The 2025 ANPhA Symposium
November 28, 2025
Institute of Physics, Academia Sinica
Taipei, Taiwan

Recent activities at CENS

Kevin Insik Hahn

Center for Exotic Nuclear Studies (CENS), IBS, Korea

Outline

- ❖ Introduction of CENS and IBS
- ❖ Selected research activities at accelerator facilities abroad
- ❖ Commissioning and First Experiments at RAON/IRIS
- ❖ Summary

Introduction of CENS, IBS (Institute for Basic Science)

IBS – Institute for Basic Science (since Nov. 2011)
CENS – Center for Exotic Nuclear Studies (since Dec. 2019)

CENS has 4 subgroups:

Nuclear Astrophysics, Nuclear Reaction, Nuclear Structure, and Nuclear Theory

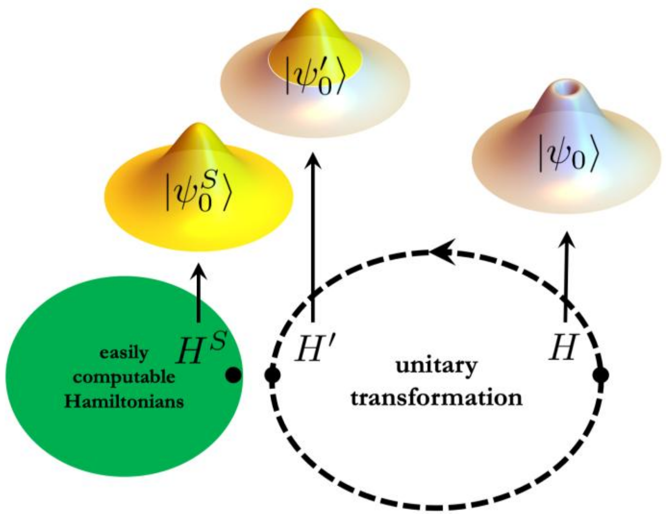
Nuclear Lattice EFT and Wavefunction Matching

3N potential

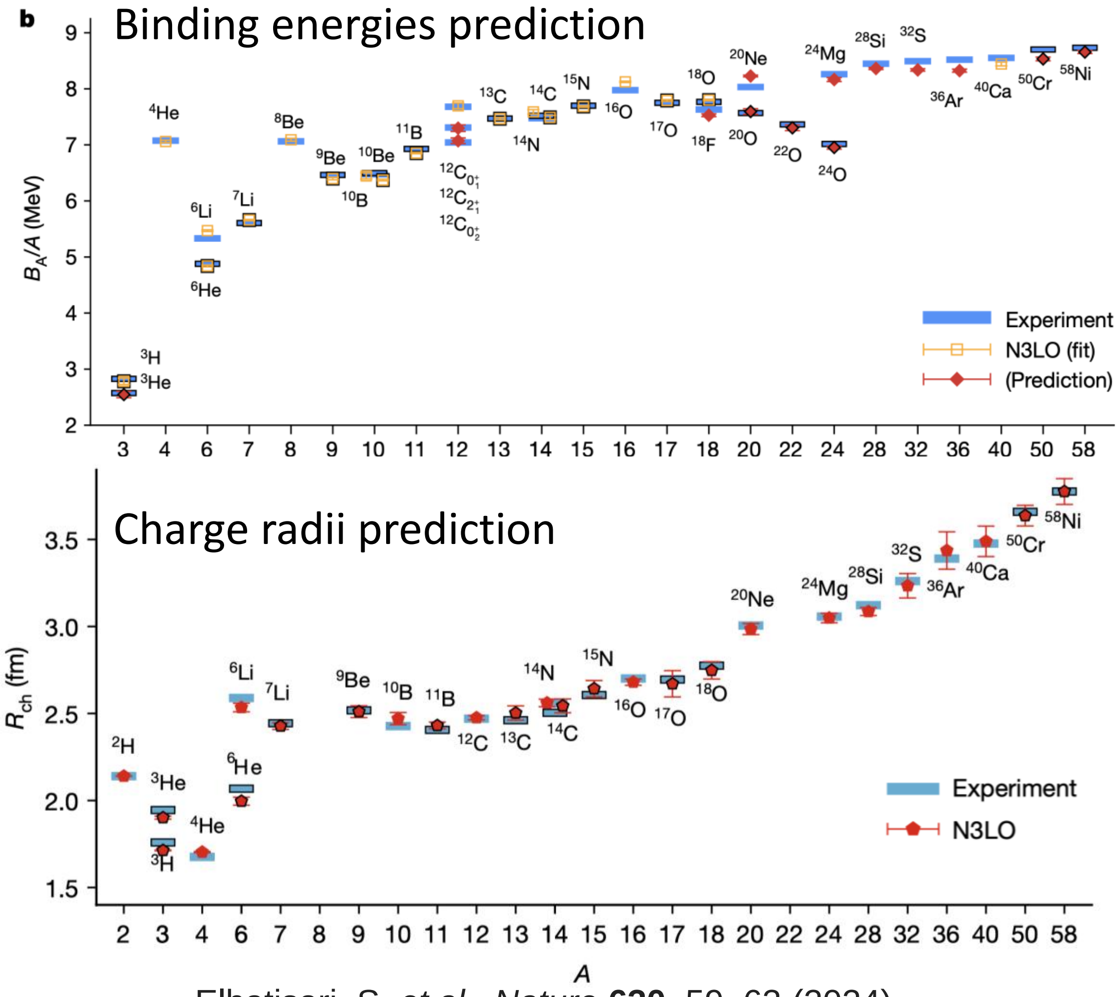
2N GIR at N3LO

$$H = K + V_{\mathrm{OPE}}^{\Lambda_\pi} + V_{\mathrm{C}\pi}^{\Lambda_\pi} + V_{\mathrm{Coulomb}} + V_{3\mathrm{N}}^{Q^3} + V_{2\mathrm{N}}^{Q^4} + W_{2\mathrm{N}}^{Q^4} + V_{2\mathrm{N,WFM}}^{Q^4} + W_{2\mathrm{N,WFM}}^{Q^4}$$

Kinetic E. | OPEP at leading order | Coulomb | 2N short-range at N3LO | WFM interaction & GIR correction



- realistic high-fidelity H (χEFT interaction at N3LO)
- avoid severe sign problems – creating a new H' (WFM method)



M. Kim

Y. Kim

Dean Lee (FRIB, MSU)

Elhatisari, S. *et al.*, *Nature* **630**, 59–63 (2024)

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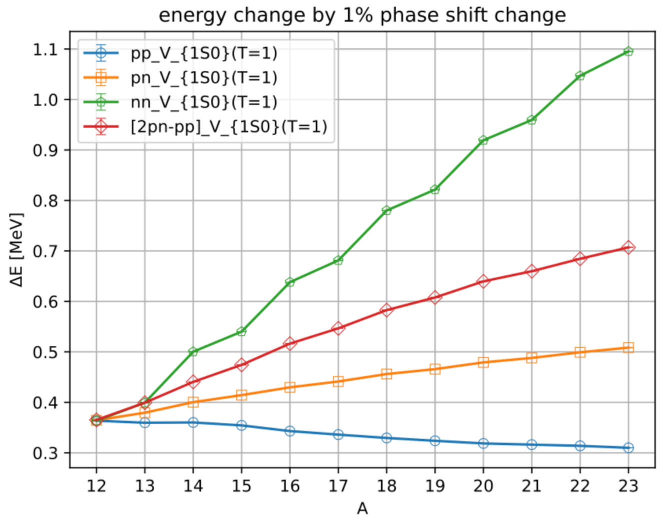
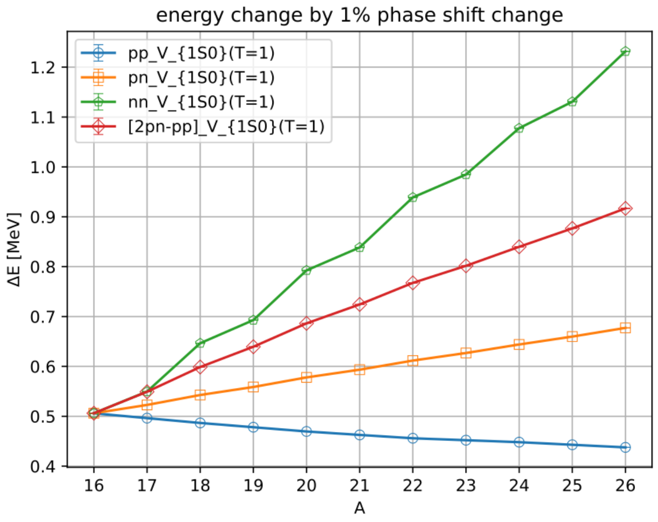
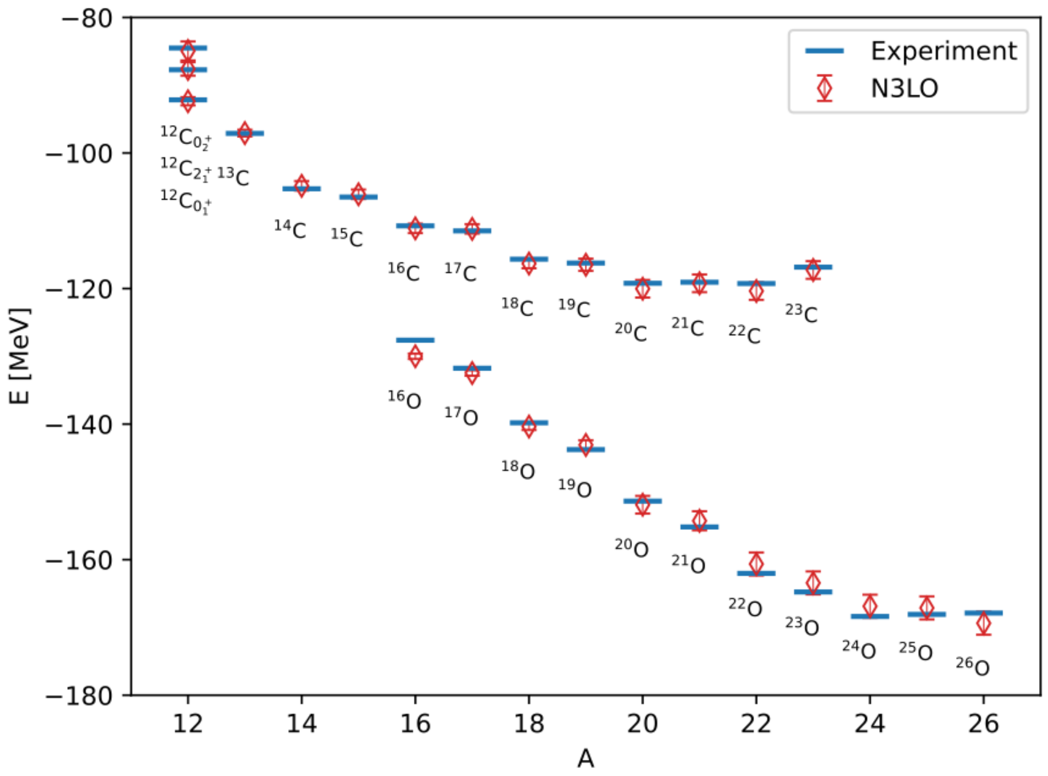
Ab initio calculations of C & O isotopes

- *ab initio* nuclear lattice calculations of *n*-rich carbon and oxygen isotopes
- extension work toward *n*-rich region with wavefunction matching
- including all 2-, 3-N interactions up to $O(Q^4)$ (N3LO)
- in good agreement with experimental data for energies of n-rich isotopes





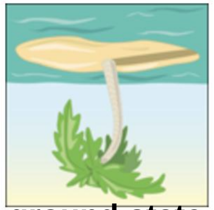


- probing the dependence on nuclear force and quantum correlations
- superfluid-type neutron paring in $^1S_0$ channel and showing clear even-odd effects in binding energies
- similar correlation patters in C & O -> universal neutron-rich feature

