# DEPARTMENT OF PHYSICS • UNIVERSITY OF JYVÄSKYLÄ • ANNUAL REPORT 2010

JYFL

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DEPARTMENT OF PHYSICS
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# JYFL

DEPARTMENT OF PHYSICS UNIVERSITY OF JYVÄSKYLÄ

## ANNUAL REPORT 2010

*Graphic design Juho Jäppinen*

# Department of Physics

Jukka Maalampi, Head of Department

This annual report provides a summary of the work and events in the Department of Physics in 2010. The Department continued its strong performance in both research and teaching.

## Research

The research activity and productivity in 2010 was high in all three of our main research areas, materials physics, nuclear and accelerator-based physics, and particle physics.

The total number of peer-reviewed research articles published in 2010 was 191, achieving the same high level as in the previous year. In addition, there were approximately 50 other publications and some 340 oral or poster presentations in conferences. As is characteristic of the Department, the research activity was very international; about 70 % of the peer-reviewed articles were based around international collaborations, and there were some 320 visits by foreign scientists to the Department, and more than 380 visits by the personnel of the Department to overseas locations. The Department participated in five EU projects and many other international projects.

The active collaboration with large international infrastructures has continued. Our research group in experimental ultra relativistic heavy ion physics carries the responsibility for ALICE in Finland and also has an important role to play at CERN. It was a great moment for the group to witness the first lead-

Photo: Juho Jäppinen.

lead collisions in the Large Hadron Collider on 7th November. In October, nine countries signed the international agreement on the construction of the accelerator facility FAIR (Facility for Antiproton and Ion Research), which will be located in Darmstadt, Germany. This long-awaited event was important for us as our Department will carry the main responsibility for Finnish participation in the FAIR project. In addition, the Department has participated in the pan-European LAGUNA project, an EU-funded design study for a construction of a large detector for low-energy neutrinos and proton decay. The study confirmed that the Pyhäsalmi mine, north of Jyväskylä, would be in many respects excellent site for the detector.

## Personnel

The total number of people working in the Department was 184, with no change from the previous year. In this year a new personnel plan of the Department, covering the years 2010-2017, was issued. The main emphasis was put on the gradual move to the four-tier tenure track system, as well as on preparing for the inevitable retirement boom among the professors within the next few years. As a first step in dealing with the challenge posed by the latter fact, two new professorships where announced, one in experimental nuclear physics and the other in theoretical particle physics, particle phenomenology and cosmology. At the same time with these professorships, several other open positions on different tiers were announced. The call was for the first time in the history of the Department organized electronically in the net, and it attracted a good number of applications, some four hundred altogether, and the majority from abroad.

## Education

This year was quite successful from the point of view of teaching. In the number of MSc degrees our standard level (35 graduations) was maintained, and the number of PhD degrees (10) was satisfactory as well. The median time to complete MSc was 6.5 years, somewhat higher than one would wish it to be. The Department has continued its persistent efforts to improve and develop teaching and the instruction of students. As a Centre of Excellence in University Education, the status designated to us by the Finnish Higher Education Evaluation Council for the years 2010–2012, we actively look for new

## Some statistical data from 2010

| | |
|---|---|
| Personnel | 183,5 |
| - professors incl. research professors | 15,5 |
| - lecturers | 5 |
| - senior assistants | 7 |
| - researchers | 131 |
| - technicians | 21 |
| - administration | 4 |
| + several research assistants (MSc students) | |
| | |
| Undergraduate students | 550 |
| of which new students | 120 |
| Graduate students | 83 |
| | |
| BSc | 50 |
| MSc degrees | 35 |
| PhLic degrees | 2 |
| PhD degrees | 10 |
| Credits (national) | 10494 |
| Median time to complete MSc (years) | 6,5 |
| | |
| Number of foreign visitors | ~240 |
| - in visits | ~320 |
| Visits abroad | ~380 |
| | |
| Peer reviewed publications | 191 |
| Conference proceedings | 40 |
| Others (articles in books etc.) | 11 |

| | |
|---|---|
| Conference and workshop contributions | |
| - Invited talks | ~110 |
| - Other talks | ~130 |
| - Posters | ~105 |
| Seminars outside JYFL | ~ 60 |
| | |
| Funding (million €) | 14,8 |
| * University budget (incl. premises) | 9,1 |
| * External funding | 5,7 |
| - Academy of Finland | 3,0 |
| - EAKR | 0,3 |
| - Technology Development Centre, T&E Centres | 0,3 |
| - International programmes | 0,4 |
| - HIP | 0,6 |
| - Contract research | 0,6 |
| - Others | 0,5 |

ways to develop the Department as an inspiring and motivating learning environment with good learning results. In this year a delightful number of 120 new students enrolled the Department, considerably more than we have been used to in recent years.

of external funding was 37 %, showing a substantial downward fluctuation from the previous year's 44 %. The fluctuation is related to the large investments in infrastructures in the corresponding years, which were realized on a different funding basis.

## Administration

The year 2010 will be remembered as a year of many changes related to the reform of the university legislation, which caused much extra work load to our administrative personnel. In spite of unsatisfactorily working new data management systems and insufficiencies in instruction, our personnel succeeded well in carrying us though the transition.

Financially the year turned out to be quite satisfactory, resulting in a considerable budget surplus. The total funding of the Department in 2010 was 14.5 M€, about 4 % more than in the previous year. The proportion

## Events

The extension of the Accelerator Laboratory and the new MCC30/15 cyclotron were subjects of a grand opening ceremony in 15$^{th}$ November. The Minister of Education, Mrs. Henna Virkkunen graced the event and gave a speech. She also cut the ribbon by pressing, together with Rector Aino Sallinen, a sizeable red button.

Yrjö Stenman or Ykä, a significant member of our support personnel and an embodiment of the community spirit, retired after a long and devoted service.

# Centre of Excellence in Nuclear and Accelerator Based Physics

Rauno Julin

The Finnish Centre of Excellence in Nuclear and Accelerator Based Physics (JYFL-CoE) nominated by the Academy of Finland for the period of 2006-2011 covers research and development work as well as ion-beam applications at the Accelerator Laboratory and theoretical nuclear physics activities carried out at JYFL. Highlights and activities of the JYFL-CoE teams in 2010 are summarized in the succeeding reports. The year was successful, resulting, for example in 115 peer reviewed publications.

The JYFL-CoE is one of 36 finalists in the CoE competition for 2012–2017. The evaluation process is going on and the results will be published by the summer 2011.

The final acceptance tests of the new MCC30/15 cyclotron were performed in April and the inauguration ceremony featuring Mrs Henna Virkkunen, Minister of Education, was held on 15th November. Major reconstruction and upgrade of the experimental stations in the JYFL Accelerator Laboratory (JYFL-ACCLAB) was started in the summer. The IGISOL facility was dismantled and construction of IGISOL4 at the new site will be completed by summer 2011. The RADEF cave was also reconstructed.

The JYFL-ACCLAB proposal for the FIRI-infrastructure call of the Academy of Finland scored well and consequently, a total of 960 k€ will be allocated for the construction or upgrade of the MARA separator, the IGISOL facility, the Pelletron accelerator and the K130 cyclotron facility.

In spite of the reconstruction work, the number of beam time hours at the K130 cyclotron used by the JYFL-CoE teams in collaboration with foreign teams for basic research and industrial applications summed up to 6215 hours. Important developments for the facilities at the Pelletron accelerator have also been carried out.

In total, 41 proposals for experiments were evaluated by the Programme Advisory Committee (PAC) of the JYFL-ACCLAB in the meetings on 4 May and 16 October, 2010.

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). The first physics results from the ALICE runs at LHC have already been reported in several publications.

The EU-FP7-IA-project ENSAR was finally approved and started on 1st September. The JYFL-ACCLAB is one of the seven ENSAR access infrastructures. It is also a beneficiary in three ENSAR-JRA projects and in two ENSAR-NA projects.

The JYFL-CoE played an active role in the writing and editing process of the NuPECC Long Range Plan

Fig. 1. Pauli Heikkinen invites Minister Henna Virkkunen and Rector Aino Sallinen to proceed with the inauguration of the new MCC30/15 cyclotron.

2010 (ESF Forward Look), published in December. The JYFL-ACCLAB and the role of stable ion beams in the future are well represented in the document.

A highlight of the year was the awarding of the Lise Meitner Prize to professor Juha Äystö for "Accurate determination of fundamental nuclear properties by the invention of innovative methods of ion guidance and its applications to radioactive ion beams".

The Richard Geller young-scientist prize was awarded to Dr. Olli Tarvainen for " Physics experiments on ECR plasmas that resulted in a deeper understanding of the plasma physics of ECR ion sources".

Paul Greenlees was appointed as Research Professor in the beginning of August, 2010. The nomination is connected to the European Research Council (ERC) grant which was awarded to him in 2008.

Ari Virtanen, who is responsible for the industrial applications of the JYFL-CoE, was appointed as Research Director.

The third international conference on Frontiers In NUclear STructure, Astrophysics and Reactions (FINUSTAR 3) co-organized by the Tandem Accelerator Laboratory of NCSR "Demokritos" and the JYFL-ACCLAB, was held on Rhodes island on 23–27 August.

**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
Samuli Hemming, science adviser. Academy of Finland

**Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory**

Michael Block, GSI, Germany
Lorenzo Corradi, INFN-LNL, Legnaro, Italy
Guenther Dollinger, Universität der Bundeswehr Muenchen, Germany
Thomas Duguet, DSM/IRFU/SPhN, France
Sean Freeman, University of Manchester, UK
Mark Huyse, Katholieke Universiteit Leuven, Belgium.

# Finland Distinguished Professor – FIDIPRO – Programme

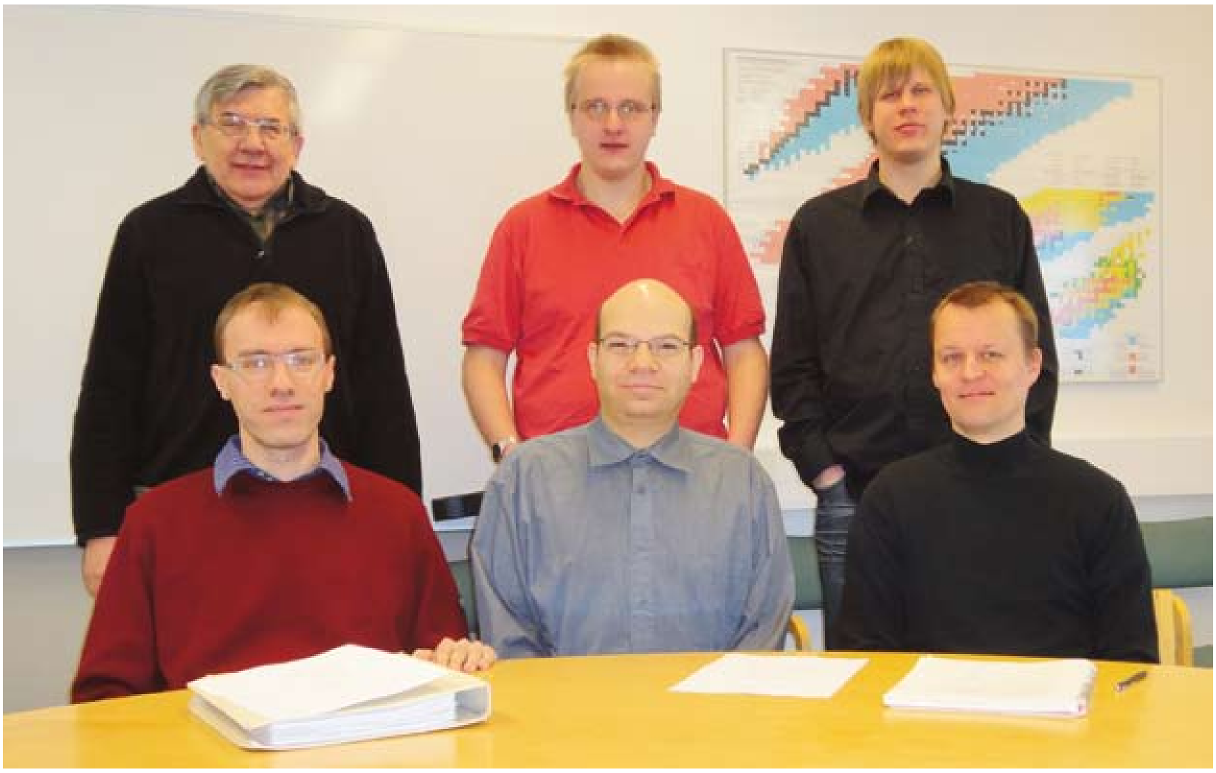
Jacek Dobaczewski

Jacek Dobaczewski, research professor
Nicolas Michel, senior researcher
Jussi Toivanen, senior researcher
Rayner Rodríguez-Guzmán, senior researcher, -31.5.
Gillis Carlsson, postdoctoral researcher, -31.3.
Alessandro Pastore, postdoctoral researcher, -31.10.
Petr Veselý, postdoctoral researcher
Francesco Raimondi, graduate student
Pekka Toivanen, graduate student

In 2010, the project has reached its final stages. The FIDIPRO team comprised 8 and 6 researchers in the first and second half of the year, respectively, 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 2010, the main focus of the project was on linking the energy-density-functional (EDF) methods to basic properties of many-body nuclear systems. In particular, we performed systematic analyses of the density-

The FIDIPRO team on January 21, 2011. Standing, from left: Jacek Dobaczewski, Pekka Toivanen, Petr Veselý, Seated, from left: Francesco Raimondi, Nicolas Michel, Jussi Toivanen



matrix expansion (DME), whereby the quasi-local EDFs can be derived from the nonlocal ones.

## Comparison of the Gogny and Skyrme Functionals

We used the Negele–Vautherin DME to derive a quasi-local density functional for the description of systems of fermions interacting with short-range interactions composed of arbitrary finite-range central, spin–orbit and tensor components. Terms that are absent in the original Negele–Vautherin approach owing to the angle averaging of the density matrix were fixed by employing a gauge invariance condition. We obtained the Kohn–Sham interaction energies in all spin–isospin channels, including the exchange terms, expressed as functions of the local densities and their derivatives up to second (next to leading) order. We illustrated the method by determining the coupling constants of the quasi-local Skyrme functional or zero-range Skyrme force that correspond to the nonlocal Gogny functional or finite-range Gogny central force. As shown in Fig. 1, the resulting self-consistent solutions reproduce the Gogny-force binding energies and radii within the precision of 1–2%.

## Convergence of the DME Expansion

We extended the DME in nuclei to higher orders in derivatives of densities and tested their convergence properties. The expansions allow for converting the interaction energies characteristic to finite- and short-range nuclear effective forces into quasi-local density functionals. We also proposed a new type of expansion that has excellent convergence properties when benchmarked against the binding energies obtained for the Gogny interaction.

In Fig. 2 (left), for the direct term we show percentage deviations between the gradient approximations

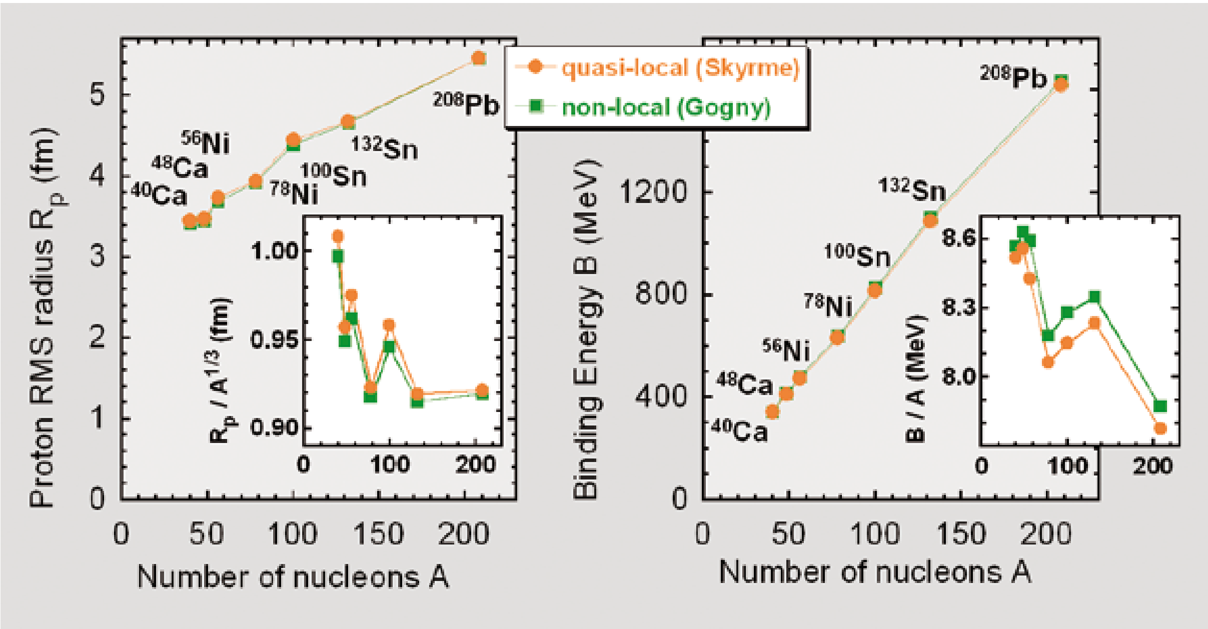
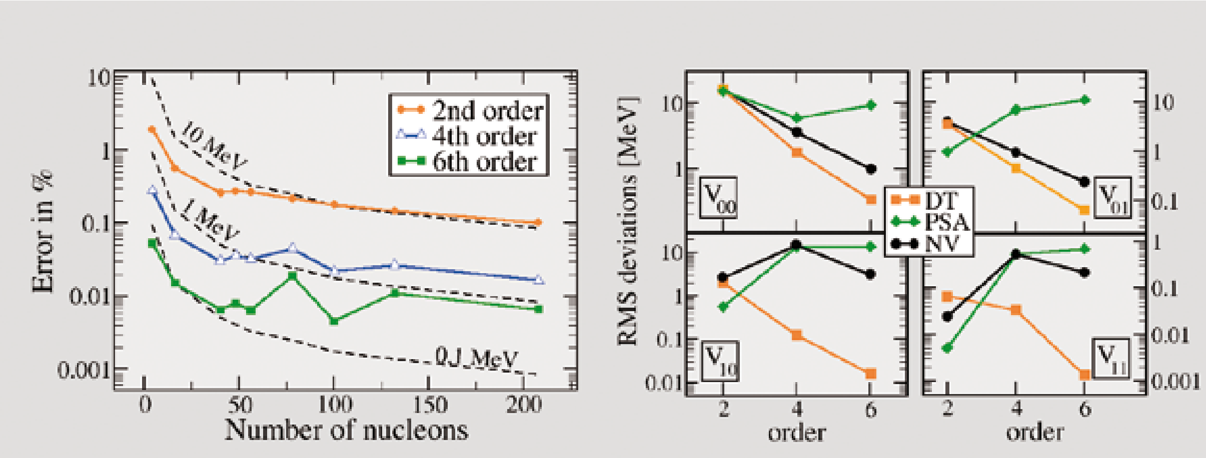



Fig. 1. Proton RMS radii (left) and binding energies (right) of doubly magic nuclei, determined by using the Gogny D1S nonlocal EDF (squares) and second-order Skyrme-like quasi-local EDF derived from the Gogny functional (circles). The insets show results in expanded scales and scaled by particle numbers A.




and the exact results. It is extremely gratifying to see that in light nuclei the sixth-order expansion allows for reaching the precision of 0.1%–0.01% or 0.1 MeV. Even more important, in each higher order the precision increases by a large factor, which is characteristic to a rapid power-law convergence. One also sees that in heavier, isospin-unsaturated nuclei the precision slightly deteriorates, probably owing to a slower convergence for the isovector densities, which fluctuate more than the isoscalar ones. In order to deal with the exchange term, we proposed a new approximation, which we called a damped Taylor (DT) expansion. In Fig. 2 (right), we show results obtained with the DT expansion compared to the exact values. The comparison was made by considering the rms deviations between the exact and approximate exchange energies. As seen in this figure, the Negele-Vautherin (NV) Bessel-function expansion used in the scalar channels works very well, whereas the alternative method used for the vector channels does not improve when evaluated beyond the second order. Our DT expansion exhibits excellent convergence properties both for the vector and scalar parts, with every next order improving the results by large factors. Note that in the vector channels, the exact exchange energies are quite small, so at second order their relative description is poor. In contrast, at higher orders their description becomes rather accurate.

Fig. 2. Left: precision of the newly proposed gradient expansions of the direct interaction energies calculated for the finite-range Gogny D1S interaction. The nine nuclei used for the test are $^{4}$He, $^{16}$O, $^{40;48}$Ca, $^{56;78}$Ni, $^{100;132}$Sn, and $^{208}$Pb. Positive (fourth order) and negative (second and sixth orders) errors are shown with open and closed symbols, respectively. Right: the rms deviations between the exact and approximate exchange energies, calculated for the nine nuclei listed above. The four panels show results obtained in the four spin-isospin channels labeled by $V_{vt}$. The damped Taylor (DT) results obtained in the present work are compared with those corresponding to the original Negele-Vautherin (NV) and phase-space-averaging (PSA) expansions.

Apart from these studies, we continued on progressing in the three main subject areas that we currently develop, namely, (i) adjustments to experimental data of the energy density functionals extended to higher order derivative terms, (ii) implementation of efficient linear-response algorithms to treat multipole excitations and β-decay probabilities in deformed nuclei, and (iii) symmetry-restoration methods applicable simultaneously to several broken symmetries.

# Accelerator Facilities

Pauli Heikkinen and Hannu Koivisto

Pauli Heikkinen, chief engineer
Hannu Koivisto, senior assistant
Olli Tarvainen, postdoctoral researcher
Tommi Ropponen, graduate student, PhD 24.2., -31.3.
Ville Toivanen, graduate student
Jani Komppula, graduate student
Vesa Aho, MSc student -30.9.
Janne Kauppinen, MSc student
Arto Lassila, laboratory engineer
Veikko Nieminen, laboratory engineer
Jaana Kumpulainen, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Ärje, laboratory engineer
Jani Hyvönen, operator
Anssi Ikonen, operator
Raimo Seppälä, technician

The year 2010 in cyclotron operations had some longer breaks. There was less need for beams mainly because the IGISOL facility started the move to the new site in the summer. Therefore there was no beam time in July. The time was mainly used for cyclotron maintenance. However, in spite of the long down-times the total operation time exceeded 6000 hours being 6215h/year with 4348 hours on target. The major beams in 2010 were beam cocktails for space electronics testing (23.2 %) and protons (22.0 %). Altogether over 20 different isotopes were accelerated in 2010.

The Final Acceptance Tests for the MCC30/15 cyclotron were carried out in April 2010, and the cyclotron was accepted. However there were some minor changes and upgrading and finishing the programming of the control system, which were left for the warranty period. The maximum measured 30 MeV proton beam intensity was 200 μA and correspondingly 62 μA for 15 MeV deuterons the guaranteed values being 100 and 50 μA, respectively.

Some ion beam related research and development time was lost due to obscure malfunctions of the 14 GHz ECRIS. Regardless of this, several projects were successfully continued or initiated. For example, the sputter technique was developed and used for the production of an intensive Zr ion beam for the use of nuclear physics experiments.

