Simulation of Cylindrical Drift Chamber Detector Response in COMET Phase-I

2022 Aoki & Yamanaka Lab. Year End Workshop

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Contents

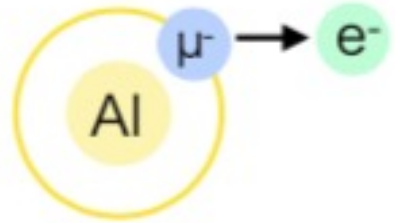
- Introduction
- Cylindrical Drift Chamber (CDC) Detector Response
- Ionization & Drift
- Electronic response
- Summary

COMET Phase-I Experiment

Search for:

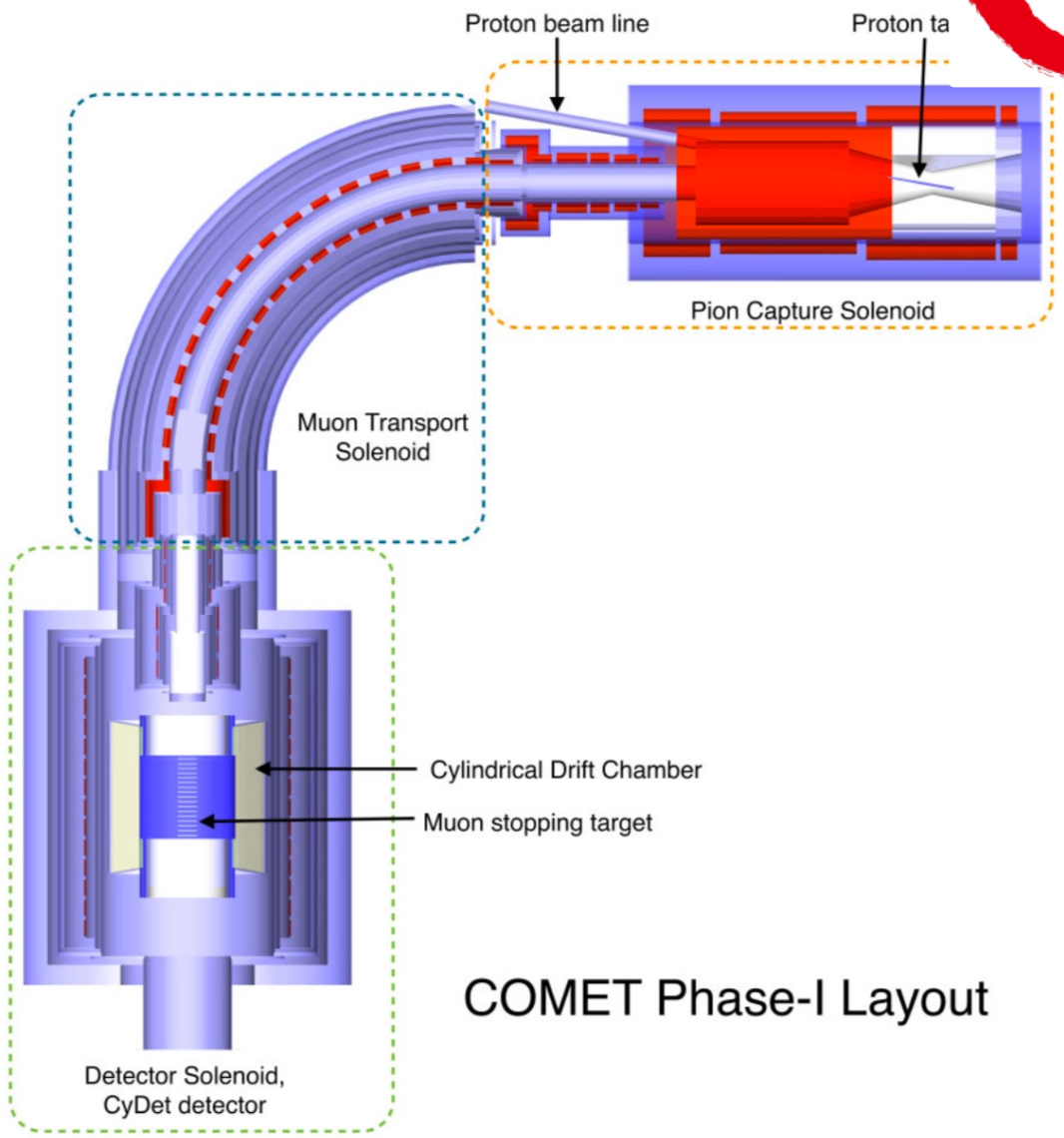
the Charged lepton flavor violation (CLFV) process

$$\mu^- + N(A, Z) \rightarrow e^- + N(A, Z)$$



Standard Model(SM): Branch Ratio(BR) O(~10^{-54})
Beyond Standard Model(BSM): Much higher Branch Ratio

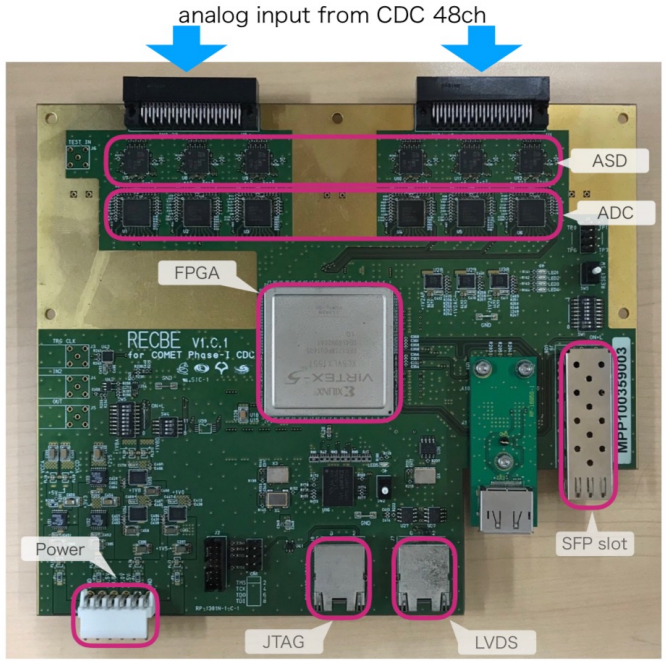
Single Event Sensitivity (SES): 3.1x10^{-15}



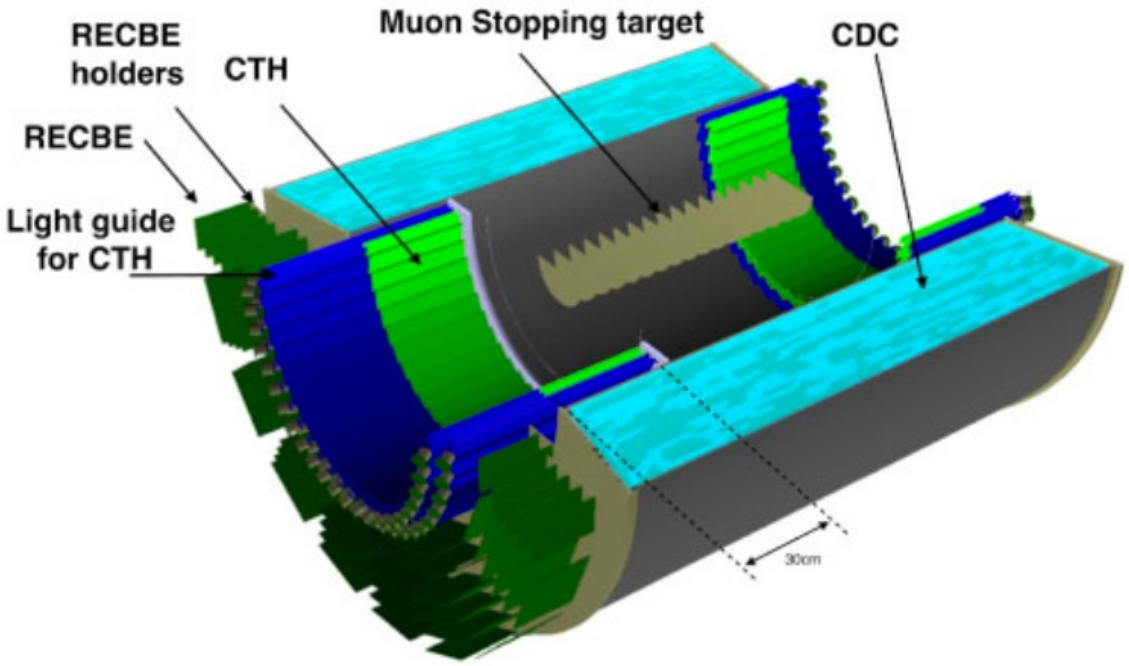
COMET Phase-I Layout

Cylindrical drift chamber (CDC)

CDC View



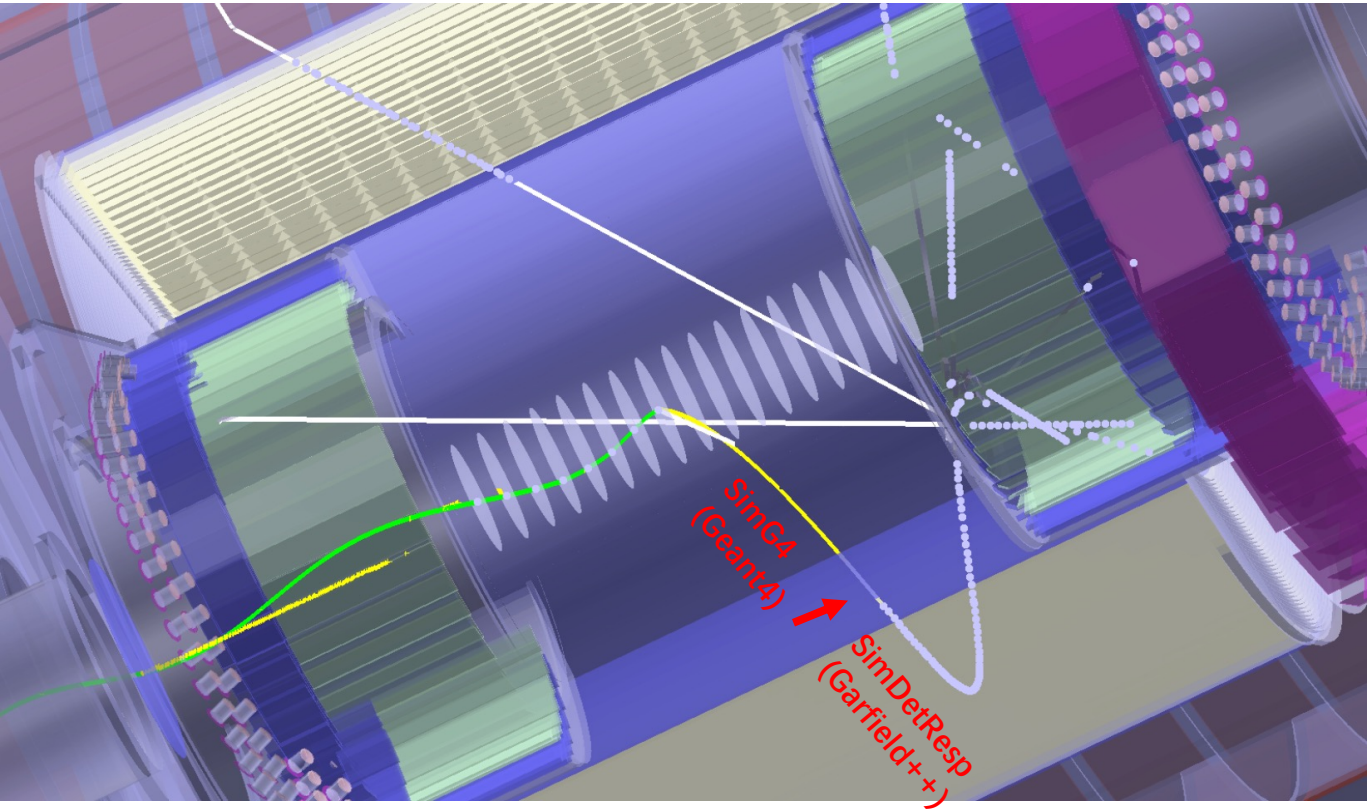
CDC readout board RECBE

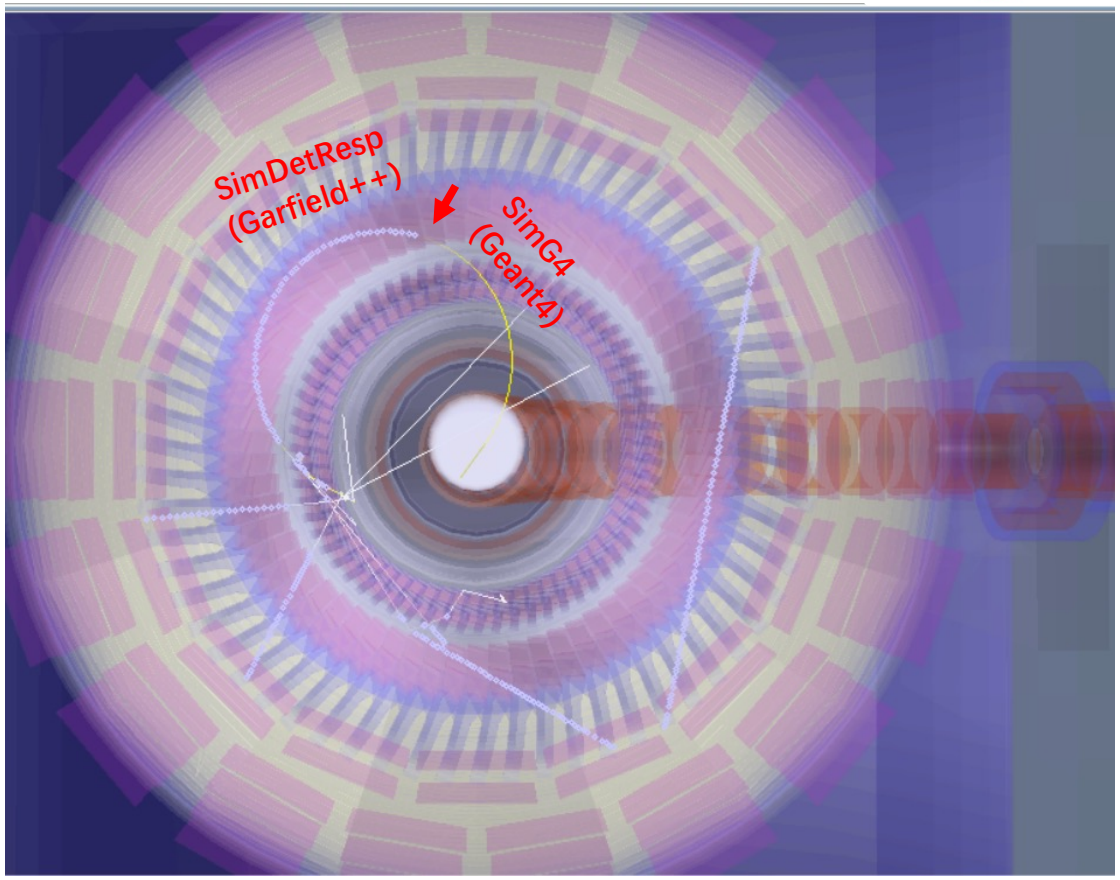


The CDC is arranged For: Momentum measurement

Particle Identification (e^-, proton, etc.)

