Study of spatial resolution in the z direction for ILC-TPC

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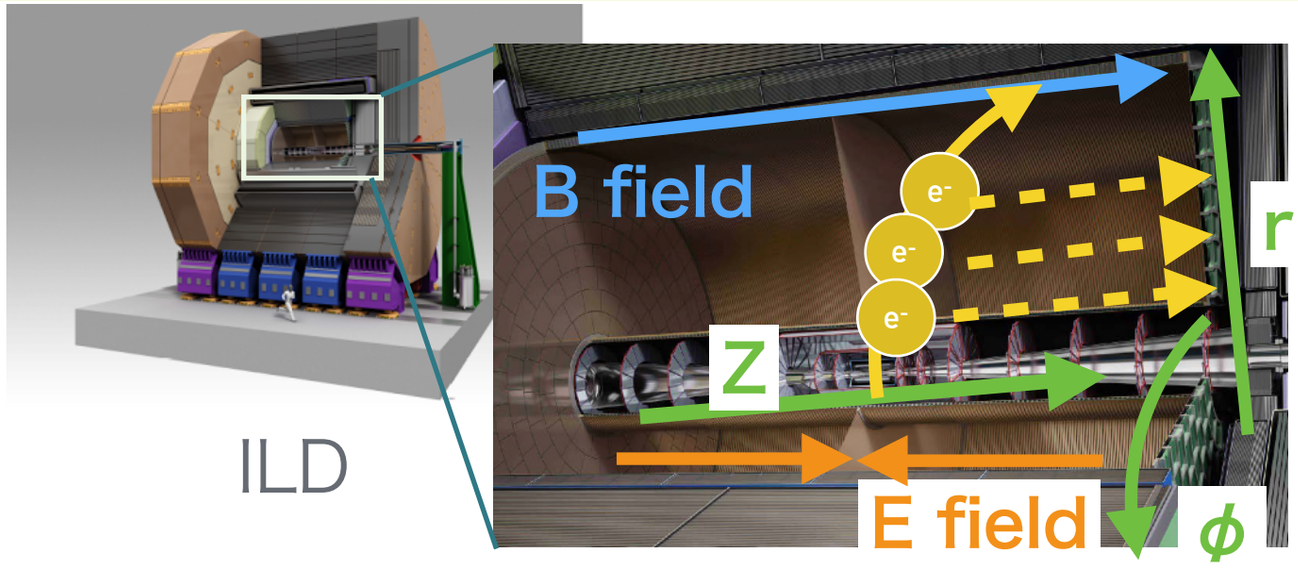
Introduction - TPC&Spatial Resolution

Time Projection Chamber

- Central tracker / gas detector
- Reconstruct 3D track position of charged particle



Recoil mass measurement is most important for precision Higgs study

→high **momentum** resolution is required

Determined by the **curvature of a charged particle track** in magnetic field

depends on the number of hit points and their **spatial resolution.**

The goal of momentum resolution (TPC only)

$$\sigma_{\frac{1}{P_T}} = 1 \times 10^{-4} GeV^{-1}$$

ILD-TPC Goal

200 hit points with

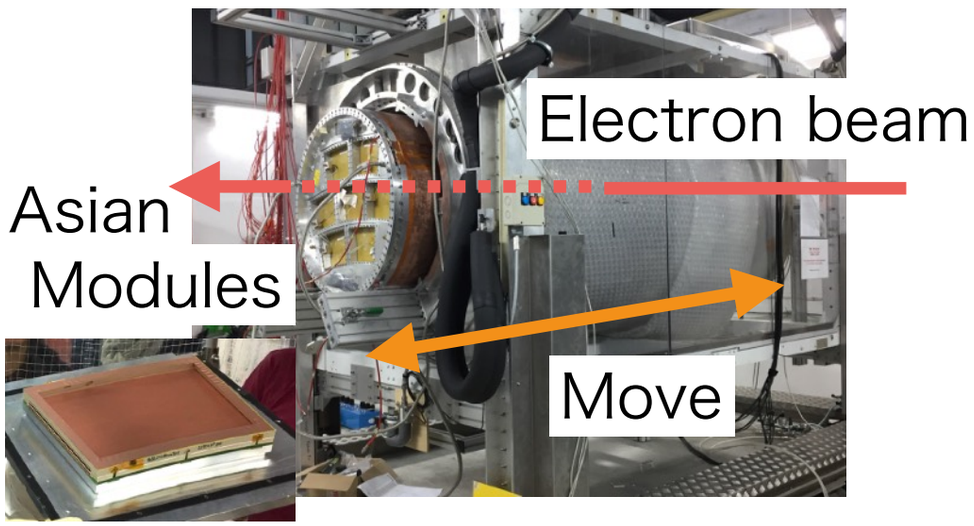
- $r\phi$ resolution : <100 μm
- Z (time) resolution : ~0.4 - 1.4 mm (for zero – full drift (2.3m)

Can we achieve rϕ resolution goal?

TPC Large Prototype

B field : 1 T

Drift length : 55 cm



Real-size TPC

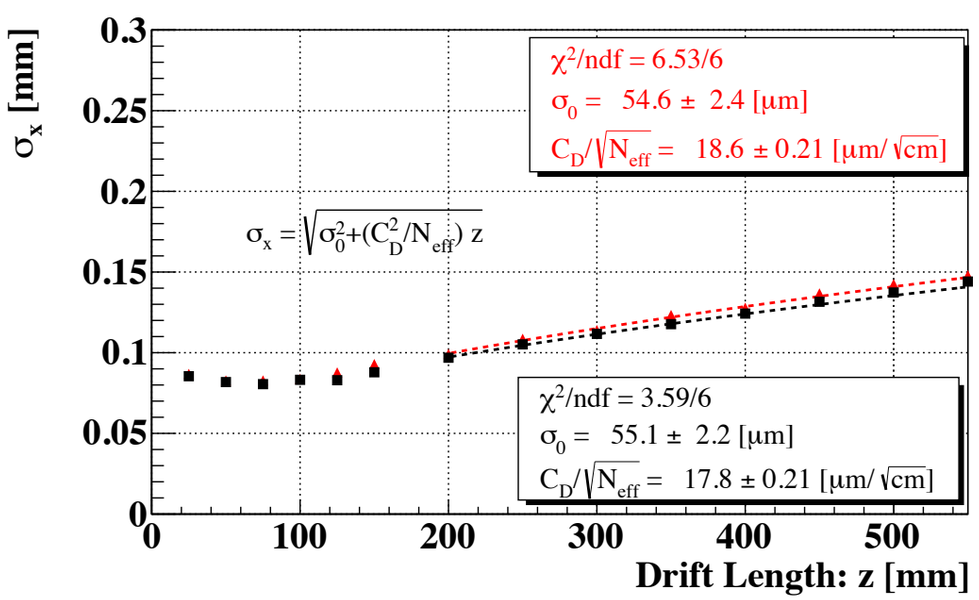
B field : 3.5 T

Drift length : 220 cm

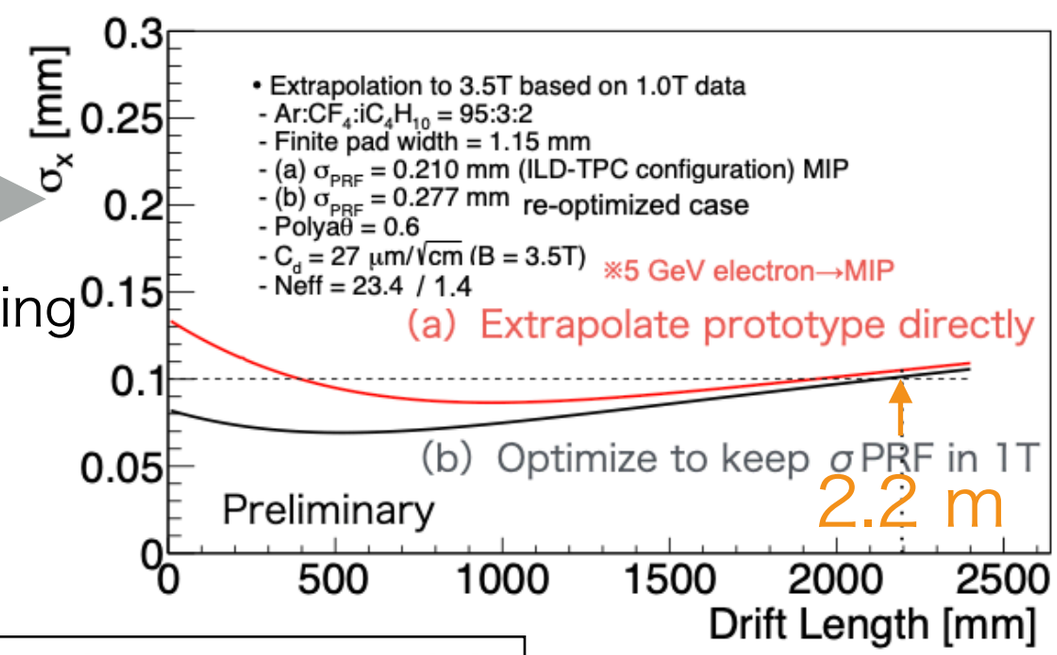
$$\sigma_{r\phi}(Z)^2 = \sigma_0(w)^2 + \frac{1}{N_{eff}} C_d(B)^2 \cdot Z$$

B field

Drift length



extrapolation using analytic formula



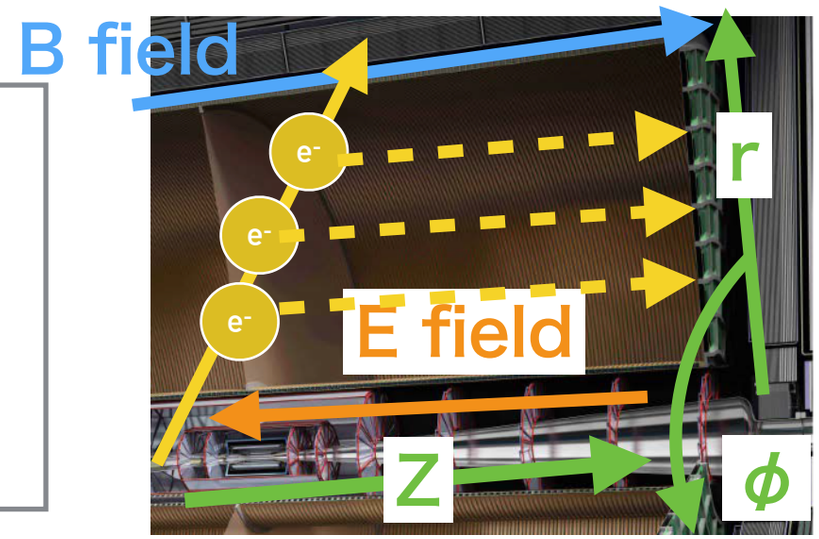
We can achieve the rϕ resolution goal !

Can we achieve z resolution goal?

