Simulation for the direct measurement of the $^{34}Ar(\alpha,p)^{37}K$ reaction

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- Detector
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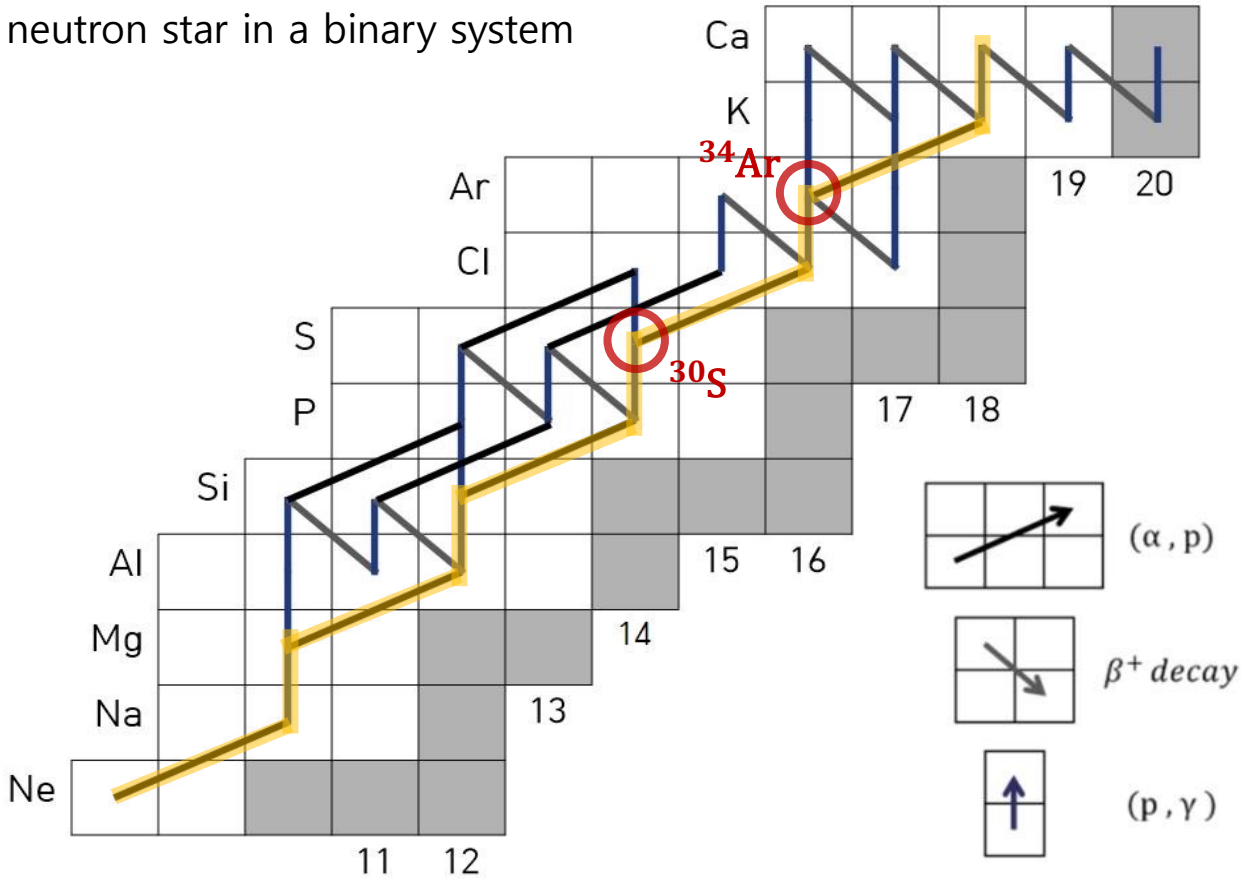
Motivation

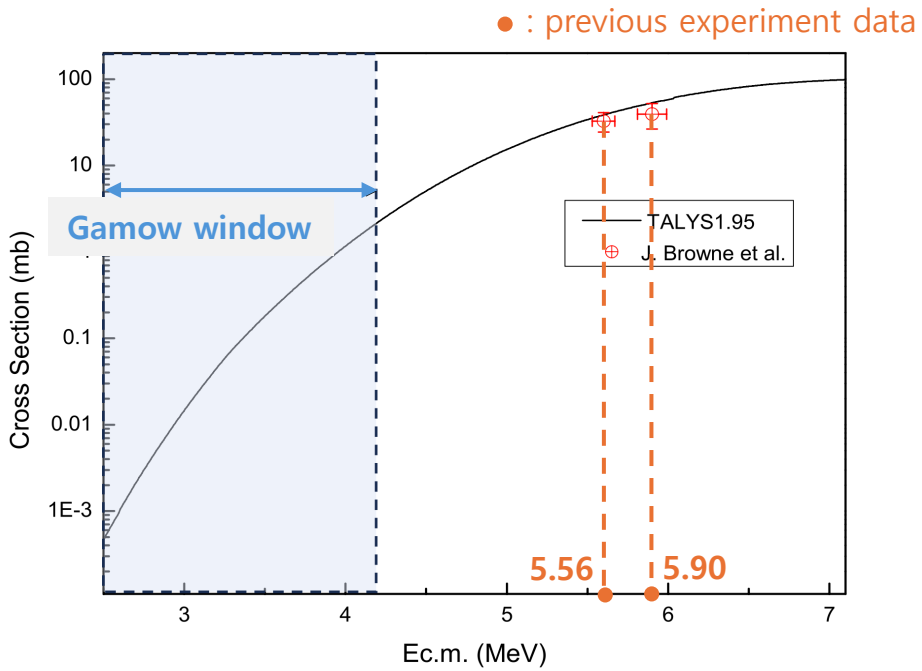
- **X-ray burst** : Thermonuclear explosion on the surface on a neutron star in a binary system

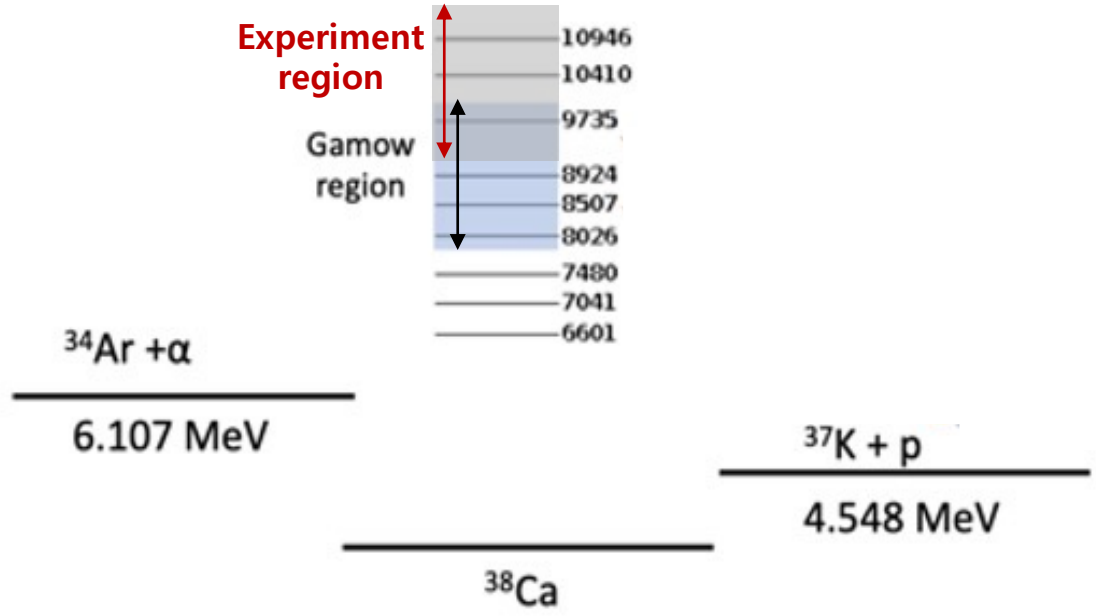
- Nucleosynthesis occurs through αp- and rp-processes
- **Heavy-element production** and **luminosity curve** of X-ray burst can be investigated through the (α,p) reaction
- Some Type-1 X-ray burst luminosity curve represent **double peaks**
- ^{30}**S** and ^{34}**Ar** can be **waiting points** which enter $(p,\gamma)-(\gamma,p)$ equilibrium due to low Q(p,γ)-value & long β-decay life time



Goals of Experiment

A.Kim, TPC Collaboration Meeting (2024)



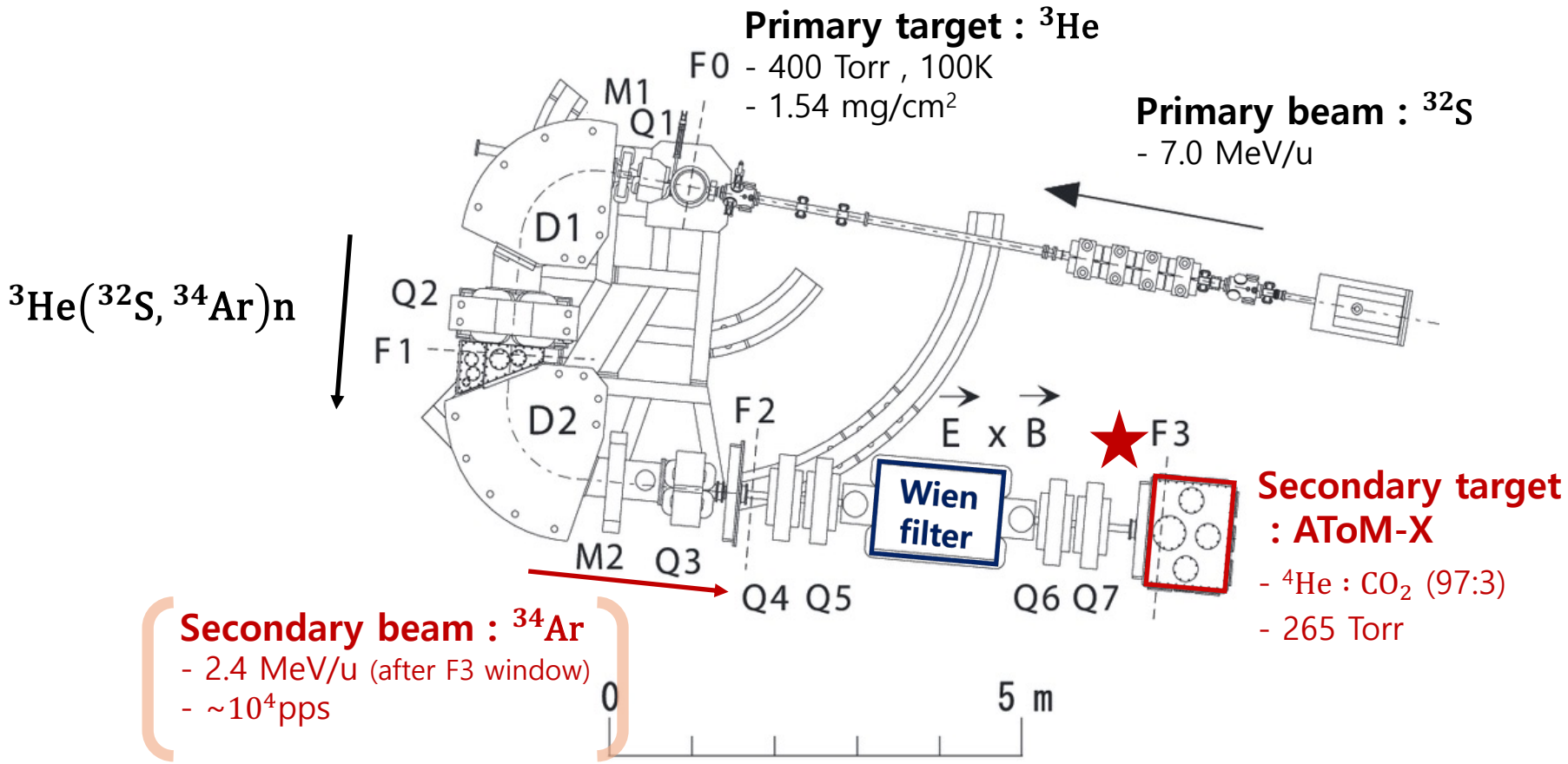


- The experimental data corresponding to energy levels within Gamow window (**7.71 MeV < $E_{x,^{38}Ca}$ < 10.21 MeV**) have not been measured.
- In our experiment, the excitation function of $^{34}Ar(\alpha,p)^{37}K$ will be obtained for **9.1 MeV < $E_{x,^{38}Ca}$ < 14.6 MeV**

- Identify the existence of resonances states in ^{38}C
- Measure the cross section of $^{34}Ar(\alpha,p)^{37}K$
- Determine the reaction rate in the Gamow window for the first time

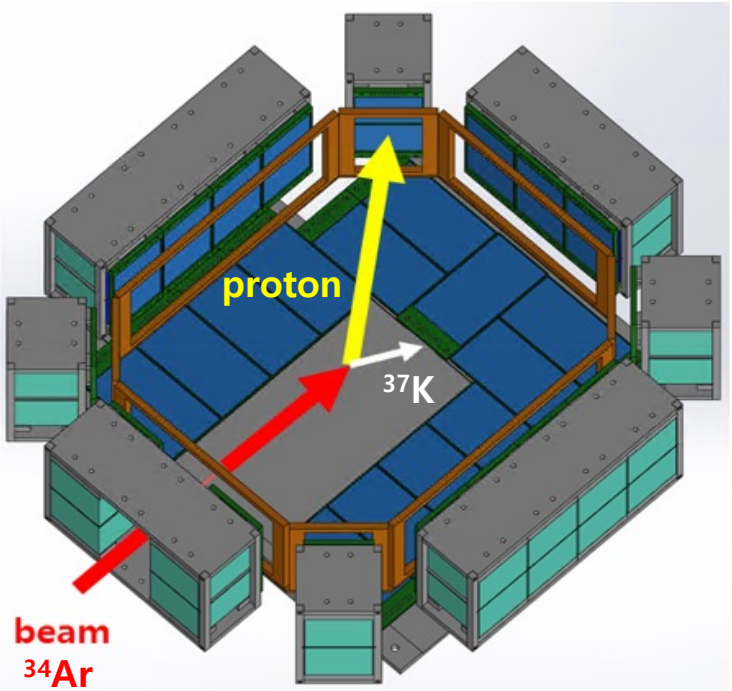
Beamline

- **CRIB (CNS Radio-Isotope Beam separator)** → constructed and operated by CNS, University of Tokyo
  → located at RIBF (RIKEN Nishina Center)



Detector

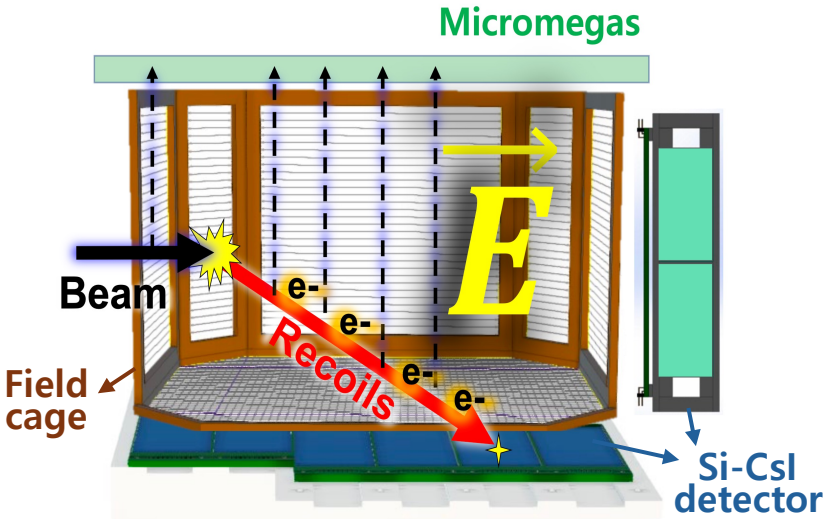
- **AToM-X (A**ctive target **T**PC f**o**r **M**ultiple nuclear e**X**periment**)**

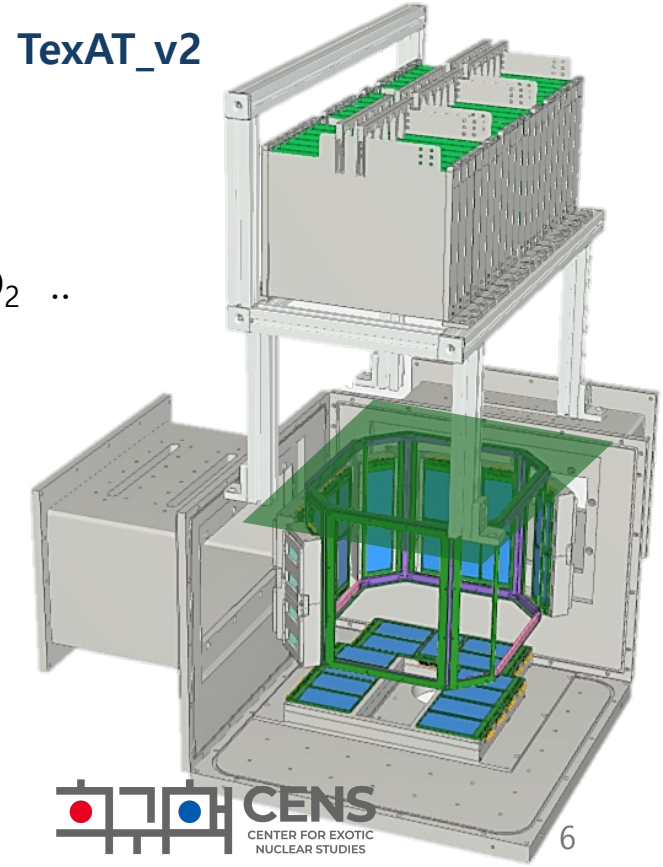


- The one of AT-TPC that enables

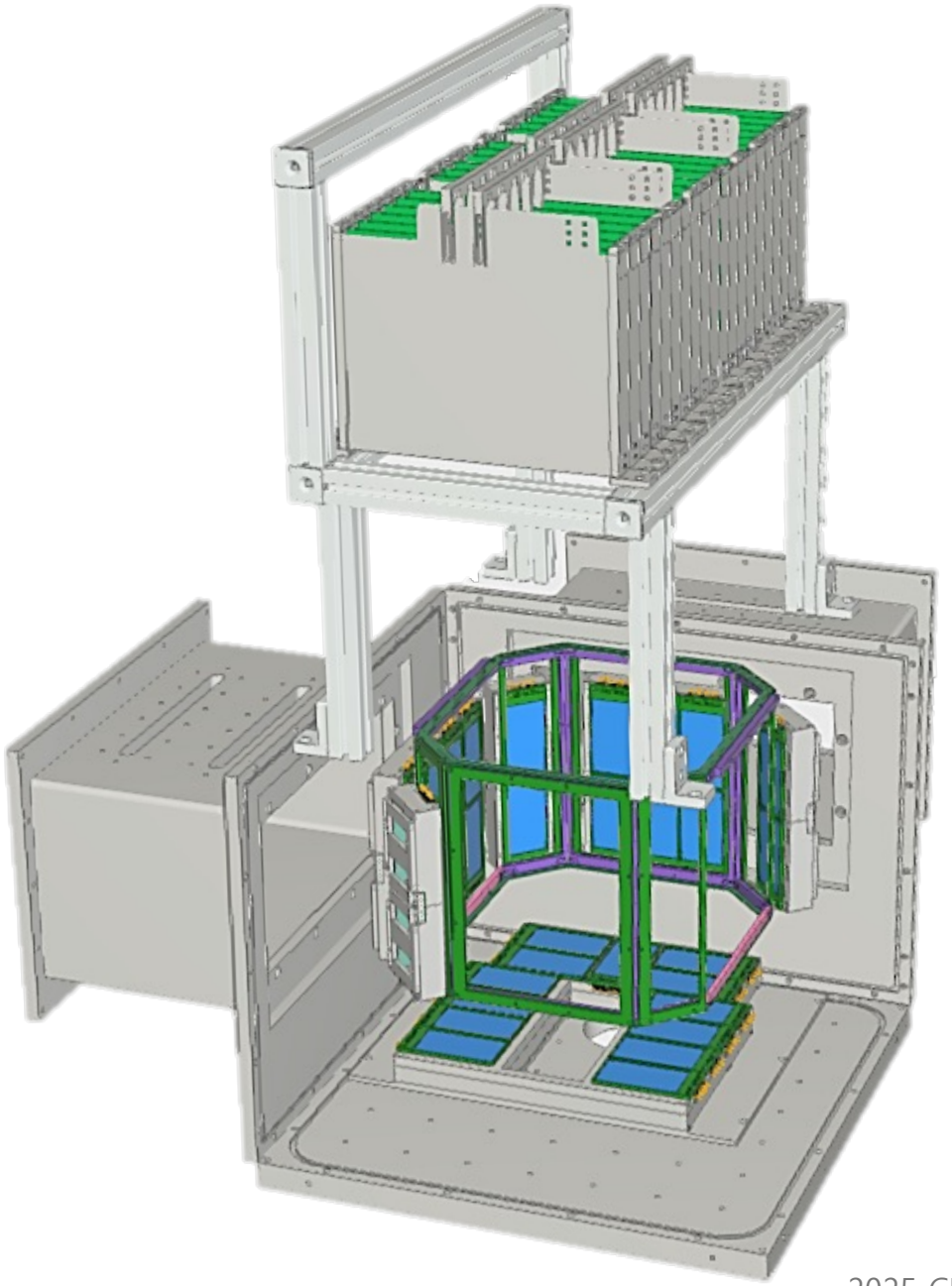
large angular coverage + **the high resolution measurement** + **the high detection efficiency**

