Introduction

This newsletter is a summary of recent events and information regarding the FAIR project and activities of the various NUSTAR Collaboration boards and committees.

Note that any information on highlights or upcoming meetings can be found on the NUSTAR@FAIR web page (see http://nustar.fair-center.eu). You can send your material to NUSTAR@fair-center.eu. Suggestions are always welcome.

Upcoming meetings (selection)

- June 9-10, 2016: FAIR/GSI Scientific Council meeting
- June 27-28, 2016: FAIR Council meeting
- September 27-30, 2016: NUSTAR Week 2016 (York, UK)
- October 13-14, 2016: FAIR AFC meeting
- December 7-8, 2016: FAIR Council meeting
- February 27 – March 3, 2017: NUSTAR Annual Meeting 2017

News from the Boards and Committees

NC (NUSTAR Council)

In the beginning of the year, the NUSTAR Council (NC) members had been asked to elect (via on-line voting) new members of the Board of Representatives (BR). In addition to the present BR members Alison Bruce and Nasser Kalantar-Nayestanaki, who were eligible for re-election, Olof Tengblad from IEM-CSIC Madrid was the third candidate for the two positions to be filled. The election result was the following (in total votes, each Council member was able to give up to two votes):

- Alison Bruce: 31
- Nasser Kalantar-Nayestanaki: 40
- Olof Tengblad: 22

The NC had its assembly during the NUSTAR Annual Meeting 2016. Besides the latest developments around GSI and FAIR as well as the work to come, the NC members discussed in detail new rules for the membership in the NUSTAR Council. The present definition (signature on the interims MoU) does not properly reflect the activity of the partner institutes and in some cases (due to administrative reasons) a signature cannot be given. Therefore, the NC decided to re-define the membership rules for institutes with the following main categories:

- Groups and/or institutes with a signed MoU
- Groups and/or institutes with (e.g.) > 50 k€ investments
- Groups and/or institutes with in-kind contributions to NUSTAR

It is foreseen that every three years, the NC sets up a committee to look at the member list and updates it accordingly. Still to be discussed is the question what a group and/or institute is and how to define “relevant” in-kind contributions to NUSTAR.
This new definition of the NC membership has also an effect on the NUSTAR MoU, since it enlarges and changes the set of institutes that may sign the Construction MoU (expected in 2017). The work together with the NUSTAR Resource Board and the NUSTAR BR will continue in the next months (see also RB news below).

The NC also started a discussion on the Scientific Advisory Committee (SAC), basically a follow up of a first discussion at BR and CC at the NUSTAR Week 2014 in Valencia. The main scope of the SAC would be looking into the science topics of the NUSTAR Collaboration. Eventually, the SAC could turn into a PAC for NUSTAR. It was decided to not rush this issue and rather wait for the installation of the new FAIR Scientific Managing Director and to start discussions as soon as appropriate.

**BR (NUSTAR Board of Representatives)**

The NUSTAR Board of Representatives met during the NUSTAR Annual Meeting 2016 in order to discuss the latest developments around FAIR and GSI and the status of the NUSTAR project.

Following the result of the election of BR members (see above), Alison Bruce (Univ. of Brighton) and Nasser Kalantar-Nayestanaki (KVI-CART/ Univ. of Groningen) had been re-elected for a second two-year term as members of the BR. Furthermore, both were unanimously proposed by the BR members and agreed to serve the NUSTAR Collaboration as Deputy Spokesperson and Spokesperson, respectively, for another two-year term.

The NUSTAR BR recapped the latest developments and actions taken by the BR over the last months. For example:

- **The BR welcomed the arrival of the new Technical Managing Director, Jörg Blaurock, at FAIR/GSI.** N. Kalantar, since the beginning of the year new BFC Chair, took the opportunity to call for a meeting of the BFC with Mr. Blaurock. One outcome of this fruitful meeting was an agreement to have the Technical Coordinators of the FAIR experimental pillars in leading positions of the new FAIR project structure. They are supposed to steer the local activities for the experiments within the FAIR project (including the coordination of the civil construction work for the experimental areas).

