A study of Charge collection noise in the LGAD with Geant4 and TCAD

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Introduction

Timing resolution σ_t is given by $\sigma_t^2 = \sigma_{tw}^2 + \sigma_j^2 + \sigma_L^2$

σ_{tw}^2 : Time walk

σ_j^2 : Jitter

$\boxed{\sigma_L^2 \text{ : Landau noise}}$

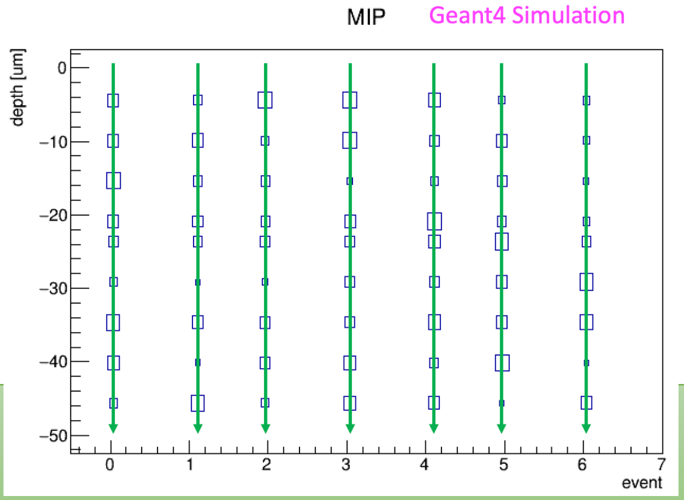
S : Pulse height

σ_n : Noise

t_r : Rise time

$$\sigma_j = \frac{\sigma_n}{\left|\frac{dV}{dt}\right|} = \frac{\sigma_n}{\left|\frac{S}{t_r}\right|} = \frac{t_r}{\left|\frac{S}{\sigma_n}\right|}$$

arises from varying energy deposit by particle in each event.



Landau noise : Charge collection noise

Motivation

Objective :

1. Calculate the magnitude of Landau noise
2. Optimize the sensor thickness

Method : Create a pulse shape using TCAD and Geant4

Geant4 : Energy deposit per event

TCAD: Pulse shape by charge at certain depth

Scale a pulse shape for each event using energy deposit.

Create a pulse shape in each event.

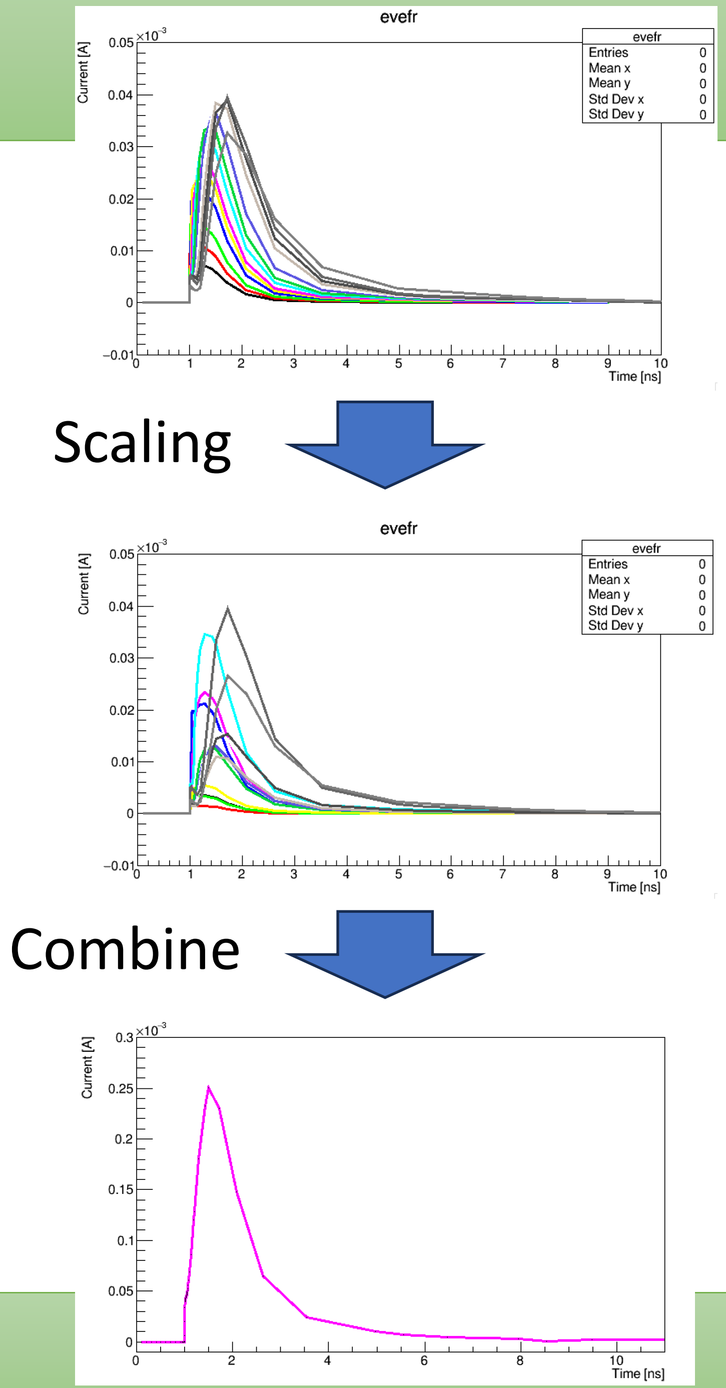
Method (TCAD&Geant4)

Pulse shape generation method

1. Prepare template for the pulse shape for energy deposit at each depth by TCAD.

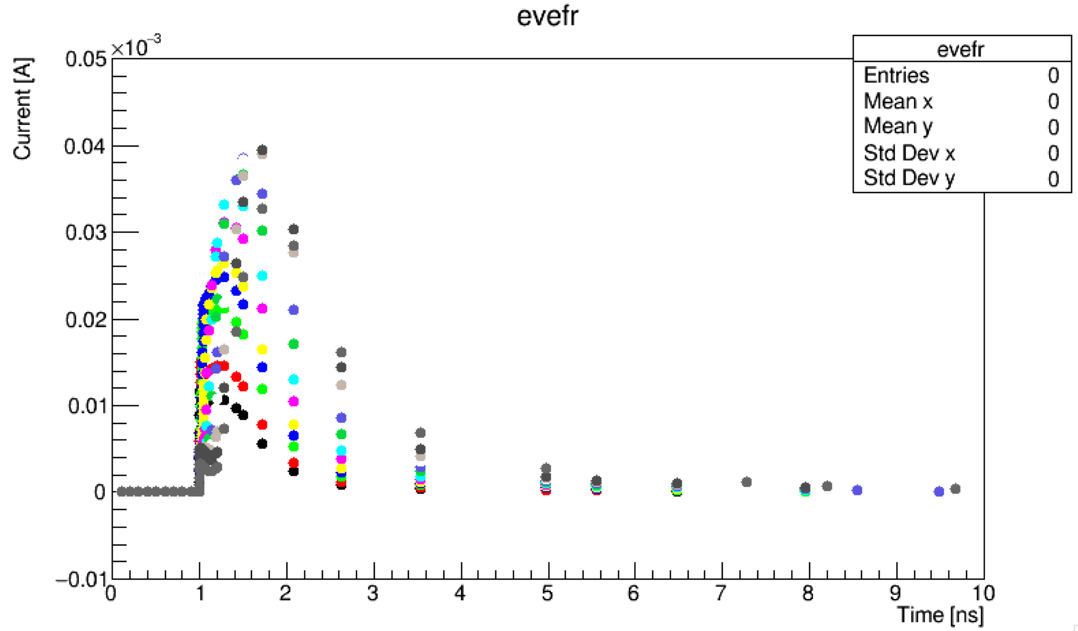
2. Scaled the pulse height template to the energy deposit simulated by Geant4.

