The spatial resolution in the first beam test of a GEM-based readout module for the ILD-TPC equipped with a large aperture GEM-like gating device

Yumi Aoki(SOKENDAI/KEK)
on behalf of the LCTPC collaboration
2018.3.20 Annual meeting@KEK

yumia@post.kek.jp

Outline

We checked performances of the module with the gating GEM

- Spacial resolution (Y.Aoki)
- dE/dx (A.Shoji)
- Amplification GEM optimization by simulation (T.Ogawa)

I mainly talk about the spacial resolution

1. About TPC
2. Momentum Resolution Goal & Ion Feedback Problem
3. A large aperture GEM-like gating device
4. Beam test
5. Results - Pad response
6. Results - Spacial resolution
7. Summary

Presentation

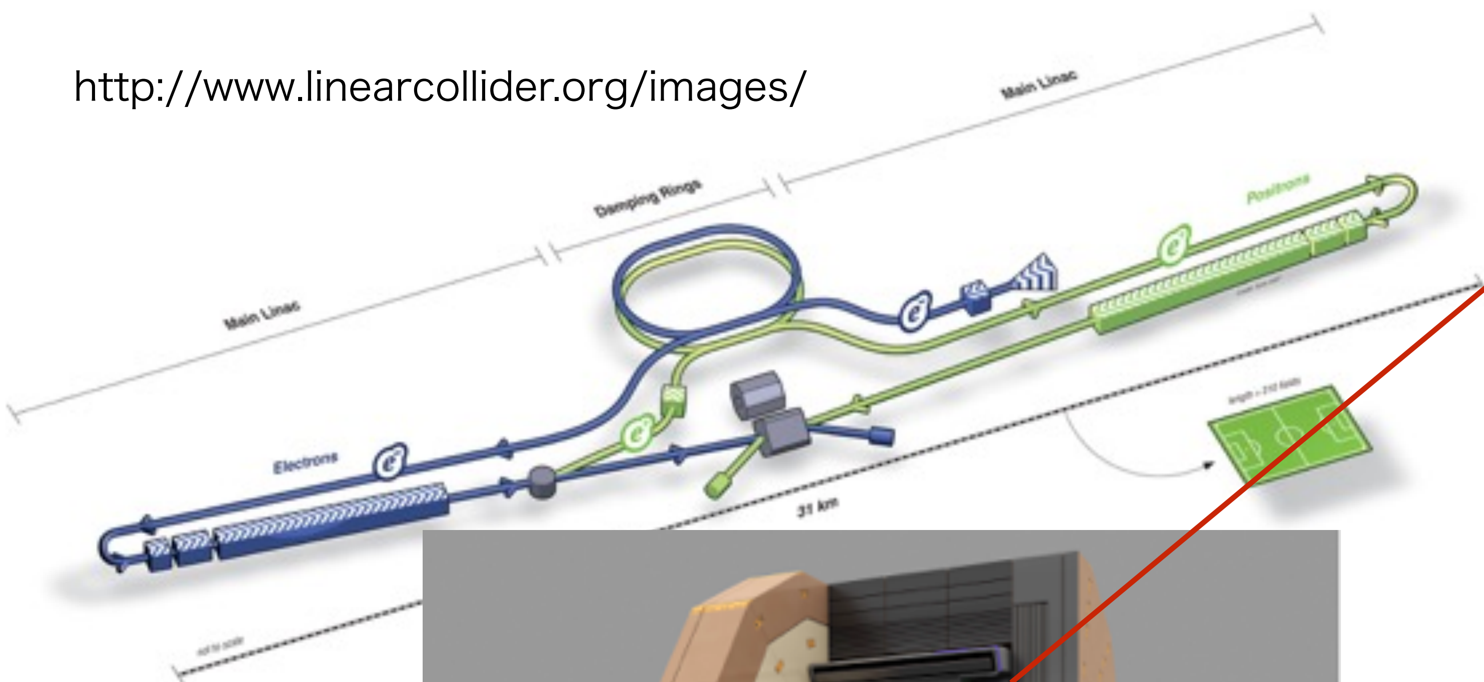
	name	URL	Speaker
May	MPGD	https://indico.cern.ch/event/581417/contributions/2556747/	Aoki
June	AWLC	https://agenda.linearcollider.org/event/7507/contributions/39322/	Aoki
		https://agenda.linearcollider.org/event/7507/contributions/39323/	Shoji
July	Summer Camp	https://agenda.linearcollider.org/event/7684/contributions/39479/ (Japanese)	Aoki
Sep	JPS	http://www.pe.div.jps.or.jp/index.html 13aS34 ガス検出器（Japanese）	Aoki Shoji
Oct	LCWS	https://agenda.linearcollider.org/event/7645/contributions/40111/	Shoji

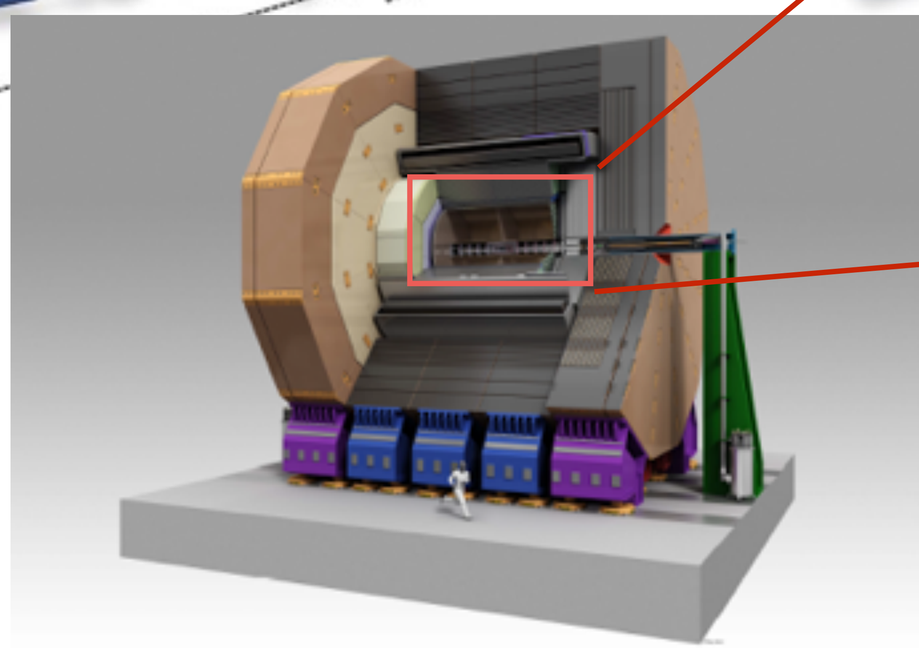
TPC

International Linear Collider

Electron positron Collider（250〜500 GeV)

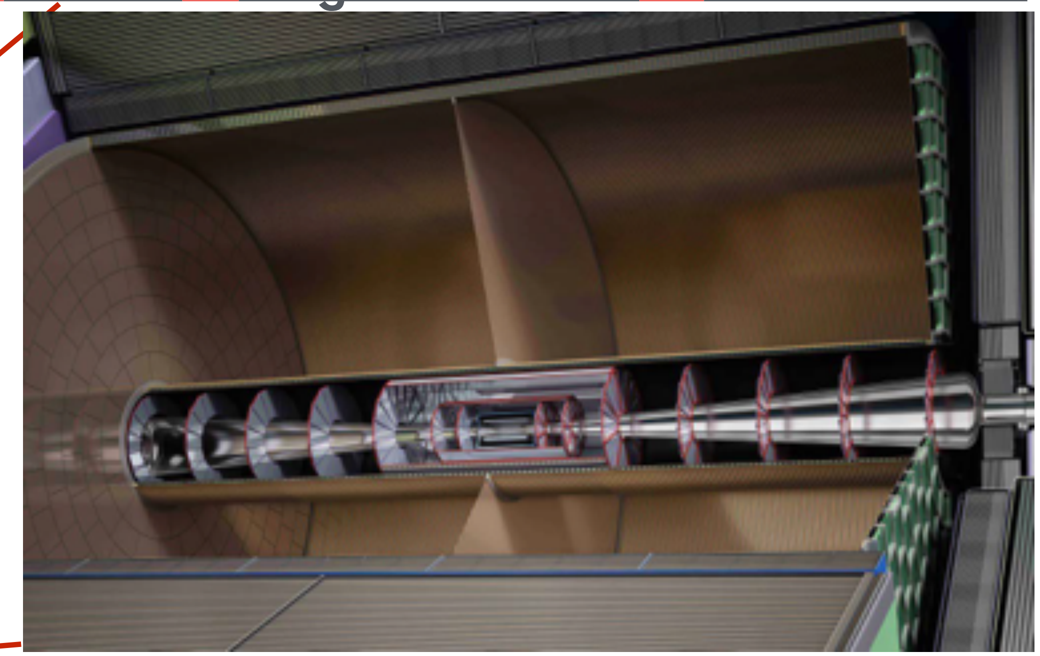
http://www.linearcollider.org/images/





International Large Detector

Time Projection Chamber



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

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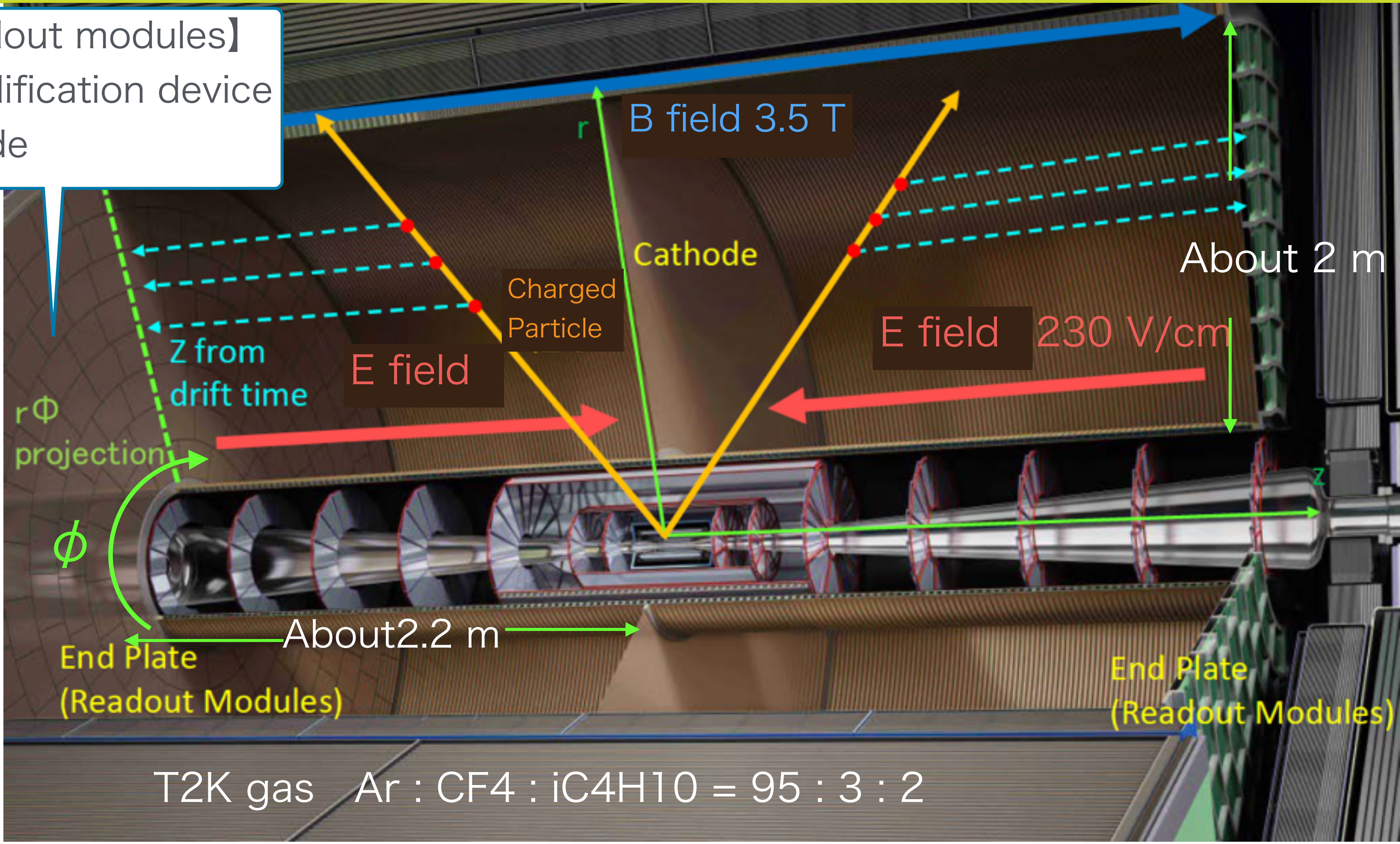
TPC

【Readout modules】
- Amplification device
- Anode



Momentum Resolution Goal

Momentum resolution Goal: $\sigma_{\frac{1}{P_T}} = 1 \times 10^{-4} GeV^{-1}$

Glueckstern Formula

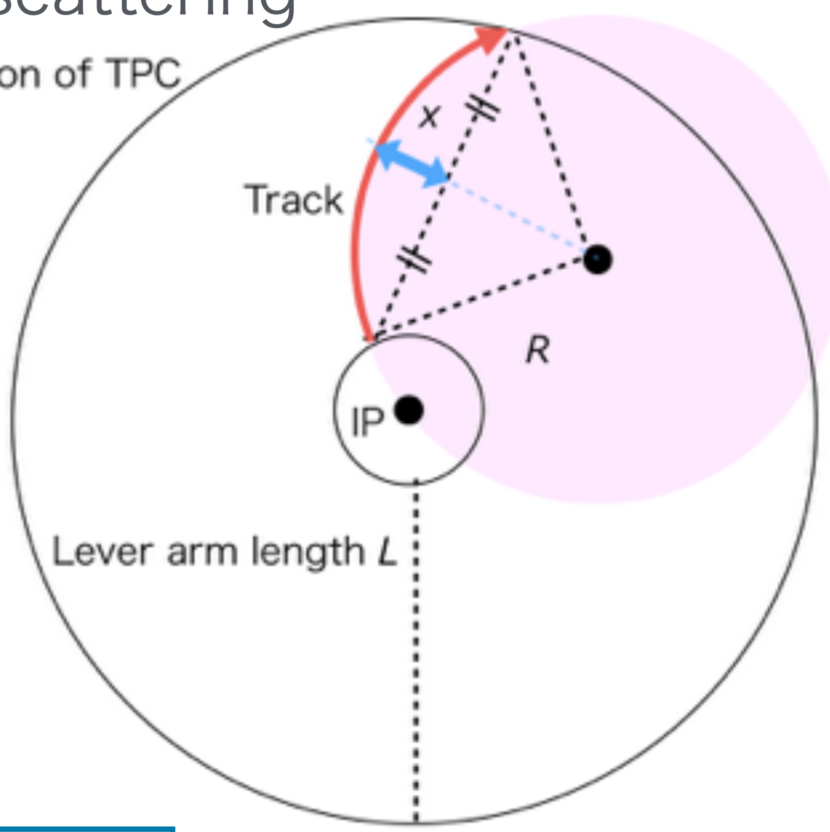
R.L. Gluckstern, NIM 24 (1963), 381

$$\frac{\sigma_{P_T}}{P_T} \simeq \sqrt{\left(\frac{\alpha' \sigma_x}{BL^2}\right)^2 \left(\frac{720}{n+4}\right) P_T^2 + \left(\frac{\alpha' C}{BL}\right)^2 \left(\frac{10}{7}\left(\frac{X}{X_0}\right)\right)}$$

Multiple scattering

Momentum resolution depends on

Position resolution σ_x, Mesurement points n, Magnetic field B, Lever arm length L



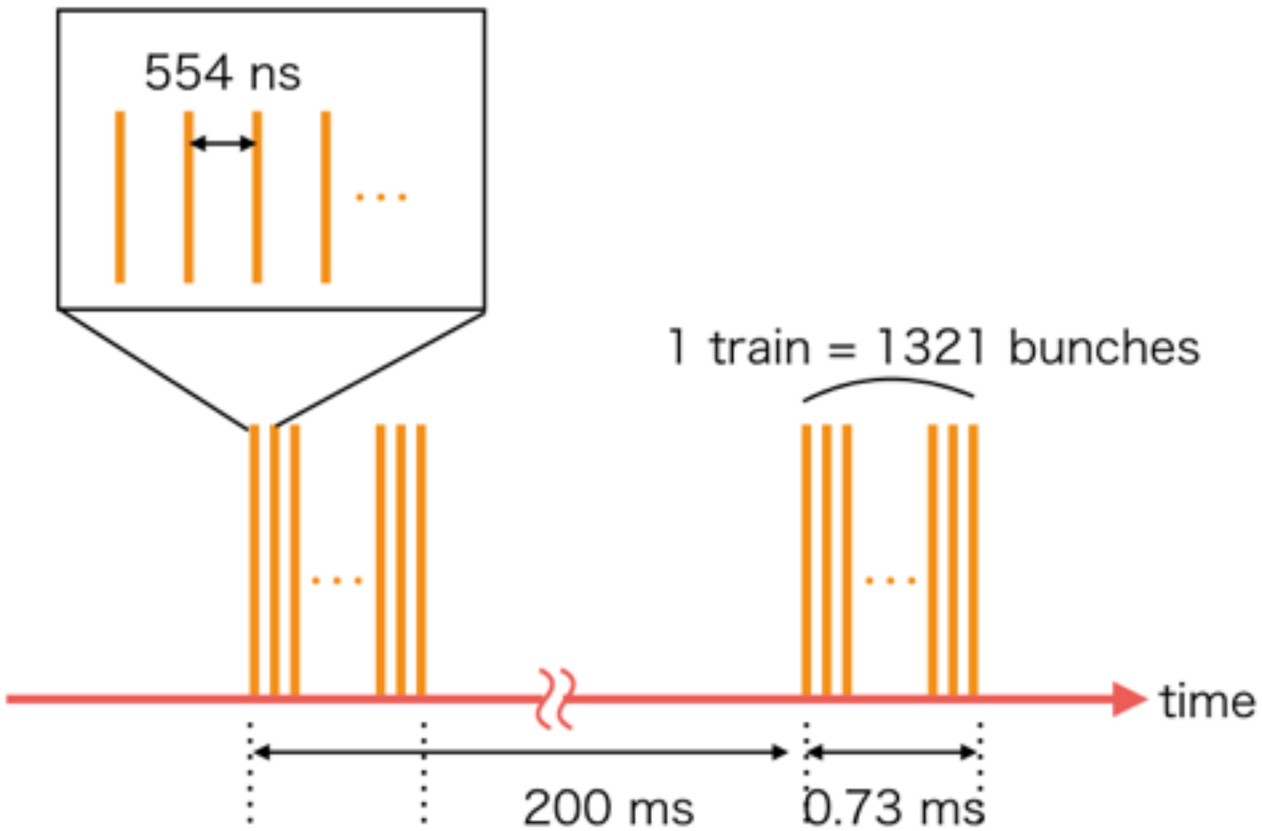
ILC-TPC :n= 220points B=3.5T L=1.5m

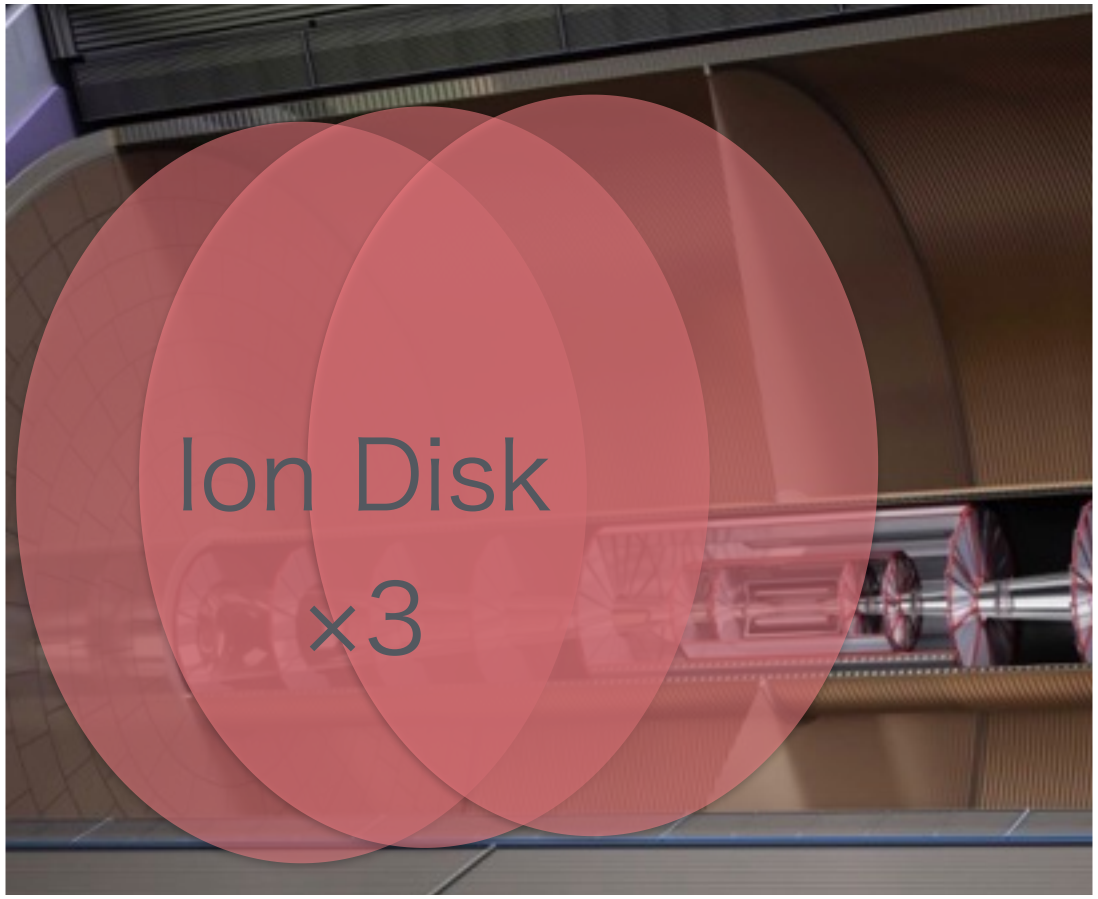
Spatial resolution goal： $\sigma_{r\phi}$<100μm

However the ion feedback prevent us to achieve this goal

Ion Feedback Problem

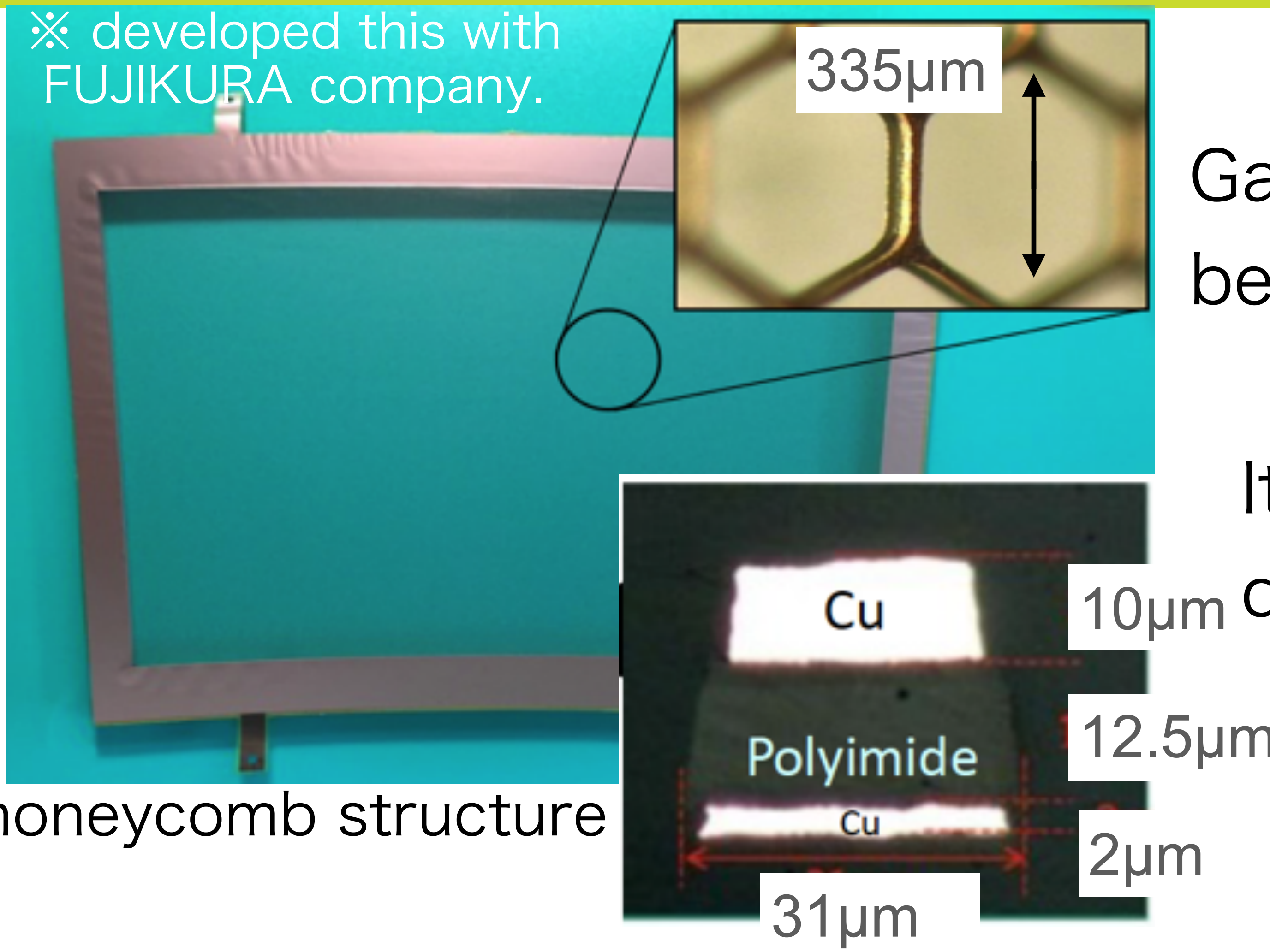
Positive ions created by gas amplification back-flow into the drift volume
→distort electric field→deteriorate position resolution





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 due to the 3 ion disks : 60μm

A Large Aperture GEM-like Gating Device

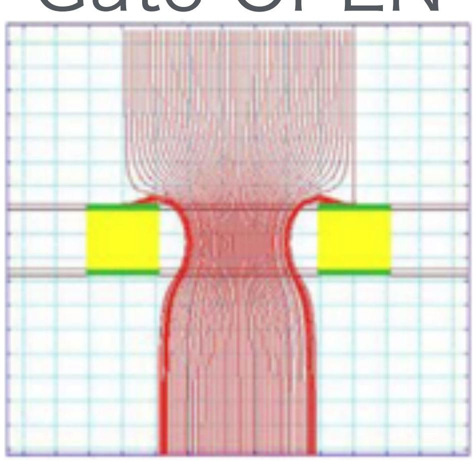


honeycomb structure

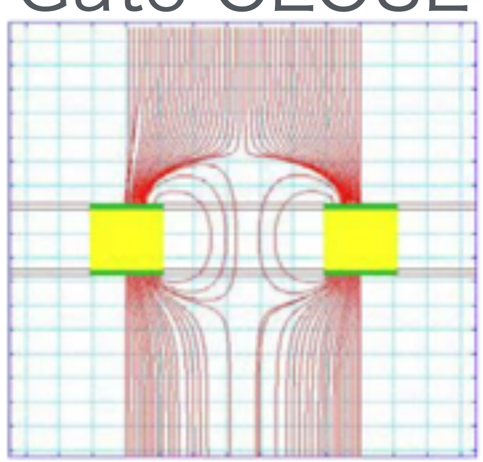
Gating GEM: the insulator sheet put between capper electrodes.

