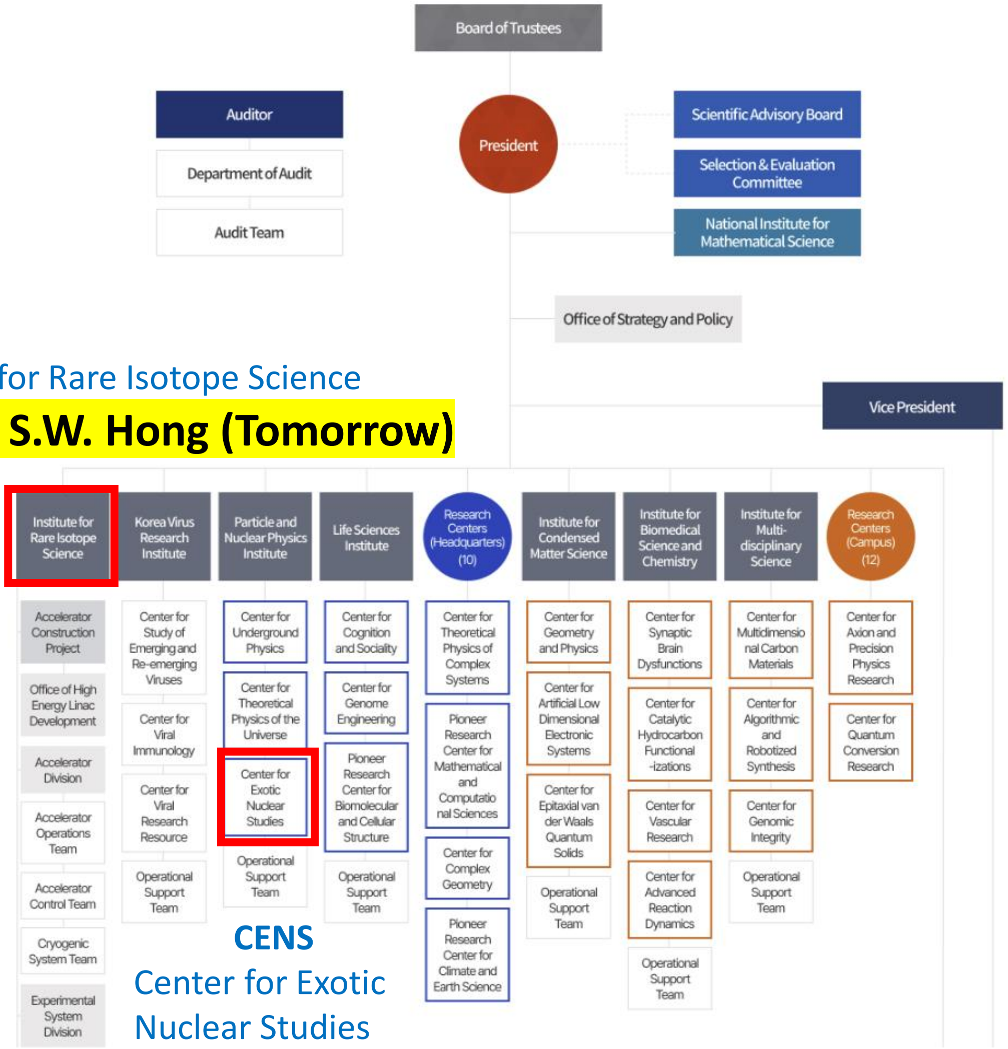
The 2024 ANPhA Symposium
November 15, 2024
Huizhou, China

Research activities on exotic nuclei

Kevin Insik Hahn

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

Introduction of IBS (Institute for Basic Science)



IRIS

Institute for Rare Isotope Science

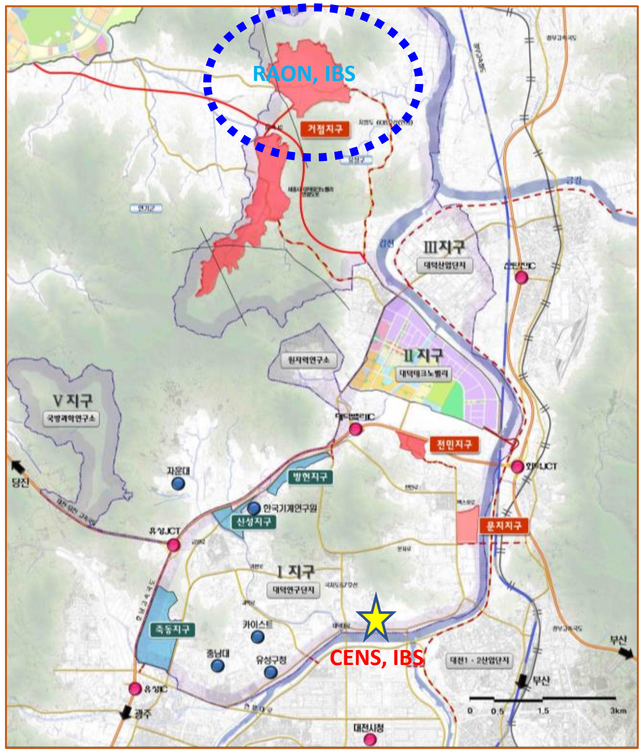
Talk by S.W. Hong (Tomorrow)

CENS

Center for Exotic Nuclear Studies

4 Institutes

30 Research Centers



기초과학연구원 Institute for Basic Science

CENS CENTER FOR EXOTIC NUCLEAR STUDIES

Introduction of CENS (history, members)

CENS member status

2020(11)	2021(18)	2022(23)	2023(26)	2024(29)
- D. Kim & S. Kim	- E. In, S. Bae, S. Cha	- Y. H. Kim*	- Y. Kim*	- V. R. Chavan
- T. –S. Park	- Q. Zhao	- M. L. Bui	- J. W. Lee	- A. Mukherjee
- J. Hwang	- X. Pereira-Lopez	- J. Y. Huh	- J. S. Ha	- A. Chekhovska
- J. Park	- D. S. Ahn*	- H. Y. Lee	- J. Won	- Y. Guo
- C. B. Moon & B. Moon	- M. Kim	- I. Mazur	- M. J. Kim	- Z. Luo
- S. Ahn*	- S. Choi			
- Z. Korkulu & L. Stuhl				

- CENS was established on Dec. 16, 2019
- We currently have 29 researchers
- * group leaders

1 Director
4 Faculty members (Research fellows)
2 Research engineers
10 Senior researchers
3 Young Scientist Fellows
9 Post-doctoral researchers
9 Ph.D. students

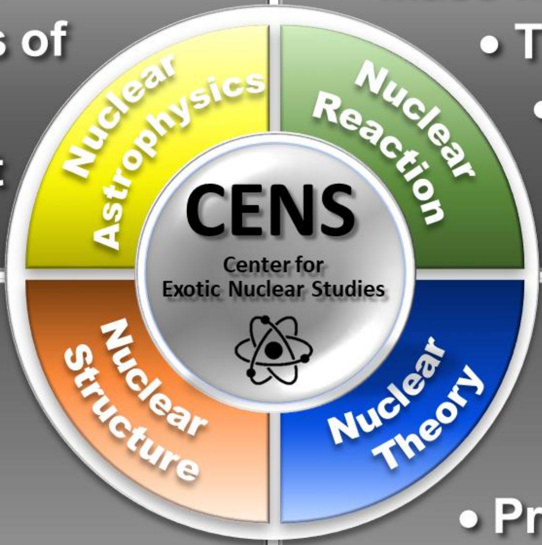
Introduction and organization of CENS

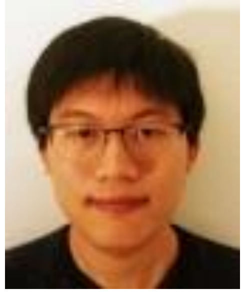
Visions

- To become one of the leading research institutions in nuclear physics
- To explore uncharted regions of nuclei and find important discoveries

- Nuclearsynthesis
- r-process/rp-process
- Origin of elements
- Nuclear properties of key nuclei
- Direct and indirect measurements

- Reaction mechanism
- Spin-isospin collectives
- Mass measurements
- Transmutation
- Dripline and new isotopes



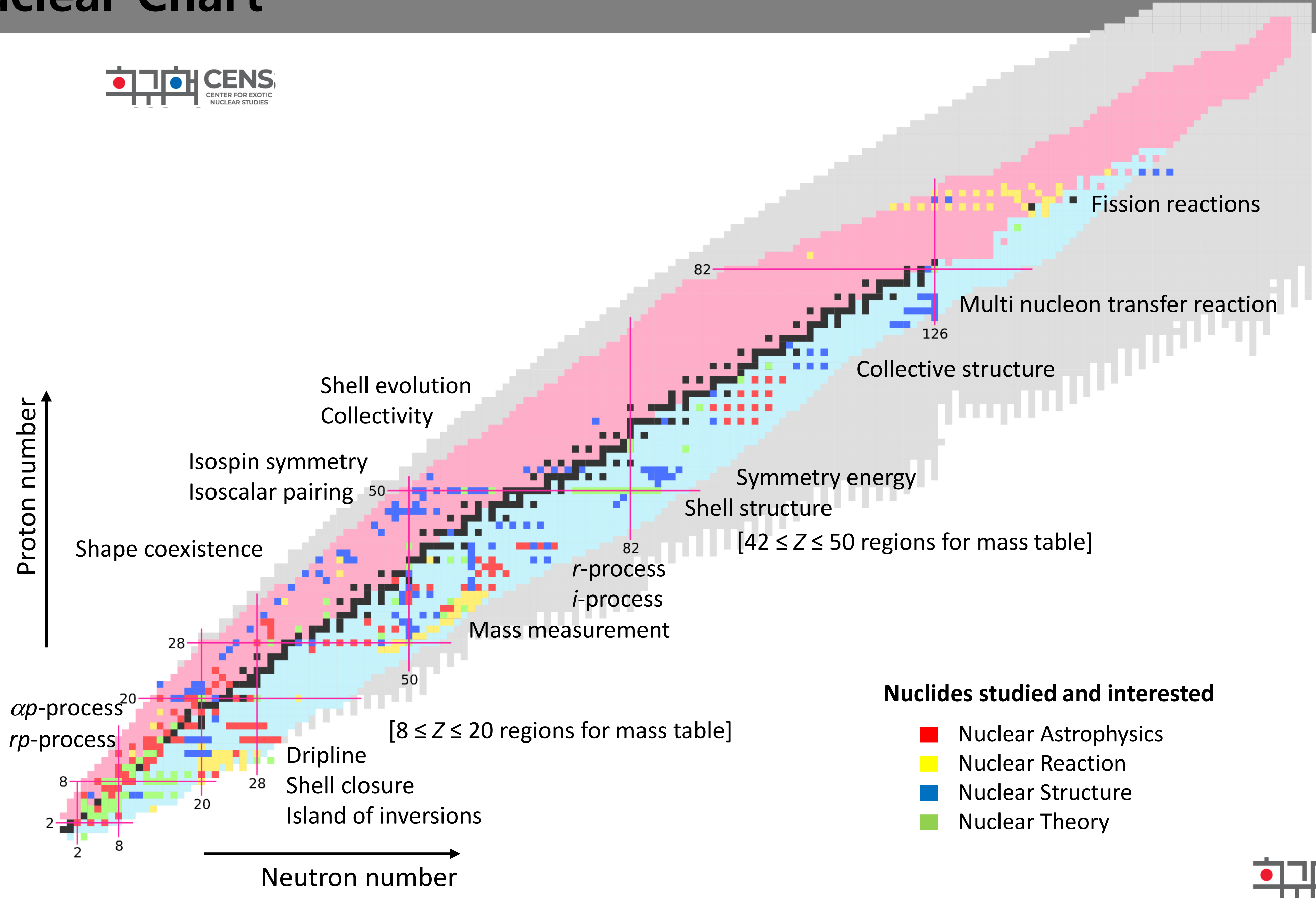


- Nuclear shell evolution
- Shape evolution
- Shape coexistence
- Isospin symmetry

- Compound and direct nuclear reaction
- Precise numerical quantum many-body calculations
- Density functional theory

- Interdisciplinary collaborations
- Research using RAON facility with ISOL and IF method
- Detector development

CENS Nuclear Chart

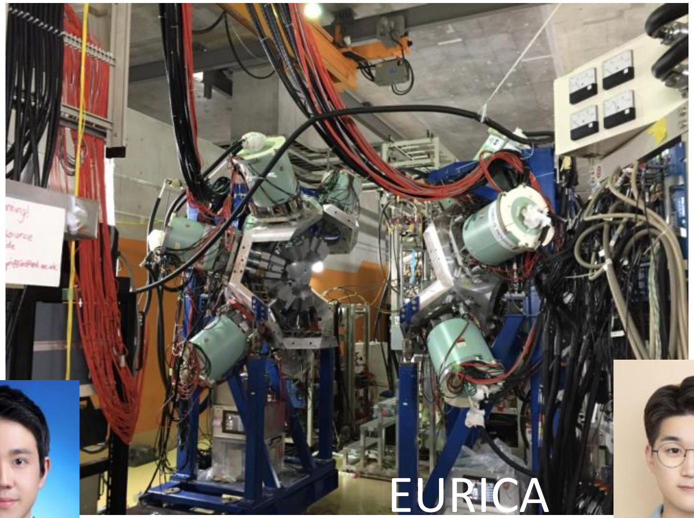


Nuclides studied and interested

- Nuclear Astrophysics
- Nuclear Reaction
- Nuclear Structure
- Nuclear Theory

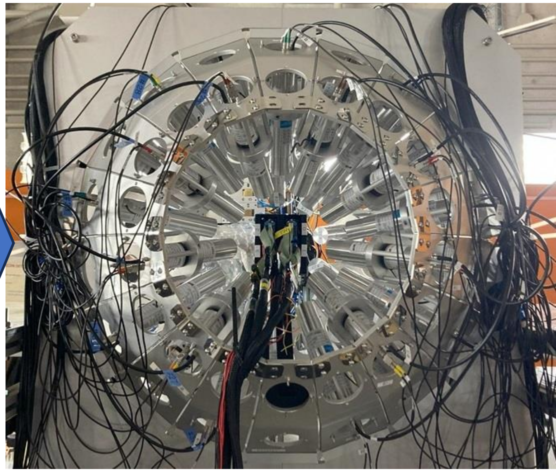
Decay spectroscopy at RIBF

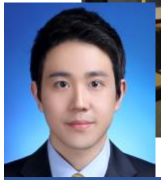
Courtesy of Y. H. Kim



- Decay spectroscopy at RIBF
  Euroball-RIKEN Cluster Array (EURICA) campaign
- More than 60 peer-reviewed publications
- Discovery of new isotopes & isomers
- Nuclear shell & shape evolution in unknown territory
- PhD of 4 CENS members (B. Moon, J. Park, J. Ha , S. Bae*)

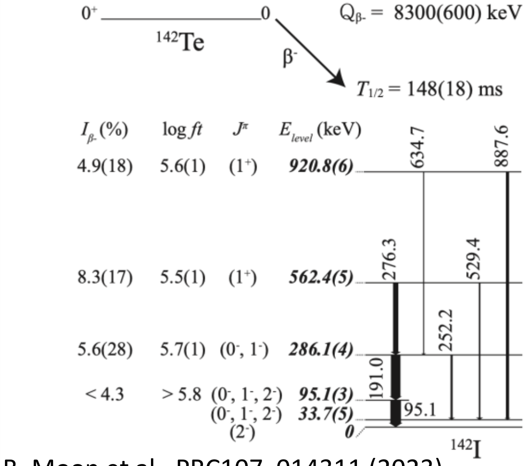
Continuation of collaboration through NEW Project IDATEN



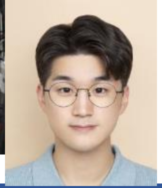


Nuclear structure evolution beyond ^{132}Sn

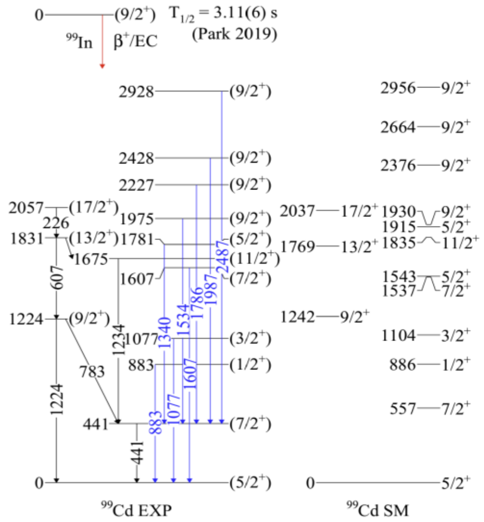
Weakened GT transition in ^{142}Te



B. Moon et al., PRC107, 014311 (2023)
B. Moon et al., PRC **105**, 034334 (2022)
B. Moon et al., PRC **103**, 034320 (2021)