- **The BR was also happy about the attendance and the program of the NUSTAR Annual meeting 2016 and is now looking ahead at the NUSTAR Week in York.** Initially, the BR had expressed its wish to have talks from the NUSTAR Theory Network as a special topic at the Annual Meeting in order to streamline activities especially in light of the upcoming physics runs and first years of operation at FAIR. Since it was not possible to shape such a program this time, the BR requested a draft schedule until the York meeting such that a special theory session can be foreseen for the next Annual Meeting.

- **Furthermore, the NUSTAR BR was also approached by interested institutes (partly from countries not yet involved in NUSTAR) and possible contributions are looked into.** In general, interested scientists may approach directly the sub-collaborations in order to find suitable work packages that are still open for new partners.

The work to come (mainly for the BR, in close contact to the CC) include:

- **The BR is looking forward to working with the appointed Scientific Managing Director installed at GSI/FAIR.** Besides many issues regarding the FAIR project, the
future structure of the FAIR/GSI research division(s), the implementation of external collaborators (e.g. fellowships), an international science program at GSI (phase 0), as well as a suitable operation cost model have to be discussed. The first official meeting with the representatives of all the four pillars is already scheduled to take place at the beginning of June.

- Next in line is the newly formed Scientific Council (for both GSI and FAIR). N. Kalantar will present the activities of NUSTAR and in particular plans for phase 0 and phase 1 in the first meeting of the SC at the beginning of June.
- The BR will support the EXL Collaboration in its effort to re-define the physics case and possible operation at the storage rings of FAIR.
- One further hot topic will be the search for a solution to the missing funding of the R³B multiplet.

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<th>CC (NUSTAR Collaboration Committee)</th>
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| During the NUSTAR Annual Meeting, the NUSTAR Collaboration Committee, discussed in principle the same topics as in the NC and BR. It was stressed that the research activities and the local groups of the GSI Research Division have to grow again. The phase-0 operation of NUSTAR is crucial not only for tests and further development, but also to train young people and to conduct research in order to be ready once FAIR starts operation in phase 1. This will also be a signal for the international community that research continues at GSI. Furthermore, the representatives of the experiments reported on the latest status:
  - In the case of HISPEC/DESPEC all TDRs for detectors that are required in phase 1 are approved and work is presently focused on the infrastructure (in connection with the planning of the LEB building). Several detector systems are in use at other RIB facilities as part of phase 0 of NUSTAR. At the NUSTAR Week in York, it is planned to discuss in detail the phase 0 physics program at GSI.
  - Similar to HISPEC/DESPEC, the MATS and LaSpec collaborations look into the infrastructure planning as part of the planning of the LEB building. This is also necessary to come to a conclusion on the required interfaces especially with respect to the cryogenic stopping cell.
  - The R³B collaboration is very happy to have the GLAD magnet in its temporary position in Cave C and the series production of e.g. NeuLAND in continuing. One major problem is the funding of the R³B multiplet, which is tackled in various boards and is being discussed with the funding agencies.
  - The ILIMA detection systems are well defined and presently the required space in the vacuum chambers is cross-checked (in connection with the TDR of the collector ring CR). Once the TDR of the CR is finalized, it is expected that TDRs for the ILIMA detectors can be written.
  - While ELISe sees an increase of interest from the community, the EXL Collaboration has decided on a new management and is now looking into the mid-term and long-term planning of the project (for the operation at FAIR).
  - The Super-FRS the multiplets are contracted. However, the dipole magnets are delayed due to a pending contract with CEA Saclay for the design of the magnets.
  - The Super-FRS Experiment Collaboration is progressing with the definition of work packages and required infrastructure and space at the various experimental locations and focal planes of the Super-FRS.
  - Finally, the SHE Collaboration has made good use of the available beam time (see some reports in the news section below).
LEB Working Group

The planning of the LEB building has made a huge progress in the last months. Starting with a kick-off meeting on January 26, 2016, there had been frequent meetings with FAIR site&buildings in order to discuss details on the requirements of experiments and to fix the space allocation plan. The new layout of the buncher/spectrometer provided by our Indian colleagues from VECC has been included in the FAIR beam line plans. This triggered an adjustment of the position of the LEB building, while the overall layout and in particular the size has not changed much. Similarly, the intersection from the Super-FRS building to the LEB cave was simplified. Presently, the LEB building is with the external architects and technical infrastructure engineers for detailed planning as well as a cost calculation.

