Heavy Ion Laboratory

ANNUAL REPORT 2018

UNIVERSITY OF WARSAW

HIL Heavy Ion Laboratory

Heavy Ion Laboratory

University of Warsaw

Annual Report

2018

Warszawa, May 2019

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The photo on the title page was taken
in front of the HIL building on 23 May 2019
by Krzysztof Łabęda and Piotr Jasiński

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A life with a great passion for nuclear physics: Jerzy Jastrzębski (1934-2018)

Professor Jerzy Jastrzębski, one of the founders and a long-time director of the Heavy Ion Laboratory of the University of Warsaw, passed away suddenly on 19th August 2018. He was an outstanding physicist in the field of experimental nuclear physics and in the applications of nuclear physics in medicine, initiator of the close collaboration between scientists from Poland and France and a member of the Polish-French Cooperation Commission for many years. He was also a representative of Poland on the Nuclear Physics European Cooperation Committee (NuPECC), establishing the permanent and important position of Polish nuclear physicists among our European colleagues.

Jerzy graduated from the Adam Mickiewicz University in Poznań in 1955 and went straight on to work at the newly founded Institute of Nuclear Research in Świerk near Warsaw, in a small group of physicists led by Professor Andrzej Sołtan. After two years he was sent on a scholarship to one of the leading French nuclear physics laboratories at Orsay. Working there in a group of excellent scientists, he became an expert in the field of nuclear spectroscopy, publishing many important results. Some of them were the subject of his doctoral dissertation (1963) and habilitation thesis (1971), both defended at the Institute of Nuclear Research. In 1981 he obtained the title of Professor. In 1983 he moved to the newly established Heavy Ion Laboratory at the University of Warsaw, becoming its director a year later.

Thanks to his heroic work, persistance and perseverance, the Heavy Ion Laboratory was built and equipped with the U-200P heavy ion cyclotron, accelerating beams of various ions up to energies of 10 MeV/nucleon. The very first beam was delivered in 1994 and the Laboratory has served and continues to serve many scientists from Poland and abroad, becoming a well recognized low energy nuclear physics laboratory in Europe.

Jerzy served as director until 2009 with a break during 1994–2000. He used this break to conduct intensive scientific research on the distribution of matter in atomic nuclei using an antiproton beam at CERN. His research done at that time still attracts a great deal of interest.

He understood the role of basic research in serving society and as a well respected scientist he was able to develop a program on the applications of radioactive isotopes in the diagnosis and therapy of cancer. He was the initiator of the Radioisotopes Production and Research Center, which, thanks to him, was built at the Heavy Ion Laboratory and opened in 2012. He created a group of scientists specializing in nuclear medicine and radiochemistry, and established collaborations with institutes from Poland and abroad carrying on intense interdisciplinary research related to the applications of nuclear methods in medicine. This activity in recent years placed him among the prominent experts in this field.

The diverse activities of Jerzy were rewarded with numerous honours: the Knight's Cross of the Order of Polonia Restituta, Palmes Academiques and the Medal of the University of Warsaw.

Professor Jerzy Jastrzębski was one of the pioneers of experimental nuclear physics in Poland. He was a scientist with many great achievements, passing on his knowledge to younger colleagues (he supervised over a dozen PhD students), initiator, organizer and builder of national research infrastructures as well as an organizer of broad scientific cooperation. He devoted himself to each of these activities with great passion to the very end of his life.

Krzysztof Rusek

Contents

Introduction

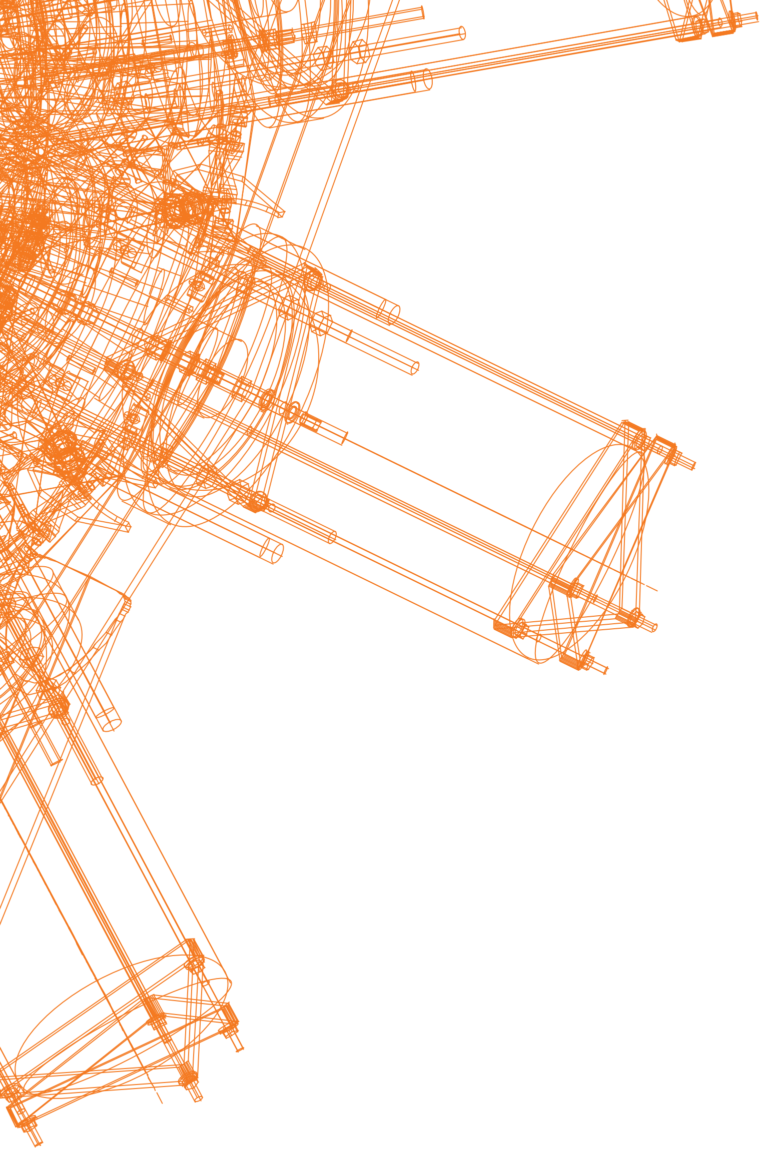
The year 2018 was marked by the sudden lost of one of our colleagues, the director of HIL for many years, Professor Jerzy Jastrzębski. In the recent years he developed a program related to the applications of radioactive isotopes in medicine. In section B of this Annual Report some recent results obtained by his group, using the proton beam from our Radiopharmaceuticals Production and Research Center, can be found. The Center, equipped with the PETtrace cyclotron and an external target system (patent No 227402 has been obtained for the design), apart from commercial production of radiopharmaceuticals, conducts research in the area of radiopharmaceuticals applied to cancer therapy. A very interesting field is related to the production of scandium radioisotopes that offers the possibility of a variety of medical applications. Research along these lines, initiated by Jerzy, will be continued by his colleagues.

Concerning fundamental research in nuclear physics, an important achievement in 2018 was the construction of the EAGLE-EYE setup that extends the experimental possibilities at HIL for fast-timing techniques. In the first test experiment the setup was supplemented by the detectors of FATIMA collaboration. Brief technical information on the setup may be found in section C. Another new instrument is the velocity filter (Wien filter) that is under construction in collaboration with the Laboratori Nazionali del Sud (LNS). The filter has passed a number of tests showing that it is a promising tool for the separation of elastic events from fusion residues. The filter will be used in fusion measurements at energies close to the Coulomb barrier at both laboratories, HIL and LNS.

The instrumentation available at HIL is developed on a regular basis. The construction of the central European Array for Gamma Levels Evaluation (EAGLE) spectrometer was completed in 2011. It remains the only device of this kind in Poland, living up to European standards. In 2012, the Radiopharmaceuticals Production and Research Center, mentioned above, was opened. The Center has enabled advances in radiopharmaceuticals applied to cancer diagnosis as well as contributing to the establishment of a collaboration with the radiopharmaceutical industry. 2014 marked the commissioning of the Supernanogan ECR ion source developed by Pantechnik. This enabled a significant increase in the range of accelerated ions. It is the only such source in the country. Work on replacing the high-frequency generators that power the U-200P heavy ion cyclotron (again a unique device in the country) will be concluded this year.

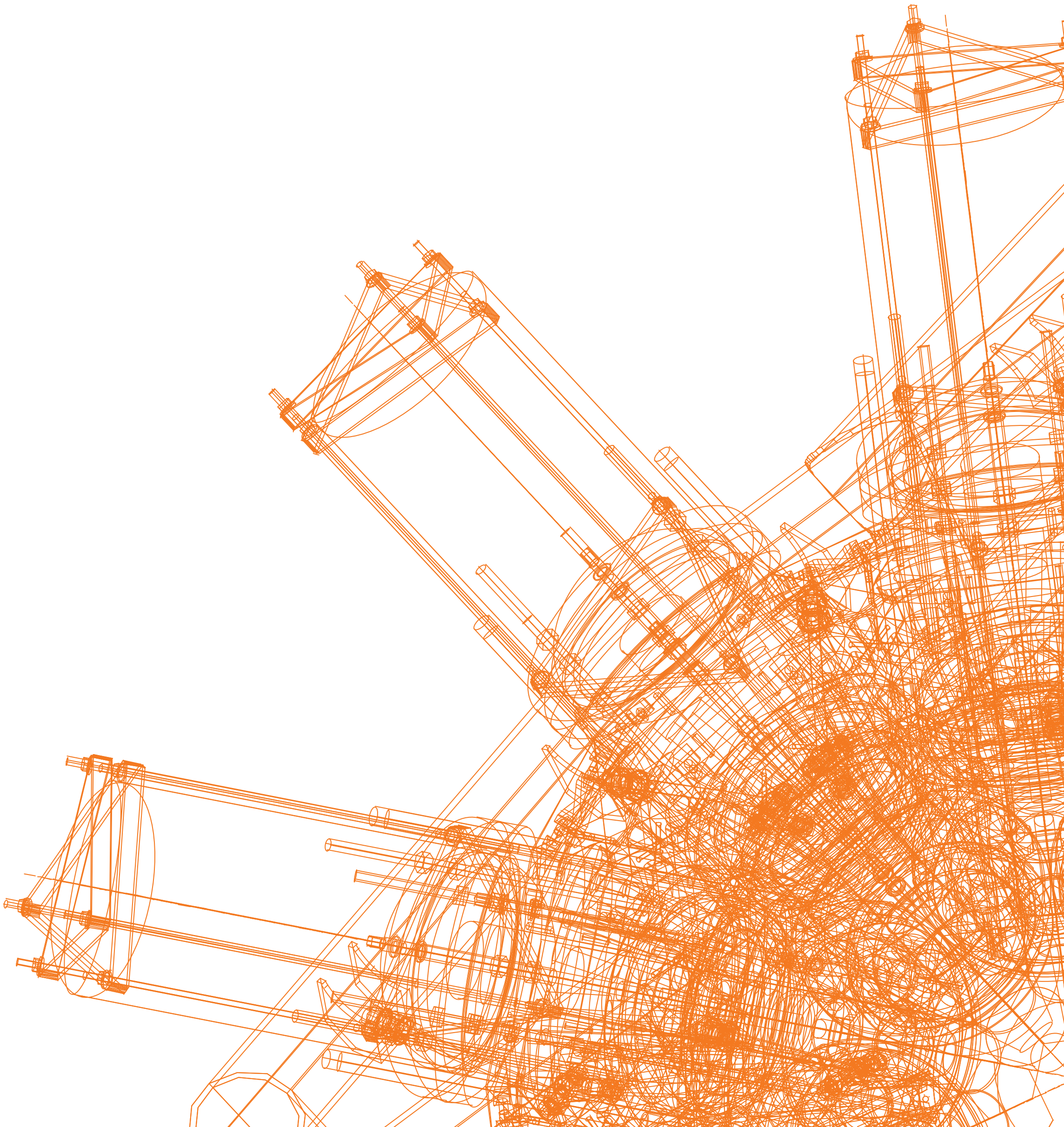
The U-200P cyclotron is the key experimental unit at HIL, delivering ion beams for 25 years. It was constructed in the seventies of the twentieth century. In 2018 the Ministry of Science and Higher Education of Poland opened a call for new projects that could be included on the Polish Road Map of Research Infrastructure. A project prepared by HIL aims at the purchase and installation of a new heavy ion accelerator to replace the existing U-200P. The new accelerator will allow the range of accelerated ions to be increased and provide the possibility to deliver ion beams of significantly higher intensity. The purchase of a next-generation cyclotron, similar to the DC-280 cyclotron installed recently at the Joint Institute for Nuclear Research in Dubna, seems a reasonable alternative. The project entitled HIL@ECOS and supported by the community of Polish nuclear physicists, was submitted to the Ministry. Its full text may be found on the web page of HIL. We do hope that it will be included in the Polish Road Map of Research Infrastructure.

Prof. Krzysztof Rusek, Director of HIL



Part A

Laboratory Overview and technical develpoments



A.1 General information

J. Choiński, P. Napiorkowski and 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 $K = 16.5$ 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 π 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 2018 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

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Operation

In 2018, after two months of operation, the U-200P cyclotron suffered a serious failure associated with its heavy use in recent years. The restoration of the normal functionality of the magnetic and electrical configuration of the acceleration system required intensive work by the technical department of the cyclotron and stopped the planned experimental work until mid-year. Nevertheless, most of the nuclear, biological and applications physics experiments planned and approved by PAC-2018 were performed in the second half of 2018 and early 2019. The experiments related to the production of medical radioisotopes were postponed to 2019 in connection with the death of the leader of this research, professor J. Jastrzębski.

Regardless of the labor-intensive involvement in the repair of the accelerating system, beam development work was continued. It concentrated mainly on obtaining metallic ions from volatile compounds using MIVOC and sputtering methods. The results are not yet satisfactory for the much-desired nickel beam which is required for the Coulomb excitation of ^{118}Sn, therefore this task will be continued in 2019.

The Program Advisory Committee for the year 2018 approved a total number of 8 experimental projects (2116 h of beam time). Three additional runs were planned to complete experiments approved but not performed in 2017. Five projects (1236 h of beam time) have been implemented of the remaining projects 2 were postponed due to the death of Prof. J. Jastrzębski and 1 due to not receiving the right Ni beam intensity. Therefore, although the total cyclotron availability was only 33% of the allocated beam time, the beam time execution accounted for 58% of the plan.

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

In 2018, 7 experimental runs were carried out, in which 60 senior and twice as many younger Polish and foreign scientists took part (see the tables at the end of the report below). Each run required from 5 days to 2 weeks continuous operation of the cyclotron.

Maintenance and development

Repair of the resonance, magnetic and electrical structure of the cyclotron

As was mentioned above, by early 2018 the cyclotron department had to repair a malfunction of the entire cyclotron due to defects in the mechanical parts. The work consisted of:

- writing special codes to model beam behavior in the central region,

- cleaning and repairing the resonance structure,
- measuring and adjusting the Dee positions,
- measuring and adjusting the vertical magnetic plug deciding about the magnetic field in the center,
- adjusting of the central part.

This task was finished in July 2018.

ECR Source

Due to demand from scientists, the cyclotron team worked on expanding the list of available beams, in particular on the preparation of metallic beams as mentioned above.

Unlike the previous year, the work was concentrated on the MIVOC method for obtaining a Ni beam. This method provided very stable beam current from the ECR source on the level of 8 µA of $^{58}Ni^{+9}$. This is 5 times less than required for the planned experiment. The ECR effectiveness strongly depends on numerous electro-magnetic parameters, plasma chamber impurities, pressure of gases and vapors in the plasma, the method of providing microwave energy for plasma heating and others. These parameters must be properly chosen and optimized. However, the mean time needed for each parameter optimization is counted in weeks. It is extremely difficult to plan this type of work in combination with delivering ion beams from the same source for experiments.

These reasons prevailed in the decision to try to obtain higher Ni currents using the sputtering method (i.e. atomizing metallic nickel with plasma escape electrons). With this method the intensity increased by a factor of 3, but the beam was very unstable.

Further efforts were continued to optimize the operation of the 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, which is necessary for experiments. The development of the above bench was continued in the scope of the European ENSAR 2 project during 2018. The bench also allows different physical phenomena occurring in plasma to be studied rather than mapping the specific production in ECRIS, so it can be used more to discover innovative solutions then to optimize a specific ECR source.

RF system

The currently used RF amplifiers have come to the end of their days 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 due to the delay of the manufacturer of the power stage of the system (Popek-Elektronik). The RF team is permanently monitoring the progress of the manufacturing work, ensuring the highest diligence in the performance of the power stages.

However, the delays in commissioning the new RF system impose a large disturbance on the cycle of cyclotron work and, as a result, its availability for experiments. We expect that this delayed project will eventually be implemented in 2019.

Power infrastructure

In addition to the normal maintenance resulting from wear and tear, the power infrastructure is constantly being refitted and upgraded. A series of infrastructure modernizations was conducted in 2016–2018 as an adaptation to the new RF system installation.

A.3 Status of the ECRIS test stand at HIL

Ł. Standyło, K. Sudlitz, J. Choiński, P. Gmaj

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The interaction of an ion beam with plasma is an important aspect of the charge breeding process. The term "charge breeding" refers to the boosting of singly charged ions to higher charge-states. Studies on ECR ion source (ECRIS) charge breeders have focused on maximizing the global efficiency of the charge breeding process and optimizing the breeding efficiency of the desired charge state [1–3]. Charge breeding involves thermalization of the injected 1^+ ions with the plasma ions in ion–ion collisions, subsequent ionization by electron impact and extraction of the n^+ ions. Experiments with a $^7Li^{+1}$ beam injected into ECRIS operating on an argon buffer gas have been performed. The experimental setup consists of the ECR [4] ion source connected with the 1^+ ion source via a special injection system (see Fig. 1) and the electromagnet analyser connected to a diagnostic chamber and forming a mass spectrometer. The extraction system consists of three-electrode Einzel lenses [5]. The ECRIS is powered with a 300 Watt, 10 GHz frequency generator.

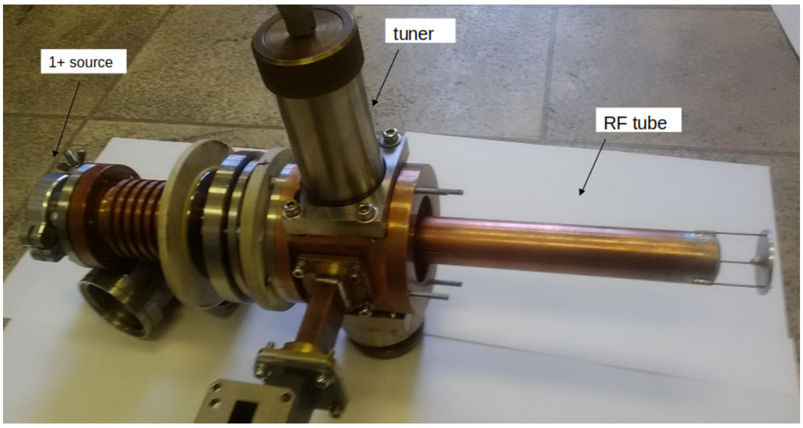

Figure 1: Primary beam injection system. Inside the RF tube (coaxial extension of the waveguide) a puller shaped electrode (tube) is mounted for extraction and defocusing of the 1^+ beam from the thermal lithium 1^+ ion source.

The optical behavior of the Li^{+1} beam when passing through the chamber was tested initially without plasma. The stable 1^+ beam current was around 0.5 µA (the maximum current was around 3 µA). The thermal 1^+ ion source consists of a tungsten filament, a cathode and a Wehnelt cap [6]. The average power consumption was around 14 W. Tests of the 1^+ beam transmission through the ECR magnetic trap with and without magnetic field were conducted. The beam current was optimized on the profiler by changing the magnetic field and the source potential. The potential for the 1^+ ion source was set to 15 kV. Primary beam measured after the analyzing magnet without plasma consisted of lithium isotopes only – ^6Li (7%) and ^7Li (93%).

Intensity measurements of the primary Li^{+1} beam passing through the Ar plasma were conducted. The preliminary results of 1^+ beam capture by the ECR plasma showed the expected effect. The primary beam was captured by the ECR plasma when a proper plasma density was obtained while adjusting the microwave power and buffer gas pressure. When there is no plasma, the primary beam passes through the chamber without any effect –

there is no interaction with the buffer gas molecules. The use of lithium as an ion beam is convenient for these initial tests, but to determine the capture efficiency more precisely it is necessary to perform measurements for heavier elements. Final measurements are still under preparation. In most cases the intensity of the primary beam decreased with microwave power increase, while maintaining constant pressure. As an example, for a gas pressure of $2.7{\cdot}10^{-6}$ mbar, the primary beam current of ^{7}Li decreased from 0.5 µA for 18 W to 0.32 µA for 180 W – Fig. 2. Instead, the secondary beam current of ^{7}Li with the same gas pressure behaved in the opposite way and with increasing power the extracted current was higher. Changing the plasma density with reduction of the operating gas resulted in a decrease in the secondary beam (Fig. 3). With a lower plasma density (around $8{\cdot}10^{-7}$ mbar with 40 W) the primary 1^{+} beam passed through without any change. To distinguish the thermalized secondary beam of lithium from other plasma components the primary beam was operated in chopping mode. Cutting the beam was realised by potential difference modulation between the 1^{+} source and the Wehnelt cap. The beam was chopped to 30% of the total Li^{+1} beam current with a frequency from 5 Hz to 5 kHz. The rise time of the square-like signal was changed from 10 ms to 10 ns. As a result, the secondary beam, chopped with the same frequency could be measured, thus allowing us to distinguish the thermalized secondary beam.

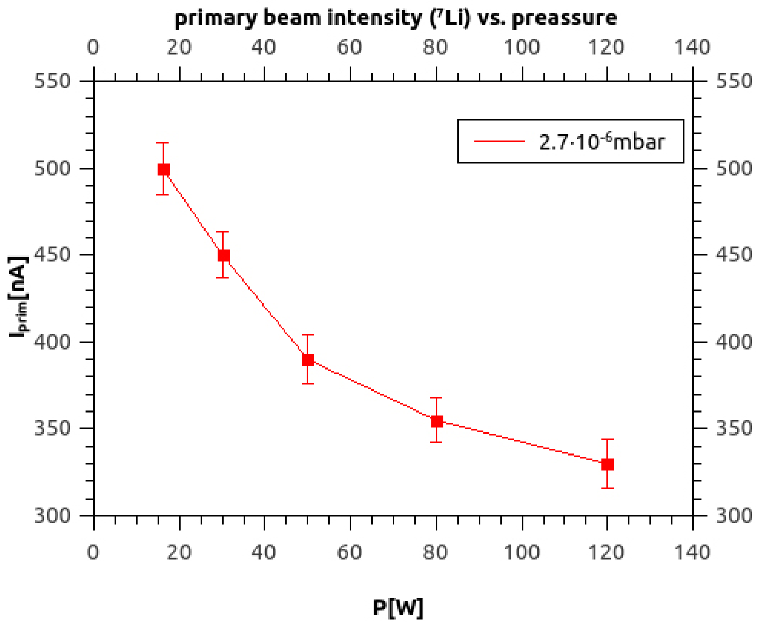

Figure 2: Primary beam intensity dependance on increasing microwave power. Buffer gas pressure was constant during the measurement.

By measuring the intensity of the primary beam and the extracted n^{+} we will study the effectiveness of the beam interaction with the plasma. The primary beam can be a good diagnostic tool for the ECR plasma. Comparing the 1^{+} beam capture efficiency for different sets of plasma conditions will give directions for further investigations. The results obtained will increase knowledge on the thermalisation process in the ECR plasma. They will ultimately show whether the use of a deflector that deflects the injected beam allows the effect of its thermalization to be increased, and hence, in increase in the ECRIS charge breeder efficiency.

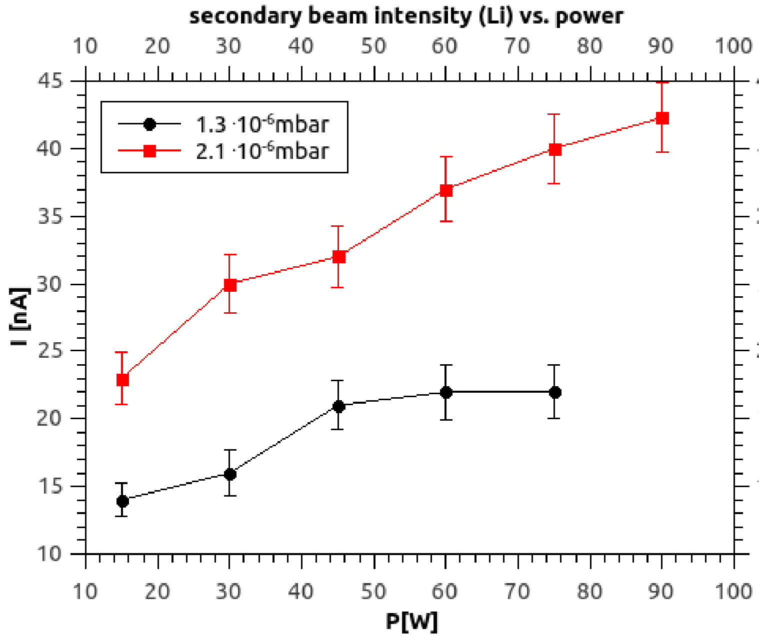

Figure 3: Thermalized secondary beam intensity dependance on increasing power and different buffer gas pressures.

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A.4 The project for replacement of the old RF generators with new ones

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During 2018 we maintained intensive contact with the power stages manufacturer POPEK-ELEKTRONIK. The HIL RF team visited the POPEK-ELEKTRONIK premises several times. Most of these visits were connected not only with control of the manufacturing process but also with training in the service of the new power stages. This training is part of the contract. On November 8 – 10, 2018 the FAT was carried out.

The test proved correct operation of the amplifier with all attached power supplies and cooling systems. The experience gained during the FAT indicated to the manufacturer a few places where some improvement needed to be done to the make whole system more reliable during longtime operation.

In December the first unit arrived at HIL. Laboratory technical staff prepared a place with all connections for its installation (see Figure 1). Final assembling will take place in the first part of 2019.

Figure 1: The power stage of the RF generator during the FAT.

The replacement of old RF generators with new ones is financed by the Ministry of Science and Higher Education, agreement no 589/FNiTP/540/2011.

A.5 Vacuum meters

M. Sobolewski, J. Miszczak, K. Olejarczyk, Z. Kruszyński

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Vacuum is maintained in the Warsaw Cyclotron (the cyclotron itself, the beam-lines, and the experimental stations) by ten vacuum pumping stations. The pumps are of different types (diffusion, turbo, cryogenic), by different manufactures, and of different ages. The newest pumping stations have automatic measurement systems built in (for both low and high vacuum), however the older ones lack such capabilities. In order to provide the cyclotron operators with information on the vacuum, six vacuum meters have been developed and built. The meters make use of common ion gauges which can be bought cheaply as new old stock. It is planned to integrate the vacuum readout into a new computerized cyclotron control system (now in the development stage).

