The EURICA Project

Proposal by the EURICA Collaboration to Host
Fifteen EUROBALL Cluster Detectors

Submitted to the Gammapool Owners Committee

July 2011

EURICA Collaboration

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Contents

Abstract

It is proposed to utilize fifteen EUROBALL Cluster detectors for experimental campaigns at the Radioactive Isotope Beam Factory (RIBF) of the RIKEN Nishina Center (RNC). The RIBF is in operation since 2007 and has shown that it is presently capable of delivering the world's most intense secondary beams from in-flight separation after fission and fragmentation reactions.

The fifteen Cluster detectors are currently in use for PreSpec campaigns, the successor of the Rare Isotope Spectroscopic INvestigation at GSI (RISING). After the possibility has been indicated that the Cluster detectors may become available for experimental campaigns at the RNC in the year 2012, a Letter of Intent (LoI) was submitted to the Gammapool Owners Committee in April 2011, in which the RNC expressed its interest and support for hosting the detector array.

In May 2011, an international workshop was held at the RNC in which the EUROBALL RIKEN Cluster Array (EURICA) collaboration was formed. During the workshop the scientific opportunities, physics case, organizational structure, schedule, and the experimental configuration were discussed.

With the present proposal the RNC bids for fifteen EUROBALL Cluster detectors, full records of assembling, test and repair of the Cluster detectors, 105 HV elbows for Ge-detectors, one manipulator (produced at Legnaro), and all equipment needed for mounting and dismounting (except standard tools) in order to host an array in the same configuration as the RISING Stopped-Beam setup.

The period bid for to commission EURICA and perform experimental campaigns of β-delayed and isomeric γ-ray spectroscopy is January 1$^{\text{st}}$, 2012 until June 30$^{\text{th}}$, 2013. Experimental preparations as transferring the detectors and other necessary equipment to the RNC and assembling the array may start as soon as this proposal is approved.

1 Introduction

After several years of successful operation with stable beams at the Laboratori Nazionali di Legnaro (1997-98) and the Institut de Recherches Subatomique (1999-2003) [1], the EUROBALL Cluster Ge-detectors were moved to GSI for the first utilization with radioactive isotope beams (RIB) produced by the fragment separator FRS [2] in the Rare Isotope Spectroscopic INvestigation at GSI (RISING) collaboration [3]. A variety of techniques is necessary to illuminate different aspects of nuclear structure, i.e., obtain information on key experimental observables. Therefore, within several RISING campaigns the Cluster detectors were utilized with three experimental setups:

- In-beam γ-ray spectroscopy at relativistic energies above 100 MeV/nucleon [3],
- g-factor measurements of isomeric stopped beams [4],
- Isomer and β-delayed γ-ray spectroscopy of stopped beams [5].

Meanwhile, after a construction period of more than ten years, the Radioactive Isotope Beam Factory (RIBF) of the RIKEN Nishina Center (RNC), located in Wako, Japan, went on-line with its first beam at 345 MeV/nucleon in 2006. The search and discovery of more than 45 new isotopes in 2007 and 2008 using an uranium primary beam at 345 MeV/nucleon and the fragment separator BigRIPS [6] demonstrated the great potential of the RIBF [7, 8]. Also with other primary beams secondary beam rates were achieved that are presently unavailable at any other in-flight facility [9, 10]. Furthermore, the first isomer and β-delayed γ-ray spectroscopy experiments performed in the neutron-rich mass $A = 100$ region already showed the physics opportunities of coupling a modest γ-ray detection equipment to the RIBF [11, 12]. Detailed information about the RNC is available on the web [13].

By hosting the EURICA spectrometer, i.e., bringing fifteen EUROBALL Cluster Ge-detectors and the PreSpec electronics and Stopped-Beam support structure to the RIBF, the RNC hopes to create unique experimental opportunities for the worldwide nuclear structure community. In this proposal we will describe our intentions to built the array at the focus F11 of the BigRIPS/ZeroDegree spectrometers of the RIBF. The first international EURICA workshop held in May at the RNC was devoted in particular to the physics case. Thus, the proposal is accompanied by Letters of Intent (LoI) that result directly from the workshop. As the EURICA collaboration is growing, additional ideas for experiments with EURICA are expected in the future.

2 Physics Case

This proposal for EURICA comprises stopped-beam experiments utilizing isomer and beta-delayed γ-ray spectroscopy. The physics case for this setup was discussed during the first EURICA workshop and resulted in LoI which are listed in Tab. 1 according to their primary beam used and nuclei of interest. They are attached to this proposal in the Appendix A.

Nuclei of Interest	Spokesperson	Primary Beam
^{41}Si	Z. Li	^{48}Ca
^{64,66}Se	B. Rubio, Y. Fujita, W. Gelletly	^{78}Kr
^{71}Kr	G. de Angelis, F. Recchia	^{78}Kr
^{55}Sc	J. Valiente Dobon, G. de Angelis	^{86}Kr
^{77}Cu	E. Sahin, V. Modamio	^{86}Kr
^{78}Zr, ^{82}Mo	A. Gadea	^{124}Xe
^{100}Sn	M. Lewitowicz, R. Krücken, S. Nishimura	^{124}Xe
^{127}Ag, ^{129}Cd	H. Watanabe	^{136}Xe
^{70,72}Fe	G. Benzoni, H. Watanabe	^{238}U
^{78}Ni	S. Nishimura	^{238}U
^{81}Cu	M. Niikura	^{238}U
n-rich Ge, Se, Kr	A. Odahara	^{238}U
^{92,94}Se	R. Krücken	^{238}U
^{110,112}Mo	T. Bäck, E. Ideguchi	^{238}U
^{108,110}Zr	T. Sumikama	^{238}U
^{128}Pd	G. Lorusso	^{238}U
^{132,134}Cd, ^{136,138}Sn	A. Gadea, A. Jungclaus, G. Simpson	^{238}U
^{137}Sb, ^{138,139}Te	R. Lozeva	^{238}U
n-rich Ba and Xe	A. Odahara	^{238}U
^{170}Dy	H. Watanabe	^{238}U

Table 1: List of isomer and β-delayed decay spectroscopy LoI that plan to use EURICA. The columns show the nuclei of interest, the spokespersons, and the planned primary beam. The LoI will be submitted as experimental proposals to the 10$^{\text{th}}$ NP-PAC, held in December 2011, and are attached to this proposal in the Appendix A. Previously approved proposals will keep their approved status. However, these proposals will have to submit revised beam time estimates based on the higher γ-ray detection efficiency for EURICA and possibly updated beam current.

Experiments that have already been proposed and approved by the RIBF Nuclear Physics Program Advisory Committee (NP-PAC) using a setup of five Clover Ge-detectors are included in the list of LoI. However, in order to use EURICA, already accepted proposals will have to be resubmitted for beam time re-evaluation to the NP-PAC as a rule. EURICA offers a factor three to ten more efficiency than the Clover setup of the RIBF. Therefore, for already approved experiments the amount of beam time maybe subject to change, depending on the NP-PAC's decisions. The approved status of these experiment will not be affected. However, in case the previously approved proposals want to change the scope of their original submission, they will be viewed as new proposals. The 10^{th} NP-PAC meeting will be held in December 2011, for which all new and accepted proposals are to be submitted.

We would like to point out that in addition to isomer and β-delayed γ-ray spectroscopy two LoI wanting to use degraded beams and aiming for the measurement of nuclear moments were submitted. These two interesting techniques are worthwhile to be further investigated and maybe employed in the future. Furthermore, as the collaboration is growing, more ideas may emerge, leading to an even richer physics case. These ideas may also be submitted as proposals for the 10^{th} NP-PAC. Also submission for a later NP-PAC is possible, as the meetings are held twice per year.

3 Experimental Configuration

The γ-ray spectroscopy experiments will be carried out with radioactive isotope beams produced after in-flight separation from the BigRIPS fragment separator at the RIBF. The EURICA spectrometer will be located at the focus F11 of the ZeroDegree spectrometer.

3.1 General Layout

A general layout of the newly constructed part of the RIBF is shown in Fig. 1. Stable beams are accelerated by the Superconducting Ring Cyclotron (SRC) up to energies of 345 MeV/nucleon and strike the production target of BigRIPS in order to produce the radioactive isotopes of interest. BigRIPS ranges from the focal points F0 to F7, while the spectrometer ZeroDegree goes from F8 to F11. Basic characteristics of BigRIPS and ZeroDegree are a momentum acceptance of $\Delta p/p = \pm 3\%$ and angular acceptances of 80 and 100 mrad for the horizontal and vertical beam axes, respectively. Due to these large acceptances in combination with a high primary beam energy, the transmission for fission fragments is about an order of magnitude higher than at other in-flight separation facilities.

Achieved and expected primary beam intensities at the RIBF are presented in Tab. 2.

Nucleus	Beam Intensity / pnA	
	Achieved	Expected FY 2011/12
^{48}Ca	230	200
^{86}Kr	30	30
^{124,136}Xe	–	10
^{238}U	0.8	5

Table 2: Examples of expected and achieved primary beam intensities at the RIBF in pnA impinging on the production target. In May 2011, an SRC beam test of ^{124}Xe using apertures at an early acceleration stage was performed. From the achieved intensity the expected intensity was extrapolated to 10 pnA.

Secondary beam intensities are correspondingly high as mentioned, for example, in Refs. [9, 10] for ^{31,32}Ne. In a search for new isotopes employing a ^{238}U beam at an intensity of up to 0.8 pnA 45 new isotopes were found [8]. The experiment was performed in November 2008 and since then a lot of development has been made to increase the beam intensity. For example, a new injector including a 28 GHz ECR ion source has been constructed and a lot of machine time was devoted for the testing of charge stripper foils. Therefore, the ^{238}U primary beam intensity at 345 MeV/nucleon is expected to be 5 pnA.

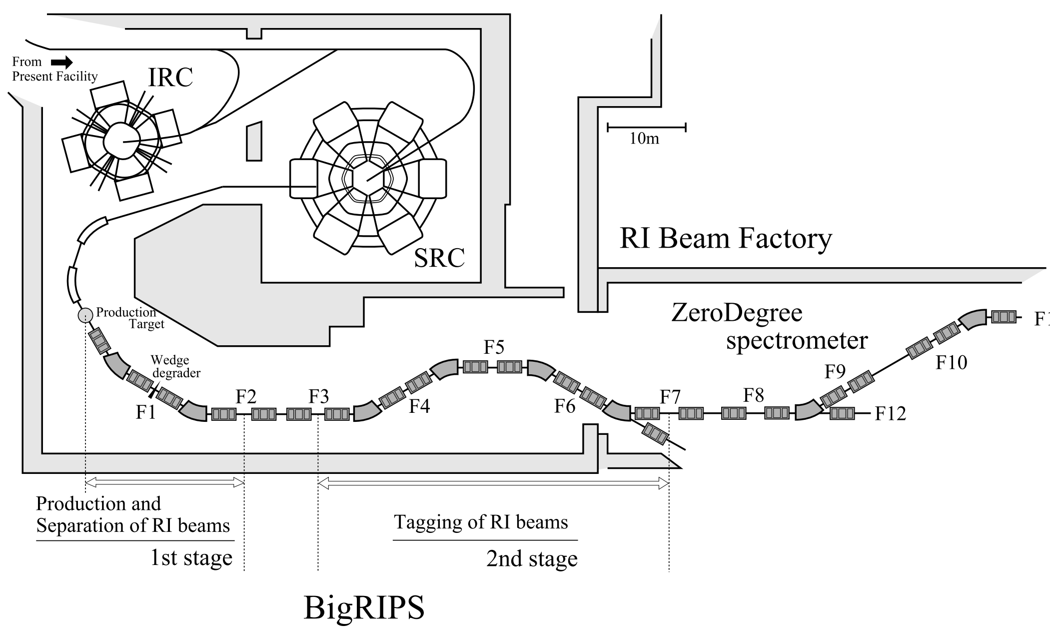


Figure 1: Overview of the RIBF facility. The radioactive ion beams are produced and separated with BigRIPS and transported to the focus F11, the location of the EURICA spectrometer.

The first stage of BigRIPS will be employed for selection and purification by the

$B\rho$–ΔE–$B\rho$ method, while in the second stage the particles will be identified using $B\rho$, ΔE, and time-of-flight (TOF) information. All necessary detectors for particle identification are already available and part of the BigRIPS standard setup. Typical particle identification resolutions are 0.5 (rms) for the element number Z and 0.05 % (rms) for the mass-to-charge ratio A/Q [8]. It is possible to make the particle identification with the ZeroDegree detectors at the same time employing the $B\rho$–ΔE–$B\rho$ method as well.

3.2 Description of the F11 Area

After transportation to the focus F11 the secondary beams will be slowed down by means of an aluminum degrader and stopped in either a passive plastic block for pure isomer spectroscopy or an active silicon detector for β-delayed γ-ray spectroscopy. The stopping position will be surrounded by the EURICA spectrometer composed of up to fifteen EUROBALL Cluster detectors.