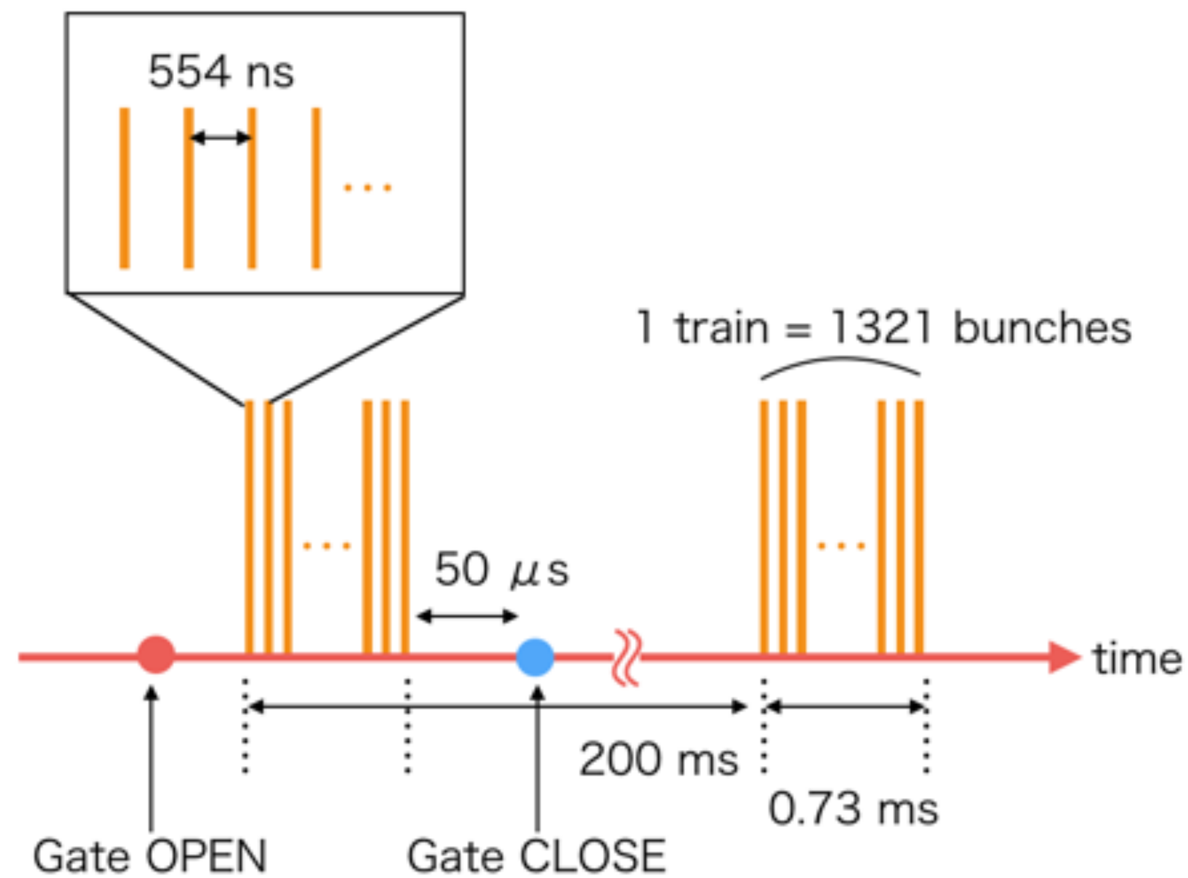
It works by adding electric potential difference to copper electrode.

Gate OPEN



Gate CLOSE

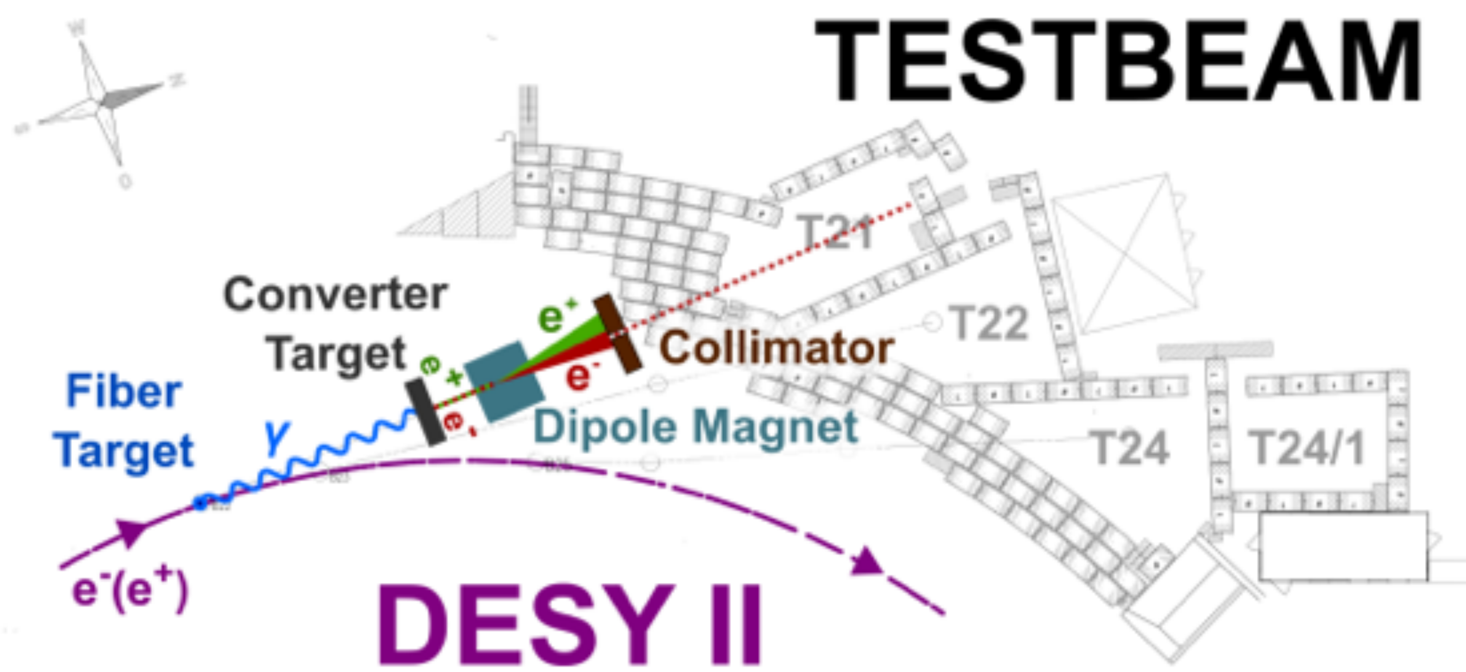


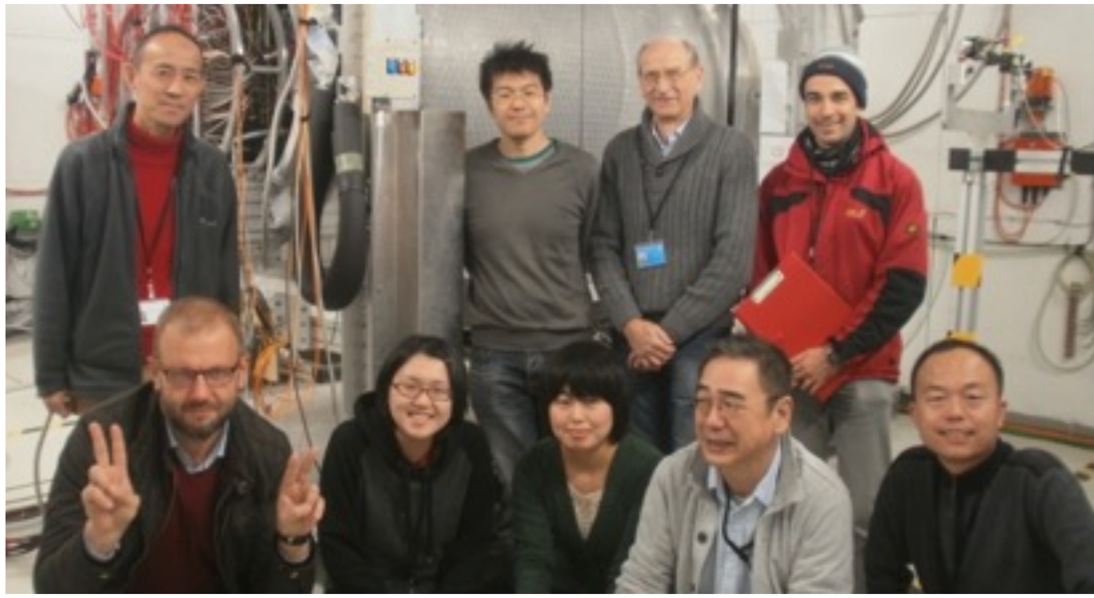


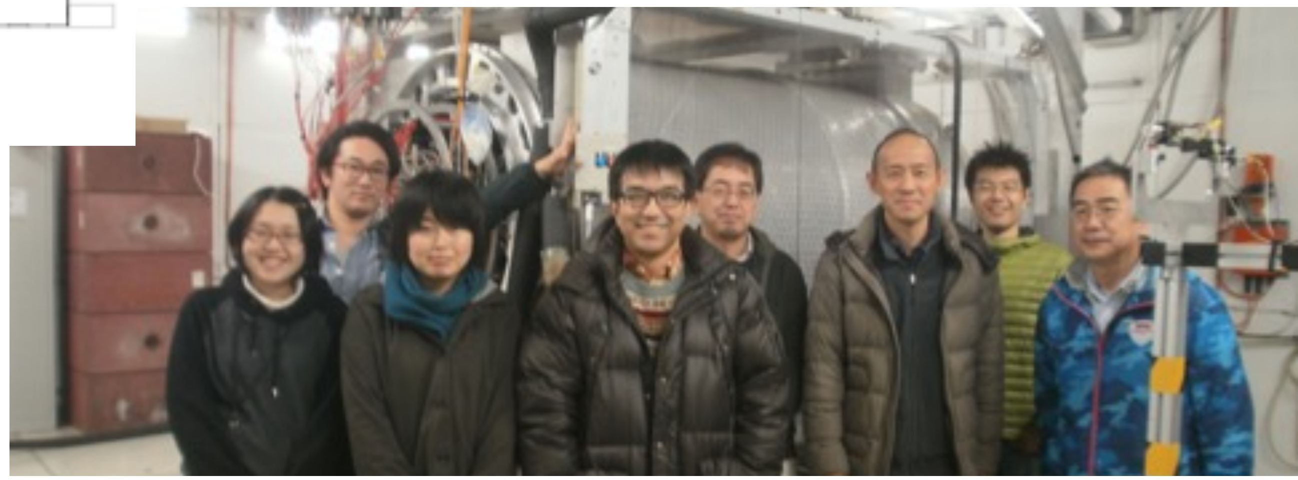
Beam test

Purpose : check performances of the module with the gating GEM

Oct.31-Nov.13, 2016 (beam time) @DESY TPC large prototype





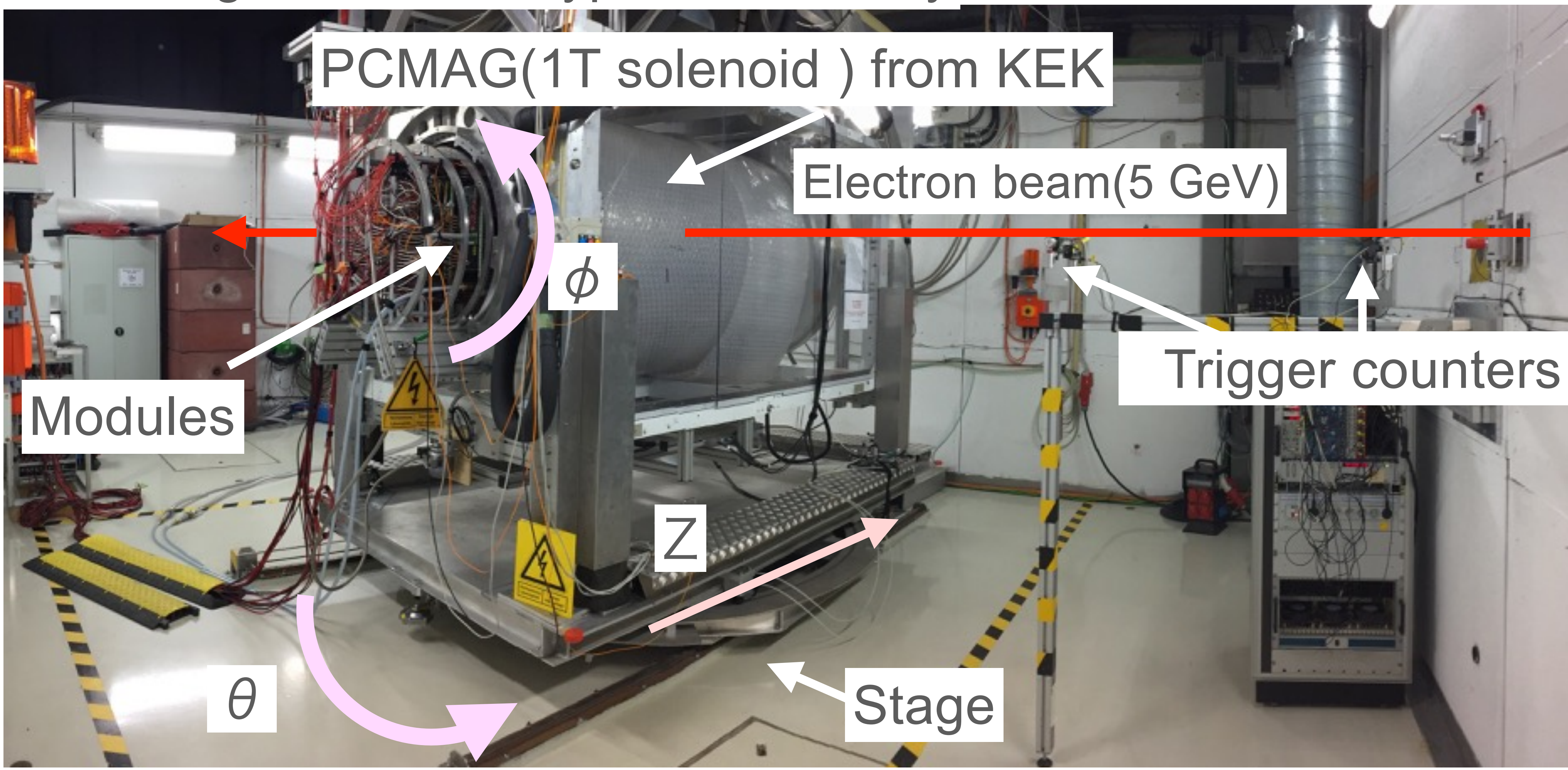


The first beam test of a GEM-readout TPC module with a gating GEM

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

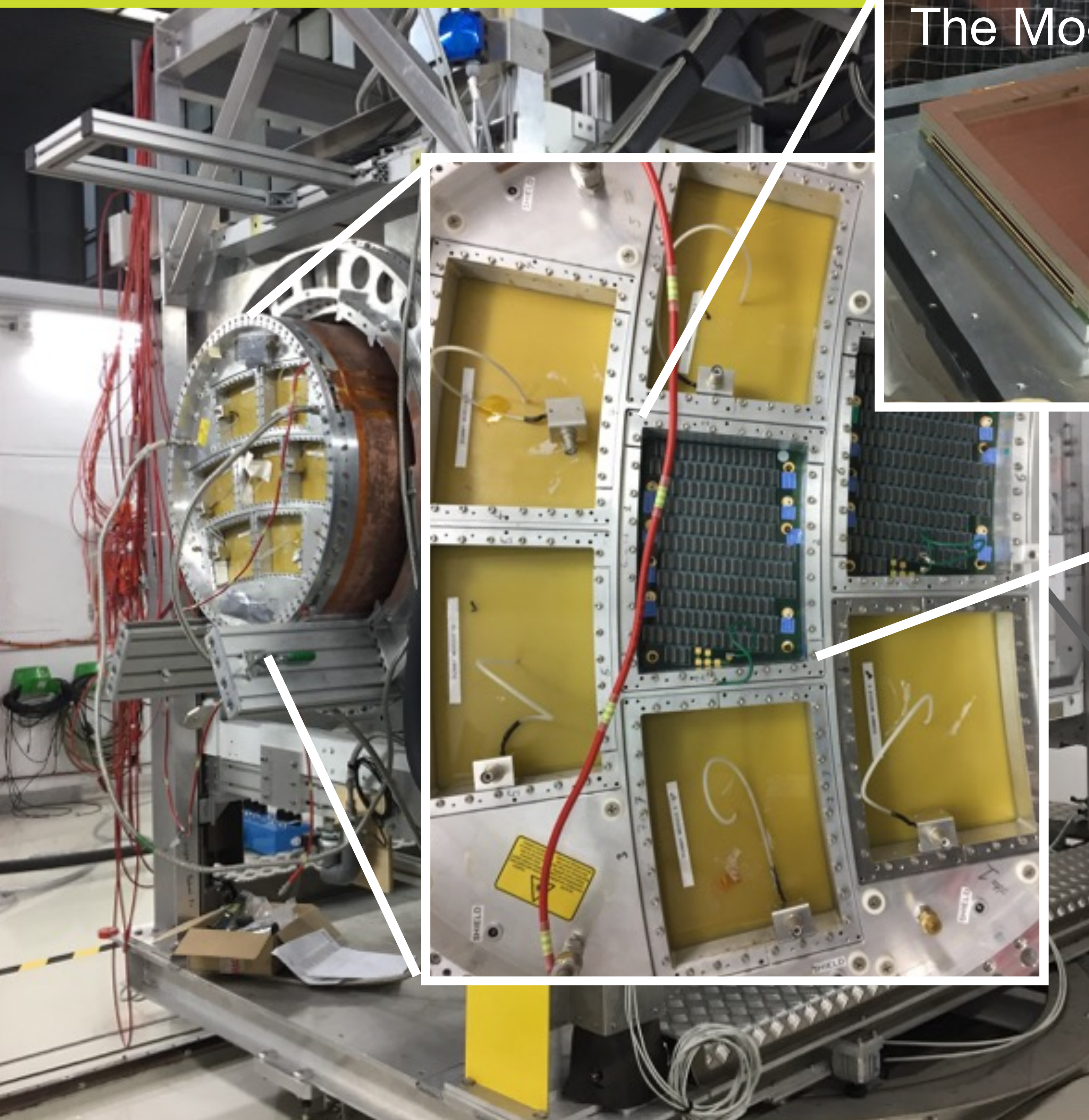
Setup

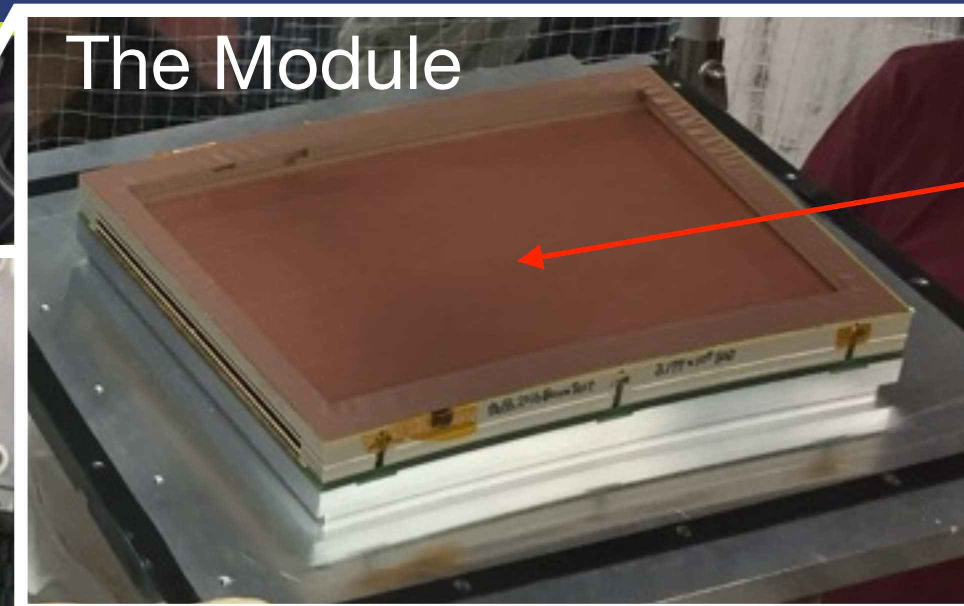
DESY Large TPC Prototype Test Facility

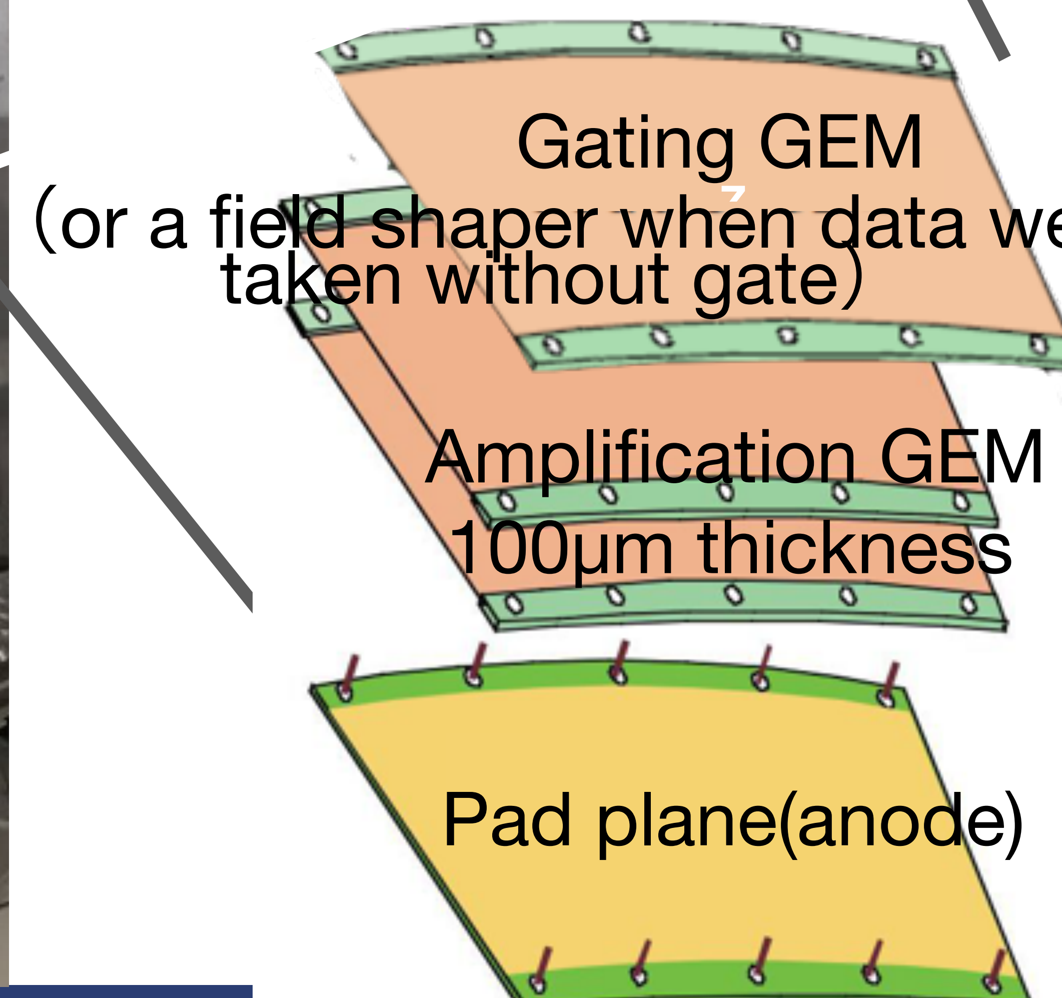


The electron beam passes two trigger counter and through the prototype.
The sensitive volume of the TPC is inside a solenoid. The TPC is mounted on a movable stage so we can change drift distance(Z) and two angles, θ and ϕ.

