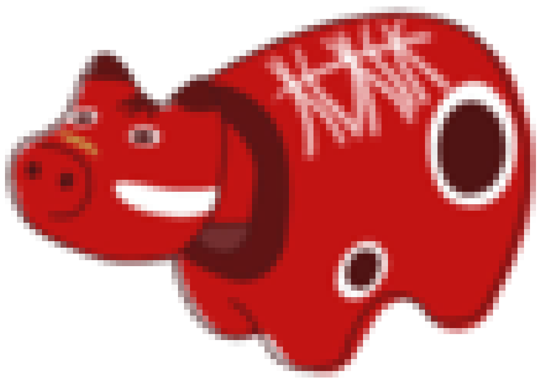
# Single-particle and collective motions from nuclear many-body correlation (PCM2025)

Tuesday, 4 March 2025 - Friday, 7 March 2025

University of Aizu



# Book of Abstracts

# Contents

**Poster session / 1**

## Isospin symmetry breaking energy density functional based on quantum chromodynamics

**Author:** Tomoya Naito[1]

**Co-authors:** Gianluca Colò [2]; Tetsuo Hatsuda [1]; Xavier Roca-Maza [3]; Hiroyuki Sagawa [4]

[1] *RIKEN iTHEMS*

[2] *Università degli Studi di Milano and INFN*

[3] *Università degli Studi di Milano, INFN, and Universitat de Barcelona*

[4] *RIKEN and University of Aizu*

**Corresponding Author:** tnaito@ribf.riken.jp

The isospin symmetry of atomic nuclei is broken due to the Coulomb interaction and the isospin symmetry breaking part of the nuclear interaction. The former gives the dominant contribution to the isospin symmetry breaking of atomic nuclei, and the latter is a small part of the whole; however, it sometimes gives important contributions to nuclear properties, such as the mass difference of mirror nuclei and the isobaric analog states [1, 2]. Especially, it has been a long-standing problem that the Coulomb interaction is not enough to describe the mass difference of mirror nuclei, which is known as the Okamoto-Nolen-Schiffer anomaly [3, 4]. It also contributes to the slope parameter of the symmetry energy, which is known as the L parameter, affecting the neutron-skin thickness non-negligibly [2]. The isospin symmetry breaking can be classified into two parts: the charge symmetry breaking and the charge independence breaking.
Recently, we pinned down the effective interaction, i.e., the energy density functional, of charge symmetry breaking interaction using the effective mass in medium of nucleons calculated based on the quantum chromodynamics sum rule [5]. We also estimated the energy density functional of the charge independence breaking based on the quantum electrody- namics effects in the one-pion exchange potential [6], where we can, in principle, consider the effective mass of pions in medium. In this talk, I will report our recent progress on the derivation of the isospin symmetry breaking energy density functional based on quantum chromodynamics.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #1 / 2**

## Theoretical study of the Isovector Monopole Resonance

**Author:** Javier Roca Maza[1]

[1] *University of Barcelona and University of Milan*

**Corresponding Author:** xavier.roca.maza@fqa.ub.edu

Motivated by the experimental and theoretical interest on the Isovector Monopole Resonance, I will present a theoretical study of the charge-exchange and non-charge exchange Isovector Monopole Resonances in 48Ca, 90Zr and 208Pb calculated within the RPA approach. I will focus on their excitation energy and sum rules and discuss the possibility to relate them with the ground state properties of the same nucleus and with the nuclear matter incompressibility.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #1 / 3**

## Quenching of Gamow-Teller and forbidden transition strength

**Authors:** Toshio Suzuki[1]; Noritaka Shimizu[2]

[1] *Nihon University*

[2] *University of Tsukuba*

**Corresponding Authors:** shimizu@nucl.ph.tsukuba.ac.jp, suzuki.toshio@nihon-u.ac.jp

Gamow-Teller (GT) strengths in medium and heavy nuclei in the giant-resonance region are suppressed compared to the Ikeda sum rule [1,2]. GT strengths in low-lying states in sd-shell and pf-shell nuclei, for example, have also been found to be suppressed: the quenching factors for the axial-vector coupling, $q_A = g_A^{eff}/g_A^{free}$, are ∼0.77 and ∼0.74 for $sd$-shell [3] and $pf$-shell [4], respectively. The origin of the quenching of the GT strength can be attributed to the restriction of the configuration space and the contributions from two-body currents, for example, those from the coupling to non-nucleonic degrees of freedom such as $\Delta_{33}$ resonance [5]. The contributions from the two-body current were studied in the GT $\beta$-decay in selected $sd$-shell nuclei with the valence space in-medium renormalization group (VS-IMSRG) method [6] and their effects were found to be important in enhancing the quenching factor by ∼0.07.

Here, we study the effects of extending the configuration space: pf-shell components are included to evaluate GT $\beta$-decay strengths in $sd$-shell nuclei. An effective interaction in the $sd$-$pf$ shell obtained by the extended Kuo-Krenciglowa (EKK) method starting from chiral interactions is used [7,8]. The effective interaction proves to be successful in descriptions of the structure of the island of inversion [7]. It also reproduces the GT strength distribution in $^{40}$Ar in the $sd^{-2}pf^2$ +$sd^{-4}pf^4$ shell-model space with $q_A$=1 [8]. The extension of the model space to the $sd$-$pf$ shell, including up to 2p-2h excitations, in the study of the GT $\beta$-decay in the $sd$-shell is found to enhance the quenching factor by ∼0.05 compared to the conventional Hamiltonians in the sd-shell [9]. The effects of more than 2p-2h excitations are estimated by including second-order core polarization contributions [5,10].

Next, we discuss the quenching of the strength in forbidden transitions. $\beta$-decay rates in the $^{208}$Pb region, including the waiting-point nuclei with N=126, are important for r-process nucleosynthesis. In this region of nuclei, there are considerable contributions from first-forbidden transitions. Large quenching in $g_A$ and $g_V$ (vector-coupling constant), or matrix elements of spin-dipole and Coulomb operators, in the first-forbidden transitions are found in the study of beta-decays in N=126 isotones [11,12], in nuclei in the south region of $^{208}$Pb [13], and in N=125 and 126 isotones [14].

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #7 / 4**

## Study of multi-neutron emission process through beta-neutron-gamma spectroscopy of $N > 50$ Gallium isotopes

**Author:** Rin Yokoyama[None]

**Co-authors:** Bertis Rasco [1]; Iris Dillmann [2]; Jose-Louis Tain [3]; Krzysztof Rykaczewski [1]; Robert Grzywacz [4]; Shunji Nishimura [5]

[1] *Oak Ridge National Laboratory*

[2] *TRIUMF*

[3] *IFIC, Universidad de Valencia*

[4] *University of Tennessee*

[5] *RIKEN*

**Corresponding Author:** yokoyama@cns.s.u-tokyo.ac.jp

Beta-delayed neutron emission occurs in neutron-rich nuclei where the decay energy window is large enough to populate states above the neutron separation energy in the daughter nucleus. Multi-neutron emission is expected to be the dominant decay mode for the nuclides far from stability, along the astrophysical r-process path. The number of neutrons emitted after β-decays affects the final isobaric abundance pattern after the r-process by providing neutrons for the late-time capture process and changing the decay path back to stability. Therefore, understanding the neutron emission process is crucial for astrophysical r-process abundance calculations.
A comprehensive β-delayed neutron-γ spectroscopy on the decay of gallium isotopes ($A = 84$ to 87) was conducted at RI beam Factory, RIKEN Nishina Center. The isotopes were examined using a high efficiency array of $^3$He neutron counters (BRIKEN) [1] and two clover-type HPGe detectors, enabling β-2n-γ coincidence measurements of the excited states of two-neutron daughter nuclei. Previously, we found large one-neutron emission probability ($P_{1n}$) values and unexpectedly small $P_{2n}$ values, even the major part of the $B(GT)$ is expected to be concentrated above two-neutron separation energy for those Ga isotopes. This was interpreted as a signature of one-neutron emission from two-neutron unbound states. This result raised the necessity of modeling the competition between multi-neutron emission channels [2].

Hauser-Feshbach statistical model calculations [3] showed that the $P_{1n}$ and $P_{2n}$ ratios and the ⊠ branching ratios are sensitive to the nuclear level density of one-neutron daughter nuclei. The statistical model calculation was optimized using experimental and shell-model level densities in the daughter nuclei, thereby improving the reproduction of the $P_{2n}/P_{1n}$ ratio. Given that neutron emissions significantly influence the final abundance pattern of r-process nucleosynthesis, these results underscore the importance of understanding level densities and the detailed decay scheme, which could be achieved by neutron spectroscopy data for multi-neutron emitters.
This work was published as Ref. [4].
This work is supported in part by the Office of Nuclear Physics, U.S. Department of Energy under Award No. DE-FG02-96ER40983 (UTK) and DE-AC05-000R22725 (ORNL).
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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Session #3 / 5**

# Generator coordinate method with basis optimization

**Author:** Moemi Matsumoto[1]

**Co-authors:** Kouichi Hagino ; Yusuke Tanimura [2]

[1] *Tohoku University*

[2] *Soongsil University*

**Corresponding Authors:** tanimura@ssu.ac.kr, moemi@nucl.phys.tohoku.ac.jp, hagino.kouichi.5m@kyoto-u.ac.jp

The generator coordinate method (GCM) has been a well-known method to describe nuclear collective motions [1]. In GCM, one *a priori* specifies collective degrees of freedom (collective coordinates), such as nuclear deformations, and superposes many Slater determinants (SDs) within the selected collective subspace. However, there always exists arbitrariness in this approach in the choice of collective coordinates, for which one has to rely on empirical and phenomenological assumption. With such choice, it is not trivial whether the collective motion of interest can be optimally described (See e.g., [2-3]). Therefore, a description of the collective motion without pre-set collective coordinates is desirable in order not to miss important degrees of freedom.
In this contribution, we present a new extension of GCM in which both the basis SDs and the weight functions are optimized according to the variational principle [4]. With such simultaneous optimization of the basis states, one does not have to specify beforehand the relevant collective degrees of freedom covered by the set of basis SDs. In this presentation, we will show results for *sd*- shell nuclei with the Skyrme energy functional. We will show that the optimized bases correspond to excited states along a collective path, unlike the conventional GCM which superposes only the local ground states. This implies that a collective coordinate for large amplitude collective motions is determined in a much more complex way than what has been assumed so far.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #7 / 6**

## Pseudo-spin symmetry and tensor force

**Author:** Hitoshi Nakada[1]

**Co-author:** Tsunenori Inakura [2]

[1] *Chiba University*

[2] *Institute of Science Tokyo*

**Corresponding Author:** nakada@faculty.chiba-u.jp

As representing the shell structure in certain regions, the pseudo-spin symmetry (PSS) has been found helpful in describing some characteristic structures of nuclei. In short, the PSS is the near degeneracy of single-particle (s.p.) orbitals with $j = 1$ and $\ell = 2$. It has been argued since the late 1990s that the PSS is a relativistic symmetry, as the s.p. orbitals have equal orbital angular momentum in the lower component of the Dirac spinor. In addition to the spherical nuclei, the PSS was extended to rotational nuclei by Bohr, Hamamoto and Mottelson (Phys. Scr. 26, 267).

The tensor force has been pointed out to give rise to proton- ($Z$) and neutron-number ($N$) dependence of the shell structure. This $Z$- and $N$-dependence of the shell structure should be relevant to the PSS. We discuss how the tensor force affects the PSS, with particular interest in the variation due to the occupation of specific orbits. The spherical Hartree-Fock calculations are applied, and the s.p. energy spacings between the PSS partners are compared among effective interactions (or energy-density functionals) with and without the tensor force. In many cases, the tensor-force effects on the PSS look analogous to the $Z$-and $N$-dependence of the PSS in the relativistic mean-field (RMF) calculations without explicit tensor force. A qualitative difference is found in the variation of the $p0d_{3/2}$-$p1s_{1/2}$ levels from $^{40}$Ca to $^{34}$Si. The experimental data is consistent with the tensor-force-driven $Z$-dependence of the PSS but not necessarily with the RMF result.

(Based on the paper to appear in Phys. Rev. C, available as arXiv:2407.05524.)

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 7**

## The l-forbidden M1 transitions of chlorine isotopes around N = 28 shell closure

**Author:** yasutaka yamamoto[None]

**Corresponding Author:** yamamo@cns.s.u-tokyo.ac.jp

The effect of meson exchange current in nuclei is studied via l-forbidden M1 transitions. The M1 transitions are caused by the single-particle-like transition of valence nucleons, the core excitation, and the meson exchange current. In the l-allowed M1 transition, the single-particle-like transition and the core excitation are the dominant effects and the meson exchange current is very small. On the other hand, in the l-forbidden M1 transition, the meson exchange current measurably affects the transition strengths. Therefore, information about the meson exchange current is extracted from the l-forbidden M1 transition strengths. To measure the l-forbidden M1 transition strengths, we carried out the in-beam gamma-ray spectroscopy experiments of chlorine isotopes at RCNP (CAGRA campaign) and RIBF (HiCARI campaign). The l-forbidden M1 transition strengths were obtained from the transition lifetimes measured by the waveform analysis method with Ge detectors. In this presentation, we will report the analysis results of experiments and the contribution of the meson exchange current in the l-forbidden M1 transition strengths.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 8**

## Microscopic study of M1 resonances in Sn isotopes

**Authors:** Gianluca Colo[None]; Hiroyuki Sagawa[None]; Ligang Cao[None]; Shuai Sun[None]

The magnetic dipole (M1) resonances of even-even 112–120,124Sn isotopes are investigated in the framework of the self-consistent Skyrme Hartree-Fock + Bardeen-Cooper-Schrieffer (HF+BCS) and quasiparticle random phase approximation (QRPA). The Skyrme energy density functionals SLy5 and T11 with and without tensor terms are adopted in our calculations. The mixed type pairing interaction is used to take care of the pairing effect for open-shell nuclei both in the ground and excited states calculations. The calculated magnetic dipole strengths are compared with available experimental data. The QRPA results calculated by SLy5 and T11 with tensor force show a better agreement with the experimental data than those without the tensor force. By analyzing the HF and QRPA strength distributions of 112Sn and 124Sn, we discuss the effect of tensor force on the M1 resonances in detail. It is found that the M1 resonance is sensitive to the tensor interaction, and favors especially a negative triplet-odd tensor one. Depending on the nucleus, a quenching factor of the M1 operator of about 0.71–0.95 is needed to reproduce the total observed transition strength. In our calculations, we also find some low-lying, pygmy-type magnetic dipole states distributed below 6.0 MeV, and they are formed mainly from the neutron configuration ν2d5/2 ⟶ ν2d3/2.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #7 / 9**

## Evolutions from 1p-1h to 2p-2h states studied within Second Random-Phase Approximation

**Author:** Futoshi Minato[1]

[1] *Kyushu University*

**Corresponding Author:** minato.futoshi.009@m.kyushu-u.ac.jp

We would like to present the effect of including two-particle two-hole (2p-2h) states in nuclear resonances. Configuration spaces of 2p-2h are known to be important to describe a spreading width of nuclear resonances. Recently, our group pointed out that its effect is also important to reproduce high-energy particle emission rates. To understand this phenomena comprehensively, it is necessary to study the evolution from one-particle one-hole states to 2p-2h states. Some of new insight obtained by our recent investigation will be discussed in this talk.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 10**

## ISGMR measurement of $^{86}$Kr with an active target CAT-M

**Author:** Fumitaka ENDO[1]

**Co-authors:** Shinsuke OTA [2]; Masanori Dozono [3]; Reiko Kojima ; Daisuke Suzuki [4]; Rin Yokoyama ; Stefano Fracassetti [5]; Nobu Imai [6]; Shin'ichiro Michimasa [7]; Yuto Hijikata [8]; Shutaro Hanai [9]; tadaaki isobe [10]; Jiatai Li [11]; Seiya Hayakawa ; Keita Kawata [11]; Ningtao Zhang [12]; Riccardo Raabe [5]; Akane Sakaue [6]; Juzo Zenihiro [13]; Tomoya Harada [14]; Eiichi Takada [15]; Tomohiro Uesaka [10]; Susumu Shimoura [16]; Kentaro Yako ; Jiawei Cai [17]

[1] *RCNP, Osaka University*

[2] *RCNP, Osaka University*

[3] *Kyoto University*

[4] *RIKEN Nishina Center*

[5] *KU Leuven*

[6] *CNS*

[7] *Center for Nuclear Study, the Univ. of Tokyo*

[8] *Dept. of Phys., Kyoto Univ.*

[9] *CNS, the University of Tokyo*

[10] *RIKEN*

[11] *Center for Nuclear Study, University of Tokyo*

[12] *Institute of Modern Physics, Lanzhou, China*

[13] *Kyoto Univ*

[14] *Toho univ. / RIKEN*

[15] *National Institute of Radiological Sciences*

[16] *Center for Nuclear Study, the University of Tokyo*

[17] *IMP*

**Corresponding Authors:** stefano.fracassetti@kuleuven.be, fendo@rcnp.osaka-u.ac.jp, keita-kawata@cns.s.u-tokyo.ac.jp, isobe@riken.jp, zhangningtao@impcas.ac.cn, cai@rcnp.osaka-u.ac.jp, riccardo.raabe@kuleuven.be, asakaue@cns.s.u-tokyo.ac.jp, shimoura@cns.s.u-tokyo.ac.jp, dozono.masanori.6v@kyoto-u.ac.jp, tomoya.harada@riken.jp, uesaka@riken.jp, hayakawa@cns.s.u-tokyo.ac.jp, juzo@scphys.kyoto-u.ac.jp, hijikata.yuto.23u@st.kyoto-u.ac.jp, ota@rcnp.osaka-u.ac.jp, yako@cns.s.u-tokyo.ac.jp, mitimasa@cns.s.u-tokyo.ac.jp, takada.eiichi@qst.go.jp, rkojima@cns.s.u-tokyo.ac.jp, jt.li@cns.s.u-tokyo.ac.jp, hanai@cns.s.u-tokyo.ac.jp, yokoyama@cns.s.u-tokyo.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp, n.imai@cns.s.u-tokyo.ac.jp

The equation of state (EOS) of nuclear matter is important not only for understanding the properties and dynamics of nuclei but also for explaining the astrophysical phenomena, such as neutron stars merger and supernova explosions. Research on the EOS from experimental nuclear physics attempts

to determine the behavior near saturation density and symmetric nuclear matter from nuclear reactions. Recent studies have suggested that high-precision and high-accuracy measurements of the isospin-dependent term of incompressibility, $K_\tau$, are crucial.

$K_\tau$ can be directly determined from the isoscalar giant monopole resonance (ISGMR). In previous studies, $K_\tau = -550 \pm 100$ MeV was obtained from ISGMR measurements of Sn isotopes based on the liquid drop model. However, the uncertainty is large due to these measurements being limited to stable nuclei and the assumptions about surface effect. Additionally, phenomena beyond the liquid drop model, such as deformation and softness, have been observed. Therefore, to elucidate the fundamental properties of nuclear matter, including incompressibility and the nuclear matter EOS, it is necessary to survey the ISGMR over a wide range of the nuclear chart and conduct a more in-depth discussion through the ISGMR strength function.

