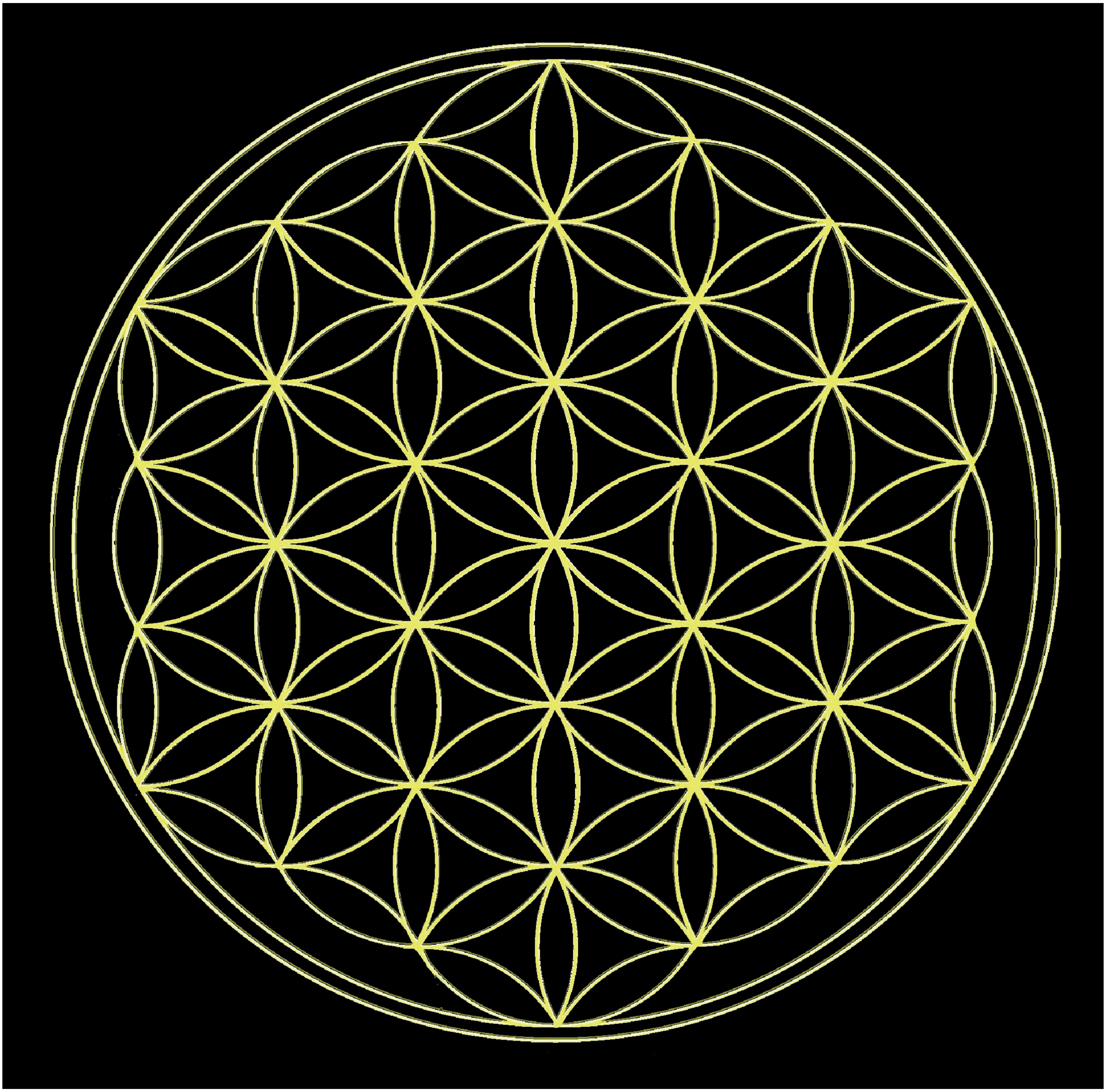
ANNUAL REPORT 2016



Department of Physics

UNIVERSITY OF JYVÄSKYLÄ

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PREFACE

This Annual Report presents the highlights of the activity of the Department of Physics in the year 2016.

RESEARCH. The research in the Department focuses on two main areas, subatomic physics and materials physics. Both fields are recognized in the University's profiling strategy. The research activity has in 2016 maintained its high level. The total number of scientific publications was about 370, out of which about 300 appeared in peer-reviewed journals. The number of foreign visitors, as well as the number of scientific visits of our own personnel, were considerably higher than in the previous year.

The experimental facilities are under continuous development. The ion source facility HIISI, the vacuum-mode recoil-mass spectrometer MARA, and the helium ion microscope or HIM belong to the most recent additions to our infrastructure.

The liaison with the Helsinki Institute of Physics plays an important role in the Department's research in subatomic physics, for both experimental and theoretical studies.

EDUCATION. In 2016, some 70 new students enrolled at the Department. The number of applicants decreased by 15 %, a worrying trend common to all natural sciences and shared with other universities. Recruiting students forms a challenge to us for the years to come. The number of master graduates (35) returned to its normal level after two weaker years. The number of doctor's degree was 16, one of our highest of all time.

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. The results obtained so far encourage us to put even more emphasis onto peer learning and self-directed studies. During the curriculum reform that takes effect in the autumn semester 2017, our main focus has been in basic studies. The studies in mathematical methods are partly replaced by compulsory minor subject studies in mathematics, the role of computational methods is increased, and the teaching of modern physics has been given more emphasis than before.

According to a survey conducted at the University level and aimed at master students who graduated in 2011, the teaching of the Department is held in quite high regard. The full 100 % of the physics students taking part in the survey were satisfied with the education they obtained in the Department. They also find their education to meet well the demands of their present work. This shows that our standards of teaching are set on a high enough level and the curriculum is suitable for physicists' work markets.

ADMINISTRATION. The total funding of the Department was 15.5 M€. The outside funding forms 43 % of the total funding, and its main sources are the Academy of Finland (3.9 M€) and the European Union (1.1 M€).

The year 2016 was marked by the reform of the university services, which influenced the operations of the Department in many respects and meant a move to new postings for most of our former administrative personnel. Our effective and well-knit departmental services were replaced by a more scattered arrangement, whose advantages for us remain to be seen.

EVENTS. One remarkable milestone was reached in 2016 when Professor Juha Äystö retired from his position. A large audience gathered to listen to Juha's farewell lecture, where he illuminatingly described the road of the Department and its Accelerator Laboratory from a small group of pioneers to an excellent research institution. Juha, with his fine scientific and administrative contributions, has played a major role in this success story.

The European Researchers' Night in September was a most successful outreach event making the scientists' work familiar to the wide audience. An amazing number of interested people (almost 1700) visited the Department during the event. The coordinators of the event in our University and Finland on the whole were from our Department.

Jukka Maalampi
Head of Department

SOME STATISTICAL DATA FROM 2016

Personnel	~170
- Professors incl. Research professors	19
- University lecturers and researchers	30
- Postdoctoral researchers	24
- Doctoral students	~70
- Technicians	27
- Administration	5
+ Several research assistants (MSc students)	
Undergraduate students	~410
of which new students	~70
Doctoral students	~70
BSc degrees	40
MSc degrees	35
PhLic degrees	3
PhD degrees	16
Median time to complete MSc (years)	6
Number of foreign visitors	267
- in visits	319
Visits abroad	332
Peer reviewed publications	~300
Conference proceedings	~40
Other (articles in books etc.)	~25
Conference and workshop contributions	
- Invited talks	~140
- Other talks	~100
- Posters	~50
Funding (million €)	15,2
- University budget (incl. premises)	8,8
- HIP cooperation	0,7
- External funding	5,7
* Academy of Finland	3,6
* European Union	1,1
* Technology Development Centre, European regional development fund	0,1
* Contract research	0,5
* Other	0,5

In addition the Department received 0,7 million euros for research infrastructures.

ACCELERATOR LABORATORY

Ari Jokinen

The Accelerator Laboratory is an integral part of the Department of Physics. Presently it includes four accelerators with a variety of ion sources and innovative instrumentation for basic research, ion-beam based material physics and applications.

https://www.jyu.fi/fysiikka/en/research/accelerator/

Demand for beam time remains high. Altogether 27 new proposals were submitted to the Program Advisory Committee (PAC) in 2016. In addition to the PAC proposals, a significant fraction of the beam time is given directly for commercial use. The request for the latter exceeded the allocated beam time. K130 accelerator provided 5650 hours of beam time for basic research and industrial applications in 2016.

The year 2016 was the second year of the second 3-year period of the present Centre of Excellence (CoE) in Nuclear and Accelerator-Based Physics. Funding for the CoE is granted by the Academy of Finland and the level of funding for the second period 2015-2017 is similar to the first period in 2012-2014.

JYFL-ACCLAB is the only national infrastructure on the roadmap of the Ministry of Education and Culture (OKM) for 2017-2020 in the category "Natural Sciences and Technology". A position on the roadmap shows the importance of the facility nationally and supports national infrastructure funding (FIRI) proposals. In 2016, the Accelerator Laboratory applied successfully for funding to the level of 1.31 M€ for a project covering various topics: Germanium detectors for MARA and IGISOL, development of a novel Auger electron spectrometer for use with the Helium Ion Microscope and to equip beam lines for reaction studies. The funding granted will also allow procurement of an AGATA module, representing the Finnish contribution to the next generation gamma-ray tracking spectrometer.

In the new strategy of University of Jyväskylä for 2015-2020, the study of basic natural phenomena is recognized as research strength with accelerator-based physics as one of the key disciplines. In 2015, the university profiling scheme commenced, which included the Accelerator Laboratory. As a result, two new professors, Timo Sajavaara and Iain Moore were hired to strengthen and widen the research program of the Accelerator Laboratory.

The Accelerator Laboratory is a partner in the Horizon 2020 proposal ENSAR2 which started in March 2016. ENSAR2 has provided support for external users since March 2016 and such a support is available for four-year period 1.3.2016-28.2.2020.

The 12th European Conference on Accelerators in Applied Research and Technology was organized in Jyväskylä 3-8 July 2016. There were in total 141 participants from 31 countries and six industrial exhibitors. The meeting was chaired by Timo Sajavaara together with co-chairs Kai Arstila and Ari Virtanen. The next meeting, ECAART13, will be held in Split, Croatia in May 2019.

Commercial services continued with 44 campaigns for 22 different companies, institutes or universities by using 1142 hours of K-130 beam time in 2016. This corresponds to approximately 20 % of the K-130 beam hours. The total revenue of RADEF (commercial and R&D projects) in 2016 was for the first time over 1 M€. The RADEF facility remains an accredited laboratory of European Space Agency (ESA). ESA has further supported the Accelerator Laboratory for the years 2015 - 2017 with partial funding of the new ECR ion source HIISI and by supporting the commissioning of the new e-linac. The e-linac will play a crucial role in testing the radiation hardness of components to be included in the Jupiter Mission. Already three campaigns at electron LINAC after the ESA-commissioning in April 2016 were performed.

Scientists of the Accelerator Laboratory participate actively in the research and development at FAIR and ISOLDE. The final commissioning of the SPEDE spectrometer, developed at JYFL, was completed with a stable ion beam at HIE-ISOLDE. The development of GEM-TPC beam tracking detectors for FAIR has progressed well with on-line tests at GSI and JYFL in 2016. This work is done in close collaboration with the Detector Laboratory of Helsinki Institute of Physics.

The former long-time head of the Accelerator Laboratory, Professor Juha Äystö, who played a significant role in the development of the JYFL Accelerator Laboratory such that it is now an internationally recognised nuclear physics research facility, retired in June 2016.

The European Researchers' Night took place across Europe on the 30th of September 2016. About 1000 people attended the event at the Accelerator Laboratory participating in a number of tours around the experimental facilities, lectures and interactive demonstrations. The European Researchers' Night event will be organised in the laboratory also in 2017.

Administration and contact persons:
Head of the Accelerator Laboratory: Ari Jokinen
Leader of the Center of the Excellence: Rauno Julin
Beam time coordinator: Mikael Sandzelius

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory:
Michael Bender, Université de Bordeaux, France
Jon Billowes, University of Manchester, UK
Bertram Blank, CEN Bordeaux-Gradignan, France (chair)
Bo Cederwall, KTH Stockholm, Sweden
Fadi Ibrahim, IPN Orsay, France
Silvia Lenzi, University of Padova, Italy

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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

THE FIDIPRO

K. Bennaceur, J. Dobaczewski, M. Kortelainen

In 2016, the FIDIPRO project entered the penultimate year of being funded by the second FIDIPRO grant awarded by the Academy of Finland and matched by the University of Jyväskylä. The FIDIPRO team included six researchers working together on common project goals. The main focus of the group was in initiating a new activity to look for ab initio derivations of nuclear functionals, and in studying configuration mixing in light nuclei, dipole resonances in heavy nuclei, and surface properties of effective Skyrme interactions.

www.jyu.fi/accelerator/fidipro/

AB INITIO DERIVATION OF MODEL ENERGY DENSITY FUNCTIONALS

We proposed a simple and manageable method [1] that allows for deriving coupling constants of model energy density functionals (EDFs) directly from ab initio calculations performed for finite fermion systems. A proof-of-principle application allows for linking properties of finite nuclei, determined by using the nuclear nonlocal Gogny functional, to the coupling constants of the quasilocal Skyrme functional. The method does not rely on properties of infinite fermion systems but on the ab initio calculations in finite systems. It also allows for quantifying merits of different model EDFs in describing the ab initio results.

NO-CORE CONFIGURATION-INTERACTION MODEL

We proposed a new variant of the no-core-configuration-interaction (NCCI) model [2] treating properly isospin and rotational symmetries. The model is applicable to any nucleus irrespective of its mass and neutron and proton-number parity. It properly includes polarization effects caused by an interplay between the long- and short-range forces acting in the atomic nucleus. The method is based on solving the Hill-Wheeler-Griffin equation within a model space built of linearly dependent states having good angular momentum and properly treated isobaric spin. The states are generated by means of the isospin and angular-momentum projection applied to a set of low-lying (multi)particle-(multi)hole deformed Slater determinants calculated using the self-consistent Skyrme-Hartree-Fock approach.

We applied the model to calculate energy spectra in N~Z nuclei that are relevant from the point of view of a study of superallowed Fermi β decays. In particular, a new set of the isospin-symmetry-breaking corrections to these decays was given. We demonstrated that the NCCI model is capable of capturing main features of low-lying energy spectra in light and medium-mass nuclei using relatively small model space and without any local readjustment of its low-energy coupling constants. Its flexibility and a range of applicability makes it an interesting alternative to the conventional nuclear shell model.

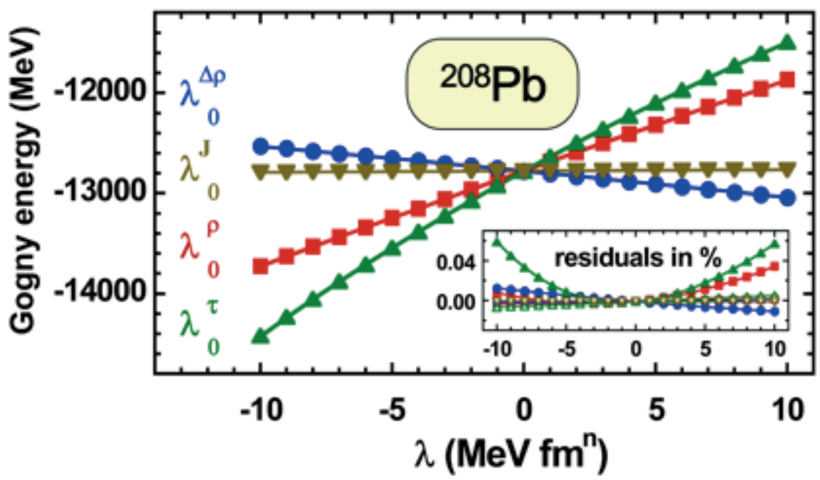

Figure 1. Isoscalar Gogny energies (lines) compared with the EDF estimates (symbols) obtained for the Skyrme EDF S1Sd coupling constants. Calculations were performed in 208Pb in function of the four Lagrange multipliers. The inset shows residuals of the adjustment in per cent.

GIANT DIPOLE RESONANCES IN HEAVY RARE-EARTH NUCLEI

Recently, the finite amplitude method (FAM) was developed in order to perform the QRPA calculations efficiently without any truncation on the two-quasiparticle model space. In [3], we discussed the nuclear giant dipole resonances (GDRs) in heavy rare-earth isotopes, for which the conventional matrix diagonalization of the QRPA is numerically demanding. The electric dipole photoabsorption cross sections were calculated within a parallelized FAM-QRPA scheme. We employed the Skyrme energy density functional (EDF) self-consistently in the DFT calculation for the ground states and FAM-QRPA calculation for the excitations. The mean GDR frequencies and widths are mostly reproduced with the FAM-QRPA, when compared to experimental data, although some deficiency is observed with isotopes heavier than erbium. The newly developed FAM-QRPA scheme shows remarkable efficiency, which enables one to perform systematic analysis of GDR for heavy rare-earth nuclei.

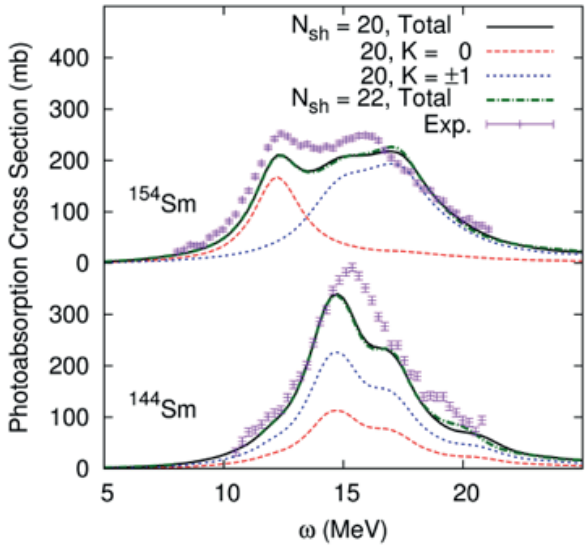

Figure 3. Photoabsorption cross sections of 144,154Sm from the FAM-QRPA calculation with 20 harmonic oscillator shells. The components from the K = 0 and K = ±1 modes are separately plotted, where K = ±1 refers to a sum of +1 and -1 modes. The total photoabsorption cross section, calculated with 22 oscillator shells, is also included in the plot.

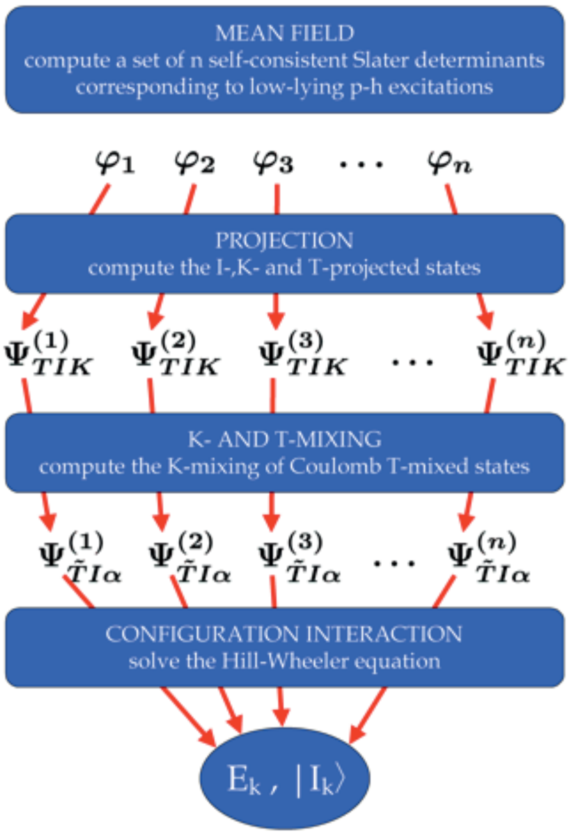

Figure 2. Computational scheme of the NCCI model.

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[1] J. Dobaczewski, *Ab initio derivation of model energy density functionals*, J. Phys. G: Nucl. Part. Phys. 43, 04LT01 (2016)

[2] W. Satuła, P. Bączyk, J. Dobaczewski, and M. Konieczka, *No-core configuration-interaction model for the isospin- and angular-momentum-projected states*, Phys. Rev. C94, 024306 (2016)

[3] T. Oishi, M. Kortelainen, and N. Hinohara, *Finite amplitude method applied to giant dipole resonance in heavy rare-earth nuclei,* Phys. Rev. C93, 034329 (2016)

ION SOURCE RESEARCH AND DEVELOPMENT

Hannu Koivisto, Olli Tarvainen, Taneli Kalvas, Janne Laulainen, Risto Kronholm, Muneer Sakildien

The ion source group has long experience in ion source related research and development work. The present work can be divided into four separate domains: 1) development of ECR ion sources and different kind of light ion sources (covering both positive/negative ions), 2) development of ion beams in terms of ion beam variety and quality, 3) development of plasma and ion beam diagnostics and 4) plasma research. Computational physics plays a significant role in the afore-mentioned R&D work.

As a result of long-lasting and decisive high-quality work the JYFL ion source group has received an active role in the international ion source community. During 2016 very fruitful joint R&D have been carried with the ion source groups of CERN, GANIL, IAP-RAS, iThemba LABS, LBNL, LPSC and NSCL. The JYFL ion source group is also coordinating networking activity, ENSAR2/MIDAS, in Horizon 2020 program. More information about the networking can be found from:

www.ensarfp7.eu/activities/networking-activities/midas

HIGHLIGHTS IN 2016

Status of the new heavy ion source (HIISI): The objective of the 18 GHz heavy ion source HIISI is to substantially increase the ion beam intensities for the nuclear physics program and the LET value of ion beams for the space electronics testing. An innovative, refrigerated large-bore permanent magnet structure makes efficient plasma heating at 18 GHz possible. At the end of 2016 the construction of HIISI has almost been completed and the construction of the injection beam line has been started. Figure 1 shows the water-cooling lines for the plasma chamber and the coolant line for the permanent magnets sextupole. Magnets can be cooled down to about -20°C, which considerably increases their ability to resist demagnetization.