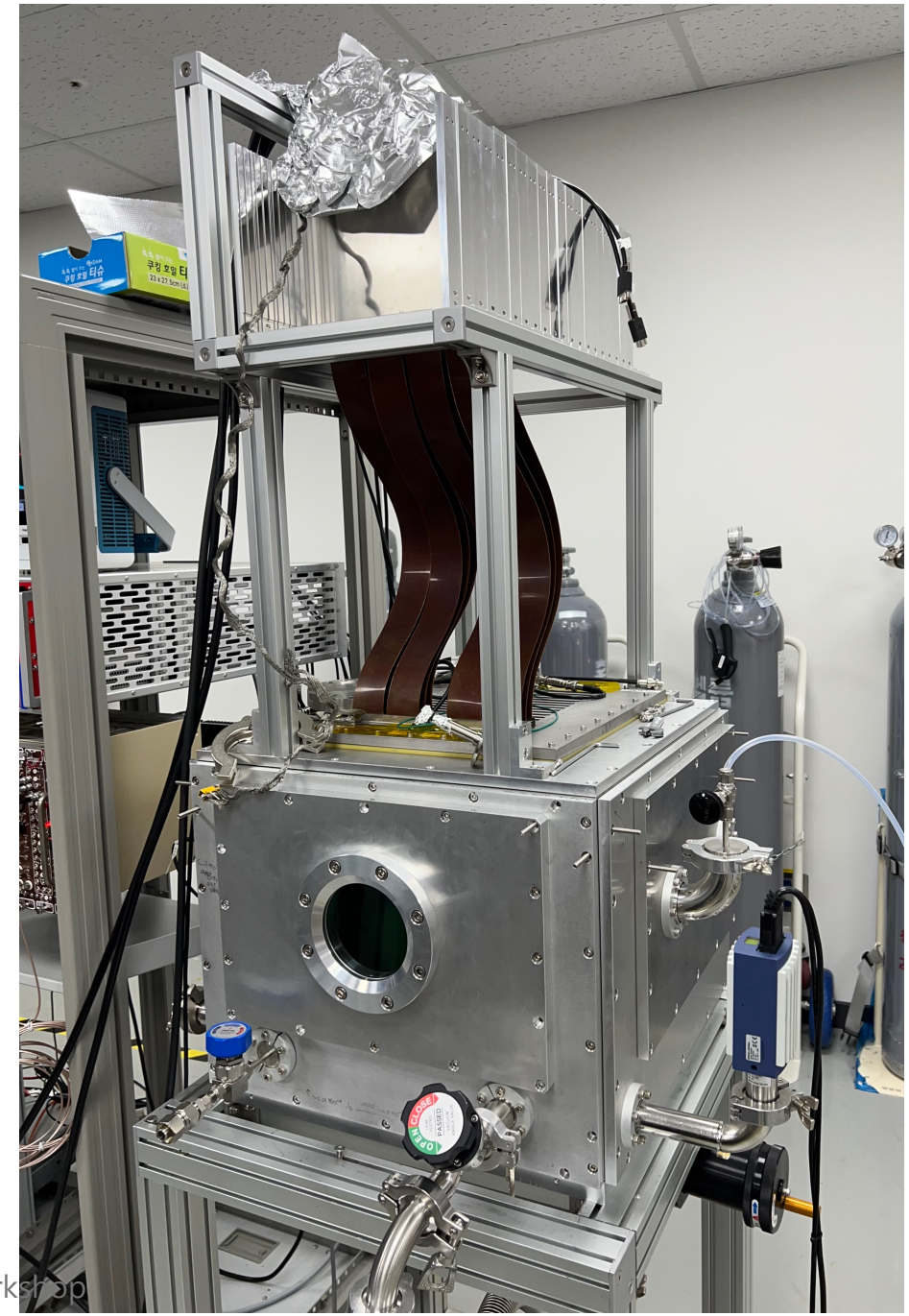
- Most of the skills and knowhows is taken from **TexAT_v2**
- The active area : 244(X) × 185(Y) × 289(Z) mm^3
- **Octagonal** shape (The dead layer effect ↓)
- Target/Detection gas : Ar , CH_4 , C_4H_{10} , He/CO_2 ..





CENS CENTER FOR EXOTIC NUCLEAR STUDIES





Simulation

Goals of Simulation

- Assess the feasibility of the actual experiment
- Measure detector efficiency
- Identify potential systematic errors
- Develop and test analysis macros

*** Garfield**

: A simulation tool modeling gas-based particle detectors and electric field configurations

*** Nptool**

: It supports *Geant4 simulations and analysis, with a particular focus on implementing reactions in Geant4 simulations

: primarily designed for nuclear physics experiments involving exotic beams

*Geant4 : Toolkit for simulating the passage of particle through matter

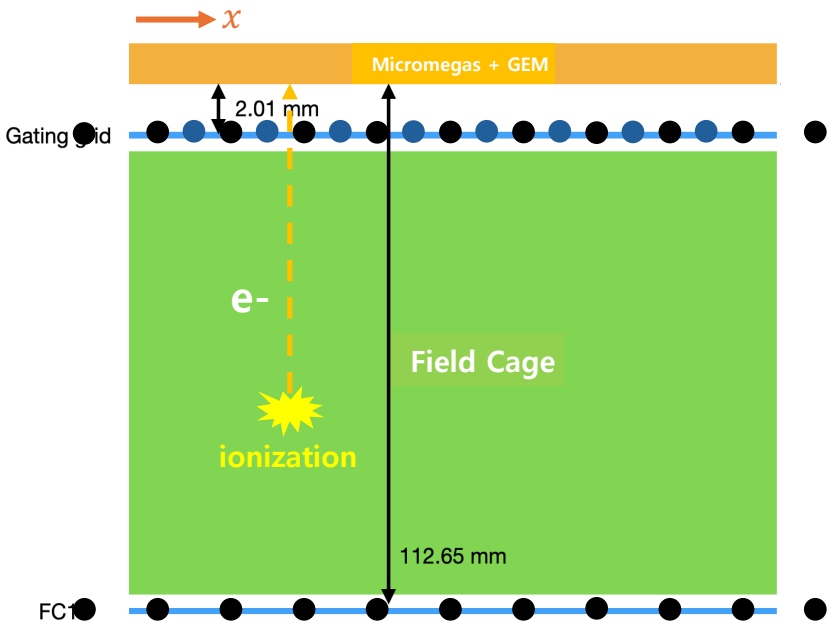
Simulation list

1. **$^{14}O(\alpha,p)^{17}F$ Garfield simulation** – Verify the **gating grid** efficiency
2. **$^{14}O(\alpha,p)^{17}F$ Garfield simulation** – Check the impact of **gating grid** from **Micromegas map**
3. **$^{34}Ar(\alpha,p)^{37}K$ Nptool simulation** – Get recoils information in active area *(Energy, Vertex, Angular Distribution, ...)*

$^{14}O(\alpha,p)^{17}F$ Garfield simulation

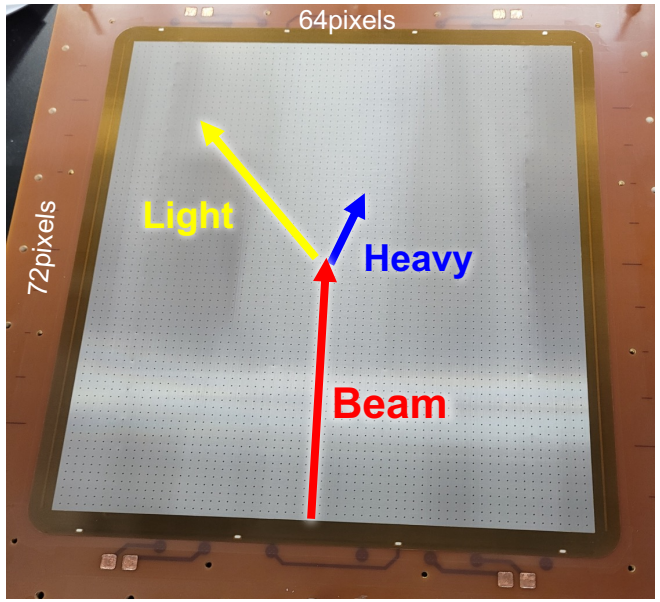
Verify the gating grid efficiency

- **Gating grid** was used in $^{14}O(\alpha,p)^{17}F$ experiment using TexAT_v2 to reduce noise by absorbing some of the electrons
- **Micromegas** (**Micro-Mesh GAS**eous detector system) consists of a highly segmented anode readout board and is designed to track charged particles

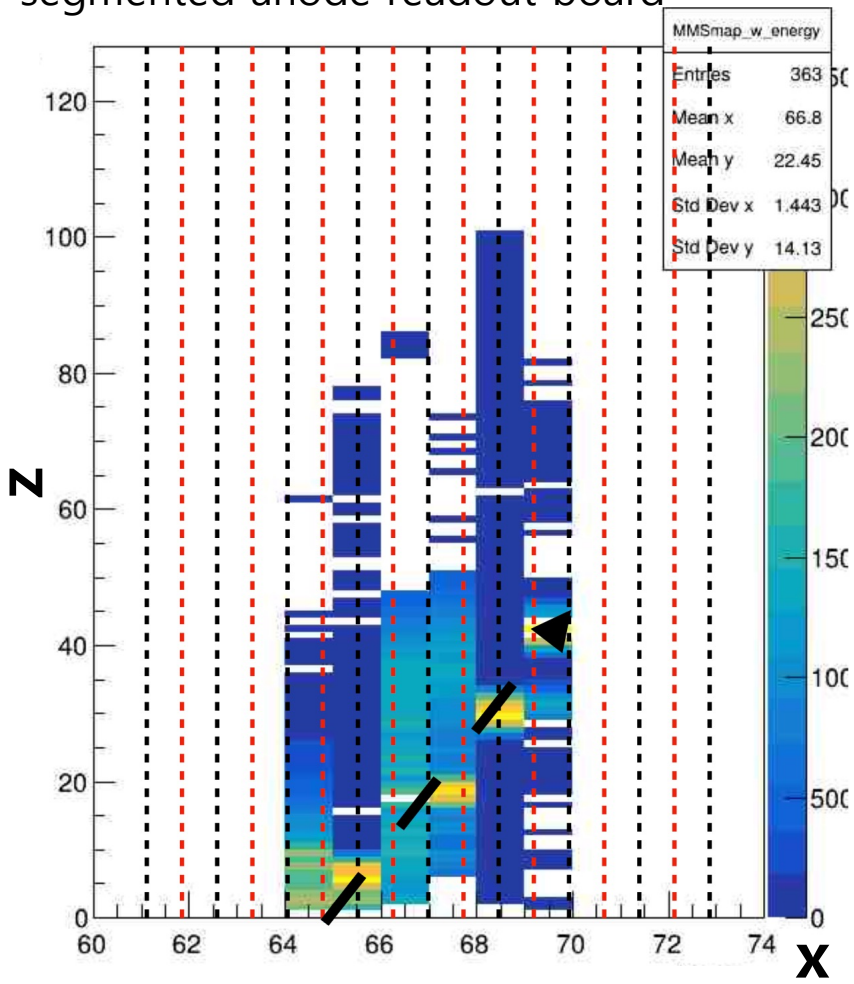


● : normal wire (anode -260V / cathode -1600V)

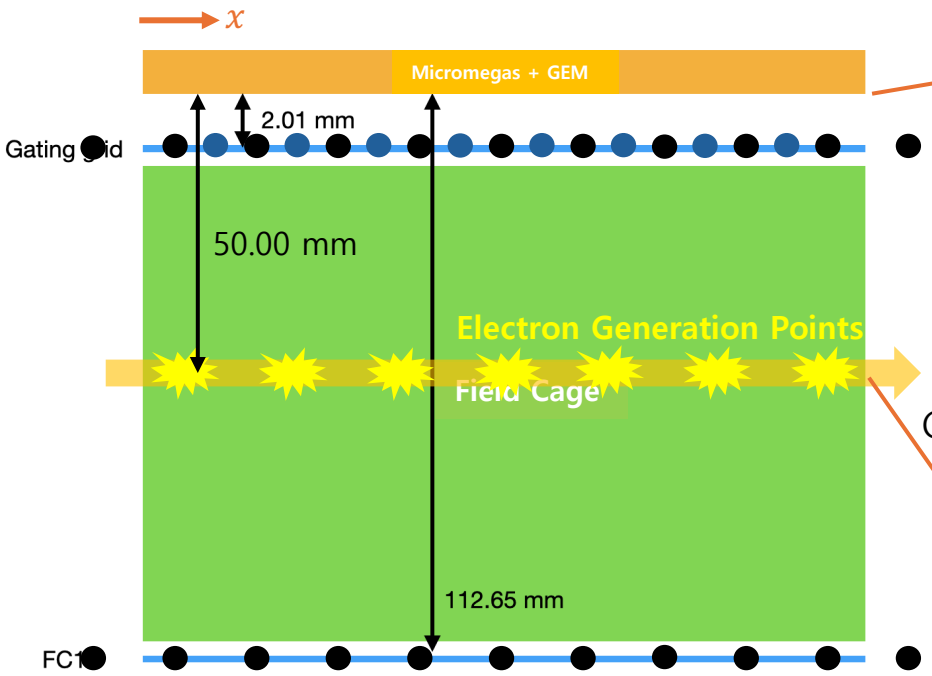
● : gating grid (-230V)



Micromegas (front-inside chamber)



$^{14}O(\alpha,p)^{17}F$ Garfield simulation



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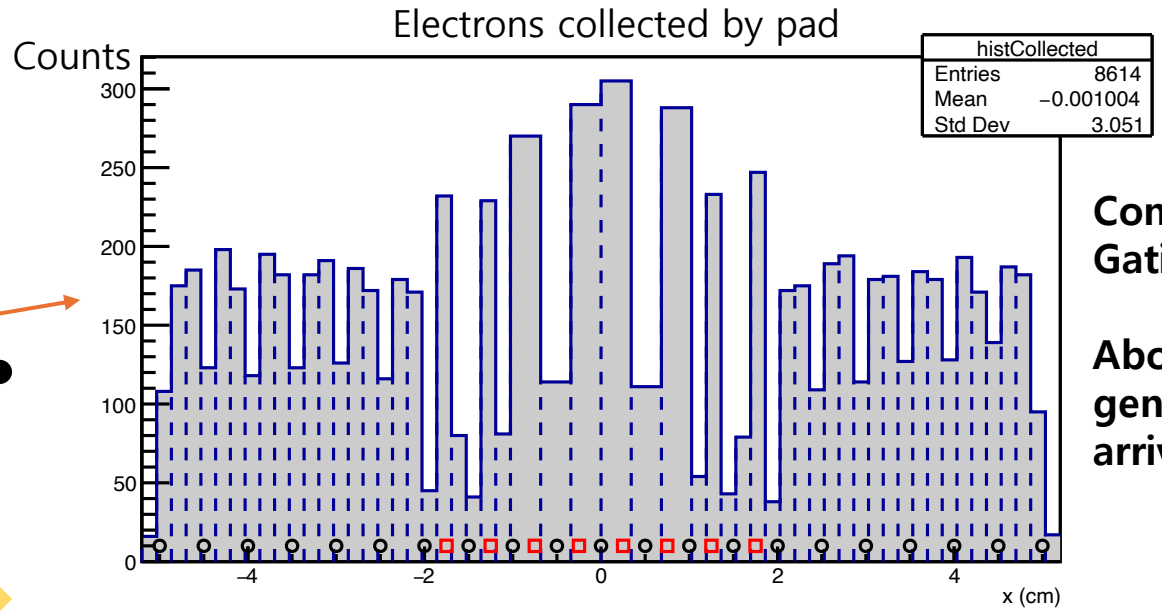
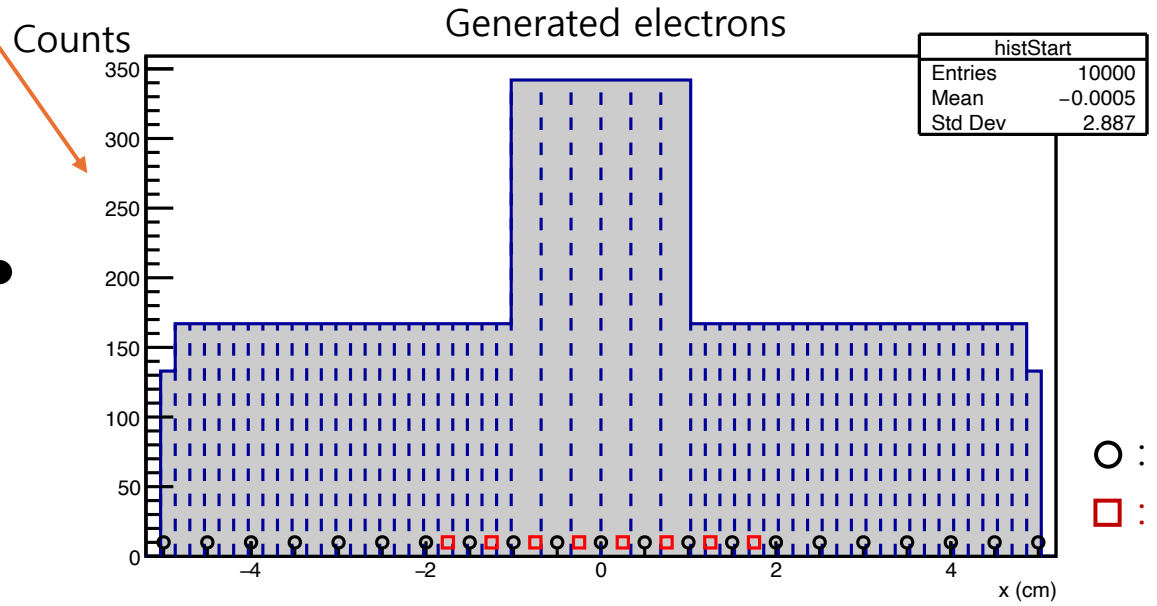