A.6 Polish Workshop on the Acceleration and Applications of Heavy Ions

U. Kaźmierczak[1], J. Samorajczyk-Pyśk[1], T. Abraham[1], M. Filipek[1,2], P. Gmaj[1], K. Kilian[1], M. Komorowska[1,3], J. Kowalska[1], P.J. Napiorkowski[1], M. Palacz[1], M. Paluch-Ferszt[1], L. Pieńkowski[4], K. Rusek[1], M. Saxena[1], A. Sentkowska[1], A. Stolarz[1], R. Tańczyk[1], A. Trzcińska[1], M. Wolińska-Cichocka[1], K. Wrzosek-Lipska[1]

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3) IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France

4) AGH University of Science and Technology, Kraków, Poland

The 14th edition of the Polish Workshop on the Acceleration and Applications of Heavy Ions was organised at HIL in October, 2018. It was addressed to students of first cycle studies interested in nuclear physics, and offered a unique opportunity to gain experience in methods of data acquisition and analysis and charged particle and gamma-ray detection techniques. Medical applications of nuclear physics were also included in the program of the Workshop.

This time 14 students attended the lectures and the practical training (see Fig. 1). There were 4 students from Warsaw University of Technology, 4 from the University of Zielona Góra, 2 from the University of Warsaw, 2 from the Silesian University in Katowice, and 1 each from Wroclaw University of Science and Technology and the Cardinal Stefan Wyszyński University in Warsaw.

In 2018, the program of lectures was as follows:

- HIL in a nutshell (K. Rusek);
- Radioprotection at the HIL (R. Tańczyk);
- Targets for research in nuclear physics (A. Stolarz);
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian);

- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (P. Napiorkowski);
- Nuclear weapons in the fight against wine counterfeiters (P. Napiorkowski);
- Nuclear reactions (K. Rusek);
- Several scenarios of the fate of nuclear energy in Poland (L. Pieńkowski).

Students took part in the following experimental tasks:

- Rutherford Scattering;
- Gamma spectroscopy with the EAGLE multidetector setup;
- Target production and thickness measurements;
- Measurement of ^{137}Cs activity in environmental samples;
- Gamma camera — a medical imaging tool.

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

Figure 1: Participants in the 14th Polish Workshop on Acceleration and Applications of Heavy Ions (photo. M. Komorowska).

A.7 "You don't need to be a nuclear physicist — to understand nuclear science" — a lesson for the "academic class" in the Jan Zamoyski XVIII General Junior High School

M. Saxena[1], M. Feigel[2], P.J. Napiorkowski[1], A. Pawłowska[2]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Jan Zamoyski XVIII General Junior High School, Warsaw, Poland

In 2018 the Jan Zamoyski XVIII General Junior High School and the Heavy Ion Laboratory launched a new program "academic class". Within the framework of the project the school and the university offer students an enhanced scope of educational events in physics. It is proposed that the students will attend lectures devoted to recent achievements in science and participle in experiments inspired by the physics activities performed in the Laboratory.

As a one of the first activities of its kind within the program, class IB had a unique opportunity to take part in a lecture on the basics of nuclear physics, conducted in English by Dr. Mansi Saxena. Dr. Saxena, a Marie Skłodowska-Curie Fellow at the Heavy Ion Laboratory, presented to the students the historical beginnings of this field of physics. She also highlighted various basic concepts and interesting phenomena in nuclear physics. The title of the presentation — "You don't need to be a nuclear physicist — to understand nuclear science" encouraged many students to ask questions. There was no language barrier — which demonstrates the good performance of the English language education in Polish schools.

As the participants later reported, a particularly interesting part of the presentation was a comparison of nuclear shapes to different fruits.

The stay of Dr Saxena in Poland was possible thanks to funds from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 665778 via the Polish National Science Centre within the programme POLONEZ-1.

Figure 1: Dr Mansi Saxena presenting a talk on the basics of nuclear physics.

A.8 ENSAR2-NUPIA Workshop "Nuclear Physics Research-Technology coaction"

T.J. Krawczyk, M. Paluch-Ferszt, J. Matuszczak, P.J. Napiorkowski

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The University of Warsaw organized the workshop "Nuclear Physics Research-Technology Coaction" on 11–12 October 2018 at the Heavy Ion Laboratory. This was a space for research laboratories and industry to meet.

Keynote speakers from nuclear-physics research centers and technology companies presented the current state of the art in research techniques and proposed commercial solutions. Achievements in both fields were presented to attract prospective customers and collaborators. During the workshop, directions for improvement in methods of technology transfer between laboratories and industry were discussed.

Twenty speakers participated in the event. The workshop welcomed 40 participants from 8 countries: Czech Republic, France, Italy, Poland, Russia, Spain, Germany, and Finland (see Fig. 1).

Figure 1: Participants in the "Nuclear Physics Research-Technology coaction" ENSAR2-NUPIA Workshop (photo. M. Komorowska).

During the workshop an exhibition by selected enterprises was also organized. The workshop allowed the presentation of recent achievements and challenges in the following areas:

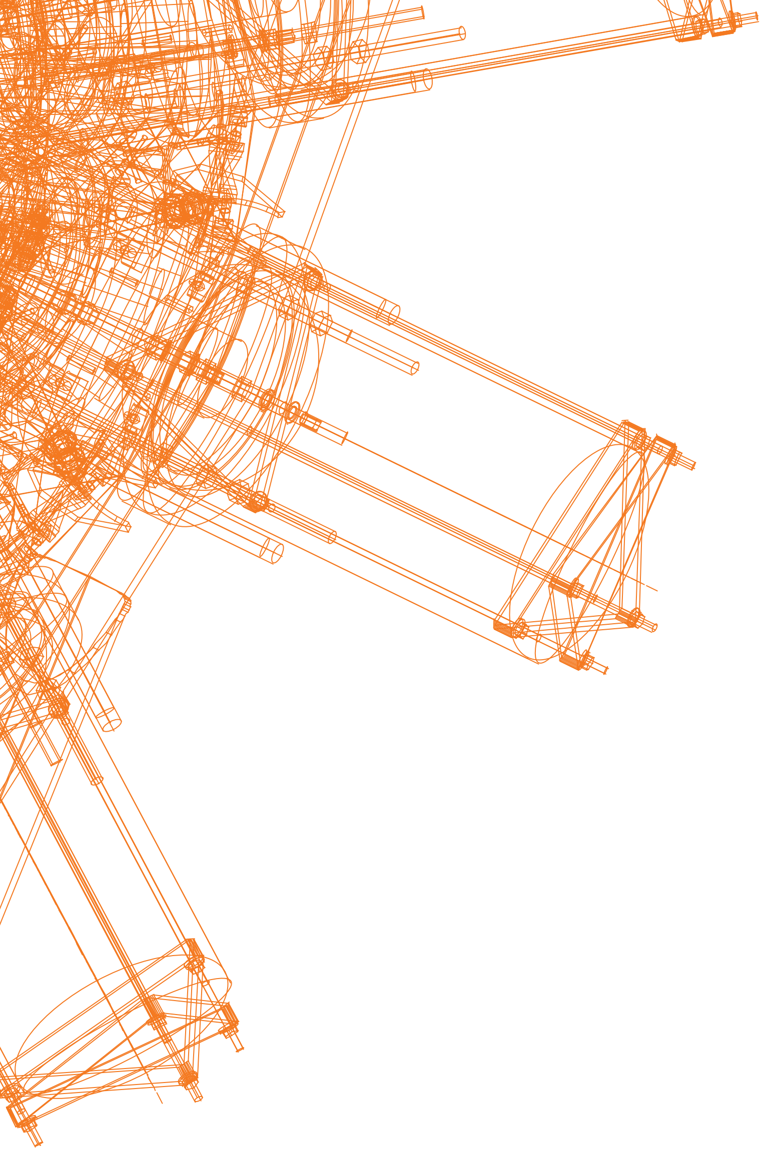
- medicine;
- radiopharmaceutical production;
- detectors and nuclear instrumentation;
- computation and information technology (big data applications, data analysis);

- energy and environmental technologies;
- radiation;
- lasers;
- digital machine tools and 3D printing services;
- metallurgy;
- collaborative research, innovation networks, technology transfer.

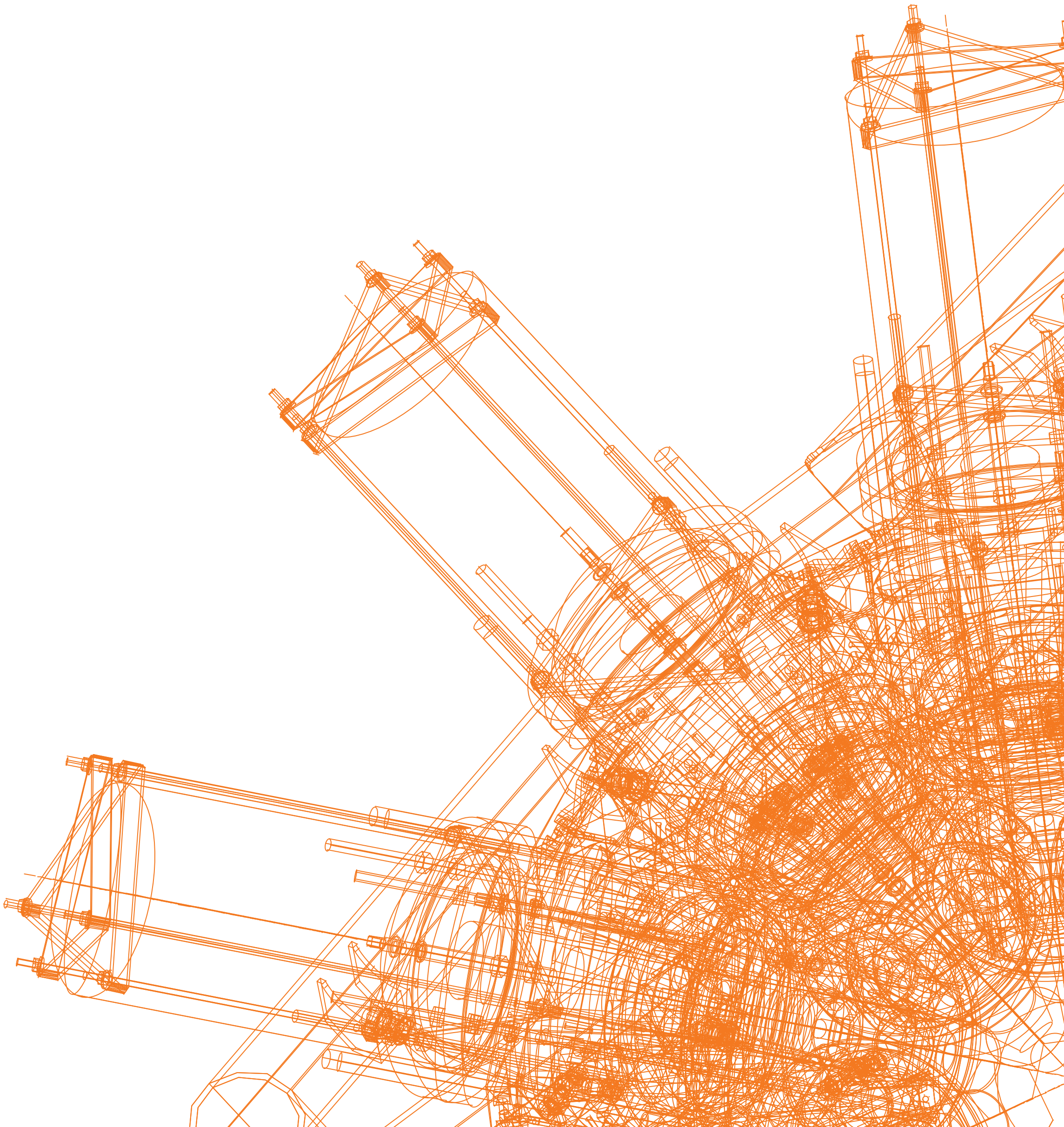
A brokerage event meeting was organized simultaneously by the Enterprise Europe Network (EEN) in the same place, which brought more companies to both workshops. The promotion of the NUPIA workshop and EEN brokerage meetings was made through the NUPIA website and the Enterprise Europe Network website. There were 34 meetings at the brokerage (EEN) event "Nuclear Physics Innovation".

A promotional movie from the event was prepared and added to the highlights of ENSAR2: `http://www.ensarfp7.eu/`.

The next workshop, "Nuclear Physics Research-Technology Coaction 2" organized under Subtask 2.1 is scheduled for November 6–8, 2019 in Sevilla.



Part B
Research for medical and biological applications



B.1 Research on production of medically interesting ^{135}La with a proton beam

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The radioisotope ^{135}La is an Auger electron emitter suitable for targeted internal radiotherapy. It has a half-life of 18.9 h and decays by electron capture primarily to the ground state of the stable ^{135}Ba. A small proportion of decays populating the 480.5 keV state contribute to a 1.5 % intensity γ-line.

^{135}La can be produced in various nuclear reactions, most importantly: ^{135}Ba(p,n), ^{136}Ba(p,2n), ^{139}La(p,x), ^{134}Ba(d,n), ^{135}Ba(d,2n) and ^{133}Cs(α,2n). Although the excitation functions are well measured, relatively little information is available with regard to possible large-scale production. A promising and accessible method leads via the proton bombardment of barium targets. It was already investigated in Ref. [1] via the ^{nat}Ba(p,x) reaction with the use of metallic target and in Ref. [2] via the ^{135}Ba(p,n) reaction on enriched $^{135}BaCO_3$. In our work we decided to verify the feasibility of ^{135}La production with $^{nat}BaCO_3$ and investigate the radioactive impurities.

In 2018 a pilot study using the PETtrace irradiation station at HIL [3] was performed. The target was prepared by pressing the $^{nat}BaCO_3$ powder into a pellet with a thickness of 430 mg/cm^2. A 10-minute irradiation with a 9.4 µA proton beam of 15 MeV produced 9.6(2) MBq of ^{135}La with radioisotopic contaminants such as ^{132}La (4 %) and ^{132}Cs (0.009 %). The measured TTY of ^{135}La was 6.1(1) MBq/µAh (see Fig. 1) which was found to be inconsistent with calculations based on the TENDL-2017 cross-section.

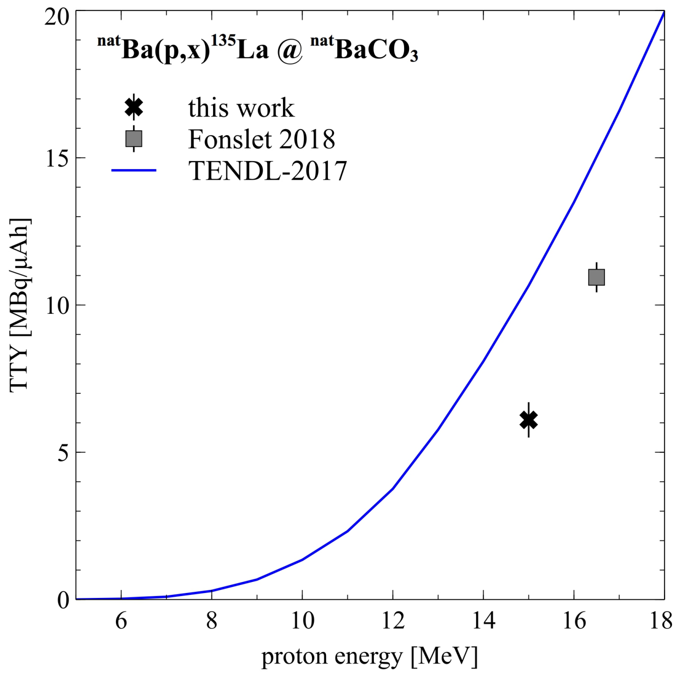

Figure 1: Thick target yields of ^{135}La production with proton projectile. The experimental point from Fonslet *et al.* [1] was recalculated from ^{nat}Ba to $^{nat}BaCO_3$ target.

We plan further irradiations of $^{nat}BaCO_3$ at different energies to verify our results.

This work is partially supported by the European Commission Horizon 2020 program, proposal 654002 "ENSAR2" and NCBiR grant PBS3/A9/28/2015.

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B.2 An external, well cooled target holder for the PETtrace cyclotron suitable for irradiation of powder targets

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The dual beam proton/deuteron PETtrace cyclotron is mainly used for commercial production of fluorine F-18. Therefore, the targets for F-18 production are constantly highly radioactive, dramatically restricting "free-entry" to the cyclotron cave by staff for maintenance or preparation of irradiations carried out with the standalone external target system. The system was designed considering irradiation of both metallic and powder targets. It was designed and built within the framework 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 (finished in 2018). The design is protected by RP patent No. 227402.

For safety reasons it was, however, necessary to upgrade some parts of the station taking into account safety conditions for operational staff and to adapt it to the specific requirements of calcium powder targets.

Currently, our beam line consists of: a drift tube with a total length of 3.4 m, two sets of steering magnets made of permanent magnets, one quadrupole doublet and a four-sector collimator, plus the shielding, a concrete wall of thickness 0.25 m (its specific weight is 3300 kg/m^3). This improved substantially the safety conditions for the staff, see Figure 1 below.

The beam line beyond the concrete wall is equipped with the standalone external target system. A vacuum turbo pump attached to the control box of the external target system and the beam line allows a value of $4{\cdot}10^{-7}$ mbar of static vacuum to be reached.

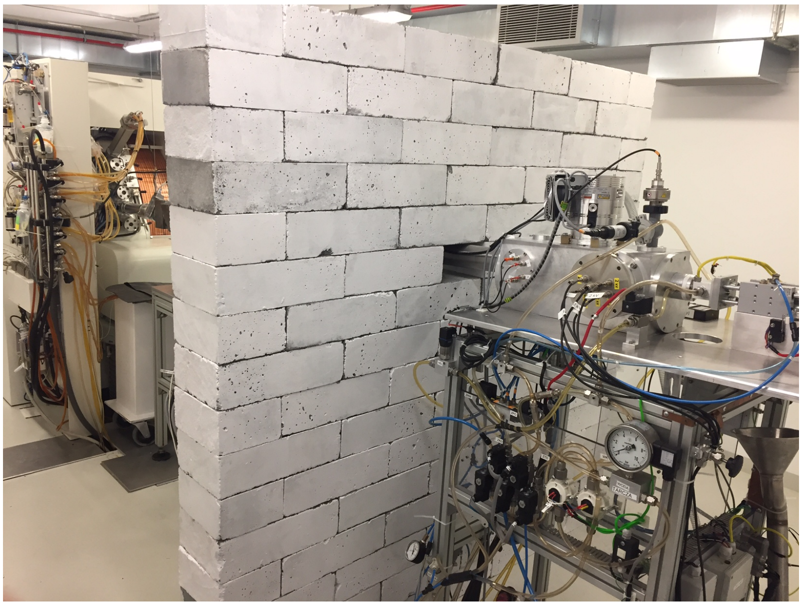

Figure 1: A view of the standalone external target system.

The beam transport efficiency to a 12 mm target reaches above 96%.

The external target system is equipped with a fully remotely controlled robot delivering the chosen target from a carousel to the head of the target system. The carousel can hold up to 8 targets. The robot target delivering is controlled via a dedicated computer code. On the main screen (see Figure 2) one can choose the control panel of the robot where the arm of the robot and carousel are depicted (see Figure 3).

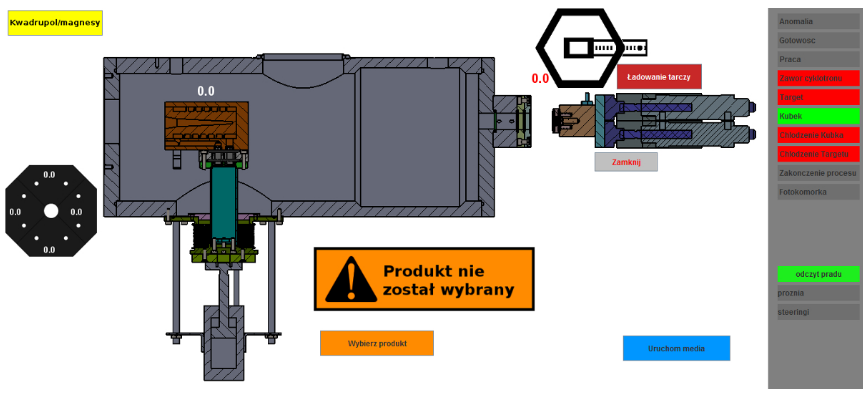

Figure 2: The main screen of the control panel.

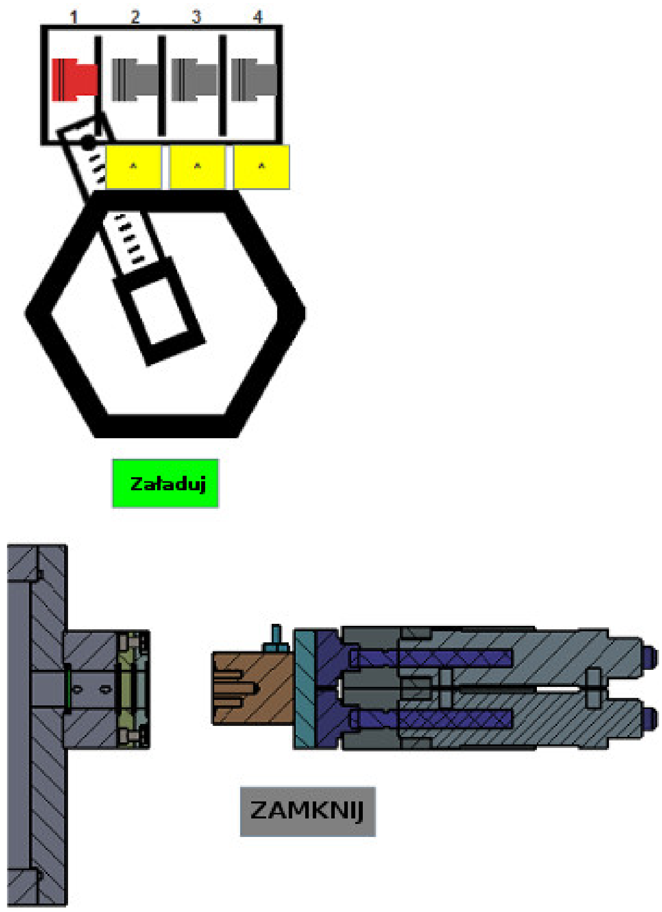

Figure 3: The control panel of the robot.

The operator decides which target will be delivered to the head of the target system and then starts movement of the robot arm. After irradiation the target falls into a lead container and is evacuated from the cyclotron on a remotely controlled trolley, see Figure 4.

Figure 4: An irradiated target inside a lead container placed on the remotely controlled trolley.

Last year we performed several dozen irradiations of targets for groups collaborating with us within the framework of the "PET-SKAND" consortium.

B.3 Reconstruction of the excitation function and production of the medically interesting ^{44}Sc

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The scandium radioisotopes offer the possibility of a variety of applications in the nuclear medicine field. Both positron emitters ^{43}Sc and ^{44}Sc are promising PET isotopes (respectively: $T_{1/2}$ = 3.89 h and 3.97 h, β+ branching = 88% and 95%, max. β+ energy = 1.20 MeV and 1.47 MeV). Additionally, ^{44m}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).

Recently we have reported on TTY (Thick Target Yield) and radioactive impurities for the production of medical scandium isotopes with the use of proton and deuteron beams and $CaCO_3$ targets [1]. Although our studies are completed, we continue the production of ^{44}Sc in amounts suitable for chemical and in-vivo studies carried out simultaneously at HIL UW [2], the Biological and Chemical Research Centre UW and the Institute of Nuclear Chemistry and Technology. Several 10 min irradiations of nat$CaCO_3$ are performed with a 10 µA proton beam delivered by the PETtrace machine [3] to produce around 1 MBq of ^{44}Sc (with 1% of radioactive impurities).

We have also used the measured TTY for ^{44}Sc production at different energies to reconstruct the excitation function of the ^{44}Ca(p,n)^{44}Sc reaction. To achieve this, we decided to fit the experimental TTY points with a formula that represents well the TTY curve:

$$TTY_{fit}(E) = \frac{ac}{2}\left(\sqrt{\pi}(b-E_{thr})\,\text{erf}\left\{\frac{E-b}{a}\right\} - a\exp\frac{-(E-b)^2}{a^2}\right) + \frac{a^2c}{2}\exp\frac{-(b-E_{thr})^2}{a^2}$$

where: E – energy of the projectile; E_{thr} – reaction threshold; a, b, c – fitting parameters. Its derivative is a modified q-Weibull distribution [4] suitable to reflect the preliminary shape of the excitation function:

$$\frac{dTTY_{fit}}{dE}[\frac{MBq}{\mu Ah}] = max[0; c(E-E_{thr})exp\frac{-(E-b)^2}{a^2}]$$

Given the fit, we estimated the cross-sections from the relation:

$$\sigma(E) = \frac{\tau[h]Ze[C]m[u]}{N_A H}\cdot\frac{dTTY_{fit}}{dE}(E)[\frac{MBq}{\mu Ah}]\cdot\frac{dE}{dx}(E)[\frac{MeV}{mg/cm^2}]\cdot 10^{42}$$

The result of the reconstructed ^{44}Ca(p,n)^{44}Sc excitation function (see Fig. 1) shows agreement with the cross-section data available in the literature. Our reconstruction method is also consistent with a method proposed earlier [5] but does not require the approximation of constant stopping-power in simulated target layers and is easier to apply in any numerical software. Therefore, we believe that our algorithm can be easily applied to fast and straight-forward estimation of the excitation function in cases where the direct cross-section measurement is not possible.