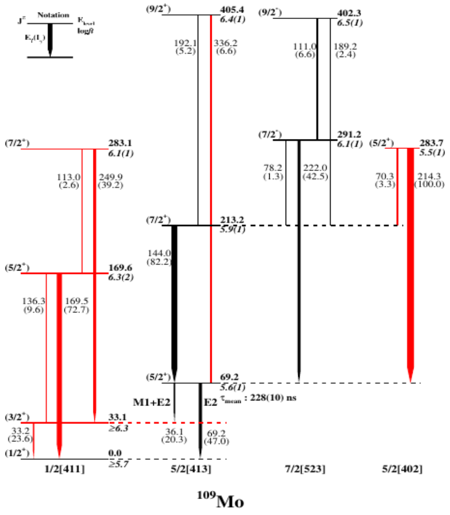


Nuclear structure evolution near ^{100}Sn



J. Park et al., PRC102, 014304 (2020)

Shell evolution study beyond N = 60

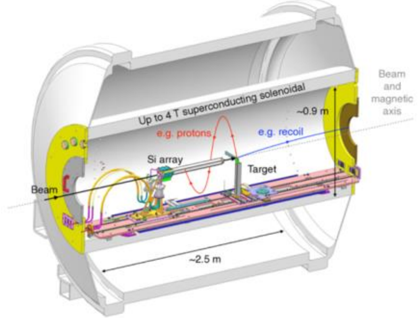


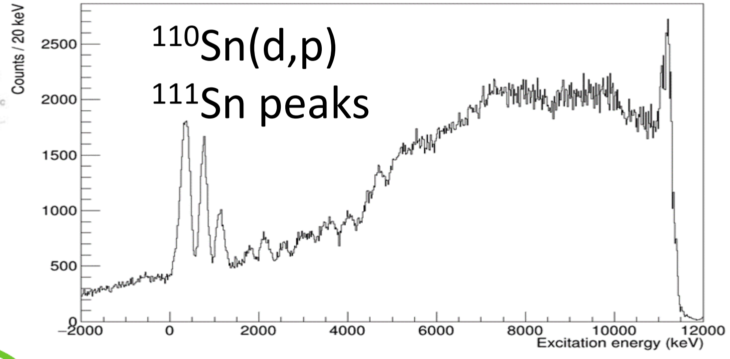
S. Bae et al., To be submitted to PRC (2023)

Experiments under analysis

Courtesy of Y. H. Kim

Shell evolution along the Sn isotope

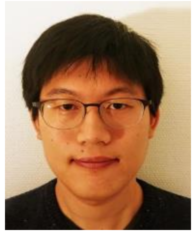


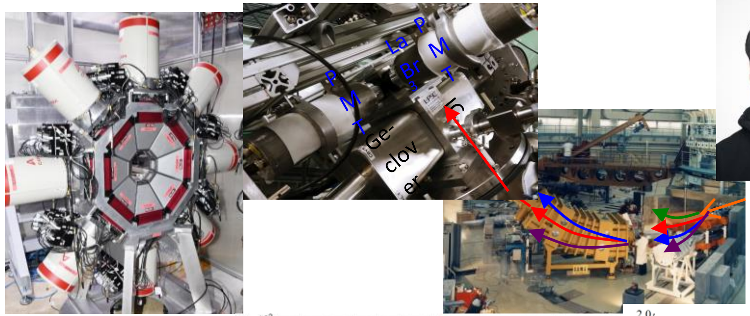


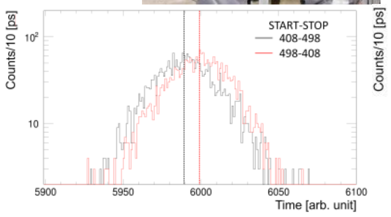
ISOLDE Solenoidal Spectrometer

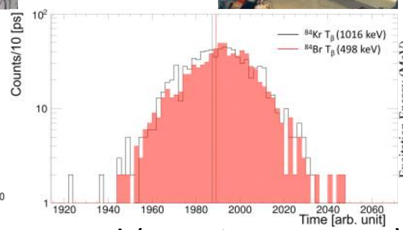
Quadrupole collectivity in ^{106,108,110}Sn
single-particle dominated states in ^{107,109,111}Sn

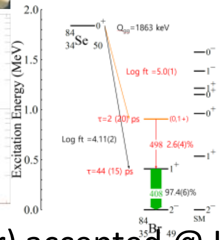
Experiment at Institute Laue Langevin









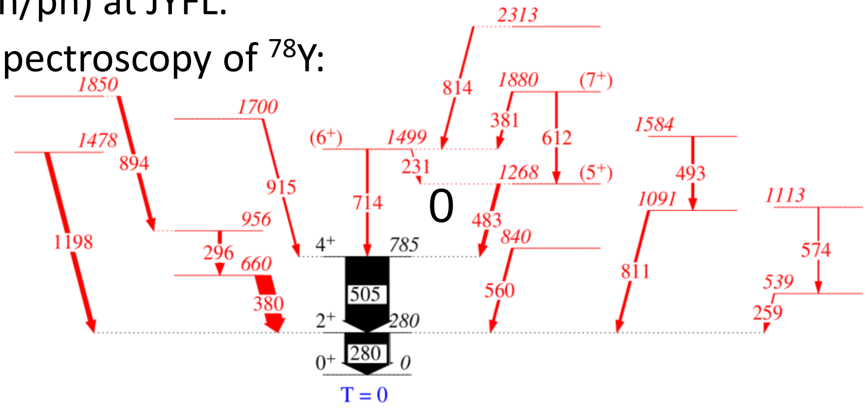


3 proposal (1 main proposer) accepted @ LOHENGRIN
LoI accepted FIPPS+Khala campaign (with B. Moon)
New transition from 84Br beta decay

isospin symmetry of ^{78}Zr & ^{78}Y

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

New transitions in red



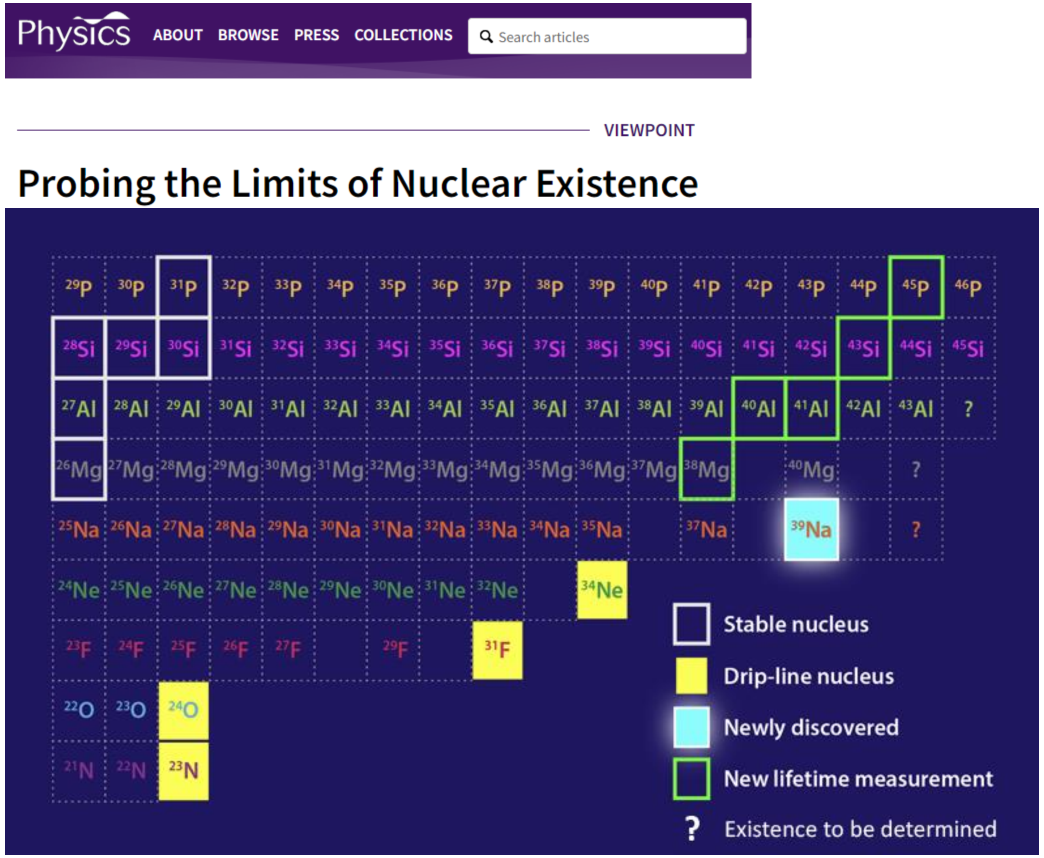
Other experiments under analysis

Experiment Title	Person involved
96Y isomeric ratio yields for anti-neutrino anomaly	Y. H. Kim, S. Bae
Fast timinig A=86 fission fragments (86Kr, 86Br)	Y. H. Kim, J. Lee
Commissioning experiment of the fast-timing γ-ray detector array IDATEN	B. Moon, J. Park, Y. H. Kim, J. Lee, Y. Jang
Spectroscopy of single-particle states in ^{109}Sn through (d,p) transfer reactions with ISS at 8 MeV/u	J. Park

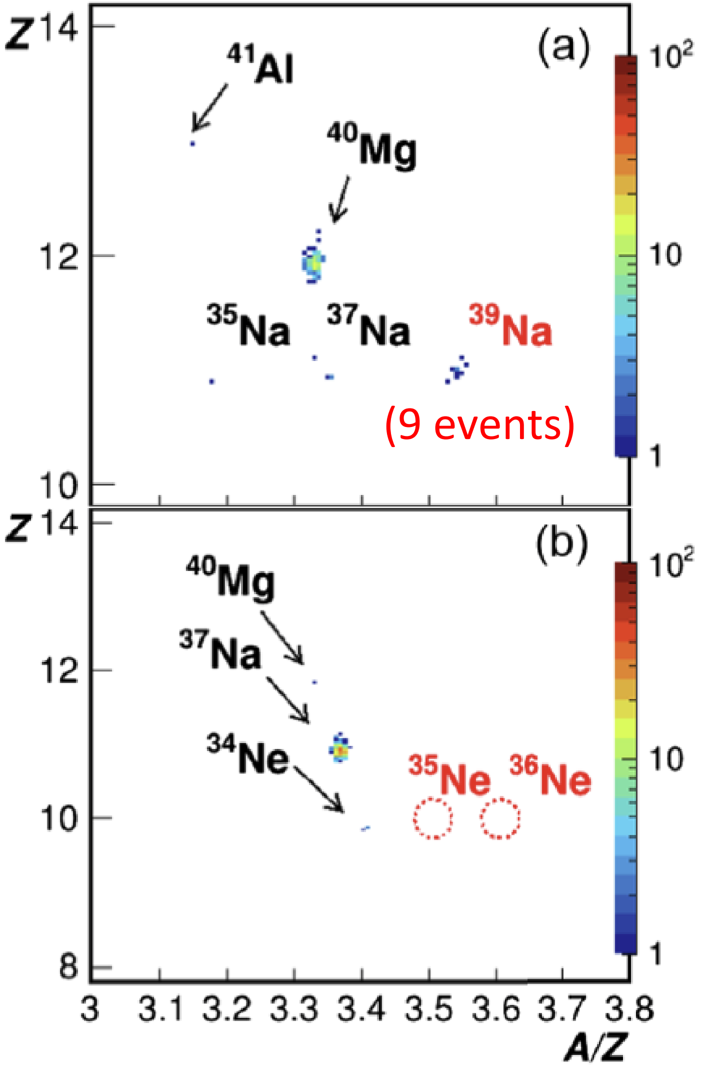
Discovery of ^{39}Na and dripline search

■ Discovery of ^{39}Na

- Search the existence of ^{39}Na→ Discovery of ^{39}Na
- Confirmed the dripline of Ne with high statistics data of ^{35,36}Ne



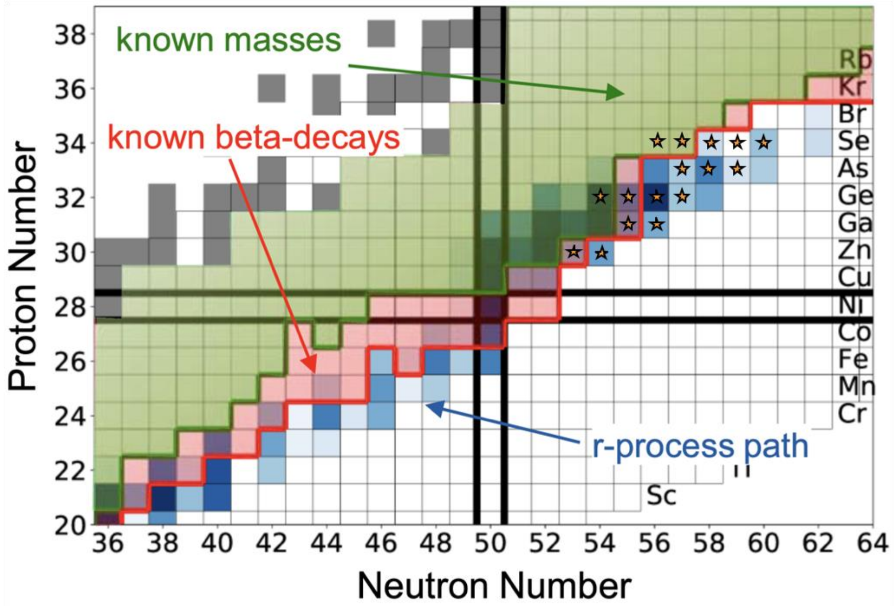
D.S. Ahn *et al.*, PRL 129, 212502 (2022)



RIKEN RIBF new isotope collaboration using BigRIPS separator

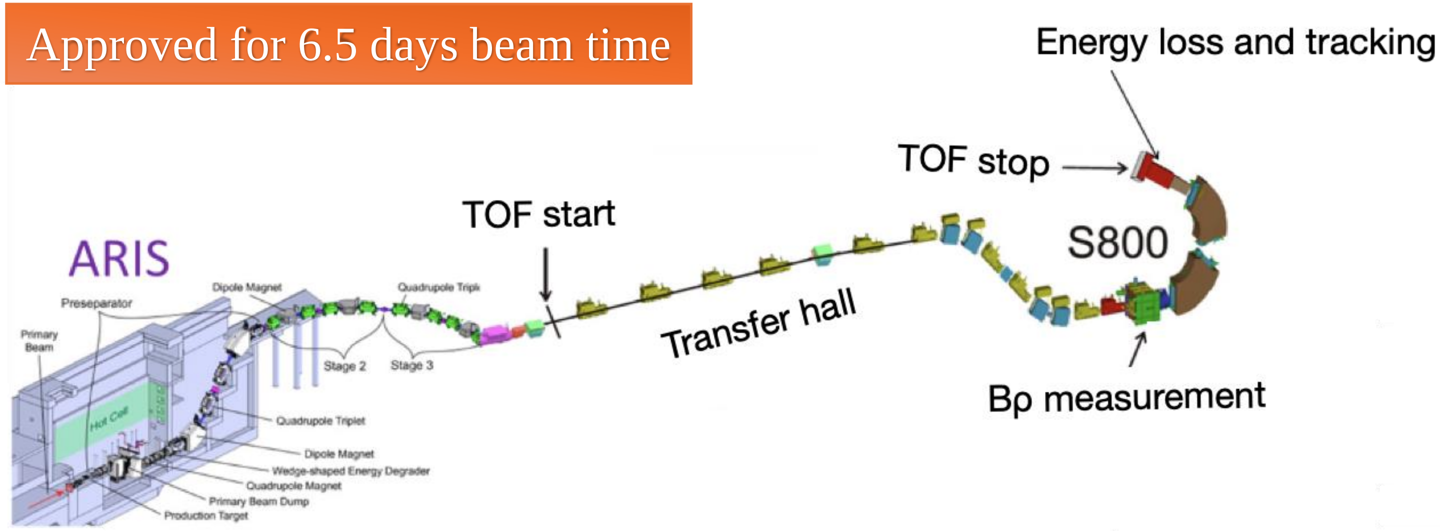
Zeren Korkulu

Mass measurements on the r-process path



- ✓ The masses of 28 neutron-rich nuclei (*Co, Ni, Cu, Zn, Ga, Ge, As, Se and Br*) will be measured using the Bρ-**TOF method.**
- ✓ **Twenty-four masses will be determined for the first time.**

Approved for 6.5 days beam time



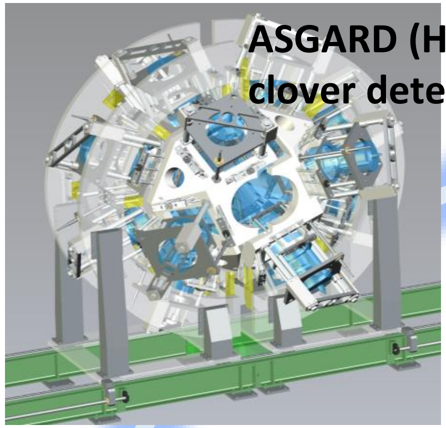
★ Masses of isotopes along the r-process path will reduce the uncertainty in r-process abundance models.

★ The masses of proposed isotopes impact the final abundance of the first r-process peak in neutron star mergers.

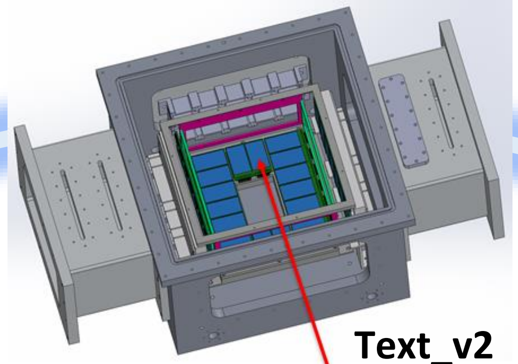
The experiment's beam time is expected in mid-2025.