To achieve purpose, we developed an active target (CAT-M), a measurement device where the target itself functions as a detector. As the first step towards the systematic measurement of ISGMR, we performed ISGMR measurements of $^{86}$Kr in HIMAC of NIRS-QST. As a result, we determined the centroid energy of the ISGMR to be 17 $\pm$ 1 MeV. In this presentation, we will report the details of this experiment and discuss future plans for ISGMR measurements in unstable nuclei.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #11 / 11**

# Atomic nucleus at the edge of stability

**Author:** Marek Ploszajczak[1]

[1] *GANIL*

**Corresponding Author:** marek.ploszajczak@ganil.fr

Loosely bound nuclei are currently at the centre of interest in low-energy nuclear physics. The deeper understanding of their properties provided by the shell model for open quantum systems changes the comprehension of many phenomena and offers new horizons for spectroscopic studies of nuclei
from the driplines to the valley of $\beta$-stability, for states in the vicinity and above the first particle emission threshold [1,2]. Systematic studies in this broad region of masses and excitation energies will extend and complete our knowledge of atomic nuclei at the edge of stability.

In this talk, I will review recent progress in the open quantum system shell model description of nuclear states. In particular, I will present selected applications of the shell model embedded in the continuum, the real-energy continuum shell model, and the complex-energy continuum shell model, the so-called Gamow shell model in the coupled-channel basis. Salient generic features will be illustrated on examples of (i) near-threshold collectivity and clustering, (ii) chameleon resonances, (iii) modification of effective NN interactions and shell occupancies in weakly bound/unbound states, (iv) exceptional point singularities in the continuum, (v) change of the electromagnetic transitions by the coupling to decay channels, and (v) low-energy reactions of astrophysical interest.

[1] N. Michel, M. P{\l}oszajczak, \textit{Gamow Shell Model - The
Unified Theory of Nuclear Structure and Reactions}, Lecture Notes in Physics \textbf{983} (Springer, Cham, 2021).

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Session #3 / 12**

## PARTICLE-VIBRATION COUPLING AND PAIRING CORRELATIONS

**Author:** Enrico Vigezzi[None]

**Corresponding Author:** vigezzi@mi.infn.it

I will present results concerning the effects of particle-vibration coupling (PVC), a topic to which Ikuko Hamamoto gave fundamental contributions.

I will discuss how to determine the PVC strength, in particular through the study of multiplet splittings.
I will then present quantitative microscopic calculations of the strength function associated with pairing modes in A+2 nuclei going beyond the RPA by including the coupling to collective excitations of closed shell A core, including continuum effects. The formalism accounts both for single-particle self-energy effects and for the pairing interaction induced by phonon exchange. Such studies are relevant for the experimental searches of collective high-lying pairing vibration, whose existence was predicted but not yet experimentally confirmed.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 14**

## Coulomb Dissociation of 17B

**Author:** Hyeji Lee[1]

[1] *Institute of Science Tokyo, University of Oslo*

**Corresponding Author:** hyeji.lee@fys.uio.no

Neutron-rich isotopes have unique structural properties, such as the neutron halo where weakly bound neutrons are spatially extended from the core. Two-neutron halo nuclei such as $^{6}$He, $^{11}$Li, and $^{19}$B are especially interesting subject since they are Borromean nuclei. A Borromean nucleus is a bound three-body system where any of the two-body subsystems are unbound. Recent Coulomb dissociation studies of $^{19}$B have identified a di-neutron correlation —a compact neutron pair —in its halo[1]. We focus on $^{17}$B as a candidate of two-neutron halo, providing a core for $^{19}$B. Investigating halo properties and di-neutron correlations in $^{17}$B could reveal critical insights into multi-neutron halo structures. Using Coulomb dissociation experiment with the SAMURAI spectrometer at RIBF, RIKEN, a $^{48}$Ca primary beam at 345 MeV/nucleon was used to generate a $^{17}$B secondary beam via

BigRIPS, followed by dissociation on a Pb target into $^{15}$B and two neutrons. The SAMURAI spectrometer and NEBULA neutron detector array allowed us to extract the exclusive cross section and relative energy spectrum for this dissociation. We will show the preliminary results on the $B(E1)$ spectrum of $^{17}$B, where we found significant soft $E1$ strength.

[1] K. J. Cook *et. al.*, Phys. Rev. Lett. 124, 212503 (2020)

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #8 / 15**

## Nuclear Mass and Fission-Fragment Studies based on the FRDM and FRLDM Models.

**Author:** Peter Moller[1]

[1] *Lund University*

**Corresponding Author:** mollerinla@gmail.com

Nuclear Mass and Fission-Fragment Studies based on the
FRDM and FRLDM Models.
Peter Möller
Department of Mathematical Physics, Lund Institute of Technology,
Box 118, SE - 22100 Lund, Sweden
The latest FRDM and FRLDM global mass models were finalized in 2012 and published in 2016[1]. We investigate how the masses in the tables agree with subsequently measured masses. The FRLDM model has been extensively applied to studies of nuclear fission [2]. We comment on what those results indicate about possible additional observable elements beyond Z = 118. Furthermore, by implementing a random walk on the calculated five-dimensional potential-energy surfaces (the Brownian Shape Motion (BSM) model) fission-fragment mass and charge distributions are obtained [3, 4]. In its usual and historical formulation the fission potential-energy-model energies do not exhibit any properties of the emerging nascent fragments so no odd-even staggering in calculated fission-fragment charge distributions appears. We discuss some tweaks to the potential-energy and the BSM models that allow the modeling of odd-even staggering and the calculations of isotopic yields Y (Z, N) [5]. We compare the calculations to recent, better-than-one-u resolution, experimental data.
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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 16**

## Towards the shell structure at Island of Stability - Investigation of heavy-ion fusion reactions in near symmetric systems

**Author:** Jiatai Li[1]

**Co-authors:** Nobu Imai [2]; Rin Yokoyama ; Shin'ichiro Michimasa [3]; Thomas Chillery ; Reiko Kojima ; Shutaro Hanai [4]; Noritaka Kitamura ; Daisuke Suzuki [5]; Daiki Nishimura [6]; Eiichi Takada [7]; Satoshi Sakaguchi [8]

[1] *Center for Nuclear Study, University of Tokyo*

[2] *CNS*

[3] *Center for Nuclear Study, the Univ. of Tokyo*

[4] *CNS, the University of Tokyo*

[5] *RIKEN Nishina Center*

[6] *Tokyo City Univercity*

[7] *National Institute of Radiological Sciences*

[8] *Kyushu University*

**Corresponding Authors:** mitimasa@cns.s.u-tokyo.ac.jp, dnishimu@tcu.ac.jp, jt.li@cns.s.u-tokyo.ac.jp, takada.eiichi@qst.go.jp, yokoyama@cns.s.u-tokyo.ac.jp, sakaguchi@phys.kyushu-u.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp, kitamura@cns.s.u-tokyo.ac.jp, n.imai@cns.s.u-tokyo.ac.jp, rkojima@cns.s.u-tokyo.ac.jp, t.chillery@cns.s.u-tokyo.ac.jp, hanai@cns.s.u-tokyo.ac.jp

Search for the Island of Stability (IoS) has been one of the most attractive problems in modern nuclear physics. IoS is predicted to exist in the neutron-rich vicinity near Z = 114, N = 184, the Super Heavy Element (SHE) within are anticipated to have a lifetime longer than a year while the lifetime of SHE synthesized in the lab are on the order of ms. The huge enhancement in the stability is expected to be triggered by the increasing shell stabilization. However, the existence of IoS is predicted based on the shell model of nuclei lighter than lead, therefore energies of single-particle levels require further confirmation when extrapolating to the SH region.

Heavy-ion fusion reaction is a promising approach to reach IoS, and it is also powerful in exploring the nuclear structure, in particular for highly excited states. Due to the neutron-rich nature of IoS, stable beam-target combinations can not be used, neutron-rich RI beams need to be applied instead. Similar to what had been done so far, Ca beam and actinide target seems to be a reasonable choice, while the beam intensity of neutron-rich Ca beam is currently too low at any facilities around the world. An alternative is to use double magic $^{132}$Sn, which is located at the fission peak of $^{238}$U. However, with the reduced mass asymmetry of the entrance channel, the formation probability of the compound nucleus will be hindered significantly. Therefore, pioneering studies of fusion reactions in near symmetric systems are needed.

A fusion reaction using $^{136}$Xe beam to bombard a natural zinc target has been performed at HIMAC. The fusion-evaporation cross section was extracted based on the $\alpha$ decay spectroscopy of the evaporation residues. In this presentation, details of the experimental setup and the data analysis will be given.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Session #4 / 17**

## Quadrupole collectivity in low-lying states in neutron-rich N=40 nuclei

**Author:** Kouhei Washiyama[1]

[1] *University of Tsukuba*

**Corresponding Author:** washiyama@nucl.ph.tsukuba.ac.jp

Recent spectroscopic measurements in neutron-rich $N = 40$ nuclei towards $^{60}$Ca give an insight into shell structure in this region [1]. Large-scale shell model calculations [2] predicted a sizable collectivity in $^{60}$Ca and the island of inversion extended to $^{60}$Ca.
In this contribution, we will present the results of low-lying states in $N = 40$ nuclei by employing the five-dimensional collective Hamiltonian (5DCH) method based on the Skyrme energy density functional. The 5DCH method explicitly treats quadupole degrees of freedom for rotation and vibration. We use the local quasiparticle random phase approximation to include important dynamical correlations to the inertial functions in the kinetic energies that have been ignored in most of the previous related works [3]. The present calculation reproduces the experimental $2_1^+$ energy and $B(E2; 2_1^+ \to 0_1^+)$ values. In particular, we discuss the property of the low-lying excited $0^+$ state and low $R_{0/2} = E(0_2^+)/E(2_1^+)$ ratio obtained in $^{60}$Ca.
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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 18**

## In-beam γ-ray spectroscopy of exotic 79Cu with HiCARI

**Authors:** Massyl Kaci[1]; Serge Franchoo[1]

**Co-authors:** Daiki Nishimura [2]; Daisuke Suzuki [3]; Ryo Taniuchi [4]; William Marshall [4]

[1] *IJCLab*

[2] *Tokyo City University*

[3] *RIKEN*

[4] *University of York*

**Corresponding Authors:** daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp, ryo.taniuchi@york.ac.uk, massyl.kaci@ijclab.in2p3.fr, dnishimu@tcu.ac.jp, serge.franchoo@ijclab.in2p3.fr, william.marshall@york.ac.uk

The in-beam $\gamma$-ray spectroscopy of $^{79}$Cu was carried out at the Radioactive Isotope Beam Factory of the RIKEN laboratory during the 2021 HiCARI campaign [1]. In-flight fission of $^{238}$U at 345 MeV/nucleon produced a wide range of exotic nuclei, including $^{80}$Zn. These nuclei were sent through the BigRIPS separator onto a beryllium target, where knock-out reactions took place. The emitted $\gamma$ rays were detected by an array of germanium detectors positioned around the target, whilst the outgoing fragments were identified in the ZeroDegree separator. Among these fragments, our interest was focused on $^{79}$Cu, which contains one proton more than doubly-magic $^{78}$Ni. To the extent that the magicity of $^{78}$Ni is maintained, the $\gamma$ spectra of $^{79}$Cu are expected to relate to the single-particle transitions of the last proton [2]. Based on the comparison of the shapes of the energy peaks with simulations, the experiment specifically aimed at the determination of the lifetimes of the de-exciting states. First results will be presented and may shed light on the collective and single-particle characters of the low-lying states in $^{79}$Cu.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session** / **19**

## Development of segmented La-GPS scintillation detector as a new β-implant detection tool

**Author:** Yasmin Anuar[None]

**Co-authors:** Nobu Imai [1]; Rin Yokoyama ; Shunji Nishimura [2]; Shunsuke Kurosawa [3]; Vi Ho Phong [2]

[1] *CNS*

[2] *RIKEN*

[3] *Tohoku University*

**Corresponding Authors:** nishimu@ribf.riken.jp, phong@ribf.riken.jp, n.imai@cns.s.u-tokyo.ac.jp, ay.anuar@cns.s.u-tokyo.ac.jp, yokoyama@cns.s.u-tokyo.ac.jp

In recent years, there have been ongoing efforts to better understand the rapid neutron capture process in the nucleosynthesis of elements. Such efforts include the measurements of β-decay and delayed multineutron emissions of these elements to allow for a more accurate input for the calculations in relation to the rapid neutron capture process modelling. Typically, β-γ spectroscopies are carried out with implantation detectors such as the Silicon strip detectors whose role is to measure the energy and position of the implant events and β-ray emissions. However, Silicon strip detectors are incapable of fast timing response for the purpose of neutron time-of-flight measurements of the delayed multineutron emissions. Furthermore, as the study progresses further away from stability and towards more neutron-rich elements, there is a need for better implantation detectors. Hence, a new implantation detector was developed using segmented Yttrium Orthosilicate (YSO) scintillator crystal which has a higher effective atomic number, Z ≈ 35 and density, ρ ≈ 4.5 g/cm$^3$. These qualities of the YSO detector allow for correlation efficiency of 80% between the implant events and the β-decay with correlation radius of 3 mm. This improvement with the YSO detector encourages the development of another with heavier scintillator crystal, $(Ga, La)_2Si_2O_7$:Ce (La-GPS) whose Z ≈ 51 and ρ ≈ 5.2 g/cm$^3$. The La-GPS detector was proposed in hopes of achieving better correlation radius and faster timing response at the same efficiency as the YSO detector. This study then entails the current development of the La-GPS detector of 1.5 x 1.5 mm segments arranged into a 32 x 32 array in the x-y plane.

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**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**session #11 / 20**

## Formation of superheavy element

**Author:** Sven Åberg[1]

**Co-authors:** B.G. Carlsson [1]; D. Rudolph [2]; J. Randrup [3]; M. Albertsson [1]; T. Døssing [4]

[1] *Mathematical Physics, Lund University*

[2] *Particle and Nuclear Physics, Lund University*

[3] *Nuclear Science Division, Lawrence Berkeley National Laboratory*

[4] *Niels Bohr Institute*

**Corresponding Author:** sven.aberg@matfys.lth.se

The production of a superheavy element in a fusion heavy-ion reaction schematically proceeds through the three stages: (i) the two colliding nuclei overcome the Coulomb repulsion and come in contact, (ii) the contact configuration evolves into a compact shape, (iii) the fused nucleus cools down by neutron evaporation. In the present presentation the second step is described in a new method [1], utilising the Langevin equation and random walk models. The two fragments come in contact with a large kinetic energy that is subject to dissipation and is transferred into heat. The dissipation process is described by the Langevin equation, where the friction strength depends on the necking of the combined object (window friction), and is characterised by drift-dominated dynamics in the center-of-mass direction. With no remaining kinetic energy several shape degrees of freedom can be explored, and the dynamics becomes diffusion dominated. The dynamics in five shape degrees of freedom is treated as Metropolis random walks, and if the inner saddle is crossed a fusion event has taken place. Quasi-fission competes with fusion events, and we count the relative number of fusion events, constituting a formation probability. The walks are controlled by calculated angular momentum dependent potential energies as well as pairing and shell-energy dependent level-densities in a large grid in deformation space, implying the fusion dynamics depends on temperature, pairing and shell structure.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session** / **21**

## Spin entanglement in time-dependent two-proton emission

**Author:** TOMOHIRO OISHI[1]

[1] *RIKEN Nishina Center*

**Corresponding Author:** tomohiro.oishi@ribf.riken.jp

I will present a theoretical evaluation of coupled-spin entanglement in the two-proton (2p) radioactive emission [1]. For this purpose, a time-dependent three-body model is utilized [2].
Spin entanglement has been evaluated in terms of the coupled-spin correlation S_{CHSH} for the two fermions. Here this S_{CHSH} is so-called Clauser-Horne-Shimony-Holt (CHSH) indicator. For the two protons produced in the 2H + p –> 2He + n reaction by Sakai et. al. [3], this quantity was measured as S_{CHSH} ~= 2.82. This is in agreement ith the non-local quantum mechanics and beyond the local-hidden-variable (LHV) theory. After this experimental success, the spin entanglement can be one measurable quantity to probe the nuclear structures and interactions.
In this work, the time-dependent calculation is performed to predict that S_{CHSH} ~= 2.65 in the 6 Be nucleus [1]: the 2p-spin entanglement beyond the LHV theory is suggested. This entanglement is sensitive to the proton-proton interaction: the short-lived, and thus, broad-width 2p-emitting state has the weaker spin entanglement. In parallel, the core-proton interactions do not harm this entanglement during the time-dependent decaying process. The sensitivity of SCHSH to the initial state, especially whether the diproton correlation exists or not, will be discussed in this contribution.
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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session** / **22**

## Collectivity along Ti isotopes towards N=40

**Authors:** Asahi Kohda[1]; Nori Aoi[2]; yasutaka yamamoto[None]; S. Iwazaki[2]; T. Koiwai[3]; Kathrin Wimmer[None]; Daisuke Suzuki[4]; Pieter Doornenbal[None]; H. Baba[None]; Frank Browne[4]; C. Campbell[None]; H. Crawford[None]; H. de Witte[None]; C. Fransen[None]; H. Hess[None]; Eiji Ideguchi[2]; J. Kim[None]; Takeshi Koike[5]; Benoît Mauss[None]; R. Mizuno[None]; B. Moon[None]; Megumi Niikura[4]; T. Parry[None]; T. T. Pham[None]; P. Reiter[None]; Ryo Taniuchi[6]; S. Thiel[None]

[1] *RCNP, Osaka University*

[2] *RCNP*

[3] *University of Tokyo*

[4] *RIKEN Nishina Center*

[5] *Tohoku University*

[6] *University of York*

**Corresponding Authors:** pieter@ribf.riken.jp, niikura@riken.jp, kohda@rcnp.osaka-u.ac.jp, frank@ribf.riken.jp, benoit.mauss@cea.fr, ryo.taniuchi@york.ac.uk, yamamo@cns.s.u-tokyo.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp, takeshi.koike.b6@tohoku.ac.jp, aoi@rcnp.osaka-u.ac.jp, ideguchi@rcnp.osaka-u.ac.jp

We have performed a Coulomb excitation experiment of $^{58}$Ti and determined its $B$(E2) value to study the evolution of collectivity in the Ti isotopes towards $N = 40$.
The neutron number $N = 40$ is a magic number in the harmonic oscillator model.
However, the magic character is not observed in most nuclei because of the narrowing of the shell gap due to spin-orbit interaction.
One exception is the proton magic nickel isotope with $N = 40$ ($^{68}$Ni), which shows magic nature having small collectivity compared to the surrounding Ni isotopes.
Fe($Z = 26$) and Cr($Z = 24$) at $N = 40$ recover large collectivity again.
It is interesting to see if the magic nature restores again or not in Ti isotopes ($Z = 22$) located near the lower edge ($Z = 20$) of the $f_{7/2}$ shell. For the Ti isotopes, $B$(E2) values, which are the most direct indicators of collectivity, have been obtained up to $^{54}$Ti with $N = 32$. The Coulomb excitation experiment was performed at RIBF using the HiCARI array consisting of the MiniBall clusters, Clover detectors, and Tracking Ge detectors. In this presentation, I will talk about the result of this experiment.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Session #4 / 23**