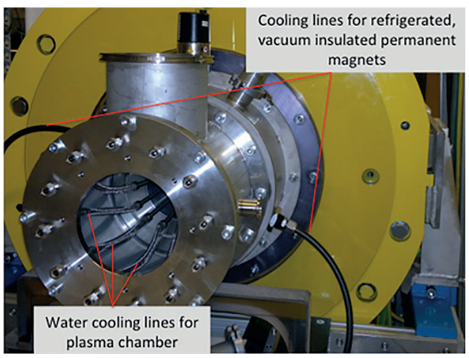

Figure 1. The cooling lines of the HIISI plasma chamber and the sextupole permanent magnets.

Visible light plasma spectroscopy: Visible light spectrometer is very efficient non-invasive tool to provide information from highly charged ion source plasma. The first experiments with a commercially available visible light spectrometer revealed very complex and interesting emission spectrum of ECR ion source plasma. However, as is demonstrated in Fig. 2 the resolving power of the spectrometer was inadequate (≈ 2 nm optical resolution) to resolve different emission lines and therefore a more powerful spectrometer (≈ 30 pm resolution) was developed by the JYFL ion source group. The resolving power of the spectrometer, named POSSU, is demonstrated in Fig. 2. This unique combination of high-resolution spectrometer and highly charged plasma will open opportunities for new discoveries and therefore will advance ion source research. It offers an access, first time, to experimentally define ion temperature directly from ECRIS plasma. The POSSU spectrometer, its control and data acquisition system are shown in Fig. 3.

Plasma instabilities: Plasma instability measurements were continued by measuring broadband microwave emission of JYFL 14 GHz ECRIS [1,2]. The dynamic spectrogram was constructed, which revealed that the power of cyclotron emission can be several kW. In addition, it was found that the emission frequency covers wide frequency range of at least 6-26 GHz.

Photoelectron emission from Cs coated surface: Low temperature hydrogen plasma induced photoelectron emission measurements have been performed to provide fundamental data to researchers working on plasmas bounded by walls (like ion sources for particle accelerators). Our earlier results, with clean metal surfaces, have shown that the total plasma induced photoemission is of the order of 1 A/kW used for plasma heating. New experimental results have shown that a thin layer of Cs on metal surface can increase the afore-mentioned plasma induced photoelectron emission by a factor of 2-3.5 at optimal layer thickness. The results can be used, for example, to improve a numerical simulation model to predict performance of various kinds of plasma devices.

Volumetric Kα emission: A silicon drift detector (SDD) was used to study characteristic radiation of ECR plasma. The experiments revealed information about the parameters affecting the volumetric rate of inner shell ionization. The study was performed using argon plasma and measured emission rates can be used as an additional tool for benchmarking the numerical plasma simulation codes.

New diagnostic tool for charge breeder: During the international EMILIE project a new diagnostic tool was developed to provide information about the plasma of charge breeders. In this method, a 1+ beam is injected through the charge breeder. The method gives information for example about the plasma densities and thermalisation processes [3].

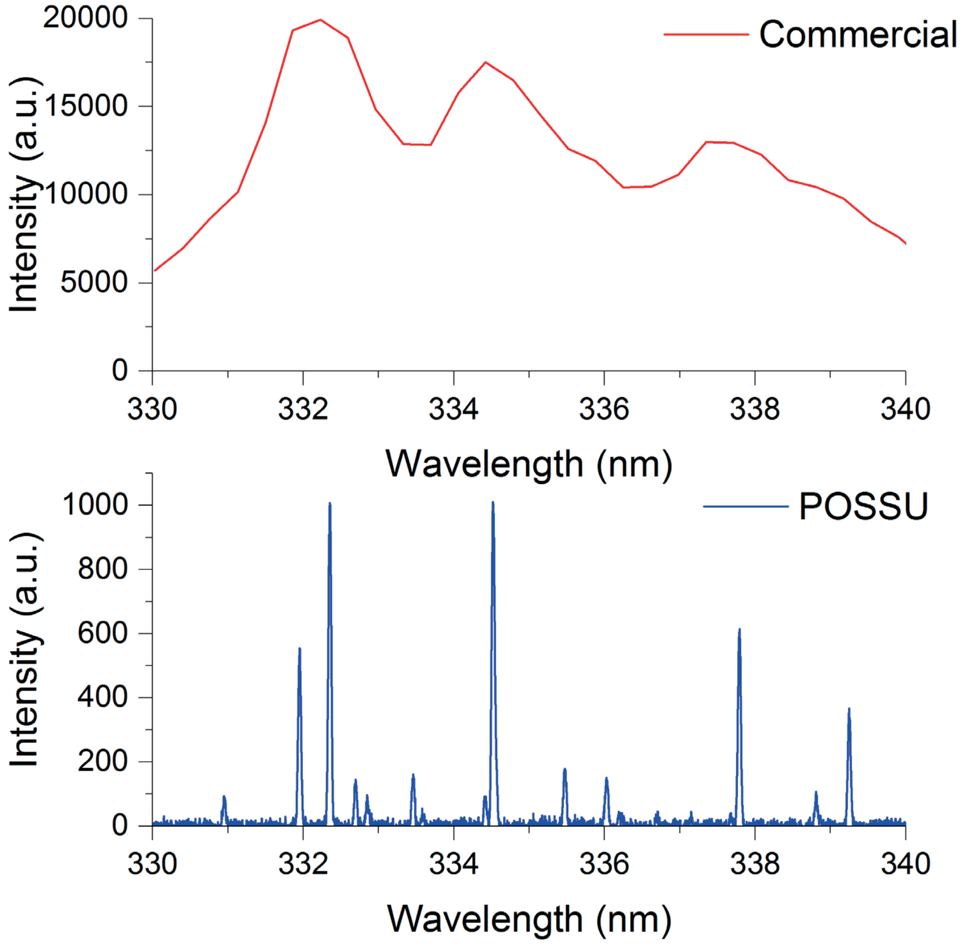

Figure 2: Visible light spectrum using commercial device and high-resolution spectrometer (POSSU) developed by the JYFL ion source group.

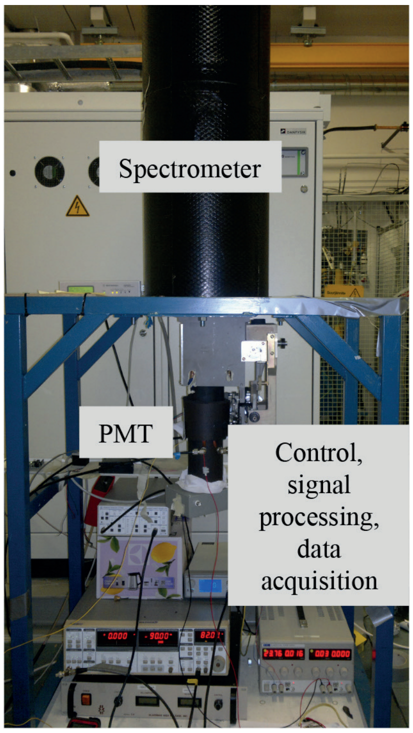

Figure 3. High-resolution spectrometer POSSU.

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[2] D. Mansfeld, I. Izotov, V. Skalyga, O. Tarvainen, T. Kalvas, H. Koivisto, J. Komppula, R. Kronholm and J. Laulainen, Dynamic regimes of cyclotron instability in the afterglow mode of minimum-B electron cyclotron resonance ion source plasma, Plasma Physics and Controlled Fusion, 58(4), (2016), 045019.

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EXOTIC NUCLEI AND BEAMS

Anu Kankainen, Iain Moore and Heikki Penttilä

The exotic nuclei and beams group studies properties of nuclei employing Penning-trap mass spectrometry as well as laser and decay spectroscopy at the IGISOL-4 facility. In 2016 the number of major nuclear physics experiments was lower than usual; instead, a significant effort was invested into improving the ion beam transmission to and through the JYFLTRAP Penning trap, resulting in record-breaking transmissions of over 30 % from the IGISOL switchyard to the post-trap setup. The improvement allowed the measurement of atomic masses for extremely exotic rare-earth nuclei including ^{158}Nd, ^{160}Pm and ^{166}Gd, as well as performing beta-delayed gamma-ray spectroscopy of neutron rich ^{128,130}In.

Our group has benefited from the EU FP7 and Horizon 2020 programs within ENSAR2, CHANDA and nuClock projects. The research at IGISOL is strongly supported by the Academy of Finland with two Academy Research Fellows and an Academy postdoctoral researcher working in the group. The Academy's FIRI funding has been essential for renewing our research infrastructure. We have also actively participated in international collaborations in research and development work at other facilities, including GANIL, ISOLDE (CERN) and GSI, the site of the future RIB facility FAIR. Many of our international activities were carried out in close collaboration with the Helsinki Institute of Physics.

www.jyu.fi/accelerator/igisol

TECHNICAL DEVELOPMENTS

Magneto-optical trapping of Cs atoms. A team from University College London (UCL) has set-up a magneto-optical trap (MOT) for cold caesium atoms at IGISOL. The trap is now fully operational and atoms are routinely cooled down to hundreds of micro Kelvin, and trapped. This is the first step of a long-term project between the UCL "cold atom team" led by Ferruccio Renzoni, and JYFL-ACCLAB. The final aim is to trap and cool neutral 135mCs fission isomers, with a view to exploring collective nuclear effects.

Post-trap decay spectroscopy was also substantially developed at IGISOL in 2016. In order to host more germanium detectors around the beta detector and to perform γ-ray angular correlation measurements, a hemisphere detector frame has been constructed and installed in collaboration with the group from the University of Warsaw. The hemisphere detector array has been successfully tested off-line, and on-line measurements will take place in 2017. In addition, the local digital data acquisition system has been further developed for the needs of typical IGISOL experiments.

Other important developments include commissioning of the off-line test ion source as well as expansion of the cw laser system for laser spectroscopy in collaboration with the University of Liverpool and with FIRI support by the Academy of Finland. The heavy-ion induced reaction ion guide (HIGISOL) platform and control system was upgraded and successfully tested in 2016. The development of a neutron-induced fission-based ion guide continued in collaboration with the University of Uppsala. The FIRI-funded MR-TOF and PI-ICR projects for faster and more precise mass measurements at JYFLTRAP have progressed nicely, and the commissioning of the PI-ICR technique will take place in 2017.

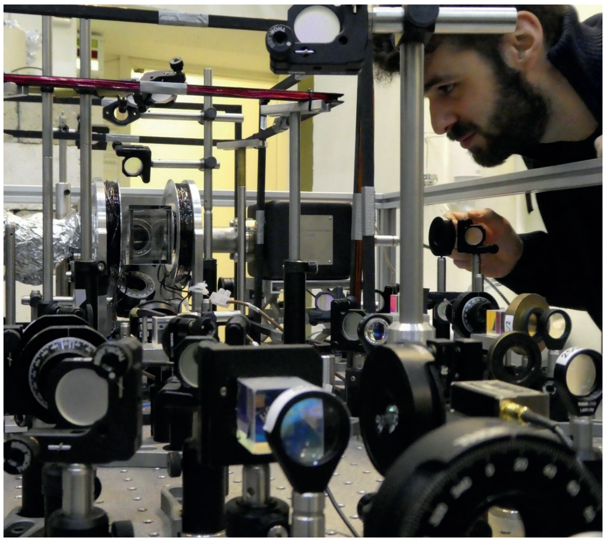

Figure 1. Alexandros Giatzoglou from University College London optimizing the Cs atom trap.

RESEARCH HIGHLIGHTS

Several important mass measurement papers from JYFLTRAP were published in 2016. Highlights include the high-precision Q-value measurements for neutrino physics at A=96, and the masses of ^{25}Al, ^{30}P and ^{31}Cl for nuclear astrophysics. In autumn 2016, we had the first mass measurement campaigns on neutron-rich nuclei after the recommissioning of JYFLTRAP at IGISOL-4 in 2014. Thanks to the improved transmission and upgrade of the IGISOL facility, nuclei that could not be measured at the old IGISOL facility, such as ^{137}Sb, were now successfully measured. The mass measurements were extended to the heavier fission-fragment region relevant for the formation of the rare-earth peak in the astrophysical r process. There, we could measure nuclei including ^{158}Nd, ^{160}Pm and ^{166}Gd, whose mass values have previously been based only on extrapolations. Of these, ^{160}Pm is so exotic that it cannot be even found from the Karlsruher Nuklidkarte 2012 edition. The mass measurement campaign was supported by a successful post-trap decay spectroscopy study to identify isomeric states observed in indium isotopes.

Figure 2. Research careers start from studies. Laboratory exercise in the "Experimental Methods in Nuclear and Accelerator-Based Physics" course at IGISOL involves on-line mass separation of isotopes produced using the MCC30 cyclotron. Exercise group in spring 2016 mentored by Sami Rinta-Antila.

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M. Alanssari, et al., *Decay Q-values among the triplet* ^{96}Zr, ^{96}Nb and ^{96}Mo, Physical Review Letters 116 (2016) 072501 DOI: 10.1103/PhysRevLett.116.072501

I. Pohjalainen, et al., *In-gas-cell laser ionization studies of plutonium isotopes at IGISOL*, Nuclear Instruments and Methods B 376: 233 -239 (2016) DOI: 10.1016/j.nimb.2016.02.019

A. Kankainen, L. Canete et al., *Mass of astrophysically relevant* ^{31}*Cl and the breakdown of the isobaric multiplet mass equation,* Physical Review C 93, 041304(R) (2016) DOI: 10.1103/PhysRevC.93.041304

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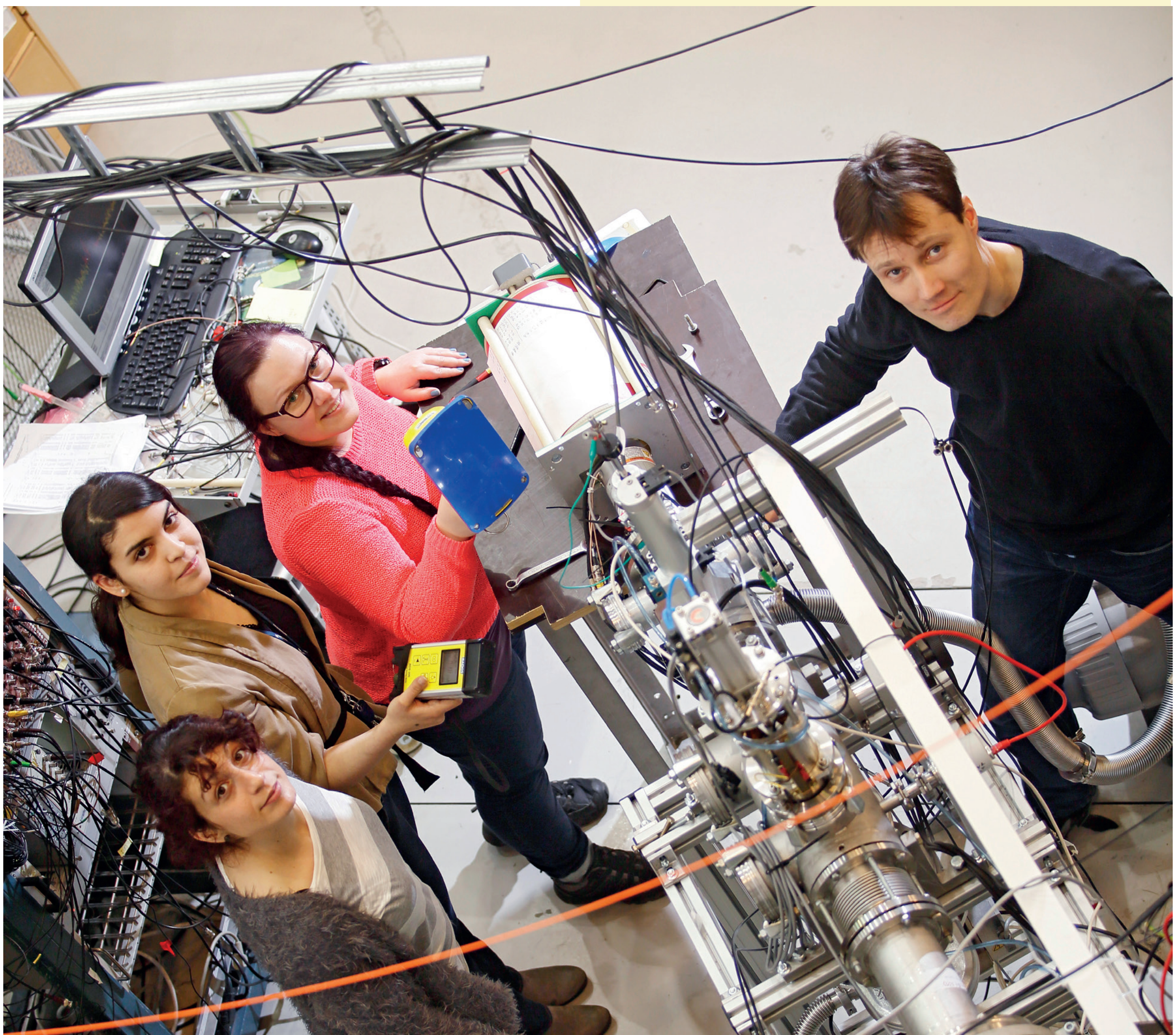

NUCLEAR SPECTROSCOPY

Paul Greenlees, Juha Uusitalo, Jan Sarén, Tuomas Grahn, Daniel Cox, Janne Pakarinen, Philippos Papadakis, Mikael Sandzelius

The group is one of the largest in the Accelerator Laboratory whose work is focused on fundamental studies of the structure of the nucleus. The main focus of the research is on experimental investigations into heavy and neutron-deficient nuclei, using in-beam and decay spectroscopic techniques. As in previous years, the group used a significant proportion of the K130 cyclotron beam time, using a total of 120 days for 11 different experiments. The group members were co-authors on 20 peer-reviewed journal articles and 7 conference proceedings. Some highlights from the year are presented in the following pages.

www.jyu.fi/fysiikka/en/research/accelerator/nucspec/

MARA ENTERS PRODUCTION MODE

An extensive campaign of commissioning experiments was performed using the recently constructed vacuum-mode in-flight mass separator MARA. The experiments employed fusion evaporation reactions with differing kinematics: normal asymmetric, symmetric, and inverse kinematics. Such reactions will to be used to study nuclei in forthcoming experimental campaigns. Simultaneously several new detector systems such as double-sided silicon strip detectors BB17 and BB20 (into which the recoiling nuclei are implanted), were tested. The full focal plane detection system consists of additional silicon detectors, a position sensitive multi-wire proportional counter and a germanium-detector array. At the target position, charged-particle scintillator detector array and germanium detectors for γ-rays were mounted. All these detectors were connected to a fully-digital data acquisition system, totaling over 400 channels. These commissioning tests showed that MARA works as expected from simulations. Scattered components (from beam or target) coming through the separator and reaching the focal plane are at a level which can be easily tolerated. The completed commissioning runs proved that MARA is ready for experimental campaigns. In addition, an experiment using ^{78}Kr beam on ^{96}Ru and ^{92}Mo targets to search for new proton emitter(s) was performed, reading fast "traces" from the digital electronics. The experiment yielded evidence for two new isotopes: ^{165}Pt, a new alpha emitter and ^{169}Au, a new proton emitter with a half-life on the μs scale.

TRANSITION PROBABILITIES IN ^{168}Os

Transition probabilities in the very neutron-deficient nucleus 168Os were measured using the Köln plunger device combined with the JUROGAM and RITU spectrometers. The results of this work are puzzling. In collective models transition probabilities increase as a function of the angular momentum within a band. According to our measurements, the reverse happens in ^{168}Os, the $B(E2;4^+\rightarrow2^+)/B(E2;2^+\rightarrow0^+)=0.34(18)$. Our results cannot be reproduced by any relevant nuclear models, thus challenging nuclear structure theory at the extremes of proton-to-neutron ratio. The collective B(E2) values and the fact that 168Os is rather far away from the closed shells mean that the generalised seniority scheme is not valid. Furthermore, coexisting structures have been observed closer to the neutron mid-shell and at higher excitation energy. The surprising results definitely warrant further investigation.

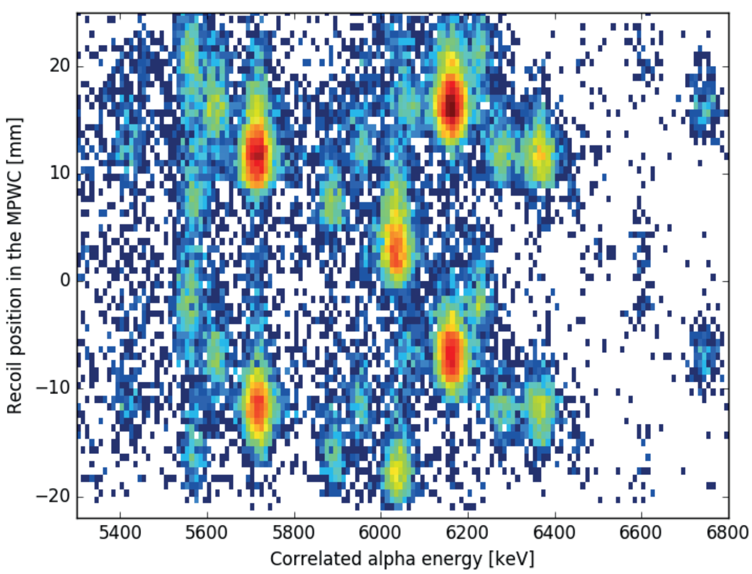

Figure 1. Matrix of m/q (mass-to-charge ratio) values of recoils correlated to alpha decays produced in the reaction of ^{78}Kr beam on a ^{96}Ru target. The x-axis shows α-particle energy and the y-axis the position of the correlated recoil in the MWPC.

