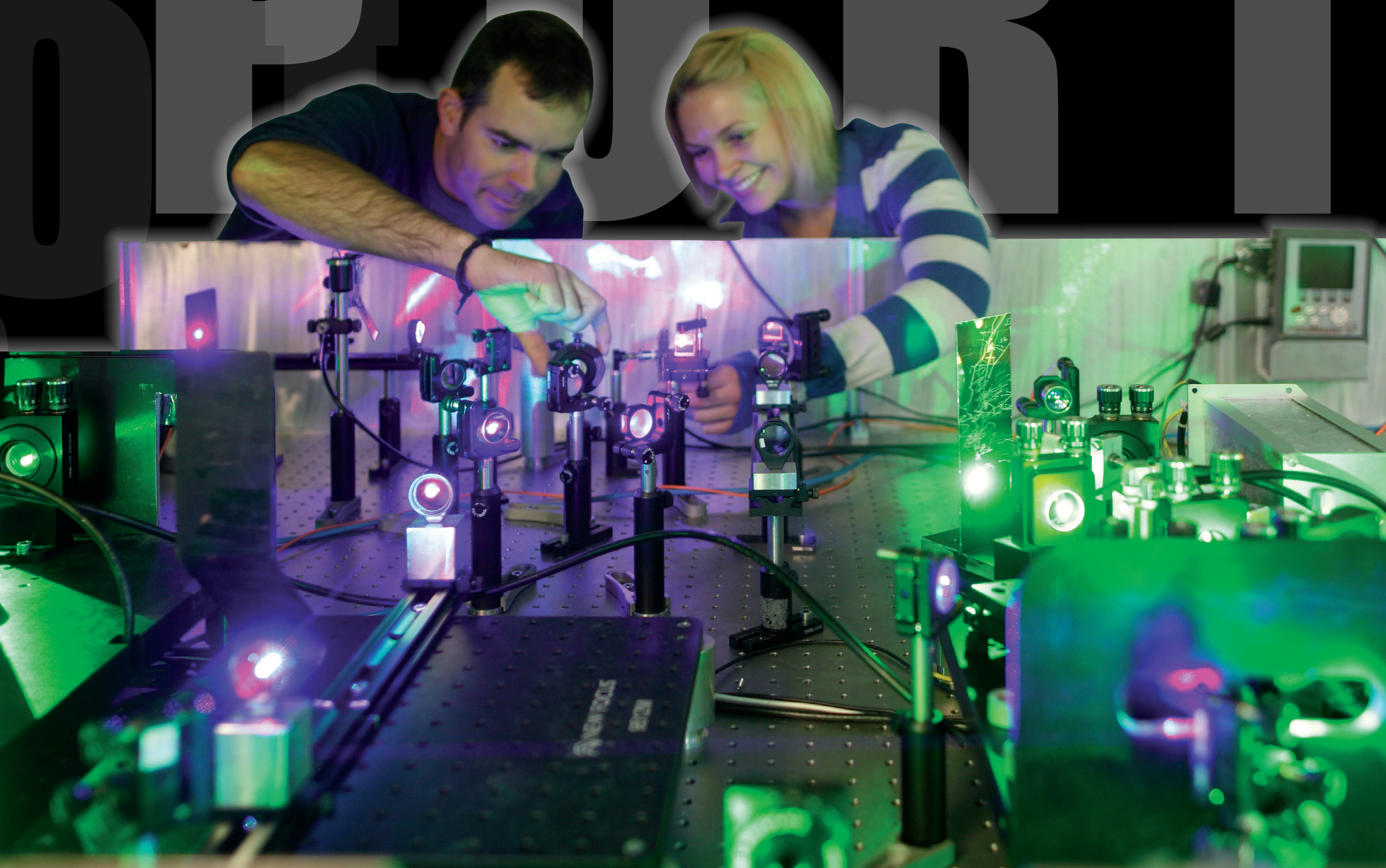
DEPARTMENT OF PHYSICS

UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT 2014



JYFL 2014

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DEPARTMENT OF PHYSICS UNIVERSITY OF JYVÄSKYLÄ

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ANNUAL REPORT

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Photo Jiri Halttunen

Contents

Preface

Jukka Maalampi
Head of the Department

The Department of Physics has a long tradition of publishing annual reports. Since 1976 these reports have documented the achievements of the Department in research and education and also recorded the important events of each year. Browsing through these reports shows the growth of a small and enthusiastic unit to the present large, internationally well-recognized – and still enthusiastic – center of research and education. The Department of Physics with 180 employees, 550 students, and a budget of 15 M€ is today the largest department in the University of Jyväskylä devoted just to one academic discipline.

The present Annual Report presents the achievements and important events of the Department of Physics in 2014.

The research profile of the Department

The research activity of the Department is focused on two main research areas, materials physics and subatomic physics.

Under the banner of materials physics, our experimental groups carry out research in the interdisciplinary Nanoscience Center, in the Nanotomography Laboratory, and in the Accelerator Laboratory. Research topics include thermal properties of nanostructures, electronic and mechanical properties of nanotubes, nanoelectronics and plasmonics, nanotomography in biophysical and materials studies, and characterization and modification of materials at the nanometre scale. Theoretical research is focused on computational nanophysics, low-temperature nanophysics, and the physics of soft materials.

In the field of subatomic physics, the Department is the largest research unit in Finland. Activity in subatomic physics covers various areas of nuclear physics, particle physics, and particle cosmology.

Experimental activity in nuclear physics is concentrated in the Accelerator Laboratory of the Department. Research interests include exotic nuclei and superheavy elements and the properties of nuclei far off the beta-stability line. Our researchers also take part in experiments carried out in laboratories abroad, e.g. at CERN ISOLDE and GSI/FAIR. In theoretical nuclear physics our groups develop microscopic nuclear models with applications in both traditional nuclear spectroscopy and processes involving connections to particle physics. Both the experimental and theoretical nuclear physics groups come together with accelerator-based materials physics and applications to form an Academy of Finland Centre of Excellence.

In particle physics the main activity is concerned with the physics of ultrarelativistic heavy ion collisions, which is studied experimentally in the CERN ALICE experiment, and theoretically. The Department is also active in underground neutrino and cosmic ray physics. In particle cosmology focus is on the study of dark matter and dark energy, as well as quantum transport

phenomena. In subatomic physics, the Department is strongly involved in and contributes to the research program of the Helsinki Institute of Physics, HIP.

The study of the structure of matter with accelerator methods is one of the areas of strategic profiling of the University of Jyväskylä. Apart from nuclear physics and particle physics, the accelerator-based study of materials, carried out by the Pelletron group, is also included under this heading.

During the year, some major infrastructure funding became available that will be to our advantage in coming years (Academy of Finland FIRI). The ECR ion source project HIISI was initiated, and funding for a helium ion microscope (HIM) was guaranteed in a project involving several departments of the Faculty.

Education

The quality of the teaching is of high priority in the Department. We are continuously pushing to develop new teaching methods and practices in order to improve the learning outcomes and to make studies more enjoyable and rewarding to our students. We encourage the students to put more emphasis onto peer learning and self-directed studies as this is known to be a more effective and deeper way to learn than via traditional lectures. To support this, a project was launched in 2014 to provide all the basic physics courses with compact audiovisual presentations on the key topics and to make them available on the internet.

According to a survey conducted at the University level of the master students who graduated in 2012, the teaching of the Department is held in quite high regard. The full 100 % of the physics

Some statistical data from 2014

Personnel	~190
Professors incl. Research professors	18
University lecturers and researchers	36
Postdoctoral researchers	17
Doctoral students	79
Technicians	29
Administration	5
Several research assistants (MSc students)	
Undergraduate students	500
of which new students	80
Doctoral students	79
BSc degrees	51
MSc degrees	25
PhLic degrees	1
PhD degrees	13
Median time to complete MSc (years)	6
Number of foreign visitors	286
in visits	372
Visits abroad	365
Peer reviewed publications	~265
Conference proceedings	~30
Other (articles in books etc.)	~25
Conference and workshop contributions	
Invited talks	~130
Other talks	~90
Posters	~50
Funding (million €)	15.7
University budget (incl. premises)	8.8
HIP cooperation	0.7
External funding	6.9
Academy of Finland	3.7
European Regional Development Fund	0.5
Technology Development Centre, T&E Centres	0.1
International programmes	0.7
Contract research	0.9
Other	0.3

Group photo of the staff taken in December 2014. A similar group photo of the staff was previously taken in 1996. Since then the number of staff has almost doubled. From left to right:

Row 1: Heikki Penttilä, Andrea Idini, Jarno Alaraudanjoki, Wladyslaw Trzaska, Matti Nurmia, Ritva Väyrynen, Esko Liukkonen, Soili Leskinen, Taneli Kalvas, Jukka Maalampi, Matti Leino, Andreas Johansson, Marjut Hilska, Minttu Haapaniemi, Anna-Liisa Blå, Ilari Maasilta, Andrii Torgovkin, Svitlana Baieva

Row 2: Tomohiro Oishi, Sami Räsänen, Kimmo Kainulainen, Kari J. Eskola, Ari Jokinen, Jaana Kumpulainen, Pauli Heikkinen, Kai Arstila, Timo Sajavaara, Juha Merikoski, Tuomas Grahn, Kosti Tapio, Matti Eskelinen, Boxuan Shen, Marko Käyhkö, Beomsu Chang, Chantal Nobs

Row 3: Mikko Rossi, Niko Säkkinen, Riku Tuovinen, Anna-Maija Uimonen, Daniel Karlson, Kari Rytkönen, Arto Javanainen, Jussi Maunuksela, Markku Kataja, Hannu Häkkinen, Pekka Koskinen, Jussi Toppari, Markus Ahlskog, DongJo Kim, Beomkyu Kim, Juha Uusitalo, Markku Särkkä

Row 4: Juha Tuunanen, Marko Puskala, Martti Hytönen, Väinö Hänninen, Juha Ärje, Markus Liimatainen, Raimo Seppälä, Jani Hyvönen, Mikael Sandzelius, Pauli Peura, Jukka Jaatinen, Arto Lassila, Anssi Ikonen, Kari Loberg, Sakari Juutinen, Vasily Simutkin, Einari Periainen, Veli Kolhinen, Jukka Koponen, Vesa Apaja

Row 5: Jussi Viinikainen, Tuukka Ruhanen, Markus Kortelainen, Mikko Haaranen, Dmitri Gorelov, Harri Niemi, Esa Liimatainen, Kai Porras, Atte Kauppinen, Olli Eränen, Sami Rinta-Antila, Kimmo Kinnunen, Catherine Scholey, Michael Mallaburn, Kai Loo, Matti Hokkanen, Maciej Slupecki

Row 6: Teemu Parviainen, Tuomas Pietikäinen, Timo Riikilä, Markku Väisänen, Vantte Kilappa, Panu Ruotsalainen, Karim Bennaceur, Roope Lehto, Hannu Leinonen, Veikko Nieminen, Jacek Dobaczewski, Axel Ekman, Tuomas Turpeinen, Laura Mättö, Yuan Gao, Sampsa Vihonen, Lingfei Yu, Hussam Badran, Olli Tarvainen

Row 7: Heikki Mäntysaari, Hannu Pohjanheimo, Jukka Paatola, Juha Kulmala, Thomas Snellman, Tommi Alanne, Perttu Luukko, Joni Parkkonen, Arttu Miettinen, Tero Harjupatana, Volker Sonnenschein, Mikko Laitinen, Mari Napari, Jari Malm, Kalle Auranen, Jari Partanen, Jaakko Julin, Olli Herranen, Mikko Palosaari

Row 8: Jarkko Peuron, Ville Vaskonen, Juhani Julin, Dongkai Shao, Joonas Konki, Laetitia Canete, Tommi Isoniemi, Andrei Herzan, Ilkka Pohjalainen, Sanna Stolze, Risto Kronholm, Janne Laulainen, Jani Komppula, Topi Kähärä, Markko Myllys, Jenni Kotila, Pekka Kekäläinen, Tuomas Puurtinen, Markku Hyrkäs

Row 9: Tommi Eronen, Timo Hyart, Peerapong Yotprayoonsak, Sami Malola

Missing from the picture are, at least, Rauno Julin, Paul Greenlees, Jouni Suhonen, Juha Äystö, Jussi Timonen, Jan Rak, Tero Heikkilä, Robert van Leeuwen, Ari Virtanen, Nina Kaari and Sanna Boman.

students taking part in the survey assessed the education they obtained in the Department as having a high quality.

Administration

The year 2014 was the last full working year of the departmental coordinator, amanuensis Soili Leskinen of the Department before her retirement in January 2015. Soili joined the Department in 1985 and has ever since been a key person of our community in many many respects. She has been in many senses the driving force of the Department with her novel and "crazy" ideas, in her determined actions, and her excellent overview of the Department as a whole. Also her role in creating the creative, open-minded and student-friendly spirit of the Department has been central. All of us, personnel and students alike, thank Soili warmly!

The transition to the new era in the administration has succeeded very well. Two new staff members were hired, Sanna Boman as a departmental coordinator and Ulla Heiskanen as a secretary. The reorganization of the office also meant that Minttu Haapaniemi and Nina Kaari were promoted to the position of departmental coordinator.

Funding

From the point of view of funding, 2014 was more challenging than some previous years. There was no substantial increase in the budget funding, implying that less resources were available for operational costs than in the previous year. The University budget now makes only 56 % of the total funding of 15.7 M€. Unfortunately, this negative tendency is foreseen to continue in coming years, in spite of the excellent performance of the Department in many respects.

According to the criteria applied by the Ministry of Education and Culture, the Physics Department earns more direct state funding to the University than any other unit. The Department is particularly profitable in publishing activity and the quality of its publications, and in raising international research funding. These are exactly the criteria we value highest ourselves and in which we are proud of our achievements.

Events

The Finnish Academy of Science and Letters awarded the prestigious Väisälä Prize to Professor Paul Greenlees for his work on the structure and stability of heavy and superheavy elements.

Matti Leino, professor of Experimental Nuclear Physics, a world-class specialist in heavy element research and a former vice-rector of the University, retired in May 2015. A full-backed lecture hall was gathered to listen to his most enjoyable farewell lecture "Höpö höpö, Leino". Happily, Matti continues his activity in the Department as an emeritus.

The year 2014 also meant a formal end of one superb teacher's career in the Department when the multifold "The Lecturer of the Year" and original character Markku Lehto retired.

On the 26th of September, the Accelerator Laboratory had open doors for the general public. During 6 hours 1150 people visited the "Hiukkasen valoa" event during which the Laboratory was filled with interactive activities, presentations, lectures and many visual effects.

Centre of Excellence in Nuclear and Accelerator-Based Physics

Rauno Julin

In 2014, the JYFL Centre of Excellence (CoE) in Nuclear and Accelerator-Based Physics began the third year of its third consecutive six-year term with this status granted by the Academy of Finland (AF). The midterm negotiations in autumn 2014 with AF were successful resulting in funding for the years 2015-2017 similar to that for the first period.

A Scientific Advisory Board (SAB) meeting of the CoE was held on 8th of May 2014. The SAB assured the Academy that the CoE continues to be successful when judged by the highest international standards. Considering the long-term planning, the SAB is requesting the CoE to launch a resource-loaded, integrated strategic plan with a long-term vision for the JYFL Accelerator Laboratory (JYFL-ACCLAB) in various scenarios, by considering possible developments at JYU, Finland, Europe, and worldwide.

The JYFL-ACCLAB is in Finland's roadmap for research infrastructures. The updated roadmap was published in March 2014. There are 18 Finnish infrastructures included, only three in natural sciences and engineering. Thanks to this status, the JYFL-ACCLAB has been successful in the FIRI infrastructure calls of the Academy of Finland.

The JYFL-ACCLAB continued to act as an EU-FP7-IA-ENSAR-access infrastructure.

Unfortunately, the ENSAR2 proposal for a continuation in Horizon2020 is so far just below the line of acceptability. The JYFL-ACCLAB still continues as an accredited test laboratory of the European Space Agency (ESA) and in addition, the RADEF team is a partner in an approved H2020 COMPET2014 (Competitiveness of the European Space Sector-2014) project R^2RAM (Radiation Hard Resistive Random-Access Memory).

The number of beam time hours at the K130 cyclotron used for basic research and industrial applications was 6360 hours. The number of proposals submitted for scientific experiments at JYFL-ACCLAB was 32.

In May 2014, after 22 years of dedicated and pioneering work in the Accelerator Laboratory, Professor Matti Leino retired from his position as Leader of the JYFL separator (RITU) group.

Professor Rauno Julin has stepped down from his duties as Head of the Accelerator Laboratory and Leader of the gamma group, and was replaced by Professors Ari Jokinen and Paul Greenlees, respectively.

Philippos Papadakis' proposal: "Investigation of proton-rich nuclei using novel techniques" for Marie Curie Fellowship was awarded funding for two years. Philippos will start his MC term in 2015.

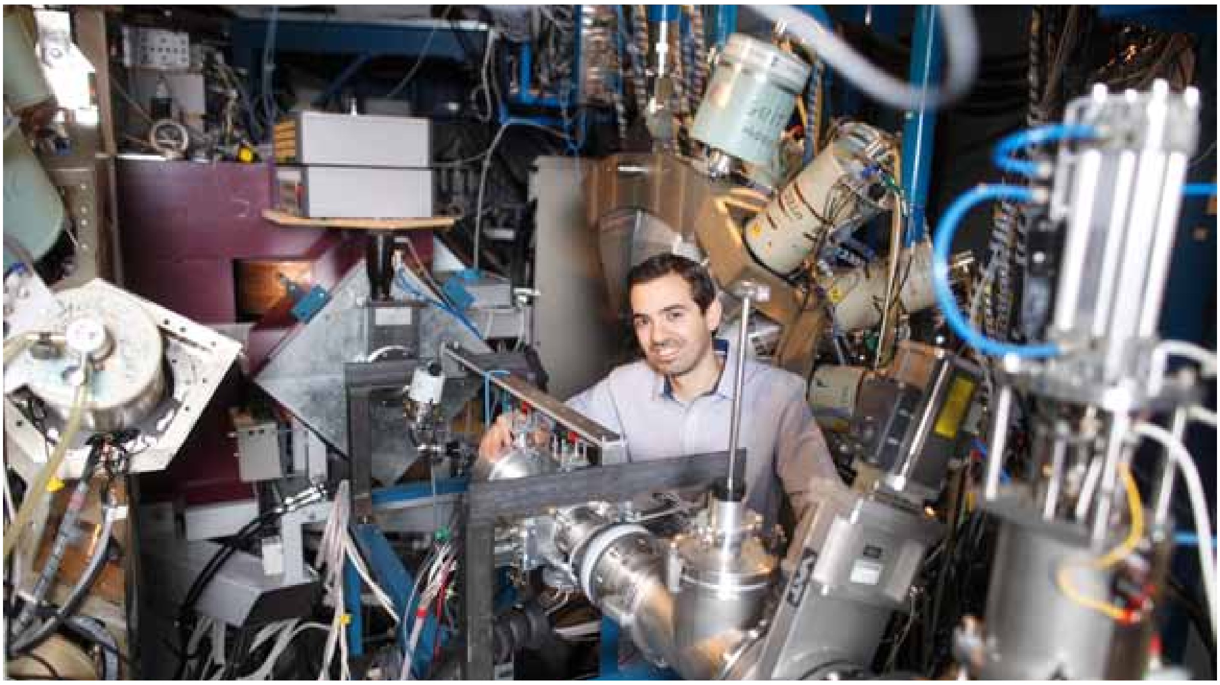


Fig. 1. Dr. Philippos Papadakis, Marie Curie Fellow of 2015-2016, installing the SPEDE spectrometer (photo Petteri Kivimäki).

The Nuclear Spectroscopy group continued its studies of nuclei close to the proton drip line with a total of 116 days of beam time dedicated to 12 different experiments. In parallel, important technical milestones were reached in the development of the MARA mass spectrometer and the SPEDE conversion electron spectrometer. In addition to the detailed spectroscopic studies, the use of high intensity beams at RITU allowed the discovery of two new isotopes, in Pa and Es.

Following commissioning of all experimental equipment, physics research dominated the IGISOL group's activities in 2014. In the first trap-assisted spectroscopy experiment, a new segmented total absorption decay spectrometer (DTAS), designed to be used by the DESPEC collaboration at NUSTAR, FAIR, was used for the first time. Later, trap-assisted spectroscopy of beta delayed neutron emitters, including the heaviest observed delayed 2-neutron emitter ^{136}Sb, was performed using the 4π neutron counter BELEN-48. Additionally, first experiments at IGISOL-4 and Louvain-la-Neuve using the new injection-locked Ti:sapphire laser represent a giant leap forward in the art of laser ionisation.

The Pelletron team got plenty of visibility due to the Tekes funded Recenart (Research Center for Art) project. Within this project the information obtained with chemical and physical methods, like ion beam analysis, is combined with the knowledge of art historians in order to determine the origin of cultural heritage artefacts. An Academy of Finland proposal (FIRI) of the team for establishing a multidisciplinary Helium Ion Microscopy Center in Jyväskylä was granted 1.25M€, and the instrument will be used for thin film research, nanopatterning and biological studies already in 2015.

The activities related to commercial applications continued at the same level as for the past years. In 2014 there were 38 campaigns for 16 different companies, institutes or universities occupying approximately 22% of the K=130 beam time. The total revenue was 758 000 €, which is an important income used to cover the running costs of the accelerators.

Fig. 2. The “Hiukkasen valoa” event attracted 1150 visitors (photo Timo Sajavaara).

The CoE theory team has continued systematic calculations of neutral-current and charged-current (anti)neutrino-nucleus scattering cross sections to lend aid to sensitivity analyses of the present and future large supernova-neutrino telescopes.

Dr. Jenni Kotila started as a post-doctoral researcher of the Academy of Finland for a 3-year project under the title “Nuclear double beta decay and neutrino properties” strengthening activities of the theory team.

In 2014 a new nuclear theory project funded by the Helsinki Institute of Physics and coordinated by Dr. Markus Kortelainen was initiated at JYFL. This 3+3 -year project aims to improve nuclear physics input to processes relevant to the various tests of weak interaction and astrophysical scenarios.

The main focus of the FiDiPro project was on defining the nonlocal energy density functionals, evaluating polarization and particle-vibration-coupling corrections to single-particle energies, implementing the Lipkin method of particle-number restoration, and studying monopole transition strength in weakly bound nuclei.

In the darkening night of September the “Hiukkasen valoa” event shed light on the research carried out in the Accelerator Laboratory. In collaboration with the City of Light, the K130 cyclotron was presented in a magical festival of light and sound by the famous light artist Kari Kola. The successful event attracted 1150 visitors to step on a guided journey into accelerator-based physics. The event was initiated and coordinated by Dr. Janne Pakarinen and Dr. Philippos Papadakis.

Scientific Advisory Board of the Centre of Excellence in Nuclear and Accelerator Based Physics

Witold Nazarewicz, professor, University of Tennessee, USA

Reiner Krücken, Head of the Science Division at TRIUMF, Canada

Pekka Koskela, professor, University of Jyväskylä

Jukka Pekola, professor, Academy of Finland

Sami Heinäsmaa, science adviser, Academy of Finland

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory

Wolfram Korten, CEA, Saclay, France (Chair)

Gerda Neyens, KU Leuven, Belgium

Thomas Nilsson, Chalmers University of Technology, Sweden

Marek Pfützner, Warsaw University, Poland

Philip M. Walker; University of Surrey, UK

Dario Vretenar, University of Zagreb, Croatia

The FIDIPRO Group

Jacek Dobaczewski

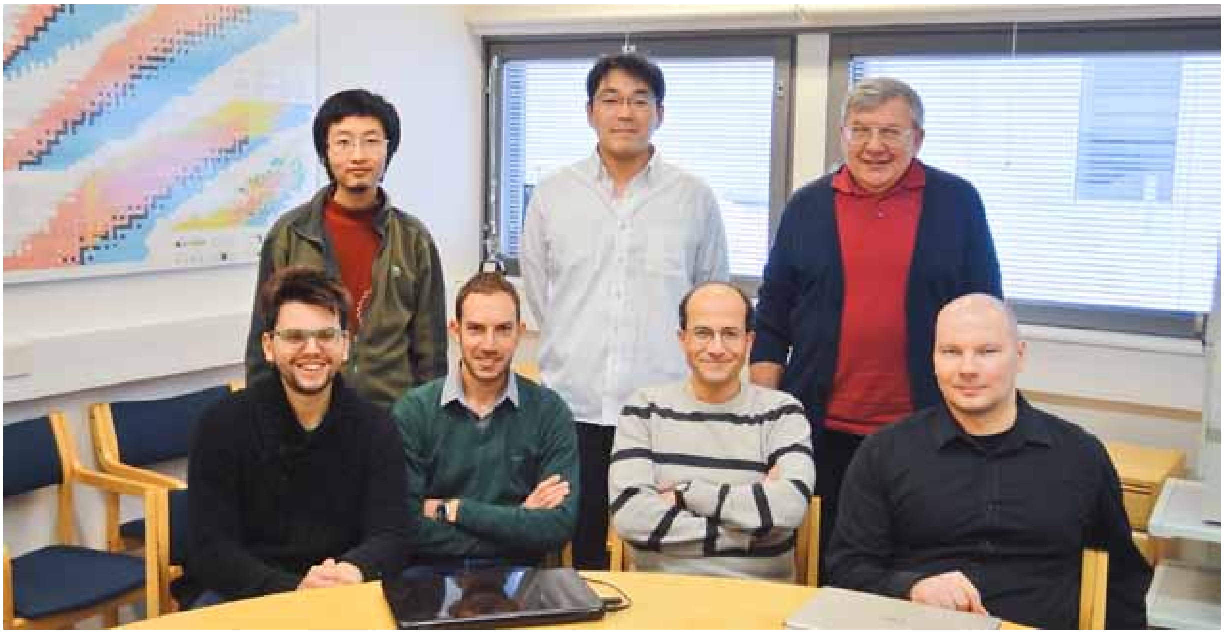
Jacek Dobaczewski, professor, team leader
Karim Bennaceur, senior researcher
Andrea Idini, postdoctoral researcher, 1.9 –
Markus Kortelainen, senior researcher
Tomohiro Oishi, postdoctoral researcher, 1.5 –
Vaia Prassa, postdoctoral researcher, – 28.2
Xiaobao Wang, postdoctoral researcher, – 31.8
Yuan Gao, doctoral student
Lingfei Yu, doctoral student

In 2014, the FIDIPRO project continued with the second year of being funded within the second FIDIPRO grant awarded by the Academy of Finland and matched by the University of Jyväskylä. The FIDIPRO team included seven researchers working together on common project goals. All detailed information on the FIDIPRO project, and on its achievements, publications, and meetings, is available on the project web page at: http://www.jyu.fi/accelerator/fidipro/.

