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NuPECC in the Nuclear Physics Landscape

The recent completion and publication of the 2017 NuPECC Long Range Plan (LRP) has defined a clear strategy for development of nuclear physics in Europe. We wish to acknowledge here the wonderful work of Professor Angela Bracco, Chair of NuPECC from 2012 to 2017, who played an essential role in the organization, writing, editing, and communication of the LRP.

One of the key recommendations proposed in the LRP is that NuPECC will pay particular attention to the completion and operation of European nuclear physics facilities, with FAIR as the flagship ESFRI infrastructure. Strong support will be given to the construction, augmentation, and exploitation of world-leading ISOL facilities (ISOLDE, JYFL, GANIL-SPIRAL2, SPES, and hopefully soon ISOL@MYRRHA), collectively associated in the EURISOL Distributed Facility initiative. ALICE and the heavy-ion program at the LHC, including its planned experimental upgrades will be strongly supported, and NuPECC will promote at all occasions the Extreme Light Infrastructure Nuclear Physics (ELI-NP) facility in Romania, which will soon start operation, opening new exciting possibilities in nuclear and interdisciplinary research with lasers and gamma beams.

NuPECC in its actions will strongly emphasize the importance of theory, overarching all domains of nuclear science, and will in particular support a further development of the European Theory Centre, ECT*, in Trento.

NuPECC, together with the whole European nuclear physics community, will in the coming years face the challenging task of implementing the above LRP recommendations. To reach this goal, which becomes the first priority of its activity, NuPECC is using and will continue to develop all traditional tools at its disposal, such as presentations of the LRP to national and international communities at meetings, seminars, and conferences, and wide distribution of the LRP document and its summary brochure toward scientists, politicians, and the general public.

However, in addition, we are convinced that the implementation of the LRP also requires a new dynamical approach. Thus, a dedicated NuPECC Task Force has been formed that includes representatives of the nuclear physics ESFRI roadmap facilities (FAIR, GANIL-SPIRAL2, ELI-NP, and NICA), NuPECC Chair, Deputy Chair and Scientific Secretary. It is charged with a challenging duty of communication on the LRP and verification of how the LRP is implemented in all NuPECC member states. Focused meetings between the Task Force and national organizations in charge of research policy are being organized by the national NuPECC representatives. Additional meetings will be arranged with the European Parliament, the European Commission, and ESFRI. The first meeting of this kind was with the Norwegian authorities, and took place in June in Oslo, while further meetings are already planned in 2018 in Austria, Poland, and Romania.

Despite the current political situation in Europe, we deeply believe that European nuclear physics, and science in general, should continue a process of integration and tighter collaboration between all European countries. Thus, NuPECC will support and follow up the EU Integrating Activity projects in nuclear physics: the ongoing HORIZON 2020 ENSAR2 project and the STRONG-2020 proposal in hadron physics, which is currently under evaluation.

Nuclear physics has long been a worldwide endeavor, and its international dimension is taking more and more importance. NuPECC will continue to work in a coordinated manner with IUPAP and sister organizations in Asia and the Americas. Moreover, an update approved in March 2018 of the NuPECC Terms of Reference opened a new possibility for research organizations from outside of Europe to join the Committee. iThemba Labs from South Africa and RIKEN Nishina Centre from Japan have already succeeded in becoming the first two NuPECC Associated Members. We expect that other European and international organizations will join the Committee, thus increasing its representativeness and reinforcing its recognition in Europe and other continents.

In April 2018, NuPECC was invited as an observer to participate in the ECFA (European Committee for Future Accelerators) and Restricted ECFA (RECFA) meetings, providing a new opportunity to tighten links with the particle physics community. NuPECC has returned the invitation to an observer from RECFA and will also actively participate in the forthcoming update of the European Particle Physics Strategy, providing its input based
on the 2017 LRP findings and recommendations.

The recent detection of gravitational waves from a neutron star merger by the LIGO–VIRGO collaboration, followed by the observation of electromagnetic radiation by numerous telescopes, boosted experimental and theoretical physics in many domains, not least nuclear physics and astrophysics. In particular, the equation of state of nuclear matter and scenarios of nucleosynthesis have been, and will be further, confronted with such observations. For nuclear physics, and indeed all physics communities, this extraordinary discovery is imposing a new interdisciplinary approach to research. Several national and international workshops and seminars, putting together astrophysicists, particle and nuclear physicists, have already taken place that were dedicated to this topic. These were organized and located both in the United States and Europe, including at the ECT*. These kinds of initiatives are certain to expand in the future, and in Europe NuPECC, together with other expert committees, societies and research organizations, should play an important role encouraging and supporting their organization. We are convinced that this topic should find a major place in the program of the first joint Astroparticle Physics European Consortium–ECFA–NuPECC meeting planned for the end of 2019.

Many outreach and communication activities of NuPECC are already well established and recognized. *Nuclear Physics News*, one of the flagship journals of the nuclear physics community, will continue to play an essential role in the communication of scientific results, portraits of laboratories, meeting reports, and many other issues of relevance to the large international community. Public Awareness of Nuclear Science, a joint activity of NuPECC and the Nuclear Physics Division of the European Physical Society, will soon propose new actions to reinforce the visibility of nuclear physics research and its actors. The NuPEX website dedicated to the public awareness of nuclear sciences is progressing in its translation to new languages and is extensively used by users including those from South America.

Starting in 2019, NuPECC has decided to sponsor the most important nuclear physics conferences and meetings.

Recently, NuPECC has undergone important changes to its internal organization. The update of the Terms of Reference mentioned above also re-defined the objectives of the Committee, simplified and clarified relationships of NuPECC with our host organization (the European Science Foundation), defined the role of representatives of NuPECC member organizations, and introduced both the Associated Membership and the possibility to appoint a NuPECC Deputy Chair. A new agenda of the NuPECC meetings was established to reflect major priorities of the Committee in the coming years, and the activities of the Committee in between meetings is now monitored regularly by a newly established management group composed of the NuPECC Chair, Deputy Chair, Scientific Secretary, and Treasurer.

In the next few years, European nuclear physics will without doubt produce many exciting new results, facilitated by the new frontline facilities progressively entering into operation. Despite the tendency that exists in several countries to concentrate only on national developments, we believe that progress in science, and in nuclear physics in particular, will be driven by European and international cooperation. NuPECC will concentrate all its effort to play a major and constructive role in this endeavor.
NUSTAR: NUclear STructure Astrophysics and Reactions at FAIR

NUSTAR is a collaboration of more than 800 scientists from 180 institutes in 38 countries who will perform key measurements to investigate the structure, decay properties, and reactions of nuclei leading to an understanding of the origin of the elements in the universe. NUSTAR is organized in nine sub-collaborations that will undertake competing and complementary measurements of important observables. In alphabetical order, the nine sub-collaborations are:

- ELiSe: Electron-Ion scattering in a Storage ring (eA collider)
- EXL: Exotic nuclei studied in Light-ion induced reactions in a storage ring
- HISPEC/DESPEC: High-resolution In-flight Spectroscopy/Decay Spectroscopy
- ILIMA: Isomeric beams, Lifetimes and Masses
- LaSpec: Laser Spectroscopy
- MATS: Precision Measurements on very short-lived nuclei using an Advanced Trapping System
- R³B: Reactions with Relativistic Radioactive Beams
- Super-FRS Experiment: High resolution spectrometer experiments
- SHE: Synthesis and study of Super-Heavy Elements

The super-heavy elements collaboration will use UNILAC beams with the highest intensities of projectiles like $^{48}$Ca and $^{50}$Ti, and the SHIP and TASCA separators. The research focus is the study of the production and decay of the heaviest elements, their nuclear and atomic structure as well as their chemical properties. Most other experiments in the collaboration will use the Super-FRS (Fragment-Separator) to resolve intense secondary beams of rare isotopes produced using the increased intensity of the suite of FAIR accelerators and a series of complementary detector setups are foreseen to investigate the properties of exotic nuclei. Results should clarify details of the structure of all nuclei and the nuclear configuration of the abundance of heavy elements, new knowledge about the interior of neutron stars, and other unsolved astrophysical puzzles. Figure 1 shows a schematic layout of the Super-FRS and the beam-lines leading to various experimental areas dedicated for the experiments listed above. Only those that are part of the startup version of the facility are shown.

Table 1 shows the observables each of the sub-collaborations addresses and how they intertwine to give an overall picture of nuclear structure. In this table and in the subsequent discussion, the Super-FRS sub-collaboration is listed first. The experiments in the high-energy branch and the low-energy branch are then described, followed by the study of super-heavy elements using the UNILAC and finally the ring branch experiments. Although the facility is still under development, first experiments using FAIR equipment (FAIR–phase 0) are scheduled for 2018 and 2019. In the case of NUSTAR, first experiments will be focused on $N \sim 126$ nuclei where FAIR currently has an advantage over other labs worldwide as the energies of the beams produced are so high that fully stripped ions can be studied. Figure 2 shows the 90% line for fully stripped ions as a function of energy and atomic
number and places different laboratories in perspective. In almost all the experiments performed in phase 0, the SIS18 accelerator and the FRS will be used to produce radioactive ions. A large fraction of the required primary beams will be $^{208}\text{Pb}$, $^{238}\text{U}$, $^{40}\text{Ar}$, and protons, which are rather standard beams. The novel NUSTAR NDAQ data-acquisition system will enable higher throughput and improved reliability. This article highlights some of the physics to be addressed by NUSTAR. It is, by definition, a subset of the work being undertaken by the collaboration.

**Super-FRS Experiment**

The Super-FRS fragment separator is a versatile and high-resolution magnetic spectrometer in the mag-

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**Table 1. The complementarity of NUSTAR experiments.**

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**Figure 2. The 90% line for fully stripped ions as a function of energy and atomic number highlighting the capabilities of different laboratories.**

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netic rigidity range up to 20 Tm. The Super-FRS Experiment Collaboration will use the uniqueness of FAIR in terms of the combination of high beam energies, the high momentum-resolution spectrometer capabilities with a momentum resolution of $\Delta p/p \sim 10^{-4}$ and the characteristics of the multiple-stage magnetic spectrometer, including dispersion-matched operation modes, for pioneering experimental studies with heavy ions at the borderline of atomic, nuclear, and hadron physics. The existing experience from FRS experiments over 28 years and the new equipment, such as the Wide Angle Shower Apparatus (WASA@FRS) (see Figure 3), the Ion Catcher, or the EXPERT setups are the base of the collaboration. This opens new and unique experimental opportunities for the production and study of exotic hyper-nuclei, $\eta'$-mesic nuclei, and delta resonances in asymmetric nuclear matter. Moreover, new decay modes such as two-proton or neutron radioactivity can be studied via in-flight-decay measurements. Specific nuclear structure and EoS properties can be obtained via total interaction cross-section and charge-changing cross-section measurements in very exotic nuclei. Accurate measurements of the slowing down of heavy ions in matter and of production cross-sections for new exotic isotopes will be of benefit to all other NUSTAR collaborations.

**R3B**

The Reactions with Relativistic Radioactive Beams (R3B) experiment will use the full energy range available from the Super-FRS without further stopping, cooling, or accumulation (i.e., 200–2,000 MeV per nucleon). It will require a kinematically complete measurement of a wide variety of scattering experiments that will produce reaction products traveling at high velocities and spread over large emittance angles. Therefore, a large acceptance zero-degree superconducting dipole magnet has been designed and constructed to collect and direct the reaction products to a range of detectors (see Figure 4). It needs to have a large magnetic rigidity because of the energy of the reaction products and a large field gap because of the range of scattering angles for the different types of reaction and, in particular, to enable a large-acceptance detection of neutrons in the forward direction. The magnet will be combined with new detection systems (tracking, neutron detection, vertex tracker, and gamma detection) to allow, for the first time, experiments with the highest energies, even up to 1 GeV/u, for neutron-rich beams to be undertaken. This will open unique opportunities even for light nuclei. Examples are the measurement of the full dipole response of halo nuclei or quasi-free $(p,pN)$ knockout reactions. The readiness of one third of the neutron detector, NeuLAND, will make high-resolution...
measurements of two-neutron decays of neutron-rich nuclei at the drip line and beyond possible, already from 2018. For heavier beams, Coulomb break-up to determine reaction rates relevant for astrophysics, and $(p,2p)$ fission measurements to investigate static and dynamical properties of fission of exotic nuclei will be among the first experiments. Completion of the full setup will allow the extension of the experimental program to address the nature of short-range correlations, the equation of state in asymmetric matter or the study of hypernuclei. Compared to competitive projects worldwide, which are the SAMURAI spectrometer at RIBF at RIKEN, and a similar setup at the future FRIB facility, $^{3}$B will be unique in the foreseeable future due to the combination of high-energy beams, large acceptance, high resolution, and large efficiency including multi-neutron detection.

**HISPEC/DESPEC**

The High-resolution In-flight Spectroscopy experiment (HISPEC) will use radioactive beams with energies of 3–300 MeV per nucleon for in-beam $\gamma$-ray spectroscopic studies with AGATA, the Advanced GAMma Tracking Array. In general, the reaction products will travel with high velocities in the forward direction, which means that $\gamma$-rays can be emitted with a considerable Doppler shift. It is, therefore, necessary to identify the secondary reaction products and measure their momenta on an event-by-event basis, and to have the best possible knowledge of the position and angle of $\gamma$-ray emission. The first of these tasks is carried out by the Lund-York-Cologne CALorimeter and the second by the position sensitivity of the AGATA detectors.

