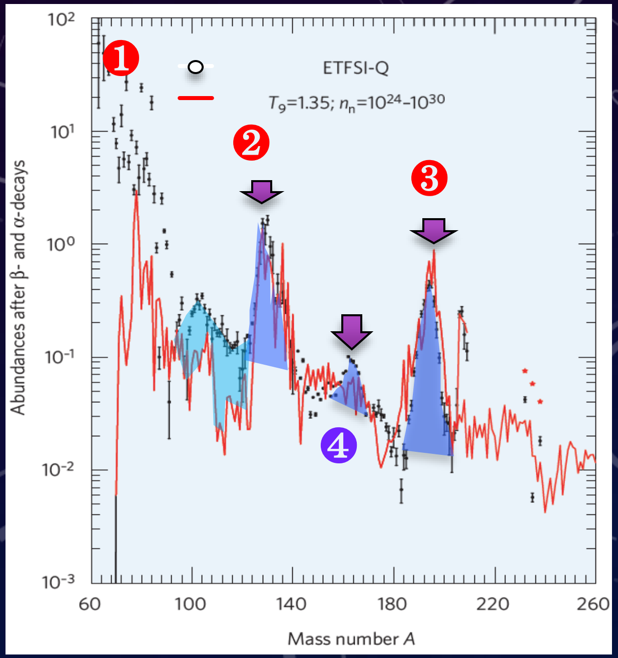
HIAF的核天体物理実験検討会@HUIZHOU, September 5, 2025

Investigation of Nuclear Properties related to Nuclear Astrophysics

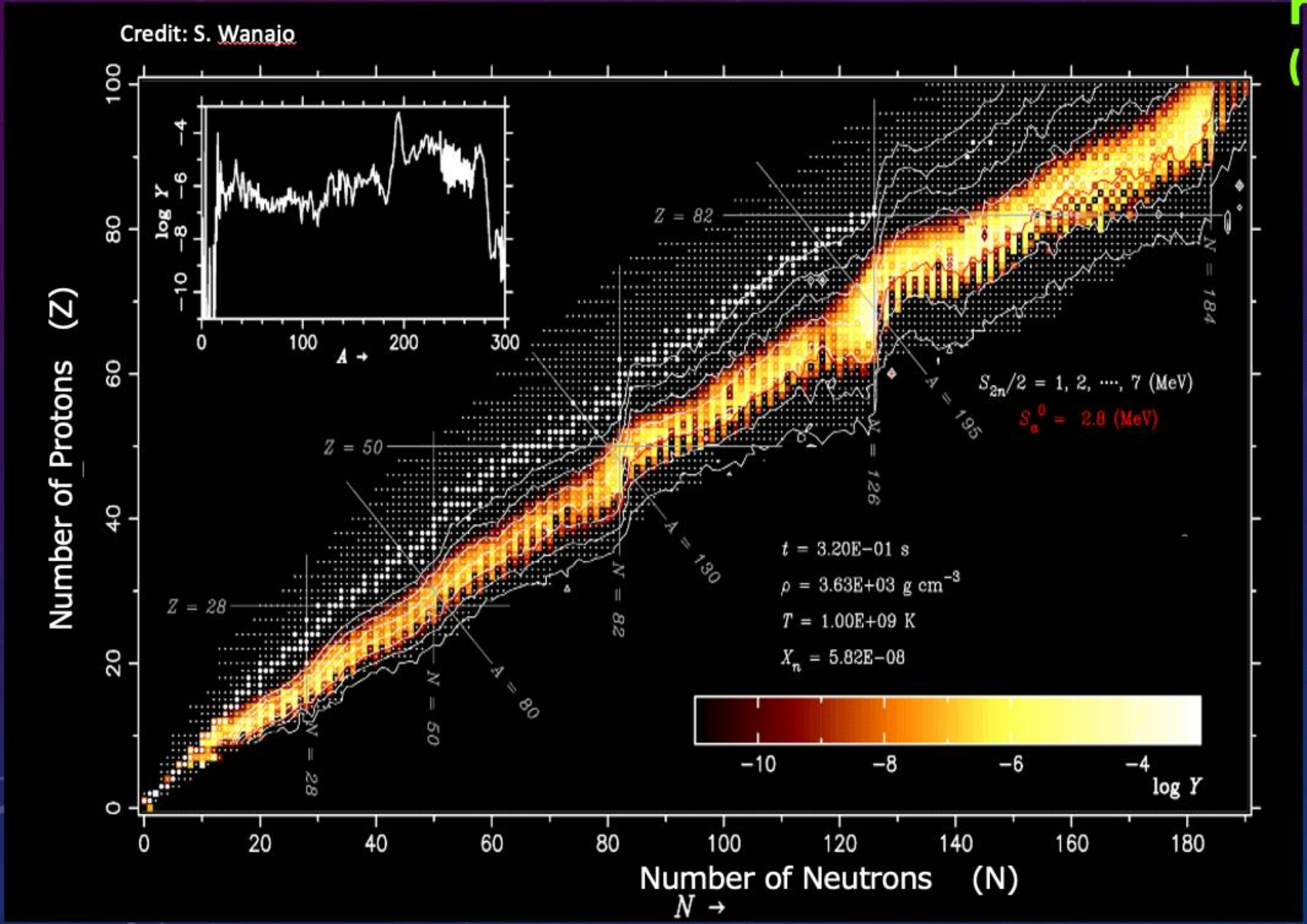
C.Sneden et al. (2008)



Shunji Nishimura

(RIKEN)

Nuclear Physics: Bridging Discoveries with Astrophysics



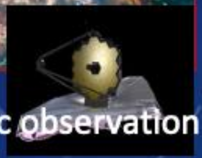
r-Process Nucleosynthesis

(rapid neutron capture process)

- Supernovae?
- Neutron star merger?
- When ?
- Dynamics in extreme conditions

Neutron Star Merger

Supernovae



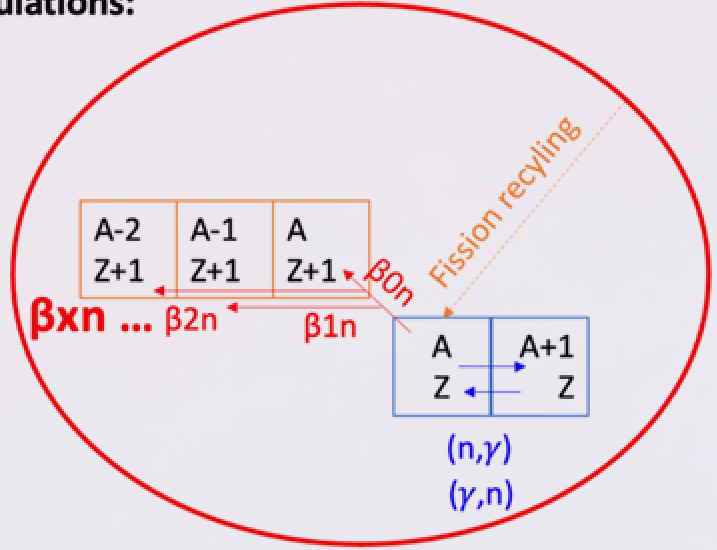
Gravitational wave observation

Electromagnetic observation

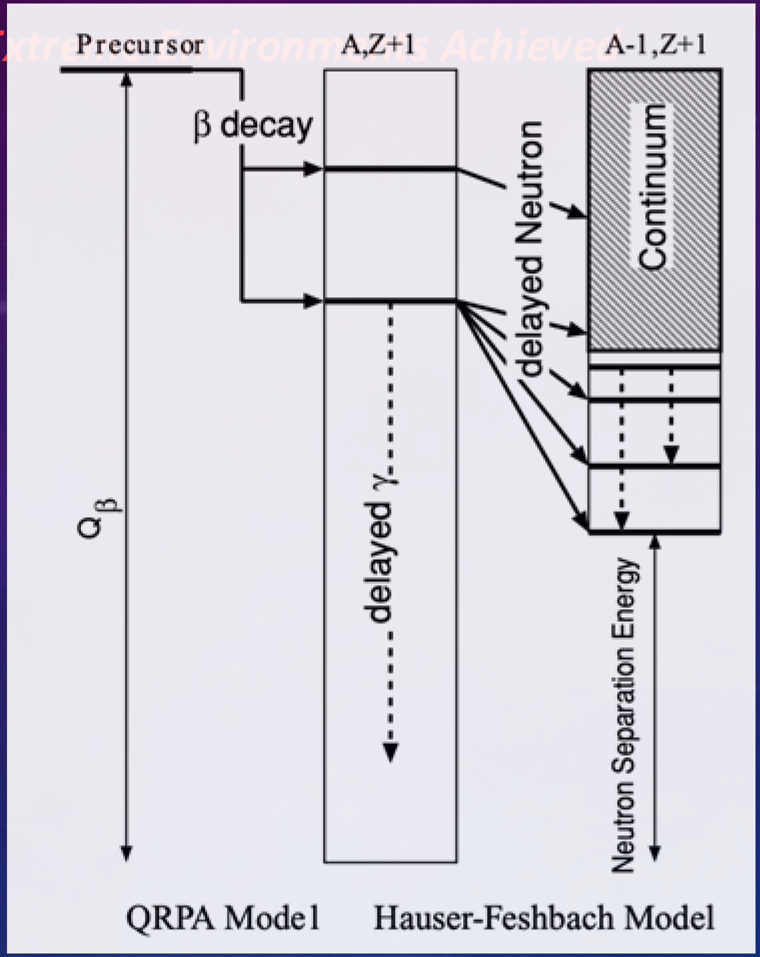
Connections with those observations

Required Nuclear Data for Nucleosynthesis (r-Process)

Reaction rates for modern dynamical r-process calculations:



T. Kawano et al. PRC 78, 054601



Several Thousands of RI to be measured..

◎ Masses:
- Determine the r-process path, global structure

◎ Beta-decays:

Half-lives:
- Speed of producing heavy elements

Beta-delayed neutron emissions:
- Determine the fine structure of r-elements
- Recapture of neutrons

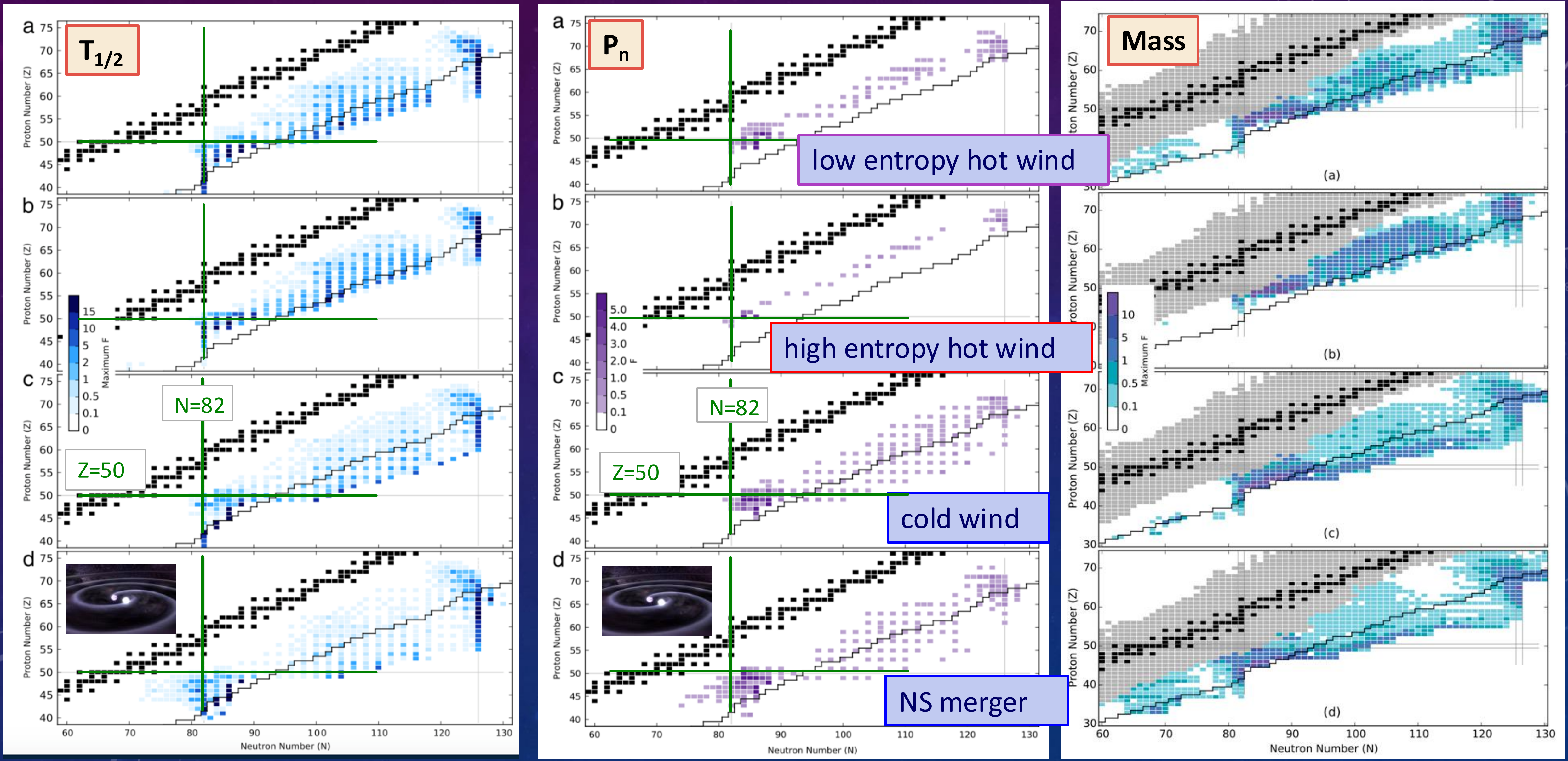
◎ Nuclear reactions ←→ Masses
- Determine the r-process path

◎Fission recycling:
- Production of heavy elements

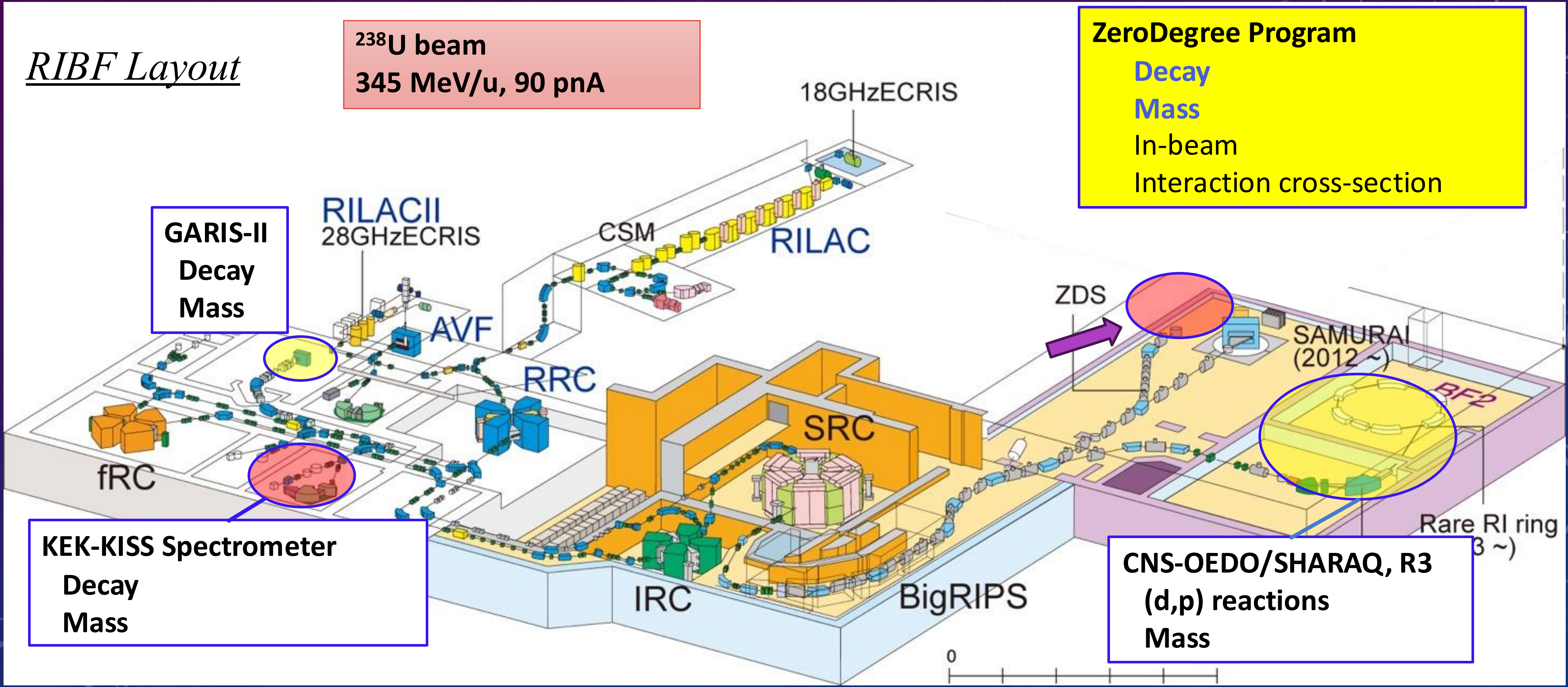
◎Equation of State:
- Explosive conditions of NS-NS, SN

Sensitivity Study of Neutron-Rich Nuclei in r-Process

M.R. Mumpower et al.(2016)



RIBF Experiments (Decay, Mass, Reaction)



^{238}U beam
345 MeV/u, 90 pnA

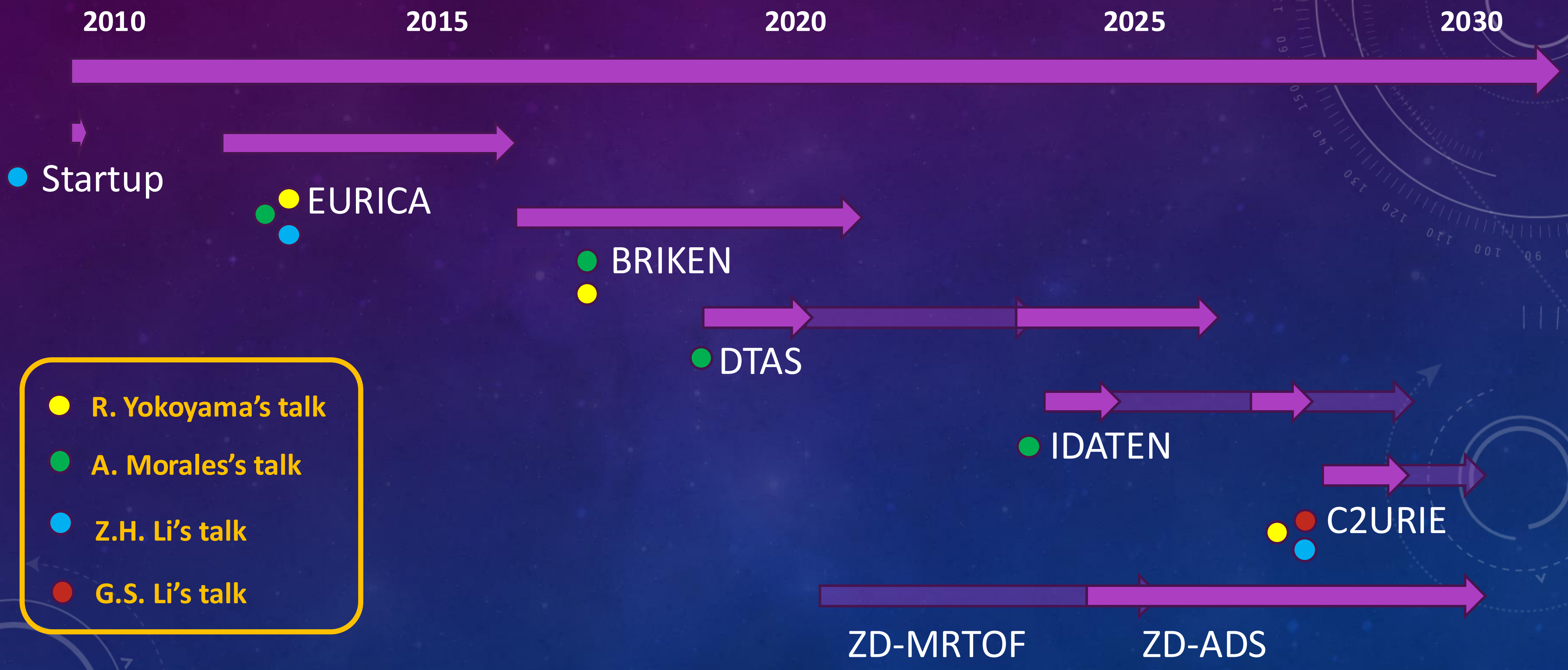
ZeroDegree Program
- Decay
- Mass
- In-beam
- Interaction cross-section

GARIS-II
- Decay
- Mass

KEK-KISS Spectrometer
- Decay
- Mass

CNS-OEDO/SHARAQ, R3
- (d,p) reactions
- Mass

Status and Future (RIBF ZeroDegree Spectrometer)



Status and Future (RIBF ZeroDegree Spectrometer)

2010 2015 2020 2025 2030

Startup

EURICA

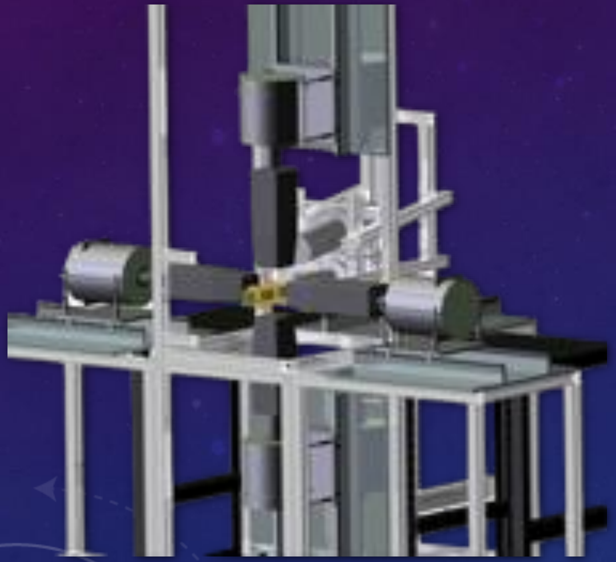
BRIKEN

DTAS

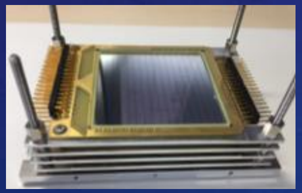
IDATEN

C2URIE

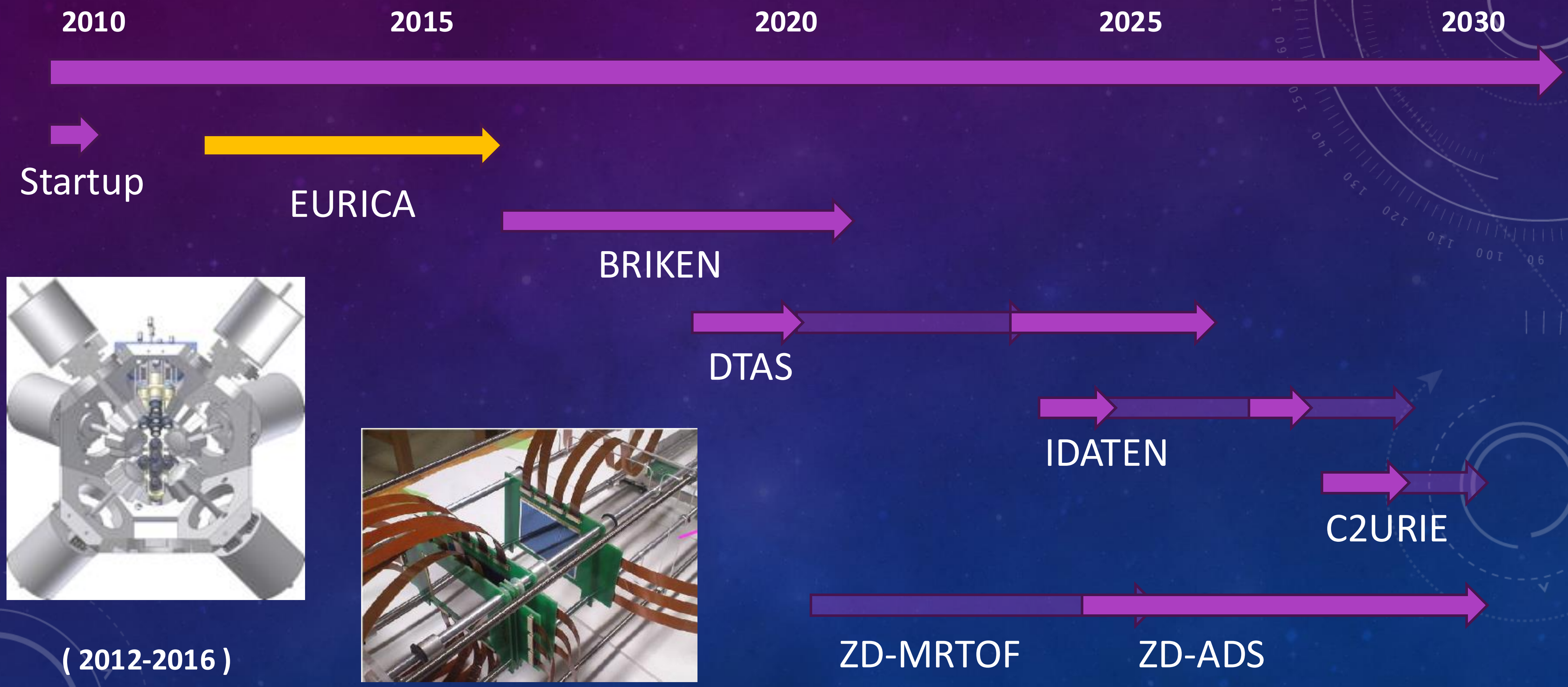
ZD-MRTOF ZD-ADS



(2009)



Status and Future (RIBF ZeroDegree Spectrometer)



Status and Future (RIBF ZeroDegree Spectrometer)

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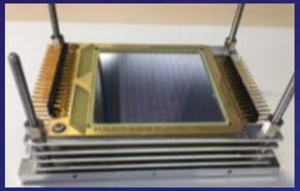
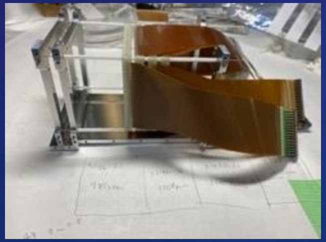
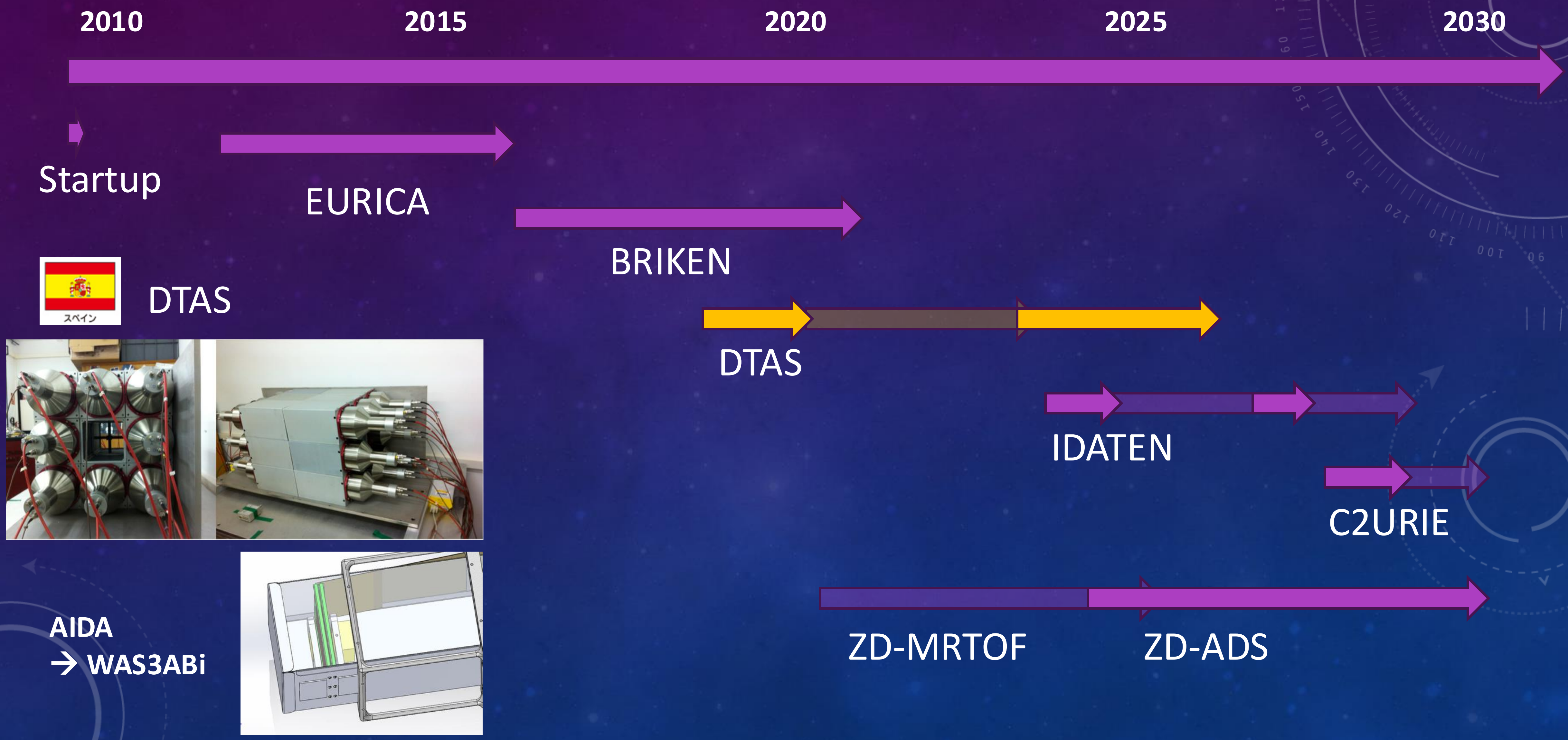




BRIKEN (2017 - 2021)

Status and Future (RIBF ZeroDegree Spectrometer)



Status and Future (RIBF ZeroDegree Spectrometer)

2010 2015 2020 2025 2030

Startup

EURICA

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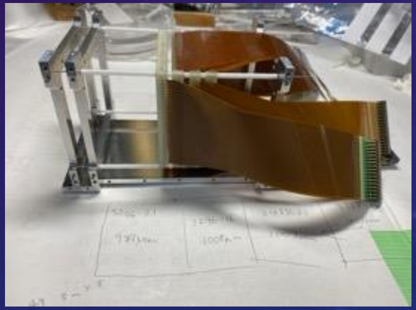
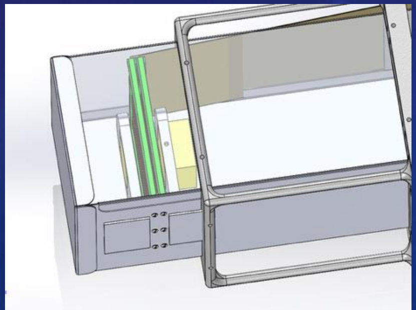
ZD-ADS