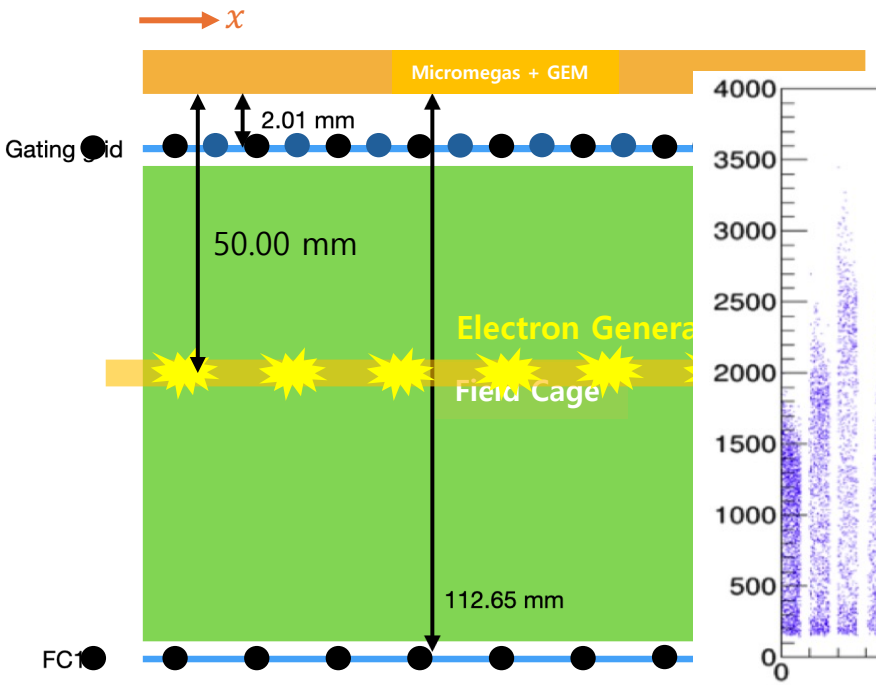
Comparing the Gating grid zone,

About 65% of the generated electrons arrive

○ : normal wire

□ : gating grid

$^{14}O(\alpha,p)^{17}F$ Garfield simulation



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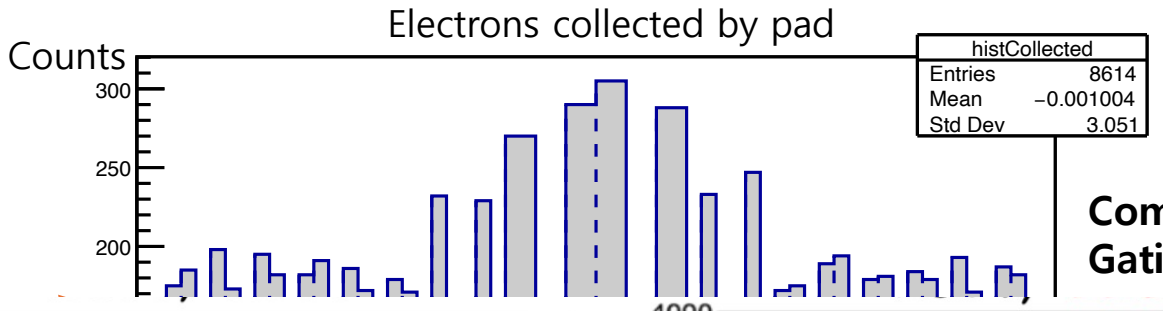

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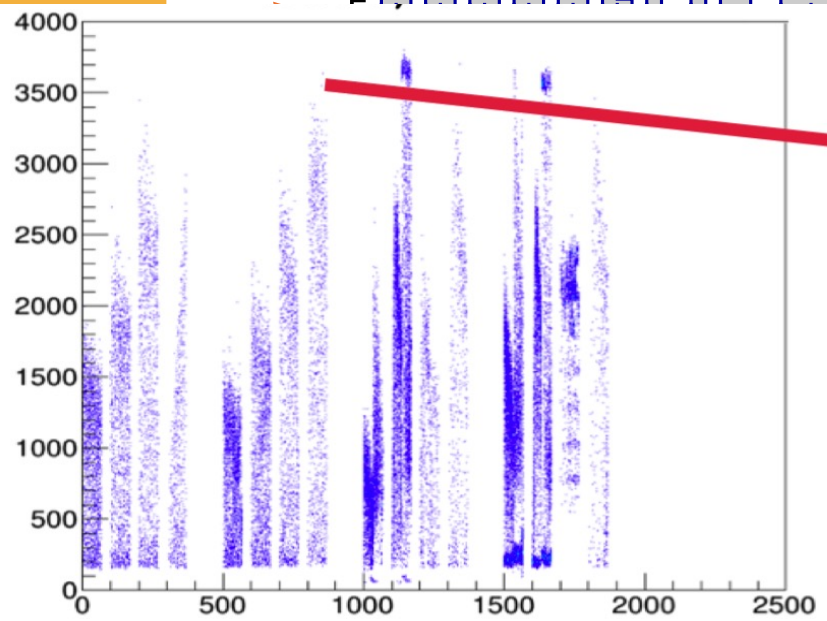
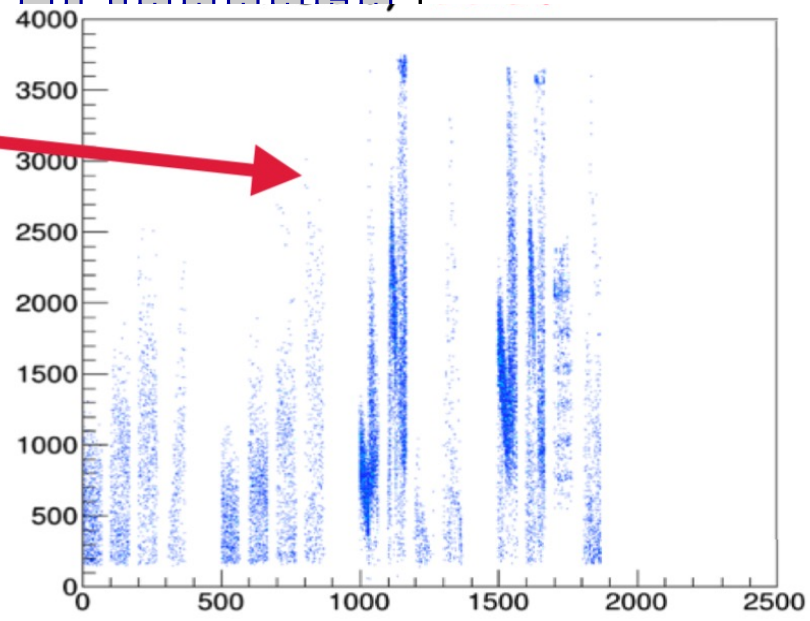
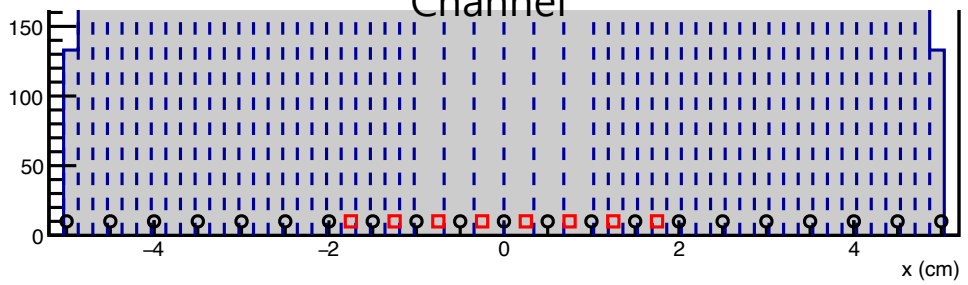




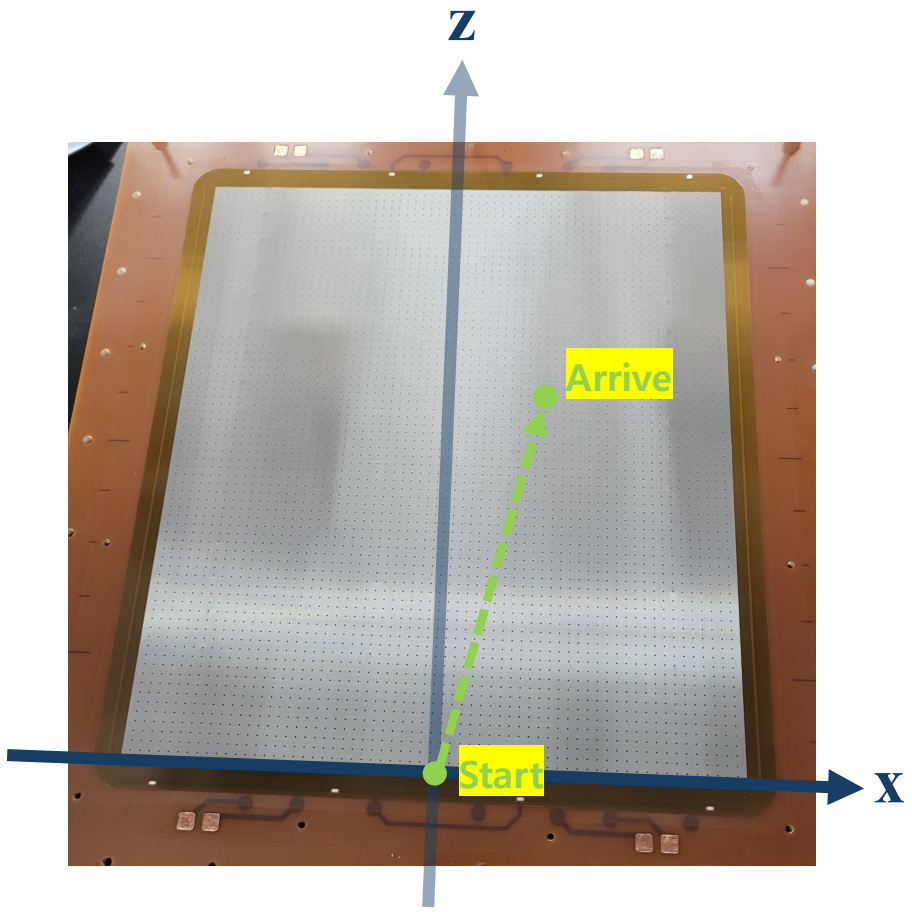


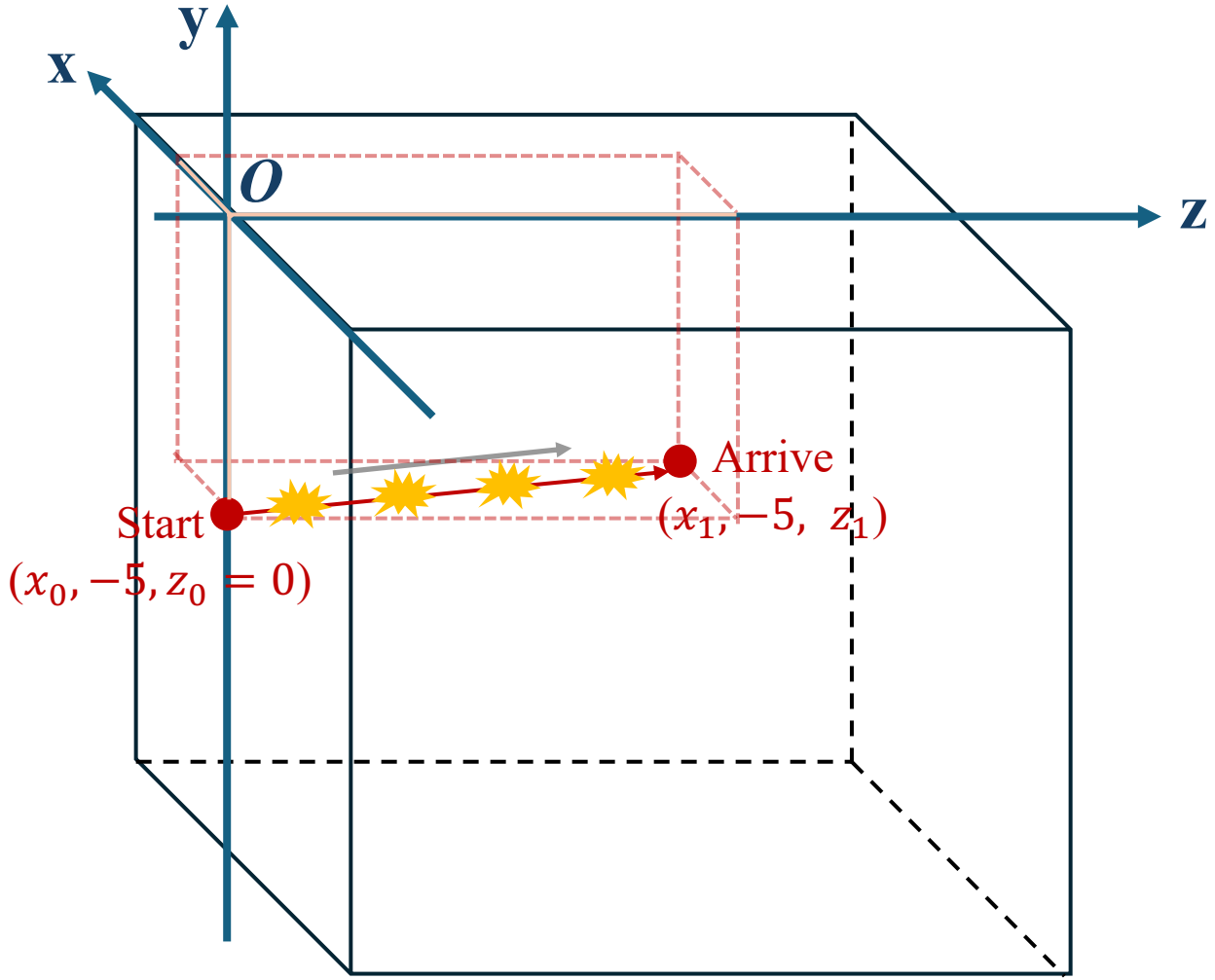
○ : normal wire

□ : gating grid

$^{14}O(\alpha,p)^{17}F$ Garfield simulation

Check the impact of gating grid from Micromegas map





$^{14}O(\alpha,p)^{17}F$ Garfield simulation

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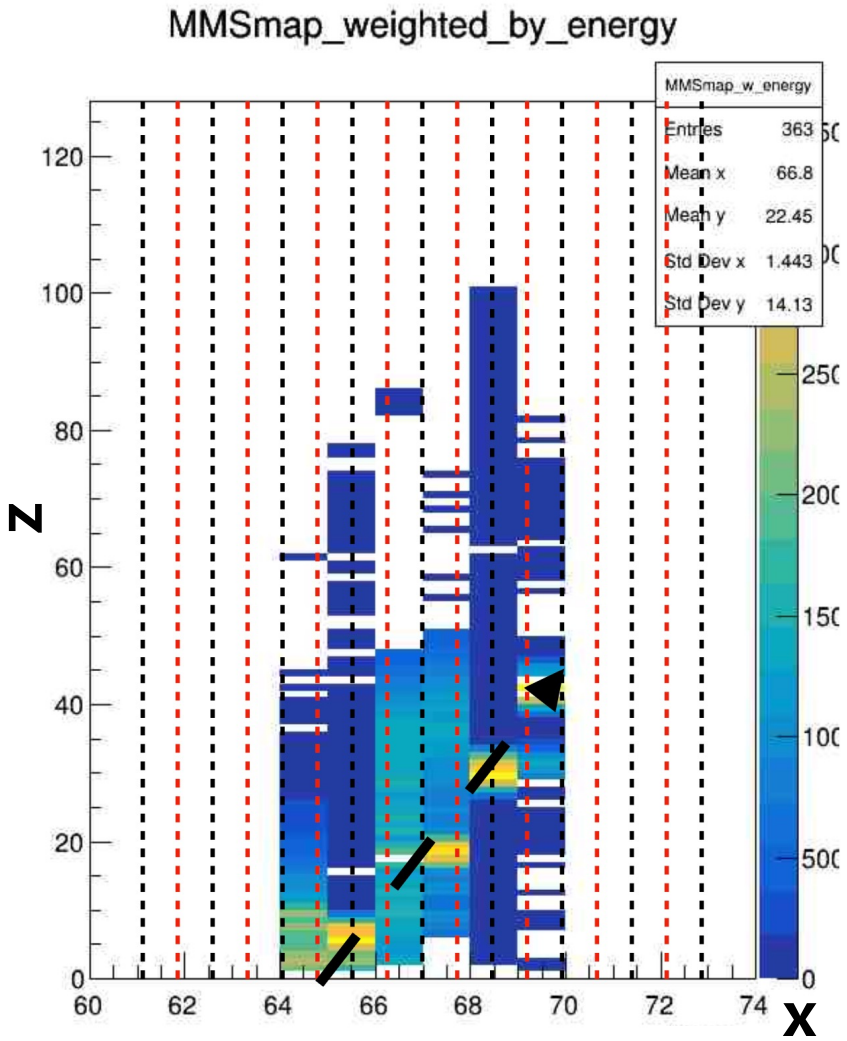
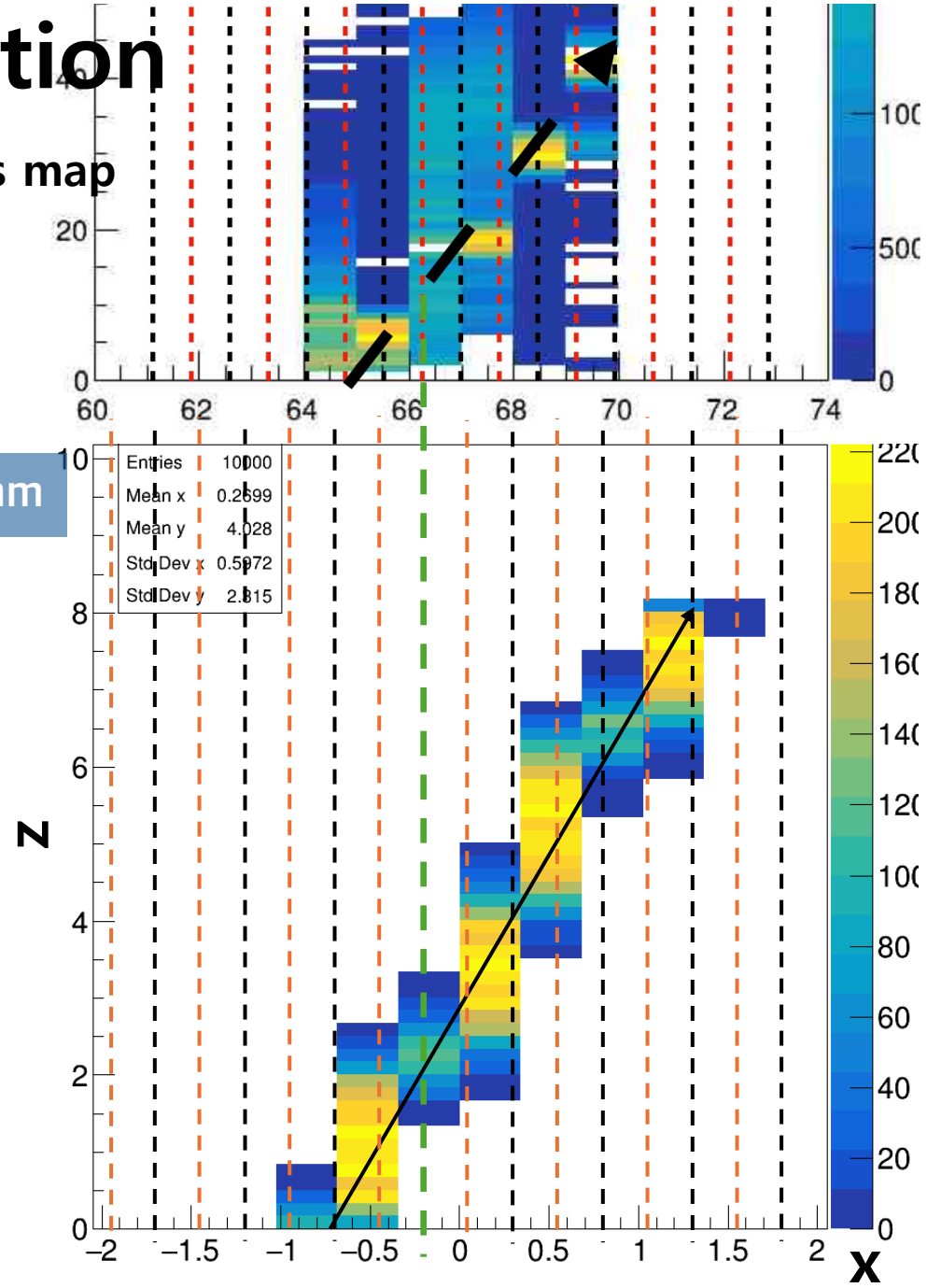