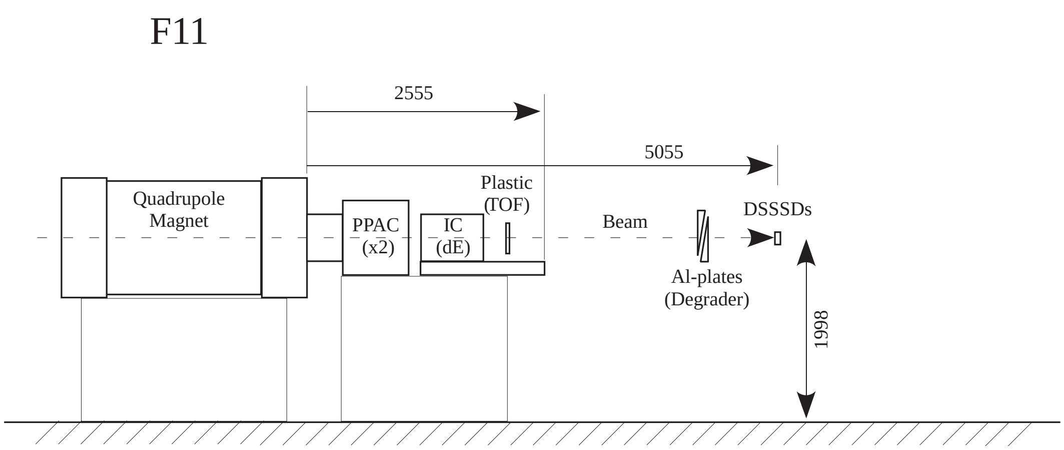


Figure 2: Schematic drawing of the F11 area as seen from the side. The EURICA spectrometer will be mounted surrounding the DSSSDs. Sufficient space (2500 mm) is available between the edge of the support table for the beam line detectors and the implantation point for the DSSSDs to mount EURICA Clusters into the support frame. For RISING, less than 2000 mm were available between table and stopping position. Furthermore, the support frame can be opened during the mounting of detectors (see Sec. 3.2.3), thereby circumventing possible space limitations due to the beam-line detector support table. The degrader setup has a width of only 100 mm and can be installed after mounting the cluster detectors.

A schematic drawing of the F11 area from the side is given in Fig. 2. The secondary beam passes two PPACs for position reconstruction, an ionization chamber, a plastic detector, and a remote-controlled Al degrader to adjust the energies before stopping in an active or passive stopper. For beam focused on the stopper, the beam spot size for fragments was measured to be around 10 mm (FWHM) in X and Y, respectively, for different fragmentation and fission beams. For an active stopper it will be defocused by the last quadrupole magnet triplet of ZeroDegree to a beam spot size of about 25 mm (FWHM).

3.2.1 The Active Stopper

For some experiments, as the intended ^{100}Sn decay study, the SIMBA array may be employed [14] for β-delayed γ-ray spectroscopy. SIMBA was already utilized for RISING [15]. In most experiments the RIBF active stopper will be employed which was already used successfully in the first β-delayed γ-ray spectroscopy at the RIBF [11, 12]. In these experiments heavy ions will be stopped in a stack of nine double-sided silicon-strip detectors (DSSSD). The dimension of one DSSSD detector (Micron W1: 16x16 strips) is 50×50 mm^2 and 1 mm thickness. The strip width is 3 mm.

Preamplifiers developed at the RIBF (CP-10 : 10ch x 46 boxes = 460ch) are used for the RIBF DSSSD. They possess a dynamic range of up to 500 MeV with standard feedback capacitance (4 pF : adjustable). For the implantation part, the dynamic-range of readout electronics is extended to 5 GeV or more by introducing the dual-preamplifier readout method with charge-division circuits. For the implantation part of SIMBA (Canberra: PF-60CT-40CD-60*40-1000EB x 3 layers) and for the RIBF DSSSD the RIBF preamplifiers and readout will be used. In a previous experiment with the RIBF system a low energy threshold below 20 keV was achieved [16].

The RIBF DSSSD readout is composed of standard CAEN shaping-amp (14 x N568B-16ch) and peak-sensing ADC (9 x V785). Beta-decay events trigger by taking the coincidence signal between the front- and back-side of the DSSSD. The timing information of all the strips as well as the self-trigger are measured with the combination of LeCroy discriminators (LeCroy 3412) and CAEN multi-hit TDCs (V1190A x 2).

Typical heavy ion implantation rates are 10 cps for “pure” half-live measurement and 200-400 cps for β-delayed γ-ray spectroscopy measurements. The RIBF DSSSD system is operated under vacuum condition and optional cooling (adjustable from -26 to 80 degree) while nitrogen at air pressure is used for SIMBA.

3.2.2 Particle and Gamma-Ray Background at F11

The particle background from reaction products produced by the target, degraders, and beam-line detectors is expected to be considerably reduced compared to RISING. This has several reasons. While the FRS at GSI is a “double-zero-degree” spectrometer composed of only four dipole magnets, BigRIPS has a passive first stage in front (see Fig. 1) and therefore an angle between the beam line at the production target and the "main" beam direction. Thus, uncharged particles produced in the target and the F1 degrader will not reach the focus F11. Charged particles produced in the production target and the F1 degrader are filtered by a second degrader placed at F5. Thick walls between BigRIPS and the ZeroDegree spectrometer perpendicular to the beam axis at F7 prevent uncharged particles to pass to F11. In fact, the ZeroDegree area, and thereby also F11, is accessible by humans during experiments with the spectrometer SHARAQ (not shown in Fig. 1), for which BigRIPS is used until F6 (and then another beam line going to SHARAQ).

Finally, the beam energy entering the F11 area is only around 200 MeV/nucleon, while it is usually about 500 MeV/nucleon for the S4 area at the FRS. Thus, in comparison to RISING, only very little background producing degrader thickness has to be inserted to slow down the beam. In conclusion, due to the little (uncharged) particle background and the very low beam rates (a few hundred) for decay spectroscopy (vs. several tenth of kHz for in-beam spectroscopy at RISING), no neutron-induced damage is expected for the Cluster detectors. The first decay experiments performed at the F11 area [11, 12] showed a "prompt flash" with an energy distribution that can be mainly attributed to atomic background.

3.2.3 EURICA Support Structure and Detector Configuration

The same support structure formerly used for the RISING stopped beam campaign at GSI [5, 17] will be employed for the Cluster detectors. Thus, full functionality enabling an easy opening of the support structure and simple mounting of the Cluster detectors will be adopted. The support structure requires a new foundation, i.e., a new rail system at F11. The beam heights at F11 and for the FRS at GSI are almost the same (2000 mm GSI compared to 1998 mm at F11), making an adoption of the support frame to the RIBF very simple. A workshop drawing of the RISING support structure is displayed in Fig. 3

The Cluster detectors will be arranged in 3 rings of 5 detectors at ϑ-angles of 51, 90, and 129 degrees, respectively, and distances of about 220 mm. The photo-peak efficiency at 662 keV is expected to be 17 %, the same as was achieved for the RISING spectrometer [5, 17]. Figure 4 displays the detector configuration schematically. We would like to point out that with EURICA composed of only twelve Cluster detectors the physics case listed in Ch. 2 will still be feasible. For such a spectrometer, some of the detectors may be moved closer to the beam stop position (up to a distance of 200 mm), so that an efficiency of 14 to 15 % at 662 keV can be kept.

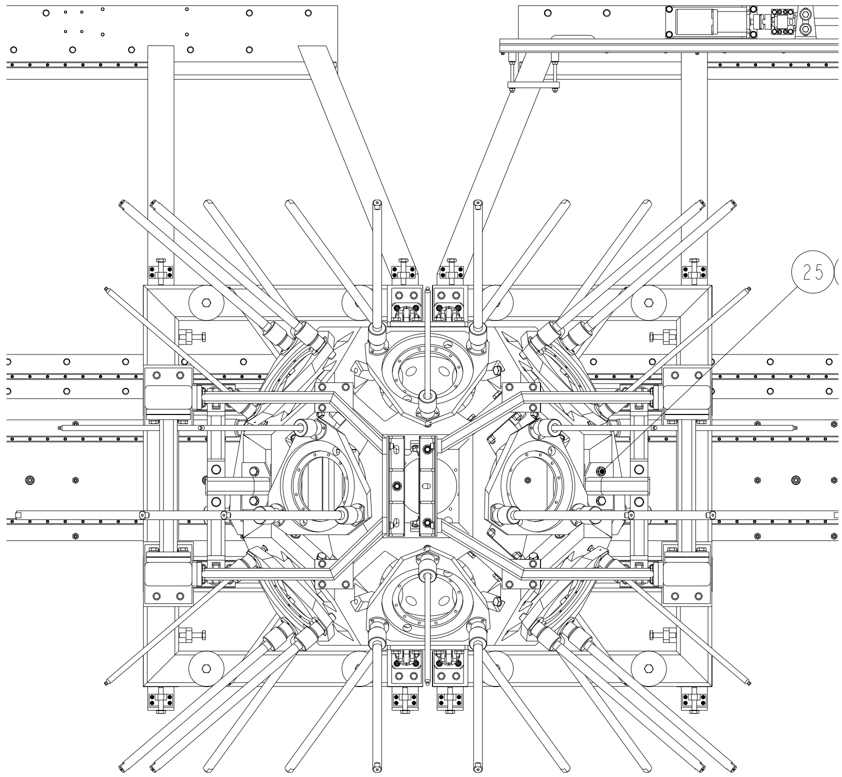
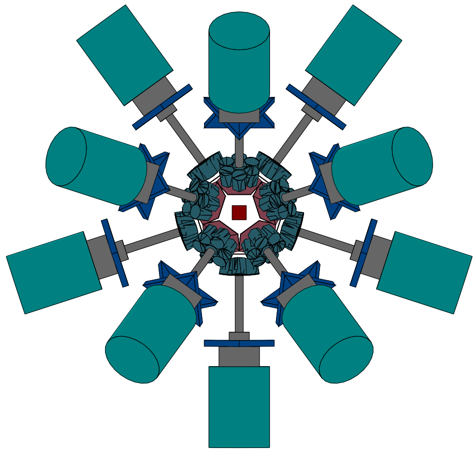


Figure 3: Workshop drawing of the support structure employed for RISING. Beam direction is from bottom to top. The support structure will be re-used for EURICA and a new rail system with corresponding distances will be installed at the F11 area.

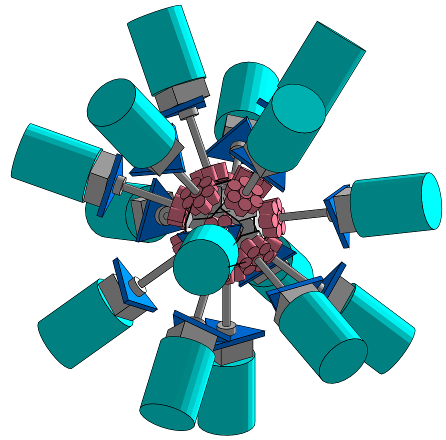
3.2.4 Cluster Electronics

The Cluster's electronics scheme will correspond to the scheme employed for RISING. The two output channels from the Cluster's preamplifiers will be sent to two individual branches for energy and timing, respectively. The energy branch will be processed by digital DGF-E modules by XIA [18]. With these modules an energy resolution of less than 3 keV was reported at 1332.5 keV for the RISING campaigns [5]. The individual DGF channel triggers will be validated by the master trigger signal of one of the various plastic scintillators in the beam-line.

The analogue timing branch will originate from the second preamplifier output of the Cluster detectors. The readout circuit will be composed of a standard TFA-CFD-TDC branch (NIM-TFA, V812 CAEN CFDs, and V775 CAEN TDCs). All digital and analogue electronic modules mentioned so far may be re-used from RISING (PreSpec). To enable isomer spectroscopy, the CFD signal is fed into a long range TDC as well.



(a) Upstream view



(b) View from 120 degrees

Figure 4: Schematic layout of the EURICA spectrometer. The 15 Cluster detectors are arranged in three rings at angles of 51, 90, and 129 degrees, respectively, and distances of about 220 mm.

Either a V767 CAEN TDC (discontinued) with a full scale range of up to 0.8 ms or a V1190A CAEN TDC with a full scale range of up to 0.1 ms will be used.

As Eastern Japan has an electrical power line voltage of 100V/50Hz, a converter unit will have to be utilized for the RISING (PreSpec) crates being used. It is estimated that a total of 7.5 kW needs to be converted.

3.2.5 High Voltage Supply and Cooling System

An automated high voltage supply and LN_2 cooling system will be employed for the EURICA spectrometer. At present, two options are under discussion. The first one is to adopt the same system as used for the RISING campaigns [19]. It would be assembled and shipped to RIKEN by GSI. Alternatively, the existing system at the F11 area, previously employed for four Clover detectors, will be expanded. This system is company built by VIC International [20] and so far never failed the LN_2 filling for the RIBF Clover detectors since year 2008.

A liquid nitrogen pipeline will lead from the large storage tank (88 m^3 / day) outside of the RIBF building to the B2F floor, the same floor as the EURICA spectrometer. Two 320 Liter buffer tanks, connected to two independently working filling stations, will be employed to fill the EURICA Ge-detectors. Up to eight detectors will be attached to one station, which will be controlled by software and fill detectors automatically every 12 hours.