So far, z resolution was thought to be independent of the magnetic field

rϕ direction

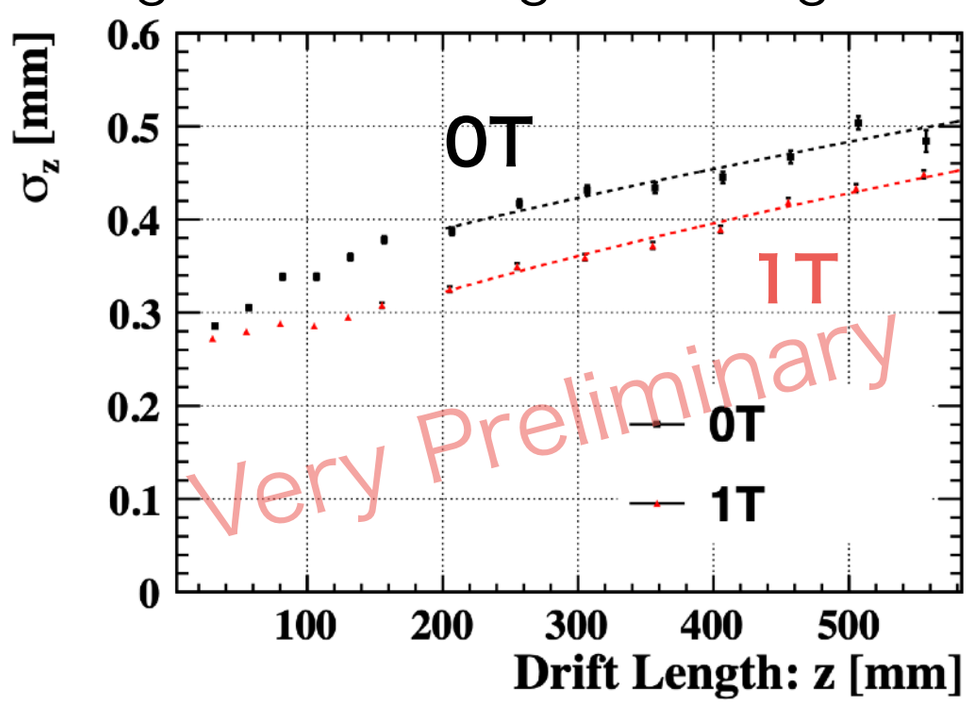
Electrons curling up
in a magnetic field
→Diffusion is suppressed



z direction

No effect of electrons
curling up
in a magnetic field

→Once the drift length dependence of the z resolution was measured for the large prototype, we thought that we could obtain the z resolution of the real TPC by curling up in the drift length even though the magnetic field would be increased to 3.5 T.



Significantly different !

~20%

Motivation of this study

Understand the magnetic field dependence of z resolution
→Check if the z resolution goal can be achieved with real-size TPC

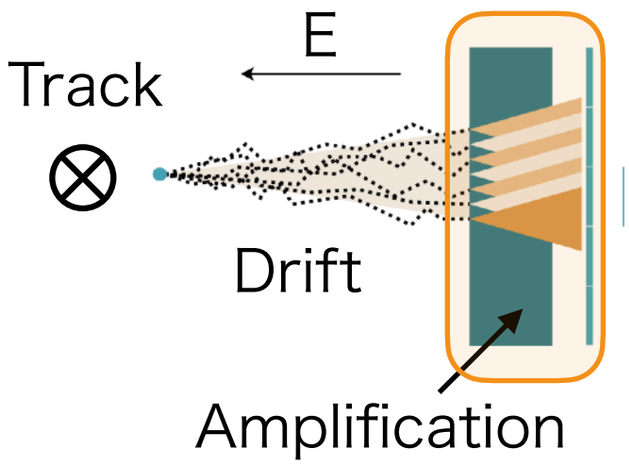
STEP 1 : What factors affect z resolution？
- How can we improve the analysis method of z resolution?

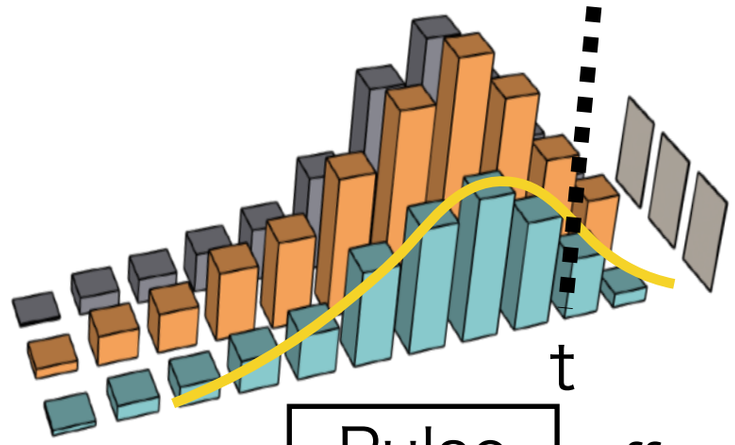
STEP 2 : Which factors are related to the magnetic field?

STEP 3 : Develop z resolution formula as a function of drift distance

→ It will then be possible to confirm whether the performance requirement of z-resolution <1.4 mm can be achieved on the real-size TPC (3.5 T, maximum drift distance 2.3 m.

z resolution & pulse





Z (time) position

The inflection point method

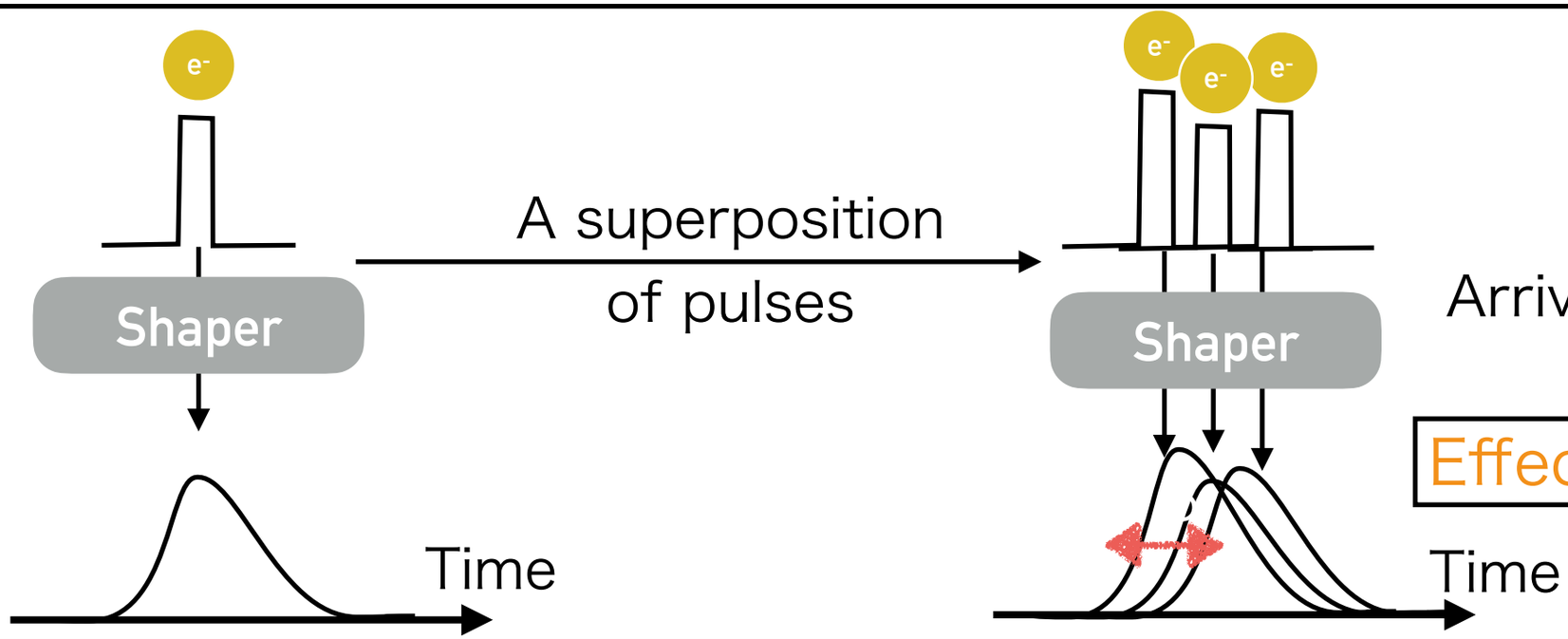
Drift velocity × Arrival time

Pulse affect the z-resolution !

What factors determine the pulse?

Assumption

<u>the average pulse shape</u> is determined only by the properties of the shaper and the longitudinal diffusion



Arrival time spread

Effect of diffusion

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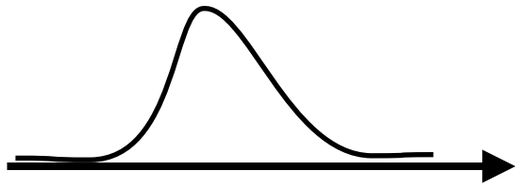
How to check pulse shape ?



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

n : shaper order , tpk : peaking time

Convolution

$\otimes$

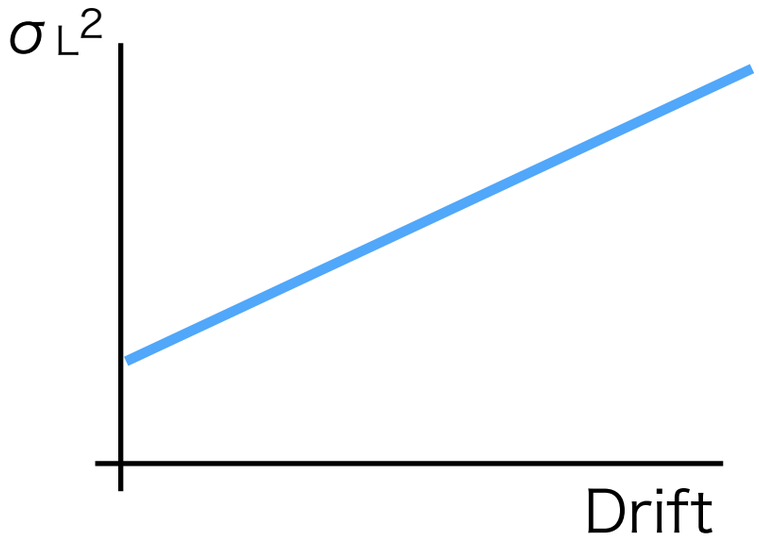
Gaussian smearing

due to the longitudinal diffusion

We can gat the "longitudinal diffusion" as a standard deviation : σ

If the assumptions are correct, the pulses in the beam test data could be fitted with this convolution function.