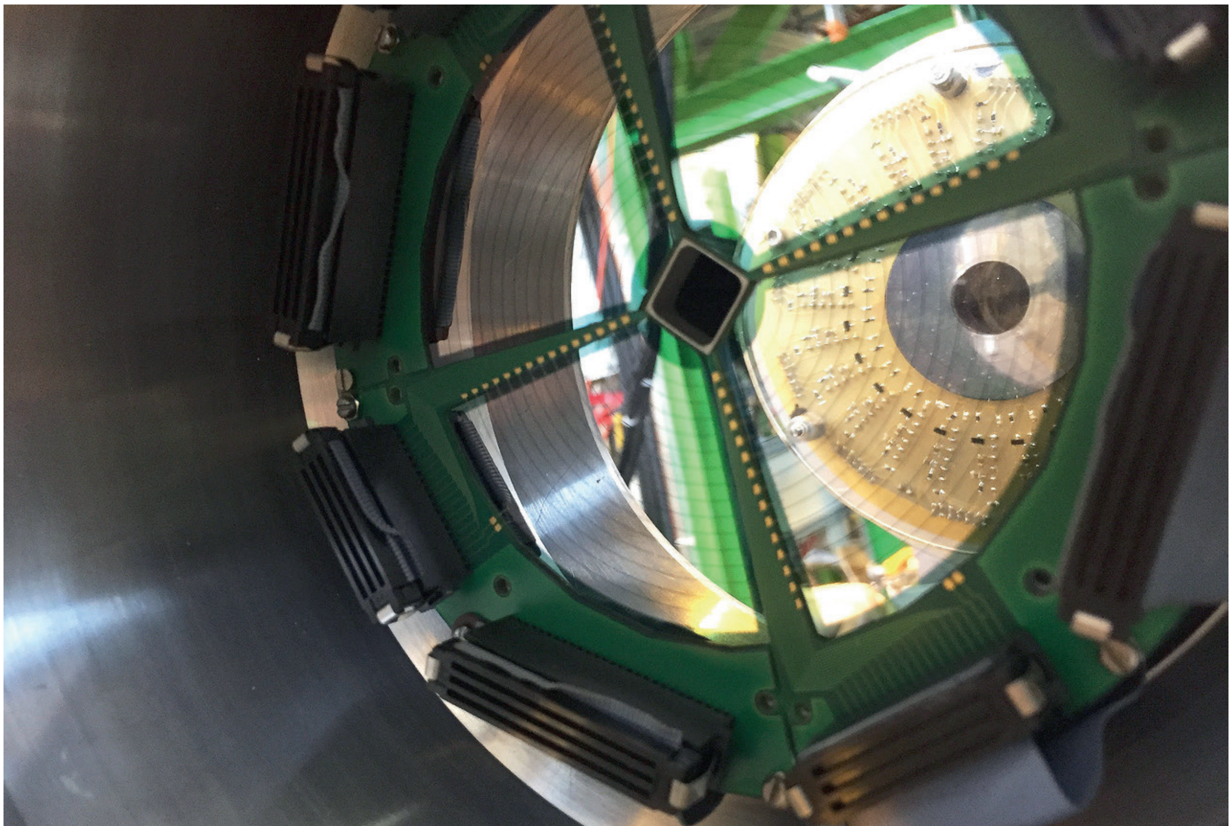

Figure 2. SPEDE installed in the MINIBALL chamber at CERN-ISOLDE.

SPEDE DEPLOYED TO CERN-ISOLDE

The conversion electron spectrometer SPEDE has been developed by an international collaboration led by Janne Pakarinen. SPEDE is employed at HIE-ISOLDE in CERN where it is coupled to the MINIBALL γ-ray spectrometer. Multi-step Coulomb excitation experiments are planned to investigate shape coexistence in the Pb region and octupole collectivity in Rn and Ra nuclei. In such experiments, significant internal conversion can occur and the combined electron and γ-ray measurements offered by SPEDE are essential in order to fully understand the experimental data.

SPEDE was successfully commissioned in CERN employing a ^{132}Xe beam from HIE-ISOLDE impinging on ^{158}Gd target at 4.5MeV/u in November 2016. The results are currently being analysed and publication is expected early in 2017. Four proposals employing SPEDE have been accepted by the INTC and are awaiting beam-time allocation.

BUSY SAGE CAMPAIGN COMPLETED

The fourth campaign using the combined conversion electron and gamma-ray spectrometer SAGE was run between January and June 2016.

Five different experiments were executed for a total of 55 days. Among these experiments, three targeted the heavy deformed shell region around N=152, where ^{254}No, ^{249}Md and ^{250}Fm were studied. In the neutron-deficient lead region, mid-shell nucleus ^{186}Pb in the heart of triple shape coexistence was revisited in a successful experiment to conclude the campaign. An experiment performed to study the neutron-deficient nucleus ^{224}U, aimed to investigate octupole collectivity, was a particular success and highlight of the campaign.

After initial problems with the high-voltage barrier were overcome SAGE performed to the best of its capacity throughout the campaign.

Source tests with a new thicker silicon detector (1.5 mm) were also carried out. Although the new detector is not yet in a reliable operational state, the preliminary tests and simulations indicate that it is possible to achieve higher efficiency above 300 keV. The new detector will form part of an upgraded SAGE for future campaigns, where SAGE could also be coupled to the MARA separator.

SELECTED PUBLICATIONS

In 2016 members of the Nuclear Spectroscopy were invited to write review articles on two the main research themes of the group – shape coexistence and superheavy elements.

Rauno Julin, Tuomas Grahn, Janne Pakarinen ja Panu Rahkila
In-beam spectroscopic studies of shape coexistence and collectivity in the neutron-deficient Z ≈ 82 nuclei
Journal of Physics G: Nuclear and Particle Physics, 43 (2) (2016)

Matti Leino
Production and properties towards the island of stability
EPJ Web of Conferences 131, 03002 (2016)

INSTRUMENTS AND METHODS IN NUCLEAR, PARTICLE, AND ASTROPARTICLE PHYSICS

Wladyslaw H. Trzaska

ALICE T0 AND FIT DETECTORS

With rapidly approaching start of the Long Shutdown 2 (LS2), the work on the new Fast Interaction Trigger (FIT) for the upgrade of the ALICE experiment continues to dominate the activity of our group.

www.jyu.fi/physics/accelerator/hendes

Fig.1. FIT collaborators during the October test at CERN. Currently there are about 50 scientists from 14 institutes in 6 countries working on FIT.

The 2019-20 upgrade of the CERN LHC injectors will boost the luminosity and the collision rate beyond the design parameters for several of the key ALICE detectors including the forward trigger detectors. FIT is being designed to remedy this problem. FIT will replace T0, V0, and FMD detectors to become the main forward trigger, luminometer, and collision time detector. It will also determine multiplicity, centrality, and reaction plane of heavy ion collisions. The first prototype of the Cherenkov module together with the frontend electronics is already installed and in operation at ALICE. The concept of the new detector and the first test results were presented at several conferences in 2016 including the 14th Vienna Conference on Instrumentation and the 38th International Conference on High Energy Physics.

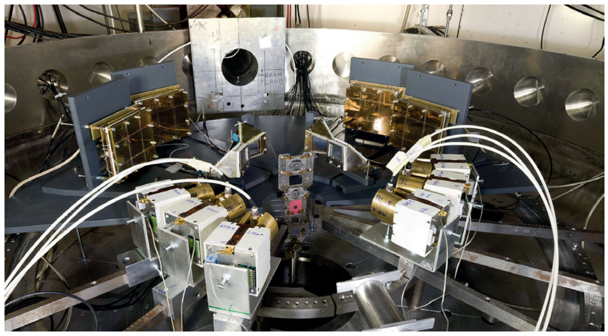

Fig. 2. Detector setup inside the Large Scattering Chamber for measuring fission-fusion reactions.

NUCLEAR REACTIONS

We have reactivated the sample shuttle for activity measurements following neutron irradiations. This system has worked well during several experiments. The latest, conducted in the summer, yielded cross section of the 18O(n,alpha)12C reaction. The measurement was a first step towards a future radioactive beam of 15C (T½ = 2.5 s). The required neutron fluxes were generated by 22 – 55 MeV deuterons on 12C and D_2O converters. The resulting neutron spectra were unfolded using known cross sections of neutron-induced reactions on elements producing suitable gamma-decay signatures. For that reason several metallic foils were activated in addition to H_2O samples 80% enriched in 18O.

The highlight of the year was EXON 2016 – the VIII International Symposium on EXOtic Nuclei held on 4-10 September in Kazan. In total there were 8 oral and 16 posters presented by members of our Russian – Finnish collaboration.

EMMA EXPERIMENT

Despite lack of direct funding EMMA continues taking data. All 11 stations are now completed and 7 are connected to the DAQ. The main emphasis is on the data from the three central tracking stations. We have finalized a code to analyze muon arrival direction and multiplicity, and a code to monitor detector efficiency and correct for air pressure changes. Also a code to determine the muon multiplicities with SC16 scintillator detector has been completed and is being used to determine single-muon flux at the depth of 75 meters. Part of the SC16 detectors is still in Canfranc Underground Laboratory in Spain measuring directional muon flux at two locations at the depth of approximately 900 meters.

In 2016 the Center of Underground Physics in Pyhäsalmi was a training base for eight summer students (5 from France, 2 from Finland, 1 from Poland) and a venue for four international workshops. Our R&D on neutrino detectors at CUPP is presented in the Neutrino Physics section of this Annual Report.

Fig. 4. Members of EMMA Collaboration celebrating the third Ph.D. resulting from the activities at the Center of Underground Physics in Pyhäsalmi.

Fig.3. Summer students from CUPP during the visit to the Accelerator Laboratory

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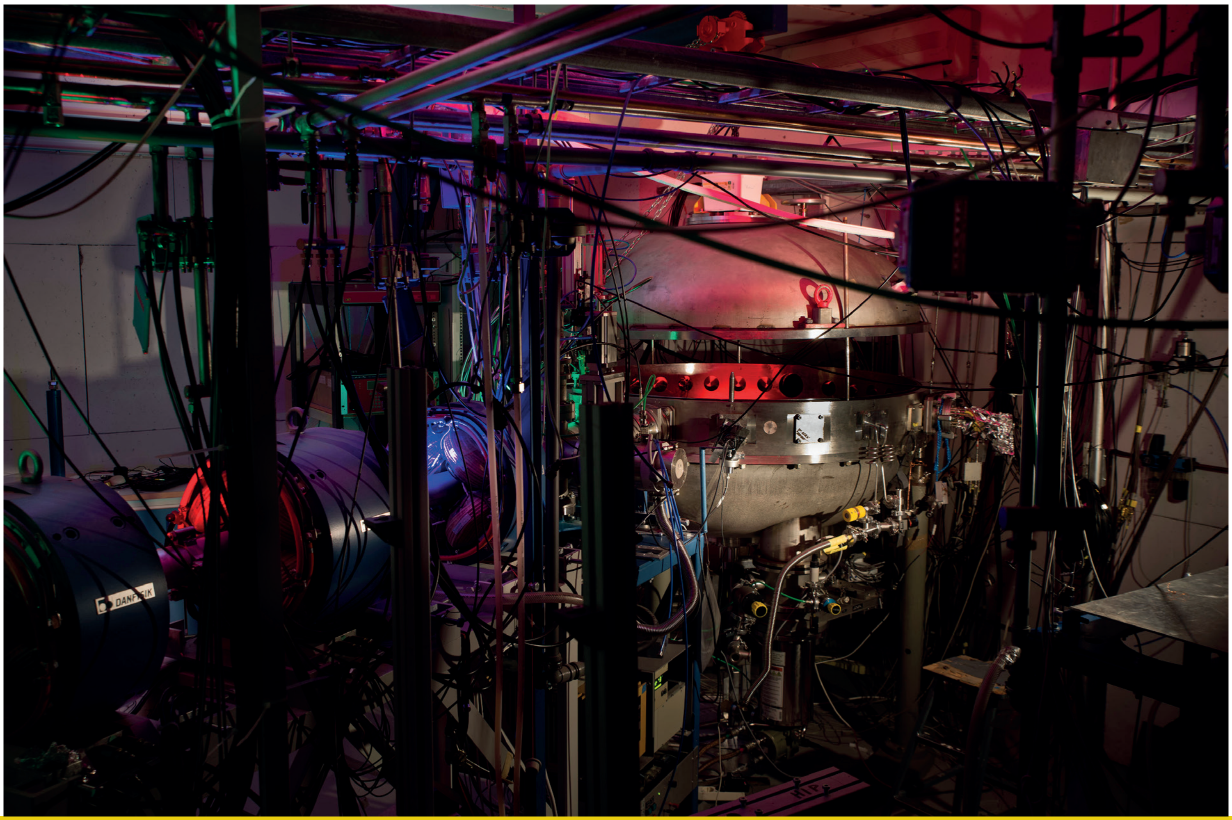
[1] W.H.Trzaska on behalf of ALICE Collaboration, Nuclear Instruments and Methods in Physics Research A 845(2017)463–466. http://dx.doi.org/10.1016/j.nima.2016.06.029

[2] G. Lhersonneau, T. Malkiewicz, M. Fadil, D. Gorelov, P. Jones, P. Z. Ngcobo, J. Sorri, W. H. Trzaska, Eur. Phys. J. A (2016) 52: 364. http://dx.doi.org/10.1140/epja/i2016-16364-x

[3] P. Kuusiniemi, T. Enqvist, L. Bezrukov, H. Fynbo, L. Inzhechik, J. Joutsenvaara, Kai Loo, B. Lubsandorzhiev, V. Petkov, Maciej Slupecki, Wladyslaw Trzaska ja A. Virkajärvi, Journal of Physics: Conference Series 718 (2016) 052021. http://dx.doi.org/10.1088/1742-6596/718/5/052021

Fig. 5. Illumination of the Large Scattering Chamber for Researchers Night – the main outreach event of 2016.



ACCELERATOR-BASED MATERIALS PHYSICS

Timo Sajavaara

The research activities of the group can be divided into three main areas: i) fundamental studies of ion–matter interactions, ii) detector, data acquisition and analysis software development and iii) application of ion beam techniques for materials and thin film studies. The key infrastructure of the group is the 1.7 MV Pelletron accelerator and all the research equipment in its beamlines. In Nanoscience Center (NSC) clean room the group is a very active user of a helium ion microscope (HIM) and a versatile atomic layer deposition (ALD) tool. The group is an active link between the two research infrastructures Accelerator Laboratory and Nanoscience Center. In addition, the group focuses strongly in detector development related to the ion beam techniques. The group is also tightly linked to the other thin film research groups and industry in Finland.

www.jyu.fi/accelerator/abasedmat/

ELASTIC RECOIL DETECTION ANALYSIS DEVELOPMENT

The performance of a time-of-flight spectrometer consisting of two timing detectors and an ionization chamber energy detector was studied using Monte Carlo simulations for the recoil creation and ion transport in the sample and detectors [1]. Complete time-of-flight–energy histograms (Fig.1) were simulated under realistic experimental conditions. The simulations were used to study instrumentation related effects in coincidence timing and position sensitivity, such as background in time-of-flight–energy histograms. In addition, a versatile system to capture and analyze signals from multi-channel plate (MCP) based time-of-flight detectors and ionization based energy detectors such as silicon diodes and gas ionization chambers (GIC) was introduced [2]. Compared to the currently used analogue electronics the digitizing system provides comparable time-of-flight resolution and improved hydrogen detection efficiency, while allowing the operation of the spectrometer be studied and optimized after the measurement.

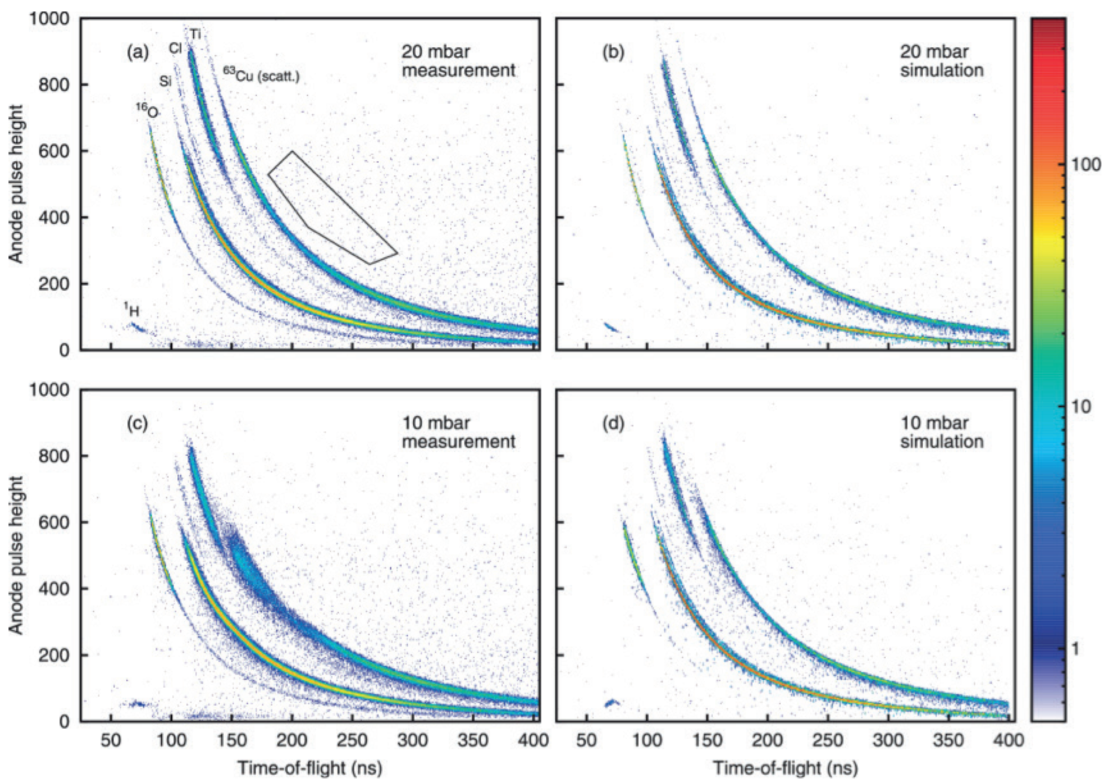


Figure 1. Time-of-flight–E histograms of a TiO2 sample. The histogram (a) was measured and (b) was simulated with 20 mbar GIC pressure, which is sufficient to stop all recoils in the active volume. The histogram (c) was measured and (d) was simulated with 10 mbar pressure. Each of the histograms has 350 000 events in total. From [1].

Figure 2. The local organizing committee of ECAART12.

ECAART12 CONFERENCE HELD IN JYVÄSKYLÄ

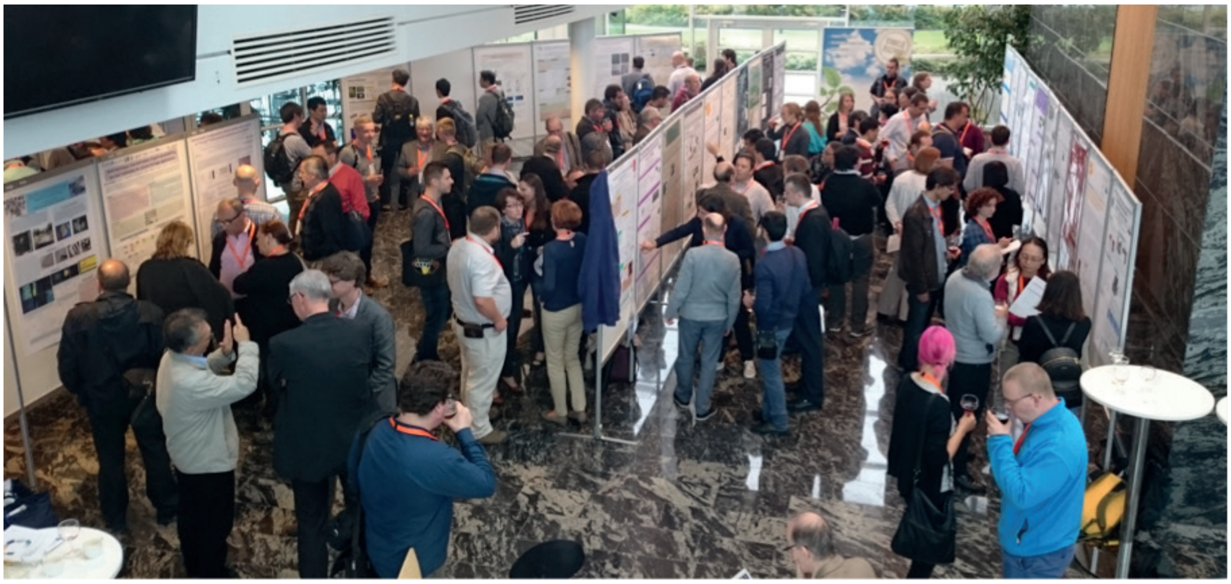
The 12th European Conference on Accelerators in Applied Research and Technology was organized by JYFL in 3-8 July in the Agora building of the University of Jyväskylä. There were in total 141 participants from 31 countries and six industrial exhibitors. Although this particular week was the coldest and rainiest week in the whole summer, not only the scientific program including lab tutorials, presentations and Accelerator Laboratory visit, but also the social program was highly appreciated by the participants. "It was not a heavy task but a joy to organize the conference with such a devoted team we had." says Timo Sajavaara, chair of ECAART12, "For me the top moment of the conference was the presentation of professor L'Écuyer who was the first author of the first elastic recoil detection analysis paper published in 1976." As one merit of success of the conference, in total 90 manuscripts were submitted for the proceedings to be published in NIMB.

SELECTED PUBLICATIONS

[1] Jaakko Julin, Kai Arstila, Timo Sajavaara, *Simulations on time-of-flight ERDA spectrometer performance,* Rev. Sci. Instrum. 87 (2016) 083309.

[2] Jaakko Julin, Timo Sajavaara, *Digitizing data acquisition and time-of-flight pulse processing for ToF-ERDA,* Nucl. Instrum. Meth. B 366 (2016)

Figure 3. Poster session of ECAART12 in Agora.



RADIATION EFFECTS AND INDUSTRIAL APPLICATIONS

Ari Virtanen, Arto Javanainen, Heikki Kettunen

The group specializes in applied research around nuclear- and accelerator-based technology and operates the Radiation Effects Facility, RADEF, for the studies of radiation effects in electronics. RADEF officially became an ESA-supported European Component Irradiation Facility (ECIF) in 2005 [ESA/ESTEC Contracts No.18197/04/NL/CP and 4000111630/14/NL/PA]. Since then the group has carried out irradiation tests not only for ESA and the European space industry, but also for other world leading space organizations (e.g. NASA, JAXA, and CNES), companies and universities. RADEF's specialty is to provide high penetration heavy ion cocktail beams, protons in wide energy range and energetic electrons. For this the RADEF group utilizes combination of JYFL's ECR ion sources and K-130 cyclotron, and the eLINAC electron accelerator. Because the emerging technologies make integrated circuits more susceptible to radiation, the group is expanding its research activities toward the radiation effects also in avionics and ground level systems. The group consists of three researchers, three technical staff members and three students. The number of students is growing along with the increased networking activity.