Isospin-Symmetric Island of Inversion

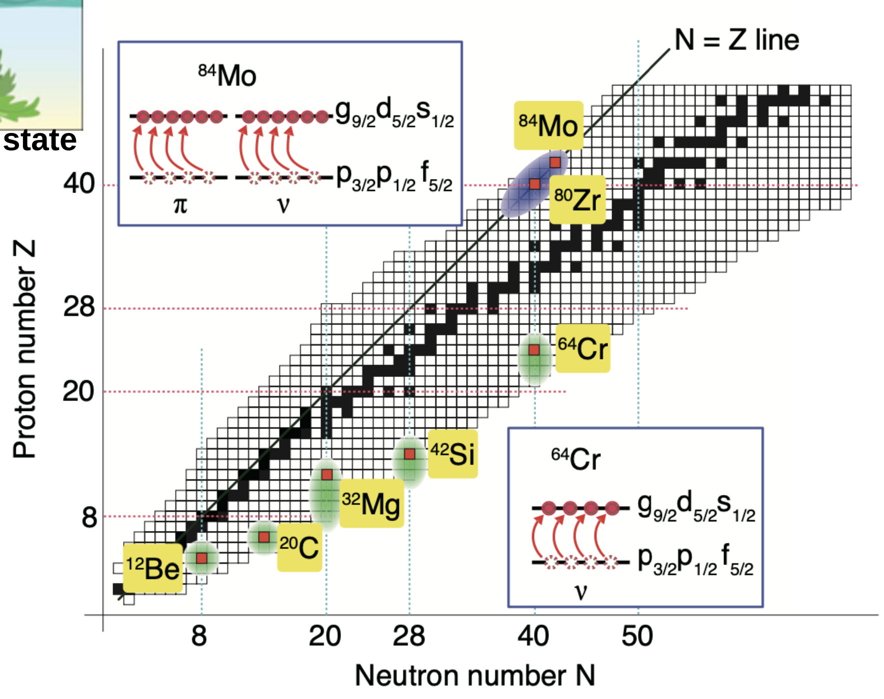
- 2_1^+ lifetime measurement at NSCL, MSU: sharp collectivity change between ^{84}Mo and ^{86}Mo
- Adding two neutrons (^{84}Mo → ^{86}Mo) opens the $g_{9/2} - d_{5/2}$ shell gap: role of 3*N* force in the deformed system
- Discovery of the new Island of Inversion (IOI) at $N = Z$
- First demonstration of the IOI in the proton-rich side

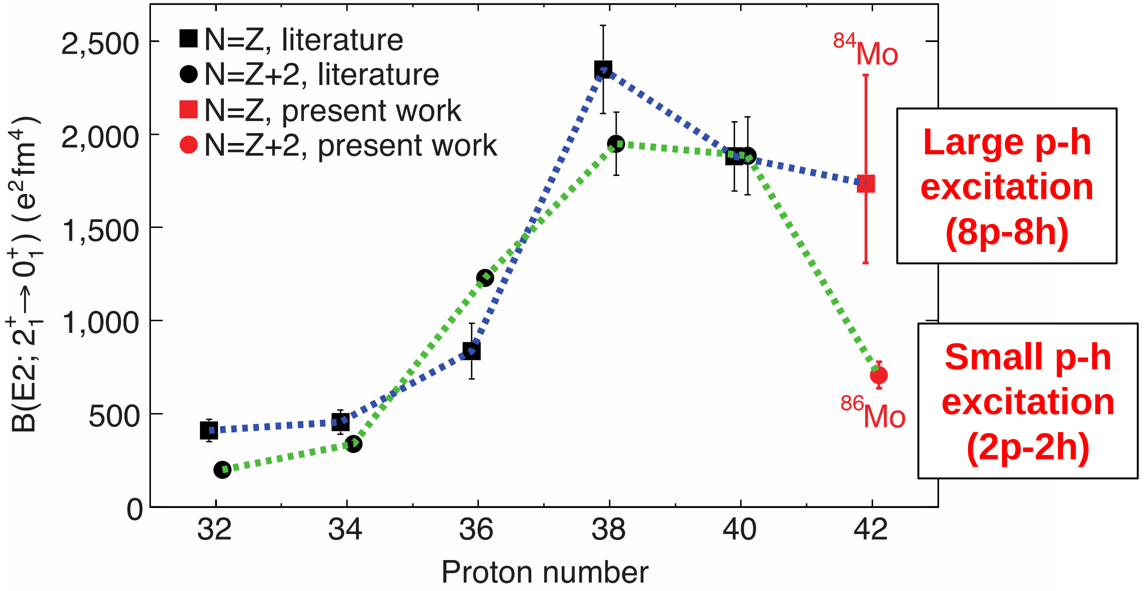
Excited state

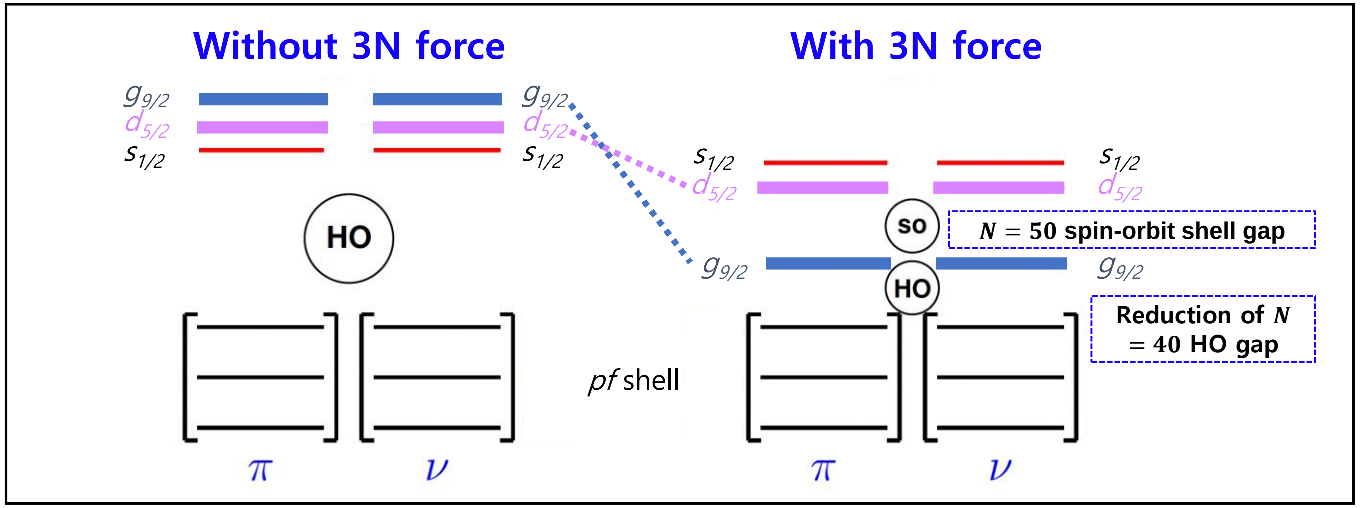


ground state

Map of Island of Inversion





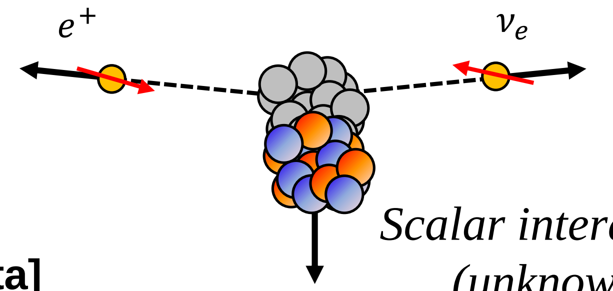


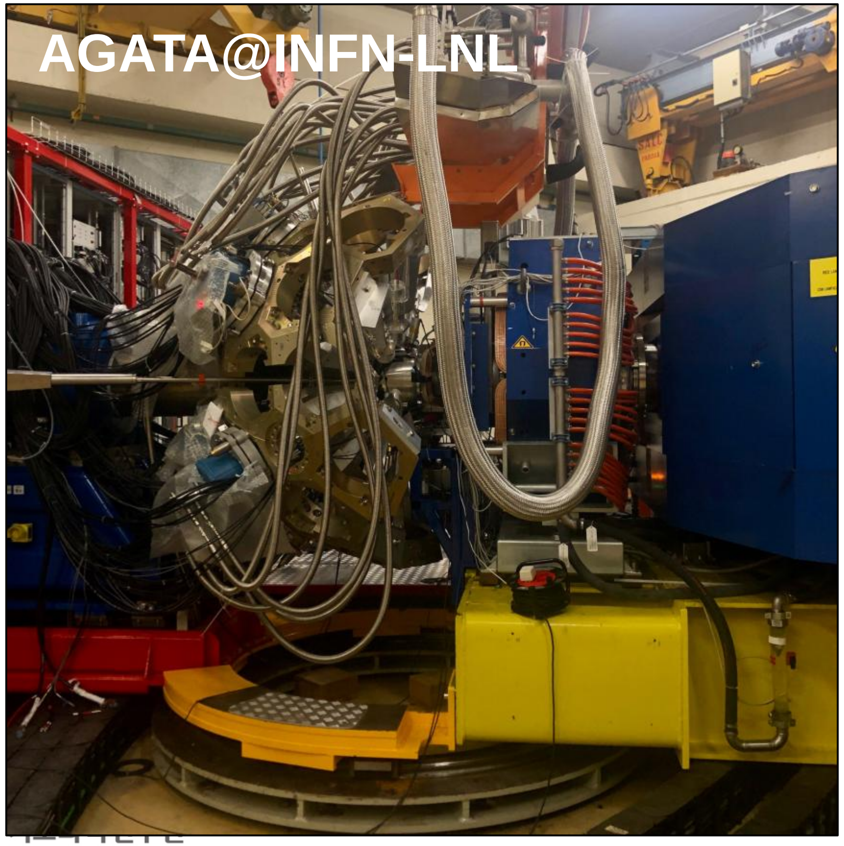
J. Ha, F. Recchia et al., accepted in *Nature Communications*

Test of the CKM Matrix Unitarity: $^{10}C\ 0^+ \rightarrow 0^+$ BR measurement

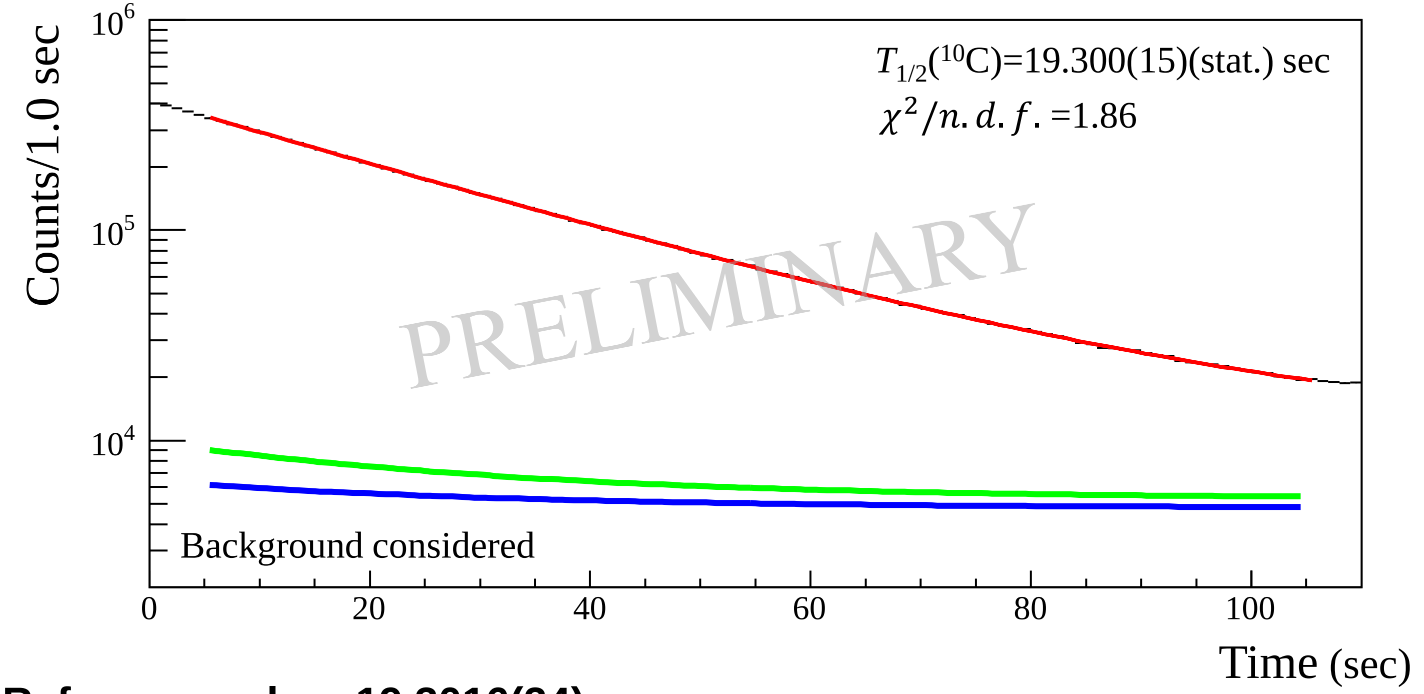
- CKM matrix: unitarity in the Standard Model, 2.5-sigma tension arises from the data
- ^{10}C superallowed β decay: largest impact to the exotic (scalar) current search
- $^{10}C\ 0^+ \rightarrow 0^+$ branching ratio (BR) still has a large uncertainty (0.13 %)
- New measurement with the AGATA performed in June 2023 and July 2025
- Analysis is in progress, including the ^{10}C β-decay half-life measurement

