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Abstract. β - and isomer-decay spectroscopy are sensitive probes of nuclear structure, and are often the only techniques capable of providing data for exotic nuclei that are produced with very low rates. Decay properties of exotic nuclei are also essential to model astrophysical events responsible for the evolution of the universe such as the rp - and r -processes. The EURICA project (EUROBALL RIKEN Cluster Array) has been launched in 2012 with the goal of performing spectroscopy of very exotic nuclei. Since 2012, five experimental campaigns have been successfully completed using fragmentation of ^{124}Xe beam and in-flight-fission of ^{238}U beam. In these proceedings we will introduce the experimental setup and highlight some key recent results around ^{78}Ni , ^{132}Sn , and ^{110}Zn published during 2014 and 2015.

INTRODUCTION

The Radioactive Isotope Beam Factory (RIBF) at RIKEN, Japan, has been delivering heavy ion beams since 2007. During this time the intensity of these beams have been increasing steadily. In 2008, a milestone was reached when a 0.4 pA $^{238}\text{U}^{35+}$ ion beam using RIKEN 18 GHz electron cyclotron resonance (ECR) ion source was obtained. During four days with this beam it was possible to measure the production of over 40 new isotopes from in-flight fission [1]. While this was an important step for RIBF to become a world-leading facility for in-flight separation of radioisotopes, several improvements have been continuously applied to secure its position and increase the intensity available. One of the most notable, the upgrade of the 18 GHz ECR that was being a bottleneck with a new superconducting electron cyclotron resonance (SC-ECR) ion source utilizing 28 GHz microwaves to provide a highly charged uranium ion beam pushing the intensity to more than 5 pA in 2011 [2]. Continuous improvements in the accelerator chain has currently allowed us to reach a maximum instantaneous intensity of 49 pA with an average of about 30 pA for uranium beams.

The first decay spectroscopy experiment at RIBF was conducted in 2009 using 0.3 pA of uranium. In this experiment the combination of BigRIPS was used for $B\rho - \Delta E - B\rho$ selection and purification and the ZeroDegree spectrometer was used for final identification by $B\rho - \Delta E$ and time-of-flight. The secondary beam was slowed and stopped in nine active double-sided silicon-strip detectors for half-lives and β -delayed γ -ray measurements. The β -counting system was surrounded by four clover-type germanium detectors to measure γ -rays from isomeric states and following β -decay. During eight hours of beam-on-target, enough data for four papers in the very neutron-rich region was collected [3–6].

Around this time the RISING project at GSI [7] was ongoing. This highly successful setup was collecting data in several configurations optimized for fast beams, stopped beams and g -factor measurements. In particular one of the flagship experiments of the stopped beam campaign was the decay spectroscopy of ^{100}Sn where 259 nuclei were implanted and their decay studied [8]. However, with the development of large γ -tracking arrays in Europe, in particular AGATA [9], and their opportunities at the present GSI fragmentation facility and the future FAIR facility, RISING was decommissioned in preparation for the PreSPEC collaboration to work on installing and running this setup. As the recent developments at RIKEN would be able to produce beam intensities of about a factor of ten higher for ^{100}Sn , this opened up the opportunity to connect the highest intensity fragmentation beam in the world at RIKEN with one of the highest efficiency germanium gamma-ray detector arrays. Thus, the Euroball-RIKEN Cluster Array (EURICA) project was born in agreement with the Gammapool Collaboration.