Module with Gating GEM



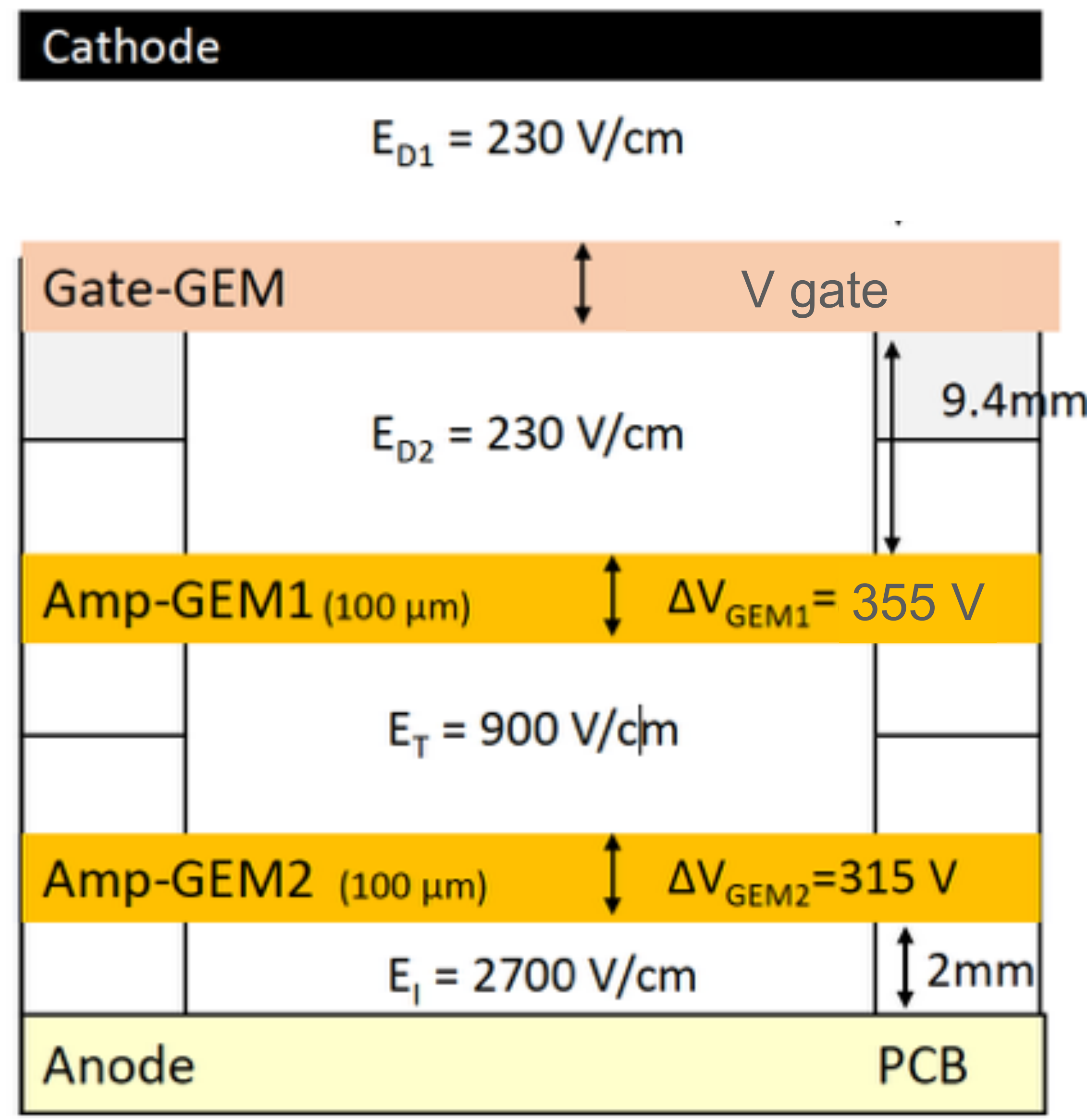




The data I analyzed in this study

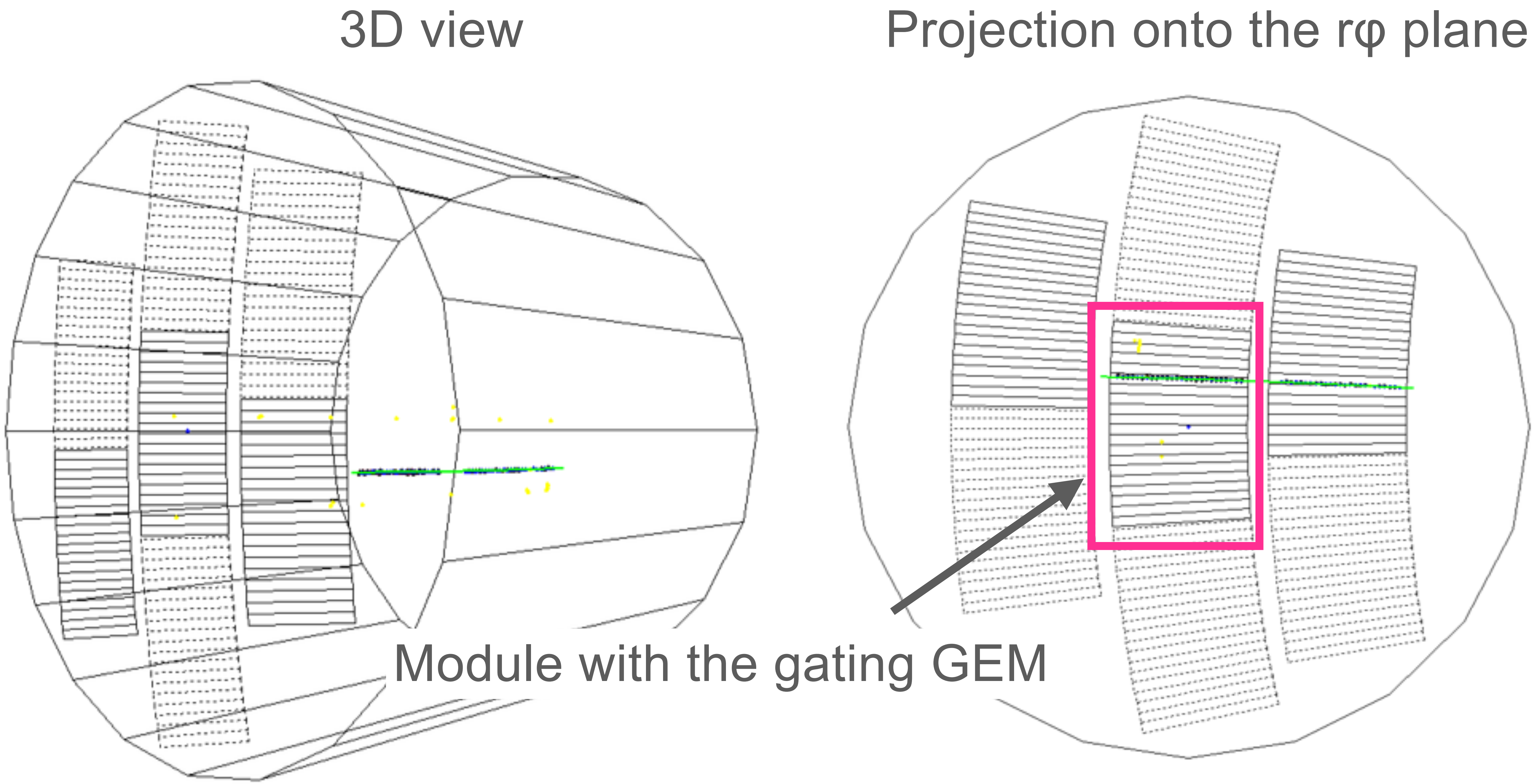
Center Module	with gatingGEM	without gatingGEM

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



Beam: 5 GeV electron beam
Gas:T2K gas (Ar : CF_4 : Iso-C_4H_{10} = 95 : 3 : 2 [%])
Flame work:MarlinTPC （20000event/1 run）

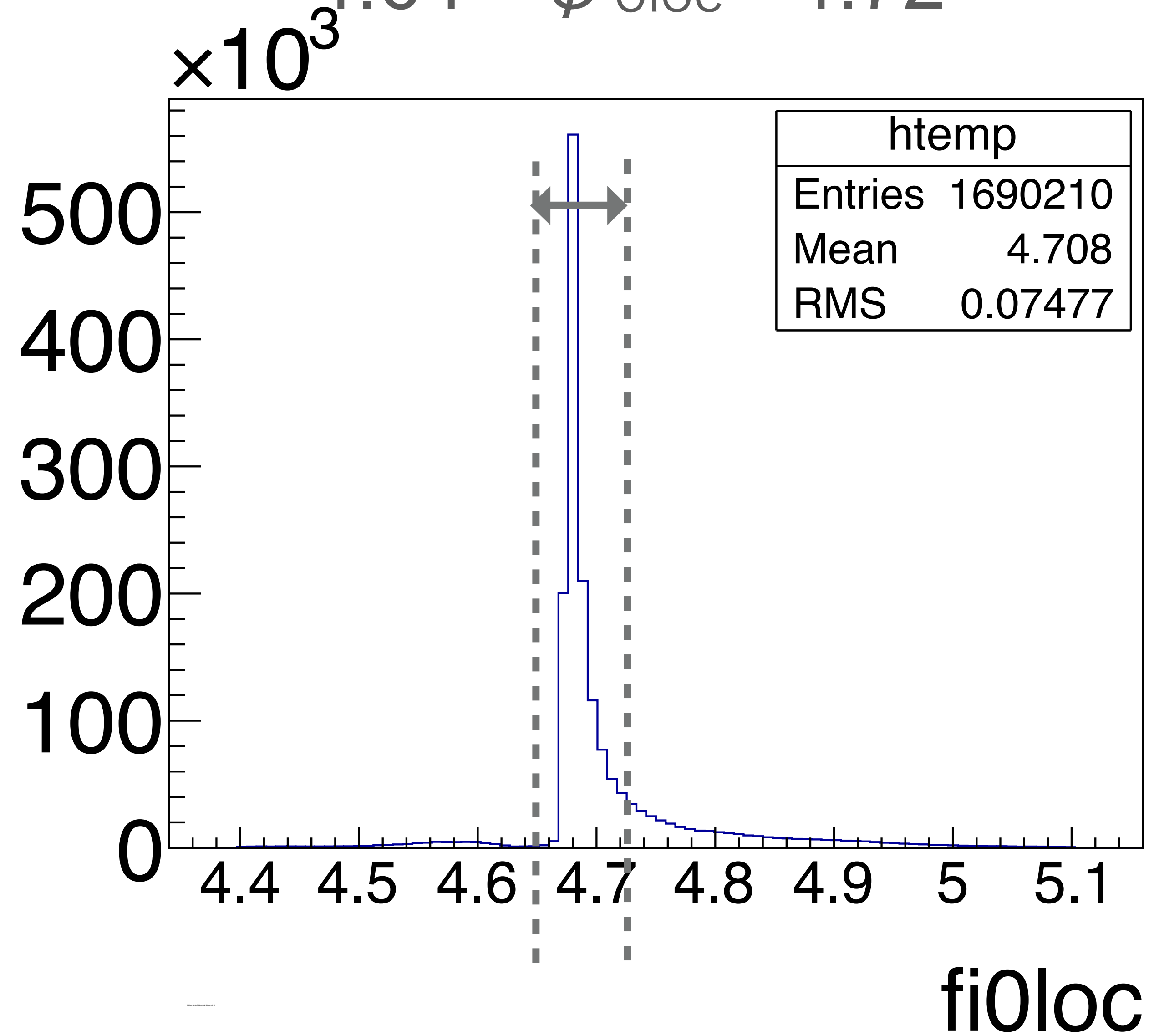
Typical event



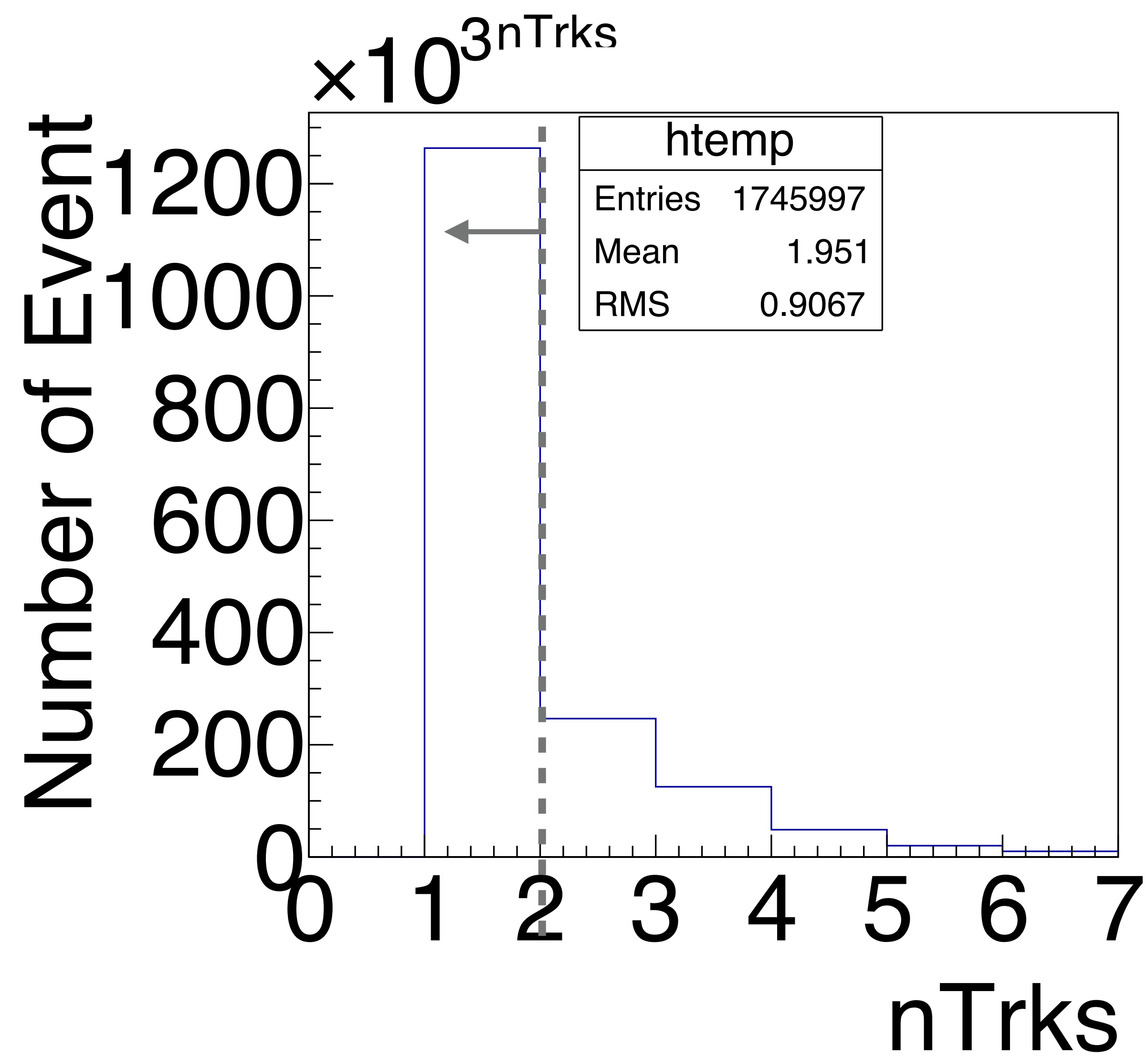
The beam goes through our module with the gating GEM in the region far enough from the module boundaries.