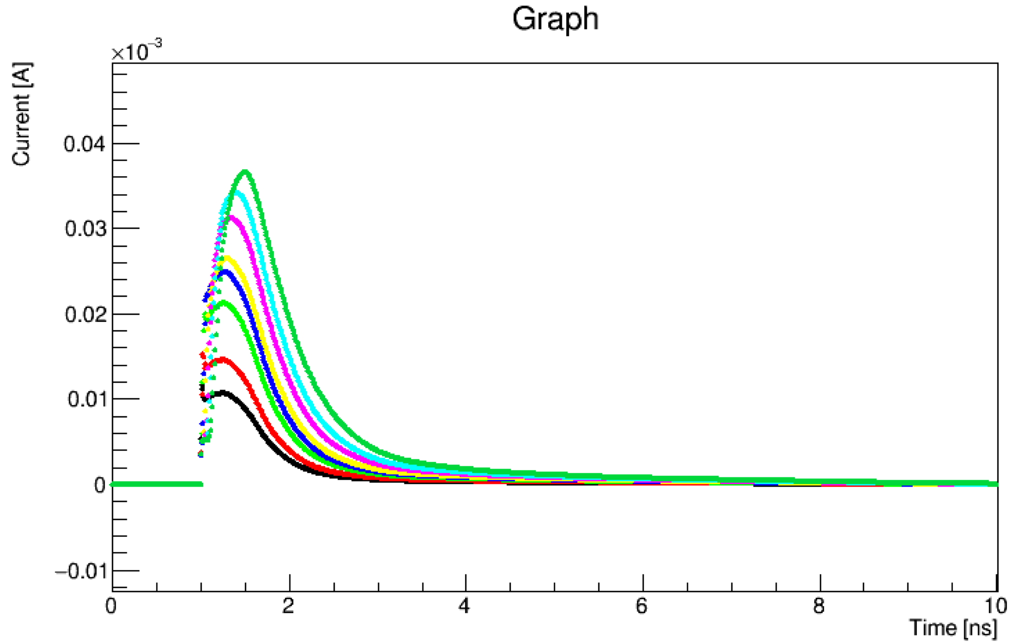
3. Combine all pulse shapes created by 2.



Method (TCAD&Geant4)

Interpolation of simulated points





Finding the arrival time is challenging due to non-continuous plots in TCAD.

→ Interpolate between data points.

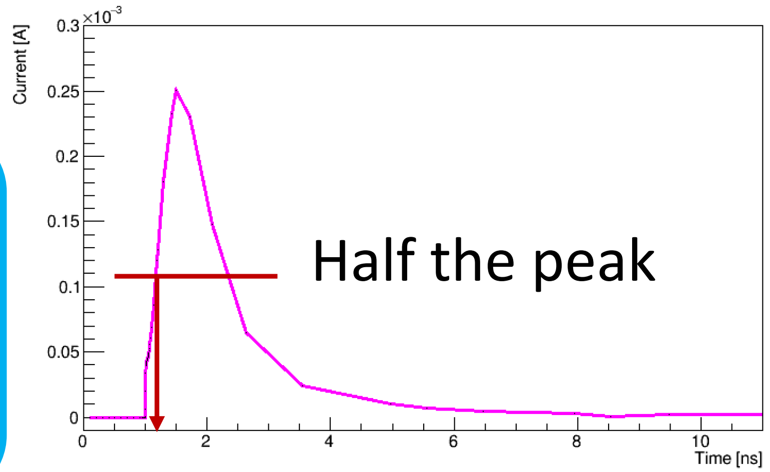
→ More accurately determining the arrival time at 50% constant fraction.

Method (TCAD&Geant4)

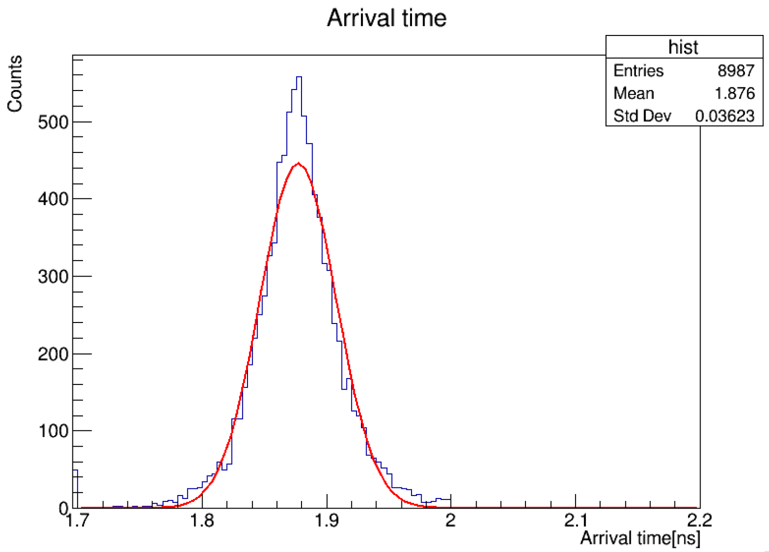
Arrival time

Defining Arrival time for the Signal : At half the peak
→ To disregard the term of σ_{tw}

$$\sigma_t^2 = \cancel{\sigma_{tw}^2} + \sigma_j^2 + \sigma_L^2$$



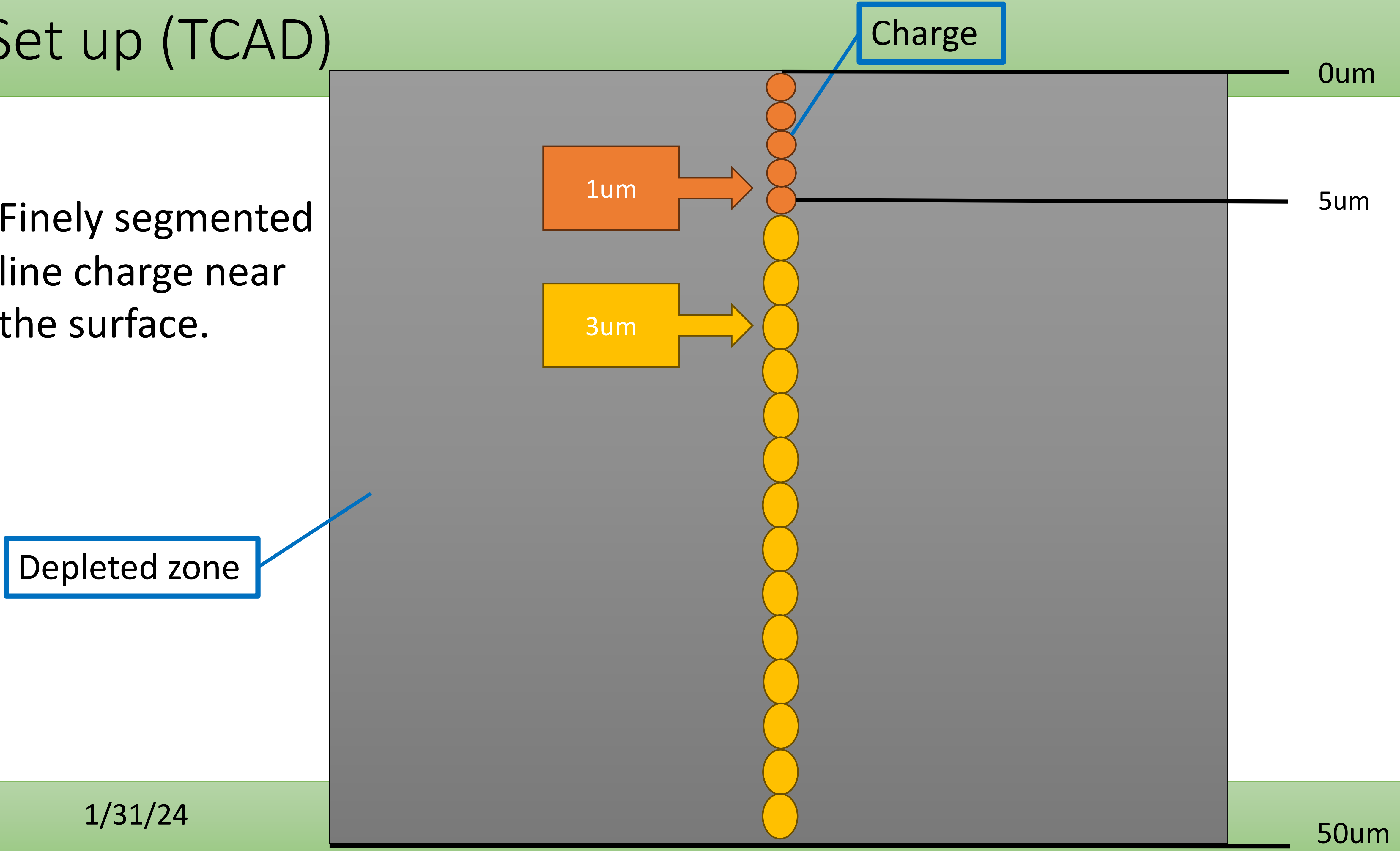
Create pulse shapes for 10,000 events.