EURICA

At the end of 2011 and beginning of 2012 the EURICA array was assembled at the end of the BigRIPS and ZeroDegree beam-line [10, 11] at RIKEN from twelve Euroball IV HPGe cluster detectors [12], the RISING stopped-beam electronics and support structure. A fully automated filling system connected from the 7000 liter CE tank outside of the RIBF building to a new buffer tank at the F11 area, where EURICA is located, was constructed for the cooling of the EURICA array. A new high-voltage system, powered by an uninterrupted power supply, was installed, facilitating remote control of the high voltage to each individual crystal. The Wide-range Active Silicon Strip Stopper Array for Beta and ion detection (WAS3ABi) was also developed for this project. WAS3ABi consists of up to eight silicon detectors that can be stacked closely together with a minimum distance of 0.5 mm from each other. The silicon detectors provide a 1 mm² position resolution with a 60-strip segmentation in the x direction and 40-strip segmentation in the y direction. A charge-sensitive preamplifier and shaping amplifier are employed to achieve high efficiency for low-energy events. Each channel of the silicon detectors can be split into a low-gain branch for measuring energy and position of the implanted ion and a high-gain branch for measuring position and energy deposited by light charged particles like electrons or protons. The position of heavy ions can also be measured redundantly in the high-gain timing branch. Some images of the setup is shown in Figure 1.

In April 2012, the setup was successfully commissioned [13] and since then a number of large data sets have been collected focused on different regions of the Segré chart, see Figure 2. In total, four days of beam time were devoted to the commissioning, using a primary beam of ^{18}O at an energy of 230 MeV/nucleon. In this experiment a WAS3ABi prototype consisting of two double-sided silicon-strip detectors (DSSSD) was used to stop the beam. The main purpose of this commissioning was to verify that the cluster detectors were working for energy and lifetime measurements of isomeric states and that it was possible to correlate energies of γ rays to a preceding β decay in the DSSSDs. For this part, BigRIPS and the ZeroDegree Spectrometer were tuned for the ^{16}N and ^{15}C nuclei following

FIGURE 1. Mounting of one of the EURICA clusters (left) and half of the final setup arranged in the spherical configuration surrounding the WAS3ABi silicon array, before closing of the surrounding shielding, mounted in the center (right).

fragmentation of the primary beam. The $0^- \rightarrow 2^-$ isomeric transition in ^{16}N , with an energy of 120.42 keV and a lifetime of $5.25(6) \mu\text{s}$ [14], was selected to verify EURICA's ability to measure isomeric lifetimes. The lifetime was extracted from an energy-time matrix, shown in Figure 2, constructed from the time difference between the detection at the clusters and at the final beam-line scintillation detector. The measured lifetime for the 0^- isomer in ^{16}N was $5.306(28) \mu\text{s}$, in agreement with literature data.

The first experiment with a uranium beam was performed in December 2012 in the ^{78}Ni region and since then β -decay data have been collected covering most of the neutron-rich part of the nuclear chart up to the rare-earth region. In parallel to the decay data, isomer decay information has been collected reaching all the way up to ^{174}Er [15]. Besides the main body of experimental data, the EURICA setup has also been used as an ancillary detector in Coulomb excitation experiments [16] and proton knock-out experiments within the SEASTAR project [17]. From these campaigns several papers have been published [18–37] and, partially, thanks to a dedicated student program several theses [38–45] have been produced as well, with more in preparation of both.

^{78}Ni REGION

The first experiment with uranium beam in EURICA was focused on ^{78}Ni . This led to the successful measurements of half-lives in this region [21, 38]. These half lives, see Figure 3, show a strong linearly decreasing trend in their systematics below $N = 50$ and above $Z = 28$. Beyond these a sharp drop in half-life is clearly visible. To understand these drops we can have a closer look at how the half life, $T_{1/2}$, depends on the β -strength function:

$$\frac{1}{T_{1/2}} = \sum_{0 \leq E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i). \quad (1)$$

As we can see, the half life is inversely proportional to the sum of the decay strengths, $S_\beta(E_i)$, into each possible final state, i , times a function that depends on the energy difference between the ground states, Q_β , minus the excitation energy of the final state, E_i . Close to stability, where the Q_β is small, the influence of the final state excitations energies will obviously be a large factor. This is one of the reasons for the strong odd-even staggering that can be observed in the half lives in those nuclei. However, for very exotic nuclei the Q_β value will be large and, thus, E_i will be negligibly small giving rise to the smooth systematics. Now, to explain the sudden drops at $Z = 28$ and $N = 50$ we use the fact that

$$f \sim (Q_\beta - E_i)^5. \quad (2)$$

FIGURE 2. Approximate distribution of nuclei detected in the experimental campaigns shown in a part of the nuclear chart with element number Z and neutron number N (left). Energy-time spectrum of the γ -rays from the commissioning experiment showing the $0^- \rightarrow 2^-$ transition in ^{16}N and neutron-scattering on the HPGe clusters (right) [46].