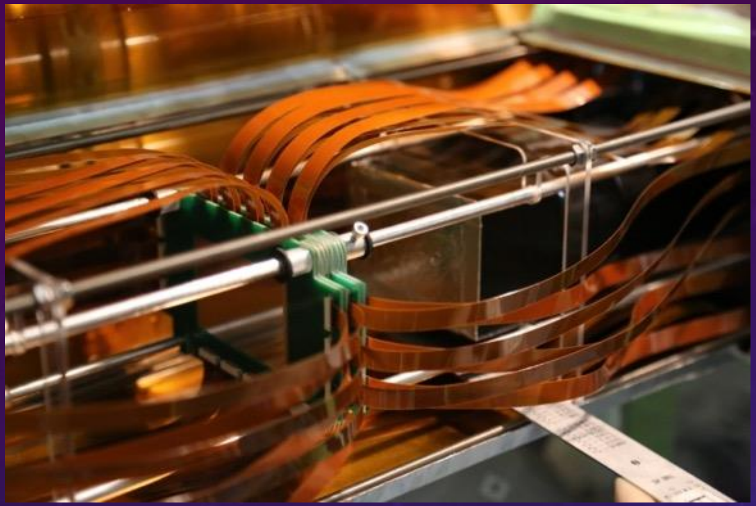




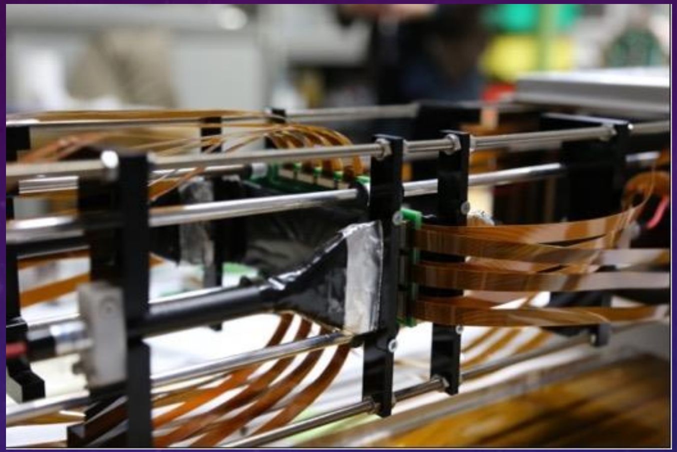
WAS3ABi Configuration for EURICA, BRIKEN, DTAS

Nitrogen air cooling ~ 10 degree.
Air cooling ~ 15 degree

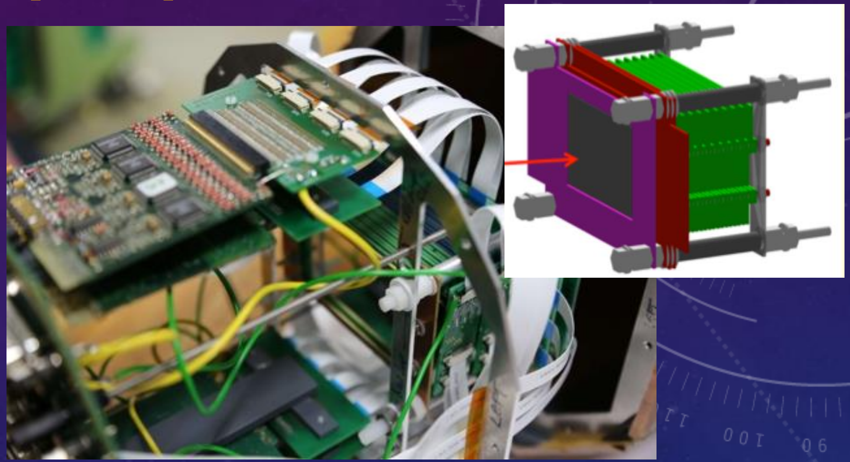
[60x40] x 8 + Plastic scintillator



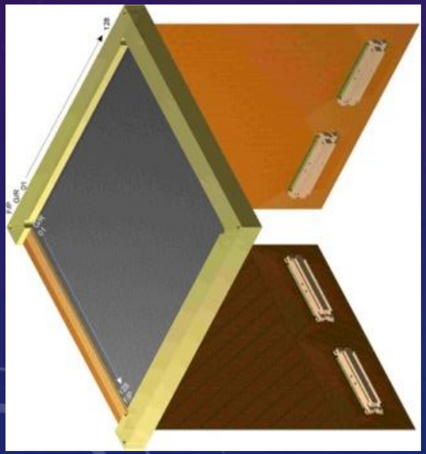
[60x40] x 4 + Plastic scintillator x 2



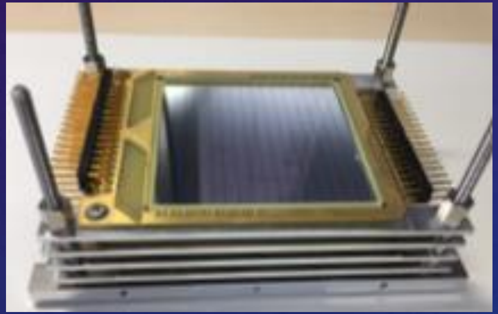
[60x40] x 3 + SSD x 10

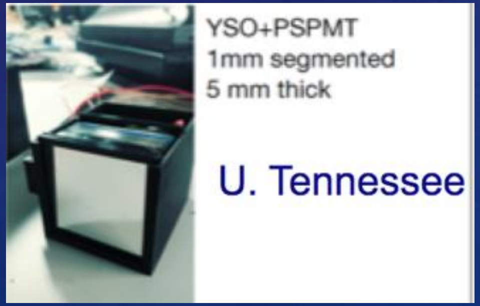


[128x128]（York Univ.)

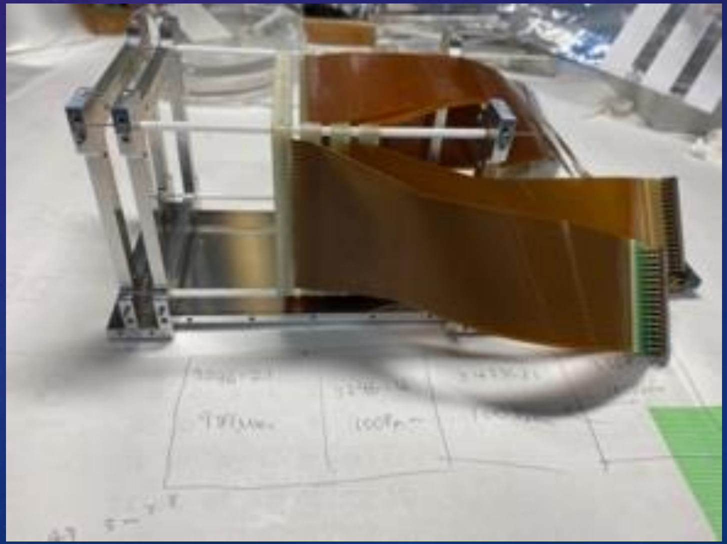


BRIKEN 2017 ... [16x16] x 4

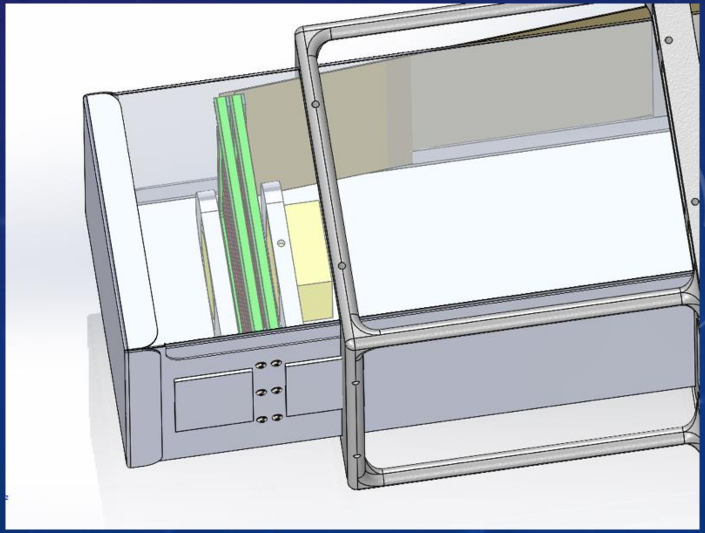




BRIKEN 2021 ... [32x32] x 4



DTAS 2024 ... [64x64] x 2 (IFIC)



Status and Future (RIBF ZeroDegree Spectrometer)

2010 2015 2020 2025 2030

Startup

EURICA

TAS

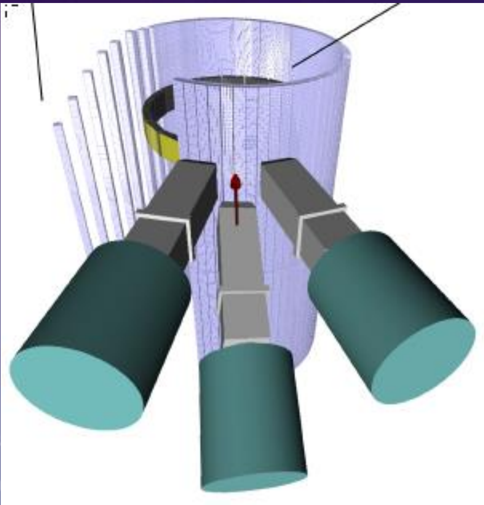
IDATEN

C2URIE

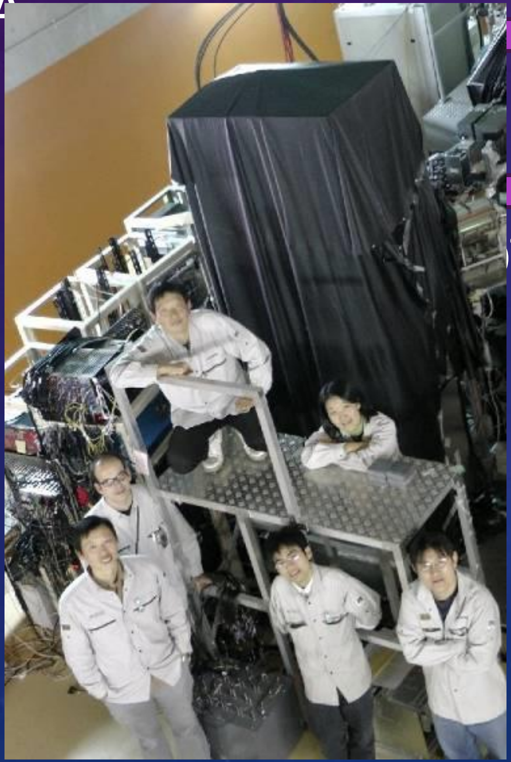
ZD-MRTOF

ZD-ADS

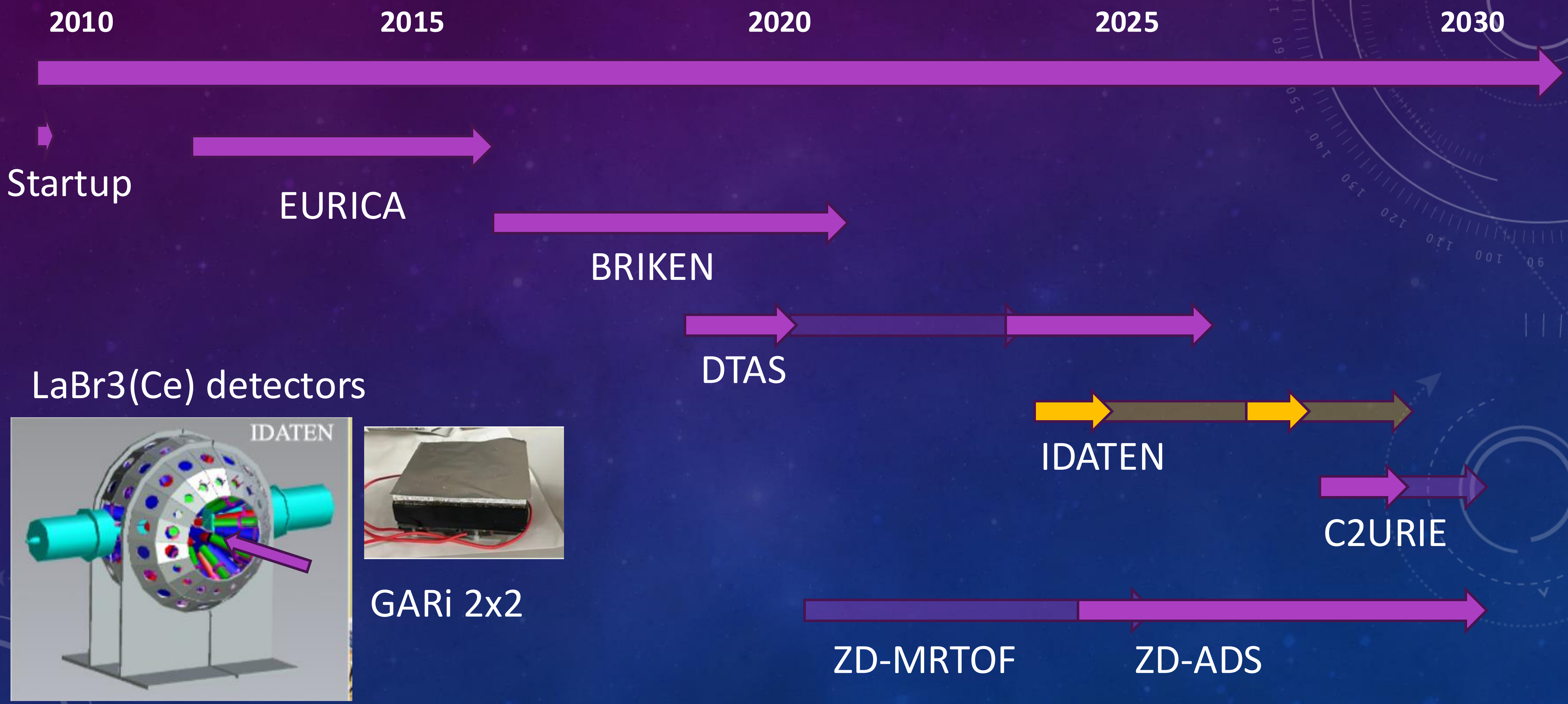
CAITEN



(2009/2010)



Status and Future (RIBF ZeroDegree Spectrometer)



Status and Future (RIBF ZeroDegree Spectrometer)

2010 | 2015 | 2020 | 2025 | 2030

Startup

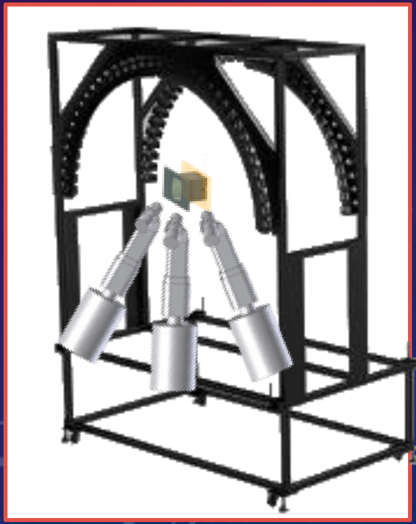
EURICA

BRIKEN

DTAS

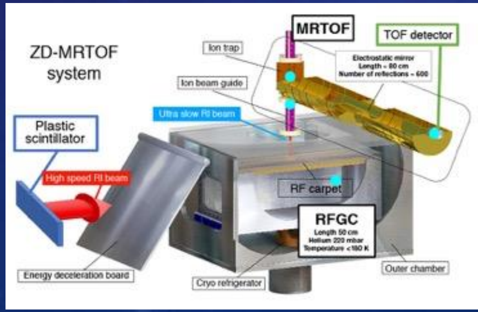
IDATEN

C2URIE



TOFU (2024 -)

GARi 2x3



ZD-MRTOF

ZD-ADS

Comparison of RIBF and HIAF

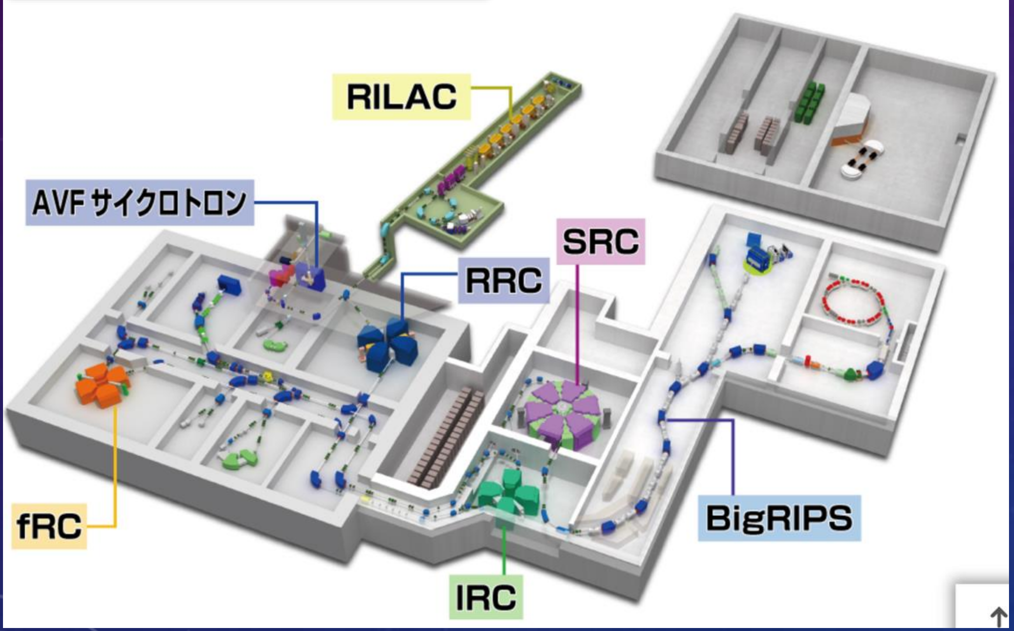
- RI Production Yield

- Particle Identification beyond A>200

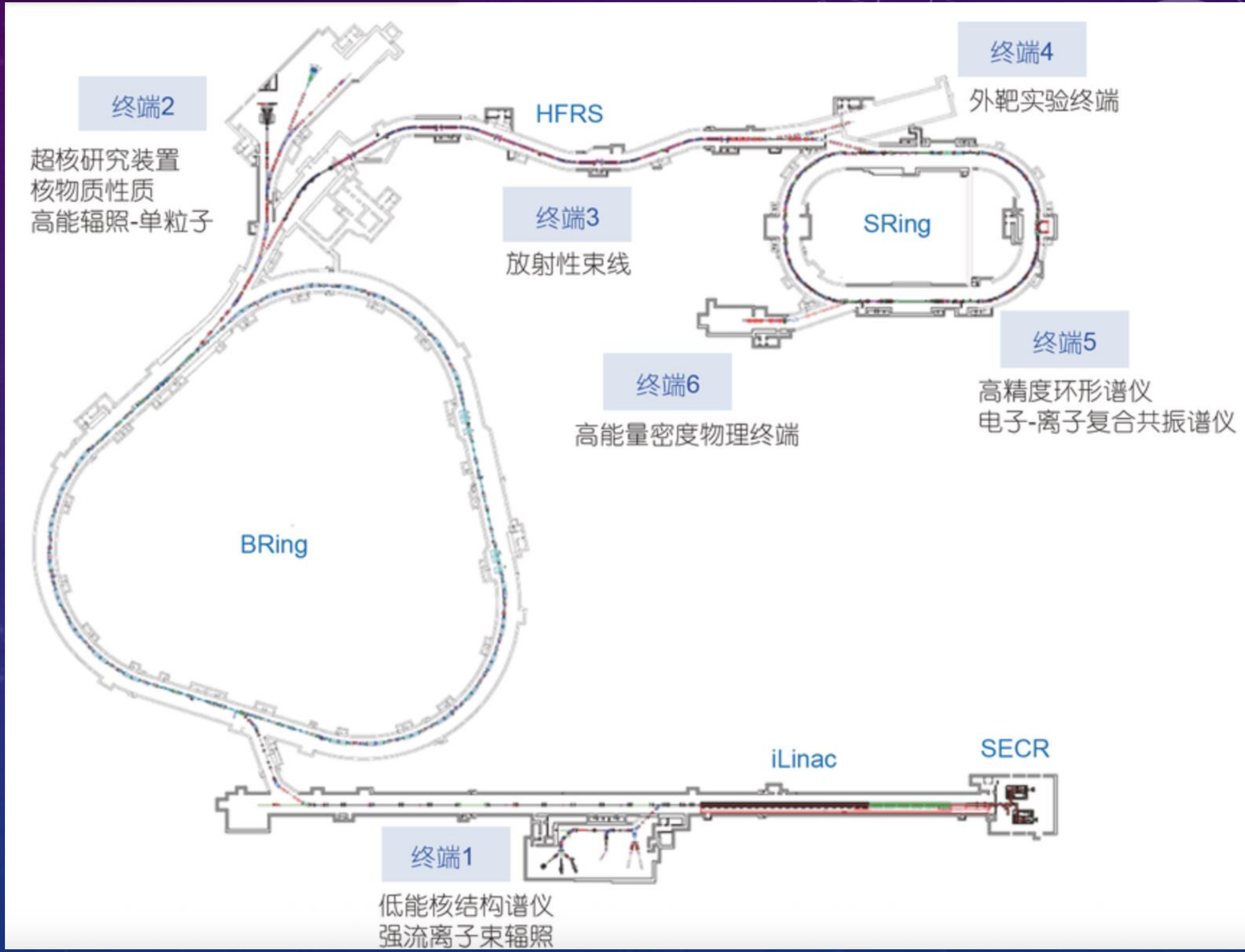
Power of RI Production

FRIB
GSI FAIR

RIBF: ~ 345 MeV/u



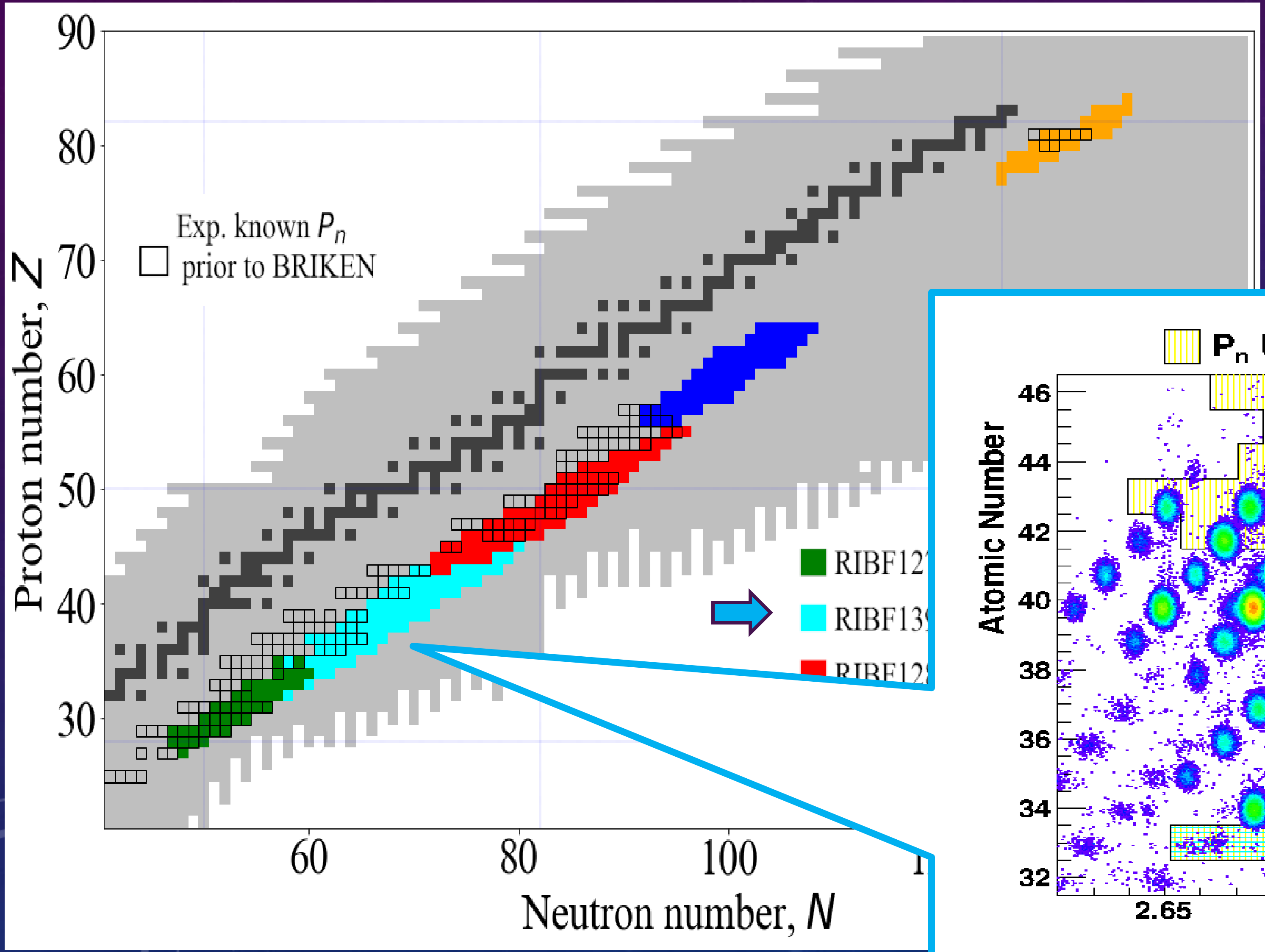
HIAF: ~ 800 MeV/u

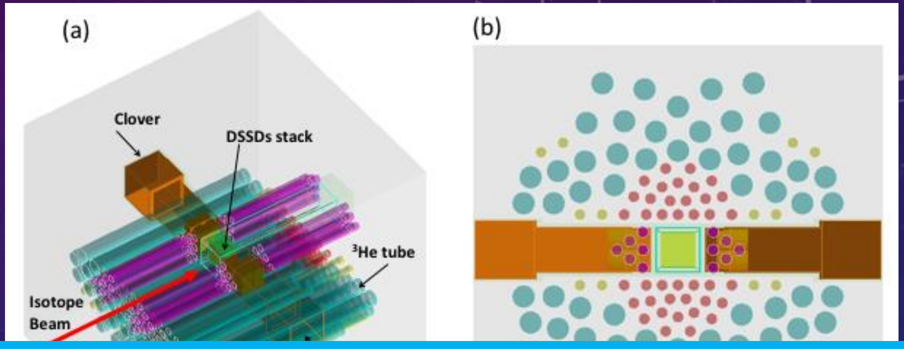


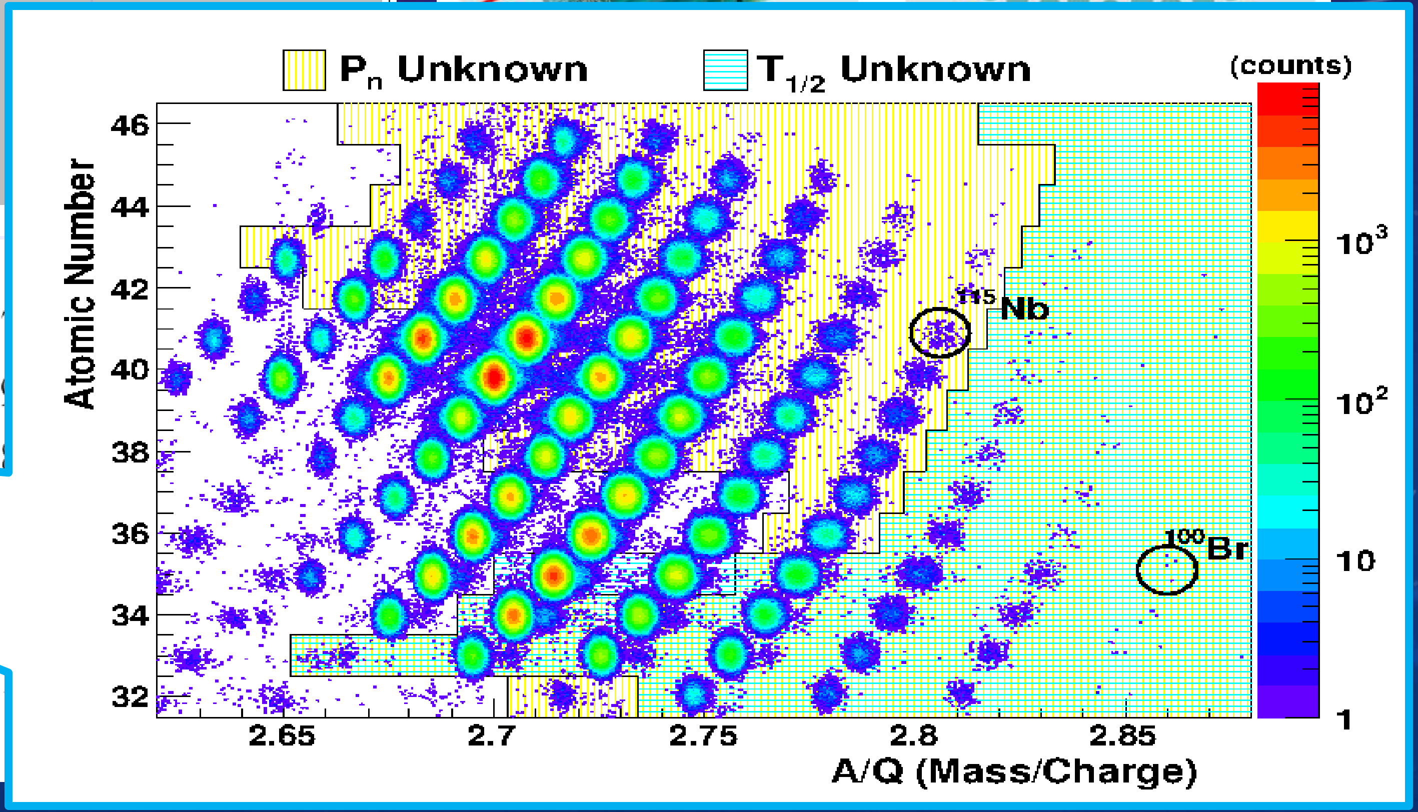
RIBF - HIAF: Equivalent production yield with thicker target (Wang He's talk)

BRIKEN (A = 86 - 126 Region)

