focus of the LHC experiments during 2012. The experimental program continues to provide increased impetus for theoretical elementary particle physics research worldwide. Our focus is on electroweak symmetry breaking (EWSB)

mechanisms and the associated Beyond Standard Model (BSM) phenomenology. 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.

We have investigated various BSM theories featuring supersymmetry but also non-supersymmetric ones like the walking Technicolor (MWT) model, which we constructed and showed to be viable in light of existing particle accelerator data in 2005. Since then, we have analysed the collider signatures, established possible dark matter candidates and studied the nonperturbative properties of MWT 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 recent studies are motivated in particular by flavour physics. During 2011 we have considered the implications of vector mesons in Technicolor theories on flavour observables. Overall, the origin of the generational structure of the Standard Model is one of its most poorly understood aspects. Also Technicolor must be extended in order to include the mechanism to generate fermion masses. As one possibility, we considered supersymmetrization of the minimal walking Technicolor. This ultraviolet complete model, interestingly, features N=4 supersymmetric sector with the maximal supersymmetry broken only by the electroweak gauging. We have shown how this model helps to alleviate the flavour and hierarchy problems present in the minimal supersymmetric Standard Model, and electroweak symmetry breaking is due to natural strong dynamics while the scalar superpartners provide for the fermion masses.

Our group has also 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 with matter. 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. During 2011 we completed the improvement of the Wilson fermion action for SU(2) and SU(3) gauge theories with fermions in fundamental or higher representations. Large scale simulations were carried out for SU(2) gauge theory with four, six and ten fermion flavours.

A complementary method to obtain nonperturbative information on strong interactions is the application of gauge/gravity correspondence, which we applied to generic walking Technicolor theories and obtained results on their finite temperature phase diagrams and vacuum spectra. We are currently extending the holographic models to correctly include fermions and chiral symmetry of the boundary theory into the bulk dynamics.

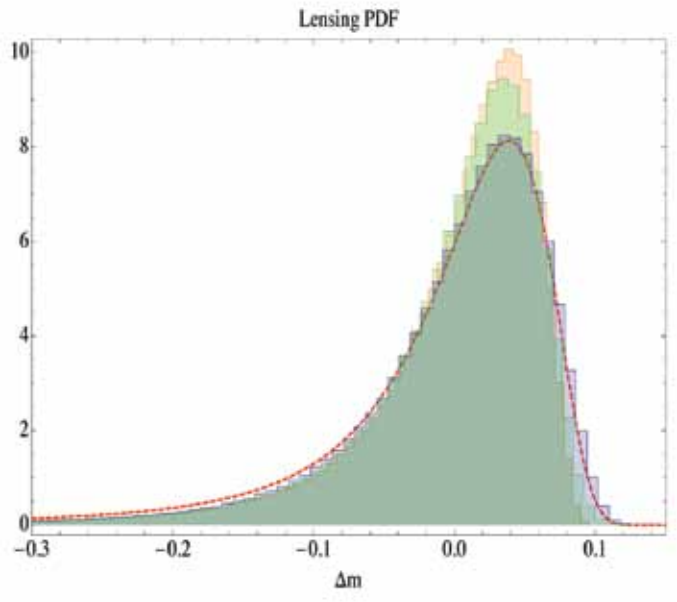
Cosmology

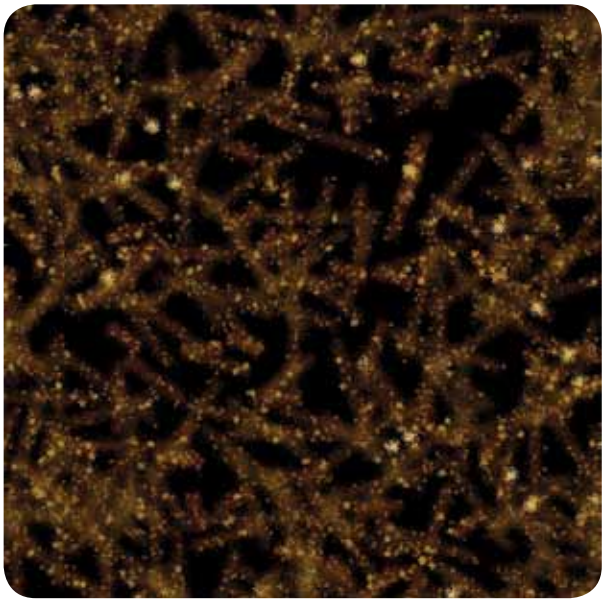
Kimmo Kainulainen

Kimmo Kainulainen, university lecturer
Valerio Marra, postdoctoral researcher –15.10.
Jussi Virkajärvi, postdoctoral researcher
Pyry M. Rahkila, graduate student
Joni Pasanen, graduate student
Mikko Pääkkönen, graduate student
Joonas Ilmavirta, MSc student