We will measure the **relevant masses with an uncertainty better than ~200 keV.**

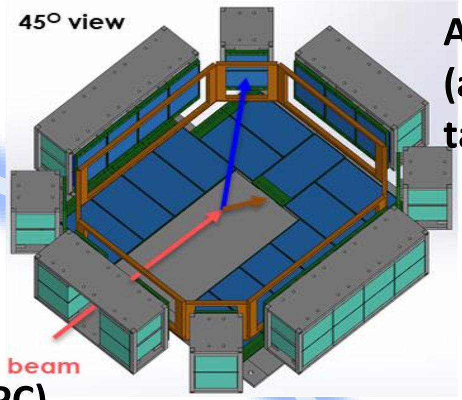
CENS detector and device development



ASGARD (HPGe clover detectors)



Text_v2
(active target TPC)



AToM-X
(active target TPC)

Decay Spectroscopy Station

A New Plunger Device

Detector System for Internal Conversion Electrons

Beam PID

Diagnostics System

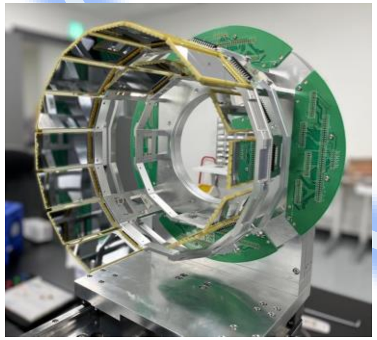
DL-MCP

GAGG Scintillator

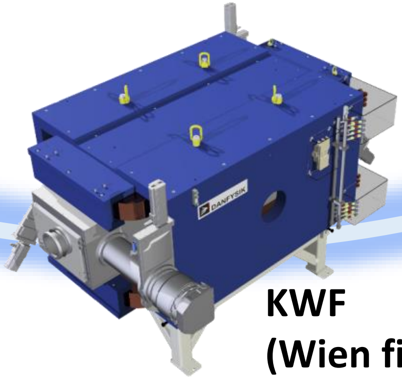
Liquid Organic Scintillator

MUSIC/IC

Gas Jet Target



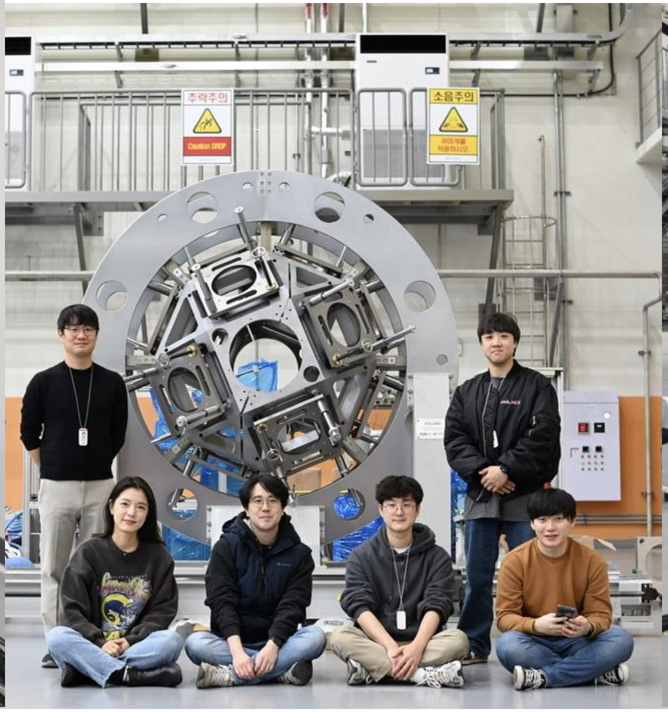
STARK (Si strip array)

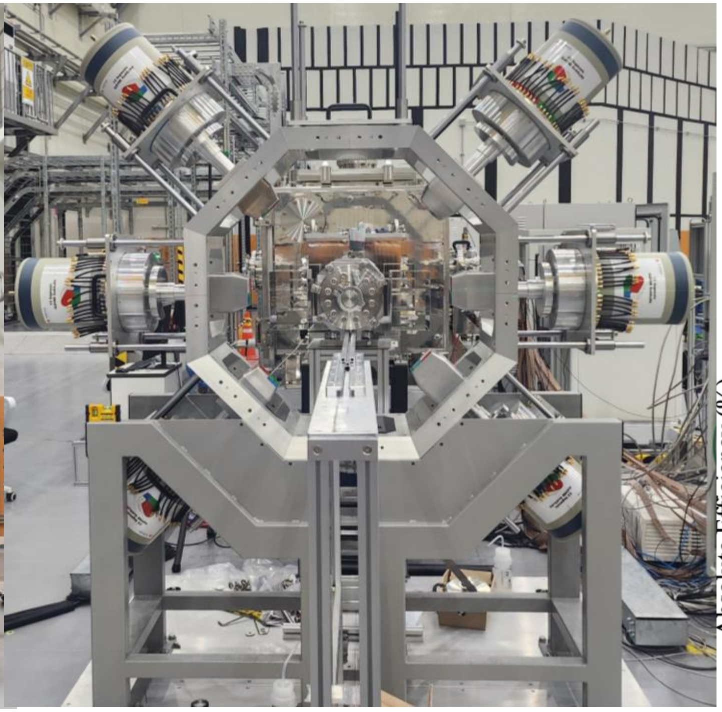


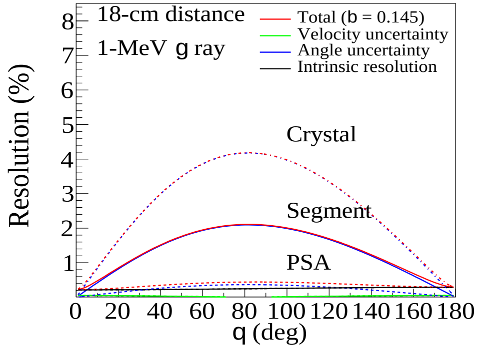
KWF
(Wien filter)

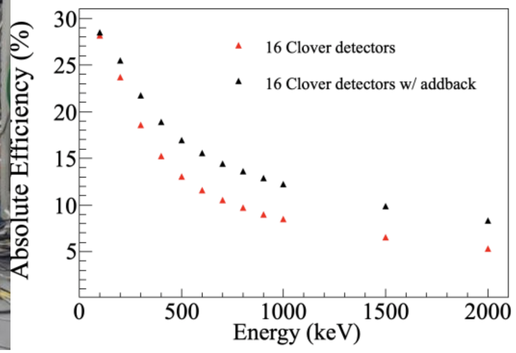
CryoSTAR
(gas target)

Detector development for inbeam spectroscopy: ASGARD project





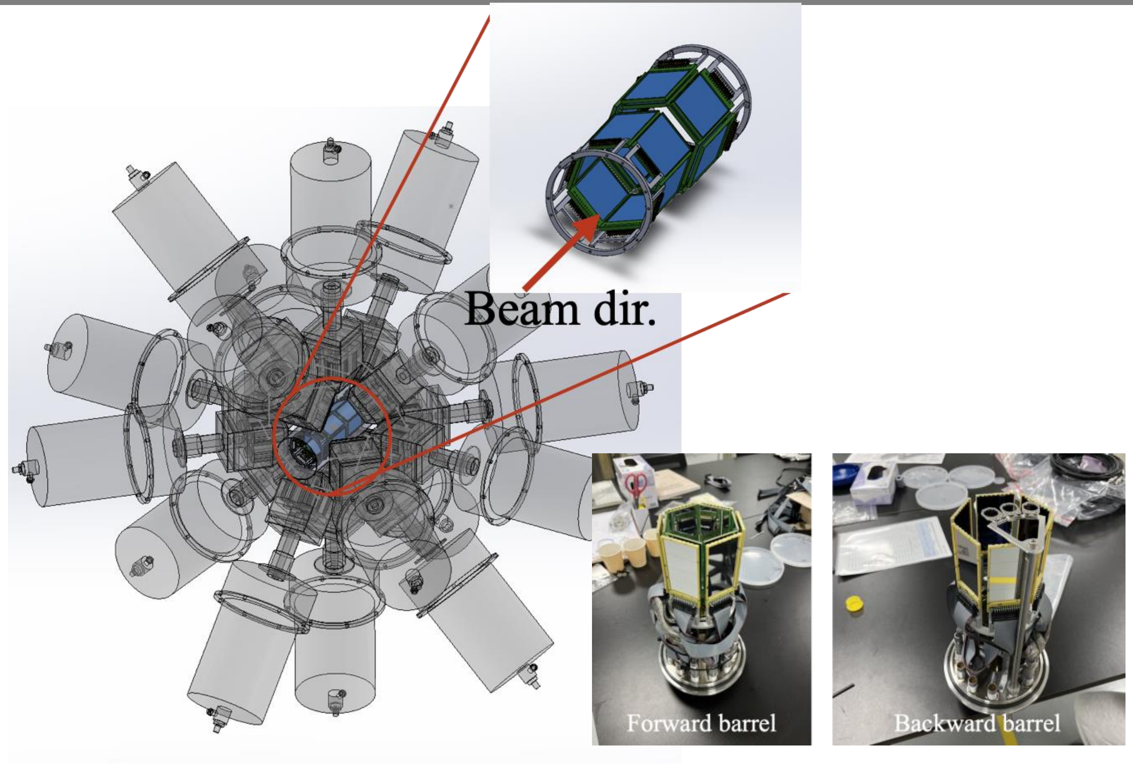




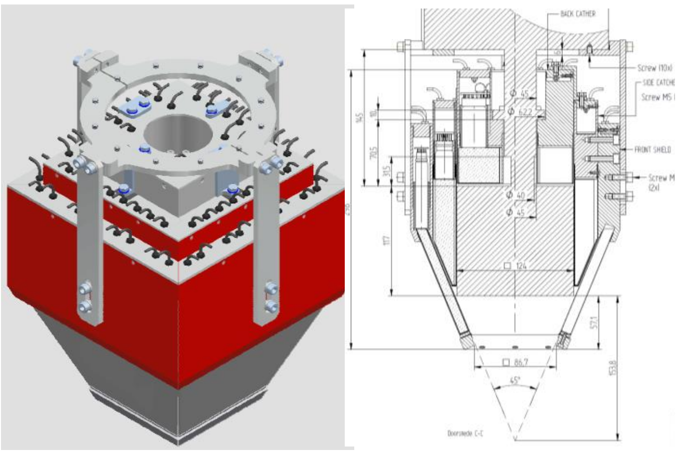
- One clover consists of 4 Ge crystals with 8 segmented electrodes: improve the energy resolution from the Doppler broadening effect & beneficial in angular distribution
- Capability of multi-purpose: low-energy in-beam or delayed γ-ray spectroscopy depending on the detector setup
- 8 detectors present, 2 more detectors this year (plan to purchase total 12 detectors)
- Currently, 14 members are involved: 9 researchers, 5 students.

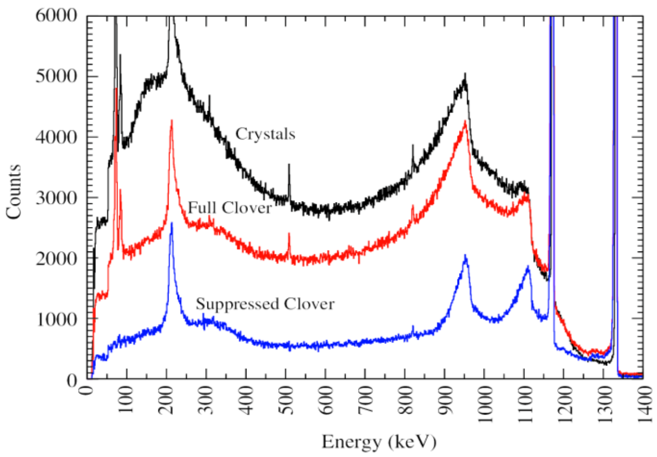
Courtesy of B. Moon

Detector development for inbeam spectroscopy: ASGARD project



- STARK Jr.: Silicon Telescope Array for inverse Kinematics studies Jr.
- Silicon barrel array for charged particles
- New design of X6, using 8 resistive strips
- Precise energy measurement by 4 standard strips
- Hexagonal shape, limited space in ASGARD





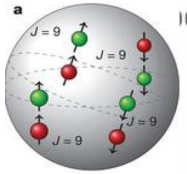
- Anti-Compton suppressor dramatically improves the sensitivity of the gamma-ray detector
- Currently, we are starting to utilize the heavy ion accelerator RAON.
- γ rays that are difficult to measure from the known rare isotope is more likely way to discover new results,
- Re-examine the international competitiveness of ASGARD, anti-Compton suppression system with maximized detection sensitivity is essential.