In 2014, the main focus of the project was on defining the nonlocal energy density functionals, evaluating polarization and particle-vibration-coupling corrections to single-particle energies, and implementing the Lipkin method of particle-number restoration.

Nonlocal energy density functionals

We introduced a finite-range pseudopotential built as an expansion in derivatives up to next-to-next-to-next-to-leading order and we calculated the corresponding nonlocal energy density functional (EDF). The coupling



Standing, from left: Yuan Gao, Tomohiro Oishi, Jacek Dobaczewski.
Seated, from left: Andrea Idini, Gianluca Salvioni, Karim Bennaceur, Markus Kortelainen.

constants of the nonlocal EDF, for both finite nuclei and infinite nuclear matter, were expressed through the parameters of the pseudopotential. All central, spin-orbit, and tensor terms of the pseudopotential were derived both in the spherical-tensor and Cartesian representation. At next-to-leading order, we also derived relations between the nonlocal EDF expressed in the spherical-tensor and Cartesian formalism. Finally, a simplified version of the finite-range pseudopotential was considered, which generates the EDF identical to that generated by a local potential.

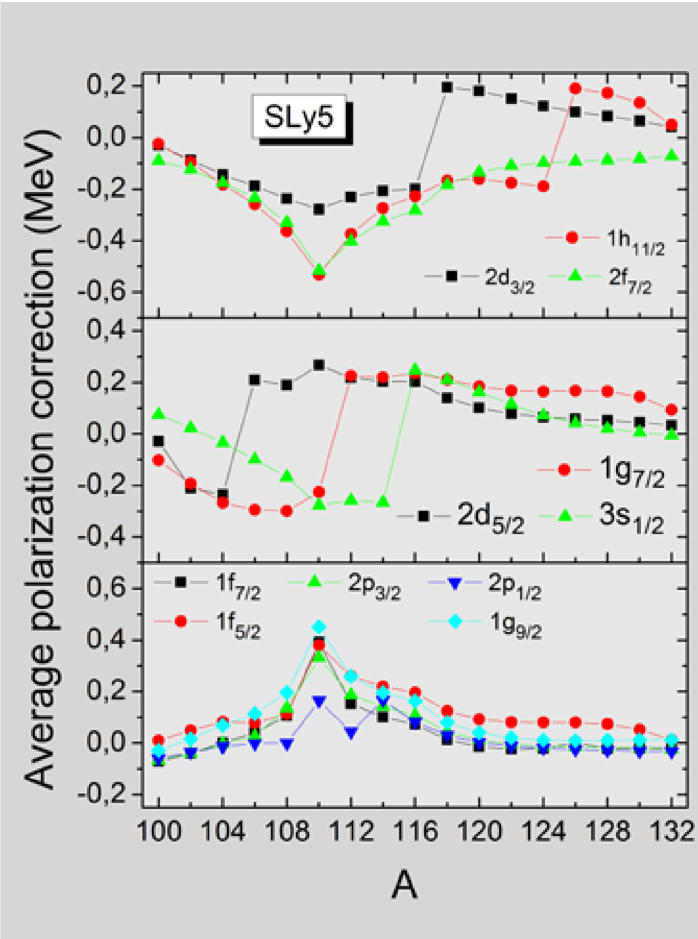


Fig. 1. Average polarization corrections in tin isotopes.

Polarization corrections to single-particle energies

Models based on using perturbative polarization corrections and mean-field blocking approximation give conflicting results for masses of odd nuclei. We systematically investigated the polarization and mean-field models, implemented within selfconsistent approaches that use identical interactions and model spaces, to find reasons for the conflicts between them. For density-dependent interactions and with pairing correlations included, we derived and studied links between the mean-field and polarization results obtained for energies of odd nuclei. We also identified and discussed differences between the polarization-correction and full particle-vibration-coupling models. Numerical calculations were performed for the mean-field ground-state properties of deformed odd nuclei and then compared to the polarization corrections determined using the approach that conserves spherical symmetry. We have identified and numerically evaluated self-interaction (SI) energies that are at the origin of different results obtained within the mean-field and polarization-correction approaches. Mean-field energies of odd nuclei are polluted by the SI energies, and this makes them different from those obtained using polarization-correction methods. A comparison of both approaches allowed for the identification and determination of the SI terms, which then can be calculated and removed from the mean-field results, giving the self-interaction-free energies.

Spectroscopic properties of energy density functionals

We addressed the question of how to improve the agreement between theoretical nuclear single-particle energies (SPEs) and observations. Empirically, in doubly magic nuclei, the SPEs can be deduced from spectroscopic properties of odd nuclei that have one more, or one less neutron or proton. Theoretically, bare SPEs, before being confronted with observations, must be corrected for the effects of the particle vibration coupling (PVC). We determined the PVC corrections in a fully self-consistent way. Then, we adjusted the SPEs, with PVC corrections included, to empirical data. In this way, the agreement with observations, on average, improved; nevertheless, large discrepancies still remained. We concluded that the main source of disagreement is still in the underlying mean fields, and not in including or neglecting the PVC corrections. This work contains full tables of empirical and calculated results.

Lipkin method of particle-number restoration

On the mean-field level, pairing correlations are incorporated through the Bogoliubov-Valatin transformation, whereby the particle degrees of freedom are replaced by quasiparticles. This approach leads to a spontaneous breaking of the particle-number symmetry and mixing of states with different particle numbers. In order to restore the particle number, various methods have been employed, which are based on projection approaches before or after variation. Approximate variation-after-projection (VAP) schemes, utilizing the Lipkin method, have mostly been used within the Lipkin-Nogami prescription. In this work, without employing the Lipkin-Nogami prescription, and using, instead, states rotated in the gauge space, we derived the Lipkin method of particle-number restoration up to sixth order and we tested the convergence and accuracy of the obtained expansion. We performed self-consistent calculations using the higher-order Lipkin method in the framework of superfluid nuclear energy-density functional theory and we also applied it to a schematic exactly solvable two-level pairing model. Calculations performed in open-shell tin and lead isotopes showed that the Lipkin method converges at fourth order and satisfactorily reproduces the VAP ground-state energies and energy kernels. The method is computationally inexpensive, making it particularly suitable, for example, for future optimisations of the nuclear energy density functionals and simultaneous restoration of different symmetries.

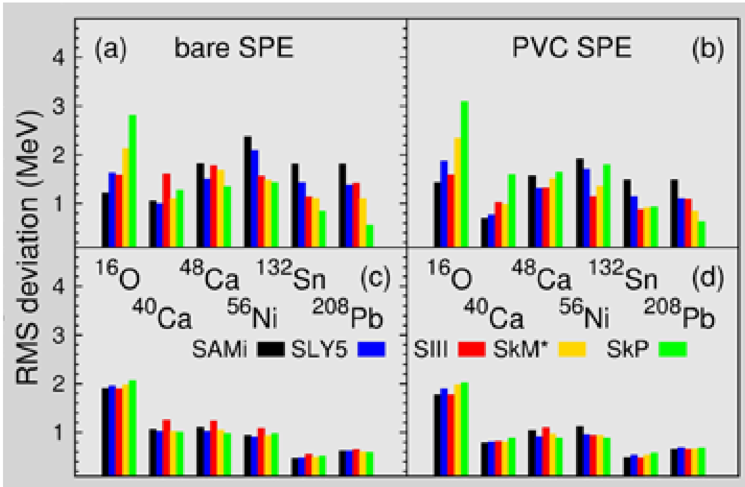


Fig. 2. Left (right) panels: root-mean-squared deviations between the bare (PVC-corrected) single-particle energies and empirical data of set A. Upper and lower panels show results obtained for standard Skyrme energy-density functionals and for refitted parameterisations, respectively.

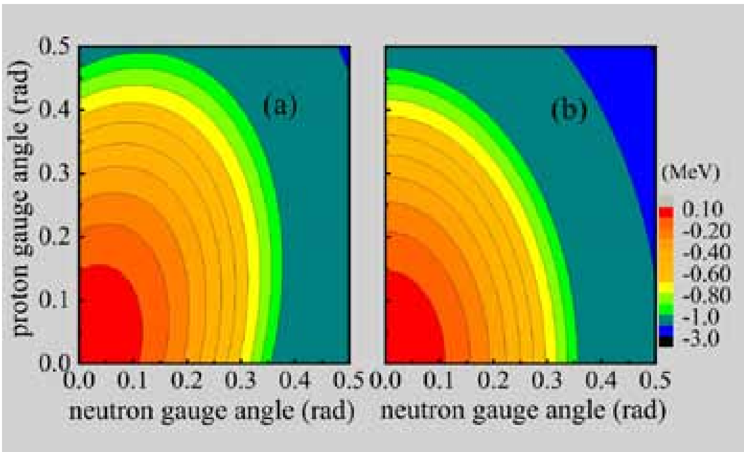


Fig. 3. Reduced energy kernel (left) compared to the reduced kernel of the Lipkin operator at sixth order (right), calculated for ^{124}Xe.

Accelerator facilities

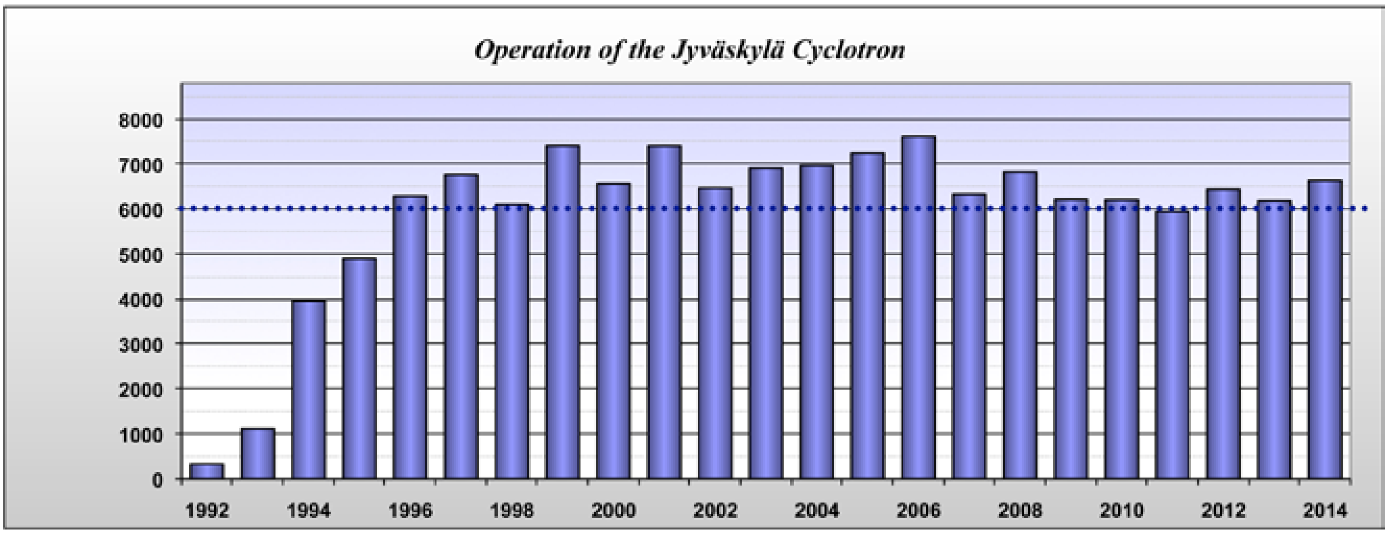
Pauli Heikkinen
and Hannu Koivisto

Pauli Heikkinen, chief engineer
Hannu Koivisto, senior lecturer
Olli Tarvainen, senior researcher
Taneli Kalvas, postdoctoral researcher
Jani Komppula, doctoral student
Janne Laulainen, doctoral student
Risto Kronholm, doctoral student 1.9.-
Jaana Kumpulainen, laboratory engineer
Arto Lassila, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Tuunanen, laboratory engineer
Juha Ärje, laboratory engineer
Markus Liimatainen, laboratory engineer
Jani Hyvönen, senior laboratory technician
Anssi Ikonen, senior laboratory technician
Raimo Seppälä, research technician

Cyclotrons

The use of the K130 cyclotron continues at a level of about 6000 hours per year. The total use of the cyclotron in 2014 was 6360 hours out of which 5513 hours on target. Since the first beam in 1992 the total run time for the K130 cyclotron at the end of 2014 was 136'978 hours. The biggest user of the cyclotron beams in 2014 was JUROGAM (29 %), the second being IGISOL (25 %). The reason for IGISOL still using a lot of K130 cyclotron beam time was some technical problems with the MCC30 cyclotron which otherwise could have accelerated most of the IGISOL beams. RADEF facility used 22 % of the beam time, mainly for industrial applications, and RITU experiments used 13 %. Altogether over 20 different isotopes were accelerated in 2014. The most commonly used beam was protons (28 %), beam cocktails for space electronics testing being the second one (14 %).

Fig. 1. Operation of the Jyväskylä K130 cyclotron in 1992-2014.



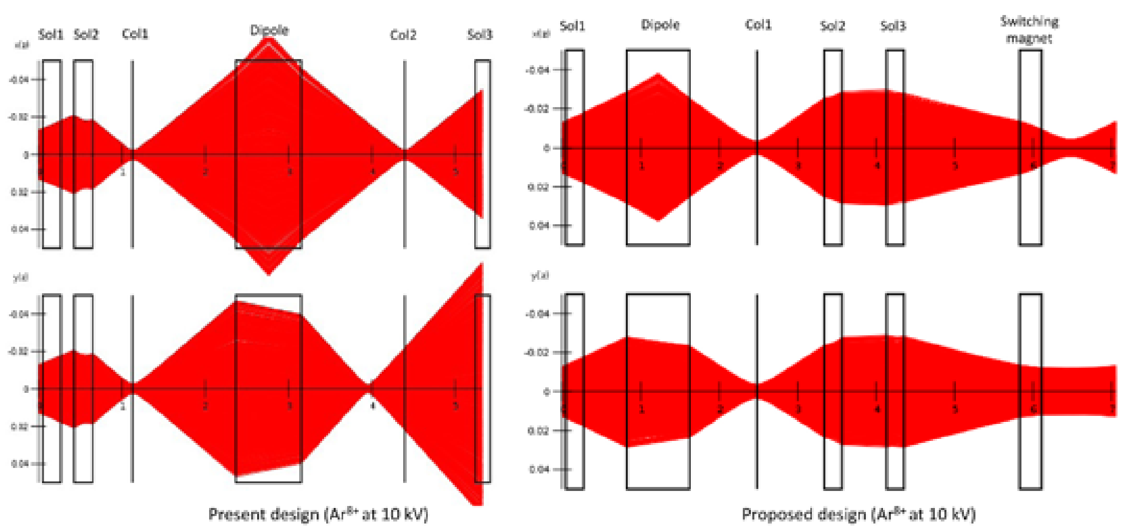
Ion sources

At the end of 2013 the Academy of Finland granted funding for a new 18 GHz ECR ion source called HIISI (Heavy Ion Ion Source Injector). The design work was started immediately and the first milestone was achieved at the end of June 2014 when the international Scientific Advisory Board accepted the scientific design guidelines of the main components (i.e. for magnetic field configuration, vacuum solutions and high voltage solutions). During the fall 2014 the mechanical design work was started and the first components were purchased. At the end of 2014 the project was on schedule and the first beam from the 18 GHz ECRIS is expected before the summer of 2016.

The first section of the JYFL 14 GHz ECRIS beam line will be modified in order to improve the ion beam transmission for K130 cyclotron. The beam properties of the upgraded extraction of the JYFL 14 GHz ECRIS were carefully characterized by the simulations and the results were verified experimentally. The beam was ray-traced though the first section of the injection line using these experimentally defined beam properties. The beam diameter is 26 mm at the z=0 plane, which corresponds to the point where the ion beam leaves the extraction area of the JYFL 14 GHz ECRIS. In simulation the divergence value of 20 mrad was used. The magnetic field of the dipole was constructed with Comsol using the mechanical pole angle of 32° and by taking into account the shimming of the dipole. This resulted in the field angle of 30.8° while the correct angle for the optimum beam transport was found to be 28.3°. Figure 2 (left-side) reveals three problems involving in the present beam optics of the JYFL 14 GHz ECRIS injection line: 1) the beam is too large inside the dipole resulting in beam losses, 2) in y-plane the focal point is about 40 cm upstream from the collimator resulting in beam losses by the collimator and 3) in y-plane the beam is too large when it enters the Solenoid3. In addition to beam losses Solenoid3 causes aberrations and emittance growth resulting in further beam losses downstream from the injection line.

According to the simulations the afore-mentioned transport problems can be avoided by three different actions: 1) move the ion source closer to the dipole in order to avoid a focal point between

Fig. 2: Beam transport through the present and proposed beam optics of the JYFL 14 GHz ECRIS injection line.



the ion source and the dipole, 2) correct the entrance and exit angles of the dipole and 3) regroup the solenoids to minimize the losses and the aberrations caused by solenoids. The new layout of the JYFL 14 GHz ECRIS is presented in right-hand-side of Figure 2. The first solenoid is used to optimize the beam angle when it enters the dipole. As is confirmed by the figure in this new configuration the beam is not cut by the dipole. The collimator is moved 38 cm closer the dipole and as a result of corrected dipole angles the beam has the same focal point in x- and y-planes. The regrouping of solenoids 1 and 2 allows the efficient beam transport downstream from the injection line. The upgrade of the injection line will be performed during the spring of 2015.

The production efficiency of the metal ion beams is poor compared to the production efficiencies of ion beams produced from gaseous elements like krypton. The objective of this study was

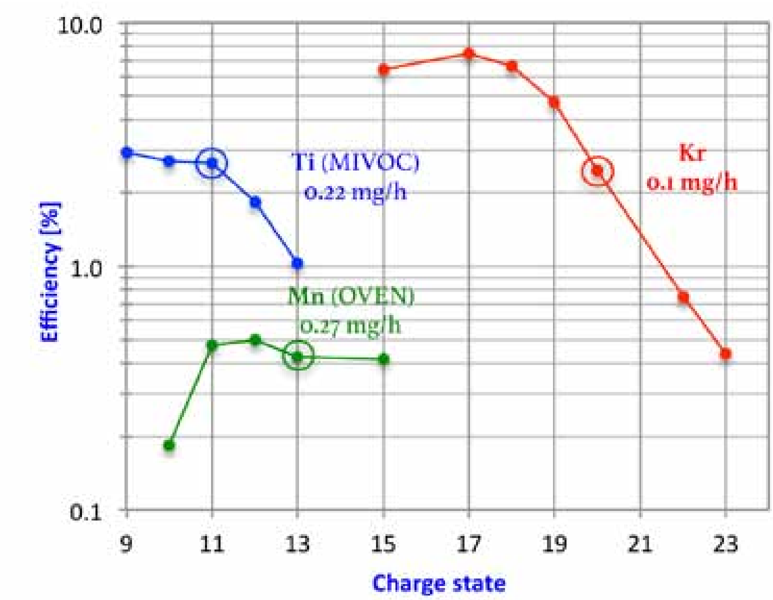


Fig. 3: Production efficiencies of Ti, Mn and Kr ion beams as a function of charge states. Manganese ion beams were produces with the evaporation oven and Ti ion beams by the MIVOC method.

to reveal more information about the cause of this tendency. Figure 3 shows the production efficiencies of some elements (Ti, Mn and Kr) as a function of charge state. The titanium ion beams were produced with the aid of the MIVOC method and the manganese ion beams were produced by using the JYFL miniature oven. In all cases oxygen was used as a mixing gas. As the figure shows the production efficiency of about 7 % is obtained for the $Kr^{16\text{-}18+}$ ion beams. Surprisingly high production efficiency values have been reached with the MIVOC method – about 3 % for the $Ti^{9\text{-}11+}$ ion beams. Remarkably lower efficiency is obtained with the evaporation oven. The data motivates us to present the question: what is the reason for much lower production efficiencies obtained with the oven? The plasma dynamics and ionization processes regarding the titanium and manganese should be approximately identical, i.e. same ionization efficiency could be achieved for Ti and Mn. This indicates that the main difference in the production efficiency can be linked to the method used to feed the solid element into the plasma and the subsequent capture process of the element. In the case of the MIVOC method the material is not heated and consequently no condensation of the gaseous molecules on the plasma chamber walls takes place before the dissociation of molecules. In the case of the evaporation ovens the atoms, which are not captured by the plasma, will be lost via condensation on the plasma chamber walls. The data presented here strongly indicates that the production efficiencies, regarding the oven methods, can be improved as a result of further development work. The oven geometry should be designed such a way that the evaporated metal atom has a very limited possibility to enter the cold plasma chamber wall. In addition, the method to guide the evaporated elements directly into the plasma should be considered.

Exotic nuclei and beams

Ari Jokinen, Iain Moore, Heikki Penttilä

Ari Jokinen, professor
Juha Äystö, professor (on leave of absence)
Heikki Penttilä, senior researcher
Iain Moore, senior lecturer
Anu Kankainen, academy research fellow, 1.9. -
Veli S. Kolhinen, senior researcher
Sami Rinta-Antila senior researcher
Paul Campbell, visiting reseacher, University of Manchester 1.8.-
Tommi Eronen, postdoctoral researcher, 1.4.-
Annika Voss, postdoctoral researcher
Vasily Simutkin, postdoctoral researcher, 1.8. -
Volker Sonnenschein, doctoral student
Jani Hakala, doctoral student
Dmitry Gorelov, doctoral student
Ilkka Pohjalainen, doctoral student
Jukka Koponen, doctoral student
Laetitia Canete, doctoral student, 1.8. -
Chantal Nobs, doctoral student (University of Brighton) 1.10. - 31.12.
Juuso Reinikainen, MSc student
Ian Murray, MSc student
Kateryna Poleshchuk, MSc student
Oleksii Poleshchuk, MSc student
Kari Rytkönen, laboratory engineer (HIP)

Fig.1. IGISOL group in January 2015 next to the laser cabins. From the left: Ilkka Pohjalainen, Paul Campbell (at the back), Ari Jokinen, Juuso Reinikainen, Iain Moore, Vasily Simutkin, Heikki Penttilä (in the front), Jukka Koponen, Bradley Cheal, Sarina Geldhof, Anu Kankainen, Tommi Eronen, Annika Voss, Sam Kelly, Juha Äystö, Kari Rytkönen, Kateryna Poleshchuk, Laetitia Canete, Ian Murray, Oleksii Poleshchuk and Veli Kolhinen.

Activity 2014

Following commissioning of all experimental equipment, physics research dominated the group's activities in 2014. Over 60 days of beam time was delivered to eight major experiments. Additional days were devoted to technical development.

Our international collaboration in FAIR and at ISOLDE in CERN has benefited from the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). In local activities, EU support from the FP7 program ENSAR and CHANDA is gratefully acknowledged.

Technical developments

Resonance laser ionization. A modified version of the inductively-heated hot cavity catcher was commissioned on-line. Release times as short as ~10 ms were observed for laser-ionized ^{107}Ag, paving the road for studies of short-lived neutron-deficient isotopes of Ag, towards N=Z=^{94}Ag in the future.