We have continued the development of our stochastic Gravitational Lensing (sGL) method for computing the weak gravitational lensing corrections on light propagation in inhomogeneous universes. The sGL method is currently capable of simulating universes with a realistic distribution of virialized Halos confined into filamentary large scale structures (see figure 1), and it matches well the results from large scale numerical simulations. We also derived analytic expressions for the expected value and the variance of the lensing PDF including arbitrary functions to model the selection biases. We are currently extending the sGL to the analysis of angular distribution of strongly lensed quasar images and of weak lensing corrections to one- and two point angular correlation functions. The latter may be of relevance both for quasars

Fig. 1. Shown in left is a depth projection of the random matter density distribution in a (100 h^{-1}Mpc)^3 cube generated by our improved Halo Model. In iHM halos (galaxies and clusters of galaxies) are stochastically distributed, but confined to filamentary low-density objects. Shown in right is the weak lensing magnification PDF computed from the iHM simulation (dark blue histogram). Also shown is the lensing PDF from the Millenium simulation (dotted line) and from a simple Halo Model simulation (orange histogram) where Halos are not constrained to filaments.





and for the CMB analysis at high multipoles. Along with the sGL papers we again release upgraded versions of our numerical code package turboGL.

We have also studied spherically symmetric inhomogeneous models with multicomponent non-comoving fluids with arbitrary equations of state. We found a particularly transparent form for the equations for the metric using physically motivated variables. These equations can be used to study a large variety of cosmological and astrophysical problems. So far we have considered a model sourced by two non-comoving dust components and a cosmological constant, and a model featuring dust and a dark energy component with a negligible speed of sound.

We are studying dark matter in a class of minimal walking technicolor models, which can provide a dynamical electroweak symmetry breaking consistently with the precision electroweak constraints along with a good 1-loop gauge unification. The complete DM sector of the model is similar to that of neutralinos in the MSSM and we are currently finalizing a comprehensive scan of the entire parameter space of the model, which appears to provide interesting and testable parameter regions containing viable DM candidates.

We extended our quantum transport formalism, which includes nonlocal coherence to the case of flavor mixing fields both for scalars fermions. See figure 2 for an illustration of the cQPA dispersion relations. For fermions we gave also an alternative covariant derivation of the cQPA equations and of the extended coherent Feynman rules. We showed that the singular coherence shell contributions to the dynamical cQPA 2-point functions are directly related to the quantum mechanical squeezing. We are currently applying our method to derive the quantum Boltzmann equations for neutrino mixing and to compute Leptogenesis with two heavy mixing Majorana neutrinos, both in the resonant and non-resonant regimes. Moreover, during 2012 we expect to have our first results of the cQPA formalism applied to the case of the electroweak baryogenesis.

