Development of a new active target TPC: AToM-X

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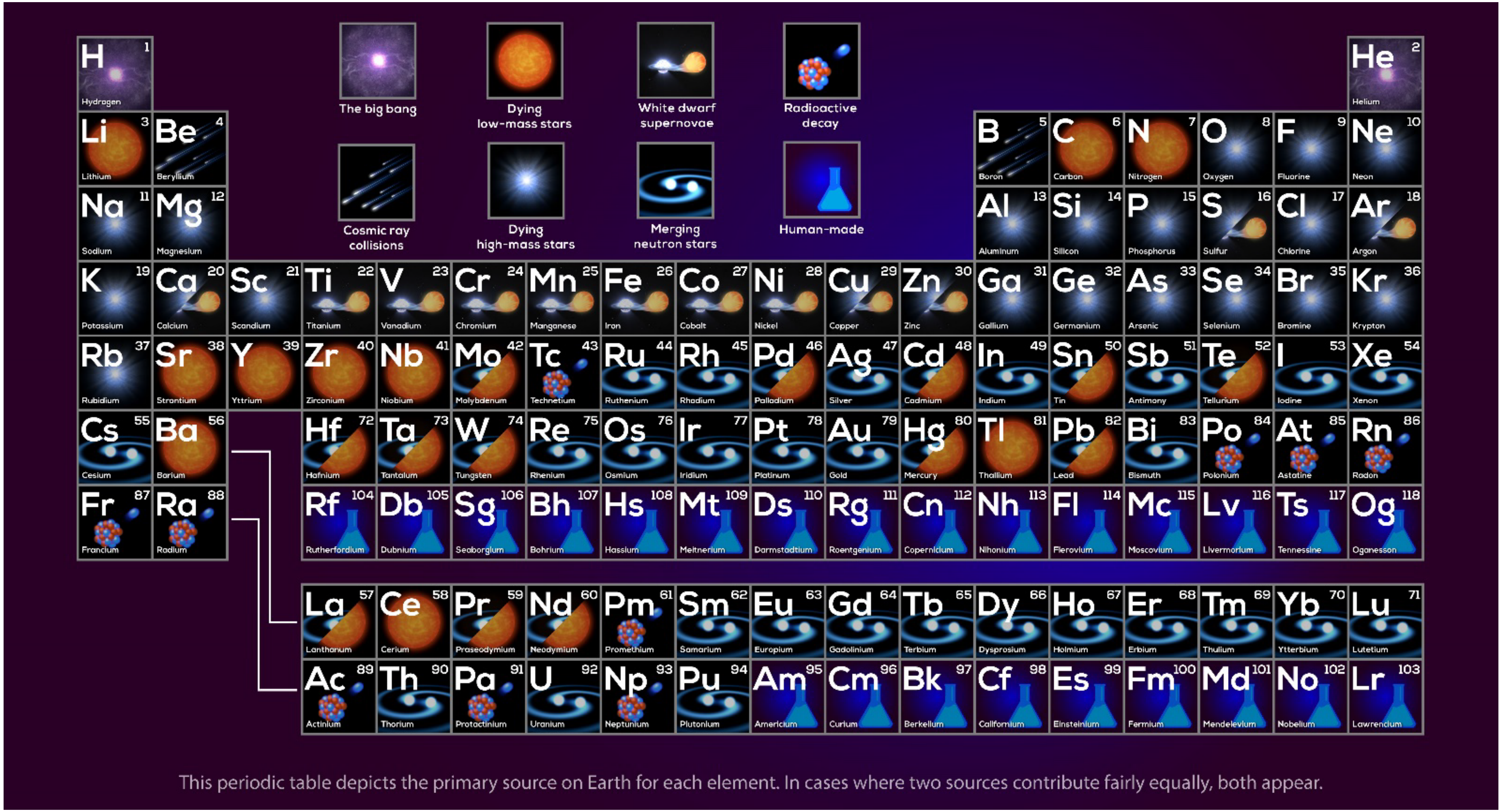
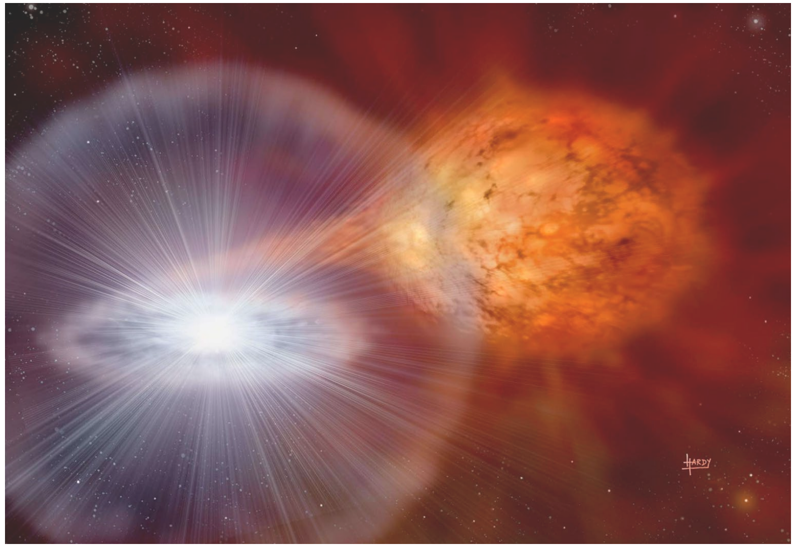
Center for Exotic Nuclear Studies, Institute for Basic Science
on behalf of AToM-X collaboration

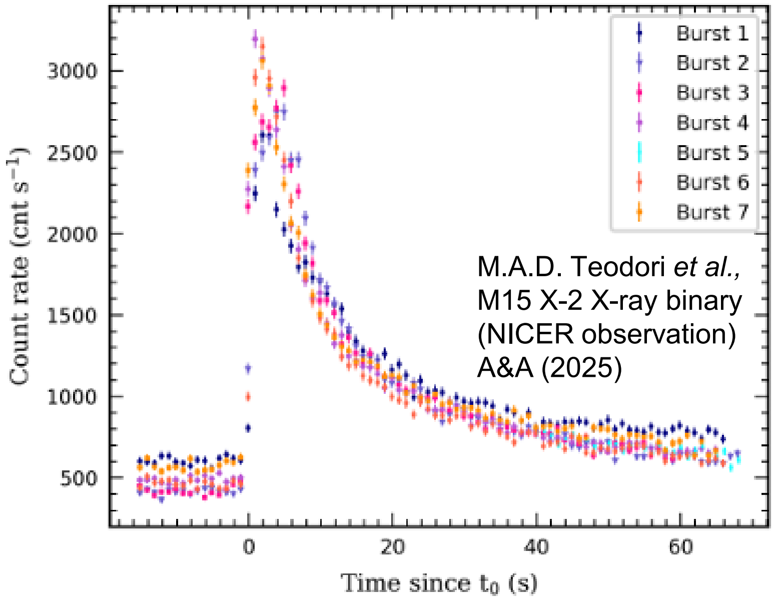
Origin of Elements: Nucleosynthesis during the stellar evolution



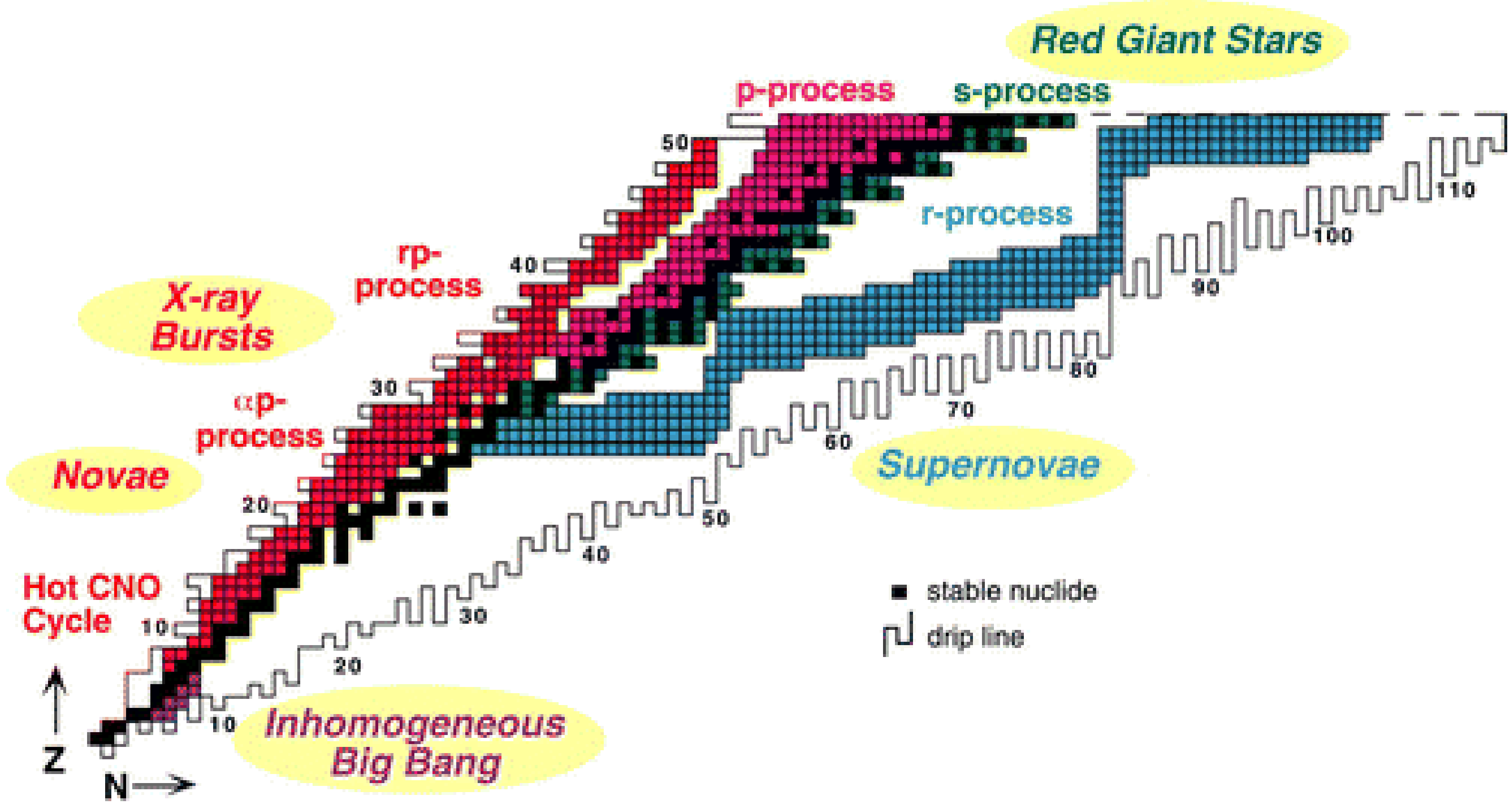
Credit: NASA's Goddard Space Flight Center

Origin of Elements: Nucleosynthesis during the stellar evolution





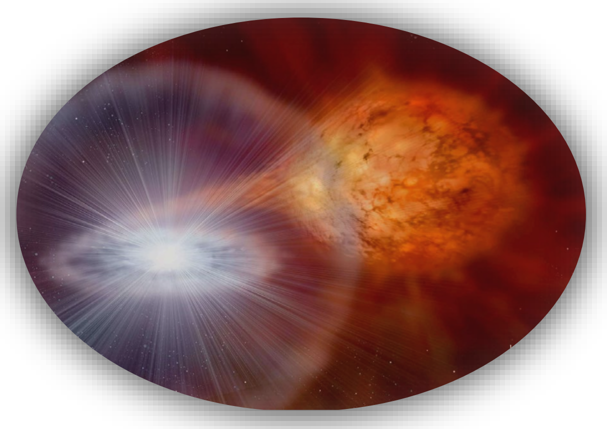
M.A.D. Teodori *et al.*,
M15 X-2 X-ray binary
(NICER observation)
A&A (2025)

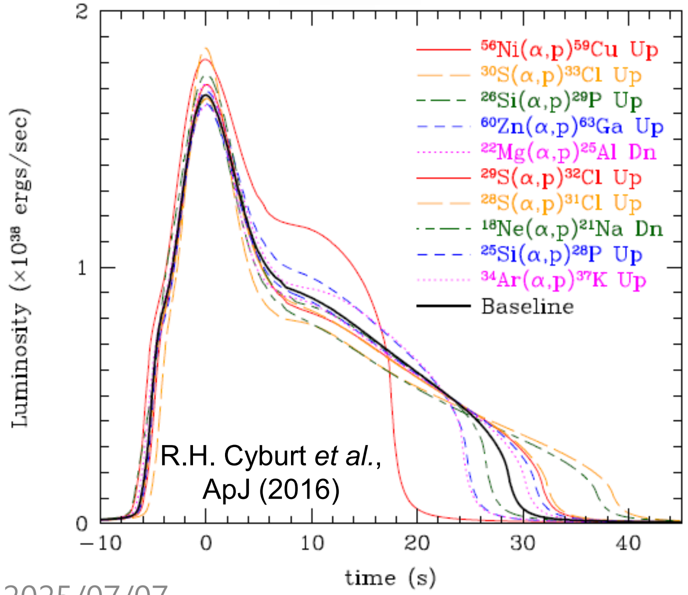


- **Nuclear physics input for understanding:**
  - ✓ **Nucleosynthesis processes**
  - ✓ **Characteristics of stellar environments**

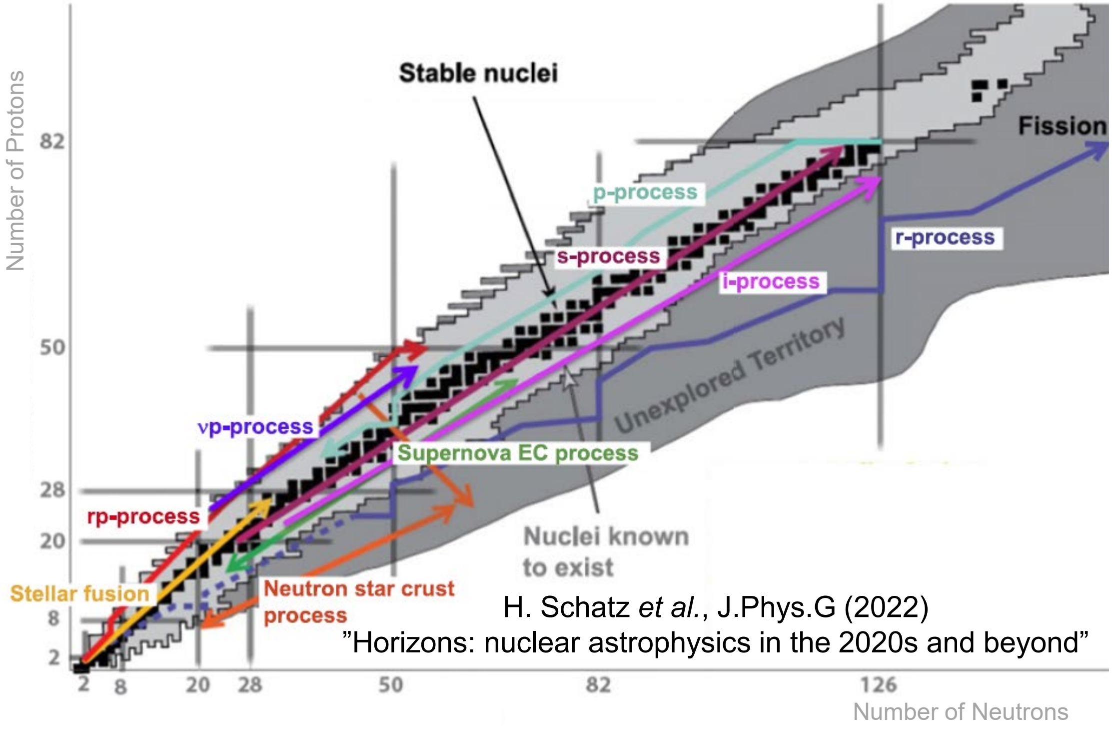
Importance of (α,p) reactions for astrophysics

- (α,p) reaction rates play an important role in understanding:
  - ✓ **Light curve, burst ashes of the X-ray burst**
  - ✓ **Nucleosynthesis in the core-collapse supernovae**





R.H. Cyburt *et al.*, ApJ (2016)



H. Schatz *et al.*, J.Phys.G (2022) "Horizons: nuclear astrophysics in the 2020s and beyond"

Very small reaction cross sections → Challenging experiments!

Reaction Rate Variations that Affect Three or More Isotopes of Interest

Reaction	Number of Isotopes Affected
^{12}C(α,γ)^{16}O	8
α(2α,γ)^{12}C	8
^{16}O(^{12}C,p)^{27}Al	8
^{13}N(α,p)^{16}O	7
^{27}Al(α,n)^{30}P	6
^{20}Ne(α,γ)^{24}Mg	6
^{44}Ti(α,p)^{47}V	5
^{42}Ca(α,γ)^{46}Ti	5
^{16}O(^{12}C,α)^{24}Mg	5
^{48}Cr(α,p)^{51}Mn	4
^{23}Na(α,p)^{26}Mg	4
^{53}Fe(n,p)^{53}Mn	3
^{52}Fe(α,p)^{55}Co	3
^{33}S(n,α)^{30}Si	3
^{30}Si(p,γ)^{31}P	3
^{28}Si(n,γ)^{29}Si	3
^{28}Al(p,α)^{25}Mg	3
^{27}Si(n,^{12}C)^{16}O	3
^{27}Al(α,p)^{30}Si	3
^{26}Mg(α,n)^{29}Si	3
^{25}Mg(p,γ)^{26}Al	3
^{25}Mg(n,γ)^{26}Mg	3
^{25}Mg(α,n)^{28}Si	3

K. Hermansen *et al.*, ApJ (2020)

Why Active Target Time Projection Chamber?

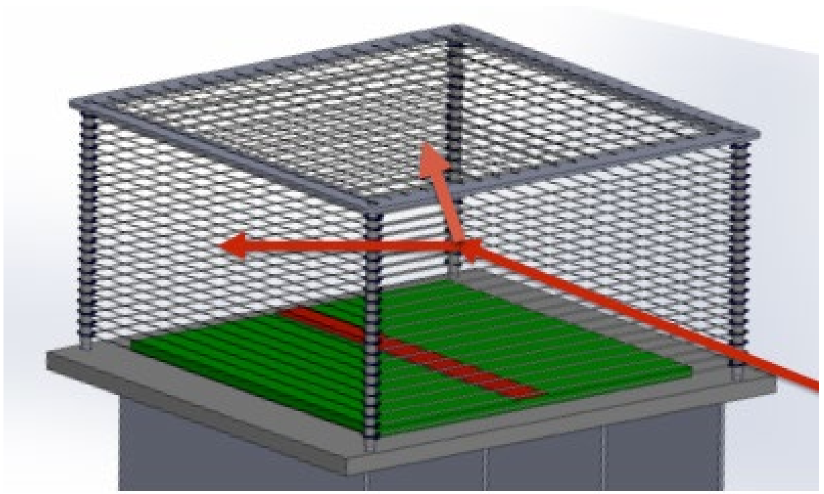
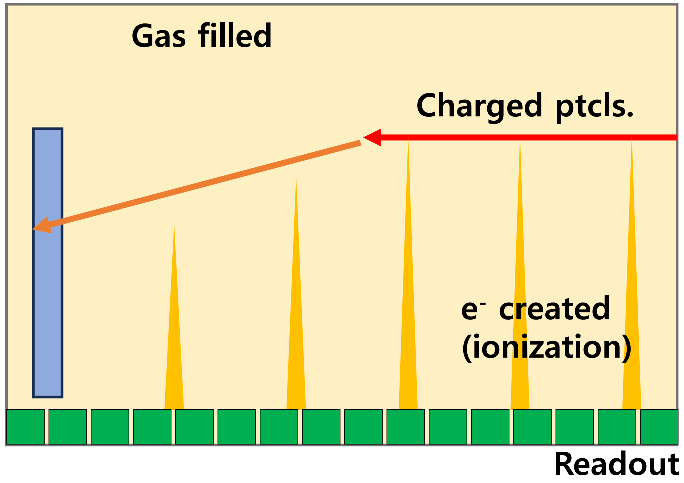
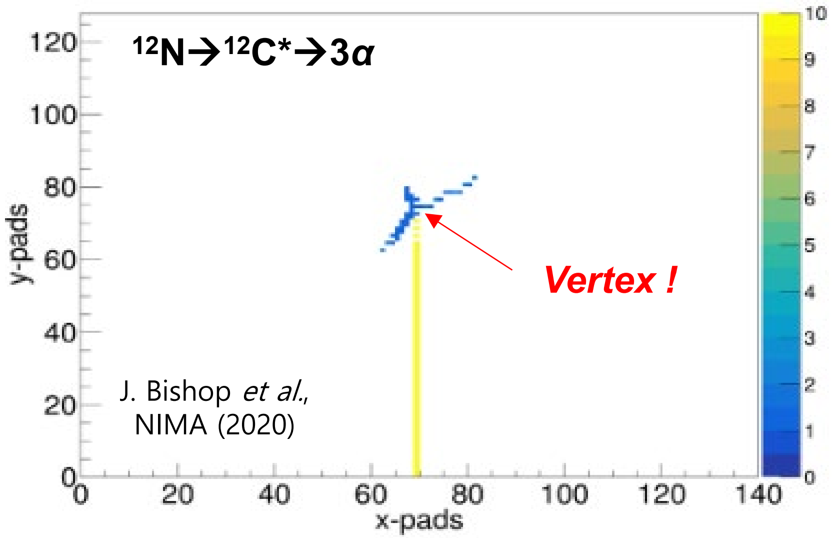


Figure from G.V. Rogachev



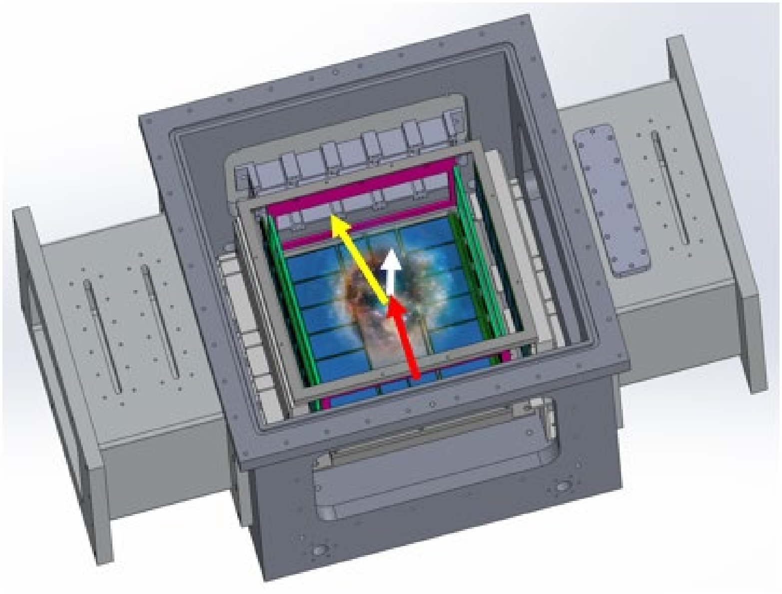


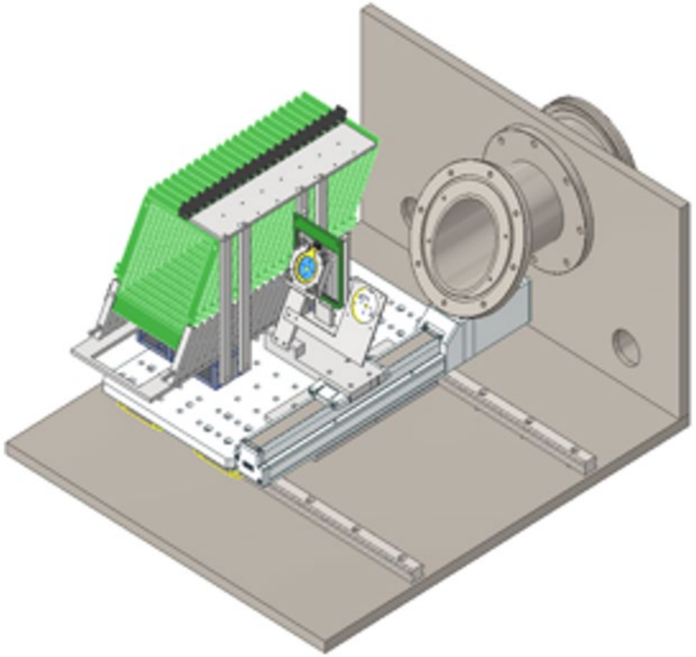
- **Active target TPC**
  - ✓ **Detection gas plays as a reaction target**
  - ✓ **3D tracking of charged particles (like 3D camera)**
    → reaction vertex measurement available

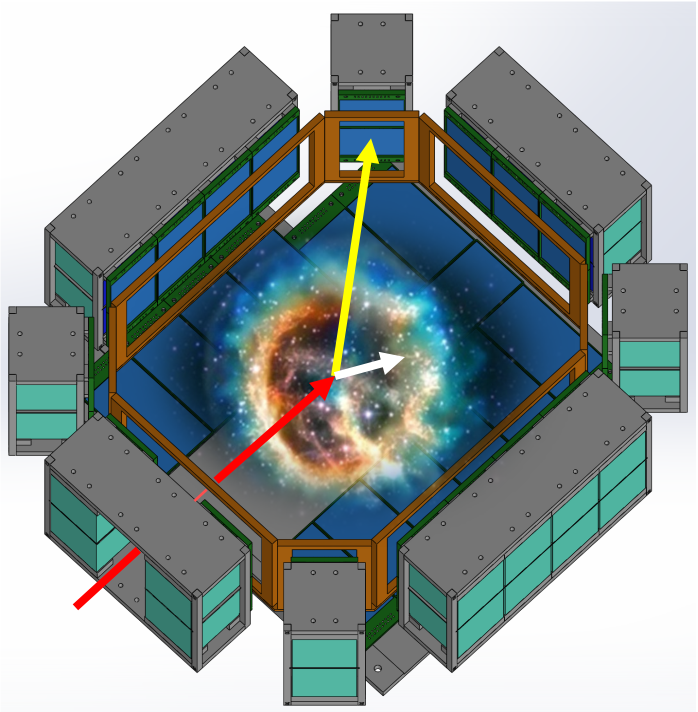
- **Challenges for direct (*α,p*) measurements**
  - ✓ **High detection efficiency**
  - ✓ **High beam rate endurable (~10^5 pps)**
  - ✓ **Good enough position and energy resolution**

Advanced AT-TPC Required !

Development of Active Target detectors at CENS







TexAT_v2

VOICE

AToM-X

Successfully used for $^{14}O(\alpha,p)^{17}F$ measurement !

