The first beam test of a GEM-readout TPC module with a large aperture GEM-like gating device

Yumi Aoki(SOKENDAI/KEK)
on behalf of LCTPC collaborations
2017.5.22 MPGD2017@Temple univ.

yumia@post.kek.jp

Outline

1. About ILC, TPC
2. A large aperture GEM-like gating device
3. Results - Electron transmission rate (from charge)
4. Results - Electron transmission rate (from N effective)
5. Conclusion

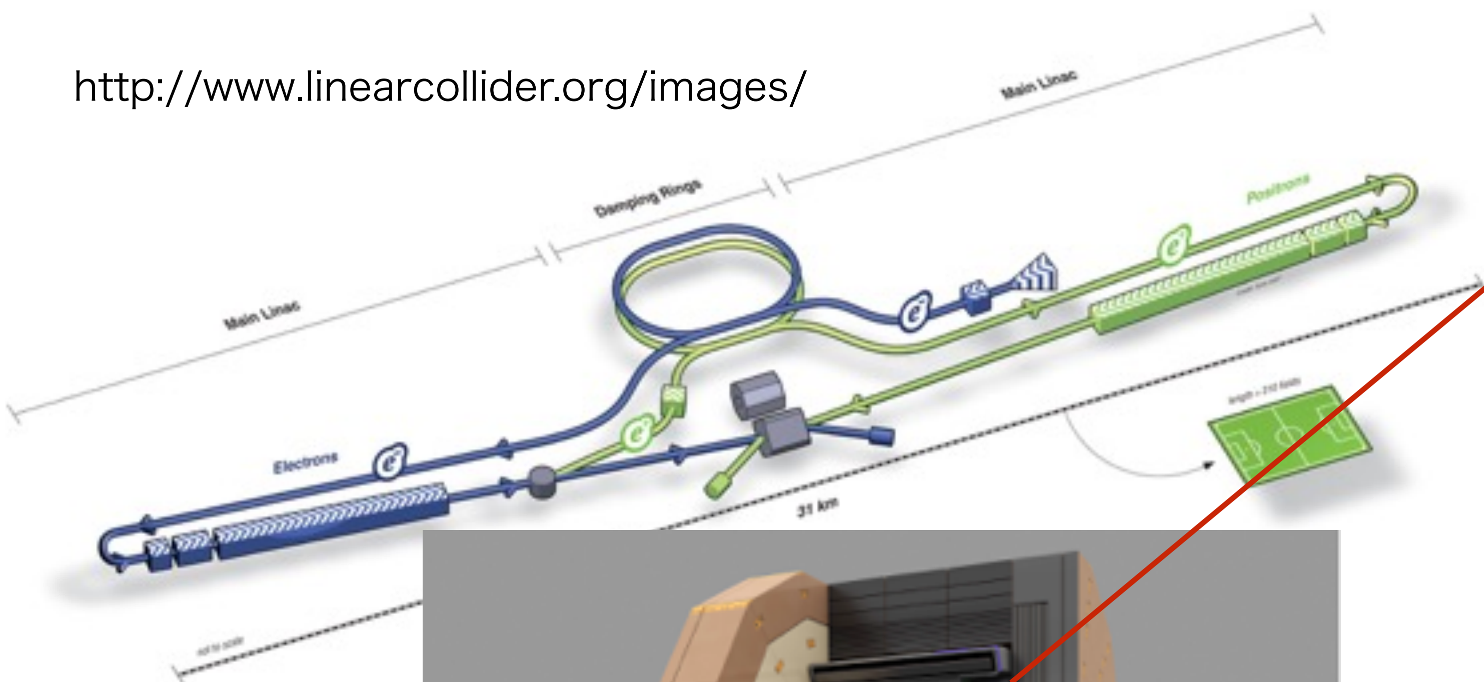
The first beam test
of a GEM-readout TPC module
with a large aperture GEM-like gating device

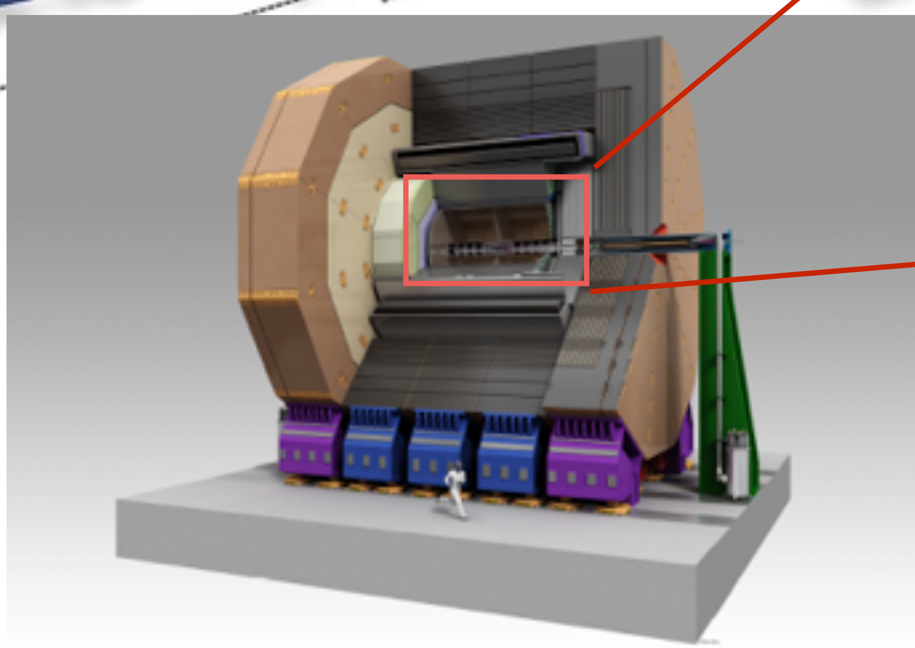
ILC

International Linear Collider

Electron positron Collider（250〜500 GeV)

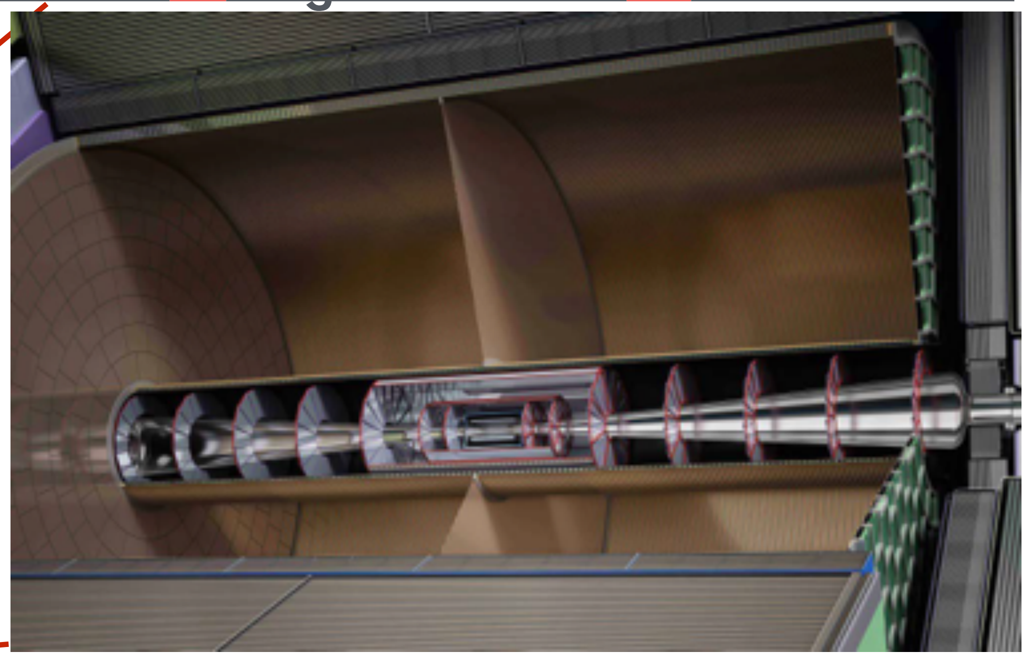
http://www.linearcollider.org/images/





International Large Detector

Time Projection Chamber



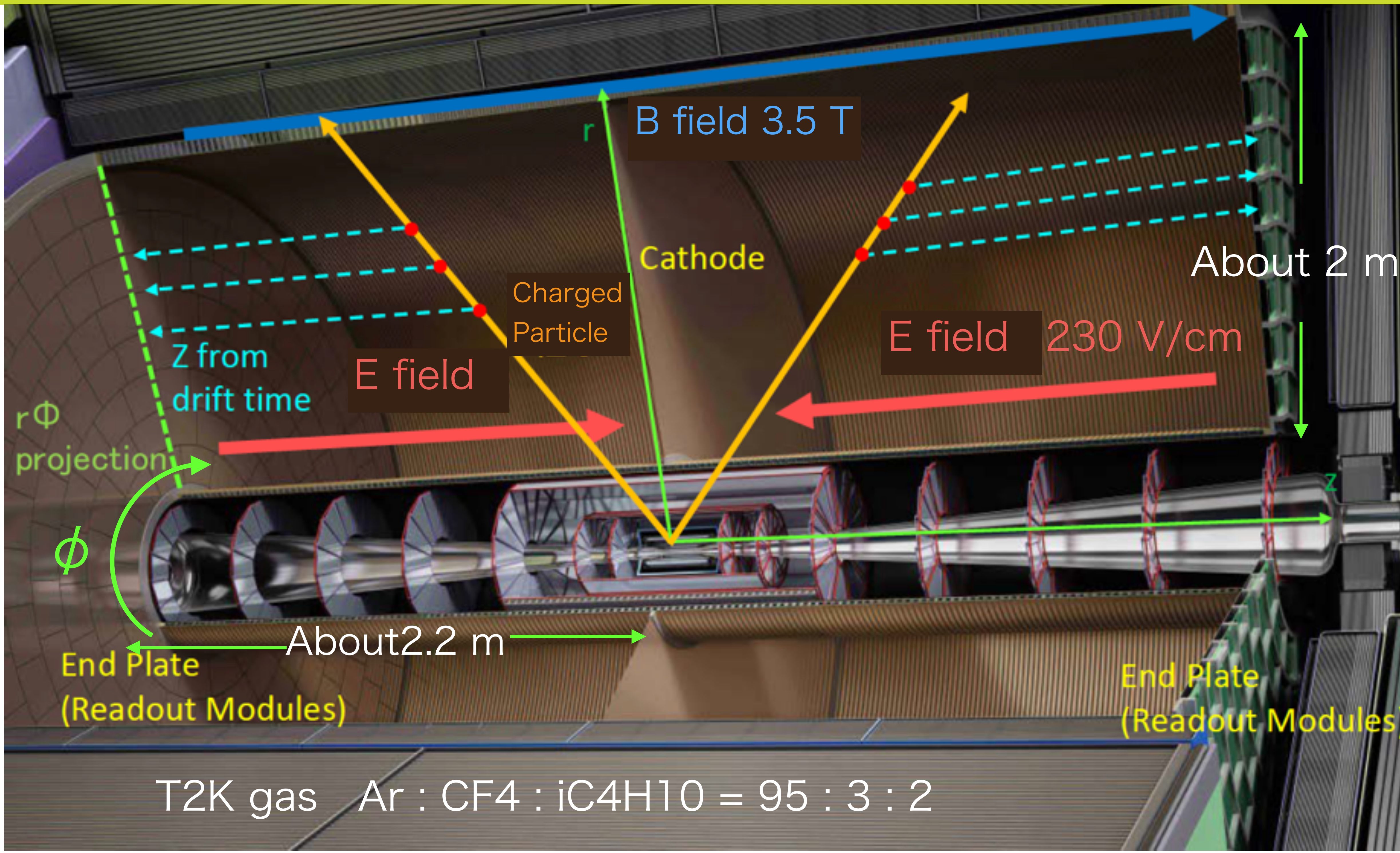
reconstruct tracks, measure their momentum and dE/dx.
(charged particles)

Required momentum resolution

$$\frac{\sigma_{P_T}}{P_T} \simeq 1 \times 10^{-4} P_T \; GeV/c$$

yumia@post.kek.jp

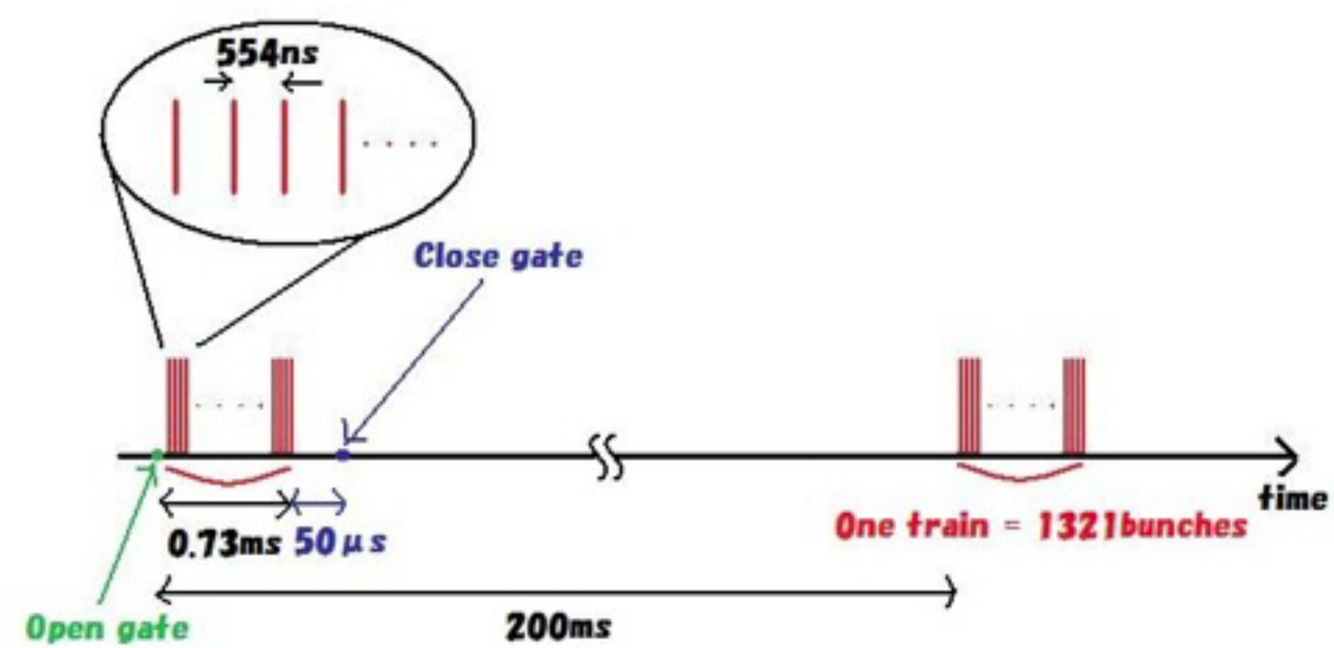
TPC

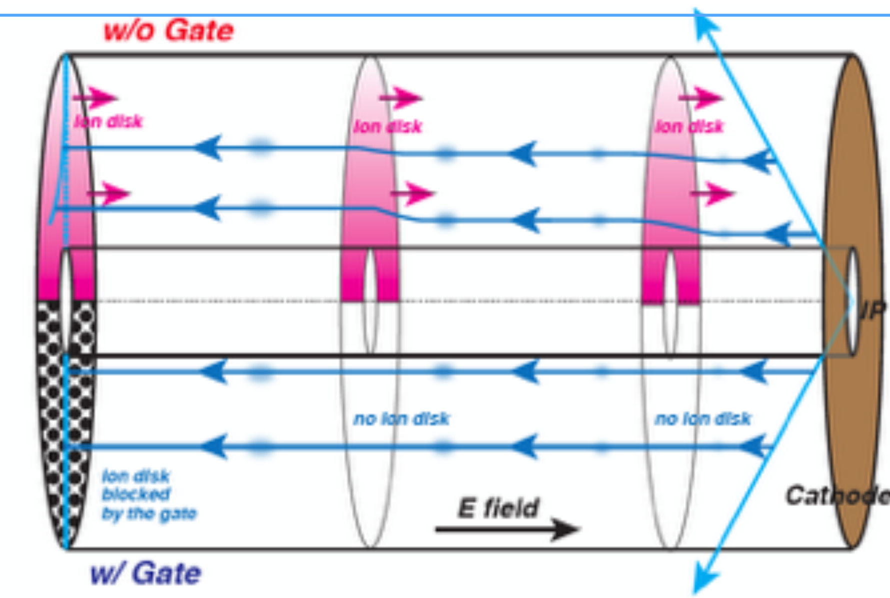


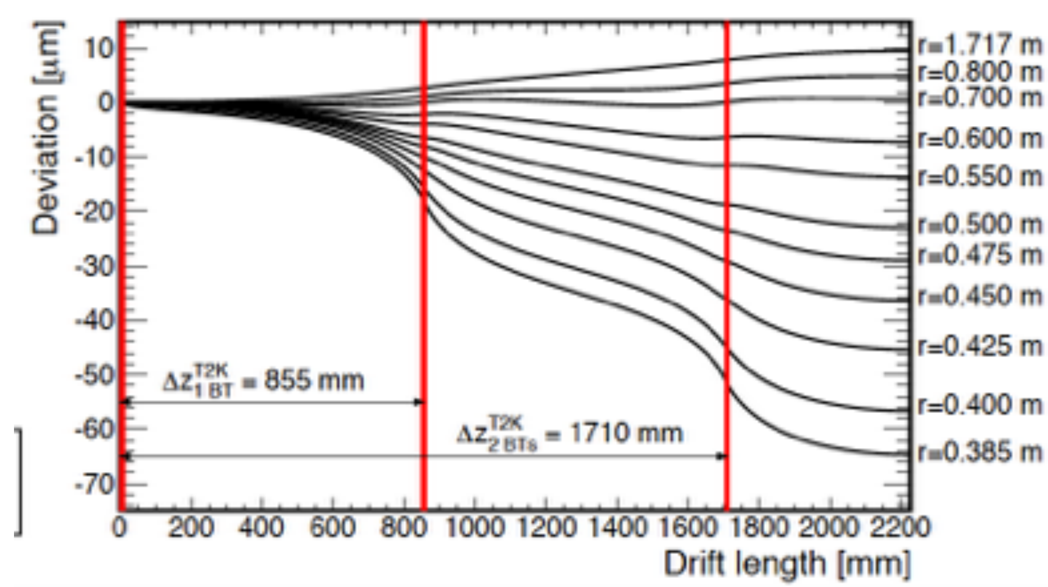
The amplification device：GEM or Micromegas

Ion Feedback Problem

Positive ions created by gas amplification back-flow into the drift volume
→distort electric field→deteriorate position resolution







The ions for a single bunch train form a disk with about 1cm thickness.
Since the ion drift velocity is O(1000) times slower than that of electrons, there will be up to 3 ion disks in the drift volume.