Thus, the situation for exotic nuclei is that the half lives are strongly dependent on Q_β and, therefore, these drops would imply a large increase in this quantity. This is a very strong indication of a doubly magic ^{78}Ni . This discussion is illustrated in Figure 3. Note that the sudden drop of half-lives beyond $N = 50$ is not clearly observed in the Zn and Ga isotopic chains and very weak in Cu. This is because the Q_β variation crossing the $N = 50$ shell is determined by the strength of the neutron shell gap and the drop in the Ni chain is enhanced by the shell at $Z = 28$. This behavior is referred to as the concept of mutual support of magicities [47].

Besides the half lives, also γ -ray transitions were measured in the ^{78}Ni region. This includes both the β -delayed γ -rays as well as isomeric transitions. These measurements were carried out both during the 2012 experiment as well as a dedicated experiment aiming for ^{70}Fe in 2013. The region between $20 \leq Z \leq 28$ and $40 \leq N \leq 50$ is of particular interest due to the severe lack of experimental data together with a complex nuclear structure evolution involving shape coexistence, sudden disappearance of the $N = 40$ subshell, and the recent results showing the extension of the island of inversion at $N = 40$ for more neutron-rich isotopes of Cr and Fe towards $N = 50$ [48]. Thus, any new information about the structure in this region is valuable for, for example, the extension of the LNPS shell-model [49, 50] that has been successfully applied to the ^{78}Ni region above $Z = 28$. The current experimental status of excited states in this region is summarized in Figure 4. In this context the 2013 experiment significantly extended the experimental data available via a wide range of observables including β -decay half-lives, neutron emission probabilities (P_n), spins and parities of the Mn isotope ground states, $\log ft$ values and the structure of excited states [30]. In particular the importance of the inclusion of the neutron $d_{5/2}$ orbital in the $V_{\text{low-}k}$ approach using the CD-Bonn nucleon-nucleon potential was shown to be critical to drive the large deformation appearing for these nuclei. The level schemes of ^{68}Fe and ^{70}Fe are shown in Figure 4 as an example of the data obtained.

All these aspects together, however, causes the description of the structure of these nuclei to be a complex problem. In order to isolate certain parameters that evolve with neutron number for theoretical development, some pure observables would be desirable. Luckily, in the 2012 experiment, an isomeric state of ^{76}Co was observed [32]. With the previous discussion about the strong indication of the double magicity of ^{78}Ni in mind, this nucleus should provide us with an ideal case for exploring the neutron-proton interaction in this region, consisting of a neutron and a proton hole outside a doubly magic core. Especially as changes in nuclear shell structure far from stability are largely associated with the monopole component of the proton-neutron interaction. In the experiment, two coincident γ rays of 192 and 446 keV from the decay of a $t_{1/2} = 3 \mu\text{s}$ isomeric state of ^{76}Co were observed. The decay of the isomer was assigned to an E1 transition with a reduced transition probability of $B(E1; 3^+ \rightarrow 2^-) = 1.79 \times 10^{-8} \text{ W.u.}$ Shell

FIGURE 3. Experimental half-lives as a function of neutron number for isotopes with $27 \leq Z \leq 31$ (left). All the solid symbols represent the half-lives determined in [21] while the open symbols are half-lives taken from literature. The systematic trends in different isotopic chains are highlighted by lines connecting the data points with a smaller uncertainty. Illustration of how the $Z = 28$ shell closure effects the β decay Q value with allowed transitions for Co (red) and Ni (black) isotopes highlighted with arrows (right).

model calculations carried out with an up-to-date LNPS interaction including monopole changes to assure the correct propagation of proton single-particles energies showed the states to be about 70% pure structures of $\pi f_{7/2}^{-1} \otimes \nu g_{9/2}^{-1}$ or $\pi f_{7/2}^{-1} \otimes \nu p_{1/2}^{-1}$ hole configurations for negative and positive parity states, respectively. Thus, the relative $\nu g_{9/2}^{-1}$ and $\nu p_{1/2}^{-1}$ positions could be fine tuned by changing the strength of the $\pi f_{7/2}^{-1} \otimes \nu p_{1/2}^{-1}$ monopole.