Tomorrow, Talk by Chaeyeon Park ☺

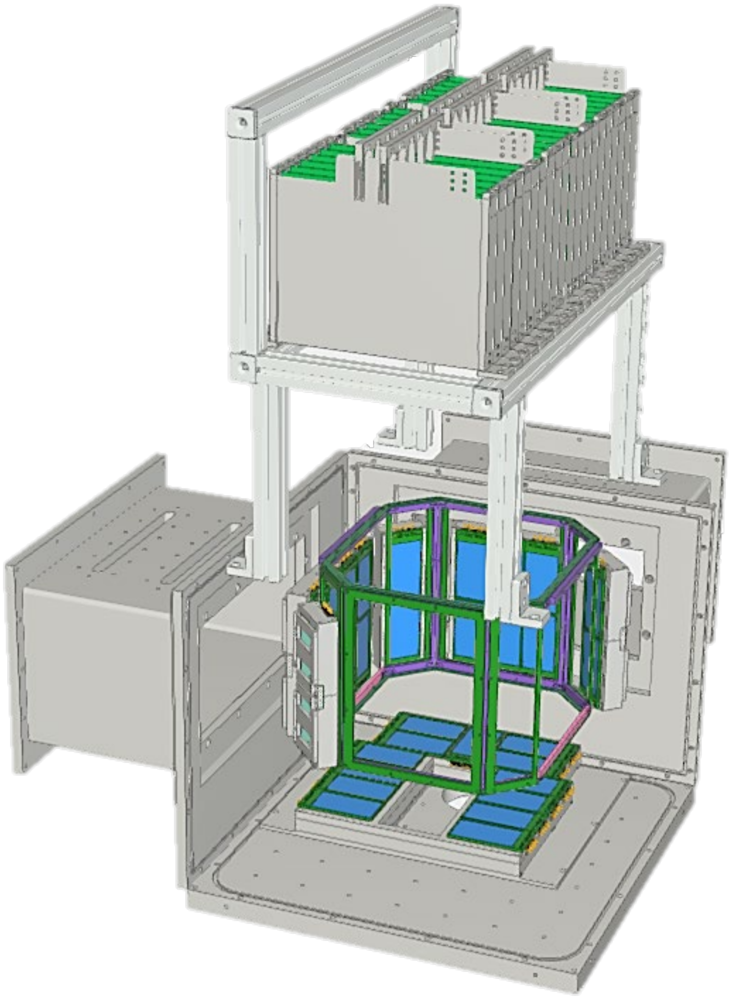
This talk ☺

AToM-X : Active target TPC for Multiple nuclear eXperiment

- Purpose?
  - ✓ Direct measurement of astrophysically important reactions : (α,p), (α,n), …
  - ✓ Elastic/Inelastic scatterings, fusion reactions, transfer reactions, charged particle decay, …

- Target gas: He+CO_2, CH_4, C_4H_{10}, CO_2, CD_4, Ar, ...

- Components:
  - ✓ Field cage
  - ✓ Micromegas *(Track measurement)*
  - ✓ Silicon and CsI detectors *(Energy, position measurement)*
  - ✓ Chamber, frames, Electronics(GET), DAQ, Softwares, ….
  - ✓ 5658 electronic channels in total *(4608 from Micromegas &1050 from aux. detectors)*



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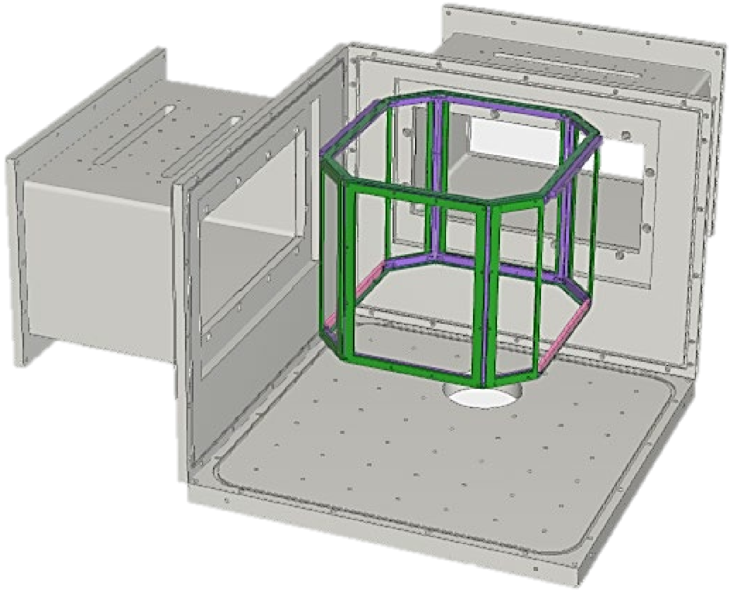

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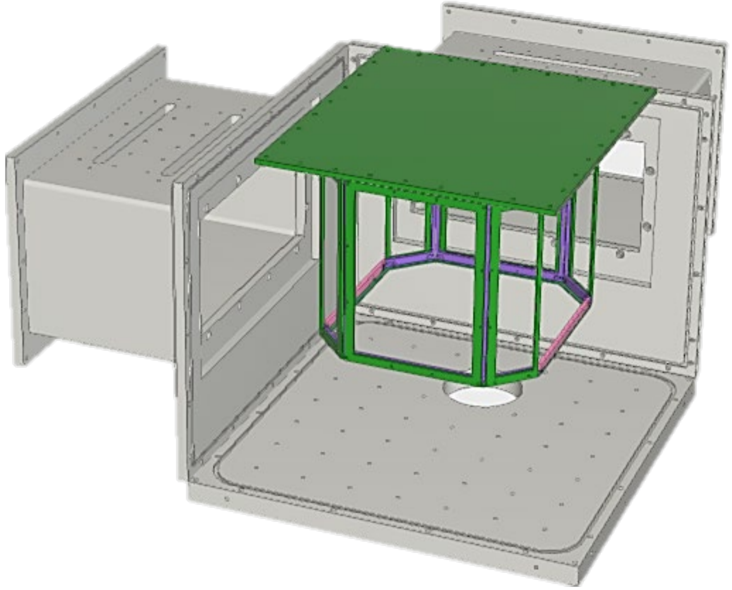

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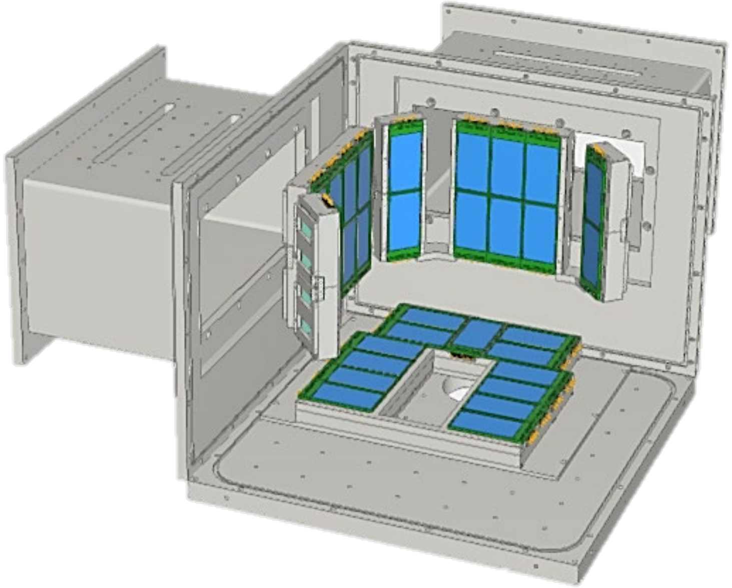

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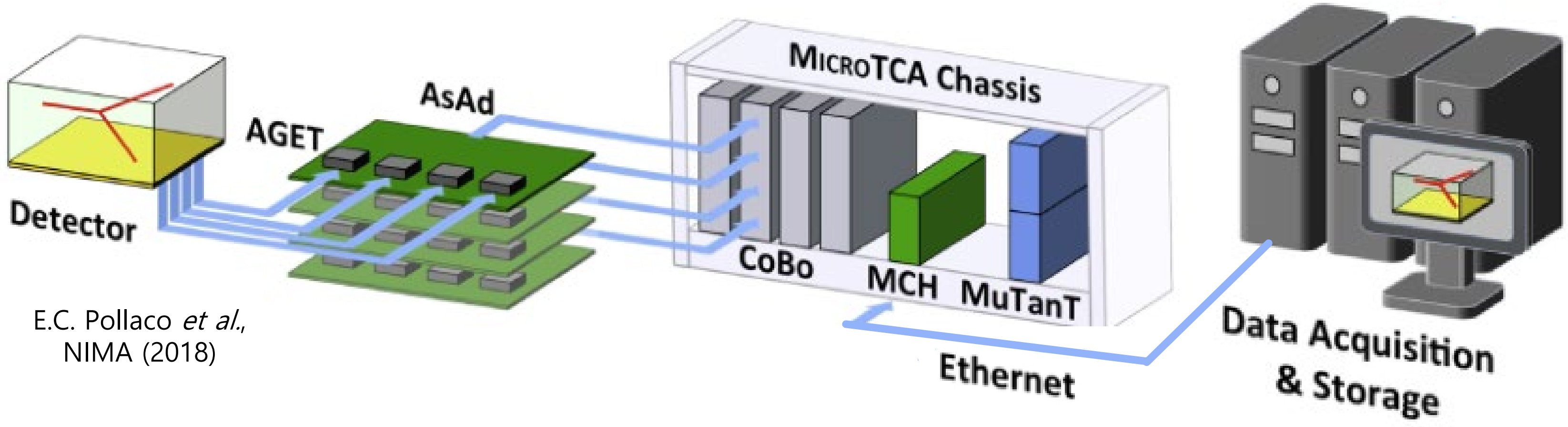
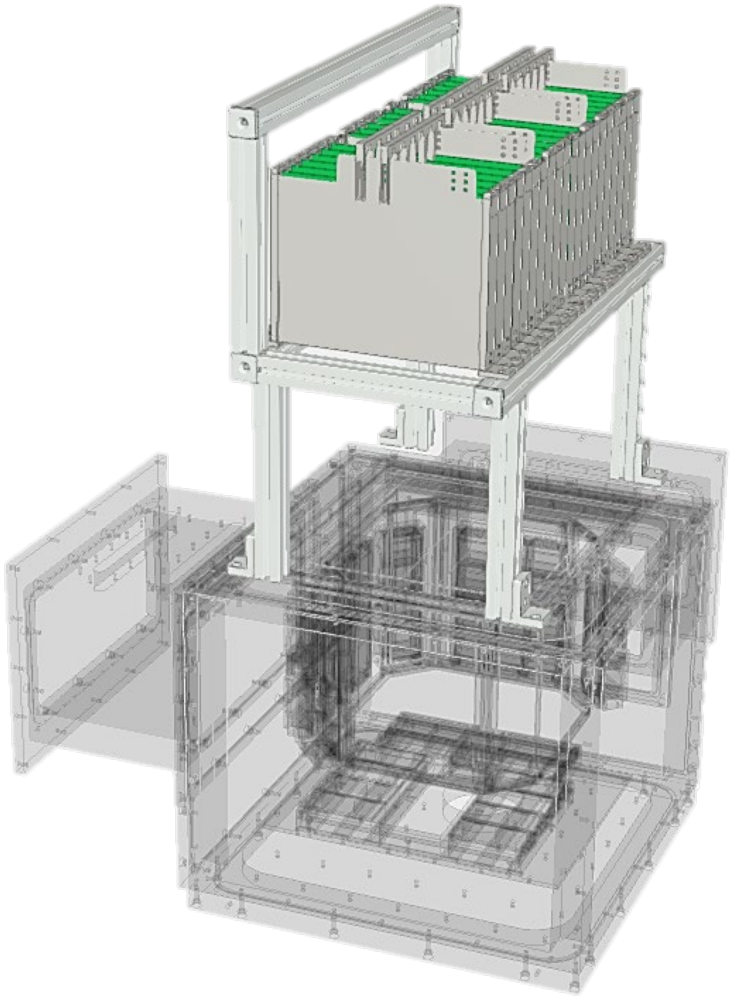


E.C. Pollaco *et al.*,
NIMA (2018)



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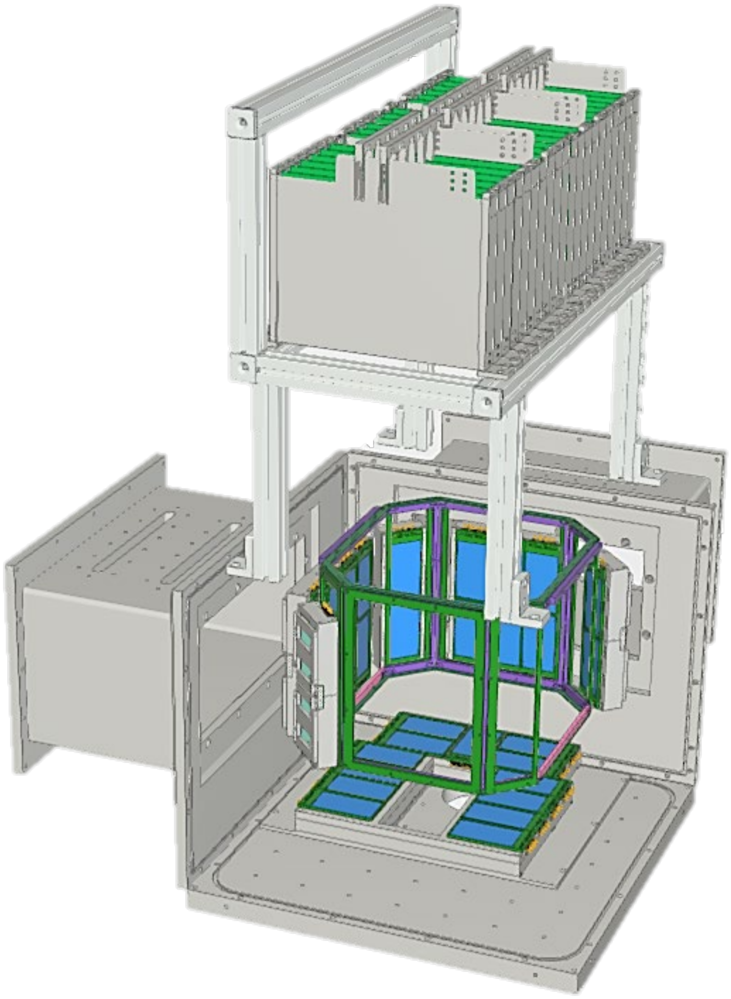
- **Dimensions :**
  - ✓ **Chamber : 504(X) x 417(Y) x 504(Z) mm^3**
  - ✓ **Wings for signal (ZAP) feed through : 236(X) x 270(Y) x 390(Z) mm^3**
  - ✓ **Assembly type→portable!**



ATOM-X : Active target TPC for Multiple nuclear eXperiment

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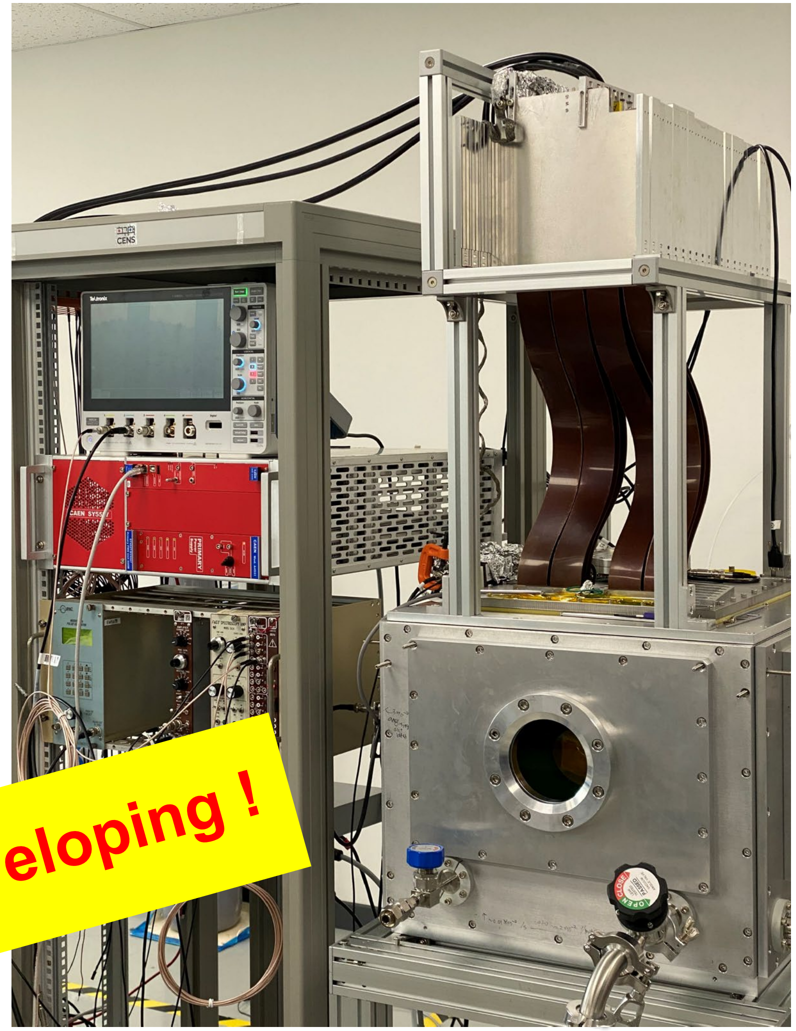
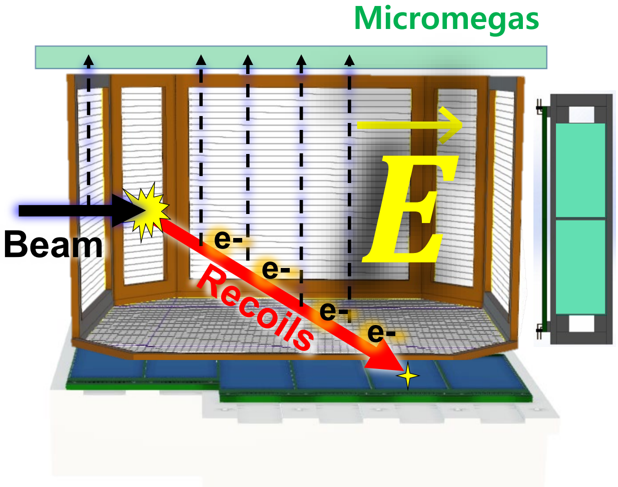
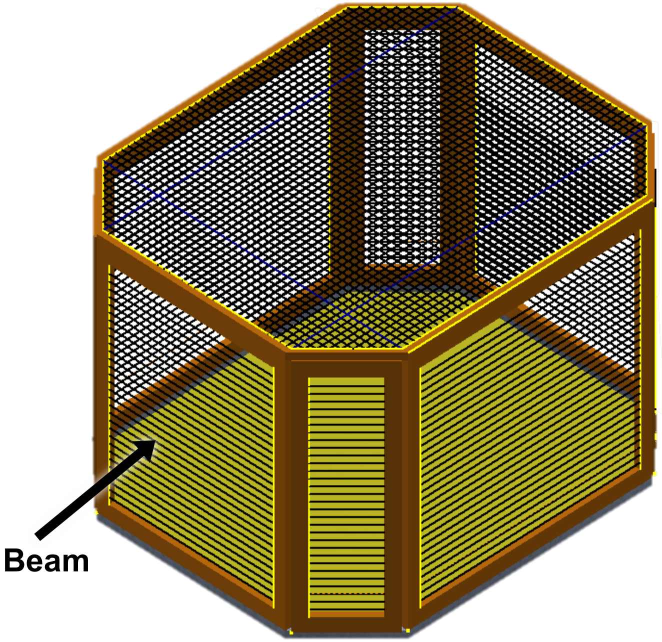


Now Developing !

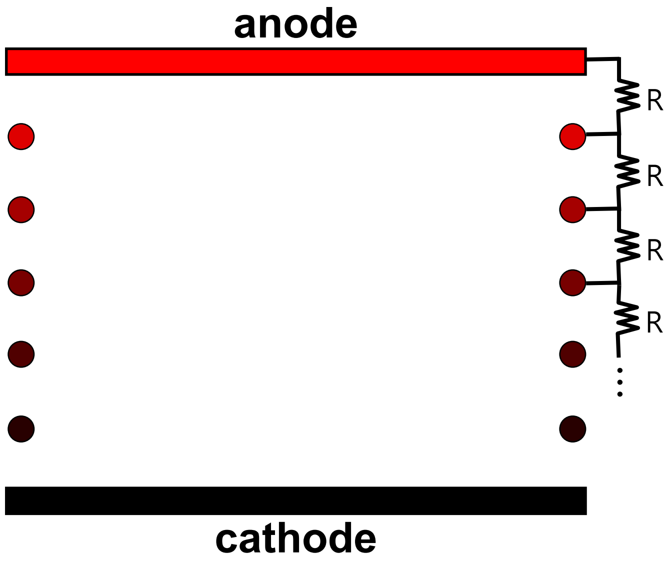
Field cage: Type-1





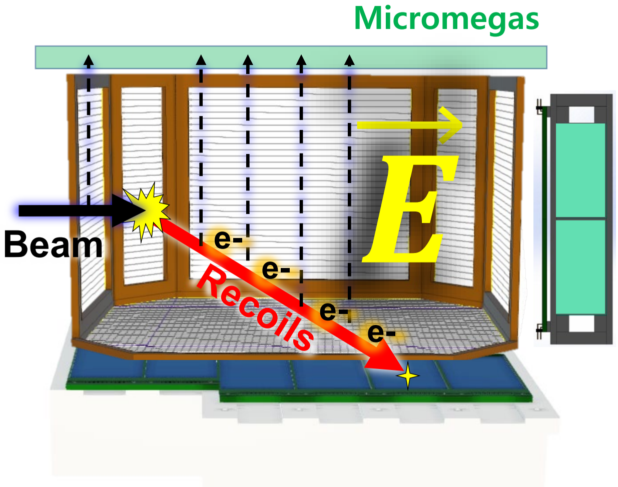
- **Providing uniform electric field in the active volume**
- **PCB boards + Polycarbonate frame**
- **cathode + anode + side planes**

- **Type-1 : Au-plated tungsten wires on PCB → Transparent !**
  ex) ^{34}Ar(α,p)^{37}K, ^{18}Ne(α,p)^{21}Na, ^{17}F(α,p)^{20}Ne, ...



guide wires at side planes
Stepping down the voltage for uniform $\vec{E}$

Field cage: Type-1



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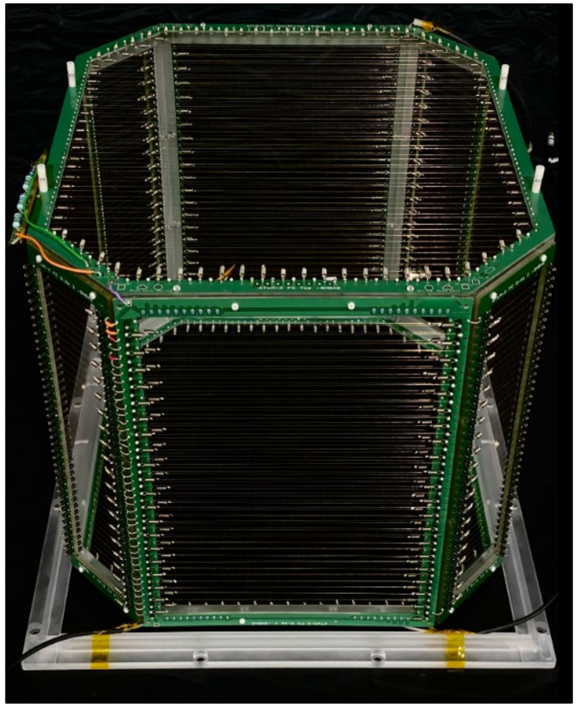
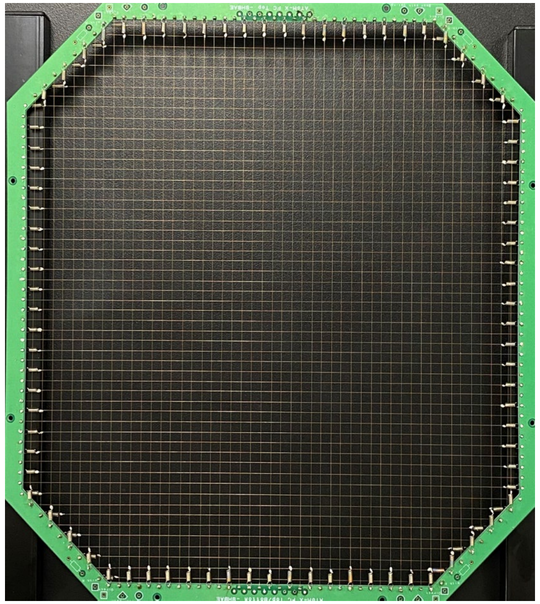
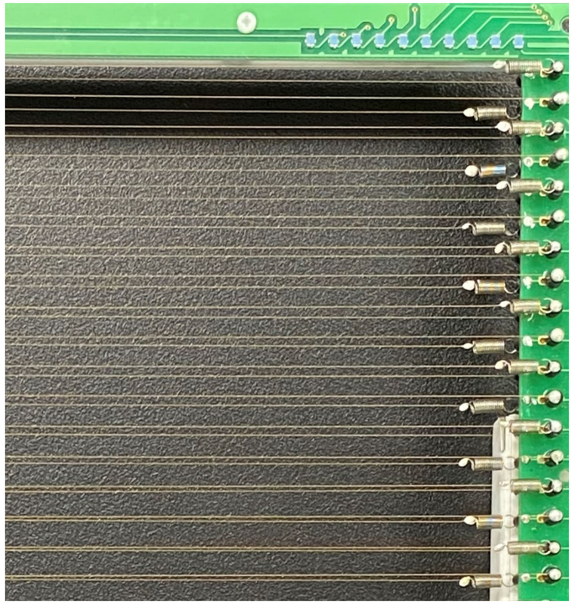
Narrow wire gaps at the beam region!