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1?$$





[718-keV γ-ray time spectrum, 2023 data]



Reference value: 19.3016(24) sec

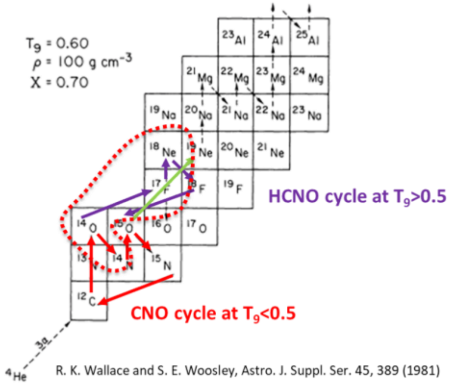
Direct measurement of $^{14}O(\alpha,p)^{17}F$ cross section at CRIB

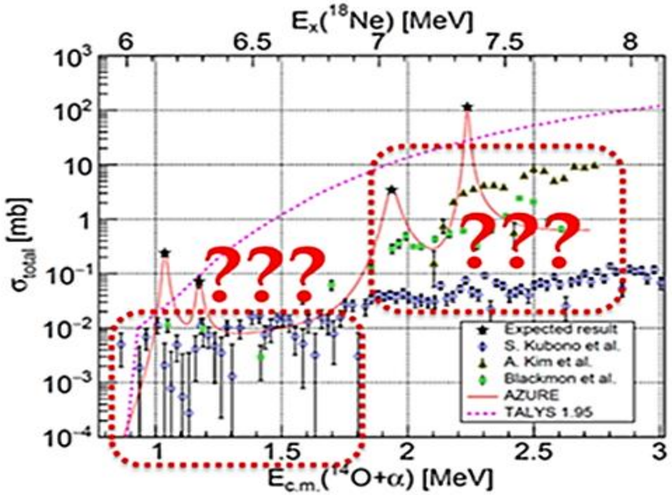
- "A direct measurement of the $^{14}O(\alpha,p)^{17}F$ reaction with the Texas Active Target detector" approved by RIKEN PAC (2020)
- Beam time was very hard to get due to the Covid-19. We performed the experiment on Mar. 2023.

R. H. Cyburt *et al.* 2016

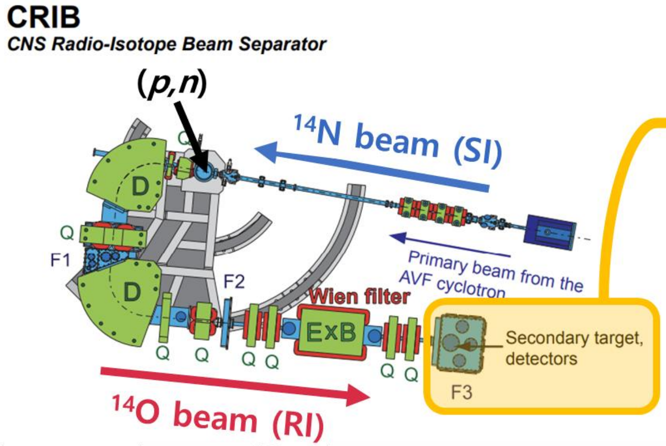
Rank	Reaction	Type	Sensitivity
1	$^{15}O(\alpha,\gamma)^{19}Ne$	D	16
2	$^{56}Ni(\alpha,p)^{59}Cu$	U	6.4
3	$^{59}Cu(p,\gamma)^{60}Zn$	D	5.1
4	$^{61}Ga(p,\gamma)^{62}Ge$	D	3.7
5	$^{22}Mg(\alpha,p)^{25}Al$	D	2.3
6	**$^{14}O(\alpha,p)^{17}F$**	D	5.8
7	$^{23}Al(p,\gamma)^{24}Si$	D	4.6
8	$^{18}Ne(\alpha,p)^{21}Na$	U	1.8
9	$^{63}Ga(p,\gamma)^{64}Ge$	D	1.4
10	$^{19}F(p,\alpha)^{16}O$	U	1.3

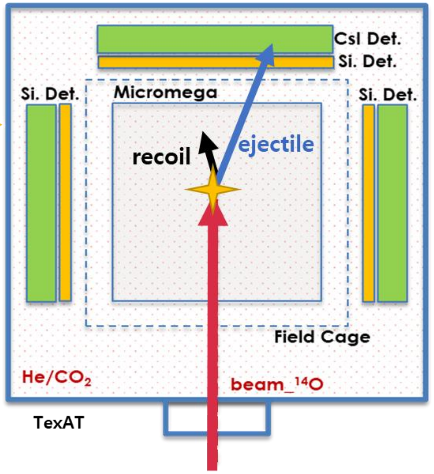
Reactions that impact the burst light curve in the multi-zone X-ray burst model



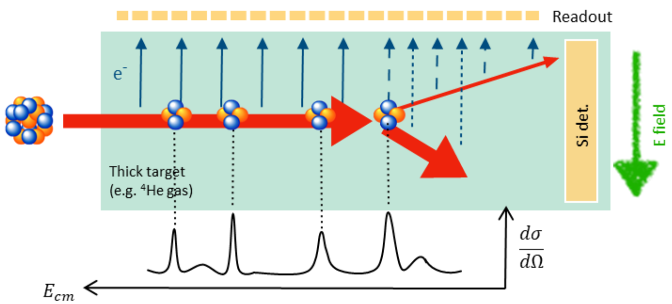


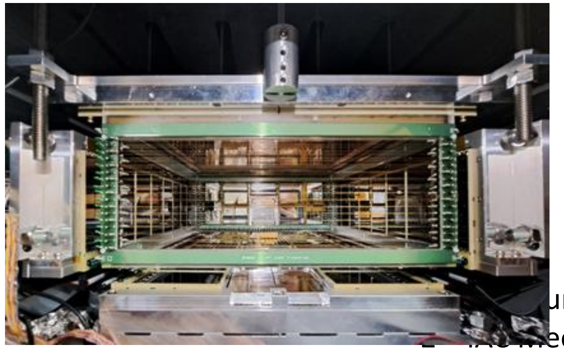
Previous measured data and calculated total cross sections of $^{14}O(\alpha,p)$ reaction

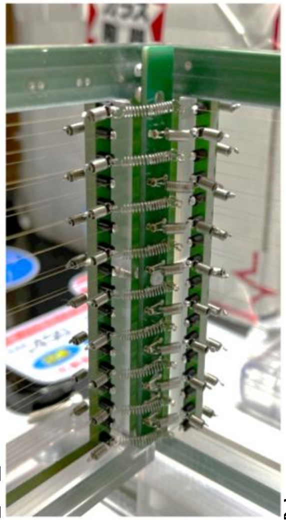




more than 40 participants!

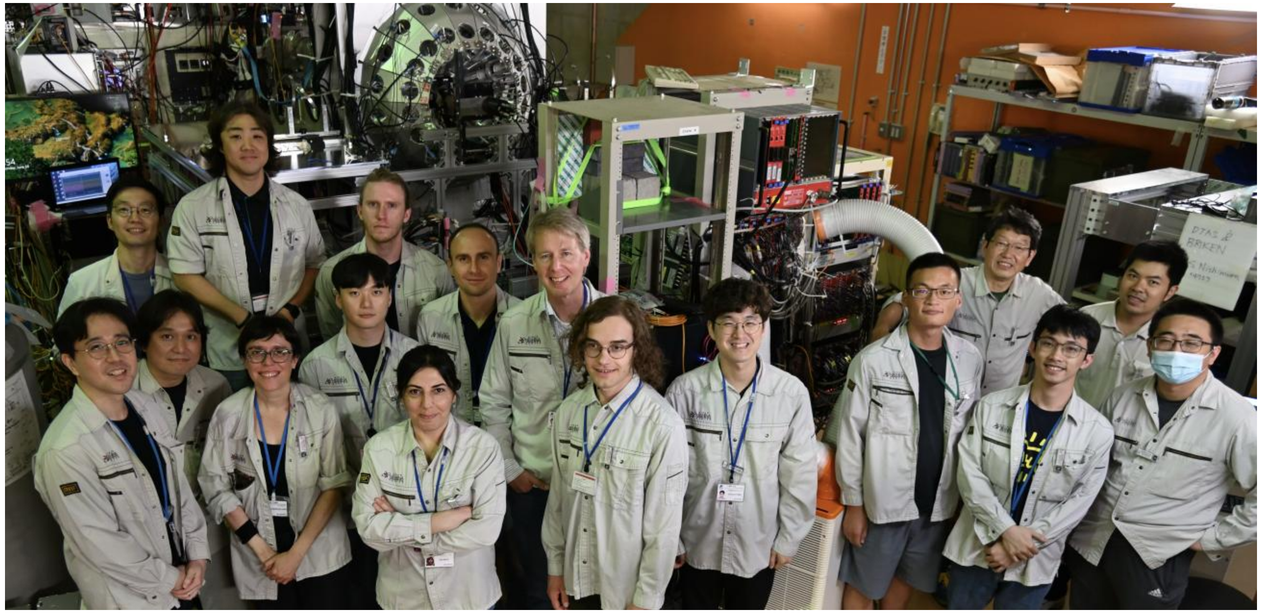


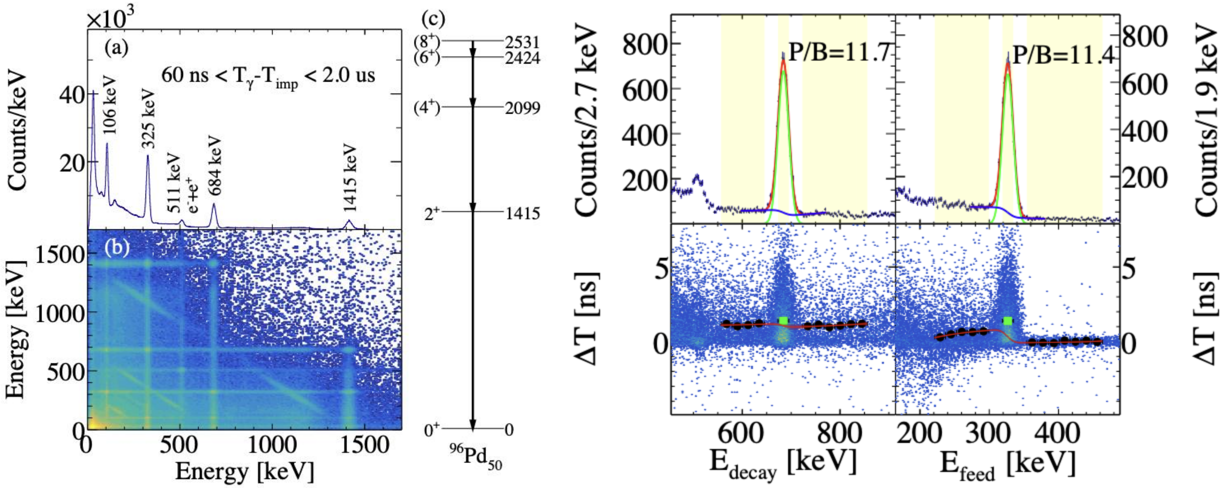




Proposed by S. Ahn & Data analysis by C. Park

Fast-timing measurement at RIBF: IDATEN





B. Moon et al., submitted to NIMA (2025)

- A large international collaboration on the fast-timing measurement at RIBF, IDATEN (International Detector Assembly of fast-Timing measurements of Exotic Nuclei)
- A total of 82 $LaBr_3$(Ce) γ-ray detectors consisting of 46 KHALA-type and 36 FATIMA-type detectors
- Nine physics experiments are approved and waiting for beam time using two primary beam species of ^{238}U and ^{124}Xe.
- A commissioning experiment of the IDATEN system was conducted at RIBF in June 2024 with a beam time of 30 hours.
- Checked compatibility and capability of the IDATEN system as the fast-timing measurement of exotic nuclei by measuring the level lifetimes of ^{96}Pd from the isomeric decay scheme
- A technical paper was recently submitted to NIMA.
- Two students are analyzing data for their Ph.D. projects and manuscripts will be soon submitted.