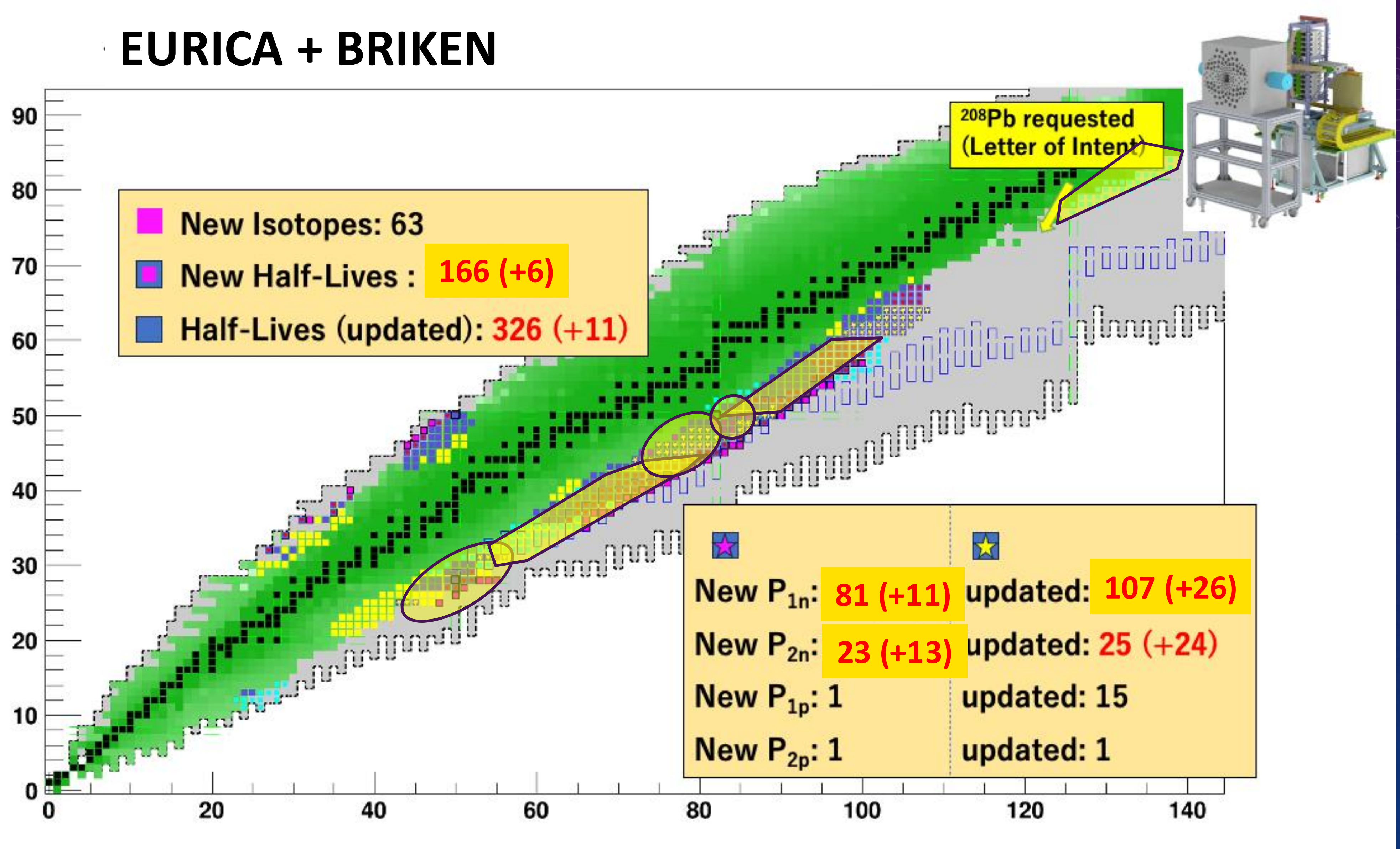
- 140 3He tubes (BELEN + 3HEN + RIKEN)
- beta counters (AIDA, WAS3ABi, YSO)
- Two Clover Ge detectors







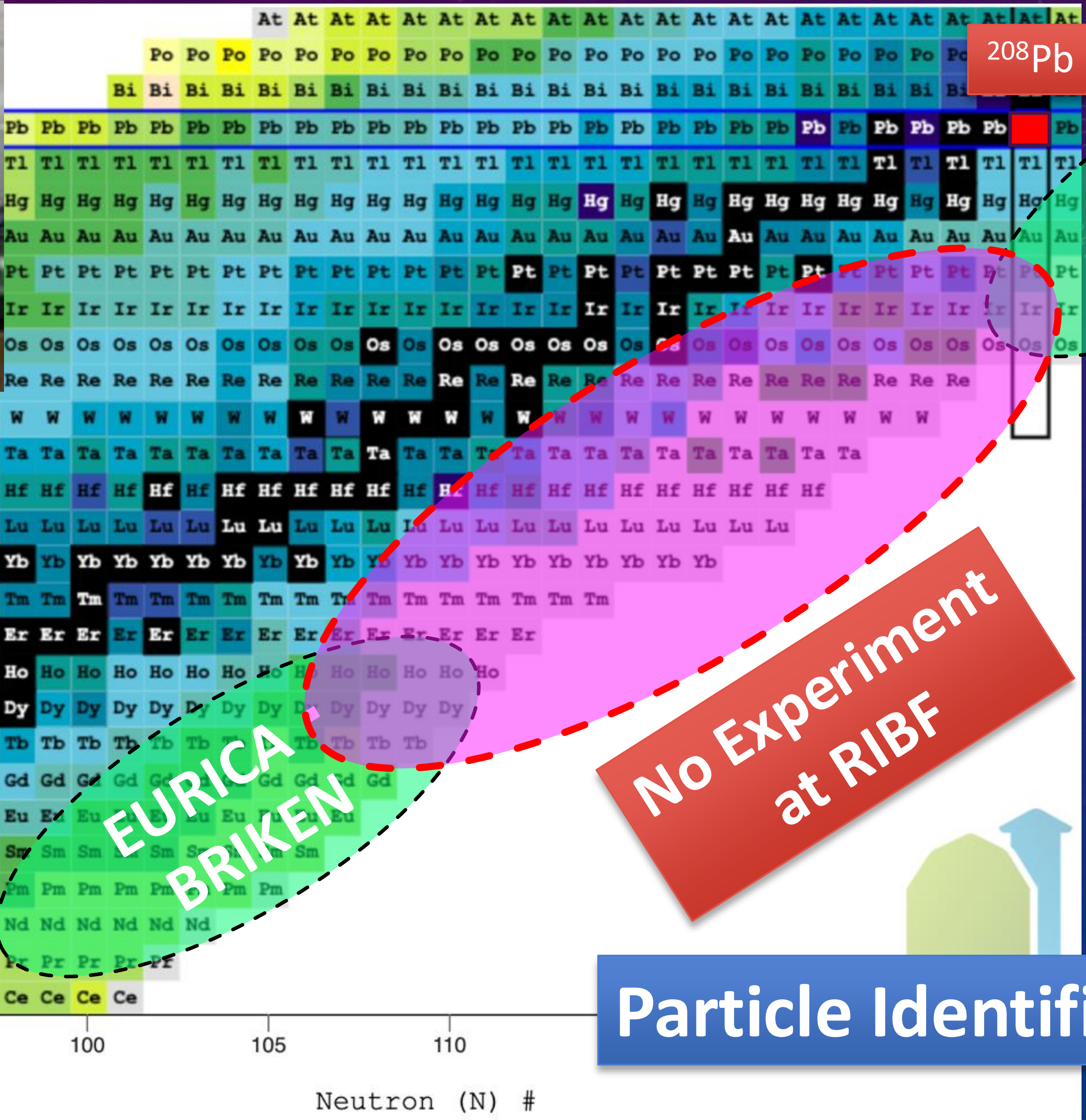
Decay Properties Surveyed



Decay Data ($T_{1/2}$, P_{xn}) ... More than 200 Isotopes expected from BRIKEN

Decay Spectroscopy toward Heavy RI

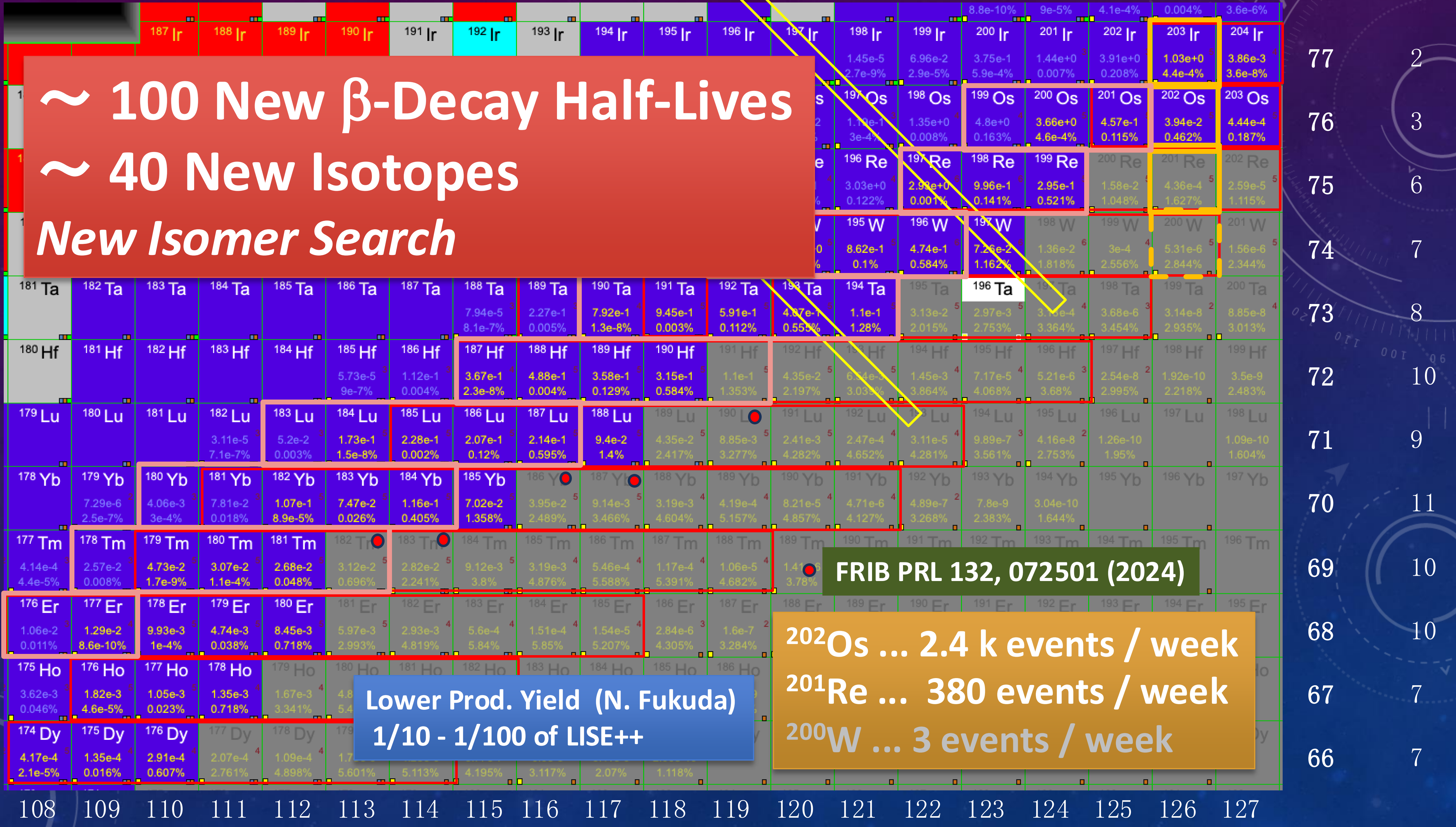
Hamamatsu Si detectors
600um x 4 layers



Particle Identification

To Be Proposed with C2URIE

LISE++ Calc. Optimized



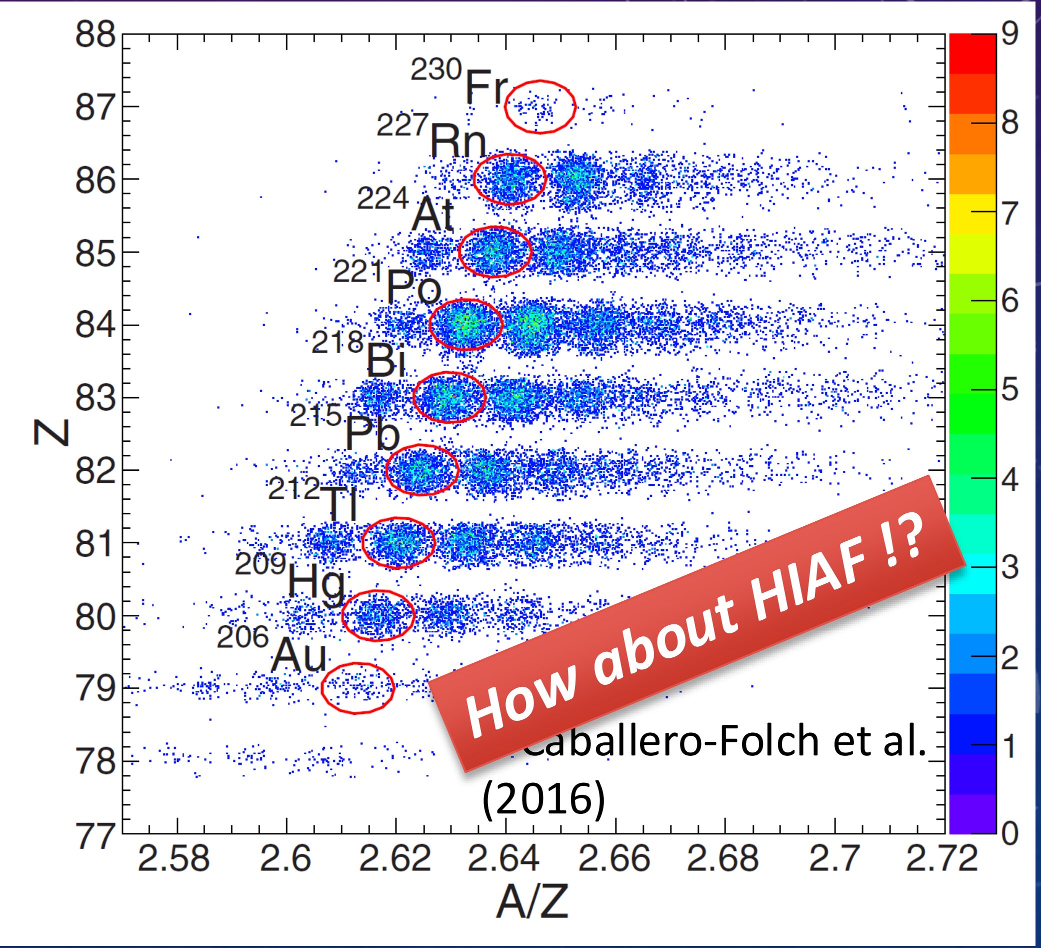
Particle Identification: A>200

	RIKEN	GSI
FWHM in A/Q	0.11 - 0.21 %	0.25 %
FWHM in Z	0.57 - 0.71 %	/
(Pb-Bi)	0.57 - 0.61 %	≲ 0.6 %

Z

BRIKEN 2021

A/Q



Can we measure Total E in Beta Counting System!?
(Additional Information for PID)

Higher energy: More contaminants in the reaction of RI in degrader

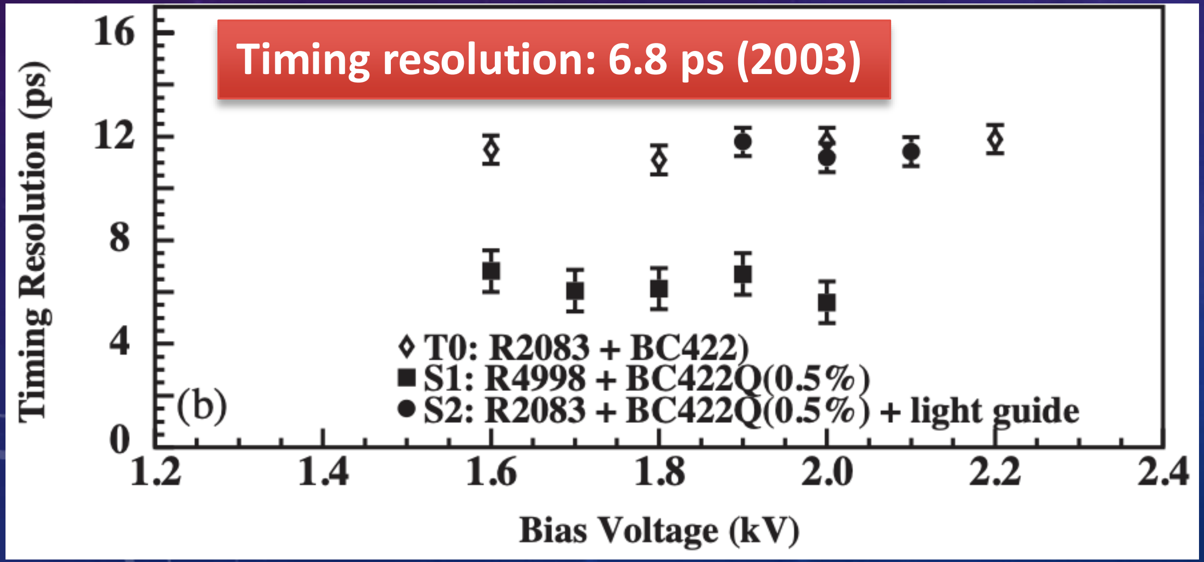
Detector Developments

Particle Identification

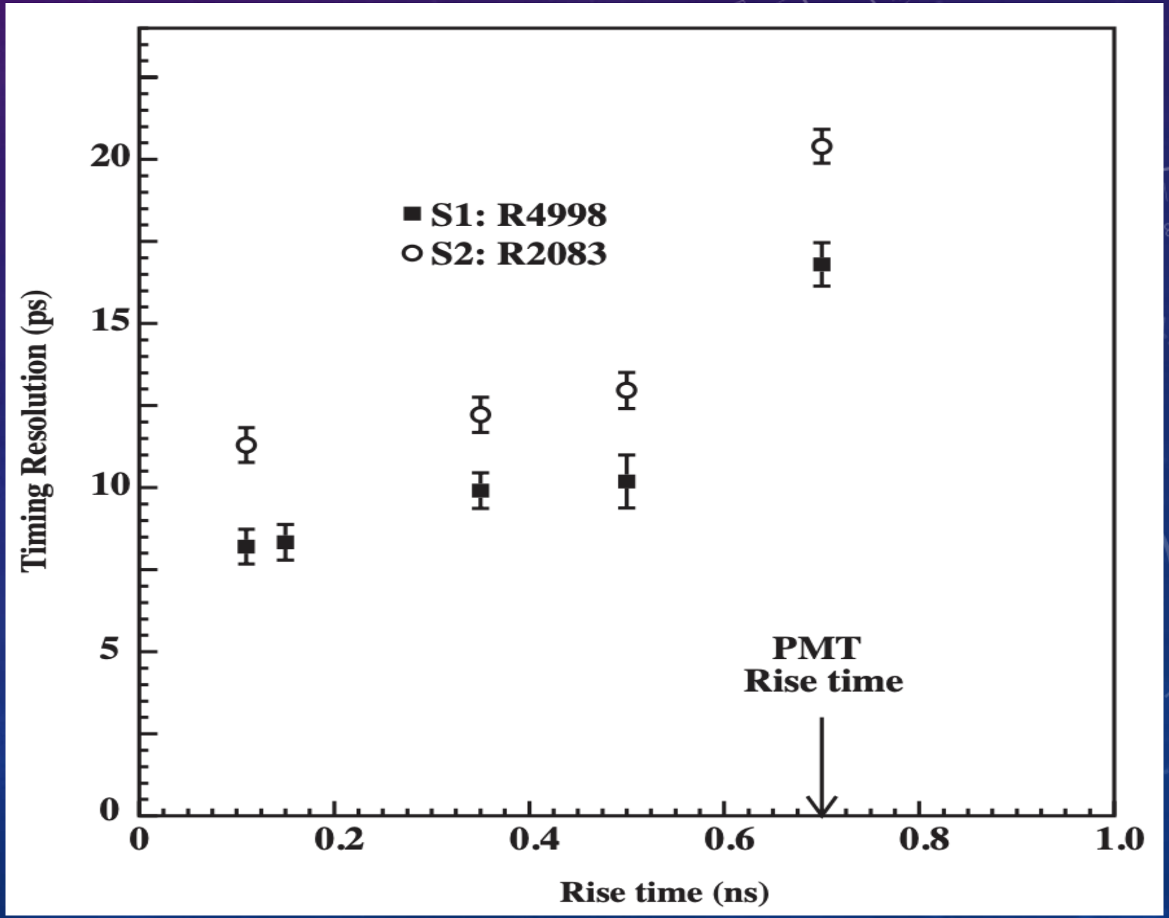
Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 510 (2003) 377–388
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Systematic studies of scintillation detector with timing resolution of 10 ps for heavy ion beam

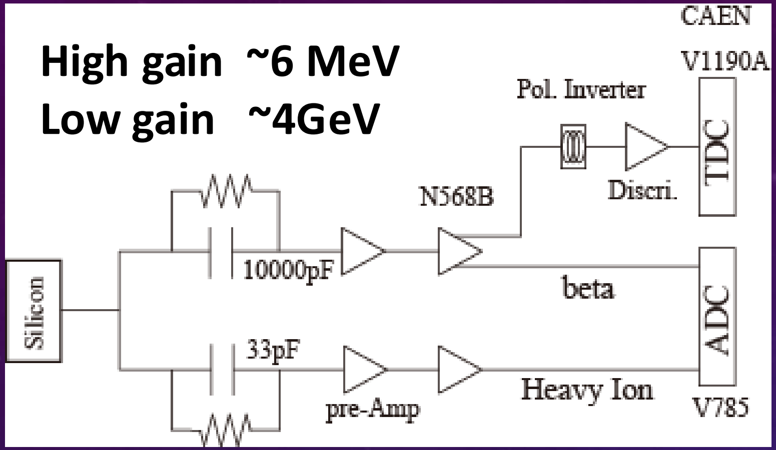
S. Nishimura*, M. Kurata-Nishimura, K. Morimoto, Y. Nishi, A. Ozawa, T. Yamaguchi[1], T. Ohnishi, T. Zheng[2], M. Chiba, I. Tanihata



Current BigRIPS is not using fast PMTs (~ 50ps?)

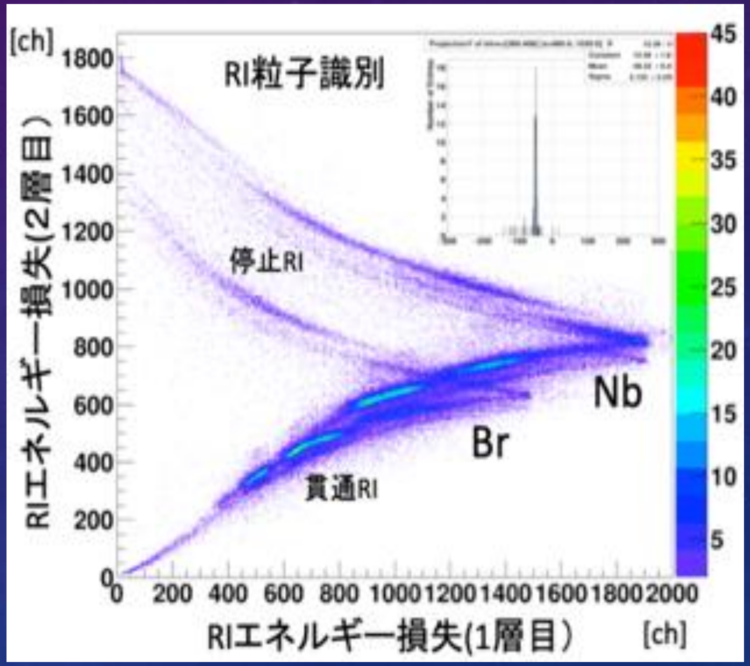


Energy Loss in Beta Counter for Particle Identification



Dual-gain readout works well !
→ Useful to remove RI contaminants with different charge states.

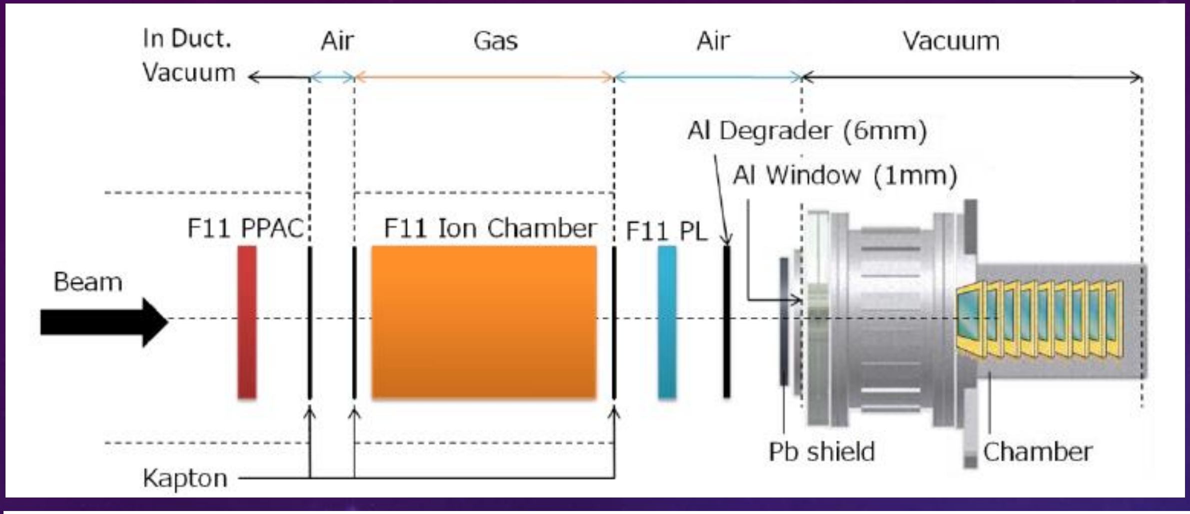
Dynamic Range： ～ 5 GeV

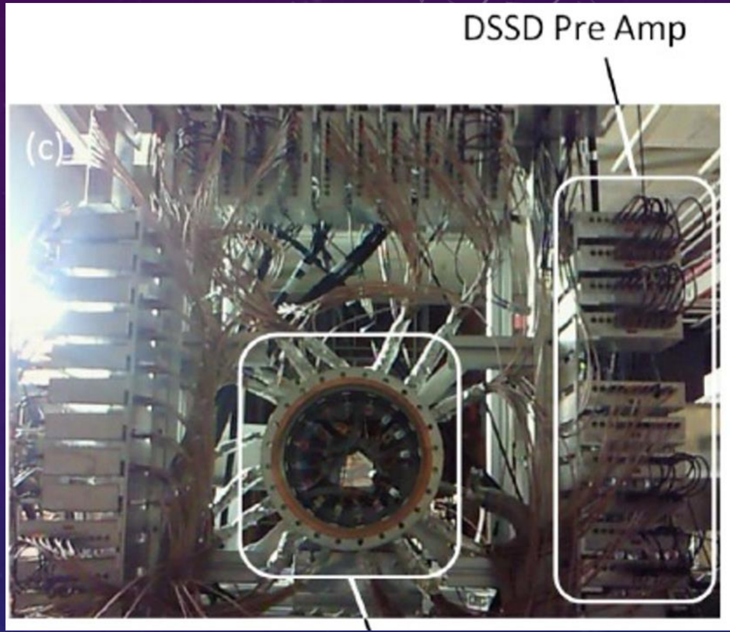


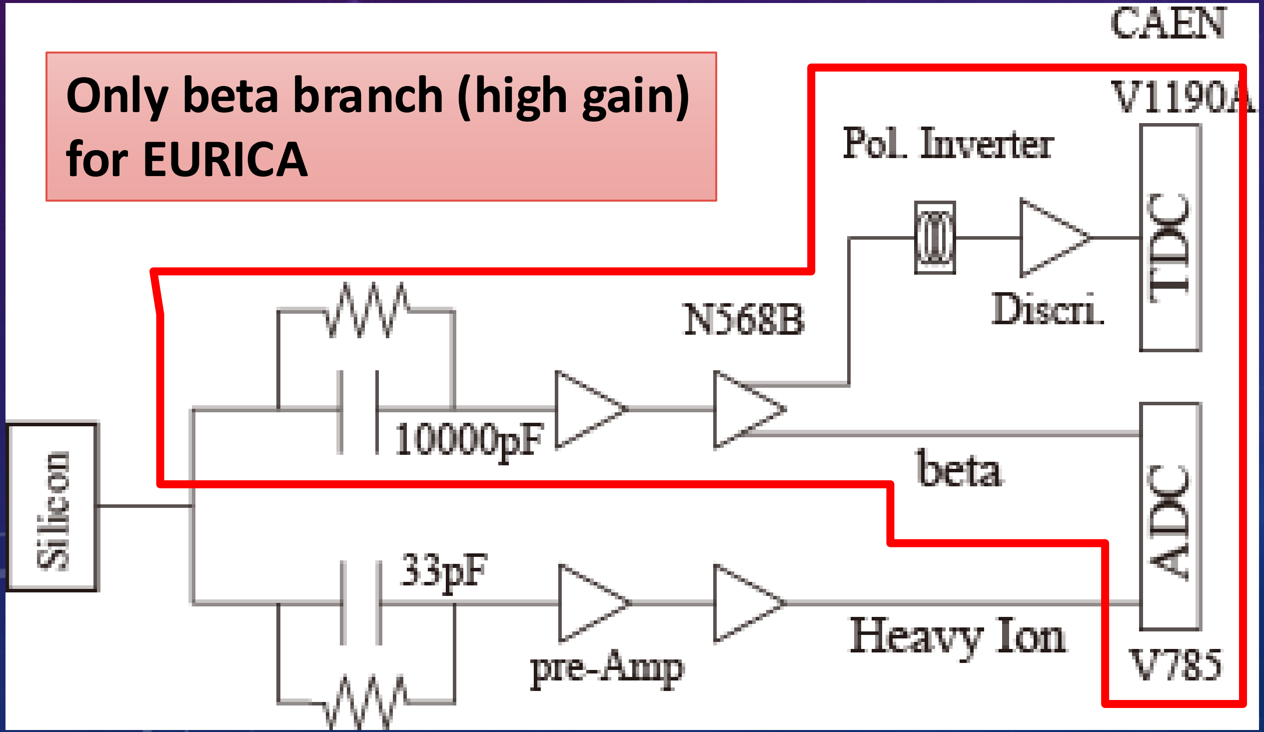
Energy resolution：σ = 0.21 %

Demonstration of energy reconstruction for all the strips and layers (BRIKEN 2017)

Readout system (2009 – 2015)







Dual preamplifier system for low/high gain.