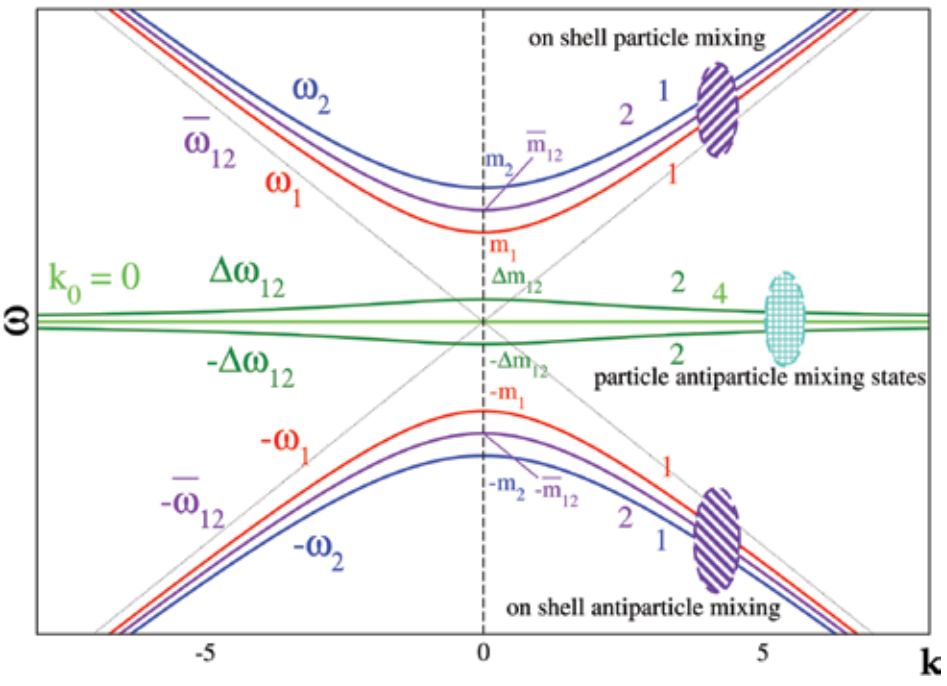


Fig 2. Shown is the cQPA shell structure for the case of two-flavor mixing fermions. Heavy state 1 (blue) has mass m1 = 3 (in arbitrary units) and light 2 (red) m2 = 2. Each curve is labeled by its energy eigenvalue and all particle-antiparticle coherence solutions are shown with dashed (green) lines. The number in parenthesis beside each eigenvalue gives the (real) degeneracy of the corresponding solution.

Industrial Collaboration

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

The Industrial Applications group of the accelerator laboratory won the first prize and a cheque for 10 000 € in an academic entrepreneurship competition, which is organized every year for Finnish universities. The organizers are the Finland Chamber of Commerce, Confederation of Finnish Industries and Federation of Finnish Enterprises.

Again in 2011, the group had numerous contacts with domestic and foreign industry and research laboratories. Thirty three irradiation campaigns for 13 international partners were performed at RADEF facility. The users were mainly from European space industry, but also researchers from NASA's Jet Propulsion Laboratory from Pasadena, USA, and Japan Aerospace Exploration Agency (JAXA) from Sengen, Japan, were doing the tests.

We also performed a specific technical assessment project for ESA on "Effects of the ion specie and energy on the oxide damage and SEGR failure". The objective of this study was to determine the worst-case conditions for SEGR testing and inject the results in ESA's SEE test guidelines. This work will continue during the spring 2012.

RADEF participated also in EU FP7-Space-2010-1 project, where the aim is to develop RadHard non volatile flash memories for space applications. The project started in September 1st and the consortium consists of two companies and six universities from Italy, Israel, Greece, Spain, Sweden and Finland. The SEE tests will be performed in Jyväskylä by using our standard high-penetration ion cocktail. The duration of the project is 30 months.

The irradiations of the polymer membranes for OxypheN GmbH also continued with the three campaigns in the year 2011. A new contract for coming six years was negotiated and signed at the end of the year.

The total beam time used for these activities during the year 2011 was 1401 hours. From those 60% was used for space related tests, 17% for membrane irradiations and the rest of beam time was used for research and R&D work. The activity with MAP Medical Technologies Ltd. stayed on stand-by situation, but negotiations to start the radioisotope production again in 2012 with the new cyclotron was started.

The Accelerator Based Materials Physics group is a research and development unit in the interdisciplinary EU-FP7 project HIghLY-SENSitive low-cost lab-on-a-chip system for Lyme disease diagnosis (HILYSENS). The project brings together 6 SMEs and the goal is to develop a low-cost disposable biomedical test kit having all the analysis functions integrated into a microfluidics chip.

In 2011 two new partially industry funded projects started: one 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 HIUDADE develops new

detectors and digitized data acquisition for ion beam analysis purposes. Both projects have several industrial partners. In addition, several new national and international customers have taken advantage on service measurements the group can offer in elemental depth profiling.