In the Decay Spectroscopy experiment (DESPEC), the radioactive ions will be stopped in a position-sensitive stack of silicon detectors, and their subsequent decay by neutron, $\alpha$, $\beta$, or $\gamma$-ray emission will be studied. The implantation detector needs to be highly segmented and also able to detect the implantation of heavy ions and to measure the energy of electrons emitted in the $\beta$ decay in close succession. For DESPEC, this will be achieved using the Advanced Implantation Detector Array (AIDA) (see Figure 5) for which an application-specific integrated circuit has been designed. First experiments planned already for 2018 and 2019 will use separately the FATIMA fast-timing array of LaBr$_3$(Ce) detectors and the DEGAS Ge array. Further experiments using a Decay Total Absorption Spectrometer and neutron detectors are envisaged. Level schemes, lifetimes of excited levels, and $\beta$-strength functions will be determined in heavy neutron-rich nuclei around $N = 126$, $Z = 82$, and also in heavy deformed nuclei. These nuclei are related to the nucleosynthesis of heavy elements in the rapid neutron capture process (third r-process abundance peak) and complex shape evolution (prolate-triaxial-oblate-spherical) in nuclei. There is, presently, no information available in the region where the third r-process peak becomes important.

These measurements can only be realized at GSI/FAIR, since RIKEN and FRIB are only competitive for regions where fission fragments dominate the scene ($A < \sim 160$) as shown in Figure 2.

**LaSpec**

Optical spectroscopy of the electronic structure of atoms and ions provides a unique window to access the fundamental ground state nuclear structure properties (nuclear spins, electromagnetic moments, and changes in mean-square charge radii) in a model-independent manner. The workhorse for the LaSpec collaboration will be the application of Collinear Laser Spectroscopy (CLS), which is routinely carried out on isotopes with yields of about 1,000 ions/s. Currently, there are developments that clearly have the potential to work with yields on the order of 1–10 ions/s and these variants of CLS at LaSpec will provide new opportunities as compared to other facilities. We expect LaSpec (placed in the low-energy building; see Figure 6) to be competitive especially in the regions of neutron-rich refractory elements, which cannot be delivered in large amounts from ISOL-type facilities. This is an interesting region to study because, for example, around $^{108}$Zr, new shape evolutions (from very deformed nuclei to spherical ones) are theoretically predicted. The region east and northeast of lead in the nuclear chart, especially beyond $N = 126$, is of high interest concerning the r-process path. Even though other facilities (e.g., in Dubna), will try to use transfer reactions to access this difficult region, FAIR’s very intense uranium beam at high energies will provide larger production yields in this region and will, therefore, be unique in comparison to research at ISOL and other in-flight facilities.
**MATS**

The MATS collaboration is aiming to apply Penning-trap and Multi-Reflection Time-Of-Flight (MR-TOF) techniques to exotic nuclei beyond the reach of the present Radioactive Ion Beam (RIB) facilities. The most recent developments include the new Phase-Imaging Ion Cyclotron Resonance technique, and the Penning trap composed of active detector material. In addition to Penning traps, the use of MR-TOF devices for mass spectrometry at RIB facilities has increased in the last years, primarily promoted by university groups in Giessen and in Greisfwald (see Figure 6 for the location of these devices). The first-stage prototype of the MATS facility is the TRIGA-TRAP, which has already proved its potential, yielding absolute mass measurements on $^{241,243}$Am, $^{244}$Pu, and $^{249}$Cf, which are of interest since these nuclei are in the vicinity of the deformed $N = 152$ neutron shell closure. The implementation of this data into the atomic mass evaluation network yields a reduced mass uncertainty for 84 nuclides.

**SHE**

The Super-Heavy Elements (SHE) sub-collaboration within NUSTAR at FAIR was established in 2014. The collaboration brings together nuclear physicists, atomic physicists, and chemists from experiment and theory from around the world in a truly interdisciplinary field. Elements with \(Z \geq 104\) supply some of the most exotic nuclei at the very limit of nuclear stability and provide a prime laboratory for studying the reaction mechanism and the impact of nuclear structure effects on nuclear stability and that of relativistic effects on an element’s chemical and atomic properties. Adding the investigation of SHE to the science portfolio of the NUSTAR collaboration extended its scientific program to studies of exotic nuclides far beyond uranium. The scientific program on SHE synthesis and exploration has continuously expanded since the construction of GSI, aiming at obtaining a comprehensive understanding of these exotic objects. Current SHE research at GSI builds on the past discovery of several new super-heavy elements and increasingly focuses on studies of their synthesis and their detailed nuclear, chemical, and atomic physics properties.

Although elements up to \(Z = 118\) have now been given names, key questions are still awaiting experimental confirmation. These include the exact location and extension of the island of stability and an independent, direct, verification of the atomic and mass numbers of nuclei produced in $^{48}$Ca-induced fusion reactions. Very low cross-sections, reaching well into the 10 fb regime, pose significant experimental challenges and have been a driving factor in the development of very high intensity stable beam operations worldwide. Experiments currently use UNILAC beams at GSI with the highest intensities of $^{48}$Ca and $^{50}$Ti and experimental equipment such as SHIP, SHIPTRAP, TASCA (see Figure 7), the chemistry beam-line ARTESIA and ancillary systems like the high efficiency TASISpec and LUNDIUM.

![Figure 6. Planned layout of the Low-Energy Branch cave for MATS and LaSpec. The EBIT and $\beta$-NMR setup are planned for Phase 2, with all other components to be ready for Phase 1 operation.](image1)

![Figure 7. The TASCA gas-filled separator that, together with the SHIP velocity filter and a wide range of ancillary detectors, allows a wide variety of studies on superheavy elements to be performed.](image2)
spectroscopy setups. These are used to perform nuclear structure and atomic physics studies in elements with $Z > 102$ and to investigate chemical properties of elements with $Z > 112$.

**ILIMA**

The ILIMA collaboration will exploit the complex of storage rings (Collector Ring [CR] and High-Energy Storage Ring [HESR]) at FAIR to study Isomeric beams, and to measure Lifetimes and Masses of exotic nuclei produced using the extraordinarily high intensities of rare isotopes transmitted via the Super-FRS. With single-ion measurement capability, ILIMA will be unique worldwide for the study of short-lived nuclei, being at least 100 times more sensitive than any facility that might be operating in 2021, thus enabling masses, half-lives, and beta-delayed neutron emission branching ratios to be measured for the first time. In particular, this is true for nuclei with $A \approx 200$ that are key to understanding the heaviest ($A \approx 195$) r-process abundance peak. For this purpose, the collaboration will use time-of-flight and particle-identification detectors in the ring and is further developing Schottky and isochronous techniques to allow for single-ion sensitivity on bare or few-electron radioactive ions even with very short half-lives ($t_{1/2} > 10 \mu$s) and atomic numbers from the lightest elements up to $Z = 92$. This will allow for measuring many nuclei for the first time, important for nuclear structure and nuclear astrophysics. In order to improve capabilities, critical developments have been carried out such as the design of a fast and sensitive resonant Schottky pick-up shown in Figure 8, which has already been successfully tested at the existing Experimental Storage Ring (ESR) providing a number of good results. If, in the future, a transfer line to the ESR were to be constructed (see the EXL subsection for more details) then ILIMA would make use of the existing ESR as well as the recently commissioned low-energy storage ring CRYRING reconstructed behind the ESR. The latter will offer slowed down beams of highly charged radionuclides for precision studies.

**EXL**

The EXL collaboration will perform experiments on EXotic nuclei studied in Light-ion-induced reactions in a storage ring. The expected high intensity of beams from the Super-FRS will allow unique experiments for nuclear structure and nuclear astrophysics studies to be performed on nuclei far off stability by using stored and cooled radioactive beams interacting in inverse kinematics with thin internal targets. The accumulation and recirculation of cooled beams together with the use of thin windowless targets will allow for high-resolution measurements, even for very slow target-like particles obtained from reactions at low momentum transfers. Pilot measurements have already taken place at the existing Experimental Storage Ring (ESR) at GSI with the setup shown in Figure 9. In phase-0, experiments can be performed with the FRS beams at the ESR with an extension of this setup. If the plans succeed, during the first phase of FAIR, experiments could be carried out at the ESR with beams from Super-FRS, transferred to the ESR from the CR via the HESR. This transfer line is presently under discussion and design.

**ELISe**

The ELISe experiment represents a challenging attempt to realize an ELECTron Ion Scattering facility us-
ing two intersecting storage rings. This experiment makes a pure leptonic probe available for the study of exotic nuclei. The main advantage over competing experiments using the so-called self-confined RI target technique, that has been already realized at the RIBF facility in Japan is the possibility to take advantage of the colliding beam kinematics, which increase the achievable luminosities and detection efficiencies. An intersecting electron-ion ring (eA collider) will allow the scattering of electrons with an energy of 125–500 MeV off exotic nuclei enabling elastic, inelastic, and quasi-elastic electron scattering off short-lived radioactive isotopes to be performed for the first time. The collider kinematics have the advantage that it will be possible to detect electrons and target-like ejectiles in coincidence. Charge distributions, transition form factors in giant resonance or electro-fission experiments, and spectral functions can be measured with a clean electromagnetic probe. One of the most challenging aspects in this context is the design of a high-resolution electron spectrometer with large acceptance adapted to the specific demands of an in-ring experiment. The experiment was originally designed for operation at the New Experimental Storage Ring at the FAIR facility. Due to its delayed realization, we are currently studying alternative ways of realizing this challenging experiment using a system of storage-cooler rings to reduce the emittance and energy spread of secondary beams created via fragmentation or fission reactions.

At the recent PAC, 39 proposals were submitted from the NUSTAR collaboration and about 1,350 shifts were requested from which 535 shifts were awarded with top priority (for both UNILAC beams as well as the SIS18 beams). Phase 0 experiments from the Super-FRS experiment, R3B, DESPEC, SHE, and ILIMA sub-collaborations are scheduled for summer and autumn of 2018 and a few months in 2019. The collaboration is looking forward to seeing its plans come to fruition.

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Photodisintegration in Stellar Environments

Nucleosynthesis in stars and stellar explosions proceeds via nuclear reactions in thermalized plasmas. Nuclear reactions not only transmute elements and their isotopes, and thus create all known elements from primordial hydrogen and helium, they also release energy to keep stars in hydrostatic equilibrium over astronomical timescales. A stellar plasma has to be hot enough to provide sufficient kinetic energy to the plasma components to overcome Coulomb barriers and to allow interactions between them. Plasma components in thermal equilibrium are bare atomic nuclei, free electrons, and photons (radiation). Typical temperatures of plasmas experiencing nuclear burning range from \(10^7\) K for hydrostatic hydrogen burning (mainly interactions among protons and He isotopes) to \(10^{10}\) K or more in explosive events, such as supernovae or neutron star mergers. This still translates into low interaction energies by nuclear physics standards, as the most probable energy \(E\) between reaction partners in terms of temperature is derived from Maxwell-Boltzmann statistics and yields \(E = T \cdot \frac{3}{2} \exp(-11.6045/\sqrt{T})\) MeV, where \(T\) is the plasma temperature in GK.

Photodisintegration reactions only significantly contribute when the plasma temperature is sufficiently high to have an appreciable number of photons (given by a Planck radiation distribution) at energies exceeding the energy required to separate neutrons, protons, and/or \(\alpha\) particles from a nucleus. Forward and reverse reactions are always competing in a stellar plasma and thus photodisintegrations have to be at the same level or faster than capture reactions in order to affect nucleosynthesis. Since the number of captures per second and volume (the capture rate) not only scales with temperature but also with plasma density [1], the threshold temperature at which photodisintegrations cannot be neglected is higher for denser plasmas. On the other hand, photons require less energy when the particle separation energies are small. This is the case when approaching the neutron- or proton-drip-line or for \((\gamma,\alpha)\) reactions in the region of spontaneous \(\alpha\)-emitters. Based on the reciprocity relation for nuclear reactions, the principle of detailed balance can be derived, which relates the reactivity of the forward reaction (capture) \(r_{\alpha}^*\) to the reaction rate of the reverse reaction \(\lambda_{\alpha}^*\) (photodisintegration) [1]. Apart from factors containing spin weights and reduced masses, \(\lambda_{\alpha}^*\) is proportional to \(T_{9}^{3/2} \exp(-11.6045/Q/T_{9})r_{\alpha}^*\), where \(Q\) is the reaction Q-value given in MeV, describing the energy release of the forward reaction. This means that mainly the Q-value sets the temperature at which the reverse reaction becomes fast enough to compete with the forward reaction and affect the amount of a given nuclide in the stellar plasma. The Q-value of a capture reaction is just the separation energy of the projectile in the final nucleus.

Due to the above relations, photodisintegrations are found to be important in roughly three contexts:

1. (Almost) complete photodisintegration at the onset of a hydrostatic burning phase;
2. Partial photodisintegration in explosive burning; and
3. Reaction equilibria between captures and photodisintegrations in explosive burning when both types of rates are fast and affecting nuclear abundances at a timescale much shorter than the process duration.