The plasma-electromagnetic wave coupling was further studied with the LNS-INFN ion source group. It was observed that in the best cases affecting the coupling by fine tuning the ion source microwave frequency can offer up to 10–20% increase to accelerated ion beam intensities compared to fixed frequency operation. However, the benefit depends strongly on the ion source tuning, resulting at certain situations in low or negligible improvement in performance.

The experiments concerning the ion beam formation using a so-called collar structure between the ECR plasma and ion source extraction were initiated. The firsts results with oxygen show that the intensity improvement of 10–30 % can be achieved for the high charge states. Later the effect will be studied using heavier elements like argon.

The plasma breakdown experiments with low energy gamma detector were continued with the LBNL (Berkeley) and NSCL (Michigan State University) ion source groups showing the first indication about the so-called superadiabatic heating in the beginning of breakdown process. In order to cover the entire energy range of photons emitted from the ion source plasma, the group also initiated the program to study the low energy photon emission with the aid of photon spectroscopy. This work can reveal new and important information, for example, about the time evolution of different plasma parameters and different charged states. The decay of the plasma was also studied in order to define the parameters affecting the so-called afterglow process. It was noticed, for example, that the decay time of different charge states is almost inversely proportional to the square of the ion charge. The result is in good agreement with a simple theoretical model based on diffusion of ions from the magnetic field of the ion source.

The development work for the low energy graphene based cold cathode electron gun, needed for the test mission of E-SAIL plasma propulsion project, was successfully performed. It is presently expected that the performance of the cold cathode electron gun will meet the requirements set by the project.

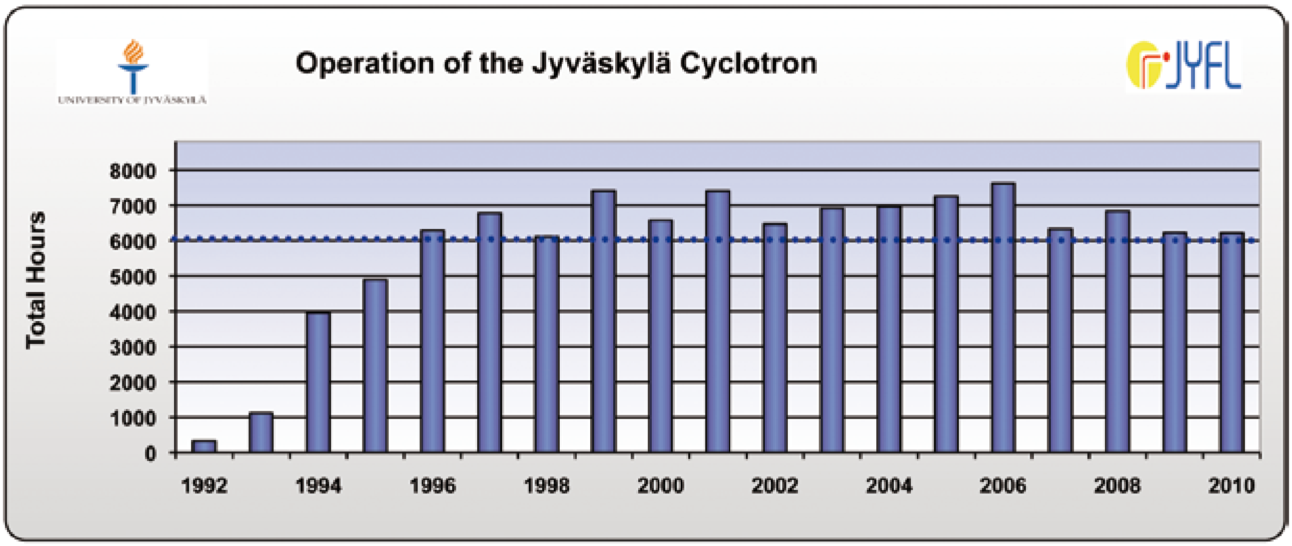



Fig 1. Operation of the Jyväskylä K130 cyclotron in 1992-2010.

# Exotic Nuclei and Beams

Ari Jokinen, Iain Moore, Heikki Penttilä and Juha Äystö

Juha Äystö, professor
Ari Jokinen, lecturer
Iain Moore, senior researcher
Heikki Penttilä, senior researcher
Valery Rubchenya, senior researcher (Khlopin Radium Institute, St. Petersburg)
Anu Kankainen, postdoctoral researcher
Tommi Eronen, postdoctoral researcher
Veli Kolhinen, postdoctoral researcher
Pasi Karvonen, graduate student, PhD 13.10.
Jani Hakala, graduate student
Dmitry Gorelov, graduate student
Juho Rissanen, graduate student
Antti Saastamoinen, graduate student
Volker Sonnenschein, graduate student
Mikael Reponen, graduate student
Jani Turunen, graduate student (STUK)
Ariel Aatsinki, MSc student
Heli Hoilijoki, MSc student
Miika Kakko, MSc student
Ilkka Pohjalainen, MSc student
Joni Parkkonen, MSc student
Laura Vainio, MSc student
Janne-Matti Littunen, conscientious objector,1.3.–

Fig 1. The IGISOL group in the IGISOL-4 target area. From the left: Janne-Matti Littunen, Veli Kolhinen, Tommi Eronen, Anu Kankainen, Ilkka Pohjalainen, Iain Moore, Pasi Karvonen, Volker Sonnenschein, Jani Hakala, Heikki Penttilä (marking the target position inside the supporting frame), Mikael Reponen, Juho Rissanen, Ari Jokinen, Juha Äystö, Dmitry Gorelov and Antti Saastamoinen.

## Activity 2010

The year 2010 witnessed a new era for the IGISOL facility. The current mass separator facility has been running since 1993 and the final experiment took place in June. The move to a new location in the Accelerator Laboratory extension started immediately. Otherwise, the activity followed the well-established path consisting of numerous experiments and R&D instrumentation both at JYFL and at ISOLDE, CERN, where the work is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). In addition, the astrophysically important radiative proton capture reaction $^{26m}Al(p,\gamma)^{27}Si$ was studied through the beta decay of $^{27}P$ at Texas A&M University.

A historical milestone in 2010 was the formal founding of the Facility for Antiproton and Ion Research (FAIR) in October. This occasion boosted the planning of the experiments within the NuSTAR collaboration for the Super Fragment Recoil Separator (S-FRS), to which our group, in collaboration with HIP, has actively participated. In general, our team has significantly benefited from collaborations with several groups from Europe and the US. Our group is involved in three EU FP7 programs – ANDES, ENSAR and ERINDA – that started in 2010.

The Fifth Conference on Trapped Charged Particles and Fundamental Physics (TCP2010) was organized in Saariselkä, Lapland, in April by our group. The meeting gathered more than a hundred participants to present their research and to exchange ideas for the future. The departure from Saariselkä became a challenge for most of the participants as Icelandic

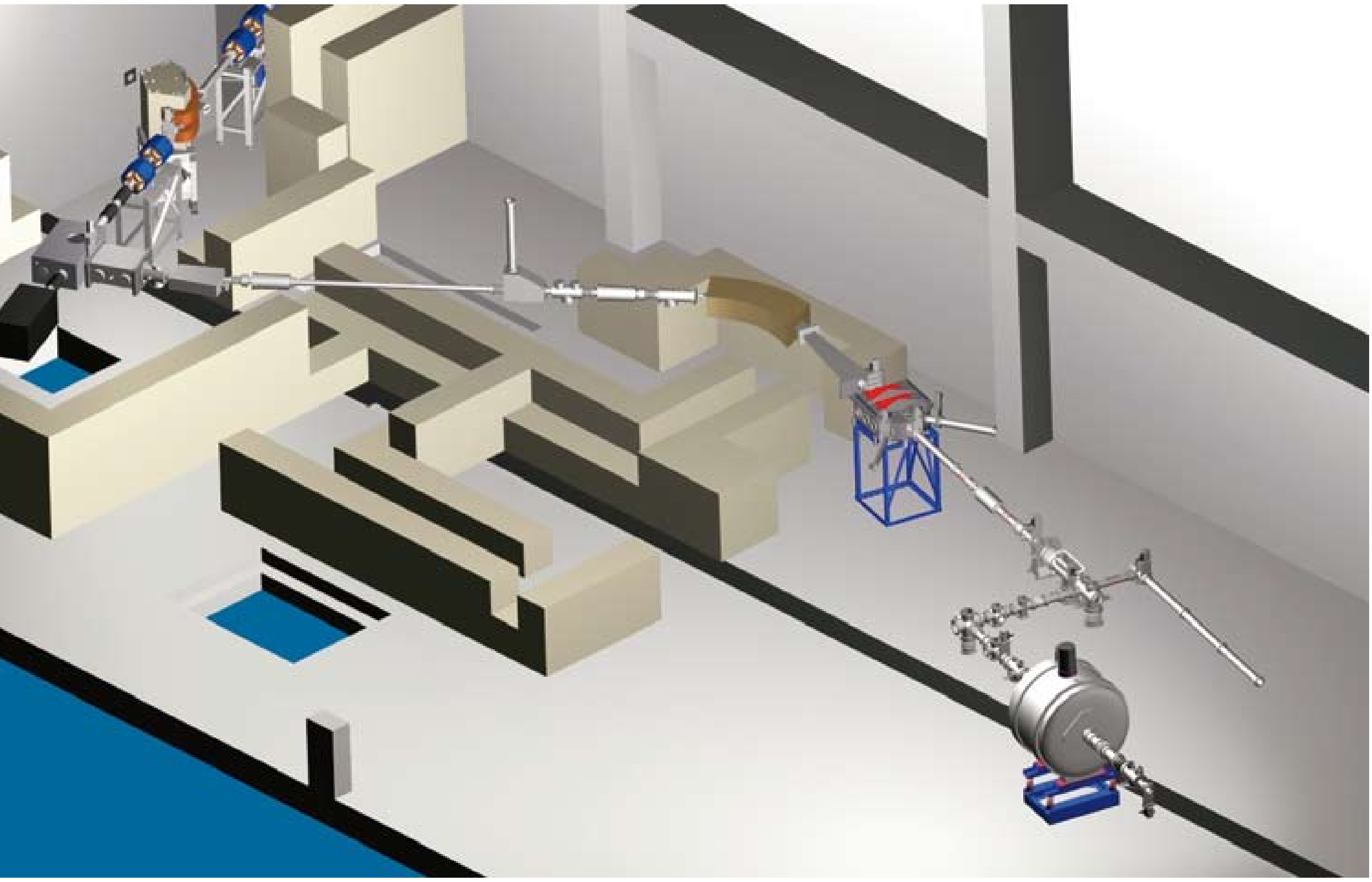


Fig 2. An artistic view of IGISOL-4: A novel facility for Rare Isotope Beam Science. The major components including the front end, dipole magnet, switchyard, rf cooler, JYFLTRAP and the collinear laser spectroscopy facility are shown.

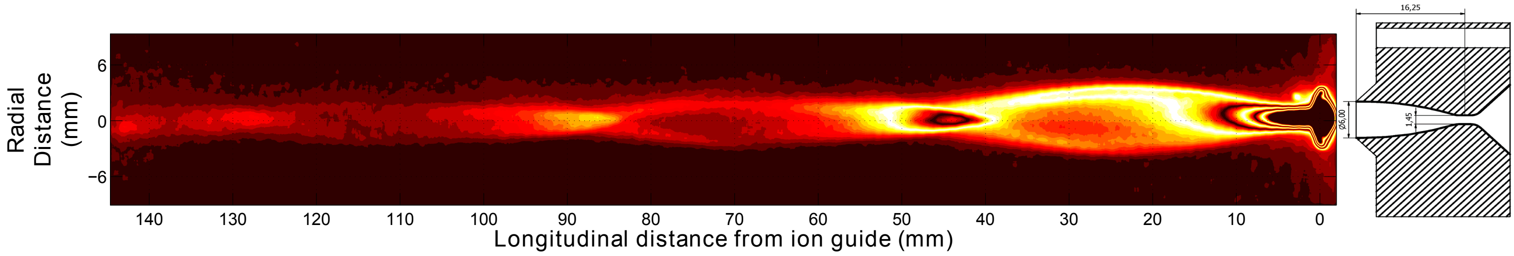



Fig 3. False colour visualization of the gas jet from a Laval nozzle.

volcanic ash closed the northern air space only a day before.

The R&D effort was significantly geared towards the realization of the renewed IGISOL-4 laboratory. Despite the tight schedule, a few R&D experiments were performed prior to shutdown. An improved collection technique for isomerically purified radioactive Xe samples needed for calibrating the detector network of CTBTO was tested in collaboration with the Finnish Nuclear Safety Authority STUK [I-155]. An inductively heated hot cavity graphite catcher was successfully tested via the implantation of a stable beam of $^{107}Ag^{21+}$. Ions were extracted in a few milliseconds and ionized in a perpendicular geometry via three-step resonant laser ionization. This is an important step towards the goal of producing the (21+) isomer of the N=Z isotope of $^{94}Ag$.

Off-line, tailored improvements were made to the gas cell-based LIST method. Currently, the efficiency of LIST applications is limited by the spatial overlap between the laser photons and the jet atoms. A study of gas jets emitted from an ion guide as a function of nozzle type and gas cell-to-background pressure ratio was completed (see Fig. 3). Finally, we teamed up with colleagues from the University of Mainz to perform Resonance Ionization Mass Spectroscopy of thorium. The ground state atomic hyperfine structure of $^{229}Th$ was determined for the first time, and will be used as an important template when searching for the existence of the low-lying (~7 eV) isomeric state in the future.

## Experimental Highlights

**Fission experiments** The traditional workhorse of the IGISOL facility, proton-induced fission, was utilized in several experiments. The fission yields in the proton-induced fission of $^{232}Th$ [I-151] were determined in collaboration with Uppsala University and the Khlopin Radium Institute. The atomic masses of heavy antimony isotopes in the vicinity of the doubly-magic $^{132}Sn$ were measured [I-139].

The capability of the IGISOL facility to produce mono-isotopic neutron-rich sources with JYFLTRAP was utilised in testing the BEta deLayEd Neutron detector (BELEN-20) [I-136], which is being developed for the FAIR/DESPEC experiment. The detector was successfully commissioned on-line in June in an experiment, which measured the beta-delayed neutron emission branching for $^{88}Br$, $^{91}Br$, $^{94}Rb$, $^{95}Rb$, and $^{137}I$, implementing the work within the ANDES EU-project. In addition, neutron branches were measured for $^{85}Ge$, $^{86}Ge$, and $^{85}As$.

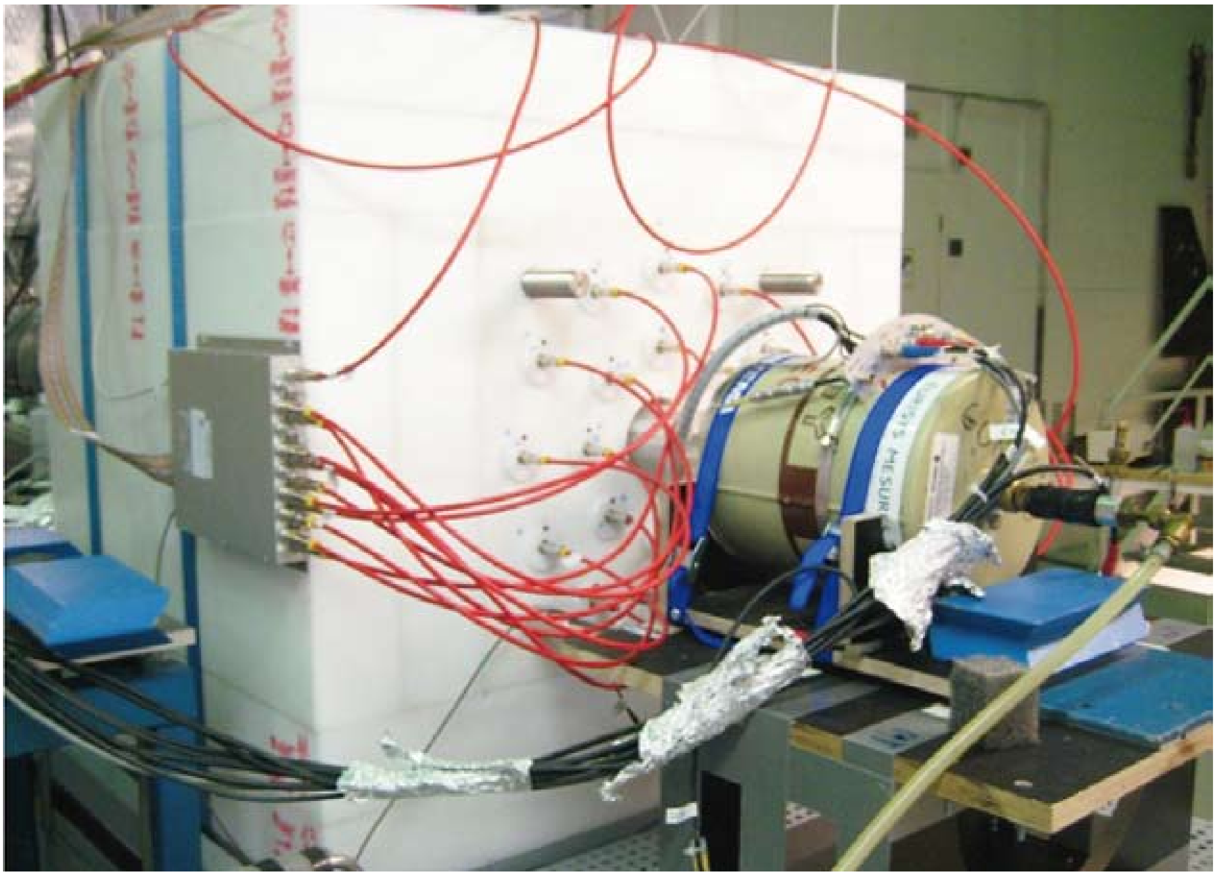
**Precision atomic mass measurements** The precision atomic mass measurement program at JYFLTRAP continued during the first half of 2010. Among the most important derivatives from atomic mass measurements are the decay energies, commonly called Q-values. Since in most cases the decay parent and daughter ions are simultaneously produced and available from IGISOL, JYFLTRAP is ideally suited for such measurements.

For stable atoms, the double-beta decay Q value was determined for $^{150}Nd$ and $^{136}Xe$. These are candidates for neutrinoless double-beta decay searches. Several large scale experiments such as DCBA, SuperNEMO and SNO+ ($^{150}Nd$), EXO and NEXT ($^{136}Xe$) are being built to find such rare decays and need the decay Q value with high precision. Moreover, the Q value of the proposed resonant double-electron capture decay of $^{136}Ce$ was deduced. The conclusion from this measurement unfortunately was that observation of this decay is very unlikely.

For radioactive isotopes, the studies around the N=Z line were continued. Three Q-values of superallowed beta emitters $^{10}C$, $^{34}Ar$ and $^{38}Ca$ were measured just two weeks before the shutdown of IGISOL [I-131]. These Q-values contribute to testing the Standard Model of particle physics. The new measurements leave only $^{14}O$ from the "most precisely known set of 9 emitters" to be determined with JYFLTRAP.

The Q values of the so-called mirror nuclei that decay over the N=Z line [I-140, I-141] are important for the studies of Coulomb displacement energies as well as for nuclear astrophysics. The Q values of $^{31}S$, $^{45}V$, and $^{49}Mn$ have been measured at JYFLTRAP with a precision of better than 0.5 keV, a significant improvement over existing literature values. In addition, the mass of $^{31}S$ has been found to deviate by 1.4$\sigma$ from the Atomic Mass Evaluation 2003. Combined with the latest data from $\beta$-delayed proton decay of $^{32}Cl$, it yields the most precise mass value for $^{32}Cl$. This has been used for testing the isobaric multiplet mass equation at A=32, confirming the persistent deviation from its quadratic form.

Fig 4. BeLEN-20 detector installed behind JYFLTRAP for the June 2010 experiment.



## Highlights at ISOLDE

High resolution optical spectroscopy on the gallium isotopes was performed at ISOLDE using the ISCOOL device resulting in the discovery of a new nuclear state in $^{80}$Ga (Z = 31, N = 49), unambiguously established via the model-independent technique of laser spectroscopy. This result is linked to an earlier high precision mass measurement using JYFLTRAP in Jyväskylä, which revealed no indications of the existence of an isomeric state in $^{80}$Ga. This suggests that both levels must be within approximately 50 keV, equivalent to the resolving power of the mass measurement. Further studies are called for to experimentally determine spectroscopic properties of these states.

### Experiment spokespersons and collaborating institutes in 2010

[I-131] Precision $Q_{EC}$-value measurements of the superallowed $0^+ \rightarrow 0^+$ β emitters of $^{10}$C, $^{14}$O, $^{34}$Cl and $^{38}$K$^m$
Spokeperson: T. Eronen
Cyclotron Institute, Texas A&M University, College Station, Texas, USA.

[I-136] Decay properties of beta delayed neutron emitters
Spokepersons: M. B. Gómez Hornillos, D. Cano-Ott, A. Algora, A. Jokinen.
JYFL liaison: J. Rissanen.
UPC-Barcelona, Spain; IFIC,CSIC-University of Valencia, Spain; CIEMAT-Madrid, Spain; Inst. of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary; PNPI, Gatchina, Russia; University of Surrey, UK; LPC - Caen, France.

[I-139] Precision atomic mass measurements of neutron-rich nuclei with JYFLTRAP
Spokeperson: A. Jokinen

[I-141] Mass measurements around A=30 for the studies of novae nucleosynthesis and IMME in T=3/2 quartets
Spokepersons: A. Kankainen, A. Saastamoinen

[I-142] Precise $Q_{EC}$ values for the T=1/2 mirror beta transitions
Spokeperson: A. Kankainen

[I-150] Study of the $^{235}$U($^3$He,xnyp) reactions in energy range of 20.6 to 42 MeV
Spokeperson: K. Helariutta
JYFL liaison: H. Penttilä
University of Helsinki, Finland; V.G. Khlopin Radium Institute, St. Petersburg, Russia.

[I-151] Independent fission yields in proton induced fission of $^{232}$Th at 25 MeV
Spokepersons: H. Penttilä, I.V. Ryzhov, S. Pomp
V. G. Khlopin Radium Institute, St. Petersburg, Russia; Uppsala University, Sweden.