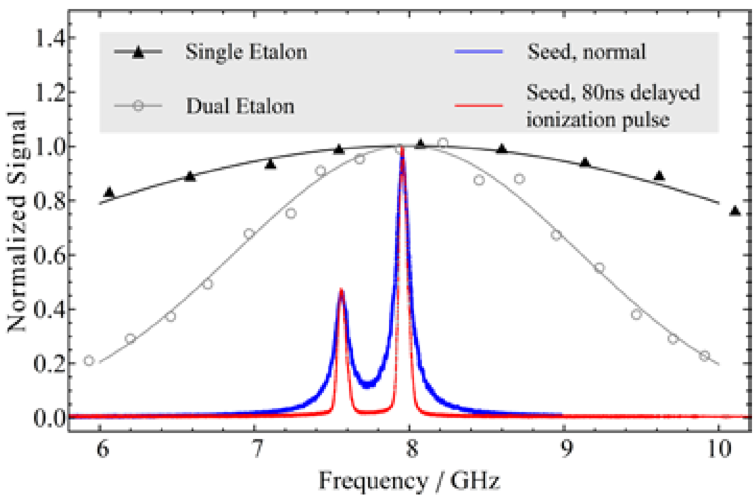


Fig.2. Ti:sapphire frequency scans of the F_g=1 → F_u=2 hyperfine components of the 244-nm transition in ^{63,65}Cu. Shown is the improvement in resolution due to the reduction in laser linewidth from single- to double etalon Ti:sa, and using the injection-locked laser with and without delayed ionization.

In the first application of the new injection-locked Ti:sapphire laser, spectroscopy of long-lived isotopes of Ac and Pu were studied at the University of Mainz. At IGISOL, spectroscopy was performed on the 244-nm transition on copper. Excellent agreement with literature was achieved for the ground state hyperfine parameters of ^{63,65}Cu. Discrepancies were seen for the excited state of ^{63}Cu, indicating possible inaccuracies in earlier work. The impact of delayed ionization on the experimental linewidth was studied, see Fig. 2.

In collaboration with Mainz and Leuven, laser ionization of Pu isotopes provided by the Mainz TRIGA reactor was performed at IGISOL [I-187]. This work aims at collinear laser spectroscopy on laser-ionized Pu^+ ions in the future.

In December, a collaborative effort resulted in an outstanding final experiment at LISOL, Louvain-la-Neuve. In-gas-jet spectroscopy was performed on ^{214,215}Ac representing a milestone for in-source spectroscopy of exotic nuclei. The injection-locked laser from JYFL was used in this work.

Collinear laser spectroscopy. The laser station has been complemented by an ultra-low energy electrostatic ConeTrap. The device, a dynamic multi-reflection trap, has been shown to successfully contain cooled ions on millisecond time scales. In the trap, laser spectroscopy, at 800 eV total acceleration energy, can be performed with collinear interaction lengths corresponding to hundreds of meters.

Neutron converter. The first neutron production test run of the beryllium-based proton-to-neutron

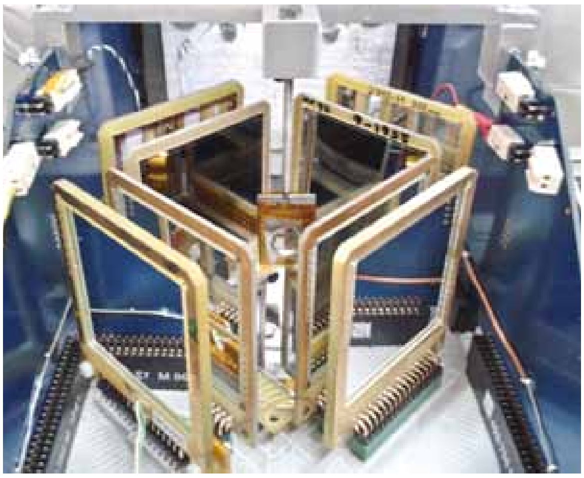


Fig. 3. In preparation for detecting the breakup of ^{12}C: the DSSSD detectors arranged in a cubic array. The top was kept open to insert the stopper-foil frame. The active area of each detector is 5 cm x 5 cm.

converter target was performed in 2014. The time-of-flight analysis at zero degree angle and neutron activation in four angles verify the result of neutron production simulations.

Experimental highlights

Beta decay studies for neutrino physics [I-183]. These experiments involved the first trap-assisted spectroscopy after the commissioning of IGISOL-4. A new, segmented total absorption spectrometer (DTAS), designed for NUSTAR, FAIR, was used for the first time. The main goal of the study was to improve the knowledge of beta decays relevant for the prediction of reactor neutrino spectra. The study is important for fundamental physics (neutrino oscillations), and also provides more precise data for the practical application of prediction of the decay heat in reactors using summation calculations.

Proton-induced fission yields [I-151, I-185]. The technique to determine the independent fission yields utilizing ion counting and the unambiguous identification of the isotopes via JYFLTRAP was developed at IGISOL-3. In two experiments, the survey of 25-MeV proton-induced fission yields of natural U and Th was completed.

The second excited 2^+ state in ^{12}C [I-161]. In the triple-alpha process, three ^{4}He nuclei fuse to form ^{12}C. This process is dominated by a single state in ^{12}C, the Hoyle state. A search for the illusive second excited 2^+ state, which, in the simplest theoretical picture, would be the rotational excitation of the Hoyle state, was performed at IGISOL in June 2014. The setup consisted of a thin carbon foil, surrounded by a cubic array of Double Sided Silicon Strip Detectors (Fig. 3). The inner detectors measured the α-particles following breakup, while the thick outer detectors,β-particles. Close to a million triple-α coincidence events were detected, which will be analyzed in the search for the 2^+ state.

First on-line mass measurements of neutron-deficient nuclei at JYFLTRAP: ^{25}Al and ^{30}P [I-191]. The experiment was mainly motivated by astrophysics. The mass of ^{25}Al is relevant for the proton capture rate $^{25}Al(p,\gamma)^{26}Si$ which has a direct effect on the amount of cosmic

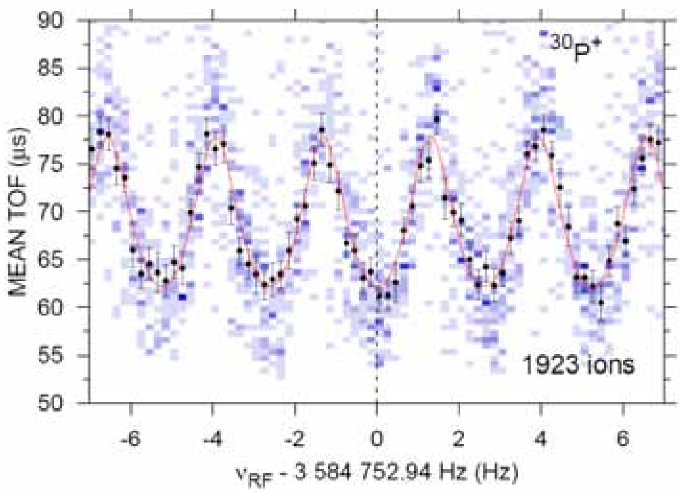


Fig. 4. Example of the time-of-flight spectra for ^{30}P.

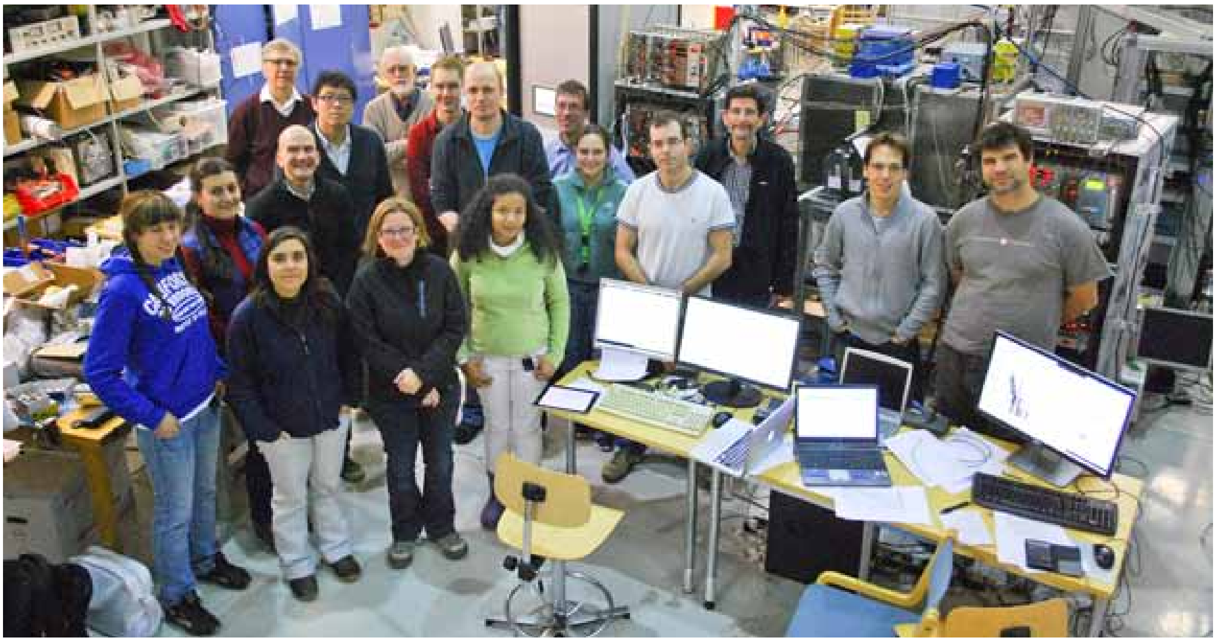


Fig. 5. Detectors and groups. Upper figure, DTAS and part of the research group behind JYFLTRAP. Lower figure, the BELEN-48 detector successfully installed at the same position 8 months later.

1809-keV gamma-rays. The mass of ^{30}P is needed for an improved calculation of the proton-capture rate $^{30}P(p,\gamma)^{31}S$ which controls the production of elements heavier than sulphur in novae. ^{25}Al and ^{30}P nuclei were produced with 40-MeV protons on magnesium and ZnS, respectively. Their masses were determined at JYFLTRAP (Fig 4.). In addition to the mass values, high-precision Q_{EC} values for ^{25}Al and ^{30}P were obtained.

Delayed neutron branchings [I-162]. The delayed neutron fraction in a reactor b_{eff} is a fundamental parameter in the safe control of nuclear power plants. In addition, the β-delayed neutron emission of nuclei along the r-process path has an impact in the r-process elemental abundance. The β-delayed neutron emission probability P_n of several fission products was measured with improved accuracy using the 4π neutron counter BELEN-48. The measured isotopes include some close to the limit of the IGISOL production.

Two-neutron emitter ^{136}Sb [I-181]. Beta-delayed multiple neutron emission is an exotic process which plays a role during the r-process. The use of JYFLTRAP was essential to separate ^{136}Sb in the experiment aiming at the observation of a weak 2N emission branch. From the on-line analysis, a few triple correlation events of the type β-N-N were indeed observed and we expect to have a positive result after a careful offline analysis.

Highlights at GSI/FAIR

Two years after the commissioning of the FRS Ion Catcher facility, GSI, the cryogenic stopping cell (CSC), coupled to a multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) was used at the FRS in October 2014. The intensity limitations of the CSC were systematically investigated. A new record was set for the areal density of stopping cells with RF structures operated with beam. The MR-TOF-MS successfully separated isomeric from ground states, and performed direct mass measurements of several nuclides. All parts of the FRS Ion Catcher exceeded expectations and worked extremely reliably.

Experiment spokespersons and collaborating institutes in 2014

[I-153] Study of nuclei relevant for precise predictions of reactor neutrino spectra.
Spokesperson: M.Fallot, U. Nantes, J.L.Tain, A. Algora, IFIC U. Valencia.
Participants: U. Nantes, France; IFIC U. Valencia, Spain; CIEMAT, Madrid, Spain; INR Debrecen, Hungary; PNPI, Gatchina, Russia; U. Surrey, Guilford, UK.

[I-154] Total absorption measurement of the β-decay of ^{100}Tc.
Spokesperson: A. Algora, J.L.Tain, IFIC U. Valencia.
Participants: U. Nantes, France; IFIC U. Valencia, Spain; INR Debrecen, Hungary; GSI, Darmstadt, Germany; U. Münster, Germany; PNPI, Gatchina, Russia; U. Surrey, Guilford, UK; U. Washington, Seattle, USA; TRIUMF, Vancouver, Canada; INFN-LNL, Padova, Italy; Osaka U., Japan; U. Nacional de la Plata, Argentina;

[I-151] Independent fission yields in proton-induced fission of ^{232}Th at 25 MeV.
Spokesperson: H. Penttilä, JYFL, I.V. Ryzhov, KRI, S. Pomp, Uppsala U.
Participants: KRI, Russia; Uppsala U., Sweden.

[I-185] Enhancement of isotopic product yield at closed neutron shells.
Spokesperson: H. Penttilä, JYFL

[I-161] Search for the second excited ^{12}C 2^+ state using ^{12}N and ^{12}B decay β-triple-α coincidence measurements at IGISOL
Spokesperson: C. Aa. Diget, U. Aarhus
Participants: U. York, York, UK; CEN Bordeaux-Gradignan, France; CSIC, Madrid, Spain; U. Aarhus, Denmark; Chalmers U. Technology, Göteborg, Sweden; GANIL, Caen, France

[I-187] Measurement of nuclear charge radii of plutonium isotopes via collinear laser spectroscopy
Spokesperson: I.D. Moore, JYFL
Participants: U. Manchester, UK; U. Liverpool, UK; U. Mainz, Germany; KU Leuven, Belgium; Lawrence Livermore Lab, USA

[I-181] Measurement of the β-delayed two-neutron emitter ^{136}Sb with the BELEN detector.
Spokesperson: I. Dilmann, Justus Liebig U., Giessen and GSI, Darmstadt
Participants: GSI, Darmstadt, Germany; Justus Liebig U., Giessen, Germany; SEN-UPC Barcelona, Spain; IFIC U. Valencia, Spain; CIEMAT, Madrid, Spain

[I-162] Delayed neutron measurements for advanced reactor technologies and astrophysics.
Spokesperson: M.B. Gomez Hornillos, SEN-UPC Barcelona; J.L.Tain, IFIC U. Valencia.
Participants: SEN-UPC Barcelona, Spain; IFIC U. Valencia, Spain; CIEMAT, Madrid, Spain; U. Surrey, Guilford, UK; U. Manchester, UK;

Nuclear Spectroscopy

Janne Pakarinen, Mikael Sandzelius, Tuomas Grahn, Cath Scholey, Jan Sarén and Paul Greenlees

In-beam spectroscopy group members

Rauno Julin, professor
Paul Greenlees, professor
Sakari Juutinen, senior lecturer
Tuomas Grahn, senior lecturer
Janne Pakarinen, academy research fellow
Mikael Sandzelius, senior researcher
Philippos Papadakis, postdoctoral researcher
Panu Rahkila, postdoctoral researcher
Hussam Badran, doctoral student
Andrej Herzán, doctoral student
Joonas Konki, doctoral student
Pauli Peura, doctoral student
Juha Sorri, doctoral student
Sanna Stolze, doctoral student
Chris McPeake, visiting doctoral student
George O'Neill, visiting doctoral student
Laura Sinclair, visiting doctoral student

Separator group members

Matti Leino, professor
Juha Uusitalo, senior researcher
Cath Scholey, senior researcher
Jan Sarén, postdoctoral researcher
Ulrika Jakobsson, postdoctoral researcher -30.6.
Panu Ruotsalainen, postdoctoral researcher -30.6.
Kalle Auranen, doctoral student
Jari Partanen, doctoral student
Michael Mallaburn, visiting doctoral student

Fig. 1. The Nuclear Spectroscopy Group (Temperature -20 °C)

In 2014 the Nuclear Spectroscopy group continued in its experimental studies of nuclei along the proton drip line. In total 116 days were dedicated to 12 different experiments. The group members co-authored 15 peer-reviewed journal manuscripts and 2 contributions to conference proceedings. In addition to the highlights discussed in more detail below, the use of beams with intensities in excess of 200 pnA allowed the production of two new isotopes at RITU (in Pa and Es).

Studies of N≈Z nuclei

The program of recoil beta-tagging studies continued with an experiment to identify T = 1 states in ^{70}Kr using the ^{40}Ca(^{32}S, 2n)^{70}Kr reaction. By comparing the excitation energies of the T = 1 isobaric analogue states between isobaric partners such as ^{70}Kr, ^{70}Br and ^{70}Se, triplet energy differences (TED) can be derived. The TED can be used to obtain information on the two-body Coulomb and isospin non-conserving interactions in the nucleus. The experiment utilized recent developments in the beta-tagging instrumentation including a charged particle veto device and a more highly pixelated DSSD. The experience gained from previous experiments led to an excellent recoil-to-beam ratio.

During the online analysis, a candidate for the 2^+ to 0^+ transition in ^{70}Kr was observed, which if confirmed in the offline analysis, will lead to a unique observation. A consecutive experiment was also performed to study ^{71}Kr. The experiment ran smoothly and the analysis is ongoing.

Lifetime measurements

A campaign of lifetime measurements of excited states was carried out with the DPUNS plunger. In the first experiment, lifetimes in ^{174}Pt were studied in order to study quadrupole collectivity as a function of spin. In this nucleus irregularities in the yrast band sequence have been attributed to shape coexistence of well-deformed and spherical structures at intermediate spin. The lifetime data will allow the mixing of the two structures as a function of spin to be studied.
The following experiment studied shape coexistence in ^{178}Hg. Being six neutrons away from the neutron mid shell at N=104, ^{178}Hg lies at the edge of the region of Hg isotopes where the shape coexistence is well defined. The aim was to study the evolution of coexisting structures as a function of both spin and neutron number, building on earlier JYFL studies of heavier Hg isotopes.

The campaign ended with measurements of proton-unbound states in ^{113}Cs. The aim was to measure lifetimes that would be used to improve the accuracy of theoretical calculations in an exotic region beyond the proton drip line. The lifetime data will be used by theory collaborators to improve advanced models of proton decays and unbound states.

MARA nears completion

The vacuum-mode recoil-mass spectrometer MARA is approaching the commissioning phase. In spring, the separator group travelled to Danfysik to participate in the final factory acceptance tests of the electrostatic deflector. After the approval, the deflector was disassembled for transportation to Jyväskylä. The final alignment of the separator elements including the deflector

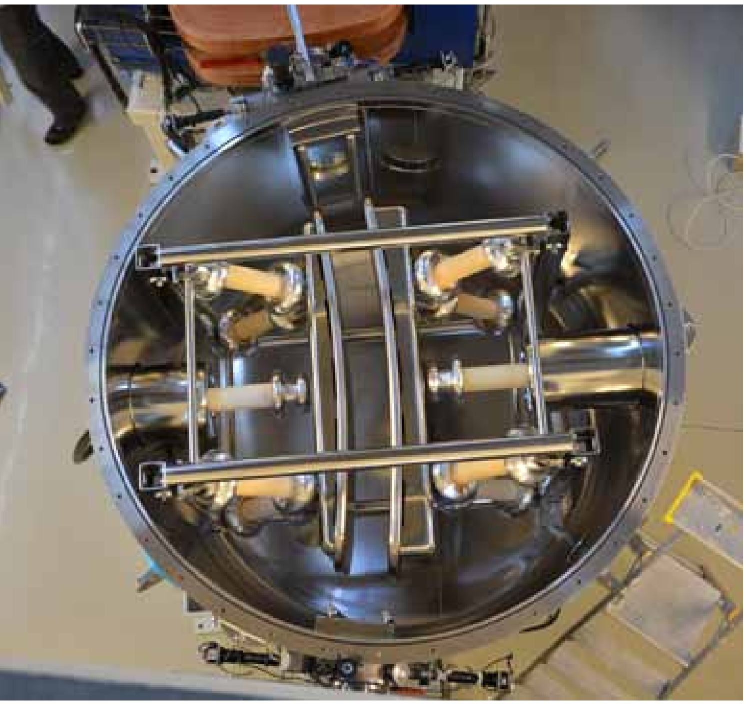


Fig. 2. A last glance at the innards of the MARA deflector

Fig. 3. The SPEDE detector mounted at the target position of RITU for the first in-beam test.

and its titanium plates was performed and the required radiation shielding added. Conditioning of the electrostatic deflector at high voltage was started just before the Christmas period. After conditioning the final ion-optical tests with an alpha source and accelerated beams will be started.

SPEDE under test

The program to investigate shape coexistence and collectivity in heavy nuclei has included complementary Coulomb excitation experiments carried out at REX-ISOLDE, CERN. Following the HIE-ISOLDE upgrade foreseen in 2015, multistep Coulomb excitation experiments will become routine. For complete analysis of data, all possible decay paths, including internal conversion, need to be measured. The SPEDE spectrometer, to be operated in conjunction with the MINIBALL g-ray spectrometer at HIE-ISOLDE, CERN, will detect conversion electrons emitted in the decay of Coulomb-excited states. SPEDE was assembled and careful tests were carried out at JYFL in 2014. The SPEDE concept was proven to work, allowing direct measurement of conversion electrons emitted from nuclei in flight without the use of an electron transport unit. SPEDE was designed and developed in close collaboration with University of Liverpool, UK, and will be commissioned in early 2015 at JYFL before the first experiments at HIE-ISOLDE later in the year.

Hands-on physics in the international Jyväskylä Summer School

A hands-on course on operating an in-flight recoil separator was held in JYFL 18th - 22nd of August as a part of the international Jyväskylä Summer School. The course content covered basic ion-optics, reaction kinematics and targets, vacuum techniques and detector systems. The highlight of the course was to set up the RITU gas-filled separator for a real fusion evaporation reaction and to observe the product, ^{205}Fr nuclei. There were 23 participants in the course. It was lectured by Matti Leino, Juha Uusitalo and Jan Sarén.

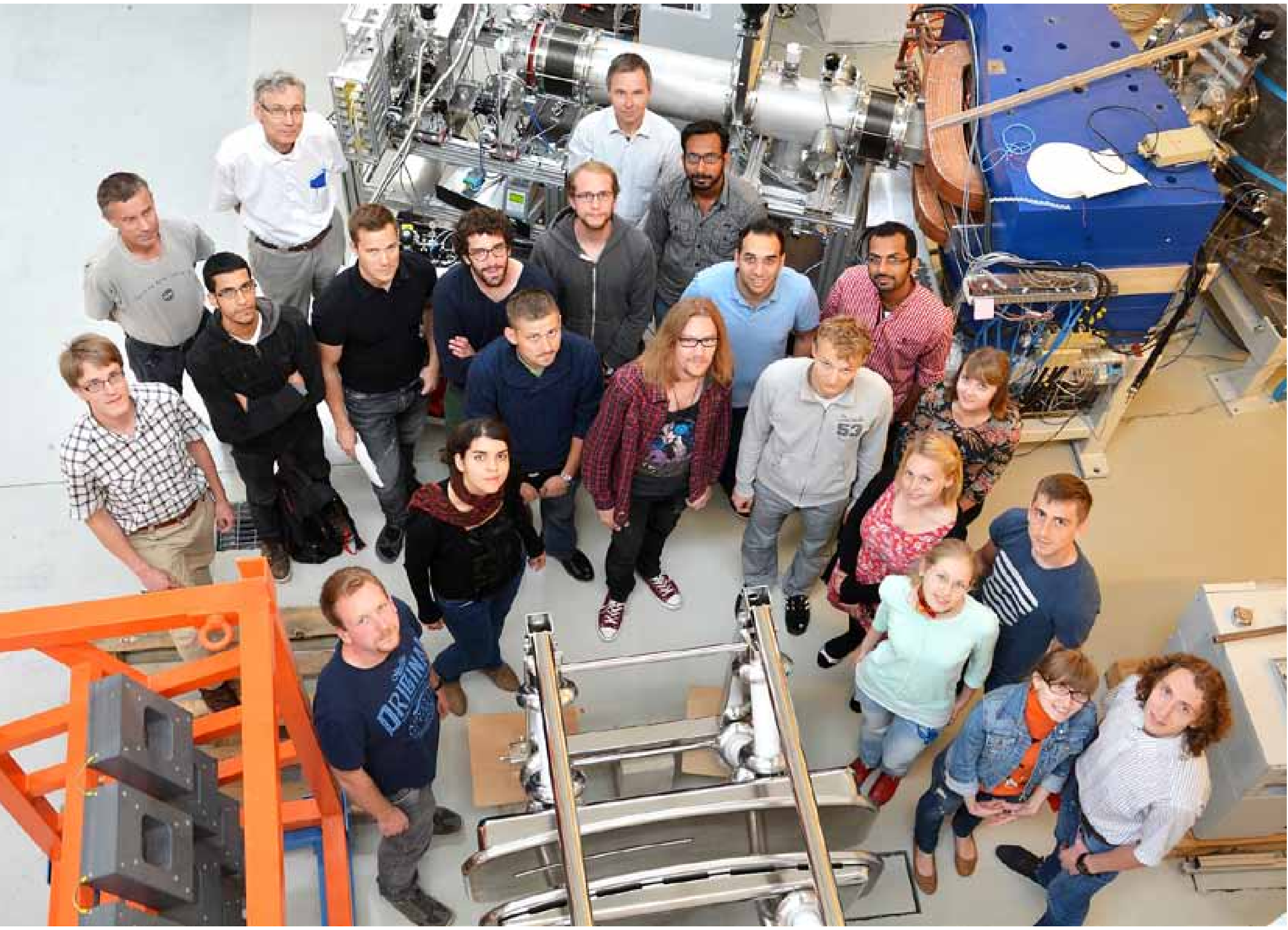


Fig. 4 Participants and lecturers of the Summer School course “Basics of Operating an On-line Recoil Separator” in front of the MARA recoil mass spectrometer.