1. Find the arrival time of pulse shape in each event.
2. Fill the arrival time of each event to the histogram and fit with a Gaussian.

Set up (TCAD)

Finely segmented line charge near the surface.



Set up (TCAD)

The Sensitive Detector region in the LGAD

- Active Thickness

Simulated pulse shape 10, 15, 20 ,30 ,40 ,50um with the same amount of charge at the certain depth.

- Temperature 20 ℃
- Bias Voltage for each thickness. → Use the voltage before break down.

Thickness [um]	20	50
Bias Voltage[V]	90	180

The Sensitive Detector region in the LGAD

- Thickness

Wafer (Thickness of the supporting wafer) 150um

Active Thickness (Thickness of the depleted zone) 10, 15, 20, 30, 40, 50um

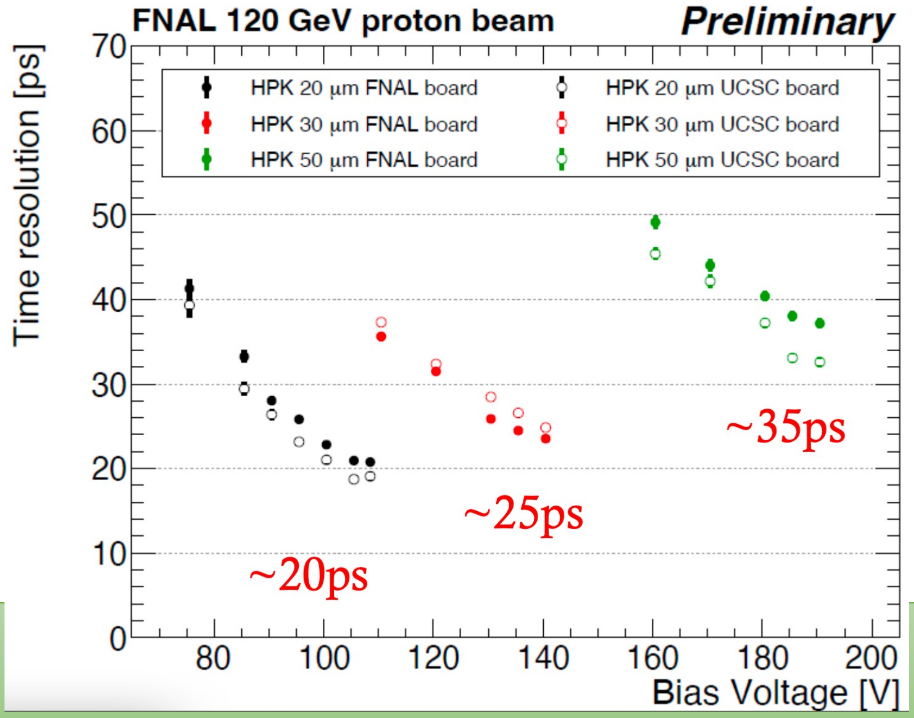
The Beam information

FTBF set-up

events : 10,000

particle : proton

energy : 120 GeV



Results(Geant4)

Example events : Depth profile of Energy deposit (proton)

Sum of energy deposit [eV/um] (1event)(max step 0.1um)[50um]

Edep(eV) / Depth	1event	2event	3event	4event	5event	6event	7event
1 um	154	255	147	154	115	104	39
2 um	212	18	213	1378	22	252	187
3 um	345	82	342	154	540	187	118
4 um	349	153	367	111	158	108	154
5 um	169	198	320	291	194	306	262
8 um	338	244	360	136	97	133	565
11um	165	223	84	144	154	100	32
14um	446	180	360	252	291	226	288
17um	313	183	1670	241	352	165	288

Results(TCAD&Geant4)

Landau noise (50um proton)

Fig 1 ： Signals from multiple events(1000events)

Fig 2 ： Filled Arrival time to the histogram and fited.

σ = 0.0366594 +– 0.000370517 [ns]

Landau noise = 36.7 +– 0.4ps

Value of measurement ： 35ps

Fig 1

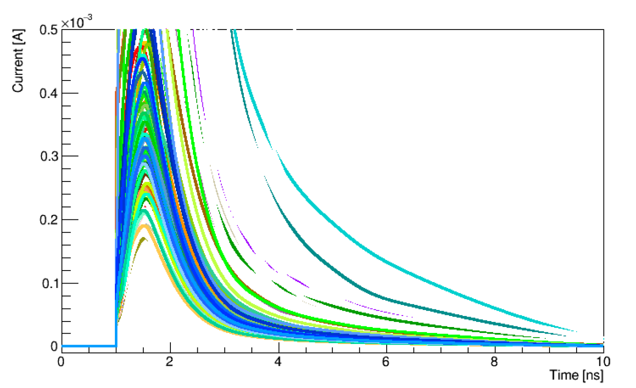
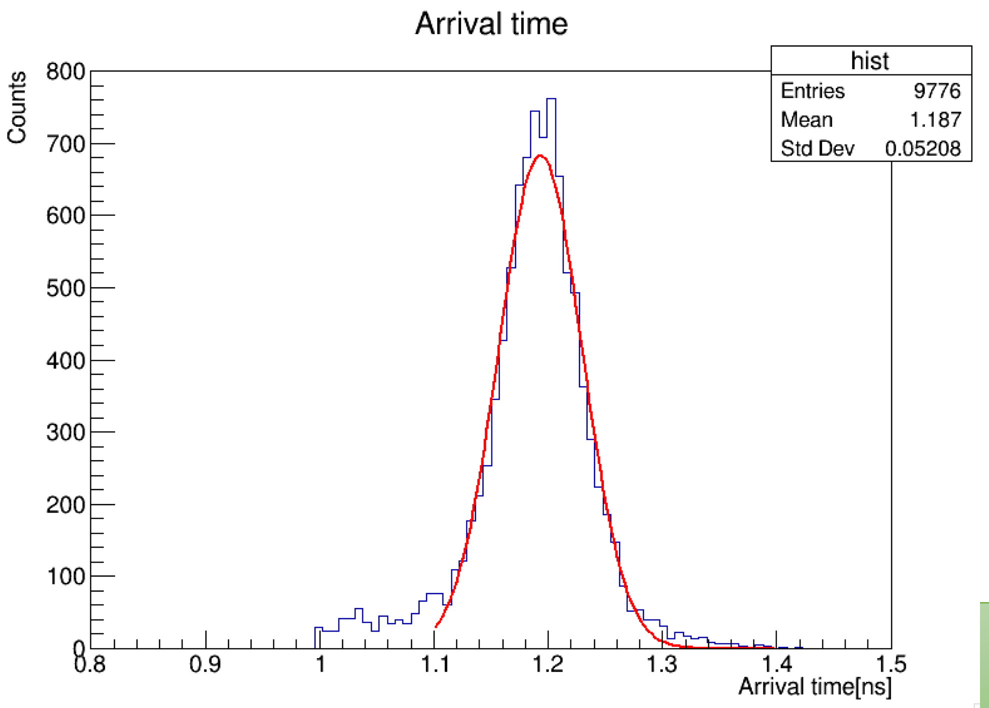
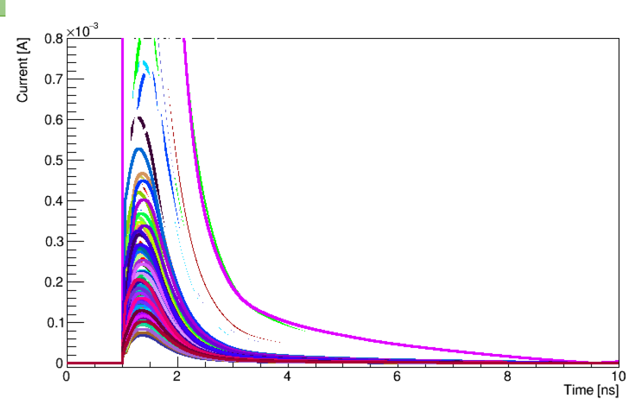


Fig 2



Results(TCAD&Geant4)