[I-155] Production and characterization of enriched $^{131m}$Xe and $^{135}$Xe samples and production of $^{133m}$Xe samples
Spokeperson: K. Peräjärvi
JYFL liaison: T. Eronen
STUK-Radiation and Nuclear Safety Authority, Helsinki, Finland

# Nuclear Spectroscopy

Tuomas Grahn, Pete Jones, Rauno Julin, Mikael Sandzelius and Juha Uusitalo

### In-beam Spectroscopy Group Members

Rauno Julin, professor
Paul Greenlees, research professor
Sakari Juutinen, senior assistant
Pete Jones, senior researcher
Tuomas Grahn, postdoctoral researcher
Päivi Nieminen, postdoctoral researcher
Mikael Sandzelius, postdoctoral researcher
Andrej Herzáň, graduate student
Steffen Ketelhut, graduate student, PhD 29.12.
Pauli Peura, graduate student
Panu Rahkila, graduate student
Juha Sorri, graduate student
Karl Hauschild, visiting scientist
Araceli Lopez-Martens, visiting scientist
Sanna Stolze, MSc student

### Separator Group members

Matti Leino, professor
Juha Uusitalo, senior researcher
Cath Scholey, senior researcher
Sami Rinta-Antila, postdoctoral researcher
Ulrika Jakobsson, graduate student
Panu Ruotsalainen, graduate student
Jan Sarén, graduate student
Jari Partanen, MSc student

Fig. 1. The Nuclear Spectroscopy Group. From left to right, first row: Steffen Ketelhut, Panu Rahkila, Andrej Herzáň, Ulrika Jakobsson, Jan Sarén, Araceli Lopez-Martens, Juha Sorri, and second row: Rauno Julin, Pauli Peura, Panu Ruotsalainen, Sami Rinta-Antila, Mikael Sandzelius, Karl Hauschild, Sakari Juutinen, Tuomas Grahn, Pete Jones, Juha Uusitalo, Matti Leino and Paul Greenlees. Päivi Nieminen and Cath Scholey are missing from the photograph.

The year began with commissioning of the SAGE spectrometer followed by three SAGE experiments. After the hot summer three RDT experiments made use of the powerful JUROGAM II + RITU + GREAT system in studies of very neutron-deficient heavy nuclei. Late autumn was dedicated to a campaign of six RDT plunger RDDS lifetime measurements. These twelve international experiments (see the list below) occupied 92 days of beam time. In addition, the group participated in experiments at REX-ISOLDE and GSI. Group members were authors in 27 peer-reviewed publications, 14 of them based on data obtained at JYFL. Panu Rahkila successfully defended his PhD thesis on “Shape evolution in even-even N < 126, Z > 82 nuclei” as did Steffen Ketelhut with his thesis on “Rotational structures and high-K isomers in $^{248,250}$Fm”.

## SAGE Spectrometer

The successful commissioning of the SAGE (Silicon And GErmanium) spectrometer was performed in January 2010 (S01). The SAGE spectrometer combines a silicon detector with the JUROGAM II Ge-detector array for simultaneous prompt in-beam detection of conversion electrons and $\gamma$ rays at the target position. SAGE comprises a highly segmented silicon detector located upstream from the target position in a collinear geometry with the beam, a powerful solenoid coil to transport the electrons to the detector, and a high voltage barrier for suppression of delta electrons.

Fig. 2. The SAGE magnetic coils and target chamber combined with JUROGAM II detectors at RITU.

The detector is 5 cm in diameter and consists of 90 segments in a ‘dart board’ geometry (see Fig. 3), with the central elements more pixelated in order to sustain higher count rates.

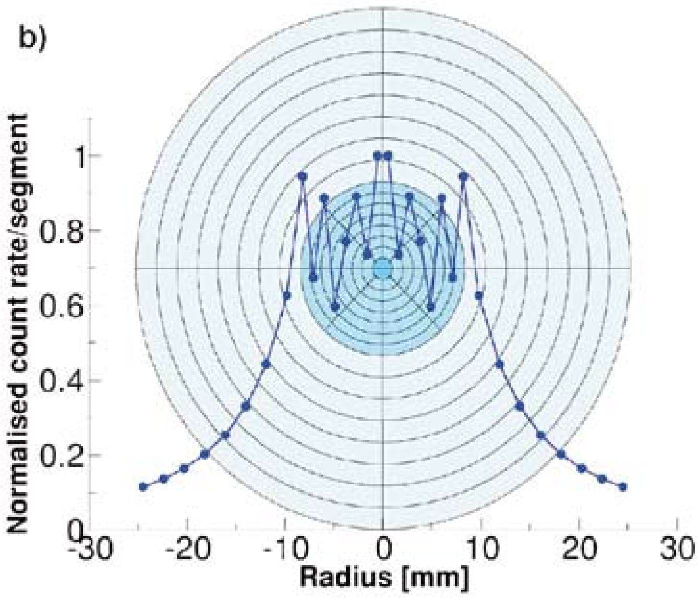



Fig.3. The SAGE Si conversion electron detector, depicting the dimension and segmented pixel geometry. Superimposed is the simulated, normalised count rate over the range of the detector diameter.

The first SAGE campaign during the spring of 2010 proved the capability of the spectrometer. Coincidence spectra of prompt conversion electrons and γ-rays were successfully collected in-beam at the target position. Thereby SAGE offers the possibility to extract information concerning previously unseen highly-converted transitions. A highlight from the first SAGE campaign was the $^{184,186}$Hg experiment (S05). The conversion coefficient of the 216 keV $2_2^+$ to $2_1^+$ transition in $^{186}$Hg extracted from the γ-ray gated electron spectrum of Fig. 4, reveals a strong E0 component in this transition.

Following the success of the first SAGE campaign, further development work and improvement of the spectrometer is currently being carried out. The second experimental SAGE campaign is expected to run in the fall of 2011.

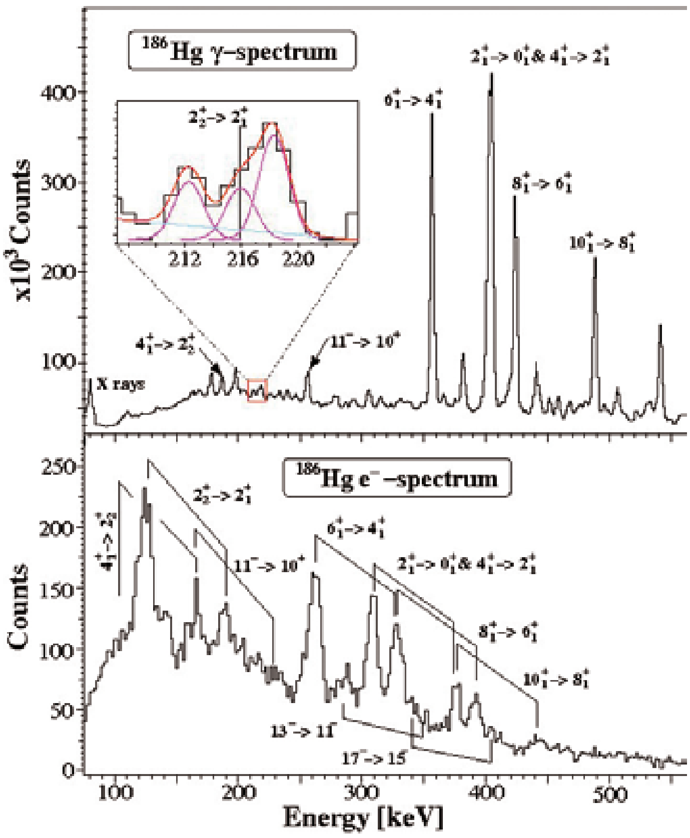



Fig. 4. SAGE data for $^{186}$Hg: Projection of the recoil-gated γγ matrix (top panel). Conversion electron spectrum obtained by gating on relevant γ ray peaks in the γe$^-$ matrix (lower panel).

## Plunger Lifetime Measurements

DPUNS is a collaborative project between JYFL and the UK Universities (Manchester, Liverpool) to build a dedicated plunger for JYFL, a sister device of the successful Cologne plunger. During 2010, the design was finalised and manufacturing of the parts has progressed well. The main chamber was vacuum tested at the end of the year and the remaining internal components are scheduled to be finalised within the first quarter of 2011. The DPUNS plunger is expected to be fully operational by the end of 2011, including the computer control feedback system which has already been assembled at JYFL and used in the campaign with the Cologne plunger during the last quarter of 2010. In this campaign, 6 experiments were carried out (see the list below).

## ISOLDE Activities

Coulomb excitation measurements employing the MINIBALL Ge- array and unique heavy Radioactive Ion Beams (RIBs) from REX-ISOLDE were carried out for studies of shape coexistence in light Rn (P. Rahkila spokesperson) and Pb (T. Grahn spokesperson) nuclei.

From the resulting spectrum shown in Fig. 5, the E2 transition rate for the $2^+$ to $0^+$ transition in $^{192}$Pb can be extracted and used to verify the nature of the $2^+$ state.

Our group has also secured more RIB time at REX-ISOLDE for studies of heavy nuclei. In addition we have submitted a Letter of Intent for HIE-ISOLDE (the upgrade of REX-ISOLDE) for Coulomb excitation and particle-transfer studies of neutron-deficient Te nuclei.

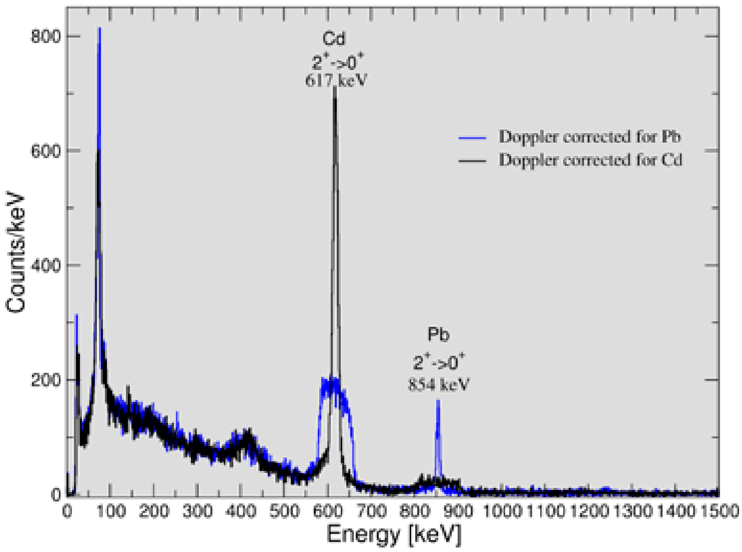



Fig. 5. Background subtracted γ-ray spectra in coincidence with particles detected in the low center-of-mass angles in the CD particle detector. The same spectrum is shown with different Doppler corrections; blue for projectile ($^{192}$Pb) and black for target ($^{112}$Cd) nuclei.

The Coulomb excitation measurements of heavy nuclei at ISOLDE have become increasingly complementary to those carried out at JYFL to probe the development of collectivity in very light Z ~ 82 nuclei. We have also carried out such complementary experiments using Gammasphere at Argonne National Laboratory.

## GSI Collaboration

The heavy-element program carried out at GSI (Germany) has been very successful. The available high beam intensities and efficient separators (SHIP and later on TASCA) have enabled very low cross-section experiments to be performed. For many decades our group has had the possibility to be involved in this programme. In 2010 two long heavy-element experiments employing the SHIP separator were performed. An isomeric state in $^{270}$Ds was confirmed by bombarding a $^{207}$Pb target with a $^{64}$Ni beam. Improved data on the $^{270}$Ds decay chain were also obtained. In the second experiment, element 116 was produced using a $^{48}$Ca beam impinging on a $^{248}$Cm target. This experiment allowed independent confirmation of earlier synthesis of element 116 at Dubna. A further highlight was the publication of the results from the 2009 study of element 114.

### Experiment spokespersons and collaborating institutes in 2010

[S01] *Commissioning of the SAGE spectrometer*
R.-D.Herzberg, University of Liverpool, U.K.
STFC Daresbury, U.K.; JYFL

[S02] *Simultaneous conversion-electron and gamma-ray spectroscopy using SAGE: An in-beam study of $^{253}$No*
R.-D.Herzberg, University of Liverpool, U.K.; STFC Daresbury, U.K.; CSNSM Orsay, France; GSI Darmstadt, Germany: IRFU CEA Saclay, France; Argonne National Laboratory, U.S.A.; University of Cologne, Germany; JYFL

[S05] *Shape co-existence in $^{182\text{-}188}$Hg*
P.A.Butler, University of Liverpool, U.K.
P.Rahkila, JYFL
P.Van Duppen, KU Leuven, Belgium
STFC Daresbury, U.K.; TU Darmstadt, Germany; University of Edinburgh, U.K.; GANIL, France; University of Göttingen, Germany; CERN-ISOLDE, Switzerland; University of Cologne, Germany; University of Lund, Sweden; University of Manchester, U.K.; University of Maryland, U.S.A.; TU Munich, Germany; University of Oslo, Norway; IRFU CEA Saclay, France; University of Sofia, Bulgaria; University of Warsaw, Poland; University of the West of Scotland, U.K.; University of York, U.K.

[S04] *Exploring shape co-existence in $^{202,204}$Rn*
D.G.Jenkins, University of York, U.K.
P.Rahkila, JYFL
A.P.Robinson, University of Manchester, U.K.
KU Leuven, Belgium; University of Liverpool, U.K.; University of Cologne, Germany; Argonne National Laboratory, U.S.A.; TU Munich, Germany; Weizmann Institute, Israel; CERN-ISOLDE, Switzerland; LMU Munich, Germany; TU Darmstadt, Germany; University of Sofia, Bulgaria; University of Edinburgh, U.K.

[JR91] *Spectroscopy above the* $22^-$ *six-quasiparticle isomer in* $^{176}$*Hf*
P.Chowdhury, University of Massachusetts, Lowell, U.S.A.
VECC Kolkata, India; University of Manchester, U.K.; Argonne National Laboratory, U.S.A.; University of Surrey, U.K.; Australian National University, Australia; JYFL

[JR97] *Establishing spins and parities via hindered decays in the debated chiral nucleus* $^{134}$*Pr*
D.M.Cullen, University of Manchester, U.K.
JYFL

[JR85] *Probing the single-particle levels in the very neutron-deficient isotope* $^{183}$*Pb*
J.Pakarinen, CERN-ISOLDE, Switzerland
D.G.Jenkins, University of York, U.K.
University of Liverpool, U.K.; KU Leuven, Belgium; Comenius University, Slovakia; JYFL

[J11] *Lifetimes of the low-lying non-yrast states in* $^{86}$*Kr*
*C.Fransen, University of Cologne, Germany*
*P.Jones, JYFL*
TU Darmstadt, Germany

[JR102] *Inverse kinematics Coulex-plunger measurements in* $^{130}$*Xe*
S.Harissopulos, NCSR Demokritos, Greece
A.Dewald, University of Cologne, Germany
TU Darmstadt, Germany; JYFL

[J10] *Lifetime measurement of prolate yrast states in* $^{182}$*Pt*
P.Peura, T.Grahn, JYFL
University of Liverpool, U.K.; University of Cologne, Germany; TU Darmstadt, Germany; TU Munich, Germany; University of York, U.K.; IRFU CEA Saclay, France; STFC Daresbury, U.K.; University of Warsaw, Poland

[JR100] *Lifetime measurements of excited states in* $^{163}$*W and* $^{164}$*W*
D.T.Joss, University of Liverpool, U.K.
T.Grahn, JYFL
KTH Stockholm, Sweden; KU Leuven, Belgium; University of Cologne, Germany; Australian National University, Australia; Nidge University, Turkey; TU Munich, Germany; TU Darmstadt, Germany; STFC Daresbury, U.K.

[JR90] *Measurement of the B(E2) values of the first excited* $2^+$ *and* $4^+$ *states in* $^{108,110,112}$*Te*
B.Cederwall, KTH Stockholm, Sweden
R.Wadsworth, University of York, U.K.
University of Cologne, Germany; University of Liverpool, U.K.; TU Darmstadt, Germany; STFC Daresbury, U.K.; University of Tokyo, Japan; Istanbul University, Turkey; JYFL

[JR92] *Investigation of X(5) critical-point nuclear symmetry in* $^{138}$*Gd using recoil-distance plunger measurements*
D.M.Cullen, University of Manchester, U.K.
University of Cologne, Germany; University of Surrey, U.K.; University of Sofia, Bulgaria; University of Liverpool, U.K.; IST Lisbon, Portugal; INFN Padova, Italy; JYFL

# Nuclear Reactions and ALICE

Jan Rak and Wladyslaw Trzaska

Jan Rak, senior assistant
Wladyslaw Trzaska, senior scientist
DongJo Kim, postdoctoral researcher
Sami Räsänen, postdoctoral researcher (HIP/JYFL)
Tuomo Kalliokoski, graduate student
Jiri Kral, graduate student
Norbert Novitzky, graduate student
BeomSu Chang, graduate student
Oleg Korniyenko, research associate (CUPP till 30.04.2010)
Mateusz Lehman, researcher (JYFL/CERN)
Kai Loo, graduate student (CUPP)
Tomi Räihä, graduate student (CUPP)
Juho Sarkamo, graduate student (CUPP)
Johannes Hissa, graduate student (CUPP)
Maciej Slupecki, MSc student (Warsaw University of Technology)
Tiia Monto, MSc student

## ALICE

ALICE detector performed beautifully throughout 2010. During most of the year the experiment was taking data at $\sqrt{s}$=7 TeV – the highest center of mass energy ever recorded. The collected p + p events contain a wealth of new information that has already yielded seven papers in high-impact journals. Many more papers are in preparation. Members of the Jyväskylä group are actively involved in the analysis of high-$p_T$ particle correlations as well as in taking shifts and operating the T0 detector.

At the end of 2010 LHC was retuned to accelerate Pb beams. On Monday, November 8th 2010 the first collision of *Pb* ions at c.m $\sqrt{s}$=2.76 TeV was recorded (see Fig. 1).

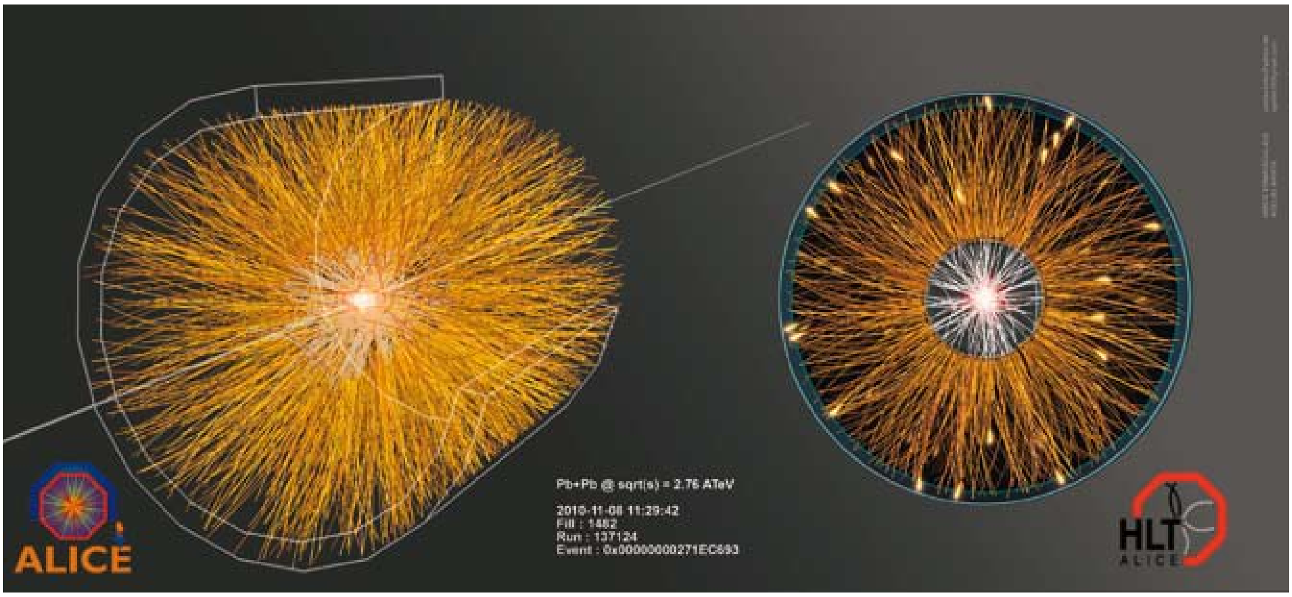



Fig. 1. Event display of the first Pb+Pb collision at c.m. $\sqrt{s}$=2.76 TeV recorded by the ALICE collaboration.

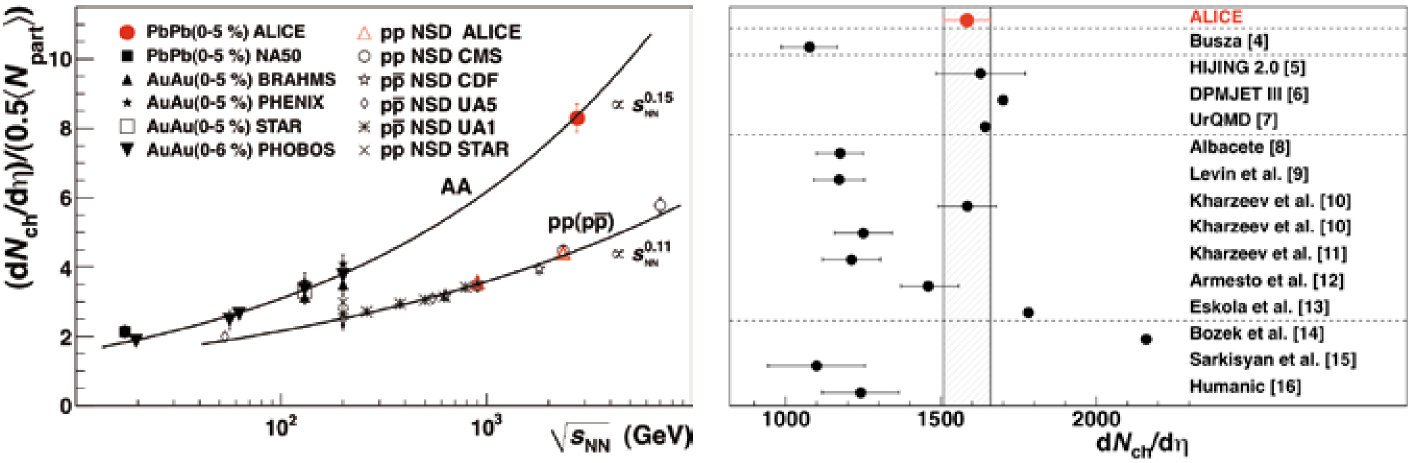


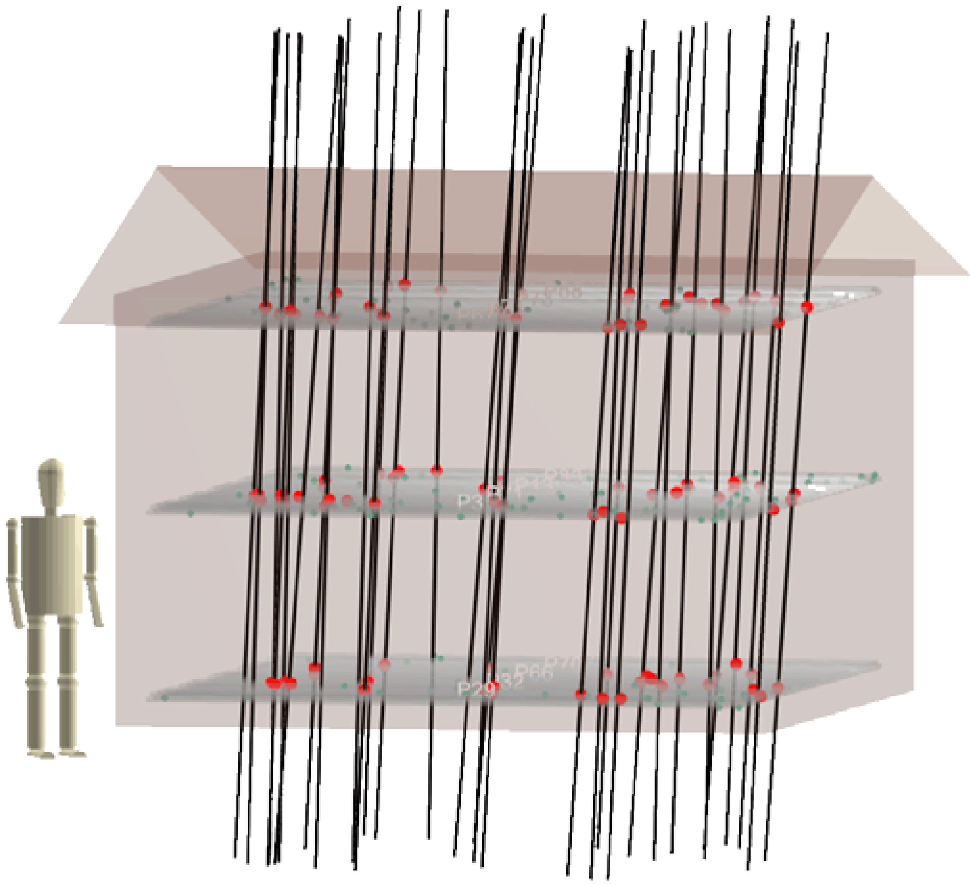

Fig. 2. First measurements of multiplicity in *Pb+Pb* by ALICE. Left panel shows increase of multiplicity as a function of collisions energy in *p+p* and *A+A* collisions. Right panel show the most recent model prediction together with ALICE measurement.

