Particle Detector Workshop 2026

Daejeon IBS, February 6-7, 2026

TPC Development: Experience (HypTPC, sTPC) and Future R&D

- HypTPC: S.H. Kim *et al*., NIMA 940, 359 (2019)
- sTPC: S.H. Kim *et al*., NIMA 962, 163687 (2020)

KYUNGPOOK NATIONAL UNIVERSITY

Shin Hyung Kim

(Kyungpook National University)

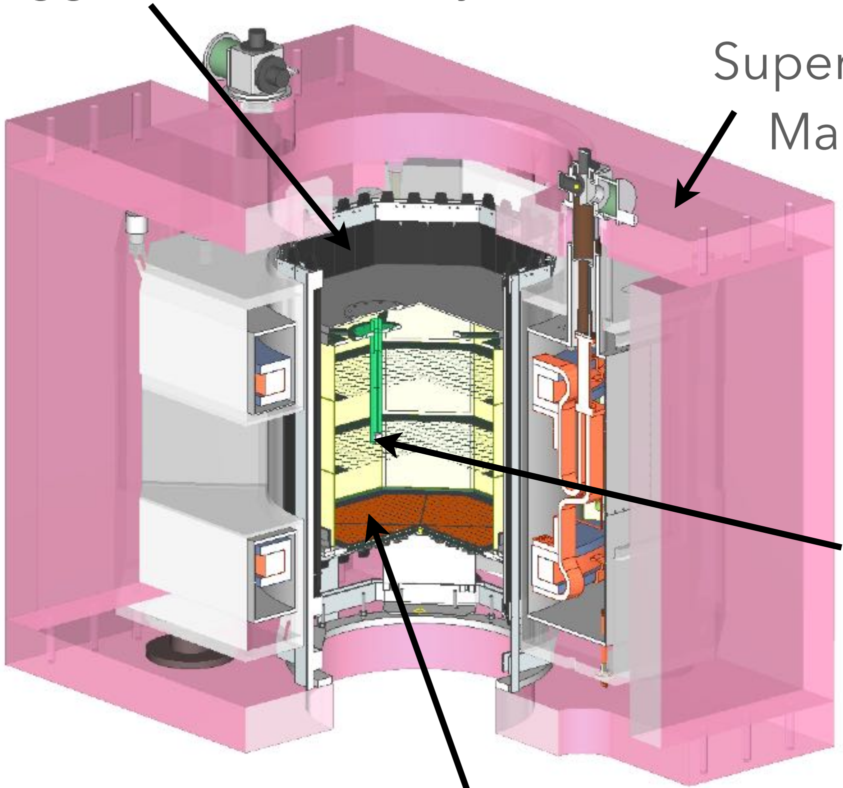
Experience (HypTPC, sTPC)

Hyperon Spectrometer

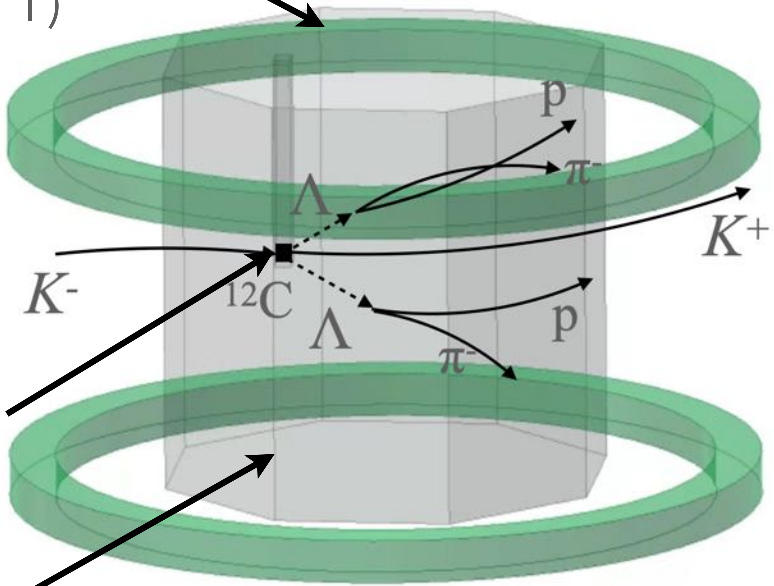
developed for hadron experiments at J-PARC

Trigger Counter Array (HTOF)

Superconducting Magnet (1 T)



Target

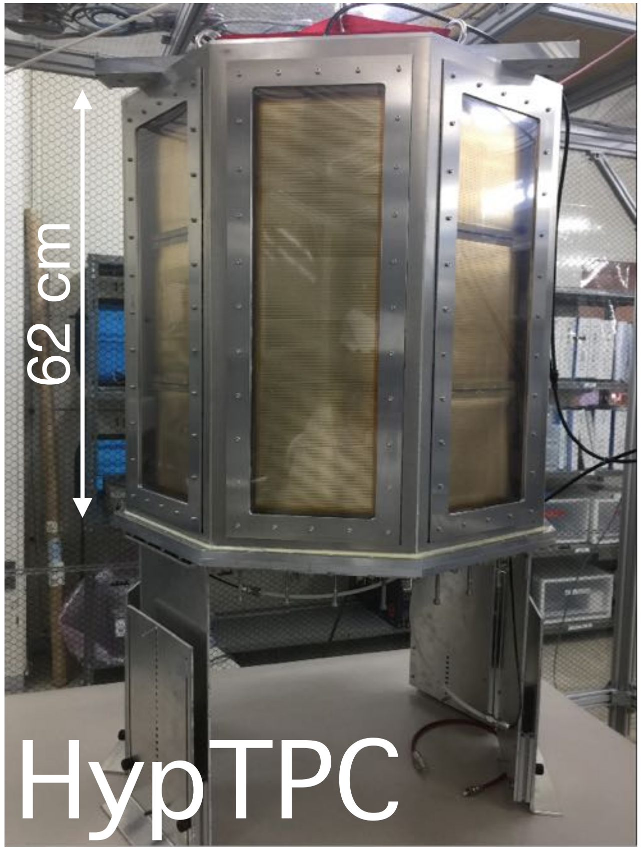


Time Projection Chamber (HypTPC)

- Large acceptance (~4π)
- High rate capability (~10^6 cps)
- High resolution (σ ~1 MeV)

HypTPC

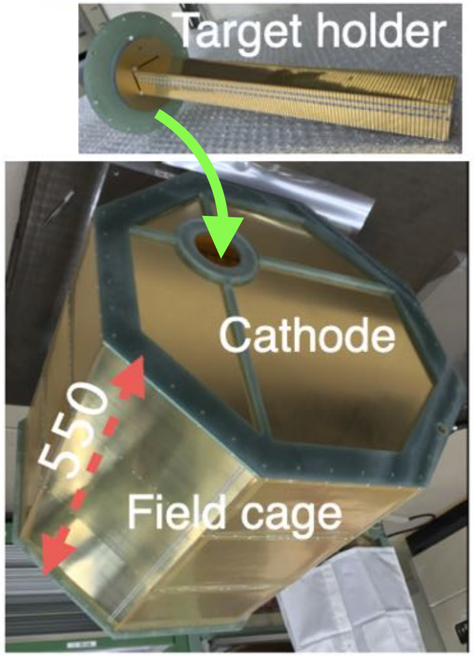
S.H. Kim *et al.*, NIMA 940, 359 (2019)

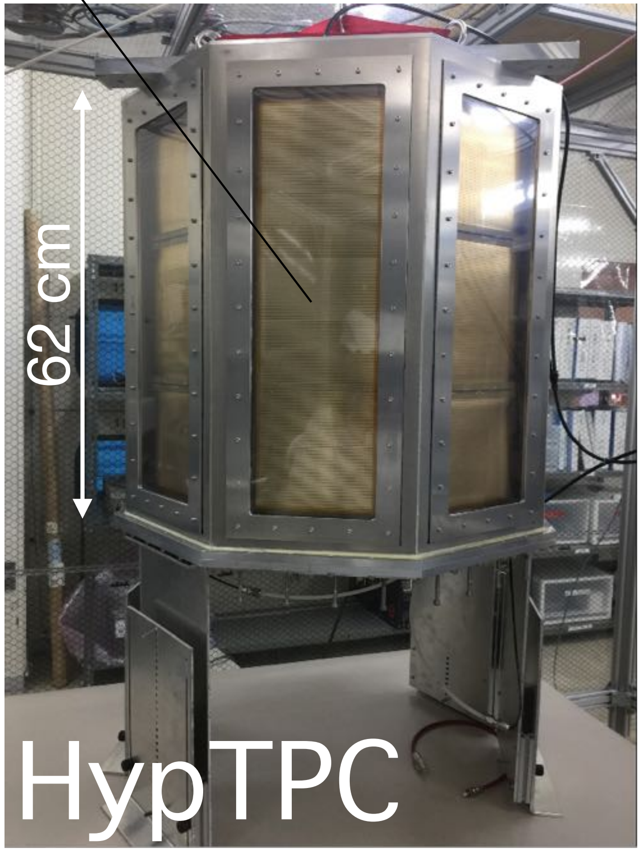


HypTPC

S.H. Kim *et al.*, NIMA 940, 359 (2019)

- 1. Drift Region





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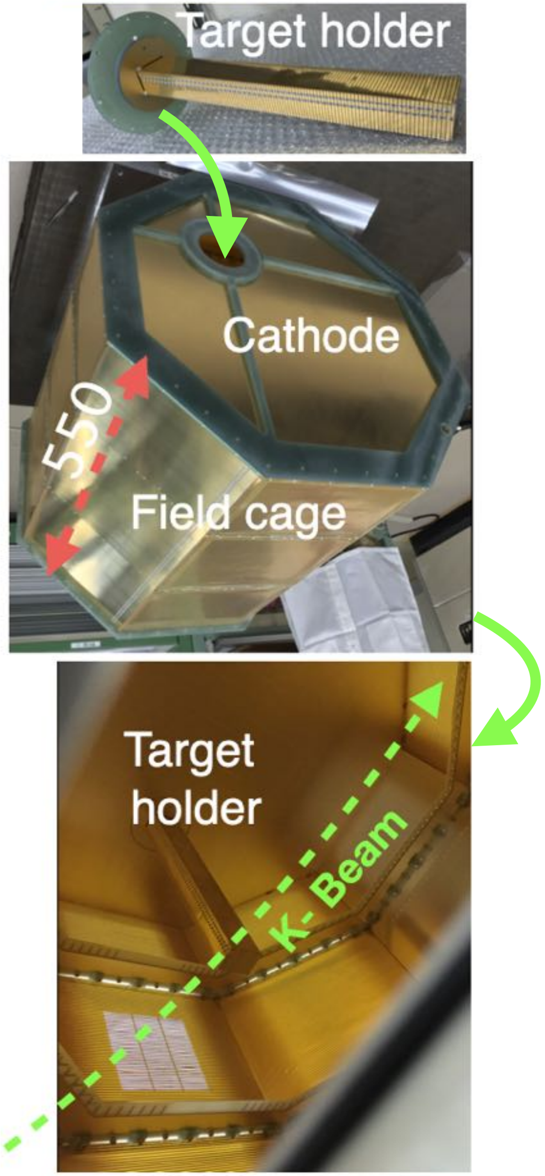

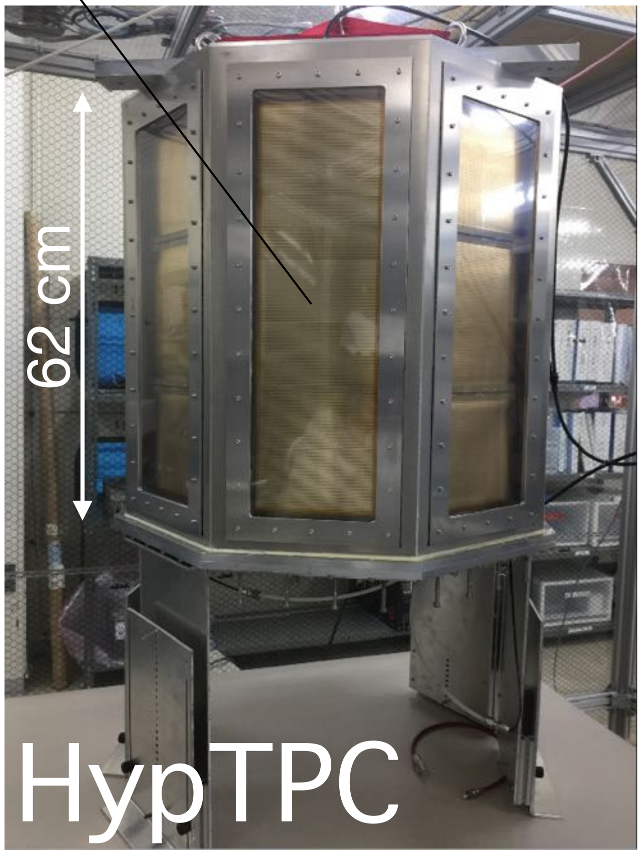

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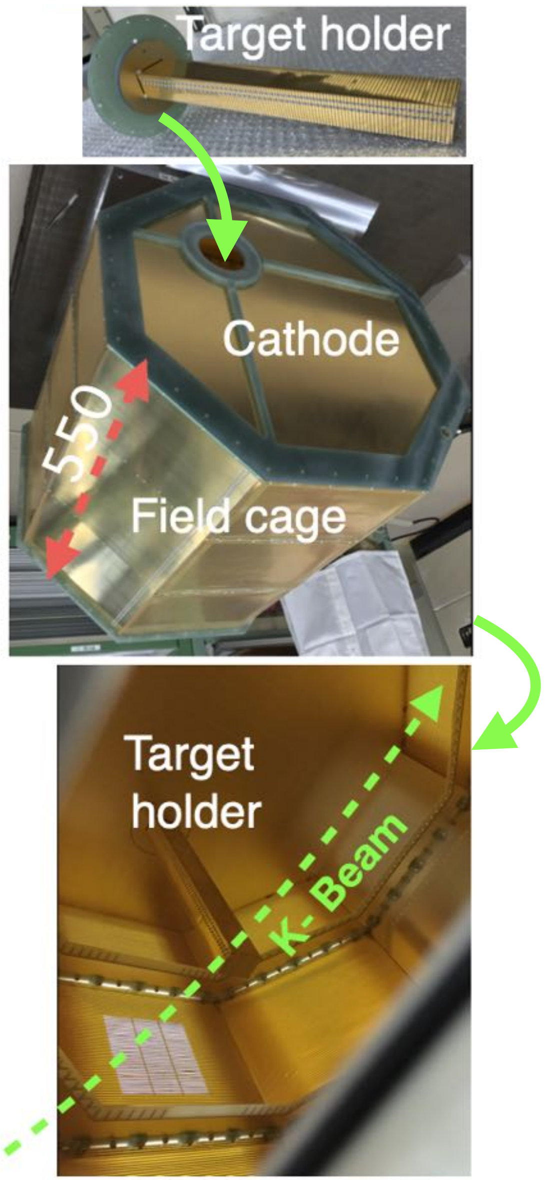

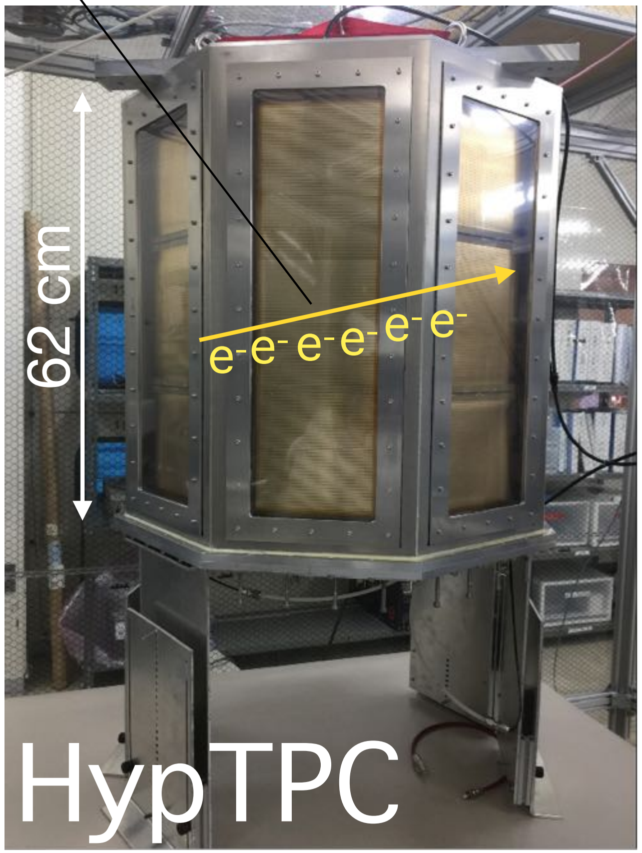

HypTPC

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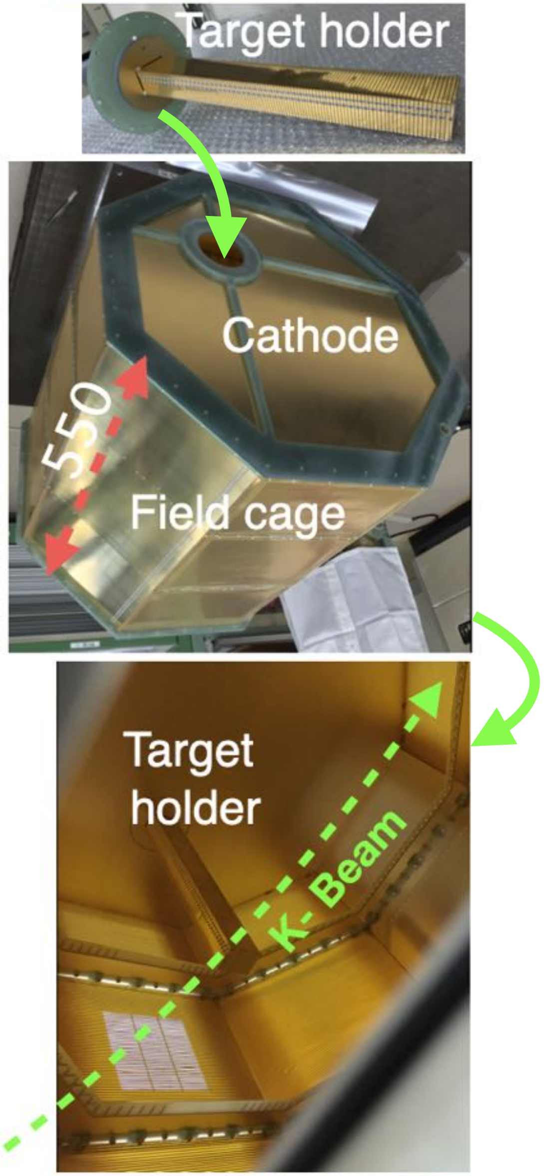

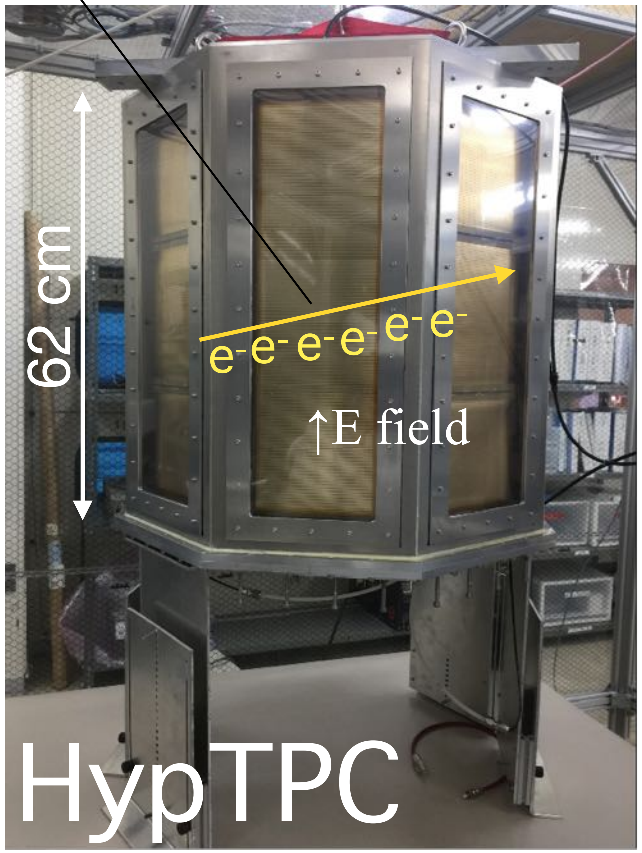

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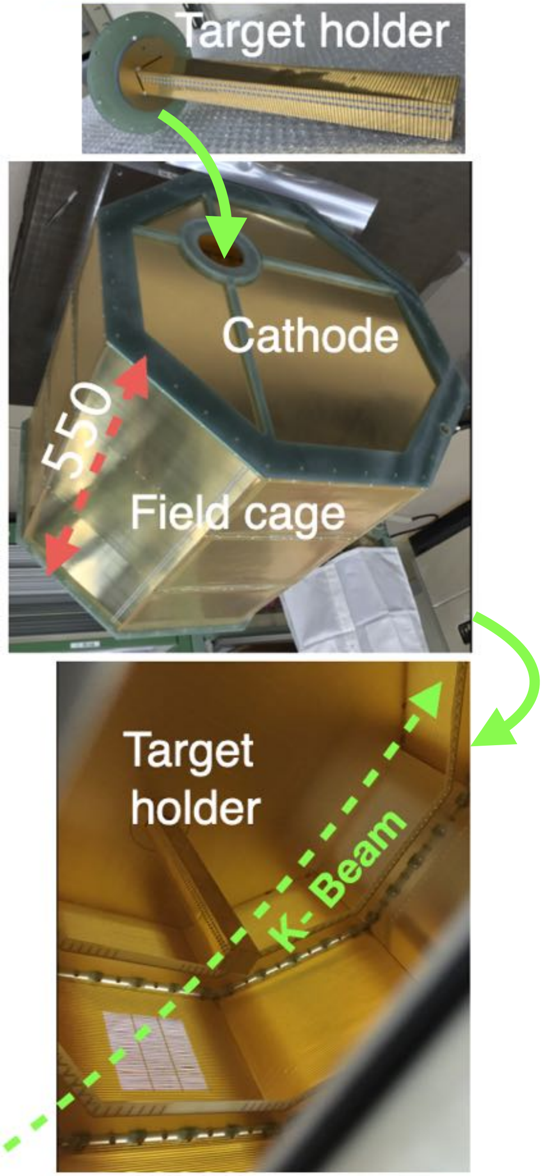

