Heavy Ion Laboratory
University of Warsaw

Annual Report

2018

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Annual Report of the
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The photo on the title page was taken
in front of the HIL building on /? /?

The editors thank Michalina Komorowska and Mateusz Filipek
for their help in collecting and formatting
the information presented in the Appendices to the Report

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ISSN 1895-6726

Cover design:
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Life with 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, 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 bulit and equipped with the heavy ion cyclotron U-200P, accelerating beams of various ions up to energy 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 a 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 being 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 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

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Part A

Laboratory overview and technical developments

A.1 Cyclotron operation in 2018 and tasks carried out in order to improve the cyclotron infrastructure and efficiency

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Operation

In 2018, after two months of operation, the U-200P cyclotron has suffered a serious failure associated with heavy use in recent years. The restoration of the normal functionality of the magnetic and electrical configuration of the acceleration system required intensive work of the technical department of the cyclotron and stopped the planned experimental work by mid-year. Nevertheless, the most of nuclear, biological and application physics experiments planned and approved for 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 labor-intensive involvement in the repair of the accelerating system, the beam development work was continued. It concentrated mainly on obtaining metallic ions from volatile compounds using MIVOC and spattering methods. The results are not yet satisfactory for the much-desired nickel beam which is required for Coulomb excitation of ^{118}Sn experiment, therefore this task will be continued in 2019.

The Program Advisory Committee for the year 2018, has approved the total number of 8 experimental projects (2116 h of the beam time). Three additional runs were planned to complete the experiments approved but not performed in 2017. The 5 projects (1236 h of beam time) have been implemented. The remaining 2 projects were postponed due to J. Jastrzębski passing 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.

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

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

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 fix malfunctioning of the entire cyclotron due to the defects of mechanical parts. The works consisted of:

- writing a 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 the demand of scientists, the cyclotron team worked on expanding the list of available beams, in particular on the preparation of metallic beams as mentioned above.

Unlike previous year, the work was concentrated on the MIVOC method for obtaining Ni beam. This method provided very stable beam current from ECR source on the level of 8 µA of $^{58}Ni^{+9}$. This is 5 times less than required for the experiment. The ECR effectiveness strongly depend on numerous electro-magnetic parameters, plasma chamber impurities, pressure of gases and vapors in plasma, the method of providing microwave energy for plasma heating and other. These parameters has to be properly chosen and optimized. However the mean time needed for each parameter optimization counts 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 a intensity increased by factor 3, but the beam was very unstable.

Further efforts were continued to optimize the operation of ECR sources basing on the special test bench, which was designed and installed in HIL in 2015. This bench was partially financed by NCBiR within the scope of EMILI-EURISOL project and its purpose is to achieve the higher ion currents and longer uninterrupted operation of the source, which is necessary for experiments. The development of the above bench was continued in scope of the European ENSAR 2 project during 2018. The bench however allows to study different physical phenomena occurring in plasma rather than maps the specific production 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 come to its days as they already are more than 30 years old. The spare parts are no longer available in the world market place. It concerns mainly such important components as power tubes GK-11A, thyristors T-160 etc. In 2015 the winners of three tenders for components of the new RF system were selected and in 2016 the two first 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 manufacturing work progress ensuring the highest diligence in the performance of above power stages.

However, the delays in commissioning of the new RF system impresses a large disturbance to 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 refilled and upgraded. A series of infrastructure modernizations was conducted in 2016–2018 as an adaptation to the new RF system installation.

A.2 Status of the ECRIS test stand at HIL

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The ion beam interaction with plasma is important aspect in charge breeding processes. Term "charge breeding" refers to singly charged ion boost to higher charge-state. 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 $^7Li^{+1}$ beam injected to ECRIS operating on argon buffer gas was performed. The experimental setup consist 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. Extraction system consist of three-electrode Einzel lenses [5]. The ECRIS is powered with a 300 Watt, 10 GHz frequency generator.

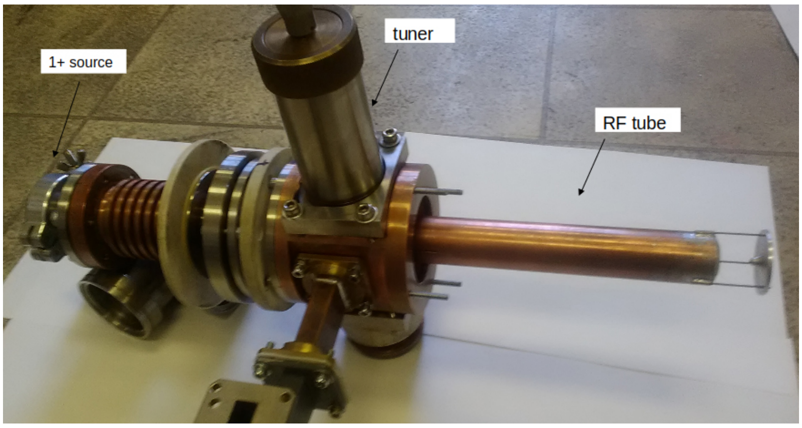

Figure 1: Primary beam injection system. Inside RF tube (coaxial extension of waveguide) puller shape electrode (tube) is mounted for extraction and defocusing of 1^+ beam from the thermal lithium 1^+ ion source.

The optical behaviour 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 (a maximum current was around 3 µA). The thermal 1^+ ion source consists of tungsten filament, cathode and 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. Potential for 1^+ ion source was set to 15 kV. Primary beam measured after analysing magnet without plasma consisted of lithium isotopes only – ^6Li (7%) and ^7Li (93%).

Intensity measurements of the primary Li^{+1} beam passing through Ar plasma were conducted. The preliminary results of 1^+ beam capture by ECR plasma showed the expected effect. A primary beam was captured by the ECR plasma when a proper plasma density is obtained while adjusting microwave power and buffer gas pressure. Whent there is no plasma, the primary beam is passing through the chamber without any effect – there is no interaction with buffer gas molecules. The use of lithium as an ion beam is convenient for these initial tests, but to determine capture efficiency more precisely it is necessary to do measurements for heavier elements. Final measurements are still under preparation. In most cases the intensity of primary beam was decreasing with microwave power increase, while maintaining constant pressure. As an example for the gas pressure of $2.7{\cdot}10^{-6}$ mbar, the primary beam current of ^{7}Li has 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 opposite way and with increasing power the extracted current was higher. Changing plasma density with reduction of operating gas resulted with decrease of secondary beam (Fig. 3). With a lower plasma density (around $8{\cdot}10^{-7}$ mbar with 40 W) the primary 1^{+} beam was passing without any change. To distinct thermalized secondary beam of lithium beam from other plasma components the primary beam was operating in chopping mode. Cutting of the beam was realised by potential difference modulation between 1^{+} source and Wehnelt cap. The beam was chopped to 30% of total Li^{+1} beam current with frequency from 5 Hz to 5 kHz. The rise time of the square-like signal was changing from 10 ms to 10 ns. As a result, the secondary beam, chopped with the same frequency could be measured thus allowing to distinguish the thermalized secondary beam.

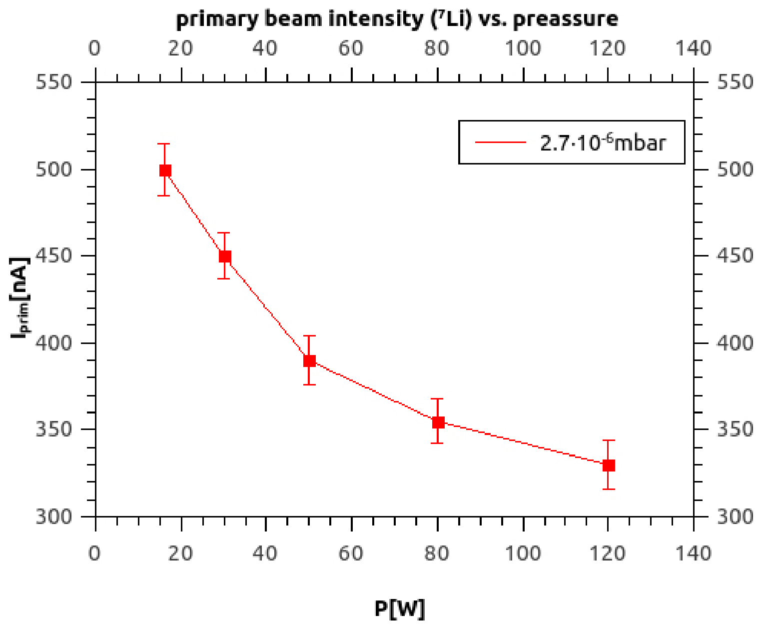

Figure 2: Primary beam intesity dependance with incrasing microwave power. Buffer gas preassure was constand during measurement.

By measuring the intensity of the primary beam and extracted n^{+} we will study the effectiveness of 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 set of plasma conditions will give direction for further investigations. Obtained results will increase knowledge about thermalisation process in ECR plasma. They will ultimately show whether the use of a deflector that deflects the injected beam allows to increase the effect of its thermalization, and hence, to increase the ECRIS charge breeder's efficiency.

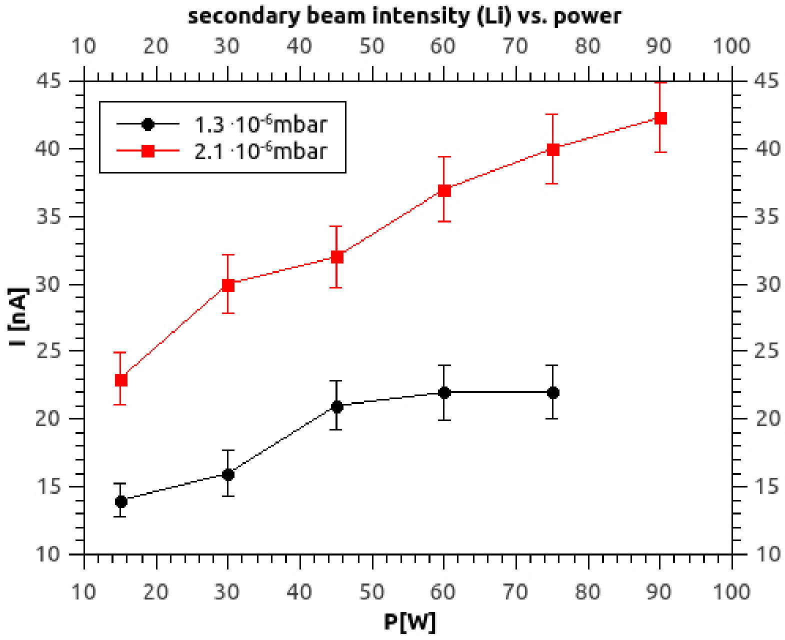

Figure 3: Thermalized secondary beam intensity dependance with increasing power and different buffer gas preassures.

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A.3 A new amplifier for the cyclotron buncher

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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 age. The newest pumping stations have automatic measurement systems built in (for both low and high vacuum), however older ones lack such capabilities. In order to provide cyclotron operators with information on the vacuum, six vacuum meters have been developed and built. The meters makes use of common ion gauges which can be bought cheaply as new old stock. It is planned to integrate the vacuum readout into new computerized cyclotron control system (now in the development stage).

A.4 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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The 14th edition of the Polish Workshop on the Acceleration and Applications of Heavy Ions was organised at HIL in October, 2018. It is addressed to students of first cycle studies interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis and in charged particle and gamma-ray detection techniques. Medical applications of nuclear physics have also been included in the programme of the Workshop.

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

In 2018, the programme 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 — medical imaging tool;

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

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

A.5 "You don't need to be a nuclear physicist — to understand nuclear science" – lesson for "academic class" in Jan Zamoyski XVIII General Junior High School

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

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1) Jan Zamoyski XVIII General Junior High School, Warsaw, Poland

From 2018 the Jan Zamoyski XVIII General Junior High School and Heavy Ion Laboratory execute a programme "academic class". Within the framework of project, the school and the university offer students an enhanced scope of educational events in physics at large. It is proposed that the students will partake lectures devoted towards recent achievements in science, they will participle in experiments and other activities inspired by the physics activities performed in the Laboratory.

As a one of the first of its kind activity, 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 of 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 manifests the good performance of the English education in Polish schools.

As the participants later reported, a particularly interesting point 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 programme 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 is presenting the talk on basics of nuclear physics.

A.6 ENSAR2-NUPIA Workshop "Nuclear Physics Research-Technology coaction"

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

the organisers of the workshop

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The University of Warsaw organised the workshop "Nuclear Physics Research-Technology Coaction" on 11–12 October 2018 in Warsaw, Poland at the Heavy Ion Laboratory of the University of Warsaw. The workshop "Nuclear Physics Research-technology coaction" was a space for Laboratories-Industry meeting.

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

20 speakers participated in the event. The workshop received 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 (fot. M. Komorowska).

During the workshop an exhibition of companies from selected enterprises was organised as well. The workshop allowed to present recent achievements and challenges in the following areas:

- Medicine;
- Radiopharmaceutical production;
- Detectors and nuclear instrumentation;

- Computation and information technology (Big data application, data analysis);
- Energy and environmental technologies;
- Radiation;
- Lasers;
- Numeric machine tools and 3D printing – services;
- Metallurgy;
- Collaborative research, innovation networks, technology transfer.

A brokerage event meeting was organised simultaneously by the Enterprise European Network (EEN) in the same place, which allowed to bring more companies to both workshops. The promotion of 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".