This smearing becomes larger as the drift distance increases



$$\sigma_L^2 = \sigma_0^2 + {C_{dL}}^2 \cdot z$$

Effect of finite time bin width

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

Diffusion constant is a parameter of the drift distance dependence of the diffusion in the drift region

Justification of the method for estimating C_{dL}

I checked if I could calculate C_{dL} properly using this method

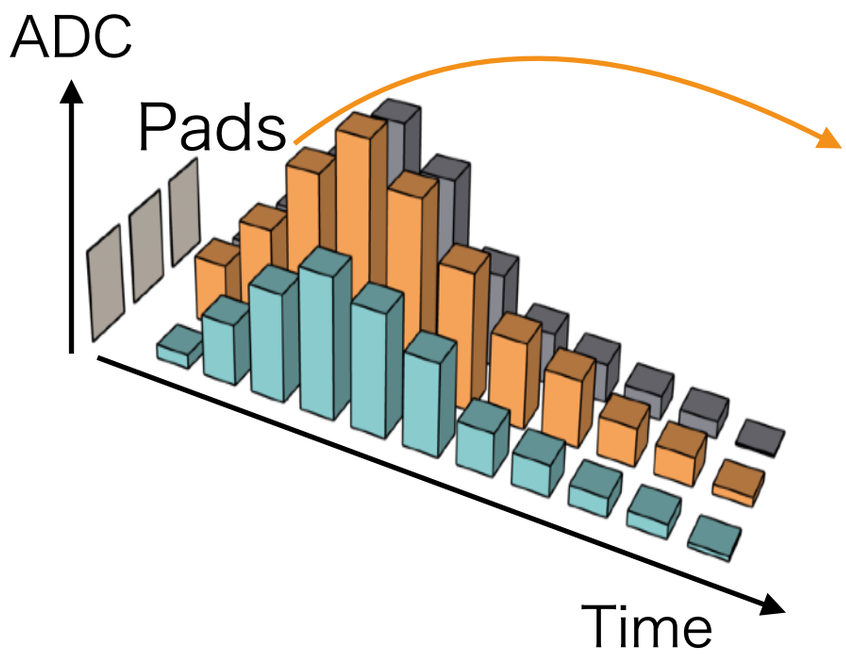
①Make pule by simulator

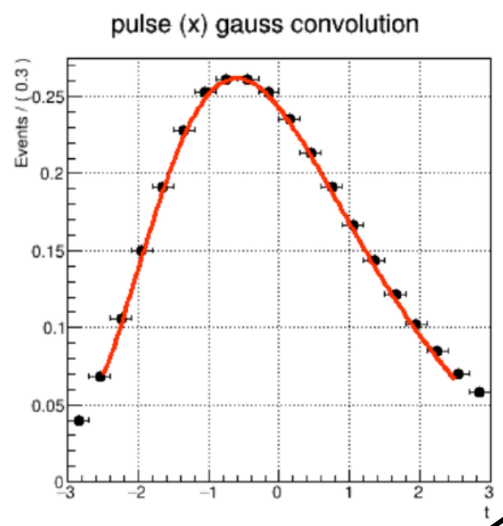
Input : C_{dL} =220 μm/√cm

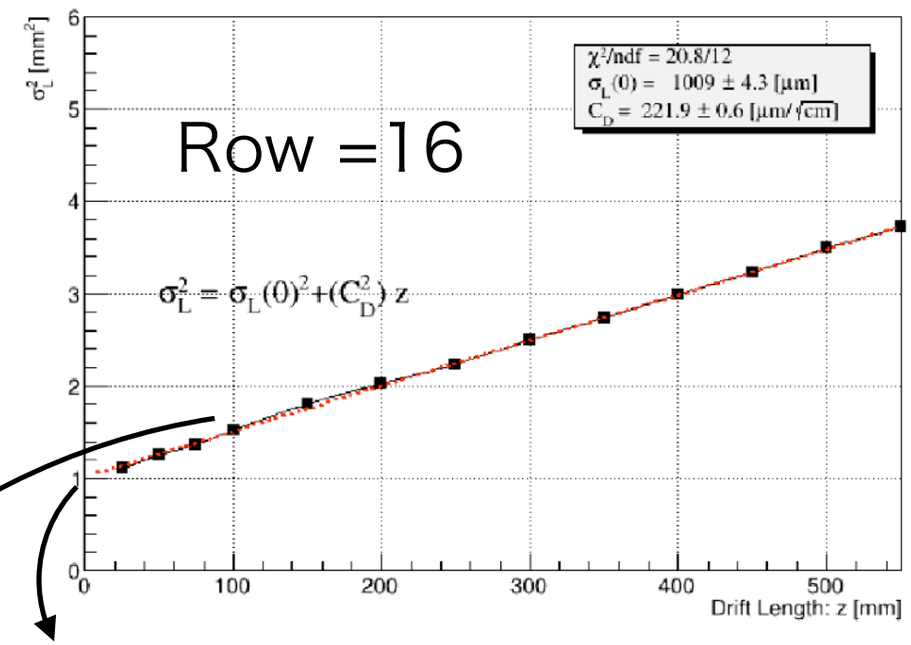
②convolution fit

n=3, tpk = 120ns

③Plot (standard deviation)^2 as a function of drift length







Result $C_{dL} \approx$ 221.9 μm/√cm

Consistent with input

√intercept $\sigma_L(0) \approx$ 1.0 mm

$$\frac{\overset{75\mu m/ns}{\text{Drift velocrty}} \times \overset{50ns}{\text{time bin}}}{\sqrt{12}} = 1.08 \text{ mm}$$

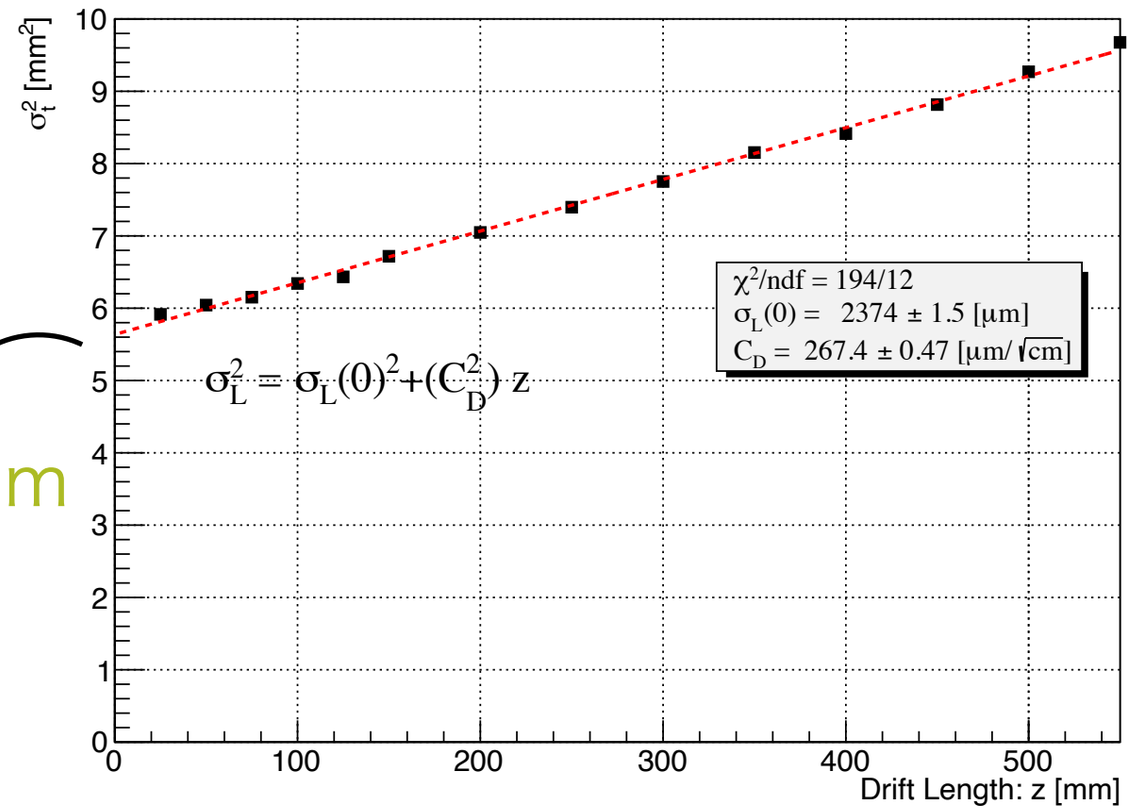
Consistent

This method works for simulation data

C_{dL} of test beam data

By using convolution method, we calculated C_{dL} of test beam data

Input : n = 3 , tpk =120 ns Row = 16



√intercept

$\sigma L(0) \approx 2.37$ mm

$C_{dL} \approx 267.4$ um/√cm

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

The assumption that the pulse shape is only determined by the shaper properties and longitudinal diffusion is NOT reasonable

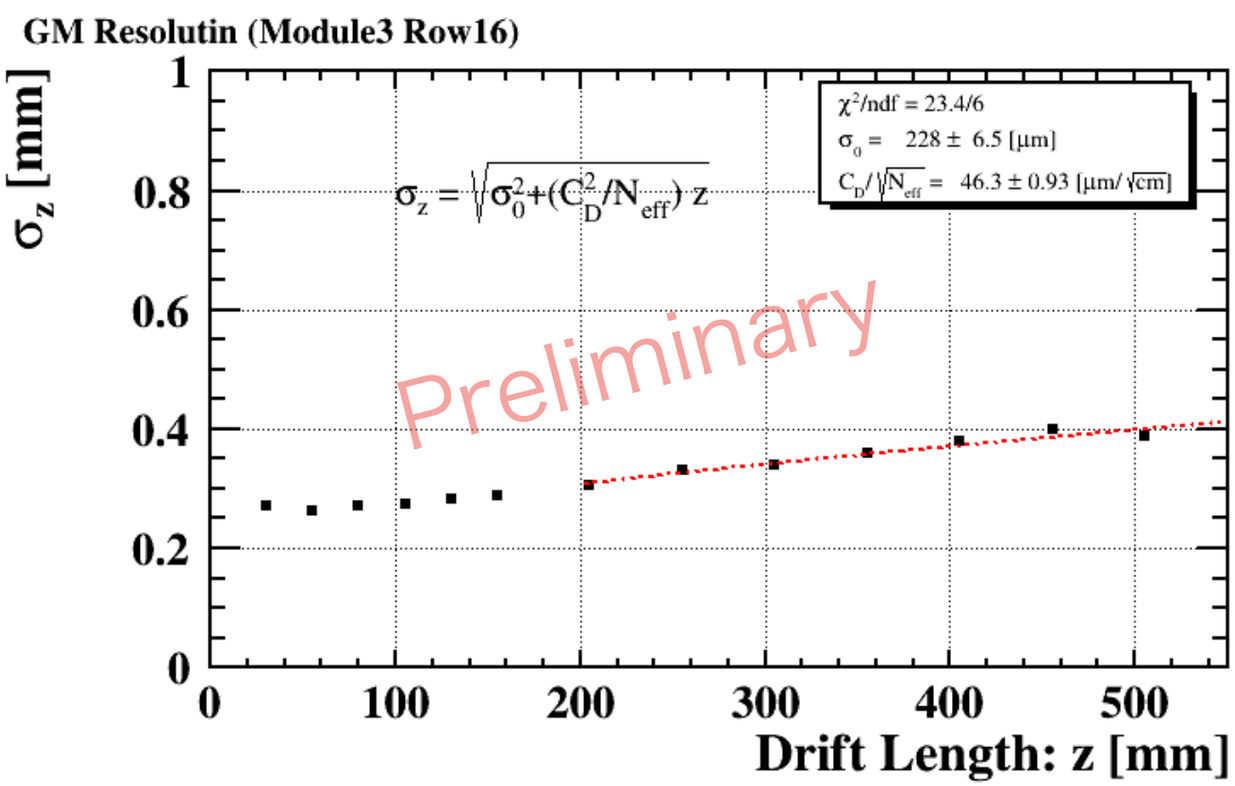
There are smearing effects other than the diffusion in the drift region