Motivation

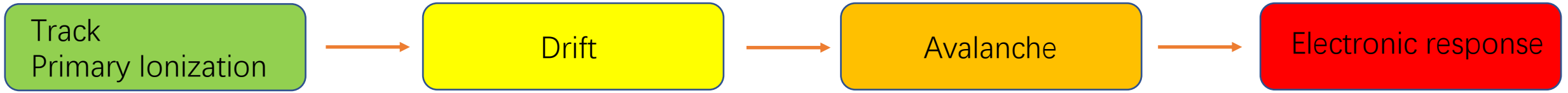




- Detector response is important for CDC occupancy, track reconstruction.
- Current Geant4 simulation can not simulate gas detector process & electronic signal

CDC Detector Response Simulation Flow

- Garfield++ is used for the simulation



Heed+
(Garfield++)

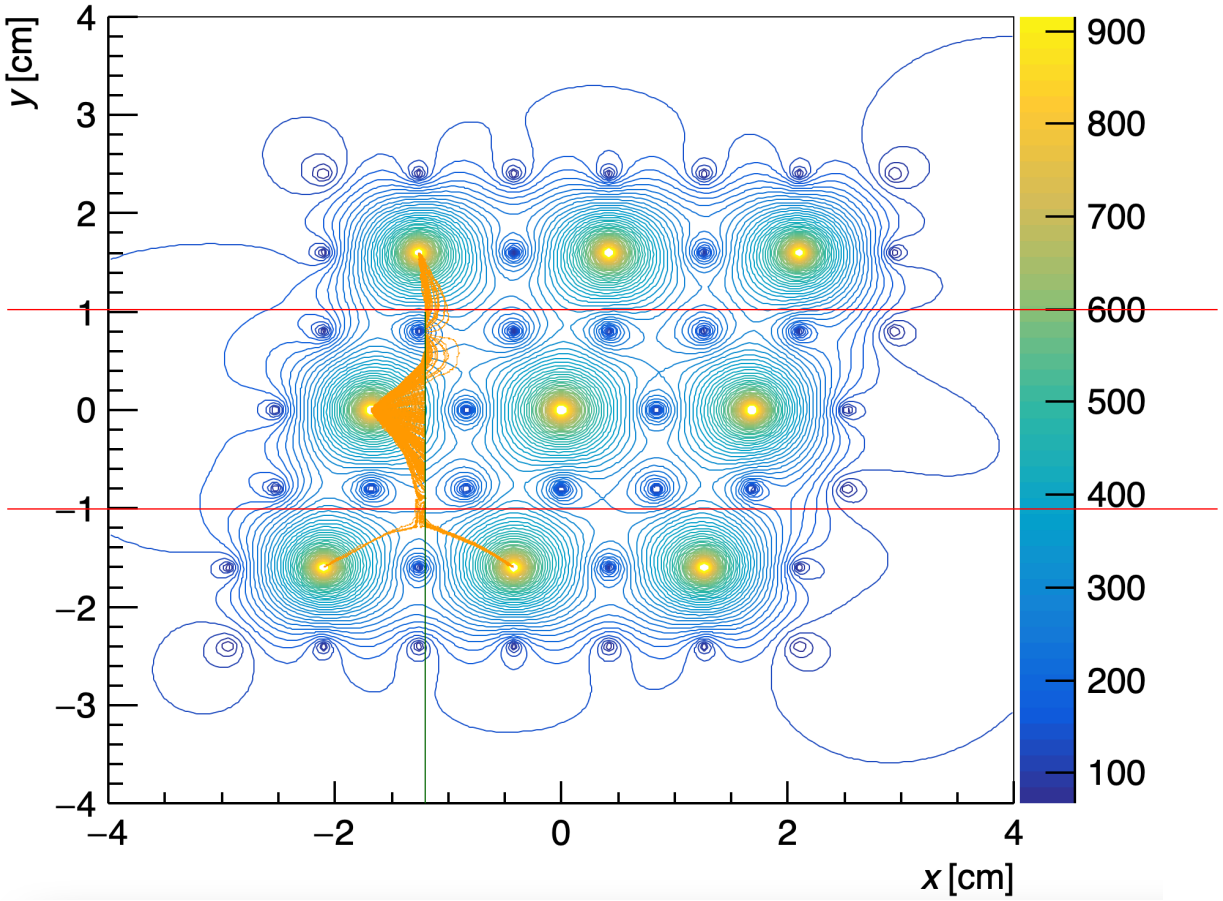
Garfield++

Avalanche Function
(by gas gain saturation study)

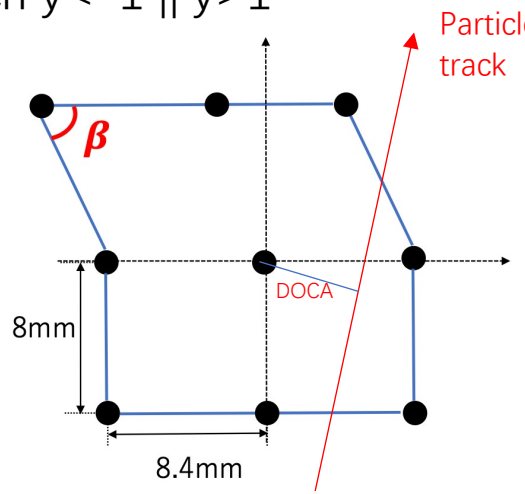
Delta response
(Garfield++)

- Garfield++ can simulate: e^+, e^-, μ^+, μ^-, π^+, π^-, K^+, K^-, p^+, p^-, D^+ ($^2H^+$), α^{2+}
- "Realistic" signal hits from sense wire instead of truth hits

Garfield++ Simulation With Different β

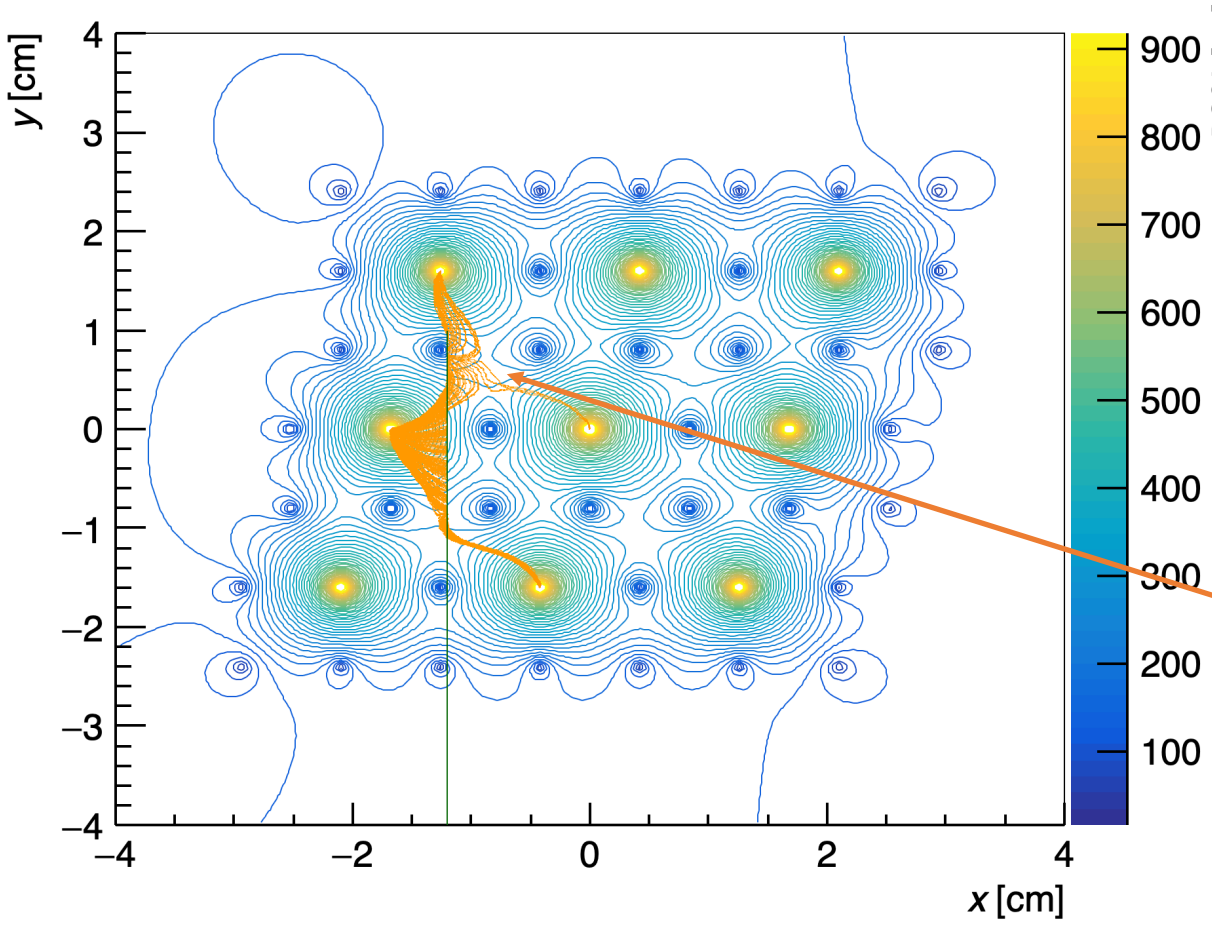


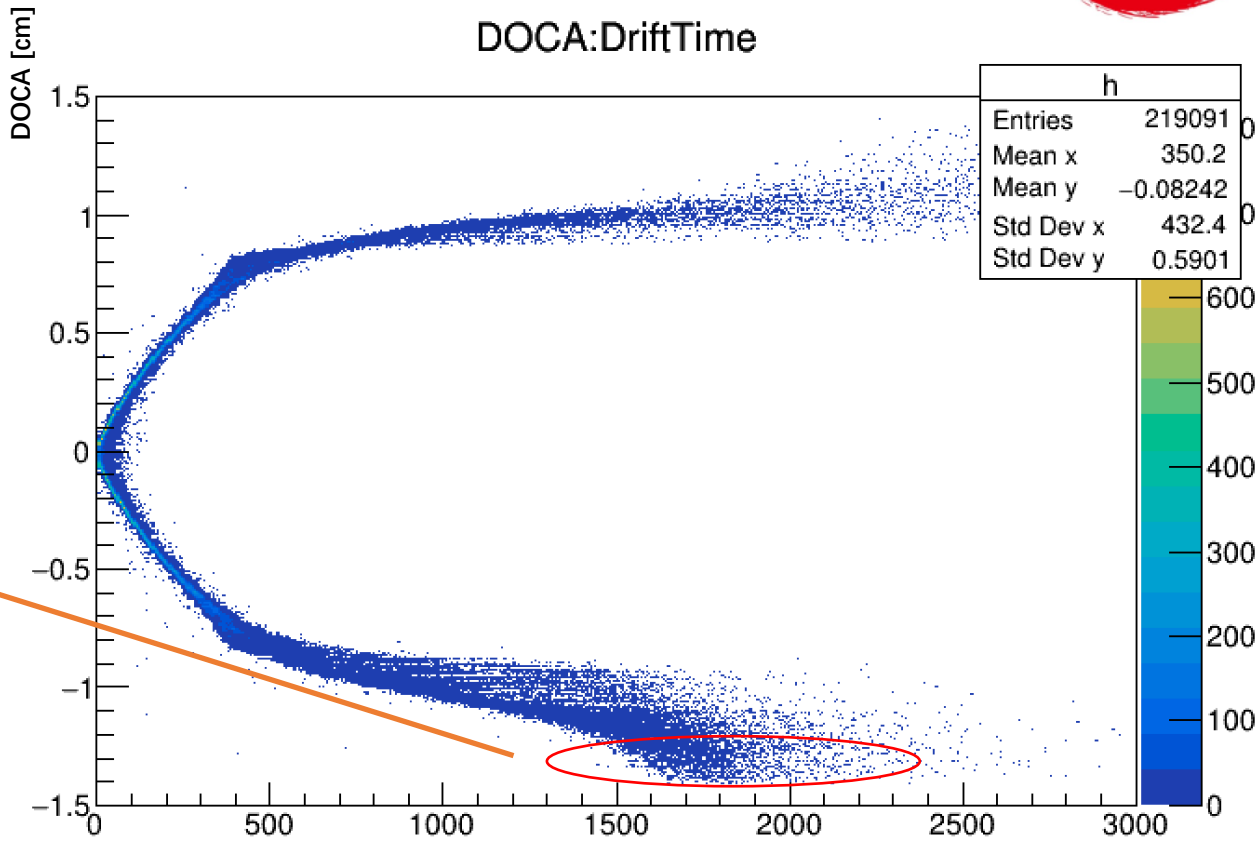
- 1800V
- β = 30°
- 1GeV muon
- w/wo magnetic field
- Abandon primary ionized electrons which y<-1 || y>1