Event Selection

Track angle cut[rad]
4.64< ϕ_{0loc} <4.72

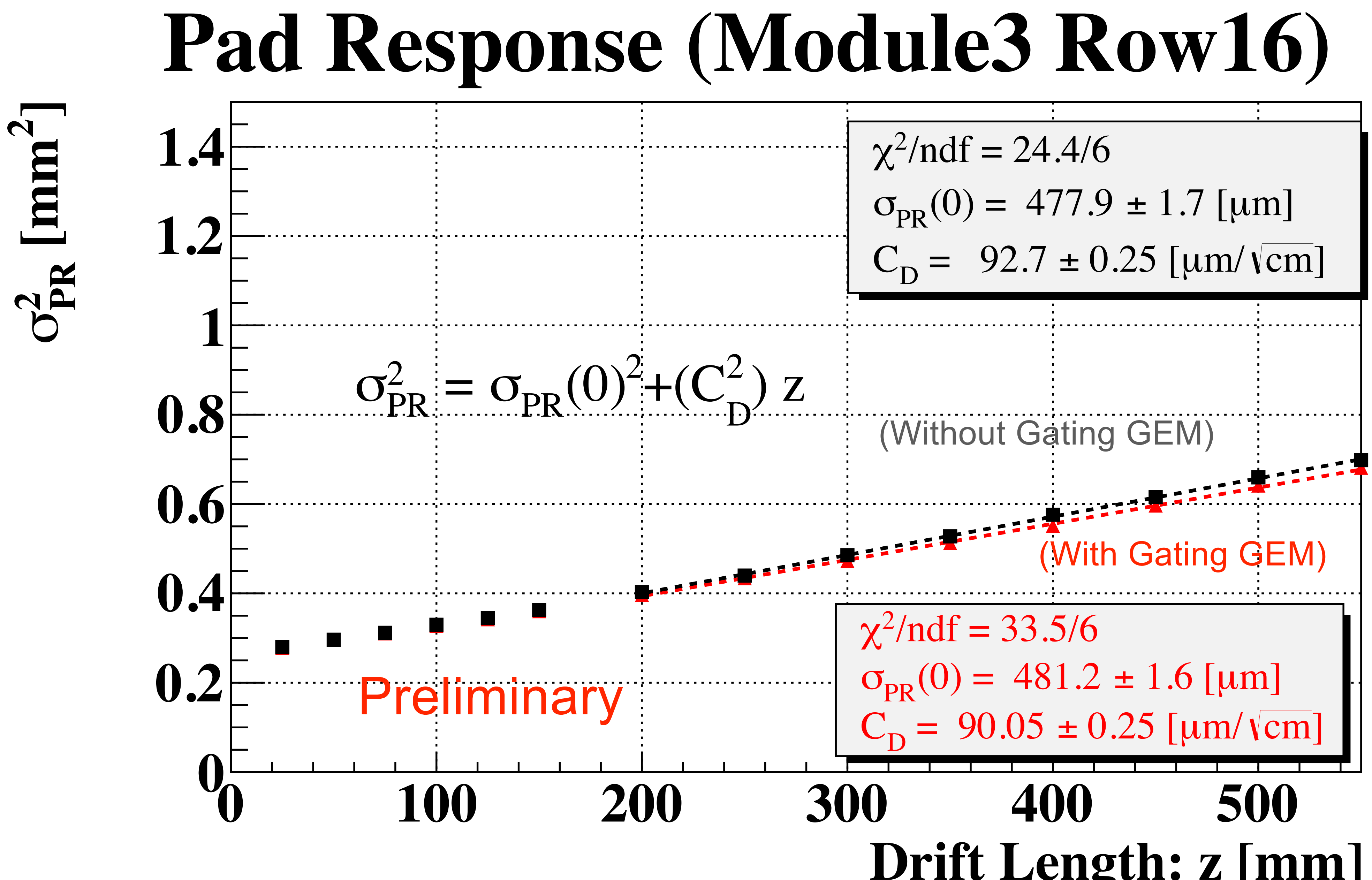


# of tracks per event
nTrks = 1



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

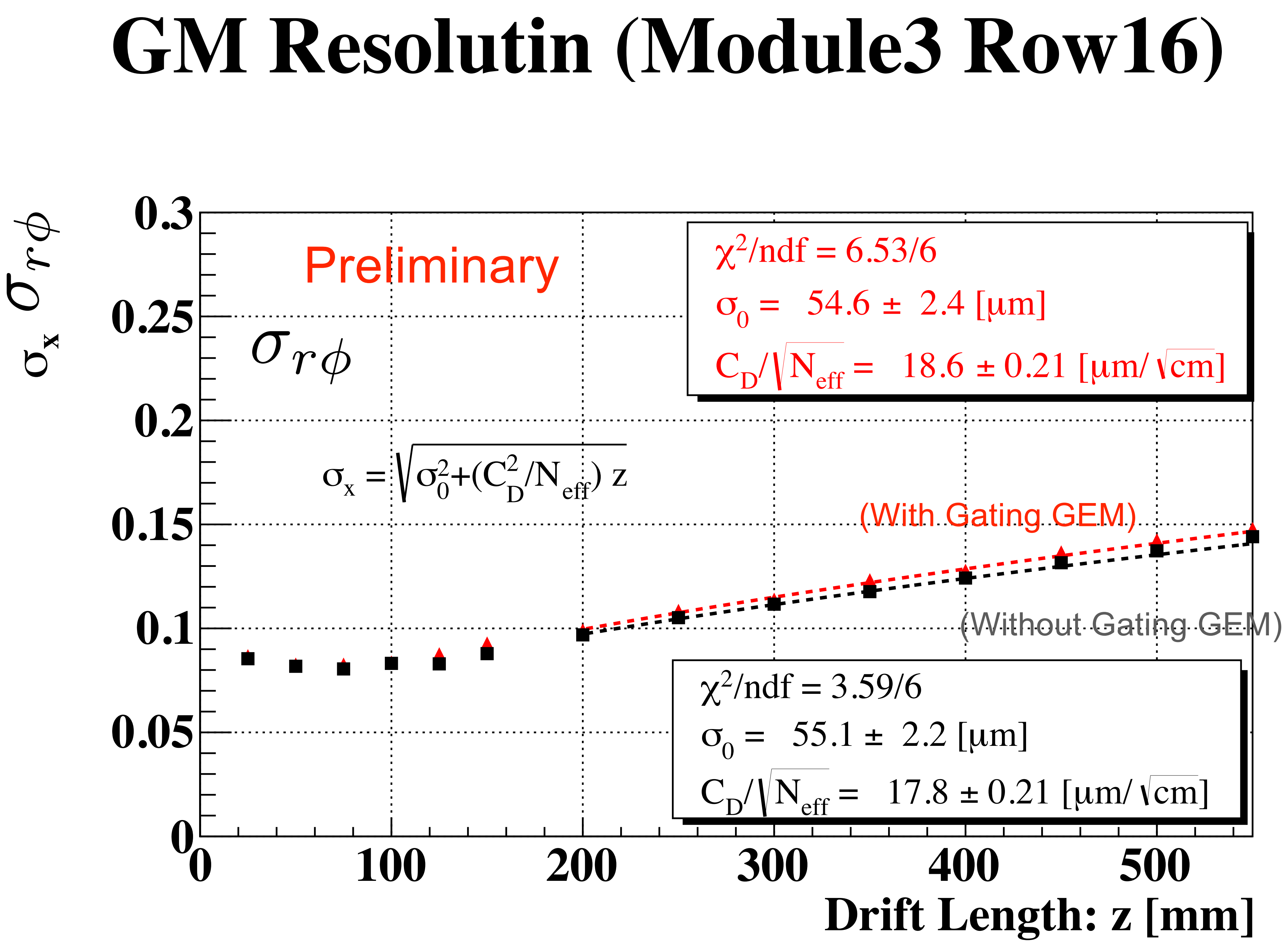
Diffusion Constant



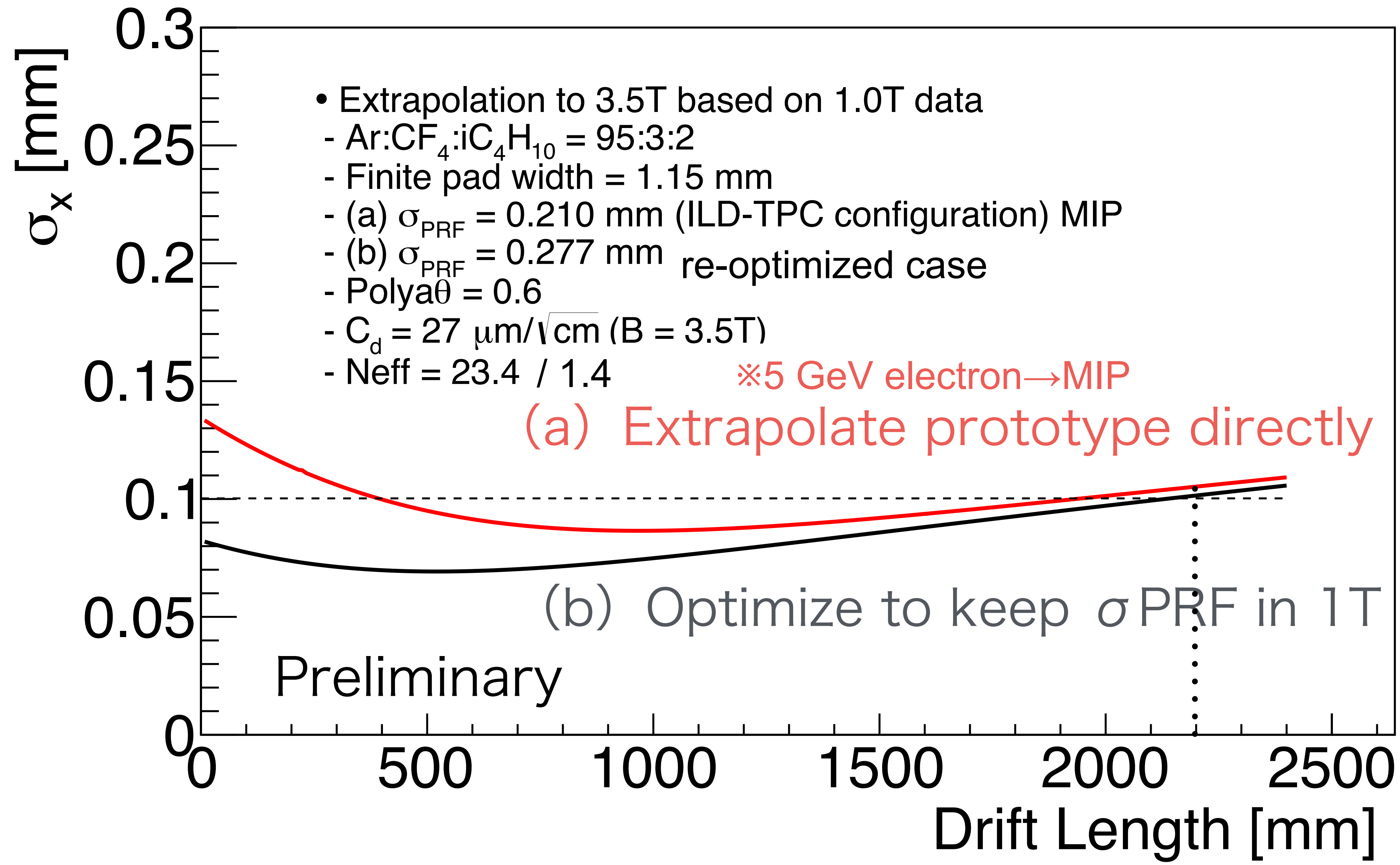
The difference between Cd of with gate and its of without gate is significant. They should be almost same.

→We are trying to find the reason.

Spacial resolution（rϕ）



The extrapolation to B=3.5 T



When we decide hit points by center of gravity, the graph is (a) because of bias.

When we optimize to keep σPRF in 1T, we get graph (b)

→The spatial resolution (100 μm) can be achieved

yumia@post.kek.jp

Summary

We checked performances of the module with the gating GEM by analyzing beam test data in this fiscal year

- The extrapolation of the beam test result to 3.5 T/2.2 m drift ILD-TPC shows that achieve spatial resolution goal of 100 μm with the gating GEM

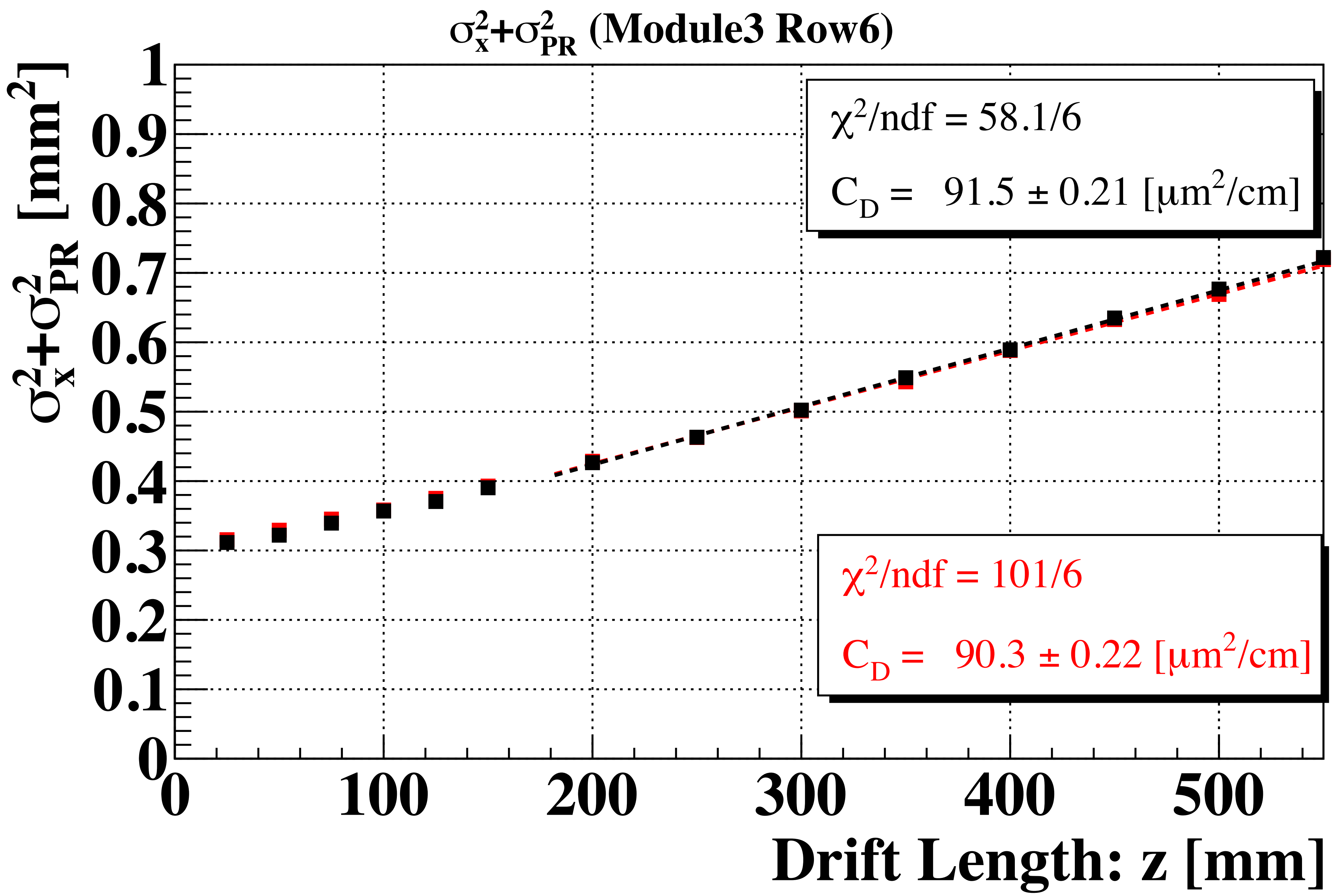
Future work

- Understand Cd difference
- Analyze angled data

yumia@post.kek.jp

Back up Slides

Diffusion Constant



To reduce short term effect, I calculated $\sigma_{r\phi} + \sigma_{PR}$.

The difference of Cd is less than its by ordinary way.

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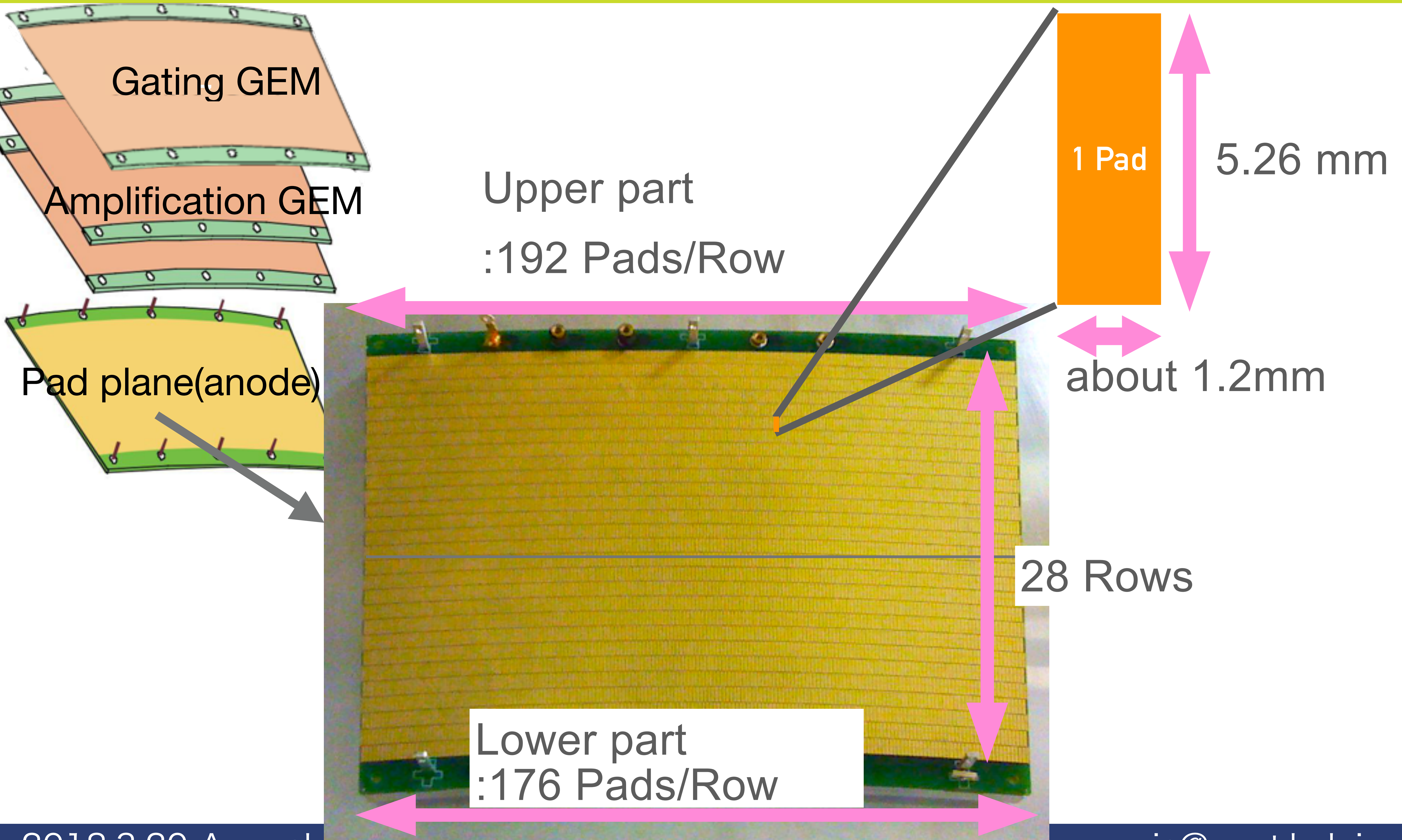
Readout Pads



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The Electron transmission

	Cd(w/ gate) [μm/√cm]	Cd(w/o gate) [μm/√cm]
measurement	90.05±0.25	92.7±0.25

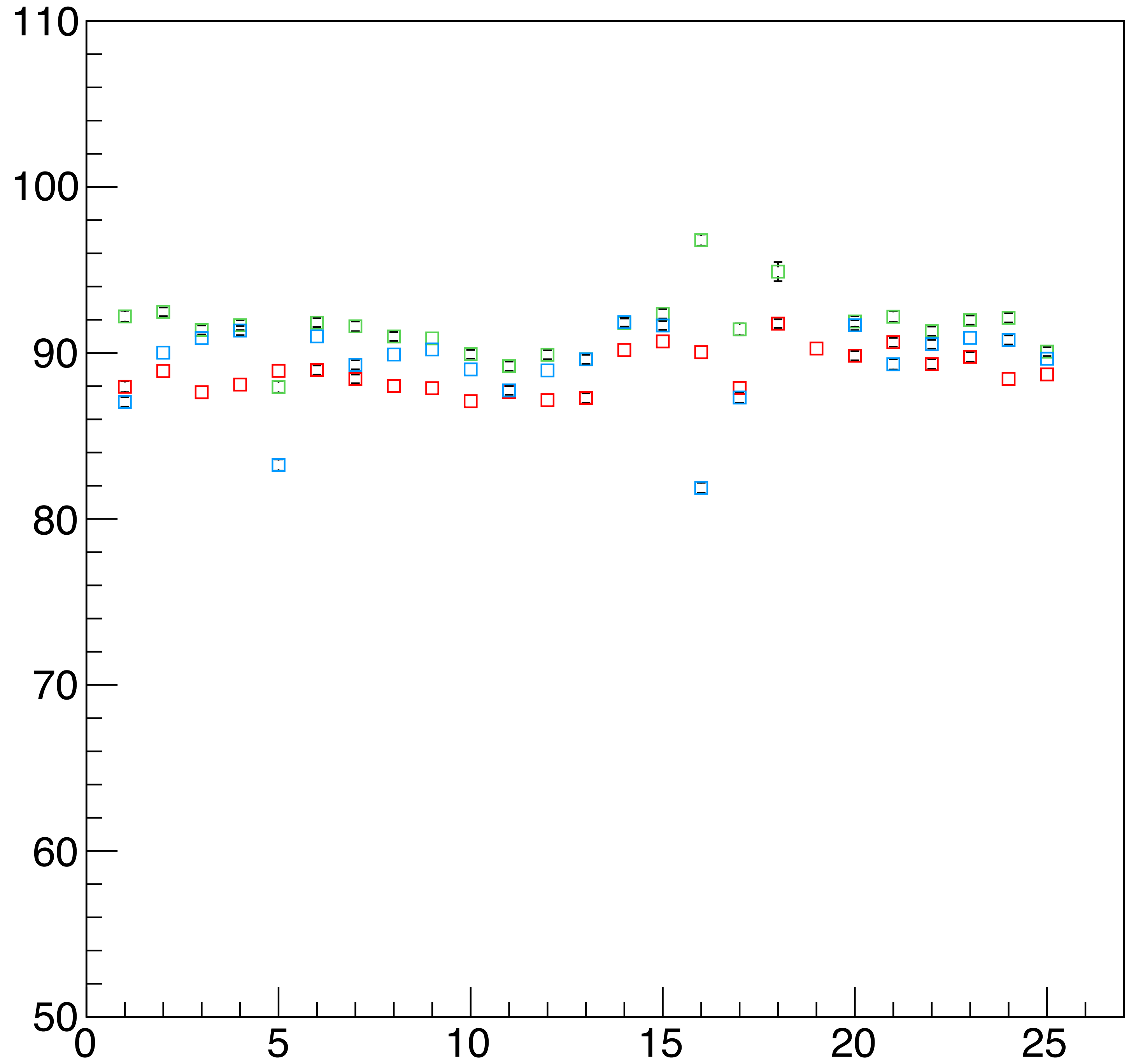
	w/ gate	w/o gate
Cd/√Neff	18.6±0.3	17.8±0.3

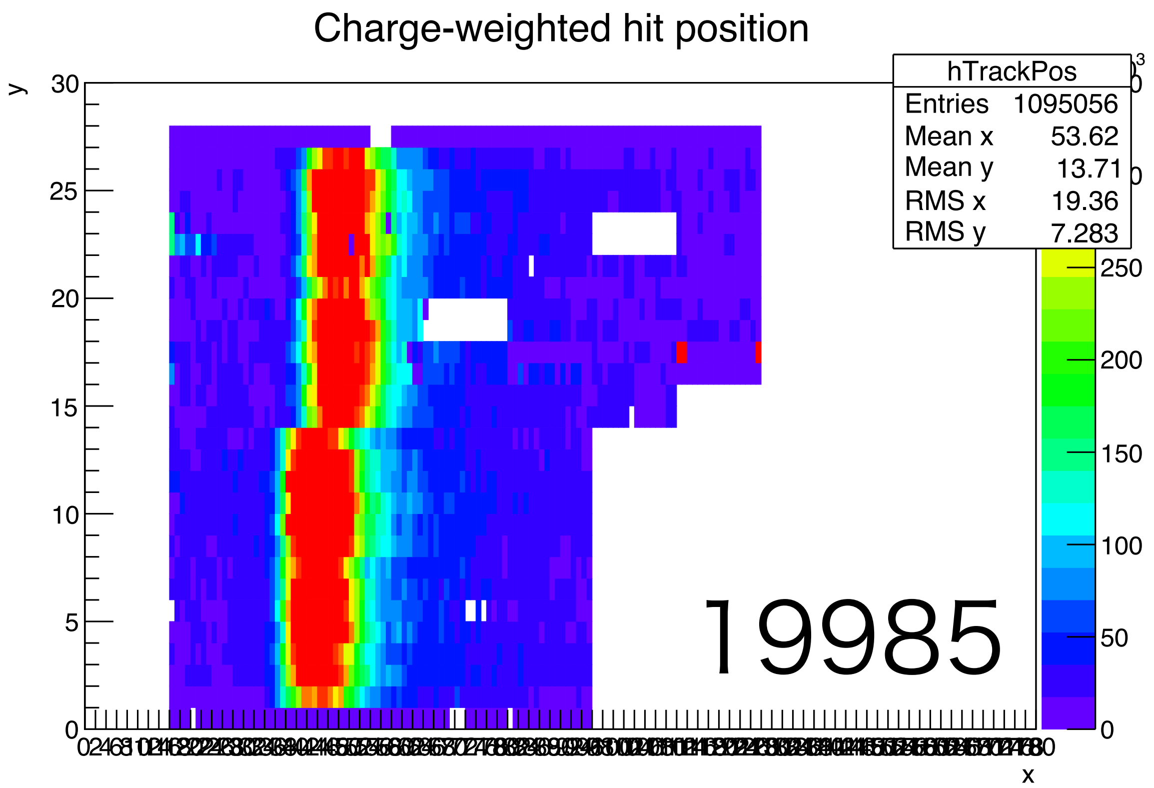
Cd [μm/√cm]	N_{eff}(w/ gate)	N_{eff}(w/o gate)	ratio[%]
measurement	23.4±0.6	27.2±0.8	86.4±3.1

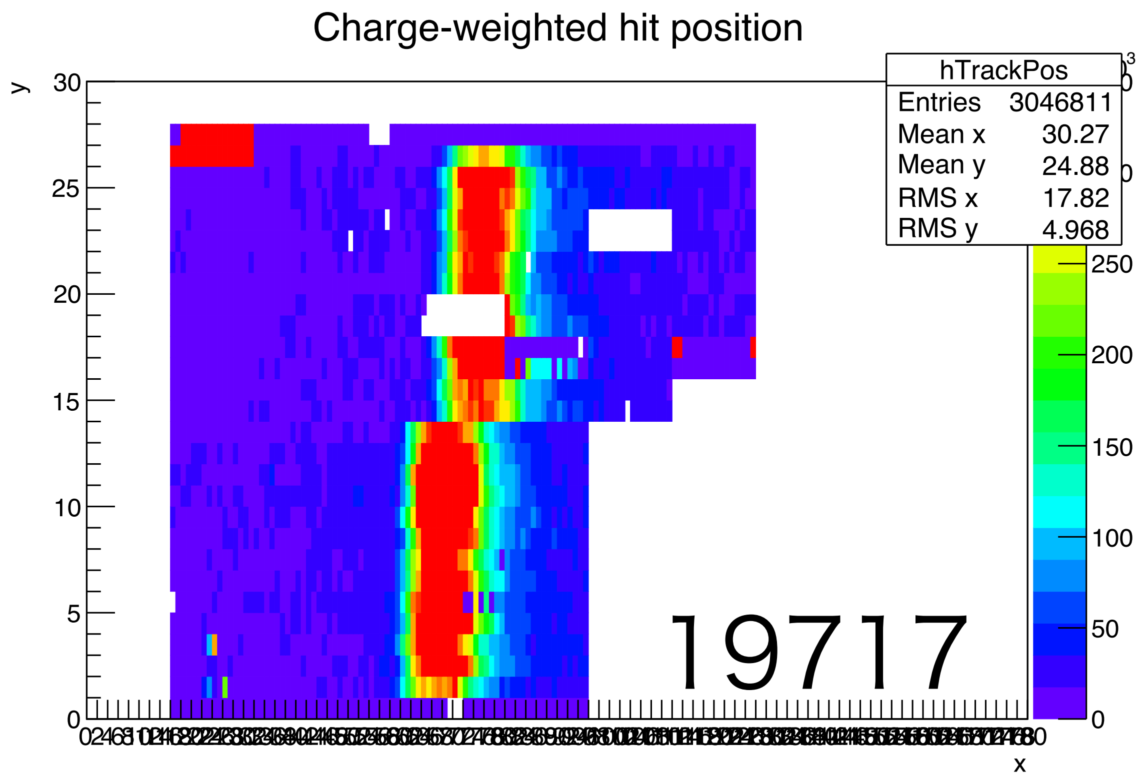
We get about 86 % electron transmission rate with gating GEM.