Hit point distortion：60μm

Goal : $\sigma_{r\phi}<100\mu m$(over maximum drift distance 2.2m in B=3.5T)

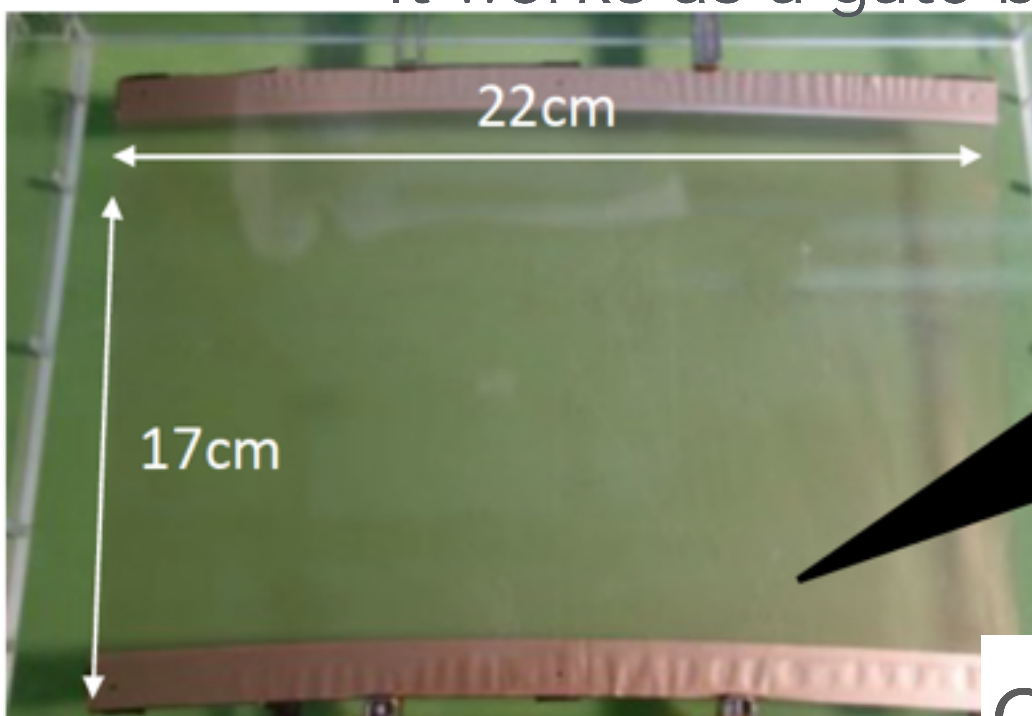
We need a gate to stop ions from returning to the drift volume.

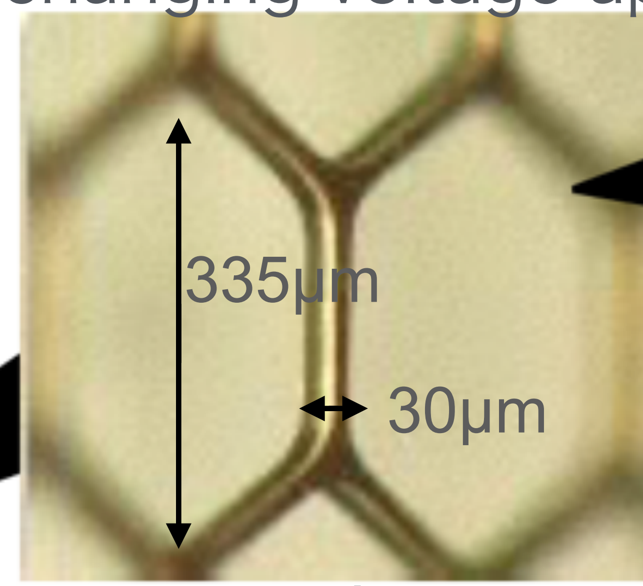
The first beam test
of a GEM-readout TPC module
with a large aperture GEM-like gating device

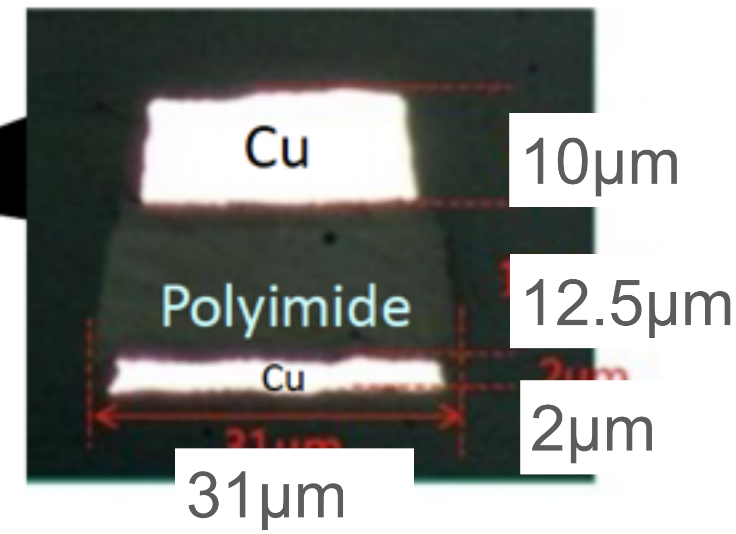
A large aperture GEM-like gating device

We developed A large aperture GEM-like gating device (gating GEM) with FUJIKURA

It works as a gate by changing voltage applied to the Cu electrode







honeycomb structure

Optical transparency= 82 %   25 μm thick

The gate should stop the ions but not disturb the transmission of electrons.

→The electron transmission is also important

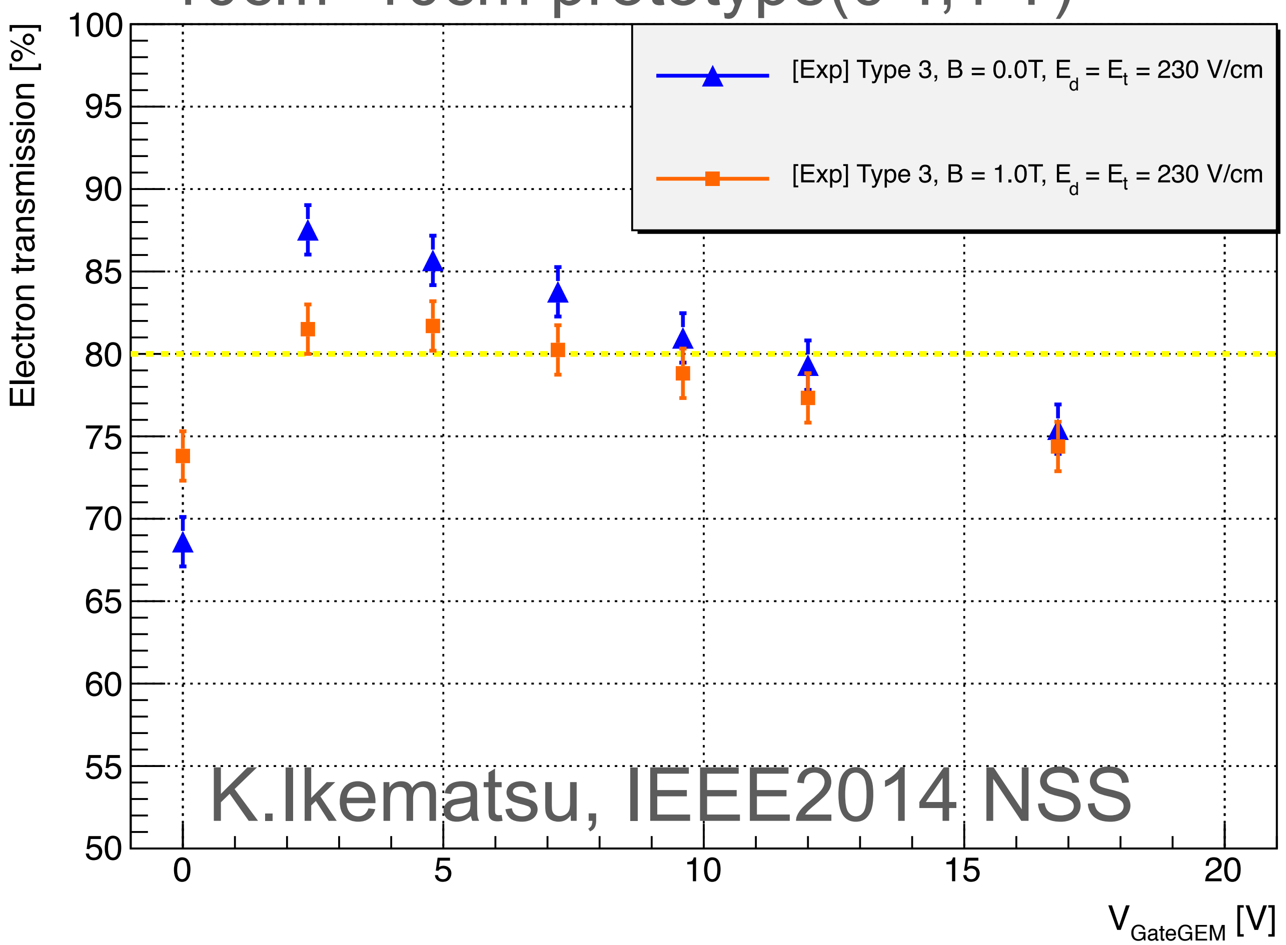
The achievable electron transmission rate in magnetic field≒Optical transparency

To achieve the target resolution
We need an electron transmission rate >80%

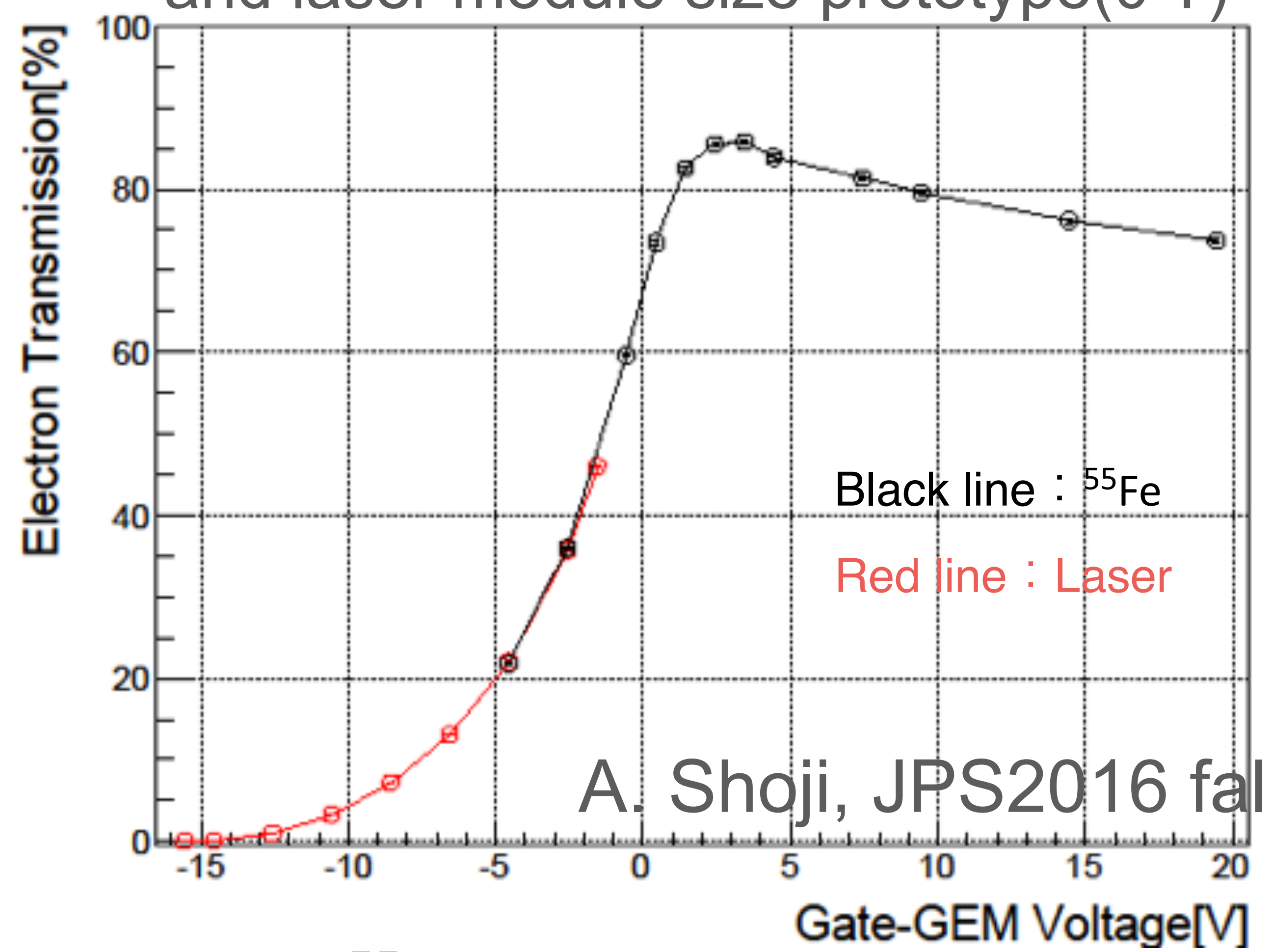
→ We measured the electron transmission by a beam test.

Electron transmission and ion stopping power

By using ^{55}Fe source
10cm×10cm prototype(0 T,1 T)



By using ^{55}Fe source
and laser module size prototype(0 T)



Previously, we measured transmission by using ^{55}Fe and laser.

We found that the electron transmission is maximum at 3.5 V so we decided to use this voltage in the beam test.

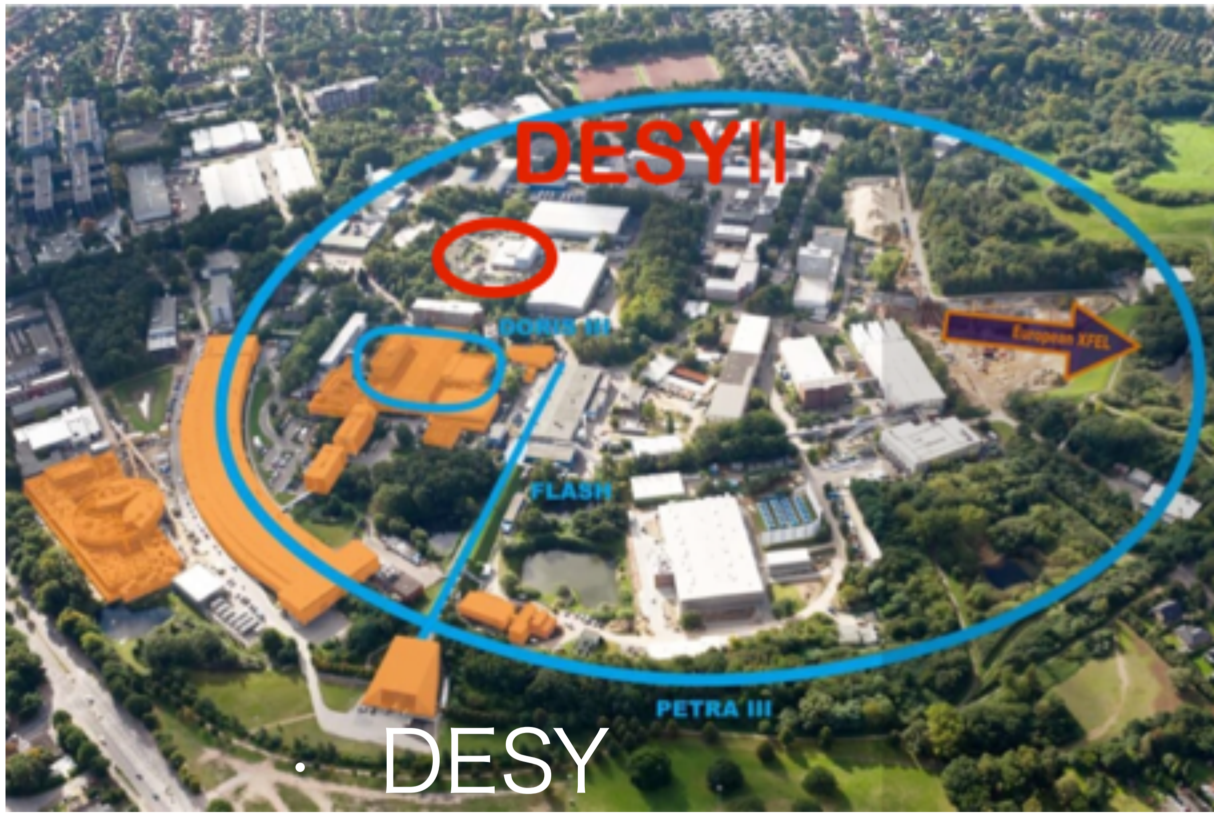
The ion stopping power estimated using electron is 99.97 % or better at -15.5 V