A new high voltage system (either one CAEN SY1527LC crate with 9 A1832 PE cards or Mpod 2H (x1) + Mpod MINI (x1) + ISEG EHS 80 60n IND SHV (x 14), both assuming that RIKEN will host fifteen Cluster detectors) will be procured. The high voltage will be applied to the individual detectors via software. Status surveillance via internet will be possible for high voltage as for the filling system.

A new low voltage power supply unit for the Cluster detector's preamplifiers will be procured (Fuji-diamond). Furthermore, an uninterrupted power supply (UPS: DENKEN-SEIKI RI-N) will be provided for the high and low voltage of the Cluster detectors as well as the filling system. The UPS system will ensure that in case of power failure the Cluster high voltage systems will shut down. It is estimated that a UPS unit providing 5 kvA is sufficient.

3.3 The EURICA DAQ System

The EURICA data acquisition (DAQ) will consist of three sub-DAQ systems. Silicon DAQ, Germanium DAQ and BigRIPS DAQ can run according to individual triggers. We plan to use the GSI DAQ system for the silicon and germanium part because it costs little effort to reuse RISING DAQ and analysis software. For the BigRIPS DAQ, we will use the standard RIBF DAQ system. Experimental data are separately acquired and stored. Each system has been used in GSI or RIBF, and online analysis software is available for both. Therefore, we can use well debugged systems from the start. Event timings between different DAQs are synchronized by a time-stamping system. This time-stamping system has been introduced in RIBF for beta-decay experiments [11, 12].

However, the time-stamping system only provides connectivity of event timings. It is also important to easily combine data taken by different DAQs. What we plan to use is an "on-demand event-builder". All data locations, time-stamp values, and some associated tags are accumulated into a database. To extract physics events from separately stored data, user clients put requests to the on-demand event-builder through the internet. The on-demand event-builder assembles the data and returns the request.

Although GSI and RIBF DAQ systems have different raw data formats, this system can treat both data formats. In addition to raw data, ROOT Tree files will be directly available. If detector data are well calibrated and stored into a ROOT Tree, the users will be able to construct physics events from calibrated data very easily. These features facilitate also the sharing of data analysis between remote places.

4 Organizational Structure of the Project

The organization for the construction and operation of EURICA comprises of the EURICA Collaboration Board (ECB), responsible for the project coordination, and the EURICA Project Management (EPM), responsible for the execution of the project along the lines defined by the ECB. The collaborating research community will be closely connected to the EPM in order to elaborate and structure the physics proposals, implement ancillary detectors, carry out experiments, etc. Furthermore, the research community is expected to assist the EPM in the installation of EURICA at the RIBF. The envisioned organizational structure of EURICA is schematically shown in Fig. 5.

It is planned to establish an ECB composed of six members. Three members should be affiliated to Japanese institutes and at least two members should be affiliated to European institutes. The ECB will set the general framework for the EPM. The tasks of the ECB have to be defined by the EURICA collaboration but should include:

1. define the scientific policy of the EURICA collaboration,
2. elect a chair and vice chair among its members,
3. affirm a Project Manager,
4. organize / coordinate experimental campaigns,
5. interact with resource providers / ancillary equipment,
6. monitor the project based on reports received from the Project Manager,
7. decide on modifications of the project proposed by the Project Manager,
8. review scientific progress of each experimental campaign based on the reports received from the individual experimental spokespersons.

The Project Manager is affirmed by the ECB to coordinate the execution of the project tasks done by the EPM and responsible for the infrastructure, safety, and technical affairs of the project. For the latter, he will be assisted by the project's technical coordinator. The EPM, supported by the RIKEN Nishina Center, will be divided into several working sub-groups responsible for infrastructure, data acquisition and analysis, electronics, mechanics, and logistics. The key personnel for these sub-groups has already been defined.

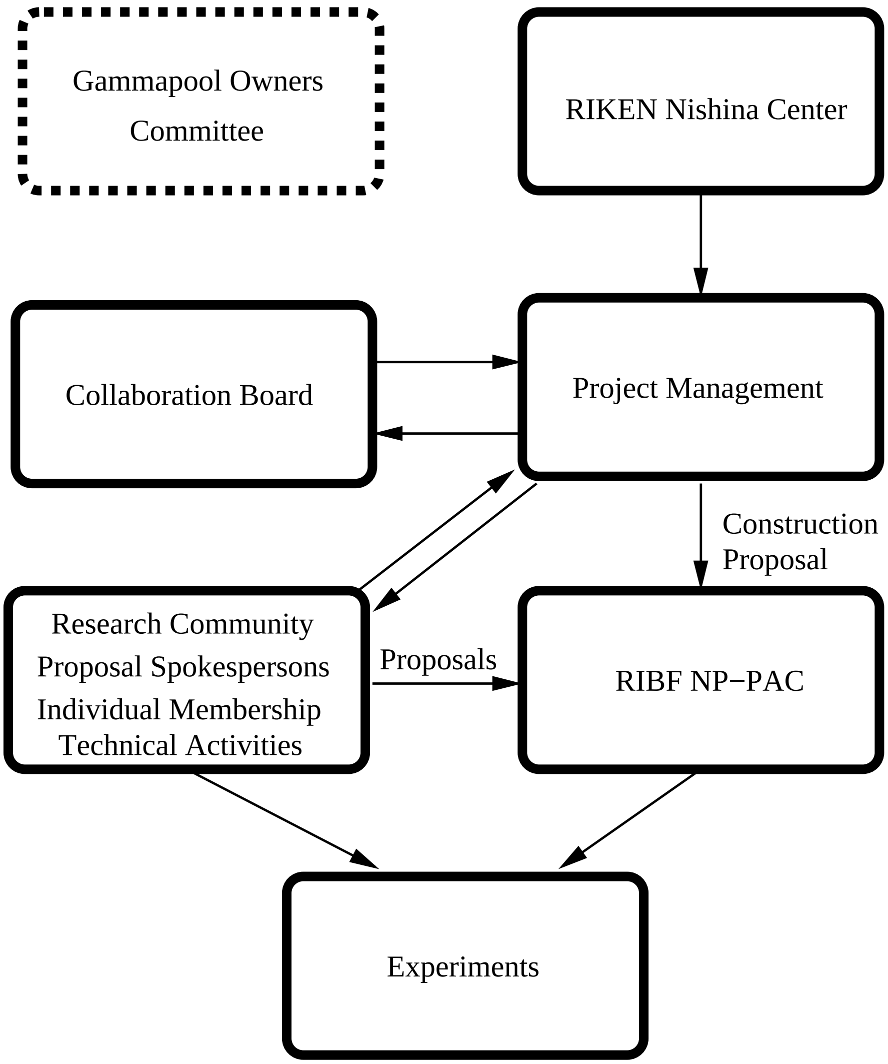


Figure 5: Tentative organizational diagram of the EURICA collaboration.

4.1 Local Technical Support

Full assistance is given by the RIKEN Nishina Center Computing and Network Team for setting up and merging the independent data acquisition systems of the BigRIPS and EURICA spectrometers.

The RIKEN Coaxial and Clover Ge-detectors have been maintained successfully for a decade by a RIKEN expert who has been working in the detector section of Canberra-Japan. The basic tools for Ge-detector handling such as vacuum maintenance, repair of electronics parts (FET and preamplifier), and annealing system are already available in the laboratory J3 and a new hut in the RNC. Basic maintenance works for the Ge-detectors (vacuum control, filling, mounting, noise/resolution check, etc.) have been carried out regularly by RNC staffs and students from various universities. The level of maintenance and repair allowed by the RIKEN expert will have to be agreed with the Gammapool Owners Committee.

In total, 22 scientist (including 12 PhD students and postdocs) at the RNC are working for the EURICA project. In addition, about ten scientists from close-by Tokyo universities and research institutes are involved in EURICA.

4.2 External Technical Support

GSI has agreed on technical expert support for mounting the EURICA spectrometer, setting-up the electronics at the RIBF, and training of the technical support team for detector maintenance and operations. Details are mentioned in the support letter from GSI.

4.3 Coming to the RNC

When coming to the RNC for research and experiments, assistance is provided by the RIBF user support office (usersupportoffice@ribf.riken.jp). For experiments, five rooms may be reserved one month before use and six room at any time at the Nishina Lodge [21]. The fee per night is either 1600 ¥ or 3300 ¥, depending on the person's position. At the RIBF, a visitor's room providing nine work-spaces and internet connectivity is available.

4.4 Young Researcher Programs

RIKEN is a far away place for European researchers. Thus, taking an active part in the experimental preparations and campaigns is an issue in particular for PhD students and postdoctoral researchers. In the following section several options for young researchers wishing to come to RIKEN for a short-term or a longer period are listed and briefly described. These programs will be advertised within the EURICA collaboration and young researchers encouraged to stay for several months at the RNC during experimental campaigns.

4.4.1 International Program Associates

Within the short-term program for International Program Associates (IPA) PhD students can come to RIKEN to carry out research activities. The period of stay is between three months up to one year. The program is open to students from institutions that have a general agreement or strategic cooperation agreements with RIKEN, or which have research agreements with RIKEN. IPA participants will receive a living allowance of 158,000 ¥ per month and can use on-campus housing at no charge or may receive a living allowance of 70,000 ¥ if they live off-campus. The student's university or research institution must pay for the round-trip transportation between RIKEN and the the IPA's home country, and the travel insurance. Call for applications for the IPA program is three times per year. Details including the IPA program for up to two years can be found in Ref. [22]. For short-term IPAs research agreements with RIKEN can be signed by the director of the RNC and the head of the student's home university of research institute.

4.4.2 Foreign Postdoctoral Researcher Program

The Foreign Postdoctoral Researcher (FPR) program offers young foreign scientist to pursue their research at RIKEN under the direction of a RIKEN laboratory head. Application period is once per year. The applications are reviewed by a screening committee comprised of scientists inside and outside RIKEN. This program is intended for foreign postdoctoral researchers that wish to stay in RIKEN for periods between one and three years. The base salary is 487,000 ¥ per month before taxes. Commuting and housing allowances are available. Moving expenses to take up the FPR position at RIKEN will be reimbursed in accordance with RIKEN regulations. Details of the program can be found in Ref. [23].

4.4.3 Japanese Society for the Promotion of Science Fellowships

The Japanese Society for the Promotion of Science (JSPS) offers three different postdoctoral fellowship programs: Standard, short-term, and summer. The short-term fellowships are awarded for staying periods between one to twelve months. Candidates for the short-term fellowships must have obtained their doctoral degree at a university outside Japan within six years of the date the fellowship goes into effect, or must be currently enrolled in a doctoral course at a university outside Japan and scheduled to receive their PhD within two years. The monthly maintenance allowance is 362,000 ¥ for PhD holders and 200,000 ¥ for non-PhD holders (tax-free). Furthermore, fellows staying for a period of more than four months will receive a 200,000 ¥ settling-in allowance.

The round-trip air ticket is covered by JSPS. There are about 6 application periods per year. Details of the different programs can be found in Ref. [24].

5 Equipment, Bid, and Costs

The equipment bid for the period of January 1st, 2012 until June 30th, 2013 is:

EUROBALL equipment:

- 15 EUROBALL Cluster detectors,
- full records of assembling, test and repair of the Cluster detectors,
- 105 HV elbows for Ge-detectors,
- 1 manipulator (produced at Legnaro), and
- all equipment needed for mounting and dismounting (except standard tools).

Some equipment necessary to realize the project belongs to the PreSpec collaboration. For the years 2012 and 2013 GSI will host the AGATA spectrometer. Therefore, some equipment will not be used and can be employed for EURICA. Equipment that may be used for EURICA includes:

PreSpec equipment:

- 1 Cluster holding structure for stopped beam campaign,
- Digital electronics (DGF-E) for 15 Cluster detectors,
- 3 CAMAC crates for digital electronics,
- 3 VME crates,
- 3 RIO3 CPUs,
- 8 V812 CAEN CFDs,
- 4 V775 CAEN TDCs,

- 15 NIM-TFA, and
- the connecting cables between the above mentioned modules.

Details of the provision and the employment of these PreSpec items will be subject to a formal letter of agreement between the PreSpec and the EURICA collaborations. Some equipment needs to be procured and/or built. In the following, we give a list of items necessary for EURICA and estimated costs. The costs are covered by the RNC.

EURICA equipment:

Budget requested for EURICA		42,650 + (30,000) (x 1k ¥)	
Item	Cost	Item	Cost
Travel	1,750	Shipping	5,000
HV Power	6,800	Rail and Stage	4,000
Liq. N2 system	4,000	Cables	5,000
UPS	1,500	220V Power	200
Cooling pipe	800	Chamber	800
F11 Extension	2,000	Turbo pump	900
Shield	500	Electronics	1,000
High power VME	900	Scroll pump	600
Connectors	400	NIM power	1,700
Rack, Cable support	300	Liq. N2 Dewar	2,500
Maintenance of Ge	2,000	(Liq. N2 line for RIBF	30,000)

The travel costs indicated in the above table are to be used for the project execution by the EURICA Project Management and the GSI technical support. A prototype transportation box for a safe shipment of the Cluster's cryostats as well as for the crystals is being developed by company [25] in close liaison with the GSI Ge-detector expert.

