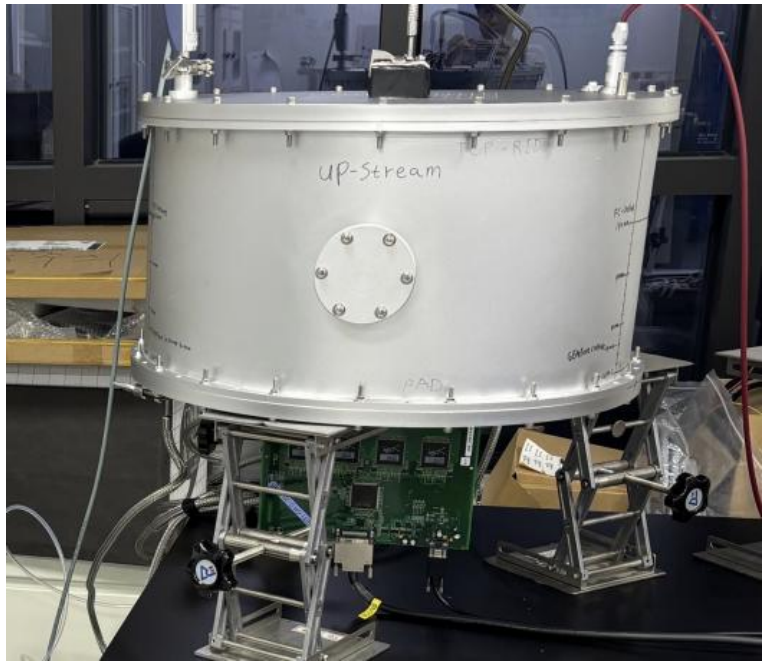
Development of an active target TPC for studying alpha cluster structure in ^{12}C and ^{16}O

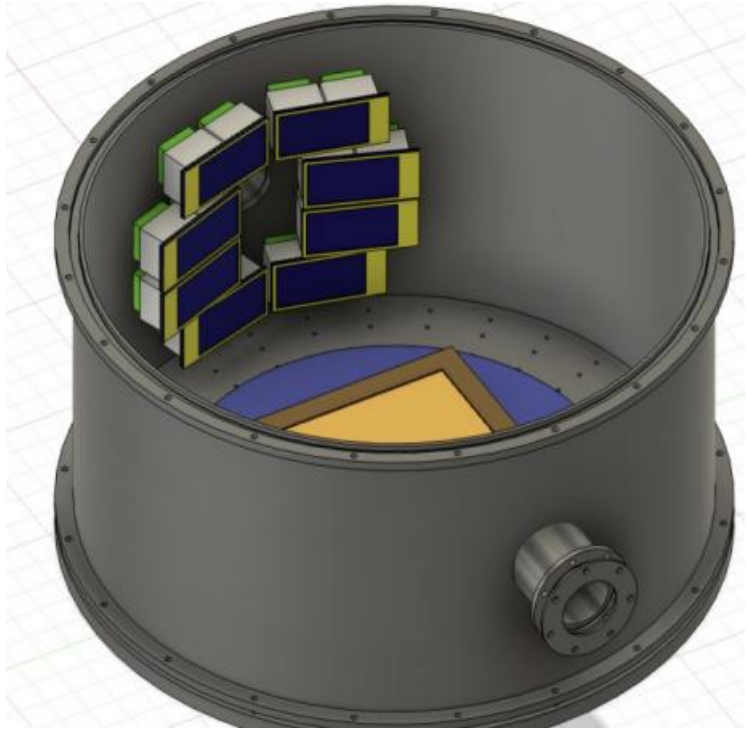
Seonggeun Hwang*, Seunghwan Lee, Yongsun Kim.

(Sejong University)

Outline

- Motivation of experiment
- Introduction to our Active-Target TPC – ”TPC-Drum”
- Results of Commissioning
- Summary



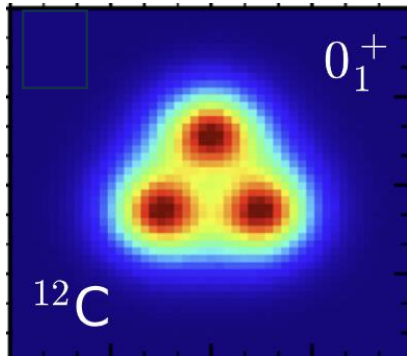


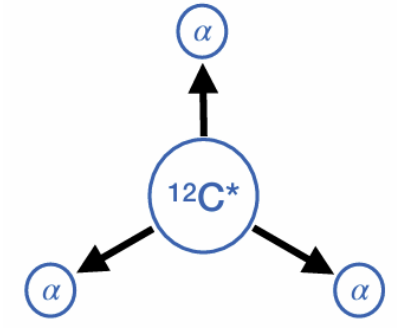
Motivation

Motivation

"Seeking for alpha cluster structure in ^{12}C and ^{16}O"

Nuclear density distribution

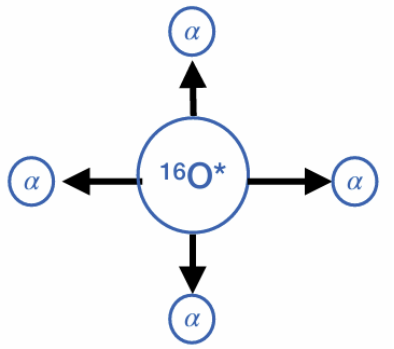




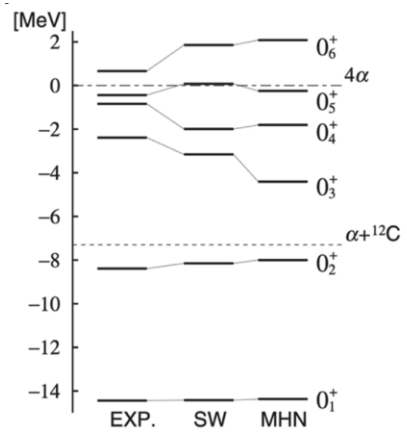
Direct 3α decay of Hoyle state

Goal #1

- Bose-Einstein Condensate-like alpha cluster state
- Excited, spinless, resonant state
- Signature is the symmetric decay of 3 alphas
- Such phenomenon **was not observed with statistical significance**



4α decay of ^{16}O at 15.1 MeV



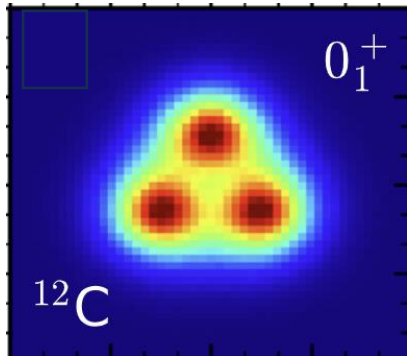
Goal #2

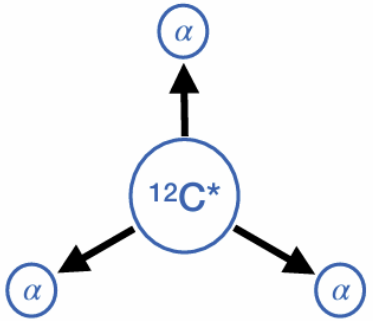
- Candidate for α-cluster of in ^{16}O
- E=15.1 MeV is just above 4α threshold
- **Not reported yet** because of the challenge to measure several alphas simultaneously

Motivation

"Seeking for alpha cluster structure in ^{12}C and ^{16}O"

Nuclear density distribution



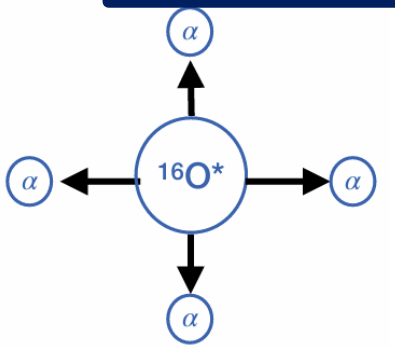


Direct 3α decay of Hoyle state

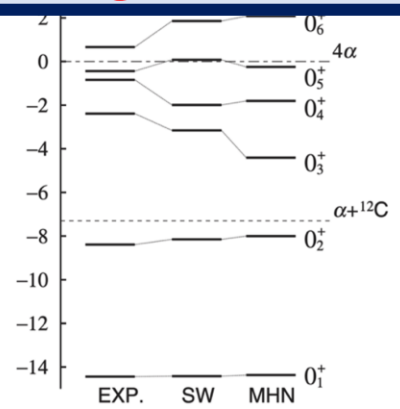
Goal #1

- Bose-Einstein Condensate-like alpha cluster state
- Excited, spinless, resonant state
- Signature is the symmetric decay of 3 alphas
- Such phenomenon was not observed with statistical significance

An Active-Target TPC is the best detector to persue both goals



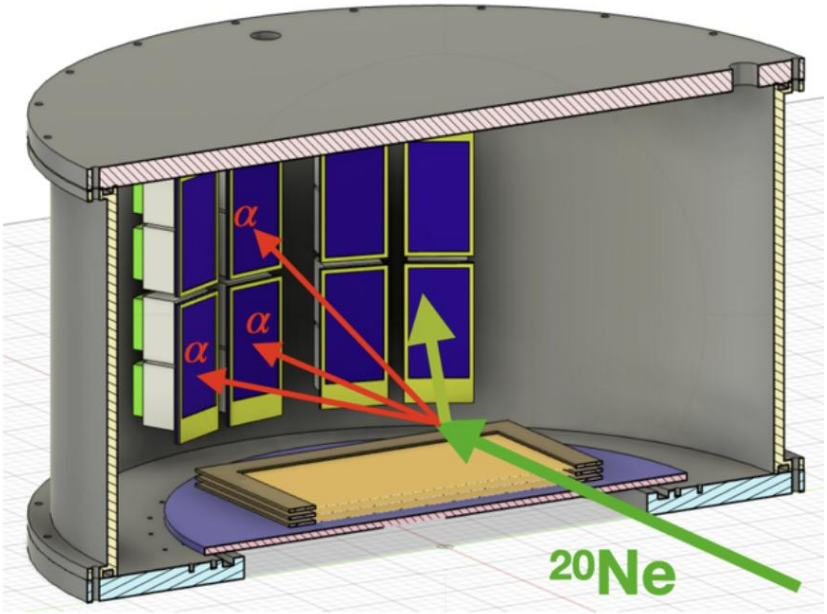
4α decay of ^{16}O at 15.1 MeV



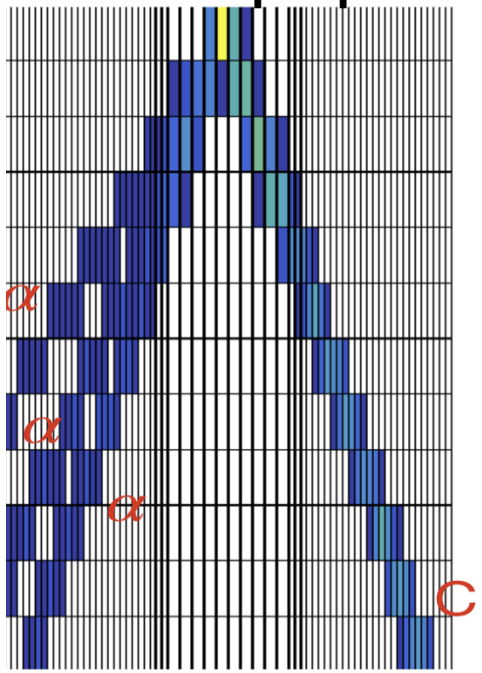
Goal #2

- Candidate for α-cluster of in ^{16}O
- E=15.1 MeV is just above 4α threshold
- Not reported yet because of the challenge to measure several alphas simultaneously

TPC-Drum



TPC-Drum padplane



Collision system : 20Ne + α at 10 MeV/u

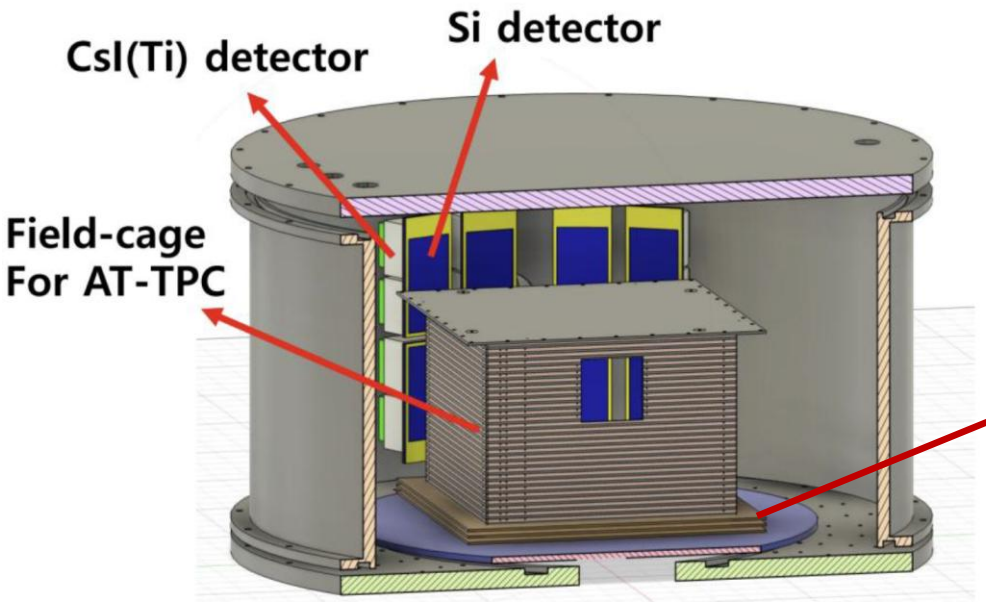
Necessary specification :

- Can measure multiple α's with high precision
- Can measure the collision vertex precisely

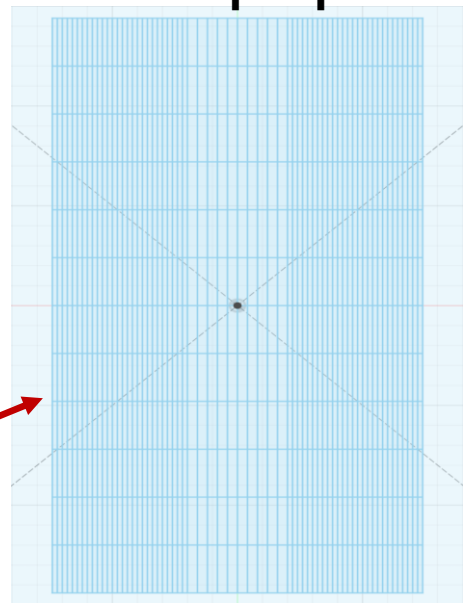
- We designed a new active target TPC for alpha cluster experiments at RAON.
- Find evidence for α-condensate state of ^{12}C and ^{16}O

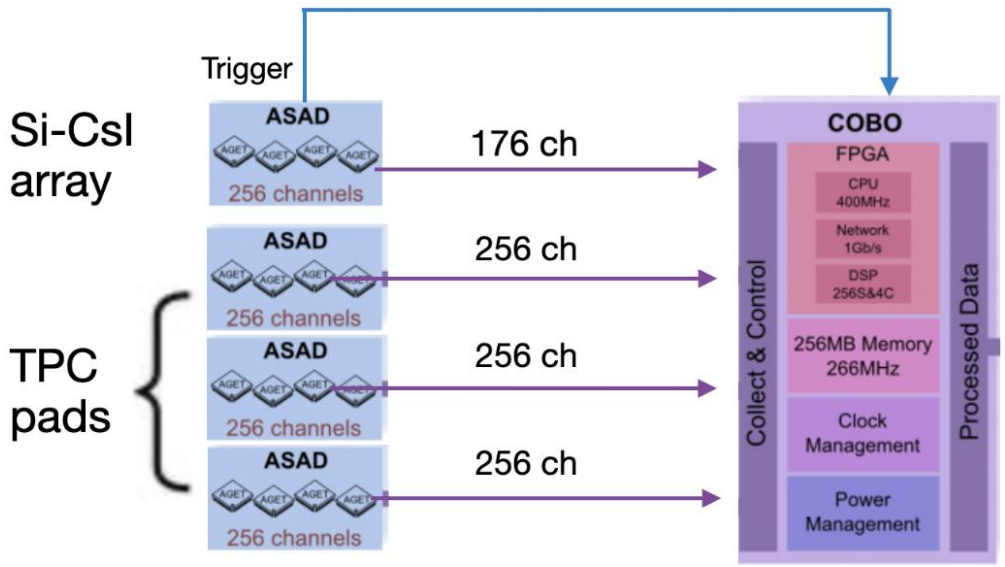
Introduction to our “TPC-Drum”

TPC-Drum



AT-TPC padplane



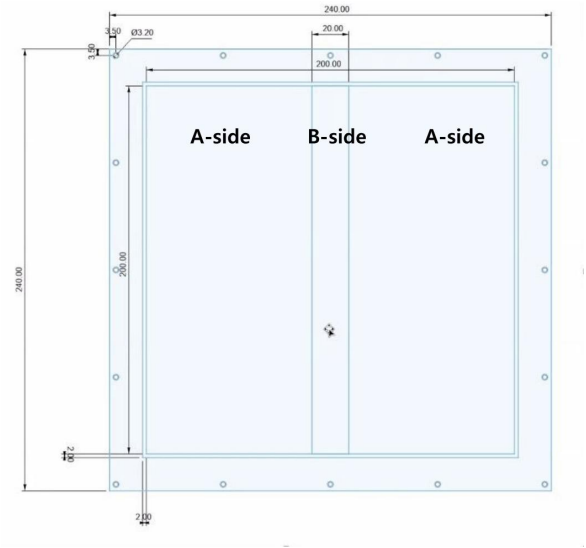


- ✓ Active target TPC with 768 channels
- ✓ He (90%) + CO2 (10%) 650, 760 Torr
- ✓ 8 Si-CsI array
- ✓ Triple GEM structure
- ✓ Using GET electronics (4AsAd + CoBo)
  - ✓ Easy data synchronization

- ✓ Energy will be measured using Si (thickness = 1*mm*)
  - ✓ Resolution for α is 40 – 50 *keV*
- ✓ Momentum vector will be determined by TPC part
  - ✓ A spatial resolution ~150 *μm* translates to an angular resolution of ~0.004 *mrad* (NIM A, 1066, 169610 (2024))
- ✓ By correlation of E (Si) and dE(TPC), α can be isolated from other nuclei

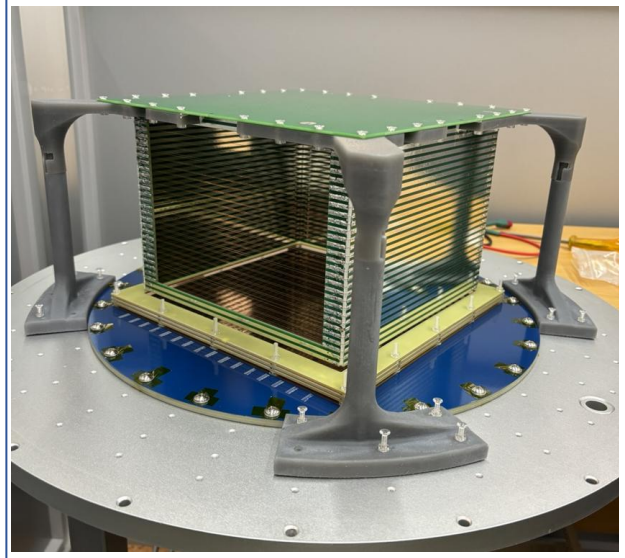
TPC-Drum

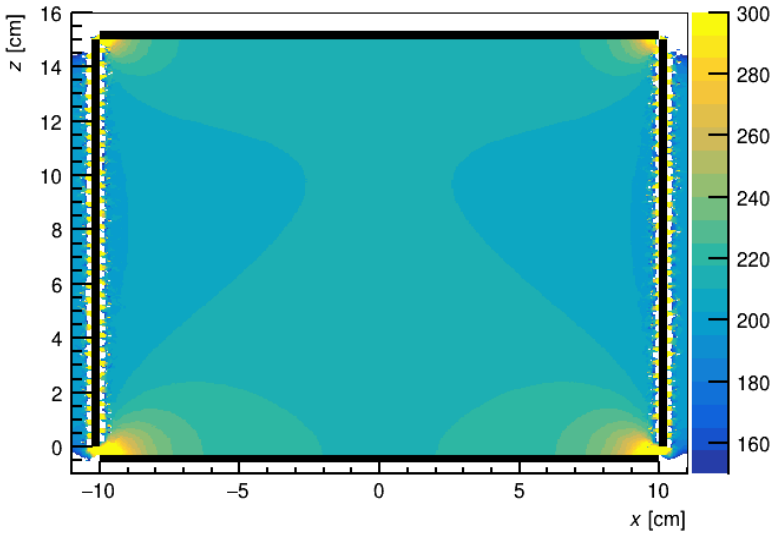
- **GEM**



- Active area : 200 x 200 mm²
- A-side : Standard gain area
- B-side : Relatively Low gain area