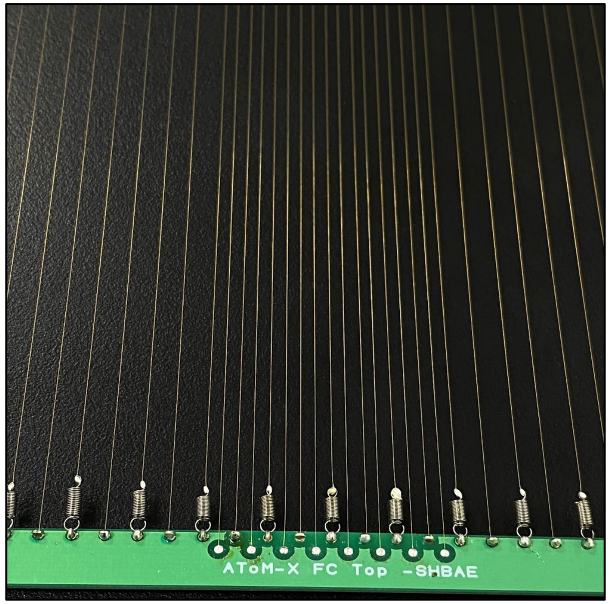




cathode

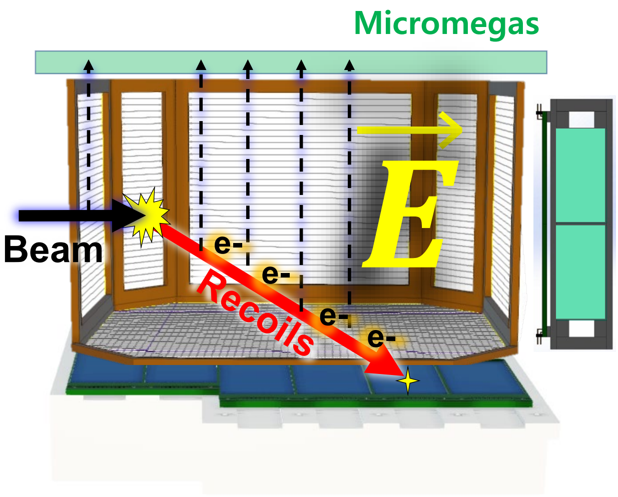


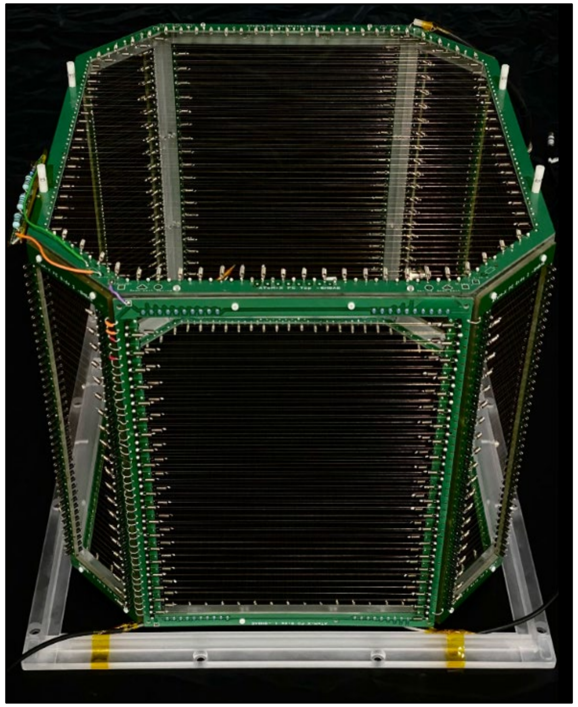
A part of side planes



A part of anode

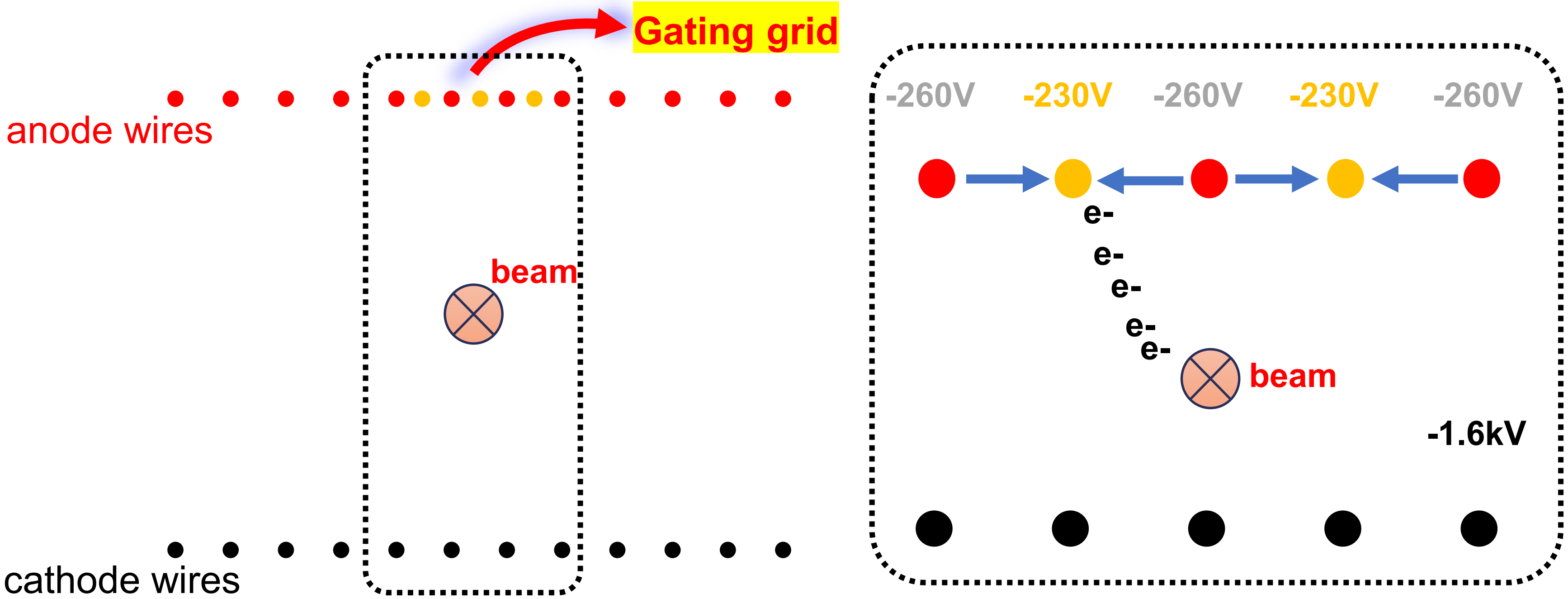
Field cage: Type-1





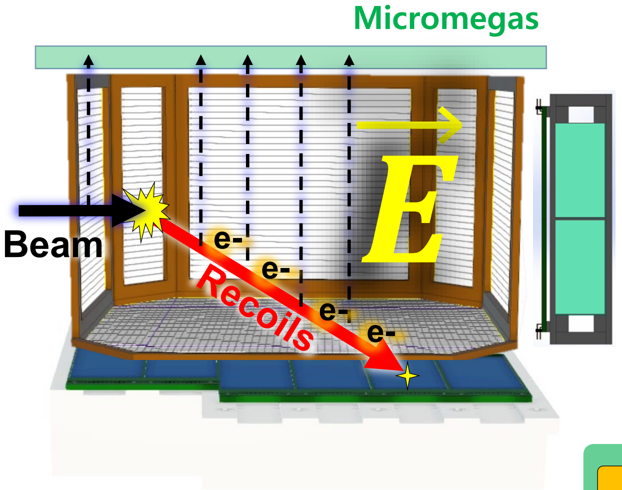
- Providing uniform electric field in the active volume
- PCB boards + Polycarbonate frame
- cathode + anode + side planes

- Type-1 : Au-plated tungsten wires on PCB → Transparent !
  ex) $^{34}Ar(\alpha,p)^{37}K$, $^{18}Ne(\alpha,p)^{21}Na$, $^{17}F(\alpha,p)^{20}Ne$, ...



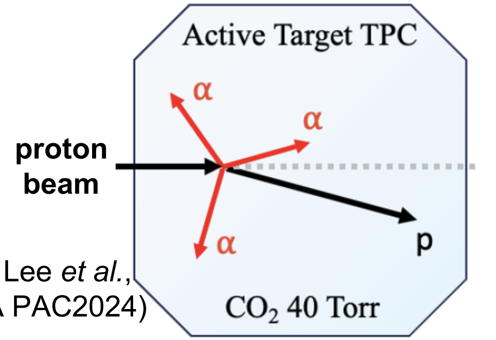
To reduce a huge amount of space charges from the high intensity beam !

Field cage: Type-2

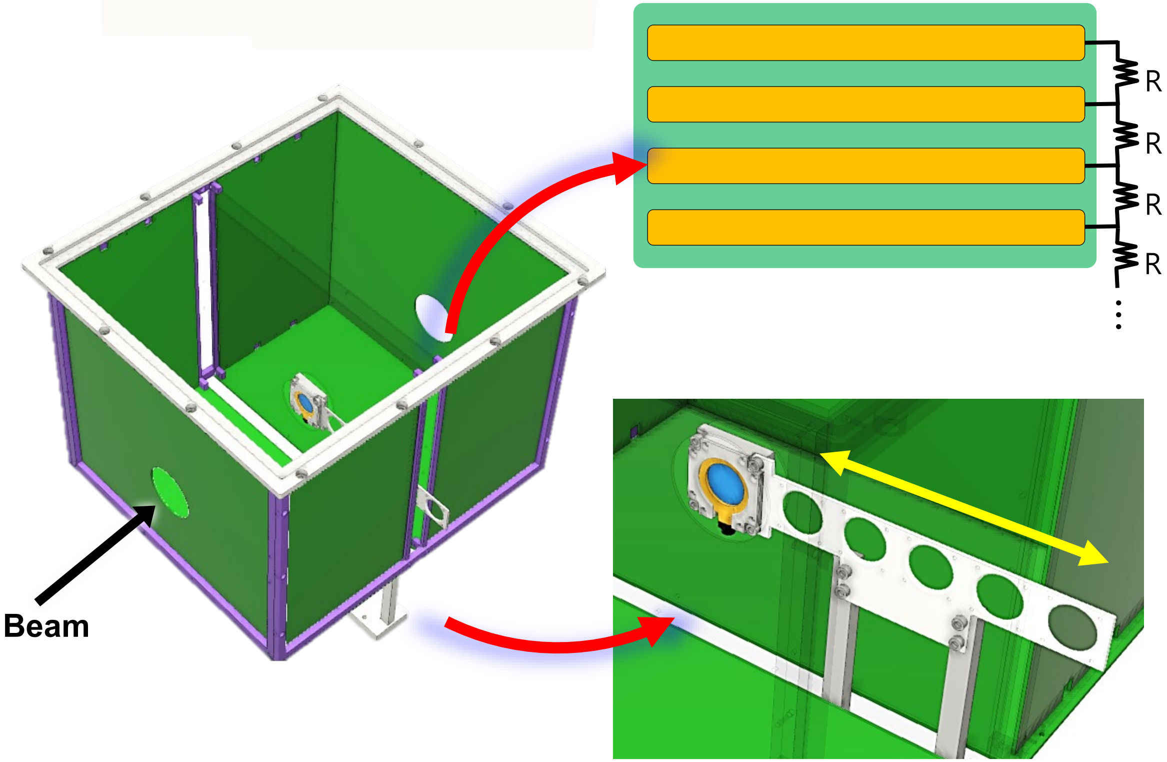


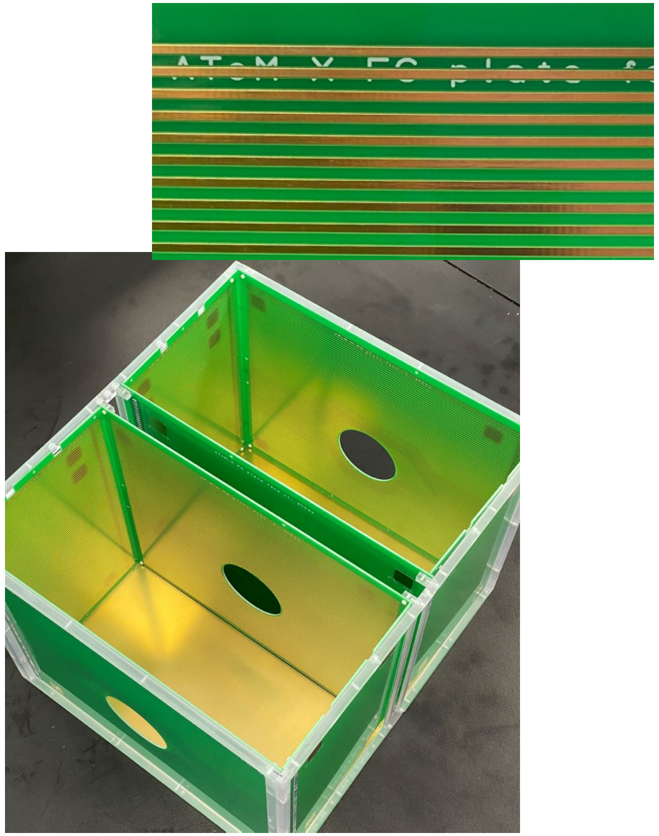
- Providing uniform electric field in the active volume
- PCB boards + Polycarbonate frame
- cathode + anode + side planes

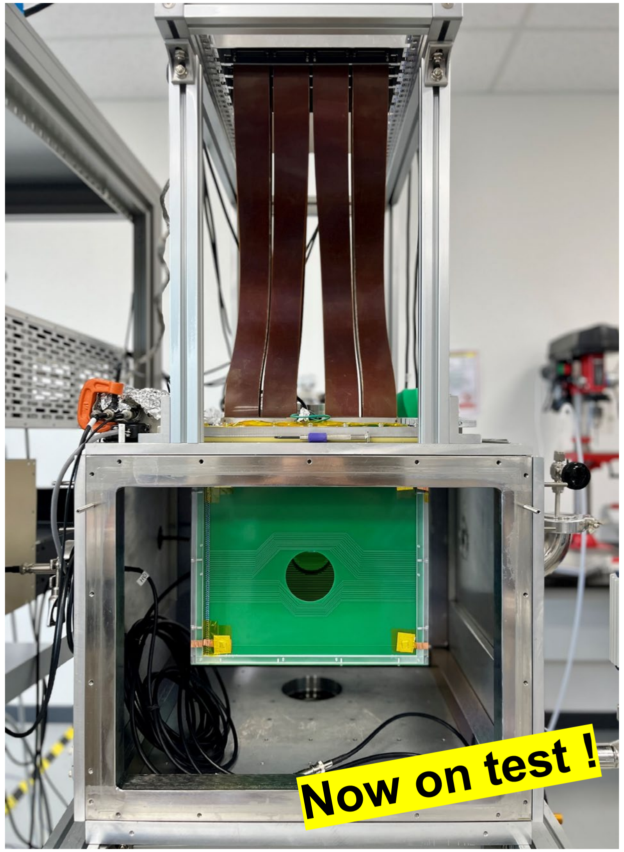
- Type-2 : Segmented copper plates on PCB
  ex) $^{12}C(p,p')^{12}C$, $^{3}He+^{208}Pb$, …



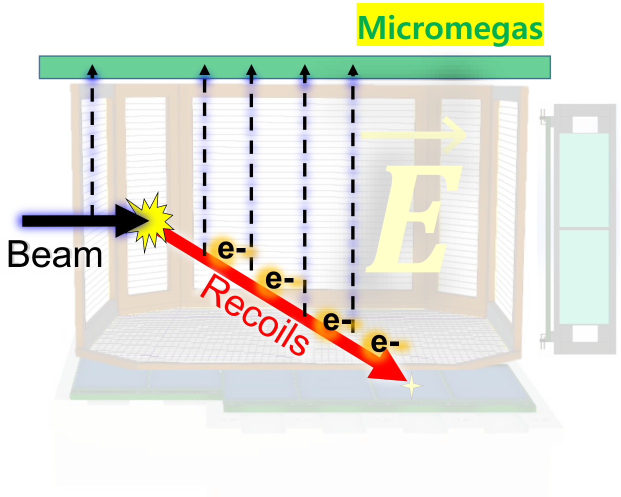
J.W- Lee *et al.*,
(JAEA PAC2024)



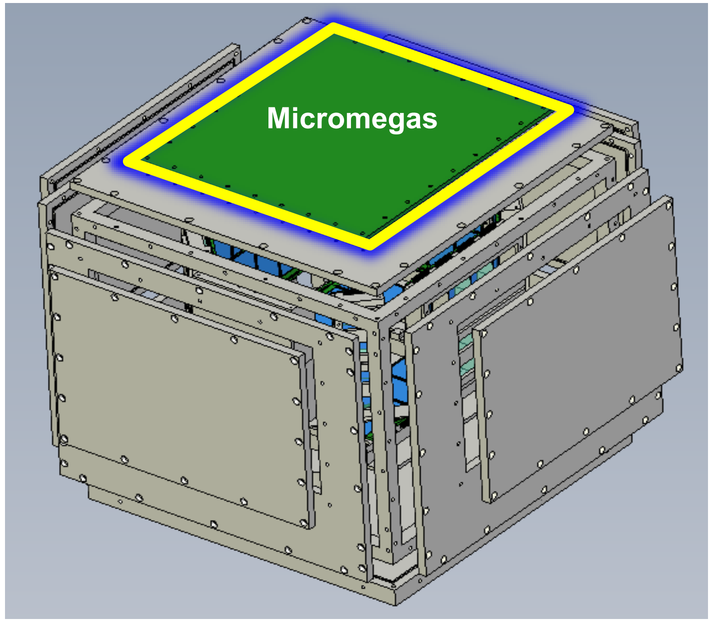


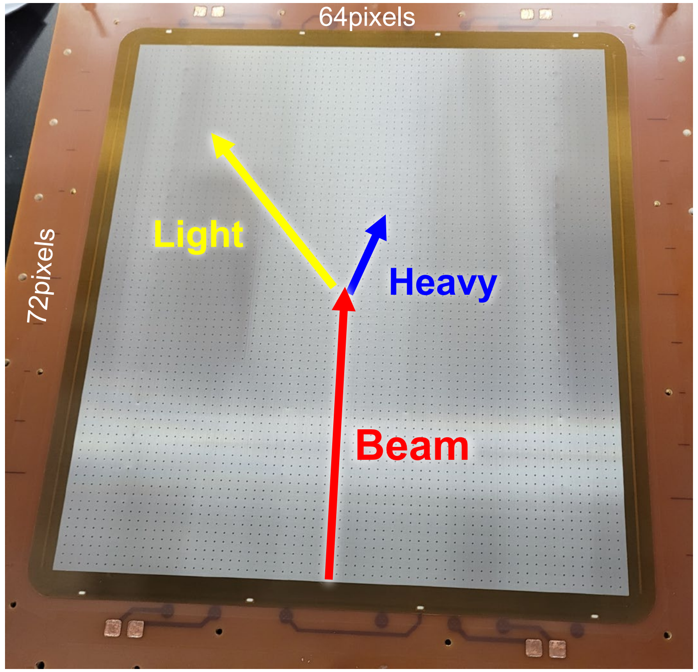


Micromegas

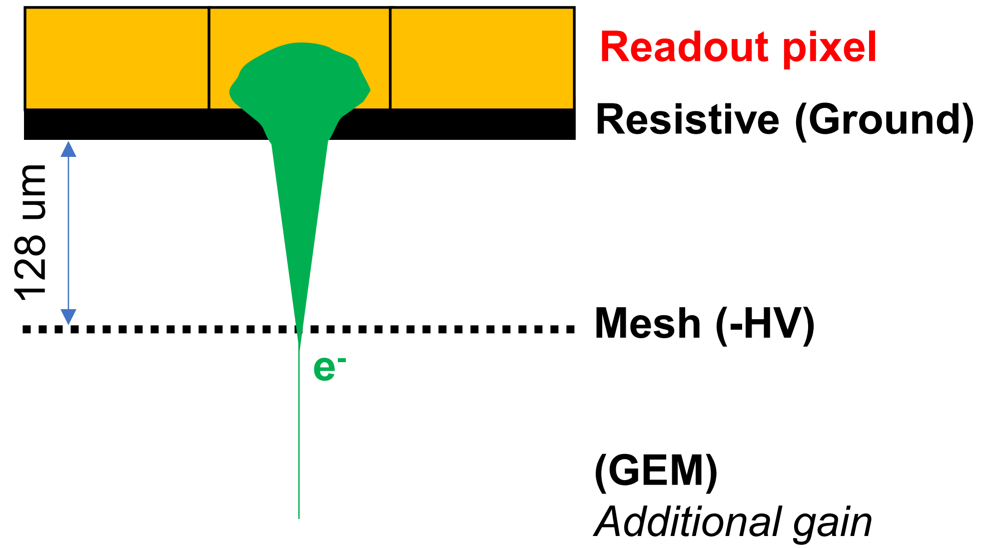


- **Tracking charged particles with readout pixels** *(beam, recoils, ...)*
- **Micromegas as a chamber flange**
- **Drift electrons from the ionization are amplified b/w mesh & readout.**
- **pixel size : 4 x 4 mm^2**
  - ✓ **Type-1 : Resistive**
  - ✓ **Type-2 : Resistive + Capacitive sharing** *(for better position resolution)*





Micromegas (front-inside chamber)



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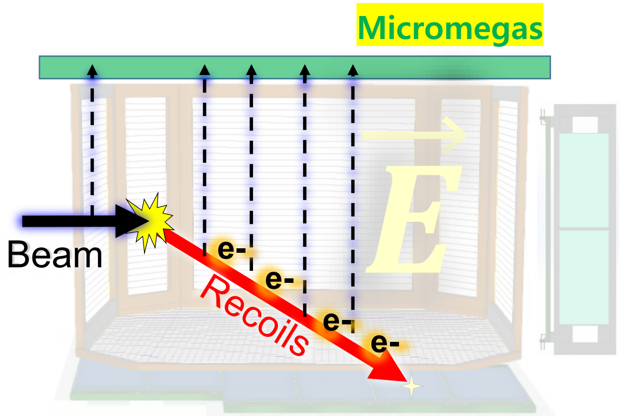

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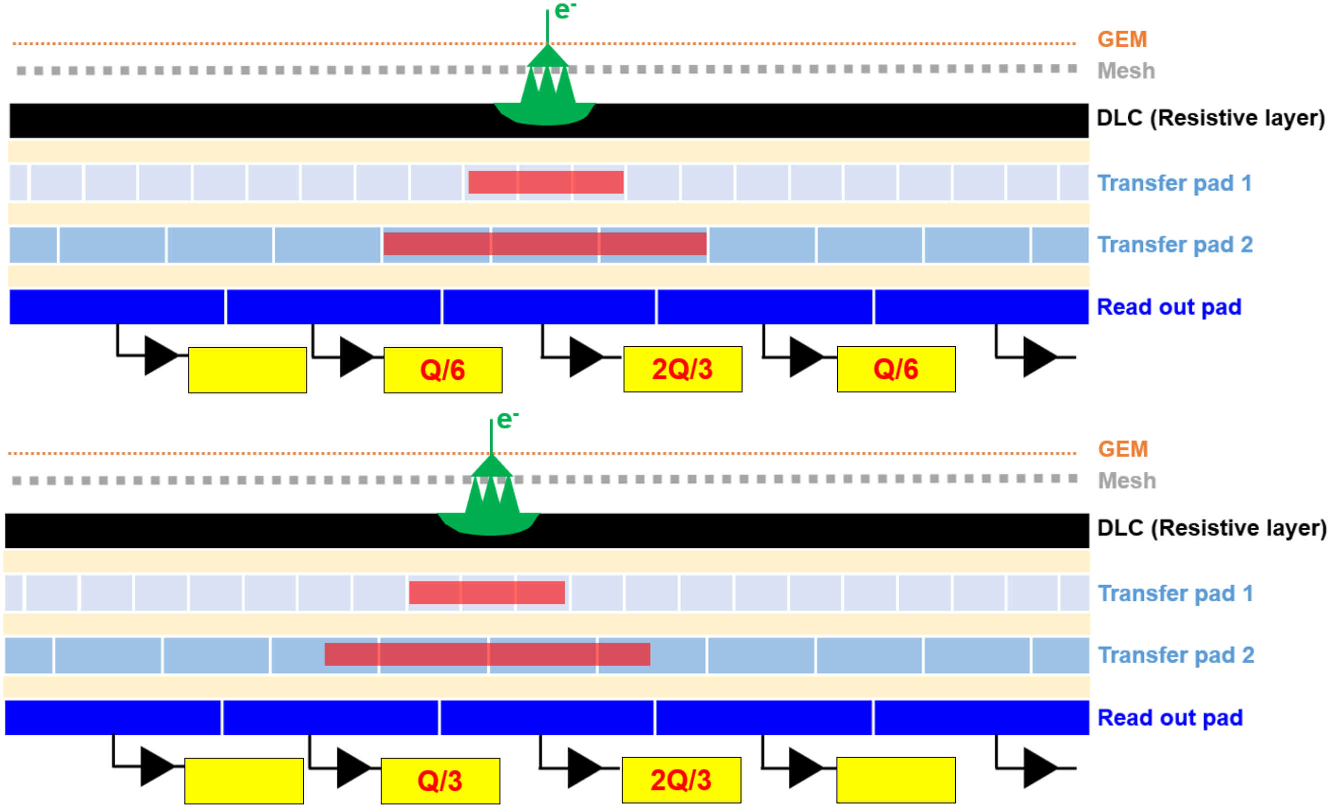
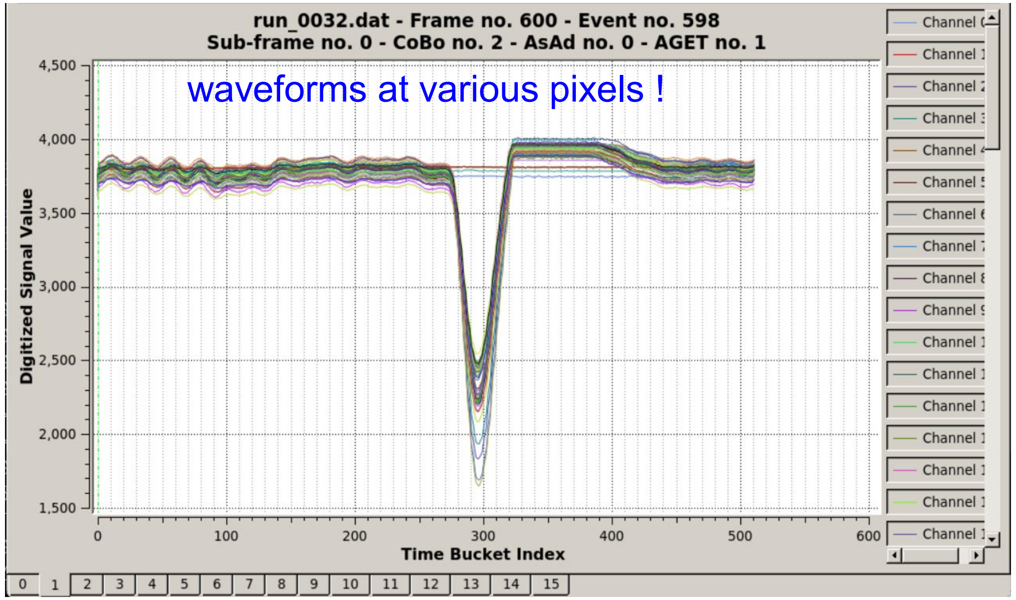


