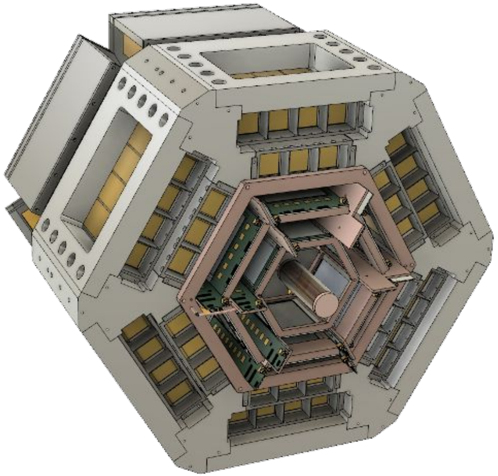
Construction of TOGAXSI array and preparation for upcoming ONOKORO-related experiments

RIKEN Nishina Center
Yuki Kubota

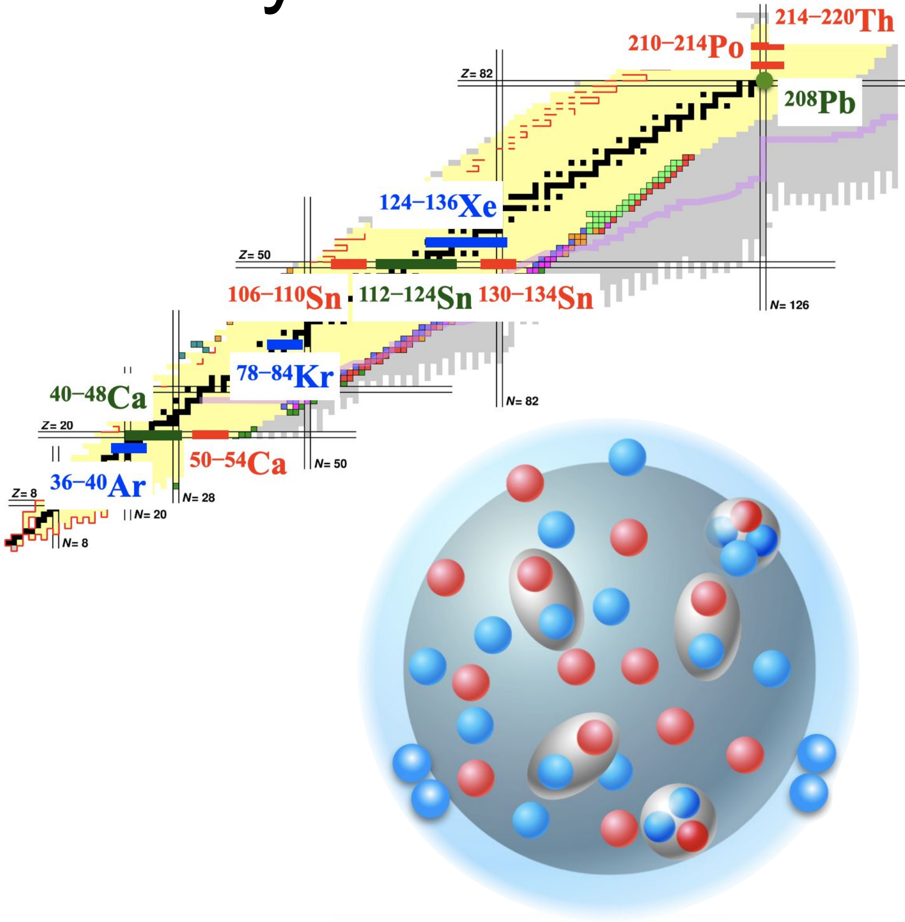


TOtal energy measurement by **GA**gg
and verte**X** reconstruction by **SI**licon

1) ONOKORO project and near-future experiments
2) Construction status of TOGAXSI telescope

Clustering in medium and heavy nuclei

- Quite little is known
- Questions to be answered
  - How can the mean-field picture be compatible with that with clusters?
  - The peculiarity of low-density surface?
- Isospin dependence is the key
- Interests specific to each cluster
  - Possible access to α preformed in α-decay nuclei
  - Search for deuteron clusters which embody tensor-correlations in nuclei
  - First determination of $t/^{3}$He ratio



ONOKORO project

科研費 KAKENHI

特推 490M JPY
for FY 2021–2025

Clustering in medium-heavy nuclei
via (p,$p\underline{X}$) knockout reaction & elastic scattering

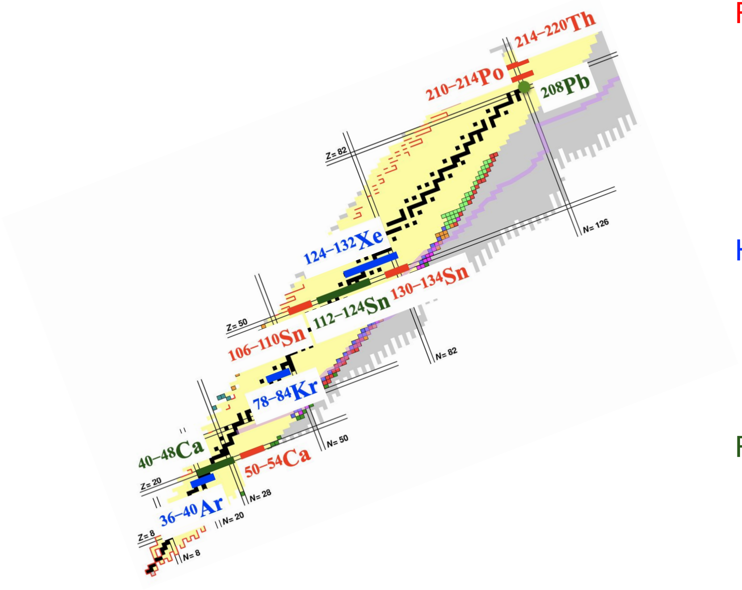
Wide mass region
A = 40–220

×

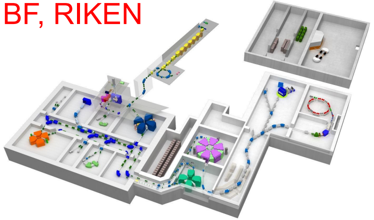
Stable and unstable
nuclei

×

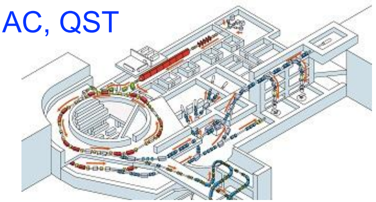
All the light clusters
***d*, *t*, ^{3}He, *α* …**