- **Field cage**

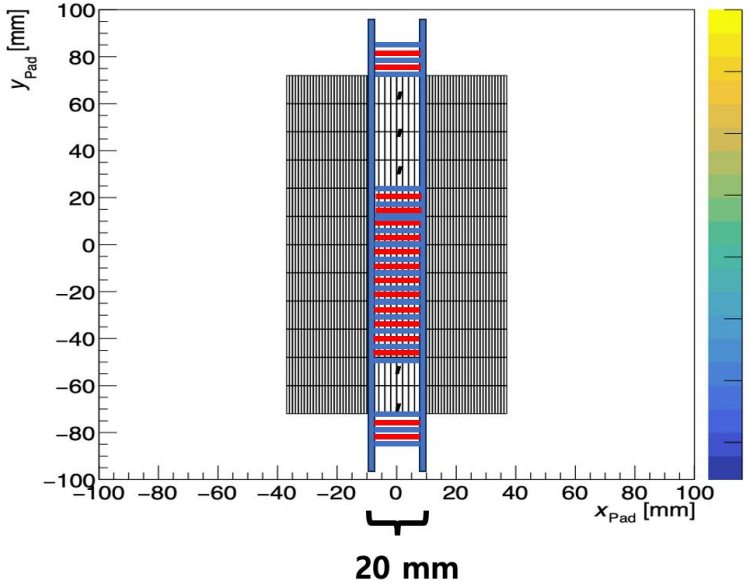


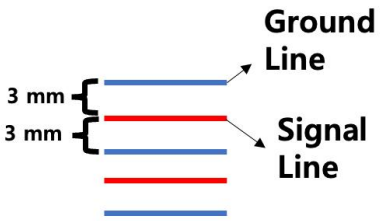


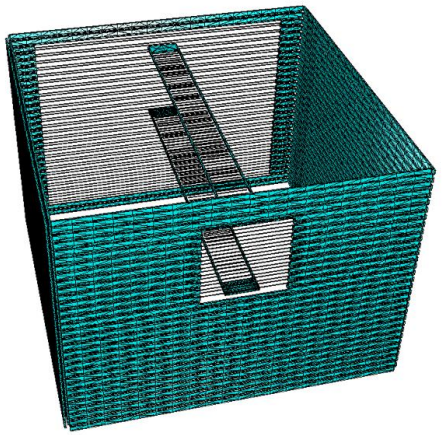
- Double-wired field cage on up- and down-stream
- Operating E field range is up to 250 V/cm
- E-field distortion area ~ 5%
- With drift velocity 1~2 cm/us

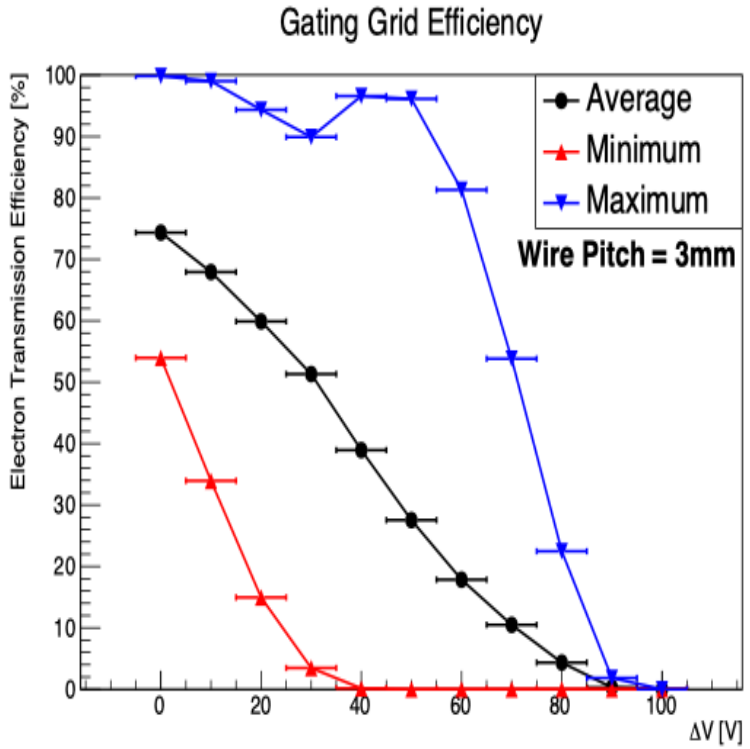
TPC-Drum

- **Gating grid**





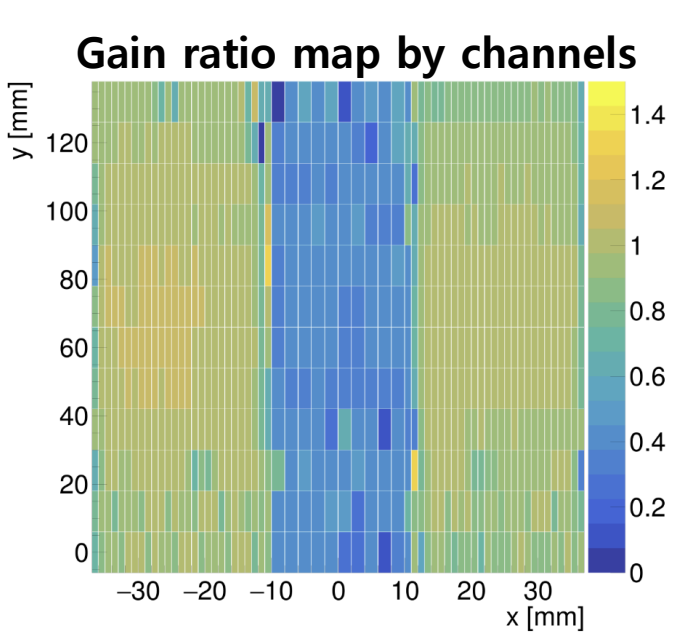


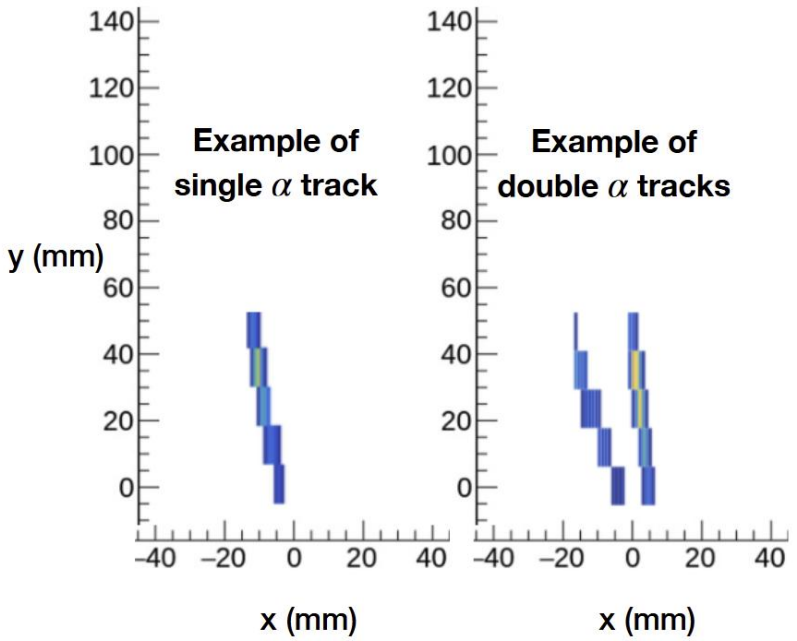


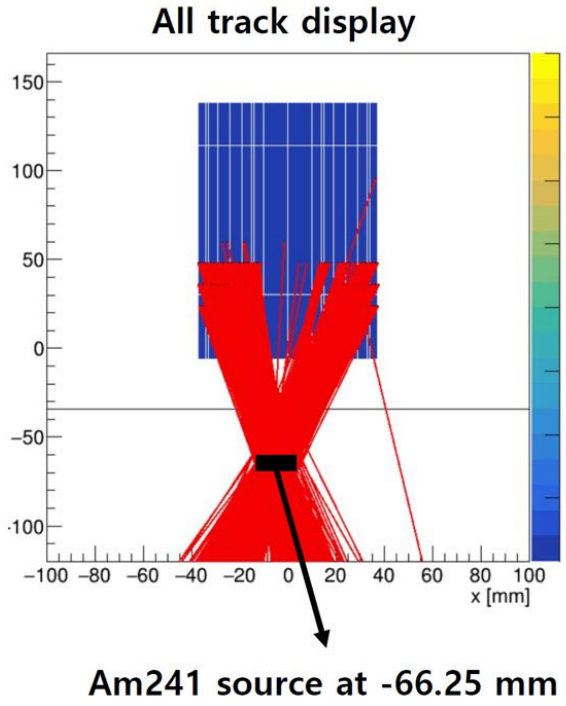
- **Gating grid were designed to reduce the space charge from ion-backflow effect in beam-line**
- **It can reduce electron clusters down to 10% level**
- **Low gain GEM + gating grid system is essential for higher beam intensity runs (> 10^5 pps)**

Commisioning results

Commissioning

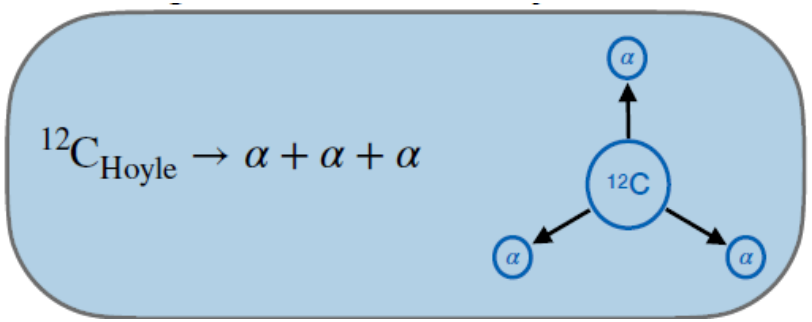


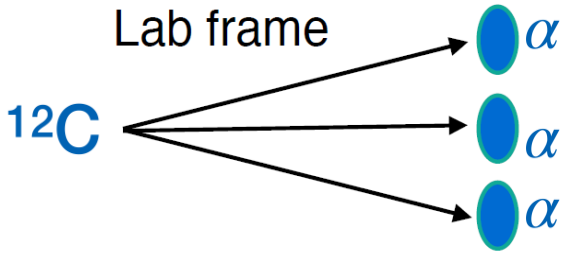




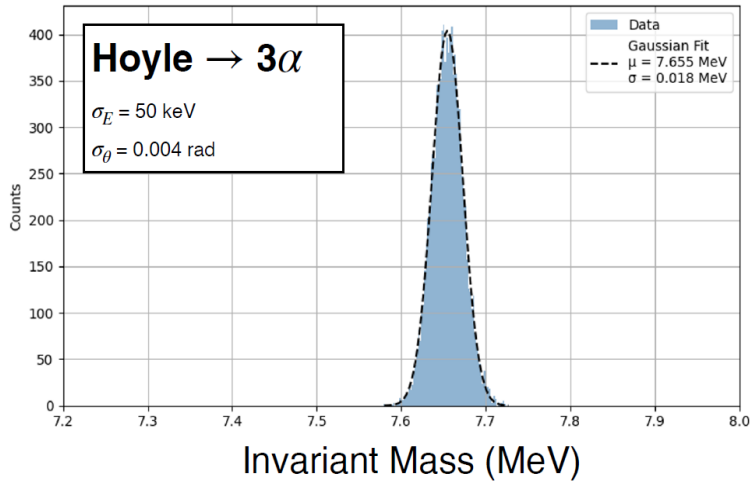
- GEM gain has been calibrated with Fe55 source
  - Calibration table prepared for position-dependent manner
- α track test with Am-241 source
- Average track length was 11.5cm, which was consistent with SRIM simulation result

Reconstruction of Hoyle state



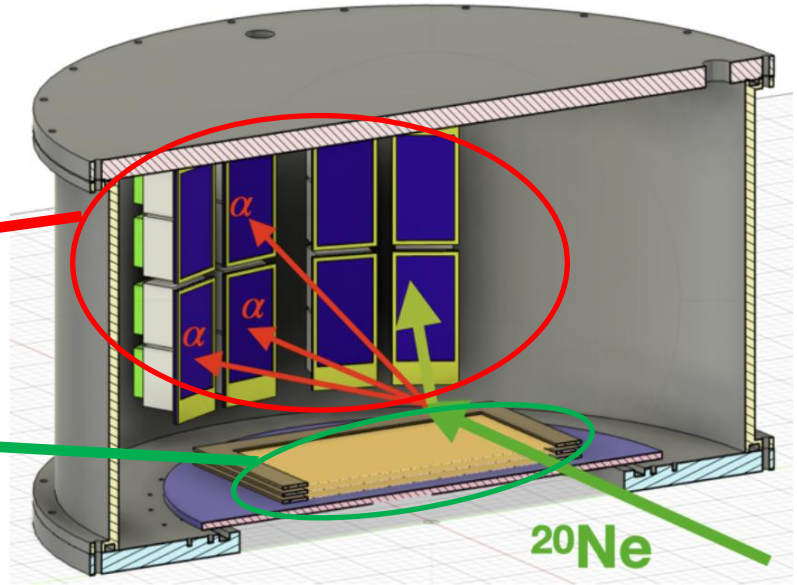


TPC-Drum (Toy MC simulation)



The 4-momentum of α particles is reconstructed by :

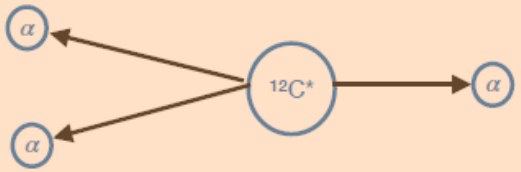
- **Si-CsI Array / Energy**
- **AT-TPC / $\vec{p}/|\vec{p}|$**
- **and α particle mass / $|\vec{p}|$**



Separation of signal to background

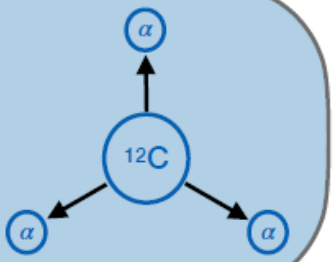
Background : Sequential decay

$^{12}C_{Hoyle} \rightarrow {}^{8}Be + \alpha \rightarrow \alpha + \alpha + \alpha$

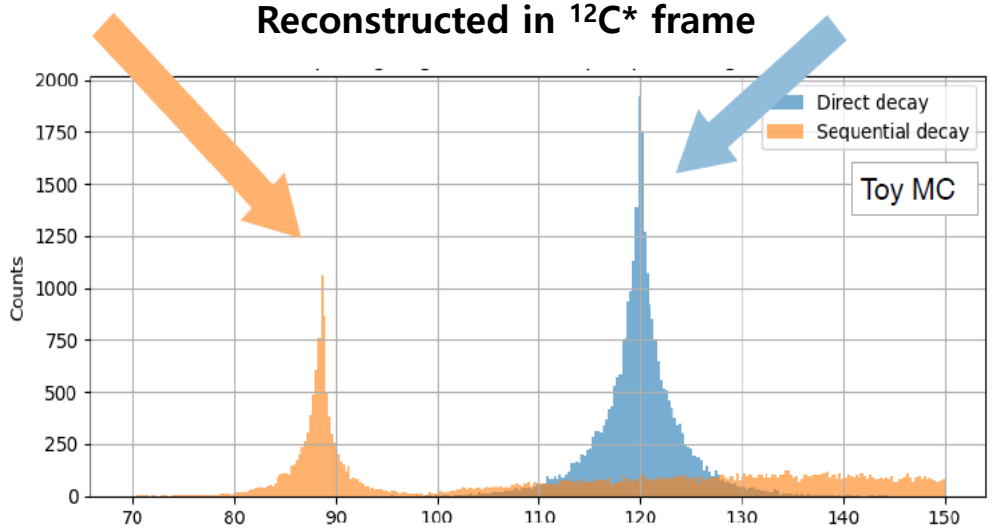


Signal : Direct decay

$^{12}C_{Hoyle} \rightarrow \alpha + \alpha + \alpha$



Reconstructed in $^{12}C^*$ frame



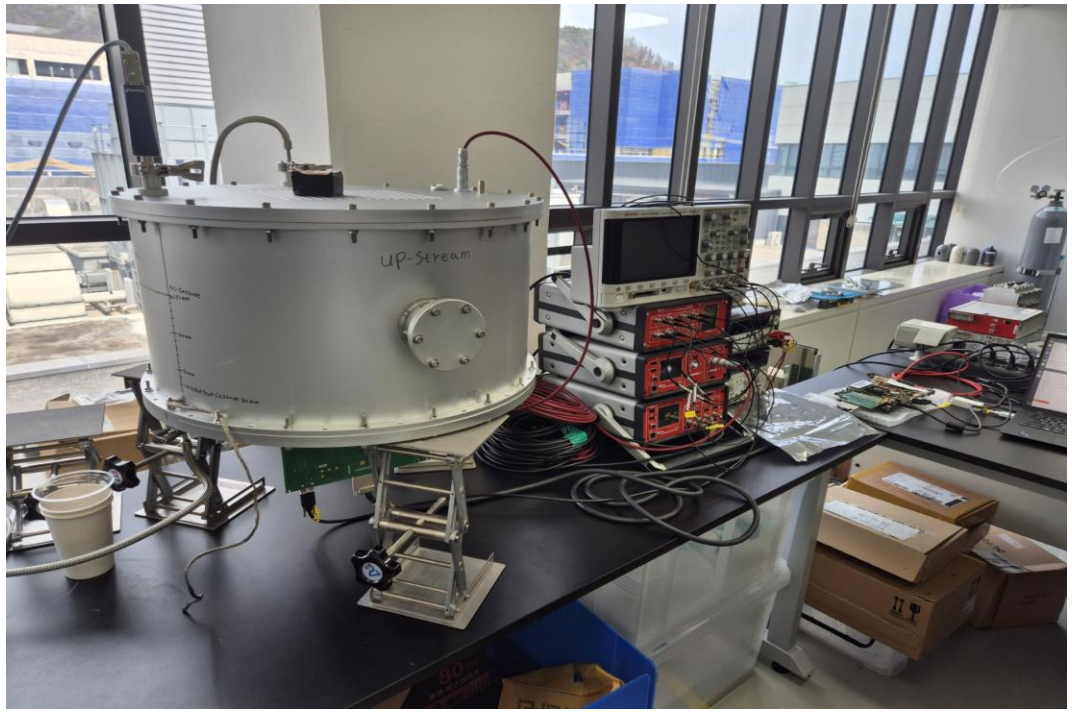
θ of all α pairs in COM frame [degree]

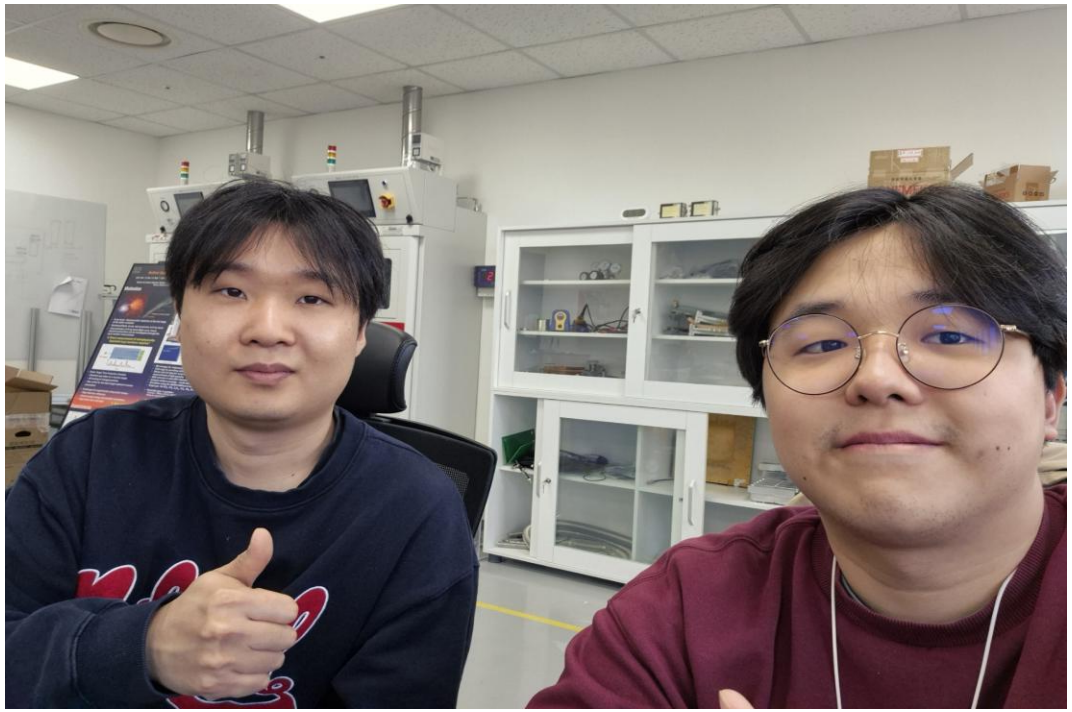
Caveat - signals and backgrounds are generated by same numbers (10k).