- ✓ **Hit information can be obtained by the different signal heights in multiple pads**
- ✓ **Reconstruction algorithm under development**
- ✓ **Expected position resolution < 1mm**

Micromegas

- **Test process**
  - ✓ **Pulser on mesh, checked wave forms at various pixels using GET + DAQ**
  - ✓ **Checked analog signals on the mesh using a ^{241}Am α source and a cathode plate**
  - ✓ **Obtained the track of α particles on the readout pad using GET + DAQ**
  - ✓ **Obtained the track using our newly-made field cage!**



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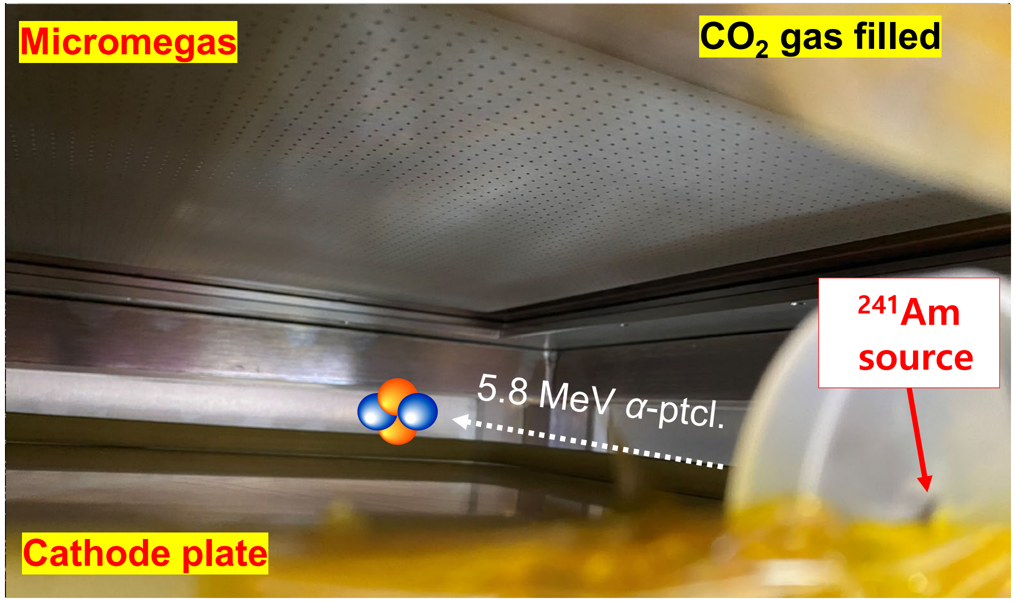
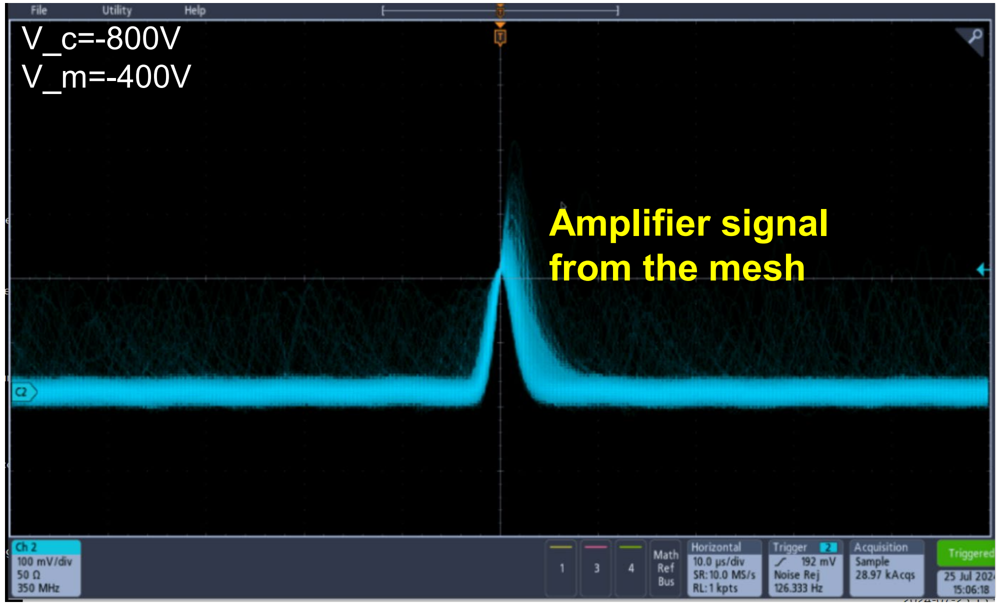
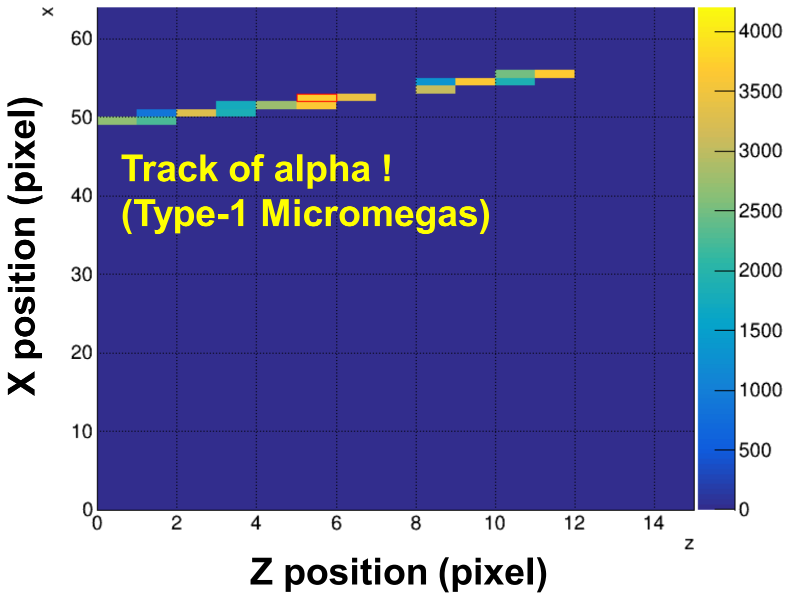
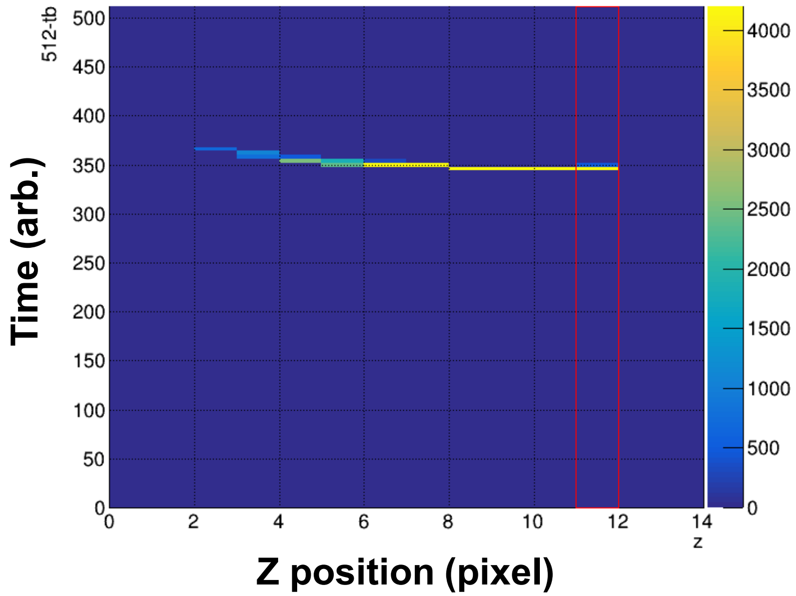


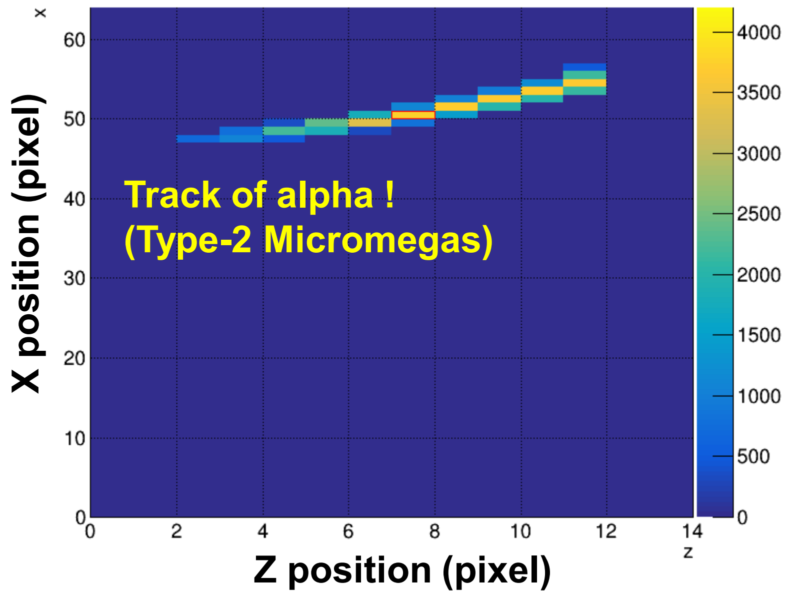


Micromegas

- **Test process**
  - ✓ **Pulser on mesh, checked wave forms at various pixels using GET + DAQ**
  - ✓ **Checked analog signals on the mesh using a ^{241}Am *α* source and a cathode plate**
  - ✓ **Obtained the track of *α* particles on the readout pad using GET + DAQ**
  - ✓ **Obtained the track using our newly-made field cage!**



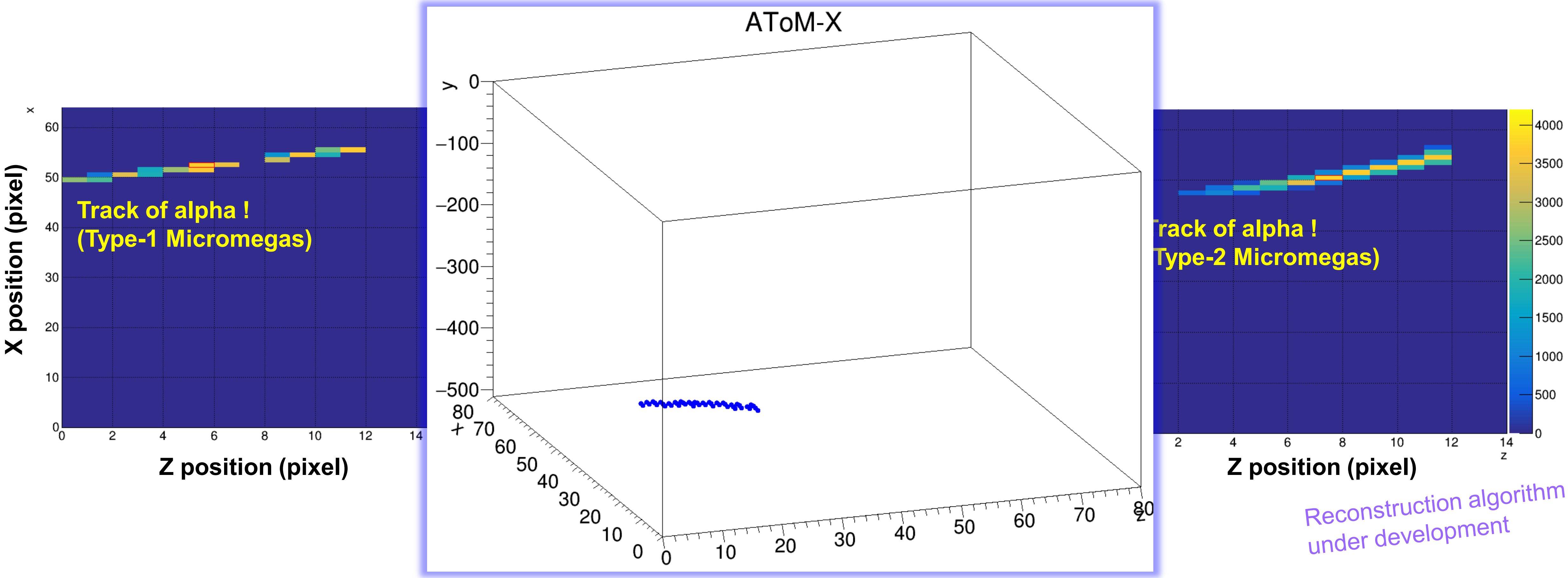




Reconstruction algorithm under development

Micromegas

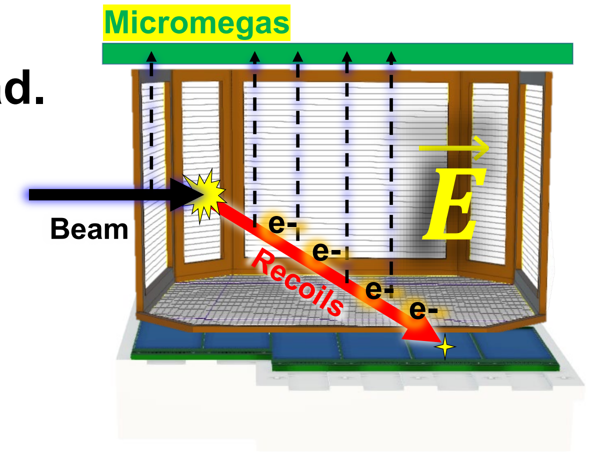
- **Test process**
  - ✓ **Pulser on mesh, checked wave forms at various pixels using GET + DAQ**
  - ✓ **Checked analog signals on the mesh using a ^{241}Am α source and a cathode plate**
  - ✓ **Obtained the track of α particles on the readout pad using GET + DAQ**
  - ✓ **Obtained the track using our newly-made field cage!**



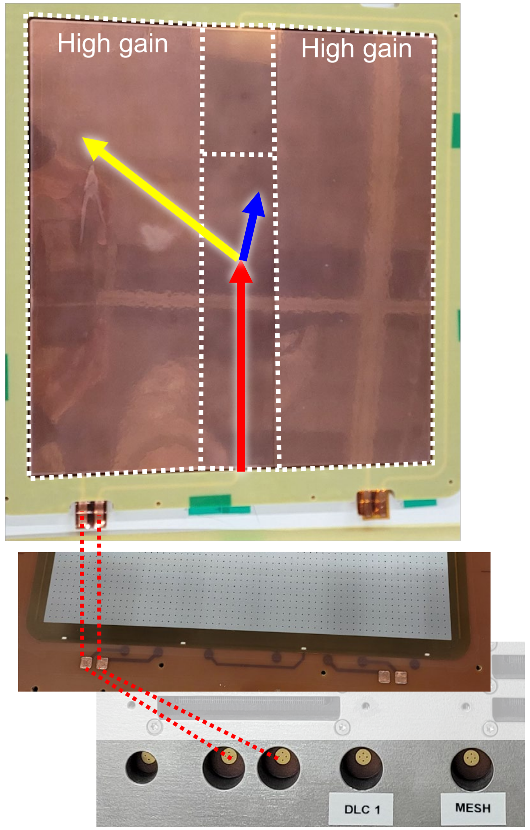
Reconstruction algorithm under development

Micromegas

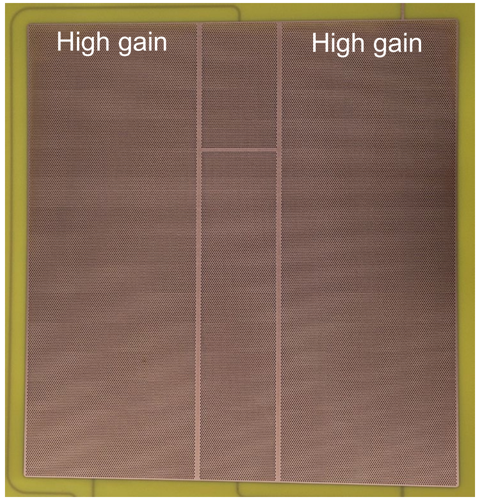
- **Tracking charged particles** *(beam, recoils, ...)*
- **Drift electrons from the ionization are amplified b/w GEM & mesh & readout pad.**
  - ✓ **Type-1 : Resistive** *(for AsAd board protection)*
  - ✓ **Type-2 : Resistive + Capacitive sharing** *(for better position resolution)*
- **GEM foils for proper gains**



GEM foil (256μm)



GEM foil (1000μm)



0.8mm holes
1.2mm pitch

✓ **Three different GEM foils**
- **Thick GEM (1000μm)**
- **Thin GEM (256μm)**
- **Thin GEM (256μm, different holes)** HG : 140/70/50
LG : 160/110/90

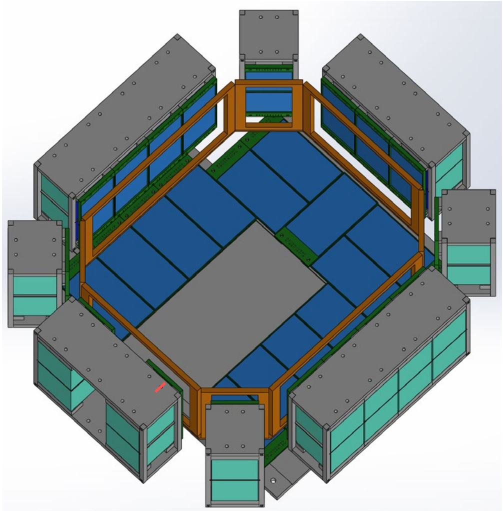
✓ **Proper gains for each section by adjusting HVs**
(low gain for beam and heavy recoils / high gain for light ptcls)

✓ **HV connections from Micromegas**

✓ **Gain calibration required**

Will be tested soon☺

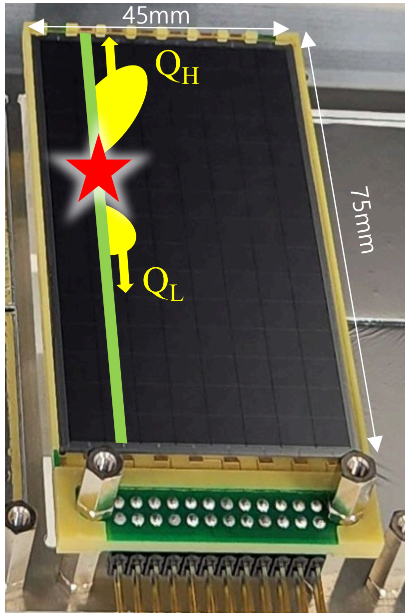
Silicon & CsI detector walls



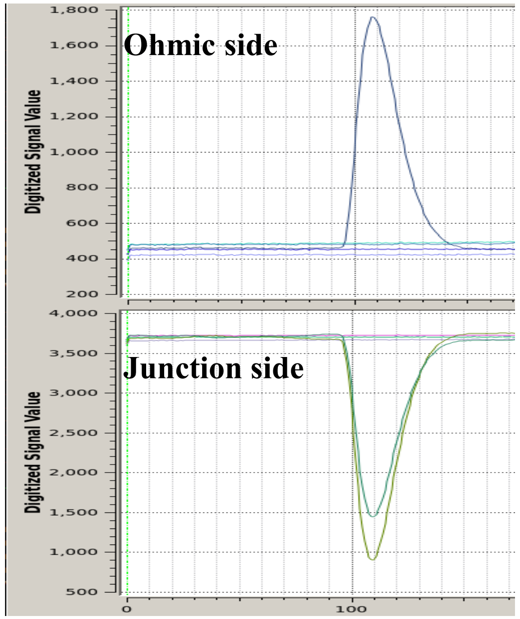
- **Measuring energy and position of charged particles or γ-rays**

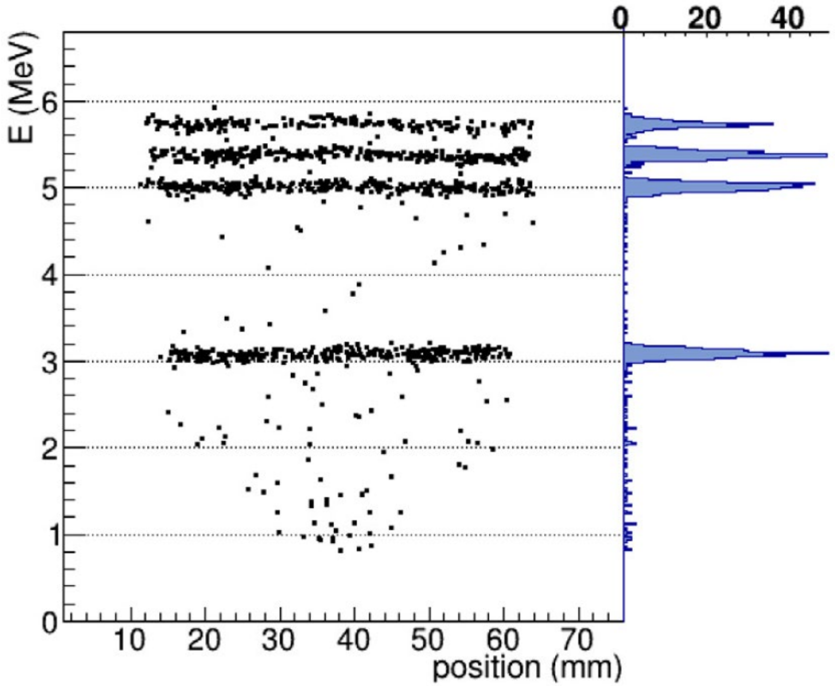
- **Silicon detectors**
  - ✓ **X6 model using the resistive technique (1000-μm-thick)** (Micron Semiconductor Co.)
  - ✓ **8 Junction strips (resistive), 4 Ohmic strips (normal)**
  - ✓ **Position : (Q_H-Q_L) / (Q_H+Q_L), ~ 1mm (FWHM)**
  - ✓ **Energy : Q_H+Q_L, ~50 keV (FWHM) using 4-peak *α* emitting source**

X. Pereira-Lopez *et al.*, NIMB (2023)
D. Kim *et al.*, NIMB (2022)

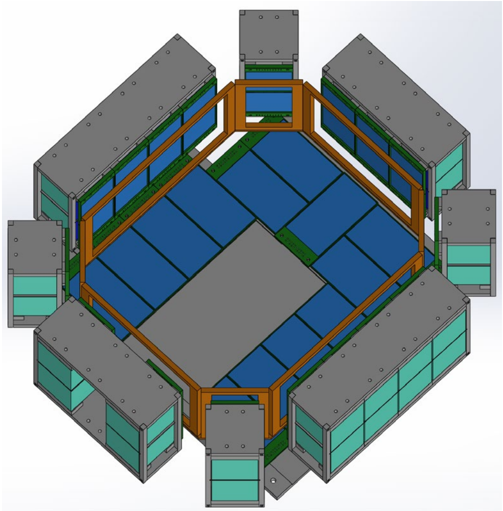


X6 signals obtained by GET electronics

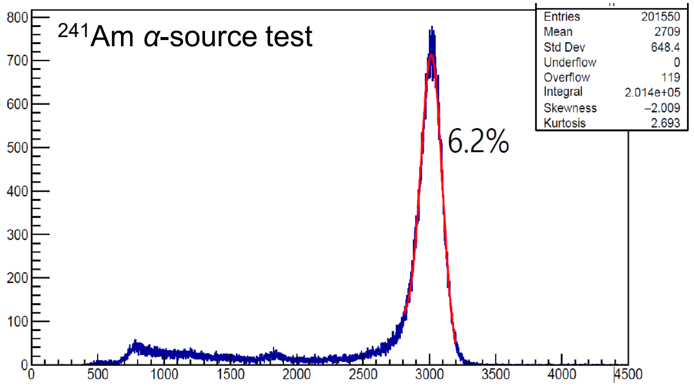


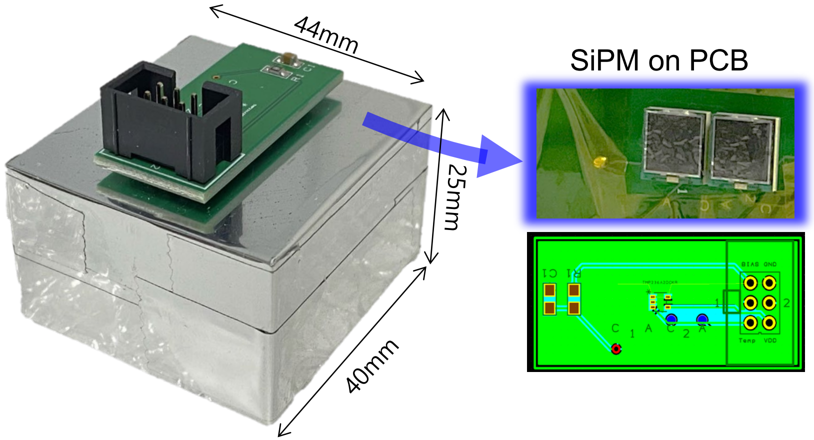


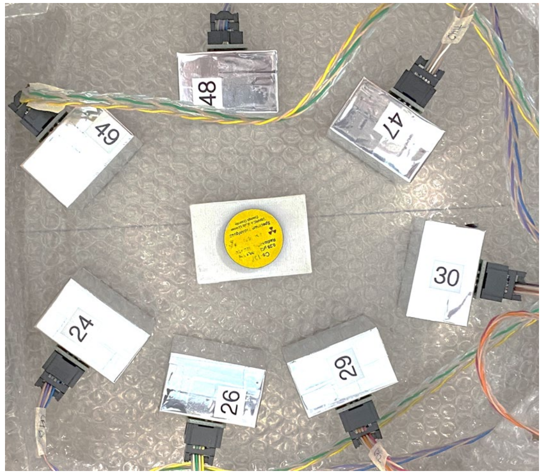
Silicon & CsI detector walls

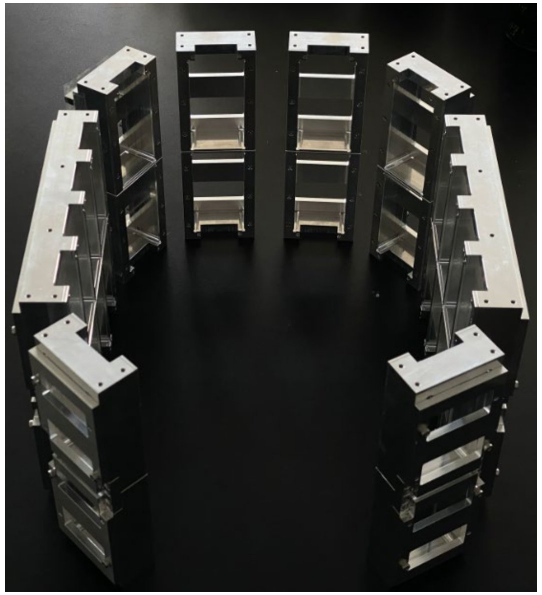


- **Measuring energy and position of charged particles or γ-rays**
- **CsI(Tl) + SiPM detectors** S. Bae *et al.*, NIMB (2023)
  - ✓ **short rise time (~0.5μs)**
  - ✓ **large signal height → no preamp for GET**
  - ✓ **off-line test results :**
    - **^{137}Cs γ-ray source ~ 12% (FWHM)**
    - **^{241}Am α-source after thin air ~ 6% (FWHM)**





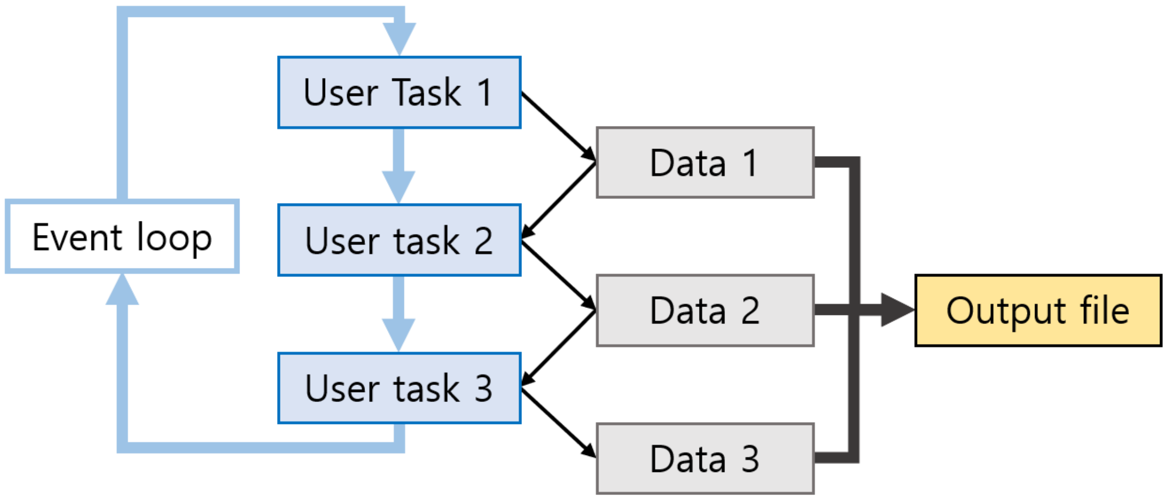




Supporting frames of Si+CsI walls

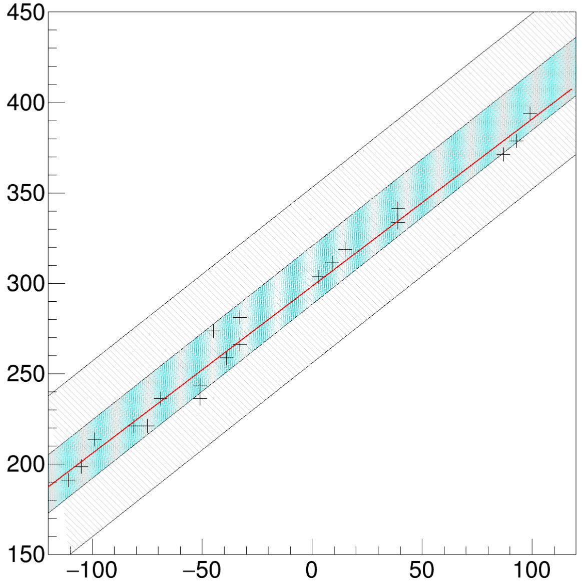
Analysis software and Simulation

- Analysis software package : LILAK (Low and Intermediate energy nucLear experiment Analysis toolKit)
  - ✓ task-based analysis toolkit
  - ✓ contains general classes for MC simulation, reconstruction (pulse shape analysis, Hough transform, RANSAC, ...), and so on.
- Garfield++ simulation for electric field (2D & 3D), electron drift, ...
- GEANT4 & NP tool simulation for kinematics, geometry, detection efficiency, ...



