Nuclear Spectroscopy projects at CENS

Capture Gamma-ray Spectroscopy

18/Jul/2023

Yung Hee KIM

On behalf of CENS members

- 1. Introduction to CENS
- 2. Recent international research activities in nuclear structure group
 - 1. Recent results
 - 2. future projects
- 3. Recent in-beam tests at RAON
- 4. Instrument developments
- 5. Summary





1. Introduction to CENS NUCLEAR STUDIES





Introduction of Center for Exotic Nuclear Studies (CENS)







Introduction of Center for Exotic Nuclear Studies (CENS)

- The Center for Exotic Nuclear Studies (CENS) was launched in December 2019.
- Founded to study properties of exotic nuclei and origin of heavy elements in the universe
- 4 research groups-Astrophysics, Structure, Reaction and Theory
- Currently, 26 researchers and 11 Ph.D.
 students as of today (1/3 foreigner, 1/4 female)



- Research using RAON facility with ISOL and IF method
- Detector developments



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CENS Nuclear Chart



2. Recent international research activities in nuclear structure group





Research proposals





Shape evolution in neutron-rich Zr isotopes











- High-resolution Cluster Array at RIBF (HiCARI) project
- Large international collaboration with various types of HPGe detectors (Miniball, IMP clover, LBNL P3, RCNP Quad)
- Lifetimes of excited states in neutron-rich Zr and Mo isotopes to investigate nuclear shape evolution.



Search for n-rich isotopes N~126 using multi-nucleon transfer reaction





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Isospin symmetry breaking



UNIVERSITY OF JYVÄSKYLÄ



Research program devoted to study nuclear structure in proton-rich nuclei to probe isospin symmetry breaking effects.

⁹⁴Ag

- First spectroscopic study of ⁹⁴Ag:
 - Comparing analog states in ⁹⁴Ag and ⁹⁴Pd.
 - Seeking evidence of T=0 np pairing.
- ⁴⁰Ca(⁵⁸Ni,p3n)⁹⁴Ag at JYFL
- First observation of $\gamma\text{-rays}$ from ^{94}Ag



⁷⁸Zr & ⁷⁸Y

- Identification of excited states in ⁷⁸Zr
 - Triplet energy differences.
- ⁴⁰Ca(⁴⁰Ca,2n/pn) at JYFL.
- Complete spectroscopy of ⁷⁸Y:



 Candidate for ⁷⁸Zr 2⁺→ 0⁺ transition observed via recoil-β-β correlations Work ongoing (preparing publication).

Study of shell evolution along the Sn isotopic chain



Quadrupole collectivity in $^{106,108,110} \rm{Sn}$ and single-particle dominated states in $^{107,109,111} \rm{Sn}$

ISS for (d,p) transfer reactions, J^{π} assignments and spectroscopic factors





Study of single particle dominated states

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- d(¹¹⁰Sn,p)¹¹¹Sn experiment at 8 A·MeV carried out in 2022
- d(¹⁰⁸Sn,p)¹⁰⁹Sn experiment will be carried out in 2023

2.2 future projects





n-induced fission fragment spectroscopy @ ILL

Conversion electron campaign @ Lohengrin





Re-measuring isotopes for new transitions & rigorous determination of level spin-parity

- Series of light FF ~A=104 collaboration with ANU & Univ. of Warsaw
- Structure of odd-odd Br-isotopes N~50

²⁴⁵Cm(n,ff) fast timing campaign @ FIPPS



Fast-timing measurement @ FIPPS+LaBr3 array

- I-isotopes : development of collectivity from N~82
- Nd-isotopes : nuclear shape evolution N>90





Isospin symmetry breaking / shell evolution ~¹⁰⁰Sn



Motivation:

- 。 CEDs in isobar nuclei Rh-Ru.
- o Influence of T=0 np pairing?
 - N=Z nuclei most likely candidates.
 - Encouraging observations for Ru, Pd, Ag and Cd.