Summary

Summary

- ✓ With the goal of exploring exotic alpha-cluster structures, we aim to measure the direct decay of Hoyle states and the 4α decay of ^{16}O states, which are phenomena of increasing interest in the nuclear physics community.
- ✓ The beam time proposal was accepted at RAON with 5 days x 8 hours in this year (grade B)
- ✓ The TPC-Drum is working very well and is ready for the experiment at RAON.



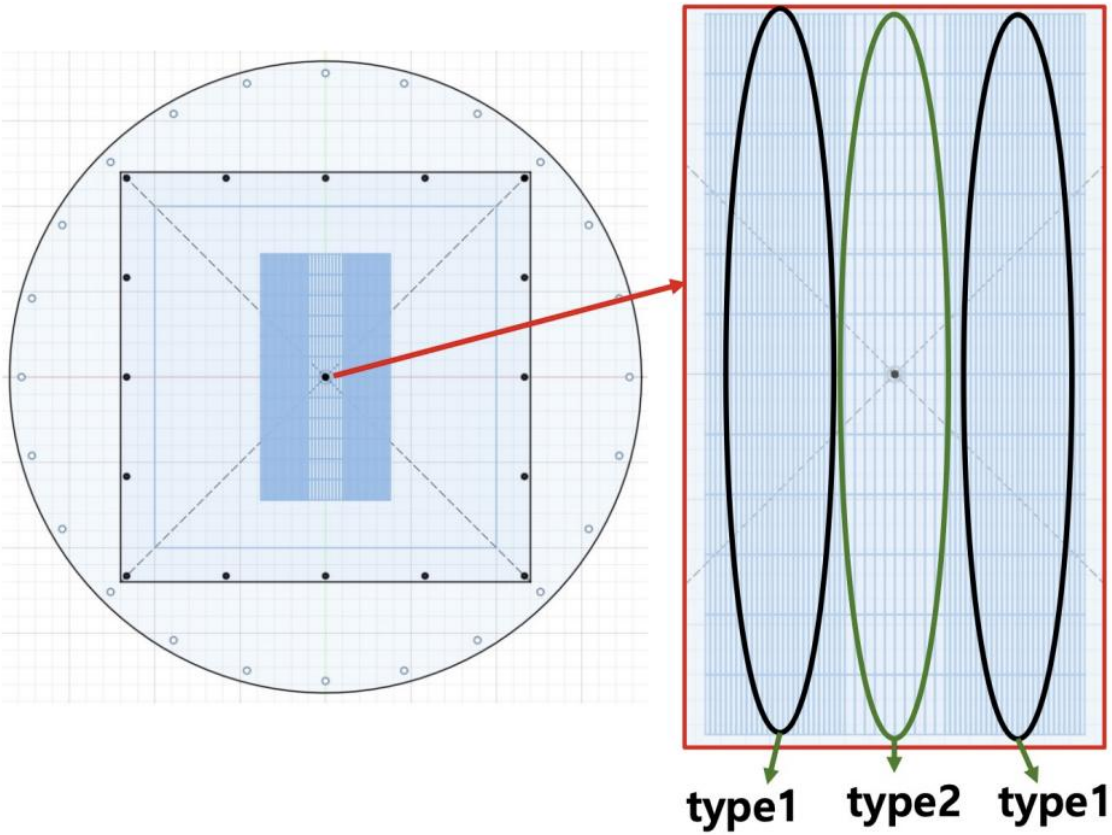


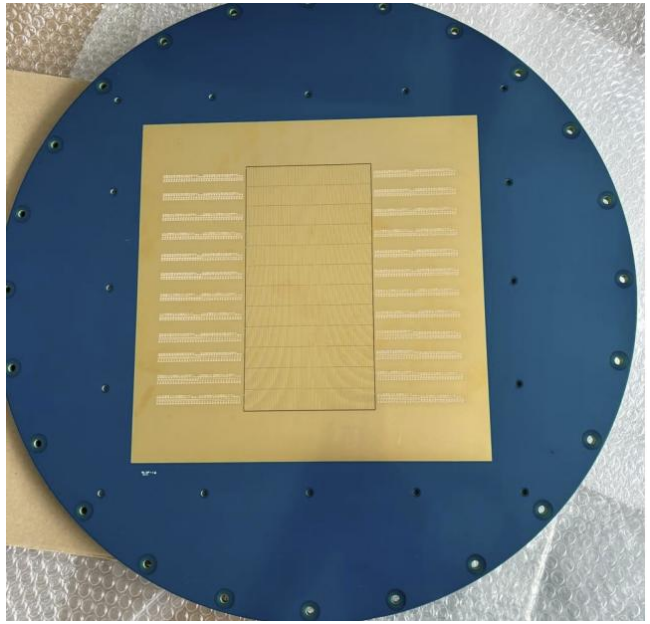
Thanks!

Backup slide

Read-out pad plane

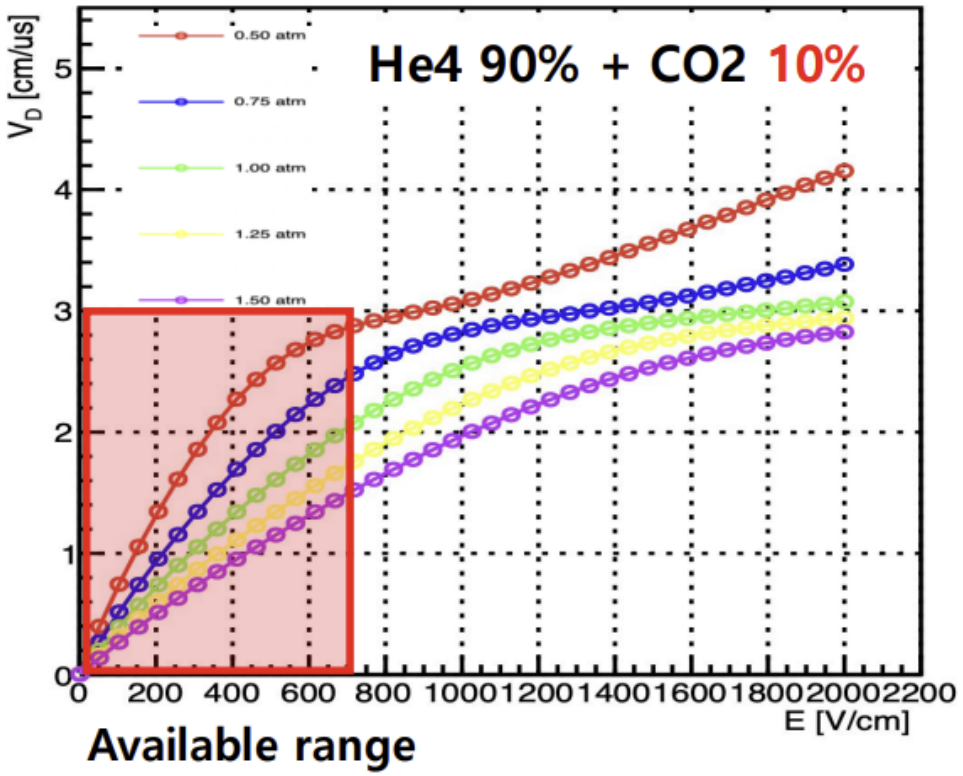
Read-out pad plane

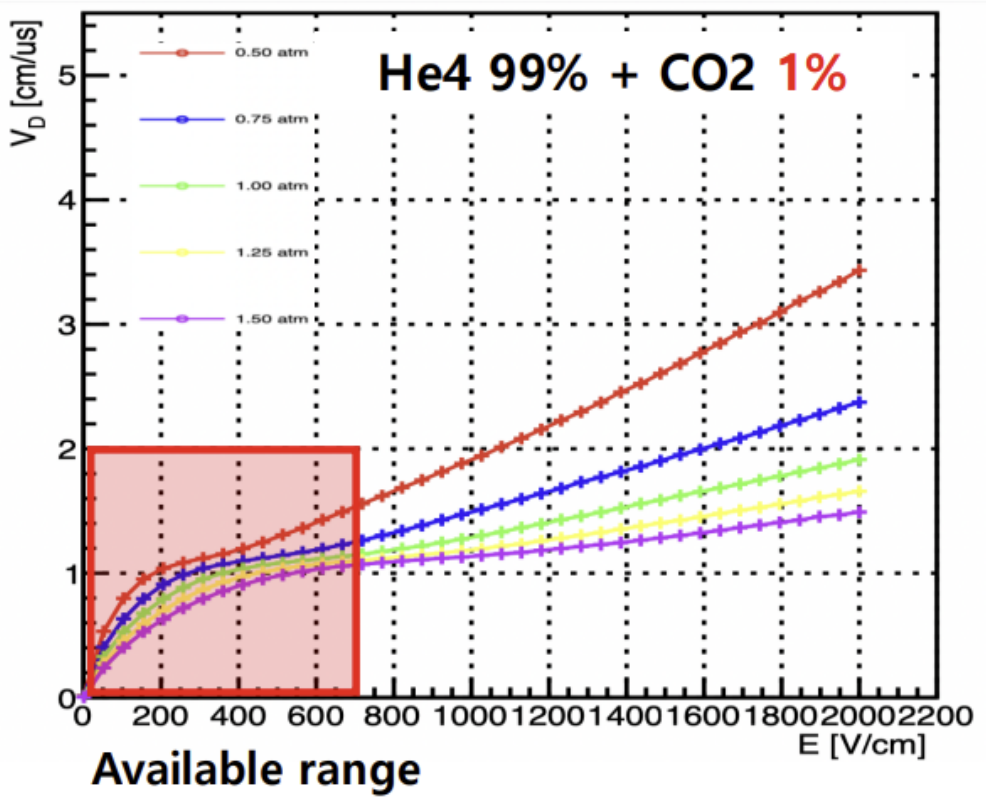




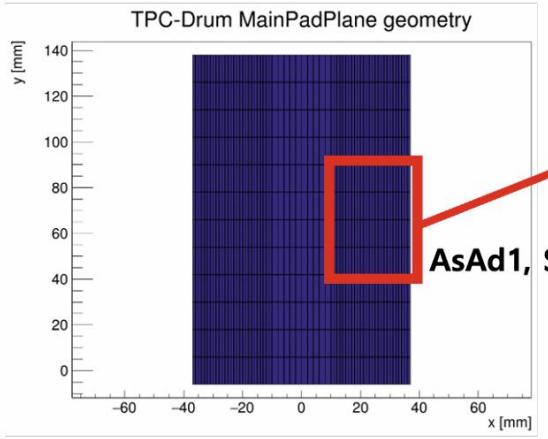
- # of channel : 768 channels
- Channel size
  - Type 1 : 0.9 * 11.9 mm^2
  - Type 2 : 1.9 * 11.9 mm^2
  - Gap size : 0.1 mm
- Pad plane considered to measure daughter particles

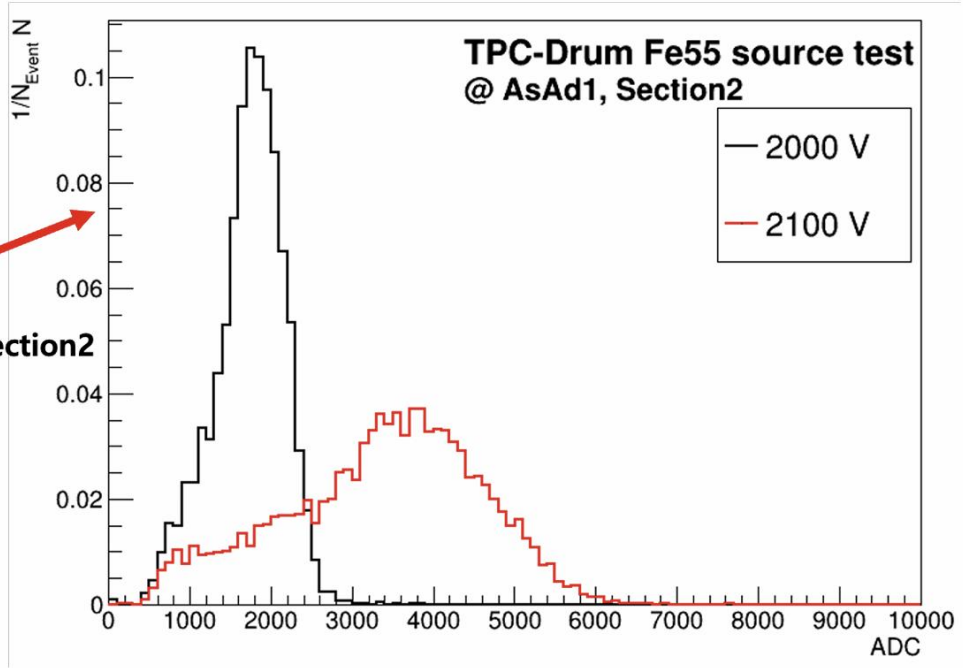
Drift Velocity in Drift area

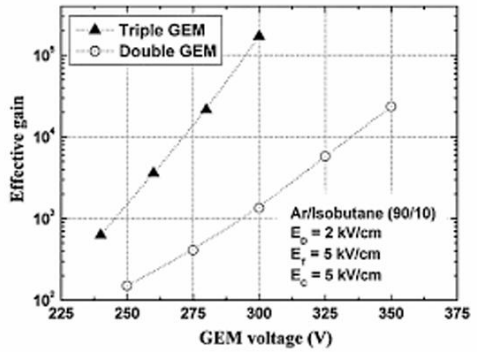




Triple GEM

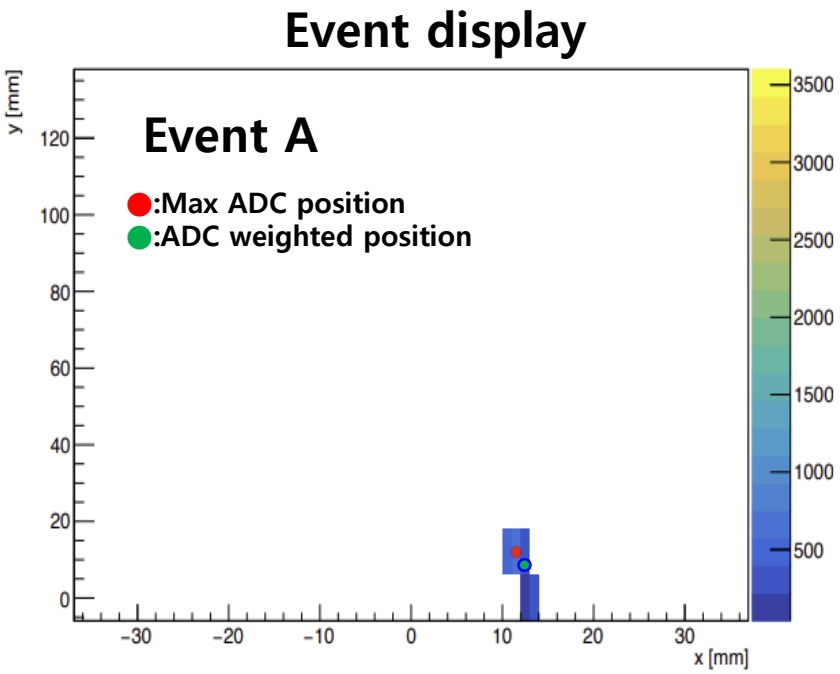

TPC-Drum MainPadPlane geometry
y [mm]
x [mm]
AsAd1, Section2

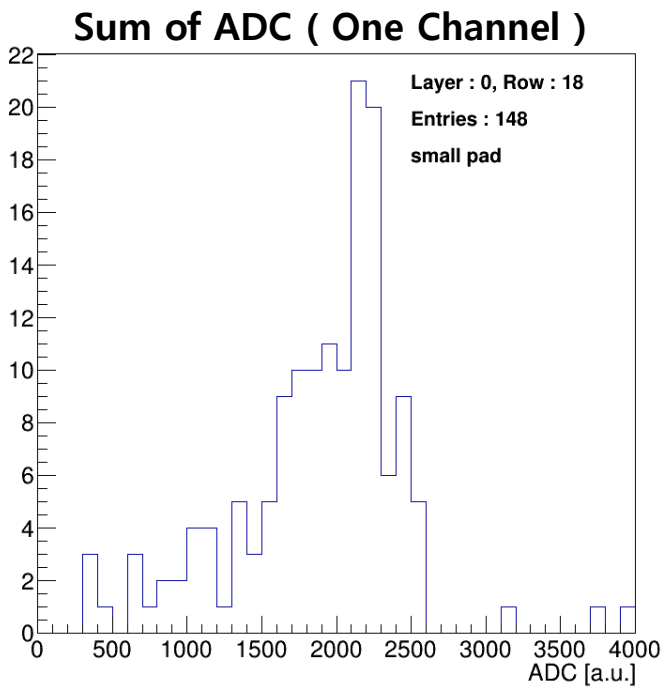

TPC-Drum Fe55 source test
@ AsAd1, Section2
2000 V
2100 V
1/N_Event N
ADC

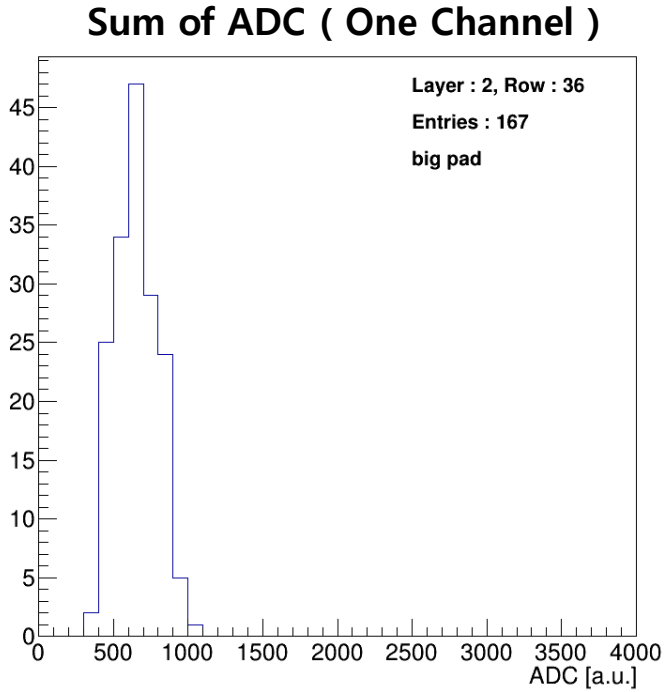

Triple GEM
Double GEM
Effective gain
GEM voltage (V)
Ar/Isobutane (90/10)
E_d = 2 kV/cm
E_t = 5 kV/cm
E_c = 5 kV/cm