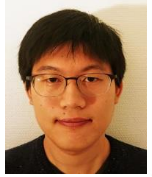
Courtesy of B. Moon

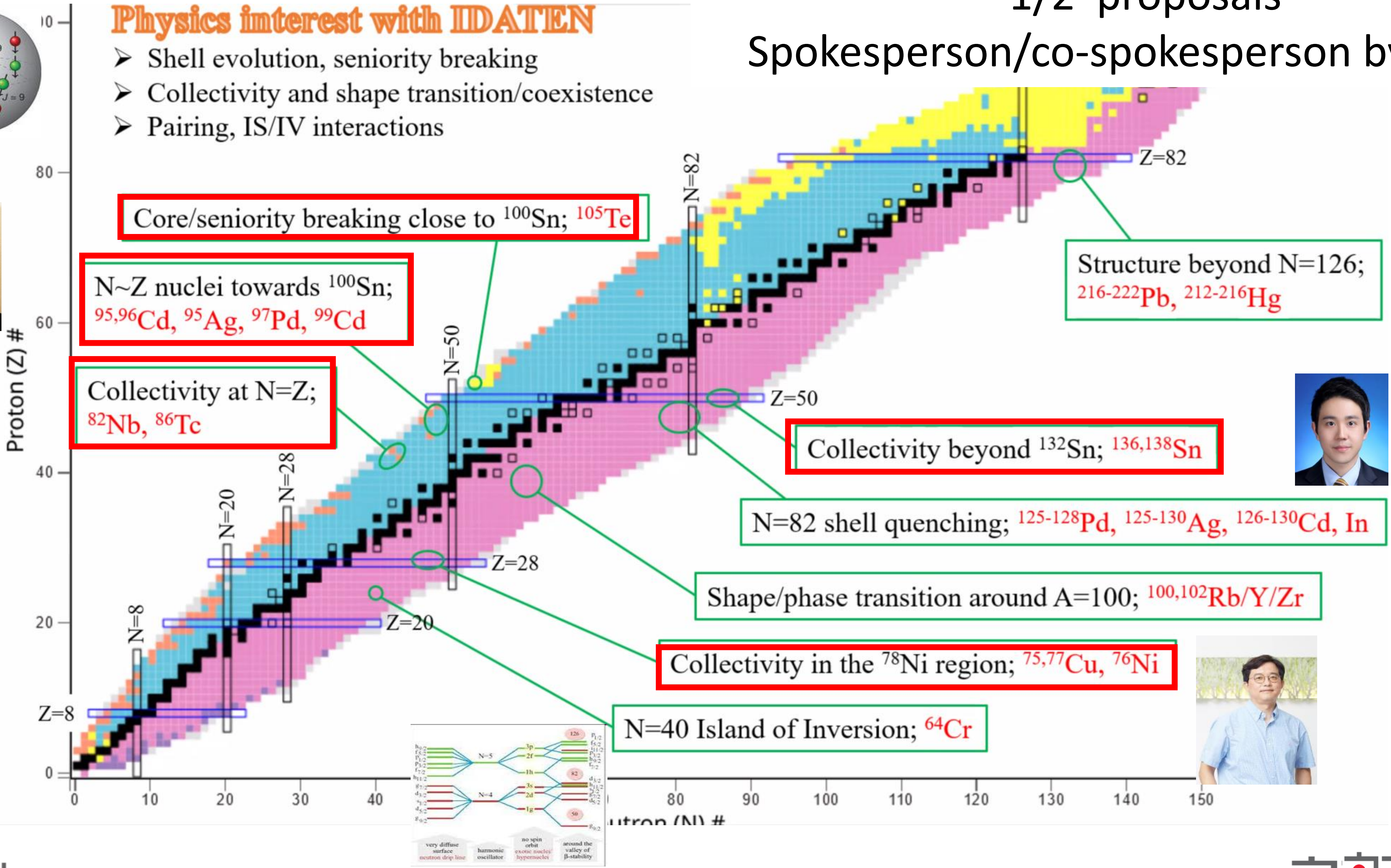
IDATEN physics

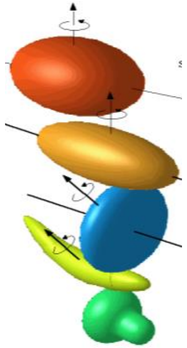
~1/2 proposals

Spokesperson/co-spokesperson by CENS

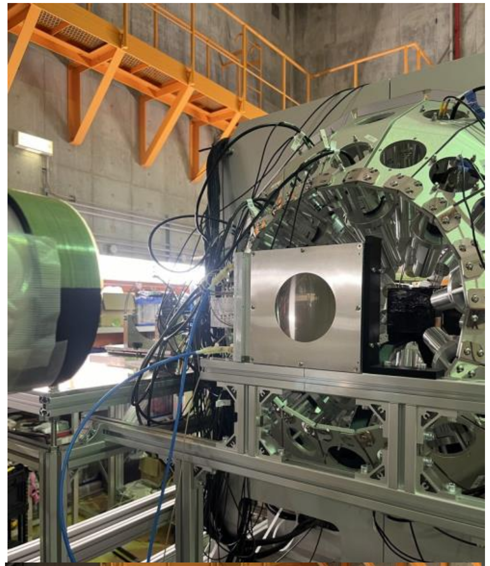


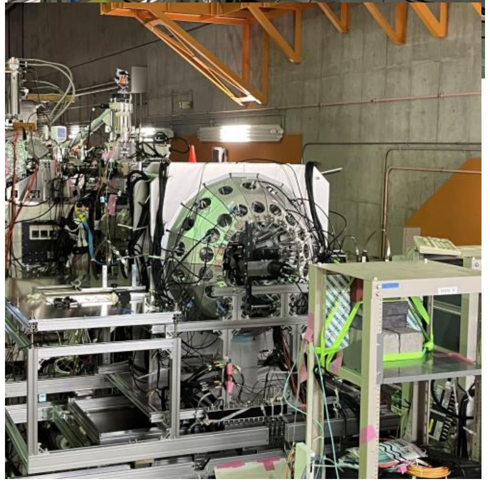


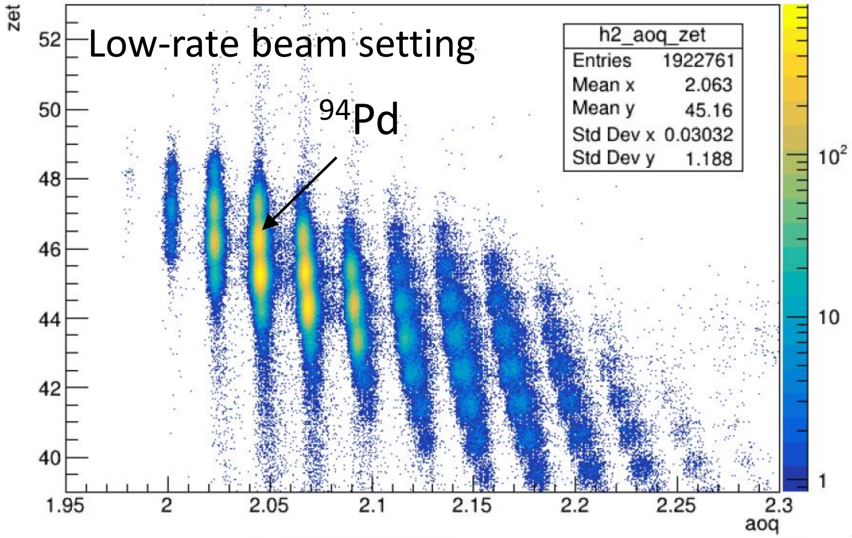


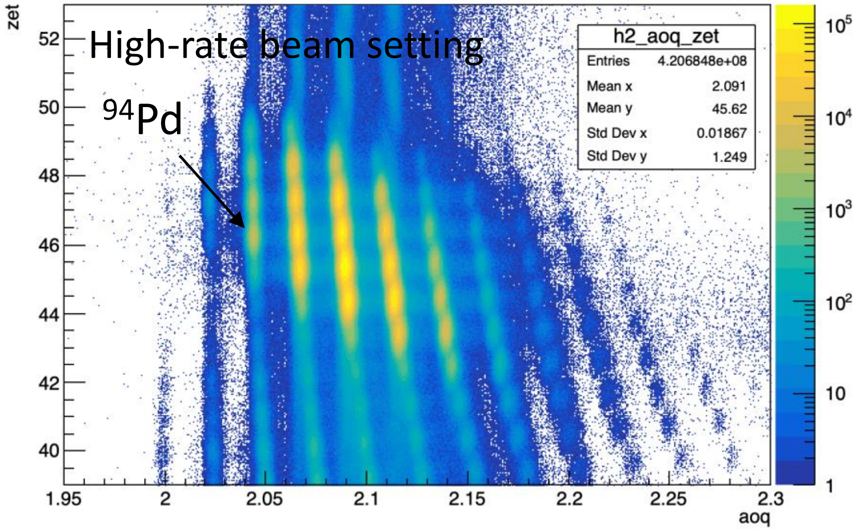


IDATEN Commissioning Experiment







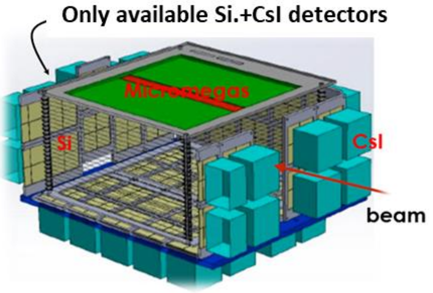


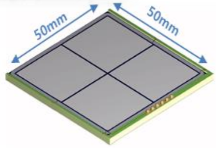
- IDATEN commissioning experiment was carried out from June 26 to June 27 (30 hours).
- 26 collaborators from Korea, Japan, China, and Europe participated.
- First experiment at RIBF mainly led by the Korean groups (devices & manpower)
- The experiment was successful, and two students will analyze data for their doctoral theses.

Courtesy of B. Moon

Development of TexAT_v2 for (α,p) reaction studies

- Goals: high beam rate (10^5 pps), large solid angle coverage, high energy and position resolution
- A new field cage built and tested at TAMU: PCB, 50μm tungsten wire and 100MΩ resistors
- High beam rate test: $^{14}N(\alpha,\alpha)$ data with 5×10^5 pps beams taken at TAMU





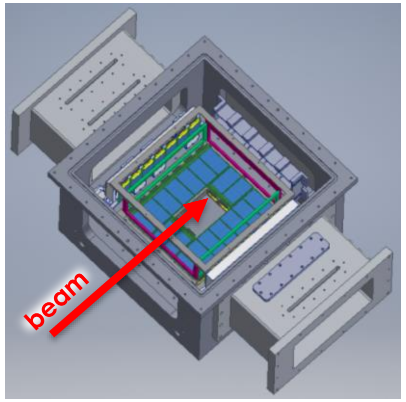
- ✓ E. Koshchiy *et al.*, NIMA 957 (2020) 163398.
- ✓ J. Bishop *et al.*, JPCS 1308 (2019) 012006.
- ✓ J. Hooker *et al.*, PRC 100 (2019) 054618.
- ✓ J. C. Zamora *et al.*, PLB 816 (2021) 136256.
- ✓ M. Barbui *et al.*, PRC 106 (2022) 054310.
- ✓ J. Bishop *et al.*, Nat.Commun. 13 (2022) 2151.
- ✓ J. Bishop *et al.*, PRC 102 (2020) 041303.
- ✓ J. Bishop *et al.*, PRC 103 (2021) L051303.
- ✓ C. Curtis *et al.*, PRC 108 (2023) L051606.

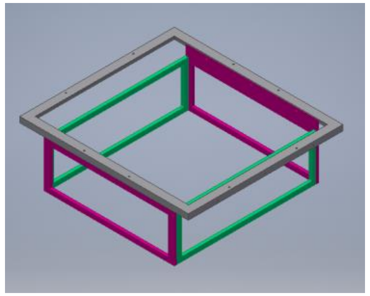
✓ Additional Si. Detectors

➔ Efficiency increased by a factor of 4.

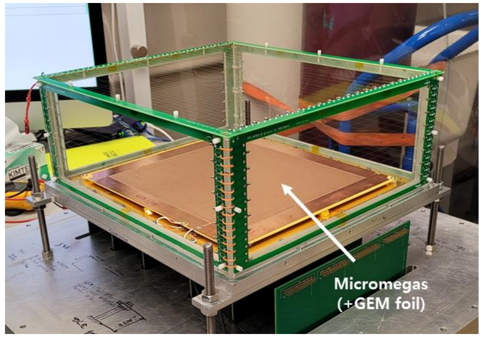
✓ CsI+PIN_diode replaced by CsI+MPPC (SiPM)

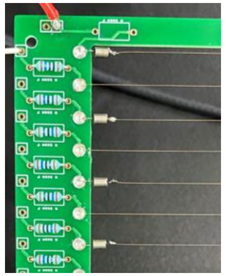
➔ Enhanced energy resolution (6%).

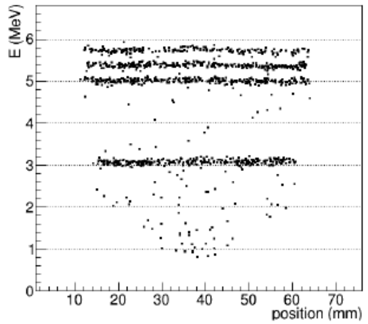


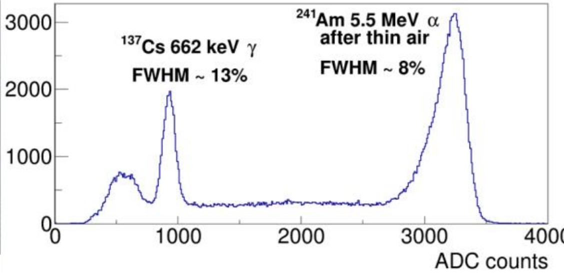


C. Park *et al.*, NIMB 541 (2023) 221.
D. Kim *et al.*, NIMB 540 (2023) 30.
X. Pereira-Lopez *et al.*, NIMB 541 (2023) 134.
S. Bae *et al.*, NIMB 541 (2023) 45.









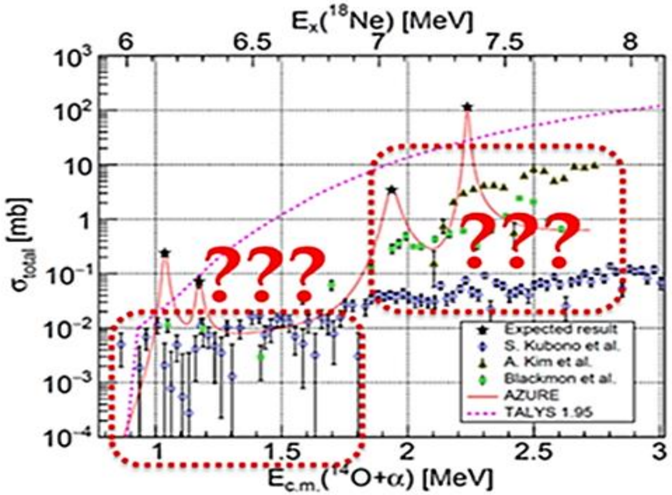
Direct measurement of $^{14}O(\alpha,p)^{17}F$ cross section at CRIB

- "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.

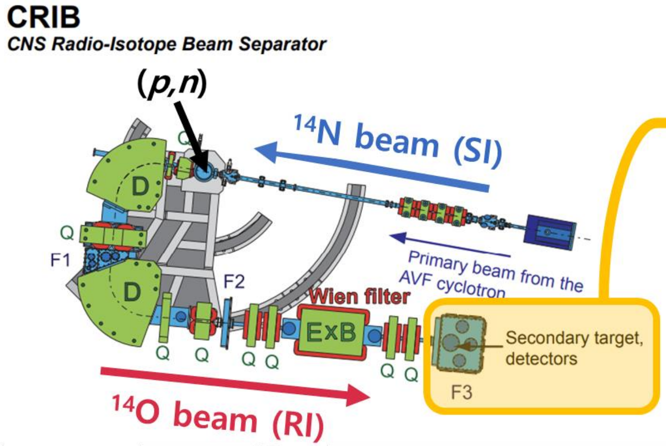
R. H. Cyburt *et al.* 2016

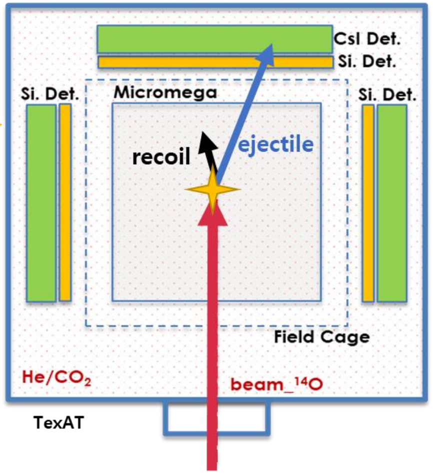
Rank	Reaction	Type	Sensitivity
1	$^{15}O(\alpha,\gamma)^{19}Ne$	D	16
2	$^{56}Ni(\alpha,p)^{59}Cu$	U	6.4
3	$^{59}Cu(p,\gamma)^{60}Zn$	D	5.1
4	$^{61}Ga(p,\gamma)^{62}Ge$	D	3.7
5	$^{22}Mg(\alpha,p)^{25}Al$	D	2.3
6	**$^{14}O(\alpha,p)^{17}F$**	D	5.8
7	$^{23}Al(p,\gamma)^{24}Si$	D	4.6
8	$^{18}Ne(\alpha,p)^{21}Na$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

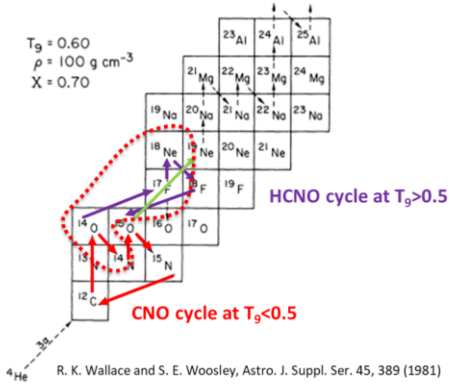


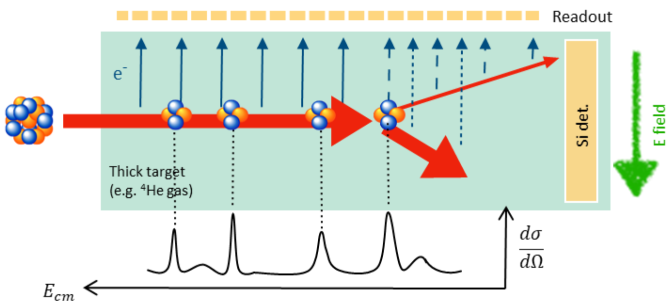
Previous measured data and calculated total cross sections of $^{14}O(\alpha,p)$ reaction

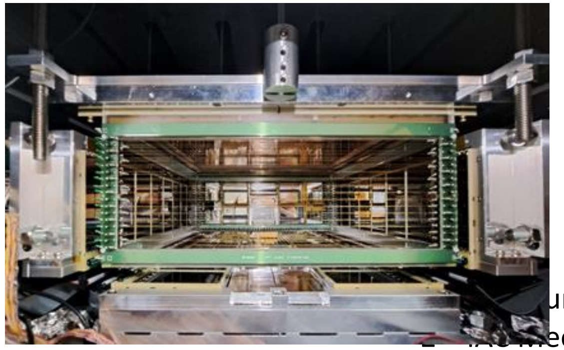


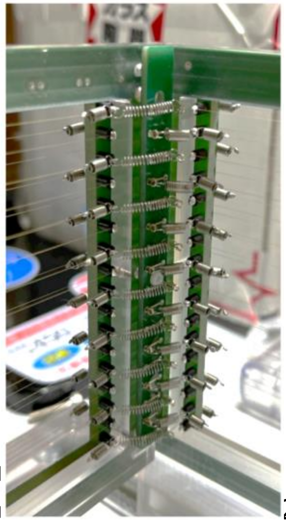


more than 40 participants!





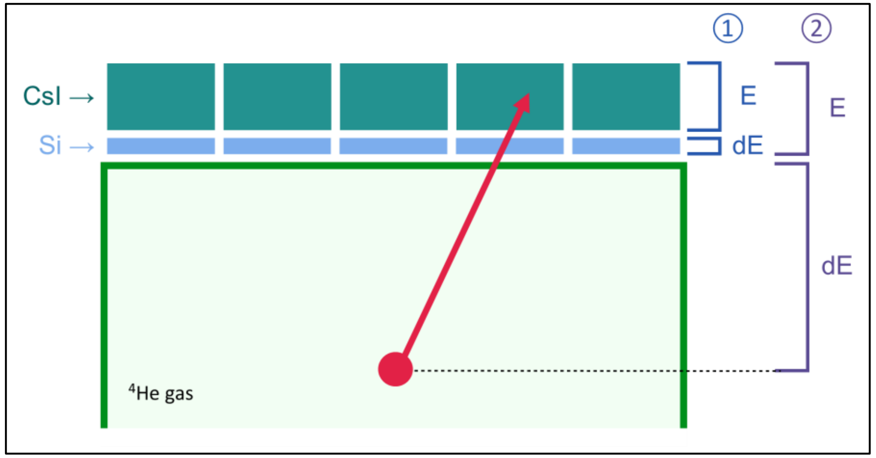


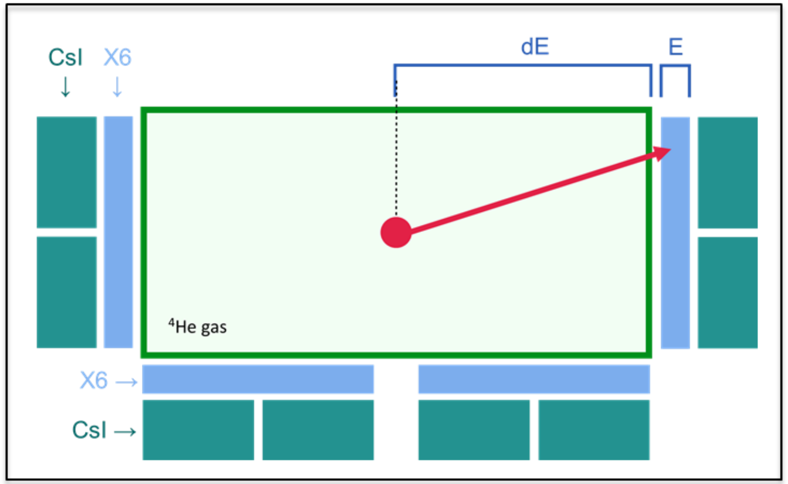


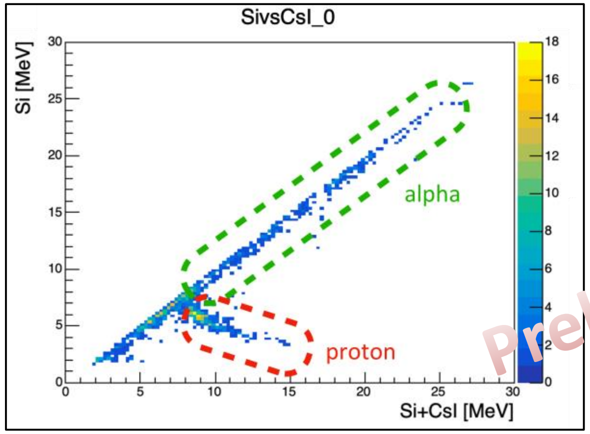
기초과학연구원 Institute for Basic Science

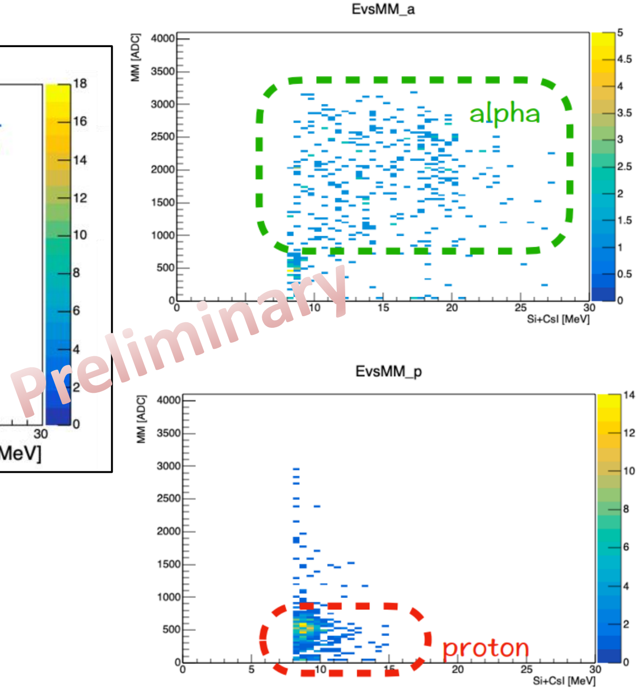
Proposed by S. Ahn & Data analysis by C. Park