Fig 1



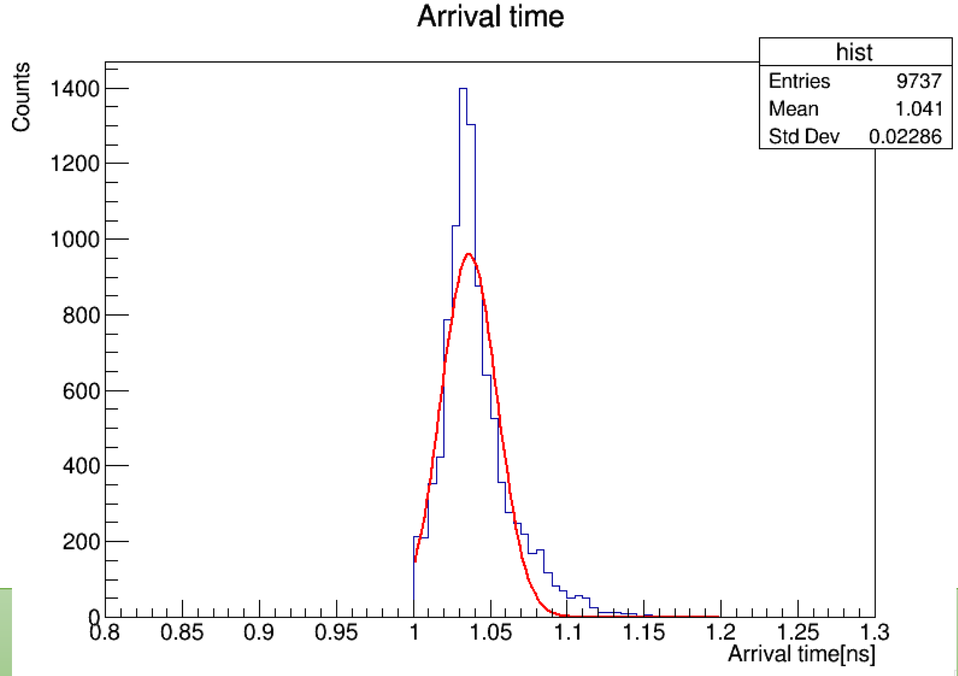
Landau noise (20um proton)

Fig 1 : Signals from multiple events(1000events)

Fig 2 : Filled Arrival time to the histogram and fited.

σ = 0.0182402 +- 0.000338450[ns]

Fig 2



Landau noise = 18.2 +- 0.3ps

Value of measurement : 20ps

Summary

- The charge collection noise (Landau noise) values obtaioned by simulation results are very close to testbeam results at FTBF.

To do

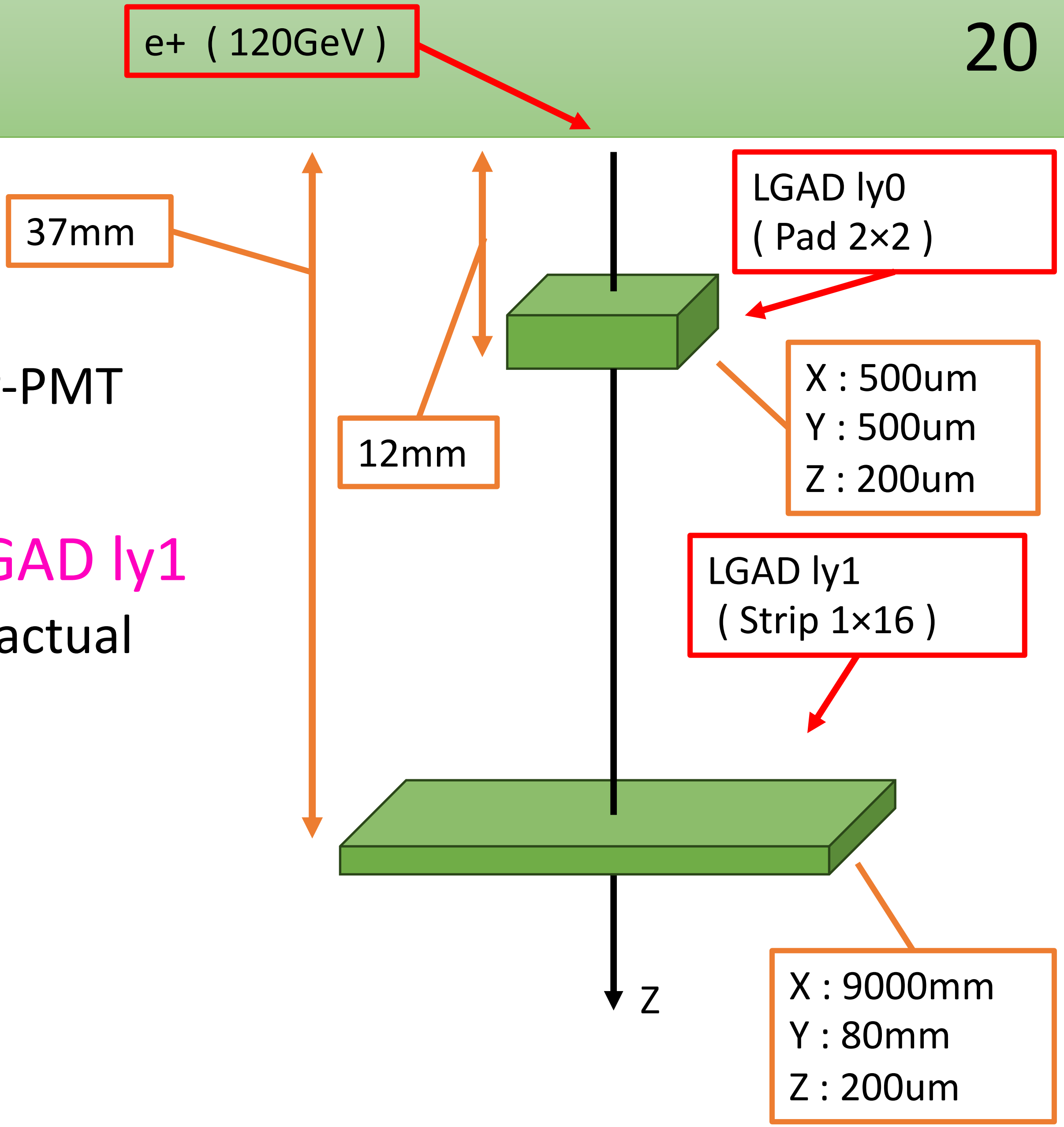
- Investigate the Landau noise for beta-ray.
- Investigate the Landau noise of other thickness to optimize sensor thickness.

Back up

Set up (Geant4)

The Geometry for proton

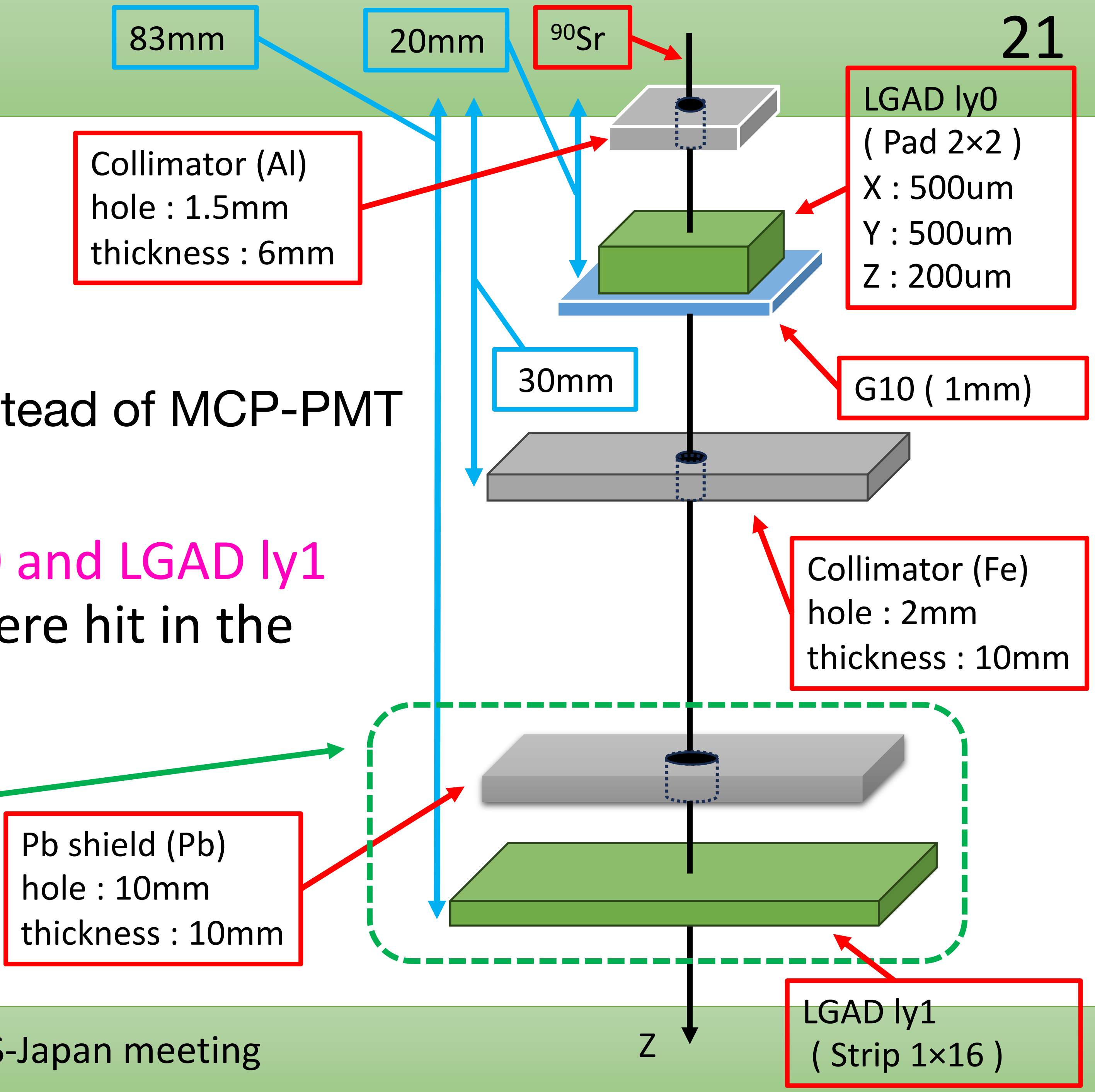
- Non-MCP-PMT
  → Assuming that lgad ly1 is used instead of MCP-PMT
- Proton beam
- Use only the events hit in LGAD ly0 and LGAD ly1
  → Only using events when both were hit in the actual measurement.