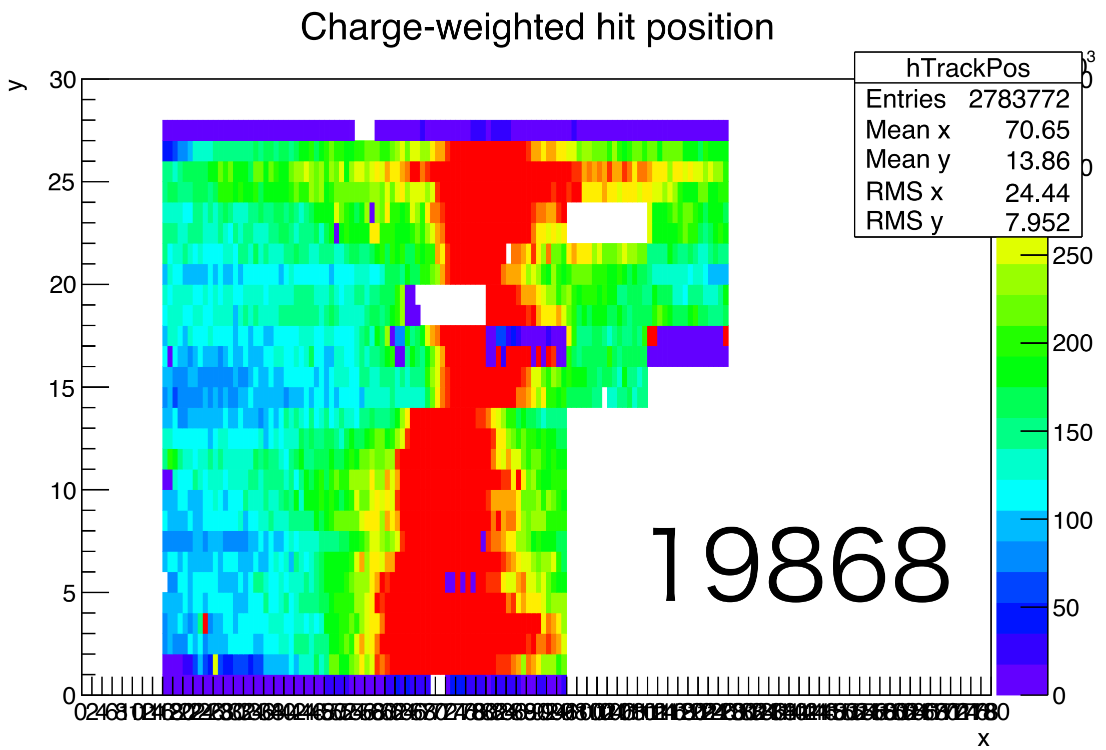
We achieved the target electron transmission rate of > 80%.

Cd vs Row

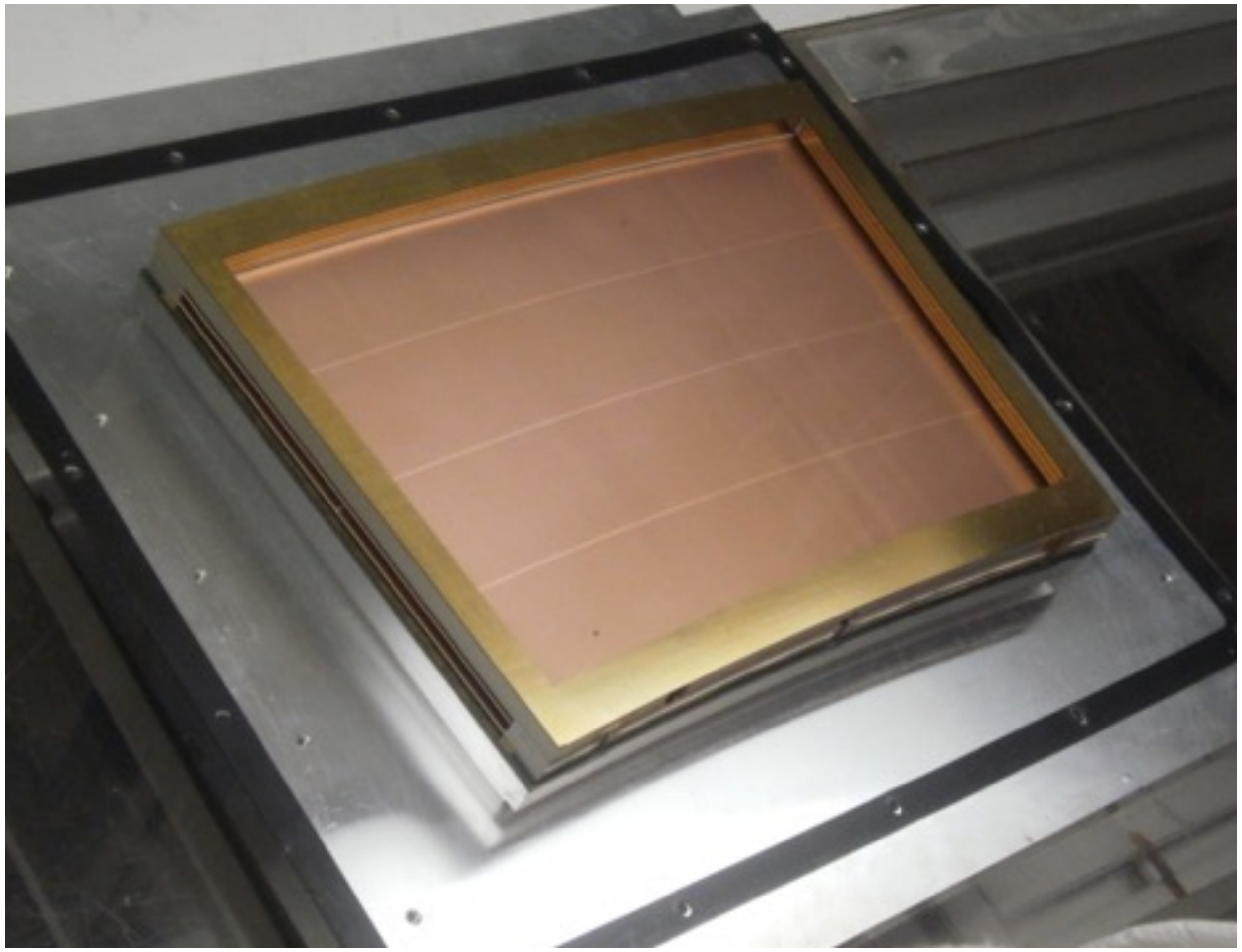



Charge-weighted hit position
hTrackPos
Entries 1095056
Mean x 53.62
Mean y 13.71
RMS x 19.36
RMS y 7.283
19985
y
x

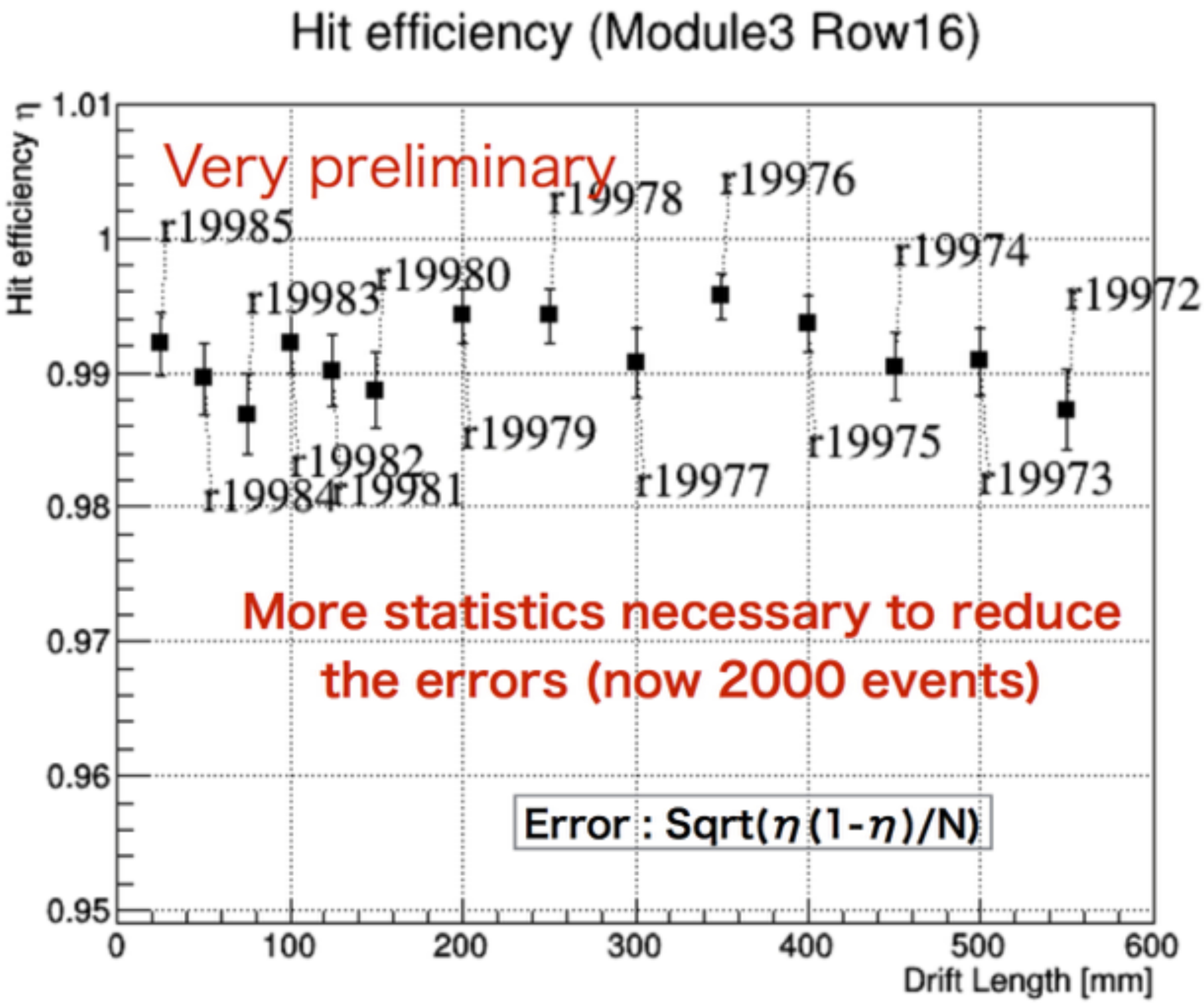

Charge-weighted hit position
hTrackPos
Entries 3046811
Mean x 30.27
Mean y 24.88
RMS x 17.82
RMS y 4.968
19717
y
x


Charge-weighted hit position
hTrackPos
Entries 2783772
Mean x 70.65
Mean y 13.86
RMS x 24.44
RMS y 7.952
19868
y
x

Field shaper



Data quality check - Hit efficiency



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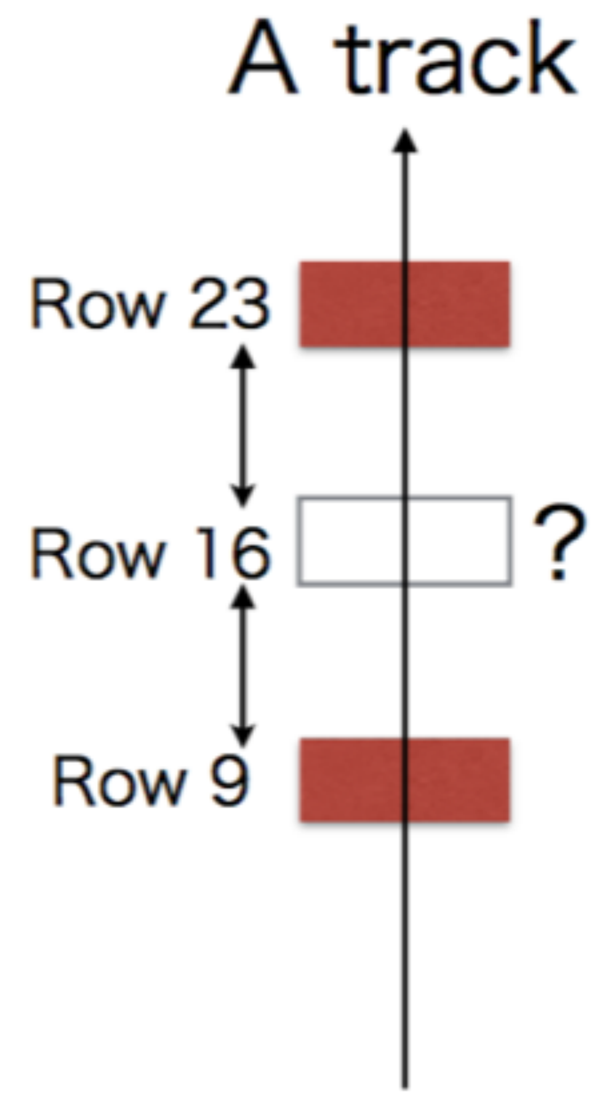
With Gating GEM

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.

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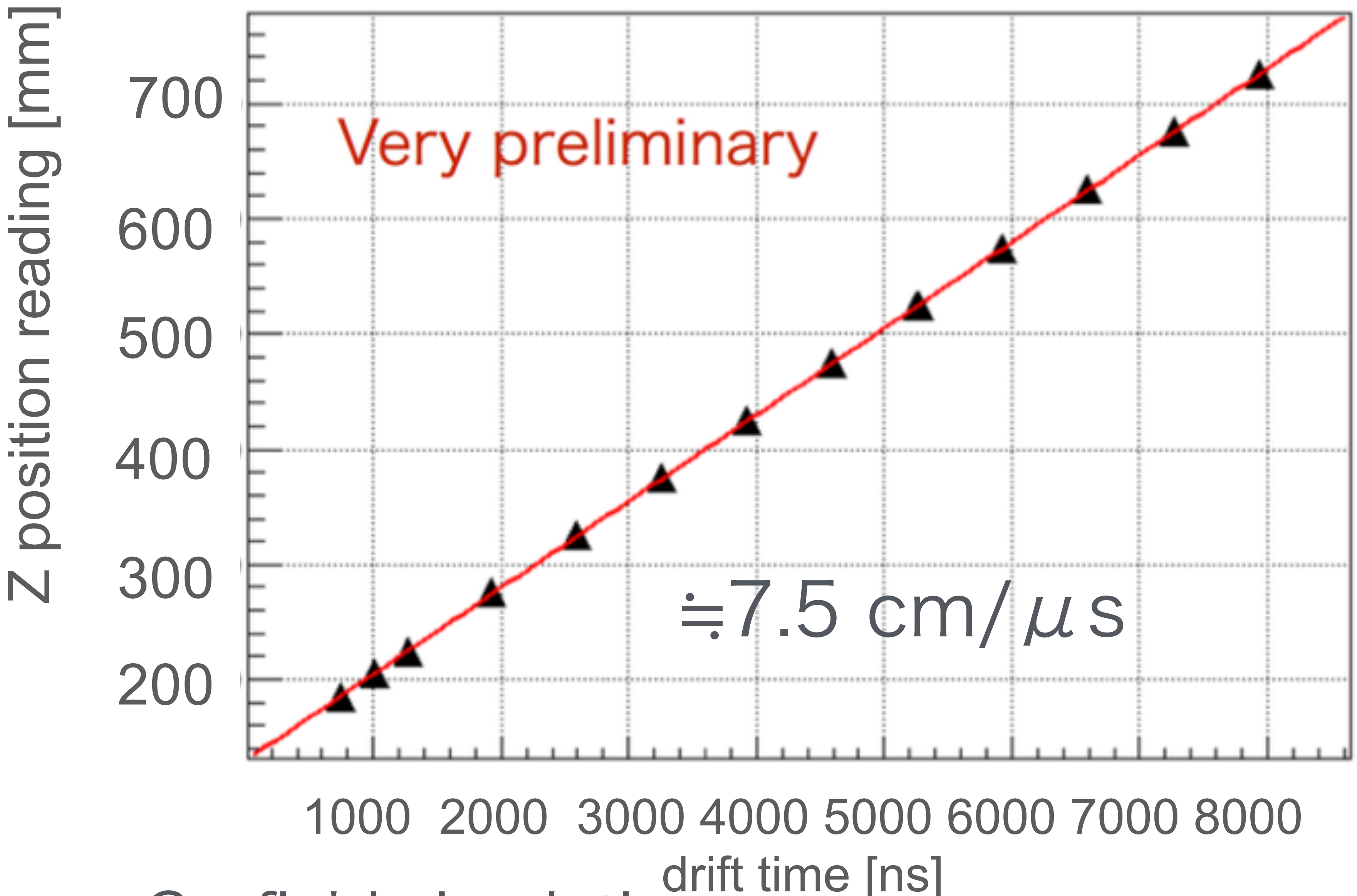
Drift velocity



	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%

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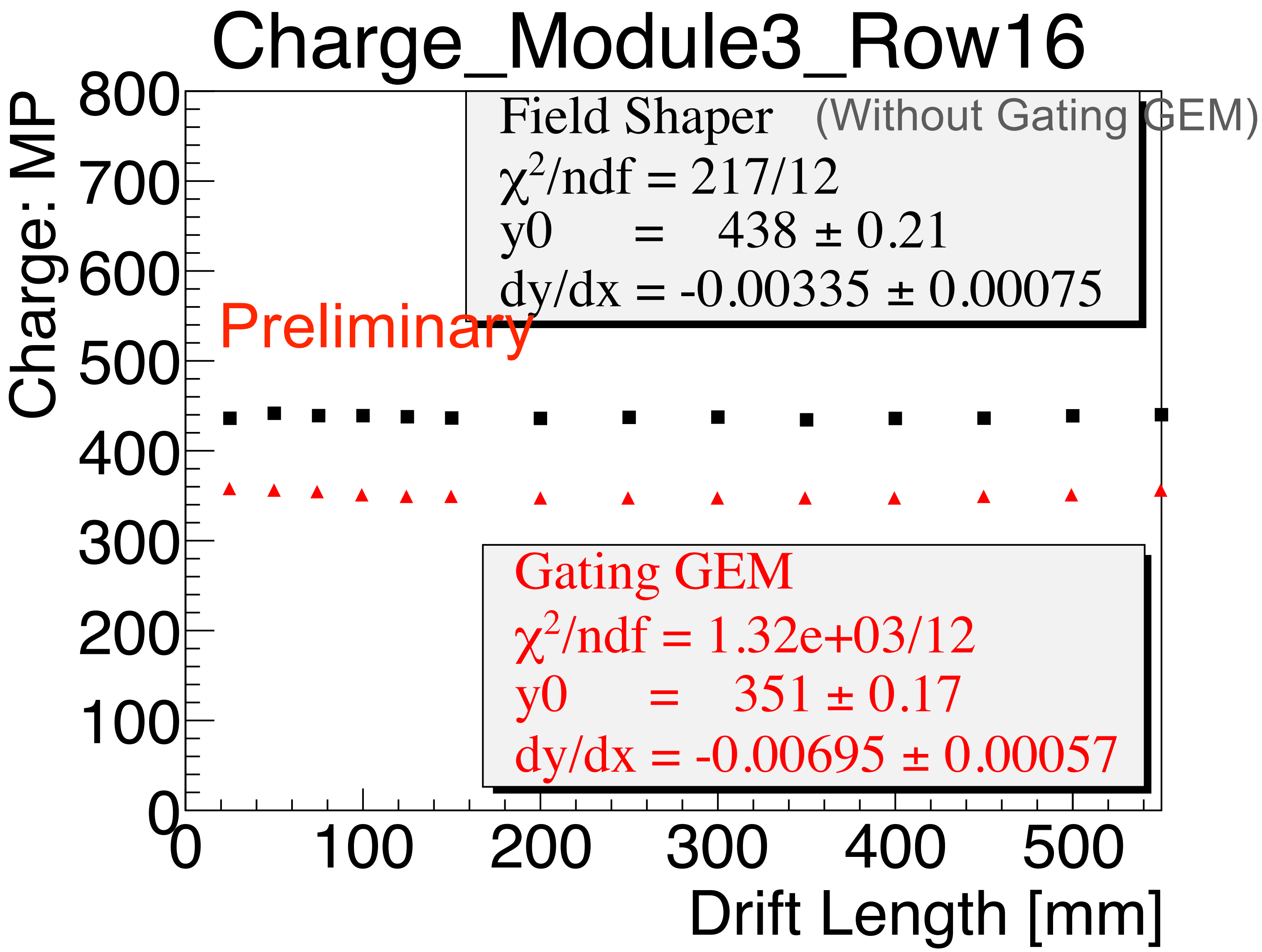
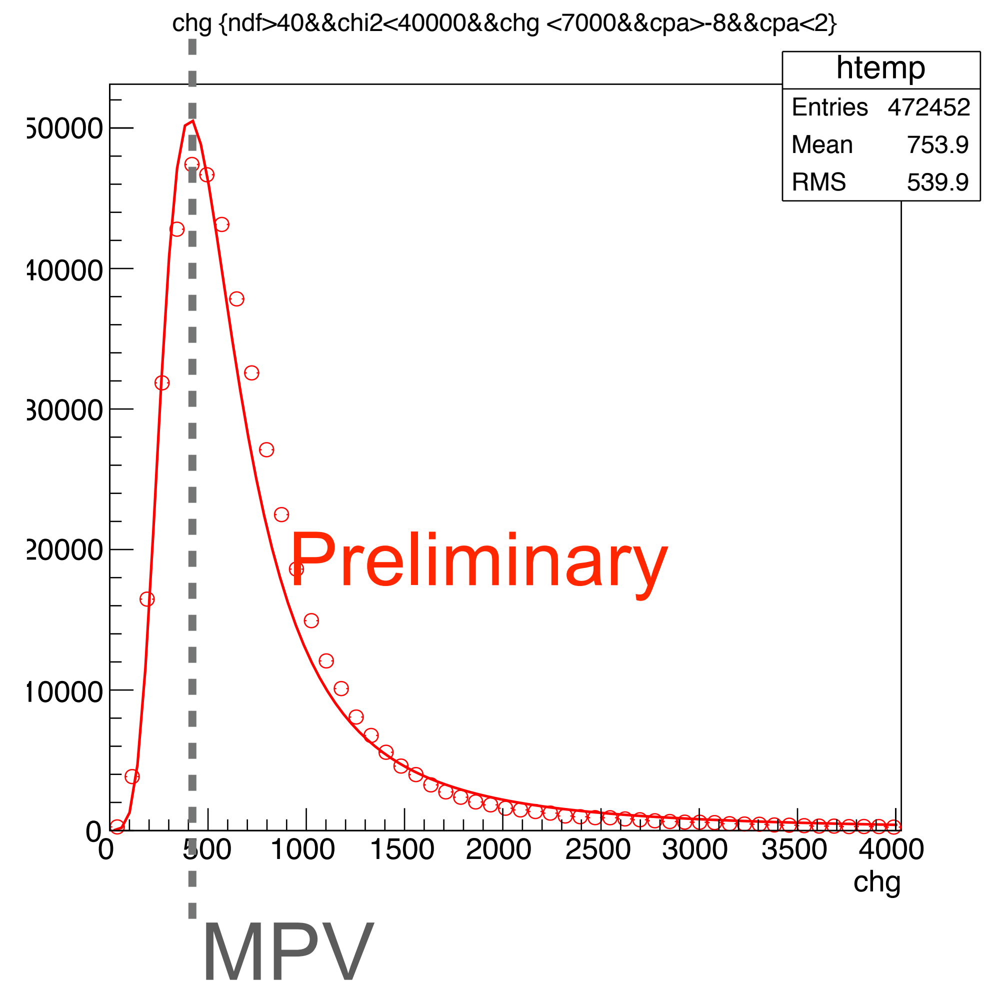
Result - Charge sum



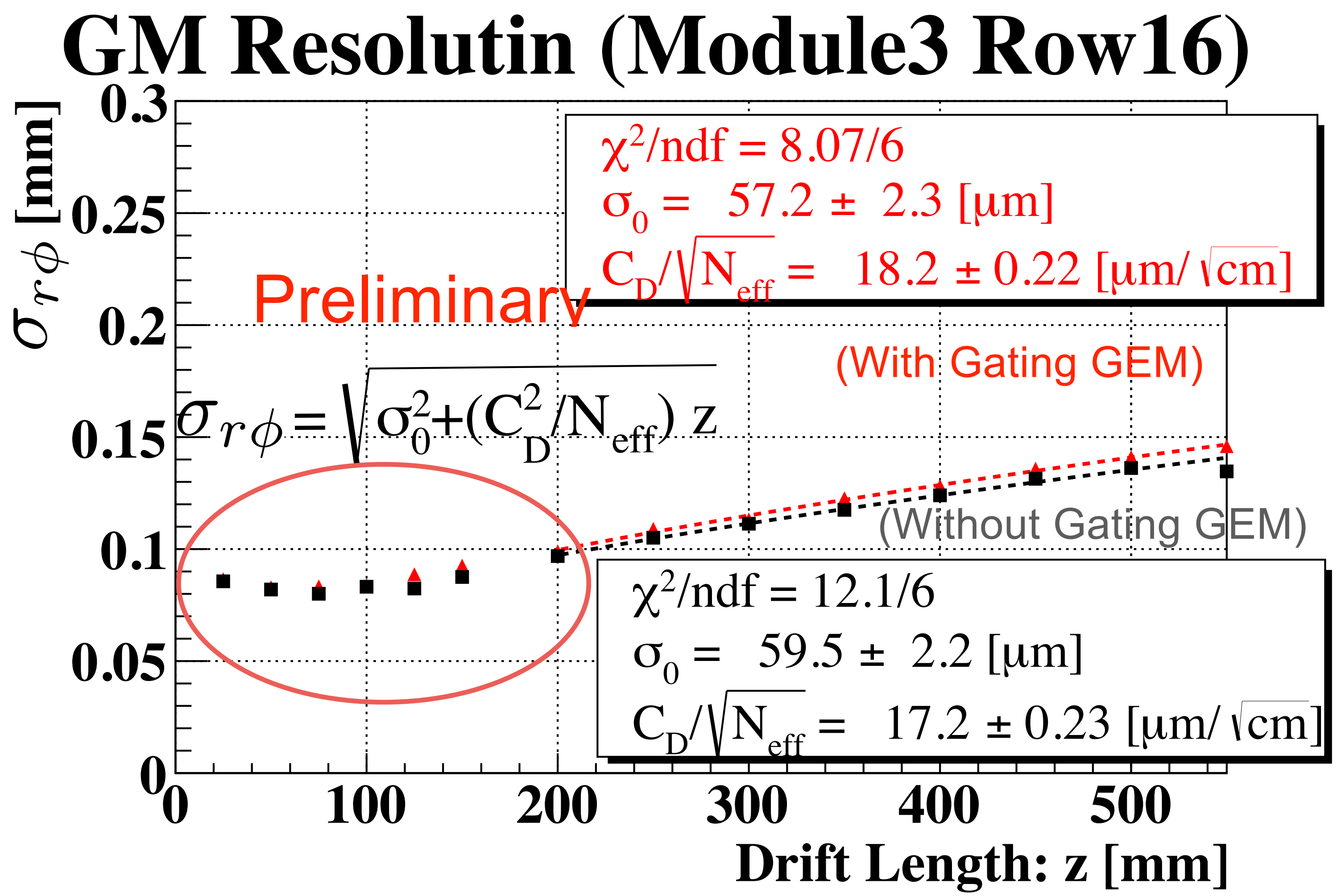


➤ There seems to be no electron attachment (P/T correction is not included)

	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”.

