Study of resolution in the time direction

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Introduction

High spatial resolution is important for tracker.

We use recoil mass to measure Higgs mass using momentum conservation raw.

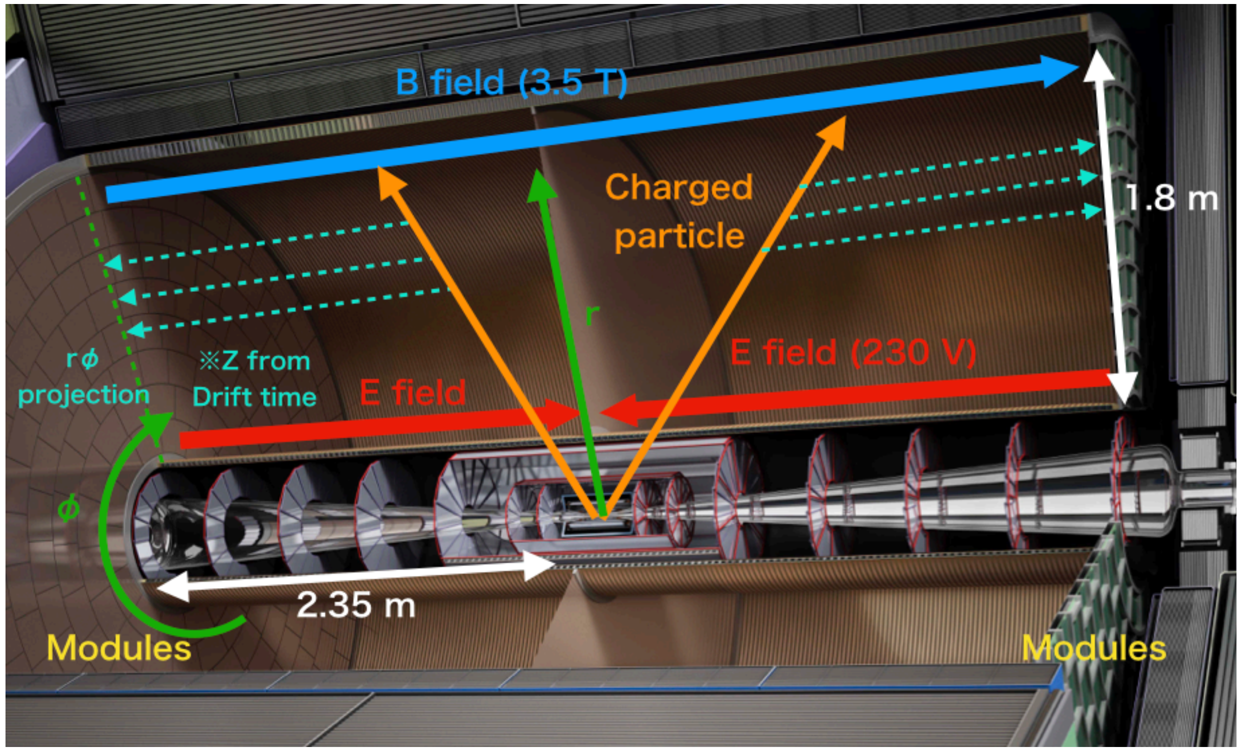
→Momentum depends on spatial resolution, so high spatial resolution is necessary for Higgs precise measurement

ILD

rφ resolution : <100μm

Z (time) resolution : ~0.4 - 1.4 mm

(for zero – full drift)



To check if we can achieve the goal is need for ILC !

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Can we achieve the high resolution?

TPC Large Prototype

B field : 1 T
Drift length : 55 cm

Real Machine

B field : 3.5 T
Drift length : 220 cm

rϕ resolution

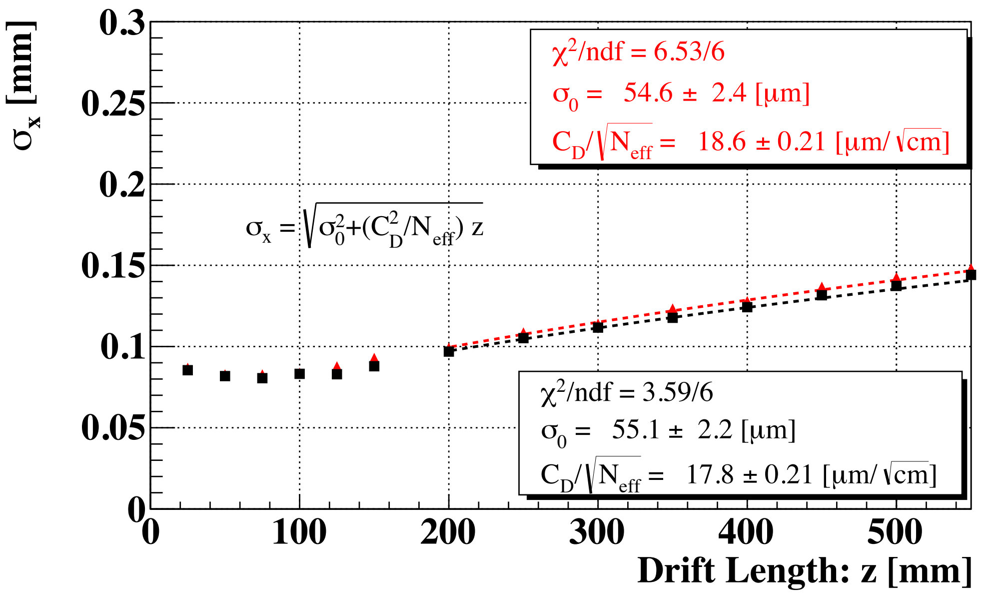
$$\sigma_{r\phi}(Z)^2 = \sigma_0(w)^2 + \frac{1}{N_{eff}} C_d(B)^2 \cdot Z$$