Detail: https://agenda.linearcollider.org/event/7371/contributions/37927/

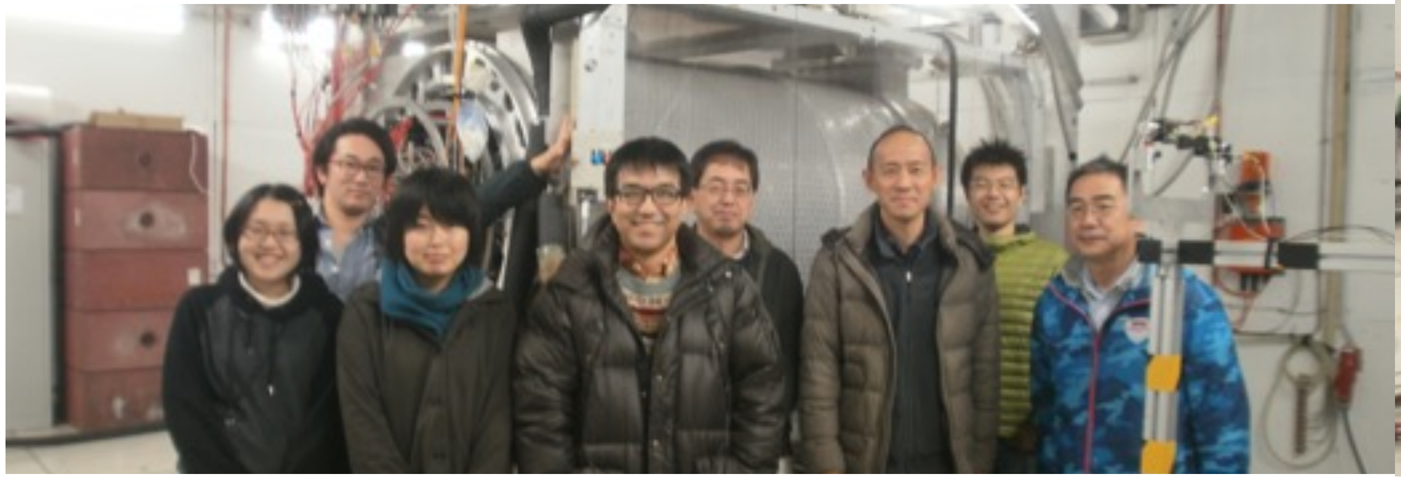
The first beam test
of a GEM-readout TPC module
with a large aperture GEM-like gating device

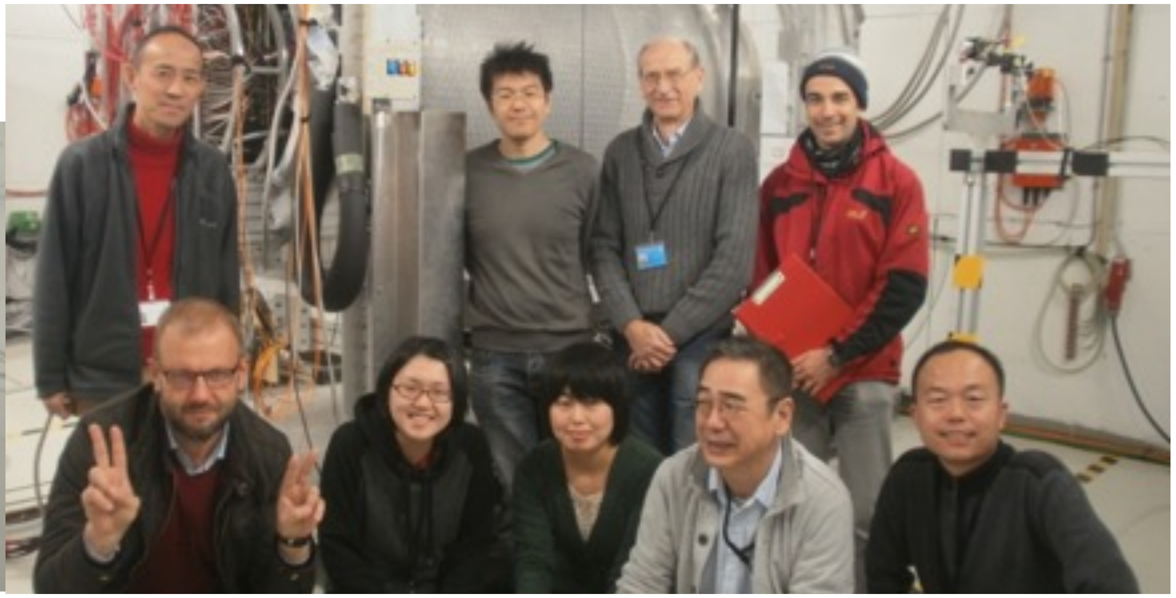
Beam test

Oct.31-Nov.13, 2016 (beam time)
@DESY TPC large prototype
The first beam test
of a GEM-readout TPC module
with a gating GEM



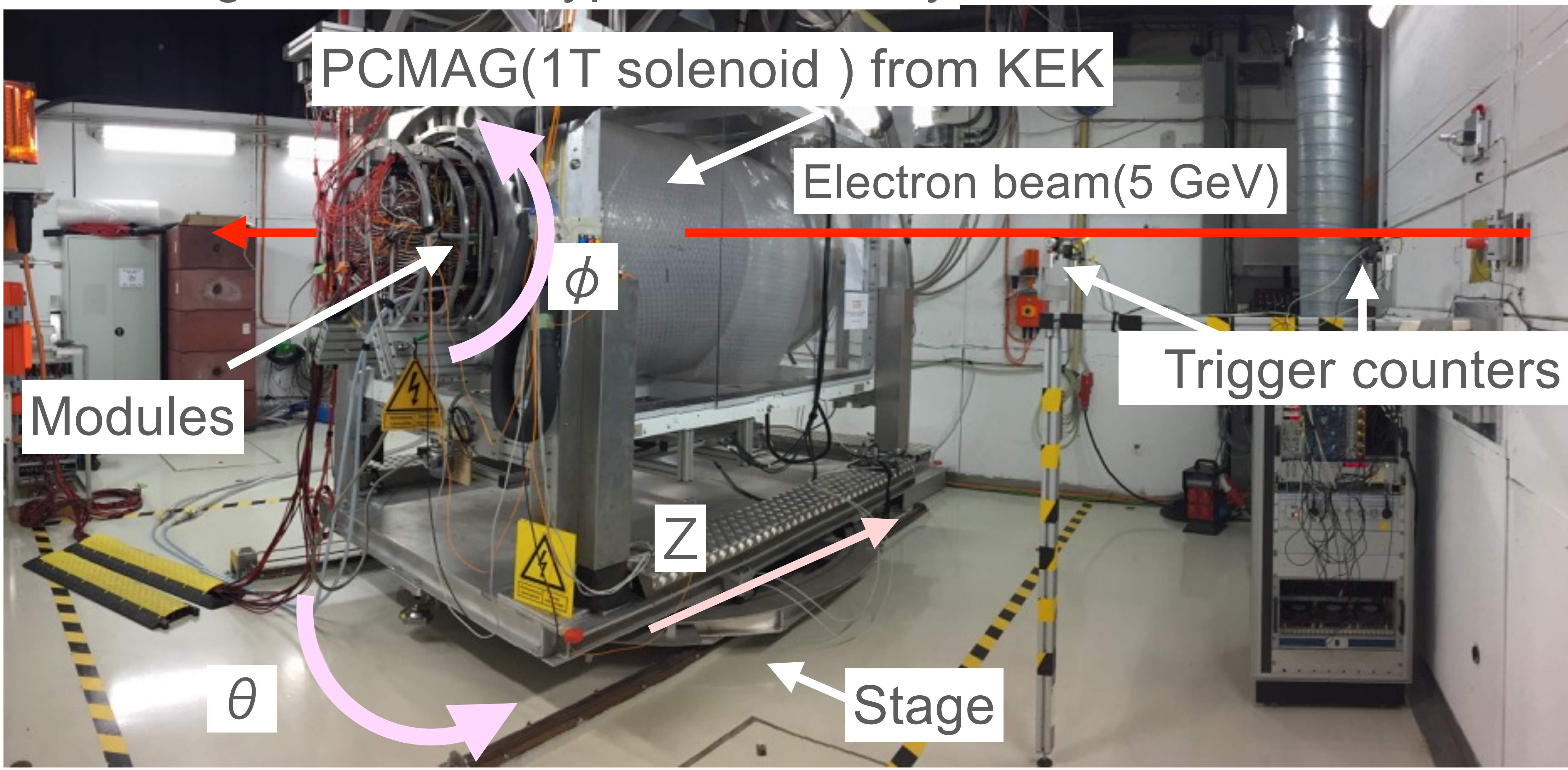
15 participants from Japan,
France, Germany, China, Sweden





Setup

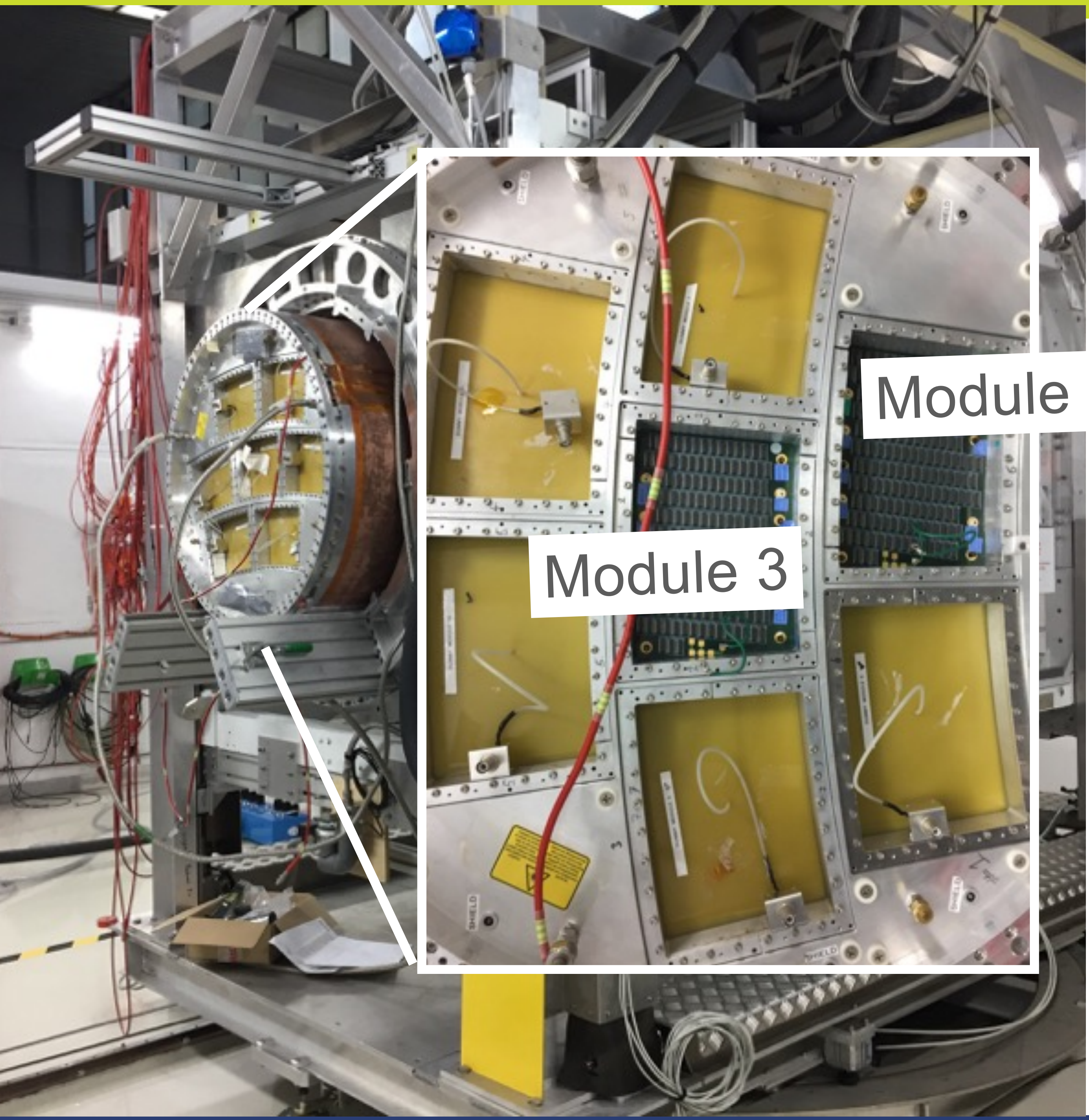
DESY Large TPC Prototype Test Facility



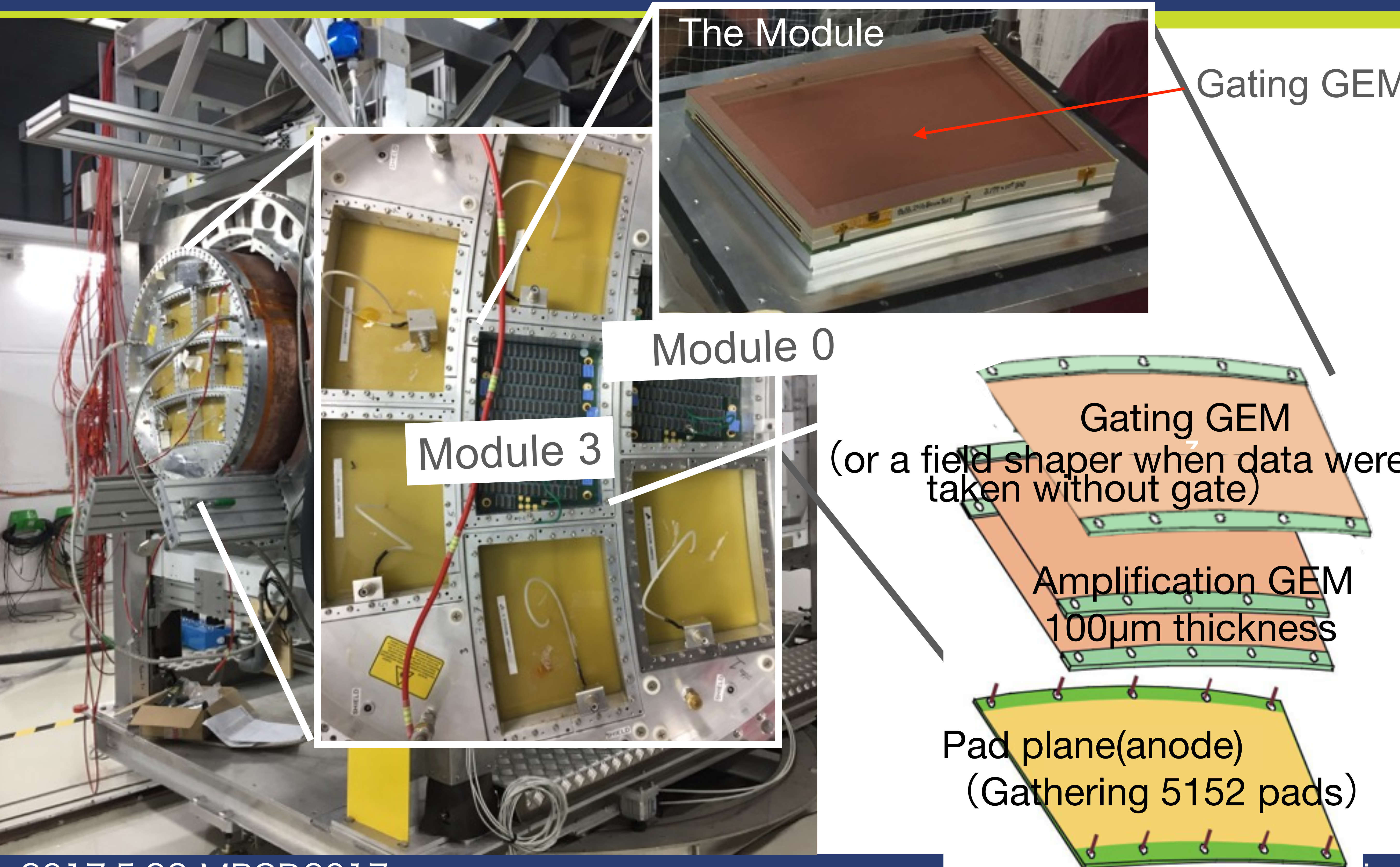
The electron beam pass two trigger counter and through the prototype like this.
A readout parts are covered with a solenoid. All devices are on the stage so we can change the length Z from readout parts to electron beam and two angle, θ and ϕ.