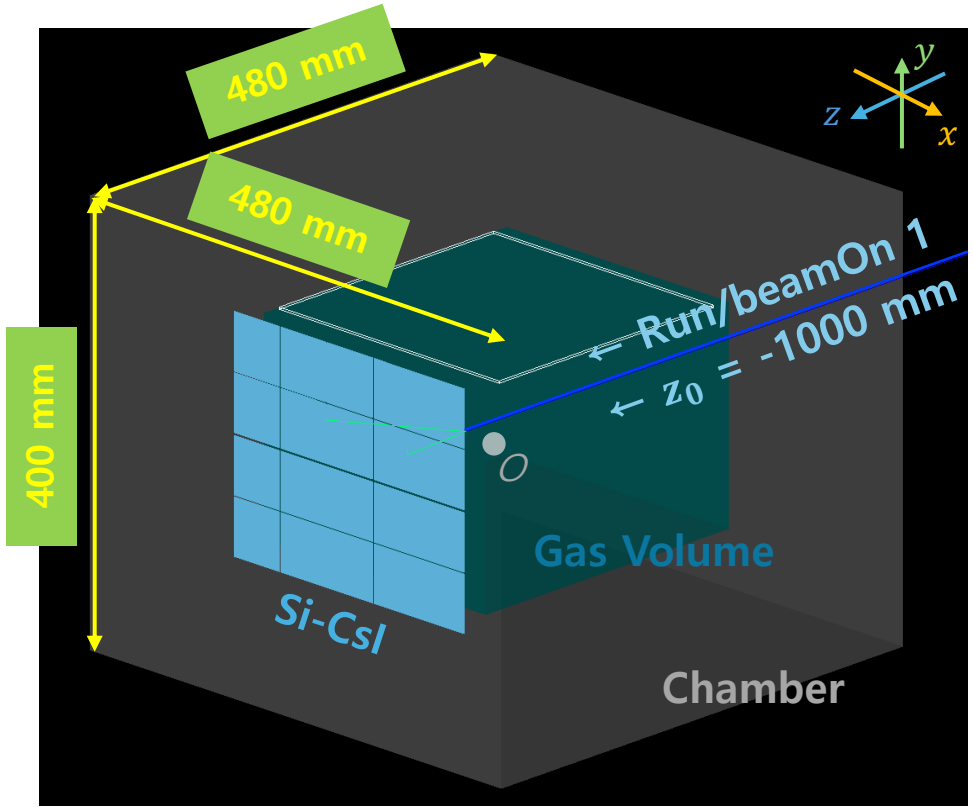
Normal / Grid

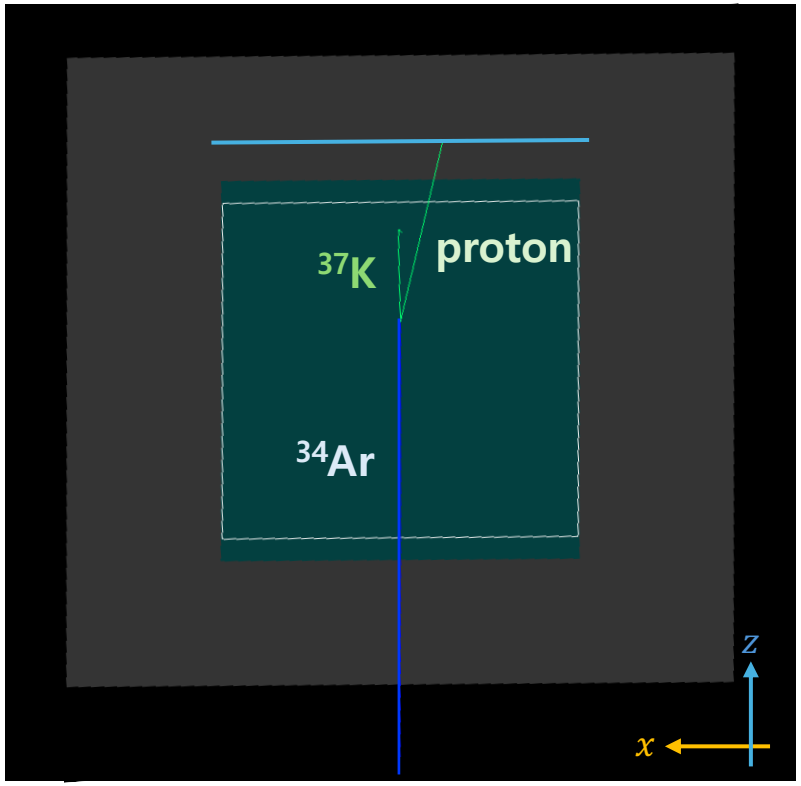


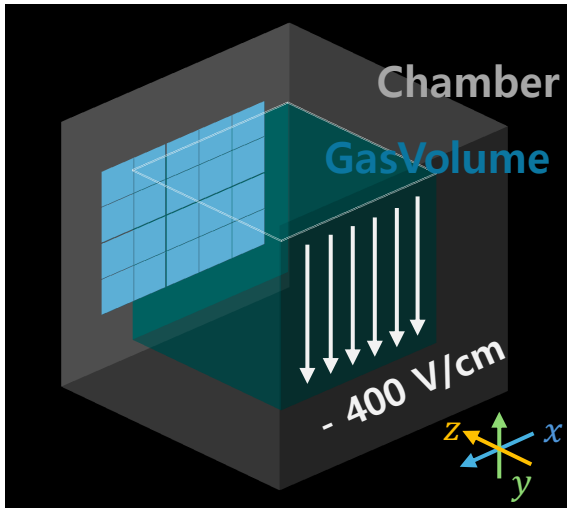
$^{34}Ar(\alpha,p)^{37}K$ Nptool simulation

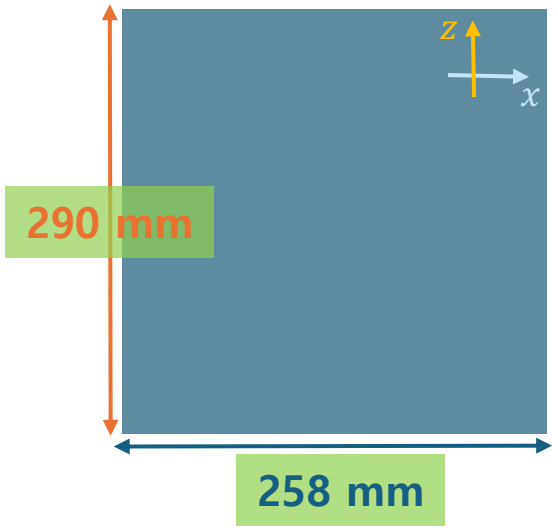
Get recoils information in active volume

- **Setting** - Beam : ^{34}Ar (20.4 MeV/u)
  - Target : ^{4}He ($^{4}He : CO_2 = 97 : 3$, Mixed gas)
  - Internal Field : -400 V/cm ($\hat{y}$)

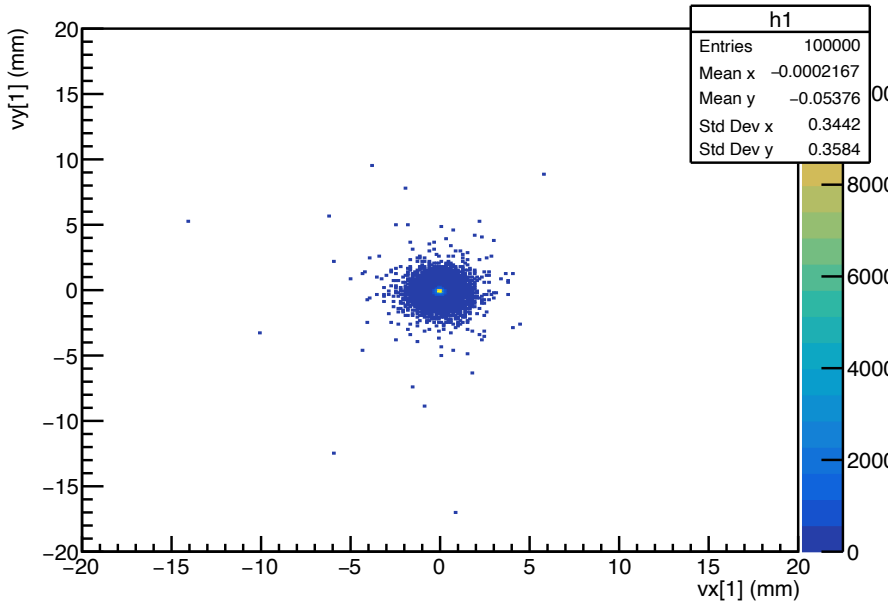




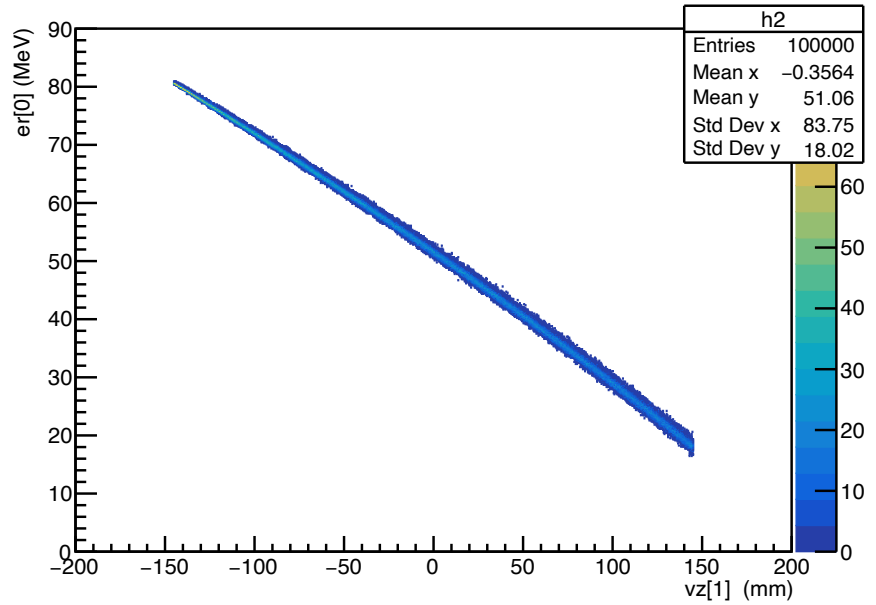




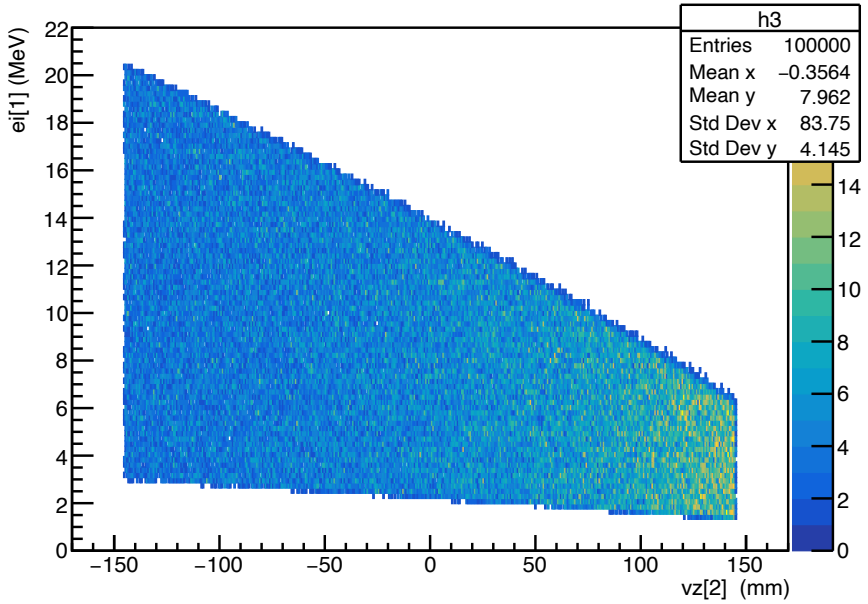
Proton Position (XY plane)



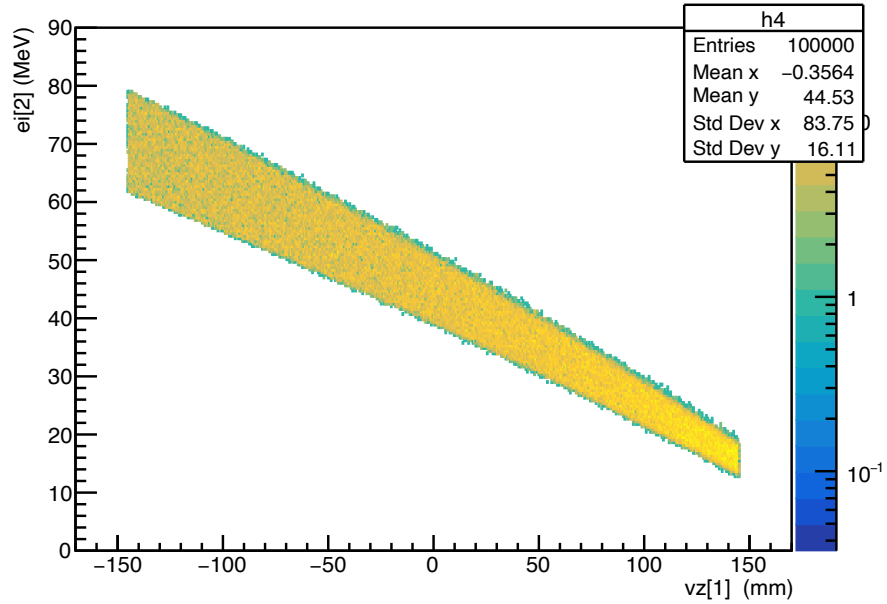
34Ar Energy at Vertex (Z-axis)



Proton Energy at Vertex (Z-axis)



37K Energy at Vertex (Z-axis)



Summary

- The $^{34}Ar(\alpha,p)^{37}K$ is one of the key reactions for understanding the luminosity curve of the double peak and nuclear synthesis mechanism in X-ray bursts

- Through this experiment, we will identify the existence of resonances states in ^{38}Ca, measure the cross section of $^{34}Ar(\alpha,p)^{37}K$, and determine the reaction rate in the Gamow window for the first time

- We will use the efficient new AT-TPC, AToM-X, that has been devised at CENS (Center for Exotic Nuclear Studies)
- To verify the reliability of the simulation, two simulations of the gating grid in the 14O(a,p) experiment were performed, confirming that the simulation results are in good agreement with the actual experiment.

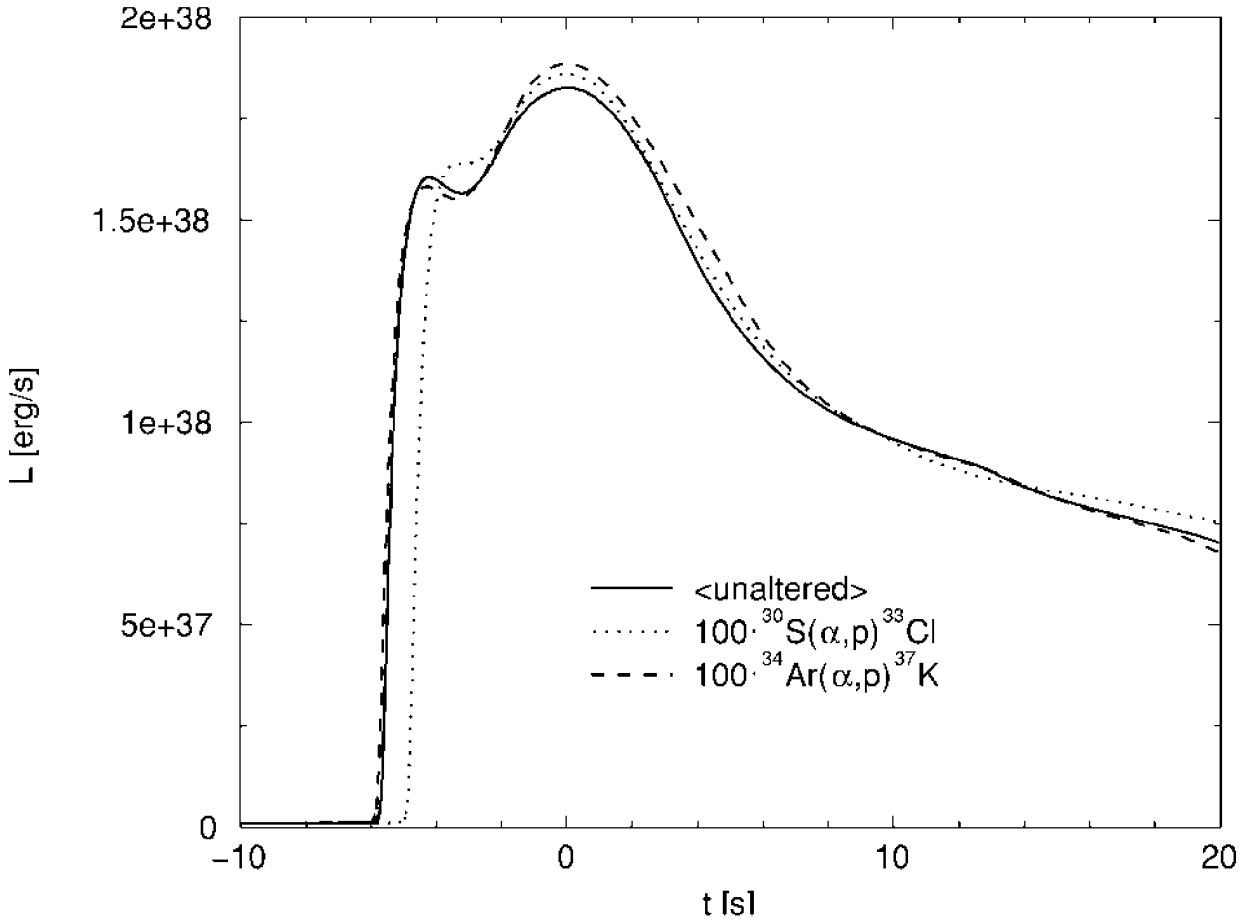
- Currently, the nptool simulation for the 34Ar(a,p) experiment needs further refinement.