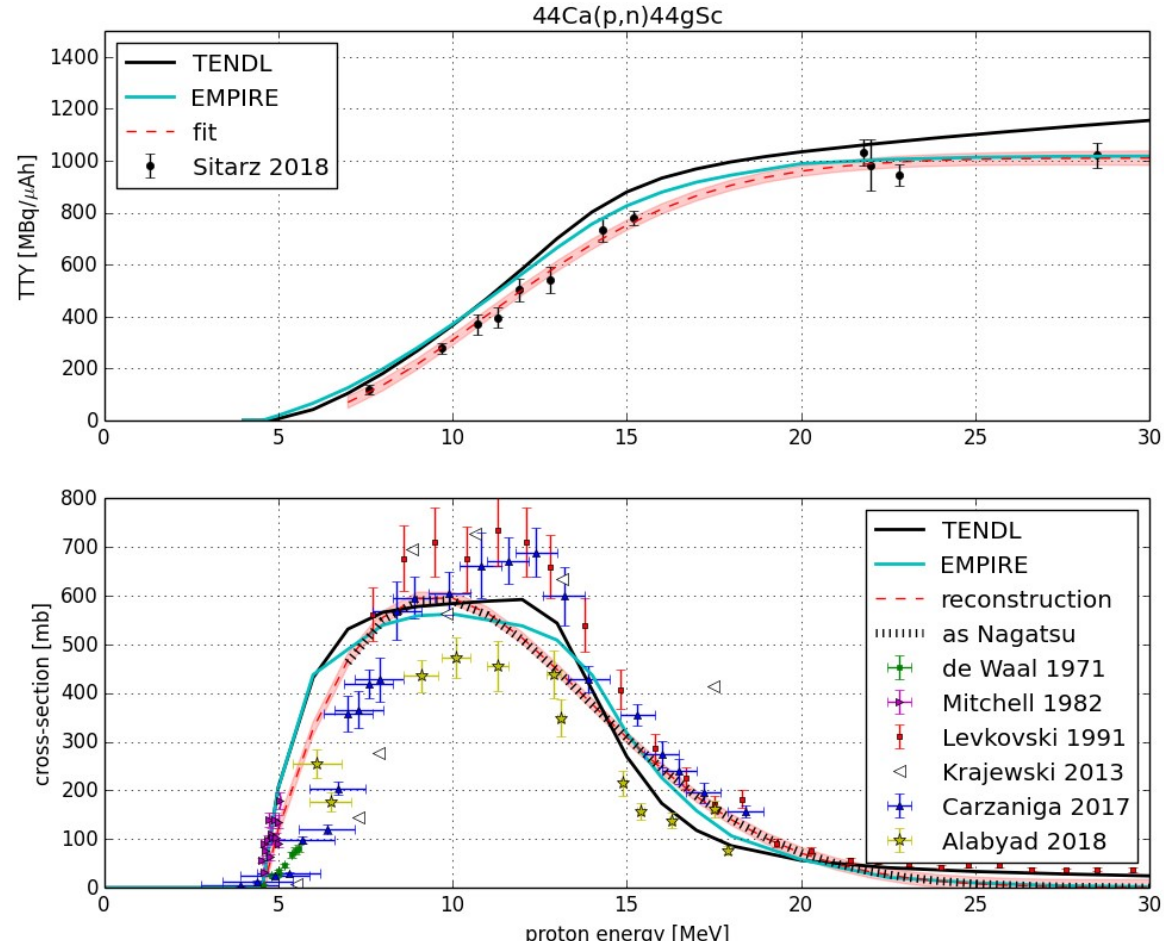

Figure 1: Reconstruction of the ^{44}Ca(p,n)^{44}Sc cross-section (lower part) based on a fit to the experimental TTY data on $^{44}CaCO_3$ enriched to 94.8% ^{44}Ca (upper part). Here: E_{thr} = 4.54 MeV, a = 8.8(6) MeV, b = 4.8(8) MeV, c = 24.5(1.0) MBq(μAh)$^{-1}$(MeV)$^{-2}$, χ^2/dof = 0.57.

This work is partially supported by the European Commission Horizon 2020 program, proposal 654002 “ENSAR2” and NCBiR grant PBS3/A9/28/2015. It has also been supported by a grant from the French National Agency for Research called “Investissements d’Avenir”, Equipex Arronax-Plus noANR-11-EQPX-0004 and Labex IRON noANR-11-LABX-18-01. The support of a French Government PhD scholarship is also acknowledged.

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B.4 Chemical form of calcium targets used for the production of Sc radioisotopes in reactions with p, d or α projectiles

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Scandium isotopes may be produced via reactions induced by p, d or α projectiles using calcium or titanium as a target nucleus. Comparison of the cross sections for reactions of both nuclei (Tab. 1) shows that reactions with Ca nuclei promise much higher production efficiency.

Table 1: Examples of cross sections for the production of ^{44}Sc and ^{44g}Sc in reactions of Ca or Ti with p, d or α [1].

Isotope produced	Calcium isotope cross section [mb]/ (beam energy [MeV])			Titanium isotope cross section [mb]/ (beam energy [MeV])	
	p	d	α	p	d
^{43}Sc	^{43}Ca 400/(9) ^{44}Ca 200/(24)	^{42}Ca 270/(5)	^{40}Ca 700/(15)	^{46}Ti 60/(15); 80/(60) ^{47}Ti 70/(25)	
^{43g}Sc	^{44}Ca 700/(10)	^{43}Ca 380/(5)	^{42}Ca 750/(25) ^{43}Ca 600/(35)	^{46}Ti 240/(35) ^{47}Ti 70/(15) ^{48}Ti 80/(25)	^{46}Ti 110/(10); 310/(75) ^{47}Ti 140/(22); 200/(100)

Chemical form of the target

Production of Sc medical radioisotopes in reactions with Ca targets can be carried out with unprocessed enriched material, i.e. with calcium carbonate ($CaCO_3$), the chemical form of the enriched Ca isotopes available commercially, or with material converted into either calcium oxide (CaO) or metal (Ca). Work with each target form has advantages and drawbacks. Both chemical compounds (carbonate and oxide) are the thermal insulators which causes problems in heat dissipation from the irradiated target. This problem can be eliminated by using metallic Ca but conversion of $CaCO_3$ into Ca is a time consuming process with limited efficiency. Also, additional impurities originating from the reduction process may be introduced into the final product. Therefore, taking these pros and cons into account and considering the level of activity produced within the same period of irradiation the most convenient is to work with targets made of CaO.

Conversion of $CaCO_3$ into CaO is an easy process. It can be done either by heating the oxide in a flow of an inert gas [2] or in vacuo using resistant heating. The second method allows instant/online control of the decomposition process, via controlling the vacuum level, and cooling down the produced CaO in the air free atmosphere. Performing the conversion in a vessel/crucible with a perforated cover (Fig. 1) and venting-in the vacuum apparatus, after completion of the procedure, with inert gas allows the transfer of the produced CaO to a glove box (for the manipulations needed to produce the final target e.g. pressing the pellet, encapsulating in a container, etc.) without additional precautions. The perforated cover slows down the gas exchange so that when the crucible filled with inert gas is taken into the ambient atmosphere it protects the CaO against contact with the air.

Figure 1: Crucible with perforated cover used for calcium carbonate conversion into oxide by resistant heating in vacuo.

In addition, decreasing the oxygen content in the target results in a significant decrease of the side radioactivity in the irradiation area related to the production of short lived ^{13}N in ^{16}O(p,x) or ^{16}O(d,x) reactions. The oxide targets prepared as inserts in a graphite bed as described in [3] survived 45 min of irradiation with a 15 µA proton beam very well. There were no signs of thermal damage to the target. The irradiation conditions are sufficient to produce $\sim$ 8 GBq of ^{44g}Sc irradiating $^{44}CaCO_3$ enriched up to 99.2%. Taking into account the activity losses during the isotope separation and labelling process, such an amount of ^{44}Sc should be enough for diagnosing $\sim$ 75 patients (an estimate based on clinical studies for ^{44}Sc [4] where 50.5 MBq of ^{44}Sc-PSMA-617 were required for a single diagnosis).

Studies of Sc radioisotope production were partly supported by the NCBiR (National Centre for Research and Development), grant no. DZP/PBS3/2319/2014 and partly performed within the framework of the EU HORIZON 2020 project RIA-ENSAR2.

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B.5 Changes in the properties of superconducting 2G HTS tapes under the influence of ^{12}C ions.

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A superconductor is a material which, when cooled below a certain temperature, called the critical temperature, T_c, has exactly zero electrical resistance. This amazing property of a superconductor can be maintained if the current density flowing through the superconducting material is smaller than the critical current density and also any external magnetic field is lower than the critical one. The critical temperature T_c, critical current density J_c and critical magnetic field H_c are the most basic characteristics of the superconducting material. Superconductors can be manufactured as bulk or thin film materials [1].

Second generation (2G), high temperature superconductor tapes (HTS) enable the generation of strong magnetic fields that do not require the use of a high-power direct current power supply, just like typical electromagnets. The tape is 12 mm wide and has the thickness of a sheet of paper. It can conduct up to 600 A at a temperature of 77 K before the superconducting state is destroyed [2].

The $REBa_2Cu_3O_{7-x}$ superconductor tape, also called "(RE)BCO", is produced by ion beam-assisted deposition (IBAD) and metal-organic chemical vapor deposition (MOCVD) [3]. The tape structure is shown in Fig. 1.

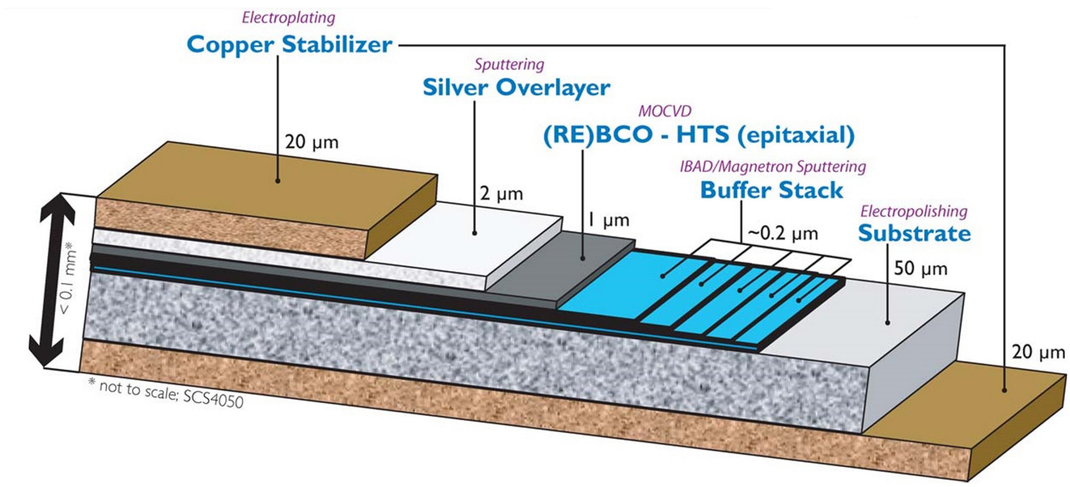

Figure 1: Illustrative drawing of the (RE)BCO tape structure [4].

The small dimensions and weight of the tape are very promising features for the construction of magnetic shields protecting crews of spacecraft against cosmic radiation [5]. The astronauts' exposure to cosmic rays is one of the most dangerous factors threatening life and health in long manned missions [6, 7]. Cosmic radiaton can also cause damage to the equipment of a spaceship. Therefore, it is necessary to examine how cosmic radiation changes or destroys the superconducting properties of HTS 2G tapes. As a preliminary study of this topic we irradiated samples of 2G HTS tapes with $^{12}C^{+3}$ heavy ions with a minimum depth of 40 µm in the tape material. In the ideal case the tape should be irradiated with types and energies of ions which correspond to real cosmic radiation like the solar wind and high-energy radiation originating from outside the Solar System [8].

The rectangular shaped samples of 2G HTS tapes were 10 mm long and had a width of 6 mm. Two samples were inserted into the irradiation chamber in one experimental run. The samples were mounted on a Carousel and inserted into the vacuum chamber. The Carousel with tapes is shown in Fig. 2. Irradiation used the maximum kinetic energy of the ions and the maximum fluence (number of particles per square cm per second). The time of irradiation (dose rate) was about 72 hours to irradiate a sample with 10^{15} ions/cm^2. The tape was oriented in such a way that the superconducting layer was towards the ion source.

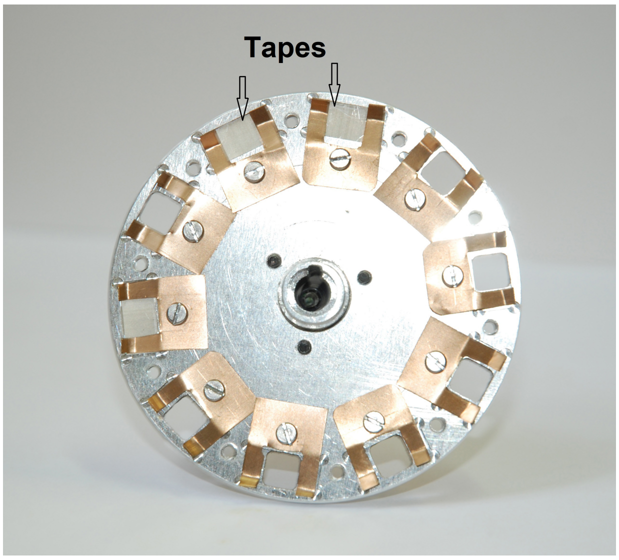

Figure 2: Two samples of 2G HTS mounted on the Carousel.

In cooperation with the AGH University of Science and Technology in Cracow the superconducting properties of the irradiated samples will be studied by AC and DC magnetic susceptibility and magneto-transport measurements. The superconducting parameters like critical temperatures T_c, T_{c0} and critical current density J_c will be evaluated [9, 10]. The microstructure of the tapes and structural damage resulting from irradiation will be examined by scanning electron microscopy.

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B.6 Comparative study of different solvents for the extraction of polyphenols from green tea

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In recent years, ionic liquid solvents (ILs), a class of chemicals composed entirely of an asymmetric large-size organic cation with an anion of weak coordination properties, have received explosive interest as alternatives to traditional organic solvents [1]. Their unique physicochemical properties include very low to negligible vapor pressure, high thermal stability and conductivity, as well as those which are tunable by proper cation-anion combinations, such as density, viscosity, hydrophobicity, polarity and acid-base properties. Among all ILs, alkylimidazolium cations combined with Cl^-, Br^-, $BF4^-$ or $PF6^-$ counter ions are the most used as extractants, in addition to separation of phenolic acids from different plant samples [2, 3]. ILs can interact with bioactive compounds via hydrogen bonding, $\pi - \pi$ interactions, ion-dipole, ion-induced dipole and permanent dipole interactions as well as dispersion forces [4]. Thus, their solvent character can be adjusted by combining particular cation-anion pairs.

The objective of this study was to evaluate the efficiency of extraction of polyhenols from green tea (Camellia sinensis) leaves using ILs. Organic solvents (ethanol-water mixture and ethyl acetate) and two imidazolium-based ionic liquids were used for comparison. The extracts from each plant were evaluated for the determination of total phenolic content by Folin-Ciocalteu assay.

The yield of polyphenol extraction from green tea varies with the solvent used, the highest content being obtained with 60% EtOH aqueous solution. The lowest yield of extraction was obtained using ethyl acetate. Extractability of the solvent mainly depends on the solubility of the compounds in the solvent system, the mass transfer kinetics of the product and the strength of the solute/matrix interactions. However, in the case of the extraction of polyphenols from green tea ILs are not competitive in relation to 60% ETOH aqueous solution.

The simple solid-liquid extraction process may require a long extraction time and usually higher yields and faster extraction of bioactive compounds can be achieved through ultrasound-assisted extraction (UAE). Ultrasonic time is generally regarded as a predominant factor influencing the efficiency of extraction, however, the use of UAE may have a significant impact on the stability of the extract [5]. The effect of ultrasonic time on the reducing capacity of plant material extracts is presented in Fig. 1. The results obtained for the maceration process without using UAE were included for comparison. The first observation that can be made is that the highest values for reducing power (the highest content of phenolic compounds) were recorded for the aqueous-ethanol solvent. The results for green tea were statistically similar ($p < 0.05$) for the maceration process as well as ultrasonic extraction in the studied time interval. The extracts with both ionic liquids exhibited lower results, which decreased with prolonged UAE for all plants.

These studies demonstrate that selection of the solvent as well as additional conditions of the extraction (e.g using UAE) must be optimized. In the case of green tea the best solvent for polyphenol extraction seems to be 60% ETOH aqueous solvent.

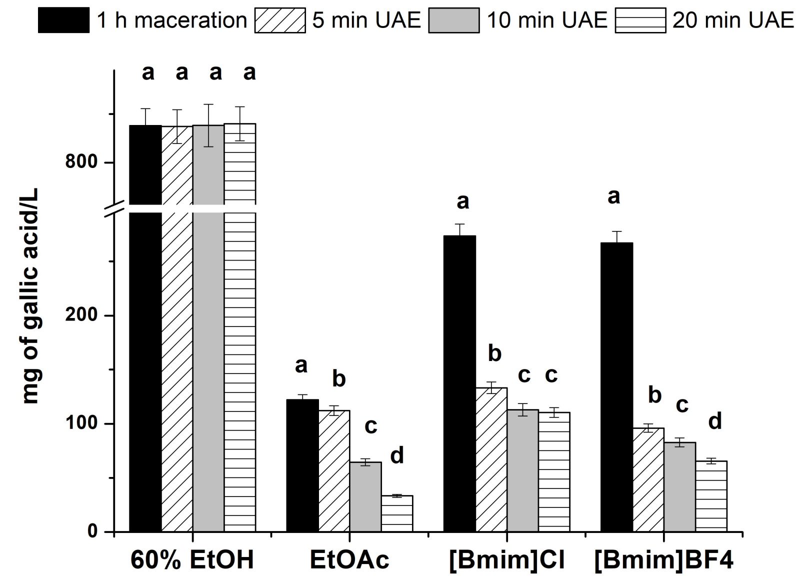

Figure 1: Effect of ultrasonic time on the antioxidant properties of the studied green tea extract obtained in FC assay. The results for maceration without UAE were included for comparison. Different letters for the same extractant indicate significant differences between samples ($p < 0.05$).

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B.7 Investigation of antioxidant activity of selenium compounds and their mixtures with other biologically active compounds

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Selenium is widely known as an essential nutrient, which is linked with some serious conditions like cancer, cardiovascular and inflammatory diseases [1]. It plays an important role in many metabolic pathways such as thyroid hormone metabolism and antioxidant defense systems [2]. Thus, selenium should be present in our diet. However, knowledge of the total selenium amount is not so important, but the content of an appropriate selenium species that is present in particular food or dietary supplements is crucial. Another point is that selenium present in e.g. a food sample can interact with other compounds present in the sample. One of the effects of these interactions is their impact on the antioxidant capacity of the samples. Such interactions can be divided into three different groups: synergistic effects [3–5], negative synergism [6, 7] and additive effects [8].

The current literature clearly states that there is no widely adopted "total antioxidant parameter" as a nutritional index available for the labeling of food or other biological samples because of the lack of standardized quantification methods [9]. There is a general consensus that antioxidant activity should be evaluated with several different methods, as they respond to and quantify different reaction mechanisms [10, 11]; therefore, this study included four different protocols, aiming at measuring the cupric reducing antioxidant capacity (CUPRAC assay), total polyphenols (Folin–Ciocalteu method), and antioxidant activity through 2,2-diphenyl-1-pikrylohydrazyl (DPPH) and hydrohyl radical scavenging radical activity (RSA) of the extracts [12]. The results indicate the mixed nature of interactions between polyphenolic compounds and various additives. For the case of quercetin, the kinetic curves with Se-methylselenocysteine and vitamin C are shown in Fig. 1. It can be seen that the addition of Se-methylselenocysteine inhibits quenching of the DPPH• radical, while the addition of ascorbic acid (vitamin C) to quercetin solution improved the scavenging of the radical. This selenoamino acid has no antioxidant properties in contrast to Vitamin C, which exhibits such properties.

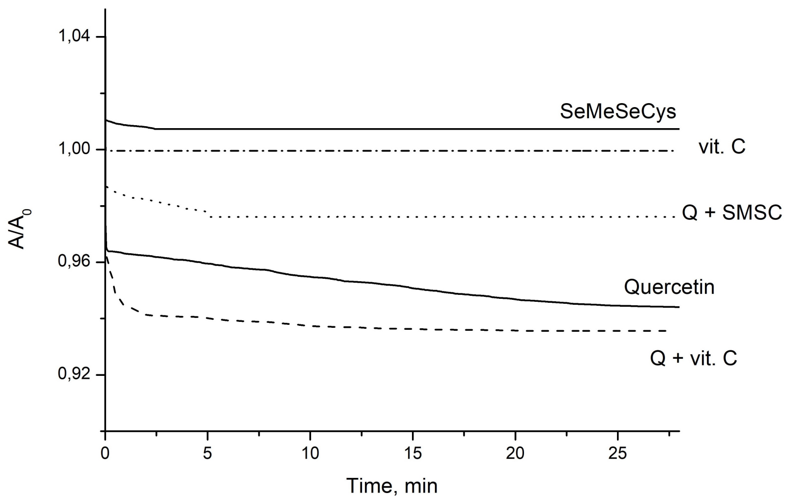

Figure 1: Kinetic curves of DPPH scavenged by the studied compounds.

These studies demonstrate the complex interactions between the different speciation forms of selenium and other biologically active components. These interactions may have a significant influence on the mixture's antioxidant activity. These results may be important from the point of view of supplementation with selenium. More studies are needed for a better description of the antioxidant interactions. Development of a procedure for the extraction of polyphenolic compounds, will facilitate their acquisition for further research, e.g. in the synthesis of radiopharmaceuticals.

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B.8 Characterization of Sc(III) complex with morin

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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 [1, 2].

The main goal of this work was to evaluate the methodology of the synthesis of the Sc (III)-morin complex. For this purpose UV-visible spectroscopy and mass spectrometry were employed. The UV-visible spectroscopy studies showed the direct interactions between morin and scandium. The morin adsorption band present at 359 nm was shifted to 410 nm. The stechiometric composition of the complex was evaluated using the molar ratio method (Yoe-Jones method). The results suggested a 1:2 molar ratio but this will be confirmed using mass spectrometry. The stability of the complex was also evaluated. The type of inorganic buffer as well as the ethanol content was studied. It turned out that the complex is stable in borate, ammonium and phosphate buffer; however, its solubility increases with increasing ethanol content. Figure 1 presents the UV spectra of the Sc-morin complex recorded in saline with different ethanol contents.

This research can be used in the development of new radiopharmaceuticals labeled with ^{44}Sc.

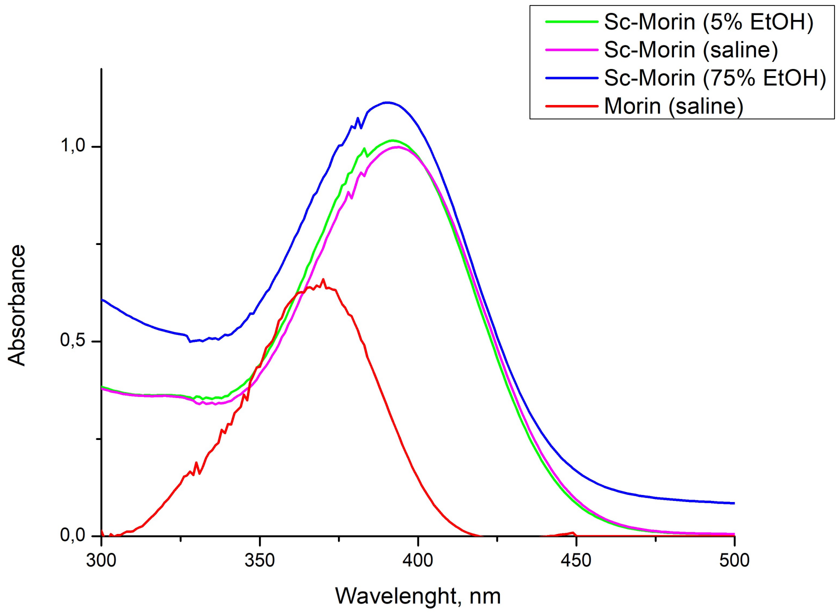

Figure 1: UV spectra of Sc-Morin complexes for different ethanol contents.

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B.9 Adsorption behavior of oxidized carbon nanotubes for separation of scandium(III) from aqueous solutions

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Since the applications of scandium in new technologies are growing, there are concerns about its accumulation in the environment following anthropogenic inputs. The exploitation of ores could create both local and regional environmental problems due to the deposition of large amounts of waste produced by the mining and metallurgy industries [1]. On the other hand β^+ decaying scandium isotopes (^{43,44}Sc and indirectly ^{44m}Sc) can be used in positron emission tomography (PET) diagnostics. Several carbon based materials have been proposed as sorbents for scandium preconcentration [2].

The present study investigates the adsorption behavior of oxidized carbon nanotubes (CNT-COOH) for separation of scandium(III) ions from aqueous solution and is a continuation of previous work [3].

Results for kinetics showed that the adsorption rate rapidly increased during the first 10 min and then, as the number of surface sites for sorption dropped, gradually tended to equilibrium and adsorption of Sc(III) was over 95% during the first 2 min, which indicated that the kinetics of adsorption equilibrium was very fast. In order to investigate the mechanism of Sc(III) adsorption four different kinetic models were applied to test the experimental data.

Table 1: Parameters of kinetic models fitted to experimental data.

Kinetic model	Equation	Parameters	
Pseudo-first order kinetic	$ln(q_e - q_t) = lnq_e - k_1 \cdot t$	k_1:	0.0643 min^{-1}
		R^2:	0.8488
Pseudo-second order kinetic	$t/q_t = 1/k^2 q_e^2 + (1/q_e) \cdot t$	k_2:	0.032 g mg^{-1} min
		R^2:	1.000
Elovich equation	$q_t = \beta ln(\alpha\beta) + \beta lnt$	α	$4.4 \cdot 10^{-2}$ mg g^{-1} min^{-1}
		β	0.0019 g mg^{-1}
		R^2:	0.9785
Intra-particle diffusion	$q_t = \Theta + k_i \cdot t^{0.5}$	k_i:	0.393 min^{-1}
		Θ	0.3930
		R^2:	0.8845

It can be concluded that adsorption of Sc(III) follows the pseudo-second order kinetic model (Fig. 1a) and the mechanism might be chemisorption. Furthermore, the intraparticle diffusion model was used to investigate the contribution of intraparticle and film diffusions to the adsorption process. A linear plot of the experimental data to the Weber-Morris equation shows the early adsorption step (up to 10 min) of the process is generally controlled by both factors. The subsequent adsorption step, characterized by a lower slope, is mainly controlled by the film diffusion (Fig. 1b).

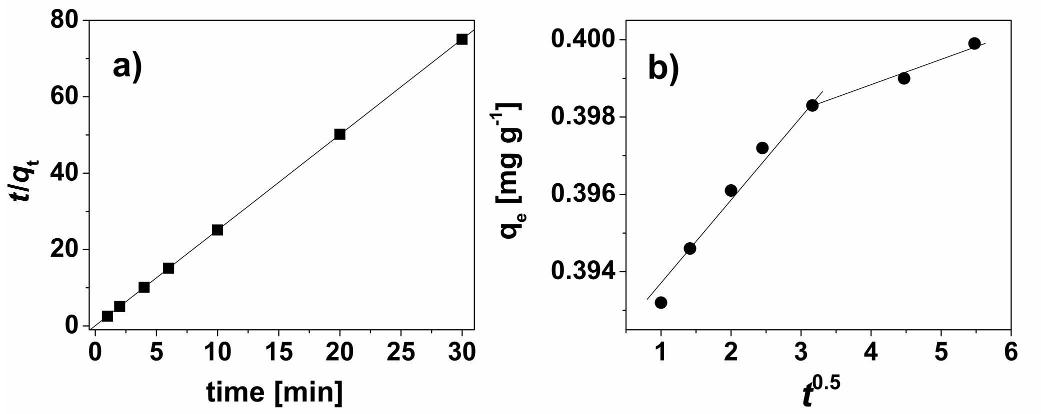

Figure 1: Modeling of Sc adsorption kinetics on CNT-COOH (models: a - pseudo-second order, b - Weber- Morris).