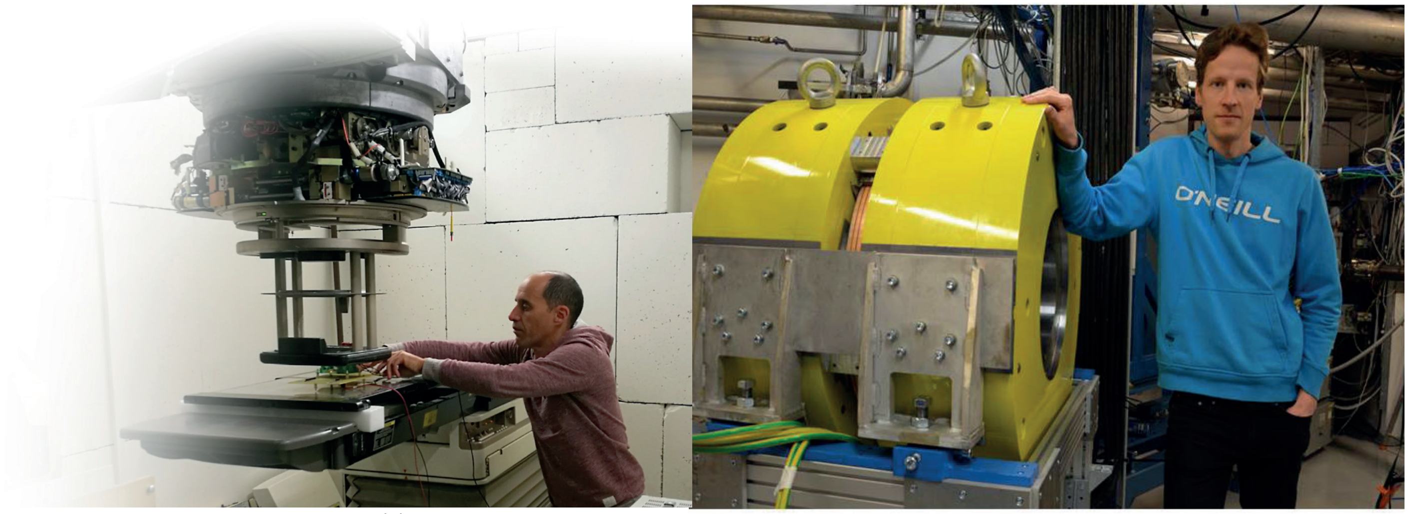
More: https://www.jyu.fi/fysiikka/en/research/accelerator/app

RECENT HIGHLIGHTS

In February 2015 the group started an ESA/GSTP programme [Contract No. 4000112736/14/NL/PA], which targeted to the refurbishing of the electron accelerator, eLINAC, for radiation effects testing, and to the development of a new high energy beam cocktail in HIISI ion source.

eLINAC: Because the extreme electron radiation in the Jovian environment and its implications in the next large-scale ESA's satellite mission JUICE (JUpiter ICy moon Explorer, to be launched in 2022), the utilization of Varian's Clinac accelerator in RADEF for radiation effects testing was considered important. The eLINAC can provide electron beams at discrete energies of 6, 9, 12, 16 and 20 MeV. The maximum intensity is 1000 MU (Monitor Units), corresponding to the dose rate of 10 Gy/min. = 1 krad/min in water. The commissioning was finalized and accepted by ESA in April and since that many customers have already performed tests at eLINAC (e.g. see Figure 1 (a)).

HIISI: The objective of the HIISI project is to extend the LET and range values of the ion beams at RADEF by increasing the ion charge states in the ECRIS that, in turn, will result in higher ion energies from the K130 cyclotron. A substantial increase in charge states, compared to the recent ECR-2, can be achieved with the newly-designed 18 GHz ECR-ion source (see Figure 1 (b)). By using novel room temperature (RT) magnet construction HIISI has been designed to produce the same magnetic field configuration as the superconducting ECRIS SUSI at NSCL/MSU for 18 GHz operation. Higher energies make it easier to test components of complex structures at large tilt incident angles, or in air. Also, the large ion range allows backside irradiations when testing flip-chip components and facilitates a safe substrate thinning. The increase in LET will be done by including ^{197}Au in the ion selection. All this will improve the services RADEF facility provides to the European satellite industry. The goal is to have first 16.2 MeV/nucleon beams produced by the end of 2017.



(a) (b)

Figure 1. (a) Dr. Miguel Ferreira from Laboratório de Instrumentação e Física Experimental de Partículas (Lisbon, Portugal) is preparing a test set-up of JUICE mission satellite components for the electron beam of eLINAC. (b) Dr. Taneli Kalvas standing next to the new vacuum chamber of HIISI.

RADSAGA

The RADSAGA (RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators) will, for the first time, bring together the European industry, European universities, laboratories and test facilities to educate 15 PhD's on the subject of electronics exposure to radiation. Three students will graduate at JYFL, two being hosted by RADEF and one by CERN. The project spans the years 2016-2020, and the kick-off meeting will be held in March 2017. This EU-MSCA-2020 ITN project was granted 3.9 M€ and is coordinated by CERN. The RADEF group is one of the seven beneficiaries. Fourteen other partners, mainly companies and research laboratories, will take part in the RADSAGA.

R²RAM

The R2RAM, EU's HORIZON-2020/RIA project, aimed at developing the knowledge necessary to design a radiation-hard non-volatile memory technology while using standard CMOS silicon processing. The strict radiation requirements demanded the use of a new memory cell technology, called "resistive random-access memory" (RRAM), that is able to sustain irradiation from heavy ions and other charged particles, as well as high total doses of ionizing radiation. The project was coordinated by IHP - Innovations for High-Performance Microelectronics (Germany). The other participants were the Italian University NanoElectronics Team, RedCat Devices Srl (Italy) and RADEF. It resulted in considerable improvements to the state-of-the-art on radiation-resistant memories and these improvements have been decided to be exploited in a new ESA-GSTP project.

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[2] A. Bosser, V. Gupta, G. Tsiligiannis, C. Frost, A. Zadeh, A. Javanainen, H. Puchner, F. Saigné, A. Virtanen, F. Wrobel and L. Dilillo, *Methodologies for the Statistical Analysis of Memory Response to Radiation,* IEEE TNS, vol. 63 (2016) pp. 2122-2128

NUCLEAR STRUCTURE, NUCLEAR DECAYS, RARE AND EXOTIC PROCESSES

Jouni Suhonen, Mikko Haaranen, Joel Kostensalo and Jenni Kotila

The nuclear-theory group of JYFL develops nuclear-structure models and applies them to topics of weak-interaction physics. The topics include neutrino-nucleus interactions at supernova energies, rare weak decays like forbidden beta decays and double beta decays, and direct dark-matter detection. The group is theory member of the large experimental underground experiments SUPERNEMO and COBRA and collaborates with experimental groups at JYFL, RCNP, etc. The group has strong theory collaboration with La Plata in Argentina, Bucharest in Romania and Yale University in USA. The group hosts currently one professor, one post-doctoral researcher and five graduate students.

www.jyu.fi/fysiikka/en/research/accelerator/nuctheory

NEUTRINOLESS DOUBLE BETA DECAY PROBED BY FORBIDDEN BETA DECAYS

Discovery of the neutrinoless double beta ($0\nu\beta\beta$) decay of atomic nuclei is at present one of the top priorities of particle physics. Its detection would imply that neutrino is a massive Majorana particle and that lepton-number conservation does not hold. Current experiments give only lower limits to the half-life of the decay but future experiments may be in a position to detect it.

The measured half-life of $0\nu\beta\beta$ decay can be translated into neutrino mass through the nuclear matrix elements (NMEs). The $0\nu\beta\beta$ decay proceeds by virtual β-decay transitions from the 0^+ ground state of the mother nucleus to the J^p multipole states of the neighboring odd-odd nucleus (here *p* is parity). These intermediate J^p states are, in turn, connected by virtual β-decay transitions to the 0^+ ground state (or some excited state) of the even-even daughter nucleus. The corresponding NME can be divided into pieces corresponding to each of the J^p multipole channels. This J^p decomposition is shown in Figure 1 for the $0\nu\beta\beta$ decay sequences ^{96}Zr-^{96}Nb-^{96}Mo and ^{136}Xe-^{136}Cs-^{136}Ba [1].

The virtual transitions can be studied by comparing their NMEs with the corresponding NMEs for the *K*-fold forbidden unique beta decays, where a single NME mediates the transition. In Figure 2 is shown the ratio $k = M$(pnQRPA)/M(qp) for the β-decay transitions between a 0^+ state and the states $J^p = 2^+,4^-,5^+,6^-,7^+,8^-$ for K=2,3,4,5,6,7, respectively. The transitions occur in different nuclei identified by the mass number *A* of the horizontal axis. Here *M(pnQRPA)* is the NME computed by using the proton-neutron quasiparticle random-phase approximation and *M*(qp) is its simple two-quasiparticle reduction. The ratio *k* is indicative of the evolution of the NMEs when going from a simple quasiparticle approximation towards a more complex configuration-interaction framework, allowing extrapolation to the true (possibly measurable) NME [2].

One further way to study the J^p multipole NMEs of the $0\nu\beta\beta$ decay is to relate them to the quenching of the value of the weak axial-vector coupling constant g_A. This is a novel approach, introduced in [3] and further advanced in [4]. This approach, coined the spectrum-shape method (SSM), is based on the observed strong sensitivity of the theoretical shape of the electron spectrum of a *K*-fold forbidden non-unique (mediated by several NMEs) beta decay to the value of g_A. In the SSM the extraction of the effective value of g_A is done by comparing the computed spectrum shape with that obtained in the present and future β-decay experiments. It turns out that the SSM is a robust tool, surprisingly independent of the details of the nuclear mean field or the adopted nuclear Hamiltonian. This is demonstrated in Figure 3 for the decay of ^{113}Cd to the ground state of ^{113}Sn, computed using three different theory frameworks: The microscopic quasiparticle-phonon model (MQPM), the nuclear shell model (NSM) and the microscopic interacting boson-fermion model (IBM). All three models point consistently to a quenched value g_A=0.9 for this 4-fold forbidden transition.

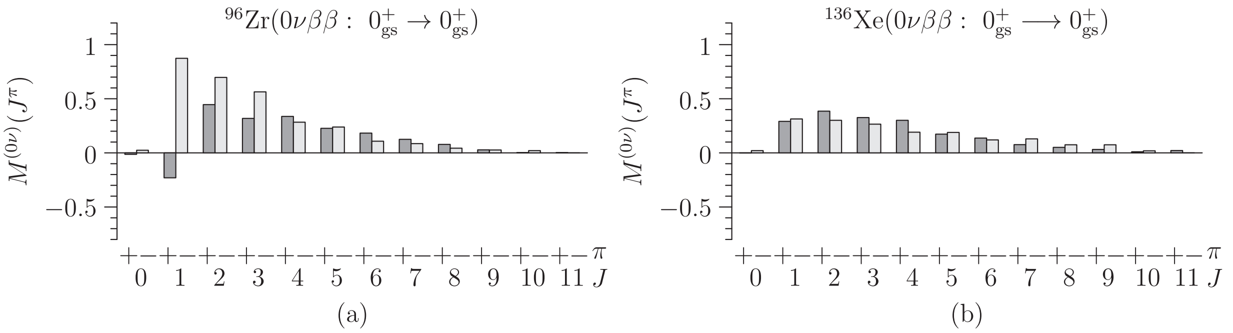

Figure 1. Decomposition of the NMEs for the 0νββ decays of ^{96}Zr and ^{136}Xe.

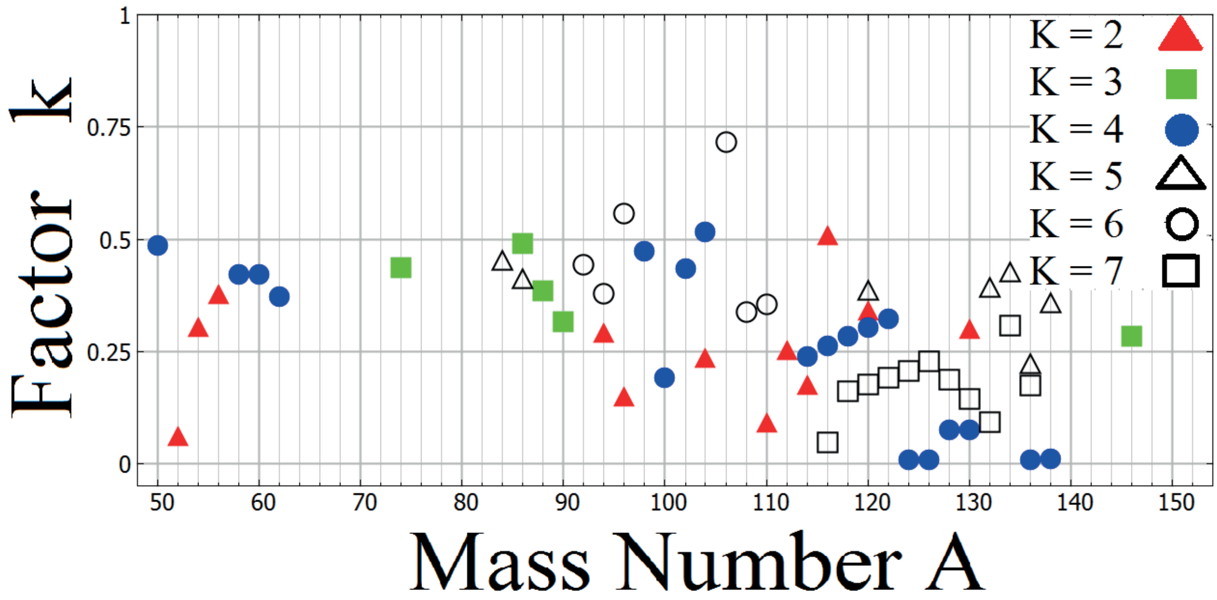

Figure 2. Ratio k as a function of the mass number A for the K-fold forbidden unique β-decay transitions.

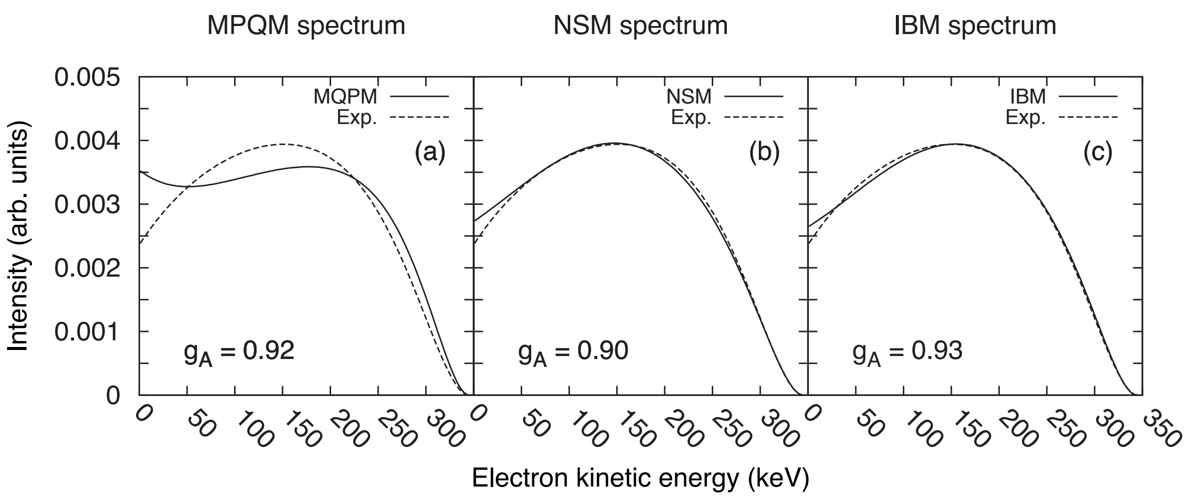

Figure 3. Comparison of the computed and experimental electron spectra for the 4-fold forbidden non-unique β-decay transition from ^{113}Cd($1/2^+$) to ^{113}Sn($9/2^+$).

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[3] M. Haaranen, P. C. Srivastava and J. Suhonen, *Forbidden non-unique β decays and effective values of weak coupling constants,* Phys. Rev. C 93 (2016) 034308

[4] M. Haaranen, J. Kotila and J. Suhonen, *Spectrum-shape method and the next-to-leading-order terms of the β-decay shape factor,* Phys. Rev. C 95 (2017) 024327

MOLECULAR TECHNOLOGY

Markus Ahlskog

The Molecular Technology group studies primarily the experimental electronic and mechanical properties of carbon nanotubes (CNTs) and devices that are based on them. The interests include both fundamental and applied aspects of CNT science and technology. The research in the group has extensively explored the basic electronic transport properties of high quality multiwalled carbon nanotubes (MWNT). Other topics within the group include the interaction between CNTs and liquid interfaces and the functionalization of CNTs with molecular species. The group utilizes for its research effort the modern microscopy instrumentation and the good fabrication and measurement facilities of the Nanoscience Center.

www.jyu.fi/fysiikka/en/research/material/nanophys/moltech/

ELECTRONIC TRANSPORT IN MWNTs

The published works on the fundamental science of single wall carbon nanotubes (SWNT) is many times more numerous than that on multiwalled carbon nanotubes (MWNT). One major reason for this is that SWNTs appear in both metallic and semiconducting forms, while in MWNTs mainly diffusive/quasiballistic metallic states have previously been reported, in a few experimental works on MWNTs electronic low temperature transport and high magnetic field properties. However, these studies have been fragmentary. For example, before our work [1,2], there was no consistent, experimentally verified description of semiconductivity in MWNTs. Transport properties on MWNTs have to date not been probed systematically at different diameters. In particular, for reasons mainly due to synthesis technology, there has been very few reports on smaller MWNTs with the diameter within the interesting range 3 - 10 nm. This has left the experimental studies on MWNTs rather disconnected from those on SWNTs and DWNTs.

In most studies on MWNTs, the working assumption has been that the outer layer, or possibly few layers, is solely responsible for the low bias transport properties. One motivation for this assumption is the very large anisotropy of conductance in graphite and few layer graphene. In principle, one should find among MWNT-based devices a division into metallic or semiconducting types, for example with respect to the outer layer. In semiconducting SWNTs, the conventional tight-binding theory calculation, gives for the dependence of the bandgap (E_G) on diameter (D) as:

$$E_G = \beta / D \qquad [1]$$

where $\beta \approx 0.7$ eVnm. Thus, in a first approximation, Eq. 1 is expected to apply to the semiconducting outer layers of MWNTs. The semiconducting properties of a MWNT can be measured, at least qualitatively, in a three-terminal field-effect device configuration, Fig. 1(a), where its bandgap shows up as a transport gap, which is the range of gate voltages where the conductance decreases strongly or vanishes, as shown in Fig. 1(b).

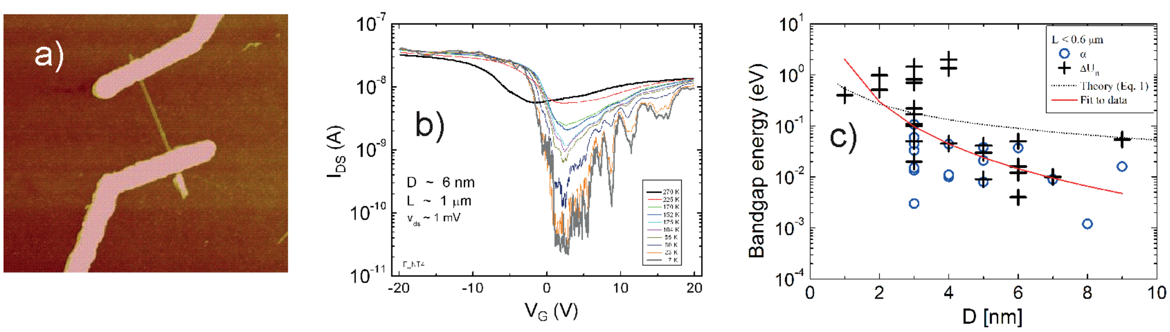

Figure 1. a) AFM image of typical MWNT device on Si/SiO$_2$. The highly doped Si substrate acts as a back-gate. b) Gate voltage (V_G) dependent conduction at different temperatures of a semiconducting MWNT. c) The bandgap energy vs. diameter D, estimated from experimental values from the low temperature conduction experiments. The black dotted line shows the standard tight-binding theory value (Eq. 1) for the diameter dependent bandgap E_G of semiconducting SWNTs.

Low temperature transport in MWNTs has been studied at different diameters and lengths, within 2 - 10 nm, and 0.3 - 3.5 µm, respectively [2]. In a majority of the samples, semiconductivity showed up as a transport gap in the gate voltage controlled conduction, but metallic MWNTs are found in all diameters. The transport gap is seen to be quantitatively determined by a diameter dependent bandgap, and length dependent localization of charge carriers. From an analysis of about 80 devices, we obtain an estimate for the bandgap of semiconducting MWNTs, as shown in Fig. 1(c). This bandgap is estimated to be smaller than that extrapolated from the conventional expression, eq. 1, applicable to semiconducting single wall carbon nanotubes.

These results have significant similarities to graphene nanoribbons (GNR), where a gap arises via quantum confinement due to the narrow width. The size of the gap is then roughly in a similar inverse relation with the width, as in the case of the diameter dependence of the MWNT's in our work.

ON-CHIP PURIFICATION OF ARC-DISCHARGE SYNTHESIZED MWNTs

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 progress [3] in MWNT purification with a method that begins with dispersing the raw MWNT material on a flat surface, e.g. piece of silicon wafer. Then a water surface interface is moved across, whereby a large part of the MWNT deposition is removed by the water surface. This removed part contains some MWNTs and nearly all the impurities. The other part consists of the highly purified and practically intact MWNT's (Figure 2).