6 Project Time-Line

The EURICA construction proposal was submitted to the 9th RIBF NP-PAC in May, with the NP-PAC meeting held in June, asking for 4 days of beam time for commissioning the array.

The RNC bids for hosting the fifteen Cluster detectors from January 1st, 2012 until June 30th, 2013 for commissioning EURICA and performing experimental campaigns. Preparation for transportation, shipment of the detectors and assembling may start as soon as approval for this proposal is given in order to start commissioning without beam from January 1st, 2012 and with beam from February 1st, 2012.

Equipment belonging to the PreSpec collaboration, i.e., support structure and electronics, can be shipped to the RNC and assembled on an independent time scale. The RIBF beam time schedule foresees two months of experiments using BigRIPS in the second half of 2011, which might occasionally prohibit construction and assembling works at the designated EURICA location. Therefore, all construction works have to be performed considering the restrictions of the beam time schedule. We would like to point out that assembling and testing of the Cluster detectors is not affected by the RIBF beam time schedule.

The physics case discussed during the workshop in May will be submitted as a set of proposals to the 10th RIBF NP-PAC to be held in December 2011 with approval or disapproval given individually for every new proposal, while beam time will be re-evaluated for already approved experiments. Commissioning of EURICA with four days of beam time can be performed in the months of February and March 2012.

Preparing a primary beam for the RIBF takes about one week. Therefore, in order to use the available RIBF machine time as efficiently as possible the experiments are planned to be run in several campaigns with the same primary beam, lasting several weeks each. If only very few beam time is requested by EURICA for a specific primary beam, EURICA experiments can be scheduled in a primary beam campaign together with non EURICA experiments, for example in-beam γ-ray spectroscopy experiments. Switching from one experiment to another is immediate and involves no beam time loss.

As stated by the support letter signed by the RNC Director, 40 % to 50 % of RIBF beam time may be allocated for EURICA during FY2012 and the first half of FY2013 (The Japanese fiscal year starts in April). The RIBF has presently an operational budget of five months per year (FY2011) and is expected to operate for close to eight months per year from FY2012. This corresponds to having three campaigns lasting about four to six weeks each, depending, of course, on the RIBF NP-PAC recommendation for beam time allocation. The three campaigns are planned for spring 2012, fall 2012, and spring 2013. Decommissioning for EURICA may start from July 1st, 2013.

Time / Task	2011									2012			
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Letter of Intent	■												
Last PreSpec Experiment		■											
EURICA Workshop		■											
Construction Proposal			■										
MoU and Proposal				■	■	■							
Shipment of Support Structure					■	■							
Shipment of Electronics					■	■							
Construction of Rail System					■	■	■						
Shipment of Detectors						■	■	■					
Construction of LN2 Pipeline						■	■	■	■				
Ass. of Support Structure							■	■	■				
Assembling of Clusters								■	■	■			
LN_2 Filling system								■	■	■			
Assembling of Electronics								■	■	■			
RIBF NP-PAC Meeting									■				
Mounting of Clusters									■	■			
Commissioning w/o Beam										■	■		
Commissioning w. Beam											■	■	
EURICA Experiments													■

Table 3: Intended time-line of the EURICA project until the first experimental campaign may start. The assembling and mounting of the Cluster detectors depends on the date the detectors are available for shipment. The experimental campaigns are planned to start in April 2012.

7 Collaboration

The EURICA collaboration was formally established during the first EURICA International Workshop, held on May 23–24, 2011 at the RNC. The EURICA collaboration has free and open access to any researcher interested in joining. At present, the institutions collaborating in EURICA are:

- University of Akdeniz, Antalya, Turkey
- VINCA, Belgrade, Yugoslavia
- CENBG Bordeaux, France
- GANIL, Caen, France
- KEK, Tokai, Japan

- Hoseo University, Chun-Nam, Korea
- GSI, Darmstadt, Germany
- TU Darmstadt, Germany
- LPSC Grenoble, France
- University of Istanbul, Turkey
- Kyoto University, Japan
- INFN LNL, Legnaro, Italy
- INFN, Legnaro, Italy
- CSIC, Madrid, Spain
- INFN Milano, Italy
- University of Milano, Italy
- Technische Universität München, Germany
- CSNSM Orsay, France
- IPN Orsay, France
- RCNP, Osaka University, Japan
- Osaka University, Japan
- University of Padova, Italy
- Peking University, China
- LRI - University of Salamanca, Spain
- Tohoku University, Sendai, Japan
- Royal Institute of Technology, Stockholm, Sweden
- IPHC, Strassbourg, France
- University of Surrey, UK
- JAEA, Tokai, Japan
- ICU, Tokyo, Japan
- Tokyo Institute of Technology, Japan

- Tokyo University of Science, Japan
- CNS, University of Tokyo, Wako, Japan
- University of Tokyo, Hongo, Japan
- University of Tsukuba, Japan
- University of Uppsala, Sweden
- University of Valencia, Spain
- TRIUMF, Vancouver, Canada
- RIKEN, Wako, Japan

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A Letters of Intent

The attached Letters of Intent reflect the EURICA physics case discussed during the first workshop. Most of these LoI are presently feasible within a reasonable amount of beam time only at the RIBF. The selection is not meant to be exclusive.

1. β-decay studies near N=28
2. β-decay studies of very neutron-deficient nuclei and their comparison with charge exchange reactions
3. Mirror energy differences beyond the fp shell: Isomeric decay of ^{71}Kr
4. Study of the N=34 subshell gap around ^{54}Ca
5. Shell structure around ^{78}Ni: β-decay studies of neutron-rich ^{75,77}Cu
6. Investigation of the proton-neutron T=0 condensate through GT decay to the quasi-deuteron 1^+ state in odd-odd N=Z nuclei
7. Decay spectroscopy in the vicinity of ^{100}Sn
8. Probing neutron-rich isotopes in the vicinity of the doubly mid-shell nucleus ^{170}Dy by β-γ and isomer spectroscopy
9. Search for long-lived isomeric states in the neutron-rich Cd, Ag, and Pb isotopes
10. Spectroscopic and isomeric study of very neutron rich Iron isotopes
11. Decay study of Fe to Zn isotopes near the N=50 shell closure
12. Neutron monopole drift towards ^{78}Ni, investigated by γ-spectroscopy following ^{81}Cu β-decay
13. Shape coexistence in the neutron-rich mid-shell isotopes Ge, Se and Kr
14. Gamow Teller strength in ^{100}Sn
15. Structural evolution of nuclei along the r-process path around A=100
16. Gamma spectroscopy and B(E2) measurements to study shape transitions in neutron rich Mo and Tc isotopes
17. Use of energy-degraded RI beams with EURICA
18. Search for tetrahedral shape around ^{110}Zr
19. Energy-degraded RI beams at RIBF

20. β-decay spectroscopy study of the very neutron rich-nuclei Nb-Ag, includingthe r-process waiting points ^{128}Pd and ^{129}Ag

21. Search for isomeric states in ^{132,134}Cd and ^{136,138}Sn and the study of their β-decays

22. Decay studies in neutron-rich Sb, Te isotopes and beyond

23. Octupole collectivity in the neutron-rich mid-shell isotopes Xe and Ba

24. Nuclear moment studies with EURICA

β-decay studies near N=28

Zhihuan Li　RIKEN

The nuclear structure in the region of nuclei around N=28 depends strongly on the filling of both proton and neutron orbitals when protons filling the ($1d_{5/2}2s_{1/2}d_{3/2}$) shell and neutrons occupying the $1f_{7/2}$ subshell. A gradual development of deformation had been found between spherical ^{48}Ca and the deformed ^{42}Si.

Similar to the case of the N=28 isotones, the N=27 isotones reveal a regular transition from sphericity to deformation according to their low-lying spectroscopies [1]. In ^{43}S, an inversion of the normal shell order has been found that the $3/2^-$ state instead of the $7/2^-$ state becomes the ground state. The $7/2^-$ state of ^{43}S is an isomeric state with lifetime of 478(48) ns, which is spherical, whereas $3/2^-$ ground state in ^{43}S is deformed. The shell model calculations for low lying energy states of ^{41}Si predicted that a similar inversion will also appear in ^{41}Si [2]. Due to the large Z=14 shell gap, the proton excitations in ^{41}Si will be hindered. Since so far no experimental data available on the exited states of ^{41}Si, it will be very worthful to measure the low lying levels of ^{41}Si, which can provide the experimental information related to the evolution of $2s_{1/2}$ and $1d_{5/2}$ states in the N=27 isotones.

In the case of ^{40}Si, the first 2^+ state has been measured by Campbell et al. [3] using the inelastic scattering and nucleon removal reaction on a liquid hydrogen target. In their work, due to the low statistics, two weak γ peaks from the nucleon removal reaction were tentatively placed above the 2^+ state.　In the shell model calculation, to reproduce the experimental result, the reduction of the n-n interaction at Z=14 is needed, which is similar to the ^{18}C and ^{20}C case. But this reduction will cause the overestimating size of N=28 shell gap. In order to verify the possible reduction in n-n interaction strength, more the higher energy level information in ^{40}Si is needed.

In the proposed experiment, we plan to make systematic study the low lying energy levels for ^{40}Si and ^{41}Si as well as the following daughter nuclei via the β-decay of $^{40-41}$Al, $^{40-42}$Si, $^{41-43}$P as well as lifetime measurements.

The β-delayed γ-rays are detected by Germanium detector array located very close geometry to the implantation detectors. The β-delayed neutrons are detected by using neutron wall. In addition, two fast $LaBr_3$ counters are placed around implantation detectors to determine the life time of the excited states using time-delayed βγγ(t) measurement.

This experimental proposal NP0912-RIBF35 has been approved for 5 days of beam time by 6th RIBF NP-PAC.

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Beta decay Studies of very neutron-deficient Nuclei and their comparison with Charge Exchange reactions.

B. Rubio, Y. Fujita and W. Gelletly for the Valencia-Osaka-Surrey-Istanbul-
Bordeaux collaboration

We have studied the Tz = -1 → 0 beta decays of ^{42}Ti, ^{46}Cr, ^{50}Fe and ^{54}Ni to the self-conjugate nuclei ^{42}Sc, ^{46}V, ^{50}Mn, and ^{54}Co respectively (Ph.D Thesis, Francisco Molina- Uni. Valencia) at GSI during the stopped beam RISING campaign. The nuclei of interest were produced in the fragmentation of a 58Ni beam of 680 MeV/nucleon at GSI. The number of implanted ions of the nucleus of interest was typically 3-6 x 10^6 in total. The excellent statistics allowed us to determine correlations between the HI-beta or HI-beta-gamma emissions and to a) measure the beta-decay half-lives with one order-of-magnitude better accuracy than the values existing in the literature, b) establish decay schemes, c) determine the direct ground state to ground state feeding in the decays, d) measure the decay intensity to the 1+ states populated in the daughter nucleus and hence the absolute B(GT) values for the Gamow-Teller beta decays. The B(GT) values are of importance inter alia in terms of a comparison with the analogous Charge Exchange (CE) reactions on the mirror nuclei (Fujita et al.,PRL95(2005)212501). An interesting observation in these experiments is the predominant M1 decay of the T=0, 1^+ states populated in the beta decay to the T=1, 0^+ g.s. No M1 gamma transitions were observed to any other T=0, 1^+ excited states. This selection rule, called a "Quasi-rule" by Warburton and Weneser (D.H. Wilkinson "Isospin in Nuclear Physics", 1969, SBN 7204 0155 0) is observed for the first time in the fp shell nuclei.

Encouraged by this success we have pursued this further in experiments at GANIL, where we have studied the beta decays of the Tz=-1 ^{58}Zn and Tz=-2 ^{56}Zn nuclei . However these nuclei are more difficult to produce due to the lack of appropriate Tz=+1 stable targets.

The high intensity beam at RIKEN together with the EURICA array would allow us to extend these studies to higher masses and more exotic cases. This would allow, for instance, the study of mirror symmetry in heavier mass systems by comparison with the corresponding charge exchange reactions.

Amongst the cases of interest are the very neutron-deficient 64 and 66Se isotopes, the first of which can be compared with the mirror CE process on 64Zn. The 66Se case is very interesting from several viewpoints, a) to study the evolution of the B(GT) strength in the fp shell, b) to study further the "Quasi-rule" for the M1 transitions and c) to study a possible proton-neutron condensate.

These experiments could be carried out using the fragmentation of a 78Kr beam at RIKEN and the EURICA array and could be coupled to the experiment proposed by B. Blank and collaborators, which focusses on two-proton radioactivity, and is already approved.