Calibrations

- ^{55}Fe source test





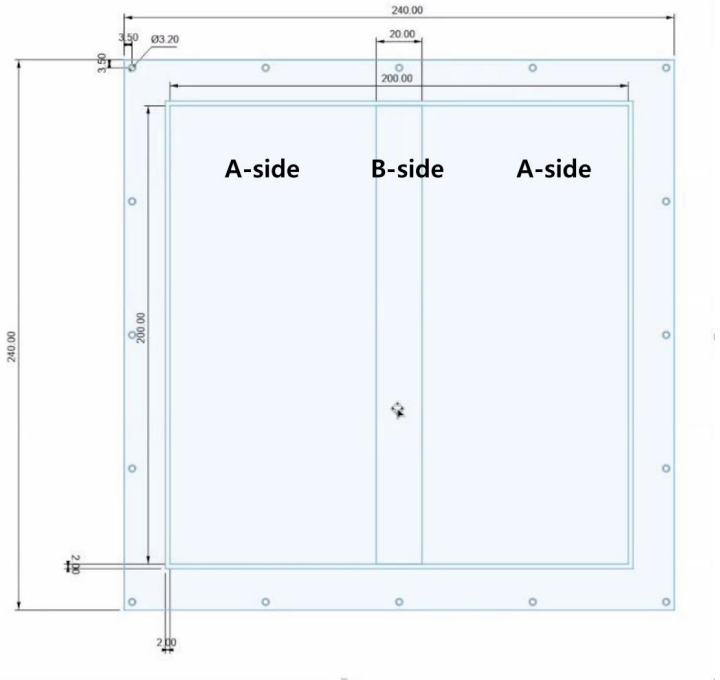


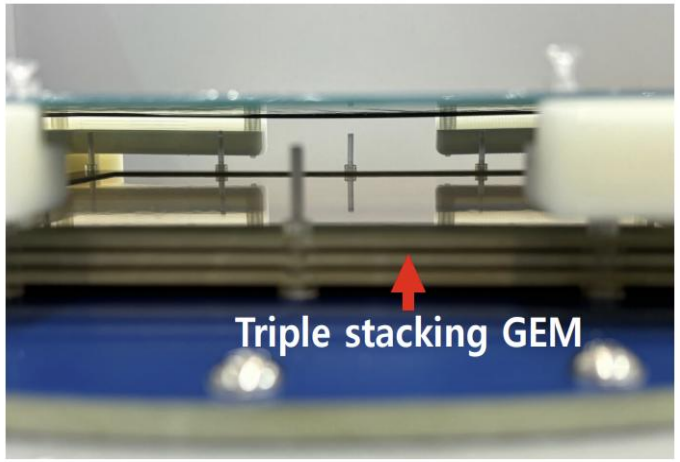
- To get a histogram of each channel, ADC weighted position is measured

GEM

TPC-Drum

- GEM



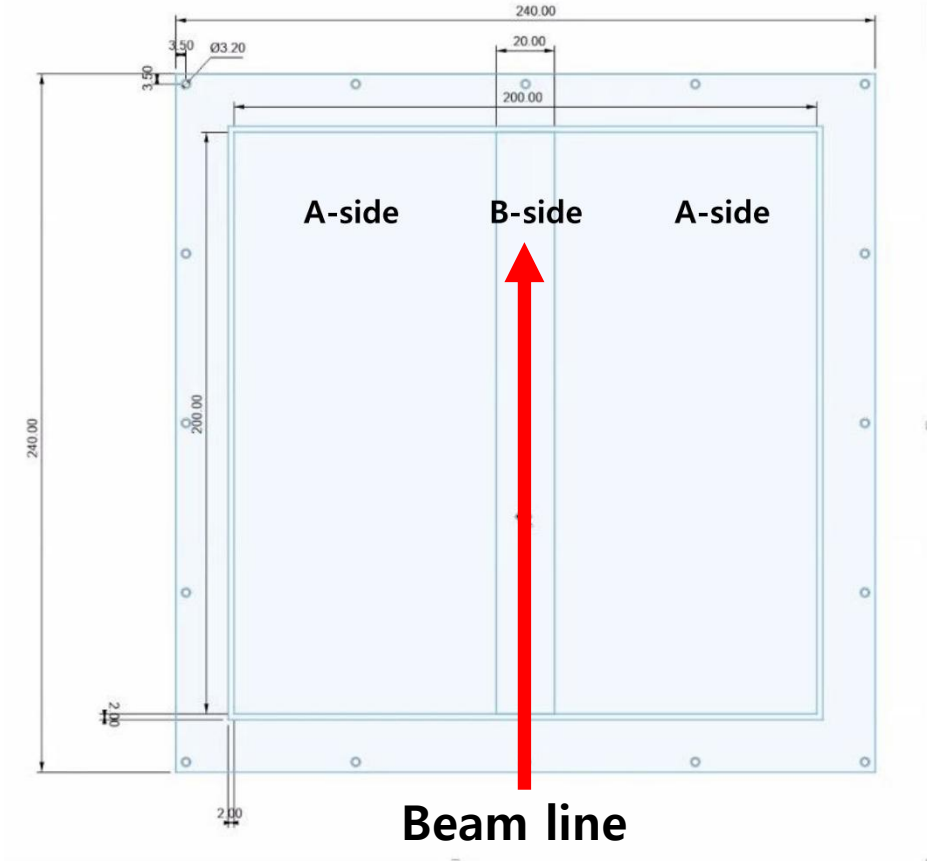


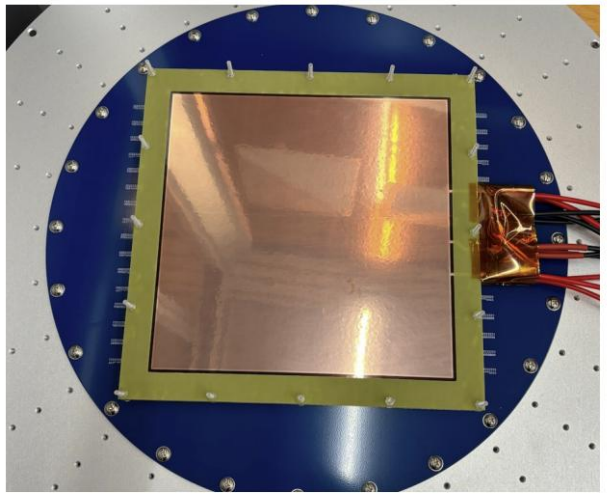
- Active area : 200 x 200 mm^2
- A-side : Standard gain area
- B-side : low gain area (Type-2 GEM)

- Triple stacking GEM used with type-1 and type-2 GEM with space 3mm

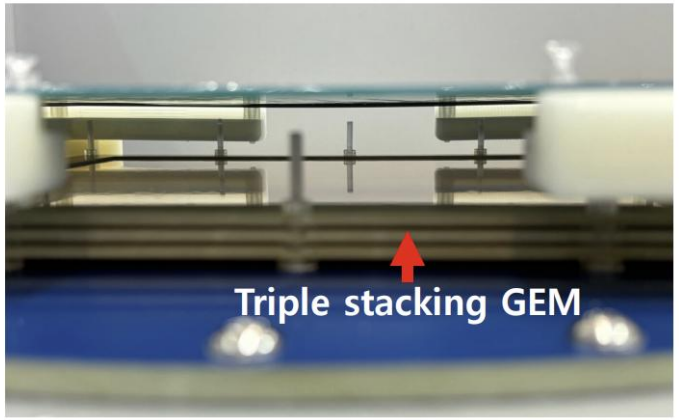
GEM

- Geometry





Top view



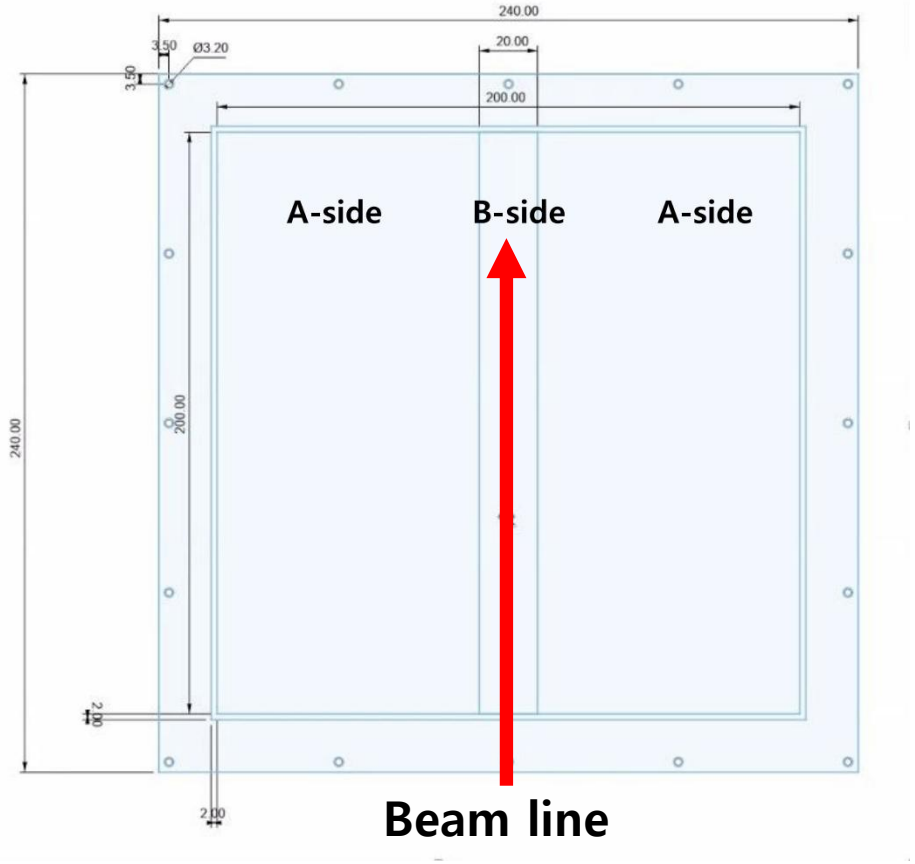
Front view

- Active area : 200 x 200 mm^2
- A-side : Standard gain area
- B-side : low gain area (Type-2 GEM)

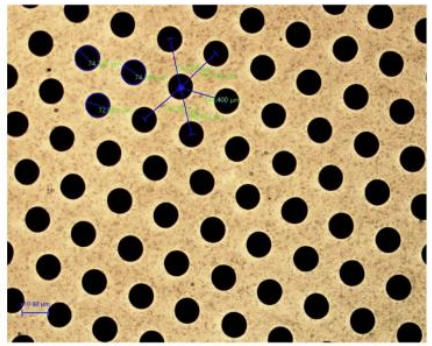
- Triple stacking GEM used with type-1 and type-2 GEM with space 3mm

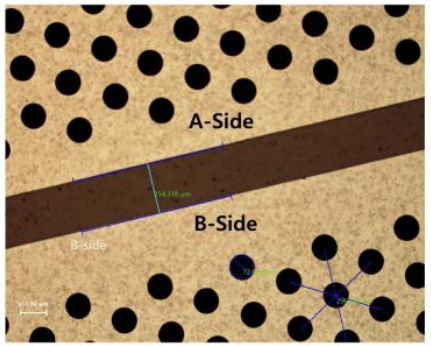
GEM

<Type – 1 >



- GEM thickness : 256 um
- Hole size (diameter) : ~ 75 um

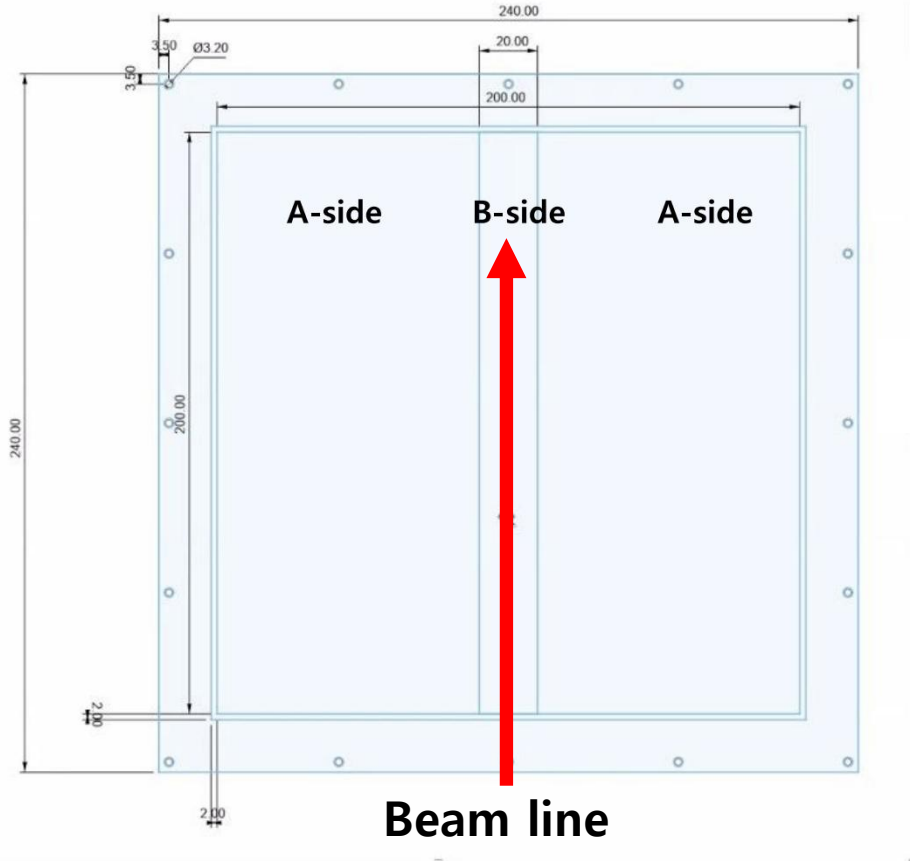




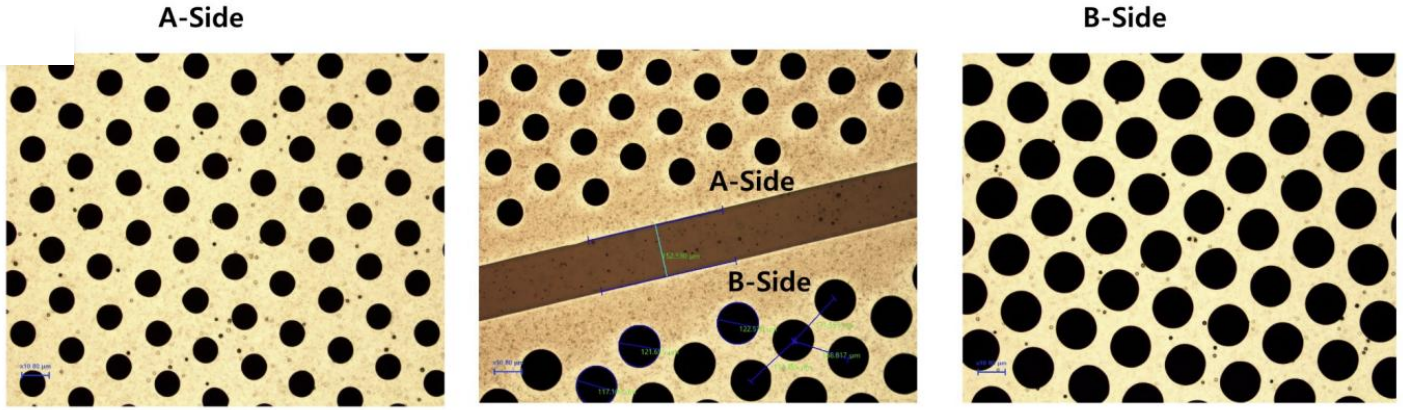
- A-side and B-side have same size

GEM

<Type – 2 >



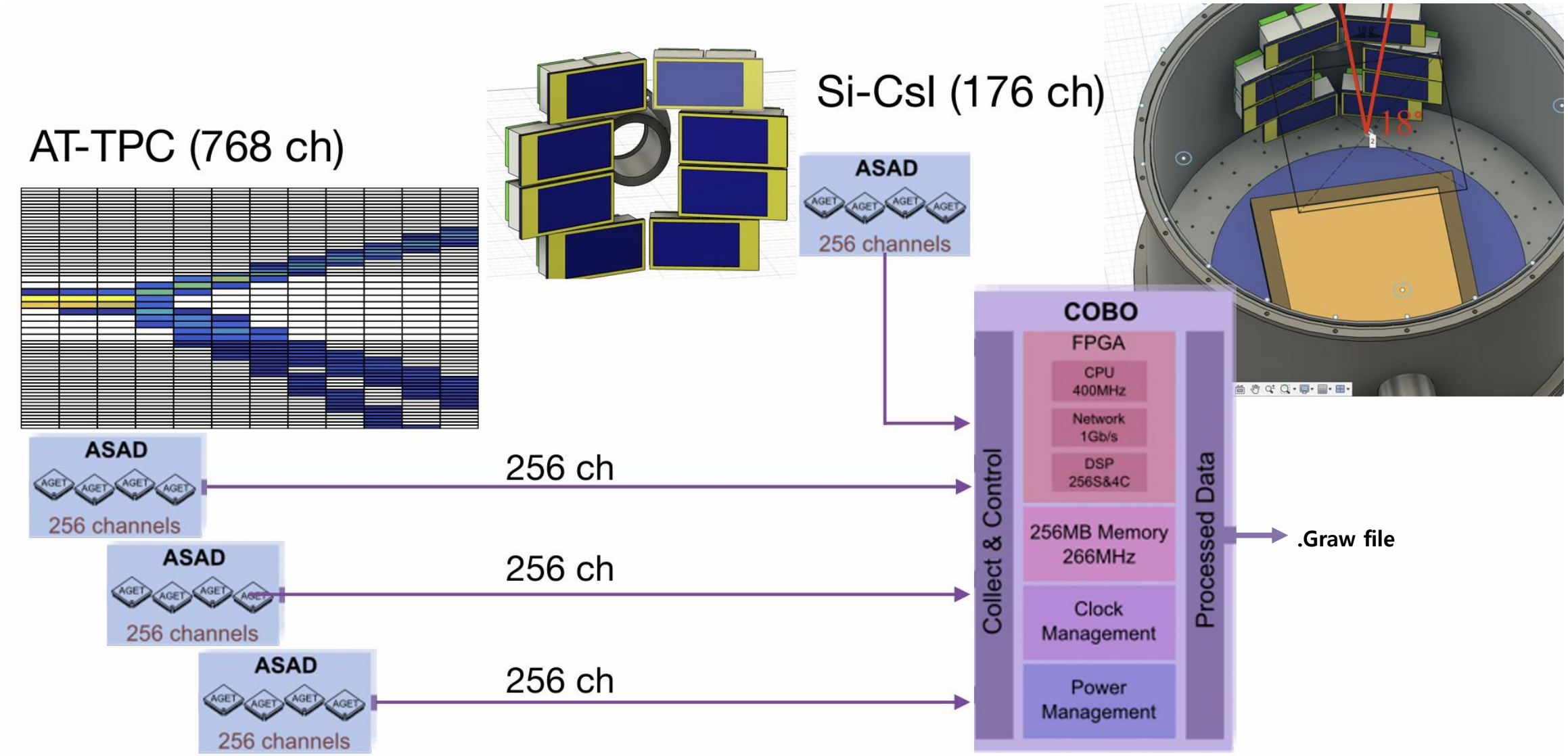
- GEM thickness : 256 um
- Hole size (diameter)
  - A-side : ~ 75 um
  - B-size : ~ 120 um