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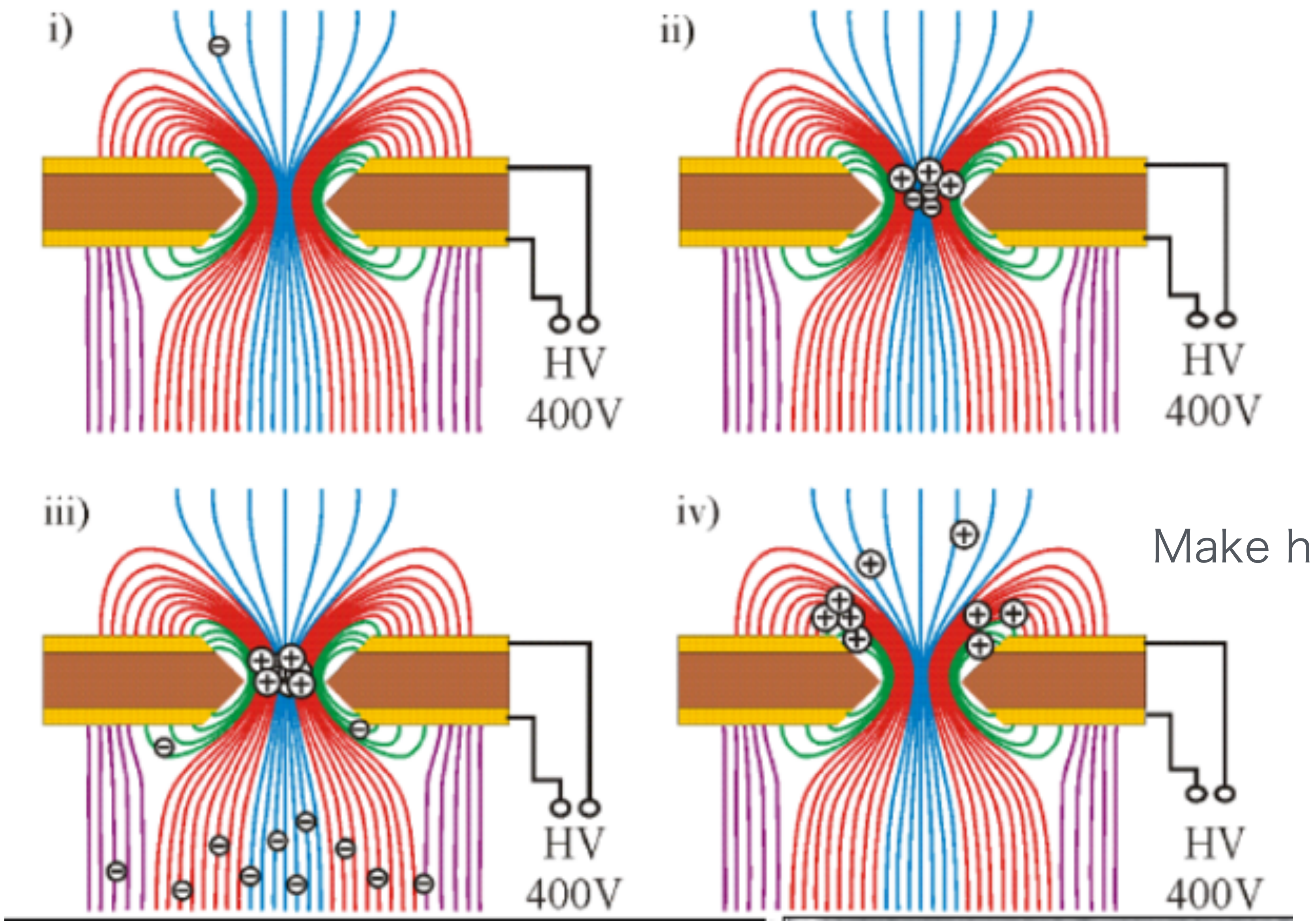
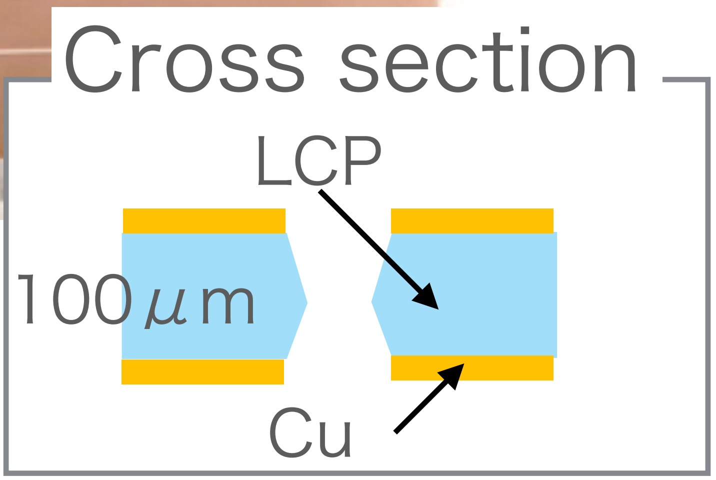
GEM

1996 Fabio Sauli(CERN) developed GEM





Make high electric field in GEM holes by HV

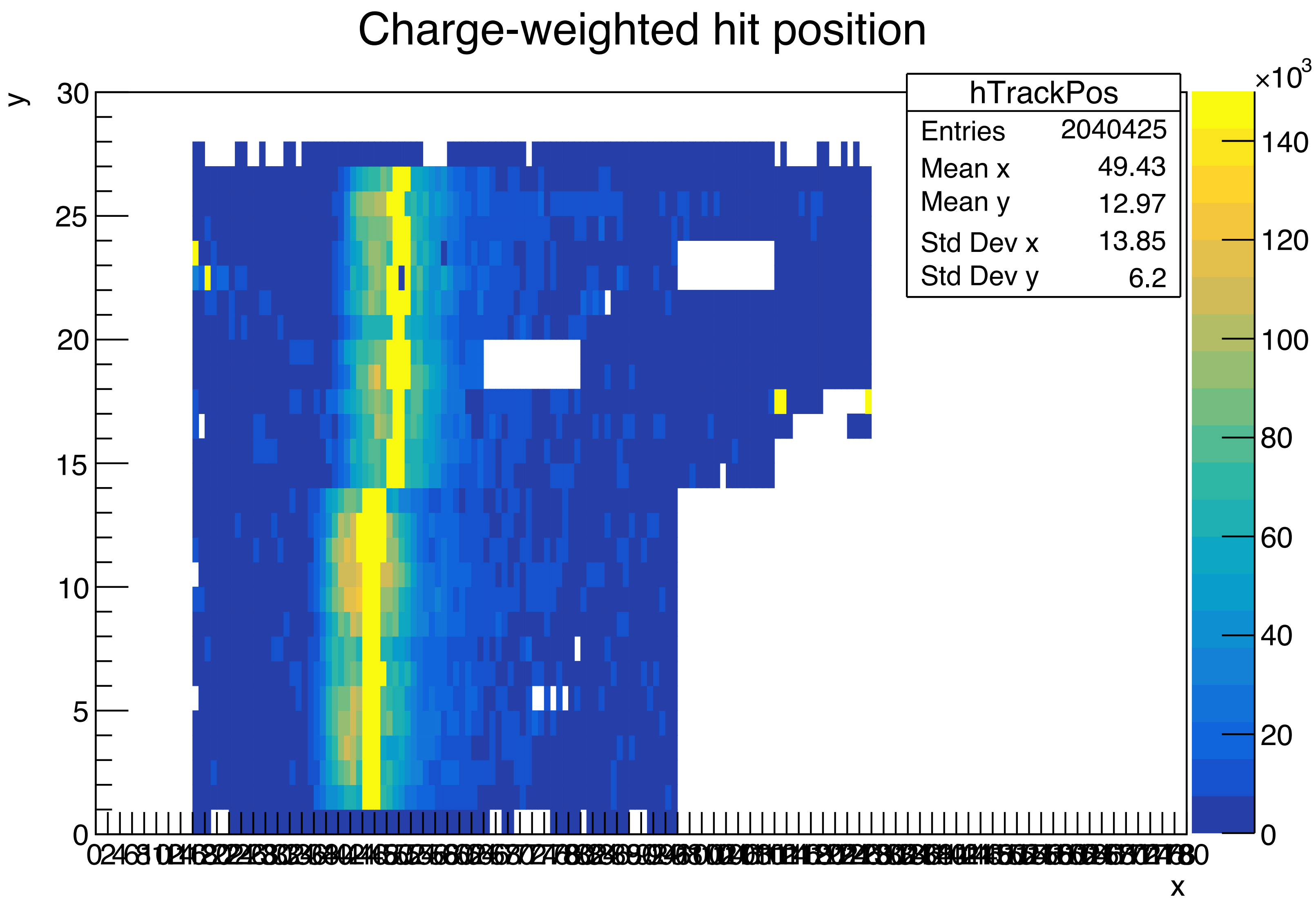
↓

Electrons accelerate, collide and ionize gas molecules (＝avalanche)

We can amplify electrons by using several GEM

However ・・・Positive ion is also created

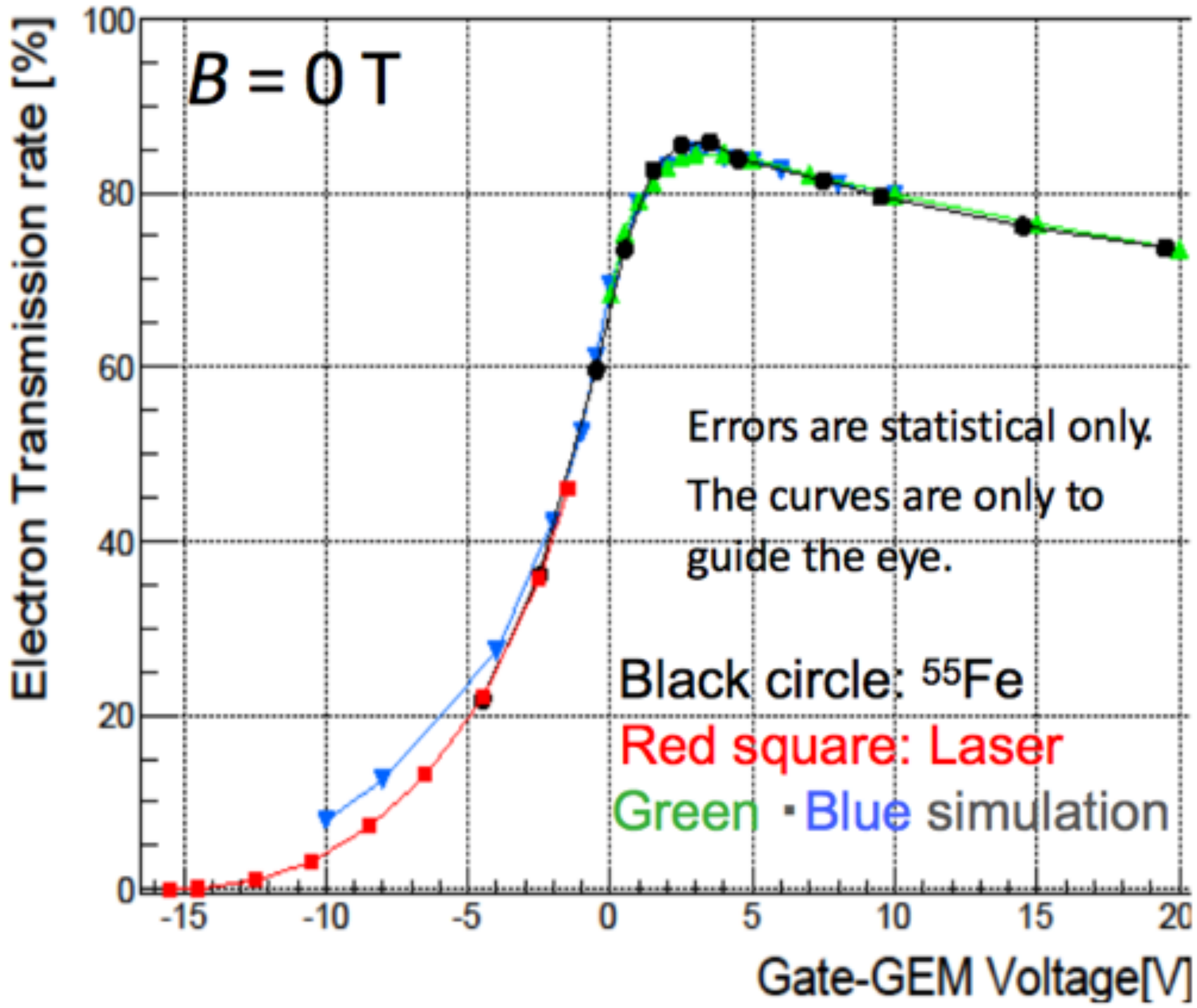
Data Quality Cuts



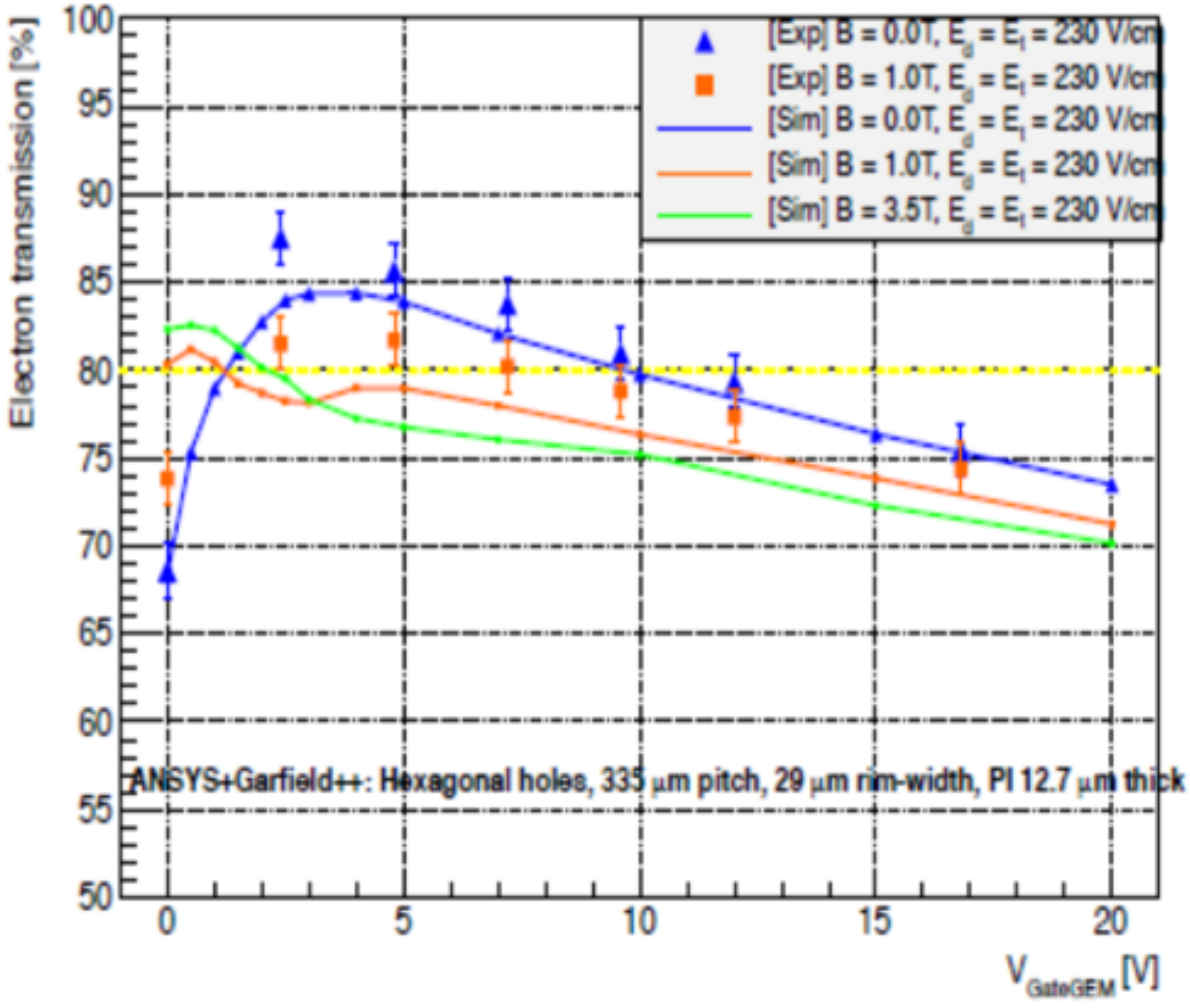
exclude row number 0, 22, 27.

Row 0, 27 may has distortion of electric field because they are the edge of module.

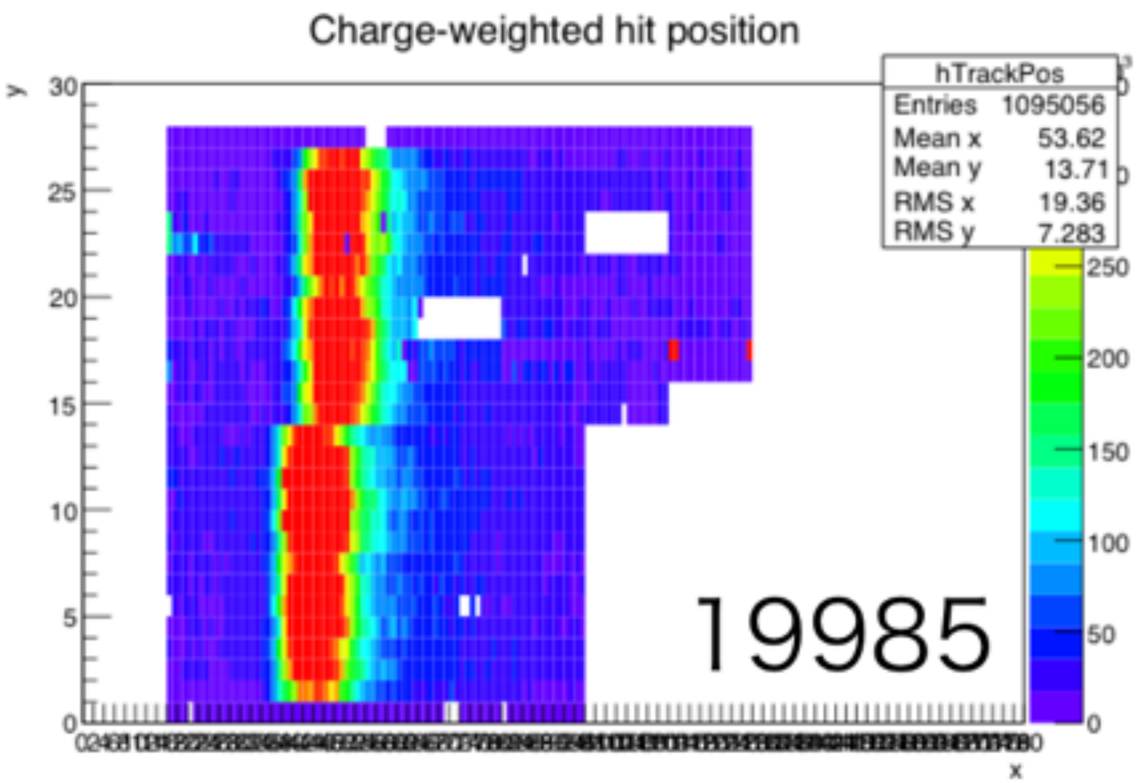
Row 22 has dead pad.