Already the first weeks of *Pb+Pb* collisions brought interesting results and four publications! For instance, the relatively small value of $dN_{ch}/d\eta = 1584 \pm 4$ (stat.) $\pm 76$ (sys.) observed by ALICE ruled out many model predictions, as shown in Fig. 2.

## Astroparticle Physics

In the spring of 2010 the cosmic ray experiment EMMA took the first underground tracking data (Fig. 3). The results were presented at the 22nd European Cosmic Ray Symposium in Turku, Finland and at the 2010

Fig.3. Reconstructed multi-muon event recorded by the underground measuring station consisting of three double-layered drift chambers.



Erice School of Particle and Nuclear Astrophysics. The EMMA DAQ has been modernized to accommodate the new scintillation array. Significant improvements were made to the analysis and visualisation codes. A dedicated server with EMMA-Wiki has been started. The installation of new underground cottages and equipping them with detectors continues with the speed determined by the available funding.

LAGUNA collaboration has applied to the FP7 for the final design study to investigate the options for measuring long-base neutrino oscillation. If successful, the decision on the construction of the Large Apparatus for Grand Unification and Neutrino Astrophysics could be taken already in 2014.

## Nuclear Reactions

An important instrumental breakthrough was achieved during our traditional Christmas-to-New-Year experiment by reducing the energy spread of the cyclotron beam down to 0.15% opening the possibility to measure the radii of the exited states of $^{13}C$.

In the preparation for the major change in the layout of the target hall in 2011, the NR group has held two workshops to outline the program and to plan the new infrastructure. One of our papers – Collinear cluster tri-partition of $^{252}Cf$ (sf) and in the $^{235}U(n_{th},f)$ reaction – has been chosen by the European Physical Journal A for the cover story of its July 2010 issue.

Fig. 4. Finnish members of the EMMA collaboration during the meeting in Pyhäsalmi in June 2010.

# Accelerator-based Materials Physics

Timo Sajavaara and Harry J. Whitlow

Harry J. Whitlow, professor
Timo Sajavaara, university lecturer
Mikko Laitinen, graduate student
Laura Mättö, graduate student
Rattanaporn Norarat, graduate student
Nittipon Puttaraksa, graduate student
Ananda Sagari A.R., graduate student
Hannele Eronen, MSc student
Jouni Heiskanen, MSc student
Jaakko Julin, MSc student
Henri Kivistö, MSc student
Mari Napari, MSc student
Lauri Olanterä, MSc student

2010 has been a year filled with equipment commissioning and development for the future.

In the spring the DREAM project was instigated which will realise a new generation MeV ion microscope and MeV ion beam lithography system. This is initially based on doublet lens, (Fig. 1.) and has a number of novel features including the possibility to measure images in the time as well as X-Y dimensions. This will open up new possibilities such as time-resolved ion beam induced charge for researchers from the RADEF community and imaging fluorescence quenching in biomedical imaging with fluorescence markers. This new microscope is designed to exploit numerical image analysis and as part of the lead-up wavelet techniques for multi-resolution image support and objective procedures for removal of disturbing Poissonian image noise have been developed in collaboration with the Centre of Ion Beam Applications at the National University of Singapore. In parallel with this our work on MeV ion beam lithography was directed towards measuring the exposure characteristics of resists and achieving direct-writing in high purity silica. A major highlight in the autumn was the start-up of the HILYSENS EU-FP7 project in which we are a partner in developing a highly-sensitive low-cost lab-on-a-chip system for Lyme disease diagnosis. Another milestone in our research related to biomedical aspects of materials was the successful development of buried interdigitated electrodes with thin-film hydoxyapatite overlayers for biosensing applications.

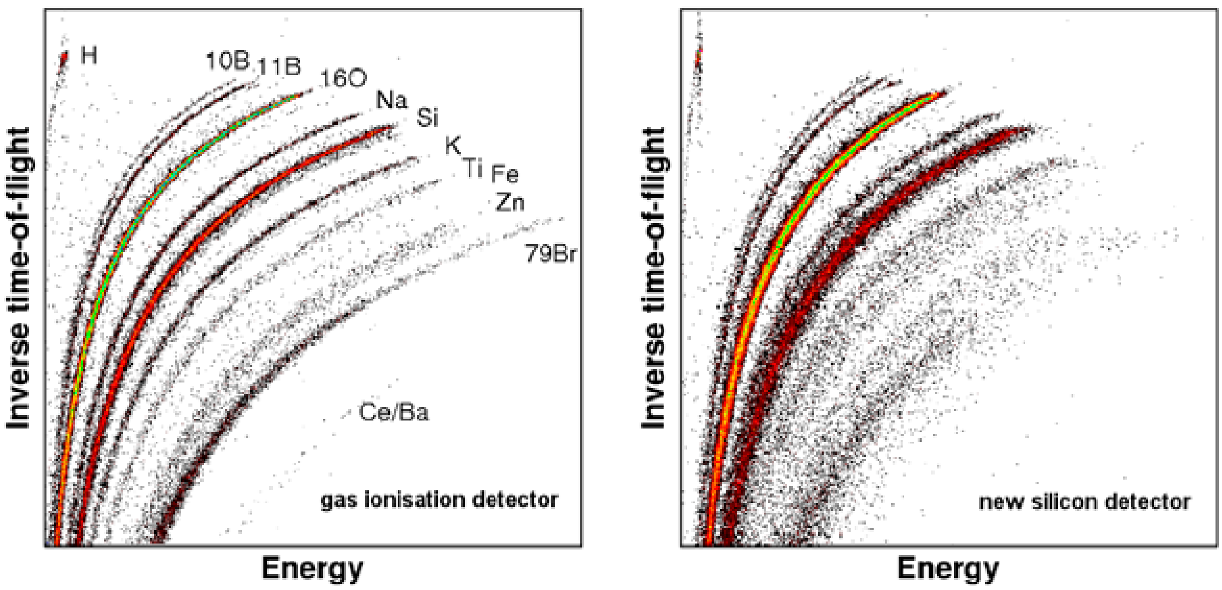
The other main research direction in the group is detector development and thin-film research using TOF-ERDA. The system can currently achieve high depth resolution of ~nm at the surface which has allowed us to study for example nanolaminates and films with thickness of well below 10 nm. In addition, the low background in the measurements makes it possible to quantify, for instance, light surface impurities even down to $10^{14}$ atoms/cm$^2$ and elemental concentrations down to 100 ppm level for thicker films. The front-line performance of this facility has attracted users from Finnish industry and research groups as well as users from Sweden and Belgium. The well working concept has raised interest towards our detector development and in 2010 two similar time pickoff detectors than in use


Fig. 1. Thermal testing of the quadrupole doublet microbeam lens.

at JYFL were delivered to the University of Montreal, Canada. During the year also a high-resolution gas ionisation detector system with a 100 nm thick $Si_3N_4$ membrane window was commissioned. This gives a dramatic improvement of the mass resolving power (Fig. 2.) for heavy elements in TOF-ERDA measurements. Pushing the resolution towards the atomistic limit requires careful verification of the underlying processes. In a theoretical study with Okayama University of Science, Japan the effect of atomic order seen by the ions as they penetrate the surface was found not to be of significance for analysed depths beyond 1–2 bond lengths in amorphous materials.

The Pelletron accelerator has functioned very well with only short maintenance breaks. The new SNICS ion source has been heavily used and also reduced maintenance downtime because service can be carried out on one source, while the other is operating. To improve the available proton beam currents for lithography and microscopy a multi-cusp ions source was designed and construction started.

Fig. 2. (Left) Time-of-flight-Energy histogram for a borosilicate glass sample measured using 10.2 MeV $^{79}$Br ions with the new gas ionisation energy detector. (Right) Corresponding data for a conventional Si energy detector.



# Industrial Applications

Ari Virtanen

Ari Virtanen, research director
Heikki Kettunen, senior researcher
Iiro Riihimäki, graduate student, PhD 7.4.
Arto Javanainen, graduate student
Taneli Kalvas, graduate student
Kalle Auranen, MSc student
Alex Hedlund, MSc student
Mikko Rossi, operator

The usage of the beam time for different purposes is shown in Fig. 1. The total beam hours used in 2010 was 1434.

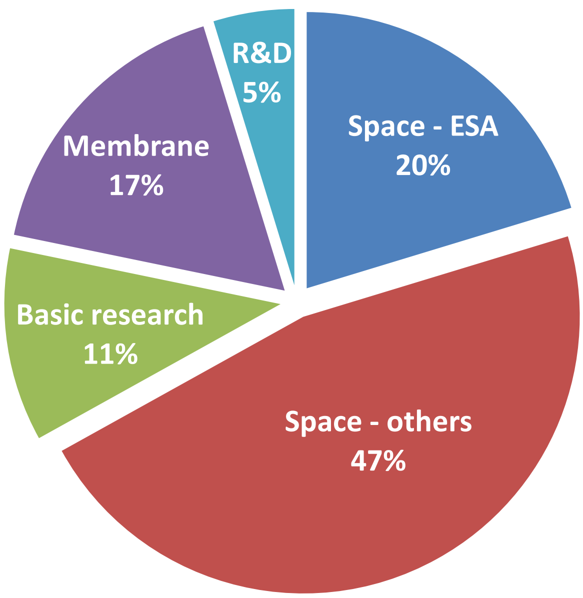



Fig. 1. Beam time distribution; Space-ESA = space component tests for ESA, Space-other = space component tests for satellite industry, Membrane = membrane irradiation, R&D = research and development of RADEF, Basic research = studies based on PAC proposals.

## Space Related Study

RADEF continued as one of ESA's external European Component Irradiation Facility (ECIF). In total 21 campaigns for 15 satellite companies or institutes were performed during 2010. These are summarized in Table 1.

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

ASRO Oy, Finland
ATMEL, France
CEA, France
EASII IC SAS, France
ESA/ESTEC, The Netherland
HIREX Engineering, France
IDA, Germany
INTA, Spain
NASA/JPL, CA, USA
RUAG Sweden
Sandia National Laboratories, NM, USA
Swedish Space Corporation
STMicroelectronics, France
Thales Alenia Space, France
TRAD, France

## Other Industrial Activities

The non-space collaborating companies and institutes are listed in Table 2.

**Table 2. Collaborating companies**

| |
|---|
| Bintec Oy, Hollola |
| Central Finland Health Care District, Jyväskylä |
| Jyväskylä Innovation Oy |
| Doseco Oy, Jyväskylä |
| Gammapro Oy, Jyväskylä |
| Metso Automation Oy, Tampere |
| Oxyphen GmbH, Switzerland |
| VTT Jyväskylä |

Oxyphen GmbH continued the irradiation of their polymer films. Three campaigns were performed in 2010. The total beam time for this activity was 244 hours.

A study work with VTT Jyväskylä was started. A measurement of calcium carbonate from a wet paper web by using x-rays was performed. A new opening was made with Metso Automation. This study is focused on a dual-energy x-ray method, which will be applied to on-line measurement of formation of additives during paper making.

## Fundamental Research

We also performed applied basic research at RADEF (see Fig. 1). This was done with Vanderbilt University (Tennessee, USA), CERN/ HIP, University of Turku and Radiation and Nuclear Safety Authority Finland, STUK.

Because of the complexity in modern electronics with deep-submicron technologies, the traditional approach using average energy deposition gives ambiguous results. A simulation tool called MRED (Monte Carlo Radiative Energy Deposition) based on Geant4 is developed in Vanderbilt University for e.g. modeling the contributions of nuclear fragmentation on single event effects. To improve these descriptions we performed an experiment, where reaction products from e.g. Au(N,X)X and W(N,X)X reactions at different scattering angles were measured.

Accurate stopping power data of ions in water are required in many branches of radiation dosimetry. For example, it is directly reflected in the dose distribution calculated in proton beam cancer therapy. For protons of energy greater than 2 MeV there is no experimental data available. Therefore, we started a series of measurements in cooperation with STUK. The first results were reported in 3rd European IRPA Congress (Helsinki, 14–18 June 2010), in International IDOS Symposium (Vienna, Austria, 9–12 November 2010) and in a manuscript submitted to Phys. Med. Biol.. Our aim is to extend the study to lower energies and other ions.

# Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Jouni Suhonen

Jouni Suhonen, professor
Mika Mustonen, graduate student, PhD 16.6.
Emanuel Ydrefors, graduate student

## Activity in 2010

### Nuclear Matrix Elements for Double Beta Decay

Nuclear matrix elements (NMEs) of neutrinoless double beta decay play a key role in physics related to the properties of the neutrino, in particular concerning its mass and basic demeanor. During 2010 our group has made evaluations of the NMEs by using cutting-edge nuclear-structure tools to limit their uncertainties. These uncertainties were studied by testing how the different orbital occupancy schemes and sizes of valence space affect the values of the NMEs for decays to the ground state of the daughter nucleus [1]. It was found that inclusion of all the spin-orbit partners of single-particle orbitals was essential in obtaining reliable NMEs in the QRPA (quasiparticle random-phase approximation) formalism. The orbital occupancies do not play as decisive role in this respect. A continuation of this survey is carried out in Ref. [2] for neutrinoless double beta decays to the first excited $0^+$ states. Interesting differences between the excited-state and ground-state decays are registered. At the same time a sophisticated many-body framework for including the four-quasiparticle degrees of freedom in the double beta calculations has been introduced. This proton-neutron version of the Microscopic Anharmonic Vibrator Approach (MAVA) has been used to study the importance of four-quasiparticle structures in the description of the two-neutrino double beta decays of $^{76}$Ge [3] and $^{100}$Mo [4].

### Neutrino-Nucleus Interactions And Supernova Neutrinos

Understanding neutrinos and their interactions with matter is essential for many applications in modern astrophysics. Important examples are the nucleosynthesis of heavy elements and modeling of supernova explosions. Neutrinos also constitute sensitive probes of physics beyond the Standard Model such as neutrino oscillations. Neutrinos can be detected by Earth-bound detectors using neutral-current and charged-current neutrino-nucleus interactions. One example of such a possibility is the MOON (Majorana/Mo Observatory Of Neutrinos) [5] detector.

Theoretical estimates of the nuclear responses to neutrinos for relevant target nuclei are of paramount importance for future experiments. We have therefore, in collaboration with the group of Theoretical Physics in Ioannina, Greece, computed cross sections for neutral-current neutrino-nucleus scattering off the stable

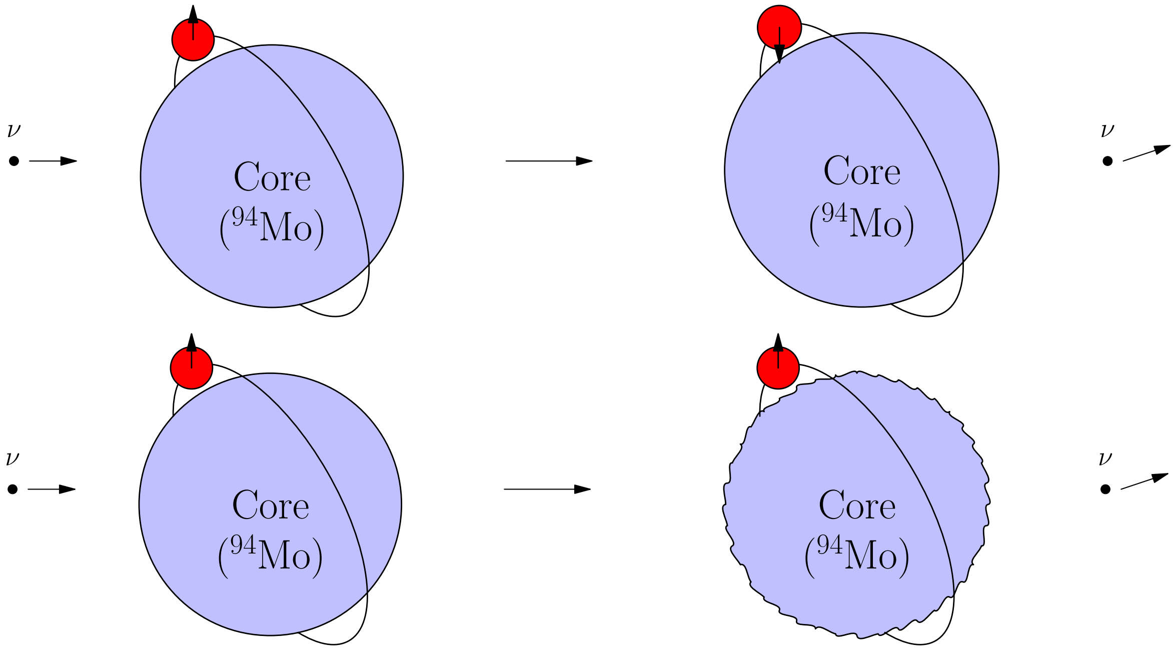



Fig 1. Neutral-current neutrino-nucleus spin-flip scattering to the 3/2⁺ state in $^{95}$Mo

Fig 2. Physical interpretation of the neutral-current neutrino-nucleus scattering to excited states of multipolarity 5/2⁺ in $^{95}$Mo

(A=92, 94,95,96,97,98,100) molybdebum isotopes using the theory for neutral-current neutrino scattering outlined in [6]. For the even-even isotopes the QRPA (quasiparticle-random-phase approximation) has been used and for the odd nuclei we have adopted the wave functions constructed in Ref. [7]. The cross sections have also been folded with appropriate neutrino spectra to give realistic estimates for the nuclear responses to supernova neutrinos. We have found that for the odd nuclei ($^{95}$Mo and $^{97}$Mo) the incoherent cross section is dominated by a transition to the second $3/2^+$ state which is visualized in Fig 1. There are in addition transitions to excited $5/2^+$ states with the simple physical interpretation of a non-spin-flip vibrational core excitation shown in Fig 2.

## Highlights

## Rare Beta-Decays with Ultra-Low Q Values

Recently the rare decay branch of $^{115}$In pushed the record of the lowest observed Q value down to the hundred-eV scale [8]. We have investigated this decay theoretically by applying the proton-neutron microscopic quasiparticle-phonon model in combination with the theory for highly forbidden beta decays. It seems that the measly Q value makes the nuclear and atomic effects mix in a delicate way [9,10,11]. The emergent atomic contributions are out of control and pose new challenges for both the theoretical and experimental communities. To verify whether these surprising features are general one needs to find other potential candidates for detection of such ultra-low-Q-value decays [12]. Finding and analyzing such cases calls for intensive collaboration with the local JYFLTRAP group responsible for the Q-value measurements with a Penning type of ion trap.

## Resonant Neutrinoless Double Electron Capture of Nuclei

During last few years experimental attention has been directed to a new interesting possibility to access neutrino properties, namely the neutrinoless double electron capture (0vECEC). In particular, it has been speculated that the resonant 0vECEC could be detected due to its potential million-fold resonant enhancement relative to the double-positron emitting processes. In the resonant 0vECEC the energy of the ground state of the mother nucleus matches the energy of an excited state of the daughter nucleus (see figure 3). Recent advances in determination of the decay Q values and in nuclear-structure calculations help determine the magnitudes of the potential resonant enhancements. Most recently we have analyzed together with the JYFLTRAP group the cases of $^{74}Se$ [13] and $^{136}Ce$ [14] for the potential resonant enhancement.

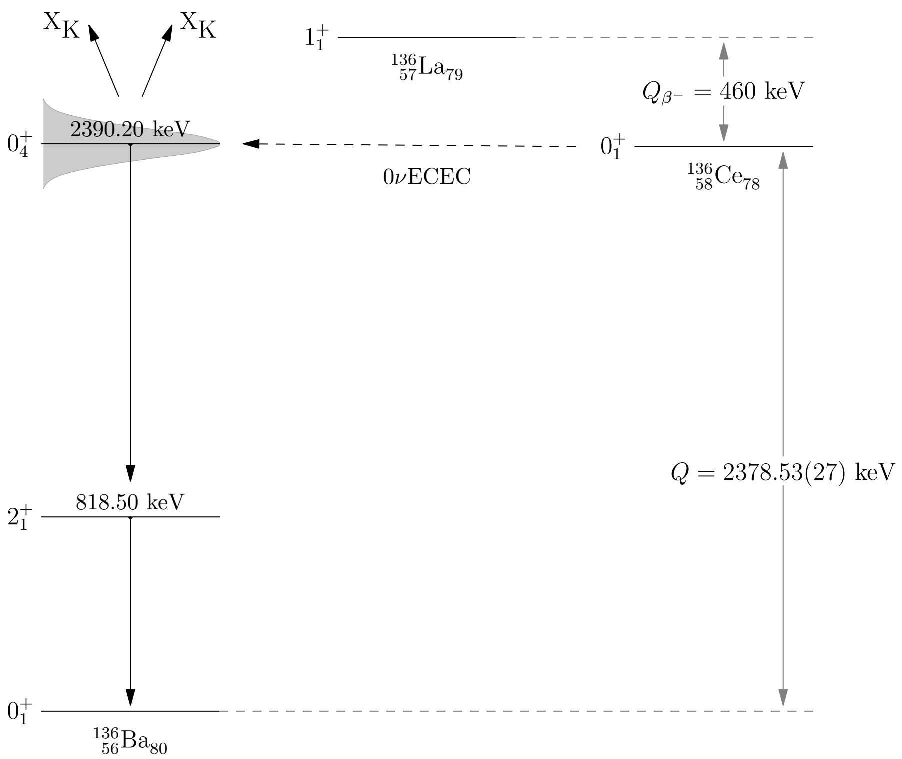



Fig. 3. Resonant neutrinoless double electron capture of $^{136}Ce$.