TB (NUSTAR Technical Board)

The NUSTAR Technical Board has met during the NUSTAR Annual Meeting. Besides the recent changes in the FAIR/GSI management as well as the status of the planning of the LEB building, the TB discussed the progress in the NUSTAR working groups and experiments. While in the case of HISPEC/DESPEC, MATS/LaSpec and R3B, almost all detector work packages are defined by TDRs and mainly infrastructure needs to be looked at, ILIMA is lacking the envisaged TDRs because the design of the CR first needs to be fixed. This will be done soon and then the technical description of the Schottky pick-ups might come in the next months.

Looking ahead to the operation at FAIR, the GSI accelerator department had requested to cross-check the list of elements and isotopes for the ion sources. This is required to plan the necessary source developments. Many of the wanted isotopes are readily available and the missing ones will all be developed in the coming years.

RB (NUSTAR Resource Board)

The NUSTAR Resource Board concentrated on the preparation of the 5th FAIR-RRB meeting. Latest major changes in funding were due to the recently approved projects within the German BMBF Collaborative Research. With respect to funding from FAIR budget, additional contributions from Finland were fixed and request for contributions from India and Romania are close to being sent to the next FAIR Council. Presently, about 63% of the overall funding is secured (including items funded by FAIR budget as well as external sources).

Following the definition of the NUSTAR phases (see NUSTAR Newsletter 2/2014), the funding agencies requested to get some more details on the status of the TDRs as well as funding related to the early use of equipment (phase 0) and the first years of operation at FAIR (phase 1). All NUSTAR sub-collaborations were asked to cross-check their projects and to look into the priorities and time lines of their work packages. An update of the project status will be given at the next FAIR-RRB meeting.

The NUSTAR MoU (for construction) is planned for end of 2017. The roadmap foresees to have a draft (with an updated organizational structure as well as preliminary lists of member institutes and scientists until this fall, e.g., at the NUSTAR Week in York) such that the NUSTAR Collaboration can clarify open questions and finalize the draft before the NUSTAR Annual meeting 2017. Afterwards, the funding agencies will receive the draft in order to participate in the editing process.
In its 7th meeting, the ECE recommended for approval the TDR of the NEDA neutron detector. For the TDR of the already submitted active target “ACTAR” of R3B, the review panel had some additional questions which need to be addressed. Several TDRs are expected to come in the next months, e.g. the NUSTAR data acquisition TDR and the TDR for the silicon tracker for R3B.

In general, the ECE congratulated all FAIR experiments for their progress. In light of the large number of TDRs still to come, the ECE requested that the collaborations shall give a priority with respect to the order of evaluation: TDRs which are urgent shall be looked at first. Furthermore, the ECE suggested to follow up on already approved TDRs and projects and also suggested to help with re-evaluating TDRs in case of technical changes after approval (if required, i.e. due to a major change of the design). The next meeting is supposed to be scheduled in fall this year (date not yet fixed).
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<td><strong>NUSTAR Collaboration meeting</strong></td>
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<td>The NUSTAR Annual Meeting 2016 was held at GSI in the week February 29 to March 4. With about 200 international participants the attendance was large again this year. The attendees were impressed by substantial progress in the development and realization of detector set-ups and their associated infrastructure. This guarantees the continuation of the successful experimental program in the field of super-heavy element research at the UNILAC at GSI and many other NUSTAR experiments at other facilities worldwide.</td>
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<td>It was shown that preparations for the NUSTAR FAIR Phase-0 experimental program planned at the FRS of GSI from 2018 onwards are on the right track. Latest research highlights from successful experiments at GSI and other laboratories were broadly discussed. The participants were satisfied by the recent organizational changes at GSI and FAIR and welcomed in particular the advances in the planning of the LEB building, which is indispensable for some NUSTAR experiments.</td>
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<td>During the full week many working groups and sub-collaborations used the opportunity to discuss their developments, to report on latest results and to plan the next steps of their work.</td>
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For details see [conference web page](#).
NEWS FROM THE NUSTAR EXPERIMENTS AND SUPER-FRS