B = 0 T
Errors are statistical only.
The curves are only to guide the eye.
Black circle: 55Fe
Red square: Laser
Green・Blue simulation
Electron Transmission rate [%]
Gate-GEM Voltage[V]



[Exp] B = 0.0T, Ed = Et = 230 V/cm
[Exp] B = 1.0T, Ed = Et = 230 V/cm
[Sim] B = 0.0T, Ed = Et = 230 V/cm
[Sim] B = 1.0T, Ed = Et = 230 V/cm
[Sim] B = 3.5T, Ed = Et = 230 V/cm
ANSYS+Garfield++: Hexagonal holes, 335 μm pitch, 29 μm rim-width, PI 12.7 μm thick
Electron transmission [%]
V GateGEM [V]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RMS x 19.36
RMS y 7.283
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250
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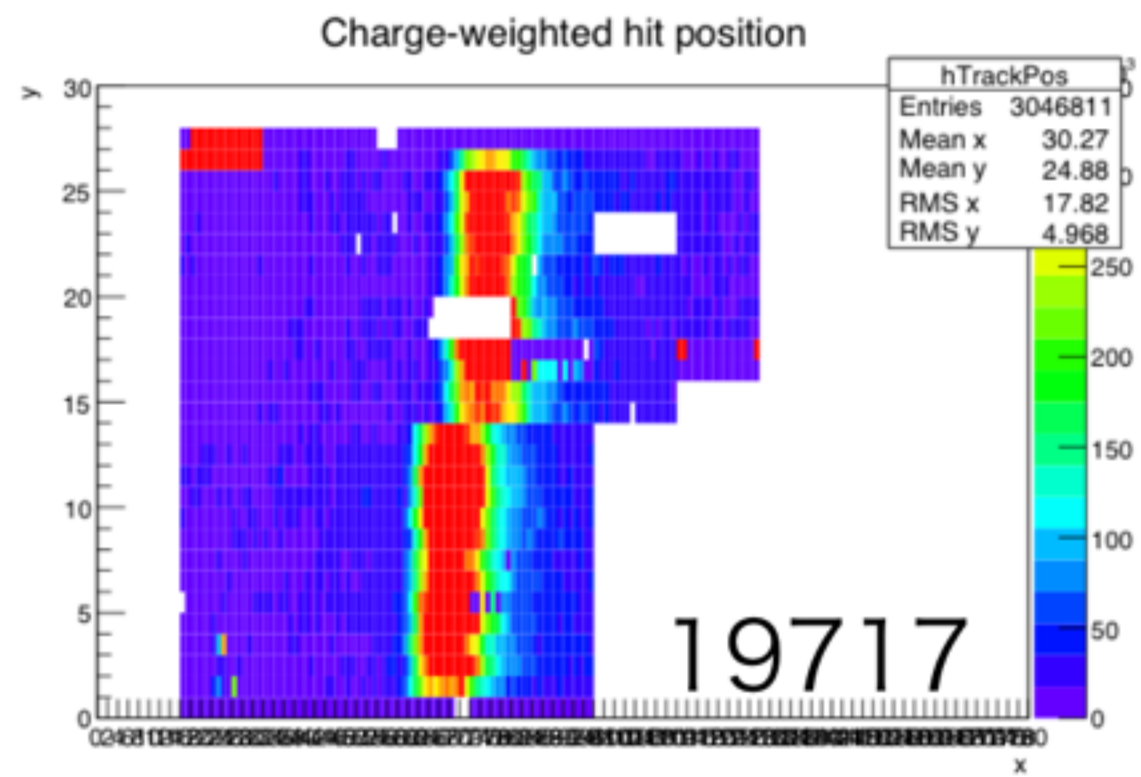
50
0
19985


Charge-weighted hit position
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Entries 3046811
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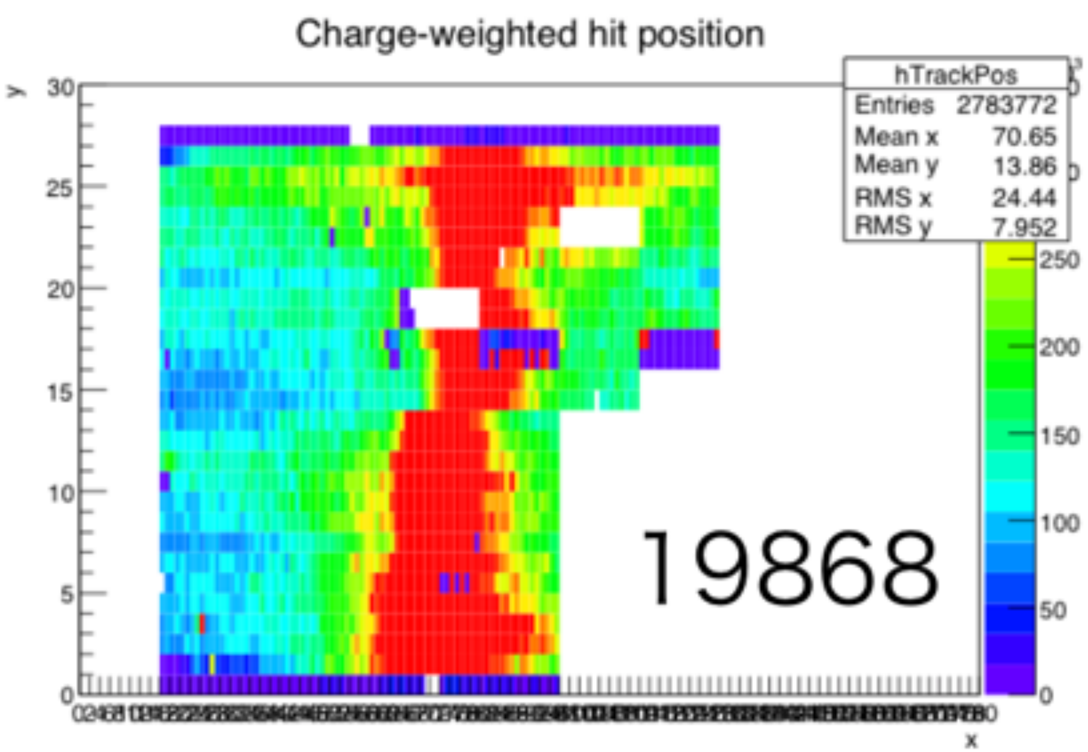
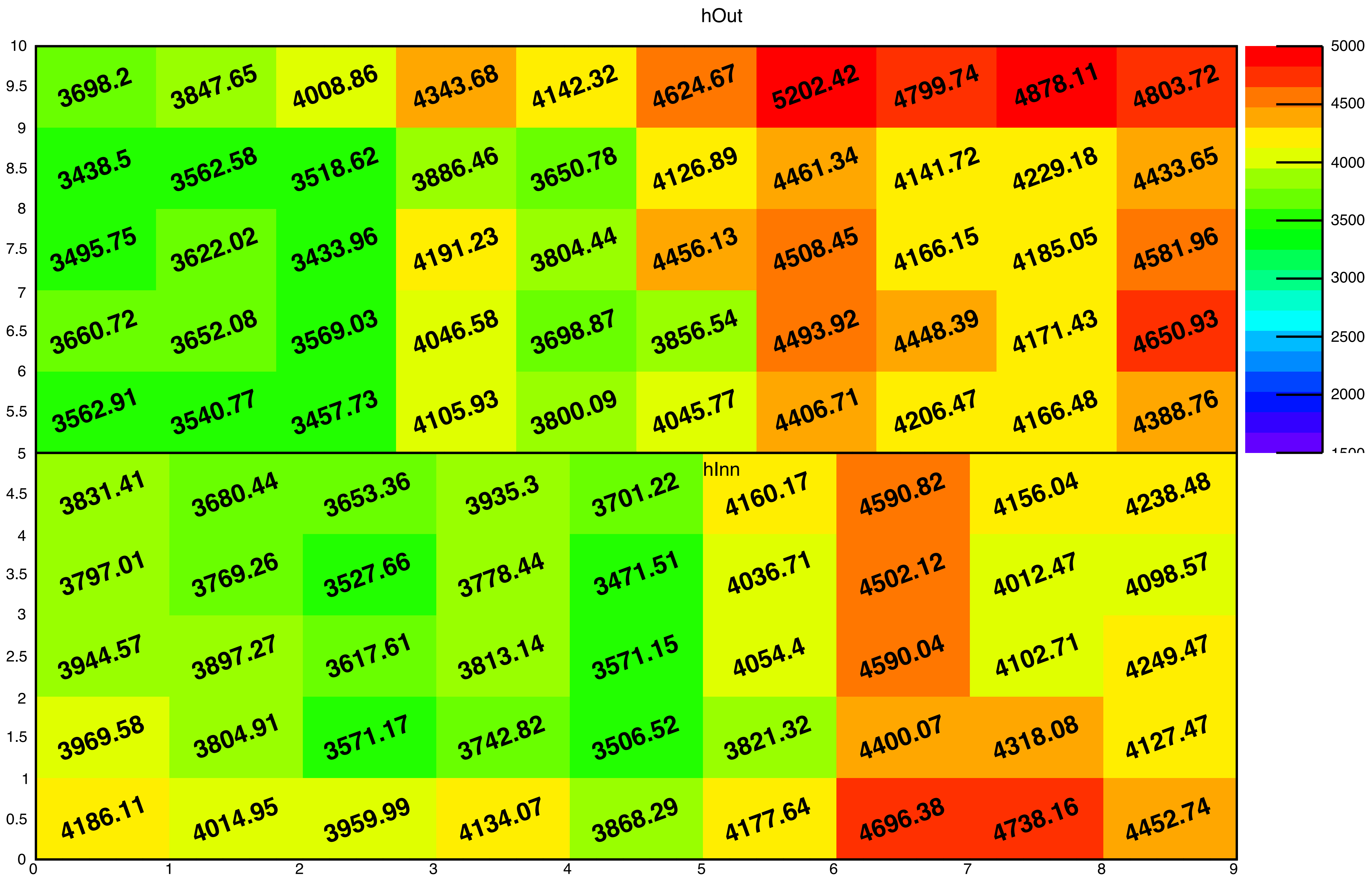

Charge-weighted hit position
hTrackPos
Entries 2783772
Mean x 70.65
Mean y 13.86
RMS x 24.44
RMS y 7.952
y
x
250
200
150
100
50
0
19868

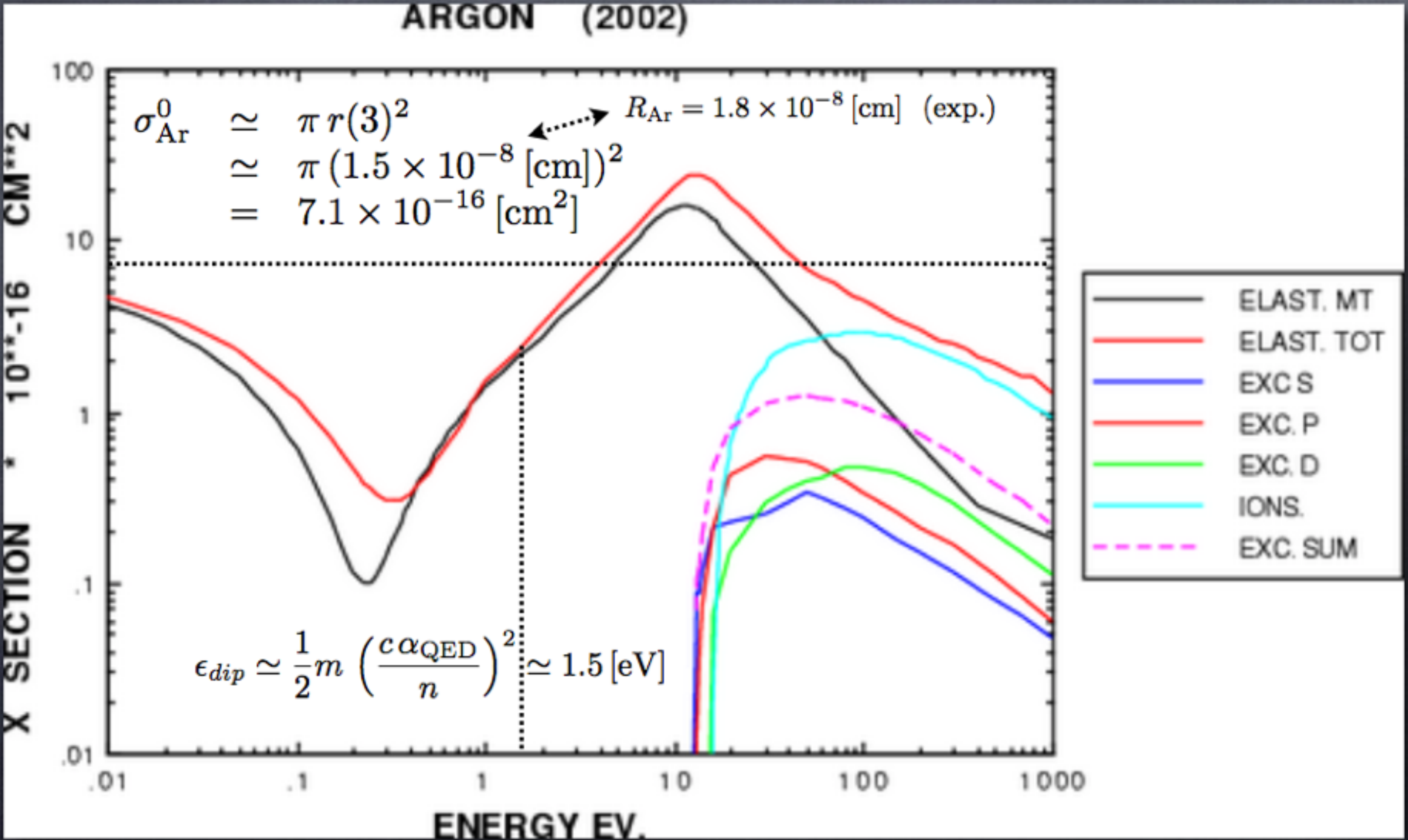
Uniformity

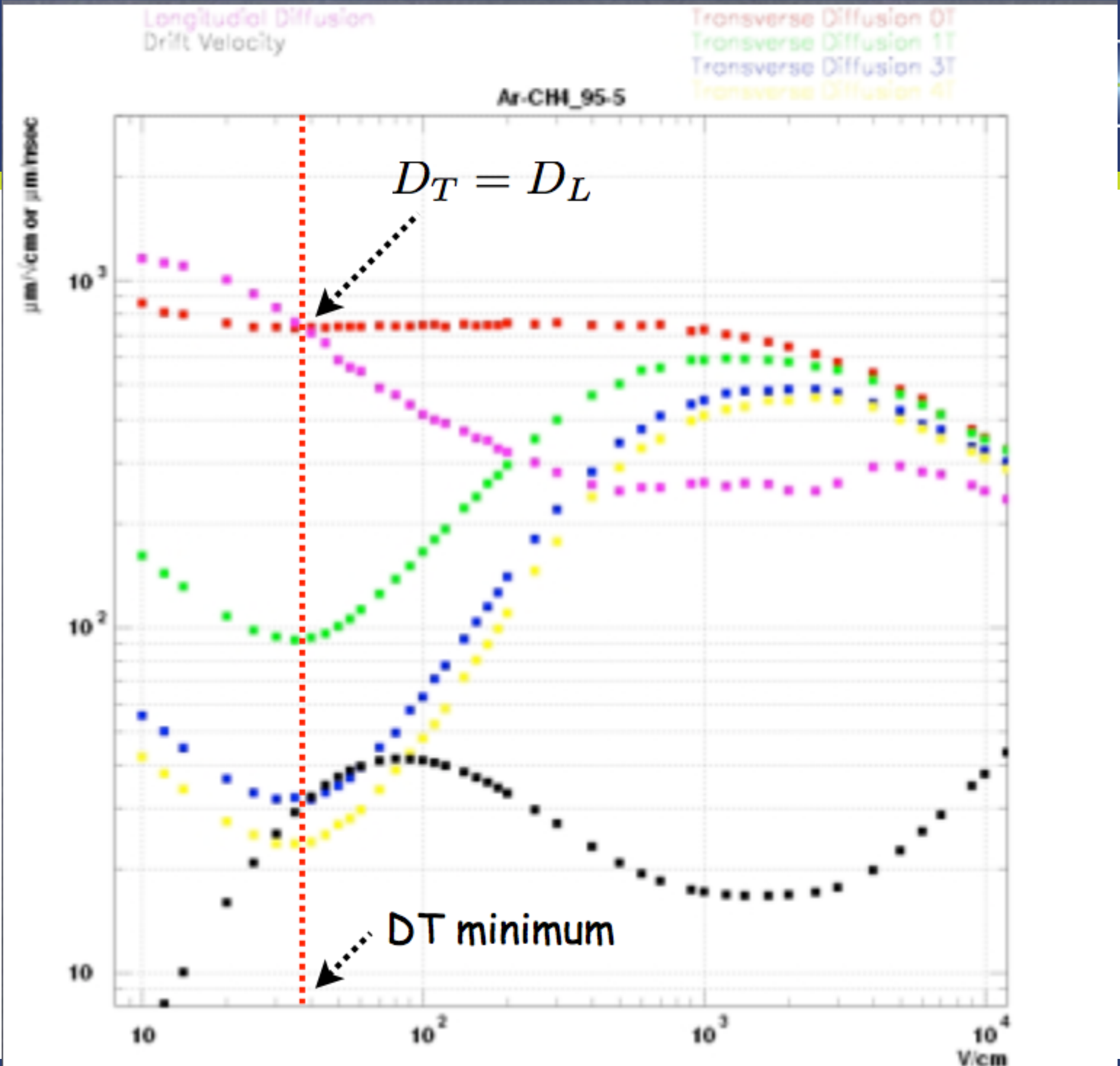


hOut
hInn
3698.2
3847.65
4008.86
4343.68
4142.32
4624.67
5202.42
4799.74
4878.11
4803.72
3438.5
3562.58
3518.62
3886.46
3650.78
4126.89
4461.34
4141.72
4229.18
4433.65
3495.75
3622.02
3433.96
4191.23
3804.44
4456.13
4508.45
4166.15
4185.05
4581.96
3660.72
3652.08
3569.03
4046.58
3698.87
3856.54
4493.92
4448.39
4171.43
4650.93
3562.91
3540.77
3457.73
4105.93
3800.09
4045.77
4406.71
4206.47
4166.48
4388.76
3831.41
3680.44
3653.36
3935.3
3701.22
4160.17
4590.82
4156.04
4238.48
3797.01
3769.26
3527.66
3778.44
3471.51
4036.71
4502.12
4012.47
4098.57
3944.57
3897.27
3617.61
3813.14
3571.15
4054.4
4590.04
4102.71
4249.47
3969.58
3804.91
3571.17
3742.82
3506.52
3821.32
4400.07
4318.08
4127.47
4186.11
4014.95
3959.99
4134.07
3868.29
4177.64
4696.38
4738.16
4452.74
5000
4500
4000
3500
3000
2500
2000

Ar Cross Section

That used in Magboltz




Longitudinal Diffusion
Drift Velocity
Transverse Diffusion 0T
Transverse Diffusion 1T
Transverse Diffusion 3T
Transverse Diffusion 4T
Ar-CH4_95-5
μm/√cm or μm/nsec
$D_T = D_L$
DT minimum
10
10²
10³
10⁴
V/cm

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Data analysis & Result

1. Event Reconstruction

   - Hit Reconstruction

   - Track Reconstruction

   - Data Quality Cuts

2. How to calculate Spatial Resolution

3. How to estimate the election transmission

4. Result

Event Reconstruction

Cluster making

- make cluster from ADC

Hit making

- determine the hit point by center of gravity
- Coordinate calculation

Track finding + fitting

- determine the track parameter

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Cluster making

- make cluster from ADC

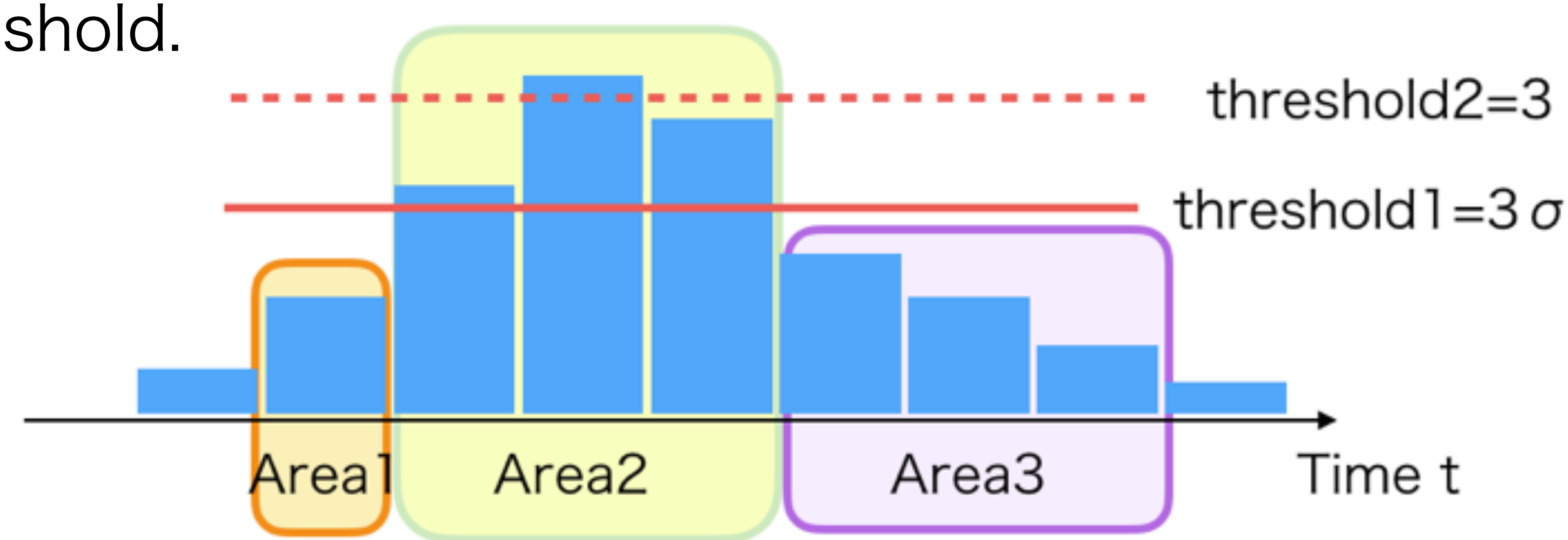
Time direction

Set pedestal σ as the standard (This time, σ=0.5)

The time bins above the threshold:3σ are regarded as a cluster

However if the peak ADC below the threshold 3 ADC counts, it is not regarded as a hit

We include in the cluster, the 1 time bin before the first time bin above the threshold, and the 3 bins after the last time bin above the threshold.

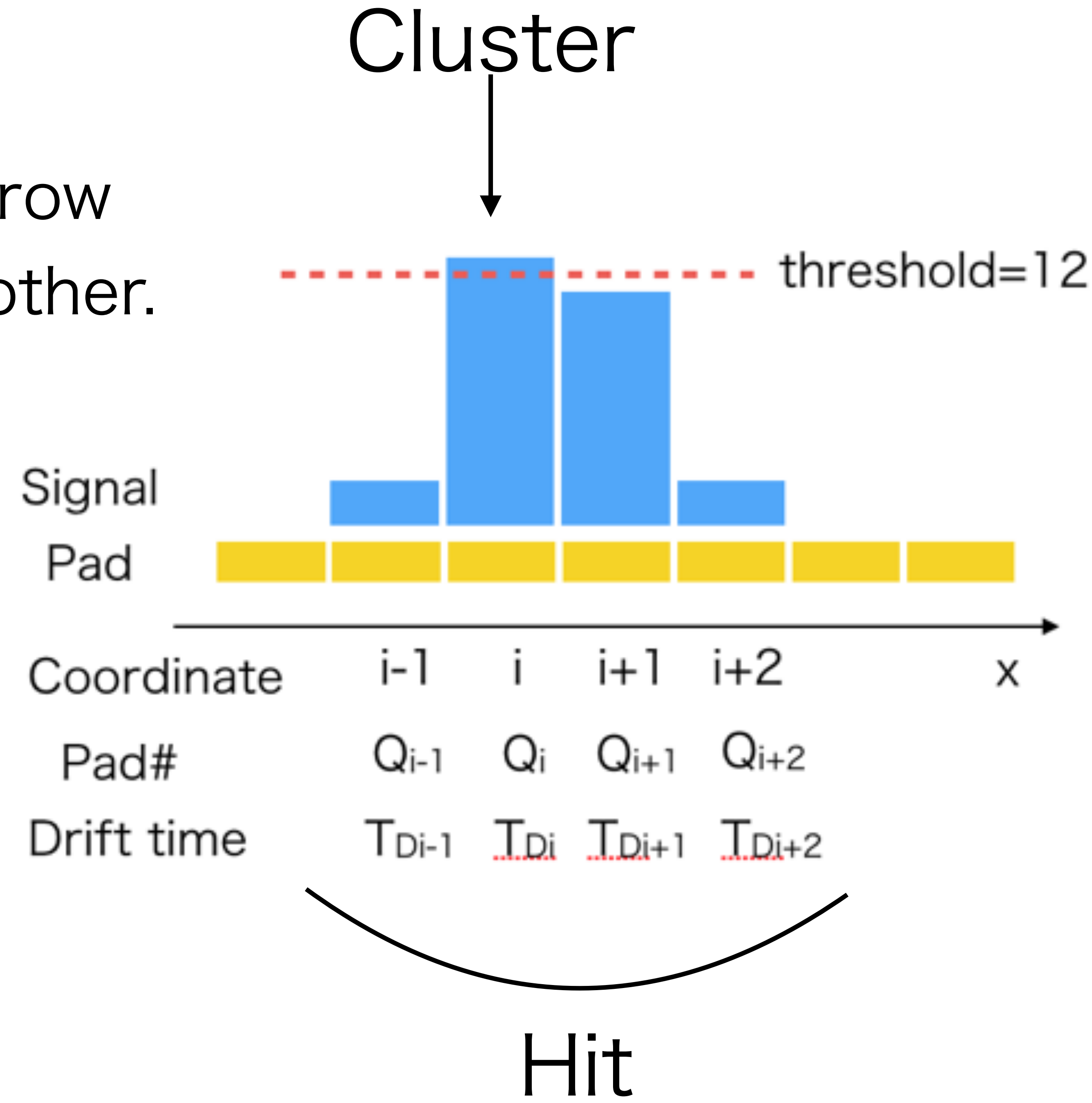


Hit making

Pad row direction

We collect all time clusters in the row direction which are touching each other.