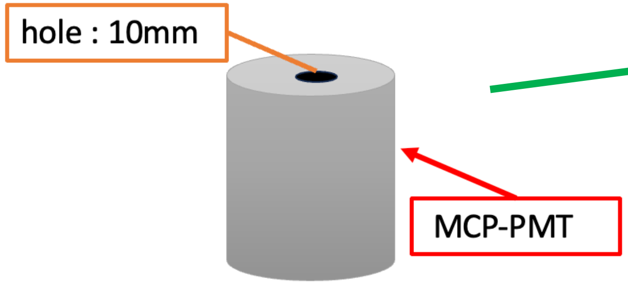


Set up (Geant4)

The Geometry for beta-ray

- Collimator (Pb , Fe , Al)
- Non-MCP-PMT
  → Assuming that lgad ly1 is used instead of MCP-PMT
- ^{90}Sr (β-ray)
- Use only the events hit in LGAD ly0 and LGAD ly1
  → Only using events when both were hit in the actual measurement.



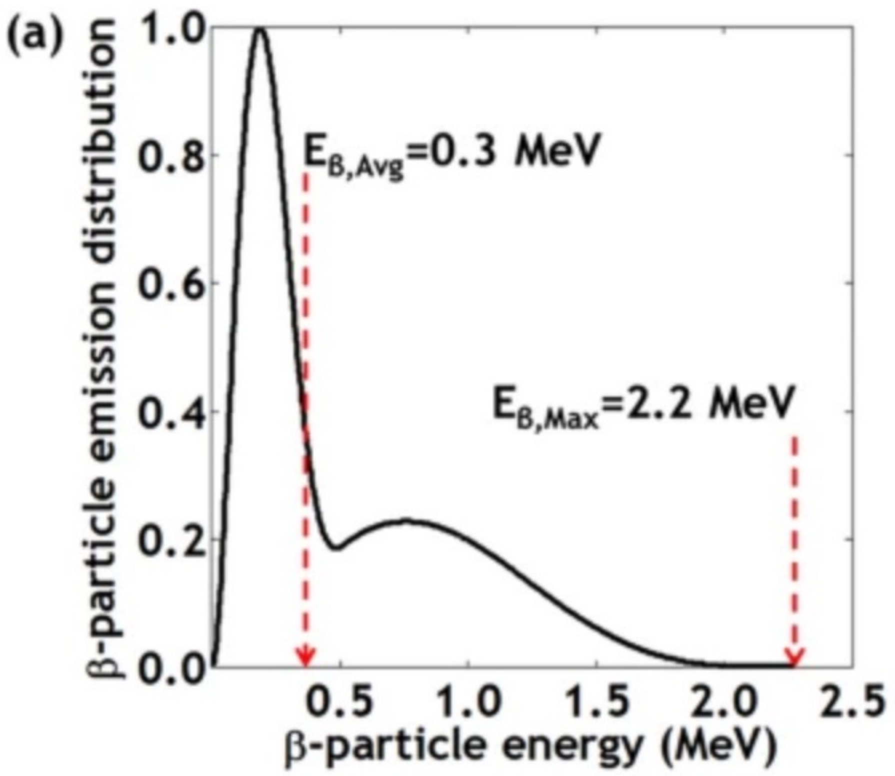


Set up (Geant4)

Spectrum of ^{90}Sr

- The spectrum of β-ray is given by this.
- For reproduction in Geant4 , mean and std-dev are necessary.
  → Attempt reproduction.

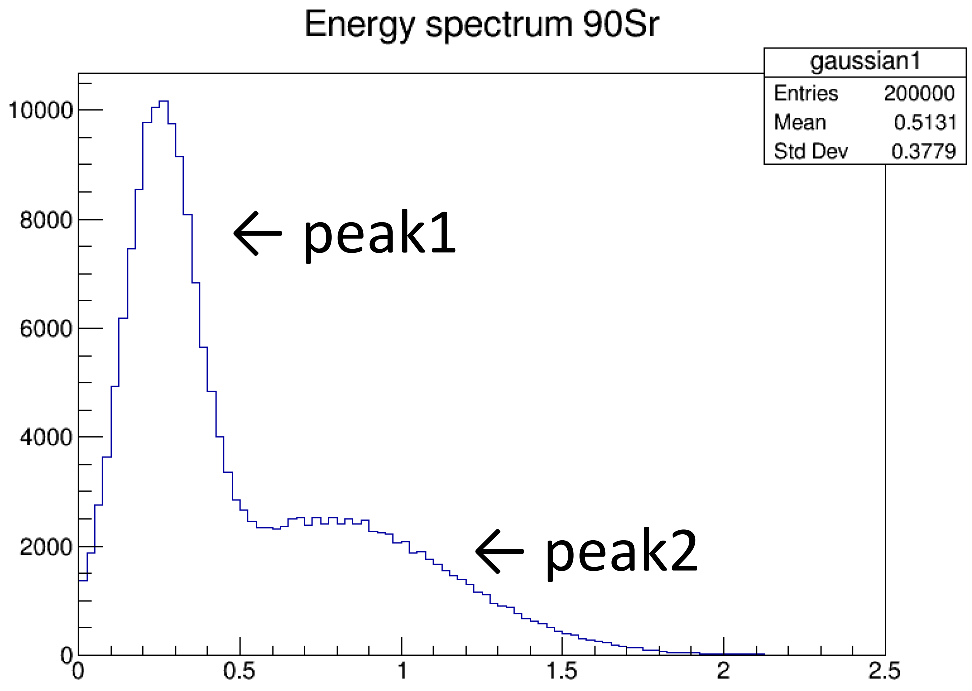
Figure 1



Ref :https://www.nature.com/articles/srep38182

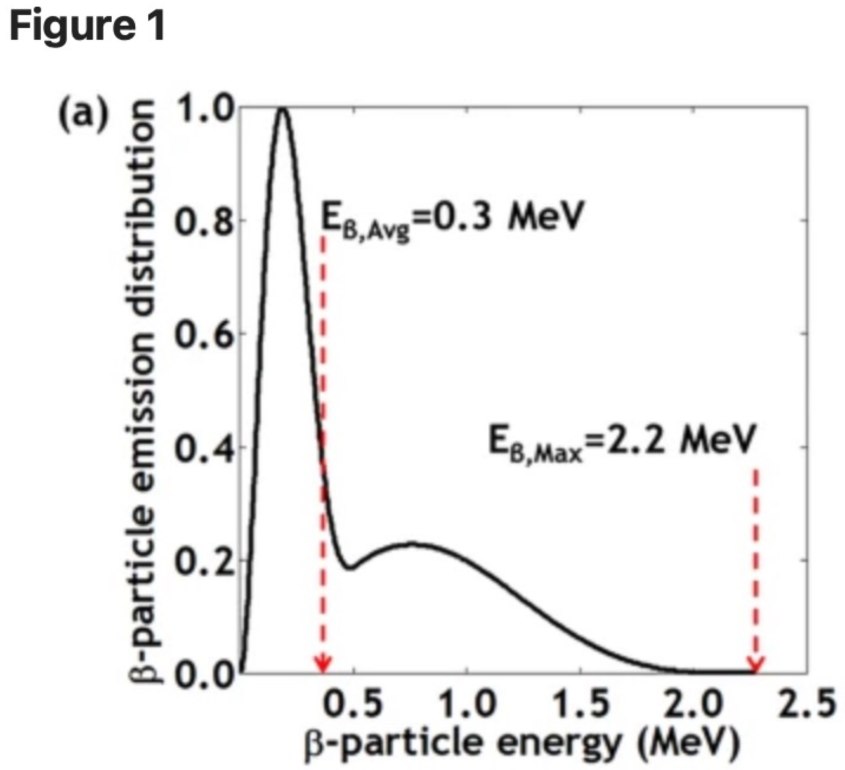
Spectrum of ^{90}Sr

Successfully reproduced？ Max Energy [peak1 : 0.54MeV , peak2 : 2.2MeV]