IRIS Campus

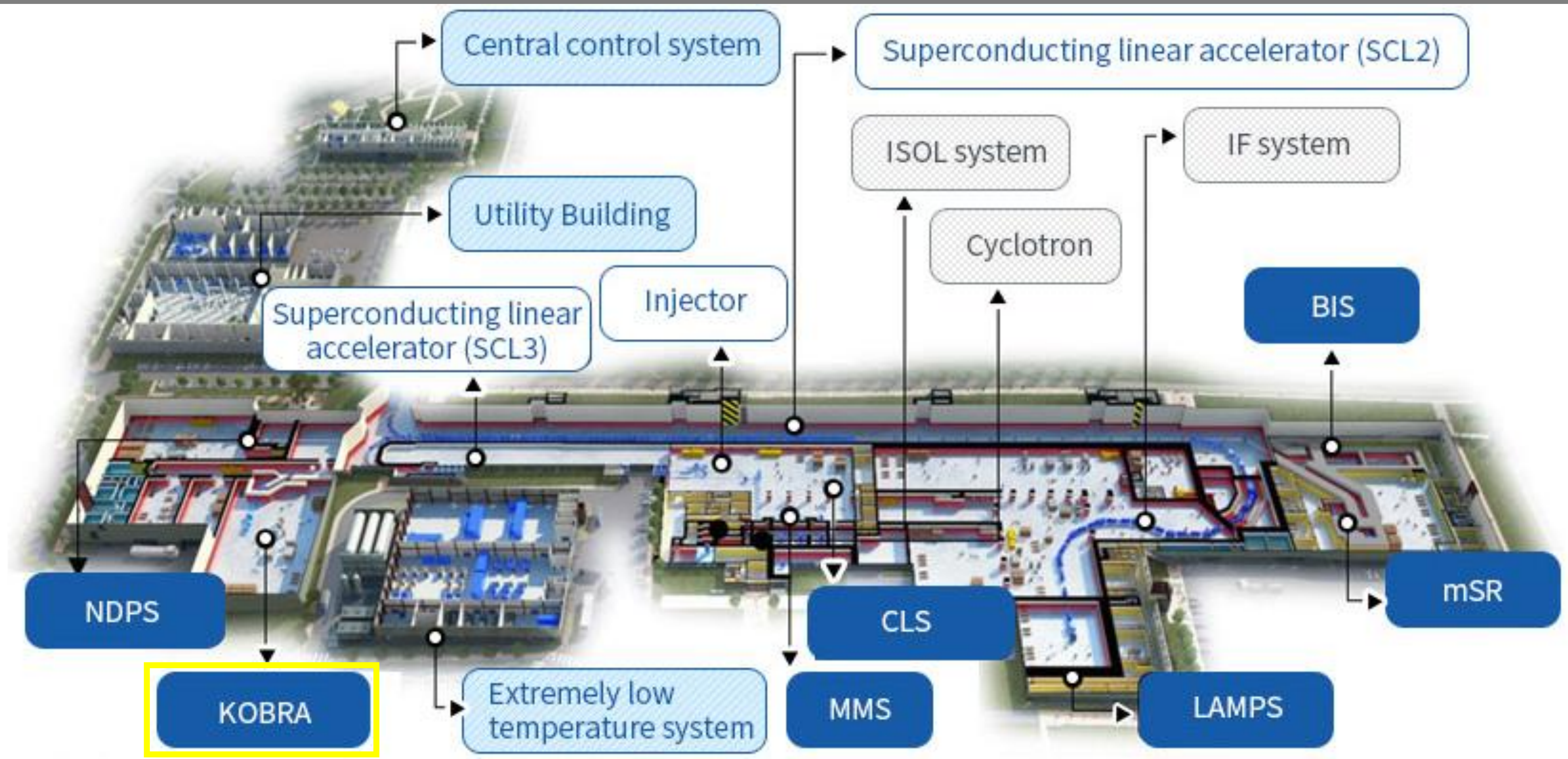
Courtesy of S.W. Hong
ANPhA 2024 talk

1M m^2

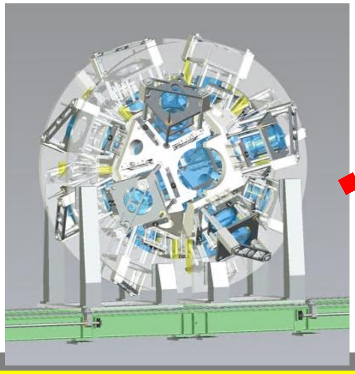
RAON

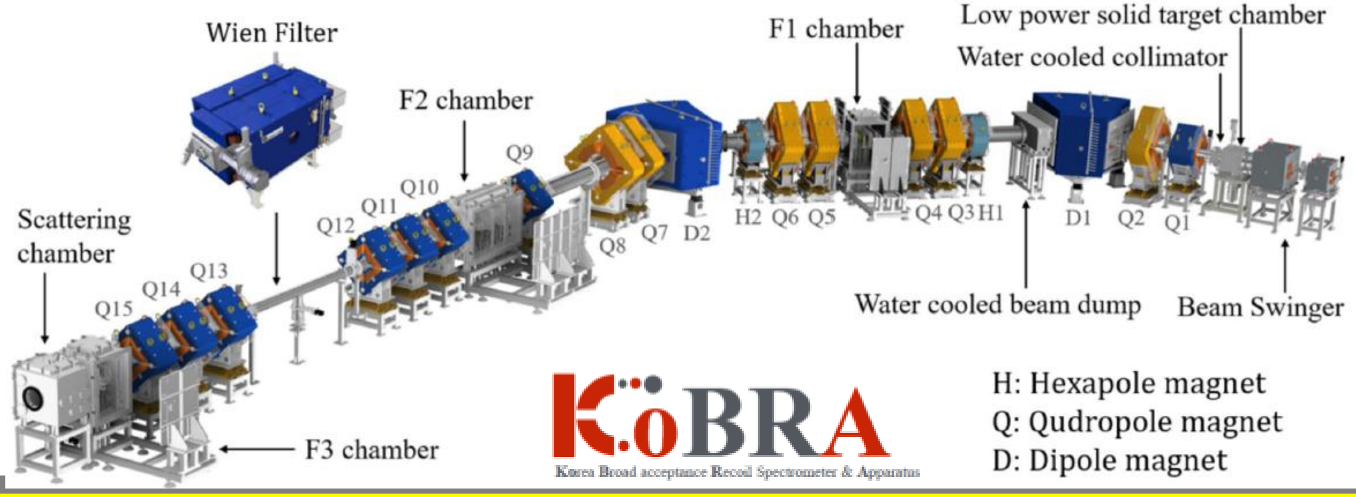
Commissioning of SCL3, ISOL, KoBRA performed in 2023 and 2024

- ISOL RIBs produced from SiC/LaC_2 targets (planed with an UC_x target in 2026)
- KoBRA spectrometer separated/identified secondary RIBs from 18.5 MeV/u $^{40}Ar^{8+}$
- Post-accelerated (16.4 MeV/u) $^{25}Na^{5+}$ RIB provided through ISOL-SCL3-KoBRA



CENS managing device for in-beam γ experiments in Oct-Nov 2025





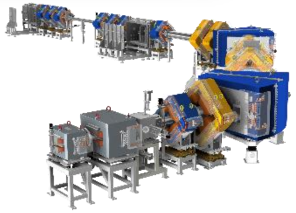
One of the first IRIS experiments (KO-24-30)

Physics motivations and our interests

- Measurement for production cross section
- Momentum distribution of projectile fragmentation

Spokesperson: Deuk Soon Ahn (CENS, IBS)
Co-Spokesperson: Jongwon Hwang (CENS, IBS)

RAON



KoBRA

RI Beam Production

❖ Which nuclides?
❖ Yields and cross sections?
❖ Momentum distributions?

Essential information to use RI beams from RAON/KoBRA

Goals

^{40}Ar, ^{20}Ne, ^{16,18}O, … primary beams **+ C, Be, Ni, Ta**,.. targets **with 20~40 MeV/u**

❖ Production rates and cross sections for each nuclide
❖ Momentum distribution and momentum peak
❖ Different primary beams & energies / targets → systematic studies

As the first step, ^{40}Ar + C at 16 MeV/u

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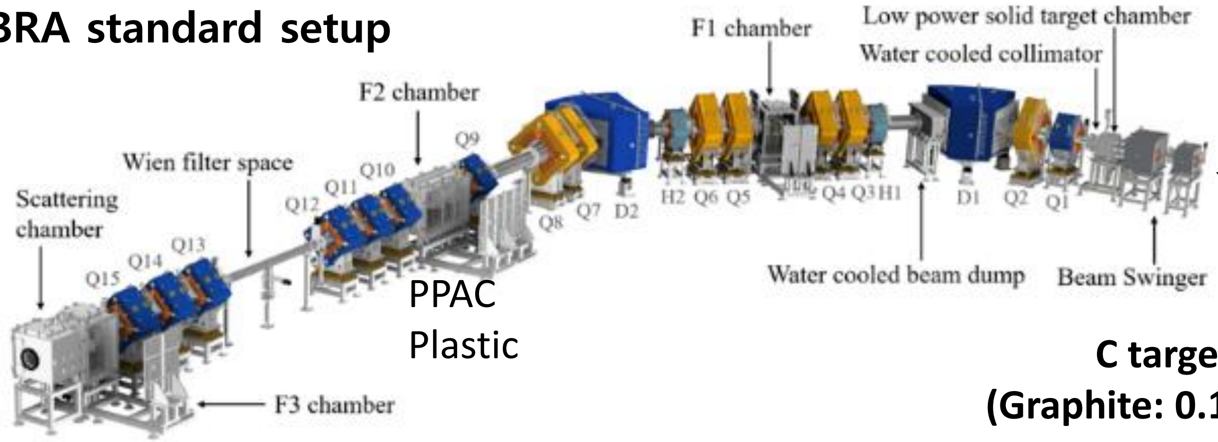
CENS CENTER FOR EXOTIC NUCLEAR STUDIES

Experimental settings and results

Experimental setup: KoBRA standard setup

D. S. Ahn, J. Hwang *et al.*



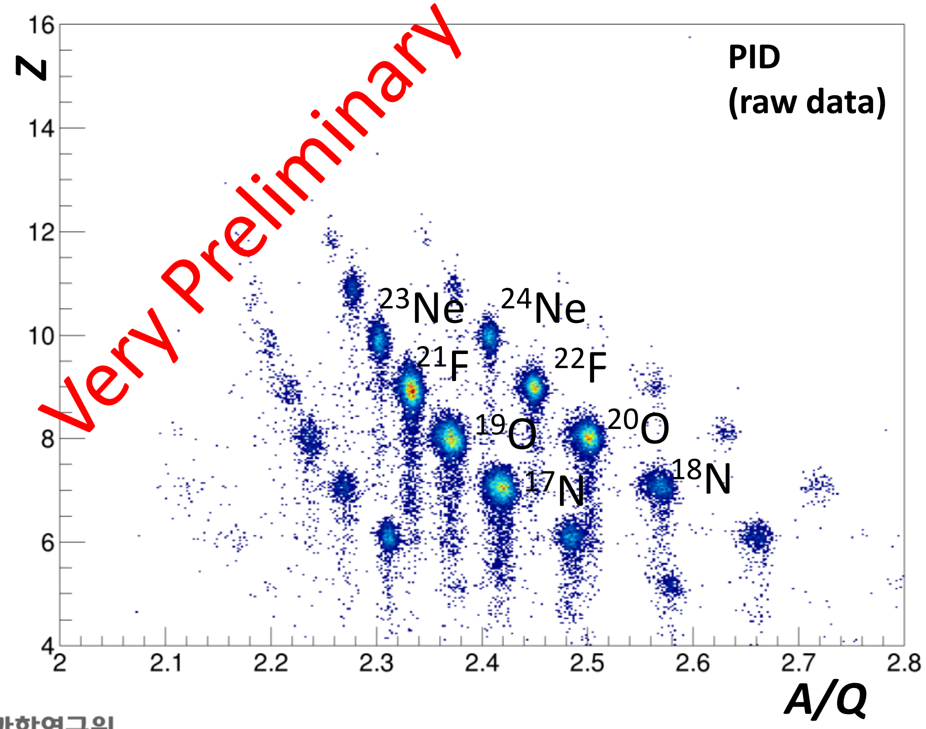
PPAC
Plastic

PPAC
Plastic
Si

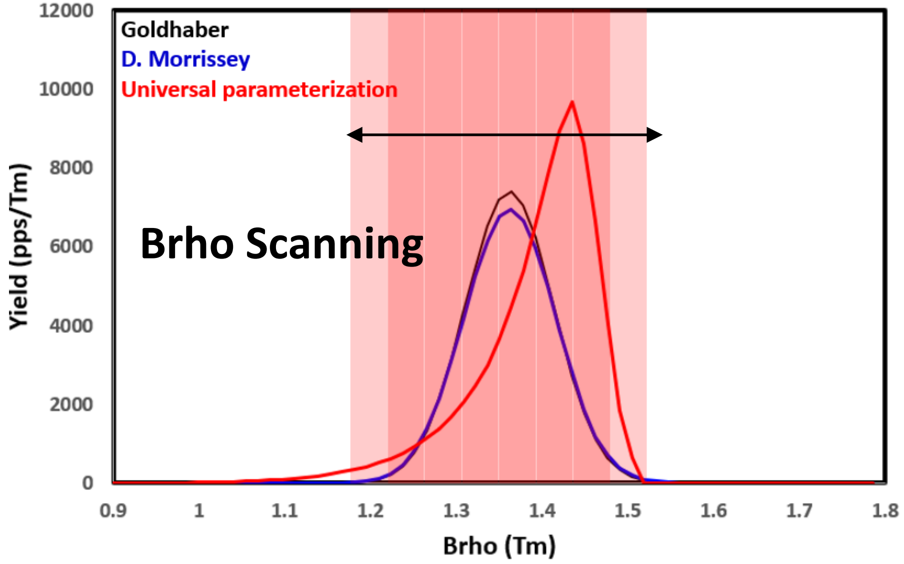
Total rate(Fragments): <1kpps

^{40}Ar beam (16.4 MeV/u)

