Heavy Ion Laboratory

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HIL
Heavy Ion Laboratory

Heavy Ion Laboratory

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Annual Report

2017

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Annual Report of the
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The photo on the title page was taken
in front of the HIL building on 17 May 2018
by Michalina Komorowska

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Contents

Introduction

The year 2017 was marked at HIL by a series of nuclear physics experiments supported by the European Union through the ENSAR2 (European Nuclear Science and Application Research 2) project within the HORIZON 2020 framework. In one of these experiments the newly developed ^{24}Mg beam was used. Not all the data sets from these measurements are ready to be presented but some of them can be found in this volume. Most of the experiments were devoted to applications of the Coulomb excitation method for investigations of electromagnetic properties of nuclei. Apart from already performed experiments it is worth mentioning a very ambitious project related to the measurement of very short life-times of nuclear levels. A setup of 24 LaBr detectors (EYE) combined with the gamma-array (EAGLE) was tested in a short run and a full experimental campaign using this setup is scheduled for February 2018.

Our laboratory is constantly promoting collaborations with external facilities and that with the Joint Institute of Nuclear Research (JINR) in Dubna is one of the most intensive. Two of our employees are presently on leave at JINR working in the Flerov Laboratory of Nuclear Reactions. In 2017, at this laboratory, the first radioactive ion beam was produced by the new fragment separator ACCULINA-2 with an intensity of an order magnitude higher than with the old facility. Its construction was supported by funds from Polish contribution to JINR. The first experiment with a ^{6}He beam from ACCULINA-2 is scheduled for the first months of 2018 and will form the PhD project of B. Zalewski from our laboratory.

For several years we have been developing medical applications of nuclear physics. These are related, among others, to the production of radioisotopes that could be used in medical diagnosis and therapy. An important achievement of 2017 was the proton-production of scandium radioisotopes offering a variety of applications. This was possible due to an external target system designed, built and installed at the PETtrace p/d cyclotron by the team of Dr. J. Choiński. This target system allows for the irradiation of solid and in particular metallic targets.

In 2017, in the framework of a Memorandum of Understanding between HIL and the Owner's Committee of the European Gamma-Ray Spectroscopy Pool (EGP), our laboratory became the home base for some highly efficient gamma detectors of EGP. A few of them were repaired in our detector laboratory and a few are still awaiting repair in 2018. All of them will be used in experiments planned for the coming years.

An important event organized in 2017 was the HIL Prize Symposium. The HIL Prize was funded by professor Takashi Tom Inamura who was a visiting professor at HIL during the years 1998–2002. In September 2017 a symposium devoted to the presentation of achievements of the prize laureates was organized and professor Inamura came from Japan, honouring the symposium with his presence.

The funding provided in 2017 by the Ministry of Science and Higher Education of Poland was for the first time in our history adequate to our needs. We are hoping that this is not a single event but a sign of a "new policy" of the Ministry that recognizes the needs of large scale, "national" facilities in Poland.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview and technical developments

A.1 General information

J. Choiński, P. Napiorkowski, K. Rusek

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The Heavy Ion Laboratory (HIL) is a unit of the University of Warsaw, the largest university in Poland. HIL was founded jointly by the Ministry of Education, the Polish Academy of Sciences and the Polish Atomic Energy Agency. It is the largest experimental nuclear physics laboratory in the country, equipped with two cyclotrons — a $K = 160$ U-200P heavy-ion cyclotron and a $K = 16.5$ GE PETtrace commercial cyclotron delivering high intensity proton and deuteron beams.

The first heavy-ion beam was extracted from the U200P in 1994 and since that time HIL has been an effective "user facility", serving up to the present time several hundred scientists from Poland and abroad, and has become a recognised element of the European Research Community. From the 1st of March 2016, HIL is among ten European laboratories with Transnational Access granted by the European Union via the ENSAR2 (European Nuclear Science and Applications Research 2) project within the HORIZON 2020 framework. Beam time is allocated by the Director based on the recommendations of the international Programme Advisory Committee. The only criteria are the scientific merit of the project and its technical feasibility. The research programme is mostly focused on nuclear physics and medical applications including the production of radio-isotopes.

Experimental teams may take advantage of permanent set-ups installed on the beam lines or use their own dedicated equipment. Available apparatus includes IGISOL — a Scandinavian type on-line separator, CUDAC — a PIN-diode array particle detection system, JANOSIK — a multi-detector system consisting of a large NaI(Tl) crystal with passive and active shields and a 32-element multiplicity filter and ICARE, a charged particle detector system used for particle identification and energy measurements, moved to HIL from IReS Strasbourg. The most recent experimental tool, still being developed and improved, is the EAGLE array — a multi-detector γ-ray spectrometer, equipped with 16 HP germanium detectors with anti-Compton shields and up to 14 HP germanium detectors from the GAMMAPOOL consortium. It can be easily coupled to ancillary detectors like the internal conversion electron spectrometer built by the University of Lodz, a $4\,\pi$ charged particle multiplicity filter (Si-ball), a scattering chamber equipped with 100 PIN-diode detectors, a 60-element BaF_2 gamma-ray multiplicity filter, a sectored HPGe polarimeter and a plunger.

Since 2012 the Radiopharmaceuticals Production and Research Centre, focused on the production of and research into Positron Emission Tomography radiopharmaceuticals, has formed an important part of HIL. The production of longer-lived radioisotopes for life-sciences applications is also carried out.

Being a university unit, HIL is in a natural way involved in teaching. On average about 15 students/year (Bachelors, Masters, PhD, ERASMUS), from Poland and abroad, work at HIL supervised by its staff members. As part of its broader educational mission, the HIL staff organizes an annual one-week workshop on "Acceleration and applications of heavy-ions" for about 20 students from various Polish universities.

A.2 Cyclotron operation in 2017 and tasks carried out in order to improve the cyclotron infrastructure and efficiency

J. Choiński, P. Gmaj, A. Bednarek, T. Bracha, A. Jakubowski, P. Jasiński, W. Kalisiewicz, M. Kopka, W. Kozaczka, P. Krysiak, K. Łabęda, K. Makowski, I. Mazur, J. Miszczak, Z. Morozowicz, O. Saeed Mohamed Nassar, B. Paprzycki, K. Pietrzak, B. Radomyski, K. Sosnowski, Ł. Standyło, K. Sudlitz

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Operation

In 2017 the cyclotron division provided ion beams for experiments related to nuclear physics research as well as biological and medical research. The complete list of cyclotron activity can be found elsewhere in this report. Some experimental results are also reported in this document. The medical experiments concentrated on the production of radioisotopes needed for the formation of chemical specimens to be used in medicine as novel radiopharmaceuticals.

Regardless of routine work, beam development work continued intensively. It resulted in providing a previously unavailable Mg beam required for an experiment probing the distribution of Coulomb barriers using the ICARE setup and in mastering the technique of obtaining metallic and non-metallic ions from volatile compounds. The Programme Advisory Committee approved a total of 12 experimental projects in 2017 (2040 h of beam time) of which 3 runs were postponed to next year and 1 run was cancelled due to the cyclotron failure. Therefore, the total cyclotron availability was 94% of the allocated beam time. The executed beam time accounted for 76% of the plan.

As in the previous few years, the main topics of the experiments were related to nuclear physics research (EAGLE, ICARE), and biological and medical research. The latter also includes includes medical radioisotope production (examples: ^{211}At, ^{43}Sc, ^{44}Sc, ^{72}Se or ^{72}As production in collaboration with the Institute of Nuclear Chemistry and Technology, the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences, and POLATOM National Centre for Nuclear Research).

Traditionally, the cyclotron division delivered beam for the students' workshop, which took place in the autumn.

In 2017 16 experimental runs were carried out, in which 73 senior and many younger Polish and foreign scientists took part (see the tables at the end of this report). Each run took from 5 days to 2 weeks of continuous cyclotron operation.

Maintenance and development

ECR Source

Due to user demand the cyclotron team worked on expanding the list of available beams, in particular on the preparation of metallic beams as mentioned above. Ions of this type are obtained in an ECR type ion source using special methods and devices, like a vapourising oven, sputtering system or the MIVOC method, all of them usually combined with a thin liner in the plasma chamber. In April 2017 the first experiment using metallic ions was carried out.

Further efforts were continued to optimizet the operation of ECR sources based on a special test bench, which was designed and installed at HIL in 2015. This bench was partially financed by NCBiR within the scope of the EMILI-EURISOL project and its purpose is to achieve higher ion currents and longer uninterrupted operation of the source, necessary for experiments. The development of the above bench was continued within the European ENSAR 2 project during 2017.

RF system

The currently used RF amplifiers have come to the end of their useful lives as they are already more than 30 years old. Spare parts are no longer available in the world market place. This mainly concerns such important components as GK-11A power tubes, T-160 thyristors etc. In 2015 the winners of three tenders for the components of the new RF system were selected and in 2016 the first two stages of the system were delivered and tested in December. The commissioning of the whole system was, however, postponed until 2018 due to the delay of the manufacturer of the power stage of the system (Popek-Elektronik). The RF team is permanently monitoring the manufacturing work ensuring the highest diligence in the performance of above power stages.

However, the delays in commissioning the new RF system have caused a large disturbance in the cycle of cyclotron work and, as a result, its availability for experiments.

Power infrastructure

In addition to normal maintenance resulting from wear and tear, the power infrastructure is constantly being refitteded and modernised. A series of infrastructure modernisation was conducted in 2016 and 2017 as an adaptation to the new RF system installation.

Projects

ECR and ICBT (Innovative Charge Breeding Techniques)

At the end of 2015 the European ERANET NUPNET EMILIE project was completed with the commissioning of the ECR test bench. This bench was built for the purpose of increasing knowledge and practice concerning ion sources of the ECR type. The work focused on optimisation of charge breeding efficiency and ECR optimisation was continued in 2017 within the scope of ICBT.

RF system (postponed to 2017)

By the end of 2017 it is planned to replace the outdated amplifiers supplying the accelerating structure of the U-200P cyclotron with new ones. The new RF system will now be commissioned by the end of 2017 due to the above mentioned manufacturer delay. This means a two years shift compared to previous predictions.

Power infrastructure

The power infrastructure will continue to be developed to adapt it to the new requirements resulting from the renewal of the power supply and control system, development of the ECR research bench and the replacement of the RF amplifiers.

Magnetic structure of the U-200P cyclotron (postponed)

In 2017 a new collaboration arrangement with JINR FLNR aimed at general reconstruction of the magnetic field was started. The first step, designing the magnetic field measurement system, was initiated.

A.3 Status of the ECRIS test stand at HIL

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The most recent research activities of the HIL ion source section are aimed at the modernisation of the existing experimental system of a simple ECR [1] source. The goal is to design and build an experimental setup for the improvement of the performance of ECR ion sources for high charge state production. The beam capture efficiency by ECR plasma as a function of beam energy and emittance is being investigated. Measurements of the intensity and energy of the primary 1^+ beam and the secondary beam that pass through the plasma are planned. The primary beam will be injected into the plasma chamber with different energies and different emittances. The concept of the injection system is presented in Fig. 1 — the setup is still under development. After injection into the source, the beam components are transformed into a higher charge state: the 1^+ beam is captured by the ECR plasma [2–4]. Injection of the 1^+ ion beam should lead to optimisation of the velocity of the 1^+ ions entering the plasma in order to maximize their capture. The energy of 1^+ beam will be controlled by the potential on the 1^+ ion source cathode. Thermalisation and 1^+ beam capture are optimal when the energy of the injected beam is approximately equal to the energy of the plasma ions (the longitudinal component of the beam velocity is equal to the most likely velocity of the plasma ions [5]), but recent simulations [6] and measurements [7] indicate that additional energy is needed to inject ions deep enough into the plasma.

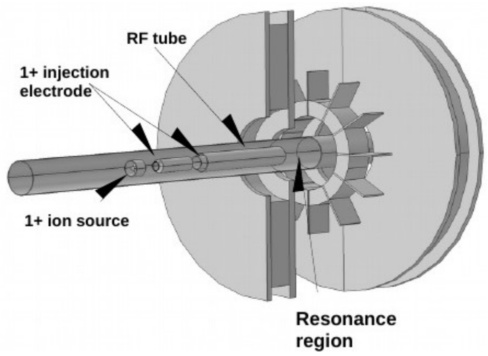

Figure 1: Schematic proposal for the 1^+ injection setup model.

The 1^+ ion source (Fig. 2) will be mounted on an injection system which will introduce beam in to the plasma chamber. Interaction of the beam with the plasma and the magnetic field of the trap will result in the creation of a secondary beam. The secondary beam will contain, in addition to the original 1^+ component, components of higher ionization states. The effectiveness of the primary beam capture will be reflected by the intensity of the highly charged components of the secondary beam. It is expected that the secondary beam will contain a component specific to the source potential, as well as a component of the undisturbed portion of the primary 1^+ beam. Due to the complicated magnetic field distribution inside the magnetic trap (and outside it), it was necessary to simulate the 1^+ beam optimal trajectory. The experimental setup will consist of the ECR source connected with the 1^+ ion source via a special injection system and an electromagnetic analyser connected to a measuring chamber and forming a mass spectrometer. ECRIS will be powered with a 300 W, 10 GHz frequency-generator. The high charge state breeding efficiency of the ion source is strongly correlated with the microwave field distribution in the plasma chamber, which depends on both the magnetic field and the frequency. The trap magnetic field will be generated by water-cooled 40 kW coils and a hexapole constructed from a neodymium magnet system (NdFeB). For measurements of secondary beam energy, an electrostatic analyser will be used. It will be calibrated with a Li 1^+ source.

Figure 2: Prototype of thermal lithium 1^+ ion source.

The performance of the Li 1^+ source was tested separately. The stable 1^+ beam current is around 0.5 µA (maximum current is around 3 µA). First tests of the 1^+ beam transmission through the ECR magnetic trap with and without a magnetic field were conducted. The beam was optimised on the profiler by changing the magnetic field and the source potential.

Construction of the mechanical parts of the experimental system is still ongoing. A series of beam injection simulations was performed, calculating the optimum shape of the magnetic field, the electrostatic systems for injection (Fig. 3) and beam formation. The structure of the ECR plasma (density, temperature) in the magnetic trap will vary depending on the operating gas used, the microwave power input, the magnetic and electrostatic field correction (beam extraction). After completing the construction of the setup, these parameters will be optimized to increase the performance of the system.

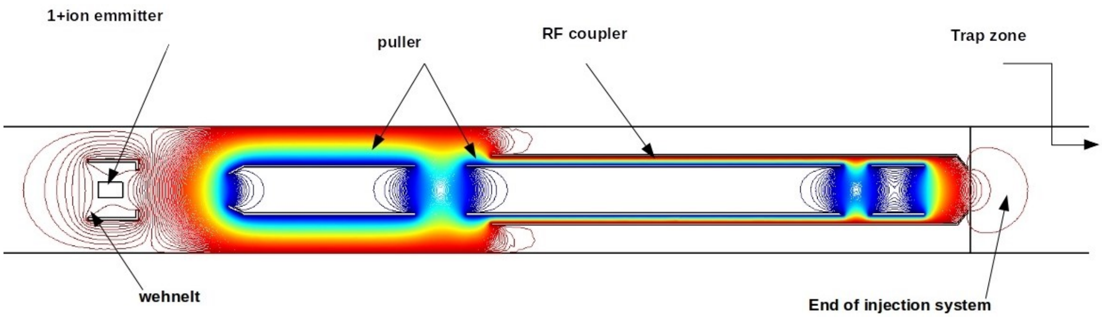

Figure 3: Equipotential lines for the 1^+ injection system mounted in the extension of the plasma chamber. Two gaps in the puller (extraction electrode from the 1^+ source) give a better optical condition of the incoming beam.

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A.4 A new amplifier for the cyclotron buncher

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Various developments of the cyclotron buncher were presented over the years in the HIL Reports, for the last time in 2011 [1]. This time a new amplifier for the buncher is described. The amplifier that was used until the end of 2017 was tube based, and the tubes had to be replaced at regular intervals (usually every 2–3 years). The tubes are readily available, but only as a so-called "new old stock" — never used, but manufactured years ago. At some point in time the stock will dry up, so a decision was made to develop a new, semiconductor based, amplifier. The new design not only replaces tubes with transistors, but also incorporates some improvements over the old amplifier, like new, simplified, tuning circuitry. The new amplifier was put into operation at the end of 2017.

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A.5 Restoring GAMMAPOOL HPGe detectors

T. Abraham, J. Srebrny, M. Kisieliński, M. Kowalczyk, R. Kopik, B. Radomyski, M. Antczak, A. Pietrzak, A. Jakubowski for the EAGLE collaboration

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The central European Array for Gamma Levels Evaluations (EAGLE) is an array of High Purity Germanium (HPGe) detectors at HIL [1, 2]. In 2017 the Laboratory become the home base for 14 highly efficient (70% relative efficiency) detectors from GAMMAPOOL and 15 Anti Compton Shields (ACS) [3]. By the end of the year the number of detectors housed increased to 18.

This year 2 detectors were fully repaired and one was partially recovered at HIL. Our partners from the University of Jyväskylä delivered another two fully operational detectors and IPN Orsay also delivered two, but one without a working Bias Shut-Down (BSD) signal.

An additional agreement was signed with the University of Jyväskylä to lend and use at HIL 8 HPGe detectors and 8 ACS till June 2018. These were detectors of "Phase 1" type (the same as GAMMAPOOL) and GASP (with a smaller dewar and cryostat). For the GASP detectors a new mounting system was designed and manufactured in HIL's workshop.

In summary there are 13 working HPGe detectors from GAMMAPOOL and 3 detectors from Jyväskylä giving 16 detectors installed on the EAGLE frame. Table 1 shows the status of the GAMMAPOOL detectors based at HIL at the end of 2017. It is important to mention that the detectors with noise in the signal or broken arrived in this state from INP Orsay. The detector laboratory at HIL has repaired 3 broken detectors and is working to recover the remaining 4.

Table 1: GAMMAPOOL detectors based at HIL with FWHM measured at an energy of 1333 keV.

No.	Number in HIL	GAMMAPOOL number	FWHM (keV)	Status
1	59	GFOC 21	Noisy	Noisy
2	61	GUOC 32	2.50	Used in experiment
3	62	GUOC 16	5.00	Noisy
4	63	GUIC 36	Noisy	Endcup needs fixing
5	64	GFOC 33	2.30	Repaired at HIL - used in experiment
6	65	GUIC 35	2.50	Used in experiment
7	67	GFOC 50	2.40	Used in experiment
8	68	GFOC 31	2.45	Used in experiment
9	69	GUOC 14	2.40	Used in experiment
10	70	GUOC 01	2.25	Repaired at HIL - used in experiment
11	71	GUIC 34	7.00	Noisy
12	72	GUOC 08	2.50	Used in experiment
13	73	GFOC 18	2.75	Used in experiment
14	75	GUOC 13	2.30	No BSD
15	76	GFOC 49	2.30	Repaired at HIL - used in experiment
16	77	GUOC 12	2.70	Used in experiment
17	79	GFOC 26	2.23	Used in experiment
18	87	GFIC 46	2.35	Used in experiment

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[2] J. Mierzejewski *et al.*, HIL Annual Report 2010, page 24.
[3] T. Abraham *et al.*, HIL Annual Report 2016, page 17.

A.6 Development of the EAGLE gamma spectrometer data acquisition system

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After final tests in 2015 [1] the CEFE logic device successfully replaced the old trigger logic modules. Experiments in which only germanium detectors are used need one CEFE module. Up to sixteen logic signals from germanium CFDs (Constant Fraction Discriminator), ACS (Anti Compton Shields) and pile-up outputs from spectroscopic amplifiers can be connected to three 16 bit ECL inputs. Each of these inputs has an independent counter, latched every second, for load and error monitoring. Additional counters, built into the module, are used to measure the dead time and the time between the start of the beam macro structure and the event trigger. The second counter is used to distinguish between "beam on" and "beam off" events. The internal down-scaler enables the acquisition of singles during coincidence measurements. All system parameters are determined by software during the experiment initialization.

In experiments with additional particle detectors, a second CEFE unit is needed, working in coincidence with the germanium module unit. The external LVDS connection is used for coincidence checking.

To reduce the acquisition system dead time, the event readout is started during the ADC conversion time, enabling read-out of the event time, patterns, and macro-structure counter before the end of the conversion. The hardware clear signal is used when possible.

During last year a new mode was added, to serve fast timing measurements [2]. In such cases up to 24 fast logic signals are connected to ECL inputs together with the same signals delayed for about 15 ns. The electronic fast logic signals open gates, which then redirect up to four active, delayed inputs to NIM outputs. The delayed signal from the lowest input number is sent to a NIM output and then used as a common start in TAC devices, the subsequent ones to three stop TAC inputs. As a result time the resolution does not decrease after connection through the FPGA device.

At the end of last year six four-input digitisers were built in the final version. The two Virtex FPGA modules from the test version were replaced by a single Zynq Z-7030 module equipped with an ARM CPU running Linux OS. We plan to run these digitisers in parallel with the existing acquisition system in the middle of next year.

Bibliography

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A.7 Polish Workshop on the Acceleration and Applications of Heavy Ions

P.J. Napiorkowski[1], A. Trzcińska[1], T. Abraham[1], P. Gmaj[1], K. Kilian[1], M. Komorowska[1,2], M. Kowalczyk[1], T. Marchlewski[1], M. Matejska-Minda[1], M. Palacz[1], K. Rusek[1], M. Saxena[1], O. Saeed Mohamed Nassar[1], J. Samorajczyk-Pyśk[1], A. Stolarz[1], R. Tańczyk[1], M. Wolińska-Cichocka[1]

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The 13th edition of the Polish Workshop on the Acceleration and Applications of Heavy Ions was organised at HIL in October, 2017. It is addressed to students of first cycle studies interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the cyclotron including beam diagnostics measurements, and in charged particle and gamma-ray detection techniques. Medical applications of nuclear physics have also been included in the programme of the Workshop.

This time 15 students attended the lectures and the practical training (see Fig. 1). The biggest group of 6 persons came from the Silesian University in Katowice. There were 4 students from the Warsaw University of Technology, 3 from the University of Warsaw and students from the Wroclaw University of Science and Technology and the Academy of Mining and Metallurgy participated in the Workshop.