In order to describe Sc(III) adsorption behaviour on carbon nanotubes, the experimental data were analyzed by three isotherm models. The Freundlich model describes adsorption on heterogeneous surfaces and is represented by the equation:

$$q_e = K_F C_e - 1/n$$

where K_F and n are the Freundlich isotherm constants related to adsorption capacity and intensity, respectively. The Langmuir model, which assumes monolayer coverage is described by the equation:

$$q_e = q_{max} K_L C_e (1 + K_L C_e) - 1$$

where q_{max} and K_L are the maximum monolayers adsorption capacity and the adsorption energy related constant, respectively. The Tempkin isotherm assumes that sorption energy decreases linearly with surface coverage and has been generally applied in the following form:

$$q_e = RT/bln(A_T C_e)$$

where A_T is the Tempkin isotherm equilibrium constant, b is the Tempkin constant related to the heat of sorption and T is the absolute temperature.

The adsorption data for Sc(III) are slightly better fit by the Freudlich equation ($R^2 = 0.9974$) than the Langmuir isotherm model ($R^2 = 0.9881$) or the Tempkin model ($R^2 = 0.7476$) reflecting multilayer adsorption. The Freudlich isotherm is often used for cases of heavy metal adsorption onto carbon materials [4].

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B.10 Wide-beam nanodosimetric experiment at HIL

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The enhanced biological effectiveness of carbon ions and other heavy charged particles is related to the ionization structure of the particle track at the nanometer level. Experimental nanodosimetry is aimed at direct measurement of the ionizations created by a single ionizing particle in a nanometric volume equivalent to a short segment of DNA (see Fig. 1).

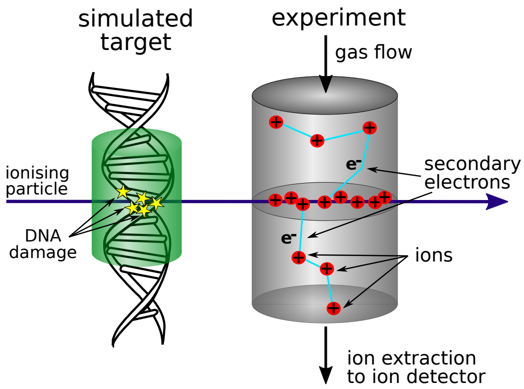

Figure 1: Short DNA segment destroyed by a heavy charged particle. The green area is the nanometric volume simulated in the experiment.

The ion counting nanodosimeter —Jet Counter (JC)— is capable of measuring the track structure of ionizing particles in a gaseous target equivalent to a nanometric volume in water. The JC consists of an interaction chamber (IC), where a simulated nanometer-size target is obtained by gas expansion from a reservoir by a pulse operating valve (repetition rate: 1–10 Hz). The target is created dynamically at each gas injection and exists during a 350 µs plateau of gas density. The IC is a cylinder 10 mm in diameter and 10 mm in height, with walls of 1 mg/cm^2 Mylar (Al covered on both sides). A single ionization cluster is measured if a single ionizing particle appears during the plateau. The cluster-size is the number of ions in the cluster and the main result of a nanodosimetric experiment is a probability distribution for the creation of a cluster of a given size, the so-called ionization cluster-size distribution (ICSD). For more details see Ref. [1, 2].

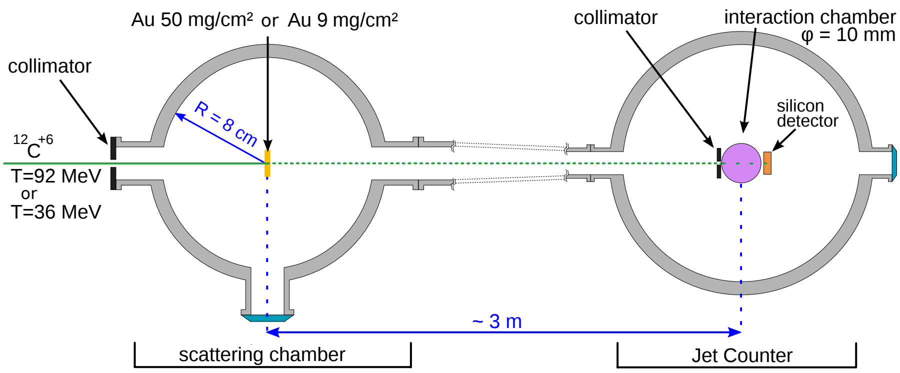

Figure 2: Schematic view of the nanodosimetric set-up on beamline A at HIL.

The reported experiments were carried out with single carbon ions crossing the nitrogen gas target directly. A number of equivalent nanometric targets in the range 1–5 nm were employed. Projectiles were scattered on gold foils to achieve a wide range of energies (20–80 MeV) inside the target. The set-up arrangement on the beamline is shown in Fig. 2.

A novelty in these experiments was the use of a two-dimensional silicon detector for the projectiles. It allowed the use of a wide collimator (3 mm in height and 8 mm in width) to study ICSDs for projectiles passing at different distances d from the center of the IC. The image of the beam is shown in Fig. 3 and some preliminary results of the mean cluster-size dependence on the distance $d = x$ are presented in Fig. 4.

The data obtained also contain other interesting information, e.g. primary particle energies for each event, drift time of nitrogen ions and arrival time of primary particles. The data will be further analyzed and used *inter alia* for comparison with MC and ion optic simulations.

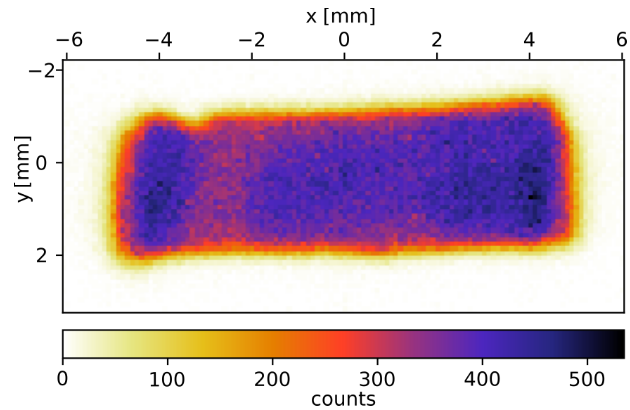

Figure 3: Image of the beam on the 2-D silicon detector. Each pixel has dimensions 0.1×0.1 mm^2.

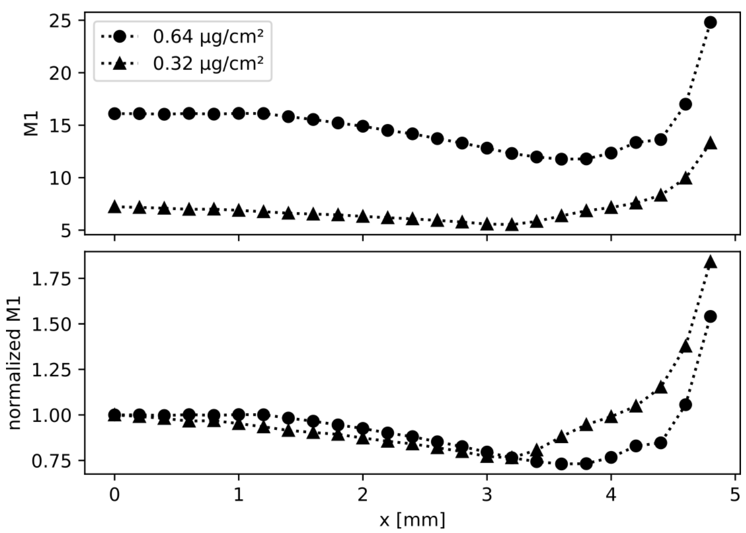

Figure 4: The dependence of mean cluster-size (M1) on the horizontal coordinate of the projectile path for two target sizes.

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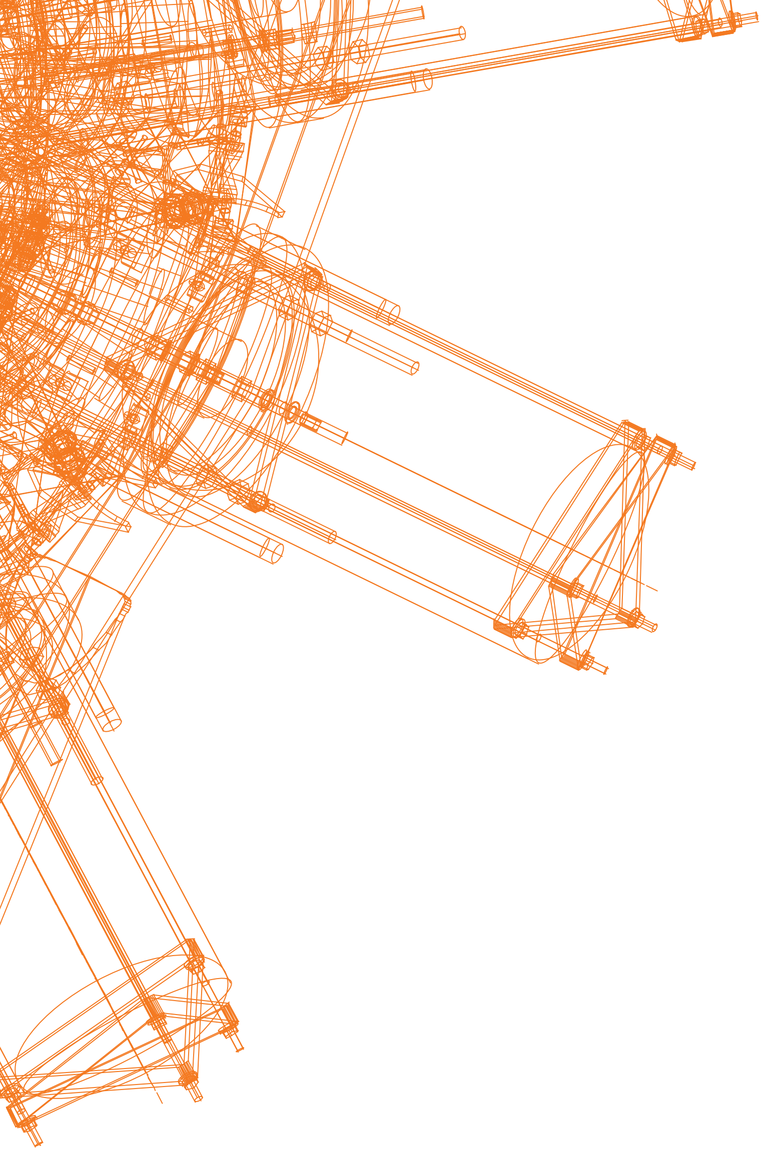
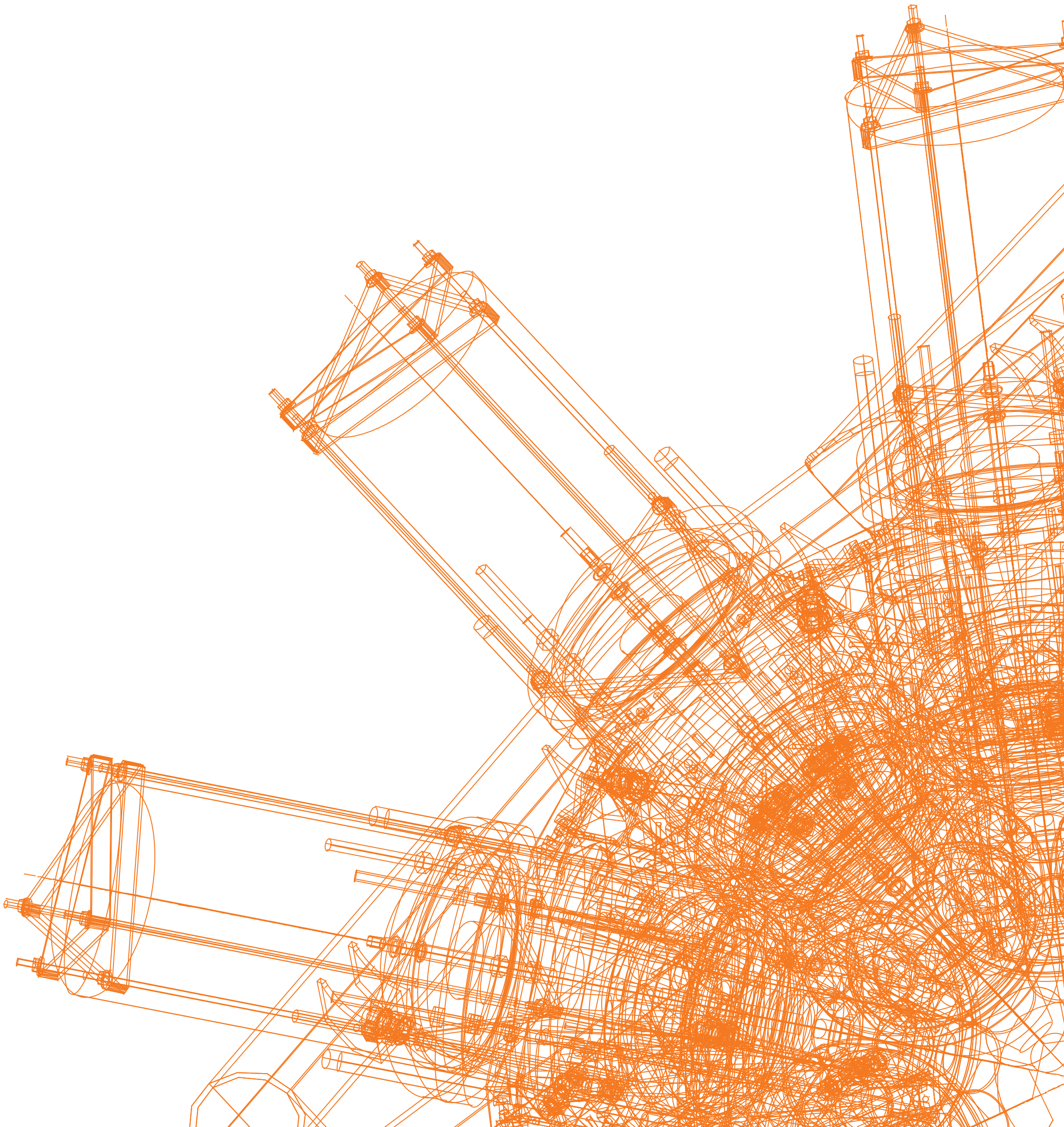


Part C
Nuclear physics



C.1 Coulomb excitation of ^{110}Cd – target composition and data analysis

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on behalf of the "Electromagnetic structure of low-lying states in ^{110}Cd studied with multiple-step Coulomb excitation" experiment collaboration

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A Coulomb-excitation experiment to study ^{110}Cd was performed at the Heavy Ion Laboratory, University of Warsaw, using a 91 MeV ^{32}S beam delivered by the Warsaw cyclotron. The γ rays depopulating Coulomb-excited states of ^{110}Cd were detected with the EAGLE HPGe array, while the back-scattered ^{32}S ions were detected by a set of silicon detectors (PiN diodes). Details of the experiment were described in [1]. In the non-Doppler-corrected spectra, numerous γ rays not originating from the collision partners were observed, as shown in Fig. 1. The analysis of these γ rays revealed that they result from nuclear reactions of the ^{32}S beam with O and C target contaminations [2]. This, in turn, led to a question about the thickness of target layers containing O and C and their possible influence on the effective ^{32}S beam energy. The latter is related to the energy range of the ^{32}S ions which Coulomb excited the ^{110}Cd nuclei.

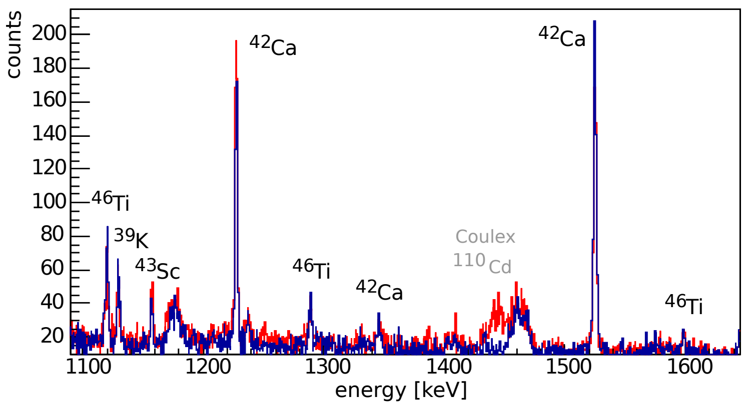

Figure 1: Portion of the prompt (red) and random (blue) particle-γ spectra, from one of the HPGe detectors. No Doppler correction was applied. The most intense of the identified γ rays resulting from ^{32}S+^{12}C and ^{32}S+^{16}O reactions are marked. The broad structure around 1450 keV is related to Coulomb excitation of ^{110}Cd.

A complementary experiment was performed in order to investigate in a quantitative way the composition of the ^{110}Cd target used in the Coulomb-excitation measurement at HIL. The experiment, using the Rutherford Backscattering Spectrometry (RBS) method, was carried out at the LABEC INFN laboratory in Florence, Italy. Proton beams with energies of 1, 1.5 and 3 MeV were delivered by the 3 MV Tandetron and scattered from the ^{110}Cd target at 120°, 150° and 165° with respect to the beam direction. Several different regions of the target were irradiated. The measured Cd target thickness was 1250 µg/cm^2. The analysis of the RBS spectra, see an example in Fig. 2, confirmed the presence of O and C in the ^{110}Cd target.

Carbon layers of 40-50 μg/cm^2 were found on each surface of the target. Due to the energy loss in this layer (about 1 MeV under the conditions of the Coulomb-excitation experiment) and the higher stopping power of ^{32}S ions in oxidized cadmium compared to that for pure ^{110}Cd material, the energy range at which Coulomb excitation of ^{110}Cd proceeded is different from what it would be for a pure ^{110}Cd target. The present study of the target composition enabled proper reconstruction of the energies of the backscattered ^{32}S ions in the ^{32}S+^{110}Cd Coulomb-excitation experiment at HIL.

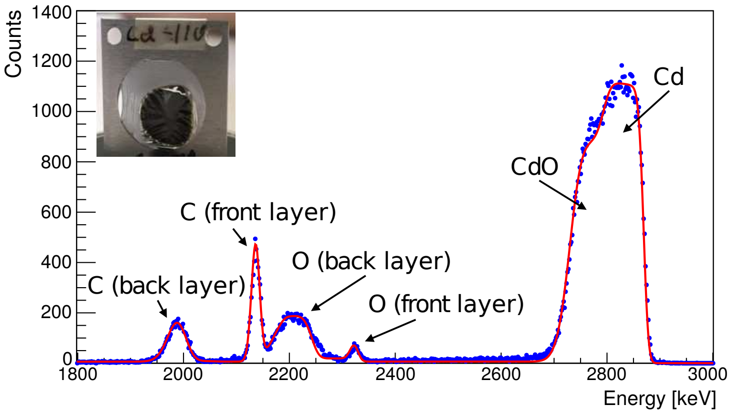

Figure 2: Experimental spectrum of 3 MeV protons scattered from the ^{110}Cd target at 165°. The experimental spectrum (blue) is reconstructed (red) using the SIMNRA code. Inset: the ^{110}Cd target under study.

The information on the target composition was crucial for further analysis of the data aimed at extraction of the reduced matrix elements of ^{110}Cd using the GOSIA code. The exact reproduction of the experimentally observed γ-ray yields requires integration over the finite scattering angle range covered by the particle detectors and over the range of bombarding energies resulting from the projectile energy loss in the target. Such an approach requires precise knowledge of the incident beam energy and stopping powers in the target material.

As reported in [1], several levels in ^{110}Cd were populated in the Coulomb-excitation experiment at HIL. A number of unknown matrix elements affect the measured Coulomb-excitation cross sections in a complicated nonlinear way. The data analysis is currently being finalised at HIL. Preliminary results yield a non-zero, negative value of the spectroscopic quadrupole moment of the 2^+_1 state in ^{110}Cd, which is consistent with the value of [3]. Complementary Coulomb-excitation experiments using heavier beams, aiming at a determination of the properties of higher-lying states in ^{110}Cd, will be proposed at HIL and LNL.

The analysis of the RBS spectra is the subject of the Bachelor's thesis of E. Pasquali at the University of Camerino in Italy.

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C.2 Status of the EAGLE array

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The central European Array for Gamma Levels Evaluations (EAGLE) is an array of High Purity Germanium (HPGe) detectors situated at HIL [1]. The flexible EAGLE frame allows for the installation of up to 30 HPGe detectors and various ancillary devices.

Since 2016 the Heavy Ion Laboratory has hosted 20 HPGe GAMMAPOOL detectors and 15 anticompton shields (ACS) [2]. An application to prolongate the loan until December 2020 was submitted to the GAMMAPOOL Owners Committee in July 2018 and was accepted in October. Out of 20 HPGe detectors formally allocated to HIL, 14 are operational, 3 cannot be used due to high leakage current (causing unacceptably high levels of noise), 1 has been sent to CANBERRA for repair (at the cost of HIL), and 2 broken ones have never been received from CNRS Orsay. The HPGe detectors are routinely serviced at HIL. Procedures like annealing, FET replacements, repair of pre-amplifiers, pumping to restore vacuum, are performed in house, see also Ref. [3]. All 15 ACS are operational (including one which has recently been repaired).

The data acquisition system of EAGLE uses CAMAC based analog units, which can serve up to 16 HPGe detectors. Work on the development of new digital electronics is in progress [4]. In the new system (see Fig. 1) boards will be used with four 160 Ms, 16 bit digitizers and a Zynq Z-7030 FPGA in each one. Each board is equipped with 4 NIM inputs for ACS, 2 additional NIM inputs, 2 NIM outputs, clock input and output, as well as a MiniDP port for inter-board communication. Six such boards have been built. Tests with radioactive sources indicate satisfactory performance of the boards, with FWHM smaller than for the analog units, the capability to work with thresholds down to 30 keV, and good linearity. Work is continuing on the FPGA coding to allow synchronization of multiple boards as well as output of short traces for timing and off-line coincidence determination. Software for user control, on-line monitoring, and handling of the data stream is also under development.

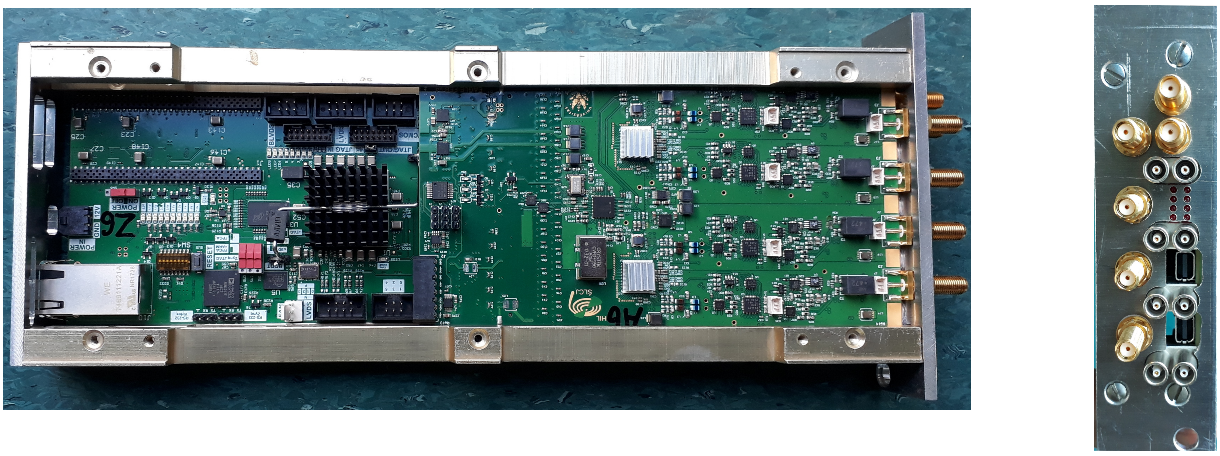

Figure 1: EAGLE digitizer board: a general view (left) and the front panel (right).

In 2018 two experiments were performed with EAGLE:

- "Lifetime measurements of the $I = 10^+$ chiral state in ^{128}Cs with HPGe-LaBr-LabBr triple" by E. Grodner et al. [5].
- "Spin deorientation measurements in the Coulomb excitation of ^{148}Nd with the plunger device" (a test experiment) by A. Tucholski et al. [6].

In the first experiment EAGLE was augmented with fast scintillator FATIMA detectors for sub-nanosecond lifetime measurements. In the latter, the HIL plunger was used. Another two experiments, originally scheduled in 2018 were postponed to 2019 due to the unavailability of the required beams. Groups responsible for experiments which were performed earlier continued data analysis and three papers based on EAGLE data were published in 2018 [7–9].

In May 2018 the EAGLE Consortium thanked Dr Julian Srebrny for his successful leadership of the γ-ray spectroscopy project at HIL, and elected Dr Marcin Palacz as the new EAGLE project coordinator. A summary of EAGLE activities over the last few years was presented by J. Srebrny at the NUSPIN workshop in June 2018, in Valencia, Spain.

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C.3 Fast-Timing EAGLE-EYE setup launched at HIL for in-beam measurements

E. Grodner[1], M. Kowalczyk[2], J. Srebrny[2], T. Abraham[2], M. Brunet[3], T. Cap[1], O. Charviakova[1], S. Lalkovski[4], T. Marchlewski[2], S. Mianowski[1], C. Mihai[5], R. Mihai[5], S. Pascu[5], M. Rudigier[3], M. Saxena[2], Zh. Toneva[4], A. Tucholski[2], A. Turturica[5]

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5) Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania

A new setup called EAGLE-EYE has been launched at HIL extending the HIL research field portfolio by rapidly developing Fast-Timing techniques. The setup has been developed in cooperation by NCNR and HIL and consists of 16 high efficiency HPGe spectrometers of the EAGLE array coupled with 24 $LaBr_3$ detectors forming the EYE Fast-Timing detection device. 24 $LaBr_3$ detectors of the FATIMA collaboration were used for the first in beam measurements with the EAGLE-EYE full configuration. While the data analysis is ongoing we present some brief technical information on the EAGLE-EYE setup below.

The fast timing logic was based on six ORTEC 935 quad CFD blocks connected with the anode signals from the 24 $LaBr_3$ detectors. Three output logic signals from each of the 24 CFD units were used forming three sets of 24 output signals utilized for 3 different purposes. Two sets were used for fast timing measurements within the 0–50 ns limit using ORTEC TAC 566 blocks. One of the two sets was directly connected to a CEFE unit [1] in order to open appropriate gates for signals coming from another set which was delayed by 15 ns. The delayed signals were then redirected to three TAC units where the signal with the lowest number was used as a common start. The remaining signals were fed into three stop TAC inputs allowing the time measurement of subsequent gamma quanta within a two-, three- or four-fold $LaBr_3$ coincidence. The last set of 24 CFD logic output signals was used for time measurements of delayed gamma quanta within the 0–500 ns range with the help of two 16-channel FERA modules. Such a design has enabled simultaneous fast timing and delayed timing measurement in one event. Fig. 1 presents the EAGLE-EYE logic scheme.

