Construction of active target TPC at CENS

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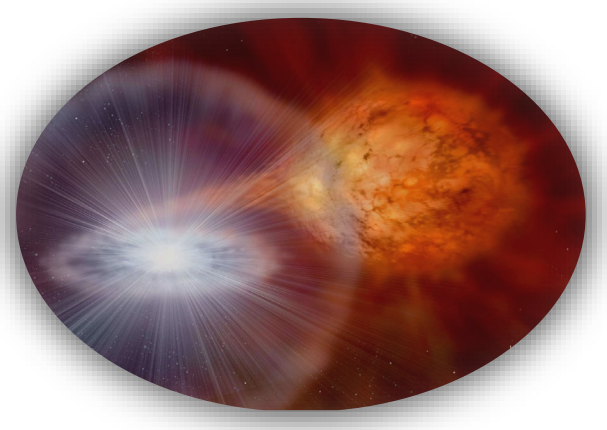
Center for Exotic Nuclear Studies, Institute for Basic Science

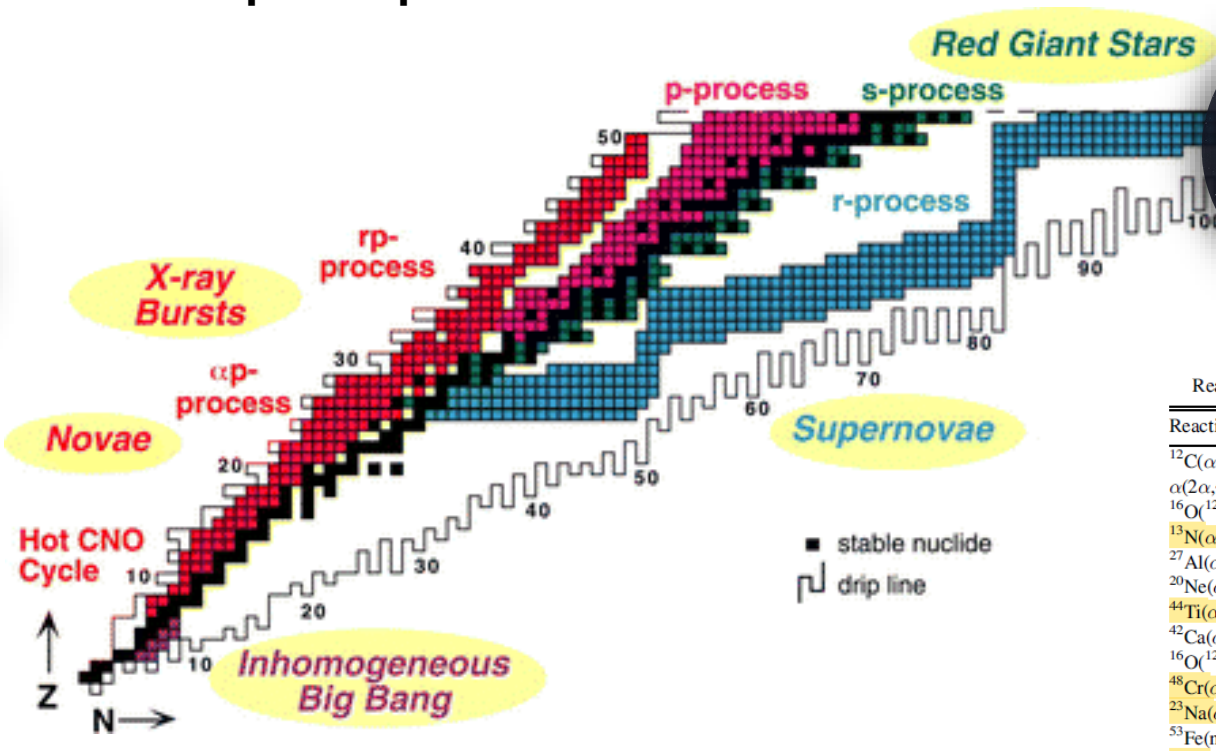
on behalf of AToM-X collaboration

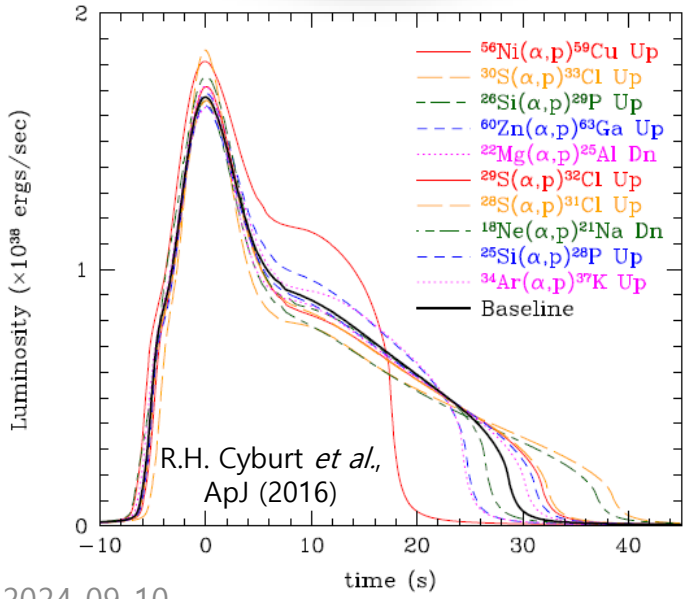
Background Image:
Courtesy of Terry Robison

Importance of (α,p) reactions for astrophysics

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







Very small reaction cross sections
→ Challenging !

Reaction Rate Variations that Affect Three or More Isotopes of Interest

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

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

Why Active Target Time Projection Chamber?

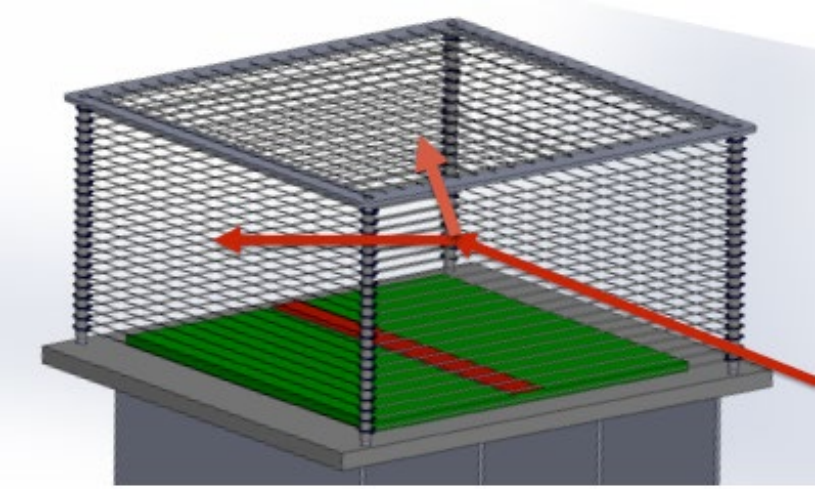
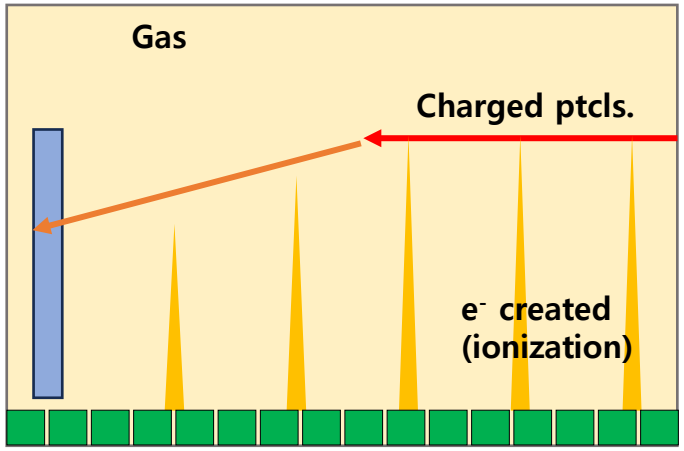
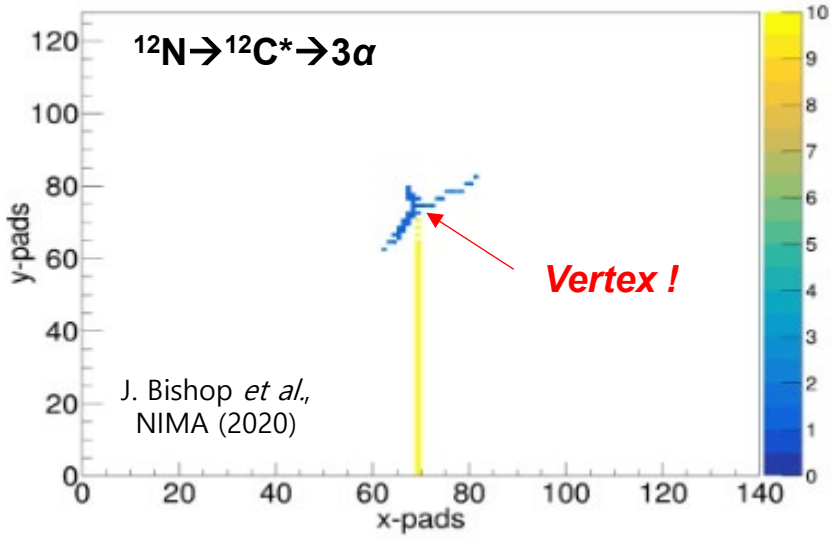


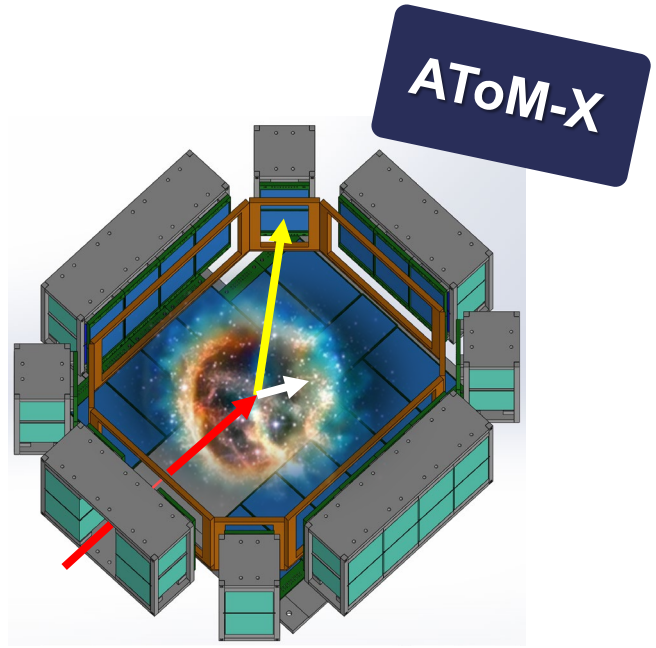
Figure from G.V. Rogachev





- **Active target TPC**
  - ✓ **Detection gas plays as a reaction target**
  - ✓ **3D tracking of charged particles → reaction vertex measurement!**

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

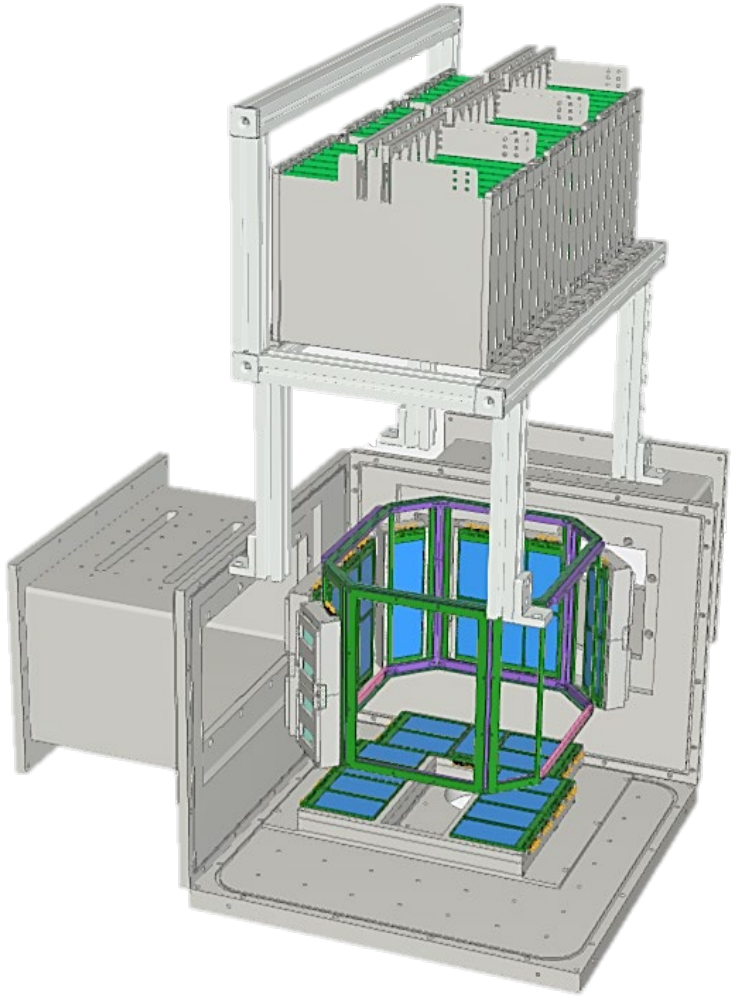


AToM-X : Active target TPC for Multiple nuclear eXperiment

- **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** *(Track measurement)*
  - ✓ **Micromegas**
  - ✓ **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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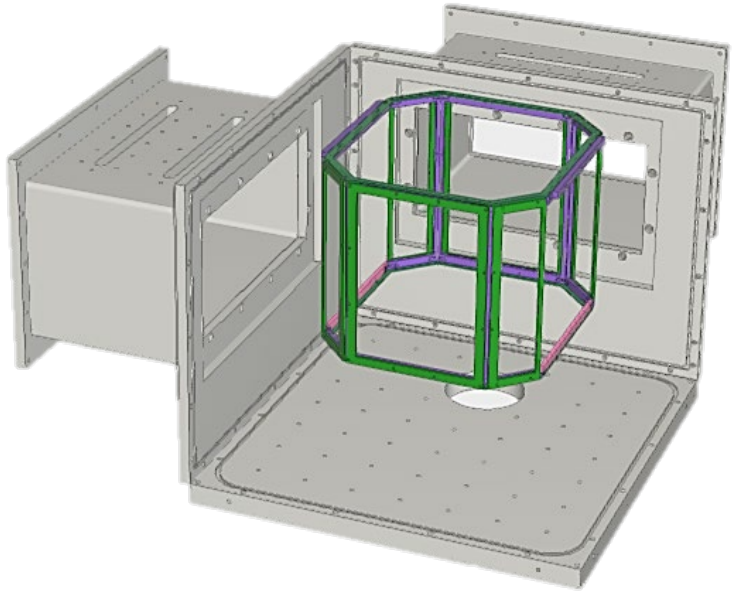

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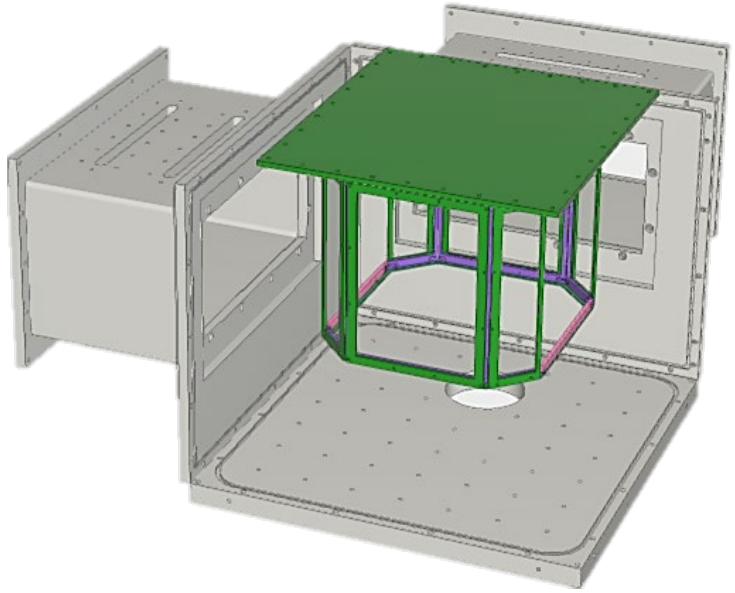