C target (Graphite: 0.13 mm)



Momentum distribution

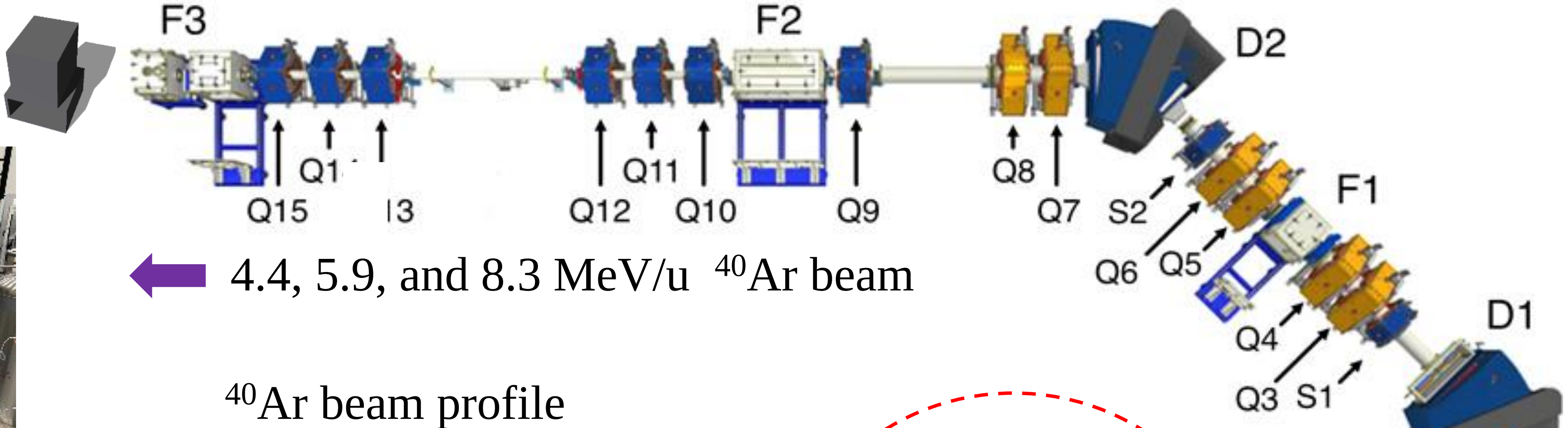


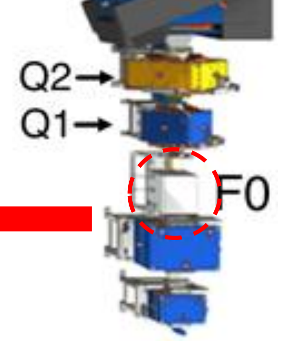
Cross Sections and momentum distributions of O~Ne isotopes.

KoBRA experiment (^{40}Ar+p elastic)

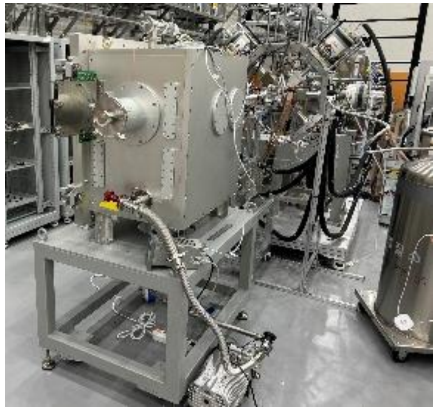
Courtesy of the KoBRA presentation

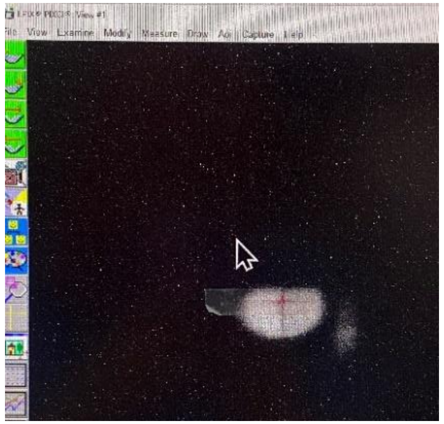
ELARK Chamber



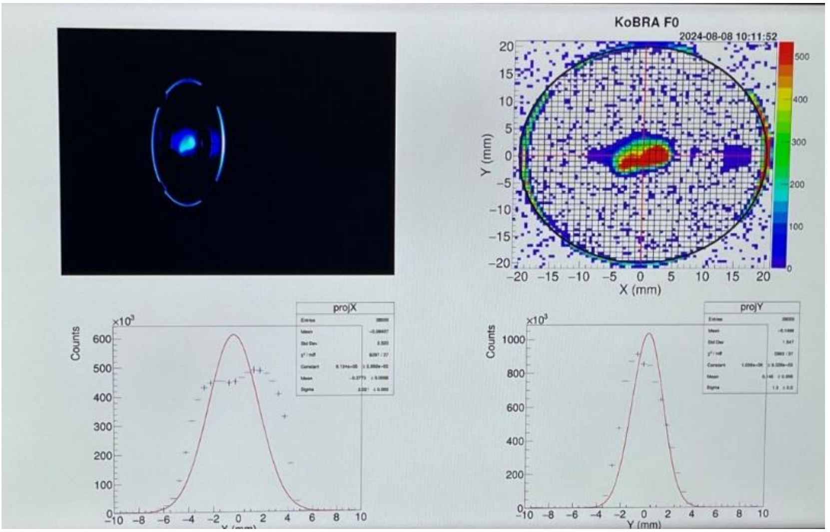


4.4, 5.9, and 8.3 MeV/u ^{40}Ar beam

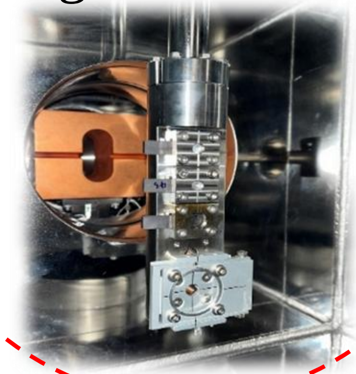




^{40}Ar beam profile

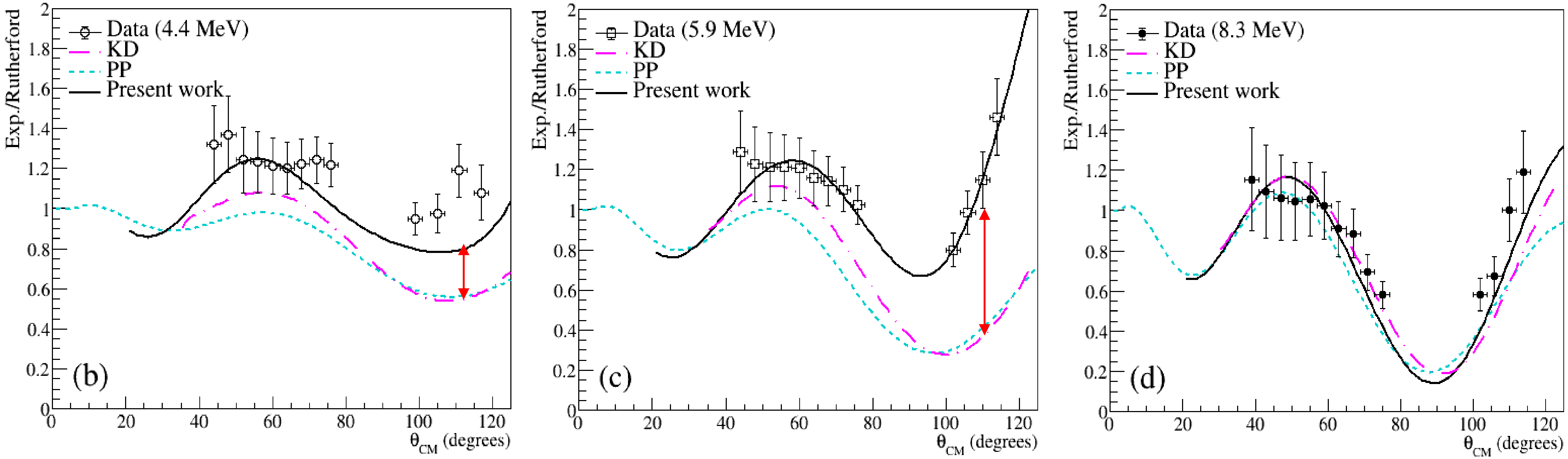


Al 30.2 & 46.3 um degraders at F0



8.3 MeV/u ^{40}Ar beam

KoBRA experiment (^{40}Ar+p elastic)



Cross-section to the Rutherford cross-sections for each beam energy

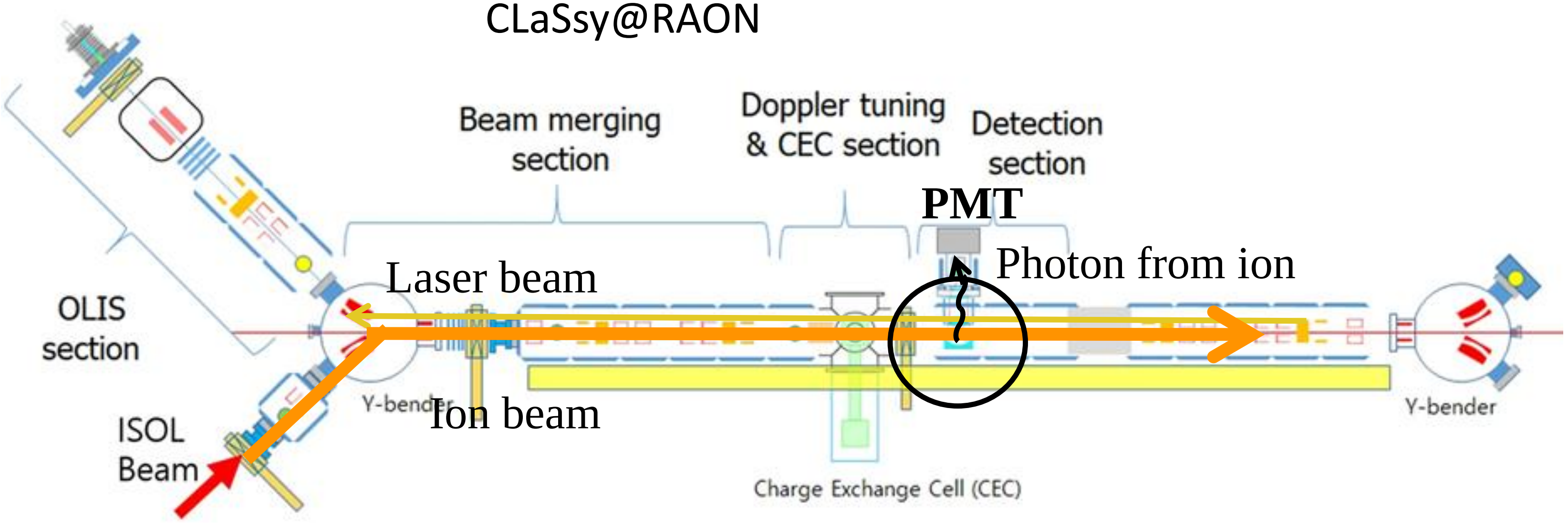
- Perey-Perey(PP) and Koning-Delaroche(KD) gOMPs work at 8.3 MeV.
- However, underestimate data at lower energies.