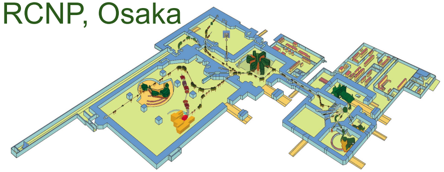
RIBF, RIKEN

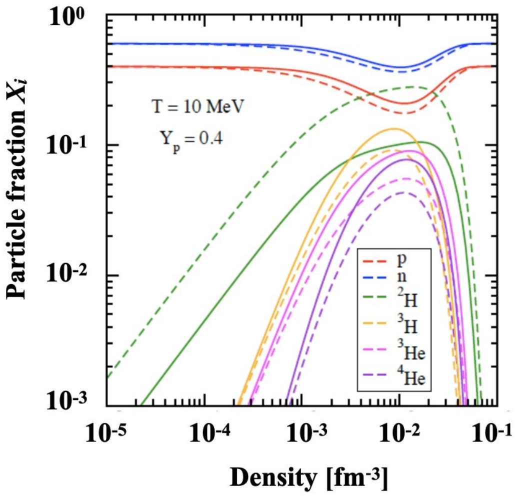


HIMAC, QST



RCNP, Osaka





Quantities to be extracted

(p,pX) [X: p, d, t, ^{3}He, α]

First comprehensive cluster knockout reaction studies for medium-mass nuclei

α: further evidence of surface-α conjectured by S. Typel

d: measure of tensor correlation

t/^{3}He: little is known, apparent isospin dependence is expected

$(p,2p)$ channel is a byproduct, but provide us with many important information.

Cross section integrated over the acceptance and momentum distributions are compared with DWIA calculation
→ "number of the cluster in the nucleus", "spatial distribution"

$(p,p\alpha)$	Typel et al. Yoshida, Ogata et al.
(p,pd)	Chazono, Yoshida, Ogata
(p,pt)/$(p,p^{3}\mathrm{He})$	to be discussed
$(p,2p)$	several existing codes
$(p,3p)$	Gomez-Ramos?

First campaign at RCNP (2023 and 2024)

^{40,42,44,48}Ca(p,pd), (p,pt), (p,p^3He), (p,$p\alpha$) at 230 (392) MeV, together with ^{6,7}Li, ^{12}C, ^{16}O data

Successful!

Collaboration

- Japan: RIKEN, Kyoto, RCNP, Kyushu, Osaka, Konan, Miyazaki
- China: Peking University
- Korea: CENS IBS
- France: IJCLab Orsay

Courtesy of R. Tsuji

Isospin asymmetry of $t/^3$He?

- TDX decreases with the increase of mass
  - Same trend as Sn($p,p\alpha$)
- ^{3}He drops faster than t
  - Neutron skin?

Near-future programs at SAMURAI

2024 Autumn
2025 Spring
2025 Autumn
→ CATANA+STRASSE?

- NP2012-SAMURAI57 (from ^{70}Zn): $^{50–52}$Ca(*p*,*pX*)
    - 3.5 days (+0.5 d for BR).
- NP2112-SAMURAI72 (any primary beam): TOGAXSI commissioning
    - 1.0 days, to be proposed in the coming MT committee meeting.
- NP2312-SAMURAI77: Proposal for Scientific Program (SEASTAR-like), 6 days (+1 d for BR)
    - $N = Z$ nuclei (^{40}Ca–^{60}Zn) from ^{78}Kr: tensor force in medium
    - Unstable tin $^{106–110,126–136}$Sn from ^{124}Xe, ^{238}U: extension of stable $^{112–124}$Sn(*p*,*pα*) at RCNP
    - *α* decay nuclei $^{214–220}$Th from ^{238}U: *α* preformation, large reduced *α* width
- NP2212-SAMURAI74 (K. Miki, M. Duer), from ^{18}O: ^{8,6}He(*p*,3*p*)^{6,4}*n*, 11 days, graded as **S**
- NP2212-SAMURAI64R1 (S. Kim), from ^{18}O, ^{40}Ar: reduction factor study via (*α*,*αp*), 9 days
- NP1812-SAMURAI33R1 (Z.H. Yang), from ^{48}Ca: $^{12–20}$C(*p*,*pα*), 5.5 days
- NP2312-SAMURAI76 (Z.H. Yang, S. Huang, Y.L. Sun), from ^{18}O: ^{9}H & ^{12}He
- NP2412-SAMURAI?? (P. Li), from ^{18}O: B(*p*,*pX*)
- NP2412-SAMURAI?? (S. Koyama), from ^{18}O: particle decay from IAS in ^{12}B,^{12}C,^{12}N

Schedule

Experiment

2024 Sep.
2024 Oct. SπRIT $^{136}\mathrm{Xe}+\mathrm{Sn}$
2024 Dec. { TOGAXSI commissioning
ONOKORO $^{50\text{–}52}\mathrm{Ca}(p,pX)$
↓ ?
~~2025 Mar.~~
2025 Apr. Miki/Duer $^{6,8}\mathrm{He}(p,3p)^{4,6}n$
2025 Oct. STRASSE $^{56}\mathrm{Ti}(p,3p)^{54}\mathrm{Ca}(0_2^{+})$
↕ ?
ONOKORO $N = Z$ / unstable Sn

TOGAXSI construction

- 64 GAGGs, Recoil Si

↓ "Demonstrator": 2/6 array

- Cluster Si
- ΔE plastic
- +10 (IBS) +10 (PKU) +25 GAGGs (109 in total)