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 2011 we finished a TEKES/EAKR and Jyväskylä Innovation funded project, where a ultrasensitive X-ray spectrometer setup was developed for novel terrestrial materials science applications. That consortium included also Aivon Oy and Star Cryoelectronics Inc. from USA as industrial partners, in addition to Oxford Instruments. A new TEKES funded project also was also approved, where the goal is now to demonstrate the new functionalities of the instrument and establish the commercial scale fabrication of the detector chips in collaboration with VTT at Micronova micro- and nanofabrication center in Espoo. The same companies are still involved, including 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 lamit.fi funded by Jyväskylä Innovation and and Suomen Luonnonvarain Tutkimussäätiö, to develop integrable solar energy collection. 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.

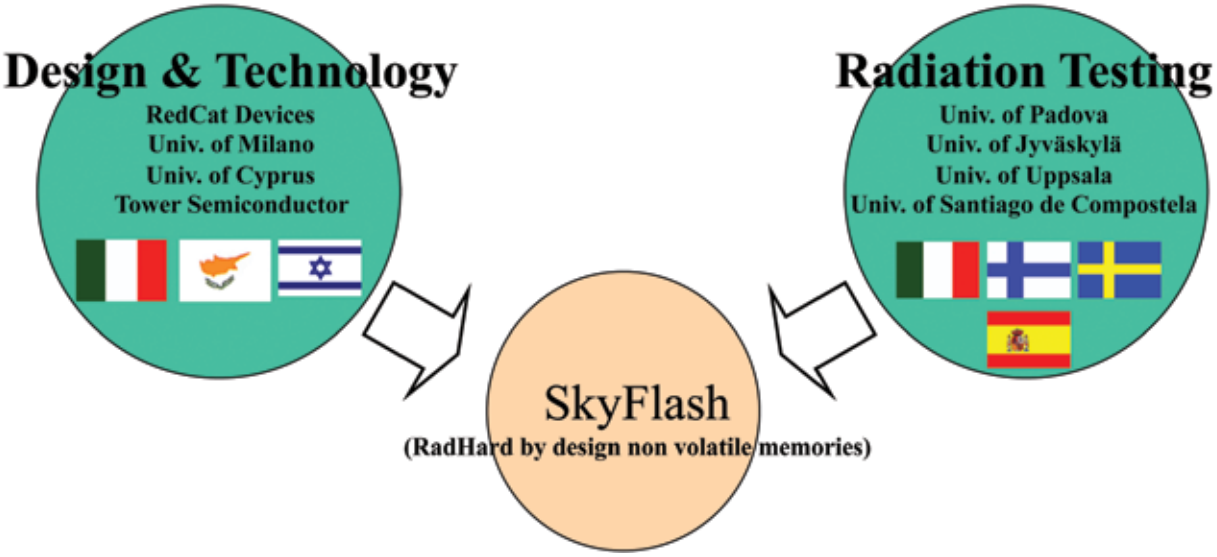
The group runs an extensive x-ray tomographic laboratory for three-dimensional imaging of material structures, which includes three x-ray scanners and sample manipulation devices. The internal micro-structure and properties of a wide variety of heterogeneous materials can and have been analyzed in the laboratory. Other imaging modalities have also been used, including e.g. electron microscopy, atomic force microscopy and confocal laser scanning microscopy. Laboratory is equipped in addition with a versatile set of devices 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 fibrous materials, and training of VTT stuff for utilizing x-ray tomographic techniques.

Individual projects were related e.g. to development of novel fibre 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.



The consortium divided in design and testing parties.

Education

Jukka Maalampi and Juha Merikoski

The year 2011 was for the Department the second 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.

Jukka Maalampi, professor
Juha Merikoski, university lecturer
Pekka Koskinen, academy research fellow
Jussi Helaakoski, graduate student
Toni Purontaka, graduate student
Timo Aho, MSc student
Jari Alftan, MSc student
Kalle Auranen, MSc student
Axel Ekman, MSc student
Anna Huuskonen, MSc student
Vesa Partanen, MSc student
Anni Rossi, MSc Student
Sami Sorvo, MSc student
Riku Tuovinen, MSc student -31.3.

From teaching to learning

The development of basic level courses has continued at the Department, with the emphasis been shifted from teaching to learning. On the first physics courses peer instruction methods utilizing clickers have been employed such that a 'lecture' proceeds through a series of multiple-choice questions for the students to discuss in small groups and answer. This provides means for immediate feedback to both the 'lecturer' and to the student, including statistics of misunderstandings. Also new ways to organize the homework problem recitals have been adopted on some courses such that the students are divided in small groups to discuss their own solutions, instead of the traditional approach, where more or less complete model solutions are given and explained to a larger group.