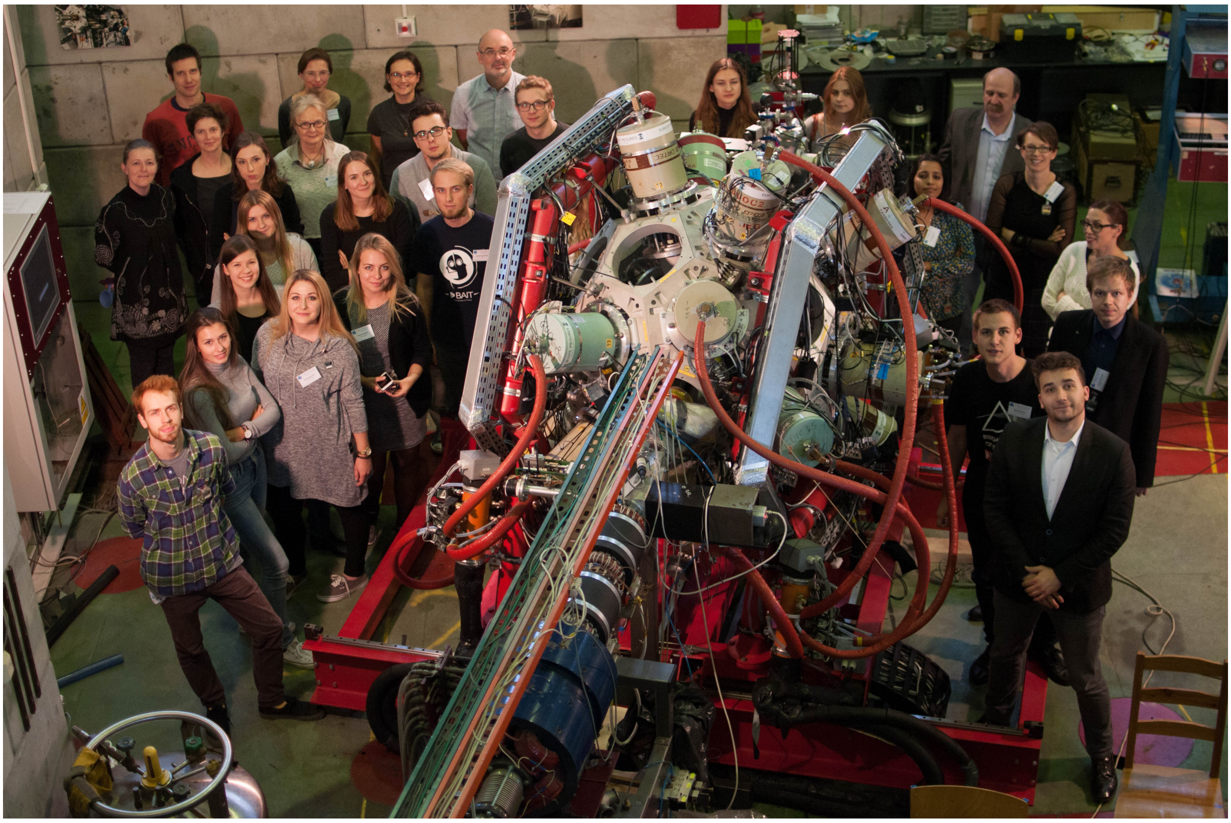

Figure 1: Participants of the 13th Polish Workshop on Acceleration and Applications of Heavy Ions.

In 2017, the programme of lectures was as follows:

- Radioprotection at the HIL (R. Tańczyk);
- HIL in a nutshell (K. Rusek);
- Introduction to heavy ion acceleration and elements of ion optics (O. Saeed Mohamed Nassar);
- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (P. Napiorkowski);
- Nuclear reactions (K. Rusek);
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian).

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration;
- Rutherford Scattering;
- Gamma spectroscopy with the EAGLE multidetector setup;
- Target production and thickness measurements;
- Measurement of ^{137}Cs activity in environmental samples.

As usual, the Workshop was completed by the student presentations session.

A.8 HIL prize symposium

P.J. Napiorkowski, M. Palacz for the organisers of the symposium

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In September 2017 a symposium devoted to the presentation of the achievements of the HIL prize laureates was organised at HIL. The symposium was honoured with the presence of Professor Takashi Tom Inamura, the founder of the prize.

Professor T.T. Inamura worked as a visiting professor at the Heavy Ion Laboratory during the years 1998–2002 and made a great contribution to its development. He founded an award which, to the amount of 5,000 USD, is presented every second year to recognise and support young researchers with outstanding experimental or technical achievements in the field of nuclear and atomic physics or related subjects. The results should be obtained using the Warsaw Cyclotron or other HIL apparatus. Candidates must be scientists or PhD students below the age of 36 on the day of application.

During the symposium the award ceremony of the 2016 edition of the Prize took place. The 2016 prize was received by Dr. Katarzyna Hadyńska-Klęk. Lectures were given by Dr. Hadyńska-Klęk and the laureates of 5 earlier editions of the prize: Dr. Łukasz Świderski (2006 laureate), Dr. Jarosław Perkowski (2008), Dr. Katarzyna Wrzosek-Lipska (2010), Dr. Joanna Czub (2012), and Dr. Urszula Kaźmierczak (2014).

Figure 1: Professor Takashi Tom Inamura and laureates of four editions of the HIL prize (left to rigth): Dr. Jarosław Perkowski, Dr. Katarzyna Wrzosek-Lipska, Dr. Joanna Czub, and Dr. Katarzyna Hadyńska-Klęk.

Part B

Research for medical and biological applications

B.1 A well cooled external target holder for the PETtrace cyclotron suitable for irradiation of powder targets

J. Choiński, T. Bracha, B. Radomyski, Ł. Świątek, M. Antczak, A. Jakubowski, P. Jasiński, J. Jastrzębski, R. Kopik, A. Pietrzak, A. Stolarz, R. Tańczyk

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In 2017 the execution of objective No. 3 of the "PET-SKAND" grant, agreement No. PBS3/A9/28/2015 awarded to a consortium of three institutions and financed by the National Centre for Research and Development, was continued. The PETtrace cyclotron in our case is additionally equipped with a standalone external target system originally designed to irradiate metallic targets, particularly molybdenum. The realization of this project has given us the opportunity to upgrade some parts of the station including safety conditions for the operational staff, and to adapt it to the specific requirements of calcium powder targets.

The dual beam proton/deuteron cyclotron is regularly used for commercial production of fluorine F-18. This means that the targets for F-18 are highly radioactive which dramatically restricts "free-entry" to the cyclotron care for centre staff in order to maintain or prepare the standalone external target system. In 2015 the station was placed very close to the cyclotron. Currently it is protected by RP patent No. 227402. During 2016 a completely new beam line (consisting of: a drift tube of total length 3.4 m, two sets of steering magnets made of permanent magnets, one quadrupole doublet and a four-sector collimator) was designed, manufactured and assembled in a temporary area. After passing all tests it was dismounted, transferred to and reassembled in its final place in the PETtrace cave. Attached to the beam line with a control box the external target system vacuum pump allows a static vacuum of 5×10^{-7} mbar to be reached. At the end of 2016 shielding, a concrete wall of thickness of 0.25 m, was assembled between the cyclotron and the diagnostic box of the target holder system. Its specific weight is 3300 kg/m^3. This improved substantially the safety conditions for the centre staff, see Figure 1. The beam transport efficiency to the target size of 12 mm reaches above 96%.

In 2017 the second and final task of objective No. 3 of the "PET-SKAND" grant was completed. The external target system was equipped with a fully remotely controlled robot. It aims to deliver the chosen target from a carousel to the head of the target system. The carousel can hold up to 8 targets, see Figure 2.

The robot delivering targets is controlled via a dedicated computer code. This code is one of the modules forming a full control program for of the standalone external target system. From the maim screen one can chose the control panel of the robot where the arm of the robot and carousel are depicted. The operator decides which target will be delivered to the head of the target system and starts the movement of the arm of the robot. A few weeks ago, after experience in handling the robot under actual conditions we have decided to modify the hardware and software responsible for communication between the computer and the robot. New versions of these devices and software are now being tested.

After irradiation the target is evacuated from the cyclotron cave in a lead container placed on a remotely controlled trolley, see Figure 3.

Last year we also made several irradiations of targets for our collaboration groups within the framework of the "PET-SKAND" grant.

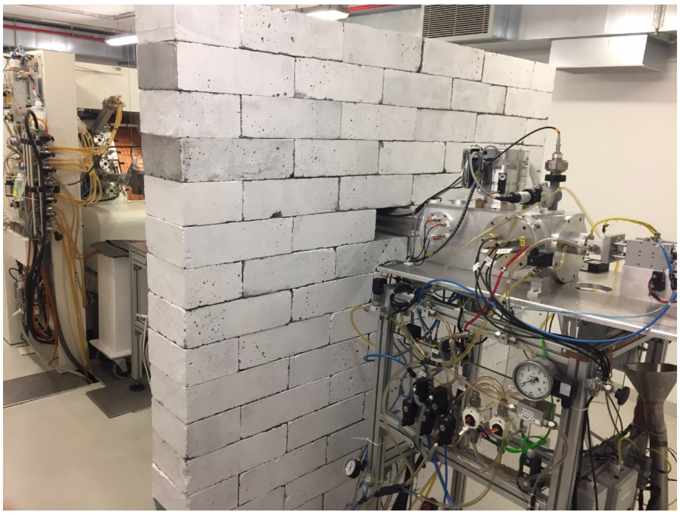

Figure 1: A view of the standalone external target system with the shielding wall and the cyclotron.

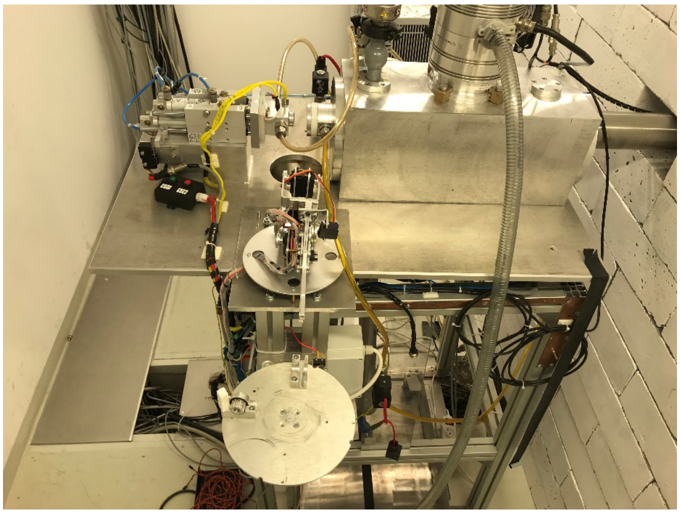

Figure 2: The standalone external target system with robot and carousel.

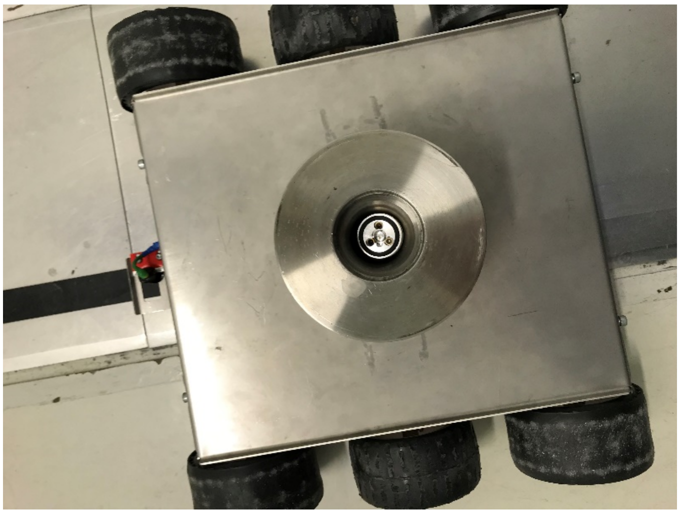

Figure 3: An irradiated target inside a lead container placed on a remotely controlled trolley.

B.2 A project of a well cooled internal target station for the U-200P cyclotron suitable for irradiation of different types of targets

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For several years the Heavy Ion Laboratory has been involved in medical radioisotope production, mostly ^{211}At using the alpha-particle beam from the U-200P cyclotron [1–3].

Currently, the cyclotron is equipped with a simple station which was designed for different purposes than production of medical radioisotopes. This station allows targets to be irradiated with the internal beam of the cyclotron. The range of available beam energies may change from a very initial up to maximum. Unfortunately, this station also has several shortcomings like for example a very weak target water cooling system and all preparations must be done manually.

Having noted the need for higher beam intensities it was decided in 2016 to design and construct a new, well cooled internal target station for the U-200P cyclotron. In 2017 we manufactured and assembled all the parts and the final version currently consists of a vacuum chamber, a target holder with tilted target, a drive system for the target holder and a drive system for the target station. We have also bought and assembled some vacuum system components. A target can be clamped in the target holder with the help of the remotely controlled drive system of the target holder. The target holder is able to be positioned inside the cyclotron valley with the help of the remotely controlled drive system of the target station.

The construction of the current version of target holder with a metallic target should be strong enough to withstand about 500 W. Typically, we use a beam of alpha particle with an energy of about 33 MeV. During target irradiation the beam current will be monitored on-line. We have also finished software and hardware for an autonomous system based on PLC responsible for the remotely controlled systems. The station is installed in a temporary location, see figure 1. This allows us to carry out mechanical, vacuum and water cooling tests and also to test the remotely controlled systems. Currently all tests have been passed positively.

In the coming year we will complete the GUI for communication between the operator of the station and the autonomous system based on PLC. During the summer vacation we plan to dismantle the old station and the new station will be assembled in its final place.

Figure 1: The station in its temporary location.

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B.3 Medical scandium radioisotopes produced by proton, deuteron and α particle beams

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The scandium radioisotopes offer the possibility of a variety of applications in the nuclear medicine field. The positron emitters ^{43}Sc and ^{44}Sc are both promising PET isotopes ($T_{1/2}$ = 3.89 h and 3.97 h, β^+ branching = 88% and 95%, max. β^+ energy = 1.20 MeV and 1.47 MeV respectively). Additionally, ^{44}Sc ($T_{1/2}$ = 58.6 h) can be used as a ^{44m}Sc/^{44}Sc long-lived in-vivo generator as it decays mainly by a low energy transition to the ^{44}Sc ground state. Meanwhile, ^{47}Sc is a β^- emitter with favorable characteristics for therapeutic purposes (average β^- energy = 162 keV, $T_{1/2}$ = 3.35 d).

In this work, we investigated and compared different production routes for these isotopes using proton, deuteron and α particle beams.

Proton and deuteron beams were obtained from the medical PETtrace p/d cyclotron [1, 2] while the α particle beam came from the K=160 heavy ion cyclotron at the Heavy Ion Laboratory, University of Warsaw. Additionally, the C30 cyclotron at the National Centre for Nuclear Research in Świerk as well as the C70 cyclotron at ARRONAX in Saint-Herblain were used for higher energy protons. These machines were used to irradiate natural and enriched targets of $CaCO_3$, Ca, KCl and TiO_2. After irradiation, the targets were measured with gamma-ray spectroscopy techniques to determine the (thick) target yields and isotopic purities of the produced radioisotopes.

The measured production yields of the scandium isotopes are presented in Table 1. Their application potentials are also affected by the available target enrichment and the level of produced impurities. The values obtained were compared with the cross-section data available in the literature [3, 6] and evaporation model predictions (see Fig. 1 and Fig. 2).

All three projectiles can be used for the production of the ^{44m}Sc/^{44}Sc generator. In Fig. 3 we show the calculated evolution of ^{44m}Sc (dashed line) and ^{44}Sc(solid line) activity after irradiation with different beams. Practically all production routes are comparable, yet the lighter the projectile, the longer one has to wait for equilibrium.

Summing up, all medically interesting scandium radioisotopes can be produced by accelerators in quantities and purity acceptable for clinical applications. However, cyclotrons accelerating α particles and protons to energies of about 30 MeV are in some cases necessary.

This work was supported by the European Commission Horizon 2020 programme, proposal 654002 "ENSAR2" and NCBiR grant PBS3/A9/28/2015. It was also supported by a grant from the French National Agency for Research called "Investissements d'Avenir", Equipex Arronax-Plus No. ANR-11-EQPX-0004 and Labex IRON No. ANR-11-LABX-18-01. The support of a French Government PhD scholarship is also acknowledged.

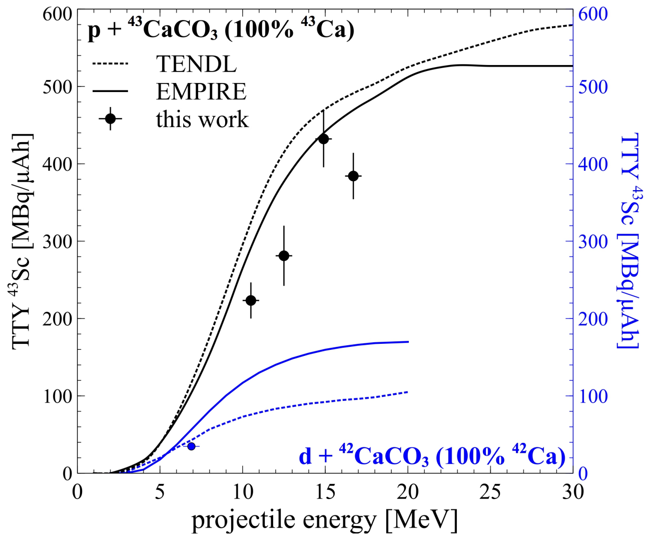

Figure 1: Thick target yields for ^{43}Sc production with proton and deuteron projectiles.

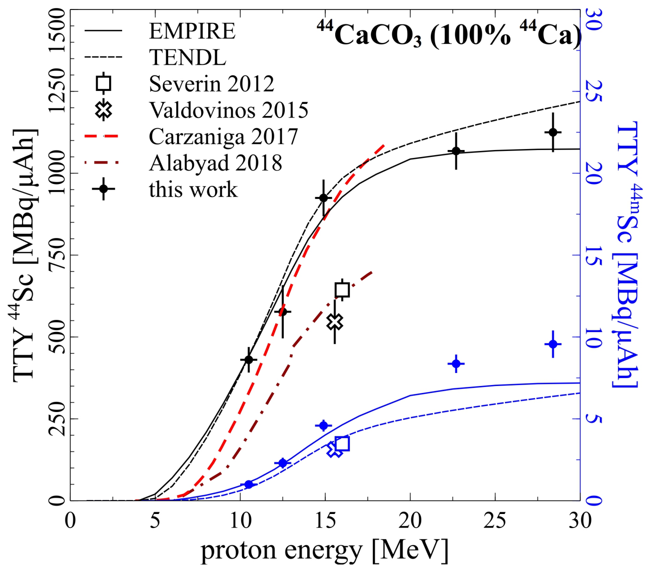

Figure 2: Thick target yields for ^{44}Sc and ^{44m}Sc production with proton projectiles.

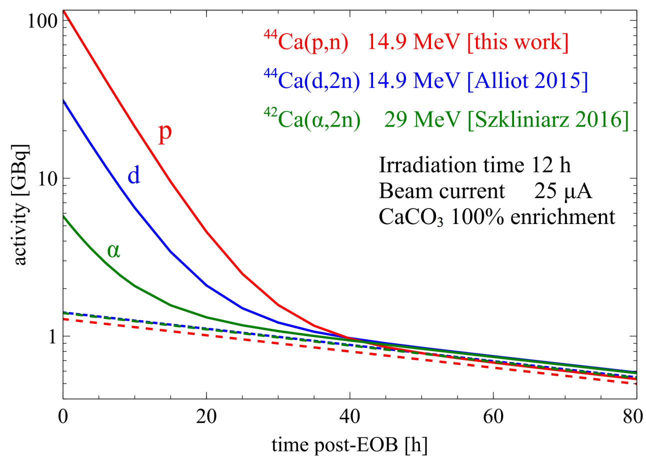

Figure 3: Calculated evolution of ^{44m}Sc (dashed line) and ^{44}Sc (solid line) activities after irradiation with different beams.

Table 1: Measured production yield of scandium isotopes.

Isotope, $T_{1/2}$	Beam	Energy (MeV)	Target	Yield (MBq/µAh)	Activity after 4 h irradiation with 1 µA beam: A_{EOB} (MBq)	Activity after 4 h irradiation with 1 µA beam: Main impurities (% A_{EOB})
^{43}Sc 3.89 h	α	20-0	$^{nat}CaCO_3$	84(4)	240(11)	^{47}Sc 0.034(5)
		20-0	^{nat}Ca	210(30)	600(86)	^{47}Sc 0.035(7)
		29-19	^{41}KCl (95.4%)	60(9)	172(26)	^{44}Sc 13(1)
	d	7-0	$^{42}CaCO_3$ (95.9%)	35(2)	100(7)	^{44}Sc 0.22(3)
	p	14.9-2.2	$^{43}CaCO_3$ (90%)	390(30)	1110(90)	^{44}Sc 10.5(1.1)
^{44}Sc 3.97 h	α	29-12	$^{42}CaCO_3$ (95.9%)	44(7)	127(20)	^{44m}Sc 13.7(8)
		20-2	^{41}KCl (95.4%)	61(10)	176(29)	^{43}Sc 15.9(7)
	p	14.9-2.2	$^{44}CaCO_3$ (94.8%)	880(50)	2520(150)	^{44m}Sc 0.67(7)
^{44m}Sc 2.4 d	α	29-12	$^{42}CaCO_3$ (95.9%)	4.7(8)	18(3)	^{43}Sc 40.6(9) apart from ^{44}Sc
		20-2	^{41}KCl (95.4%)	3.0(6)	12(2)	^{43}Sc 233(15) apart from ^{44}Sc
	p	14.9-2.2	$^{44}CaCO_3$ (94.8%)	4.3(3)	17.0(1.3)	^{48}Sc 0.96(14) apart from ^{44}Sc
^{47}Sc 3.35 d	α	20-0	$^{44}CaCO_3$ (94.8%)	0.91(10)	3.3(4)	^{43}Sc 51(3)
	p	22.7-17.0	$^{48}CaCO_3$ (97.1%)	57(9)	230(30)	^{48}Sc 27(9)
		28.4-16.3	$^{48}CaCO_3$ (97.1%)	109(16)	430(50)	^{48}Sc 27(5) ^{46}Sc 0.88(17)
		27.9-18.2	$^{48}TiO_2$ (99.6%)	3.1(5)	12.1(1.8)	^{44}Sc 220(40)

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B.4 Dynamic study of Sc(III) sorption onto carbon-based materials

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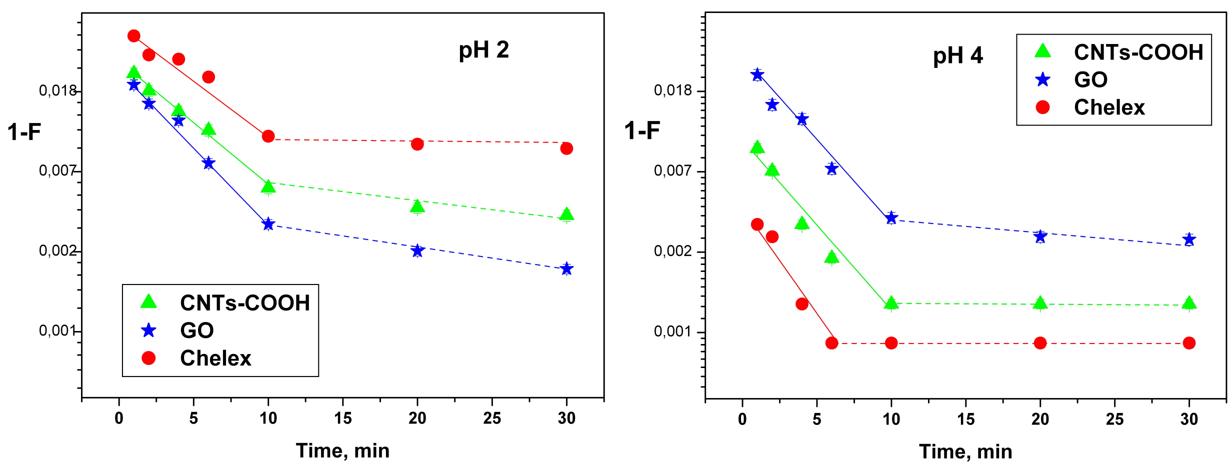
The sorption of Sc(III) onto solid materials must be considered as a liquid-solid phase reaction which includes the diffusion of ions from the aqueous phase to the sorbent surface (film diffusion), the diffusion of ions within the sorbent (particle diffusion) and the chemical reaction between ions and functional groups. The sorption kinetics are governed by the slowest of the above processes. The rate equations for the above two cases are:

$ln(1 - F) = -kt$ for film diffusion

$ln(1 - F2) = -kt$ for intra-particle

where F is the fractional attainment of equilibrium and k the experimentally observed rate constant, which depends on the diffusion coefficient in the film, the concentration of the incoming ion in the solution and in the sorbent, the radius of the particle and the film thickness.