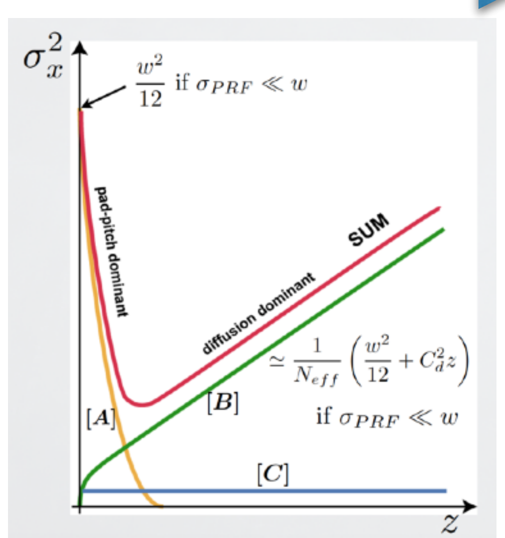
hodoscope effect

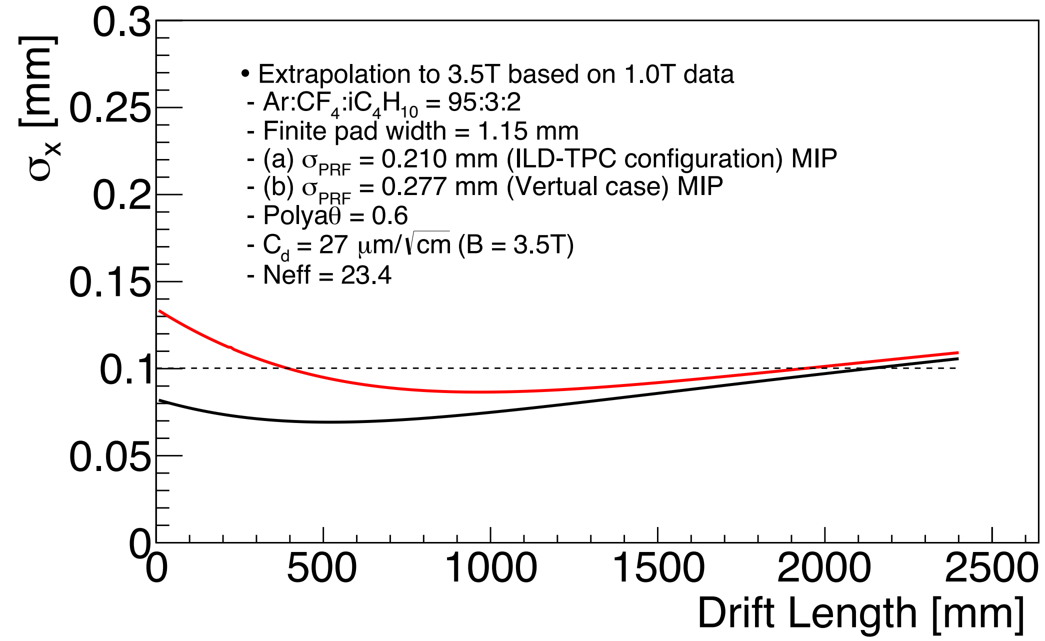
w: pad pitch

Transverse diffusion constant

YONAMINE, Ryo. "Measuring the top Yukawa coupling at the ILC at√ s= 500 GeV and R&D for the ILD-TPC." (2012).







However we didn't know resolution formula for time direction

Can we achieve the high resolution?

TPC Large Prototype

B field : 1 T
Drift length : 55 cm

→

Real Machine

B field : 3.5 T
Drift length : 220 cm

Time resolution

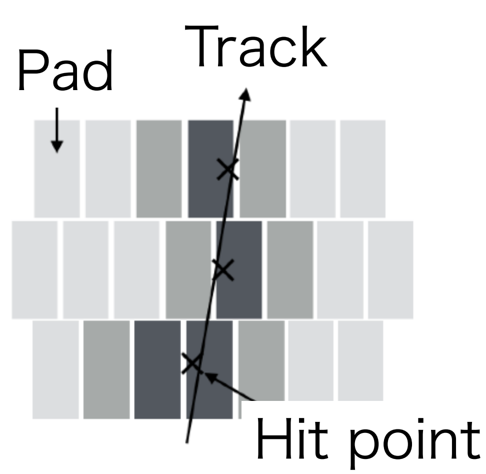
$$\sigma_Z(Z)^2 \overset{?}{=} \sigma_{0L}(w_t)^2 + \frac{1}{N_{eff}} C_{dL} \cancel{(B)}^2 \cdot Z$$

hodoscope effect w_L: time bin Longitudinal diffusion constant

r ϕ direction

Measure charge of pads

Magnetic filed efect

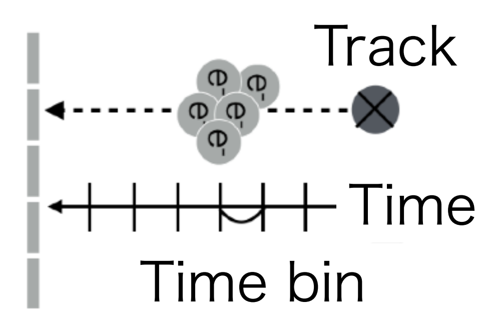


time direction

Measure charge of time bin

Assumption

Magnetic field doesn't affect the time resolution



Can we achieve the resolution goal in time direction?

Motivation of this study

Construction of time resolution formula

$$\sigma_Z(Z)^2 \overset{?}{=} \sigma_{0L}(w_t)^2 + \frac{1}{N_{eff}} C_{dL}(B)^2 \cdot Z$$