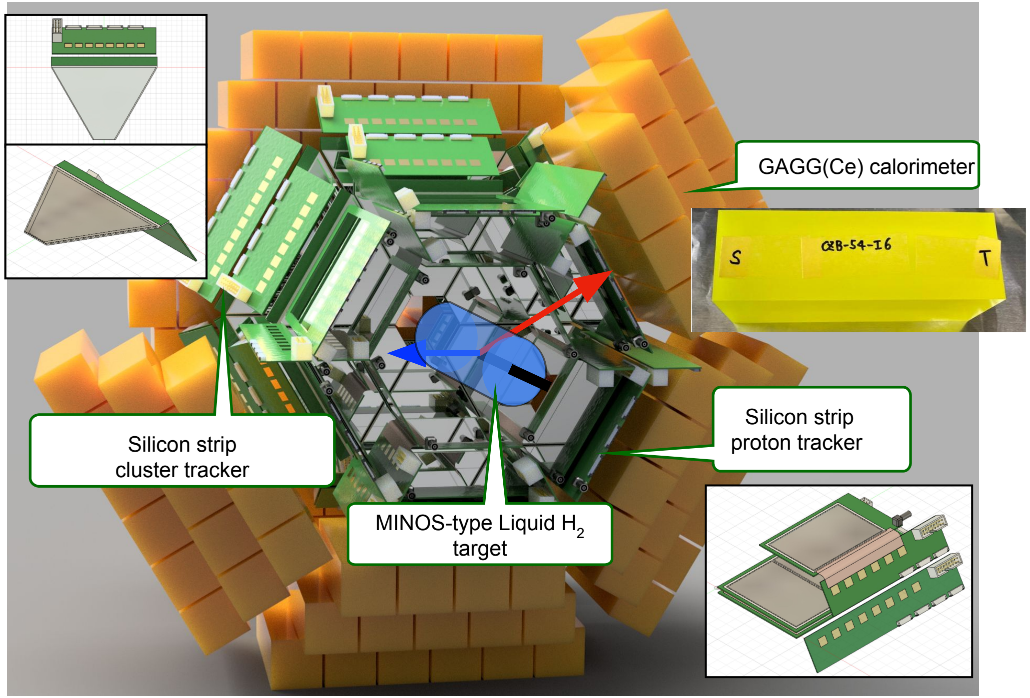
↓ "1st generation": 4/6 array

- 138 GAGGs are needed. (+29 more)

⋮ "Full array": 6/6 array

TOGAXSI (戸隠) telescope for cluster knockout measurement

J. Tanaka et al., Nucl. Instr. Meth. B **542**, 4 (2023).



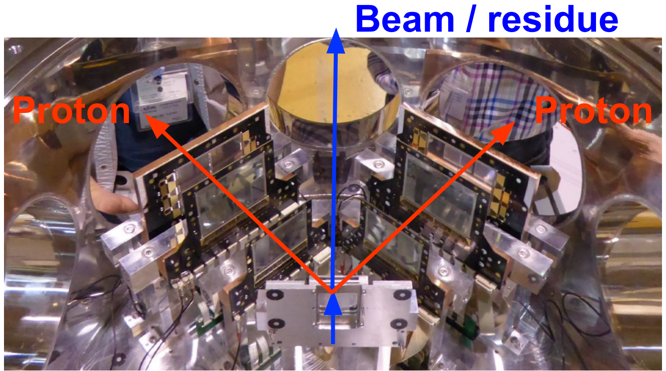
c.f. STRASSE + CATANA for (*p*,2*p*)

- Recoil proton array
  - Angle 35–70°
  - Energy 80–250 MeV
- Knock-out cluster array
  - Forward angle 8–30°
  - High energy 250A MeV
  - Particle identification: *p*, *d*, *t*, ^{3}He, *α*
  - High rate ~10^4 cps

- Si tracker
  - 100-μm thick, 100-μm pitch
  - APV25 readout developed at TU Munich
- GAGG(Ce)
  - Fast, bright, dense, easy to treat (no hygroscopic nature)
  - Large size: 35 mm x 35 mm x 120 mm
  - Photo diode + Digitizer CAEN V2730

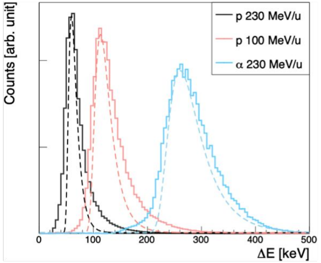
Courtesy of S. Reichert

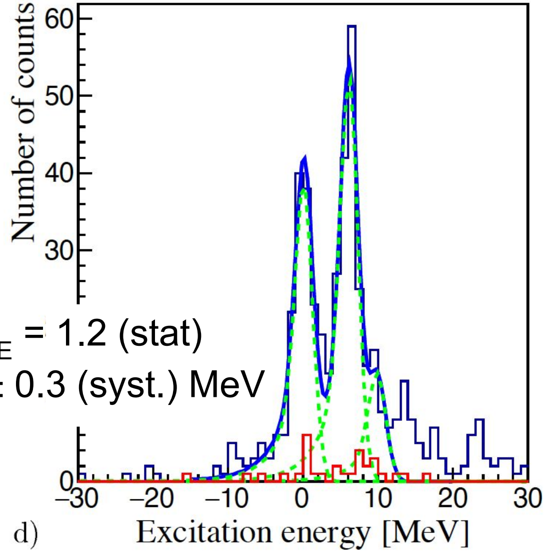
Si tracker (Sasano-TUM design)



^{16}O(p,2p) @HIMAC, Feb. 2016

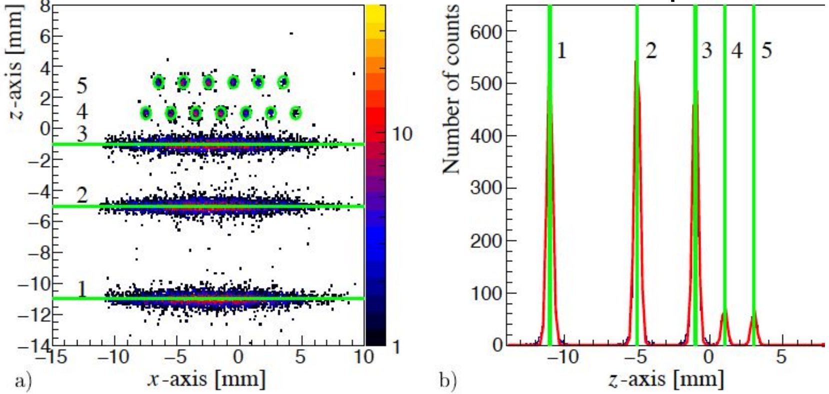
- Hamamatsu wafer
- 100-μm thick
- 100-μm pitch
- APV25 readout
- Noise <5 keV