Thank you !

Motivation

- **X-ray burst** : Thermonuclear explosion on the surface on a neutron star in a binary system

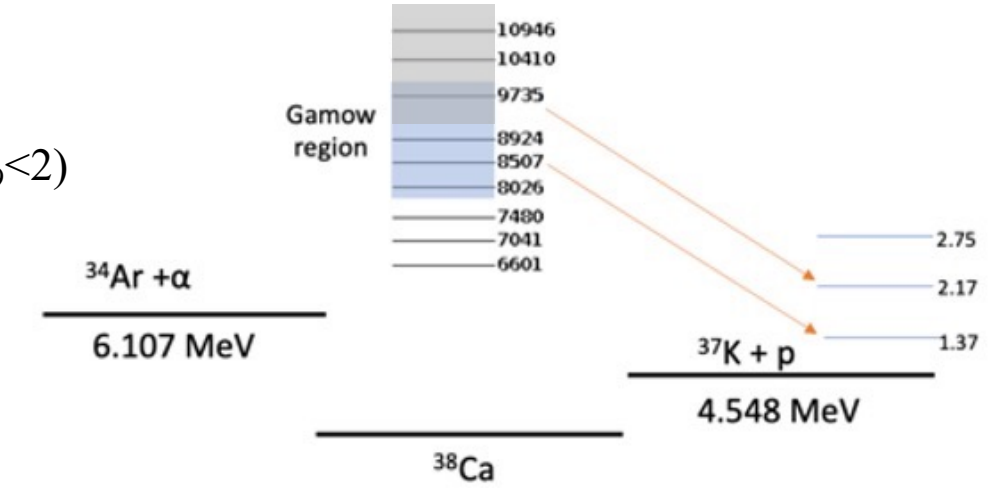
- Nucleosynthesis occurs through αp- and rp-processes
- **Heavy-element production** and **luminosity curve** of X-ray burst can be investigated through the (α,p) reaction
- Some Type-1 X-ray burst luminosity curve represent **double peaks**
- **^{30}S** and **^{34}Ar** can be **waiting points** which enter $(p,\gamma)-(\gamma,p)$ equilibrium due to low Q(p,γ)-value & long β-decay life time



$^{34}Ar(\alpha,p)^{37}K$

Gamow window **1.6 MeV < $E_{c.m.}$ < 4.1 MeV** ($1<T_9<2$)

Compound nucleus : ^{38}Ca (E_x=7.71 - 10.21 MeV)



- We will measure the $^{34}Ar(\alpha,p)^{37}K$ reaction in the region of 3.0 MeV < $E_{c.m.}$ < 8.5 MeV
  using a ^{34}Ar beam from CRIB and an active target time projection chamber

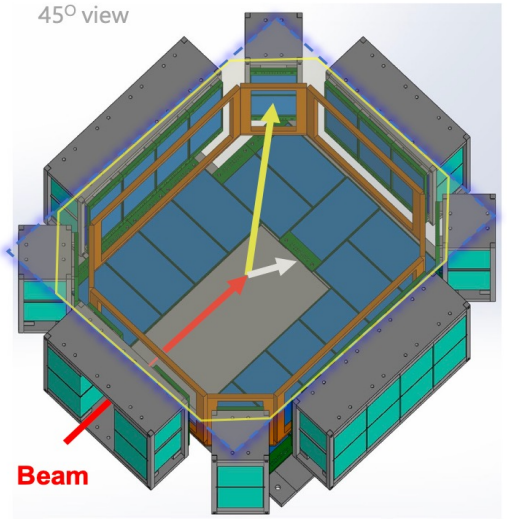
- Excitation function of $^{34}Ar(\alpha,p)^{37}K$ will be obtained for E_x= 9.1 – 14.6 MeV (in ^{38}Ca)
  , which includes partially the Gamow window

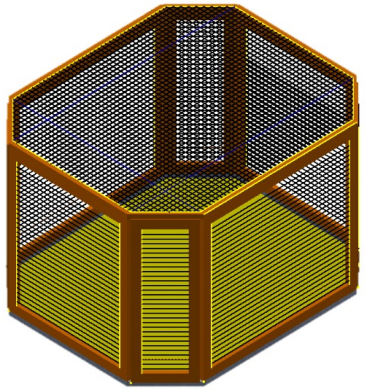
Identify the existence of resonances states in ^{38}Ca
Measure the cross section of $^{34}Ar(\alpha,p)^{37}K$ & Determine the reaction rate in the Gamow window for the first time

AToM-X

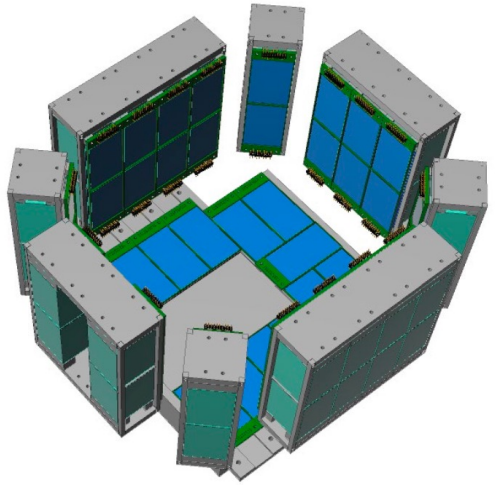
: **A**ctive target **T**PC f**o**r **M**ultiple nuclear e**X**periment

- **Consists of**

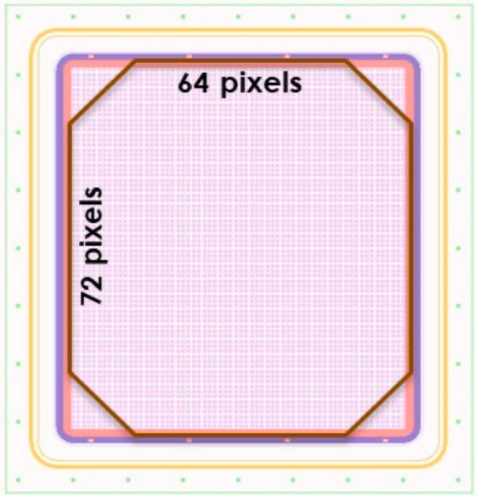




Field cage



Silicon + CsI array



Micromegas

1) Field cage

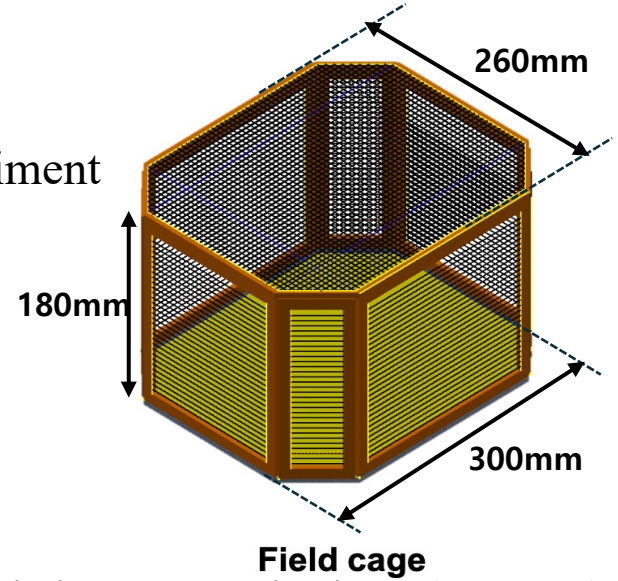
2) Solid state detector (Silicon and CsI detectors)

3) Micromegas (**MICRO ME**sh **GAS**eous detector system)

4) Chambers, Electronics …

AToM-X

: **A**ctive target **T**PC f**o**r **M**ultiple nuclear e**X**periment

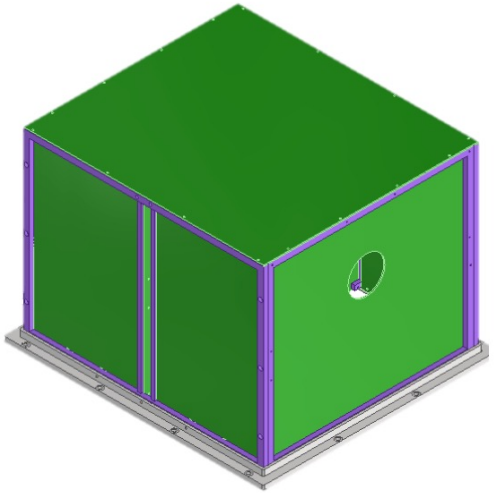


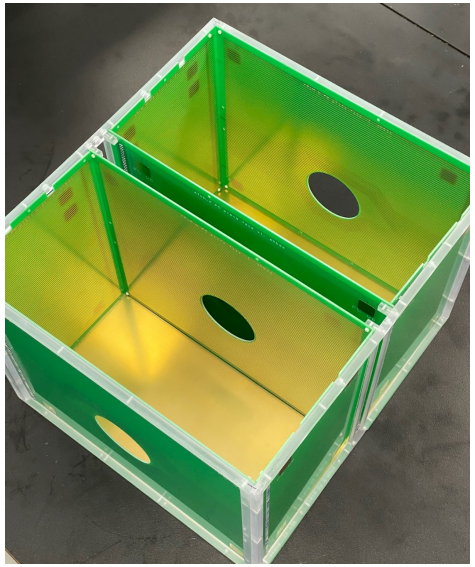
Field cage

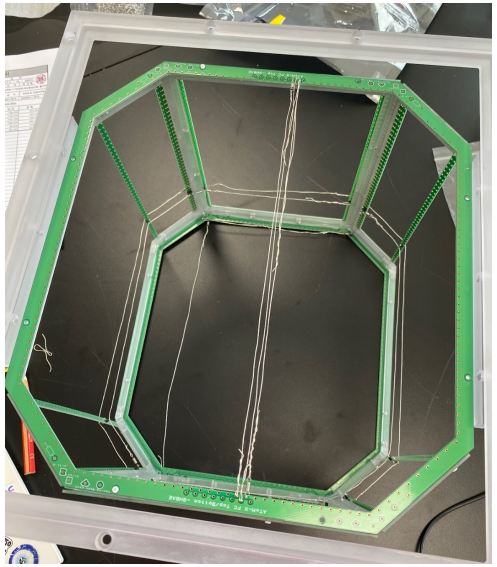
- **Consists of**

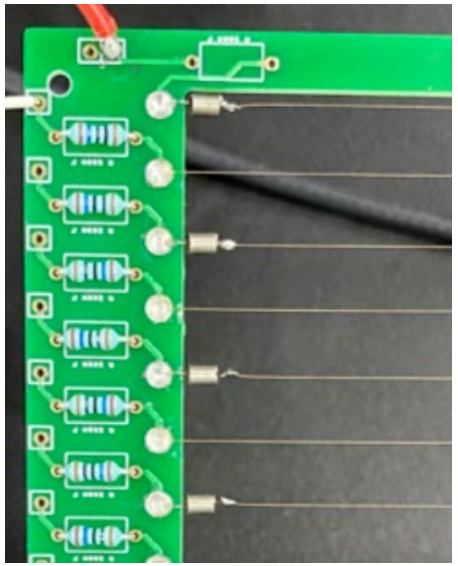
1) Field cage

- It provide **uniform Electric field** in the active volume
- It made of PCB board (Type 1) and
  Au-plated tungsten wire (50μm-thick) (Type 2) due to the particle transmission (99.5%) .


Type-1







AToM-X

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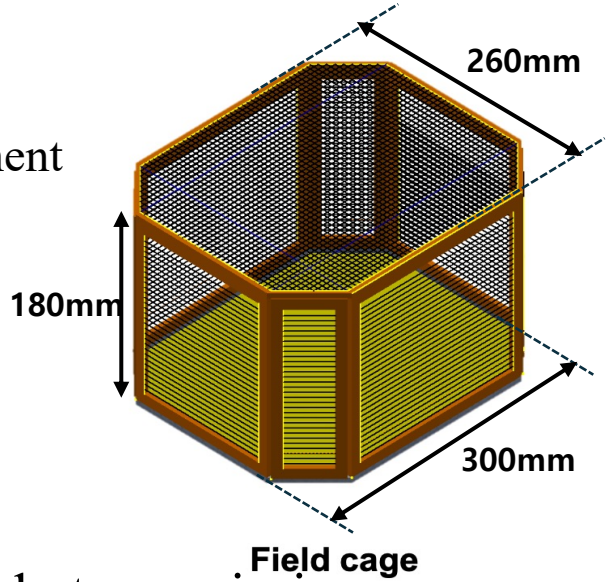

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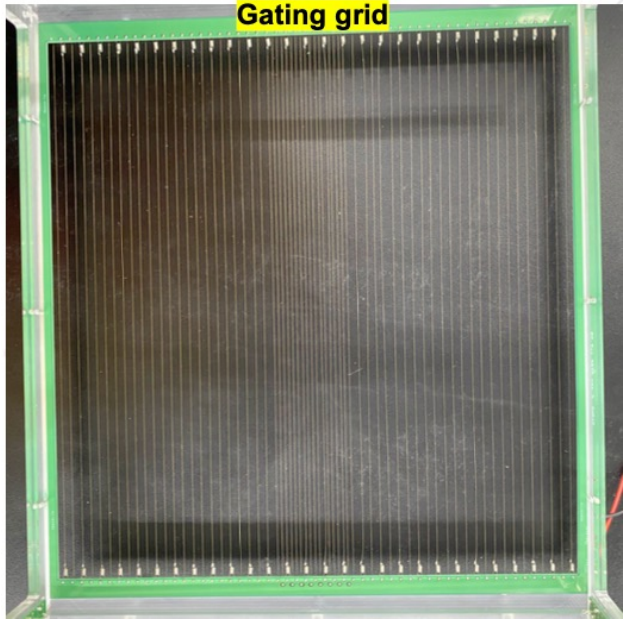
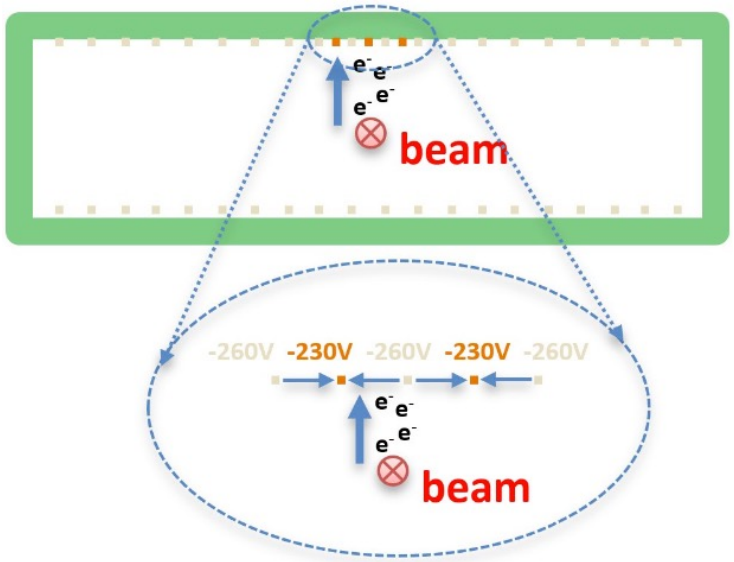
  Au-plated tungsten wire (50μm-thick) (Type 2) due to the particle transmission.





AToM-X

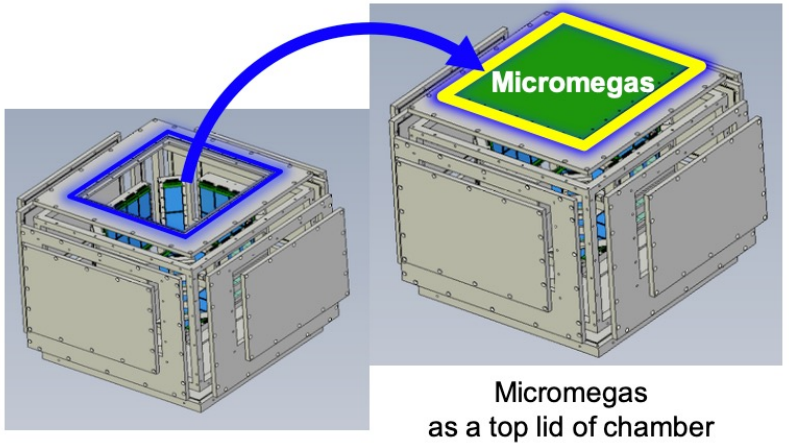
: **A**ctive target **T**PC f**o**r **M**ultiple nuclear e**X**periment

- **Consists of**

3) Micromegas (A gaseous particle detector)

ver.1

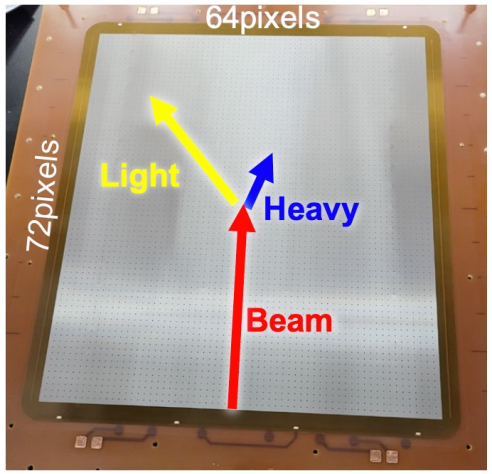
- Tracking charged particles (beam, recoils, ..)
- Electrons from the ionization are amplified between GEM & mesh & readout pad



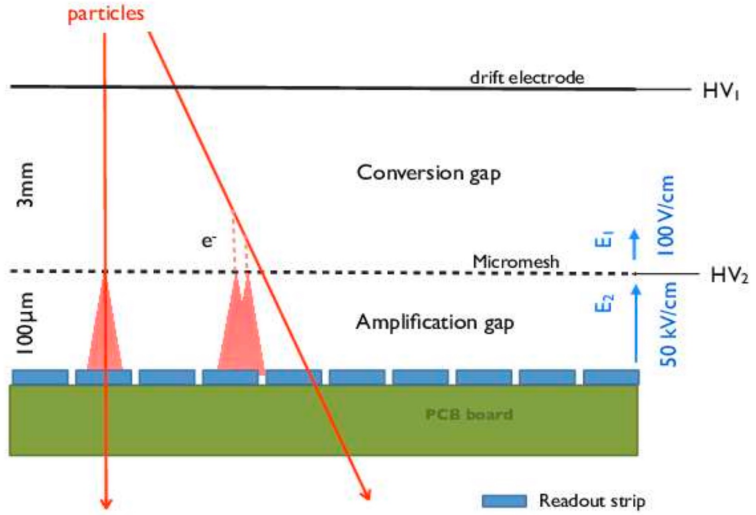
Micromegas
as a top lid of chamber

ver.2

- **Resistive layer technique**
  - **+ Capacitive sharing method applied**



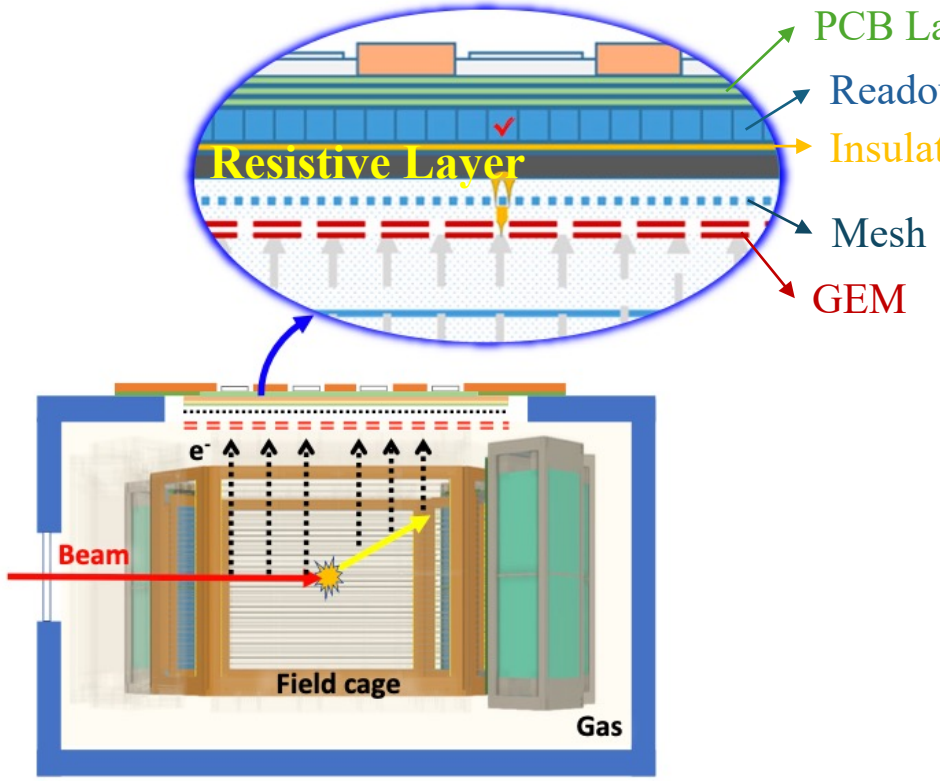
Micromegas (front)