hodoscope effect $\frac{w_L^2}{12}$

w_L: time bin

Longitudinal diffusion constant

First, I take notice of C_{dL}

We assume that magnetic field doesn't affect the time resolution

Simple assumption

- There is no diffusion in amplification region
- No B effect

I'm making TPC simulator for this study

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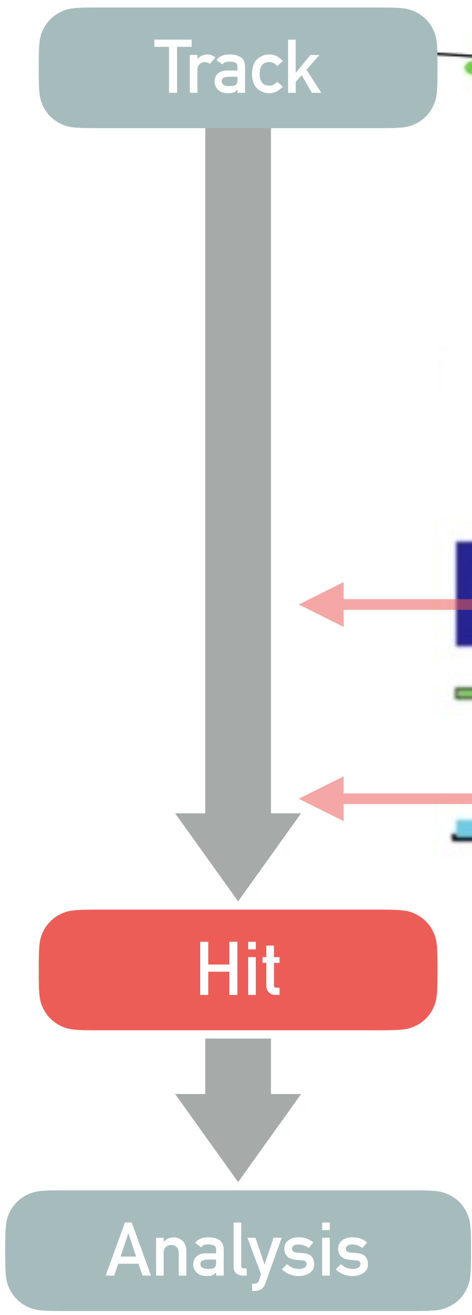
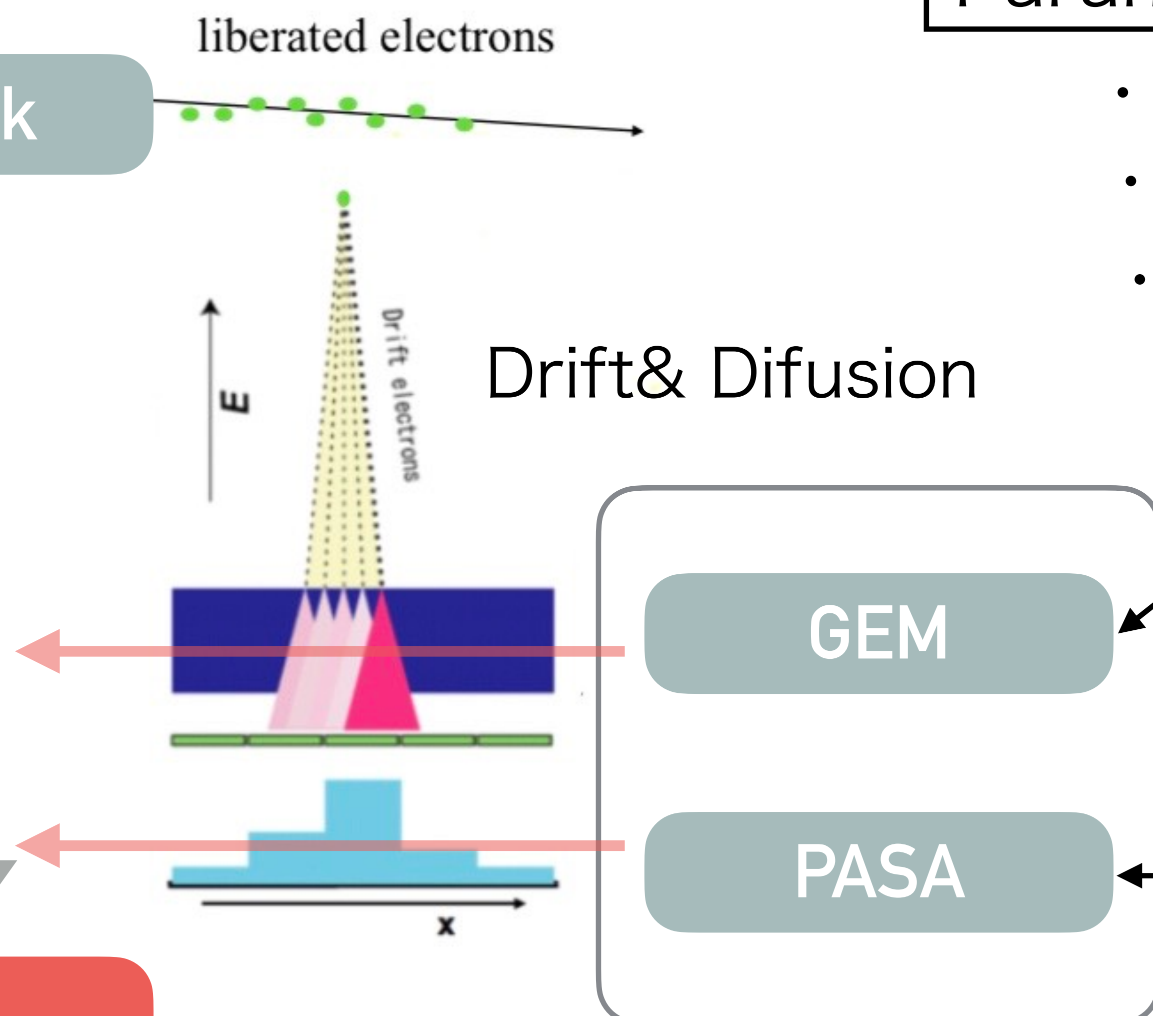
TPC simulator





Parameter

- Position, angle of track
- # of primary ionization
- Diffusion constant

Create the readout structure

- Pad size
- Drift velocity
- Average gas gain

Define how to treat electrons

- Peaking time
- Shaper order
- time bin width

Assumption

- Ignoring diffusion in amplification region

※ I use a pad having largest charge in the row

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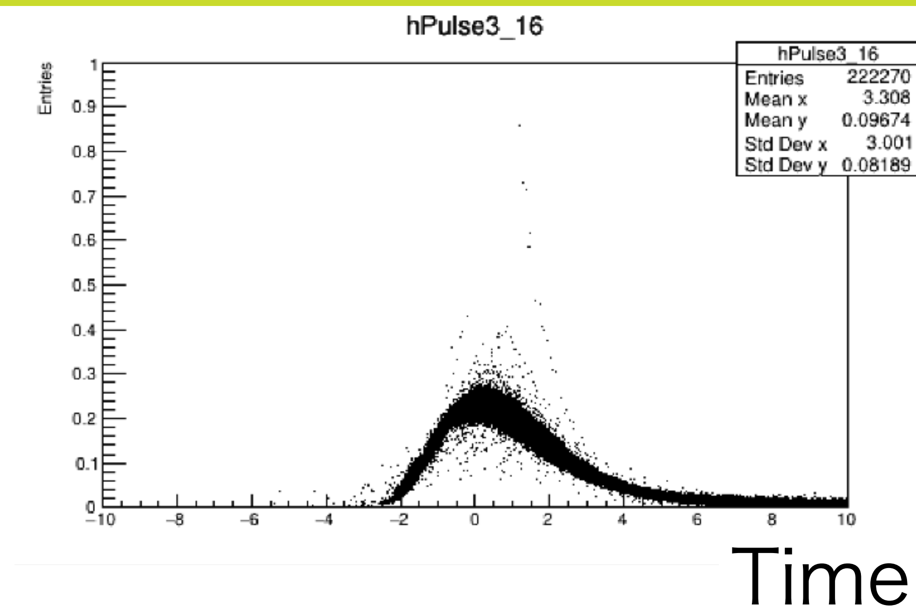
How to calculate C_{dL}

Electrons make pulse in time direction

Pulse shape is defined by structure of readout electronics

For accurate pulse fit, I use convolution fit.



$$f(t) = \frac{1}{n!(t_{pk}/n)} \left(\frac{t}{t_{pk}/n} \right)^n e^{-\left(\frac{t}{t_{pk}/n} \right)} \otimes \underline{\text{Gaussian}}$$

Effect of diffusion

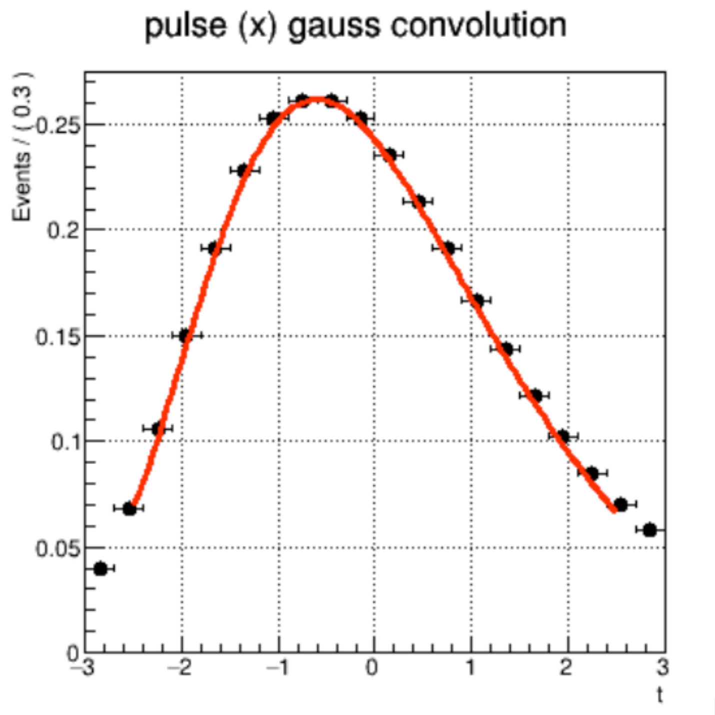
n : shaper parameter , tpk : peaking time