E(U)RIKA LOI

Mirror energy differences beyond the fp shell. Isomeric decay of ^{71}Kr

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Spokepersons: G. de Angelis, F. Recchia

Isospin formalism, which describes the neutron and the proton as two states of the same particle, the nucleon, is amongst the essential descriptive tools of a broad range of nuclear phenomena. In this formalism, nucleons are discriminated by the projection $T_z=\pm 1/2$ of their isospin vector T. The broad success of the isospin symmetry concept belies its broken nature. Not only is the symmetry broken by the proton-neutron mass difference and the Coulomb interaction, bat also by the nucleon-nucleon interaction itself. The investigation of isospin symmetry conservation and breaking effects has revealed a wealth of nuclear structure information. The so-called MED are defined by the differences in the excitation energies of analog states and are regarded as a measure of isospin symmetry breaking in an effective interaction that includes the Coulomb force. The MED have been extensively studied for mirror pair nuclei in the upper sd- and the lower fp-shell regions. In both cases a remarkable agreement between experimental data and shell model calculations has been achieved, allowing a clear identification of the origin of the MED based on the isospin-non conserving Coulomb and strong NN force [1].

For mirror nuclei in the upper part of the fp shell the situation is different. Recent experimental data have revealed large mirror energy differences (MED) between high-spin states in the mirror nuclei ^{67}Se and ^{67}As [2]. Also only recently large-scale shell model calculations including the $g_{9/2}$ orbit have become available. One of the open problems here concerns the strength of the isospin non conserving NN force.

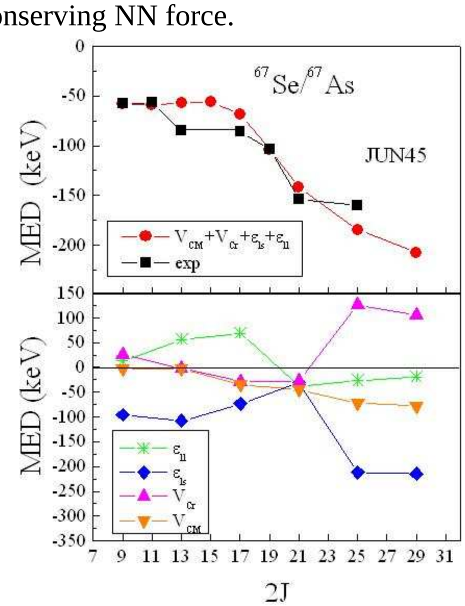

Figure 1: Experimental (black) and calculated MED for the mirror pair ^{67}Se-^{67}As (up). Contributions to the MED of the different monopole and multipole terms (see ref. [2]). The calculations are performed using the JUN45 residual interaction.

Figure 1 shows the good agreement obtained between the experimental and the calculated MED for the A=67 mirror pair. The good agreement is obtained without involving an explicit isospin non conserving NN force. However those results do not allow to conclude that the isospin non conserving term is not important.

Another important aspect of the upper fp shell concerns the possible breaking of the isospin symmetry due to shape coexistence. An anomalous behavior of the MED is shown by the A=70 isobaric triplet, see figure 2, and seems to indicate the presence of different deformation mixing among mirrors with a prolate deformation predicted for the ^{70}Kr and an oblate deformation for the ^{70}Se nuclei [3,4,5].

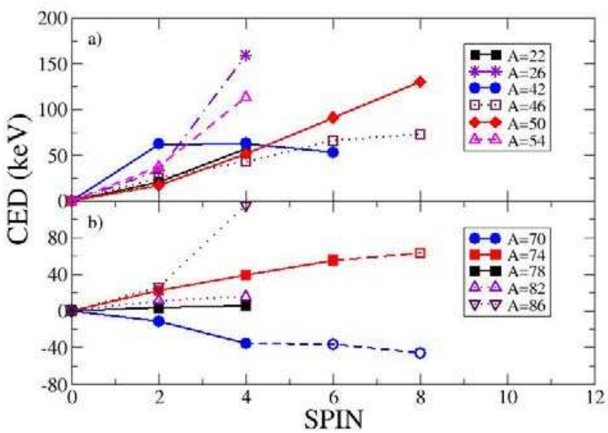

Figure 2: MED for isobaric triplets (a) in the sd and in the lower part of the fp shells and (b) in the upper part of the fpg shell. The flat or negative behaviors of the MED can be related to the shape coexistence effects.

Shape coexistence has been reported in ^{71}Br and in many other nuclei in this region. The nucleus is well known and some of the published studies are in refs [5-8]. According to the latest results by Fischer the first excited states correspond to different deformation, from oblate to prolate.

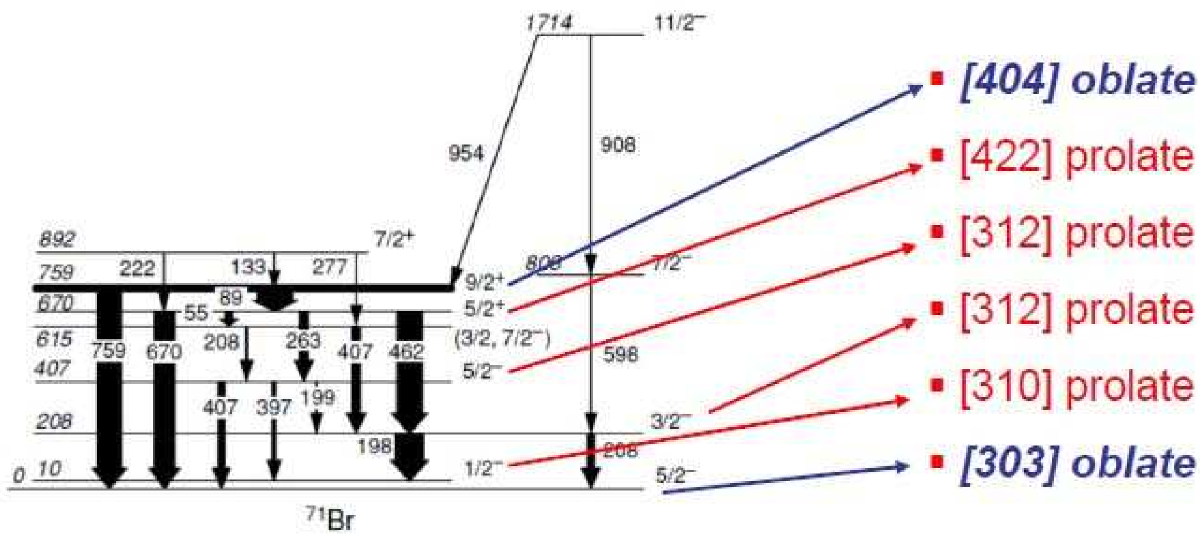

Figure 3: deformation in the lowest lying levels of ^{71}Br populated by the decay of the $9/2^+$ isomer and their identification with the Nilsson configuration in agreement with [6].

Regarding ^{71}Kr, the only information available are coming from beta decay. A long discussion is ongoing since 10 years regarding the spin of its ground state. The assignment to the g.s. was done first by Arrison [6] and Oinonen [7] just using the mirror symmetry. Hamamoto pointed out [8] that

this could be the first case of mirror nuclei where the isospin symmetry is broken at the g.s. This was deduced from Nilsson calculations and proposed a change of the spins of the first states.
Finally Fischer [9] changed back the first excited states in ^{71}Br observing the angular distribution of the 759 keV transition and so the g.s. spin of ^{71}Kr was proposed as $5/2^-$.
Anyway the fact that 30% this beta decay goes to excited states is something different from all the other decays between mirror nuclei observed so far.

In this LOI we intent to investigate the MED of the A=71 mirror nuclei. A 33 ns $9/2^+$ isomeric state is known to exists in ^{71}Br [9]. The same isomeric state is predicted to exist in ^{71}Kr, with a lifetime of the order of about 100 ns due to the excitation energy distortion introduced by the electromagnetic spin orbit interaction. We propose therefore to investigate at RIKEN the gamma decay from such isomeric states using the E(U)RIKA set-up in the stopped beam configuration.

Isomeric states in the ^{71}Kr should be produced by in flight fragmentation of ^{78}Kr beam at 345 MeV/nucleon. Fragments will be separated in-flight using the BigRIPS facility. The first stage of the BigRIPS separator will be used to collect and separate fission fragments while the second stage will be used as a spectrometer for particle identification.
Assuming a primary beam intensity of 30 pps of ^{78}Kr we estimate a particle rate of about 500 pps for ^{71}Kr. With a gamma efficiency of the E(U)RIKA spectrometer in the stopped beam configuration of about 15% and an isomeric ratio of 5% scaled from ref. [10], we expect about 10^5 counts per day.

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Study of the N=34 subshell gap around ^{54}Ca

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Shell closures are a fundamental concept in nuclear physics and most of our knowledge of effective nucleon-nucleon interactions comes from the study of nuclei with few valence particles around doubly-magic cores. There are by now a wealth of data coming from the study of exotic nuclei showing that the relative energies of the shell-model orbitals are not immutable but can change and evolve as a function of neutron number. This leads to the disappearance of well established magic numbers or to the appearance of new ones. For example, the presence of a N=32 subshell closure has been recently derived from various experiments on neutron-rich nuclei from Ca to Cr. The existence of this energy gap at N=32 around Z=20 arises from a large energy spacing between the neutron p3/2 orbital and the higher lying p1/2 and f5/2 orbitals.
Otsuka and collaborators have also predicted that the N=34 isotones around Z=20 could exhibit characteristics of a shell closure due to the proton f7/2 - neutron f5/2 monopole tensor interaction. This effect could be revealed by measuring the first excited states involving the f5/2 neutron single particle orbital in the 55Sc nucleus. The most direct evidence of the subshell at N=34 would be the high energy of the first 2+ state in ^{54}Ca, not accessible today. However, the low-lying excited states of ^{55}Sc, populated via the beta decay of ^{55}Ca (g.s. 5/2-), involving the f5/2 neutron single particle orbital will help to elucidate the gap at N=34 and this will represent a crucial test for theoretical calculations predicting a new shell closure at N=34 around Z=20. This nucleus will be produced in a fragmentation reaction at relativistic energies, using a ^{86}Kr primary beam at 350MeV/n. The BigRIPS fragment separator in combination with some of the Euroball Cluster detectors will be used for this study. Around a total of 7 days of beam time would be enough to perform this experiment with final relevant results.

E(U)RIKA LOI

Shell structure around ^{78}Ni : Beta-decay studies of neutron-rich ^{75,77}Cu

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The magic numbers, originated by the large shell gaps in the energy spectrum of the single-particle states, represent a fundamental quantity governing nuclear structure. They can be reproduced using a single-particle harmonic oscillator potential with a strong spin-ortbit interaction and they are predicted to change for large N/Z ratios. Exotic nuclei close to the shell closures on the neutron drip-line play an important role on nuclear shell structure studies since they allow to search for possible modifications of magic numbers with increasing N/Z ratio. The tensor component, one of the non-central components of the effective nucleon-nucleon interaction, is expected to modify the relative single particle energies when one goes further from stability on the neutron drip line [1,2]. It is expected an attraction for orbitals with anti-parallel spin configuration and a repulsion for orbitals with parallel spin configuration. The change of the shell structure due to the tensor mechanism has been recently discussed in different mass regions [3, 4]. The magic numbers at N=20 and 28 disappear with increasing neutron number and new magic numbers at N=14, 16 and 32 seem to appear. It is also predicted that the Z=28 gap for protons in the pf-shell becomes smaller moving from ^{68}Ni to ^{78}Ni as a result of the attraction between the $f_{5/2}$ and the $g_{9/2}$ orbits and repulsion between the $f_{7/2}$ and $g_{9/2}$ configurations.

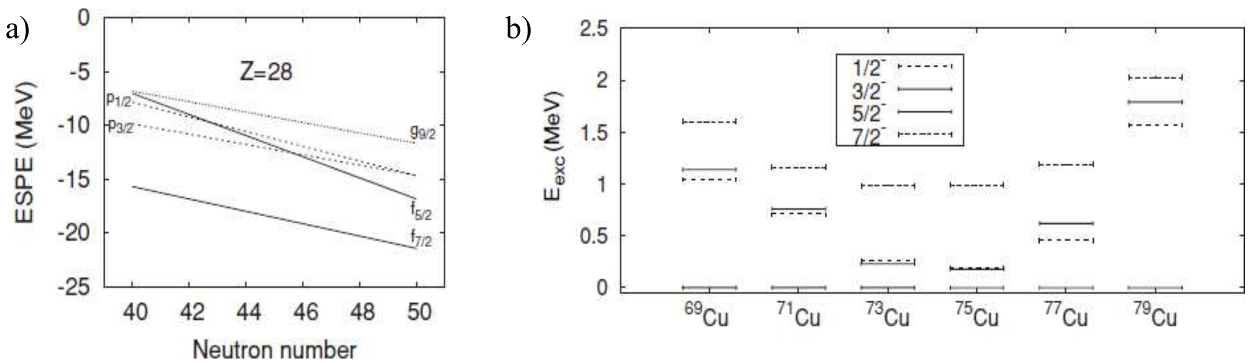

Figure 1: a) The evolution of the proton effective single-particle energies between ^{68}Ni and ^{78}Ni, b) The low-lying levels in copper isotopes resulting from shell model calculations from Ref [5].