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

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

Part B

Research for medical and biological applications

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

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The radioisotope ^{135}La is an Auger electron emitter suitable for the targeted internal radiotherapy. It has a half-life of 18.9 h and decays by electron capture primarily to the ground state of stable ^{135}Ba. A small proportion of decays populating the 480.5 keV state contributes to the 1.5 % intensive 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 not much research is available with regards to the possible large-scale production. The promising and accessible method leads via the proton bombardment of barium targets. It was already investigated by [1] via ^{nat}Ba(p,x) reaction with the use of metallic target and by [2] via ^{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, the pilot study using the PETtrace irradiation station at HIL [3] was performed. Target was prepared by pressing the $^{nat}BaCO_3$ powder into a pellet with the thickness of 430 mg/cm^2. The 10-minutes irradiation with 9.4 µA proton beam of 15 MeV produced 9.6(2) MBq of ^{135}La with the 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 not consistent with the calculations based on TENDL-2017 cross-section.

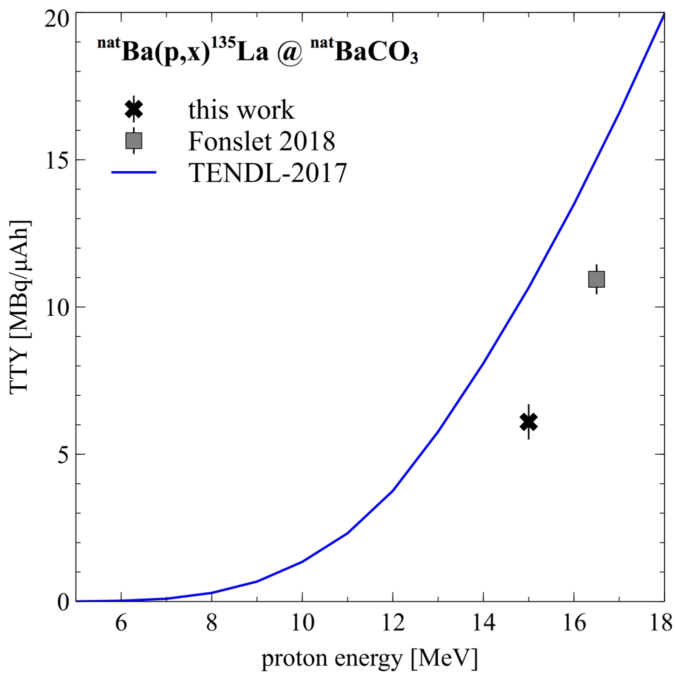

Figure 1: Thick target yields for ^{43}Sc production with proton and deuteron projectiles.

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

This work is partially supported by 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

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

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The dual beam proton/deuteron cyclotron is mainly used for a commercial production of fluorine F-18. Therefore, the targets for F-18 production are constantly highly radioactive what dramatically restricts a "free-entry" to the cave of cyclotron for staff for maintenances or preparation of irradiations carried out with use of the standalone external target system. The system was designed considering irradiation of both metallic and powder targets. It was designed and build within the frame of grant "PET-SKAND", 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). Applied solution is protected by the RP patent no 227402.

But for safety reason it was necessary to upgrade some parts of the station taking into account safety conditions for operational staff and to adopt it to the specific requirements of calcium powder targets.

Currently, our beam line consists of: a drift tube length a total of 3.4 m, two sets of steering magnets made of permanent magnets, one quadrupole doublet and a four-sector collimator and with the shielding, concrete wall thickness of 0.25 m (its specific weight is 3300 kg/m^3). This improved substantially 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 a control box of the external target system and the beam line allows to reach value of $4{\cdot}10^{-7}$ mbar of static vacuum.

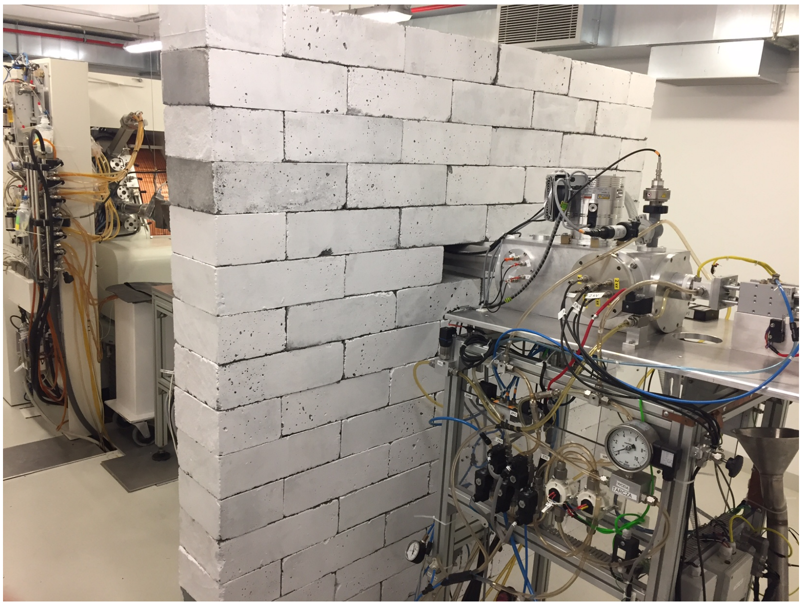

Figure 1: A view of the standalone external target system.

A beam transport efficiency to the target sized of 12 mm reaches above 96%.

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

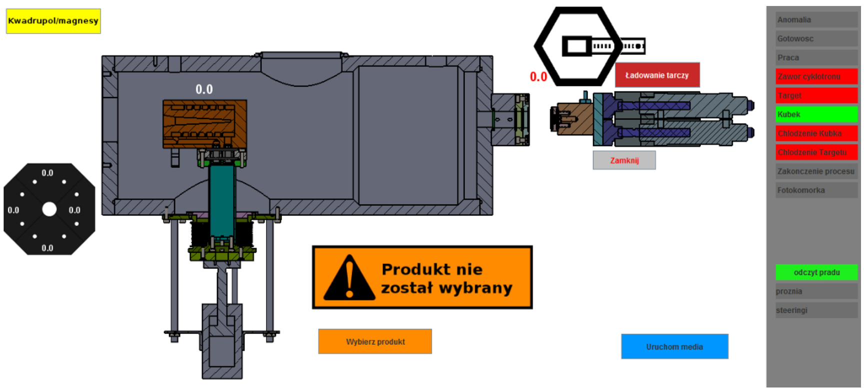

Figure 2: The main screen of the control panel.

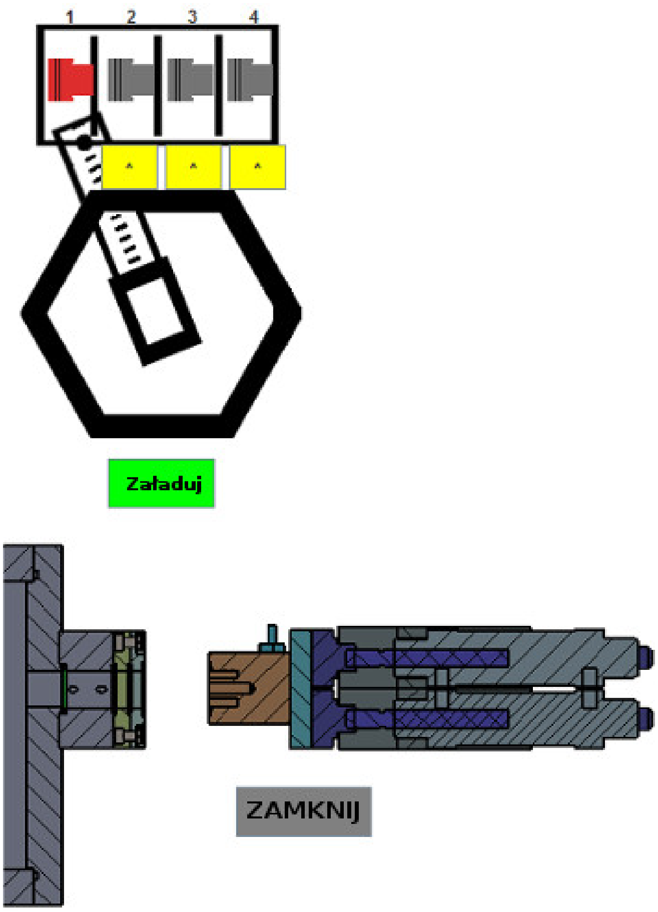

Figure 3: The control panel of the robot.

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

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

Last year we did several dozens of irradiations of the targets for groups collaborating with us within the frame of the "PET-SKAND" consortium.

B.3 The project of replacement old RF generators with new one

J. Choiński, A. Bednarek, T. Bracha, K. Sosnowski

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

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

On December first unit arrived to the 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 RF generator during FAT.

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

B.4 Reconstruction of the excitation function and production of the medically interesting ^{43}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 ^{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 characteristic for therapeutic purposes (average β- energy = 162 keV, $T_{1/2}$ = 3.35 d).

Recently we have reported 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 amount suitable for the chemical and in-vivo studies carried simultaneously at HIL UW [2], Biological and Chemical Research Centre UW and at Institute of Nuclear Chemistry and Technology. Several 10 min irradiations of nat$CaCO_3$ are performed with 10 µA proton beam delivered by PETtrace machine [3] to produce around 1 MBq of ^{44}Sc (with 1% of radioactive impurities).

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

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

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:

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

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

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

The result of reconstructed ^{44}Ca(p,n)^{44}Sc excitation function (see Fig. 1) shows the agreement with the cross-section data available in the literature. Our reconstruction method is also consistent with the 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 in fast and straight-forward estimation of the excitation function in cases where the direct cross-section measurement is not possible.

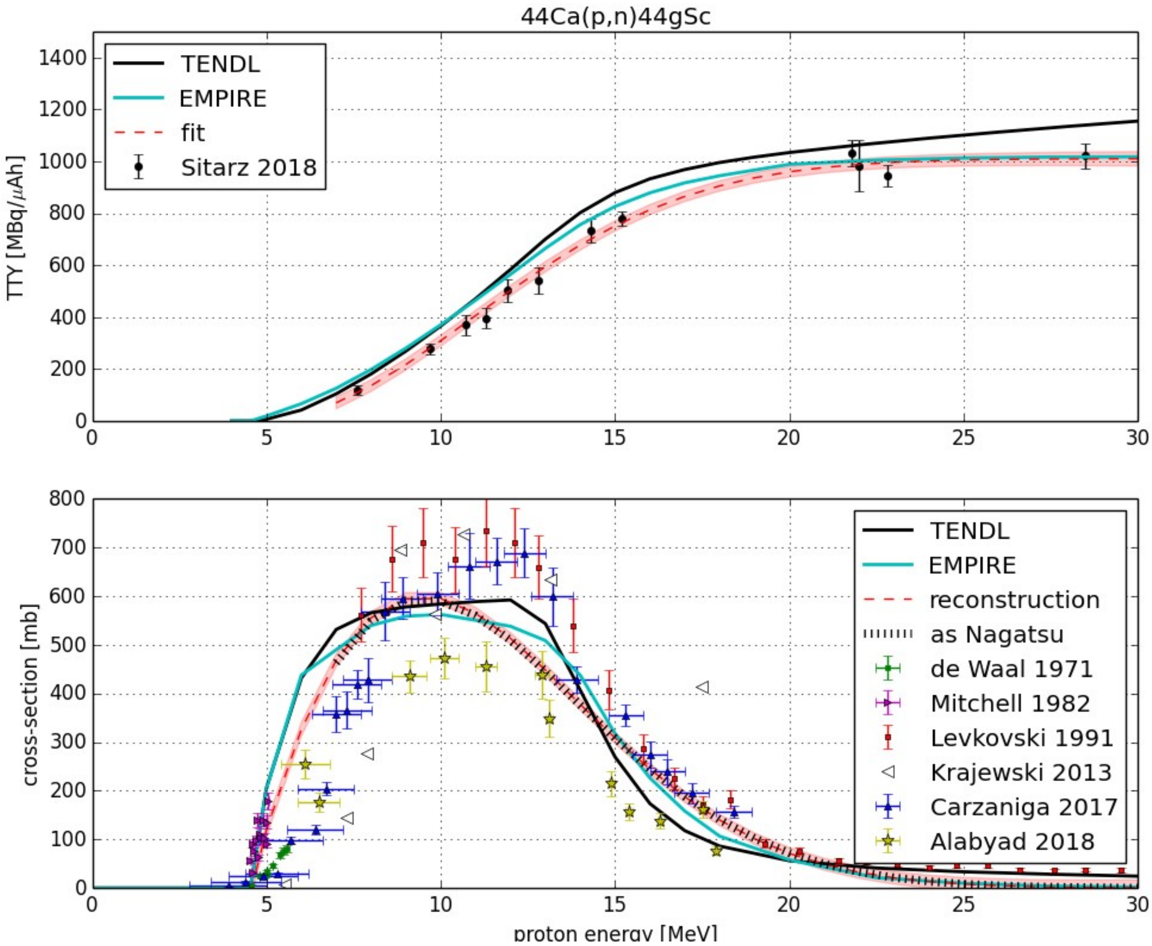

Figure 1: Reconstruction of ^{44}Ca(p,n)^{44}Sc cross-section (lower part) based on the fit to experimental TTY data on $^{44}CaCO_3$ enriched in 94.8% ^{44}Ca (upper part). Here: E_{thr} = 4.54 MeV, a = 8.8(6) MeV, b = 4.8(8) MeV, c = 24.5(1.0) MBq(μAh)$^{-1}$(MeV)$^{-2}$, χ^2/dof = 0.57.