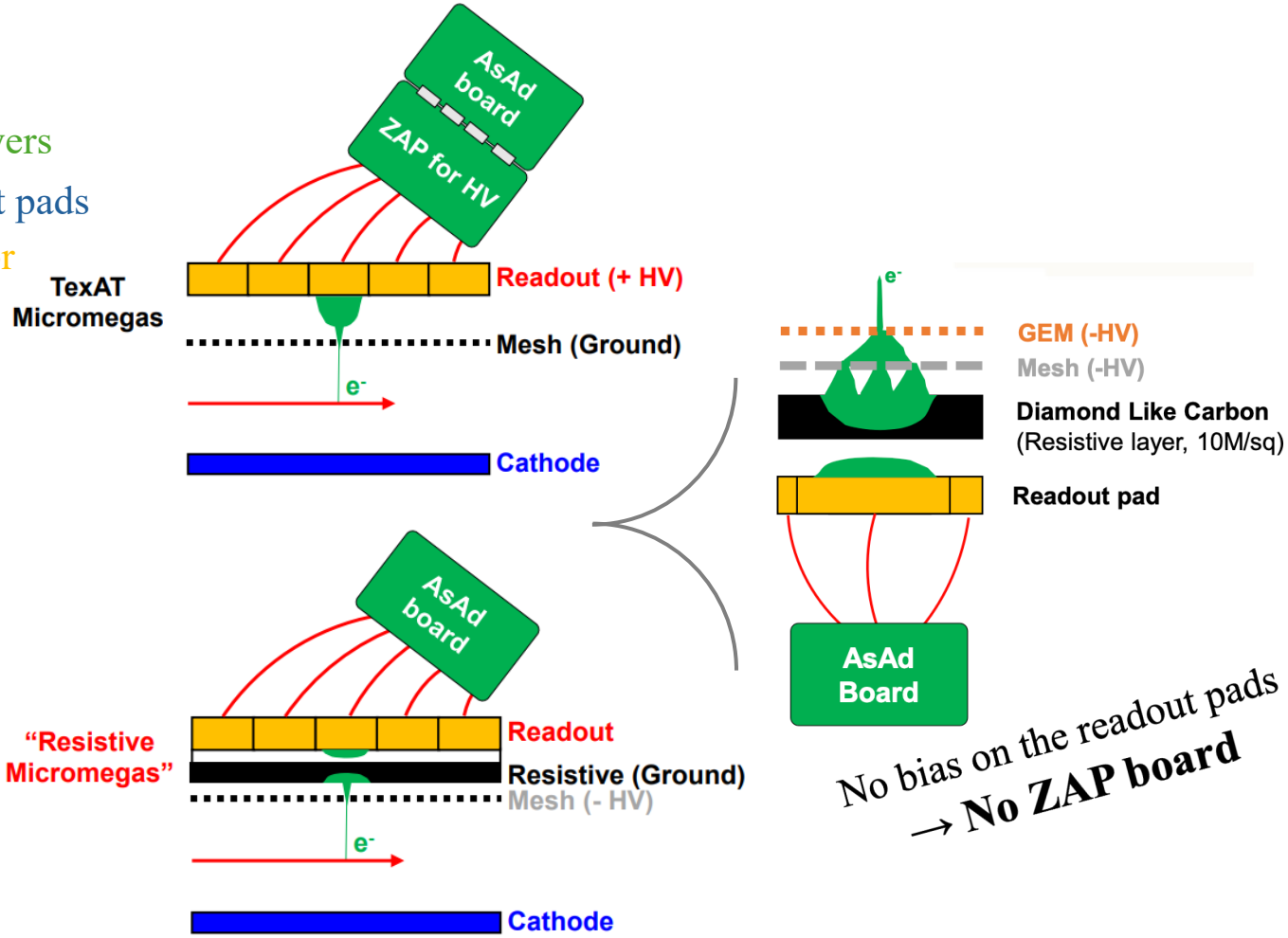


AToM-X

: Active target TPC for Multiple nuclear eXperiment

ver.2 Resistive layer technique + Capacitive sharing method applied



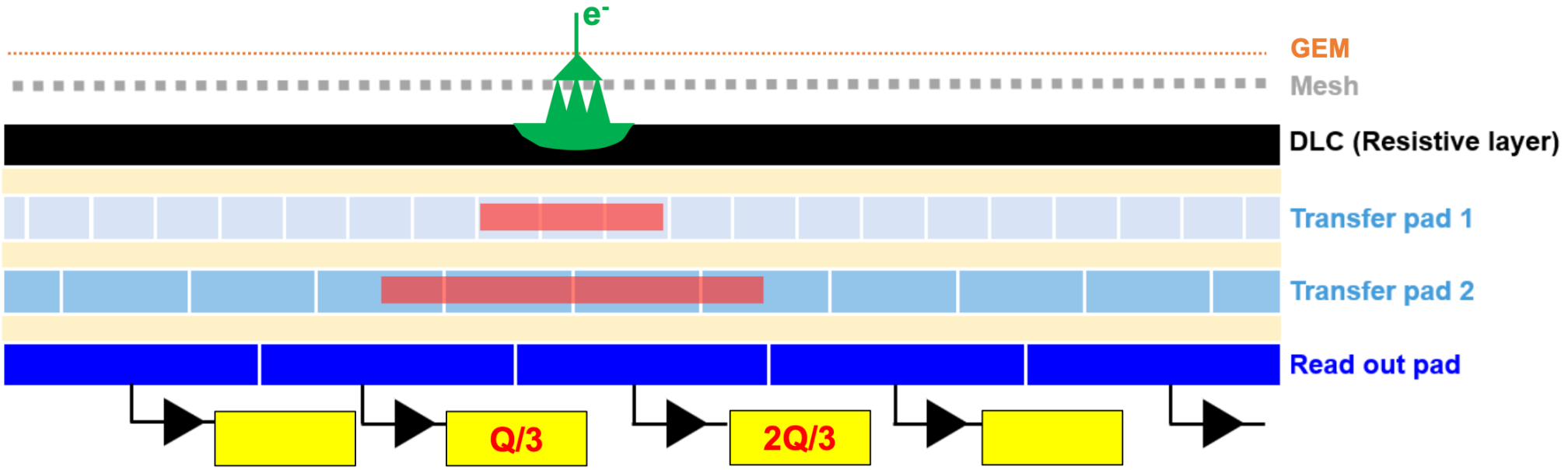


AToM-X

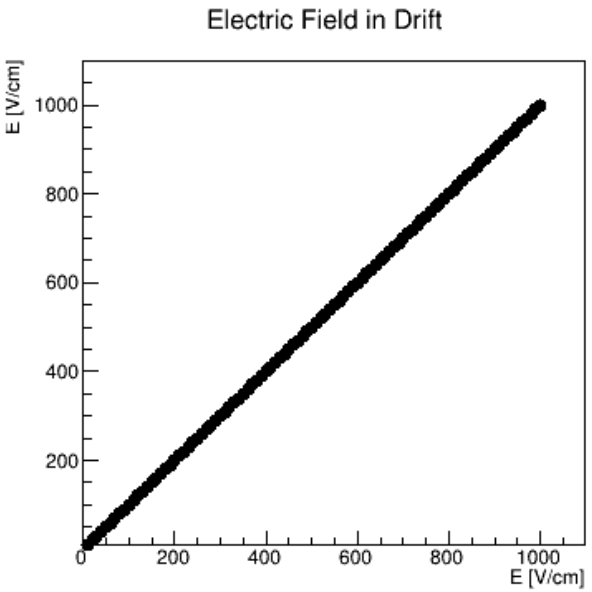
: **A**ctive target **T**PC f**o**r **M**ultiple nuclear e**X**periment

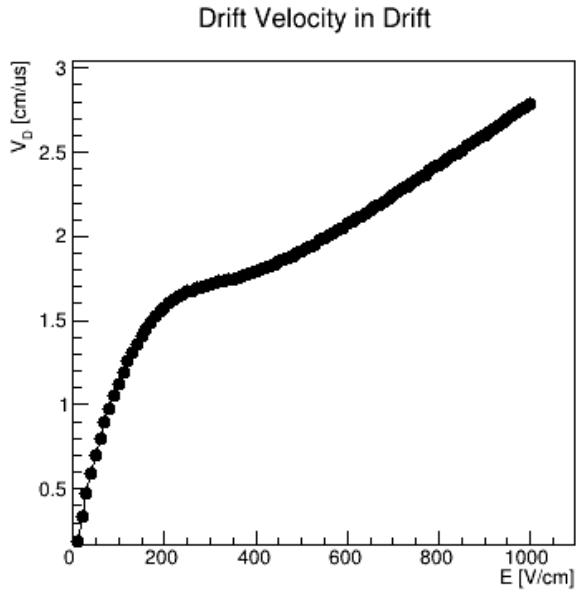
ver.2 **Resistive layer technique + Capacitive sharing method applied**

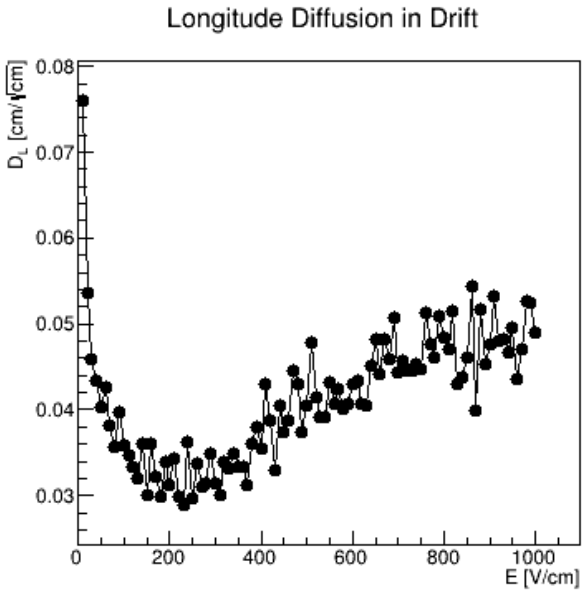
- Pixel size : 4×4 mm^2 pads (expected **position resolution < 1mm**)
- Hit information can be obtained by **different signal heights** in multiple pads.