FMA+GAMMASPHERE

- **Goal:** measure low-lying excited states in ⁹⁰Rh for the first time.
- Production Method: ⁵⁴Fe(⁴⁰Ca,p3n)
- Measure ${}^{90}\text{Rh}(\beta) t \gamma$ coincidence

Shell evolution in light Sn isotopes



- Motivation: Structure of neutron orbitals above doubly magic ¹⁰⁰Sn important for shell evolution
- **Goal:** Study single-particle dominated states in ^{107,109,111}Sn submitted to CERN-ISOLDE
- Method: (d,p) using ISOLDE Solenoidal Spectrometer, at E_{beam} = 8 A·MeV on CD₂ target
- Measurement: Proton energies and angles from (d,p) reaction in inverse kinematics

IDATEN project



- Creating largest LaBr3 array ever collected at RIKEN RIBF Zero-degree spectrometer position
- Construction Spokespersons (Hiroshi Watanabe, Paddy Regan, Byul Moon)
- Core Collaboration KR+JP+CH+UK+DE











IDATEN project – Role of CENS

Frame Structure

GEANT4 simulation toolkit



- Frame structure designed & fabricated (by B. Moon & Y. Jang)
- Will be transported to RIBF this summer



J. Lee, Y. H. Kim et al., NIMB

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- Major hardware & software development by CENS
- Future Schedule
 - Commissioning: End of 2023 / Early 2024
 - Physics run: Mid-End of 2024
- Essential role in the project



3. First beam tests @ RAON

New Baby Accelerator









Overview of RAON low energy facility







ISOL: first online beam test with SiC target







ISOL: first online beam test with SiC target



End of 2023: production of ²⁶Al, ^{26m}Al beam using laser ion source and delivery to MMS or CLS



Courtesy of Dr. Jinho. Lee



Overview of RAON low energy facility



Beam on target soon decay spectroscopy





Overview of KoBRA recoil separator



- First beam on target ⁴⁰Ar(~18.6 MeV/u) fragmentation with C target

Courtesy of K. Tshoo





KoBRA: First RI production test



- First beam test in June (3 days) with 18.6 MeV/u ⁴⁰Ar beam with limited power 0.3W (due to radiation safety)
- PID of Li/Be region successful with only 3 days of test beamtime.
- 2nd commissioning test planned in Dec 2023.

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KoBRA: First commissioning physics experiment planned



1. Fast-timing measurement with LaBr₃ detectors



2. ⁴⁰Ar+p and ⁴⁰Ar+d elastic scattering studies





3. Activation method method in inverse kinematics for astrophysical studies with ³⁹Cl





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NDPS: fast neutron facility

CENS



Courtesy of Dr. K. Tshoo

4. Instrument development projects

New **Baby** Accelerator







CENS detector development



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ASGARD (Array of Super-clover Gamma-Ray Detector)

Simulated efficiency



- TIGRESS detector type segmented super clover detector for Doppler correction for in-beam γ-ray spectroscopy
- 6 detector @ RAON, total 11 detectors will be purchased at CENS (5 existing+3 this year)
- New DAQ system (Notice Korea), support structure expected end of 2023

Courtesy of B. Moon





Fast-timing LaBr3 detector array Khala



- 1.5"x1.5" cylindrical LaBr3 crystal
- Good energy (2.4% 1332keV) and timing resolution (~330 ps FWHM @511keV)
- Lifetime measurement of nuclear excited state τ> 10 ps
- 12 detectors @ CENS (from SNU)+48 detectors @ Korea University (CENuM)
- DAQ system: TWINPIX-TAMEX electronics from GSI





Development of large acceptance position-sensitive silicon strip

STARK(Silicon Telescope Array for Reaction studies in inverse Kinematics)

- Powerful experimental method to study direct reaction experiments.
- One of the best tools to probe a broad range of nuclear properties
- Providing information into the nuclear structure of exotic nuclei



- Array consisting of 40 double-sided resistive silicon strip detectors.
- Barrel shaped a arrangement
- Wide angular coverage: 43° $78^\circ\,$ and $105^\circ-150^\circ\,$

Measure energy, angular momentum, cross section, spectroscopic factor

Large solid angle silicon detector array intended for direct reactions experiments. Commissioning experimental campaign @ JAERI

D. Kim et al., NIMB 540 (2023) 30, X. Pereira-Lopez et al., NIMB 541 (2023) 134



Courtesy of Sunghoon AHN & DeukSoon AHN



TexAT_v2 and AToM-X

<u>Micromegas + silicon detector array + CsI(TI) detector array</u>

TexAT_v2 (Upgrade of Texas Active Target TPC)



Detection efficiency x4 larger than TexAT.

- Active area: 241(X) x 152(Y) x 135(Z) mm³
- Portable Scattering chamber: 20"(X) x 13.5"(Y) x 20" (Z)
- Beam tracker (Micromegas) after the window for beam intensity and purity
- Silicon and CsI detectors wall for total energy of particles
- Upgrade lead by collaboration between Texas A&M and CENS

2022-08-18

Time projection chamber (TPC) enables 3D particle track information and measures its total energy deposition in Si and CsI(Tl).