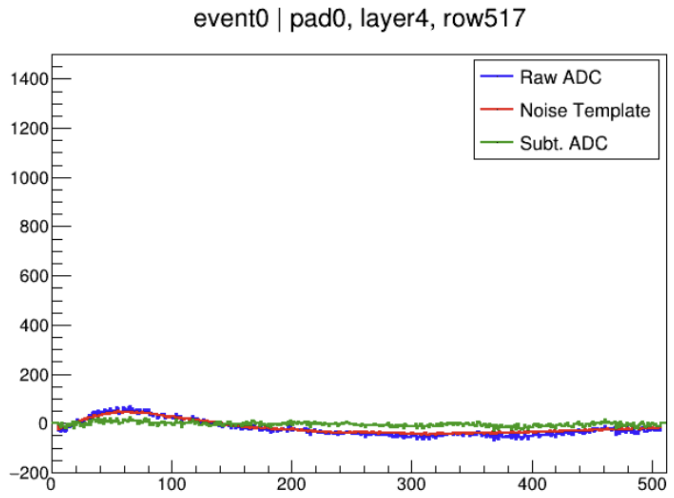
- Type-2 GEM designed to reduce the space charge for high-rate beam ion

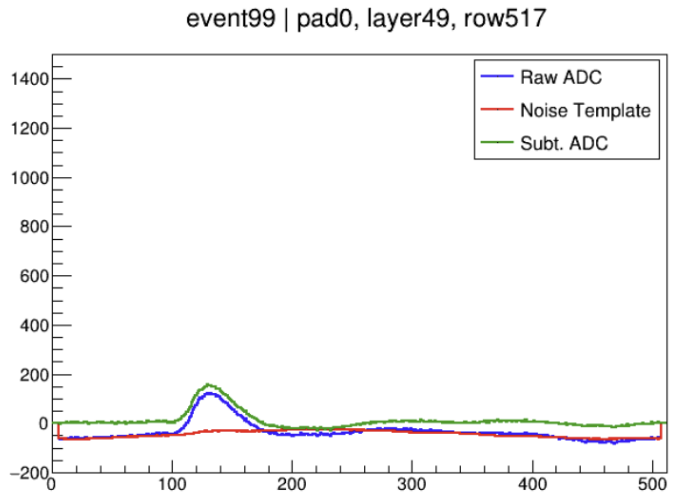
Noise subtraction

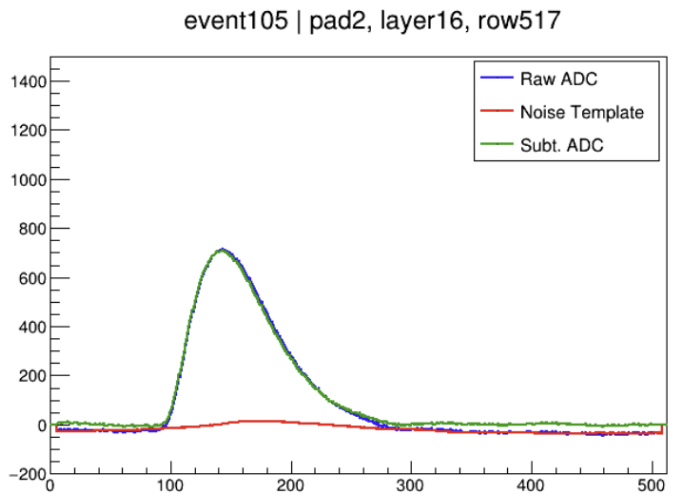
DAQ Setup

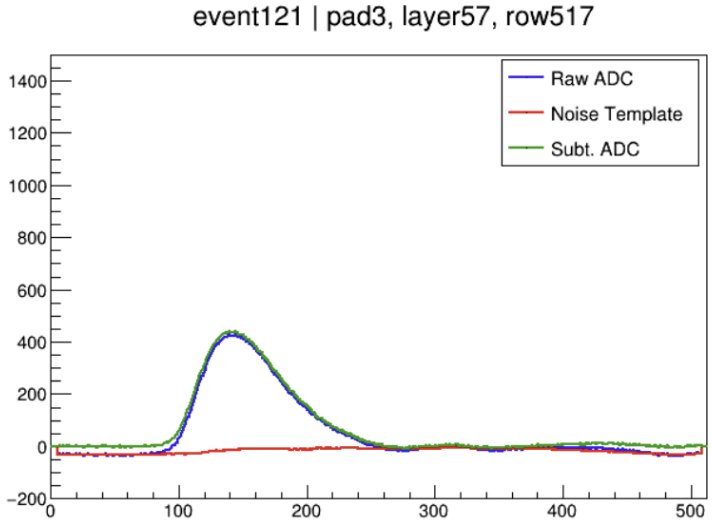

AT-TPC (768 ch)
Si-CsI (176 ch)
18°
ASAD
AGET
256 channels
256 ch
256 ch
256 ch
COBO
FPGA
CPU
400MHz
Network
1Gb/s
DSP
256S&4C
256MB Memory
266MHz
Clock
Management
Power
Management
Collect & Control
Processed Data
.Graw file

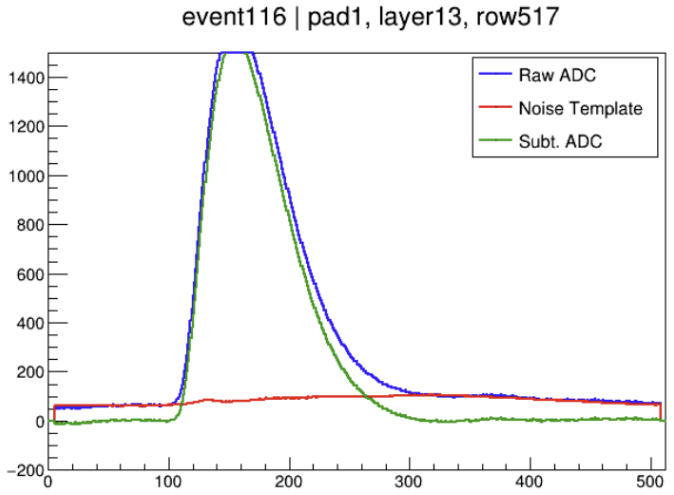
Pulse noise subtraction

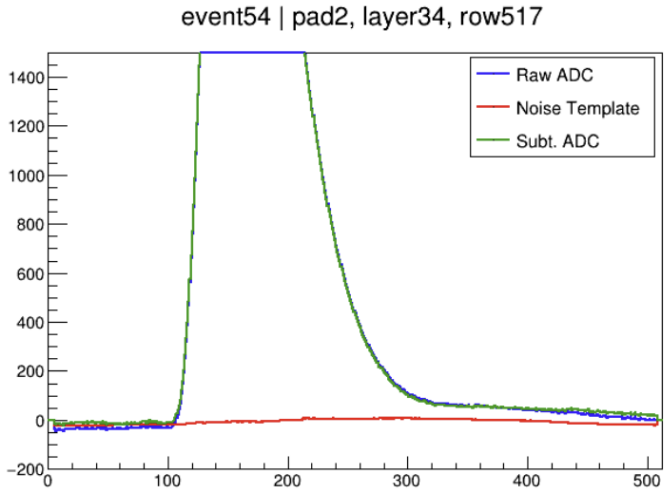








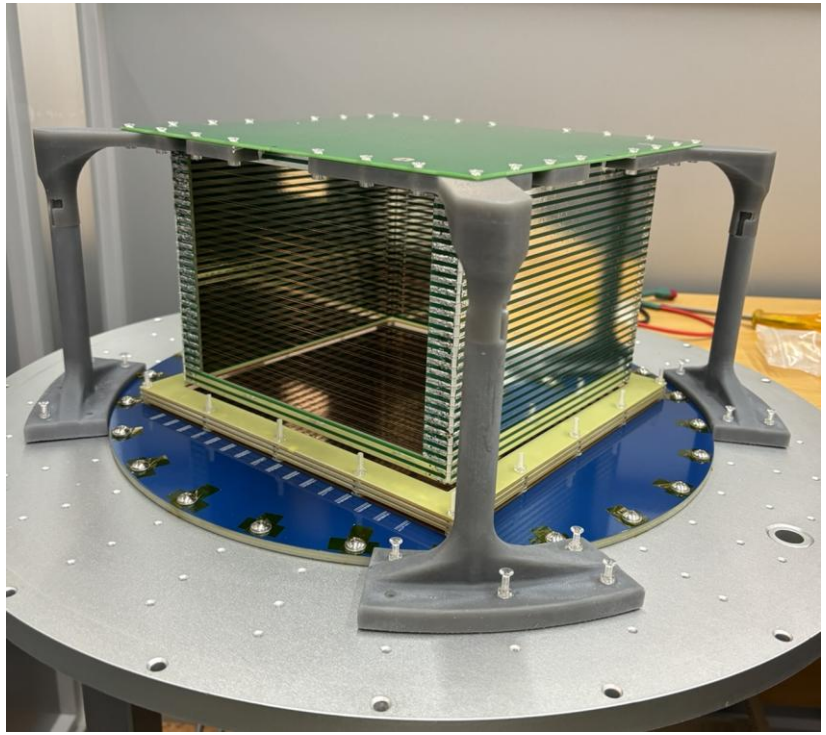




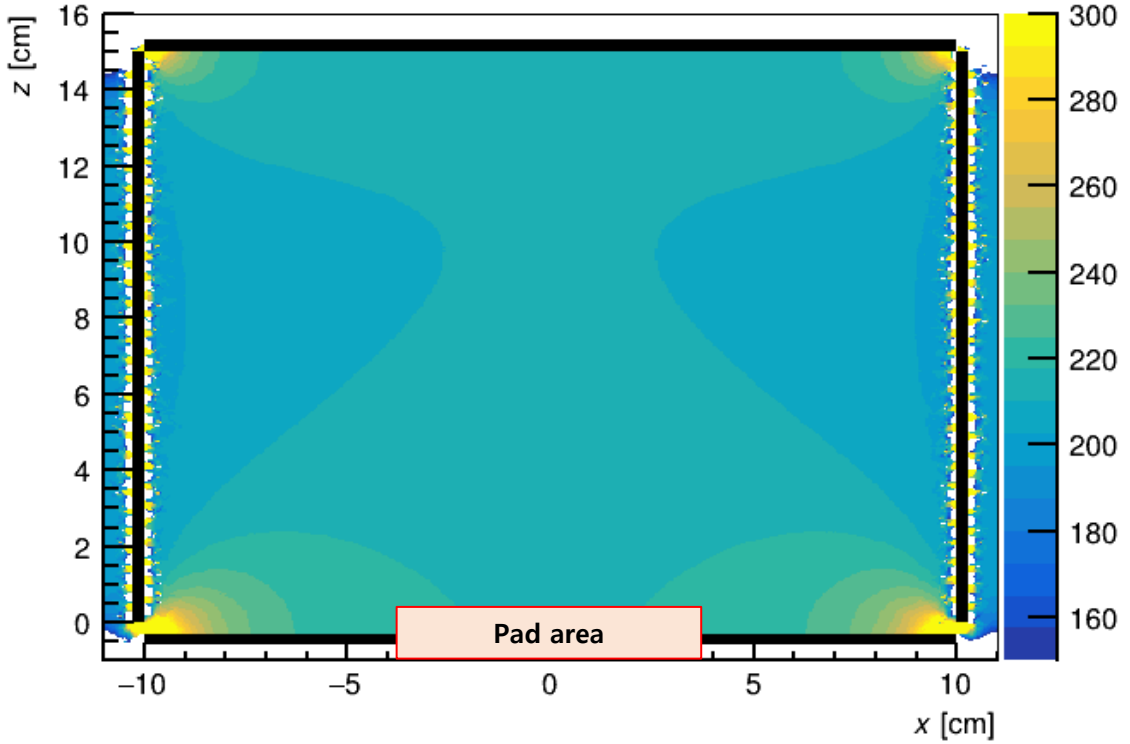
Field cage

TPC-Drum

- **Field cage**



Garfield++ simulation



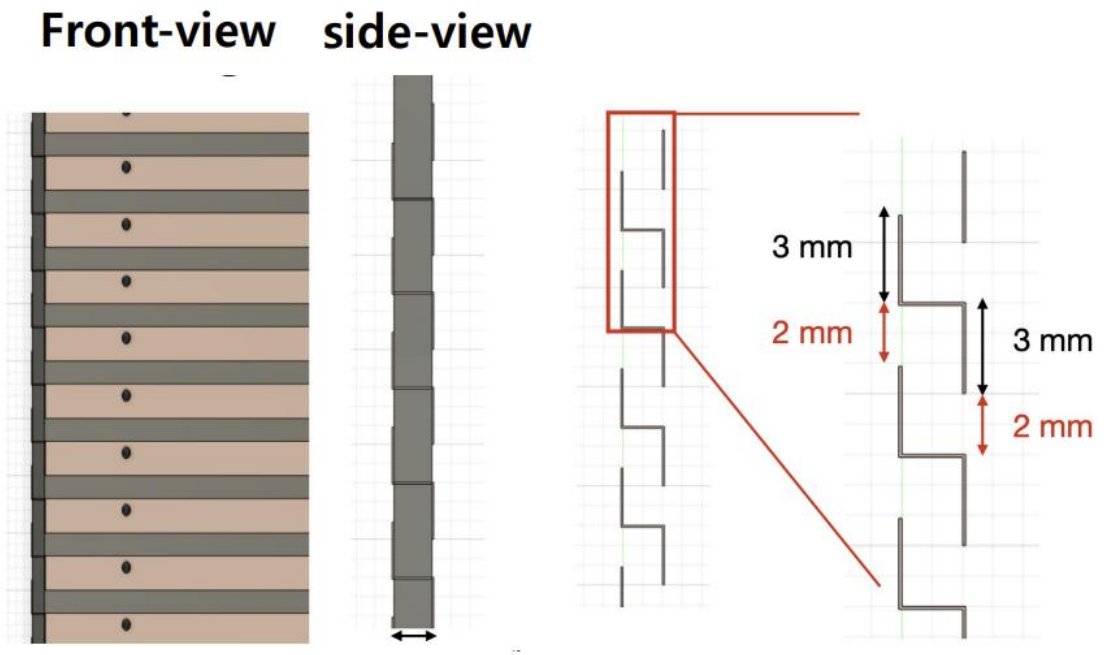
- **We constructed the field cage by referring to the design of the STAR TPC.**
- **Operating E field range is up to 250 V/cm**

Field cage

- **Schematic view**

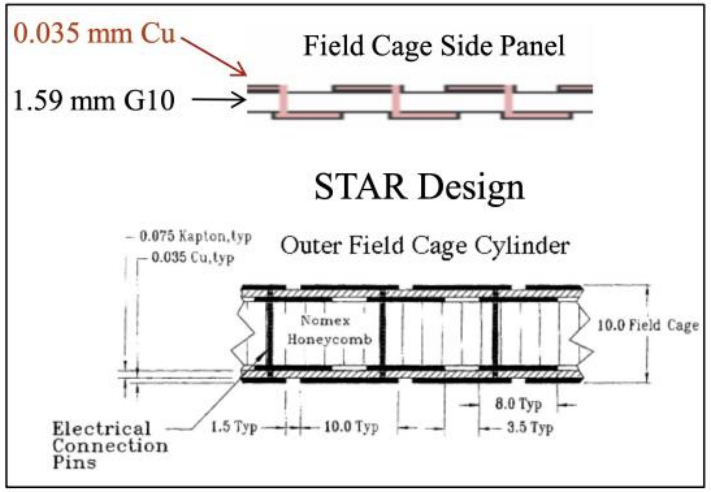
#Electrode layer : 30

#Layer spacing : 5 mm



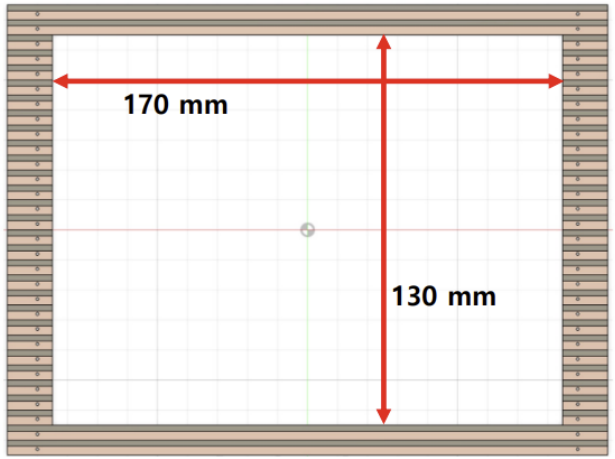
- **Field-cage reference**

(Sprit TPC and STAR TPC)

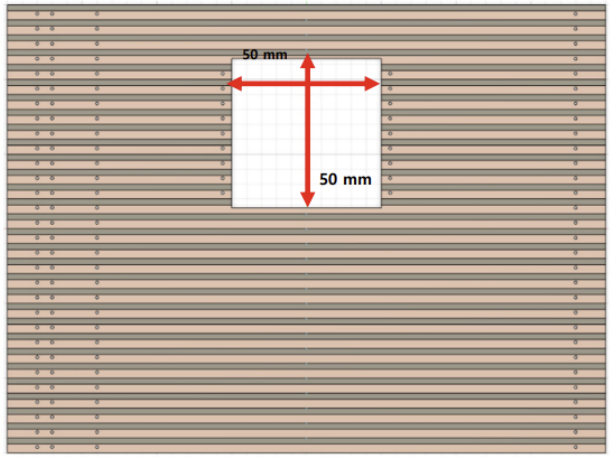


Field cage

- Schematic view



Down-stream plane



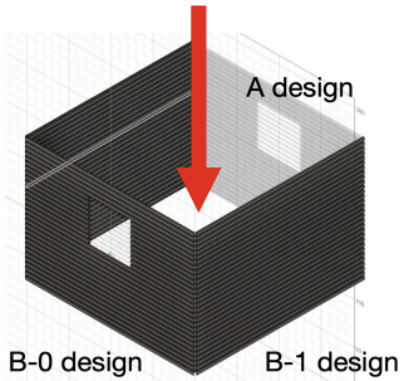
Up-stream plane

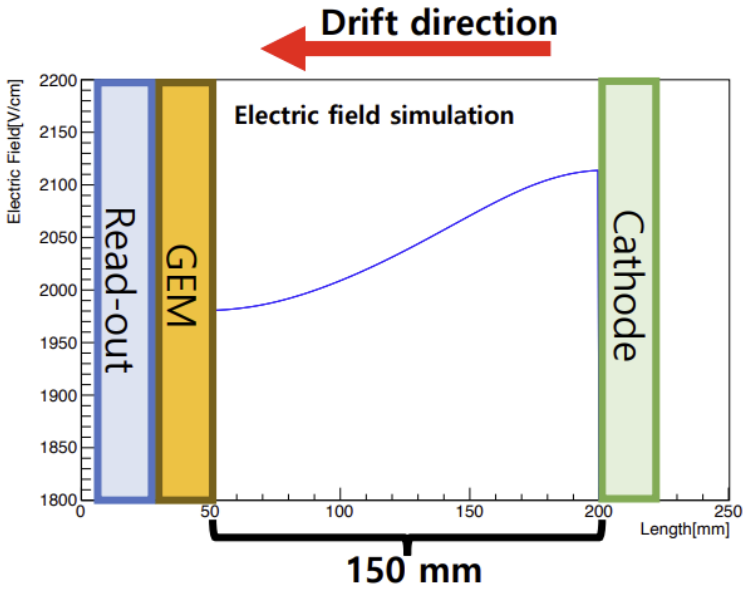
Down stream view

- Empty area has a double-wire structure to avoid particle energy loss and scattering