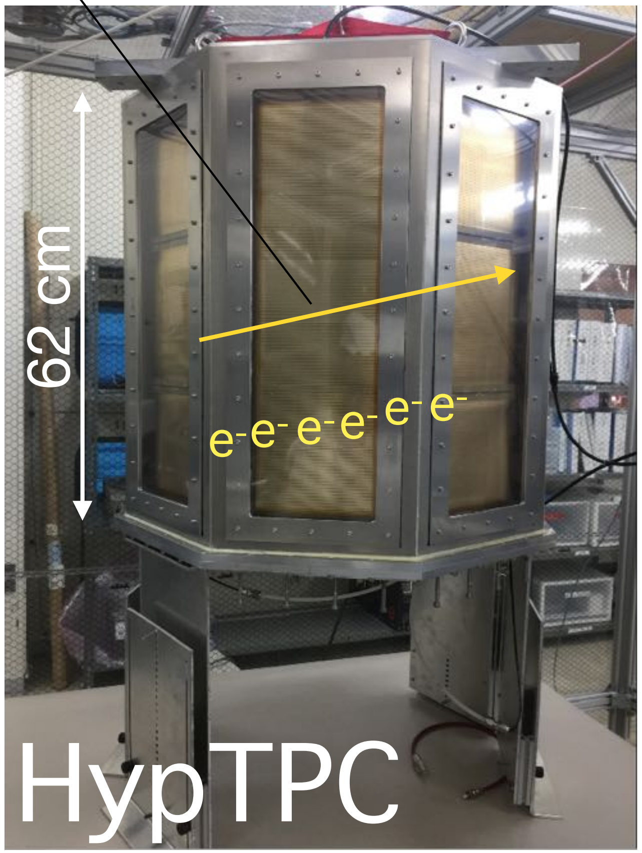

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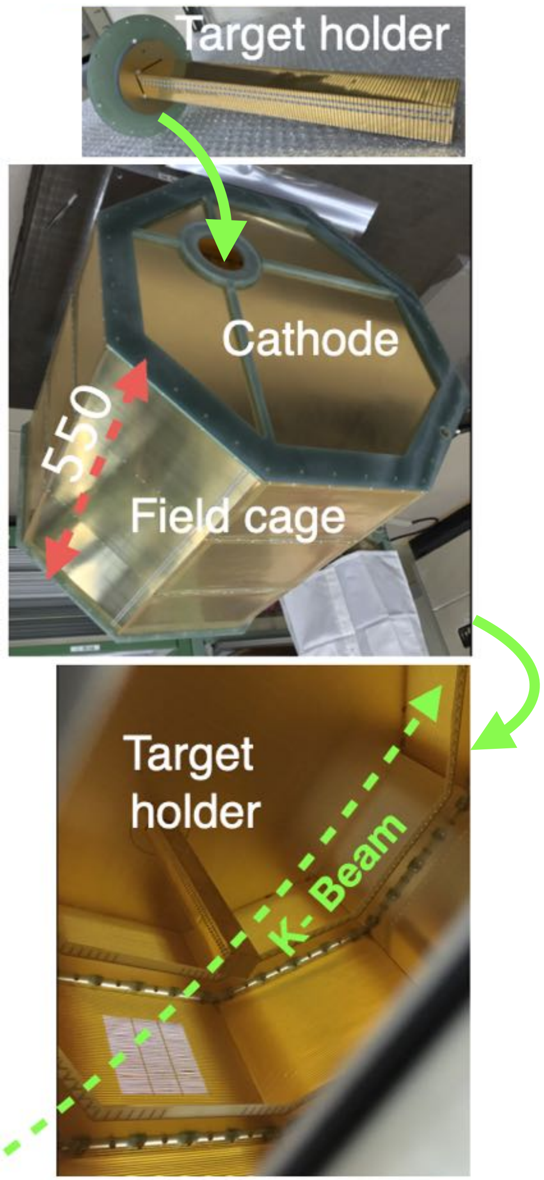
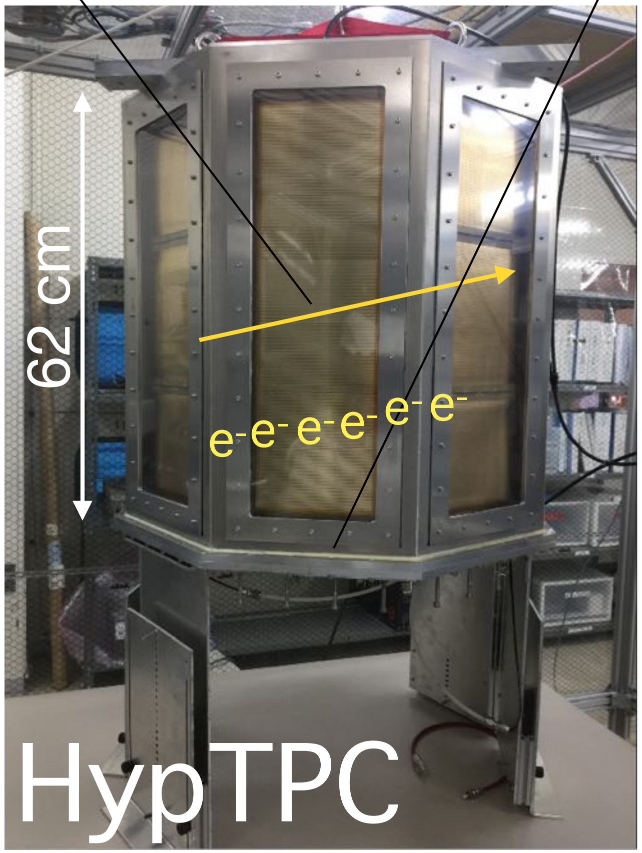
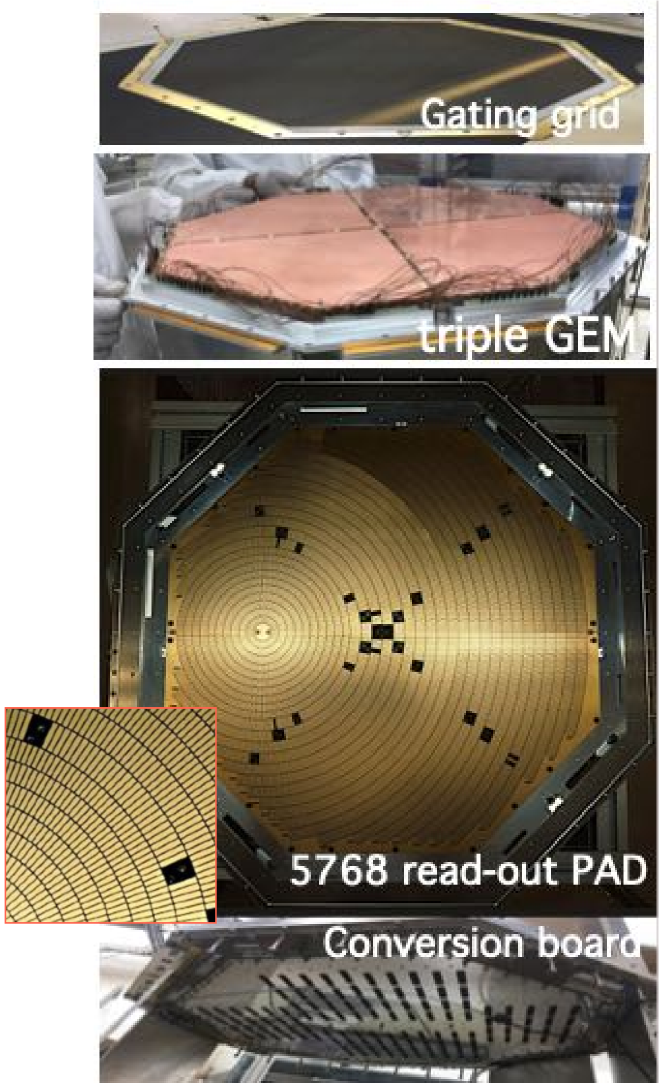




- 2. Amplification Region



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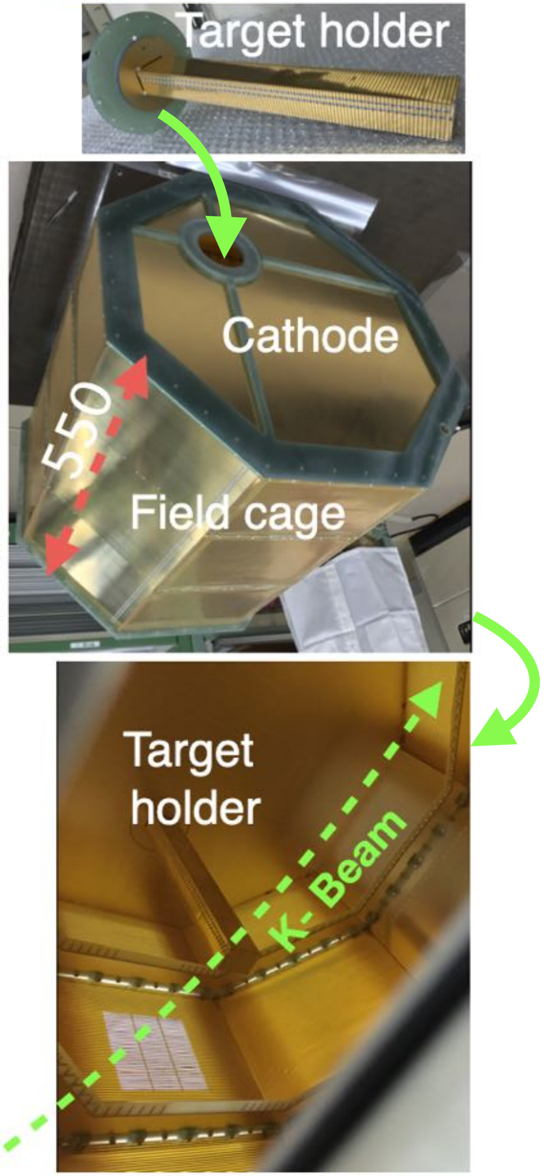

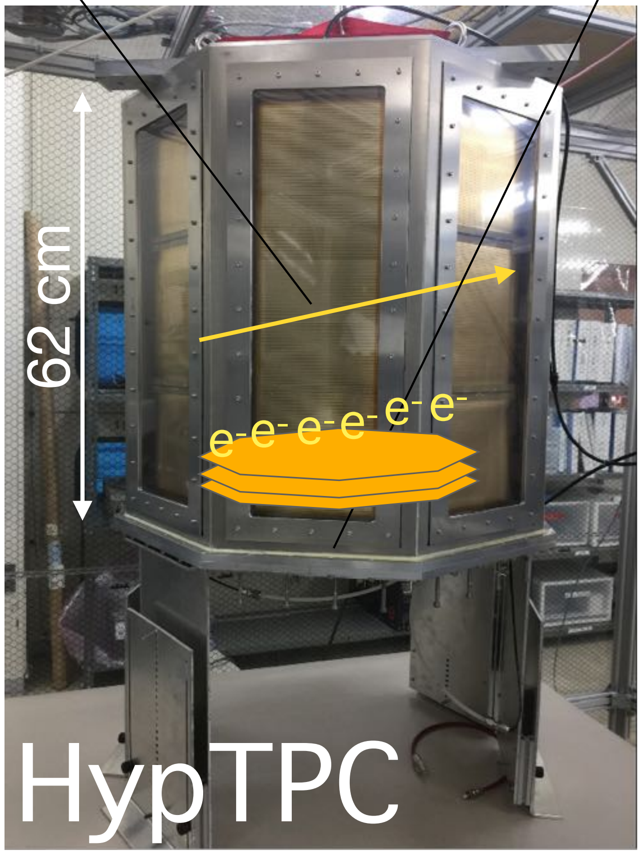

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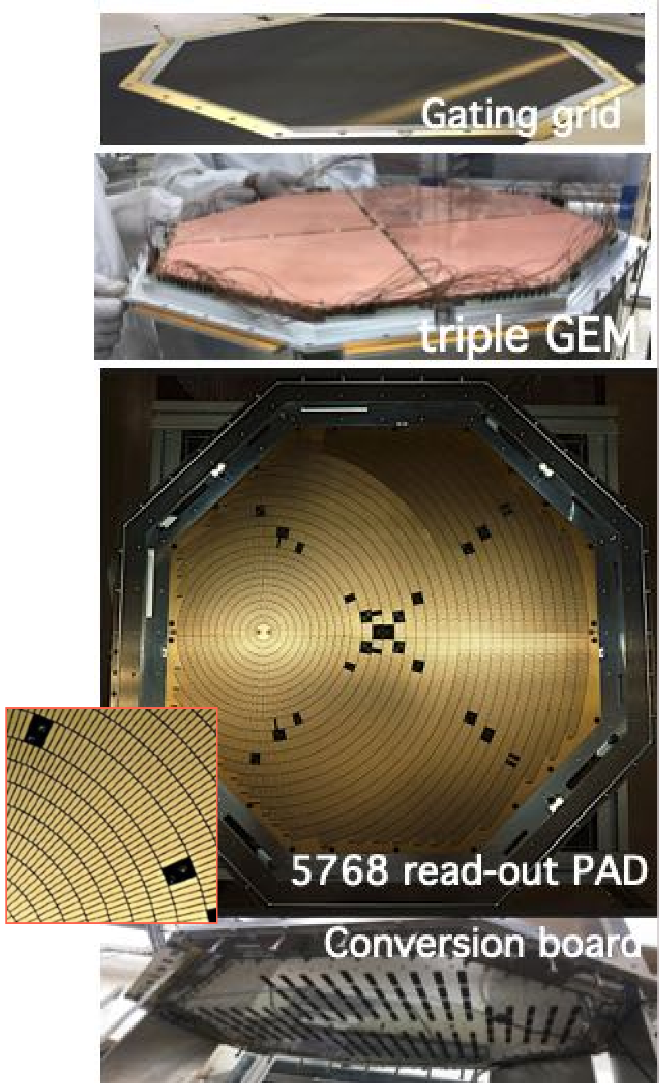

HypTPC

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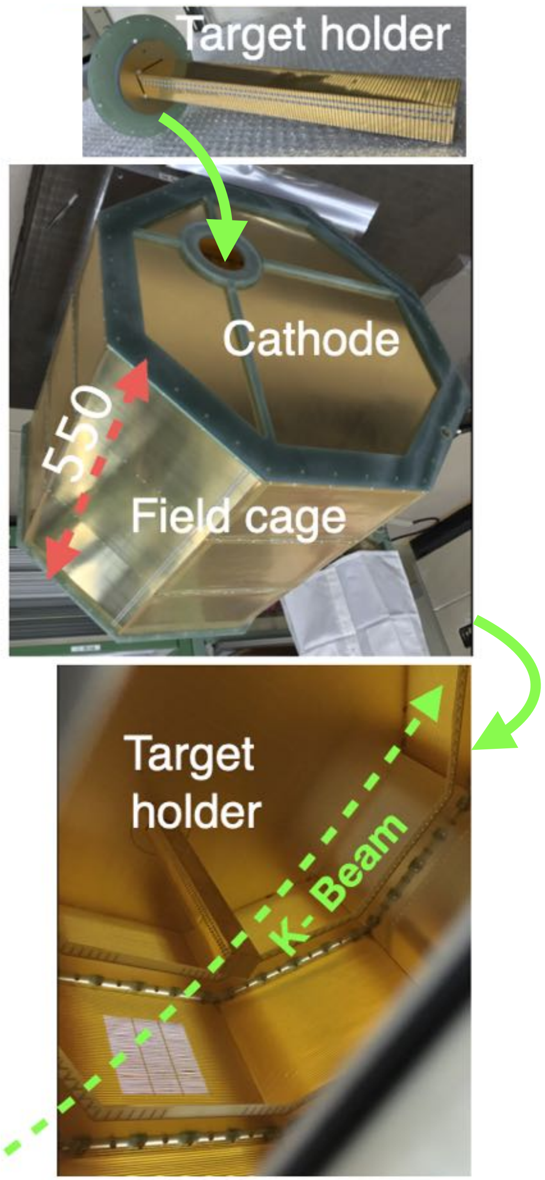

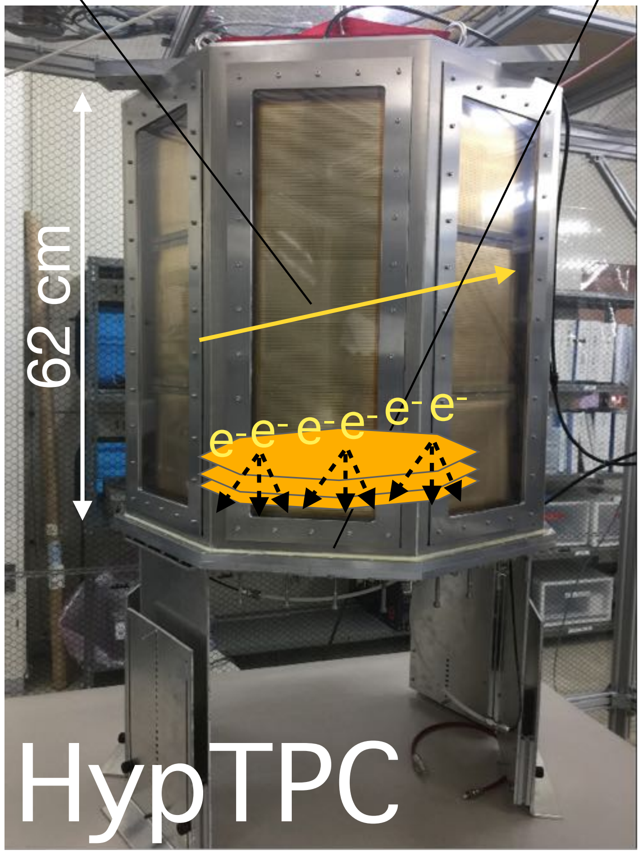

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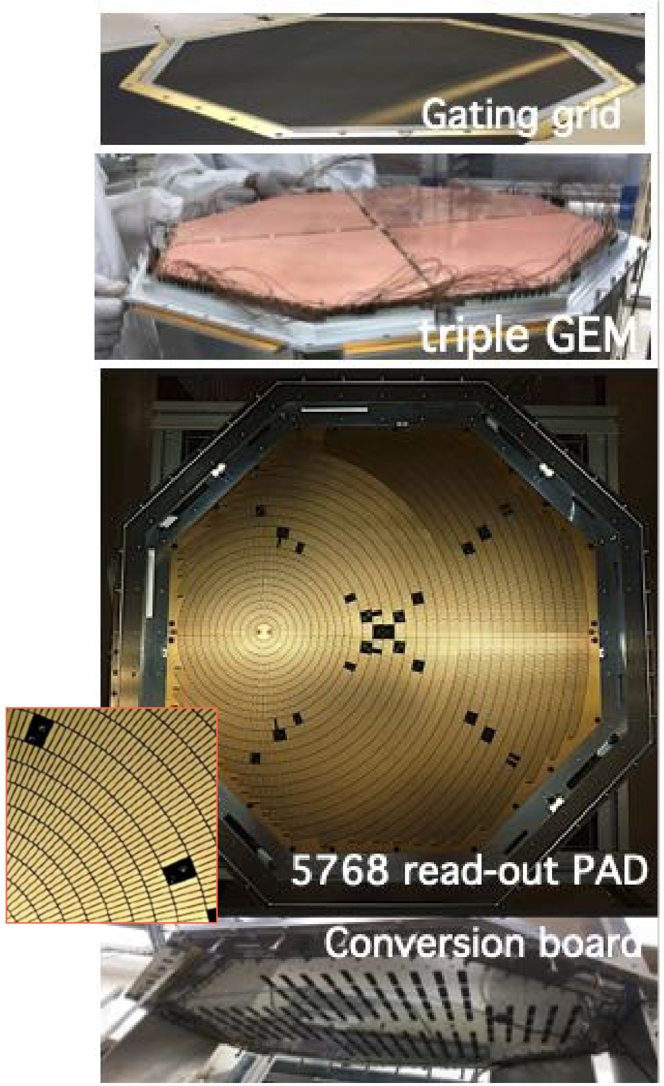

HypTPC

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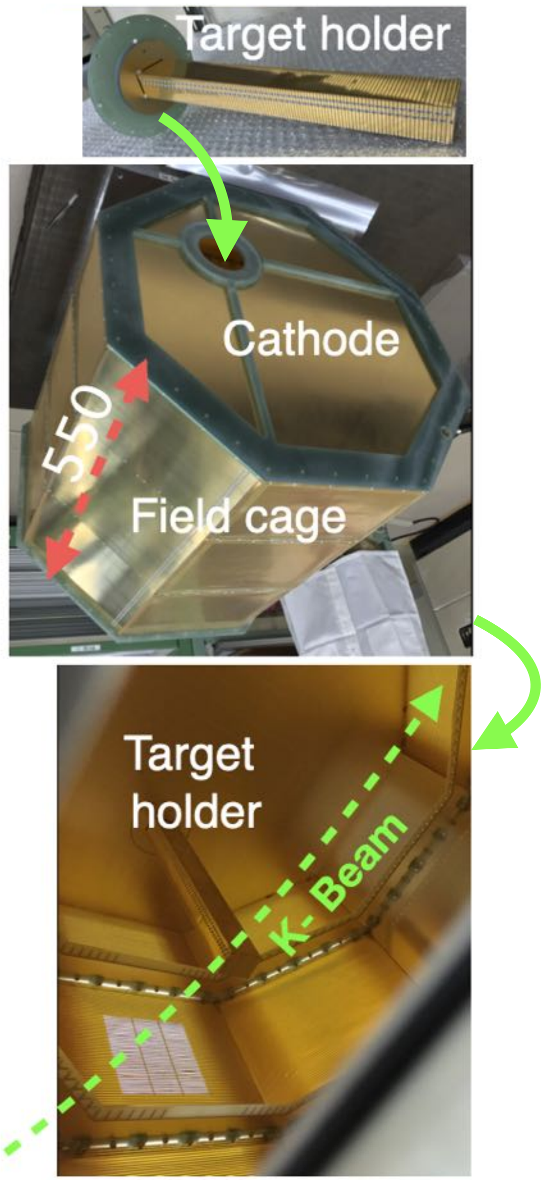

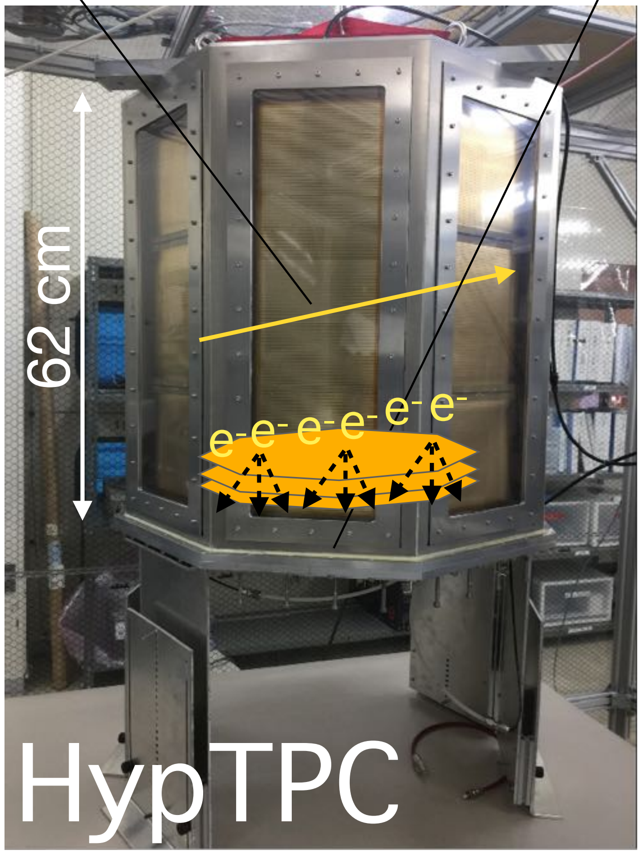

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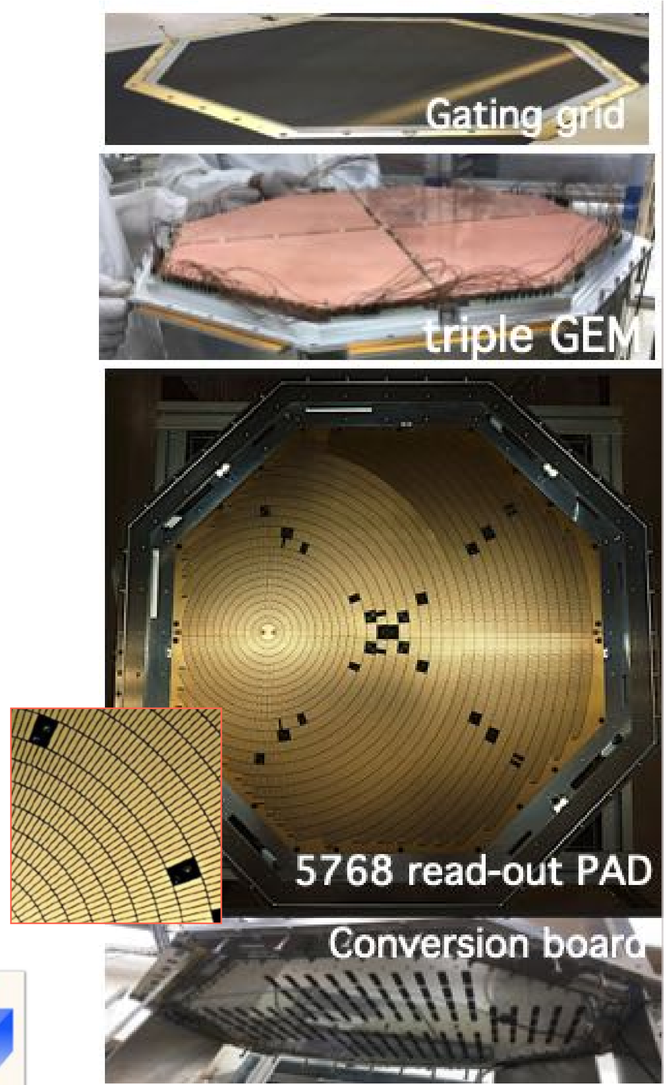
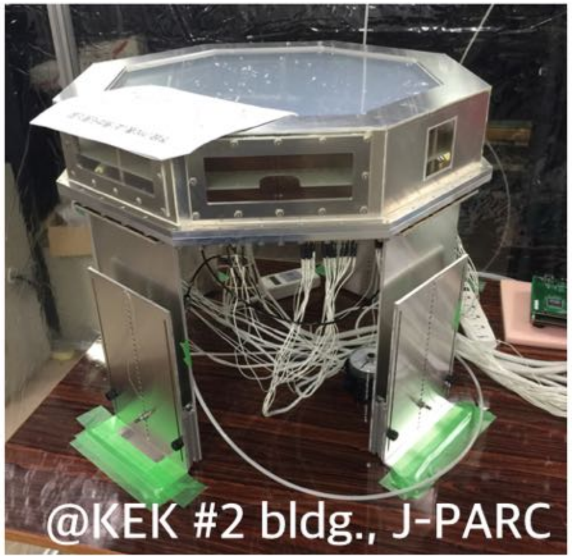


- 3. Read-out Electronics

Time Projection Chamber (HypTPC)