This work is partially supported by European Commission Horizon 2020 program, proposal 654002 "ENSAR2" and NCBiR grant PBS3/A9/28/2015. It has been also 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 the French Government PhD scholarship is also acknowledged.

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B.5 Chemical form of calcium targets used for production of Sc radioisotopes in reactions with p, d or α projectiles

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Scandium isotopes production can be done 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 reaction with Ca nucleus promises much higher production efficiency.

Table 1: Example of cross sections for production of ^{44}Sc and ^{44g}Sc on 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 the Sc medical radioisotopes in reaction of Ca nucleus can be done working 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 what causes problems in heat dissipation from the irradiated target. Problem can be eliminated by using the metallic Ca but conversion of $CaCO_3$ into Ca is a time taking process with limited efficiency. Also additional impurities originating from the reduction process may be introduced to the final product. So, taking those 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 flow of the inert gas [2] or in vacuum using the resistant heating. The second method allows the instant/online control on 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 the 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 the glove box (for manipulations needed to produce the final target e.g. pressing the pellet, encapsulating into container, etc.) without additional precautions. Perforated cover slows down the gas exchange so when crucible filled with inert gas is taken into the ambient atmosphere it protects CaO against contact with air.

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

In addition decrease of 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 into graphite bed as described in [3] survived 45 min irradiation with 15 µA proton beam very well. There were no signs of thermal damage of the target. The irradiation conditions are sufficient to produce $\sim$ 8 GBq of ^{44g}Sc irradiating the enriched up to 99.2% $^{44}CaCO_3$. Taking into account the activity loses during isotope separation and labelling process, such amount of ^{44}Sc should be enough for diagnosing $\sim$ 75 patients (the estimation based on clinical studies for ^{44}Sc [4] where 50.5 MBq of ^{44}Sc-PSMA-617 were applied for single diagnosis).

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

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B.6 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 cooled below a certain temperature, called critical temperature T_c, has exactly zero electrical resistance. This amazing property of superconductor can be maintained if current density flowing through superconducting material is smaller than the critical current density and also an 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 films material [1].

The second generation (2G), high temperature superconductor tapes (HTS) allows for generating strong magnetic fields that do not require the use of high-power direct current power supply, just like the typical electromagnets. The tape is 12 mm wide and has a thickness of the paper sheet. It can conduct up to 600 A current at the 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 the ion beam-assisted deposition (IBAD) and the metal-organic chemical vapour deposition (MOCVD) processes [3]. Tape structure is shown in Fig. 1.

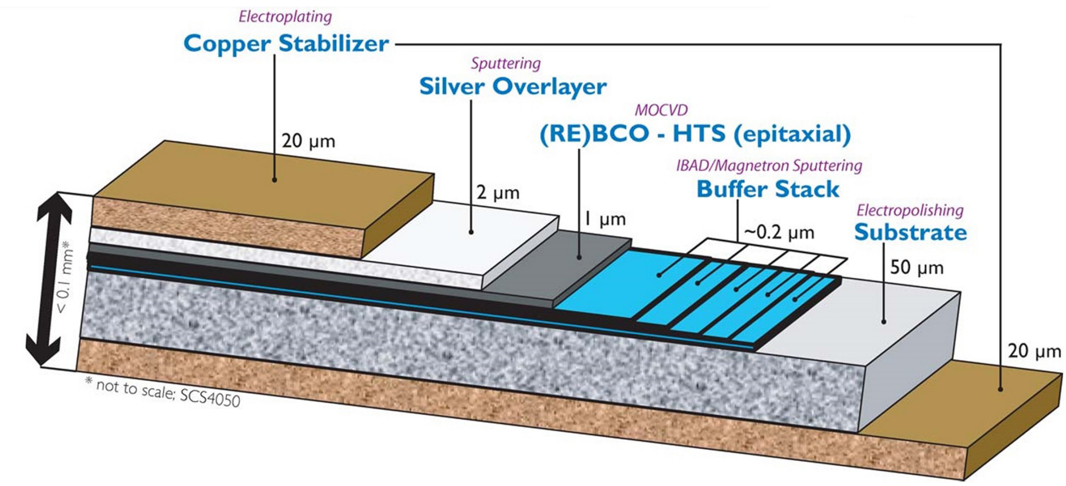

Figure 1: The illustrative drawing of the (RE)BCO tape structure [4].

The small dimensions and weight of the tape are very promising features to be used in the construction of magnetic shields protecting crews of spacecrafts 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 spaceship. Therefore it is necessary to examine how cosmic radiation changes or destroys the superconducting properties of HTS 2G tapes. To preliminary study on this topic, we irradiated the samples of 2G HTS tapes by heavy ions

^{12}C (3+) with a minimum deep of 40 µm in the tapes material. In the ideal case the tape should be irradiated with types and energies of ions, which will be corresponding to the real cosmic radiation like solar wind and high-energy radiation originating from outside of 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 in the Carousel and inserted into the vacuum chamber. The Carousel with tapes is shown in Fig. 2. Irradiation was done for the maximum kinetic energy of ions and also 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 oriented towards the ions source.

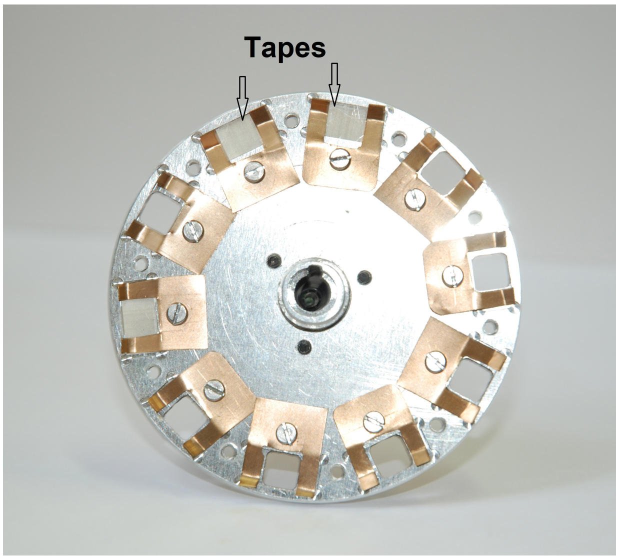

Figure 2: Two samples of 2G HTS monuted on the Carousel.

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}, critical current density J_c will be evaluated [9, 10]. The microstructure of tapes and structural damages resulting by irradiation will be examined by scanning electron microscopy.

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B.7 Comparative study of different solvents for the extraction of polyphenols from green tea

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Over the last 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 vapour pressure, high thermal stability and conductivity, as well as those which are tunable by proper cation-anion combination, 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, also for 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 dipoles 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 polyphenols extraction from green tea varies with the solvent used, obtaining the highest content for 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 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]. Effect of ultrasonic time on the reducing capacity of plant material extracts is presented on Fig. 1. The results obtained for 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 aqueous-ethanol solvent. The results for green tea were statistically similar ($p < 0.05$) for maceration process as well as ultrasonic extraction in the studied time interval. The extracts with both ionic liquids exhibited lower results, which were 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 case of green tea the best solvent for polyphenols extraction seems to be 60% ETOH aqueous solvent.

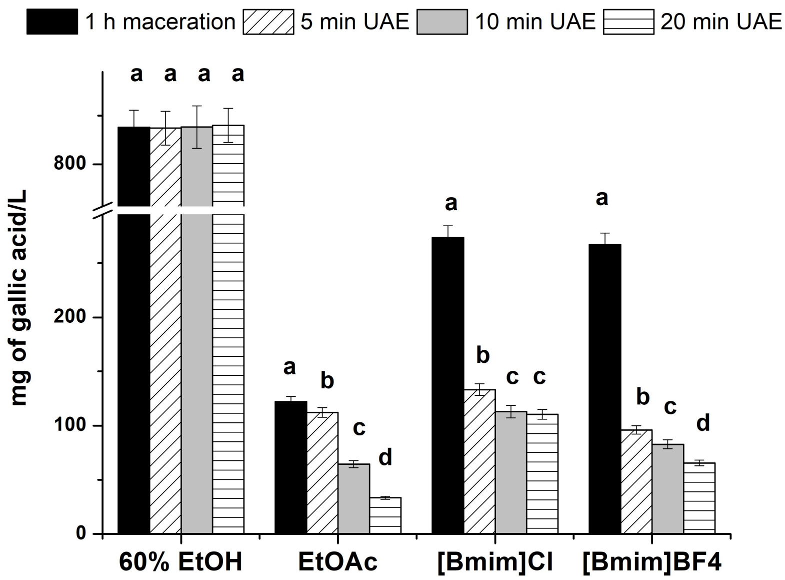

Figure 1: Effect of ultrasonic time on the antioxidant properties of the studied green tea extract obtained in FC assay. The results for maceration without UAE were included for comparison. Different letters for the same extractant indicate significant difference between samples ($p < 0.05$).

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B.8 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, antioxidant defense systems [2]. It all causes that selenium should be present in our diet. However, the 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. food sample can interact with other compounds present in such 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 effect [8].

The current literature clearly states that there is no widely adopted "total antioxidant parameter" as a nutritional index available for the labelling 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. In the case of quercetin, wherein the kinetic curves with Se-methylselenocysteine and vitamin C shows Fig. 1. It can be seen that the addition of Se-methylselenocysteine inhibits quenching 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.

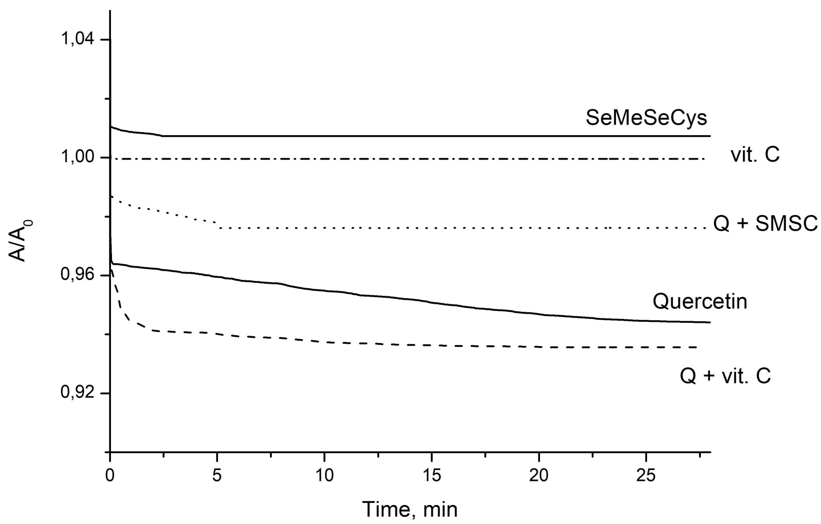

Figure 1: Kinetic curves of scavenged DPPH by studied compounds.

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 antioxidant activity. These results may be important from the point of view of supplementation with selenium. More studies are needed to be performed for better describing the antioxidant interactions.

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B.9 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 acts 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 Sc (III)-morin complex. For this purpose UV-visible spectroscopy and mass spectrometry was 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 the 1:2 molar ratio but this will be confirmed using mass spectrometry. Also the stability of the complex was evaluated. The type of inorganic buffer as well as the content of ethanol was studied. It turned out that the complex is stable in borate, ammonium and phosphate buffer, however its solubility increases with increasing content of ethanol. Figure 1 presents the UV spectra Sc-morin complex recorded in saline with different content of ethanol.

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

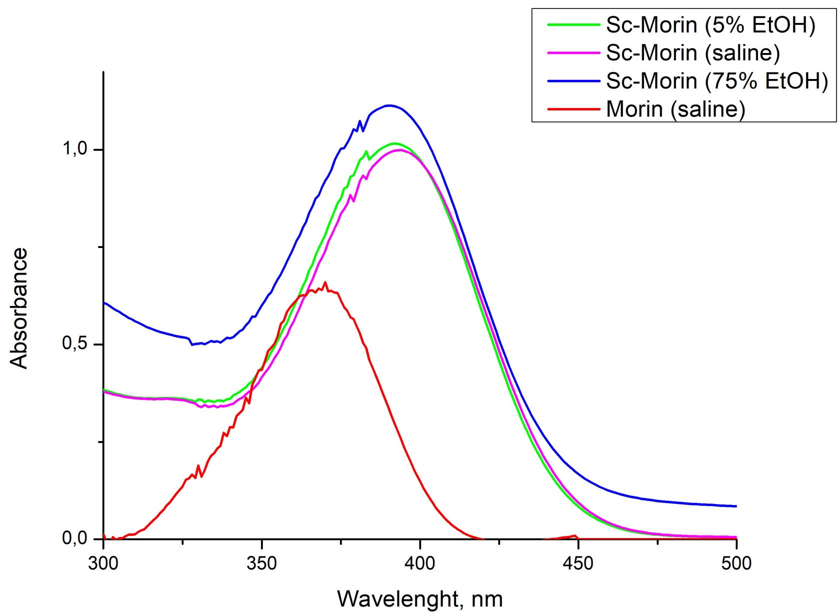

Figure 1: UV spectra of Sc-Morin complexes in different content of ethanol.

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B.10 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 deposition of the large amounts of wastes 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 has been proposed as sorbents for scandium preconcentration [2].