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# Experimental Nanophysics and Nanotechnology

Markus Ahlskog, Konstantin Arutyunov, Ilari Maasilta and Jussi Toppari

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Ilari Maasilta, professor
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Kimmo Kinnunen, graduate student
Mikko Koponen, graduate student
Janne Lehtinen, graduate student
Jarkko Lievonen, graduate student
Veikko Linko, graduate student
Davie Mtsuko, graduate student
Minna Nevala, graduate student
Mikko Palosaari, graduate student
Antti Pennanen, graduate student
Yaolan Tian, graduate student, 1.9.–
Peerapong Yotprayoonsak, graduate student
Benjamin Ames, MSc student
Hannu-Pekka Auraneva, MSc student
Svitlana Baieva, MSc student
Zhuoran Geng, MSc student
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Antti Juutilainen, MSc student, –15.8.
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Seppo Paasonen, MSc student
Teemu Parviainen, MSc student
Boxuan Shen, MSc student
Vikramjit Singh, Msc student
Kosti Tapio, MSc student
Andrii Torgovkin, MSc student

## 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 2010:

Tunnel junctions are versatile components, which have been used widely as radiation detectors, superconducting quantum interference (SQUID) magnetometers, single electron transistors and pumps, and superconducting qubits, and in our group especially as normal metal-insulator-superconductor (NIS) tunnel junction coolers and thermometers. Thus, improvement of their characteristics can have a wide impact in many applications. We have studied how vacuum thermal annealing affects the intrinsic low-frequency 1/f resistance noise of submicron Al–AlO*x*–Al tunnel junctions [1]. We observed that the annealing process could lead to an order of magnitude reduction in the 1/f noise power after vacuum annealing. The resistance noise spectral density obtained after the treatment was about an

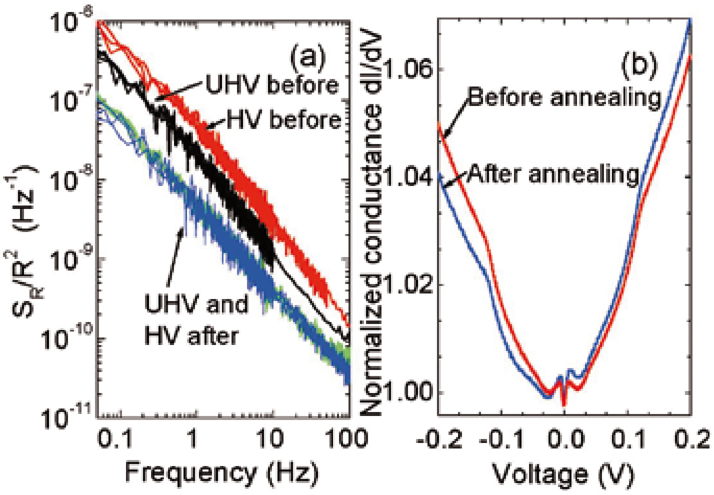


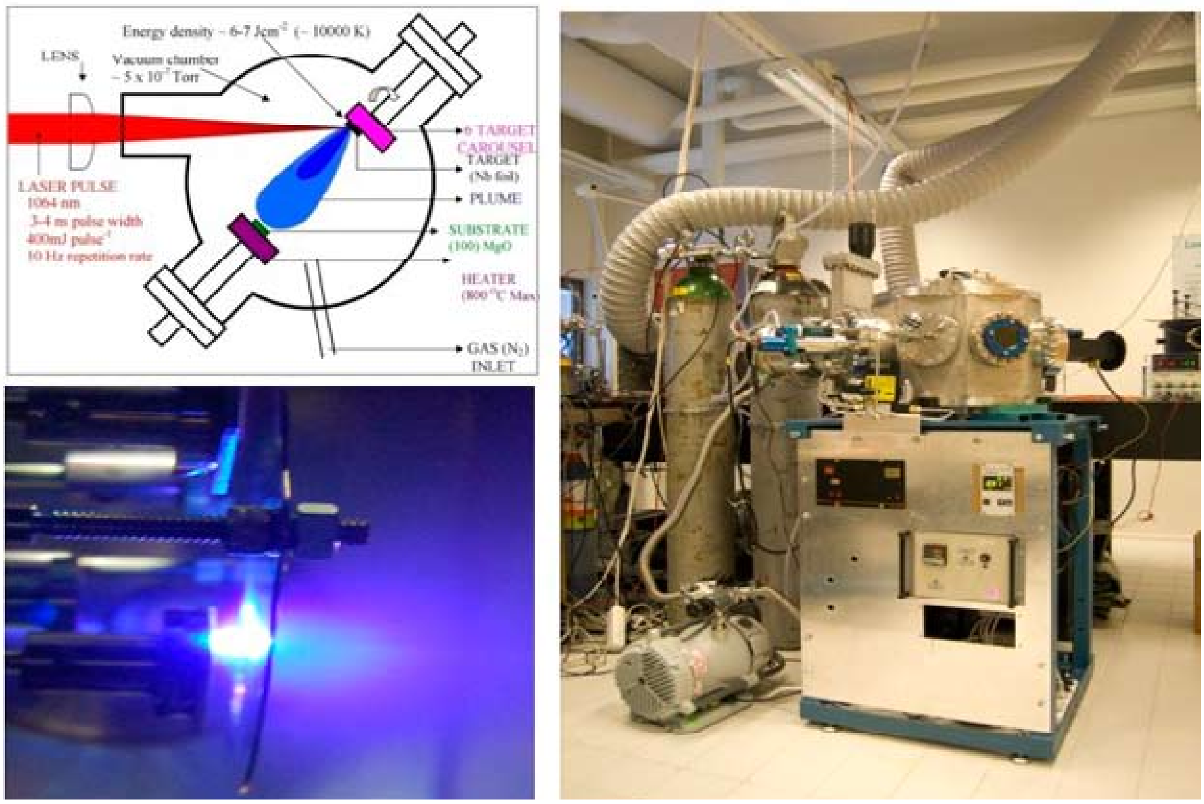

Fig.1. Left: The resistance noise spectrum before and after annealing for two different sample types (fabricated either in high vacuum (HV) or ultra-high vacuum (UHV). Right: the conductance spectrum before and after annealing for UHV samples.

Fig. 2. Left: A novel cryogenic X-ray spectrometer based on an adiabatic demagnetization refrigerator (ADR).
Right: A photograph of the 50 mK stage with the detector array chip and SQUID readout electronics.

order of magnitude below that of typical results in the literature. The results are consistent with a model where the density of charge trapping two level-systems within the tunneling barrier is reduced by the annealing process.

Another focus field has been development of superconducting transition-edge X-ray detectors. We

Fig. 3. Pulsed laser deposition (PLD) system at the Nanoscience Center (NSC). Left top: Schematics of the principle of PLD. Left bottom: the plasma plume caused as a result of interaction of nanosecond laser pulses with matter. Right: Photograph of the system.



have continued our collaborative project with Lund University and NIST Boulder, where we are developing a unique state-of-the-art versatile X-ray spectrometer utilizing superconducting sensors, which could be used for sub-ps time-resolved X-ray absorption fine structure (XAFS) spectroscopy, for example. In 2010 we finished the design and construction of the detector stage for the dry refrigerator (no liquid He involved) based on an pulse tube cooler and an adiabatic demagnetization refrigerator (ADR), capable of reaching sub-50 mK temperatures (Fig. 2). We also demonstrated an energy resolution of ~ 3 eV at 6 keV at Lund. The cryogenic system was successfully installed and tested at NSC in the fall of 2010, and first X-ray measurements here will commence in spring 2011.

In another development of instrumentation, we have successfully installed a new pulsed laser deposition (PLD) system (Fig. 3), and fabricated superconducting niobium nitride thin films on single crystals of magnesium oxide using 1064 nm (photon energy ~ 1.16 eV) laser pulses from an Nd:YAG laser [2]. A correlation between the superconducting transition temperature, the nitrogen base pressure during deposition and the lattice parameter of the produced NbN films was observed, with a highest achieved transition temperature of 15.5 K. Normal metal-insulator-superconductor (NIS) tunnel junctions were also successfully fabricated using the PLD grown NbN as the superconductor.


[1] J. K. Julin, P. J. Koppinen and I. J. Maasilta, "Reduction of low-frequency 1/f noise in Al-AlOx-Al tunnel junctions by thermal annealing ", Appl. Phys. Lett. 97, 152501 (2010)

[2] S. Chaudhuri, M. R. Nevala, T. Hakkarainen, T. Niemi and I. J. Maasilta, " Infrared pulsed laser deposition of niobium nitride films", IEEE Trans. Appl. Supercond., in press (2011)


## Molecular Technology

Markus Ahlskog

The Molecular Technology group studies electronic and mechanical properties of macromolecular particles and devices that are based on them. The main focus is on carbon nanotubes (CNTs), while biological particles are under consideration as well.

Combined techniques for measurement of structural, electron transport, and optical properties of individual carbon nanotubes are very important. We have developed a method to suspend nanotubes over narrow slits, see Fig. 4 (a) and (b). In this sample geometry we have combined Raman spectroscopy and TEM electron diffraction to get two mutually independent determinations of the individual chiral structure. The suspended geometry also gives a heavily reduced background signal in the optical measurements, which has allowed us to perform the first femtosecond four-wave-mixing (FWM) spectroscopy on a single carbon nanotube [1], see Fig. 4 (c). The FWM signal is plotted versus delay time between the Stokes and the probe pulses, and shows broadening compared to the reference BBO trace. The achievement opens the door to direct studies of electronic and vibrational dynamics of individual carbon nanotubes. The studies are done in an interdisciplinary collaboration with the groups of Prof. Mika Pettersson at University of Jyväskylä and Prof. Esko I. Kauppinen at Aalto University.

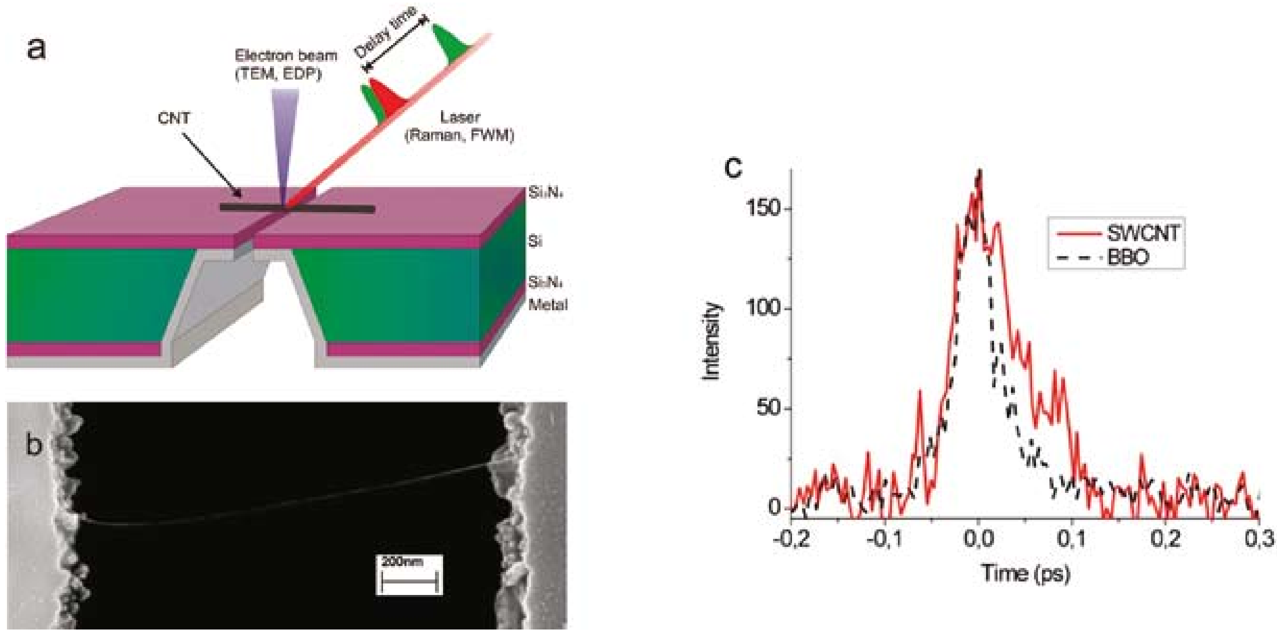



Fig 4. a) Schematic of our suspended carbon nanotube samples. b) Scanning electron micrograph of a CNT suspended across a slit. c) Femtosecond FWM data from a CNT with the chiral indices (28;4).

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 [2] 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. 5 (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 5 (b). The doping consists

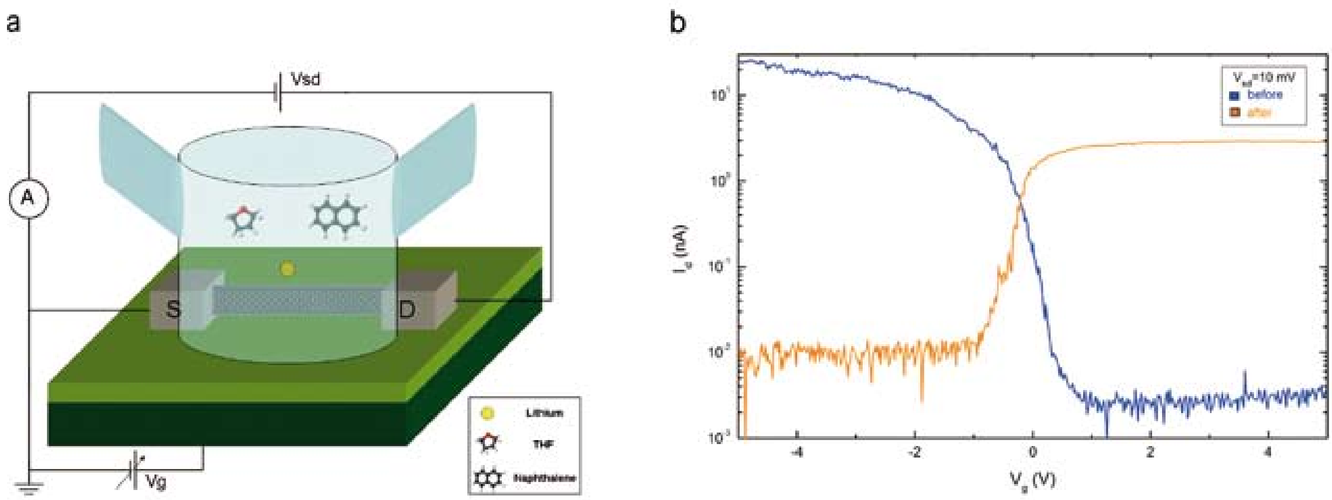



Fig. 5. a) Schematic of CNT FET liquid-phase doping and measurement setup. b) Transfer characteristics from a CNT FET before (blue) and after (orange) liquid-phase n-doping.

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, or other nanoscale devices probed [3].

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 ($MoS_2$).

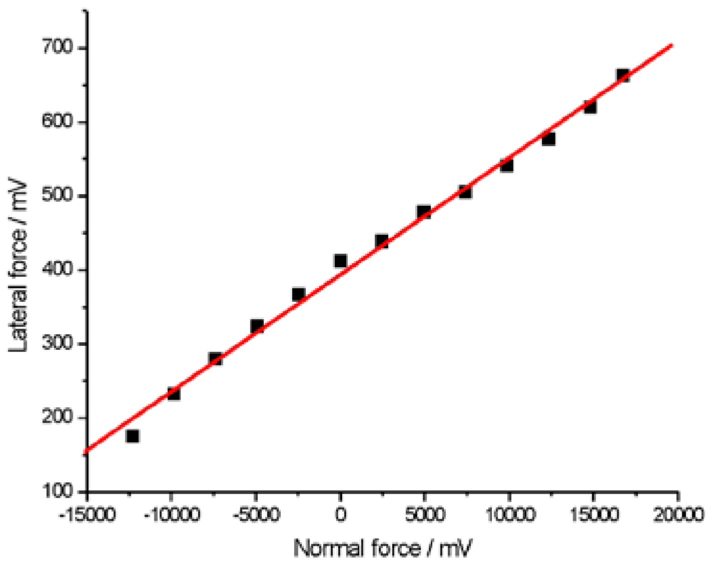



Fig. 6. Lateral force (a.k.a. friction) measured with different scanning forces on a $MoS_2$ surface.

Their properties in the nanoscale domain are not well understood and will certainly be to some extent different. We have begun the study of these with the AFM, as shown in Fig. 6.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"Femtosecond four-wave-mixing spectroscopy of suspended individual semiconducting single-walled carbon nanotubes"
*ACS Nano* . **4**, 6780 (2010).

[2] P. Yotprayoonsak, K. Hannula, T. Lahtinen, M. Ahlskog, A. Johansson
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*In preparation.*

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"Strain sensing with sub-micron Al-AlOx-Al tunnel junctions"
*Review of Scientific Instruments* , **81**, 023901 (2010).


## Quantum Nanolectronics


Konstantin Arutyunov


The activity of *Quantum nanoelectronics group* can be formally separated into four topics: (I) quantum size phenomena at nanoscales; (II) interface phenomena at nanoscales; (III) molecular nanoelectronics; and (IV) applied nanotechnology.

### Quantum Size Phenomena at Nanoscales

The group continued its study of quantum fluctuation phenomena in nano-scale superconductors. Additionally to the already observed suppression of zero resistivity in ultra-narrow superconducting

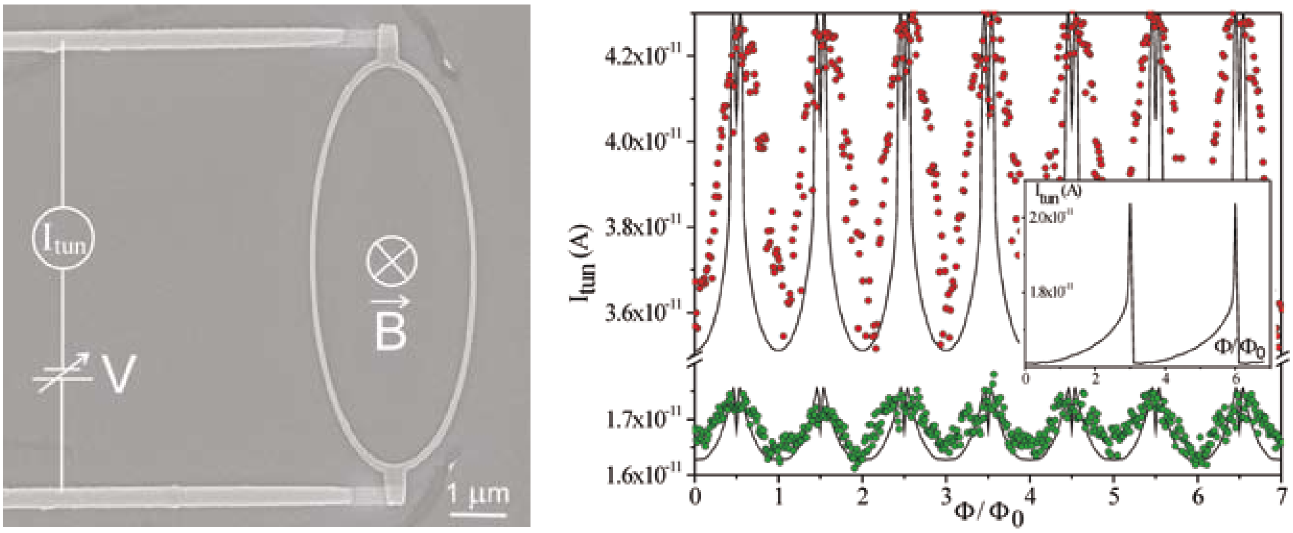



Fig. 7. Left: SEM image of a SISIS tunnel structure with the loop-shaped central electrode and the schematics of the experiment. Right: oscillations of the tunnel current (~ persistent current in the loop) in the same structure with wide (top) and narrow (bottom) line width different just by few nm. The dramatic difference in the shape and magnitude of the oscillations is the manifestation of quantum fluctuations. Solid lines represent calculations, inset – calculations in the classical limit (no fluctuations) [unpublished].

nanowires, the group extended the studies on checking the fundamentally important property of a superconductor – persistent currents in nanorings – where the quantum fluctuations quench the diamagnetic response (Fig. 7). The discovery is of fundamental importance indicating breakdown of the text-book diamagnetism in superconductors due to the new quantum phenomenon.

## Interface Phenomena at Nanoscales

Conversion of electric current at the interface of different materials is a common situation in almost all electric applications. Being of an essentially non-equilibrium origin the effect might be of little concern at macroscales. However, if the dimensions of the whole structure are comparable to the characteristic relaxation length, the whole system might become an "interface". Of our particular interest is the conversion of normal metal current, transported by single electrons, to pairs of electrons (Cooper

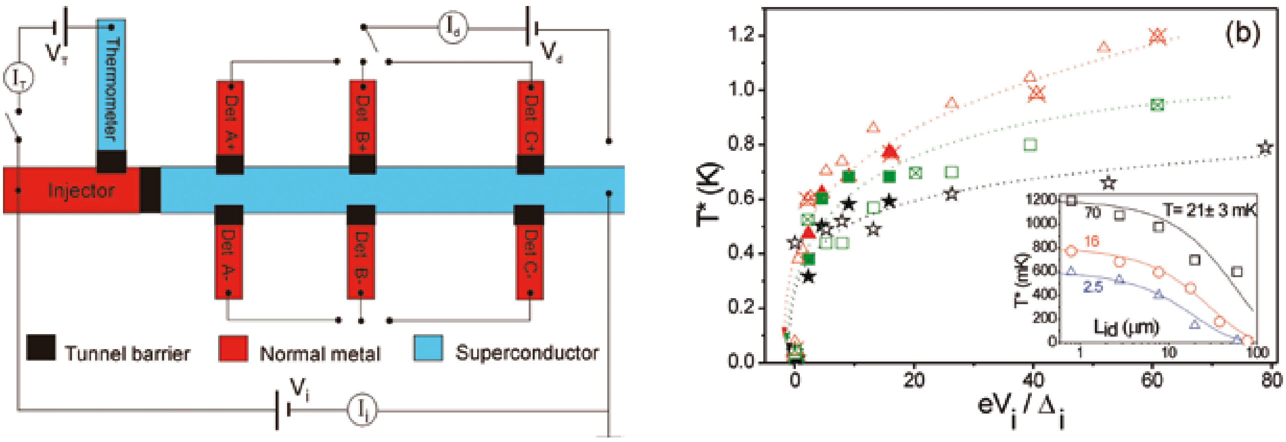



Fig. 8. (Left) Schematics of the experiment. (Right) Effective temperature of a superconductor T* as function of the quasiparticle injection energy at a base temperature T=20 mK at various distances from the injector. Inset: spatial variation of T* at different excitation energies [unpublished].