## Neutron-rich nuclear moment studies using spin-oriented RI beams

**Author:** Yuichi Ichikawa[1]

[1] *Kyushu University*

**Corresponding Author:** yuichikawa@phys.kyushu-u.ac.jp

The magnetic dipole moment and the electric quadrupole moment are the nuclear moments that provide us with key information about the proton and neutron configurations in a nucleus and the shape of a nucleus, respectively. In the study of nuclear structure through the measurement of the nuclear moments, a technique to produce spin orientation of RI beams has played important roles. In the precision nuclear spectroscopy of the nuclear moments of unstable nuclei, because the motion of their spins can be monitored using anisotropy of radiation from the spin-oriented unstable nuclei, techniques to produce spin orientation of RI beams have played important roles. Recently, a scheme of the two-step projectile fragmentation was developed to produce high spin alignment in RI beams and was applied to the frontier of the study for nuclear structure of neutron-rich nuclei, such as $^{75}$Cu and $^{99}$Zr. In this presentation, recent activities of the nuclear-moment measurements using highly spin-aligned beams at RIKEN RIBF will be reviewed, and future perspectives of nuclear-moment measurements will be discussed.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #5 / 24**

## In-gas-cell laser ionization spectroscopy of the nuclei in the vicinity of N=126 at KISS

**Author:** Yoshikazu HIRAYAMA[1]

[1] *WNSC, IPNS, KEK*

**Corresponding Author:** yoshikazu.hirayama@kek.jp

We have developed the KEK Isotope Separation System (KISS) [1] at RIKEN to study the nuclear structure of the nuclei in the vicinity of neutron magic number $N = 126$ from the astrophysical interest. These neutron-rich nuclei have been produced by using multinucleon transfer reactions [2] with the combinations of the low-energy $^{136}$Xe beam and the production targets of W, Ir, and Pt. At the KISS facility, radioisotopes are ionized by applying in-gas-cell laser ionization technique. In the ionization process, we can perform laser ionization spectroscopy of the refractory elements with the atomic number $Z = 70$-78 such as Hf, Ta, W, Re, Os, Ir, and Pt, which can not be performed in other facilities. Laser spectroscopy can be used to effectively investigate the nuclear structure through the measured magnetic moments, isotope shifts (IS), changes in the mean-square charge radii, and quadrupole deformation parameters. We have performed in-gas-cell laser ionization spectroscopy of $^{199g,199m,200,201}$Pt [3], $^{196,197,198}$Ir [4], $^{194,196}$Os [5], and $^{191,192}$Re produced at KISS.
In this conference, we will report the recent results of laser ionization spectroscopy, and the perspective of future plan at KISS.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #1 / 25**

## Study of Gamow-Teller giant resonances in unstable nuclei at RIBF

**Author:** Masaki Sasano[1]

[1] *RIKEN Nishina Center*

**Corresponding Author:** sasano@ribf.riken.jp

The Gamow-Teller giant resonance is one of the most basic collective modes in nuclei and belongs to the spin-isospin (pion) channel. This mode has long been studied for stable nuclei to clarify a variety of nuclear properties such as the behavior of spin-isospin residual interactions, nuclear weak responses. Recently, with the advent of RI falicities worldwide, the study of GTR has been extended to a braod region of nuclear chart including unstable nuclei. In this talk, GTR studies performed at RIBF for 132Sn and 11Li, which are flagship nuclei in medium-heavy and light mass regions, respectively, will be presented.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 26**

## The pair collective mode caused by the neutron pairing interaction in stable nuclei

**Author:** Chisato Ruike[1]

**Co-authors:** Nobuo Hinohara [2]; Takashi Nakatsukasa [2]

[1] *College of physics, School of science and engineering, University of Tsukuba*

[2] *University of Tsukuba*

**Corresponding Authors:** nakatsukasa.takas.gf@u.tsukuba.ac.jp, ruike@nucl.ph.tsukuba.ac.jp, hinohara@nucl.ph.tsukuba.ac.jp

Spin-zero pairing correlation in finite nuclei produces a systematic difference between the ground-state energies of even and odd-mass nuclei. We customarily use the odd-even mass staggering when discussing pairing correlation, but it is difficult to precisely calculate the energies of odd-mass ground states, especially in the nuclear density functional theory (DFT). Another physical observable that avoids this problem, the moment of inertia of pairing rotation, has been suggested as a pairing indicator [1,2]. A pair-(boson) condensed state caused by the pairing correlation in a nucleus breaks the number-gauge symmetry and has a specific direction in the number-gauge space. It can be viewed as a "deformation" of the nuclear wave function and rotates in the number-gauge space to restore the broken symmetry. Therefore there exist a pairing rotational energy and an inertia which are obtained from the analogy of spatial rotation.Experimental data and nuclear DFT calculations in open-shell nuclei support the interpretation of binding energy systematics in terms of the pairing rotational bands [1].
The isotopic (or isotonic) trend of the ground state energy measured from a reference neutron- (or proton-) number system and after subtracted the linear particle-number term forms a band structure that is interpreted as a harmonic vibration (pairing vibration) when the reference system is magic, and rotational excitation (pairing rotation) in other systems.The pairing vibrational mode is the fluctuation of the order parameter of the rotational symmetry breaking in the gauge space, and this mode affects the pair transfer reaction.

In this presentation, first, we focus on revealing the fundamental properties of the pairing rotational moments of inertia. We adopt a monopole pairing Hamiltonian and calculate the neutron pairing rotational bands and their moments of inertia within the BCS approximation and its extension for Ni, Sn, and Pb isotopes. As a result, the pairing moments of inertia decrease when increasing the deformation in gauge space (i.e., the order parameter of the pair condensation) in open-shell nuclei. On the other hand, in closed-shell nuclei, the pairing moments of inertia increase when the order parameter is small.We obtain the same conclusion when the Skryme interaction is used within the Hartree-Fock-Bogoliubov approximation, but this relation between the moments of inertia and deformation in pairing rotation contradicts that in spatial rotation.We will discuss the qualitative

reason for these results using both BCS [3] and cranking approximation.
Toward the description of the collective dynamics governed by the pairing correlation based on realistic effective interactions, we will show the current status for constructing the pairing collective Hamiltonian by calculating the potential curve, the pairing rotational moments of inertia, and the inertial mass of the pairing vibration as a function of the pairing gap using the constraint BCS+Local QRPA [4] calculation.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #6 / 27**

## Semiclassical origin of nuclear exotic deformations and their systematics

**Author:** Kenichiro Arita[1]

[1] *Nagoya Institute of Technology*

**Corresponding Author:** arita@nitech.ac.jp

The shapes of nuclei are essentially determined by the single-particle shell structures. Semiclassical periodic orbit theory (POT) gives us a very powerful tool in describing the origin of gross shell structures and their properties. The POT formula expresses the quantum level density in terms of the contributions of classical periodic orbits (POs). The major gross shell structure is governed by the shortest PO, and finer structures are reproduced as the interference effect by superposing the contributions of longer POs. In this talk, I will discuss the origin of the systematics in nuclear octupole and hexadecapole deformations. The breaking of reflection symmetry is one of the most important topics in nuclear structure physics. It is suggested experimentally and theoretically that the ground-state octupole deformation exclusively appear around the 'north-east' neighbors of doubly magic nuclei on the nuclear chart. This systematics has been long attributed to the octupole correlations between nearly-degenerate $\Delta l = 3$ levels above the fermi energy, but I would like to emphasize the significance of the role of gross shell structure originated from a particular PO family and its bifurcation. To clarify the essential feature, numerical analyses are carried out with the simple mean-field models. The hexadecapole shape degree of freedom also play important roles in stabilizing nuclei. It is suggested that on the way varying nucleon numbers from a spherical magic to the upper magic one, diamond-type hexadecapole shapes (with $\beta_4 > 0$) appear first and then turn into oblong-types (with $\beta_4 < 0$). This simple systematics found in realistic mean-field models are also reproduced in simpler mean-field models as cavity and oscillator. I will show that the origin of such systematics can be explained in a simple manner using the POT in relation to the dynamical symmetry restorations.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 29**

## Coulomb breakup reaction of $^{14}$Be

**Author:** Yuma Ohsawa[1]

**Co-authors:** Hideaki Otsu [2]; Nobuyuki Kobayashi [3]; Takashi Nakamura [4]; Yousuke Kondo [2]; Yoshiteru Sato [5]; Yasuhiro Togano [2]; SAMURAI Commisioning Collaboration

[1] *Institute of Science Tokyo, Dept. of physics*

[2] *RIKEN Nishina Center*

[3] *RCNP*

[4] *Tokyo Tech*

[5] *Institute of Science Tokyo, Department of physics*

**Corresponding Authors:** osawa.y.af@m.titech.ac.jp, nakamura@phys.titech.ac.jp, kondo@mail.nucl.ap.titech.ac.jp, togano@ribf.riken.jp, sato.y.ae@m.titech.ac.jp, kobayash@rcnp.osaka-u.ac.jp, otsu@ribf.riken.jp

We report on the kinematically complete measurement of the Coulomb breakup of the two-neutron halo nucleus $^{14}$Be on Pb at 220 MeV/nucleon at SAMURAI at RIBF. The previous study [1] showed significantly large E1 excitation of $^{14}$Be at low excitation energies, which was indicative of the revelation of the soft E1 excitation for halo nuclei, while the statistics was low and the quantitative comparison with theories was not sufficient. The current measurement has significantly higher statistics, and the gamma rays were measured in coincidence to evaluate the core-excited contribution which was missing in the previous work. We will present the energy spectrum of Coulomb breakup cross sections and E1 strength distribution dB(E1)/dEx. We apply the integrated B(E1) strength to extract the information on the dineutron correlation using the non-energy weighted E1 sum rule, which is important to assess how the spatial dineutron correlation appears. The configuration of the valence two neutrons in $^{14}$Be is considered to be a mixture of 2s-1p-1d, which may show different dineutron properties in $^{14}$Be, compared with $^{11}$Li[2,3] and $^{6}$He[4].We discuss the characteristic feature of the E1 response and dineutron correlation in $^{14}$Be.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session / 30**

## Equation of State of Spin-polarized Matter in Relativistic Hartree-Fock Theory

**Author:** Toi Tachibana[1]

**Co-authors:** Kenichi Yoshida ; Kouichi Hagino ; Qiang ZHAO [2]

[1] *Kyoto University*

[2] *RCNP, Osaka University*

**Corresponding Authors:** tachibana.toi.78e@st.kyoto-u.ac.jp, qzhao@rcnp.osaka-u.ac.jp, kyoshida@rcnp.osaka-u.ac.jp, hagino.kouichi.5m@kyoto-u.ac.jp

We used the Relativistic Hartree-Fock theory to calculate the equation of state (EOS) of spin-polarized matter, where the spins of nucleons are biased either up or down. Similar to the slope parameter of the isospin-symmetry energy in spin unpolarized matter, we define the "spin slope parameter"of the spin-symmetry energy to characterize the variation of the energy as the spin polarization is varied. In this contribution, we will discuss the correlation between the slope parameters and the spin slope parameters in varying the parameter sets. We will show that the slope parameters and the spin slope parameters have a negative correlation when neutrons and protons are spin-polarized along the same direction, while the spin slope parameter is nearly independent of the slope parameter when neutrons are spin-polarized along the opposite direction to protons.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session / 31**

## The first β delayed γ-ray spectroscopy for 109Mo focusing on low-lying quasi-particle states

**Author:** Sunghan Bae[1]

**Co-authors:** Toshiyuki Sumikama [2]; Philip M. Walker [3]; Jianguo Li [4]; Furong Xu [5]; Seonho Choi [6]; Jeongsu Ha [7]; Frank Browne [2]; Alison Bruce [8]; the RIBF26 collaboration

[1] *Center for Nuclear Study*

[2] *RIKEN Nishina Center*

[3] *Department of Physics, University of Surrey*

[4] *CAS Key Laboratory of High Precision Nuclear Spectroscopy, Institute of Modern Physics*

[5] *School of Physics, Peking University*

[6] *Department of Physics and Astronomy, Seoul National University*

[7] *Katholieke Universiteit Leuven*

[8] *School of Computing, Engineering, and Mathematics, University of Brighton*

**Corresponding Author:** shbae@cns.s.u-tokyo.ac.jp

The rapid spherical to prolate shape transition at N = 60 in the mid-shell region around Z = 40 has been evidenced from diverse experiments [1-5], and the shape evolution for more neutron-rich nuclei has been of interest because of the emergence of the triaxial degree of freedom. Theoretical predictions suggested further phase transitions such as a shape transition to oblate spheroid [6-8], a transition to triaxial ground shapes [6, 9] and doubly magic behavior at N = 70 [10]. Experimental information for the low-lying states of even-odd nuclei can be the key since they exhibit the properties of orbitals of the un-paired nucleon near the Fermi surface and the orbital configuration is sensitive to the nuclear shape.
The shape and shell evolution for molybdenum nuclei (Mo, Z = 42) with N ≥ 60 have been studied in various experiments [11-16] but the detailed shell structure near the Fermi surface is still unresolved. The excited states of 109Mo were studied through the spontaneous fissions of 248Cm and 252Cf [11, 12], but the recent discovery of an isomeric transition in 109Mo has revealed that previous studies on 109Mo were limited to the excited states above the ground state [16, 17].
In the present study, the low-lying states in 109Mo are investigated from the γ-rays detected following the β decay of 109Nb. The data was collected as part of the EURICA project in RIKEN [18]. Two new isomeric γ-rays are identified together with the known isomeric γ-ray [16, 17]. Their transition

multipolarities have been scrutinized considering internal conversion coefficients and recommended upper limits [19]. New excited states including a new first excited state below the isomeric state are assigned. The results of mean-field calculations [20] and intrinsic gyromagnetic moment calculations [21] are considered to assign associated neutron orbitals for the low-lying states. The analysis results for the most likely quasi-particle configurations of the low-lying states including ground band and isomeric band will be presented.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Session #2 / 32**

## Superfluid phonon in inner crust of neutron stars

**Author:** Masayuki Matsuo[None]

**Co-authors:** Arata Nishiwaki ; Toshiyuki Okihashi

**Corresponding Author:** matsuo@phys.sc.niigata-u.ac.jp

Inner crust of neutron stars, which consists of lattice of neutron-rich nuclei immersed in dilute neutron superfluid, may exhibits distinct low-lying excitations. Collective oscillation of displacement motion of nuclei leads to the lattice phonon while another phonon excitation is also possible in neutron superfluid, known as the superfluid phonon or the Anderson-Bogoliubov mode. The superfluid phonon has attracted attention in connection with the astrophysical issues such as the colling of inner crust in the magnetar and the quasi-periodic oscillation after the X-ray burst, etc[1,2]. The two kinds of phonon may couple to each other, and this coupling influences the matter property such as the heat conductivity and the phonon dispersion relation.

We study the superfluid phonon and its coupling to the nuclear lattice using the Skyrme-Hartree-Fock-Bogoliubov model (HFB) and the quasiparticle random phase approximation (QRPA), in which all the nucleon degrees (of both nuclei and neutron superfluid) are treated on an equal footing. Numerical calculations are performed using a Wigner-Seitz approximation (describing a single spherical cell with a large radius) and the standard Skyrme and pairing parameters. We found that the superfluid phonon mode appears as the lowest energy excitation modes of the QRPA solutions. The

superfluid phonon interacts with the nucleus in such a way that it does not penetrate into the nucleus[3].

The HFB+QRPA results can be utilized to evaluate the macroscopic properties such as the thermal conductivity. For this purpose, we introduce an equivalent boson model in which the neutron superfluid is represented by a Bose-Einstein condensate interacting with the nuclear lattice. We will discuss the implication of the HFB+QRPA results in terms of this boson model. We found that the coupling between the superfluid phonon and the nuclear motion is much weaker than an estimate assuming a non-interacting superfluid phonon. It implies a large thermal conductivity.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #12 / 33**

## Role of triaxiality in deformed halo nuclei

**Author:** Kotaro Uzawa[1]

**Co-authors:** Kouichi Hagino ; Kenichi Yoshida

[1] *Kyoto Univ.*

**Corresponding Authors:** kyoshida@rcnp.osaka-u.ac.jp, hagino.kouichi.5m@kyoto-u.ac.jp, uzawa.kotaro.37s@st.kyoto-u.ac.jp

It is known that nuclear deformation plays an important role in inducing the halo structure in neutron-rich nuclei by mixing several angular momentum components. While previous theoretical studies on this problem in the literature assume axially symmetric deformation, we here consider non-axially symmetric deformations. With triaxial deformation, the Ω quantum number is admixed in a single-particle wave function, where Ω is the projection of the single-particle angular momentum on the symmetric axis, and the halo structure may arise even when it is absent with the axially symmetric deformation. In this way, the area of halo nuclei may be extended when triaxial deformation is considered. We demonstrate this idea using a deformed Woods-Saxon potential for nuclei with neutron number N=13 and 43.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Session #4 / 34**

## Exotic structures in N~20 neutron-rich nuclei investigated by spin-polarized β-γ spectroscopy

**Author:** Hiroki Nishibata[1]

**Co-author:** the TRIUMF PDS collaboration

[1] *Kyushu University*

**Corresponding Author:** nishibata@phys.kyushu-u.ac.jp

One of the long-standing subjects of nuclear physics is the exotic structure of nuclei located far from the $\beta$-stability line. Particularly, neutron-rich nuclei around $N \sim 20$ have been attracting significant attention, and intensive experimental and theoretical studies have been performed to reveal their nuclear structures. Various structures have been predicted, as a result of the competition between the mean field, favoring spherical shape and the nuclear correlations, causing deformation, for the excited states as well as the ground states, such as shell evolution, shape coexistence and so on. To experimentally clarify these exotic structures should provide valuable insights into the isospin dependence of nuclear interactions in the neutron-rich region. However, up to now, experimental information on the excited states has been very limited. We have developed a unique method of $\beta$-decay spectroscopy with spin-polarized nuclei, enabling experimental spin-parity assignments of the excited states. The experimental spin-parity assignments enabled level-by-level comparisons between the experimental and theoretical levels.
So far, we have successfully applied this method to the $N = 20$ island-of-inversion nuclei, $^{28,29,30,31}$Mg and $^{31,33}$Al isotopes, to investigate the variation of the structure as a function of neutron number. In Mg isotopes, our results not only demonstrated structural changes as a function of neutron number but also revealed the coexistence of various types of structures in a narrow excitation energy region, $i.e.$, the shape coexistence of such as spherical and prolately-deformed states, a $\gamma$-vibrational band, and a candidate state for scissors mode.
In this presentation, the experimental methods and the structures of Mg and Al isotopes will be discussed.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 35**

## Interaction and charge-changing cross sections of neutron-rich Cu isotopes, and derivation of proton and neutron distribution radii.