Present study investigates the adsorption behavior of oxidized carbon nanotubes (CNT-COOH) for separation of scandium(III) ions from aqueous solution and it is 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 comes down, gradually tended to equilibrium and adsorption of Sc(III) was over 95% during the first 2 min, which indicated that kinetics adsorption equilibrium was very fast. In order to investigate 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 pseudo-second order kinetic model (Fig. 1a) and the mechanism of that process might be chemisorption. Furthermore, intra-particle diffusion model was used to investigate the contribution of intraparticle and film diffusions into adsorption process. The linear plot of experimental data to Weber-Morris equation shows early adsorption step up to 10 min the process is generally controlled by both factors. The subsequent adsorption step, characterized by lower slope, is mainly controlled by the film diffusion (Fig. 1b).

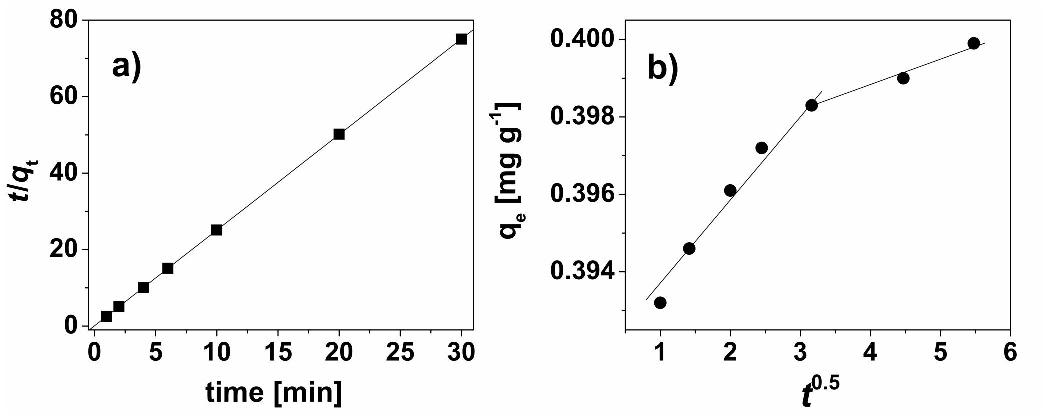

Figure 1: Modeling of Sc adsorption kinetics on CNT-COOH (models: a - pseudo-second order, b - Weber- Morris).

In order to describe Sc(III) adsorption behaviour on carbon nanotubes, the experimental data was analysed by three isotherm models. The Freundlich model describes adsorption on heterogeneous surfaces and is represented by 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 heat of sorption and T is the absolute temperature.

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

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B.11 Wide-beam nanodosimetric experiment at HIL

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The enhanced biological effectiveness or carbon ions and other heavy charged particles is related to the ionisation structure of the particle track at the nanometre level. Experimental nanodosimetry is aimed at direct measurement of the ionisations created by a single ionising particle in a nanometric volumes equivalent to a short segments of DNA (see Fig. 1).

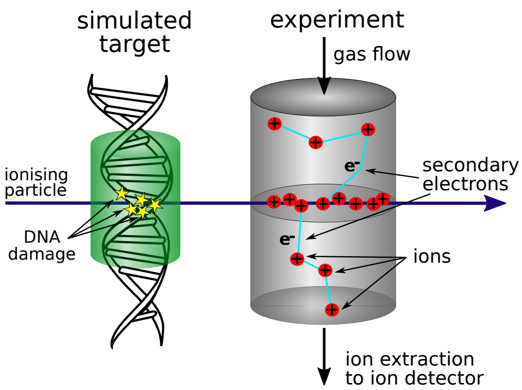

Figure 1: Short DNA segment destroyed by heavy charged particle. Green area is a nanometric volume simulated in the experiment.

The ion counting nanodosemeter —Jet Counter (JC)— is capable of measuring track structure of ionizing particles in a gaseous target equivalent to a nanometric volume in water. JC consists of an interaction chamber (IC), where a simulated nanometre-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 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 ionisation cluster is measured if a single ionising 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 of creating cluster of a given size, so called ionisation cluster-size distribution (ICSD). For more details see Ref. [1, 2].

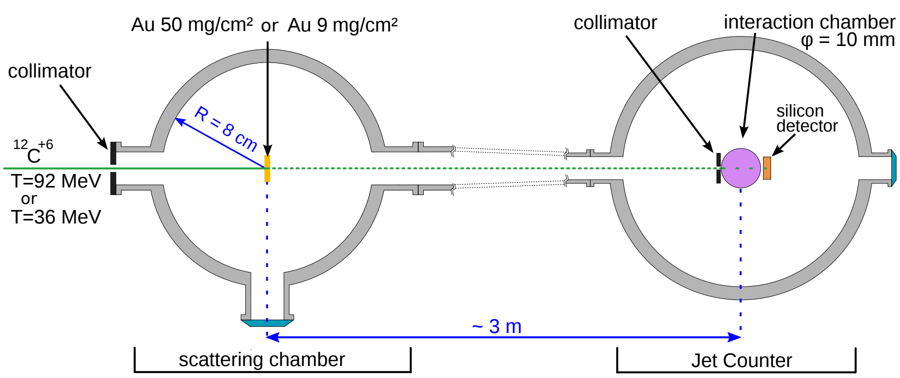

Figure 2: Schematic view of nanodosimetric set-up on beamline A at HIL.

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

A novelty in these experiments was the use of a two-dimensional silicon detector for projectiles. It allowed for 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 the Fig. 3 and some preliminary results of the mean cluster-size dependence on the distance $d = x$ are presented in the Fig. 4.

Obtained data contain also 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 analysed and used i.a. for comparison with MC and ion optic simulations.

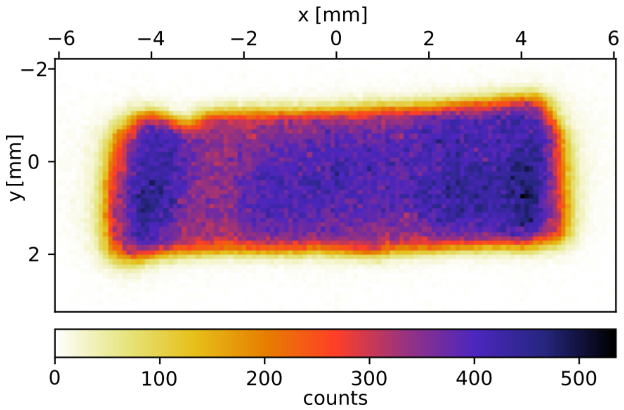

Figure 3: Image of the beam on the 2-D silicon detector. Each pixel has dimensions 0.1×0.1 mm^2.

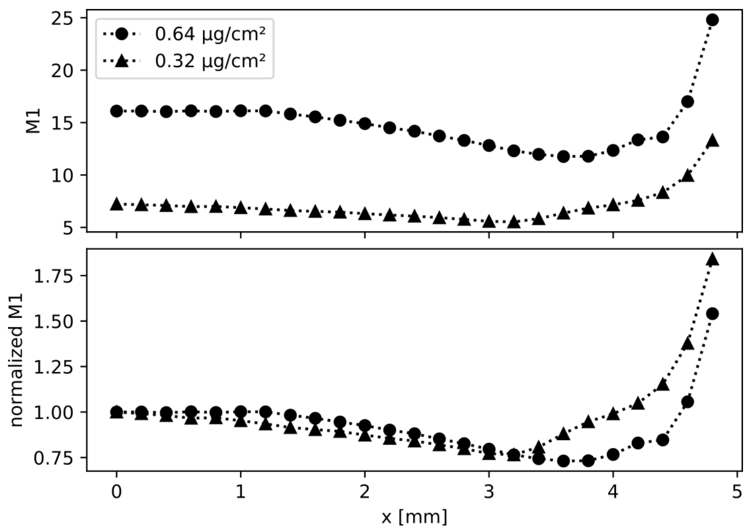

Figure 4: The dependence of mean cluster-size (M1) on the horizontal coordinate of the projectile path for two target sizes.

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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 Heavy Ion Laboratory, University of Warsaw, using a 91 MeV ^{32}S beam delivered by the Warsaw cyclotron. The γrays 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 γrays not originating from collision partners were observed, as shown in Fig. 1. The analysis of these γrays 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 ^{32}S ions which Coulomb excited the ^{110}Cd nuclei.

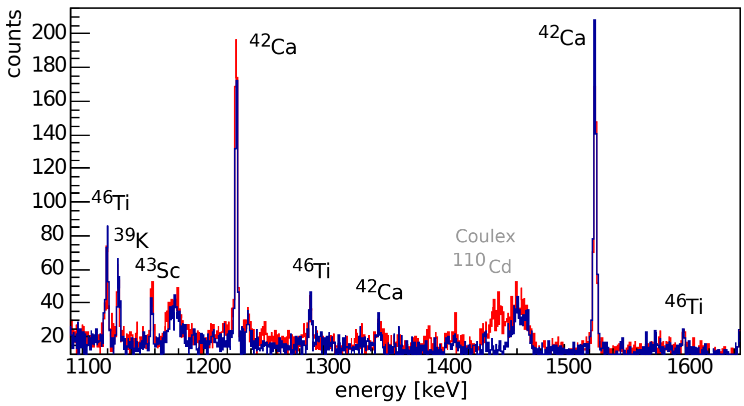

Figure 1: Portion of the prompt (red) and random (blue) particle- γspectra, from one of the HPGe detectors. No Doppler correction was applied. The most intense of the identified γrays resulting from ^{32}S+^{12}C and ^{32}S+^{16}O reactions are marked. The broad structure around 1450 keV is related to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

A complementary experiment has been 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 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 in the conditions of the Coulomb-excitation experiment) and higher stopping powers for ^{32}S ions in oxidized cadmium, as compared to those 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 backscattered ^{32}S ions in the ^{32}S+^{110}Cd Coulomb-excitation experiment at HIL.

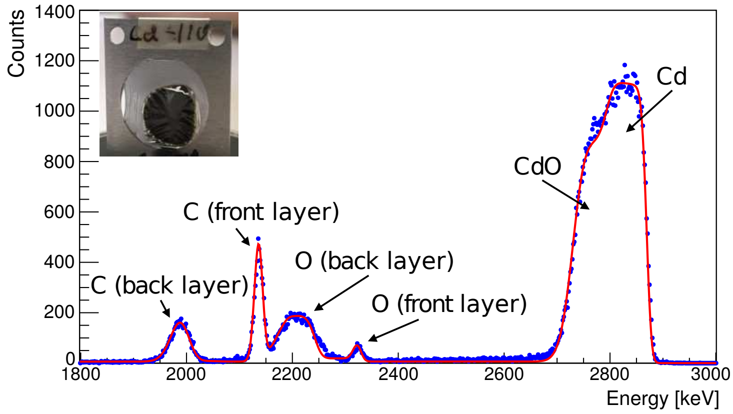

Figure 2: Experimental spectrum of 3 MeV protons scattered on the ^{110}Cd target at 165°. The experimental spectrum (blue) is reconstructed (red) using the SIMNRA code. Inset: the ^{110}Cd target under study.

The information on the target composition was crucial for further analysis of the data aiming at extraction of reduced matrix elements in ^{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 a 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 determination of 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 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 hosts 20 HPGe GAMMAPOOL and 15 anti-compton 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 a high leak current (causing unacceptable high level of noise), 1 has been sent to CANBERRA for a reparation (at a HIL cost), and 2 broken have never been received from CNRS Orsay. The HPGe detectors are routinely serviced at HIL. Procedures like annealing, FET replacements, reparation 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 analogue 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 digitisers 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 analogue units, capability to work with thresholds down to 30 keV, and a good linearity. Work is continued on the FPGA coding to allow synchronisation 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.

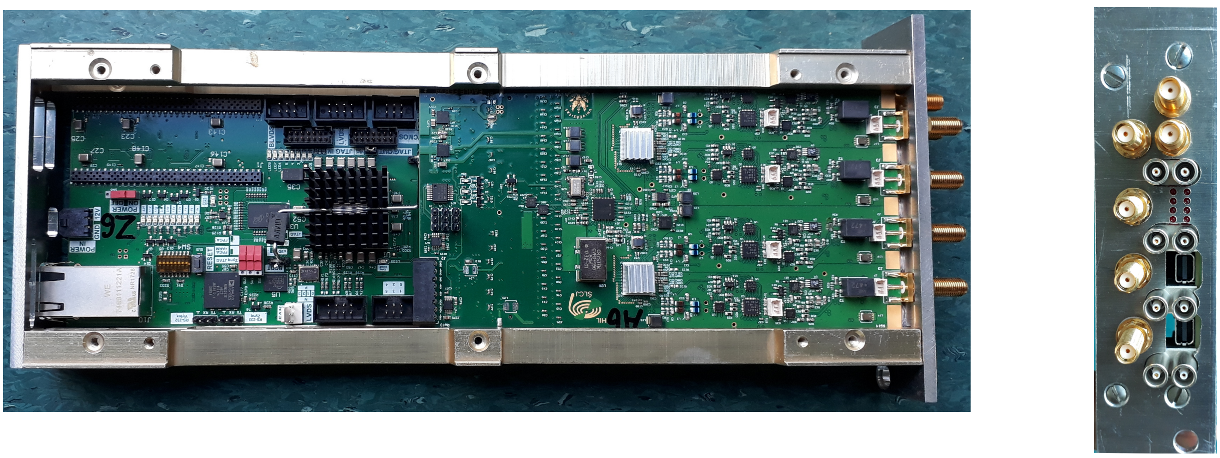

Figure 1: EAGLE digitiser board: a general view (left) and the front panel (right)

In 2018 two experiments were performed with EAGLE:

- "Lifetime measurements of $I = 10^+$ 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 plunger device" (a test experiment), by A. Tucholski et al. [6].