^{110}Zr REGION

As the experiment in the first decay-spectroscopy campaign at RIKEN, before EURICA, was aiming for ^{108}Zr it was natural to revisit this area of the nuclear chart as a part of the EURICA project with higher-efficiency detectors and a higher intensity beam. Furthermore, for this experiment EURICA was complemented with an array of $\text{LaBr}_3(\text{Ce})$ detectors for fast timing to maximize the possible physics output. An illustration of this setup is shown in Figure 5. These detectors were supplied by the University of Surrey and the University of Brighton as a part of the FATIMA project [52, 53]. $\text{LaBr}_3(\text{Ce})$ crystals are very fast scintillators with that also have a good energy resolution. Thus, they are ideal for γ -ray decay time measurements, capable to measure half-lives less than 100 ps. The crystals had a diameter of $1.5'' \times 2''$ and were coupled to H10570MOD Hamamatsu photomultiplier tubes. Each crystal was also equipped with removable 5 mm lead shield to prevent cross talk between detectors. For this experiment two plastic scintillators were added upstream and downstream to WAS3ABi to provide a stop signal for the short-range TDC of the $\text{LaBr}_3(\text{Ce})$ detectors. These had a size of $45 \times 150 \times 2 \text{ mm}^3$ and were placed about 5 mm from the first and last silicon detectors. For more information, see Ref. [54].

Using this mixed HPGe- $\text{LaBr}_3(\text{Ce})$ array it was possible to measure the life-times of the first excited states in the ^{110}Zr region [29]. This is a particularly interesting region, as at proton number $Z = 40$, the shape of neutron-rich Zr isotopes changes drastically from spherical to deformed at neutron number $N = 60$ [56]. The quadrupole deformation is known to increase toward $N = 64$, however, at the time of these measurements the evolution of the deformation beyond $N = 64$ was still unknown. Several different types of nuclear shapes have been predicted around $N = 70$, for example a transition from prolate to oblate, a spherical subshell gap at $N = 70$ [57], or even exotic shapes like stabilized tetrahedral symmetry [58]. Typical signatures of the amount of ground state deformation includes a low 2^+ energy and an increase in the reduced matrix element, $B(E2; 2^+ \rightarrow 0^+)$, assuming an axially symmetric rigid rotor.

FIGURE 4. Overview of the experimental status of the $20 \leq Z \leq 28$, $40 \leq N \leq 50$ region of the nuclear chart (left). Blue boxes show discovered isotopes and gray boxes show undiscovered predicted isotopes. Red labels show isotopes with spectroscopic information available before RIKEN experiments. Nuclei surrounded by green dashed lines have γ -ray information have been published from the EURICA project [30, 32] and yellow dashed lines from the SEASTAR project [48]. Partial level schemes following β -decay of $^{68}\text{Mn} \rightarrow ^{68}\text{Fe}$ and $^{70}\text{Mn} \rightarrow ^{70}\text{Fe}$ (right). Q_β values are taken from [51].