Regarding case 1, a star with more than 8–10 times the solar mass evolves through a series of hydrostatic burning phases named after the main element used up as “nuclear fuel” for energy generation. These phases are, in this order, H-, He-, C-, Ne-, O-, and Si-burning. There is no stable burning phase after Si-burning but the core of the star collapses to essentially nuclear density, turning into a neutron star. As a consequence of this collapse, thermal and kinetic energy is deposited into the outer layers of the star, causing a shock-wave running outward and ejecting most of these layers. This is called a core-collapse supernova. The hydrostatic burning phases leading up to the final collapse mainly involve fusion reactions, including fusion of the main fuel and additional captures of protons and/or \(\alpha\)-particles on nuclides along stability up to the Fe-region. Free neutrons do not play a role in regular hydrostatic burning but are released in larger amounts in the He-shells of thermally pulsing AGB stars, where they cause the production of nuclei heavier than Fe by neutron captures along stability. This is called the main s-process [2]. The reaction Q-values of all these captures along stability are of the order of a few tens MeV and so the reverse reactions—the photodisintegrations—do not play a role in hydrostatic burning and s-processing because the plasma temperatures are not high enough. The only two exceptions are photodisintegration of \(^{20}\)Ne, which initiates the Ne-burning phase of a star, and photodisintegration of...


28Si at the start of the Si-burning phase. The α-separation energy in 28Ne is only 4.73 MeV, permitting the destruction of 20Ne before other reactions set in. Typical conditions of hydrostatic Ne-burning are 1.2 GK at a density of 1,000 kg/cm³. The released α-particles then react with the remaining nuclides by (α,γ), (α,n), and (α,p) reactions leading the way to further reactions with the released nucleons, and so on. A similar destruction of 28Si occurs at the start of the Si-burning phase, when 28Si is destroyed by (γ,α), (γ,p), (γ,α) reactions at about 3–4 GK, giving rise to a suite of subsequent reactions. At such temperatures and Si-burning densities of about 10⁴ kg/cm³, reaction equilibria as mentioned above in case 3 can already be established. This implies that after the initial destruction of 28Si the resulting abundances of nuclides in the plasma are not determined by individual reactions anymore but rather by equilibrium abundances. This is explained in more detail below.

Regarding case 2, the prerequisites for partial destruction of nuclei by photodisintegration are sufficiently high temperature but also lower densities than those in Si-burning and a short process duration to avoid complete destruction. Such conditions are found in explosive Ne/O-burning of a core-collapse supernova, when the supernova shockwave passes the Ne- and O-layers of the star, raising the temperature to 2–4 GK for a few seconds. Similar conditions are also found in simulations of the thermonuclear explosion of a white dwarf, called type Ia supernova or thermonuclear supernova (not to be confused with a core-collapse supernova). In such a thermonuclear supernova, some regions of the white dwarf, which is completely disrupted in the explosion, experience thermodynamic conditions suited for partial disintegration of the nuclei contained therein. These two sites have been suggested to be the source of the so-called p-nuclides, which are 32 proton-rich isotopes of elements from Sr to Hg [3]. Their existence cannot be explained by neutron captures in the s- and r-processes (producing all other nuclides beyond Fe) and thus require a different production mechanism. These proton-rich isotopes can be reached by sequences of (γ,n) reactions on stable nuclei pre-existing in the hot plasma. These (γ,n) reactions then compete with (γ,p) (below neutron number 82) and (γ,α) (for \( N \geq 82 \)) when reaching unstable nuclei on the proton-rich side of stability.

Regarding case 3, a reaction equilibrium can be established when both forward and reverse reactions are sufficiently fast to alter the abundance of a nuclide during the nucleosynthesis period. Process timescales are of the order of a few seconds in explosive nucleosynthesis and thus the reaction rates have to allow for a significant number of reactions during that time in both reaction directions. If the equilibrium can be established, the abundances of the nuclides in the plasma assume their equilibrium value, which is independent of the actual rates but depends on temperature, density, nuclear binding energy or separation energy, and the neutron-to-proton ratio [1]. A full nuclear statistical equilibrium with all reactions, except for those mediated by the weak interaction, being in equilibrium is encountered in the innermost parts of a star, which are barely ejected in a core-collapse supernova. It can also be established in some parts of hot accretion disks around black holes and in neutron star mergers.

We can also distinguish several types of partial equilibria. One type is found in hydrostatic and explosive Si-burning, where groups of nuclei are in equilibrium and the groups are connected by slower reactions not in equilibrium (quasi-statistical equilibrium). An equilibrium between neutron captures and (γ,n) reactions is found in the hot r-process occurring in hot, neutron-rich matter ejected in neutron star mergers and possibly also in magnetized jets formed in some types of core-collapse supernova explosions [4, 5]. Here, the isotope abundances in each isotope chain are set by the \((n,\gamma)-(\gamma,n)\) equilibrium abundances and β-decays connect neighboring isotope chains. As the equilibrium within a chain of nuclides is much faster than any β-decay half-life even far off stability, the most abundant nuclei were often called “waiting points,” as the r-process flow to heavier elements is halted until they decay. In hot, proton-rich environments, a \((p,\gamma)-(\gamma,p)\) equilibrium can be found, involving proton-rich, unstable nuclides. Such environments include proton-rich, dense inner zones of a core-collapse supernova which are ejected under influence of a neutrino wind, giving rise to a vp-process [6]. Another site developing a \((p,\gamma)-(\gamma,p)\) equilibrium is thermonuclear burning on the surface of a neutron star, causing \(X\)-ray bursts [7]. Due to the Coulomb barriers, the most abundant nuclei in the isotonic chains are not as far off from stability as the ones in the r-process, although higher temperature is required to establish this equilibrium. Furthermore, the extension of the production chains to heavier elements is more limited than in the r-process, not only due to increasing Coulomb barriers but also because of the region of spontaneous α-emitters found on the proton-rich side of the nuclear chart at higher mass numbers. When the reaction flow runs into this region, α-emission will be faster than proton emission, limiting the further progress [8].

Common to all these equilibria is the fact that photodisintegration reactions compete with capture reactions but at the same time it is not necessary to know the individual capture and photodisintegration rates to determine the nuclear abundances. The rates cancel out in the final expression for the abundance of a nucleus due to the reciprocity relation between forward and reverse rate.
Photodisintegration Experiments for Astrophysical Applications

As outlined above, there is only a limited number of reactions for which the photodisintegration rates have to be known explicitly. These are the ones contributing to the production of p-nuclides, as outlined in case 2. It is tempting to assume that the required cross-sections could be determined directly through a laboratory measurement. This is not feasible, however. The problem is not so much the fact that many of the relevant reactions involve unstable nuclei but rather that reactions on excited states of nuclei have to be included in the calculation of the stellar rates whereas experiments only measure cross-sections of nuclei in the ground state [9]. The situation is sketched in Figure 1. In a reaction \( A + x \leftrightarrow B + \gamma \) occurring in a stellar plasma, the nuclear states in nuclides \( A \) and \( B \) are connected by particle- and \( \gamma \)-transitions in both reaction directions. Excited states are bombarded by particles and photons with energies given by a Maxwell-Boltzmann and Planck distribution, respectively, at plasma temperature \( T \). The situation is sketched in Figure 1. In a reaction the direction of positive reaction \( Q \)-value is affected less by contributions from excited states. Moreover, it was shown that the contribution of excited states is larger by orders of magnitude for photodisintegrations than for captures, even for endothermic captures [1, 10–12]. Furthermore, the higher the plasma temperature, the more excited states contribute. This worsens the situation since photodisintegrations are only important in nucleosynthesis at high temperature. The ground state contribution to the stellar rate for reactions concerning p-nuclides typically is only a few tenths per mille [13]. Thus, a determination of the photodisintegration cross-section only determines a small fraction of the actual stellar rate and is not suited to constrain the rate.

Photodisintegration experiments can only be used to derive information on certain nuclear properties required for the calculation of the stellar rates and thus to test and support theory [9]. One typical goal of an experiment is the determination of the \( E1 \) photon strength function determining the strength of the \( \gamma \)-transitions between excited states that enter the calculation of the rate. However, only photon energies larger than the particle separation energy can be probed when studying photo-induced particle emission. The really interesting energy range would, however, be at about half of that (typically 3–4 MeV), due to the necessity of folding the strength function with the number of available final states, as given by the nuclear-level density, in the calculation of the total rate [14]. (The relative importance of \( \gamma \)-energies contributing to the stellar rate is also shown in Figure 1.) Nevertheless, the knowledge of the position of the peak of the \( E1 \) Giant Dipole Resonance (GDR), which can be determined at higher photon energy is a valuable additional piece of knowledge to normalize theoretically predicted GDR energies. A combination of \( (\gamma,\gamma') \) data with theoretical considerations has been used in the determination of stellar rates [15].

An interesting application of \( (\gamma,n), (\gamma,p), \) and \( (\gamma,a) \) experiments, respectively, is the determination of the relative strengths of particle emissions to excited states of the final nucleus. Such an experiment is sketched in Figure 2. It serves the purpose of testing the predictions of transitions from and to excited target states in stellar capture reactions. One has to be careful in the interpretation of such experiments, however, because starting from a specific ground state introduces a selection of possible quantum numbers (relative angular momenta) that may be different from the astrophysically relevant ones. Nevertheless, in testing the predicted ratios relative to the ground state transitions, for example \( (\gamma,n_1)/(\gamma,n_0), (\gamma,n_2)/(\gamma,n_0), \) or \( (\gamma,a_1)/(\gamma,a_0), (\gamma,a_2)/(\gamma,a_0) \), the dependence on the \( E1 \) strength cancels out. Such a probing of particle transitions may help to improve the reaction models used to predict reaction rates [9].

The number of accessible states, and thus of contributing transitions, is reduced in nuclides with a low nuclear level density at the separation energy of particle \( x \) in the compound nucleus \( B \). In this case direct capture into a final state is more probable than a reaction via a compound state. The energy difference between the initial system \( A + x \) and the final system \( B \) is emitted as a single \( \gamma \)-ray. In analogy, the

*Figure 1. Sketch of particle transitions (brown arrows) and \( \gamma \)-transitions (green arrows) contributing to the stellar rate of a reaction \( A + x \leftrightarrow B + \gamma \), proceeding via a compound state (red). Under stellar conditions forward and reverse reactions are in equilibrium and reactions commence also from excited states in nucleus \( A \) and \( B \).*
reverse reaction can also proceed directly by photo-induced emission of the particle $x$. In the stellar environment both reaction directions and all initial and final states accessible under consideration of quantum mechanical selection rules and available energy have to be considered, as sketched in Figure 3. Nevertheless, a photodisintegration experiment measuring a direct reaction starting with a nucleus in the ground state may subsume a larger fraction of the total stellar rate compared to the case of compound reactions discussed above. Direct reactions are important for the lightest nuclides (mass number $A \leq 10$) or for heavier nuclides with low particle separation energies (e.g., close to the proton- or neutron-drip-line). Even when astrophysical photodisintegration is not of immediate importance for most of such nuclei (reaction equilibria are established when reaching conditions to synthesize nuclides close to the drip-lines), a photodisintegration experiment may still provide additional information on a considerable fraction of the contributing transitions and could be combined with theory to obtain an improved constraint of a stellar direct capture rate.

Despite the restrictions with respect to astrophysical reaction rates, photonuclear experiments can complement other types of measurements, to provide nuclear structure information also for astrophysical application as well as further test cases for models predicting nuclear properties and cross-sections. Not discussed here as it concerns completely different process conditions in astro-particle physics, the knowledge of photo-induced reaction cross-sections at high energy is also essential for the investigation of the origin and the propagation of Galactic Cosmic Rays, involving nuclei moving at relativistic velocities through a radiation background (see, e.g., Ref. [16] and references therein).

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The AGATA Campaigns at GSI and GANIL
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Introduction to AGATA
The AGATA array [1] is the European forefront instrument based on semiconductor Germanium detectors, for high-resolution \( \gamma \)-ray spectroscopy. It is to be used in the nuclear research facilities operating presently in Europe but especially important for the experimental conditions at the future facilities for intense radioactive and high-intensity stable ions.

The European experimental \( \gamma \)-ray spectroscopy community has a long-standing tradition of coordinated efforts to build large-scale high-energy resolution arrays. Since the early nineties it has joined forces to build instruments with the highest possible sensitivity (e.g., the escape-suppressed spectrometer EUROBALL, 1995–2004). The escape-suppression technique provides excellent peak-to-total (signal to background) ratios but limits the solid angle covered by the Ge detectors, thus limiting the sensitivity of the arrays.

AGATA is the result of the early European Commission–financed initiative, the TMR network “Development of \( \gamma \)-ray tracking detectors” [2], with the participation of most of the present AGATA partner countries. Between 1996 and 2001 it encouraged the development of the highly segmented position-sensitive Germanium detector technology.

The inception of the Ge position-sensitive detectors technology has opened the possibility to build arrays of detectors based on the \( \gamma \)-ray tracking concept, providing an unprecedented level of sensitivity and efficiency. Only two arrays with such technology are being built in the world. The European implementation of the tracking array is realized in the AGATA project. The second one is the GRETA array, is under construction in the United States [3].

AGATA is being built in a collaborative effort of more than 40 institutes in 12 countries. The conceptual design of AGATA foresees a \( 4\pi \) array with 60 triple clusters containing 180 Ge encapsulated detectors [4]. Nevertheless, smaller sub arrays of AGATA have been implemented, first as a proof of concept for a tracking array at INFN-LNL [5] and later to prove the potential of AGATA in different experimental conditions as well as to profit from the scientific possibilities, as limited as they could be, provided by the early AGATA implementations.

Since 2012 AGATA sub-arrays have been installed at the FAIR/NUSTAR-precursor PRESPEC set-up, placed at the focal plane of the FRS Fragment Separator in GSI, where experiments with in-flight highly relativistic exotic beams were performed, and at GANIL and SPIRAL where experiments with high-intensity stable beams and reaccelerated ISOL radioactive beams will be performed.

In the sections that follow we will describe the activities and achievements reached in these two AGATA sub-array campaigns.