**Author:** Gen Takayama[1]

**Co-authors:** Akira Homma [2]; Akira Ozawa [3]; Andrej Prochazka [4]; Asahi Yano [3]; Chihaya Fukushima [5]; Christoph Scheidenberger [4]; Daiki Nishimura [6]; Daisuke Nagae [7]; Eri Miyata [2]; Hans Geissel [4]; Hiroyoshi Sakurai [7]; Isao Tanihata [8]; JIN ONG [9]; Kensaku Matsuta ; Kensuke Kusaka [7]; Kenta Itahashi [7]; Koichi Yoshida [7]; Korkulu Zeren [10]; Masao Ohtake [7]; Masaomi Tanaka [11]; Maya Takechi ; Mei AMITANI ; Miki Fukutome [12]; Mitsunori Fukuda [12]; Mototsugu Mihara [12]; Naoki Fukuda [7]; Naoto Inabe [7]; Norihide Noguchi [2]; Ryo Taguchi [1]; SOUMYA BAGCHI [13]; Shinji Suzuki [3]; Soshi Ishitani [12]; Takashi Ohtsubo [2]; Takayuki Yamaguchi [14]; Takeshi Suzuki [14]; Takuji Izumikawa [15]; Tetsuaki Moriguchi [3]; Toshiyuki Sumikama [16]; Yohei Shimizu [7]; Yoshiyuki Yanagisawa [7]

[1] *Osaka Univ.*

[2] *Niigata Univ.*

[3] *Univ. of Tsukuba*

[4] *GSI*

[5] *Tokyo City University*

[6] *Tokyo City Univercity*

[7] *RIKEN Nishina Center*

[8] *Osaka Univ. RCNP*

[9] 中国科学院近代物理研究所

[10] *IBS*

[11] *Kyushu Univ.*

[12] *Osaka University*

[13] *Indian Institute of Technology*

[14] *Saitama Univ.*

[15] *Niigata Univ. RI*

[16] *RIKEN*

**Corresponding Authors:** ozawa@tac.tsukuba.ac.jp, dnishimu@tcu.ac.jp, ishitani@ne.phys.sci.osaka-u.ac.jp, mihara@vg.phys.sci.osaka-u.ac.jp, taguchi@ne.phys.sci.osaka-u.ac.jp, asahi.yano@riken.jp, g2381902@tcu.ac.jp, tohtsubo@np.gs.niigata-u.ac.jp, takayama@ne.phys.sci.osaka-u.ac.jp, moriguchi@tac.tsukuba.ac.jp, mtanaka@artsci.kyushu-u.ac.jp, fukutome@ne.phys.sci.osaka-u.ac.jp, g2381908@tcu.ac.jp, yamaguti@mail.saitama-u.ac.jp, onghjin@impcas.ac.cn, fukuda.slics@osaka-u.ac.jp, sakurai@ribf.riken.jp, sbagchi@iitism.ac.in, izumika@med.niigata-u.ac.jp, mtakechim@gmail.com, suzuki@mail.saitama-u.ac.jp, hrocho@vodacionline.sk

Determining the equation of state for nuclear matter is one of the primary goals in nuclear physics, and is essential for understanding the macroscopic properties of nuclear matter in equilibrium states in both finite systems (nuclei) and infinite systems (neutron stars). The objective of our study is to derive the density-dependent term L for the symmetry energy, focusing on the symmetry energy term based on the density difference between protons and neutrons, and deduce it from the isotope dependence of neutron skin thickness. To this end, we measured the interaction cross sections and the charge-changing cross sections of $^{63-81}$Cu at 260A MeV using the BigRIPS isotope separator at RIKEN RIBF. This allowed us to determine the nuclear matter radius from the interaction cross sections and the proton distribution radius from the charge-changing cross sections, and thus the neutron skin thickness from the difference between these two. However, for $^{63-81}$Cu, we used the proton distribution radius already measured by the isotope shift method, and for $^{79-81}$Cu, we will derive the proton distribution radius from the charge-changing cross section. In addition, the origin of the odd-even staggering effect of nuclei in the charge radius remains unclear, and insights from the staggering of both charge radius and matter radius of Cu isotopes are anticipated. In this presentation, we will discuss 1) the measurement results of the interaction and charge-changing cross sections of $^{63-81}$Cu, 2) the derived proton and neutron distribution radii, 3) the neutron skin thickness, and 4) the staggering in odd-even nuclei.

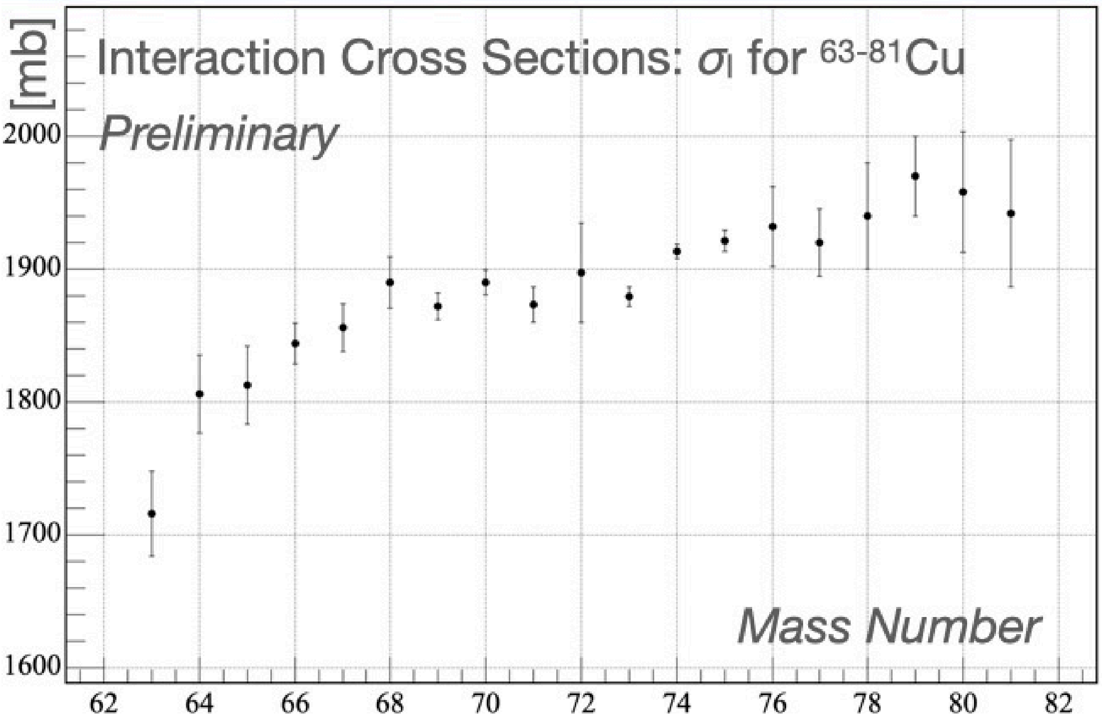


Figure 1: Preliminary results of Interaction Cross Sections of Cu isotopes

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**session #9** / **36**

## Delta-isobar resonance effects on beta and double beta decays in medium heavy nuclei

**Author:** Hiroyasu Ejiri[1]

[1] *RCNP Osaka Univ.*

**Corresponding Author:** ejiri@pop07.odn.ne.jp

Astro-$\nu$ interactions are studied by inverse $\beta$ decays and $\nu$-properties beynod the standard model are studied by neutrinoless double beta decays ($0\nu\beta\beta$). The $\beta$ and $\beta\beta$ nuclear matrix elements (NMES) consist mainly of the axial-vector spin ($\sigma$) isospin($\tau$) components, The delta-isobar ($\Delta$) resonance excited by the quark $\tau\sigma$ excitation of nucleon in the nucleus is shown to quench the axial-vector components of NMEs. The effects are evaluated by using experimental energies and the strengths of the Gamow-Teller (nuclear $\tau\sigma$) resonsnces. The quenching effect is incorpolated by the effective axial-vector coupling around $g_A^{eff}$ ≈0.7±0.1 in units of $g_A$ for a free nucleon. Impact of the $\Delta$ resonsnce on neutrino studues in nuclei is discussed.
H. Ejiri et al., Phys. Rep. 797, 1 2019, Phys. Rev. C105, L022501, C108, L11302 2023.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #8** / **37**

## Understanding Shell Evolution: Where and How?

**Author:** Hooi Jin Ong[1]

[1] *Institute of Modern Physics, Chinese Academy of Sciences*

**Corresponding Author:** onghjin@impcas.ac.cn

Atomic nuclei are finite quantum many-body systems consisting of protons and neutrons. Their structures are governed by the strong interactions. Extensive experimental and theoretical studies over the past decades have yielded sophisticated phenomenological realistic nucleon-nucleon, as well as (semi-phenomenological) chiral two- and three-nucleon interactions. However, it is still not possible to understand even the nuclear structures of relatively light nuclei such as carbon and oxygen isotopes. The tensor interactions of the realistic nucleon-nucleon interactions, for instance, are suggested to play dominant role in the shell evolutions observed in the neutron-rich nuclei. Besides, the tensor interactions also generate high-momentum components in nuclei, but their effect on nuclear structure has been largely unknown. In this talk, I will present experimental studies on neutron-rich carbon isotopes [1,2], studies of tensor-force effect in 16O through high-momentum transfer (p,d) reactions [3,4] as well as ongoing and future plans at IMP, RCNP, RIBF and GSI-FAIR.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #6 / 38**

# Shape transition and proton intruder state of $^{13}$B via helium induced proton-transfer reaction

**Author:** Shinsuke OTA[1]

[1] *RCNP, Osaka University*

**Corresponding Author:** ota@rcnp.osaka-u.ac.jp

Intruder orbitals in the shell structure play important roles in the existence and disappearance of the magic numbers and the nuclear shape. Magicity loss of $N = 8$ in light beryllium nuclei is one of the attractive subject from this viewpoint.
The $^{12}$Be has low-lying $0^+$ isomeric state at 2.2~MeV due to the narrow gap at $N = 8$ caused by the intruder orbital from $sd$-shell1 and its ground state is largely deformed[2]. As the origin of the narrow gap at N=8, the effect of the monopole interaction[3], the deformation[2], and the weakly bound nature[4] were suggested but there relationship was not clear. The neighboring nucleus $^{13}$ has one more proton and its ground state is spherical shape. Adding one proton to $^{12}$Be causes drastic change of the ground state structure. But the excitation structure of $^{13}$B was not known well since the spin-parity of the excited states was not determined. Considering the proton orbitals in $^{13}$B, binding energy is large enough and the counter orbital of the neutrons for the monopole interaction is fully occupied. However, the deformation of the matter shape can still have effect on the structure if it exists. To reveal the effect of one proton addition to the deformed nucleus, proton single particle excitation in $^{13}$B was studied via the helium induced proton transfer reaction on $^{12}$Be[5].

The experiment was performed at RIPS course of the former RIBF, the RARF, in RIKEN. The high intensity (200~kcps) $^{12}$Be beam was produced as the fragmentation of the projectile of $^{18}$O primary beam and separated by using RIPS. The direction and arrival timing of the $^{12}$Be was measured by using two delay-line readout parallel plate avalanche counters and plastic scintillator located upstream of the secondary target. The $^{12}$Be beam bombarded the secondary target of liquid helium surrounded by the position sensitive gamma-ray detector array, the GRAPE. The beam-like outgoing particle of $^{13}$B was detected and identified by using plastic scintillator hodoscope, which is also the position sensitive. The $^{13}$B was identified event-by-event basis via TOF-dE-E method. The excited state of $^{13}$B was identified via the gamma-ray spectroscopy after the doppler correction and the scattering angle was deduced from the incident direction of the $^{12}$Be and the outgoing direction of $^{13}$B.

The de-excitation gamma ray from the 4.8-MeV excited state is clearly observed. The spin-parity of this state is assigned as $1/2^+$ from the DWBA analysis of the angular distribution of the differential cross section, which has forward peak corresponding to the transfer angular momentum of zero. Since the ground state of the $^{13}$B has the spin-parity of $3/2^-$ and the energy of $1/2^+$ state seems smaller than the normal shell gap at $Z = 8$, the 4.8-MeV $1/2^+$ state is concluded to be the low-lying proton intruder state. The existence of the proton intruder state is explained by the Nilsson orbit in deformed $^{12}$Be nucleus assuming the one-body potential is equally deformed for protons and neutrons. This indicates that the one proton excitation in the spherical nucleus causes the phase transition to the deformed nucleus dynamically.

In this paper, we discuss dynamical shape transition in $^{13}$B relating to the magicity loss of $^{12}$Be.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session / 39**

## The study of double Gamow–Teller giant resonance using double charge exchange reaction of (12C, 12Be(0+2))

**Author:** Akane Sakaue[1]

**Co-authors:** Daisuke Suzuki [2]; Hidetada Baba [3]; Hiroshi Suzuki [3]; Hiroyuki Takeda [3]; Jiatai Li [4]; Junki Tanaka [5]; Juzo Zenihiro [6]; Kenta Itahashi [2]; Kentaro Yako ; Koichi Yoshida [2]; Kosuke Sakanashi [7]; Kota Horikawa [8]; Masahiro Yoshimoto [3]; Masaki Sasano [2]; Masanori Dozono [9]; Motonobu Takaki ; Naoki Ebina [8]; Naoki Fukuda [2]; Nobu Imai [1]; Nobuhisa Fukunishi [3]; Nobuyuki Kobayashi [10]; Noritaka Shimizu [11]; Noritsugu Nakatsuka [8]; Pieter Doornenbal ; Riku Matsumura [12]; Ryohei Sekiya [9]; Ryotaro Tsuji [9]; Seiya Hayakawa ; Shin'ichiro Michimasa [13]; Shinsuke OTA [14]; Shoko Takeshige [15]; Shota Matsumoto [9]; Shutaro Hanai [16]; Siwei Huang ; Susumu Shimoura [17]; Takahiro Nishi [3]; Tatsuya Furuno [7]; Thomas Chillery ; Tomohiro Uesaka [3]; Tomoki Matsui [8]; Tomoya Harada [18]; Toshiyuki Sumikama [2]; Yasuhiro Togano [2]; Yohei Shimizu [2]; Yoshiki Tanaka [3]; Yousuke Kondo [2]; Yukie Maeda [19]; Yuto Hijikata [20]; Zaihong Yang [21]

[1] *CNS*

[2] *RIKEN Nishina Center*

[3] *RIKEN*

[4] *Center for Nuclear Study, University of Tokyo*

[5] *Riken, Nishina Center*

[6] *Kyoto Univ*

[7] *Osaka University*

[8] *Institute of Science Tokyo*

[9] *Kyoto University*

[10] *RCNP*

[11] *University of Tsukuba*

[12] *Saitama University*

[13] *Center for Nuclear Study, the Univ. of Tokyo*

[14] *RCNP, Osaka University*

[15] *Rikkyo University*

[16] *CNS, the University of Tokyo*

[17] *Center for Nuclear Study, the University of Tokyo*

[18] *Toho univ. / RIKEN*

[19] *University of Miyazaki*

[20] *Dept. of Phys., Kyoto Univ.*

[21] *Peking University*

**Corresponding Authors:** n.imai@cns.s.u-tokyo.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp, hanai@cns.s.u-tokyo.ac.jp, jt.li@cns.s.u-tokyo.ac.jp, mitimasa@cns.s.u-tokyo.ac.jp, t.chillery@cns.s.u-tokyo.ac.jp, togano@ribf.riken.jp, pieter@ribf.riken.jp, kobayash@rcnp.osaka-u.ac.jp, kondo@mail.nucl.ap.titech.ac.jp, yako@cns.s.u-tokyo.ac.jp, ota@rcnp.osaka-u.ac.jp, shimizu@nucl.ph.tsukuba.ac.jp, hijikata.yuto.23u@st.kyoto-u.ac.jp, juzo@scphys.kyoto-u.ac.jp, hayakawa@cns.s.u-tokyo.ac.jp, uesaka@riken.jp, tomoya.harada@riken.jp, dozono.masanori.6v@kyoto-u.ac.jp, shimoura@cns.s.u-tokyo.ac.jp, asakaue@cns.s.u-tokyo.ac.jp, sasano@ribf.riken.jp, takaki@cns.s.u-tokyo.ac.jp, riku@ribf.riken.jp, sakanashi@ne.phys.sci.osaka-u.ac.jp, junki.tanaka@riken.jp, siwei.huang@riken.jp, furuno@rcnp.osaka-u.ac.jp

The double Gamow–Teller (DGT) transition is a nuclear process such that both of the spin and isospin are flipped twice without changing the orbital angular momentum. The nuclear response of the DGT transition is hardly known especially in the high excitation energy region. The existence of giant resonance in DGT transition, DGT giant resonance (DGTGR), is expected. The experimental observables of the DGTGR will provide the information about the two-phonon excitation in which the spin-degrees of freedom contribute. It is also important in the connection to the nuclear matrix element of neutrino-less double $\beta$ decay.
The first experiment using the double charge exchange reaction of $(^{12}\mathrm{C},^{12}\mathrm{Be}(0_2^+))$ at RIBF was performed in 2021, aiming at the observation of the DGTGR. We measured for the $^{48}\mathrm{Ca}$ target with primary beam of $^{12}\mathrm{C}$ with the energy of 250 MeV/nucleon. We obtained the excitation energy distribution of the double differential cross section with the resolution of 1.5 MeV. The forward-peaking structure was observed at around 20 MeV in the excitation energy in $^{48}\mathrm{Ti}$. The integrated $0°$ cross section below 34 MeV is 1.33$\pm$0.12 $\mu$b/sr.
In order to extract the DGT components, the experimental angular distributions were compared with the calculated one. The extracted DGT strength below 34 MeV is $22^{+17}_{-6}$% of the sum rule value.
In this contribution, we will report the outline of the experiment and the analysis.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 40**

## Study on the shell structure of 11C with alpha scattering by using MATE

**Author:** Zhichao Zhang[1]

**Co-author:** Hooi Jin Ong [2]

[1] *IMP,CAS*

[2] *Institute of Modern Physics, Chinese Academy of Sciences*

**Corresponding Authors:** onghjin@impcas.ac.cn, zhangzc@impcas.ac.cn

The nuclear shell structure provides an important guide for our understanding of the nuclear structure and the underlying nuclear forces. Following a series of studies on the weakly-bound nuclear region far away from the stability line, many exotic phenomena have been found, such as the emergence of new magic numbers. The study of new magic numbers can provide us with a good perspective to understand the evolution of the nuclear shell structure. Recently, the existence of the new proton magic number Z = 6 was found in the neutron-rich carbon isotopes, which raised the question of whether the Z = 6 magic number persists in the neutron-deficient carbon isotopes. At present, there exist only the experimental results of 10C on the neutron-deficient side, which shows greater neutron contribution to E2 transition than that of protons. To further investigate the neutron-deficient

carbon isotopes, we carried out an alpha inelastic scattering experiment to study the structure of 11C.

The a(11C, a*) experiment was carried out at the RIBLL1, HIRFL. A primary beam 12C bombarded a beryllium target to produce a 55-MeV/u secondary beam 11C. The 11C beam was incident on an active target Time Projection Chamber (TPC) named MATE (Multi-purpose Active target Time projection chamber for nuclear astrophysical and exotic beam Experiments). MATE is a new detector developed at IMP in recent years, and is mainly composed of TPC and silicon detectors. By measuring the yield of the recoil alpha particles, a differential cross section can be obtained. The ratio of the neutron and proton contribution to the excitation Mn/Mp will be obtained from reaction theory analysis, combining the results from this work and earlier (p, p′) measurement. The results will shed light on the important question of whether or not there exists a proton subshell closure in 11C. The experimental data is currently being further analyzed.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session / 42**

## Double beta decay phase space factor calculation using Coulomb potential determined by density functional theory

**Author:** Atsuya Kanai[1]

**Co-author:** Nobuo Hinohara [1]

[1] *University of Tsukuba*

**Corresponding Authors:** kanai@nucl.ph.tsukuba.ac.jp, hinohara@nucl.ph.tsukuba.ac.jp

In some nuclei, a phenomenon called double beta decay, in which two nucleons simultaneously undergo beta decay, is known to occur rarely. In this case, two neutrinos are emitted. Neutrinos may be Majorana particles, which do not distinguish between particles and antiparticles among Fermi particles. In that case, double beta decay without neutrino emission ($0\nu\beta\beta$) may occur. If the half-life of this decay can be measured experimentally and quantities called the phase space factor and the nuclear matrix element can be calculated theoretically, the effective neutrino mass can be obtained.