In the former experiment EAGLE was augmented with fast scintillator FATIMA detectors, for sub-nanosecond lifetime measurements. In the latter one, the HIL plunger was used. Other two experiments, originally scheduled in 2018 were postponed to 2019 due to unavailability of beams. Groups responsible for experiments which were performed earlier continued data analysis and four papers based on EAGLE data were published in 2018 [7–10].

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 a 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

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 of NBCJ and HIL and consists of 16 high efficiency HPGe spectrometers of EAGLE array coupled with 24 LaBr3 detectors forming the EYE Fast-Timing detection device. 24 LaBr3 detectors of FATIMA collaboration were used for the first in beam measurements with EAGLE-EYE full configuration. While the data analysis is ongoing we present a brief technical information of the EAGLE-EYE setup below.

The fast timing logic was based on six ORTEC 935 quad CFD blocks connected with anode signals from 24 LaBr3 detectors. Three output logic signals from each of 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 0-50 ns limit using ORTEC TAC 566 blocks. One of the two sets was directly connected to CEFE unit [1] in order to open appropriate gates for signals coming from another set which was delayed by 15 ns. The delayed signals are then redirected to three TAC units where the signal with the lowest number was used as a common start. The remaining signals were put on three stop TAC inputs allowing the time measurement of subsequent gamma quanta within a two-, three- or four-fold LaBr3 coincidence. The last set of 24 CFD logic output signals were used for time measurements of delayed gamma quanta within 0–500 ns range with help of two 16 channels 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.

Main features of the EAGLE-EYE setup for in-beam experiments are among others:
- proper identification of gamma quanta registered by LaBr3 crystals by using additional spectra form HPGe spectrometers,
- Fast-Timing measurements in two-, three- or four-fold LaBr3 coincidence events,
- LaBr3 energy spectra cleaning by gating on contaminating gammas in HPGe detectors spectra,
- Determination of Compton background under the peak of interest by removing the peak with HPGe gating,
- Selection of prompt and delayed gamma quanta in LaBr3 spectra by using Fast-Timing and delayed-timing logic branches.

The remarkable feature of the setup is its flexibility of mounting different types of LaBr3 detectors that may have different dimensions, types of casing and overall sizes. Thanks to this flexibility several types of LaBr3 detectors coming form FATIMA, RHOSPHERE, University of Warsaw and NCBJ were successfully used during recent measurements. Fig. 2 shows a drawing of the EAGLE-EYE setup with possible half-sphere LaBr3 arrangement.

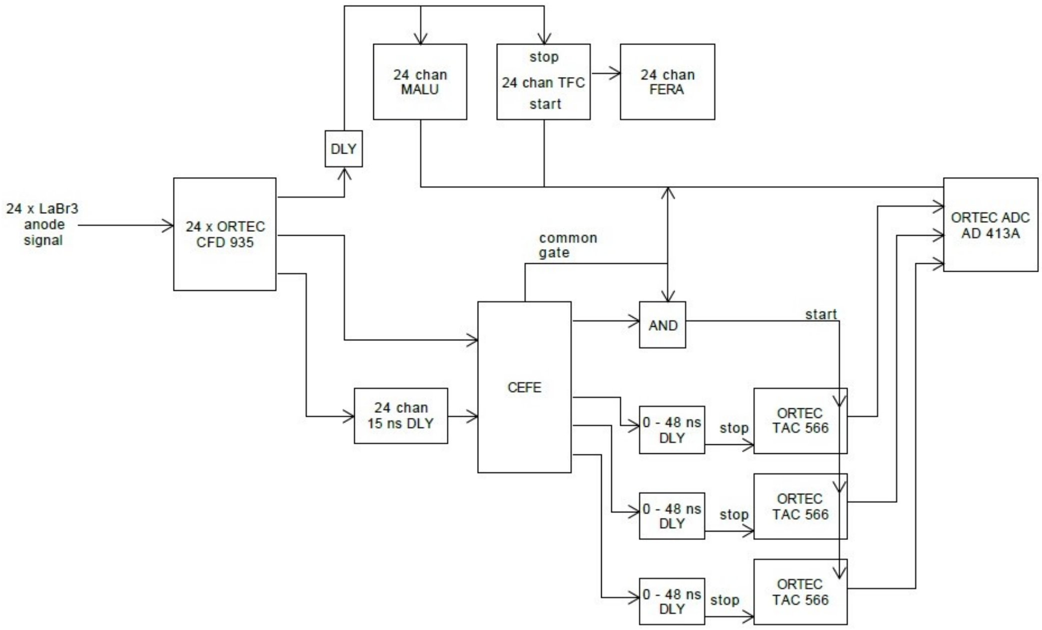

Figure 1: The EAGLE-EYE logic used during in-beam experiments in 2018. Part of the logic scheme only relevant to LaBr3 detectors is shown.

It also shows a single cluster of three LaBr3 detectors that can be replaced with a HPGe spectrometer on demand.

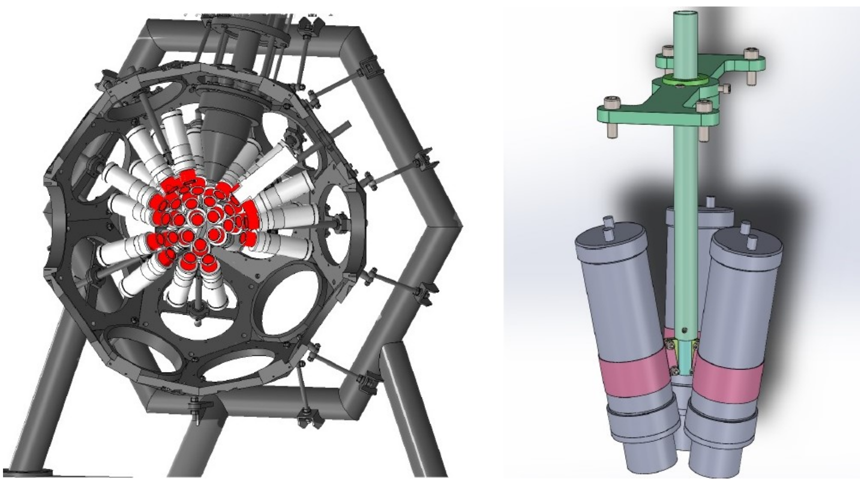

Figure 2: Schematic drawing of the EAGLE-EYE setup with the LaBr3 arrangement forming a half-sphere geometry. Single triple LaBr3 detectors cluster is replaceable with HPGe spectrometer.

The above properties allow several experimental techniques to be applied for study of isomeric decays, fast single-particle nuclear transitions or collective nuclear states. In addition to fundamental spectroscopy study the EAGLE-EYE setup is a helpful device for research and further development of the 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 plunger device. 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]

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

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

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

In the first test experiment the following problems were investigated:
1) The crucial issue was the implementation of Si detector inside plunger to get a coincidence trigger particle-gamma. The ^{10}B beam particles ejected from ^{148}Nd target will be registered in Si detector. In this run the noise in particle detector was very high and many unwanted random coincidences were registered. Now this problem was solved and will be tested in May'19.
2) The spectrum of Coulomb excitation of ^{148}Nd have been obtained (Fig. 1).

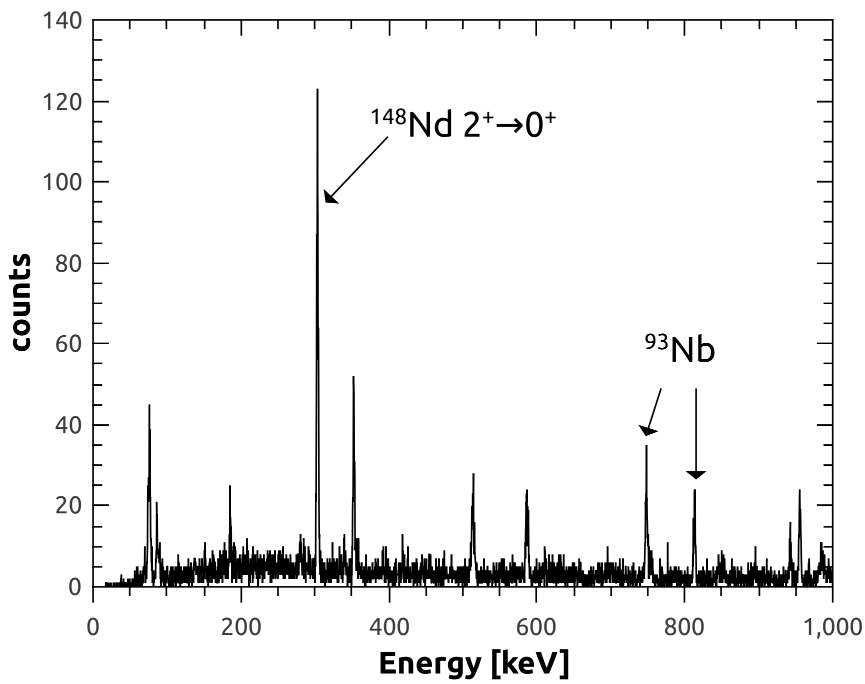

Figure 1: The energy spectra of γ-rays.

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

The gamma energy spectrum collected during our test experiment are presented in Fig. 1. The clean peak at 301.7 keV comes from the Coulomb excitation of 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 and with low background.

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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 been often 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 electromagnetic properties of these nuclei have shown that such simple picture has to be revised, which led to a fresh interest of theoreticians e.g. [3, 4]. This report presents selected results of a research aimed at obtaining of a description of nuclear collective dynamics based on the microscopic mean-field theory. The research is an extension of the work [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 at the deformation (β,γ) plane. In the calculations I use four distinct Skyrme type effective microscopic interactions (SIII, SLy4 and 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 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 a quadrupole deformation and are accessible from both 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 an operator of 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 a 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 $\langle\cos 3\delta\rangle = \big\langle Q^3\cos(3\delta)\big\rangle/\langle Q^2\rangle^{3/2}$.

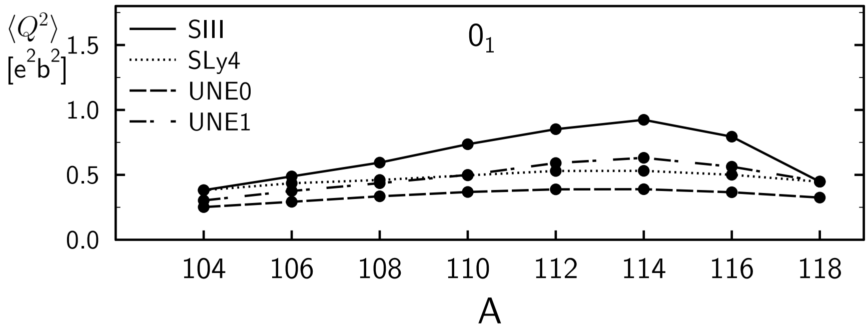

Figure 1: Value of the invariant $\langle Q^2\rangle$ for the ground state in Cd isotopes.

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

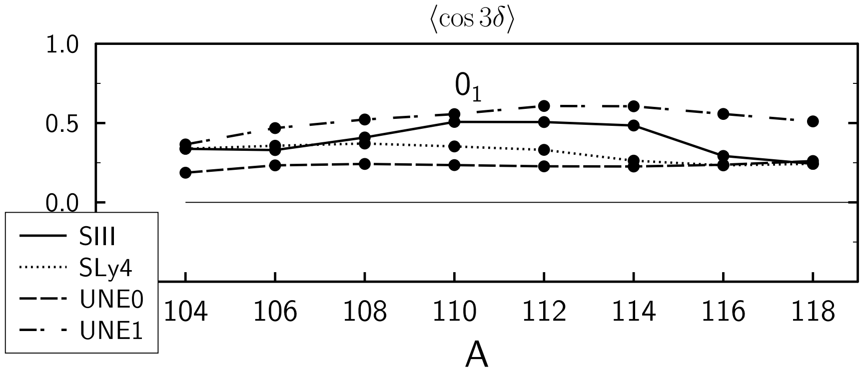

Figure 2: Value of $\langle\cos 3\delta\rangle$ for the ground state in Cd isotopes.

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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 physical motivations and the status of the (supported by the Heavy Ion Laboratory of Warsaw) construction of 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 centers of mass of the two colliding ions. It is known that at incident energy close the Coulomb barrier there is a coupling between the relative motion and internal degrees of freedom of participans. As a consequence, enhancement of the fusion cross section with respect to the simple quantum tunneling predictions is observed [1, 2]. In the frame 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 gets replaced by a distribution. There are two experimental approaches of its determination. In 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 fusion products should be done at almost 0°, so they must be separated from the beam and intensive elastics. Because of this many measurements were done using an indirect method. It consists [5] in the measurement of those ions which did not penetrate the Coulomb barrier, but got quasielastically backscattered from it, i.e. the sum of elastic and inelastic scatterings, transfer and breakup products, without 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 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 sides, so they are in a way complementary, but the question to what extent they give similar results rests open. To check it one should carefully compare experimental D_{qe} and D_{fus}. As explained above, this requires dedicated device to efficiently get rid of the intensive background close to 0°.