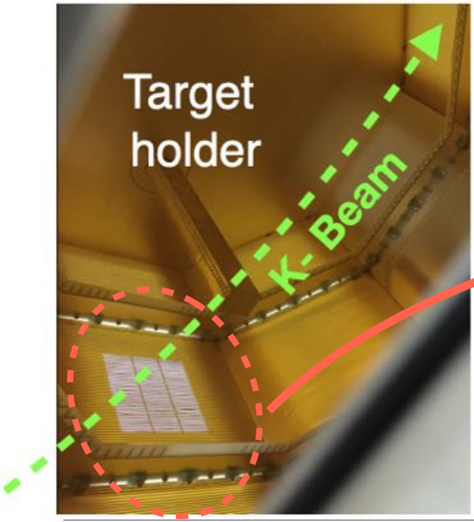


2015

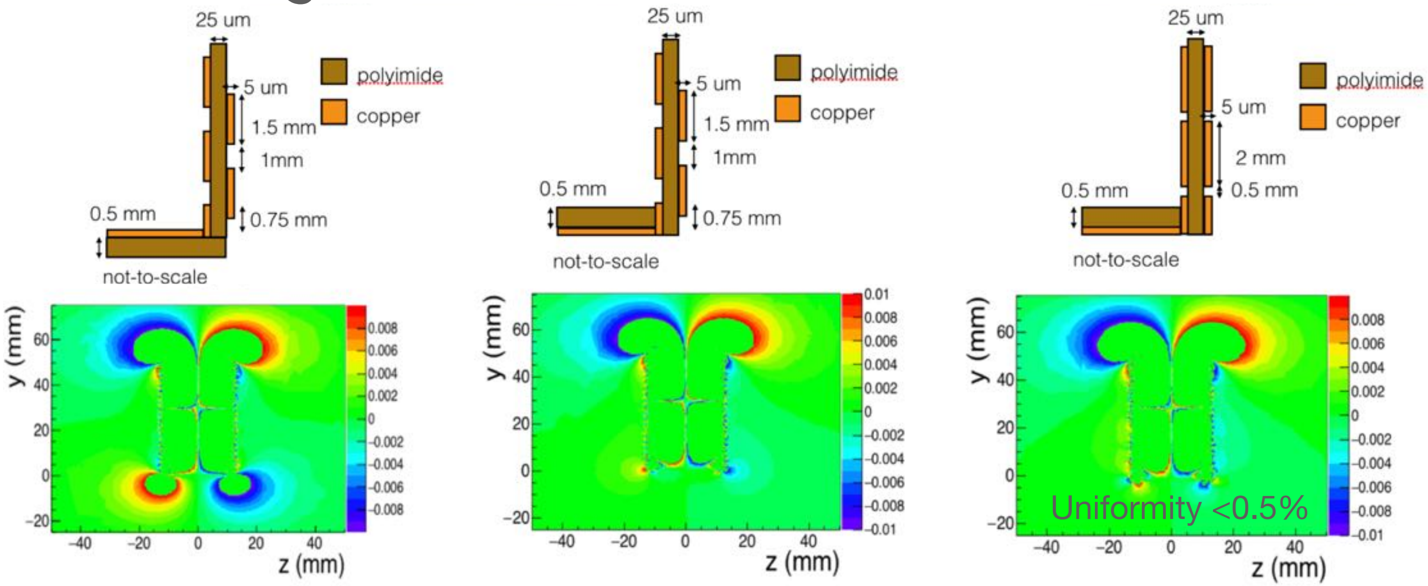
Oct. 2016

Drift Region

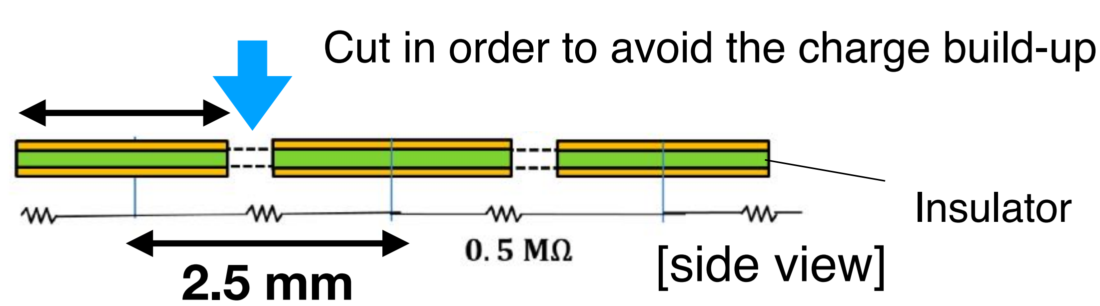
‣ *!! Challenges !! Uniform E field -> high resolution*



- Drift length : 55 cm, 1 atm P-10 gas, 130 V/cm
- optimized the field strip design for the field uniformity.
- Near target holder

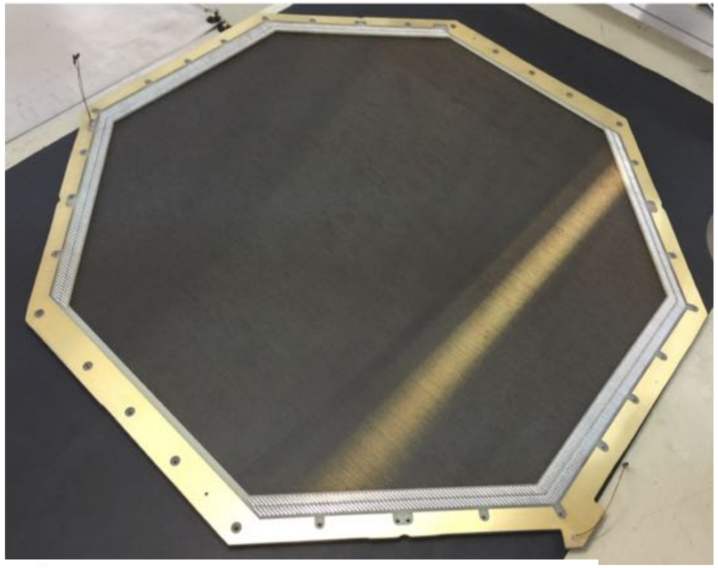


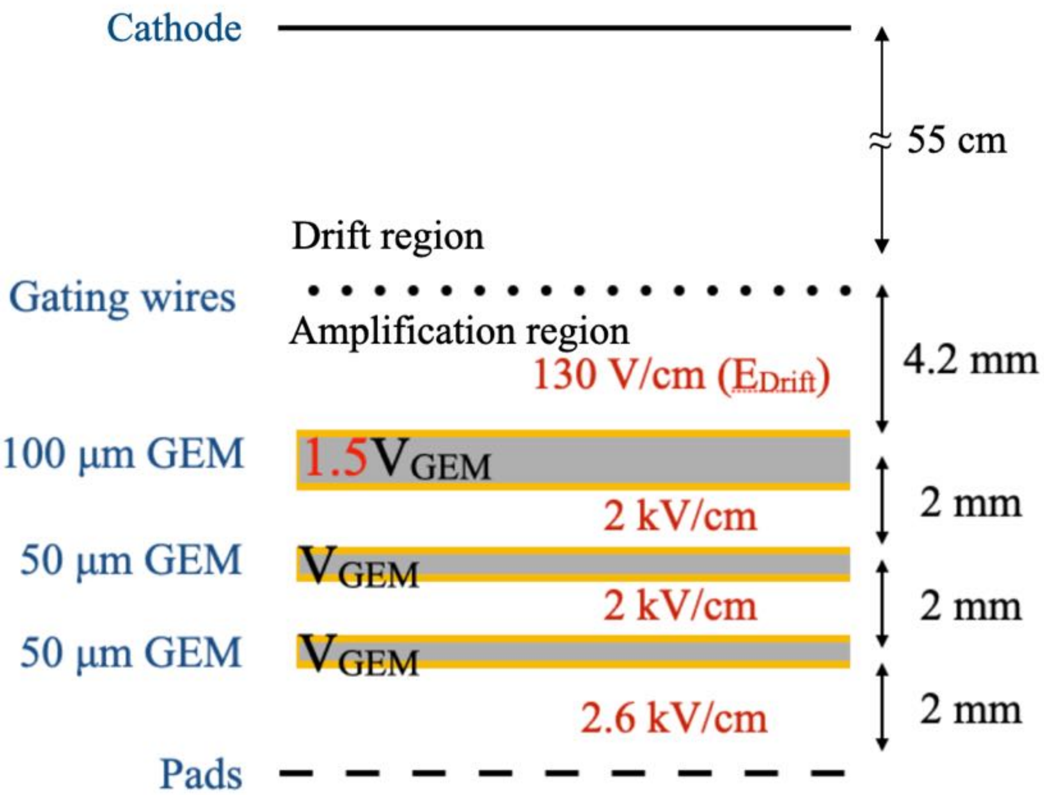
- Beam-through region

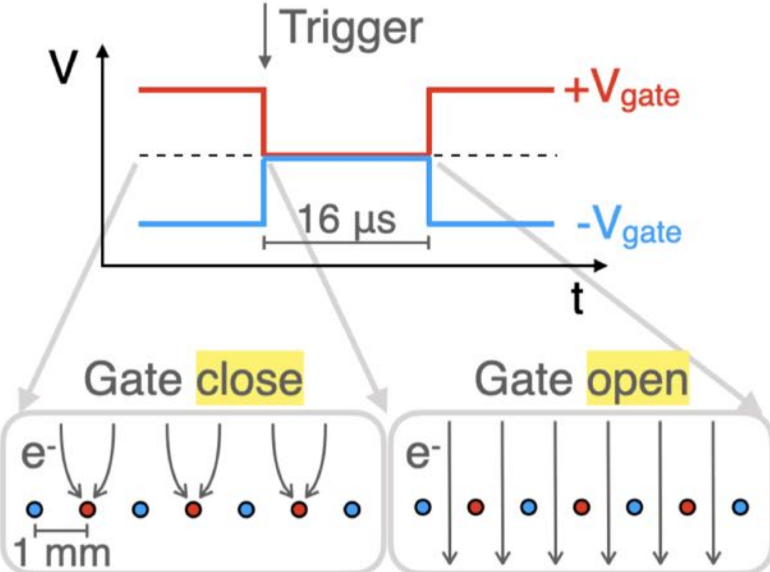


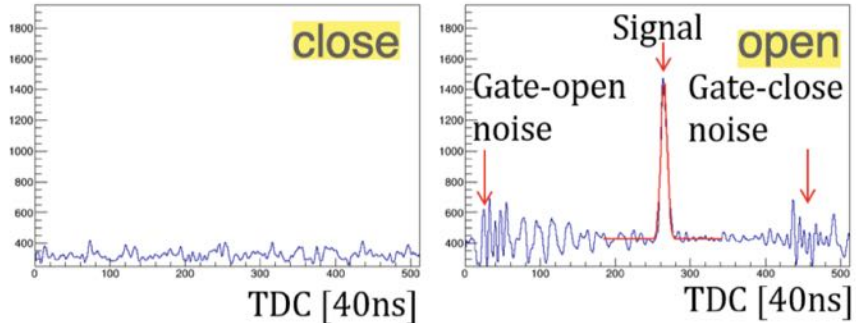
Gating Wire Plane

- Between Drift & Amplification Region
- to suppress the ion backflow
- ϕ50 μm gold-plated Cu-Be wires separated by 1 mm.

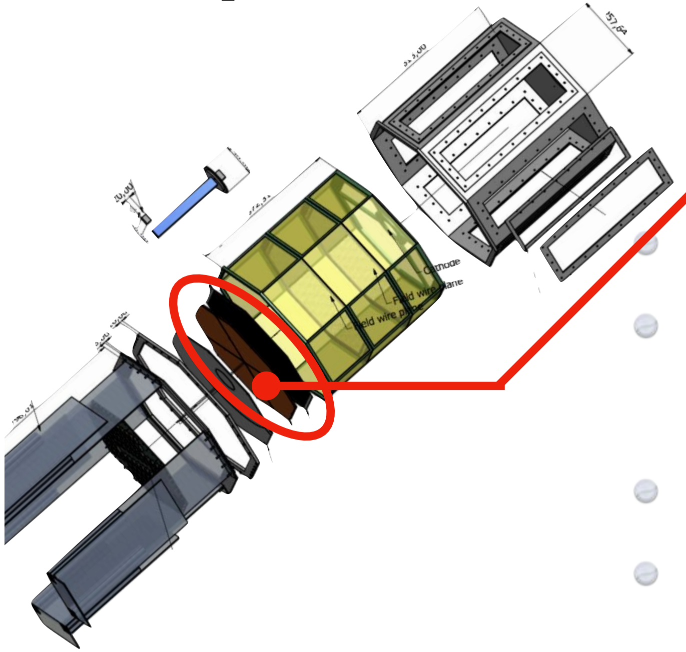






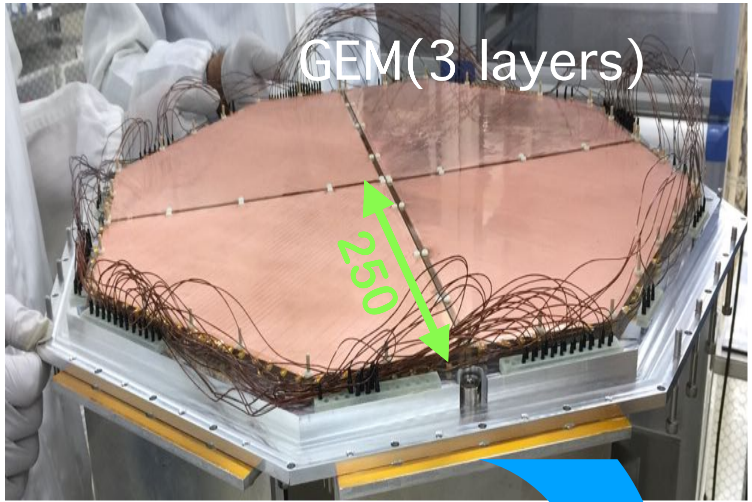


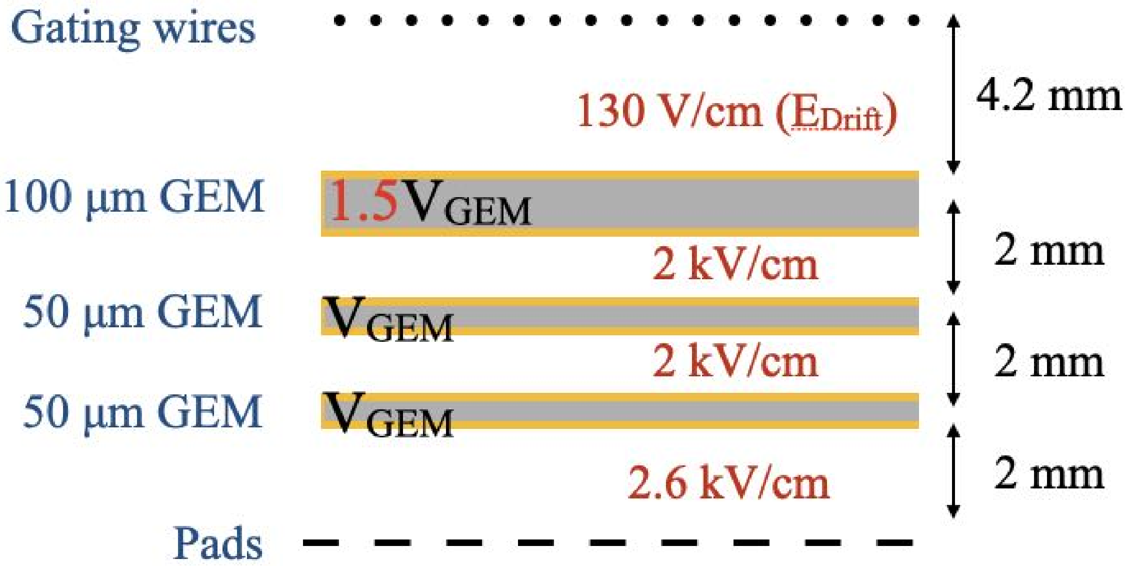
Triple GEM Layer



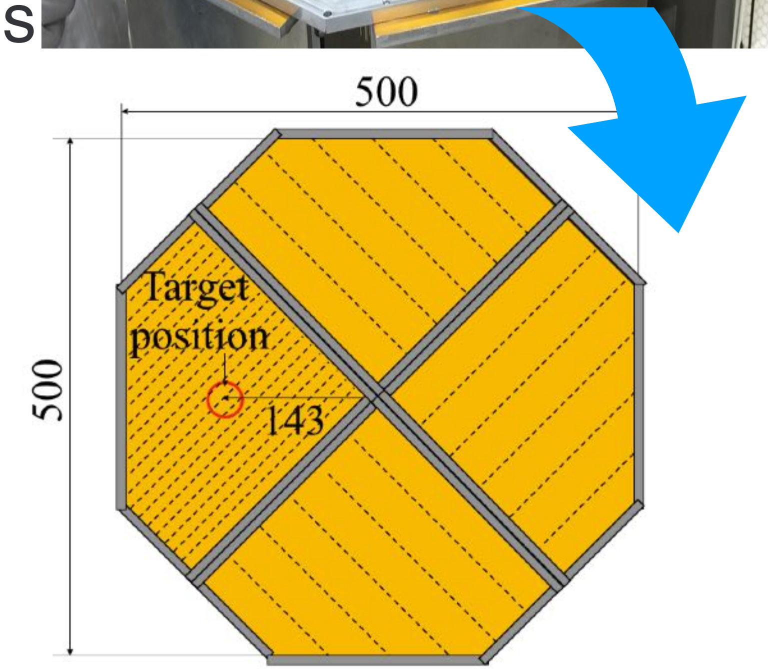
Amplification Region

- Low ion backflow rate
- Triple GEM layers (100+50+50 um)
- Gain ~10^4
- Segmented electrodes





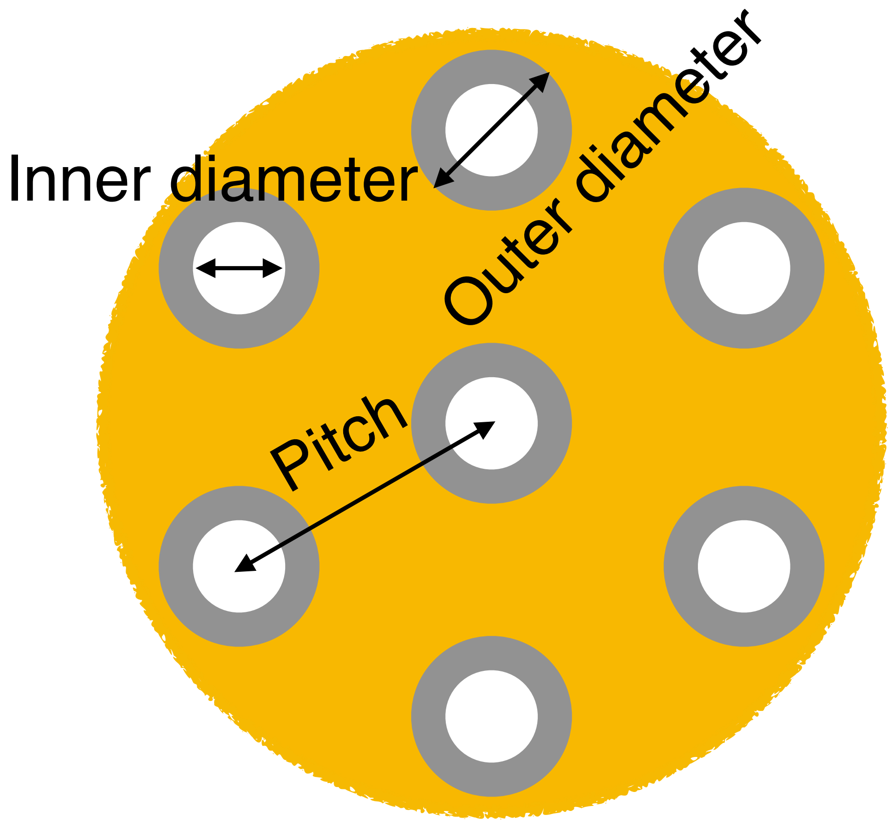
[side view]

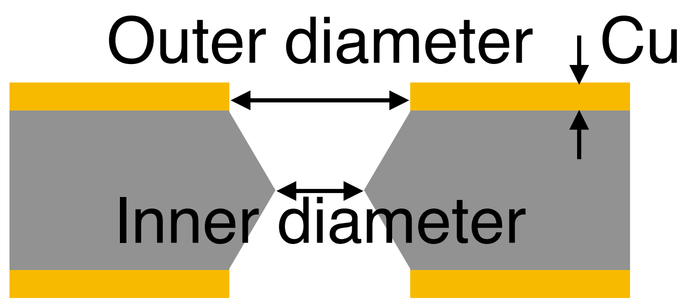


[top view]

GEM Specification

	50 µm GEM	100 µm GEM
Manufacturer	Raytech*	Raytech*
Insulator	Polyimide (PI)	Liquid Crystal Polymer (LCP)
Etching method	Wet	Laser
Cu thickness	4 µm	9 µm
Pitch	140 µm	140 µm
Inner diameter	25 ± 10 µm	35 ± 10 µm
Outer diameter	55 ± 5 µm	65 ± 5 µm

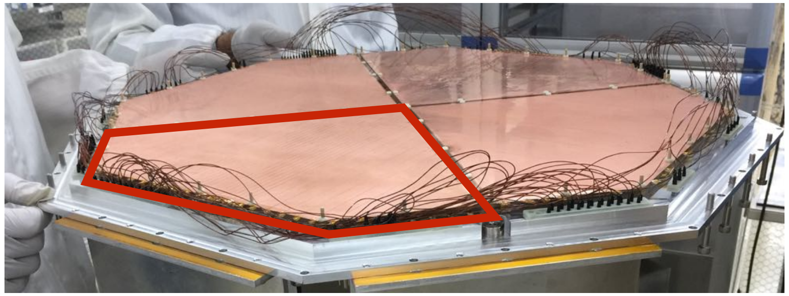




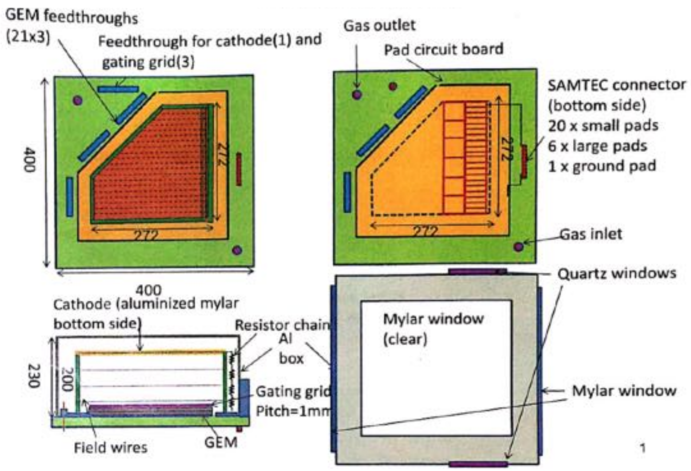
*Raytech company is now merged into Toray company.