HISPEC/DESPEC

News from DESPEC

The fast-timing array FATIMA, developed for DESPEC, passed an important milestone. In an experiment lasting six weeks over the recent Christmas and New Year period at the Argonne National Laboratories, 25 LaBr₃(Ce) detectors of the FATIMA array were coupled to the “Gammasphere” Ge array with the aim to measure lifetimes in ps-ns range in fission products of ²⁵²Cf. It was the first occasion that the EDAQ developed for FATIMA, consisting of a digital branch for the energy measurement and an analogue one for the high precision timing, was used. Previously the LaBr₃(Ce) detectors of FATIMA were used in a series of experiments in different accelerator laboratories (RIKEN, ISOLDE, Jyväskylä, Bucharest, Cologne) and at the ILL reactor in Grenoble.

25 FATIMA detectors were coupled to 51 Ge detectors of the Gammasphere array at the Argonne National Laboratories. The idealized conceptual design and the set-up in reality are shown.

Therefore FATIMA is the latest member of the family of the commissioned DESPEC detector systems, joining the total absorption spectrometer (DTAS), the neutron counter (BELEN) and the implantation and decay detector (AIDA). All these subsystems are ready for high-impact experiments using the GSI beams starting in 2018.

Contact: Zsolt Podolyak (Univ. of Surrey)

R³B

R³B neutron detector NeuLAND for experiments at RIBF in Japan

Part of the R³B neutron detector NeuLAND has been successfully commissioned and used for a first experiment at the RIBF at RIKEN in Japan. Four double planes of NeuLAND have been integrated in the SAMURAI setup and combined with the neutron detector NEBULA. The combination allowed for the first time to detect four neutrons in coincidence.

The first experiment has been performed successfully end of 2016 to search for the ²⁸O ground-state resonance. This nucleus is four neutrons beyond the neutron drip line and decays into ²⁴O and four neutrons. From the kinematically complete measurement of the reaction products, the ground state energy and the width of the resonance state can be extracted. This result will serve as a bench mark for modern many-body nuclear theory.
NeuLAND (center) and NEBULA (left) as combined system behind the SAMURAI magnet (right) at RIKEN.

Contact: Thomas Aumann (TU Darmstadt)

R3B

GLAD magnet moved into Cave C

On Thursday, February 11, the large acceptance dipole magnet GLAD was moved from its preliminary testing location into Cave C of GSI. With the help of air cushions, the 110-ton ALADIN magnet was first moved out of the experimental cave in order to make place for the 60-ton successor.

GLAD magnet at the new location in the Cave C of GSI.
In Cave C, the GLAD magnet will undergo further extensive testing. Furthermore, additional components of the R³B experiment will be step by step connected and placed in Cave C. It is foreseen to use this initial R³B setup for first experiments from 2018 onwards until the new experimental cave at FAIR is ready for the installation of the full R³B setup and operation with beams from Super-FRS.

Contact: Haik Simon (GSI)

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**ILIMA**

**Progress on Schottky detector developments**

ILIMA aims at performing accurate mass and lifetime measurements of exotic nuclei in the future FAIR project. One of the main playgrounds of ILIMA is the planned Collector Ring (CR) for which several Schottky detectors are planned and are currently in the R&D phase. In the following we report on their status.