Field cage

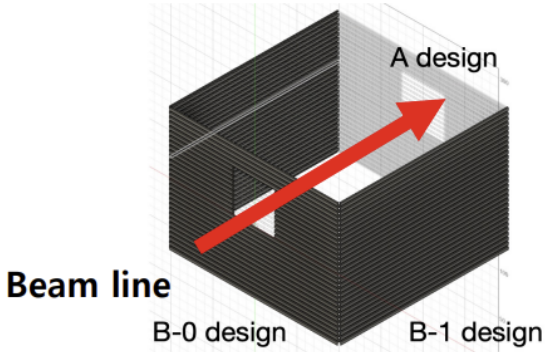
- **Electric Field**

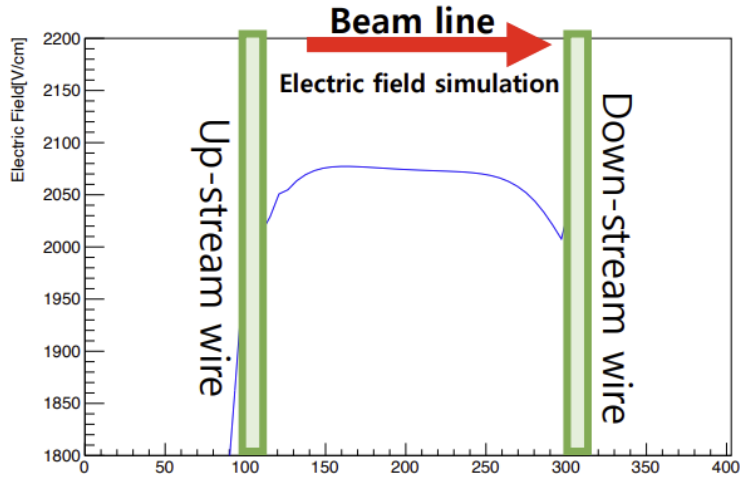




Longitudinal Electric field

6.3% Distortion





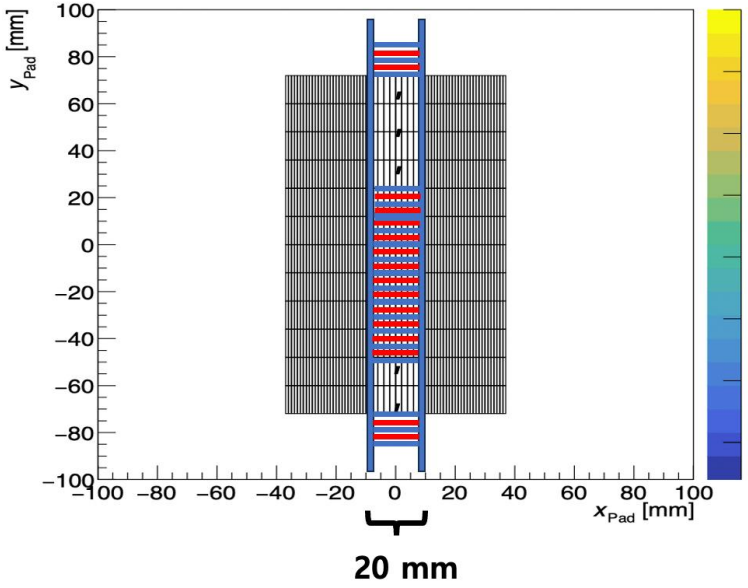
Beam-line Electric field

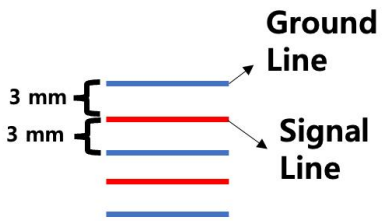
4% Distortion

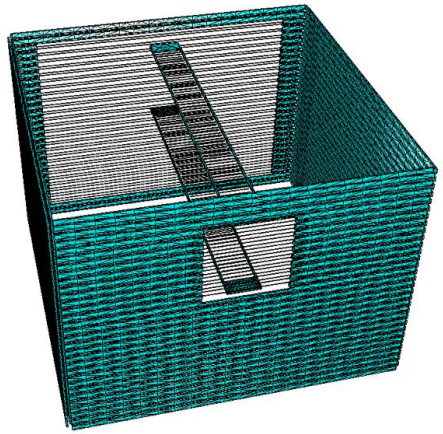
Gating grid

TPC-Drum

- **Gating grid**



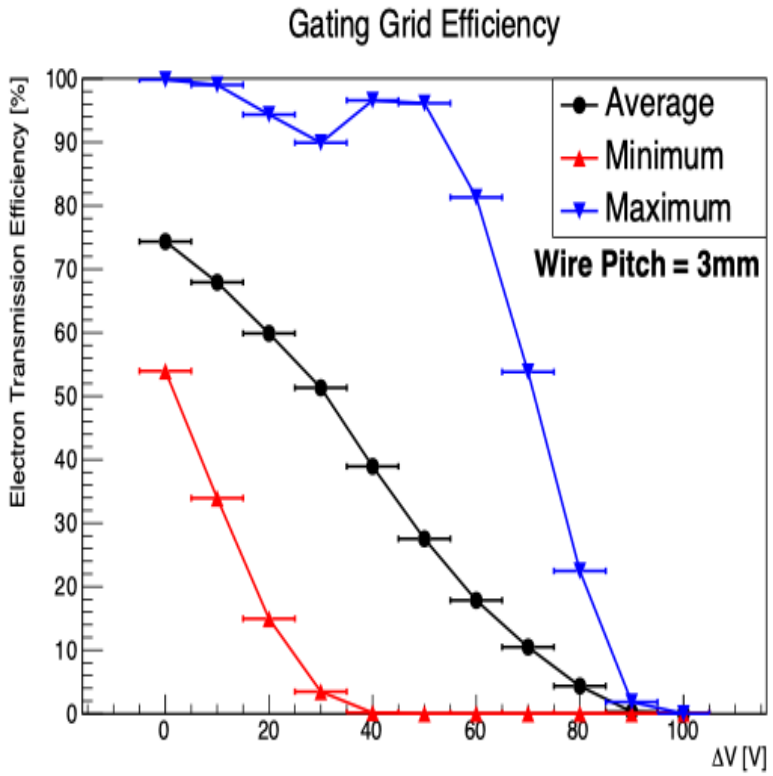




Wire distance : 3 mm

Gating grid with : 20 mm

Signal-Ground wire Voltage difference : 30~100V (not determined yet)



- **Considering beam intensity, voltage of gating grid will be determined**

Title of Experiment	Search for Rare α-Cluster Structures Using an AT-TPC		
Application Area	☒Nuclear Physics ☐Energy ☐Medicine ☐Industry ☐Environment ☐Other Applications		
Experimental Devices	☒KoBRA ☐MRTOF ☐CLaSsy ☐Cyclotron ☐Others		
Beam Time Unit*	☐ 1 BTU ☐ 2 BTU ☒ ___10 BTU____		
Beam Request	Beam	Energy (MeV/u)	Intensity (pnA / pps)
	^{20}Ne	6 – 10 MeV/u	10^5 pps

* 1 BTU = 8 hours

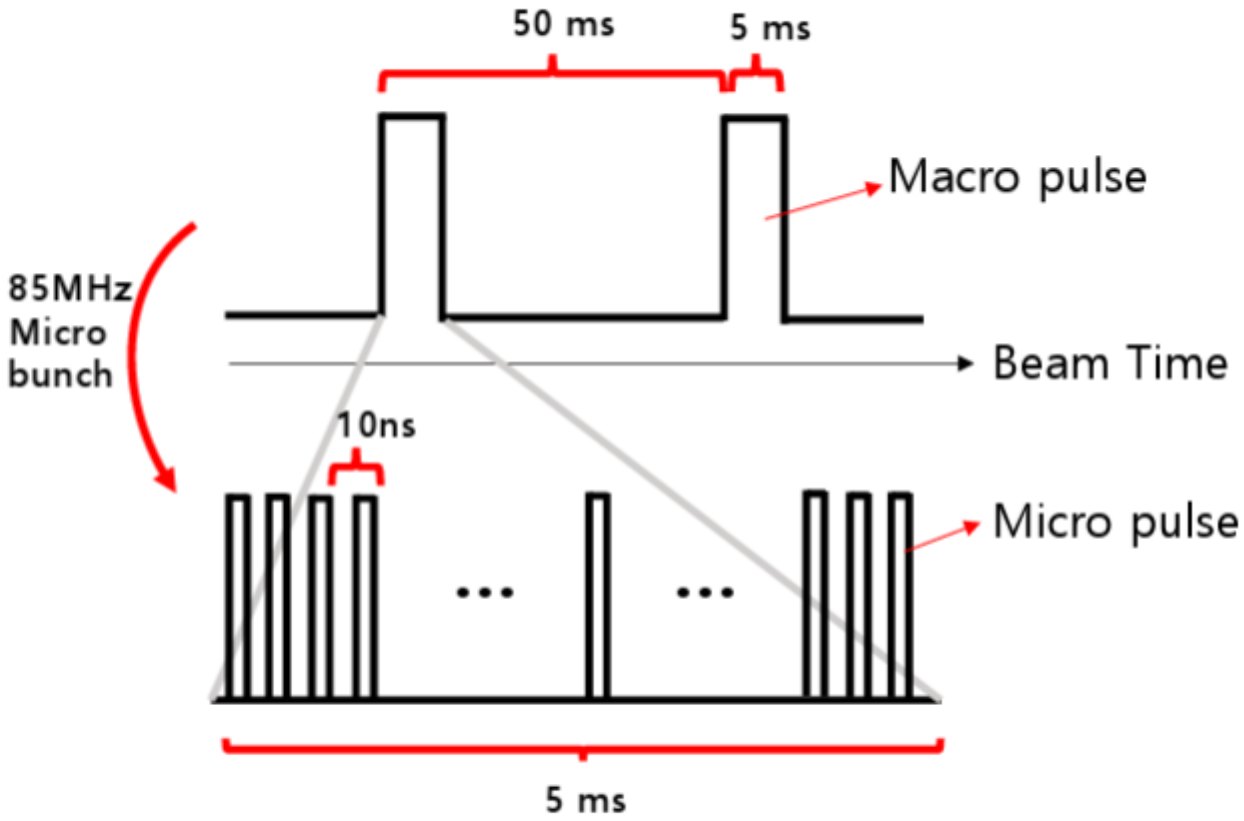
Macro pulse per 1s = 20

Micro pulse in Macro pulse = 5×10^5

10^5 pps = particle per second

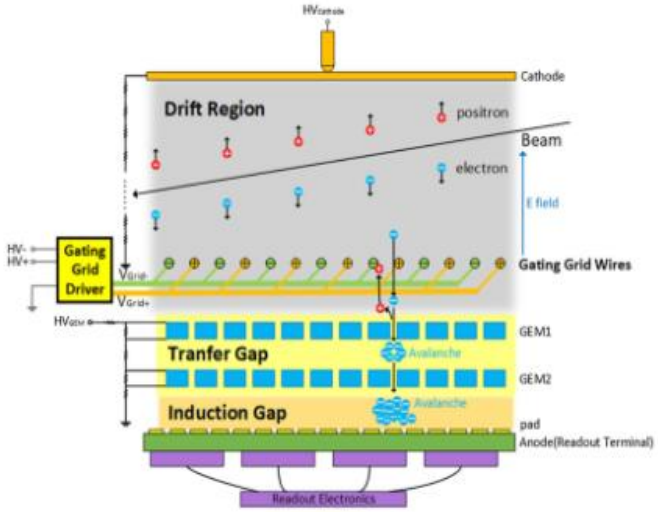
particle per macro pulse = 5×10^3 particle/5ms

➔ 0.01 particle per 10ns ~ 1 partice per 1us

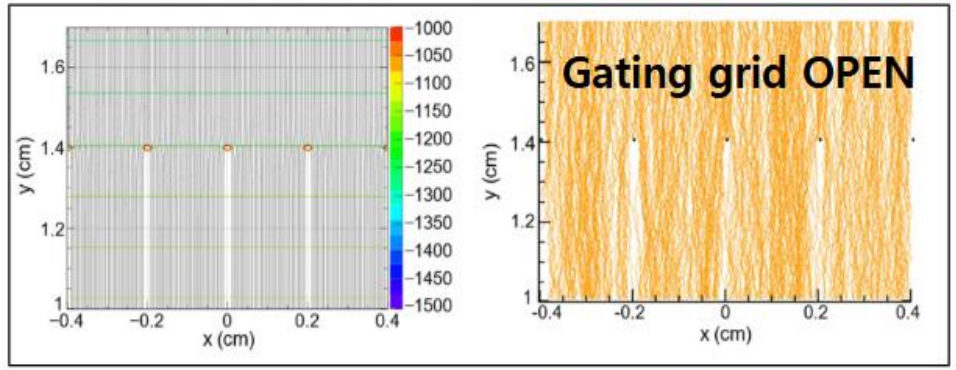


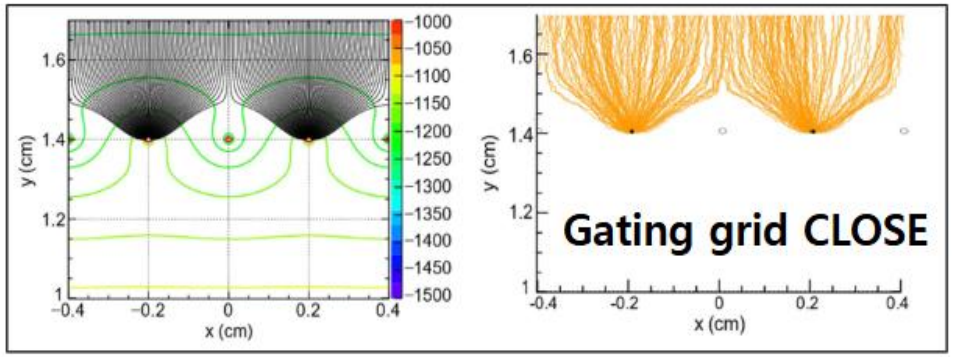
Gating grid

Development of a gating grid driver of TPC for exotic beam experiments, Eur. Phys. J. C (2023) 83:600



- **Wire diameter = 70um**
- **Wire pitch = 2mm**





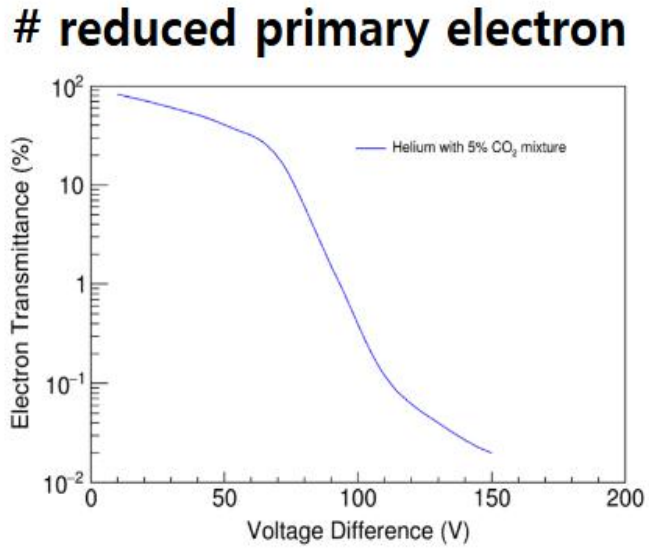
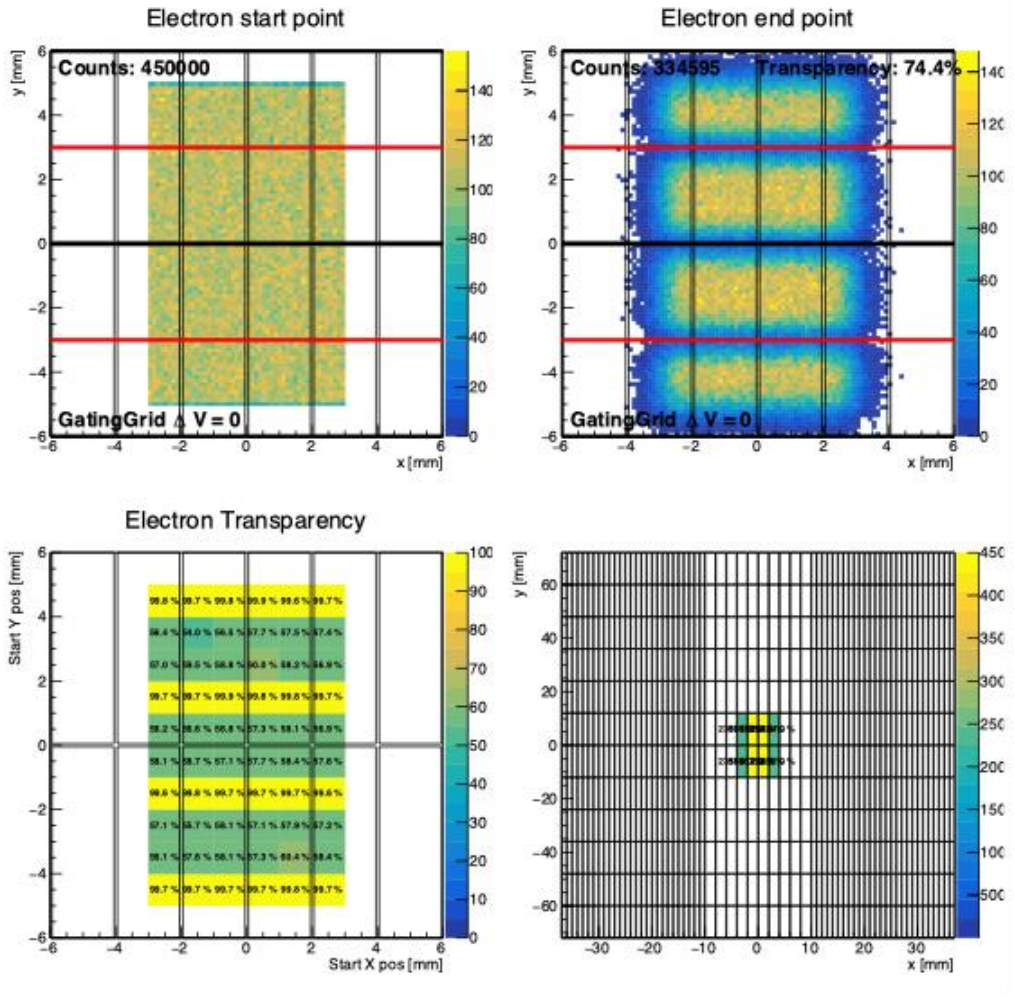