Simulation & another estimation

Garfield++ Simulation

	1 T	0 T
Temperature[K]	291.28	291.11
Pressure[hPa]	1010.79	1007.29
$C_{dL}[\mu m/\sqrt{cm}]$	$226.1 \pm 1.54\%$	$224.4 \pm 2.64\%$

If we assume that N_{eff} is the same as in the rϕ resolution at same time, we can also estimate CdL from the analysis of z resolution



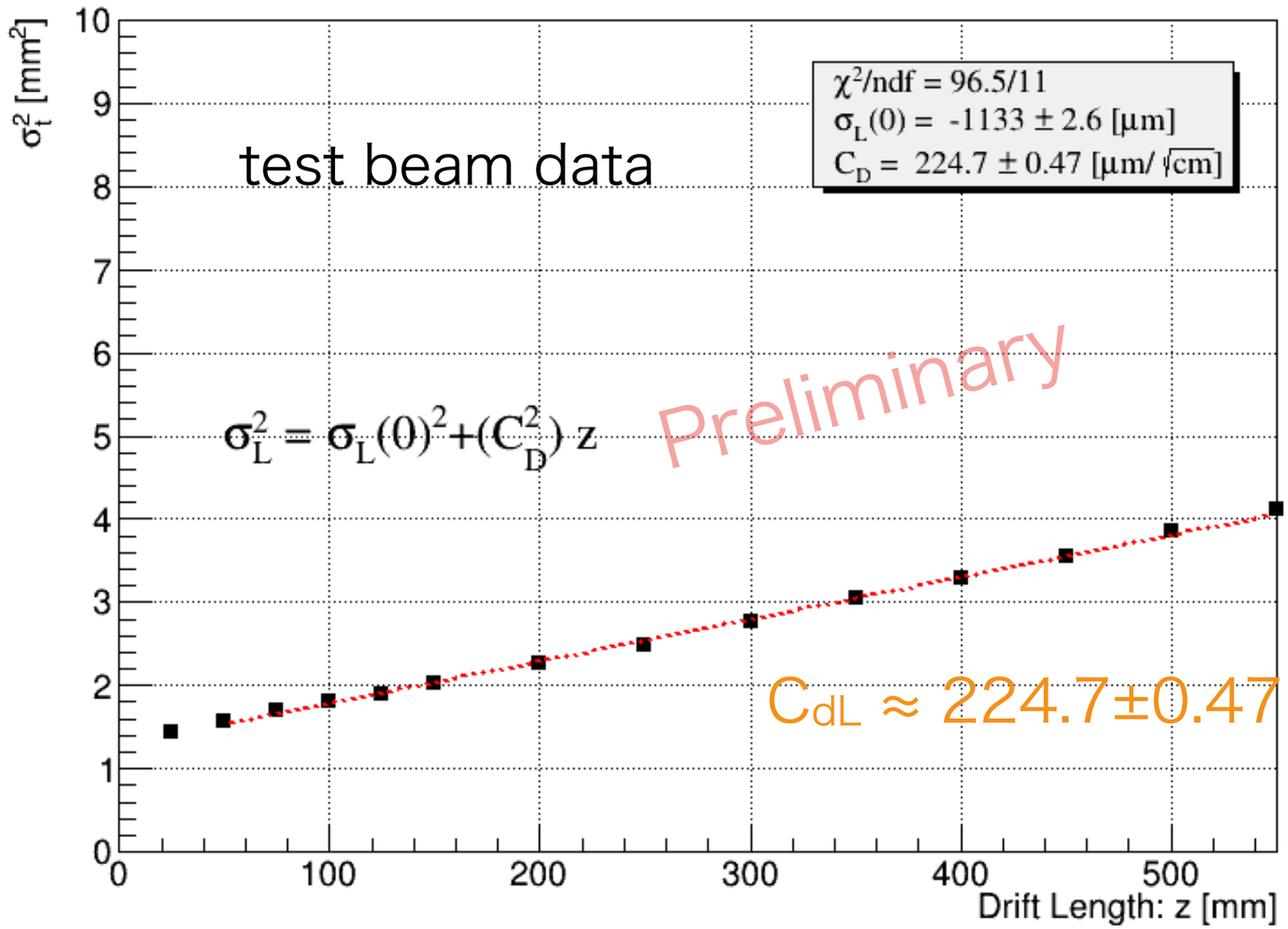
N_{eff}=23.9±0.7 (From rϕ analysis)

C_{dL}/N_{eff} = 46.3±0.93 μm/√cm

C_{dL} = 226.3±5.6 μm/√cm

Adjusting tpk

Input : n = 3 , tpk =135 ns, Row = 16 (Specification sheet: tpk =120)



$C_{dL} \approx 224.7 \pm 0.47$ um/√cm

Garfield++: C_{dL} = 226±1.5%

This method of C_{dL} estimation is rather sensitive to the input shaper parameters

What are the possible smearing effects?

Future plans

Is the pulse shape really according to theory?

・Shaper parameter n=3, tpk = 120ns are from specification sheet

→ We are planning to measure pulse shape directory

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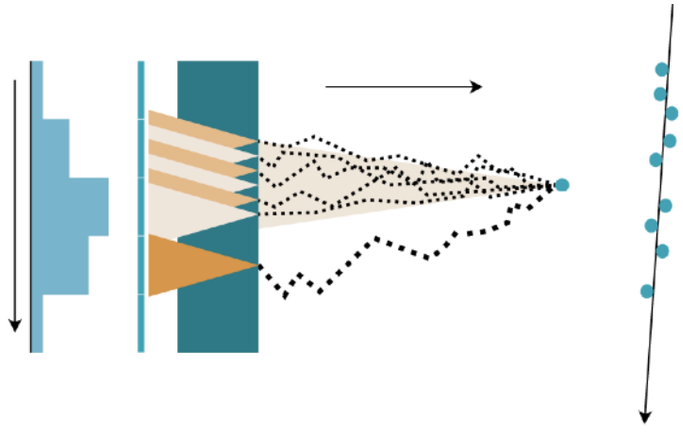
What are the possible smearing effects?

Future plans

There are at least 2 candidates



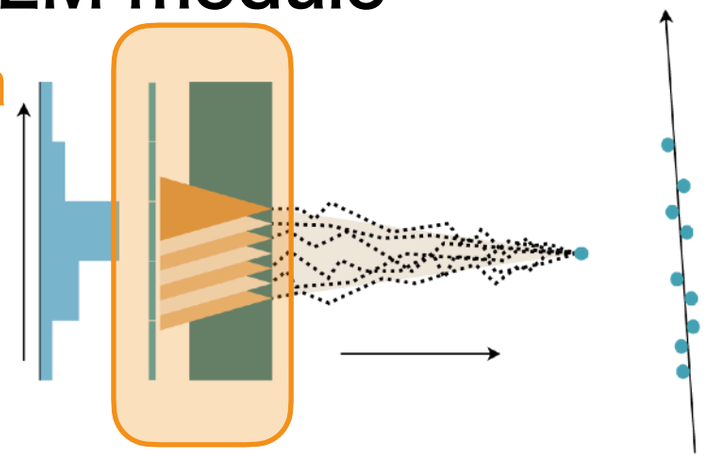
(A)**Distortion of isochron**

The drift line may be distorted
by the deformation of the GEM foil, the electrode gap, etc...
In this case, the magnetic field causes the distortion of drift line due to ExB.

→ Approach from beam test analysis

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

Currently, diffusion effects in the amplified region are not taken into account in our simulation.
This can be estimated since the size and electric field of each region in the GEM module are known.



→ Approach from simulator improvement

Conclusion

In the TPC of ILD, achieving a high position resolution is essential for precision Higgs measurements.

To check if the performance goals can be achieved with Real-size TPC, we started studying magnetic field dependence of z resolution

Comparison of beam test results with simulations shows that the assumption that the shape of the pulse is determined only by the shaper properties and longitudinal diffusion is not appropriate

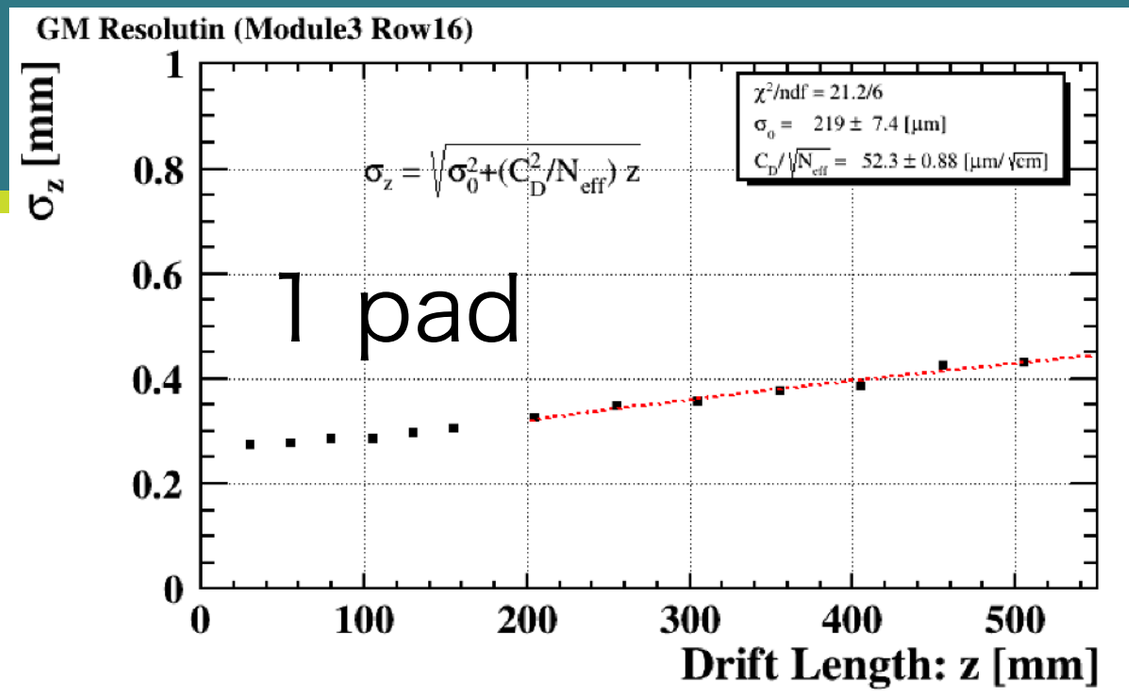
We found that there are some unknown effects which widen the resolution by 2 mm