The main features of the EAGLE-EYE setup for in-beam experiments are among others:

- proper identification of gamma quanta registered by the $LaBr_3$ crystals using additional spectra from the HPGe spectrometers,
- Fast-Timing measurements in two-, three- or four-fold $LaBr_3$ coincidence events,
- $LaBr_3$ energy spectra cleaning by gating on contaminating gammas in the HPGe-detector spectra,
- Determination of the Compton background under the peak of interest by removing the peak with HPGe gating,
- Selection of prompt and delayed gamma quanta in the $LaBr_3$ spectra using the Fast-Timing and delayed-timing logic branches.

The remarkable feature of the setup is its flexibility of mounting different types of $LaBr_3$ detectors that may have different dimensions, types of casing and overall sizes. Thanks to

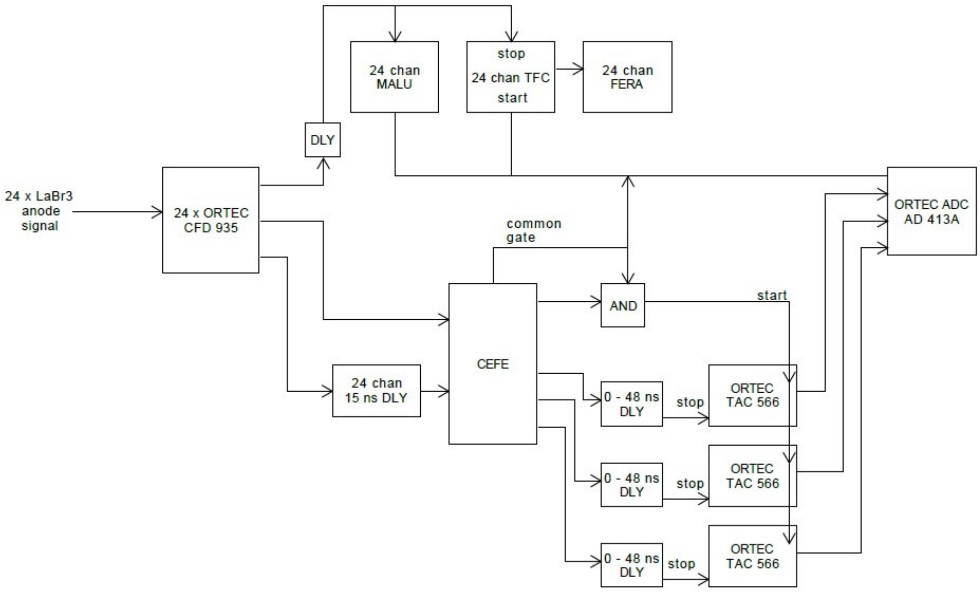

Figure 1: The EAGLE-EYE logic used during in-beam experiments in 2018. Only part of the logic scheme, relevant to $LaBr_3$ detectors, is shown.

this flexibility several types of $LaBr_3$ detectors coming form FATIMA, RHOSPHERE, the University of Warsaw and NCNR were successfully used during recent measurements. Fig. 2 shows a drawing of the EAGLE-EYE setup with a possible half-sphere $LaBr_3$ arrangement. It also shows a single cluster of three $LaBr_3$ detectors that can be replaced with a HPGe spectrometer on demand.

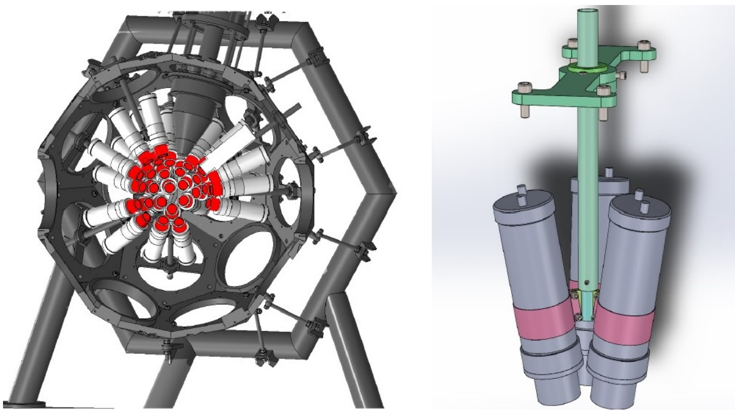

Figure 2: Schematic drawing of the EAGLE-EYE setup with the $LaBr_3$ arrangement forming a half-sphere geometry. A single triple $LaBr_3$-detector cluster is replaceable by a HPGe spectrometer.

The above properties allow several experimental techniques to be applied to the study of isomeric decays, fast single-particle nuclear transitions or collective nuclear states. In addition to fundamental spectroscopy studies the EAGLE-EYE setup is a helpful device for research into and further development of fast-timing techiques with various types of detectors by imposing various coincidence conditions.

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C.4 Spin deorientation measurements in the Coulomb excitation of ^{148}Nd with the plunger device. A test experiment.

A. Tucholski[1], J. Srebrny[1], Ch. Droste[2], T. Marchlewski[1,2], P.J. Napiorkowski[1], T. Abraham[1], M. Palacz[1], A. Stolarz[1], M. Kowalczyk[1], J. Samorajczyk-Pyśk[1], K. Wrzosek-Lipska[1]

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We plan to study the magnetic moments of short-lived states in Nd isotopes using the recoil in vacuum method (RIV) [1] by measuring time dependent γ ray angular distributions in ^{148}Nd. The idea is to obtain the strength of the hyperfine field in the ^{148}Nd recoils by measuring deorientation of the 2^+ state, the g-factor of which is already known. Having this, one can measure the g-factor in other Nd isotopes, in particular ^{136}Nd. The g-factor of the 10^+ state in ^{136}Nd measured by Billowes et al. [2] can not be applied to the calibration of the hyperfine field because of the large, 30% errors.

The proposed experiment with the plunger device centered in the EAGLE array makes it possible to measure the angular distribution along the distance in the plunger device. The ^{148}Nd targets were prepared at the University of Cologne by C. Fransen and A. Blazhev.

The target consisted of: the Nb supporting foil of thickness 4.7 mg/cm^2 and the ^{148}Nd layer, 0.6–0.7 mg/cm^2 thick, evaporated on top of the Nb foil. To avoid fast oxidation of the ^{148}Nd a Au layer of about 0.07–0.08 mg/cm^2 was evaporated on top of the Nd.

In the first test experiment the following problems were investigated:

1. The crucial issue was the implementation of a Si detector inside the plunger to give a particle-gamma coincidence trigger. The ^{10}B beam particles ejected from the ^{148}Nd target will be registered in this Si detector. In this run the noise in the particle detector was very high and many unwanted random coincidences were registered. This problem has now been solved and will be tested in May'19.

2. The spectrum of the Coulomb excitation of ^{148}Nd has been obtained (Fig. 1).

In the May test we will increase the ^{10}B beam energy to 55–57 MeV, giving 52 MeV on target. This light projectile and the high energy result in a relatively high energy of the ejectiles in the Si detector. According to our calculations the energy of the back scattered ^{10}B ions from ^{148}Nd registered in the Si detector will be around 34 MeV, much above the noise.

The gamma energy spectrum collected during our test experiment is presented in Fig. 1. The clean peak at 301.7 keV comes from the Coulomb excitation of the 2^+ state of ^{148}Nd. The peaks at 744 keV and 808 keV are from Coulomb excitation of the supporting foil made of ^{93}Nb. The spectrum is very clean with low background.

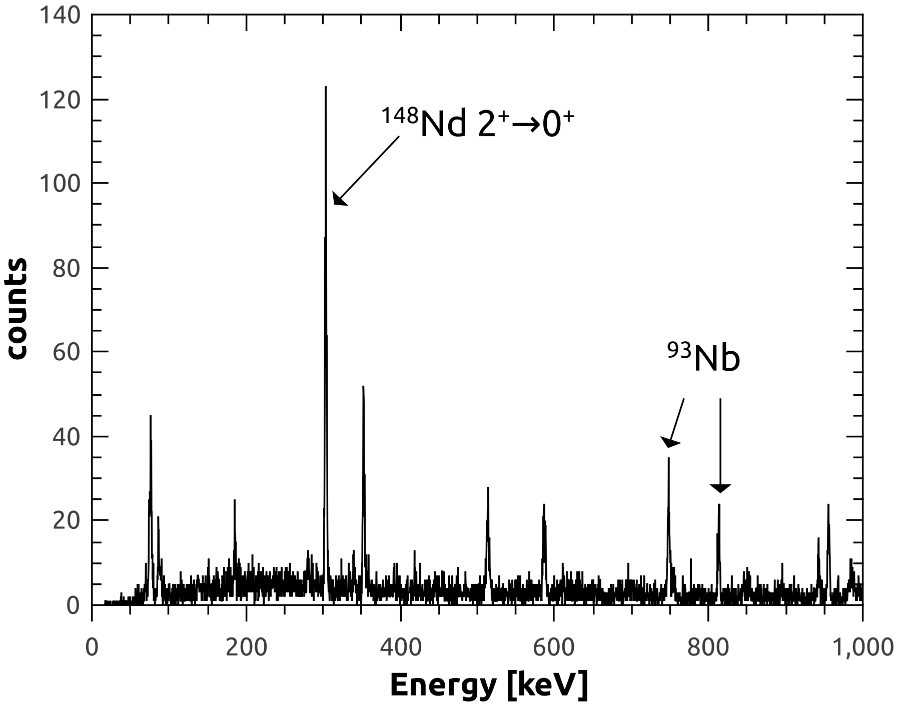

Figure 1: The energy spectra of γ rays.

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C.5 Electromagnetic properties of stable even-even Cd isotopes within the mean field theory

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Stable even-even Cd isotopes have often been regarded as very good examples of vibrator-like nuclei. In other, more precise, words their low-lying collective states are well described by a simple harmonic oscillator model. Recent experimental studies, e.g. [1, 2], of the electromagnetic properties of these nuclei have shown that such a simple picture has to be revised, which led to fresh interest by theoreticians, e.g. [3, 4]. This report presents selected results of research aimed at obtaining a description of nuclear collective dynamics based on the microscopic mean-field theory. The research is an extension of Ref. [5].

Our theoretical approach has two stages. In the first stage the Adiabatic Time Dependent HFB (ATDHFB) method is applied to obtain the so-called mass parameters (inertial functions) and the potential energy for a quadrupole collective motion. In order to do this constrained HFB calculations are performed on a grid containing around 150 points on the deformation (β,γ) plane. In the calculations I use four distinct Skyrme-type effective microscopic interactions (SIII, SLy4 and the more recent UNEDF0 and UNEDF1 [6, 7]). The considered interactions were constructed using different experimental data sets, different protocols and with slightly different aims. The second purpose of our study is to find a possible correlation between the way in which a given interaction is built and the degree of accuracy of reproducing experimental data. One should keep in mind that collective properties (energies, B(E2)s etc) are not used in the construction of the interactions. The second stage of our approach consists in solving the eigen equation for the General Bohr Hamiltonian (GBH) with the calculated potential energy and mass parameters. The GBH describes full quadrupole dynamics including both vibrational and rotational degrees of freedom, for which the harmonic oscillator is an extremely simple special case. The general theory of our method can be found in [8], while examples of its application to Mo and Xe isotopes are given in [9, 10].

In the present report I consider a chain of even-even Cd isotopes with $A = 104$–118 among which $^{106\text{-}116}$Cd are stable. I present a small sample of results focusing on the so-called quadrupole invariants which are synthetic measures of quadrupole deformation and are accessible from both the theoretical and experimental sides. Of course, experimental determination of the invariants is much more difficult but still possible, as can be found e.g. in [11].

The lowest quadrupole invariants for a given state i are defined as:

$$\langle Q^2 \rangle = \sqrt{5}\langle i||[E2 \times E2]_0||i\rangle \tag{1}$$

$$\langle Q^3 \cos(3\delta) \rangle = -\sqrt{35/2}\langle i||[E2 \times E2]_2 \times E2_0||i\rangle \tag{2}$$

where $E2$ is the operator of an E2 transition. The value of the r.h.s. of the above equations can be determined experimentally by expanding the r.h.s. over a complete set of intermediate states which leads to an expression of (1,2) through E2 matrix elements, both transitional and diagonal ones. This is the foundation of the so-called Kumar-Cline sum rules method [12].

In Figs. 1 and 2 I present theoretical predictions for the values of: $\langle Q^2 \rangle$ and $\langle \cos 3\delta \rangle = \langle Q^3 \cos(3\delta) \rangle / \langle Q^2 \rangle^{3/2}$.

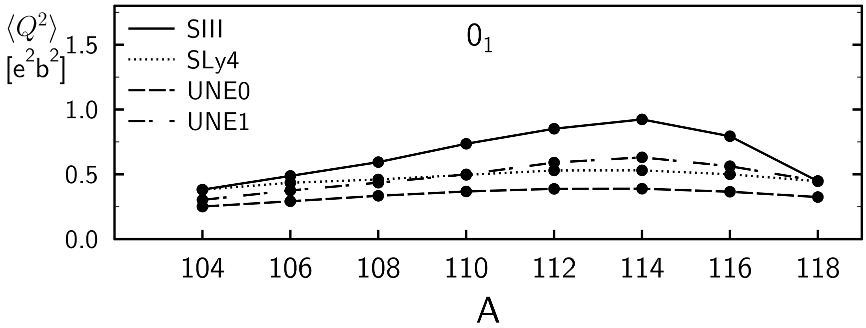

Figure 1: Value of the invariant $\langle Q^2 \rangle$ for the ground state in Cd isotopes.

To determine the values of the invariants experimentally one needs a large set of E2 matrix elements which can be obtained using Coulomb excitation. In the case of Cd isotopes such a very extensive study was done only for ^{114}Cd [11], where 40 matrix elements were deduced which allowed a determination of $\langle Q^2 \rangle$ for several states. In particular, for the ground state $\langle Q^2 \rangle_{\rm exp} = 0.53(1)\ e^2\rm{b}^2$ and $\langle \cos 3\delta \rangle_{\rm exp} = 0.16(10)$. As can be seen from Figs. 1,2 the Sly4 interaction gives results which are closest to the experimental ones for both invariants, but to draw a more general conclusion one needs to consider all experimental data, also for other isotopes, that is energies of excited states and $B(E2)$ transition probabilities.

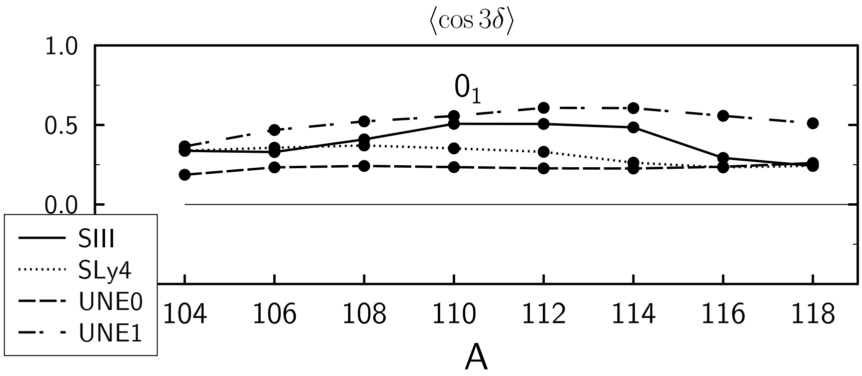

Figure 2: Value of $\langle \cos 3\delta \rangle$ for the ground state in Cd isotopes.

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C.6 The Wien filter: construction and tests at LNS

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In the present communication we report on the physical motivation and the status of the construction (supported by the Heavy Ion Laboratory of Warsaw) of a Wien Filter separator at the Laboratori Nazionali del Sud (Catania, Italy).

The fusion cross section between two heavy ions can be described in terms of a central potential, possibly deformed, depending on the relative distance of the centers of mass of the two colliding ions. It is known that at incident energies close to the Coulomb barrier there is a coupling between the relative motion and the internal degrees of freedom of the participants. As a consequence, enhancement of the fusion cross section with respect to simple quantum tunneling predictions is observed [1, 2]. In the framework of the Coupled Channel (CC) method [3] this phenomenon is explained as a result of the interplay of different reaction channels. As a consequence, a single value of the fusion barrier is replaced by a distribution. There are two experimental approaches to its determination. In a direct measurement it is necessary to determine the fusion excitation function in order to obtain the barrier distribution through the relation: $D_{fus} = \frac{d^2}{dE^2}(E\sigma_{fus})$ [4]. This method is difficult to realize since the measurement of the fusion products should be carried out at almost 0°, so they must be separated from the beam and intensive elastics. Because of this many measurements were made using an indirect method. It consists [5] in the measurement of those ions which did not penetrate the Coulomb barrier, but were quasielastically backscattered from it, i.e. the sum of the elastic and inelastic scattering, transfer and breakup products, without the necessity of identification of different reaction channels. In this case the barrier distribution is given by the formula: $D_{qe}(E) = -\frac{d}{dE}\frac{\sigma_{qe}}{\sigma_{Ruth}}$, where the Rutherford cross section in the denominator normalizes the quasielastic scattering cross section σ_{qe} [5, 6]. Using the second approach a series of measurements performed at the Heavy Ion Laboratory of Warsaw University and at LNS have shown significant discrepancies between experimental data and the results of CC calculations [7, 8]. The authors explain this disagreement in terms of numerous weak couplings with noncollective, single particle target excitations, not taken into account in the standard CC method, but well reproduced using the CC + Random Matrix model [9]. Both methods, the direct and non-direct ones, have their weak and strong points, so they are in a way complementary, but the question as to what extent they give similar remains rests open. To check this one should carefully compare the experimental D_{qe} and D_{fus}. As explained above, this requires a dedicated device efficiently to remove the intensive background close to 0°.

At LNS, in collaboration with Warsaw Laboratory, a velocity filter (Wien filter), of the type described in [11] is under construction [10]. The filter has dimensions: $106 \times 150 \times 250$ mm. In the two parallel planes (Fig.1), there are 20 permanent magnets made of rare-earth elements (Sm_2Co_{17}), each one having dimensions of $41 \times 41 \times 11$ mm, producing at the surface a magnetic field of 1.3 kG (0.13 T) and energy density of

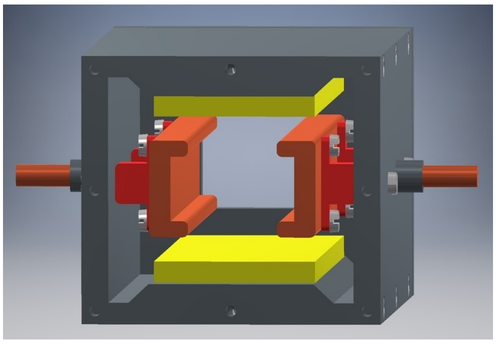

Figure 1: Schematic view of the Wien filter. Electrodes are shown in red, permanent magnets in yellow.

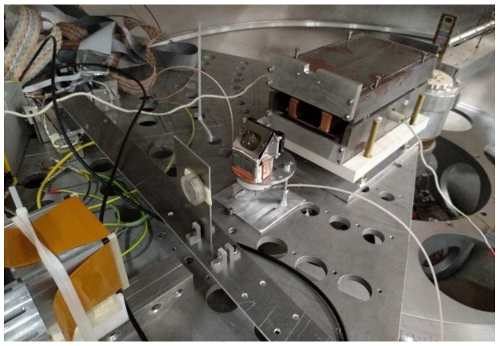

Figure 2: The Filter (right side) in the 2000 Chamber. In the center the start MCP device is shown, on the left side: the stop DSSSD detector.

225 kJ/m^3. The two magnet planes are at a distance of 60 mm from each other and the magnets generate a total magnetic field in the central plane of 1.7 kG. Perpendicular to the magnetic field, an electric field is generated by two electrodes placed at a distance of 44 mm and alimented with high voltage up to ± 40 kV each.

The first 2 tests were performed at LNS using a ^{24}Mg beam delivered by the tandem accelerator with an incident energy of 90 MeV on a Zn target. The tests were performed in the 2000-Chamber and in order to detect the elastic scattering and the fusion residues, a double sided silicon strip detector (DSSSD) 300 µm thick was used (see Fig. 2). The silicon detector consists of 32 vertical strips on the front side and 32 horizontal strips on the rear covering an area of 64 × 64 mm. The goal of the first test experiment was to demonstrate that the filter is able to separate by different deflection the fusion residues and the elastic scattering in the angular range 0 deg to ≅ 5° in the lab frame. The test confirmed our expectations but it turned out that we have to improve the effect-to-background ratio. Because of this in the 2nd test we added to the system a ToF device, which worked well. However, we have to improve even more the effect-to-background ratio.

In conclusion we can say that the Wien filter under construction is a promising tool for separating elastic scattering from fusion residues. More tests have to be made in order to master the techniques necessary to identify better the fusion residues. In the near future the Wien filter will be used in an experiment for the direct measurement of fusion residues near the Coulomb barrier.

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C.7 Scaling of the fusion cross-section for exotic helium isotopes

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A simple energy scaling was introduced [1] allowing for the prediction of the fusion cross section for various scattering systems at energies around the Coulomb barrier. From the inspection of many data sets it was noticed that the fusion cross section depends on the Q-value. It was proposed that, when comparing fusion excitation functions for different systems, the experimental energy $E_{c.m.}$ should be replaced by a reduced energy parameter, E_r, defined as

$$E_r = \frac{E_{c.m.} + Q}{V_C + Q}, \tag{1}$$

where V_C is the Coulomb barrier height

$$V_C = \frac{e^2 Z_1 Z_2}{R^2}, \tag{2}$$

and $R = 1.44\, b\, (A_1^{1/3} + A_2^{1/3})$ fm.

With the parameter b varying from 0.92 to 0.95, the excitation functions for various pairs of stable nuclei plotted against E_r formed a band with a width corresponding to a factor of about 2-3 for the fusion cross section. Application of this Q-value criterion to a few sample data involving weakly bound nuclei did not show any distinct difference between normal and weakly bound systems [1].

Since at present more fusion data sets for weakly bound exotic systems are available, it is of interest to compare these data by means of the Q-value criterion of Wolski [1] in order to find if this criterion could be used to predict fusion cross sections below the Coulomb barrier for planned experiments with exotic projectiles.

The result of the comparison is plotted in Fig. 1. All the ^{6}He fusion data sets are plotted with open circles while the ^{8}He data are plotted with filled squares. Most of the data correspond to fusion with heavy targets (from Sm to Bi). Only two ^{8}He data points at the highest E_r were obtained with a Cu target. For comparison with the results for a well bound nucleus the data set for ^{17}O + ^{144}Sm from Wolski [1] is also plotted (crosses and the solid line connecting the data points). The Q-values range from about -25 MeV up to about 34 MeV, the largest for the two ^{8}He data sets. While the ^{6}He data are in very good agreement with the ^{17}O results (thus, with the criterion of Wolski), the data for ^{8}He form a different curve suggesting that due to the very high positive Q-values the ^{8}He data do not obey the Q-value rule of ref. [1]. In order to reach a more solid conclusion more fusion data are needed.

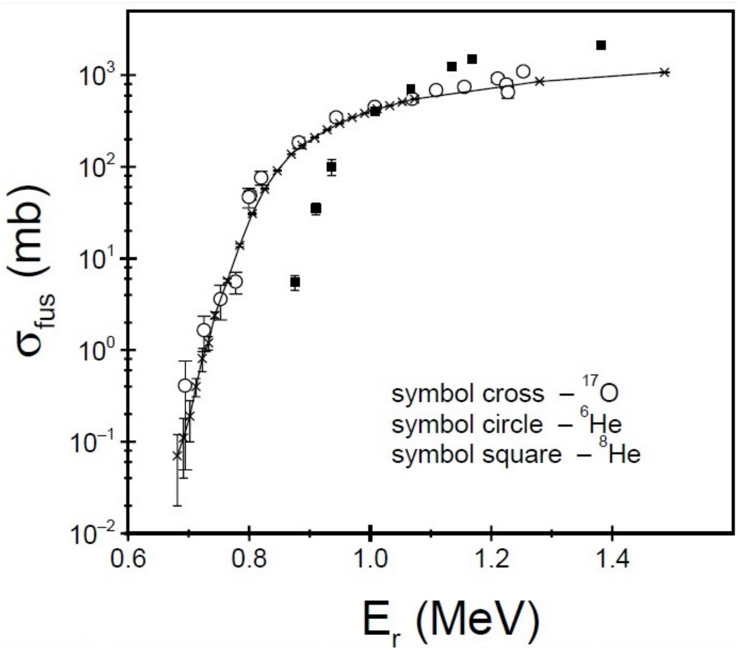

Figure 1: Experimental fusion data from the papers listed in Table 1 plotted as a function of reduced energy (eq. 1, parameter $b = 0.93$ was used for all data sets). The curve connecting the ^{17}O data points guide the eye.

Table 1: Experimental data discussed in this work.

	Q (MeV)	ref.
^{17}O + ^{144}Sm	-24.9351	[2]
^{6}He + ^{209}Bi	+0.5888	[4]
^{6}He + ^{206}Pb	+4.1761	[3]
^{6}He + ^{188}Os	+11.2154	[5]
^{6}He + ^{192}Os	+11.6138	[5]
^{8}He + ^{197}Au	+24.2891	[6]
^{8}He + ^{65}Cu	+34.0456	[7]

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C.8 Four low lying states with spin I=0 in the ^{140}Sm nucleus.

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In this report we present the result of a recent experiment where the low-lying states of ^{140}Sm were studied. In this experiment the statistics were about five times larger than in our previous work [1]. As a result we have measured spins for seven excited states of the ^{140}Sm nucleus (including four states with I=0).

The states of ^{140}Sm were populated in the ^{140}Eu → ^{140}Sm and ^{140}Gd → ^{140}Eu → ^{140}Sm decays. The ^{140}Gd and ^{140}Eu nuclei were produced in the ^{104}Pd+^{40}Ar reaction at a beam energy of 187 MeV. The ^{40}Ar beam was provided by the U-200P cyclotron of the Heavy Ion Laboratory (University of Warsaw). The γ rays were registered using twelve HPGe detectors from the EAGLE array [2].

In our work the level scheme from Refs. [1, 3, 4] has been modified (Fig. 1). Two new levels were added (red lines in Fig. 1) and two levels (1933.15 keV and 2482.34 keV) suggested in Ref. [3] were removed.