Cell Defination

Electrons Drift in Gas Chamber



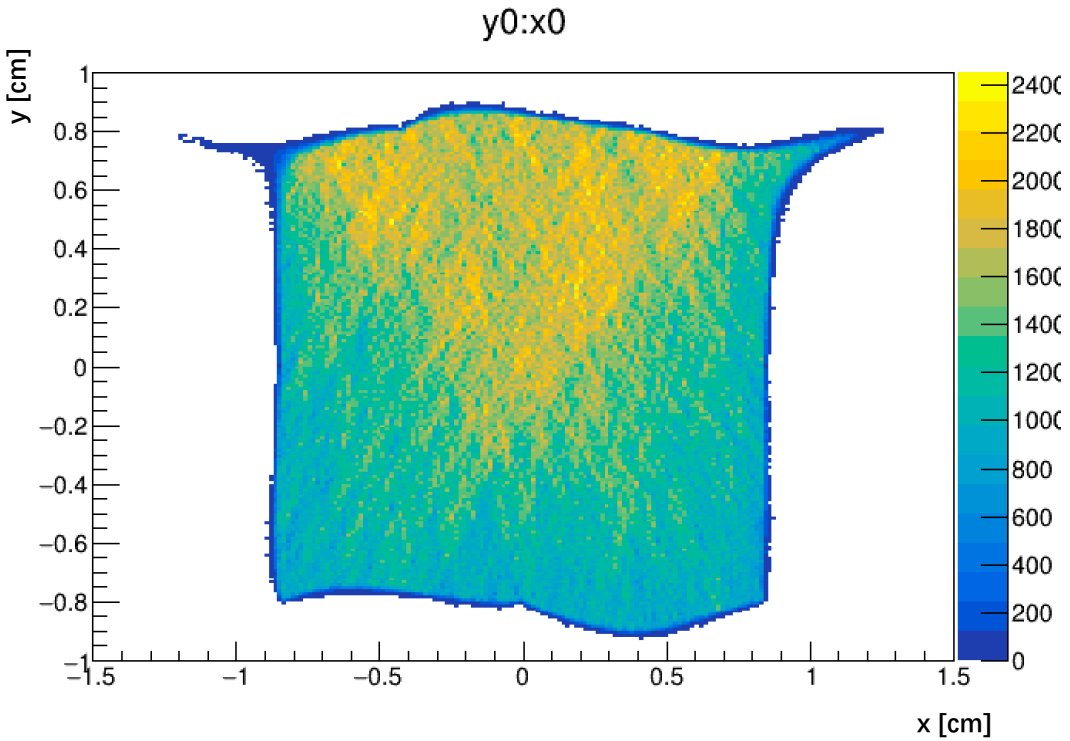


1T beta 120° 1GeV/c μ-

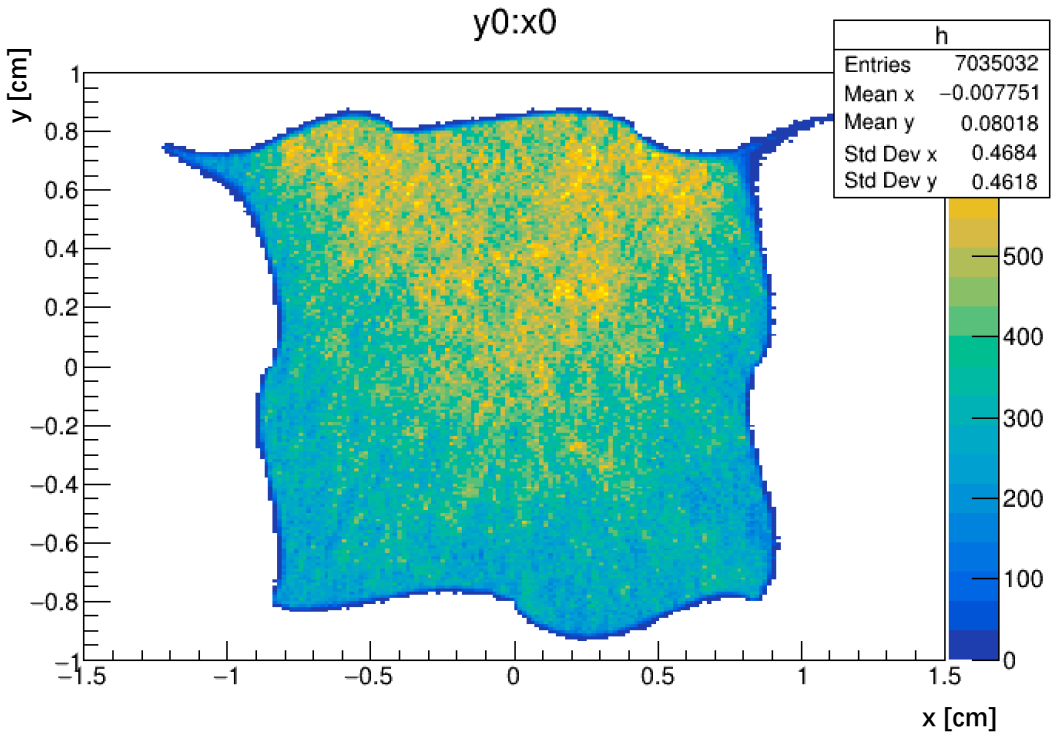
Drift Velocities are different at left corner and right corner

Cell Shape at β = 120°

- Different cell shapes are obtained with/without magnetic field

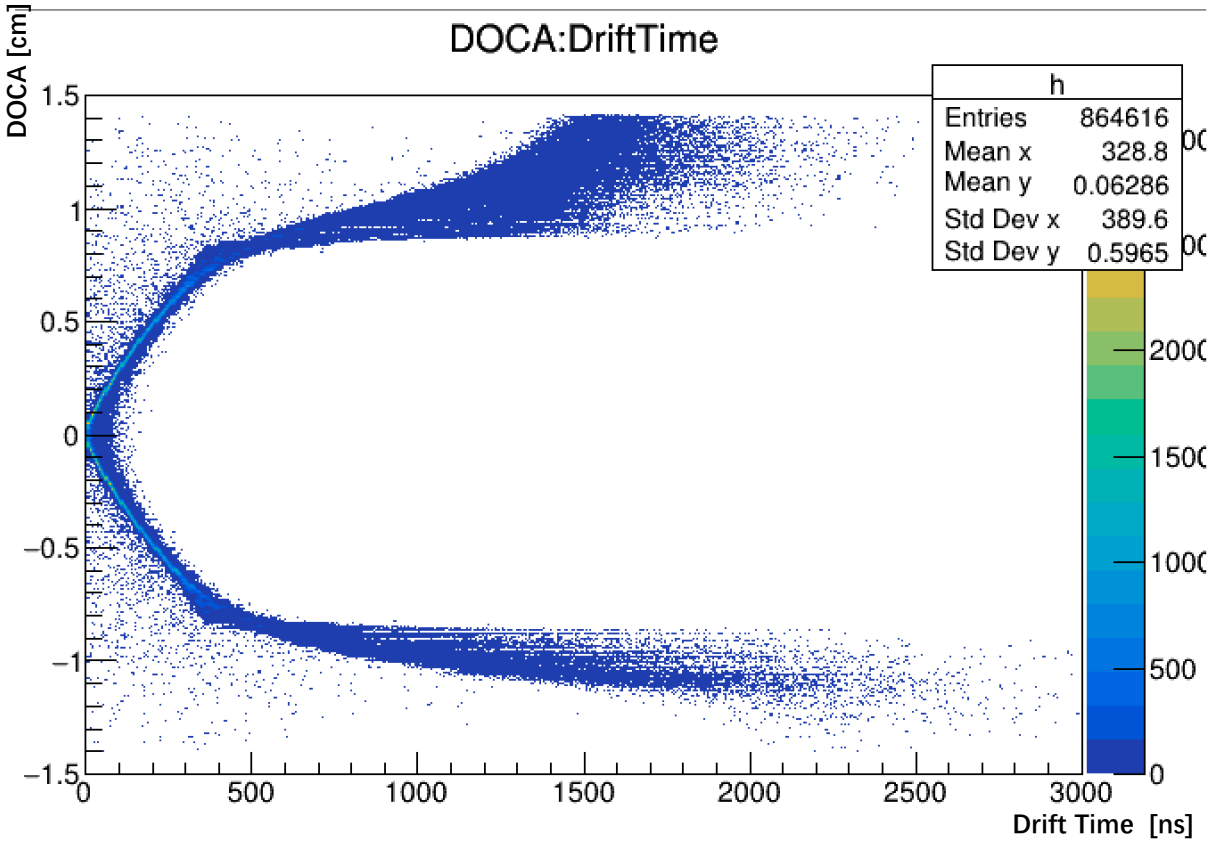


0T magnetic field

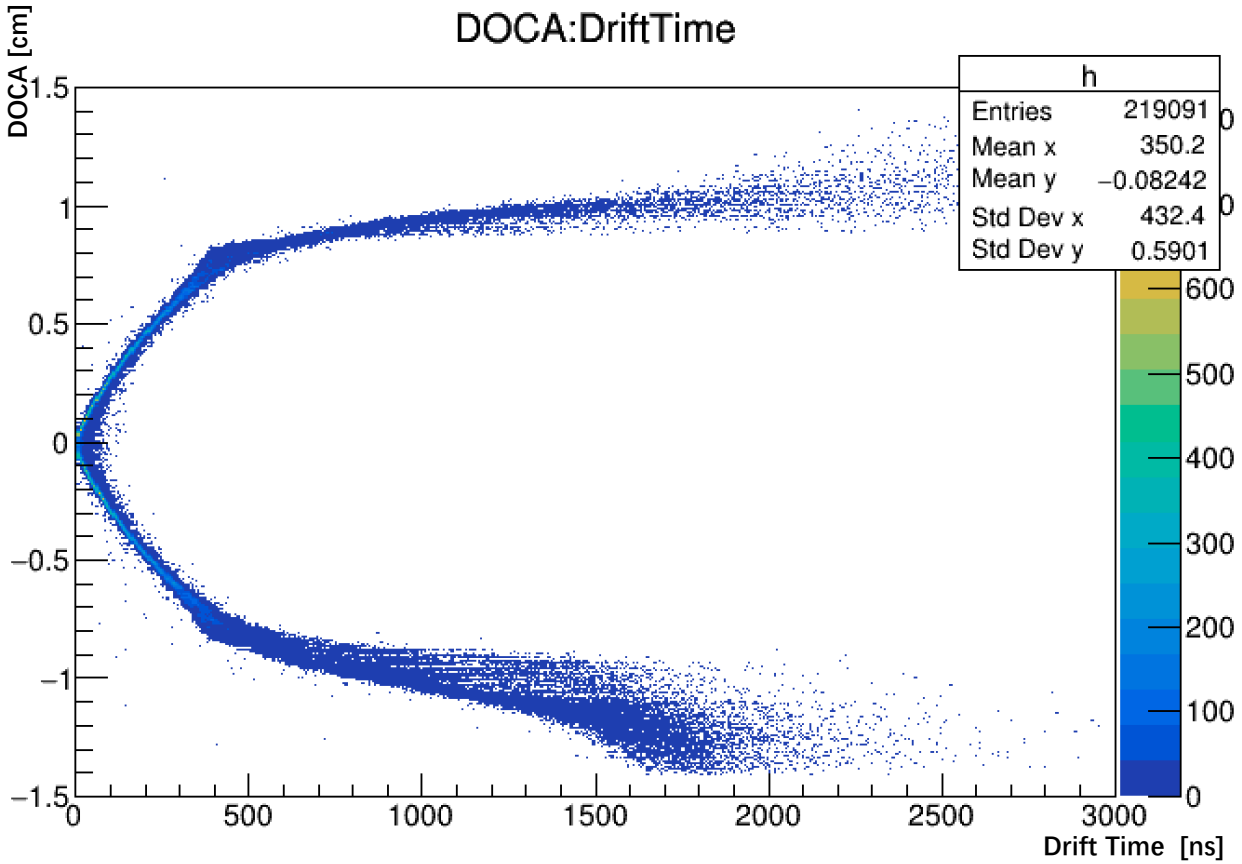


1T magnetic field

XT Relation

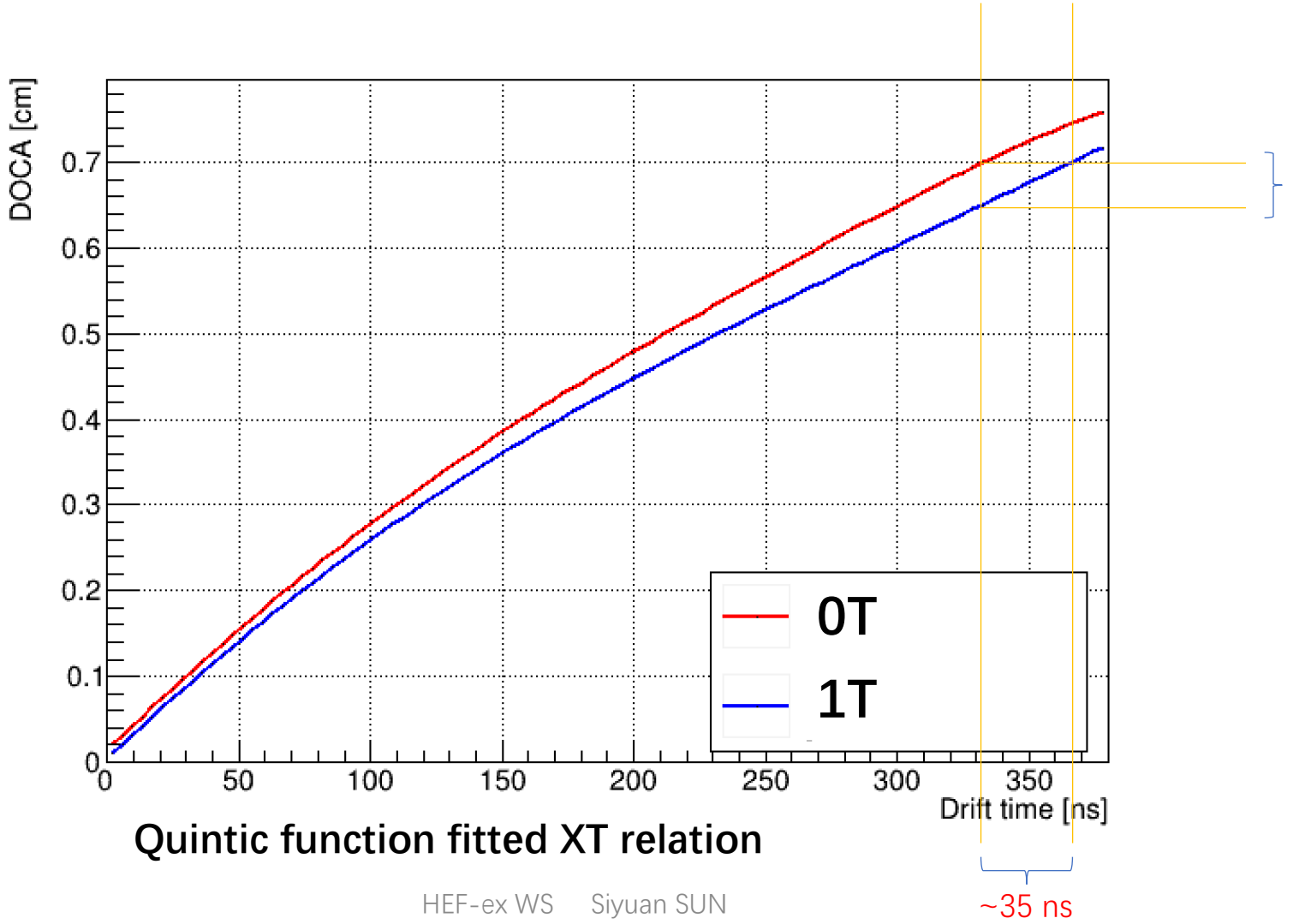


0T beta 120° 1GeV/c μ-



1T beta 120° 1GeV/c μ-

XT Comparison at [β = 120°]

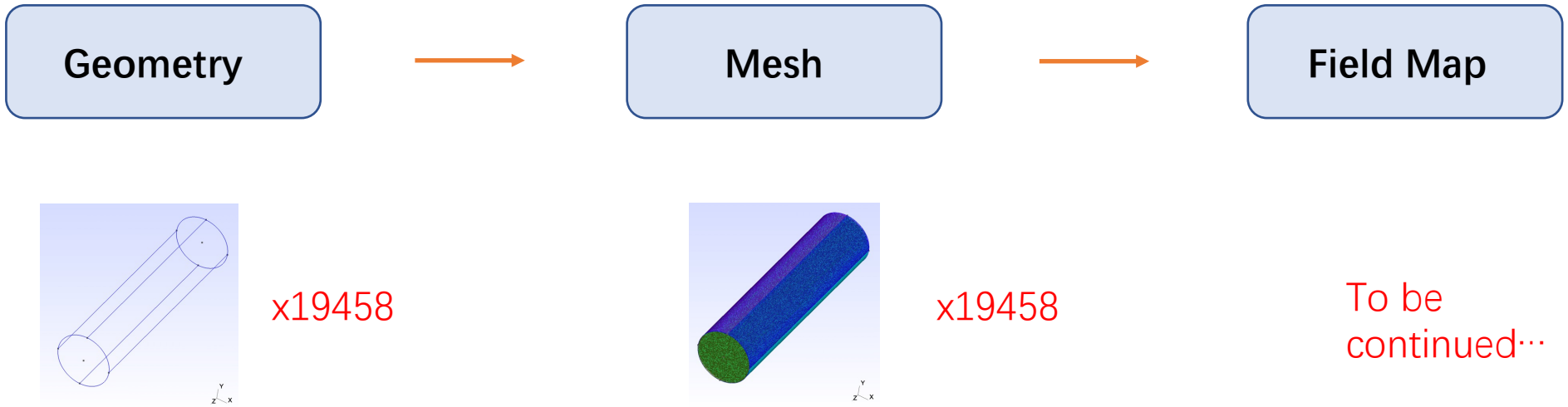


Quintic function fitted XT relation

Larger than CDC spatial resolution!