**Longitudinal Schottky detectors:** Based on successful experiences with the ESR storage ring at GSI [1], two longitudinally sensitive detectors are planned for the straight sections of the CR. Unlike the ESR resonator, these will have a fully evacuated design albeit with a mechanism that allows for variable sensitivity. A R&D prototype of such detectors has been constructed and is ready for the manufacturing process.

![Scaled models of transversal cavities for bench-top test (Photo: X. Chen [5]).](image)

**Transversally sensitive Schottky detectors:** One of the main problems of Schottky mass measurement [2] in Isochronous mode is the undesirable effect of anisochronicity, which can be corrected, if additionally to the revolution frequency, also the magnetic rigidity of the particles are known. In order to achieve this, a conceptual design based on a cavity with an elliptical geometry was introduced [3], where the position of the particles is proportional to the coupling impedance and hence to the Schottky signal power. Further work, including simulations and measurements on scaled bench-top models (see Figure above), have confirmed analytical results [4, 5]. The next step is the design of an evacuated cavity for an actual beam test.

**Software defined radio for Schottky signals:** Established tools in communication systems, software defined radio (SDR) methods also prove invaluable for the experimental physics. This is in particular interesting for acquisition of narrow-band Schottky signals using cost-efficient hardware solutions available on the market. The electronics can be managed by likewise market-available, small but powerful single-board computer nodes running standard Linux operating system. A prototype is under conception in order to explore computational challenges for the signal analysis from multiple CR Schottky systems.
References:

Contact: M. Shahab Sanjari

EXL

New Spokesperson for EXL Collaboration

During the NUSTAR Annual Meeting 2016, the EXL Collaboration elected a new management team:

- Thomas Aumann (Spokesperson)
- Rene Reifarth (Deputy Spokesperson)
- Haik Simon (GSI Liaison).

The EXL Collaboration thanks the former team (Nasser Kalantar-Nayestanaki, Peter Egelhof, and Helmut Weick) for its support in the past and for conducting the first EXL scattering experiment at the ESR, which was a fantastic success.

It is planned to upgrade the existing detection system for operation at the ESR from 2018 on, and to update the physics case and detector concepts of EXL towards operation at the planned storage rings of FAIR.

Contact: Thomas Aumann (TU Darmstadt)

SHE / MATS

Long-standing problem with the Q-value of the electron capture in $^{163}$Ho solved

In the winter-spring period of 2015 an international group of scientists carried out a direct measurement of the Q-value of the electron capture (EC) in $^{163}$Ho with an unprecedentedly high accuracy of a few ten eV [1]. The experiment was conducted within the framework of the ECHo-project - one of the new-generation experiments under development devoted to a determination of the neutrino mass with a sub-eV uncertainty. The ECHo-experiment is based on the analysis of the full-energy spectrum of atomic de-excitation, which follows the capture of an atomic orbital electron by the $^{163}$Ho nucleus.

The success of the ECHo-experiment depends to great extent on the accurate knowledge of the Q-value of the EC in $^{163}$Ho, in its first phase on a level of at least a few ten eV. A very
strong scattering of the Q-values from 2.4 keV to 2.9 keV resulted from a bunch of experiments based on various indirect methods of the Q-value determination and had triggered the direct Q-value determination via measuring the mass difference of $^{163}$Ho and $^{163}$Dy with the Penning-trap mass-spectrometer SHIPTRAP employing the novel Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique [2,3].

An artistic illustration of the experimental setup is presented in the Figure above. Singly charged ions of $^{163}$Ho and $^{163}$Dy were produced with a laser-ablation ion source by irradiating the corresponding Ho and Dy samples with a laser beam. For the production of the Dy sample, a few milligrams of natural Dy in powder form were spread over a small titanium plate. $^{163}$Ho is radioactive with a half-life of 4570(25) years and thus first had to be produced in sufficient amount and in a high-purity form. The production of $^{163}$Ho involved neutron irradiation of an enriched $^{162}$Er sample in the high-flux reactor of the Institut Laue-Langevin and the subsequent electron capture decay of the resulting $^{163}$Er into $^{163}$Ho. This was followed by a chemical separation based on ion chromatography optimized to separate neighboring lanthanides. Finally, the Ho sample for the laser ion source was prepared by putting a drop of $^{163}$Ho nitrate on a titanium plate and letting it dry. The sample preparation procedure was optimized at the TRIGA-TRAP facility [4], the predecessor of the MATS@FAIR Penning-trap mass spectrometer. The final Ho sample contained about 1016 $^{163}$Ho atoms.