Experiment spokespersons and collaborating institutes in 2014

[JR126] Spectroscopic Studies of Excited States above and below the 6^+ Isomer in ^{102}Sn
J. Nyberg, Uppsala University, Sweden
A. Atac, KTH Stockholm, Sweden
J. Uusitalo, JYFL
Ankara University, Turkey
University of York, U.K.
Oslo University, Norway

[J19] Defining the nature of the ultrahigh-spin region of ^{162}Hf
J. Simpson, STFC Daresbury, U.K.
E. S. Paul, University of Liverpool, U.K.
M. A. Riley, Florida State University, U.S.A.
JYFL
iThemba Labs, South Africa

[JR103] Magnetic Rotation and Shape Coexistence in ^{144}Dy
D. M. Cullen, University of Manchester, U.K.
JYFL
University of the West of Scotland, U.K.

[JR127] Prompt and delayed spectroscopy of the proton-unbound nucleus ^{201}Fr
U. Jakobsson, JYFL
J. Uusitalo, JYFL

[R46] Alpha-decay study of the proton unbound $^{211-213}Pa$
J. Uusitalo, JYFL

[JR130] Shape coexistence and quadrupole transition strengths in ^{174}Pt
M. Taylor, University of Manchester, U.K.
JYFL
University of Liverpool, U.K.
University of the West of Scotland, U.K.
University of Köln, Germany

[JR122] Shape coexistence in neutron deficient ^{178}Hg: First measurement of E2 transition strengths in the yrast band
C. Fransen, University of Köln, Germany
JYFL
University of Manchester, U.K.

[JR129] DPUNS: Lifetimes of Proton-Unbound States in deformed ^{113}Cs
D.M. Cullen, University of Manchester, U.K.
JYFL
University of the West of Scotland, U.K.
University of Köln, Germany

[JR132] Identification of excited states in ^{70}Kr
R. Wadsworth, University of York, U.K.
D. Jenkins, University of York, U.K.
JYFL
University of Oslo, Norway
CEA, Saclay, France
University of Edinburgh, U.K.

[JR135] Search for breakdown of T=1/2 mirror symmetry: Recoil-β^+ tagging and decay spectroscopy of ^{71}Kr
D. Jenkins, University of York, U.K.
H. David, Argonne National Laboratory, U.S.A.
JYFL

[JR131] Development and Commissioning of the SPEDE spectrometer
J. Pakarinen, JYFL
University of Liverpool, U.K.
University of York, U.K.
Katolische Universiteit, Leuven, Belgium

[R48] Synthesis and nuclear structure study of neutron-deficient Cf and Es isotopes
J. Khuyagbaatar, GSI, Germany
J. Uusitalo, JYFL
Orsay, France
CEA Saclay, France
University of Liverpool, U.K.
Australian National University, Canberra, Australia
University of Manchester, U.K.

Instruments and Methods in Nuclear, Particle, and Astroparticle Physics

Wladyslaw Trzaska

Wladyslaw Trzaska, senior researcher
Kai Loo, doctoral student
Maciej Slupecki, doctoral student
Juho Sarkamo, doctoral student (Oulu University)
Johannes Hissa, doctoral student (Oulu University)
Mikhail Smirnov, CIMO exchange student (St. Petersburg, Russia)
Patryk Edyko, summer student, 1.6.-31.8.2014
Katja Karppinen, summer student, 1.6.-31.8.2014
Joni Ollikainen, summer student, 1.6.-31.8.2014
Patryk Socha, summer student, 1.6.-31.8.2014
Agnieszka Sobczyk, summer student, 1.6.-31.8.2014
Jukka Sorjonen, summer student, 1.6.-31.8.2014
Mateusz Zybert, summer student, 1.6.-31.8.2014
Grigori Tiurin, visiting researcher (Radium Institute, Russia)

EMMA experiment

The photo below, taken in Pyhäjärvi in June 2014, shows the Finnish team of the EMMA Collaboration together with our summer students at the start of their 3-months term at CUPP. Our official 2014 EMMA Day Collaboration Meeting took place in May and was attended by the physicists from the Institute of Nuclear Reactions of Russian Academy of Sciences and from the Moscow Institute of Physics and Technology. In addition, we had international EMMA meetings in September and in December. In 2014 we have completed the construction of the detector stations. All of the planned 11 stations are now ready and are being instrumented with detectors.

By the end of the year we have increased the number of fully equipped, data taking stations from 4 to 6. The data acquisition was running for the total of 260 days. There were also periodic 1-2 day test runs to monitor the performance of the detector array. An important milestone was the successful defense of the Ph.D. thesis by Juho Sarkamo dealing with the DESIGN, CONSTRUCTION AND COMMISSIONING OF THE EMMA EXPERIMENT. His opponent was Bruno Alessandro – the coordinator of cosmic ray measurements with ALICE detector. In our outreach program we have hosted visits from six local high schools (lukio) showing and explaining the EMMA experiment to approximately 90 students and teachers.

ALICE T0 and FIT detectors

Test measurements are crucial part of detector R&D. The smiling faces pictured in July 2014 at the T10 beam line in the East Area of the PS at CERN testify to the success of the first in-beam measurements of the prototypes of the Fast Interaction Trigger (FIT) modules for the upgrade of ALICE experiment. In 2014 FIT detector Technical Design Report has been fully approved at CERN following the evaluations by the ALICE Collaboration, by the LHC Committee and by the Upgrade Cost Group. There are already 9 institutes from Denmark, Finland, Mexico, Russia and the United States participating in this project that has been proposed and is coordinated by our group. R&D on FIT went in parallel with preparations of ALICE for the Run 2 and in particular with re-commissioning of the T0 detector after the major latency reduction reported last year. This work is progressing well and, in November 2014, T0 has successfully participated in the first beam injection from LHC after the Long Shutdown.

Nuclear reactions

Participants of this year "Christmas Run" at the Jyväskylä K139 cyclotron came from Kurchatov Institute in Moscow, JINR in Dubna, Radium Institute in St. Petersburg, Institute of Nuclear Physics in Almaty, and Scientific Research Institute of Experimental and Theoretical Physics of Kazakhstan. Unfortunately, our colleagues from Ukraine were not allowed to participate. Last year (2014) was very productive for the Nuclear Reactions group from JYFL. Twelve of our experimental papers were published as well as 4 theoretical papers based on the data from our measurements. The EXON 2014 conference had a special session devoted explicitly to the reaction studies carried out in collaboration with our team. Last but not least, we have helped to design a new beam line at the Warsaw Cyclotron for the study of molecular resonances with heavy ion beams.

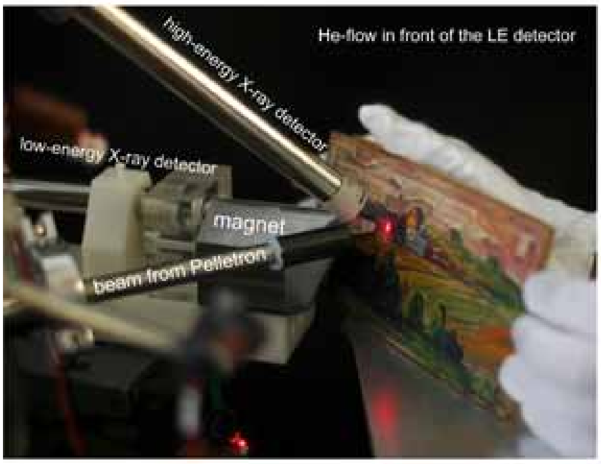
Accelerator-based Materials Physics

Timo Sajavaara

Timo Sajavaara, senior lecturer
Kai Arstila, senior researcher
Jari Malm, postdoctoral researcher
Mikko Laitinen, laboratory engineer
Jaakko Julin, doctoral student
Marko Käyhkö, doctoral student
Laura Mättö, doctoral student
Mari Napari, doctoral student
Viivi Hyppönen, MSc student
Sami Kinnunen, MSc student
Henri Kivistö, MSc student
Kasper Leppänen, MSc student
Juha-Pekka Pentikäinen, MSc student

After several years of continuous upgrades around the Pelletron accelerator, the main focus in 2014 was in the implementation of the developed tools and instrumentation for materials research. A new development in the laboratory was an external beam setup for PIXE. In 2015 the instrumental development will again be more active as the beam lines will be reoriented and a new negative He-ion source, developed by the ion source group, will be installed to replace the 30 year old Alphatross. The materials characterization possibilities will be greatly improved in 2015 as the Academy of Finland granted funding for a helium ion microscope (HIM). In this two-year joint project between biologists and physicists the Pelletron group will have a central role.

In 2014 a TEKES funded project Recenart was launched. The project combines the knowledge of art historians and material scientists in the studies of the origins of cultural heritage objects. Related to this project, several pilot studies involving, for instance, old Chinese ceramics, statues, coins and paintings were performed using the new external beam PIXE. The setup consists of high- and low-energy silicon drift detectors for measuring the X-rays above 0.5 keV energies. The vacuum window for the proton beam is 200 nm thick silicon nitride membrane.



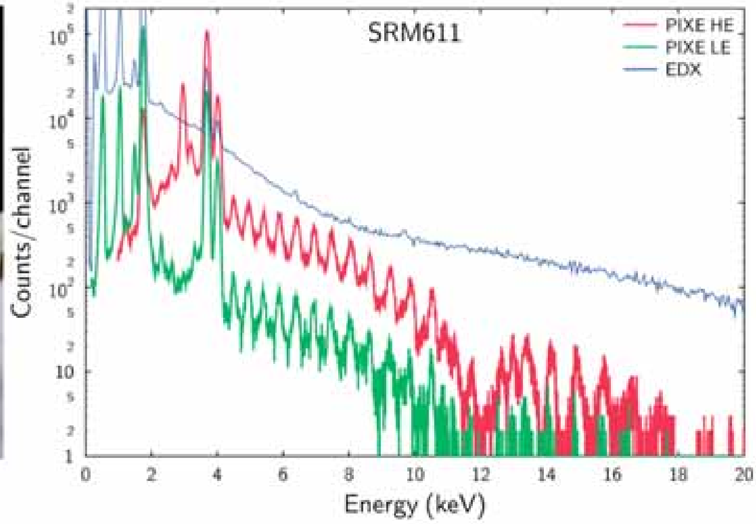


Fig. 2 (left) External beam PIXE setup with high and low-energy X-ray detectors. The studied painting is German origin from 1920s. (right) The high and low-energy PIXE energy spectra from NIST SRM611 reference sample 'Trace elements in glass' are compared to a spectrum measured with SEM-EDX at 30 keV electron energy.

Thin film research with the Beneq TFS200 atomic layer deposition (ALD) tool installed in the NSC cleanroom was a major activity of the group. The tool was commissioned in late 2013 and this was the first full and very active year of operation. The first all-Jyväskylä ALD study of low-temperature growth of ZnO film on PMMA was accepted for publication. The strength of having both own equipment for thin film deposition and powerful ion beam analysis has realized in fast optimization of demanding deposition processes. After initially focusing more towards the thermal-ALD, now also intensive depositions using the plasma-enhanced ALD are on going. In addition to the ion beam analysis, JYFL could also contribute to the film depositions in the highly productive MECHALD-project, which ended in 2014.

The ion beam analysis development focused on basic understanding of the physics behind the performance of the time-of-flight elastic recoil detection analysis (TOF-ERDA) telescope and the transition edge sensor (TES) used for PIXE. Over the two full years of operation, the gas ionization chamber (GIC) with 200 nm Si_3N_4 vacuum window has worked faultless as a part of the TOF-ERDA telescope. The good timing resolution of about 150 ps combined with the high energy resolution of the GIC detector result in excellent mass resolution in the TOF-

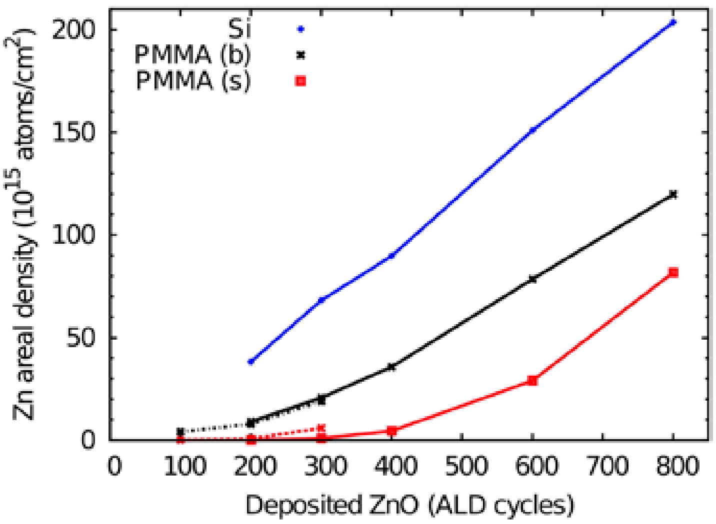


Fig. 3 Areal density of Zn in ZnO films on Si, bulk (b) PMMA, and spin coated (s) PMMA substrates measured with Rutherford backscattering spectrometry as a function of ZnO ALD cycles. The solid and dashed lines represent the growth on the films deposited using 0.15 and 0.30 s precursor pulses, respectively.

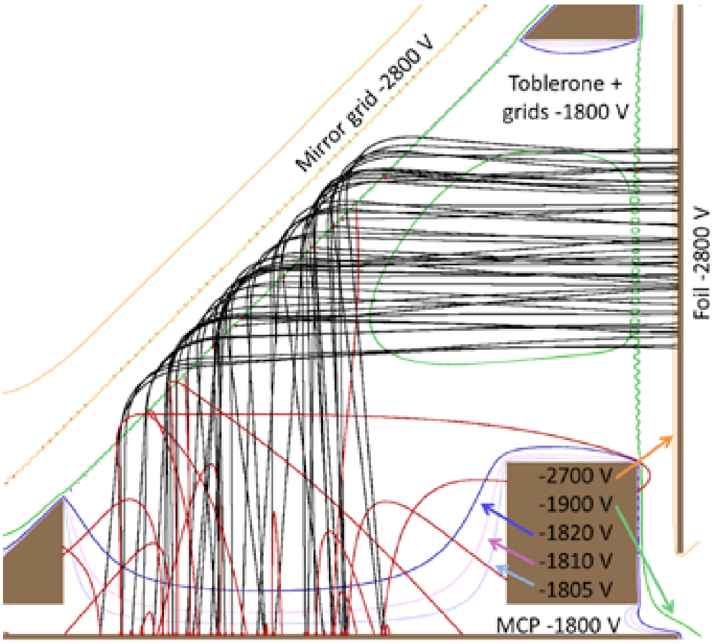


Fig. 4 Electron paths in the second timing gate of our TOF-ERDA telescope simulated using the SIMION software. Some of the electrons are scattered either from the microchannel plate (MCP) surface or from the grids, and generate a delayed timing signal.

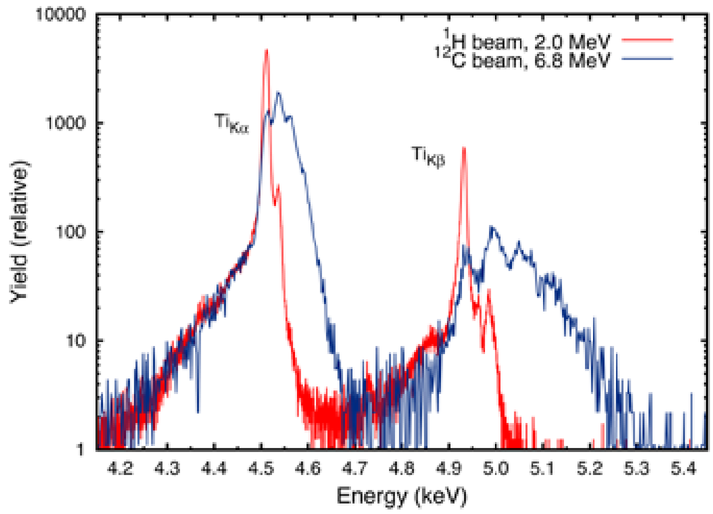


Fig. 5 Characteristic X-ray peaks of Ti from Ti metal thin film sample measured using 2 MeV ^{1}H and 6.8 MeV ^{12}C beams.

ERDA measurements. The JYFL-type GIC was also installed at Imec, Belgium, as an upgrade to the TOF-telescope delivered a year earlier. In the TES-PIXE studies the main interest was to maximise the number of active pixels in the detector and to obtain a detection efficiency curve as a function of energy for the whole TES array. Chemical shifts and intensity changes of the characteristic X-ray peaks were studied for Ti metal and Ti compounds using proton and heavy ion beams.

Basic studies of interactions of energetic ions with matter continued as energy-loss straggling of 0.5–12 MeV/u ^{28}Si ions was measured in He, N_2, Ne, Ar and Kr gases in collaboration with RADEF group and international partners. A new JYFL driven research project 'High Resolution Study of Heavy Ion PIXE Data with a TES Detector and MC Simulations for MeV-SIMS Technique' which forms part of the IAEA Coordinated Research Project 'F11019' entitled 'Development of molecular concentration mapping techniques using MeV focussed ion beams' started in 2014.

INDUSTRIAL APPLICATIONS

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The use of the beam time

The usage of the beam time was 1315 hours and the distribution to different categories is shown in Fig. 1. The revenue was at about the same level as in previous years being 758 k€ in 2014.

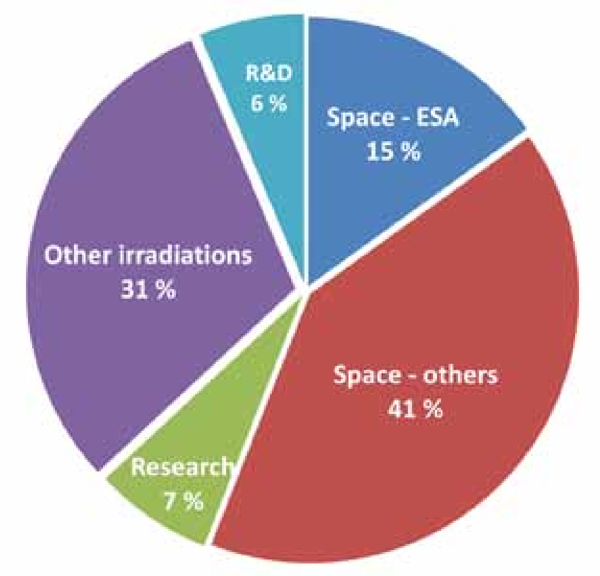

Fig. 1. Distribution of beam time usage in RADEF; Space-ESA = space component tests for ESA, Space-others = space component tests for satellite industry, Other irradiations = membrane irradiations etc.., R&D = facility development, upgrades etc…, Research = research based on PAC proposals.

RADEF continued as ESA's external European Component Irradiation Facility (ECIF) for serving European satellite industry. In total 41 campaigns for 14 companies or institutes and for two universities were performed. Different users are summarized in Table 1.

The contract with ESA was renewed for the following two years: "Utilization of the High Energy Heavy Ion Test Facility (RADEF) at the University of Jyväskylä (JYFL) for Component Radiation Studies 2014-2015" (ESA Contract No. 4000111630/ 14/NL/PA).

Table 1. Companies, institutes and universities, which performed tests at RADEF in 2014.

Aalto University, Helsinki
AIRBUS, Elancourt, France
ARQUIMEA, Madrid, Spain
ASRO, Turku, Finland
ATMEL, Nantes, France
CEA, Gif-sur-Yvette, France
DLR, German Aerospace Center, Wessling, Germany
ESA, Noordwijk, The Netherlands
HIREX Engineering, Toulouse, France
INTA, Madrid, Spain
OXYPHEN, Wetzikon, Switzerland
RUAG Sweden, Gothenburg
STUK, Radiation Safety Authority of Finland, Helsinki
SURREY Satellite, Guildford, UK
TRAD, Labege, France
University of Montpellier 2, France

SkyFlash (262890 EU-FP7) project was finalized by March and its aim to develop a RadHard by design (RHBD) methodology for non-volatile flash memories was successful. Other partners were from Cyprus, Israel, Italy, Spain and Sweden (http://www.skyflash.eu/).

The SkyFlash collaboration also spawned a new EU project: "Radiation Hard Resistive Random-Access Memory (R2RAM)", where the coordinator is IHP GmbH - Leibniz-Institut of Innovations for High Performance Microelectronics (Germany). In addition to RADEF, the other beneficiaries are RedCat Devices (Italy) and IUNET - Italian Universities Nano-Electronics Team, which composes of seven universities. The project starts at the beginning of 2015 and it was the first approved HORIZON-2020 project in our university. The basic goal is to give a methodology for the development of a new rad-hard nonvolatile RRAM memory with high-performance features like good retention, re-programmability and cycling, and realize a prototype (1Mbit RRAM memory) in order to validate the approach.

A low energy proton facility was constructed in the RADEF beam line. A novel method for energy selection with a very high resolution down to below 500 keV was developed and the first experiment was performed by using two memory test vehicles fabricated with 28 nm technology.

The collaboration with University of Montpellier 2 continued by developing dynamic test methods for COTS SRAMs. These methods were evaluated by heavy ion and atmospheric-like neutron irradiation of two COTS SRAMs of 90 nm and 65 nm technology.

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

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Rare weak decays and nuclear structure

Rare weak decay processes are driven by (a) tiny decay energies (Q values), (b) large differences in spins of the initial and final states of decay and (c) decay channels of second order in weak interactions [1,2]. A parade example of the category (a) is the decay of ^{115}In [3] with the smallest known Q value of nuclear decays. Such decays can, in principle, be used for detection of the neutrino mass [1,2]. The decays of ^{48}Ca [4] and ^{50}V [5] belong to the category (b). There the long half-lives result from the 4th- and 6th-forbidden beta-decay transitions between the ground and excited states. The case for ^{48}Ca is demonstrated in Figure 1. The category (c) spans various modes of double beta decays [1,2] and these are addressed below.

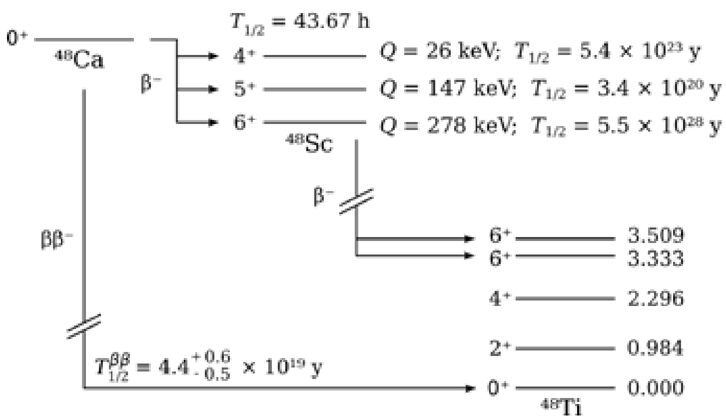

Fig. 1: Single and double beta decay of ^{48}Ca. The decay rate is dominated by the direct double beta transition to the ground state of ^{48}Ti.

Theoretical description of two-neutrino and neutrinoless double beta decays

The question whether neutrinos are Majorana or Dirac particles, and of what are their masses and phases in the mixing matrix remains one of the most intriguing problems in physics today. A direct measurement of the average mass can be obtained from the observation of the neutrinoless double beta decay or competing modes. Recently, we have performed systematic evaluation of phase-space factors and nuclear matrix elements for all processes of interest [6], including resonant neutrinoless double electron capture [7], which is a process that can only occur when the energy of the initial state matches precisely that of the final state. These studies also offer information about single electron and summed electron spectra, as well as angular correlations [8]. These are elements that are crucial for planning future experiments and essential for interpretation of the current experimental results. Lately, a comprehensive calculation of the nuclear matrix elements of the neutrinoless double beta decay, mediated by light or heavy Majorana neutrinos, was carried out in [9]. Furthermore, the NEMO (Neutrino Ettore Majorana Observatory) collaboration has performed up-to-date measurements for the double-beta-decay modes of ^{100}Mo [10,11].

Isovector spin monopole excitations and Gamow-Teller strength functions

Excitation of the isovector spin monopole (IVSM) 1^+ mode can pollute experimental data on Gamow-Teller strength functions in charge-exchange reactions. Since these strength functions can be used in surveys of the contributions to the double-beta nuclear matrix elements false conclusions about these contributions could be drawn due to the IVSM contamination. We have examined theoretically the possible IVSM contamination in the Gamow-Teller strength functions generated by the (p,n) and (n,p) charge-exchange reactions in several medium-heavy and heavy nuclear systems [12].

Effective value of the axial-vector coupling constant

The value of the weak axial-vector coupling constant g_A plays an important role in beta and especially in double beta decays. Thus, it is of utmost importance to have an idea of the effective value of this constant. For this purpose, in [13] we have studied the effective renormalization of g_A within the framework of the quasiparticle random-phase approximation for Gamow-Teller beta decays in triplets of isobaric nuclei. A slightly modified approach has been adopted in [14] where extensive systematics of similar transitions was analyzed within a more schematic random-phase approximation model.

Contributions from the 1^+ and 2^- states are conspicuous for the nuclear matrix elements related to neutrinoless double beta decays. It is thus of paramount importance to study the quenching effects of these contributions through the renormalization of g_A. It has been shown very recently [15] that a similar quenching as for the Gamow-Teller transitions applies also to the first-forbidden unique 2^- to 0^+ transitions. Also, the studies [6] and [7] address the quenching issues in double-beta decays from a different theory formalism point of view.