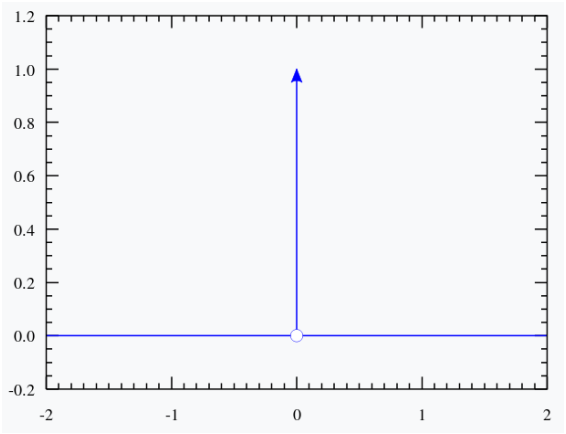
Drift and Electric Field Map in 3D

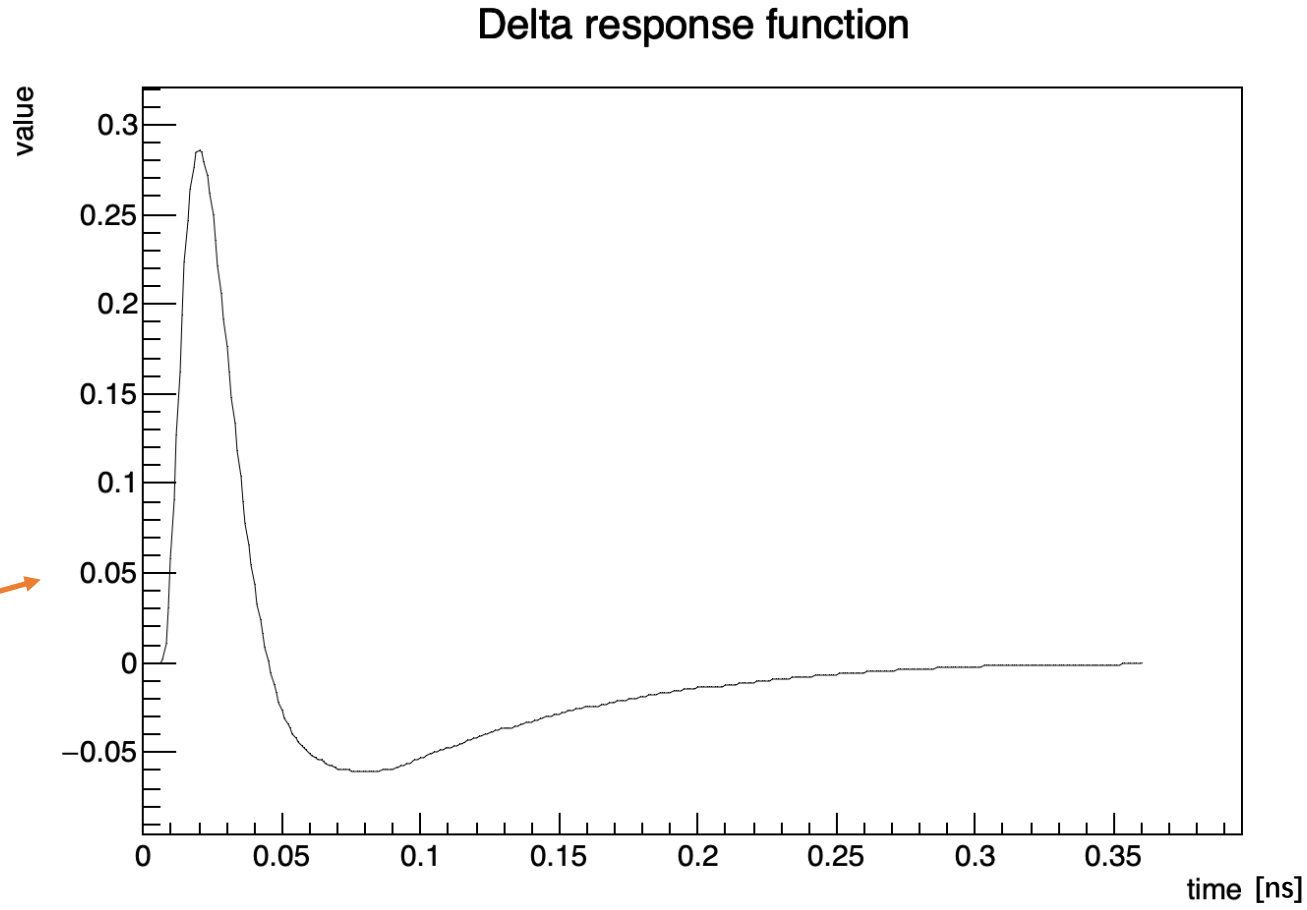
- Field map is needed for 3D simulation.
- Feasibility under investigation for 3D field map



Delta Response Function

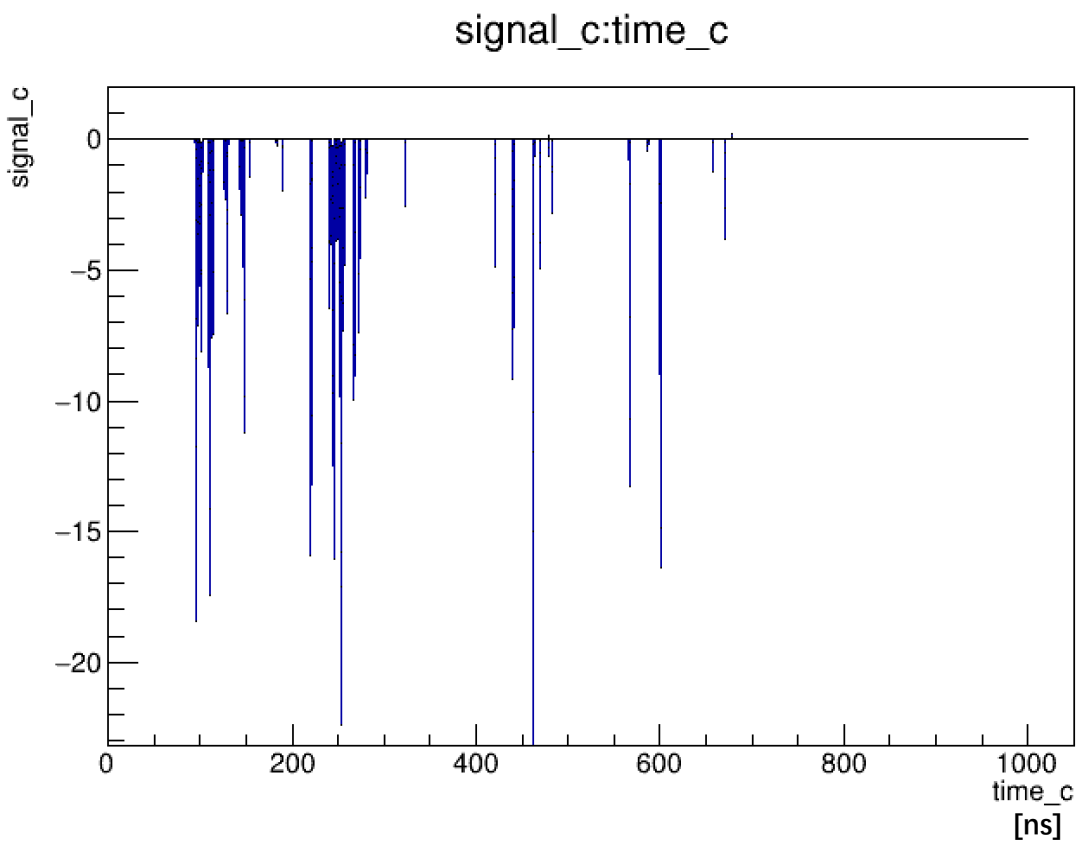
- Delta Response Function given by Garfield++
- RECBE may have different response function



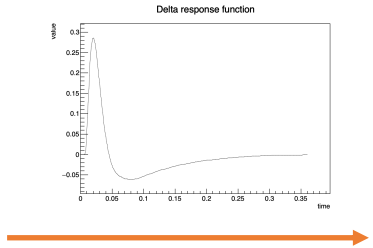


Induced Charge to Signal

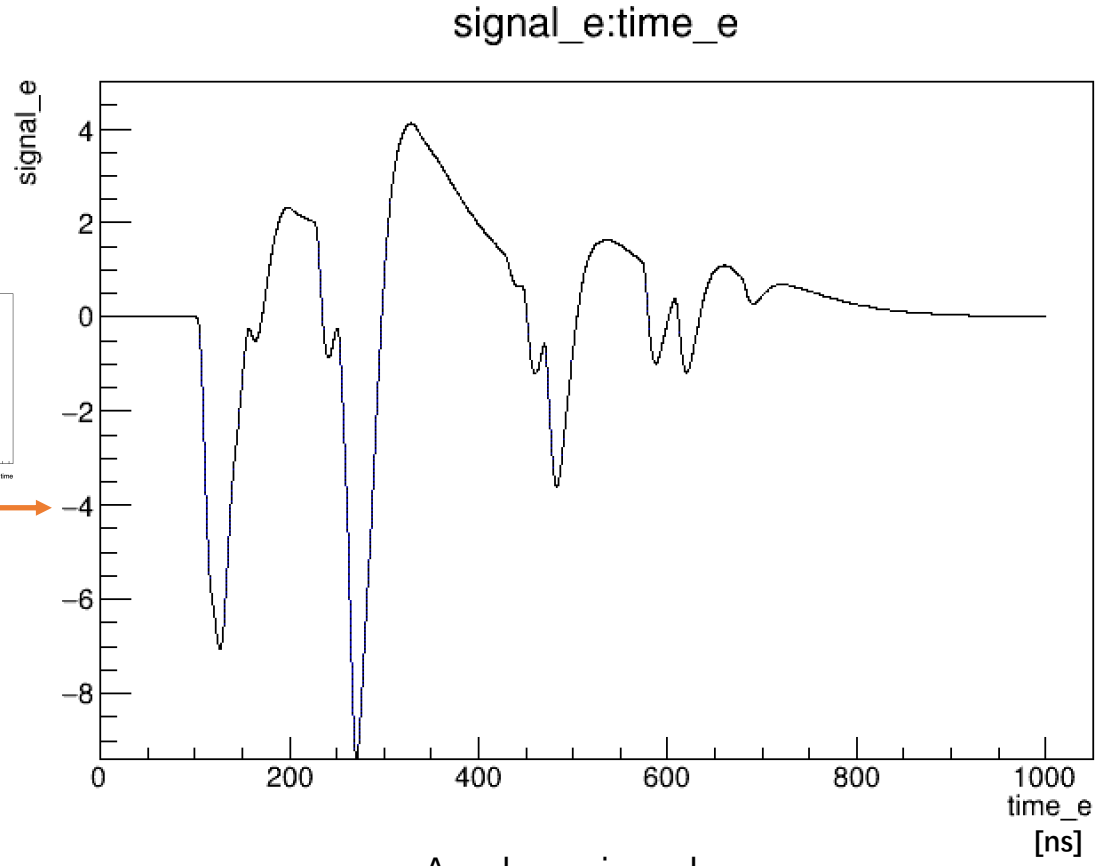
- Induced charge convoluted to signal by delta response