yumia@post.kek.jp

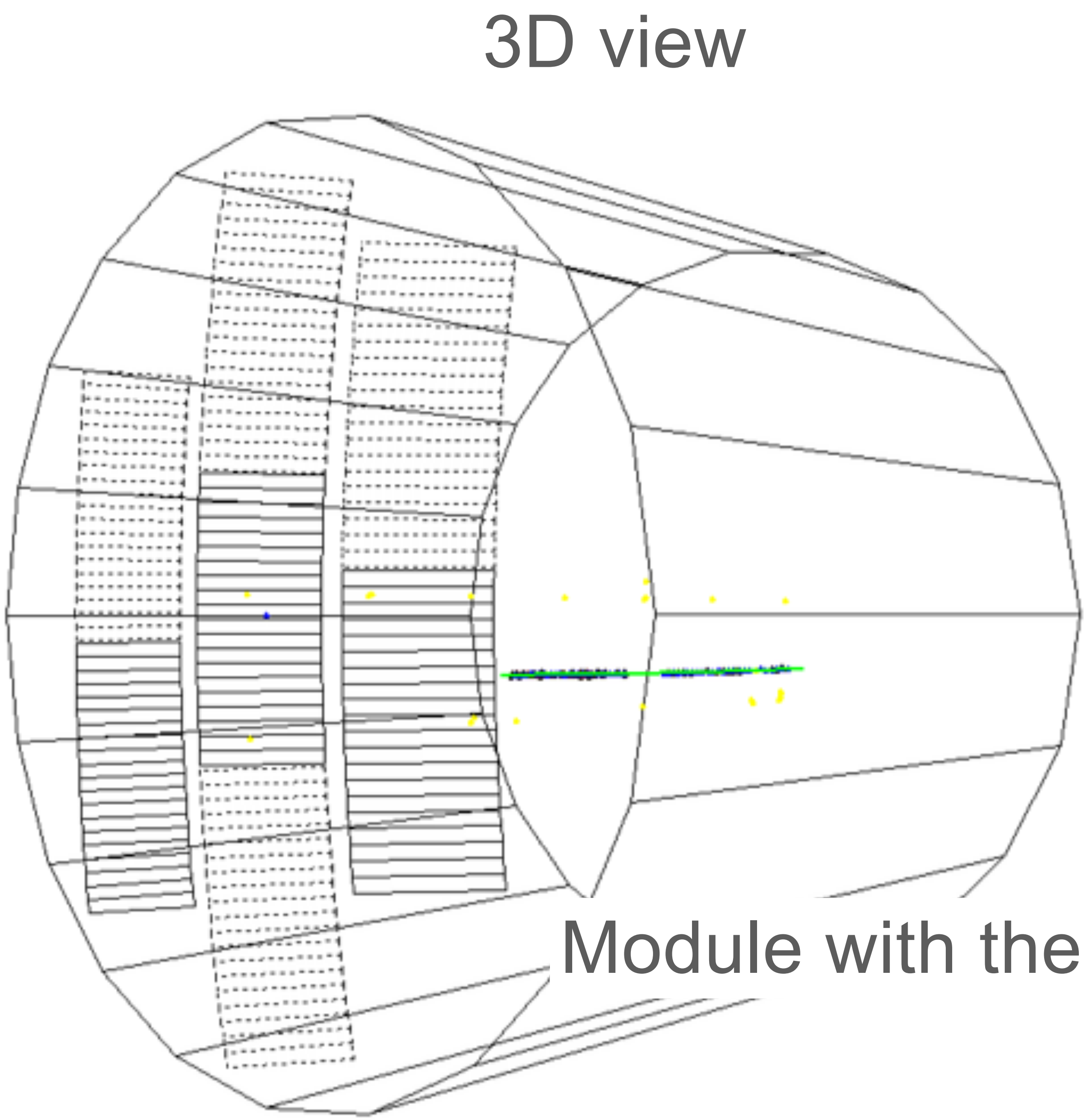
Modules

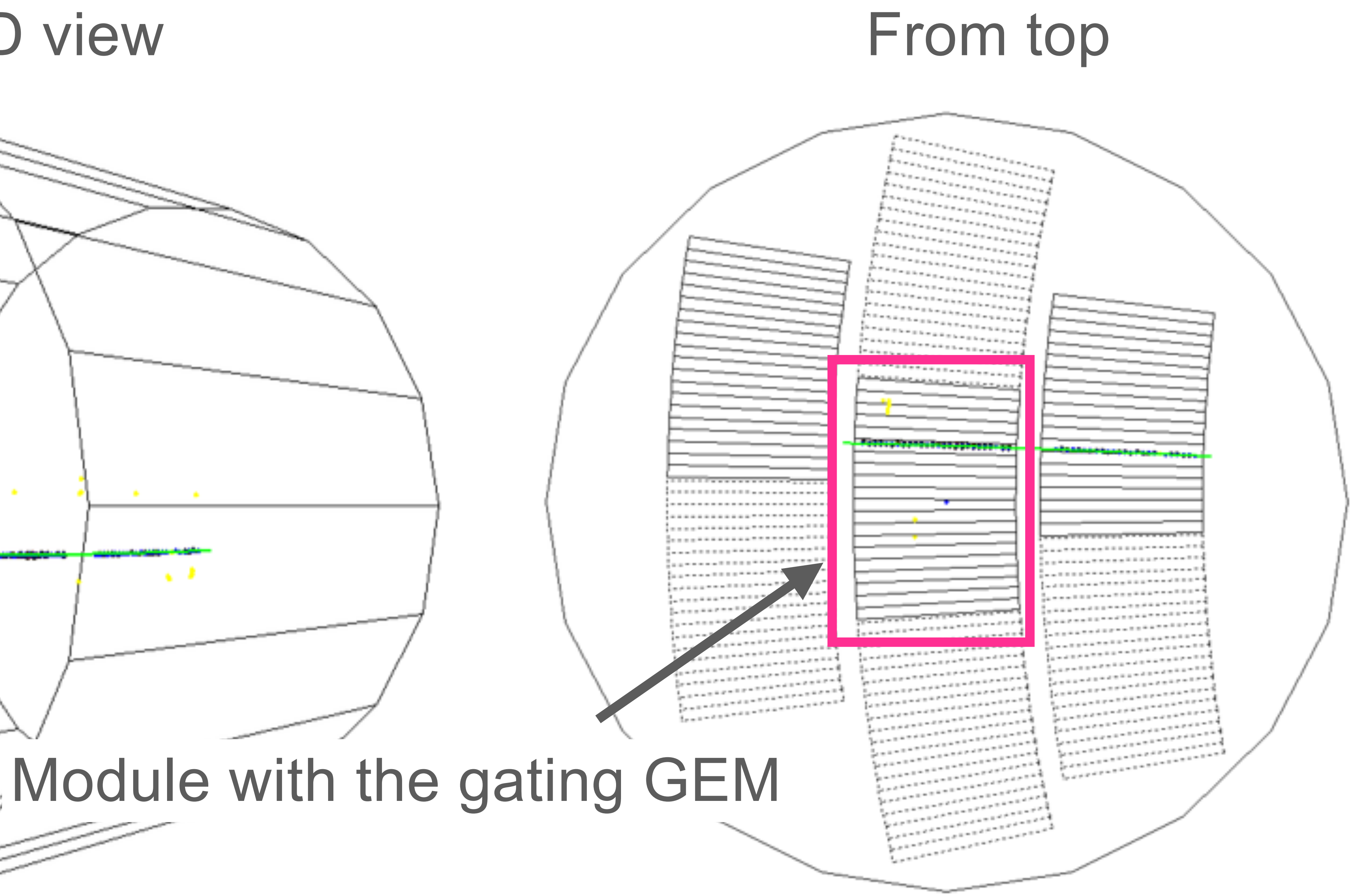


Module with Gating GEM



Typical event



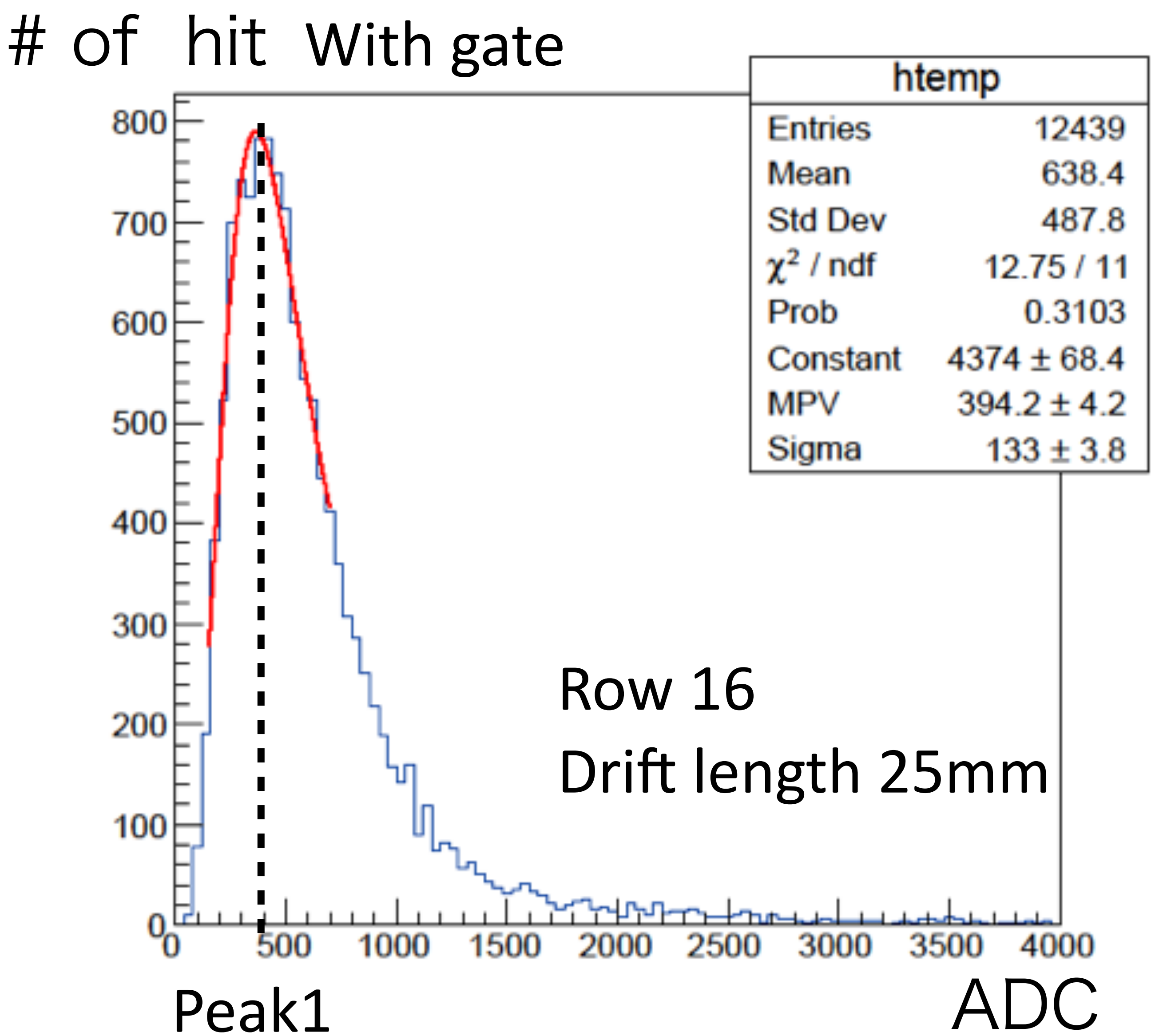


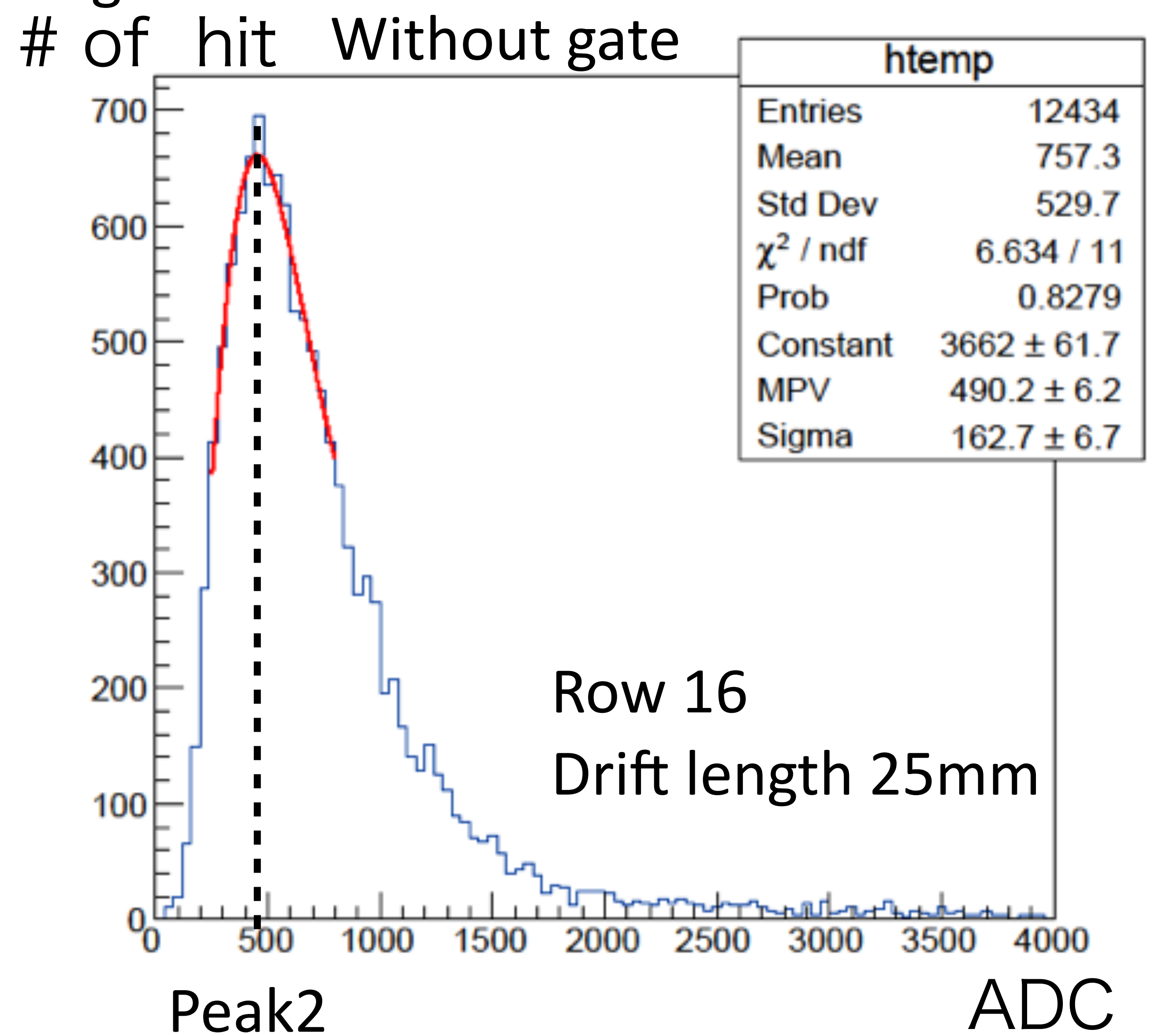
The beam goes through our module with the gating GEM in the region far enough from the module edge.

How to get electron transmission[1]

The electron transmission calculated by hit charge

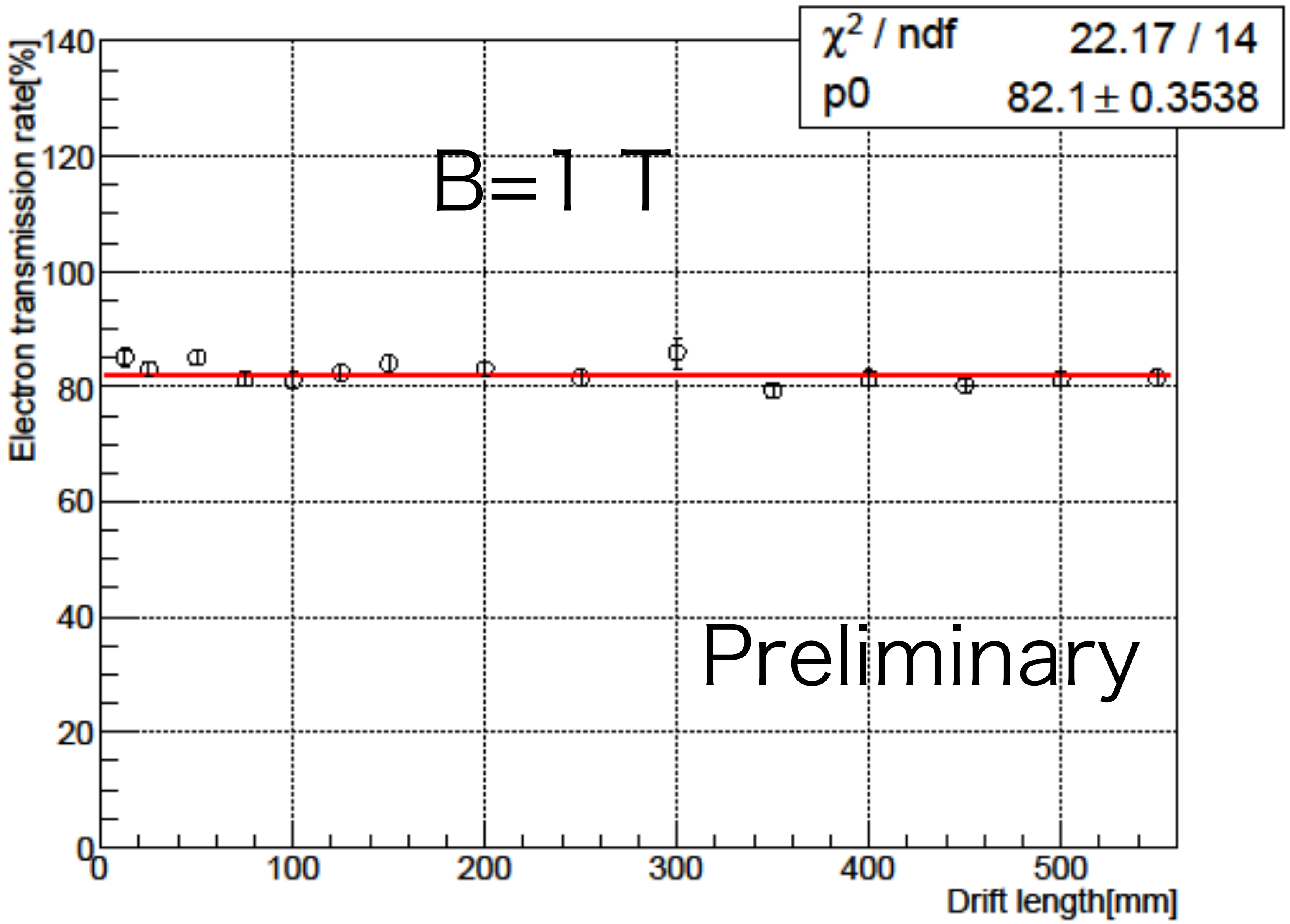
Examples of the pulse height distribution





$$R_{e.t.} = \frac{< Q_{\mathrm{w/\,Gate}} > \text{ (Peak1)}}{< Q_{\mathrm{w/o\,Gate}} > \text{ (Peak2)}} \times 100 \ [\%]$$

Electron transmission vs Drift length



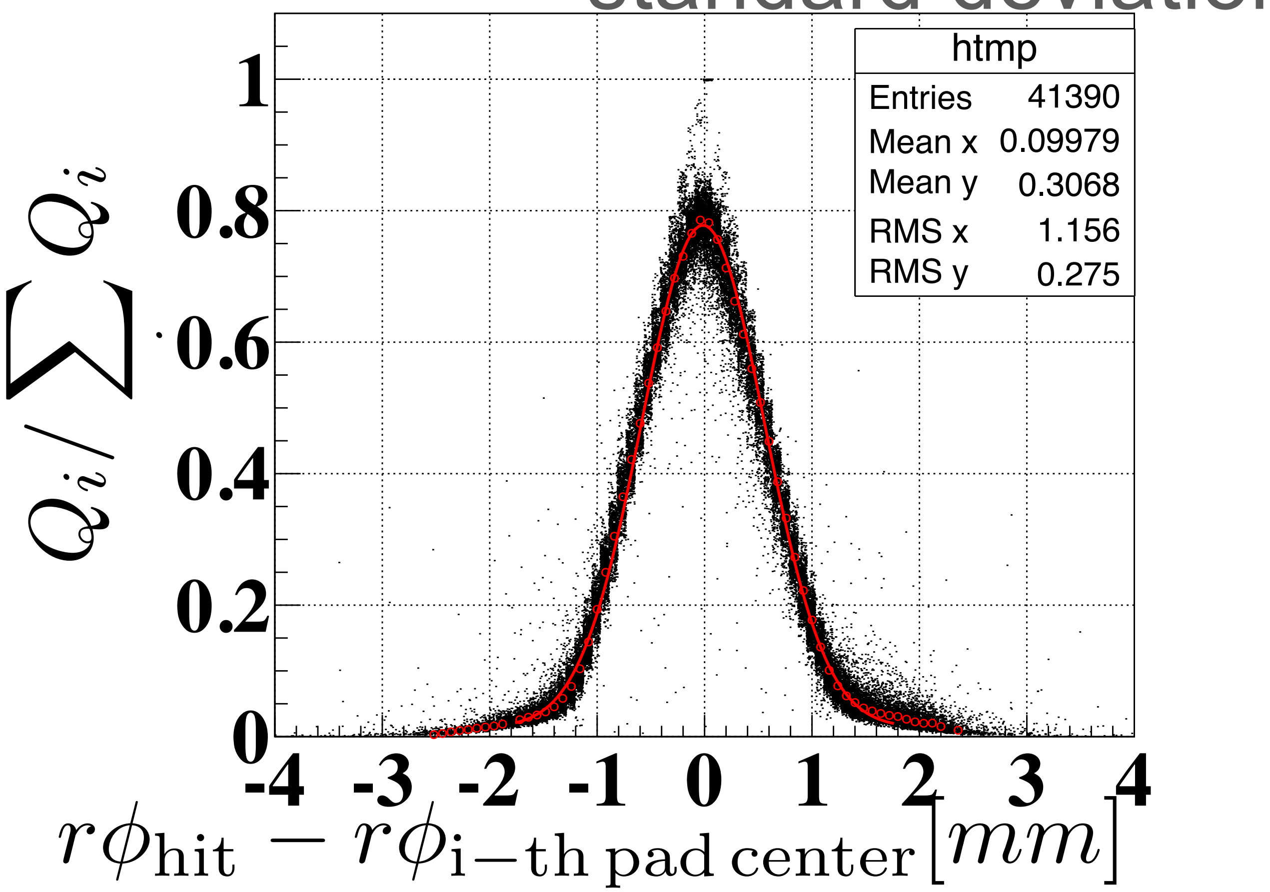
Gas gain correction has been made here for temperature and pressure variations.