Studies of collectivity, symmetries and quantum phase transitions in nuclei

During the past few decades, major developments have been seen in the experimental study of nuclear structural evolution. Recently, we have studied the sudden increase of collectivity in neutron-rich nuclei when approaching the neutron number N=40 by investigating the development of collectivity along the chromium and iron isotopic chains [16].

The calculations were performed within two different theoretical perspectives, and compared with the available experimental data. The onset of collectivity was studied through nuclear quantities and observables that suggest differences in the nuclear structure of Cr and Fe isotopic chains. Furthermore, a shape transition from a spherical vibrator to a gamma-soft rotor was predicted, with the nucleus ^{58}Cr standing at the critical point.

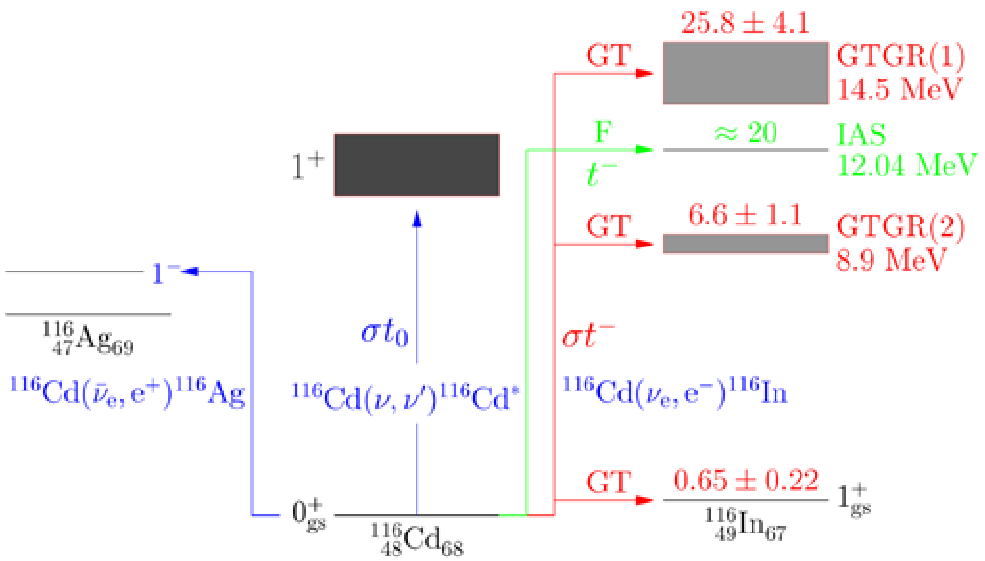

Fig. 2: Neutral-current and charged-current scatterings off ^{116}Cd. The CC electron-neutrino scattering probes the isospin properties of states in ^{116}In.

Neutrino-nucleus scattering at supernova energies

Accurate estimates of nuclear responses to supernova neutrinos are needed for studies of neutrino properties and modeling of supernovae and nucleosynthesis of heavy elements. The related scattering events can be classified to neutral-current (NC) and charged-current (CC) processes.

We have recently studied these processes for the stable cadmium isotopes in [17]. Similar calculations have just been finalized for the ^{136}Xe nuclear target in [18]. We have also performed a nuclear-structure study of the ^{116}Cd nucleus by using 10 different Skyrme interactions in collaboration with the FIDIPRO group [19]. In this study we concentrate on the spin and spin-isospin properties of charge-changing transitions to states in ^{116}In, and on the charged-current neutrino and anti-neutrino scattering properties to states in ^{116}In and ^{116}Ag. A schematic of the isospin properties and the NC and CC scatterings is shown in Figure 2.

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Experimental Nanophysics and Nanotechnology

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Thermal properties of nanostructures and radiation detector development

Ilari Maasilta

The main research direction of the thermal nanostructure research team is to understand and engineer energy flow mechanisms in low-dimensional geometries, develop thermometric techniques for the study of thermal phenomena and use the obtained physical know-how in the development of ultrasensitive radiation sensors for applications (bolometry). A few highlights of the activity in 2014:

We have demonstrated for the first time that it is possible to change the thermal conductance of a material by tuning the wave-like properties of heat flow, by orders of magnitude, using nanostructuring. The results were published in the journal Nature Communications [1], and later reviewed in an invited review in the APS membership journal Physics Today [2]. Theoretically it has been known long that heat can be thought as a collection of the motion of many different kinds of quantized waves, or phonons. However, the wave nature of phonons has never before been used to control heat transport. This was achieved by fabricating a nanoscale mesh structure (or a so called phononic crystal), Fig. 1, whose period is of the same order as the wavelength of the phonons that carry heat, about a micrometer in this case.

Then the phonon waves interact strongly with the phononic crystal structure and change their speed by almost an order of magnitude. Because the waves move much more slowly, the thermal conductance is strongly reduced. The experiment was performed near absolute zero of temperature in order to increase the wavelength of the thermal phonons to a length scale, where fabrication using common nanofabricating tools is possible.

In the future, the demonstrated concept can possibly be used in many ways. At low temperatures, there are direct applications in the development of ultrasensitive radiation detectors, where the control of heat transport is essential. This kind of applied research is also conducted in our group. In addition, if the demonstrated concept can be made to work at room temperature range, it might have impact on the development of future more efficient thermoelectric devices, which can be harnessed to generate electricity from waste heat.

In addition to phononic crystals, we also theoretically showed that other methods, such as rough surfaces of insulators (Casimir limit) can be very effective in reducing the thermal conductance is sub-Kelvin temperature range [3].

The work in the field of novel high-performance superconductor material and device development has also continued, by successfully fabricating normal-metal-insulator-superconductor (NIS) tunnel junction devices from superconducting tantalum nitride (TaN) films grown by infrared pulsed laser deposition [4], with critical temperatures up to 5 K. This is the first time that superconducting TaN was used in tunnel junction devices. We demonstrated good performance in thermometry, and some promise for applications in microrefrigeration.

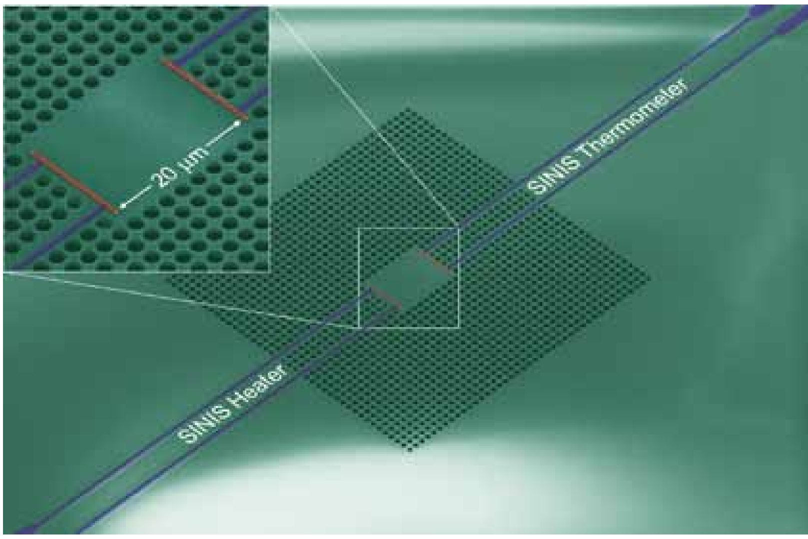

Fig. 1. Scanning electron micrograph of a phononic crystal structure used to control heat flow.

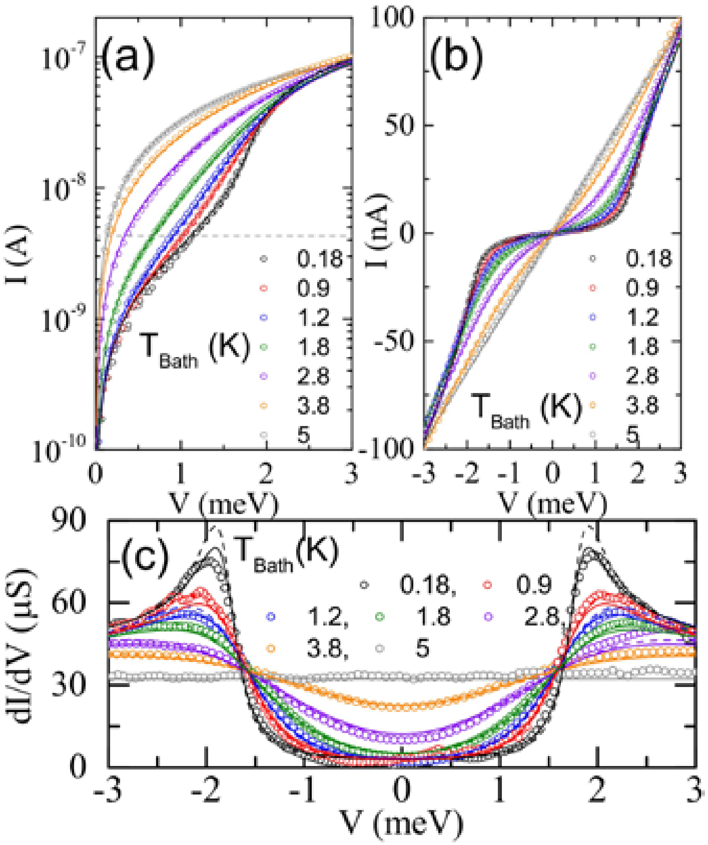

Fig. 2. Temperature dependence of the current-voltage characteristics of a double junction Cu-AlOx-Al-TaNx NIS device at various temperatures plotted in (a) log-linear and (b) linear scale. (c) Differential conductance characteristics corresponding to plots in (a).

Fig.3. SEM image of a structure fabricated with the 3D lithography tool at NSC.

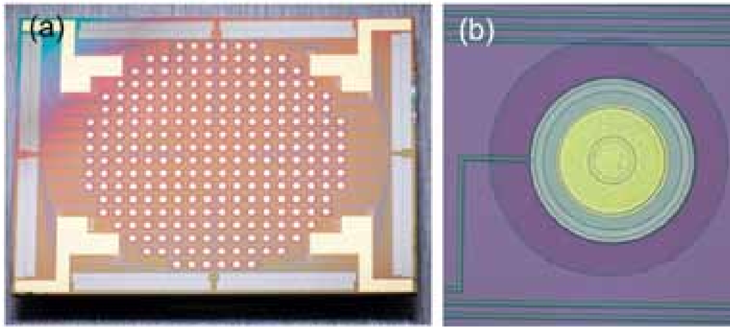

Fig. 4. Fig. 1. (a) 256 pixel X-ray TES array chip. The size of the chip is 15 mm × 19 mm. (b) Micrograph of a circular shaped single pixel. The center area is covered by a Au absorber that contacts the Mo/TiW/Cu TES film in the inner circle area. The leads are superconducting Nb, and the device sits on a circular SiN membrane (diameter 500 µm).

We have also continued the development of direct lithography of complex 3D structures, using the new 3D laser-lithography tool capable of three-dimensional patterning down to ~100 nm scales. The tool, so far unique in Finland, was installed in 2013 in the NSC clean room, and the investment was made possible by the EU regional funds (EAKR). Fig. 3 shows an example of a 3D microstructure fabricated at NSC clean room. In addition to 3D patterning, we also developed 2D lithography with the device, achieving for example the fabrication of 2 cm long, 400 nm wide metal nanowires, a task that has direct relevance for industrial applications in nanoelectronics.

The development of ultrasensitive superconducting transition-edge sensor (TES) X-ray detectors and their applications has also continued strong. In 2014, significant progress was made in the fabrication of novel large 256 pixel Mo/TiW/Cu trilayer TES arrays in collaboration with VTT Micronova [5] in a TEKES funded project (Fig. 4). In addition, we have continued the development of a unique new materials analysis tool with TES detectors, using accelerator-based excitation of characteristic X-rays from materials (TES-PIXE), in collaboration with the accelerator-based materials physics group at JyU and NIST Boulder. The system was upgraded to accommodate 160 pixels, allowing much faster measurement times and better statistics for spectroscopy. The instrument is also used in a new TEKES project Recenart, which advances scientific methods for the study of art, such as authentication. The TES detectors allow us to see much smaller impurity concentrations and obtain chemical information in some cases, in addition to the identification of elements and their abundance.

Molecular Technology

Markus Ahlskog

The Molecular Technology group studies electronic and mechanical properties of carbon nanotubes (CNTs) and devices that are based on them.

In a gate-controlled conduction measurement, a strong gap in the current-gate voltage (V_G) characteristics, the so called transport gap, is evident in Single walled carbon nanotubes (SWNT) already at room temperature. In stark contrast, in Multiwalled carbon nanotubes (MWNT) transport gaps have usually not been reported, and in particular not systematically studied. Those transport and other measurements on single MWNT's that have been reported in the literature have usually been performed on tubes with diameter (D) ≥ 10 nm, in some cases exceeding 20 nm. This fact has left the experimental studies on SWNT's (D < 3 nm) and MWNT's somewhat disconnected from each other. Our group has done fundamental work on the transport properties of MWNTs by undertaking a systematic experimental study on the D- and length (L) dependence of MWNTs, covering in diameter the range 2 - 20 nm, and especially the range D < 10 nm, which has largely been neglected before. Our results that are the only systematic study of the size effects in MWNT's. We find in most of the D < 10 nm tubes a transport gap (Fig. 5) which depends on diameter and length. A minority of these MWNTs are strictly metallic. The transport gap is seen to be quantitatively determined by a D-dependent bandgap of the outer layer, and length dependent localization of charge carriers. The bandgap of semiconducting MWNTs is estimated to be smaller than that extrapolated from the conventional expression applicable to semiconducting single wall carbon nanotubes. The results constitute the first systematical study on size dependent transport and especially of semiconductivity in MWNTs.

CNT's are considered as the active elements in chemical and biochemical sensor devices. For this purpose, the effects of protein adsorption on the conductance have been measured in single CNT devices [6]. In this context, nearly always

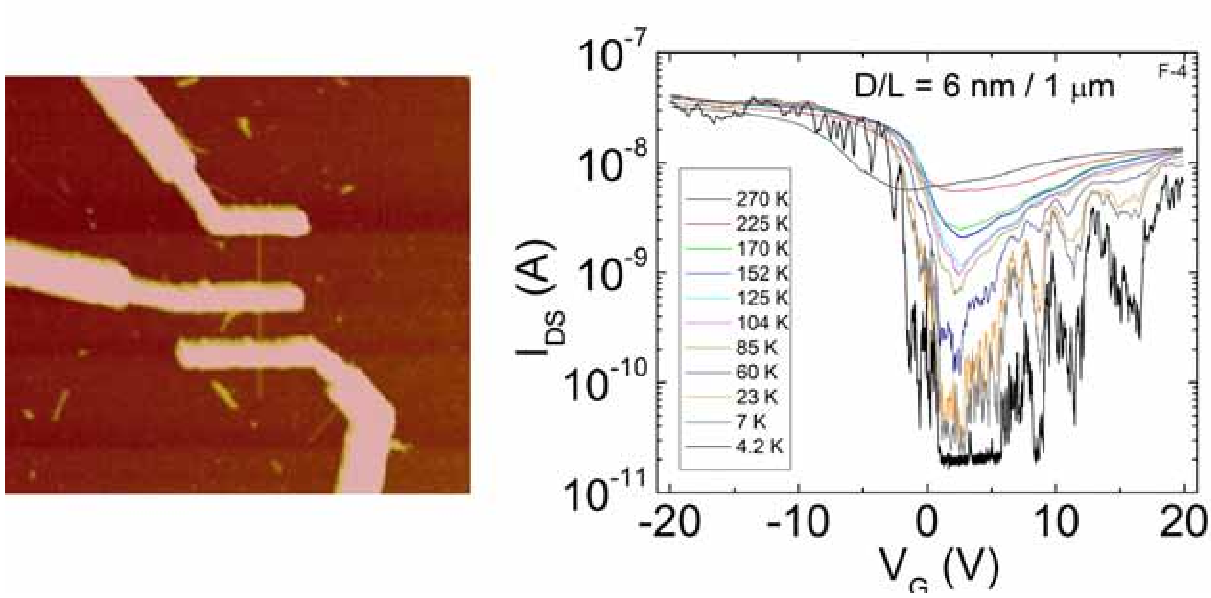

Fig. 5 a) AFM image of typical MWNT device. b) Gate voltage (V_G) dependent conduction at different temperatures of a semiconducting MWNT.

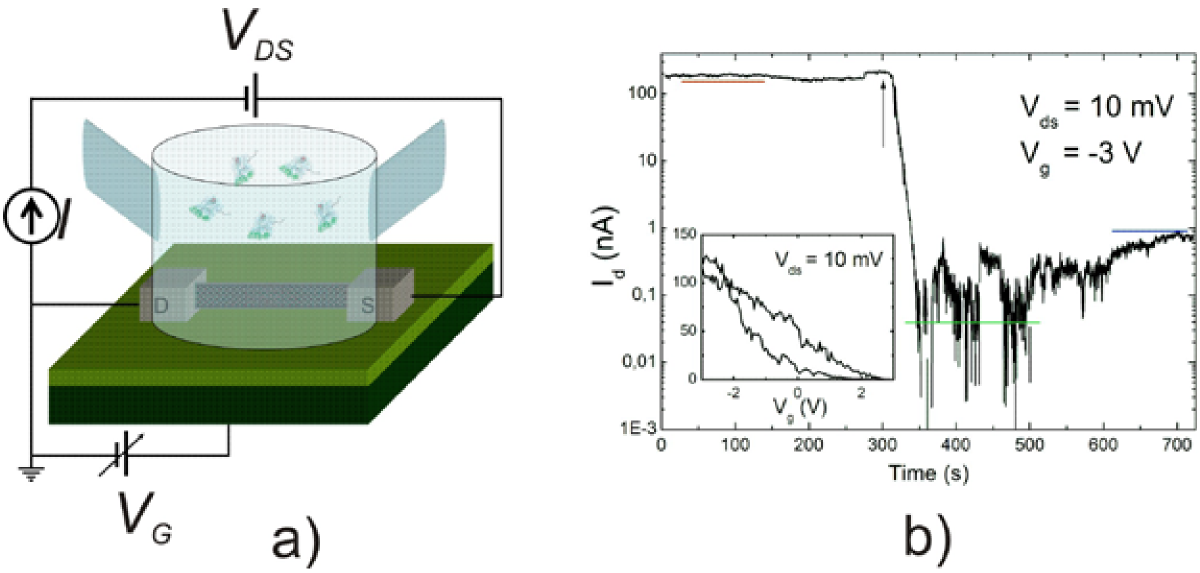

Fig. 6. a) A schematic picture of the measurement setup, with a SWNT-FET device having a flow cell on top while HFBI protein molecules are injected. b) Time dependence measurement with constant V_G, showing the change as HFBI is mixed into the buffer solution.

the CNT is a semiconducting SWNT forming the active channel in a field effect transistor (SWNT-FET). In this work, CNTs have been for the first time employed for electronic detection of hydrophobin (HFBI) protein molecules. HFBI is a surface active protein having both hydrophobic and hydrophilic functional groups which has previously been used for CNT functionalization and solubilization. Our result indicates a decrease in device conductance after exposure to ~ 100 nM NCysHFBI in phosphate buffer solution. This decrease could be drastic when measured in situ in solution, see Fig. 6.

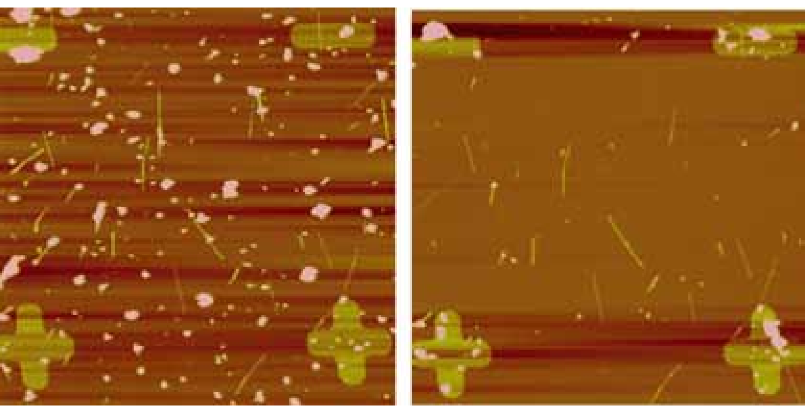

Fig. 7. AFM images (10 mm) show same location before and after purification treatment.

A major difficulty for experimental research on individual MWNT's is the issue of sample quality. Arc-discharge synthesized MWNT's (AD-MWNT) are typically of high quality but the macroscopic material contains excessively amorphous carbon. AD-MWNT material has been purified with different methods, but all of these have serious problems in that the MWNT quality suffer from the purification steps. We have made important progress in the technique of MWNT purification. The method consists of dispersing the raw MWNT material on a flat surface, e.g. silicon. Then a water surface interface is moved across, whereby one part, which is removed by the water surface, contains some MWNTs and nearly all the impurities. The other part consists of the highly purified and practically intact MWNT's (Figure 7).

Molecular Electronics and Plasmonics

Jussi Toppari

Group studies nanoelectronics and plasmonics, especially phenomena related to molecules. The main interests are self-assembled DNA structures, their trapping and electrical characterization [10], as well as utilization of surface plasmon polaritons in nanophotonics and coupling of them with molecules [11].

DNA origami, especially the recently developed 3D DNA origami, is a widely used method for fabrication of custom-shaped nanostructures. However, to further utilize these versatile nanoarchitectures one needs to be able to manipulate them within a very high precision. We have demonstrated guiding and anchoring of individual 3D DNA origami structuress with different design between nanoscale electrodes on a chip by dielectrophoretic (DEP) trapping [10]. The results show that the DEP technique can be exploited in assembling of complex origami geometries. More interestingly, we found that trapping of a brick-like DNA origami with densely-packed thiol-linkers on both ends, tended to induce an etched “nanocanyon” in the SiO_2 substrate precisely at the location of the trapped origami as shown in figure 8. This finding has great potential to be used in patterning of nanostructures.

Doped graphene can support unusual plasmons with an extreme two-dimensional confinement. Resonant plasmon modes appearing in nanoscale graphene structures depend on size and shape of the structures. However, as a special feature of graphene, these plasmons can be tuned with electrical gating and/or chemical doping also. For studying coupling between vibrational molecular excitations and graphene plasmons, we have fabricated nanosized discs by using

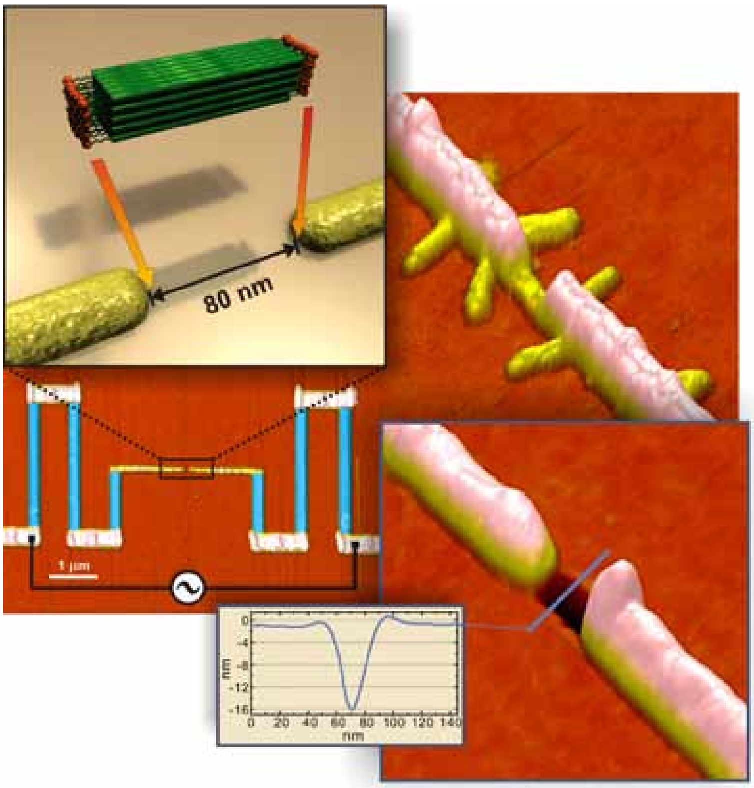

Fig. 8: Top-left float: schematics of guiding and anchoring of DNA origami with thiol-linkers. AFM image of a single brick-like structure trapped between gold electrodes is shown in the back-image as well as the implemented electrode geometry. The blue areas are Ti-resistors used for limiting the electrical current. Low-right float: AFM image as well as the cross-section of the “nanocanyon” in SiO_2 substrate between the electrodes after trapping of the brick-like DNA origami.

polymer balls as a mask for etching (Fig. 9). The plasmons in graphene discs of similar size can be excited with infrared (~10 µm) photons.