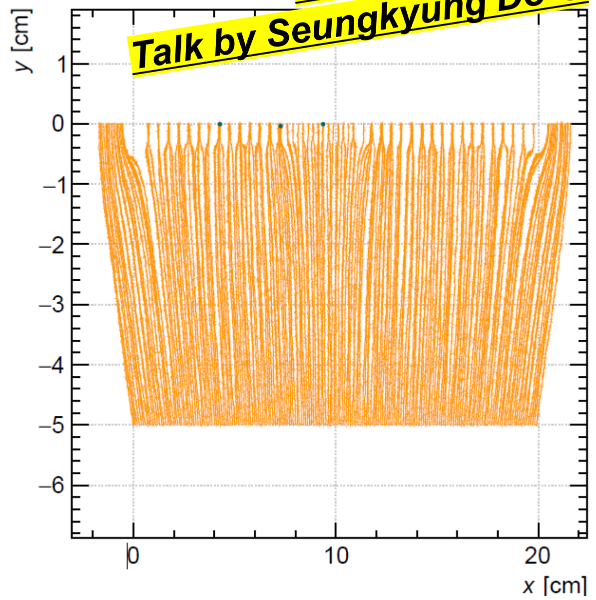
https://github.com/lilak-project

Contact : JungWoo Lee☺



Example of the track reconstruction using Hough transform

Today, Talk by Seungkyung Do ☺



Garfield simulation for electron drifts with gating grid on the field cage

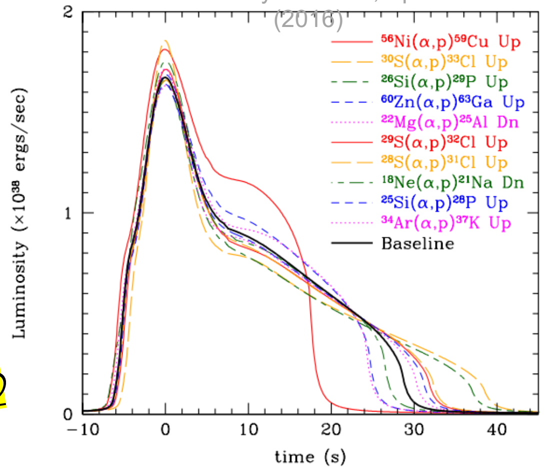
Physics plans

- **Direct measurement of astrophysically important reactions**
  - ✓ **^{34}Ar(*α,p*)^{37}K at CRIB in RIKEN** A. Kim *et al.*, (RIBF NP-PAC-24, **approved**)
  - ✓ **^{10}Be(p,*α*)^{7}Li at CRIB in RIKEN** M.J. Kim *et al.*, (RIBF NP-PAC-25, **approved**)
  - ✓ **^{18}Ne(*α,p*)^{21}Na, ^{17}F(*α,p*)^{20}Ne, ...**

Today, Talk by Aram Kim☺

Tomorrow, Talk by Minju Kim☺

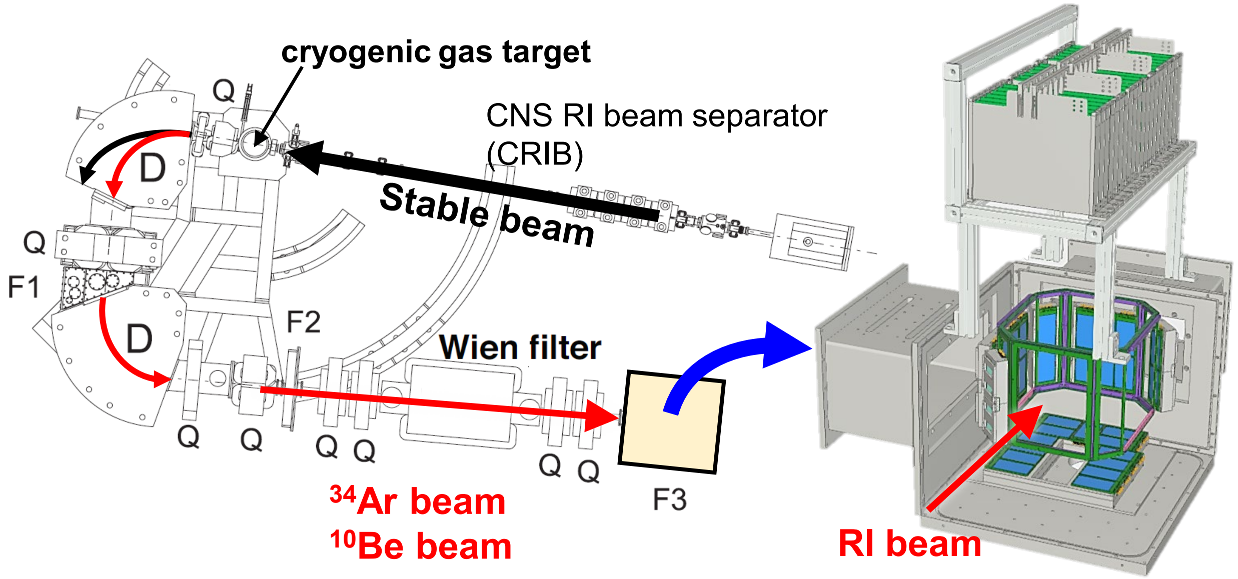
R.H. Cyburt *et al.*, ApJ (2016)

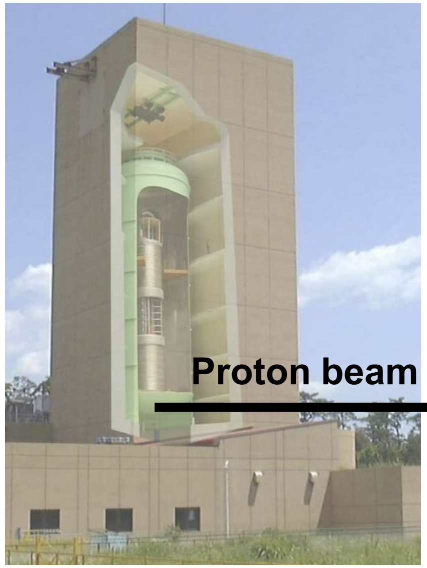


- **Elastic/Inelastic scattering**
  - ✓ **^{12}C(*p,p'*)3*α* reaction for triple-*α* process** J.W. Lee *et al.*, (JAEA PAC2024, **approved**)

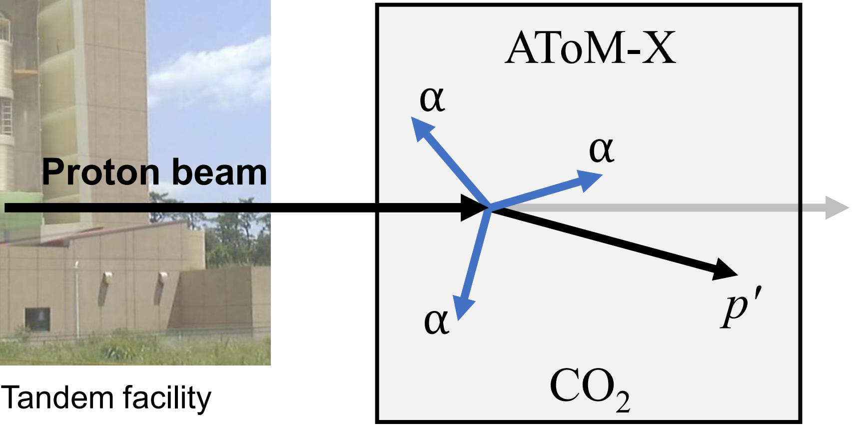
Tomorrow, Talk by Jungwoo Lee☺

- **Direct measurement of nuclear fusion reaction of exotic nuclei**
  - ✓ **^{6,8}He + ^{40}Ar fusion, …**





JAEA Tandem facility



Welcome to join our collaboration !

CENS, IBS

Korea Univ.

Texas A&M Univ.

The Univ. of Tokyo

JAEA

CEA, Saclay

Sungkyunkwan Univ.

Ewha womans Univ.

IMP

PKU

Background Image:
Courtesy of Paul Montague
“Neighbors”
Astronomy photographer of the year 2023

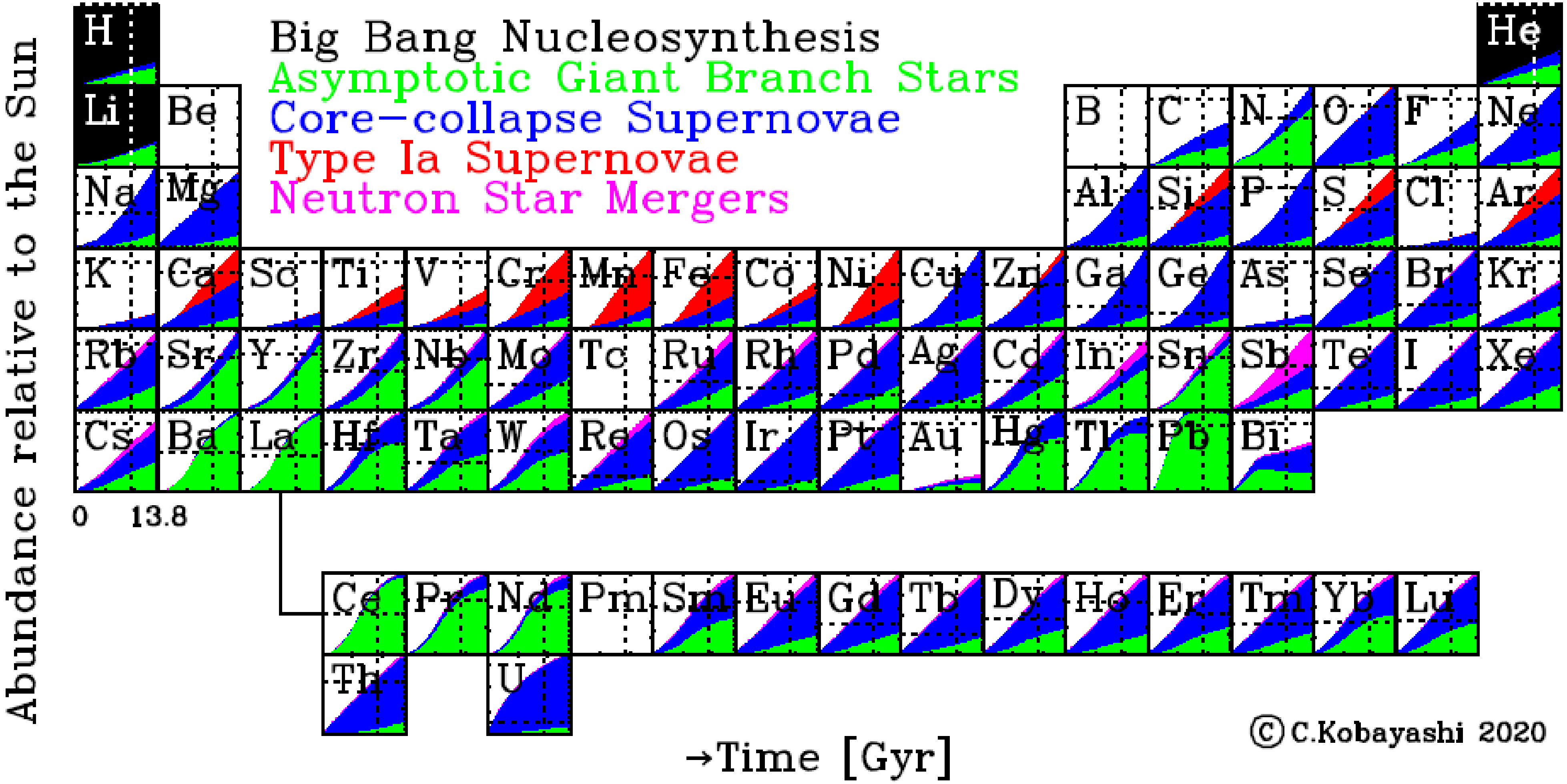
Summary

- Active Target Time Projection Chamber (AT-TPC) allows a precise measurement of nuclear reactions using rare isotope beams at the present and future nuclear physics facilities.
- Active Target TPC for Multiple nuclear physics eXperiments (AToM-X) is under development.
- AToM-X consists of a highly segmented Time Projection Chamber (TPC) using a Micromegas, a field cage, and solid state detectors.
- AToM-X enables the high resolution measurement of the 3-dimensioinal particle tracks, energy, and position with the high detection efficiency.
- Softwares for AToM-X including analysis toolkit (lilak) and simulations are under the development.
- In-house test is processing, and interesting experiments will be performed next year !

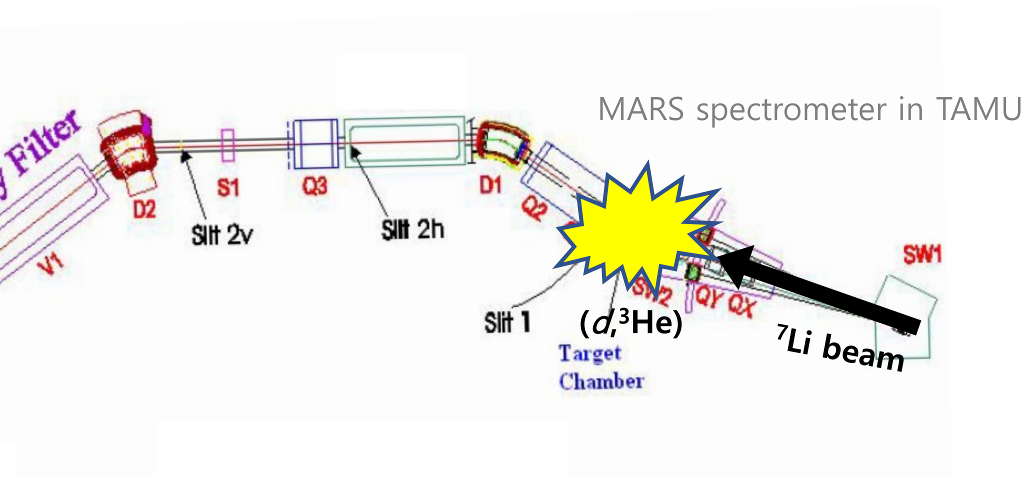
Backup

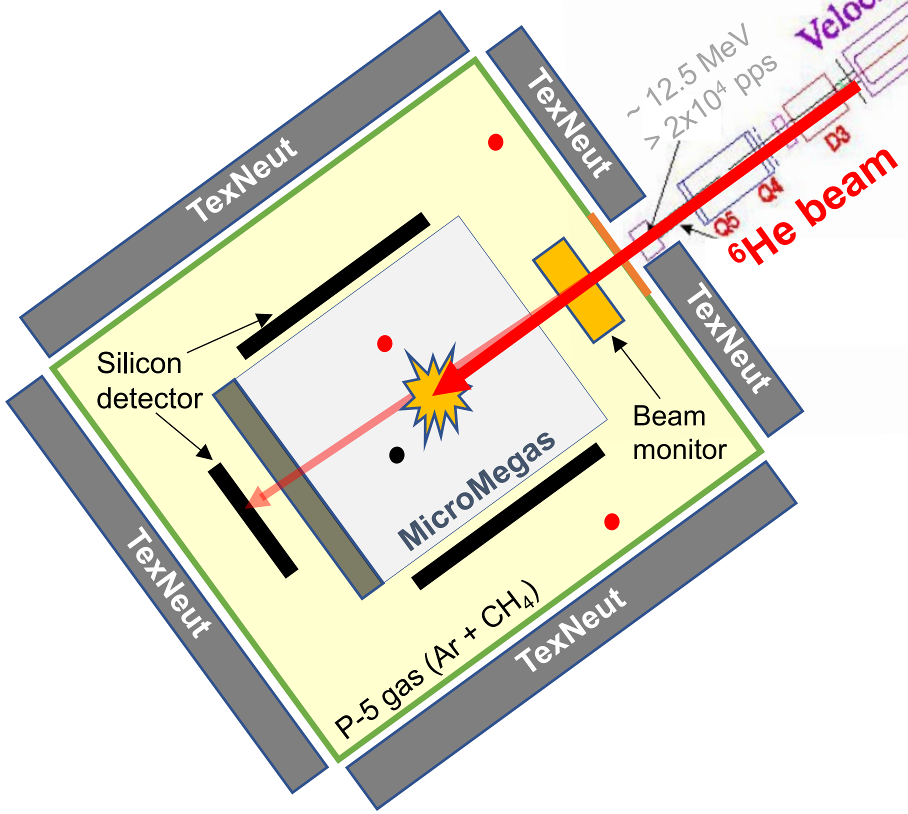
Backup

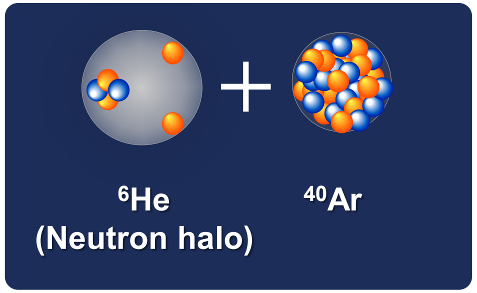
Backup

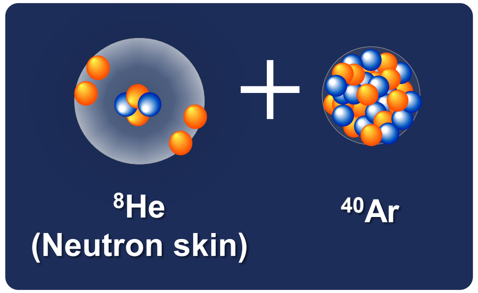

Big Bang Nucleosynthesis
Asymptotic Giant Branch Stars
Core−collapse Supernovae
Type Ia Supernovae
Neutron Star Mergers
Abundance relative to the Sun
H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi
Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Th U
0 13.8
→Time [Gyr]
© C.Kobayashi 2020

Backup


MARS spectrometer in TAMU
Velocity Filter
6He beam
7Li beam
(d,3He)
Target Chamber
Slit 1
Slit 2v
Slit 2h
S1
Q3
D1
D2
D3
Q2
Q4
Q5
V1
SW1
SW2
QY QX


~ 12.5 MeV
> 2x10^4 pps
TexNeut
TexNeut
TexNeut
TexNeut
TexNeut
TexNeut
Silicon detector
Beam monitor
MicroMegas
P-5 gas (Ar + CH4)


6He
(Neutron halo)
40Ar

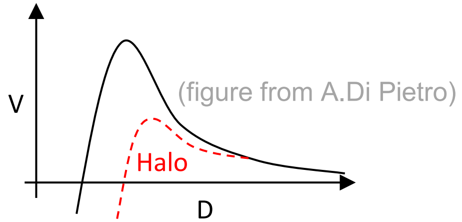

8He
(Neutron skin)
40Ar

Nuclear fusion of halo nucleus ^{6}He

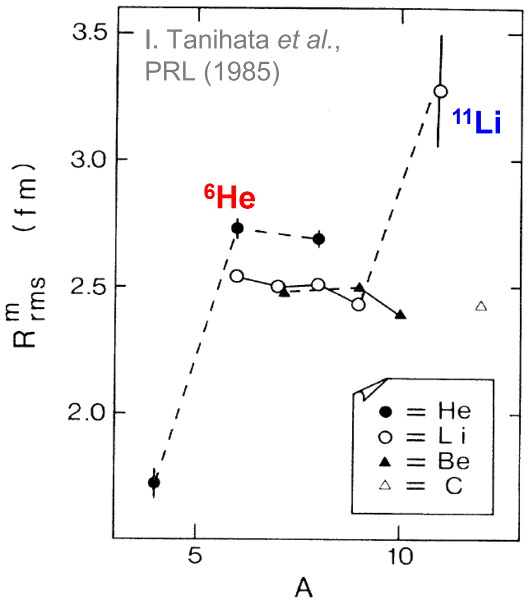
- **Characteristics of halo nuclei**
  - **- Extended density distribution**
  - **- Low binding energy**

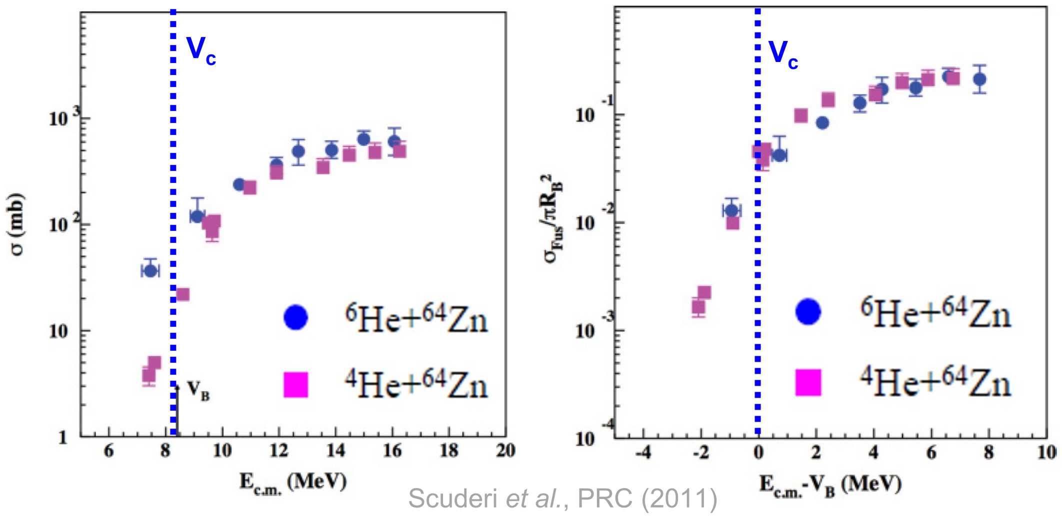
→ Fusion probability can be enhanced due to the diffuseness!

"Static effect"



Different potential barrier height,
Different curvature, ...



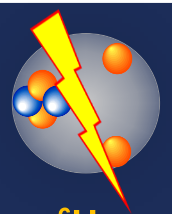


Scuderi *et al.*, PRC (2011)

- **^{6}He+^{64}Zn & ^{4}He+^{64}Zn measurement @ Louvain-la-Neuve**
- **Sub-barrier fusion enhancement due to the diffuse ^{6}He halo structure?**
- **^{6}He fusion data stop at the Coulomb barrier**

More data required !

Nuclear fusion of halo nucleus ^{6}He



^{6}He
Neutron halo
Borromean
S_{2n}=0.972 MeV

- **Characteristics of halo nuclei**
  - Extended density distribution
  - **Low binding energy**

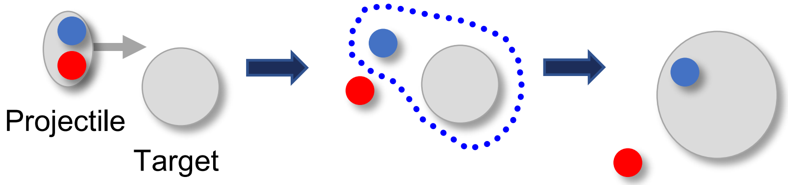
→ Break up channel affects on the fusion/reaction mechanism !