The intensities of the lines under study are compared with the results of Ref. [3] (Fig. 2). It is seen that the experimental points including their errors do not deviate by more than about 25% from the weighted mean value (except the γ-line with an energy of 1097 keV - see text below). The admixture of "parasitic"γ-lines could be the reason for observed deviations. The influence of such admixtures on the angular correlations has been investigated in this work. This problem is a general one. In our case it turns out that for the $2_2 \to 2_1 \to 0_1$ and $0 \to 2_1 \to 0_1$ cascades (531–1068 keV, 531–1491 keV, 531–2064.5 keV) admixtures do not change the spin assignment. They only influence the mixing ratio for the $2_2 \to 2_1 \to 0_1$ cascade.

The $\gamma - \gamma$ angular correlations were measured for the 459.9, 1068.0, 1097.7, 1420.3, 1491.3, 1752.8 and 2064.9 keV photons in coincidence with 531 keV photons (Fig. 3). For the 1097 keV γ-transition (mentioned above) the experimental point (A_{22}, A_{44}) is very close to the theoretical value for the 0-2-0 correlation (see Fig. 3) but the admixtures are unknown. Therefore, we propose I = (0) for the 1628 keV level.

The new results confirmed the spin assignments for the 2^+; 990 keV and 0^+; 1599 keV levels which were measured in our previous work [1]. The presence of four low-lying states with spin I = 0 is very interesting (especially the structure of the two close lying states with energies of 1599 keV and 1628 keV). Currently, the structure of the ^{140}Sm nucleus

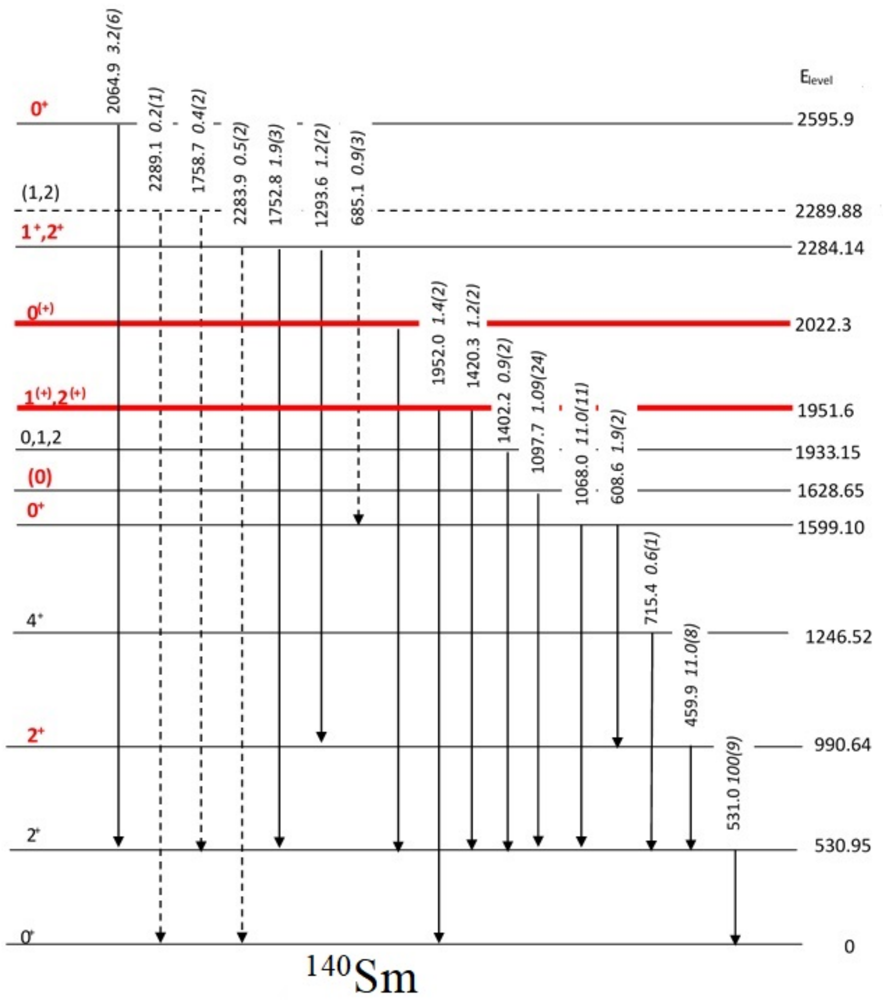

Figure 1: Partial level scheme of ^{140}Sm taken from Refs. [1, 3, 4] and modified in our present work. The spin values marked in red were determined in our measurements. Red lines indicate the new levels proposed by us.

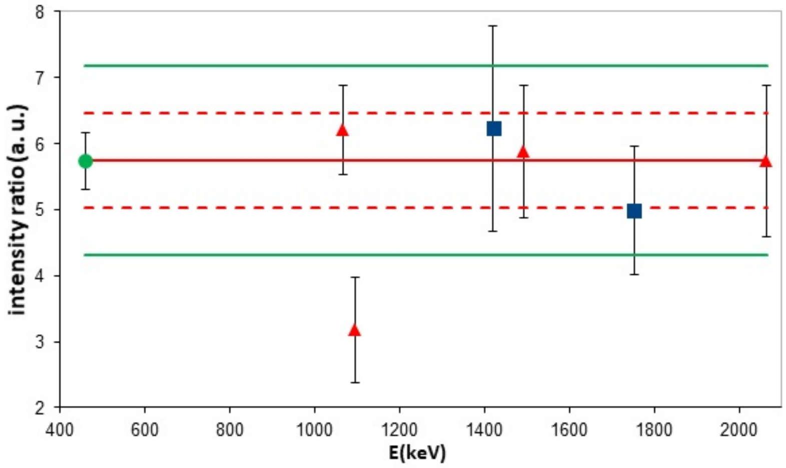

Figure 2: The ratio of intensities of γ-lines measured in this work to intensities given in Ref. [3]. The solid and dashed red lines indicate the weighted mean value and its errors. The solid green lines show the deviation from the mean value by 25%.

is being tested within the framework of the collective quadrupole model with softness in triaxiality (γ-soft model) [5].

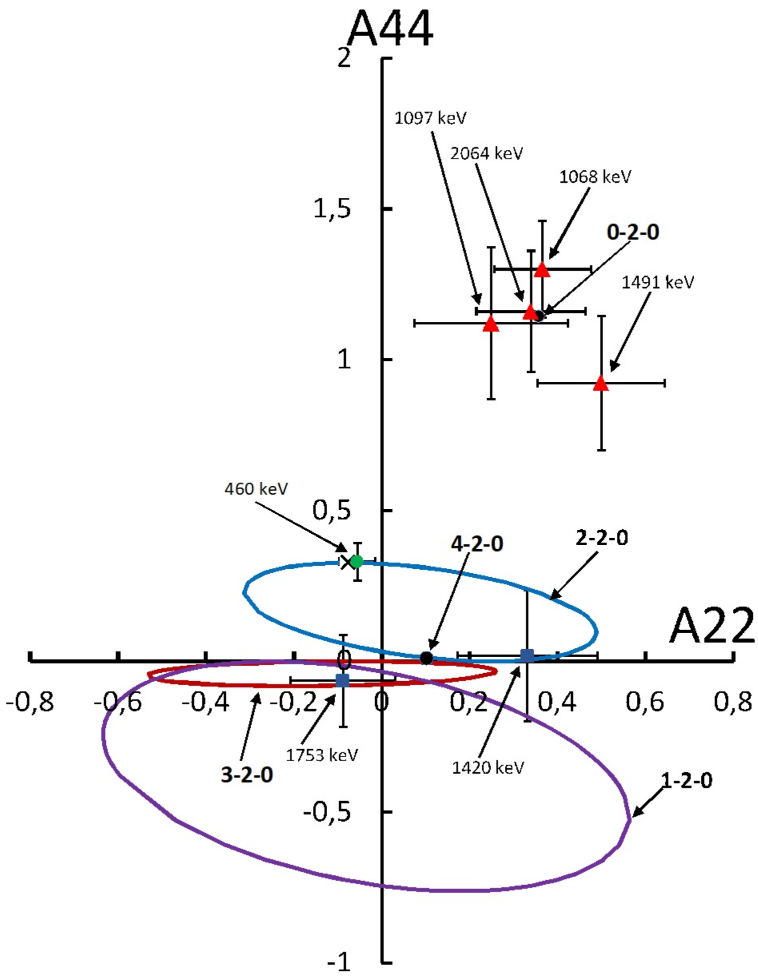

Figure 3: Parametric plot of the A_{22} and A_{44} angular correlation coefficients for the $I \to 2 \to 0$ cascades. Full black circles and crosses indicate the pure quadrupole transitions.

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C.9 Experimental measurements and theoretical investigation of ^{10}B + ^{12}C elastic scattering at 41.3 MeV

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Elastic transfer studies showed a remarkable increase of the differential cross sections at backward angles for different nuclear system such as ^{16}O + ^{12}C [1–4] and ^{20}Ne + ^{16}O [5–7] due to α-cluster transfer. A similar situation is observed in studying nuclear systems with one nucleon (proton or neutron) difference between their masses. The current work is devoted to a study of the concept of deuteron transfer and its role in the formation of the cross section in the backward hemisphere. We have measured the angular distributions of the elastic scattering ^{12}C(^{10}B,^{10}B)^{12}C and deuteron transfer ^{12}C(^{10}B,^{12}C)^{10}B at E_{lab}(^{10}B) = 41.3 MeV.

The measurements were carried out with the ^{10}B beam extracted from the K = 160 cyclotron of the Heavy Ion Laboratory, University of Warsaw. The charged particles were detected and identified by four ΔE-E counter telescopes which were installed in the ICARE experimental chamber. A self-supporting target of ^{12}C with a thickness of $\sim$ 0.141 µg/cm^2 was mounted in the chamber. The spectra were analyzed with the use of ROOT [8] software. A typical two-dimensional spectrum (ΔE, E) is shown in Fig. 1. The angular distributions of the scattered ^{10}B nuclei were measured in the angular range 5° – 40° in the laboratory system. The differential cross sections of the scattered ^{10}B nuclei at angles greater than 100° were obtained by recording the ^{12}C recoil nuclei.

The experimental data were analyzed within the framework of the double folding optical potential (DFOP) model using the FRESCO code [9]. The DWBA method was used to reproduce the data in the backward hemisphere (elastic transfer). The comparison between the experimental data and the theoretical calculations for the ^{10}B + ^{12}C system at an energy 41.3 MeV is shown in Fig. 2.

Both the elastic scattering and the elastic transfer calculations were performed using the DFOP model with a renormalization factor N_r = 0.82 for the real part of the potential. The comparison between the experimental data and the theoretical calculations is fairly good over the full angular range. The SA was extracted for the ^{12}C→^{2}H+^{10}B configuration. The optimum potential parameters are listed in Table 1.

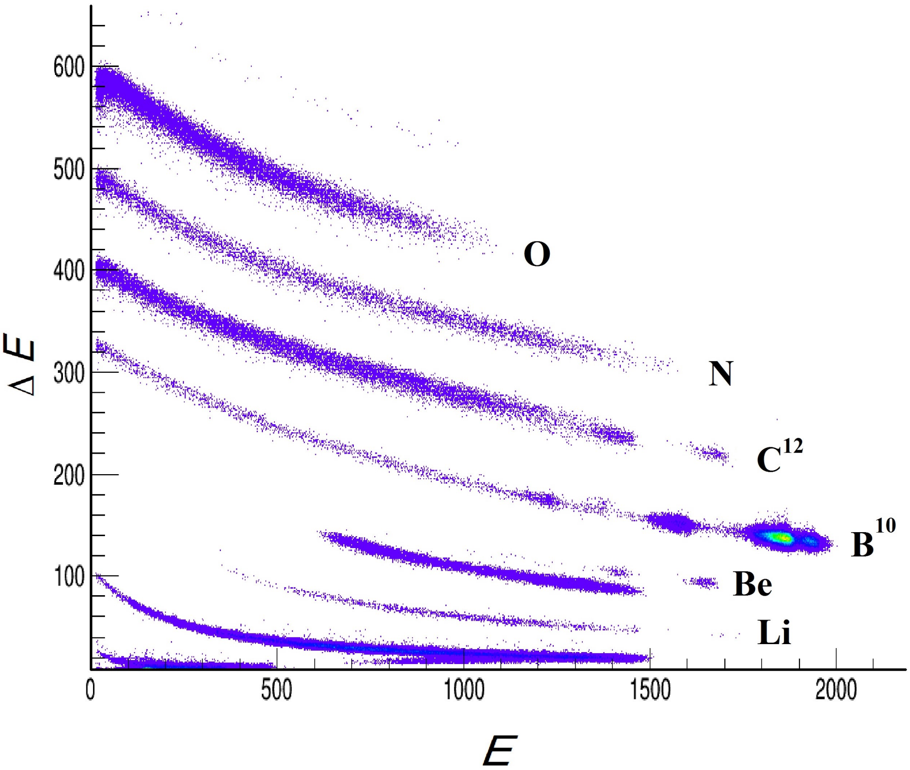

Figure 1: Typical ΔE-E spectrum of the $^{12}C(^{10}B, X)$ reaction products at $E_{lab}(^{10}B) = 41.3$ MeV.

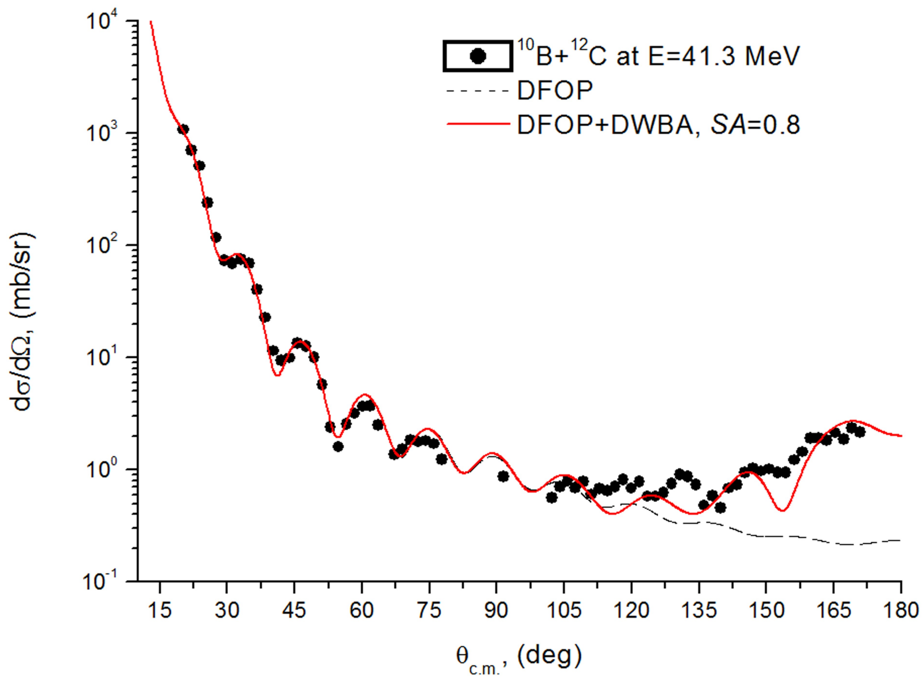

Figure 2: Angular distribution of the elastic scattering of ^{10}B by ^{12}C at $E_{lab} = 41.3$ MeV. Circles are the experimental data, the dashed black curve is the DFOP model prediction, and the red line represents a DWBA calculation including the deuteron transfer process $^{12}C(^{10}B,^{12}C)^{10}B$.

Table 1: Optimum potential parameters for $^{10}B + ^{12}C$ at E_{lab} = 41.3 MeV. The Coulomb radius parameter was fixed at 1.25 fm

Model	N_r	W_0(MeV)	r_W(fm)	a_W(fm)	SA
DFOP	0.82	68.04	1.27	0.28	
DFOP-DWBA	0.82	68.04	1.27	0.28	0.8

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 654002.

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C.10 High radiation hardness of a 23 µm, self-biased, epitaxial silicon detector operated in a built-in-field bias potential

A.J. Kordyasz, M. Wolińska-Cichocka, A. Trzcińska, M. Kisieliński

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The problem of detector radiation hardness is very important for experimental physics. In an attempt to improve detector radiation hardness special detector technologies and new materials like diamond or silicon carbide have been tried. The aim of this work is to test a thin silicon epitaxial detector operated in a built-in-field bias potential. It seems to be more resistant to radiation damage due to the extremely low detector bias potential generated by the internal built-in-field potential and low detector thickness. Low detector thickness prevents doping of the detector material since all heavy ions are not stopped in it.

The detectors were constructed using silicon epitaxial n^+–n structures of resistivity epitaxial layer > 400 Ω·cm and thickness about 23 µm. The detector n^+–n–p^+ junction was obtained using B^+ implantation into the epitaxial n– type side using the low-temperature technique [1]. To reduce the detector electric capacitance, the large-area detectors consisting of a 23 µm thick membrane with n^+–n–p^+ junction were broken down into smaller detector pieces (small detectors with n^+–n–p^+ junctions). The selected detectors were mounted in detector housings supplied with collimation entrance windows of diameter 2 mm. After gluing 50 µm silver wire contacts to the detector Al surfaces using two component silver paste hardened at a temperature of about 80°C, the self-biased thin detectors operating with internal built-in-field potential (without any external bias potential) were ready to work with charged particles and heavy ions. A photograph of a tested detector with external collimation cover removed is shown in Fig. 1.

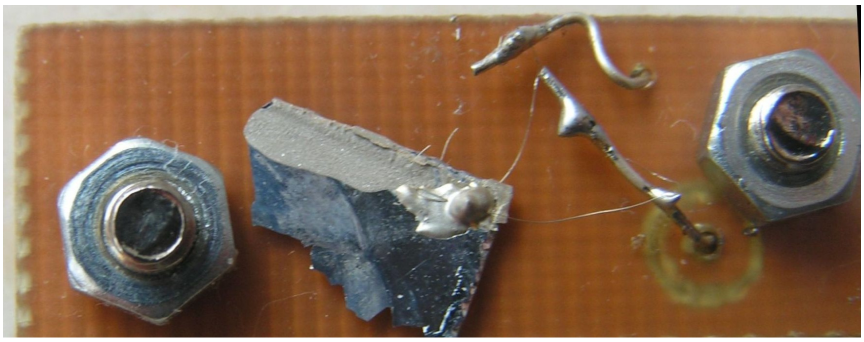

Figure 1: Thin epitaxial silicon detector with collimation cover removed with a 2 mm entrance hole. The 50 µm silver wire contacts were glued to both sides of the detector. The other ends of the wire contacts were soldered to a thick detector external wire connection.

The radiation damage tests were performed using 90 MeV ^{14}N beam scattered by 10 µm ^{197}Au target at 6 deg and distance 40 cm from the target during 5 days at the Heavy Ion Laboratory, University of Warsaw. Self-biased thin epitaxial detectors were irradiated with the total dose of 90 MeV, ^{14}N ions about $7.1\cdot10^{10}$ ions/cm^{-2} without any observed considerable detector radiation damage, see Table 1.

Table 1: Energy resolution of thin detectors DE_4 and DE_7 as a function of dose 90 MeV ^{14}N ions were measured using of α - particles from ^{241}Am (measured before and after of scattered beam). Errors of preliminary measured energy resolutions are of the order 100 keV.

Dose [i/cm^2]	0	$4.8 \cdot 10^7$	$3.3 \cdot 10^8$	$8.3 \cdot 10^9$	$1.1 \cdot 10^{10}$	$1.4 \cdot 10^{10}$	$2.1 \cdot 10^{10}$	$3.3 \cdot 10^{10}$	$4.9 \cdot 10^{10}$	$7.1 \cdot 10^{10}$
DE_4 FWHM [MeV]	1.2	0.7	1.3	1.2	1.3	1.2	1.5	1.7	1.9	1.7
DE_7 FWHM [MeV]	0.5	0.3	0.5	0.5	0.4	0.5	0.4	0.3	0.4	0.9

Its means that the detector internal built-in-field potential was not damaged by the exposed dose. The difference of carriers concentration between detector substrate (n^+) and epitaxial layer (n^-) created the build-in potential difference as [2]:

$$V = -(kT/q) \ln (n^+/n^-)$$

where k is the Boltzmann constant, T is the absolute temperature and q is the electron charge. Since 90 MeV ^{14}N ions punch through a thin detector carriers concentrations therefore n^+ and n^- remain unchanged. According above formula the built-in potential difference should not be sensitive on the 90 MeV ^{14}N ions exposed dose. It is very important to check this the above conclusion.

To do this now we are preparing the next radiation damage experiment with high dose of ^{14}N beam ions directly hitting the thin silicon detectors.

Acknowledgements

We would like to thank E. Piasecki and M. Kowalczyk for their help and participation in the experiment.

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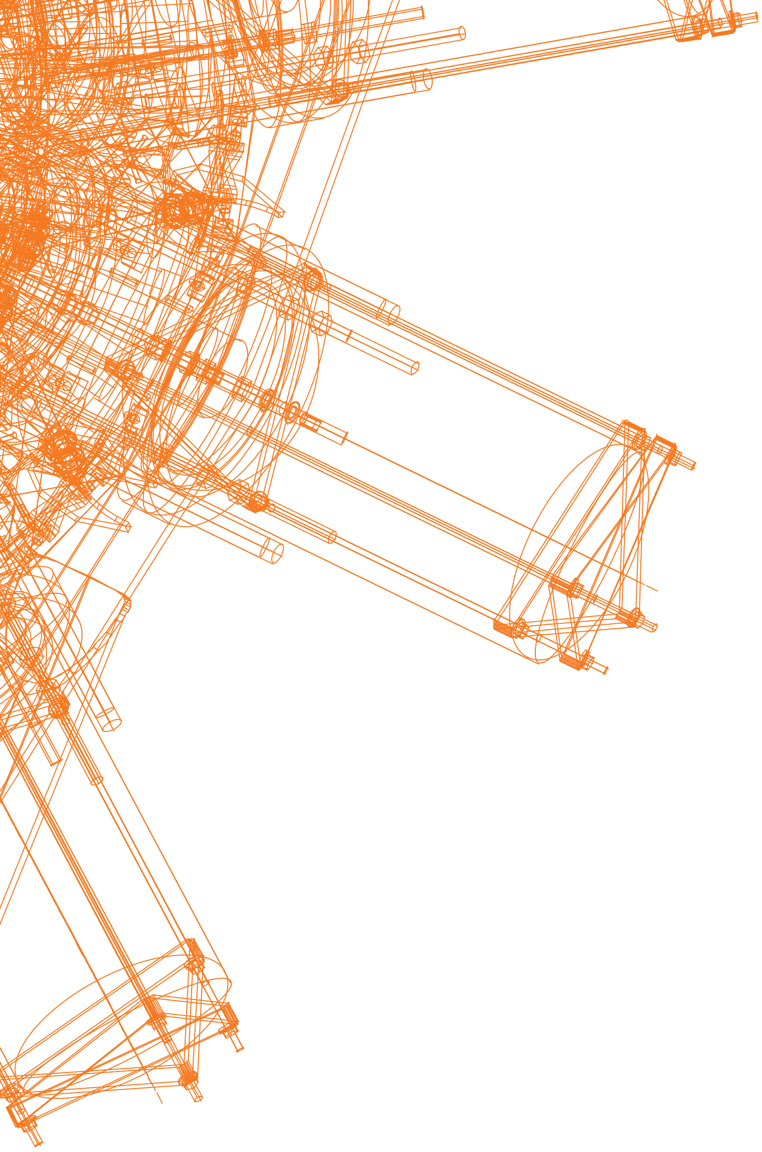
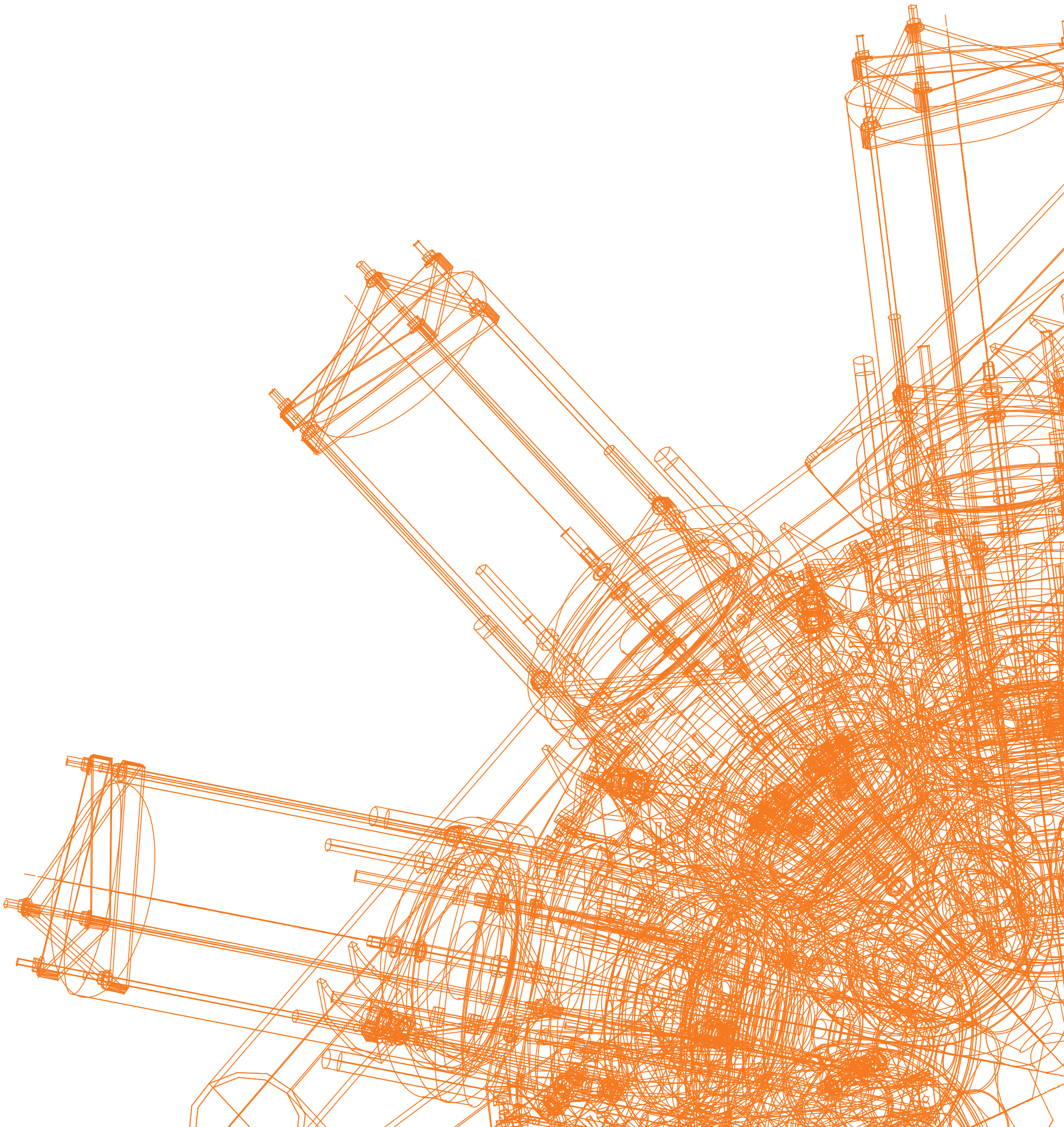


Part D

Experiments using external facilities



D.1 Study of ^{6}He-d reactions over a wide angular range

B. Zalewski[1,2], A. Bezbakh[1], S.G. Belogurov[1], V. Chudoba[1], A.S. Fomichev[1], E.M. Gazeeva[1], M.S. Golovkov[1], A.V. Gorshkov[1], L.V. Grigorenko[1], G. Kamiński[1,2], S.A. Krupko[1], I.A. Muzalevsky[1], E.Yu. Nikolskii[1], W. Piątek[1,2], P. Pluciński[1,3], K. Rusek[2], A. Serikov[1], S.I. Sidorchuk[1], R.S. Slepnev[1], P.G. Sharov[1], N. Sokołowska[4], G.M. Ter-Akopian[1], A. Trzcińska[2], R. Wolski[1]

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2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
3) AGH University of Science and Technology, Kraków, Poland
4) Faculty of Physics, University of Warsaw, Warszawa, Poland

As a first experiment at the ACCULINNA-2 fragment separator, a measurement of the reactions of ^{6}He with a deuterium target was performed in inverse kinematics at a beam energy of 26 MeV/n. ACCULINNA-2 is part of the Dubna Radioactive Ion Beam (DRIBs) project [1]. It is a new in-flight facility installed on the primary beam line of the U-400M cyclotron for the study of exotic nuclear systems with atomic number $Z < 20$. In the experiment, a primary beam of ^{15}N the from U-400M cyclotron with an energy of 49.7 MeV/n bombarded a beryllium target. The separator was used to produce a ^{6}He secondary beam with an intensity of 10^5 pps. The beam energy was determined by the time-of-flight technique over a 12 m base, while ion identification was performed with the ΔE-ToF method. Beam tracking on target was performed with Multi-Wire Proportional Chambers (MWPC) [2, 3]. Deuterated polyethylene foil was used as the target.