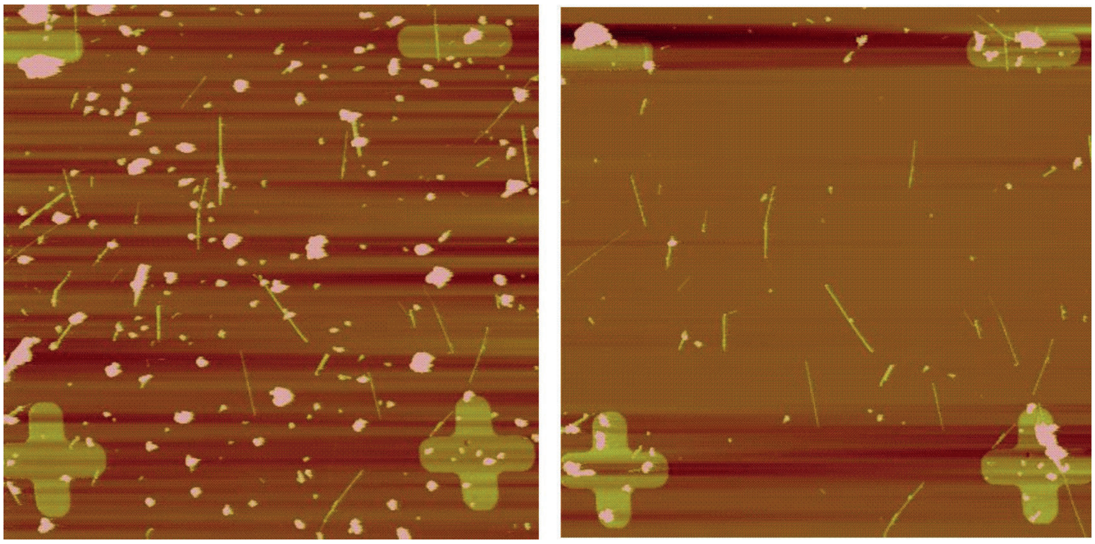

Figure 2. AFM images (10 µm in size) show same location before and after purification treatment.

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THERMAL NANOPHYSICS

Ilari Maasilta

The main research direction of the thermal nanophysics research group is to understand and engineer energy flow mechanisms in low-dimensional geometries, develop thermometric techniques for the study of thermal phenomena (e.g. tunnel junctions) and use the obtained physical know-how in the development of superconducting ultrasensitive radiation sensors for materials science applications (bolometry). The group is a heavy user of the facilities of the Nanoscience Center (NSC), where most of the experiments are performed in sub-Kelvin temperature range, using either helium dilution refrigerators or adiabatic demagnetization refrigerators to reach such low temperatures. A lot of expertise has also been developed in nanofabrication using different lithographic and self-assembly methods, including electron-beam lithography, three-dimensional laser lithography and helium ion beam lithography and milling.

The group has currently 1 senior researcher, 5 graduate students and 3 master's students. It is one of the heaviest users of the NSC clean room facilities, and also collaborates with top national and international groups from all over the world, for example with NIST Boulder, NASA Goddard, VTT Micronova, Aalto University and Oslo University to name a few.

www.jyu.fi/fysiikka/en/research/material/nanophys/thermal

A FEW HIGHLIGHTS OF THE ACTIVITY IN 2016:

THERMAL PROPERTIES OF PHONONIC CRYSTALS

We have continued our ground breaking research on controlling the thermal properties coherently using periodic nanoscale structures (phononic crystals), with most of the focus on two-dimensional structures consisting of nano- to microscale holes in a thin SiN plate (fig 1). We recently showed in a numerical study [1] that thermal conductance can be reduced by orders of magnitude by increasing the hole size and the lattice constant. No limit was achieved, indicating that imperfections leading to decoherence are expected to play a major role in determining how much conductance can be reduced in real samples. In addition, an enhancement is also possible with smaller periodicities, both in thermal conductance and in heat capacity [2], which can increase over four times, even if 70 % of the material is *removed*. The mechanism behind this effect is that the phonon waves interact strongly with the phononic crystal structure, changing the density of states by orders of magnitude. In the future, the demonstrated concepts can possibly be used in the development of ultrasensitive radiation detectors, where the control of heat is essential.

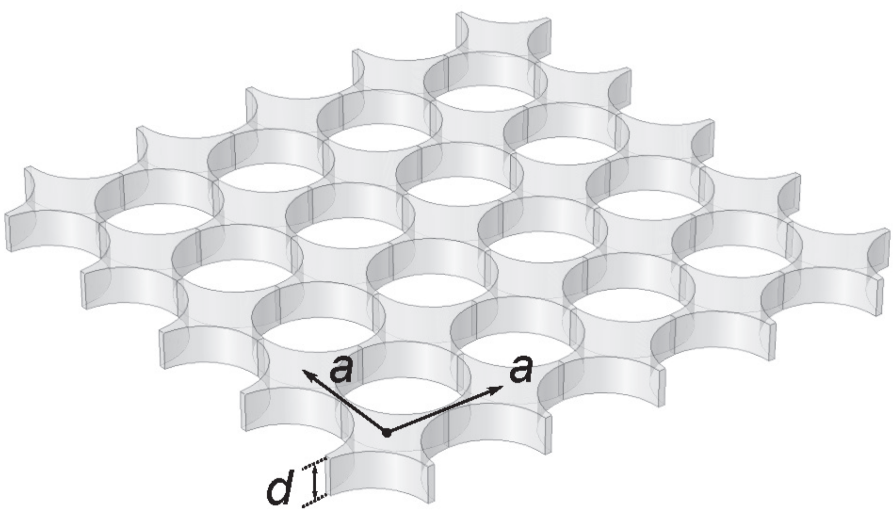

Figure 1. A schematic of a 2D hole array phononic crystal with dimensions d = 300 nm, a = 1 µm.

DEVELOPMENT OF SUPERCONDUCTING TRANSITION-EDGE SENSOR SPECTROMETERS

Work on ultrasensitive superconducting transition-edge sensor (TES) detector development has advanced in recent years towards real life applications. A TES spectrometer with 160 pixels inside a dry adiabatic demagnetisation refrigerator was developed in collaboration with NIST Boulder, and it was used in combination with a Pelletron accelerator to do particle-induced X-ray emission (PIXE) spectroscopy of materials [3], in collaboration with the accelerator laboratory. The superior energy resolution allowed the identification of trace-level impurity elements from samples where traditional silicon detectors fail. Chemical shifts of emission lines of magnitude ~1 eV were also detected in Ti compounds. Our results are very promising for future applications in analysis of thin films and biological samples.

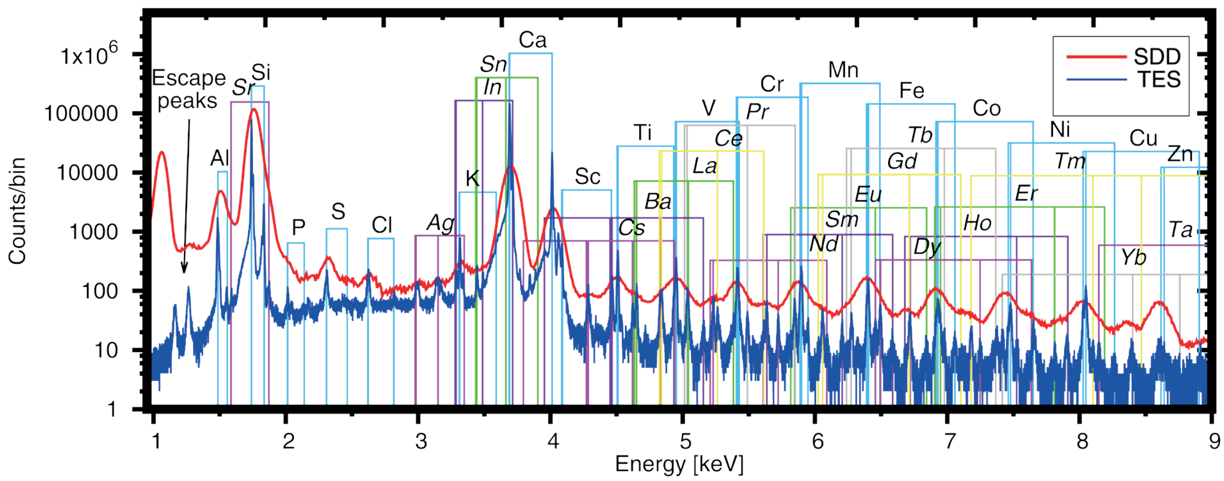

Figure 2. A multi-element reference sample measured with both TES (blue line) and SDD (red line) detectors. Note how many more elements can be resolved with TES detectors because of its superior energy resolution.

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MOLECULAR ELECTRONICS AND PLASMONICS

Jussi Toppari

The group studies nanoelectronics and -plasmonics, concentrating on phenomena related to molecules. One of the main interests, on which the group has a long experience, is self-assembled DNA structures. The main focus is on DNA origami structures; their modifications and utilization in nanofabrication of electrical and optical/plasmonic nanodevices. Another main interest is the coupling between surface plasmons and molecules, especially in a strong coupling limit. This limit brings about hybrid plasmon-molecule -states possessing new fundamental properties enabling, e.g., totally new ways for controlling chemistry. Other topics studied are molecular level mechanisms and properties of fluorescent proteins, enhancing their fluorescence for bioimaging by plasmonics, and utilization of plasmonics for solar energy, as well as plasmonic/optical properties of graphene and conducting polymers.

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TOWARDS DNA-BASED SINGLE ELECTRON ELECTRONICS

We have demonstrated a method to fabricate single electron transistor (SET) by utilizing the molecule of the heritage, i.e. DNA, and its unique self-assembly properties [1]. The DNA itself is not taking part to the actual electrical function, but acts as a scaffold to organize a linear, pearl necklace like nanostruc-ture consisting of three gold nanoparticles (AuNP) as shown in Figure 1. The whole process is based on DNA self-assembly, and thus yields countless of structures within a single patch.

The nature of electrical conduction in nanoscale materials differs vastly from macroscale structures having countless electrons forming the current. For example, addition of even a single electron into a nanosized piece of metal can increase its energy enough to prevent further conduction through it. Devices based on this phenomenon, i.e., single electron devices, have been fabricated within the scale of tens of nanometers by conventional micro- and nanofabrication methods for some time now. However, the weakness of these structures has been the cryogenic temperatures needed for them to work. The operation temperature scales up as the size of the component decreases. The ultimate aim is to have the devices working at room temperature, which is hardly possible by conventional nanofabrication methods. However, as shown here – metallic nanoparticles with the size of only few nanometers together with DNA based self-assembly – offer a very suitable toolkit for this purpose [1].

After fabrication, we trapped our self-assembled structures by dielectrophoresis between firgertip-type gold nanoelectrodes and measured its IV-characteristics. We observed clear Coulomb blockade (see inset in Figure 1), which is essential for SET operation, all the way up to room temperature. This demonstrates for the first time that this kind of scalable fabrication methods based on DNA self-assembly can be efficiently utilized to fabricate single electron devices functioning at room temperature.

The research was done in collaboration with BioMediTech in University of Tampere and Leibniz Institute of Photonic Technology (Jena, Germany), and funded by the Academy of Finland.

TO UNDERSTAND LIGHT SENSING MECHANISM IN PLANTS AND BACTERIA

Conversion of light into chemical energy by proteins is central for life. The role of the photosensory proteins is remarkable in this conversion. Scientists from the University of Jyväskylä and University of Gothenburg have determined the inner workings of one of these proteins – phytochromes. These proteins are found in all plant leaves, many bacteria and fungi. The proteins inform the cell whether it is day or night, or whether it is cloudy or sunny. Phytochromes were studied the means of by biochemistry [2], spectroscopy [2-4], X-ray scattering [2,3], and serial femtosecond crystallography [4].

Our Academy of Finland postdoctoral researcher Heli Lehtivuori was involved in this collaboration to carry out the UV-Vis spectroscopic measurements. In addition, this study included other measurements carried out at experimental facilities in France, Switzerland, Finland and the USA.

CHEMICAL COMPOSITION OF TWO-PHOTON OXIDIZED GRAPHENE

In this study we collaborated with a Taiwanese group to analyze the chemical composition of two-photon oxidized graphene, using µm X-ray photoelectron spectroscopy at National Synchrotron Radia-tion Research Center (Hsinchu, Taiwan). We were able to follow how the first hydroxyl groups appear and dominate, followed by a minor formation of epoxy groups at higher two-photon exposures as shown in Figure 2. Carboxylic groups did not seem to form, with a very small and constant signal throughout. The study shows a significant difference of composition compared to chemically produced graphene oxide, which typically has a higher fraction of epoxy groups and a clear presence of carboxylic groups. The take-home-message is that two-photon oxidation is a more controlled and gentle oxidation process, leaving graphene more structurally intact than chemical oxidation.

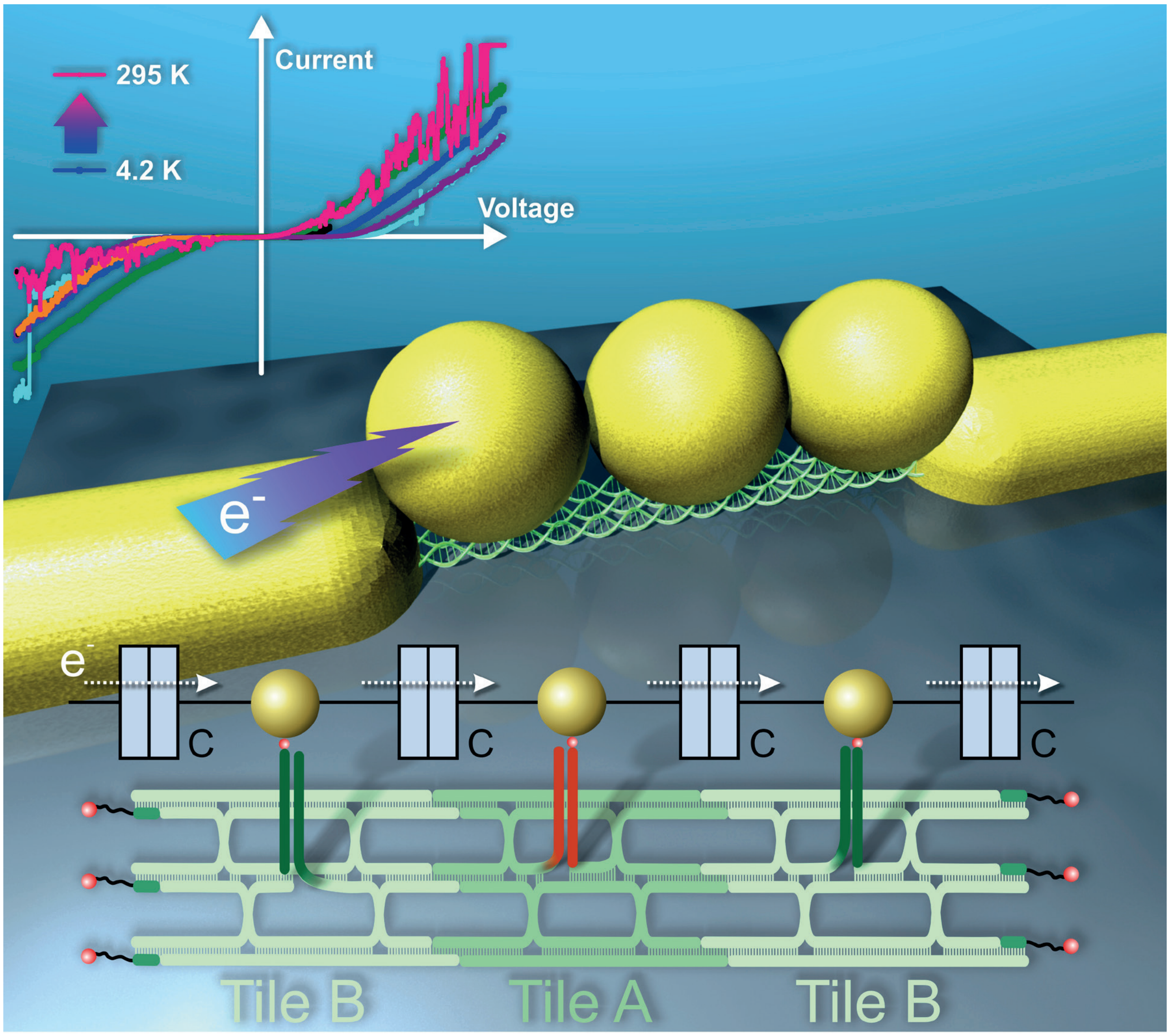

Figure 1. The schematic picture and an artistic view of the DNA-AuNP assembly. The green lines represent DNA helixes. The capacitances C represent the tunneling gaps between the AuNPs and electrodes. Inset shows IV-characteristics of one DNA-AuNP assembly with the Coulomb blockade visible from 4.2 K up to room temperature.

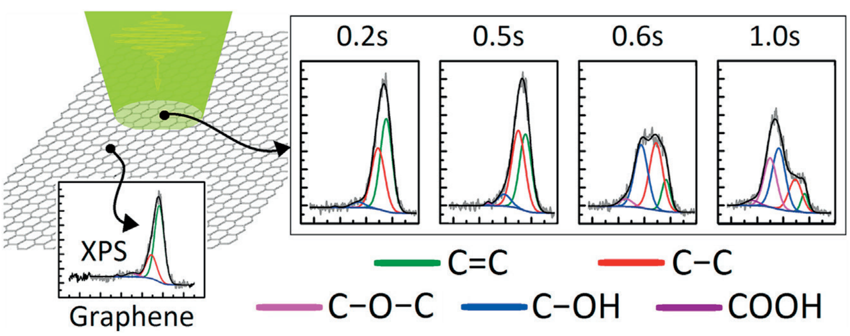

Figure 2. Illustration of the chemical composition of graphene oxide during two-photon oxidation.

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THEORETICAL NANOPHYSICS AND COMPUTATIONAL NANOSCIENCE

Hannu Häkkinen, Robert van Leeuwen, Tero Heikkilä, Francesco Massel, Pekka Koskinen, Mikhail Silaev

Our computational nanosciences research focuses on the basic research of atomic clusters, low-dimensional structures, and other nanoscale objects. The quantum many-body theory group studies many-particle interactions in molecular and solid state systems with a focus on systems out of equilibrium. Our theoretical nanophysics research concentrates on superconductivity, magnetism, open quantum systems and topological media. We use various computational and phenomenological approaches, including time dependent density-functional theory, non-equilibrium and quasiclassical Green's functions, real-time path integral techniques, quantum Langevin equations, molecular dynamics, and Monte Carlo methods. Our group is interdisciplinary by mixing researchers from physics, chemistry and biology departments, and it consists of three professors, six senior researchers, ten post-docs, as well as around 15 PhD and master students.

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CONFORMATION AND DYNAMICS OF THE LIGAND SHELL OF A WATER-SOLUBLE AU102 NANOPARTICLE

Inorganic nanoparticles, stabilized by a passivating layer of organic molecules, form a versatile class of nanostructured materials with potential applications in material chemistry, nanoscale physics, nanomedicine and structural biology. While the structure of the nanoparticle core is often known to atomic precision, gaining precise structural and dynamical information on the organic layer poses a major challenge. Here we report [1] a full assignment of 1H and 13C NMR shifts to all ligands of a water-soluble, atomically precise, 102-atom gold nanoparticle stabilized by 44 para-mercaptobenzoic acid ligands in solution, by using a combination of multidimensional NMR methods, density functional theory calculations and molecular dynamics simulations. Molecular dynamics simulations augmented the data by giving information about the ligand disorder and visualization of possible distinct ligand conformations of the most dynamic ligands. The method demonstrated here opens a way to controllable strategies for functionalization of ligated nanoparticles for applications.

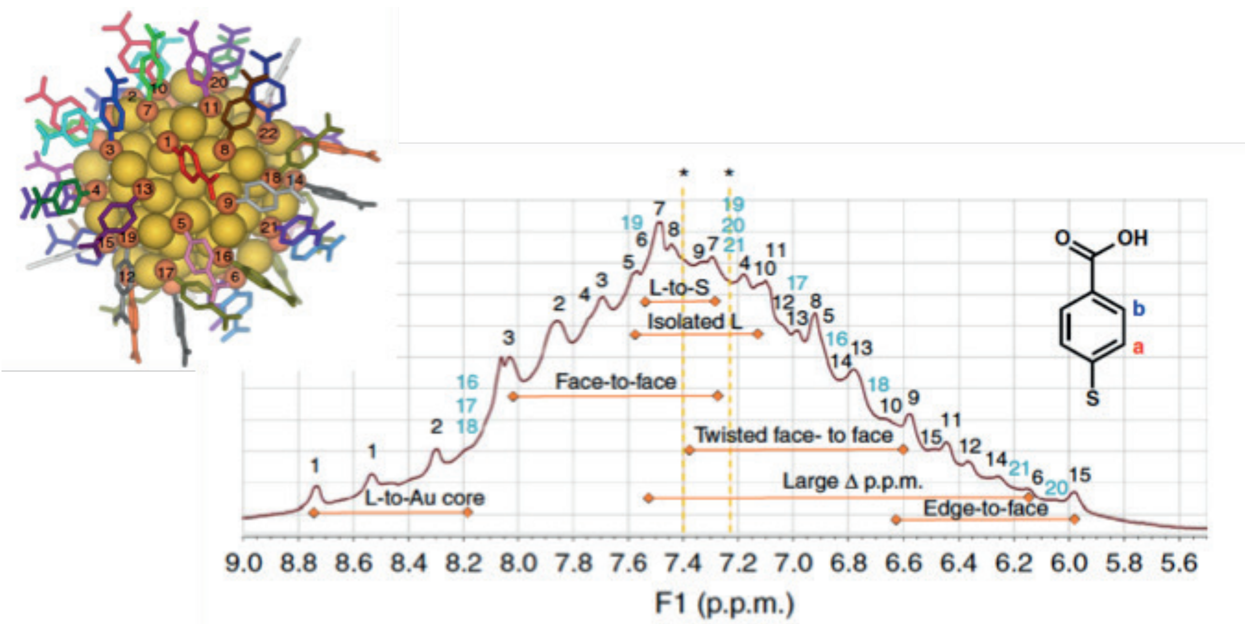


Figure 1. Proton-NMR spectrum of Au_{102}(p -MBA)$_{44}$ nanocluster. The p-MBA (para-mercaptobenzoic acid) has two inequivalent protons (a,b; on the right); the ligand shell has C2 symmetry which produces in total of 44 proton signals. Each of these signals have been associated to given ligands numbered on the structural model of the cluster (top left), based on the known crystal structure of Au_{102}(p-MBA)$_{44}$.