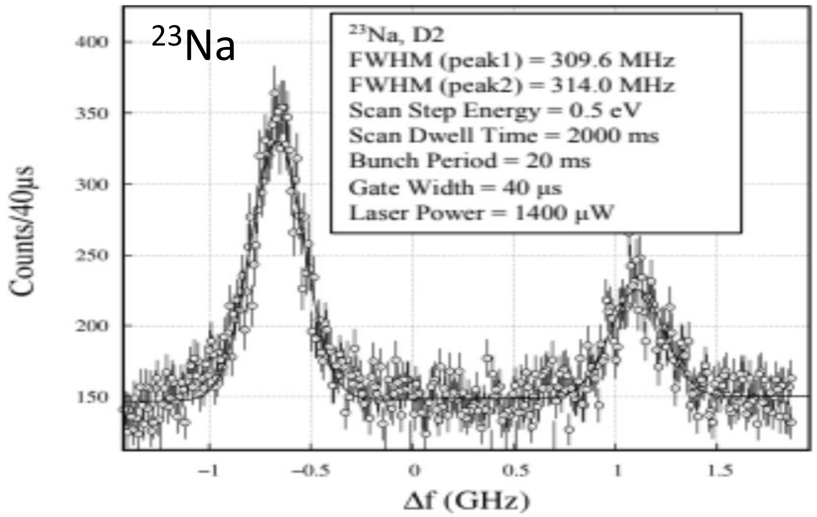
Energy (MeV)	V (MeV)	r_v (fm)	a_v (fm)	W_d (MeV)	r_d (fm)	a_d (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
4.4	58.1	1.19	0.672	0.050	1.29	0.540	5.75	0.996	0.590
5.9	43.2	1.39	0.430	5.97	1.87	0.368	5.75	0.996	0.590
7.77 [13]	55.8	1.19	0.672	6.35	1.29	0.540	5.75	0.996	0.590
8.3	57.5	1.19	0.672	8.02	1.29	0.540	5.75	0.996	0.590
9.36 [13]	55.1	1.19	0.672	8.21	1.29	0.540	5.75	0.996	0.590
10.5 [13]	56.0	1.19	0.672	8.63	1.29	0.540	5.75	0.996	0.590
14.1 [13]	52.0	1.19	0.672	8.96	1.29	0.540	5.75	0.996	0.590

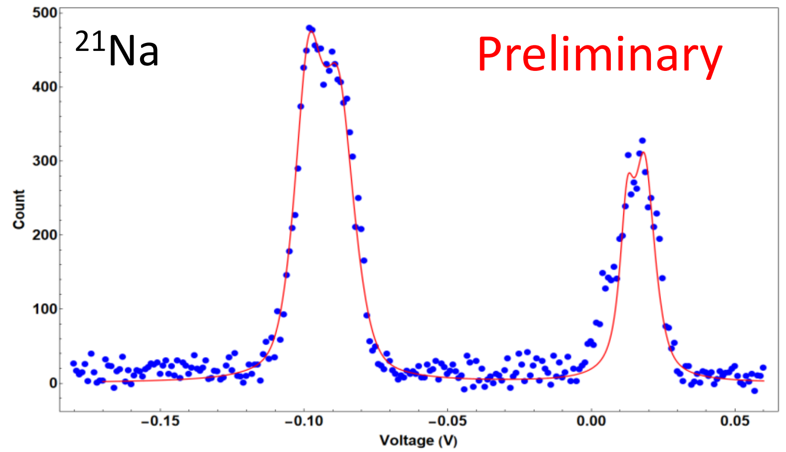
Extracted new optical model parameters using SFRESCO.

Collinear laser spectroscopy of neutron-deficient Na isotopes

CLaSsy@RAON







Measurement of neutron radii of Na isotopes with good accuracy

- proton distribution in nuclei r_p
- dRc=$r_n - r_p$ from the Mirror Energy Difference (MED)

Commissioning measurement successfully finished last Dec.

- Measurement ^{23,22}Na as commissioning
- Physics case measurement ^{21}Na analysis on ^{21}Na under way

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Courtesy to J. Ha, J. Won, C. Lim and CLS team

CENS CENTER FOR EXOTIC NUCLEAR STUDIES

CENS proposals submitted to the 2nd IRIS PAC (2025)

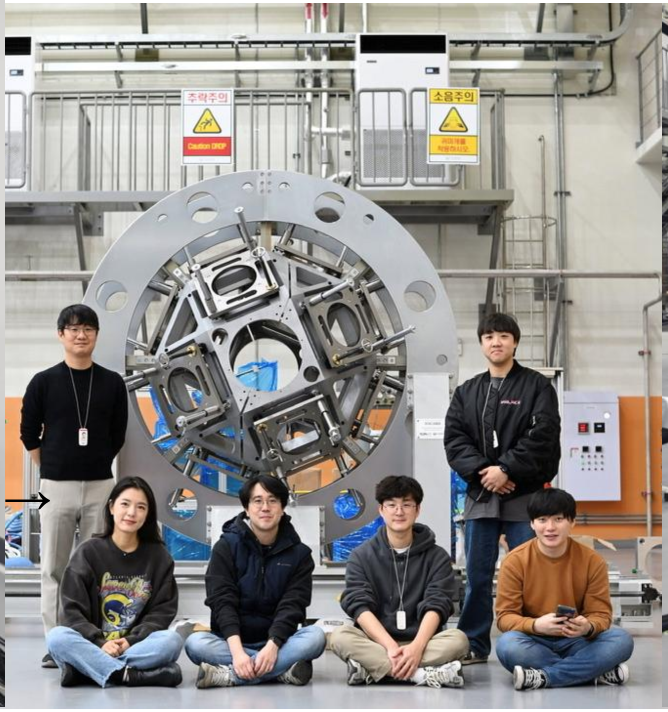
Proposed experiments	Beam	Experiment device
Probing isospin symmetry and the systematics of single-nucleon removal with mirror reactions	Xesus Pereira-Lopez	KoBRA (^{20}Ne)
High-spin spectroscopy of N~20 nuclei towards the island of inversion by RIB-induced fusion-evaporation reactions	Hiroshi Watanabe	KoBRA (^{25}Na)
Explore Triaxiality and re-measure the lifetime of the excited states in A ~ 80 using fusion evaporation reaction	Arunita Mukherjee	KoBRA (^{20}Ne)
Test experiment for neutron induced in-beam gamma-ray spectroscopy in search for shape co-existence	Yung Hee KIM	NDPS (neutron)
Collinear Laser Spectroscopy of $^{21\text{-}25}$Na	**Junho Won**	**CLaSsy ($^{21\sim25}$Na)**
Production of medical isotopes ^{97}Ru, ^{103}Ru, and ^{105}Rh with 35-70 MeV protons	Anastasiia Chekhovska	Cyclotron (proton)
Indirect measurement of the ^{12}C(^{12}C,p)23Na reaction at deep subCoulomb barrier energies via the Trojan horse method	Zifeng Luo	KoBRA (^{24}Na)
Fusion Reaction Study of Stellar Neon Burning	**Sunghoon Ahn**	**KoBRA (^{20}Ne)**
Target dependence study of production cross section with ^{40}Ar beam	**Deuk Soon Ahn**	**KoBRA (^{40}Ar)**
Spectroscopy and deformation in ^{20}Ne and ^{22,24,26}Mg	Sunghan Bae	KoBRA (^{20}Ne)
^{40}Ar + α reaction cross section measurements using a VOICE	Minju Kim	KoBRA (^{40}Ar)
^{21,25}Na+p elastic scattering for study of deformation effect in nuclear optical model	Jung Woo Lee	KoBRA (^{21}Na,^{25}Na)
Study of the ^{20}Ne(n,γ)^{21}Ne reaction rate with a surrogate method	Dahee Kim	KoBRA (^{20}Ne)
Experimental studies for RI beam production of neutron-rich nuclei using the ISOL and IF method	**Deuk Soon Ahn**	**KoBRA (^{40}Ar,^{25}Na)**

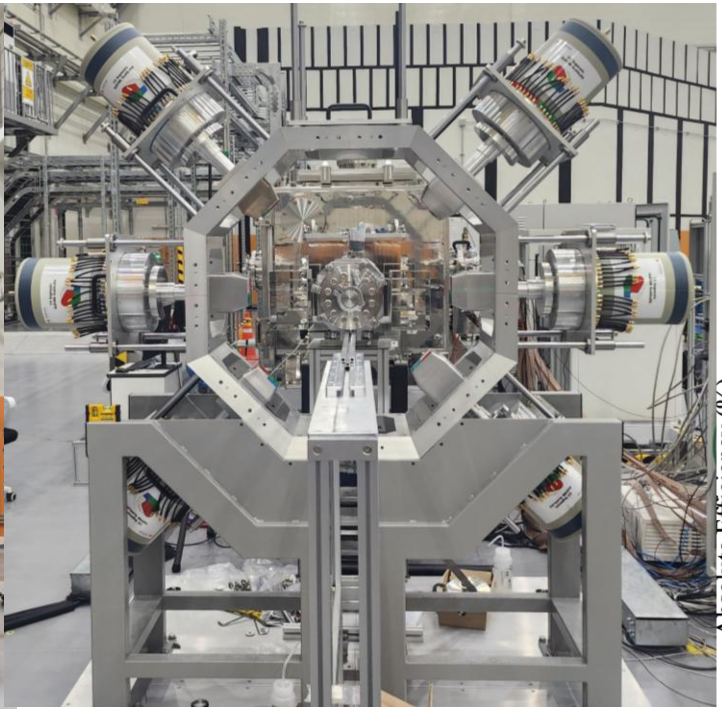
14 proposals (among 22 total) submitted from CENS!

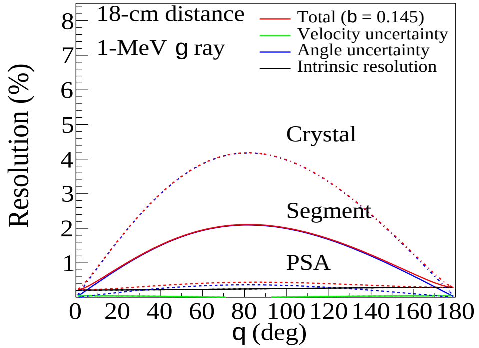
(11 KoBRA beamline, 1 NDPS beamline, 1 CLaSsy, 1 proton beamline)