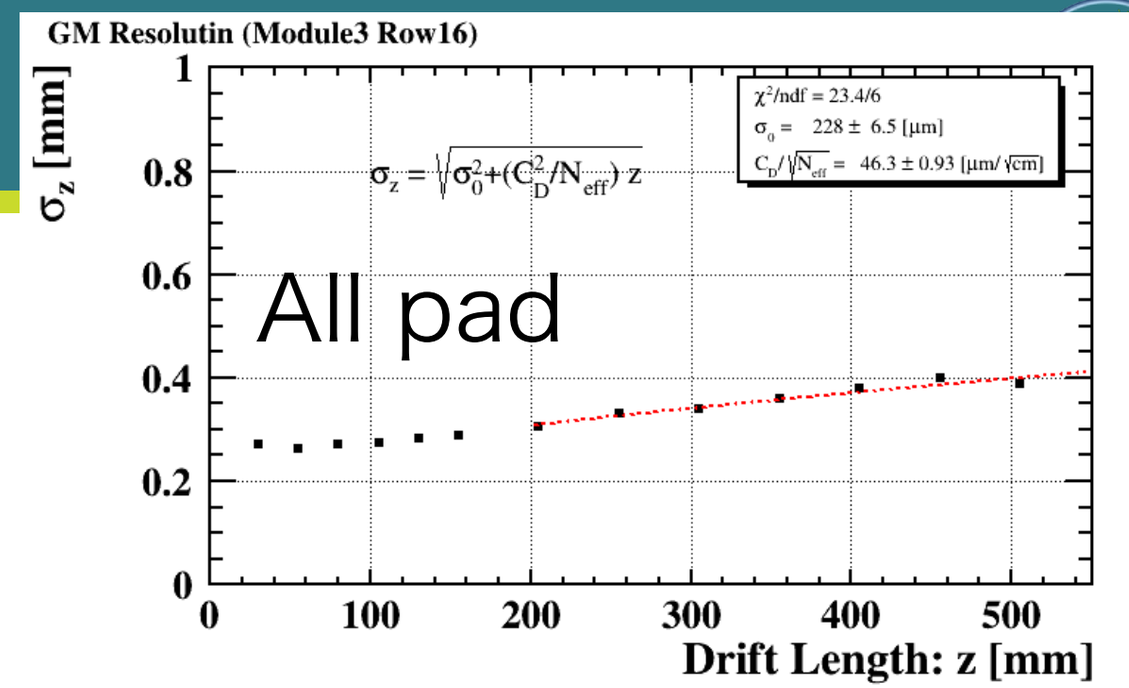
Future work

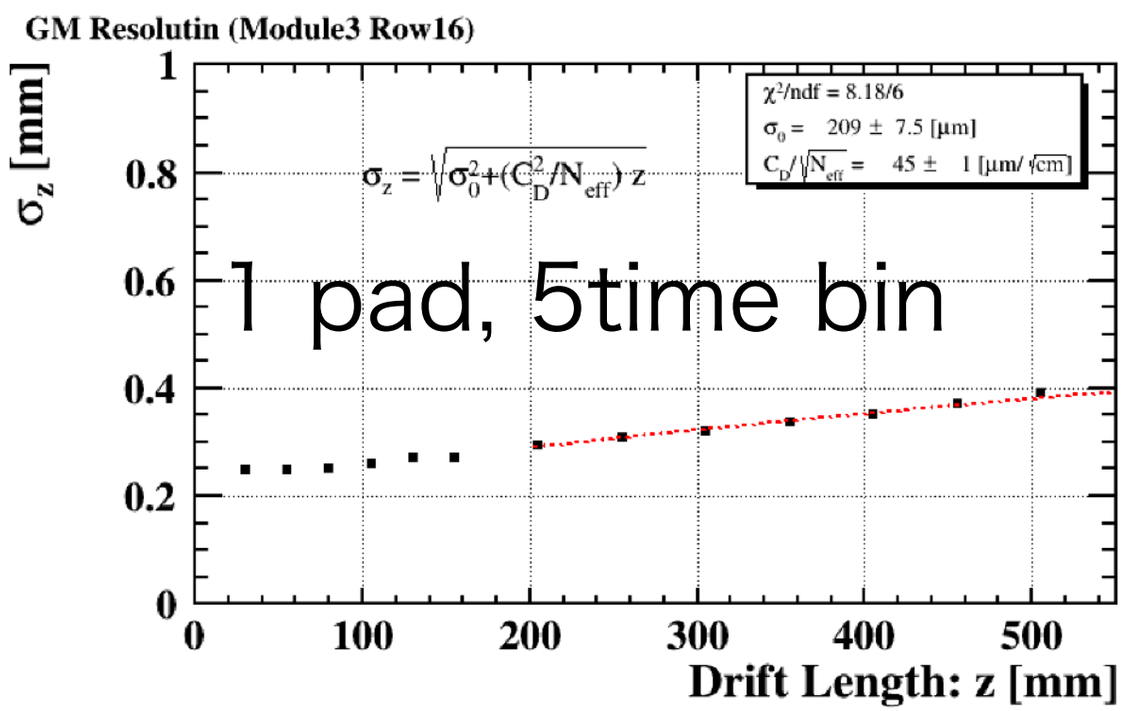
Identify what effect is widening the position in the z direction

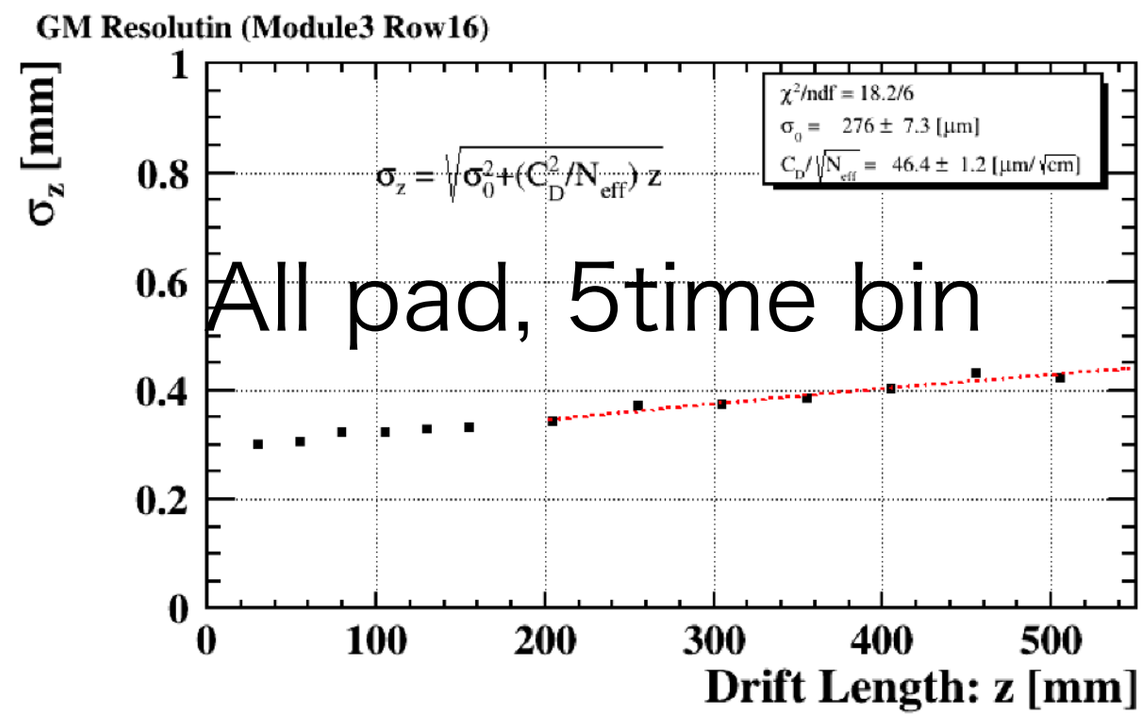
- Estimate the effect of distortion of isochron
- Simulator improvement

Backup









	$C_{dL}/N_{eff}[\mu m/\sqrt{cm}]$	$C_{dL}[\mu m/\sqrt{cm}]$
Inflection point(1 pad)	52.3 ± 0.88	255.7 ± 5.7
Inflection point (All pads)	46.3 ± 0.93	226.3 ± 5.6
C.O.G (1pad, 5 time bins)	44.2 ± 1.3	216.1 ± 7.1
C.O.G (All pads, 5 time bins)	46.4 ± 1.2	226.8 ± 6.7