"Dynamic effect"

Conflicts !

Dasso *et al.*, PRC (1994)

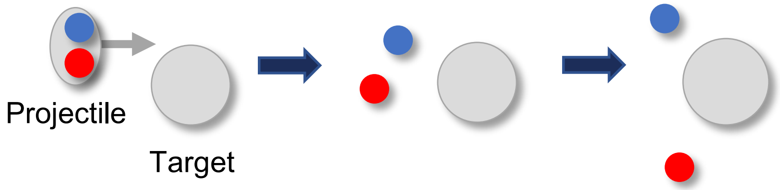
Fusion Enhancement
(∵ additional reaction channels)



"Incomplete fusion"

VS

Fusion Suppression
(∵ incident flux reduced)



Hussein *et al.*, PRC (1992),
Takigawa *et al.*, PRC (1993)

"Elastic breakup"

Nuclear fusion of halo nucleus ^{6}He

^{6}He

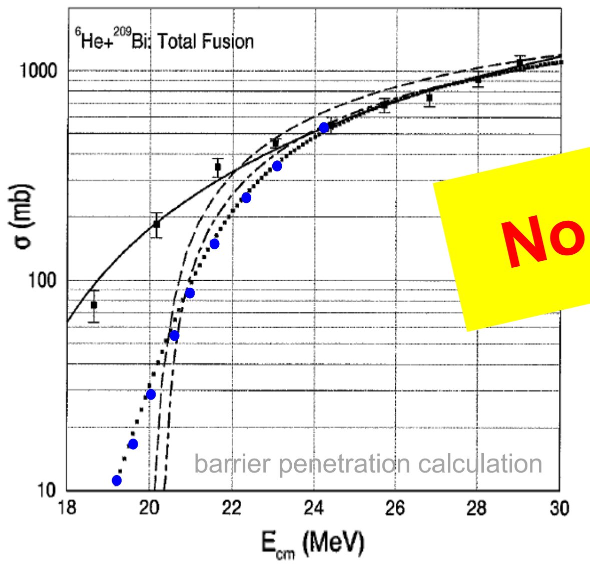
Neutron halo
Borromean
S_{2n}=0.972 MeV

- **Characteristics of halo nuclei**
  - Extended density distribution
  - **Low binding energy**

→ Break up channel affects on the fusion/reaction mechanism !

"Dynamic effect"

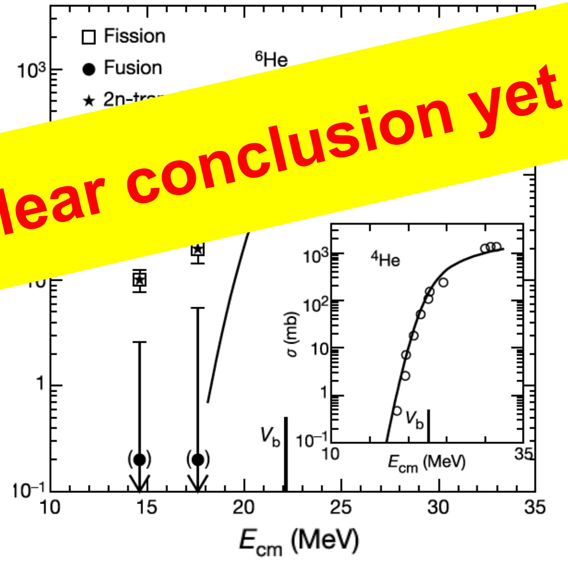
No clear conclusion yet !



^{6}He+^{209}Bi

"Strong sub-barrier fusion enhancement"

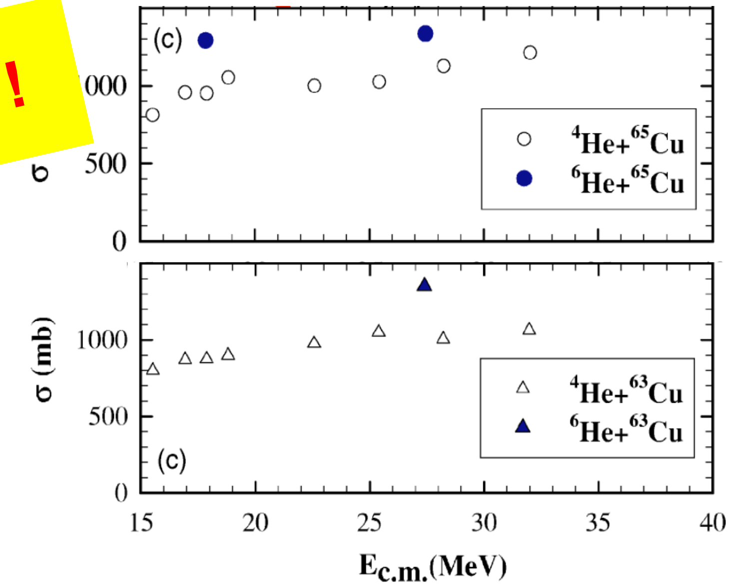
J. J. Kolata *et al.*, PRL (1998)



^{6}He+^{238}U

"No fusion enhancement"

R. Raabe *et al.*, Nature (2004)



^{4,6}He+^{63,65}Cu

"Fusion enhancement due to the transfer channels (ICF)?"

Navin *et al.*, PRC (2004)
Chatterjee *et al.*, PRL (2008)

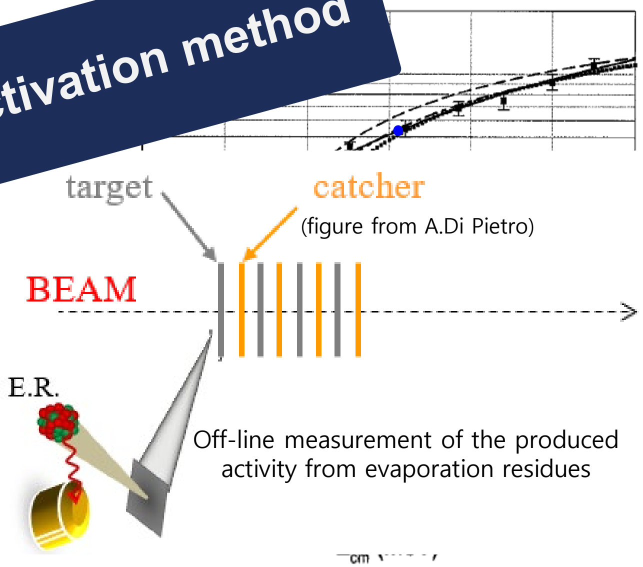
Nuclear fusion of halo nucleus ^{6}He

^{6}He
Neutron halo
Borromean
S_{2n}=0.972 MeV

- **Characteristics of halo nuclei**
  - Extended density distribution
  - **Low binding energy**

→ Break up channel affects on the fusion/reaction mechanism !

Activation method

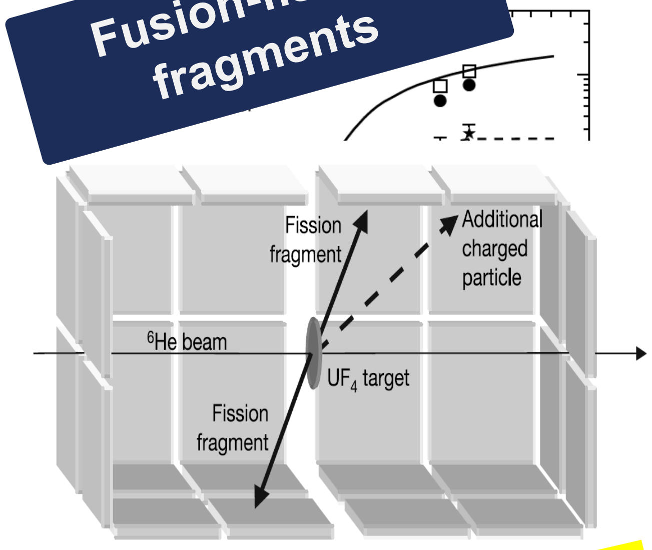


^{6}He+^{209}Bi

"Strong sub-barrier fusion enhancement"

J. J. Kolata *et al.*, PRL (1998)

Fusion-fission fragments

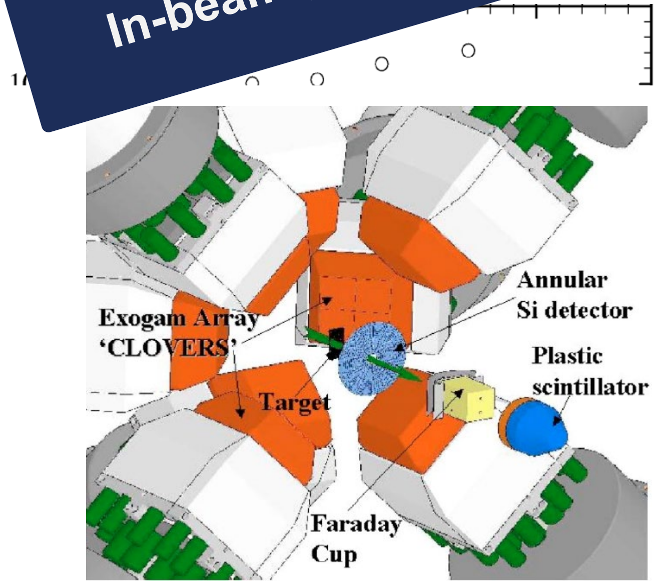


^{6}He+^{238}

al., Nature (2004)

In-beam γ-ray

"Dynamic



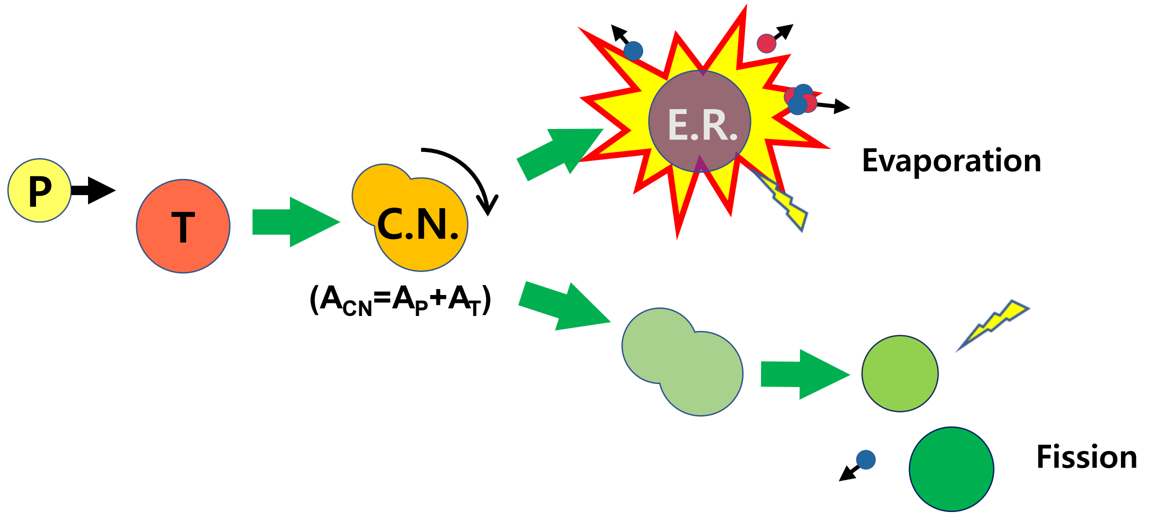
^{4,6}He+^{63,65}Cu

"Fusion enhancement due to the transfer channels (ICF)?"

Navin *et al.*, PRC (2004)
Chatterjee *et al.*, PRL (2008)

Indirect methods !

Direct fusion study using active target TPC



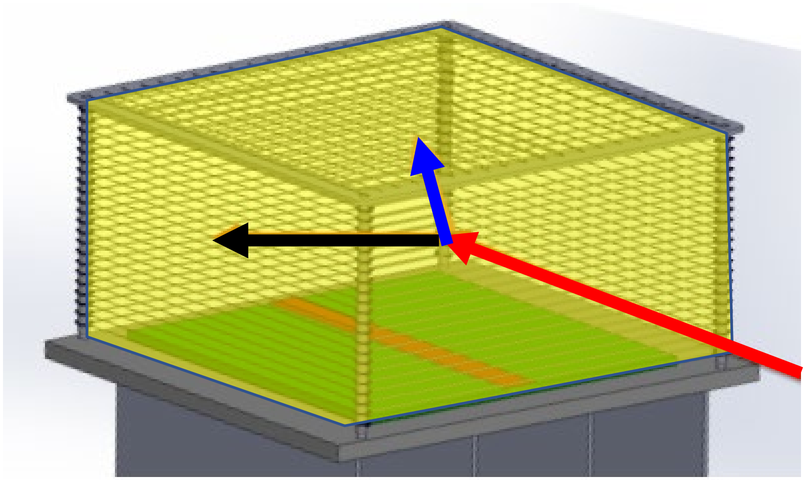


Figure from G.V. Rogachev

- Light projectile, heavy target
  → Evaporation Residue (E.R) has small $V_{c.m}$
  → E.R suck into target, cannot reach to detector
  → Direct measurement of E.R. not available...

- Previous fusion measurements :
  (off-line) radioactivities, evaporated particles, γ-rays,...
  indirect method – model dependent !

Active Target TPC

Target gas = Detection gas

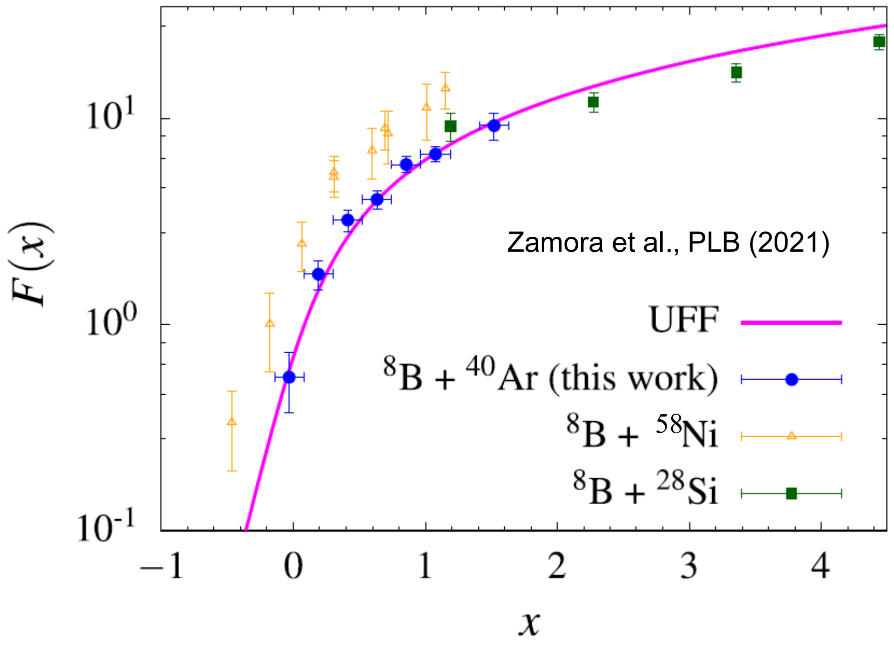
E.R. can be measured in the target

Direct identification of the $^6He+^{40}Ar$ nuclear fusion events !

J.J. Kolata *et al.*, NIMA (2016)

Fusion reaction induced by *p*-halo VS *n*-halo

Fusion of proton halo nuclei



Prediction : Larger sub-barrier fusion enhancement

Valence proton – polarization – reducing the barrier

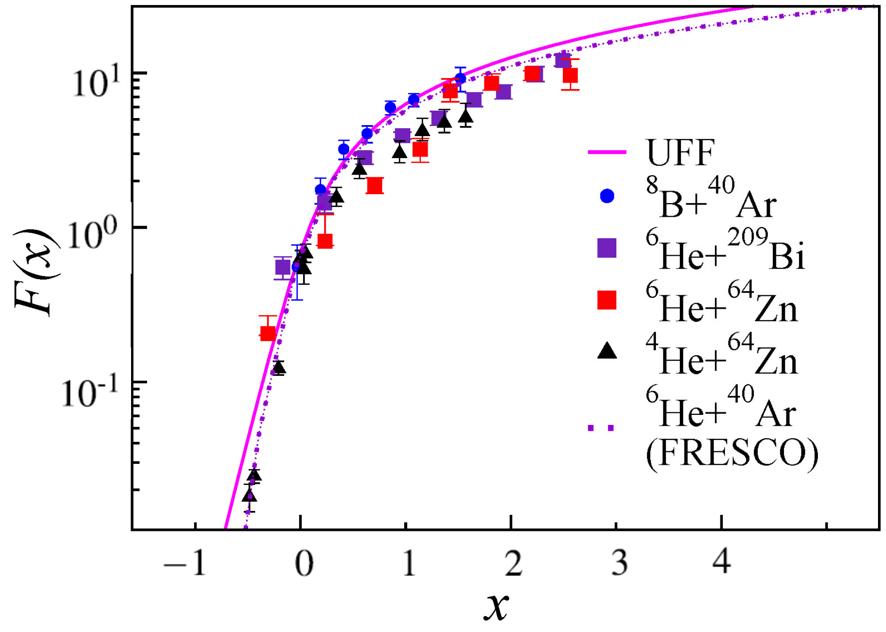
Observation :

Direct fusion measurement of ^{8}B+^{40}Ar

→ No sub-barrier fusion enhancement

(No strong influence by the breakup)

Fusion of neutron halo nuclei



No clear conclusion yet

Direct fusion measurement of ^{6}He+^{40}Ar

→ ideal probe for clarifying the difference of the dynamic channel coupling effect !

(same target, same technique)

First direct fusion study of the $^{6}He+^{40}Ar$ system

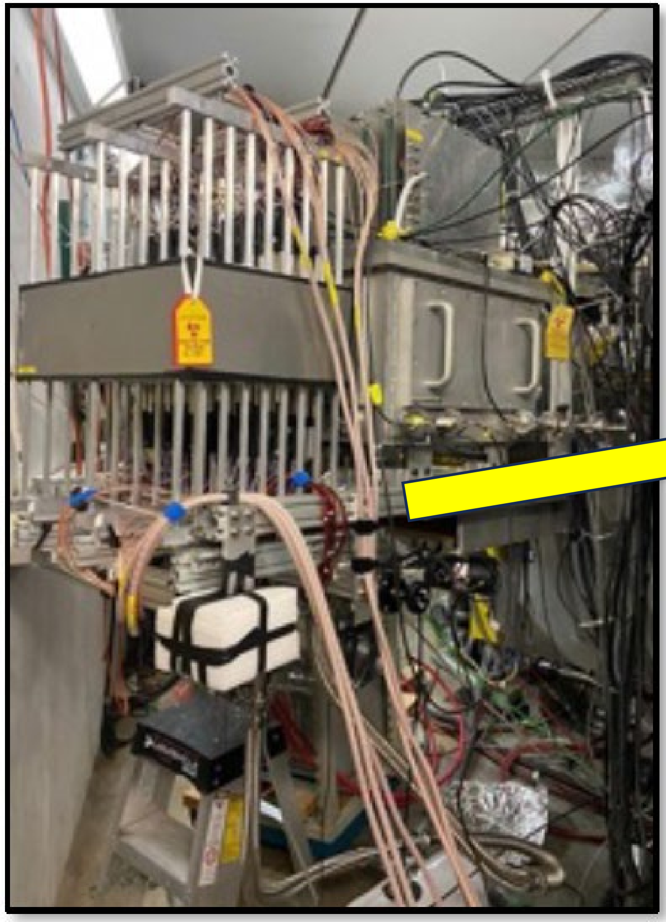
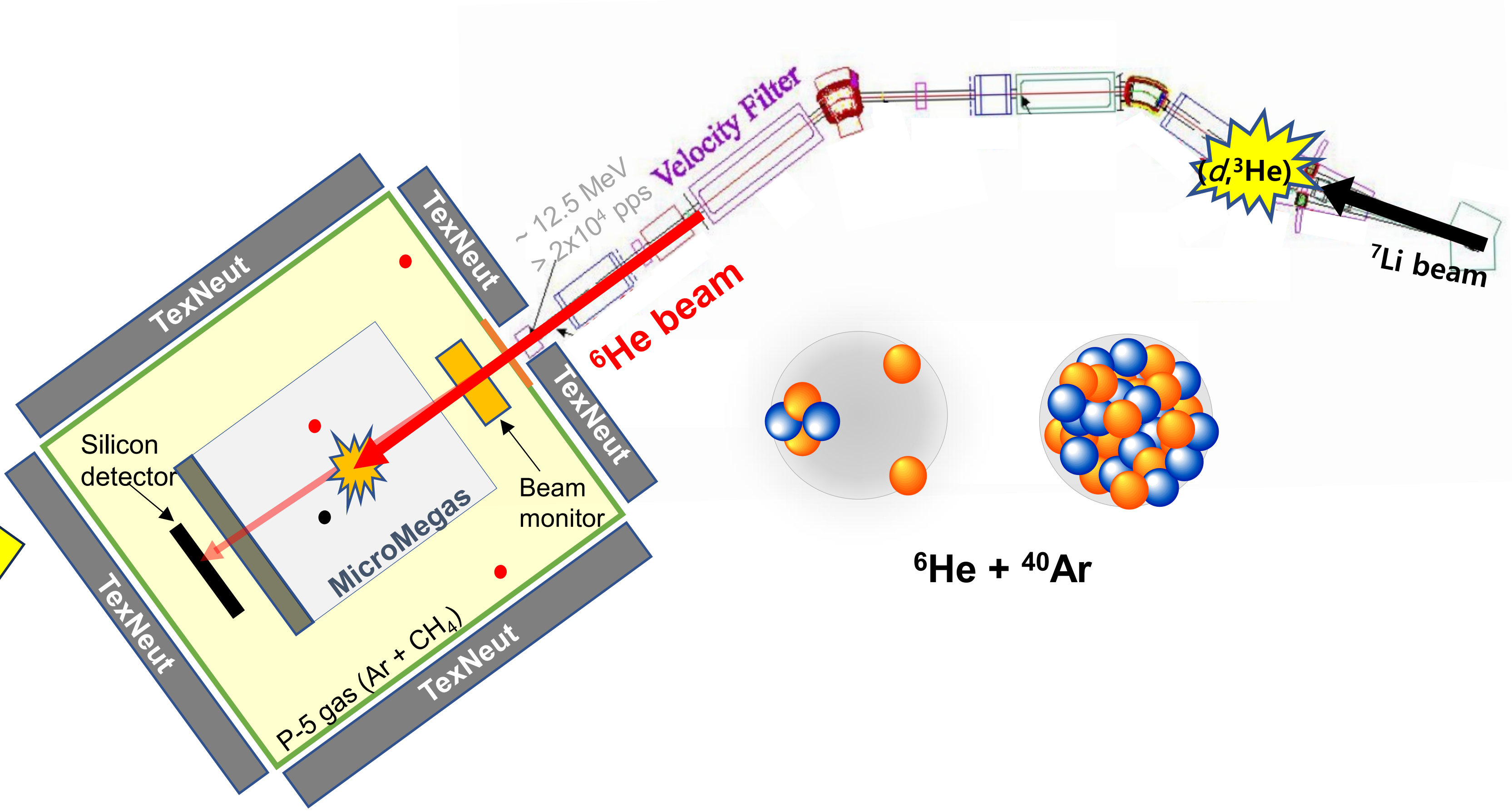


Figure from D. P. Scriven

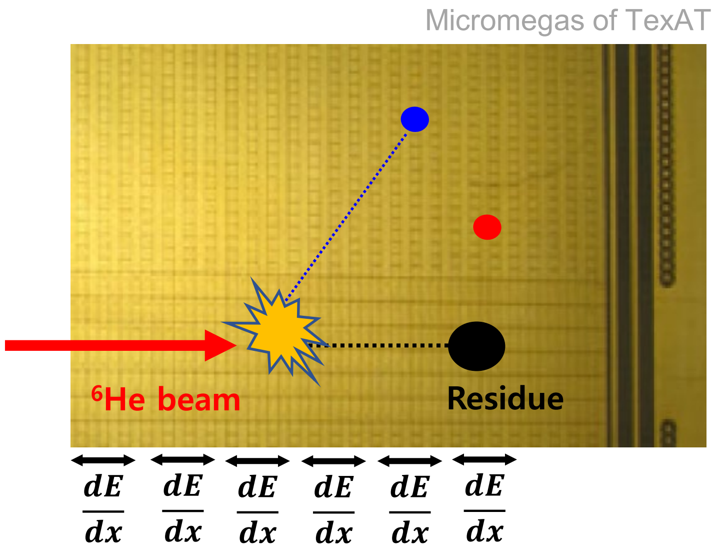


- ^{6}He + ^{40}Ar fusion measurement will be performed in Dec.2024 at MARS in Texas A&M University
- TexAT (active target TPC) + TexNeut (neutron detector) combination

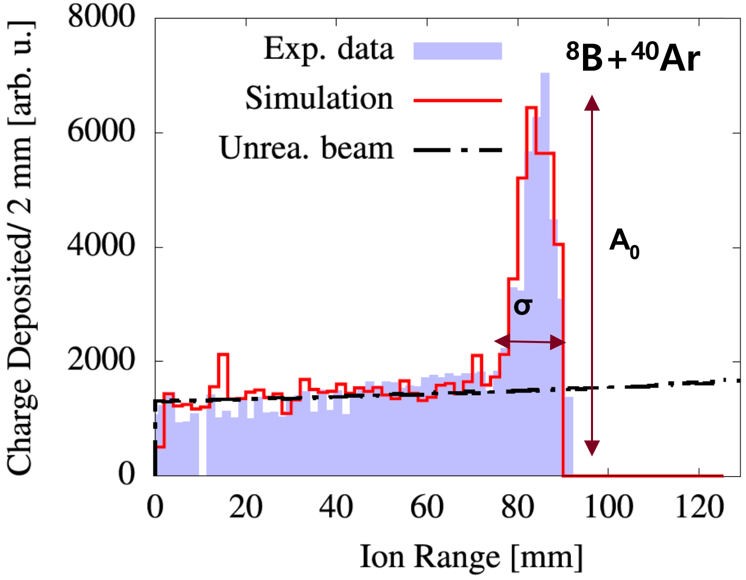
Total fusion
Micromegas – track of charged particles