Nuclear astrophysics experiment e.g. ¹⁴O(α,p)¹⁷F reaction Commissioning experiment @ Texas A&M RIBF experiment



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Csl energy [MeV]

5



20

25

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AToM-X (Active Target for Multiple nuclear eXperiments)



NEXT GENERATION ACTIVE TPC

- Active area: 256(X) x 180(Y) x 288(Z) mm³
- Scattering chamber: similar to TexAT chamber to make portable!
- Target gas: CH_4 , C_4H_{10} , CD_4 , $He/CO_2(98/2\%)$ and CO_2
- Silicon and CsI detectors wall for total energy of particles
- Position sensitive strips on Si. Detector (X6) using resistive layer





CryoSTAR(Cryogenic Stable Target)

Cryogenic targets in gas or liquid can reach higher densities at very low temperature than that in the room temperature, resulting in a large number of reaction yields in nuclear experiment. Light element gases(H2, D2, ³He, and ⁴He) have often been used as a RI beam production target.



Decay Station Initiator for RAON



Decay spectroscopy of Low E beam (~60keV) from IS

- Precision γ & e-spectroscopy for nuclear & particle physics
- Mobile frame set for KoBRA beamline
 - High efficiency versatile setup for KoBRA beamline.
 - Decay spectroscopy of exotic channels, γ - γ angular correlation, β -delayed neutron emission



Other detector developments

SiPM detectors



CsI detector for TexATver2 & Atom-X



Active stopper for KoBRA experiment Beta counter for ANL experiment

- Compact & versatile detection system for nuclear astrophysics & structure
- Fast response time
- Gamma-ray, light ions & beta-detection



SCEPTER: conversion electron detector



- High efficiency & E-resolution+ angular distribution
- Si detector & cooler under purchasing process
- Under decay station project

Neutron Monitoring detector for NDPS



- Neutron ToF, postion measurement for neutron production study
- Test carried out with source, cosmic ray
- Veto system under construction



Summary

- Center for Exotic Nuclear Studies (CENS) were founded Dec 2019 to study properties of exotic nuclei and origin of heavy elements in the universe
- Members with diverse interests in various parts of the nuclear chart, closely working with other groups.
- Active physics program with strong international collaborations in Europe, Japan and US
- Various instrument development / physics program for future experiments at RAON accelerator







Advertisement 1: Conferences

NIC-XVII (2023)

17th International Symposium on Nuclei in the Cosmos

Sep. 17 - 22, 2023

Institute for Basic Science, Daejeon, Korea



NIC XVII

Conference Topics

nic2023@ibs.re.kr https://indico.ibs.re.kr/event/NIC2023

Nuclear reaction rates and stellar abundances
 The s-process
 Nuclear properties for astrophysics
 High-density matter
 Novae and X-ray bursts
 Type la supernova and the p-process
 Core-collapse supernovae, mergers
 and the r-process
 Underground nuclear astrophysics
 Galactic evolution
 The early universe
 Radioactivity and meteorites
 Stellar modeling
 Others (new facilites, instruments, tools, etc)

Local Organizing Committee

ndrik Schat: Sunghoon Ahn Institute for Basic Science Michael Smith Institute for Basic Science Soomi Cha Xiaodong Tang Kyungyuk Chae SungKyunKwan University Soonchul Choi Institute for Basic Science Robert Tribble Kevin Insik Hahn Institute for Basic Science Philip Woods Dahee Kim Institute for Basic Science Kyujin Kwak Taeksu Shin Institute for Basic Science



INPC (2025)



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Advertisement 2: Job posting

	No.	Job Position	Recruitment Area	Required Qualifications	Affiliation (workplace)	Number of openings	
	1	Postdoctoral Research Associate	experimental nuclear physics, nuclear astrophysics, or other related field.	 Degree : Doctoral degree (Those who do not exceed 5 years after obtaining doctoral degree, or those who are expected to obtain a doctoral degree within 3 months from the appointment start date(September 1st, 2023)) Major : Experimental nuclear physics, nuclear astrophysics, or other related field. 	Center for Exotic Nuclear Studies (Daejeon, HQ)	4	I N FO NEA
=	2	Senior Researcher	experimental nuclear physics, nuclear astrophysics, or other related field	-Degree : Doctoral degree(must be obtained by appointment start date(September 1 st , 2023)) -Major : Experimental nuclear physics, nuclear astrophysics, or other related field.	Center for Exotic Nuclear Studies (Daejeon, HQ)	3	



Deadline for application submission: July 31st 2023 (15:00) KST S 기초과학연구원 Any inquiries E-mail : <u>cens_recruit@ibs.re.kr</u>