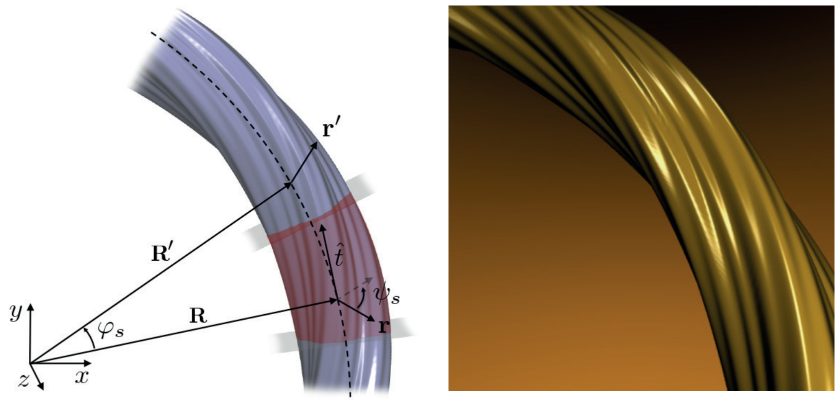


Figure 2. Novel symmetry operation for periodic, one-dimensional nanostructures can be used to perform electronic structure calculations under arbitrary deformations.

QUANTUM SIMULATIONS OF NANOSTRUCTURES UNDER ARBITRARY DEFORMATIONS

A powerful technique was introduced for simulating mechanical and electromechanical properties of one-dimensional nanostructures under arbitrary combinations of bending, twisting, and stretching (Figure 2). The technique was based on a novel control of periodic symmetry, which eliminated artifacts due to deformation constraints and quantum finite-size effects, and allowed transparent electronic structure analysis. Via density-functional tight-binding implementation, the technique demonstrated its utility by predicting novel electromechanical properties in carbon nanotubes and abrupt behavior in the structural yielding of Au_7 and Mo_6S_6 nanowires [2]. The technique drove simulations markedly closer to the realistic modeling of these slender nanostructures under experimental conditions.

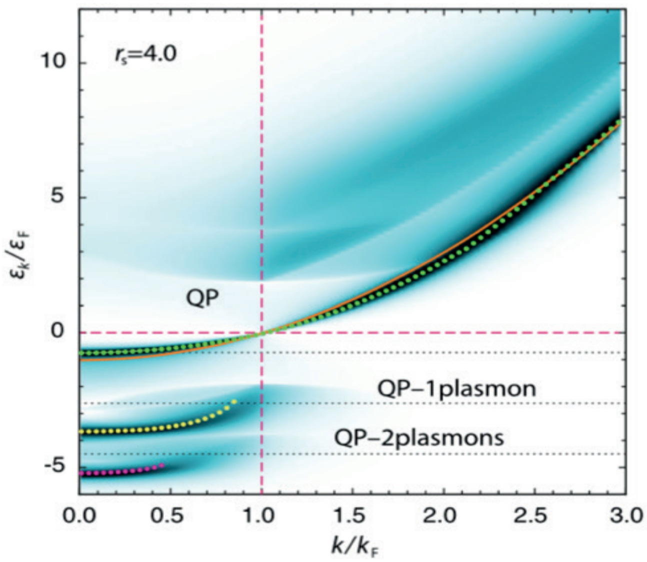


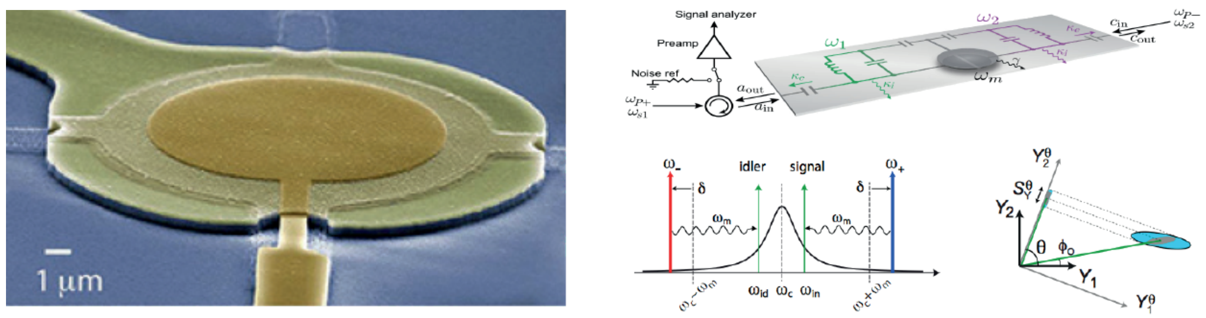
Figure 3. The spectral function of the homogeneous electron gas as a function of energy and momentum calculated with the new many-particle method. We clearly see the quasi-particle peak and the appearance of two plasmon satellite branches.

A NEW APPROACH IN THE STUDY OF MANY-BODY INTERACTIONS

We present a systematic study of vertex corrections in a homogeneous electron gas at metallic densities using a new method which yields a positive-definite diagrammatic expansion for the spectral function. The vertex function not only provides corrections to the well known plasmon and particle-hole scatterings, but also gives rise to new physical processes such as the generation of two plasmon excitations or the decay of the one-particle state into a two-particle–one-hole state. By an efficient Monte Carlo momentum integration we are able to show that the additional scattering channels are responsible for a reduction of the bandwidth, the appearance of a secondary plasmon satellite below the Fermi level, and a substantial redistribution of spectral weights. The feasibility of the approach for first-principles band-structure calculations is also discussed. The results were recently published in Physical Review Letters [3].

QUANTUM-LIMITED AMPLIFICATION OF MICROWAVE SIGNALS IN OPTOMECHANICAL SYSTEMS

Together with the experimental group of M. Sillanpää, Aalto University, we have studied means of approaching and even overcoming the quantum limits of amplification in circuit quantum optomechanical systems consisting of superconducting microwave cavities coupled to nano- or micromechanical resonators close to their quantum limit (Fig. 1). We have realized and studied two schemes for such optomechanical microwave amplifiers [4,5] and demonstrated how the added noise in these devices approaches the quantum limit set by the Heisenberg uncertainty principle. In this property these devices rival the best microwave amplifiers based on Josephson junction setups, but with a much-improved dynamical range. These amplifiers can especially be used in handling tiny signals, as needed in quantum information applications, or possibly in gravitational wave detection.



(a) (b)

Figure 4. (a) A typical nanodrum resonator employed in the work. (b) Schemes for attaining and going beyond the quantum limit. Top: Two-cavity setup with a coupling to a common resonator [4] allows for cooling of the resonator via one driven cavity while amplifying the noise sent to either of the cavities. Bottom: Two-pump scheme (left) allowing also for cooling of the resonator while amplifying the signal [5]. In this case the amplifier becomes phase sensitive, which means that the added noise becomes squeezed to an ellipse. Therefore, the added noise to one of the quadratures is reduced below the quantum limit at the expense of an increased noise in the other quadrature.

CONFINEMENT-DECONFINEMENT TRANSITION DUE TO EXCITON CONDENSATION IN QUANTUM HALL BILAYERS

The role of the electron-electron interactions for the experimentally accessible topological media is best appreciated in quantum Hall (QH) systems. One state of particular interest is the exciton condensate state occurring in bilayers when the filling factors of the Landau levels in the two layers satisfy $vT=v1+v2=1$, where $v1$ and $v2$ are the individual filling factors in the two layers. In this case the number of electrons $v1$ (filled states) in the upper layer equals the number of holes $1-v2$ (empty states) in the lower layer, and the large density of states due to the flat Landau levels triggers the excitonic instability. Together with our collaborators in Microsoft Station Q, University of British Columbia and TU Braunschweig we have studied the properties of this kind of exciton condensate state in bilayer system supporting a band-inversion of the conduction and valence bands [6]. In the quantum Hall regime this system supports both counterpropagating helical edge states and excitonic correlations.

The exciton condensate order parameter can be considered as a pseudospin magnetization, allowing graphical representation of the ground state and excitations (see Fig. 5). We found [6] that the low-energy excitations in the helical QH exciton condensate are pseudospin textures, which in a narrow closed system carry a fractional charge ±ν1e at the edges of the sample. While charged excitations in the absence of exciton condensation are deconfined (charges can be created independently on the opposite edges), in the exciton condensate state they are confined: a charge +ν1e on one edge always gives rise to charge -ν1e at the other edge. This mechanism can be compared to the color confinement of quarks. Also the quarks carry fractional quantum numbers, but at low energies they are always held together by gluons. The force mediated by gluons does not decrease with increasing distance, and therefore it confines quarks into bound states (hadrons) carrying integer charge. Although fractionally charged particles can appear in several condensed matter systems, the realization of the confinement physics requires also an analogy of the gluons. In our system this confinement is provided by the exciton condensate in the bulk. In contrast to confinement of quarks, the confinement physics and the confinement-deconfinement transition in this kind of system can be studied using a large number of different experimental techniques, e.g. with the help of the transport geometry illustrated in Fig. 5(c).

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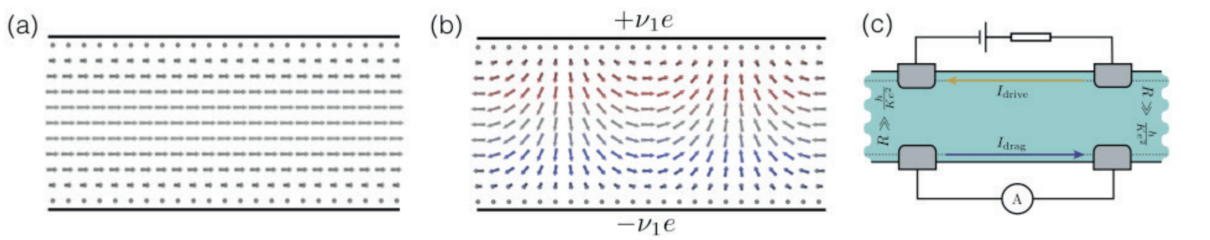

Figure 5. (a) The ground state pseudospin texture for the helical QH exciton condensate. (b) In a narrow system low-energy excitations can be created by letting the pseudospin rotate slowly along the edge. These fractionally charged excitations are confined: a charge +ν1e on one edge is always associated with an opposite charge -ν1e at the other edge. (c) Transport geometry to demonstrate the charge confinement. A drive current applied on one of the edges gives rise to exactly opposite drag current at the other edge.

COMPLEX MATERIALS

Markku Kataja, Arttu Miettinen, Timo Riikilä, Joni Parkkonen

The research scope of the group includes heterogeneous materials, theoretical and numerical modelling, complex fluid mechanics and rheology, X-ray tomography and 3D image analysis, as well as their applications in various industrial problems. The group runs an extensive X-ray Tomography Laboratory that includes three X-ray scanners used in non-invasive three-dimensional imaging and analysis of the internal microstructure of a wide range of heterogeneous materials. The research topics of the group include also statistical characteristics of random packings of elongated particles, structural analysis related to development of new biocomposites, complex flow dynamics and transport in heterogeneous materials.

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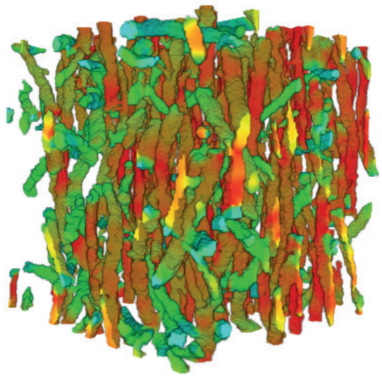
X-RAY TOMOGRAPHY LABORATORY

The primary research facility within the X-ray Tomography Laboratory includes three 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. The laboratory is also equipped with specific devices for measuring various mechanical and transport properties of materials. The entire facility has high utilization rate in basic and applied research related e.g. to development of novel organic materials, and to analysis of structural and transport properties of complex materials such as composites and bentonite clay.

(a)



(b)

Figure 1. (a) Xradia Multiscale X-ray tomographic facility. A microtomograph (right) and a nanotomograph capable of 50 nm resolution (left). (b) A microtomographic image of regenerated cellulose fibres. Fibre orientation indicated by color scale.

TIME-RESOLVED X-RAY MICROTOMOGRAPHIC MEASUREMENT OF WATER TRANSPORT IN WOOD-FIBRE REINFORCED COMPOSITE MATERIAL

Many materials are prone to absorb moisture from the environment. Moisture absorption may lead to degradation of the properties of the material. We have developed a method for direct non-intrusive measurement of local moisture content inside a material sample. The method is based on X-ray microtomography, digital image correlation and image analysis, and it has been applied to study axial transport of water in a cylindrical polylactic acid/birch pulp composite material sample with one end exposed to water. The method seems to give plausible estimates of water content profiles inside the cylindrical sample. The results may be used, e.g., in developing and validating models of moisture transport in biocomposites.

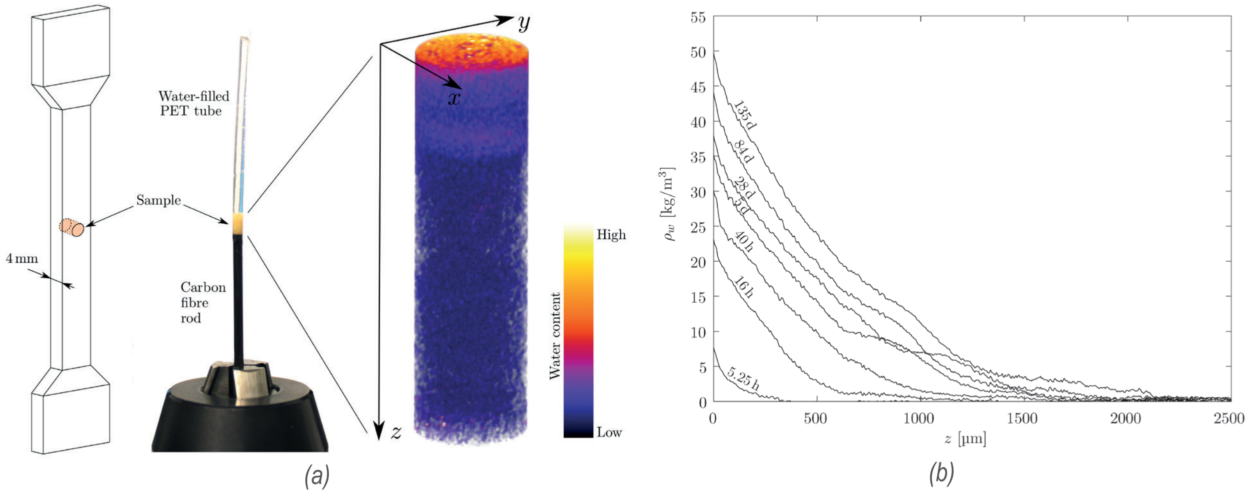


Figure 2. (a) Sample assembly for determination of axial water concentration profile (left, middle) and 3D visualization of water content in the sample (right). (b) Measured water content profiles in the sample at various wetting times, obtained using X-ray tomographic techniques.

DISCRETE ELEMENT MODEL FOR GLACIER DYNAMICS

Global warming is one of the greatest threats that mankind has to face in the beginning of this century. Related to this is the incontrovertible mass loss of glacier ice in polar regions. Understanding the behaviour of large ice masses is thus crucial for estimating, and perhaps hindering the propagation of mass loss. In order to avoid shortcomings of continuum models, traditionally used to study glacier dynamics, a new discrete element model (DEM) for viscoelastic materials with fracture is developed [1]. In DEM models, material is comprised of a large number of particles that are bound together with interaction potentials, e.g. springs or beams. Fracture and fragmentation is introduced through a breaking threshold of an interaction. With proper setting of properties of the particles themselves and the interaction potentials between them, the material can be made to realise a wide variety of elastic, plastic and viscoelastic behaviour.

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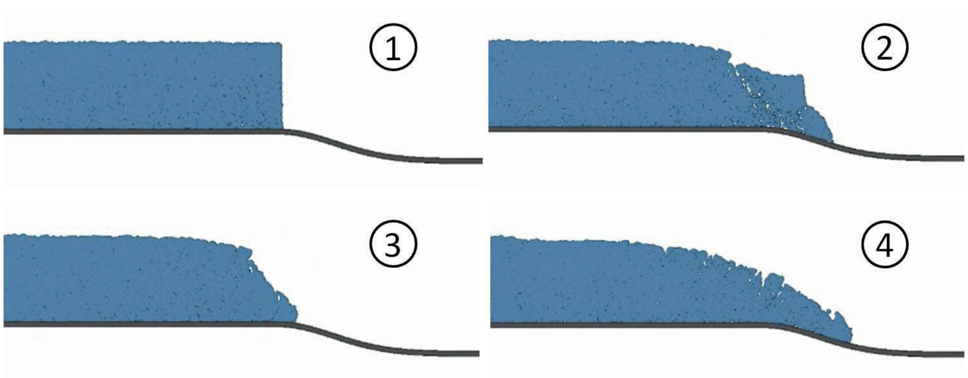

Figure 3. Time series of an icefall simulation produced with 2-dimensional glacier-DEM model.

ALICE

Jan Rak, Wladyslaw Trzaska and Sami Räsänen

In 2016 ALICE operated during the entire running period of the LHC collider at CERN. The bulk of the data, totalling the equivalent 70 days, were taken for proton-proton collisions at the center of mass energy of 13 TeV. At that time ALICE collected 822 million events at the minimum bias trigger and 514 million of high-multiplicity events. Especially important for ALICE were the three heavy ion (HI) runs at the end of the year: the 5.8 day equivalent p-Pb run at 5 TeV followed by 5.6 days of p-Pb collisions at 8 TeV.

Our group has running and maintenance responsibilities in two detector systems. The T0 timing detector operated very well throughout 2016. The time resolution stayed below 50 ps even for 1 MIP events and the time alignment was 5 ps for HI and 10 ps for all pp runs. T0 also operated as the main vertex and luminosity meter, importance of which was underlined during the HI runs. The other highlight relevant to our contribution to ALICE was the excellent performance of the level-0 (L0) single photon EMCal trigger system used in the rare trigger data taking throughout the year.

A significant part of our work is committed to the upgrade of the ALICE detector. During the Long Shutdown scheduled for 2019 – 2020 the LHC luminosity will be increased substantially and the interaction rate in heavy ion collisions will rise to 50 kHz. To cope with these new requirements, all the major subsystems of ALICE need significant improvements. In particular a new Fast Interaction Trigger (FIT) has to be designed and build. In addition to T0, our team (W.H.Trzaska) is also the CERN Project Leader for FIT coordinating the work of about 50 scientists from 14 institutions in 6 countries. In 2016 the R&D on FIT made a significant progress by completing two in-beam tests of the prototypes at CERN PS and continuously operating a full-chain prototype in the actual position inside of the ALICE magnet and taking real LHC data. FIT has also successfully met all the milestones and passed all the scheduled CERN reviews. The detector concept and performance were reported at major conferences including the 14th Vienna Conference on Instrumentation (VCI 2016) and the 38th International Conference on High Energy Physics (ICHEP 2016).

Our group is also involved in the upgrade of the Time Projection Chamber (TPC), and the Fast Interaction Trigger (FIT) system, the successor of the T0 detector. Our main task within the TPC upgrade is to perform quality assurance studies of about 300 m2 of Gas Electron Multiplier (GEM) foils, which will replace the old TPC readout chambers. We measure gain uniformity and leakage currents via optical measurements in the clean room at the Helsinki Institute of Physics. Our instrumentation has worked very well and the Wigner Institute in Budapest decided to copy the same test setup to their facilities. Our PhD student Marton Vargyas helped in starting the new setup and performed measurements in Hungary. We proudly can report that in the end of 2016 the QA production of the ALICE TPC ROC GEM foils has successfully started at HIP. The QA center was prepared in time and ready at the start of the production. The first batches of in total 42 GEM foils were processed at twice the foreseen production rate of 18 GEM foils per month.

The current main directions of the physics analysis performed by our group involve high-pT triggered correlations and studies of the jet transverse structure. When studied in pp, pPb and PbPb collisions, the results provide insight of the QCD radiation and its modifications in the cold nuclear matter and in the quark gluon plasma. We study also flow patterns via correlations among Fourier coefficients of detailing the azimuthal anisotropies of the final hadron momentum distributions in PbPb collisions. These correlations are used to constraint the transport properties of the strongly interacting matter, like shear viscosity to entropy ratio of QGP.

Jussi Viinikainen finished his analysis on transverse structure of jets via two-particle correlations in pp and pPb collisions. Earlier studies at CCOR and PHENIX have showed that transverse momentum spread of the final hadrons around the jet axis can be described using a single Gaussian with a width of roughly 600 MeV [1] and with very

Figure 1: Members of the ALICE team inspect one of the GEM foils for the ALICE TPC ROC.

little dependence on momentum of the trigger particle at the event. A new finding in Jussi's analysis was that at the LHC energies the transverse spread clearly has two distinct components, narrow and wide. Left (right) panel in Figure 2 show the narrow (wide) component as a function of trigger particle momentum. The narrow component, again of the order of 600 MeV, does not show trigger momentum dependence and is associated with non-perturbative component in jet fragmentation. The wide component, related to gluon radiation, increases with the trigger momentum. Jussi presented his results in the Hard Probes 2016 conference, Wuhan, China [2].

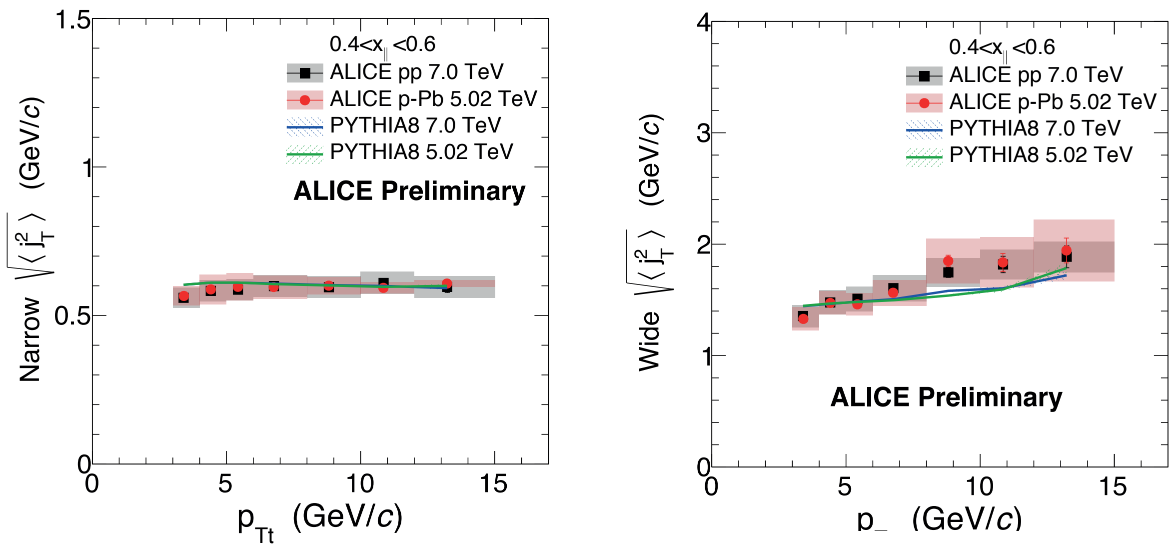

Figure 2: Narrow (left) and wide (right) component of the jet transverse width using two-particle correlations.