Induced charge on sense wire

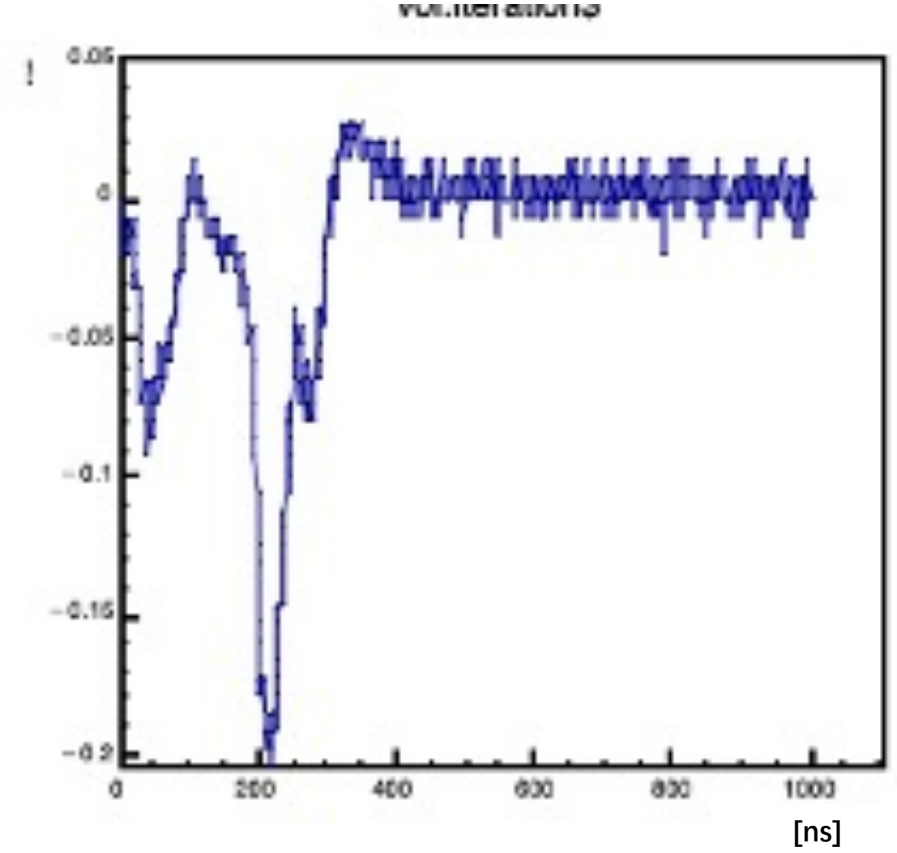


Convolution

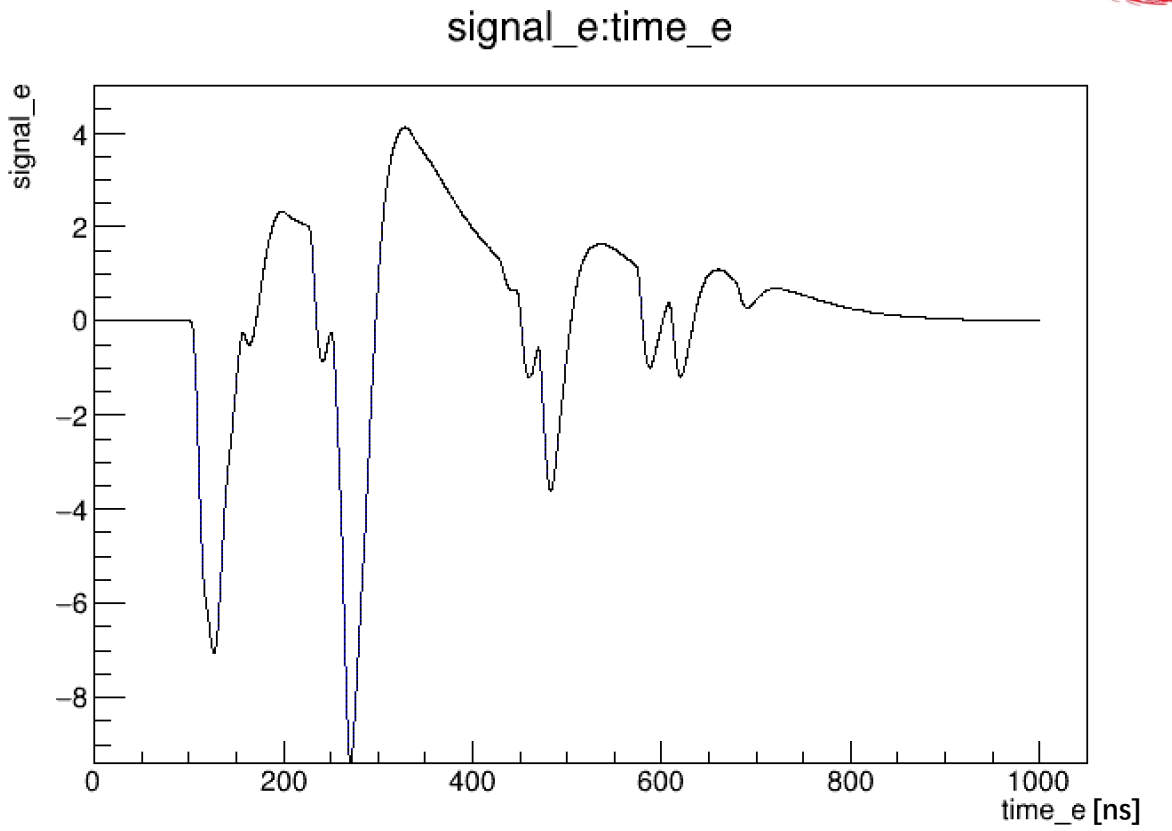


Analog signal

Compare with Data



Cosmic ray 1600V
prototype chamber



Garfield++ 1GeV/c μ- 1800V

RECBE Delta Response

- Test by Yu Nakazawa with pulsed function
- Tail information lost
- Better to redo…

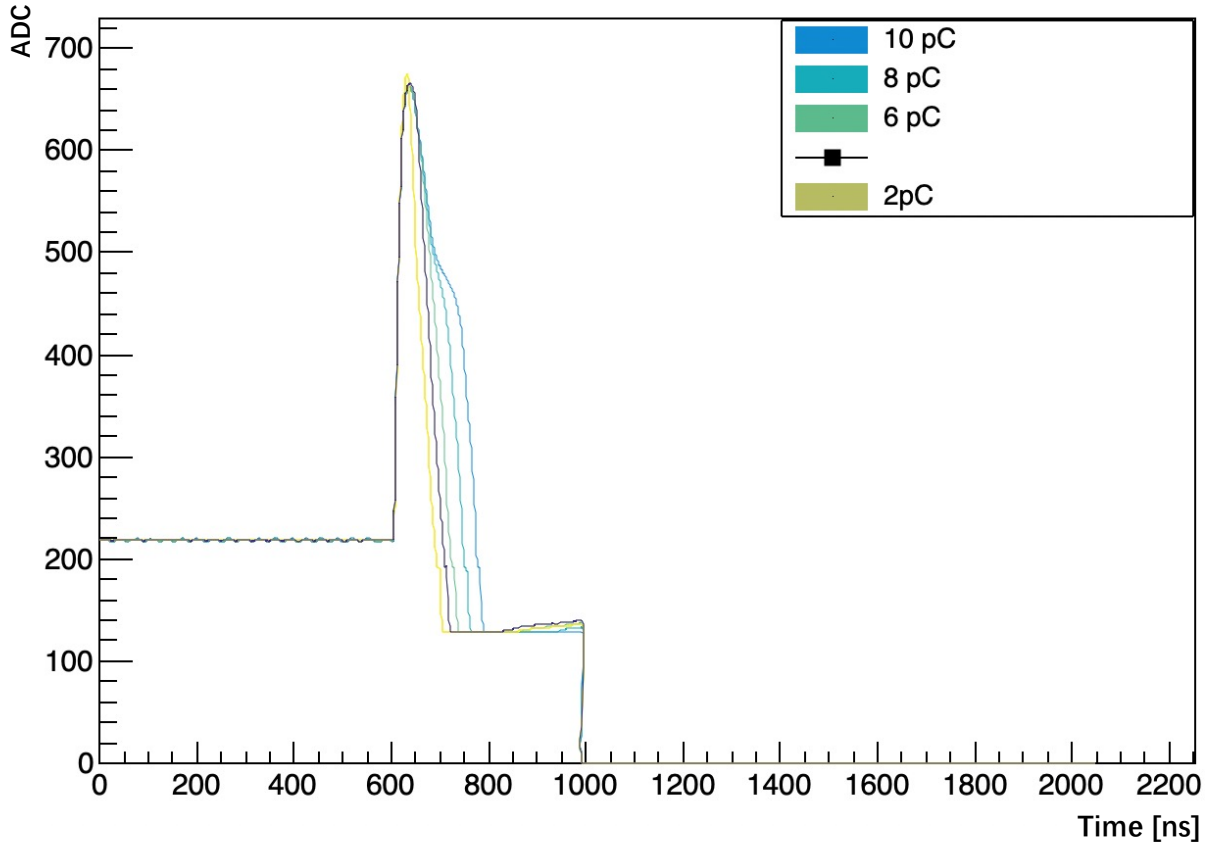
Function Generator

↓

RECBE

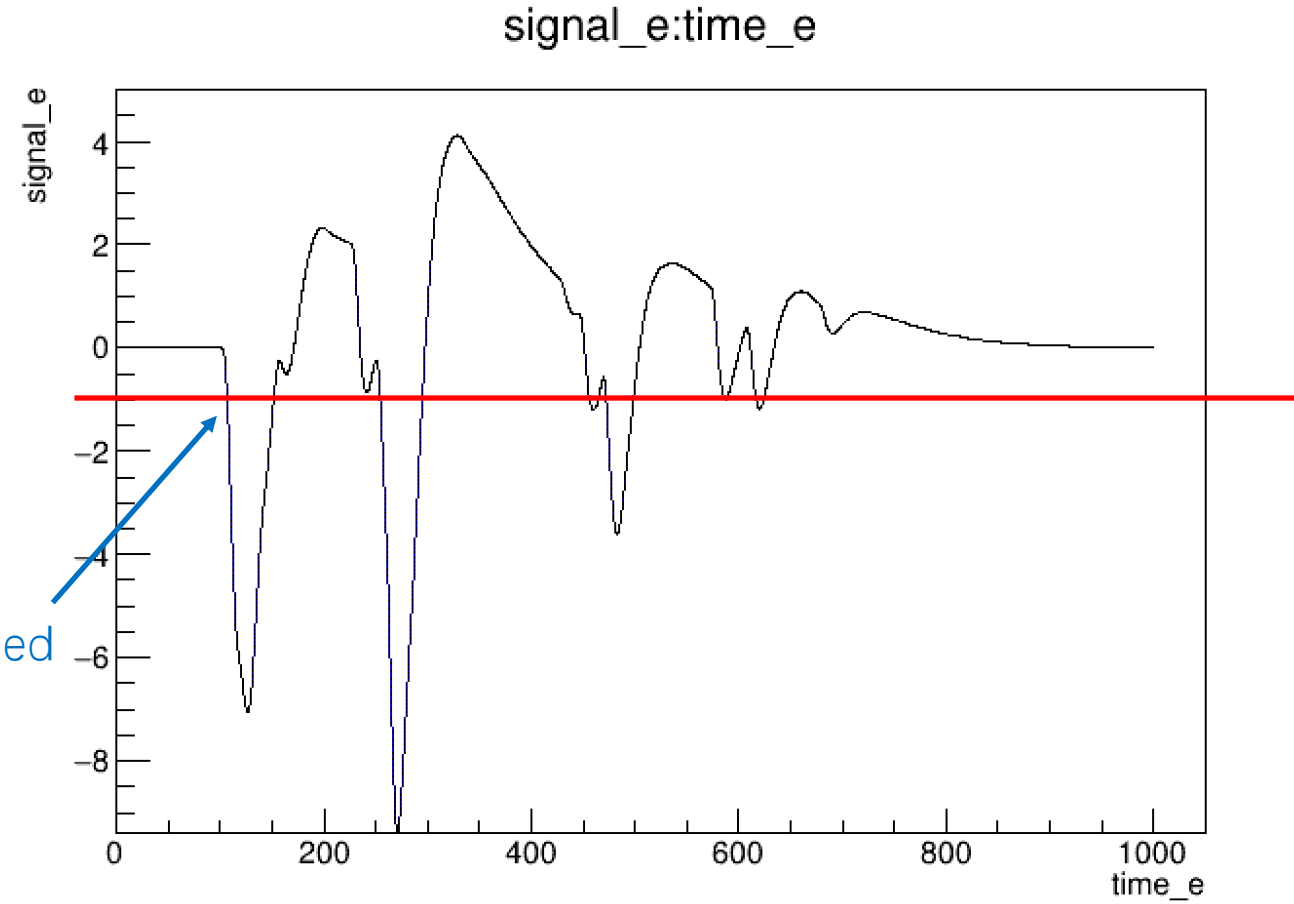
↓

ADC output



How to obtain hits in CDC

- TDC information by delta response, with a “threshold”
- ADC values (no implementation in Garfield++)
- No DOCA, dE/dx, etc. (no truth information)



Summary

- CDC response simulation with 2D model in Garfield++.
- Preliminary result shows different XT relation with/without magnetic field.
- 3D model of simulation under construction.
- Electronic simulations done to obtain signal waveforms.
- Problem remained: time delay in electronics, on wire, etc.
- To be continued…

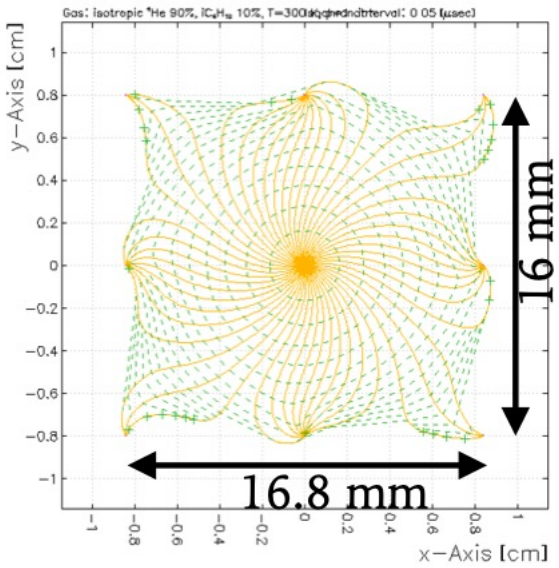
Back Up

Cylindrical drift chamber (CDC)

Table 7.1: Main parameters of the CDC.

Inner wall	Length	1495.5 mm
	Radius	496.0∼496.5 mm
	Thickness	0.5 mm
Outer wall	Length	1577.3 mm
	Radius	835.0∼840.0 mm
	Thickness	5.0 mm
Number of sense layers		20 (including 2 guard layers)
Sense wire	Material	Au plated W
	Diameter	25 μm
	Number of wires	4986
	Tension	50 g
Field wire	Material	Al
	Diameter	126 μm
	Number of wires	14562
	Tension	80 g
Gas	Mixture	He:i-C_4H_{10} (90:10)
	Volume	2084 L

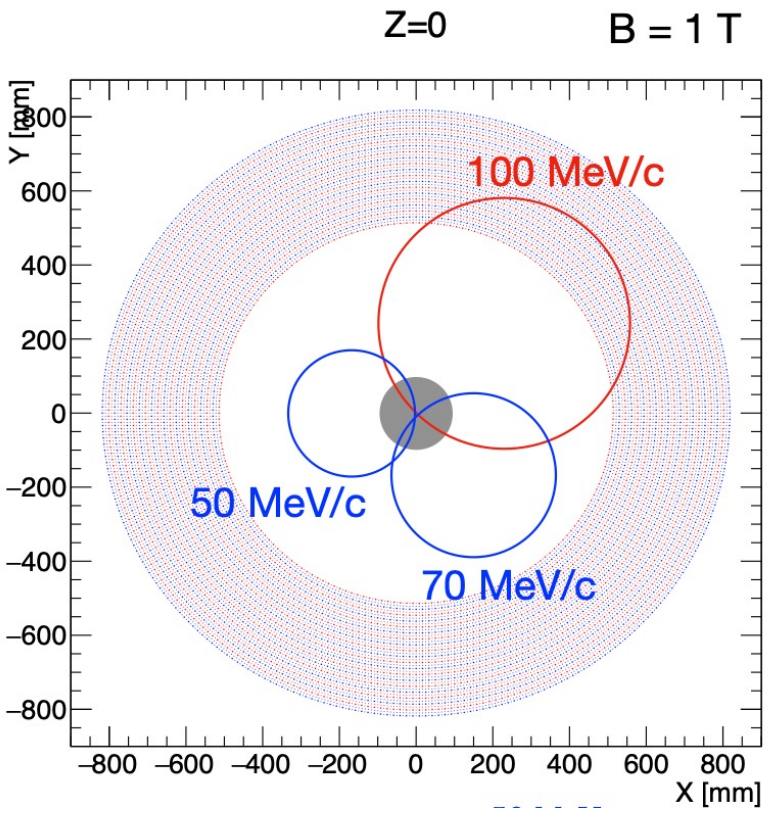
- Stereo angle applied for layers: 64-75 mrad for longitudinal resolution