Unipolar Signal Shaping

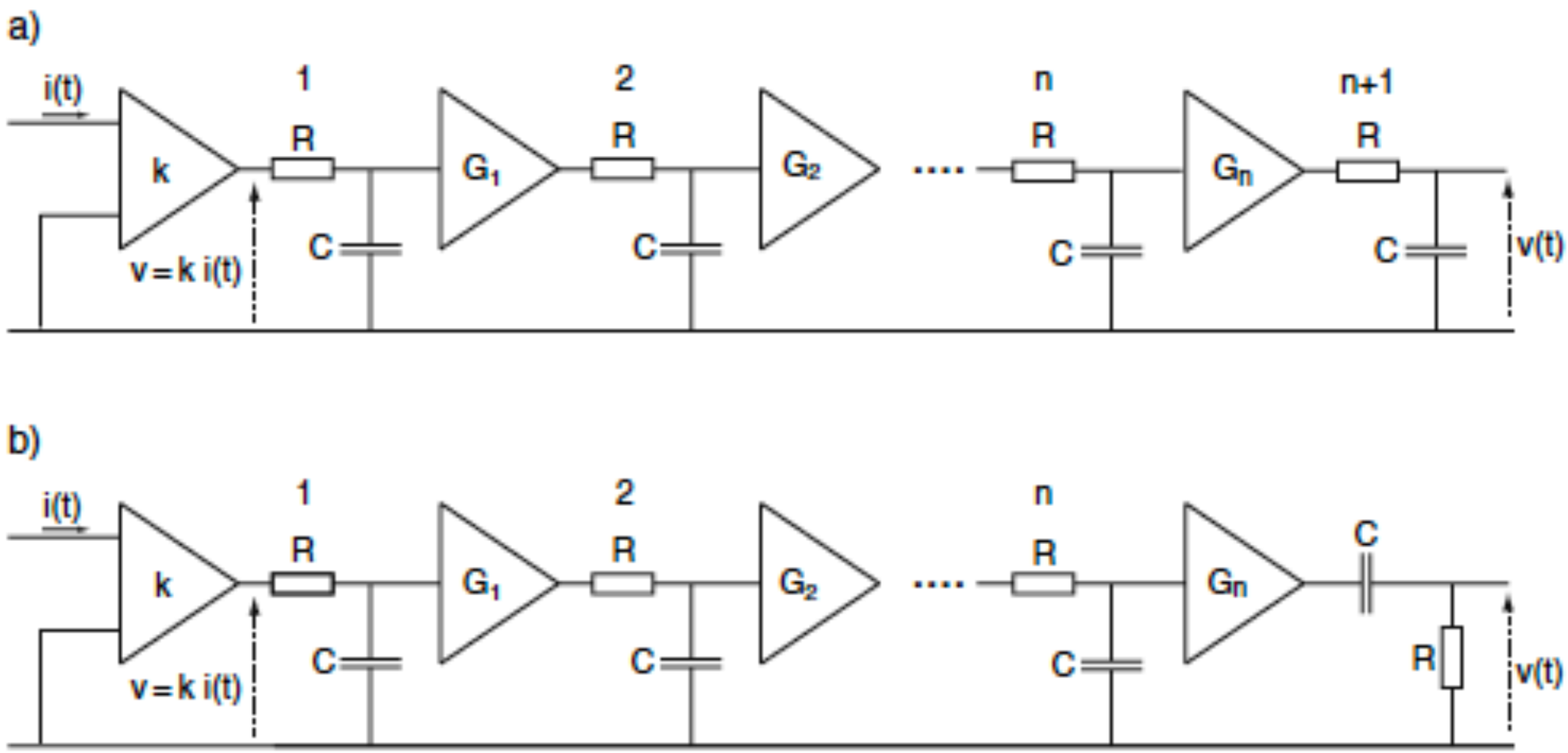
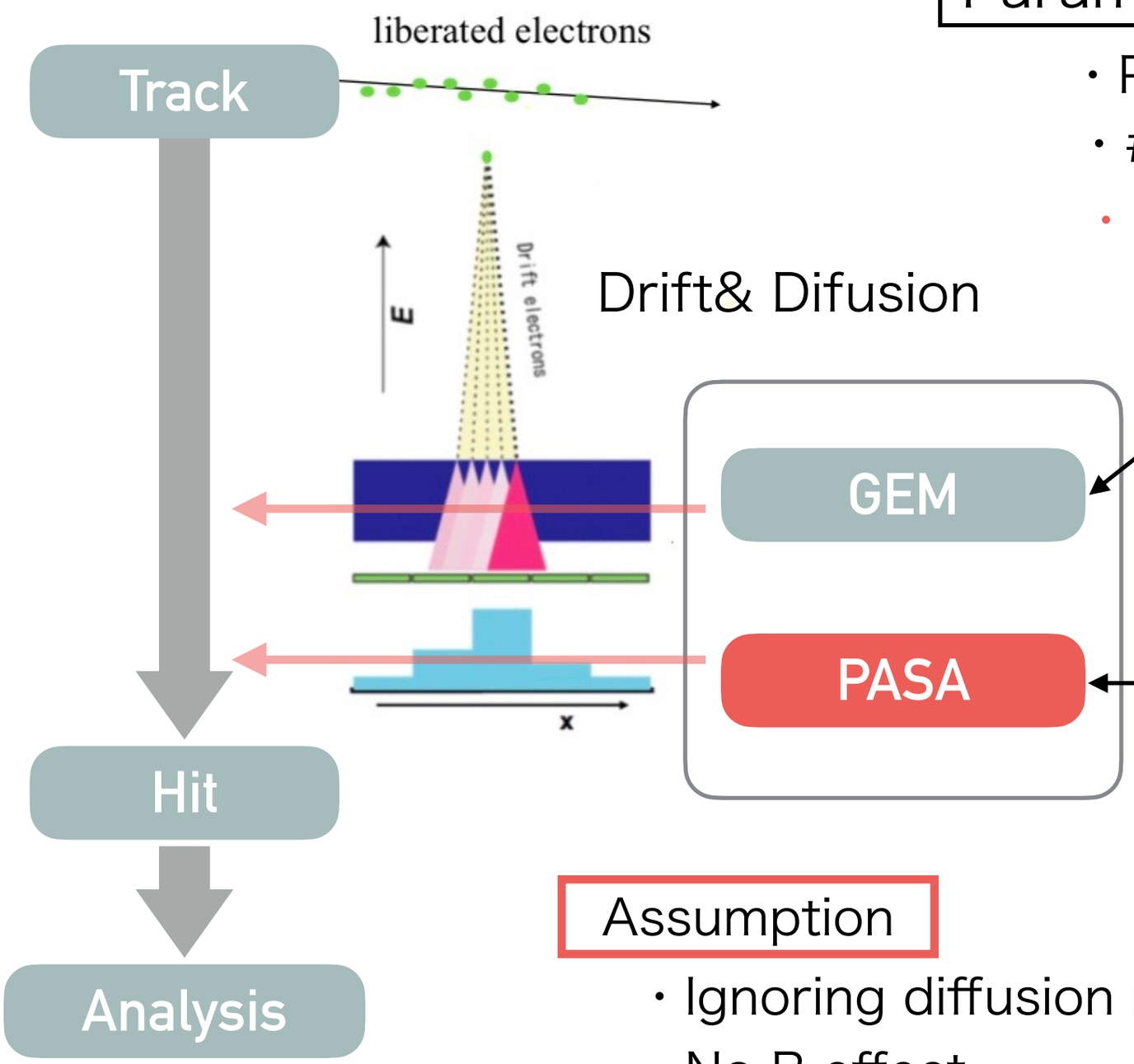


Fig. 6.13 (**a**) Unipolar shaping circuit consisting of $n+1$ identical RC filters which are separated by ideal voltage buffers. (**b**) Bipolar shaping circuit consisting of n identical RC filters and a single CR filter with the same time constant