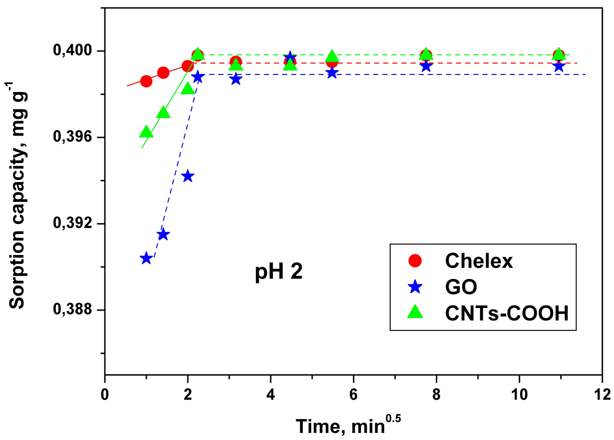
Tests of the first mathematical model of the sorption of Sc(III) ions onto the three sorbents studied at pH 2 and 4 are presented in Fig. 1. The plots obtained can be divided into two parts. In the early step, fast sorption is observed and the subsequent step is characterised by a very low slope for each sorbent. From these data it seems that scandium ion sorption during the equilibration period could generally be controlled by both limiting factors. At higher F values a deviation from linearity was observed, which may reflect a change of rate-controlling process. Generally, scandium uptake by the tested sorbents is better fitted by the film diffusion controlled mechanism, and carbon nanotubes exhibited the highest values of rate constant.



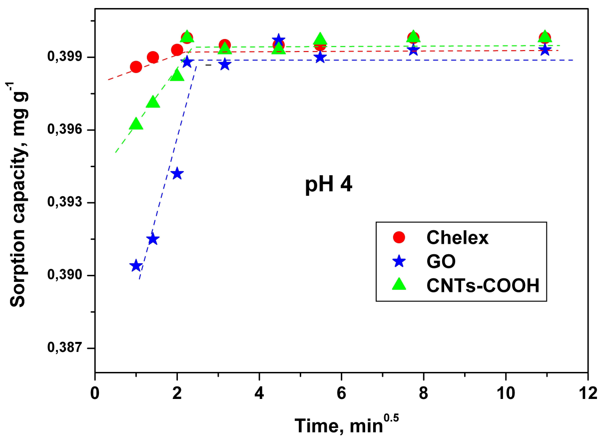
(a) ph 2 **(b)** ph 4

Figure 1: Fractional attainment for Sc(III) sorption by different sorbents.

The sorption processes from the liquid phase involve several stages that can have distinct kinetics, such as: (i) external mass transport of the sorbate from the bulk liquid to the sorbent particles, (ii) movement of the sorbate through the external liquid film that surrounds the sorbent surface (film diffusion), (iii) migration of the sorbate within the pores (intra-particle diffusion) and (iv) sorption at an internal active site. The first process can be neglected, because the batch studies included vigorous shaking. The last stage is also considered to make a minor contribution to limiting the adsorption rate because Sc(III) cations instantly bind to the active sites. Thus, steps (ii) and (iii) may mainly affect the sorption mechanism. This enables the determination of which of these two diffusion processes is the rate controlling step Figure 2 shows the diffusion plots for three sorbents at pH 2 and 4. It is seen that each plot is linear, does not pass through the origin and can be divided into two parts. Thus, the film diffusion and the intra-particle diffusion control the first, quick step. The kd values change in the following order at pH 2: CNTs-COOH > GO > Chelex, whilst at pH 4: GO > CNTs-COOH > Chelex. Similar high values for the film diffusion rates for sorption onto carbonaceous materials were obtained which indicated that the film of fluid around individual nanotubes is relatively thin.



(a) ph 2



(b) ph 4

Figure 2: Intra-particle diffusion plots for graphene oxide, carbon nanotubes and Chelex 100 resin.

This research was partially supported by The National Centre for Research and Development, Poland, project PBS3/A9/28/2015.

B.5 Alpha-tocopherol serum levels are increased in Caucasian women with uterine fibroids

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Uterine fibroids (UFs) are benign tumours of the reproductive tract, arising from smooth muscle cells of the uterus. Steroid hormones, estrogens and progesterone, are considered to be the most important links in the pathophysiology of UFs. Alpha-tocopherol (AT) is the most active form of vitamin E. What is important as far as UFs are concerned is that ATs contain structural determinants, which makes them possible ligands for estrogen receptors (ERs).

We present a retrospective cohort study performed in a university teaching hospital. We included a total of 162 patients divided into 2 groups: with UFs and controls. The effects of age, body mass index (BMI), positive medical history, parity, and AT serum concentrations on the risk of the development of UFs were investigated.

Determination of serum α-tocopherol

Blood samples were collected for biochemical analysis in fasting patients. In UF-positive patients, the blood samples were taken one day before surgery. Serum AT was measured using the high-performance liquid chromatography (HPLC) method.

Instrumentation

Chromatographic analysis was carried out using the Shimadzu LC system consisting of binary pumps LC20-AD, degasser DGU-20A5, column oven CTO-20AC, autosampler SIL-20AC and an 8030 Mass spectrometer (Shimadzu, Japan). The MS system was equipped with an electrospray ionization source (ESI) operated in negative or positive-ion mode according to the species being determined. Evaporation of solvents during the preparation of samples was performed using an Eppendorf® centrifugal vacuum concentrator. The chemicals were supplied by Sigma-Aldrich.

Samples preparation

Blood samples (5 ml) were collected in serum tubes and centrifuged at 3000 rpm for 5 min; serum samples were put in 0.5 ml microtubes and stored at -20°C until usage. Concentration of α-tocopherol in serum samples was determined by the modified procedure described by Cheng et al. [1].

Briefly, thawed plasma samples (0.1 ml) were added to 0.1 ml of α-tocopheryl acetate (25 µg/ml), which was an internal standard, and 0.1 ml of 1% pyrogallol in ice-cold ethanol. Samples were vortexed for 1 min and then 1.5 ml of n-hexane was added to the obtained solution, followed by 4 min of vortexing. After centrifugation at 1100 rpm for 5 min the upper layer containing hexane was collected and evaporated at 45°C using a concentrator. The obtained residue was dissolved in 0.1 ml of methanol: chloroform (2:1, v/v) and analysed by reversed phase chromatography LCMS. 10 µl of the sample was injected into the chromatograph, equipped with a Kinetex C18 (150 × 3.00 mm, 2.6 µm) column. The isocratic separation was conducted in 95:5 v/v methanol: 8 mmol/l formic acid (pH 2.8) with 0.4 ml/min flow. Column temperature was 30°C. ESI conditions were as follows: capillary voltage 4.5 kV, DL temperature and Heat Block temperature 230°C, source gas flow 2 l/min, drying gas flow 15 l/min. Detection of positive ions in MRM mode: alpha-tocopherol (precursor m/z 430.60, products (m/z, collision energy eV) 165.00, -34; 163.95, -38; 293.95, -30); tocopherol acetate (internal standard) (precursor m/z 473.25, products (m/z, collision energy eV) 207.20, -21; 165.20, -48; 69.10, -43). Attempts in negative ion mode resulted in lower sensitivity a higher limit of detection.

Results

Mean AT serum concentrations were 11.66±4.97 µg/ml and 7.83±3.13 µg/ml (medians: 10.56 µg/ml and 7.42 µg/ml) in patients with UFs confirmed on ultrasound and controls, respectively. The presented difference was statistically significant. Higher BMI, positive family history, and low parity were found to be major risk factors for UFs.

In our study, we confirmed that elevated serum AT concentration might be an important risk factor for UFs in Caucasian women. Further research in this area is necessary.

The Heavy Ion Laboratory gratefully acknowledges funding for the equipment (LC-MS) from the European Regional Development Fund under the Innovative Economy Programme (POIG.02.02.00-14-024/08-00) project: Center of Preclinical Studies and Technology (CePT).

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B.6 Separation and enrichment of Sc(III) on oxidized carbon nanotubes in the presence of Ca

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The purpose of this research was to develop a solid phase extraction approach using oxidized carbon nanotubes (CNT-COOH) for the separation and preconcentration of trace amounts of scandium ions from aqueous solutions. Carbon nanotubes (CNTs) have been proposed as a novel sorbent for various inorganic and organic compounds due to their large specific surface area, but without specific preparation they offer limited value for ion extraction. Oxidation of carbon surfaces can offer not only a more hydrophilic surface structure but also a larger number of functional groups, that increase the ion-exchange capability of carbon material. In environmental samples Ca(II) ions occur in large excess to Sc(III) and may interfere with the extraction and determination of scandium. In radiopharmaceutical applications the ^{44}Sc nuclide is usually produced from biomedical cyclotrons via the ^{44}Ca(p,n)^{44}Sc route. Although calcium is not toxic and can be present in radiopharmaceutical preparations in quite large amounts, it could lower the yield of the radiolabeling process and should thus be removed to the greatest possible extent before radiosynthesis. Previous work showed the potential of carbon based materials for the separation and enrichment of scandium ions [1, 2].

The effect of various experimental parameters on the recovery of Sc were investigated and optimized [3]. Batch static sorption experiments on CNT-COOH increasing scandium removal from solution with the increase of pH up to 3, above which quantitative sorption occurred. To check the role of the precipitation of $Sc(OH)_3$ on scandium removal pH dependent experiments were also conducted without the sorbent. Results show insignificant sorption in pH>4 because the precipitation curve overlaps with the sorption curve (Fig. 1).

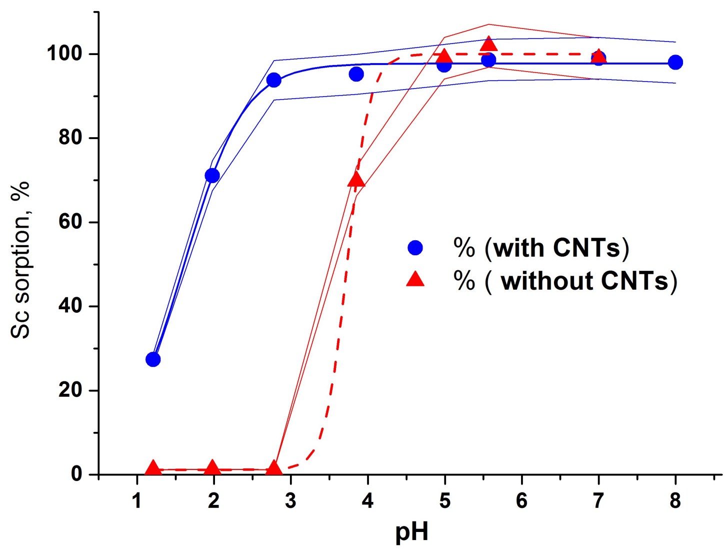

Figure 1: The effect of pH and precipitation on Sc(III) removal with and without CNTs.

Although the greatest difference between both curves is obtained for pH 3, due to the possibility of sorption of calcium under these conditions pH 2.0 was selected for further experiments in column mode. A sample loading flow rate of 5 ml/min was established under dynamic conditions, as recoveries were close to 100%, while using a higher flow rate decreased recovery. For elution of scandium, 2 ml of 2 mol/l HNO_3 was found to be enough for $96.8 \pm 3.0\%$ recovery. This procedure was applied for samples up to 500 ml.

Particular attention was paid to the presence of calcium matrix as in both environmental samples and dissolved target solution Ca(II) ions occur in large excess to Sc(III). Two mixtures containing 1 mg/l Sc(III) and calcium at concentration of 100 mg/l or 600 mg/l at pH 2.0 were prepared and passed through columns filled with 50 mg of CNTs. The effluent from these columns as well as the 5 ml fractions of 0.01 mol/l HCl solution used for removing Ca(II) were subjected to analysis for calcium and scandium determination. The obtained results are presented in Fig. 2.

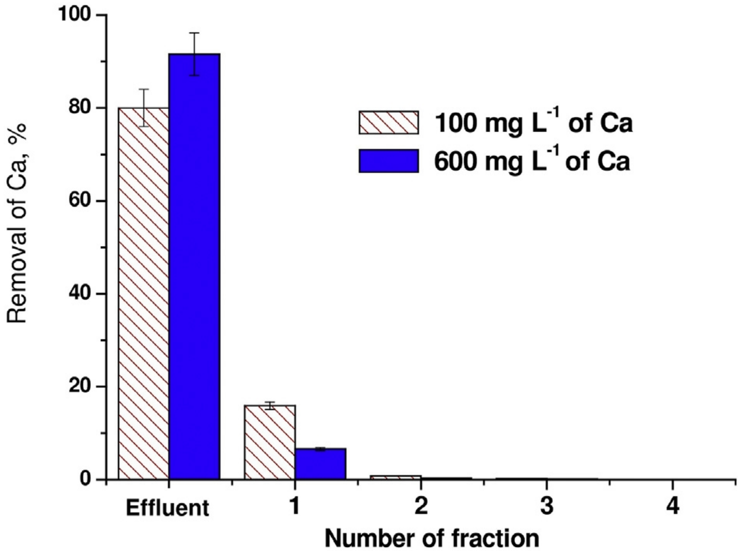

Figure 2: Removal of Ca(II) by the use of CNTs from mixtures containing calcium at concentrations of 100 mg/l or 600 mg/l.

The major portion of the calcium ions could be removed by the use of CNT-COOH as they exhibit very weak affinity at pH 2.0. The remaining residue can be eluted with 0.01 mol/l HCl solution. A total volume of 15 ml was sufficient effectively to rinse out the excess of calcium ions without loss of sorbed scandium ions. The proposed procedure was applied to the determination of Sc(III) in water samples (tap water and certified reference materials spiked with scandium) with almost 100% recovery.

This research was partially supported by The National Centre for Research and Development, Poland, project PBS3/A9/28/2015.

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B.7 Synthesis and characterisation of Ga(III) complex with morin

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The gallium isotope ^{68}Ga is most often used in radiopharmaceutical work for oncology diagnostics, for imaging of myocardial and pulmonary perfusions, inflammation and infection [1]. Various types of ligands have been studied for its chelators, e.g. polyaminoplycarboxylate, hydroxyaromatic, macrocyclic and amine-thiol-type ligands. The principal requirements are that they should form a stable complex with Ga(III), preferably of octahedral geometry in order to yield stability.

Morin (3,5,7,2',4'- pentahydroxyflavone) is a well known natural antioxidant present in fruit, vegetables, tea and coffee. It can act as a chelating agent and its complexes play an important role in human health [2–4].

The main goal of this work was to examine the methodology of the synthesis of a Ga(III) — morin complex. For the characterisation of this complex UV-visible, infrared and mass spectroscopy studies were performed. The UV-visible spectroscopy studies showed the direct interaction between morin and gallium. The morin adsorption band present at 359 nm was shifted to 419 nm after gallium addition. The stoichiometric composition of the complex was evaluated using the molar ratio method (Yoe-Jones method). The results confirmed the 1:1 stoichiometric ratio, previously predicted by mass spectrometry measurements (Fig. 1). IR spectra of morin and its complex were recorded in the range 500–4000 cm^{-1}. The observed spectral changes in the region 1500–1700 cm^{-1} indicated that coordination of Ga(III) occurs through the carbonyl oxygen atom and the 3-OH or 5-OH group of the morin molecule.

This research can be used in the development of new PET radopharmaceuticals labelled with ^{68}Ga.

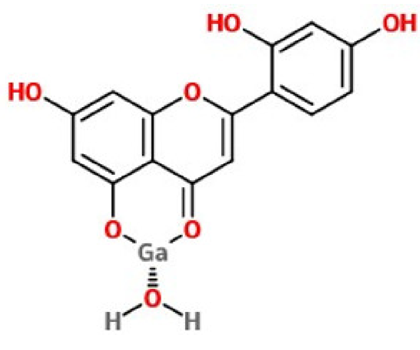

Figure 1: The structure of Ga (III) complex with morin.

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B.8 Hydrophilic interaction liquid chromatography in the speciation analysis of selenium

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Selenium is an important element from the environmental and biological point of view [1]. It has been recognised as an essential nutrient because it plays a key role in several major metabolic pathways such as thyroid hormone metabolism, antioxidant defence systems and immune functions [2].

In this study hydrophilic interaction liquid chromatography (HILIC) coupled to mass spectrometry was employed to study the retention behaviour of selected selenium compounds using different HILIC stationary phases. Two organic solvents, methanol and acetonitrile, were compared as a component of the mobile phase. Selenite, selenomethionine and methyl-selenocysteine were selected due to the fact that they are present in plant material supplemented with selenium compounds [3–5]. Such material (onion leaves) was used in this study to test the potential of the optimised method in the analysis of a real sample.

It turned out that methanol is beneficial for the peak shapes and lowering the LOD and LOQ values. It was therefore chosen as an organic component of the mobile phase used for the real sample analysis. The best column for the separation of selenium compounds was a silica column. The developed method is competitive with respect to reverse phase chromatography where no inorganic selenium separation has been achieved. The separation of selenium compounds in the extract from onion leaves is presented in Fig. 1.

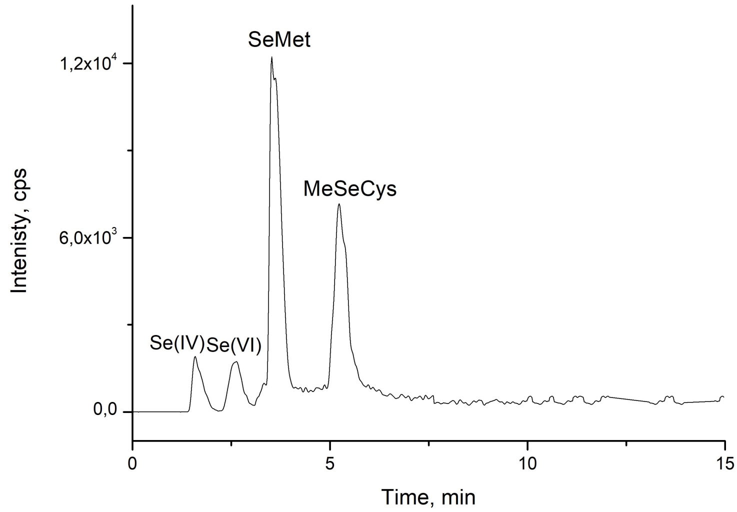

Figure 1: The chromatogram of extract from onion leaves supplemented with selenite. Column: Atlantis HILIC (silica), eluent: 85% methanol and 8 mM ammonium acetate, pH 7 (isocratic mode).

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B.9 Flavonoid content and antioxidant properties of different extracts of *Calluna vulgaris* (L.) flowers

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Heather (*Calluna vulgaris* (L.)), a member of the Ericaceae family, can be found in most parts of Europe and Northern America. Despite this, there is no information in the literature about the antioxidant properties of this plant.

This study evaluated the effects of four different solvents, i.e., water ethanol, water-ethanol and ethyl acetate, on the antioxidant activity of wild and cultivated heather (*Calluna vulgaris* (L.)) plants. The extracts from each plant were also evaluated for the determination of total flavonoid content, reducing power by the cupric reducing antioxidant capacity (CUPRAC) method, scavenging ability on 1,1-diphenyl-2-pirylhydrazyl radicals (DPPH) and chelating activity on Fe^{2+} ions.

The results have provided an insight into the effect of the solvent used for extraction of major flavonoids from the aerial parts of wild and greenhouse cultivated *C. vulgaris* (L.) Hull plant. Flavonoid content and antioxidant activities are strongly dependent on the nature of the extracting solvent due to the presence of different antioxidant compounds of varied chemical characteristics and polarities. Ethyl acetate and ethanol-water mixture were proven to be the best solvents. The highest values of antioxidant activities were obtained for samples extracted using these two solvents. The extract of garden-white cultivar had the highest total flavonoid content. Antioxidant capacity of the studied extracts was also assessed on the basis of their scavenging effect on the stable DPPH radical. In this study, ethanol and ethanol-water fraction were found to be the most effective in producing scavenging activity against DPPH radicals, with the highest values observed for garden-violet cultivar. The metal-chelating effect of the extracts of heather flowers increased in the order: ethanol $<$ ethyl acetate $<$ ethanol-water mixture $<$ water. The highest Fe^{2+} chelating activity was observed for greenhouse white cultivar.