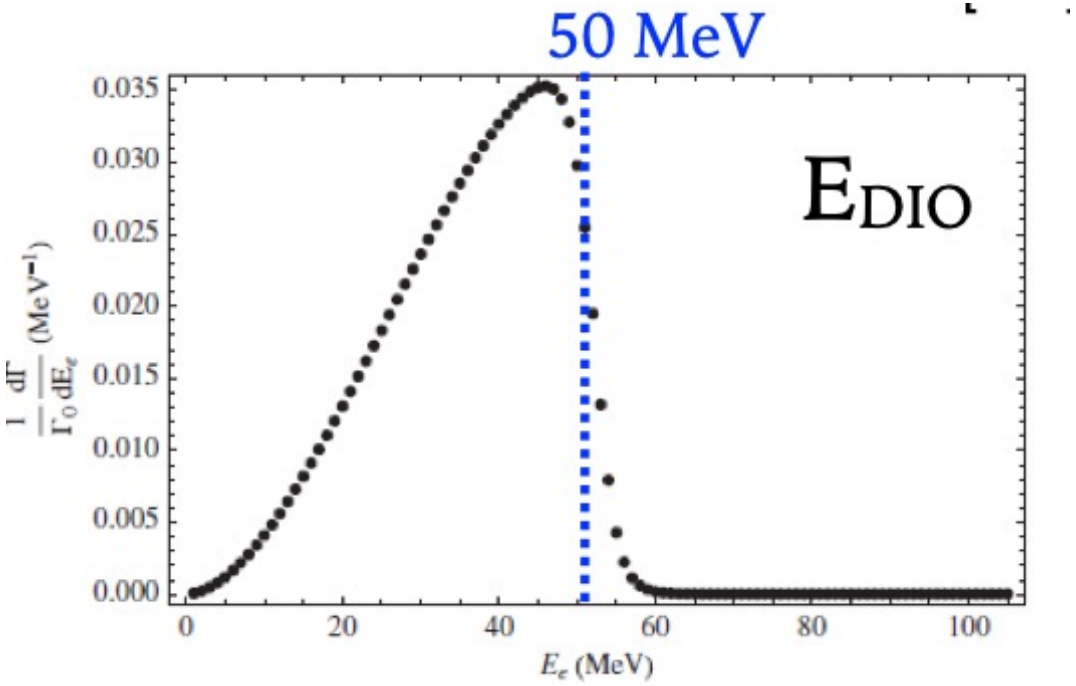


Cell structure

Cylindrical drift chamber (CDC)

to suppress DIO-electron hits



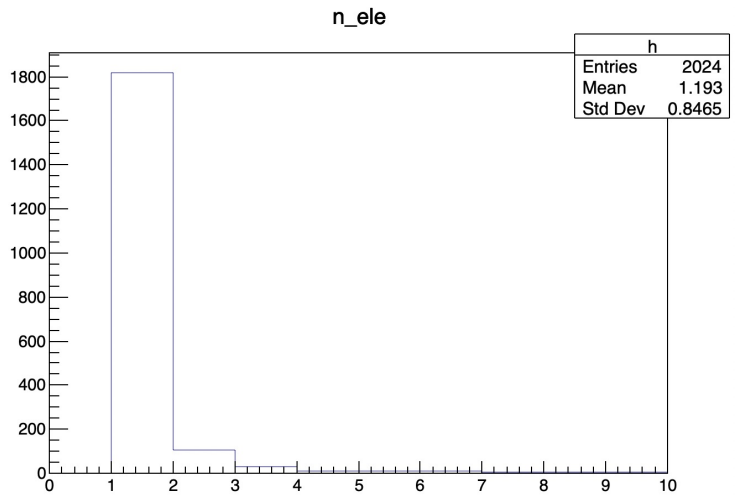


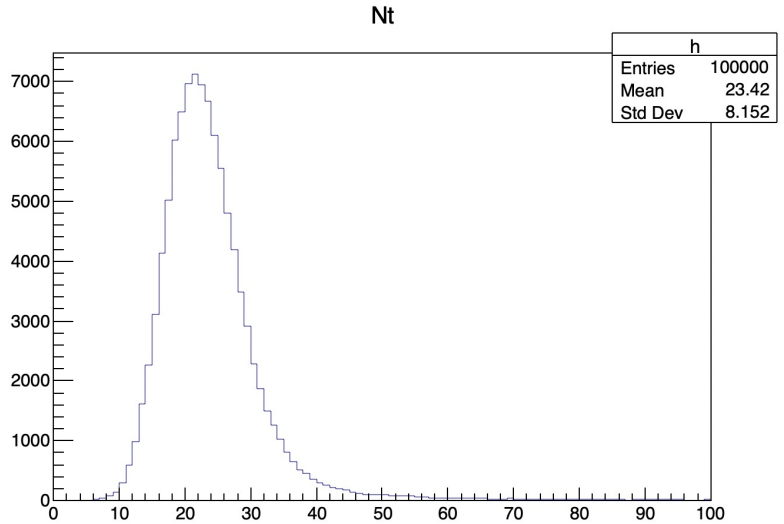
Most of DIO stays less than 50 MeV

- Large inner radius is designed to avoid DIO beam.

Properties of Simulation

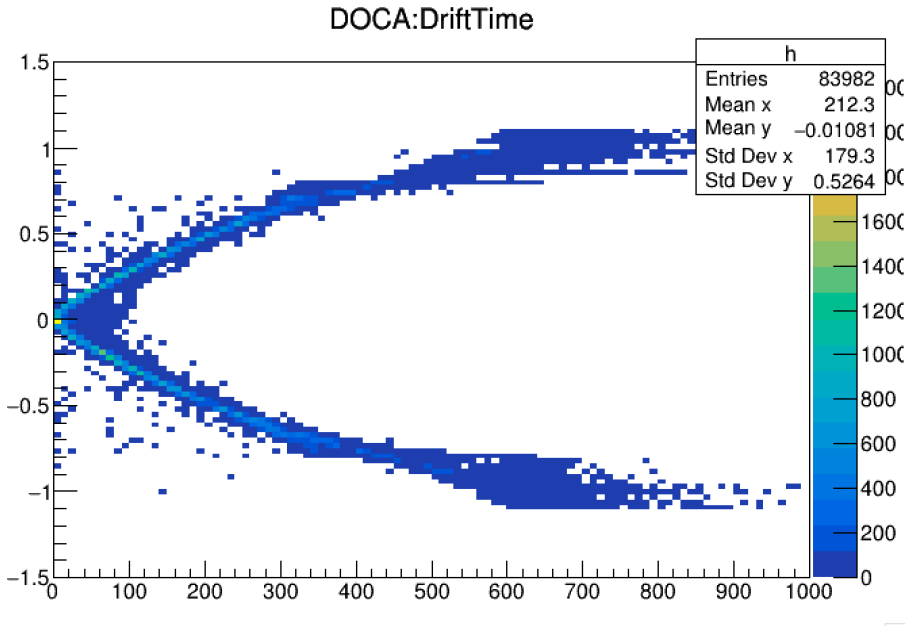
1GeV Muon simulation

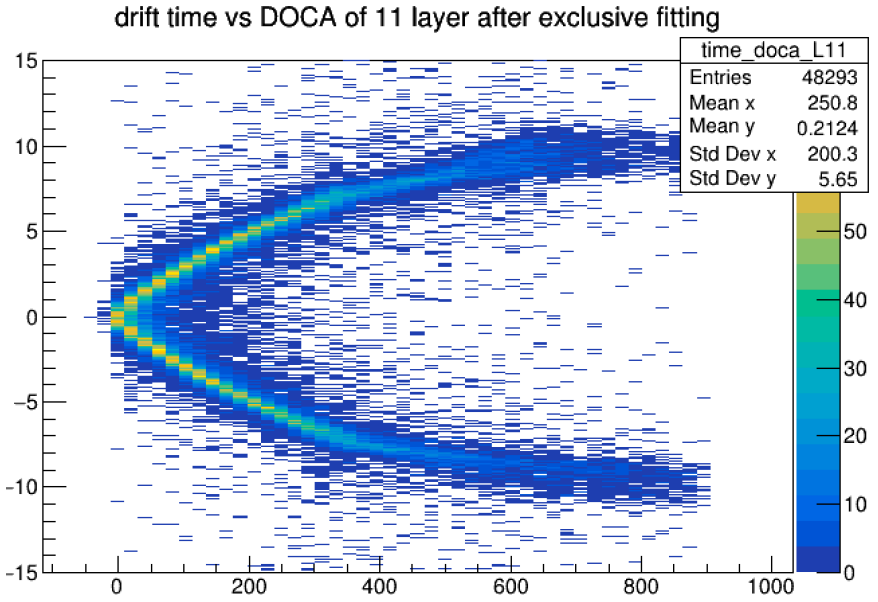




- Most of number of electrons in a cluster stay in 1
- Nt (Number of Total ionized electrons) ~23.42/1.6cm = ~15/cm
- Np (Number of clusters in a track) ~12.5/cm

XT Simulation Compare with CRT



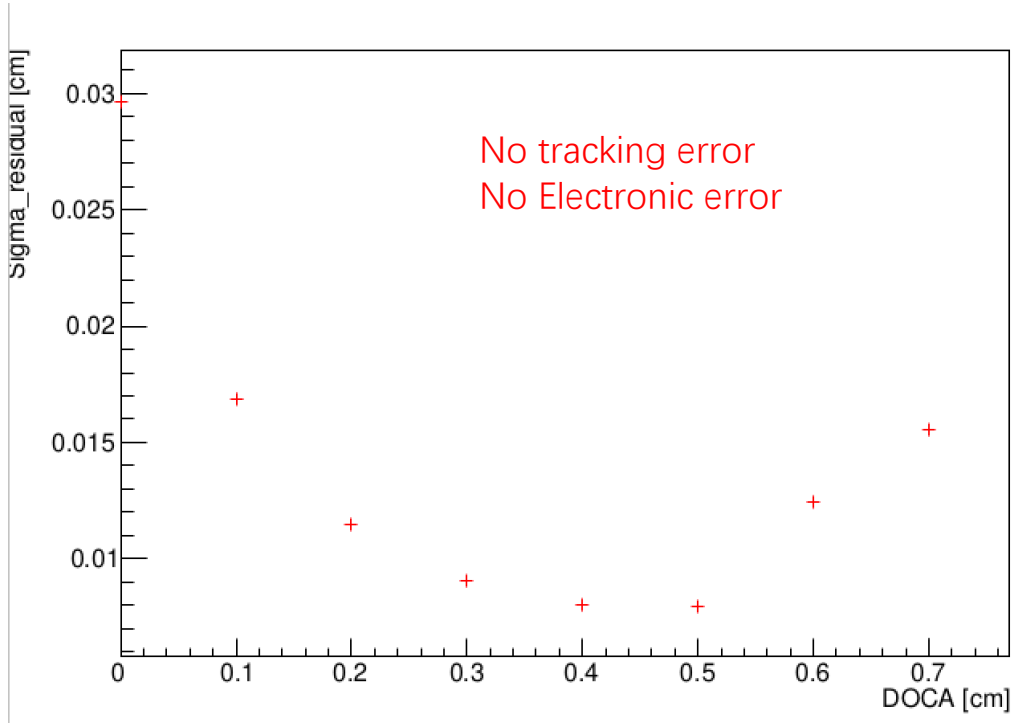


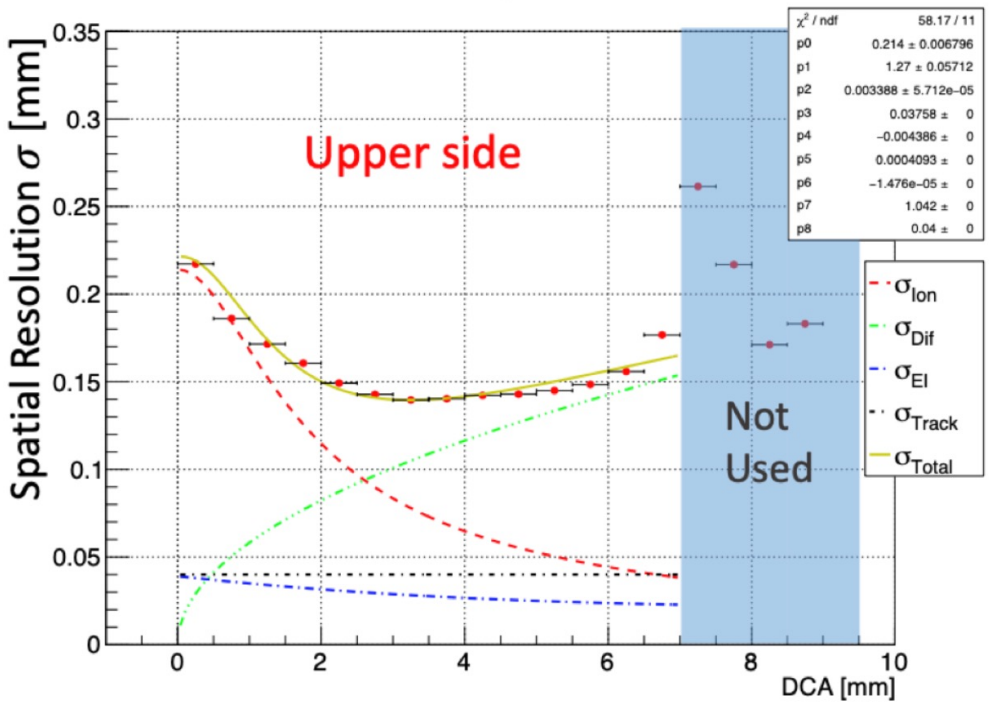
- 100k events
- Random position/direction tracks
- Square shaped cell