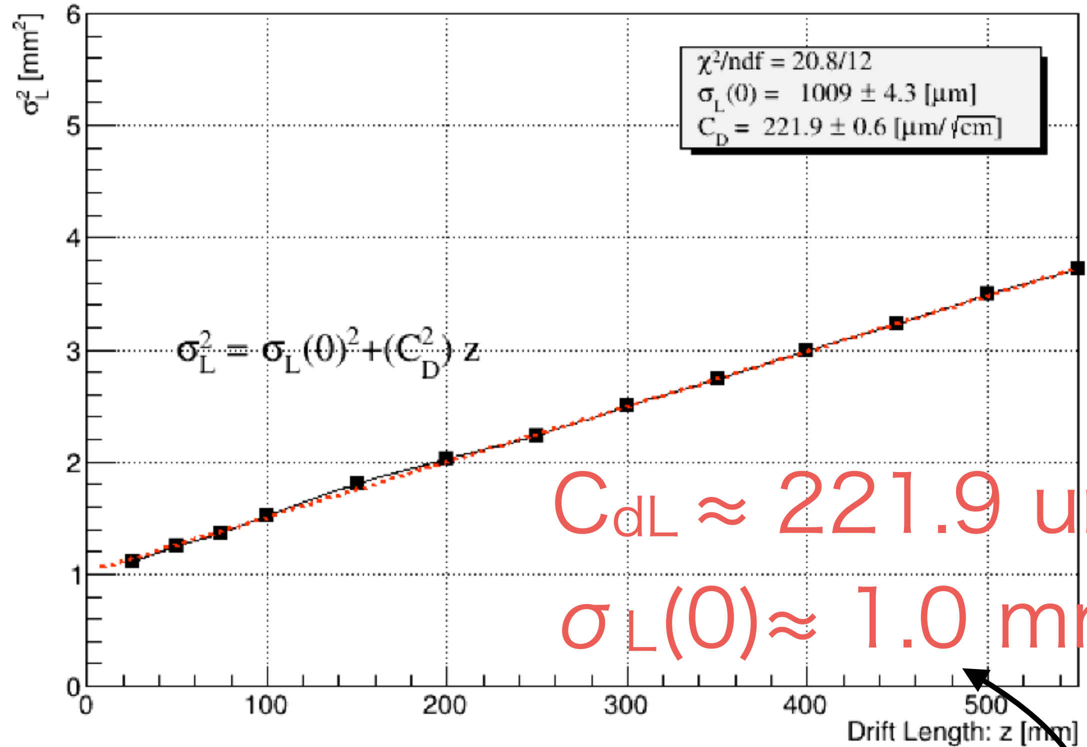
n and tpk is decided by electronics.

(Beam test setup : n=3, tpk=120ns) →Former term is fixed

→We can calculate longitudinal diffusion by σ of Gaussian

Simulation input : n=3, tpk = 120ns, C_{dL} =220 um/√cm





C_{dL} ≈ 221.9 um/√cm

$\sigma_L(0)$≈ 1.0 mm

An square root of intercept means expanse hit ← Effect of time bin width

Theory $$\frac{\text{Drift velocrty} \times \text{time bin}}{\sqrt{12}} = \frac{75\mu m/ns \times 50ns}{\sqrt{12}}$$ =1.082 mm

Under the assumption that the only smearing effect is diffusion in the drift region, this estimation method of C_{dL} is reasonable.

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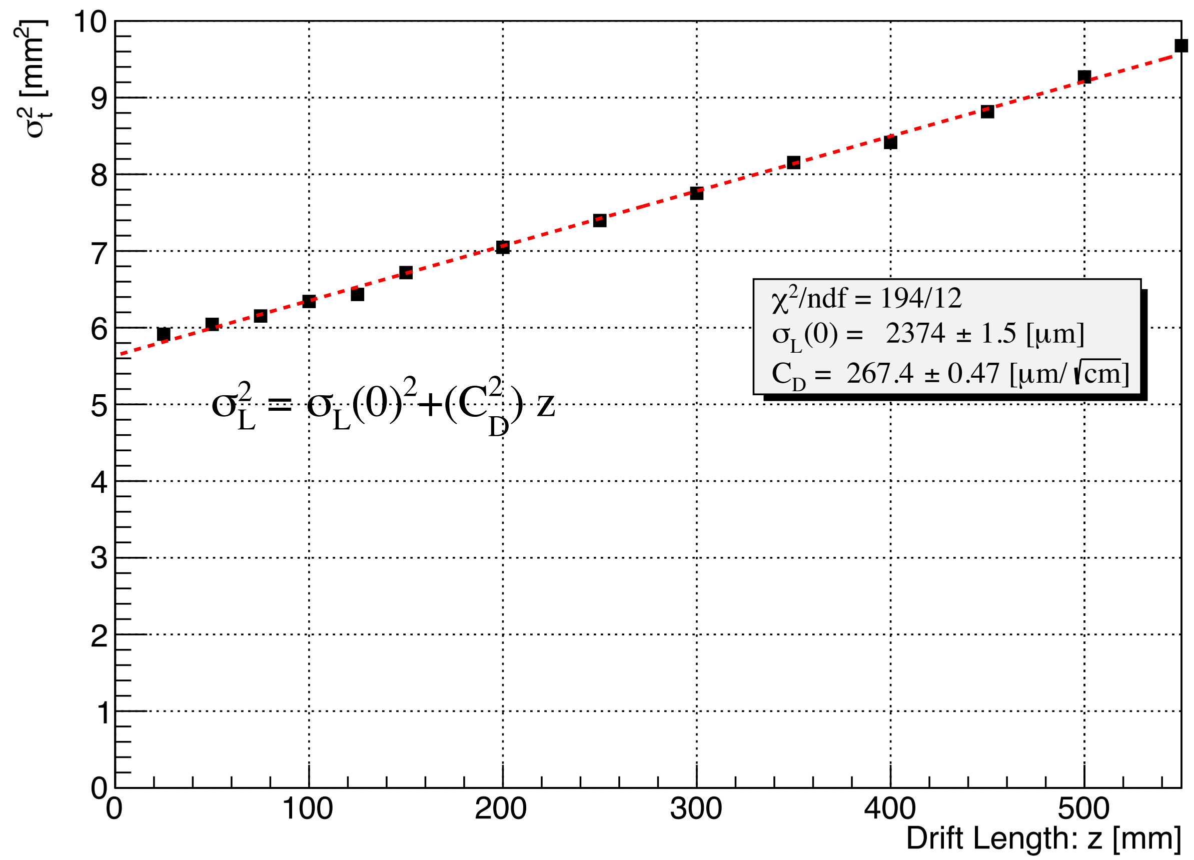
C_{dL} of test beam data

Input : n = 3 , tpk =120 ns Row = 44



$C_{dL} \approx 267.4$ um/√cm

σL(0) ≈ 2.37 mm

$$\frac{\text{Drift velocrty} \times \text{time bin}}{\sqrt{12}} = 1.082 \text{ mm}$$

Difference : √(2.374 mm)^2 - (1.082 mm)^2 = 2 mm

This result turns out that the assumption is wrong !