TPC simulator



Drift& Difusion

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

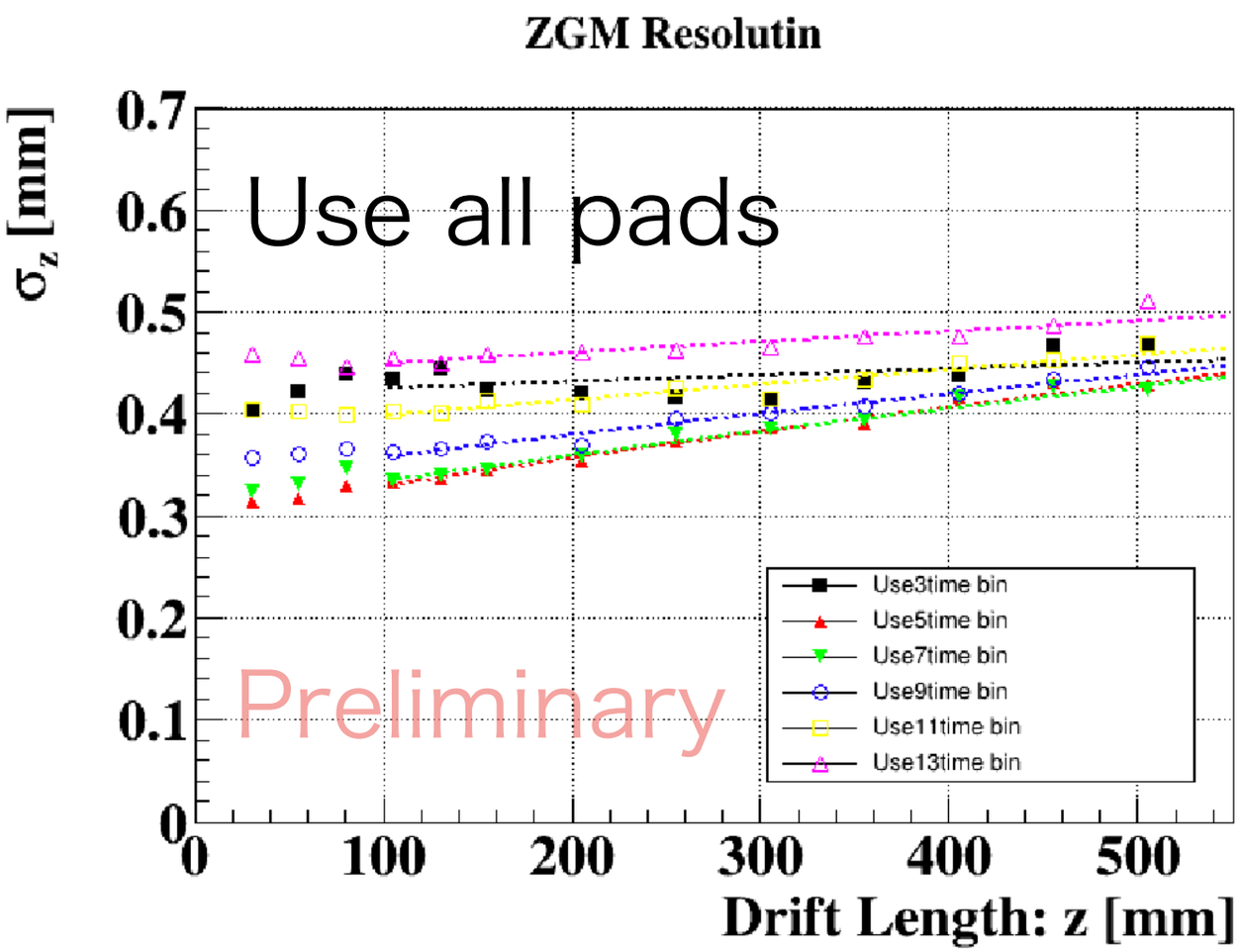
Assumption

- Ignoring diffusion in amplification region
- No B effect

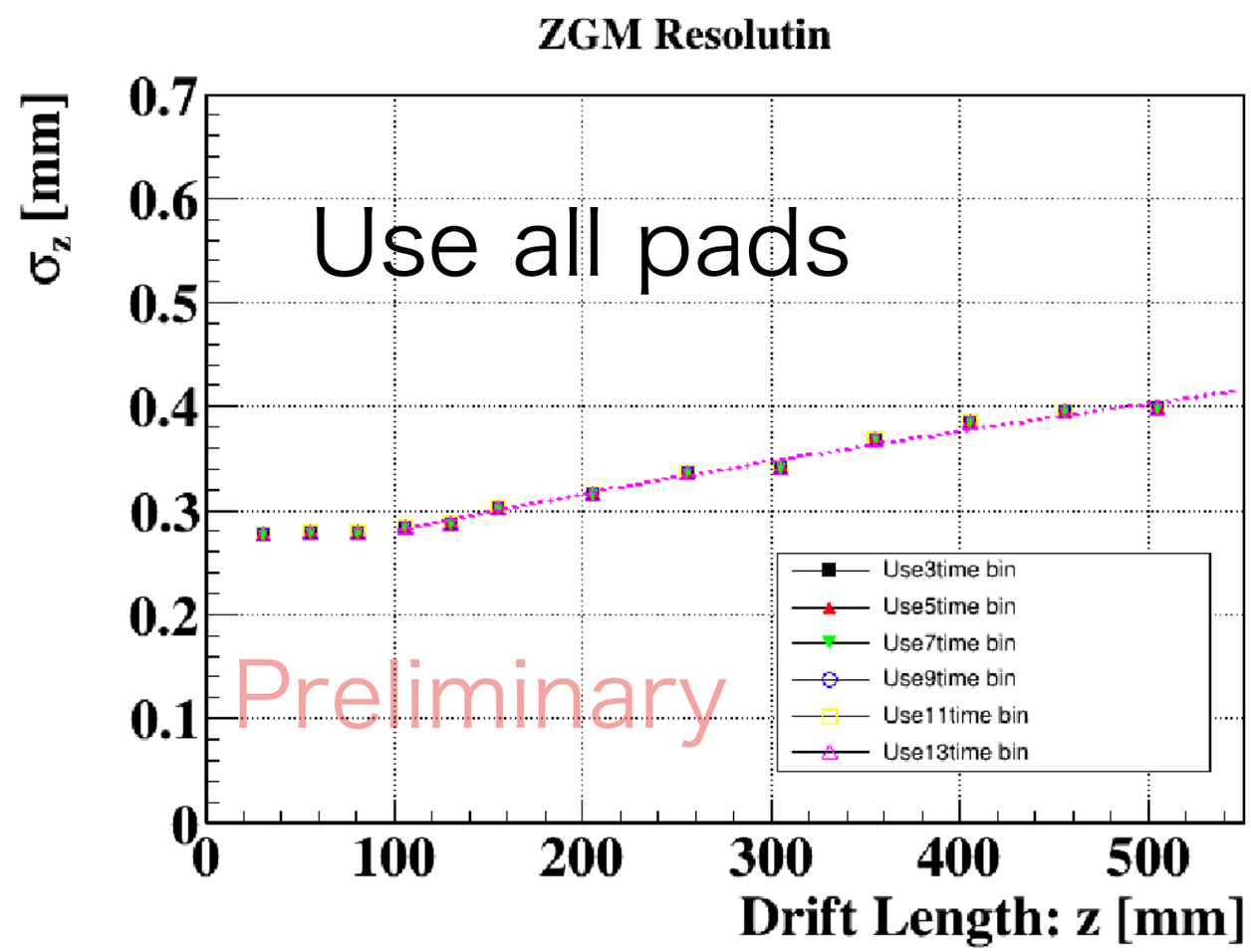
※ I use a pad having largest charge in the row

Comparison by # of time bins

Center of gravity



Inflection point



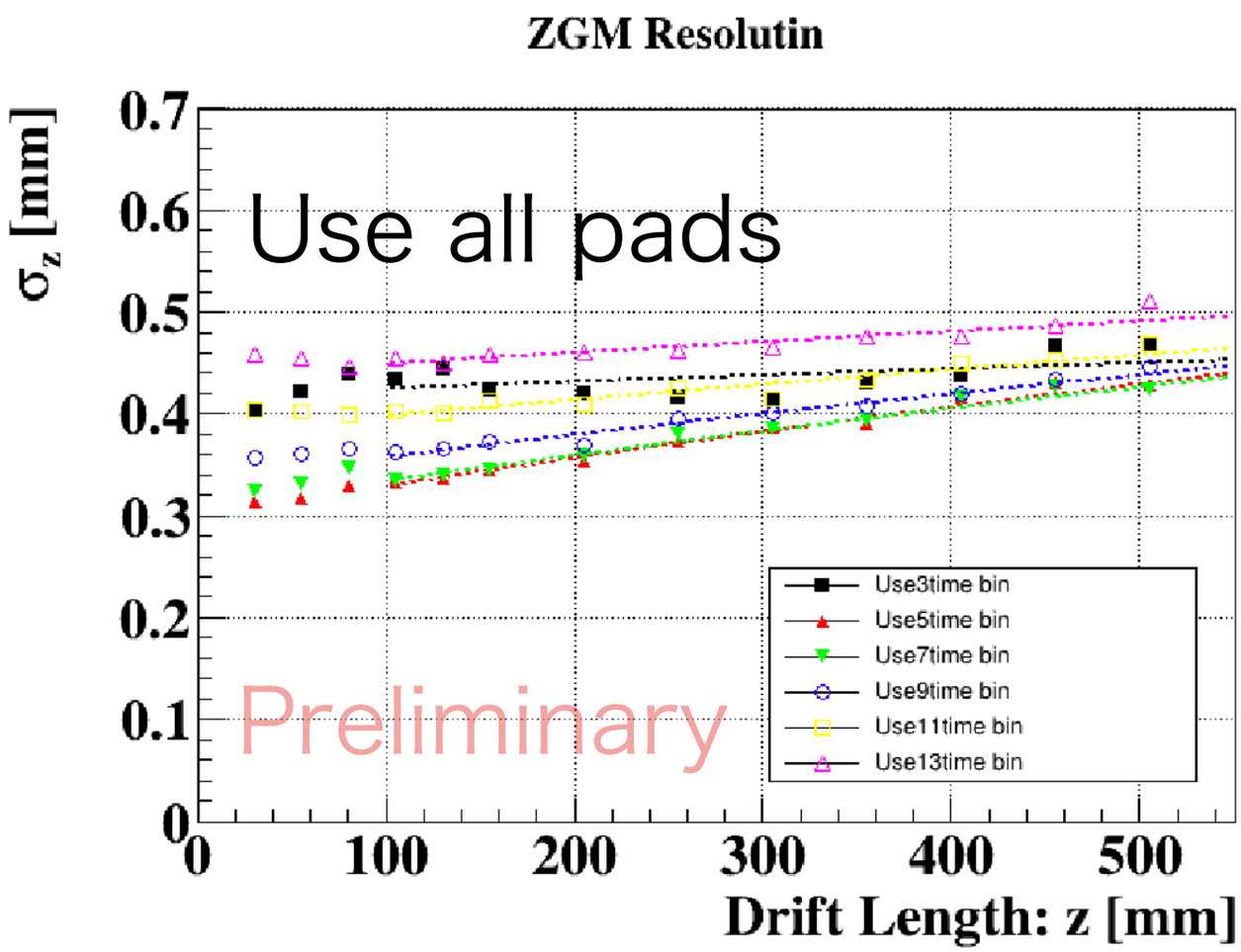
In the case of C.O.G, when we use 5 time bins, the time resolutions is the best.

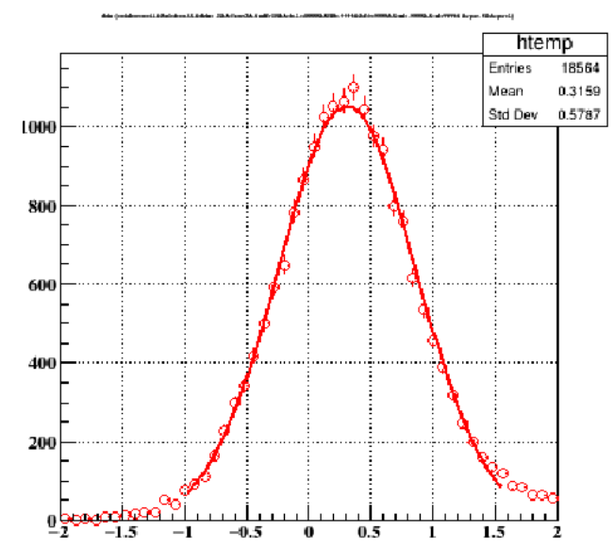
Since inflection point method only use former part of pulse,
resolution is not affected by # of time bins using time calculation.