In the case of Cu isotopes the changing of effective single-particle energies comes directly from the attraction between the $\pi f_{5/2}$ and the $\upsilon g_{9/2}$ orbits and the repulsion between the $\pi f_{7/2}$ and the $\upsilon g_{9/2}$ orbits. Recent calculations in the fpg shell seems to indicate that the Z=28 shell gap gets reduced by about 0.7 MeV when filling the neutron $g_{9/2}$ orbital [5]. The same Shell Model calculations together with the effect of the tensor force performed for the neutron-rich Cu isotopes predict a lowering of the $\pi f_{5/2}$ state causing an inversion of the $\pi f_{5/2}$ -$\pi p_{3/2}$ effective single-particle states when approaching ^{78}Ni. This inversion has been recently confirmed by nuclear spin and magnetic moment measurements for ^{75}Cu by identifying its spin of the ground state as I= 5/2 [6].

Aim of the present proposal is to identify experimentally the location of such low-lying excitations as test of the microscopic interaction in the fpg shell model space.

Unlikely to its neighboring isotope ^{75}Cu [7], no evidence for isomerism was found in ^{77}Cu according to the fragmentation study of 86Kr at 140 MeV/a at the Coupled Cyclotron Facility of NSCL/MSU [8]. Therefore, the nuclei of interest, ^{75,777}Cu will be populated via beta-decay of the ^{75,77}Ni through the in flight fragmentation of ^{86}Kr beam at 350 MeV/nucleon. Fragments will be separated in-flight using the BigRIPS facility. The detailed information on the experimental settings will be given in the presentation.

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E(U)RIKA LOI

Investigation of the proton-neutron T=0 condensate through GT decay to the quasi-deuteron 1^+ state in odd-odd N=Z Nuclei

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It is well known that in the atomic nucleus, alike nucleons (neutrons or protons) in time reverse orbits, couple in pairs giving rise to nuclear superfluidity, with very significant impact in the structure as well as in the collective properties of the nucleus. In addition, nuclei consist of a combination of two fermionic fluids (neutrons and protons) and as a consequence of the isospin (T) degree of freedom, four types of pairs, the triplet with T=1, J=0 and the singlet T=0 J>0, are expected. It has been shown that T=0 pairs will be only relevant in the vicinity of N=Z nuclei[1,2]

In medium mass N=Z nuclei, the existence of T=0 pairing has been studied searching for the absence of Coriolis Anti-Pairing effects at high angular momentum in rotational bands[1,2,3]. It has been suggested as well that the structure of heavy N=Z nuclei as the ^{92}Pd can be due to proton-neutron isoscalar pairing correlations [4]. Nevertheless no clear-cut signature has been found, in particular on the existence possibility of a T=0 pairing condensate. It has been suggested that enhanced Gamow-Teller (GT) β-decay rates between the ground state of an even-even N+2=Z nucleus and the lowest I=1 state of its odd-odd N=Z daughter nucleus can be the fingerprint of T=0 pairing. The role played in β-decay by proton-neutron coherent pairs (bosons) have been extensively discussed by F.Iachello [5,6] in the framework of the proton-neutron boson scheme (IBM-4).

While in light nuclei strong GT transitions to low lying states result from the presence of approximate SU(4) symmetry, the existence of strong spin-orbit splitting, in heavier nuclei, suppresses the symmetry. The GT strength can then be fragmented over many final states resulting in a reduced B(GT) for the low lying ones [7,8,9,10].

Recently, the Gamow-teller β-decay of the ^{62}Ge T=1 0+ g.s. into excited states of the odd-odd N=Z ^{62}Ga have been studied for the first time at the GSI laboratory with the Fragment Separator (FRS) and the RISING Ge-array coupled to an active implantation setup. The aim was to seek for an enhancement of the B(GT) as fingerprint of the proton-neutron T=0 condensate in the odd-odd N=Z nuclei. Contrary to expected, a diminish B(GT)=0.07±17 $g_A^2/4\pi$ has been observed for the transition to the first 1^+ state lying at 571 keV excitation energy. A lifetime of τ=119.6 ±20 ms has been measured for the ^{62}Ge ground state.

The reason for choosing the ^{62}Ge T=1 0+ g.s decay was mainly the secondary beam intensities available at FRS during the Rising Stopped beam campaign. Nevertheless, there are strong indications that only in heavy masses A~80 it would be possible to find a real T=0 p-n pairing condensate.

In the present LoI we propose the study of the Gamow-Teller decay of the ^{78}Zr or ^{82}Mo, Tz=-1 nuclei, T=1 0+ g.s to the odd-odd N=Z ^{78}Y or ^{82}Nb. While probably the 82Mo is a better choice, the secondary beam intensities might prove the experiment unfeasible.

The ^{78}Zr nuclei will be produced by fragmentation of a ^{124}Xe primary beam at 345 MeV.A in a 1000 μm Be target. The yield with BigRIPS, assuming a primary beam with 10 pnA , will be of the order of 9.0 10^{-2} leading to the implantation of 7000 ^{78}Zr atoms per day. To achieve the sensibility obtained in the 62Ge case 4 days of beam time will be required.

The ^{82}Mo nuclei can be as well produced by fragmentation of a ^{124}Xe primary beam at 345 MeV.A in a 1000 μm Be target. The yield with BigRIPS, assuming a primary beam with 10 pnA , will be of the order of 2.0 10^{-2} leading to the implantation of 1500 ^{78}Zr atoms per day. To achieve the sensibility obtained in the ^{62}Ge case 10 days of beam time will be required. A minimum of 7 days has to be allocated for the ^{82}Mo case

The active stopper, for the beta-decay studies, is required.

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Decay spectroscopy in the vicinity of 100Sn

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Abstract

^{100}Sn presumably the heaviest doubly magic and particle-stable nucleus with N=Z,, has been the subject of many experimental and theoretical efforts. A study of the doubly closed-shell nuclei as well as those located a few nucleons apart is important for testing nuclear structure models. One way to obtain experimental information on the structure of nuclei far from stability is through studies of Gamow-Teller (GT) beta-decay. The ^{100}Sn nucleus dominantly decays via a pure GT spin-flip transition converting a $g_{9/2}$ proton into a $g_{9/2}$ neutron. This makes of this nucleus an exceptionally interesting case.
The β – transition strength, an observable, which is proportional to the observed half-life and roughly to the fifth power of β – endpoint energy, is suitable for a comparison with theoretical predictions.
The accurate analysis of the decay properties associated to model predictions, will eventually illuminate the question of the missing GT- strength. It might be possible to determine the degree of renormalisation of the axial vector coupling constant in the nuclei with respect to the free neutron value. The presently available information shows that the accuracy of the measured GT strength for ^{100}Sn needs to be significantly improved in order to make a comparison with the theoretical values. A meaningful precision would be at least 15%. A reliable prediction of the GT strength is also important for the analysis of the rapid proton capture process occurring under stellar processes and for neutrino physics.
From the measurement of gamma-ray cascade emitted after the beta-decay of ^{100}Sn it should be possible to confirm the prediction that a single 1+ state is populated. From the 1+ excitation energy and β – endpoint energy one could deduce ^{100}Sn-^{100}In mass difference.
Simultaneously with measuring decay radiation from implanted ^{100}Sn one could search for delayed gamma-radiation emitted from the isomeric 6^+ state predicted by large-scale shell model calculations.

In the Z=N=50 region there are several interesting isomeric states, which can be explored in parallel to the ^{100}Sn decay studies. A precise measurements of the decay characteristics of the isomers in N=50 nuclei will be of particular interest and will provide crucial information on shell gaps and residual interaction in the sdg model space.

An experiment aiming at exploring the decay properties of ^{100}Sn has been approved (10 days) at the BigRIPS separator at RI Beam Factory in RIKEN. It is anticipated that a test aiming at obtaining realistic production yields will be performed in spring 2012 while the experiment

itself will be scheduled few months later. The EURICA setup and the proposed campaign are essential in order to maximize the gamma-ray detection efficiency for the 100Sn experiment. This first experiment should be seen as a beginning of a broader programme dedicated to the decay and isomer spectroscopy in the region close to and above 100Sn.

Title: Probing neutron-rich isotopes in the vicinity of the doubly mid-shell nucleus ^{170}Dy by β-γ and isomer spectroscopy

Spokesperson: Hiroshi Watanabe (RIKEN Nishina Center)

The rare-earth isotopes with N > 90 are known as well-deformed nuclei. If the collectivity of nucleus is enhanced as the number of valence nucleons increases, it is conjectured that the maximum ground-state deformation occurs in ^{170}Dy, which lies at the middle of the major shells for both proton (Z = 50 - 82) and neutron (N = 82 - 126). In actual nuclei, however, the stability of shape is more or less influenced by the presence of sub-shell closures and residual interactions. The degree of quadrupole deformation can be inferred from the low-lying level properties, such as the excitation energy of the first 2^+, 4^+ and the second 2^+ states, and the lifetime of the first excited level in even-even nuclei. Nevertheless, spectroscopic information on the excited states is still scarce due to the difficulties in access to this doubly mid-shell region, which lies in the neutron-rich side of the β-stability line.

We propose to investigate neutron-rich nuclei with Z = 62 - 68 and A ≈ 170, which will be produced by projectile fragmentation of ^{238}U at 345 MeV/nucleon. The low-lying levels in even-even nuclei can be populated following the β-decay of the respective odd-odd parents. Taking into account the RI production rate simulated by the LISE++ code (assuming 1 pnA beam intensity) and the detection efficiency of the EURICA array combined with the DSSSD active stopper, statistics are estimated to be 99 and 14 counts/day for γ-ray singles and γ-γ coincidence measurements, respectively, for the ^{170}Tb→^{170}Dy decay. The other aims of this proposal are to characterize the forbidden decays from multi-quasiparticle states. The focus is primarily on isomers in the neutron-rich N = 104 and 106 isotones, where K = 6^+ and 8^+ isomers have been systematically identified, respectively. The identification of such K-isomers will provide valuable information on intrinsic orbits near the Fermi surface, pairing energies, and the degree of axial symmetry.

Title: Search for long-lived isomeric states in neutron-rich Cd, Ag, and Pd isotopes

Spokesperson: Hiroshi Watanabe (RIKEN Nishina Center)

In the vicinity of the doubly magic nucleus ^{132}Sn, there are unique parity $g_{9/2}$ and $h_{11/2}$ orbitals just below the Z = 50 and N = 82 shell-gaps, respectively. These high-j orbitals play a significant role in forming characteristic isomers in this region. One example of such an yrast trap to be explored is an 18^+ isomer in ^{128}Cd. A shell-model calculation predicts that the 18^+ state is depressed energetically below the 16^+ level by the strongly attractive two-body interactions between the $g_{9/2}$ proton and $h_{11/2}$ neutron holes. As a result, the 18^+ state can not help decaying by a high-multipolarity electromagnetic transition such as E4, or alternatively, by β decay, leading to a long-lived isomeric state with a half-life in the millisecond range. Similar type of the "spin-gap" isomer with multi-quasiparticle configuration is known in ^{129}In, and expected to appear also in ^{129}Cd and ^{127}Ag. Because the properties of isomeric states, such as the excitation energy and lifetime, are very susceptible to the nature of the effective interactions and the single-particle ordering which underlies the shell structure, the spin-gap isomers serve as a benchmark for testing shell-model calculations. Also, the proposed measurements involve a systematic study of β-decaying isomers at low excitation energy in odd-mass isotopes in this neutron-rich region.

The isomers of interest will be populated by projectile fragmentation of ^{136}Xe at 345 MeV/nucleon. For this experiment, the beam time has been already approved for 6 days by the 3rd PAC meeting at RIBF. Gamma rays depopulating the millisecond isomers will be measured by the EURICA array in coincidence with β rays and/or internal conversion electrons detected by the DSSSD active stopper. Furthermore, β-γ spectroscopy of neutron-rich Pd isotopes approaching N = 82 is also within the scope of the proposed measurements. In addition to the first 2^+ and 4^+ states in even-even nuclei, the second 2^+ state is the key to quantifying structural evolution involving axially asymmetric γ softness. These low-lying levels can be fed following the β decay of the odd-odd Rh isotopes. The identification and characterization of these levels will reveal the nuclear collectivity in this neutron-rich region, shedding light on the problem regarding the quenching of the N = 82 shell closure.

Spectroscopic and isomeric study of very neutron rich Iron isotopes

Spokesperson: Giovanna Benzoni INFN sez. Milano

Co-Spokesperson: Hiroshi Watanabe RIKEN Nishina Center

In the region of the neutron rich iron isotopes, around the r-process starting point, only few spectroscopic information is available. We aim to determine life times, beta and isomeric decays and built first level schemes in $^{70-72}$Fe and around. We plan to use the unique combination of the high beam intensities available at RIKEN together with BigRIPS-ZeroDegree spectrometer and the EURICA and DSSSD pixel array.

Recently, [1,2] experimental information in the region around N=40 neutron subshell closure in Fe, Cr and Ni isotopes suggests that the N=40 energy gap is not strong enough to sustain spherical shapes and that deformation sets in. Mean-field and beyond mean-field calculations show that isotones with N=40 are dynamically deformed. In the iron isotopes beta and beta-gamma decay is only known up to odd ^{67}Fe and even ^{68}Fe. Projected shell-model calculations [3] point to a soft deformation for neutron-rich Fe isotopes mainly due to increasing occupation of g9/2 and d5/2 neutron orbitals. This fact needs further experimental investigation going to more neutron rich iron isotopes

Following the above discussion we propose to measure even and odd Fe isotopes with mass number around A=70-72. The beta, beta-gamma and prompt gamma decay will be studied. Presence of predicted possible high-k isomeric states will also be searched for [3]. In particular for the first time beta decay information will be compared to theoretical predictions for the Fe isotopes [4].