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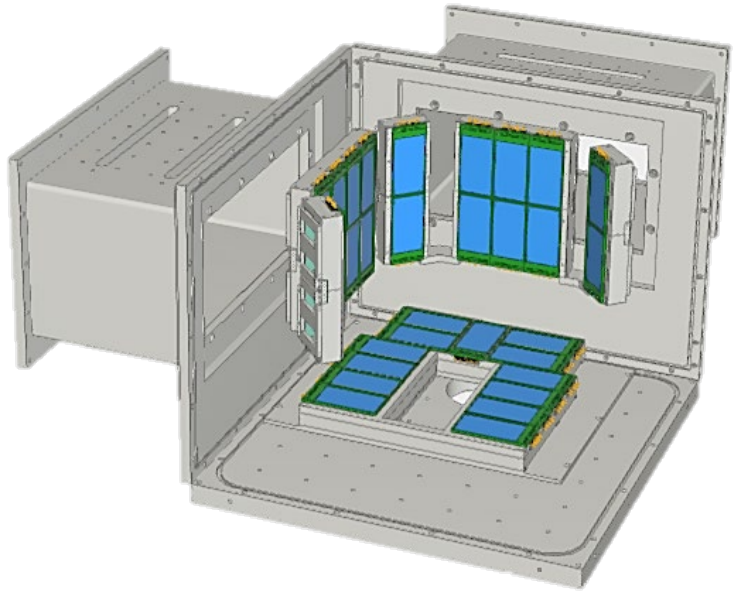

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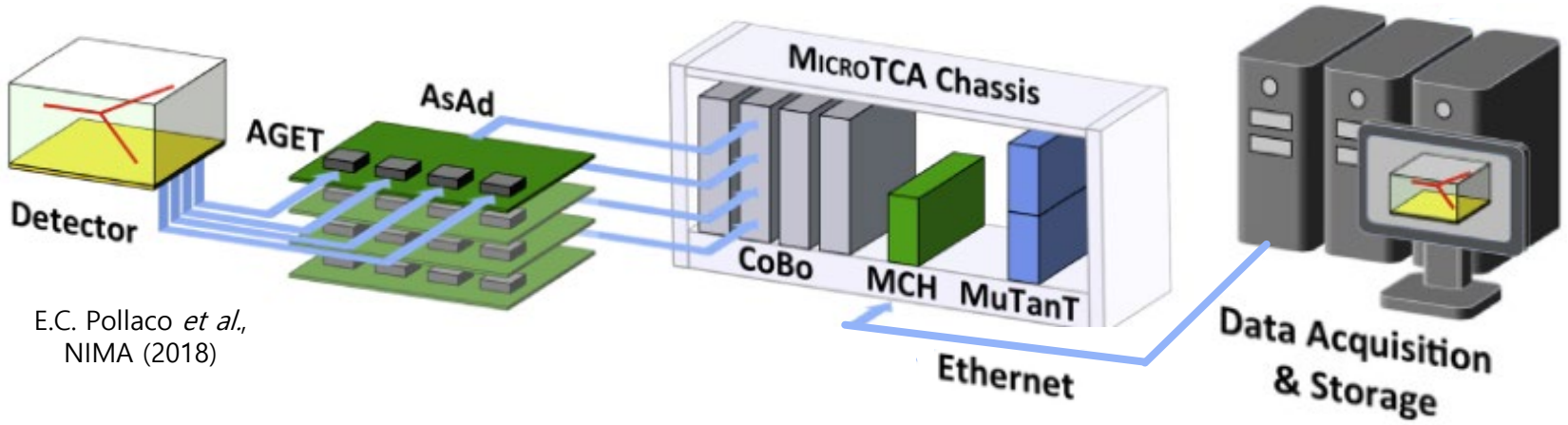
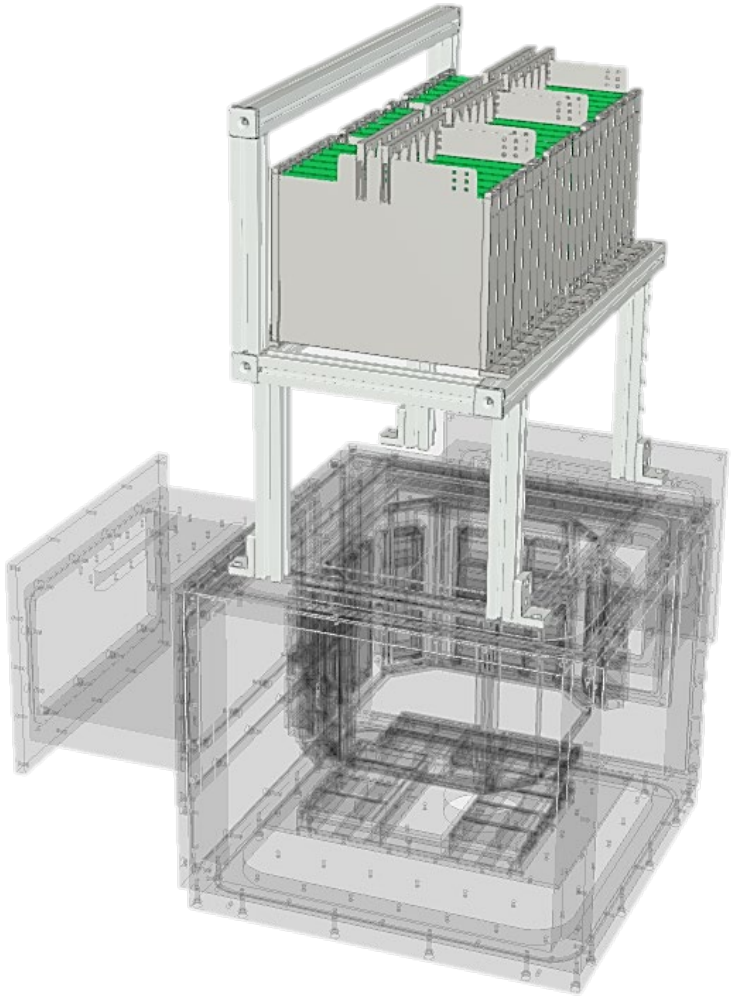


E.C. Pollaco *et al.*,
NIMA (2018)



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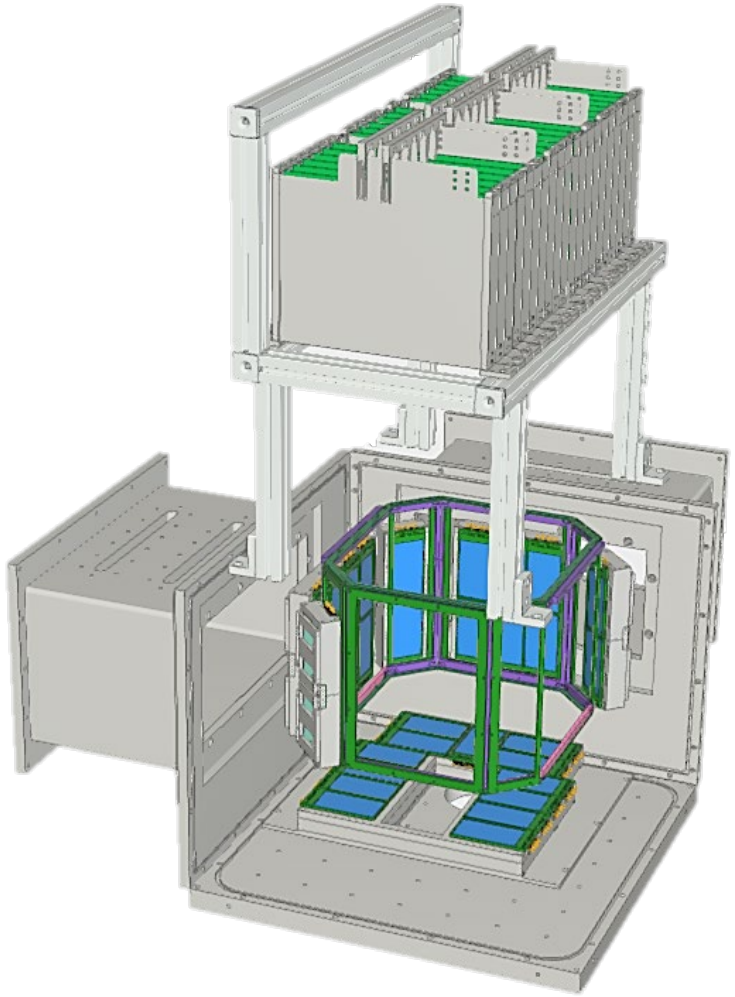
- **Dimensions :**
  - ✓ **Chamber : 504(X) x 417(Y) x 504(Z) mm^3**
  - ✓ **Wings for signal (ZAP) feed through : 236(X) x 270(Y) x 390(Z) mm^3**
  - ✓ **Assembly type→portable!**



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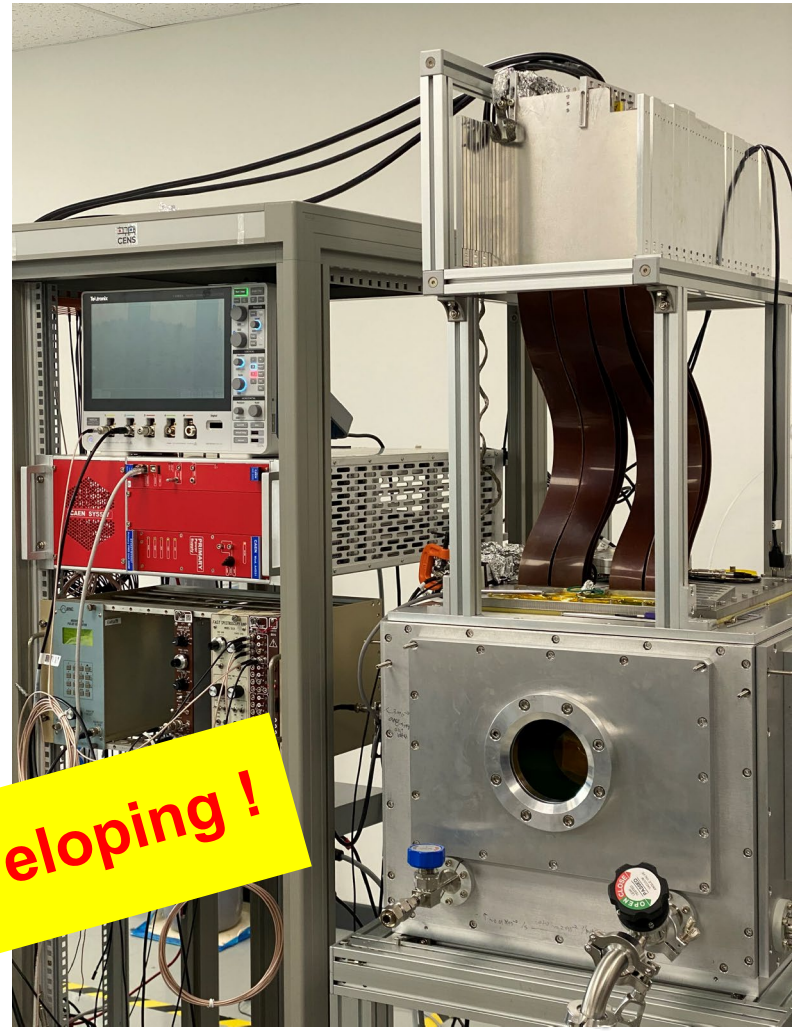
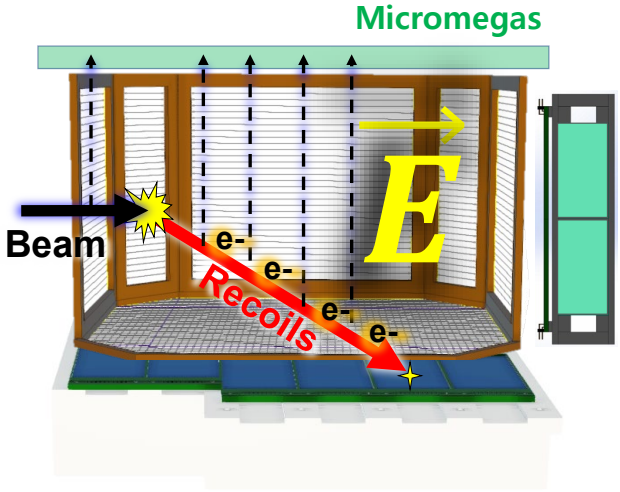
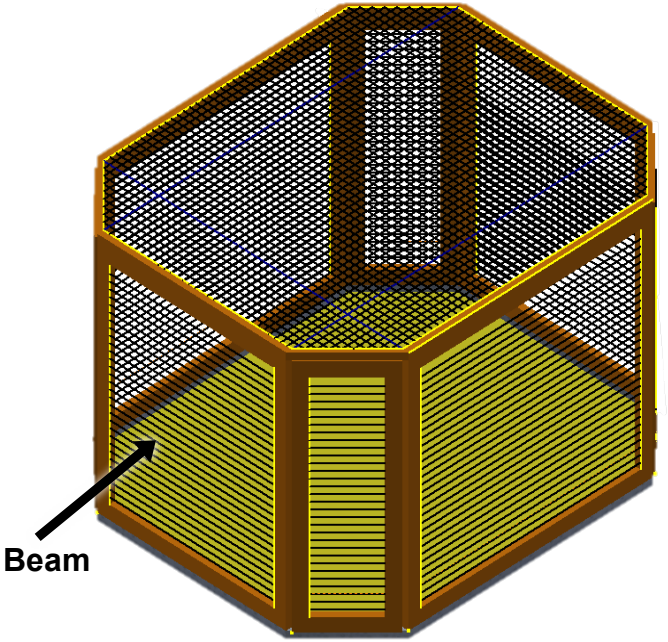
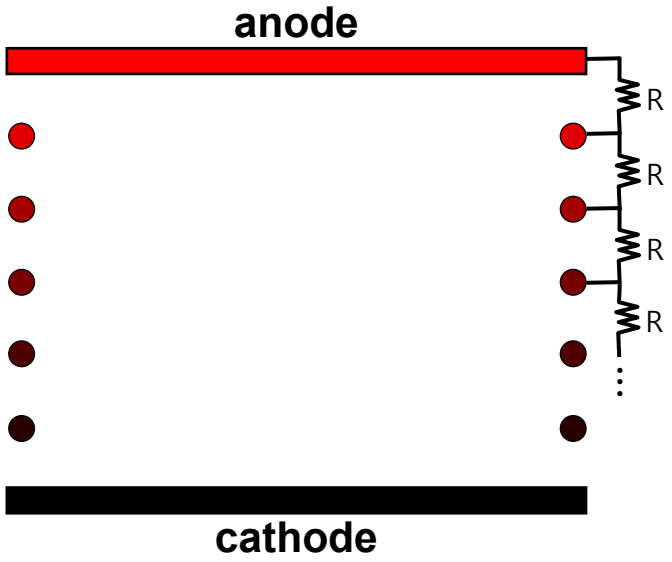


Field cage



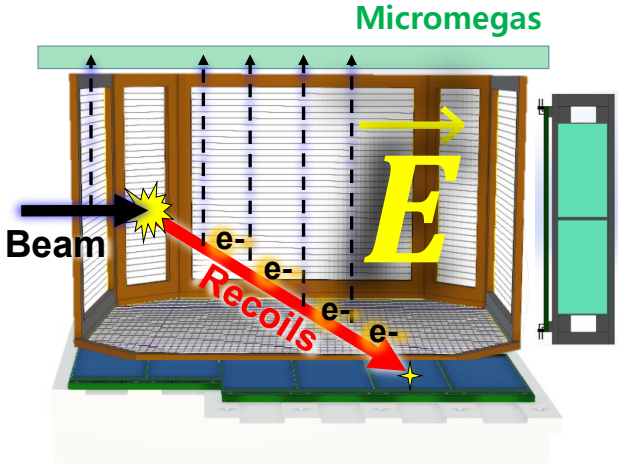
- Providing uniform electric field in the active volume
- PCB boards + Polycarbonate frame
- cathode + anode + side planes





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

Field cage

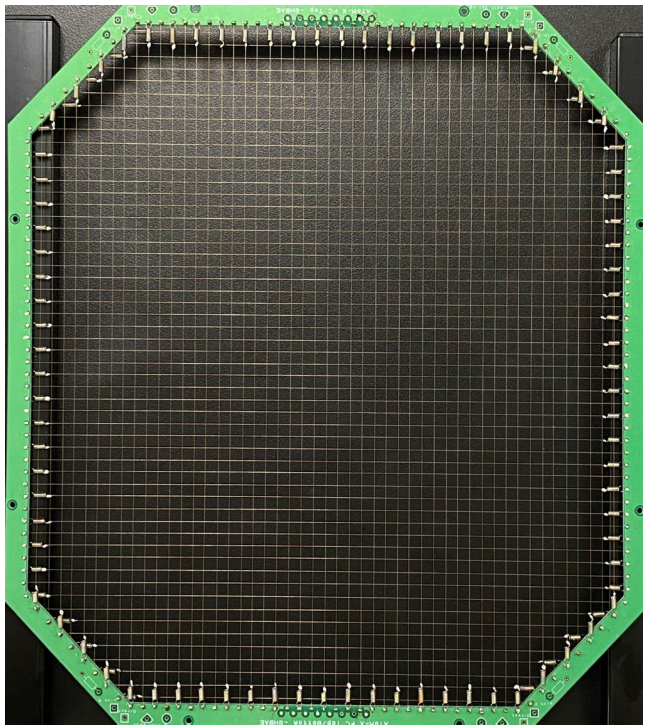


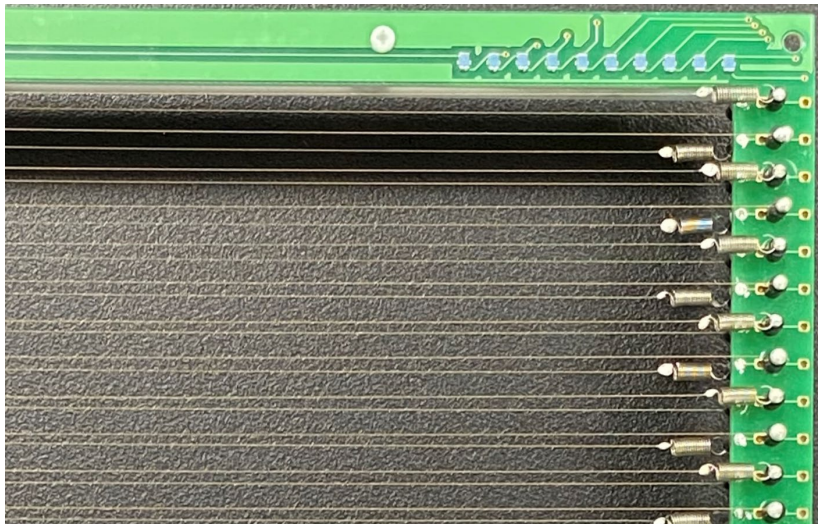
- **Providing uniform electric field in the active volume**
- **PCB boards + Polycarbonate frame**
- **cathode + anode + side planes**

- **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, ...