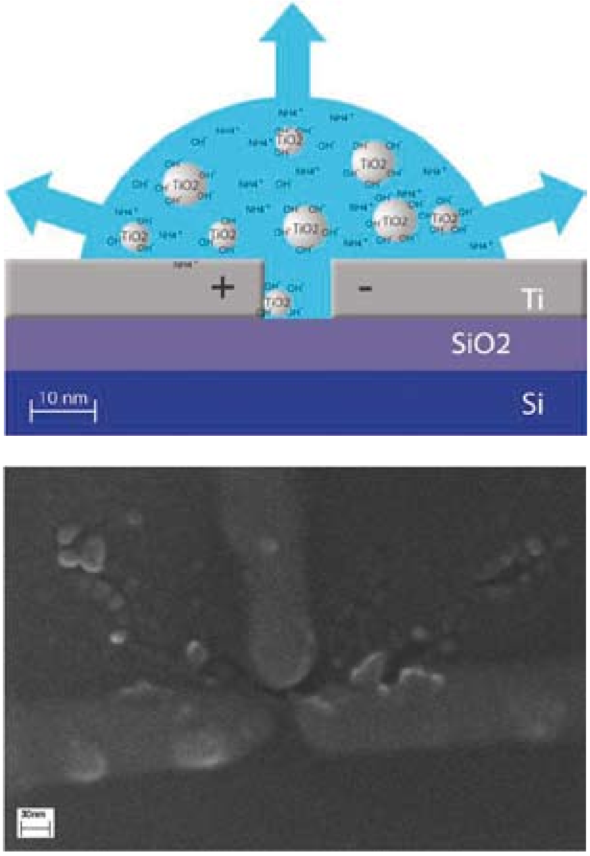



Fig. 9. (a) Schematics of a nanoparticle trapping method; (b) SEM image of $TiO_2$ nanoparticles trapped between Ti electrodes on $Si/SiO_x$ surface [unpublished].

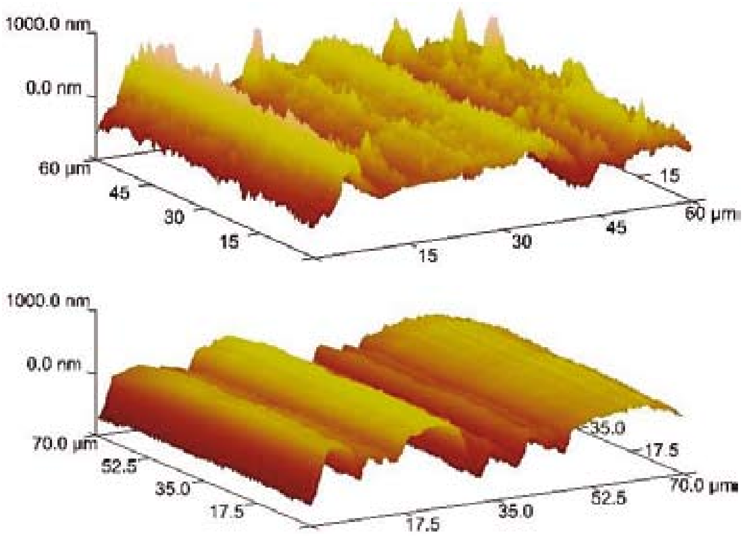



Fig. 10. SPM images of commercial gear wheel tooth surface (left) and the same sample after the ion beam polishing (right).

pairs) in a superconductor. The topic has been studied in multi-terminal structures (Fig. 8) where the electrons were injected into the superconductor (Al) from the normal metal (Cu) through a tunnel barrier ($AlO_x$). Our experiments gave an astonishing result: at ultra-low temperatures (T~20 mK <<$T_c$~1.4 K) the energy relaxation happens at 'astronomical' (for a superconductor) scales ~ 50 µm. The study is of fundamental importance for the basic science and for numerous applications of hybrid (tunnel) nanosystems.

## Molecular Nanoelectronics

In collaboration with the team of Prof. J. Korppi-Tommola (NSC, Dept. of Chemistry) the group continued the experimental study of the dye-based molecular nanostructures. The group has developed high vacuum compatible and nanofabrication "friendly" method of deposition of organic dye molecular layers *[P. Jalkanen, L. Anttila, J. Korppi-Tommola, and K. Yu. Arutyunov, Synthesis and characterization of vacuum deposited fluorescein thin films, Thin Solid Silms, 2010]*. The absorption spectra showed clear resemblance with the conventionally fabricated (by soaking in a solution) dye samples, indicating the good quality of the organic films. The technology has been applied for trapping $TiO_2$ / dye molecules between nanoscale electrodes (Fig.9)

## Applied Nanotechnology

The group extended the patented (application FI-20060719) technology of the ion beam downscaling of nanostructures. The method can be used for multiple applications. An example of the effect of the ion beam polishing on commercial gear wheel is presented in Fig. 10. The activity is been supported by TEKES project DEMAPP LOLUBS and is made in collaboration with several academic industrial partners.

# Molecular Electronics and Plasmonics

Jussi Toppari

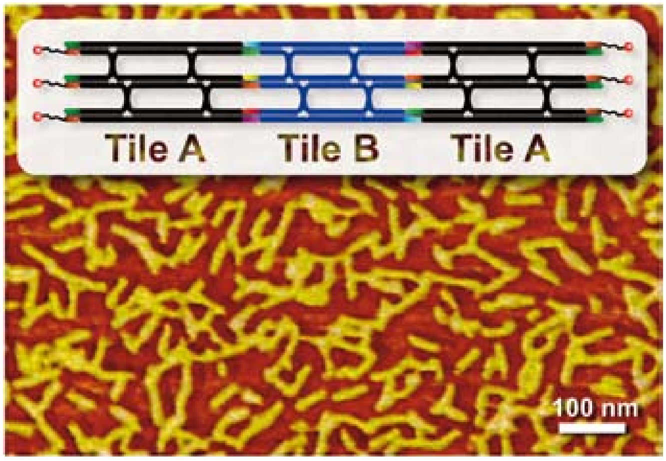


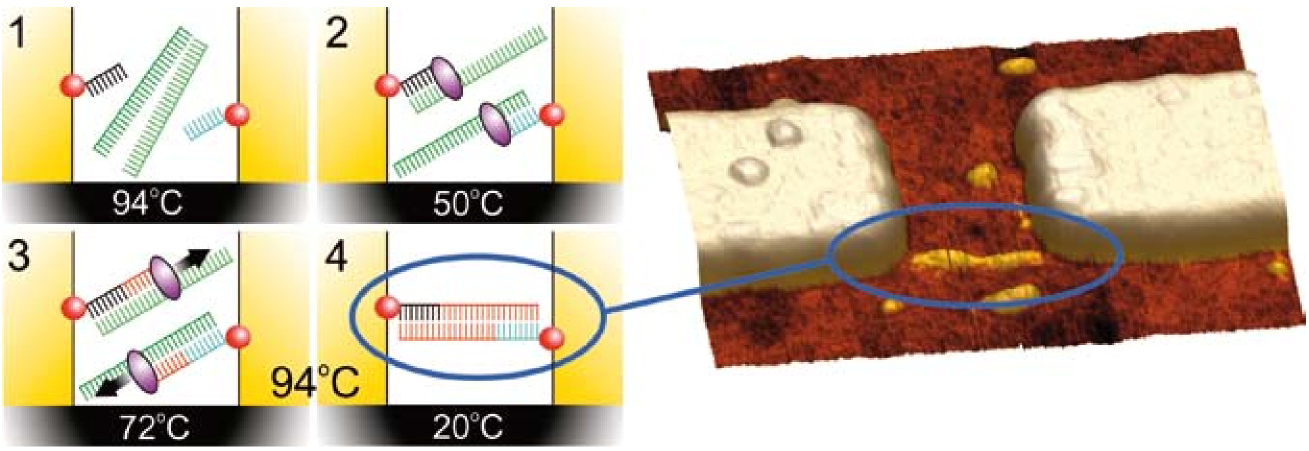

Fig. 11. AFM image of ~60 nm long A-B-A TX tile constructs dried on a mica surface, and a schematic view of the construct. The tiles are conjugated together via the sticky end pairing.

Superior self-assembly properties of DNA can be efficiently utilized in the bottom-up fabrication of complex nanoelectronic systems or nanodevices. Various DNA-based structures, e.g. DNA origamis or arrays of so-called TX-tile complexes, have been realised. We have fabricated a novel self-assembled defined-sized TX tile DNA complex, which can be incorporated into molecular electronic devices especially as a scaffold (see Fig. 11). The fabricated complexes were guided to certain locations by dielectrophoretic (DEP) trapping and immobilized between gold nanoelectrodes via thiol-linkers. We have also demonstrated that the developed structure can be functionalized. The electrical conductivity of the trapped TX tiles was analyzed by AC impedance spectroscopy and the results revealed that the conductivity is small enough for one to build almost any kinds of electrical devices without having to take the scaffold into account. The approach is similar to our previous conductivity measurements performed for DNA origamis, and thus the method also gives crucial information about the conductivity of DNA constructs in general.

In addition, we have developed a method for controlled connection of nanoscale electrodes with individual dsDNA molecules by utilizing polymerase chain reaction (PCR). Single-stranded thiol-modified oligonucleotides have been immobilized to gold electrodes by means of DEP trapping, and extended in a PCR procedure finally forming a complete dsDNA bridging the gap between the electrodes as shown in the Fig. 12. The technique opens up opportunities for detecting single molecules or molecule combinations, and also for fabricating bottom-up based nanostructures from DNA at desired locations on a chip.

## Usage of alternative and renewable energy sources

Fig. 12. Schematic cartoon of the method to connect nanoelectrodes by immobilized PCR and an AFM image of successful bridging.



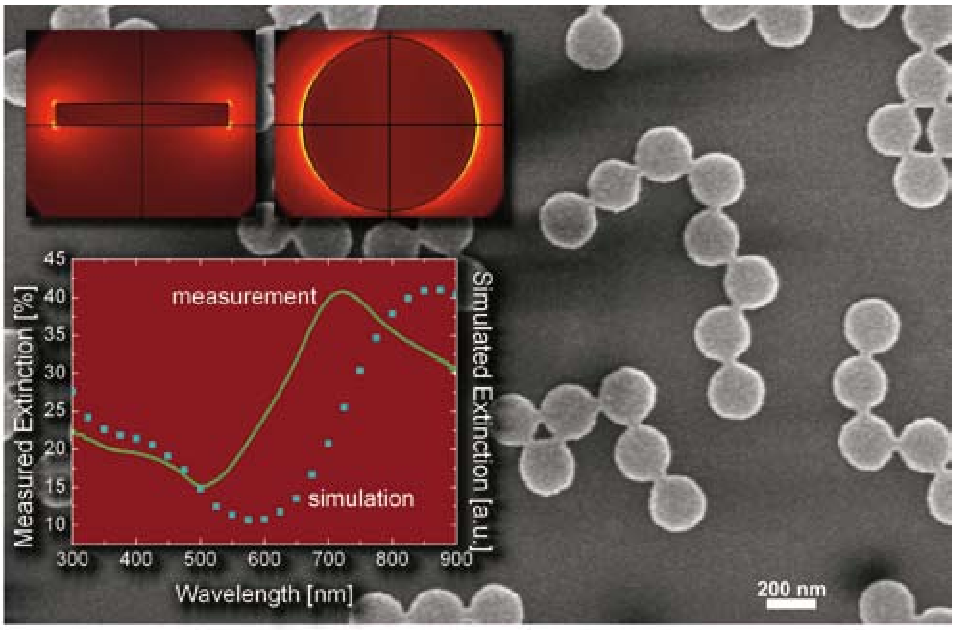



Fig. 13. Upper left image shows a simulated electrical near field induced onto a 200 nm wide and 25 nm high gold nanoparticle (side and top view), by a light with wavelength of 875 nm. Lower left image shows the simulated extinction spectrum and an experimental one measured from the particles shown in the SEM image on background.

has risen rapidly during this millennium. Solar energy is one of the most promising among the renewables. A lot of effort is put into developing of solar energy technologies to be more energy and cost efficient. Research of plasmonics plays a major role in this development. We are studying light trapping and guiding properties of structures based on plasmonic nanoparticles. Metallic nanoparticles are capable of scattering and absorbing light with great efficiency over a wavelength range that is tunable by altering the dimensions and environment of the particle (see fig. 13). These properties make plasmonic structures a promising phenomenon for solar energy applications.

We have also studied interactions between dye molecules and waveguided SPPs and demonstrated a strong coupling between SPPs and several kinds of molecules, with single or double Rabi splittings. This work has been carried out as collaboration with a group of Prof. Päivi Törmä in Aalto University and professors Mika Pettersson and Henrik Kunttu from Department of Chemistry, JYU.

# Computational Nanosciences

Jaakko Akola, Hannu Häkkinen, Pekka Koskinen, Matti Manninen,
Esa Räsänen and Robert van Leeuwen

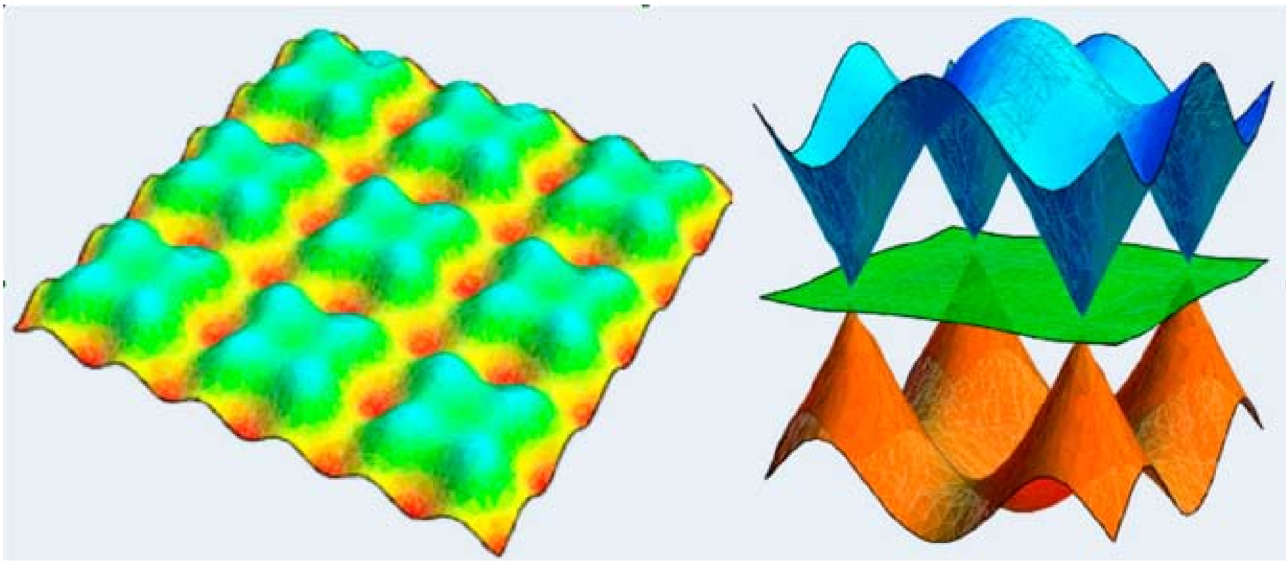
Matti Manninen, professor
Hannu Häkkinen, professor (physics and chemistry)
Robert van Leeuwen, professor
Karoliina Honkala, academy researcher (chemistry)
Esa Räsänen, academy researcher
Jaakko Akola, senior researcher -31.7.
Vesa Apaja, senior researcher
Olga Lopez-Acevedo, postdoctoral researcher
Adrian Stan, postdoctoral researcher
Julen Larrucea, postdoctoral researcher 1.2.-
Klaas Giesbertz, postdoctoral researcher 1.8.-
Andre Clayborne, postdoctoral researcher, 1.4.-
Michael Ruggenthaler, postdoctoral researcher, 1.9.-
Mikkel Strange, postdoctoral researcher, -31.8.
Pekka Koskinen, postdoctoral researcher
Sami Malola, postdoctoral researcher, -31.6.
Jenni Andersin, graduate student (chemistry)
Katarzyna Kacprzak, graduate student, -31.6.
Elena Heikkilä, graduate student, -31.7
Janne Kalikka, graduate student
Oleg Kit, graduate student
Ville Kotimäki, graduate student
Perttu Luukko, graduate student
Petri Myöhänen, graduate student
Ville Mäkinen, graduate student
Lauri Nykänen, graduate student (chemistry)
Antti Putaja, graduate student
Anna-Maija Uimonen, graduate student
Niko Säkkinen, graduate student
Jyri Hämäläinen, MSc student
Markku Hyrkäs, MSc student
Manana Koberidze, MSc student
Anton Laakso, MSc student
Janne Nevalaita, MSc student
Juho Ojajärvi, MSc student
Pauli Parkkinen, MSc student (kemia)
Janne Solanpää, MSc student
Riku Tuovinen, MSc student

## Dynamics of Fermionic Atoms in an optical lattice with a Flat Band and Dirac Cones

Vesa Apaja and Matti Manninen

We showed that using six pairs of lasers it is possible to create an optical lattice, which has a nearly completely flat band and Dirac cones at the Brillouin zone boundary [Phys. Rev. A 82, 041402 (2010)]. Figure 1 shows the resulting potential of this edge-centered square lattice and the three lowest bands resulting from the lattice. The band structure can be accurately described with a simple tight binding model with one quantum state per lattice site. This allows us to study dynamical effects, such as atom mobility.

We simulated a suggested experiment where the edge centered optical lattice is superimposed with a harmonic confinement which initially concentrate the atoms in the central region of the lattice. With a strong repulsive potential between the trapped atoms only one atom is allowed in each lattice site. When the harmonic confinement is removed most of the atoms fly away very fast, due to the repulsive interaction, but those atoms occupying the flat band remain immobile, as shown in figure 2.



Fig, 1.  Edge-centered optical lattice (left) and the resulting band structure (right) showing a flat band at the center an Dirac cones at the corners of the Brillouin zone.

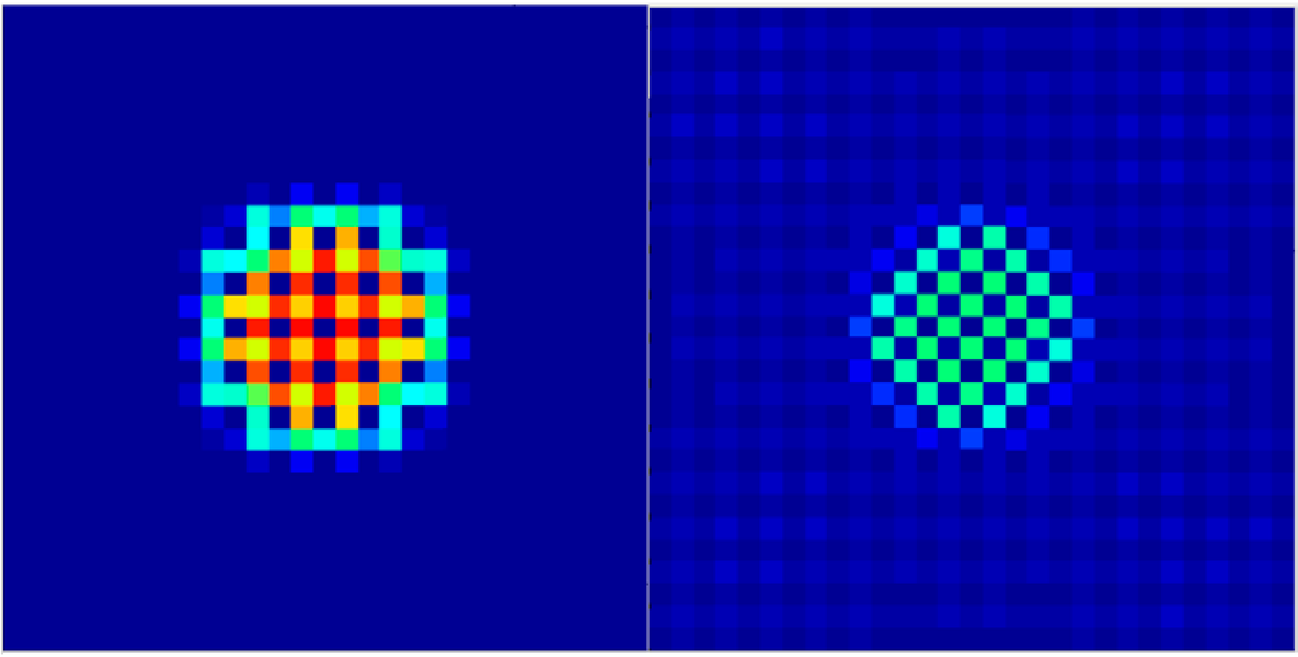


Fig. 2.  Density of atoms at the lattice before (left) and after (right) removing the harmonic confinement.

## Mathematical Foundations of Density Functional Theory

Robert van Leeuwen and Michael Ruggenthaler

Time-dependent density functional theory is an important theoretical approach that allows for the calculation of properties of time-dependent many-particle quantum systems within an effective one-particle framework. This framework relies on a one-to-one mapping between externally applied potential fields and the particle densities generated by these potentials. It further relies on the possibility to reproduce the density of an interacting many-particle system within an effective noninteracting system, also known as the noninteracting v-representability question. Proof of the one-to-one correspondence was initially given by Runge and Gross [Phys.Rev.Lett. 52,997 (1984)]. Noninteracting v-representability, as well as an extension of the Runge-Gross theorem was proven by our own group [R.van Leeuwen, Phys. Rev. Lett. 82, 3863 (1999)].These works, however, made some restrictive assumptions on the Taylor-expandability in time of the external potentials.

We recently found a completely new approach [M.Ruggenthaler and R.van Leeuwen, cond-mat arXiv:1011.3375] that avoids these assumptions and thereby generalizes the formal applicability of time-dependent density functional theory. The central idea is to restate the fundamental one-to-one correspondence between densities and potentials as a global fixed point question for potentials on a given time-interval. Mathematically this relates to the question whether a contractive mapping exists on the Banach space of potentials. We prove that the unique fixed point, i.e. the unique potential generating a given density, is reached as the limiting point of an iterative procedure and show its convergence under some mild conditions. This then generalizes the works cited above to the case of time non-analytic potentials. Owing to its generality, the proof not only answers basic questions in density-functional theory but also has potential implications in other fields of physics. We are currently exploring extensions of our approach as well as further applications to other many-body approaches such a density matrix theories.

## Nano-construction Sites Got New Building Blocks

Pekka Koskinen

The building blocks of matter have always been rectilinear–until now. Modeling of macroscopic materials has been done with one type of a building block, duplicating it linearly in different directions, such as building a huge wall from single-format

Illustration 1. Bent nanotubes, for example, can be now simulated efficiently using the revised Bloch's theorem.

Lego-blocks. This modeling has been enabled by Bloch's theorem, an 81-year-old cornerstone of material science.

Meanwhile, nanoscience has introduced new structures, nanotubes, nanotori, nanowires and atomically thin membranes and films. Unlike a chunk of metal, flimsy nanostructures stay rarely sraight, but get frequently twisted, bent, wrapped, rippled, or otherwise distorted in practice. Rectilinear order gets broken and building blocks get distorted; Bloch's theorem becomes invalid.

To solve this fundamental problem, we updated Bloch's theorem for the new millennium *[Phys. Rev. Lett. 105, 106401 (2010); Editor's suggestion]*. The update provides nanoscientists new building blocks that can be distorted in many ways, to enable computer modeling of realistic nanostructures. "The results can be compared with a situation where a boy, bored in building the same old straight walls using the same rectangular Lego-blocks, finds blocks with new shapes–an opportunity to build something completely new," describes Pekka Koskinen the significance of the result.