σ_E = 1.2 (stat) ± 0.3 (syst.) MeV

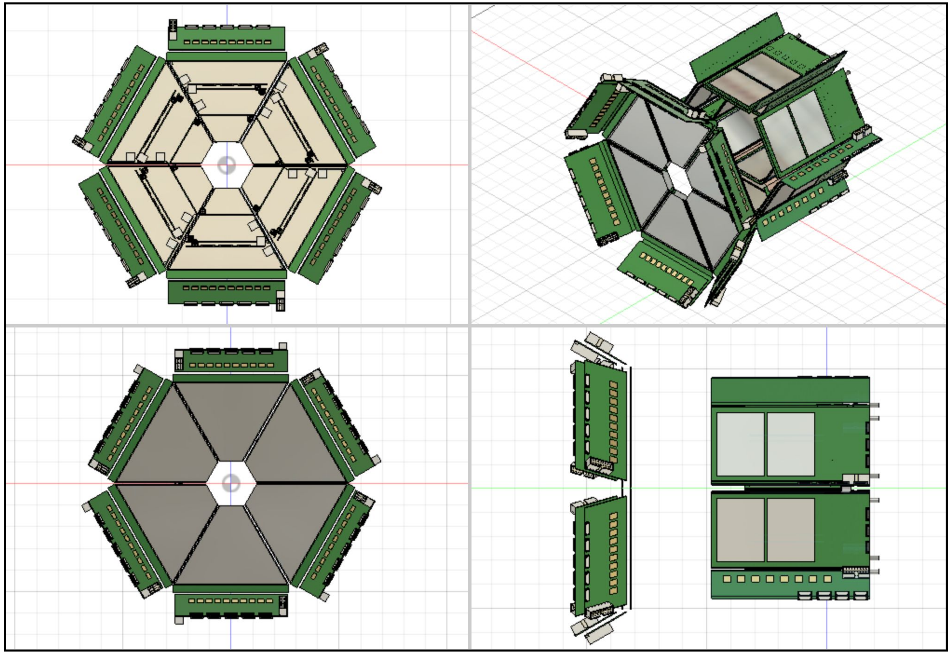
Reaction vertex reconstructed from protons

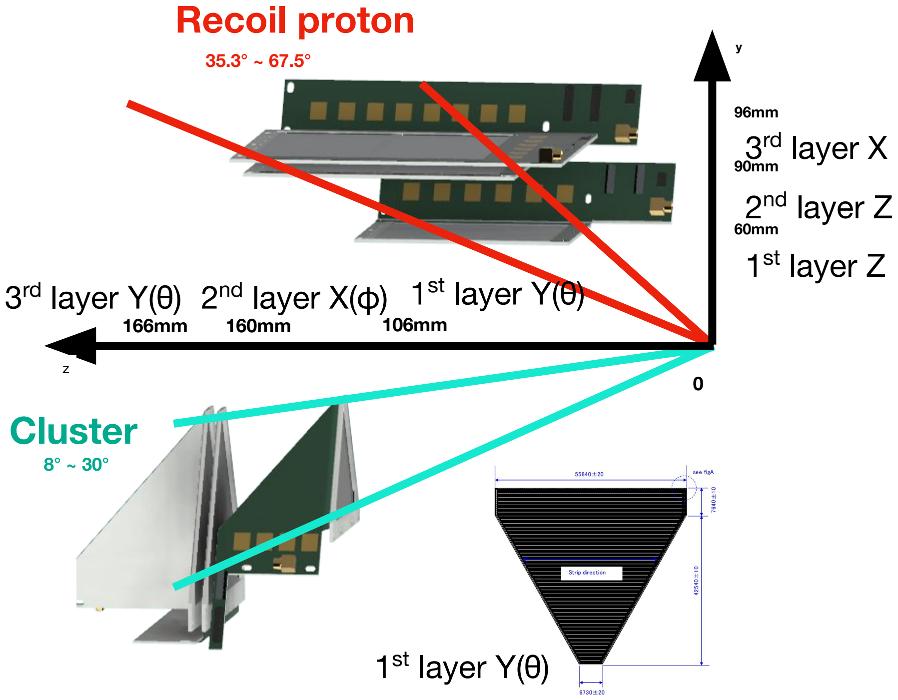


Implementation on flexible printed circuits (FPC)

K. Higuchi

Schematic of Si tracker





Recoil proton

35.3° ~ 67.5°

Cluster

8° ~ 30°

3rd layer Y(θ)
166mm
2nd layer X(ϕ)
160mm
1st layer Y(θ)
106mm

96mm
3rd layer X
90mm
2nd layer Z
60mm
1st layer Z

1st layer Y(θ)

GAGG(Ce) calorimeter

Made-in-Japan inorganic scintillator

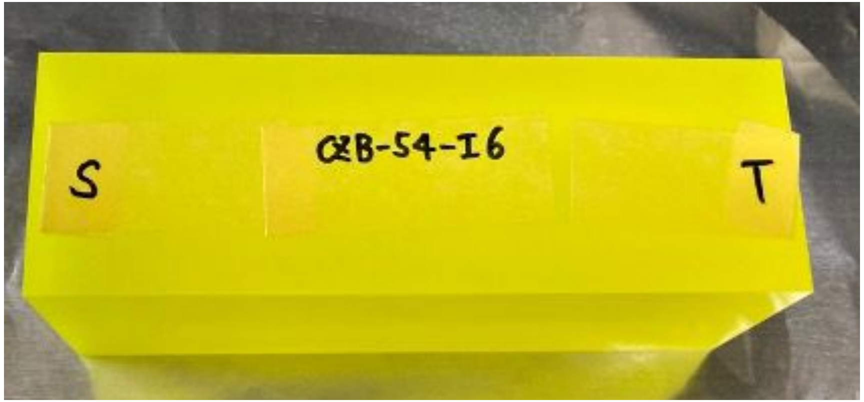
	GAGG(Ce)	NaI(Tl)	CsI(Tl)
Density [g/cm^3]	6.63	3.67	4.53
Decay time [ns]	92	230	1050
Hygroscopic nature	No	Yes	Yes
# of photon [/MeV]	56000	45000	56000

Large stopping power → compact setup

Fast decay → high late tolerance (>10 kHz)