Extract of *C. vulgaris* may be considered a good source of compounds with high antioxidant properties and may be explored in pharmaceuticals, foodstuffs, feed additives and cosmetics.

B.10 Relative biological effectiveness for CHO-K1 cells irradiated using mixed ion beams

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CHO-K1 (Chinese Hamster Ovary) cells were irradiated using a mixed beam of carbon and oxygen ions. The mixed beam was accelerated by the cyclotron located at the Heavy Ion Laboratory of the University of Warsaw and guided to a measurement station located at position A in the cyclotron hall. At this station the cells were irradiated in specially designed Petri dishes. The experimental setup for radiobiological studies was described in detail in [1, 2]. The effects of irradiation were determined using a survival test. The survival curves are shown in Figure 1 (left part) [2]. The Relative Biological Effectiveness (RBE) was determined using survival curves for mixed beams and a survival curve obtained after irradiation of cells with gamma rays from a cobalt beam (the cobalt data were published in [1]). RBE as a function of the mean LET (Linear Energy Transfer) value for different survival fractions (SF) is shown in Figure 1 (right part) [2].

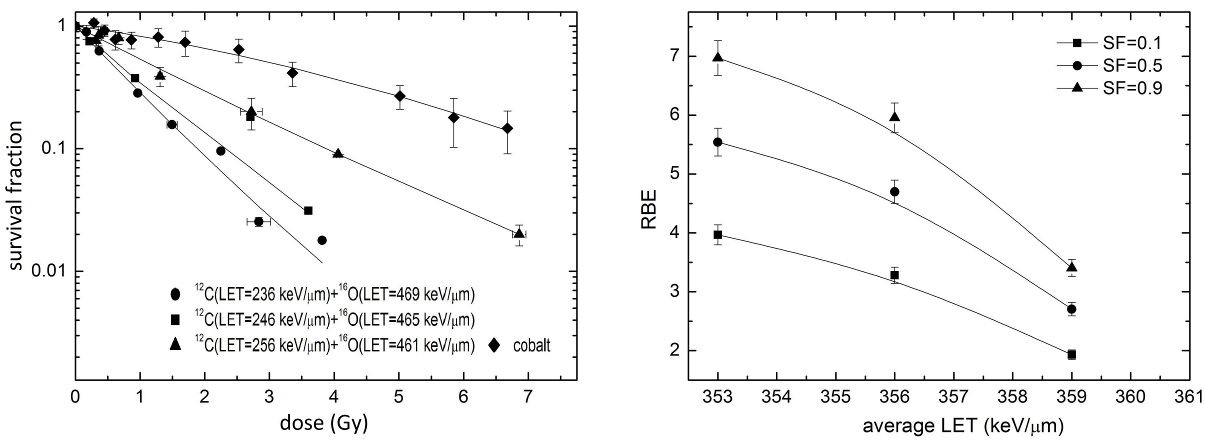

Figure 1: Survival curves for CHO-K1 cells irradiated by mixed ion beams (left part) and RBE in average LET function (right part) [2].

The results show that the SF of CHO-K1 cells and RBE decrease with increasing absorbed dose (see Figure 1, left part) and mean LET value (see Figure 1, right part), respectively [2].

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Part C

Nuclear physics

C.1 Coulomb excitation of ^{107}Ag measured with EAGLE – data analysis

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on behalf of the "Quadrupole moments of excited states in ^{107}Ag" experiment collaboration

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A Coulomb excitation (Coulex) experiment to study ^{107}Ag was performed at the Heavy Ion Laboratory, University of Warsaw, using an 84 MeV ^{32}S beam delivered by the Warsaw cyclotron. The γ rays depopulating Coulomb-excited states of ^{107}Ag were detected by the EAGLE HPGe array, while the back-scattered ^{32}S beam ions were detected by 48 silicon PiN diodes. Details of the experiment were described in [1]. In the current report chosen aspects of the performed analysis are presented.

The data were collected in particle-γ coincidence mode. A typical particle-γ time coincidence spectrum is shown in Fig. 1. The distance of around 70 ns between the maxima present in the time spectra is related to the pulsed structure of the beam delivered by the Warsaw cyclotron. Prompt and random coincidence gates are marked.

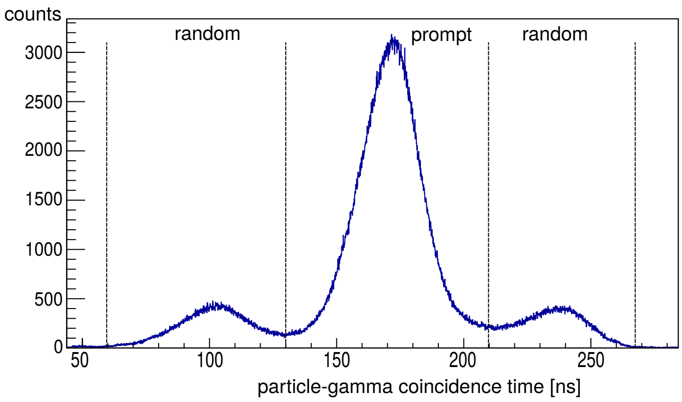

Figure 1: The particle-γ coincidence spectrum collected by one of the germanium detectors in the ^{32}S+^{107}Ag Coulomb excitation experiment. Prompt and random coincidence gates are marked.

Several states in ^{107}Ag were populated. The level scheme of ^{107}Ag presented in [1] was revised. A careful analysis of the γ-ray spectra, collected in prompt and random coincidence with ^{32}S beam ions, showed that the highest state populated in the Coulomb excitation experiment is the $9/2^-_1$ at an energy of 1147 keV.

In Fig. 2 partial γ-ray spectra of ^{107}Ag collected by two HPGe detectors are presented. Detectors were placed at 37 and 79 degrees with respect to the beam direction. The γ ray spectra are random subtracted with the use of time gates as shown in Fig 1. The structure of a few γ-ray lines is clearly broadened which is due to the Doppler shift which occurs when γ rays are emitted in flight. In the case when the mean lifetime of the excited state is smaller than the stopping time of the recoils in the target ($t_s \simeq 1.2$ ps) the γ rays are predominantly emitted in flight and the detected γ-ray transitions are Doppler shifted. An example of such a case is the decay of the $3/2^-_2$ state with $\tau = 0.39(12)$ ps through the emission of 787 keV and 462 keV γ rays.

No Doppler shift is observed when the mean lifetime of a state is longer than the stopping time, $\tau \geq t_s$, as it is for the case of the $5/2^-_1$ state ($\tau = 43(3)$ ps) which depopulates through the emmision of a 423 keV γ ray. When the mean lifetime of a state is similar to the stopping time, some γ rays are emitted in flight and some after the recoils are stopped in the target. As a consequence both stopped and shifted components of the γ-ray transition are visible in the spectrum. Such a situation occurs in the case of the decay of the $5/2^-_2$ state at an energy of 959 keV with τ = 1.96(26) ps (see 526 keV and 625 keV γ-ray transitions in Fig. 2).

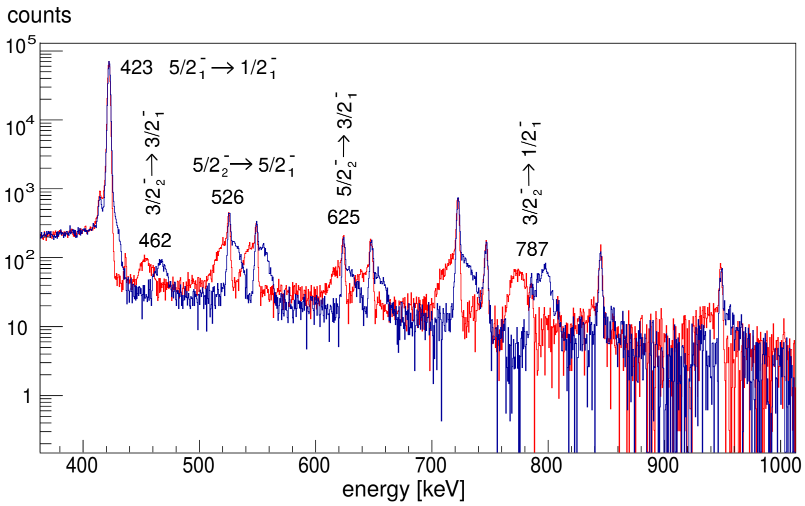

Figure 2: Partial γ-ray spectra of ^{107}Ag collected by two HPGe detectors. Detectors were placed at 37° (red) and 79° (blue) with respect to the beam direction. The γ-ray spectra are random subtracted.

In order to determine the matrix elements using ^{107}Ag Coulomb-excitation the least-squares fitting code GOSIA [2, 3] was used. The code fits a set of reduced matrix elements to the γ-ray yields measured in the Coulomb excitation experiment, taking into account known spectroscopic data: lifetimes, γ-ray branching ratios, $E2/M1$ mixing coeffcients [4, 5] related to electromagnetic matrix elements. At the first stage of the analysis, it was decided to sum all spectra from individual Ge and Pin-diode detectors, maximizing in this way the statistics collected for each observed γ-ray transitions. No Doppler correction was performed. In the case of γ lines which were broadened due to the Doppler shift, the number of counts was obtained by fitting a superposition of two or three gaussian shapes.

Preliminary results for several B(E2) and B(M1) reduced transition probabilities were evaluated for the first time and the analysis is on-going. In order to determine the quadrupole moments of excited states in ^{107}Ag further analysis is required. Subdivision of the experimental data based on the projectile scattering angle is needed to disentangle contributions of various excitation paths, thus gaining sensitivity to subtle higher order effects.

This work was the subject of the MSc thesis of M. Hlebowicz defended on December 2017 at the Faculty of Physics, Warsaw University of Technology.

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C.2 Coulomb excitation of ^{118}Sn – particle gamma coincidence measurement with EAGLE array

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The aim of the present experiment was to investigate nuclear collectivity in ^{118}Sn by determining the signs and magnitudes of the quadrupole moments of the excited low-lying 2^+ states and the reduced transition probabilities of other low-lying states, via multi-step Coulomb excitation. ^{118}Sn is a isotone of ^{120}Te with number of neutrons equal to 68. Previously, we measured the reduced transition probabilities of low-lying states and the quadrupole moments of the first excited 2^+ and 4^+ states in ^{120}Te [1, 2]. If we compare the Te and Sn isotopic chains, we note that the collectivity, B(E2; $0^+ \rightarrow 2^+$), in tellurium is two to three times larger than for the tin nuclei. This can be understood in terms of the two additional protons in Te above the Z = 50 shell closure. For ^{120}Te we obtain a Weisskopf estimate of 36 s.p.u., which corresponds to 12 s.p.u. for ^{118}Sn. In order to understand the dramatic change from the tin isotopes to the neighbouring tellurium isotopes, the present Coulomb excitation of ^{118}Sn nuclei was performed.

The experiment was carried out using a ^{32}S beam at 91 MeV from the U-200P cyclotron at Heavy Ion Laboratory, University of Warsaw, Poland. A highly enriched ^{118}Sn target of ~ 1.0 mg/cm^2 supported by a 10-20 µg/cm^2 carbon backing was used for the measurement. The de-exciting γ rays from the Coulomb excited target recoils were detected by the EAGLE array consisting of 15 HPGe detectors of 70% efficiency equipped with anti-Compton BGO shields from GAMMAPOOL. A compact Coulex chamber (the so-called Munich Chamber), equipped with 48 PIN-diodes of 0.5×0.5 cm^2 active area, was used for the detection of backscattered ^{32}S ions to select particle-γ coincidences which uniquely ascribe the observed γ rays to the collision kinematics and later allow us to perform a precise Doppler correction of the measured γ rays. The PIN-diodes were placed at angles from 120 to 167 degrees with respect to the beam axis to enhance the probability of multi-step excitation.

The present data analysis was performed using a dedicated code written using the ROOT based GO4 software package [3]. Fig. 1 shows the low-lying excited states in ^{118}Sn observed in the present experiment. Doppler correction was performed for the measured γ rays for the target excitation (see Fig. 2). The experimentally obtained γ-ray yields were found to be comparable to the yields calculated using the GOSIA code [4]. We plan to continue our investigation by performing another experiment using a heavier projectile (^{58}Ni). The higher Z beam will enhance multi-step excitation to several other higher-lying states, yielding better statistics.

The authors would like to thank the accelerator group of HIL, University of Warsaw for delivering a stable beam throughout the experiment.

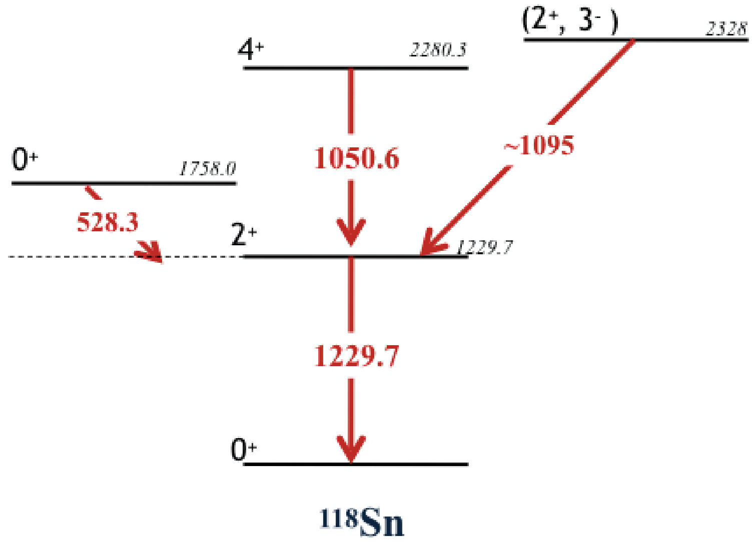

Figure 1: Partial level scheme of ^{118}Sn observed in the present experiment. The level and transition energies are given in keV.

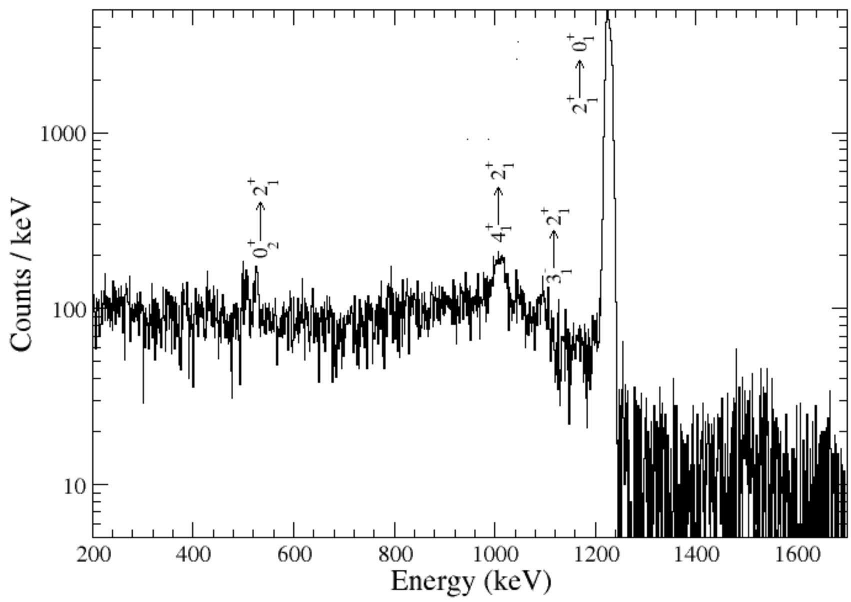

Figure 2: Preliminiary Doppler shift corrected γ-ray energy spectrum for the ^{32}S + ^{118}Sn system.

Table 1: Experimental γ-ray yields vs. simulated yields calculated using the GOSIA code.

Transition	Energy (keV)	Exp. Yields	Calc. Yields
$2_1^+ \to 0^+$	1229.7	1.5×10^5	3.1×10^5
$4_1^+ \to 2_1^+$	1050.6	1.2×10^3	3.2×10^3
$0_2^+ \to 2_1^+$	528.3	1.0×10^3	2.3×10^3
$3_1^- \to 2_1^+$	1095.0	1.1×10^3	1.1×10^3

This work was supported by the National Science Centre, Poland under the fellowship grant POLONEZ-1 (2015/19/P/ST2/03008). This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 665778. We also acknowledge support from ENSAR2 and this project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654002. The EAGLE collaboration thanks the European Gamma-Ray Spectroscopy Pool GAMMAPOOL for the loan of Ge detectors. One of the authors (MMM) acknowledges support from the Polish National Science Centre under the FUGA 3 postdoctoral fellowship grant No. DEC-2014/12/S/ST2/00483.

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C.3 First fast-timing measurement with triple coincidence techniques at HIL. Construction of the EAGLE-EYE setup

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Advanced fast-timing techniques have been tested at the Heavy Ion Laboratory as a part of a fast-timing measurements programme devoted to a study of the nuclear chirality phenomenon. Triple HPGe-LaBr-LaBr coincidence techniques were applied to excited ^{128}Cs nuclei produced with the ^{10}B(^{122}Sn,4n)^{128}Cs reaction in beam at the U200P cyclotron. Triple coincidences were registered by the dedicated EAGLE-EYE (EAGLE s**E**quential gamma ra**Y**s d**E**tection) setup (see Fig. 1).

The EYE setup of 24 LaBr detectors was developed by the HIL design office commissioned by the National Centre for Nuclear Research. It was used for the first time with 10 LaBr detectors obtained from IFIN (Romania), NCBJ (Poland) and UW (Poland).

The HPGe detectors of the EAGLE array were used for selection of the gamma decay sequence leading to the $I = 9^+$, 56 ns isomeric state in ^{128}Cs which is the band-head of the $\pi h_{11/2} \otimes \nu^{-1} h_{11/2}$ chiral rotational band. After selecting the proper reaction product and feeding by the EAGLE spectrometer, the EYE setup served as a start-stop detector for the remaining gamma-gamma coincidences.

The EAGLE-EYE combination allows us to apply several fast-timing techniques for lifetime measurements within the 10 ps to 10 ns range like: (i) cleaning the LaBr energy spectra by gating on γ rays registered by the HPGe detectors,(ii) cleaning the LaBr energy spectra with the help of delayed coincidences registered by the HPGe detectors, (iii) using standard gamma-gamma coincidences registered by the EYE LaBr array.

The requirements of these techniques were investigated during a test experiment performed in November 2017. The actual experimental campaign is scheduled for February 2018.

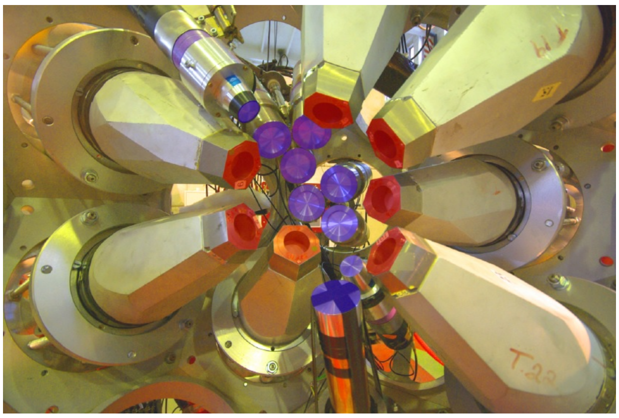

Figure 1: The first stage of the EAGLE-EYE setup with 10 LaBr detectors marked in blue. HPGe spectrometers are marked in red.

C.4 Study of the K-isomer in ^{186}Hg

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The mechanism of the electromagnetic decay of K-isomers, in spite of being the subject of extensive studies, is still frequently discussed [1, 4]. The K-isomeric states with spin/parity $I^\pi = 8^-$ and quantum number K equal to 8 (where K is the projection of the total angular momentum onto the symmetry axis of a nucleus) are found in nuclei in the mass regions around 130, 150 and 250. These isomeric states are observed in even-even nuclei with neutron numbers N = 74, 106 and 150. Often, they decay many orders of magnitude slower than expected from the Weisskopf single-particle estimate.

The main goal of this experiment was the determination of the multipolarities of the two gamma transitions at 241.5 and 811.2 keV de-exciting the $I^\pi = K^\pi = 8^-$ isomeric state in ^{186}Hg and verification of its spin and parity. Measurement of coincidences between gamma-rays and internal conversion electrons (ICE) allows to determine the internal conversion coefficients and, in consequence, to deduce the transition multipolarities. To perform this measurement the ULESE electron spectrometer [5] and the EAGLE array [6] were used.

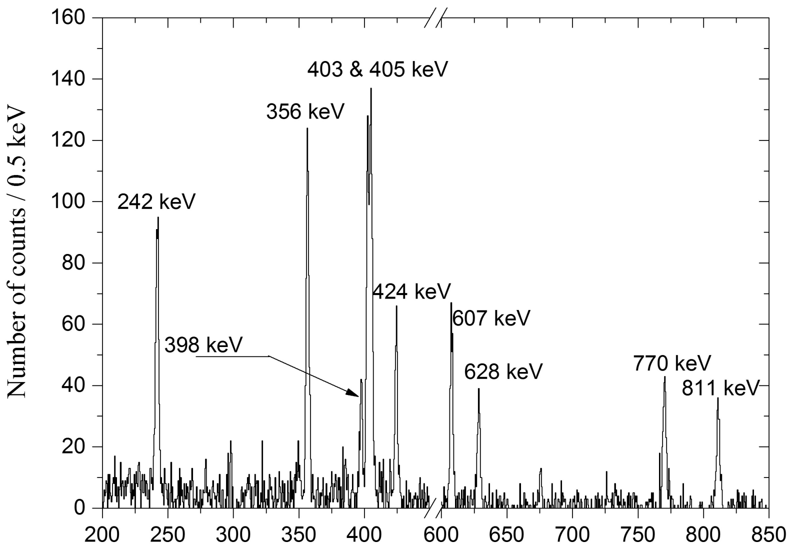

Figure 1: The coincidence gamma spectra with 403 and 405 keV transitions collected during two time spans after the end of the cyclotron beam pulse. The transitions from the decay of the $I^\pi = K^\pi = 8^-$ isomeric states in ^{186}Hg are labelled.