Now on fabrication !

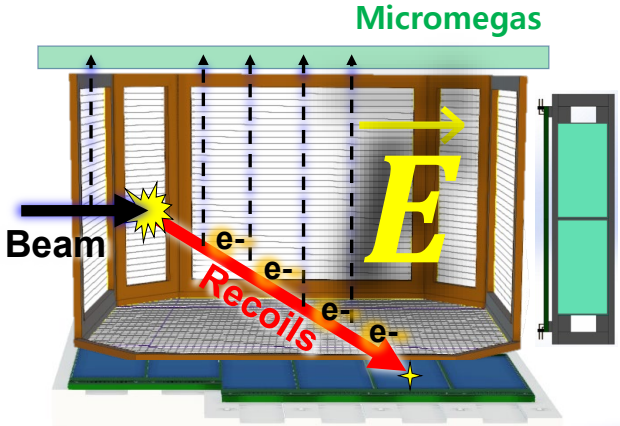
cathode





A part of side planes

Field cage



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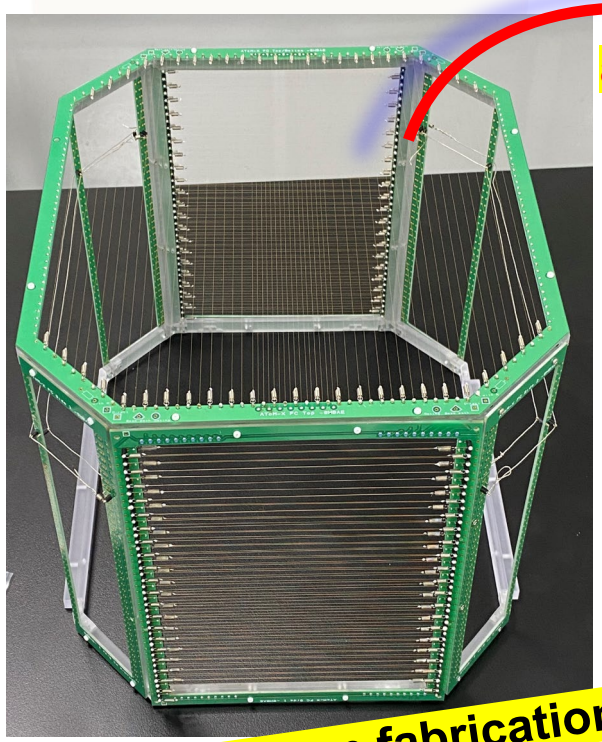

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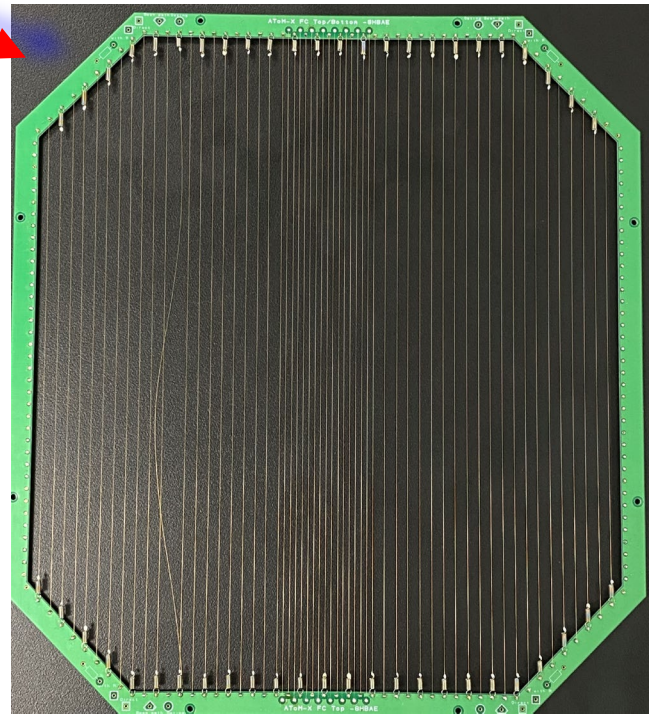
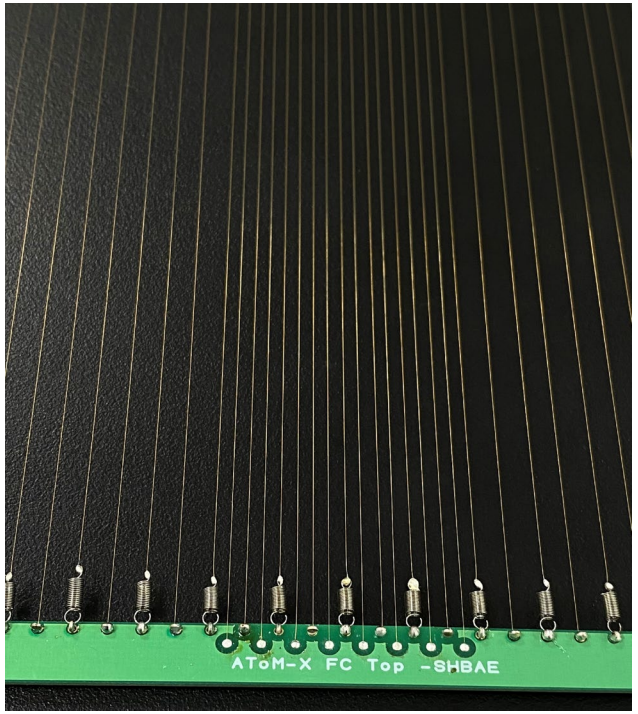
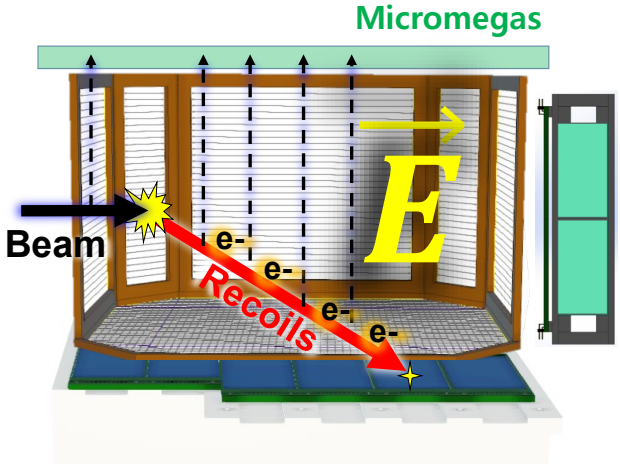


Narrow wire gaps!



Field cage



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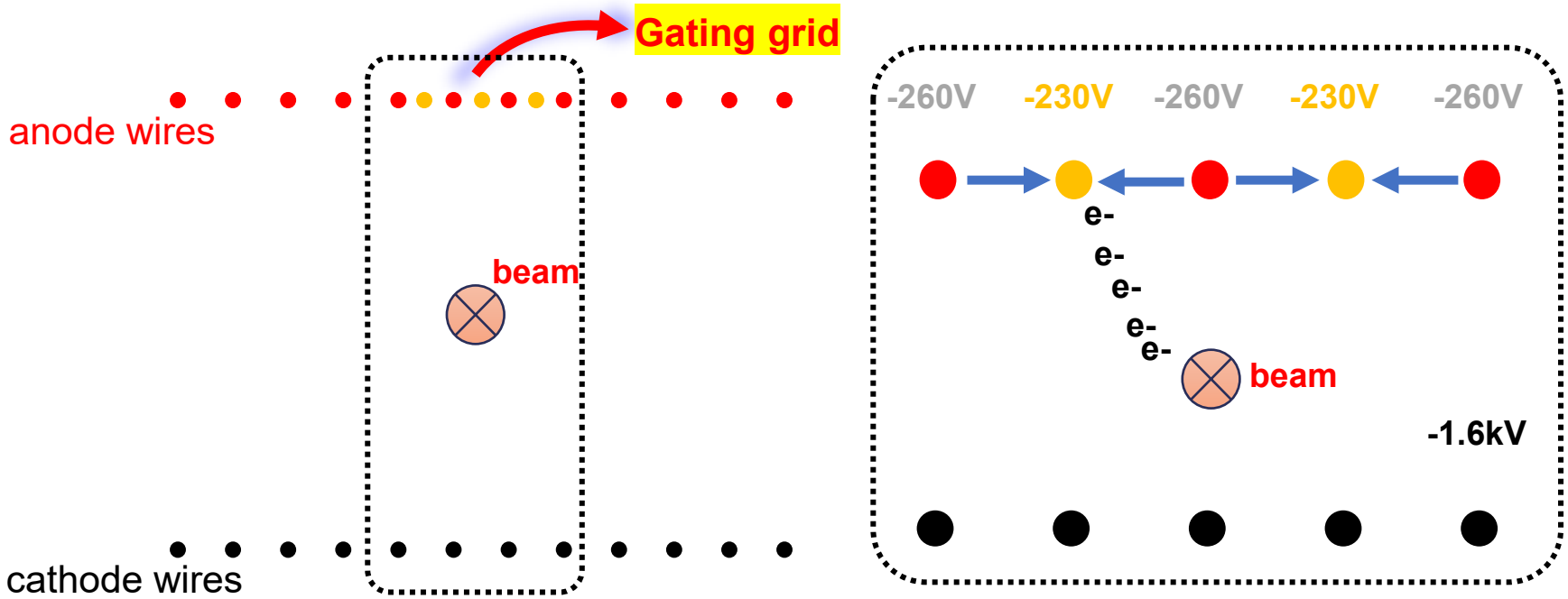
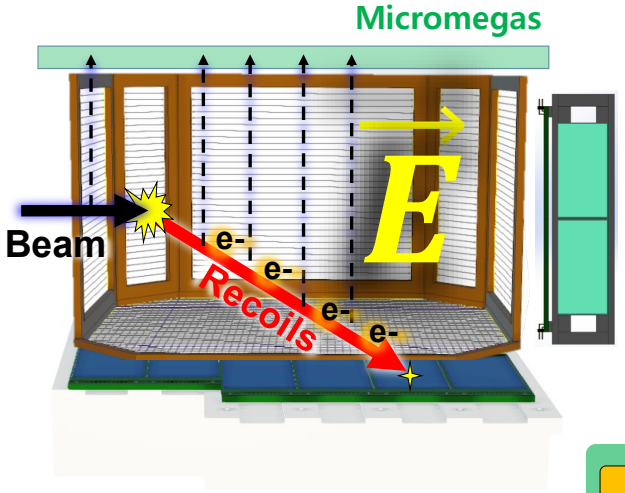


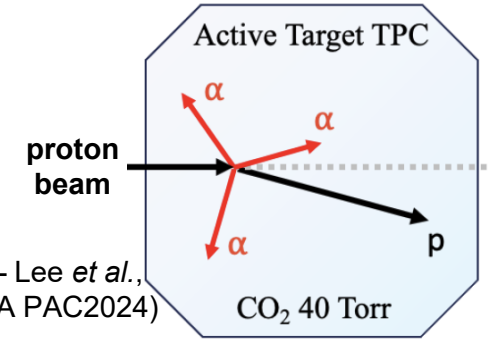
Reducing a huge amount of space charge from the high intensity beam !

Field cage

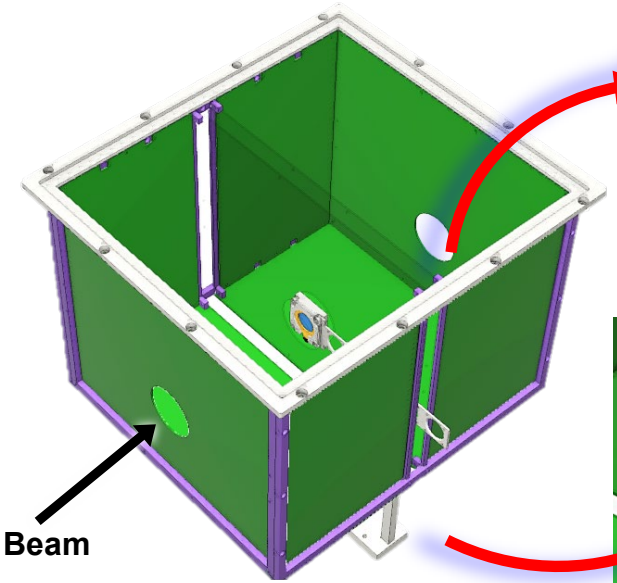


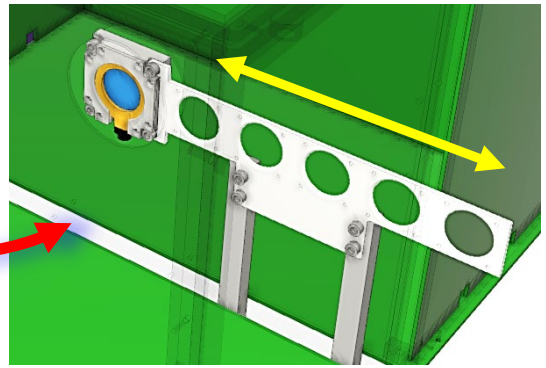
- **Providing uniform electric field in the active volume**
- **PCB boards + Polycarbonate frame**
- **cathode + anode + side planes**

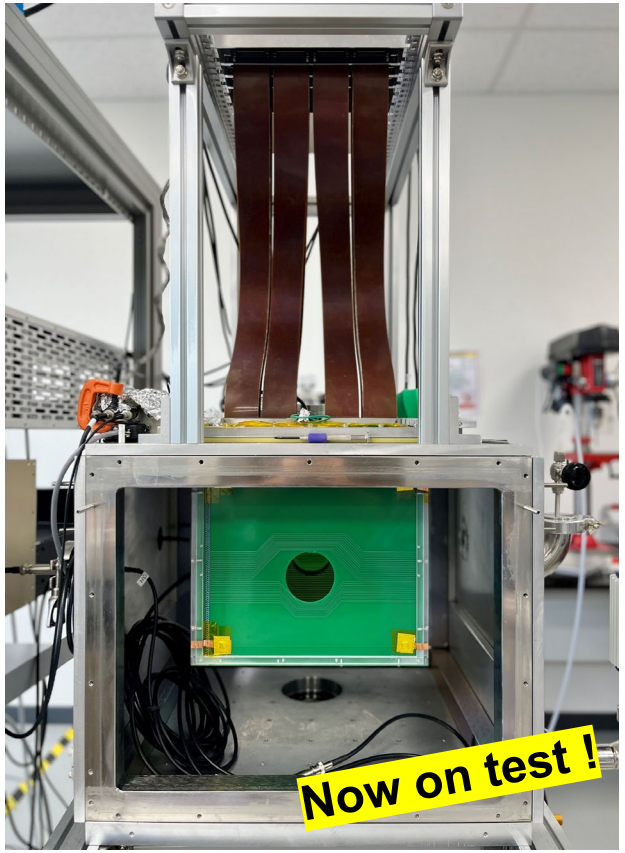
- **Type-2 : Segmented copper plates on PCB**
  ex) $^{12}C(p,p')^{12}C$, $^{3}He+^{208}Pb$, …



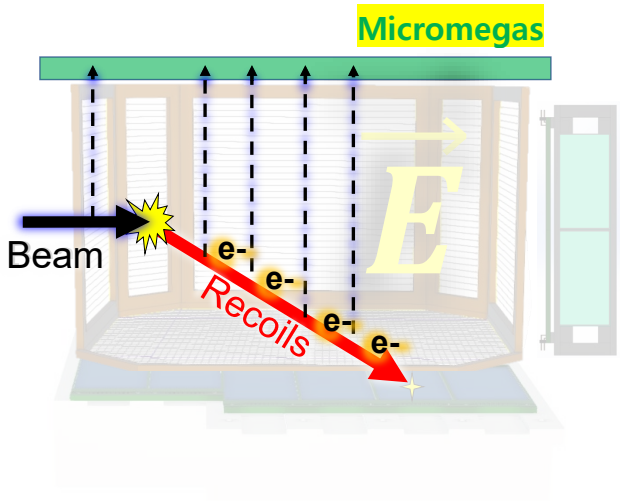
J.W- Lee *et al.*,
(JAEA PAC2024)