The PRESPEC-AGATA Campaign at GSI
With the establishment of FAIR, the European nuclear structure community got heavily committed to a future program of in-flight spectroscopy of highly exotic nuclei produced from the Super-FRS. Groundbreaking experiments are encompassed by the HISPEC project (Hi-resolution In-flight SPECTroscopy), which groups around AGATA, and which represents one of the first experiments of the entire FAIR facility to take beam at day one. To position the research community to take full advantage of this unique opportunity, and to build up the vital experience of the novel techniques and methodologies, the pre-cursor experiment PRESPEC-AGATA was established, on track of the previous successful RISING [6] project. The overarching goal of the PRESPEC collaboration was to perform a physics-driven campaign, which in parallel commissioned HISPEC-DESPEC equipment.

The scientific program for the PRESPEC-AGATA in-flight campaign [7, 8] performed at GSI in 2012 and 2014 comprised topics of major significance in contemporary nuclear structure physics. These include the evolution and modification of shell structure with increasing neutron excess, the breakdown of isospin symmetry in the \( A = 46 \) isobaric multiplet, the onset of collectivity in yet unexplored mass regions around \( ^{208}\text{Pb} \), as well as the shape evolution in neutron-rich medium-heavy nuclei. Furthermore, a study of the electric dipole strength in heavy Fe isotopes has been...
accomplished and relativistic M1-Coulomb excitation, employing $^{85}$Br as test case, was performed for the first time.

All the experiments profited from the unique combination of (i) relativistic energy beams from the SIS synchrotron, (ii) high-intensity exotic beams produced and selected by the FRS, and (iii) high-efficiency and high-resolution $\gamma$ detection with the AGATA Ge-detector array. The exotic beams were produced at relativistic energies ($\beta \sim 0.4–0.5$) in fragmentation or fission reactions of relativistic projectiles delivered from the UNILAC-SIS accelerator complex. The FRS was employed to select the fragments of interest. A thick secondary target positioned at the final focal plane of the FRS was used for Coulomb excitation or (secondary) fragmentation of the separated nuclei. Gamma rays emitted in these reactions were detected by AGATA. Up to 25 Ge crystals in double and triple configuration at forward angles around the beam pipe were employed. The Lorentz boost of the strongly Doppler shifted $\gamma$ rays helped to enhance the efficiency of the array to up to 10%. The fragments produced at the secondary target were identified and tracked by the Lund-York-Cologne Calorimeter Array (LYCCA) [9], a HISPEC development already available in its early implementation LYCCA-0. The experimental setup is shown in Figure 1. The beam comes from the right in this figure, hitting the target in the spherical chamber. The AGATA array at forward angles is seen in the center and LYCCA at the left side.

Compared to the RISING Cluster array the 3-D position resolution and the tracking ability of AGATA allowed placing the array much closer to the target, thus gaining in $\gamma$-ray efficiency and peak-to-background performance, while at the same time also improving on the achievable energy resolution for in-flight $\gamma$-ray emission. Along with the upgraded primary beam intensities at GSI and the improved capabilities of the FRS detectors the AGATA-PRESPEC setup [8] provided a very significant improvement over RISING with a sensitivity gain of up to a factor of 10. Lifetimes were determined with a relativistic version of the Doppler-shift-attenuation method using the systematic shift of the energy after Doppler correction of a $\gamma$-ray transition with a known energy. This new relativistic Doppler-shift attenuation method is only possible with a tracking array like AGATA and allowed the determination of mean lifetimes from 2 to 250 ps in heavy Mo isotopes [10]. A triple stacked target for plunger type measurements was introduced as another novel and unique experimental technique to determine nuclear lifetimes.

The analysis of the experimental data obtained in the PRESPEC-AGATA campaign is rather complex and is therefore still ongoing. It can be stated already now that all runs performed in 2012 and 2014 reveal new, interesting nuclear structure data. Moreover, experience gained in the campaign is very valuable and will be used to further improve the instrumentation, the analysis algorithms, and the experiment methodology for later in-beam $\gamma$-spectroscopy experiments with HISPEC at the FAIR facility.

The AGATA Campaign at GANIL

The Grand Accélérateur National d’Ions Lourds, Caen, France, offers many possibilities for in-beam $\gamma$-ray spectroscopy. The CSS cyclotron complex can deliver stable beams at high intensity from carbon to uranium elements from the Coulomb barrier to the intermediate energies regimes. In addition, the SPIRAL1 facility is currently being upgraded and will offer new radioactive beams that can be post-accelerated to the Coulomb barrier by the CIME cyclotron. A large HP-Ge array associated to the magnetic spectrometer VAMOS or the fragment separators as LISE and coupled to state-of-the-art detection systems for charged particle (DIAMANT, MUGAST), neutron (NEDA), and high-energy $\gamma$-ray (PARIS/FATIMA) opens unique opportunities for high-resolution $\gamma$-ray spectroscopy of exotic nuclei. The AGATA array was transferred to the GANIL facility in 2014 and was installed at the target position of the VAMOS++ magnetic spectrometer [11]. Figure 2 shows the experimental setup and the initial configuration of AGATA at GANIL. The conceptual design offers the possibilities to associate AGATA with several ancillary detectors [12]. The AGATA collaboration has defined a campaign strategy to benefit from the different complementary detectors and beams. Four identified campaigns have been extracted from a prospective work in the collaboration.
first campaign using the VAMOS++ magnetic spectrometer is ongoing, where very exotic nuclei are populated in heavy-ion collisions at the Coulomb barrier and identified in mass, charge, and atomic number by the spectrometer. Prompt spectroscopy is then performed at the target position by the AGATA arrays composed of 45 detectors maximum (1p of the solid angle). Level schemes as well as lifetime of excited states using the Doppler Shift Attenuation Method, the Recoil Distance Doppler Shift method or the Fast-Timing technique for lifetime in the range of the fs to the ns are determined. A second campaign, making use of the efficient combination of the NEDA neutron detector [13] and the DIAMANT CsI array [14] for charged particle detection, will investigate neutron-deficient elements populated in heavy-ion fusion evaporation reactions. After the completion of the SPIRAL1 upgrade, radioactive elements will be studied by secondary reactions such as Coulomb excitation and nucleon transfer reactions using the MUGAST array. Finally, heavy elements will be studied in heavy-ion fusion evaporation reactions, separated from the un-reacted primary beam using the VAMOS Gas Filled mode, and identified by their unique radioactive decay.

Among the proposed physics cases studied in the GANIL campaign one can mention: the evolution of the shell structure in neutron rich nuclei and the effect of three body forces, exotic nuclear shapes and shape-coexistence phenomena, proton-neutron pairing and isospin symmetry along the N = Z line, clusterization phenomena, the effect of the coupling to the continuum in weakly bound systems, the structure of super-heavy nuclei and properties of nuclear astrophysics interest. From the first campaign, a wide physics program has been covered by the performed experiments using AGATA at GANIL. One of the current problems in nuclear structure physics is the investigation of the near shell and sub-shell closures in the islands of inversion. These new regions of deformation are characterized by collective structure constructed on well-deformed intrinsic states with a main configuration involving intruder orbitals from the above main shell. While a signature of deformation is given by the energy of the first excited states, the measurement of their lifetimes allows a better understanding of their properties.

At the N = 40 sub-shell closure, the very first experiment has measured the lifetimes of several nuclei in the Island of Inversion around N = 40 via the multi-nucleon transfer $^{238}$U + $^{64}$Ni reaction in inverse kinematics. Lifetimes of the $4^+$ states in $^{62,64}$Fe and the $11/2^-$ states in $^{61,63}$Co and $^{59}$Mn were measured [15]. Beyond N = 28 toward N = 40, lifetimes in neutron rich Ti and V isotopes have also been measured. At the N = 50 shell closure, proton-rich nuclei toward $^{100}$Sn have been populated for the first time during this campaign by multi-nucleon transfer reactions in two
experiments with AGATA and VAMOS++. One experiment aimed at measuring the lifetimes of the first excited states in $^{106-108}$Sn. A second experiment using this experimental method measured the lifetimes of the even–even N = 50 isotones $^{92}$Mo and $^{94}$Ru. On looking at the evolution of the shell structure far from stability, a very interesting problem is that related to the size and stability of the gap at the magic number N = 50 in very neutron rich systems, together with the energy of the single-particle levels around it. To investigate this mass region, the ideal reaction mechanism that exploits the optimum characteristics of the AGATA plus VAMOS++ setup is the fusion–fission reaction in inverse kinematics. Several experiments have been performed with this technique. The first one aimed at the measurement of excited states involving cross-shell configurations in N = 50 isotones in $^{81}$Ga, $^{82}$Ge, and $^{83}$As and by using a plunger device new lifetimes have been measured in $^{88}$Kr, $^{86}$Se, and $^{82-84}$Ge. Other nuclei near N = 60 have been populated allowing to identify new excited states in $^{96}$Kr that show a sudden transition from strongly deformed to almost spherical shapes in the N = 60 isotones [16]. To better characterize the interplay between single-particle and collective degrees of freedom at N = 60, using a plunger device and the FATIMA array since 2017 for fast timing measurement, new lifetimes in these nuclei have been measured.

Using the unique Doppler correction capabilities of AGATA thanks to the Pulse Shape Analysis and the tracking algorithms, Doppler Shift Attenuation measurements to measure lifetimes of excited state in the range of the femto-second were performed in $^{23}$Mg for astrophysical interest. Finally, lifetimes in the non-yrast excited states of neutron rich C and O isotopes have been measured to probe the three-body contribution in the nuclear interaction. For this last experiment, AGATA was coupled to two PARIS clusters.

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Introduction
The Center for Isotopic Research on Cultural and Environmental heritage (CIRCE) of the University of Campania L. Vanvitelli was established in 2005 within the action POR CAMPANIA 2000/2006—MISURA 3.16 funded by the European Union and the Region Campania. The aim was to create a research center devoted to basic and applied research, as well as service, using isotopic methodologies applied to the diagnostics of cultural and heritage artifacts and to the study of environmental processes. In this framework, the Tandem laboratory was created and since then its activity has been extended, on one side, toward basic nuclear physics and nuclear astrophysics and, on the other side, toward industrial applications. Correspondingly, the equipment of the laboratory has grown: Figure 2 first mention

Correspondingly, the equipment of the laboratory has grown: Figure 1 shows a panoramic view of the laboratory and Figure 2 its present layout.

This article focuses on the nuclear astrophysics experiments at CIRCE, that presently use about 40% of the allocated beamtime per year.

Applications of AMS
The 3 MV tandem accelerator is the core of the CIRCE Accelerator Mass Spectrometry (AMS) system [1] enabling ultrasensitive measurements of the relative abundance—at the level of $10^{-15}$—of several cosmogenic rare isotopes. The unparalleled sensitivity of this methodology is essentially due to the virtually complete suppression of the stable molecular species that can interfere with the rare atomic isobars: this is accomplished accelerating negative ions to MeV energies in the low-energy side of a tandem accelerator and stripping them to charge states high enough to break molecular bonds. Atomic interferences are suppressed either at the ion source or exploiting the Z-dependence of swift ion energy loss (i.e., complete stripping, higher Z ion stopping, gas filled magnets, etc.).

The above features make AMS a very powerful analytical technique.

Figure 1. Panoramic view of the CIRCE Tandem Laboratory.

Figure 2. Layout of the CIRCE Tandem Laboratory.
both for stable and radioactive isotopes, but its most important applications regard long lived cosmogenic radioisotopes in a wide variety of disciplines (from earth science to environment, from archaeology to life sciences, from material science to atomic and nuclear physics). In the following, we will discuss two examples of application to nuclear astrophysics.

**14C as an Indicator of Astrophysical Events**

The most widely known application of 14C AMS is certainly dating of archaeological remains, thanks also to the tiny amounts (hundreds of μg or less) of organic material needed. It is also well known that the experimental conventional radiocarbon age needs to be calibrated to be converted into calendar age. This is accomplished using an extended database (IntCalxx, where the last two digits represent the year of the last update), based—for the last 14 ky—on several thousands of measurements performed using dendrochronologically dated tree ring samples. Most of these samples are actually groups of five or ten rings, resulting in a RCage-Calage curve characterized by smooth wiggles on a multi-decadal timescale because of the experimental averaging effect. In recent years, a few annual-resolution measurement series have highlighted short-term variations in the atmospheric 14C content due to sudden changes—of extra terrestrial origin—in its production rate [2]. Two events have been so far identified in the years 774–775 AD and 993–994 AD [3], consisting of a rapid increase in the 14C/12C isotopic ratio followed by a smooth decrease, due to the response function of the global system. Even if it has not been clearly demonstrated whether the 14C overproduction is due directly to the increase in the proton component of cosmic rays or to a modulation of the intensity of cosmic rays hitting the stratosphere due to modifications of the helio-geomagnetic field, the two events have been ascribed to Solar Proton Events.

An alternative explanation of these—or similar—events could be the explosion of nearby supernovae. We have analyzed a dendrochronologically dated conifer-tree ring sequence (larix from NE Italy) covering the interval from 1044 AD to 1070 AD; that is, the period in which SN 1054 (the Crab Nebula supernova) exploded “only” at 2.2 kpc from the earth. The preliminary data, shown in Figure 3, exhibit a large annual increase in the interval 1054–1070 AD with a different pattern compared to previous observations. Nevertheless, before speculating on a possible different origin of this event, related to a different astrophysical scenario, it has

![Figure 3. 14C/12C isotopic ratios of single-year tree rings in “percent Modern Carbon (pMC)” as a function of dendrochronologically determined growth year (blue squares). The corresponding decadal averages are reported as red diamonds for comparison with the Intcal13 data.](image-url)
facilities and methods

to be proven that we are dealing with a global effect, through measurements performed on trees grown in other parts of our planet.