The ^{186}Hg nucleus was produced in the following reaction: $^{40}\mathrm{Ar}+^{150}\mathrm{Sm} \rightarrow {}^{186}\mathrm{Hg}+4\mathrm{n}$. To clean up the gamma spectra from long-lived ($T_{1/2} > 1$ ms) lines which do not originate from the isomeric state decay ($T_{1/2} \approx 80$ µs), events collected between 1.05 and 2.4 ms after the end of the cyclotron beam pulse were subtracted from the events collected in the time span between 0.05 and 0.4 ms. The gamma spectrum obtained using this procedure is shown in Fig. 1. The half-life of the $I^{\pi} = K^{\pi} = 8^{-}$ isomeric state in the ^{186}Hg nucleus was determined based on time spectra gated on a few gamma lines originating from this isomeric state. The sum of the time spectra is presented in Fig. 2. In our experiment the half-life of this isomeric state was determined to be 89(10) µs and agrees very well with the value of 82(5) µs from the NNDC data base [7].

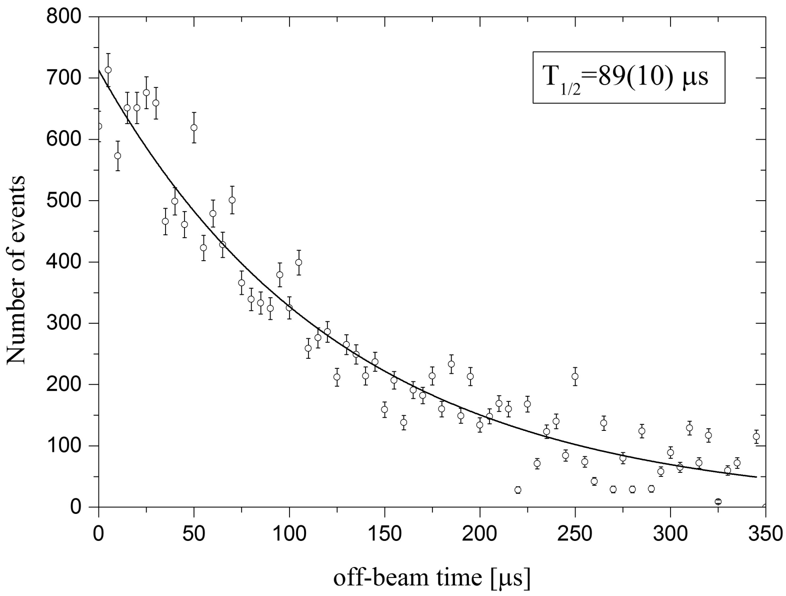

Figure 2: The sum of the time spectra gated on the following transitions 241, 402, 405, 356, 425, 771, 811, 628 and 607 keV from the $I^{\pi} = K^{\pi} = 8^{-}$ isomeric state in ^{186}Hg.

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C.5 Theoretical description of low-lying collective states in ^{120}Te

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The characteristic pattern of low-energy levels in ^{120}Te suggests that this nuclei can be regarded as a good example of an harmonic vibrator. However, the electromagnetic properties, e.g. the quite large value of the quadrupole moment of the 2_1^+ state, do not confirm such a simple description. Similarly, the collective excitations of the Cd isotopes, typically treated as harmonic vibrations, present a more complicated picture [1].

Recently, Coulomb excitation experiments were performed to obtain more detailed information on the electromagnetic properties of the low-energy part of the ^{120}Te spectrum [2, 3]. In [3] experimental data were compared with the results of phenomenological models: the Davydov-Filippov model and the interacting boson model (IBM2).

To gain insight into the properties of ^{120}Te on a more fundamental level we applied the General Bohr Hamiltonian approach based on microscopic mean-field theory [4]. The GBH approach allows us to treat all quadrupole degrees of freedom (vibrational and rotational) on an equal footing. We used two variants of the Skyrme effective interaction: the well known and widely used SLy4 interaction and the recently proposed UNEDF0 [5]. Fig. 1 shows the collective potential energy (relative to that of a spherical shape) calculated for both these interactions. Generally, the energy landscapes obtained are similar to each other but the UNEDF0 gives more stiffness with respect to the β variable.

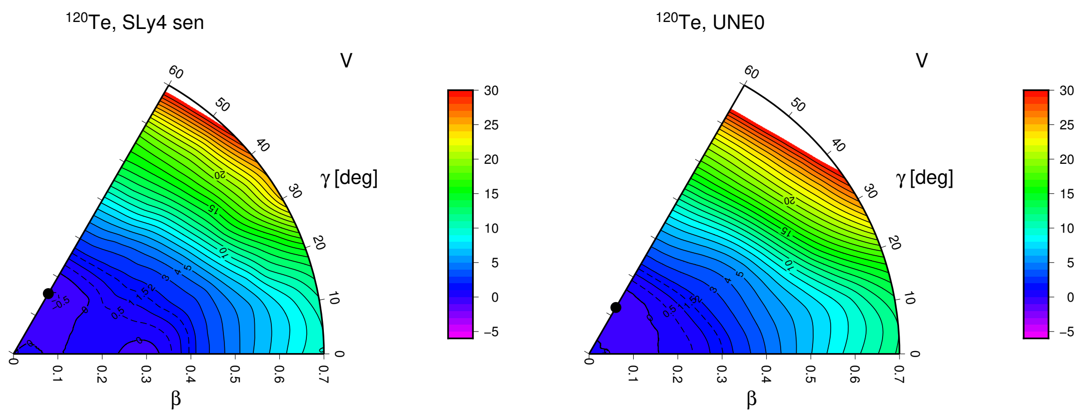

Figure 1: Collective potential energy (relative to that of a spherical shape) for ^{120}Te.

Calculated and experimental energy levels of positive parity are shown in Fig. 2, where one can see that the present theory (for both variants of interaction) gives a satisfactory agreement with experiment. It should be stressed that no theoretical parameters were fitted to experimental data for ^{120}Te.

The GBH theory also gives us the possibility to calculate the matrix elements of the E2 transition operator using input from mean-field theory, without introducing the so-called effective charge. Several E2 reduced matrix elements (both non-diagonal and diagonal) are listed in Table 1. One can see that the non-diagonal matrix elements are very well reproduced by the theoretical calculations. The results obtained from the UNEDF0 variant are systematically lower and slightly closer to experiment than those from SLy4. However, there is a significant difference between the two variants in the case of the diagonal elements.

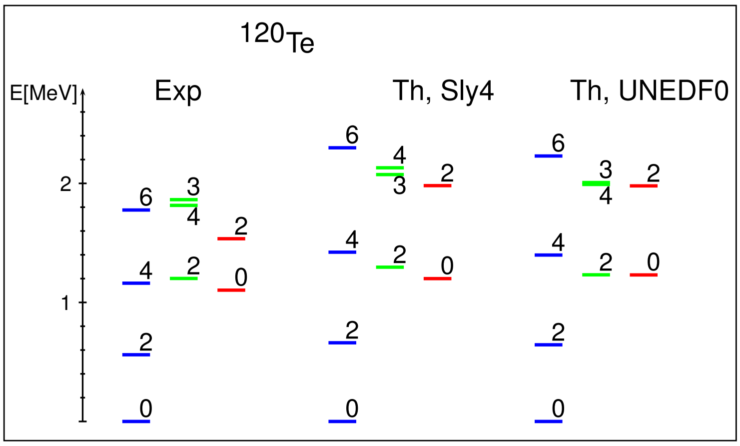

Figure 2: Experimental and theoretical energy levels in ^{120}Te.

The values obtained using SLy4 are much larger (as absolute values) and much closer to the experimental results than those of UNEDF0. A remark about the interpretation of the negative value of the diagonal matrix element for the 2_1 state: within a simple rotational picture such a value suggests a prolate-like shape. However, in the present theory a value of -0.421 eb (the SLy4 variant) is obtained for a state with a quite large value of γ, $\langle\gamma\rangle \approx 23$ deg. Of course, due to the γ-softness of the potential energy (see Fig. 1) this is not in contradiction with a position of the minimum of energy on the oblate axis. A more extensive analysis of the shape of the ^{120}Te nucleus based on the sum rules method, which allows us to obtain the so-called rotational invariants from experimental E2 transitions, is in progress.

Table 1: Experimental and theoretical matrix elements of the $E2$ operator (in [eb]).

I_1	I_2	$\langle I_1\|\|E2\|\|I_2\rangle$ Exp	Th, SLy4	Th, UNEDF0
Non-diagonal				
2_1	0_1	0.778 ± 0.014	0.850	0.698
4_1	2_1	1.342 ± 0.019	1.598	1.298
2_2	2_1	0.955 ± 0.020	1.119	0.955
2_2	0_1	0.161 ± 0.011	0.054	-0.019
Diagonal				
2_1	2_1	-0.55 ± 0.04	-0.421	-0.140
4_1	4_1	-1.02 ± 0.25	-0.982	-0.419

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C.6 Transfer cross sections at near-barrier energy for the ^{24}Mg + ^{90,92}Zr systems

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An experiment performed in 2017 aimed at determining the transfer cross sections at a near-barrier energy for the ^{24}Mg + ^{90,92}Zr systems at 142.5 degrees in the laboratory frame. It was a complementary measurement to the studies of the barrier height distribution (D_{qe}) for these systems.

In the recent experiment performed at the LNS, Catania, we investigated the barrier height distribution of the ^{24}Mg + ^{90,92}Zr systems [1, 2]. The very strong deformation of the ^{24}Mg projectile should give rise to similarly structured shapes of D_{qe} for both systems. However, according to our preliminary findings [1] the D_{qe} pattern appears to be structured for ^{90}Zr, and smooth for ^{92}Zr. The determined shapes of the barrier distributions are also found to disagree with predictions of standard CC calculations, taking into account only the collective excitations of the systems. The aim of this work was to verify whether these discrepancies were caused by transfer reactions.

The measurement of the transfer cross sections was performed at the Heavy Ion Laboratory, University of Warsaw, with the help of the multidetector system ICARE. The experimental set-up was very similar to that described in [3, 4]. The Time of Flight (ToF) technique was used to identify the masses of back-scattered ions. The "start" signal was given by a Microchannel Plate (MCP) detector. The "stop" signal was triggered by one of four 20 mm$\times$20 mm Si detectors placed at a laboratory polar angle $\theta_{lab} = 142.5°$. The base length of the ToF system was 78 cm. Three Si detectors mounted at the forward angle of $\theta_{lab} = 30°$ were used to monitor the beam energy. The targets were bombarded with ^{24}Mg ions. The laboratory beam energy $E_{lab} = 76$ MeV was chosen in order to investigate the region of the "structure" in the barrier height distribution [1]. The ^{90}Zr and ^{92}Zr targets were of ~100 µm/cm^2 thickness, evaporated onto 20 µm/cm^2-thick carbon supports.

The raw two-dimensional spectra (time of flight vs. energy) of back-scattered ions are shown in Fig. 1. Groups of events corresponding to different transfer reactions are marked by the appropriate atomic mass values of the registered ions. Within the available statistics and resolution, stripping reactions involving up to 8 nucleons, and reaction channels with pickup of up to 2 nucleons were identified.

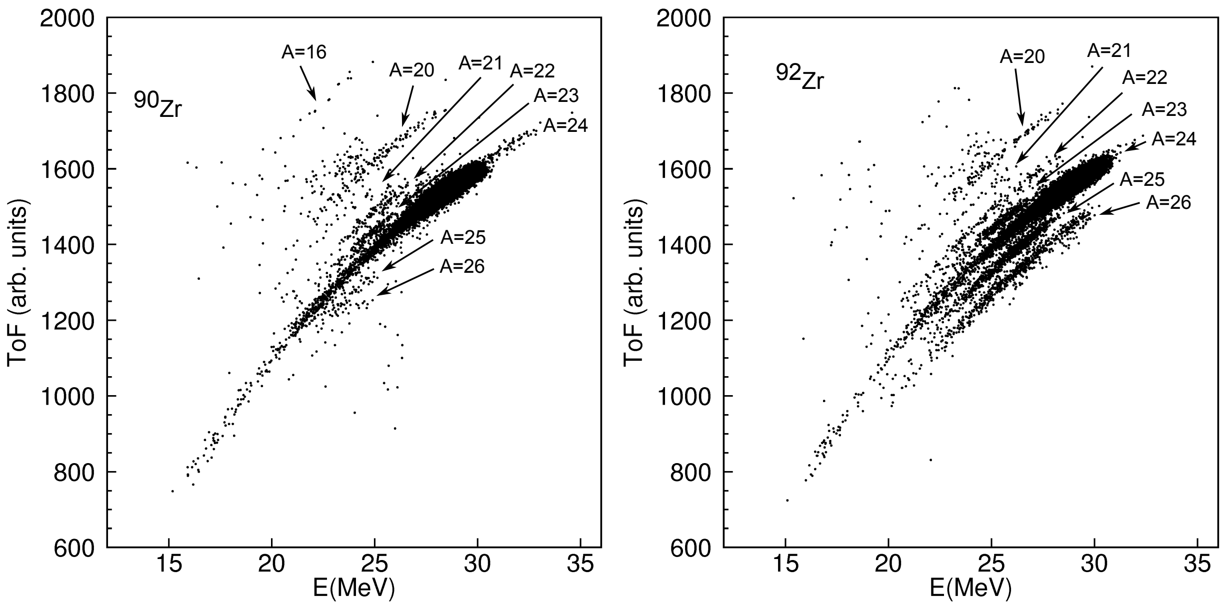

Figure 1: The raw E-ToF spectra of back-scattered ions, measured at $\theta_{lab} = 142.5°$ for the ^{24}Mg + ^{90}Zr (left panel) and ^{24}Mg + ^{92}Zr (right panel) systems.

The sum of the transfer cross sections in the ^{24}Mg + ^{90,92}Zr systems for $E_{lab} = 76$ MeV, at 142.5 degrees were found to be: 0.48 ± 0.02 mb/sr, and 1.74 ± 0.04 mb/sr, respectively, that is less than half as large as for the ^{20}Ne + ^{90}Zr system [5].

One should recall that in the ^{20}Ne + ^{90}Zr system the D_{qe} has significant structure, while smoothing of the structure for the ^{20}Ne + ^{92}Zr system was identified as being caused not by transfer processes but by non-collective excitations. In the ^{24}Mg + ^{92}Zr system the transfer cross section is even smaller than in the ^{20}Ne + ^{92}Zr system. This finding leads to the conjecture that in the ^{24}Mg + ^{92}Zr system the lack of structure is also probably caused not by transfers but rather by the influence of weak but numerous non-collective excitations. This conclusion is supported by our calculations in the frame of the model of Refs. [6, 7]. In this context, it should be mentioned that the ^{92}Zr nucleus has two extra neutrons in comparison with the semi magic ^{90}Zr nucleus, which enhances by an order of magnitude the level density of single-particle states [8].

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C.7 Structure of the experimentally constrained parameter space; an example using ^{7}Li+^{208}Pb elastic scattering

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Relatively easy access to grids of supercomputers opens possibilities for statistical analysis of complex theoretical models employing Monte Carlo sampling methods. The present work is focused on learning how to visualize the results of multi-dimensional parameter searches. Existing elastic scattering data for ^{7}Li+^{208}Pb in the energy range from 27 MeV up to 60 MeV [1] were analysed by means of the Optical Model (OM). The computer program SFRESCO [2] supplemented by a Monte Carlo sampling option was applied. The program has been installed on the PL-GRID supercomputer enabling a variety of calculations using many parallel processors [3]. Six parameters of the OM potential, consisting of real and imaginary parts of standard Woods-Saxon shape, were sampled (V, r_V, a_V, W, r_W, a_W). Statistically allowed parameters p_i were selected by the condition:

$$\chi^2_N(p_i) \leq (\chi^2_N(p_{0i}))_{min} + 1, \tag{1}$$

where χ^2_N is the value of the χ^2 function per experimental point and p_{0i} are the parameters corresponding to its minimum value. Thus, the allowed, experimentally constrained parameter space is represented in a six dimensional (6D) Monte Carlo sampling hypercube by points p_i fulfilling the condition (1). In the analysis ten processors run in parallel were used, allowing for up to 10 000 solutions obtained within a few hours. In the analysis of the results conventional 2D-displays of the 6D-hypercube were found to be rather unsatisfactory. Instead, the following methods of presenting the results appeared to be useful.

1. The r_V parameter was fixed (at one or a few discrete values) and V and a_V were changed. In this case it was found that the 3D-parameter space was not uniformly filled by MC sampling but consisted of a "fibrous" structure — for each r_V there is only one "fiber" seen in the (V, a_V) 2D-plot, corresponding to the known continous ambiguity [4]. The position of this "fiber" depends on the r_V value (see Fig. 1).

2. Monte Carlo solutions uniformly generated in the whole 6D-hypercube and fulfilling the condition (1) are rather rare. Thus, many solutions must be rejected. The method to avoid this problem is to fill the hypercube non-uniformly, in the corridor close to the "fiber".

In Fig. 1 the parameters (V, a_V) are displayed for the 44 MeV data set and for a set of discrete values of r_V. This illustrates that the experimentally allowed space is in fact a 2D-surface embeded in a 3D-cube. A similar effect was also observed for the (W, r_W, a_w) set of parameters. The analysis was performed at seven projectile energies: 60 MeV, 44 MeV, 39 MeV, 35 MeV, 33 MeV, 29 MeV and 27 MeV, allowing for the evolution of the experimentally constrained parameter space with energy to be studied.

The resulting population of the hypercube exhibits structure in the form of local condensations which may correspond to discrete ambiguities of the OM potential. Some of them have been described in the literature [4].

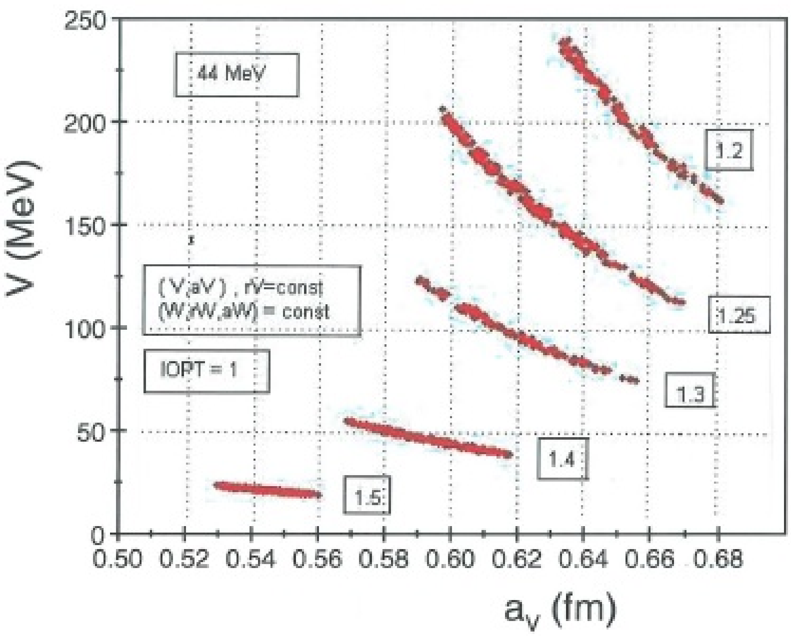

Figure 1: (V, a_V) correlations for different r_V, for ^{7}Li+^{208}Pb elastic scattering at 44 MeV.

The example presented above does not exhaust the list of possible analyses with SFRESCO as the main program. We may e.g. mention the following problems:
1. Use other direct reaction models to analyse the parameter space of the inelastic or reaction form factors and their correlations. The sets of experimental data can be supplied not only by suitable differential cross sections but also by polarization observables.
2. Add an extra correction function for these form factors in order to optimize their parameters by MC or Evolutionary Programs.
3. In a further perspective, it would be useful to replace the optimization of potentials and reaction form factors by the optimization of the S-matrix elements directly connected to the observables.
4. It would be very useful to rewrite existing programs including functions enabling internal calculations with the help of the multiprocessor method. For FORTRAN, there exist a small number of commands enabling such calculations (e.g. OpenMP or MPI-n systems).
A report presenting the complete results of the analysis performed within this project will be available on the web page of HIL.

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C.8 Cluster structure of ^{15}N from elastic scattering studies

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It is well known that in the scattering of strongly clustered nuclei such as ^{6}Li, ^{7}Li, ^{9}Be, ^{12}C, ^{16}O and ^{20}Ne there is a pronounced rise of the differential cross sections in the backward hemisphere. This behaviour can be reproduced in calculations only by taking into account the contribution of cluster-transfer between the projectile and target nuclei. Elastic scattering and α-cluster transfer for the ^{15}N+^{11}B system was studied by Rudchik et al. [1] at an energy of 84 MeV and a significant increase in the differential cross sections at backward angles was observed.

In this work we present the results of a similar experiment devoted to a study of ^{15}N+ ^{10,11}B elastic scattering and cluster-transfer at the lower energy of $E_{lab}(^{15}\mathrm{N}) = 43$ MeV, performed at the U-200P cyclotron (Heavy Ion Laboratory, University of Warsaw). The charged-particle detection system ICARE was used for identification and energy measurements. The ICARE system was equipped with three silicon monitor detectors placed at forward angles and four $\Delta E - E$ telescopes. All the Si E-detectors were of 300 µm thickness whereas the ΔE detectors were ionization chambers filled with Isobutane gas (gas pressure inside the chamber was equal to 25 tor).

Experimental data for the ^{15}N+^{11}B and ^{15}N+^{10}B nuclear systems at $E_{lab} = 43$ MeV were analysed within the framework of the optical model (OM) accounting for the pure elastic scattering mechanism and the Distorted Wave Born Approximation (DWBA) method to include the effect of cluster-transfer. The differential cross section was the squared sum of the scattering amplitude from the OM calculation and the amplitude due to the transfer (DWBA). Two OM potentials were used: a phenomenological potential (OP) of Woods-Saxon shape (real and imaginary) and a microscopic potential (DFP) with the real part derived from the nucleon-nucleon interaction by means of the double folding method, supplemented by an imaginary part of standard Woods-Saxon shape. All the calculations were performed by the code FRESCO [2].

The angular distribution data for ^{11}B(^{15}N,^{15}N)^{11}B and ^{10}B(^{15}N,^{15}N)^{10}B at an energy of $E_{lab} = 43$ MeV were first analysed by means of OM calculations at angles up to 90 deg. (forward hemisphere) to exclude the effect of cluster-transfer. The parameters of the OM and DFP potentials extracted from the calculations are listed in Table 1.

Next, the cluster-transfer was added with the spectroscopic amplitudes for the $^{15}\mathrm{N}\rightarrow{}^{11}\mathrm{B}+\alpha$ and $^{15}\mathrm{N}\rightarrow{}^{10}\mathrm{B}+{}^{5}\mathrm{He}$ configurations fitted to the data. The comparisons between the experimental data and the theoretical calculations for both systems are shown in Figures 1 and 2.