→ High gain only (EURICA)

Trigger by leading edge discriminators after shaping amplifiers (N568B)

Dead time ... 0.2 msec for beta

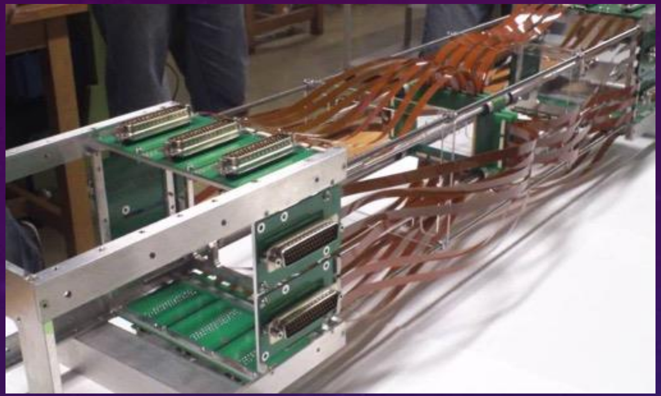
... 0.5 – 0.7 msec for ion

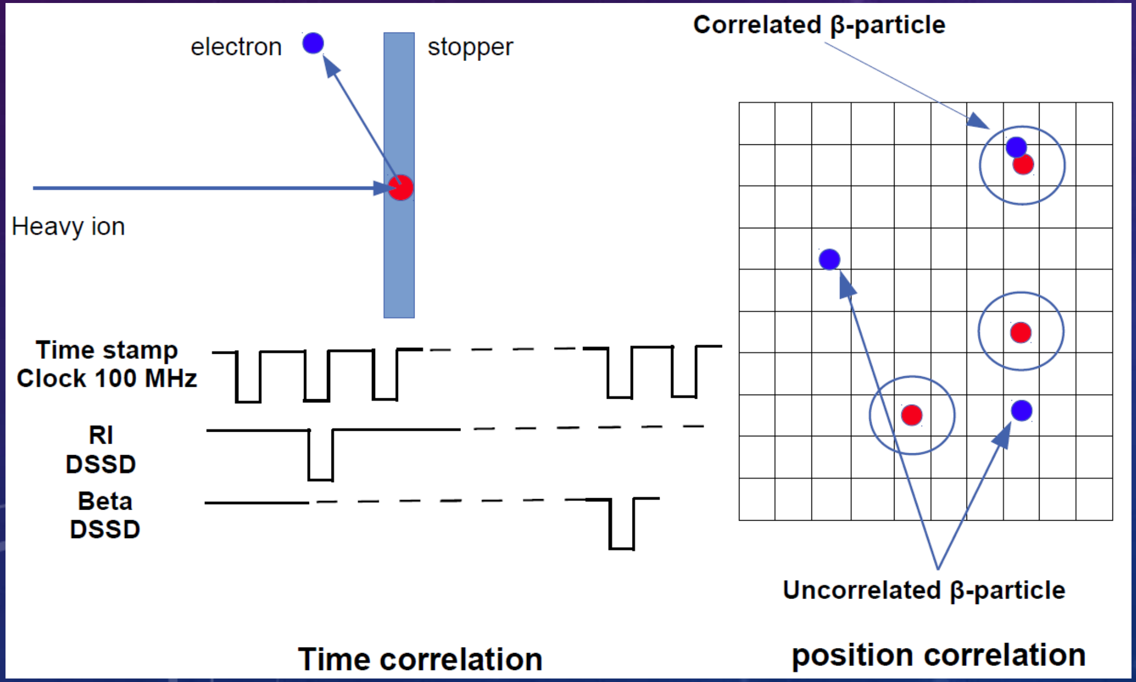
Reconstruction of RI (Position)

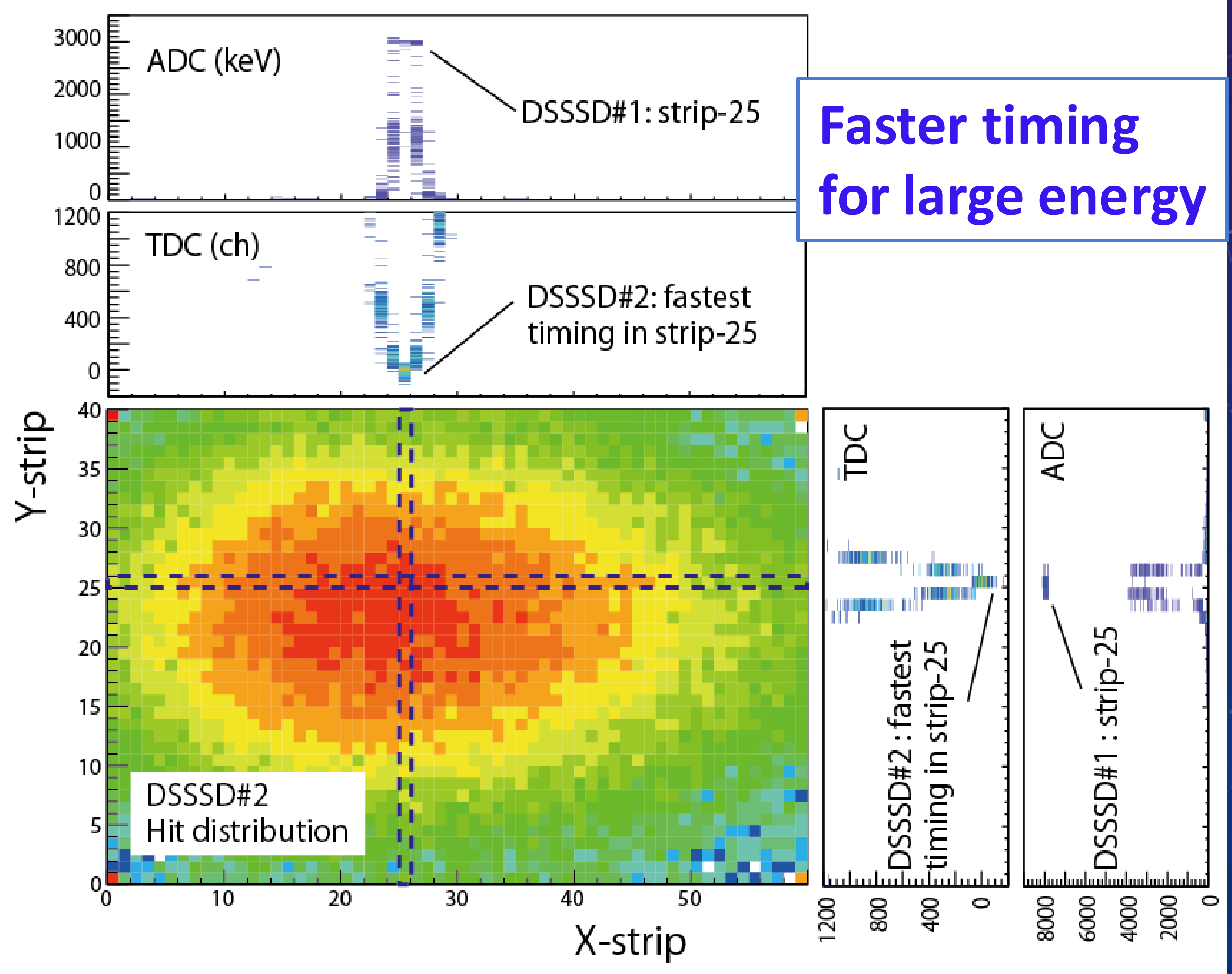
Energy loss of RI in 1mm Si: ~ 1GeV ~ 20 GeV

Leading edge discriminator for beta trigger

Timing information is used for reconstruction of RI position. (Time walk eff.)

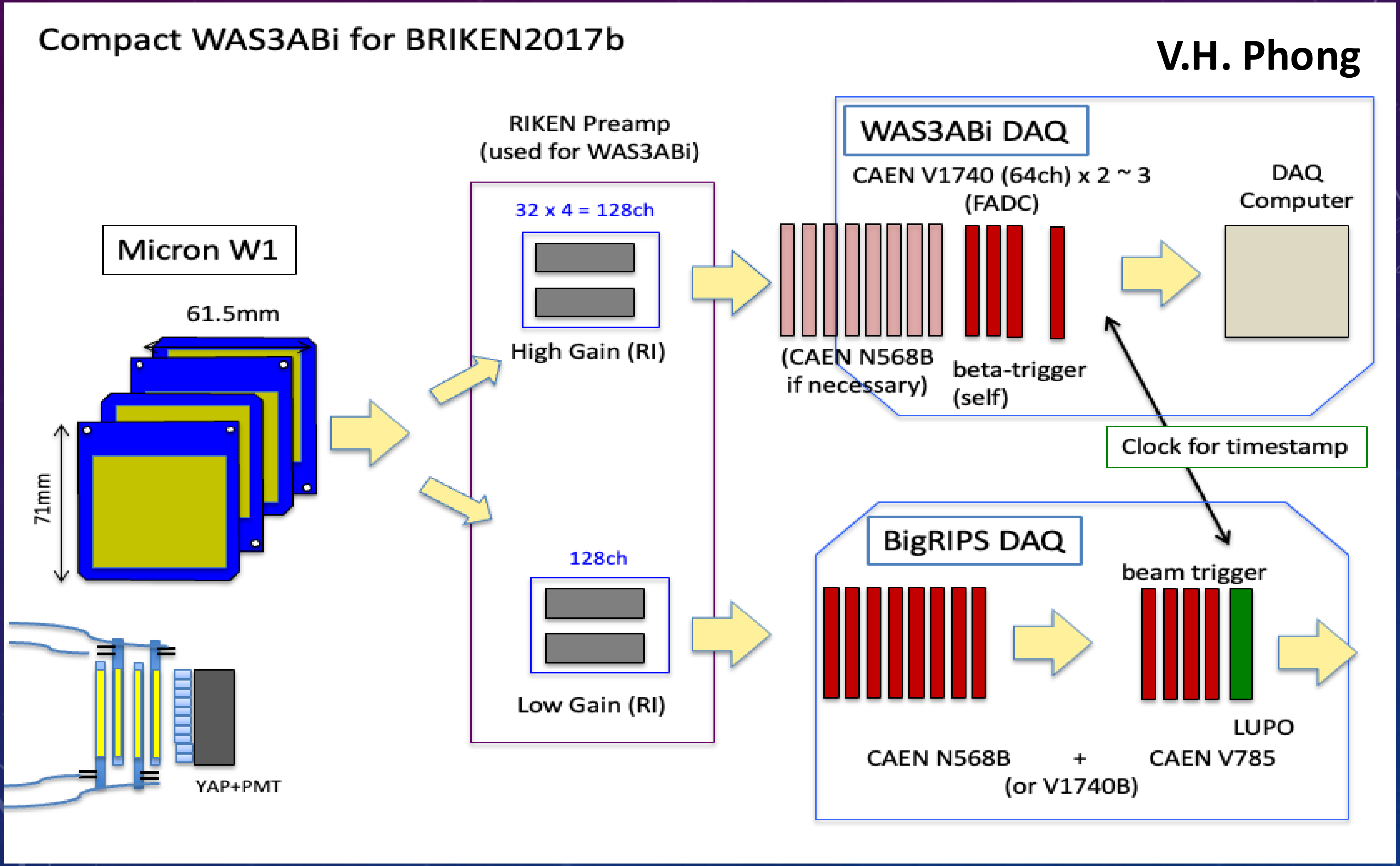






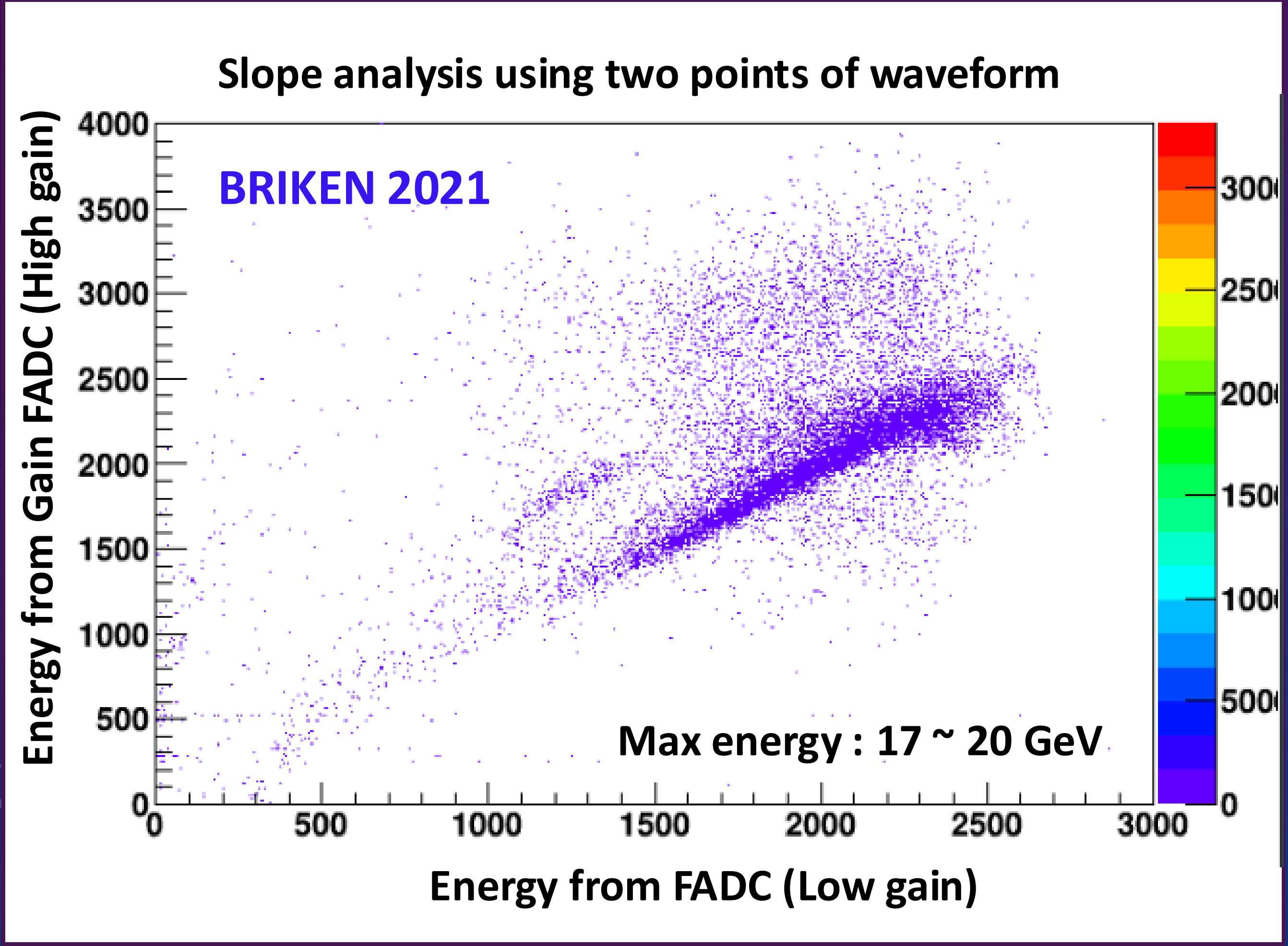
Faster timing for large energy

Upgrade of readout system with Flash ADCs (2017 – Present)

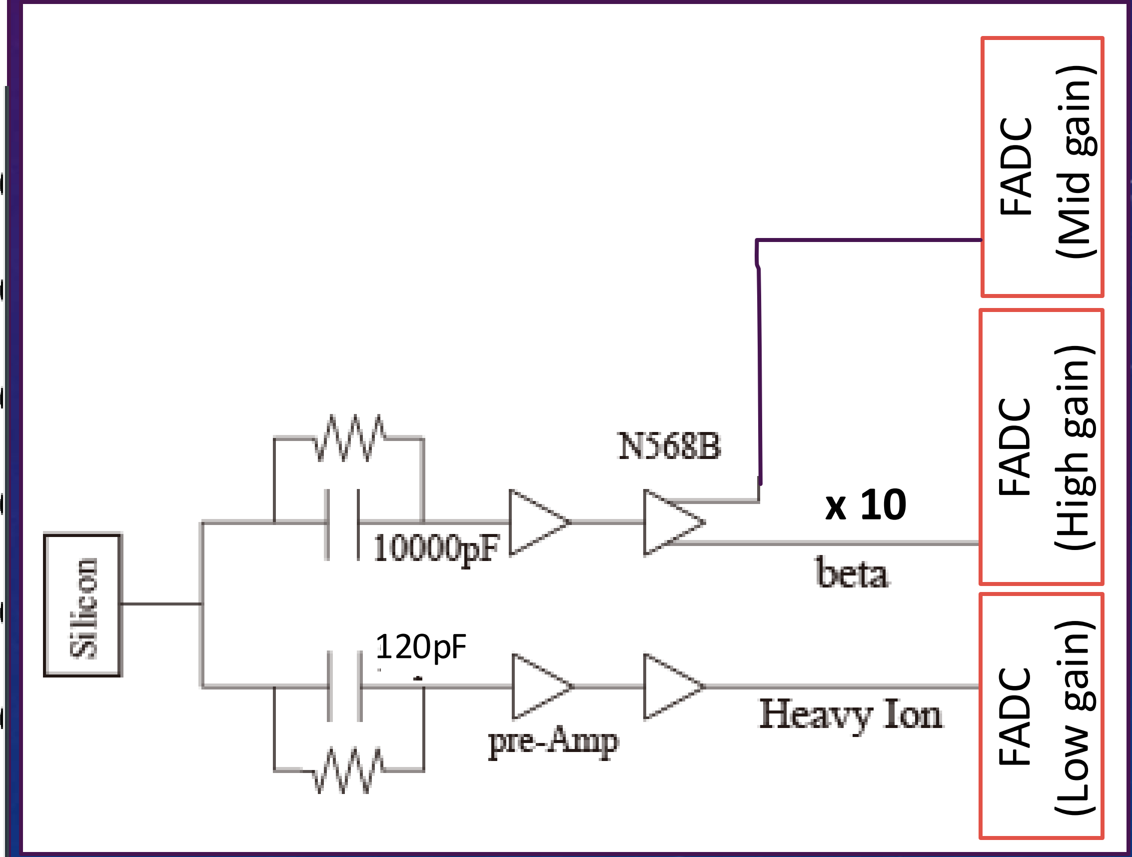


Energy Loss in Beta Counter for Particle Identification

Demonstration: Reconstruction of Implantation Energy using waveform of high-gain beta branch

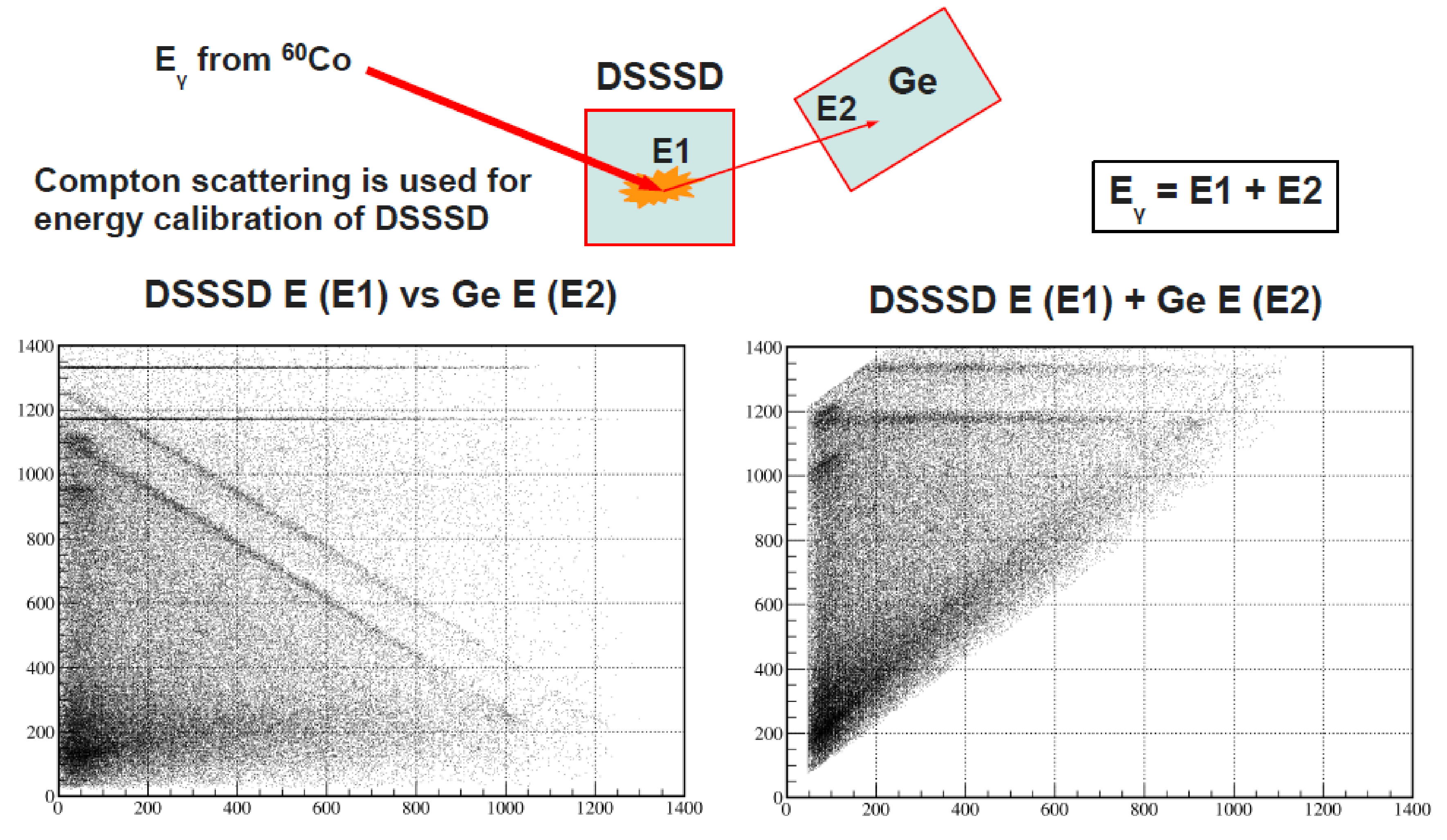


BRIKEN 2021



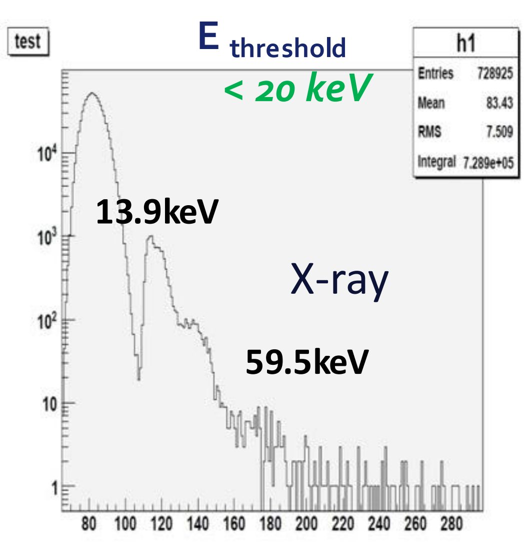
Energy threshold, resolution, and calibration for beta

EURICA



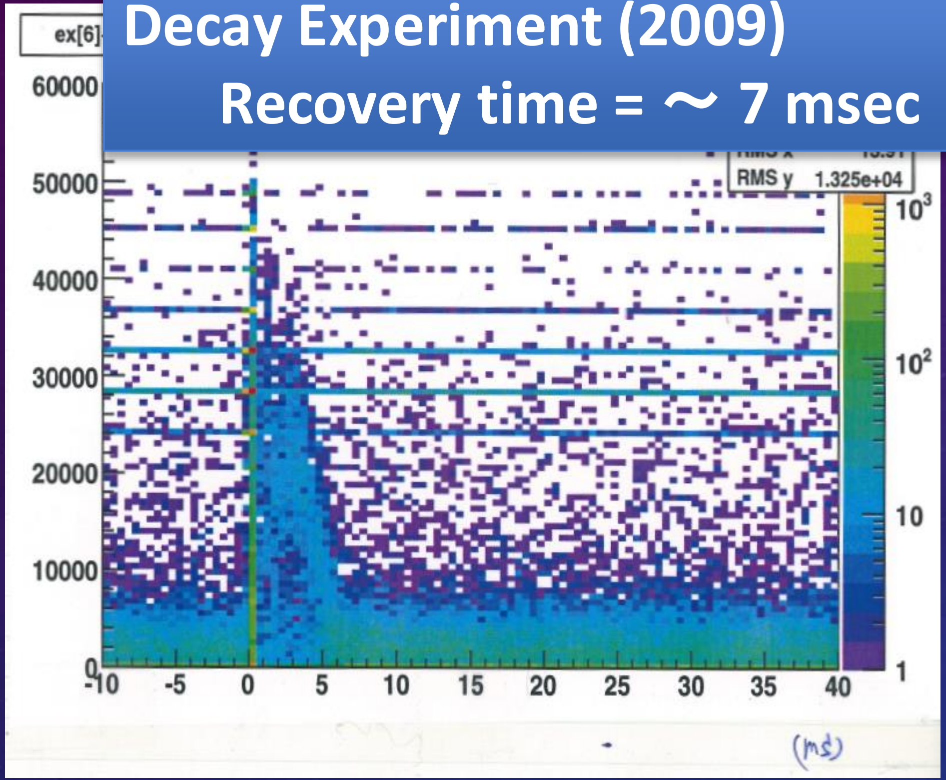
Resolution: average 40 keV around 1 MeV

Bench test



Recovery Time after Implantation

Critical for short-lived isotopes (exotic)



Decay Experiment (2009)
Recovery time = ~ 7 msec

Overflow of shaping amplifier (N568B)

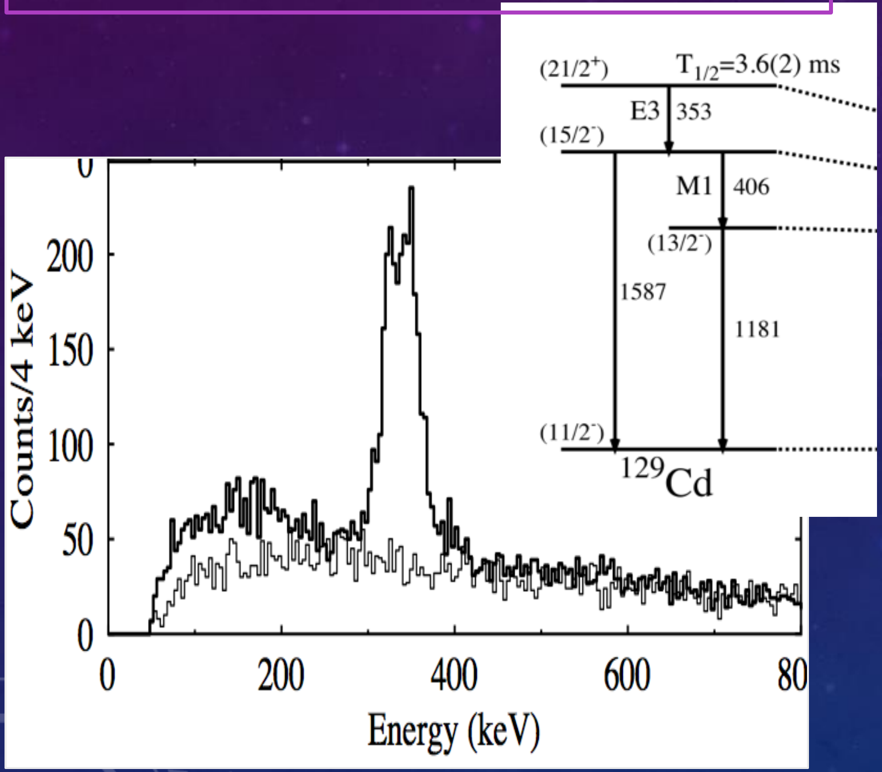
Decay Experiment (2012 – Present)
Recovery time ~ 0.5 msec with small feedback resistance 1 MΩ.

Several options of faster recovery below 0.1 msec (to be tested)
- → pole-zero adjustment
- → Reduction of gain
- → Thinner DSSD (0.6 mm)
- → Mesytec logarithmic amp

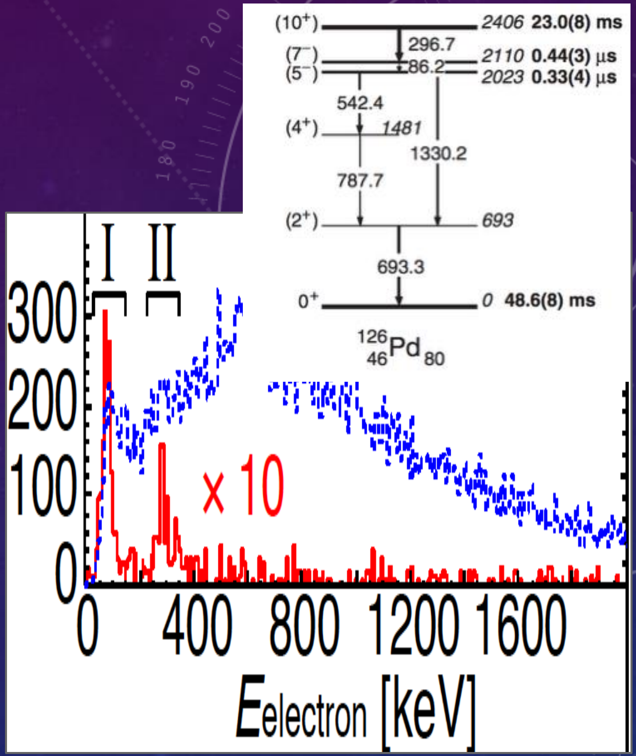
Energy Resolution & Recovery Time

⇒ Identification of Conversion Electrons

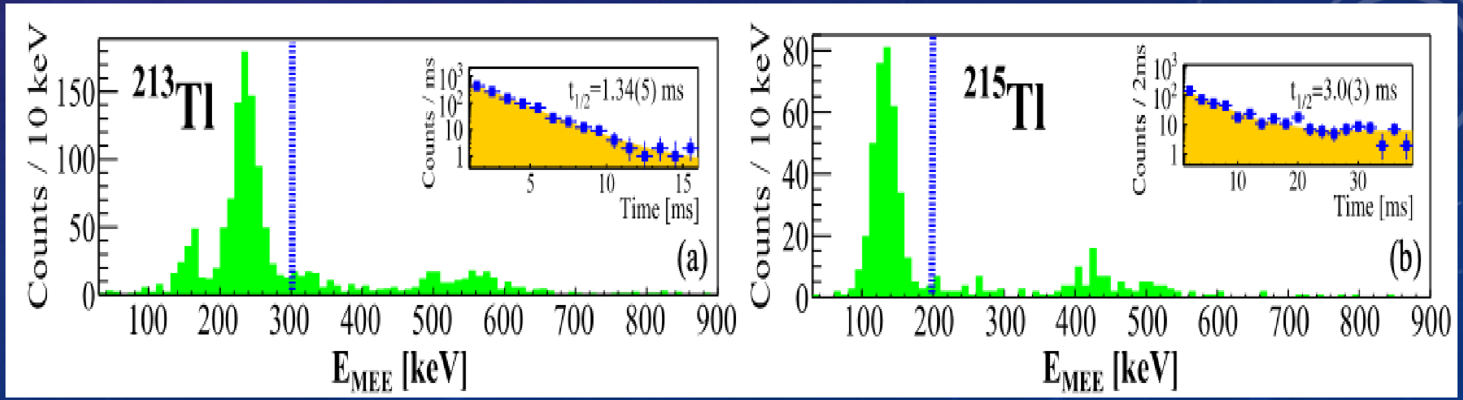
J.Taprogge, A.Jungclaus et al.
Phys. Lett. B 738 (2014) 223.