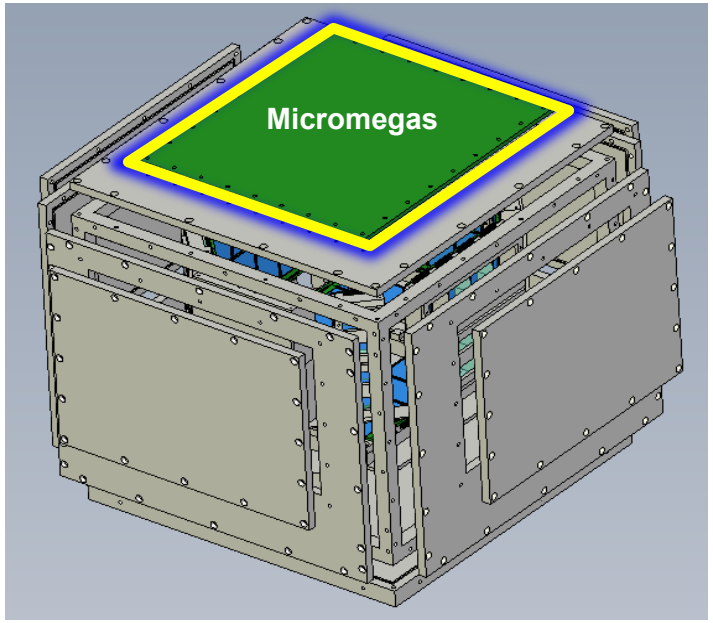


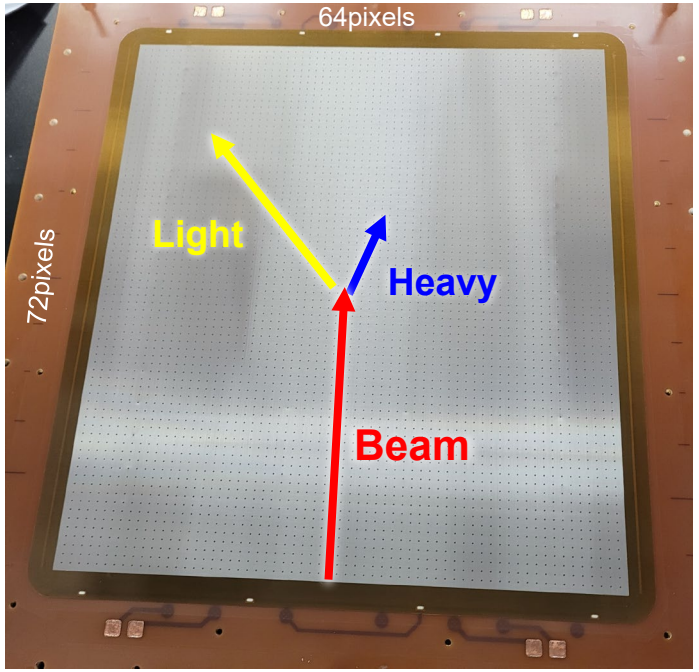


Micromegas

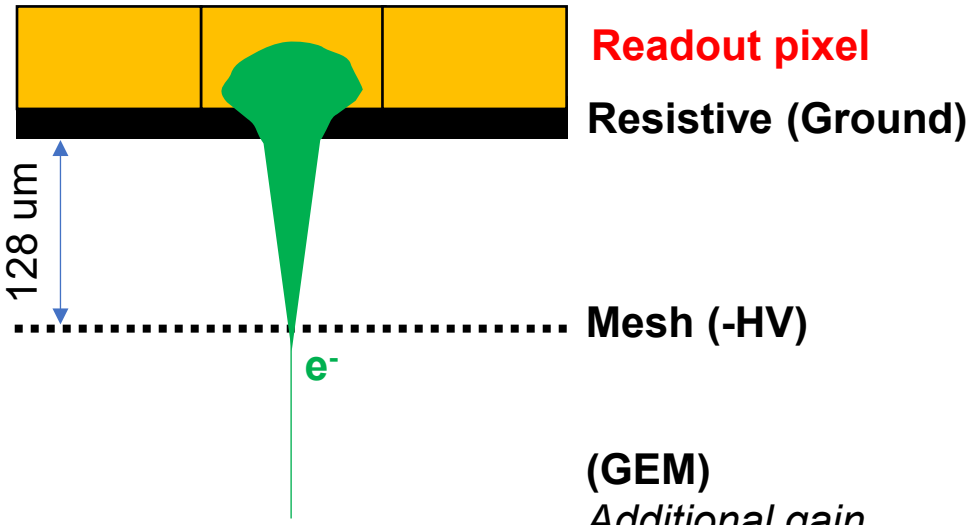


- **Tracking charged particles with readout pixels** *(beam, recoils, ...)*
- **Micromegas as a chamber flange**
- **Drift electrons from the ionization are amplified b/w mesh & readout.**
- **pixel size : 4 x 4 mm²**
  - ✓ **Type-1 : Resistive**
  - ✓ **Type-2 : Resistive + Capacitive sharing** *(for better position resolution)*





Micromegas (front-inside chamber)



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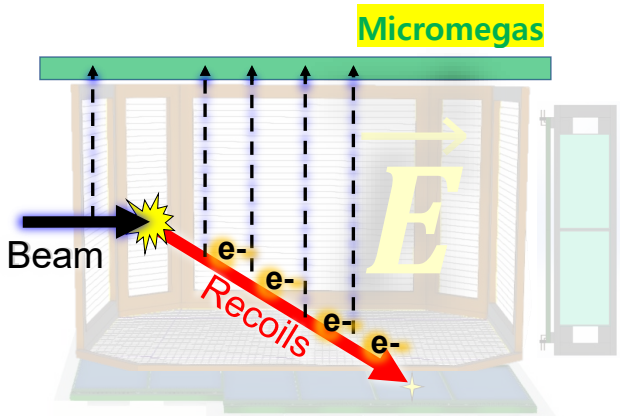

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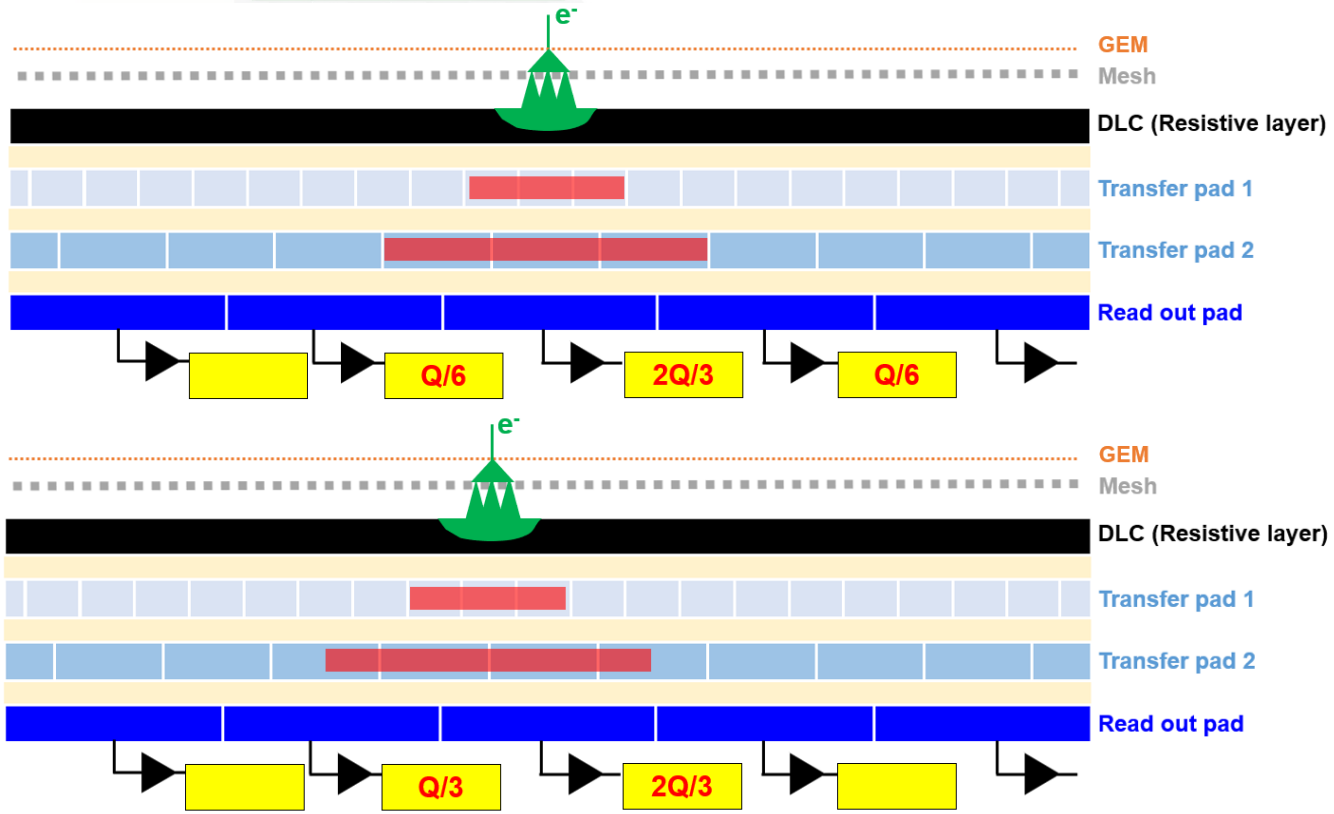
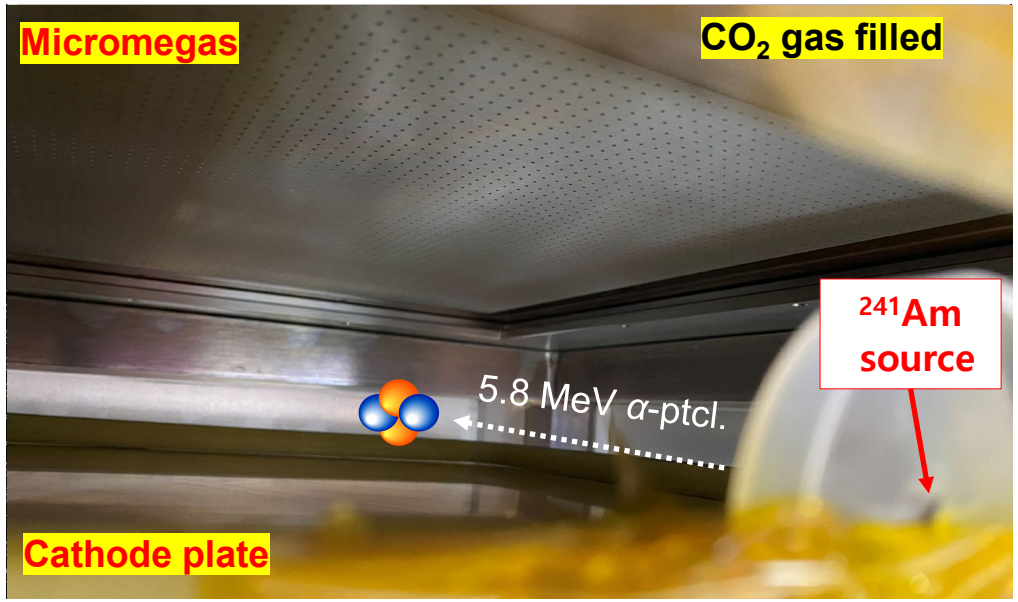
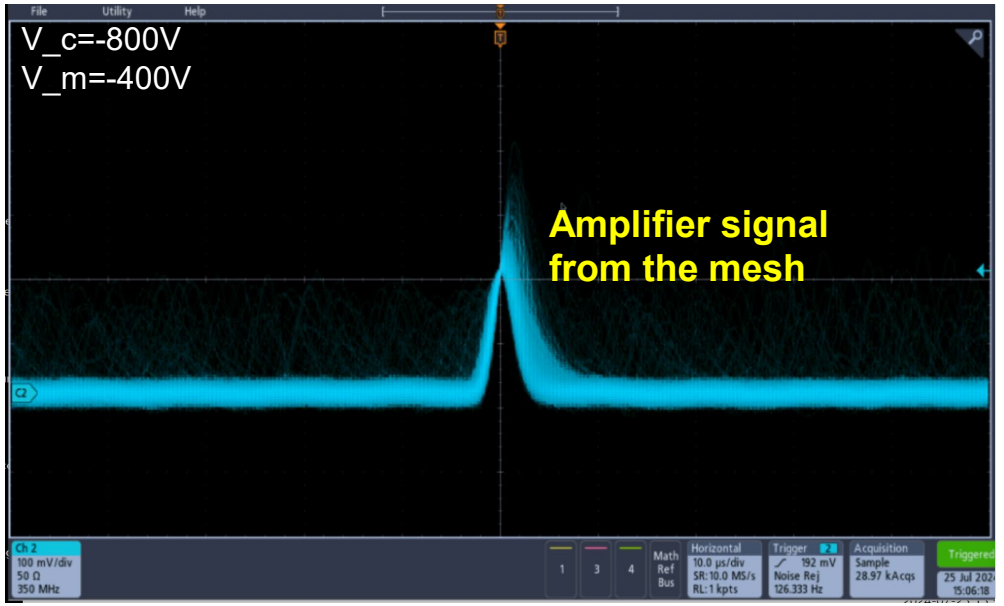


- ✓ **Hit information can be obtained by the different signal heights in multiple pads**
- ✓ **Reconstruction algorithm under development**
- ✓ **Expected position resolution < 1mm**

Micromegas

- **Test 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!**





Micromegas

- **Test status**
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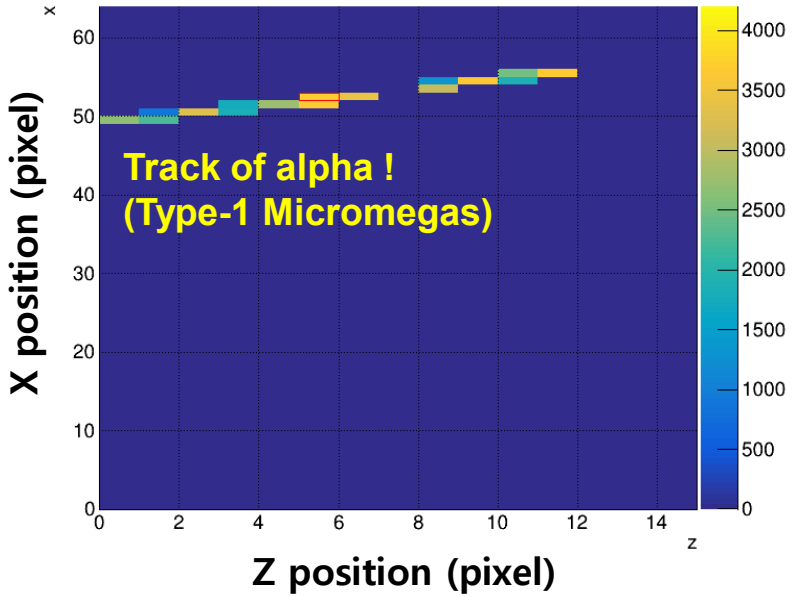
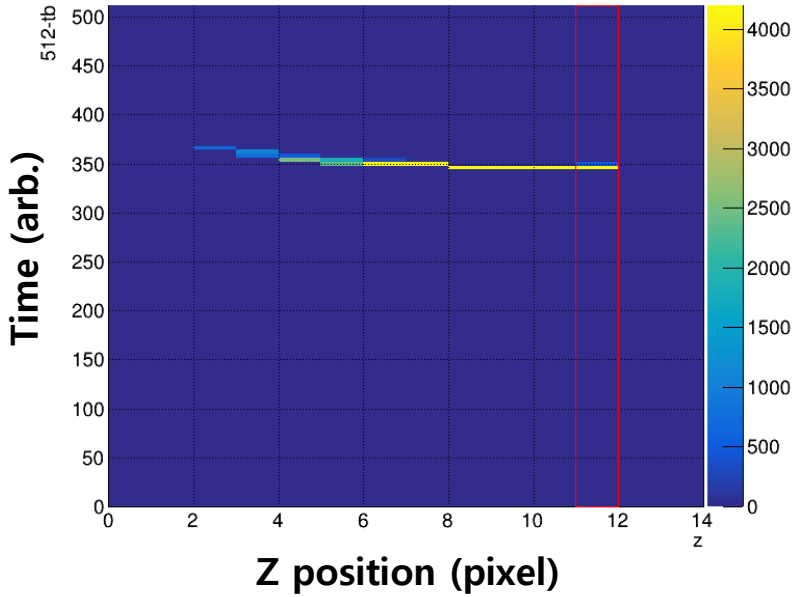
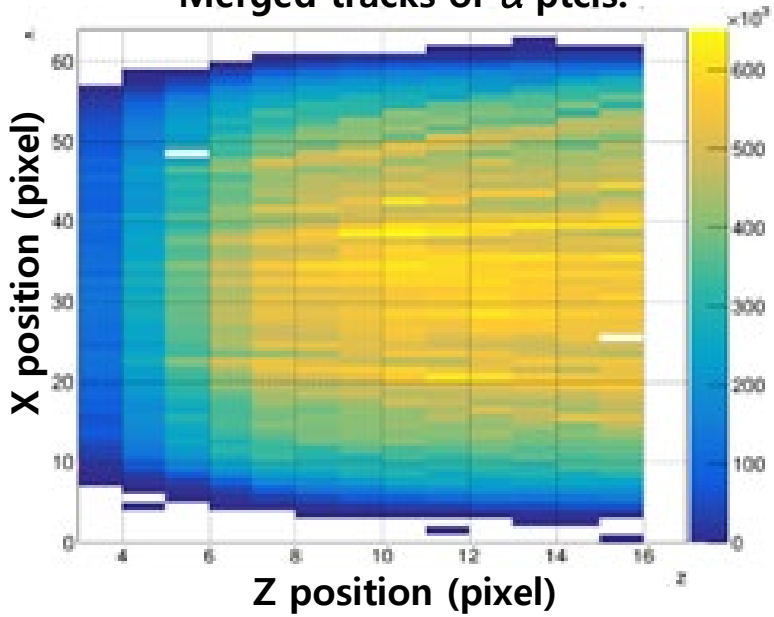
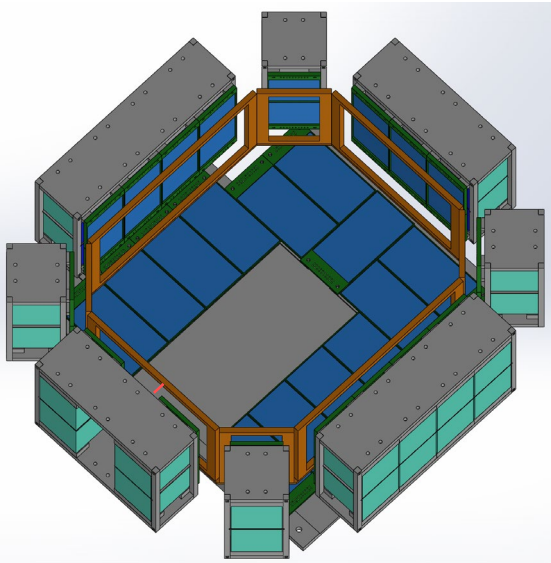