Transparent conducting polymers have shown high performance for applications in electronics, and their solution-processability enables low-cost printing techniques. For optoelectronics the optical properties of films produced with printing techniques are relevant, but the common ellipsometry is not suitable for characterization of these relatively uneven and optically absorbing and anisotropic films. In these cases, total

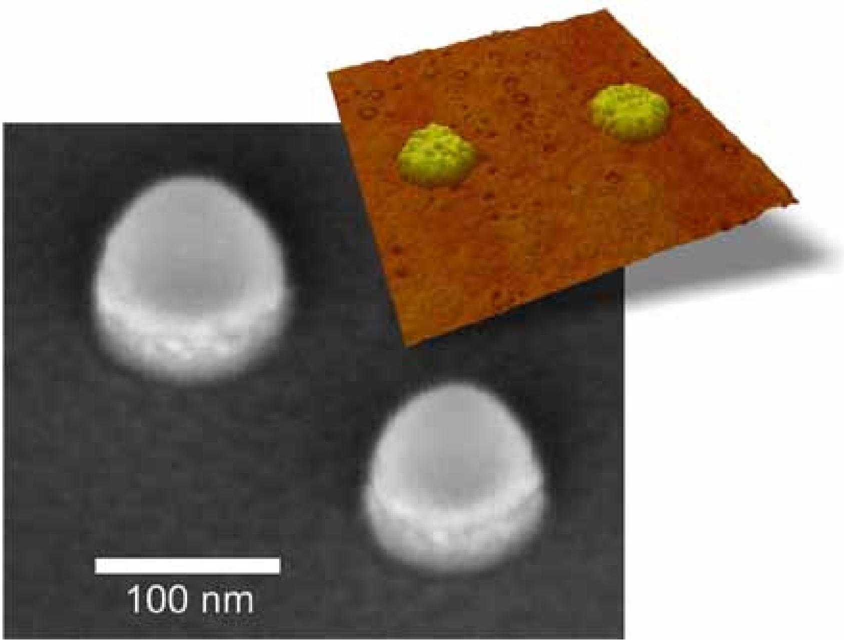

Fig. 9: Scanning electron micrograph of 50 nm thick gold discs made with modified hole-mask colloidal lithography. The discs are topped with slightly molten balls of polystyrene, diameter of 100 nm. The inset on top shows an AFM image of two graphene disks fabricated with the same method. Image is ~1 mm width and has been taken before the final cleaning of polymer leftovers.

internal reflection spectroscopy can be used, and the optical anisotropy can be detected by comparing differences in reflection with different polarizations. We have studied polymer thin films of transparent conducting polymer poly(3,4-ethylene dioxythiophene):poly(styrene sulfonate) (PEDOT:PSS), and investigated the effect of embedded graphene flakes, used as a conductivity-enhancing additive [12].

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Computational nanosciences

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Diagrammatic perturbation theory for positive spectral functions

Robert van Leeuwen

Electron-electron interactions have a large effect on the structure of photo-absorption and photo-emission spectra of molecules and solids. Commonly used many-body techniques, such as the GW approximation, are successful in describing plasmon excitations in solids but important qualitative features are lacking, notably the description of plasmon satellites. The theoretical description of such features requires the study of vertex corrections in diagrammatic many-body perturbation theory. It is, however, a longstanding problem that the simplest diagrammatic corrections lead to negative spectral functions, thereby violating the probability interpretation of spectra. We developed a method (1) which cures the problem of negative spectral functions which arises from a straightforward inclusion of vertex diagrams beyond the GW approximation. Our approach consists of a two-step procedure: We first express the approximate many-body self-energy as a product of half-diagrams and then identify the minimal number of half-diagrams to add in order to form a perfect square. The resulting self-energy is an unconventional sum of self-energy diagrams in which the internal lines of half a diagram are time-ordered Green's functions, whereas those of the other half are anti-time-ordered Green's functions, and the lines joining the two halves are either lesser or greater Green's functions (Fig. 2).

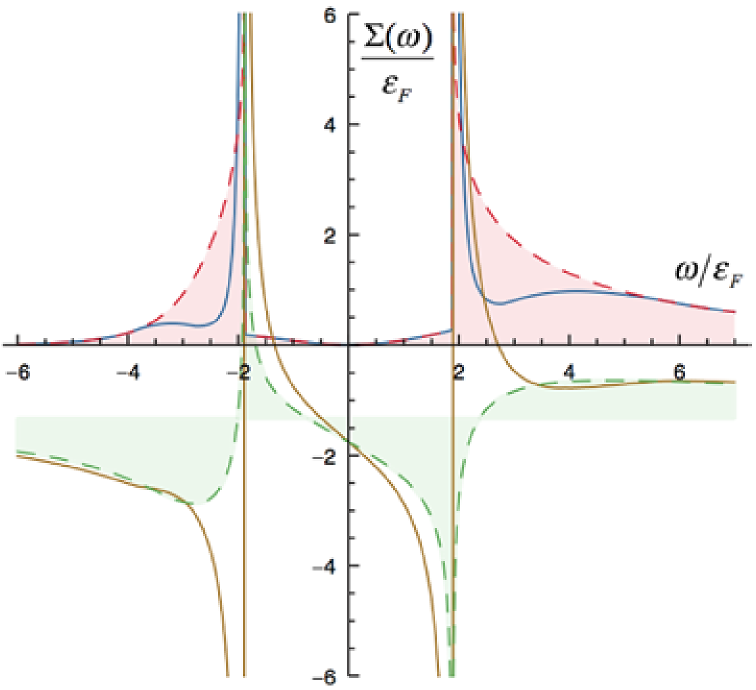

Fig.2. The real and imaginary part of the retarded self-energy of the 3D electron gas calculated with vertex corrections, using the cutting procedure for Feynman graphs.

Thermoelectric effects and spin injection into superconductors

Tero Heikkilä

We have shown that spin-filter interfaces to superconductors carrying a Zeeman field produces a huge thermoelectric effect (2), where temperature difference across the interface results into a large charge current. We have also explored how a related effect in superconducting Josephson junctions produces a large thermophase from a temperature difference (3). Besides, we have studied the nonequilibrium state formed inside the superconductor as a result of the charge, spin, and energy injection from such an interface (4,5). The behavior of this state depends on the relative orientation of the magnetization in the spin filter and the Zeeman field inside the superconductor, and on the role of spin and energy relaxation. For non-collinear magnetization and Zeeman field, the latter leads to a rotation of the injected spin. We show how superconductivity affects this spin Hanle effect (4). The effects depend on the dominating spin relaxation mechanism, and superconductivity can either suppress or enhance both the relaxation and the oscillations of the signal. This effect can hence be used for characterizing the spin relaxation mechanisms beyond their mere strength as is the case in normal metals. On the other hand, we have shown that in the presence of a collinear Zeeman field, the nonequilibrium heating of the superconductor can lead to a spin accumulation (5). This finding explains recent experiments claiming anomalously long spin relaxation in superconductors.

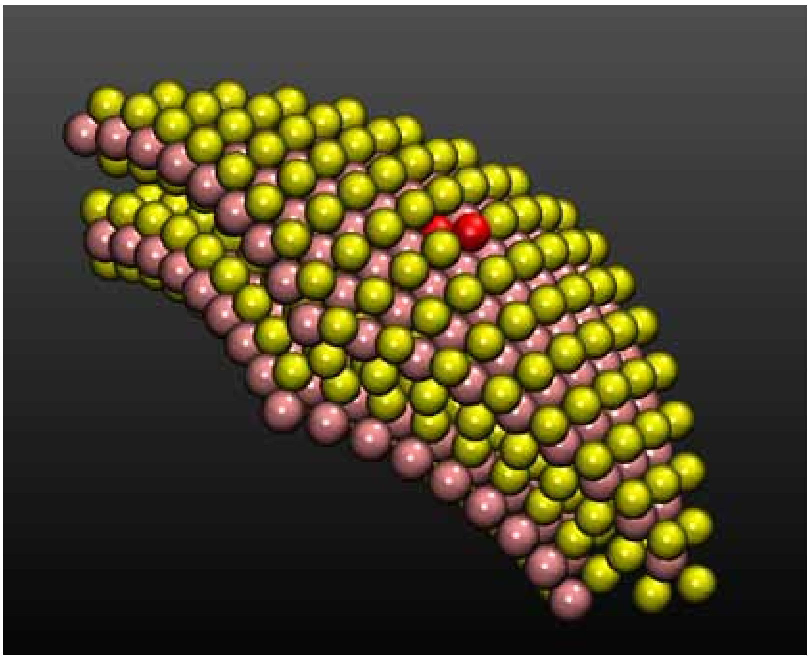

Fig. 3. When applied with an MoS_2 bilayer, curvature breaks the layer degeneracy and localizes electronic states to either the layer under tensile or compressive strain. The electronic structure simulations used revised periodic boundary conditions to model local curvature, using a simulation cell containing only six atoms (the red spheres).

Bending breaks layer degeneracy in bilayer transition metal dichalcogenides

Pekka Koskinen

Monolayer transition-metal dichalcogenides (TMDCs) display valley-selective circular dichroism due to the presence of time-reversal symmetry and the absence of inversion symmetry, making them promising candidates for valleytronics. In contrast, in bilayer TMDCs both symmetries are present and these desirable valley-selective properties are lost. In a recent work, we used density-functional tight-binding electronic structure simulations and revised periodic boundary conditions (Fig. 3.) to show that bending of bi- and multilayer MoS_2 sheets breaks band degeneracies and localizes states on separate layers due to bending-induced strain gradients across the sheets (6,7). As a corollary from the observation, we were able to propose a strategy for employing bending deformations in bilayer TMDCs as a simple yet effective means of dynamically and reversibly tuning their band gaps while simultaneously tuning valley-selective physics (7).

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Soft Condensed Matter and Statistical Physics

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Jarno Alaraudanjoki, laboratory engineer

X-ray tomography laboratory.

The primary research facility within the X-ray Tomography Laboratory includes three up-to-date tomographic scanners including two microtomographs and a nanotomograph. Together, these devices are capable of non-intrusive three-dimensional imaging of the internal structure of heterogeneous materials

with resolution ranging from 40 µm up to 50 nm. The laboratory is equipped with comprehensive set of instruments for sample preparation and manipulation, including a novel laser system for accurate cutting of small samples, a sample holder that allows mechanical straining of the sample and a device for controlling the air humidity inside the sample chamber during imaging. In 2014, two new sample holder stages,

Figure 1. Xradia Multiscale X-ray tomographic facility. A microtomograph (right) and a nanotomograph capable of 50 nm resolution (left).

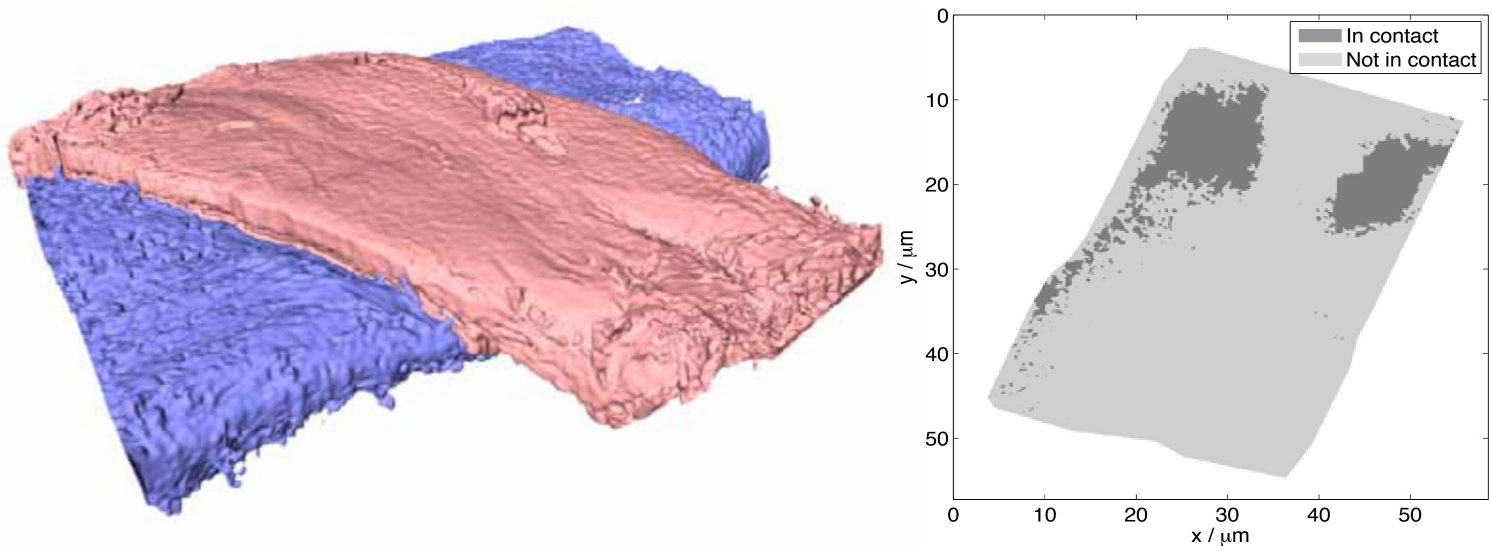


Figure 2. (a) A nanotomographic image of a single contact between two wood fibres. Imaging resolution 150 nm. (b) The actual bonded area in the fibre contact region as analysed from the tomographic image (light gray color).

namely a cooling stage and a heating stage, were acquired by which the sample temperature can be controlled during tomographic imaging with 0.5°C accuracy in the range -10°C to +85°C. The laboratory is also equipped with specific devices for measuring various transport properties of materials. The entire facility had a high utilization rate in basic and applied research related e.g. to development of novel organic materials, and to analysis of structural properties of minerals and biological materials such as cells (soft X-ray tomography at LBNL), bone and bentonite clay.

Image analysis

X-ray tomographic images typically contain large amounts of detailed information about the three dimensional structure of heterogeneous materials, and can be used to obtain diverse statistical and physical properties of those materials. These images also facilitate numerical simulations of the e.g. mechanical and transport phenomena based on the true microscopic structure of actual material samples. In order to fully utilize the information contained in the tomographic images, effective image processing and image analysis methods are necessary. The group has devoted a substantial effort in developing such methods for a wide variety of applications.

Denoising and segmentation (separation and recognition of various material components or internal structures of the sample,) are important part of most tomographic analyses. We have exhaustively tested and developed new denoising algorithms suitable for 3D tomographic data. In addition to general segmentation algorithms based on gray-scale value, methods for recognizing structural components based on their shape have been developed. These methods have been used in analysing various geometrical and statistical properties of porous and fibrous materials such as paper, cardboard, composites, rock, bentonite, bone, wood, various membranes, as well as fibre length- and diameter distributions [1]. The methods have been utilized e.g. in analyzing and improving the injection moulding process of novel biocomposites, quantification

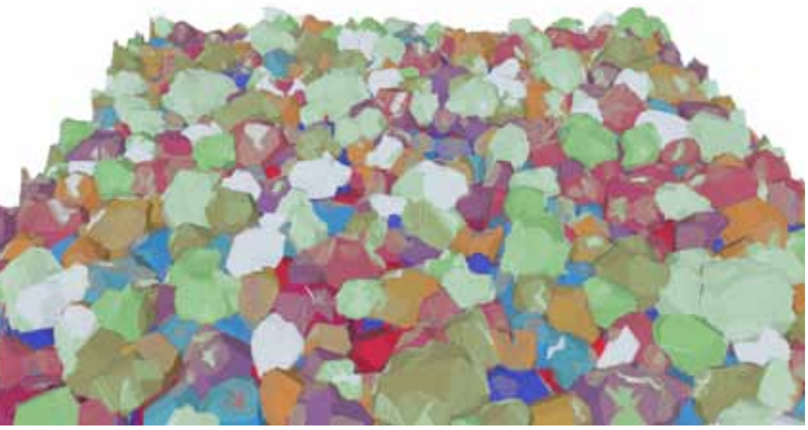


Figure 3. 3D visualization of segmentation of sand grains. Each grain is separated from other grains and labelled with a random colour.

and improving a method for friction welding of wood, and to find the relative contact area of two wood fibres.

Other examples of image analysis method development include those for analysing slow temporal changes of the 3D deformation state and density distribution in a material sample using time series tomographic imaging (4D imaging), a novel imaging methods for detecting counterfeit stamps and banknotes, and a semi-automatic method for registration of nanotomographic X-ray projection images.

Heterogeneous materials

The group has participated in several domestic and international research projects in basic and applied material physics. The active research topics include statistical characteristics of random packings of elongated particles, properties of biological materials such as growing soft tissue, structural and acoustic properties of bone and their probing by ultrasound, structural analysis related to development of new biocomposites, and fracture dynamics of brittle materials such as ice.

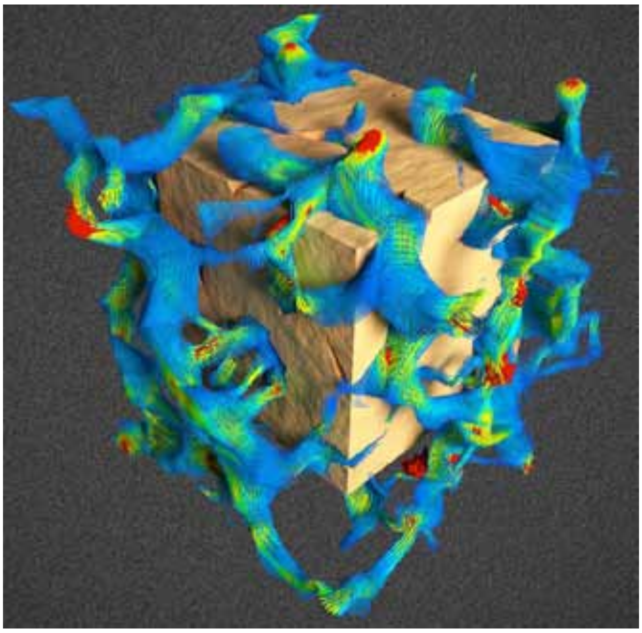
In the last problem results were applied to analysis of glazier dynamics. To this end a discrete element method and the related simulation code were developed in cooperation with CSC-IT Centre for Science. The model included both brittle and viscous behaviour of the material, implemented using Newtonian dynamics to describe the time evolution of a large number of massive material particles connected by massless elastic units (beams) which were allowed to break and reform. This model was used to study properties of calving glaziers together with field observations. Properties such as fragment size distributions, waiting times between subsequent calving events and event size distributions were analysed. Results indicate that calving termini of glaziers and ice sheets behave as self-organized critical systems

Figure 4. A simulation result for Kronebreen terminus. A 100 m long Finnish ice breaker included for scale.

Figure 5. The prototype of a bone ultrasonometer based on a tunable photo-acoustic source which permits an efficient reduction of disturbances caused by the soft tissue covering the bone.

that readily flip between states of sub-critical advance and super-critical retreat in response to changing external conditions, an observation also supported by extensive experimental data.

Another example on applications is development of ultrasonic methods for improved assessment of osteoporosis [3]. In addition, a new clinically useful prototype of a bone ultrasonometer was designed and assembled (Figure 5).



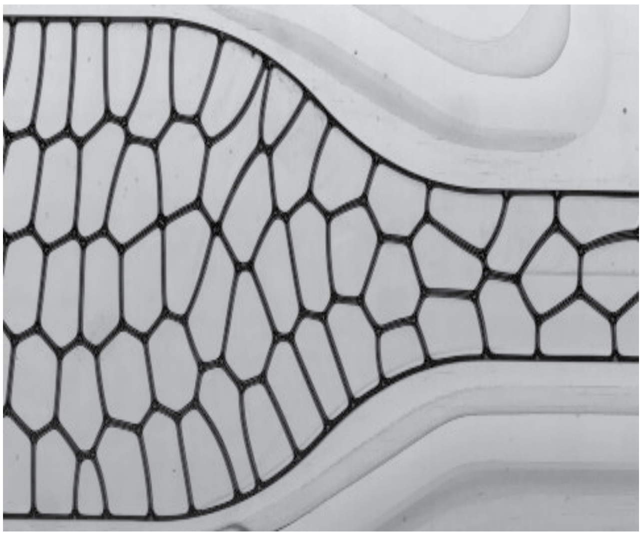


Figure 6. (a) A simulated flow field in a flow geometry given by a synthetic X-ray tomographic image of Fontainebleau sandstone sample. (b) Instantaneous configuration of a foam flowing through a channel constriction solved by the DySMaL foam model developed by the group.

Multiphase flow dynamics and Transport phenomena

The reserch activities in complex flows and transport in heterogeneous materials includes modelling, experiments and development of numerical methods for a variety of applications. The research related to nuclear waste deposition and safety assessment involves particle transport and retention in bed-rock fractures, hydromechanical behaviour of bentonite buffer and bentonite erosion studies. Through various collaborations, the group has also been involved in developing experimental methods for rheological and boundary layer flow properties of complex fluids and in tube transport of water vapour (with meteorological applications).

In numerical methods development has concentrated on high-performance numerical computing and flow dynamics of foams. Long-term interest has been on Lattice-Boltzmann method (LBM), which is a numerical simulation technique suitable for many complex flows and transport phenomena [4]. The group has been active in developing modelling and algorithms, discretization schemes, parallel processing and code optimization for LBM. The results were applied e.g. to multiphase flows, matrix diffusion, diffusive transport over thin membranes and fluid flow in porous media. The major advancements include extremely large-scale, parallel fluid flow simulations involving up to 16384^3 lattice nodes in a realistic application (see Figure 6). Furthermore, a Graphics Processing Unit (GPU) -implementation of the LBM was developed in collaboration with Åbo Akademi, reaching 1.8 PFLOPS with 16384 GPUs in a porous media fluid flow simulation.

Selected publications

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A Large Ion Collider Experiment - ALICE

Jan Rak, Sami Räsänen and Wladyslaw Trzaska

2014 was the last year of the long LHC shutdown and thus the main focus of the ALICE collaboration was on the preparation for the upcoming run 2. It includes the consolidation of existing detector subsystems and the installation of new detector components. ALICE has extended its capability to measure electromagnetic probes and high-p_T jets by installation of 8 new ElectroMagnetic CALorimeter (EMCAL) supermodules which complements an existing EMCAL in the back-to-back configuration. This improves significantly the physics scope of ALICE allowing to study the fully reconstructed di-jets produced in the hard scattering events. Our PhD student Jiří Král was a project leader of the fast trigger system during this upgrade.

Another important activity carried out in our group is the preparation for the second long shutdown in 2018. The main tracking detector of ALICE, the Time Projection Chamber (TPC), with the existing multi-wire proportional readout chambers is limited to about 500 Hz of maximum readout speed. This is certainly by far insufficient for the future LHC runs and thus the ALICE collaboration decided to replace all readout chambers by the Gas Electron Multiplier (GEM) based technology. Our postdoc Erik Brücken and PhD student Timo Hildén are involved in the production of about 150 m^2 of GEM foils. The main commitment of our group is to carry out the optical and electrical quality assurance studies of GEM foils in the HIP detector laboratory. Erik Brücken and Timo Hildén made a significant progress in the preparation for this massive GEM production and found a new method of gain mapping, based on optical scanning which can replace the expensive and time consuming electrical measurement. The promising correlation between the results of the optical scanning and the electrical measurement using a radioactive source is shown on Fig. 1. This development is part of the PhD thesis of Timo Hildén and is published in the NIMA paper "Optical quality assurance of GEM foils" NIMA, 2015, 770, 113-122.

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Erik Brücken, post doctoral researcher (HIP)
Jiri Kral, doctoral student (JYFL/HIP)
Timo Hildén, doctoral student (HIP)
Beomsu Chang, doctoral student (JYFL/HIP)
Esko Pohjoisaho, doctoral student -31.5.2014
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Jyvaskyla group is also involved in the ALICE T0 and FIT detectors project led by Wladyslaw Trzaska. More details can be found on page 29 of this report.

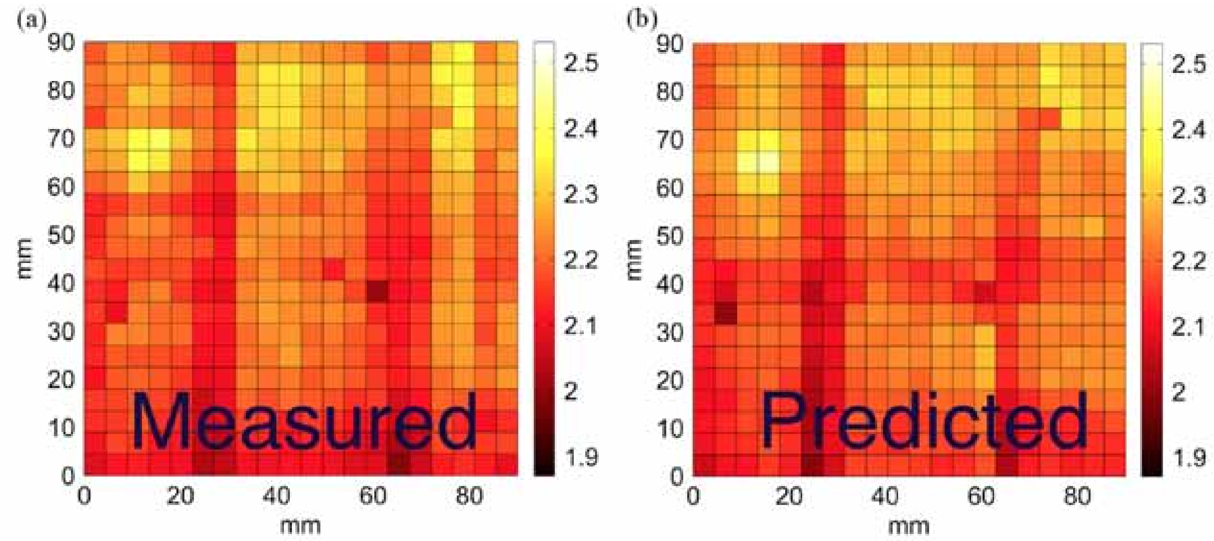

Fig. 1 The comparison of measured GEM foil individual hole gain (a) with the gain predicted from the optical scan (b).