However if the peak cluster below the threshold 12 ADC counts, it is not regarded as a hit



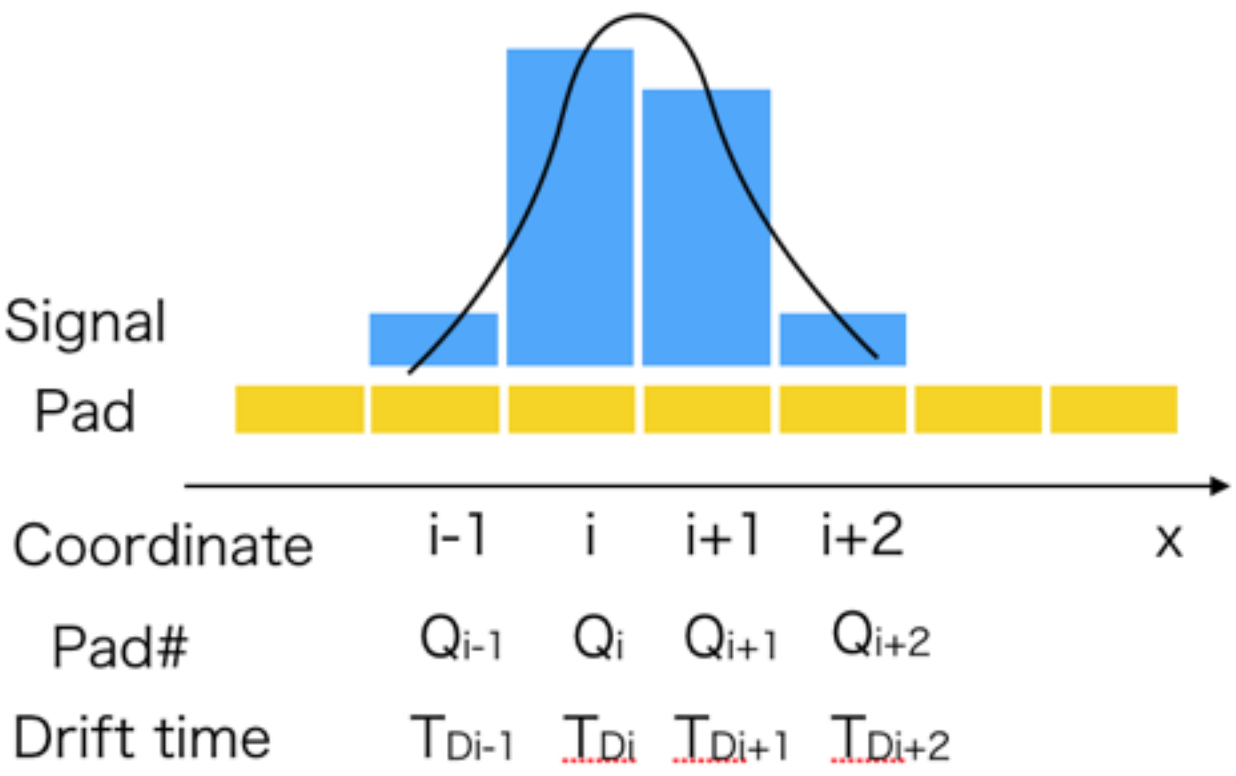
Hit making

Coordinate calculation

①Row direction

Determine the hit coordinate by the center of gravity in the pad row direction

$$C.O.G = \frac{\sum(Q_i \cdot x_i)}{\sum Q_i}$$

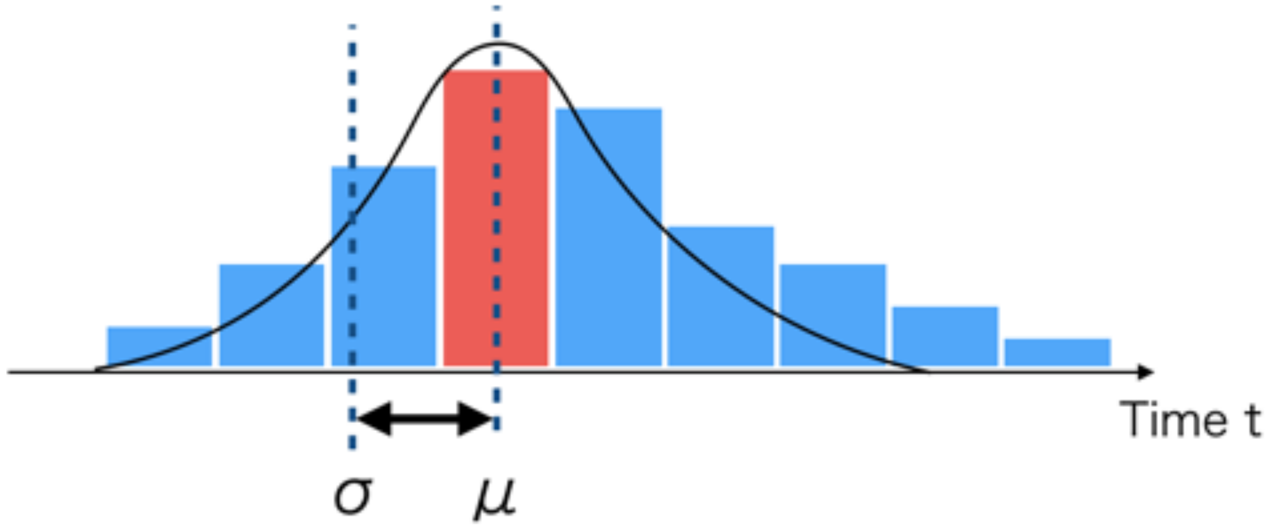


②Time

the inflection point

$t = \mu - \sigma$

(50 ns/1 bin)



Track Reconstruction

We use Kalman filter to reconstruct tracks

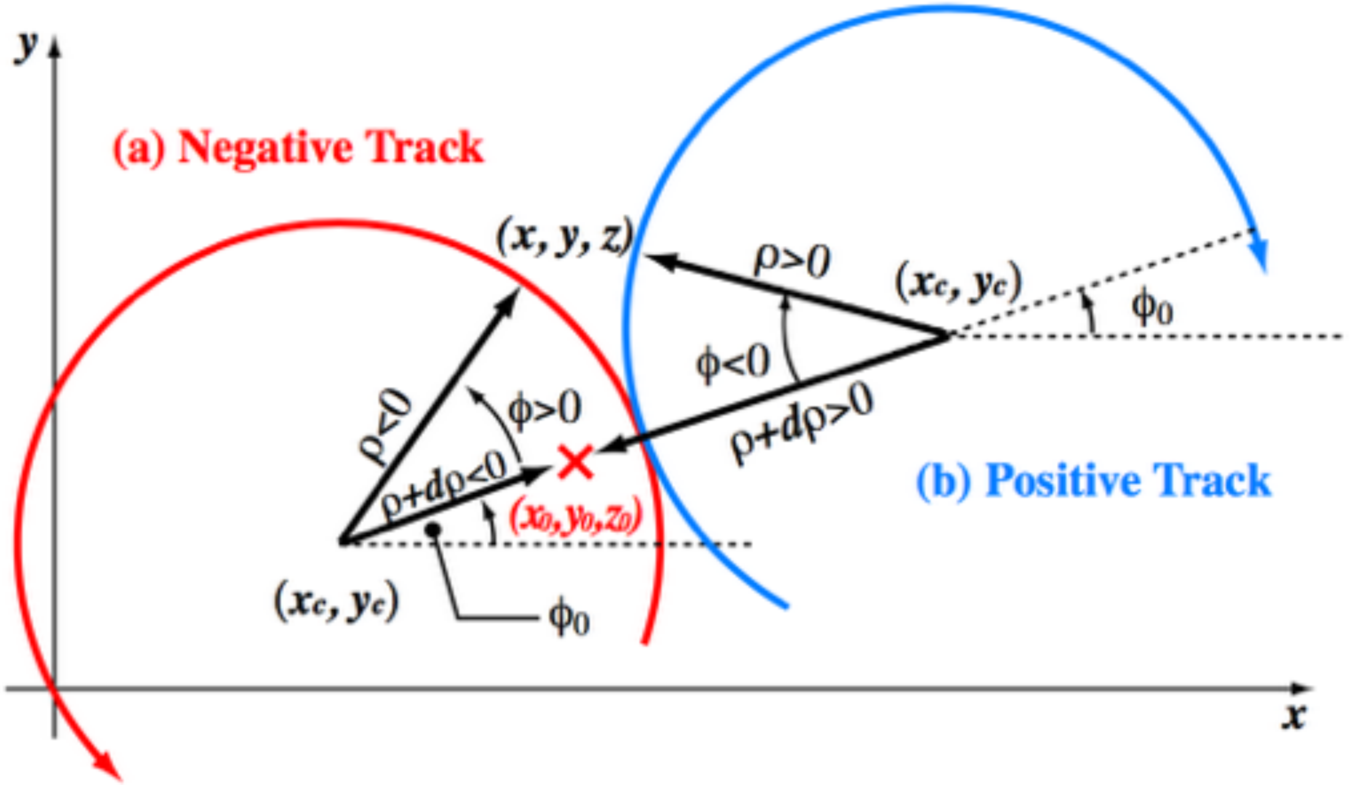
(MyTrackMakingKalmanFilterProcessor)

①Find a hit point around a predicted area

②Fit tracks

③Get 5 track parameters

$$\mathbf{a} \equiv (d_\rho, \phi_0, \kappa, d_z, tan\lambda)^T$$



d_ρ : The distance bitween pivot and track in the plane vertical from z-axis

ϕ_0 : azimuthal angle of the pivot to the center of the helix

κ : Q/Pt(transverse momentum)

d_z : The distance bitween pivot and track in z-axis

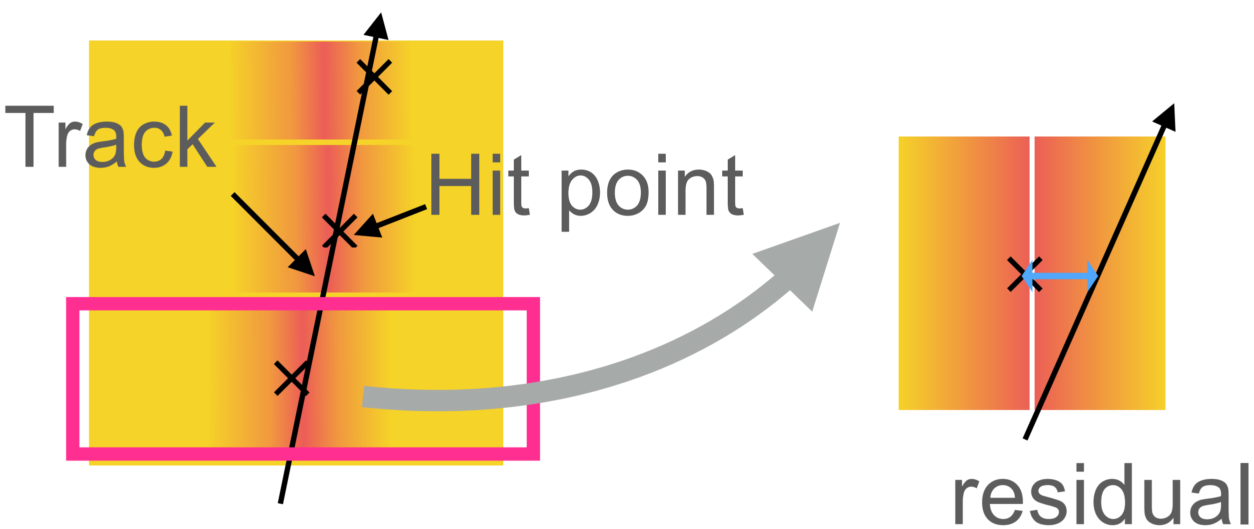
$tan\lambda$: The dip angle from vertical plane to helix axis

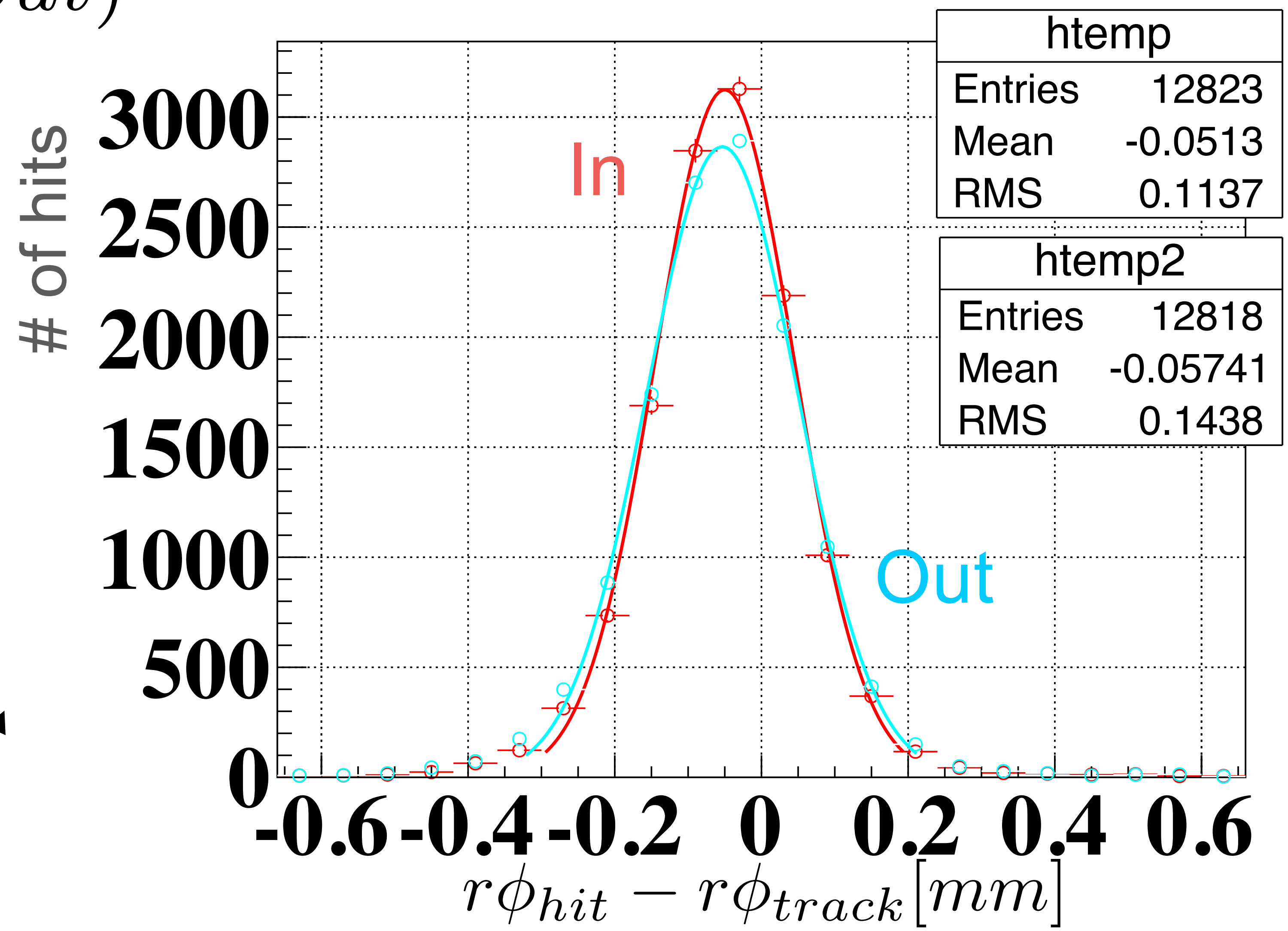
How to get spatial resolution

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

$\sigma_{r\phi(in)}$ hit in question included in the track fit

$\sigma_{r\phi(out)}$ excluded from the fit





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How to estimate Electron transmission

Neff : Effective number of ionization electrons which decides spatial resolution

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

G : gas amplification

$\bar{G}$: average of gas amplification

Ratio of Neff≒Electron transmission ratio

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

How to get Neff

For large enough drift distances, spatial resolution with respect to drift distance can be written in the following form

$$\sigma_{r\phi}(Z) = \sqrt{\sigma_0^2 + \frac{C_d^2}{N_{eff}} \cdot Z}$$

$\sigma_{r\phi}$: spatial resolution for azimuth angle ($r\phi$)

σ_0: spatial resolution without electron diffusion(constant term)

C_d : diffusion constant

Neff : Effective number of ionization electrons $N_{eff} = \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}} \right)^2 \right\rangle \right]^{-1}$

Z : drift distance

G : gas amplification

$\bar{G}$: average of gas amplification

The diffusion constant can be obtained from pad responce.

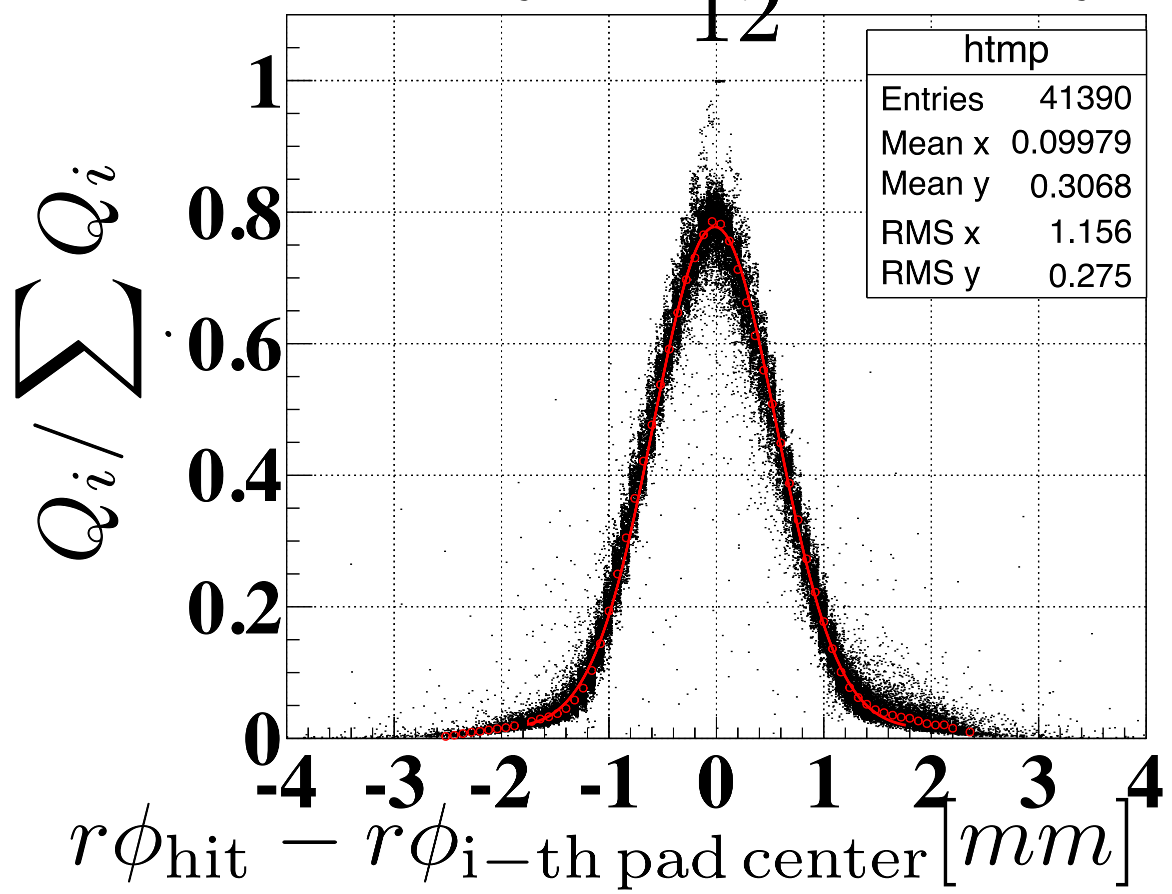
I'll explain how to get Cd from pad response.

Pad responce（σ_{PR}）

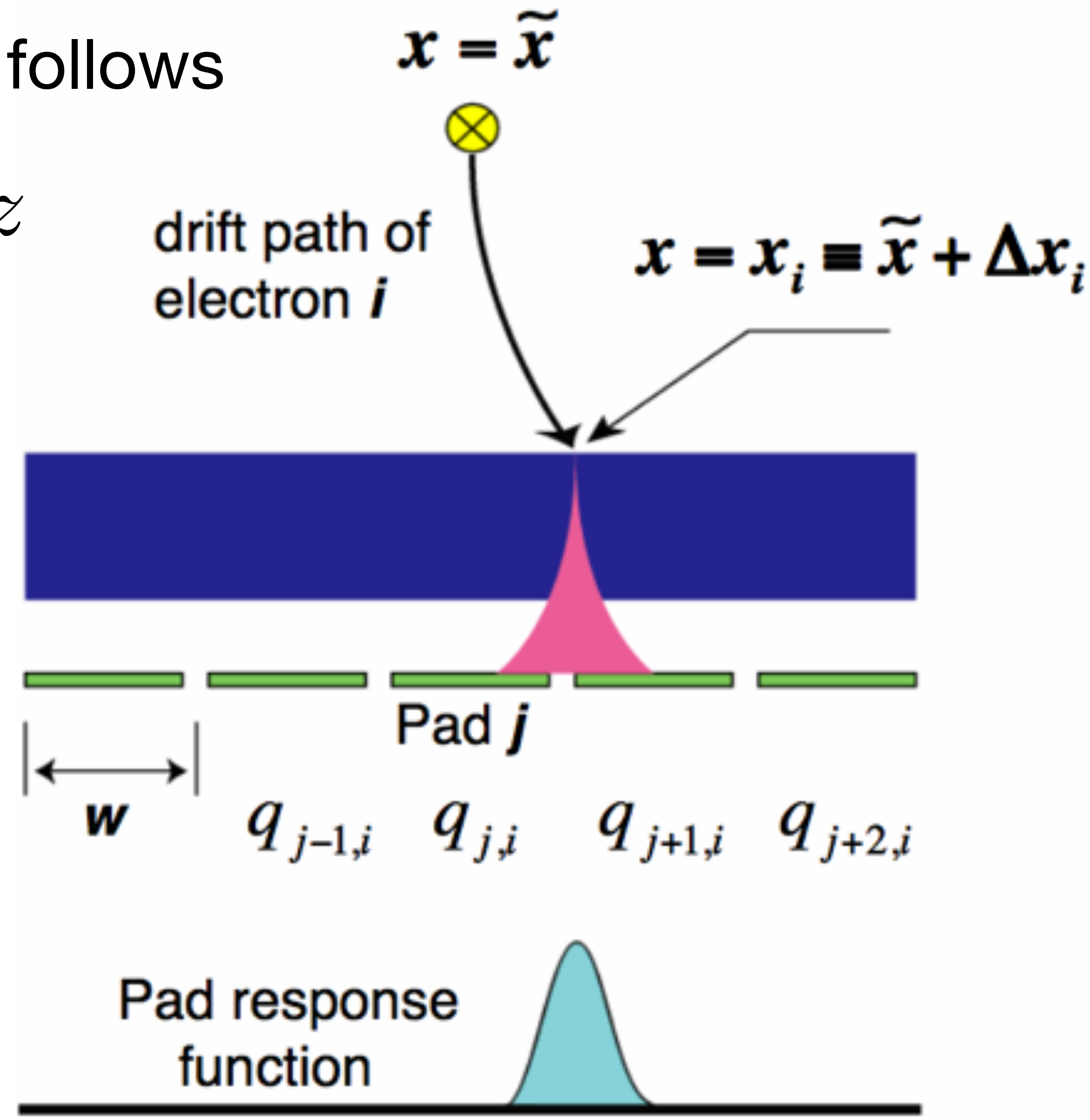
The width of the pad response function（σ_{PR}）is obtained as follows
First, we plot the charge fraction on each pad as a function of the distance of the pad center from the hit point. Then we fit this distribution to a Gaussian and get σ_{PR} as the standard deviation.

On the other hand, σ_{PR} can be expressed as follows

$$\sigma_{PR}^2 = \frac{w^2}{12} + \sigma_{PRF}^2 + C_d^2 z$$



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



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How to get electron transmission

Pad responce（σPR）

plot vs distance Z

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

Diffusion constant

GM resolution（σrφ）

plot vs distance Z

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

Calculate Neff

↓

Calculate electron transmission

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

yumia@post.kek.jp