Merged tracks of α ptcls.



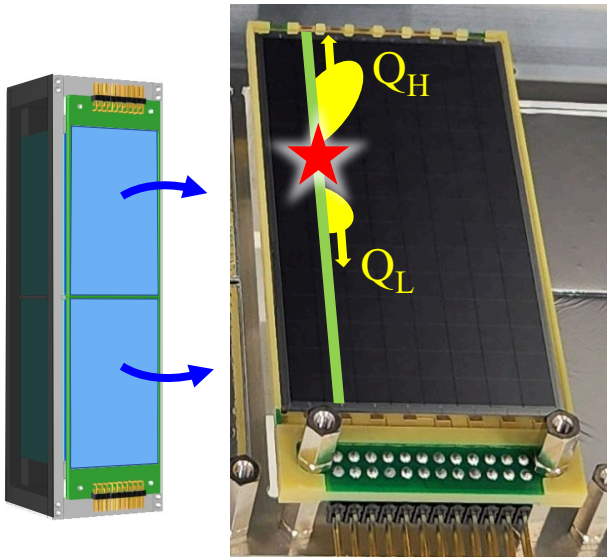
Silicon & CsI detector walls

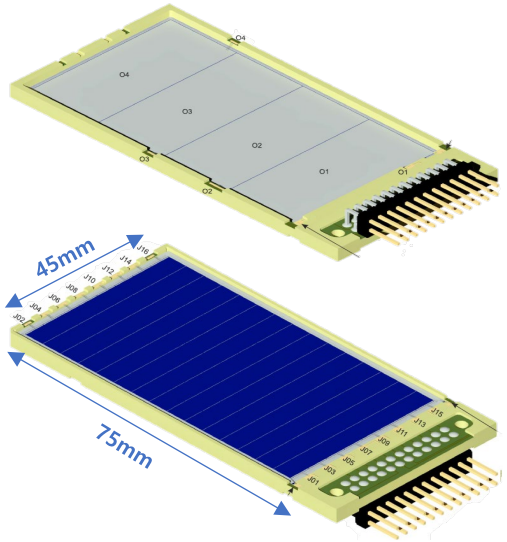


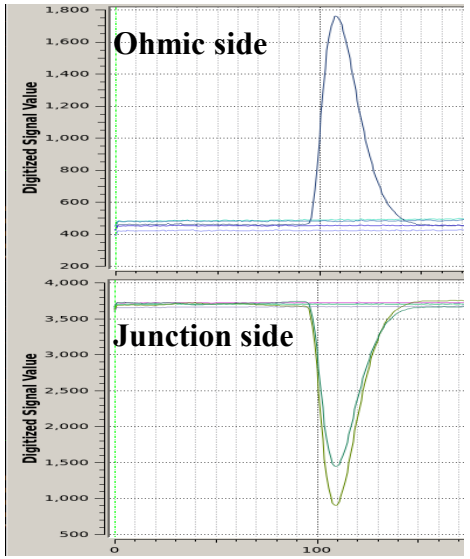
- **Measuring energy and position of charged particles or *γ*-rays**

- **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**

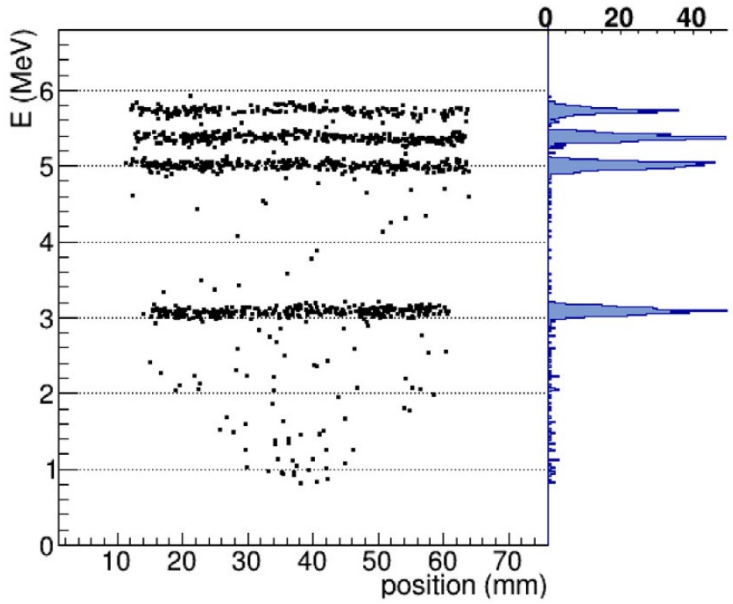
X. Pereira-Lopez *et al.*, NIMB (2023)
D. Kim *et al.*, NIMB (2022)