As expected there is no drift length dependence.
After averaging over drift distance, we got 82.1% for the electron.

How to get electron transmission[2]

Pad responce (σ_{PR})

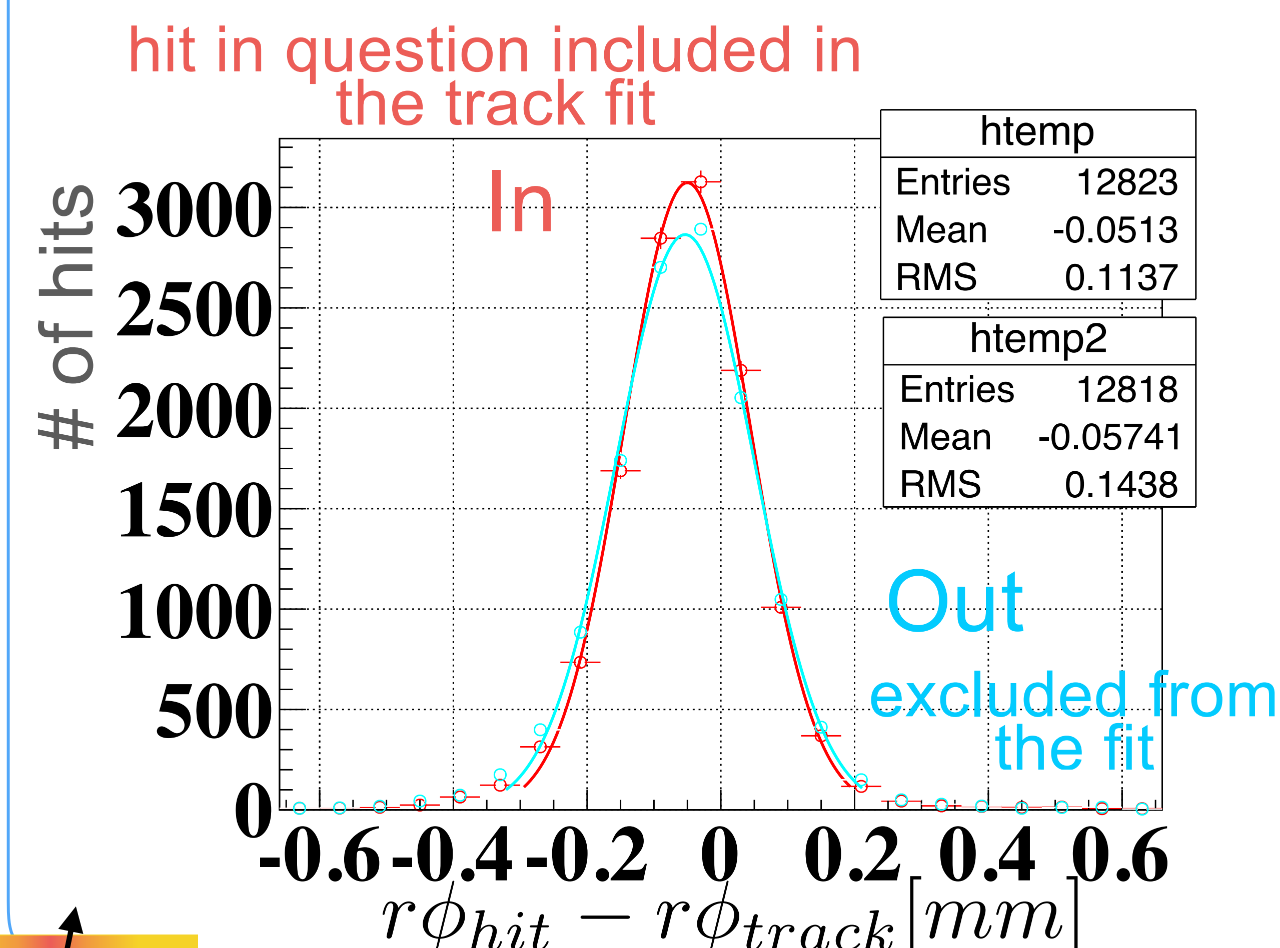
standard deviation

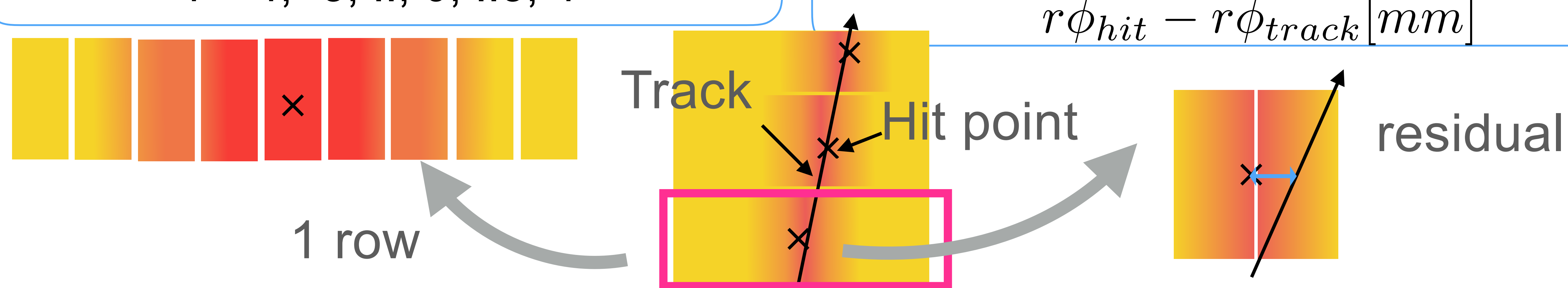


i= -4, -3, .., 0, ..3, 4

GM resolution ($\sigma_{r\varphi}$)

$$\sigma_{r\phi} = \sqrt{\sigma_{r\phi(in)}\sigma_{r\phi(out)}}$$





How to get electron transmission[2]

Pad responce（σ_{PR}）

plot vs distance Z

$$\sigma_{PR}{}^2 = \sigma_{PR}(0)^2 + \boxed{(C_D{}^2)} z$$

Diffusion constant

GM resolution（$\sigma_{r\varphi}$）

plot vs distance Z

$$\sigma_{r\phi} = \sqrt{\sigma_0{}^2 + \boxed{\frac{(C_D{}^2)}{N_{eff}}} z}$$

N effective $N_{eff} = \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}} \right)^2 \right\rangle \right]^{-1}$

Calculate Neff

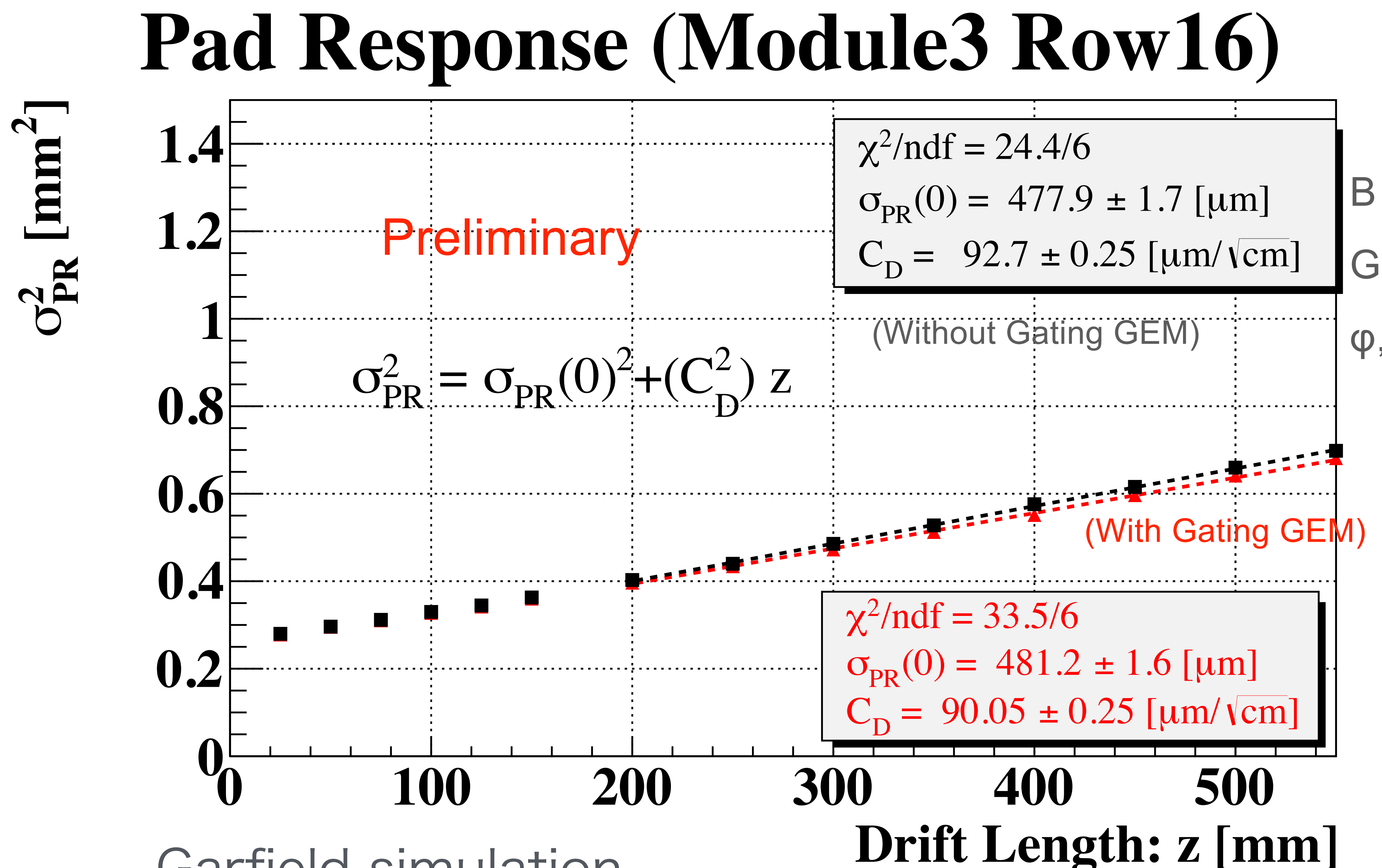
↓

Rate of Neff≒Electron transmission rate

$$\frac{N_{eff}(\mathrm{w/\ Gate})}{N_{eff}(\mathrm{w/o\ Gate})} \approx R_{e.t.}$$

yumia@post.kek.jp

Diffusion Constant



B = 1 T

Gate GEM Voltage 3.5 V

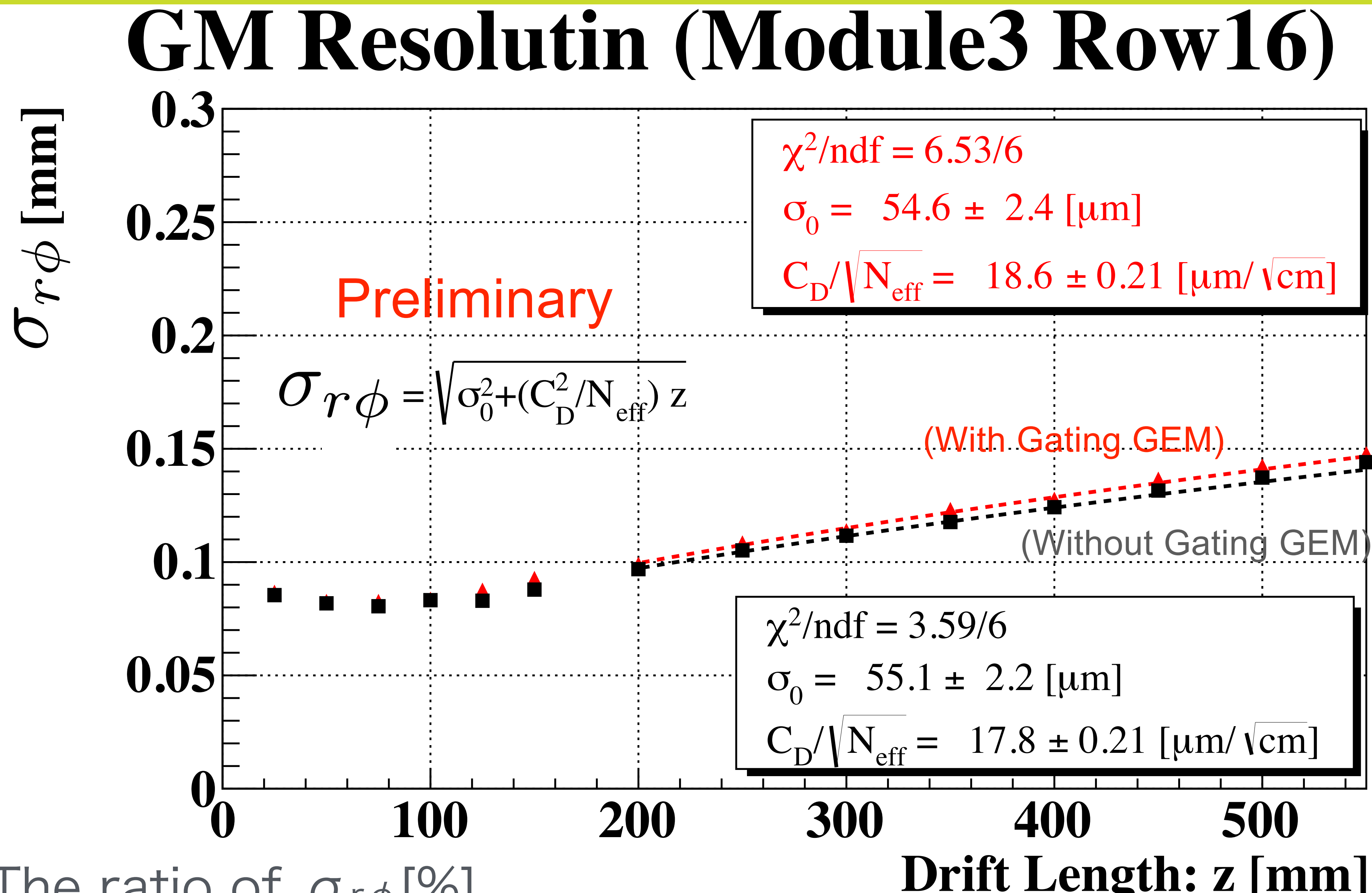
φ,θ = 0°

Garfield simulation

Cd(with gating GEM) 94.0 μm/√cm +/- 0.2%

Cd(without gating GEM) 94.2 μm/√cm +/- 0.3%

Position resolution（rϕ）



B = 1 T

Gate GEM Voltage 3.5 V

φ,θ = 0°

The ratio of $\sigma_{r\phi}$ [%]