ALICE also continues with the analysis of the run 1 data taken in the 2010-2013 period. The main focus was to continue to explore the somewhat unexpected observations in proton-lead ($\sqrt{s_{NN}}$=5.02 TeV) collisions that resemble collective effects earlier seen in heavy ion collisions. For example, Fig. 2 shows an enhancement of heavy particle yields (protons, cascades and their antiparticles) in p-Pb collisions as compared to p-p. In heavy ion collisions this "baryon anomaly" is studied within thermal production and recombination models, both indicating dense system with collective behavior. However, the question whether the observed behavior in the proton-lead collisions is due to the QCD phase transition as seen in the heavy ion collisions or some other mechanism related to e.g. initial state saturation effects remains unanswered. This underscores the importance of new data from run 2.

Fig. 2 Relative inclusive yield of identified particles as a function of transverse momentum compared to scaled yield in proton-proton collisions.

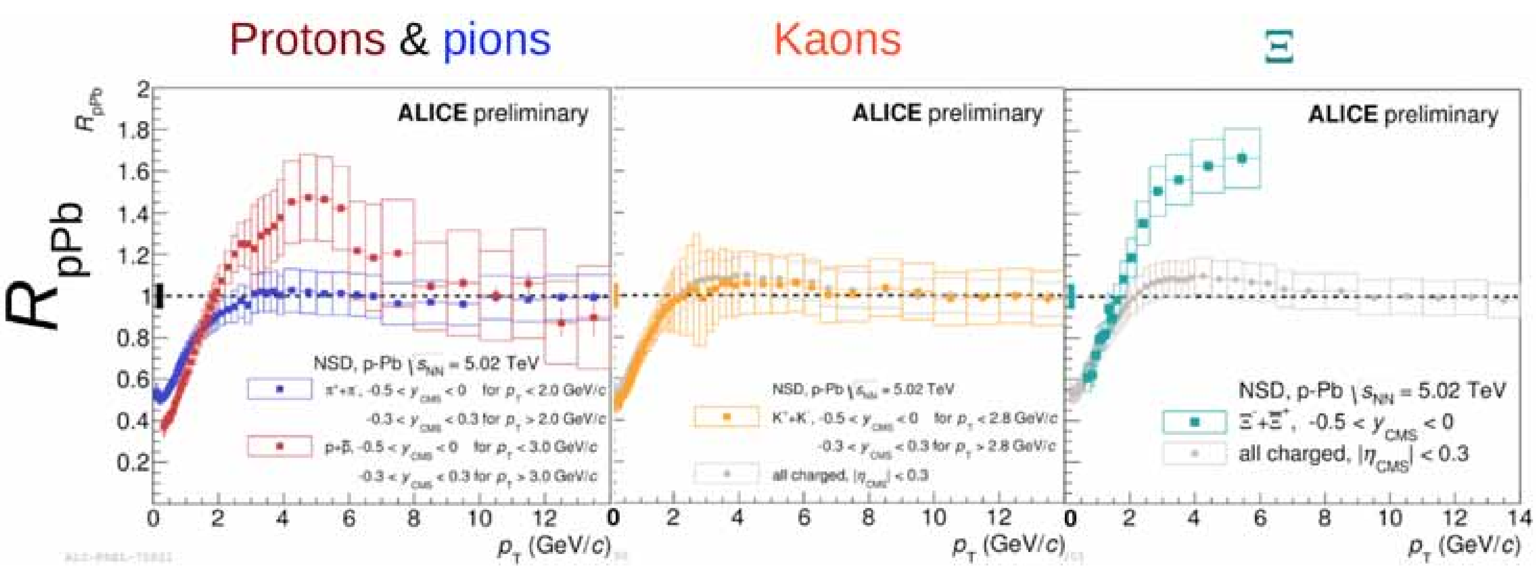

Fig. 3 Group photo from Prof. Thomas Hemmick lectures in the 24th Jyvaskyla summer school.

Our group develops several physics analysis projects for studying the soft QCD radiation. Transverse structure of jets, sensitive to final state radiation and fragmentation of partons, was studied using jet reconstruction and two-particle correlations in all collision systems (p-p, p-Pb and Pb-Pb). We also continued di-jet acoplanarity studies which can gain sensitivity to the initial state and may give constraints to models that include significant nuclear broadening at the initial state.

Our group is also participating in the PHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven Nat. Lab., USA. The RHIC collider, unlike LHC, can study large variety of colliding species and allows to study the Quark Gluon Plasma formation in a broad range of center of mass energies. Hence the RHIC/PHENIX provides a nice complementary view of the physics of ultra-relativistic heavy ion collisions.

Besides the hardware involvement and the physics analysis our group was involved in organization of 24th Jyväskylä summer school. We invited excellent speakers from the USA (prof Thomas Hemmick of Stony Brook University) and CERN (Dr. Andreas Morsch) to speak in the session "Introduction to Relativistic Heavy Ion Collisions: The Beauty of the Partonic Many-Body Problem and Exploring the Medium with Hard Probes", see Fig. 3.

Ultrarelativistic Heavy Ion Collisions – Theory

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Tuomas Lappi

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Petja Paakkinen, MSc student, summer trainee
Tapani Stylman, MSc student, summer trainee
Aili Asikainen, summer trainee

The main goal of ultrarelativistic heavy ion collisions (URHIC) is to study strongly interacting elementary particle matter, the Quark Gluon Plasma (QGP). We aim at understanding QCD matter properties and collision dynamics through various observables measurable in the CERN-LHC and BNL-RHIC experiments. We are funded by the Academy of Finland, the PANU graduate school and private foundations. We are also part of Lappi's new QCD theory project at HIP. In 2014 we participated in the physics planning of the possible future colliders in the U.S. (EIC) and CERN (LHeC, FCC), contributed to the EU network I3-HP3 TURIC activities, participated with a high profile in the largest conferences in our field, and organized the annual Particle Physics Day in Jyväskylä. Lappi received the 2014 Zimányi medal, the most prestigious young-scientist award in this field. Renk's Academy position ended. Helenius and Paatelainen reached the PhD degree and started as postdocs at Lund and Santiago de Compostela.

In heavy-ion phenomenology, the relativistic hydrodynamical studies of the spacetime evolution of QCD matter, our group's longtime expertise, are now a cornerstone of URHIC physics. In computing the produced QGP initial densities, now for viscous hydrodynamics, we extended our NLO-improved perturbative QCD + saturation (EKRT) framework to event-by-event (EbyE) studies: Analysing simultaneously the centrality dependence of the LHC and RHIC multiplicities, p_T spectra, azimuthal asymmetries (Fourier harmonics v_n) and different correlations, we aim at pinning down the shear viscosity of the QCD matter in its different phases. We released also a fully 3+1 dimensional viscous hydro code and studied the rapidity dependence of elliptic flow. The necessity of hydrodynamics in explaining the EbyE fluctuation spectrum of elliptic flow was demonstrated (Fig. 1). The applicability of hydrodynamics in small systems like p+A collisions was addressed by charting the Knudsen number which characterizes the required microscopic-macroscopic length scale separation. In addition, using our EbyE hydro framework, we calculated the triangular flow anisotropy of thermal photons in Pb+Pb collisions at the LHC.

High-p_T observables, such as single hadron spectra, jets and correlations of these, are another cornerstone of the experimental URHIC programs at the LHC and RHIC. The YaJEM MC code, developed and extensively tested by Renk, describes in-medium parton showers relevant for understanding these observables. Using YaJEM, we studied, e.g., jet- and hadron-triggered hadron yields, in-medium jet shapes, and the dependence of high-p_T hadron suppression on rapidity as well as on a suggested enhancement of the medium opacity near the deconfinement transition.

Nuclear parton distribution functions (nPDFs) are needed for the computation of all collinearly factorizable hard-process cross sections in nuclear collisions. Our global EPS09 analysis literally defines the current state of the art for the nPDFs and their uncertainties: EPS09-based NLO calculations of hard processes typically serve nowadays as the theory comparison-baseline for LHC experiments. Consequently, our EPS09-paper was cited over 100 times in 2014 alone. In identifying observables to constrain the nPDFs further, we studied pion and direct photon production at forward rapidities in p+Pb collisions at the LHC. As a preparatory work for an LHC-data-updated global analysis, we developed a Hessian PDF reweighting technique with which we can now beforehand quantify the effect of adding a new data set into the global analysis.

In the Color-Glass-Condensate (CGC) framework, we are continuing our studies of high energy QCD relevant e.g. for the QGP initial state in URHIC. As the first group worldwide, we presented a numerical solution of the NLO BK equation. We also continued our work for including heavy quarks in our Balitsky-Kovchegov (BK) equation fits to HERA DIS data. For the EIC, we proposed a novel way to measure centrality in incoherent nuclear diffraction, using ballistic protons seen in forward "Roman Pot" detectors. This proposal gained immediate interest from the experimental community. We finished a study of chromomagnetic flux loops in the classical fields of the initial stages of a heavy ion collision. This study showed that the transverse Wilson loop has a remarkable universal area-dependence in the infrared, characterized by a nontrivial anomalous scaling exponent. We also continued our work for developing numerical methods to study the Debye mass in classical color field simulations.

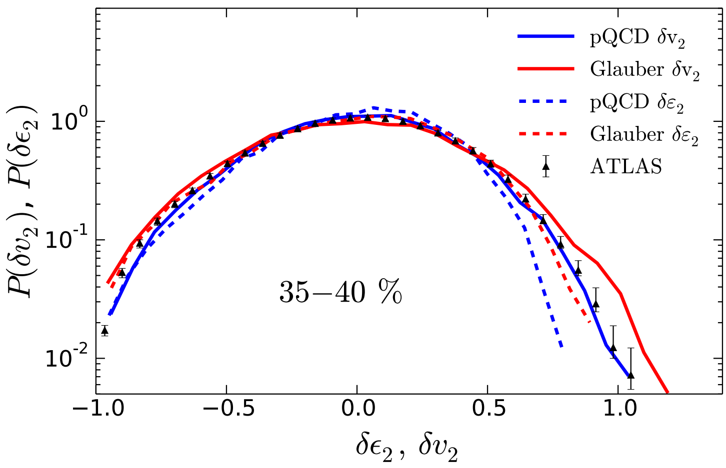

Fig. 1. Probability distributions of relative fluctuations of v_2 of charged hadrons in semi-peripheral Pb+Pb collisions at the LHC. Our results revealed that the relative initial eccentricities ($\delta\varepsilon_2$, blue dashed) cannot explain the ATLAS measurement but hydrodynamics is required (blue solid).

Neutrino Physics and Beyond the Standard Model Physics

Jukka Maalampi,
Wladyslaw Trzaska

Jukka Maalampi, professor
Wladyslaw Trzaska, senior researcher
Roshan Foadi, postdoctoral researcher
Chitta Das, visiting scientist -30.6.
Tommi Alanne, doctoral student, in collaboration with the cosmology group
Timo Alho, doctoral student - 31.8.
Kai Loo, doctoral student
Ville Vaskonen, doctoral student, in collaboration with the cosmology group
Sampsa Vihonen, doctoral student

Neutrino Experiments

Over the past years our group was tightly involved in the EU-financed FP7 Design Study Projects devoted to the plans and physics program for a future large underground neutrino facilities in Europe. The final phase of this program, known as LAGUNA-LBNO, was summarised at LAGUNA 2014 (https://www.jyu.fi/fysiikka/en/laguna2014). This Open General Meeting was co-organized by our team and held in Hanasaari Cultural Centre in Espoo. The outcome of the Design Study exceeds 4000 pages of printed material and is publicly available. The study

Fig.1. LAGUNA 2014 group photo

gives to the Pyhäsalmi mine, just 180 km north of Jyväskylä, the highest priority for the location of the future European large scale underground neutrino observatory.

In response to the long-term goals of the physics community and in particular to the European Particle Physics Strategy document, CERN Council has released significant resources for the new established CERN Neutrino Platform. Over the next 5 years 55 MCHF as well as the necessary infrastructure will be available to bring neutrino detector R&D to the level of the construction of actual demonstrators allowing for major technical decisions. One of the beneficiaries is the WA105 experiment, which aims at the construction and testing of a 6m x 6m x 6m prototype – the LAGUNA-LBNO demonstrator - of a two-phase Liquid Argon TPC detector. Our team is part of the WA105 collaboration.

Theoretical studies

In neutrino physics, the main topic of theoretical research has concerned with the oscillation parameters, in particular the oscillation angle θ_{23}. The value of this angle is known to be close to 45 degrees, but one does not know yet does it lie in the first or second octant. We have investigated the prospects for determining the octant of θ_{23} in long baseline oscillation experiments for the different values of the unknown CP violation angle and the intensities of neutrino beam. We have also investigated the neutrino oscillation effects in the Sun to find possible signals of the existence of possible additional neutrino types, the so called sterile neutrinos.

In strong interaction physics, one of the research topics has concerned with the gauge/gravity correspondence, a realization of the so-called holographic principle. A holographic model in the limit of large number of colors, Nc, and massless fermion flavors, Nf, but constant ratio Nf/Nc was analyzed at finite temperature and chemical potential. A new quantum critical regime is found at zero temperature and finite chemical potential. This activity is led by Kimmo Tuominen, working now in the University of Helsinki.

Cosmology

Kimmo Kainulainen

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Jussi Virkajärvi, postdoctoral researcher 1.10.-
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Henri Jukkala, doctoral student
Mikko Pääkkönen, doctoral student
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Ville Vaskonen, doctoral student
Antti Hämäläinen, MSc student
Laura Laulumaa, MSc student
Olli Koskivaara, MSc student
Matti Eskelinen, MSc student

The Standard Cosmological Model (SCM) contains, to balance its spectacular success, several ingredients of unknown origin. The nature of the dark matter (DM) and of the dark energy (DE), which control the evolution of the universe at large scales, is a mystery. We also do not have a particle physics model for inflation responsible for the initial density perturbations, or for the dynamical mechanism that was the origin of the matter in the Universe.

In the context of homogeneous SCM the observed accelerated expansion of the universe requires existence of dark energy. Yet, the universe is known to be inhomogeneous. We therefore study the effects of large nonlinear structures in cosmology. In particular we investigate the evolution of large spherical inhomogeneities with multiple fluids. Such systems exhibit interesting features absent in SCM, such as large local variations in the metric (see figure). Also, early reionization epoch can induce a large differences between the DM and baryon fluid velocities, and therefore local variations in the structure formation efficiency and matter-to-light ratio.

Alternatively, accelerated expansion may be signalling that general relativity (GR) fails at large distances. In our group we have studied scalar-tensor and f(R)-gravity models as alternatives for GR. Also weak gravitational lensing by nonlinear structures can affect the interpretation of the cosmological observations.

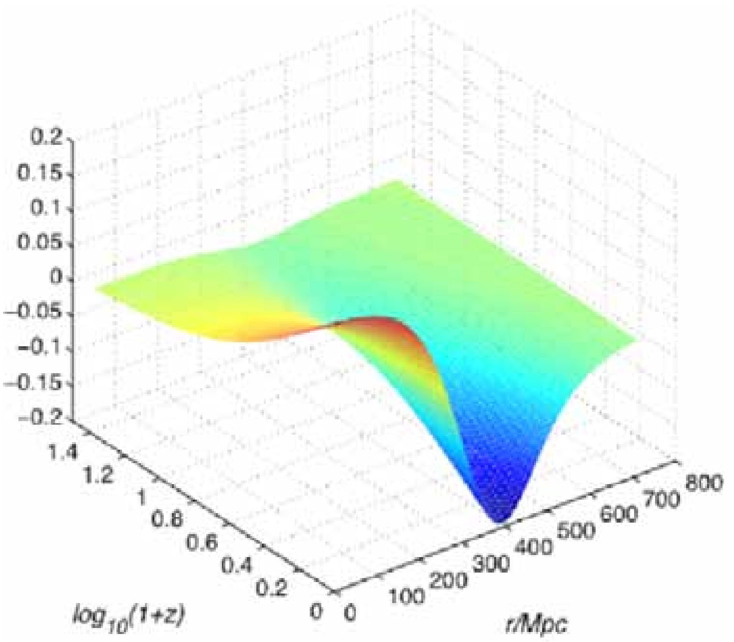


Fig. 1: Shown is the evolution of the radial scale factor a_r relative to the average background scale factor a ($y=a_r/a-1$), as a function of time and co-moving radius for a 1Gpc bubble (a void) with an intial (at $z_{in}=10^4$) central relative density contrast Δ = -1.5×10^{-5}.

WL corrections can be studied by large scale N-body simulations, but these are very time-consuming. We have therefore developed a fast and accurate stochastic method the sGL, to compute the WL effects. We are adapting the sGL and the associated bublic code turboGL, to compute WL distortions to the angular CMB power spectrum and on analysis of the angular distribution of quasar double images.

The second major unknown component in the SCM is the dark matter. We have studied several particle DM candidates in our group. In one such model, set in the context of minimal walking technicolor, we have shown that we can simultaneously induce a dynamical electroweak symmetry breaking, solve the hierarchy problem, give a gauge coupling unification and provide a viable DM candidate, fully consistently with existing cosmological and laboratory constraints. On the other hand, we have thoroughly investigated the simplest particle physics DM candidate, a singlet scalar and found an interesting mass window $m_{DM} \approx$ 55-62.5GeV, which is difficult to rule out by any foreseeable experiment or observation. We are also investigating scalar DM models with more complicated structures. In one category of such models both the DM and the Higgs particle are pseudo-goldstone bosons of a higher symmetry group. These models provide both the DM and an alternative natural explanation for the smallness of the Higgs boson mass.

Third problem in the SCM concerns the existence of the matter-antimatter asymmetry in the Universe. Because SCM incorporates inflation, a period of early superluminal expansion, which completely erases any pre-inflationary particle distributions, this asymmetry cannot be imposed as an initial condition. The dynamical mechanism that created baryons after inflation is not known, but it must involve interacting and coherent quantum fields in out-of-equilibrium conditions. Modelling such systems requires advanced quantum transport theory methods and our group is one of the world leaders in this field. Our coherent Quasi Particle Approximation (cQPA) can be used to study for example Leptogenesis and the Electroweak Baryogenesis (EWBG). In the latter case cQPA is the only known method that can consistently account for quantum reflections. In slowly varying backgrounds semiclassical methods developed earlier in our group are applicable, and indeed routinely employed by diverse groups, eg. to study EWBG in various extensions of the particle physics standard model. We are continuing to develop the cQPA method and to applying it in various contexts in the early universe.

Industrial Collaboration

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

Again in 2014, The Industrial Applications group of the accelerator laboratory had several contacts with domestic and foreign industry and research laboratories. Forty one irradiation campaigns for 14 companies or organizations and two universities were performed at RADEF facility. In addition to ESA also AIRBUS and the institutes like German Aerospace Center (DLR) and French Alternative Energies and Atomic Energy Commission (CEA) visited the facility. Also, Surrey Satellite Technology Ltd from Guilford, UK, was performing a test campaign for the first time at RADEF.

In 2014 the contract with ESA was renewed for the coming two years with a title of “Utilization of the High Energy Heavy Ion Test Facility (RADEF) at the University of Jyväskylä (JYFL) for Component Radiation Studies 2014-2015” (ESA Contract No. 4000111630/ 14/NL/PA).

Although the EU’s FP7-project SkyFlash (http://www.skyflash.eu/) finished last year it spawned a new EU’s Horizon2020-project “Radiation Hard Resistive Random-Access Memory (R2RAM)”, where the coordinator is IHP GmbH - Leibniz-Institute of Innovations for High Performance Microelectronics (Germany). In addition to RADEF, the other beneficiaries are RedCat Devices (Italy) and IUNET - Italian Universities Nano-Electronics Team, which composes of seven universities. The project starts at the beginning of 2015 and it was the first approved Horizon-2020 project in our university. The basic goal is to give a methodology for the development of a new rad-hard nonvolatile RRAM memory with high-performance features like good retention, re-programmability and cycling as well as realize a prototype (1Mbit RRAM memory) in order to validate the approach.

The irradiations of the polymer membranes for Oxyphen AG were also continued with several campaigns in the year 2014.

The total beam time used for these activities was 1315 hours. From those 56 % was used for space related studies, 31 % for other irradiations and the rest of beam time was used for R&D work and basic research. The revenue continued at the established level, being 758 k€ in the year 2014.

The Accelerator Based Materials Physics group within the Accelerator Laboratory has continued active industrial collaboration both with international and domestic companies in 2014. The group was a research partner in a major TEKES project MECHALD, which ended in October 2014. In MECHALD the mechanical properties of atomic layer deposited films were studied within a consortium including groups from Aalto University and VTT as well as several participating companies. The export of JYFL designed and constructed analysis instruments continued by signing a contract for the delivery and installation of a gas ionization chamber energy detector for ion beam analysis to Imec, Belgium. As part of the NANOPALVA project, the highly versatile atomic layer deposition system in the NSC clean room has, in close connection to all the characterization tools available at the campus, opened new possibilities for industrial collaboration. This NANOPALVA project which ended in December 2014 was funded by the EU through the Regional Council of Central Finland, University of Jyväskylä and local companies. As a new opening of the activities at the Pelletron accelerator, the elemental compositions of different types of culture heritage objects from several customers were measured using PIXE. This activity was funded through TEKES project Recenart, which will go on until mid 2016.

The Experimental Nanophysics groups have well established collaboration with a few companies in Finland. In the past years, ultrasensitive superconducting radiation detectors for X-rays have been developed in collaboration with industry. In 2014 a TEKES funded project continued, where our new ultrasensitive X-ray spectrometer setup developed in a previous TEKES project is being used for novel terrestrial materials science applications in collaboration with the accelerator based materials physics group. In addition, in the same project commercial wafer scale superconducting detector fabrication is being developed in collaboration with VTT Micronova micro- and nanofabrication center in Espoo. The industrial partners include Oxford Instruments Nanotechnology Tools Ltd from the UK, Star Cryoelectronics Inc. from USA and Aivon Oy from Helsinki. All nanophysics groups were also actively involved in the NANOPALVA EU funded project, where novel nanoscience instrumentation tools are developed for industrial applications, such as the previously mentioned atomic layer deposition tools, as well as 3D laser lithography tool and the nanosensor test station with environmental control combined with sophisticated measurement strategies. Collaboration with Microsoft Finland Oy ensued on applications of 3D laser lithography. The molecular electronics and plasmonics group continued collaboration with lamit.fi on integrable solar energy collection, and established new collaborations with several companies: Fimlab Laboratoriot Oy, Oy Panimolaboratorio – Bryggerilaborator, BioNavis Oy, and Orion Diagnostica Oy, within a new TEKES project on SERS based detection of microbial contaminations on food. In addition, the Molecular Technology group has collaborated with nEMCEI Ltd., a local start-up company, in investigating the conductive properties of carbon nanotubes solubilized with hemi-cellulose. The company obtained in 2013 a patent on the solubilization method.

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

The group runs an extensive x-ray tomographic laboratory that includes three x-ray scanners used in non-invasive three-dimensional imaging and analysis of the internal microstructure a wide range of heterogeneous materials. The laboratory is also equipped with adequate sample preparation and manipulation devices, a versatile set of instruments for measuring transport properties in porous materials, and with an ultra fast camera system. All these devices were widely used in applied research with industrial partners, e.g. for the analysis of structural and transport properties of novel fibre based materials and of minerals. Experimental work was complemented with material modelling and with development of numerical methods and three-dimensional image analysis. The close collaboration with VTT Technical Research Centre of Finland was continued, involving e.g. analysis of various types of materials of industrial relevance.

The applied projects were related e.g. to development of novel bio-based materials, their barrier properties, strength, deformation, fracture, printing and optical transmission properties, and to the safety analysis of repositories of spent nuclear fuel. The group has successfully continued its long-term development of ultrasound methods for the assessment of bone quality, and for diagnosing osteoporosis, including related device development.

Industrial collaborators included Stora Enso, UPM-Kymmene, Posiva, Numerola, Oscare Medical, CSC (IT Centre for Science Ltd). Through an EU FP7 projects collaboration was also continued with Enthought Ltd., Hellma GmbH & Co. KG, Biofluidix, Allinea Software (UK), Cray UK Ltd, German Aerospace Centre, The Center for Information Services and High Performance Computing (Germany) and The European Centre for Medium-Range Weather Forecasts.