peak1 : mean = 0.25 , std_dev = 0.11

peak2 : mean = 0.75 , std_dev = 0.4

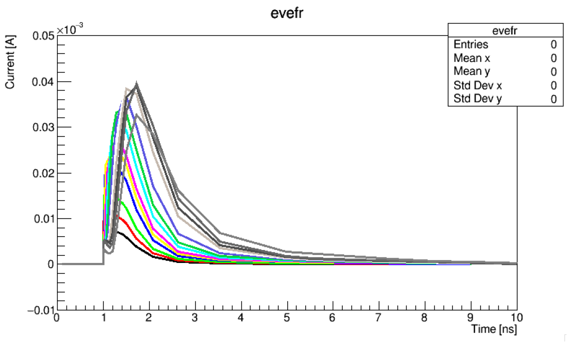


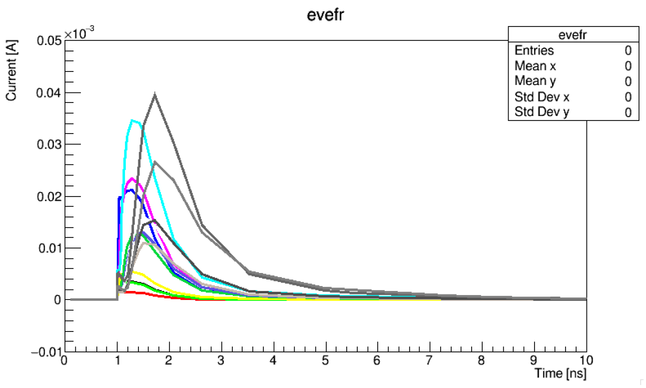
Ref :https://www.nature.com/articles/srep38182

Scaling process

Edep/3.6 = [?] eh pairs

Pulse shape x [?] /86





Example

Depth	Edep(eV) 1event	eh pairs
5 um (1-5um)	632	87
10 um(6-10um)	600	83
20 um(16-20um)	568	78
25 um(21-25um)	480	66
30 um(26-30um)	292	40
35 um(31-35um)	911	126
40 um(36-40um)	721	100
45 um(41-45um)	306	42

÷3.6

Beta-ray

Results(TCAD&Geant4)

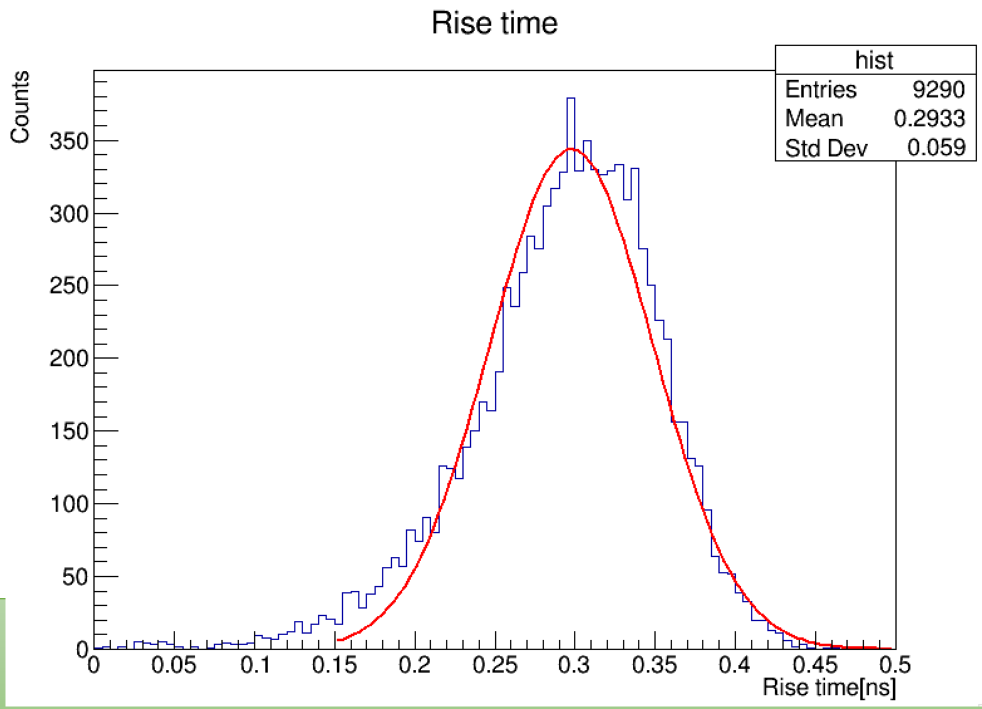
50um beta-ray

右下図： 得られた Rise time を histに詰め、gausで fit

Rise time ：Peakの 20% と80% における到達時間の差を Rise timeとする。

σ = 0.0511741 +- 0.000428595

Rise time = 51.2+- 0.4ps



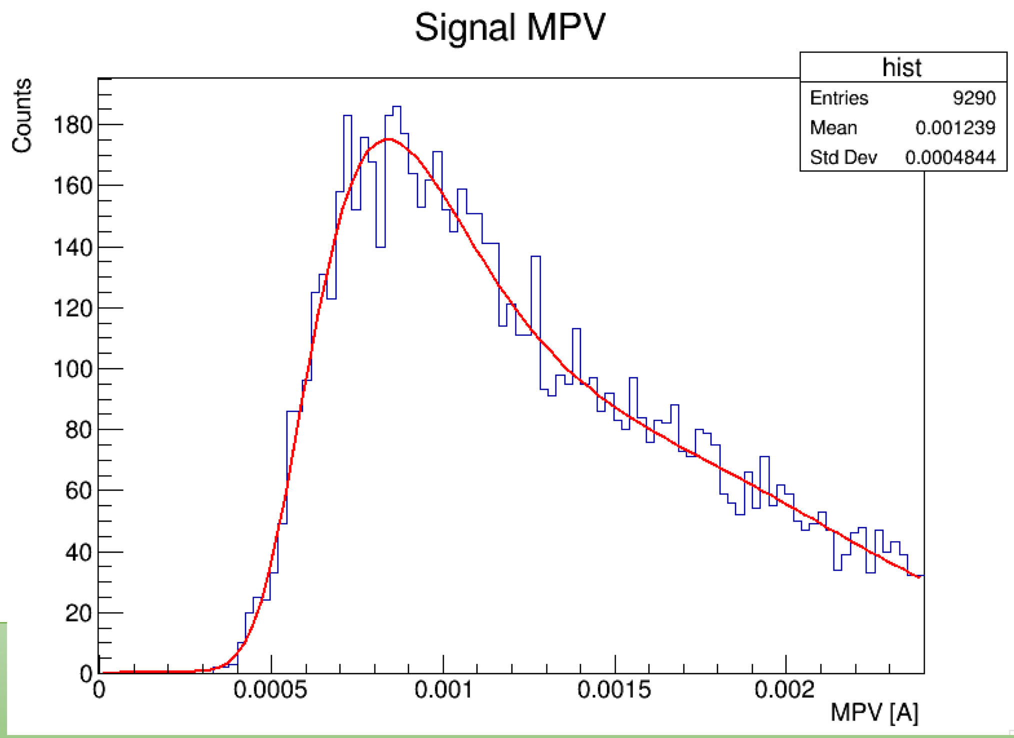
Results(TCAD&Geant4)

50um beta-ray

右下図：右上図のPulse Shape から得られるMPVを
histに詰め、landau+gaus で fit

MPV = 0.867660 +- 0.0133960 [A]