This experiment was the first time a fast-timing measurement from nuclides produced via the in-flight fission mechanism have been performed. In the first paper of the mixed EURICA-LaBr₃(Ce) the lifetimes of the first 2^+ states in $^{104,106}\text{Zr}$ were presented. An improved precision of $2.90^{(+25)}_{(-20)}$ ns for the lifetime of the 2^+ state in ^{104}Zr was obtained which confirmed that the method was working well, as well as a first measurement of $2.60^{(+20)}_{(-15)}$ ns for the 2^+ state in ^{106}Zr . This corresponds to the reduced transition probabilities of $B(E2; 2^+ \rightarrow 0^+) = 0.39(2) \text{ e}^2\text{b}^2$ and $B(E2; 2^+ \rightarrow 0^+) = 0.31(1) \text{ e}^2\text{b}^2$, respectively. These measurements indicate that the prolate deformation persist up to $N = 66$ mid-shell, although there is a decrease at ^{106}Zr means that the actual deformation maximum is located at $N = 64$. While this is consistent with calculations using the Interacting Boson Model (IBM-1) [55], the decrease observed is significantly larger than predicted, see Figure 5. This was interpreted as the IBM-1 Hamiltonian not reflecting the axial symmetry of the zirconium nuclei for $N > 60$. As these detectors were present in the entire Spring 2013 campaign, several more results are expected from this mixed setup. We have also managed to prove the feasibility of using this type of mixed array for lifetime measurements following the β decay of radioactive isotope beams to extract spectroscopic information far out in the neutron rich region. This will provide a valuable experience for future experiments both at RIKEN and at future facilities like FAIR [52, 59].

^{132}Sn REGION

The region around ^{132}Sn is of particular interest both from the point of view of the evolution of the nuclear shell structure, being one of only two neutron-rich doubly magic regions currently experimentally accessible, as well as being the critical region where the $A \sim 130$ peak is formed during the rapid neutron-capture (r) process. Thus, during the first experimental campaign with a uranium beam, two experiments were performed focusing on these nuclei.

^{132}Sn and its nearest Sn and Sb neighbors have been studied in detail in the past [60–62] and consequently almost all the neutron single-particle and hole states as well as the proton single-particle states with respect to ^{132}Sn are firmly established. However, information about proton-hole states in the neutron-rich In and Cd nuclei below ^{132}Sn is scarce. Several changes in the shell structures have been proposed in this region, including the possible $N = 70$ spherical magic number discussed in the previous section, but also a fast reduction, or quenching, of the $N = 82$ shell gap [63] that could help explain some discrepancies in the r -process abundance spectrum. There has been several experimental works trying to confirm this prediction, including one of the early EURICA results where no evidence for such a shell

FIGURE 5. CAD drawing showing part of the EURICA frame, containing three of the HPGe clusters and two of the LaBr₃(Ce) clusters (left). The γ -ray energy spectrum of the delayed (solid blue) and prompt (dashed red) components of the energy-time-difference matrix in coincidence with β -decay electrons detected within 1 s of an ^{106}Y implantation (top right). The inset shows the background subtracted time difference spectrum for the $2^+ \rightarrow 0^+$ transition. Experimental $B(E2; 2^+ \rightarrow 0^+)$ values of even-even $^{96-106}\text{Zr}$ isotopes, compared with and IBM-1 [55] calculations (bottom right).

quenching could be observed in ^{128}Pd [19]. Instead of going in depth with regarding these results, we will in the rest of this section discuss some newer results that can shed light on some other issues regarding the shell evolution in these nuclei and the nature of the r -process.

In one of these experiments a new transition in ^{131}In , one proton hole outside ^{132}Sn , was observed. The energy of this transition firmly determined the energy of the $\pi p_{3/2}^{-1}$ energy level. Exploiting this new information, it was possible to expand the shell model study of very neutron-rich nuclei along $N = 82$ far beyond what currently is accessible experimentally. These shell-model calculations were performed down to ^{122}Zr ($Z = 40$) and ^{120}Sr ($Z = 38$). In these calculations a two-body effective interaction derived from the CD-Bonn nucleon-nucleon potential was used and renormalized by the $V_{\text{low-}k}$ approach [64]. This interaction was constructed using the full $50 \leq N \leq 82$ ($g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$ and $h_{11/2}$) and $28 \leq Z \leq 50$ ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$ and $g_{9/2}$) shells outside a ^{132}Sn closed core. Using this interaction, the two-proton gap, $\Delta 2p$, and the energies of the first excited 2^+ states were calculated for nuclei along the $N = 50$ and $N = 82$ isotonic chains. An interesting trend that appears in these calculations is that, while the structure of the $N = 50$ chain are well reproduced, the $N = 82$ chain appears very smooth with a constant $\Delta 2p$ within 70 keV between Kr ($Z = 36$) and Cd ($Z = 48$). This suggests that both the $g_{9/2}p_{1/2}$ ($Z = 40$) and $p_{1/2}p_{3/2}$ ($Z = 38$) proton shell gaps disappears along $N = 82$, and that this quenching strongly depends on the measured energy of the $3/2^-$ level in ^{131}In , as with an increase of just 300 keV the traditional shell closures start to appear. The situation with quenching of shells deeper inside the core is illustrated in Figure 6.