CRT analysis from Yohei

XT Simulation

1GeV Muon simulation





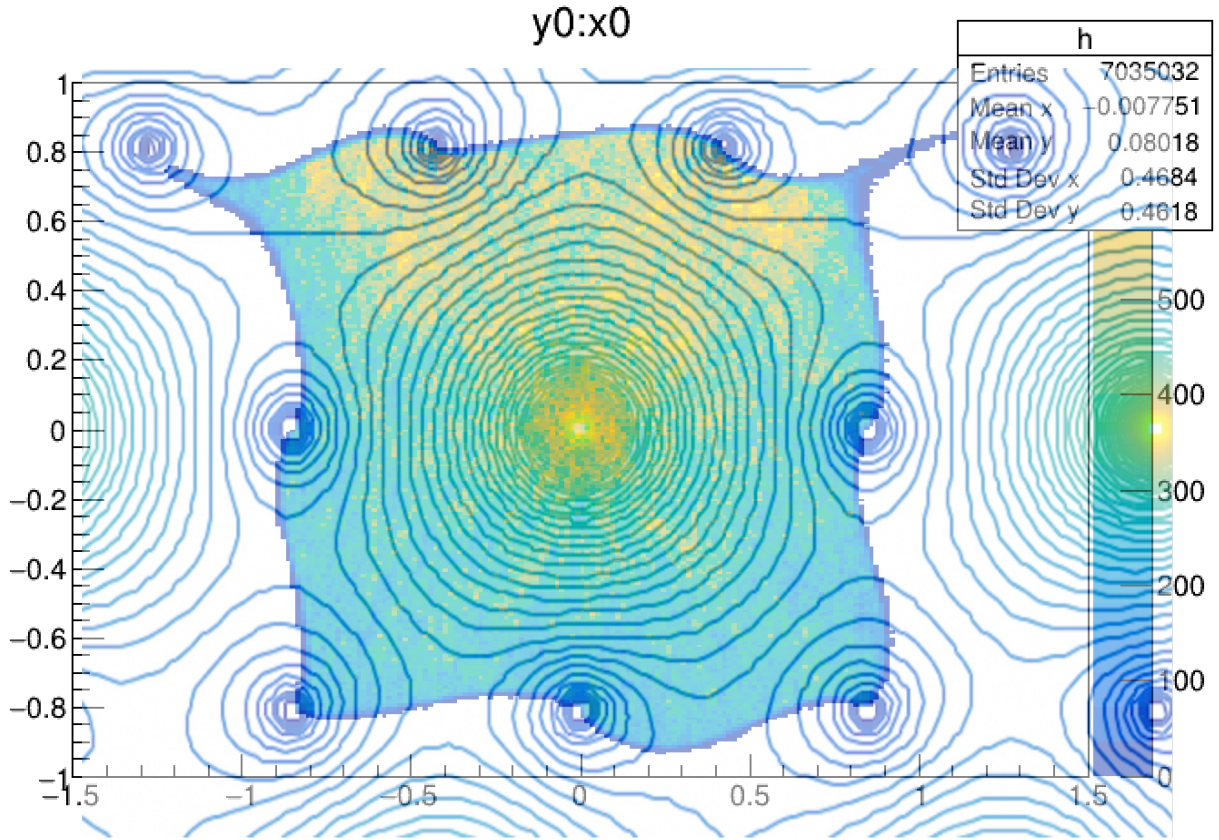
180 μm average spatial resolution got from simulation

Cell Shape

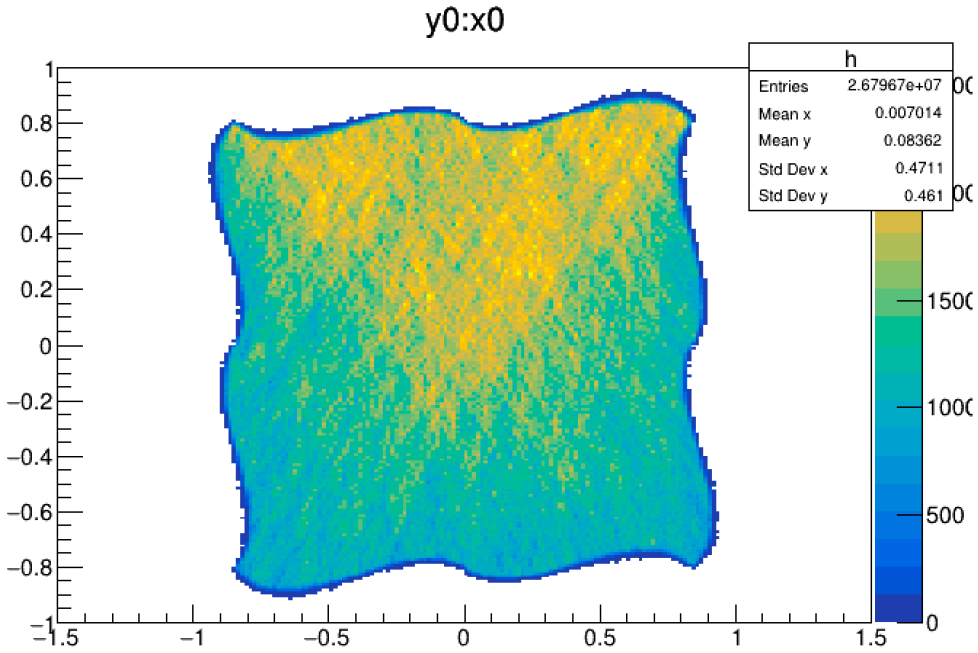
- Cell shape affected by magnetic field

Region that ionized electrons can drift to the sense wire can be affected by magnetic field

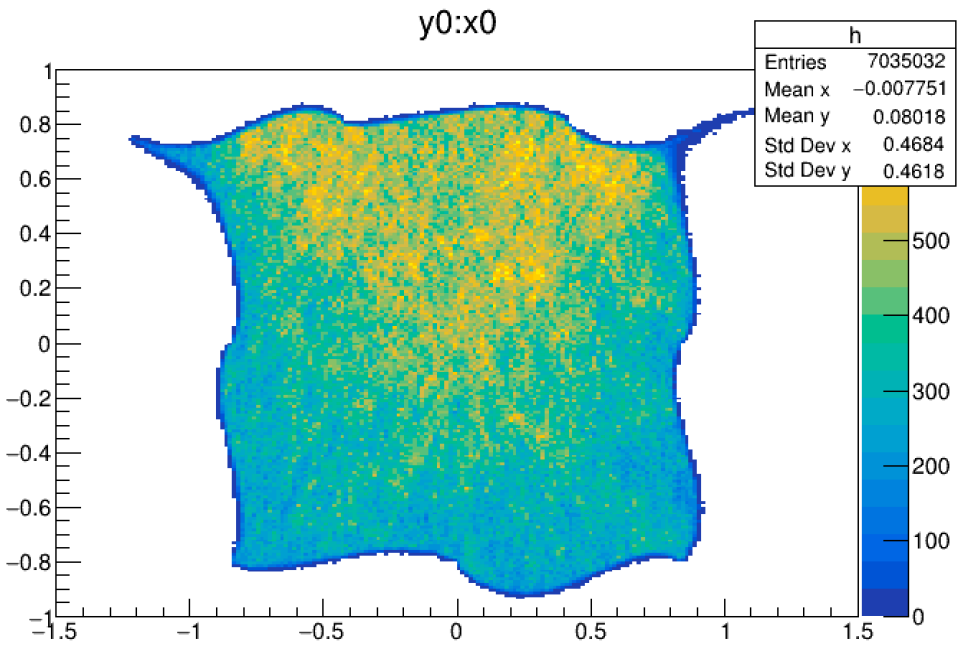
How to define track length?