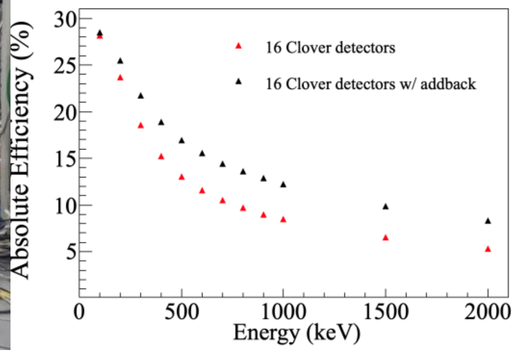
Four A-grade proposals

ASGARD (Array of Super-clover Gamma Ray Detectors) project







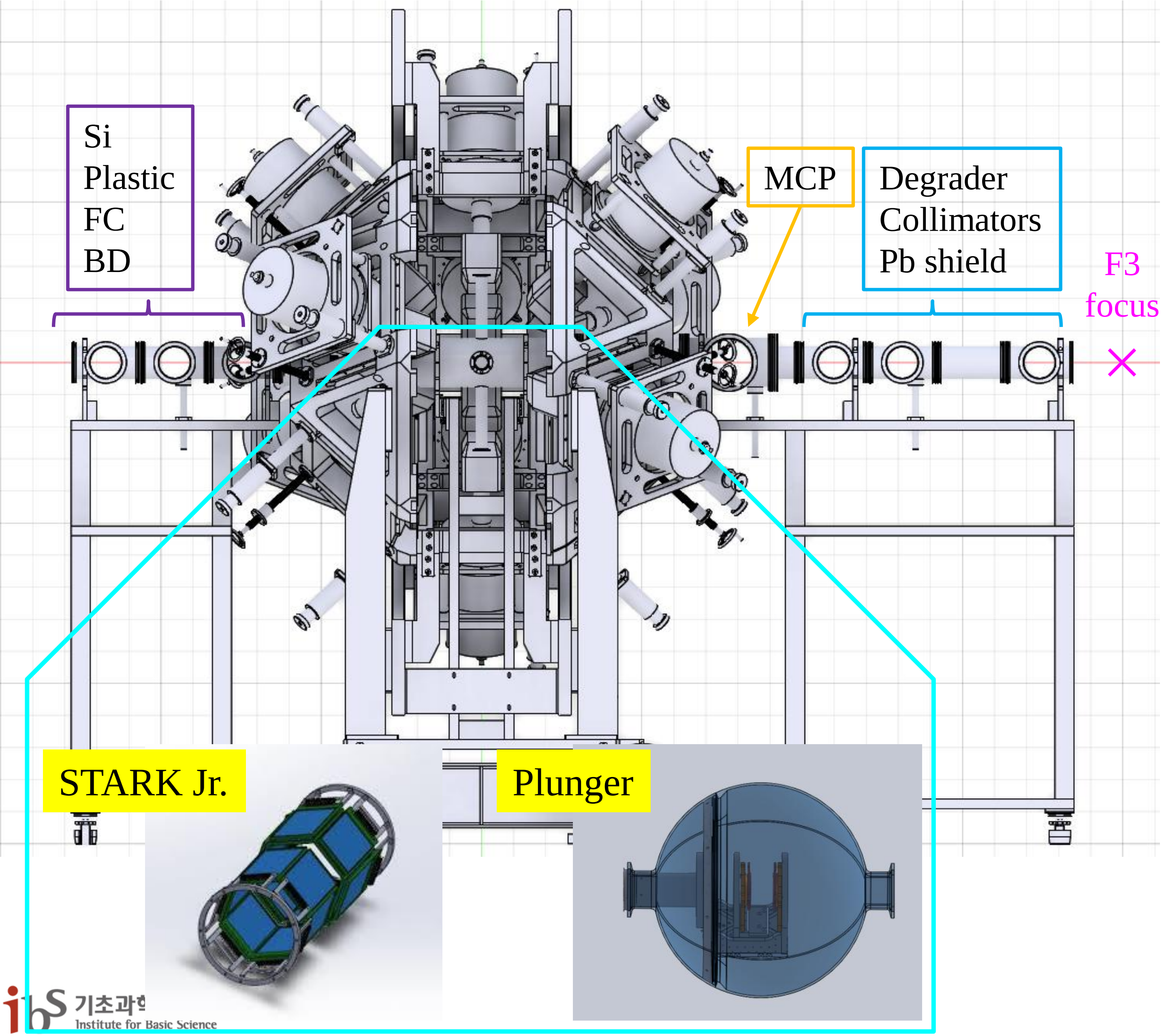


- Each clover consists of 4 Ge crystals X 8 segmented electrodes

  → Improve the energy resolution from the Doppler effect / Good angular distribution
- Capability of multi-purpose: in-beam / delayed γ-ray spectroscopy
- 10 detectors (Dec. 2024) →12 at the end of this year (2025)

Courtesy of B. Moon

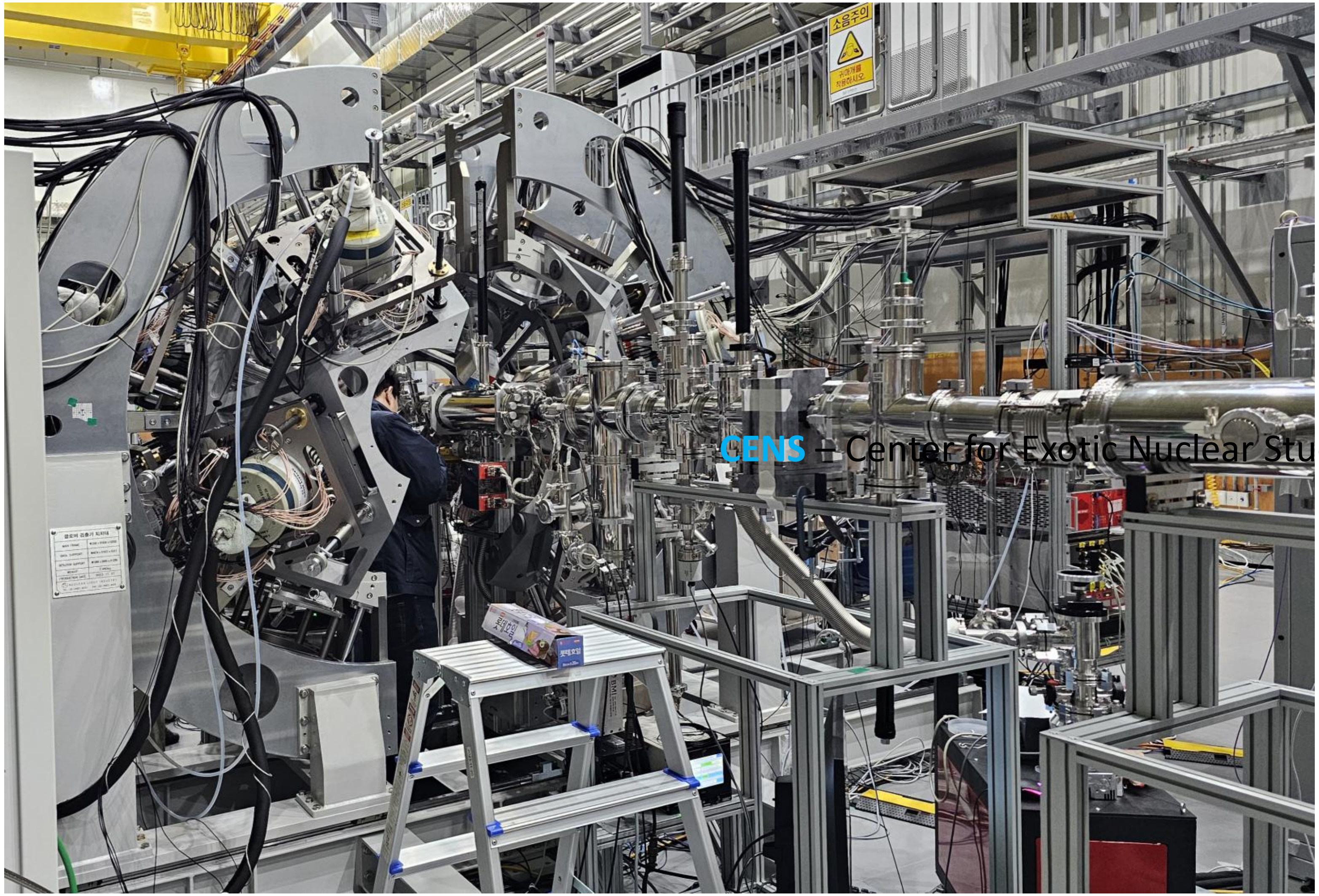
Experimental setup for Fall 2025 Exp. at KoBRA

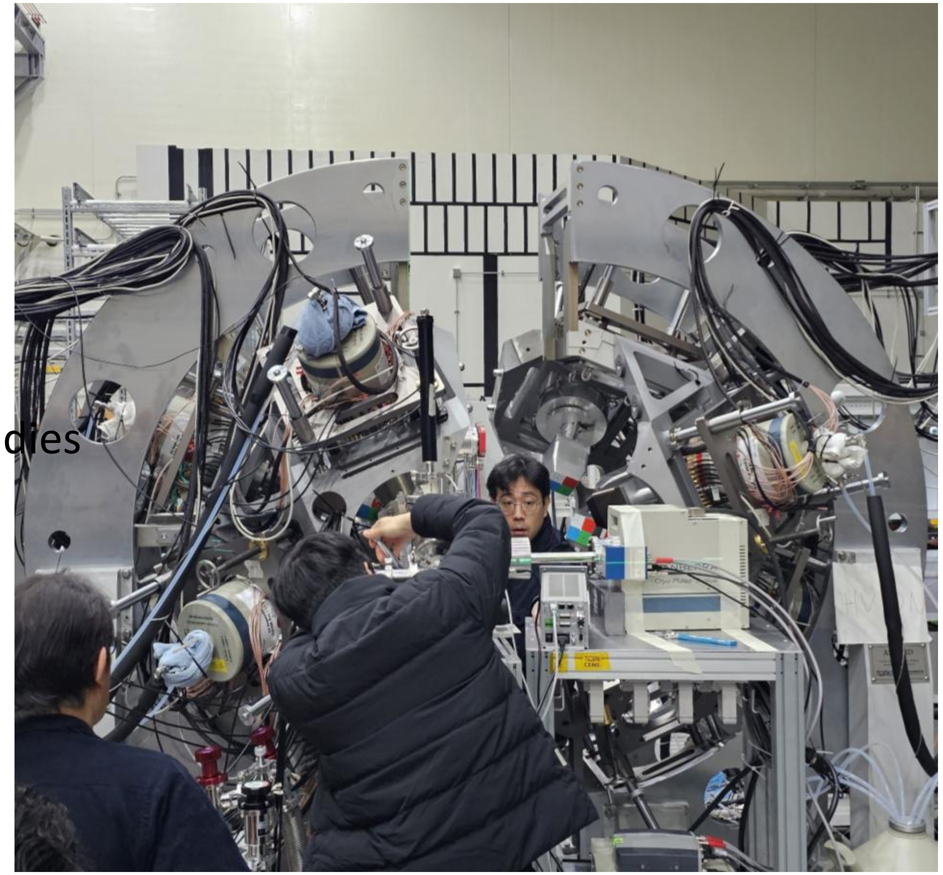


First beam experiment with ASGARD

- 10 Clover HPGe detectors on the ASGARD frame
- Target position ~2 m downstream from the original F3 focal point
- STARK Jr. or Plunger installed at the array center
- 2 PPACs in the F3 chamber
- Degrader, 2 collimators, beam viewer (MCP) installed in the upstream of the target
- Si detectors, plastic, FC, beam dump located in the downstream of the target

Experimental setup at KoBRA in Nov. 2025





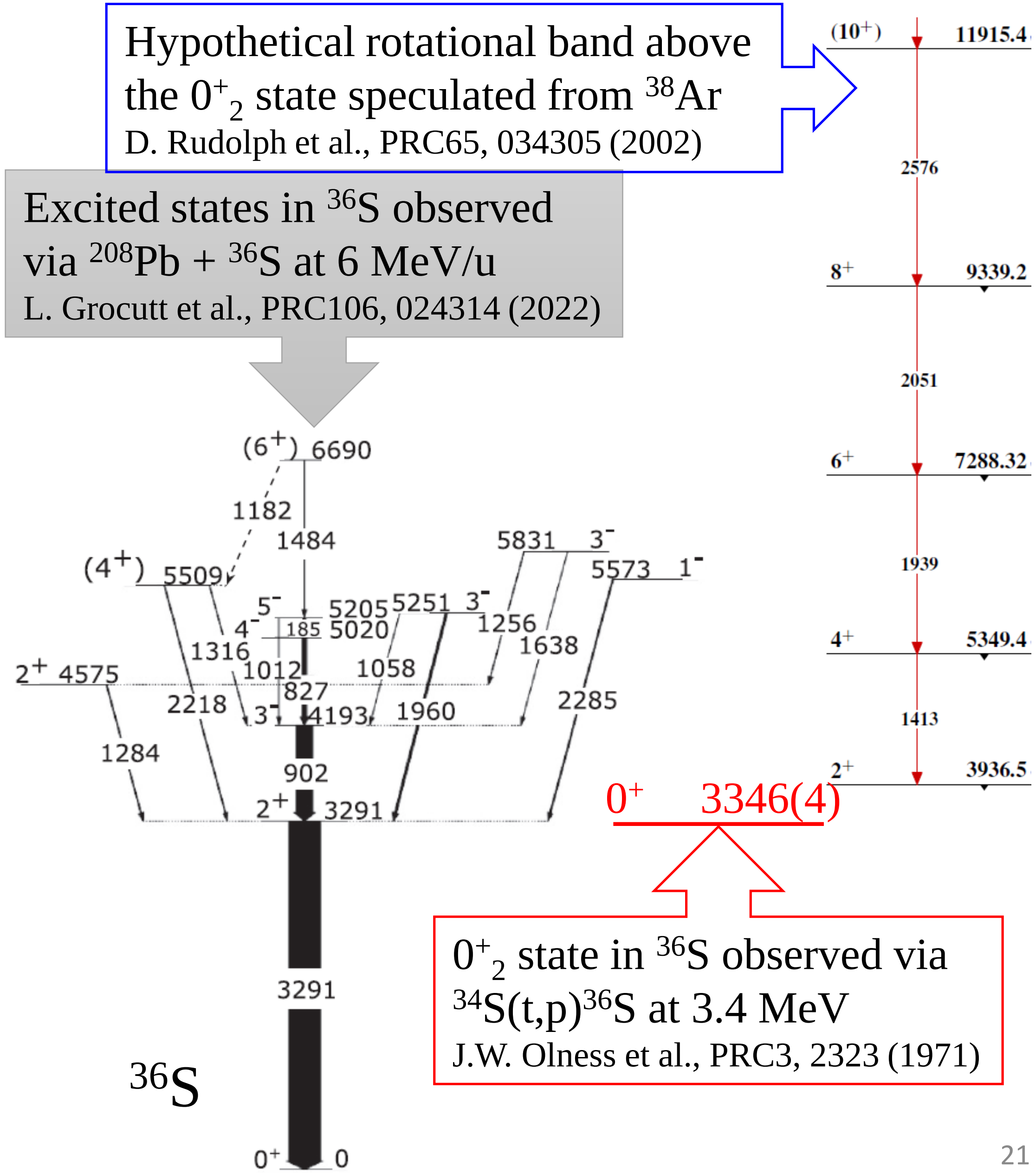
CENS – Center for Exotic Nuclear Studies