The phase space factors include the information on the emitted electron wave functions. They have been calculated by solving the Dirac equation for the emitted electrons by including the finite-size effect (the nuclear charge distribution assuming a uniform charge distribution or derived from Woods-Saxon potential) and the electron screening effect based on the Thomas-Fermi equation [1,2].

We are performing a precise calculation of the phase space factor based on the nuclear and atomic density functional theory (DFT); nuclear charge distribution based on the nuclear DFT and the electron screening effect based on the atomic DFT.

In this presentation, I will show the results of the phase space factor calculation for double-beta decaying nuclei based on the nuclear/atomic DFT.

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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**Poster session / 43**

## Charge symmetry breaking effects with $\omega$-$\rho^0$ mixing

**Author:** Yusuke Tanimura[1]

**Co-authors:** Hiroyuki Sagawa ; Myung-Ki Cheoun ; Tomoya Naito

[1] *Soongsil University*

**Corresponding Author:** tanimura@ssu.ac.kr

One of the primary goals of nuclear physics is to achieve a unified understanding of baryon-baryon interactions based on flavor symmetry and its breaking. Charge symmetry breaking (CSB) represents a part of the flavor symmetry that is violated by nuclear forces, leading to differences in neutron-neutron and proton-proton interactions, as well as in neutron-Lambda and proton-Lambda interactions. The CSB effects are indeed observed in the mirror binding energy differences of both normal nuclei and hypernuclei [1-3].

In this work, we introduce CSB through $\omega$-$\rho^0$ mixing [4] within a relativistic mean-field model, along with corrections for electromagnetic (EM) interactions (such as the EM form factors of nucleons and vacuum polarization). An advantage of our model is its applicability to hypernuclei on an equal footing with normal nuclei. In this talk, we focus on normal nuclei and examine the effects of $\omega$-$\rho^0$ mixing on observables such as binding energy and charge radius. We also compare the CSB strength in our model with that of Skyrme-type CSB models.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**Session #2 / 44**

## Measurement of Interaction Cross Sections through the TRIP-S3CAN Project at RIKEN RIBF

**Author:** Daiki Nishimura[1]

**Co-authors:** Tetsuaki Moriguchi [2]; Masaomi Tanaka [3]; Chinami Inoue [4]; Kento Matsuyama [5]; Ryo Taguchi [6]; Gen Takayama [7]; Asahi Yano [2]; Kazuhiro Adachi [8]; Mei AMITANI [9]; Hidetada Baba [10]; Mitsunori Fukuda ; Naoki Fukuda [10]; Chihaya Fukushima [5]; Miki Fukutome [11]; Yuto Ichinohe [10]; Soshi Ishitani [11]; Nao Ito [5]; Rinon Kageyama [12]; Yuta Kikuchi [13]; Naoyuki Kitagawa ; Hayato Kobayashi [14]; Kensuke Kusaka [10]; Shin'ichiro Michimasa [10]; Mototsugu Mihara [11]; Misaki Mikawa [15]; Maoto Mitsui [15]; Yuki Nakamura [9]; Satoru Nishizawa [13]; Masao Ohtake [10]; Takashi Ohtsubo [16]; Akira Ozawa [2]; Rena Sasamori [8]; Toshiya Shimamura [8]; Yohei Shimizu [10]; Hiroshi Suzuki [10]; Hiroyuki Takeda [10]; Kazuki Takiura [13]; Koki Tezuka [8]; Yasuhiro Togano ; Nao Tomioka [13]; Tasuku Tsujisaka [11]; Kohei Watanabe [13]; Takayuki Yamaguchi [17]; Yoshiyuki Yanagisawa [10]; Keigo Yasuda [11]; Masahiro Yoshimoto [10]; Hanbin Zhang [15]; for TRIP-S3CAN Collaboration

[1] *Tokyo City Univercity*

[2] *Univ. of Tsukuba*

[3] *Kyushu Univ.*

[4] *Tokyo City Univerisity*

[5] *Tokyo City University*

[6] *Depertment of Physics, Osaka University*

[7] *Osaka Univ.*

[8] *Niigata University*

[9] *Tokyo City Univerisyt*

[10] *RIKEN Nishina Center*

[11] *Osaka University*

[12] *Tokyo City Univeisity*

[13] *Saitama University*

[14] *Univiersity of Tsukuba*

[15] *University of Tsukuba*

[16] *Niigata Univ.*

[17] *Saitama Univ.*

**Corresponding Authors:** ozawa@tac.tsukuba.ac.jp, g2117006@tcu.ac.jp, dnishimu@tcu.ac.jp, togano@ribf.riken.jp, ishitani@ne.phys.sci.osaka-u.ac.jp, mihara@vg.phys.sci.osaka-u.ac.jp, taguchi@ne.phys.sci.osaka-u.ac.jp, asahi.yano@riken.jp, g2381902@tcu.ac.jp, tohtsubo@np.gs.niigata-u.ac.jp, takayama@ne.phys.sci.osaka-u.ac.jp, moriguchi@tac.tsukuba.ac.jp, mtanaka@artsci.kyushu-u.ac.jp, fukutome@ne.phys.sci.osaka-u.ac.jp, g2381908@tcu.ac.jp, yamaguti@mail.saitama-u.ac.jp, masahiro.yoshimoto@riken.jp, hsuzuki@ribf.riken.jp, tsujisaka@ne.phys.sci.osaka-u.ac.jp, g2481904@tcu.ac.jp, ichinohe@ribf.riken.jp, yanagisa@riken.jp, yshimizu@ribf.riken.jp, g2381906@tcu.ac.jp, n.tomioka.116@ms.saitama-u.ac.jp, nfukuda@riken.jp, g2117007@tcu.ac.jp, tezuka@np.gs.niigata-u.ac.jp, baba@ribf.riken.jp, shimamura@np.gs.niigata-u.ac.jp, sasamori@np.gs.niigata-u.ac.jp, s2111572@u.tsukuba.ac.jp, kitagawa.naoyuki.809@s.kyushu-u.ac.jp, s2420197@u.tsukuba.ac.jp yasuda@ne.phys.sci.osaka-u.ac.jp, s.nishizawa.746@ms.saitama-u.ac.jp, mohtake@riken.jp, adachi@np.gs.niigata-u.ac.jp, s2420198@u.tsukuba.ac.jp, mitimasa@riken.jp, takeda@ribf.riken.jp, kkusaka@riken.jp, g2117055@tcu.ac.jp, s2320200@u.tsukuba.ac.jp, k.watanabe.210@ms.saitama-u.ac.jp, y.kikuchi.985@ms.saitama-u.ac.jp, k.takiura.439@ms.saitama-u.ac.jp, fukuda.slics@osaka-u.ac.jp

The nuclear matter radius is one of the fundamental physical quantities, and the interaction cross section measurement is a method used to deduce this radius. Measurement of interaction cross sections using the transmission method achieves an accuracy of 0.5% with statistics from only 10^5 to 10^6 particles, owing to the large cross section and the ability to use thick targets. This corresponds to a nuclear radius determination accuracy of approximately 0.01–0.03 fm. The ability to determine radii with relatively high precision from a limited number of events makes this method applicable to unstable nuclei far from the stability line, enabling simultaneous measurement of over a dozen nuclei within a single cocktail beam. To extend these measurements to a broad range of nuclei, the S3CAN (Symbiotic Systematic and Simultaneous Cross-section Measurements for All over the Nuclear Chart) experiments have been launched.
In the 2024 fiscal year, we successfully measured the interaction cross sections of approximately 150 nuclides within 48 hours as part of this project. While each result will be detailed in poster presentations by the co-authors, this presentation will provide an overview of the experimental methodology for cross-section measurements, recent progress, and future plans.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 45**

## Investigating Shell Structure at $N = 32$ and $34$ in Neutron-Rich Nuclei Using High-Precision Mass Measurements

**Authors:** Shun Iimura[1]; with SLOWRI collaboration[None]

[1] *Rikkyo University*

**Corresponding Author:** shun.iimura@rikkyo.ac.jp

In this study, we discuss the shell structure at $N = 32$ and 34, newly recognized magic numbers in neutron-rich nuclei, in the context of deformation toward $N = 40$ based on nuclear mass implications. Mass measurements of isotopes $^{55}$Sc, $^{55-58}$Ti, and $^{55-59}$V were conducted during the first commissioning of the ZD-MRTOF system at the RIBF/RIKEN under the SLOWRI project. The newly installed experimental system, situated downstream of the ZeroDegree (ZD) spectrometer in the BigRIPS experimental area at RIBF/RIKEN, includes a radiofrequency carpet-type helium gas cell (RFGC) coupled with a multi-reflection time-of-flight mass spectrograph (MRTOF). In this initial low-energy experiment at BigRIPS, high-energy products were captured and decelerated in helium gas, then extracted through an aperture using an RF microstructure into a Paul trap ion guide. The cooled, thermalized ions were injected into the MRTOF system as a high-quality beam for high-precision mass measurements. We present the features of the ZD-MRTOF system and share experimental results. These new data allow us to examine the $N = 32$ and 34 sub-shell structures in comparison with predictions from the Monte Carlo shell model (MCSM). Furthermore, we expand our discussion by incorporating recent research trends related to the evolution of nuclear shell structure in neutron-rich isotopes.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 46**

## Shell-model study using density functionals

**Author:** Kota Yoshinaga[1]

**Co-authors:** Noritaka Shimizu [1]; Takashi Nakatsukasa [1]

[1] *University of Tsukuba*

**Corresponding Authors:** shimizu@nucl.ph.tsukuba.ac.jp, nakatsukasa.takas.gf@u.tsukuba.ac.jp, yoshinaga@nucl.ph.tsukuba.ac.jp

The parameter set of many kinds of density functionals are designed not only to reproduce the basic properties of finite nuclei but also to satisfy the saturation properties of nuclear matter. Consequently, calculations using density functionals can describe experimental data in various mass regions. However, the mean-field calculations using the functionals miss some many-body correlations. Especially, the odd nuclei are often treated with the equal filling approximation. In contrast, there are semi-empirical methods that construct a shell-model Hamiltonian by fitting experimental values. The shell-model calculations can consider correlations beyond mean fields because these calculations can include configuration mixing, but we must determine the model space and then fit the effective interactions with experimental results.
In this study, a hybrid approach is attempted by using density functionals to shell-model calculations. The resultant density-dependent interaction of the shell-model Hamiltonian is self-consistently determined. In contrast to semi-empirical methods, this hybrid model can compute shell-model Hamiltonian including the density-dependent force on the ground-state density. The purpose of this calculation is to investigate which nucleon-nucleon interactions make important contributions to the shell structure systematically from stable nuclei to unstable nuclei. We investigate excitation spectra, separation energies, and reduced transition probabilities of not only the even-even nuclei but

also the odd nuclei with correlations beyond the mean-field.
In this presentation, we will present results in comparison with the experimental results from sd-shell nuclei to pf-shell nuclei. In particular, we will focus on the calculation with the isospin-dependent tensor force and show that the isospin dependence is necessary to describe characteristics in neutron-rich nuclei.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 47**

## Effect of Coulomb interaction on nuclear properties

**Author:** kenta hagihara[1]

**Co-authors:** Nobuo Hinohara [1]; Takashi Nakatsukasa [1]

[1] *University of Tsukuba*

**Corresponding Authors:** hinohara@nucl.ph.tsukuba.ac.jp, nakatsukasa.takas.gf@u.tsukuba.ac.jp, hagihara@nucl.ph.tsukuba.ac.jp

The energy density functional method provides a systematic approach to analyzing nuclear properties across the entire nuclear chart. We have performed calculations for nuclei from the proton drip line to the neutron drip line, including superheavy nuclei. Using the HFBTHO program (Axially deformed solution of the Skyrme-Hartree–Fock–Bogoliubov equations using the transformed harmonic oscillator basis (II)), we investigate the effect of Coulomb interaction on the deformation of even-even nuclei and the position of the drip lines. The results show that Coulomb interaction enhances nuclear deformation and extends the neutron drip line toward the neutron-rich side. Notably, we find that the Coulomb interaction provides additional binding energy to nuclei near the neutron drip line, attributed to a change in the single-particle energy of neutrons. We will present an analysis of this mechanism from a quantum mechanical perspective.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #5 / 48**

## Quasi-Particle Structure and Collective Properties of Transfermium Nuclei

**Author:** Roderick Clark[1]

[1] *Berkeley Lab*

**Corresponding Author:** rmclark@lbl.gov

The study of the heaviest elements remains a compelling scientific endeavor. By investigation of nuclei in the trans-fermium region, we can learn about the quasi-particle structure, pairing correlations,

and excitation modes in these nuclei. Berkeley Lab scientists have led several recent experiments to study the excited level structure of nuclei in this region through prompt and delayed gamma-ray spectroscopy including, notably, the odd-Z nuclei 249,251Md (Z=101). The latest results and findings from these spectroscopic studies will be discussed.

While such studies of the quasi-particle structure are vital to understanding the stability of the heaviest elements, the question remains as to how far we can push investigations of the heaviest nuclei. Experiments have been carried out at the 88-Inch Cyclotron using the Berkeley Gas-filled Separator (BGS) to investigate this issue. The very latest progress of studies aimed at creation of superheavy elements (Z>103) using 50Ti-induced fusion-evaporation reactions will be highlighted.

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**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #12 / 49**

## DIrect Mass measurments of fp-shell nuclei in the vicinity of proton dripline via TOF-Brho method

**Author:** Shutaro Hanai[1]

**Co-author:** SHARAQ13 Collaboration

[1] *CNS, the University of Tokyo*

**Corresponding Author:** hanai@cns.s.u-tokyo.ac.jp

The two-proton radioactivity (2p decay), where two protons are simultaneously emitted during nuclear decay, was theoretically predicted over 60 years ago1. In the early 2000s, 2p decay was discovered in very proton-rich nuclei such as 45Fe and 48Ni [2, 3]. The energy level structure and one- and two-proton separation energies (Sp, S2p) are essential to evaluate the two-proton emission probability of the 2p emitter penetrating through the Coulomb and centrifugal potentials. Since the level structure and mass difference among one- and two-proton removal nuclei are directly related to Sp and S2p, the systematic measurement of the masses of nuclei around the 2p emitter leads to a complete understanding of 2p decay.

We performed direct mass measurements of proton-rich Fe isotopes including 45Fe using the TOF-B technique[4] at the SHARAQ beamline of RIBF. Proton-rich isotopes were produced by the fragmentation of the 78Kr primary beam at 345 MeV/nucleon in a 9Be target with a thickness of 2.2 g/cm2. The fragments were separated by the BigRIPS separator and transported to the OEDO beam line followed by the SHARAQ spectrometer. OEDO and SHARAQ were operated as a single spectrometer in the dispersion matching mode, which achieved a momentum resolution of 1/15,000. The time of
ight
(TOF) was measured by diamond detectors installed at the beginning and end of the beamline. Two multiwire drift chamber (MWDC) tracking detectors were also installed to correct the
ight-pass length. To measure the B value, a strip-readout parallel-
plate avalanche counter (SR-PPAC) newly developed for measuring high-rate heavy-ion beams[5] was used at the intermediate focal plane. Gamma-ray detection systems were placed after the SHARAQ to identify isomers, which could shift the peak in the measured mass spectra.

Proton-rich Ti, Cr, Fe, and Ni isotopes were detected in the vicinity of the proton drip line. Masses of nine isotopes were newly determined for the rst time in the present experiment. The separation energies deduced from the mass values exhibit the possible

candidates of 2p decay in some proton-rich isotopes beyond the dripline.
This work is supported by JSPS KAKENHI Grant Number JP20H01910 and JP23KJ0609.
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**Type of contribution**:

**Are you a student or postdoc?**:

yes

**session #10 / 50**

## CP-odd nuclear moments evaluated by nuclear shell model

**Author:** Kota Yanase[None]

**Corresponding Author:** yanase@cns.s.u-tokyo.ac.jp

Permanent electric dipole moment (EDM) of elementary or composite particle is one of the promising probe for CP violation in beyond the standard model. In particular, the EDMs of diamagnetic atoms including $^{129}$Xe and $^{199}$Hg are sensitive to the CP-odd interactions in the hadronic sector. The hadronic CP-odd interactions can induce the nuclear Schiff moment, which induces the atomic EDM through the interactions with electrons. We compute the Schiff moments of $^{129}$Xe and $^{199}$Hg by using the nuclear shell model. It is found that the theoretical uncertainty can be reduced by considering the apparent correlation with other observables like isoscalar dipole resonance, electric transition strengths, and magnetic moment.

**Type of contribution**:

**Are you a student or postdoc?**:

yes

**51**

## Structure within the N=40 Island of Inversion

**Author:** Heather Crawford[1]

**Co-author:** Carlotta Porzio [2]

[1] *Lawrence Berkeley National Laboratory*

[2] *CERN*

**Corresponding Authors:** carlotta.porzio@cern.ch, hlcrawford@lbl.gov

The focus of this work is neutron-rich Fe and Mn isotopes with N~40, which lie within an Island of Inversion approximately centered at <sup>64</sup>Cr. Here, a quenching of the N=40 sub-shell gap allows multi-particle multi-hole excitations and deformation to develop in the ground-state configurations of nuclei in the region. Limited spectroscopic information has been collected so far in the

region of N~40 below <sup>68</sup>Ni. For the even-even nuclei, the 2<sup>+</sup><sub>1</sub> and 4<sup>+</sup><sub>1</sub> state energy systematics has been explored and, for the Fe and Cr isotopes, of B(E2; 2<sup>+</sup><sub>1</sub>->0<sup>+</sup><sub>1</sub>) values have been measured up to <sup>68</sup>Fe and <sup>64</sup>Cr. Large-scale shell model (LSSM) calculations well reproduce the energy systematics of the observed low-lying states of the even-even Fe and Cr isotopes around N=40. However, spectroscopic factor and more complete level scheme predictions in the region have not yet been benchmarked by experimental results.
Proton knockout reactions on the neutron-rich N=38 and N=40 isotopes <sup>64,66</sup>Fe and <sup>63,65</sup>Mn have been performed to investigate the proton spectroscopic factors of the parent nuclei. We will discuss the results of this measurement as well as a complementary secondary fragmentation measurement, and interpret in comparison with both LSSM and Nilsson model calculations.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**Poster session** / **52**

## Halo formation in neutron-rich ishotope 29Ne

**Authors:** Nobuyuki Kobayashi[1]; RIBF-55 Collaboration[None]

[1] *RCNP, Osaka University*

**Corresponding Author:** kobayash@rcnp.osaka-u.ac.jp

Very neutron-rich isotopes, including 28−32Ne, in the vicinity of N = 20 are known to exhibit ground states dominated by fp-shell intruder configurations: the "island of inversion." Systematics for the Ne-isotopic chain suggest that such configurations may be in strong competition with normal shell-model configurations in the ground state of 29Ne. A determination of the structure of 29Ne is thus important to delineate the extent of the island of inversion and better understand structural evolution in neutron-rich Ne isotopes. In order to investigate the structure of 29Ne, we have measured cross sections for one-neutron removal on carbon and lead targets and the parallel momentum distribution of the 28Ne residues from the carbon target at around 240 MeV/nucleon at RIKEN RI Beam Factory. The combined analysis of the carbon and lead cross sections suggests that the ground state of 29Ne has a spin parity of 3/2−. Detailed comparisons of the measured inclusive and partial cross sections of the two targets and the parallel momentum distribution of the carbon target with reaction calculations, combined with spectroscopic information from large-scale shell-model calculations, are all consistent with a 3/2− spin-parity assignment. The results are also well understood in the Nilson diagram. In the presentation, we will discuss our results and recent relevant date.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**session #10** / **54**

## Octupole correlations in 118Xe; A fresh look via lifetime measurement

**Author:** Sanjay Kumar Chamoli[1]

**Co-authors:** Anand Pandey [1]; Ravi Bhushan [1]

[1] *Department of Physics and Astrophysics, University of Delhi, Delhi, India*

**Corresponding Author:** skchamoli@physics.du.ac.in

The Xe nuclei with mass A < 120 are perfectly placed to study the octupole correlations phenomena. For these nuclei, the presence of octupole driving h11/2 and d5/2 orbitals near the Fermi surface make them suitable to exhibit octupole correlation. Other than Xe nuclei such octupole correlations have also been reported in several other isotopes of Cs and Ba having N < 70. In previous high spin gamma ray spectroscopy measurements in 118Xe nuclei though the octupole correlations have been reported in Refs. but in almost all the cases a precise data on parity assignments and the quadrupole moment of the bands involved were missing. Also, in cases where the octupole correlations has been discussed in relation to the observed inter-band transitions, 1022 keV (7− ⟶ 6+), 846 keV (9− ⟶ 8+), 726 keV (11− ⟶ 10+) and 924 keV (8− ⟶ 8+) in 118Xe, the quoted B(E1) values have errors in the range from 4% to 28%. One of the important source of uncertainty in these E1 values is the quadrupole moment of the bands involved apart from the observed low intensity of these transitions. In the present work, the 118Xe nucleus was reinvestigated with the aim: 1) to update the level scheme with inclusion of more γ transition in the non-yrast bands (if any), 2) to confirm the suggested parities of various excited bands with polarisation measurements and 3) to get a precise value of the quadrupole moment of the bands involved in octupole correlations by lifetime measurement of excited states. We have also performed the triaxial projected shell model (TPSM) calculations to investigate the observed band structures further.
High spin states in 118Xe have been populated via 93Nb (28Si, xpyn) 118Xe fusion-evaporation reaction at a beam energy of 115 MeV provided by the 15 UD pelletron accelerator facility at the Inter University Accelerator Center, New Delhi. In the experiment, several new γ-transitions have been found and are placed appropriately in the level scheme. Theoretical study using the triaxial projected shell model (TPSM) approach suggests that the first band-crossing is due to the alignment of two neutrons, and a parallel band tracking the yrast configuration is the γ-band built on the two-quasiparticle state. Enhanced E1 transition rates have been obtained between opposite parity bands, involving νh11/2 and νd5/2 orbitals having Δj = Δl = 3, indicates the presence of octupole correlation in this nucleus. More details of the analysis and the physics outcomes will be discussed during the presentation.