Assumption

- There is ~~no~~ diffusion in amplification region
- ~~No~~ E×B effect (E and B field is uniform)

What is the reason ?

Smearing effect is not only due to diffusion in the drift region

→There is other smearing effect to expand pulse 2 mm for time direction

Candidate list

(A)**Distortion of isochron**

The drift line may be distorted by the distortion of the GEM foil, the electrode gap, etc...

In this case, a magnetic field causes the distortion of drift line due to ExB.

(This part depends on the magnetic field, so resolution change at 3.5 T!)

(B) **Width of arrival time due to diffusion in the GEM module**

This can be estimated since the size and electric field of each region in the GEM module are known.

Summary & Next steps

- We try to make TPC simulator for constructing time resolution formula
- We checked diffusion constant for time direction
- According to comparison between test beam data and simulation data, we realize that there is effect which we haven't evaluate to expand pulse 2 mm for time direction

Future work

- Identify what makes hits expand
  - -Check the another row data
  - -Estimate diffusion in the GEM module
  - -Check 0T data

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Backup

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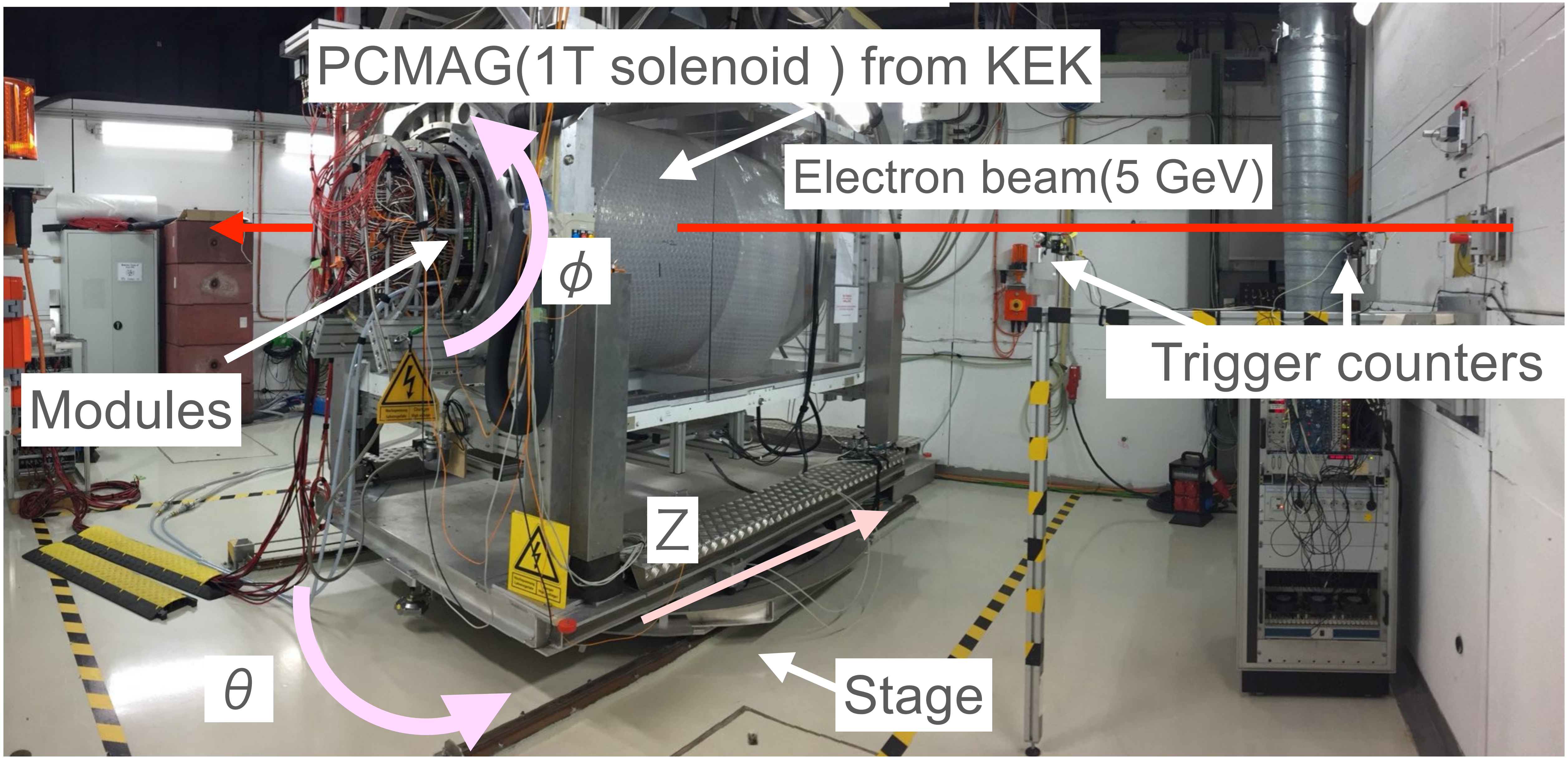
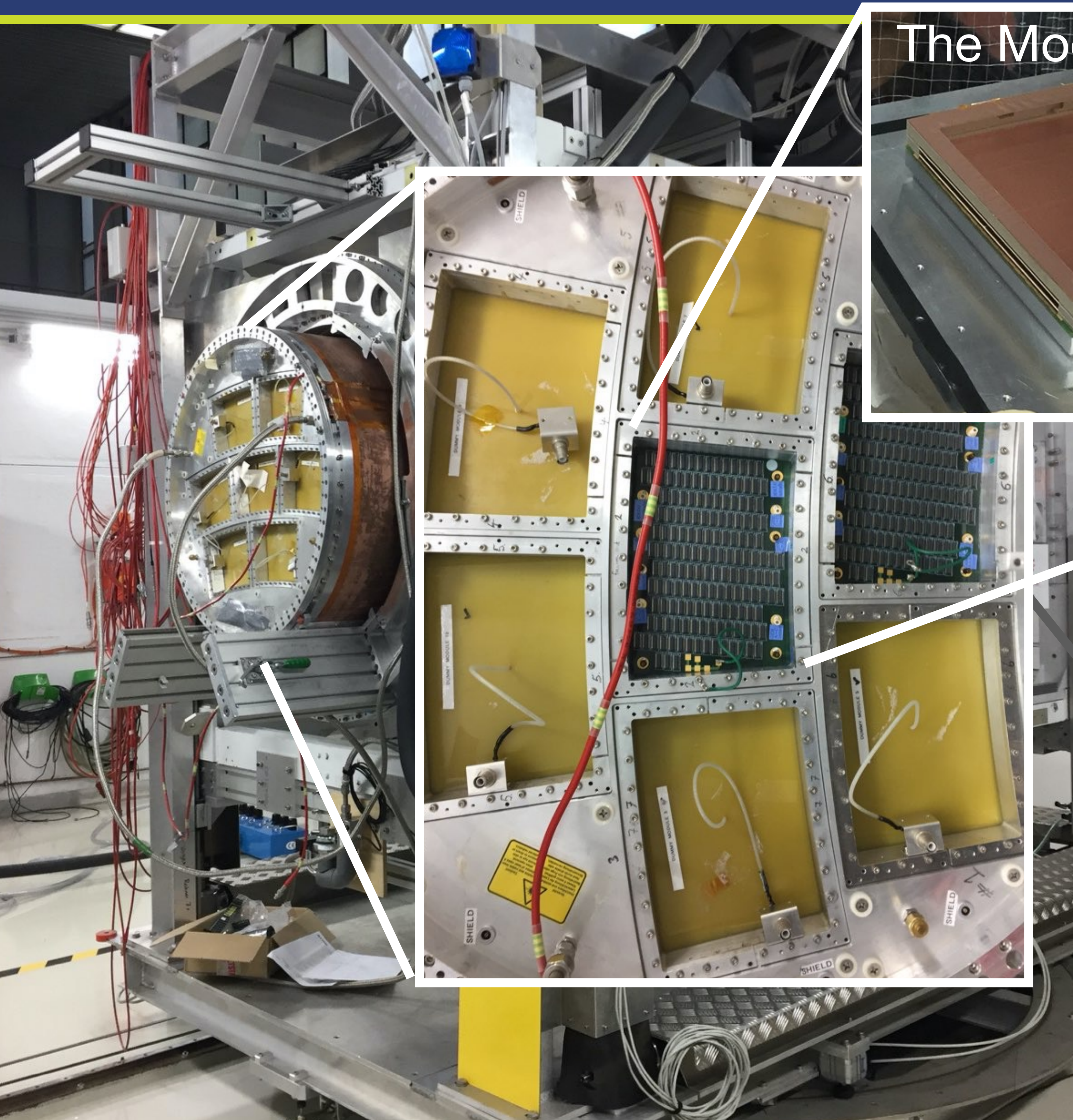
Setup