The reaction products were measured with the use of two telescopes: one to detect hydrogen (d-telescope) and one to detect He ions (He-telescope). Both telescopes consisted of 1 mm thick Double Sided Strip Detectors as a energy loss detector, ΔE and an array of 16 CsI(Tl) crystals each coupled with a Hamamatsu R9880U PMT and used as a total kinetic energy detector, E. The scheme of the experimental setup is presented in Fig. 1.

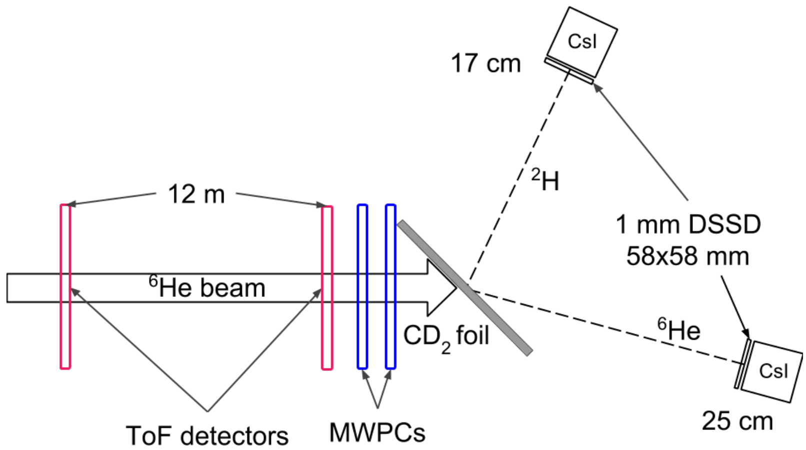

Figure 1: A scheme of the experimental setup.

The measurement was performed in three runs, with the d-telescope covering the following angular ranges in the laboratory frame: 25°–45°, 40°–60° and 55°–75°. The He-telescope was fixed at a position covering the range from 5° to 25°. Coincidence of deuterons in the d-telescope with ^{6}He in the He-telescope was determined as the best way to identify the elastic scattering process. Since even the first excited state of ^{6}He immediately decays into ^{4}He and two neutrons, one can distinguish between elastic and inelastic scattering. Isotope identification is obtained through an analysis of the ΔE-E spectra. In the range of lower deuterium energies the ΔE-E particle identification method is not possible and only the correlation between the angles of the scattered particles can be used as a method for identification of the elastic scattering. The number of recorded counts after normalization to the number of particles impinging on the physical target is presented in Fig. 2 as a function of CM angle.

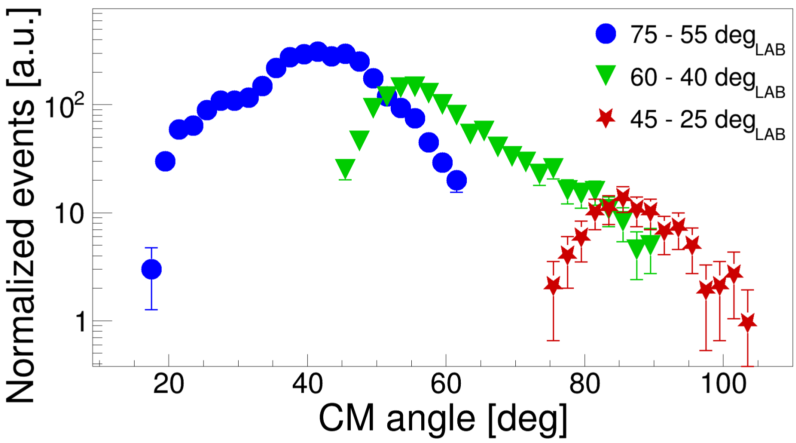

Figure 2: Normalized event numbers obtained at different CM angles for the elastic scattering channel ^{2}H(^{6}He,^{6}He) at E_{CM} = 39 MeV. Different colours correspond to results obtained at three different angular ranges of the d-telescope.

The geometrical distribution of the particles on the target causes a decrease in detection efficiency, which in turn leads to a decrease in the event count rate on the edges of each of the ranges. A Monte Carlo simulation of the experiment using the Geant4 package will be used to calculate the detection efficiency in order to obtain the differential cross-section for the elastic scattering of ^{6}He on deuterium.

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D.2 β-delayed neutron emission properties relevant to understanding the formation of the Rare Earth r-process Peak (REP) measured with BRIKEN

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Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

A new measurement campaign using the BRIKEN detector array and aimed at the determination of new β-delayed branching ratios was performed at the Radioactive Ion Beam Factory at the RIKEN Nishina Research Center (Wako, Japan) in autumn 2018. The BRIKEN setup is the world's largest array of ^{3}He counters [1, 2] dedicated to decay spectroscopy and is aided by the highly segmented Advanced Implantation Detector Array (AIDA) [3]. At the RIBF ^{238}U projectiles were accelerated to 345 MeV per nucleon and struck a production target of ^{9}Be. The separated and transmitted exotic neutron-rich nuclei were implanted into the stacked double side silicon-strip detectors (DSSSDs) of AIDA. The AIDA detector was surrounded by the BRIKEN neutron detector, which detects emitted neutrons in time correlation with beta decays from the implanted ions (β-delayed neutrons). The detector is a hybrid setup composed of an array of 140 ^{3}He counters mounted in a high-density polyethylene moderator (HDPE). The setup also includes two high-purity Germanium clover detectors for precision gamma spectroscopy. The setup configuration for this experiment is shown in Fig. 1.

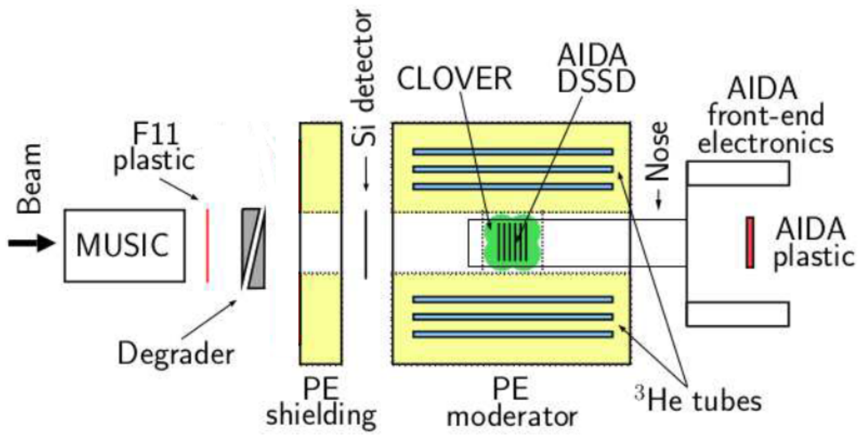

Figure 1: The experimental setup at the RIKEN Laboratory [4]. The drawing is not to scale.

This experiment was focused on the study of the β-delayed neutron emission probabilities (Pn), half-lives and masses of very neutron-rich isotopes, which are most important to an understanding of the formation of the rare earth peak (REP) during r-process nucleosynthesis. The main mass region of interest for this campaign was around A=160. The separator settings were defined for the maximum intensity of ^{161}Pm. The particle identification 2-dimensional plot (PID) for this BigRIPS setting is shown in Fig. 2. These are preliminary data, the displayed statistics was collected during $\sim$ 30 h of measurements and will be improved during a full off-line analysis, which is ongoing.

This research was also sponsored by 2017/01/X/ST2/01144 from the National Science Center, Poland.

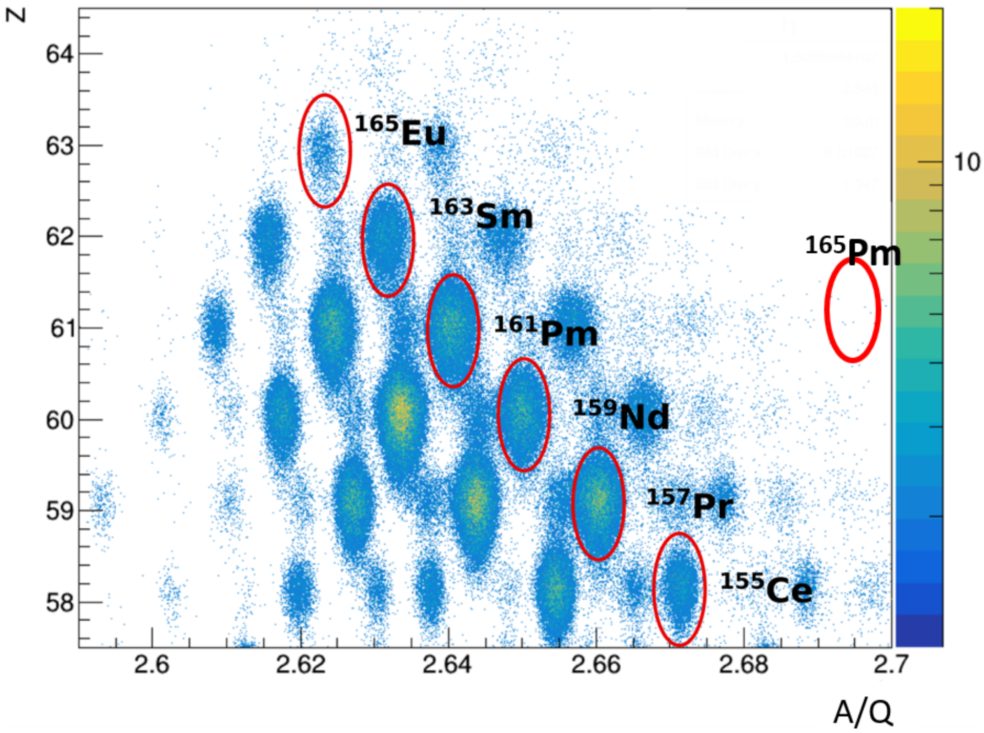

Figure 2: The particle identification 2 dimensional plot (PID) collected in ~ 30 h of measurements.

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D.3 First experiments with NEDA and AGATA at GANIL

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1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy

A group at HIL have participated in the construction of the new NEutron Detection Array (NEDA) since 2007. This project, pursued by a broad international collaboration, was covered in contributions to earlier editions of the HIL annual report [1] and described in more detail in several regular papers, see [2, 3] and references therein. The primary application of NEDA is to act as a neutron multiplicity filter in experiments in which γ ray detectors are used to study the properties of exotic proton-rich nuclei, produced in-beam in fusion-evaporation reactions. In this kind of experiment the efficiency and quality of the neutron detection are the main factors which set the feasibility limits of studies of more and more exotic nuclei.

The inherent property of fast neutron detectors is that they also detect γ rays with high efficiency. As far as the quality of the detection is concerned, the most important limiting parameter is thus the probability that a detected γ ray is misinterpreted as a neutron, $P_{\gamma\to n}$. Values of $P_{\gamma\to n} \lessapprox 0.005$ are expected for NEDA. The detected neutrons can be distinguished from γ rays by setting limits in 3 dimensional space of the time-of-flight, shape of the signal and amount of light detected (see Fig. 1). Other methods of the discrimination are also evaluated (see Ref. [4]). Note that in NEDA applications, the detection of neutrons, which are rare, takes place in a high γ ray multiplicity environment.

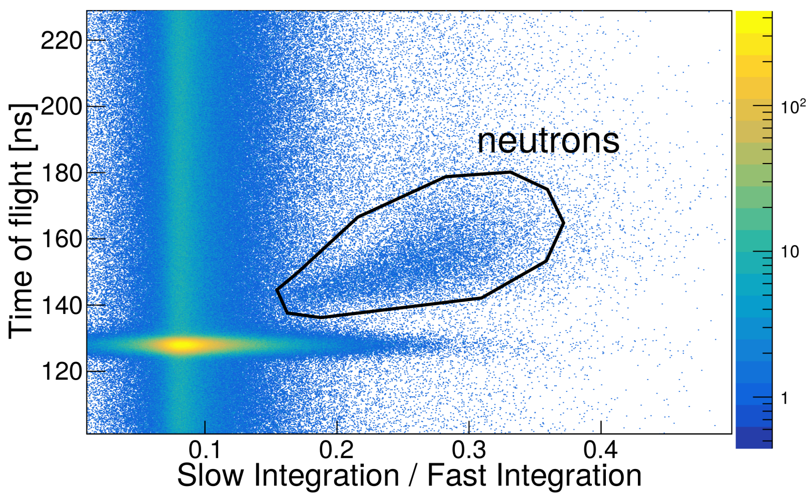

Figure 1: Discrimination of γ rays and neutrons using the time-of-flight and shape of the signal.

NEDA will ultimately consist of 355 identical detectors containing liquid scintillator (approx. 3 liters in each single detector), located in the front half of the solid angle around the target, at a distance of about 1 m from it. NEDA is being built in stages. In 2018 the construction of NEDA Phase1 was completed. Consecutively, the setup of the NEDA array, the Diamant charged particle detector [5] and 1π AGATA [6] was commissioned in-beam at GANIL, Caen, France, and five experiments were run in spring and summer 2018, operating for a total of 1136 hours of beam time. In these studies 54 NEDA detectors placed at forward angles were accompanied by 42 Neutron Wall detectors arranged in an arch placed at angles close to 90° with respect to the beam direction. This geometry, shown in Fig. 2, covers 1.60π of the solid angle.

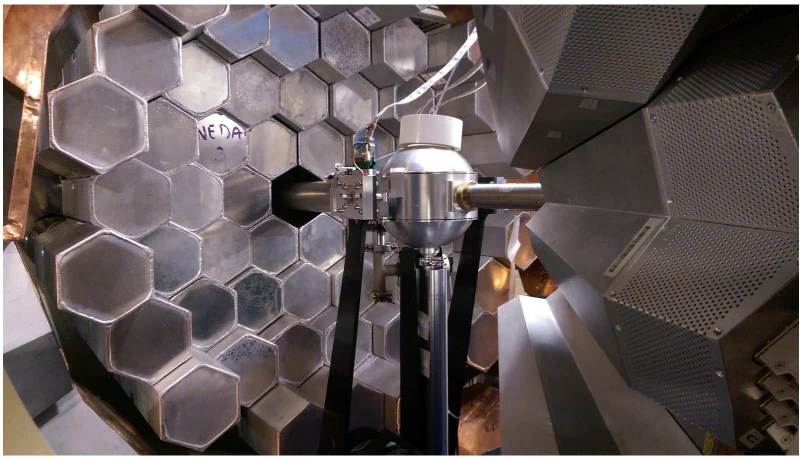

Figure 2: NEDA with AGATA at GANIL. From right to left (the beam direction): AGATA clusters, ion guide, target chamber with DIAMANT inside, NEDA array. Two triple Neutron Wall detectors are visible at the lower left corner.

The physical phenomena addressed by these experiments were: (i) isospin symmetry breaking for $A = 63$ and 71 mirror nuclei, (ii) two-body neutron interactions, single-particle energies and core-excitations derived from excited states of $^{102\text{-}103}$Sn, (iii) isoscalar pairing in ^{88}Ru, and (iv) octupole and quadrupole correlations of xenon isotopes. The analysis of the collected data is in progress.

The Warsaw group is concentrating on the analysis of the E703 experiment data in which γ rays emitted from excited states of the ^{102,103}Sn nuclei should be observed. This experiment, aimed at nuclei produced with extremely low cross sections (of the order of a few microbarns), in particular requires careful optimization of the treatment of NEDA signals. This can be done off-line using the digitized waveforms of the signals, stored during the experiments.

Acknowledgements

The Polish contribution to NEDA and related investigations of rare proton-rich isotopes is supported by the Polish National Science Center (grants nos. 2017/25/B/ST2/01569 2016/22/M/ST2/00269, and 2014/14/M/ST2/00738), COPIN-IN2P3, COPIGAL, and POLITA projects.

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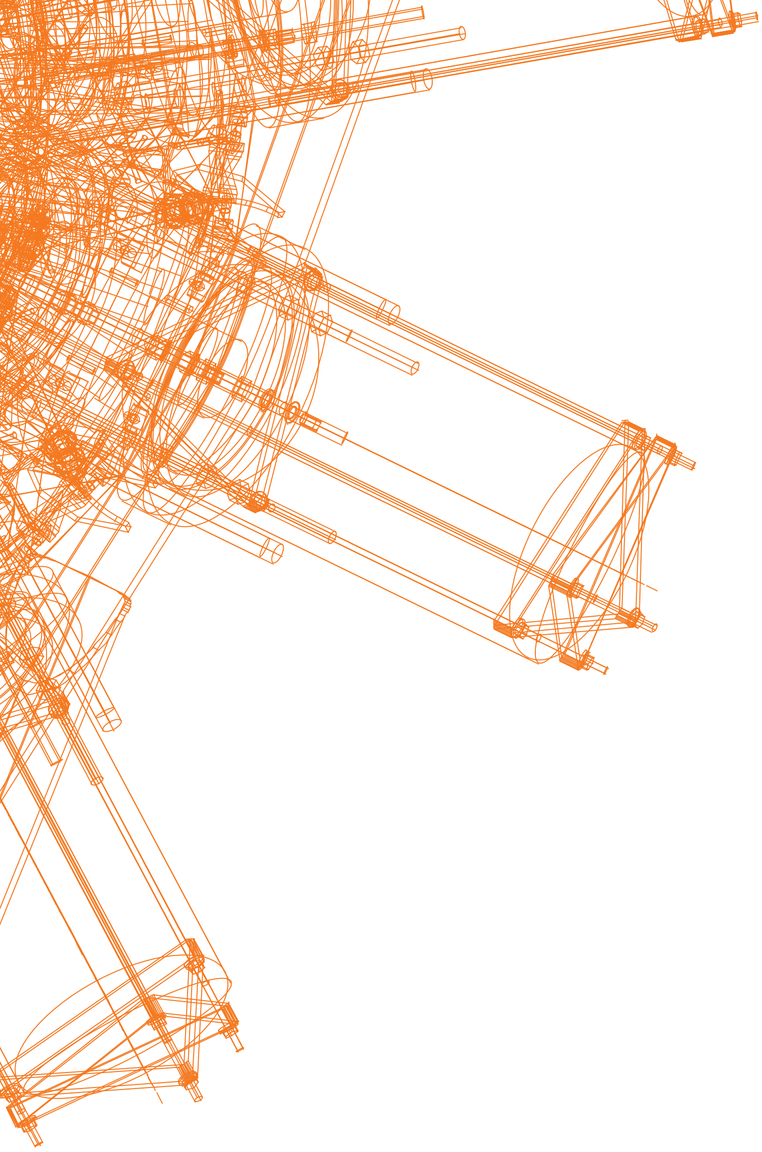
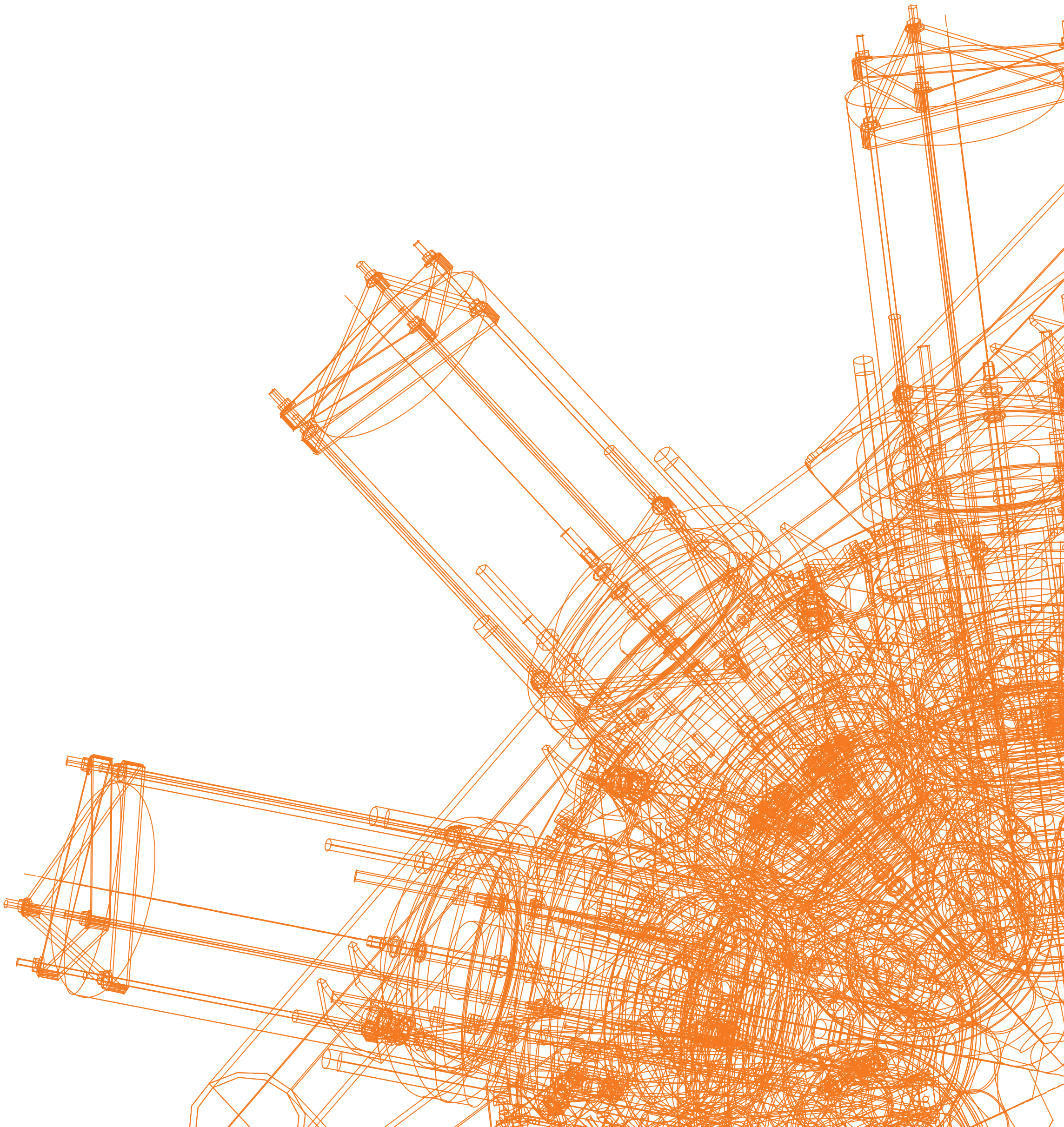


Part E
Appendices



E.1 List of experiments performed at HIL in 2018

A list of the experiments performed in 2018 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;
- AGH Kraków — AGH University of Science and Technology, Kraków, 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 Center for Heavy Ion Research, Darmstadt, Germany;
- IB JKU Kielce — Jan Kochanowski University, Institute of Biology, Kielce, Poland;
- IFIN-HH Bucharest — 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;
- ICBM Warszawa — Institute of Ceramics and Building Materials, Dept. of Ceram. Techn., Warszawa, Poland;
- 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 Center "Kurchatov Institute", Moscow, Russia;
- SU Sofia — Sofia University "St. Kliment Ohridski", Sofia, Bulgaria;
- 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;
- US Surray — University of Surrey, Guildford, Surrey, United Kingdom;
- 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.

$^{10}B^{+2}$ — 56 MeV — EAGLE 12.02–23.02
HIL068 — Lifetime measurements of the I=10^{+} chiral state in ^{128}Cs with HPGe–LaBr–LaB2 triple coincidences (E. Grodner, J. Srebrny)
IFIN-HH Bucharest, FP UW, NCNR Świerk, HIL

$^{12}C^{+2}$ — 45 MeV — Radiobiology 8.10–12.10
HIL078-2 — Particle track structure for carbon ions (M. Pietrzak, A. Bantsar)
NCNR Świerk, FP UW, HIL

$^{20}Ne^{+3}$ — 50 MeV — EAGLE, ICARE 22.10–26.10
HIL001 — Students' workshop
HIL

$^{12}C^{+3}$ — 92 MeV — Radiobiology 5.11–9.11
HIL069 — Examination of radiation damage in superconductors (Z. Szefliński, P. Pęczkowski)
HIL, ICBM, AGH Kraków

$^{12}C^{+3}$ — 92 MeV — Radiobiology 13.11–16.11
HIL076b — Particle track structure for carbon ions (A. Bantsar, Z. Szefliński)
NCNR Świerk, HIL

$^{14}N^{+2}$ — 33 MeV — EAGLE 19.11–23.11
HIL073 — Spin deorientation measurements in the Coulomb excitation of ^{148}Nd with the plunger device (A. Tucholski)
HIL

$^{10}B^{+2}$ — 34 MeV — ICARE 26.11–7.12
HIL071 — Study of the nucleon transfer reactions in $^{10}B+^{12}C$ and $^{10}B+^{16}O$ interactions at energies near the Coulomb barrier for nuclear astrophysics (N. Burtebayev, W. Trzaska)
INP Almaty, UJ Jyväskylä, GENU Astana, INP Tashkent, JINR, AUFS Antalya, NRCKI Moscow, SPSU Saint-Petersburg, HIL

^{58}Ni 7.03, 29.03–30.03
HIL000 — Test of new beams from the ECR (P. Gmaj)
HIL

E.2 Degrees and theses completed in 2018 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
Korelacje oktupolowe w jądrach atomowych z obszaru $N \sim 88$
Pear-shaped Nuclei in the $N \sim 88$ mass region
Supervisors: dr hab. L. Próchniak, dr P. Napiorkowski, dr W. Korten, dr M. Zielińska. (program cotutelle) Expected completion date: 2020.