Commissioning for FE reactions with RIB

- Beamtime (KO-25-07) : November 12-18, 2025
- Beam: ^{25}Na, 4.5→2.5 MeV/u, >10^5 pps
- Target: Enriched ^{13}C, 1-2 mg/cm^2

  ⇒ ^{13}C(^{25}Na, 1p1n)^{36}S

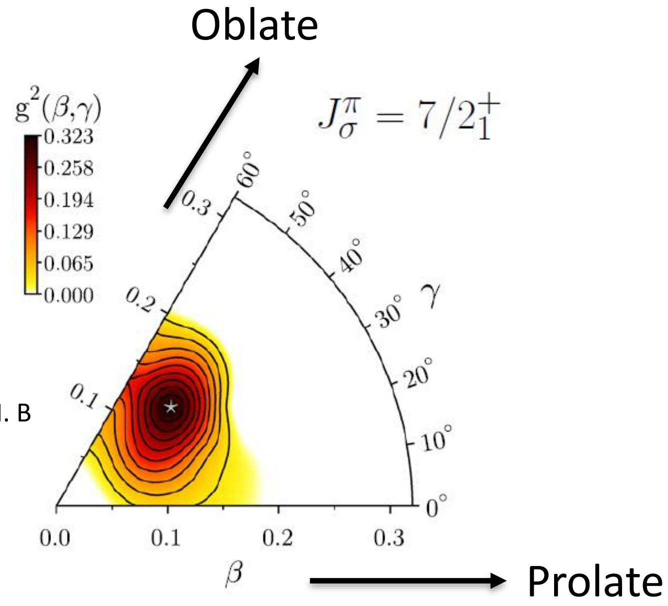
- Establish the methodology for RI-beam induced fusion-evaporation reactions at RAON
  - Development of low-energy ^{25}Na beams from ISOL-SCL3-KoBRA
- Measure the excitation function of the ^{25}Na+^{13}C fusion-evaporation reactions for feasibility check
- Explore high-spin states in ^{36}S and its vicinity



Courtesy of H. Watanabe

Courtesy of J. Park

Motivation

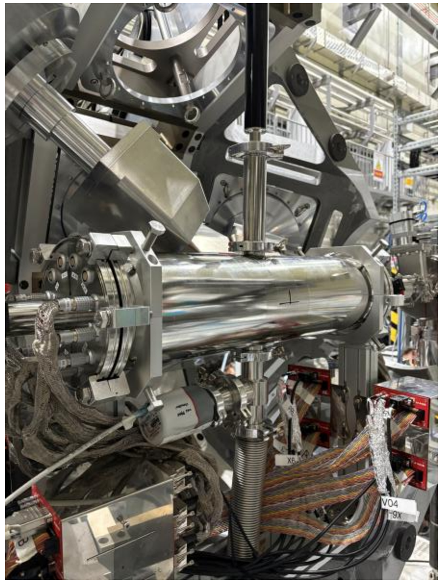


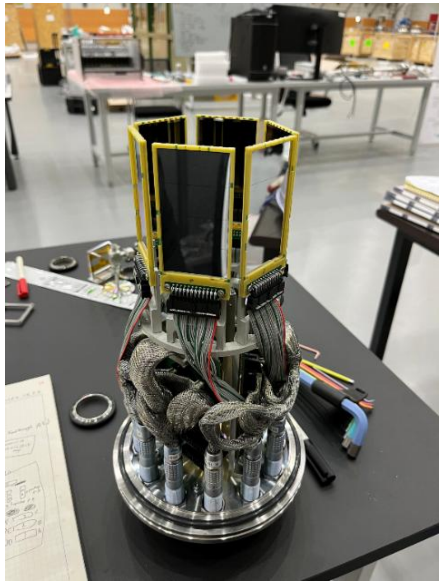
Taken from
B. Bally, G. Giacalone and M. Bender, EPJA 59, 58 (2023)

1. Explore shapes of excited states in ^{181}Ta, ^{197}Au through **new** measurements of spectroscopic quadrupole moments

2. Commissioning of ASGARD (HPGe) and STARK Jr. (Si) detectors for in-beam γ-ray spectroscopy program at IRIS

Method





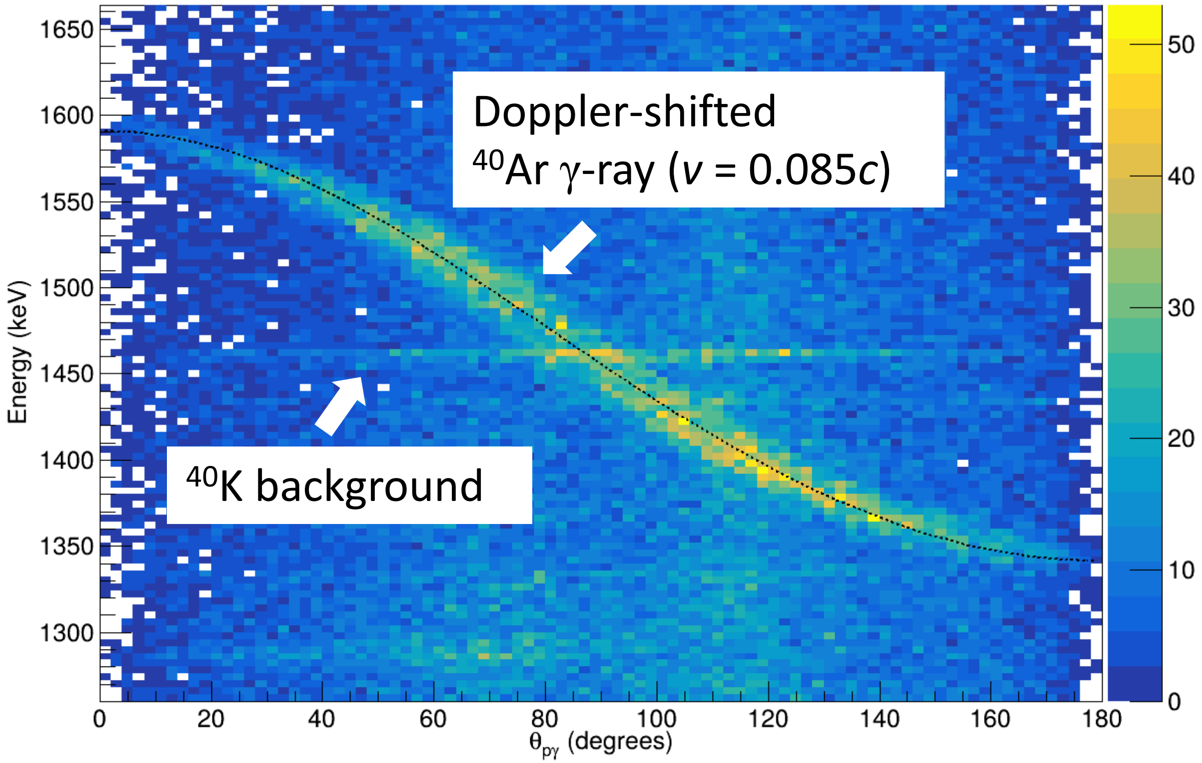
$^{40}Ar^{8+}$ beam from SCL3 sent to KoBRA spectrometer
E_{beam} = 4.42 MeV/u, I_{beam} ~ 10^6-10^7 pps
^{181}Ta and ^{197}Au targets, thickness = 1 μm

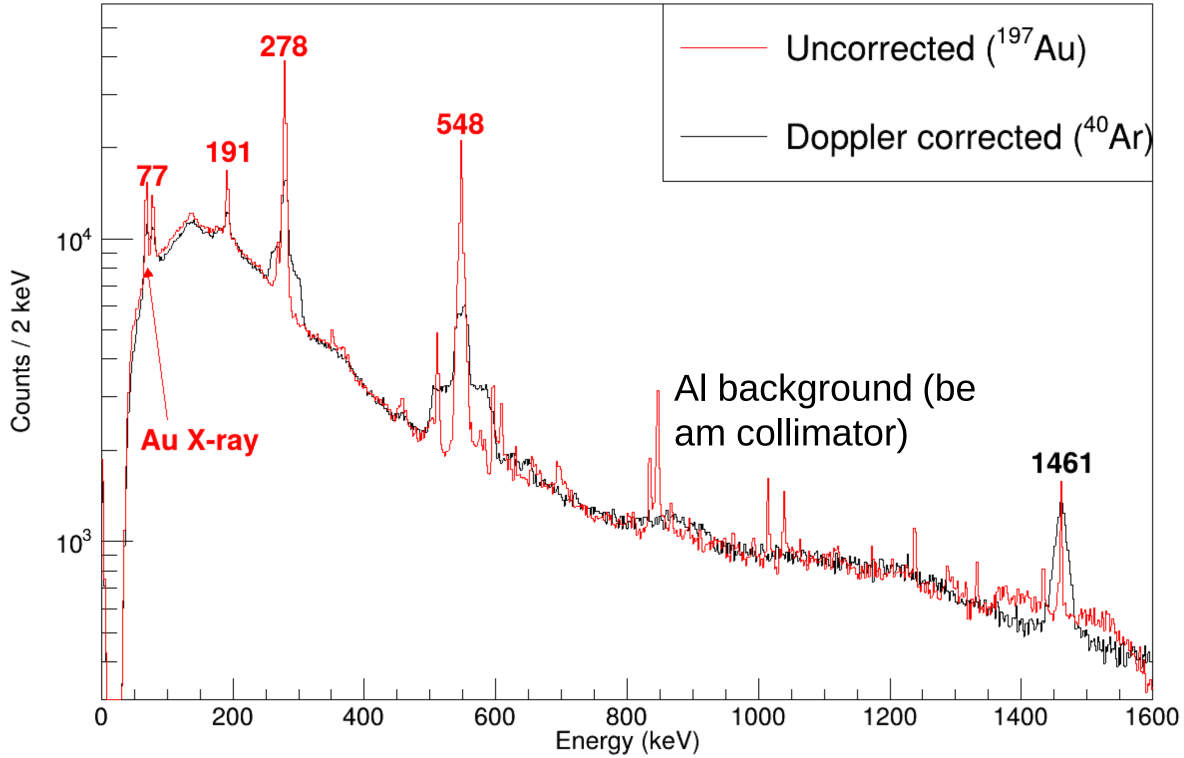
ASGARD + STARK Jr. installed downstream of F3

Event selection for "safe-energy" Coulomb excitation (pure electromagnetic interactions)

Preliminary results (1 day of beam on ^{197}Au)

Courtesy of J. Park





Successful Doppler correction of 1461-keV γ-ray from ^{40}Ar using STARK Jr. and ASGARD data

This transition is important for normalization of target γ-ray yields

Observed known γ-ray transitions in ^{197}Au (in red) with good statistics

Beam on ^{181}Ta target is also planned for this experiment

Analysis with semiclassical Coulomb excitation code GOSIA to follow after the experiment

Summary

❖ The IBS Center for Exotic Nuclear Studies has been actively involved in research activities related to nuclear lattice EFT, the island of inversion, astrophysically important (a,p) reaction, weak interaction, and more.

❖ Korea has constructed the RI accelerator facility called RAON and the first phase of the project-comprising the low energy accelerator SCL3, experimental facilities and ISOL facility-has been completed. RAON is expected to deliver more stable beams and ISOL beams in the future.

❖ We performed first experiments at RAON in 2024. We are carrying out several experiments using ASGARD and devices CENS developed in 2025.

Thank you for your attention!