The use of a sample with just a few micrograms of radioactive material for measuring the mass difference of heavy nuclides with a sub-ppb uncertainty is a unique feature of this experiment. From the laser-ablation ion source $^{163}$Ho$^+$ and $^{163}$Dy$^+$ ions were alternately transferred into a preparation trap for ion cooling and further transferred into a measurement trap for mass determination with the PI-ICR technique.

The obtained result for the atomic mass difference of $^{163}$Ho and $^{163}$Dy is in perfect agreement with the value yielded by cryogenic micro-calorimetry – the basic technique of the ECHo-experiment [5,6]. This confirms on the level of the present accuracy the correctness of the theoretical and experimental principles, which underlie the ECHo-experiment. Thus, the long-standing problem with the discrepancy in the Q-value of the electron capture in $^{163}$Ho is finally solved in favor of the ECHo- and similar projects.

References:

Contact: Michael Block (GSI/HIM/Univ. Mainz), Sergey Eliseev (MPI-K Heidelberg)

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**Last known magic neutron number weakens in heavy elements**

An international team of scientists has succeeded to create and detect extremely short-lived atomic nuclei of the element uranium. Having far fewer neutrons than the kind of uranium nuclei found in nature, they exist only for about a millionth of a second. The new data provide key information on how the numbers of neutrons and protons inside exotic heavy nuclei influence their stability. This is important to give better guidance for experiments on the search for new super-heavy elements.

In atomic nuclei, protons and neutrons arrange in individual shells. Nuclei containing just the right numbers to fill a proton and a neutron shell are considerably more stable than their neighbors. For protons, 82 is the last known of these “magic numbers”, while it is 126 for neutrons.
for neutrons. This makes $^{208}\text{Pb}$, with 82 protons and 126 neutrons, the heaviest “doubly-magic nucleus” known to date. $^{208}\text{Pb}$ is the main ingredient in lead as used in daily life like in car batteries. For decades, scientists tried finding out how many protons will fit into the next shell, which was conjectured to give rise to an "island of stability" in the region of super-heavy elements. Current theoretical models still disagree: some favor 114, others prefer 120 or even 126. Element 114 is known, but can be studied at rates of only about one atom per day. Elements 120 and 126 are yet unknown. Scientists thus look for other experimental data allowing to refine their models.

In their recent work, an international team led by Jadambaa Khuyagbaatar from the Helmholtz Institute Mainz, Germany, and the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany, traced this last neutron shell closure towards heavier elements. The question is whether the neutron number 126 remains as dominant in these increasingly unstable nuclei as it is known to be in $^{208}\text{Pb}$. For this, they produced nuclei uranium, with extra ten protons when compared to lead. Usual uranium nuclei as found in nature, like $^{238}\text{U}$, have far more neutrons than around 126, so the researchers first produced the new $^{221}\text{U}$ and acquired new and improved data on $^{222}\text{U}$, of which only three atoms were observed in a study dating back to 1983.

One of eighty-one registered traces of a triple-signal associated with the implantation of $^{222}\text{U}$ into the detector (red), its emission of an $\alpha$ particle with 9.31 MeV energy (blue) leading to $^{218}\text{Th}$, followed by the very fast $\alpha$ decay of this latter nucleus by emission of a 9.67 MeV $\alpha$ particle (green), leading to $^{214}\text{Rn}$, the decay of which occurred after the end of the shown trace but was registered in a different branch of the data acquisition system.