Simple housing → minimization of energy loss

Good energy resolution

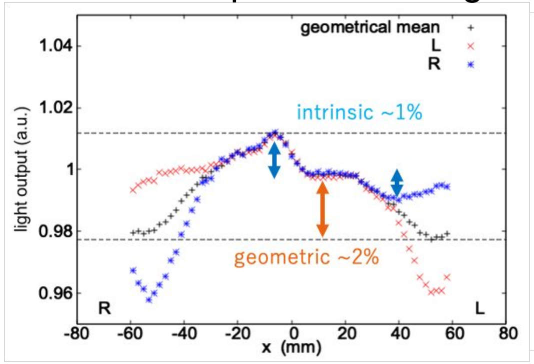


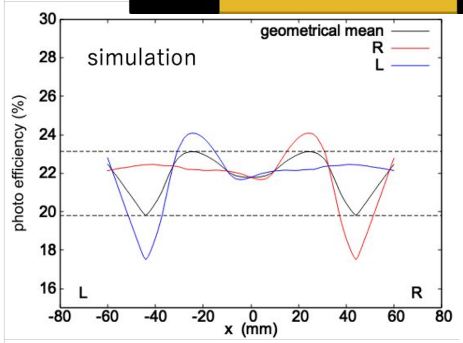
Large crystal: 35 mm x 35 mm x 120 mm

Courtesy of R. Tsuji

Selection of photo sensor

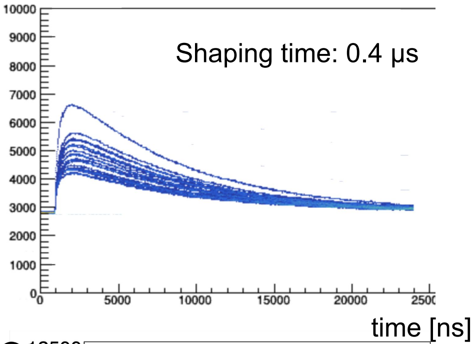
Position dependence of light output



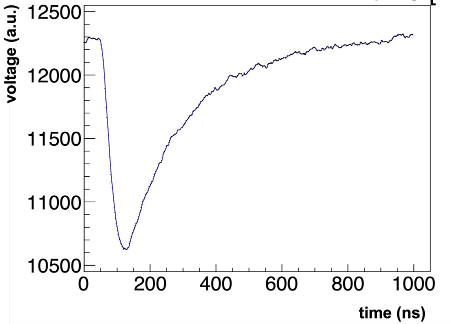


	PD (S3584-08)	**APD (S8664-1010)**	**PMT (R11265U-20)**
Quantum efficiency @ 520 nm	~80%	~80%	~20%
Gain	1	10~100	<10^6
Time response	Slow	Fast	Fast
Effective area	28 mm x 28 mm	10 mm x 10 mm	23 mm x 23 mm
Energy resolution @100MeV proton	~0.5%	~1%	~1%

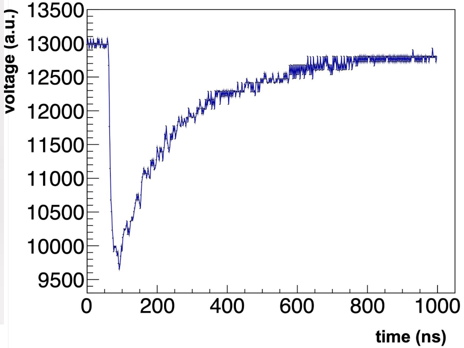
PD S3584-08



APD S8664-1010



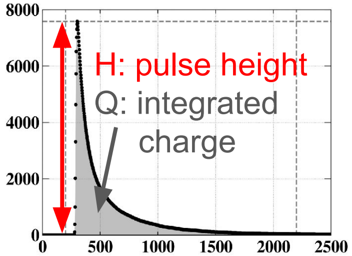
PMT R11265U-20



Courtesy of T. Yano

Particle identification by pulse shape analysis (w/ PMT)

Proton
Deuteron



Large dE/dx (*d* > *p*)
→ Slow component

Amplitude (a.u.)

Time [ns]

3σ separation of *p* and *d*
at E*p* > 60 MeV.

^{4}**He**

^{3}**He**

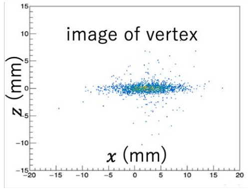
t

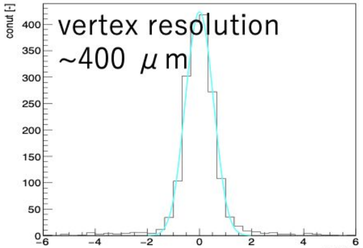
d

p

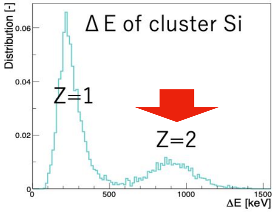
Proof-of-Concept exp. at HIMAC(1): *p-α* elastic w/ CH_2