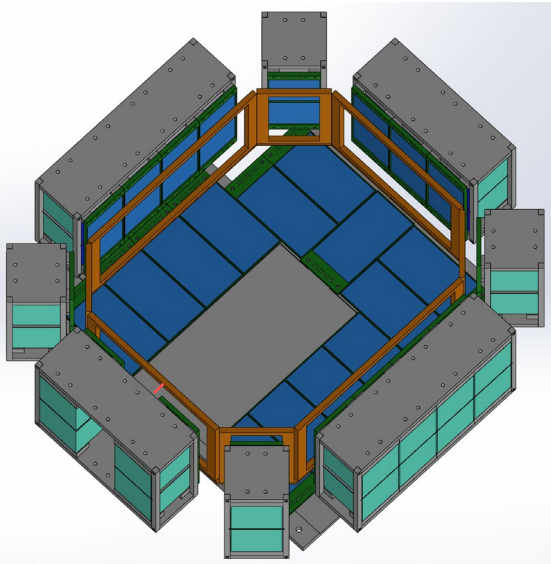




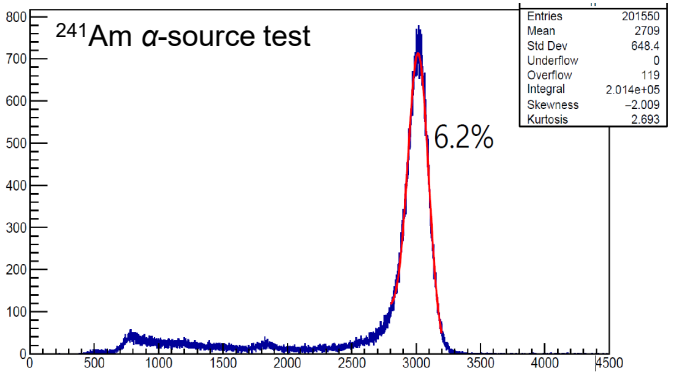
X6 signals obtained by GET electronics

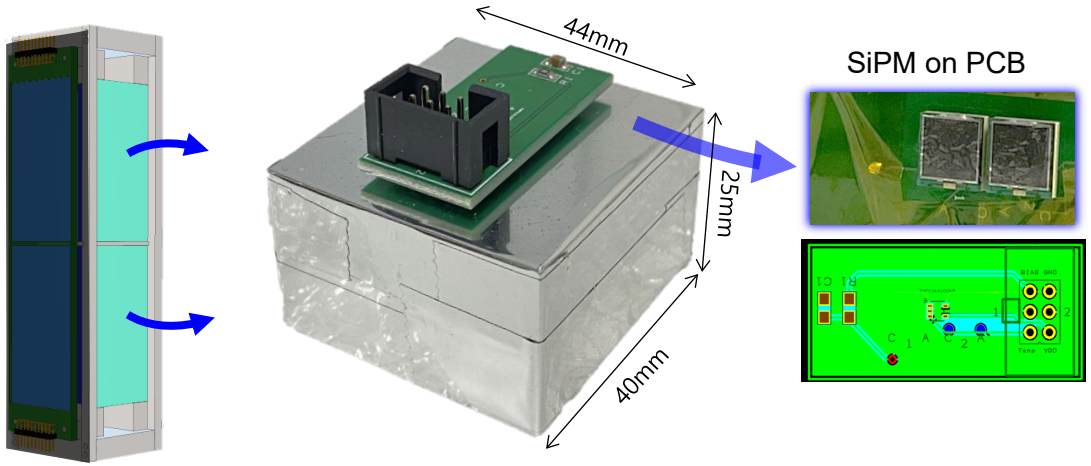


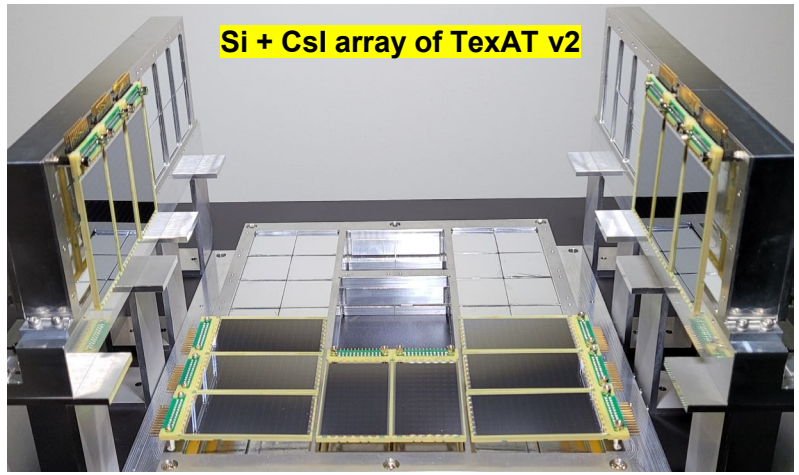
Silicon & CsI detector walls



- **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)**

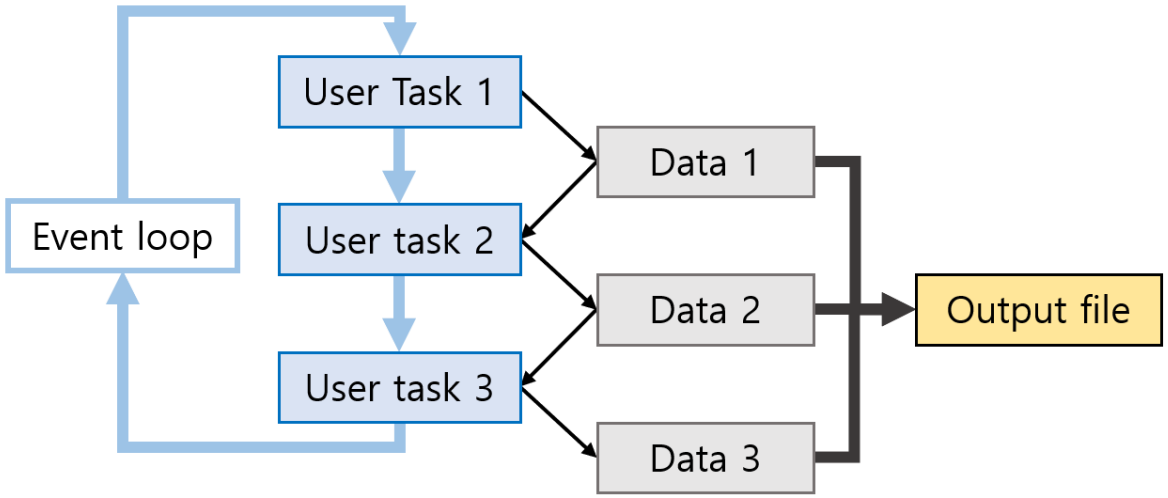


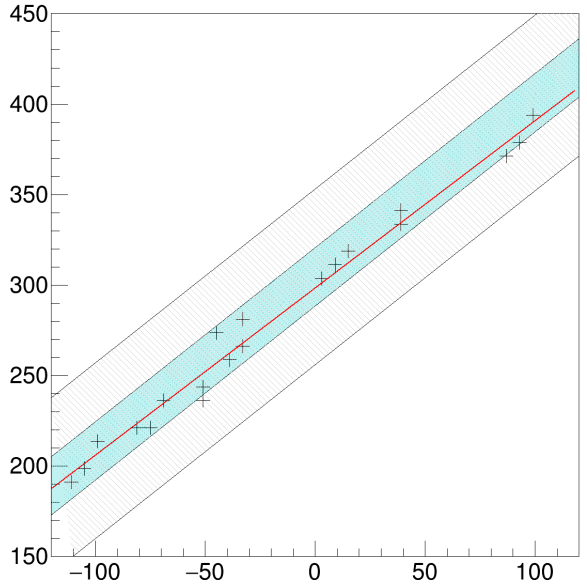




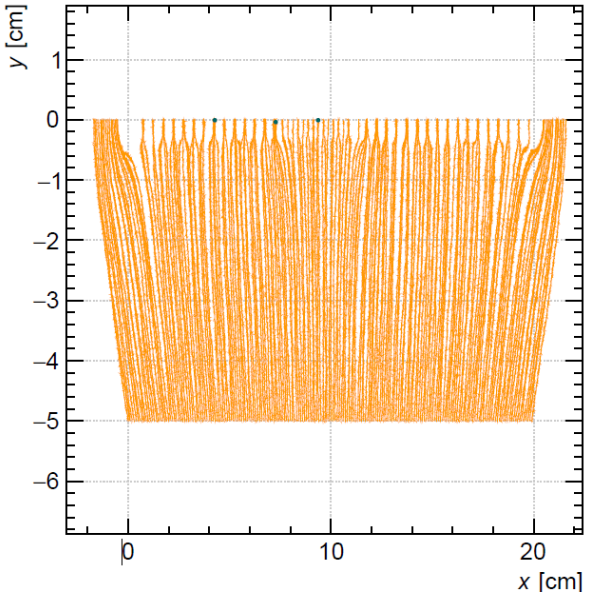
Analysis software and Simulation

- **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, ...**





Example of the track reconstruction using Hough transform



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

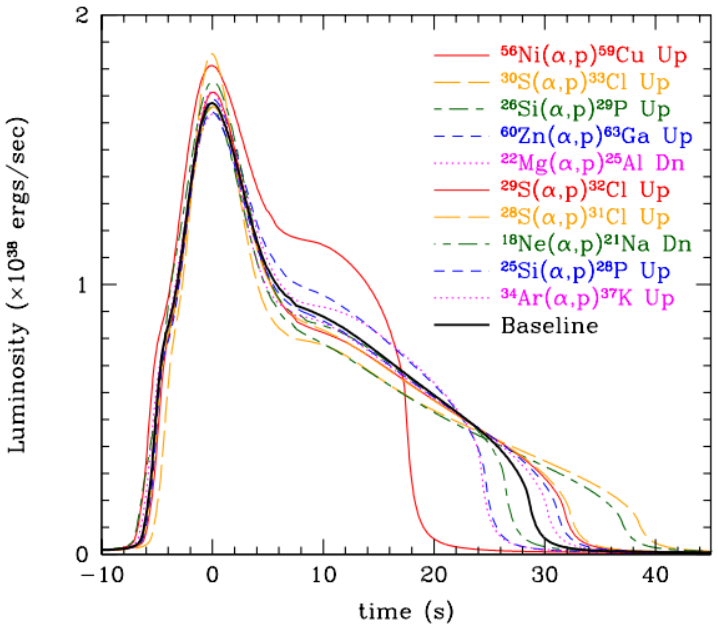
Physics plans

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

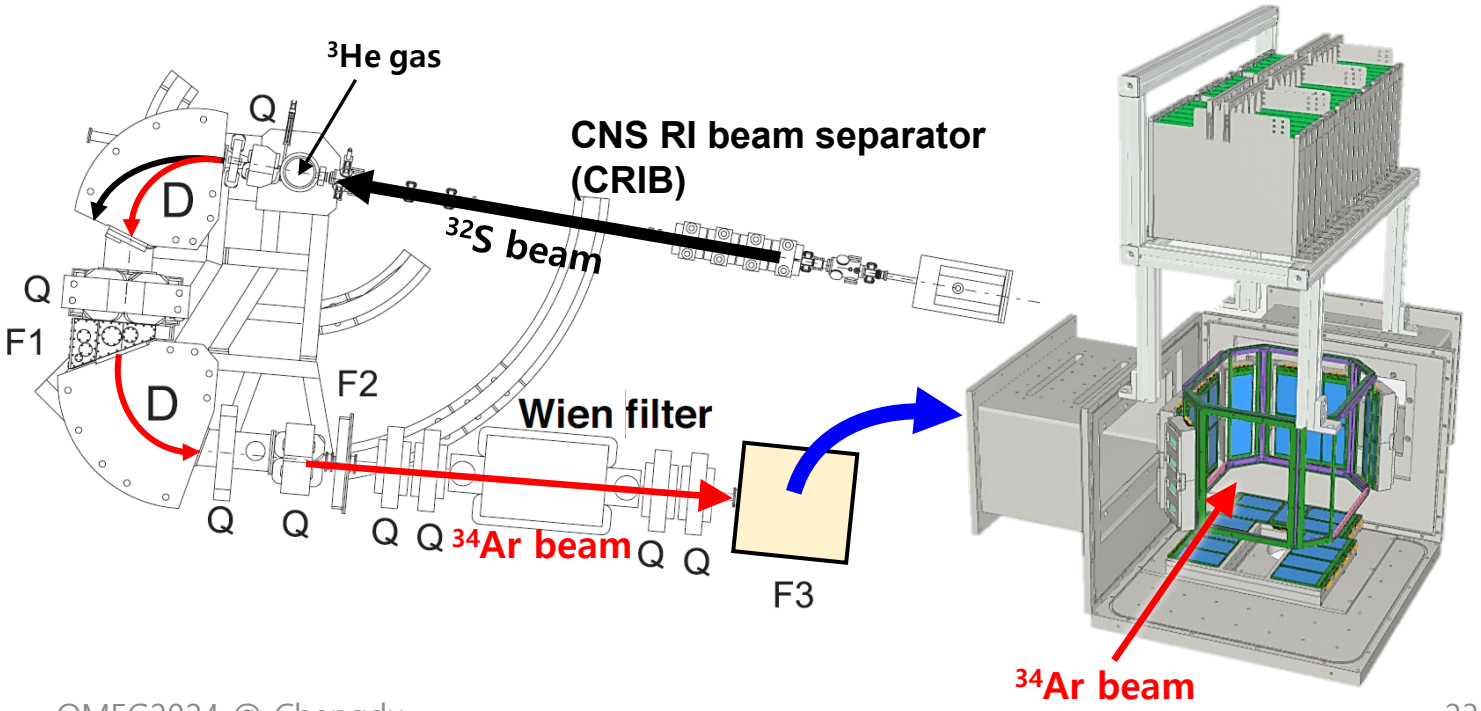
- **Elastic/Inelastic scattering**
  - ✓ **^{12}C(p,p')3α reaction for triple-α process** J.W- Lee *et al.*, (JAEA PAC2024, **accepted**)

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

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



Rank	Reaction
1	^{56}Ni(α, p)^{59}Cu
2	^{59}Cu(p, γ)^{60}Zn
3	^{15}O(α, γ)^{19}Ne
4	^{30}S(α, p)^{33}Cl
5	^{26}Si(α, p)^{29}P
6	^{61}Ga(p, γ)^{62}Ge
7	^{23}Al(p, γ)^{24}Si
8	^{27}P(p, γ)^{28}S
9	^{63}Ga(p, γ)^{64}Ge
10	^{60}Zn(α, p)^{63}Ga
11	^{22}Mg(α, p)^{25}Al
12	^{56}Ni(p, γ)^{57}Cu
13	^{29}S(α, p)^{32}Cl
14	^{28}S(α, p)^{31}Cl
15	^{31}Cl(p, γ)^{32}Ar
16	^{35}K(p, γ)^{36}Ca
17	^{18}Ne(α, p)^{21}Na
18	^{25}Si(α, p)^{28}P
19	^{57}Cu(p, γ)^{58}Zn
20	^{34}Ar(α, p)^{37}K
21	^{24}Si(α, p)^{27}P
22	^{22}Mg(p, γ)^{23}Al
23	^{65}As(p, γ)^{66}Se
24	^{14}O(α, p)^{17}F
25	^{40}Sc(p, γ)^{41}Ti



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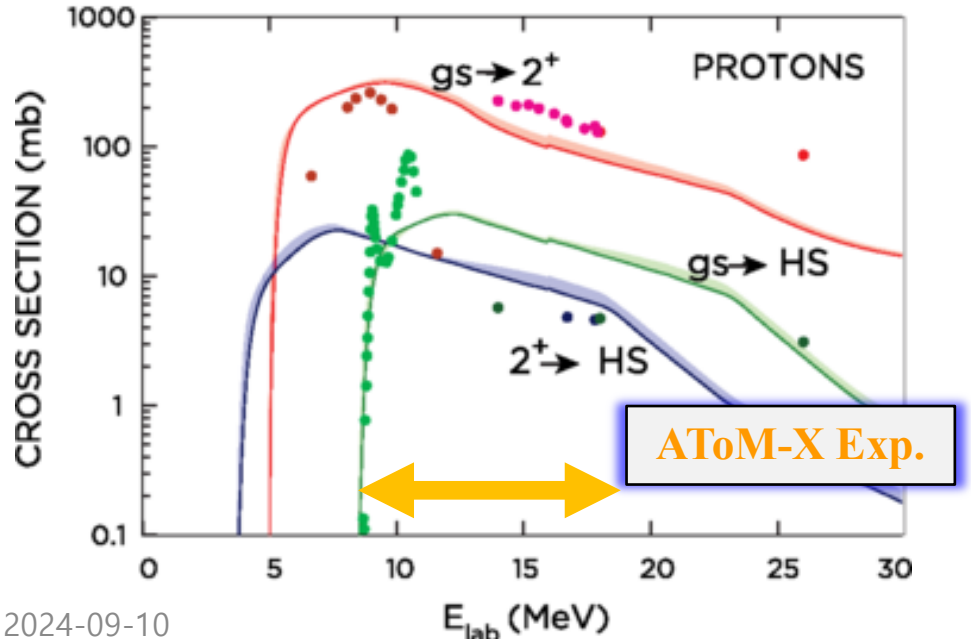
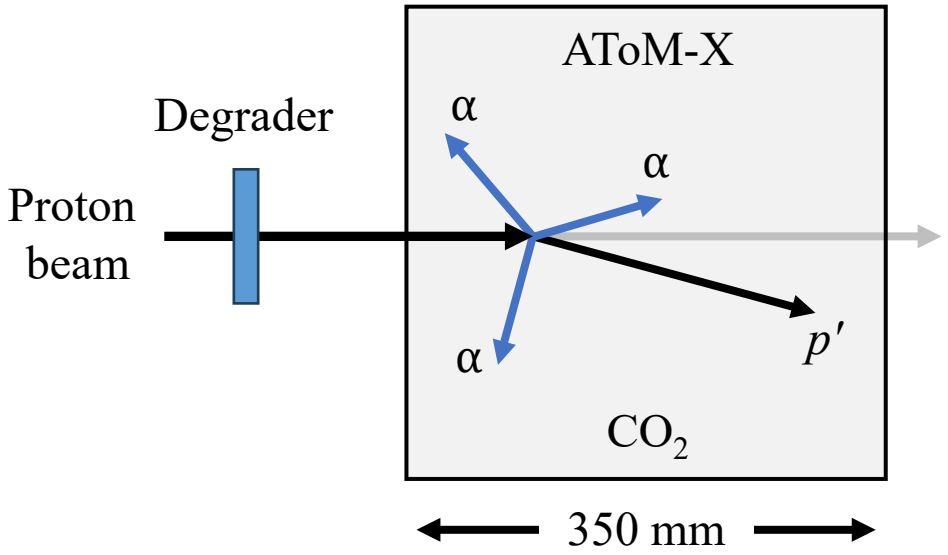
Hauser-Feshbach

**Mary Beard et al., Phys. Rev. Lett. 119 (2017) 112701*



JAEA Tandem facility



List of collaborators

Welcome to join our collaboration !

CENS, IBS

Korea Univ.

Texas A&M Univ.

CEA, Saclay

The Univ. of Tokyo

JAEA

Ewha womans Univ.

Sungkyunkwan Univ.

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

We would like to meet you here again!

INPC 2025

The 29th International Nuclear Physics Conference

May 25-30, 2025
Daejeon, Korea

https://inpc2025.org

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

Micromegas

- **Test status**
  - ✓ **Pulser on mesh, checked wave forms at various pixels using GET + DAQ**
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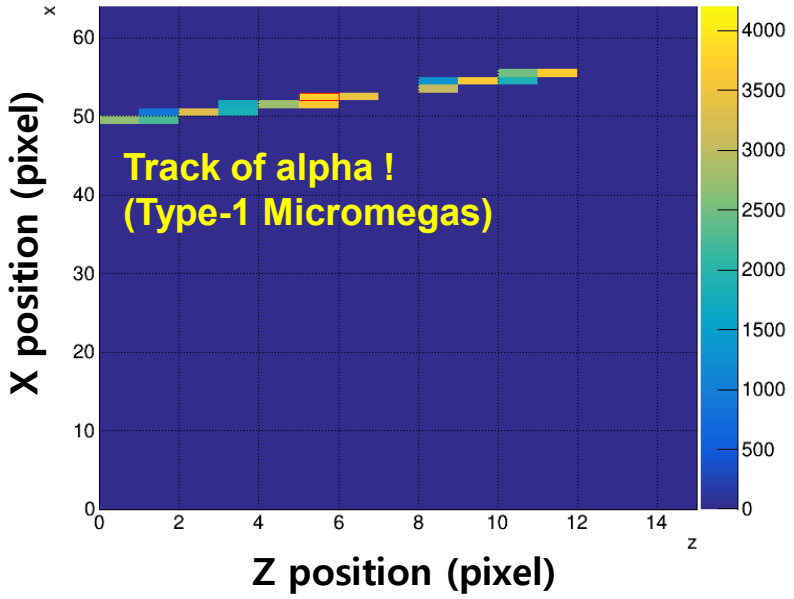
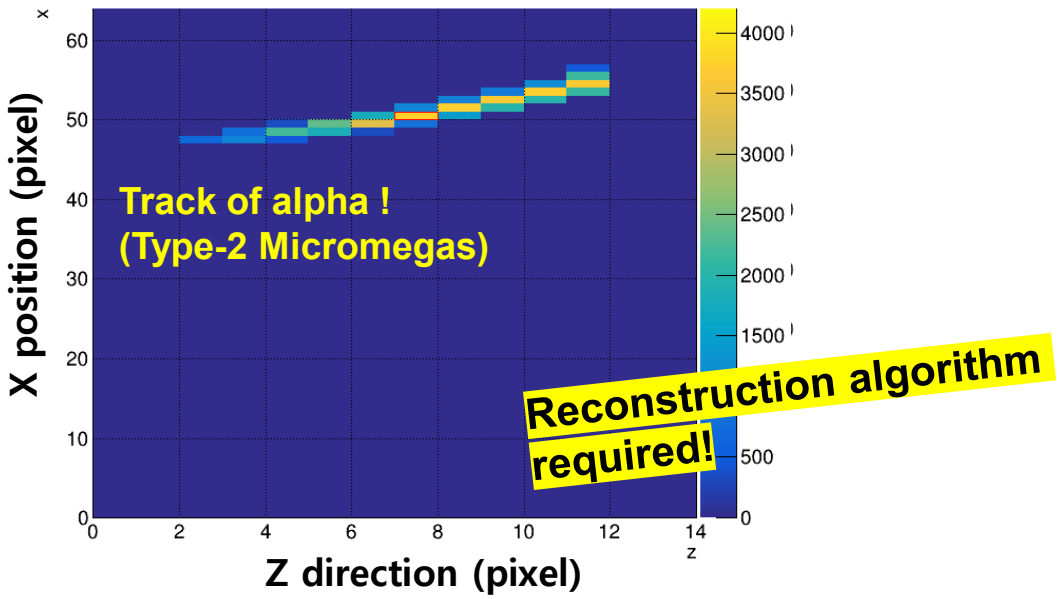
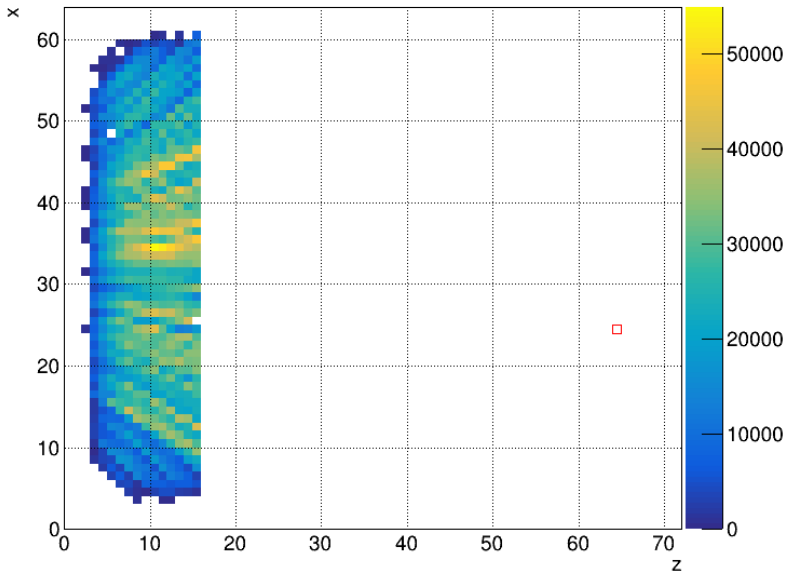
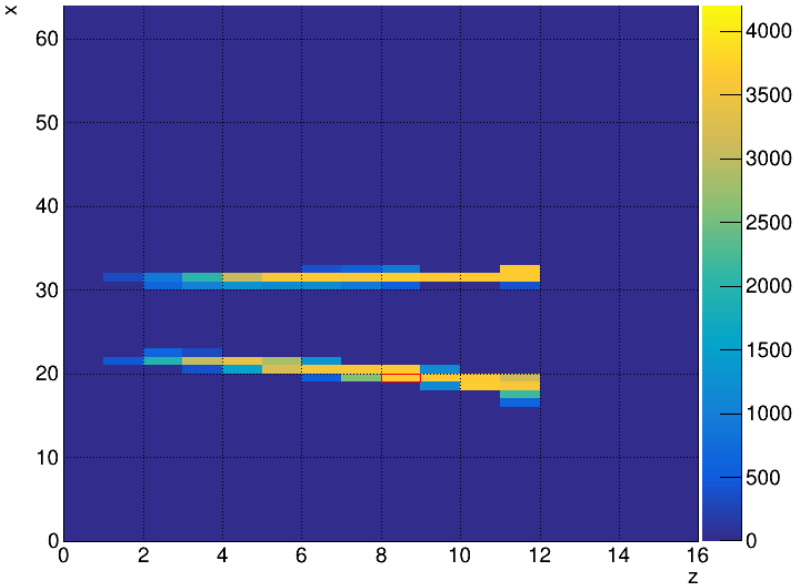
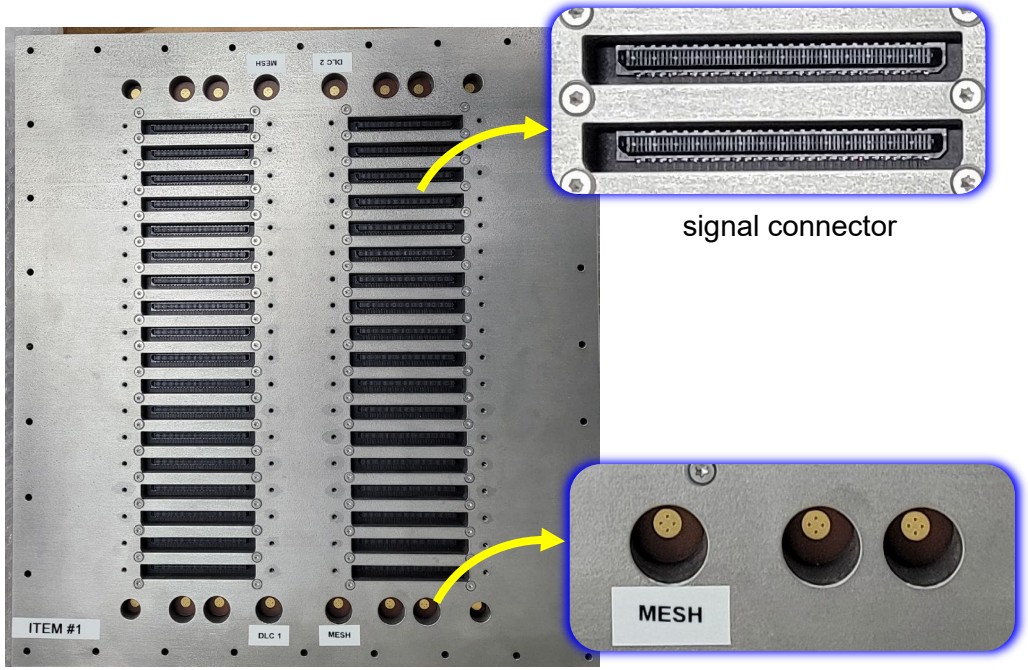