H.Watanabe et al.
Phys. Rev. Lett. 113
042502 (2014)



T.T. Yeung, A.I. Morales et al.,
PRL 133, 072501 (2024) (BRIKEN 2021)



Energy Threshold

Silicon detector WAS3ABi ... 20 keV ～ 40 keV depend on adjustment

✓ Silicon detector: Micron (BRIKEN, DTAS), Camberra (EURICA)

✓ Trigger after shaping amplifier (shaping time : 0.2 – 3 μsec)

- Not sensitive to high frequency noise
- Slow time response

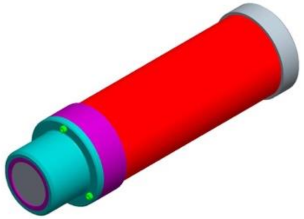
→ Position of RI using timing information

Scintillation detector CAITEN, GARi, MACi ... ～ 20 keV

✓ Scintillator (EJ228, EJ200) & Flat-panel PMT (H8500, H12700A)

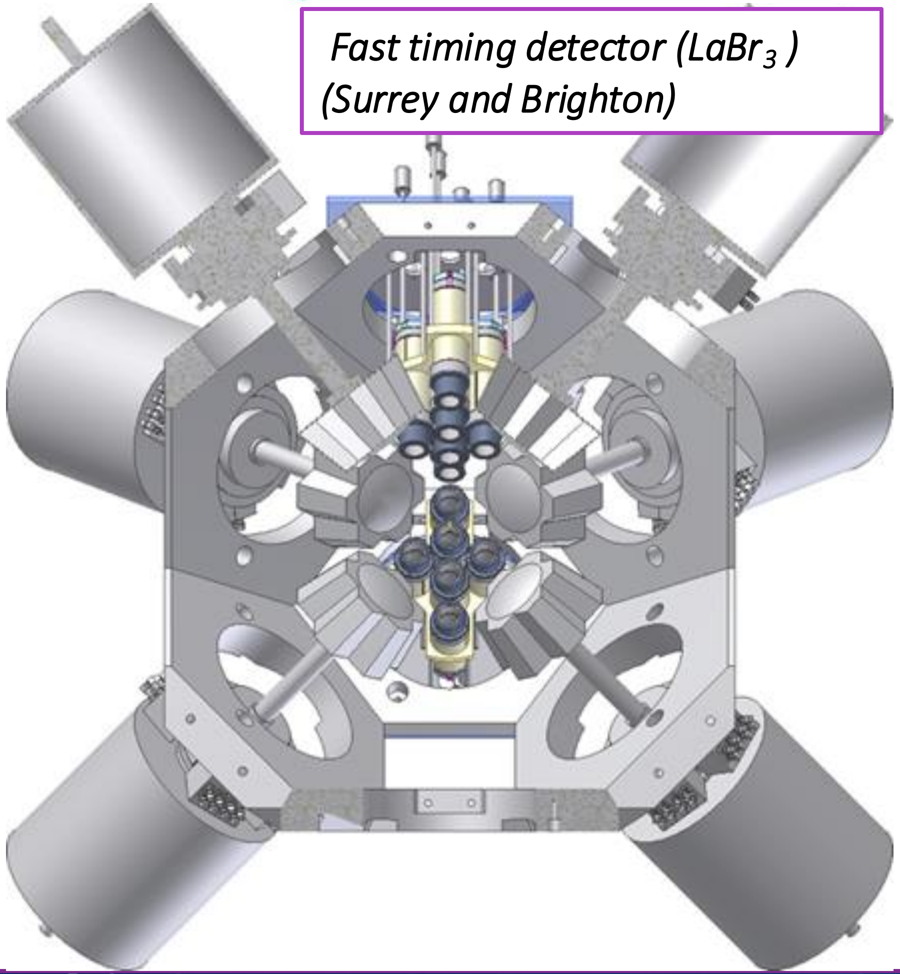
✓ Trigger after fast amplifier of dynode signal

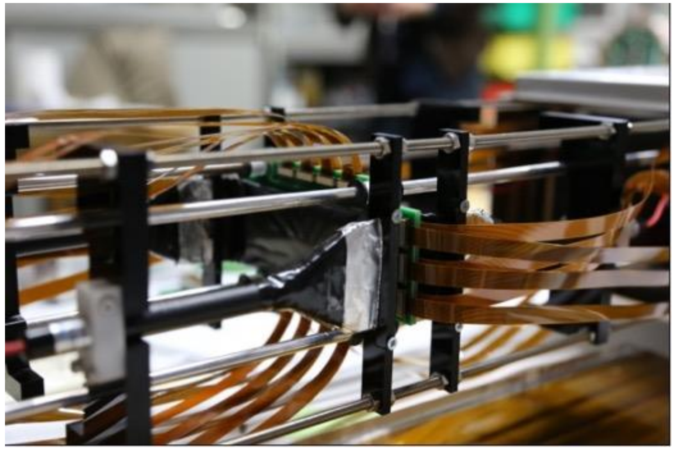
EURICA with LaBr3(Ce) detectors: WAS3ABi + Plastic Scintillators



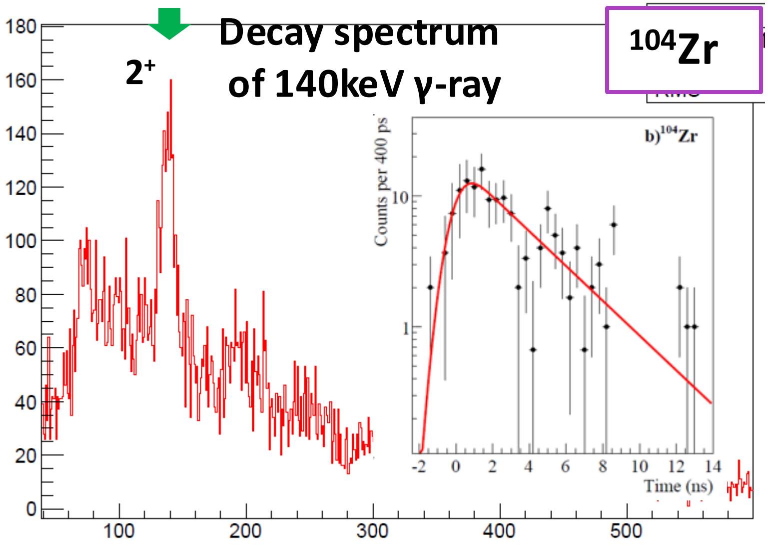
- For short life-times a $LaBr_3$ array for fast timing has been installed to complement the HPGe detectors

Fast timing detector ($LaBr_3$) (Surrey and Brighton)





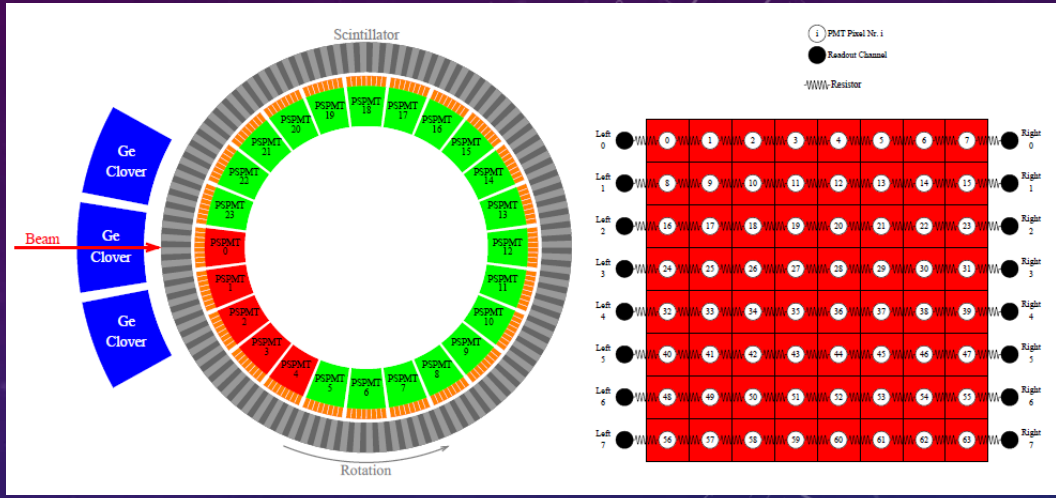
^{104}Y beta-decay is used as start.



F.Browne

Beta Counting System CAITEN

High Rate RI

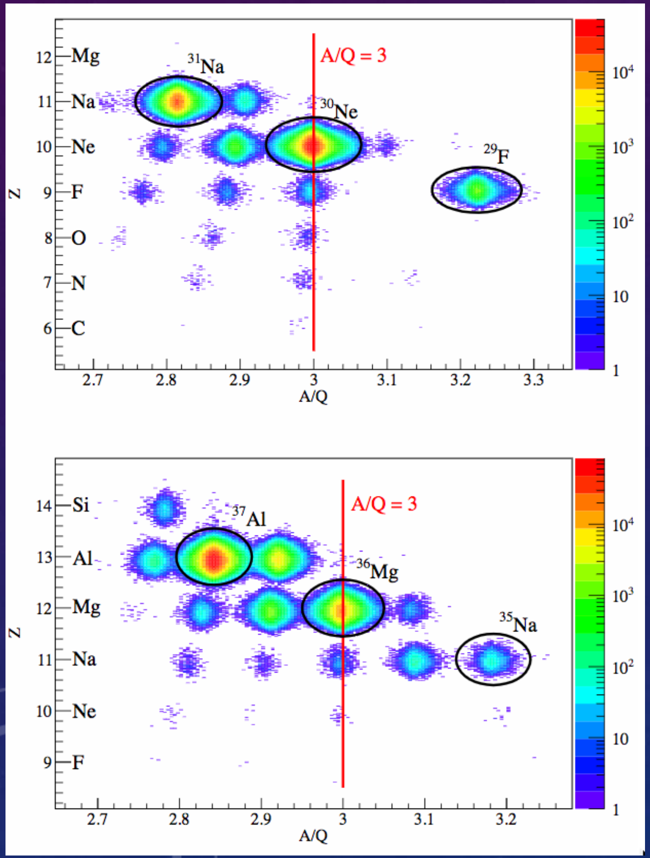


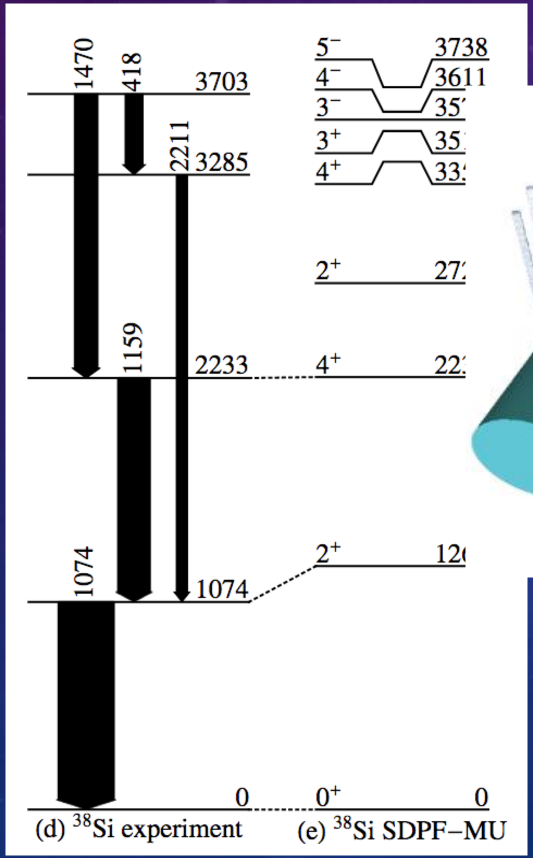
Symbiotic decay experiment with in-beam gamma (2010)

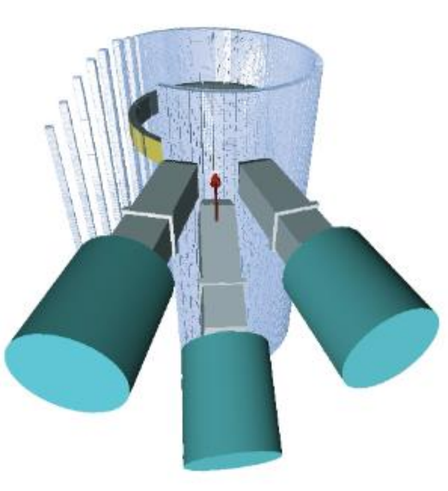
Nuclear structure of $^{37,38}Si$ investigated by decay spectroscopy of $^{37,38}Al$

Eur. Phys. J. A (2015) 51

K. Steiger[1], S. Nishimura[2], Z. Li[2,3], R. Gernhäuser[1,a], Y. Utsuno[4,5], R. Chen[2], T. Faestermann[1], C. Hinke[1], R. Krücken[1,6,7], M. Kurata-Nishimura[2], G. Lorusso[2], Y. Miyashita[8], N. Shimizu[5], K. Sugimoto[8], T. Sumikama[9], H. Watanabe[2,10,11], and K. Yoshinaga[8]







➔ Simplified for Fast Timing Decay Spectroscopy

Simplified Version of CAITEN : No Rotation / Compact

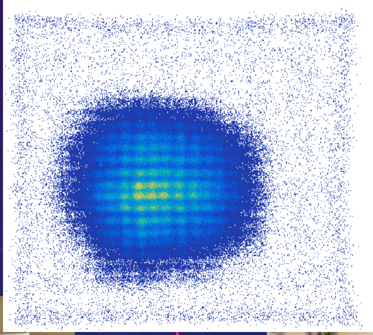
Position Sensitive Beta Counter : GARi 2x3

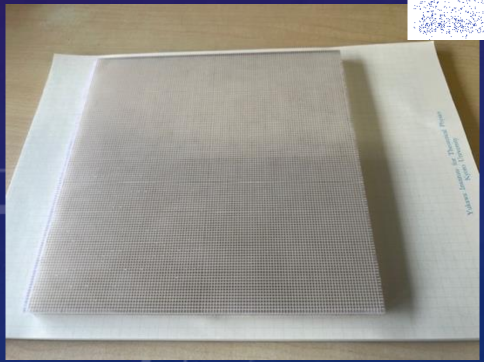
PMT : H12700A x 6

Plastic scintillator : EJ228

100 x 150 mm^2

Pixel size : 1.5x1.5mm^2



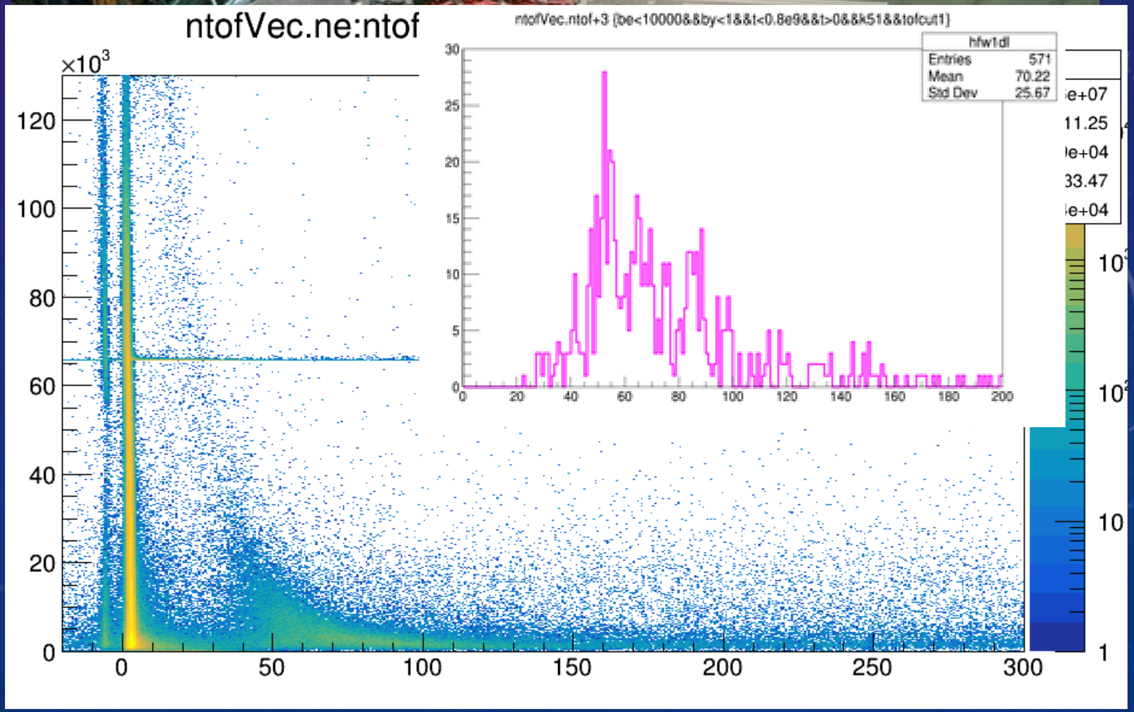


Q. Zeng@IMP

Neutron Time-Of-Fligt Detectors: TOFU

PMT : H11934-200

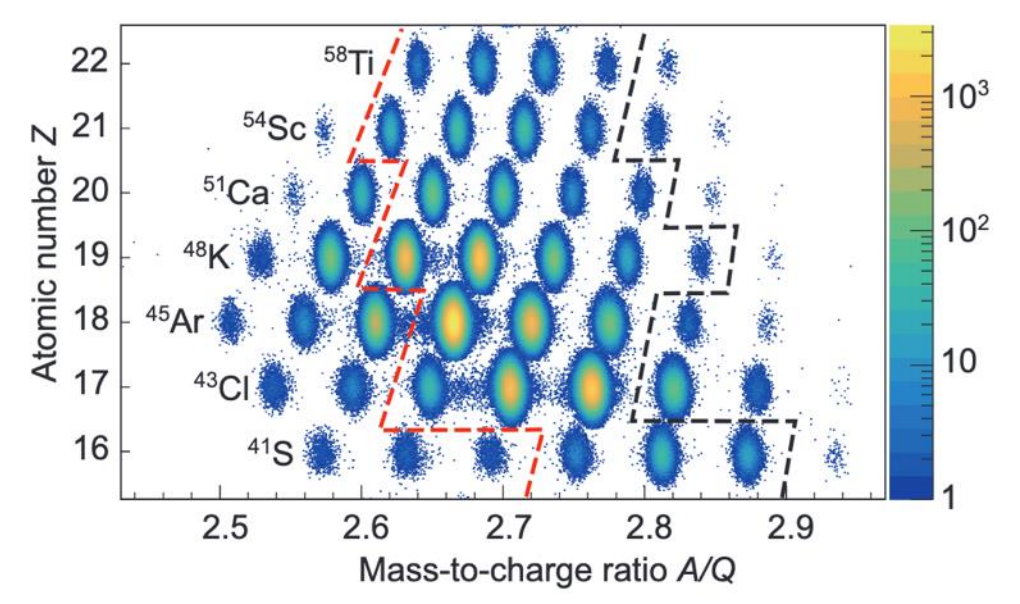
Plastic scintillator : EJ200



Decay & Mass Measurements (2024 -)

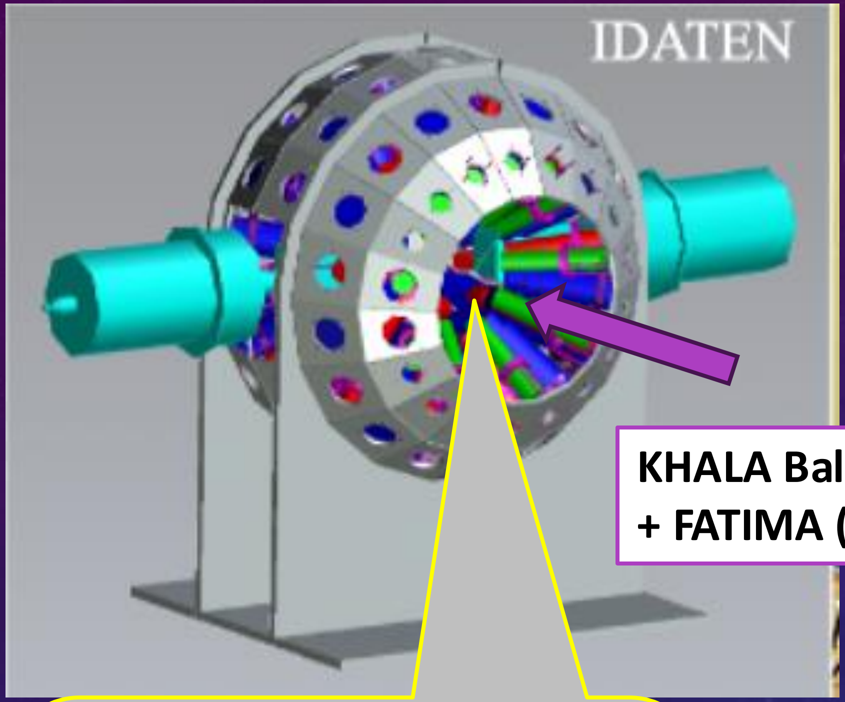
β-decay Half-lives of Neutron-rich Sulfur to Potassium: Evolution of the $N = 32$ and 34 Subshell Closures below Calcium

Q. B. Zeng,[1,2,3,*] S. Nishimura,[3,†] V. H. Phong,[3] S. Yoshida,[3,4] Z. H. Li,[5] Z. Liu,[1,2] H. Y. Wu,[6,5] C. Y. Fu,[7,3] D. S. Hou,[7] H. Ishiyama,[3] Y. Jang,[8] M. Khandelwal,[9] J. Lee,[8] A. I. Morales,[10,3] T. Niwase,[11] M. Rosenbusch,[3] P. Schury,[12] A. Takamine,[11] M. Wada,[12] W. D. Xian,[7,13] T. T. Yeung,[14,3] A. Estrade,[15] N. Fukuda,[3] L. Guo,[16]



Submitted to PRL

Simplified Version of CAITEN : No Rotation / Compact



KHALA Ball (Korea)
+ FATIMA (UK)

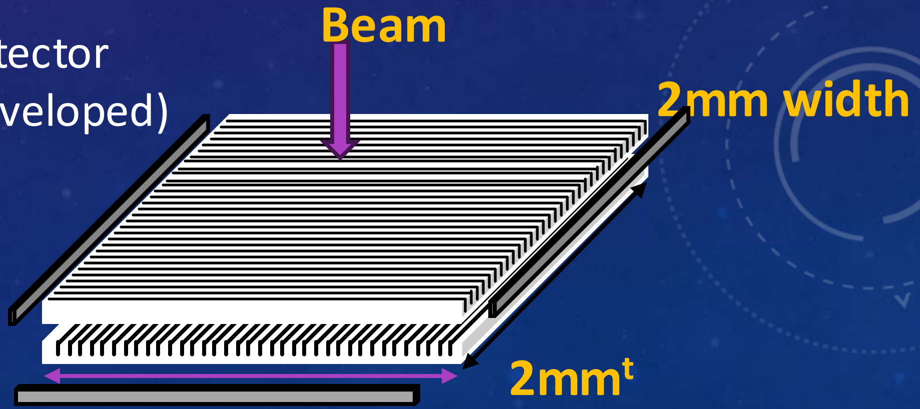
Absorption of
gamma-rays in the PMTs..

PMTs & Charge-divider used for CAITEN (H8500B)

Passive stopper

KHALA Ball (Korea)
+ LBC/LaBr3 (RIKEN)

MACi Detector
(to be developed)



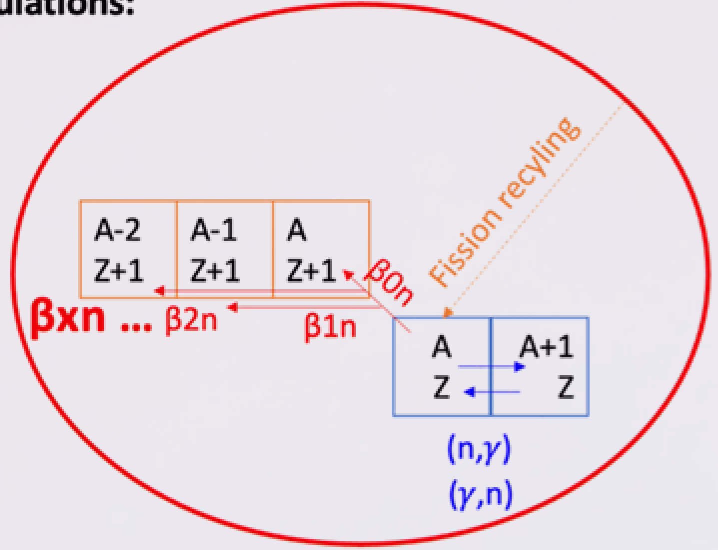
Decay & Mass

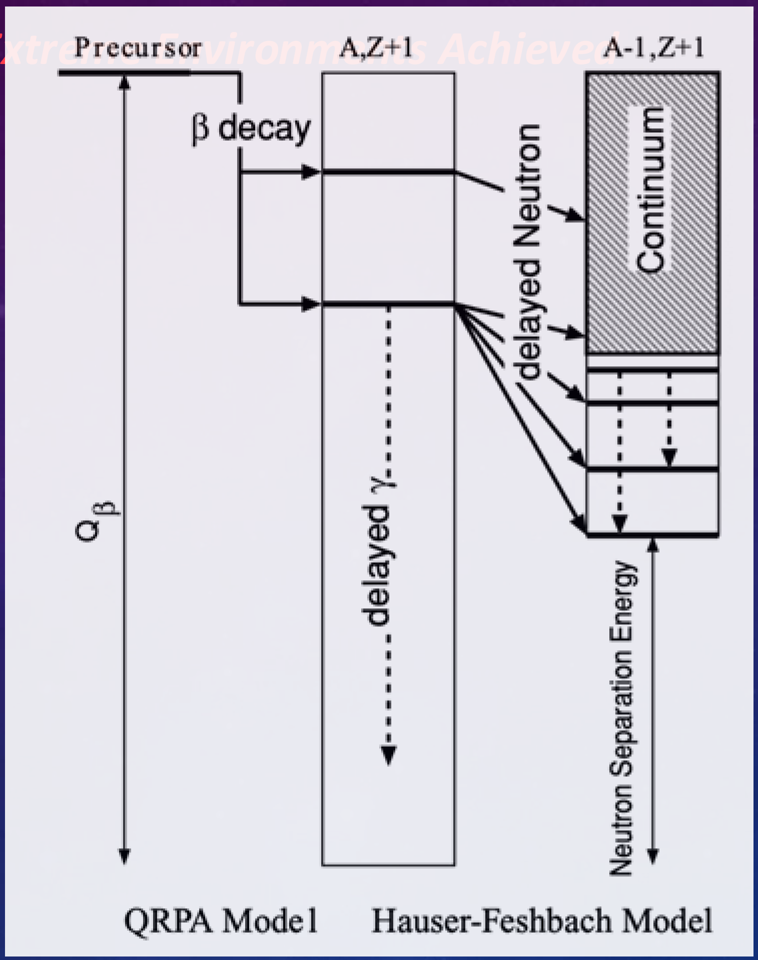
Maximizing Beam Time

Required Nuclear Data for Nucleosynthesis (r-Process)

T. Kawano et al. PRC 78, 054601

Reaction rates for modern dynamical r-process calculations:





Several Thousands of RI to be measured..

◎ **Masses:**
- **Determine the r-process path, global structure**

◎ **Beta-decays:**

Half-lives:
- **Speed of producing heavy elements**

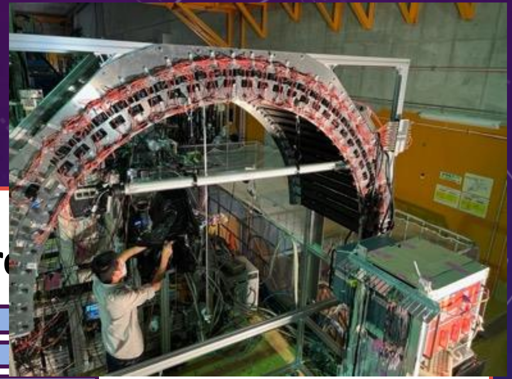
Beta-delayed neutron emissions:
- **Determine the fine structure of r-elements**
- **Recapture of neutrons**

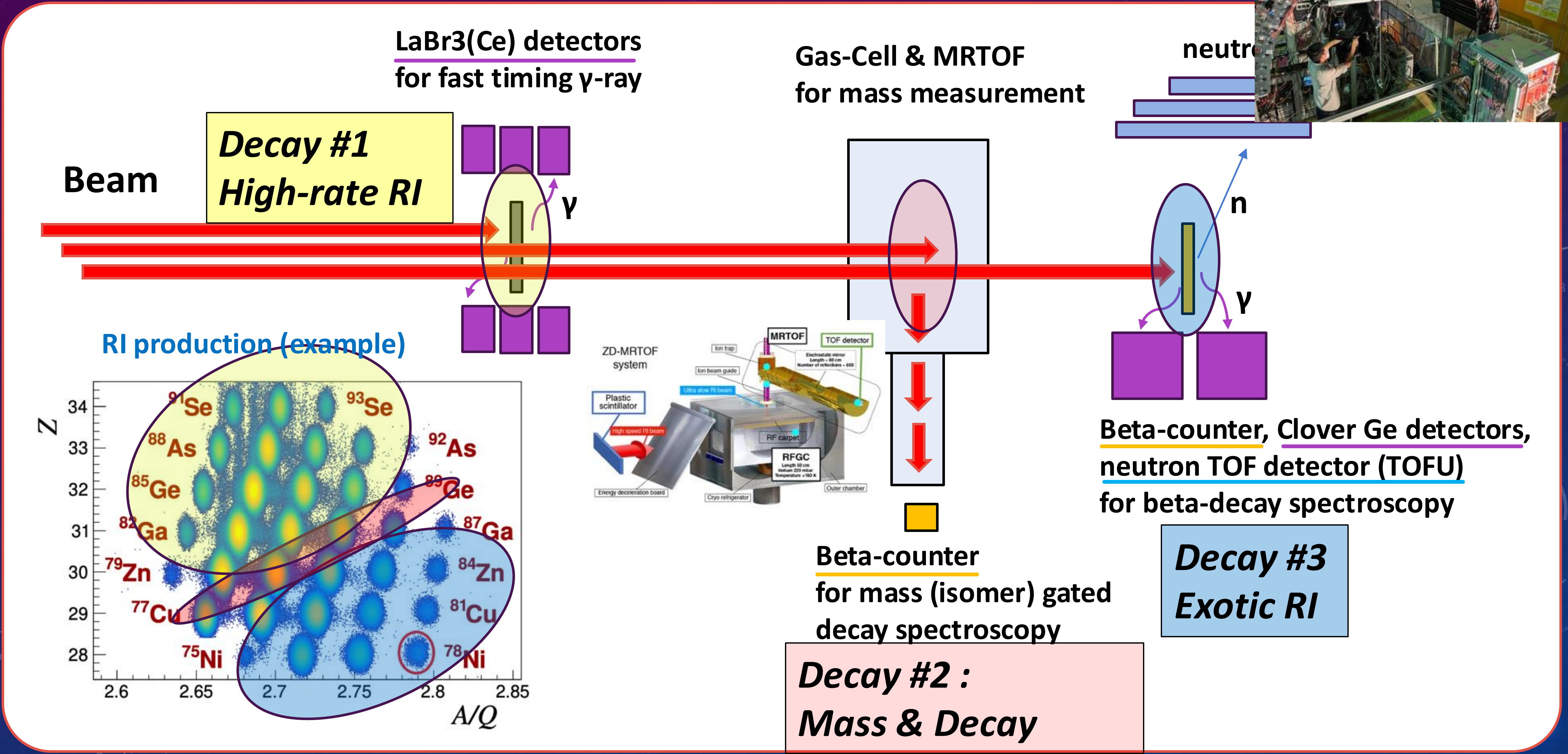
◎ **Nuclear reactions ←→ Masses**
- **Determine the r-process path**

◎**Fission recycling:**
- **Production of heavy elements**

◎**Equation of State:**
- **Explosive conditions of NS-NS, SN**

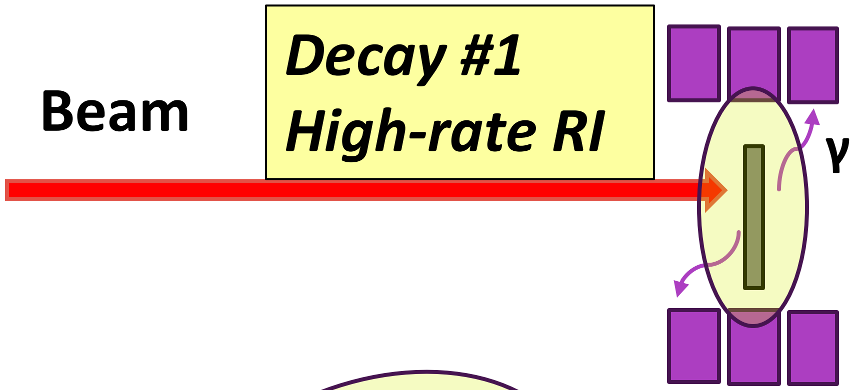
Project III: Mass & Decay Spectroscopy

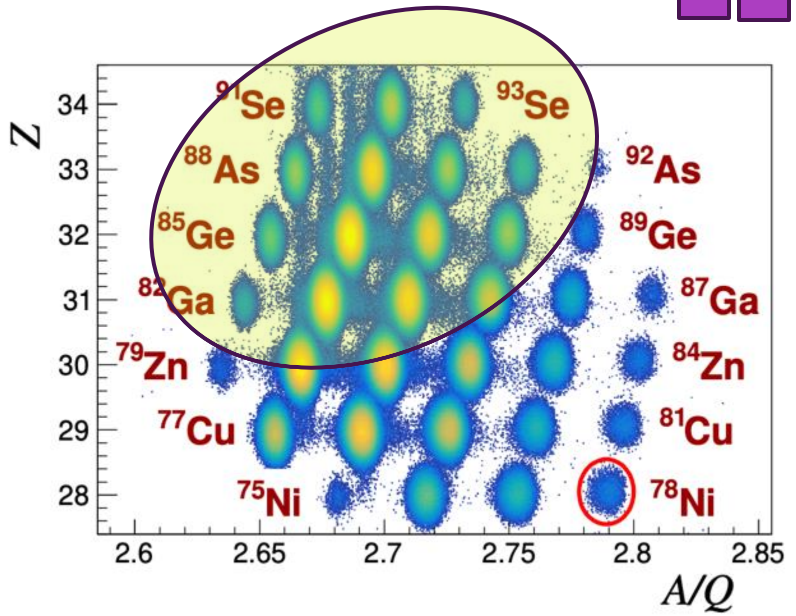




Project III: Mass & Decay Spectroscopy: Decay #1

LaBr3(Ce) detectors
for fast timing γ-ray

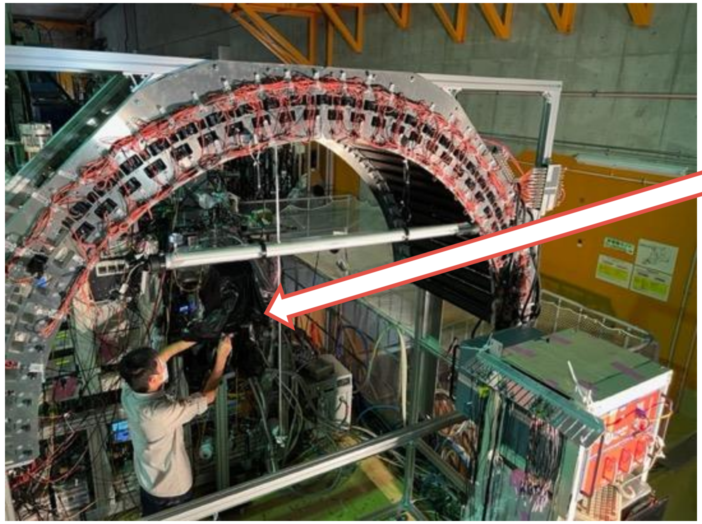


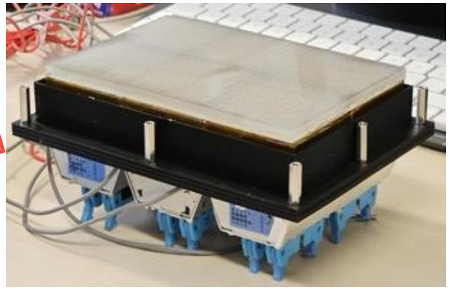


Testing KHALA
DAQ (2024 Dec.)