The proposed experiment aims at using the high intensity uranium beam at RIKEN to produce the neutron rich iron isotopes. According to LISE++ simulations, taking also into account the efficiency of the EURICA and DSSSD array, we expect around 4000 cts/day in the gamma ray spectrum of ^{70}Fe, which should be sufficient to built up a level scheme in about 2 days. In the case of ^{72}Fe we expect around 40cts/day which should allow to determine basic spectroscopic information such as the energy of the first 2^+ and 4^+ states. Similar rates are expected also for the odd isotopes and neighbor isotopes like ^{74}Co and ^{70}Mn. In all cases we plan to search for predicted and unknown isomeric high-k states [3].

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Decay Study of Fe to Zn isotopes near the N=50 shell closure

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Study of doubly-closed-shell and neighboring nuclei provides great opportunities for testing of nuclear models and expanding our knowledge of nucleosynthesis processes. Especially, the region around ^{78}Ni (Z=28, N=50) has attracted great interests because of its extreme neutron-to-proton ratio in the region far from the valley of stability. Despite of a lots of theoretical activities devoted to the ^{78}Ni, a little is known for ^{78}Ni itself experimentally and nothing beyond because of their extremely low production yield at the present radioactive isotope facility [1].

RIBF facility has started providing very neutron-rich nuclei with the worlds highest intensity of uranium beam. Recent discovery of 45 of very neutron-rich nuclei including ^{79}Ni [2] assures that systematic study of decay properties of nuclei around ^{78}Ni becomes feasible eventually. A first decay spectroscopy program (RIBF-026) was performed successfully around ^{110}Zr region using high efficiency RIKEN beta-counting system together with four clover type Ge-detectors and large size of LaBr3 detectors from Italian collaboration [3,4]. Here, the RIKEN beta-counting system consisting of 9 stacks of double-sided-silicon-strip detectors has been developed to reconstruct half-lives of very neutron-rich nuclei such as the ^{110}Zr[5].

We have proposed a decay spectroscopy experiment (RIBF-010) of the very neutron-rich $^{74-76}$Fe, $^{75-78}$Co, $^{76-80}$Ni, $^{78-82}$Cu, and $^{79-83}$Zn isotopes to study their decay curves and their low-lying states around the N=50 shell closure using the same experimental setup [6]. Here, We propose an update of the RIBF-010 program with the EURICA collaboration to enhance the physics capability of studying the beta-delayed gamma and the possible isomeric states around ^{78}Ni region, if the euroball cluster array (EURICA) will be available for coming decay campaign at the RIBF.

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Neutron monopole drift towards ^{78}Ni investigated by γ-spectroscopy following ^{81}Cu β-decay

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We propose to investigate the beta decay of the neutron rich N=52 nucleus ^{81}Cu for EURICA campaign at RIKEN RIBF, in order to observe for the first time the low lying excited states in the N=51 isotone ^{81}Zn.

Above ^{78}Ni the natural valence space which opens up corresponds to the filling of the proton fp-$g_{9/2}$ single particle states and the neutron *dgs* N=4 shell. This valence space has been extensively studied close to stability, especially with the aim to describe the Zr (Z=40) region and the well known spectacular shape transitions which occur there. In the quadrant extending from Z=28 to Z=40 and N=50 to N=82, corresponding to very neutron-rich nuclei, there exist only limited attempts for detailed spectroscopy studies. This is partially due to the very limited data available in this largely uncharted and experimentally hard to reach region.

In particular, the exact neutron single-particle energy sequence and its evolution from stability to Z=28 is still poorly known or understood both from theoretical and experimental sides. N=51 odd isotones constitute the best cases to study the neutron single-particle effective energy evolution towards ^{78}Ni. It is well established that the ground-state spin value of the N=51 odd isotones from ^{83}Ge up to ^{101}Sn is $5/2^+$ originating from the occupation of the $\pi 2d_{5/2}$ orbital by the valence neutron. The excitation energies of first $1/2^+$ states which are known to carry the major part of the $\pi 3s_{1/2}$ strength decrease continuously further from stability [1,2], and one can expect the inversion of ground state spin-parity from $5/2^+$ to $1/2^+$ in ^{81}Zn. This possibility was already hinted at in the first ^{81}Zn→^{81}Ga decay study performed at ALTO [3], but not confirmed by Oak Ridge group [4].

In this context, the study of low-lying level sequence in ^{81}Zn will provide critical data to predict the neutron single-particle evolution in the ^{78}Ni field. It is expected to shed light on the structure of ^{78}Ni itself, which could be the most neutron rich example of a doubly magic nucleus in the nuclide chart.

The study will be performed by means of β-decay spectroscopy using EURICA γ-ray array, which will be installed at final focal plane of ZeroDegree spectrometer. The secondary beam of ^{81}Cu will be produced by in-flight fission of U beam at 345 MeV/u on a Be production target and separated by BigRIPS. From the pior experiment at BigRIPS [5], a beam intensity of ^{81}Cu can be estimated to be about 100 particles per day at the implantation Si detectors. Considering 15% and 50% γ- and ß-ray efficiency and 60% β-decay branch [6], a one week beam time of ^{81}Cu will be enough to observe low-lying excited states in ^{81}Zn.

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Shape coexistence in the neutron-rich mid-shell isotopes, Ge, Se and Kr

A. Odahara [1] and EURICA collaboration

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Study of the neutron-rich nuclei with $Z = 32 - 36$ is important to reveal the mechanism of the change of various deformations as the small change of proton and neutron numbers. Shape evolution and shape coexistence can be expected in this mass region far from the double-magic nuclei. Change of the deformation from spherical shape to γ softness and triaxial deformation for Ge isotopes with N = 50, 52, 54, respectively, could be theoretically extracted by the HFB calculation [1].

We would like to propose the experiment based on the isomer- and β-γ spectroscopy method. To study of shape coexistence in this mass region, isomer search is one of the good probes, because large shape difference is considered to produce shape isomers. And also to investigate the shape coexistence, the low-lying states around the ground states will be investigated to observe the band heads with different shapes. These states could be populated by the β decay.

The neutron-rich Ge, Se, and Kr isotopes can be produced by using the in-flight fission of a 345 MeV/u U beam and will be transported with particle selection through BigRIPS up to Zerodegree separators. Particle-identified reaction products will be implanted and β rays will be detected in a nine double-sided silicon-strip detector system which was successfully used in day-two experiment on 2009 [2]. Gamma rays will be measured by the EURICA. This combined system will be powerful tool to study the neutron-rich nuclei in this mass region.

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Gamow Teller strength in 100Sn

Spokesperson: R. Krücken (TRIUMF)

The recent experiment to study ^{100}Sn at GSI Darmstadt - lead by my TU Munich group - succeeded to perform spectroscopy on 259 produced ^{100}Sn nuclei. With this data is was possible to make significantly improved measurements of the half-life and beta-end point energy of the decay of ^{100}Sn. This enabled the determination of the GT strength B_{GT} = 9.1+4.3-2.3 for the dominantly populated 1^{+} state in ^{100}In. While this value is in excellent agreement with LSSM calculations including 5p5h excitations, the uncertainties are still quite large, predominantly due to the error in the beta decay end-point energy. The fact that the LSSM calculations predict the GT strength of this state so well without any quenching of the GT operator is a remarkable fact. Also, the energy of the excited 1^{+} state in ^{100}In could not be established firmly due to a lack of statistics for gamma-transition in ^{100}In. An experiment at RIBF with the factor¿10 higher production yield for ^{100}Sn and the same gamma-ray detection efficiency as in the GSI experiment would allow for another breakthrough in the study of ^{100}Sn. The GT strength could be determined with higher precision and the relevant states in ^{100}In could be firmly established on the basis of gamma-gamma coincidences. In addition the search for the so far elusive isomeric 6^{+} state would be enabled since about 30 decays of this state would be expected if the lifetime of the state is sufficiently long (>200 ns) and an isomeric ratio of about 15time establish excited states in ^{100}Sn. The same experiment would also be used to study states in nuclei around ^{100}Sn, which would enable further tests of the LSSM calculations.

Structural evolution of nuclei along the r-process path around A=100

Spokesperson: R. Krücken (TRIUMF)

RIBF can produce very neutron rich nuclei in the A=90-110 region with unprecedented intensities. The structural evolution in this mass region is particularly rich since substantial energy gaps between various deformation driving Nilsson orbitals exist and configurations of different shape compete at low excitation energies. At the same time the properties of these nuclei are relevant for the dynamics in time and isospin of the material flow of the astrophysical rapid neutron capture process through this mass region. The recent half-live measurements at RIBF in this mass region have indicated that the r-process flow may be faster through this mass region than anticipated from using traditional models for the prediction of the ground state properties. However, more detailed structural information will be very helpful in understanding the details of the structural evolution in this region and further constrain theoretical models. In particular the half-lives of very neutron-rich Rb isotopes beyond A=102 and the structural evolution in the very neutron rich Sr, Zr, Mo, Pd isotopes would be of great interest in this investigation.
We are also particularly interested the decay spectroscopy of neutron-rich As allowing access to Se isotopes around A=100, which lie between the single-particle dominated Ge and the collective Kr isotopes in this mass region. This transition has yet to be mapped out. The Se isotopes around $^{92-94}$Se are particularly noteworthy. In the Sr and Kr isotopes, there is a sudden change from transitional behavior to strong prolate deformation at neutron number N=60. However, in the Ge isotopes heavier than ^{82}Ge, there is recent evidence pointing to the emergence of a new shell closure at N=58 arising due to the tensor forces responsible for other emergent behavior at the extremes of neutron excess. These Se isotopes, then, are likely to lie not only along the r-process, but along a frontier beyond which the tensor forces dominate the nuclear structure. These nuclei are truly on the frontier; nothing is known about them, beyond being nucleon-bound. RIBF's particle identification and separation techniques are ideally suited to unambiguous measurement and assignment of decay properties (half-lives, gamma rays, etc) to these exotic nuclei.

Gamma spectroscopy and B(E2) measurements to study shape transitions in neutron rich Mo and Tc isotopes

E. Ideguchi, T. Bäck

We plan to perform an experiment at the BigRIPS fragment separator at RIKEN to study prolate-oblate shape transitions in neutron rich Mo and Tc nuclides. Existing mean field calculations predict dramatic changes in the ground-state shape in this part of the nuclide chart. To test the validity of the theoretical model framework in the regime, new experimental data in the form of energies of excited states and transition rates are of fundamental importance. Studying shell effects in this region could also shed more light on the astrophysical scenarios along the r-process path. Our proposed experiment aims at, using gamma-ray spectroscopy, measuring B(E2;0+→2+) values in the nuclides ^{110,112}Mo as well as identifying excited states for the first time in A>111 Tc isotopes. EURICA spectrometer at final focal plane (F11) could be utilized to perform a life-time measurement of $^{110,\,112}$Mo so as to obtain B(E2;$2^+\to0^+$) values.

Use of energy-degraded RI beams with EURICA

E. Ideguchi

The observation of excited levels of unstable nuclei far from the stability line was so far limited to the low-lying state, but the study of higher-spin states will be useful to understand the collectivity since a presence of a rotational band is a clear evidence of the deformed structure. In order to realize such study, we plan to apply low-energy nuclear reactions such as multiple Coulomb excitations and fusion-evaporation reactions by using energy-degraded RI beams. Previously, we have successfully developed an energy-degraded ^{46}Ar beam produced by the fragmentation of 64AMeV ^{48}Ca primary beam. It was used for a fusion-evaporation reaction with a ^{9}Be target. Gamma rays emitted from high-spin states were clearly observed and high-spin level structures in neutron-rich Ti isotopes ($^{49\text{-}51}$Ti) were investigated. Same techniques to make low-energy RI beam could be applied to heavier RI beams at RIBF. Some physics cases are described below.

1) Prolate-oblate shape coexistence

In the neutron-rich Fe and Mo region, shape changes between prolate and oblate were predicted. These regions are suitable for studying prolate-oblate shape coexistences and the role of single particle orbitals to produce such deformation. By the multiple Coulomb excitation using energy-degraded RI beams, we hope to study high-spin levels and extract B(E2) values of transitions. In addition, by the reorientation effect in the multiple Coulomb excitation, we expect to deduce the sign of the quadrupole moment which is a clear signature to determine the shape.

2) Deformed shell structures in ^{48}Ca region

After the systematic high-spin studies, A=30~40 mass region is found to be a 'new island' of superdeformation. In this region, deformed shell gaps appear such as 18,20,22,28, in addition to the spherical shell gaps. Especially in ^{40}Ca, rich deformed structures such as normal deformed and superdeformed states appear after cross-shell excitation of a few nucleons. Such transition is also expected in doubly closed ^{48}Ca since this nucleus also corresponds to the deformed shell-closed (Z=20 and N=28) nucleus. We would like to study high-spin states by the fusion-evaporation reaction using energy-degraded RI beams since the use of low-energy neutron-rich RI beam is a unique method to realize such studies.