These developments have further activated the students resulting in considerably better learning outcomes. The new six compulsory courses on mathematical methods have now each been given at least once. 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 adopt more interactive teaching methods on higher-level physics courses. To facilitate new teaching methods, a second lecture hall is going to be renovated and equipped to be better suitable for supervised work in small groups.

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.

GIREP-EPEC conference

In August one of the largest international conferences devoted to physics education, the GIREP-EPEC conference, this time with the theme *Physics Alive*, was organized at the Department. The conference program consisted of over one hundred presentations and nine workshops, attracting 154 participants from 34 countries.

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 21st Jyväskylä International Summer School.

Contacts with schools

To provide high-school students a hands-on experience on research work the Department offered, in summer 2011 for a third time, summer jobs for students interested in science. The newspaper advertisement produced about 84 applicants from 21 schools, of whom ten most promising students 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 2011 there were 650 applicants for physics studies, with 390 of them indicating physics as their first choice. As a whole, 85 undergraduate students enrolled in autumn 2011. Additionally 20 undergraduate students enrolled in January 2011. Over 90% of the new BSc students are admitted based on their high school record and national maturity test result, the rest via a traditional entrance examination. The total number of undergraduate students is almost 540. Some students with a polytechnic engineering background study in the master programs for industrial physics and renewable energy. At the Department there are 84 post-graduate students aiming at the PhD degree. In 2011 the number of MSc degrees taken at the Department was 39, seven of them with teacher qualifications. The number of PhD degrees was 14.

Personnel

HEAD OF THE DEPARTMENT

Jukka Maalampi, prof.

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Rauno Julin, prof.
Markku Kataja, prof.

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Paul Greenlees (ERC award)

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Claudia Gomes da Rocha 22.6.-
Karl Hauschild –30.7.
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Veli Kolhinen
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Pekka Koskinen -31.8.
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Araceli Lopez-Martens –30.7.
Olga Lopez Acevedo –30.6.
Valerio Marra (HIP/JYFL) -15.10.
Keijo Mattila -30.6.
Nicolas Michel -10.9.
Petro Moilanen
Iain Moore (Rector's "tenure track" funding)
Astrid Morreale 1.10.-
Mika Mustonen -30.6.
Harri Niemi 1.10.-
Päivi Nieminen
Heikki Penttilä
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Tuomas Puurtinen 1.7.-
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Wladyslaw Trzaska
Juha Uusitalo
Petr Vesely -6.9.
Jussi Virkajärvi
Ari Virtanen
Nobuyki Zen -25.3.

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Ville Toivanen
Riku Tuovinen
Tuomas Turpeinen
Anna-Maija Uimonen
Mikko Voutilainen
Markku Väisänen
Emanuel Ydrefors
Peerapong Yotprayoonsak

MSc students are listed in research reports.

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Antti Nuottajärvi (on leave 1.–31.12.)
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Raimo Seppälä
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Soili Leskinen
Ritva Väyrynen

Peer Reviewed Articles

ACCELERATOR FACILITIES

O. Tarvainen, T. Kalvas, J. Komppula, H. Koivisto, E. Geros, J. Stelzer, G. Rouleau, K. F. Johnson and J. Carmichael
Effect of Ion Escape Velocity and Conversion Surface Material on H– Production
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J. Noland, O. Tarvainen, J. Benitez, D. Leitner, C. Lyneis and J. Verboncoeur
Studies of electron heating on a 6.4 GHz ECR ion source through measurement of diamagnetic current and plasma bremsstrahlung
Plasma Sources Sci. Technol. 20 (2011) 35022

T. Ropponen, O. Tarvainen, I. Izotov, J. Noland, V. Toivanen, G. Machicoane, D. Leitner, H. Koivisto, T. Kalvas, P. Peura, P. Jones, V. Skalyga and V. Zorin
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V. Toivanen, H. Koivisto, O Steczkiewicz, L. Celona, O. Tarvainen, T. Ropponen, S. Gammino, D. Mascali and G. Ciavola
Erratum: Effect of electron cyclotron resonance ion source frequency tuning on ion beam intensity and quality at Department of Physics, University of Jyvaskyla (vol 81, 02A319, 2010)
Rev. Sci. Instrum. 82 (2011) 029901