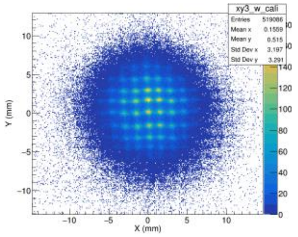
LaBr3(Ce) detectors
Peking Group
(2025 May, June)

Project III: Mass & Decay Spectroscopy: Decay #3

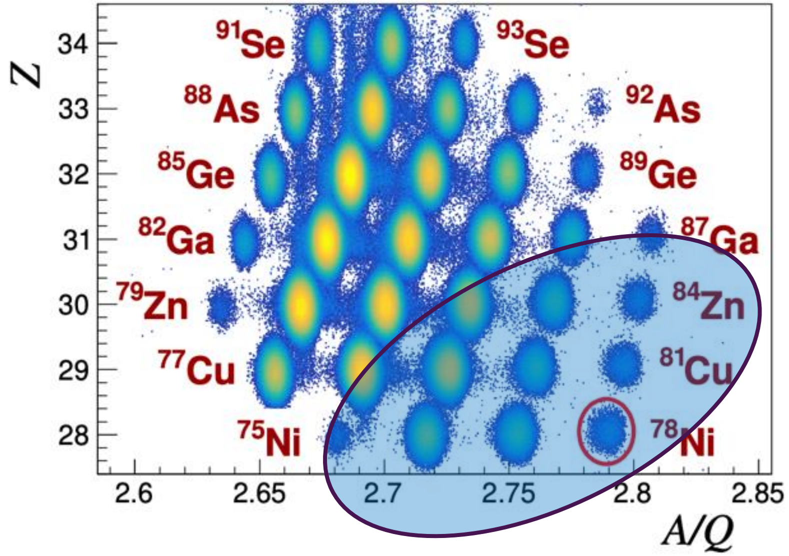


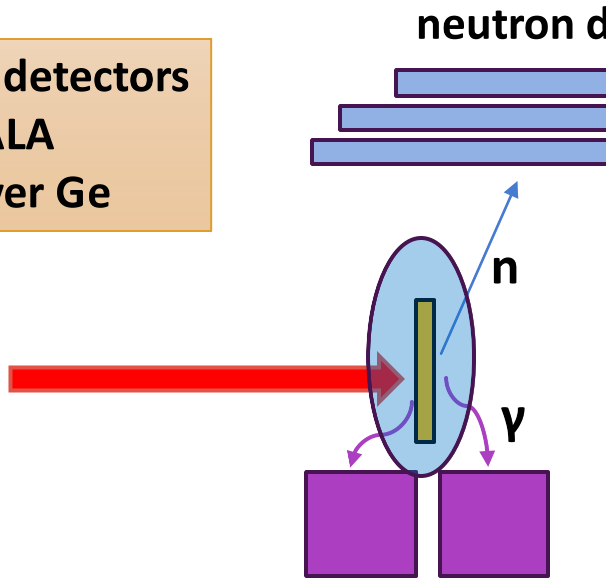


Beta hit pattern (^{90}Sr source)



γ-ray detectors
- KHALA
- Clover Ge





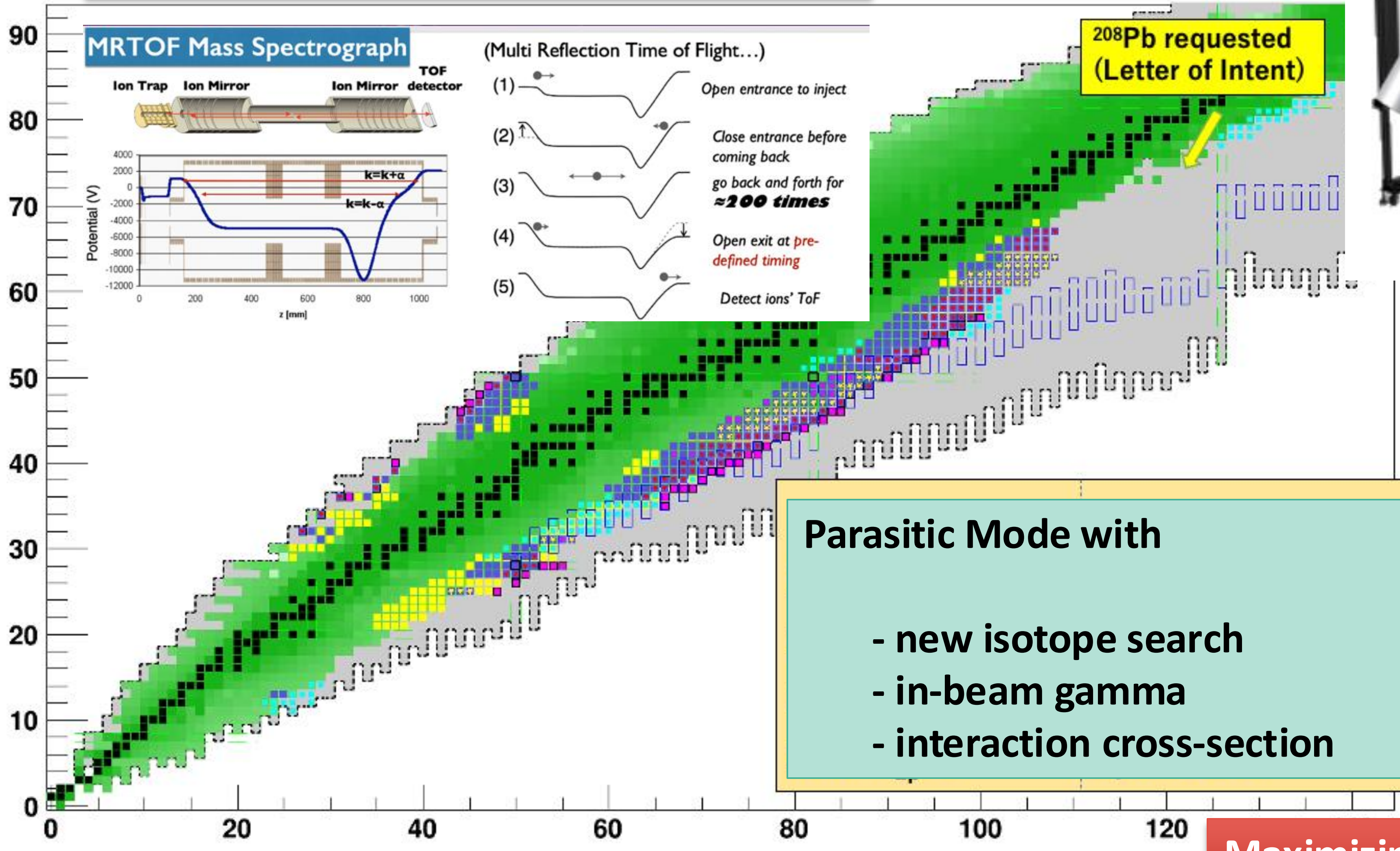
Beta-counter, Clover Ge detectors, neutron TOF detector (TOFU) for beta-decay spectroscopy

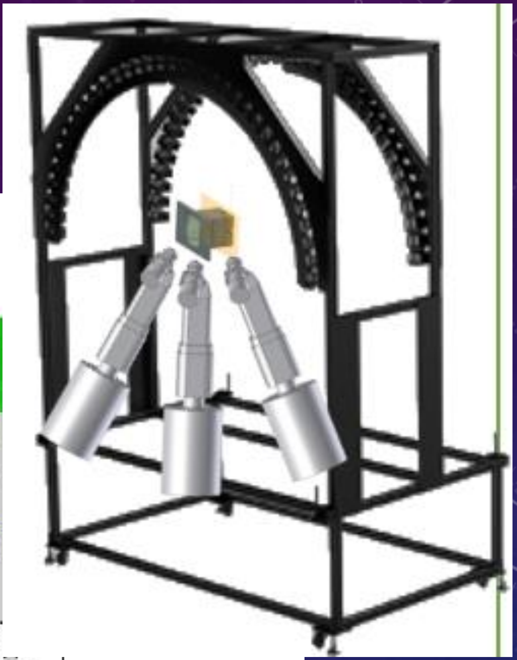
Decay #3
Exotic RI

Clover Gdetectors
Peking Group

Project III: Mass & Decay Spectroscopy

Mass & Decay Measurements (Approved)



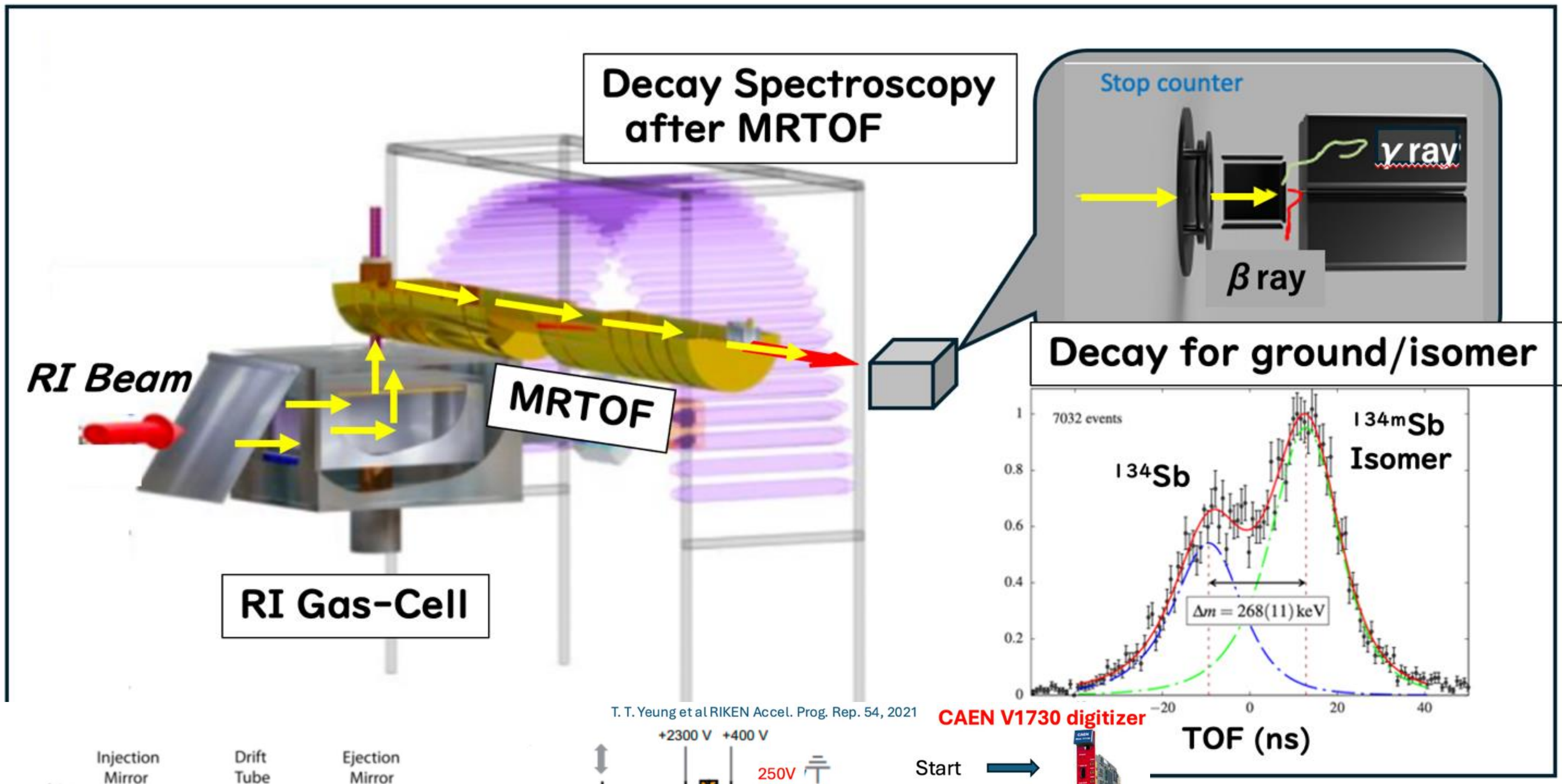


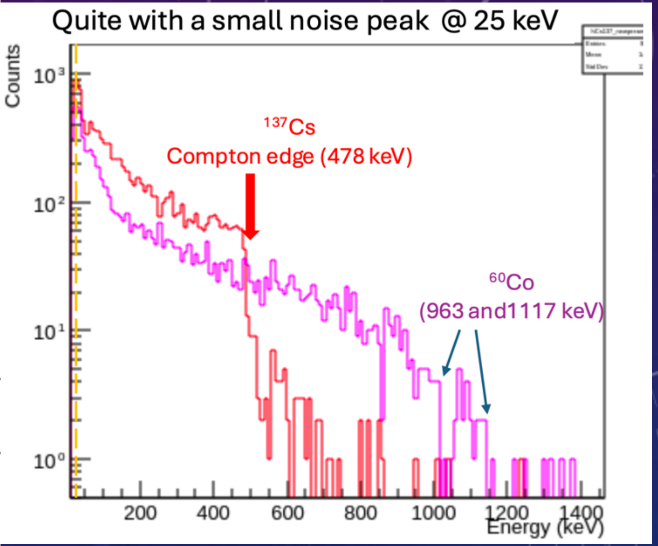
Parasitic Mode with

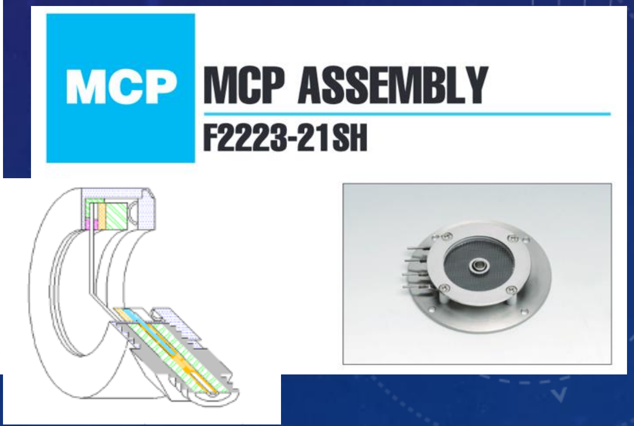
- new isotope search
- in-beam gamma
- interaction cross-section

Maximizing the Physics Outputs

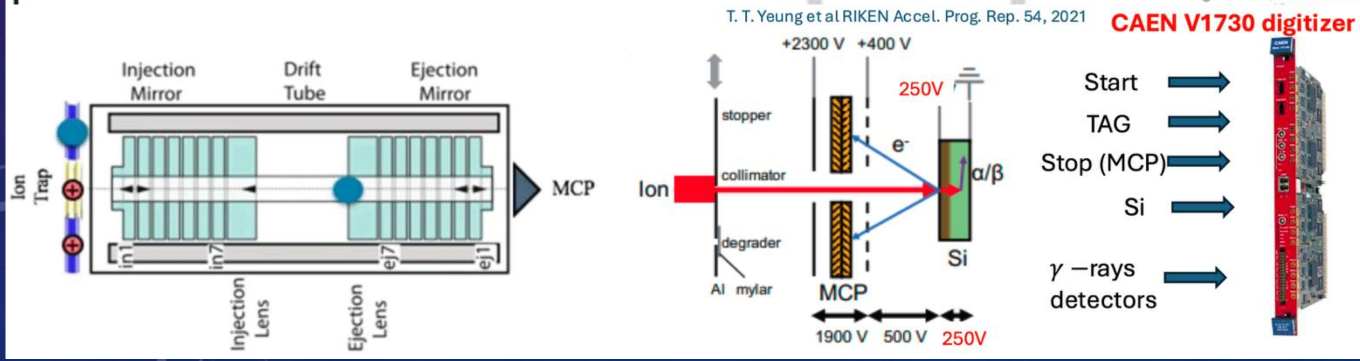
Tagged Isomer: Decay Spectroscopy







Camberra
PIPS

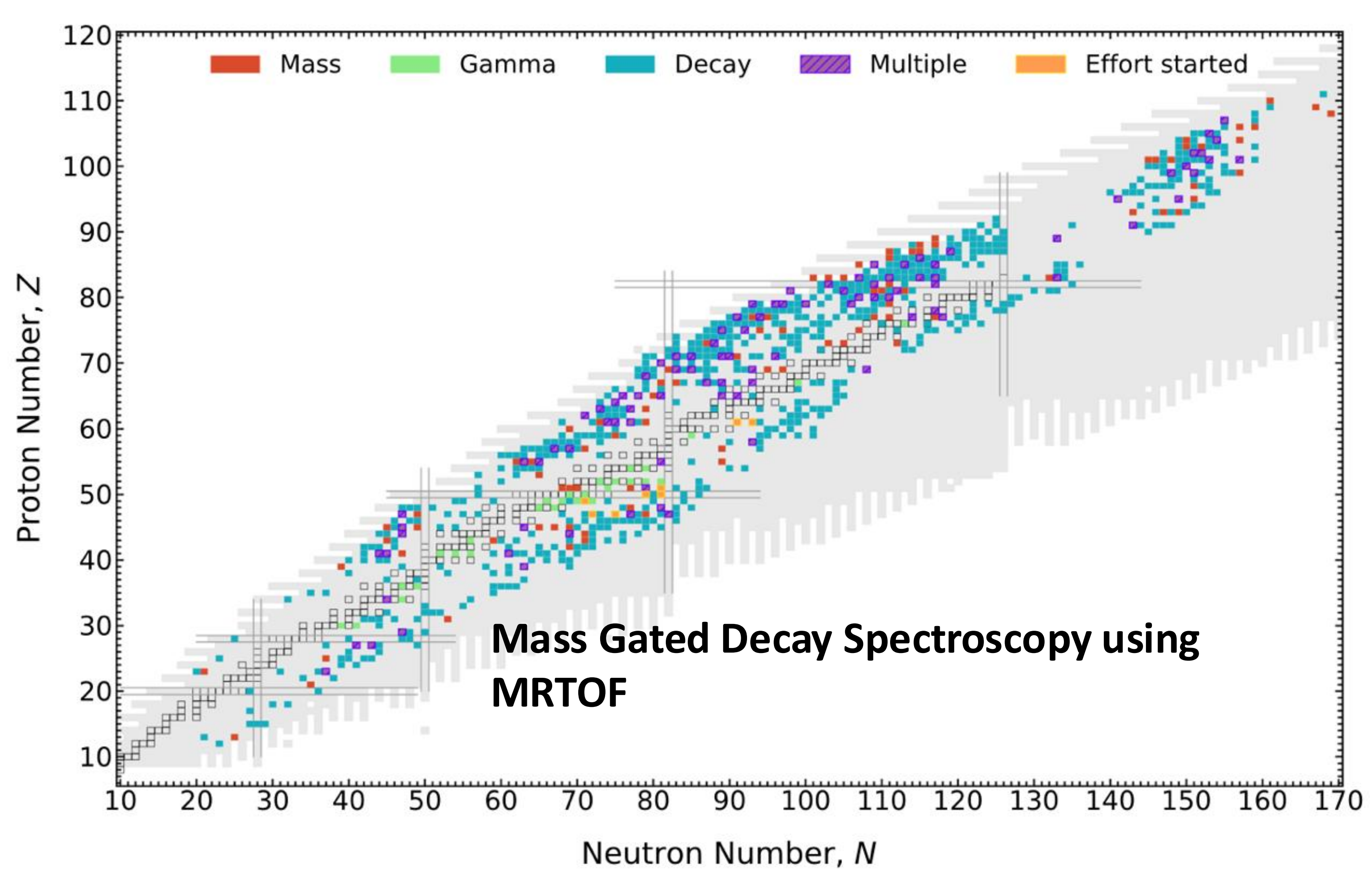


Role of Isomers in Nucleosynthesis

Astromers: status and prospects

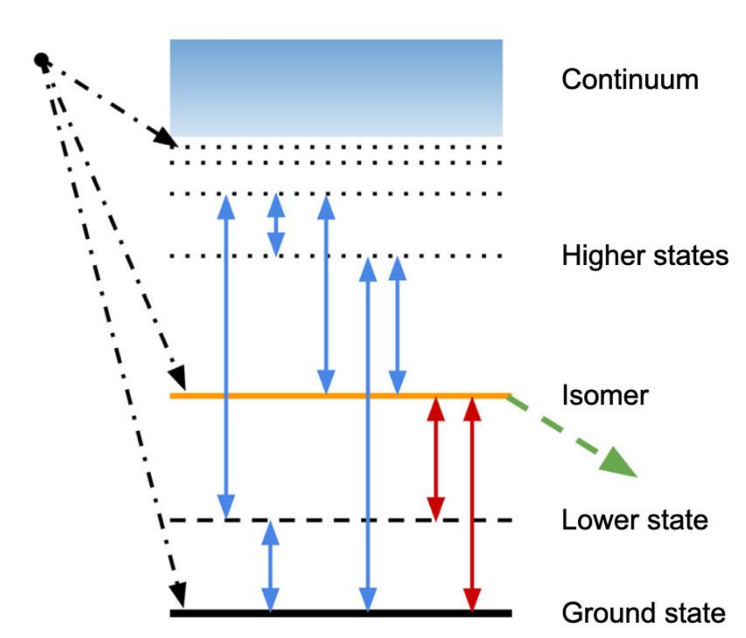
G. Wendell Misch[1,3,a] and Matthew R. Mumpower[2,3,b]

Eur. Phys. J. Spec. Top. (2024) 233:1075–1099
https://doi.org/10.1140/epjs/s11734-024-01136-z



Mass Gated Decay Spectroscopy using MRTOF

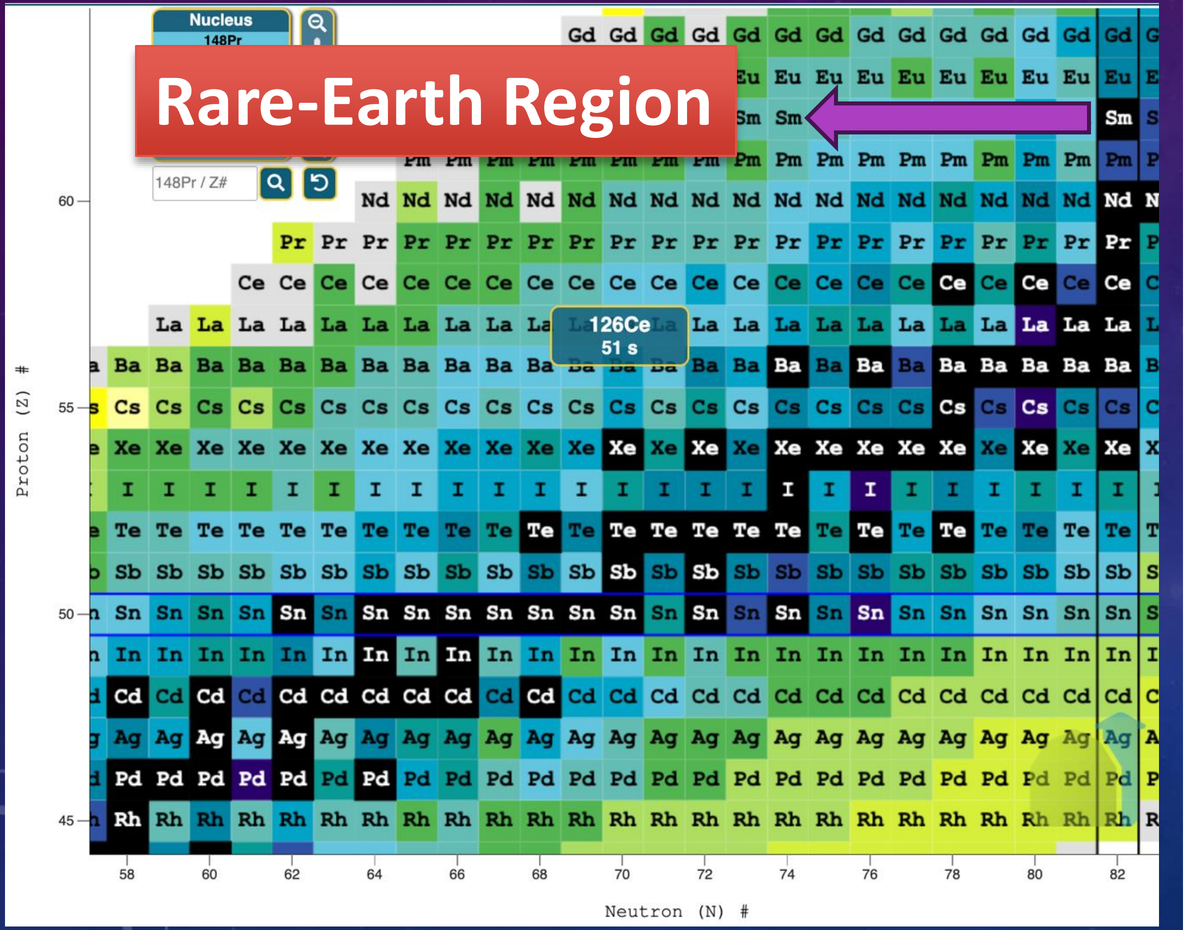
Fig. 5 Unknown nuclear data contribute to uncertainties in astromer behavior. Incomplete data include level energies (mass), transition rates (gamma), and branching ratios (decay). The light gray shading indicates the possible extent of bound nuclei. See text for details

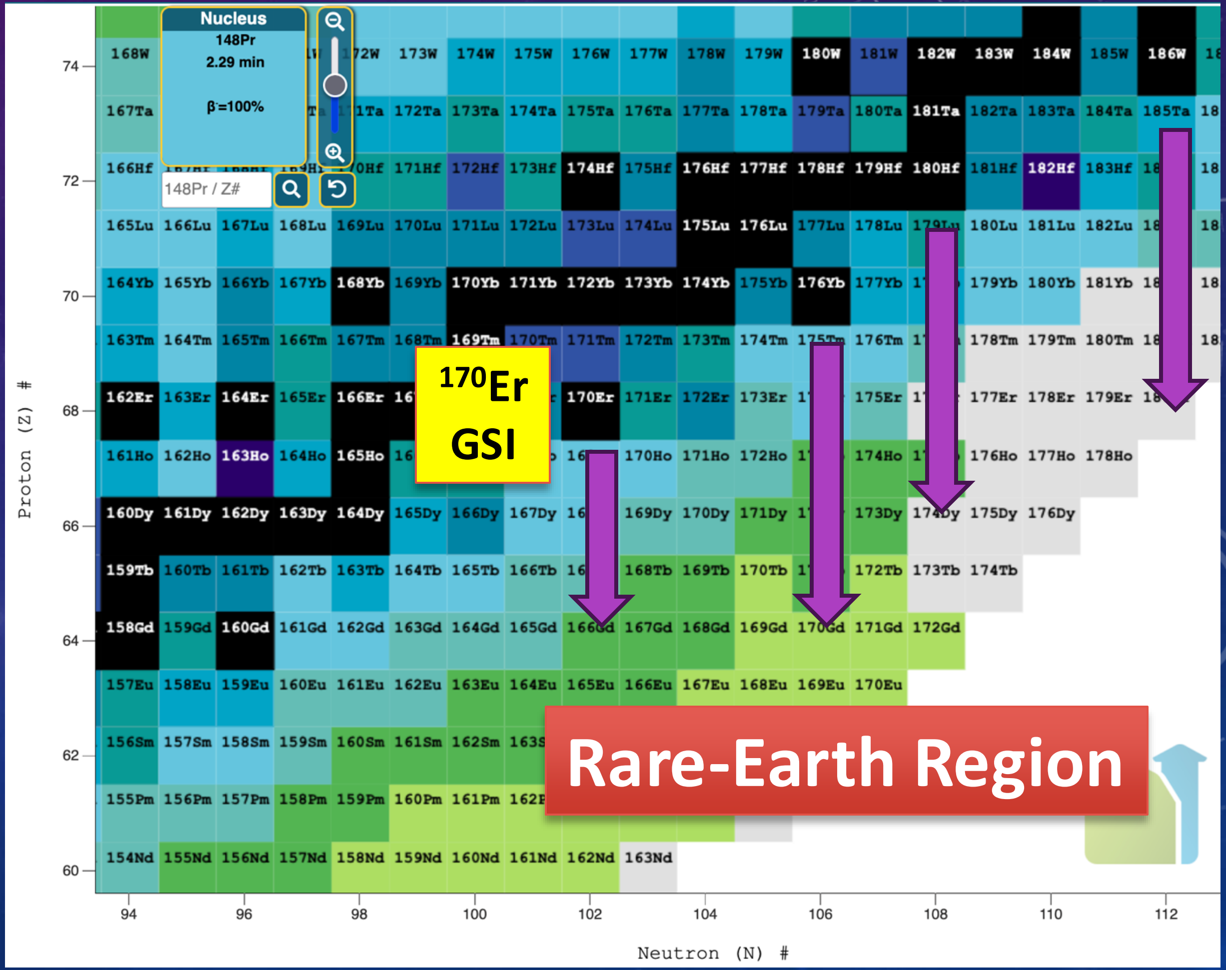


Possible Experiments at HIAF

- Beam Production with different primary beam
- Detectors for low energy reactions, fission
- High Density Nuclear Matter

Beam Production with Different Primary Beam





Required Nuclear Data for Nucleosynthesis (r-Process)