Test Chamber

- For the systematic study of GEM
- Accommodates a quarter of HypTPC GEM



Design

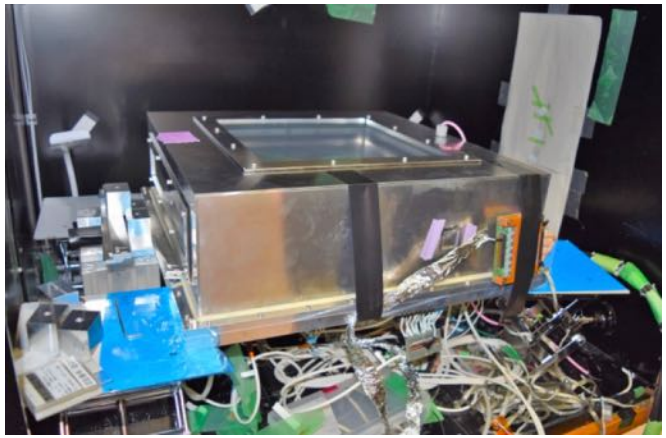


Feb. 2016

Fabrication

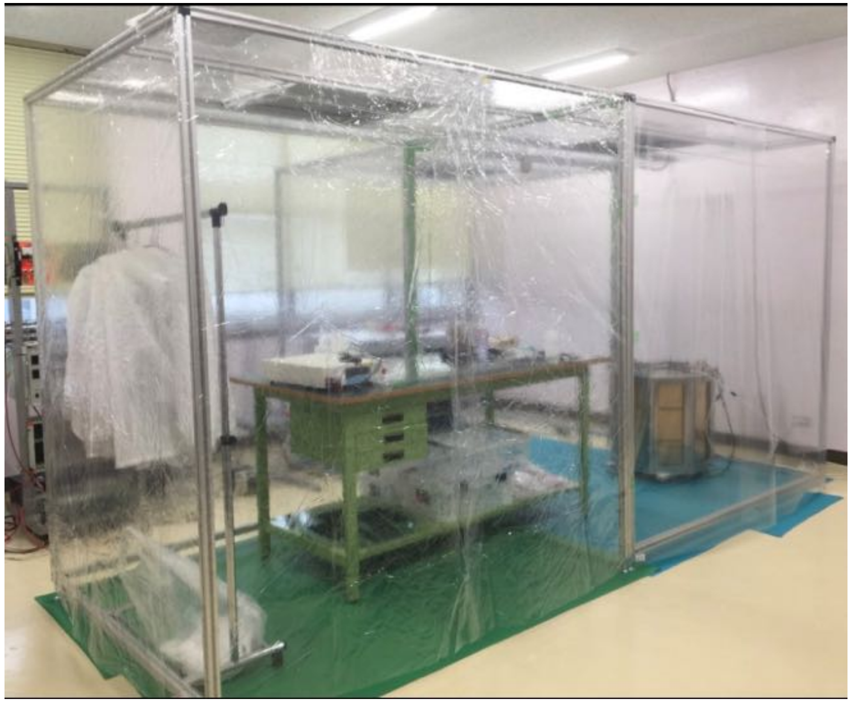
Jul. 2016

Complete

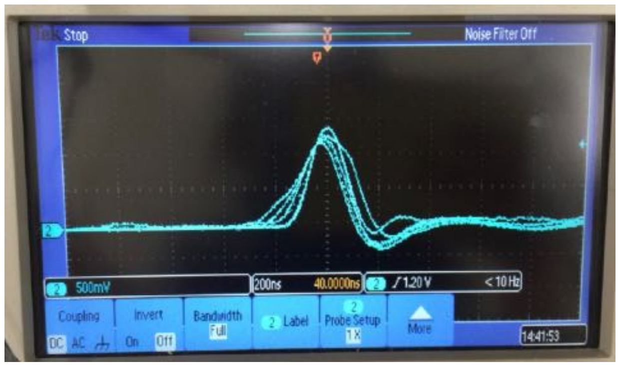


Aug. 2016

New GEM Test Bench at Co60



Jun. 2017 **Oct. 2017** **Apr. 2017**



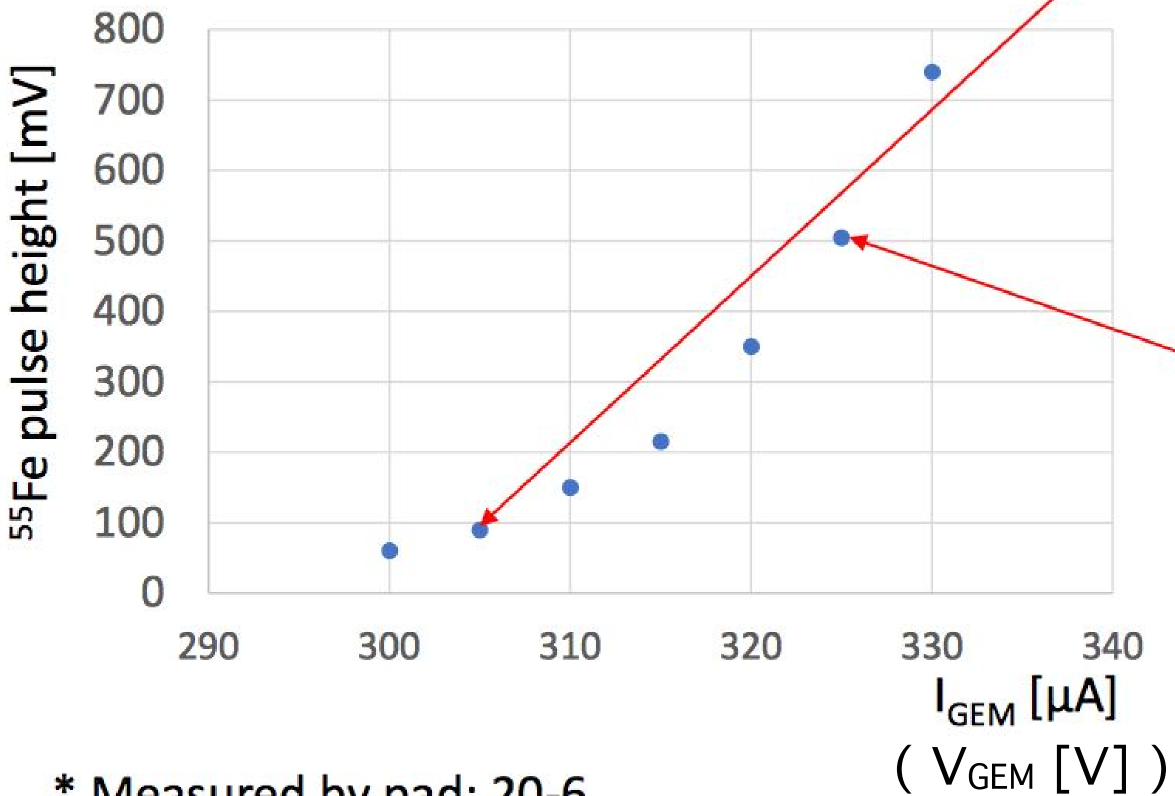
^{90}Sr signal

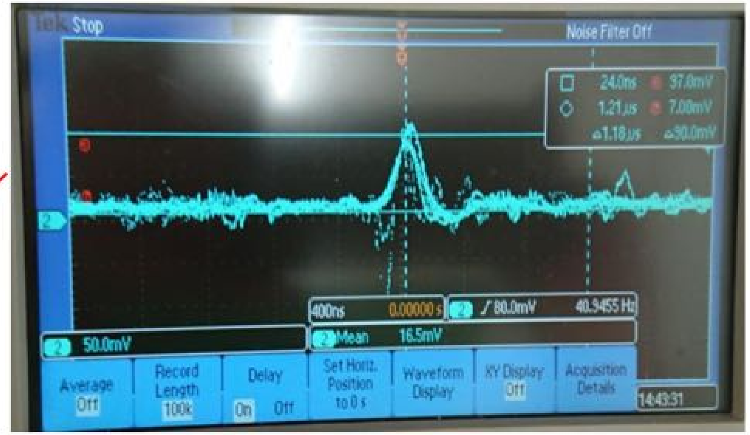
Aug. 2017

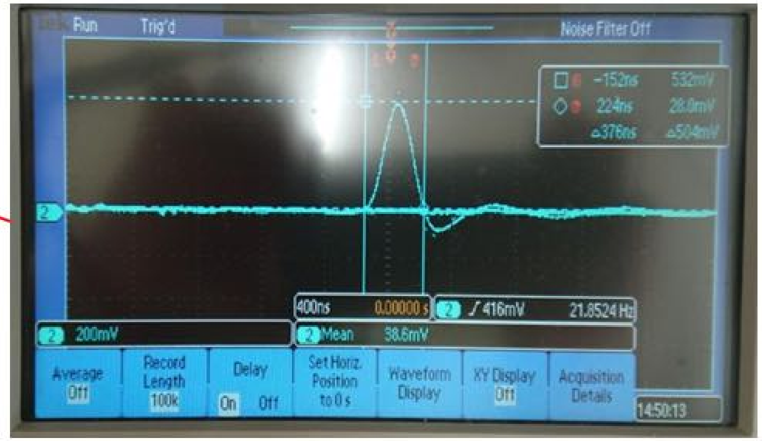
^{55}Fe Signal Height vs. V_{GEM}

^{55}Fe signals were clearly seen.

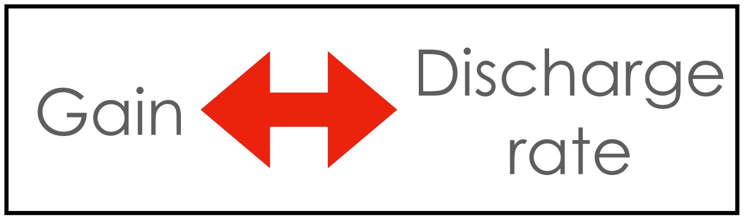
(GEM Sector 2)







* Measured by pad: 20-6.

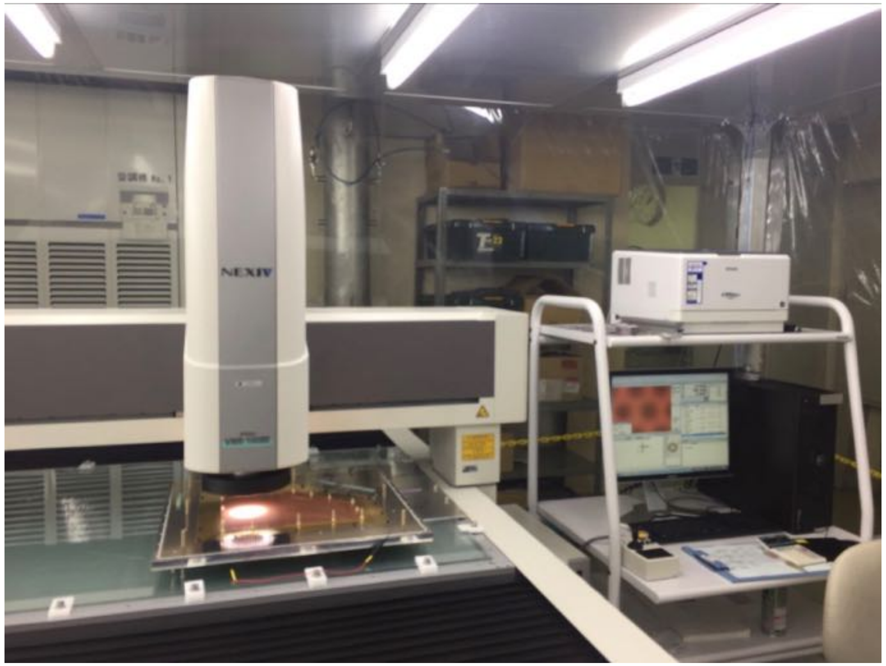


GEM Sagging Problem

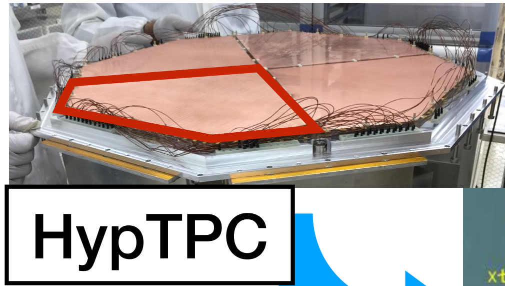
Jun. 2017

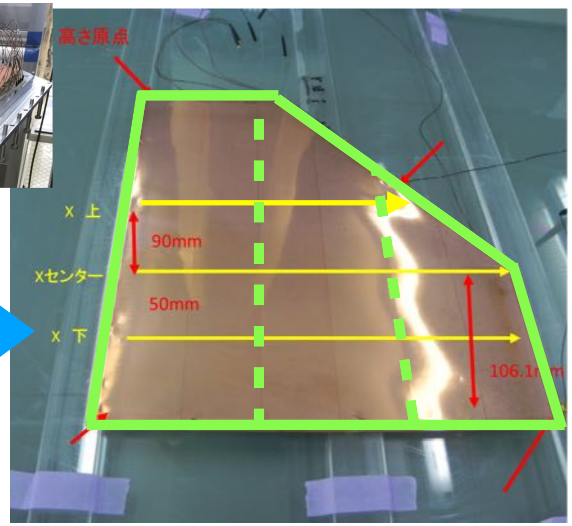
- Affects the discharge rate, the field uniformity, the dE/dx resolution
- The supporting frame was added and the gluing method was changed to solve the sagging problem.

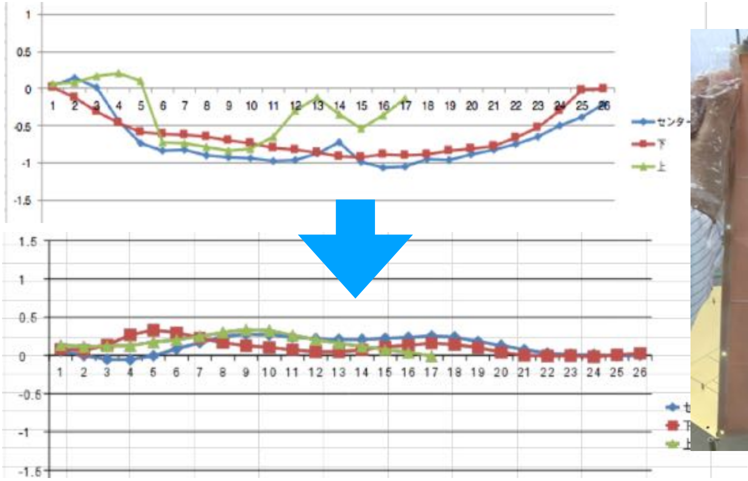
GEM height measurement



@Hayashi-REPIC



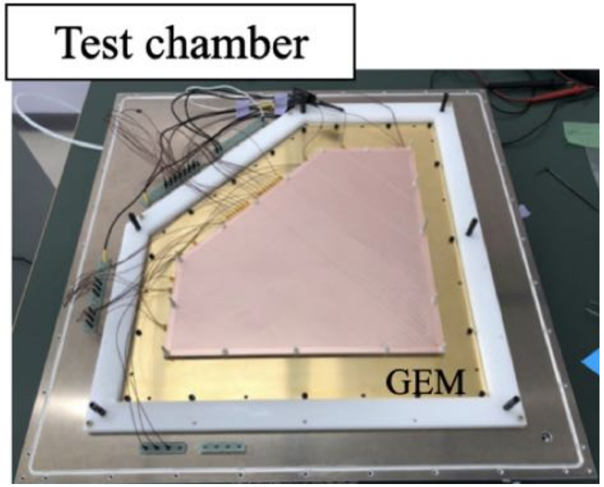


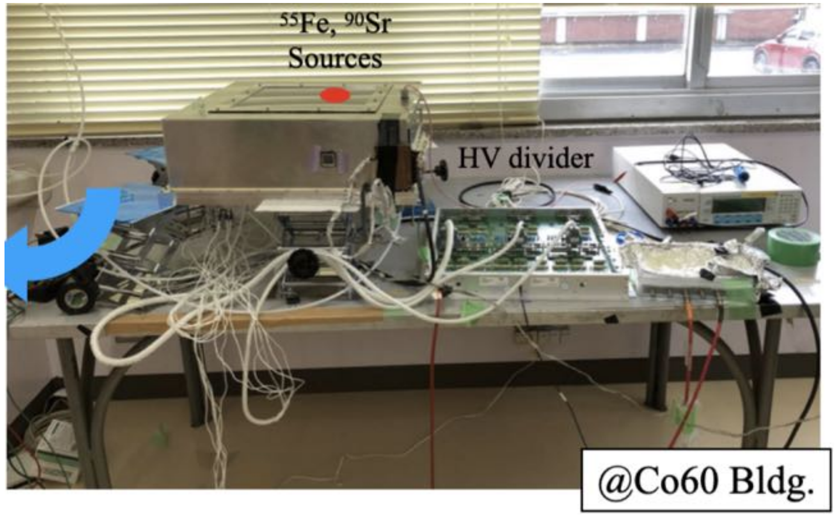


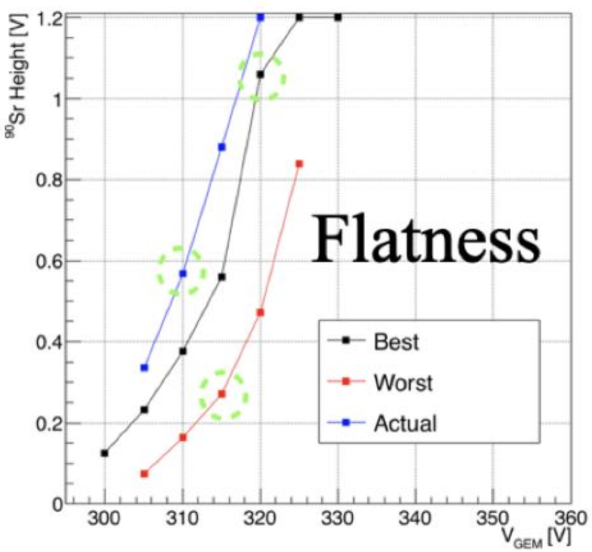
GEM Optimization

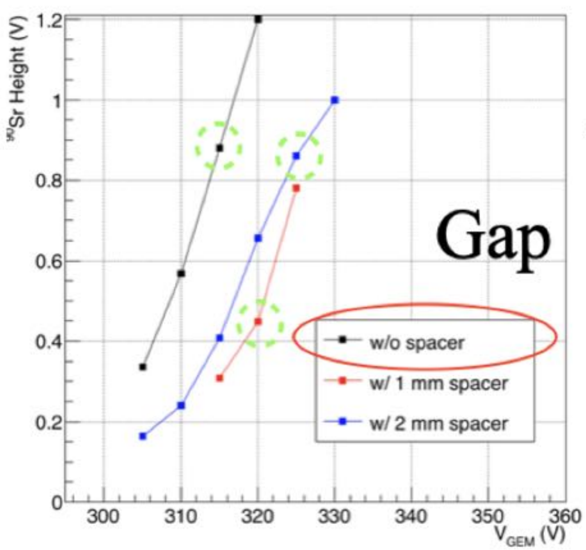
Mar. 2018

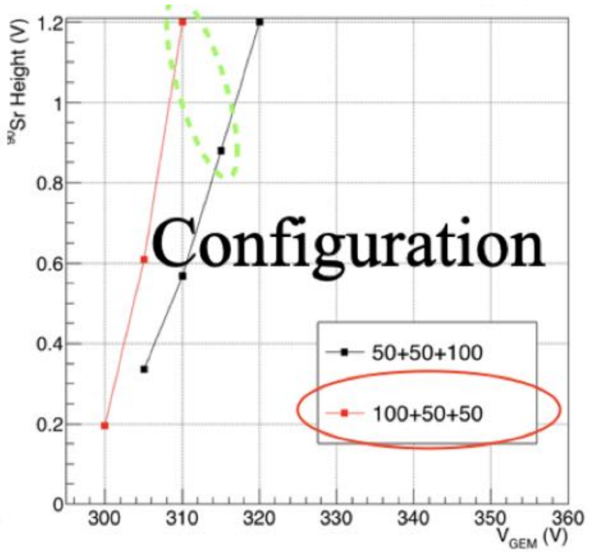
- Measure the ion backflow rate and the gain
- GEM systematic study to decide the final GEM configuration.



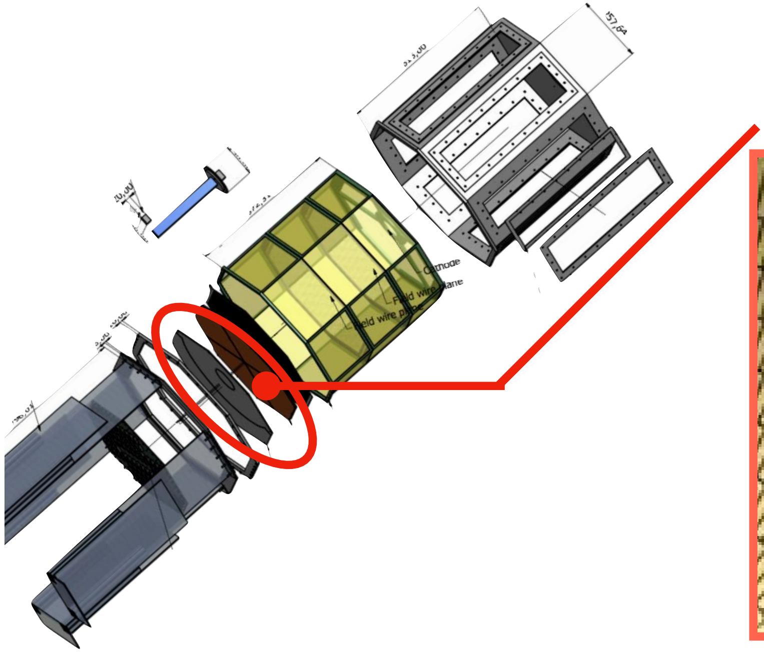


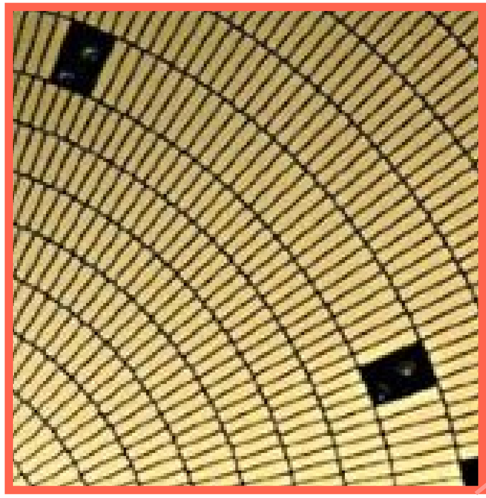


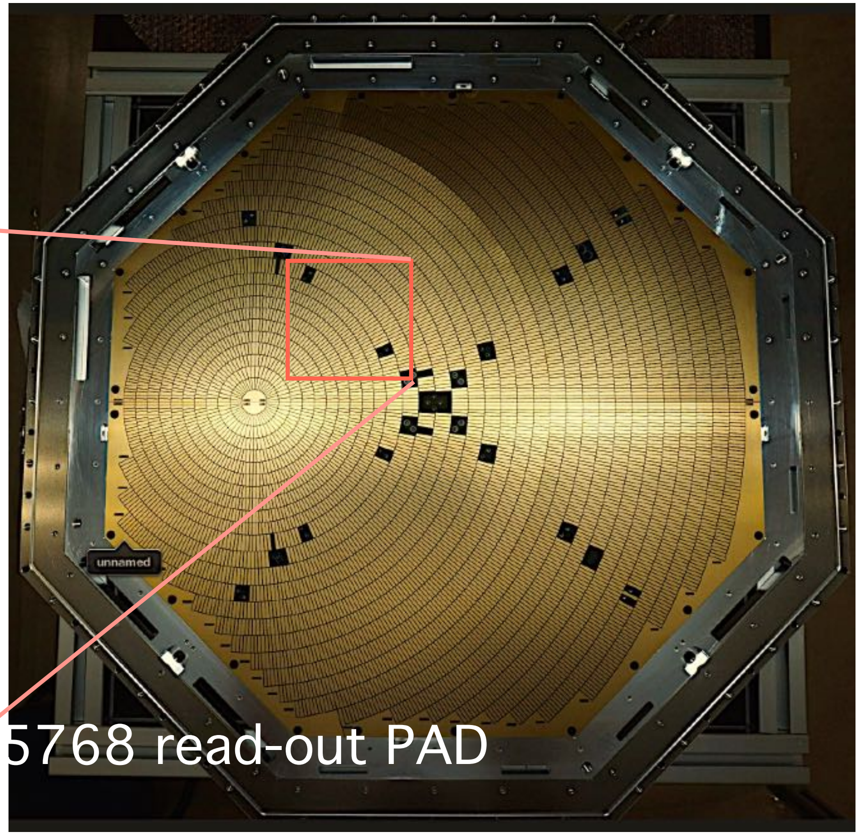




Pad Plane



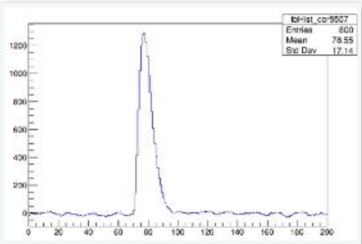


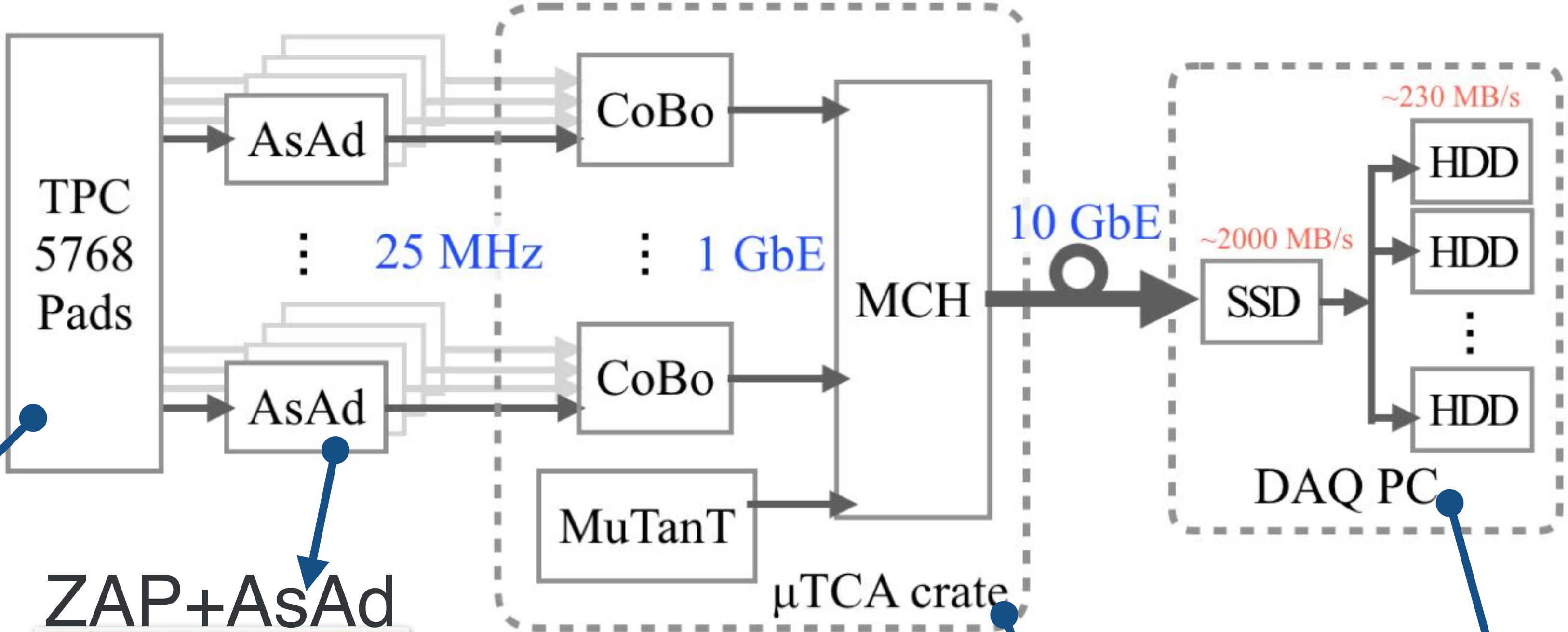


- 5768 readout pads
- Concentric configuration around the target
- 10 inner layers:
  2.1-2.7 × 9 mm²
- 22 outer layers:
  2.3-2.4 × 12.5 mm²

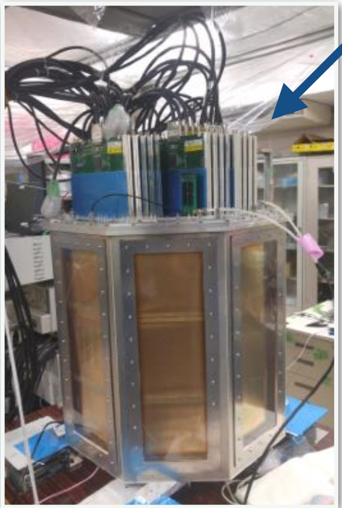
GET(General Electronics for TPCs)

E. Pollacco et al., NIMA 887 (2018) 81

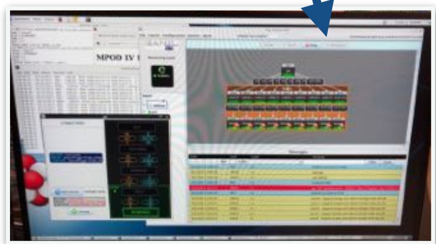




HypTPC



ZAP+AsAd



4 AGET chips
- Preamplifier(gain 120 fC-10 pC)
- Shaper(peaking time 50 ns-1 μs)
- Circular Buffer(sampling rate 1-100 MHz)

12-bit ADC

CoBo
- Data processing
- Data formatting

MuTanT
- synchronous trigger

MCH(μTCA Carrier Hub)