Cell Shape

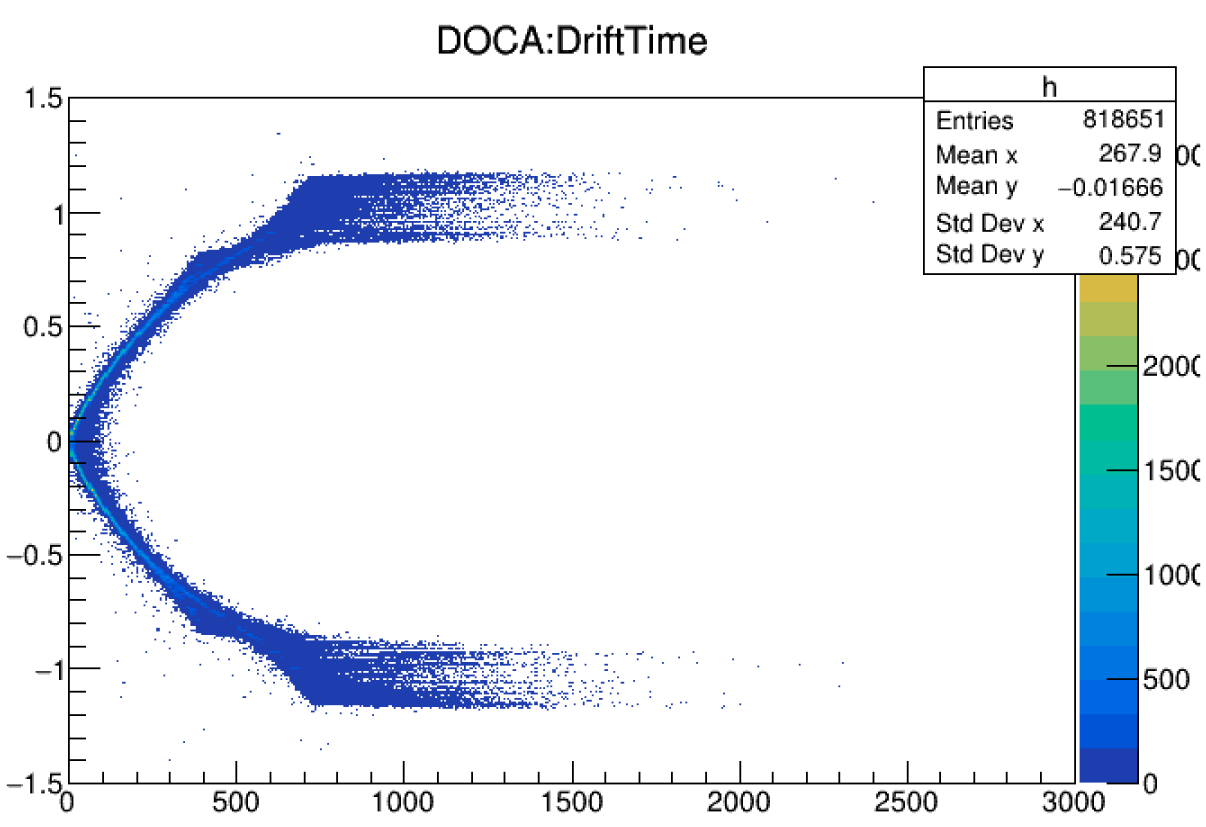


1T Beta 0°

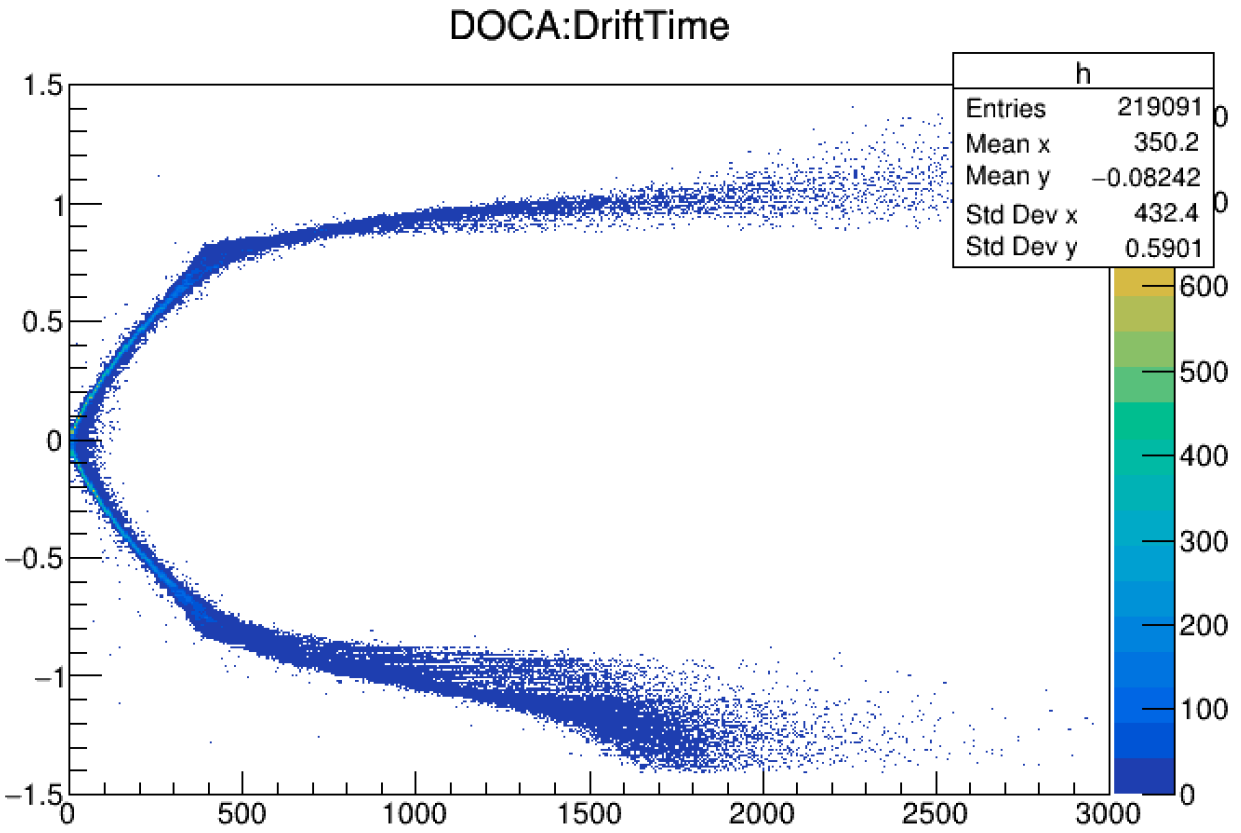


1T Beta 30°

XT Relation

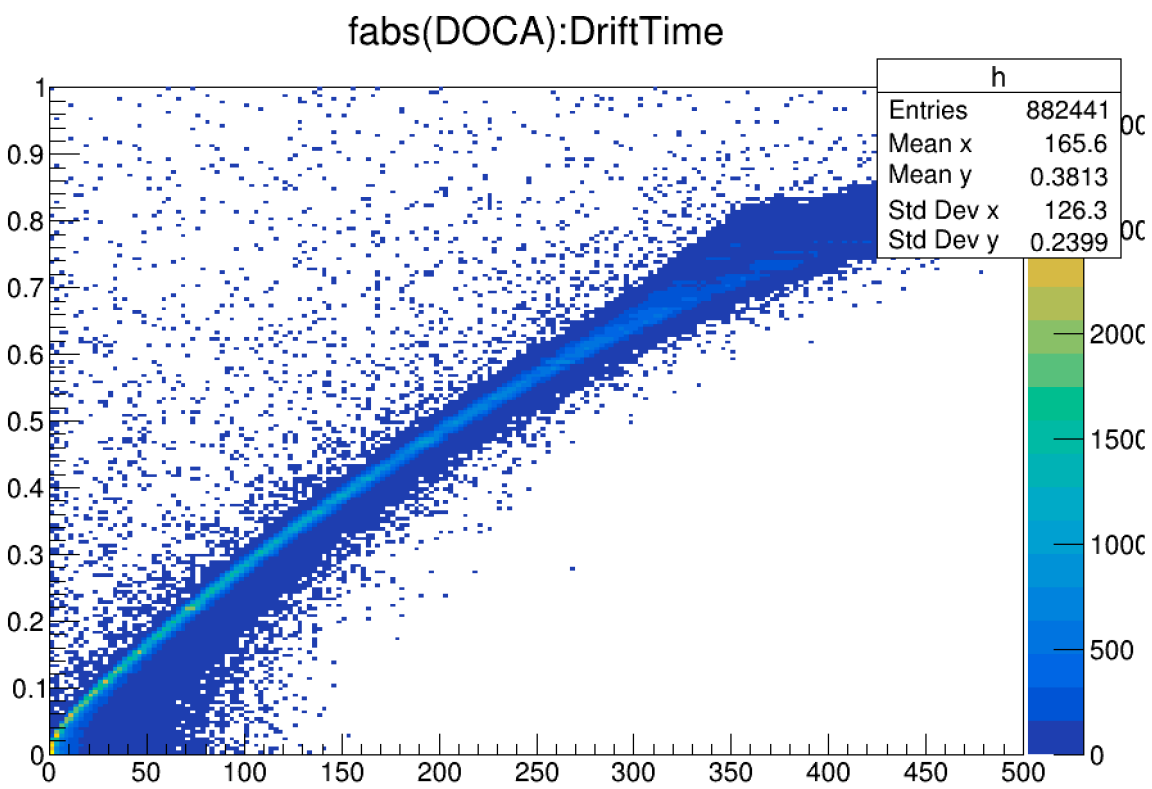


1T beta 0°

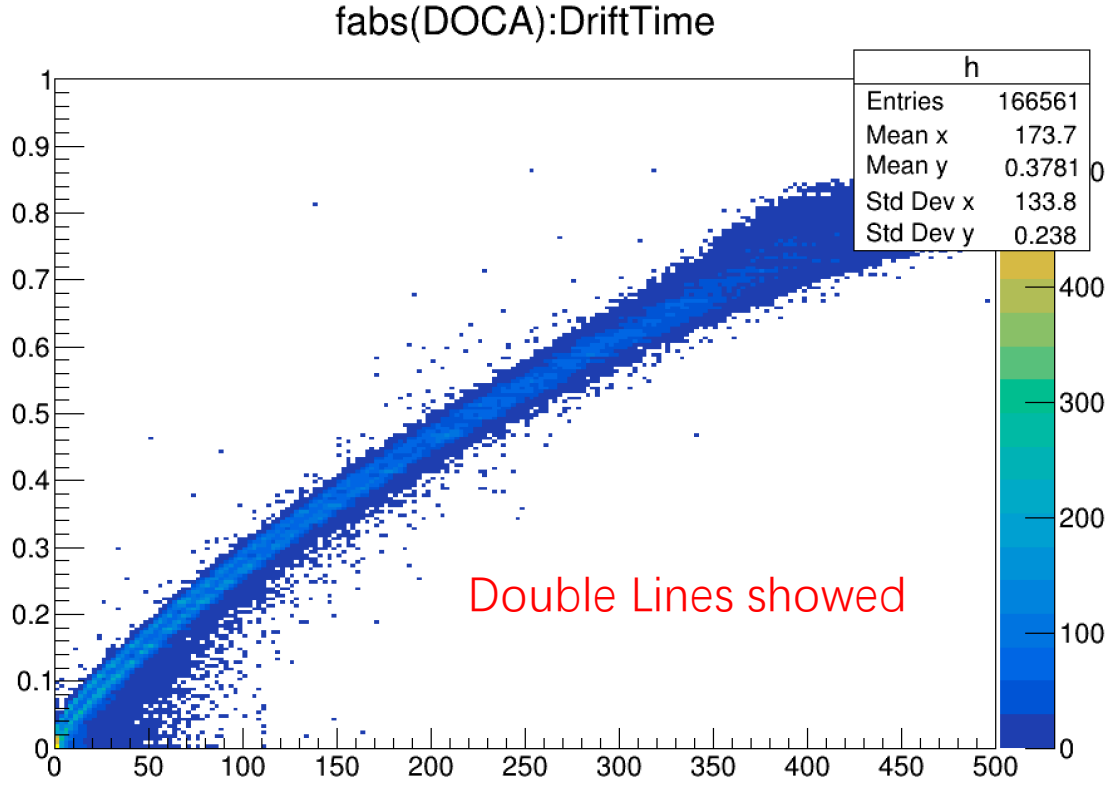


1T beta 30°

XT vs DOCA>0 and DOCA<0

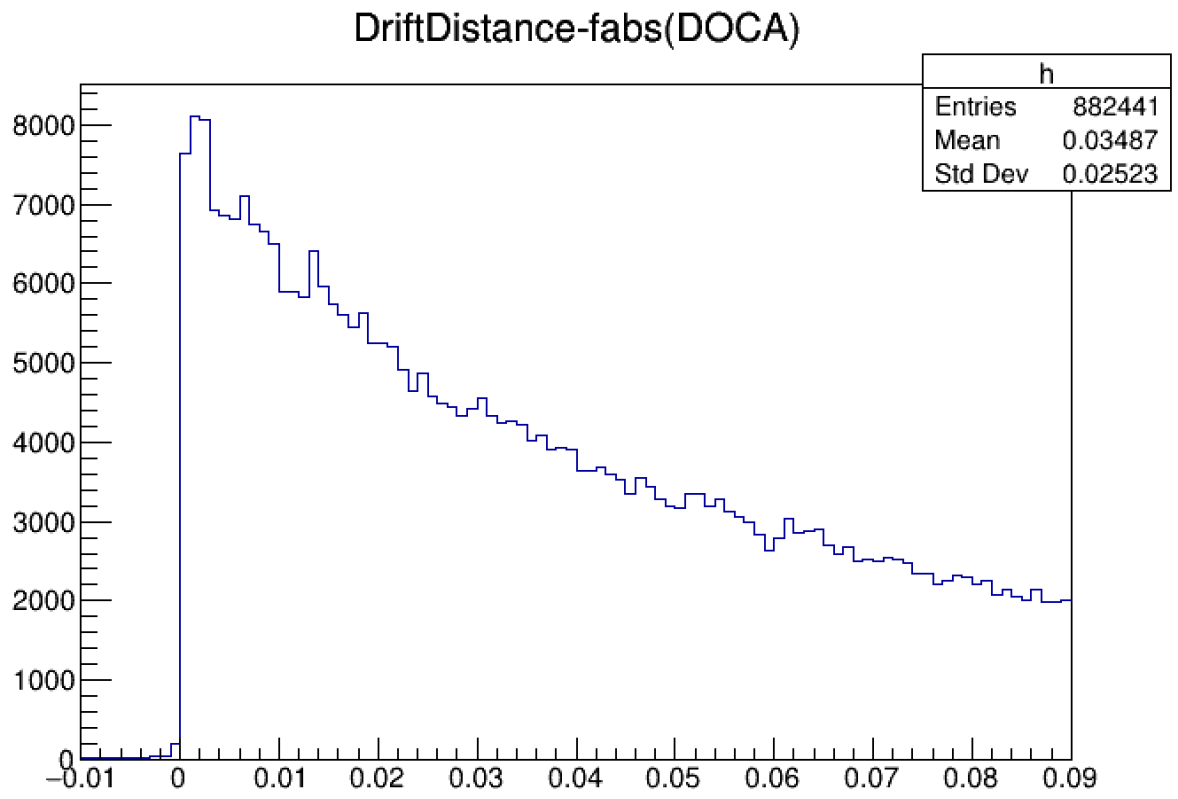


0T beta 30° 1GeV muon

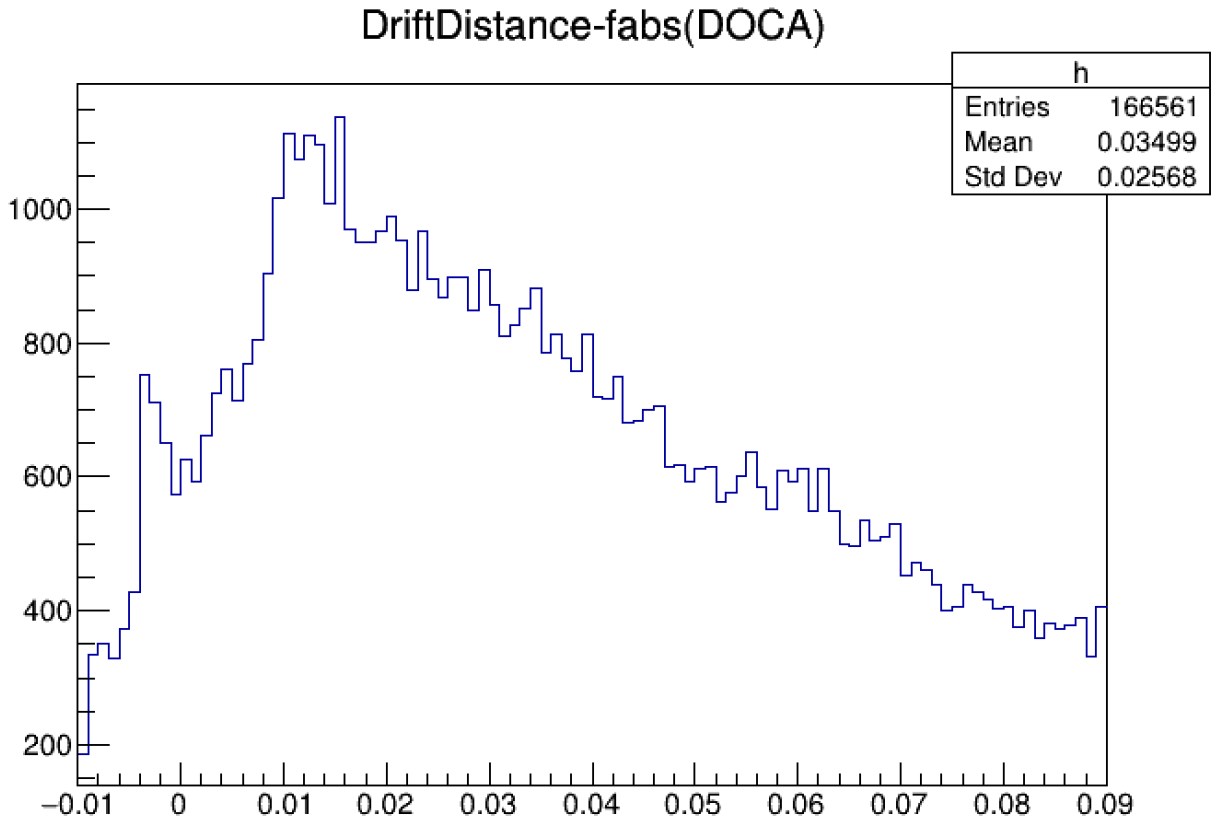


1T beta 30° 1GeV muon

DOCA vs DriftDistance



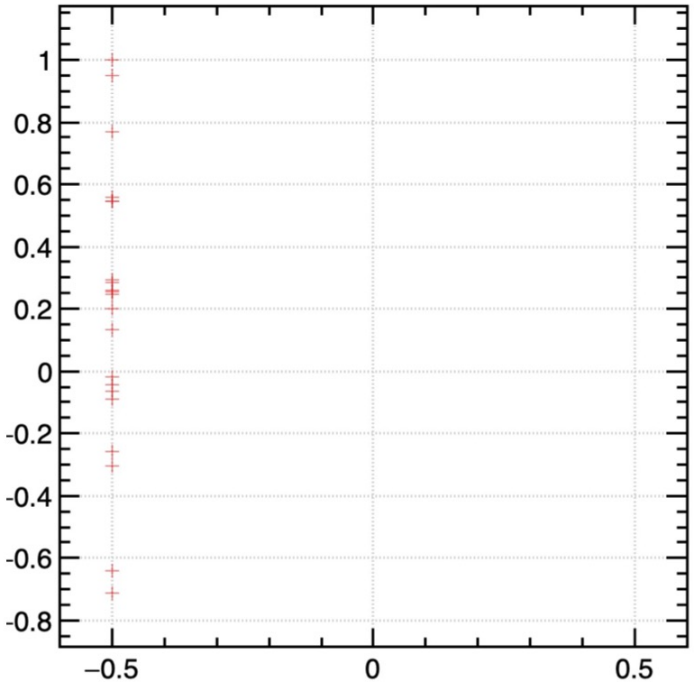
0T beta 30° 1GeV muon



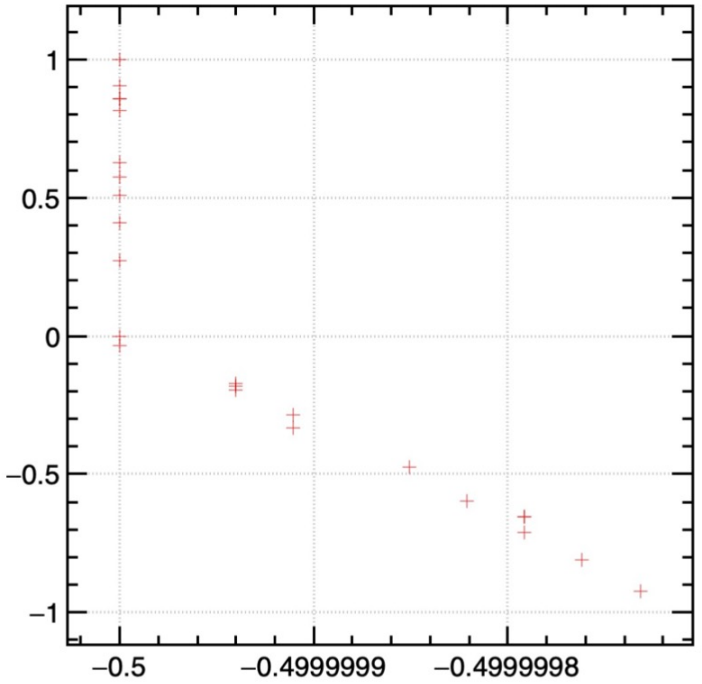
1T beta 30° 1GeV muon

Delay effect shows in 1T simulation

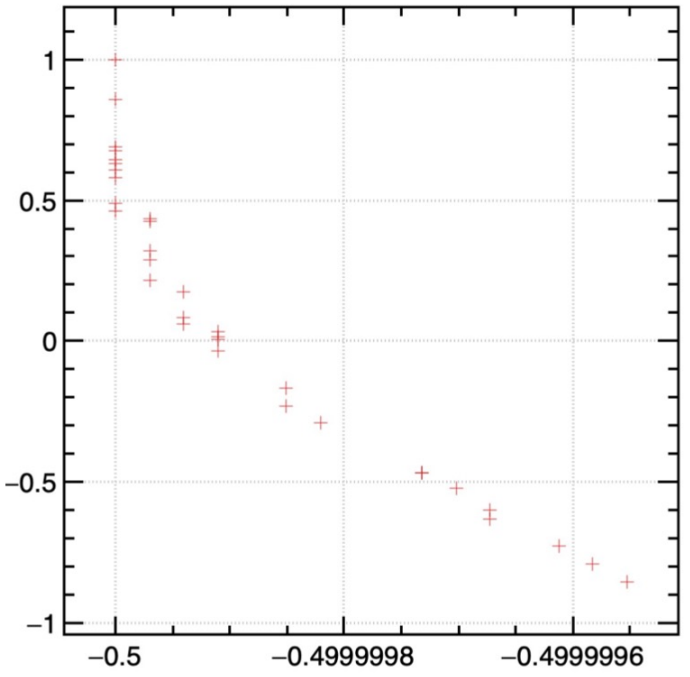
Error of DOCA Calculation in Simulation



Max step length 100 cm



Max step length 1 cm



Max step length 10 um

Error of DOCA calculation is small between using straight line or curvature model for track.