C.O.G by # of time bins

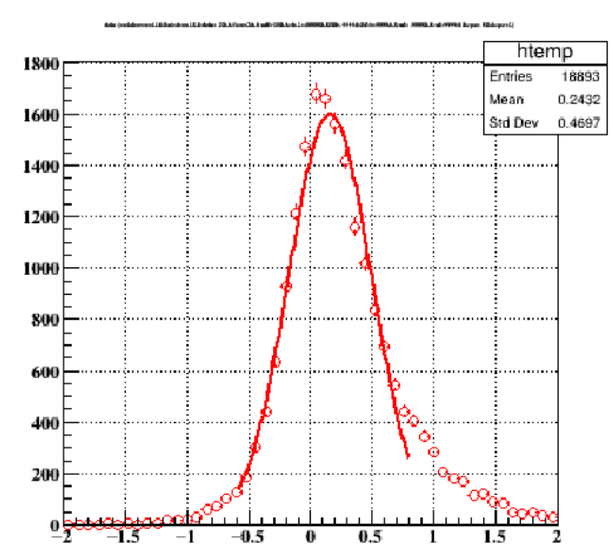
Drift length ≈ 15cm

Center of gravity



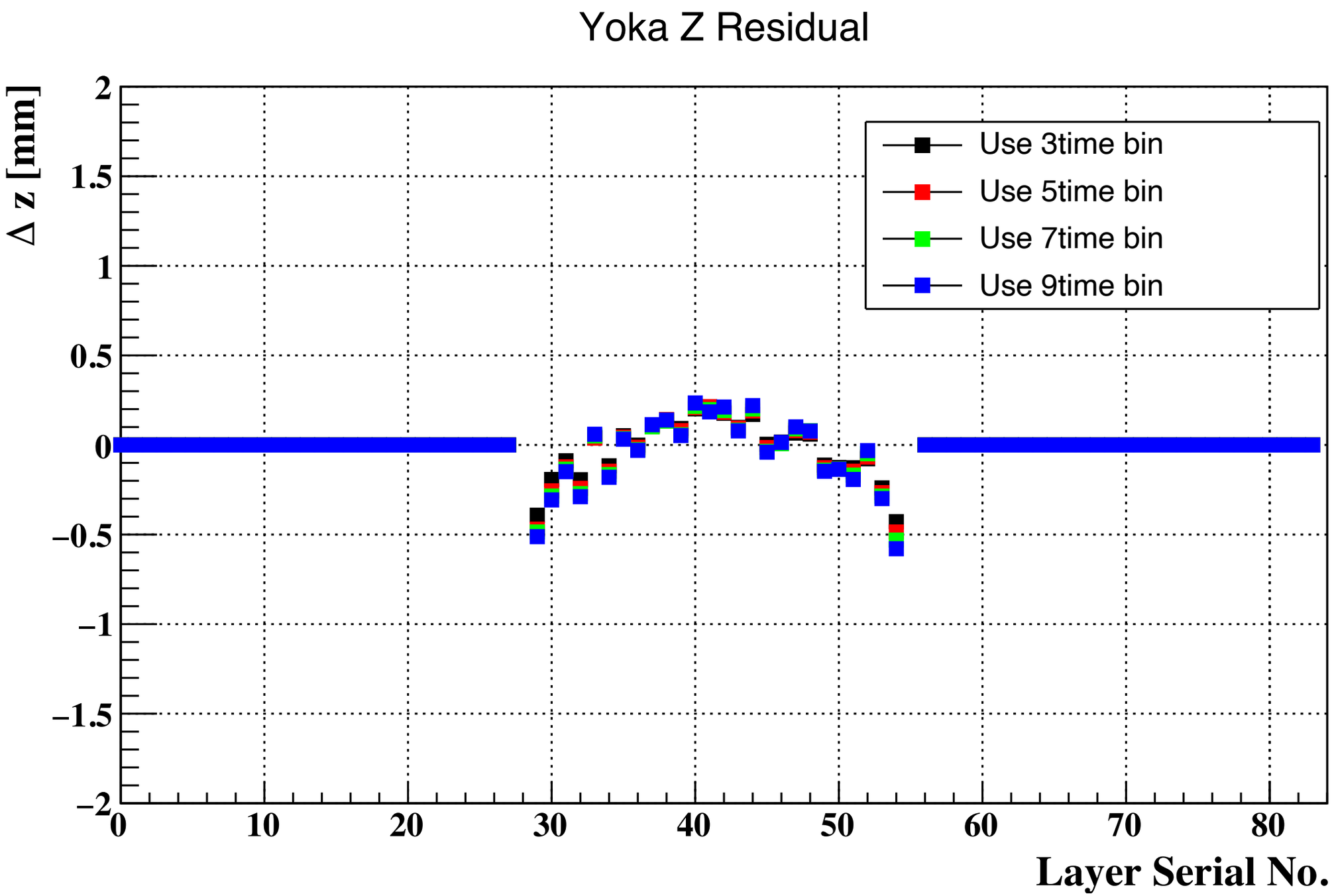


Use 17 time bins



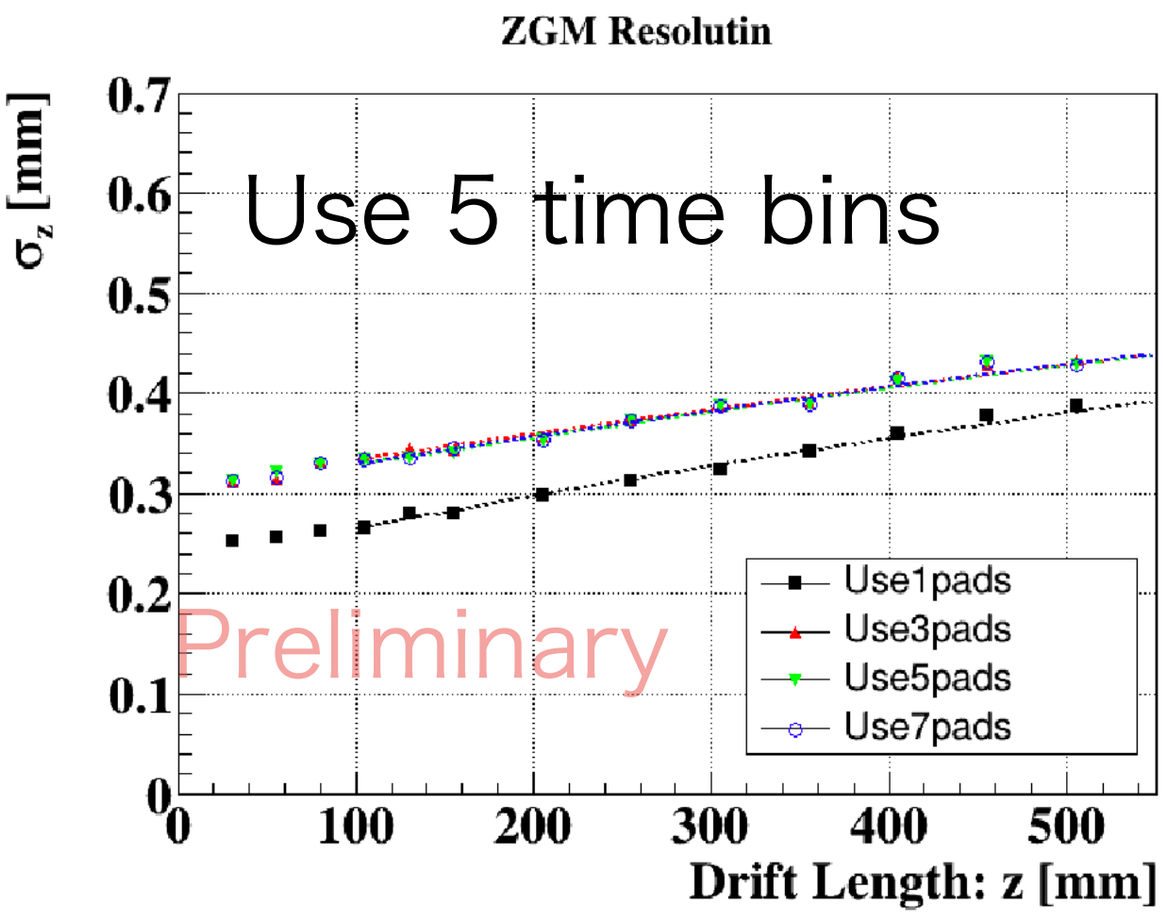
Use 5 time bins

Comparison Z residual by # of time bins

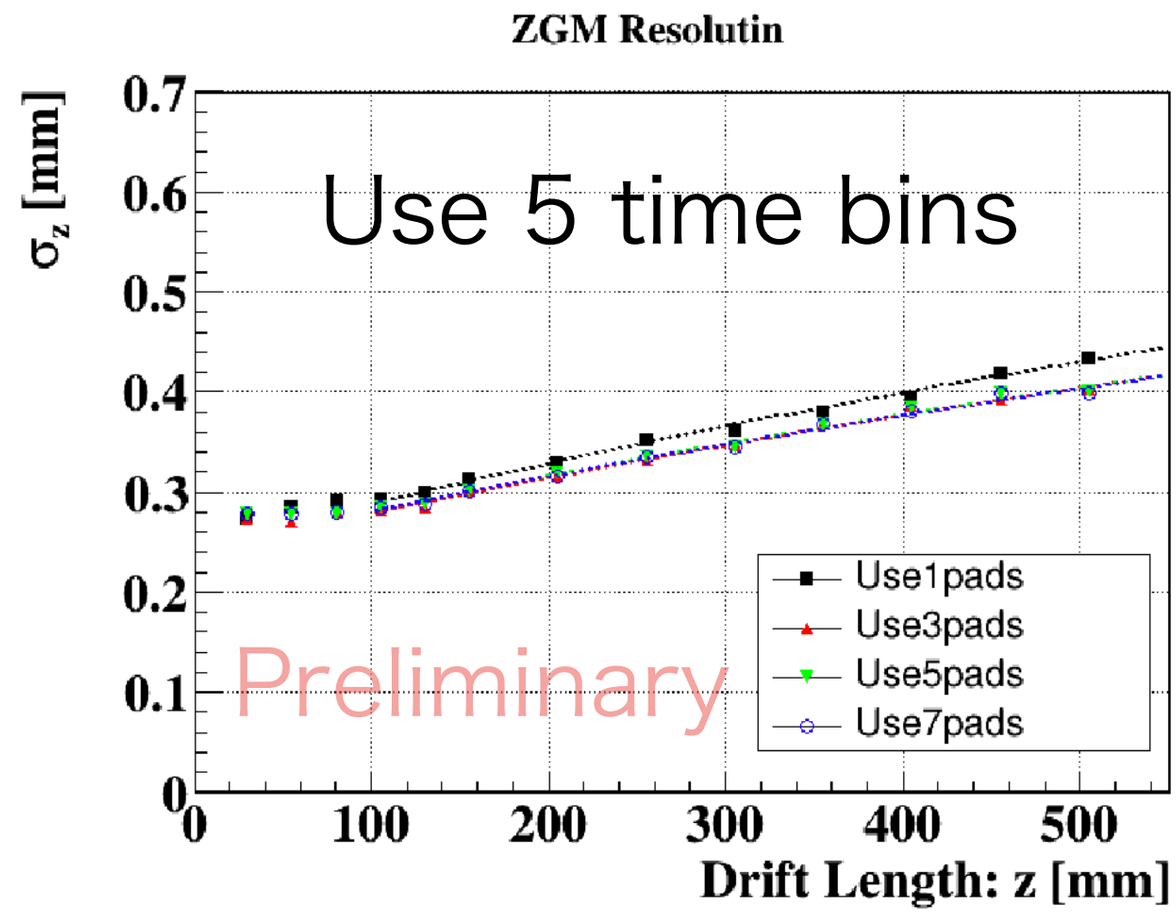


Comparison by # of pads

Center of gravity



Inflection point



Marlin framework

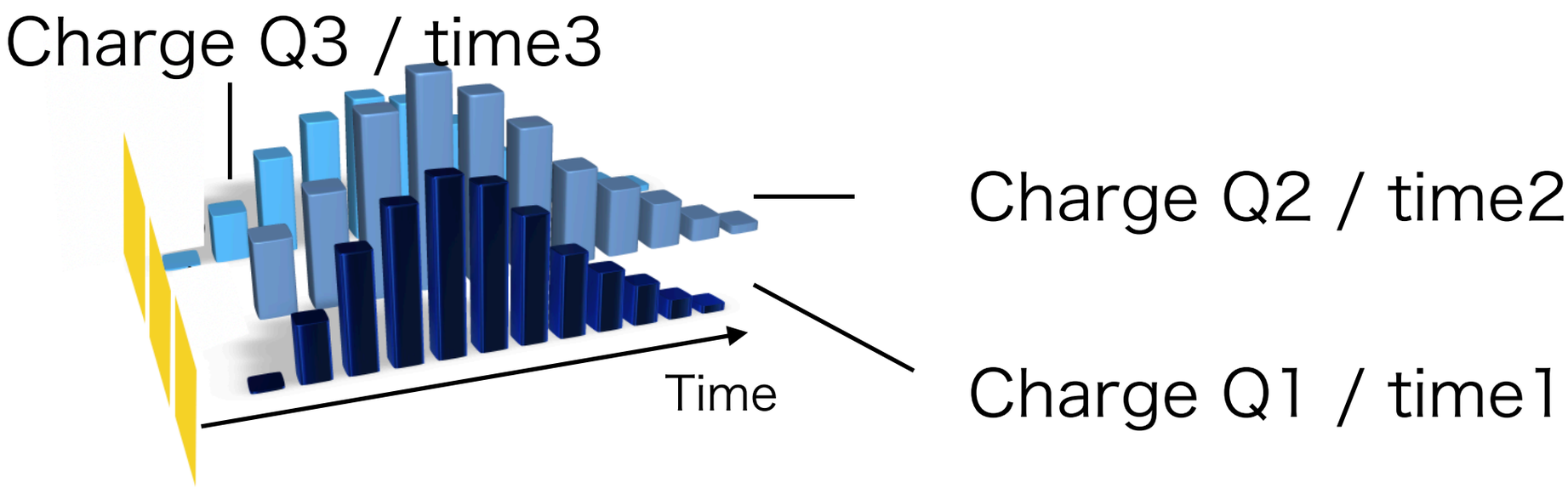
Both behave differently only when only one pad is used.

How to gather pads?

We used to use 1 pad which having maximum charge

→To use all information, we consider to use all pads

How to gather all pads?



$$\frac{1}{\sum_i Q_i} \sum_i Q_i \times time_i$$

Add pulse time weighted by charge