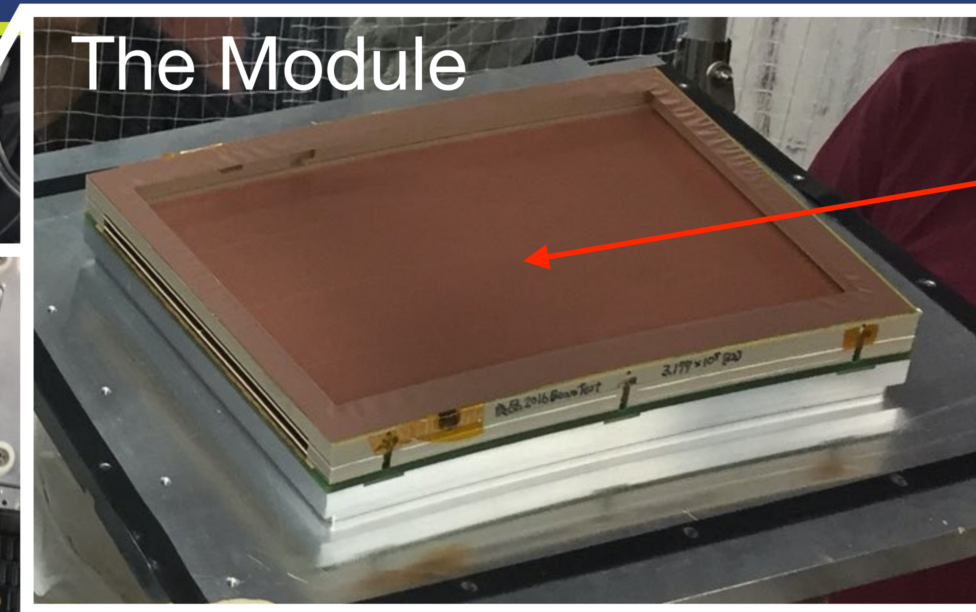
DESY Large TPC Prototype Test Facility

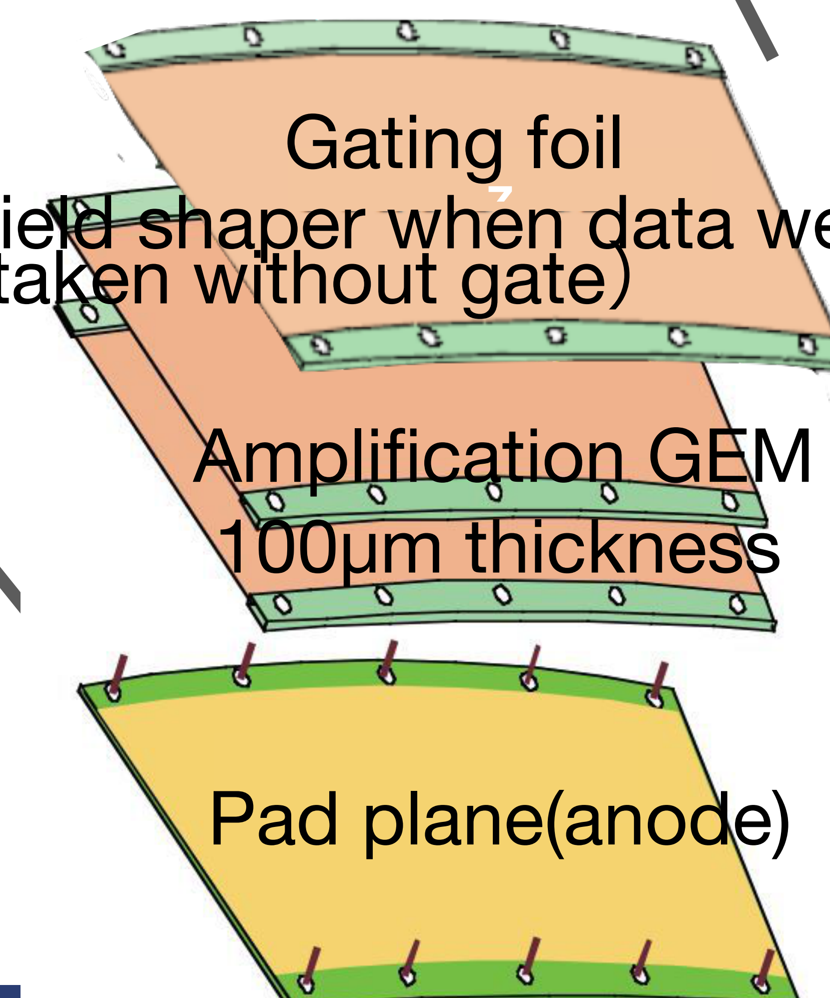


The electron beam passes two trigger counter and through the prototype.
The sensitive volume of the TPC is inside a solenoid. The TPC is mounted on a movable stage so we can change drift distance(Z) and two angles, θ and ϕ.