Table 1: Optimum OP and DFP parameters for the ^{15}N+^{11}B and^{15}N+^{10}B systems at E_{lab} = 43 MeV; SA for the configurations ^{15}N→^{11}B+α and ^{15}N→^{10}B+^{5}He are also listed. The Coulomb radius parameter was fixed at 1.25 fm

Nuclear system	Model	V_0	r_V (MeV)	a_V (fm)	N_r (fm)	W_0	r_W (MeV)	a_W (fm)	SA (fm)
^{15}N+^{11}B	OP	349.68	0.79	0.799		40.0	1.25	0.799	
	OP+DWBA	349.68	0.79	0.799		40.0	1.25	0.799	0.8
	DFP				1	20.0	1.25	0.8	
	DFP+DWBA				1	20.0	1.25	0.8	0.6
^{15}N+^{10}B	OP	216.27	0.79	0.831		11.0	1.25	0.949	
	OP+DWBA	216.27	0.79	0.831		11.0	1.25	0.949	1.1
	DFP				1	11.0	1.25	0.949	
	DFP+DWBA				1	11.0	1.25	0.949	1.2

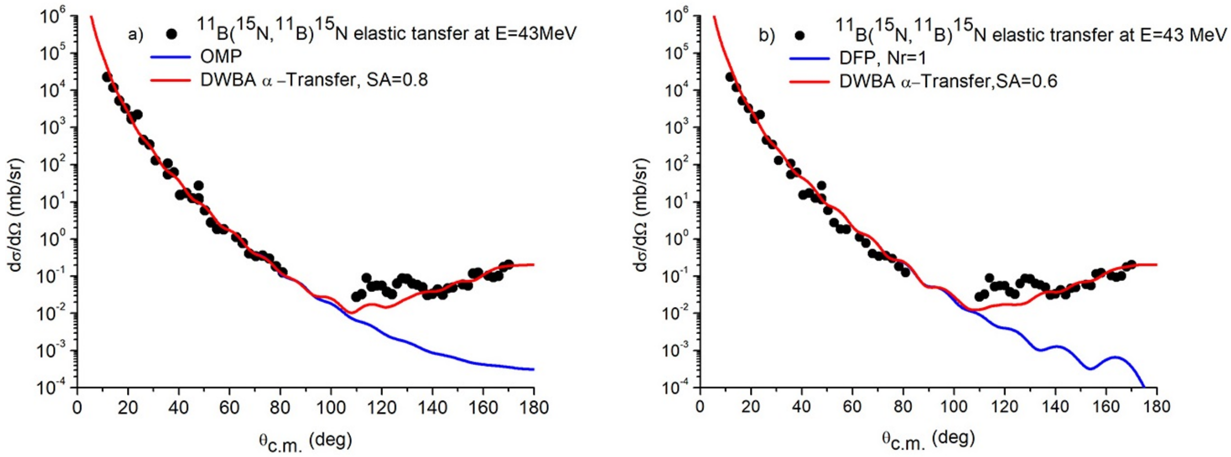

Figure 1: Comparison between experimental data (black points) for the ^{15}N+^{11}B system and OM calculations (pure elastic scattering, blue curves) and OM+DWBA (red curves) using two OM potentials: a) OP and b) DFP.

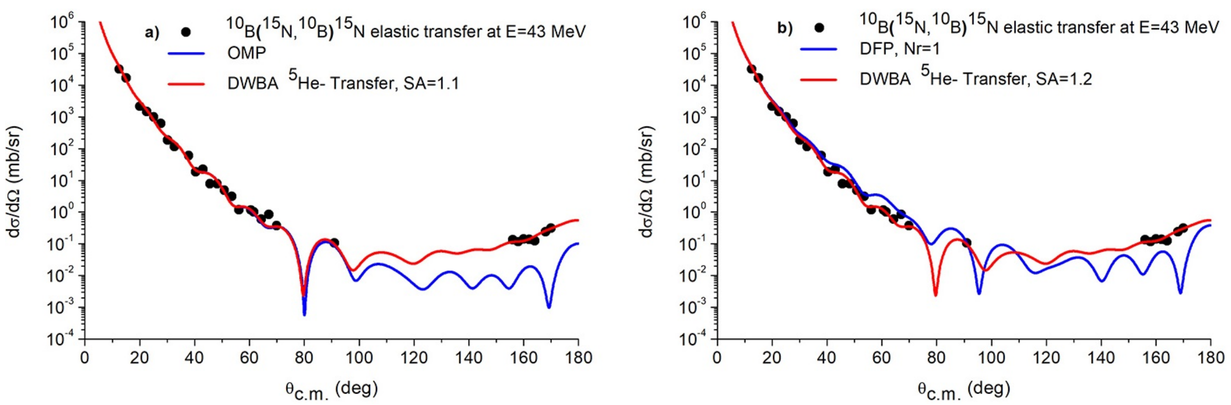

Figure 2: Comparison between experimental data (black points) for the ^{15}N+^{10}B system and OM calculations (pure elastic scattering, blue curve) and OM+DWBA calculations (red curves) using two OM potentials: a) OP and b) DFP.

It is found that the gross features of the angular distributions of the differential cross section at large angles are due to cluster-transfer. Spectroscopic amplitudes (SA) for the cluster configurations $^{15}N \to ^{11}B + \alpha$ and $^{15}N \to ^{10}B + ^{5}He$ extracted from the calculations are listed in Table 1.

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C.9 Test of a $\Delta E - E$ telescope consisting of a pair 26 µm thick strip detectors with strips 300 µm wide using 6.1 MeV α-particles from ^{252}Cf

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Leading towards the idea of a vertex detector made of very thin silicon strip detectors [1] produced using the low temperature technique [2–4], we have performed test measurements of a $\Delta E - E$ telescope consisting of a pair 26 µm thick strip detectors with strips 300 µm wide using 6.1 MeV α-particles from ^{252}Cf, see Figs. 1,2,3. The first picture (Fig. 1) shows the energy lost in one strip of the ΔE detector and the second picture shows the energy of particles stopped in one strip of the E detector (Fig. 2). The $\Delta E - E$ two-dimensional spectrum is shown in the third picture (Fig. 3). Since the width of the strips is very narrow (300 µm) it is almost impossible to make collimation of single strips. The collimation during the measurements was about 1.5 mm in diameter and we also registered α particles from the inter-strip regions, where their energies are shared by adjacent strips. For this reasons, lower energy α particles from inter-strip regions distort the registered ΔE main peak in Fig. 1 and these particles form a separate lower energy peak in the E detector (Fig. 2). This is also visible in the $\Delta E - E$ two-dimentional spectrum shown in the third picture (Fig. 3). To recover the proper energy of α particles from the inter-strip regions it is necessary to add charges from adjacent strips. This will be done with our multi-parameter system based on a 32 channel low-noise/low-power high dynamic range charge sensitive fast triggering circuit of the VATA family, with simultaneous sample-and-hold and calibration facilities. This multi-parameter system is currently under construction.

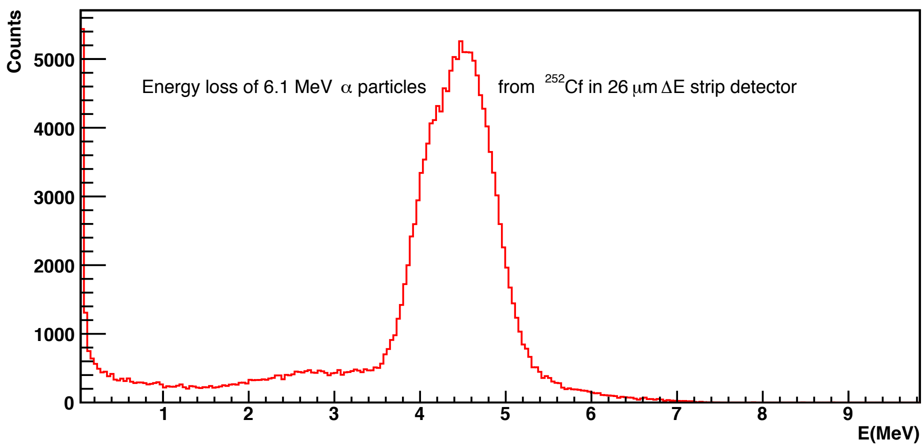

Figure 1: Energy loss of 6.1 MeV α particles from ^{252}Cf in the ΔE detector.

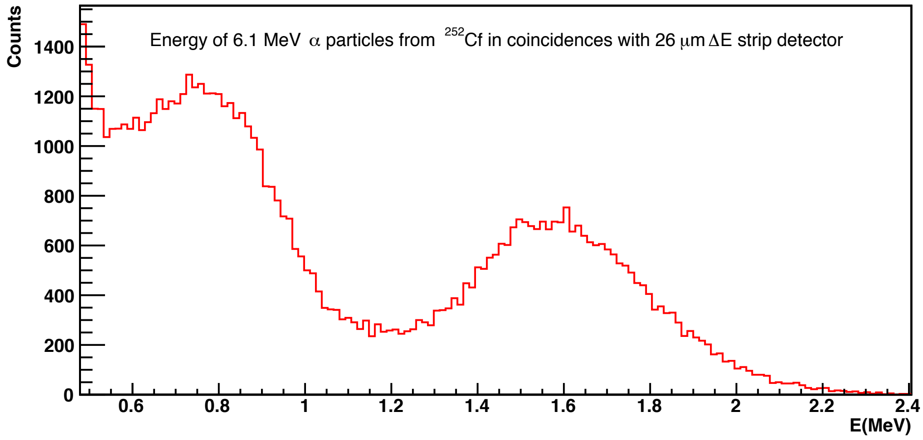

Figure 2: Energy of α particles stopped in a strip of the E detector.

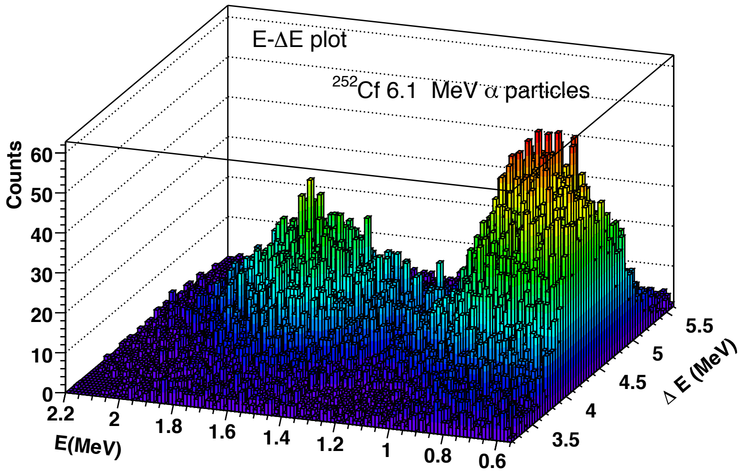

Figure 3: Two-dimentional spectrum of 6.1 MeV α particles registered in the $\Delta E - E$ telescope.

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Part D

Experiments using external facilities

D.1 First radioactive beams at the ACCULINNA-2 facility

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In 2016, a new fragment separator ACCULINNA-2 (see Fig. 1) was installed at the U-400M cyclotron beam line (~ 53 m in total) in JINR, Dubna. The separator and part of the primary beam line were designed and built in collaboration with the SIGMAPHI company [1].

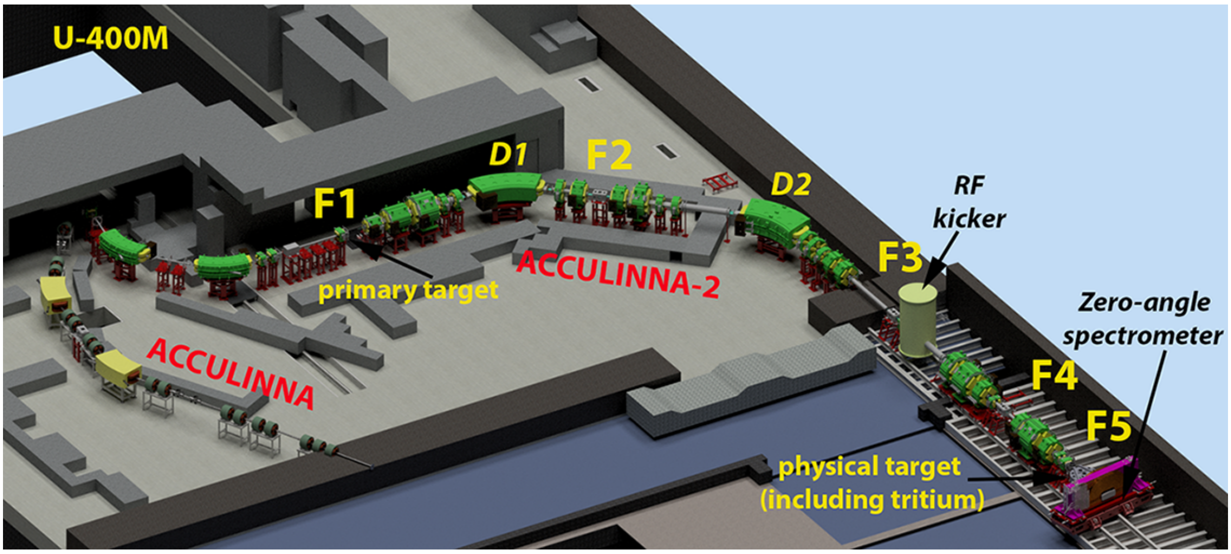

Figure 1: Layout of the ACCULINNA-2 fragment separator at the U-400M cyclotron. The 5 separator focal planes are indicated by F1 to F5.

In construction, ACCULINNA-2 is an achromatic separator consisting of two 45° dipoles (D1-D2), 14 quadrupoles (Q1-Q14), 5 multipoles (M1-M5) and 2 steering magnets (ST1-ST2). The in-flight fragmentation technique is used for production of radioactive ion beams. The production target is installed at the entrance focal plane, F1. Secondary ions are separated in flight using a combination of magnetic field analysis and energy losses in an achromatic wedge degrader located at the intermediate dispersive focal plane, F2. The first technical launch of the ACCULINNA-2 facility was performed when a primary beam of ^{32}S of energy 51.5 AMeV was transported to the F2 focal plane, and the beam characteristics were examined using a couple of Faraday cups (located at the U-400M output and at F2) and a luminophore located at F2. The beam transmission from the U-400M to F1 and from F1 to F2 was found to be more than 90% and 100%, respectively. These values, together with the size and the beam profile observed in F2, were in accordance with the simulations and fully met the requirements of the project [2, 3].

In March 2017 the first radioactive ion beams were produced at ACCULINNA-2. A primary beam of ^{15}N with an energy of 49.7 AMeV was delivered to the F1 focal plane where a 2 mm thick beryllium production target was installed. The secondary beam was cleaned by means of a wedge shape degrader, made of natural beryllium, with a thickness of 1 mm, located at F2. The fragmentation products were registered by a system of RIB diagnostics consisting of time-of-flight (TOF) and energy loss silicon detectors. The TOF array consisted of a couple of plastic scintillators (BC404), thickness 250 µm, with a sensitive area of diameter 60 mm. Each scintillator was coupled with four R7600 photomultiplier tubes. The TOF detectors were located at the F3 and F5 focal planes at a distance of 12.3 m and a time resolution of the TOF system better than 500 ps was established. A 300 µm thick double-sided silicon strip detector (Micron-Semiconductor BB7) with a sensitive area of 64 × 64 mm^2 and 32 strips on each side was located behind the second TOF detector at F5. This detector served for the measurement of energy losses and beam profile at the final focal plane.

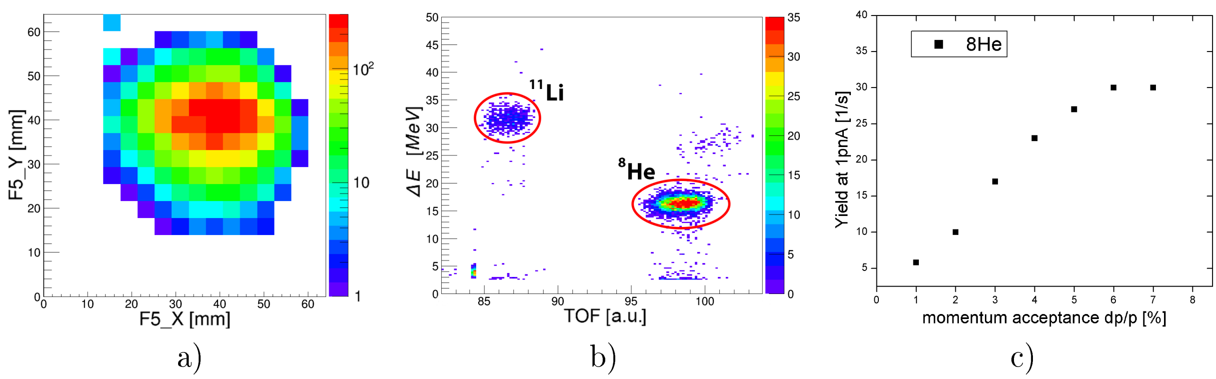

Figure 2: Typical spectra for the settings on ^{8}He. a) XY profile at the F5 focal plane obtained by a double-sided Si strip detector. b) ΔE vs. TOF fragment identification spectra. c) Dependence of the ^{8}He yield on the momentum acceptance of ACCULINNA-2 measured in the focal plane F5. Measurements were performed with a 1 mm beryllium wedge and $\Delta p/p = \pm\ 2\%$ at F2, $B\rho$(D2) = 2.67 Tm.

Typical two-dimensional plots presenting the beam spot measured in the F5 final focal plane and the ΔE-TOF identification pattern obtained when the separator was tuned for a ^{8}He secondary beam are shown in Fig. 2a and Fig. 2b, respectively. Another characteristic for RIB production is the dependence of intensity on the momentum acceptance set in the wedge position, i.e. in the dispersive focal plane, F2. Such a dependence is shown for ^{8}He in Fig. 2c, indicating that the maximum momentum acceptance of ACCULINNA-2 is about ±3%.

The basic parameters of RIBs such as intensity and purity, obtained for different groups of RIBs delivered to the final focal plane F5 of the ACCULINNA-2 separator are presented in Table 1. The intensity of the primary beam was limited to a few pnA because of the absence of shielding from radiation in the area around the production target (F1) and beam dump (F2).

Table 1: Production rates and purity values for several light neutron-rich RIBs obtained in the focal plane F5 in the reaction of a 49.7 AMeV ^{15}N primary beam at 1 pnA, with a 2 mm beryllium target. RIB intensities and purities were obtained with a 1 mm beryllium wedge and $\Delta p/p = \pm$ 2% at F2.

RIB	Energy (AMeV)	Intensity (s^{-1})	Purity (%)
^{14}B	37.7	120	65
^{12}Be	39.4	150	92
^{11}Li	37.0	4	67
^{9}Li	33.1	1100	50
^{8}He	35.8	25	89
^{6}He	31.5	2700	46

Summarizing, the new fragment separator ACCULINNA-2 was commissioned at FLNR JINR and the first radioactive beams were obtained. The basic ion-optical characteristics of ACCULINNA-2 described in the Letter of Intent [2] have been confirmed experimentally for a number of RIBs.

The RIB intensities obtained are by about 15 times larger in comparison with the old ACCULINNA facility. A study of the ^{6}He+^{2}H scattering reaction was begun in November 2017 and will be continued in March 2018. The next step is a search for the ^{7}H nucleus planned in the near future.

This work was partly supported by the RSF 17-12-01367 grant, the MEYS Projects (Czech Republic) LTT17003, LM2015049, and the Polish Plenipotentiary Representative at JINR, regulation 388/07.06.2017/13. The authors express their deep gratitude to FLNR director S.N. Dmitriev and to scientific leader Yu.Ts. Oganessian for the support provided to this work.

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D.2 Measurements of new β-delayed neutron emission properties with BRIKEN

M. Wolińska-Cichocka for the BRIKEN collaboration

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

In previous years, I was involved in planning and performing the β-delayed gamma and β-delayed neutron measurements at HRIBF (Oak Ridge, USA) and RIKEN Nishina Research Centre (Wako, Japan). At RIKEN, the BRIKEN collaboration has built the world's most efficient β-delayed neutron array, to study the decay properties of heavy ion fragmentation products selected in RIKEN's BigRIPS. These decay properties are used as input to the modelling of nucleosynthesis within the astrophysical r-process as well as being important signatures of the evolution of nuclear structure towards the neutron drip line.

Among the contributors to this project are Oak Ridge National Laboratory, RIKEN, UPC Barcelona, IFIC Valencia, the University of Tennessee Knoxville (UTK), TRIUMF as well as the University of Warsaw. The main goal of the measurement campaign performed in autumn 2017 was to study the decays of very exotic neutron-rich nuclei, for example the isotopic chains from $^{74\text{-}78}$Co to $^{110\text{-}118}$Mo.

At RIKEN's Radioactive Ion Beam Factory (RIBF), ^{238}U projectiles were accelerated to 345 MeV per nucleon with a beam intensity up to 60 pnA and hit a production target of ^{9}Be. Neutron-rich fragmentation products were filtered out by the BigRIPS fragment separator. The identified isotopes were transmitted through the Zero Degree-Spectrometer and implanted into two parts of ion-β counting systems, the WAS3ABi Si array [1] and a segmented-YSO scintillation detector developed at UTK, both positioned at the centre of the neutron detector BRIKEN [2] (see Fig. 1).

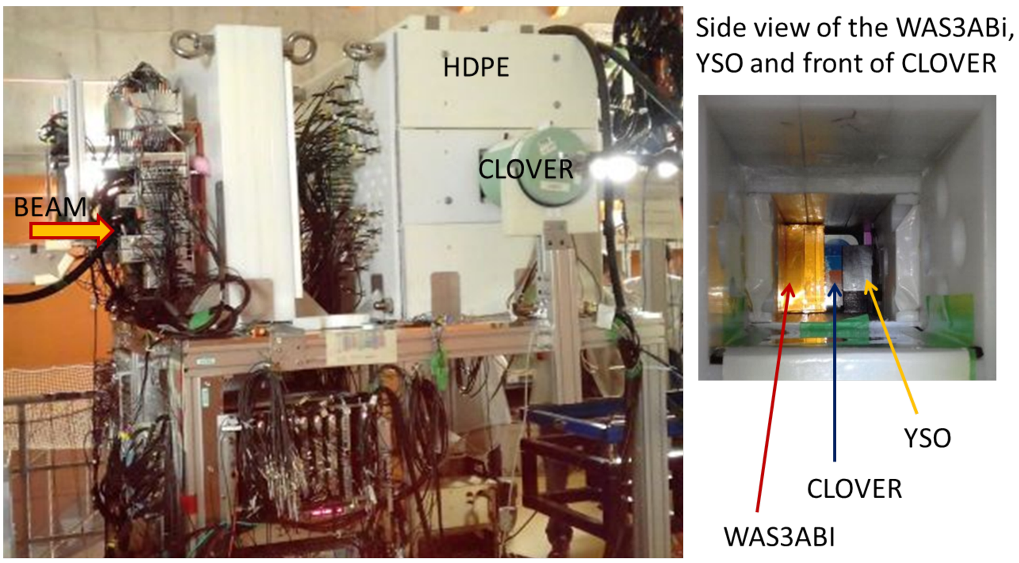

Figure 1: The BRIKEN setup.