**Type of contribution**:

**Are you a student or postdoc?**:

no

**55**

## Analysis of superdeformed bands using semi classical models in A ~ 190 mass region

**Author:** Annanya Mahajan[1]

**Co-author:** Harish Mohan Mittal Guide [1]

[1] *NIT Jalandhar*

**Corresponding Authors:** annanyamahajan865@gmail.com, mitalhm@nitj.ac.in

The Semi-classical models like Vibration Distortion Model and Particle Rotor Model have been employed to analyze new perspectives in superdeformed bands in A ≈
190 mass region especially in Hg isotopes for the first time. The transition energies, band head spin, alignment, and moments of inertia are determined by employing the models. In addition, the effect of vibrational mode in the high spin rotational structure of the superdeformed bands in A ≈
190 mass region in Hg isotopes has been established using Vibration Distortion Model.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**56**

## Description of moment of inertia of superdeformed bands in lower mass region

**Authors:** Annanya Mahajan[1]; Harish Mohan Mittal Guide[1]

[1] *NIT Jalandhar*

**Corresponding Authors:** annanyamahajan865@gmail.com, mitalhm@nitj.ac.in

The Variable moment of inertia (VMI) and its extension based on Nuclear Softness (VMINS3) concept with three parameters have been applied to comprehend the systematic of the superdeformed rotational bands (SDRB) in A ≈ 60-90 lower mass region. The band head spin has been assigned to all SD bands used in the present manuscript using VMI and VMINS3 model. The experimental transition energies have been least square fitted to obtain parameters of the model. The variation of the experimental kinematic moment of inertia J(1) and dynamic moment of inertia J(2) against the NpNn product are examined in A ≈ 60-90 lower mass region. In addition, the comparison between experimental and calculated J(2) is drawn out against rotational frequency $\hbar\omega$ and the variation of band head moment of inertia J0 with softness parameter σ is also examined.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**session #11 / 57**

## Shape coexistence of octupole shapes in the superheavy nucleus $^{286}$No

**Author:** Peter Ring[1]

[1] *Technical University Munich, Peking University*

Covariant density functional theory is applied on a three-dimensional lattice in a microscopic and fully self-consistent manner, without imposing any symmetry restrictions 1, to investigate the superheavy nucleus $^{286}$No. Our findings reveal that the ground state exhibits a distinct non-axial octupole shape, which coexists with a tetrahedral isomeric state. The energy difference between these states is merely 0.12 MeV, and they are separated by a potential barrier of approximately 0.5 MeV. We analyze the presence of octupole correlations by examining the evolution of single-particle levels near the Fermi surface, which are influenced by octupole deformations [2].

1 B. Li, Z.X. Ren, P. W. Zhao, Phys. Rev. C 102 (2020) 044307
[2] F. F. Xu, B. Li, P. Ring, P. W. Zhao, Phys. Lett. B 856 (2024) 138893

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**session #8 / 58**

## Cluster aspects of ground and excited states: monopole and dipole excitations

**Author:** Yoshiko Kanada-En'yo[1]

[1] *Kyoto University*

**Corresponding Author:** yenyo@ruby.scphys.kyoto-u.ac.jp

Nuclear systems show two kinds of natures, i.e., cluster and mean field aspects, providing rich phenomena in nuclei. The cluster aspect is found in ground state correlations, which induce nuclear deformations and polygon shapes such as the triangle of $^{12}$C and tetrahedron of $^{16}$O. In the excited states, it contributes to low-lying monopole and dipole excitations. Proton and alpha scattering reactions are useful in clarifying the properties of those cluster states. Particular attention is paid on the monopole transitions via inelastic scattering. The monopole mode in $^{8}$He is also discussed.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 59**

## Ab-initio reaction calculation for t(p,n)3He

**Author:** Shigeyoshi Aoyama[1]

[1] *KEK CRC*

**Corresponding Author:** aoyamash@post.kek.jp

The issue of tritium water caused by the Fukushima nuclear power plant disaster has become a social problem.  In this presentation, the tritium transmutation reaction to 3He is analyzed and reported from the viewpoint of ab-initio calculation of nuclear force.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 60**

## Statistical analysis of nuclear low-lying states and double-beta decay with a covariant energy density functional

**Author:** Xin Zhang[1]

**Co-authors:** Jiangming Yao [2]; Chenrong Ding [2]; Chencan Wang [2]

[1] *Kyoto University*

[2] *Sun Yat-Sen University*

**Corresponding Authors:** zhang.xin.38d@st.kyoto-u.ac.jp, yaojm8@mail.sysu.edu.cn

We present a statistical analysis of nuclear low-lying states within the framework of multireference covariant density functional theory (MR-CDFT) using a relativistic point-coupling energy density functional (EDF). This study is made possible by the newly developed subspace-projected (SP)-CDFT, where the wave functions of nuclear low-lying states for target EDF parameter sets are expanded in a subspace spanned by the wave functions of low-lying states from training parameter sets. We analyze the global sensitivity of excitation energies, electric quadrupole transition strengths, and the nuclear matrix element of neutrinoless double-beta decay in $^{150}Sm$ and $^{150}Nd$ to EDF parameters, and explore the correlations between these quantities and nuclear matter properties. Furthermore, we quantify the statistical uncertainty of low-lying states through their posterior distributions.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**session #7 / 61**

## Single-Neutron Excitations Outside of $^{132}$Sn and the Fate of Spin-Orbit Partners in Weakly Bound Systems

**Author:** Benjamin P. Kay[1]

[1] *Physics Division, Argonne National Laboratory*

**Corresponding Author:** kay@anl.gov

Recent works using direct reactions and the solenoidal-spectrometer technique have revealed insights into the single-particle structure of weakly bound nuclei. Using CERN's HIE-ISOLDE facility and the ISOLDE Solenoidal Spectrometer, the single-neutron strengths and energies of the $1f_{7/2}$, $2p_{3/2}$, $2p_{1/2}$, $0h_{9/2}$, $1f_{5/2}$, and $0i_{13/2}$ valence neutron orbitals outside of doubly magic $^{132}$Sn have been determined via the $^{132}$Sn($d$,$p$)$^{133}$Sn reaction at 7.65 MeV per nucleon. The results suggest that the single-neutron strength for each orbital is carried in a single excitation, affirming the notion that 132Sn, the heaviest short-lived doubly magic nucleus, exhibits one of the strongest shell closures of all nuclei. These data and other data for weakly bound $N \approx 20$ and 28 nuclei have revealed a decrease in the separation of spin-orbit partners in line with the predictions of the late Professor Hamamoto's work. I attempt to show this reduction in a systematic way using experimental data.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 62**

## Shell model calculation for medium-heavy nuclei based on effective interaction derived from the VS-IMSRG method

**Author:** Takumi Shoji[1]

**Co-authors:** Noritaka Shimizu [1]; Takayuki Miyagi [1]

[1] *University of Tsukuba*

**Corresponding Authors:** miyagi@nucl.ph.tsukuba.ac.jp, shimizu@nucl.ph.tsukuba.ac.jp, shoji@nucl.ph.tsukuba.ac.jp

We have investigated the nuclear structure properties of the medium-heavy nucleus like Cd isotopes in the framework of the nuclear shell model.
We have used the ab initio shell model Hamiltonian from the in-medium Similarity Renormalization Group (IMSRG) approach.
Here, two types of IMSRG approaches have been used, namely IMSRG(2) and a factorized approximation of IMSRG(3).
In this work, using these approaches we calculated 2 neutron separation energies, excitation energies and some other physical quantities.
In our analysis, we have found that the IMSRG(2) approach overestimates the 2+ excitation energies of the Cd isotopes about two factor than experimental one.
On the other hands, a factorized approximation of IMSRG(3) has been developed, which reproduces the 2+ excitation energies of Cd isotopes more reasonable than IMSRG(2) approach.
We will discuss our recent shell model results of nuclear structure properties of medium-heavy nucleus in comparison with experimental data and also discuss the origin of difference between the two ab initio approaches IMSRG(2) and IMSRG(3).

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Session #3 / 63**

## Nuclear collective excitation based on the finite-amplitude method for the quasiparticle random-phase approximation

**Author:** Nobuo Hinohara[1]

[1] *University of Tsukuba*

**Corresponding Author:** hinohara@nucl.ph.tsukuba.ac.jp

Nuclear collective excitation such as giant resonances provides valuable information on understanding the structure of finite nuclei and the equation of state for infinite nuclear matter. The quasiparticle random-phase approximation (QRPA) is a suitable theoretical framework that is capable of

describing collective excitation as a superposition of the two-quasiparticle excitation, but it requires a large-dimensional matrix diagonalization and large computational resources.
The finite-amplitude method (FAM) 1 has been proposed as a solution of the QRPA problem under the presence of a one-body external field. The FAM is an iterative approach that makes is possible to calculate the strength distribution function of giant resonance without additional truncation in the two-quasiparticle model space. Combined with a contour integration technique in the complex-energy plane for the applied frequency of the external field, discrete low-energy collective states as well as the sum-rule values can be obtained [2,3]. The formulation based on the contour integration enables us to compute various types of the QRPA solutions, such as the low-energy collective modes, beta-decay rates, zero-energy pairing rotational modes, sum rules, and the nuclear matrix elements of the double-beta decay. I will review the recent progress and applications of the FAM for various problems including very recent extensions for further reduction of the computational costs based on the reduced basis method [3].
1 T. Nakatsukasa, T. Inakura, and K. Yabana, Phys. Rev. C 76, 024318 (2007).
[2] N. Hinohara, M. Kortelainen, and W. Nazarewicz, Phys. Rev. C 87, 064309 (2013).
[3] C. Drischler, J. A. Melendez, R. J. Furhnstahl, A. J. Garcia, and X. Zhang, Front. Phys. 10, 1092931 (2023).

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 64**

## Measurements of Isomer Ratio for $^{12}$Be beams and Precise Branching Ratio and Half-Life

**Author:** Ryo Taguchi[1]

**Co-authors:** Akira Ozawa [2]; Asahi Yano [2]; Atsushi Kitagawa [3]; Chihaya Fukushima [4]; Daiki Nishimura [5]; Gen Takayama [6]; Hiroyuki Takahashi [7]; Junta Sonoda [4]; Kazuya Takatsu [8]; Keigo Yasuda [1]; Kengo Okubo [9]; Kenta Sasaki [9]; Kohei Watanabe [10]; Koki Tezuka [11]; Masaomi Tanaka [12]; Mei AMITANI ; Miki Fukutome [1]; Mitsunori Fukuda [1]; Mototsugu Mihara [1]; Norihide Noguchi [8]; Rinon Kageyama [13]; Satoru Nishizawa [9]; Shigekazu Fukuda [3]; Shinji Sato [3]; Sora Sugawara [4]; Soshi Ishitani [1]; Takashi Ohtsubo [8]; Takato Sugisaki [1]; Takayuki Yamaguchi [9]; Takeshi Suzuki [9]; Takuji Izumikawa [14]; Tetsuaki Moriguchi [2]; Toshiya Shimamura [11]; Yukari Koizumi [9]; Yuki Nakamura ; Yuki Tazawa [8]; Yuta Kikuchi [10]

[1] *Osaka University*

[2] *Univ. of Tsukuba*

[3] *QST*

[4] *Tokyo City University*

[5] *Tokyo City Univercity*

[6] *Osaka Univ.*

[7] *tokyo city university*

[8] *Niigata Univ.*

[9] *Saitama Univ.*

[10] *Saitama University*

[11] *Niigata University*

[12] *Kyushu Univ.*

[13] *Tokyo City Univeisity*

[14] *Niigata Univ. RI*

**Corresponding Authors:** ozawa@tac.tsukuba.ac.jp, dnishimu@tcu.ac.jp, ishitani@ne.phys.sci.osaka-u.ac.jp, mihara@vg.phys.sci.osa u.ac.jp, taguchi@ne.phys.sci.osaka-u.ac.jp, asahi.yano@riken.jp, g2381902@tcu.ac.jp, tohtsubo@np.gs.niigata-u.ac.jp, takayama@ne.phys.sci.osaka-u.ac.jp, moriguchi@tac.tsukuba.ac.jp, mtanaka@artsci.kyushu-u.ac.jp, fukutome@ne.phys.sci.osaka-u.ac.jp, g2381908@tcu.ac.jp, yamaguti@mail.saitama-u.ac.jp, g2481904@tcu.ac.jp, g2381906@tcu.ac.jp, tezuka@np.gs.niigata-u.ac.jp, shimamura@np.gs.niigata-u.ac.jp, yasuda@ne.phys.sci.osaka-u.ac.jp, s.nishizawa.746@ms.saitama-u.ac.jp, k.watanabe.210@ms.saitama-u.ac.jp, y.kikuchi.985@ms.saitama-u.ac.jp, mfukuda@phys.sci.osaka-u.ac.jp, izumika@med.niigata-u.ac.jp, suzuki@mail.saitama-u.ac.jp, g2181904@tcu.ac.jp, b3d34f4c7286wpq40@gmail.com, k.sasaki.509@ms.saitama-u.ac.jp, fukuda.shigekazu@qst.go.jp, tazawa@np.gs.niigata-u.ac.jp, g2017037@tcu.ac.jp, sato.shinji@qst.go.jp, k.okubo.813@ms.saitam u.ac.jp, y.koizumi.365@ms.saitama-u.ac.jp, sugisaki@ne.phys.sci.osaka-u.ac.jp, kitagawa.atsushi@qst.go.jp, takatsu@np.gs.niigata-u.ac.jp

The study of isomeric states in nuclei is crucial for understanding the nuclear structure, as these states often exhibit structures significantly different from their ground states. The neutron-rich nucleus $^{12}$Be has an isomeric $0_2^+$ at $E_x = 2.3$ MeV with a half-life of 230 ns (see level diagram in the upper right of Fig. 1). This state undergoes deexcitation via an E2 transition through an intermediate $2_1^+$ state or via an E0 transition directly to the $0_1^+$ ground state, accompanied by positron annihilation $\gamma$-rays produced through E0 internal pair production.
Previous studies[1, 2] have indirectly suggested that the isomeric state in $^{12}$Be exhibits a large nuclear radius based on $\gamma$-ray measurements. However, it is still an open problem due to the uncertainties of that discussion. Thus, we propose a direct measurement of the radius of the isomeric state in $^{12}$Be via its interaction cross section. Since producing a pure beam of isomeric $^{12}$Be is challenging, we aim to measure interaction cross sections using beams with different isomer ratios, where the isomer ratio represents the fraction of isomeric nuclei within the beam.
In this study, $^{12}$Be beams were produced at the HIMAC synchrotron facility through the projectile fragmentation of $^{13}$C and $^{18}$O beams on Be or Al targets at 250 MeV/nucleon. The isomer ratios of the $^{12}$Be beams were measured, and the branching ratio and the half-life of the isomeric state were determined with high precision by analyzing delayed $\gamma$-rays emitted from stopped $^{12}$Be. The time spectrum of these delayed $\gamma$-rays is shown in Fig. 1. The results of these measurements will be presented and the dependence of the isomer ratio on beam conditions will be discussed.

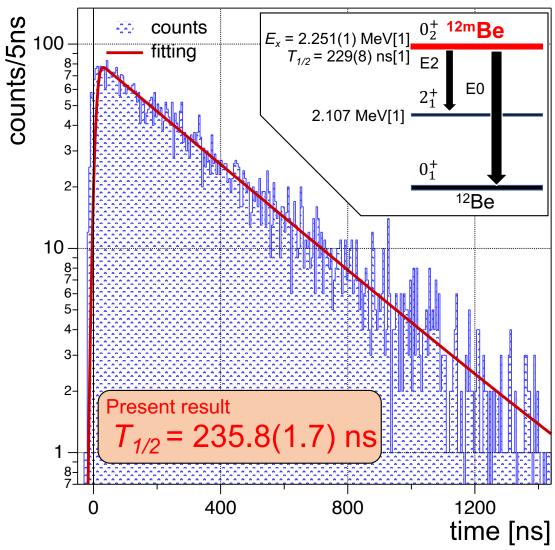


Figure 2: The level diagram of $^{12}$Be below its isomeric state (upper right) and the time spectrum of the delayed annihilation gamma-rays with the present fitted result. The energy levels and half-life values in the level diagram are adopted from Ref. [1].

Reference
[1] S. Shimoura et al., Phys. Lett. B. 654, 87 (2007).
[2] I. Hamamoto and S. Shimoura, J. Phys. G: Nucl. Part. Phys. 34, 2715 (2007).