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

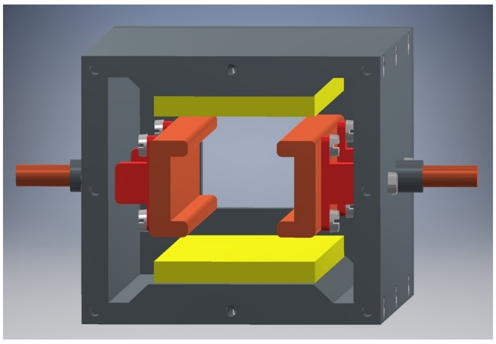

Figure 1: Schematic view of the Wien filter. Electrodes are shown in red, permanent magnets in yellow.

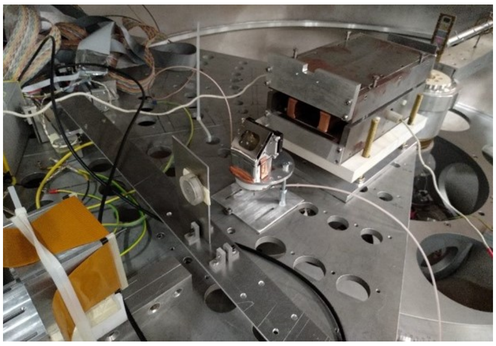

Figure 2: The Filter (right side) in the Chamber 2000. In the center the start MCP device is shown, on the left side: the stop DSSSD detector.

density of 225 kJ/m^3. The two magnet planes are at the distance of 60 mm each from 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 $\pm$ 40 kV each.

The first 2 tests were done at LNS using the ^{24}Mg beam delivered by the tandem accelerator with the 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) of 300 µm of thickness was used (see Fig. 2). The silicon detector is consisting of 32 vertical strips in the front side and 32 horizontal strips in the back side covering an area of 64 x 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 $\cong 5°$ 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 the 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 done in order to master the techniques able to better identify the fusion residues. In the next future the Wien filter will be used in the experiment for direct measurement of fusion residues near the Coulomb barrier.

The research leading to these results has received funding from the European Union HORIZON2020 research and innovation programme under Grant Agreement No. 654002 - ENSAR2.

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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 prediction of the fusion cross section for various scattering systems at energies around the Coulomb barrier. From 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 hight

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

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 example of data involving weakly bound nuclei did not show any distinct difference among stable and weakly bound systems [1].

Since at present some 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 the 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 the open circles while the ^{8}He data are plotted with the filled squares. Most of the data corresponds to fusion with heavy targets (from Sm to Bi). Only two ^{8}He data points at the highest E_r were obtained with the Cu target. For comparison with the result for well bound nuclei 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 being the largest for the two ^{8}He data sets. While the ^{6}He data are in a 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 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 some more fusion data are needed.

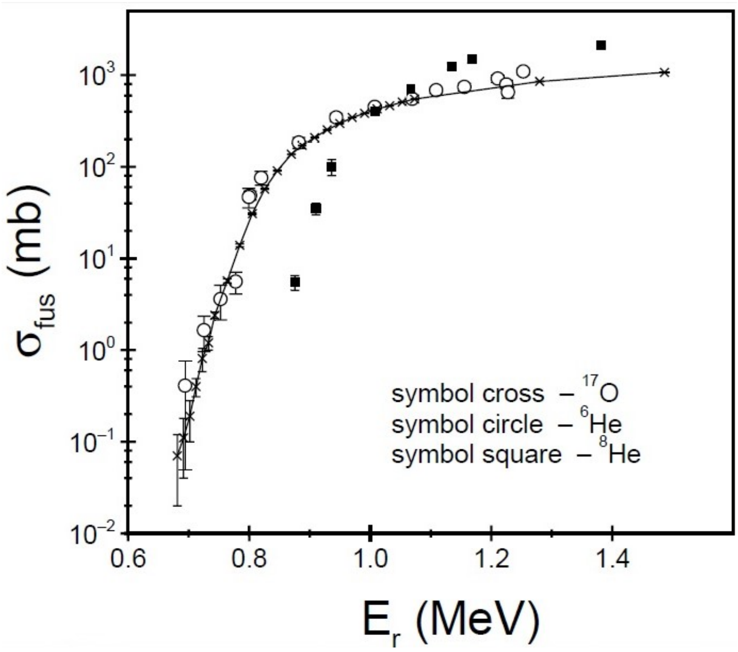

Figure 1: Fusion experimental data from the papers listed in Table 1 plotted as a function of reduced energy (eq. 1, parameter $b = 0.93$ was used for all data sets). The curve connecting the ^{17}O data points is for guiding the eye.

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 our new experiment, where the low-lying states of ^{140}Sm were studied. In this experiment the statistics was about five times larger than in the our previous work [1]. As a results 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 lines being the subject of study are compared with the results of Ref. [3] (Fig. 2). It is seen that experimental points including their errors do not deviate more than about 25% from the weighted mean value (except the γ-line with energy of 1097 keV - see text below). The admixture of the "parasitic"γ-lines can be a reason of 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 $2_2 \rightarrow 2_1 \rightarrow 0_1$ and $0 \rightarrow 2_1 \rightarrow 0_1$ cascades (531-1068 keV, 531-1491 keV, 531-2064.5 keV) admixtures do not change spin assignement. They only influence on the mixing ratio as it is for the $2_2 \rightarrow 2_1 \rightarrow 0_1$ 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 being in coincidence with 531 keV photons (Fig. 3). For the 1097 keV γ-transition (that was mentioned above) experimental point (A_{22}, A_{44}) is very close to theoretical value for the 0-2-0 correlation (see Fig. 3) but admixtures are unknown. Therefore we propose I = (0) for the 1628 keV level.

The new results confirmed the spin assignment 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 seems to be very interesting (especially the structure of two close lying

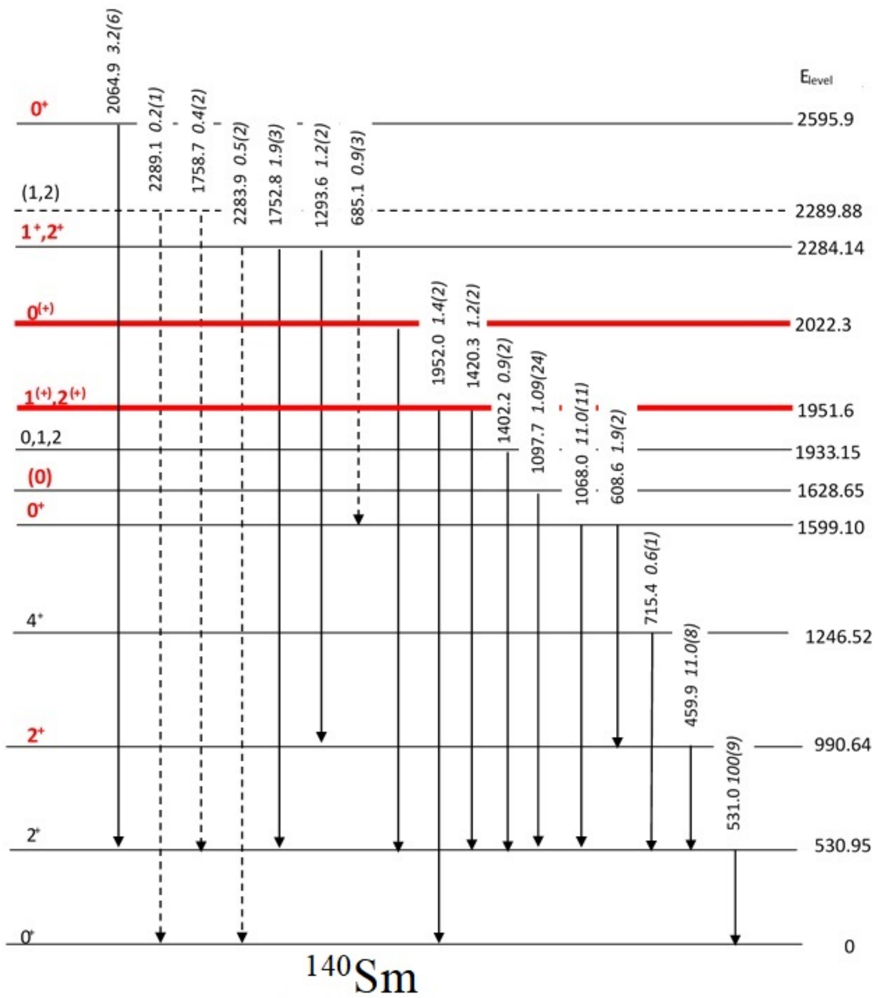

Figure 1: Partial level scheme of ^{140}Sm taken from Refs. [1, 3, 4] and modified in our present work. The spin values marked in red were determined in our measurements. Red lines indicate the new levels proposed by us.

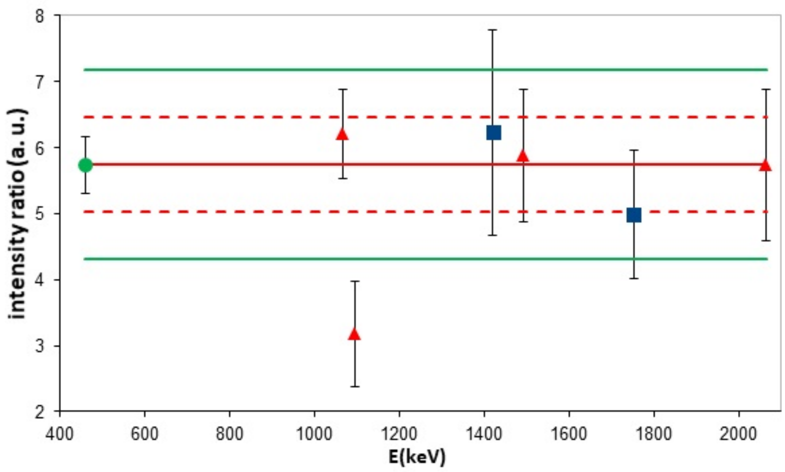

Figure 2: The ratio of intensities of γ-lines measured in this work to intensities given in Ref. [3]. The red solid and dashed lines show the weighted mean value and its errors. The green solid lines show the deviation from the mean value by 25%.

states with energies of 1599 keV and 1628 keV). Currently, the ^{140}Sm nucleus structure is tested in the framework of the collective quadrupole model with softness in triaxiality (γ-soft model) [5].

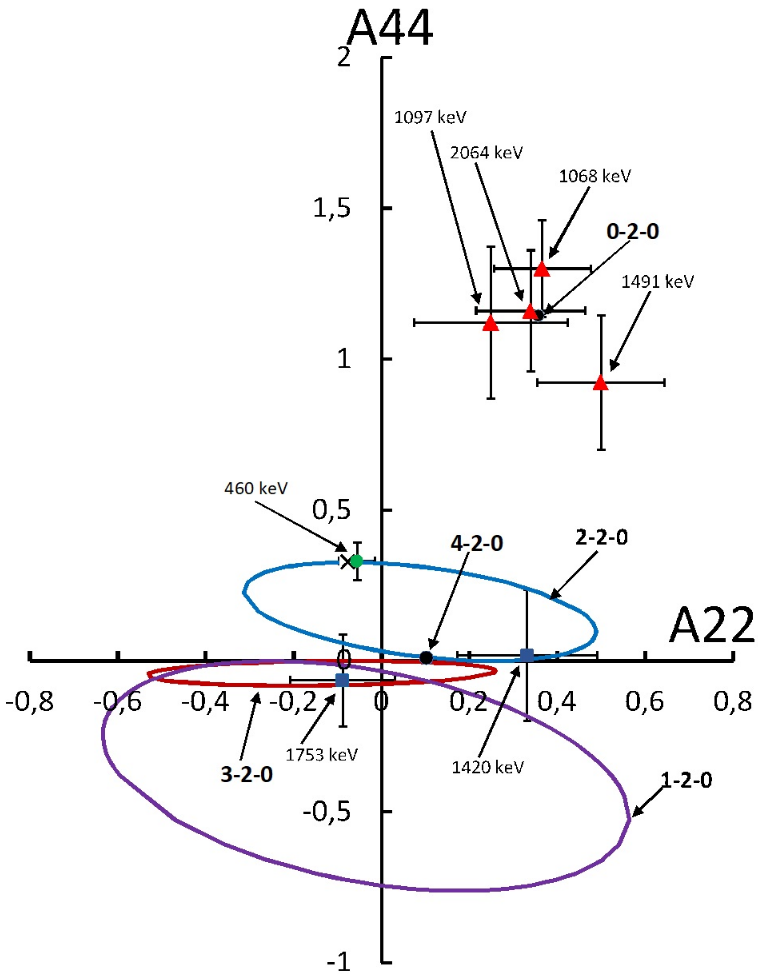

Figure 3: Parametric plot of the A_{22} and A_{44} angular correlation coefficients for the $I \rightarrow 2 \rightarrow 0$ cascades. Full black circles and cross indicate the pure quadrupole transitions.

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

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Elastic transfer studies showed a remarkable increase of the differential cross sections at backward angles for the different nuclear system such as ^{16}O + ^{12}C [1–4] and ^{20}Ne + ^{16}O [5–7] due to α-cluster transfer. The similar situation is observed in studying nuclear systems with one nucleon (proton or neutron) difference between their masses. The current work is devoted to study the concept of the deuteron transfer and its role in the formation of the cross sections at 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 at the beam ^{10}B extracted from the K = 160 cyclotron of the Heavy Ion Laboratory, University of Warsaw.