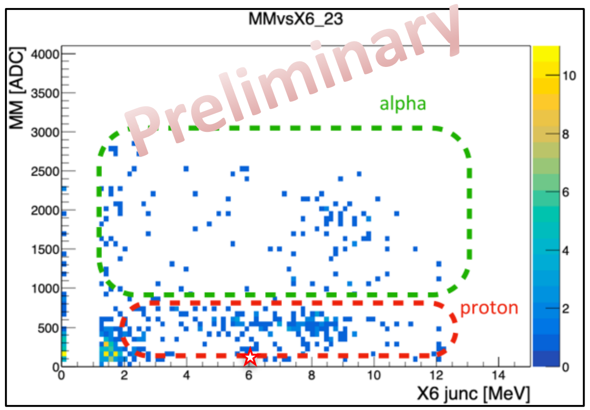
Data Analysis Results - Preliminary

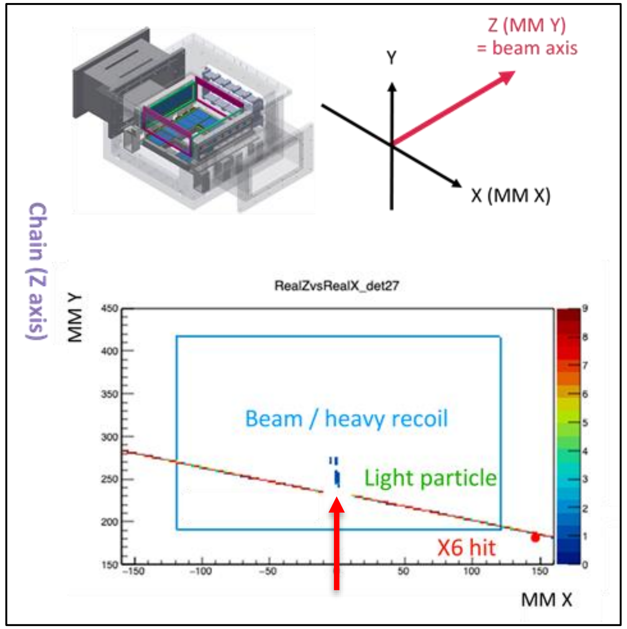




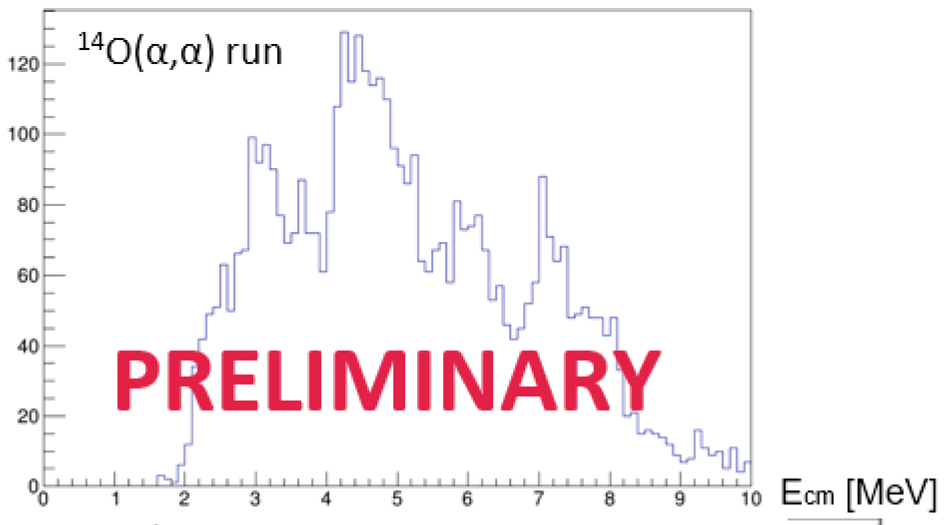


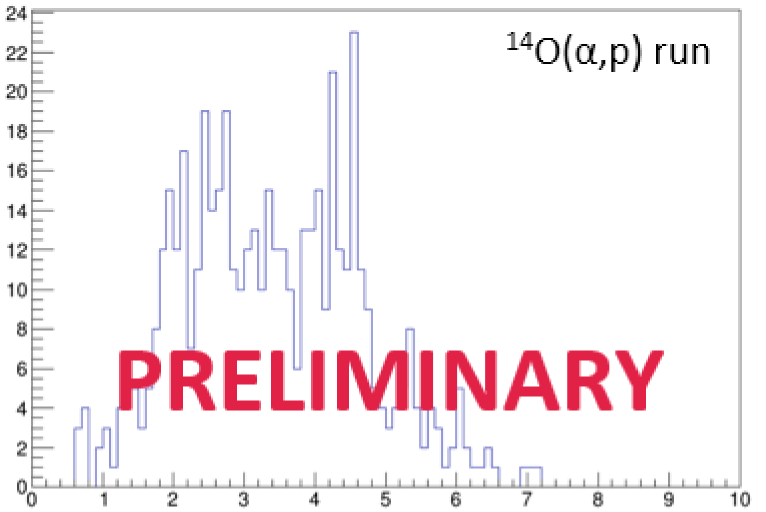


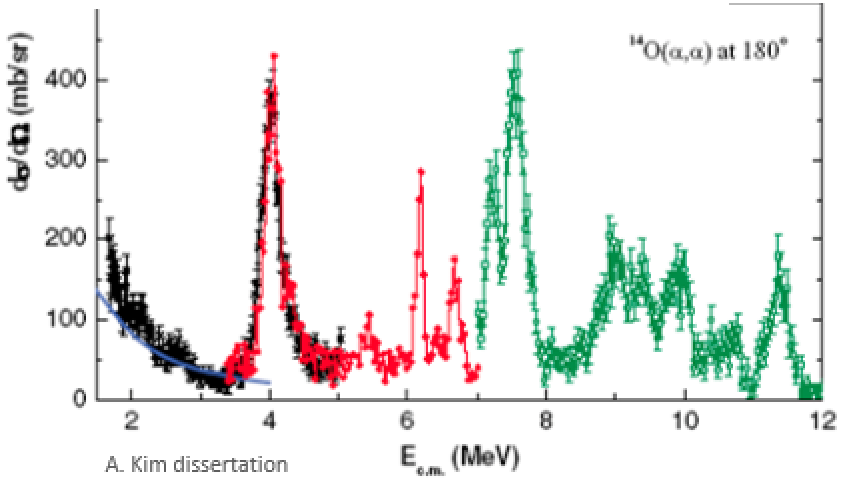




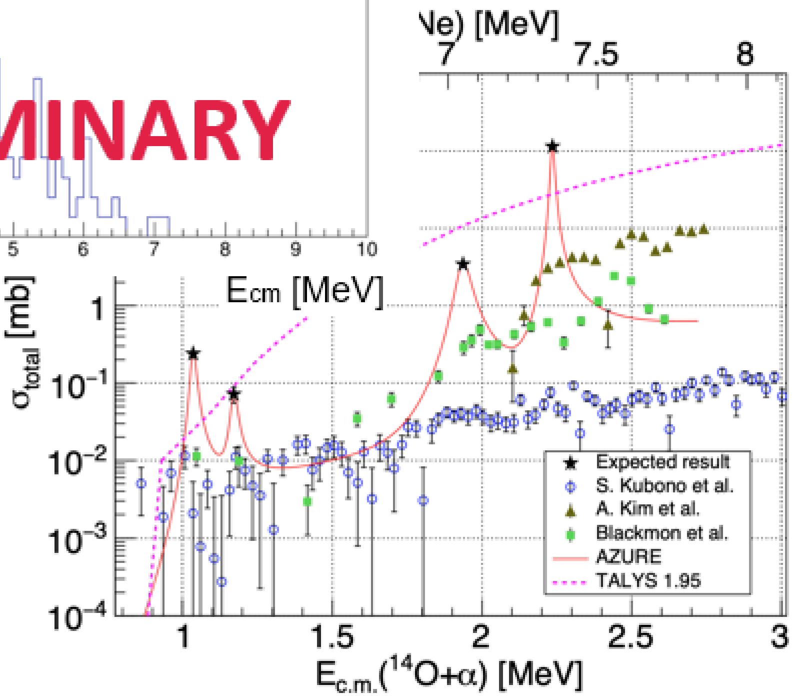
Data Analysis Results - Preliminary







A. Kim dissertation



12

2024.10.23 Chaeyeon Park

Courtesy of Tony Ahn

IRIS PAC proposals from CENS

Courtesy of Y. H. Kim

TITLE	SPOKESPERSON
40Ar+p and 40Ar+d elastic scattering studies for a new OMP	*Dahee Kim*
Exploring the existence of low/high spin isoscalar np pairing in sd shell	Yunghee Kim
Evolution of shell and collectivity in the transition region beyond ^{40}Ca: Lifetime measurement of excited states of ^{39}Cl	*Yunghee Kim*
Spectroscopic study of energy levels in ^{25}Al	Minju Kim
Collinear laser spectroscopy of $^{21-23}$Na	**Jeongsu Ha & Junho Won**
Investigation of bubble proton density in ^{34}Si through proton elastic scattering	Byul Moon
Fusion-fission studies in the ^{20}Ne+^{197}Au reaction at 10 MeV/nucleon	Zeren Korkulu
Production of ^{43}K using ^{40}Ar(a,p)^{43}K reaction	Sunghoon Ahn
Coulomb excitation of ^{181}Ta and ^{197}Au with ^{40}Ar	Joochun Park
Activation method in inverse kinematics for ^{40}Ar(p,2p)^{39}Cl	*Laszlo Stuhl*
Investigation of multiparticle-multihole (mp-mh) shape coexistence in A ~90	Arunita Mukherjee
Probing isospin symmetry and the systematics of single-nucleon removal with mirror reactions	Xesus Pereira Lopez
Measurement for production cross section and momentum distribution of projectile fragmentation	Deuksoon Ahn

TOTAL 13 proposal submitted from CENS! (among 30 total)

(11 KoBRA beamline, 1 CLS, 1 proton beamline)

Two A-grade proposals

IRIS PAC experiment (KO-24-30)

Courtesy of D.S. Ahn

Spokesperson: D. S. Ahn
Co-Spokesperson: J. Hwang

@ IRIS PAC

- ❖ How many RI beams we can produce in RAON facilities is important for designing experiments.
- ❖ Many models are used to estimate the **production cross sections and momentum distribution**, but their results are not consistent.

- ❖ Systematics of production rates and cross sections
- ❖ Momentum distribution and momentum peak of each fragment of RI and neighboring nuclei

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

- ❖ Essential measurement for RAON
- ❖ Systematics studies for production cross sections with different primary beams, targets, and energies
- ❖ Experimental data are insufficient in 20~40MeV/u energy.
- ❖ These measurements can provide good prediction of RI beam productions.

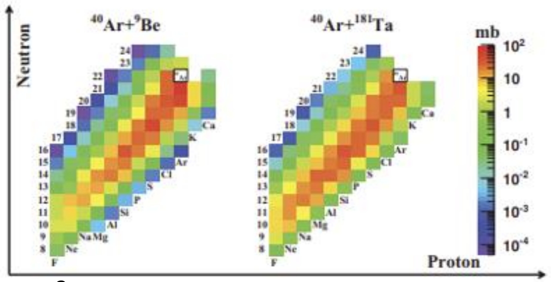
Measurement of production cross sections

Courtesy of D.S. Ahn

- ❖ **Comparison of the experimental data and calculations for the yield and cross sections**
- ❖ **Systematics studies of production cross sections for the proton/neutron-rich isotopes**
- ❖ Production cross sections dependent on the primary beam species
- ❖ Production cross sections dependent on the target material and thickness

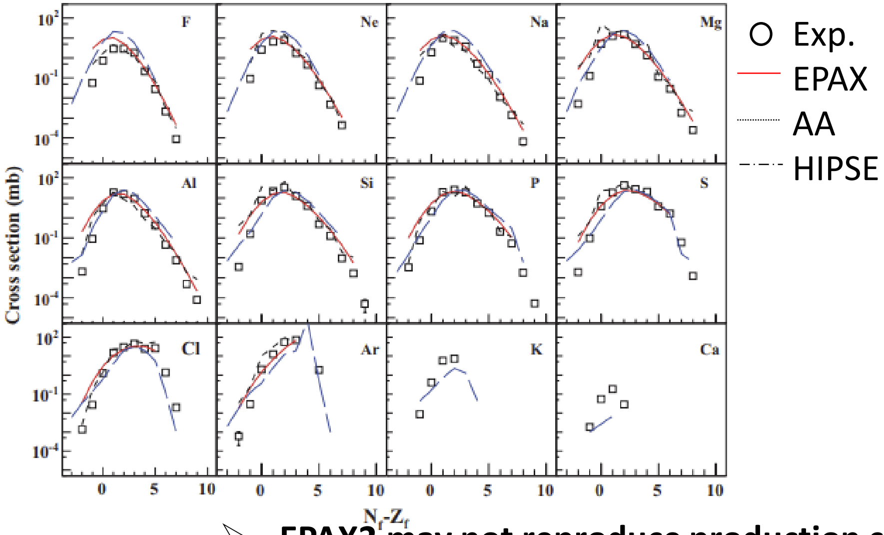
^{40}Ar(57MeV/u) beam on ^{9}Be/^{181}Ta target

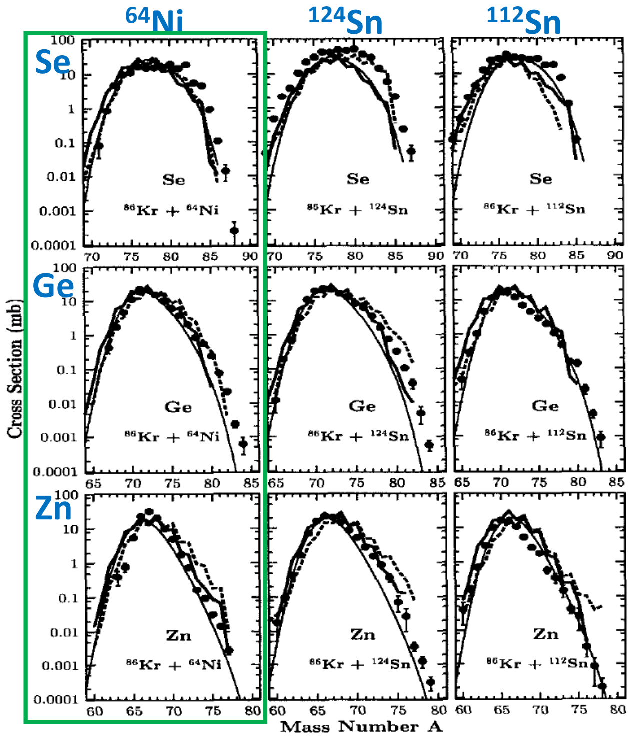
^{86}Kr(25MeV/u) beam on ^{64}Ni/ ^{124}Sn/ ^{112}Sn target



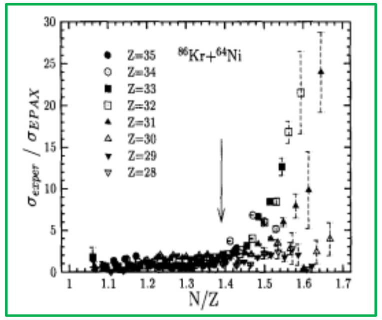
RIBLL@HIRFL

^{40}Ar+^{9}Be reaction X. H. Zhang *et al.*, PRC85 (2012)





Texas A&M



G.A. Souliotis *et al.*, NPA734 (2004)

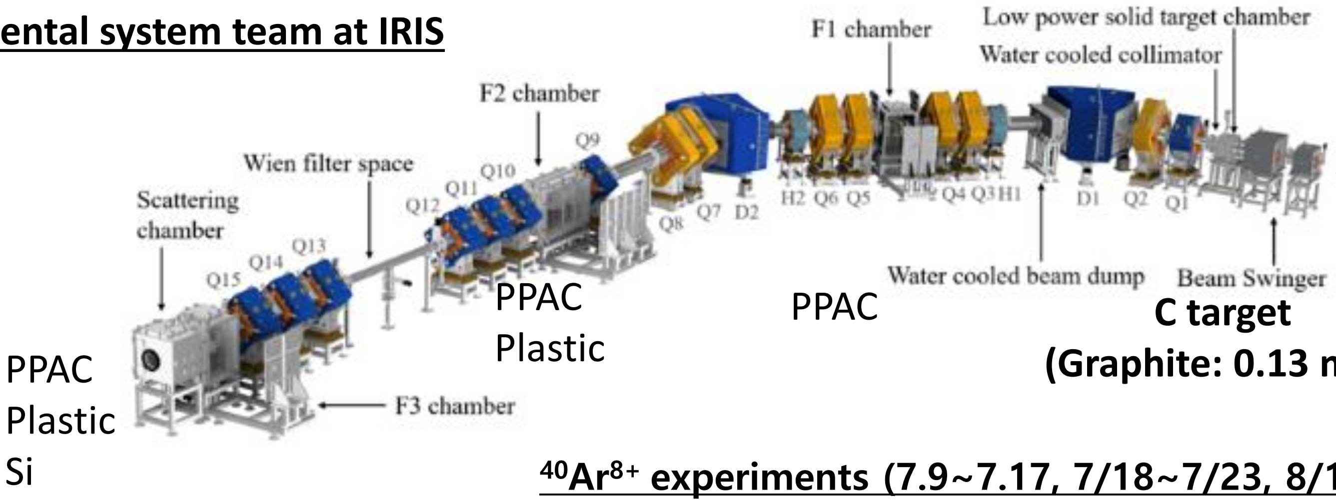
➢ **EPAX2 may not reproduce production cross sections in the neutron-rich side.**