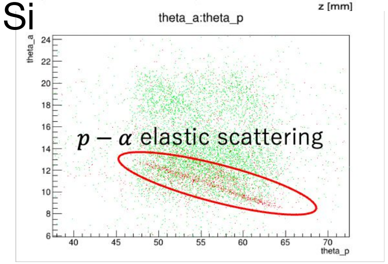
1. Vertex reconstruction



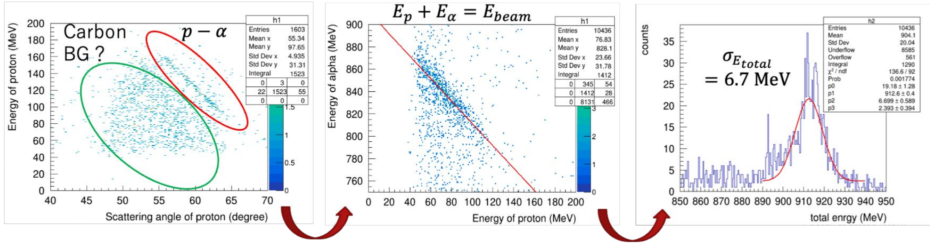


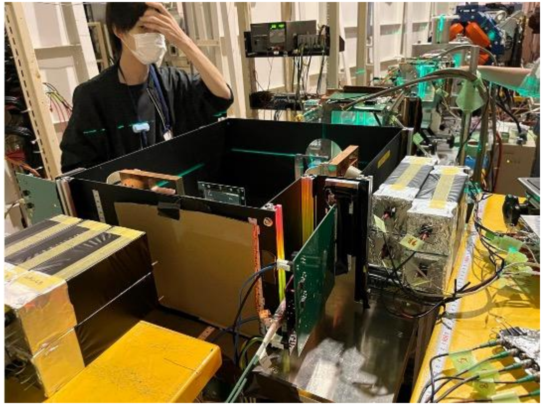
2. Z separation by cluster Si

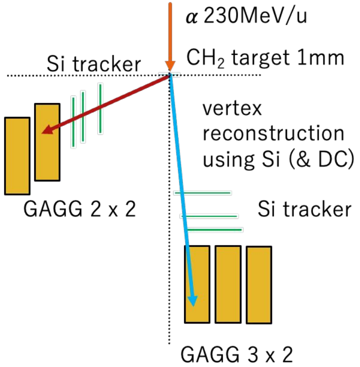




3. GAGG energy calibration (w/o pos. dep. corr.)



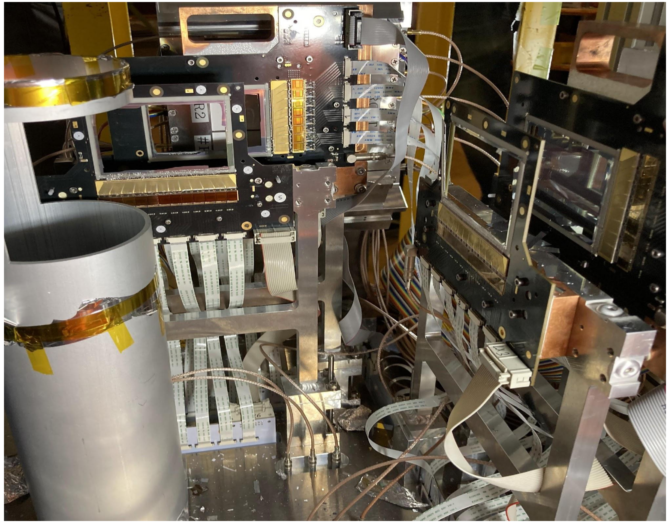


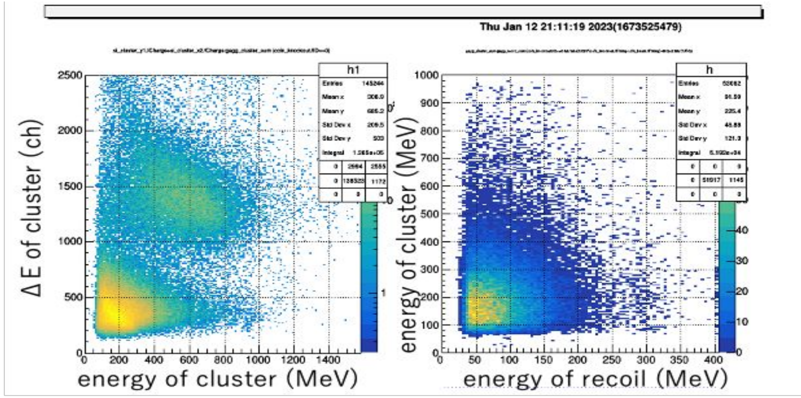


Sasano-TUM Si was used.

Proof-of-Concept exp. at HIMAC(2): (*p,pα*) w/ liq. H_2

ϕ40 mm x 100 mm,
50-μm Kapton





Passed pressure resistance test in accordance with KEK's safety guideline for liq. H_2 target

… But exploded and Sasano-TUM Si were heavily damaged

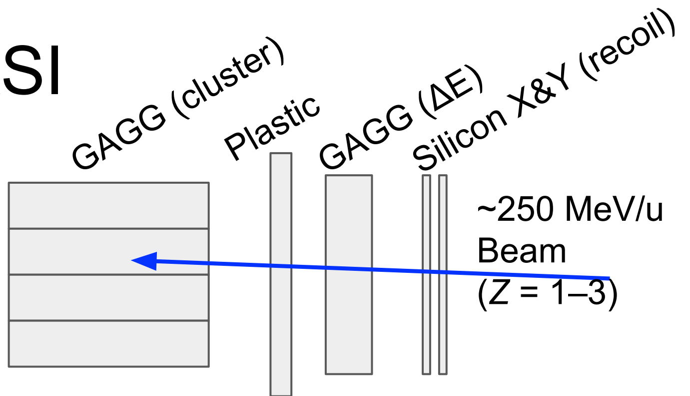
Difficulty in PID was recognized.

Only Z separation is possible.

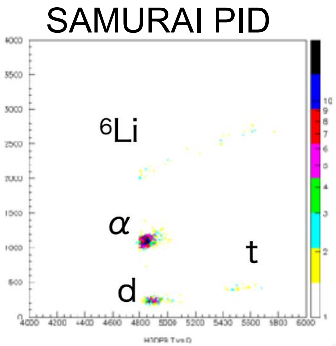
^{3}He/^{4}He separation would be very tough.

→ Need for additional ΔE detector

Beam irradiation at RIBF: mini TOGAXSI

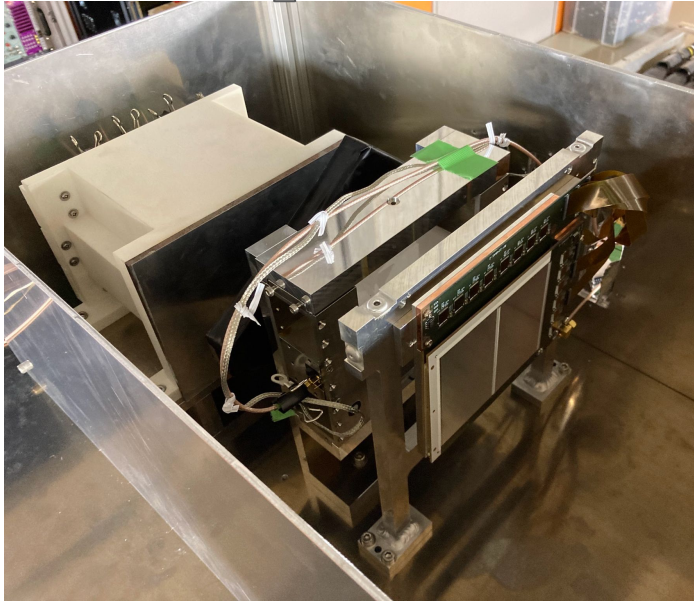


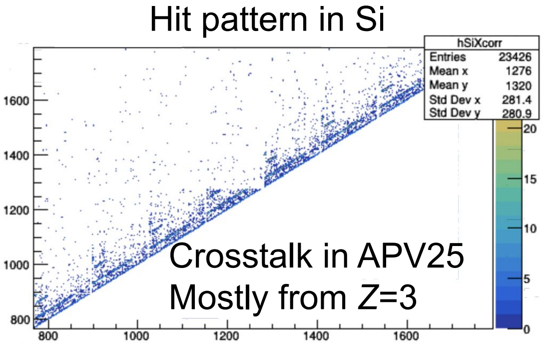
~250 MeV/u
Beam
(Z = 1–3)