The BRIKEN detector array consists of 140 ^{3}He tubes detecting β-delayed neutrons after slowing down in a High Density Polyethylene moderator, and two high-purity Ge clover detectors inserted in the side-holes of the HDPE and placed in close geometry with respect to the β-counters to maximize the γ-ray detection efficiency. This hybrid setup has over 60% efficiency for detecting single neutrons with an energy of up to 1 MeV and over 50% for 5 MeV neutrons.

In the last campaign tens of new β–delayed neutron precursors were measured and several exotic isotopes were identified for the first time. The next set of BRIKEN measurements is planned for the autumn of 2018.

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D.3 Towards investigations of proton-rich nuclei using the AGATA-NEDA setup at GANIL

M. Palacz[1] for the NEDA and N=Z Collaborations

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Studies of nuclei situated on the proton-rich side of the chart of the nuclides, and in particular close to the doubly magic ^{100}Sn nucleus, have for a long time been the focus of research pursued by many experimental and theoretical teams, including one group from HIL. In 2017 we concentrated on the preparation of experiments which we plan to run employing the new neutron detector NEDA, situated at GANIL, Caen, France, connected to the AGATA γ-ray spectrometer.

The construction of the NEDA array, by a broad international collaboration during the last decade, was described in several earlier editions of the HIL Annual report, including last year's [1] and in regular papers [2, 3]. The primary application of NEDA is to act as a neutron multiplicity filter in experiments in which exotic proton-rich nuclei are produced in-beam in fusion-evaporation reactions.

NEDA will ultimately consist of 355 identical detectors containing liquid scintillator (each single detector of approx. 3 litres volume) located in the front half of the solid angle around the target, at a distance of about 1 m from it. Photons generated in the scintillator will be collected by photomultiplier tubes. The output of the photomultiplier signals will be analysed using digital electronics. Each detector will provide information about the time of detection, the intensity of the generated light and the shape of the resultant electronic pulse. The scintillator used in NEDA has a light response which depends on the type of the registered radiation, which leads to different pulse shapes for neutrons and gamma rays. Thus, pulse shape analysis, in combination with a measurement of the time of flight of the detected radiation, enables a precise distinction between neutrons and gamma rays. Otherwise, gamma rays detected in neutron detectors form a disturbing background, significantly limiting the neutron detection capabilities. NEDA will be used at GANIL for the first time in 2018, together with the AGATA array [4], in a configuration consisting of 54 detectors, augmented by the older detectors of the Neutron Wall [5–7].

In 2017 work on the construction of the aforementioned initial version of NEDA reached its final phase. In November 17 detectors were installed at GANIL in connection with the EXOGAM HPGe detectors and three short in-beam test measurements were performed. This proved that the NEDA project is ready for the first experimental campaign which starts in April 2018. Five experiments will be performed with this setup in the period April to July 2018.

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[7] The Neutron Wall web page, `nsg.physics.uu.se/nwall`.

Part E

Appendices

E.1 List of experiments performed at HIL in 2017

A list of the experiments performed in 2017 is presented in the following pages.
The following acronyms of institution names are used in the list:

- HIL — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland;
- AUFS Antalya — Akdeniz University, Antalya, Turkey;
- CENT — Centre of New Technologies, University of Warsaw, Warszawa, Poland;
- CIAE Beijing — China Institute of Atomic Energy, Xinzhen, Fangshan, Beijing, China;
- FPACS UŁ — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland;
- FP UW — Faculty of Physics, University of Warsaw, Warszawa, Poland;
- GENU Astana — L.N. Gumilyov Eurasian National University, Astana, Kazakhstan;
- GSI-HS Darmstadt — GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany;
- IB JKU Kielce — Jan Kochanowski University, Institute of Biology, Kielce, Poland;
- IFIN-HH Bucurest — Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania;
- IKP TU Darmstadt— IKP, Technical University Darmstadt, Darmstadt, Germany;
- INFN LNS Catania — INFN Laboratori Nazionali del Sud, Catania, Italy;
- INP Almaty — Institute of Nuclear Physics, Almaty, Kazakhstan;
- INP Kraków — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland;
- INP Tashkent — Uzbekistan Academy of Sciences, Institute of Nuclear Physics, Tashkent, Uzbekistan;
- IP JKU Kielce — Jan Kochanowski University, Institute of Physics, Kielce, Poland;
- IUAC New Delhi — Inter University Accelerator Centre, New Delhi, India;
- JINR — Joint Institute for Nuclear Research, Dubna, Russia;
- NCNR Świerk — National Centre for Nuclear Research, Otwock, Poland;
- NRCKI Moscow — National Research Centre "Kurchatov Institute", Moscow, Russia;
- SPSU Saint-Petersburg — Saint Petersburg State University, Saint Petersburg, Russia;
- TU Tanta — Faculty of Science, Tanta University, Tanta, Egypt;
- UJ Jyväskylä — Department of Physics, University of Jyväskylä, Finland;
- USC INFN Catania — Universita degli Studi di Catania, INFN-Sezione di Catania, Italy;
- WU Wrocław — University of Wrocław, Wrocław, Poland;

For each experiment the following information is provided: ion, energy, setup/beam line information, date, proposal number, subject, spokespersons and institutions.

$^{40}Ar^{+8}$ — 195 MeV — EAGLE 16.01–25.01
HIL059 — Study of K-isomer in ^{186}Hg (J. Perkowski)
FPACS UŁ, FP UW, HIL

$^{12}C^{+3}$, $^{16}O^{+4}$ — 90 MeV, 118 MeV — Radiobiology 17.10–21.10
HIL057 — CHO K1 Irradiation (J. Czub)
IP JKU Kielce, IB JKU Kielce, HIL

$^{12}C^{+3}$, $^{12}C^{+2}$ — 90 MeV, 35 MeV — Radiobiology 17.10–21.10
HIL062 — Particle track structure for carbon ions (M. Pietrzak)
NCNR Świerk, HIL

$^{4}He^{+1}$ — 30 MeV — Internal beam 20.02-24.02
HIL058 — Medical radioisotopes (J. Jastrzębski)
HIL

$^{24}Mg^{+4}$ — 80 MeV 7.03, 29.03-30.03
HIL000 — Test of new beam (P. Gmaj)
HIL

$^{24}Mg^{+4}$ 05.04-07.04, 10.04-11.04
HIL000 — Test of new beam (P. Gmaj)
HIL

$^{24}Mg^{+4}$ — 77 MeV — ICARE 18.04–29.04
HIL063 — Transfer cross sections at near barrier energies for the $^{24}Mg+^{90,92}Zr$ systems (W. Trzaska, A. Trzcińska)
UJ Jyväskylä, HIL, GSI-HS Darmstadt, INFN LNS Catania, FP UW, IFIN-HH Bucurest, INP Kraków, USC INFN Catania, CIAE Beijing

$^{20}Ne^{+5}$ — 159 MeV — Radiobiology 08.05-12.05
HIL064 — Introduction of defects to the crystal structure of silver fluorides (W. Grochala, J. Choiński)
CENT, HIL

$^{15}N^{+3}$ — 43 MeV — ICARE 15.05–26.05
HIL065 — Measurement of the elastic scatering and one-nucleon transfer reactions for the $^{15}N+^{11}B$ system at the ^{15}N beam energy close to the coulomb barrier (N. Burtebayev)
INP Almaty, GENU Astana, INP Tashkent, JINR, AUFS Antalya, NRCKI Moscow, SPSU Saint-Petersburg, HIL

$^{4}He^{+1}$ – 30 MeV — Internal beam 29.05-02.06
HIL066 — Medical radioisotopes (J. Jastrzębski)
HIL

$^{32}S^{+5}$ – 90 MeV — EAGLE 22.06-27.06
HIL067 — Coulomb excitation of ^{118}Sn (M. Saxena, R. Kumar, C. Henrich)
HIL, IUAC New Delhi, IKP TU Darmstadt, FP UW, TU Tanta, JINR, HIL

$^{4}He^{+1}$ – 30 MeV — Internal beam 03.07-05.07
HIL066 — Medical radioisotopes (J. Jastrzębski)
HIL

$^{10}B^{+2}$ 19.09, 25.09-26.09
HIL000 — Test of the cyclotron (P. Gmaj)
HIL

$^{10}B^{+2}$ 03.10-05.10, 13.10
HIL000 — Test of the cyclotron (P. Gmaj)
HIL

$^{10}B^{+2}$ — 56 MeV — EAGLE 16.10–20.10
HIL068 — Lifetime measurements of I=10$^+$ chiral state in ^{128}Cs with HPGe–LaBr–LaBr triple (E. Grodner)
NCNR Świerk, IFIN-HH Bucurest, WU Wrocław, FP UW, HIL

$^{20}Ne^{+4}$ — 54 MeV — EAGLE, ICARE 23.10–27.10
HIL001 — Students' workshop
HIL

E.2 Degrees and theses completed in 2017 or in progress

E.2.1 PhD theses of students affiliated to HIL, of HIL staff members, and supervised by HIL staff

Michalina Komorowska, Faculty of Physics, University of Warsaw
Pear-shaped Nuclei in the $N \sim 88$ ***mass region***
Supervisors: dr hab. L. Próchniak, dr P. Napiorkowski, dr W. Korten, dr M. Zielińska.
Expected completion time: 2018.

Tomasz Marchlewski, Faculty of Physics, University of Warsaw
Measurement of nuclear excited state lifetimes in ^{124}***Cs; study of the mechanism of spontaneous chiral symmetry breaking***
Supervisors: prof. dr hab. K. Rusek, dr E. Grodner. Expected completion time: 2018.

Mateusz Pęgier, Faculty of Chemistry, University of Warsaw
Synteza i kontrola jakości radiofarmaceutyków znakowanych izotopem ^{44}***Sc***
Synthesis and quality control of radiopharmaceuticals labelled with ^{44}*Sc*
Supervisor: prof. dr hab. K. Pyrzyńska. Expected completion time: 2018.

Mateusz Sitarz, Faculty of Physics, University of Warsaw and Faculty of Science and Technology, University of Nantes
Supervisors: prof. dr hab. T. Matulewicz, dr A. Trzcińska, prof. F. Haddad.
Expected completion time: 2019.

E.2.2 Other PhD theses based on experiments performed at HIL

Katarzyna Szkliniarz, Silesian University
Cyklotronowa produkcja i badanie radioizotopów stosowanych w diagnostyce i terapii medycznej
Cyclotron production and research of radioisotopes for diagnostic and medical therapy
Supervisor: prof. dr hab. W. Zipper. Defended in May 2017.

Maria Pęgier, Faculty of Chemistry, University of Warsaw
Macrocyclic compounds labelled with metallic isotopes for application in positron emission tomography
Supervisors: prof. dr hab. K. Pyrzyńska, dr K. Kilian. Expected completion time: 2018.

Sunil Dutt, Aligarh Muslim University, Aligarh, (U.P.) India
Supervisor: prof. A. Rizvi. Expected completion time: 2019.

E.2.3 MSc and BSc theses supervised by HIL staff members

Mateusz Filipek, Faculty of Physics, University of Warsaw
Badanie wydajności detekcji jonów w nanodozymetrze Jet Counter
Study of ion detection efficiency in the Jet Counter nanodosimeter
Supervisor: dr hab. Z. Szefliński. MSc thesis completed in June 2017.

Agnieszka Orlińska, Faculty of Physics, University of Warsaw
^{18}F-MISO synthesis on Synthra RN synthesizer
Supervisors: dr hab. M. Kamiński, dr K. Kilian. MSc thesis completed in July 2017.

Kamil Kapinos, Faculty of Physics, University of Warsaw
Wydajność produkcji i czystość radioizotopowa ^{43}Sc i ^{44}Sc, jako emiterów pozytonów wytwarzanych w reakcji z protonami i deuteronami
Production yield and radioisotope purity of ^{43}Sc and ^{44}Sc as positron emiters in reactions with protons and deuterons
Supervisor: dr A. Trzcinska, dr B. Brzozowska. MSc thesis completed in September 2017.

Katarzyna Zofia Krutul, Faculty of Physics, University of Bialystok
Badanie ^{104}Pd metodą wzbudzeń kulombowskich.
Study of ^{104}Pd with Coulomb excitation.
Supervisor: dr P. Napiorkowski, dr K. Perzyńska. MSc thesis completed in September 2017.

Agnieszka Strzeżek, Faculty of Physics, University of Warsaw
Analiza wykrywalności guzów o podwyższonej aktywności na rzeczywistych i symulowanych obrazach w tomografii pojedynczych fotonów (SPECT).
Analysis of detection of tumours with increased activity in real and simulated images in single photon tomography (SPECT).
Supervisor: dr hab. Z. Szefliński. MSc thesis completed in September 2017.

Maja Hlebowicz, Faculty of Physics, Warsaw University of Technology
Wyznaczenie momentów kwadrupolowych niskoleżących stanów energetycznych jądra ^{107}Ag.
Quadrupole moments of low-lying nuclear states in ^{107}Ag.
Supervisor: dr K. Wrzosek-Lipska, prof. dr hab. P. Magierski. MSc thesis completed in December 2017.

Roman Szenborn, Faculty of Physics, University of Warsaw
Analysis of random γ-γ coincidences in DSA experiments with the EAGLE array
Supervisors: dr I. Skwira-Chalot, dr J. Srebrny. MSc thesis. Expected completion time: 2018.

Tobiasz Zawistowski, Faculty of Chemistry, University of Warsaw
The design and optimization parameters of the flow system for the separation of radiometals for positron tomography.
Supervisors: dr A. Korgul, dr K. Kilian. BSc thesis completed in January 2017.

Kamila Żujewska, Faculty of Physics, University of Warsaw
Badanie struktury trajektorii cząstki alfa oddziaływującej w rozrzedzonym molekularnym azocie.
Examination of the structure of the trajectory of alpha particles interacting in rarefied molecular nitrogen.
Supervisor: dr hab. Z. Szefliński. BSc thesis completed in June 2017.

Beata Pszczółkowska, Faculty of Physics, University of Warsaw
Ocena jakości obrazowania izotopami metalicznymi z wykorzystaniem skanera do badań przedklinicznych
Evaluation of imaging quality with metallic isotopes using the preclinical scanner.
Supervisor: dr K. Kilian. BSc thesis completed in September 2017.

Małgorzata Rytel, Faculty of Physics, University of Warsaw
Ocena zawartości radionuklidów w glebie wybranych parków Warszawy.
Evaluation of the content of radionuclides in the soil of selected parks in Warsaw.
Supervisor: dr hab. Z. Szefliński. BSc thesis. Expected completion time: 2018.

Joanna Zgardzińska, Faculty of Physics, University of Warsaw
Badanie zniekształceń w rekonstruowanych obrazach SPECT.
Study of distortions in reconstructed SPECT images.
Supervisor: dr hab. Z. Szefliński, dr U. Kaźmierczak. BSc thesis. Expected completion time: 2018.

E.3 Publications

E.3.1 Publications in journals of the Journal Citation Reports (JCR) list

A. Boso, S.M. Lenzi, F. Recchia, J. Bonnard, S. Aydin, M.A. Bentley, B. Cederwall, E. Clement, G.D. France, A.D. Nitto, A. Dijon, M. Doncel, F. G. Moradi, A. Gottardo, T. Henry, T. Huyuk, G. Jaworski, P.R. John, K. Juhasz, I. Kuti, B. Melon, D. Mengoni, C. Michelagnoli, V. Modamio, D.R. Napoli, B.M. Nyako, J. Nyberg, M. Palacz and J.J. Valiente-Dobon. *Isospin Symmetry Breaking in Mirror Nuclei ^{23}Mg-^{23}Na.* Acta Phys. Pol. B **48**, 313 (2017).

D.T. Doherty, J.M. Allmond, R.V.F. Janssens, W. Korten, S. Zhu, M. Zielińska, D.C. Radford, A.D. Ayangeakaa, B. Bucher, J.C. Batchelder, C.W. Beausang, C. Campbell, M.P. Carpenter, D. Cline, H.L. Crawford, H.M. David, J.P. Delaroche, C. Dickerson, P. Fallon, A. Galindo-Uribarri, F.G. Kondev, J.L. Harker, A.B. Hayes, M. Hendricks, P. Humby, M. Girod, C.J. Gross, M. Klintefjord, K. Kolos, G.J. Lane, T. Lauritsen, J. Libert, A.O. Macchiavelli, P.J. Napiorkowski, E. Padilla-Rodal, R.C. Pardo, W. Reviol, D.G. Sarantites, G. Savard, D. Seweryniak, J. Srebrny, R. Varner, R. Vondrasek, A. Wiens, E. Wilson, J.L. Wood and C.Y. Wu. *Triaxiality near the ^{110}Ru ground state from Coulomb excitation.* Phys. Lett. B **766**, 334 (2017).

P. Drozdz, A. Sentkowska and K. Pyrzynska. *Biophenols and antioxidant activity in wild and cultivated heather.* Nat. Prod. Res. **31**, 1181 (2017).

L. Dziawer, P. Koźmiński, S. Męczyńska-Wielgosz, M. Pruszyński, M. Łyczko, B. Wąs, G. Celichowski, J. Grobelny, J. Jastrzębski and A. Bilewicz. *Gold nanoparticle bioconjugates labelled with 211At for targeted alpha therapy.* RSC Adv. **7**, 41024 (2017).

A. Ertoprak, B. Cederwall, U. Jakobsson, B. M. Nyako, J. Nyberg, P. Davies, M. Doncel, G.D. France, I. Kuti, D.R. Napoli, R. Wadsworth, S.S. Ghugre, R. Raut, B. Akkus, H. Al-Azri, A. Algora, G. de Angelis, A. Atac, T. Back, A. Boso, E. Clement, D.M. Debenham, Z. Dombradi, S. Erturk, A. Gadea, F.G. Moradi, A. Gottardo, T. Huyuk, E. Ideguchi, G. Jaworski, H. Li, C. Michelagnoli, V. Modamio, M. Palacz, C.M. Petrache, F. Recchia, M. Sandzelius, M. Siciliano, J. Timar, J.J. Valiente-Dobon and Z.G. Xiao. *Lifetime Measurements with the Doppler Shift Attenuation Method Using a Thick Homogeneous Production Target-Verification of the Method.* Acta Phys. Pol. B **48**, 325 (2017).

A. Fijałkowska, M. Karny, K.P. Rykaczewski, B.C. Rasco, R. Grzywacz, C.J. Gross, M. Wolińska-Cichocka, K.C. Goetz, D.W. Stracener, W. Bielewski, R. Goans, J.H. Hamilton, J.W. Johnson, C. Jost, M. Madurga, K. Miernik, D. Miller, S.W. Padgett, S.V. Paulauskas, A.V. Ramayya and E.F. Zganjar. *Impact of Modular Total Absorption Spectrometer measurements of β decay of fission products on the decay heat and reactor $\nu(bar)_e$ flux calculation.* Phys. Rev. Lett. **119**, 052503 (2017).

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E.3.3 Articles in books

Z. Szefliński *Elements of Nuclear Physics.* An article in monograph: M. Smolarkiewicz, R. Piec, A. Chmielewska-Łukaszek *Safety of Nuclear Power.* Wydawnictwo Szkoły Głównej Służby Pożarniczej, Warszawa 2017, ISBN: 978-83-88446-93-1.

Z. Szefliński *Physics of Nuclear Reactors and Nuclear Fuels.* An article in monograph: M. Smolarkiewicz, R. Piec, A. Chmielewska-Łukaszek *Safety of Nuclear Power.* Wydawnictwo Szkoły Głównej Służby Pożarniczej, Warszawa 2017, ISBN: 978-83-88446-93-1.