FINLAND DISTINGUISHED PROFESSOR –FIDIPRO – PROGRAMME

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Isospin mixing in nuclei around N~Z and the superallowed beta-decay
Acta Phys. Pol. B42 (2011) 415

P. Veselý, J. Dobaczewski, N. Michel and J. Toivanen
Finite-range separable pairing interaction within the new N^{3}LO DFT approach
AIP Conference Proceedings 1377 (2011) 456

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Theses and Degrees

THESES

BSc THESES
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Timo Aho, Newtonin I laki ja sen opettaminen lukiofysiikassa

Mikko Ahonen, Kuitusupension tutkiminen kameralla

Saara Alatalo, Sateenkaaret peruskoulun ja lukion fysiikassa

Jari Alftan, Eksoplaneetat

Mikko Haaranen, Ytimen Cd-115 beetahajoaminen

Matti Hakkarainen, Energian siirtyminen perusopetuksen kirjoissa

Tero Harjupatana, Röntgentomografia ja sen käyttö materiaalien 3D muodonmuutosten mittaamiseen

Markku Hyrkäs, Kvanttimekaanisen aaltopaketin potentiaalivallisironnan mallintaminen

Juhani Hyvärinen, Nesteen pintajännityksen määrittäminen vertailemalla teoreettisia ja kokeellisia pisaraprofiileja

Jyri Hämäläinen, Aharonov-Bohm effect in concentric quantum rings

Joonas Ilmavirta, Coherence in Neutrino Oscillations

Henri Jukkala, Leptonien heikko vuorovaikutus Fermin teoriassa

Jaakko Julin, Nopeiden hiukkasten energiamittaus puolijohdeilmaisimella

Joonas Kiviniemi, Neutronirikkaiden zirkonium-isotooppien tutkiminen IGISOL- ja JYFLTRAP-menetelmillä

Topi Korhonen, Exact electron dynamics in quantum rings

Janne Laulainen, Plasman vanginnan ja elektronitiheyden vaikutus ECR-ionilähteen suorituskykyyn

Juuso-Matias Maijanen, Aivojen toiminta

Tatu Mustonen, Leptonien syvä epäelastinen sironta, partonimalli ja DRELL-YAN-prosessi

Janne Nevalaita, Density functional studies on water-gas shift catalysis with gold

Tero Oravasaari, Syvä epäelastinen sironta, partonimalli ja rakennefunktiot

Toni Pikkarainen, Penningin loukku osana Jyväskylän yliopiston IGISOL-laitteen toimintaa

Anni Rossi, Fysiikan yliopisto-opetuksen kehittäminen

Verneri Ruonala, Methods in functionalizing DNA

Aki Saarela, Lämpövoimakone termodynaamisen prosessin mallina lukio-opetuksessa

Juuso Saikko, Opiskeltavan aiheen yhdistäminen aiempaan tietorakenteeseen lukion laskutehtävissä: pyöriminen ja gravitaatio

Ilkka Sirjonen, Niobilangan valmistus käyttäen polymeeritöntä SIN/SIO maskia

Joonas Soininen, Lineaarikiihdyttimet ja pelletron

Janne Solanpää, Configurational and Dynamical Properties of Finite Wigner Crystals

MSc THESES
(alphabetical order)

Timo Aho, Opettajien pedagoginen sisältötieto yläkoulun virtapiirien opetuksessa

Tommi Alanne, Supersymmetrinen tekniväri

Benjamin Ames, Yksittäisten TiO2 anataasi nanopartikkelien valmistus, manipulointi ja loukutus

Kalle Auranen, Energeettisten protonien jarruuntuminen nestemäisessä vedessä

Svitlana Baieva, Pintaplasmonien vuorovaikutus sulforodaami 101 väriaineen kanssa

Gül Bekcioglu, Orbital-free method for large-scale electronic-structure calculations

Irina Bostan, Study of linear response in Hubbard chains using many-body perturbation theory

Axel Ekman, Determining the number of fibre-fibre contacts in cardboard samples using tomographic imaging