◎ Masses:
- Determine the r-process path, global structure

◎ Beta-decays:
Half-lives:
- Speed of producing heavy elements

Beta-delayed neutron emissions:
- Determine the fine structure of r-elements
- Recapture of neutrons

◎ Nuclear reactions ←→ Masses
- Determine the r-process path

◎Fission recycling:
- Production of heavy elements

◎Equation of State:
- Explosive conditions of NS-NS, SNz

Signatures of Quark-Hadron Phase Transition in Neutron-Star Mergers

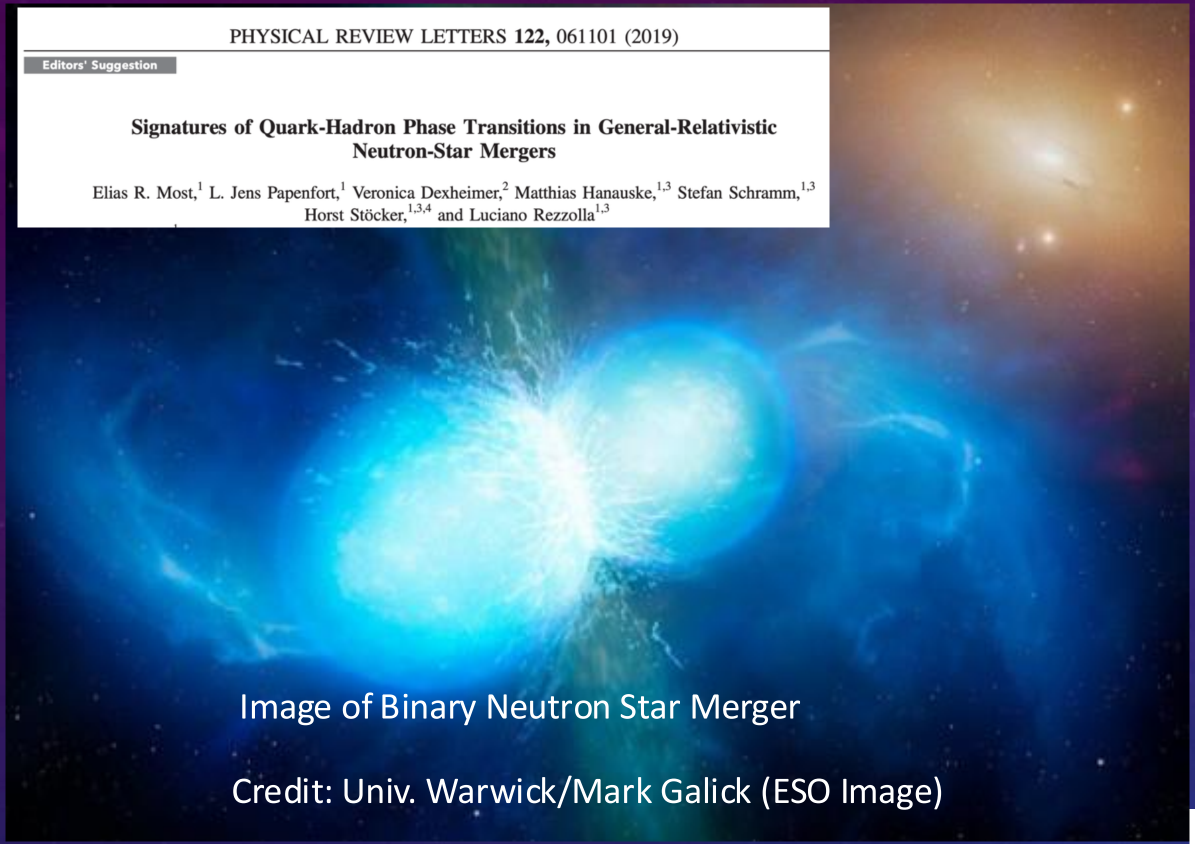
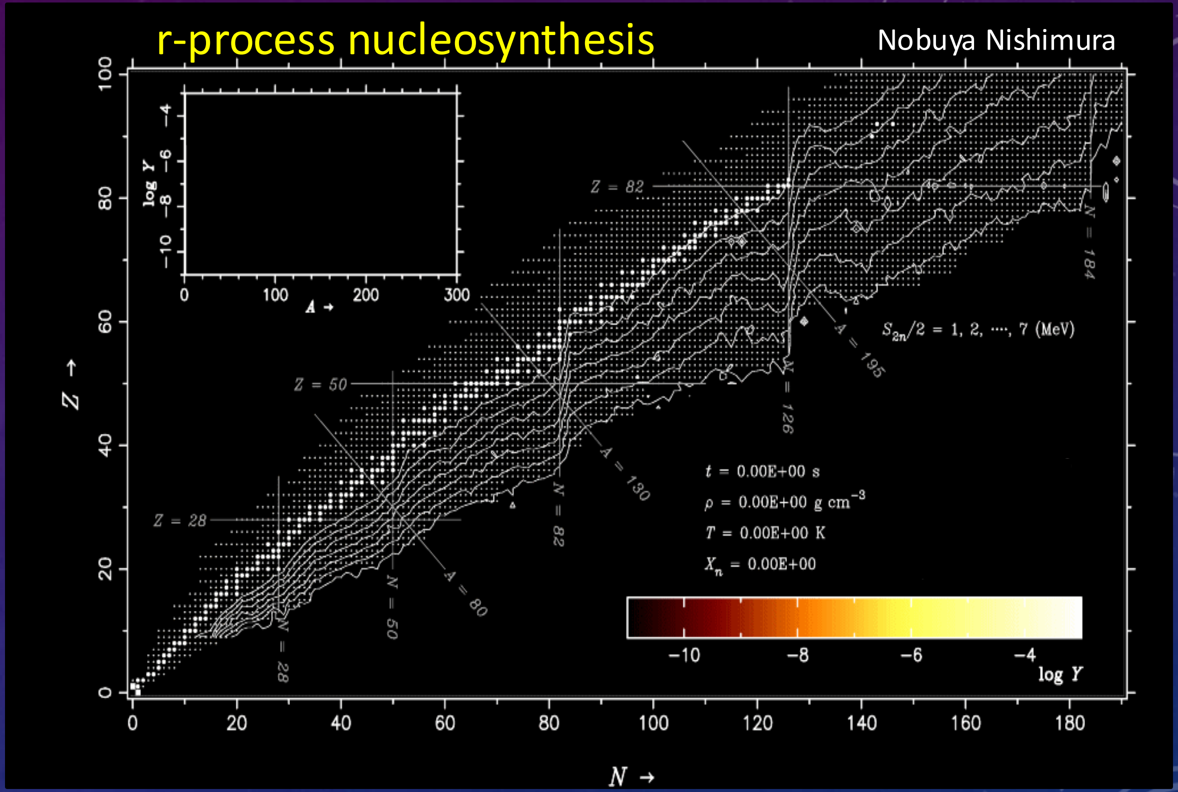
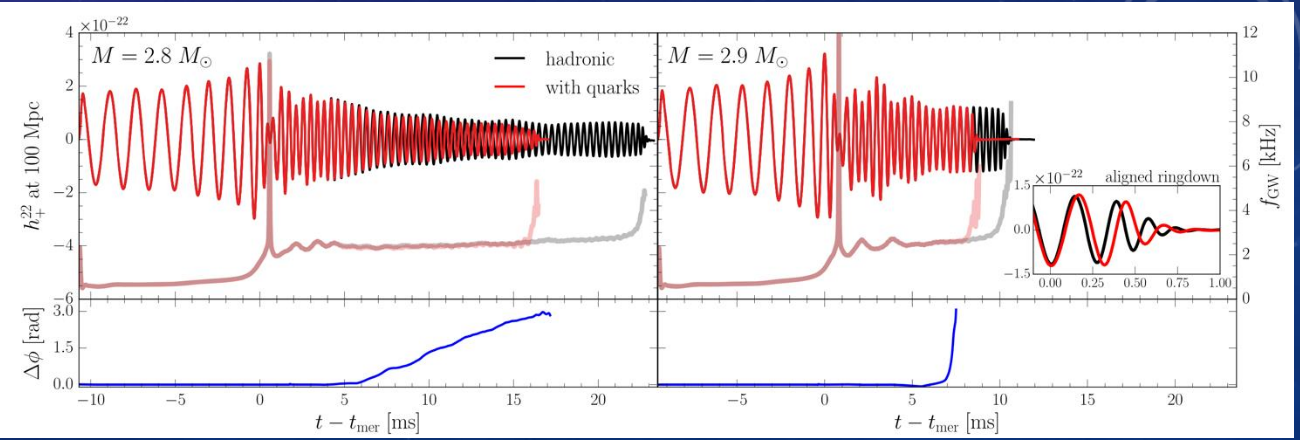


Image of Binary Neutron Star Merger

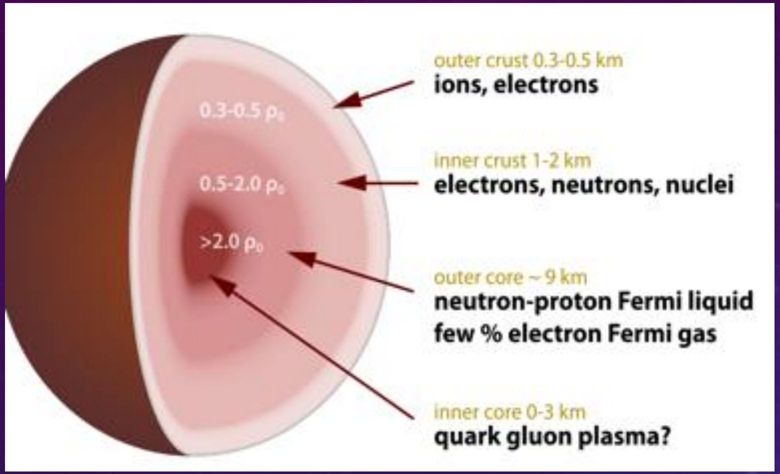
Credit: Univ. Warwick/Mark Galick (ESO Image)

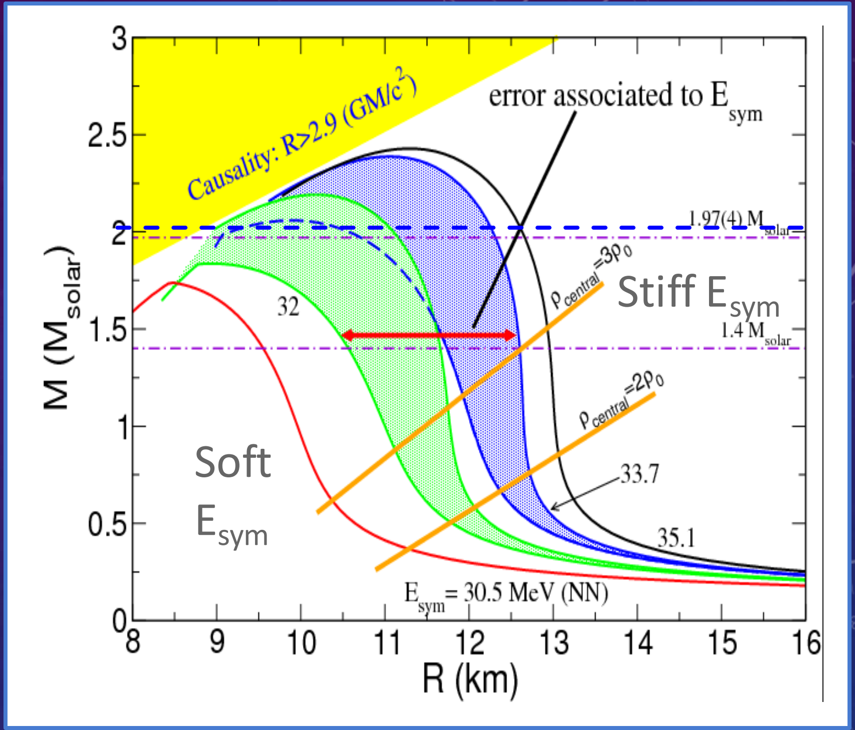




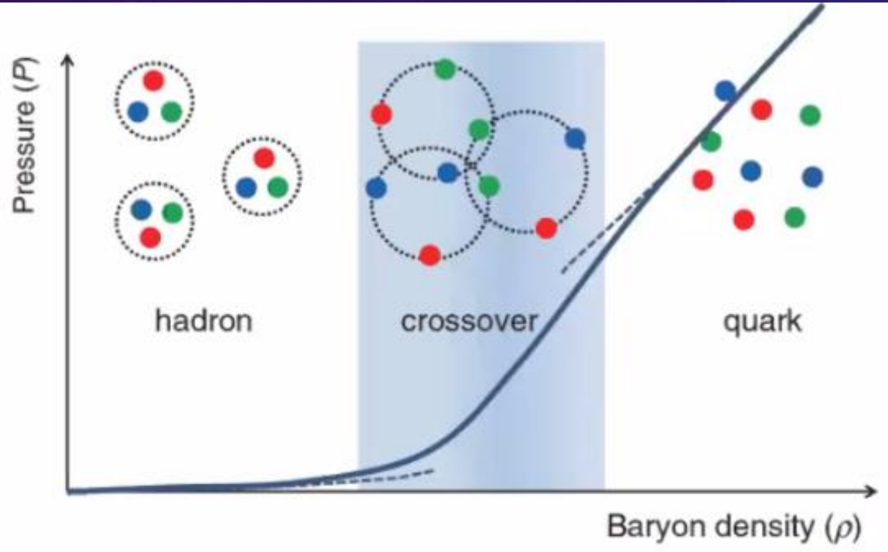
- ○ **EOS, Compressibility**
  → **Supernovae, Neutron-star merger**
- ○ **r-process nucleosynthesis**

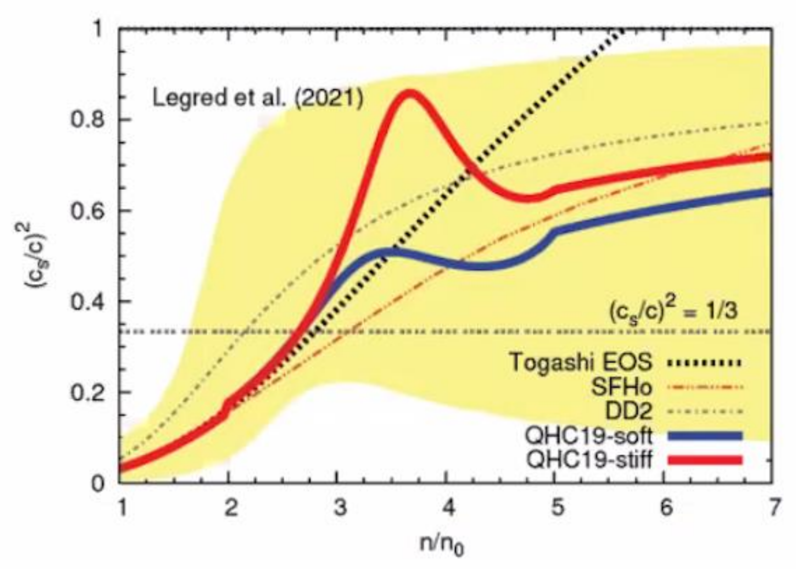
Neutron Star : M vs R





T. Kojo, G. Baym, and T. Hatsuda, Astrophys. Jour 934, 46（2022）





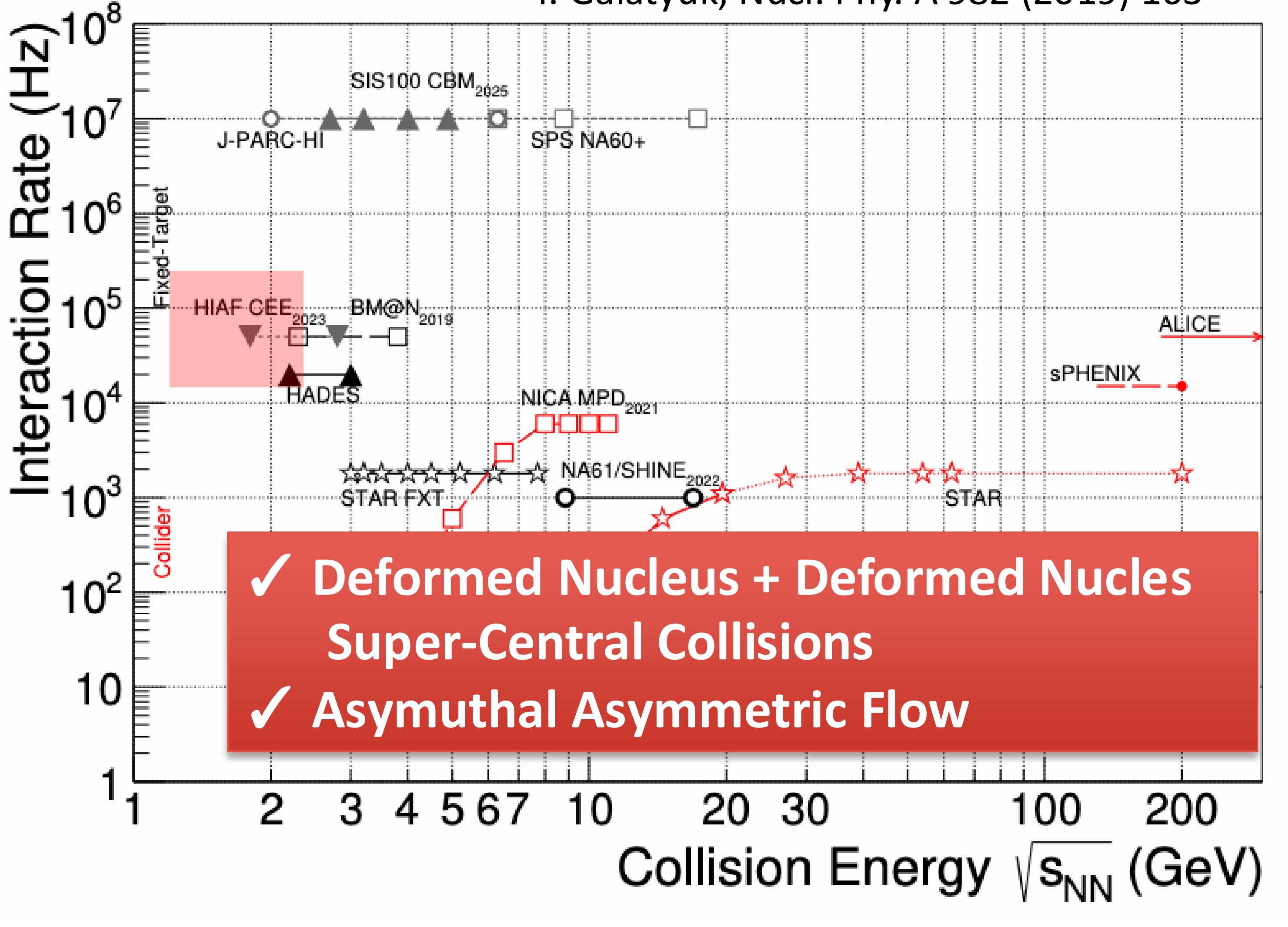
Equation of State (EOS)

High Density Nuclear Matter vs Beam Energies

The 2nd International Workshop on Physics at High Baryon Density
(PHD2025, 第二届高重子密度物理国际研讨会)

Oct 16 – 18, 2025
Guiyuan Hotel

T. Galatyuk, Nucl. Phy. A 982 (2019) 163



✓ Deformed Nucleus + Deformed Nucles
Super-Central Collisions

✓ Asymuthal Asymmetric Flow

1） High Density Nuclear Matter
←→ Neutron Star

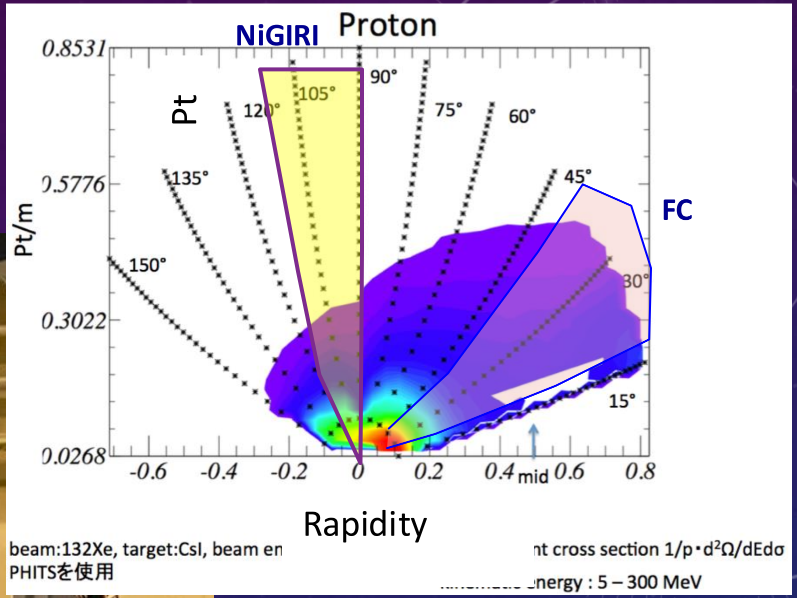
2） Search for Rare Collisions
Super Central Collisions (b=0)

✓ Spherical Shape Nuclei
✓ Deformed Shape Nuclei

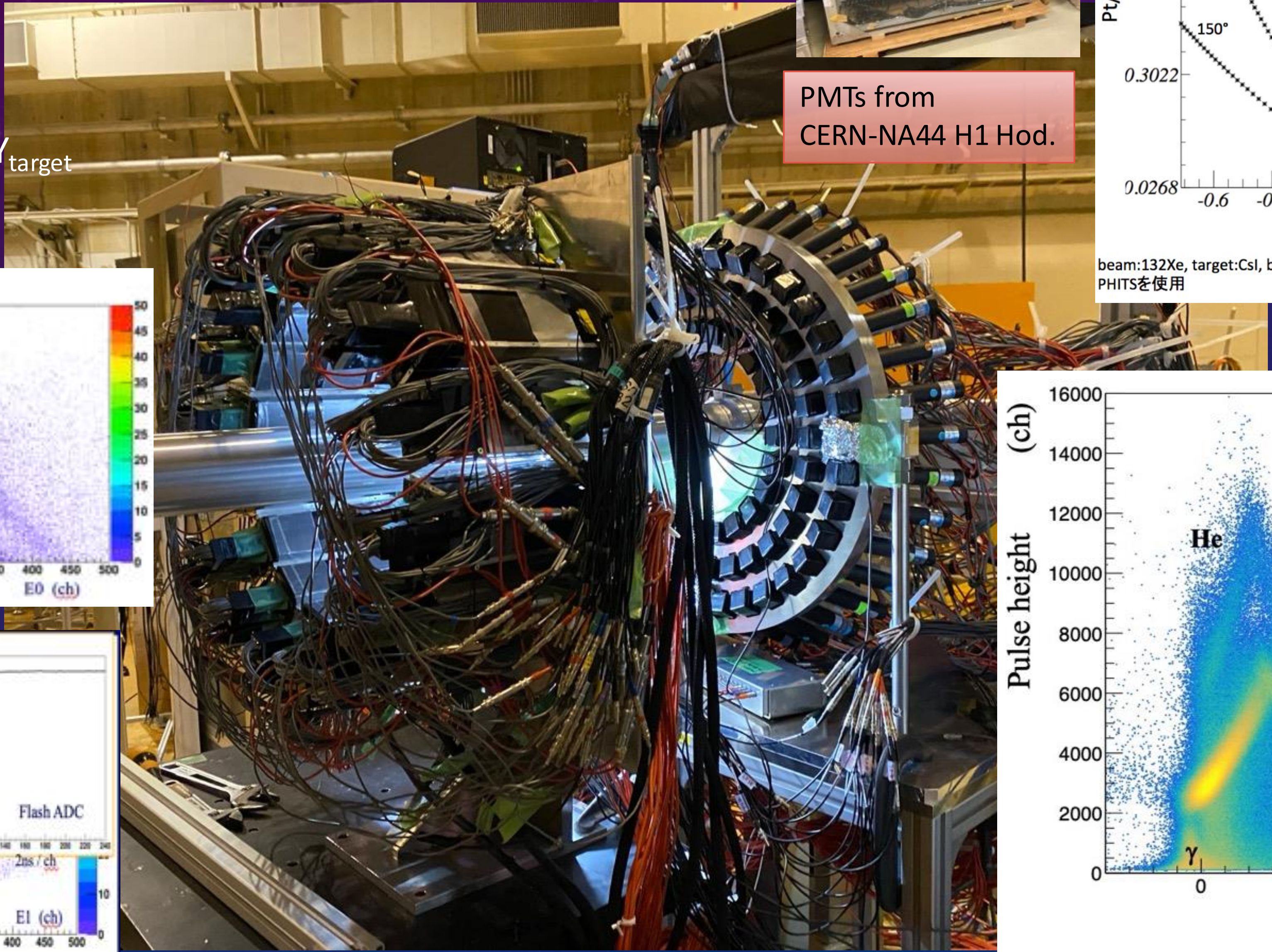
3） Collective Flow
✓ Radial Flow
✓ v1 (directed flow)
✓ v2 (elliptic flow)

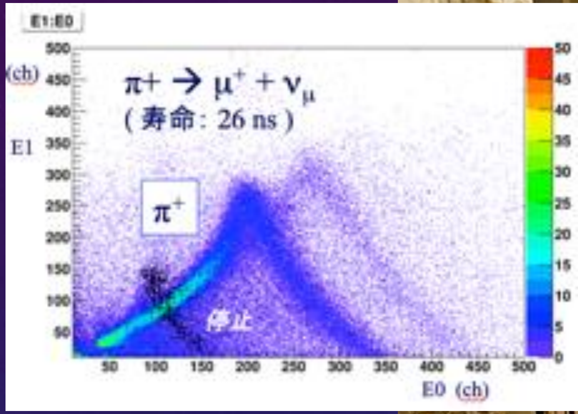
Pilot Flow Experiment at HIMAC H447
^{132}Xe + CsI Collisions at 400 AMeV

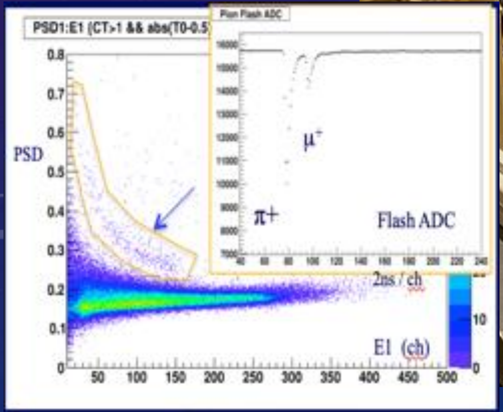
PMTs from CERN-NA44 H1 Hod.

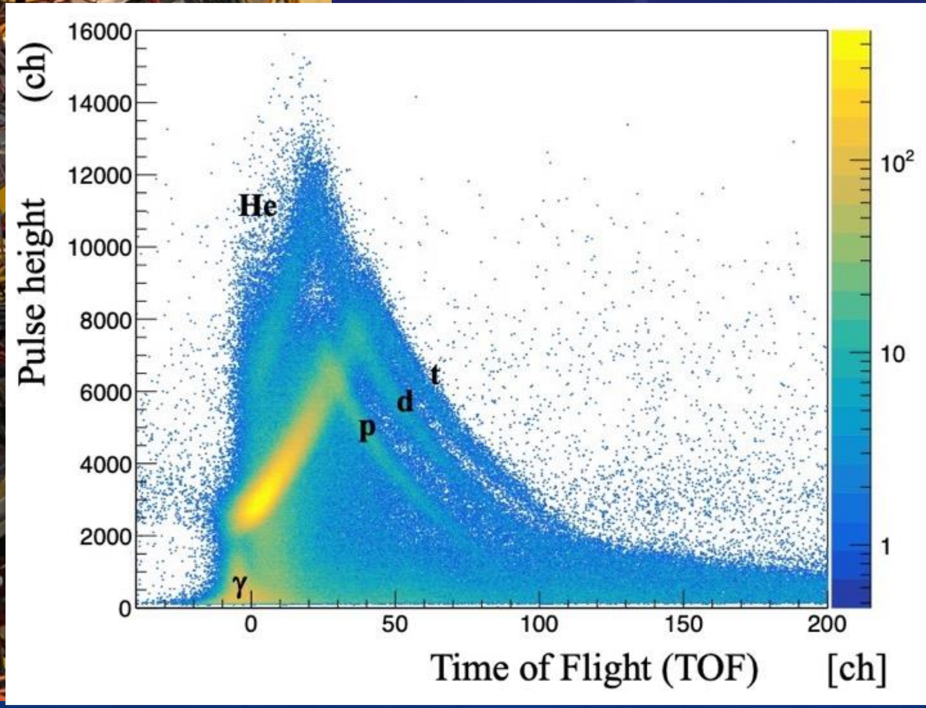


NiGIRI detector@Y_{target}

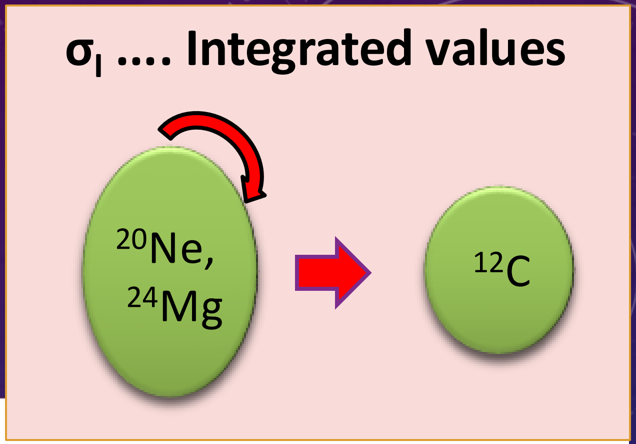






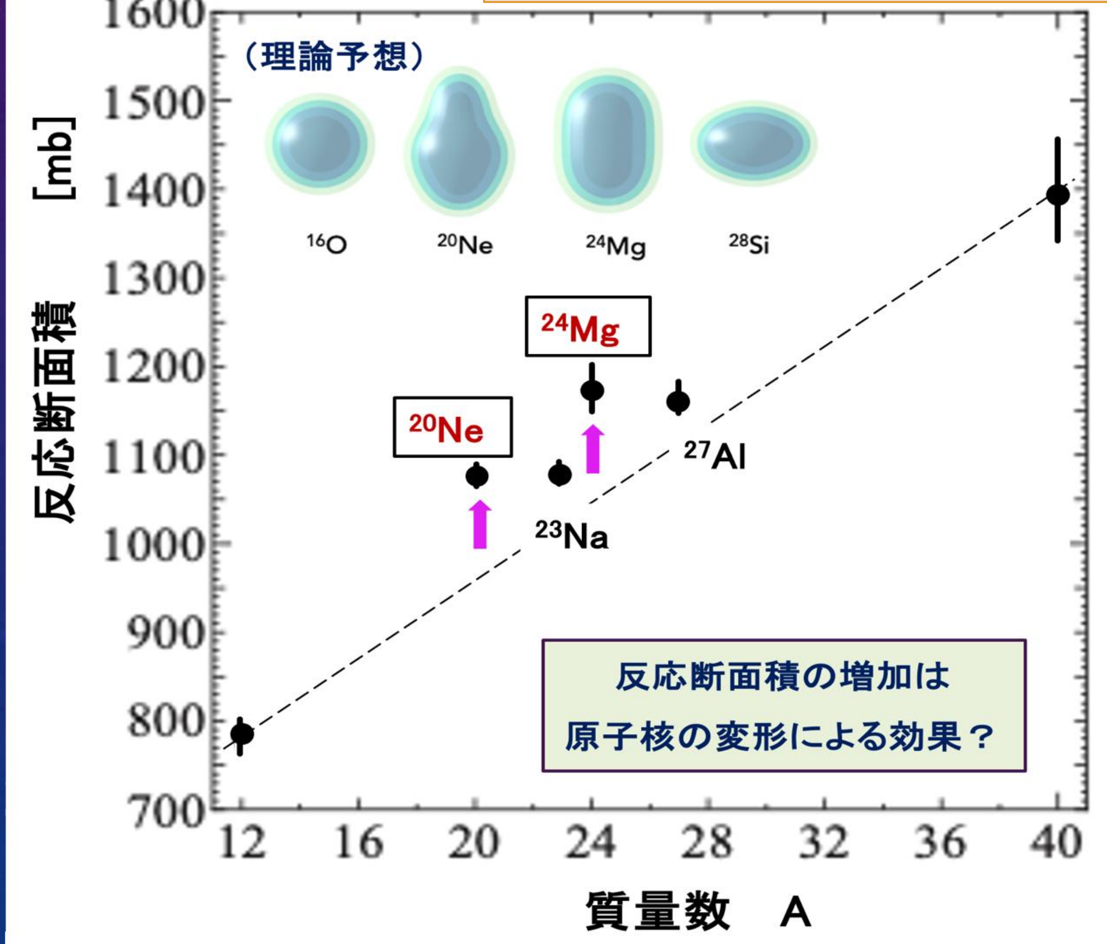


Variation of Deformation Parameter among Theory
^{20}Ne, ^{23}Na, ^{24}Mg, and ^{27}Al



S. Watanabe et al.,
PRC 89, 044610 (2014)

Theory β2	NNDC	FRDM	CEA(p)	CEA(n)	AMD	KTUY α2
^{16}O	0.353	-0.010	0	0		
^{20}Ne	0.72	0.364	0.68	0.662		0.164
^{23}Na		0.386	0.738	0.738		0.174
^{24}Mg	0.613	0.393	0.747	0.729	0.42	0.147
^{27}Al		-0.392	-0.464	-0.469		0.022



Nuclear Structure & Deformation of Nuclei

- (1) Excited States (In-beam gamma, decay)
- (2) Interaction cross-section
- (3) : :

Experimental results suggest large deformation for ^{20}Ne and ^{24}Mg

^{24}Mg + ^{24}Mg Collision (0.5 GeV/n)

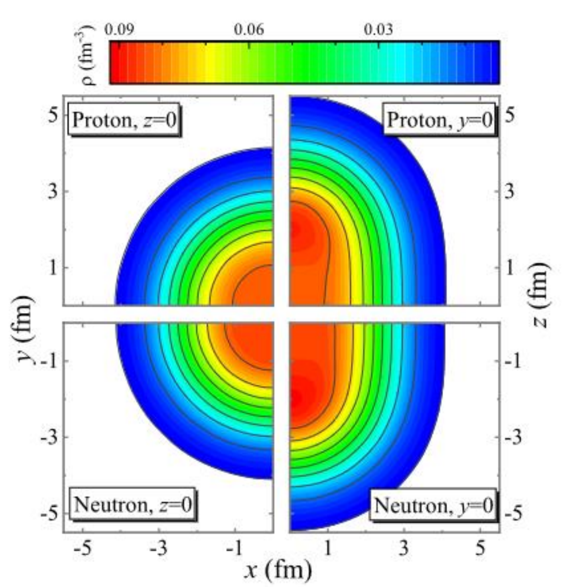


FIG. 1. The neutron and proton densities for ^{24}Mg in the ground state in the x-y ($z = 0$) and x-z ($y = 0$) planes calculated by relativistic mean field with DD-PC1 interaction.