MPV = 867.7+- 13.4mA



Results(TCAD&Geant4)

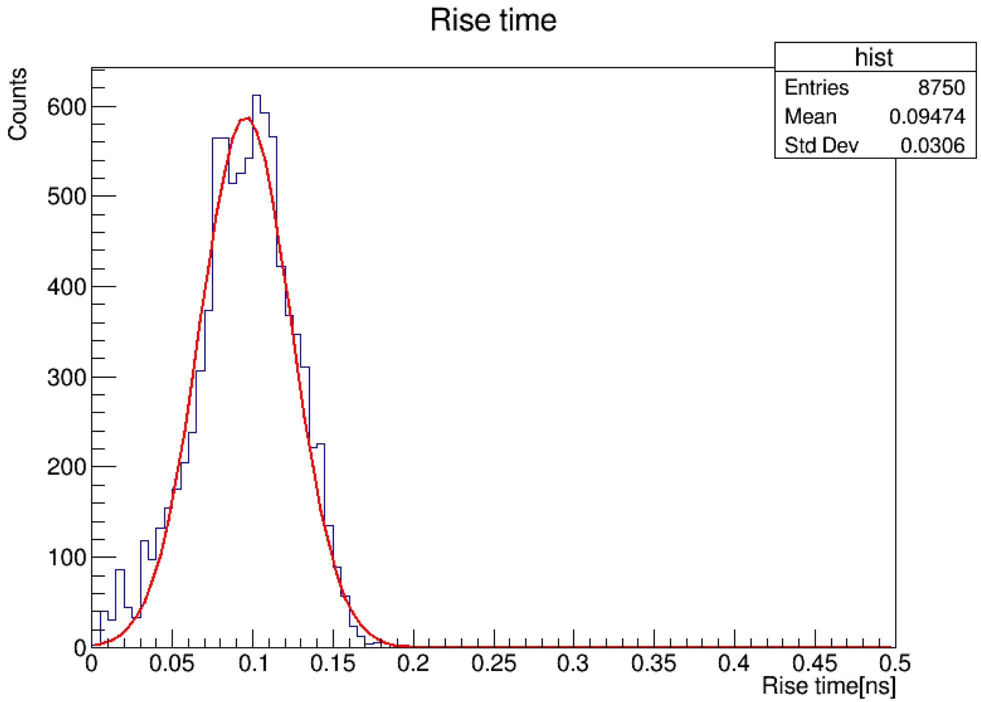
20um beta-ray

右下図： 得られた Rise time を histに詰め、gausで fit

Rise time ：Peakの 20% と80% における到達時間の差を Rise timeとする。

σ = 0.0284967 +− 0.000230491

Rise time = 28.5+− 0.2ps



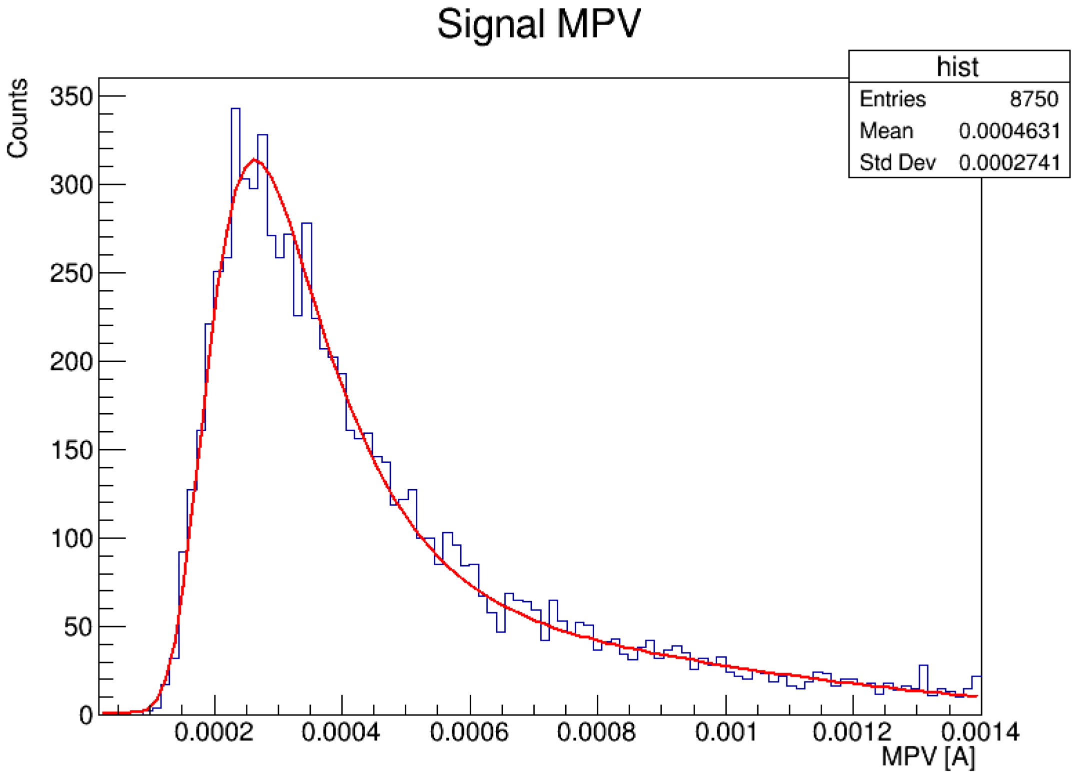
Results(TCAD&Geant4)

20um beta-ray

右下図：右上図のPulse Shape から得られるMPVを
histに詰め、landau+gaus で fit

MPV = 0.276459 +- 0.0224658 [A]

MPV = 276.5+- 2.2mA



Proton

Results(TCAD&Geant4)

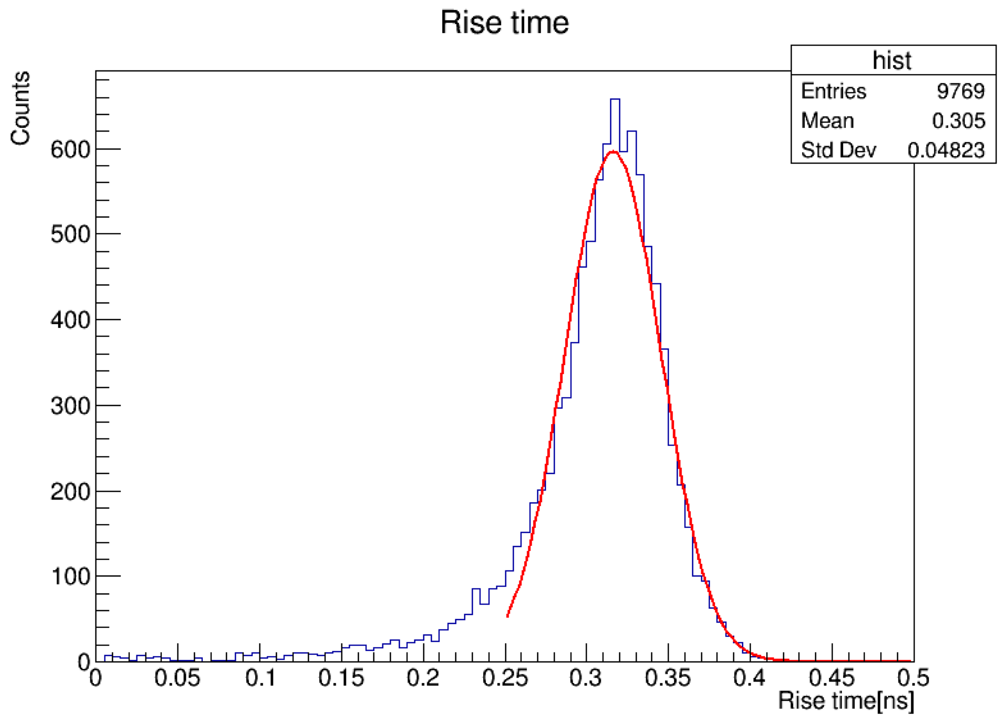
50um proton

右下図： 得られた Rise time を histに詰め、gausで fit

Rise time ：Peakの 20% と80% における到達時間の差を Rise timeとする。

σ = 0.0294424 +- 0.000284029

Rise time = 29.4+– 0.3ps



Results(TCAD&Geant4)