One of the highlights of ALICE scientific program is the detailed study of correlation functions among identified particles in pp collisions at 7 TeV [3].

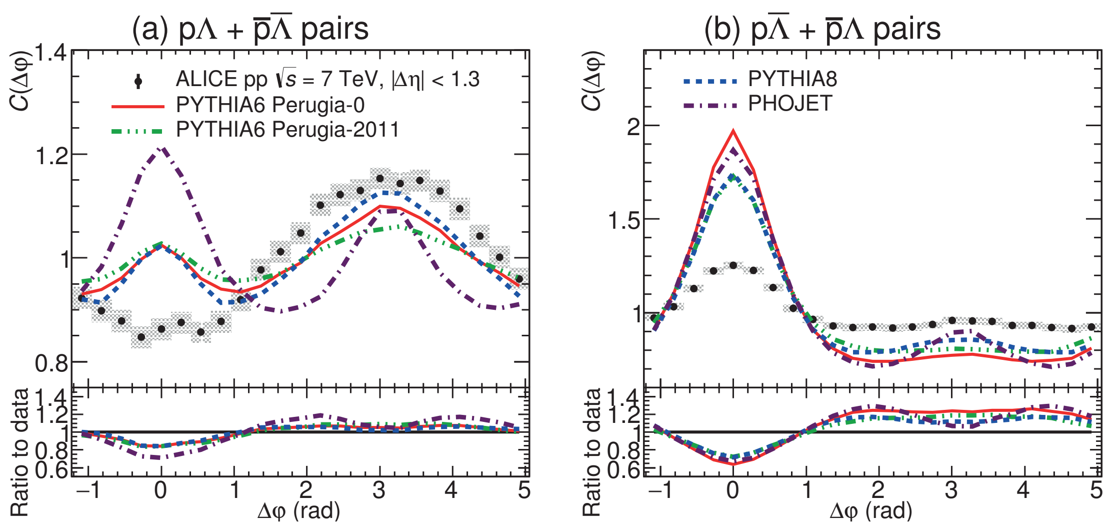

Figure 3: Azimuthal correlation functions of identified baryon-baryon and baryon-anti-baryon pairs in proton-proton collisions compared to event generators.

Left panel of Figure 3 shows the depletion of the near side in the baryon-baryon correlations that none of the standard event generators can produce. This depletion is not seen in the baryon-anti-baryon correlations shown in the right panel. It turned out that the most used event generators, PYTHIA and Phojet, cannot reproduce these correlation functions although they provide a good description of the meson correlations. This implies that baryon production mechanisms need to be revised in the event generators and can provide insight to baryon production in fragmentation.

[1] PHENIX Collaboration, Phys. Rev. D74 (2006) 072002

[2] Jussi Viinikainen for the ALICE Collaboration, arXiv: 1612.05475 [hep-ex]

[3] ALICE Collaboration, arXiv:1612.08975 [nucl-ex]

ULTRARELATIVISTIC HEAVY ION COLLISIONS – THEORY

Kari J. Eskola and Tuomas Lappi

The main goal of ultrarelativistic heavy ion collisions (URHIC) is to explore strongly-interacting elementary-particle QCD matter, the Quark Gluon Plasma in particular. We aim at understanding QCD matter properties and nuclear collision dynamics through various observables at CERN-LHC and BNL-RHIC. Our main tools are perturbation theory, renormalization group equations, the classical color-field formulation of QCD, and relativistic hydrodynamics. We are funded by the Academy of Finland, European Research Council and private foundations, and associated also with the Helsinki Institute of Physics via Lappi's QCD theory project. In 2016, we organized URHIC summer school lectures at JYFL, joined the Users group of the planned EIC collider in the U.S., contributed to the physics planning of the possible future collider CERN-FCC, and participated with a high profile in the largest conferences in our field. Boguslavski, Escobedo and Paatelainen started as new postdocs in Lappi's projects, and Paukkunen as a University researcher in Eskola's new 4-year Academy project. Lappi's 5-year ERC Consolidator grant project started in 10/2016.

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NUCLEAR PARTON DISTRIBUTION FUNCTIONS (NPDFS)

Nuclear PDFs are needed for the computation of all collinearly factorizable hard-process cross sections in nuclear collisions. Our earlier global EPS09 analysis, defining the standard for the nPDFs and their uncertainties already for several years, now reached 700 citations. A clear highlight in 2016 was that we completed a new global analysis of nPDFs, resulting in the set EPPS16, which is the very first one constrained by LHC data (dijets, Z, W) [1]. Also data from neutrino-nucleus deep inelastic scattering and dilepton production in pion-nucleus collisions were used as new input. The data constraints now allow for a much greater parametrization freedom, significantly reducing the theoretical bias in the error analysis. Thus, EPPS16 now represents the state of the art in this field (Fig. 1). Related to nuclear hard processes, we also studied the neutron-skin effect at the LHC, and participated in the FCC physics planning.

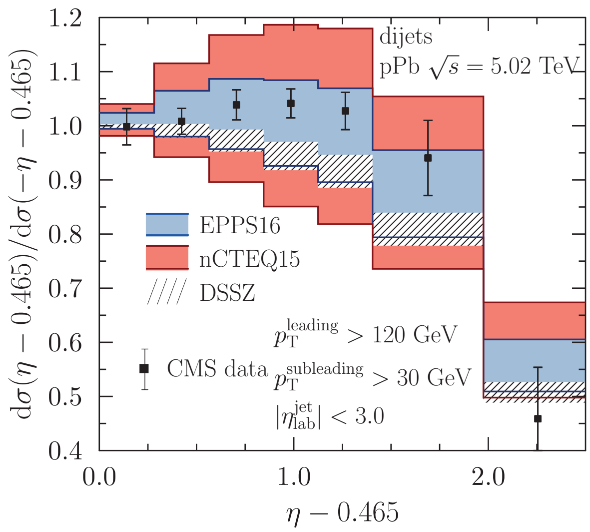

Figure 1. Comparison of the new EPPS16 and other nuclear parton distributions with CMS dijet data, showing both the good agreement with and the constraining power of the new data [1].

COLOR GLASS CONDENSATE (CGC)

In the CGC framework we study different aspects of high energy QCD scattering, in particular the initial stages of heavy ion collisions. In the CGC picture the dense system of brehmsstrahlung gluons inside a high energy nucleus is described as a classical gluon field. The equilibration of the initial overoccupied gluon fields in a heavy ion collision is characterized by a gradual separation of the temperature and the plasmon mass scales which are initially the same. We developed new methods to measure the plasmon mass from classical gauge fields on a real time lattice [2] and a new algorithm for a controlled study of linearized fluctuations around the classical gauge field.

An important tool in the CGC picture is the Balitsky-Kovchegov (BK) evolution equation. It is a weak coupling renormalization group equation describing the energy dependence of field correlators that are needed for calculating QCD scattering cross sections. We solved for the first time the generalization of the BK equation to the odderon, a parity-odd component of the scattering amplitude permitted by the symmetries of QCD [3] (Fig. 2). This formalism is frequently applied to single inclusive particle production at forward rapidity. The process is formulated as a quark or gluon passing through the classical color field. Recent calculations of this cross section at the next-to-leading order level in perturbation theory have yielded negative values, indicating an instability in the perturbative expansion. We managed to isolate the origin of this negativity in the earlier renormalization procedure, and proposed a new way to calculate this NLO cross section [4].

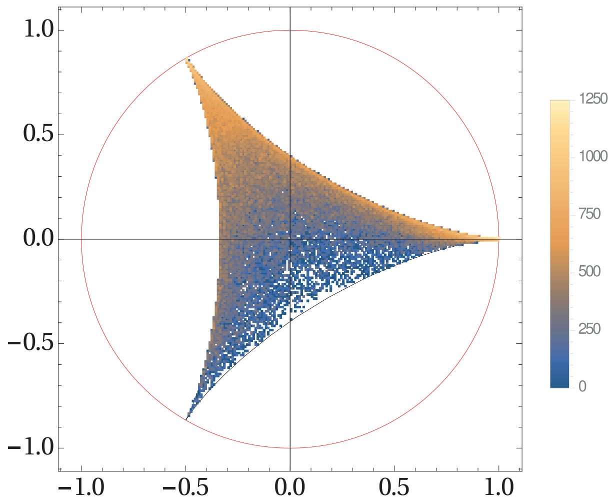

Figure 2. Quark-antiquark scattering matrix element in the complex plane, within the SU(3) hypocycloid and with a strong asymmetry in the imaginary axis direction, indicating an odderon [3].

HEAVY ION PHENOMENOLOGY: EVENT BY EVENT EKRT MODEL

Relativistic hydrodynamical studies of QCD matter spacetime evolution – our group's longtime specialty – are now a cornerstone of URHIC physics. Our EKRT model successfully predicts the produced fluctuating QCD-matter initial densities from next-to-leading order perturbative QCD and gluon saturation, and evolves the system in space and time event by event with dissipative fluid dynamics. Comparing a multitude of global and flow-related observables with RHIC and LHC data we set constraints on the temperature dependence of the QCD matter shear viscosity [5]. Our multiplicity and flow predictions compared very well with the first LHC-ALICE data measured at the highest lead-lead collision energy so far [6]. In 2016, we also provided the ALICE and RHIC-STAR experiments with our predictions of various flow correlators, to be compared with their data.

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[1] K.J. Eskola, P. Paakkinen, H. Paukkunen, C.A. Salgado, EPPS16: *Nuclear parton distributions with LHC data,* arXiv:1612.05741 [hep-ph], to appear in Eur. Phys. J. C

[2] T. Lappi, J. Peuron, *Plasmon mass scale in classical nonequilibrium gauge theory,* Phys. Rev. D 95 (2017) 014025

[3] T. Lappi, A. Ramnath, K. Rummukainen, H. Weigert, *JIMWLK evolution of the odderon* Phys. Rev. D94 (2016) 054014

[4] B. Ducloué, T. Lappi, Y. Zhu, *Single inclusive forward hadron production at next-to-leading order*, Phys. Rev. D93 (2016) 114016

[5] H. Niemi, K.J. Eskola, R. Paatelainen, *Event-by-event fluctuations in perturbative QCD + saturation + hydro model: pinning down QCD matter shear viscosity in ultrarelativistic heavy-ion collisions,* Phys. Rev. C93 (2016) no.2, 024907

[6] H. Niemi, K.J. Eskola, R. Paatelainen, K. Tuominen, *Predictions for 5.023 TeV Pb + Pb collisions at the CERN Large Hadron Collider,* Phys. Rev. C93 (2016) no.1, 014912

NEUTRINO PHYSICS

Jukka Maalampi and Wladyslaw H. Trzaska

The long-term goal of our group is to contribute both experimentally and theoretically to the solution of the remaining neutrino puzzles such as the still unknown mass hierarchy, determination of the phase of CP violation in the leptonic sector, and the existence and properties of the sterile neutrinos. Our phenomenological studies have concentrated on the question of the so-called θ_{23} octant and nonstandard neutrino interactions in the framework of long baseline experiments. With simulation studies we have investigated the sensitivity of the planned long baseline experiments for resolving whether $\theta_{23} > 45°$ or $\theta_{23} < 45°$ and determining various parameters describing the strength of possible non-standard neutrino interactions.

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DUNE AND JUNO EXPERIMENTS

Our group has joined DUNE (Deep Underground Neutrino Experiment) in January 2016. Since that time the collaboration has grown to include nearly 1000 scientists from over 160 institutes in 30 countries. The approval by the USA Department of Energy of the Critical Decision 3a formally enables construction of caverns for four 10 kton (fiducial) liquid argon detectors, the cryogenic systems and other utilities at Sanford Lab in South Dakota.

In the recently completed Neutrino Platform Hall (EHN1) at CERN two massive tanks are being erected to house two prototype detectors, ProtoDUNE Single Phase and ProtoDUNE Dual Phase (DP) detector, both with a 6 x 6 x 6 m^3 fiducial volume. Both detector types will be tested with charged particle beams at CERN in 2018. The data will provide the necessary calibration of the detector and benchmark reconstruction algorithms. This project is a crucial milestone for DUNE.

Figure 1. Finnish scientists and students involved in neutrino physics research. The photo was taken on 16 December 2016 right after Kai Loo had defended his Ph.D. thesis entitled "Extending Physics Potential of Large Liquid Scintillator Neutrino Detectors", the first thesis in experimental neutrino physics in Finland.

Figure 2. M. Slupecki and S. Vihonen inspecting cryogenics and readout of the 3x1x1 demonstrator at CERN in October 2016.

R&D on DP detector is being carried out by the WA105 experiment at CERN. Our main contribution to DUNE comes specifically thought this experiment where our team participates in operation, software design, and data analysis. Just as 6 x 6 x 6 m^3 is a prototype of the 10 kton unit, the WA105 team has build at CERN a 3 x 1 x 1 m^3 demonstrator of the Dual Phase detector. By the end of 2016 the 3x1x1 demonstrator was fully assembled and was ready to be cooled down for the first measurements in 2017.

Over the past decade our main experimental interest was in the giant liquid scintillator detectors as the Pyhäsalmi mine was the prime location for the LENA detector. As LENA was not funded, all of the European groups involved in LENA R&D have now joined JUNO transferring the know-how and the remaining resources to China. JYFL has a status of an observer in JUNO. We also continue, together with Oulu University, radio-purity measurements of organic scintillators in the new underground laboratory at the 1430 m level in the Pyhäsalmi mine.

SELECTED PUBLICATIONS

[1] Katri Huitu, Timo J. Kärkkäinen, Jukka Maalampi, Sampsa Vihonen, *Constraining the nonstandard interaction parameters in long baseline neutrino experiment,* Physical Review D93 (2016), no. 5, 053016.

[2] Kai Loo, Yu N. Novikov, Mikhail Smirnov, Wladyslaw Trzaska, and M. Wurm, *Omnibus experiment: CPT and CP violation with sterile neutrinos,* Journal of Physics, Conference Series 718 (2016) no.6, 062063.

COSMOLOGY

Kimmo Kainulainen and Sami Nurmi

We work mainly in the interphase between particle physics and cosmology. Our research topics include *the dark matter* and *dark energy* problems and *baryogenesis* problem, cosmic *inflation* and inhomogeneous cosmologies. Our recent work includes studies of electroweak baryogenesis and dark matter in models featuring extended scalar sectors to the SM providing portal to dark sector. We also worked out novel isocurvature constraints on very weakly coupled portal dark matter models, impelled by inflation. Our group currently consists of two permanent staff members, one postdoctoral researcher and six PhD-students.

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ISOCURVATURE CONSTRAINTS ON WEAKLY COUPLED PORTAL MODELS

We have shown that a large class of higgs portal Dark Matter models, where the dark sector is *ultraweakly* coupled with the Standard Model, are strongly constrained by the CMB limits on isocurvature perturbations. Specifically, we assumed a hidden sector with a singlet scalar s and a sterile DM neutrino ψ. During inflation, an s-condensate is generated. As the condensate decays, its isocurvature perturbation gets imprinted onto the dark matter. The Planck limit then constrains the fraction of the DM that can arise from such condensate. This leads to a novel constraint between the DM mass mDM, its self-coupling λs and the scale of inflation H: $m_{DM}/\text{GeV} < 0.2\lambda s^{3/8}(H/10^{11}\text{GeV})^{-3/2}$.

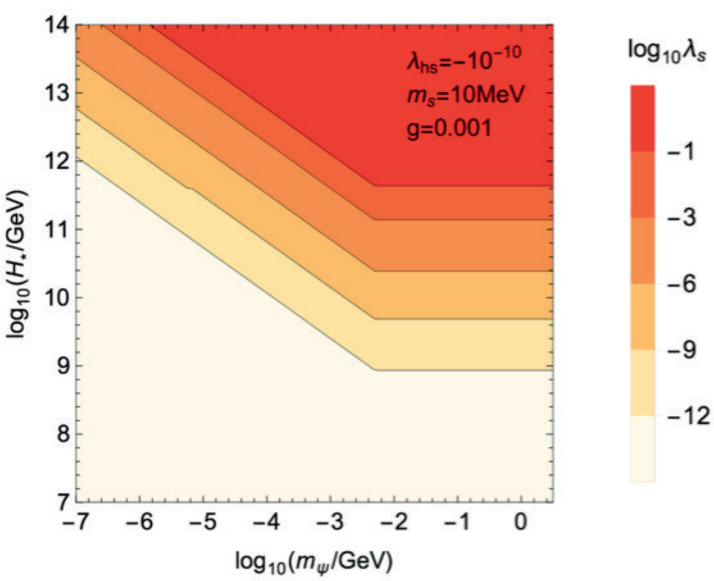


Figure 1: Isocurvature constraint excludes areas right and up from the contours labelled by different values of λs as indicated by the colour bar

SELECTED PUBLICATIONS IN 2016

[1] Tommi Alanne, Kimmo Kainulainen, Kimmo Tuominen and Ville Vaskonen, *Baryogenesis in the two doublet and inert singlet extension of the Standard Model*, JCAP 1608 (2016) no.08, 057, arXiv:1607.03303.

[2] Kari Enqvist, Mindaugas Karciauskas, Oleg Lebedev, Stanislav Rusak and Marco Zatta, *Postinflationary vacuum instability and Higgs-inflaton couplings*, JCAP 1611 (2016) 025, arXiv:1608.08848.

[3] Kimmo Kainulainen, Sami Nurmi, Tommi Tenkanen, Kimmo Tuominen and Ville Vaskonen, *Isocurvature Constraints on Portal Couplings*, JCAP 1606 (2016) no.06, 022, arXiv:1601.07733.

[4] Kari Enqvist, Sami Nurmi, Stanislav Rusak and David Weir, *Lattice Calculation of the Decay of Primordial Higgs Condensate*, JCAP 1602 (2016) no.02, 057, arXiv:1506.06895 [astro-ph.CO].

EDUCATION

Pekka Koskinen, Jukka Maalampi, Jussi Maunuksela and Juha Merikoski

The Department of Physics is a major physics educator in Finland. It educates Candidates in physics, and Masters, Licentiates and Doctors in physics, theoretical physics and applied physics. About one third of the masters graduated have physics' teacher's qualifications and move to a career in education, one third is employed in industry, and one third aims research and doctor's degree. The Department is continuously developing the syllabus and the content of the courses in order to better meet the demands of physicists' working life.

PRIMETIME LEARNING - COLLABORATIVE AND INTERACTIVE PHYSICS TEACHING

The development of teaching has continued at the Department, with emphasis put on peer learning in small groups and self-directed studies, known to be a more effective and deeper way to learn than traditional lectures. A new practical approach to teach physics on regular courses has been developed and studied. It was adopted on a second-year thermodynamics and optics course and contained no lectures, no recitation classes and no end-of-course exams. Instead, the teaching was founded on computer-supported collaborative problem solving in small groups using a weekly repeating four-stage learning process (Figure 1). The learning process is supported by formative assessment complemented by self-, peer- and teacher assessment at the end of the course. By using the known advantages of strong personal interactions among students and between students and the teacher, this new approach promotes students' social integration and overall student well-being.

While developing these new teaching methods, and even more in the coming years, we started to systematically integrate numerical problem-solving into students' routine activities. Over time experience in numerical and symbolic calculations will give students better opportunities to learning, more tools to solve realistic physics problems, and improved readiness for working life.

A NEW WAY OF TEACHING COMMUNICATION AND LANGUAGES FOR PHYSICISTS

The language and communication courses, a part of every student's curriculum, have proved not to support optimally our students' communication and language competence. To better the situation, the University's Language Centre, in collaboration with the staff and students at the Department, has been developing a new way of training these skills, where the communication and language teaching are integrated into students' discipline-specific studies. In the first phase, this development process focused on interaction and group work skills, study skills and multilingualism. These courses were piloted on autumn semester 2014. The second phase has focused on communication and presentation competence as well as multilingualism. This course was piloted on second year physics students in the beginning of academic year 2015-2016. Planning for the third and last phase was completed in autumn 2015, this stage will see the close integration of Physics Bachelor's Thesis course with the Research Communication course and it will be a co-teaching pilot taking place in spring semester 2017.

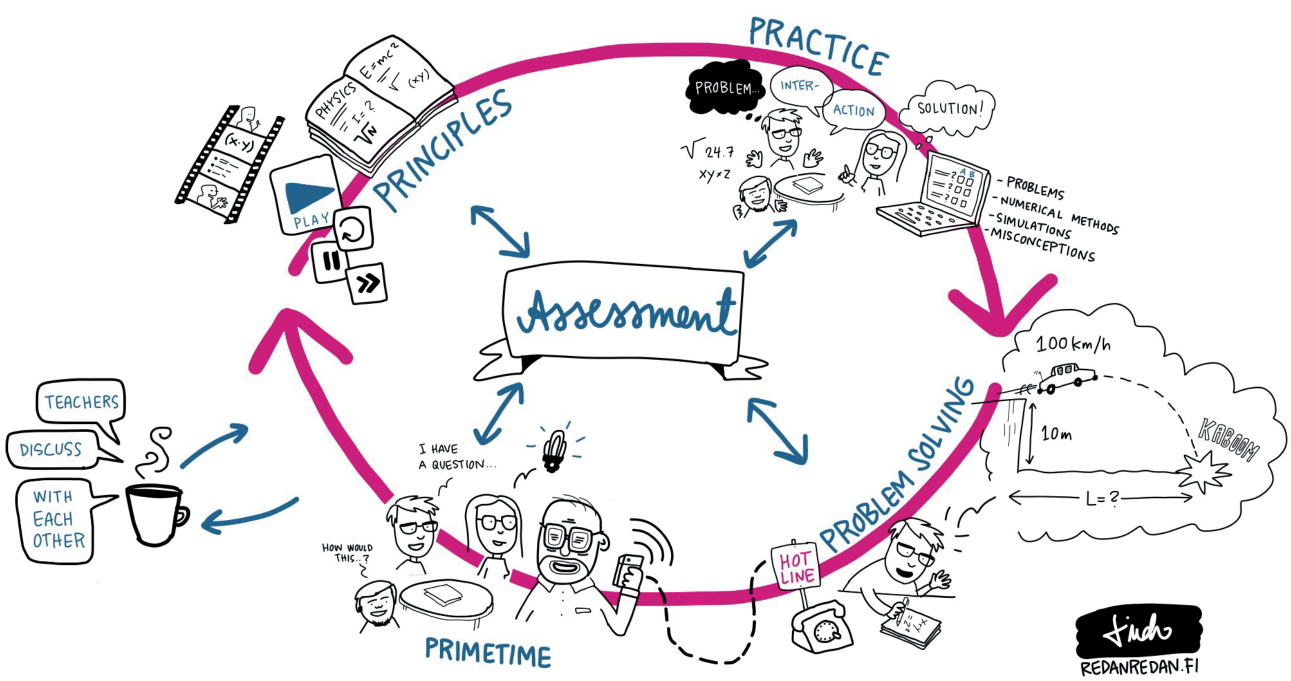


Figure 1. The primetime learning cycle.