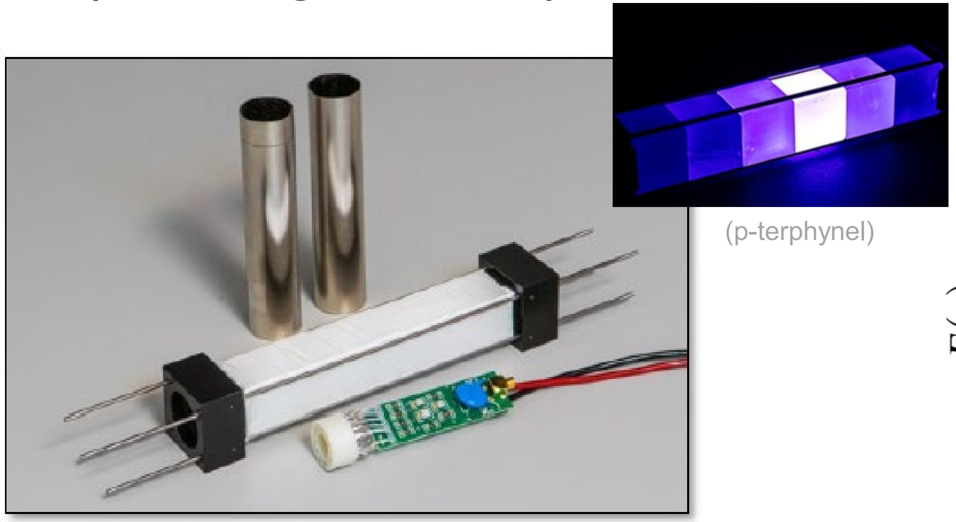
Incomplete fusion, n-evaporation
(ex. alpha transfer, …)

Experimental setup

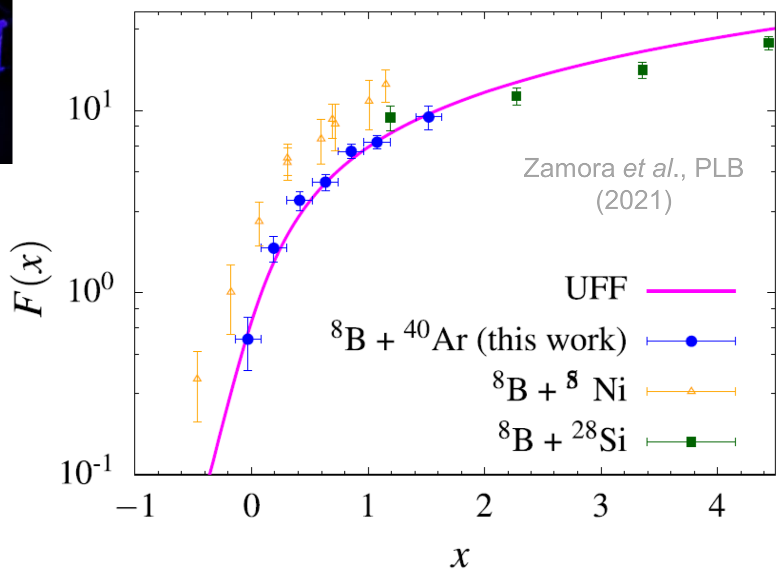


- **Measurement of energy deposition along the tracks in TPC by using Micromegas**
- **Direct identification of fusion events is available by analyzing the shape of the Bragg curves (large & strongly localized dE/dx !!!)**
- **Measurement of neutrons from the fusion evaporation & *α*-transfer channel by using TexNeut**
- **Fusion excitation function can be obtained with a single beam energy (thick target method).**

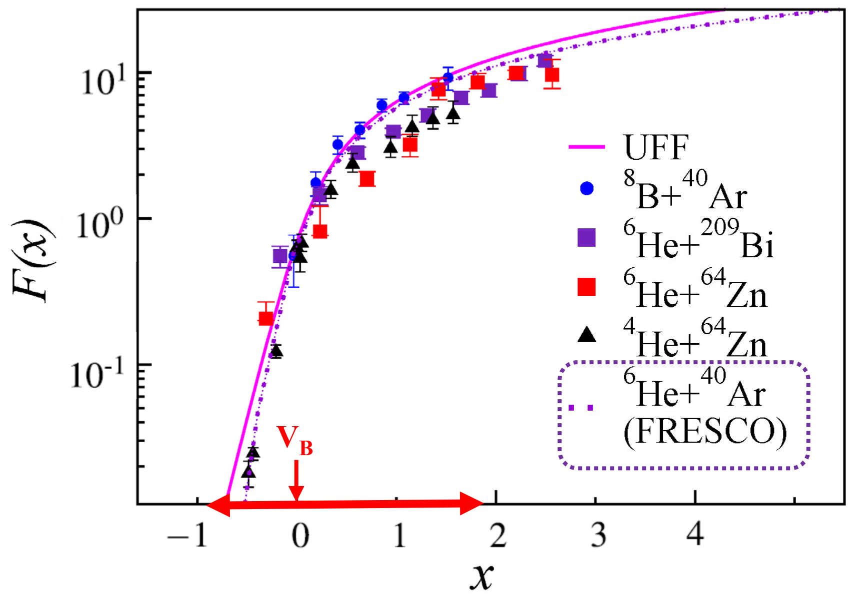




TexNeut : Figure from D. P. Scriven

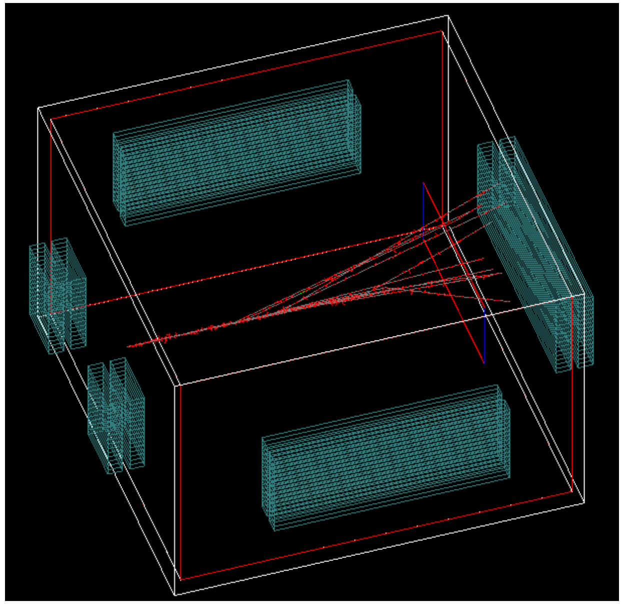


Yield estimation and simulation



simple PACE4 calculation : $^6He+^{40}Ar$

Z	N	A	events	percent		x-section(mb)
20	25	45 Ca	17	1.7%	1n	18.1
19	26	45 K	9	0.9%	1p	9.58
20	24	44 Ca	730	73%	2n	777
19	25	44 K	94	9.4%	1p + 1n	100
20	23	43 Ca	99	9.9%	3n	105
19	24	43 K	2	0.2%	1p + 2n	2.13
18	24	42 Ar	2	0.2%	alpha	2.13
18	23	41 Ar	47	4.7%	2p + 3n	50.1
TOTAL			1000	100		1064.96

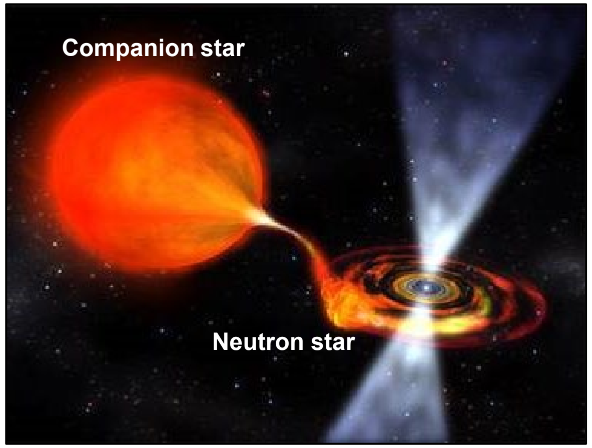


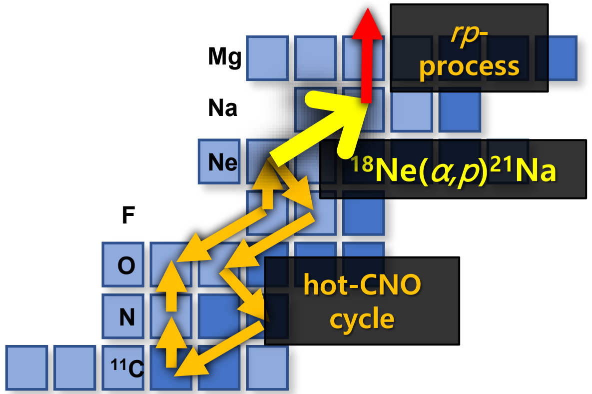
$^6He + ^{40}Ar$ measurement (V_c ~ 5.5 MeV)			$^4He + ^{40}Ar$ measurement (V_c ~ 5.9 MeV)		
$E_{c.m.}$ (MeV)	σ_{TF} (mb)	Expected counts (/bin /day)	$E_{c.m.}$ (MeV)	σ_{TF} (mb)	Expected counts (/bin /day)
3.478	0.27	3.7	3.636	0.23	4.1
4.348	10.9	151	4.545	5.6	96
5.217	108.8	1500	5.454	47.4	819
6.087	339	4674	6.364	173.1	2991
6.957	565	7799	7.273	349.3	6035

Yield estimation based on the FRESCO

- **Total fusion cross section already obtained by the FRESCO code**
- **Incomplete fusion cross section and neutron angular distribution calculation using CDCC is on-going.**
- **GEANT4 simulation for better detection efficiency is on-going.**

Direct measurement of $^{18}Ne(\alpha,p)^{21}Na$ reaction





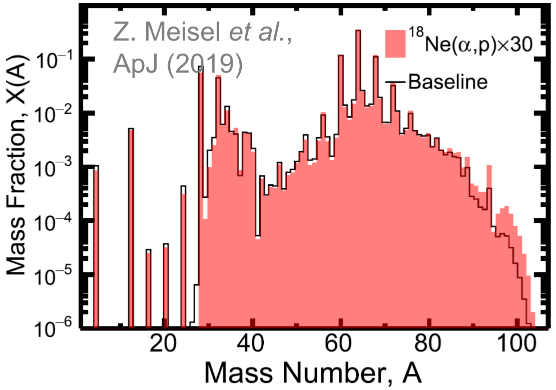
- one of the break-out candidates from the hot-CNO cycle, fueling the *rp*-process
- affects on the characteristics of X-ray burst (light curve, ash composition)
- Discrepancy among the measurements !
- Recent ^{18}Ne+α resonant scattering experimental result pointed out the importance of the direct measurement !

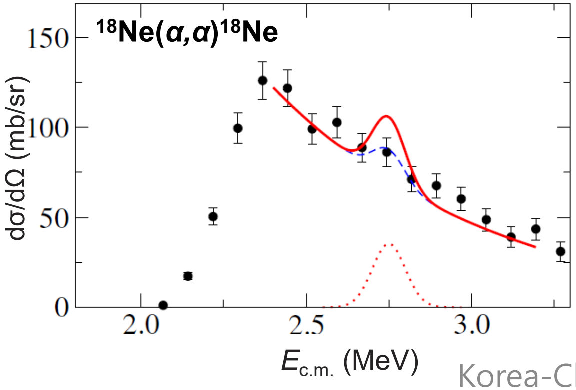
S.M. Cha *et al.*, Front. in Phys. (2023)

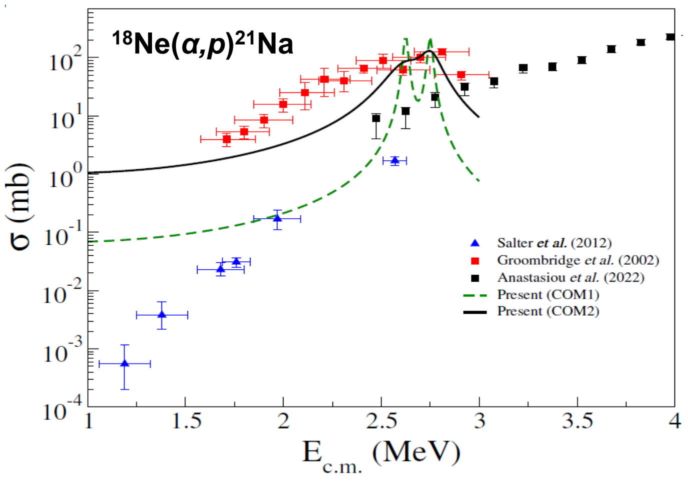
- **Then, $^{18}Ne(\alpha,p)^{21}Na$ measurement using AToM-X !**

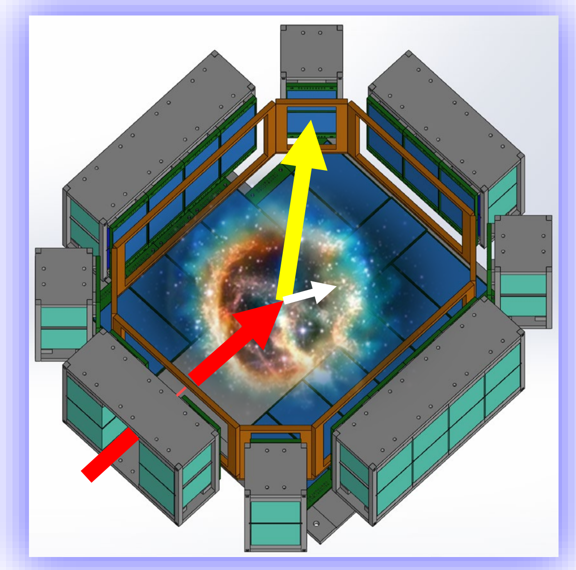
Rank	Reaction
1	$^{15}O(\alpha,\gamma)^{19}Ne$
2	$^{56}Ni(\alpha,p)^{59}Cu$
3	$^{59}Cu(p,\gamma)^{60}Zn$
4	$^{61}Ga(p,\gamma)^{62}Ge$
5	$^{22}Mg(\alpha,p)^{25}Al$
6	$^{14}O(\alpha,p)^{17}F$
7	$^{23}Al(p,\gamma)^{24}Si$
8	$^{18}Ne(\alpha,p)^{21}Na$
9	$^{63}Ga(p,\gamma)^{64}Ge$
10	$^{19}F(p,\alpha)^{16}O$
11	$^{12}C(\alpha,\gamma)^{16}O$
12	$^{26}Si(\alpha,p)^{29}P$
13	$^{17}F(\alpha,p)^{20}Ne$
14	$^{24}Mg(\alpha,\gamma)^{28}Si$
15	$^{57}Cu(p,\gamma)^{58}Zn$
16	$^{60}Zn(\alpha,p)^{63}Ga$
17	$^{17}F(p,\gamma)^{18}Ne$
18	$^{40}Sc(p,\gamma)^{41}Ti$
19	$^{48}Cr(p,\gamma)^{49}Mn$

R. H. Cyburt *et al.*, ApJ (2016)

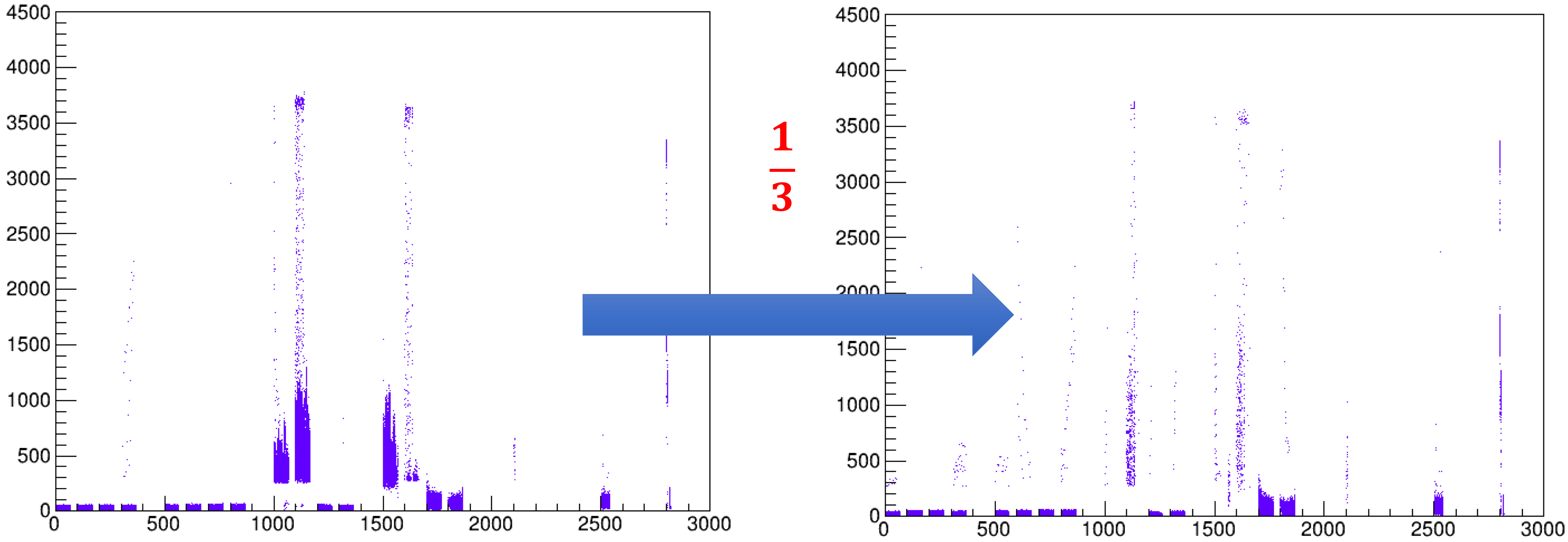






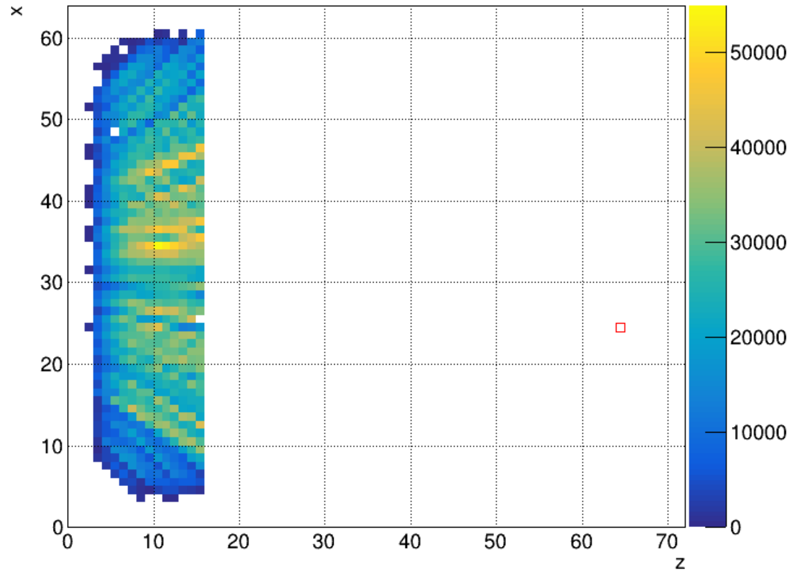


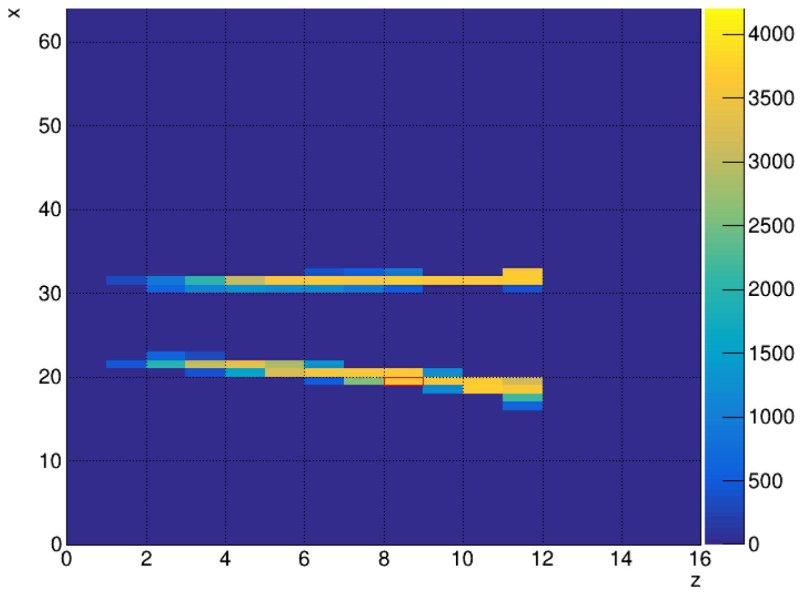
Backup

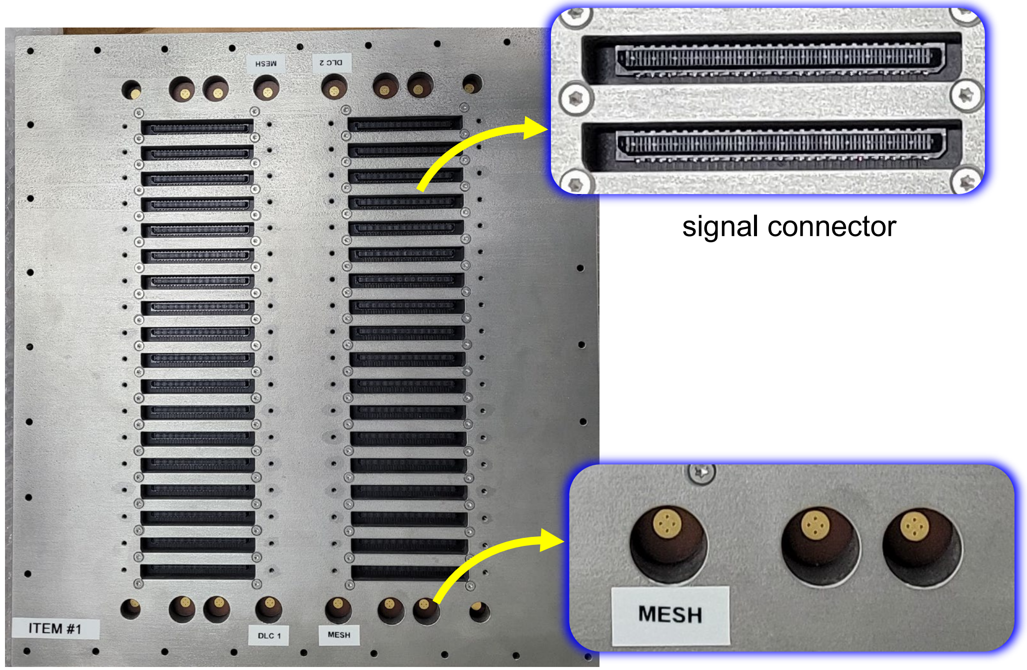


Effect of gating grid
TexAT v2, $^{14}O(\alpha,p)^{17}F$

Backup







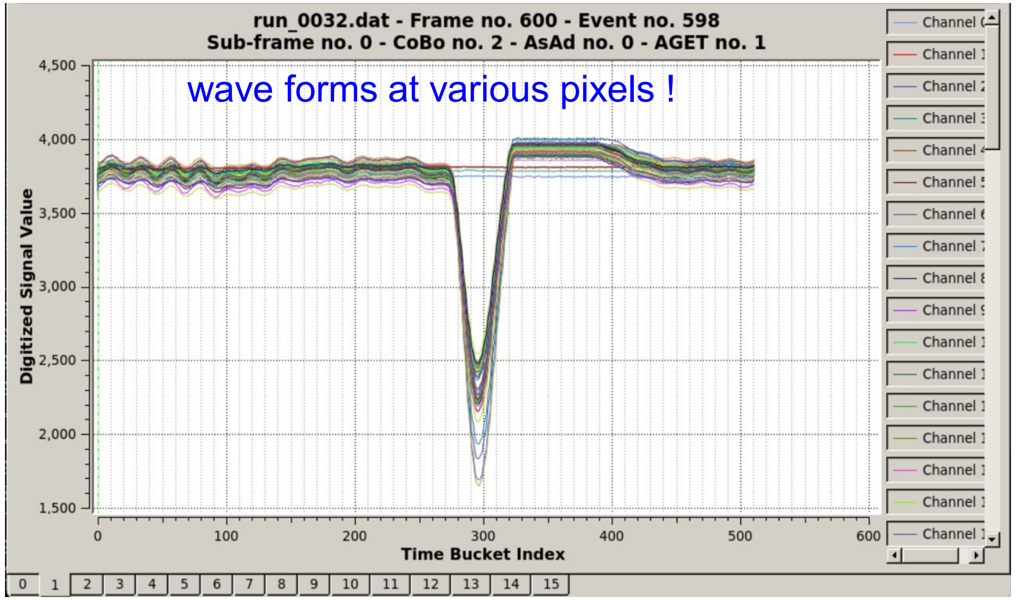
signal connector

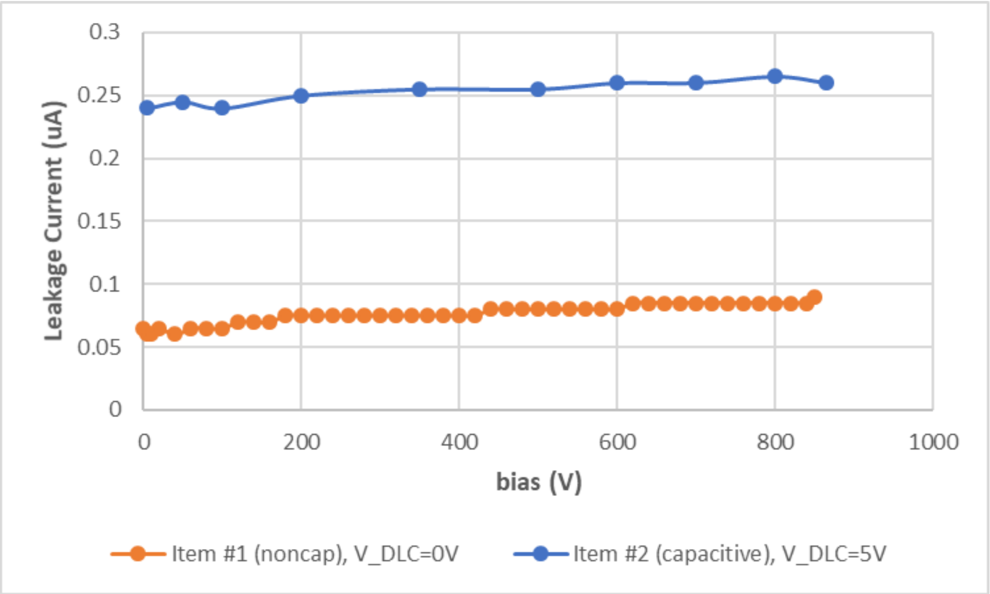
Micromegas (back : stiffener)