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 65**

# Study of nuclear structure in $^{32}$Al and $^{33}$Al by $\beta$-delayed-neutron decay of spin-polarized $^{33}$Mg

**Authors:** M. Matsuda[1]; R. Miyahara[1]; A. Odahara[1]; Y. Yamamoto[2]; H. Nishibata[2]; T. Shimoda[1]; N. Itakura[1]; Nurhafiza M. Nor[1]; J. Lassen[3]; R. Li[3]; A. Teigelhoefer[3]; R. Yasuda[4]; A. Hatakeyama[4]; Y. Hirayama[5]; S. Iimura[6]; M. M. Rajabali[7]

[1] *Dept. of Phys., Osaka Univ.*

[2] *Dept. of Phys., Kyushu Univ.*

[3] *TRIUMF*

[4] *TUAT*

[5] *KEK*

[6] *Dept. of Phys., Rikkyo Univ.*

[7] *Dept. of Phys., Tennessee Tech Univ.*

**Corresponding Authors:** odahara@phys.sci.osaka-u.ac.jp, matsuda@ne.phys.sci.osaka-u.ac.jp

Shape coexistence has been observed in nuclei located close to the "Island of Inversion", where the disappearance of the magic number $N$ = 20 is well known. This nuclear structure is one of the important topics that has been extensively studied both experimentally and theoretically. Our group has systematically investigated nuclear structure in this mass region, focusing on the isotopes of Mg and Al. We have used our original method to clearly confirm spin and parity of the states in daughter nuclei using $\beta$-ray spatial asymmetry. In 2023, experiment on $\beta$- and $\beta$-delayed-neutron decays of $^{33}$Mg to $^{33}$Al ($N$=20) and to $^{32}$Al, respectively, was performed using a spin-polarized beam at TRIUMF in Canada.
As neutron-rich nucleus $^{33}$Al has large $\beta$-decay $Q$ value and low neutron-separation energy, it is important to measure not only $\gamma$-ray, but also neutron in the energy of several tens of keV to several MeV. Spin polarized $^{33}$Mg beam with energy of 30 keV and intensity of 8 kpps was implanted into MgO stopper which was surrounded by magnets with magnetic field of 0.34 T to keep the spin polarization. The polarization of this beam was around 8.2%. Gamma ray was detected by seven Ge detectors. $\beta$-ray was measured by ten plastic scintillators. The $\beta$-decay spatial asymmetry was obtained by using data from two of $\beta$-ray detectors, which were positioned along the polarization axis. $\beta$-delayed neutron was detected by ten plastic scintillators and one Li glass scintillator for high- and low-energy neutron, respectively.
In order to construct the decay scheme of $\beta$-delayed neutron of $^{33}$Mg to $^{32}$Al, $\beta$-$\gamma$-n coincidence data has been analyzed. The energy of the $\beta$-delayed neutron is deduced using time-of-flight (TOF) method. Using this neutron information, the level scheme of the neutron unbound states in $^{33}$Al has been also constructed. These states are compared to theoretical calculation using large scale shell model to understand nuclear structure such as shape coexistence in these nuclei.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 66**

# Towards the study of neutron-distribution in unstable nuclei through low-energy electron scattering

**Author:** Rika Danjo[1]

**Co-authors:** Clement Legris [2]; Kengo Hotta [3]; Toshimi Suda [3]

[1] *Tohoku University, Research Center for Accelerator and Radioisotope Science*

[2] *Tohoku University*

[3] *RARiS, Tohoku University*

**Corresponding Authors:** suda@lns.tohoku.ac.jp, rika.danjo.t8@dc.tohoku.ac.jp, legris.clement.victor.r5@dc.tohoku.ac.jp, kengo.hotta.q6@dc.tohoku.ac.jp

The charge density distributions of nuclei, ρ(r), are the best determined by elastic electron scattering, and those of the stable nuclei that have been studied so far have played an essential role in revealing their internal structure.

Recently, the 4th-order moment of the charge density distribution, $< r_c^4 >$, is shown to be a novel way to access neutron-distribution radius (ref.1).

Experimental determination of $<r_c^4 > canbeperformedbythetwomethods; 1) obtainedfromthe (r) derivedfromthe$ dependence), and 2) obtained via Taylor expansion of F(q) at low q region.

In the year 2023, the world's first electron scattering for online-produced neutron-rich unstable nuclei has been successfully conducted at the SCRIT facility of RIKEN (ref. [2]). Here, it is interesting to point out that elastic electron scattering for unstable nuclei at low q region may allow access to the neutron-distribution radius of neutron-rich unstable nuclei using the method 2) as well as the proton-distribution radius.

In reality, F(q) cannot be obtained directly, instead we usually use ρ(r) from the cross section to calculate $< r_c^4 >$ . However, for the method 2), F(q) is essential. Therefore to use the method 2), we are proposing a new approach to extract $<r_c^4 > withintheframeworkofPlaneWaveBornApproximation(PWBA), b$ as a benchmark. In addition to the theoretical approach, experimental verification is currently underway at the low energy facility (ULQ2) at RARiS, Tohoku University. In this talk, I will discuss the current status of this project and also the future possibilities at the SCRIT facility.

Reference

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[2] K. Tsukada, "The first electron scattering has been successfully performed at the self-confining radioactive-isotope ion target (SCRIT)facility", Phys. Rev. Lett. 131.092502(2023).

R. Danjo[1], T. Goke[1], Y. Honda[1], K. Hotta[1], C. Legris[1], Y. Maeda[3], T. Muto[1], T. Ohnishi[2], H. Sakaguchi[4], T. Suda[1], T. Suzuki[1], K. Tsukada[2,5], T. Yamauchi[1], K. Yoshimoto[1]

1: Research Center for Accelerator and Radioisotope Science
2: Nishina Center for Accelerator-Based Science, RIKEN
3: Faculty of Engineering, Miyazaki University
4: Research Center for Nuclear Physics, Osaka University
5: Institute for Chemical Research, Kyoto University

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 67**

## Neutron-rich nuclei around $^{78}$Ni with the VS-IMSRG-based interaction

**Author:** ANIL KUMAR[1]

**Co-authors:** Noritaka Shimizu [2]; Takayuki Miyagi [2]; Yusuke Tsunoda [3]; Yutaka Utsuno [4]

[1] *Center for Computational Sciences, University of Tsukuba, Tsukuba, Japan*

[2] *CCS, University of Tsukuba, Japan*

[3] *CNS, Tokyo University, Japan*

[4] *JAEA, Tokai, Japan*

**Corresponding Author:** anil@nucl.ph.tsukuba.ac.jp

Exploring the nuclear shell structure of neutron-rich $N = 50$ nuclei is one of the most interesting and mysterious phenomena in nuclear physics, and it has become the forefront of both experimental and theoretical research in recent years. We have constructed the shell model Hamiltonian in the $\pi(fp)$-$\nu(sdg)$ model space based on {\it ab-initio} approach VS-IMSRG(3f$_2$) with minimal phenomenological adjustments to the single-particle energies to reproduce the recently available experimental data in $N = 50$ region. To perform the large-scale shell model calculations, we have carried out the state-of-the-art advanced Monte-Carlo Shell Model (MCSM) to interpret the nuclear structure properties of nuclei near the neutron magic number $N = 50$. Our MCSM calculated nuclear structure properties with the new shell model Hamiltonian based on VS-IMSRG(3f$_2$) is obtained in a rather good qualitative agreement with the experimental data and previous shell model predictions. The prediction of structural properties in the $N = 50$ region has important implications for nuclear astrophysics, as they influence nucleosynthesis pathways and contribute to the distribution of elemental abundance in the universe.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 68**

## Non-Axial Octupole Deformation in Atomic Nuclei: A Group-Theoretical Comparison of Tetrahedral and Octahedral Symmetries

**Author:** Xiaosheng Xing[1]

**Co-author:** Kenichi Yoshida

[1] *RCNP*

**Corresponding Authors:** xxing@rcnp.osaka-u.ac.jp, kyoshida@rcnp.osaka-u.ac.jp

Recent experimental advancements have provided substantial evidence for octupole deformation in atomic nuclei, revealing complex deformation modes beyond the quadrupole level. Conventional axially symmetric models struggle to fully capture these deformations, necessitating an exploration of non-axial modes. Previous studies employing the Oh group symmetry faced limitations, as spatial inversion symmetry inherently excludes rotational degrees of freedom in the decomposition of $l$ = 3 spherical harmonics. To overcome this, we investigate the $T_d$ (tetrahedral) and $O$ (octahedral) groups, both of which successfully yield the $T_1$ irreducible representation—associated with rotational degrees of freedom—allowing for the construction of an intrinsic coordinate system for

octupole deformation. However, differences in the decomposition of one-dimensional irreducible representations under $T_d$ and $O$ symmetries lead to distinct linear combinations of spherical harmonics as basis functions. This raises fundamental questions regarding the optimal choice of symmetry for parameterizing octupole deformation in nuclei. By systematically exploring these symmetry constraints, this work aims to establish a robust group-theoretical framework for describing non-axial octupole modes, paving the way for refined theoretical models of nuclear structure.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 69**

## Alpha particles as building block of 16O ground state probed by alpha knockout reaction

**Author:** Taichi Miyagawa[1]

**Co-authors:** COLLABORATION ONOKORO ; Junki Tanaka [2]

[1] *Research Center for Nuclear Physics, Osaka university*

[2] *Research Center for Nuclear Physics, Osaka U*

**Corresponding Authors:** junki@rcnp.osaka-u.ac.jp, miyatai@rcnp.osaka-u.ac.jp

Can alpha particles be the basic building blocks of atomic nuclei? The conventional mean-field picture with nucleons as basic degrees of freedom is considered to dominate, particularly in the ground state of the doubly magic nucleus 16O. On the other hand, alpha cluster theories have predicted their existence in the ground state of 16O [1, 2, 3]. Recently, proton-induced alpha-knockout reactions have been established as an effective probe for studying alpha clusters in the nuclei [4]. The reaction cross section of 16 O(p, pα) is a good measure for the number of alpha clusters.
We performed an experiment at RCNP using a 400 MeV proton beam incident on an oxygen-containing target. A double-arm spectrometer analyzed the energies and momenta of recoil protons and alpha particles emitted by the 16 O(p, pα)12 C reaction.
The measured alpha separation energy spectrum and its yield provide direct evidence of alpha clusters in the ground state of ^{16}O. Furthermore, the spectrum reveals three distinct peaks, each corresponding to different types of alpha cluster motion inside the nucleus. Ongoing analysis of the momentum distribution of alpha clusters in ^{16}O will further clarify their motion.
we will discuss the experimental results of the 16O(p,pα)12C reaction and their interpretation.

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[4] J. Tanaka, Z.H. Yang et. al, Science 371, 260-264 (2021).

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 70**

## Nuclear moment measurements of 130Sn and 132Sn isomers at RIBF

**Author:** Ryusei Matsui[1]

**Co-authors:** Georgi Georgiev [2]; Shintaro Go [3]; Yuichi Ichikawa [1]

[1] *Kyushu University*

[2] *IJCLab, Orsay, France*

[3] *RIKEN Nishina Center*

**Corresponding Authors:** matsui.ryusei.752@s.kyushu-u.ac.jp, georgi.georgiev@ijclab.in2p3.fr, yuichikawa@phys.kyushu-u.ac.jp, go@riken.jp

The doubly-magic nucleus $^{132}$Sn and its surrounding nuclei are expected to provide crucial insights into the nuclear shell model structure. In order to extend the nuclear structure studies for low lying states so far, here we carried out the measurement of nuclear magnetic moments of $^{130}$Sn and $^{132}$Sn, by focusing on their higher spin isomeric states. The $^{130}$Sn and $^{132}$Sn isomers have excitation energies of 2435 keV and 4715 keV, half-lives of 1.6 $\mu$s and 20 ns, and spin-parity of $10^+$ and $6^+$, respectively.

The experiments were conducted at the RIKEN RIBF. The nuclear moments of the $^{130}$Sn and $^{132}$Sn isomers were measured by means of the Time-Dependent Perturbed Angular Distribution (TDPAD) method and the Time-Dependent Perturbed Angular Correlation (TDPAC) method, respectively.

In this poster, we will present the production of $^{130}$Sn and $^{132}$Sn isomers through the BigRIPS spectrometer, the principles and setup of the TDPAD and TDPAC measurements, and the prospects for future data analysis.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 71**

## Effects of antisymmetric spin-orbit forces due to three-body nuclear forces using density functional theory

**Author:** Hiroki Kida[1]

[1] *Kyushu university*

**Corresponding Author:** kida.hiroki.324@s.kyushu-u.ac.jp

Density functional theory, widely adopted in nuclear physics, incorporates many-body correlations by expressing the interaction between nucleons constituting a nucleus using a density-dependent Hamiltonian. In addition to two-body nuclear forces, three-body nuclear forces are known to be important in the interaction between nucleons, and density functional theories of the Skyrme and Gogny types have been proposed. The parameters related to the interactions that appear in the density functional are determined to reproduce the typical properties of nuclei, such as radius, density saturation, and mass. However, the strengths of the two-body and three-body nuclear forces used in the above density functional are determined in light of experimental facts about nuclei, and thus do not necessarily embody the actual properties of nuclear forces. Therefore, there have been active

attempts to explain the properties of nuclei from realistic interactions. A study of large-scale shell model calculations using nuclear forces obtained from chiral effective field theory has revealed that three-body nuclear forces have a large influence on the spin-orbit splitting produced by spin-orbit forces, and in particular, the contribution of the vector component of three-body nuclear forces, called the antisymmetric spin-orbit force, is dominant. However, the nuclei investigated in this study are mainly limited to light nuclei, and the qualitative effects of three-body nuclear forces on spin-orbit splitting are not yet known for heavy nuclei. The purpose of this study is to formulate the antisymmetric spin-orbit force derived from chiral effective field theory based on density functional theory and to investigate its effect by adding it to the conventional density functional. The Skyrme-Hatree-Fock+BCS method is employed as the density functional to obtain single-particle energies and spin-orbit splittings for tin isotopes, which are medium-heavy nuclei. The results show that the antisymmetric spin-orbit force has the property of decreasing the radius of the nucleus and decreasing the single-particle energy. This is an effect that cannot be produced by the spin-orbit force due to the two-body nuclear force alone.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 72**

## Measurement of interaction cross sections for neutron-rich nuclei in the vicinity of Z=14 at RIBF

**Author:** Kento Matsuyama[1]

**Co-authors:** Chinami Inoue [2]; Daiki Nishimura [3]; Tetsuaki Moriguchi [4]; Ryo Taguchi [5]; Gen Takayama [6]; Masaomi Tanaka [7]; Asahi Yano [4]; Kazuhiro Adachi [8]; Mei AMITANI ; Hidetada Baba [9]; Mitsunori Fukuda [5]; Naoki Fukuda [9]; Chihaya Fukushima [10]; Miki Fukutome [5]; Kensuke Kusaka [9]; Yuto Ichinohe [9]; Soshi Ishitani [5]; Nao Ito [10]; Rinon Kageyama [11]; Yuta Kikuchi [12]; Naoyuki Kitagawa [13]; Hayato Kobayashi [14]; Shin'ichiro Michimasa [9]; Mototsugu Mihara [5]; Misaki Mikawa [15]; Maoto Mitsui [15]; Yuki Nakamura ; Satoru Nishizawa [12]; Masao Ohtake [9]; Takashi Ohtsubo [16]; Akira Ozawa [4]; Rena Sasamori [8]; Toshiya Shimamura [8]; Yohei Shimizu [9]; Hiroshi Suzuki [9]; Hiroyuki Takeda [9]; Kazuki Takiura [12]; Koki Tezuka [8]; Yasuhiro Togano [9]; Nao Tomioka [12]; Tasuku Tsujisaka [5]; Kohei Watanabe [12]; Takayuki Yamaguchi [17]; Yoshiyuki Yanagisawa [9]; Keigo Yasuda [5]; Masahiro Yoshimoto [9]; Hanbin Zhang [15]

[1] *Tokyo city university*

[2] *Tokyo City Univerisity*

[3] *Tokyo City Univercity*

[4] *Univ. of Tsukuba*

[5] *Osaka University*

[6] *Osaka Univ.*

[7] *Kyushu Univ.*

[8] *Niigata University*

[9] *RIKEN Nishina Center*

[10] *Tokyo City University*

[11] *Tokyo City Univeisity*

[12] *Saitama University*

[13] *Kyushu University*

[14] *Univiersity of Tsukuba*

[15] *University of Tsukuba*

[16] *Niigata Univ.*

[17] *Saitama Univ.*

**Corresponding Authors:** ozawa@tac.tsukuba.ac.jp, g2117006@tcu.ac.jp, dnishimu@tcu.ac.jp, togano@ribf.riken.jp, ishitani@ne.phys.sci.osaka-u.ac.jp, mihara@vg.phys.sci.osaka-u.ac.jp, taguchi@ne.phys.sci.osaka-u.ac.jp, asahi.yano@riken.jp, g2381902@tcu.ac.jp, tohtsubo@np.gs.niigata-u.ac.jp, takayama@ne.phys.sci.osaka-u.ac.jp, moriguchi@tac.tsukuba.ac.jp, mtanaka@artsci.kyushu-u.ac.jp, fukutome@ne.phys.sci.osaka-u.ac.jp, g2381908@tcu.ac.jp, yamaguti@mail.saitama-u.ac.jp, masahiro.yoshimoto@riken.jp, hsuzuki@ribf.riken.jp, tsujisaka@ne.phys.sci.osaka-u.ac.jp, g2481904@tcu.ac.jp, ichinohe@ribf.riken.jp, yanagisa@riken.jp, yshimizu@ribf.riken.jp, g2381906@tcu.ac.jp, n.tomioka.116@ms.saitama-u.ac.jp, nfukuda@riken.jp, g2117007@tcu.ac.jp, tezuka@np.gs.niigata-u.ac.jp, baba@ribf.riken.jp, shimamura@np.gs.niigata-u.ac.jp, sasamori@np.gs.niigata-u.ac.jp, s2111572@u.tsukuba.ac.jp, kitagawa.naoyuki.809@s.kyushu-u.ac.jp, s2420197@u.tsukuba.ac.jp, yasuda@ne.phys.sci.osaka-u.ac.jp, s.nishizawa.746@ms.saitama-u.ac.jp, mohtake@riken.jp, adachi@np.gs.niigata-u.ac.jp, s2420198@u.tsukuba.ac.jp, mitimasa@riken.jp, takeda@ribf.riken.jp, kkusaka@riken.jp, g2117055@tcu.ac.jp, s2320200@u.tsukuba.ac.jp, k.watanabe.210@ms.saitama-u.ac.jp, y.kikuchi.985@ms.saitama-u.ac.jp, k.takiura.439@ms.saitama-u.ac.jp, mfukuda@phys.sci.osaka-u.ac.jp

The interaction cross section is a key physical quantity for deducing nuclear radii and plays an essential role in understanding nuclear structure, particularly for neutron-rich isotopes. In this study, we measured the interaction cross sections of Al, Si, and P isotopes near Z=14 to investigate their mass-number dependence and explore nuclear deformation effects.
The experiment was carried out at the RI Beam Factory (RIBF) of RIKEN utilizing the BigRIPS separator. A primary 70Zn beam was accelerated to 345 MeV/u and directed onto Be target positioned at F0, generating a secondary beam that included the isotopes of interest. This secondary beam, with an approximate energy of 250 MeV/u, was subsequently transported through BigRIPS, where particle identification was achieved via the TOF-Bρ-ΔE method. The time-of-flight (TOF) was measured using plastic scintillators placed at the F3, F5, and F7 focal planes, while the energy loss (ΔE) was measured with ionization chambers (ICs) at F3 and F7.
A wedge-shaped C target with a central thickness of 1.5 g/cm² was placed at the F5 focal plane. The interaction cross sections were determined using the transmission method, which evaluates the exponential attenuation of particle counts due to nuclear reactions within the target. By comparing the particle identification results before and after the target, the interaction cross sections were extracted.
The obtained interaction cross sections exhibit an increasing trend with mass number. Further analysis will focus on extracting nuclear radii from the measured cross sections and exploring possible contributions from nuclear deformation and differences in proton and neutron distributions.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 73**