INDUSTRIAL COLLABORATION

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

Several research groups at the Department of Physics have continued their collaboration with a number of Finnish and European companies in long-term and short-term applied research projects. A recent highlight is the approval of the H2020-MSCA-ITN-2016 RADSAGA project, where Department of Physics is one of the beneficiaries. The goal is to innovate and train young scientists and engineers in all aspects related to electronics exposed to radiation. It is coordinated by CERN and will, for the first time, bring together European industry, universities, laboratories and test-facilities (Figure 1) in order to produce 15 PhDs, of which 3 at Department of Physics. A second highlight is the highly competed PoDoCo (Post Docs in Companies) position awarded for Mikko Laitinen, who now spends a sabbatical year in Recenart company bridging research between university and company. Recenart is a spin-off of University of Jyväskylä established in 2016, and combines art historical research with state-of-the-art scientific techniques for authentication, dating and other forensic purposes.

Figure 1. The RADSAGA training network provides an intersectoral structure based on a unique mixture of private companies, universities and national laboratories. The host companies of the students' training periods are: 3D-Plus (FR), Airbus D&S (FR), MAGICS Instruments (BE), Yogitech (IT, part of Intel's Internet of Things Group) and Zodiac Aerospace (FR).

The Industrial Applications group of the Accelerator Laboratory continued the utilization of RADEF facility under ESA's Technical Research Programme (TRP). This is done in close collaboration with European space industry. The annual revenue in 2016 was 1 003 366 €, first time over 1 M€ in the history of the laboratory's Industrial Application Progamme. The use of RADEF's K-130 beam time in 2016 was 1142 hours being about 20 % from the total running hours of the cyclotron. In total, 44 test campaigns for 22 companies or institutes were performed at RADEF. This includes also three campaigns at electron LINAC after its ESA-commissioning in April.
Radiation tests of the PHY transceiver electronics with heavy ions and protons were performed at RADEF. It was done as a sub-contract work for Airbus GmbH, Bremen, Germany. Samples from three different transceiver manufacturers were evaluated. The total ionizing dose tests were conducted at the ESA/ESTEC Co-60 facility in Noordwijk, The Netherlands.

The Accelerator Based Materials Physics group within the Accelerator Laboratory has continued its active industrial collaboration both with international and domestic companies in 2016. The need for ion beam analysis services is growing and to answer that need, a new analysis beam line was designed for Pelletron accelerator in 2016 and will be taken into use in 2017. The helium ion microscope installed in late 2015 has in 2016 been used in several industrial projects.

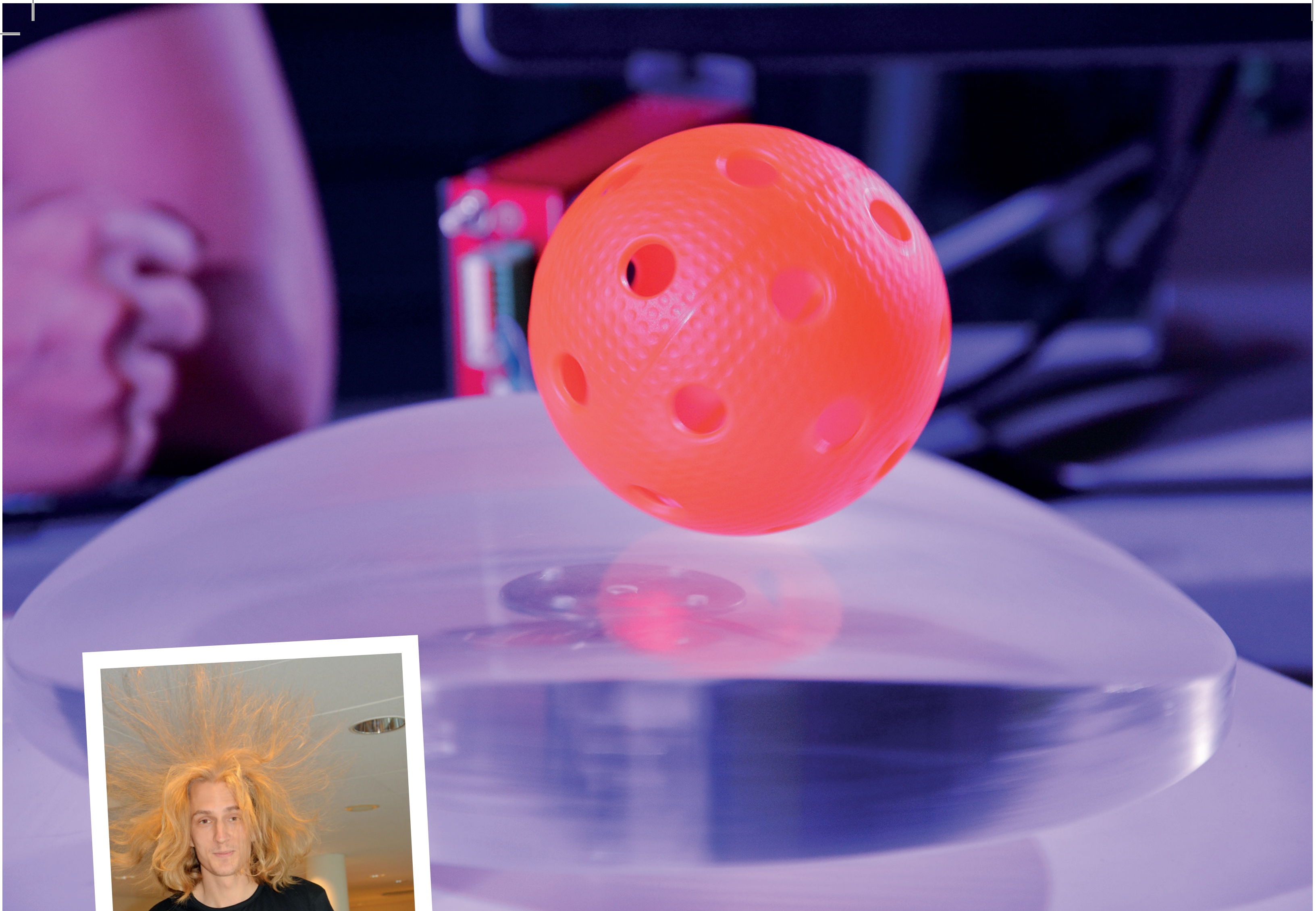
The Experimental Nanophysics groups have well established collaboration with a few companies in Finland and abroad. The superconducting radiation detector work has involved collaboration with global, industry leading small and medium scale high tech companies, including one from the USA. In addition, national laboratories such as VTT Micronova and NIST Boulder have been involved. Collaboration with the NASA Goddard Space Flight Center in the US has also started, and contacts to the Jyväskylä start-up company Recenart are also close.

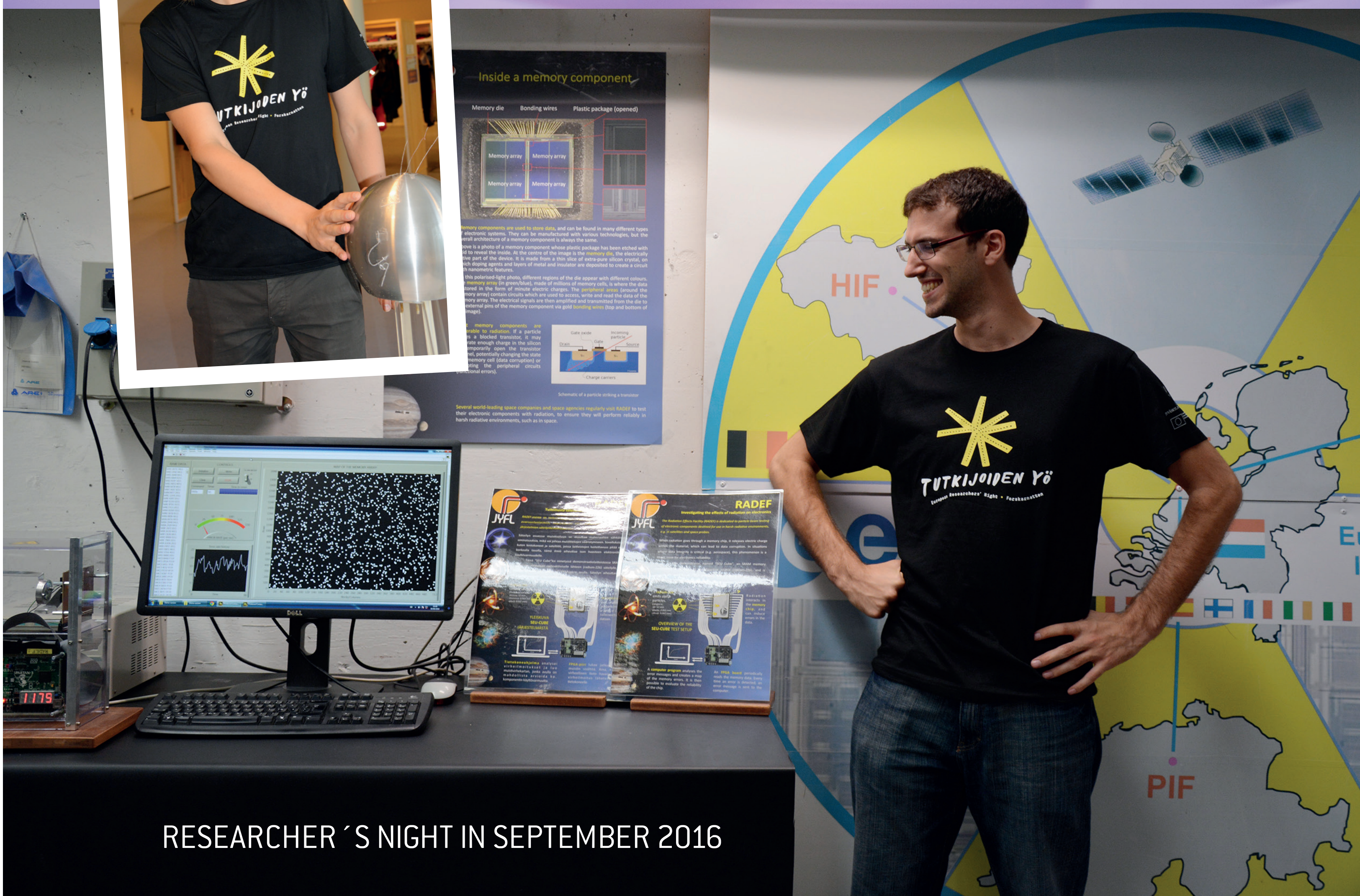
The Molecular electronics and plasmonics group continued collaboration with lamit.fi, a company from Jyväskylä concentrating on renewable energy. This Academy funded project on building integrable solar energy collection involves research groups also from Germany, India and Norway. In addition, the Molecular Technology group has collaborated with Morphona Oy, a local start-up company, in investigating the physical properties of carbon nanotubes solubilized with hemi-cellulose. Thin films made from this material shows promising high-frequency conductive properties.

The Complex materials group utilizes the X-ray tomographic facility in applied research with industrial partners, e.g. for the analysis of structural and transport properties of fibre based materials, ceramics and minerals. Experimental work was complemented with material modelling taking basic research results of the group in immediate practical use. Individual projects were related e.g. to development of novel bio-based materials, safety analysis of repositories of spent nuclear fuel, structural properties of fibrous materials and the analysis of moisture transport and defects in composite materials.

The collaborators included several major Finnish forest industries as well as domestic and European companies and applied research institutes related to novel materials manufacturing, nuclear safety, geology, building materials and to other industrial research and development. Especially, the close collaboration with VTT Technical Research Centre of Finland was continued, involving e.g. 3D structural analysis of various types of materials of industrial relevance, and development of novel methods for materials analysis. In addition to industry, funding to applied research was received from Academy of Finland, Ministry of Employment and the Economy and European Union.

INDUSTRIAL COLLABORATION





RESEARCHER´S NIGHT IN SEPTEMBER 2016

APPENDIX

JYFL PERSONNEL 2016

HEADS OF THE DEPARTMENT

Jukka Maalampi, professor, Head of Department
Ari, Jokinen professor, Vice Director, Head of the Accelerator Laboratory
Markku Kataja, professor, Vice Director

ACCELERATOR LABORATORY

Administration and contact persons:
Ari Jokinen, Head of the Accelerator Laboratory
Rauno Julin, Leader of the Center of the Excellence
Mikael Sandzelius, Beam time coordinator
Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory:
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Dario Vretenar, University of Zagreb, Croatia
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NUCLEAR AND ACCELERATOR BASED PHYSICS

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Karim Bennaceur, senior researcher
Tiia Haverinen, doctoral student
Andrea Idini, postdoctoral researcher
Markus Kortelainen, senior researcher
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Kristian Petrik, postdoctoral researcher
Gianluca Salvioni, doctoral student

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Sami Rinta-Antila, senior researcher
Mikael Reponen, academy postdoctoral researcher
Dmitrii Nesterenko, postdoctoral researcher
Annika Voss, postdoctoral researcher
Laetitia Canete, doctoral student
Sarina Geldhof, doctoral student
Ilkka Pohjalainen, doctoral student
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Juuso Reinikainen, MSc student
Afrina Khanam, MSc student
Sara El Youbi, MSc student
Marjut Hukkanen, MSc student
Jari Partanen, laboratory Engineer

NUCLEAR SPECTROSCOPY

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Matti Leino, professor emeritus
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Juha Uusitalo, senior researcher
Catherine Scholey, senior researcher
Tuomas Grahn, senior lecturer
Janne Pakarinen, academy researcher
Mikael Sandzelius, senior researcher
Panu Rahkila, senior researcher
Philippos Papadakis, senior researcher
Jan Sarén, senior lecturer
Daniel Cox, postdoctoral researcher
Panu Ruotsalainen, postdoctoral researcher
Jari Partanen, laboratory engineer
Juha Sorri, doctoral student
Sanna Stolze, doctoral student
Joonas Konki, doctoral student
Hussam Badran, doctoral student
Tom Calverley, doctoral student
Joshua Hilton, doctoral student
Jarkko Liimatainen, MSc student
Joonas Ojala, MSc student
Olavi Neuvonen, MSc student

INSTRUMENTS AND METHODS IN NUCLEAR, PARTICLE, AND ASTROPARTICLE PHYSICS

Wladyslaw Henryk Trzaska, senior scientist
Kai Loo, doctoral student
Maciej Slupecki, doctoral student
Johannes Hissa, doctoral student (Oulu University)
Yerzhan Mukhamejanov doctoral student (Almaty University, Kazakhstan)
Antto Virkajärvi, student (Lappeenranta Technical University)
Roope Sarala, student

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Kai Arstila, university researcher
Mikko Laitinen, laboratory engineer
Laura Mättö, doctoral student
Mari Napari, doctoral student
Marko Käyhkö, doctoral student
Sami Kinnunen, doctoral student
Henri Kivistö, MSc student

RADIATION EFFECTS AND INDUSTRIAL APPLICATIONS

Ari Virtanen, research director
Heikki Kettunen, laboratory engineer
Arto Javanainen, postdoctoral researcher
Taneli Kalvas, postdoctoral researcher
Mikko Rossi, laboratory engineer
Jukka Jaatinen, laboratory engineer
Alexandre Bosser, doctoral student
Maris Tali, doctoral student
Corinna Martinella, doctoral student
Valtteri Lahti, MSc student

NUCLEAR STRUCTURE, NUCLEAR DECAYS, RARE AND EXOTIC PROCESSES

Jouni Suhonen, professor
Jenni Kotila, postdoctoral researcher
Wafa Almosly, doctoral student
Mikko Haaranen, doctoral student
Juhani Hyvärinen, doctoral student
Pekka Pirinen, doctoral studentt
Lotta Jokiniemi, doctoral student
Joel Kostensalo, MSc student

MATERIALS PHYSICS

MOLECULAR TECHNOLOGY
Markus Ahlskog, professor
Matti Hokkanen, doctoral student
Dongkai Shao, doctoral student
Antti Lukkarinen, MSc student
Saara Lautala, MSc student
Joonas Saari, MSc student

THERMAL NANOPHYSICS
Ilari Maasilta, professor
Tuomas Puurtinen, senior researcher
Zhuoran Geng, doctoral student
Samuli Heiskanen, doctoral student
Miika Leppänen, doctoral student
Ilmo Räisänen, doctoral student
Andrii Torgovkin, doctoral student
Ari Helenius, MSc student
Teemu Loippo, MSc student
Jaakko Mastomäki, MSc student
Kimmo Kinnunen, laboratory engineer (shared)
Tarmo Suppula, laboratory engineer (shared)

MOLECULAR ELECTRONICS AND PLASMONICS
Jussi Toppari, university lecturer
Andreas Johansson, university researcher
Heli Lehtivuori, postdoctoral researcher
Janne Simonen, postdoctoral researcher
Eero Hulkko, postdoctoral researcher
Siim Pikker, postdoctoral researcher
Svitlana Baieva, doctoral student
Tommi Isoniemi, doctoral student
Boxuan Shen, doctoral student
Kosti Tapio, doctoral student
Jan Borovsky, doctoral student
Vesa-Matti Hiltunen, doctoral student
Mikael Kautto, MSc student
Kevin Roberts, MSc student
Jyrki Manninen, MSc student

THEORETICAL NANOPHYSICS AND COMPUTATIONAL NANOSCIENCE
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Tero Heikkilä, professor
Vesa Apaja, senior researcher
Karoliina Honkala, lecturer (chemistry)
Pekka Koskinen, lecturer
Gerrit Groenhof, academy research fellow (chemistry)
Lauri Lehtovaara, academy research fellow (chemistry)
Francesco Massel, academy research fellow
Mikhail Silaev, academy research fellow
Sami Malola, senior researcher
Mihail Silaev, academy research fellow
Philippe Djorwé, postdoctoral researcher
Andrey Bazhenov, postdoctoral researcher (chemistry)
Serena Donnini, postdoctoral researcher (biology)
Sahoo Gokarneswar, postdoctoral researcher (chemistry)
Timo Hyart, postdoctoral researcher
Rosalba Juarez-Mosqueda, postdoctoral researcher
Elena Kuisma, postdoctoral researcher
Mikael Kuisma, postdoctoral researcher
Mikhail Kuklin, postdoctoral researcher
Johan Lindgren, postdoctoral researcher (chemistry)
Dmitry Morozov, postdoctoral researcher (chemistry)
Pauli Virtanen, postdoctoral researcher
Janne Nevalaita, postdoctoral researcher
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Faluke Aikebaier, doctoral student
Luis Cort, doctoral student
Lars Gell, doctoral student (chemistry)
Markku Hyrkäs, doctoral student
Sami Kaappa, doctoral student
Daniel Karlsson, doctoral student
Topi Korhonen, doctoral student
Richard Lynn, doctoral student
Janne Nevalaita, doctoral student
Teemu Peltonen, doctoral student
Emmi Pohjolainen, doctoral student
Elli Selenius, doctoral student
Elena Semina, doctoral student (chemistry)
Niko Säkkinen, doctoral student
Sakari Tuokko, doctoral student (chemistry)
Riku Tuovinen, doctoral student
Saku Antikainen, MSc student
Antti Pihlajamäki, MSc student
Aili Asikainen, MSc student
Saara Lautala, MSc student
Sampsa Kiiskinen, MSc student
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Juho Koivula, MSc student
Kalle Kansanen, MSc student
Petri Kuusela, MSc student
Risto Ojajärvi, MSc student

COMPLEX MATERIALS
Markku Kataja, professor
Jussi Timonen, professor emeritus
Arttu Miettinen, postdoctoral researcher
Keijo Mattila, postdoctoral researcher
Jussi Virkajärvi, postdoctoral researcher
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Topi Kähärä, postdoctoral researcher
Tuomas Puurtinen, postdoctoral researcher
Axel Ekman, postdoctoral researcher (abroad)
Joni Parkkonen, laboratory engineer

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Tero Harjupatana, doctoral student
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PARTICLE PHYSICS

ALICE

Jan Rak, professor
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DongJo Kim, university researcher
Sami Räsänen, university researcher
Erik Brücken, postdoctoral researcher, Helsinki
Time Hildén, postdoctoral researcher, (Helsinki)
Beomsu Chang, doctoral student
Jussi Viinikainen, doctoral student
Marton Vargyas, doctoral student
Tomas Snellman, doctoral student

ULTRARELATIVISTIC HEAVY ION COLLISIONS – THEORY

Kari J. Eskola, professor
Tuomas Lappi, academy research fellow, HIP project leader
Hannu Paukkunen, university researcher
Kirill Boguslavski, postdoctoral researcher
Bertrand Ducloué, postdoctoral researcher
Miguel Escobedo, postdoctoral researcher
Risto Paatelainen, postdoctoral researcher
Yan Zhu, postdoctoral researcher (HIP)
Petja Paakkinen, doctoral student
Jarkko Peuron, doctoral student
Andrecia Ramnath, doctoral student
Henri Hänninen, MSc student, summer trainee
Mikko Kuha, MSc student, summer trainee
Tapani Stylman, MSc student

NEUTRINO PHYSICS

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Kai Loo, postdoctoral researcher
Maciej Slupecki, doctoral student
Sampsa Vihonen, doctoral student
Kerem Cankocak, visiting scientist
Giovanni Misitano, MSc student
Heidi Rytkönen, MSc student
Roope Sarala, MSc student
Jukka Sorjonen, MSc student

COSMOLOGY

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Mindaugas Karciauskas, postdoctoral researcher
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Henri Jukkala, doctoral student
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