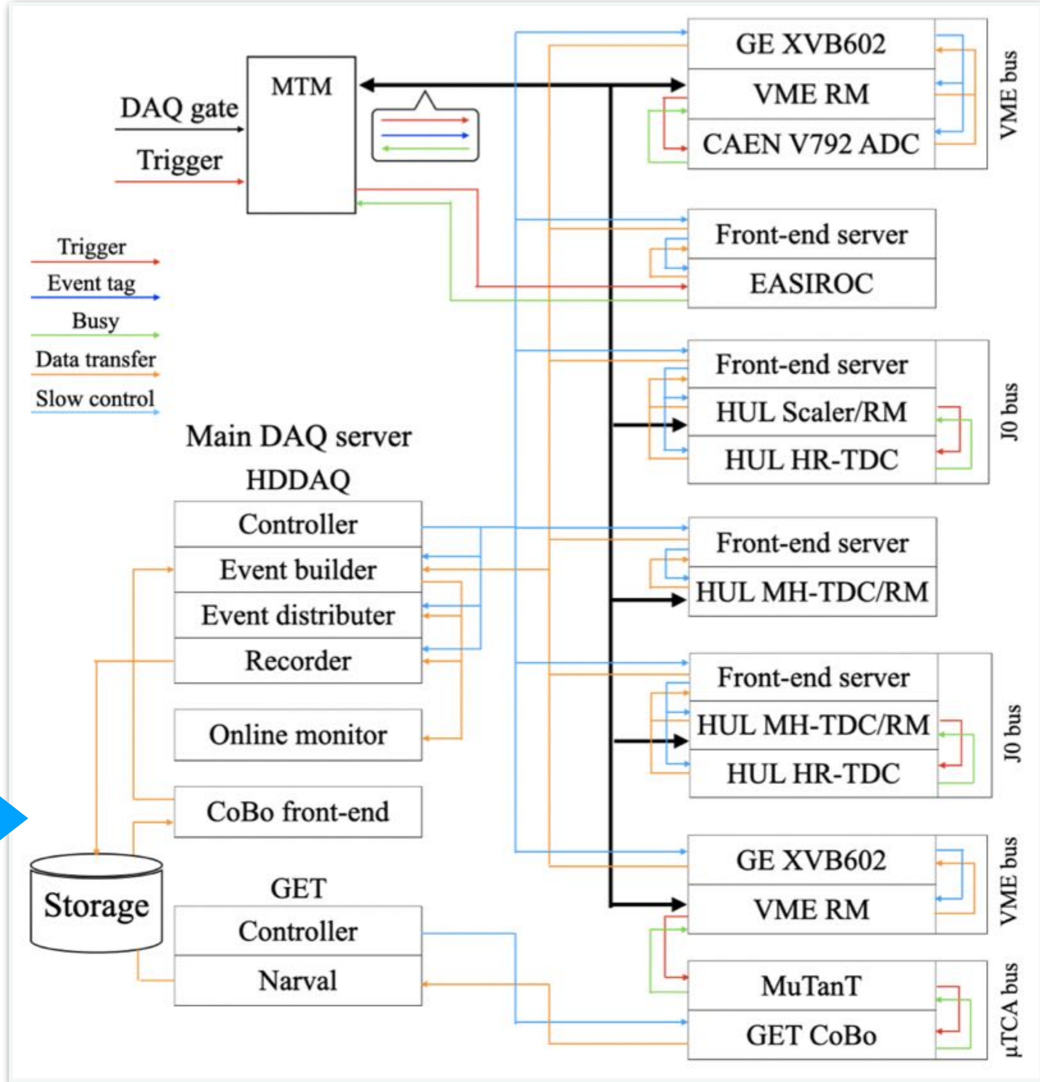
DAQ PC
- Run control
- Data flow manage
- Data storage

HypTPC DAQ Software

GetController **2015**

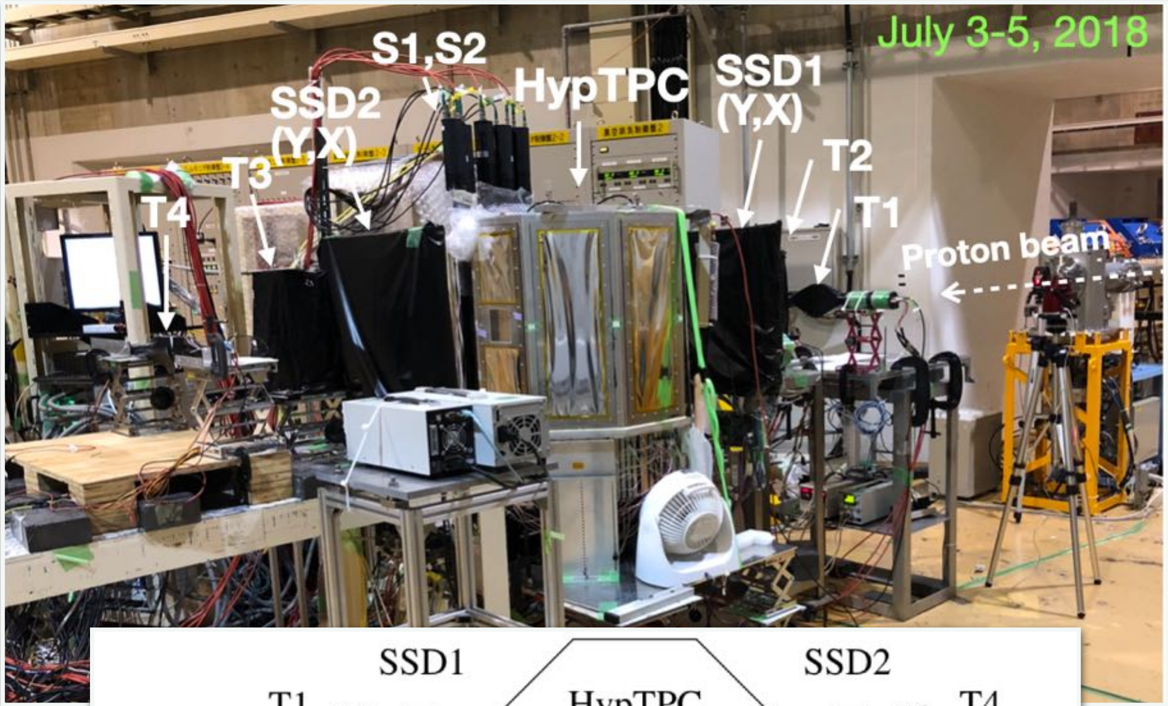
GANIL DAQ **Nov. 2017**
for multi-CoBo system

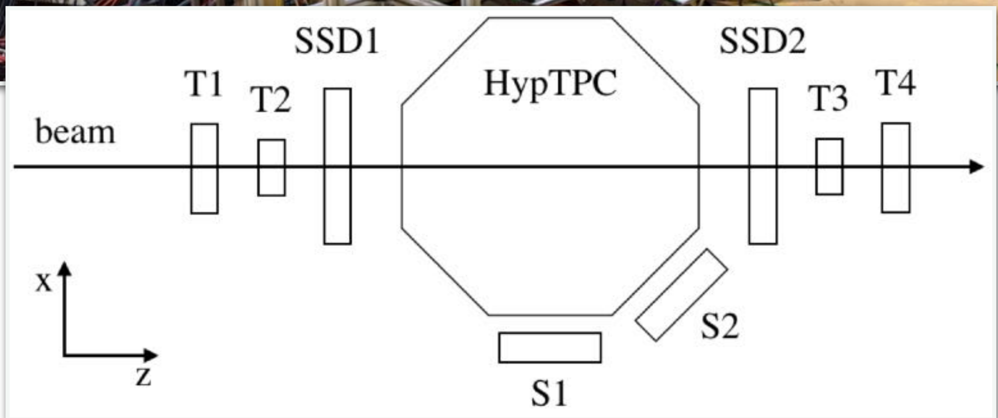
Combined with HDDAQ **2021**



HypTPC Commissioning at HIMAC Jul. 2018

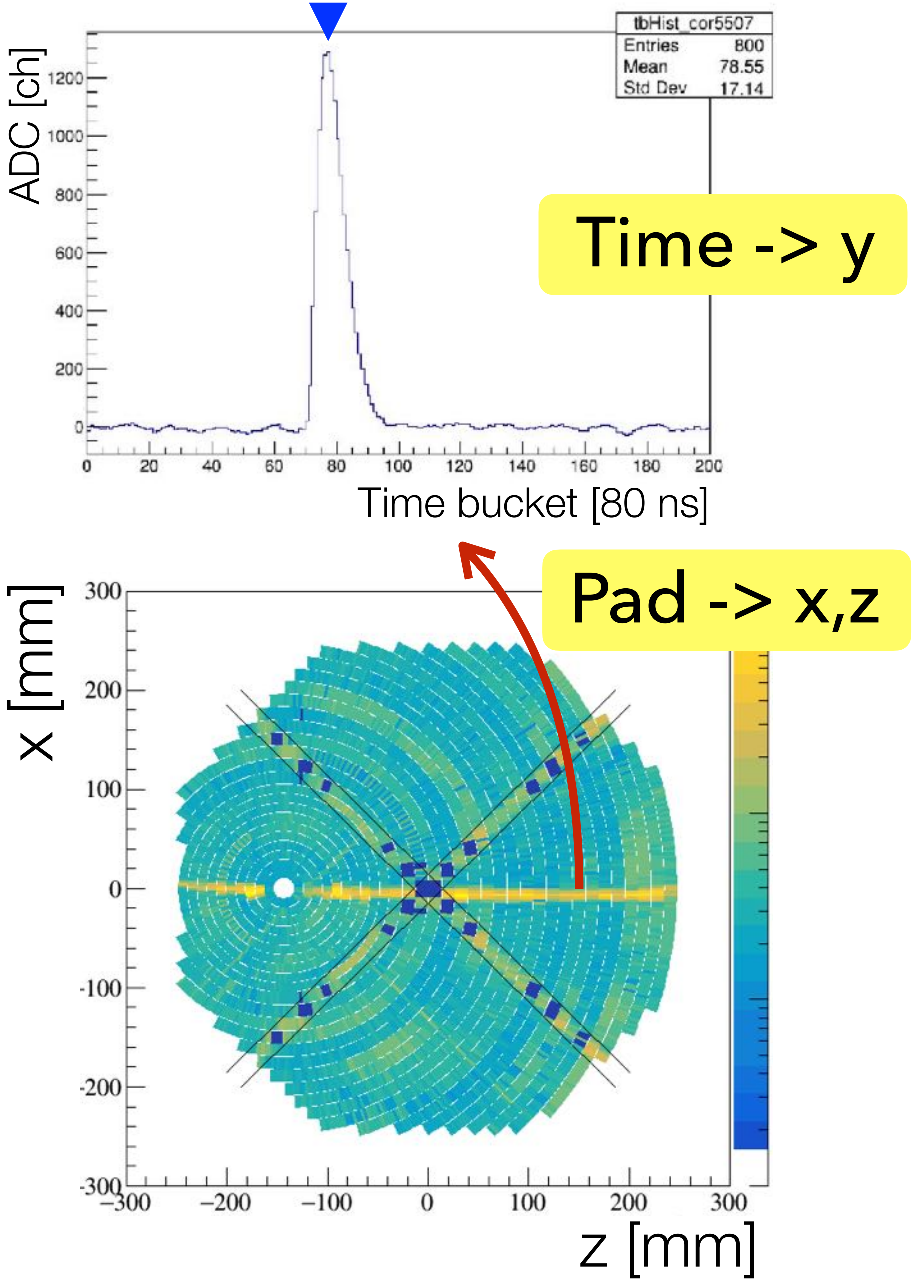
- To confirm the basic performance and high rate capability of HypTPC