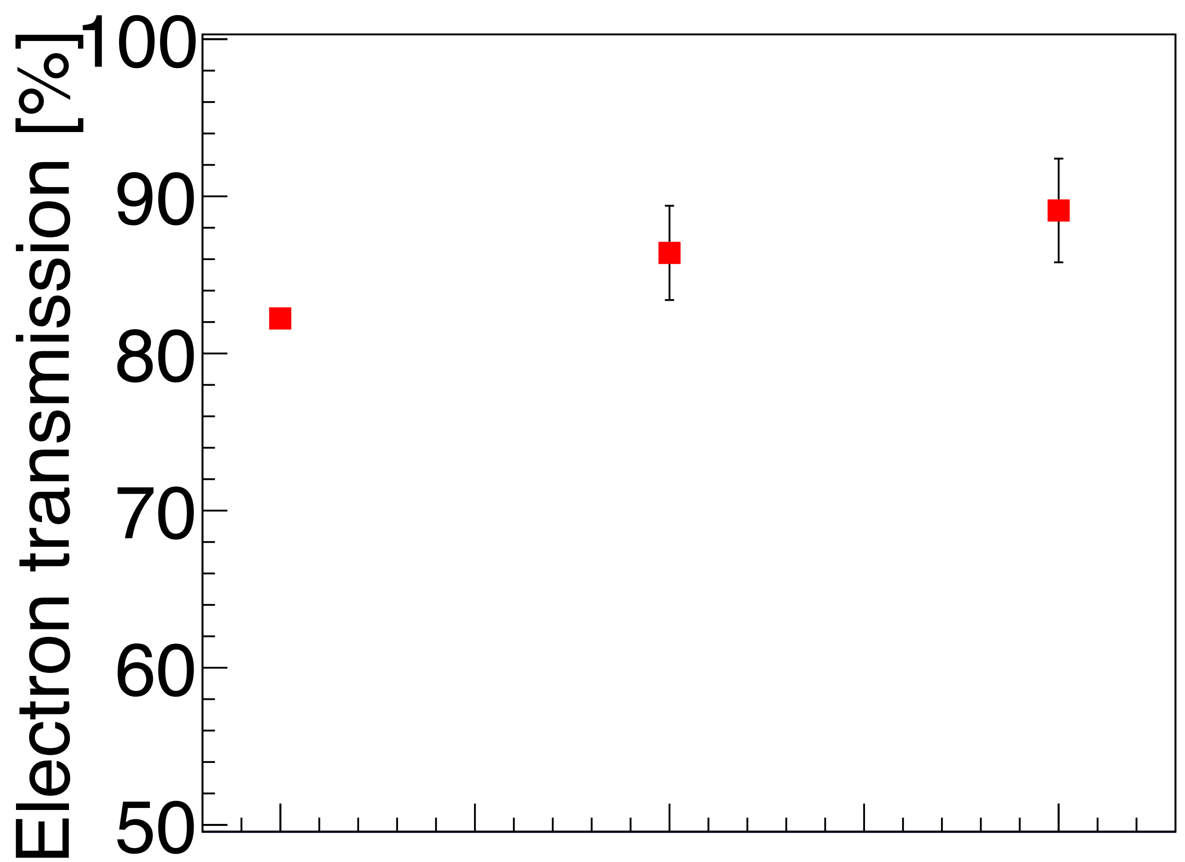
	2.5	5	7.5	10	12.5	15	20	25	30	35	40	45	50	55
Ratio /%	101.7 ±0.1	101.2 ±0.1	102.9 ±0.1	100.7 ±0.1	105.8 ±0.1	105.8 ±0.1	102.4 ±0.1	103.3 ±0.1	102.1 ±0.1	104.8 ±0.1	103.0 ±0.1	104.0 ±0.1	103.8 ±0.1	102.7 ±0.2

Expected ratio：110 %

Preliminary(Stat. only)

Electron transmission rate

Used Cd values [μm/√cm]	N_{eff}(W/ gate)	N_{eff}(W/O gate)	rate[%]
measured	23.4±0.6	27.1±0.7	86.4±3.0
Simulated(Garfield++)	26.7±0.7	30.0±0.9	89.1±3.3



Method 1 (from hit charge)

Method 2(from Neff) with measured Cd

with simulated Cd

This result are consistent within the statistical errors.

Conclusion

The ion stopping power estimated using electron is 99.97 % or better at -15.5 V.

We succeeded in the first beam test of a GEM-readout TPC module with a large aperture GEM-like gating device

↓

The electron transmission from Neff measurements is 86.4 ± 3.0%
The electron transmission from charge measurements is 82.1 ± 0.4%

We achieved the target electron transmission rate of > 80%.

Remaining issue

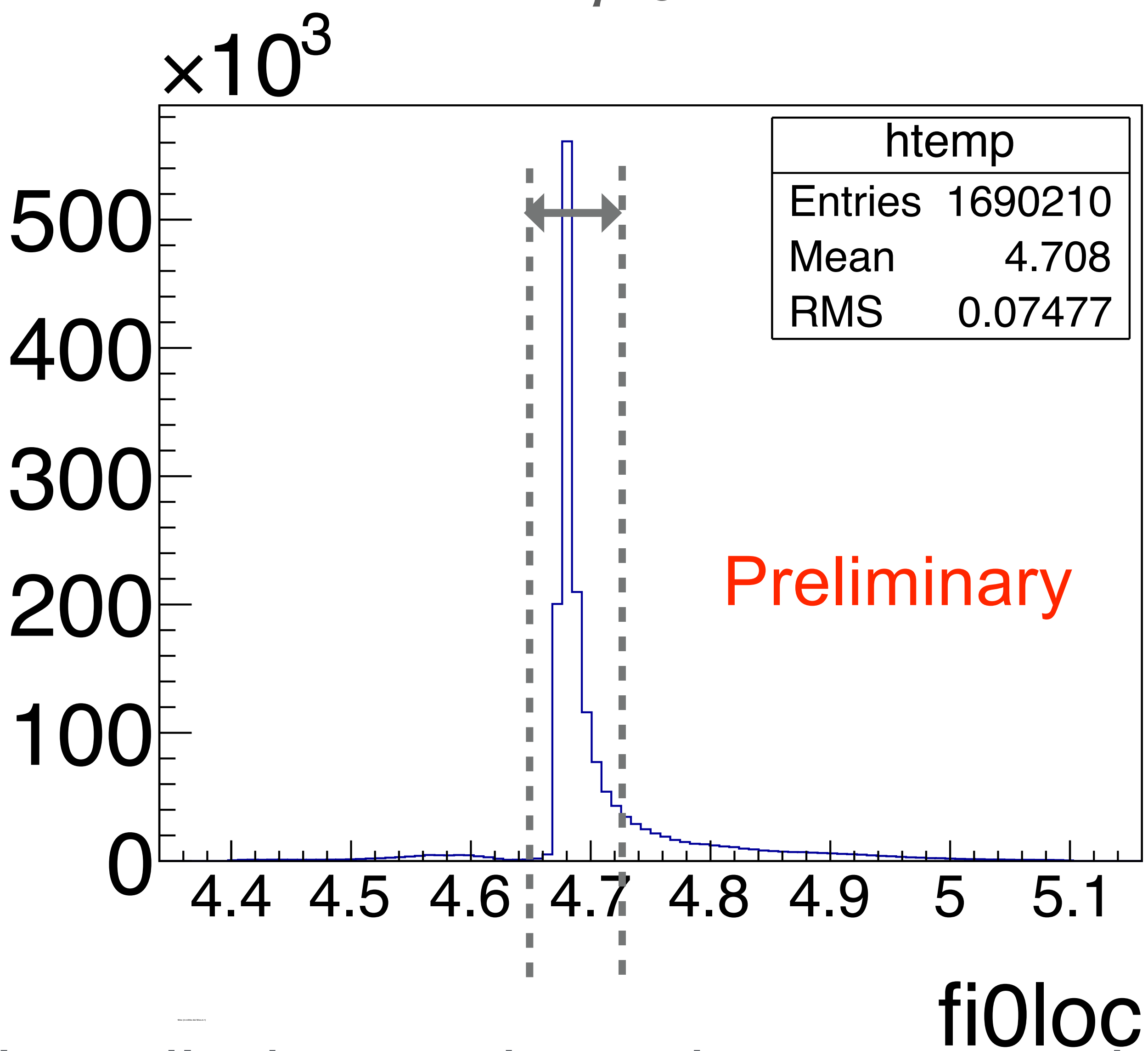
The difference between Cd values measured with and without the gating GEM.

We will investigate this issue further.

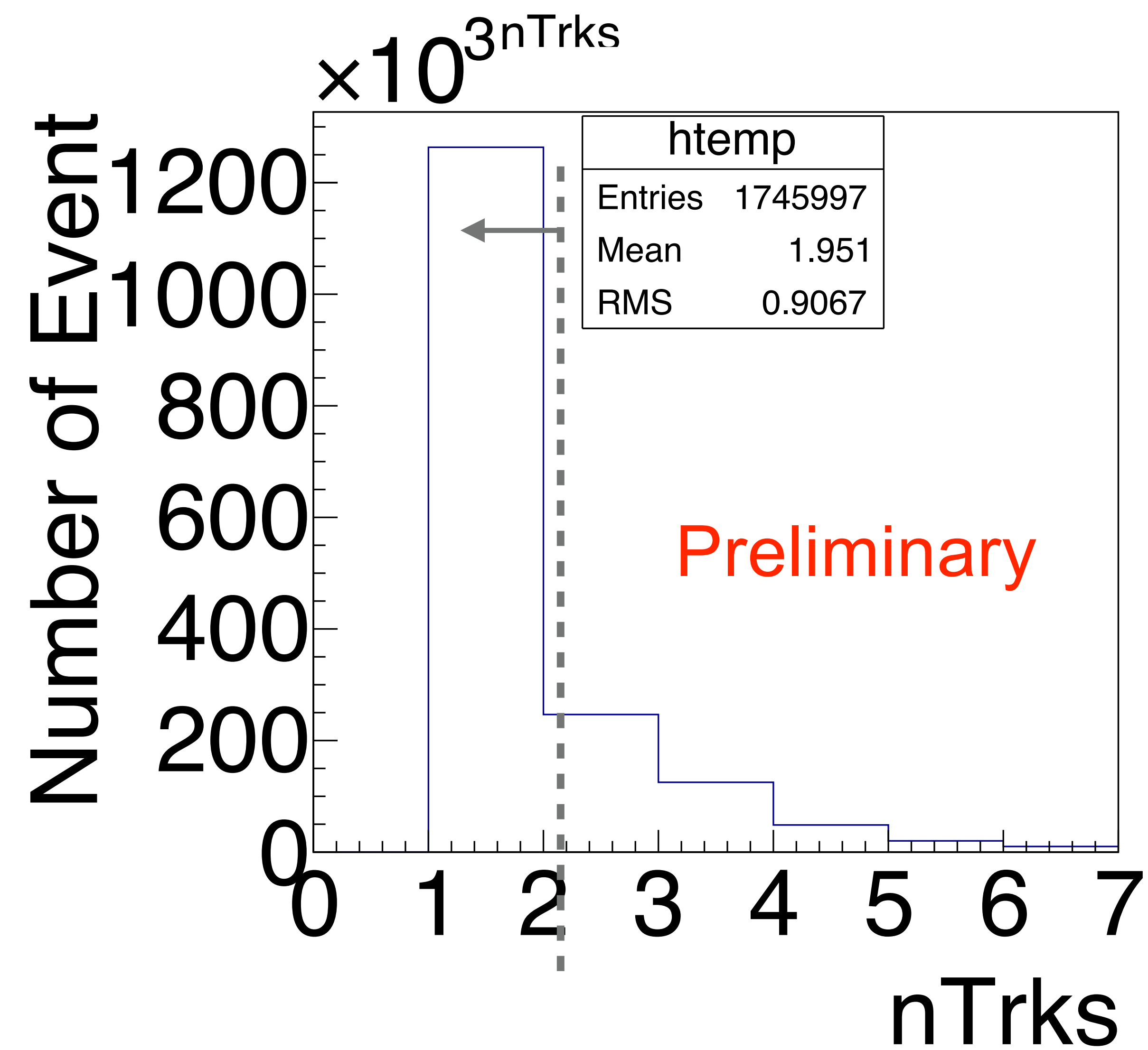
Back up Slides

Event Selection

Track angle cut[rad]
4.64< ϕ_0 <4.72



# of tracks per event
nTrks = 1



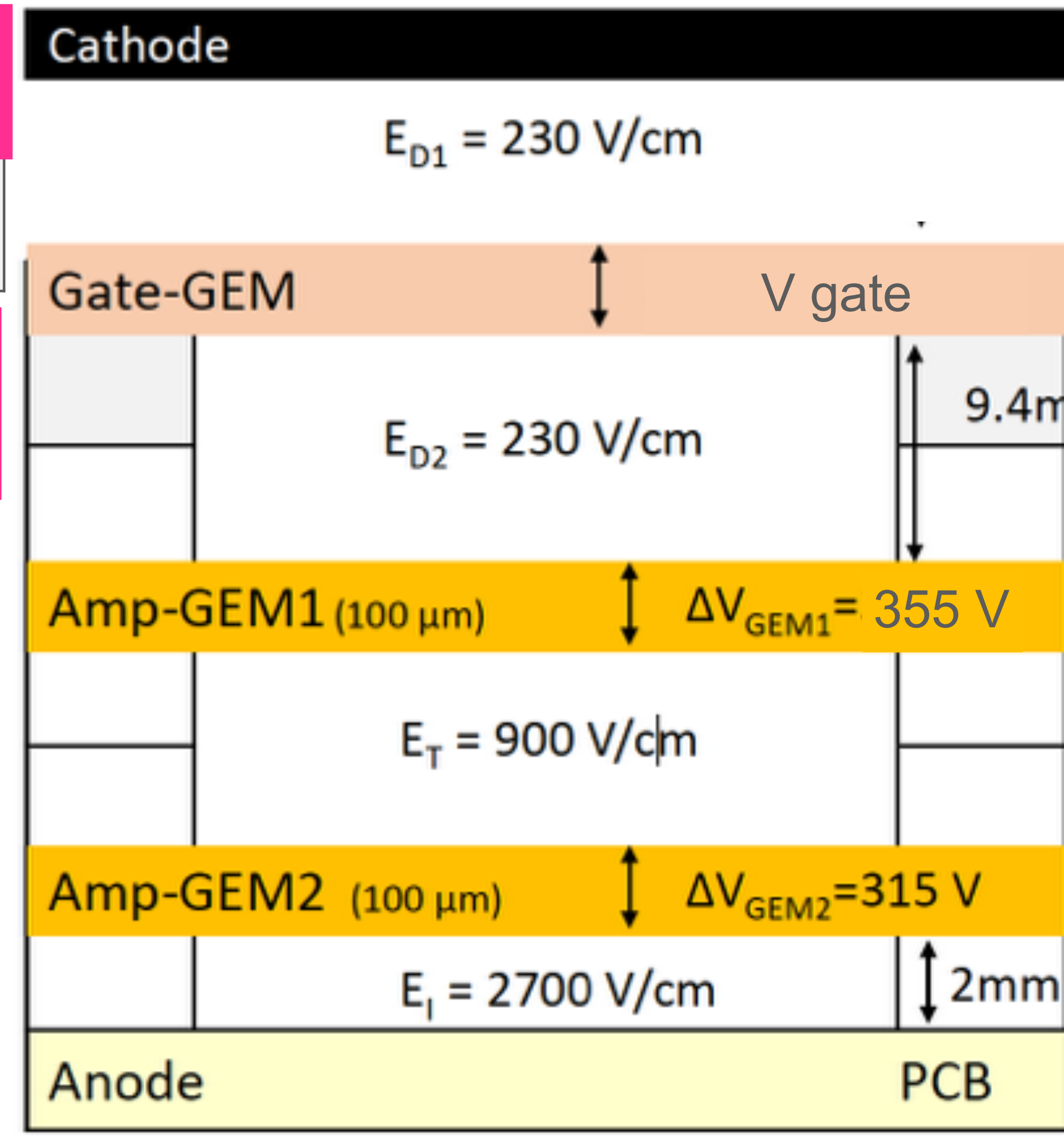
I applied a track angle cut to exclude angled tracks and a cut on nTrks to eliminate events with multiple tracks caused by electromagnetic shower in the upstream.

Condition

Module 3	With Gating GEM	Without Gating GEM
Module 0	Without Gating GEM	Without Gating GEM

Z[cm] (Drift length)	1.25,2.5,5,7.5,10,12.5,15,20 25,30,35,40,45,50,55
ϕ [degree]	0,10,20
θ [degree]	-20,-10,0,10,20
V_{gate}[V]	-3.5,0,3.5
B[T]	0,1

Analyze condition of



Beam: 5 GeV electron

Gas:T2K gas (Ar : CF_4 : Iso-C_4H_{10} = 95 : 3 : 2 [%])

Analytics framework:MarlinTPC（Analysis 20000 event/1 run）

Introduction- Why we need high electron transmission?