**26 Al Production in the Universe**

Because of its relatively short lifetime (ca 1 My), 26 Al is an indicator of ongoing nucleosynthesis, which can be observed using gamma-ray observatories on satellites (e.g., COMPTEL and INTEGRAL/SPI).

The main source of 26 Al is 25Mg(p,γ)26Al, where the most important astrophysical site for the activation of this reaction is the hydrogen-burning shell (HBS), which may be active in off-main-sequence stars, and carbon and neon burning shells of massive stars. In the HBS, 25Mg(p,γ)26Al starts when the temperature exceeds about T₆ = 30 and for T₆ = 40–60—corresponding to a Gamow energy of about 100 keV—all the 25Mg is converted into 26Al. At higher temperatures, the destruction of 26Al by 26Al(p,γ)27Si and the refurbishment of 25Mg by the sequence 24Mg(p,γ)25Al(β) 25Mg begins to play a relevant role.

At CIRCE we have exploited AMS to measure the strength of a low energy resonance (E = 304 keV) in 25Mg(p,γ)26Al, irradiating a 25Mg target with an intense proton beam at LUNA–LNGS and, after a proper chemical treatment, counting the number of produced 26Al nuclei. The use of AMS to measure cross-sections requires some modification of the usual methodology, which allows ultrasensitive measurements of the abundance of rare isotopes of the same chemical element. The strong dependence of the sputtering yield in the ion source upon the chemical form of the sample and from the operating conditions inhibits the measurement of the abundance of isotopes of different elements, unless the so-called spike method of the spike is viable.

This requires the abundance of a given isotope of the same element of the isotope investigated to be, in the original sample, virtually zero. In this case, addition of a known mass of the spike isotope at the beginning of the sample treatment can be used for normalization. In the case of 25Mg(p,γ)26Al, the addition of a known amount of stable 27Al to the sample material after proton irradiation made possible a precise determination of the absolute 26Al content in the sample from the experimental 26Al/26Al isotopic ratio. Due to the short lifetime of the 26Al isomeric state, this off-line technique yields directly the astrophysically important ground state contribution to the resonance strength. A non-irradiated target served as an AMS blank sample for background reference. In Table 1 the AMS result for the measurement of the strength of the 304 keV resonance is compared with the on-line measurement performed using a 4π BGO annular detector as summing crystal [4].

**Measurements of Radiative Capture Reactions with ERNA**

The application of AMS to the measurement of reaction cross-sections is limited to cases where the reaction products are unstable, with a half-life long enough to allow for the chemical preparation of the samples and the measurements themselves. However, if the reaction kinematic information is preserved, it is possible to achieve mass separation of stable and short lived nuclei. This is the working principle of on-line recoil mass separators, as depicted in Figure 4.

This approach is suited to study nuclear reactions where the two interacting nuclei merge, producing a single nucleus and emitting one or more gamma rays. These reactions are generally referred to as radiative capture reactions.

In a radiative capture reaction, the fusion of projectile and target nuclei produces a nucleus that recoils in the laboratory system with the same average momentum p₀ of the projectile. In fact, gamma-ray emission determines a change of the momentum of the recoils depending on the gamma ray emission angle. As a result, the trajectories of the recoils lay within a cone centered on the beam axis with an opening angle γ = arctan(Eγ/(cp₀)), where Eγ represents the gamma-ray energy and c the speed of light. Correspondingly, the momentum of the recoils varies in a momentum range equal to 2 ∙ Eγ/c around p₀.

If the target is thin enough (usually a windowless gas target), the recoils can be collected in a final detector (e.g., an ionization chamber), with a rate proportional to the reaction rate, provided full acceptance for the selected charge state is achieved. Since the beam-to-recoil ion number ratio at the target is of the order of 10¹⁰ to 10¹⁸ depending on the reaction cross-section, an efficient on-line mass

<table>
<thead>
<tr>
<th>Target</th>
<th>AMS N₂⁶Al[×10⁶]</th>
<th>BGO prompt Nγ x fγ / BGO [×10⁶]</th>
<th>(ωγgs)AMS / (ωγgs)BGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>304-S</td>
<td>224 ± 7</td>
<td>218 ± 9</td>
<td>1.03 ± 0.03a</td>
</tr>
<tr>
<td>304-R</td>
<td>3.02 ± 0.12</td>
<td>3.02 ± 0.13</td>
<td>1.00 ± 0.04b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.02 ± 0.05d</td>
</tr>
</tbody>
</table>

*aIncludes systematic uncertainty of 2.5%.
*bIncludes systematic uncertainty of 4%.
*cStatistical uncertainties only.
*dSystematic uncertainty not common to both methods were added quadratically.
The separator must be used to suppress the beam ions. The European Recoil mass separator for Nuclear Astrophysics (ERNA) collaboration set up such a system at the Dynamitron Tandem Laboratory of the Ruhr Universität Bochum. ERNA operated at the DTL from 1998 to 2008, providing new data on $^{12}$C($\alpha,\gamma$)$^{16}$O [5–6] and $^3$He($\alpha,\gamma$)$^7$Be [7]. In 2009 ERNA was moved to CIRCE, which created the opportunity of a substantial upgrade. After the gas target, the separator consists sequentially of a 30° dipole magnet, a magnetic quadrupole triplet, a Wien filter, a magnetic quadrupole singlet, a 60° dipole magnet, a magnetic quadrupole doublet, a Wien filter, and finally a detector for the recoils. Additionally, Faraday cups, slit systems, and apertures are installed along the beam-line for setting-up and monitoring purposes. Typical beam suppression factors range from $10^{-10}$ to $10^{-13}$, which is effectively improved by about three orders of magnitude using a detector able to discriminate them from the leaky projectile beam ions. Different detectors are available for the detection of recoils: a $\Delta E$–$E$ ionization chamber telescope and a TOF-E (Time-Of-Flight vs. Energy) setup. Once the installation was completed, first experiments focused on $^7$Be($p,\gamma$)$^8$B and $^{15}$N($\alpha,\gamma$)$^{19}$F.

As regards the first case, its rate relative to the $^7$Be electron capture in the Sun determines the ratio of $^7$Be to $^8$B solar neutrinos. These neutrinos have a great interest, since they represent a large fraction of the high energy solar neutrino flux, to which most neutrino observatories are mainly sensitive.

The same reaction also plays an important role in cosmology, since it influences the amount of $^7$Li at the end of the Big Bang Nucleosynthesis, an important observational constraint to cosmological models.

The importance of $^7$Be($p,\gamma$)$^8$B triggered several experiments to determine its cross-section at the relevant astrophysical energies ($E_{\text{sun}} \sim 5$ keV, $E_{\text{BBN}} \sim 300$ keV). A thorough review of the experimental status is reported in [8]. All direct experiments producing results with sufficient precision to constrain astrophysical models used intense proton beams on radioactive targets. A significant discrepancy between different data sets limits the overall precision and accuracy, possibly related to uncontrolled systematic effects.

An alternative approach using a radioactive ion beam and a hydrogen gas target is presented in Ref. [9] and later in Ref. [10]. In both cases a recoil mass separator was employed to detect the $^8$B recoils. However, those experiments could not achieve a sufficient precision because of the low ion beam intensity (10$^7$ pps).

A new experiment was started exploiting the same method, with the improvement of the much higher ion beam intensity available at CIRCE, where a $^7$Be ion beam is routinely produced [11] with intensity of $\sim$10$^9$ pps. Measurements have been completed in the energy range $E_{\text{cm}} = 370$ to 800 keV. Figure 5 shows an identification matrix at $E_{\text{cm}} = 660$ keV. Data analysis is in progress and soon a new estimate of the rate of $^7$Be($p,\gamma$)$^8$B will be available [12].

$^{15}$N($\alpha,\gamma$)$^{19}$F is another interesting case, being related to the production of $^{19}$F, an intriguing, and still widely debated issue in Nuclear Astrophysics. Various sites and reaction networks have been proposed, all of them requiring the $^{15}$N($\alpha,\gamma$)$^{19}$F reaction as a leading production process. Its rate at relevant AGB temperatures ($T \sim 100$ MK) is determined by a number of narrow resonances, the Direct Capture component and the tails of two broad resonances at $E_{\text{cm.}} = 1323$ and 1487 keV. The widths $\Gamma_\gamma$ and $\Gamma_\alpha$ of the latter two, were determined with an improved precision of about 5%, using ERNA. The reaction yield was directly measured using an extended $^4$He target and an intense $^{15}$N ion beam. Further details can be found in [Ref. 13]. The extension of measurements toward lower energy will hopefully cover the very important $E_{\text{cm.}} = 364$ keV resonance, which is presently known only through indirect measurements, and allow a direct determination of the DC component at around $E_{\text{cm.}} \sim 1$ MeV.

Other Measurements

Other reactions of astrophysical interest are studied at CIRCE through...
the spectroscopy of proton- and alpha-particles. At present the $^{12}$C + $^{12}$C fusion processes are under study since they are particularly relevant for the advanced burning phases occurring in massive stars (M > 8 M$^\odot$) at characteristic temperatures of 0.3 to 1.9 GK, corresponding to interaction energies $E_{\text{cm}} \sim$ 1.0 to 3.5 MeV. Several channels are open. The main two are $^{12}$C($^{12}$C,p)$^{23}$Na and $^{12}$C($^{12}$C,α)$^{20}$Ne.

A severe complication is due to the beam-induced backgrounds involving especially hydrogen and deuterium contaminants in the graphite targets, as it was found in a series of measurements reported in Ref. [14]. Therefore, in order to arrive at more reliable determinations of the cross-section, a detailed study of the targets and their behavior under high intensity beam bombardment is needed. Measurement campaign to understand how contaminants concentration evolve in graphite targets as a function of their temperature, were conducted with two stages silicon detector telescopes, to detect reaction products, and thermography to correlate background yields with the temperature [15].

For the actual measurements a large scattering chamber has been installed at the 20° beam-line in order to host the newly developed array GASTLY (GAs-Silicon Two-Layer sYstem). The array is formed by up to eight two-stage detectors, formed by an ionization chamber and a large area silicon strip detector. The telescopes are specifically designed to reach large solid angle coverage, high angular- and energy resolution, low intrinsic background, and low detection thresholds.

The scattering chamber can be equipped with either a solid or a supersonic gas jet target [16].

**Conclusions**

Although the mission of the CIRCE laboratory was, and still is, applied research and technological transfer to the industry, a balanced sharing with basic research was established. The installation of the recoil mass separator ERNA and a new scattering chamber, as well as the development of experimental procedures based on AMS, allowed the establishment of a broad program in Nuclear Astrophysics, in the framework on an international collaboration led by INFN and including several universities and research institutes worldwide. CIRCE is included in the 2012 NuPECC International Access to Nuclear Physics Facilities in Europe Handbook and is open to users as a collaborative facility.

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Radionuclide Metrology and Standards in Nuclear Physics

The development of radionuclide standards for metrology has underpinned nuclear physics since its inception [1]. The current frontier of radionuclide metrology relies on developments in radiation detection and signal processing combined with accurate nuclear decay data evaluations [2] and contributes to a myriad of scientific disciplines. Radionuclide metrology represents a crucial part of the scientific jigsaw that enables societal benefits from nuclear physics research.

Measurements that are traceable to internationally accepted primary standards can give the public confidence in the characterization of civilian nuclear waste materials such as 90Sr, 134,135,137Cs, 237Np, 239,240Pu, and 241Am and measurements of naturally occurring radioactive materials (NORMs) such as 3H, 7Be, 14C, 210Po, 210Pb, 214Bi, 214Pb, 222Rn, 223Ra, 226Ra, 228Ac, and 234,235,238U. Other applications include assay of Technologically Enhanced NORM with potential radiological impact on workers in the oil and mineral production industries, and the use of radio-pharmaceutical isotopes such as 18F, 82Rb/82Sr, 89Zr, 99mTc, 124,131I, 211At, 223Ra, and 227Th for diagnostic imaging and therapy. This article explains the concept of international traceability and how accurate radiation standards are determined for different radioactive decay modes.

Primary Radioactivity Standards

National Measurement Institutes (NMIs) are responsible for the development and upkeep of primary measurement standards. Primary standards are used to calibrate instruments and/or to certify reference materials; these can then be distributed to other laboratories and used to calibrate their own instruments in an uninterrupted chain of calibrations to the final end-user. All measurements are essentially ratios back to these primary standards. NMIs cross-check their primary standards against sources from other countries through international comparison exercises co-ordinated by the Bureau International des Poids et Mesures (BIPM).

The first primary standard of radioactivity was based on radium. The inaugural Radium Standards Committee was held in Brussels in 1910 and chaired by Lord Rutherford at which 1 curie (Ci) was defined as the amount of radon in equilibrium with 1 g of radium [1]. The radioactivity measurement system based on radium standards became outdated following developments in accelerator technology, which led to an increased range of artificially created radionuclides. In 1950, the curie was redefined as 3.7 × 10¹⁵ disintegrations per second and, in 1975, the 15th Conférence Générale des Poids et Mesures adopted the becquerel (Bq), which is equal to one inverse second for the SI unit of activity [3, 4].