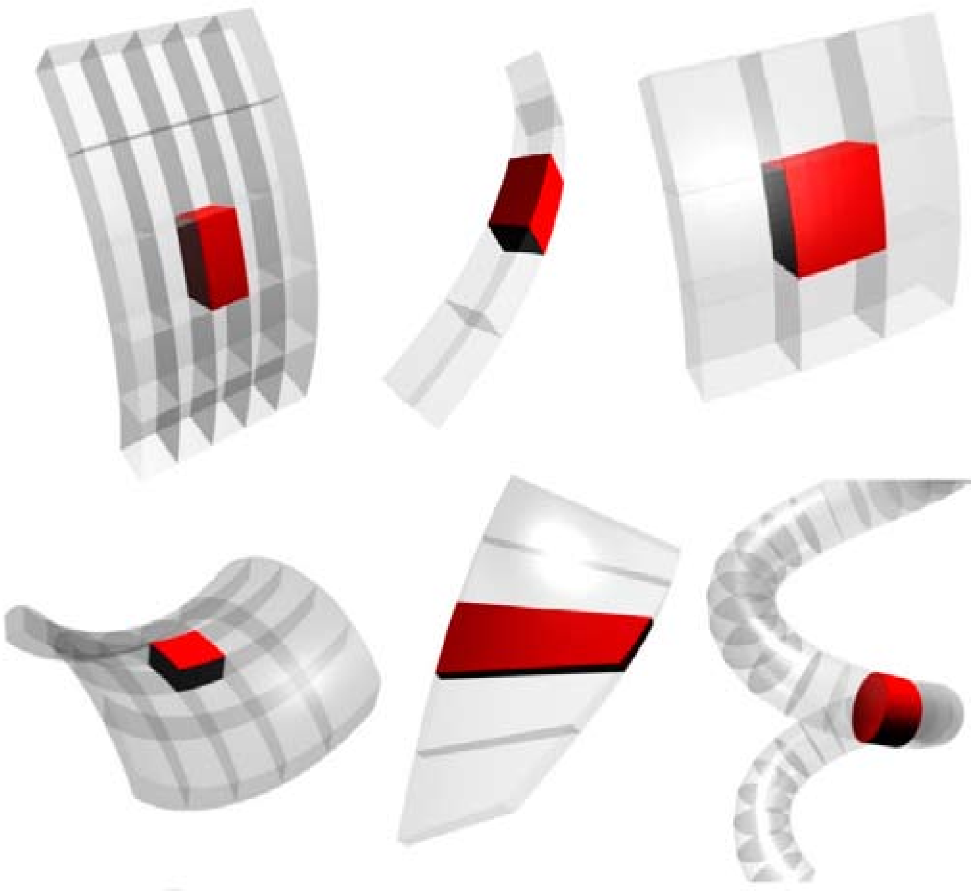


Illustration 2. Small unit cell (the red one) can be used to simulate distorted structures.

# Soft Condensed Matter and Statistical Physics

Markku Kataja, Juha Merikoski and Jussi Timonen

Jussi Timonen, professor
Markku Kataja, professor
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## Elastic Properties of Membranes

Our discrete element model for elastic materials with either elastic/elasto-plastic beam elements or triangular plate elements was used to analyze the elastic properties of thin sheets (membranes) with van der Waals type of self-adhesive interaction. Adhesive membranes were considered at non-zero temperatures by Langevin dynamics. We demonstrated that rigid adhesive membranes can reach low-energy conformations by folding or scrolling, but confining them into a small spherical volume was as hard as for their non-adhesive counterparts. It seems that truly compact conformations are unattainable for large membranes under simple confinement. The existence of free-standing collapsed conformations was limited by the unbinding temperature in analogy with flexible membranes. In general, it seems that rigid microscopic membranes such as e.g. graphene are mechanically and thermally stable under widely varying conditions in agreement with recent experimental findings.

A similar model was applied to analyze the mechanics and stability of thin-walled structures, and we found that under vertical compression the deformation of a thin-walled box differs from that of, e.g., a cylindrical shell. A set of generic scaling laws representing three successive regimes was derived for compression of a box. A linear Hookean regime was followed first by a wrinkled and then a collapsed regime.

The wrinkled regime was shown to be analogous to compression of thin-film blisters and it appears as a result of buckling of flat faces connected at sharp edges with an exact balance of bending and in-plane compression energies, while the final collapsed regime was shown to have all the characteristics of membrane crumpling. The theoretical scaling laws were confirmed by numerical simulations.

## Stochastic Systems

We continued our studies of stochastic discrete many-particle models including internal degrees of freedom coupling with transport, time-dependent electric fields and dynamic constraints. For large molecules in Feynman ratchets we analyzed in detail the probability currents in the steady state so as to identify the dominant transport mechanisms for molecules with variable charge distribution. For diffusion and driven flow of particles between soft fluctuating interfaces we found transitions related to coinciding characteristic time scales of the particles and interfaces. Another line of research consisted of simulation studies on mass transport in zero-range processes that exhibit condensation transitions. For these models, phase metastability was shown to result in a wide crossover region for up to quite large system sizes.

## Transport Properties

The method to measure the heat diffusion coefficient of thin samples of solid material based on time development of an induced temperature distribution was developed further. Heat losses by controlled convection and radiative heat transfer were better controlled experimentally and by modelling so that the method was also applicable to materials of fairly low heat diffusion coefficient. The loss resulting from convective heat transfer was then completely eliminated by doing the experiment in a vacuum chamber, whereby still lower heat diffusivities could be determined. The effect of porosity on heat transfer was analyzed in sintered bronze plates of varying porosity, using also structural analysis of the plates based on x-ray tomographic imaging.

A new mass-flux-based inlet boundary condition was introduced for the Lattice-Boltzmann method. This work was motivated by simulation of blood flow in tumor vasculature. The normal correlation of flow velocity is lost in tumour vessels due to the substantial reduction in their structural organisation. Corrosion casts of tumor vasculature were thus imaged by x-ray tomography, and their structural organization was characterized. Then parts of the imaged vasculature were chosen for flow simulations. At the inlets and outlets in these tomographic images, cross-sections of the vessels had varying shape and their orientation was not uniform. This type of configuration is challenging for simulations. We thus introduced a scheme in which a given average velocity was enforced at the inlet. The novelty of the scheme is that the inlet density and local inlet velocities are free to evolve in time as only the average velocity is fixed. Interesting results for the flow velocity distribution in tumor vasculature could be derived with the new scheme.

Development of new modelling techniques for simulating diffusion of viral proteins in living cells was continued. A 3D digital model cell was constructed from the cell analyzed, in which the diffusive motion of proteins was simulated numerically by the lattice-Boltzmann method. To account for the effect of internal membrane structures in the cell it was described as an effective porous material. With such modelling techniques we could reproduce by simulation the fluorescence recovery after photobleaching (FRAP) experiments on the same cell. A clear difference was found in two cell lines that were analyzed between diffusion in the liquid phase of the cytoplasm and the whole cytoplasm with the internal membranes included. Conventional modelling of the same FRAP experiments produced much too low diffusion coefficients.

We constructed analytical solutions to transport systems in which a tracer pulse is advected past a porous matrix and undergoes matrix diffusion, and validated the modelling for the particular case of a finite depth of the matrix. The matrix-diffusion models considered also include the effects of a varying aperture of the flow channel, the shape of the input pulse, and longitudinal diffusion and Taylor dispersion of the tracer in the flow channel. A finite depth of the porous matrix was shown to have a noticeable effect on the breakthrough curve of the tracer. Furthermore, rigorous results for the asymptotic form in this case of the breakthrough curve show a markedly different behaviour from that for an infinitely-deep porous matrix. For validation purposes laboratory experiments were carried out in a specifically designed measuring system. It could be convincingly demonstrated that model results provided excellent fits to the measured breakthrough curves with very consistent values for the diffusion coefficients.

## X-ray Tomography Laboratory

After a major upgrade completed in 2009, the x-ray tomography laboratory operated by the group now includes three tomographic devices that are used in 3D imaging of internal micro-structure of heterogeneous materials with resolution ranging from 40 µm down to 50 nm. In addition to x-ray scanners, the laboratory is equipped with specific devices for measuring e.g. 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 bone.

## X-ray Tomography: 3D Image Analysis Methods

A number of novel 3D image processing and image analysis methods were developed with a view to analyse various structural and transport properties of heterogeneous materials using x-ray tomographic images. These methods include dynamic interface recognition, pore segmentation and individual fibre segmentation algorithms together with various filtering methods.

The dynamic interface recognition algorithm is useful especially when analysing the topology of surfaces and the structure of layered materials. The algorithm locates the interface by simulating a falling flexible surface using Edwards-Wilkinson dynamics with parameters related to the gray-scale values in the tomographic image, which correlate with the density of the material. The interface is found at the location where the speed of the surface vanishes. The algorithm is flexible and easy to use. It can be applied to spherical and cylindrical interfaces in addition to planar geometries. Possible applications include finding the structure of spherical objects such as cells and analysing coating layers of various materials.

The pore segmentation algorithm divides the pore space of a porous material into individual pores and pore throats separating them, and, based on

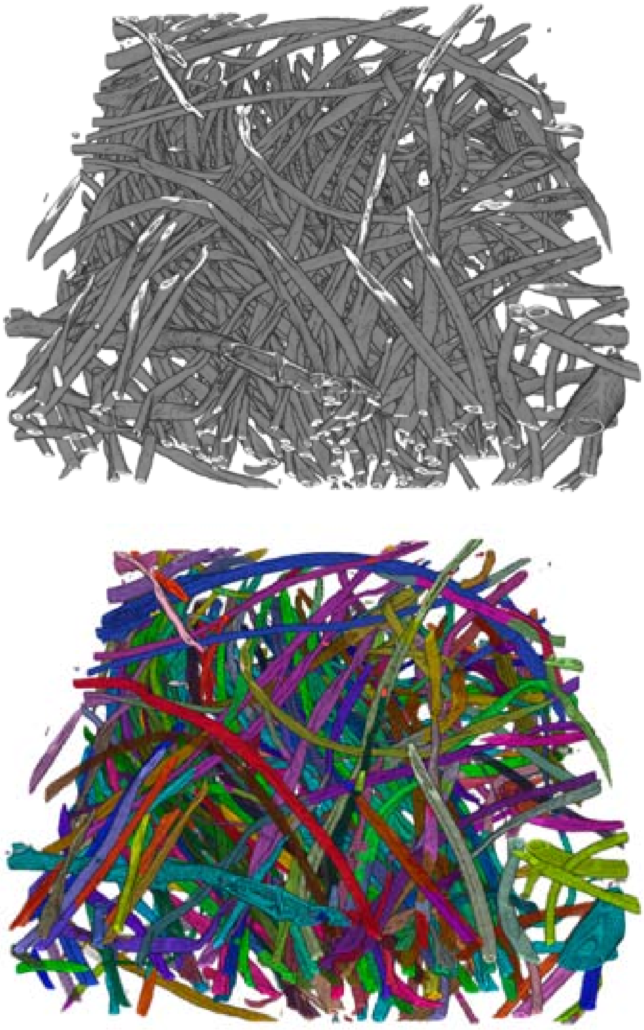

Fig. 1. Tomographic image of the fibre network of a felt material (upper image), and the individual fibres (indicated with random colours) as found by the automatic fibre recognition algorithm (lower image).

this information, forms a network that represents the 3D topology of the pore network. This information provides various local and statistical properties of the material and can be used to analyse transport phenomena such as Darcian flow, imbibition and diffusion in the porous material.

A fibre segmentation algorithm was developed which allows automatic recognition of individual fibres from a tomographic image of a fibre network (see Fig. 1). This enables analysis of many important characteristics of the network including the number and distribution of inter-fibre contacts and their area. The results can be applied *e.g.* to assessing the tensile properties of fibrous and fibre reinforced composite materials.

## Inversion Methods for Structural Analysis of Paper

Inversion based methods were applied to studying the structure of paper. A Bayesian inversion framework was used to retrieve approximately the areal mass distribution of paper from its optical transmission image. In this method indirect optical measurement data were augmented with some a priori knowledge of the mass distribution. This knowledge was gained by microtomographic imaging of the sample and analyzing then the scaling properties of the coefficients of its three dimensional wavelet transformation. In this way the optical transmission image could be transformed so that it resembled fairly closely the corresponding x-ray transmission image. Furthermore, a novel wavelet-based curvelet analysis was introduced for measuring the orientation distribution and orientation anisotropy in paper.

## Thermo-hydro-mechanical Modelling of Bentonite Buffer

This research is part of the safety analysis of the final disposal facility of nuclear waste at Olkiluoto. The previously developed thermo-mechanical model for the bentonite buffer has been updated to include large elasto-plastic deformations of the solid phase such that the original free-energy formalism of the model is maintained. The model is based on a covariant spatial formalism in which the finite strain measure

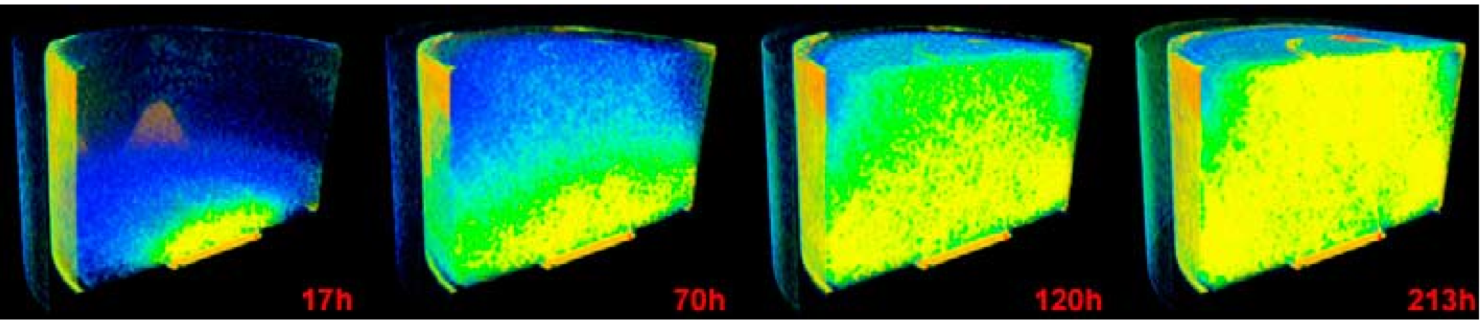


Fig. 2. Series of x-ray tomographic images showing a gradual imbibition of water in a cylindrical compacted bentonite sample during a period of about 9 days. Shown is a cross-section of the sample wetted through a porous block in contact with its bottom surface. Light color indicates increased density of bentonite arising from presence of water.

is defined by representing the metric tensor in a coordinate system co-moving with the deforming material. It appears that the theory is consistent with both hypo-elastic and hyper-elastic formulations of large strains. This opens the possibility to include also plastic deformations in the theory.

In order to find a realistic constitutive model for bentonite we also developed experimental methods to measure its yielding properties under hydrostatic pressure and one-dimensional compression. These methods can be used to study both elastic and plastic properties of bentonite for varying moisture content. In addition, we studied transport properties of water in bentonite using x-ray tomography for monitoring the propagation of water in compactified samples (see Fig. 2).

## Assessment of Bone by Ultrasonic Methods

Methods were continued to be 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) could 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 ($r=0.7$-$0.8$; $p<0.001$). Further clinical studies are planned to show the diagnostic efficiency of this FAS mode. The other mode, SGW, was consistent with the Lamb A0 mode and showed excellent sensitivity to cortical bone thickness. It is challenging, however, to excite and detect SGW through an overlying soft tissue coating even though the mode propagates in the embedded bone. To this end, development of photo-acoustic excitation and detection seems was started in collaboration with the Department of Electrical and Information Engineering at the University of Oulu, and the Department of Physics at the University of Helsinki. Initial results from experiments in bone phantoms were positive, suggesting that photo-acoustic methods enable the measurement of SGW through a thin coating layer.

# Ultrarelativistic Heavy Ion Collisions – Theory

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

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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 (SM). 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 workshops, European graduate-school networks and EU networks, and interact closely also with the local ALICE/PHENIX experimental group. Our group members are frequently invited as speakers in major international conferences. Dr. Chatterjee started as our new postdoc in 2010.

## Heavy-ion Phenomenology

The long-awaited LHC era in URHIC started with Pb+Pb collisions in autumn 2010. With great excitement, we compared the first LHC results on charged-particle multiplicity, elliptic flow ($v_2$), and $p_T$ spectra with the predictions from our framework, where the initial QGP densities are computed from perturbative QCD (pQCD) and gluon saturation, and the space-time evolution of the produced system is modelled by relativistic hydrodynamics: Our multiplicity predictions, made already in 2001, agreed quite well, within 7%, with the measured value in central collisions. Also the magnitude of $v_2$ and the shape of the $p_T$ spectrum reflecting the transverse flow and onset of pQCD dynamics (Fig. 1) are consistent with what we have more recently predicted.

In hydrodynamical modeling of URHIC, we have developed a Monte Carlo (MC)-based event-by-event framework, which accounts for the initial QCD-matter density fluctuations (Fig. 2) and is consistent with the experimental $v_2$ analysis. In this approach, we have solved the centrality problems of the predicted $v_2$, and also launched further studies on thermal photon production.

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 especially at the LHC. We are currently developing MC simulations for modeling the hard-parton interactions with a hydrodynamically evolving QCD medium. Our systematic studies of different combinations of medium evolution and parton-medium interaction models show that the microscopical mechanism underlying the parton-medium interaction cannot be incoherent. We have also for the first time illustrated the role of bulk matter viscosity for high-$p_T$ observables. Currently, we are investigating the effects of the initial QCD-matter density fluctuations on hard probes.

## Effective Theories for QCD

We have explored effective models of chiral fields and the Polyakov loop for two-flavor QCD at finite temperature and density, to obtain a description of QCD thermodynamics relevant for URHIC. The location of the critical point in the (T,μ) phase diagram has been studied as a function of quark mass. Topi Kähärä reached the PhD degree on this subject in 2010. The application of these results to the hydrodynamic description of URHIC is in progress.

## Nuclear Parton Densities

Nuclear parton distribution functions (nPDFs) are needed for the computation of *all* collinearly factorizable hard-process cross sections in nuclear collisions. Our pioneering contribution in the global pQCD analysis of nPDFs, the set ***EKS98***, is a standard reference in the field, while our latest ***EPS09*** package defines currently the state of the art for the nPDFs and their uncertainties. We are applying the ***EPS09*** nPDF sets, e.g. to the computation of the produced initial QGP densities in URHIC and to direct photon production in nuclear collisions at RHIC and LHC.

We have also continued our studies of the nuclear gluon densities in the Color-Glass-Condensate framework, which describes QCD in the high-energy limit. Addressing the new observations of a ridge-like correlation in p+p collisions reported by the CMS experiment, we have investigated long-range correlations in gluon production in A+A and p+p collisions. We have also studied nuclear diffractive deep inelastic scattering, an important part of the research program of next generation experiments.

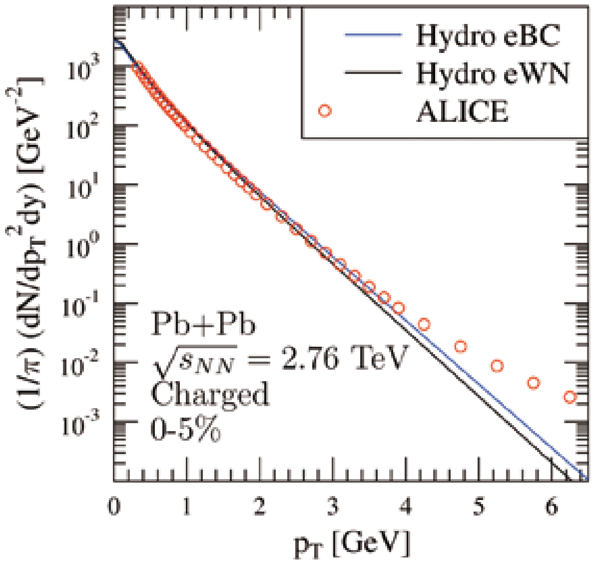


Fig. 1. The $p_T$ spectrum of charged hadrons in central Pb+Pb collisions at the LHC. Shown are the ALICE data and results from our recent hydrodynamical calculation with two different transverse profiles of the initial matter energy density.

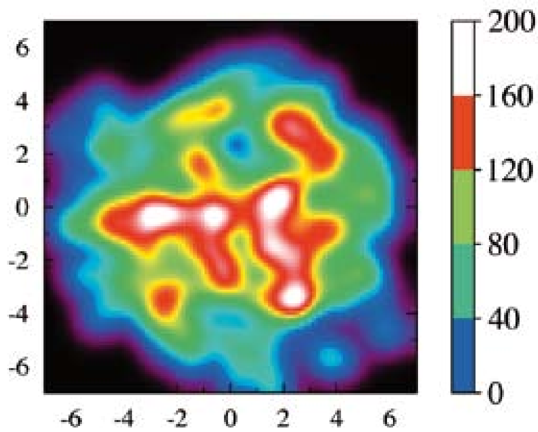


Fig. 2. An example of the initial QCD-matter energy-density fluctuations (in GeV/fm$^3$) in central Au+Au collisions at RHIC, shown as a function of the transverse coordinates (in fm).

# Particle Phenomenology

Kimmo Kainulainen, Jukka Maalampi, Wladyslaw Trzaska and Kimmo Tuominen

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## Neutrino Physics

Jukka Maalampi and Wladyslaw Trzaska

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. We have studied the scenario where the three mass states of the ordinary active neutrinos actually split, as a result of mixing of active neutrinos with sterile neutrinos, into pairs of quasi-degenerate states with a tiny mass difference. Although these quasi-degenerate pairs will look in most laboratory experiments identical to single active states, their sterile components may manifest itself e.g. through their effect e.g. on neutrino fluxes from the Sun, supernovae and active galactic nuclei. They may as well offer new sources for the CP violation in the lepton sector. Sterile neutrinos play a central role also in the 5D "hybrid" model we have investigated as a possible framework for the leptogenesis, the creation of the baryon asymmetry of the universe through neutrino physics phenomena.

Our group participates the LAGUNA (Large Apparatus for Grand Unification and Neutrino Astronomy), a pan-European project aiming at constructing a large scale underground experiment (the Megaton) for studying low-energy neutrinos of astronomical and terrestrial origin and the stability of the proton. The design study of this project is funded by EU through the FP7-Infrastructures programme. Apart from the scientific importance of the planned experiment, our interest in and activity related to the project is further boosted by the fact that the Pyhäsalmi mine, not far from the Department, is among of the leading candidates for the site of the new detector.

Of the three proposed technologies LENA – the liquid scintillator detector is likely to be the first of the LAGUNA detectors to be realized. The impressive length of LENA (100 m) combined with the low detection threshold for neutrino-electron scattering and a sufficiently strong monoenergetic neutrino source of the type used by GALLEX experiment would make neutrino oscillometry possible. Oscillometry is a new, elegant way to solve a number of questions related to neutrino oscillations: a precise determination of the mixing angle $\theta_{13}$ and the oscillation length $L_{23}$, the confirmation of the results of the "global" analysis of the oscillation data, and – by making a long baseline measurement with the same detector – determination of the neutrino mass hierarchy. As part of the work on the upcoming White Paper our group has made calculations to verify feasibility of oscillometric measurements with LENA. The long baseline oscillation studies using the existing and planned beams from CERN will form the core of the next LAGUNA Design Study.