- Spatial Resolution vs Electron Transmission

$$\sigma_{r\phi} \propto 1/\sqrt{N_{eff}} \propto 1/\sqrt{R_{e.t.}}$$

$$\frac{\sigma_{r\phi}(\mathrm{w/\ Gate})}{\sigma_{r\phi}(\mathrm{w/o\ Gate})} \approx \frac{1}{\sqrt{R_{e.t.}}}$$

$$\left(N_{eff} = \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}} \right)^2 \right\rangle \right]^{-1} \right.$$

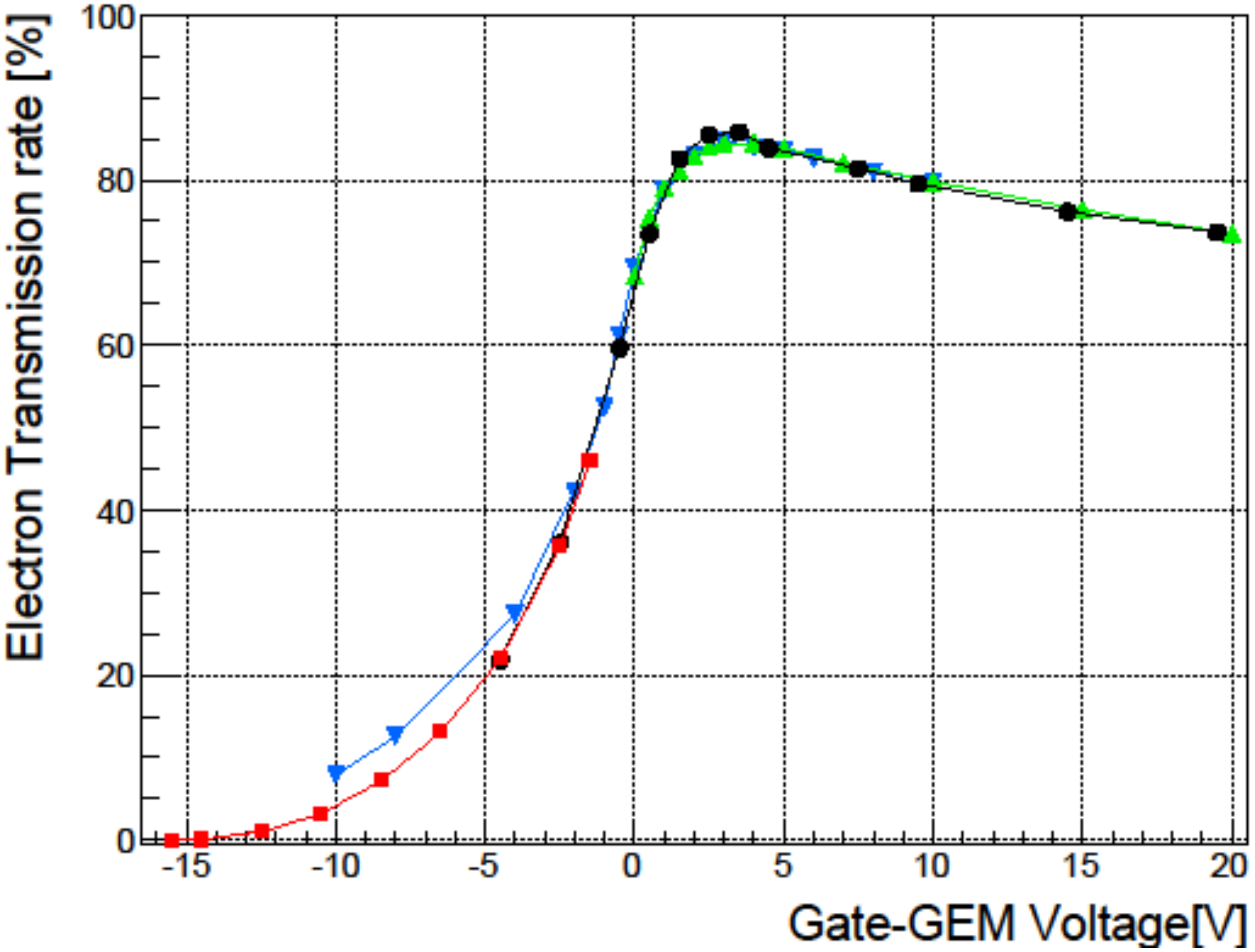
$$R_{e.t.} = \frac{< Q_{\mathrm{w/\ Gate}} >}{< Q_{\mathrm{w/o\ Gate}} >}$$

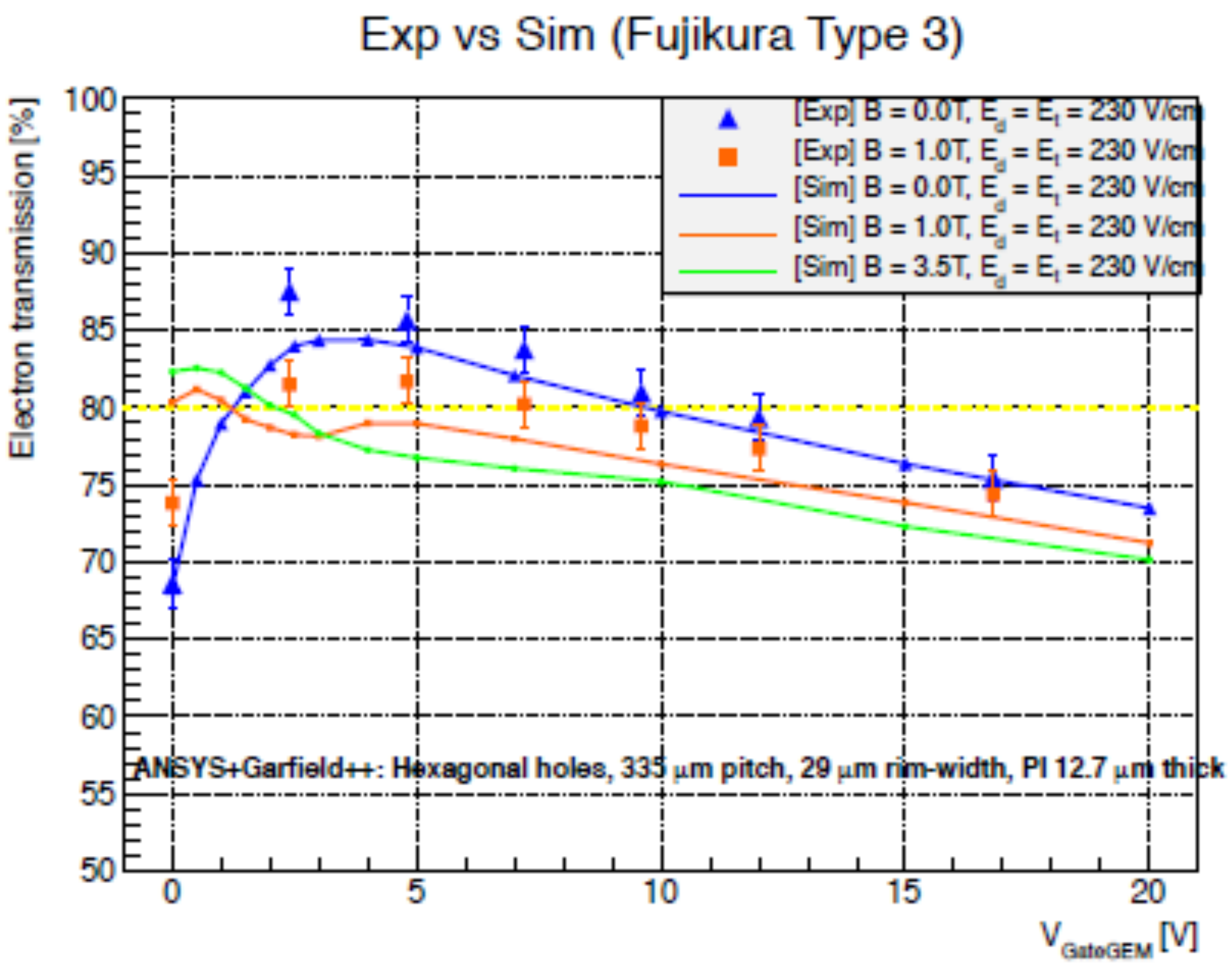
We need high electron transmission to keep good resolution:

$$R_{e.t.} > 0.8$$

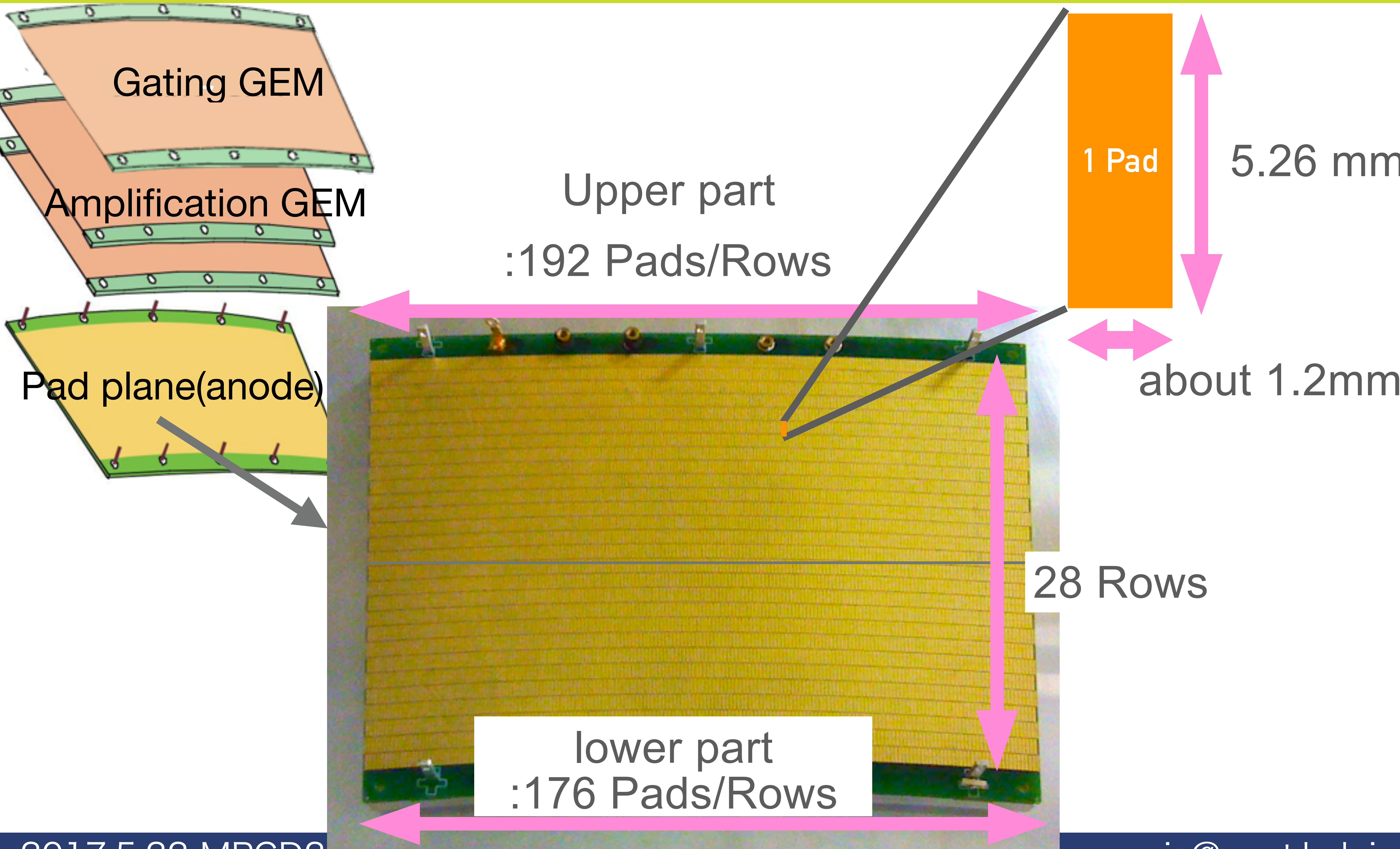
for point resolution better than 100μm at B=3.5 T over the full drift length of 2.2 m of the ILC TPC.

So we measured resolution and other parameters related it.

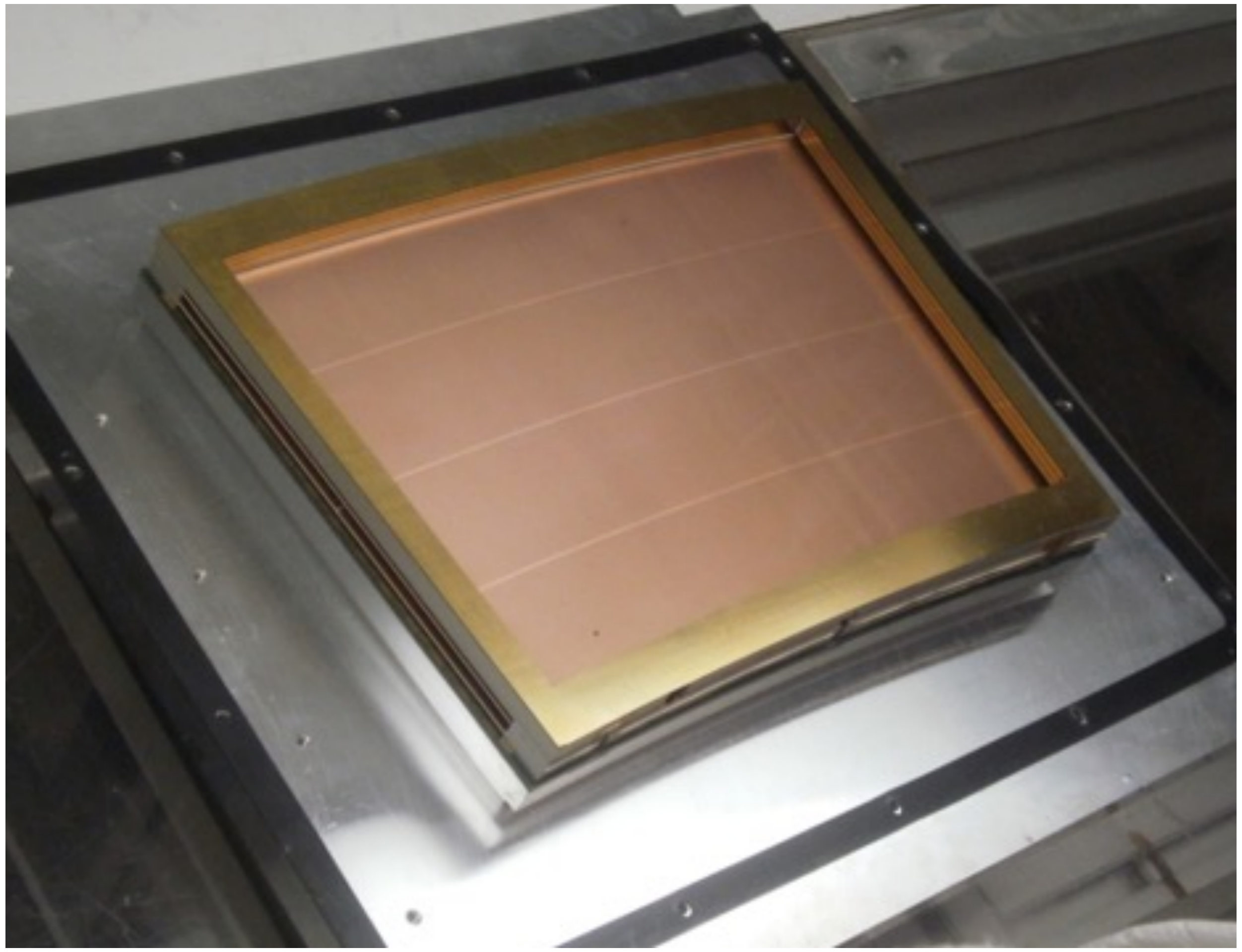

Electron Transmission rate [%]
Gate-GEM Voltage[V]


Exp vs Sim (Fujikura Type 3)
Electron transmission [%]
[Exp] B = 0.0T, E_d = E_t = 230 V/cm
[Exp] B = 1.0T, E_d = E_t = 230 V/cm
[Sim] B = 0.0T, E_d = E_t = 230 V/cm
[Sim] B = 1.0T, E_d = E_t = 230 V/cm
[Sim] B = 3.5T, E_d = E_t = 230 V/cm
ANSYS+Garfield++: Hexagonal holes, 335 μm pitch, 29 μm rim-width, PI 12.7 μm thick
V_GateGEM [V]

Readout Pads

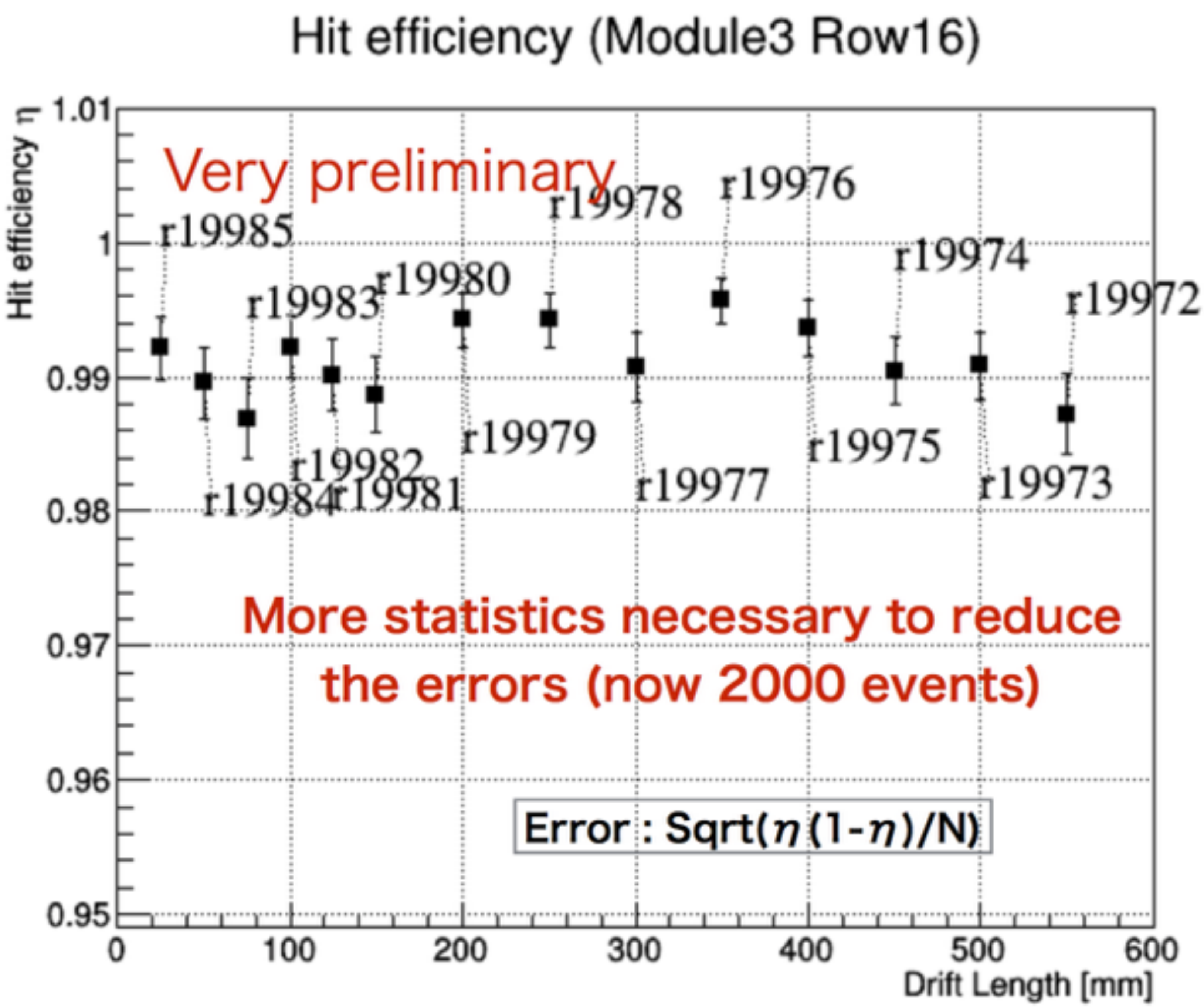


Field shaper



- To arrange the electric filed

Data quality check - Hit efficiency



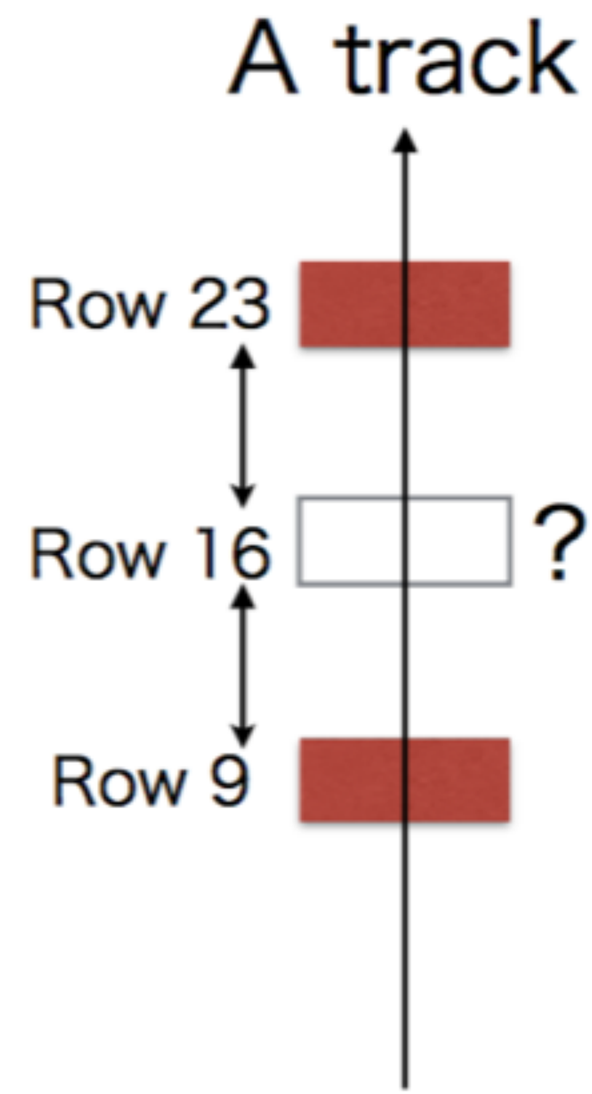
With Gating GEM

- Missing track is about 1%

Hit efficiency estimation

Looked at row-16 (module 3)

7rows away to avoid
effects by the diffusion.