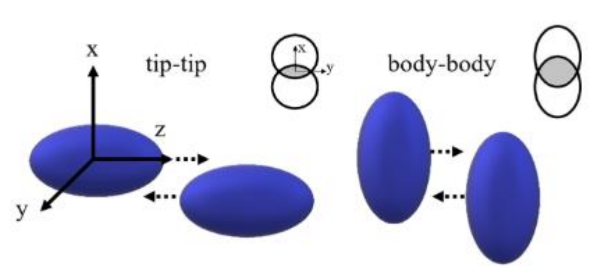
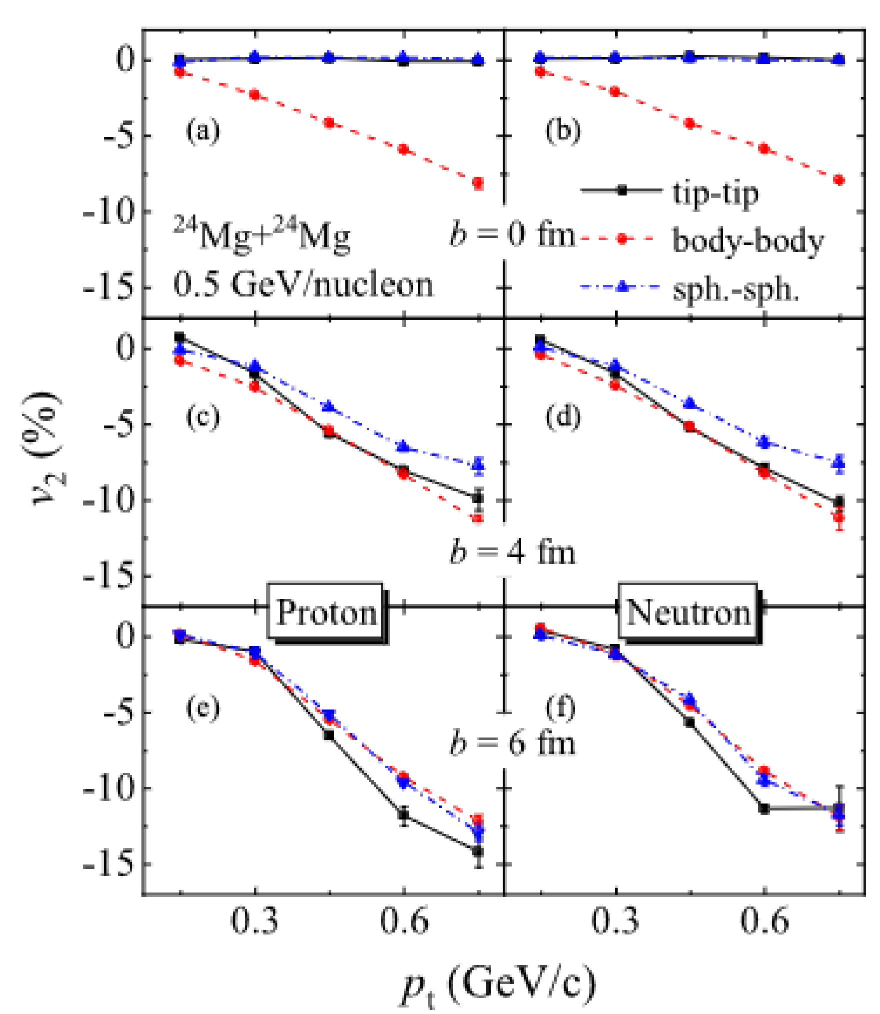
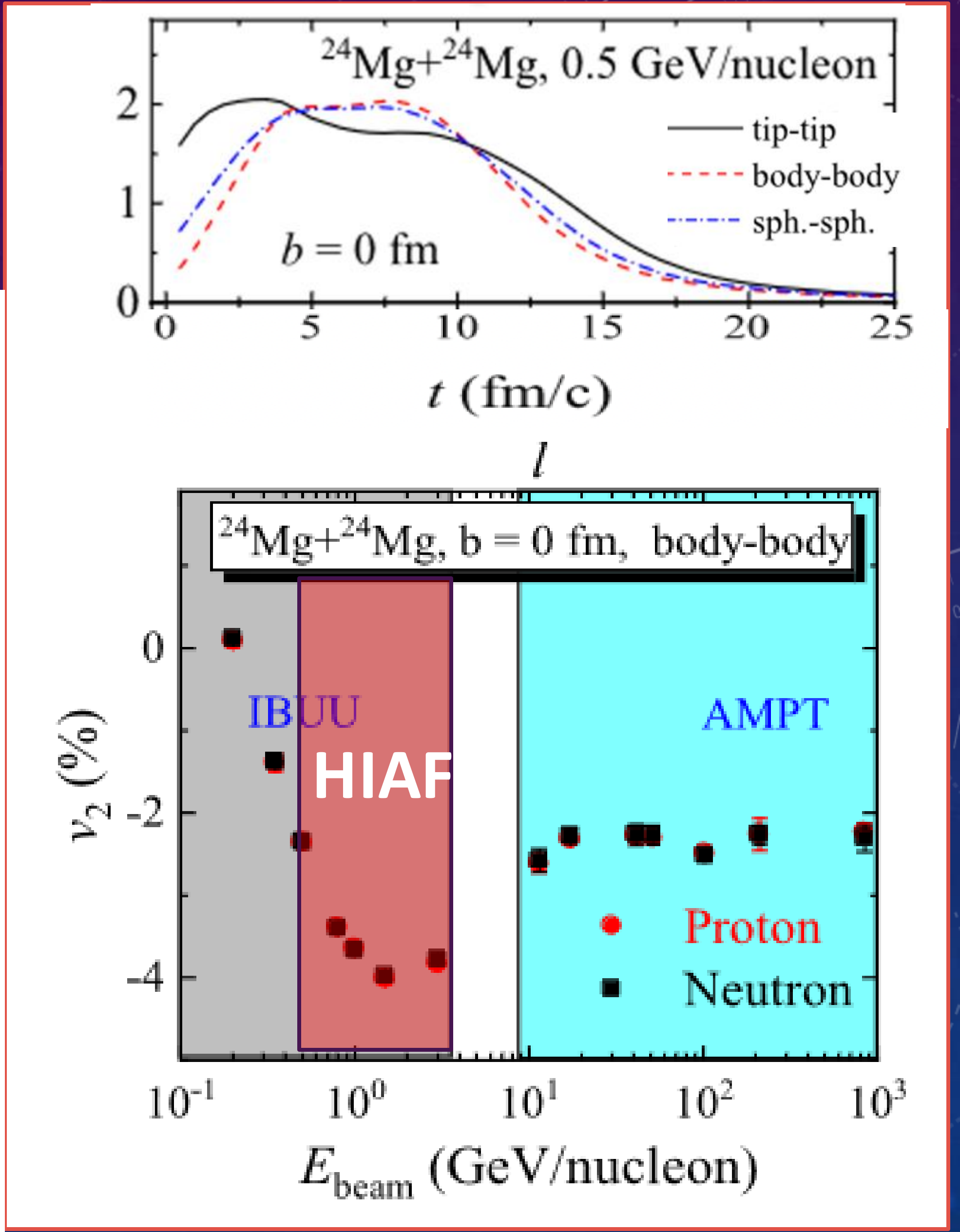


FIG. 2. Simulated schematic for tip-tip collision and body-body collision of ^{24}Mg + ^{24}Mg, where the x-z plane is the reaction plane. In the upper right corner, resulting transverse areas of overlap are shown.

X-H. Fan, Z-X. Yang, P-H. Chen, SN, Z-P. Li, PRC 108, 034607 (2023)





Super-Central Collisions

→ No Fragment Spectator

Deformed Nucleus-Nucleus Collisions II ： $^{238}U + {}^{238}U$

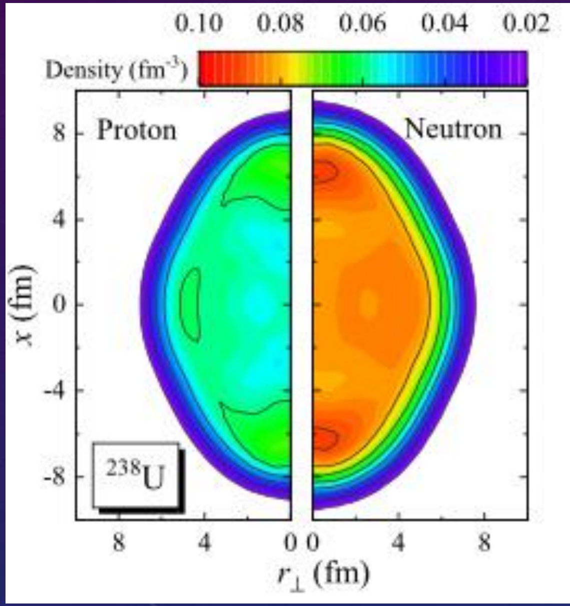
Z.X. Yang, X.H. Fan, Z.P. Li, S.Nishimura, PLB 848 (2024) L38359

Mar. 5, 2024 Research Highlight Physics / Astronomy

AI tool reveals the orientation of nuclei in heavy-ion collisions

The orientation of deformed atomic nuclei in particle collisions can be determined using a newly developed neural network

HIAF Energy



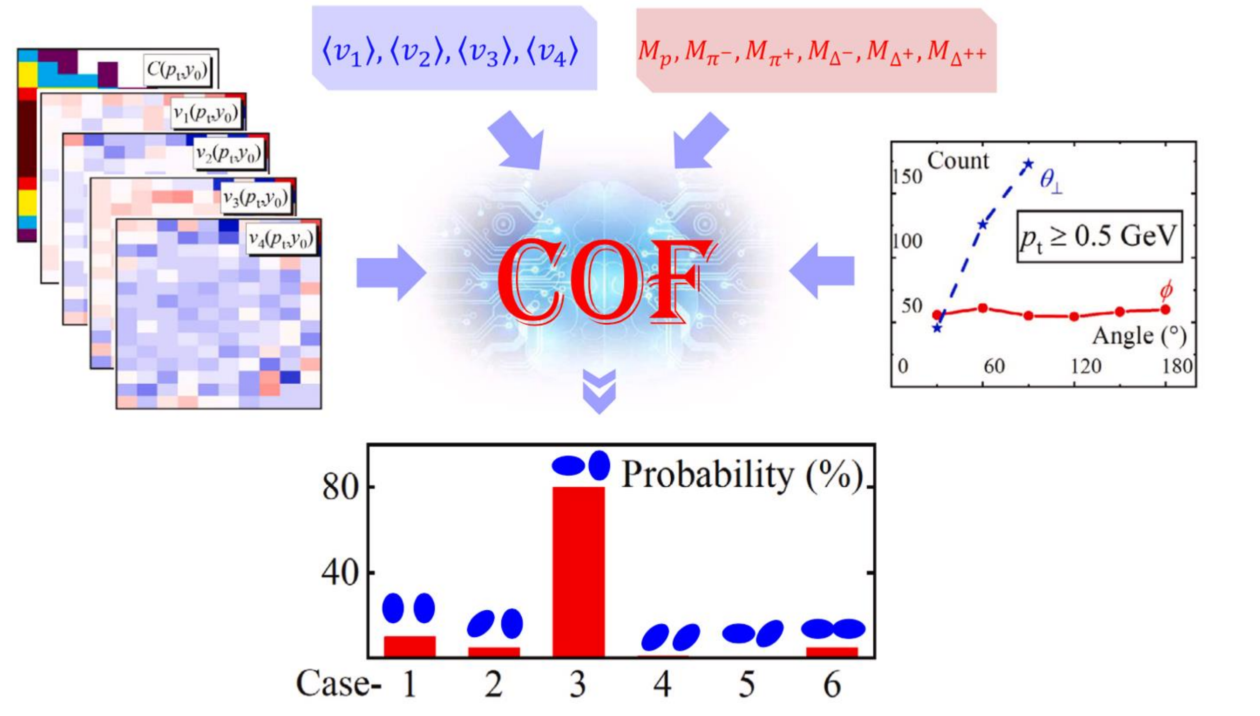
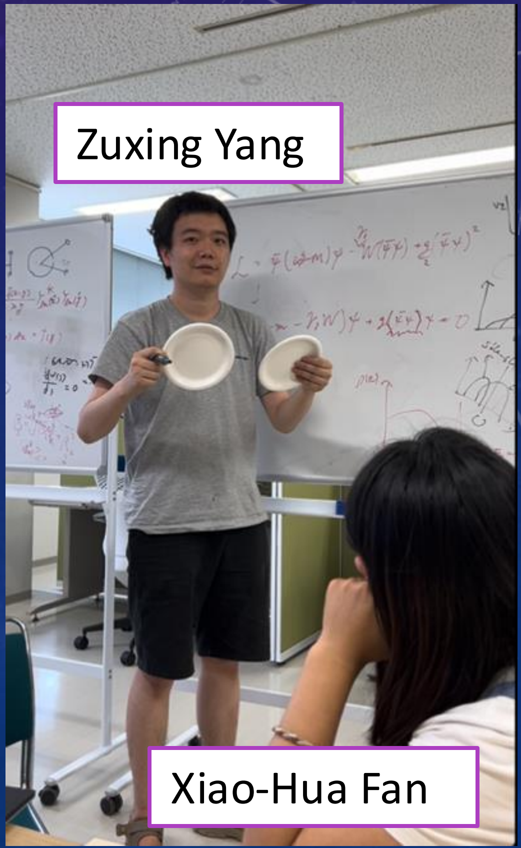
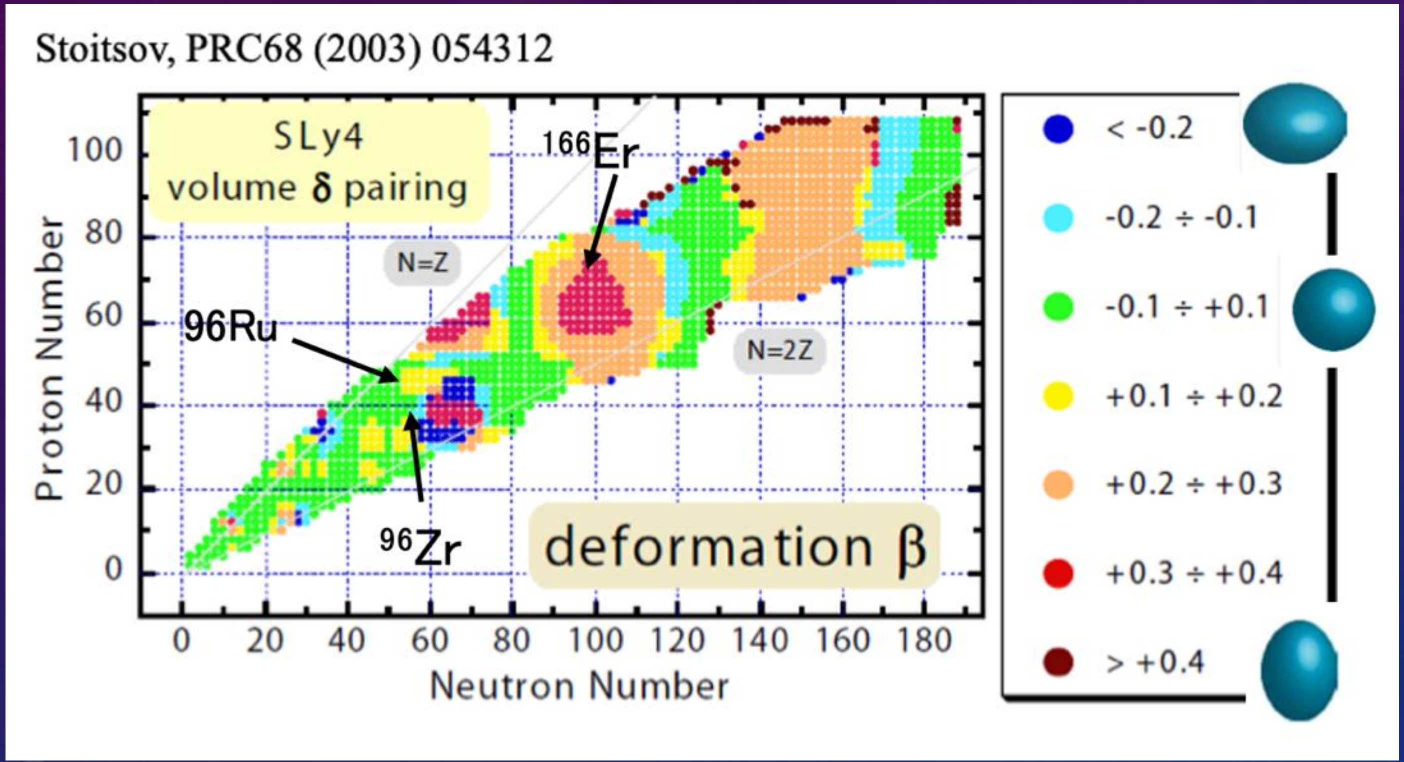


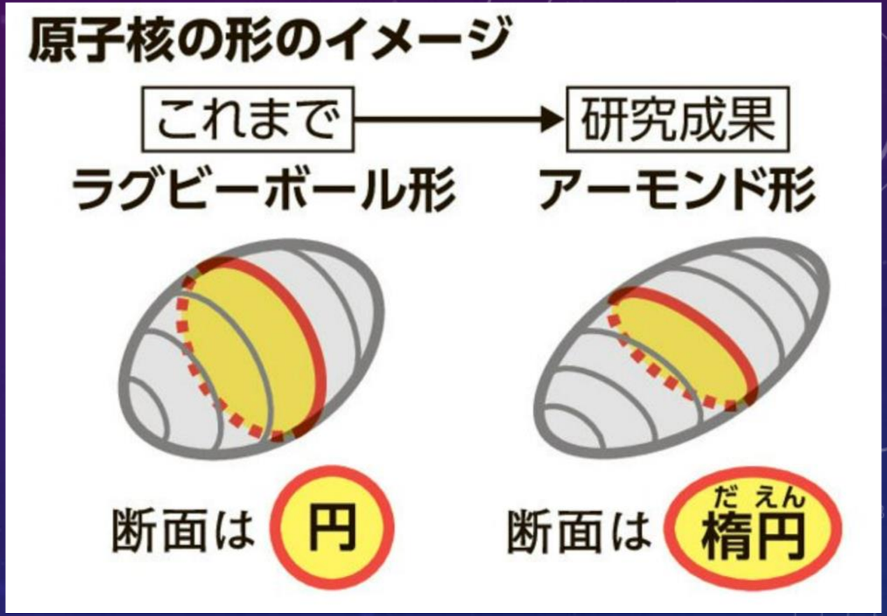
Fig. 4. Schematic diagram of the structure of the convolutional orientation filter (COF) neural network.



Deformed Nucleus-Nucleus Collisions III ： $^{166}Er + ^{166}Er$

A. Rosenhauer, J.A. Maruhn, H. Stocker, and W. Greiner
Phys. Lett. 159B, (1985)





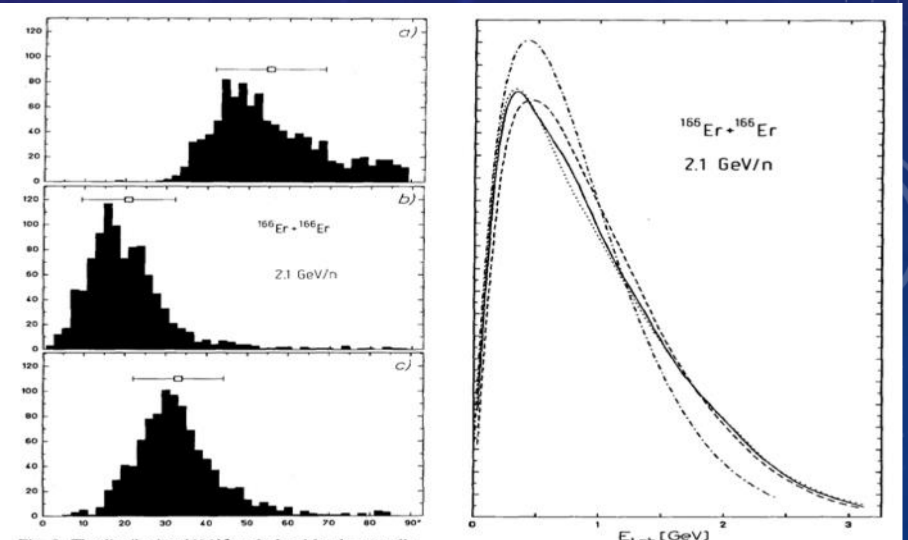


Fig. 2. The distribution $dN/d\theta_F$ calculated for the constellations HoH (a), BoB (b) and SoS (c). The multiplicities as a function of θ_F and the resulting mean value (square) with the corresponding standard deviation (error bars) are plotted on the basis of 1000 evaluated reactions of the system $^{166}Er + ^{166}Er$ at 2.1 GeV/n.

Fig. 3. Energy distribution dN/dE of all participant particles detected by the plastic ball. The spectrum obtained in the lab-system has been plotted for the cases HoH (dashed line), BoB (dotted line) and SoS (full line). The dash–dotted line shows the energy spectrum of a fireball.

T. Otsuka, Y. Tsunoda et al., Eur. Phys. J. A (2025) 61:126
“Prevailing triaxial shapes in atomic nuclei and a quantum theory of rotation of composite objects"

Proof of Nuclear Shape via 166Er+166Er Collisions!?

Study on Heavy-Ion Collisions at HIAF（Simulation & AI）

RiNA-Net
RIKEN International Nuclear Astrophysics Network

^{24}Mg + ^{24}Mg Collisions

PHYSICAL REVIEW C **108**, 034607 (2023)

Impact of quadrupole deformation on intermediate-energy heavy-ion collisions

Xiao-Hua Fan,[1,2] Zu-Xing Yang,[2,1,*] Peng-Hui Chen,[3] Shunji Nishimura,[2] and Zhi-Pan Li[1]
[1]*School of Physical Science and Technology, Southwest University, Chongqing 400715, China*
[2]*RIKEN Nishina Center, Wako, Saitama 351-0198, Japan*
[3]*College of Physics Science and Technology, Yangzhou University, Yangzhou, Jiangsu 225002, China*

Exploring the nuclear momentum anisotropy based on intermediate-energy heavy-ion collisions

Xiao-Hua Fan [a b c], Zu-Xing Yang [b a], Peng-Hui Chen [d], Zhi-Pan Li [a], Wei Zuo [e f], Masaaki Kimura [b], Shunji Nishimura [b]

Physics Letters B
Volume 866, July 2025, 139503

^{238}U + ^{238}U Collisions

Phys. Lett. B 848 (2024) 138359

A neural network approach for orienting heavy-ion collision events

Zu-Xing Yang [a,b], Xiao-Hua Fan [b,a,*], Zhi-Pan Li [b], Shunji Nishimura [a]
[a] *RIKEN Nishina Center, Wako, Saitama 351-0198, Japan*
[b] *School of Physical Science and Technology, Southwest University, Chongqing 400715, China*

Cross-checking the geometric effects in heavy-ion collisions at 500 MeV/nucleon

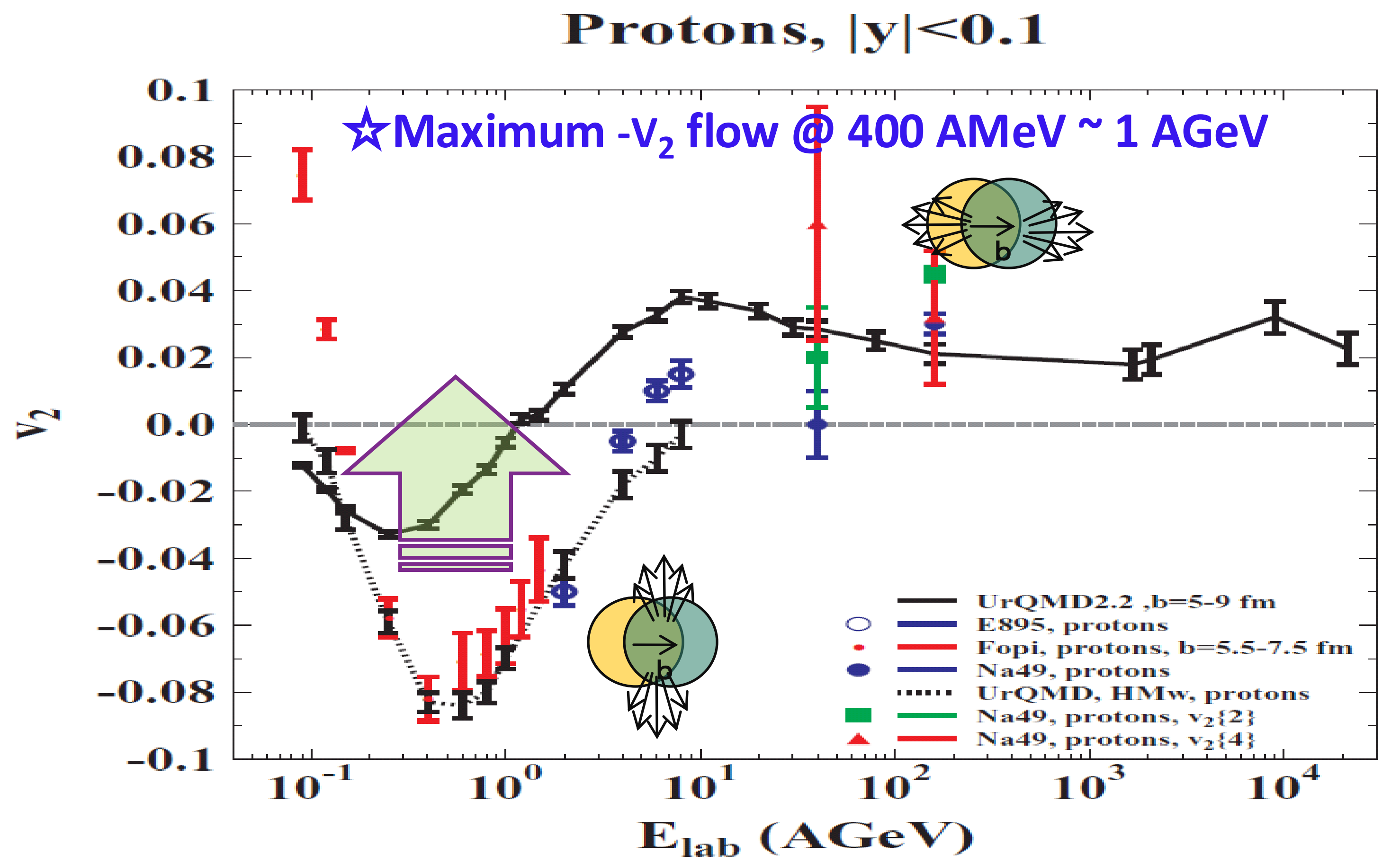
Zu-Xing Yang[1,2], Xiao-Hua Fan[2,3,1,*], Zhi-Pan Li[2], and Shunji Nishimura[1]

Phys. Rev. C **112**, 024606 – **Published 8 August, 2025**

DOI: https://doi.org/10.1103/fnzz-vxgq

Energy Dependence of Elliptic Flow V_2 (Au+Au, Pb+Pb Collisions)

H.Petersen, et al. PRC74 (**2006**) 064908



Deformed nucleus central collision
almond shape collisions
Sunny Weather

- Polarity of V_2 might be flipped below 10 GeV using the deformed nucleus-nucleus collisions !?
- V_2(proton) vs V_2(neutron) as function of energy will provide new physics approach for EOS

Summary

Extreme Environments Achieved

○ RI Production & Particle Identification
- Development of Primary Beams
- Development of Detectors/Device

○ Decay, Mass, Reactions, Fissions
- Development of Detectors/Devices

○ High Density Nuclear Matter
- Best Energies : HIAF
- Deformed Nucleus + Nucleus Collisions
→ Nuclear Shape ←→ Nuclear Structure

◎ Masses :
- Determine the r-process path, global structure

◎ Beta-decays:
Half-lives :
- Speed of producing heavy elements

Beta-delayed neutron emissions :
- Determine the fine structure of r-elements
- Recapture of neutrons

◎ Nuclear reactions ←→ Masses
- Determine the r-process path

◎Fission recycling :
- Production of heavy elements

◎Equation of State :
- Explosive conditions of NS-NS, SN