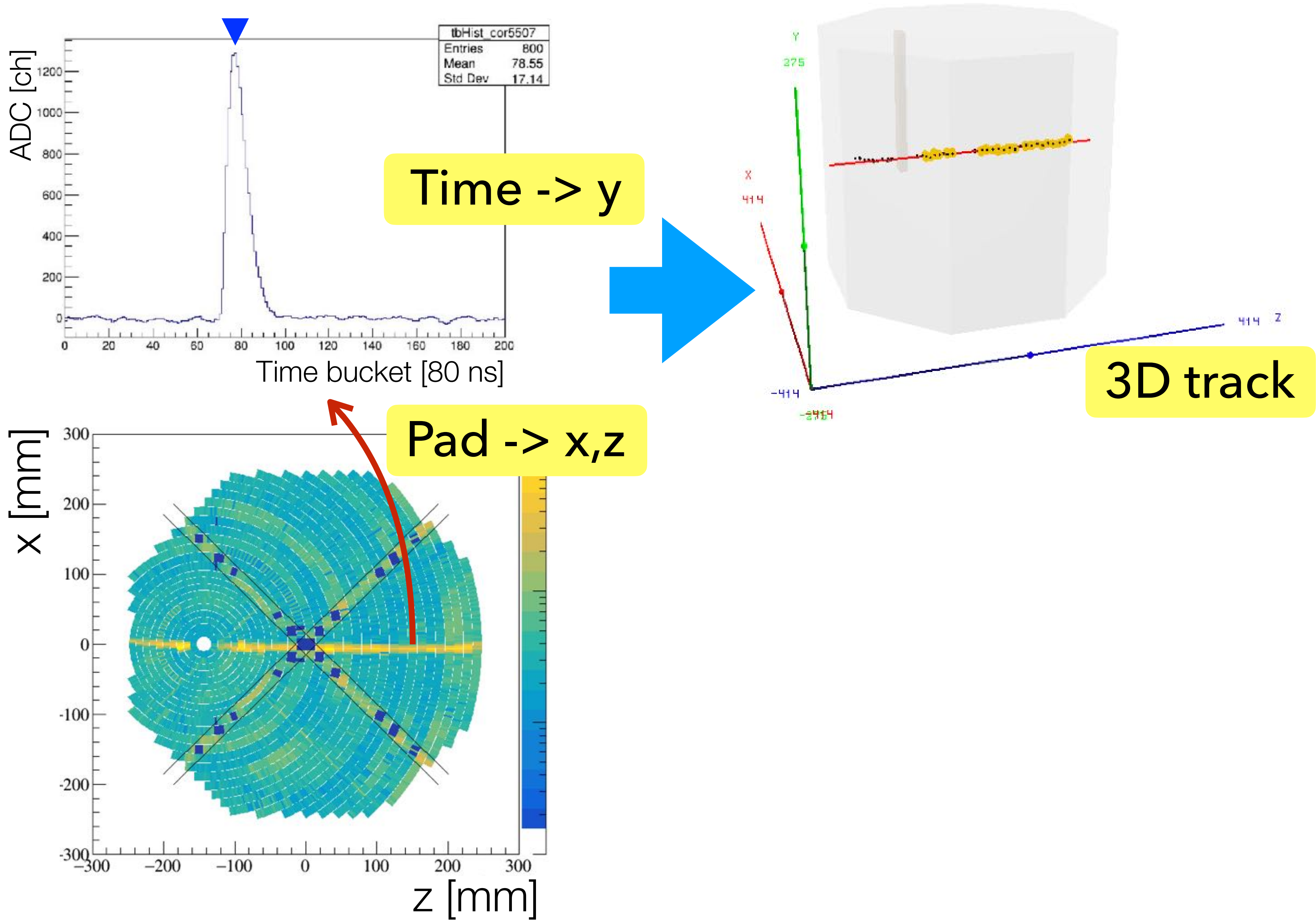


NIMA 940 (2019) 359

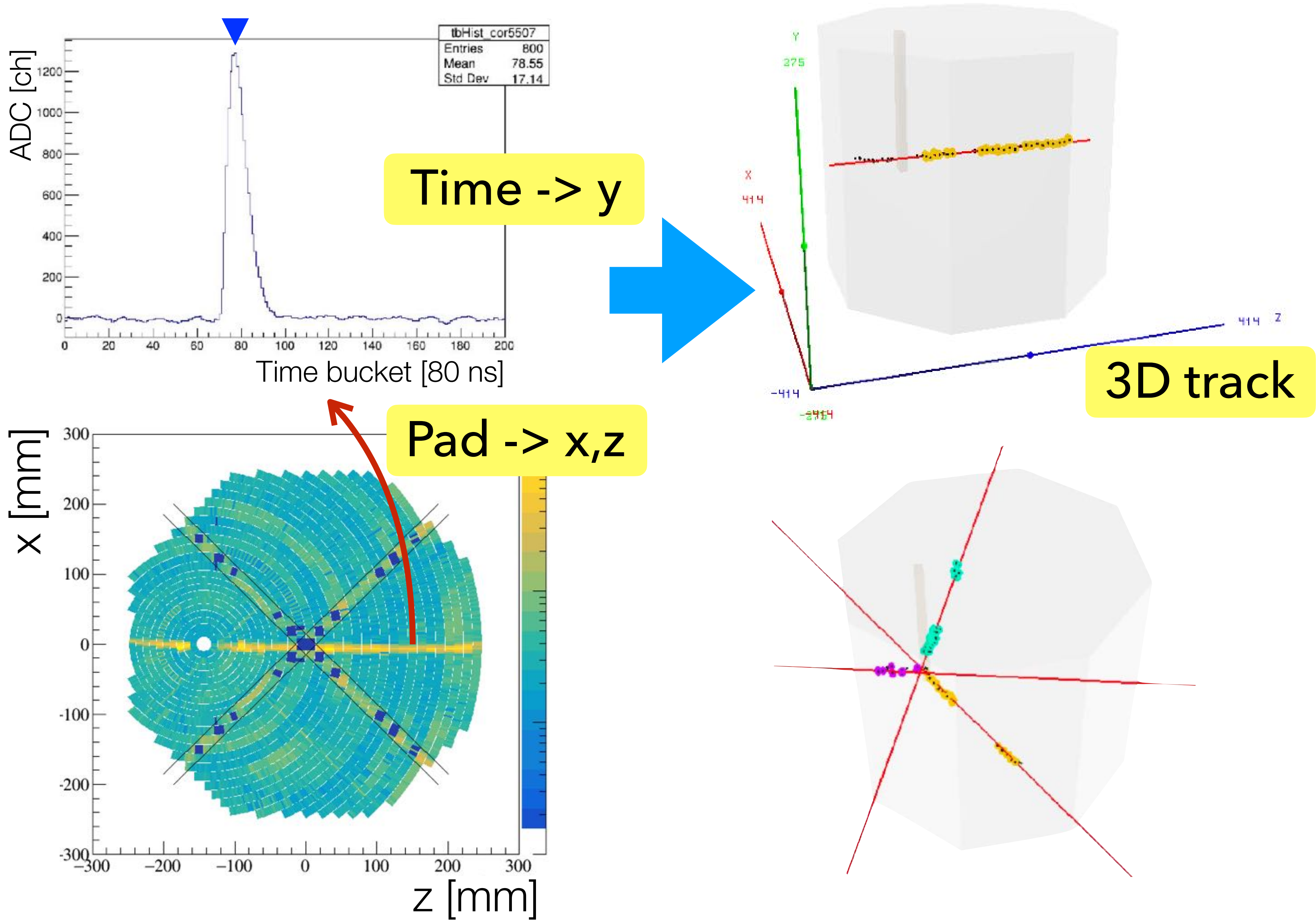
Track Reconstruction



Track Reconstruction

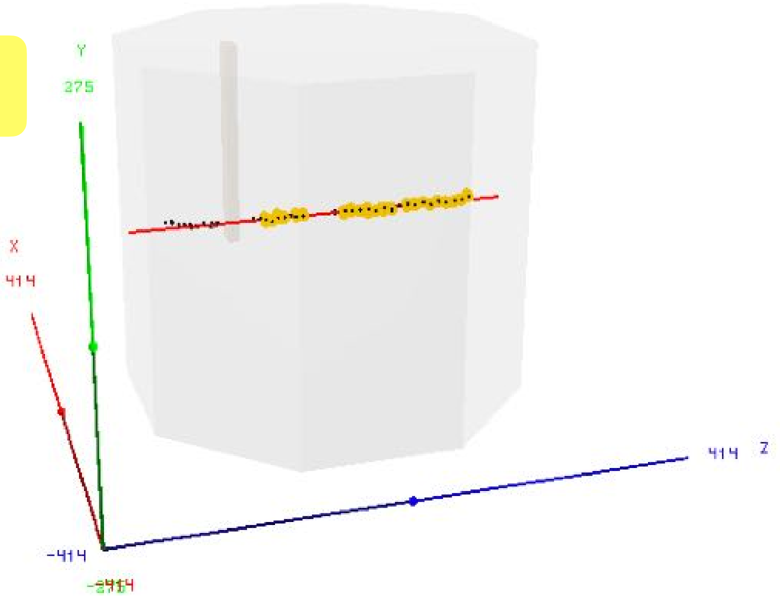


Track Reconstruction

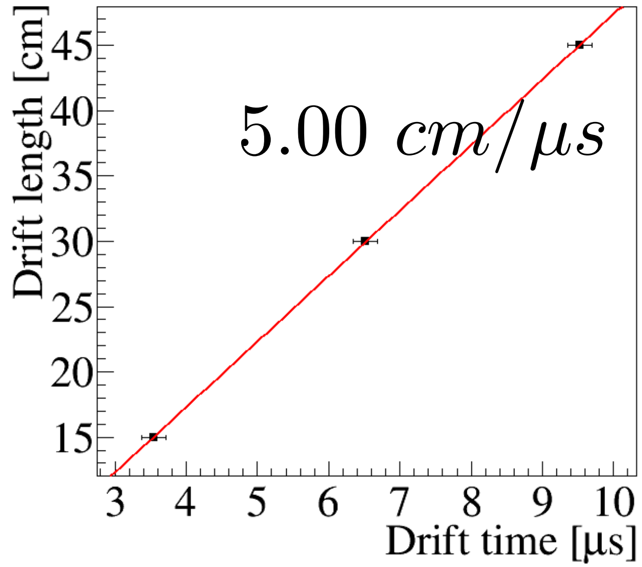


Basic Performance

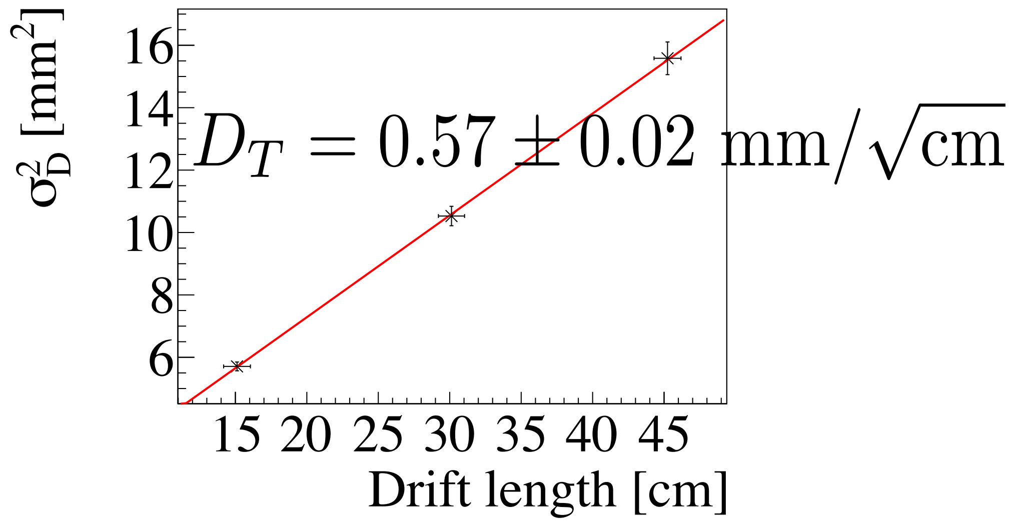
3D track



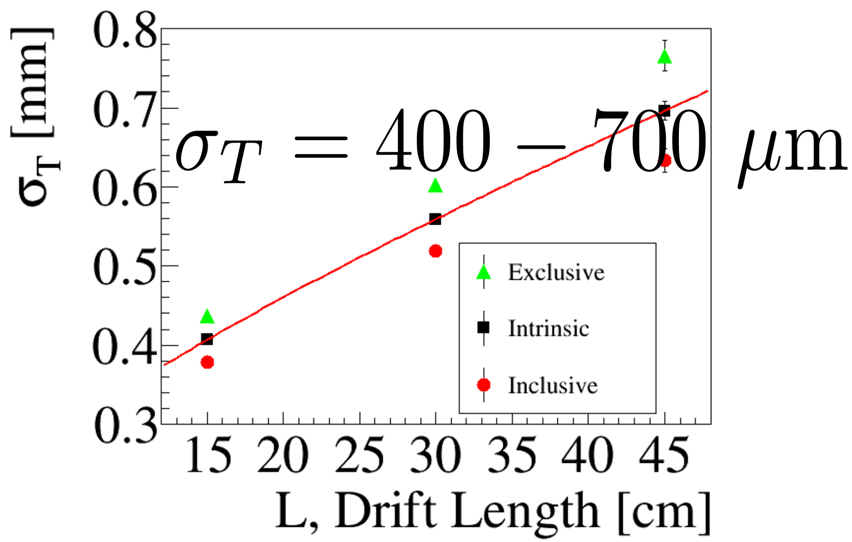
▸ Drift velocity



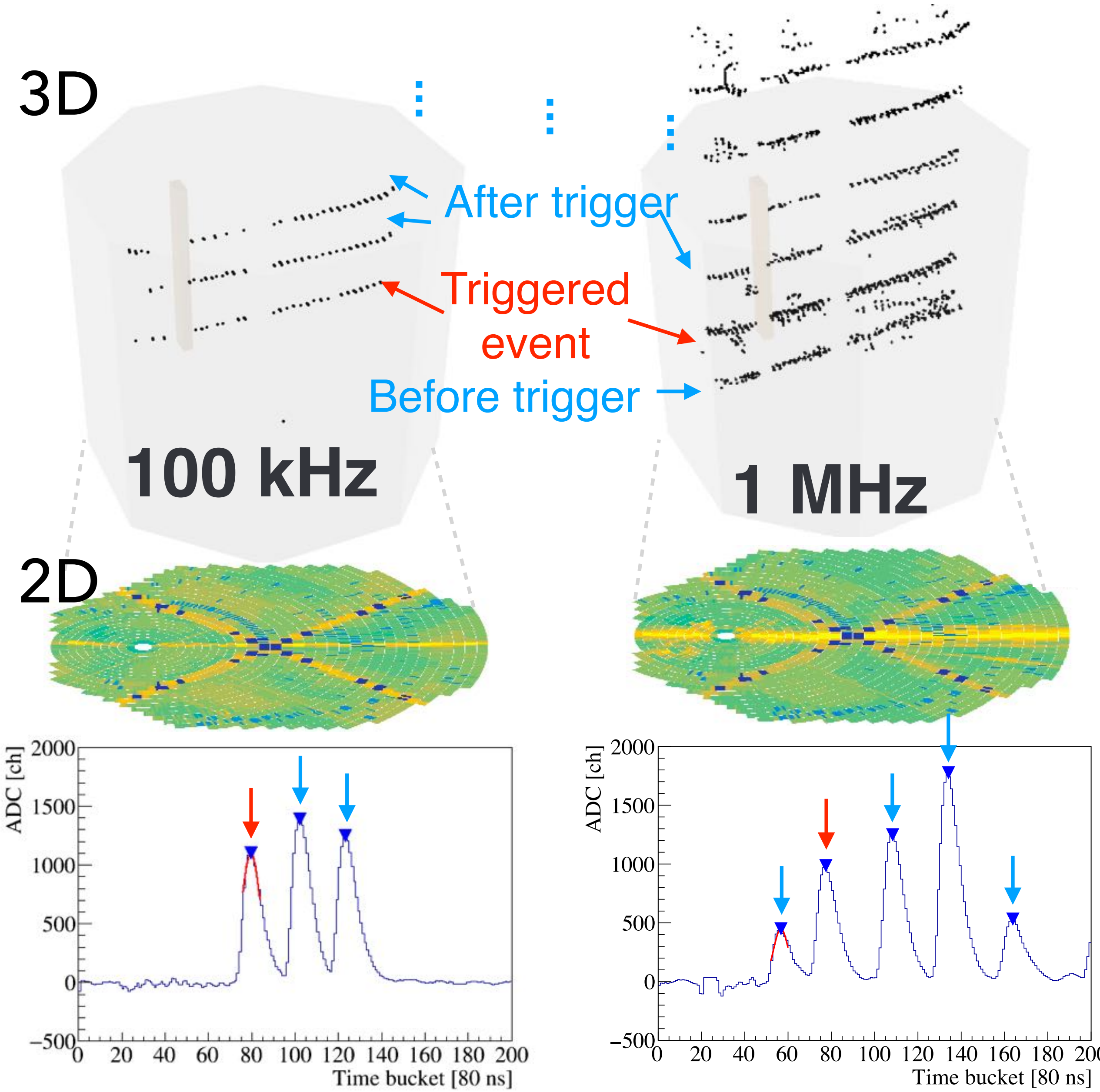
▸ Diffusion Coefficient



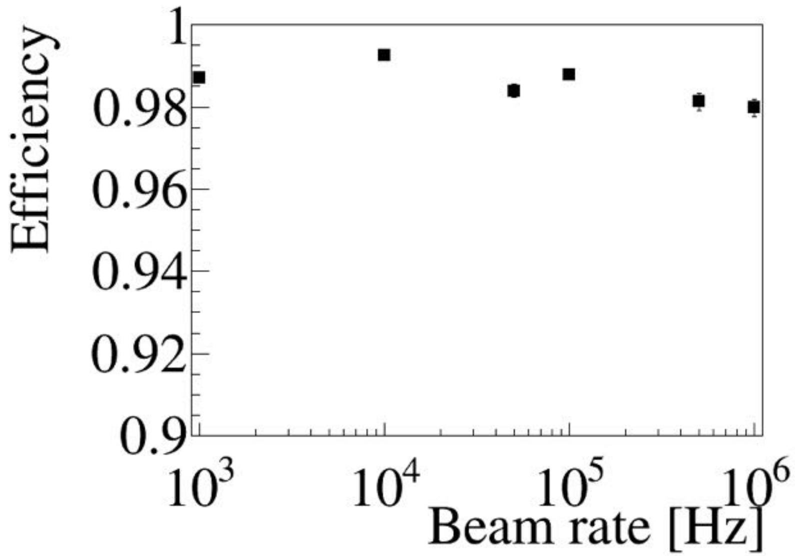
▸ Spatial Resolution



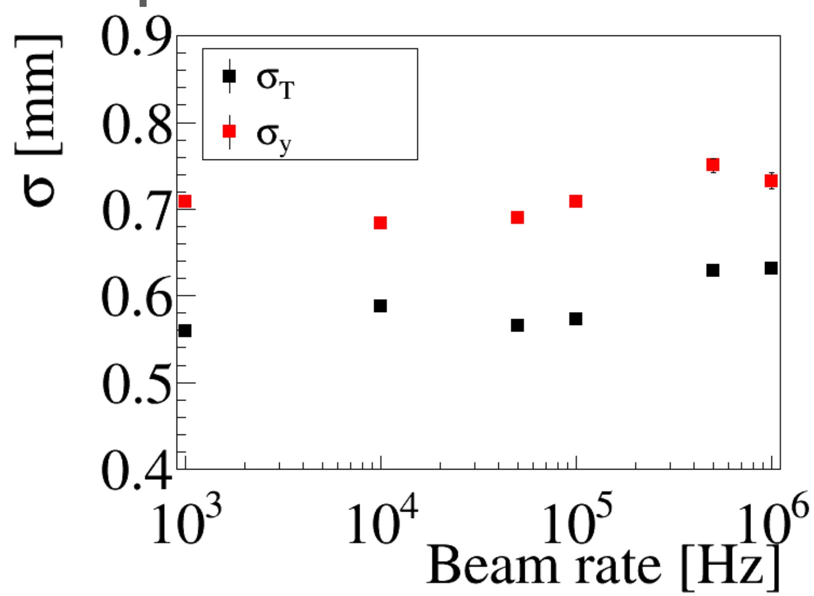
High-rate Capability



- Pad Efficiency



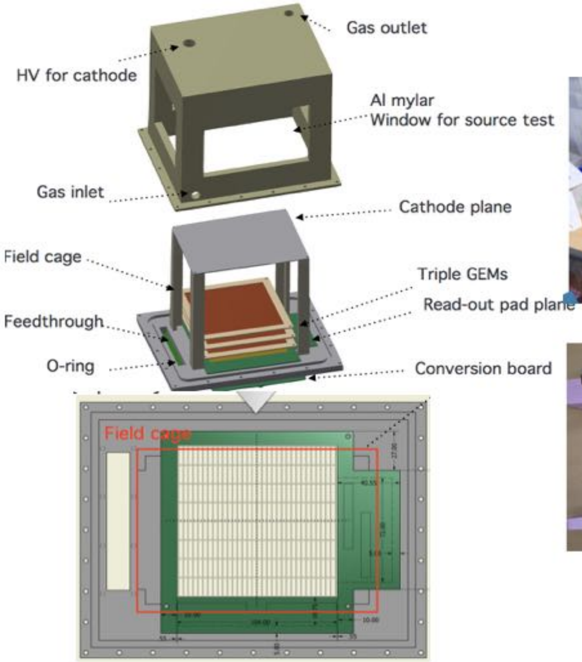
- Spatial Resolution

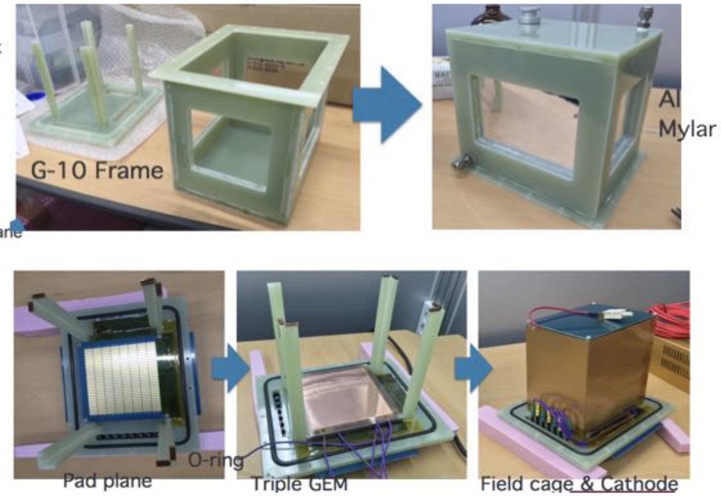


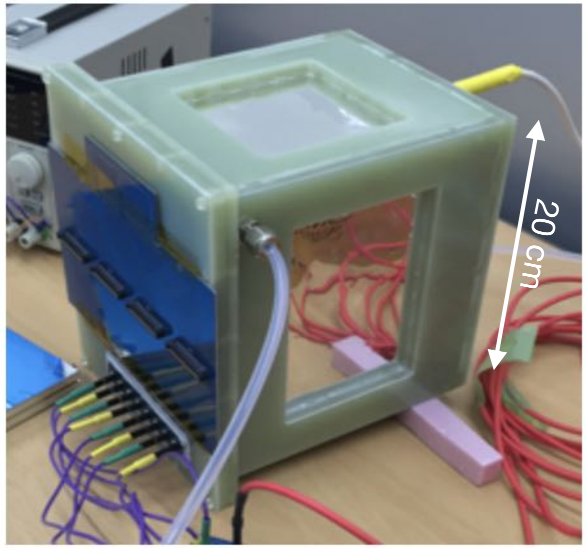
sTPC **Jan. 2015~**

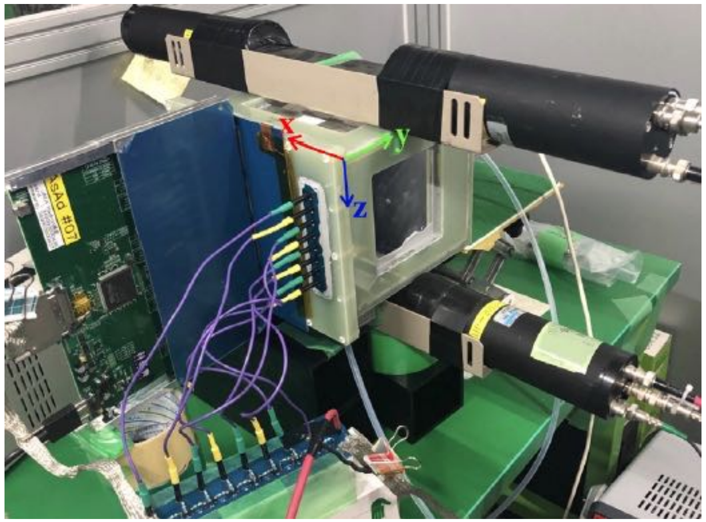
S.H. Kim *et al.*, NIMA 962, 163687 (2020)

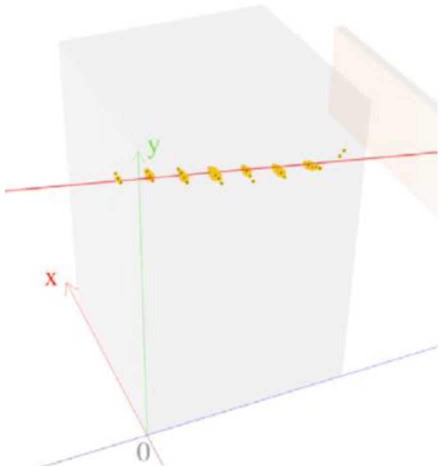
Design & Order parts | Fabrication | Complete

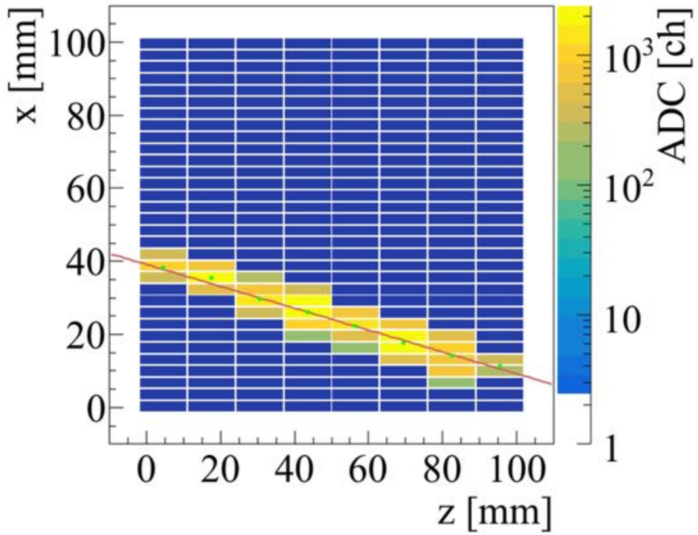








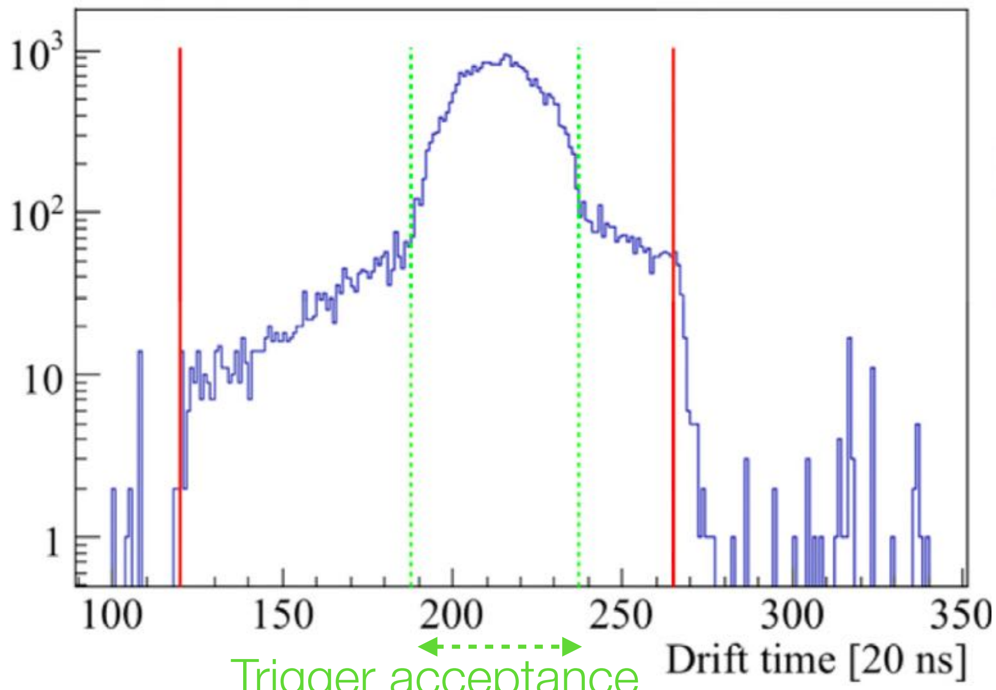




3D Track Reconstruction

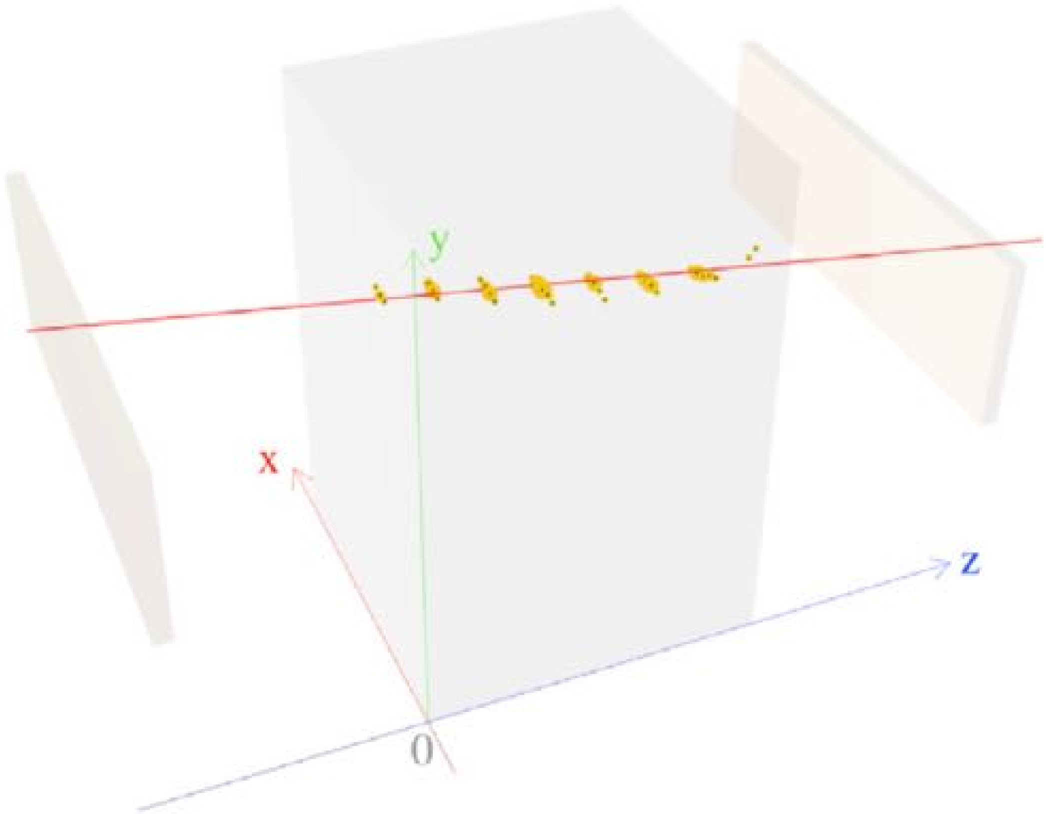
At E=150 V/cm in P-10 gas,
Drift Velocity = **5.21 cm/μs**

x, z <- pad plane
y <- drift time

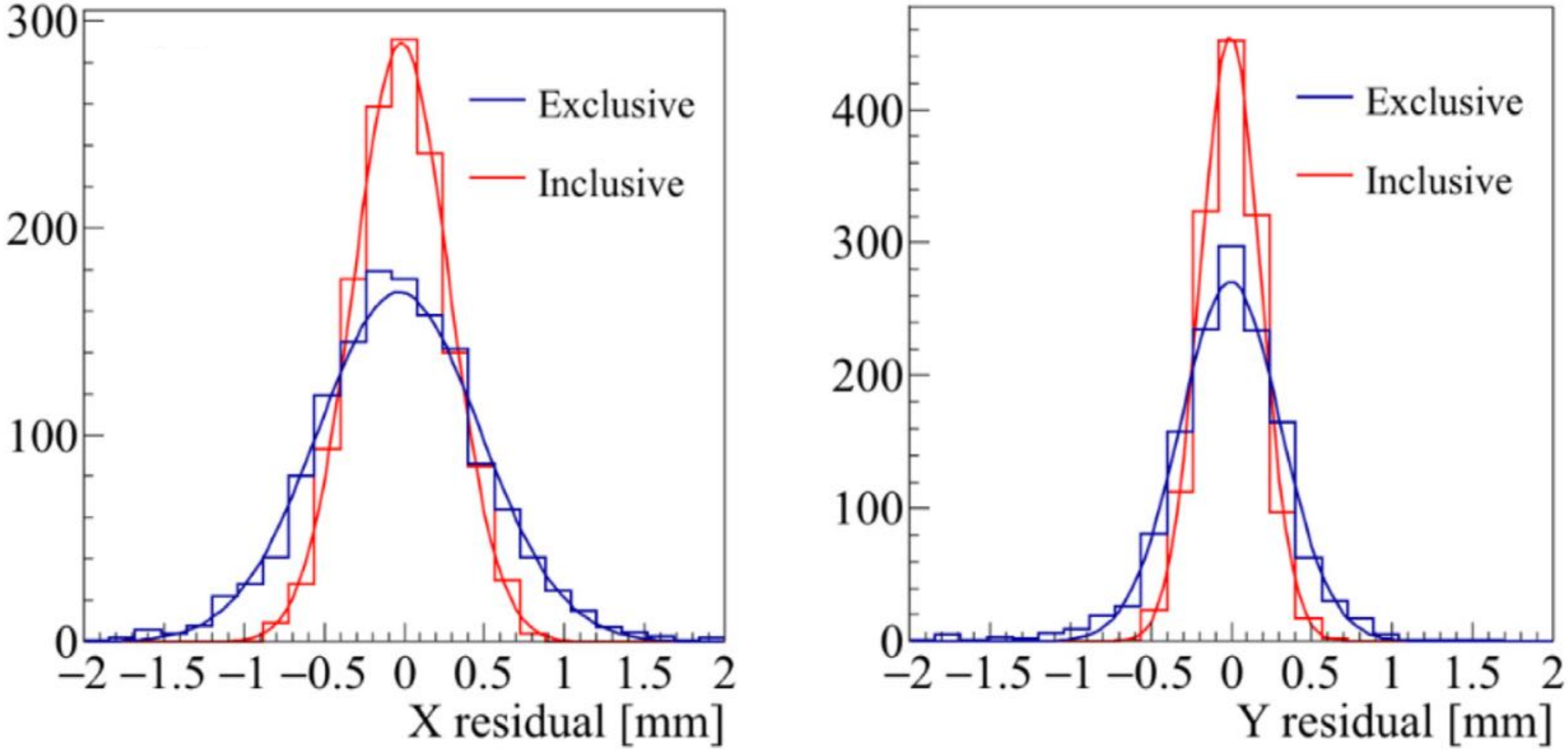


Trigger acceptance

sTPC drift length



Position resolutions



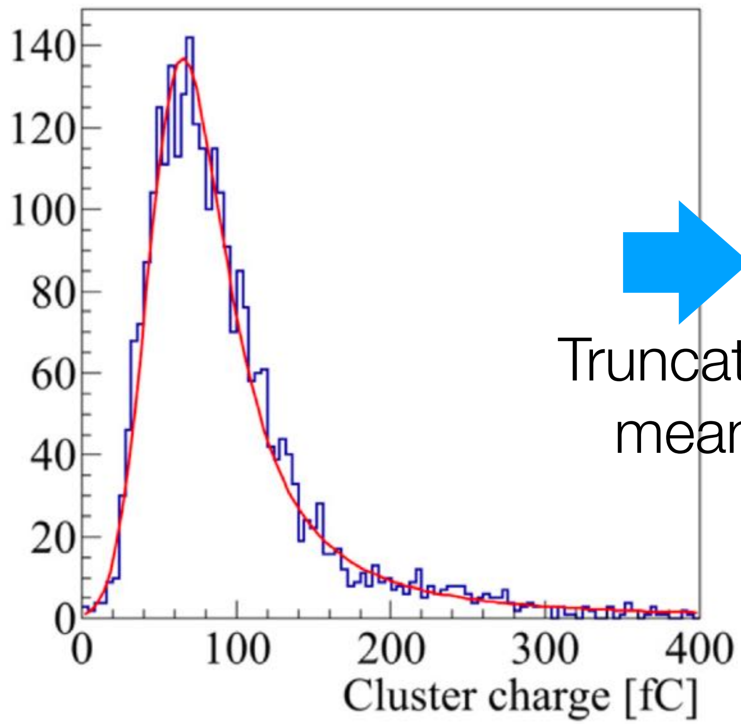
E=150 V/cm, B=0, P-10 gas

→ σ_{incl}, σ_{excl}

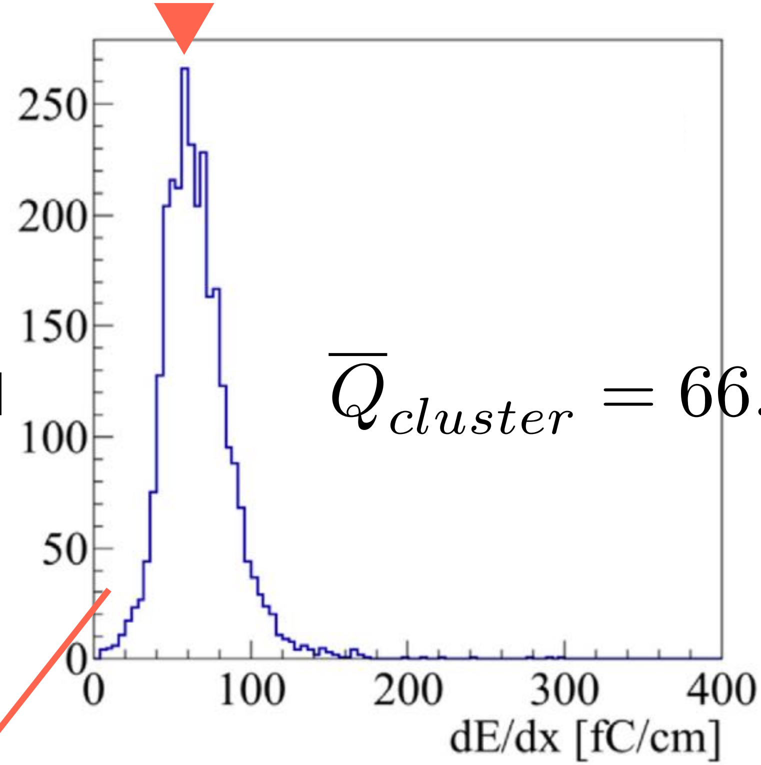
$$\sigma = \sqrt{\sigma_{\text{incl}} \cdot \sigma_{\text{excl}}}$$