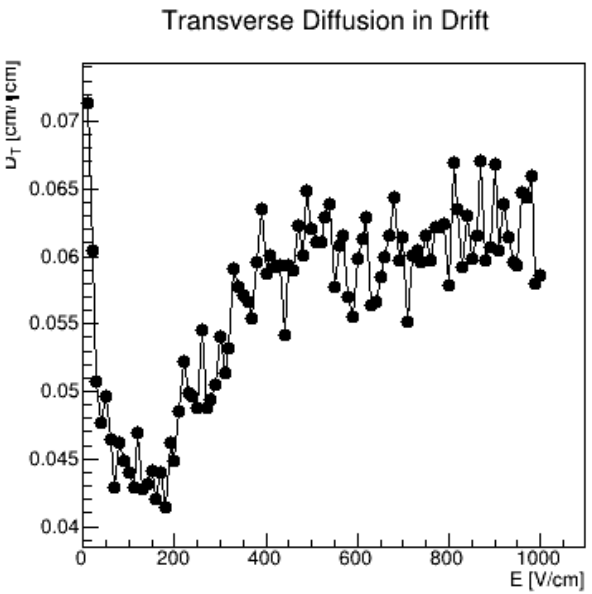


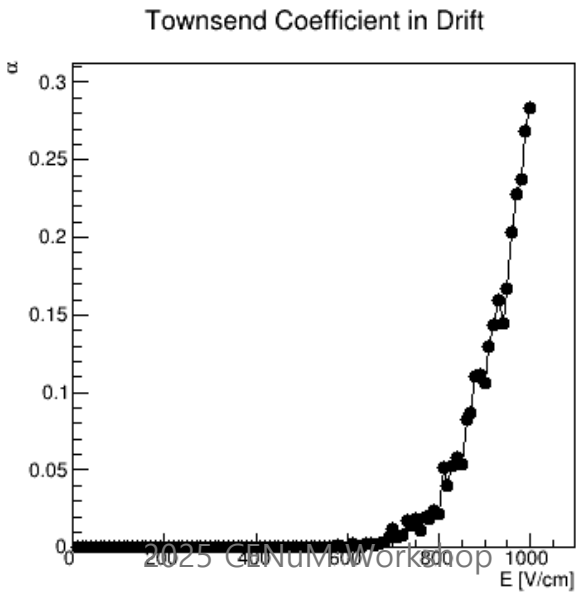
Garfield Simulation

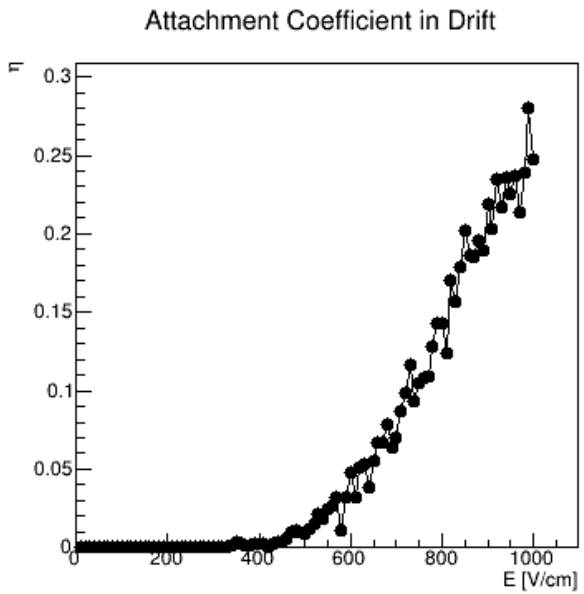






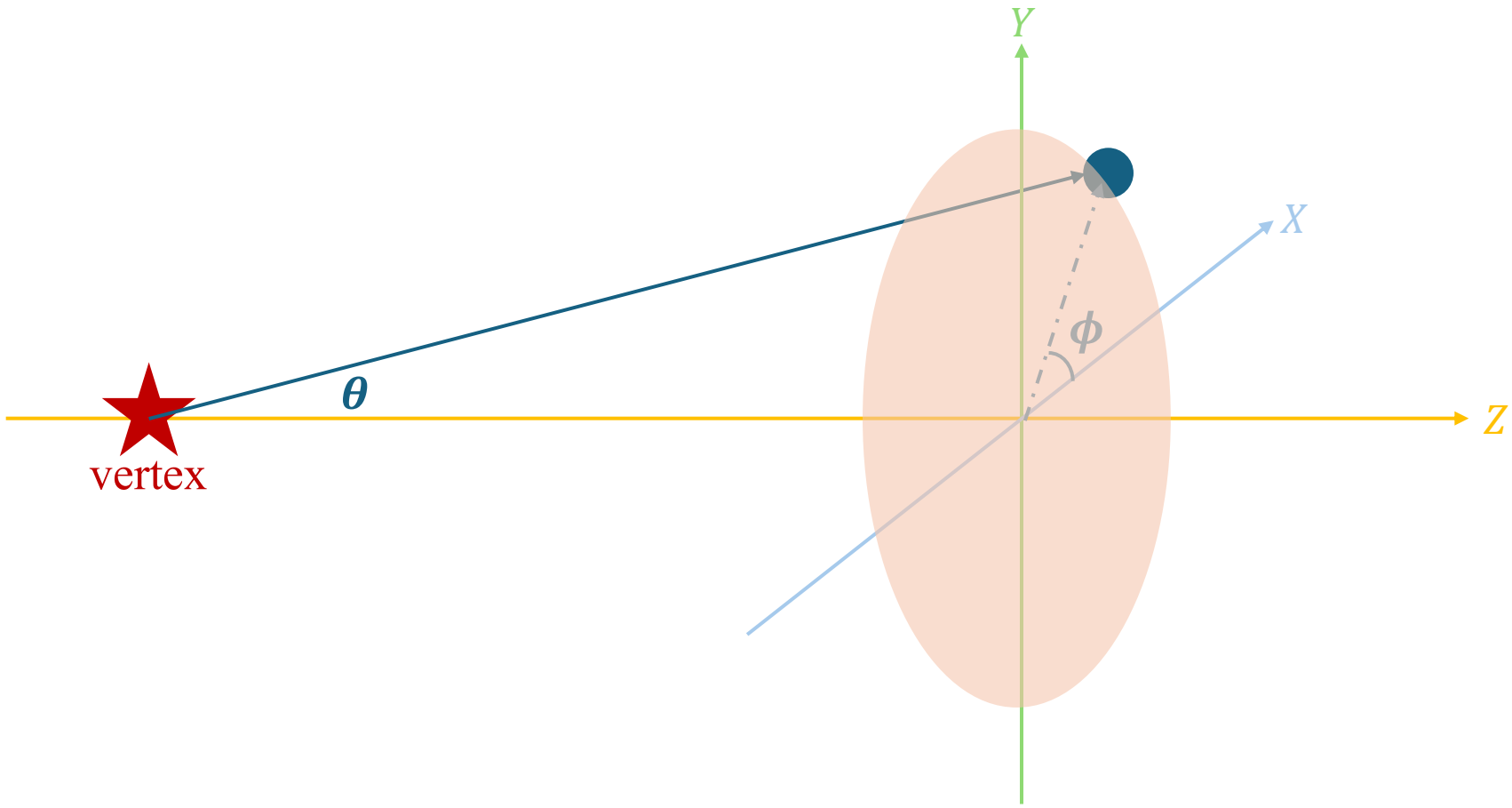






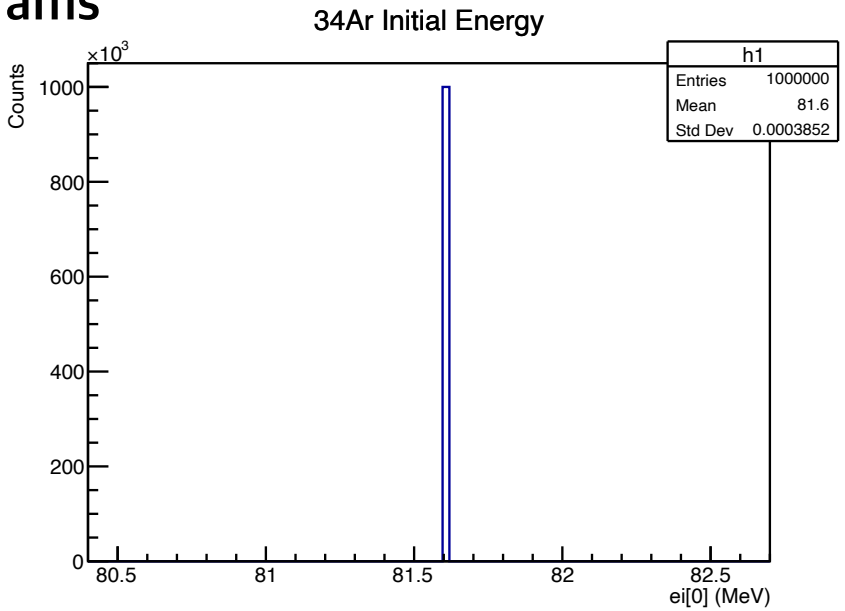
Output RootFile

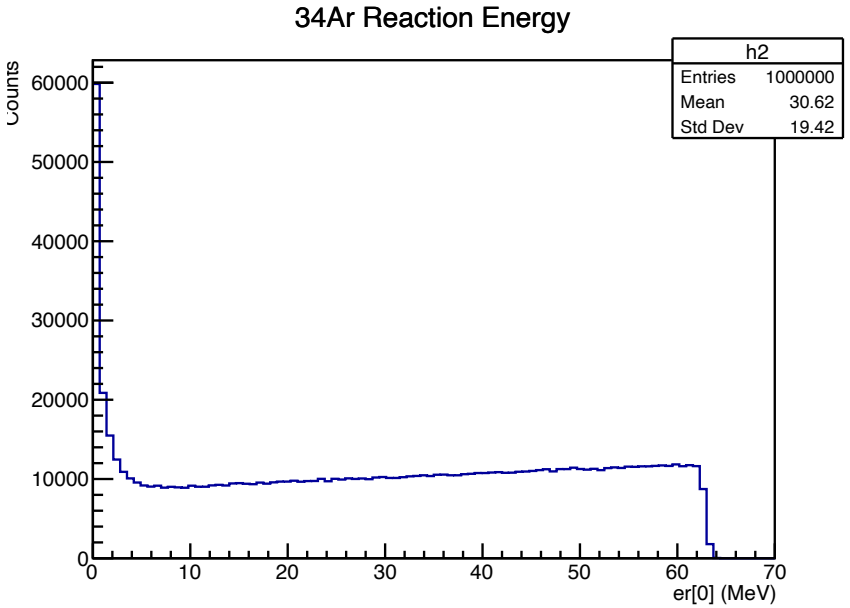
- Histograms

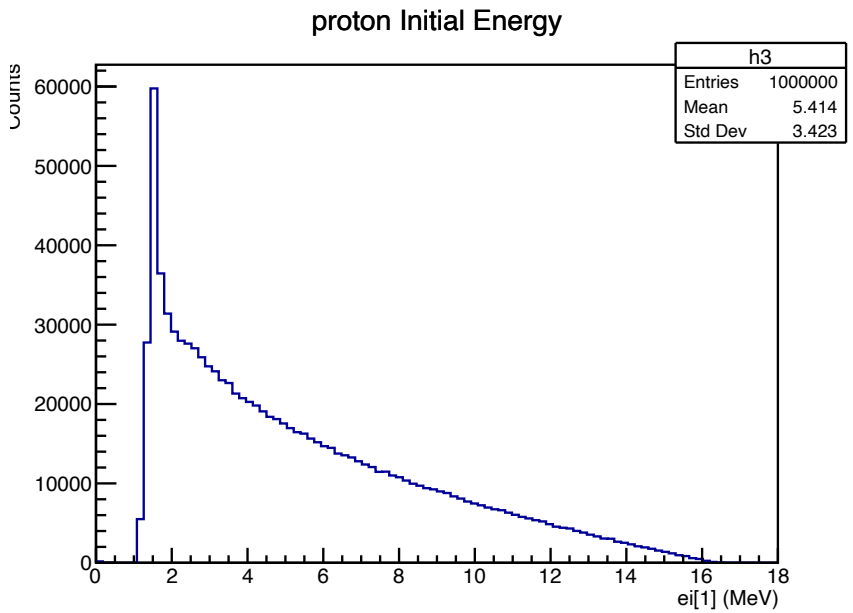


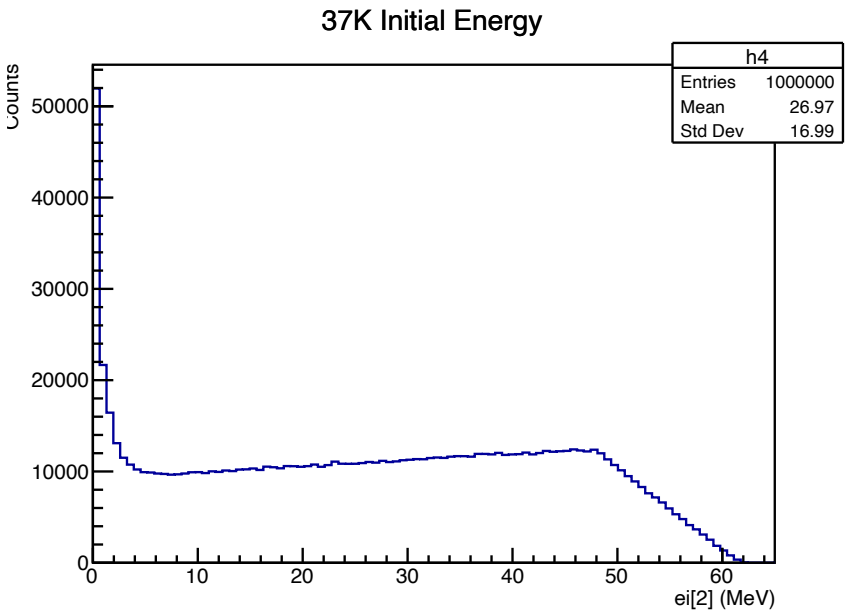
Output RootFile

- Histograms

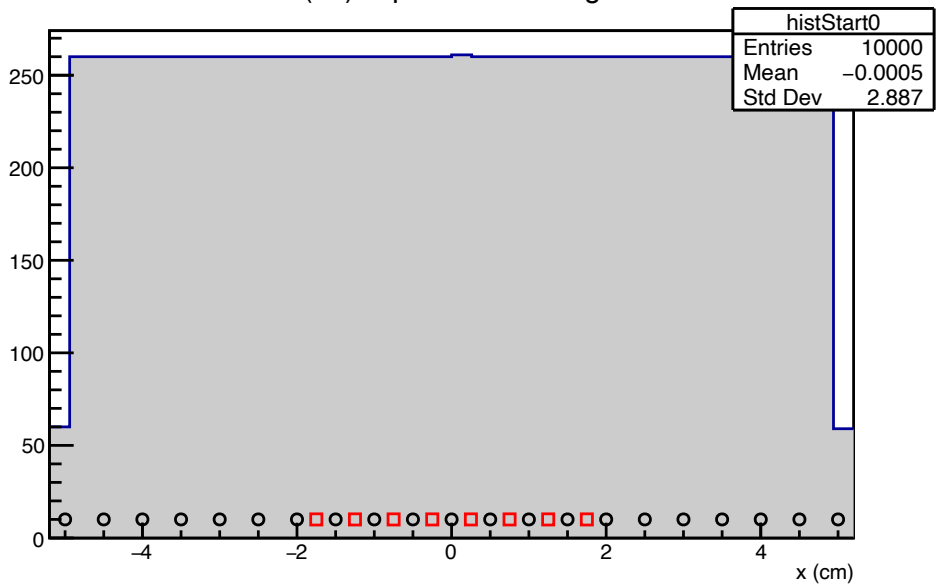




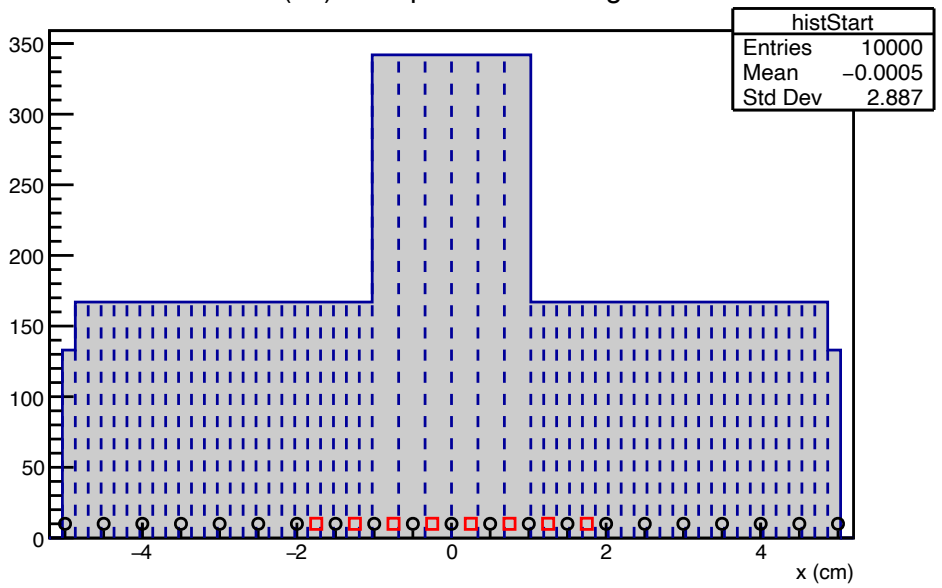




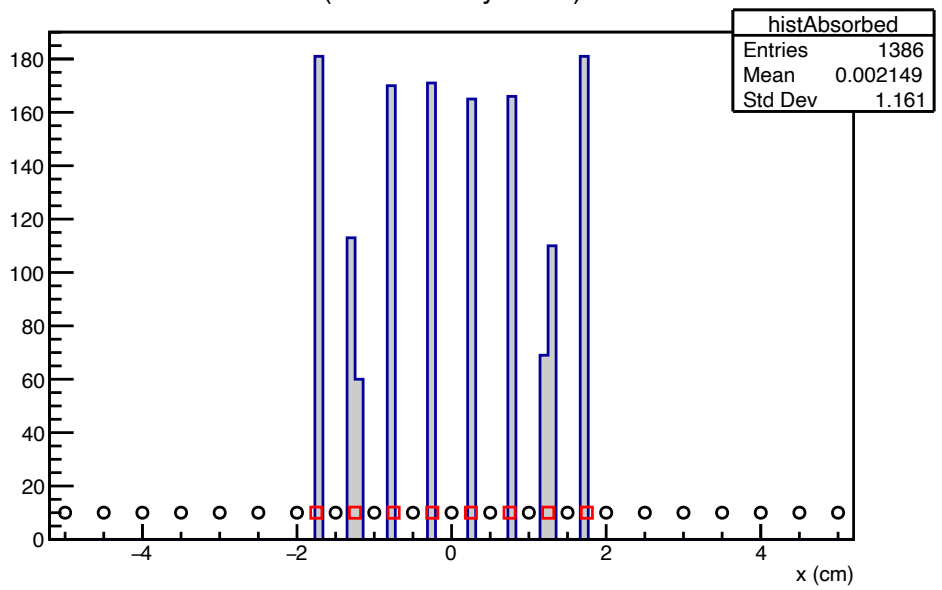
(All) Equal size binning



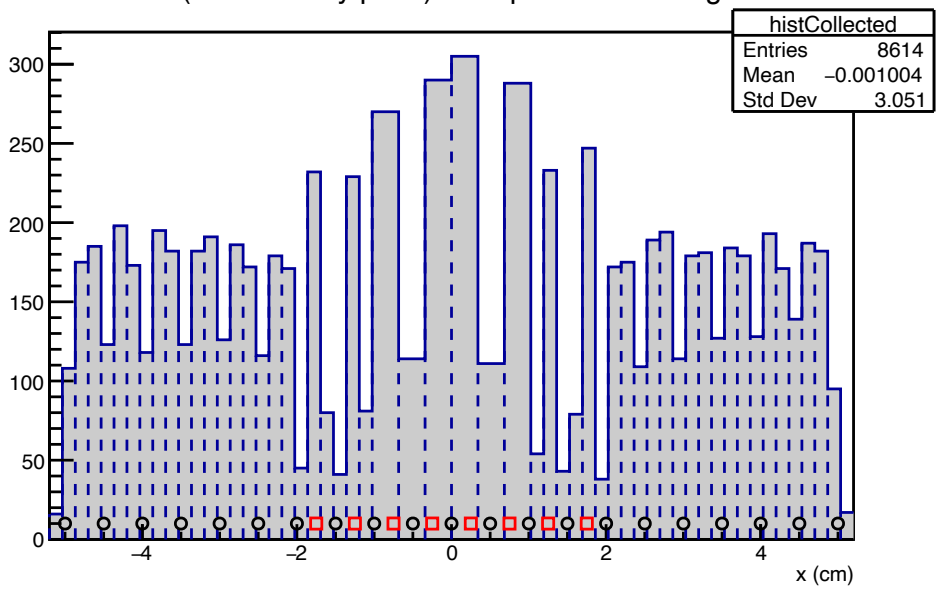
(All) Real pad size binning

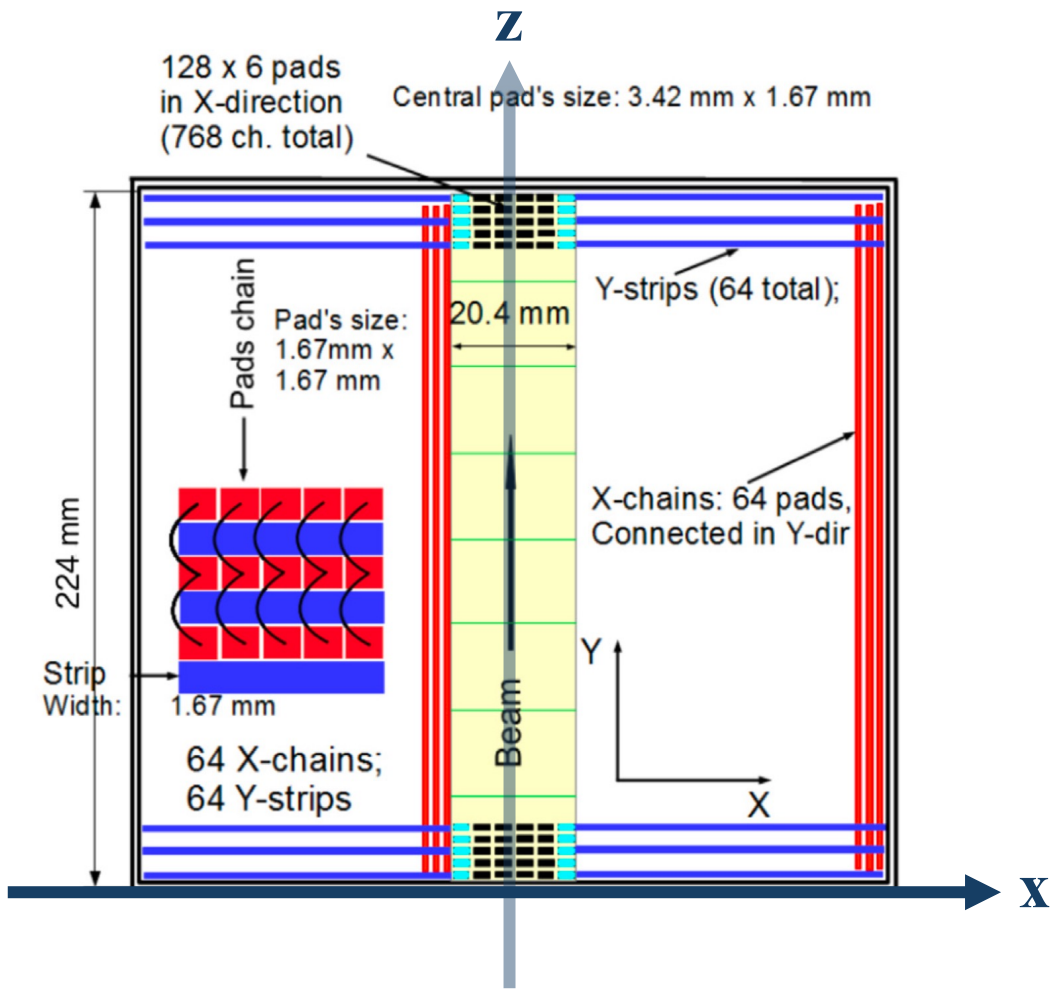


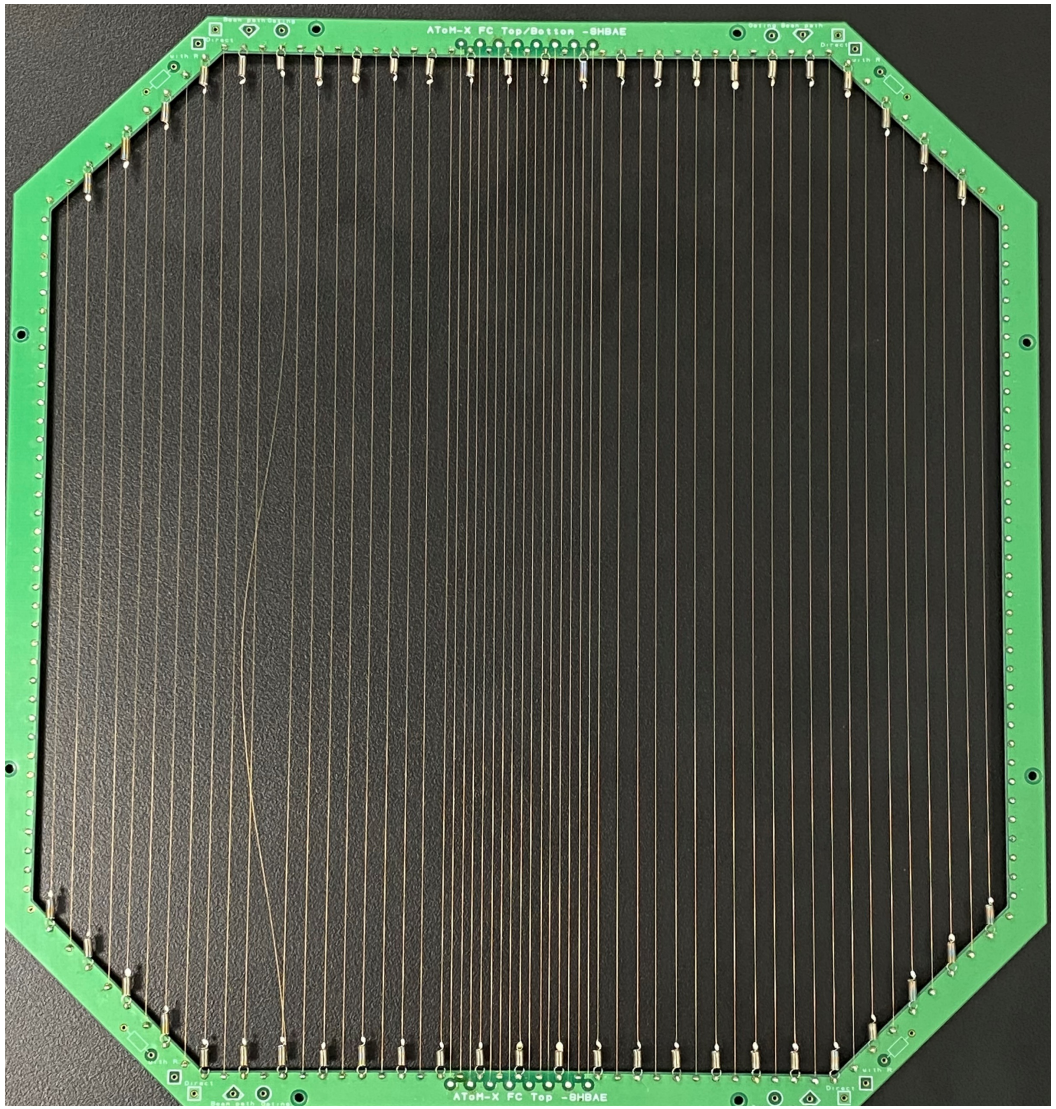
(Absorbed by wires)