In 1958, The International Committee for Weights and Measures of the BIPM created the Comité Consultatif des Rayonnements Ionisants (CCRI). The CCRI is responsible for organizing international comparisons, enabling NMIs to cross-check their primary standards. The International Reference System, implemented in 1975, is based on a pressurized well-type ionization chamber based at BIPM [4]. This is a permanent, stable measurement instrument tool that is available to NMIs to compare primary standards of gamma emitters. A primary standard of radioactivity allows the number of decays from a source in a finite time period to be determined using a technique that does not itself need calibration. Since the activity of each radionuclide species depends on unique decay properties, different experimental techniques are needed for the primary standardizations of individual radioisotopes. The particular technique depends on the radioactive decay mode(s), half-life, decay scheme of the daughter nucleus and branching ratios for competing decay modes. Most modern radioactivity standards are aqueous solutions, quantified by their activity per unit mass on a given reference date [3, 4]. The main methodologies used for primary radionuclide standardization are discussed below.

High-Geometry Methods

Perhaps the simplest method is to count the number of photons or particles emitted by a source into the full 4π steradians of solid angle [3]. The perfect 4π detector does not exist and the “non-detection” probability must be accounted for, either by examining the rate of coincidences between multiple detectors or using Monte-Carlo particle transport simulation codes.

For a complex decay scheme of excited states populated in the daughter nucleus, the 4π counting technique can be exploited using either a single well-type NaI(Tl) or two NaI(Tl) detectors sandwiching the source. A higher number of coincident cascade gammas emitted per decay leads to reduced uncertainties from non-detec-
tion. Internal conversion transitions can also play a role in increasing the counting efficiency since any associated X-ray emissions can contribute to the integral count rate. Excited levels of the daughter with intrinsic half lives of the order of the detector dead time may lead to random summing of an apparent single decay transition, which requires appropriate corrections. The gamma-ray counting efficiency may be complemented by a high-efficiency charged particle detector surrounding the source and placed within the well of the gamma detector. Since both detectors may register counts from the same decay event the coincident signals must be subtracted to avoid double counting; this arrangement is known as 4πβ + 4πγ counting.

Liquid Scintillation Counting techniques use samples mixed with an organic solvent that produces ultraviolet photons following excitation by ionizing radiation [5–7]. These are detected using a photomultiplier tube or a silicon photodiode array. In the efficiency tracing technique, a model of the response of the detector is used, normalized using a tritium standard, which due to its low Q-f-value (18 keV) provides a reproducible quantification of the low-energy counting losses. The Triple-to-Double-Coincidence Ratio technique overcomes the requirement for a standard through the use of a counting system with three photomultiplier tubes. The model is normalized by matching the measured and modelled ratio of triple to double coincidences.

In both techniques, the efficiency (ε) is determined from the non-detection efficiency in each photomultiplier tube using a model based on Poisson statistics. Here ν is the energy deposited per decay divided by the energy required to produce a countable pulse, such that,

\[ \varepsilon = 1 - p(0) = 1 - \exp(-\nu) \]

Since this energy is typically ~1 keV for radioactivities that can deposit hundreds of keV or more per decay, the non-detection efficiency is virtually negligible. These techniques are particularly useful for radionuclides with no clear gamma-ray decay branch, including “pure” beta emitters such as 3H, 14C, 32P, and 90Sr.

**Defined Solid Angle Counting**

Defined solid angle counting is particularly useful for the standardization of alpha-emitting radionuclides and relies on the isotropic emission from a point-like source. In a vacuum, charged particles travel along a straight line through a collimating diaphragm covering a detector with assumed 100% intrinsic detection efficiency [8]. The system includes baffles to absorb alpha particles emitted in other directions. Only the fraction of the radiation emitted into the solid angle, Ω, subtended by the diaphragm is counted. The observed count rate is corrected for the geometric factor Ω/4π as well as for dead-time and decay half-life effects. To minimize counting losses related to source self-absorption, particular care is taken in the preparation of thin, homogeneous sources on flat substrates. Typical source-diaphragm distances of 5–40 cm are used to restrict the counting to particles emitted in a well-defined region perpendicular to the source plane.

Using these techniques, it is possible to standardize a radionuclide with an uncertainty of the order of 0.1%.

**Coincidence Counting**

Coincidence counting uses two or more detectors, where each detector is sensitive only to one type of radiation [3, 9]. A typical setup involves a charged particle detector such as proportional or scintillation counter situated as close as possible to a γ-ray detector (e.g., NaI(Tl), LaBr3, or HPGe). The individual detector count rates are measured together with the coincidence rate within a finite coincidence resolving time and are corrected for detector and electronic dead-times, detector backgrounds, and accidental coincidences between separate decays.

In the idealized case of β-decay to a single excited level of the daughter nuclide that de-excites 100% via prompt γ-ray emission, if the count rates of the β and γ-ray detection channels are Nβ and Nγ, respectively, and Nc is the coincidence counting rate then:

\[ N_c = A \cdot N_\beta \cdot N_\gamma \]

where A is the unknown source activity and εβ and εγ are the absolute detection probabilities for the β and γ channels respectively. These equations combine to give

\[ A = N_\beta \cdot N_\gamma / N_c \]

These expressions assume that the β and γ-ray detectors are sensitive to β particles and γ rays exclusively; however, “non-detection” of the β particle leaves that detector available to count γ rays and/or other ionizing radiations, such as internal conversion and Auger electrons. An additional term εbg describes this global additional efficiency, yielding the modified expression

\[ A = N_\beta / \left[ e_{bg} + (1 - e_{bg}) e_{bg} \right] \]

Estimates of the β channel counting efficiency may be formed using the measured ratio Nc/Nβ, together with the apparent activity at a particular effective detection efficiency, Nβ/Nc. The expressions are modified to account for multiple β-decay branches and, if required, competing electron capture decays, internal conversion and Auger electrons, characteristic X-rays, and so on. The absolute activity A is obtained from the extrapolation of a fit to unit β efficiency (see Figure 1).
Coincidences between multiple coincident cascade gamma-ray transitions can also be used to determine absolute activity values for decay modes where the coincidence level-scheme in the daughter nucleus is well known, such as the decay of $^{60}$Co \cite{10}. The National Nuclear Array (NANA) is a coincident gamma-ray spectrometer based at NPL that uses a multidetector array of LaBr$_3$(Ce) detectors to allow such measurements, including corrections for angular correlation effects, see Figure 2.

**Transfer Instruments**

Most standardization laboratories maintain a suite of transfer instruments such as ionization chambers calibrated with material standardized using primary techniques. In a re-entrant gas ionization chamber samples are inserted into a well at the top of the device (see Figure 3). The current produced is measured and converted via a calibration factor to an activity for that radionuclide and sample geometry. Since the manufacturing process for ionization chambers is reproducible and the response is steady over decades, calibration factors measured on a master chamber can be applied to replicants. For this reason, ionization chambers are commonly used in hospitals to check radiopharmaceuticals prior to administration to patients and also provide very accurate decay half-life data \cite{10}.

Gamma-ray spectroscopy may be used as a secondary transfer method and also provides precision nuclear decay data. Hyper-pure germanium detectors can be used to measure any sample type and are isotopically selective, enabling measurement with more than one radionuclide present. If the specific activity ($A$) is pre-determined by a primary standard technique, a

**Figure 1.** An efficiency extrapolation fit used in the standardization of a $^{60}$Co based on the gamma full-energy peak coincidences with the $4\pi$ proportional counter \cite{9}.

**Figure 2.** Upper: The UK National Nuclear Array (NANA), which can be used for primary standardizations using the gamma-ray coincidence method; Lower: Example of raw and angular correlation corrected primary activity values for a $^{60}$Co standard taken using NANA \cite{10}.
precise full-energy peak detection efficiency for a gamma-ray detection system can be established from the expression,

\[ A = \frac{N}{\gamma P_{\gamma} e_{\gamma}} \]

where \( N \) is the background subtracted peak area, \( t \) is the measurement time (which should be small relative to the decay half-life), \( P_{\gamma} \) is the gamma emission probability per decay and \( e_{\gamma} \) is the absolute full-energy peak detection efficiency \( e_{\gamma} \). Since the provision of independent primary standards allows accurate determination of full-energy peak detection efficiencies, such measurements can establish very precise \( P_{\gamma} \) values [12, 13], which are used in subsequent secondary calibration sources (see Figure 4).

**Ongoing Applications of Standards**

The application of radioisotopes for combined, parallel diagnostic and therapeutic use is another growth area where different isotopes of the same element that possess identical chemical properties (such as \(^{44}\)Sc/\(^{47}\)Sc, \(^{64}\)Cu/\(^{67}\)Cu, and \(^{152,155}\)Tb/\(^{149,161}\)Tb) are particularly useful [14]. Radionuclide standards and reference materials are also required to determine the activity from environmental sources. Public confidence in all nuclear pursuits stems from traceable measurement, underpinned by precise and evaluated nuclear decay data. Such measurements are essential for applications including environmental radioactivity monitoring and decommissioning, verifying compliance with the Comprehensive Test Ban Treaty and within nuclear medicine. Specifically, there are a number of emerging technologies in the radiopharmaceutical arena that require novel and challenging primary standardizations before they can be exploited in a clinical scenario. Each application has an impact in connecting nuclear science measurements with societal exploitation through the dissemination of results from nuclear physics.
research. Simply put, without traceable standards there can be no confidence in any radiation measurement.

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References

The Seventh Asia-Pacific Conference on Few-Body Problems in Physics (APFB 2017)

The Seventh Asia-Pacific Conference on Few-Body Problems in Physics (APFB 2017) was held on 25–30 August 2017 in Guilin, China, jointly hosted by Guangxi Normal University, Guilin, Guangxi Province, and Institute of High Energy Physics, Chinese Academy of Sciences (Figure 1). As one of the most influential conference series in the field of particle, nuclear, and atomic physics, the APFB Conference runs every three years in the Asian area and has been an inspiring platform for exchanging the progresses on few-body physics from atomic phenomena to nuclear and high-energy particle physics. This series was initiated in 1999 from Tokyo, and continued in other places, namely, Shanghai (2002), Thailand (2005), Indonesia (2008), Seoul (2011), and Adelaide (2014).

APFB 2017 attracted more than 130 participants from 17 countries around the world, and a broad range of topics were reported and discussed at the conference. Hot subjects include the most recent experimental results on heavy and light flavor hadron spectroscopy, exotic hadron searches at BESIII, Belle, LHCb, and studies of few-body nuclear physics at PANDA, JLab and J-PARC. Theoretical progress on the interpretations and method developments in Lattice QCD calculations, effective field theory studies, and phenomenological model buildings were also reported and hotly discussed. The ab initio calculations of light nuclei on the lattice have inspired intensive discussions on the nature of strong interaction dynamics and how amazingly the fundamental quark–gluon interaction manifested itself by the emergence of dramatic phenomena when the strong interactions evolved to low energies. Sophisticated few-body calculations for nucleon and hyperon systems, and fascinating Efimov physics observed in ultra-cold atomic systems also brought a lot of insights into the quantum world of few-body microscopic systems.

The conference place, Guilin, is a famous tourist city for its spectacular and unique Karst landscape. The city sits on the bank of Lijiang River (Figure 2), which is one of the most well-known tourist attractions in China. The city has attracted hundreds of thousands of tourists every year, and was listed as a World Natural Heritage site in 2014. During the conference, every day after the scientific program, the conference participants could enjoy either a nice walk along the green belt on the riverbank, which is full of local culture, or just stop by a small bar to have a pint of local beer.

On the eastern side of the Lijiang River is located the campus of Guangxi Normal University (GXNU).
As one of the high-standard universities in China and one of the top universities in Guangxi province, GXNU offers 35 subjects in 15 academic disciplines, including science, education, philosophy, literature, economics, law, history, engineering, agriculture, medicine, management, the arts, and so on. Apart from other research fields, the College of Physics and Technology has a strong faculty group with research interests in theoretical and experimental particle, nuclear, and atomic physics. As the local host, the GXNU has provided huge support for the conference and succeeded in making the APFB 2017 a beautiful memory for all of the participants. It was also announced at the end of the conference that the next APFB will be held in Kanazawa, Japan, in 2020.

**Figure 2. The Lijiang River.**

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The SHE 2017 Symposium was held in the picturesque town of Kazimierz Dolny in Poland, from 10–14 September 2017. It was organized by the Joint Institute for Nuclear Research (JINR, Dubna), the Maria Curie-Skłodowska University (UMCS, Lublin), the National Centre for Nuclear Research (NCBJ, Warsaw) and the University of Warsaw (UW, Warsaw), with Michał Warda (UMCS) serving as chair. Michał Kowal (NCBJ) and Sergey Dmitriev (JINR) co-chaired the Symposium, and Yuri Oganessian (JINR) acted as chair of the Scientific Committee. This 3rd Symposium on Super-Heavy Elements, organized several
months after four new elements, $Z = 113$ Nihonium (Nh), $Z = 115$ Moscovium (Mc), $Z = 117$ Tennessine (Ts), and $Z = 118$ Oganesson (Og) officially joined the Periodic Table, followed by the meetings at Texas A&M University, College Station, (USA) chaired by Greg Chubarian in 2013 and 2015.

The meeting started with a gathering of participants in Warsaw organized on 9 September followed by a next day tour of the Marie Curie-Skłodowska museum in the Old Town of Warsaw. At the beginning of the Symposium at Kazimierz Dolny the lectures given by Prof. Oganessian, Hoffman, and Itkis were dedicated to the memory of Walter Greiner and his achievements. Walter Greiner was one of the most active nuclear scientists of the last decades who also made important contributions to SHE science.