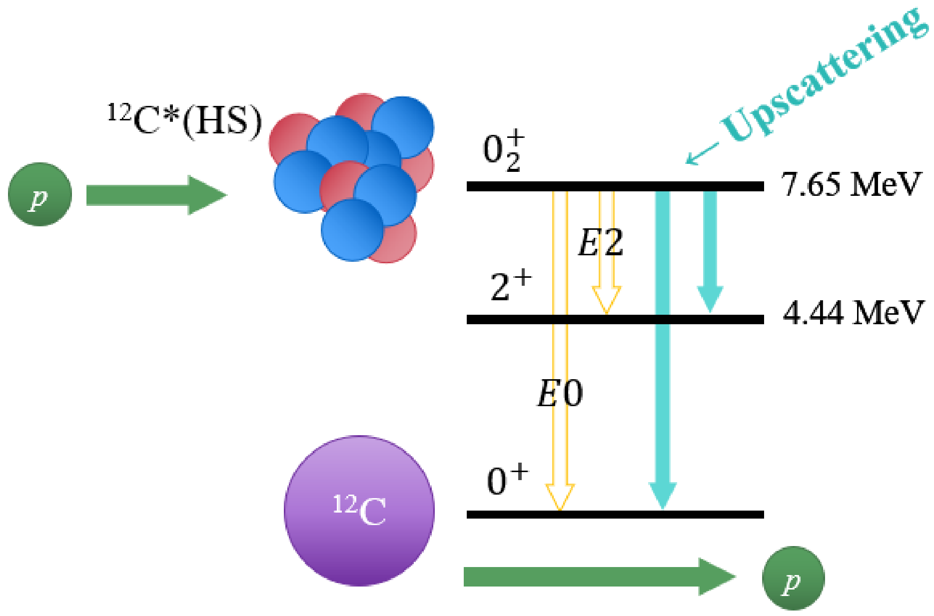
HV connection

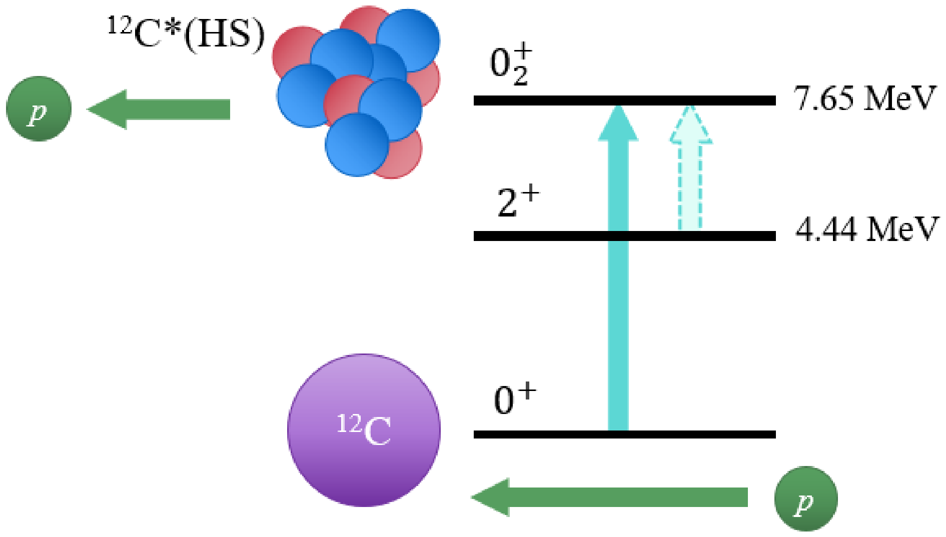
Micromegas

- **Test status**
  - ✓ **Pulser on mesh, checked wave forms at various pixels using GET + DAQ**
  - ✓ **Checked analog signals on the mesh using a ^{241}Am *α* source and a cathode plate**
  - ✓ **Obtained the track of *α* particles on the readout pad using GET + DAQ**
  - ✓ **Now trying to obtain the track using our newly-made field cage!**



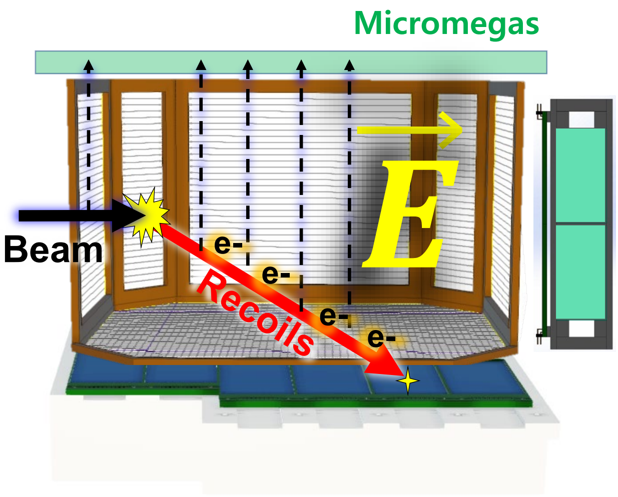






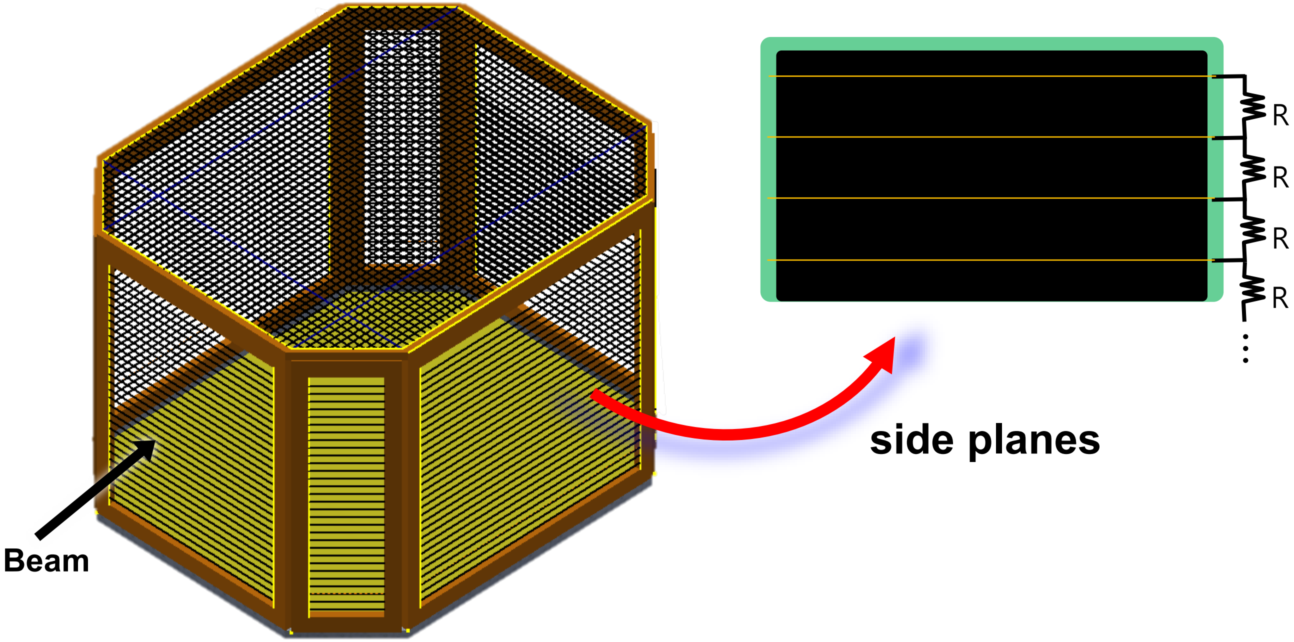
- Motivation
  - Total cross section of ^{12}C*(*p*,*p*')^{12}C*(HS) was measured up to 2.3 MeV above Hoyle state in previous work. Above region was predicted using Hauser-Feshbach calculation, however, was not sensitive to the resonance and failed to predict neutron upscattering result.
- Experiment setup
  - R3 beam line, proton beam with 8 – 18 MeV (1 MeV interval).
  - Active target TPC AToM-X with CO_2 gas target.
- Goal of the experiment
  - Measure total cross section of ^{12}C*(*p*,*p*')3α, 0 – 12 MeV above Hoyle state threshold.
- 7 days of beam time is approved at JAEA tandem accelerator.

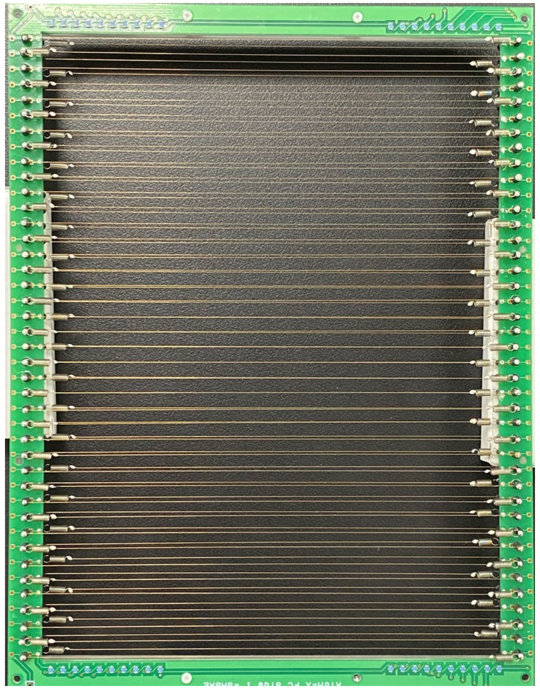
Field cage

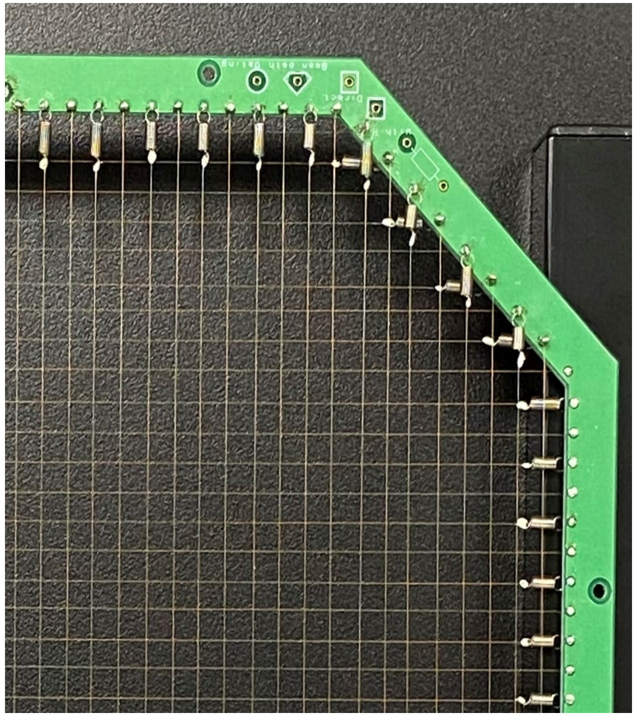


- **Providing uniform electric field in the active volume**
- **PCB boards + Polycarbonate frame**
- **cathode + anode + side planes**

- **Type-1 : Au-plated tungsten wires on PCB → Transparent !**
  ex) ^{34}Ar(α,p)^{37}K, ^{18}Ne(α,p)^{21}Na, ^{17}F(α,p)^{20}Ne, ...



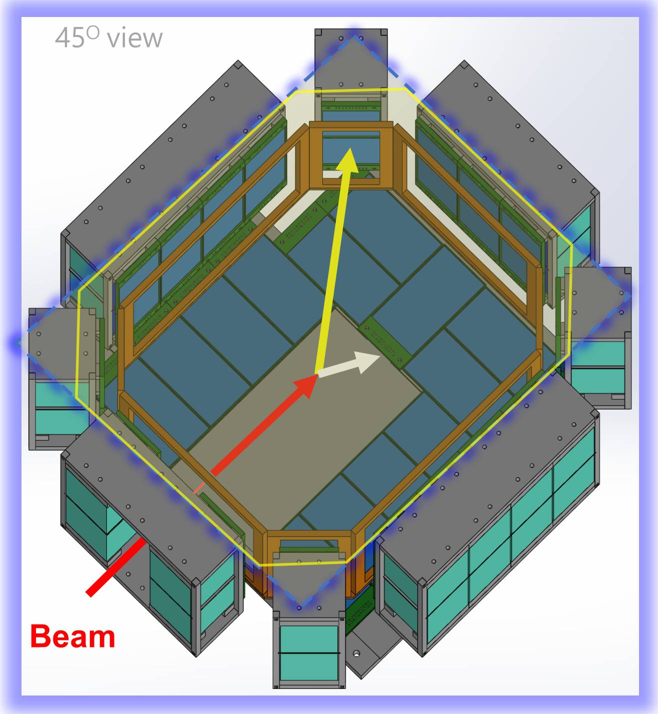


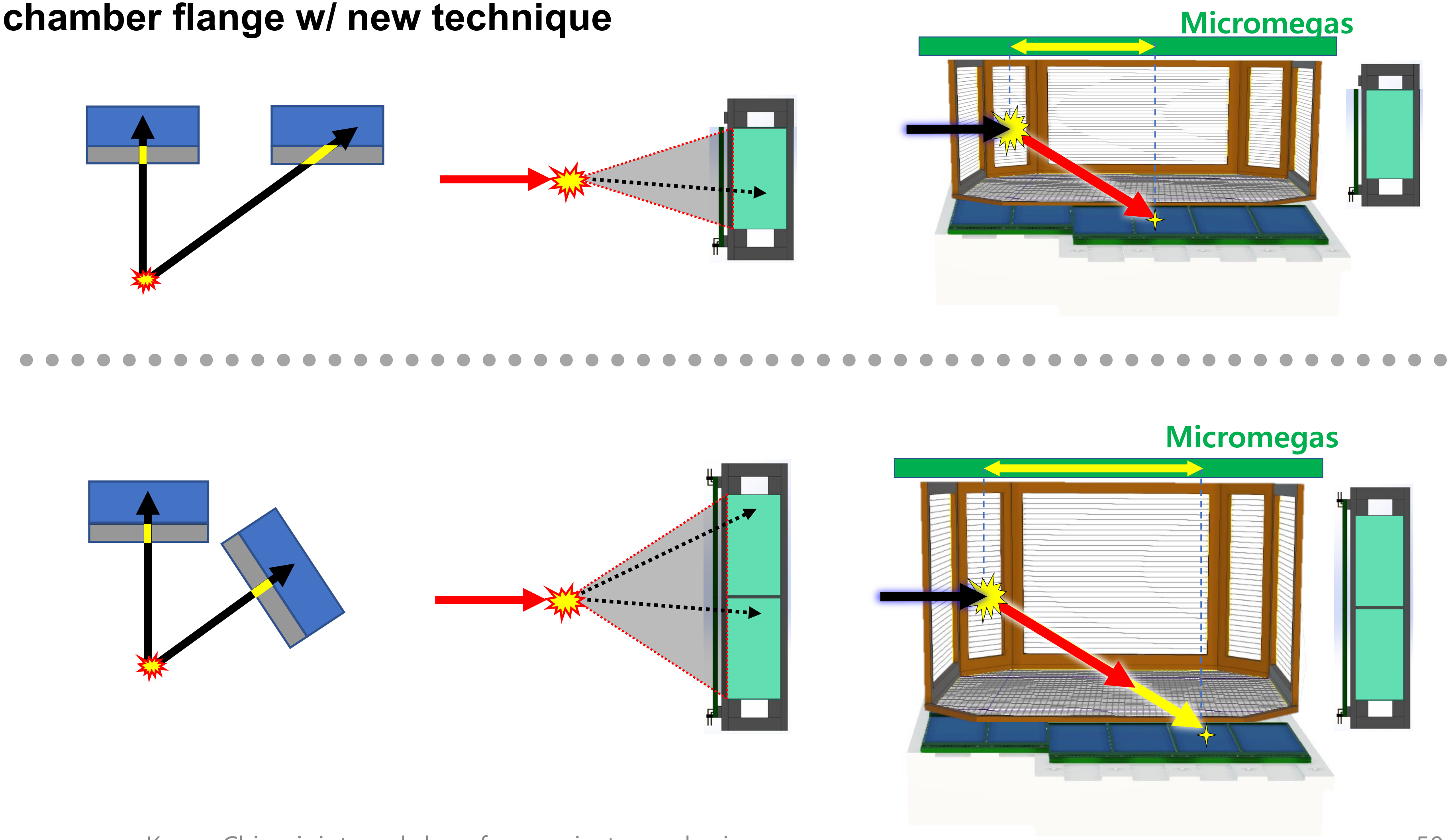


wires both X&Y direction

Major changes?

- Octagonal shape → reduced the dead-layer effect of silicon detectors
- Double layer of aux. detectors → better angular coverage
- Extended FC → longer track can be measured.
- External Micromegas as a chamber flange w/ new technique





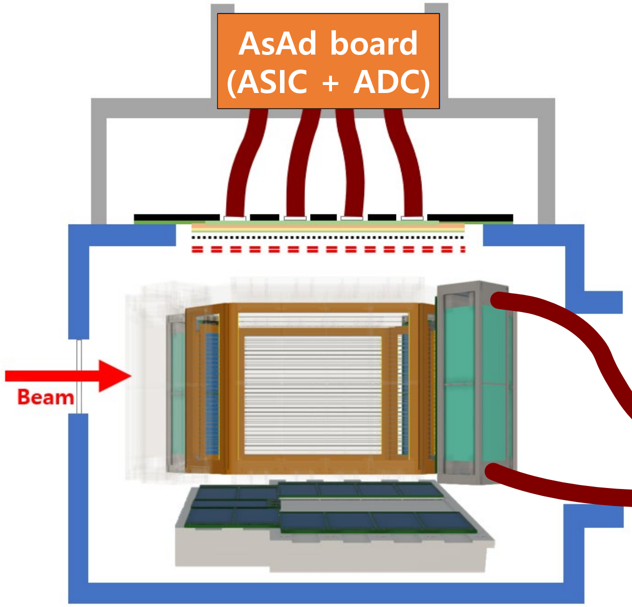
Chamber and Data acquisition system

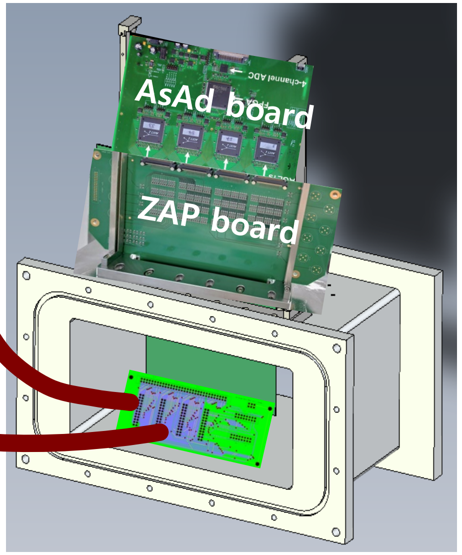
- **Assembly type chamber** (1/2”-thick aluminum)

- **General Electronics for TPCs (GET) system based on ASIC**
  - ✓ **handling large number of channels w/ high data transfer rate**
  - ✓ **5650 electronic channels in total** (4600 from Micromegas & 1050 from aux. detectors)

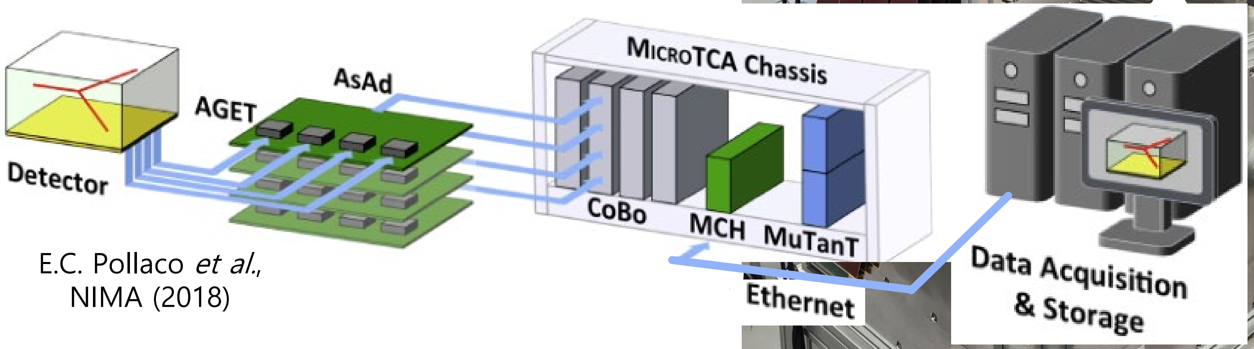
- **Signal merging PCB & ZAP board (bias and signal processing) for aux. detectors**

E.C. Pollaco *et al.*, NIMA (2018)

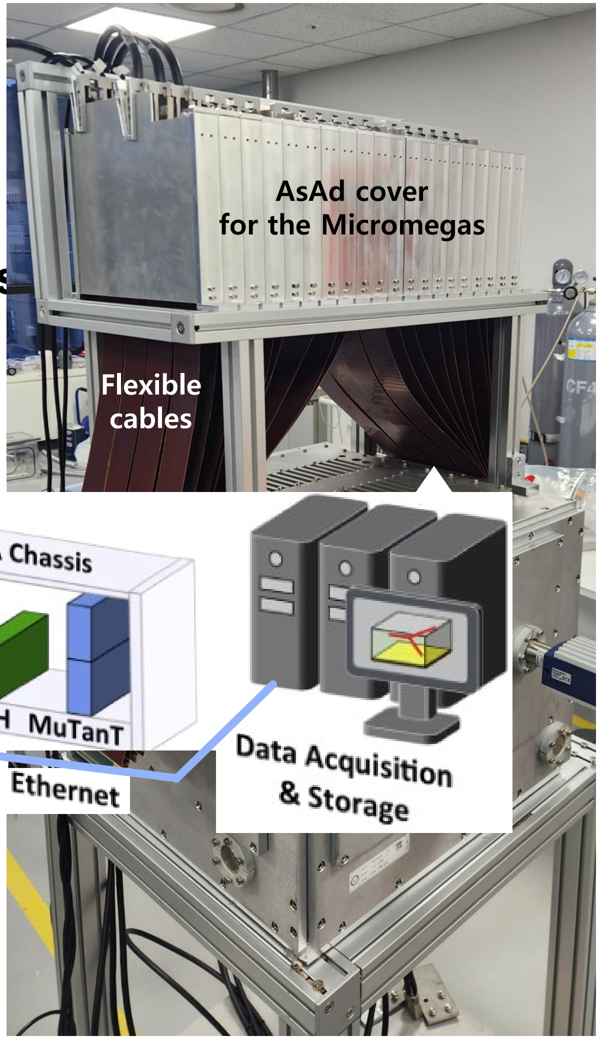




Chamber wings

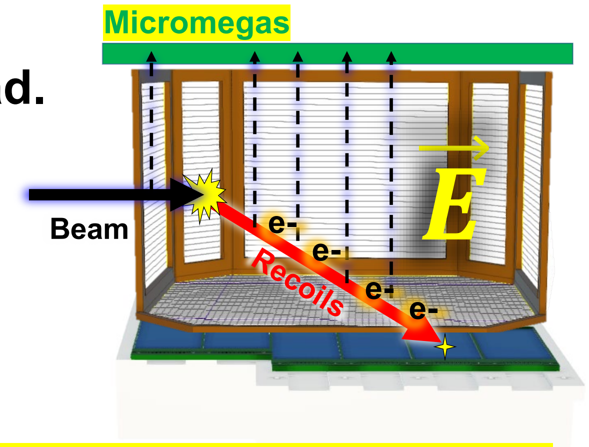


E.C. Pollaco *et al.*, NIMA (2018)

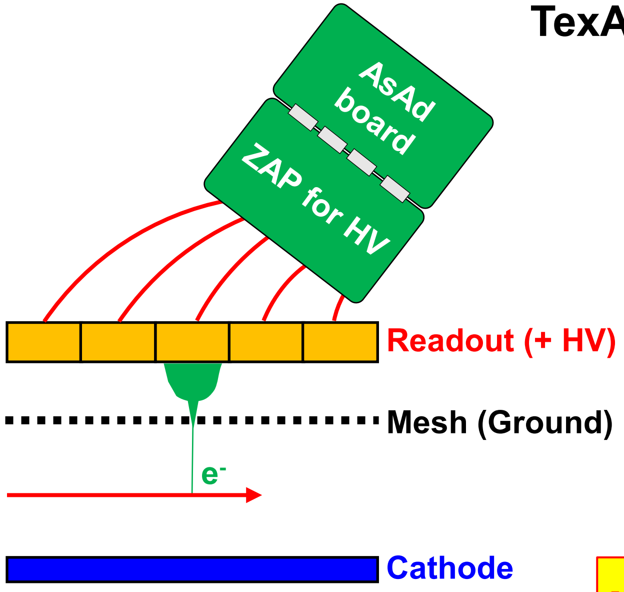


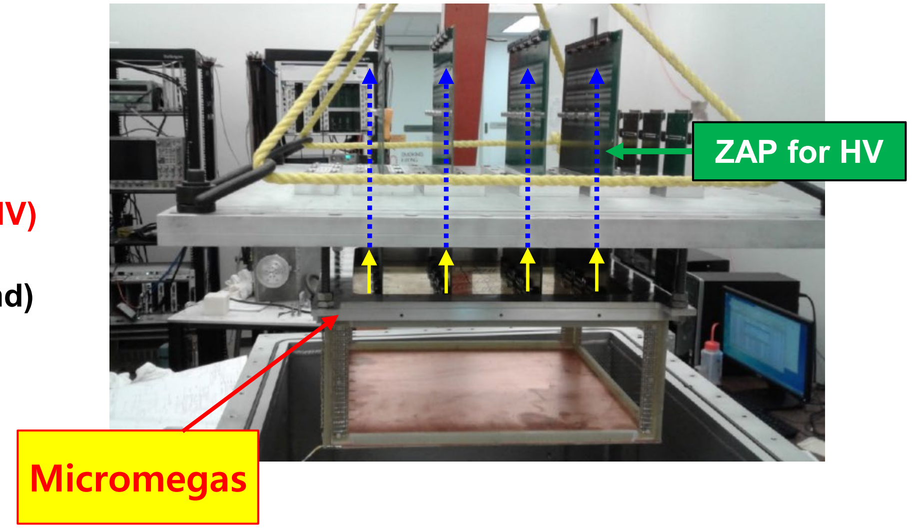
Micromegas

- **Tracking charged particles** *(beam, recoils, ...)*
- **Drift electrons from the ionization are amplified b/w GEM & mesh & readout pad.**
  - ✓ **Type-1 : Resistive** *(for AsAd board protection)*
  - ✓ **Type-2 : Resistive + Capacitive sharing** *(for better position resolution)*
- **No ZAP board required (No bias on the readout pad)**
- **Micromegas as a chamber flange**



TexAT Micromegas





Resistive Micromegas for AToM-X