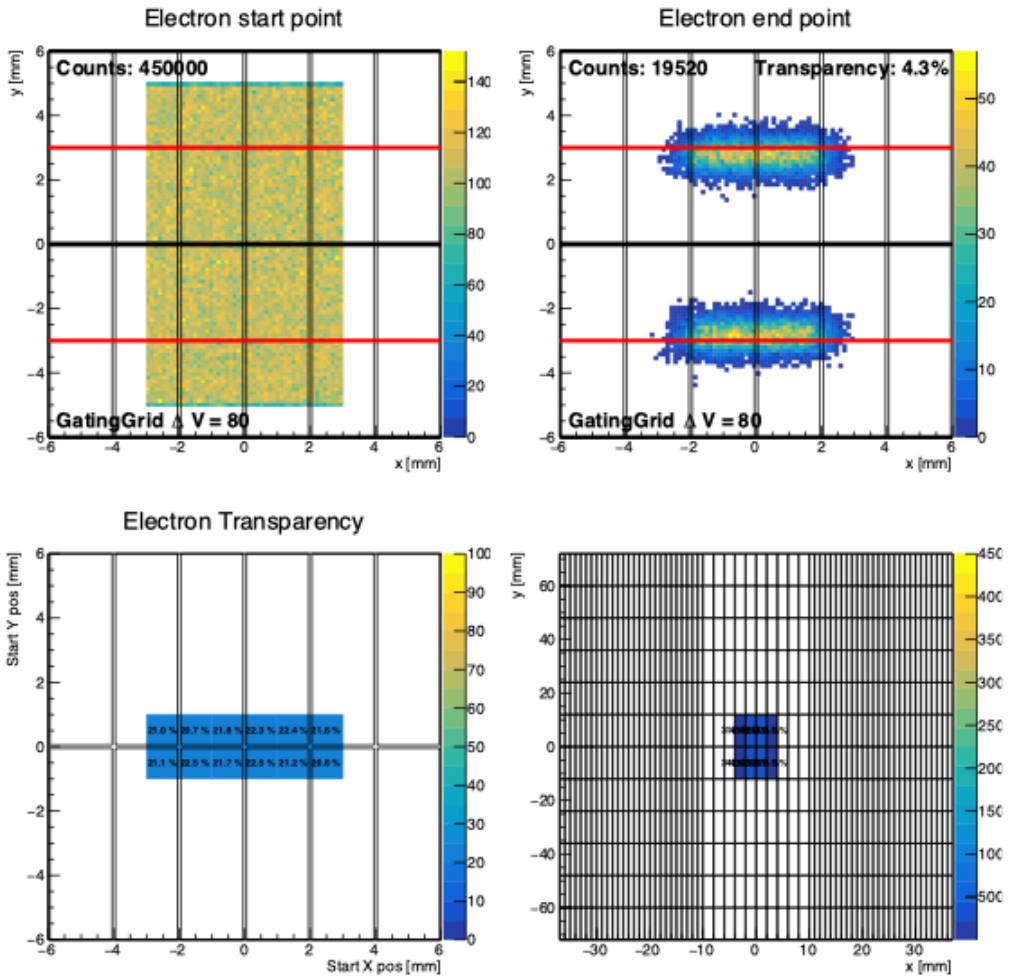
Fig. 4 The variation in electron transmittance with an increasing voltage difference ($2\Delta V$)

Gating grid

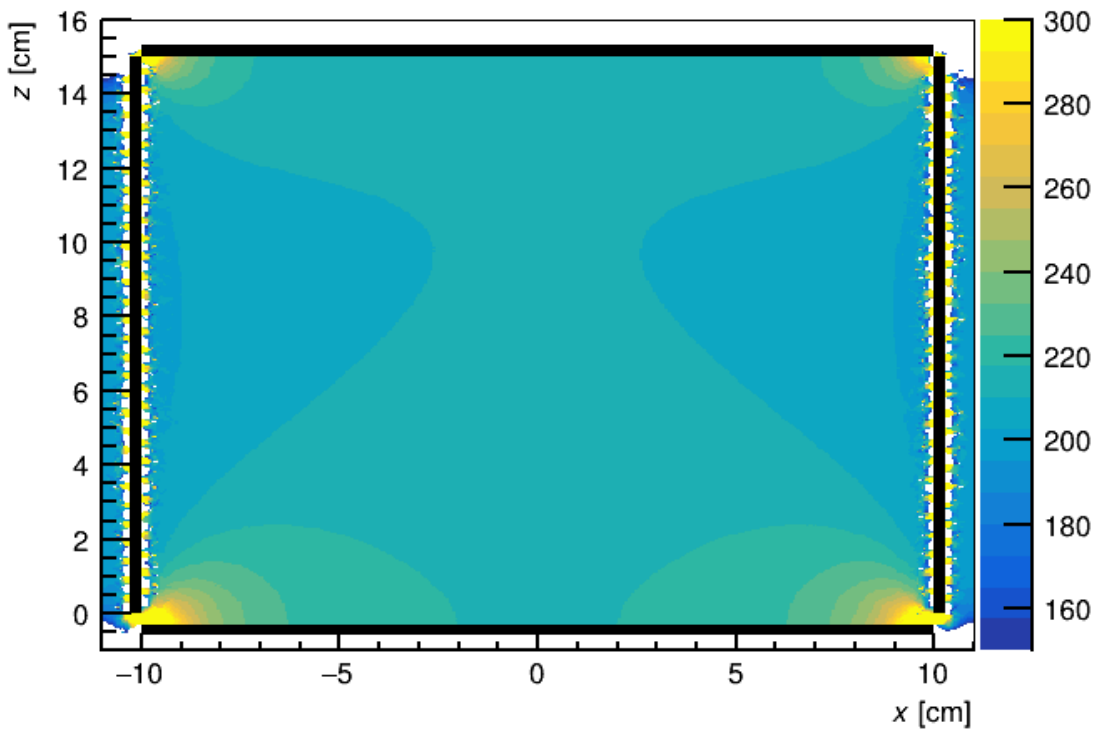
Gating grid voltage ΔV = 0 V

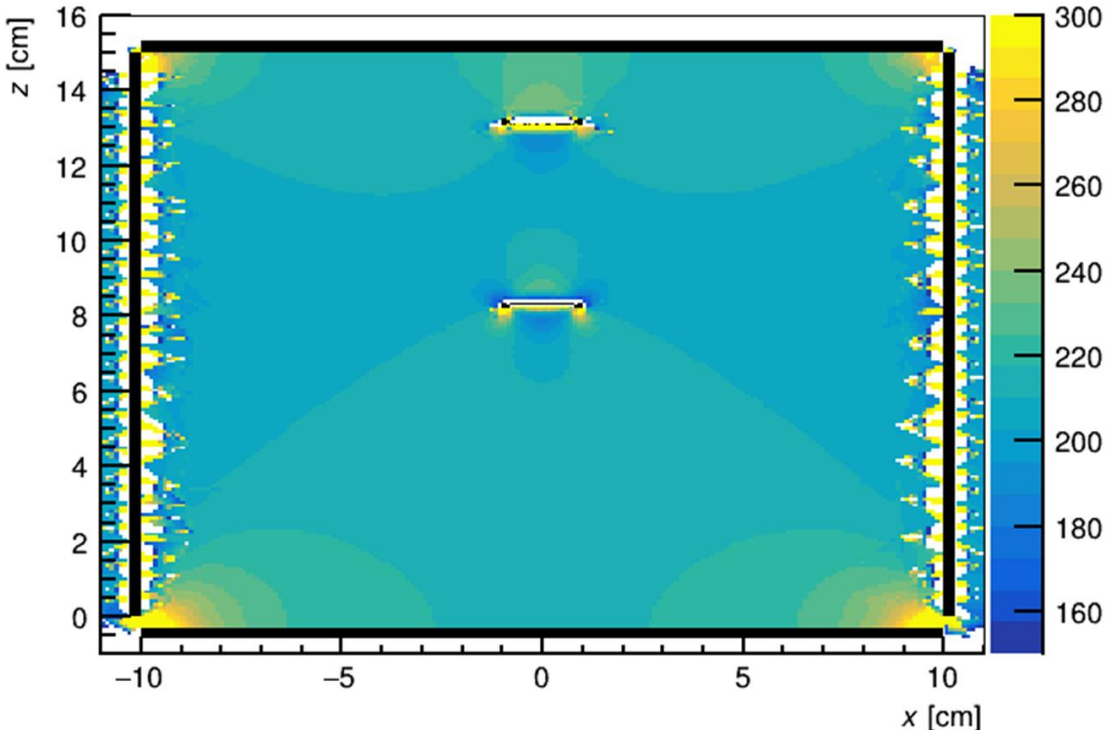


Gating grid voltage ΔV = 80 V



Gating grid


z [cm]
16
14
12
10
8
6
4
2
0
−10
−5
0
5
10
x [cm]
300
280
260
240
220
200
180
160

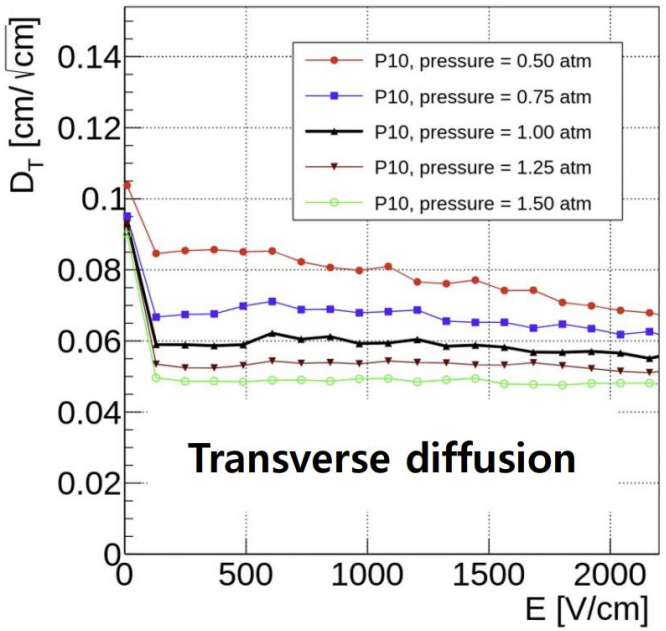

z [cm]
16
14
12
10
8
6
4
2
0
−10
−5
0
5
10
x [cm]
300
280
260
240
220
200
180
160

Gas system

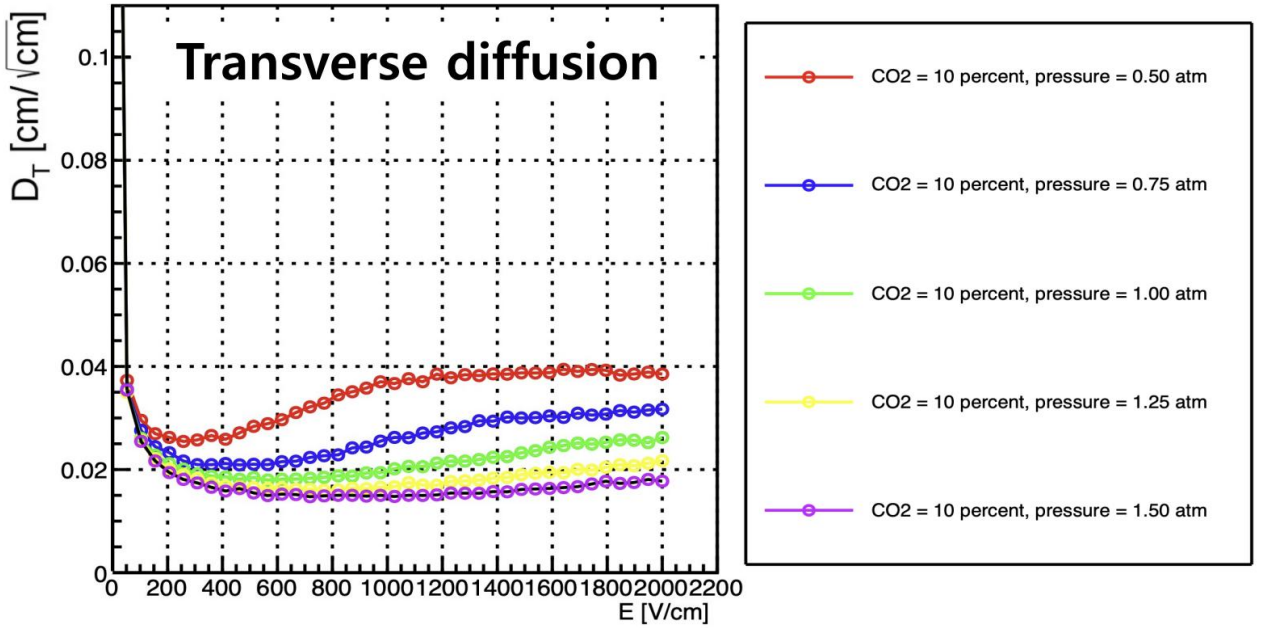
Gas system

- **Gas properties**

P10 gas (reference)



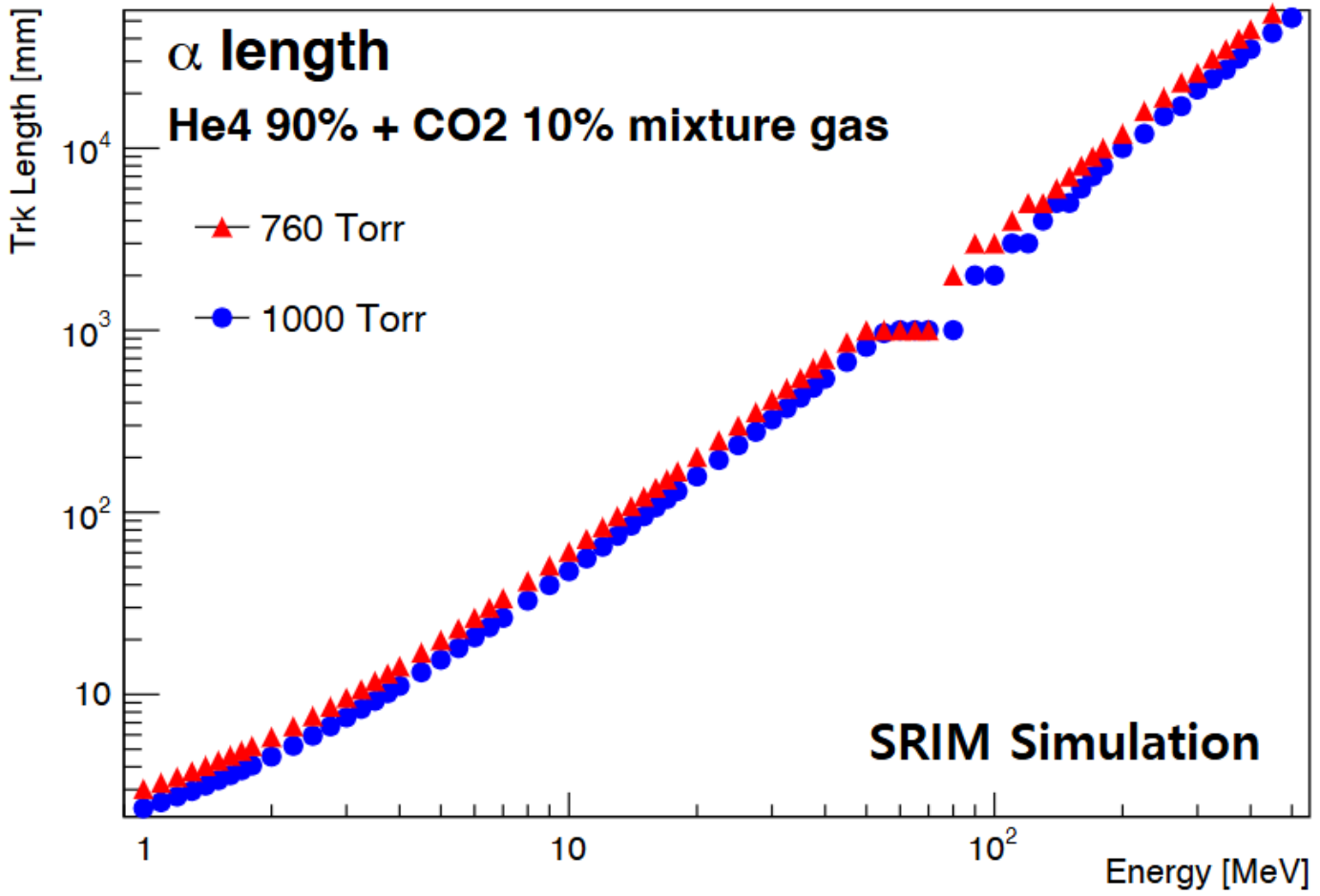
^{4}He (90%) + CO_2 (10 %) gas (Garfield++)



- **^{4}He + CO_2 gas mixture is three times less diffusion than P10 gas.**
- **We also reduced the pad width to cluster each hit.**

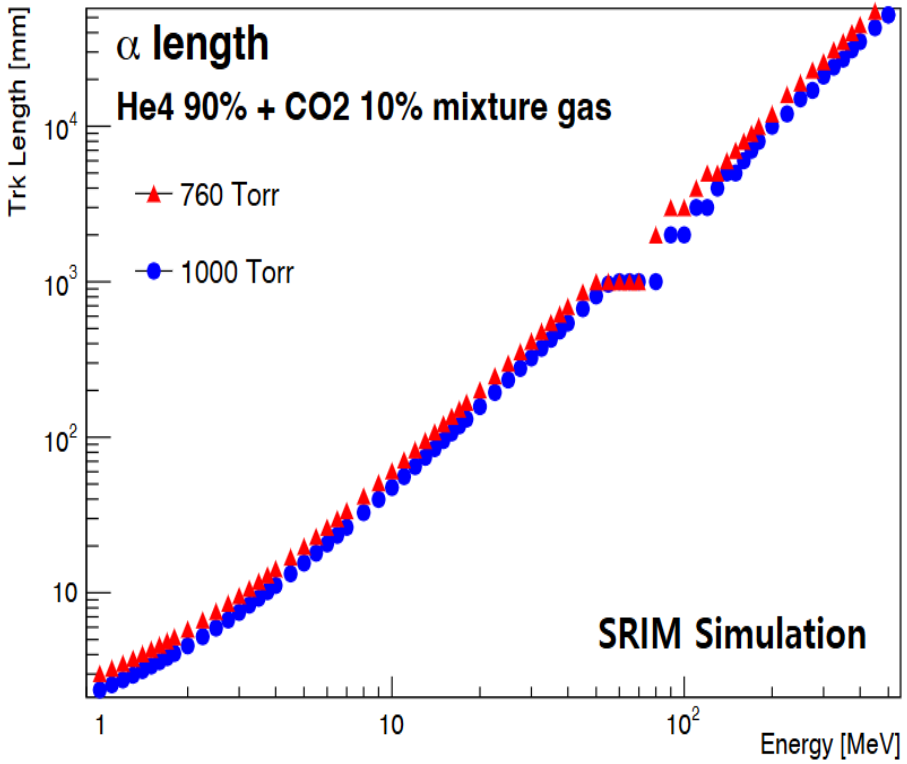
Calibrations

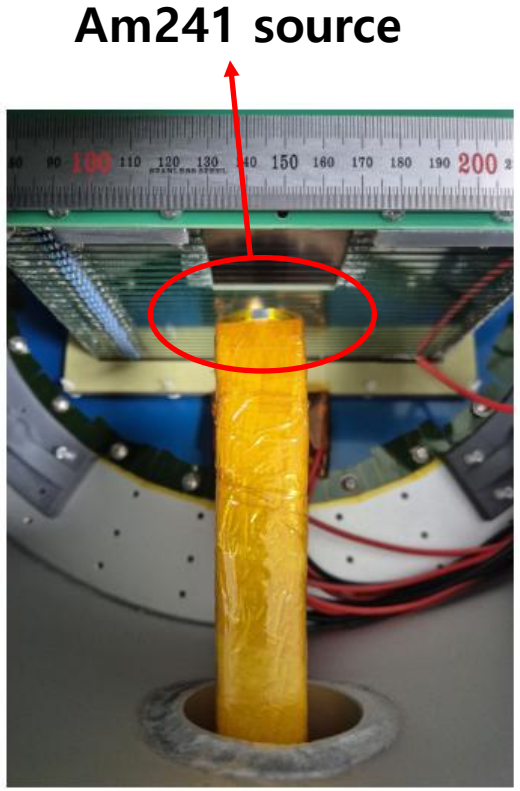
- **Alpha source test**



Source test

Alpha source test





w/ Field-cage (120 V/cm)

GEM gain (255V)

Run : 250304003

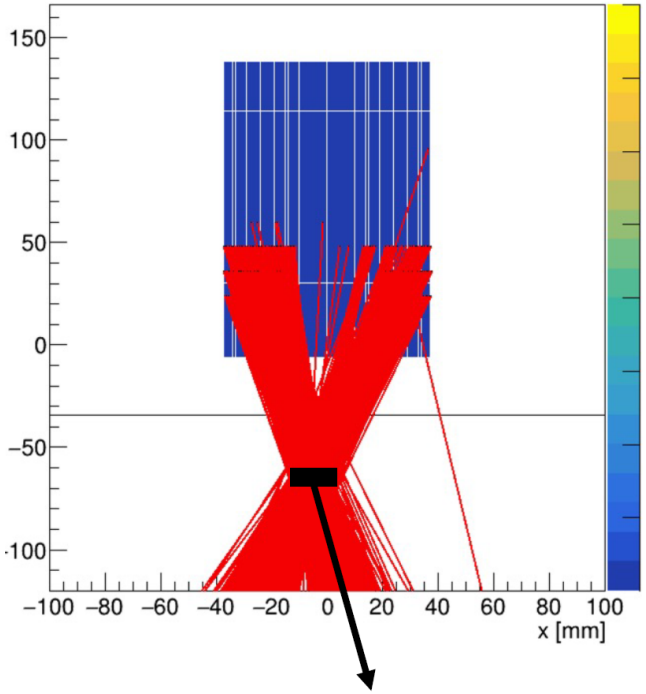
Am241 source test

760 Torr

- Alpha source is installed in position (-5mm, -66mm) from the pad origin
- Considering its pressure condition, track length will be around 11.5 cm