SAMURAI PID

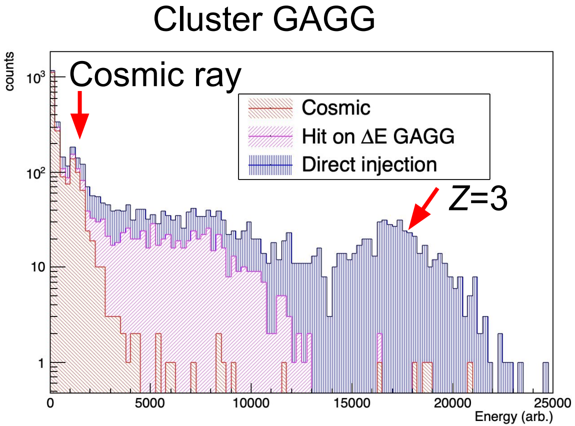
- New DAQ scheme (event build w/ timestamp)
    - ○ Quick semi-online analysis
    - ○ Simultaneous cosmic-ray measurement
- Successful operation of “recoil Si”
- Test data for absolute energy calibration





Hit pattern in Si

Crosstalk in APV25
Mostly from Z=3



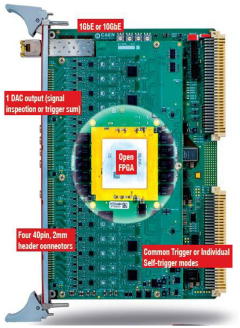
Cluster GAGG

Cosmic ray

Z=3

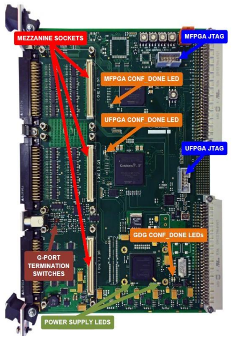
Workarounds for slow trigger generation (GAGG)

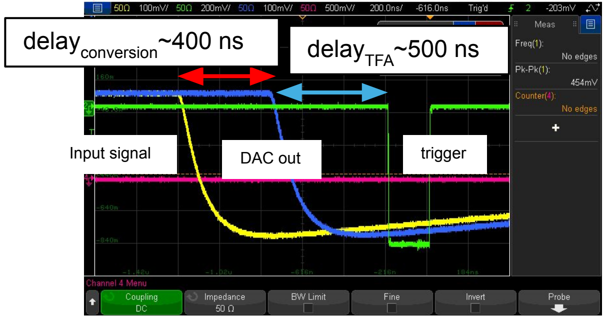
Digitizer VX2740



+

Programmable logic unit V2495





$\text{delay}_{\text{conversion}}$ ~400 ns

$\text{delay}_{\text{TFA}}$ ~500 ns

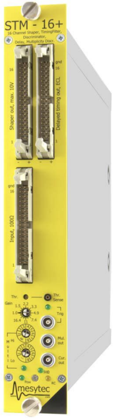
Input signal

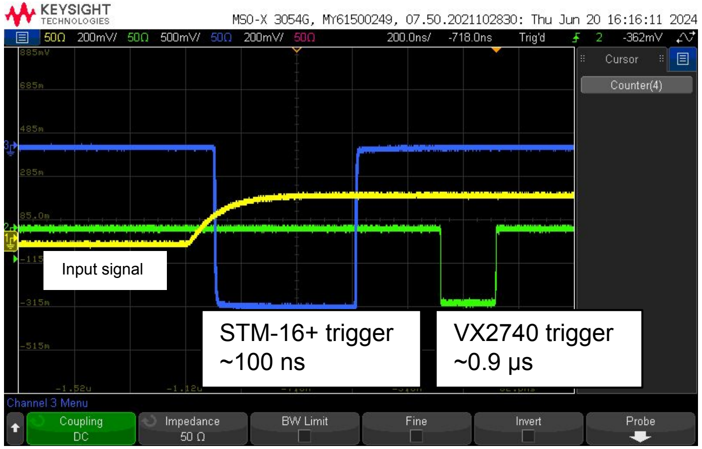
DAC out

trigger

Trigger generation takes ~μs

① Fast discrimination using Mesytec STM-16+





Input signal

STM-16+ trigger ~100 ns

VX2740 trigger ~0.9 μs

“Intelligent” trigger cannot be made.

- (p,pX): recoil × cluster → OK
- (p,$3p$) → ???

② Implementation of Mira QDC or “delayed gating” in HOD.

→ Talk on 16th: “Upgrade of SAMURAI DAQ”

Schedule

Experiment

2024 Sep.

2024 Oct. SπRIT ^{136}Xe+Sn

2024 Dec. { TOGAXSI commissioning
ONOKORO $^{50-52}$Ca(p,pX)

↓ ?

~~2025 Mar.~~

2025 Apr. Miki/Duer ^{6,8}He(p,3p)$^{4,6}n$

2025 Oct. STRASSE ^{56}Ti(p,3p)^{54}Ca(0_2^+)

↕ ?

ONOKORO N = Z / unstable Sn

TOGAXSI construction

↓

- 64 GAGGs, Recoil Si

"Demonstrator": 2/6 array

↓

- Cluster Si (2 of 3 layers)
- ΔE plastic
- +10 (IBS) +10 (PKU)
  +25 GAGGs (109 in total)

"1st generation": 4/6 array

↓

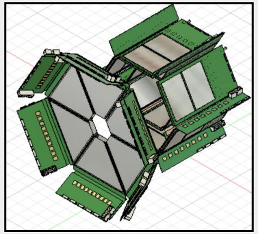
- 138 GAGGs are needed.
  (+29 more)

"Full array": 6/6 array

Schedule

Experiment

- Readiness of the Si detector



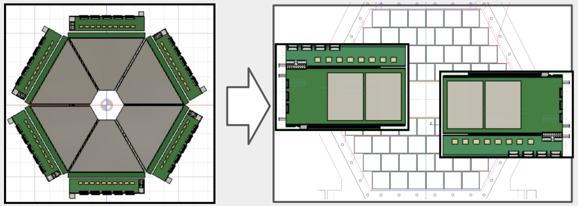
Recoil Si … already commissioned.