Search for tetrahedral shape around ^{110}Zr

Toshiyuki Sumikama (Tokyo University of Science)

Tetrahedral symmetry brings a different degeneracy in single particle levels from the quadrupole deformed shape. The stability of the tetrahedral shape is not established in the atomic nuclei. Neutron-rich nucleus ^{110}Zr, which has the doubly magic numbers of tetrahedral shape, $Z = 40$ and $N = 70$, is one of the candidates to search for the tetrahedral shape. Recently, the candidate of the tetrahedral shape isomer has been discovered in ^{108}Zr at RIBF, but the energy of isomeric state has not been determined due to low statistics. We propose β-γ and isomer spectroscopies of the isomer in ^{108}Zr, and search for isomer in ^{110}Zr, $^{110,112}Mo$ with EURICA at RIBF. The neutron-rich nuclei are produced through the in-flight fission reaction of ^{238}U beam. Two-order-higher statistics for single γ-ray spectra are expected than the previous experiment by using the EURICA with high-γ-ray efficiency, one order higher primary beam within 10-days beam time. We will discuss possibilities of tetrahedral shape from the energy of isomeric state and systematic search for long-lived isomer in even-even nuclei.

Energy-degraded RI beams at RIBF

Toshiyuki Sumikama (Tokyo University of Science)
Eiji Ideguchi (CNS, University of Tokyo)

Low-energy nuclear reactions such as fusion-evaporation, multi-step Coulomb excitation, transfer reactions, etc. are important probes to investigate exotic structure of unstable nuclei. While RIBF provides world's most intense RI beams, an energy of about 250 MeV/A is much higher than required energies for low-energy reactions. Test beam time to produce energy-degraded RI beams has been already approved. We plan to use neutron-rich Mo beam in the beam development. We will develop a momentum-bunched and achromatic RI beam, which is achieved by the combination of the momentum bunching degrader and new optics mode at the second stage of BigRIPS. With this new method, the momentum spread will be reduced from 6% to 2.4% after the second stage, and the energy down to 5 MeV/u will be obtained. This energy-degraded RI beam can be coupled with the EURICA. This combination will provide best opportunities for in-beam γ spectroscopy with low-energy reaction.

β-decay spectroscopy study of the very neutron rich-nuclei Nb-Ag, including the r-process waiting points $^{128}Pd_{82}$ and $^{129}Ag_{82}$

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We propose a β-decay spectroscopy study for a wide range of nuclei in the critical region around the N=82 shell closure, including the nuclei ^{128}Pd and ^{129}Ag that are expected to be r-process waiting points in most r-process models. While nothing is known for ^{128}Pd, the half-life of ^{129}Ag under stellar conditions is still uncertain due to a possible low-lying β-decaying isomeric state, for which there is some inconclusive experimental evidence [1].

The measurement of the half-life of ^{128}Pd, and the ^{129}Ag isomer will dramatically improve the reliability of r-process calculations with implication for the r-process dynamics and elemental abundance distribution. In addition, new half-lives will be measured for more than 30 isotopes with N < 82 reaching the r-process path, finally accessing the r-process nuclei ^{124}Ru, ^{113}Nb that are predicted to be waiting points in some r-process models.

This experiment will also extend the $E(2^+)$ systematics of the Pd isotopic chain to ^{124,126}Pd. These nuclei are the first isotopes that are affected by the rapid decrease in deformation predicted by the FRDM model that for more exotic nuclei leads to pronounced changes in the r-process path.

With our experimental apparatus we will be able to measure half-lives, β-delayed γ rays as well as photons from the decay of microsecond isomers. The results will have implications for nuclear structure studies by providing data to improve the parametrization of mass formulas, and will reveal new insights into important open questions such as shell quenching [2] and the neutron pairing interaction [3, 4].

The nuclei of interest will be produced by fission of a 345 A/MeV ^{238}U beam colliding with a ^{9}Be target. Fission fragments will be selected by the BigRIPS spectrometer, and will be transmitted to the eleventh focus (F11), where they will be implanted in a stack of Si detectors. The experimental apparatus includes the EURICA spectrometer, a thick Ge detector downstream of the Si stack and $LaBr_3$ γ detectors.

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Physics case for the EURICA project: Search for isomeric states in ^{132,134}Cd and ^{136,138}Sn and the study of their β-decays

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Abstract

Within the future EURICA project at RIKEN we propose to perform combined isomer and β-decay spectroscopy on the neutron-rich nuclei ^{132,134}Cd and ^{136,138}Sn beyond the N=82 shell closure. It is our aim to observe for the first time γ-rays emitted in the decay of 6^+ $\nu(f_{7/2})^2$ isomers in ^{136,138}Sn as well as 8^+ $\pi(g_{9/2})^2$ isomeric states in ^{132,134}Cd. These seniority isomers are known to exist in a number of nuclei in this region, the 2qp neutron state for example in ^{134}Sn and the 2qp proton state in ^{130}Cd. If successful this experiment would provide the first information on excited states in these very neutron-rich isotopes for which the predictions of different avaiable shell model calculations vary significantly.

The study of the β-decays of the neutron-rich Cd and Sn isotopes would provide valuable information with respect to excited states in the odd In and Sb nuclei. In particular the ^{132}Cd $\rightarrow$ ^{132}In decay is of great interest because ^{132}In is the proton hole - neutron particle valence nucleus with respect to ^{132}Sn and the observation of the $\nu f_{7/2}$ $\pi g_{9/2}^{-1}$ multiplet of states would allow to fix TBME's crucial for all shell model calculations in this region.

All isotopes of interest would be studied in a single setting keeping a low total rate at F11 which means allowing to perform isomer and β-decay spectroscopy at the same time. The expected particle rates vary between 50 per day for the by far most exotic case of ^{134}Cd and 5x10^5 per day for ^{136}Sn. Assuming a 15% efficiency of the EURICA setup and a typical isomeric ratio in this region of 10% the expected γ-ray yields are 170, 0.8, 7800 and 60 γ-rays per day for ^{132,134}Cd and ^{136,138}Sn, respectively. Except for the case of ^{134}Cd these rates seem high enough to perform isomer spectroscopy even in the case of considerable losses due to decays in flight (a precise estimate of the lifetime limit will be given in the full proposal).

Decay studies in neutron-rich Sb, Te isotopes and beyond

R. Lozeva (IPHC, CNRS, IN2P3) et al

The structures of the nuclides with odd number of nucleons that are adjacent to double-magic nucleus provide the best opportunities to develop and test two-body matrix elements for the *pn* interaction and offer a stringent test and input to the nuclear theories. In this respect, we aim to search for isomeric states in the neutron-rich nuclei beyond ^{132}Sn, concentrating on the odd-mass Sb, Te, I and Xe isotopes. Such measurements could be directly compared to other experimental attempts to study the *nn* interaction in the Sn vicinity with N>82.

While in the even Sb (e.g. ^{134}Sb) a $g_{9/2}$ proton is coupled to various neutron configurations from $h_{9/2}$, $f_{7/2}$ and $f_{5/2}$, in the odd isotopes a mixing could be expected. In ^{135}Sb, yrast excitations [1] arise from a $\nu h_{9/2}$, $\nu f_{7/2}$ or $\nu f_{5/2}$ coupled to the $(\pi g_{7/2} \nu f_{7/2})_{7-}$ isomer in ^{134}Sb and leads to a $23/2^+$ spin-gap [2, 3]. The last known seniority isomer $(\pi(g_{7/2})\nu\ (f_{7/2})^3)_{6-}$ in ^{136}Sb [4] is in the μs region. Increasing the mass, increases the mixing, which reduces the lifetime of the isomeric spin-traps and, according to theory, possibly their formation due to an onset of collectivity. Therefore, until now it has been very difficult to perform detailed spectroscopy of the heavier, respectively more exotic neighbours, to search for shorter-lived isomers and to study the evolution of the single-particle versus collective excitations toward the neutron-drip line.

Core-coupled states in ^{134}Te from $\pi(g_{7/2})^2$ are mostly contributing to its level scheme [5], however for ^{136}Te in the wave function of the 6^+ state, contributions from $(g_{7/2})^2$ and $\pi g_{7/2}$ x $\nu h_{9/2}$, $f_{7/2}$ and $f_{5/2}$ of strongly mixed character are observed, leading to ns isomers [5,6]. As for the $19/2^-$ states e.g. in ^{135}Te, which are found to preserve the proton structure of the two 6^+ states, only the half-life of the lowest one has been measured to be of 0.5 μs, which is rather close to that of the first 6^+ state. The $E2/M1$ transition rates imply core-polarization effects [7]. Therefore, going to the heavier Te will provide a sensitivity to core polarisation and will allow to find out if e.g. with $19/2^-$ spin-gaps form isomers in the neighbouring nuclei, if seniority isomers can be observed as in ^{136}I $\pi(g_{7/2})^3\nu\ (f_{7/2})$ in the β-decay of ^{135,136}Te [8] etc.

Whether such simple quasiparticle states persist with the addition of few more protons and neutrons or whether collective excitation patterns emerge in these nuclei making them transitional, with both single-particle and collective structures, are questions worth investigating with the EURICA spectrometer. It will allow for a first time to reach for spectroscopy nuclei, never accessed before as ^{137}Sb, ^{138,139}Te and beyond. A setting on e.g. ^{139}Te would allow the Sb to Xe neighbours in the vicinity to be produced e.g. by the fission of 5nA ^{238}U beam. Therefore, isomer spectroscopy, as well as β-γ decay investigations should be possible within 3-4 days, taking into account about 10% isomeric ratio and about 15% γ-ray efficiency of the standard EURICA setup.

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Octupole collectivity in the neutron-rich mid-shell isotopes, Xe and Ba

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Neutron-rich isotopes around ^{146}Ba are known to be nuclei with strong octupole correlations which can explain well the low-lying negative-parity states. Nuclei with very strong octupole correlations are fairly localized around proton and/or neutron numbers of 34, 56, 88, and 134, because of the interactions of between (N,l,j) and (N-1,l-3,j-3) orbitals on the spherical single-particle framework. Shape evolution is expected by the theoretical results which indicate the increase of the prolate deformation without octupole one as the neutron number increases for the Xe and Ba isotopes [1].

We would like to propose the experiment based on the β-γ spectroscopy method. Study of the β decay is expected to be good tool to populate the low-lying states around the ground states. Study of the β delayed-neutron decay is also important to populate the states with both positive and negative parities for the investigation of octupole correlations.

The neutron-rich Xe and Ba isotopes can be produced by using the in-flight fission of a 345 MeV/u U beam and will be transported with particle selection through BigRIPS up to Zerodegree separators. Particle-identified reaction products will be implanted and β rays will be detected in a nine double-sided silicon-strip detector system which was successfully used in day-two experiment on 2009 [2]. As the conversion electrons could be also detected in this system, information of them will be used to determine the spins and parities of the states. Gamma rays will be detected by the EURICA. This combined system will be powerful tool to study the neutron-rich nuclei in this mass region.

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Nuclear moment studies with E(U)RICA

R. Lozeva (IPHC, CNRS, IN2P3) et al

Magnetic moments and g-factors, directly related to the magnetic moments trough the nuclear spin, are one of the most sensitive probes to the single-particle properties of the nuclear states and give an extremely precise information on the purity of the nuclear wave functions. In particular, the neutron-deficient ^{100}Sn as well as the neutron-rich ^{132}Sn regions are of outmost nuclear structure interest as a significant influence of intruder orbitals is expected, and the only way to study the real nuclear configuration is trough the knowledge of magnetic moments. The parameter most sensitive to the deformation of the nucleus is the quadrupole moment, whose sign informs about its type prolate or oblate. Several protons above the Sn systems are located the transitional nuclei, where the nuclear shape evolves fast. Therefore, the knowledge of quadrupole collectivity is an essential part for understanding the structure of these nuclei away from stability.

The E(U)RICA spectrometer at the RIBF facility, RIKEN will provide unique opportunities to study isomeric states of radioactive beams, currently not accessible in any other nuclear installation [1]. Many new high-spin spectroscopic studies can be performed and new nuclei can be observed for a first time. These exotic nuclei can be produced by fragmentation or fission and will be particularly suited to nuclear moment studies. On one hand, a high degree of nuclear alignment will be obtained in the reaction methods [2,3], which is a necessity for moment measurements and on another, a total momentum selection can be performed due to the large acceptance of the spectrometer [1], that is a great advantage in these investigations.

One of the most powerful techniques for nuclear moment measurements of isomeric states is the TDPAD method. It can be applied in a dedicated version of the E(U)RICA setup in combination with an electromagnet providing an external magnetic field for magnetic moment investigations, similarly to those performed at RISING [4]. A more compact type 4π geometry will be beneficial for quadrupole moment studies [5]. Both type of investigations are particularly suitable for the investigation of isomeric states in the μs region and at start these could address e.g. nuclei around the Sn isotopic chain.

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