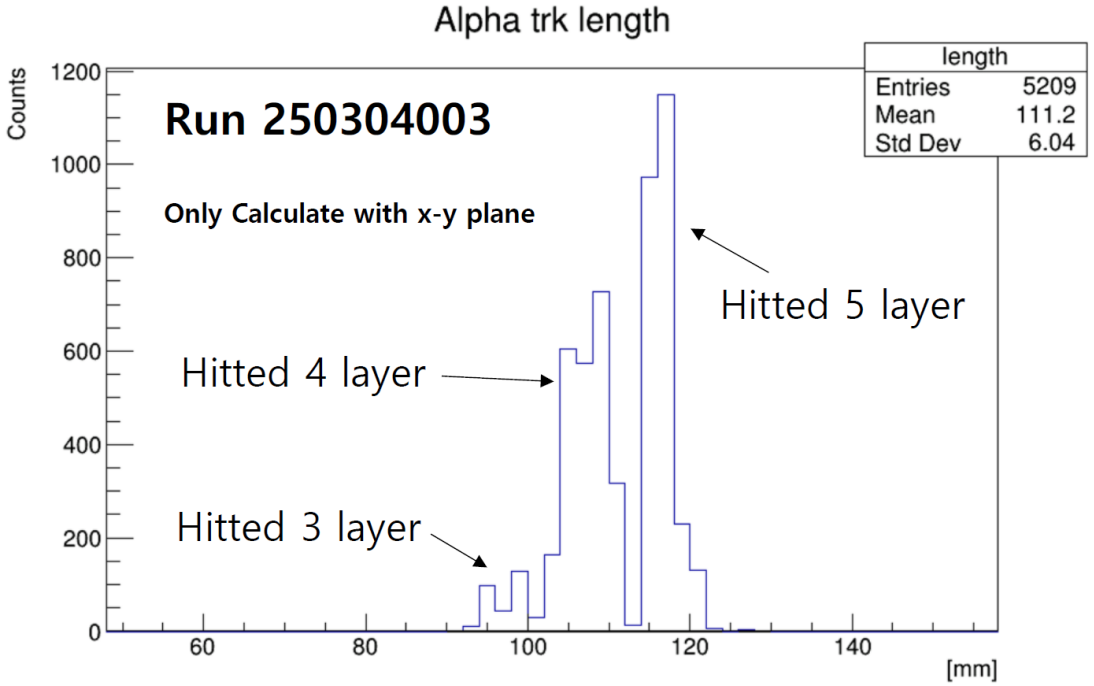
Alpha source test

All track display



Am241 source at -66.25 mm

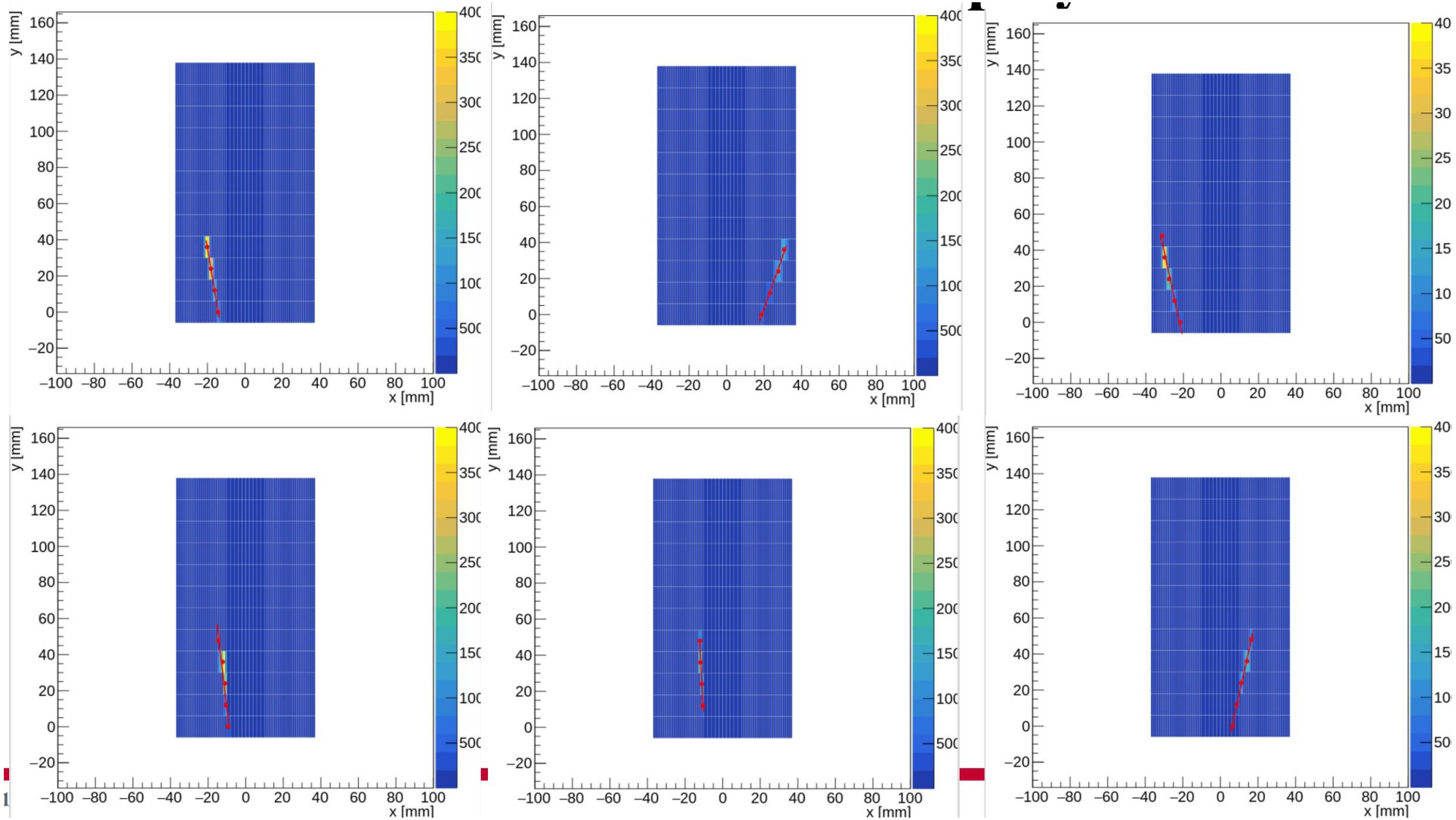
(with tiny vertex finding method)



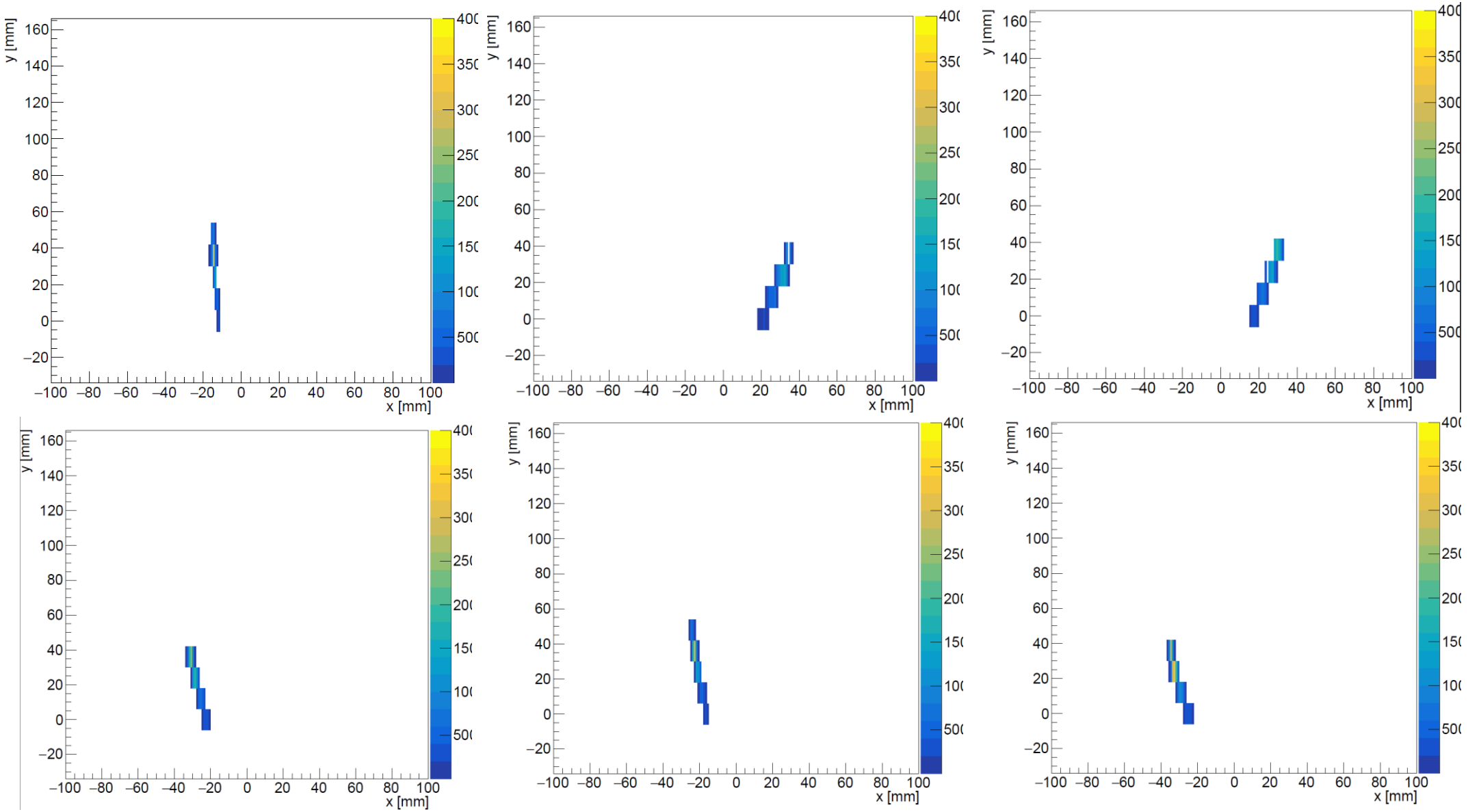
SRIM calculation ~ 11.5 cm

- **Estimated track length of alpha is 11.5cm, as expected in SRIM simulation**

Alpha source test (241Am)

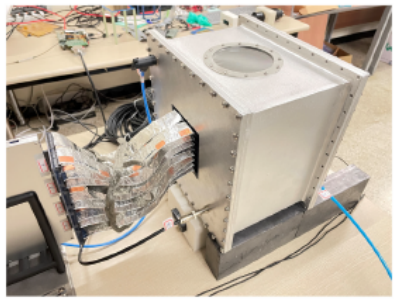


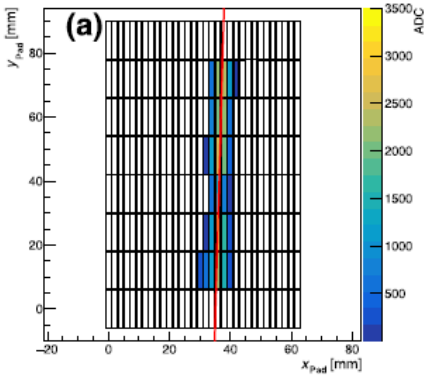
Alpha event

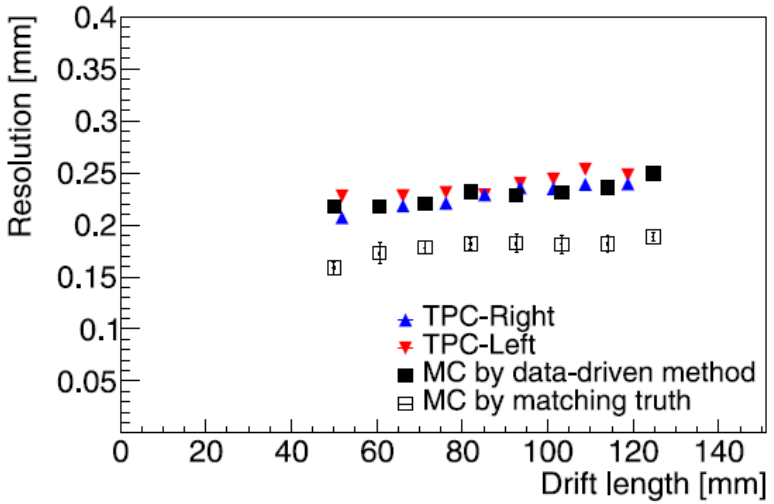


Prototype performance published in NIMA

We made two cubic TPC's were to measure the quasi-free elastic scattering in ^{12}C + p at HIMAC







Nuclear Instruments and Methods in Physics Research A 1066 (2024) 169610

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Full Length Article

Characteristics of the prototype LAMPS TPC for low-energy nuclear collisions at RAON

Yechan Cheon [a,b], Seunghwan Lee [a,b], Deuk Soon Ahn [c], Jung Keun Ahn [d,b], Joonsuk Bae [g], Yunseul Bae [h], Jeongsu Bok [e], Sung Wook Choi [d,b], Seungkyung Do [d,b], Cheong Heo [h], Byungsik Hong [d,b], Jangyong Huh [c], Jaein Hwang [d,b], Seonggeun Hwang [a,b], Youngseub Jang [d,b], Byungmin Kang [d,b], Aram Kim [d,b], Beomkyu Kim [g], Chong Kim [e], Eun-Joo Kim [j], Giyeong Kim [f,b], Hyunchul Kim [h], Jiseok Kim [d,b], Jiyoung Kim [f,d,b], Shin Hyung Kim [k], Yongsun Kim [a,b], Young Jin Kim [f], Yongjun Kim [c], MinJung Kweon [f,b], Cheong Soo Lee [i], Hyo Sang Lee [i], Jaehwan Lee [d,b], Jong-Won Lee [d,b], Jung Woo Lee [c], Junseok Lee [d,b], Haein Lee [d,b], Hyungjun Lee [g], Seoung Hun Lee [f,b], Sungjune Lee [d,b], Sanghoon Lim [c], Dong Ho Moon [b], Seon Ho Nam [d,b], Jeonghyeok Park [d,b], (The LAMPS Collaboration)

ARTICLE INFO

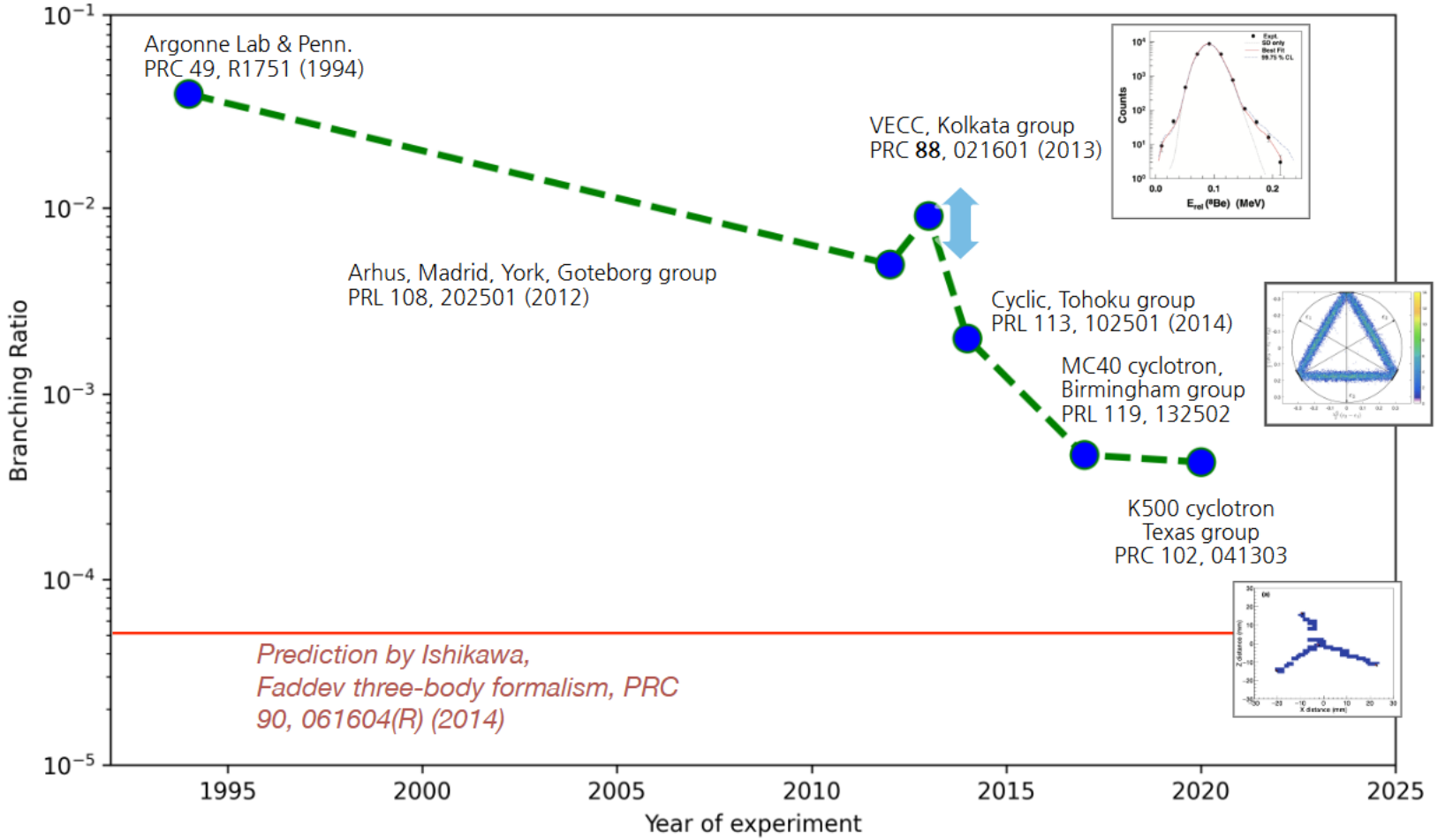
Keywords:
TPC
AT-TPC
HIMAC
Proton
LAMPS
RAON

ABSTRACT

The time projection chambers (TPCs) with triple GEM amplifiers are tested at HIMAC using ^{12}C beams to investigate their nucleus track reconstruction capability. The two identical TPCs, each having an active volume of 96 × 64 × 144 mm^3 and rectangular pixel pads, have been developed as prototypes of the LAMPS collaboration's low-energy active target TPC (AT-TPC). The responses to light nuclei, such as particle identification and spatial resolution, have been investigated. The Si-CsI detectors located next to the TPCs further facilitate the identification of incident particles, as well as the matching tracks. This paper presents the technical details of the experimental setup, pulse shape analysis, tracking algorithm, and spatial resolution measurement. Comparisons of the experimental data with the calculations by the Monte Carlo (MC) simulation are also discussed.

- Tracking and vertex finding are very successful
- Position resolution — 150 μm
- Great PID performance of Si-CsI array
- Our MC framework well agrees with data in terms of electron diffusion and position resolution over a wide range of drift length

Upper limit of the Branching Ratio of direct decay



References

- Shen, S., *et al.*, Emergent geometry and duality in the carbon nucleus. *Nature Communications*, **14**, 2777 (2023). [DOI: 10.1038/s41467-023-38391-y]