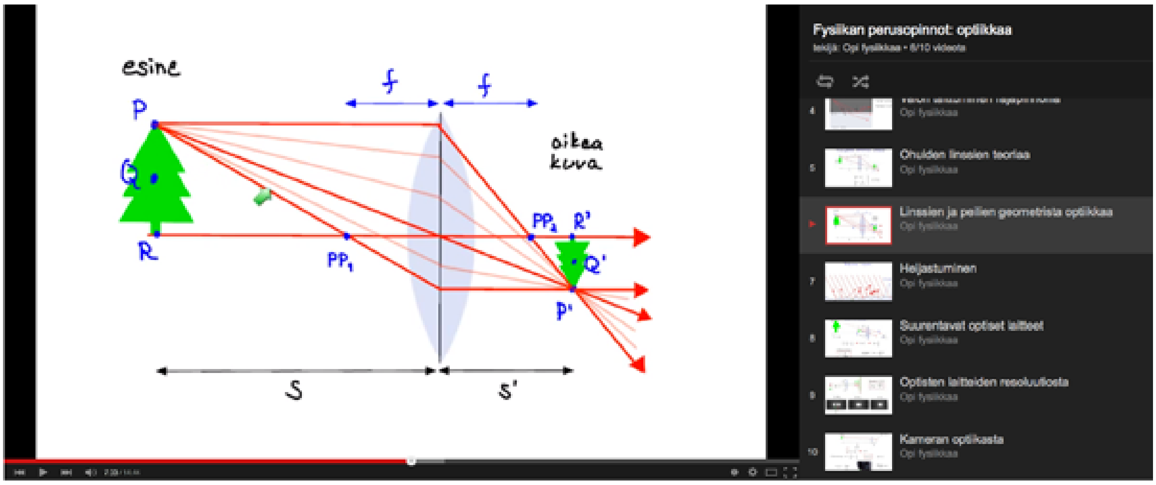
In addition to industry, funding to applied research was received from Academy of Finland, Finnish Program for Strategic Centres for Science, Technology and Innovation (SHOK), EAKR/Regional Council of Central Finland, Technology Development Centre of Finland and the Ministry of Employment and the Economy.

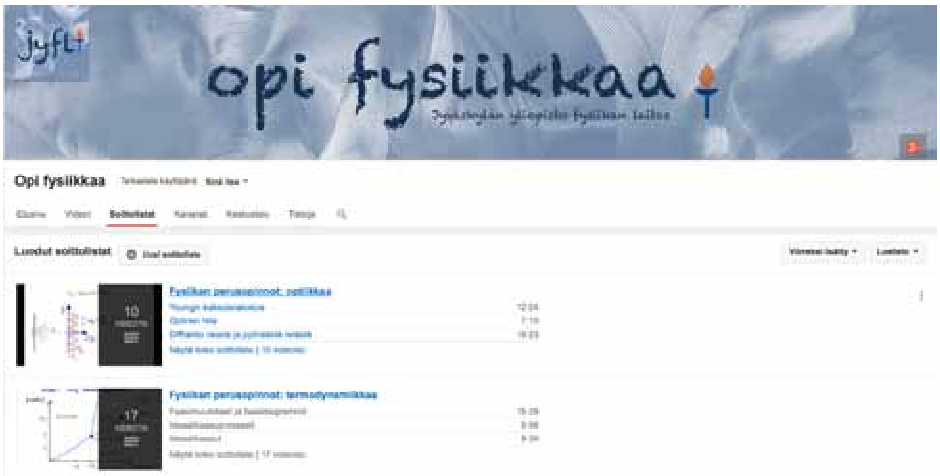
Education

Jukka Maalampi
Jussi Maunuksela
Juha Merikoski

Jukka Maalampi, professor
Juha Merikoski, senior lecturer
Jussi Maunuksela, senior lecturer
Pekka Koskinen, academy research fellow
Mikko Laitinen, laboratory engineer
Matti Leino, professor

The development of teaching has continued at the Department, with emphasis put onto peer learning in small groups and self-directed studies, known to be a more effective and deeper way to learn than traditional lectures. The new teaching practices, applied in many courses, have activated students and resulted in better learning outcomes. To support self-directed learning, a program was started to create audiovisual instruction material for the basic courses, freely available on the internet. The second-year Thermodynamics and Optics' course was piloting this, and it turned out the students made good use of this new learning possibility.





The short instruction videos are hosted both by YouTube in the open Opi fysiikkaa -channel and by opetus.tv, which is a nationally established website for instructional science videos.

Master's studies in nuclear and particle physics

The international master's program in nuclear and particle physics, launched a couple of years ago, is gradually finding its final shape with first students graduating soon. The studies require two years of full-time study, 120 ECTS credits, for a Master of Science degree. The Department has supported students with annual grants. The program has attracted students from all around the world, e.g. from Canada, Great Britain, Italy, Spain, Ukraine, Pakistan and Syria.

Physicist's communication and language competence

The Department of Physics is closely co-operating with the University Language Centre to integrate communication and language studies into major studies in physics. It has been observed that too often students delay compulsory communication and language studies until they are forced to take them in order to fulfill degree requirements. In order to facilitate the timely completion of studies, the compulsory communication and language studies are being linked with basic and intermediate physics study modules. Planning this development was carried out in winter 2013, and the first courses were arranged in autumn 2014. The realization of this integration began with the introduction of two courses: Academic Literacy and Collaborative Skills courses linked with Mechanics, introductory part and continuation courses, respectively.

In Autumn 2015 the integration will continue with the course Languages of Modern Physics. The study module will be completed for the first time in spring 2017 with the introduction of course Research Communication Skills that will be linked with the Department's Bachelor Thesis -course.

Supplementary education

In summer 2014 the Department started a series of supplementary education courses directed to those having at least a master's degree in physics or a related field. Three courses were given, one on sustainable energy, one on nanotechnology and a special course for school teachers on radiation. During the last one the teachers e.g. learned to build a simple cloud chamber for detection of cosmic particles.

Statistics

After the highest ever number of graduated masters (50) in 2013, it was not surprising that the number of master's degrees in 2014 was below the average, ending up to 25, including nine graduates with teacher's qualifications. The average graduation time was about 6 years, considerably above the goal of 5 years. On the positive side, the number of bachelor's degrees has been growing steadily and in the number of doctor's degrees we achieved our goal of 13 doctors. We enrolled 80 new students in 2014. The total number of undergraduate students was about 500 and that of doctoral students about 80.

Personnel

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Markku Kataja, prof.

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MSc students are listed in the research reports.

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Sanna Boman 17.11.-
Minttu Haapaniemi
Marjut Hilska
Nina Kaari
Soili Leskinen

International Peer Reviewed Articles

The FIDIPRO Group

W. Satuła, J. Dobaczewski, M. Konieczka and W. Nazarewicz
Isospin mixing within the symmetry restored density functional theory and beyond
XXXIII Mazurian Lakes Conference on Physics Frontiers in Nuclear Physics, Piaski, Poland, September 1-7, 2013
Acta Phys. Pol. B 45 (2014) 167

G. X. Dong, X. B. Wang, F. R. Xu and S. Y. Yu
Collective properties of neon isotopes investigated by projected shell model
Chinese Science Bulletin 59 (2014) 3847

K. Bennaceur, J. Dobaczewski and F. Raimondi
New density-independent interactions for nuclear structure calculations
25th International Nuclear Physics Conference (INPC 2013), Florence, Italy, June 2-7, 2013
Eur. Phys. J. Web of Conf. 66 (2014) 02031

X. B. Wang, G. X. Dong and F. R. Xu
Systematic study of shell-model effective interaction in ***sd*** shell
25th International Nuclear Physics Conference (INPC 2013), Florence, Italy, June 2-7, 2013
Eur. Phys. J. Web of Conf. 66 (2014) 02108

F. Raimondi, K. Bennaceur and J. Dobaczewski
Nonlocal energy density functionals for low-energy nuclear structure
J. Phys. G: Nucl. Part. Phys. 41 (2014) 055112

J. Dobaczewski, W. Nazarewicz and P.-G. Reinhard
Error Estimates of Theoretical Models: a Guide
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A. Dumitru, T. Lappi and Y. Nara
Structure of longitudinal chromomagnetic fields in high energy collisions
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T. Renk
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G. S. Denicol, H. Niemi, I. Bouras, E. Molnár, Z. Xu, D. H. Rischke and C. Greiner
Solving the heat-flow problem with transient relativistic fluid dynamics
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E. Molnár, H. Niemi, G. S. Denicol and D. H. Rischke
On the relative importance of second-order terms in relativistic dissipative fluid dynamics
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R. Perez-Ramos and T. Renk
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H. Paukkunen and P. Zurita
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T. Lappi and H. Mäntysaari
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Diffractive vector meson production in ultraperipheral heavy ion collisions from the Color Glass Condensate
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Neutrino Physics and Particle Physics Beyond the Standard Model

S. K. Agarwalla, L. Agostino, M. Aittola, B. Andrieu, D. Angus, A. Ariga, T. Ariga, R. Asfandiyarov, D. Autiero, P. Ballett, I. Bandac, D. Banerjee, G. J. Barker, G. Barr, F. Bay, V. Berardi, I. Bertram, A. M. Blebea-Apostu, A. Blondel, E. Borriello, S. Boyd, I. Brancus, A. Bravar, M. Buizza-Avanzini, F. Cafagna, M. Calin, M. Campanelli, C. Cantini, O. Caretta, G. Cata-Danil, M. G. Catanesi, A. Cervera, S. Chakraborty, L. Chaussard, D. Chesneanu, F. Chipesiu, G. Christodoulou, J. Coleman, P. Crivelli, T. Davenne, J. Dawson, I. DeBonis, J. DeJong, Y. Déclais, P. DelAmoSanchez, A. Delbart, C. Densham, F. DiLodovico, S. DiLuise, D. Duchesneau, J. Dumarchez, A. Eliseev, S. Emery, K. Enqvist, T. Enqvist, L. Epprecht, A. Ereditato, A. N. Erykalov, T. Esanu, A. J. Finch, M. D.Fitton, D. Franco, V. Galymov, G. Gavrilov, A. Gendotti, C. Giganti, J. J. Gomez, C. M. Gomoiu, Y. A. Gornushkin, P. Gorodetzky, N. Grant, A. Haesler, M. D.Haigh, T. Hasegawa, S.H aug, M. Hierholzer, J. Hissa, S. Horikawa, K. Huitu, J. Ilic, A. Izmaylov, A. Jipa, K. Kainulainen, T. Kalliokoski, Y. Karadzhov, J. Kawada, M. Khabibullin, A. Khotjantsev,

E. Kokko, A. N. Kopylov, L. L. Kormos, A. Korzenev, S. Kosyanenko, I. Kreslo, D. Kryn, Y. Kudenko, J. Kumpulainen, P. Kuusiniemi, J. Lagoda, I. Lazanu, J.-M. Levy, R. P. Litchfield, K. Loo, P. Loveridge, J. Maalampi, L. Magaletti, R. M. Margineanu, J. Marteau, C. Martin-Mari, V. Matveev, K. Mavrokoridis, E. Mazzucato, N. McCauley, A. Mercadante, O. Mineev, A. Mirizzi, B. Mitrica, B. Morgan, M. Murdoch, S. Murphy, S. Narita, D. A. Nesterenko, K. Nguyen, K. Nikolics, E. Noah, Yu. Novikov, H. O'Keeffe, J. Odell, A. Oprima, V. Palladino, S. Pascoli, T. Patzak, D. Payne, M. Pectu, E. Pennacchio, L. Periale, H. Pessard, C. Pistillo, B. Popov, P. Przewlocki, M. Quinto, E. Radicioni, Y. Ramachers, P. N. Ratoff, M. Ravonel, M. Rayner, F. Resnati, O. Ristea, A. Robert, E. Rondio, A. Rubbia, K. Rummukainen, R. Sacco, A. Saftoiu, K. Sakashita, J. Sarkamo, F. Sato, N. Saviano, E. Scantamburlo, F. Sergiampietri, D. Sgalaberna, Majiec Slupecki, M. Sorel, A. Stahl, D. Stanca, A. R. Sterian, P. Sterian, B. Still, S. Stoica, T. Strauss, J. Suhonen, V. Suvorov, M. Szeptycka, R. Terri, G. Toma, A. Tonazzo, C. Touramanis, W. Trzaska, K. Tuominen, A. Vacheret, M. Valram, F. Vanucci, G. Vasseur, T. Viant, A. Virtanen, A. Vorobyev, D. Wark, A. Weber, M. Weber, C. Wiebusch, J. R. Wilson, S. Wu, N. Yershov, J. Zalipska, and M. Zitok
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Cosmology

T. Alanne, S. Di Chiara and K. Tuominen
LHC Data and Aspects of New Physics
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T. Alanne, K. Tuominen and V. Vaskonen
Strong phase transition, dark matter and vacuum stability from simple hidden sectors, Nucl. Phys. B 889 (2014) 692

Other Publications

M. Rantala, S. Lassas, J. Sampo, J. Takalo, J. Timonen and S. Siltanen
Modelling and analysing oriented fibrous structures
2nd International Conference on Mathematical Modeling in Physical Sciences 2013 (IC-MSQUARE 2013) (pp. 012089). Journal of Physics: Conference Series (490). Bristol: Institute of Physics Publishing Ltd (IOP) (2014)

J. Takalo
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Filatelisti, pp.26-29. (2014)

THESES AND DEGREES

THESES

BSc THESES

(alphabetical order)

Saku Antikainen, Van der Waals -vuorovaikutus laskennallisessa nanotieteessä

Juho Ala-Myllymäki, Fotonisäteilyn laadunvalvonta lineaarikiihdyttimissä

Elias Barba Moral, Annihilation process $e^+ + e^- \rightarrow \gamma + \gamma$ to leading-order in QED perturbation theory

Niko-Ville Hakkola, Pintaplasmonit grafeenikomposiittirakenteissa

Samuli Heiskanen, Rakorakenteen valmistaminen 3D-litografian avulla

Vesa-Matti Hiltunen, Graphene Synthesis by Chemical Vapor Deposition and its Characterization

Pauli Hytölä, Pyörimisliikkeen käsittely lukion oppikirjoissa

Henri Hänninen, Hafniumin isomeerin soveltuvuus energian varastointiin

Lotta Jokiniemi, Täysparisten ydinten kollektiiviset viritykset

Kaisa Jokiranta, The Effectiveness of Practical Work in Science Education

Kalle Kansanen, Vaahdon muodostaminen tutkimuskäyttöön

Käpy-Maaria Kärkkäinen, Fysiikan ylioppilaskokeiden vuoden 2013 tehtävien arvioiminen uudistetulla Bloomin taksonomialla

Juhani Lepistö, Ac-225 valmistaminen Ra-226:sta (p,2n)-reaktiolla

Jarkko Liimatainen, Hiukkas-aukkoydinten E2- ja E3-siirtymien systematiikka

Joakim Linja, Globaalit rakenneoptimointimenetelmät laskennallisessa fysiikassa

Joni Lämsä, Sähkömagneettiset siirtymät yksihiukkas- ja yksiaukkoytimissä

Juuso Manninen, Quantum and Classical Fluctuation Theorem Fundamentals

Keijo Mönkkönen, Tyypin Ia supernovat pimeän energian jäljillä

Lauri Nuuttila, Photocycle and Dark Reversion of Deinococcus Radiodurans Phytochromes

Petja Paakkinen, Sähköheikko Drell-Yan-dileptonituotto alimmassa kertaluvussa 7 TeV:n protoni-protoni-törmäyksissä

Oula Paattakainen, Säteily-ympäristöt maata kiertävien satelliittien kiertoradoilla

Jasper Parkkila, Kylmän plasman mallinnus PIC-MCC-menetelmällä

Hannu Pasanen, Gold-Nanoparticles: Synthesis, Applications and Self-Assembled Monolayers

Juha-Pekka Pentikäinen, Pyörrevirtahäviöt johteessa

Reetta Pihlajamaa, Röntgentomografian käyttö selluloosakuitujen välisten sidosten tutkimuksessa

Joonas Pylväinen, Mittalaitteen valmistus kitkan tutkimiseen kivien murtumapinnoissa

Jaro Ruuskanen, Kvanttimekaniikan tulkinta, Bohr vastaan Everett

Janne Saastamoinen, Konjugoidut DNA-rakenteet: karakterisointi atomivoimamikroskoopilla

Roope Sarala, Kultaklustereiden analyysin automatisointi TEM -kuvista

Ville Saunajoki, Fabrication of Carbon Nanotube Field-Effect Transistors

Elli Selenius, Metalliklusterien kuorirakenne

Kristiina Siilin, Hopean ja orgaanisten yhdisteiden rajapinta

Markku Sironen, Fysiikan ja musiikin oppiaineintegrointi lukiotasolla

Marja Similä, Pimeä aine galakseissa ja galaksiryhmissä

Iina Sirviö, ELF-VLF-aallot geofyysiikan tutkimuskohteena

Tapani Stylman, Higgsin bosonin hajoaminen

Marko Suomalainen, Hämähäkinseitin biomimetiikka hiilinanoputkilla

Antti Takkinen, Ionisoivan säteilyn havaitseminen

Saana Uljas, Opetuksen haasteita lukion fysikaalisessa ja geometrisessa optiikassa

Markus Valkama, Langmuir-anturin käyttö plasmadiagnostiikassa

Veli-Pekka Vihonen, Energiankulutus paperinvalmistusprosessissa

Markus Vilén, Use of Xenon within the CTBTO

Arttu Väänänen, Epäsymmetrinen eksluusioprosessi

MSc THESES

(alphabetical order)

Seyed Mehdi Alavi, Techno-economic Pre-feasibility Study of Wind and Solar Electricity Generating Systems for Households in Central Finland

Tanja Andrejeff, Selective trapping of oligos to triangular gold nanoparticles utilizing dielectrophoresis

Jukka Huttunen, Röntgen-mikrotomografia ja erilaisten viljelykiertojen vaikutus hietamaan rakenteeseen

Viivi Hyppönen, Nanodiamond Seeding for Thin Film Growth

Kaisa Jokiranta, Opettajan puheen luonne kokeellisen työskentelyn aikana yläkoulun fysiikassa

Henri Jäntti, Luonnontieteellisen tiedon luonteen ymmärryksen mittaaminen fysiikan ylioppilaskokeessa

Hanna Kronholm, Piirrosten tekemisen ja simulaation käytön vaikutuksista toisiinsa lukiofysiikassa

Risto Kronholm, Nopean kaasunsyöttölaitteiston, paineenmittauksen ja valodiagnostiikan kehittäminen ECR-ionilähteessä

Pekka Kurki, Liikkeen ja voiman kuvitus yläkoulun ja lukion fysiikan oppikirjoissa

Käpy-Maaria Kärkkäinen, Alakoulun 6. luokan oppilaiden kognitiiviset taidot sähköopin simulaatioharjoituksissa

Miika Leppänen, Lämpösähköisen materiaalin lämmönjohtavuuden määrittäminen matalissa lämpötiloissa käyttäen 3-omega-menetelmää

Jasmin Luostarinen, Aurinkosähkön tekninen potentiaali Jyväskylässä

Tero Mononen, Kokonaisten rakennusten energiamallintaminen kuukausi- ja tuntitasolla

Johannes Nokelainen, Boorinitridinanorakenteiden laskennallinen mallinnus tiheysfunktionaaliteoriaan perustuvan tiukan sidoksen mallilla

Juha-Matti Ojanperä, Hamiltonin formalismi klassisessa mekaniikassa, kvanttimekaniikassa ja yleisessä suhteellisuusteoriassa

Matias Pekkarinen, Tietokoneohjelma epälineaaristen elektroniikkapiirien suunnitteluun

Jarkko Peuron, Determination of the Non-Abelian Debye Screening Mass Using Classical Chromodynamics

Pekka Pirinen, Effective Axial-Vector Coupling in Beta Decay of Mass Region A=100-134 Isotopes

Emmi Pohjolainen, Molecular Dynamics Simulations of Echovirus 1

Kari Romppanen, Vaihdemarkkinoiden uudet kasvulähteet

Tuukka Ruhanen, Rasterikuvakorrelaatiospektroskopiamittauksia Nikon A1R+ -konfokaalimikroskoopilla

Juuso Saikko, Simulaatioiden käyttö kotitehtävien osana yläkoulun fysiikan opetuksessa

Ville Saunajoki, Hiilinanoputki-hemiselluloosakomplexista muodostuvan ohutkalvon johtavuusmittaukset

Markku Siironen, Fysiikan ja musiikin oppiaineintegrointi lukiotasolla

Sampsa Vihonen, CERN-Pyhäsalmi-neutriinokokeen simulointeja GLoBES-ohjelmalla

Matti Väisänen, Luonnontieteellisen tiedon luonteen tutkiva oppiminen luokanopettajakoulutuksessa

PhD THESES

(chronological order)

Tero Isotalo, Periodic Nanostructures for Thermal Engineering Applications
JYFL Research Report 1/2014

Timo Alho, Gauge theory phase diagrams from holography
JYFL Research Report 2/2014

Olli Herranen, Experimental characterization of electronic, structural and optical properties of individual carbon nanotubes
JYFL Research Report 3/2014

Janne Lehtinen, Quantum fluctuations in superconducting nanostructures
JYFL Research Report 4/2014

Peerapong Yotprayoonsak, Complexes of carbon nanotubes with ions and macromolecules; studies on electronic conduction properties
JYFL Research Report 5/2014

Ilkka Helenius, Spatially Dependent Parton Distribution Functions and Hard Processes in Nuclear Collisions
JYFL Research Report 6/2014

Jiri Kral, Intrinsic Transverse Momentum Distribution of Charged Hadrons in Jets Measured in p–Pb Collisions by ALICE
JYFL Research Report 7/2014

Risto Paatelainen, Minijet initial state of heavy-ion collisions from next-to-leading order perturbative QCD
JYFL Research Report 8/2014

Mikko Pääkkönen, Spherically Symmetric Inhomogeneous Cosmological Models
JYFL Research Report 9/2014

Rudolf Klemetti, Analysis of stability against falling by movement simulation in human walking
JYFL Research Report 10/2014

Vantte Kilappa, Ultrasound Measurements in Bone Using an Array Transducer
JYFL Research Report 11/2014

Jarmo Kouko, Effects of Heating, Drying and Straining on the Relaxation and Tensile Properties of Wet Paper
JYFL Research Report 12/2014

Pauli Peura, Spectroscopic studies of Pt-173 and Pt-175
JYFL Research Report 13/2014

BSc DEGREES

(main subject is physics)

Ala-Myllymäki, Juho
Asikainen, Aili
Hakkola, Niko-Ville
Hiltunen, Vesa-Matti
Huttunen, Jukka
Hyppönen, Viivi
Hytölä, Pauli
Hänninen, Henri
Jokiniemi, Lotta
Jokiranta, Kaisa
Jäntti, Henri
Kangas, Matias
Kansanen, Kalle
Kinnunen, Sami
Kostian, Jenna
Kronholm, Hanna
Kronholm, Risto
Kärkkäinen, Käpy-Maaria
Kääriäinen, Topi
Laajala, Ilari
Laitila, Valtteri
Linja, Joakim
Luostarinen, Jasmin
Lämsä, Joni
Manninen, Juuso
Manninen, Jyrki
Moisala, Terhi
Mononen, Tero
Mönkkönen, Keijo
Nevalainen, Tiia
Nokelainen, Johannes
Nuuttila, Lauri
Nykänen, Anssi
Ojanperä, Juha-Matti
Paattakainen, Oula

Pasanen, Hannu
Pekkarinen, Matias
Pirinen, Pekka
Pylväinen, Joonas
Ruhanen, Tuukka
Ruuskanen, Jaro
Saastamoinen, Janne
Sarala, Roope
Saunajoki, Ville
Selenius, Elli
Siilin, Kristiina
Siironen, Markku
Sirjonen, Ilkka
Sirviö, Iina
Suomalainen, Marko
Valkama, Markus

MSc DEGREES

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

Andrejeff, Tanja (physics)
Huttunen, Jukka (applied physics)
Hyppönen, Viivi (physics)
Jokiranta, Kaisa (physics)*
Jäntti, Henri (physics)*
Kronholm, Hanna (physics)*
Kronholm, Risto (physics)
Kurki, Pekka (physics)*
Kärkkäinen, Käpy-Maaria (physics)*
Lehtinen, Antti (physics)*
Luostarinen, Jasmin (applied physics)
Mononen, Tero (applied physics)
Nokelainen, Johannes (theoretical physics)
Ojanperä, Juha-Matti (theoretical physics)
Pekkarinen, Matias (applied physics)
Peuron, Jarkko (theoretical physics)
Pirinen, Pekka (theoretical physics)
Pohjolainen, Emmi (physics)
Romppanen, Kari (applied physics)
Ruhanen, Tuukka (physics)
Saikko, Juuso (physics)*
Saunajoki, Ville (physics)
Siironen, Markku (physics)*
Vihonen, Sampsa (theoretical physics)
Väisänen, Matti (physics)*

PhD DEGREES

Isotalo, Tero (physics)
Alho, Timo (theoretical physics)
Herranen, Olli (applied physics)
Lehtinen, Janne (physics)
Yotprayoonsak, Peerapong (physics)
Helenius, Ilkka (theoretical physics)
Kral, Jiri (physics)
Paatelainen, Risto (theoretical physics)
Pääkkönen, Mikko (theoretical physics)
Klemetti, Rudolf (physics)
Kouko, Jarmo (applied physics)
Kilappa, Vantte (physics)
Peura, Pauli (physics)

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