Experimental settings and preliminary results

Courtesy of D.S. Ahn

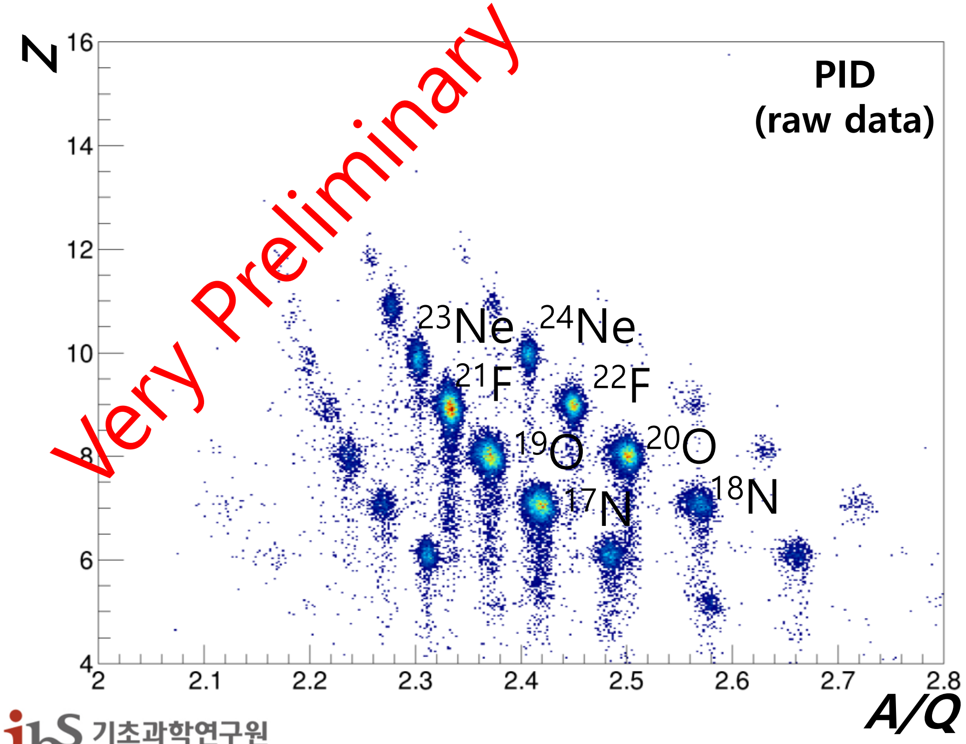
Collaboration of CENS and Experimental system team at IRIS

Experimental setup: KoBRA standard setup

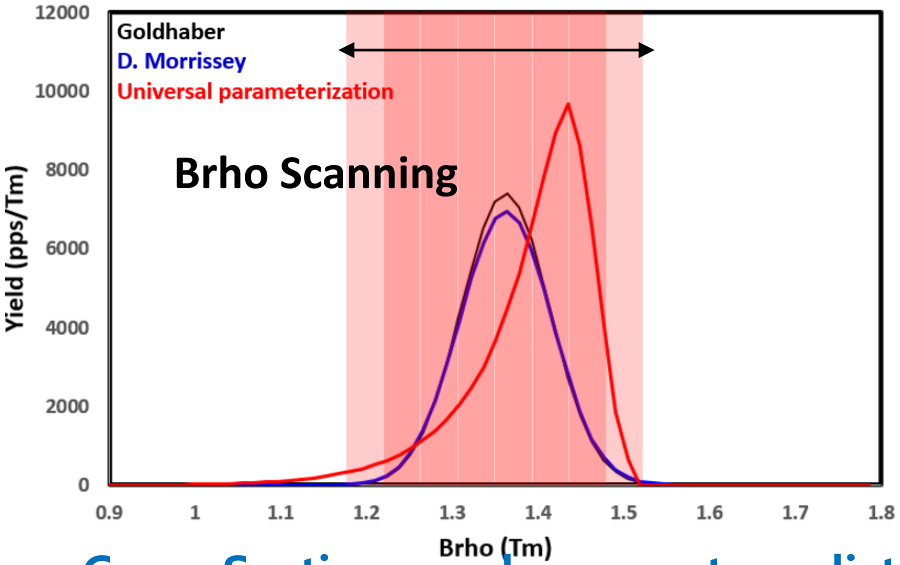


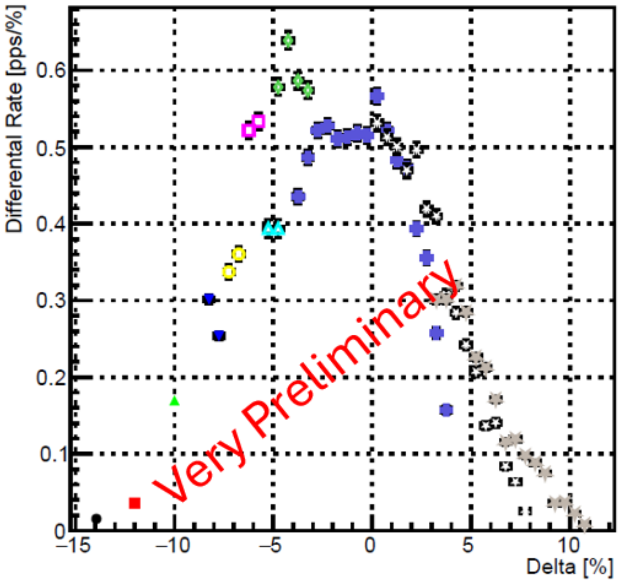
^{40}Ar beam (16.4 MeV/u, 5 pnA)

$^{40}Ar^{8+}$ experiments (7.9~7.17, 7/18~7/23, 8/12~8/14, 8/22~8/23 in 2024)



Momentum distribution

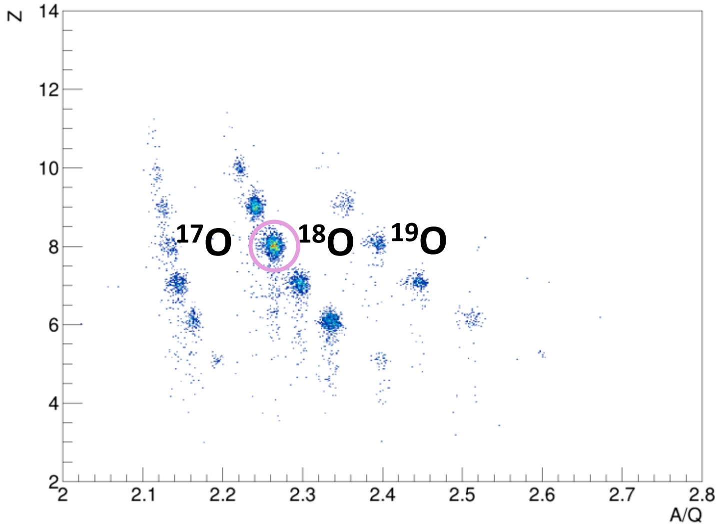




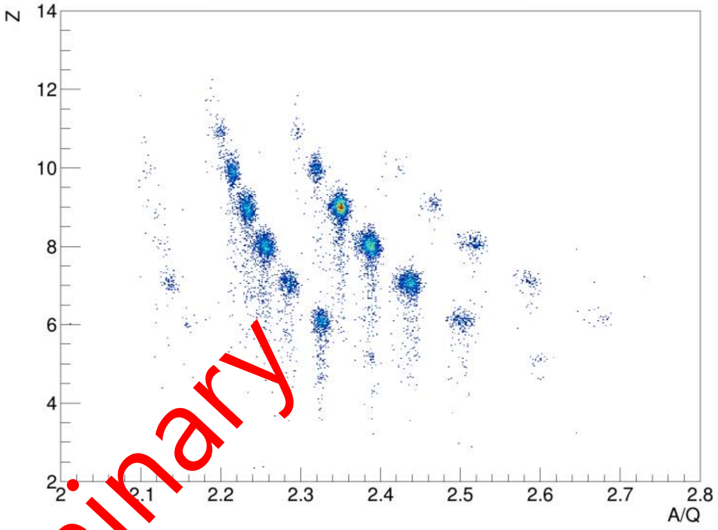
Cross Sections and momentum distributions of O~Ne isotopes.

Particle Identification for cross sections measurement (O isotopes)

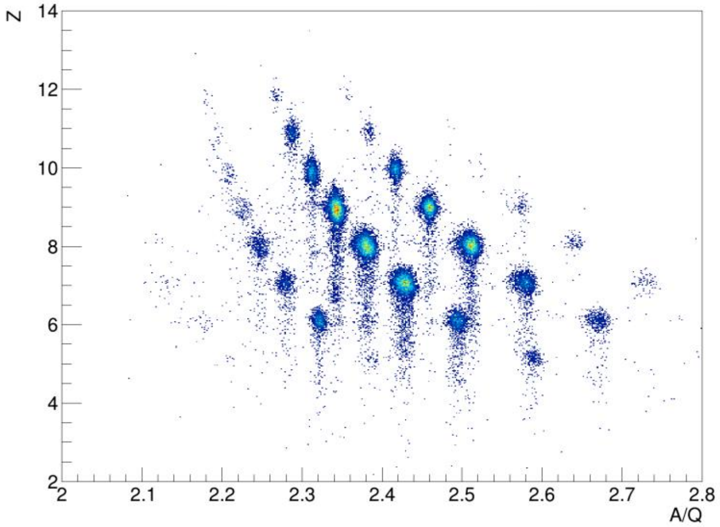
^{18}O setting



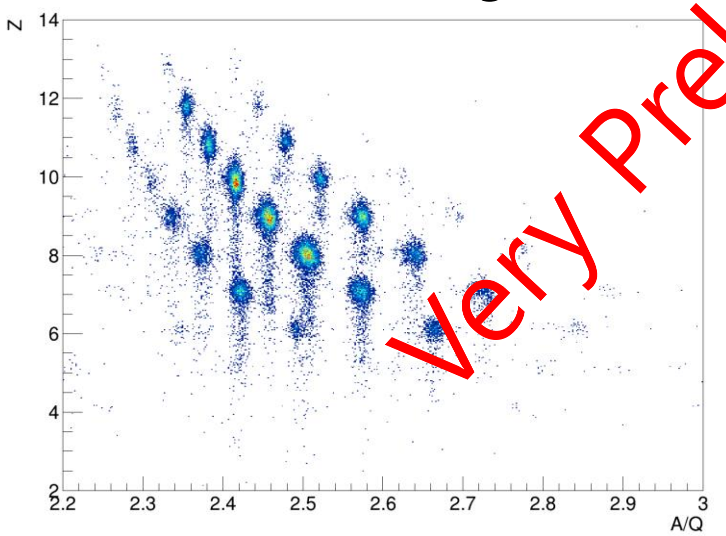
^{19}O setting



^{20}O setting

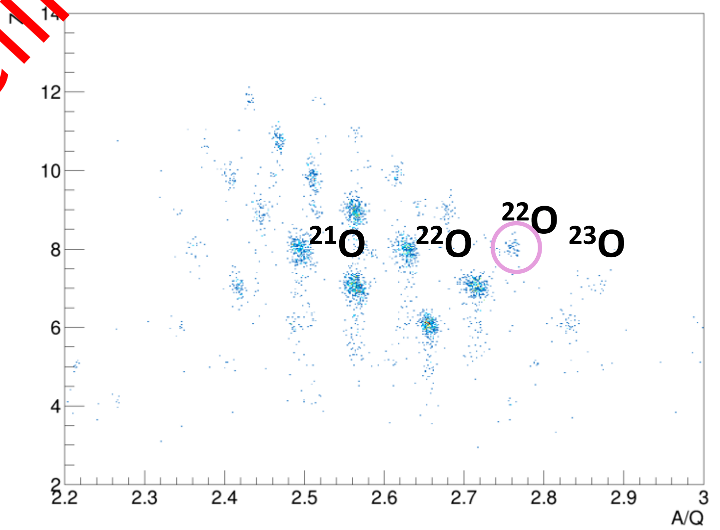


^{21}O setting

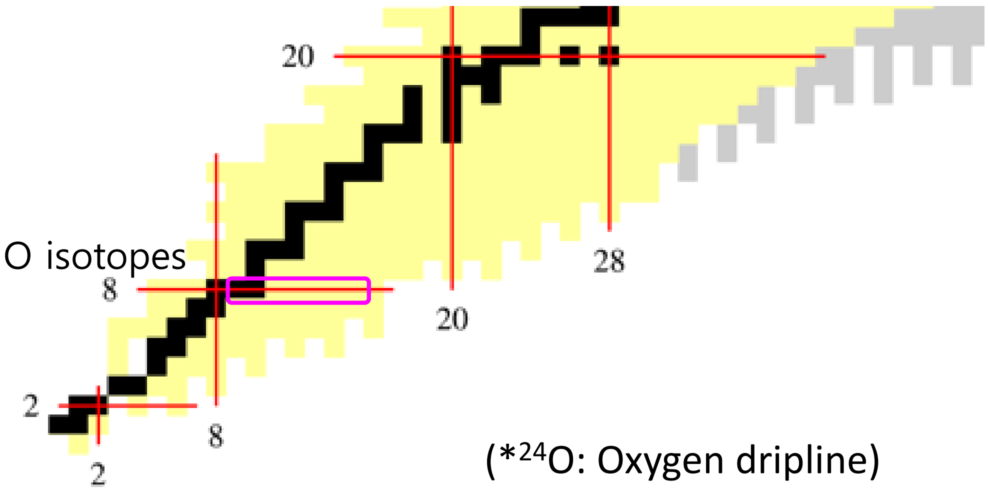


Very Preliminary

^{22}O setting



O isotopes

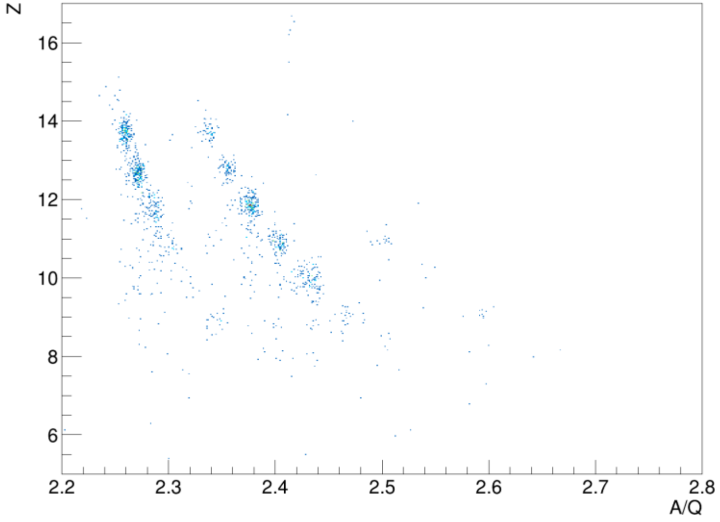


(*^{24}O: Oxygen dripline)

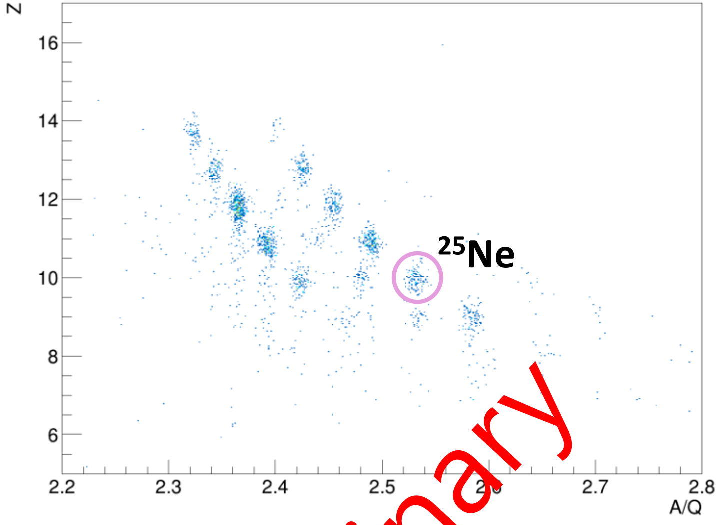
Clear PID and produced RI beams near the Oxygen dripline.