## Measurement of the interaction cross sections for nuclei near the N=Z line between 40Ca and 56Ni

**Author:** Chinami Inoue[1]

**Co-authors:** Kento Matsuyama [2]; Daiki Nishimura [3]; Tetsuaki Moriguchi [4]; Ryo Taguchi [5]; Gen Takayama [6]; Masaomi Tanaka [7]; Asahi Yano [4]; Kazuhiro Adachi [8]; Mei AMITANI ; Hidetada Baba [9]; Mitsunori Fukuda [5]; Naoki Fukuda [9]; Chihaya Fukushima [1]; Miki Fukutome [5]; Kensuke Kusaka [9]; Yuto Ichinohe [9]; Soshi Ishitani [5]; Nao Ito [1]; Rinon Kageyama [10]; Yuta Kikuchi [11]; Naoyuki Kitagawa [12]; Hayato Kobayashi [13]; Shin'ichiro Michimasa [9]; Mototsugu Mihara [5]; Misaki Mikawa [14]; Maoto Mitsui [14]; Yuki Nakamura ; Satoru Nishizawa [11]; Masao Ohtake [9]; Takashi Ohtsubo [15]; Akira Ozawa [4]; Rena Sasamori [8]; Toshiya Shimamura [8]; Yohei Shimizu [9]; Hiroshi Suzuki [9]; Hiroyuki Takeda [9]; Kazuki Takiura [11]; Koki Tezuka [8]; Yasuhiro Togano [9]; Nao Tomioka [11]; Tasuku Tsujisaka [5]; Kohei Watanabe [11]; Takayuki Yamaguchi [16]; Yoshiyuki Yanagisawa [9]; Keigo Yasuda [5]; Masahiro Yoshimoto [9]; Hanbin Zhang [14]

[1] *Tokyo City University*

[2] *Tokyo city university*

[3] *Tokyo City Univercity*

[4] *Univ. of Tsukuba*

[5] *Osaka University*

[6] *Osaka Univ.*

[7] *Kyushu Univ.*

[8] *Niigata University*

[9] *RIKEN Nishina Center*

[10] *Tokyo City Univeisity*

[11] *Saitama University*

[12] *Kyushu University*

[13] *Univiersity of Tsukuba*

[14] *University of Tsukuba*

[15] *Niigata Univ.*

[16] *Saitama Univ.*

**Corresponding Authors:** ozawa@tac.tsukuba.ac.jp, g2117006@tcu.ac.jp, dnishimu@tcu.ac.jp, togano@ribf.riken.jp, ishitani@ne.phys.sci.osaka-u.ac.jp, mihara@vg.phys.sci.osaka-u.ac.jp, taguchi@ne.phys.sci.osaka-u.ac.jp, asahi.yano@riken.jp, g2381902@tcu.ac.jp, tohtsubo@np.gs.niigata-u.ac.jp, takayama@ne.phys.sci.osaka-u.ac.jp, moriguchi@tac.tsukuba.ac.jp, mtanaka@artsci.kyushu-u.ac.jp, fukutome@ne.phys.sci.osaka-u.ac.jp, g2381908@tcu.ac.jp, yamaguti@mail.saitama-u.ac.jp, masahiro.yoshimoto@riken.jp, hsuzuki@ribf.riken.jp, tsujisaka@ne.phys.sci.osaka-u.ac.jp, g2481904@tcu.ac.jp, ichinohe@ribf.riken.jp, yanagisa@riken.jp, yshimizu@ribf.riken.jp, g2381906@tcu.ac.jp, n.tomioka.116@ms.saitama-u.ac.jp, nfukuda@riken.jp, g2117007@tcu.ac.jp, tezuka@np.gs.niigata-u.ac.jp, baba@ribf.riken.jp, shimamura@np.gs.niigata-u.ac.jp, sasamori@np.gs.niigata-u.ac.jp, s2111572@u.tsukuba.ac.jp, kitagawa.naoyuki.809@s.kyushu-u.ac.jp, s2420197@u.tsukuba.ac.jp, yasuda@ne.phys.sci.osaka-u.ac.jp, s.nishizawa.746@ms.saitama-u.ac.jp, mohtake@riken.jp, adachi@np.gs.niigata-u.ac.jp, s2420198@u.tsukuba.ac.jp, mitimasa@riken.jp, takeda@ribf.riken.jp, kkusaka@riken.jp, g2117055@tcu.ac.jp, s2320200@u.tsukuba.ac.jp, k.watanabe.210@ms.saitama-u.ac.jp, y.kikuchi.985@ms.saitama-u.ac.jp, k.takiura.439@ms.saitama-u.ac.jp, mfukuda@phys.sci.osaka-u.ac.jp

The interaction cross section is one of the physical quantities that can be used to deduce the nuclear radius, and its measurement contributes to the understanding of the structure of unstable nuclei. While charge radii provide information about the proton distribution, deriving nuclear matter radii from interaction cross sections allows us to gain additional insights into the neutron distribution inside the nucleus. Furthermore, a previous study 1 has reported a linear correlation in the charge radius difference of mirror nuclei as a function of isospin dependence. Investigating whether a similar correlation exists for nuclear matter radii may provide further insights into isospin symmetry breaking.
In this study, we measured the interaction cross sections for the nuclei around 40Ca and 56Ni, as well as for their neighboring mirror nuclei, as part of the S3CAN (Symbiotic Systematic and Simultaneous Cross-section Measurements for All over the Nuclear Chart) program within the TRIP use case. The experiment was conducted at the RI Beam Factory (RIBF) of RIKEN using the BigRIPS separator. A 70Zn primary beam was accelerated to 345 MeV/nucleon and irradiated onto a beryllium target placed at F0, generating a secondary beam containing the nuclei of interest via projectile fragmentation. The secondary beam was transported through BigRIPS, where particle identification was performed using the Bρ-TOF-ΔE method. A wedge-shaped carbon target with a central thickness of approximately 1.5 g/cm² was placed at the F5 focal plane. By comparing the particle identification before and after the target, the interaction cross section was determined using the transmission method.
We will discuss the mass-number dependence of the obtained interaction cross sections and derived nuclear matter radii, as well as the differences in nuclear matter radii between mirror nuclei.

Reference
1 T. Li et al., Atomic Data and Nuclear Data Tables, 140, (2021) 101440.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 74**

## Detailed in-beam gamma-ray spectroscopy of 32Mg and 30Mg

**Author:** Noritaka Kitamura[None]

**Corresponding Author:** kitamura@cns.s.u-tokyo.ac.jp

In the so-called "island of inversion,"ground states of neutron-rich sd-shell nuclei around N=20 exhibit strong admixtures of intruder configurations involving the fp orbitals, leading to the breakdown of the N=20 shell gap. The nucleus 32Mg, which has played a central role in island-of-inversion studies, serves as an important benchmark for nuclear models and our understanding of evolving shell structure.
We performed detailed in-beam gamma-ray spectroscopy of 32Mg using GRETINA at NSCL, primarily to determine spin-parity assignments of excited states in this key nucleus. Owing to the strong selectivity of direct nucleon removal reactions, the measurement has allowed us to construct a significantly updated level scheme, highlighting different structures coexisting in 32Mg. We will present findings from the latest spectroscopy of 32Mg 1, together with our earlier result on 30Mg [2] obtained from the same experimental setup, with an emphasis on the evolution of the fp orbitals.

1 N. Kitamura, K. Wimmer, A. Poves et al., Phys. Lett. B 822, 136682 (2021).
[2] N. Kitamura, K. Wimmer, N. Shimizu et al., Phys. Rev. C 102, 054318 (2020).

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Poster session / 75**

## Study of triaxiality of $^{154}$Sm by low-energy electron scattering

**Author:** Kengo Hotta[1]

**Co-author:** Toshimi Suda [1]

[1] *RARiS, Tohoku University*

**Corresponding Authors:** suda@lns.tohoku.ac.jp, kengo.hotta.q6@dc.tohoku.ac.jp

In the 1950s, Bohr and Mottelson established the picture that most heavy nuclei deform into a prolate shape consisting of one long axis and two short axes of equal length.
However, the recent theoretical calculation by T. Otsuka et al.1 indicates that these nuclei prefer a triaxial shape, with all three axes having different lengths. Additionally, the presence of excited states due to rotational bands in the short-axis plane caused by triaxial asymmetry has also been suggested.
While $^{154}$Sm has long been regarded as a prolate nucleus, calculations by T. Otsuka et al. show that it weakly deforms into a triaxial shape, suggesting the existence of the excited state, $2^+_{g\gamma}$, around $E_x$ = 2.7 MeV. By measuring this excited state through low-energy electron scattering, we can determine the total angular momentum of this state by the momentum transfer dependence of the form factor.
The experiment to measure this excited state is planned at RARiS, Tohoku University. We performed the test experiment in November 2024.
From the measurement at 92° and beam energy 60 MeV, We didn't find peak of expected transition strength around $E_x = 2.7$ MeV.
This work will discuss the results obtained in this experiment and future studies.

Reference
1 T. Otsuka et al., 2024, arXiv:2303.11299.

K. Hotta, T. Otsuka[1], T. Ohnishi[1], T. Goke, R. Danjo, K. Tsukada[2], Y. Honda, T. Muto, H. Yamauchi, K. Yoshimoto, C. Legris, T. Suda

RARiS Tohoku Univ., RIKEN Nishina Center [1], ICR Kyoto Univ.[2]

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**Poster session / 76**

## Study of Nuclear Fragmentation using Isomeric States

**Author:** Keita Kawta[1]

**Co-authors:** Kentaro Yako ; Shinsuke OTA [2]

[1] *RCNP*

[2] *RCNP, Osaka University*

**Corresponding Authors:** ota@rcnp.osaka-u.ac.jp, yako@cns.s.u-tokyo.ac.jp, kkawata@rcnp.osaka-u.ac.jp

Nuclear fragmentation has been established as one of the most effective methods for producing fast beams of unstable nuclei at radioactive beam facilities. In nuclear fragmentation, a projectile nucleus collides with a target nucleus, producing fragments with significantly different proton and neutron configurations than the projectile.
The objective of this study is to understand the reaction mechanism of fragmentation and explore new methods for producing a wider variety of unstable beams, including those of isomeric states. The availability of isomer beams is expected to broaden the scope of nuclear reaction and structure studies.
The present study focuses on the roles of momentum and angular momentum transfer in nuclear fragmentation. This was achieved by investigating the production of nuclei around $^{52}$Fe.

The experiment was performed at the SB2 course of HIMAC in Chiba. The primary beams of $^{58}$Ni and $^{59}$Co at 350 MeV/u bombarded a 14-mm thick $^{9}$Be target.
Fragments of $^{52}$Fe, $^{53}$Fe, and $^{54}$Co are momentum-analyzed by a magnetic fragment separator. The de-excitation gamma rays from $^{52}$Fe(12+), $^{53}$Fe(19/2-), and $^{54}$Co(7+) were detected by four Ge detectors. Momentum distributions of these high-spin isomeric states and their ground states were extracted from the data.

By selecting specific isomeric states and comparing their momentum distributions with those of the ground states, we identified a correlation between angular momentum and parallel momentum transfer. This finding is in line with a classical model where the angular momentum and parallel momentum transfer is modelled as occurring on the nuclear surface. We also found a correlation between isomeric ratios and angular momentum transfer.

In this presentation, we summarize these findings and discuss the
current understanding of reaction mechanisms of nuclear fragmentation.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

yes

**session #12 / 77**

## Weak-binding and continuum-coupling effects on the structure of neutron-rich nuclei

**Author:** A. O. Macchiavelli[1]

[1] *Physics Division, Oak Ridge National Laboratory*

The structure of nuclei far from the stability line is a central theme of research in Nuclear Physics. Key to this program has been the worldwide development of advanced radioactive beam facilities and novel detector systems, which provide the tools needed to produce and study these exotic nuclei.

One of the intellectual drivers guiding current experimental and theoretical research concerns the effects of weak binding and coupling to the continuum on the evolution of collective motion towards the neutron dripline.

We have studied the coupling of weakly bound (halo) valence neutrons to a deformed core using a Weak-Coupling phenomenological approach and the Particle-Rotor model. Despite its simplicity, our phenomenological model captures the main physical ingredients and provides a framework that allows us to examine possible coupling schemes involving a core and halo.

I will illustrate our results using the known properties of $^{38,40}$Mg to discuss the impact of weak binding on the low-lying excitation spectrum, one proton removal reaction cross sections and transition probabilities.

I will also discuss some ideas for future experiments that will shed further light on this interesting topic.

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**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**Session #4 / 78**

## Nuclear magnetic properties from first principles

**Author:** Takayuki Miyagi[1]

[1] *University of Tsukuba*

**Corresponding Author:** miyagi@nucl.ph.tsukuba.ac.jp

Nuclear magnetic properties provide valuable insights into nuclear structure. In particular, the magnetic dipole moment is sensitive to how much the nucleus is dominated by the single-particle picture. Reproducing magnetic dipole moments has been one of the major challenges in nuclear ab initio theory. With the valence-space in-medium similarity renormalization group (VS-IMSRG), one of the ab initio calculation methods applicable for medium-mass and heavy nuclei, it was found that the absolute size of the magnetic dipole moments is underestimated. The effect of two-body current (2BC, also known as the meson exchange current) is non-negligible in light nuclei, as studied by Green's function Monte Carlo and no-core shell model. Thus, including 2BC effects in medium-mass and heavy nuclei calculations is a natural step forward. In this presentation, using the VS-IMSRG, I will discuss the 2BC effect on the magnetic dipole moments of nuclei near doubly magic systems from oxygen to bismuth. Additionally, I will present the effects of 2BC on magnetic transitions and form factors.

**Type of contribution**:

poster

**Are you a student or postdoc?**:

no

**session #9 / 79**

## Electromagnetic responses of weakly-bound nuclei

**Author:** Hiro Iwasaki[1]

[1] *FRIB/MSU*

**Corresponding Author:** iwasaki@frib.msu.edu

At the limit of stability, atomic nuclei can exhibit unique structure due to the proximity to the particle-
decay threshold. In particular, if orbitals near the Fermi surface have low angular momenta, they can
induce spatially extended wave functions for valence neutrons, forming nuclear halo. In light p and psd
shells, halo nuclei have so far served as a benchmark for understanding of nuclear structure and
dynamics of weakly-bound systems. However, for an unexplored heavier-mass neutron-rich region, halo
formation and excitation properties can be more extensive than hitherto expected due to increasing
degrees of collectivity and correlations.
As a way to investigate the dynamics of neutron-rich weakly-bound systems, we have performed
excited-state lifetime measurements on neutron-rich C and Ne isotopes [1,2,3]. The experiments were
performed utilizing the combination of fast beams of rare isotopes, GRETINA, TRIPLEX plunger device
and S800 Spectrograph. Experimentally extracted transition probabilities are used to characterize the
electromagnetic responses of weakly-bound states through comparison with data available in
neighboring nuclei as well as theoretical calculations. Examples of our recent results include an
unexpectedly large E1 strength discovered in the neutron-rich 27 Ne isotope [2] as well as an enhanced E2
strength observed for the 29 Ne isotope in the vicinity of N=20 [3].
The experimental results will be presented and discussed in terms of an interplay between the shell

erosion, deformation, and weakly bound nature of nuclei far from stability. Perspectives for ongoing and
future studies at FRIB will also be discussed.

1 K.Whitmore et al., Phys. Rev. C 91, 041303(R), (2015)
[2] C.Loelius et al., Phys. Rev. Lett. 121, 262501, (2018)
[3] A.Revel et al., Phys. Lett. B838, 137704, (2023)

**Type of contribution**:

**Are you a student or postdoc?**:

**Opening / 80**

## Welcome

**Author:** Michio Honnma[1]

[1] *University of Ai*

**Opening / 81**

## Opening

**Authors:** Daisuke Suzuki[1]; Masayuki Yamagami[2]

[1] *RIKEN Nishina Center*

[2] *University of Aizu*

**Corresponding Authors:** yamagami@u-aizu.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp

**session #1 / 82**

## Single-particle states in odd nuclei and spin-isospin excitations

**Session #2 / 83**

## TBA

**session #5 / 84**

## The emergence of nuclear collective excitations- puzzles and new insights

**session #9 / 85**

## An approach to particle vs collective motion in reaction theory

**session #10 / 86**

## Nuclear triaxiality: Wobbling, chirality and shape fluctuations

**Author:** Stefan Frauendorf[1]

[1] *University of Notre Dam*

The concepts of triaxiality and -softness are introduced based on the collective liquid model. Pertaining signatures are the quadrupole shape invariants derived from the E2 matrix elements, the energy ratios and the staggering of the energies of the band . Microscopic Triaxial Projected Shell Model (TPSM) calculations have been carried out for nine nuclei with extended sets of E2 matrix elements from COULEX.
Good agreement with the TPSM energies and individual E2 matrix elements is found. Triaxiality and -softness are discussed based on the derived signatures. The classical wobbling mode of the triaxial rotor (TR) is defined and its appearance in the quantal TR states is visualized by means of the spin coherent state representation. The modification of wobbling by the presence of high-j quasiparticles is discussed in frame work of the particle+TR (PTR) model, which leads to the classification as transverse (TW) and longitudinal (LW) wobbling. The instability of TW with increasing angular momentum is discussed for 135 Pr.
The microscopic TPSM calculations are consistent with the PTR results both accounting for the experiment. The TPSM resolves the apparent inconsistency of the PTR, which assumes a rigid TR core while the even-even neighbors display -softness, as the consequence of the missing exchange terms between the TR core and the valence quasiparticles.

**Type of contribution**:

**Are you a student or postdoc?**:

**session #11 / 87**

## Direct Reactions as Quantum Probes of Nuclei

**Corresponding Author:** shimoura@cns.s.u-tokyo.ac.jp

In studies of nuclear physics during the last decades, the area of nuclides in the nuclear chart available for experiments increases drastically because of developments of rare isotope beam facilities as well as of experimental technique. Systematic studies of nuclear structure are performed as a function of numbers of protons and neutrons, which show evolution of structures, exotic phenomena and so on. Among various kinds of nuclear reactions, direct reactions are unique and important tools for studying quantum properties of nuclei, where actions with certain quantum numbers are instantaneously applied to nuclei.
In this talk, I will present examples of direct reactions in these days based on the view that such reactions provide sudden transition to the target with various quantum numbers.

**Type of contribution**:

**Are you a student or postdoc?**:

**session #6 / 88**

## Study of 12Be from the single-particle and collective perspective

**session #12 / 89**

## Deformation driven neutron halos

**Type of contribution**:

**Are you a student or postdoc?**:

**Award ceremony and closing / 90**

## Award ceremony

**Corresponding Author:** aoi@rcnp.osaka-u.ac.jp

**Award ceremony and closing / 91**

## Closing

**Corresponding Authors:** yamagami@u-aizu.ac.jp, daisuke.suzuki@nex.phys.s.u-tokyo.ac.jp