→ $\sigma_x = 350\ \mu\text{m},\ \sigma_y = 250\ \mu\text{m}$

Gain



Truncated mean



$\overline{Q}_{cluster} = 66.0 \text{ fC}$

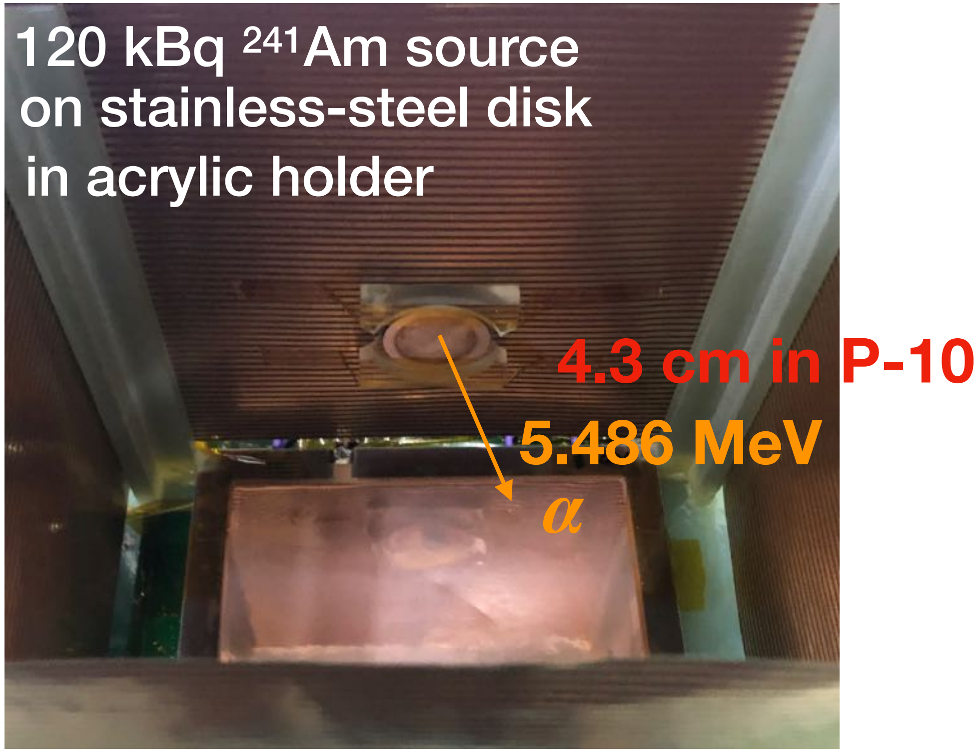
$$G = \frac{\overline{Q}_{\text{cluster}}}{(\Delta E / \overline{I}) \cdot e} = \frac{\overline{Q}_{\text{cluster}}}{Q_{\text{in}}} = 4.4 \times 10^3 \quad (V_{\text{GEM}} = 330 \text{ V})$$

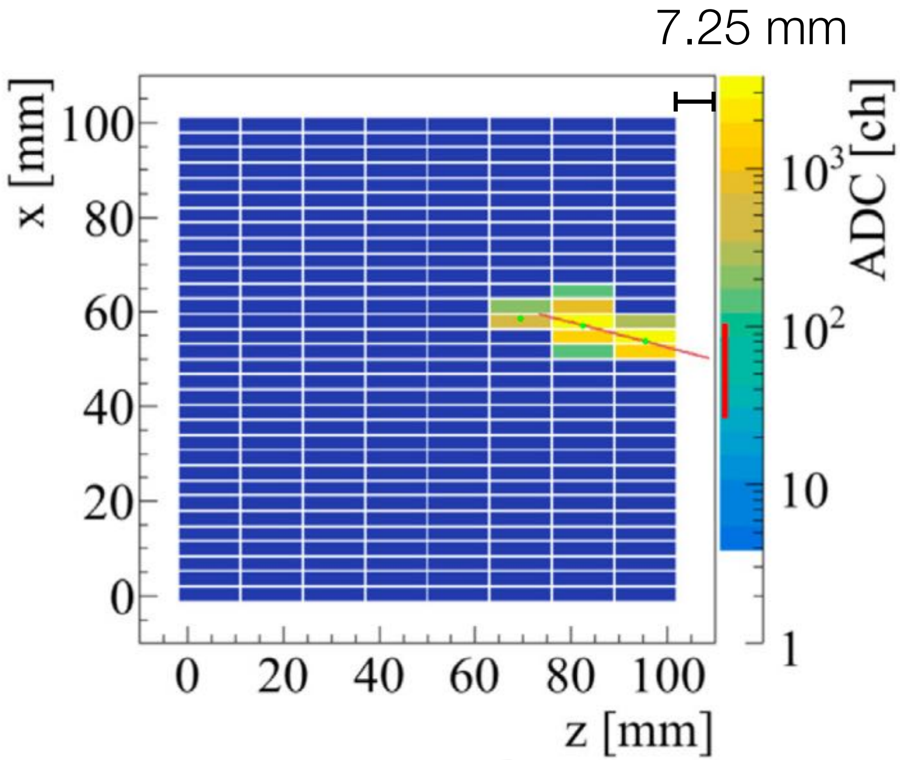
where $\Delta E = 2.43 \text{ keV}$ (for minimum ionizing particles)

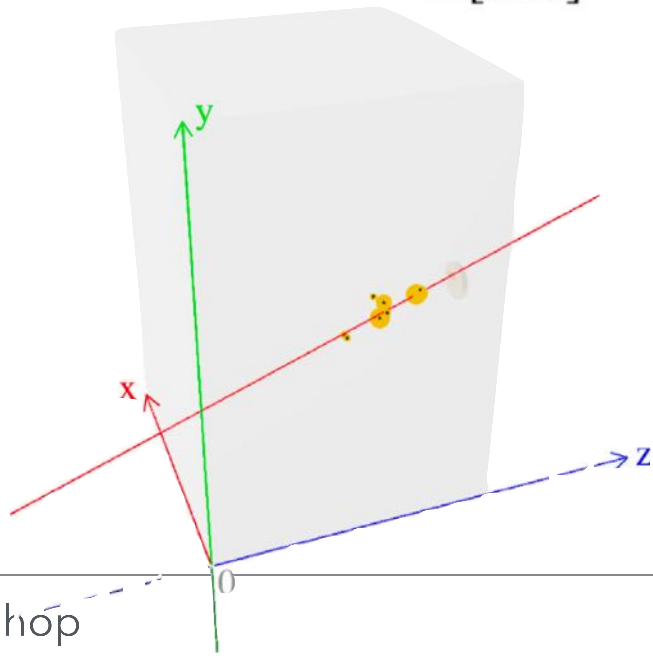
$\overline{I} = 26.2 \text{ eV}$ (average ionization potential for Ar)

$e = 1.602 \times 10^{-19} \text{ C}$

Alpha source test

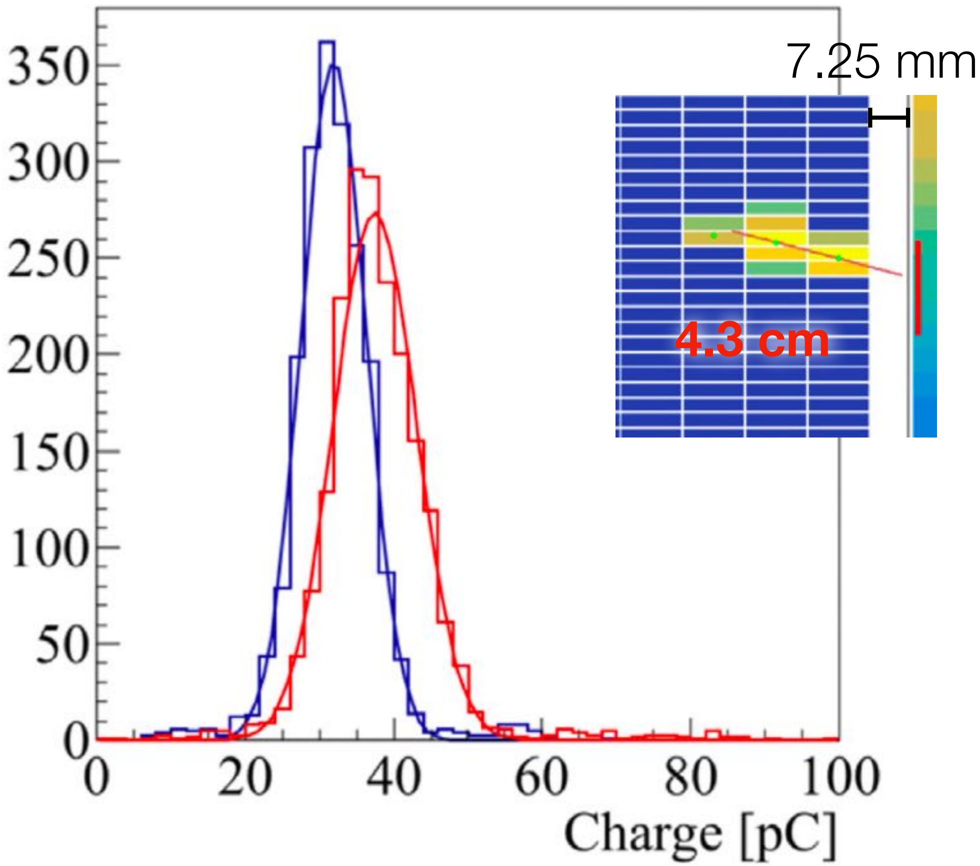






	dE/pad	AGET range	V_{GEM}
MIP(cosmic)	3 keV	120 fC (min.)	330 V
Alpha(^{241}Am)	~1.2 MeV	**10 pC (max.)**	**300 V**

Alpha energy spectrum



$$\Delta E = 5.486 \text{ MeV}$$
$$\overline{Q} = 37.5 \text{ pC}$$

$$G = 1.1 \times 10^3$$
(V_{GEM} = 300 V)

	dE/pad	AGET range	V_{GEM} (Gain)	ADC ratio
MIP(cosmic)	3 keV (1)	120 fC (min.) (1)	330 V (4,400) (4)	1
Alpha(^{241}Am)	~1.2 MeV (400)	**10 pC (max.)** (83)	**300 V (1,100)** (1)	1.2

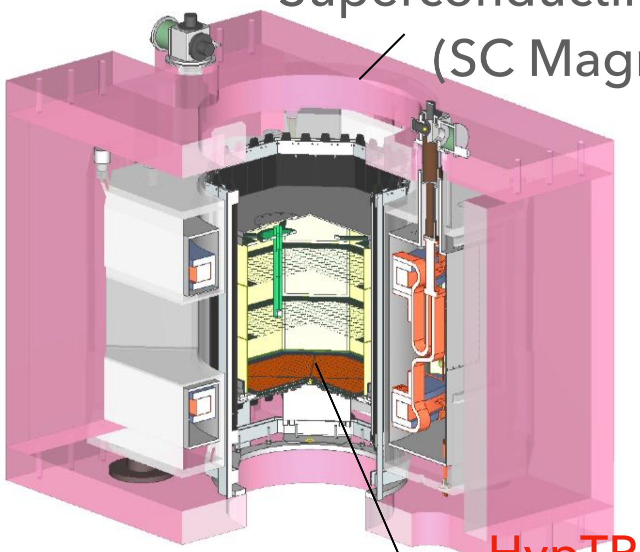
Future R&D

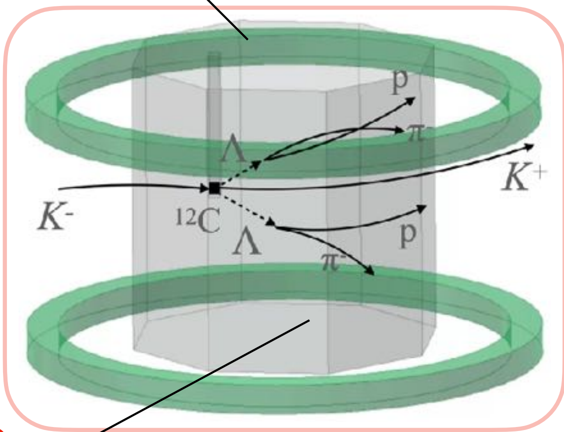
GEM Discharge Problem

Jun. 2021

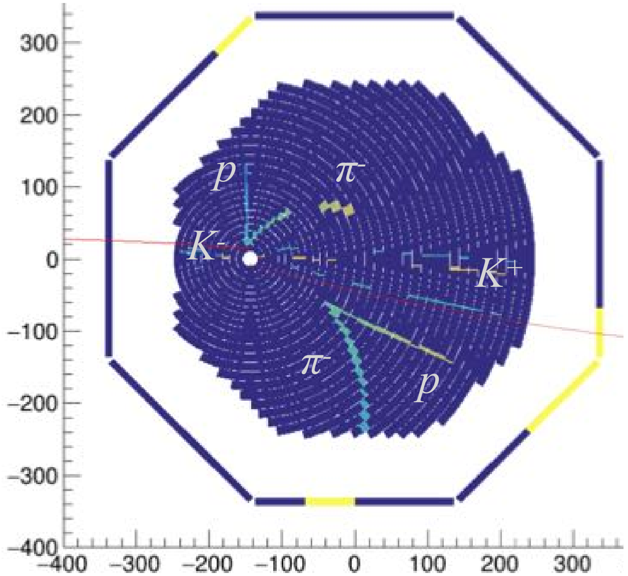
- Beam intensity and GEM bias voltage were limited by the GEM discharge rate.

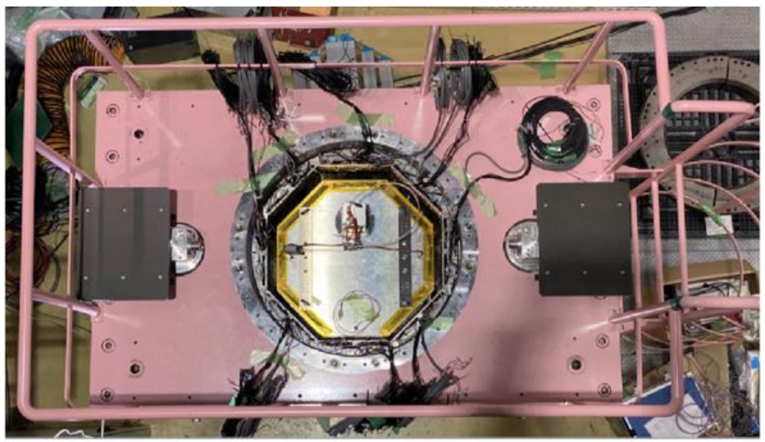
Superconducting Magnet (SC Magnet)

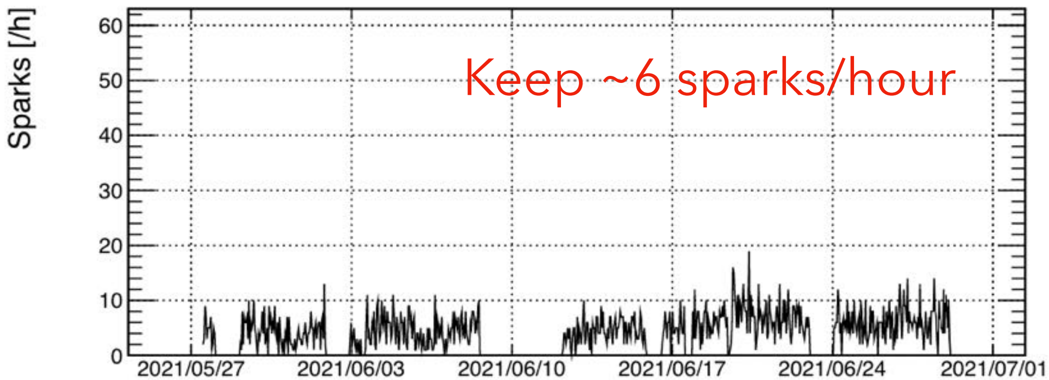




HypTPC





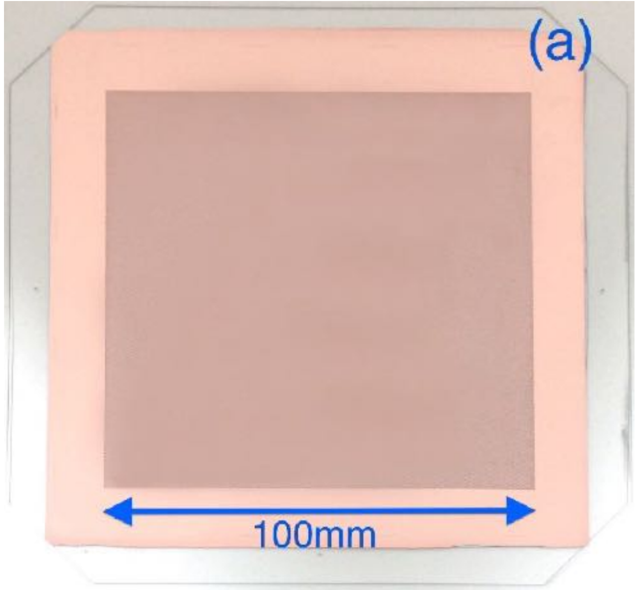


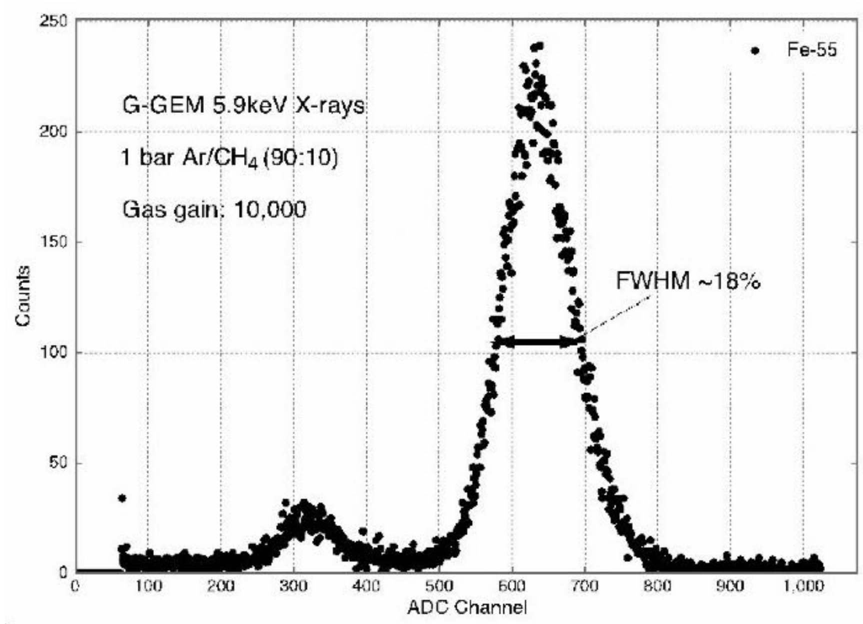
- Beam intensity/ V_{GEM}(307 V) were limited by spark rates.

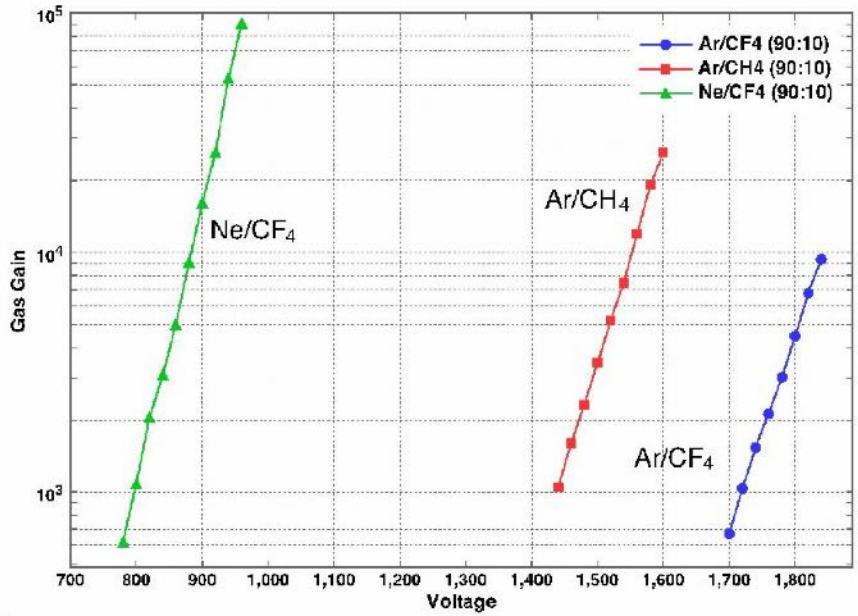
Introduction of Glass GEM

- **Rigid** – self-supporting structure
- **High gain** – up to 90,000 with single layer
- **Robust** – tolerant against discharge

[1] T. Fujiwara, et al., MPGD2011
[2] H. Takahashi, et al., NIM A, vol. 724, pp. 1-4, (2013)
[3] T. Fujiwara, et al., JINST, vol. 9, pp. 11007 - 11007, (2014)



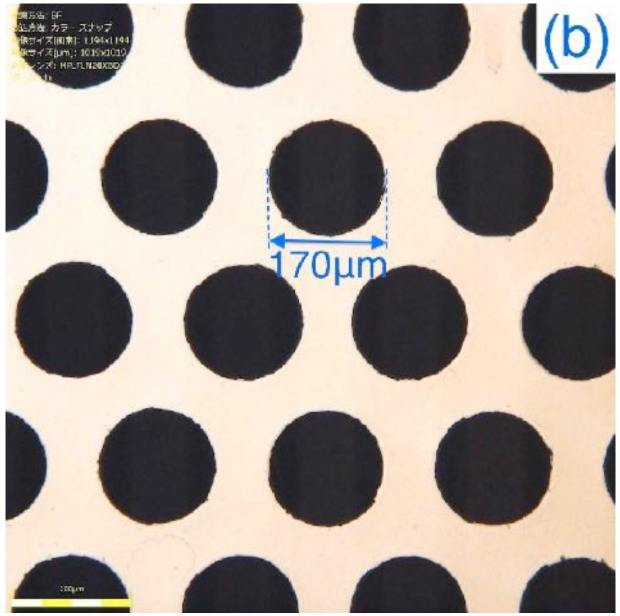


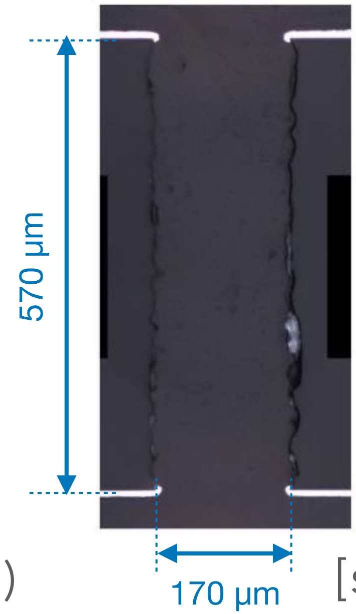


Glass GEM Spec

	50 µm GEM	100 µm GEM	570 µm Glass GEM
Manufacturer	Raytech*	Raytech	AIST Rediment
Insulator	Polyimide (PI)	Liquid Crystal Polymer (LCP)	Glass
Etching method	Wet	Laser	Wet
Cu thickness	4 µm	9 µm	3-4 µm
Pitch	140 µm	140 µm	280 µm
Inner diameter	25 ± 10 µm	35 ± 10 µm	170 µm
Outer diameter	55 ± 5 µm	65 ± 5 µm	170 µm (No rim)

[top view]



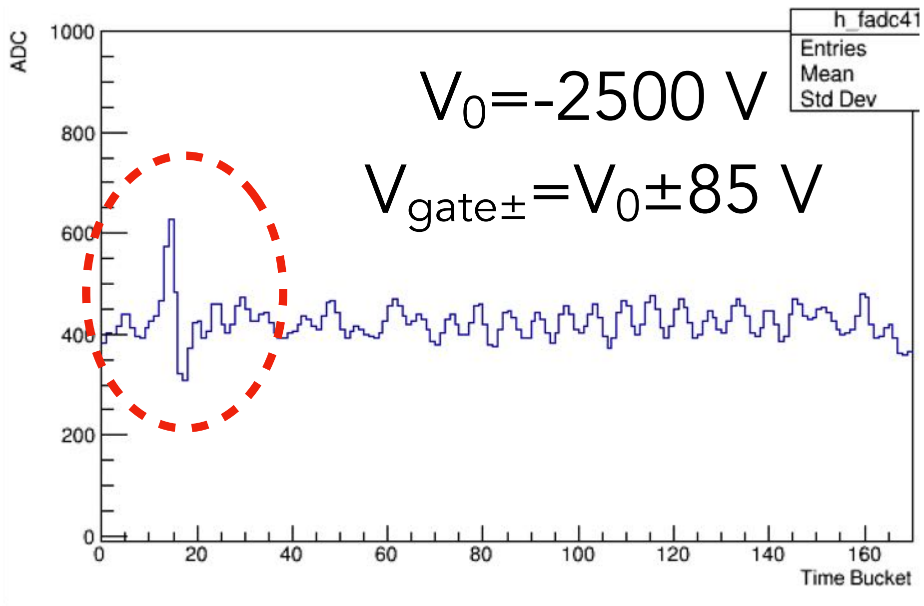


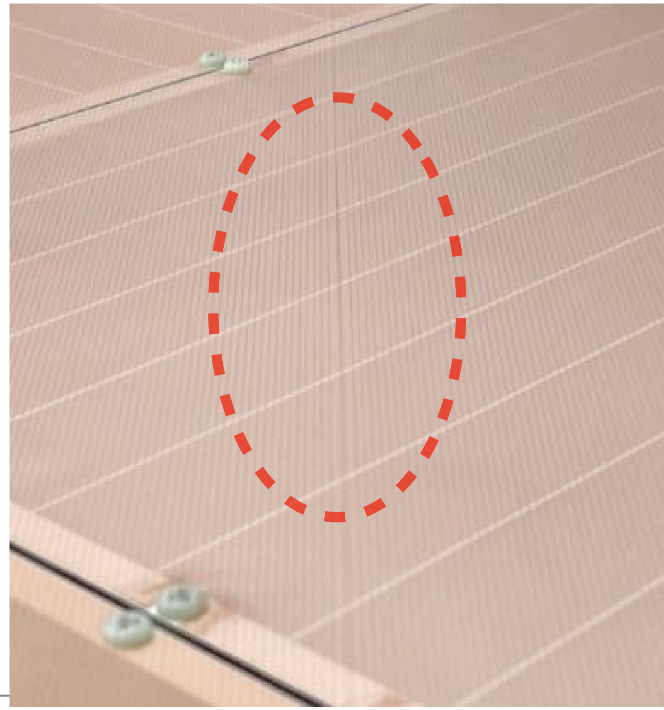
[side view]

- Developed by T. Fujiwara, et al. in AIST.
  Commercially available from private company (Radiment Lab, Inc.)

Gating Wire Problem

- Noise problem: A very slight imbalance between $V_{gate\pm}$ in fast pulsing creates spike-like noise at the gate open/closed time.
- Structural stability problem: one of the V_{gate+} and V_{gate-} was once suddenly turned off due to a current trip of the power supply, causing two neighboring gate wires to be shorted each other.