The scientific part of the conference started on the evening of 10 September and continued till Wednesday afternoon (Figure 1). The Symposium attracted over 100 participants from 15 countries all over the world. A record high for a 3-day meeting, nearly 90 oral presentations were delivered including over 50 invited lectures presented during the plenary sessions and 36 talks given during three parallel sessions.

The scientific scope of the Symposium was governed by several fundamental questions concerning the physics and chemistry of super heavy nuclei and elements:

- What are the effects of the strongest Coulomb fields on atomic properties?
- Can we understand the spontaneous fission process of SHN competing with other decay modes?
- How many protons and neutrons can a nucleus hold?
- What is the most effective way to synthesize even heavier nuclei and new elements?
- Where are the limits of the Island of Stability and of the Periodic Table?
- How can the description of the nuclear properties of SHN be developed and unified?

The goal of the meeting was to help define a strategy for improving our understanding of the heaviest isotopes and atomic elements.

Powerful new laboratories enabling us to start a new chapter in SHE science were presented in the opening session of the Symposium. Talks included the Super-Heavy Element Factory at Dubna (Dmitriev), the SPIRAL-II facility at GANIL (Lewitowicz), as well as major upgrades at RIKEN (Enyo). Roberto (ORNL) presented a reasonably secure future for neutron-rich actinide production at ORNL’s HFIR/REDC complex and discussed fascinating ideas for creating new heavier target materials like $^{254}$Es and separated $^{251}$Cf. Combining new intense beams with radioactive targets and profiting from improved separation and detection methods, the latter covered in several talks, can help us to answer the above questions and continue the discoveries at the top of the nuclear and atomic worlds. However, a number of presentations on the fission process and the modeling of cross-sections for reactions leading to new heavier elements convinced us that it will not be an easy task and the total beam dose required will greatly exceed $10^{20}$ particles.

The keynote talks on studies of the physics and chemistry of super heavy elements were presented by Nazarewicz (FRIB), Oganessian (JINR), and Schwerdtfeger (Massey University), while recent results were discussed by several speakers including Utyonkov (JINR), Morimoto (RIKEN), and Block and Hoffman (GSI), as well as Gregorich and Gates (BNL) and Savard and Seweryniak (ANL).

The fission process can be seen as the main obstacle to reaching nuclei beyond $^{294}$Og. Nishio (JAEA Tokai) addressed the problem of understanding fission yields and distributions as a function of the excitation energy of the fissioning heavy nucleus. His talk was followed by theoretical analyses of fission within different approaches by Skalski (NCBJ), Carjan (JINR), and Schunck (LLNL). Warda (UMCS) extended the fission and alpha decay description to heavy cluster emission.

Finding the most efficient path to new elements is not possible without an understanding of the production mechanism. Cross-section analyses for fusion-evaporation reactions were presented by Umar (Vanderbilt) and Wilczynska (UW), as well as Adaniam and Knyazeva (JINR). Karpov (JINR) analyzed the possibility of reaching neutron rich heavy nuclei through multinucleon transfer reactions, while Ter-Akopian (JINR) analyzed the information on fission obtained through quasi-elastic transfer reactions.

An understanding of the nuclear structure of the heaviest isotopes is needed for the analysis of their optimum production and decay path. State-of-the-art Macroscopic-Microscopic model descriptions were applied to this problem by Kowal (NCBJ), Moeller (Moeller Scientific Computing), and Pomorski (UMCS), while Afanasjev (Mississippi) and Magierski (Warsaw Technical University) used energy density functional theory.

The atomic structure of super heavy elements studied in experiments aided by chemical methods was presented during the plenary sessions by Gaeggeler (PSI), Nagame (JAEA Tokai), Eichler (PSI Villingen), and Gregorich (BNL).

There were several parallel sessions with a total of 36 talks given during the Symposium. The leading
themes and speakers are listed at http://she2017.ncbj.gov.pl/programme/. The presentations were arranged under the following headings: new approaches to the production and study of SHE, acceleration and separation, beams and targets, detectors, fusion of SHE, spectroscopy of SHE, atomic structure and chemistry, and theoretical descriptions of SHE. Reports from these parallel sessions were given in the plenary session on the last day of the Symposium by the respective parallel session chairmen, Hessberger, Block, Muenzenberg (GSI), Gates (LBNL), Robledo (UAM Madrid), Ackermann (GANIL), Hinde (ANU Canberra), and Gaeggeler (PSI Villingen).

During the open panel discussions after the lectures, Witek Nazarewicz and Yuri Oganessian pointed out major challenges for further studies: Can we extend the chart of the nuclides toward the next elements, beyond oganesson, and to isotopes with higher neutron numbers? Is it possible to cross the “fission corridor” and find an experimental link between “hot” and “cold” fission regions? Can we proceed with the chemistry of the heavy elements to the heaviest atomic numbers and isotopes of very short half-lives? Theory tasks included intensive studies of exotic structures (like exotic topologies, metastable configurations) and the role of super heavy nuclei in the Cosmos.

The 3rd Symposium on Super Heavy Elements and Nuclei was concluded with the presentation ceremony for the 2017 Flerov Awards. The Joint Institute for Nuclear Research (Dubna) honored Witek Nazarewicz from FRIB-MSU for his achievements in theoretical studies of the atomic and nuclear properties of the heaviest elements. A special Prize for synthesis of elements with atomic numbers 115 (Moscovium) and 117 (Tennessee) was awarded to James Roberto (ORNL), Vladimir Utyonkov (JINR), and Alexander Shushkin (Elektrokhimprilbor, Russia). On behalf of the JINR Director Victor Matveyev, the awards were presented by Sergey Dmitriev and Yuri Oganessian.

We are looking forward to the next discoveries in both experiment and theory. Our community will be able to meet again in 2019 in Japan to discuss progress in research at the next Symposium in the series.

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The International Symposium on Physics of Unstable Nuclei 2017

The International Symposium on Physics of Unstable Nuclei (ISPUN17) was held in Halong Bay, Vietnam, from 25–30 September 2017. It was organized by the Institute for Nuclear Science and Technology and Institute of Physics in Hanoi, and French counterparts (IPN Orsay and IRFU Saclay) in the nuclear physics collaboration between France and Vietnam. ISPUN17 was endorsed and supported by the National Foundation for Science and Technology Development of Vietnam, the Vietnam Academy of Science and Technology.
CNRS and CEA of France, Helmholtz International Center for FAIR, the Asian Nuclear Physics Association, and the Asia Pacific Center for Theoretical Physics.

The main topics of ISPUN17 were well covered in the invited talks and oral presentations by more than 150 participants from 22 countries (Figure 1). Concerning the nuclear physics facilities, RIKEN RIBF was presented by Tohru Motobayashi, who also highlighted the results obtained with the unstable beams on the structure of drip-line nuclei and r-process nucleosynthesis. The status of FAIR and perspectives for the nuclear physics, astrophysics, and applied sciences at FAIR were presented by Thomas Aumann. We also learned about the status and scientific perspectives of FRIB in MSU from Paul Mantica. The future research with the high-power lasers at the ELI-NP facility (Bucharest) was discussed by Syd- ney Gales, Nicolae Zamfir, Calin Ur, Loris D’Alessi, and Paul Constantin. Interesting updates on the facilities in Poland, India, and South Africa were presented by Adam Maj, Alok Saxena, and Rudolph Nchodu. The in-flight RIB facility in Dubna was introduced by Yulia Parfenova. The beam degrading facility OEDO at RIKEN RIBF for the direct reaction experiments was discussed by Susumu Shimoura. Other important experimental setups like AGATA (GANIL), SPES (Legnaro), the electron scattering facility for unstable nuclei SCRIT (RIKEN), ISOLDE (CERN), ALTO (Orsay), and the nuclear physics program at J-PARC were presented by Bradley Cheal, Mathieu Lebois, Silvia Lenzi, Gianfranco Prete, Ronaldo Garcia Ruiz, Toshimi Suda, Kazuhiro Tanaka, David Verney, and Xiaofei Yang.

The forefront topics of nuclear structure were well presented at ISPUN17. The recent experimental results on the shell structure, shape transitions and deformations, excitation, and decay modes of drip-line nuclei were discussed by Andrei Andreiev, Kalle Auranen, Martha Cortes, Pieter Doornenbal, Georgie Georgiev, Philipp Schrock, Olivier Sorlin, and Oleg Tarasov. The efforts to observe different exotic excitations of unstable nuclei like the double Gamow-Teller giant resonances (Tomohiro Uesaka), electric dipole response and pygmy states (Atsushi Tami, Angela Bracco), and high-precision measurement of nuclear lifetimes and masses (Klaus Blaum, Clement Delafosse) were presented in the experimental sessions. John Sharpey-Schafer (the most senior experimental attending ISPUN17) proposed several stiff deformed nuclei based on the data of γ-ray spectroscopy. Peter Thirolf has shown that a precise measurement of the excitation of 229Th isomer can be a milestone for a new nuclear clock. On the theoretical sessions, the traditional mean-field topics, energy density functional, shell model, nonrelativistic or covariant approaches to nuclear structure were discussed by Danilo Gambacurta, Marchella Grasso, Nobuo Hinohara, Elias Khan, Wen-Hui Long, Hiroshi Masui, Jie Meng, Hitoshi Nakada, Takaharu Ot suka, Peter Ring, Hiroyuki Sagawa, Chavdar Stoyanov, Viktor Voronov, and Kouhei Washiyama. The progress of the ab initio calculations was shown by Mark Caprio, Gaute Hagen, Jason Holt, and Petr Navratil.

Like previous ISPUN meetings, the physics of nuclear clusters was well presented both experimentally (Jack Bishop, Tzany Kokalovsa, Yanlin Ye) and theoretically (Makoto Ito, Masaaki Kimura, Peter Schuck, Chang Xu). The review by Christian Beck was a nice overview of the whole subject. Strangeness nuclear physics, a new subtopic of ISPUN, was presented by Kazuhiro Tanaka and Takehiko Saito. Interesting talks were given on nuclear reactions and decays. New information on the shell structure obtained from the nucleon knock-out reactions was discussed by Kathrin Wimmer and Ong Hooi Jin. The low-temperature detectors and first (p,p’) measurement at CCB Krakow were shown by Peter Egelhof and Maria Kmiecik. Anna Corsi discussed the future study of neutron skin with the antiproton beam (PUMA project). The single and double β decays were discussed by Mathieu Babo and Javier Menendez. We learned about the extension of the CDCC method to the 4-body system (Pierre Descouvemont), the prediction of nuclear reactions for unstable nuclei with TALYS program (Arjan Koning), nucleon- and α-cluster transfer reactions (Enrico Vigezzi, Nguyen T. T. Phuc), and nucleon-nucleus and nucleus-nucleus scattering and reaction (Victoria Durant, Takenori Furumoto, Wataru Horiuchi, Doan Thi Loan, and Henryk Witala). Naftali Auerbach (the most senior theoretician attending ISPUN17) gave a nice talk on the single and double charge exchange reactions. New results of fission and fusion studies were discussed by Gurgen Adamian, Nicolai Antonenko, Radu Budaca, Maria Chusnyakova, Kouchi Hagino, Manoj Sharma, Mohammad Shuaib, and Alexandr Svirkhin.

Nuclear astrophysics is a very special topic of ISPUN17. We heard interesting talks on the equation of state (EOS) of neutron-rich nuclear matter (Stefano Gandolfi, Ingo Tews) and EOS of the hot hadronic matter of protoneutron star and core-collapse supernova (Shun Furusawa, Ngo Hai Tan). The impact of the symmetry energy on the EOS of nuclear matter and its link to the isobaric analog excitations in finite nuclei were discussed by Pawel Danielewicz and Xavier Roca-Maza. The important weak processes in the stellar and supernova environ-
ment was discussed by Toshio Suzuki, Myung-Ki Cheoun, and Andrej Vdovin. On the experimental side, Michael Paul talked about testing the r-process reactions in the laboratory and Shigeru Kubono and Hidetoshi Yamaguchi presented the nuclear astrophysics studies carried out at CRIB of CNS Tokyo. The perspectives of nuclear astrophysics research at FAIR were discussed by Karlheinz Langanke. Similar prospects of the experiments planned for RAON in Korea were shown by Kevin Hahn and Byungsik Hong. Weiping Liu updated us on the JUNA project, aiming to measure in the underground very important reactions, like $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$, with the ultra-low background.

The new data of low-energy reactions taken at INFN-LNS and the interpretation using the Troyan Horse Method were shown by Aurora Tumin. The nuclear astrophysics studies at the n_TOF facility at CERN were highlighted by Giuseppe Tagliente. The low-energy reaction data relevant for nucleosynthesis were shown by Javier Praena and Lam Yek Wah.

Last, but not least, the social program of ISPUN17 was also an interesting and unforgettable experience for all participants.

After the first edition of the international conference on nuclear physics “Shapes and Symmetries in Nuclei: From Experiment to Theory” held in November 2016, its second edition was held from 6 November to 10 November 2017 on the CNRS campus, Gif sur Yvette in the Paris area. Organized by the Centre de Sciences Nucléaires et Sciences de la Matière (CSNSM), Orsay, France, and co-chaired by the CSNSM and Institut Pluridisciplinaire Hubert Curien (IPHC), Strasbourg, France, the Conference given the acronym SSNET-17, was devoted to presenting the newest achievements focusing on:

- Methods and instrumentation
- New facilities

- Experimental studies: Deformation of nuclei in ground and excited states
- Theoretical methods: Exotic collective excitations and exotic symmetries

Within the conference program two special topical sessions were organized: one related to the Physics of Nuclear Isomers and one addressing the Ab Initio Methods in Nuclear Structure Physics.