Zhuoran Geng, Development of an inductive NIS thermometer

Mikko Hasanen, Hiekan sedimentoituminen yksiulotteisessa suotometrissa

Alex Hedlund, Ydinreaktioiden sisällyttäminen SEU-virheiden ennustamiseen

Heli Hoilijoki, JYFLTRAP-laitteistolla mitattujen atomimassojen vertailu atomimassamalleihin

Matti Hokkanen, Hiilinanoputkien käyttö transistori-komponenteissa: hiilinanoputkinäytteiden laadun parantaminen, transistorikomponentti

Tuomas Huopana, Energy efficient model for biogas production in farm scale

Anna Huuskonen, Lukion sähköopin ja sähkömagnetismin opetusmateriaalin tietorakenteiden kartoittaminen ja kehitysehdotusten etsiminen

Markku Hyrkäs, Kvantti-ilmiöt yksiulotteisissa optisissa vakiovyöhiloissa

Jaakko Julin, Hyvän energiaerotuskyvyn kaasuionisaatioilmaisimen kehittäminen rekyylispektrometriin

Antti Juutilainen, Fabrication of engineered tunneling junctions to individual carbon nanotubes

Sampsa Kaijaluoto, Teknisten ja katsojasta riippuvien tekijöiden vaikutus radiologisten kuvien havainnointiin

Pasi Keinänen, Hiilinanoputkien kemiallinen funktionalisointi amiinilla

Joonas Kiviniemi, CMaS Spektrianalysoinnin automatisointi

Joonas Konki, Geant4 simulations and measurements of the performance of the SAGE spectrometer

Topi Korhonen, Many-particle approach to lead-molecule interactions and the image-charge effect

Jason Kramb, Potential applications of nanotechnology in bioenergy

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Ilkka Mäkinen, Supersymmetry, supergravity and the AdS/CFT correspondence

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Janne Nevalaita, Veden hajoamisreaktion ja vesi-kaasu -reaktion energetiikka MgO, MgO/Ag ja Au/MgO/Ag -pinnoilla

Seppo-Tapio Paasonen, Conductivity measurements of DNA TX tile and origami structures

Joni Parkkonen, Riippumattomien isotooppisten fissiotuottojen määrittäminen 25 MeV:n ja 50 MeV:n protoneilla indusoidussa 238U:n fissiossa

Vesa Partanen, Kompakti automatisoitu laserionijärjestelmä

Aki Puurunen, Radioaktiivisten jätteiden kartoitus kiihdytinlaboratoriossa

Aki Saarela, Termodynamiikan peruskäsitteet lukion fysiikassa ja kemiassa

Sami Sorvo, Tehokasta kielitiedettä – opetus-puheen koodausoppaan kielitieteellinen perusta ja tutkimus fysiikan vaikutuspiirien merkityksestä sähkötehon oppimistuloksiin

Sanna Stolze, Determining the lifetime of the first 4+ state in 182Pt

Camtu Tale, Determination of TIP Profile for Atomic Force Microscopy

Riku Tuovinen, Many-body approach to the image charge effect

Hannes Vainionpää, Compact Wien filter for measuring light ion beams

Chen Zhang, Net-zero energy technical shelter

PhLic THESES

Antti Vanhanen, Säteilybiologisten riskimallien soveltaminen sädehoidon aiheuttamien determinististen myöhäishaittojen ja sekundaarisen syövän riskin arvioimisessa
JYFL Laboratory Report 1/2011

PhD THESES

(chronological order)

Janne Juntunen, Diffusion in evolving environment: Monte Carlo studies of discrete models
JYFL Research Report 1/2011

Veikko Linko, Dna-based applications in molecular electronics
JYFL Research Report 2/2011

Nitipon Puttaraksa, Development of MeV ion beam lithography technique for microfluidic applications
JYFL Research Report 3/2011

Hannu Holopainen, Event-by-event hydrodynamics and thermal photon production in ultra-relativistic heavy ion collisions
JYFL Research Report 4/2011

Juho-Antti Rissanen, Penning-trap-assisted decay spectroscopy studies of neutron-rich nuclei in the A = 110 region
JYFL Research Report 6/2011

Jan Sarén, The ion-optical design of the MARA recoil separator and absolute transmission measurements of the RITU gas-filled recoil separator
JYFL Research Report 7/2011