Backup





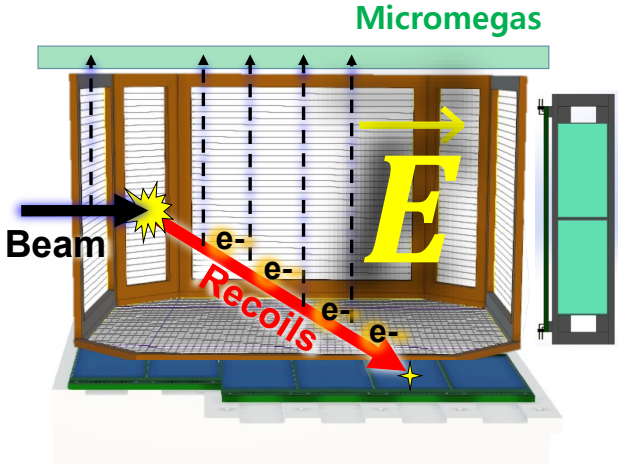


signal connector

Micromegas (back : stiffener)

HV connection

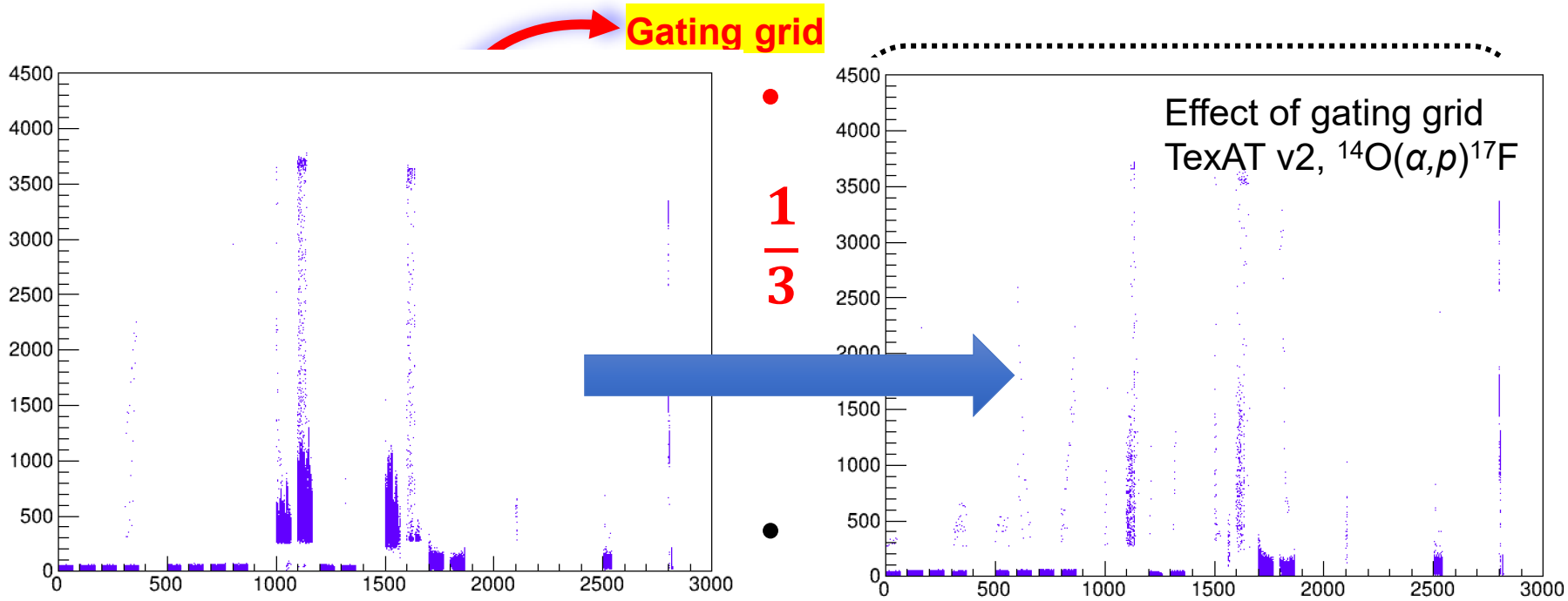
Field cage



- 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) $^{34}Ar(\alpha,p)^{37}K$, $^{18}Ne(\alpha,p)^{21}Na$, $^{17}F(\alpha,p)^{20}Ne$, ...

Now on fabrication !



Reducing a huge amount of space charge from the high intensity beam !

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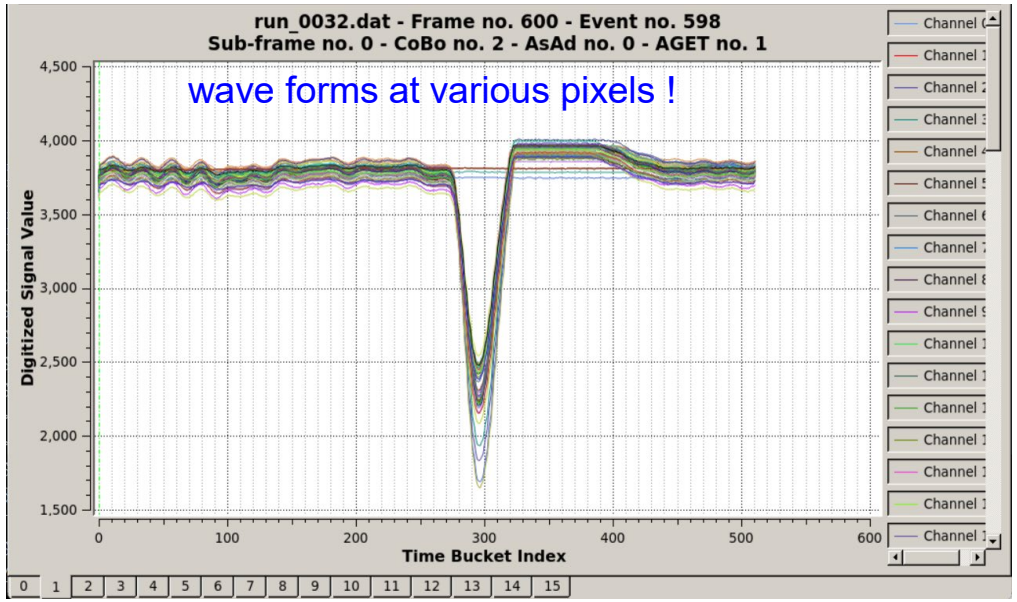
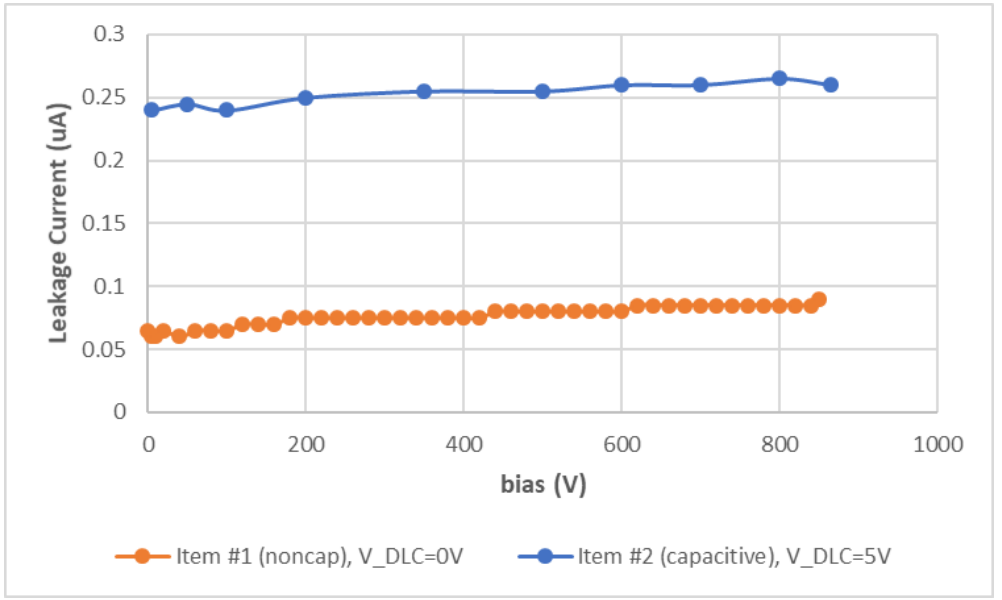
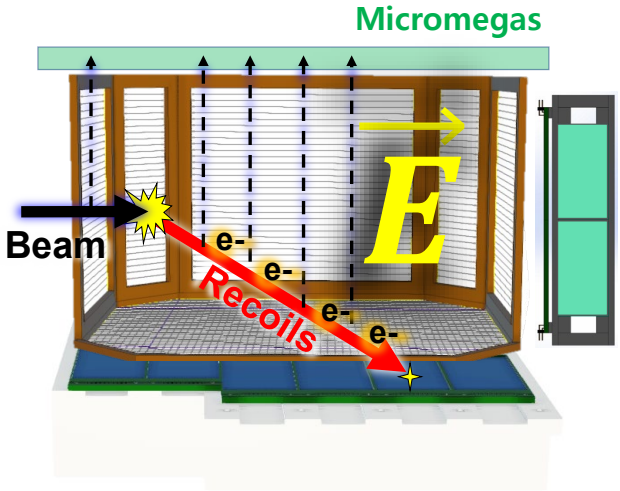




Field cage



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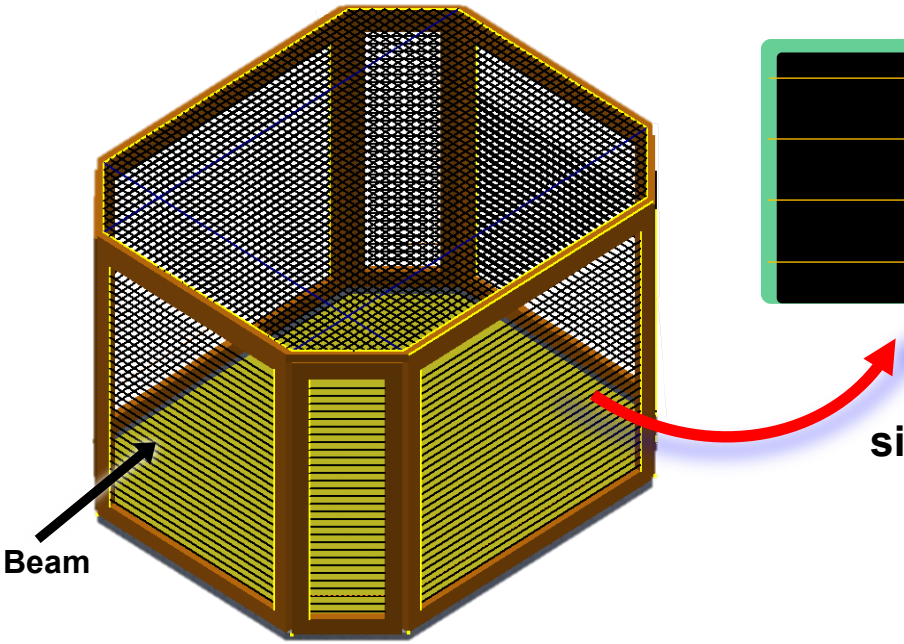
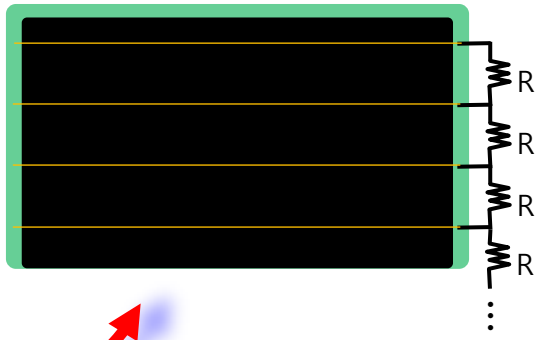
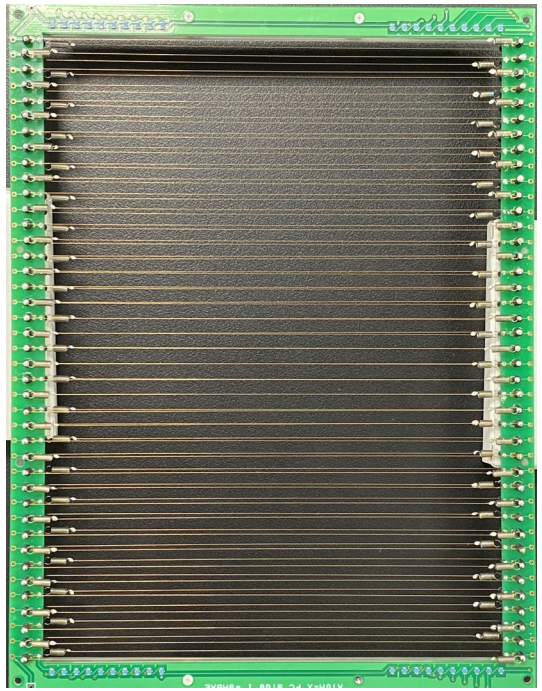
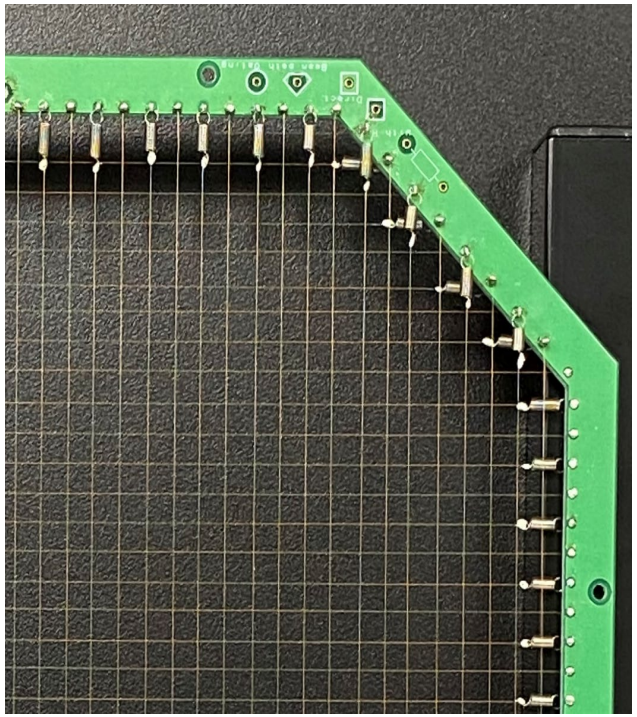




side planes

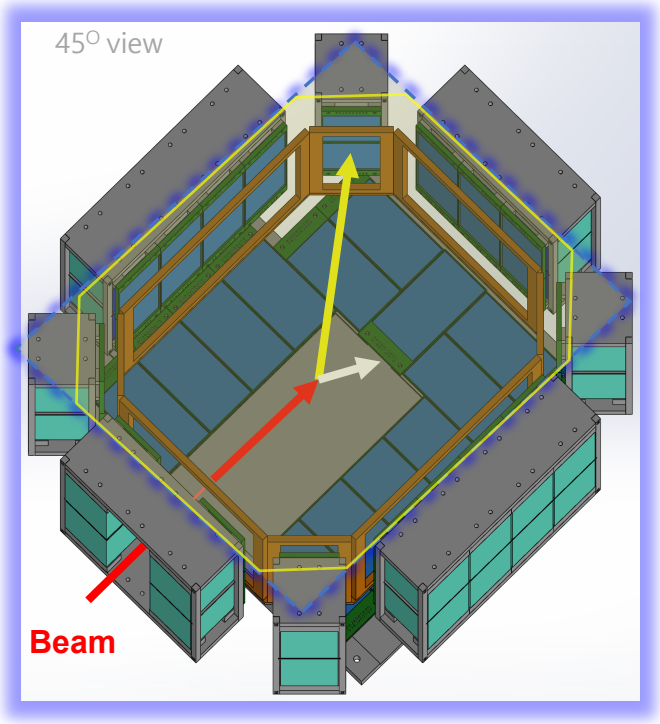


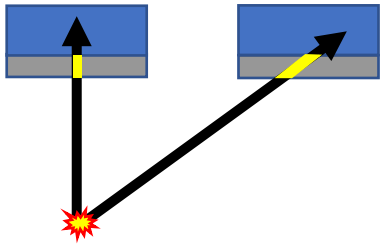


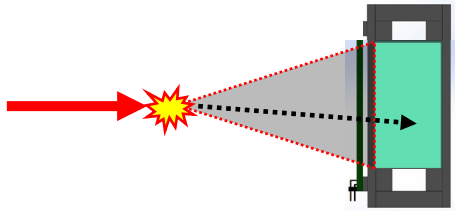
wires both X&Y direction

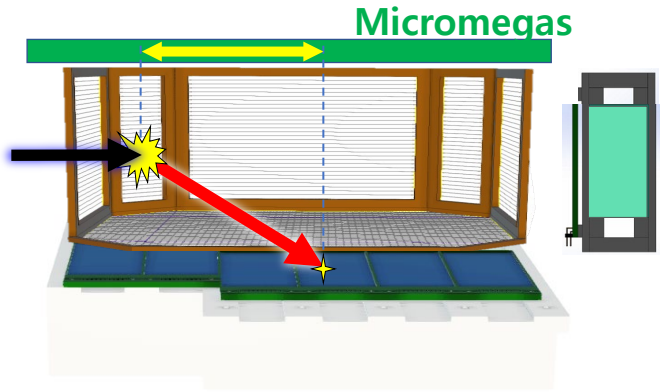
Major changes?