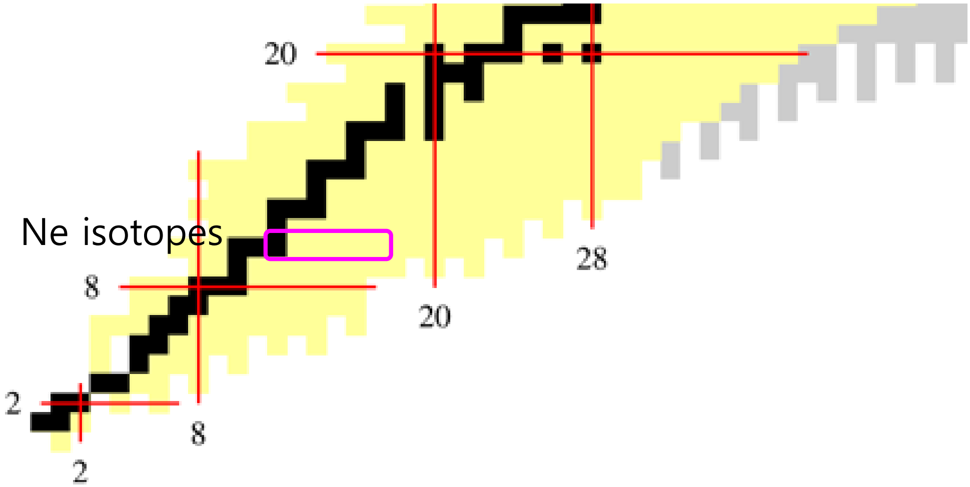
Particle Identification for cross sections measurement (Ne isotopes)

^{24}Ne setting

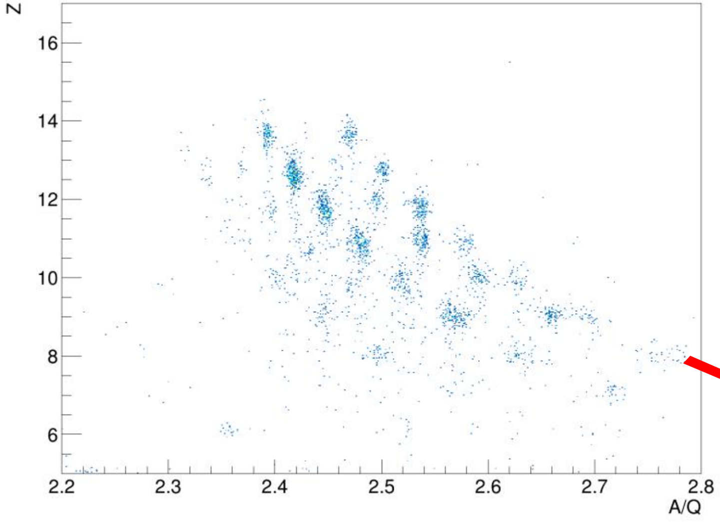


^{25}Ne setting

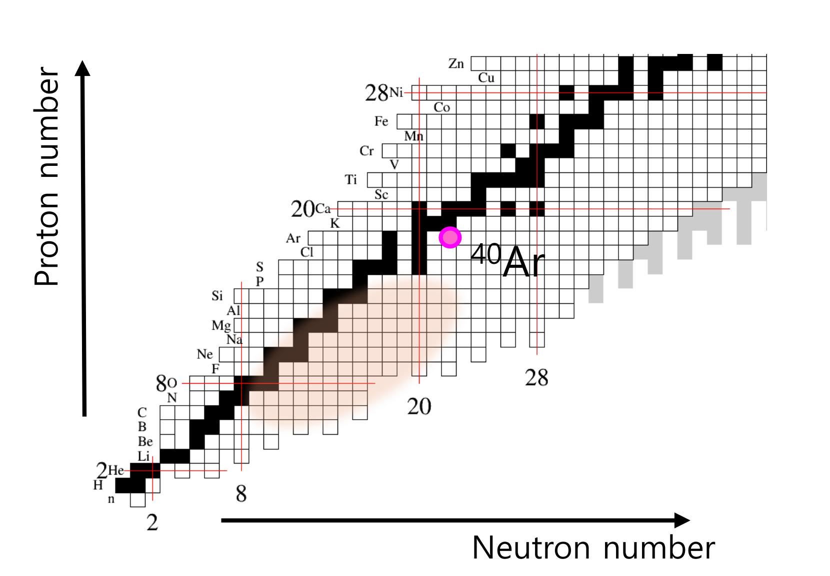




^{26}Ne setting

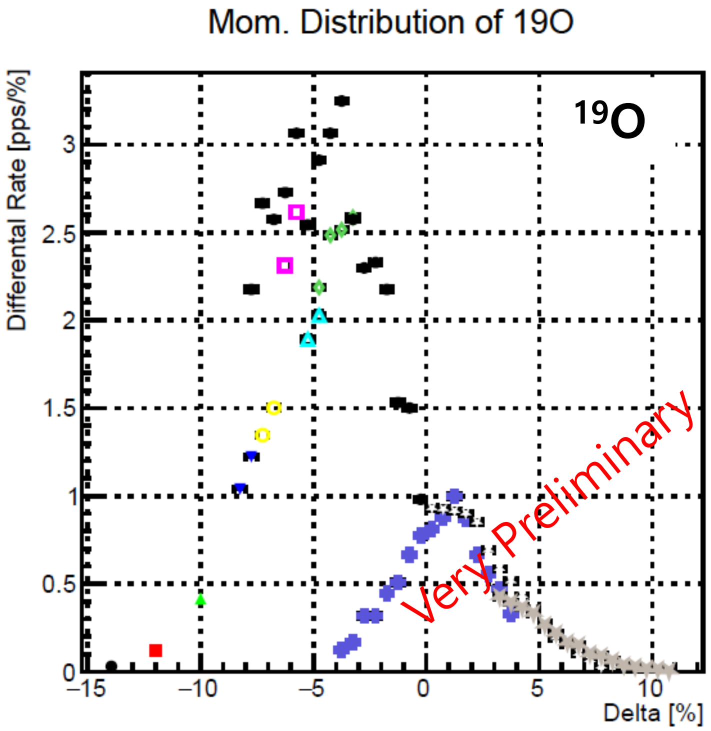


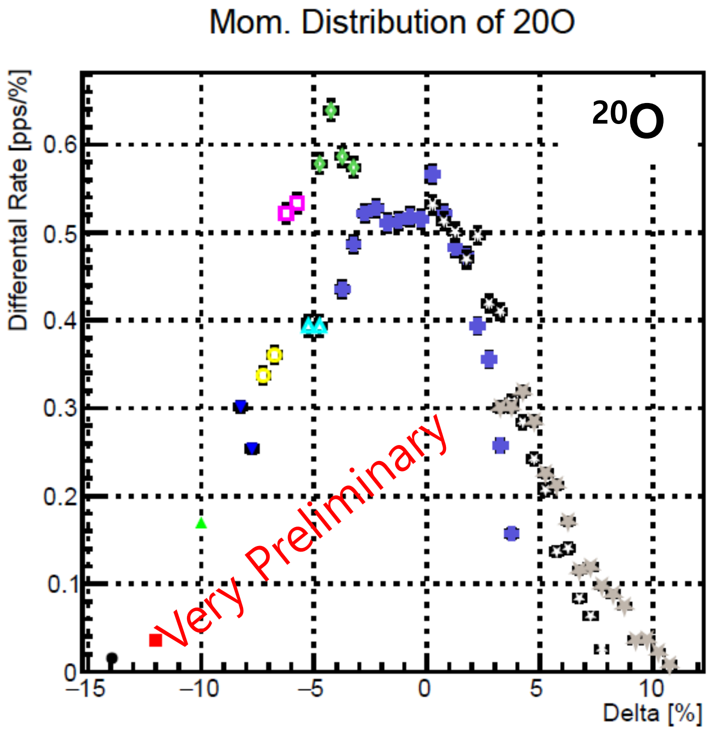
Very Preliminary

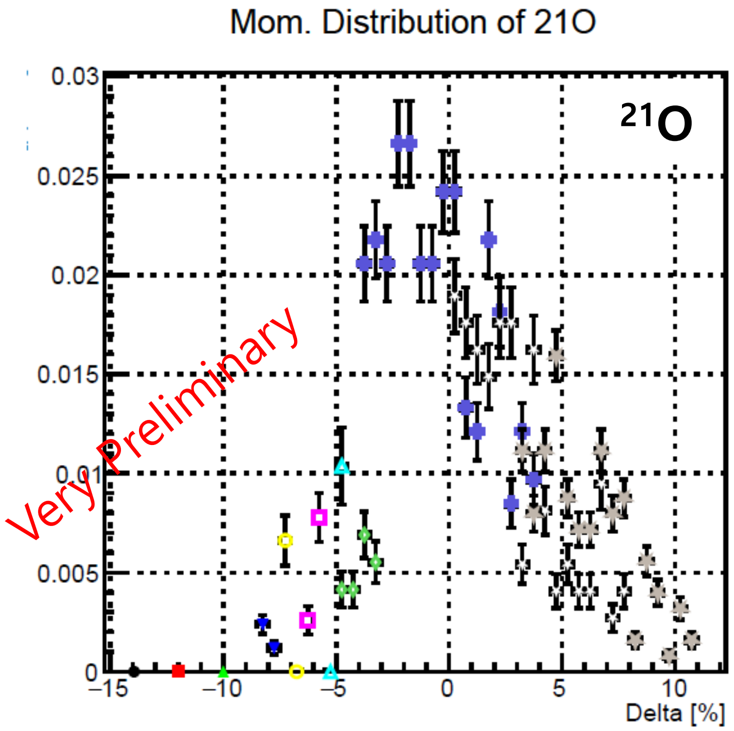


Courtesy of D.S. Ahn

Momentum distributions (O isotopes)



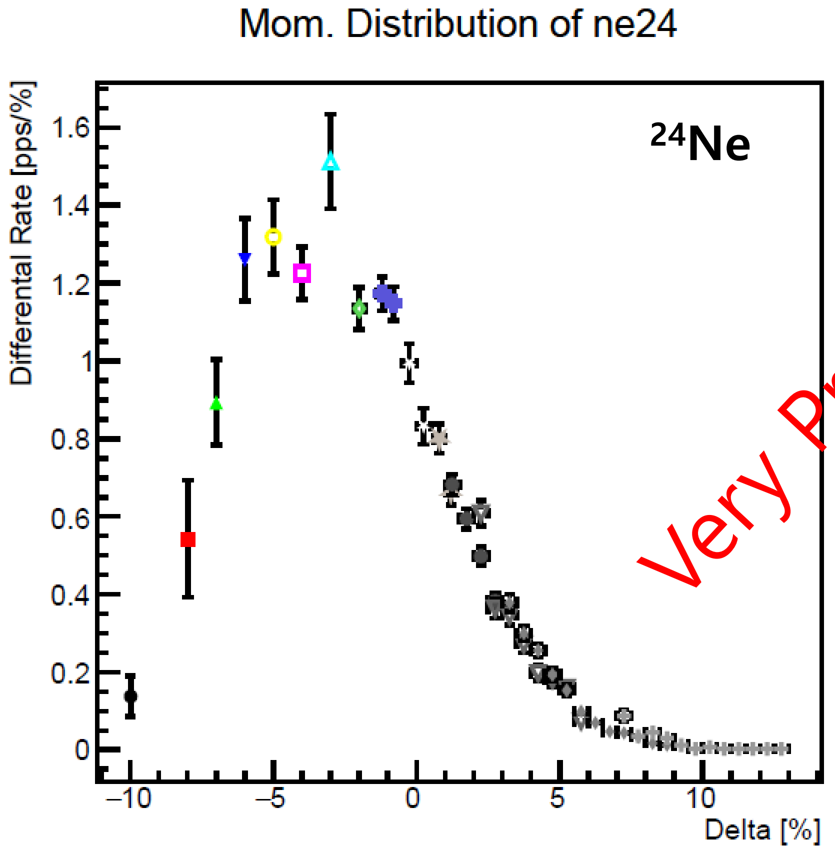


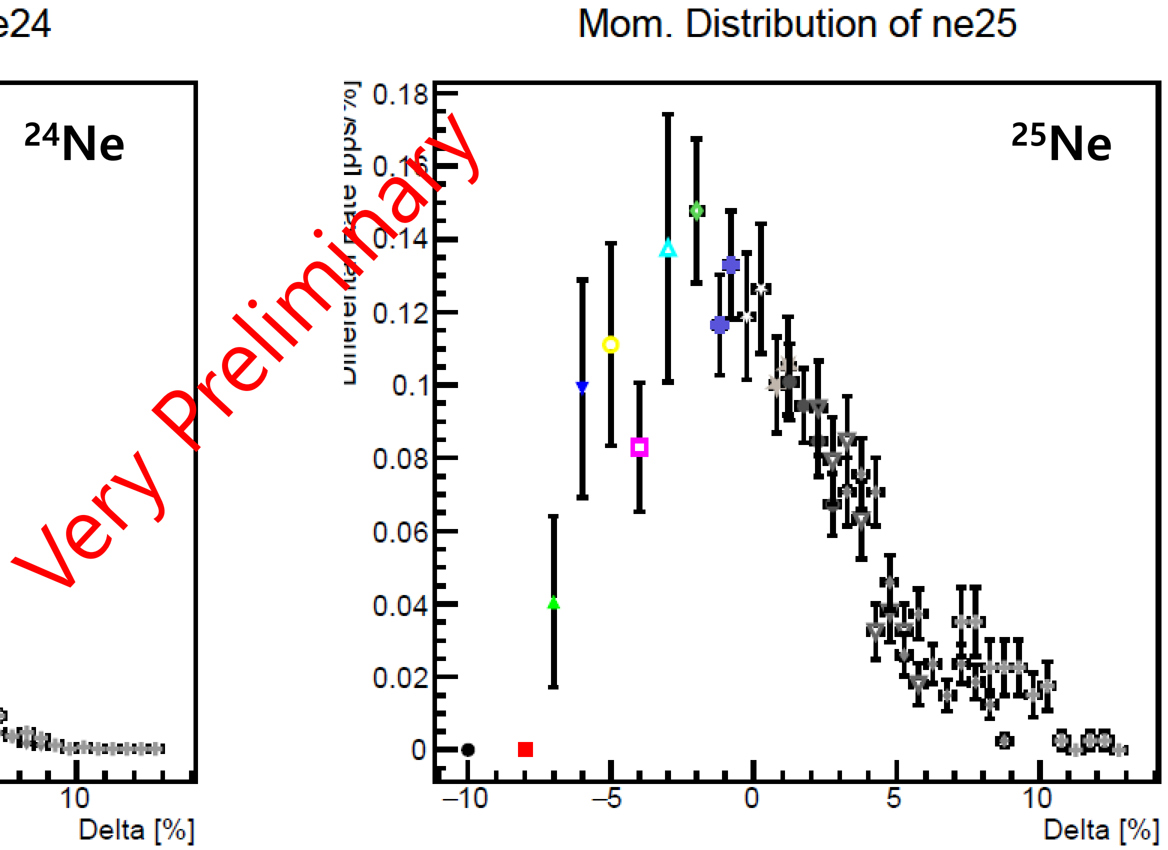


Brho: 1.4048 Tm (δ: 0%)

Courtesy of D.S. Ahn

Momentum distributions (Ne isotopes)



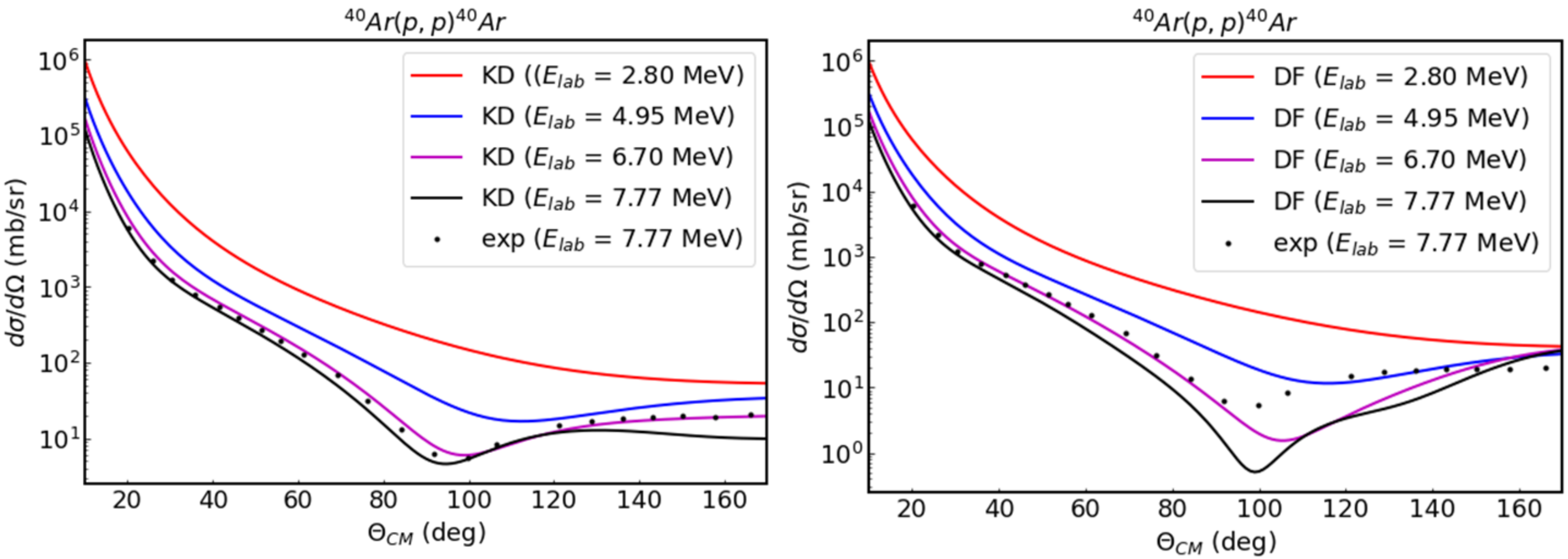


Brho: 1.3076 Tm (δ : 0%)

Courtesy of D.S. Ahn

Optical Model Potential Study with ^{40}Ar + p elastic scattering

Theoretical predictions for the cross-section in KD and DF models at low energies (E_{lab} = 2.80, 4.95, and 6.70 AMeV)