The charged particles were detected and identified by the four ΔE-E counter telescopes which were installed in the ICARE experimental chamber. Self-supporting target of ^{12}C with a thickness of $\sim$ 0.141 μg/cm^2 were 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 by ^{12}C nuclei were measured in the angular range of 5° - 40° in the laboratory system. The differential cross sections of the scattered ^{10}B nuclei at angles greater than 100° were obtained by ^{12}C recoil nuclei.

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

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

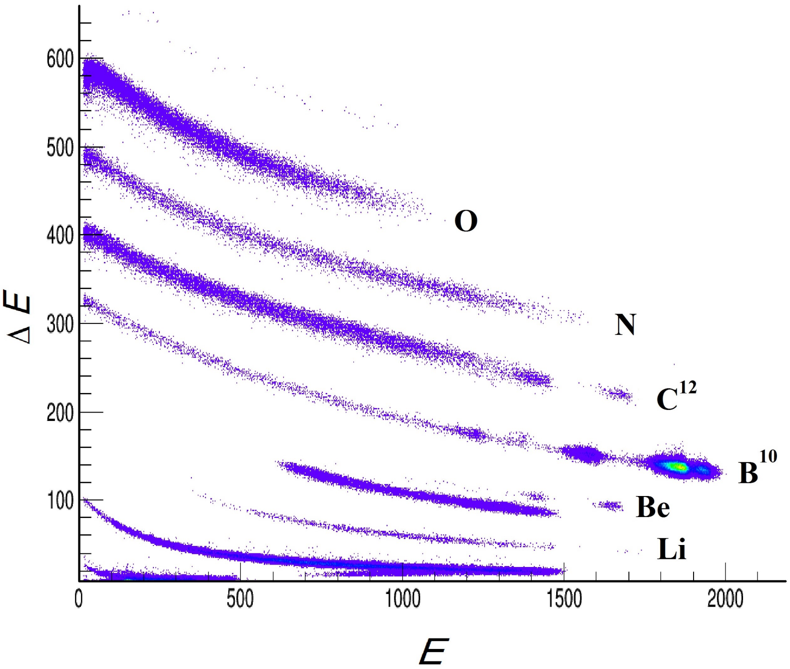

Figure 1: Typical ΔE-E spectrum of the ^{12}C(^{10}B, X) reaction products at $E_{lab}(^{10}\text{B}) =$ 41.3 MeV.

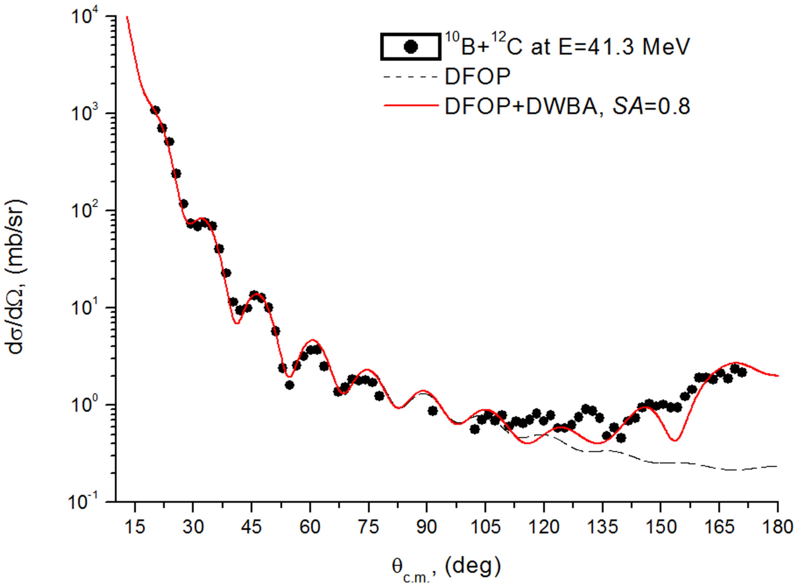

Figure 2: Angular distribution of the elastic scattering of ^{10}B by ^{12}C at $E_{lab} = 41.3$ MeV. Circles are the experimental data; the dashed black curve is the DFOP model prediction, and the red line represents the DWBA calculations including the deuteron transfer process ^{12}C(^{10}B,^{12}C)^{10}B.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 654002.

Table 1: Optimal potential parameters for $^{10}B + ^{12}C$ at $E_{lab} = 41.3$ MeV. 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

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

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The problem of detector radiation hardness is very important for experimental physics. To improve detector radiation hardness people try use special detector technologies and new materials like diamond or silicon carbide. The aim of this work is testing of thin silicon epitaxial detector operated in build-in-field bias potential. It seems to be more resistant for radiation damage due to extremely low detector bias potential generated by the internal build-in-field potential and low detector thickness. Low detector thickness prevents doping of 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 junction n^+–n–p^+ was obtained using B^+ implantation into epitaxial n– type side using low-temperature technique [1]. To reduce detector electric capacitance, the large-area detectors consisting of 23 µm thick membrane with junction n^+–n–p^+ was broken down into little detector pieces (little detectors with junctions n^+–n–p^+). The selected little detectors were mounted in detector housings supplied with collimation entrance windows of diameter 2 mm. After gluing of 50 µm silver wires contacts to detector Al surfaces using two components silver paste hardened with temperature about 80°C, the self-biased thin detectors operating with internal build-in-field potential (without any external bias potential) were ready to work with charged particles and heavy ions. The photo of tested detector with removed external collimation cover is shown by Fig. 1.

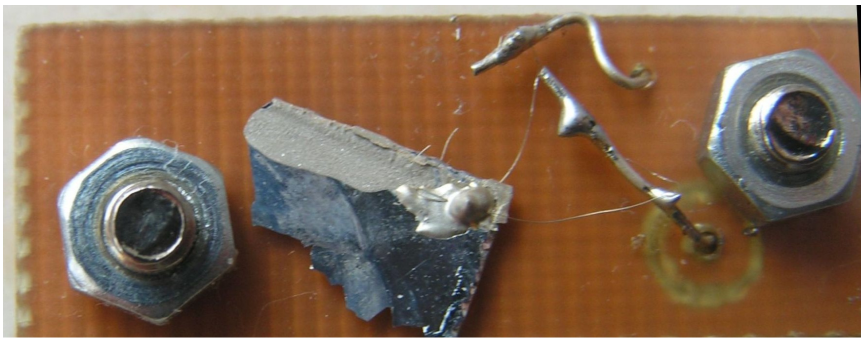

Figure 1: Thin epitaxial silicon detector with removed collimation cover with 2 mm entrance hole. The 50 µm silver wires contacts were glued to both sides of the little detector. Other ends of wire contacts were soldered to thick detector external wire connection.

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 Heavy Ion Laboratory University of Warsaw. Self-biased thin epitaxial detectors were irradiated with total dose of 90 MeV, ^{14}N ions about $7.1 \cdot 10^{10}$ 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 build-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]:

$$V = -(kT/q)\ln\left(\mathrm{n}^+/\mathrm{n}^-\right)$$

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 thin detector carriers concentrations therefore n$^+$ and n$^-$ remain unchanged. According above formula the build-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 next radiation damage experiment with high dose of ^{14}N beam ions directly hitting on 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 in wide angular range

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2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
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4) Faculty of Physics, University of Warsaw, Warszawa, Poland

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

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

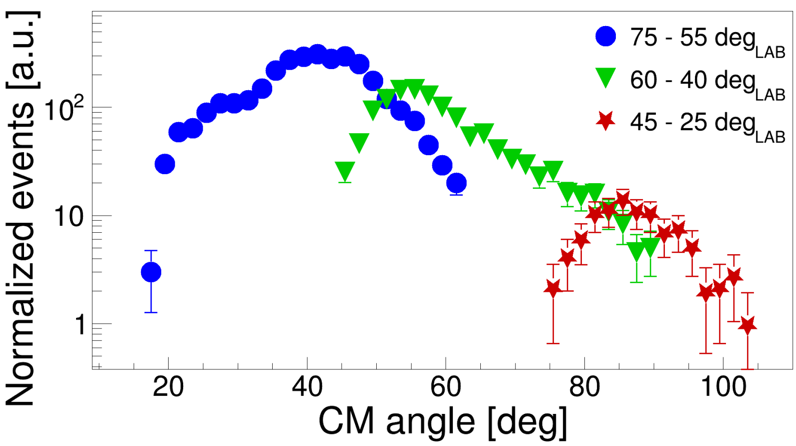

Figure 1: A scheme of the experimental setup.

The measurement has been performed in three runs, each of them with d-telescope covering following angular ranges in the laboratory frame: $25° - 45°$, $40° - 60°$ and $55° - 75°$. He-telescope was fixed at the 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 a best way to identify elastic scattering process. Since even 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 analysis of ΔE-E spectra. In the range of lower deuterium energies ΔE-E particle identification method is not possible and only correlation between angles of scattered particles can be used as the method for elastic scattering identification. The statistics obtained after normalization to the number of particles impinging on the physical target is presented in Fig. 2 as a function of CM angle.

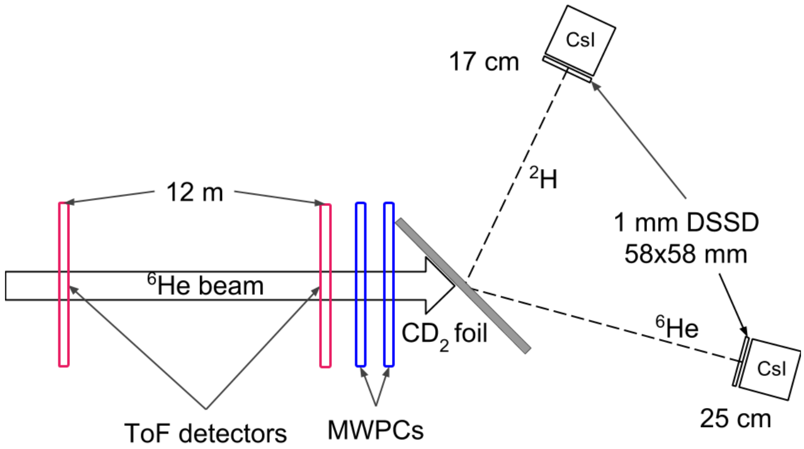

Figure 2: Normalized event numbers obtained at different CM angles for the elastic scattering channel ^{2}H(^{6}He,^{6}He) at ECM = 39 MeV. Different colours correspond to results obtained at three different angular ranges of the d-telescope.

Geometrical distribution of particles on the target is causing decrease of detection efficiency, which in turn leads to decrease in event count on the edges of each of the ranges. Monte Carlo simulation of the experiment with use of Geant4 package will be used to calculate detection efficiency, in order to obtain differential cross-section for elastic scattering of ^{6}He on deuterium.

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

M. Wolińska-Cichocka for the BRIKEN collaboration

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New measurement campaign using BRIKEN detector array and aimed in the determination of new β-delayed branching ratio was performed at the Radioactive Ion Beam Factory at RIKEN Nishina Research Centre (Wako, Japan) in autumn 2018. BRIKEN setup is the world-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, the ^{238}U projectiles were accelerated to 345 MeV per nucleon and hit 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) 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 by 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 sown at Fig. 1.

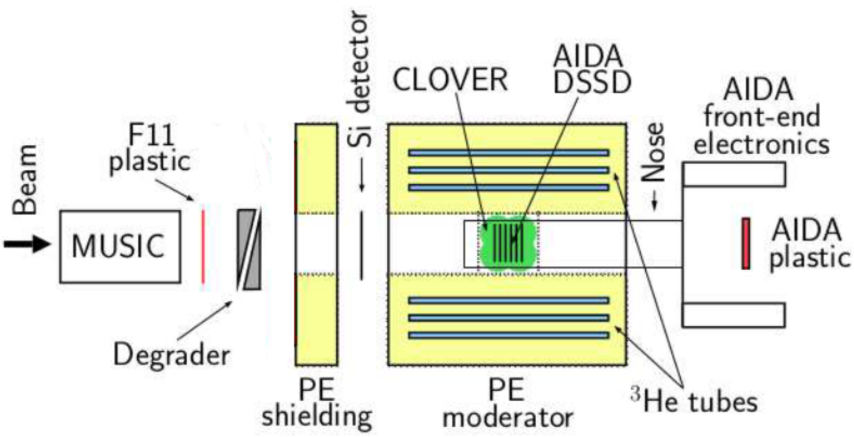

Figure 1: The experimental setup at RIKEN Laboratory [4]. The drawing is not to scale.

This experiment was focused on the study of the β-delayed neutron emission probabilities (Pn), half-lives and masses at very neutron-rich isotopes, which are most important understanding 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 /mbox2-dimension plot (PID) for this BigRIPS setting is shown at Fig. 2. These are preliminary data, the displayed statistic 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 Centre, Poland.