Another aim of this experiment was to investigate in detail the neutron-neutron part of the nucleon-nucleon effective interactions in semi-magic Sn nuclei. As the 6^+ isomer was known in ^{134}Sn , the same isomer should be present in $^{136,138}\text{Sn}$ if the structure stays relatively similar. Indeed, delayed γ -ray cascades from new isomeric states of $^{136,138}\text{Sn}$ were observed with half lives of 46 and 210 ns, respectively. This makes ^{136}Sn the shortest lived isomer observed so far within the EURICA project. With a flight time through BigRIPS and the ZeroDegree spectrometer of about 600 ns, more than ten half lives of the isomer, it shows the power of this setup. The nearly constant energies observed for the 2^+ , 4^+ and 6^+ levels show that they seem to be perfect seniority two excitations, consisting of one broken $\nu f_{7/2}$ pair. These are also well reproduced by shell model calculations using the $V_{\text{low-}k}$ approach. However, the

FIGURE 6. Illustration of the impact of one-proton hole states in ^{131}In on the quenching of shells deeper inside the core, in particular the $3/2^-$ state measured in [20] (left). β -decay half-lives of $N=82$ isotones from this work (solid circles) in comparison with previous measurements (open triangles) and several theoretical models [65–68] (right). The red ellipsis highlights ^{130}Cd , the nucleus for which the shell model quenching parameter has been tuned preceding this experiment.

measured $B(E2; 6^+ \rightarrow 4^+)$ of ^{136}Sn is much faster than what predicted by several realistic shell-model calculations and a simple seniority scheme. The experimental transition rates can be reproduced by reducing the $\nu f_{7/2}^2$ diagonal and off-diagonal matrix elements by approximately 150 keV. This results in the 4^+ of ^{136}Sn consisting of a four-particle state with almost equal contribution of seniority two and four. This could be a hint towards a reduced pairing for the very neutron-rich $Z = 50$ isotopes and provide a key benchmark for shell-model interactions far from stability. These results are reproduced in other models as well, for example the RCDB interaction, where a similar reduction of the $\nu f_{7/2}^2$ matrix elements also yields a pure $\nu = 2$ seniority scheme in ^{134}Sn and ^{138}Sn with a seniority mixing in ^{136}Sn [69].

Furthermore, the β -decay half-lives of 110 neutron-rich isotopes of the elements $37 \leq Z \leq 50$ were measured. This include remeasuring and correcting of several known half lives as well as 40 new half lives deep into the r -process path. Thus, the new data have direct implications for r -process calculations. In particular, the half lives of ^{129}Cd and ^{130}Cd have been overestimated in the past with measured values of 242(8) and 162(7), respectively [70], while in our measurements the obtained values were 154.5(20) and 127(2). These measurements are particularly important due to the impact on the long standing discussion about shell quenching. As seen in fig, these data points have been used to tune this aspect of the shell model, giving a systematic overestimation of the half lives all the way down to, at least, $Z = 45$, while producing a correct trend in the half-life systematics, see Figure 6.