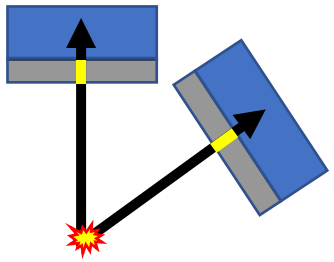
- Octagonal shape → reduced the dead-layer effect of silicon detectors
- Double layer of aux. detectors → better angular coverage
- Extended FC → longer track can be measured.
- External Micromegas as a chamber flange w/ new technique

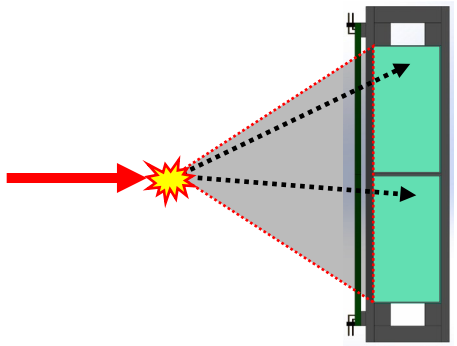


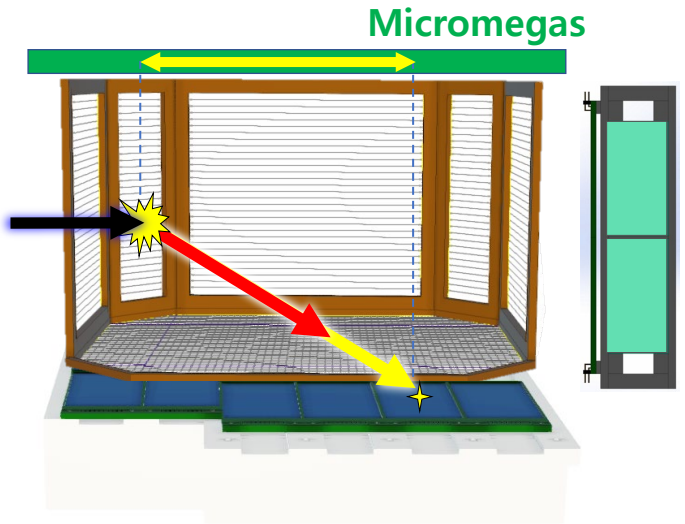






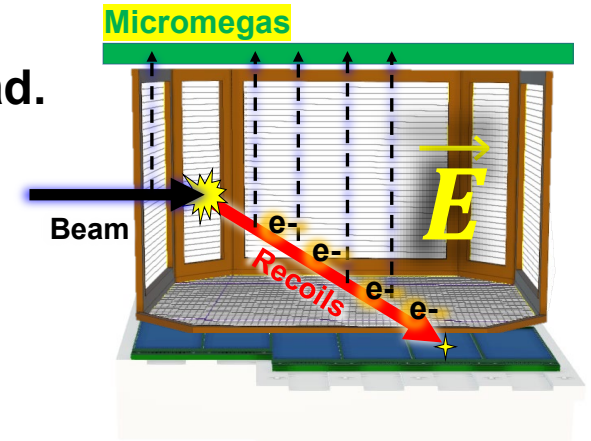




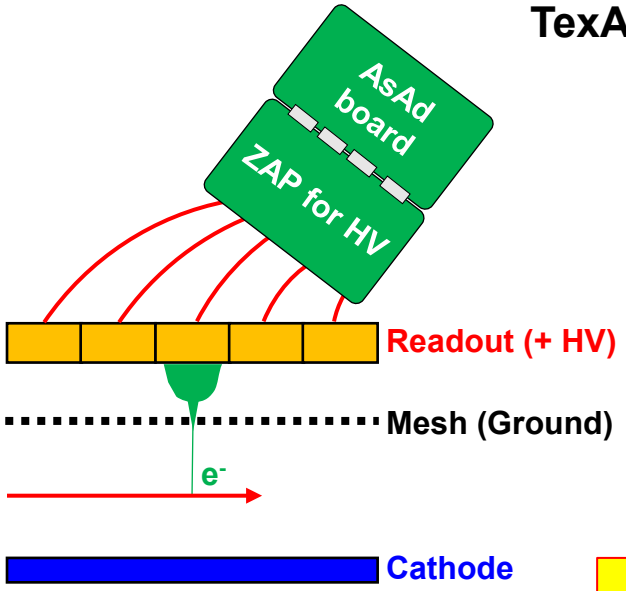


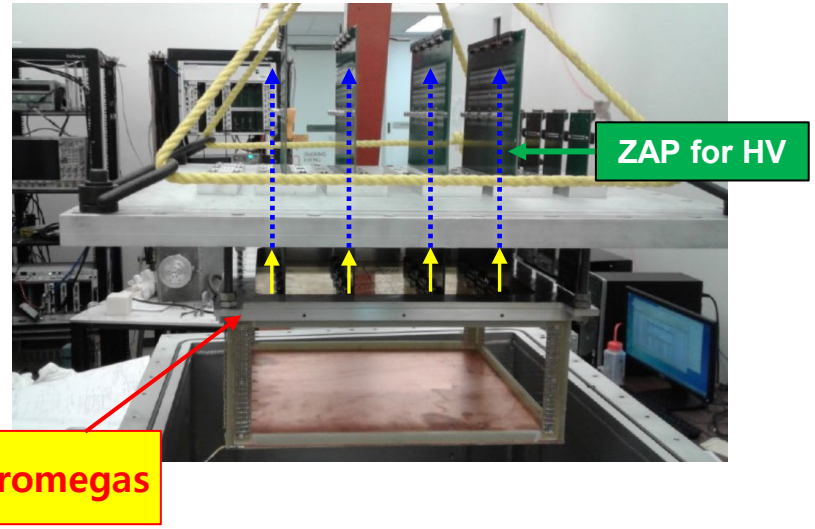
Micromegas

- **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**

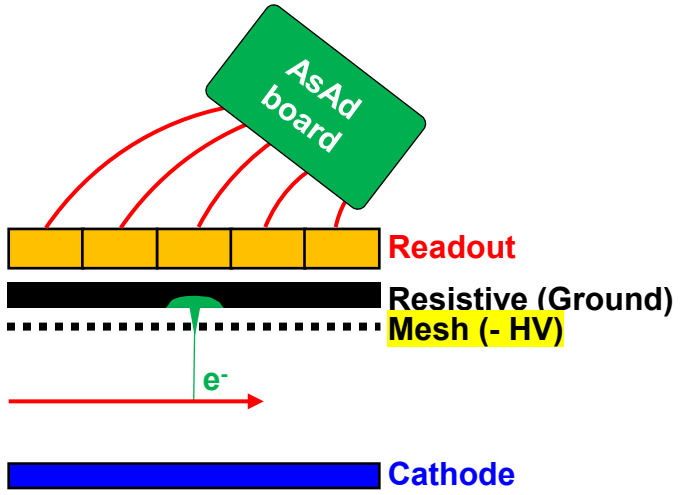


TexAT Micromegas



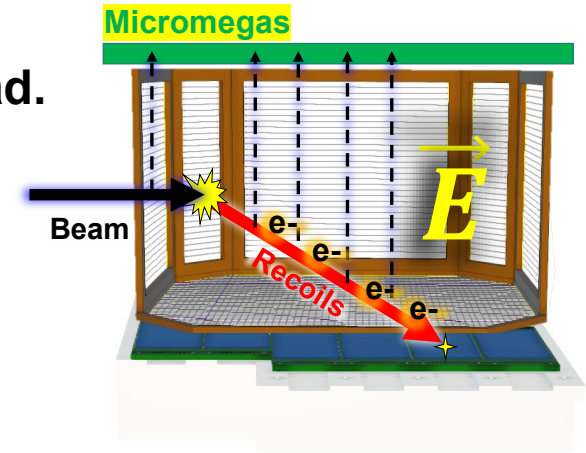


Resistive Micromegas for AToM-X

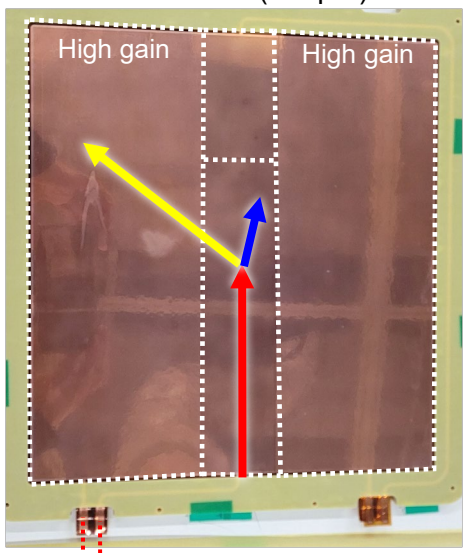


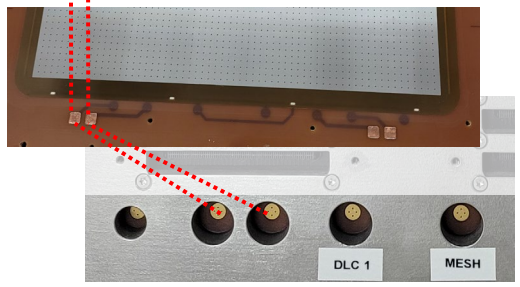
Micromegas

- **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**

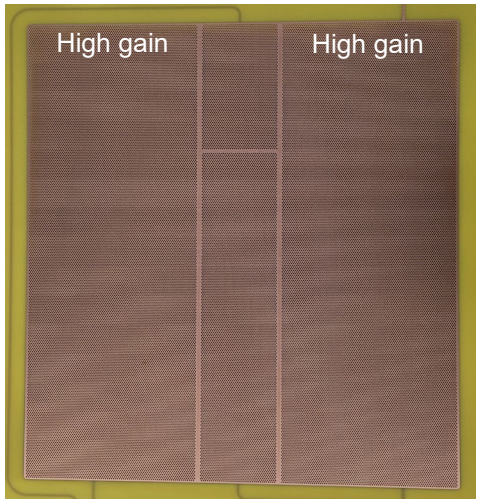


GEM foil (256μm)





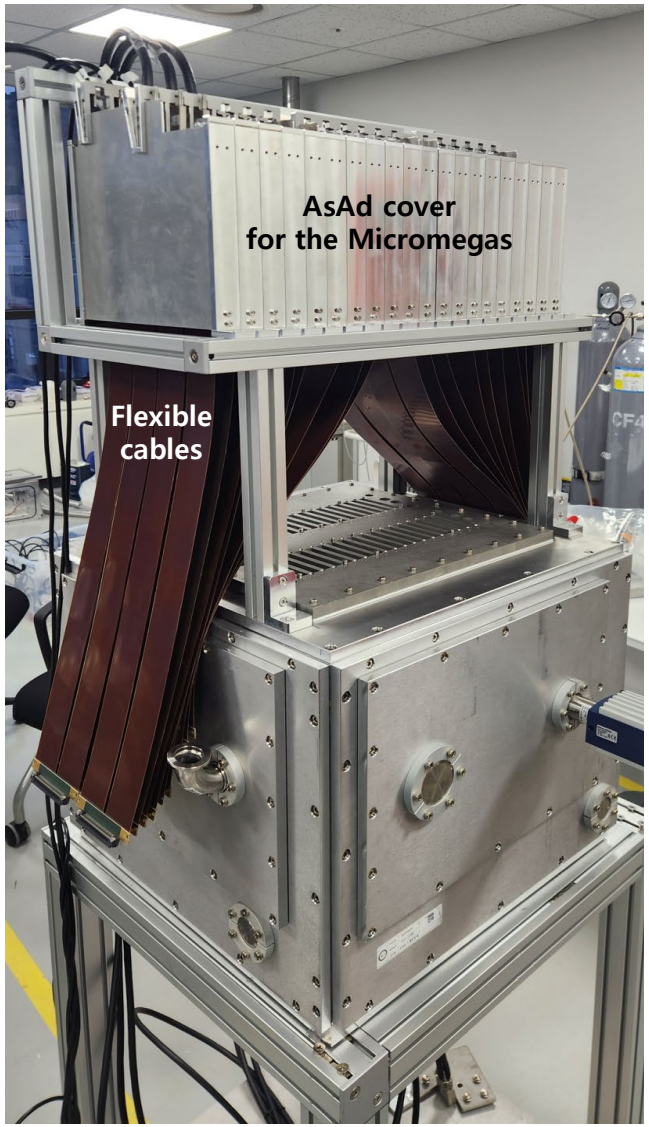
GEM foil (1000μm)



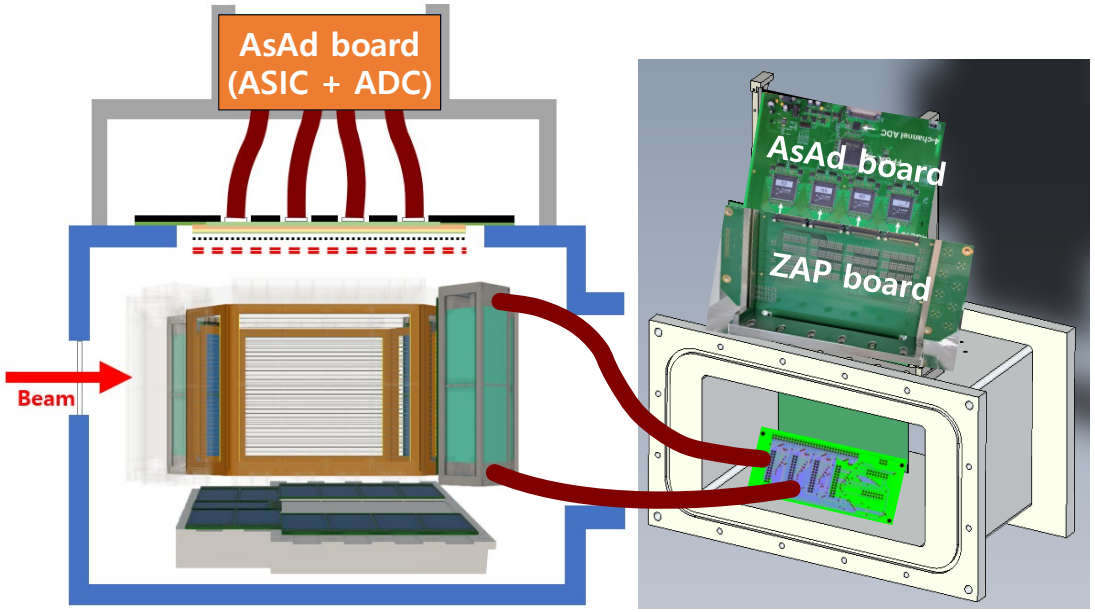
0.8mm holes
1.2mm pitch

- ✓ **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**

Chamber and Data acquisition system



- **Assembly type chamber** (1/2”-thick aluminum)
- **General Electronics for TPCs (GET) system based on ASIC** E.C. Pollaco *et al.*, NIMA (2018)
  - ✓ **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**



Chamber wings (ex. TexAT v2)