For this, an intense beam of $^{50}\text{Ti}$ ions (element 22) was accelerated at GSI Darmstadt and used to irradiate a foil containing $^{176}\text{Yb}$ (element 70). Fusion led to uranium nuclei (element 92), which were separated in the gas-filled recoil separator TASCA and guided to a detector suitable to register their decay. In this way, the team studied these nuclei’s instability and found them to decay within microseconds. Such short lifetimes could only be registered thanks to a new, advanced data acquisition system and data analysis techniques. The study of combined data of isotopes of elements from lead up to uranium at and above the 126 neutron shell suggests this to no longer be a pronounced magic neutron number in uranium. These data allow benchmarking models that, e.g., guide efforts to search for new super-heavy elements.


Contact: Jadambaa Khuyagbaatar (HIM/GSI)
Electron Capture Decay of $^{257}$Rf and $^{257m}$Rf

Besides α emission and spontaneous fission, electron capture decay (EC) is another essential radioactive decay mode in the region of super-heavy elements. However, investigation of this process is challenging, as it is not accompanied by emission of characteristic particles that can be measured with sufficiently high efficiency. Enhanced experimental sensitivity, achieved during the past two decades now allows for measuring conversion electrons (CE) and characteristic X-rays emitted during this process.

Fig. 1: (a) and (b): α spectra of $^{257}$Lr measured in delayed coincidence with CE from EC decay of $^{257}$Rf from (a) “direct” production and (b) from α-decay of $^{261}$Sg (red lines); the black lines represent the α spectra measured in beam pause. (c) spectrum of photons measured in coincidence with CE; the red curves represent the K X-ray lines of lawrencium. (d) sketch of a possible EC decay scheme of $^{257}$Rf.

At SHIP, recently EC of $^{257g,257m}$Rf was investigated by measuring delayed coincidences between CE, X-rays and α decays of the EC daughter $^{257}$Lr. Figures 1a and 1b show the spectra of α decays preceded by CE within a time interval Δt < 1.5 s (red lines). For comparison the α-spectra taken between the beam pulses are shown by the black lines. Part of the α-spectra were found in coincidence with photons, which predominantly could be attributed to K X-rays of lawrencium (see Fig. 1c), proving that the CE indeed stem from the CE process.

To study differences in the EC properties of $^{257}$Rf and $^{257m}$Rf we compared the results from a “direct” production via $^{208}$Pb($^{50}$Ti,n)$^{257}$Rf, where both, $^{257}$Rf and $^{257m}$Rf were produced (Fig.
1a), and from a production via α decay of $^{261}$Sg [1], where only $^{257}$Rf was produced (Fig. 1b). Significant differences in the energy distribution of the α particles were observed. In the indirect production we found a strong component at $E_\alpha < 8.83$ MeV, while in the direct production the peak at $E_\alpha \approx 8.80$ MeV was more pronounced. So it seems meaningful to ascribe the events of the lower energy essentially to EC decay of $^{257}$Rf, the higher energy essentially to EC decay of $^{257m}$Rf. A careful analysis resulted in energies and half-lives of $E_\alpha = 8811 \pm 25$ keV, $T_{1/2} = 203$ ms and $E_\alpha = 8878 \pm 12$ keV, $T_{1/2} > 0.5$ s. Both α lines have been assigned to $^{257}$Lr so far [2]. The different production mechanisms and half-lives, however, suggest that they stem from the decay of different states in $^{257}$Lr, as sketched in Fig. 1d. The occurrence of a low excited isomeric state in $^{257}$Lr is not surprising. In odd-mass Lawrencium isotopes the 1/2$^+$[521] and 7/2$^+$[514] Nilsson levels are predicted in close vicinity at low excitation energies [3]. The “large” difference of $\Delta I = 3 \hbar$ favors the occurrence of long-lived isomeric states at low excitation energies as already identified in the neighboring isotopes $^{253}$Lr [4] and $^{255}$Lr [5].

References:

Contact: Fritz Peter Heßberger (GSI/HIM)