## Strong Dynamics and Theories Beyond the Standard Model

Kimmo Tuominen

The first year of successful running of the CERN Large Hadron Collider (LHC), and its prospects for 2011, provide increased impetus for theoretical elementary particle physics research worldwide. Our focus is on electroweak symmetry breaking mechanisms and the associated Beyond Standard Model 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 Minimal 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. The origin of the generational structure of the Standard Model is one of its most poorly understood aspects. In Technicolor the problem is complicated further, since even the mechanism to generate fermion masses must be provided by some other dynamical mechanism. 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 introduced the model and studied some of its properties in the weak and strong coupling regimes of the N=4 sector; further analyses are in progress.

In our studies on DM candidates we have established an extension of MWT, which leads to properties typically associated with minimal supersymmetric standard model: the hierarchy problem is solved, the SM coupling constants unify and a viable DM candidate exists.

Our group has a 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 2010 we completed this improvement of the Wilson fermion action for MWT and also for an SU(2) gauge theory with fermions in the fundamental representation. The production runs for physics results in these models are in progress.

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. We are currently in progress with the analysis of the vacuum spectra using gauge/gravity correspondence methods.

We have also studied properties of ordinary strong interactions with applications to QCD matter physics and ultrarelativistic heavy ion collisions. We have constructed and analysed effective models for chiral fiels and Polyakov loop constrained by lattice data and observed vacuum properties. The main feature of these models is their ability to account for the interplay of chiral symmetry restoration and center symmetry breaking. We are currently in progress of extending these models to study deconfinement and chiral restoration in theories relevant for MWT and other Technicolor models.

## Cosmology

Kimmo Kainulainen

We have extended our stochastic Gravitational Lensing (sGL) method for computing the weak gravitational lensing effects on light propagation in an inhomogenous universe, including both arbitrary halo mass distributions (the Halo Model) and modelling of filaments. The extended sGL results were confronted with the Millenium simulation results with an excellent agreement. sGL method (at a level of single mass HM) was used to study weak lensing effects on cosmological parameter extraction. Potentially large corrections were found, which may affect the cosmological parameter estimation from supernova magnitude measurements. Along with the sGL papers we released new upgraded versions of our numerical code package *turboGL*.

We have studied hybrid cosmologies with both a large local void with an LTB metric and a cosmological constant. Subjecting this model to available cosmological data we found that, barring the baryon acoustic oscillation (BAO) data, both the pure void and the pure $\Lambda$CDM are equally good solutions, but that the mixed models are disfavoured. BAO data appears to favor the $\Lambda$CDM model, but the conclusion is not tight, because the BAO-feature cannot yet be computed with a good enough precision in the LTB-background.

We continued developing the quantum transport theory with nonlocal coherence, which is based on the coherent quasiparticle approximation (cQPA) on the dynamical two-point functions. During this year we reformulated our coherent transport theory in the usual 4-spinor notation and derived a compact set of (exended) Feynman rules for defining and computing a loop expansios for the self energies including coherence excitations. Theory was developed in

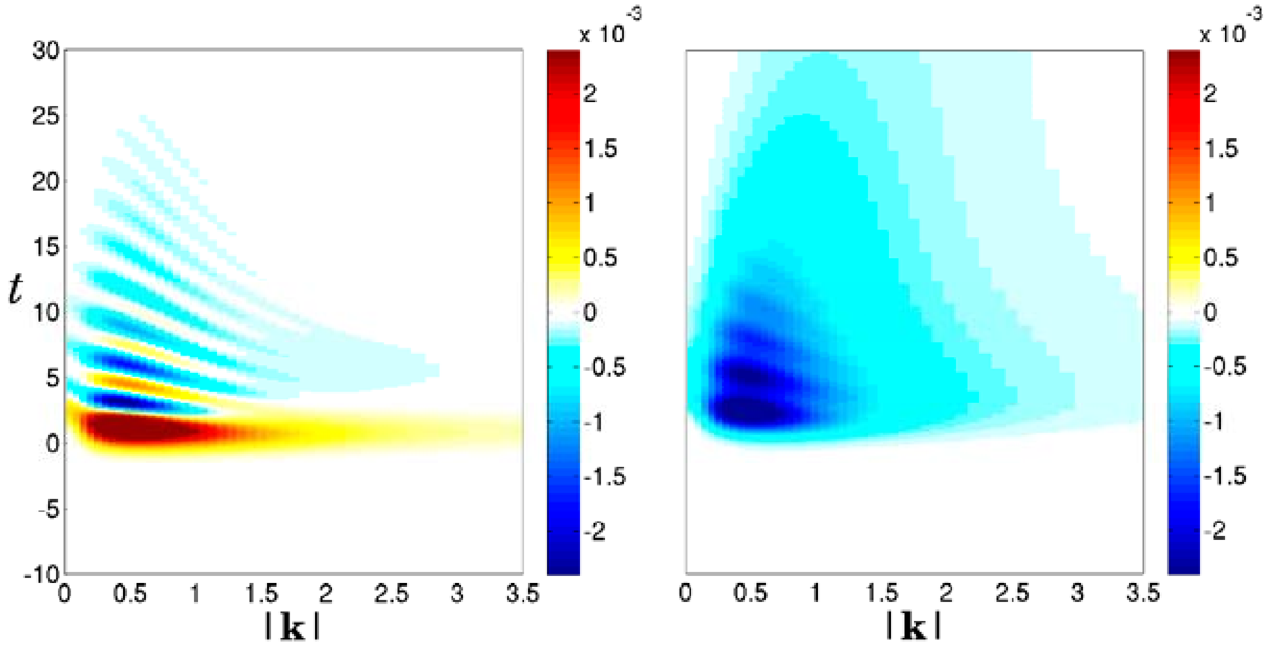


Fig. 1. Shown is the evolution of total right chiral number density (left) and the total charge density (right) as a function of the wave vector |k| and time

parallel for both fermionic and bosonic fields and its use was demonstrated with examples including particle creation and a simple toy model for coherent baryogenesis. We are currently finishing up the extension of the cQPA QTT to the case of mixing scalar and fermion fields, as well as applying the formalism to the neutrino mixing.

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 most general DM sector of the model is similar to the neutralino sector in the MSSM. During 2010 we worked to perfrom a comprehensive scan of the entire parameter space of the model. We are currently finishing up this work, which has provided us with interesting parameter regions containing viable DM candidates.

# Industrial Collaboration

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

**The Industrial Applications group of the accelerator laboratory** had numerous contacts with domestic and foreign industry and research laboratories. Twenty one irradiation campaigns with 15 international partners were performed in RADEF facility. Also researchers from NASA's Jet Propulsion Laboratory from Pasadena, USA, were performing the tests. The irradiations of the polymer membranes for OxypheN GmbH also continued with the three campaigns in the year 2010. The total beam time used for these activities during the year 2010 was 1434 hours. From those 67% 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 2011 with the new cyclotron was started. The industrial collaboration continued with about eight national companies in 2010. Measurements of calcium carbonate from a wet paper web by using x-rays were performed in collaboration with VTT Jyväskylä. This produced a MSc. thesis. A new opening was made with Metso Automation. This study was focused on a dual-energy x-ray method, which will be applied to on-line measurement of formation of additives during the paper making

The Accelerator Based Materials Physics group is heavily involved in an 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 kit having all the analysis functions integrated into microfluidics chip. The installation of Time-of-Flight Elastic Recoil Detection Analysis (TOF-ERDA) tool in late 2010 has increased the activity of service measurements and brought new industrial customers for ion beam analysis activities in 2010.

**The Experimental Nanophysics groups** have well established collaboration with a few companies in Finland. For example: the former Nanoelectronics group in collaboration with the companies Enermet, Metso Drives, and JSP (Jyväskylä Science Park), was earlier funded by Tekes within the Miniaturization of Electronics research. The project focused on microand nanosensors and a patenting process has been started as a result of this former project. During the year 2010 the industry collaboration was continued under new projects and including companies interested in nanotechnology such as Nokia, Planar and Vaisala, with funding from the FinNano Nanotechnology Programme of Tekes. In addition, short term collaboration with other companies, e.g. ABB Oy, exists also in the form of co-supervised master thesis. 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 2010 a TEKES/EAKR and Jyväskylä Innovation funded project continued, where the goal is to develop terrestrial applications of these detectors for materials analysis. The consortium includes also Aivon Oy and Star Cryoelectronics Inc. as industrial partners in addition to Oxford Instruments. In addition, there has been collaboration with companies Beneq Oy and lamit.fi funded by Jyväskylä Innovations within integrable solar energy collection.

**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, coating layers, minerals and thin films. 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 printing, optical transmission and fracture properties, strength, deformability and barrier properties of thin walled cardboard structures, 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. This work was successfully continued.

Industrial collaborators included Stora Enso, UPM-Kymmene, Metsä-Botnia, Posiva, M-real, Metso, Numerola, Paperra, Jyväskylä Innovation, Paroc, Borealis, Critical Medical and Institute for Surface Chemistry (YKI).

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.

# Education

Jukka Maalampi and Juha Merikoski

Jukka Maalampi, professor
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Jussi Helaakoski, graduate student
Toni Purontaka, graduate student
Tuomas Heinonen, MSc student
Anna Huuskonen, MSc student
Jenni Pekkarinen, MSc student
Anne-Mari Piippo, MSc student
Esa Ritvanen, MSc student
Aku Talikka, MSc student

The year 2010 was the first year of the three-year term 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. Education given at the Department of Physics is closely connected with frontline basic research and its applications and well-educated students are one cornerstone of the success of local research gourps. In addition to interactive teaching, informal interaction among students and between students and the personnel are strongly promoted. The whole Department including the laboratories is seen as a learning environment and, from the beginning of their studies, the students are immersed in its activities.

## Teaching Development

In basic teaching the year 2010 has been one with big changes. The first six basic physics courses have been reorganized and teaching is now based on a new textbook using a modern pedagogical approach based on recent research in physics education. During the academic year 2010-11 also the series of compulsory courses in mathematical methods is being completely rewritten and reorganized in short courses to have it better correspond to the increasingly diverse backgrounds and needs of the incoming students. At the same time, the lecturers for the first-year courses are changing, in part because of retirements of experienced teachers. The basic courses are now spread on three full semesters, instead of two, to give more time to learn well the basic skills. For the method courses, we have introduced so-called ex tempore exercise sessions, where after an introductory lecture the students in smaller groups solve a set of problems in an hour or so and then get support and immediate feedback as well as course points. This is part of our ongoing project aiming at reducing the amount of conventional lecture hours at all study levels and increasing supervised small group work.

## Recruitment and Contacts with Schools

A big challenge at the moment is how to recruit new physics students with good motivation and capability. To provide high-school students a hands-on experience on research workthe Department offered, in summer 2010 for a second time, summer jobs for students interested in science. The newspaper advertisement produced about 60 applicants, of whom eight most promising students from different high schools in the Central Finland district were chosen to work in the research groups at the Department. The experience was, again, very positive. In addition, many high school groups visit the Accelerator laboratory and the Nanoscience center. 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 arranged, attracting hundreds of visitors. Work has been initiated to make the next year's program more attractive and memorable, one with more personal touch. Since personal contacts have proven to be the most effective way of student recruitment, we are reviving our visit program to schools. This is even more important now, because the intake of students for the next autumn in the faculty will be ten percent smaller than it has previously been.

## Teacher Education

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 trilateral co-operation between the Departments of the Faculty, the Department of teacher education and the Teacher training school was continued and work to establish a LuMa center, officially founded January 2011, in Jyväskylä has continued. The Department participates in the *Finnish graduate school of mathematics, physics, and chemistry education*, with three students working on a degree of doctor or licentiate of philosophy in physics education.

## Other Education Activities

In addition to its regular teaching program, the Department has continued the co-operation with the Open University supplementary-education program. The Department arranged five courses in the 18th Jyväskylä International Summer School.

## Statistics

In 2010 there were 600 applicants for physics studies, with 360 of them indicating physics as their first choice. As a whole, about 120 undergraduate students enrolled in 2010. 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 500. Some 30 students, many of them with a polytechnic engineering background, study in the master programs for industrial physics, nanoelectronics and renewable energy. At the Department there are 90 post-graduate students aiming at the PhD degree. In 2010 the number of MSc degrees taken at the Department was 35. The number of PhD degrees was 11 and there exists potential for almost 20 in the year 2011.

**Teaching development group**

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Pekka Koskinen, researcher
Anna-Leena Latvala, PhD student
Joonas Ilmavirta, MSc student
Soili Leskinen, departmental administrator

### Head of the Department
Jukka Maalampi, prof.

### Vice-Heads of the Department
Rauno Julin, prof.
Markku Kataja, prof.

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Kari J. Eskola
Hannu Häkkinen
Rauno Julin (on leave 1.8.–)
Markku Kataja
Matti Leino
Jukka Maalampi
Ilari Maasilta
Matti Manninen
Jouni Suhonen
Jussi Timonen
Robert van Leeuwen
Harry J. Whitlow (on leave)
Juha Äystö

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Vesa Ruuskanen

### Research professor
Jacek Dobaczewski (FidiPro award)
Paul Greenlees (ERC award) 1.8.-

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## Accelerator Facilities

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Henri Perämäki, Monte Carlo -menetelmien käyt-tö fysiikassa

Jalmari Pirhonen, Putkiluufantomien valmistus ultraäänitutkimusta varten

Vesa Pitkänen, Musta kappale ja sen säteilylait keskittyen Max Planckin säteilylakiin sekä kvantti-mekaniikan varhaisvaiheita

Esko Pohjoisaho, 2-Component Model for $x_T$ Scaling

Pauli Repo, Elektronin löytyminen

Merja Tanhua-Tyrkkö, Thermal and hydrological pre-models for CEMPRO-project

Kosti Tapio, Itsejärjestäytyvät järjestelmä-Kolmen TX-tiilen rakenne

Laura Vainio, Peiliydinten beta-hajoamisten ft-arvojen määrittäminen JYFLTRAP-laitteistolla

Hannes Vainionpää, Accelerator Driven Neutron Source (ADNS)

Valtteri Vanhala, Sähkön ja magnetismin yhteys

Jussi Viinikainen, Triggering in the EMCal detec-tor in the ALICE experiment

Vikramjit Singh, Radiation Resistance of an An-tenna

## MSc THESES

(alphabetical order)

Kristian Afflekt, Viskositeetin mittaaminen pietso-sähköherätteisellä värähtelijällä

Vesa Aho, Elektronien lämmitys ja maksimiener-gia ECR-ionilähteen plasmassa

Sunliang Cao, State of the art thermal energy storage solutions for high performance buildings

Hannele Eronen, Novel sample preparation meth-od for bilogical PIXE measurements: calcium as a model element

Jaakko Halkosaari, Niobipohjaiset SINIS-tunneli-liitokset ja niiden käyttö lämpömittareina

Tuomas Heinonen, Virtausmekaniikan verkko-kurssi

Jouni Heiskanen, Monte-Carlo simulaatioiden käyttö rekyylispektrometrimittausten analysoinnissa

Ilkka Helenius, The Structure Functions to the Order alpha_s in Deep Inelastic Neutrino Scattering Processes

Janne Hirvonen, Kaatopaikkakaasun puhdistaminen ja analysointimentelmät

Tommi Isoniemi, Dielectrophoresis as an assembly method for carbon nanotube memory elements

Manana Koberidze, Computational studies of torsional properties of single-walled carbon nanotubes

Jani Komppula, Kalsiumkarbonaatin mittaaminen märästä paperirainasta röntgensäteilyn avulla

Jukka Koponen, Tiedonkeruu ja -analysointi mikro CHP koelaitteistolla

Tapani Korhola, Puukuitususpension putkistovirtaus, viskositeetti ja häviökorrelaatiomalli

Jukka Kuva, Mineraalinäytteiden tutkiminen röntgentomografialla

Anton Laakso, Taipuneiden hiilinanoputkien elastiset ja elektroniset ominaisuudet

Roope Lehto, Huokosrakenteen vaikutus nestepisaroiden absorptioon

Ulpu Leijala, Aurinko- ja maalämpöjärjetelmien käyttömahdollisuudet

Mari Napari, Korroosioyhdisteiden analysointi tulistinputkista hiukkasherätteisen röntgen-emission avulla

Nooramari Nevalainen, Sähkömagneettinen suojaus

Juho Ojajärvi, Tetrahedral chalcopyrite quantum dots in solar-cell applications

Mika Oksanen, Annealing study of bismuth thin films

Lauri Olanterä, Varauksenkuljettajajakaumien mittaus puolijohteissa

Risto Paatelainen, Quark and gluon scatterings in the leading and next-to-leading order QCD perturbation theory

Jenni Pekkarinen, Sähkömagneettinen induktio tietokoneavusteisesti opetettuna Coach-6 ohjelman avulla

Anna-Mari Piippo, Peruskoulun yläluokkien oppikirjojen kuvat oppilaiden virheellisten ennakkokäsitysten vahvistajana: valo ja siihen liittyvät ilmiöt

Ilkka Pohjalainen, Experimental gas jet studies for the IGISOL LIST method and simulation modeling

Mikko Pääkkönen, LTB-models and Local-Void Scenario

Esa Ritvanen, Fysiikan oppituntien käsitteellisen rakenteen analyysi

Paitoon Saengyuenyongpipat, Demonstrating measure-correlate-predict algorithms for estimation of wind resources in Central Finland

Jaakko Saukkonen, Kuormituslistojen pintavikojen vaikutus paperin vanaisuuteen

Aku Talikka, Lukiolaisten taustakäsityksistä ja tehtävien esitystapojen hallinnasta mekaniikassa

Merja Tanhua-Tyrkkö, Modelling hydrological and chemical phenomena during interaction of bentonite and high pH plume

Daavid Väänänen, Neutriino-oskillaatiot tyhjiössä ja aineessa astrofysiikkaan sovellettuna

## PhLic THESES

Marko Avikainen, Paper formation measurement and characterization
JYFL Laboratory Report 1/2010

Jussi Haanpää, 123I-FP-CIT-dopamiinitransportteritutkimukset Seinäjoen keskussairaalassa vuosina 2007-2009
JYFL Laboratory Report 2/2010

## PhD THESES

(chronological order)

Tommi Ropponen, Electron heating, time evolution of bremsstrahlung and ion beam current in electron cyclotron resonance ion sources
JYFL Research Report 1 /2010

Iiro Riihimäki, Point-defect mediated diffusion in intrinsic SiGe-alloys
JYFL Research Report 2/2010

Panu Rahkila, Shape evolution in even-even N≤126, Z≥82 nuclei
JYFL Research Report 4/2010

Mika Mustonen, Microscopic calculations for rare beta decays
JYFL Research Report 5/2010

Katarzyna Kacprzak, Density functional studies of the electronic structure and catalytic properties of small bare and ligand-protected gold clusters
JYFL Research Report 6/2010

Pasi Karvonen, Fission yield studies with SPIG-equipped IGISOL: A novel method for nuclear data measurements
JYFL Research Report 7/2010

Jussi Virkajärvi, Weakly interacting dark matter in walking technocolor theories
JYFL Research Report 8/2010

Viivi Koivu, Analysis of fluid flow through porous media based on x-ray micro-tomographic reconstructions
JYFL Research Report 9/2010

Matti Heikinheimo, Technicolor and new matter generations
JYFL Research Report 10/2010

Steffen Ketelhut, Rotational structure and high-K isomerism in Fm-248,250
JYFL Research Report 11/2010

Topi Kähärä, Thermodynamics of two-flavor QCD from chiral models with Polvakov loop
JYFL Research Report 12/2010

## DEGREES

(alphabetical order)

### BSc DEGREES

(main subject is physics)

Aho, Vesa
Alanne, Tommi
Eloranta, Aaro
Hakala, Petri)
Halkosaari, Jaakko
Hannula, Konsta
Hasanen, Mikko
Hedlund, Alex
Hirvonen, Janne
Huopana, Tuomas
Ihaksinen, Heidi
Isoniemi, Tommi
Kaijaluoto, Sampsa
Kauppinen, Janne
Komppula, Jani
Konki, Joonas
Koponen, Jukka
Korhola, Veikko
Kuva, Jukka
Könönen, Niina
Laakso, Anton
Lehto, Roope
Monto, Tiia
Mäntysaari, Heikki
Napari, Mari
Nenonen, Tero
Nevalainen, Noora-Mari
Nyrhinen, Hannu
Ojajärvi, Juho
Oksanen, Mika
Olanterä, Lauri
Paasonen, Seppo-Tapio
Pakarinen, Maire
Pekkarinen, Jenni
Perämäki, Henri
Piippo, Anna-Mari
Pirhonen, Matti
Pohjoisaho, Esko

Pääkkönen, Mikko
Singh, Vikramjit
Talikka, Aku
Tanhua-Tyrkkö, Merja
Tapio, Kosti
Tuovinen, Riku
Vainionpää, Jaakko
Valve, Assi
Vanhala, Valtteri
Vankka, Anna
Viinikainen, Jussi
Väänänen, Daavid

## MSc DEGREES

(main subject)

*=MSc includes teachers pedagogical studies

Afflekt, Kristian (appl. physics)
Aho, Vesa (physics)
Cao, Sunliang (appl. physics)
Eronen, Hannele (appl. physics)
Halkosaari, Jaakko (physics)*
Halonen, Kimmo (physics)
Heinonen, Tuomas (physics)*
Heiskanen, Jouni (physics)
Helenius, Ilkka (theor. physics)
Hirvonen, Janne (appl. physics)
Huovinen, Ville (physics)*
Isoniemi, Tommi (appl. physics)
Koberidze, Manana (physics)
Komppula, Jani (physics)
Koponen, Jukka (physics)
Korhola, Veikko (appl. physics)
Kuva, Jukka (physics)
Laakso, Anton (theor. physics)
Lehto, Roope (physics)*
Leijala, Ulpu (physics)*
Napari, Mari (appl. physics)
Nevalainen, Noora-Mari (physics)
Nyrhinen, Hannu (theor. physics)
Ojajärvi, Juho (physics)
Oksanen, Mika (physics)
Olanterä, Lauri (physics)
Pekkarinen, Jenni (physics)*
Piippo, Anna-Mari (physics)*
Pohjalainen, Ilkka (physics)
Pääkkönen, Mikko (theor. physics)
Ritvanen, Esa (physics)*
Saengyuenyongpipat, Paitoon (appl. physics)
Talikka, Aku (physics)*
Tanhua-Tyrkkö, Merja (physics)
Väänänen, Daavid (theor. physics)

## Phil.Lic DEGREES

Avikainen, Marko (appl. physics)
Haanpää, Jussi (appl. physics)

## PhD DEGREES

Heikinheimo, Matti (theor. physics)
Kacprzak, Katarzyna (theor. physics)
Karvonen, Pasi (physics)
Ketelhut, Steffen (physics)
Koivu, Viivi (appl. physics)
Kähärä, Topi  (theor. physics)
Mustonen, Mika (theor. physics)
Riihimäki, Iiro (physics)
Ropponen, Tommi (physics)
Virkajärvi, Jussi (theor. physics)