Tomasz Marchlewski, Faculty of Physics, University of Warsaw
Pomiar czasów życia jądrowych stanów wzbudzonych w izotopie ^{124}Cs — badanie mechanizmu spontanicznego łamania symetrii chiralnej
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 date: 2019.

Mateusz Pęgier, Faculty of Chemistry, University of Warsaw
Wykorzystanie techniki ekstrakcji do fazy stałej do wydzielania i zatężania jonów skandu
Application of solid phase extraction for separation and preconcetration of scandium ions
Supervisor: prof. dr hab. K. Pyrzyńska. Expected completion date: 2019.

Olga Saeed Mohamed Nassar, Faculty of Physics, Warsaw University of Technology
Optyka jonowa w centrum cyklotronu U-200P
Ion trajectories in the central region of the U-200P cyclotron
Supervisors: dr hab. M. Palacz, dr I. Ivanenko. Expected completion date: 2021.

Mateusz Sitarz, Faculty of Physics, University of Warsaw and Faculty of Science and Technology, University of Nantes
Badanie produkcji nowych izotopów medycznych z wykorzystaniem cyklotronu
Research on the production of new medical radioisotopes with a cyclotron
Supervisors: prof. dr hab. T. Matulewicz, dr A. Trzcińska, prof. F. Haddad. (program cotutelle) Expected completion date: 2019.

Łukasz Standyło, National Centre for Nuclear Research, Świerk
Badanie mechanizmu wychwytu i termalizacji strumieni jonów i atomów wprowadzonych do plazmy wytwarzanej metodą elektronowego rezonansu cyklotronowego
Investigation of the capture and thermalization mechanism of ion and atom beams injected into plasma produced by an electron cyclotron resonance
Supervisor: prof. dr hab. K. Rusek, dr K. Sudlitz. Expected completion date: 2021.

Bogumił Zalewski, Faculty of Physics, University of Warsaw
Badanie oddziaływania ^{6}He+d
Study of the ^{6}He+d interaction
Supervisor: prof. dr hab. K. Rusek. Expected completion date: 2021.

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

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

Feruzjon Ergashev, Institute of Nuclear Physics, Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
Study of the nucleon transfer reactions in the ^{10}B+^{16}O interaction at the energies near the Coulomb barrier for nuclear astrophysics
Supervisor: prof. S. Artemov. Expected completion date: 2021.

Bakytbek Mauey, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
Investigation of the elastic scattering of ^{15}N ions from 1p-shell nuclei at energies near the Coulomb barrier
Supervisor: prof. A. Morzabayev. Expected completion date: 2019.

Maulen Nassurlla, Al-Farabi Kazakh National University, Almaty, Kazakhstan
Effects of cluster structure of stable boron and lithium isotopes in forming the products of nuclear reaction in the interaction with deuterium and helium isotopes
Supervisor: prof. N. Burtebayev. Expected completion date: 2019.

Maria Pęgier, Faculty of Chemistry, University of Warsaw
Macrocyclic compounds labeled with metallic isotopes for application in positron emission tomography
Supervisors: prof. dr hab. Krystyna Pyrzyńska, dr Krzysztof Kilian. Expected completion date: 2019.

Daniel Andrzej Pięta, Faculty of Electronics and Information Technology,
Warsaw University of Technology
Metoda oceny jakości wyników z eksperymentów wzbudzeń kulombowskich z wykorzystaniem algorytmu genetycznego
Evaluation method based on a genetic algorithm for results of Coulomb excitation experiments
Supervisors: dr hab. inż. P. Bilski, dr P. Napiorkowski. Expected completion date: 2021.

Auganbek Sabidolda, Al-Farabi Kazakh National University, Almaty, Kazakhstan
Study of nucleon transfer reactions in the ^{10}B+^{12}C interaction at energies near the Coulomb barrier for nuclear astrophysics
Supervisor: prof. N. Burtebayev. Expected completion date: 2022.

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

Monika Adamowicz, Faculty of Chemistry, University of Warsaw
Complexes of scandium for molecular imaging purposes
Supervisors: prof. dr hab. K. Pyrzyńska, dr A. Sentkowska. MSc thesis. Expected completion date: 2019

Monika Rykała, Faculty of Physics, University of Warsaw
Synteza radiofarmaceutyków znakowanych izotopem skandu-44
Synthesis of radiopharmaceuticals labeled with the scandium-44 isotope
Supervisor: dr Krzysztof Kilian. BSc thesis completed in July 2018.

Tomasz Lehmann, Faculty of Physics, Warsaw University of Technology
Badanie struktury elektromagnetycznej stanów wzbudzonych w jądrze ^{107}Ag
Electromagnetic structure studies of excited states in ^{107}Ag
Supervisors: dr K. Wrzosek-Lipska, prof. dr hab. P. Magierski. MSc thesis. Expected completion date: 2019.

E.3 Publications

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

M.L. Avila, L.T. Baby, J. Belarge, N. Keeley, K.W. Kemper, E. Koshchiy, A.N. Kuchera, G.V. Rogachev, K. Rusek, and D. Santiago-Gonzalez. *Sub-Coulomb He-3 transfer and its use to extract three-particle asymptotic normalization coefficients.* Phys. Rev. C **97**, 014313 (2018).

A. Boso, S.M. Lenzi, F. Recchia, J. Bonnard, A.P. Zuker, S. Aydin, M.A. Bentley, B. Cederwall, E. Clement, G. de France, A. Di Nitto, A. Dijon, M. Doncel, F. Ghazi-Moradi, A. Gadea, 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, J. Timar, and J.J. Valiente-Dobon. *Neutron Skin Effects in Mirror Energy Differences: The Case of Mg-23-Na-23.* Phys. Rev. Lett. **121**, 032502 (2018).

N. Burtebayev, M. Nassurlla, M. Nassurlla, N. Saduyev, A. Sabidolda, D. Zazulin, T.K. Sadykov, S.B. Sakuta, A. Trzcińska, and M. Wolińska-Cichocka. *Scattering of alpha-particles by B-11 nuclei at an energy of 40 MeV and role of the exchange mechanism with transfer of Li-7.* Int. J. Mod. Phys. E **27**, 1850094 (2018).

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M. Ciebiera, J. Szymańska-Majchrzak, A. Sentkowska, K. Kilian, Z. Rogulski, G. Nowicka, G. Jakiel, P. Tomaszewski, and M. Wlodarczyk. *Alpha-Tocopherol Serum Levels Are Increased in Caucasian Women with Uterine Fibroids: A Pilot Study.* BioMed Res. Int. 6793726 (2018).

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D. Dell'Aquila, I. Lombardo, G. Verde, M. Vigilante, G. Ausanio, A. Ordine, M. Miranda, M. De Luca, R. Alba, L. Augey, S. Barlini, E. Bonnet, B. Borderie, R. Bougault, M. Bruno, A. Camaiani, G. Casini, A. Chbihi, M. Cicerchia, M. Cinausero, D. Fabris, Q. Faible, L. Francalanza, J.D. Frankland, L. Grassi, F. Gramegna, D. Gruyer, A.J. Kordyasz, T. Kozik, R. LaTorre, N. Le Neindre, O. Lopez, T. Marchi, L. Morelli, P. Ottanelli, M. Parlog, G. Pastore, G. Pasquali, S. Piantelli, D. Santonocito, A.A. Stefanini, G. Tortone, S. Valdre, and E. Vient. *OSCAR: A new modular device for the identification and correlation of low energy particles.* Nucl. Instrum. Methods Phys. Res. A **877**, 227 (2018).

S. Dutt, M. Saxena, R. Kumar, A. Jhingan, A. Agarwal, A. Banerjee, R.K. Bhowmik, C. Joshi, J. Kaur, A. Kumar, M. Matejska-Minda, V. Mishra, I.A. Rizvi, A. Stolarz, H.J. Wollersheim, and P.J. Napiorkowski. *Re-measurement of reduced transition probabilities in Ba-132.* Acta Phys. Pol. B **49**, 535 (2018).

A. Ertoprak, B. Cederwall, C. Qi, M. Doncel, U. Jakobsson, B.M. Nyako, G. Jaworski, P. Davies, G. de 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, H. Li, C. Michelagnoli, V. Modamio, J. Nyberg, M. Palacz, C.M. Petrache, F. Recchia, M. Sandzelius, M. Siciliano, J. Timar, J.J. Valiente-Dobon, and Z. G. Xiao. *M1 and E2 transition rates from core-excited states in semi-magic Ru-94.* Eur. Phys. J. A **54**, 145 (2018).

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E.3.2 Other publications in journals and conference proceedings not included in the JCR list

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E.3.3 Articles in books

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E.4 Seminars

E.4.1 Seminars co-organized by HIL

Seminars organized 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

M. Lewitowicz — GANIL, Caen, France 11 January 2018
Quo Vadis Nuclear Physics in Europe?

M. Kmiecik — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland 18 January 2018
Pomiary rozpadu gamma kolektywnych wzbudzeń jąder atomowych wytwarzanych z zastosowaniem wiazek protonow w CCB IFJ PAN w Krakowie
Measurements of the gamma decay of collective excitations of atomic nuclei produced using proton beams at CCB IFJ PAN in Krakow

A. Kowalska — Institute of Physics, University of Szczecin, Szczecin, Poland 25 January 2018
Czy pokrywanie się śladów jonowych może wytłumaczyć kwadratową zależność krzywych dawka-efekt obserwowanych dla aberracji chromosomowych?
Can overlapping of ion tracks explain the square dependence of dose-effect curves observed for chromosomal aberrations?

Z. Patyk — National Centre for Nuclear Research 1 March 2018
Wyznaczanie mas dla nuklidow dalekich od ścieżki stabilności
Mass determination of nuclides far from stability

M. Palacz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 8 March 2018
Układ AGATA-NEDA, nowe narzędzie do badania struktury jąder atomowych bogatych w protony
The AGATA-NEDA setup, a new tool to study proton rich nuclei

K. Siwek-Wilczyńska — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland 15 March 2018
Sympozjum SHE 2017 "Challenges in studies of super heavy nuclei and atoms"

J. Samorajczyk — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 12 April 2018
Jak pomiar korelacji kątowych w EAGLE wpłynął na wyniki badań jądra ^{140}Sm widziane w REX-ISOLDE
The influence of the angular correlation measurements performed with EAGLE on ^{140}Sm studies at REX-ISOLDE

K. Mazurek — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland 19 April 2018
Theoretical description of the de-excitation of hot nuclei

G. Wrochna — National Centre for Nuclear Research 26 April 2018
Polska energetyka jądrowa — fakty i mity
Polish nuclear power — facts and myths

L. Próchniak — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 10 May 2018
Własności oktupolowej przestrzeni kolektywnej
Properties of octupole collective space

J. Rzadkiewicz — National Centre for Nuclear Research 17 May 2018
Pierwsza eksperymentalna obserwacja procesu wzbudzenia jądra atomowego poprzez wychwyt elektronu do powloki elektronowej atomu
First experimental observation of nuclear excitation by electron capture

P. Walker — Department of Physics, University of Surrey, Guildford, UK 24 May 2018
Aspects of nuclear isomerism and shape coexistence

P. Wojtowicz — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland 7 June 2018
Składowanie i unieszkodliwianie odpadów promieniotwórczych
Storage and disposal of radioactive waste

J.L. Wood — School of Physics, Georgia Institute of Technology, Atlanta, GA, USA 14 June 2018
Particle-core coupling in deformed nuclei: odd-A and doubly even-A identical bands

K. Rusek, A. Trzcińska, M. Sitarz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 4 October 2018
Od antyprotonów do izotopow medycznych; dorobek naukowy profesora Jerzego Jastrzębskiego
From anti-protons to medical isotopes; professor Jerzy Jastrzębski's academic achievements

K.W. Fornalski — PGE EJ1, Warsaw, PolandEx-Polon Laboratory, Łazy, Poland 11 October 2018
Biofizyka radiacyjna: ryzyko nowotworowe dla niskich dawek promieniowania jonizującego
Radiation biophysics: cancer risk for low doses of ionizing radiation

A. Fijałkowska — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland 18 October 2018
Spektroskopia neutronów opoźnionych po rozpadzie beta
Spectroscopy of beta-delayed neutrons

A. Merzlaya — Jagiellonian Univ., Kraków, Poland 8 November 2018
Open charm measurements at SPS energies in the NA61/SHINE experiment

A. Staszczak — Inst. of Physics, Maria Curie-Sklodowska Univ., Lublin, Poland — 15 November 2018
Toroidalne izomery w najcięższych jądrach atomowych
Toroidal isomers in the most heavy nuclei

M. Klusek-Gawenda — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland — 22 November 2018
Ultraperyferyczne zderzenia ciężkich jonów źródłem produkcji par cząstek i rozpraszania światla na świetle
Ultraperipheral heavy ion collisions as a source of particle pairs and light-by-light scattering

G. Kamiński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 29 November 2018
Status of the new fragment separator Acculinna-2 and the first experiments

K. Siwek-Wilczyńska — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland — 6 December 2018
Badania stosunków izomerycznych w reakcjach typu (n,2n) mode nadprzewodnikowy gęstości poziomów jądrowych
Studies of isomeric ratios in reactions of the (n, 2n) type and superconductivity density of nuclear levels

J. Srebrny — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 6 December 2018
Badania spektroskopowe i wyprawa do Dubnej
Spectroscopic studies and an expedition to Dubna

Z. Szefliński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 6 December 2018
Zimna fuzja
Cold fusion

A. Turos — Institutge of Electronic Materials Technology, Warszawa, Poland — 6 December 2018
Mikroanaliza jądrowa na Hożej
Nuclear microanalysis at Hoża

M. Wolińska-Cichocka — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 13 December 2018
BRIKEN — Badania własności rozpadów beta z emisją opóźnionych neutronów w jądrach neutrono-nadmiarowych
BRIKEN — Studies of the properties of beta decays with the emission of delayed neutrons in neutron-rich nuclei

K. Cichy — Adam Mickiewicz University, Poznań, Poland — 20 December 2018
Nucleon structure from Lattice Quantum Chromodynamics

E.4.2 Other seminars organized at HIL

Internal semi-formal HIL seminars

M. Sitarz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 21 March 2018
Badania w zakresie medycyny nuklearnej w Arronax
Nuclear medicine studies at Arronax

R. Wolski — Joint Institute for Nuclear Research, Dubna, Russia — 25 April 2018
Nowe objaśnienie zjawiska zwiększonego przekroju czynnego w podbarierowej fuzji ciężkich jonów
New explanation of the phenomenon of increased cross-section in sub-barrier fusion of heavy ions

A. Sentkowska — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 16 May 2018
Poszukiwanie nowych ligandów do analizy radiochemicznej
The search for new ligands for radiochemical analysis

J.L. Wood — School of Physics, Georgia Institute of Technology, Atlanta, GA, USA — 13 June 2018
The challenge of establishing triaxial shapes in nuclei

T. Abraham — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 26 September
Hands on Workshop on Operation, Test and Repair of Ge Detectors

Y. Stepanenko — Institute for Nuclear Research, Ukrainian National Academy of Sciences, Kyiv, Ukraine — 14 November 2018
Development of Hadron Therapy Technology in the Kyiv Institute for Nuclear Research

E.4.3 External seminars given by HIL staff

M. Palacz — 26 January 2018
NEDA — status of
The Annual PARIS Collaboration Meeting, Warsaw, Poland

M. Filipek — 17 March 2018
Nanodozymetria — badanie wydajności jonów w nanodozymetrze Jet Counter
Nano-dosimetry — ion efficiency testing in the Jet Counter nano-dosimeter
Sympozjum doktoranckie Warszawa – Fizyka – Kraków, Kraków, Poland

K. Wrzosek-Lipska 22–25 May 2018
Experimental evidences of shape coexistence in the Z=82 and A∼100, N∼60 regions
The 9th international workshop "Quantum Phase Transitions in Nuclei and Many-body Systems", Padova, Italy

M. Filipek 24 May 2018
Nanodozymetria – badanie wydajności jonów w nanodozymetrze Jet Counter
Nano-dosimetry – ion efficiency testing in the Jet Counter nano-dosimeter
Ogólnopolska Konferencja Fizyka Medyczna - Farmacja Fizyczna, Warsaw, Poland

M. Sitarz 24 May 2018
Cyklotronowa produkcja medycznych radioizotopów skandu
Cyclotron production of medical radioisotopes of scandium
Fizyka Medyczna Farmacja Fizyczna Warsaw, Poland

A. Sentkowska 11–13 June 2018
Application of hydrophilic interaction liquid chromatography in the speciation analysis of selenium
Euro Chemistry Conference, Rome, Italy

M. Sitarz 11–15 June 2018
Production of medically interesting ^{97}Ru via ^{nat}Mo(alpha,x) above 40 MeV at ARRONAX
15th Varenna Conference on Nuclear Reaction Mechanisms, Varenna, Italy

J. Srebrny 25–29 June 2018
EAGLE – GAMMAPOOL 2010-2018 cooperation
3rd Workshop of the Nuclear Spectroscopy Instrumentation Network of ENSAR2 (NuSpIn), NUSPIN 2018, Valencia, Spain

A. Sentkowska 1–5 July 2018
Application of hydrophilic interaction liquid chromatography in the speciation analysis of selenium
Zastosowanie chromatografii oddziaływań hydrofilowych w analizie specjacyjnej selenu
X Polska Konferencja Chemii Analitycznej, Lublin, Poland

K. Wrzosek-Lipska 5–10 August
Shape coexistence studied with Coulomb excitation in the neutron-deficient Z=82 region
Nuclear Structure (NS2018), MSU, Michigan, USA

K. Kilian 26 August – 2 September 2018
Separation of scandium from solid targets for PET, principles and experience
Zakopane Conference on Nuclear Physics, Zakopane, Poland

M. Sitarz 27–31 August 2018
Research on the production of ^{97}Ru with the use of a Radionuclide Yield Calculator at ARRONAX
17th International Workshop on Targetry and Target Chemistry, Coimbra, Portugal

M. Palacz 17 September 2018
Neda performance (a progress report)
NEDA Collaboration Meeting, Istanbul, Turkey

M. Pęgier 20–21 September 2018
Adsorption of Sc(III) on oxidized carbon nano-tubes for separation and preconcentration from aqueous solutions - study of the mechanism
14th International Student Conference Modern Analytical Chemistry, Prague, Czech Republic

K. Rusek 26–30 September 2018
Studies of SHE in Poland — the future of experimental nuclear physics at HIL
XXV Nuclear Physics Workshop, Kazimierz Dolny, Poland

M. Sitarz 6 October 2018
Research on monoelement theranostic pairs
ENSAR NEXT meeting, Katania, Włochy

U. Kaźmierczak 11 October 2018
Dosimetry in radiobiological studies at HIL
Nuclear Physics Research - Technology coaction, Warsaw, Poland

A. Stolarz 12 October 2018
Calcium targets for production of medical Sc radioisotopes in reactions with p, d, or alpha projectiles
29th INTDS, MSU, East Lansing, USA

K. Wrzosek-Lipska 5–9 November 2018
Deformation and shape coexistence studied with Coulomb excitation in neutron-deficient Po and Hg isotopes
Shapes and Symmetries in Nuclei from Experiment to Theory (SSNET'2018 Conference) CNRS, Gif-sur-Yvette, France

E.4.4 Poster presentations

M. Sitarz 17–19 April 2018
Medical scandium radioisotopes produced by proton, deuteron and alpha particle beams
ENSAR2 Town Meeting, Groningen, Netherlands

Ł. Standyło 17–19 April 2018
Status of the ECRIS multi-test stand at HIL
ENSAR2 Town Meeting, Groningen, Netherlands

M. Filipek 24 May 2018
Wydajność detekcji jonów w nanodozymetrze Jet Counter
Ogólnopolska Konferencja Fizyka Medyczna — Farmacja Fizyczna, Warsaw, Poland

M. Pęgier 8 June 2018
Wykorzystanie nanorurek węglowych do zatężania i wydzielania jonów skandu
XV Warszawskie Seminarium Doktorantów Chemików ChemSession'18, Warsaw, Poland

M. Filipek 18–22 June 2018
Review of recent Jet Counter experiments
Sixth International Conference of Radiation and Applications in Various Fields of Research, Ohird, Macedonia

J. Choiński 2–6 September
Heavy Ion Laboratory, University of Warsaw - development of experimental set-ups connected to cyclotrons
41st European Cyclotron Progress Meeteng, Dubna, Russia

E.4.5 Lectures for students and student laboratories

K. Kilian summer semester of the academic year 2017/2018, 60 hours
Pracownia radiofarmaceutyków
Laboratory of Radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2017/2018, 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 2017/2018, 30 hours
Techniki jądrowe w diagnostyce i terapii medycznej
Nuclear techniques in Medical Diagnostics and Therapy
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Wrzosek-Lipska summer semester of the academic year 2017/2018, 15 hours
Wzbudzenie kulombowskie — narzędzie do badania jąder atomowych w ramach Wykłady monograficzne z fizyki jądrowej
Coulomb excitation — a tool for studying atomic nuclei in the Monographic lectures on nuclear physics series
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2018/2019, 20 hours
Zarzadzanie Środowiskiem
Environmental Management
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2018/2019, 30 hours
Metody izotopowe i chemia radiofarmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2018/2019, 30 hours
Energetyka konwencjonalna, odnawialna i jądrowa
The conventional, renewable and nuclear power industries
Faculty of Physics, University of Warsaw, Warszawa, Poland

E.4.6 Science popularization lectures

M. Palacz 16 November 2018, lecture for students of the Warsaw Univ. of Technology

Środowiskowe Laboratorium Ciężkich Jonów (60 min)
The Heavy Ion Laboratory

A. Sentkowska lectures at The Science Festival

Przypadki chodzą po ludziach czyli o przypadkowych odkryciach w chemii (2 x 60 min)
Accidents will happen, accidental discoveries in chemistry

Z. Szefliński lectures for middle school pupils

Radon wokół nas (2 x 60 min)
Radon around us

E.5 Honors and Awards

The Rector of the University of Warsaw awards

In 2018 the following employees of the Heavy Ion Laboratory received the Rector of the University of Warsaw award:
Eliza Balcerowska, Jarosław Choiński, Przemysław Gmaj, Wiesław Kalisiewicz, Jolanta Matuszczak, Paweł Napiorkowski, Anna Odziemczyk, Ewa Sobańska, Krzysztof Sosnowski, Łukasz Standyło, Lidia Strzelczyk, Katarzyna Wrzosek-Lipska, Magdalena Zawal.

E.6 Laboratory staff

Director:	Krzysztof Rusek
Deputy directors:	Paweł Napiorkowski
	Jarosław Choiński
Financial executive:	Eliza Balcerowska

Senior scientists:

Jerzy Jastrzębski[a,b], Andrzej Kordyasz[a,c], Marcin Palacz, Ernest Piasecki[a,d], Krzysztof Rusek, Anna Stolarz, Zygmunt Szefliński[a]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Jarosław Choiński, Przemysław Gmaj, Andrzej Jakubowski[e], Grzegorz Jaworski[f], Grzegorz Kamiński[g], Urszula Kaźmierczak, Krzysztof Kilian, Maciej Kisieliński[a,d], Marian Kopka, Michał Kowalczyk, Paweł Matuszczak[a,h], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Krzysztof Olejarczyk[i], Monika Paluch-Ferszt, Wojciech Piątek, Bogdan Radomyski, Olga Saeed Mohamed Nassar[j], Justyna Samorajczyk-Pyśk, Mansi Saxena[d], Aleksandra Sentkowska, Mateusz Sobolewski[a,k], Julian Srebrny[a,d], Łukasz Standyło, Krzysztof Sudlitz[a], Roman Tańczyk, Agnieszka Trzcińska, Andrzej Tucholski, Marzena Wolińska-Cichocka, Katarzyna Wrzosek-Lipska, Bogumił Zalewski[g], Nadia Zandi[l]

Doctoral candidates:

Mateusz Filipek[m], Michalina Komorowska[m], Tomasz Marchlewski[m], Mateusz Pęgier[n], Mateusz Sitarz[m]

Technicians:

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

Administration and support:

Anna Błaszczyk-Duda, Marek Budziszewski, Przemysław Czwarnok[o], Barbara Kowalska[a], Joanna Kowalska, Jolanta Matuszczak, Anna Odziemczyk, Jolanta Ormaniec, Magdalena Piwowarczyk[a], Anna Ratyńska[p], Ewa Sobańska, Lidia Strzelczyk, Andrzej Wiechowski, Katarzyna Włodarczyk[a], Magdalena Zawal

Voluntary scientists:

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

[a] part time
[b] until 19 August
[c] until 30 September
[d] until 31 October
[e] until 31 September
[f] since 1 December
[g] on leave
[h] until 31 July
[i] until 8 September
[j] on maternity leave
[k] until 31 August
[l] since 1 August
[m] PhD student at the Faculty of Physics, University of Warsaw
[n] PhD student at the Faculty of Chemistry, University of Warsaw
[o] until 5 November
[p] since 1 February

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. NCNR
    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 Program 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 Program 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 Jarosław Perkowski (the University of Łódź).

E.9 External HIL users

In 2018 there were **55** external HIL users and visitors from **21** scientific institutions, including 32 people from 9 scientific institutes in Poland, 12 people from 7 scientific institutions in the European Union and associated countries and 11 people from 5 scientific institutes in other countries.

External HIL users and visitors were from:

Poland

- Faculty of Mathematics and Natural Studies, Cardinal Stefan Wyszyński University, Warszawa, Poland
- Faculty of Physics, University of Warsaw, Warszawa, Poland
- National Centre for Nuclear Research, Otwock, Poland
- The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
- University of Silesia, Katowice, Poland
- Inst. of Physics, Maria Curie-Sklodowska Univ., Lublin, Poland
- University of Zielona Góra, Zielona Góra, Poland
- Warsaw University of Technology, Warszawa, Poland
- Wrocław University of Technology, Wrocław, Poland

European Union and associated countries

- Department of Physics, University of Jyväskylä, Finland
- GANIL, Caen, France
- H. Hulubei Nat. Inst. of Phys. and Nucl. Eng., Bucharest, Romania
- IKP, Technical University Darmstadt, Darmstadt, Germany
- Padova University, Padova, Italy
- University of Surrey, Guildford, Surrey, United Kingdom
- Sofia University, Sofia, Bulgaria

Other countries

- Inter University Accelerator Centre, New Delhi, India
- Joint Institute for Nuclear Research, Dubna, Russia
- Institute of Nuclear Physics, Almaty, Kazakhstan
- National Research Center "Kurchatov Institute", Moscow, Russia
- Uzbekistan Academy of Sciences, Institute of Nuclear Physics, Tashkent, Uzbekistan

List of Authors