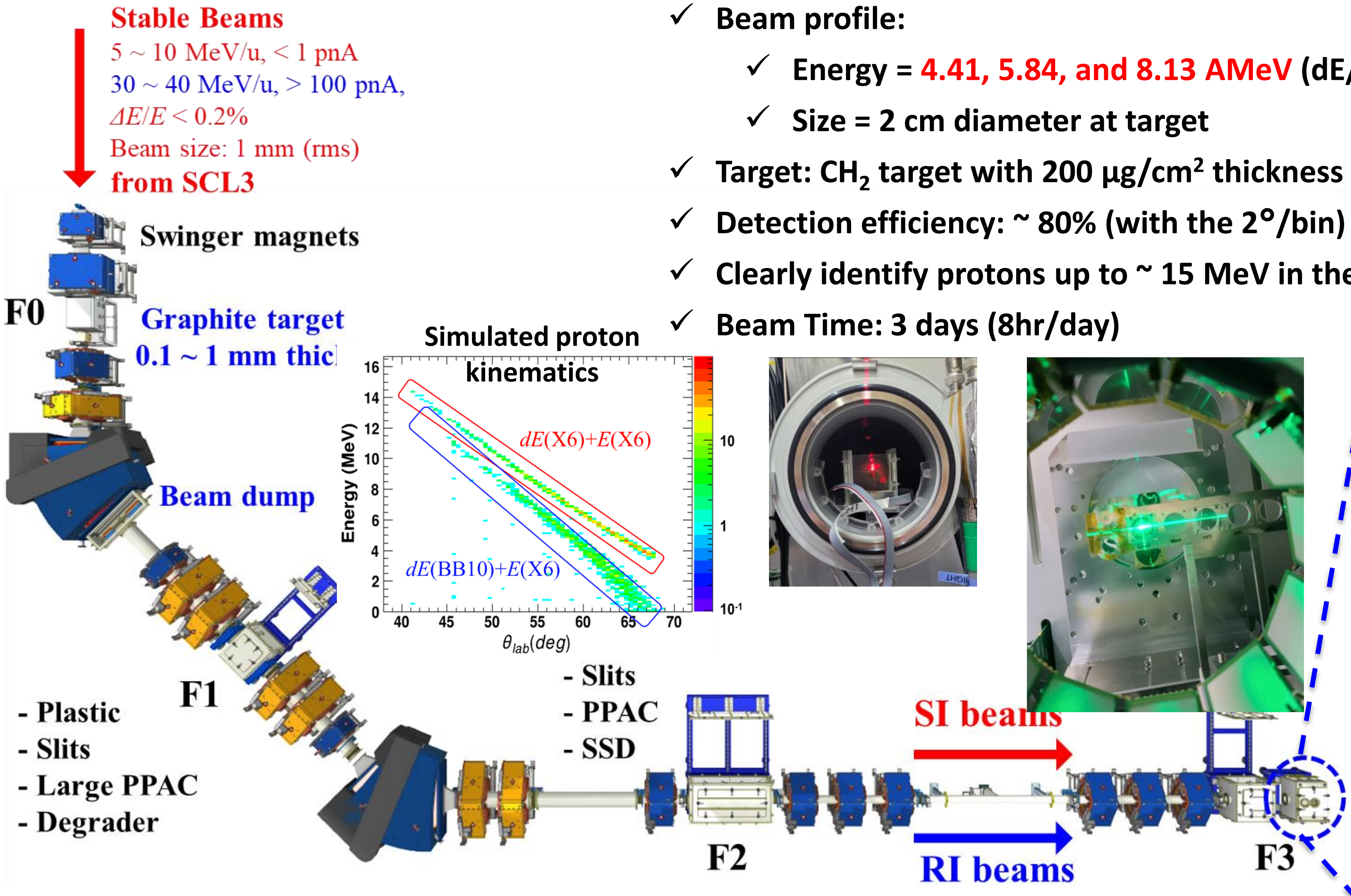


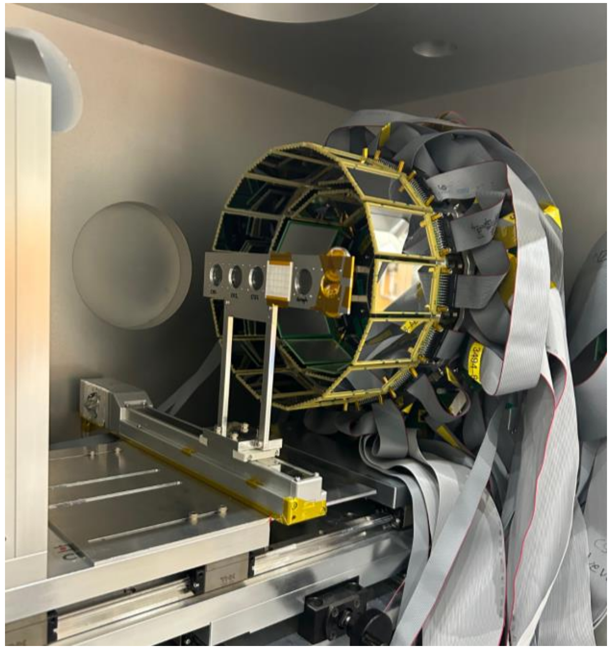
Calculated by Dr. Y. H. Song (IRIS) and Myunghee Park (CENS)

[Main Goal] Compare the phenomenological and microscopic optical model for ^{40}Ar+p elastic scattering in lower energy region.

Experimental Setup of ^{40}Ar+p elastic scattering

- ✓ Beam profile:
  - ✓ Energy = 4.41, 5.84, and 8.13 AMeV (dE/E = 0.5% FWHM at F0)
  - ✓ Size = 2 cm diameter at target
- ✓ Target: CH_2 target with 200 μg/cm^2 thickness (plus Phosphor, Carbon and blank)
- ✓ Detection efficiency: ~ 80% (with the 2°/bin)
- ✓ Clearly identify protons up to ~ 15 MeV in the range of 40° < θ_{lab} < 70°
- ✓ Beam Time: 3 days (8hr/day)



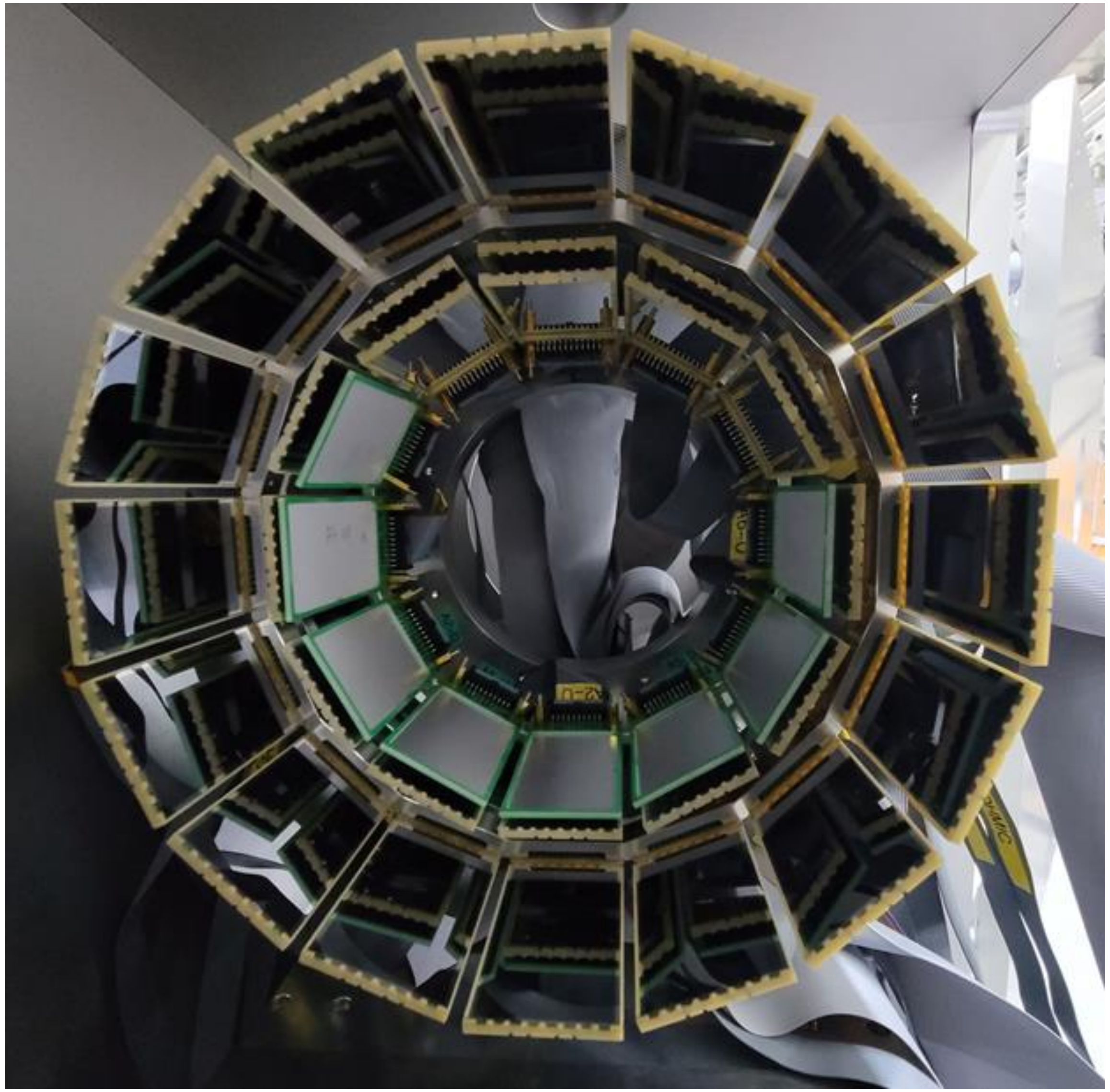


STARK

M. Kwag, CENS-KoBRA Collaboration Meeting (2019)

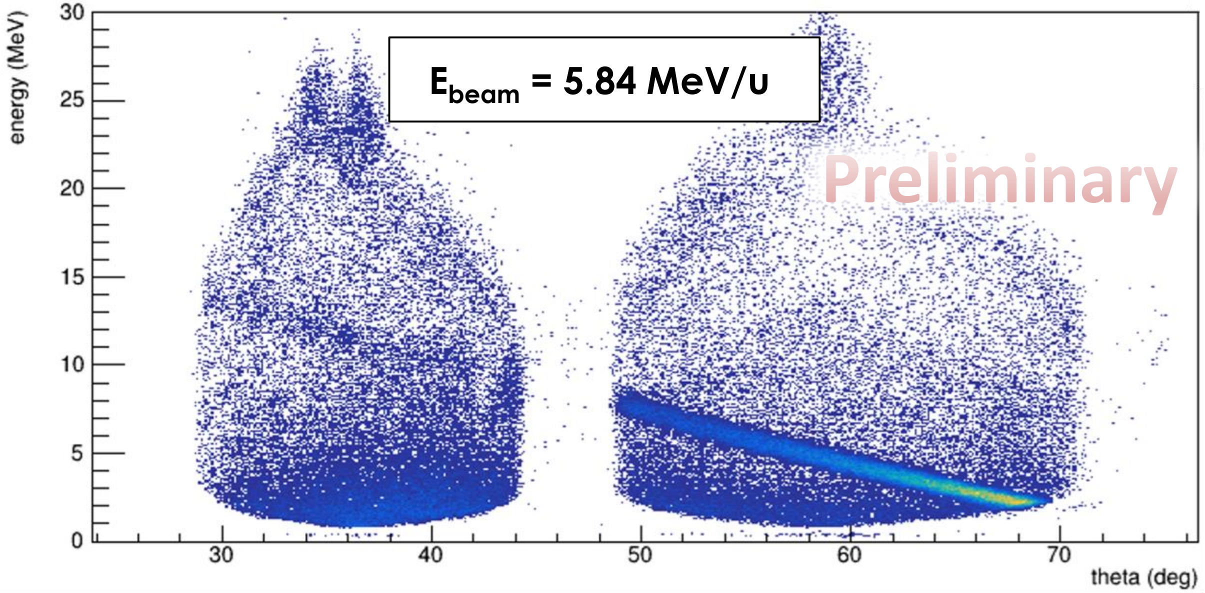
Courtesy of Tony Ahn

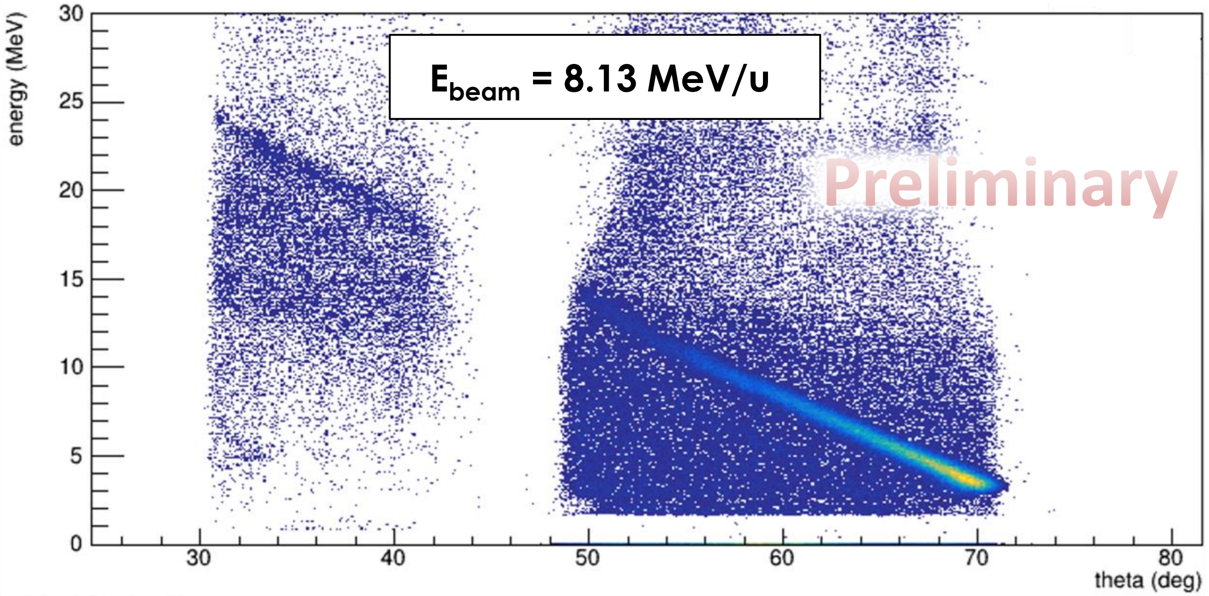
Experimental setup photos

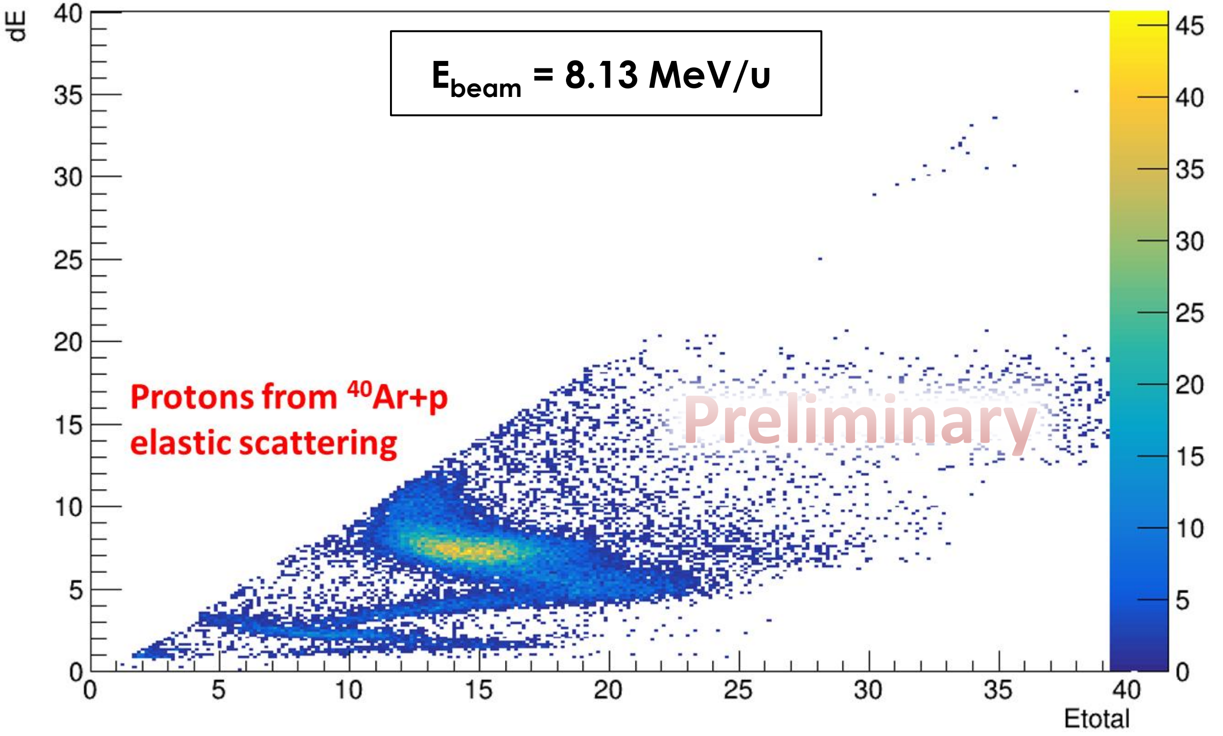


Courtesy of Tony Ahn

Online plots from the ^{40}Ar+p scattering data - preliminary







Courtesy of Tony Ahn

Summary

❖CENS started 5 years ago to perform experiments using RI and stable beams at accelerator facilities around the world including RAON in Korea.

❖ We have developed major devices to be used at RAON and other RI accelerator facilities.

Clover HPGe detectors, Wien filter, Silicon detectors, Active target TPC, Cryogenic gas target, etc.

❖ We performed commission experiments at RAON this summer. With international collaborators, we carried out experiments at other accelerator facilities around the world.

❖ We welcome you to collaborate with us. Please consider to perform experiments at IRIS in the future.

https://www.ibs.re.kr/cens/

International Nuclear Physics Conference (INPC2025)

Thank you for your attention!