Module with Gating foil



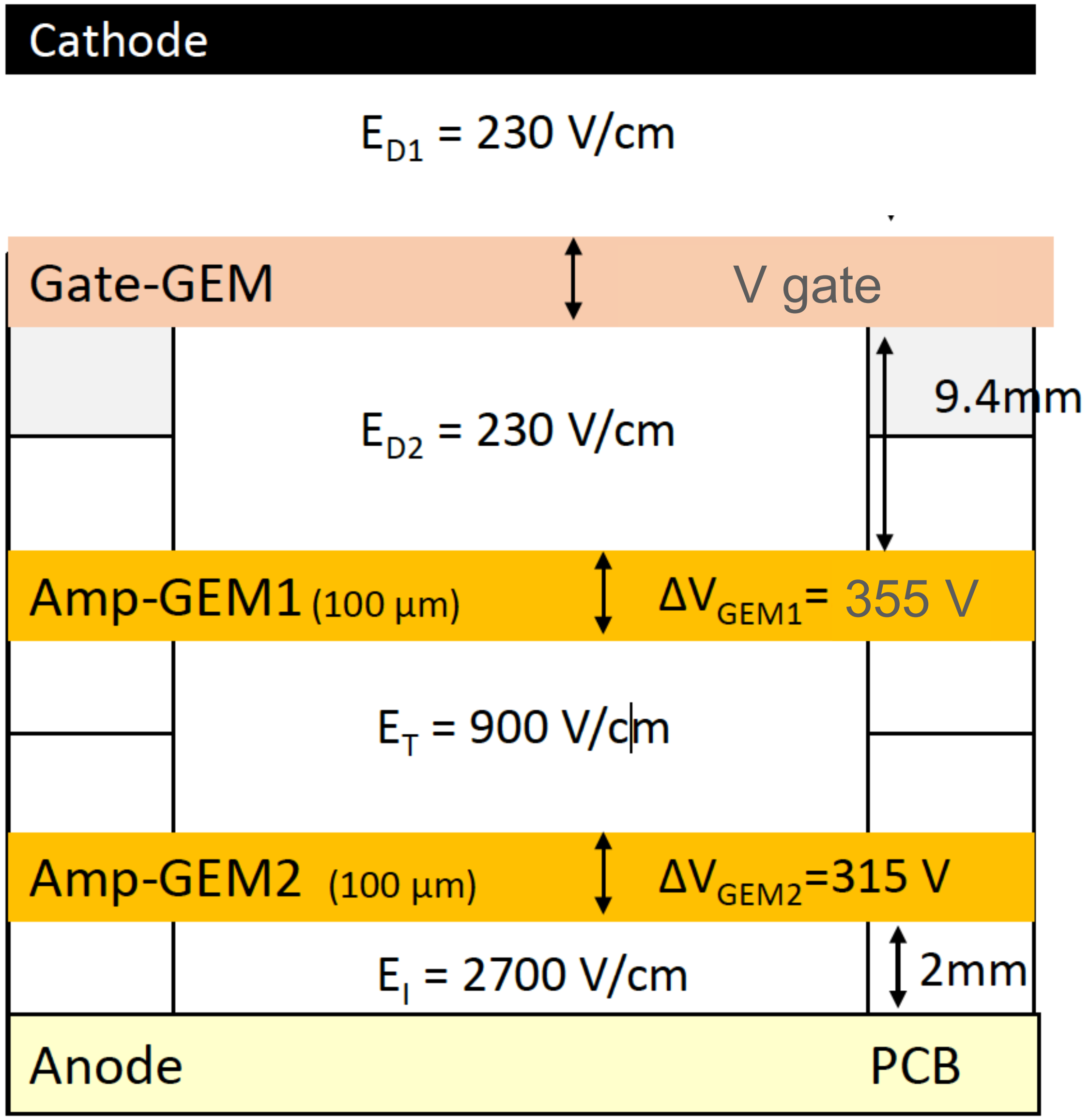




The data I analyzed in this study

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: yokaRowMon（20000event/1 run）

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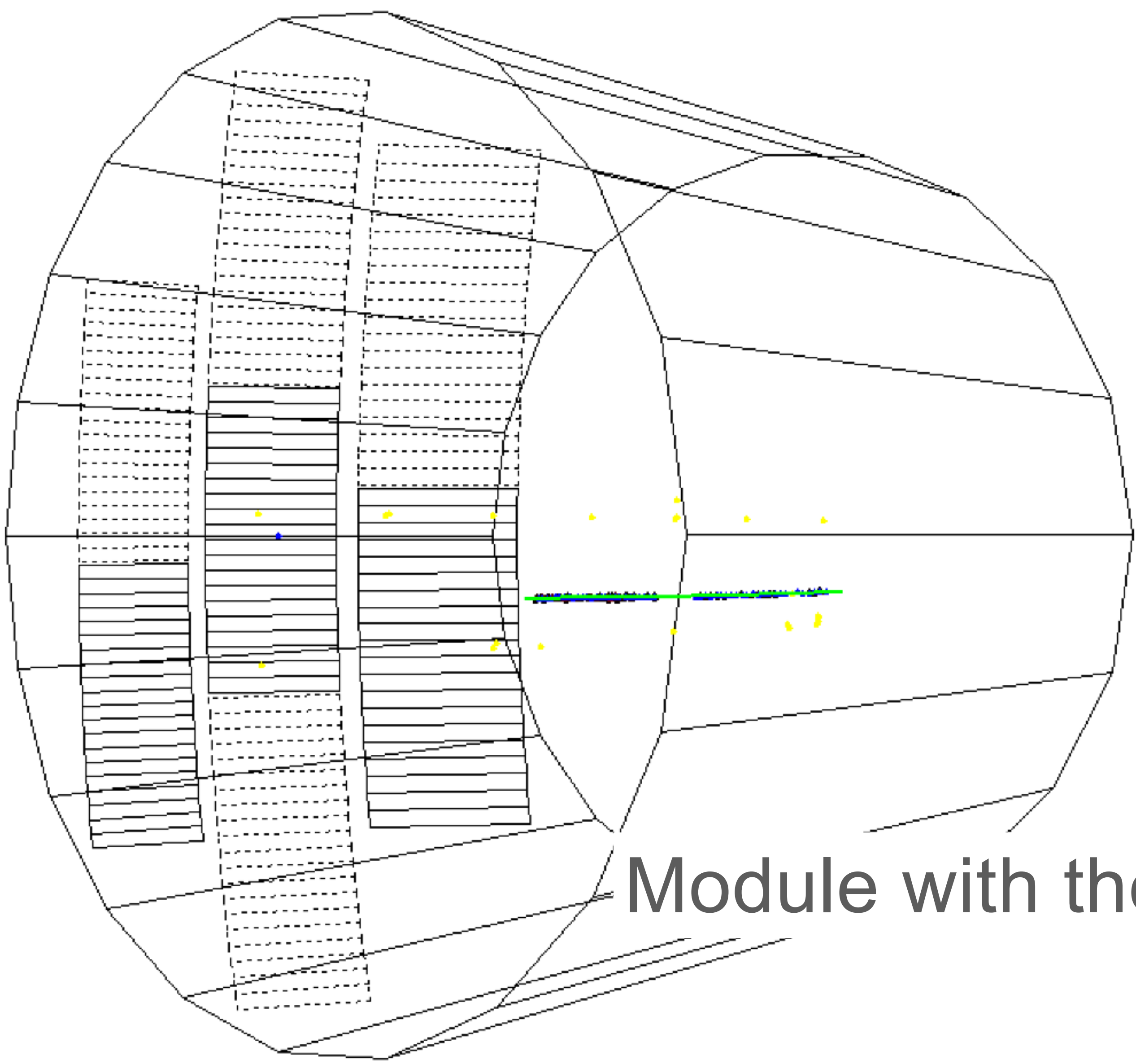
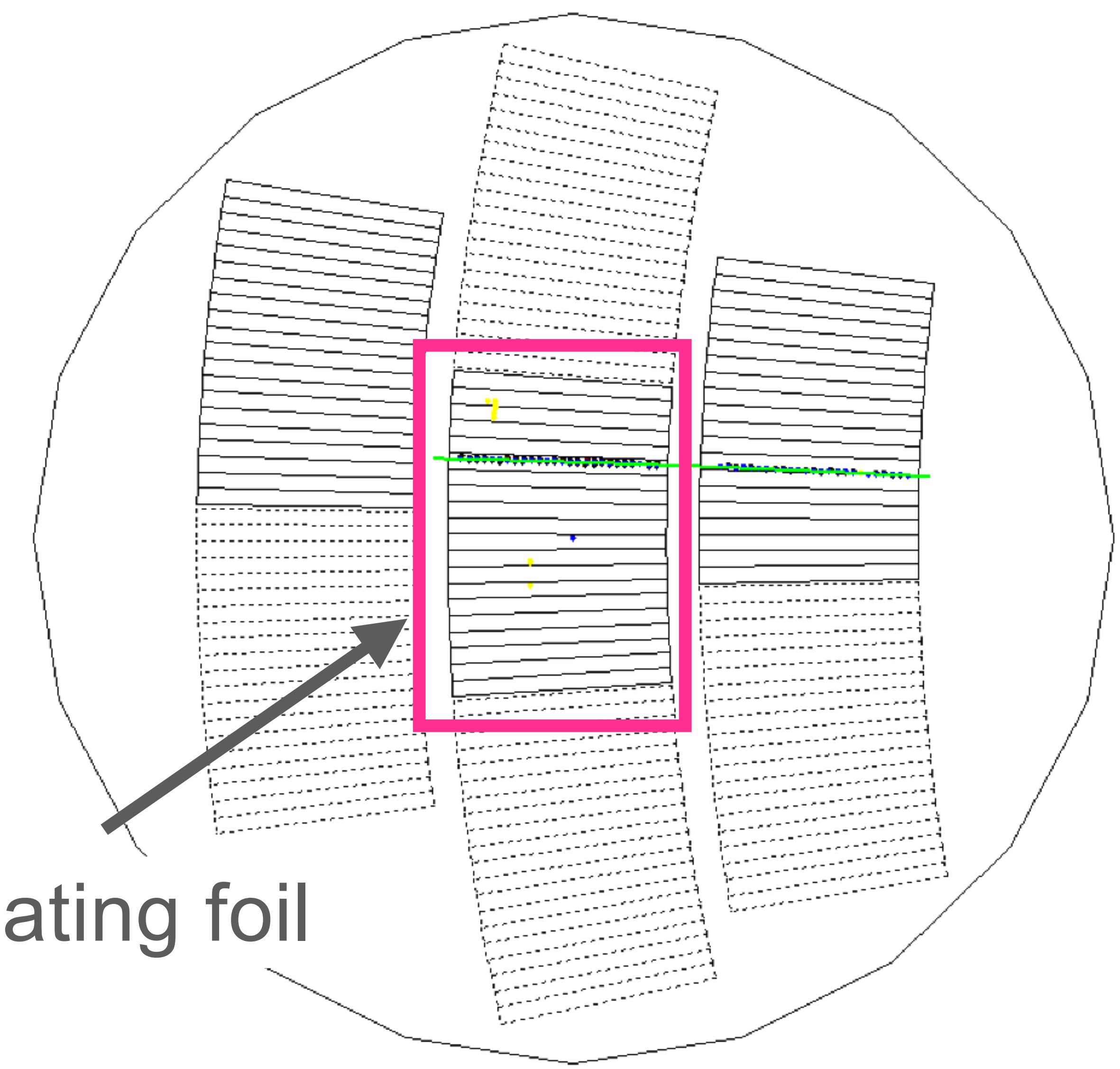
Typical event