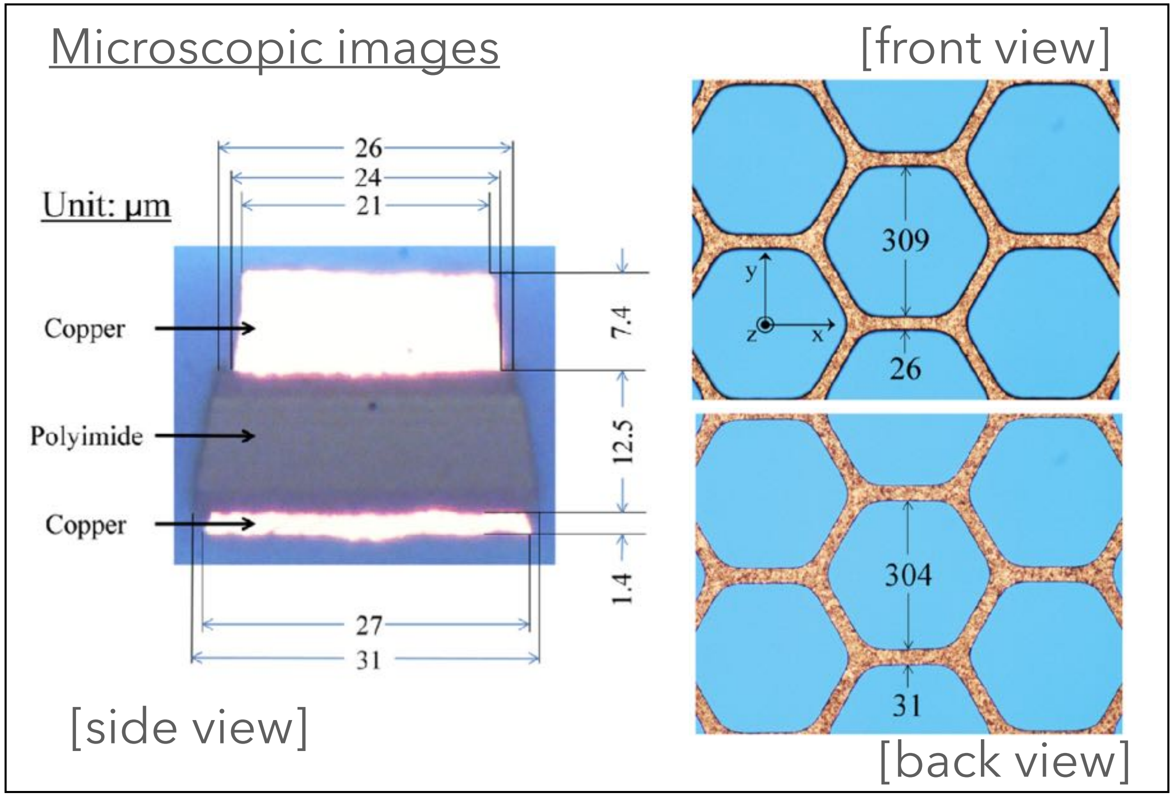




Introduction of Gating Foil

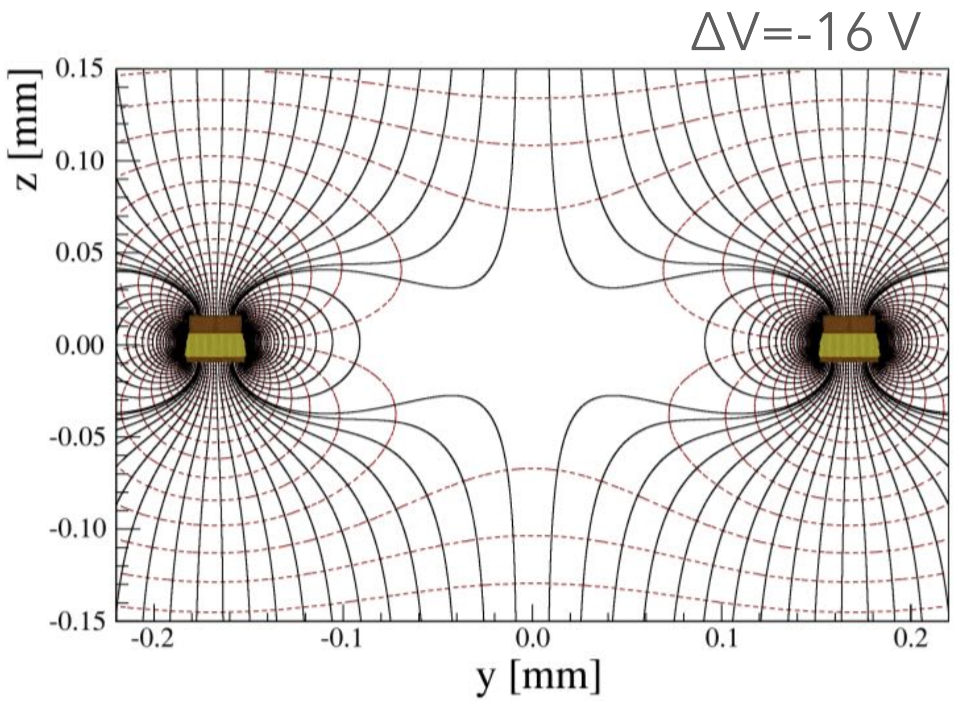
- First proposed by F. Sauli for the ILD-TPC in ILC
- GEM-like structure with a higher optical aperture ratio and functions as an ion gate without gas amplification
- Fabricated by Fujikura Ltd. using FPCB production techniques

Optical transparency: ~82%



M. Kobayashi et al., Nucl. Instrum. Methods A 918, 41 (2019).
F. Sauli, L. Ropelewski and P. Everaerts, Nucl. Instrum. Methods A 560, 269 (2006).

Gate Operation



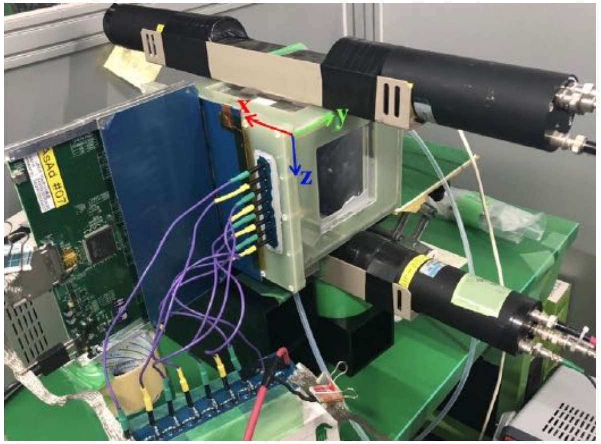
- ΔV: voltage across the gating foil
  The negative sign indicates the E field direction within the holes of the gating foil opposite to the drift field.
- No field line penetrates the foil, indicating that the foil is almost opaque in the absence of diffusion.

- Gate is closed at ΔV<0.
  ➔ required to block the positive ions (➔ ion blocking power)
- Gate is open at ΔV≥0.
  ➔ required to have high transparency to drift electrons (➔ electron transmission rate)

Summary

HypTPC (2014~)

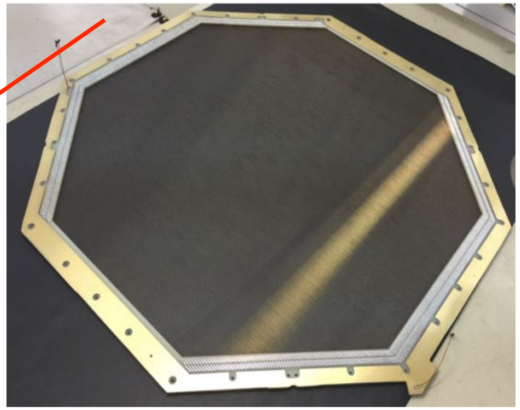
sTPC (2015~)

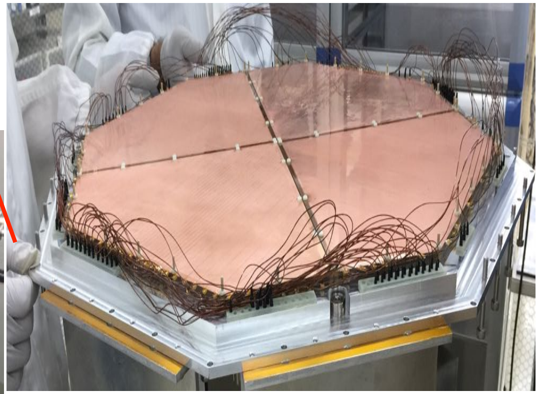


- HypTPC: S.H. Kim *et al*., NIMA 940, 359 (2019)
- sTPC: S.H. Kim *et al*., NIMA 962, 163687 (2020)

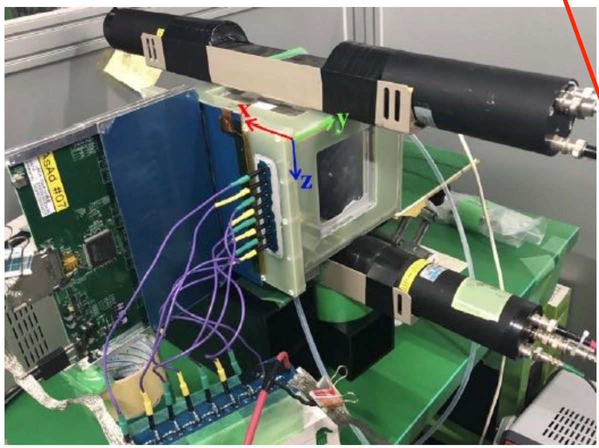
Summary

HypTPC (2014~)





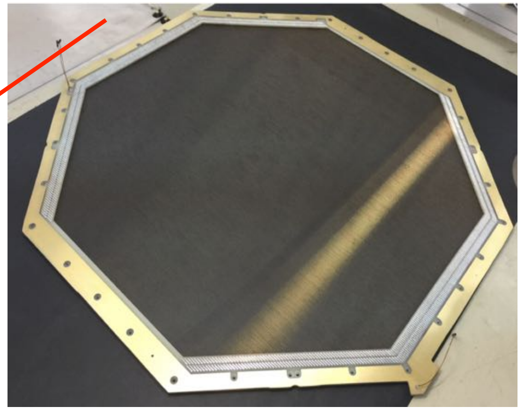
sTPC (2015~)



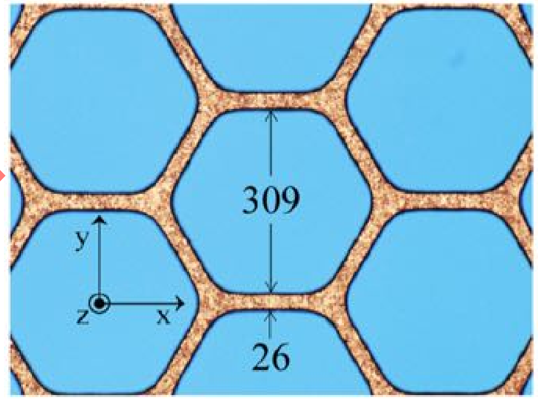
- HypTPC: S.H. Kim *et al.*, NIMA 940, 359 (2019)
- sTPC: S.H. Kim *et al.*, NIMA 962, 163687 (2020)

Summary

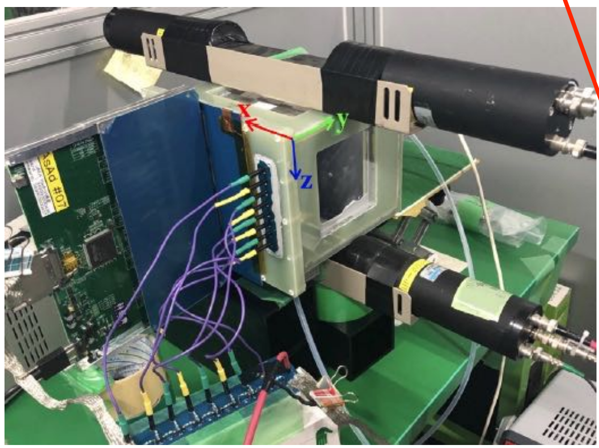
HypTPC (2014~)

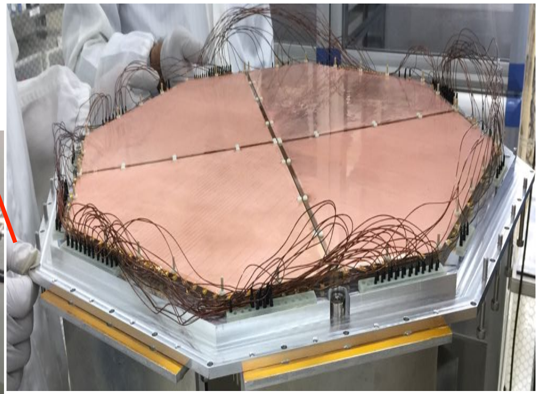


Gating Foil

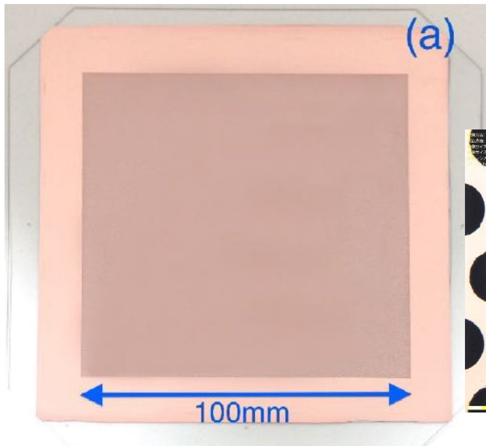


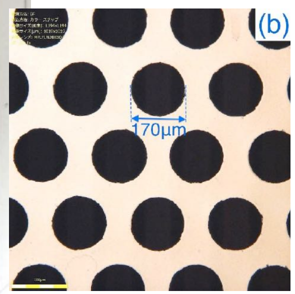
sTPC (2015~)





Glass GEM



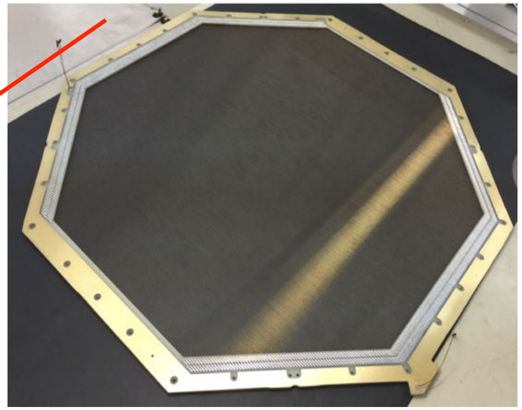


- HypTPC: S.H. Kim *et al*., NIMA 940,
- sTPC: S.H. Kim *et al*., NIMA 962, 163[illegible] (2020)

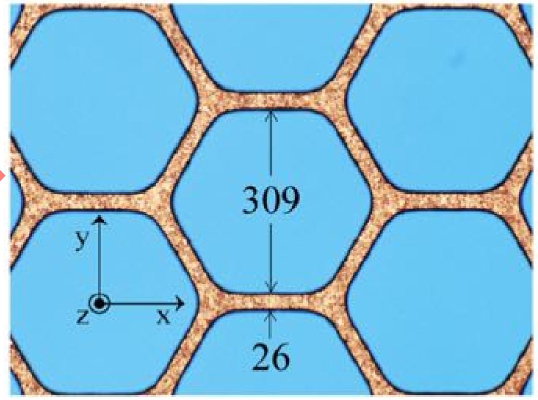
Summary

HypTPC (2014~)

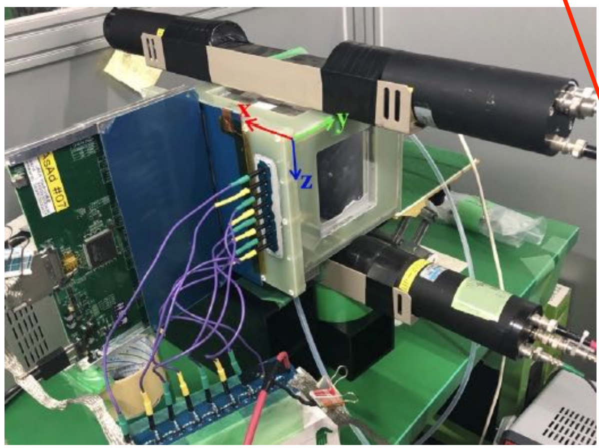
+ Gas system
HV system
Electronics

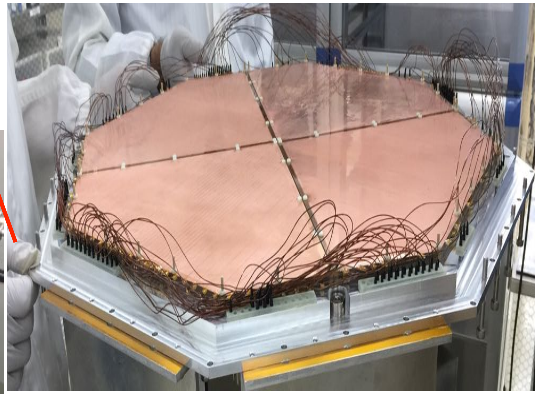


Gating Foil

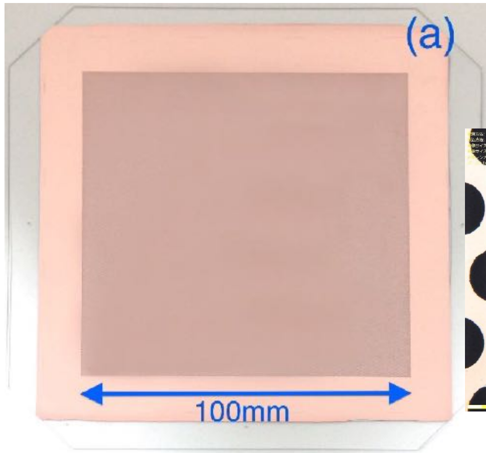


sTPC (2015~)



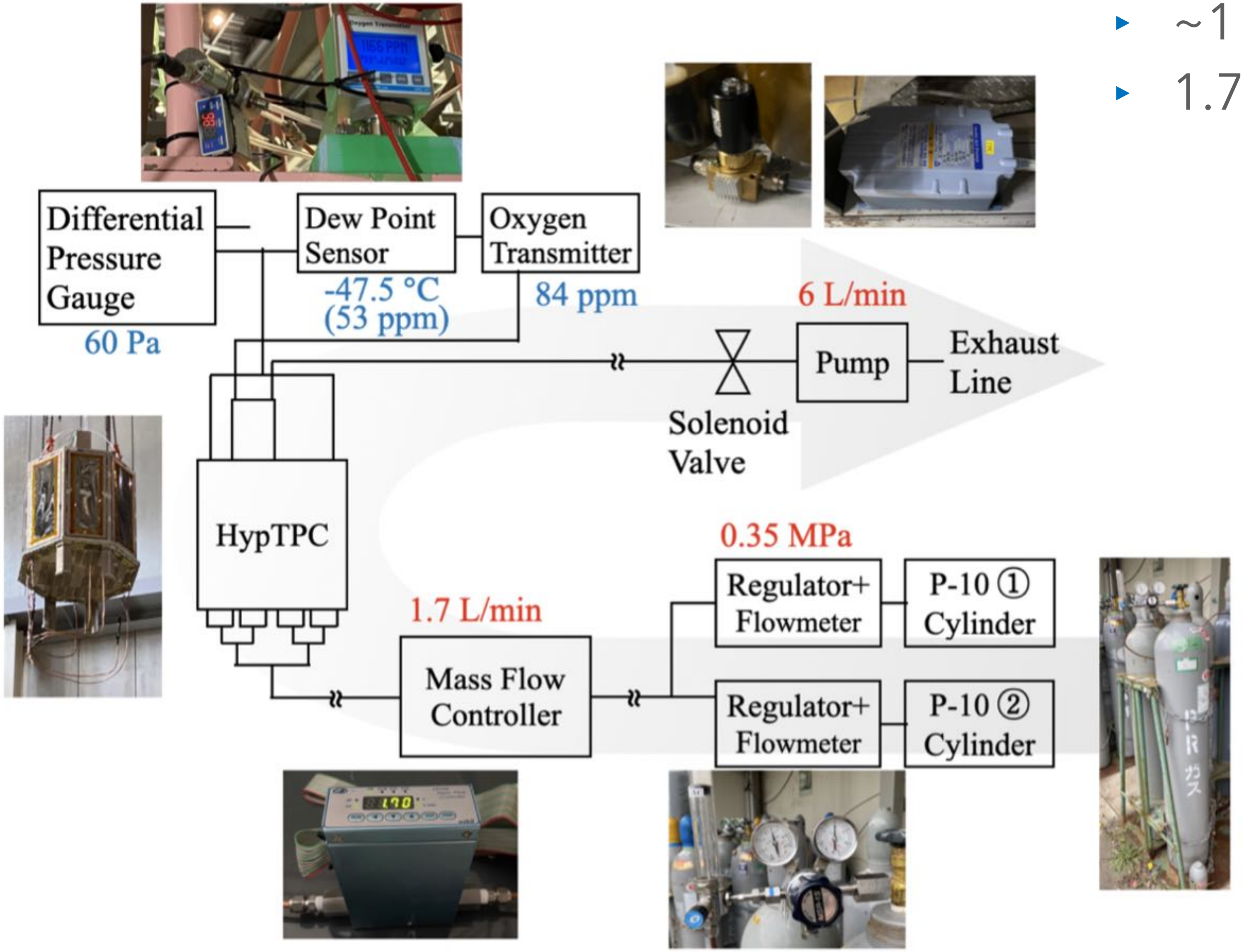


Glass GEM



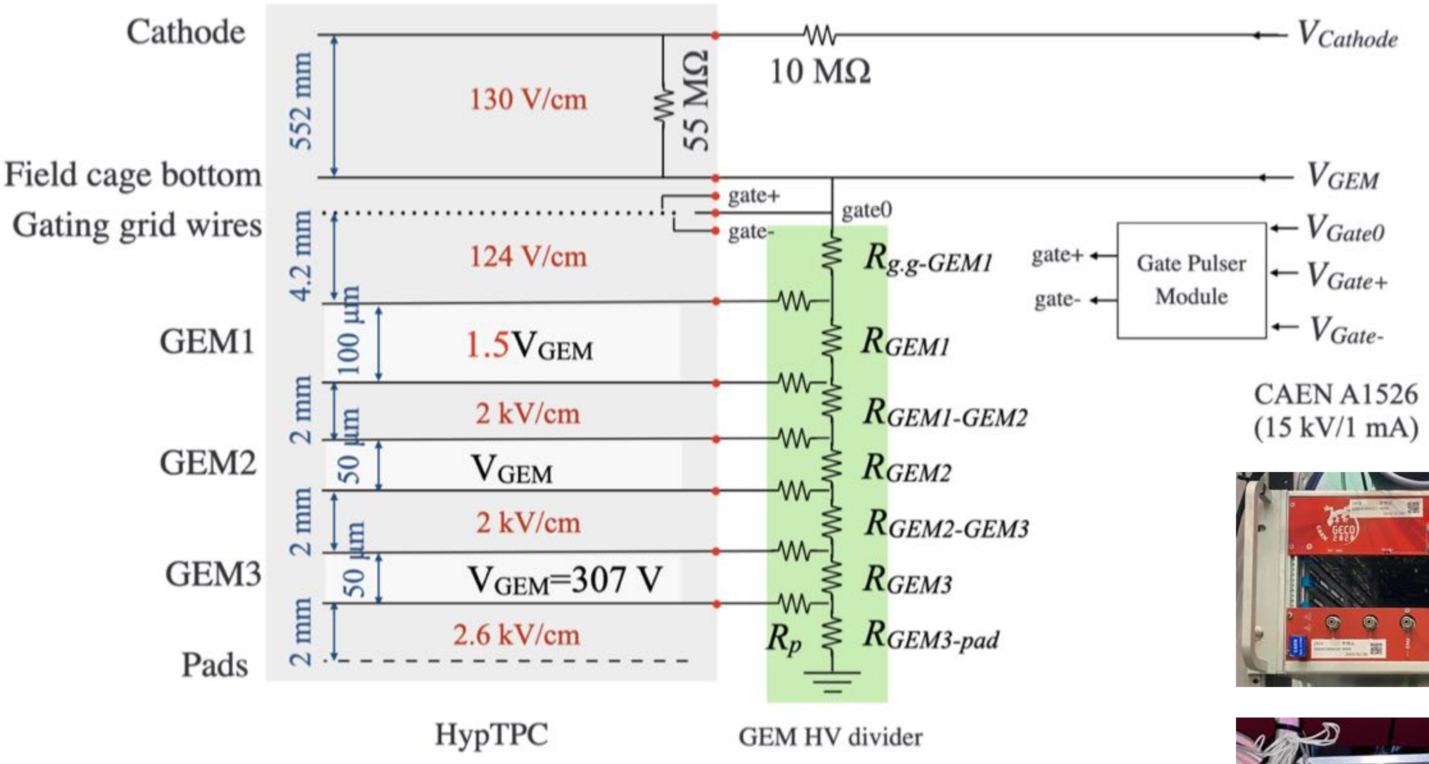
- HypTPC: S.H. Kim *et al.*, NIMA 940,
- sTPC: S.H. Kim *et al.*, NIMA 962, 163087 (2020)

HypTPC Gas System



- ~1 atm P-10 gas
- 1.7 L/min

HypTPC HV System



CAEN A1526
(15 kV/1 mA)

	R [MΩ]		V [V]	I [μA]
GG–GEM1	0.169	Cathode	−10909	129.9
GEM1	1.5	GEM	−2459	177.1
GEM1–GEM2	1.33	GATE0	−2459	357.4
GEM2	1.00	GATE+	−2373	345.2
GEM2–GEM3	1.33	GATE−	−2544	369.4
GEM3	1.00		(V_{GEM} = 307 V)	
GEM3–pad	1.7		(V_{Gate} = +86, −85 V)	