E.4 Seminars

E.4.1 Seminars co-organised by HIL

Nuclear Physics Seminars

Seminars organised jointly by the divisions of Nuclear Physics and Nuclear Structure Theory of the Faculty of Physics, University of Warsaw, and the Heavy Ion Laboratory, University of Warsaw

E. Stephan — Institute of Physics, University of Silesia, Katowice, Poland — 12 January 2017
Układ kilku nukleonów jako laboratorium do badania oddziaływań jądrowych
Few-nucleon system as a laboratory to study nuclear interactions

K. Sieja — IPHC, Strasbourg, France — 19 January 2017
Collectivity above ^{78}Ni and ^{132}Sn cores

A. Maj — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland — 2 March 2017
NUPECC Long Range Plan 2017

M. Sitarz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 9 March 2017
Badanie wytwarzania radioizotopów medycznych w Środowiskowym Laboratorium Ciężkich Jonów
Study of medical radioisotopes production at Heavy Ion Laboratory

J. Szabelski — National Centre for Nuclear Research, Otwock, Poland — 16 March 2017
Eksperymenty satelitarne JEM-EUSO i POLAR — promieniowanie kosmiczne najwyższych energii
Satellite experiments JEM-EUSO and POLAR — highest energy cosmic radiation

K.W. Kemper — Physics Department, Florida State University, Tallahassee, USA — 23 March 2017
Future plans for nuclear physics in the United State and some current studies

A. Sobiczewski — National Centre for Nuclear Research, Otwock, Poland — 30 March 2017
Przewidywanie własności jądra $^{296}118$
Predictions for $^{296}118$ *nucleus properties*

T. Marchlewski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 6 April 2017
Chiralność w fizyce jądrowej na przykładzie ^{124}Cs
Chirality in nuclear physics with ^{124}Cs as an example

N. Keeley — National Centre for Nuclear Research, Otwock, Poland 20 April 2017
Light charged particle production in reactions induced by weakly-bound projectiles: Still an open question

B. Fornal — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland 27 April 2017
W poszukiwaniu jądrowych izomerów kształtu
In search of nuclear shape isomers

E. Czerwiński — Medical College, Jagiellonian University, Kraków, Poland 11 May 2017
J-PET modułowy detektor szerokiego zastosowania, czyli jak w Polsce łączyć badania podstawowe i stosowane
J-PET broad usage modular detector or how to merge fundamental and applied research

M. Konieczka — Inst. of Theoretical Physics, Univ. of Warsaw, Warszawa, Poland 18 May 2017
Rozpad beta w uogólnionym modelu jądrowego funkcjonału gęstości
Beta decay in generalised density functional

P. Jachimowicz — Fac. of Phys. and Astron. Univ. of Zielona Góra, Zielona Góra, Poland 25 May 2017
Przegląd symetrii minimów i punktów siodłowych najcięższych jąder atomowych
A review of the saddle points minima and maxima symmetry for the heaviest atomic nuclei

P. Geltenbort — Institut Laue Langevin, Grenoble, France 1 June 2017
News from the ILL ultracold neutron physics program

M. Czerwiński — Inst. of Exp. Physics, Univ. of Warsaw, Warszawa, Poland 8 June 2017
Poszukiwanie efektów kolektywnych w neutronowo-nadmiarowych izotonach o N=53
Search of collective effects in neutron-rich N=53 isotones

E. Piasecki — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 5 October 2017
Wpływ dyssypacji na wysokość barier kulombowskich
Dissipation influence on Coulomb barrier height

A. Korgul — Inst. of Exp. Physics, Univ. of Warsaw, Warszawa, Poland 19 October 2017
Badanie własności neutrono-nadmiarowych nuklidów w okolicy podwójnie magicznego jądra ^{132}Sn
Study of neutron-rich nuclei in the vicinity of double magic ^{123}Sn

A. Celler — Departament of Radiology, University of British Columbia, Vancouver, Canada 26 October 2017
Co fizyk jądrowy może robić w medycynie? — czyli projekty badawcze Medical Imaging Research Group
What a nuclear physicist could do in medicine — research projects at Medical Imaging Research Group

A. Pollo — National Centre for Nuclear Research, Otwock, Poland 9 November 2017
Świecące galaktyki w ciemnej (kosmicznej) sieci
Shining galaxies in a dark (cosmic) network

Ł. Janiak — Inst. of Exp. Physics, Univ. of Warsaw, Warszawa, Poland 16 November 2017
Badanie opóźnionych protonów z rozpadu jąder ^{26}P i ^{27}S
Study of delayed protons from ^{26}P and ^{27}S decay

J. Srebrny — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 23 November 2017
Konferencja XXIV NPW Kazimierz Dolny 20–23 IX 2017 "Spontaneous symmetry breaking in nuclear physics" 20-lecie badań zjawiska chiralności w jądrach atomowych
XXIV Nuclear Physics Workshop in Kazimierz Dolny 20–23 IX 2017 "Spontaneous symmetry breaking in nuclear physics" 20 years of studies of chirality in atomic nuclei

P. van Duppen — Instituut voor Kern- en Stralingfysica, K.U. Leuven, Leuven, Belgium 30 November 2017
Shape coexistence along Z=82 and the stability of the N=126 shell closure studied using laser ionization spectroscopy

M. Warda — Inst. of Physics, Maria Curie-Sklodowska Univ., Lublin, Poland 7 December 2017
Spontaniczne rozszczepienie jąder superciężkich jako emisja klastrów
Spontaneous fission of superheavy nuclei as cluster emission

M. Saxena — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 14 December 2017
Shapes and Collectivity of nuclei around Z=50 by Coulomb excitation

E.4.2 Other seminars organized at HIL

Internal semi-formal HIL seminars

W. Piątek — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 18 January 2017
Nowa strona WWW laboratorium
New website of HIL

E. Piasecki — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 25 January 2017
Co nowego dzieje się w "Barierach"
What's new is happening with "Bariers"

M. Pietrzak — Inst. of Exp. Physics, Univ. of Warsaw, Warszawa, Poland 22 March 2017
Nanodozymetria na wiązce jonów węgla w ŚLCJ — redukcja występowania wielokrotnych koincydencji przy zwiększonej intensywności wiązki
Nanodosimetry on carbon beam at HIL — reduction of multiple coincidences with increased beam intensity

D. Sacchi — ORTEC, Oak Ridge, Tennessee, USA 26 May 2017
New technological development in gamma spectroscopy

E.4.3 External seminars given by the HIL staff

M. Wolińska-Cichocka 24 March 2017
Modular Total Absorption Spectrometer the powerful array to study the beta-strength and anti-neutrino properties
6th Workshop on Nuclear Fission and Spectroscopy of Neutron-Rich Nuclei, Chamrousse, France

Ł. Standyło 30 March 2017
HIL ECRIS charge breeder status
Innovative charge breeding techniques meeting, CERN, Switzerland

K. Sudlitz 30 March 2017
HIL ECRIS charge breeder status
Innovative charge breeding techniques meeting, CERN, Switzerland

A. Kordyasz 6 April 2017
New future improvements of silicon detectors for FAZIA $\Delta E - E$ telescopes
FAZIA Days, Caen, France

K. Rusek 5–6 May 2017
Everything is coupled: reaction with weakly bound projectiles
4th Workshop of Hellenic Institute of Nuclear Physics, Ioannina, Greece

P.J. Napiorkowski 16 May 2017
Nuclear triaxiality — a next challenge for the Coulomb excitation technique
ISTROS 2017, Častá-Papiernička, Slovakia

A. Trzcińska 28 June 2017
Barrier height distribution studies for ^{24}Mg + ^{90,92}Zn systems
LNS, Catania, Italy

K. Kilian 3 June 2017
Synthesis of ^{18}F fluoromidasole and imagining of hypoxia in small animals with micro-PET
International Workshop on PET and MR Imaging, Kraków, Poland

M. Sitarz 4–9 June 2017
Research on the production of the medical radioisotopes at Heavy Ion Laboratory
2nd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland

A. Sentkowska 9 June 2017
Analiza specjacyjna selenu z wykorzystaniem chromatografii oddziaływań hydrofilowych
Speciation analysis of selenium using hydrophilic interaction chromatography
Metody chromatograficzne w nauce, przemyśle i medycynie, Lublin, Poland

M. Matejska-Minda 26–29 June 2017
Electromagnetic properties of ^{45}Sc studied by low-energy Coulomv excitation
Second Workshop of the Nuclear Spectroscopy Instrumentation Network of ENSAR2, NUSPIN, GSI Darmstadt, Germany

P.J. Napiorkowski 26–29 June 2017
Electromagnetic properties of ^{45}Sc studied by low-energy Coulomv excitation
Second Workshop of the Nuclear Spectroscopy Instrumentation Network of ENSAR2, NUSPIN, GSI Darmstadt, Germany

M. Pęgier 2–8 July 2017
Sorption of Sc(III) on solid carbon nanomaterials
17th International Symposium and Summer School on Bioanalysis, Macedonia

A. Sentkowska 28 August – 1 September 2017
Synthesis and investigation of Ga(III) complex with morin for molecular imaging
Euroanalysis 2017, Stockholm, Sweden

M. Matejska-Minda 3–9 September 2017
Electromagnetic properties of ^{45}Sc studied by low-energy Coulomb excitation
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

K. Wrzosek-Lipska 10–15 September 2017
Kształty jąder atomowych badane metoda wzbudzeń kulombowskich w ŚLCJ UW
Nucleus shapes studied by Coulomb excitation at HIL UW
44 Zjazd Fizyków Polskich, Wrocław, Poland

T. Marchlewski 20–24 September 2017
Search for critical frequency in chiral Cs isotopes; review of experimental evidence
XXIV Nuclear Physics Workshop, Kazimierz Dolny, Poland

P.J. Napiorkowski 20–24 September 2017
Experimental and theoretical measure of quadrupole triaxiality in atomic nuclei
XXIV Nuclear Physics Workshop, Kazimierz Dolny, Poland

J. Srebrny 20–24 September 2017
Rich experimental data on ^{119}I: γ-soft or γ-rigid and possible wobbling
XXIV Nuclear Physics Workshop, Kazimierz Dolny, Poland

A. Trzcińska 3–9 September 2017
Influence of single particle excitations on barrier distributions: ^{24}Mg + ^{90,92}Zn
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

E.4.4 Poster presentations

Z. Szefliński 12–16 June 2017
Effect of irradiation of CHO-K1 cells by mixed beam containing carbon and oxygen ions
Fifth International Conference on Radiation and Applications in Various Fields of Research, Budva, Montenegro

M. Filipek 6 May 2017
Learn before you measure: Method of single-isolated errors for ArcCheck
36 ESTRO, Vienna, Austria

K. Kilian 11–12 May 2017
Optymalizacja warunków kompleksowania jonów miedzi porfiryną do zastosowania w PET
Optimisation of the conditions of complexation of porphyrin copper ions for use in PET
V Łódźkie Sympozjum Doktorantów Chemii, Łódź, Poland

K. Kilian 11–12 May 2017
Sorpcja jonów sodu (III) na stałych materiałach węglowych
Sorption of sodium (III) ions on solid carbonaceous materials
V Łódźkie Sympozjum Doktorantów Chemii, Łódź, Poland

M. Pęgier 11–12 May 2017
Sorpcja jonów skandu(III) na stałych materiałach węglowych
Sorption of scandium ions (III) on solid carbonaceous materials
V Łódźkie Sympozjum Doktorantów Chemii, Łódź, Poland

M. Saxena 28 May – 2 June 2017
Study of static quadrupole moments in ^{120}Te isotope
Advances in Radioactive Isotopes Science, Keystone, Colorado

K. Kilian 1–3 June 2017
Obrazowanie stanu niedotlenienia tkanki nowotworowej w modelu zwierzęcym z wykorzystaniem 18Fluoromizonidazolu (18FMISO)
Imaging of tumor tissue hypoxia in an animal model using 18Fluoromizonidazolu (18FMISO)
Konferencja Polskiego Towarzystwa Fizyki Medycznej, Poznań, Poland

K. Kilian 1–3 June 2017
Poszukiwanie znacznika do obrazowania rozwoju raka jasnokomórkowe nerki w modelu mysim
Search for a marker for imaging the development of cancer of the clear kidney cells in the mouse model
Konferencja Polskiego Towarzystwa Fizyki Medycznej, Poznań, Poland

K. Kilian 3 June 2017
Synthesis of ^{18}F fluoromidasole and imagining of hypoxia in small animals with micro-PET
International Workshop on PET and MR Imaging, Kraków, Poland

M. Pęgier 9 June 2017
Wykorzystanie materiałów węglowych jako potencjalnych sorbentów dla jonów skandu (III)
The use of carbon materials as potential sorbents for scandium ions (III)
XIV Warszawskie Seminarium Doktorantów Chemików ChemSession'17, Warszawa, Poland

K. Kilian 28 August – 1 September 2017
Synthesis and investigation of Ga(III) complex with morin for molecular imaging
Euroanalysis 2017, Stockholm, Sweden

A. Sentkowska 28 August – 1 September 2017
Synthesis and investigation of Ga(III) complex with morin for molecular imaging
Euroanalysis 2017, Stockholm, Sweden

M. Matejska-Minda 3–9 September 2017
Electromagnetic properties of ^{45}Sc studied by low-energy Coulomb excitation
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

P.J. Napiorkowski 3–9 September 2017
Electromagnetic properties of ^{45}Sc studied by low-energy Coulomb excitation
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

P.J. Napiorkowski 3–9 September 2017
Laboratories for Fundamental Laws of Nature
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

K. Rusek 3–9 September 2017
Pairing in light, neutron rich nuclei
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

M. Saxena 3–9 September 2017
Evidence of rotational behavior in ^{120}Te isotope
XXXV Mazurian Lakes Conference on Physics, Piaski, Poland

U. Kaźmierczak 10–15 September 2017
Dawka lokalna i jej rola w biologicznej odpowiedzi linii komórkowych ssaków in vitro
Local dose and it's role in the biological response of mammalian cell lines in vitro
44 Zjazd Fizyków Polskich, Wrocław, Poland

M. Matejska-Minda 10–15 September 2017
Wzbudzenie kulombowskie ze zmianą parzystości na przykładzie ^{45}Sc
Coulomb excitation with parity change with ^{45}Sc as an example
44 Zjazd Fizyków Polskich, Wrocław, Poland

J. Samorajczyk-Pyśk 10–15 September 2017
Badanie spinów niskoleżących poziomów w jądrze ^{140}Sm wykorzystując korelacje kątowe γ-γ
Test of low-level spins in ^{140}Sm nucleus with γ-γ angular correlations
44 Zjazd Fizyków Polskich, Wrocław, Poland

M. Saxena 10–15 September 2017
Evidence of rotational behaviour in ^{120}Te isotope
44 Zjazd Fizyków Polskich, Wrocław, Poland

K. Kilian 19–22 September 2017
Comparative study of Sc(III) sorption onto carbon-based materials
23rd International Symposium on Separation Sciences, Vienna, Austria

K. Kilian 21–25 October 2017
^{68}Ga(III) complex with morin for kidney cancer cells labeling
EANM Congress, Vienna, Austria

E.4.5 Lectures for students and student laboratories

K. Kilian winter semester of the academic year 2017/2018, 20 hours
Zarzadzanie Środowiskiem
Environmental Management
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2017/2018, 30 hours
Metody izotopowe i chemia radiofarmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2016/2017, 60 hours
Pracownia radiofarmaceutyków
Laboratory of Radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2016/2017, 15 hours
Radiofarmaceutyki — synteza, wytwarzanie i zastosowania
Radiopharmaceuticals — synthesis, production and applications
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2016/2017, 30 hours
Energetyka Jądrowa
The nuclear power industry
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2016/2017, 30 hours
Techniki jądrowe w diagnostyce i terapii medycznej
Nuclear techniques in Medical Diagnostics and Therapy
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2016/2017, 30 hours
Energia w Środowisku — technika ograniczenia i koszty
Energy in the environment — technique limitations and costs
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2017/2018, 45 hours
Fizyka I
Physics 1, mechanics, lecture
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2017/2018, 15 hours
Fizyka I — ćwiczenia do wykładu
Physics 1, mechanics, class plenary
Faculty of Physics, University of Warsaw, Warszawa, Poland

E.4.6 Science popularization lectures

P.J. Napiorkowski lectures for middle school pupils

Fizyka dla bramkarzy (2x60 min)
Physics for goalkeepers

E.5 Honours and Awards

The Rector of the University of Warsaw awards

In 2017 the following employees of the Heavy Ion Laboratory received the Rector of the University of Warsaw award:
Mariusz Antczak, Anna Błaszczyk-Duda, Marek Budziszewski, Jarosław Choiński, Przemysław Czwarnok, Andrzej Jakubowski, Piotr Jasiński, Robert Kopik, Andrzej Kordyasz, Krzysztof Łabęda, Agnieszka Maciejewska, Ernest Piasecki, Andrzej Pietrzak, Leszek Próchniak, Bogdan Radomyski, Krzysztof Rusek, Julian Srebrny, Zygmunt Szefliński, Katarzyna Włodarczyk

E.6 Laboratory staff

Director: Krzysztof Rusek
Deputy directors: Jarosław Choiński
Paweł Napiorkowski
Financial executive: Agnieszka Maciejewska

Senior scientists:

Jerzy Jastrzębski[a], Andrzej Kordyasz[a], Marcin Palacz, Ernest Piasecki[a], Leszek Próchniak, Krzysztof Rusek, Anna Stolarz, Józef Sura[b], Zygmunt Szefliński[a]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Jarosław Choiński, Przemysław Gmaj, Andrzej Jakubowski, Urszula Kaźmierczak, Krzysztof Kilian, Maciej Kisieliński[a], Marian Kopka, Michał Kowalczyk, Magdalena Matejska-Minda[b], Paweł Matuszczak[a], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Monika Paluch-Ferszt[c], Wojciech Piątek, Bogdan Radomyski, Olga Saeed Mohamed Nassar, Justyna Samorajczyk-Pyśk, Mansi Saxena, Aleksandra Sentkowska, Mateusz Sobolewski[a], Julian Srebrny[a], Łukasz Standyło, Krzysztof Sudlitz[a], Roman Tańczyk, Agnieszka Trzcińska, Andrzej Tucholski, Marzena Wolińska-Cichocka, Katarzyna Wrzosek-Lipska, Bogumił Zalewski[d]

Doctoral candidates:

Mateusz Filipek[e], Michalina Komorowska[e], Tomasz Marchlewski[e], Mateusz Pęgier[f], Mateusz Sitarz[e]

Technicians:

Mariusz Antczak, Tomasz Bracha, Elżbieta Filutowska[g], Andrzej Górecki, Piotr Jasiński, Bartosz Kalisiewicz[h], Wiesław Kalisiewicz, Robert Kopik, Wojciech Kozaczka, Zbigniew Kruszyński, Piotr Krysiak, Krzysztof Łabęda, Kamil Makowski, Zygmunt Morozowicz, Bogusław Paprzycki, Andrzej Pietrzak[a], Krzysztof Pietrzak, Krzysztof Sosnowski, Łukasz Świątek

Administration and support:

Eliza Balcerowska, Anna Błaszczyk-Duda, Marek Budziszewski, Przemysław Czwarnok, Barbara Kowalska[a], Joanna Kowalska, Agnieszka Maciejewska, Jolanta Matuszczak, Anna Odziemczyk[i], Jolanta Ormaniec[j], Magdalena Piwowarczyk[a,k], Ewa Sobańska, Lidia Strzelczyk, Andrzej Wiechowski, Katarzyna Włodarczyk[a], Magdalena Zawal,

Voluntary scientists:

Jędrzej Iwanicki, Piotr Pluciński, Jan Kownacki, Andrzej Wojtasiewicz, Irena Żejmo

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[a] part time
[b] until 30 November
[c] since 15 December
[d] on leave
[e] PhD student at the Faculty of Physics, University of Warsaw
[f] PhD student at the Faculty of Chemistry, University of Warsaw
[g] since 1 June
[h] since 1 May
[i] since 1 February
[j] on maternity leave
[k] since 1 November

E.7 Laboratory Council

1. Prof. dr hab. Józef Andrzejewski
Nuclear Physics Division
University of Łódź, Łódź

2. Prof. dr hab. Janusz Braziewicz
Institute of Physics
Jan Kochanowski University, Kielce

3. Prof. dr hab. Mieczysław Budzyński
Institute of Physics
Maria Curie-Skłodowska University, Lublin

4. Prof. dr hab. Ewa Bulska
Biological and Chemical Research Centre
University of Warsaw, Warszawa

5. Prof. dr hab. Katarzyna Chałasińska-Macukow
Faculty of Physics
University of Warsaw, Warszawa

6. Dr Jarosław Choiński
Heavy Ion Laboratory
University of Warsaw, Warszawa

7. Prof. dr hab. inż. Andrzej Chmielewski
Institute of Nuclear Chemistry
and Technology, Warszawa

8. Przemysław Gmaj
(representative of the HIL staff)
Heavy Ion Laboratory
University of Warsaw, Warszawa

9. Prof. dr hab. Jerzy Jastrzębski
Heavy Ion Laboratory
University of Warsaw, Warszawa

10. Prof. dr hab. Marta Kicińska-Habior
(**Chairman of the Council**)
Faculty of Physics
University of Warsaw, Warszawa

11. Prof. dr hab. Stanisław Kistryn
M. Smoluchowski Institute of Physics
Jagiellonian University, Kraków

12. Prof. dr hab. Franciszek Krok
Department of Physics
Warsaw University of Technology, Warszawa

13. Prof. dr hab. Leszek Królicki
Department of Nuclear Medicine
Medical University of Warsaw, Warszawa

14. Dr hab. inż. Krzysztof Kurek, prof. NCBJ
The National Centre for Nuclear Research
Świerk k/Warszawy

15. Prof. dr hab. Adam Maj
(**Deputy Chairman of the Council**)
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences, Kraków

16. Prof. dr hab. Tomasz Matulewicz
Faculty of Physics
University of Warsaw, Warszawa

17. Dr Paweł Napiorkowski
Heavy Ion Laboratory
University of Warsaw, Warszawa

18. Prof. dr hab. Wojciech Nawrocik
Faculty of Physics
Adam Mickiewicz University, Poznań

19. Prof. dr hab. Paweł Olko
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences, Kraków

20. Dr hab. Leszek Próchniak
Heavy Ion Laboratory
University of Warsaw, Warszawa

21. Prof. dr hab. Krzysztof Rusek
(Director of HIL)
Heavy Ion Laboratory
University of Warsaw, Warszawa

22. Prof. dr hab. Adam Sobiczewski
The National Centre for Nuclear Research
Otwock

23. Dr hab. Elżbieta Stephan, prof. UŚ
Institute of Physics
University of Silesia, Katowice

E.8 Programme Advisory Committee

PAC members

- Konrad Czerski (Institute of Physics, University of Szczecin, Szczecin, Poland)
- Gilles de France (GANIL, Caen, France)
- Nicholas Keeley (National Centre for Nuclear Research, Otwock, Poland)
- Maria Kmiecik (Institute of Nuclear Physics PAN, Kraków, Poland)
- Andrzej Magiera (Inst. of Phys., Jagiellonian Univ., Kraków, Poland)
- Chiara Mazzocchi (Faculty of Physics, University of Warsaw, Warszawa, Poland) (**Deputy Chairman of the PAC**)
- Marco Mazzocco (Padova University, Padova, Italy)
- Leszek Próchniak (Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland)
- Siergiej Sidorczuk (Joint Institute for Nuclear Research, Dubna, Russia)
- Władysław Trzaska (Department of Physics, University of Jyväskylä, Finland) (**Chairman of the PAC**)

The international Programme Advisory Committee of the Heavy Ion Laboratory usually meets twice a year, in spring and autumn. The deadline for submitting proposals is three weeks before a PAC meeting. PAC approved experiments are scheduled at the meetings of the Users' Committee, which also serves as a link between cyclotron users and the Laboratory. The Users' Committee is chaired by Julian Srebrny (the Heavy Ion Laboratory).

E.9 External HIL users

In 2017 there were **73** external HIL users and visitors from **25** scientific institutions, including 34 people from 7 scientific institutes in Poland, 15 people from 6 scientific institutions in the European Union and associated countries and 24 people from 12 scientific institutes in other countries.

External HIL users and visitors were from:

Poland

- Centre of New Technologies, University of Warsaw, Warszawa, Poland
- Fac. of Phys. and Appl. Comp. Sci., University of Lodz, Łódź, Poland
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