Cluster Si … not yet delivered.
→ Recoil Si will be used instead.

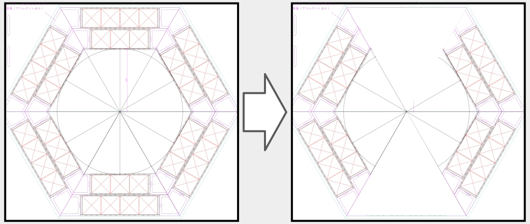
- # available GAGGs: **84** = **64** (RIKEN) + **10** (IBS) + **10** (PKU)
  - Recoil: 7/seg, 4 seg.
  - Cluster: ~18/seg, 2 seg.
  - ΔE (cluster): 4/seg, 2 seg.

→ Requires **72** in total

Cluster part: 6/6 → ~2/6



Recoil part: 6/6 → 4/6



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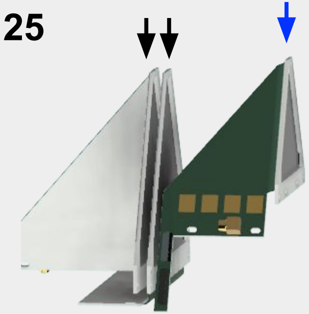
Schedule

Experiment

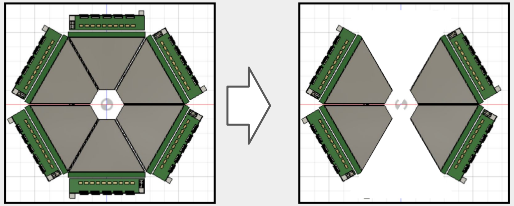
- Cluster Si (2 of 3 layers) will be ready.
  - Is the missing 1st layer necessary for tracking?
→ Simulation is ongoing (Pohl).
  - Budget funded (Miki), but production not yet started.

- # available GAGGs: **109** = 64 + 10 + 10 **+ 25**
  - **+25** crystals will be delivered.
  - Recoil: 7/seg, 4 seg.
  - Cluster: 19/seg, 4 seg.

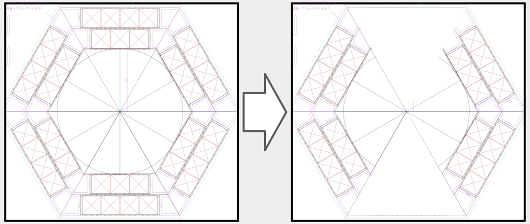
→ Requires **104** in total



Cluster part: 6/6 → 4/6



Recoil part: 6/6 → 4/6



TOGAXSI construction

- 64 GAGGs, Recoil Si

“Demonstrator”: 2/6 array

- Cluster Si (2 of 3 layers)
- ΔE plastic
- +10 (IBS) +10 (PKU)
+25 GAGGs (109 in total)

“1st generation”: 4/6 array

- 138 GAGGs are needed.
(+29 more)

“Full array”: 6/6 array

Schedule

Experiment

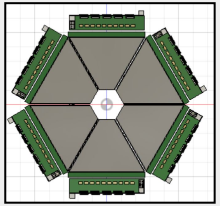
- # available GAGGs: **109**
  - Recoil: 7/seg, 6 seg.
  - Cluster (side): 14 (19)/seg, 4 seg.
  - Cluster (top/bottom): 10/seg, 2 seg.

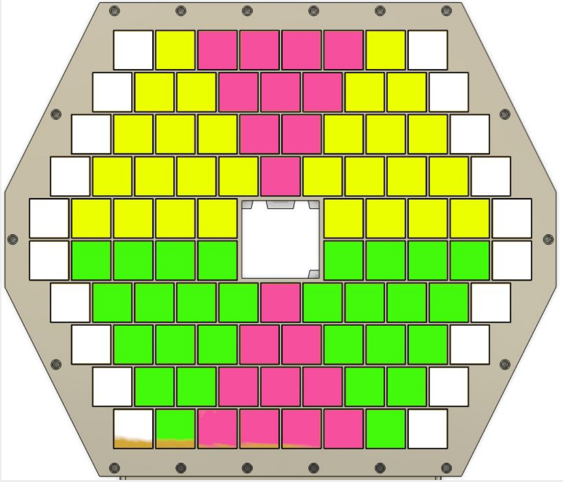
→ Requires **118 (138)** in total

→ +9 (29) GAGGs are needed to complete the full array.

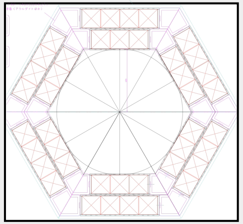
15 kUSD/crystal → 135 (435) kUSD

Cluster part: 6/6





Recoil part: 6/6



TOGAXSI construction

- 64 GAGGs, Recoil Si

“Demonstrator”: 2/6 array

- Cluster Si (2 of 3 layers)
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  +25 GAGGs (109 in total)

“1st generation”: 4/6 array

- 138 GAGGs are needed.
  (+29 more)

“Full array”: 6/6 array

Commissioning

- Will be proposed to the coming MT committee meeting
- Secondary beams: *p*, *d*, *t*, ^{3}He, *α*, ^{12}C or ^{16}O
- Intensity: 1 kcps (tuning) ~ 1 Mcps (trigger rate measurement)
- Beam time request: 1.0 days
  - 6 h: startup of detector, electronics, trigger
  - 6 h: *p-X* elastic scattering for *p*, *d*, *t*, ^{3}He, *α*
    - Energy calibration of GAGG
    - Alignment of Si tracker
  - 12 h: First (*p,pX*) in inverse kinematics (^{12}C or ^{16}O)

Summary

- ONOKORO: clustering in heavy nuclei via knockout reaction
- TOGAXSI: detector array for cluster knockout in inverse kinematics
    - Demonstrator in summer 2024
    - 1st generation in spring 2025
- First SAMURAI experiment in December 2024
- We welcome new collaborators and GAGGs! onokoro-contact@ml.riken.jp
    - Kickoff meeting for RIBF exp. on **July 23 (Tue) 16:30 (JST) / 9:30 (CEST)**