The new experimental nuclear structure results obtained with various detection systems like AGATA, GAMSHPHERE, GRETINA, GRIFFIN, JUROGAM, AFRODITE, FIPPS, and CAGRA were presented in parallel with the corresponding theoretical results.

In collaboration with the Institute of Physics Publishers and the Physica Scripta Journal we encourage the participation in the publication project referred to as SSNET INITIATIVE. The latter represents a Special Edition publication, which differs from the traditional proceedings-type format in several aspects. First, only the original articles containing unpublished results are invited; however, both the participants of the Conference as well as anybody else willing to contribute with one or more articles in line with the Conference’s scientific profile are welcome. Independently, a special class of publications referred to as mini-review articles are invited, addressing in a pedagogical manner research summa-
ries in selected domains of subatomic physics, addressing both a broad-profile readership as well as young researchers, post-docs, and/or Ph.D. students. The articles are published only in electronic format, which allows to eliminate the page limits and make the submission deadlines flexible.

One of the main objectives of the SSNET INITIATIVE is to provide a lasting contribution in the form of electronic publication of the progress and evolution in the research of the nuclear shapes and symmetries: by continuing the series (SSNET-18 Conference has already been announced [https://indico.in2p3.fr/event/16782/]) we hope to be able to continue the initiative in the future. The Special Issue corresponding to the SSNET-16 contains over 30 articles that so far have reached over 2,000 downloads.

It has been a great pleasure to observe that many participants enjoyed greatly both the scientific program of the SSNET meetings as well as the agreeable services provided by the restaurant at the CNRS campus together with the pleasant surroundings of the conference site with all conference buildings placed in a park area of the campus within walking distance. Many participants strongly encouraged the organizers to continue the series of SSNET Conferences and transform it in a scientific tradition.

In this context it is of particular importance to acknowledge the strong support received from both academic institutions (IN2P3/CNRS, University Paris Saclay, P2IO Labex) and from private companies (Mirion Technologies, Caen).

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Submitted on behalf of the organizing committee of SSNET-17 by

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CSNSM Orsay, France

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XX Escola de verão de Física Nuclear Experimental “Jorge André Swieca”: 29 January–9 February 2018, Instituto de Física da Universidade de São Paulo, São Paulo, SP

Maintaining the biannual tradition initiated in 1984, the 20th edition of the Jorge André Swieca Summer School on Experimental Nuclear Physics was held from 29 January to 9 February 2018 at the Physics Institute of the University of São Paulo. Organized by the Brazilian Physical Society, the JAS-School aims to provide contact with the most recent and exciting aspects of Experimental Nuclear Physics to graduate students from Brazil and Latin America (Figure 1). The 2018 edition of the JAS-School covered the effects and the interaction of accelerated heavy ions on electronic devices and electronic systems, ranging from a simple transistor to complex Field Programmable Gate Arrays (FPGA), as well several aspects on nuclear instrumentation and the relationships between these two topics. The students had to perform all aspects of a Nuclear Physics experiment, from planning to execution, and interpret the results. The students also tested complex electronic failures caused by interaction with heavy ions, using failure-counting algorithms in digital circuits. The School used the facilities of the Open Laboratory

Figure 1. Group picture of the participants of the XX Summer School Jorge André Swieca on Experimental Nuclear Physics.
for Nuclear Physics, LAFN, which houses an 8 MV Tandem-Pelletron accelerator and the Laboratory for Ion Beam Analysis of Materials, LAMFI-USP, with its 5SDH 1.7 MV accelerator. Both laboratories have beam-lines for Material Analysis using ion beams either in air or in vacuum. The LAFN has a dedicated beam-line for testing electronic devices under ionizing radiation, able to control the particle flux from $10^2$ to $10^7$ particles/s·cm$^2$. Numerous research groups from the state of São Paulo, as well as research groups from other Brazilian states, have used this beam-line to study complex electronic circuits or the performance of mitigation processes in digital circuits. The 20 selected participants, mostly graduate students from Brazil, Colombia and Argentina, were divided into four groups to perform their activities simultaneously in four different laboratories. A mini-course, taught in the first week by Prof. Rogelio Palomo from the Seville University, covered the most relevant aspects on the effects of ionizing radiation in electronic devices. Complementary lectures covered other practical Nuclear Physics subjects: kinematics, nuclear instrumentation, features of particle detectors, ion beam transport, radiation interaction with matter, total ionizing dose, single event effects, heavy-ion beam effects in transistor simulation, ion-beam analysis, vacuum technology, circuit development, architecture, and electronic system tests and radiation fault tolerant circuits. Practical activities comprised the characterization of some electronic devices and the measurement of single event upsets and total dose effects in analog and digital devices. A poster session let the participants present their research activities. The organizing committee, composed by N. Added, V.A.P. Aguiar, M.A. Guazzelli, E.L.A. Macchione and N.H. Medina, acknowledge financial support from FAPESP, Capes, CNPq, USP, Fei University Center, and ICTP-Itay.

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**LEAP 2018: The Low Energy Antiproton Physics Conference**

The 13th edition of the Low Energy Antiproton Physics (LEAP 2018) conference was held from 12–16 March 2018 at the Sorbonne University Conference Center in Paris (http://leap2018.lkb.upmc.fr). The LEAP conference has been held every two or three years since 1990 to discuss the latest findings and exchange information about interdisciplinary fields related to the physics of low energy antiprotons. About 100 participants from 17 countries attended the event (Figure 1).

The scientific program consisted of 50 plenary talks, including a general public lecture, and poster sessions.

Since one of the main motivations in this domain is to search for explanations for the lack of antimatter in the present Universe, the meeting started with talks on antimatter in space and alternative theories on antimatter gravity. The development of the facilities at CERN’s Antiproton Decelerator (AD) (ELENA) and at Darmstadt’s FLAIR were described (in particular CRYRING and HITRAP). Talks on...
POETIC 8: 8th International Conference on “Physics Opportunities at an ElecTron-Ion Collider,” Regensburg, 19–23 March 2018

The POETIC conference series differs in scope and profile from the many other EIC-related conferences and workshops. Large events like the annual EIC User Group meetings cover aspects of all fields its more than 700 members work on and many small workshops address specific R&D topics of accelerator and detector design. The POETIC meetings focus on new developments and long-term efforts in EIC theory. The program, which covers both the lower energy EIC in the US and the high energy LHeC at CERN, consists traditionally of plenary talks only. As the challenge for theory to meet the experimental accuracy expected for an EIC is very high, a substantial fraction of the talks addressed recent developments in higher-order/higher-twist perturbative QCD and high precision Lattice QCD calculations. Within both approaches, we have witnessed in recent years tremendous progress in controlling systematic uncertainties, in particular, for the rather delicate objects that dominate much of the theory discussion: GPDs, TMDs, Wigner functions, Distribution Amplitudes, and Double Parton Distributions. Such achievements are very non-trivial; however, the progress reported by the 78 participants has demonstrated that the aim of matching the experimental precision by the time the EIC is operational is not unrealistic. Vital to this endeavor is the ever closer collaboration of experiment, analytic QCD, and numerical QCD. In addition, POETIC 8, as with all POETIC meetings, served as a testing ground for new ideas that enrich the EIC physics case. POETIC 8 was supplemented by a satellite workshop on dedicated and improved Monte Carlo Event Generators for an EIC. In summary, POETIC 8 demonstrated how rapidly the reach of first principles QCD calculations as well as experimental techniques in hadron physics are expanding and motivated its participants to focus even more on contributing to this development.

Andreas Schäfer
Universität Regensburg
Bradly M. Sherrill, Professor of Physics at Michigan State University and Director of the National Superconducting Cyclotron Laboratory (NSCL) recently received the 2018 Tom W. Bonner Prize in Nuclear Physics from the American Physical Society (APS) (see Figure 1). The APS established the Bonner prize in 1965 to recognize and encourage outstanding experimental research in nuclear physics, including the development of a method, technique, or device that significantly contributes in a general way to nuclear physics research. Brad joins a list of previous recipients that include National Academy members, Nobel Laureates, and leaders of the field who have contributed enormously to the advancement of nuclear physics in some way. Brad’s research and leadership in nuclear physics through the years make him a deserving person to be within this distinguished group. Brad’s Bonner Prize citation reads “for his scientific leadership in the development and utilization of instruments and techniques for discovery and exploration of exotic nuclei, and for his community leadership in elucidating the physics of rare isotope beams and advancing the realization of the Facility for Rare Isotope Beams facility.”

In 1986 Brad received an APS Dissertation Award for work performed as a Ph.D. student at MSU. He is a Fellow of both the APS and the American Association for the Advancement of Science. Brad served on the Department of Energy/National Science Foundation Nuclear Science Advisory Committee during the mid 2000s and was the chair of the Division of Nuclear Physics of the APS in 2005. For his service to the nuclear physics community, he received the 2014 DNP Distinguished Service Award. Brad has led in the development of some of the most used equipment at the NSCL, including the S800 spectrometer and the A1200 and A1900 fragment separators.

The final part of Brad’s Bonner citation points to the future. Brad’s tireless efforts in pursuing the dreams of a new Facility for Rare Isotope Beams (FRIB) in the United States are coming to fruition today at Michigan State University. FRIB will provide scientists worldwide with one of the most powerful tools for studying those processes which led to the production of elements in stellar evolution, supernova explosions, and neutron star mergers. FRIB will also provide exemplary data that will guide in the development of a comprehensive theoretical framework that describes the properties of all nuclei. As the FRIB scientific director, Brad will continue to influence and lead this area of nuclear physics for many years to come.

DAVID DEAN
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

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Grand Gold Medals for Nuclear Physicists

The Lomonosov Grand Gold Medals of the Russian Academy of Sciences were awarded to Yuri Oganessian and Björn Jonson on 30 March 2018, in Moscow (Figure 1).

The award ceremony was held at the General Meeting of the Russian Academy of Sciences.

Established in 1959, this, the Academy’s highest accolade, is intended to award outstanding achievements in natural sciences and humanities. This medal has been presented every year since 1969 to one Russian and one foreign scientist. There are many eminent researchers among the previous recipients of the medal, including Nobel Prize laureates. Meanwhile, only several nuclear scientists were honored with this high award throughout the decades. Among those are Hideki Yukawa (1963), Juli Khariton (1982), Hans Bethe (1989), and Spartak Belyaev (2010).

Björn Jonson, a professor in the Department of Physics at Chalmers University of Technology in Sweden, was awarded the Grand Gold Medal for his extensive contributions within the “fundamental study of the nuclear structure and nuclear stability of exotic lightest nuclei at the boundaries of nucleon stability.” Björn is also known within the Nuclear Physics Community as a successful researcher in other fields of subatomic physics. He is one of the founding fathers of the ISOLDE/CERN physics who contributed to the pioneering explorations of many phenomena, and the neutrino mass measurement occupies the impressive place among them. Presently Bjoern plays the leading role in the FAIR-project in Darmstadt contributing to the future of physics.

Yuri Oganessian, the academician of the Russian Academy of Sciences and a scientific leader of the G. Flerov Laboratory of Nuclear Reactions at the Joint Institute for Nuclear Research in Dubna (Russia), was awarded for his “fundamental investigations in the field of heavy nuclear interaction and for experimental confirmation of a hypothesis of the existence of the Island of stability of superheavy elements” in the periodic table. Over the decade 2000–2010 Yuri and his team in Dubna, with the cooperation of American researchers from the Lawrence Livermore and Oak Ridge National laboratories, discovered several new chemical elements. Among those, the last element with the sequence number of Z = 118 was named after him—“oganesson.” Only a dozen out of 118 chemical elements of the periodic table had been named after people. However, only seaborgium was named likewise, while the American scientist Glenn Seaborg was alive.

Yuri Oganessian dreams of further structuring of the table of elements. In order to fulfill this goal, a new ion factory is being constructed in Dubna. It should serve as a factory for production of the nuclides of new elements.

The Nuclear Physics Community congratulates the laureates of this prestigious scientific award.

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### 2018

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<tr>
<td>September 16–21</td>
<td>Beijing, China. 29th Linear Accelerator Conference LINAC’18</td>
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<td>CERN Geneva, Switzerland. EMIS2018</td>
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<td>September 24–28</td>
<td>Berkeley, CA, USA. CNR*18 – Compound-Nuclear Reactions and Related Topics</td>
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<td>September 25–30</td>
<td>Kazimierz Dolny, Poland. XXV Nuclear Physicis Workshop “Structure and dynamics of atomic nuclei”</td>
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<td>September 30–October 5</td>
<td>Traverse City, MI, USA. 7th International Conference on Trapped Charged Particles and Fundamental Physics 2018 (TCP-2018)</td>
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<td>October 22–26</td>
<td>Lanzhou, China. 14th International Conference on Heavy Ion Accelerator Technology (HIAT2018)</td>
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<td>October 23–27</td>
<td>Waikoloa, HI, USA. 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan</td>
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<td>October 29–November 3</td>
<td>Cape Town, South Africa. COMEX6 (Collective Motion in Nuclei under Extreme Conditions)</td>
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<td>November 5–9</td>
<td>Gif-sur-Yvette, France. SSNET’18</td>
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<td>November 13–17</td>
<td>Tsukuba, Japan. 8th International Conference on Quarks and Nuclear Physics</td>
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### 2019

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<td>June 23–27</td>
<td>Ghent, Belgium. ENYGF19</td>
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More information available in the Calendar of Events on the NuPECC website: http://www.nupecc.org/