As these half lives are directly in the hot r -process path they will have a direct impact on the abundance pattern and how the second ($A \sim 130$) and the rare-earth-element ($A \sim 160$) abundance peaks may result from the freeze-out of an $(n, \gamma) \rightleftharpoons (\gamma, n)$ equilibrium. If the r -process conditions are such that this equilibrium is fulfilled, the new half-lives are important factors to determine the abundance at least up to of rare-earth elements and influences the discussion of r process universality. This, in turn, would help us determine which elements that would be critical to detect in the earliest metal-poor stars. The situation with $(n, \gamma) \rightleftharpoons (\gamma, n)$ equilibrium is relevant for some of the most promising r -process sites such as neutrino-driven wind in core-collapse supernovae. The measurement of β -decay half-lives in [26] demonstrates the persistence of shell effects and robust half-lives systematics, consistent with the discussion above. No evidence of structural changes capable of substantially modifying the gross properties of the nuclei could be observed when compared to predictions of theoretical model. Using this new data together with reaction-network calculations we were able to reinforce the model where the r -process abundance pattern result from the freeze-out of a $(n, \gamma) \rightleftharpoons (\gamma, n)$ equilibrium.

Following these half-life measurements further developments have been made in adjusting the nuclear models to better reproduce these half lives. In particular, there has been work using a self-consistent co-variant density functional theory framework [71]. In that work, both the ground states and excited states of all nuclei are calculated using a relativistic Hartree-Bogoliubov model and the proton-neutron relativistic quasiparticle phase approximation, respectively. Specifically, in relation to the EURICA measurements, all the measured half lives from Rb to In, ranging between $65 \leq N \leq 89$, are reproduced within a factor of two with very little scatter for different isotopic chains.

OUTLOOK

While these proceedings have focused on neutron-rich nuclei between the ^{78}Ni and ^{132}Sn regions these are just a subset of the results that have been produced in EURICA and that are either published or in preparation, as seen in Figure 2. One major region on the neutron-rich side that have not been included in these proceedings is the rare-earth region. The already published results for these nuclei are the discovery of the two quasi-particle isomers in ^{166}Gd and ^{164}Sm [25], a four quasi-particle isomer in ^{160}Sm [33] and the evolution of the yrast band in the Dy chain up to ^{170}Dy [72]. However, besides these several more results are expected for a full discussion of this part of the nuclear chart. These results include a comprehensive measurement of the β -decay half-lives and the astrophysics implication [73, 74] as a continuation of Ref. [26], as well as new information from isomer [75, 76] and β -decay spectroscopy [77, 78].

Besides the neutron-rich nuclei several experiments have also been carried out on the proton-rich side of the nuclear chart. One experiment that was mentioned in the beginning, one of the driving experiments for starting the EURICA project, being ^{100}Sn with a production intensity a factor of ten higher than at GSI. The data from this region is currently under analysis [79–82]. Another nucleus of particular interest in this region is ^{72}Kr which is a waiting point for the rp -process. The life time of this particular nucleus under X-ray burst conditions may be significantly reduced by the two-proton capture reaction $^{72}\text{Kr}(2p, 2\gamma)^{74}\text{Sr}$ which is highly sensitive to the low-energy state of the unbound intermediate ^{73}Rb [83]. In the most recent EURICA experiment, in Spring 2015, the proton drip-line around ^{59}Ge , ^{63}Se , and ^{67}Kr was mapped out with particular emphasis on two-proton decay properties [84].

Finally, one more dedicated EURICA experiment has been scheduled for isomer and β -decay studies of neutron-rich V, Mn and Ti isotopes [85] before the expected decommissioning of the EURICA array in the later half of 2016.

SUMMARY

In these proceedings we have presented the EURICA project from conception until the last year of operation. We have given an overview of the setup with the cluster HPGe array and the WAS3ABi silicon detector system, as well as the project of adding $\text{LaBr}_3(\text{Ce})$ detectors for fast timing. An overview of physics results were also presented, in particular with focus on the ^{78}Ni , ^{110}Zr and ^{132}Sn regions and results published from these during 2014 and 2015. We have also provided a small outlook of what to expect from this setup in the future both with respect to already performed experiments and experiments scheduled during 2016, the last year of EURICA operation.

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