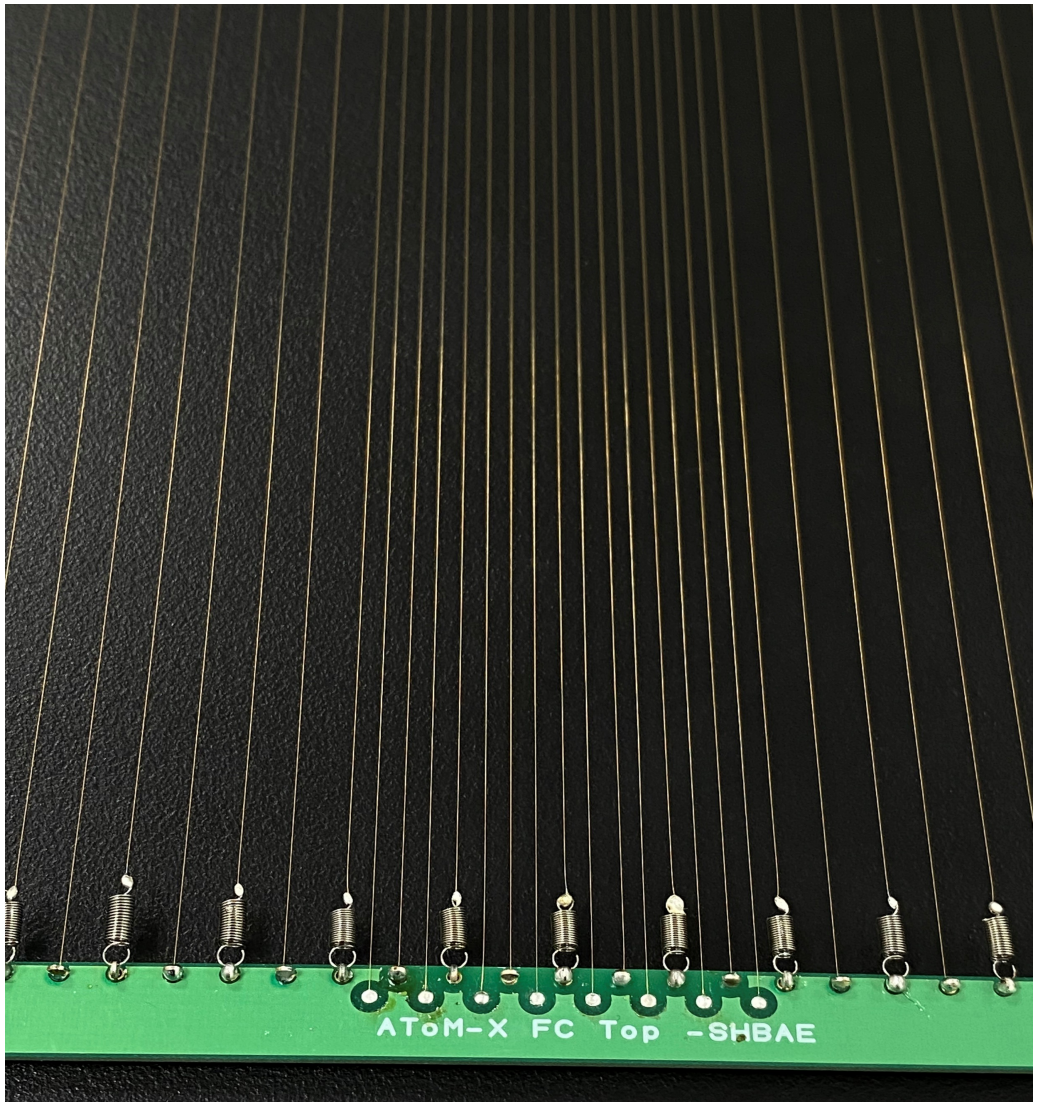


(Collected by pads) Real pad size binning



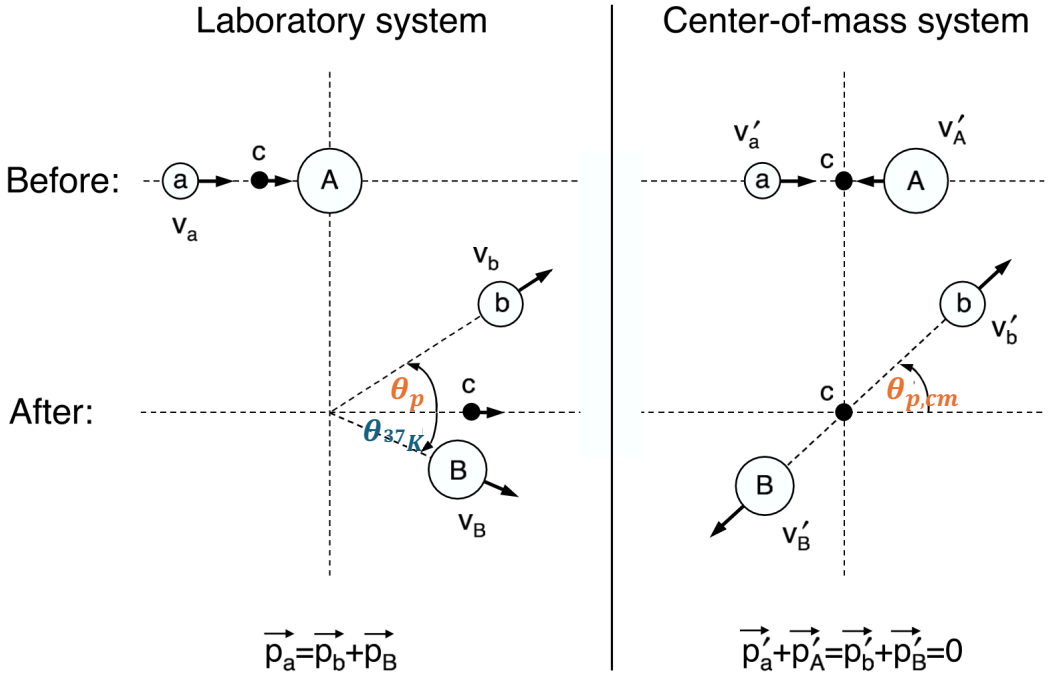

z
128 x 6 pads
in X-direction
(768 ch. total)
Central pad's size: 3.42 mm x 1.67 mm
Pads chain
Pad's size:
1.67mm x
1.67 mm
20.4 mm
Y-strips (64 total);
224 mm
X-chains: 64 pads,
Connected in Y-dir
Strip
Width:
1.67 mm
Y
Beam
64 X-chains;
64 Y-strips
X
x

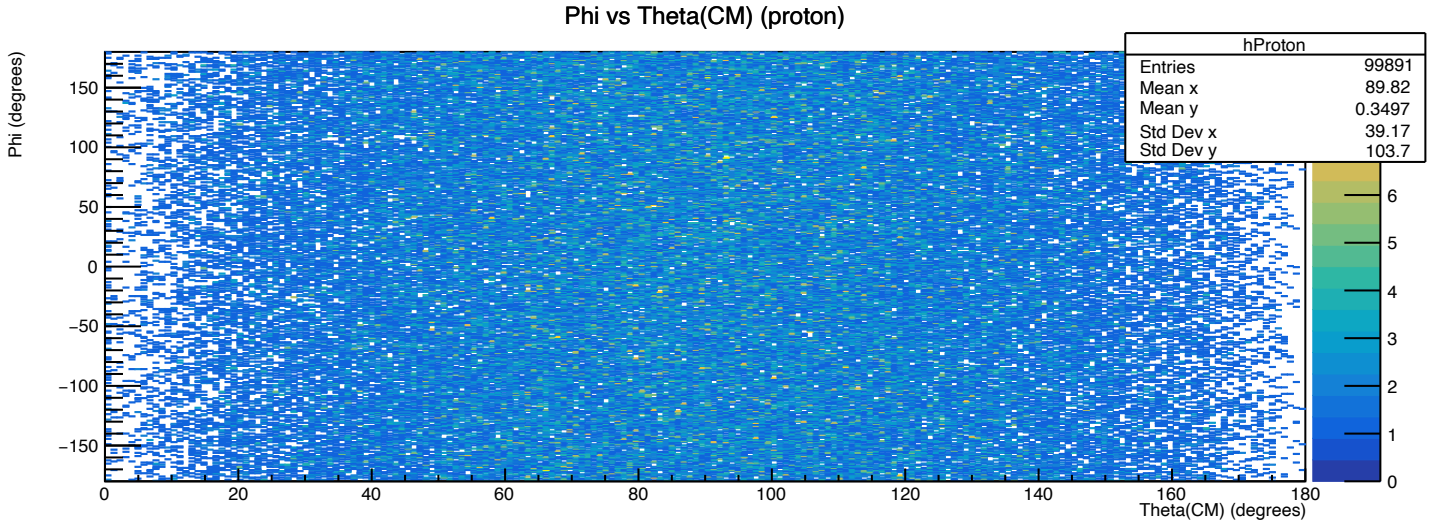

AToM-X FC Top/Bottom -SHBAE
AToM-X FC Top -SHBAE

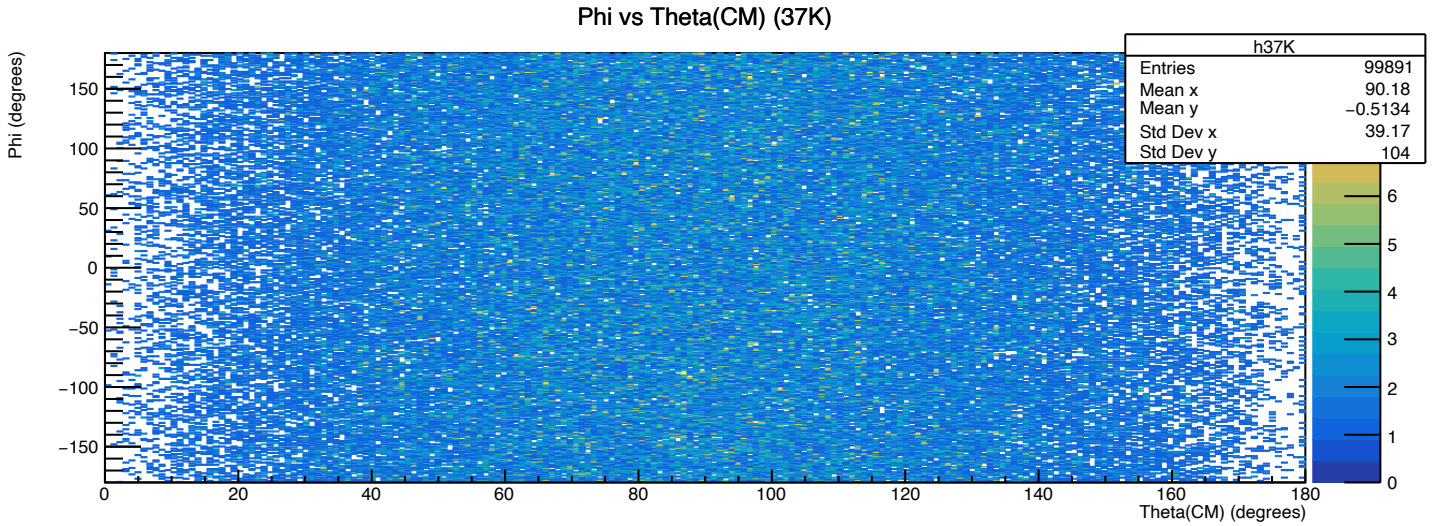

AToM-X FC Top -SHBAE

$^{34}Ar(\alpha,p)^{37}K$ Nptool simulation

Nuclear Physics of Stars (2007)







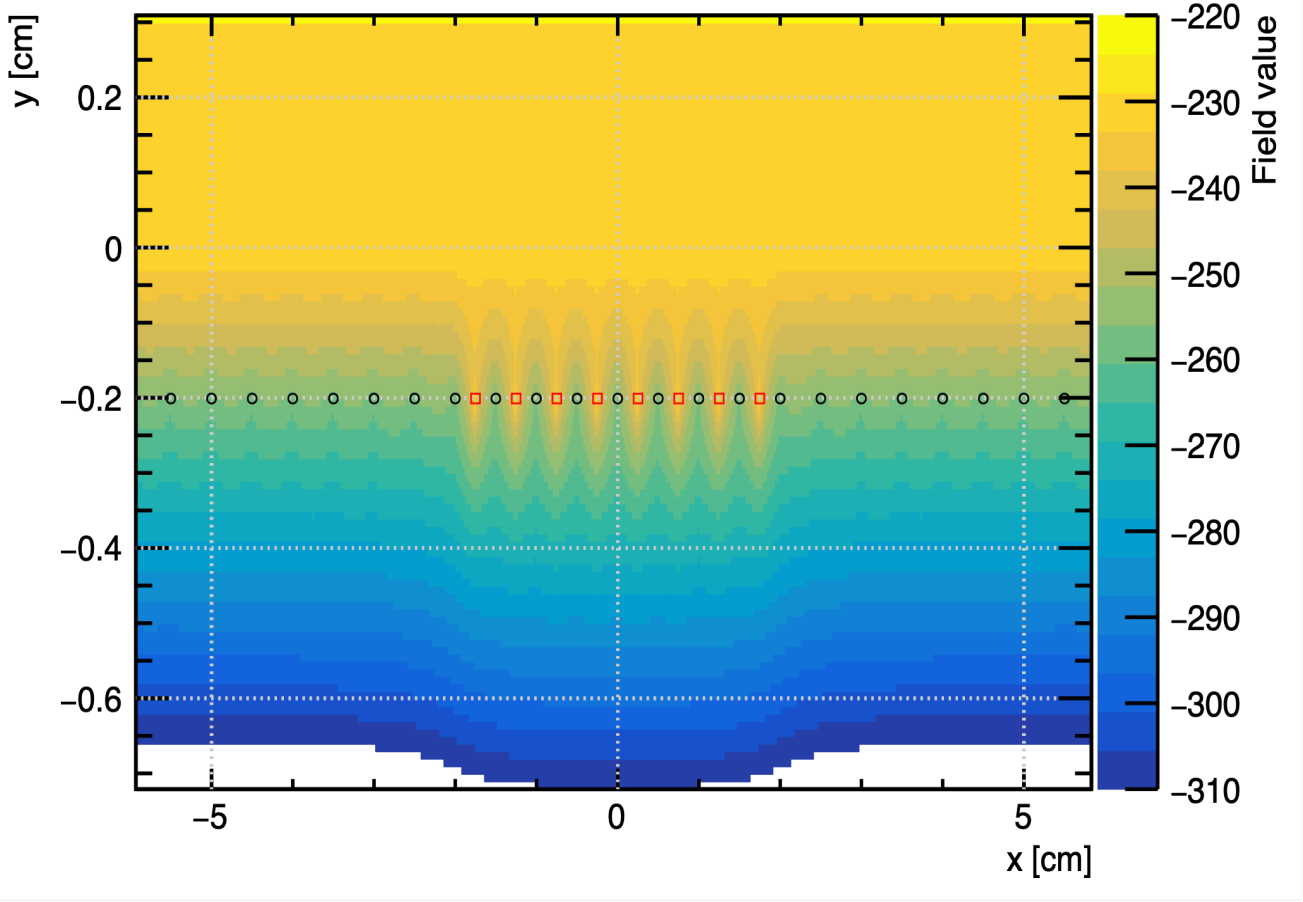
*** Non-relativistic**

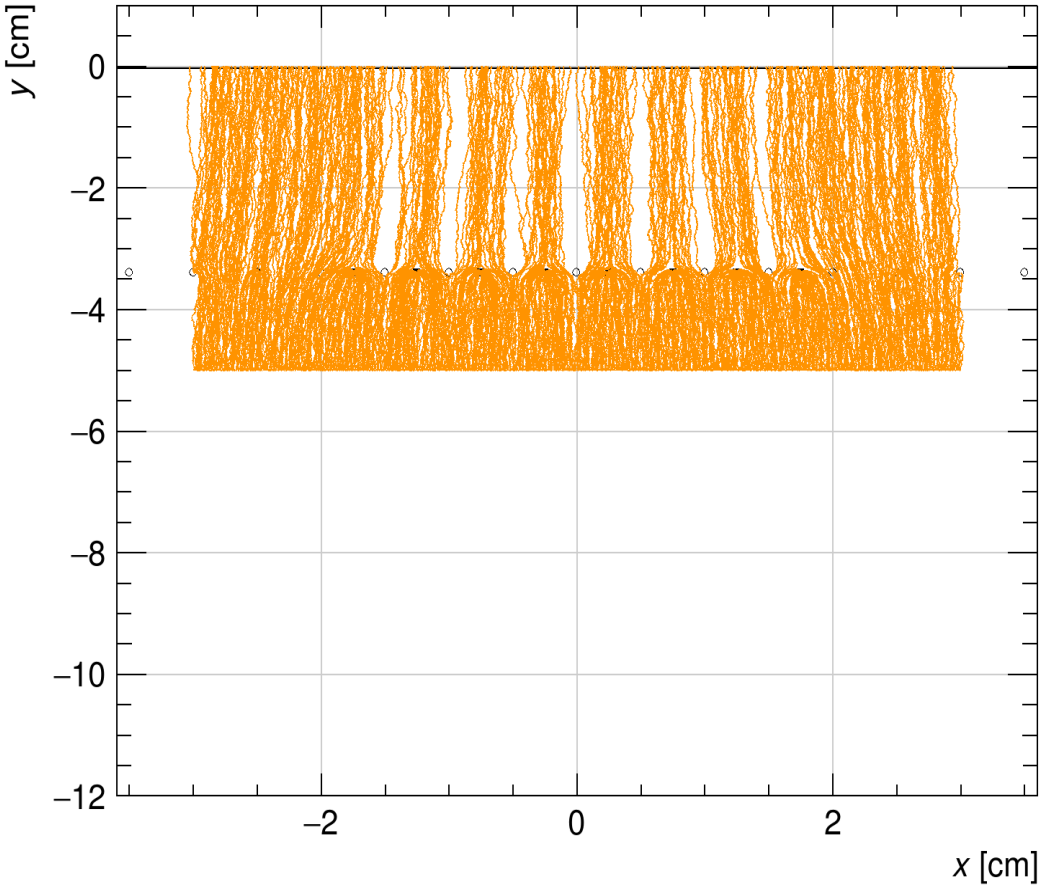
$$\overrightarrow{v_{CM}} = \frac{\sum_i m_i \overrightarrow{v_i}}{\sum_i m_i}$$

$$\overrightarrow{p_{CM}} = \overrightarrow{p_{Lab}} - m\overrightarrow{v_{CM}}$$

$$\theta = \arccos\left(\frac{p_{CM,Z}}{p_{CM}}\right)$$

$$\phi = \tan^{-1}\left(\frac{p_{CM,Y}}{p_{CM,X}}\right)$$


y [cm]
0.2
0
−0.2
−0.4
−0.6
−5
0
5
x [cm]
Field value
−220
−230
−240
−250
−260
−270
−280
−290
−300
−310


y [cm]
0
−2
−4
−6
−8
−10
−12
−2
0
2
x [cm]