3D view



Projection onto the rφ plane



Module with the gating foil

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

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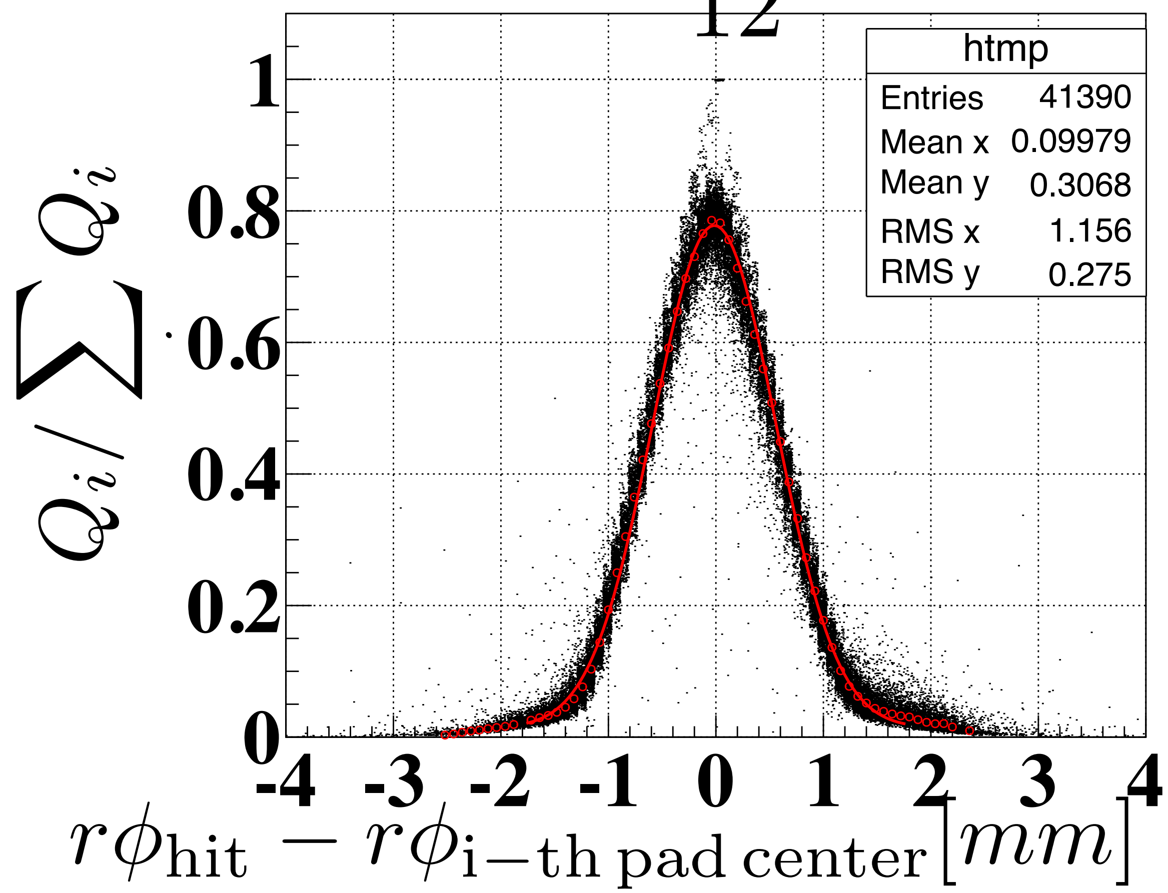
Pad responce（σ PR）

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