Jarkko Lievonen, Force measurements and tip shape approximation with the atomic force microscope
JYFL Research Report 8/2011

Antti Saastamoinen, Studies of Tz = -3/2 Nuclei of Astrophysical Interest
JYFL Research Report 9/2011

Francesco Raimondi, Higher-order energy density functionals in nuclear self-consistent theory
JYFL Research Report 10/2011

Lasse Miettinen, In-plane conductive heat transfer in solid and porous planar structures
JYFL Research Report 11/2011

A.R. Ananda Sagari, Ca-P-O thin film preparation, modification and characterisation
JYFL Research Report 12/2011

Kimmo Kinnunen, Studies of transition-edge sensor physics: noise and thermal models
JYFL Research Report 13/2011

Janne Keränen, Increasing the drying efficiency of cylinder drying
JYFL Research Report 14/2011

DEGREES

(alphabetical order)

BSc DEGREES

(main subject is physics)

Aho, Timo
Ahonen, Mikko
Alatalo, Saara
Auranen, Kalle
Ekman, Axel
Haaranen, Mikko
Harjupatana, Tero
Hyrkäs, Markku
Hämäläinen, Jyri
Ilmavirta, Joonas
Iso-Ahola, Pekka
Jukkala, Henri
Julin, Jaakko
Juutilainen, Antti
Kiviniemi, Joonas
Konttinen, Mikko
Laulainen, Janne
Mustonen, Tatu
Mäkinen, Ilkka
Nevalaita, Janne
Nikkarikoski, Jarkko
Oravasaari, Tero
Paatelainen, Risto
Partanen, Jari
Partanen, Vesa
Repo, Pauli
Riikilä, Timo
Rossi, Anni
Ruonala, Verneri
Saarela, Aki
Saukkonen, Jaakko
Sorvo, Sami
Stolze, Sanna
Toikka, Tauno
Vainio, Laura

MSc DEGREES

(main subject)
**=MSc includes teachers pedagogical studies*

Aho, Timo (physics)*
Alanne, Tommi (theor. physics)
Ames, Benjami (appl. physics)
Auranen, Kalle (physics)*
Baieva, Svitlana (physics)
Bekcioglu, Gül (physics)
Bostan, Irina (physics)

Ekman, Axel (physics)*
Geng, Zhuoran (physics)
Hasanen, Mikko (appl. physics
Hedlund, Alex (physics)
Hoilijoki, Heli (physics)
Hokkanen, Matti (appl. physics)
Huopana, Tuomas (appl. physics)
Huuskonen, Anna (physics)*
Hyrkäs, Markku (theor. physics)
Julin, Jaakko (physics)
Juutilainen, Antti (appl. physics)
Kaijaluoto, Sampsa (appl. physics)
Keinänen, Pasi (appl. physics)
Kiviniemi, Joonas (physics)
Konki, Joonas (physics)
Kramb, Jason (appl. physics)
Könönen, Niina (appl. physics)
Mäkinen, Ilkka (theor. physics)
Mäntysaari, Heikki (theor. physics)
Nevalaita, Janne (physics)
Paasonen, Seppo-Tapio (appl. physics)
Paatelainen, Risto (theor. physics)
Parkkonen, Joni (physics)
Partanen, Vesa (physics)*
Puurunen Aki, (physics)
Saukkonen Jaakko, (appl. physics)
Sorvo, Sami (physics)*
Stolze, Sanna (physics)
Tale, Camtu (physics)
Tuovinen, Riku (theor. physics)*
Vainionpää, Jaakko (physics)
Xhang, Chen (appl. physics)

Phil.Lic. DEGREES

Vanhanen, Antti, (appl. physics)

PhD DEGREES

Arcot Rajashekar Anandasagari (physics)
Holopainen, Hannu (theor. physics)
Juntunen, Janne (physics)
Keränen, Janne (appl. physics)
Kinnunen, Kimmo (physics)
Lievonen, Jarkko (physics)
Linko, Veikko (physics)
Miettinen, Lasse (physics)
Puttaraksa, Nitipon (physics)
Raimondi, Francesco (theor. physics)
Rahkila, Panu (physics)
Rissanen, Juho-Antti (physics)
Saastamoinen, Antti (physics)
Sarén, Jan (physics)