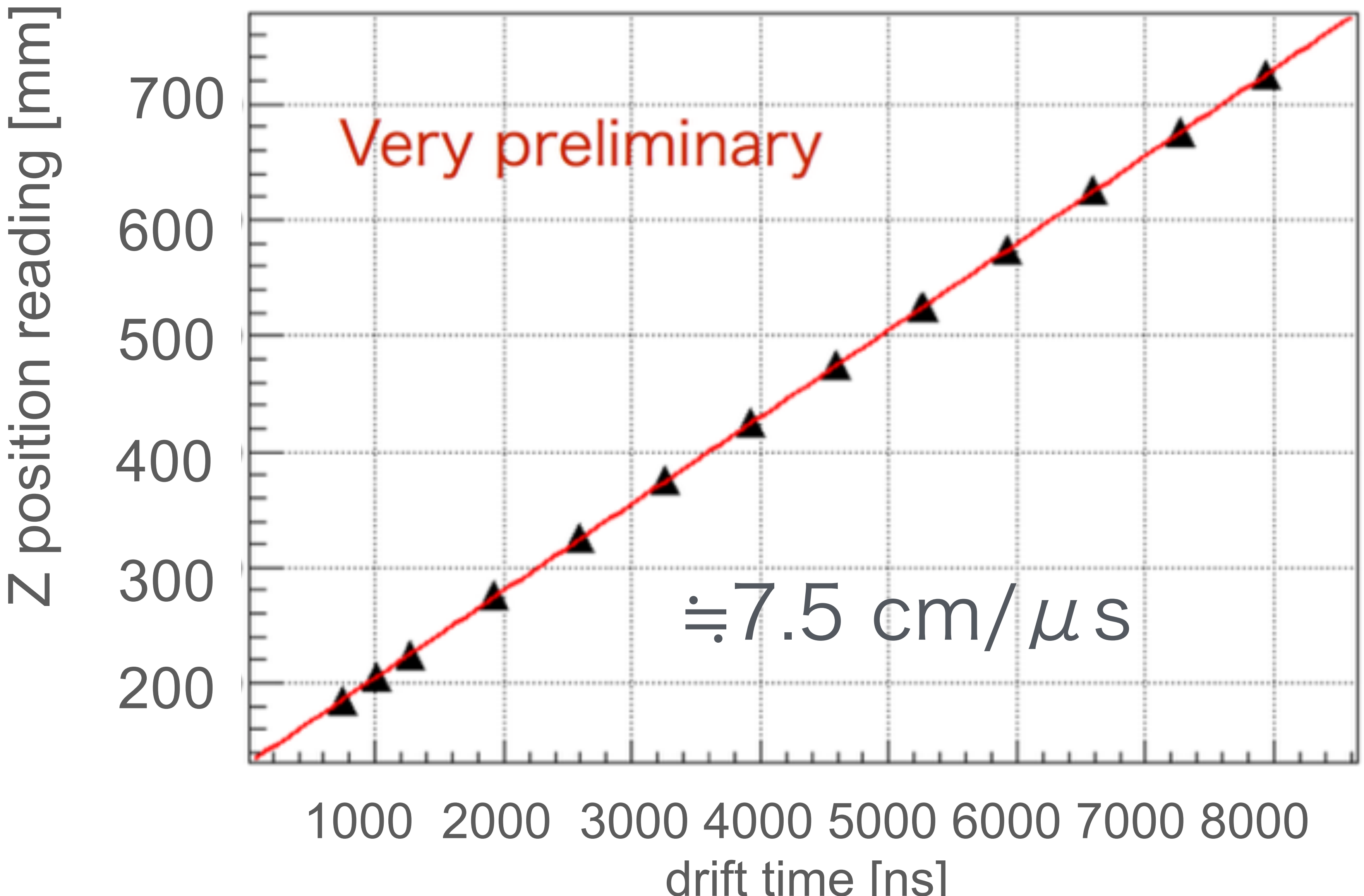


Basic idea :

Test if Row16 has a hit associated with a track
that has hits both on Row9 and Row23.

To reduce biases, minimum number of hits per track
is set to be a relatively small value (=10)
in the track reconstruction step.

Drift velocity



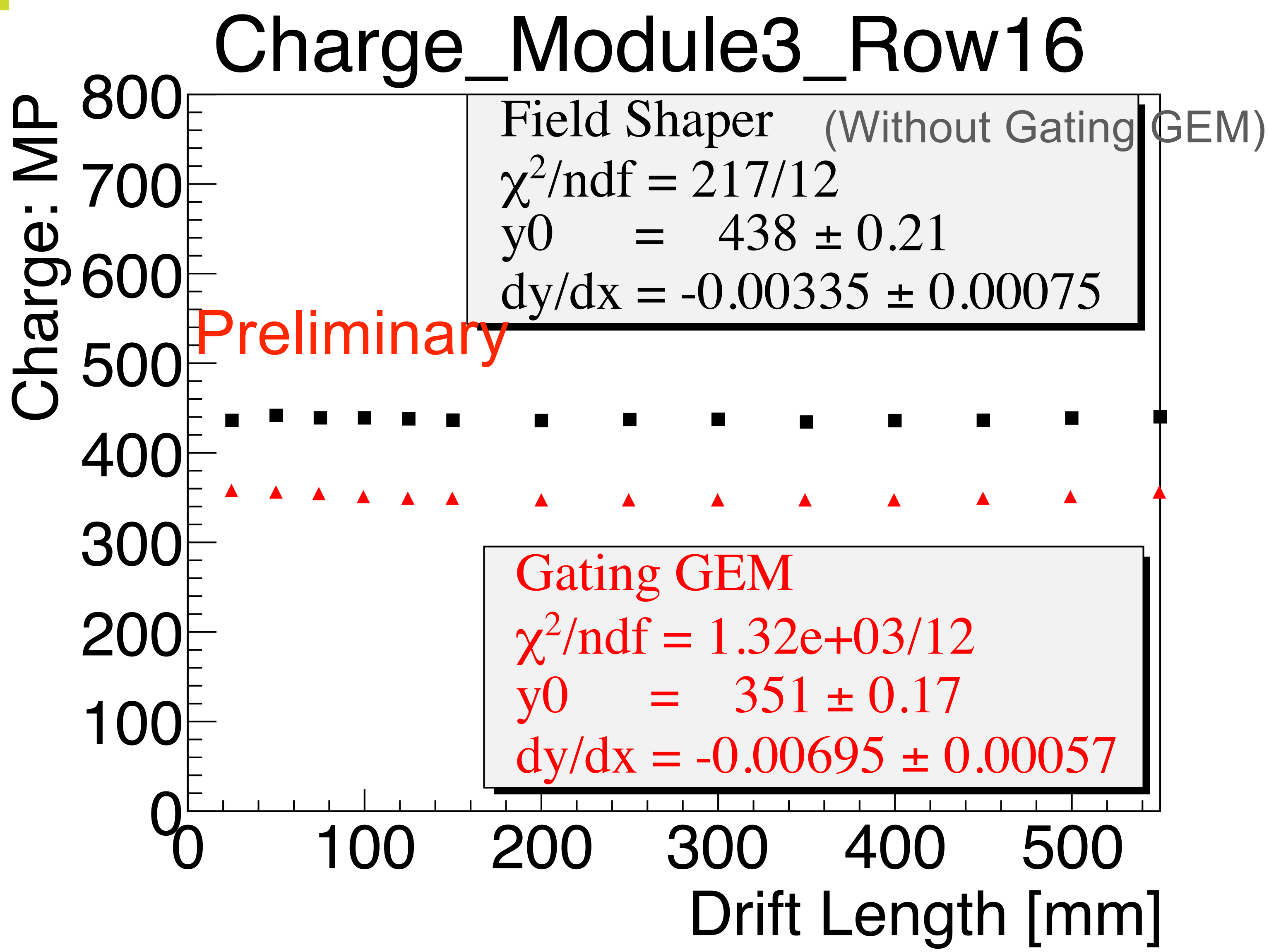
	W/ gate	W/O gate
Temp.[K]	291.28	290.4
Pres [hPa	1010.79	1005.31

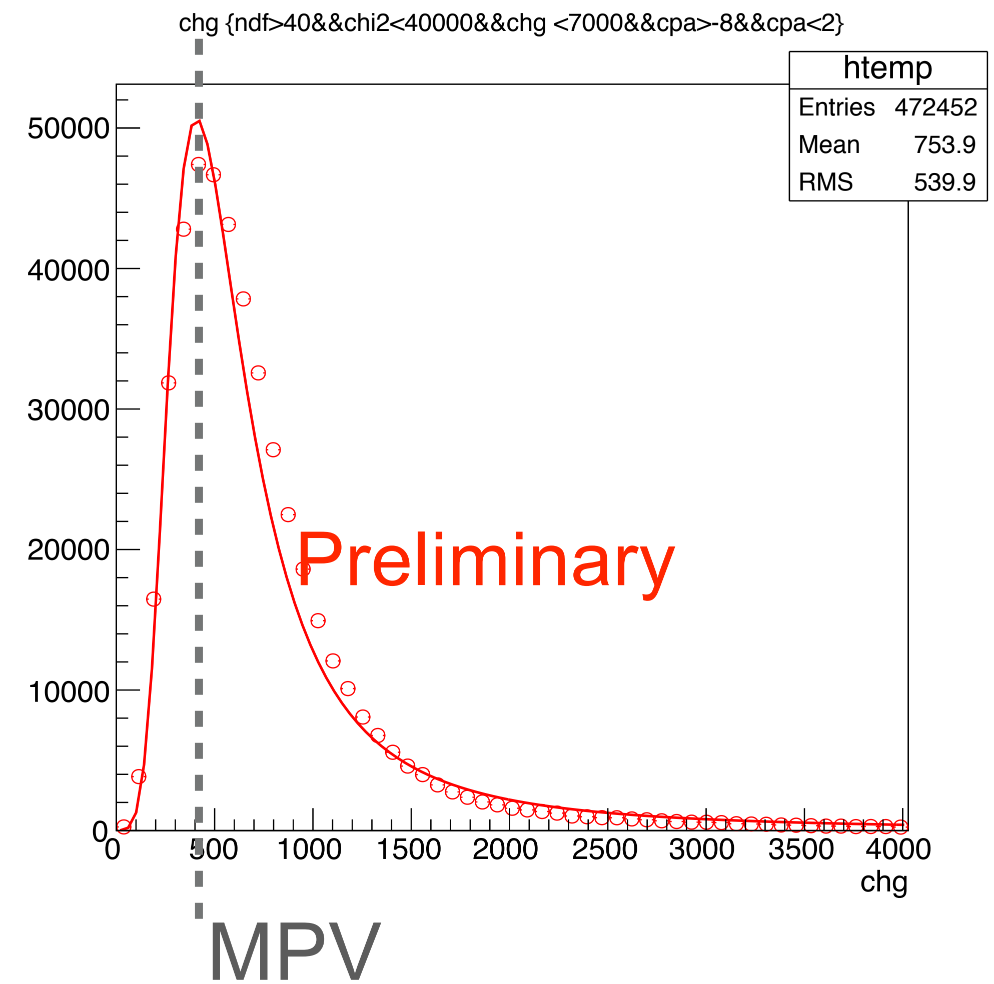
Garfield simulation

W/ gate 76.7 cm/μs +/- 0.0013%

W/O gate 7.68 cm/μs +/- 0.0022%

Result - Charge sum



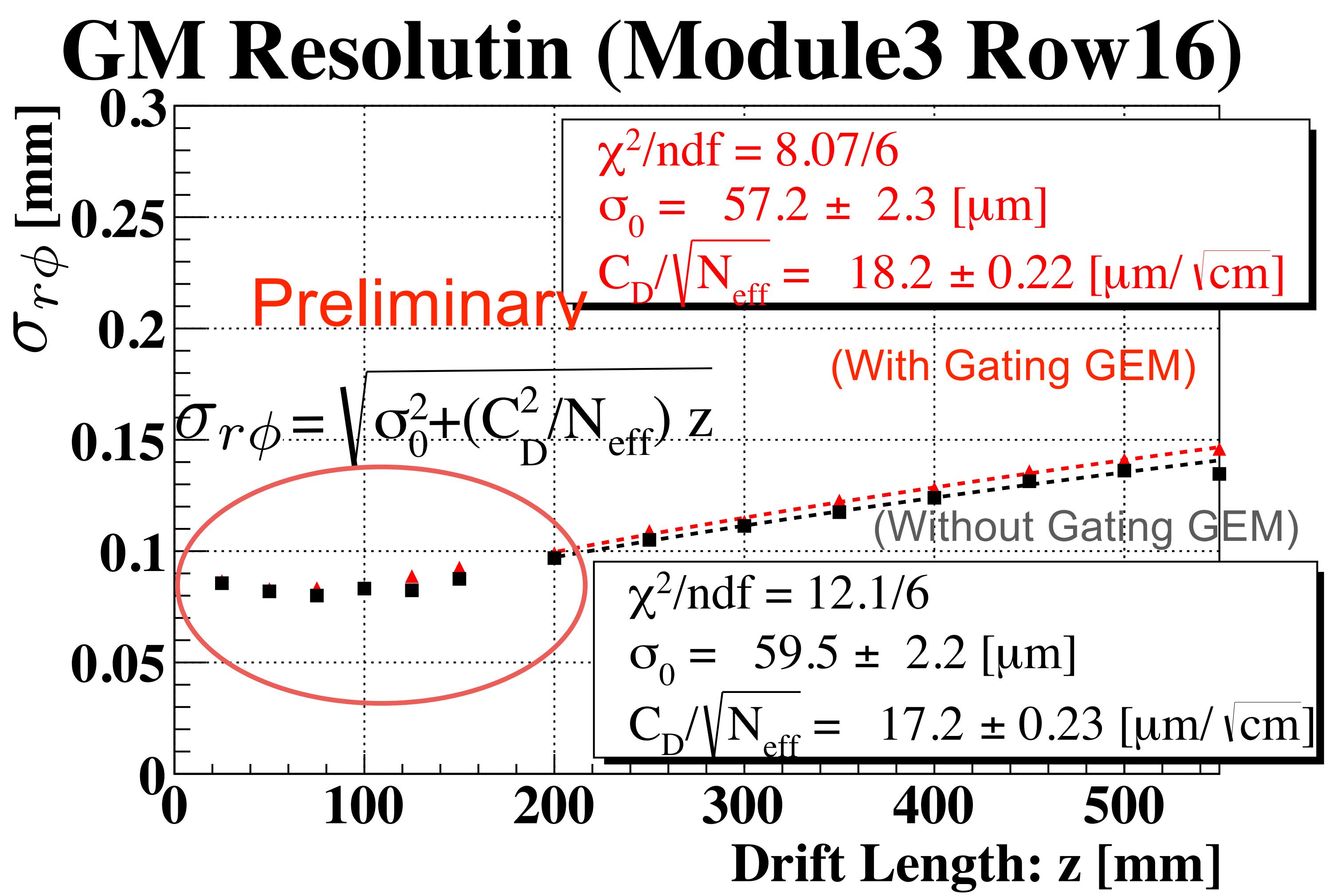


➤ There seems to be no electron attachment (P/T correction is not included)

	2.5	5	7.5	10	12.5	15	20	25	30	35	40	45	50	55
Ratio /%	82.0 ±0.1	80.4 ±0.1	80.4 ±0.1	79.9 ±0.1	79.7 ±0.1	79.7 ±0.1	79.4 ±0.1	79.2 ±0.1	79.0 ±0.1	79.7 ±0.1	79.6 ±0.1	79.9 ±0.1	79.7 ±0.1	80.6 ±0.2

Preliminary(Stat. only)

Hodoscope effect



Hodoscope is one of the tracker.

The detector using scintillators.

(not using the center of gravity method)

Therefore, we call the single pad effect “hodoscope effect”.

Expected ratio：110%

$$\sigma_{r\phi} = \sqrt{\cancel{\sigma_0}^2 + \frac{(C_D{}^2)}{N_{eff}} z}$$

If Neff become 80%

Ratio＝√1/0.8

=√1.25

＝1.1