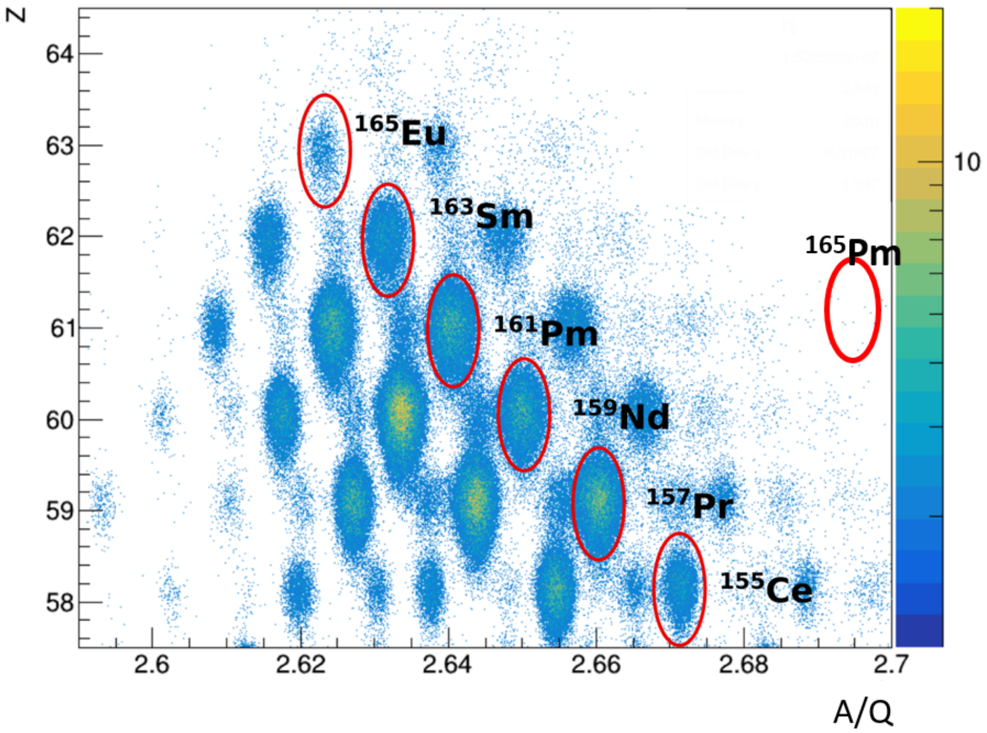

Figure 2: The particle identification 2 dimension plot (PID) for this measured collected in ~ 30 h of measurements.

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[4] A. Tolosa-Delgadoa *et al.*, arXiv:1808.00732 [physics.ins-det] (2018).

D.3 First experiments with NEDA and AGATA at GANIL

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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 the earlier editions of the HIL annual report [1?] and described more in details in several regular papers, see [2, 3] and references therein. The primary application of NEDA is to act as neutron multiplicity filter in experiments in which γ-ray detectors are used to study properties of exotic proton-rich nuclei, produced in-beam in fusion evaporation reactions. In this kind of experiments, the efficiency and quality of the neutron detection are the main factors which set 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 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. ??. 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.

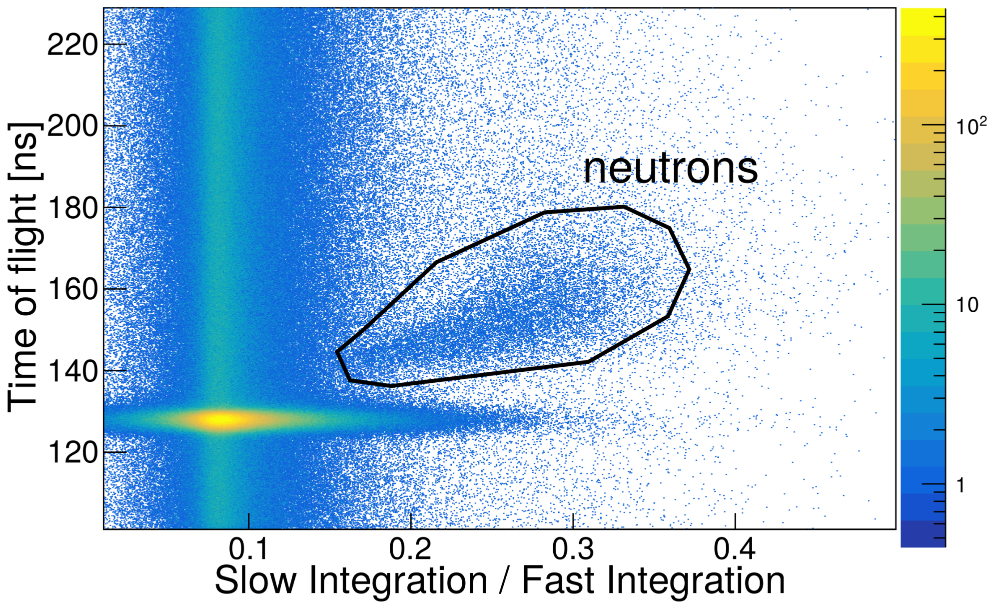

Figure 1: Discrimination of γ rays and neutrons using the time-of-flight and shape of the signal.

NEDA will ultimately consist of 355 identical detectors containing liquid scintillator (approx. 3 litres 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 built in stages. In 2018 the construction of NEDA Phase1 was completed. Consecutively, the setup of the NEDA array, Diamant charge 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 in the forward angles were accompanied by 42 Neutron Wall detectors arranged in the 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.

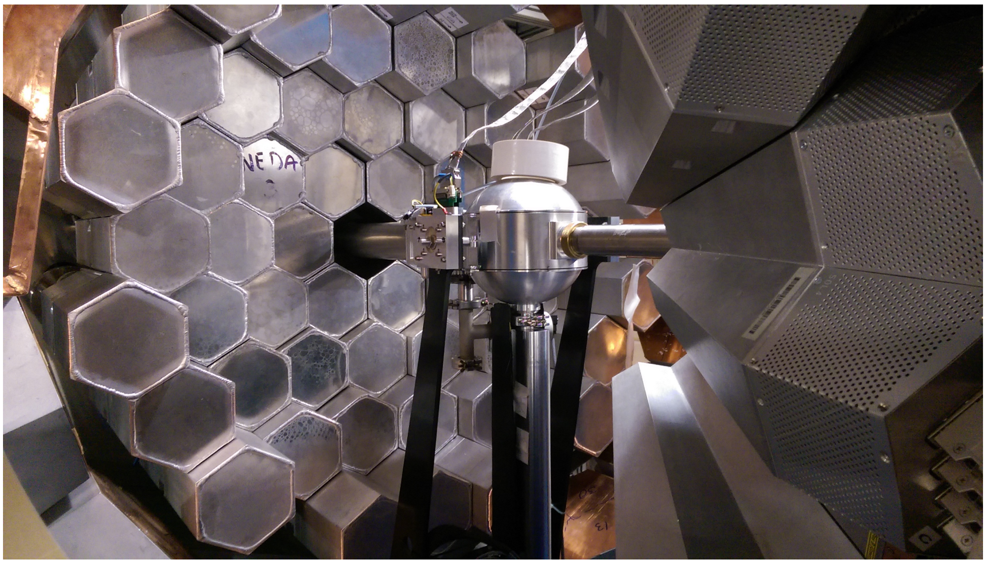

Figure 2: NEDA with AGATA at GANIL. From right to left (the beam direction): AGATA clusters, ion guide, target chamber with DIAMANT inside, NEDA array. Two triple Neutron Wall detectors are visible on the left bottom corner.

The physical phenomena addressed with the performed 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 concentrates on the analysis of the E703 experiment data in which γ-rays rays emitted from excited states of the ^{102,103}Sn nuclei should be observed. This experiment, aiming at nuclei produced with extremely low cross section (on a few micro-barn level), in particular requires careful optimisation of the treatment of NEDA signals. This can be done off-line using the digitised waveforms of the signals, stored during the experiments.

Acknowledgement: the Polish contribution to NEDA and related investigations of rare proton-rich isotopes are supported by the Polish National Science Centre (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 Centre 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 Centre "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 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 the radiation damage at superconductor (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 excitatin of ^{148}Nd^{p}lunger 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 nad ^{10}B+^{16}O interaction at the 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

Ni 7.03, 29.03-30.03
HIL000 — Test of new beam from 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 time: 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 time: 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 time: 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. (on maternity leave) Expected completion time: 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 production of new medical radioisotopes with cyclotron
Supervisors: prof. dr hab. T. Matulewicz, dr A. Trzcińska, prof. F. Haddad. (program cotutelle) Expected completion time: 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 capture and thermalization mechanism of ions and atoms beams injected into plasma produced by the electron cyclotron resonance
Supervisor: prof. dr hab. K. Rusek, dr K. Sudlitz. Expected completion time: 2021.

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

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

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

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

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

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

Maulen Nassurlla, Al-Farabi Kazakh National University, Almaty, Kazakhstan
Effects of cluster structure of stable boron and lithium isotopes to form the outputs of nuclear reaction in the interaction with deuterium and helium isotopes
Supervisors: prof. N. Burtebayev. Expected completion time: 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 time: 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 time: 2021.

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

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

Monika Rykała, Faculty of Physics, University of Warsaw
Synteza radiofarmaceutyków znakowanych izotopem skandu-44
Synthesis of radiopharmaceuticals labeled with a scandium-44 isotope
Supervisors: 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 time: 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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L. Auditore, C. Beck, E. Bonnet, B. Borderie, G. Cardella, A. Chbihi, A. D'Onofrio, J. Frankland, E. Geraci, E. La Guidara, G. Lanzalone, P. Lautesse, N. Le Neindre, K. Mazurek, A. Pagano, E. Pagano, M. Papa, E. Piasecki, L. Quattrocchi, F. Rizzo, E. Rosato, G. Spadaccini, A. Trifirò, and G. Verde. *Study of the 78;86Kr+40;48Ca reactions at 10 a MeV: Comparison with theoretical models.* Acta Phys. Pol. B Proc. Suppl. **11**, 189 (2018).

E.3.3 Articles in books

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E.4 Seminars

E.4.1 Seminars co-organised by HIL

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

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 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
AGATA-NEDA setup, new tool to study proton rich nuclei

K. Siwek-Wilczyńska — Inst. of Exp. Physics, Univ. of Warsaw, Warszawa, Poland 15 March 2018
Sympozjum SHE 2017 "Challenges in the studies of super heavy nuclei and atoms
0.5

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 correlations 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 hot nuclei de-excitation

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 — Inst. of Exp. Physics, Univ. 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
0.6

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 — Inst. of Exp. Physics, Univ. 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
Heavy ions ultraperipheral collisions as the 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 first experiments

K. Siwek-Wilczyńska — Inst. of Exp. Physics, Univ. 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 type (n, 2n) 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 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 on 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 of 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
0.6

T. Abraham — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 26 September
Hands on Workshop o Operation, Test and Repairs 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 Kyiv Institute for Nuclear Research

E.4.3 External seminars given by the 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

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

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 natMo(alpha,x) above 40 MeV at ARONAX
15th Varenna Conference on Nuclear Reaction Mechanisms, Varenna, Italy

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. 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 production of ^{97}Ru with the use of Radionuclide Yield Calculator at ARONAX
17th International Workshop on Targetry and Target Chemistry, Coimbra, Portugal

J. Choiński 2–6 September 2018
Heavy Ion Laboratory, University of Warsaw – development of experimental set-ups connected to the cyclotrons
41st European Cyclotron Progress Meeting , Dubna, Russia

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 mechanism
14th International Student Conference Modern Analytical Chemistry, Prague, Czech Republic

K. Rusek 26–30 September 2018
Study 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 the radiobiological studies at HIL
Nuclear Physics Research - Technology coaction, Warsaw, Poland

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

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

K. Wrzosek-Lipska 5–9 November 2018
Deformation and shape coexistence studied with the 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 ECRIS multi-test stand ant HIL
ENSAR2 Town Meeting, Groningen, Netherlands

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

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

M. Filipek 18–22 June 2018
Review of the 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 the 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 Monographic lectures on nuclear physics
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
Conventional, renewable and nuclear power industry
Faculty of Physics, University of Warsaw, Warszawa, Poland

E.4.6 Science popularization lectures

M. Palacz lecture for students

Środowiskowe Laboratorium Ciężkich Jonów (60 min)
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 Honours 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 1December
[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. NCBJ
    The National Centre for Nuclear Research
    Świerk k/Warszawy
15. Prof. dr hab. Adam Maj
    (**Deputy Chairman of the Council**)
    The Henryk Niewodniczański
    Institute of Nuclear Physics
    Polish Academy of Sciences, Kraków
16. Prof. dr hab. Tomasz Matulewicz
    Faculty of Physics
    University of Warsaw, Warszawa
17. Dr Paweł Napiorkowski
    Heavy Ion Laboratory
    University of Warsaw, Warszawa
18. Prof. dr hab. Wojciech Nawrocik
    Faculty of Physics
    Adam Mickiewicz University, Poznań
19. Prof. dr hab. Paweł Olko
    The Henryk Niewodniczański
    Institute of Nuclear Physics
    Polish Academy of Sciences, Kraków
20. Dr hab. Leszek Próchniak
    Heavy Ion Laboratory
    University of Warsaw, Warszawa
21. Prof. dr hab. Krzysztof Rusek
    (Director of HIL)
    Heavy Ion Laboratory
    University of Warsaw, Warszawa
22. Prof. dr hab. Adam Sobiczewski
    The National Centre for Nuclear Research
    Otwock
23. Dr hab. Elżbieta Stephan, prof. UŚ
    Institute of Physics
    University of Silesia, Katowice

E.8 Programme Advisory Committee

PAC members

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

The international Programme Advisory Committee of the Heavy Ion Laboratory usually meets twice a year, in spring and autumn. The deadline for submitting proposals is three weeks before a PAC meeting. PAC approved experiments are scheduled at the meetings of the Users' Committee, which also serves as a link between cyclotron users and the Laboratory. The Users' Committee is chaired by 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 Centre "Kurchatov Institute", Moscow, Russia
- Uzbekistan Academy of Sciences, Institute of Nuclear Physics, Tashkent, Uzbekistan

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