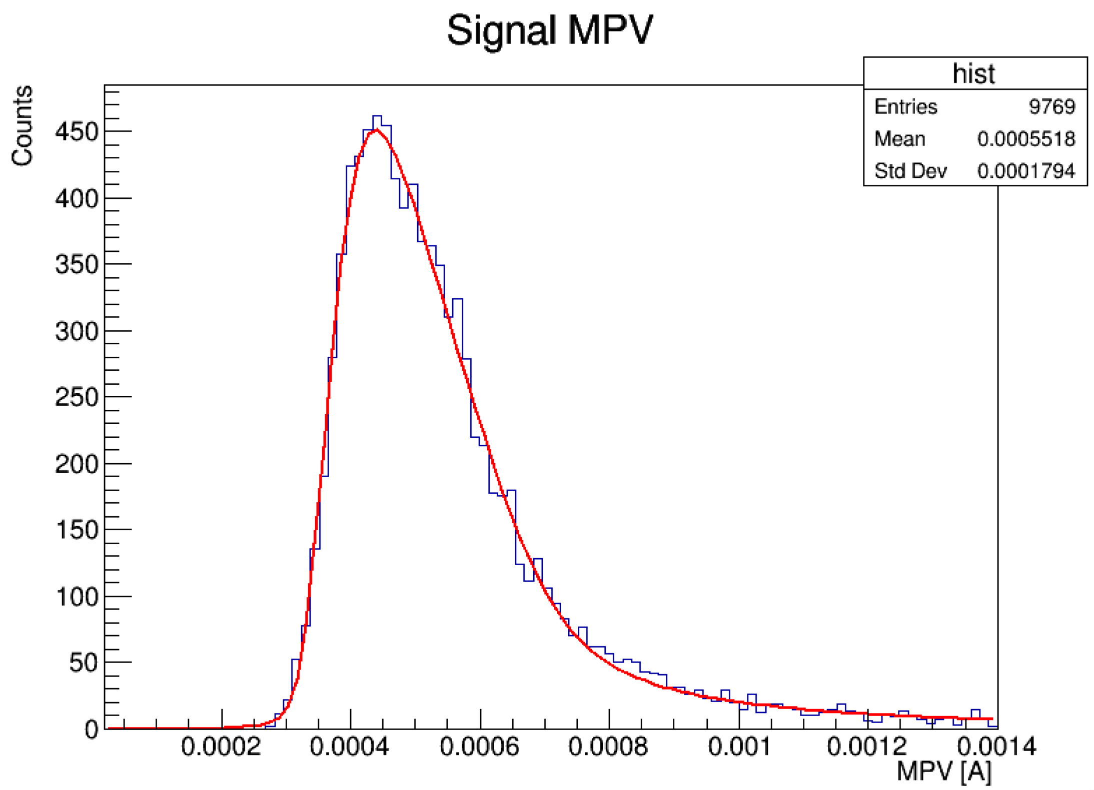
50um proton

右下図：右上図のPulse Shape から得られるMPVを
histに詰め、landau +gausで fit

0.438359 +− 0.00182167

MPV = 0.438359 +− 0.00182167 [A]

MPV = 438.4+− 1.8mA



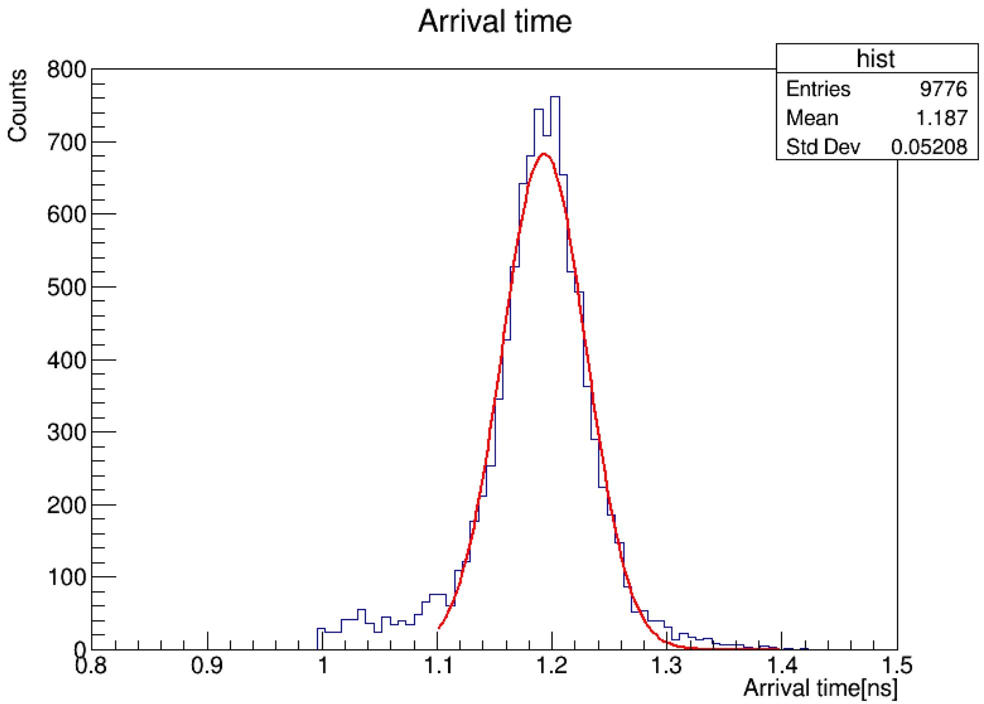
Results(TCAD&Geant4)

50um proton

右下図： 得られた arrival time を histに詰め、gausで fit

σ = 0.0366594 +- 0.000370517

Landau noise = 36.7+–0.4ps



Results(TCAD&Geant4)

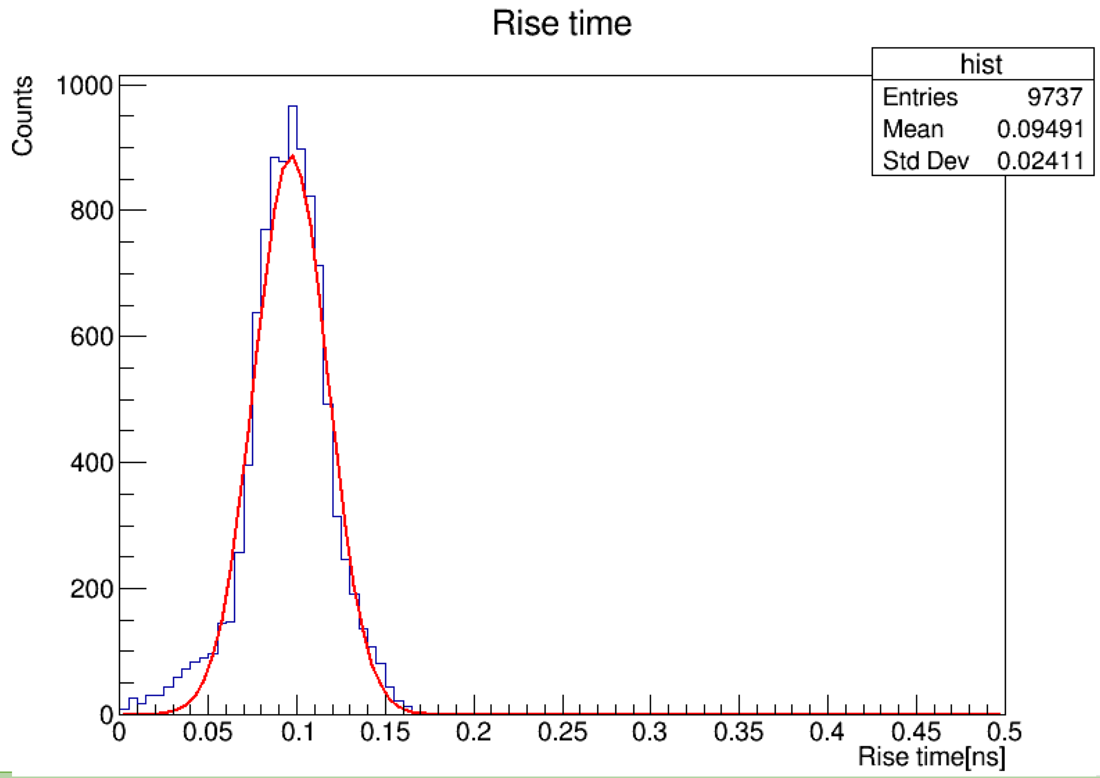
20um proton

右下図： 得られた Rise time を histに詰め、gausで fit

Rise time ：Peakの 20% と80% における到達時間の差を Rise timeとする。

σ = 0.0208266 +− 0.000216161

Rise time = 20.8+− 0.2ps



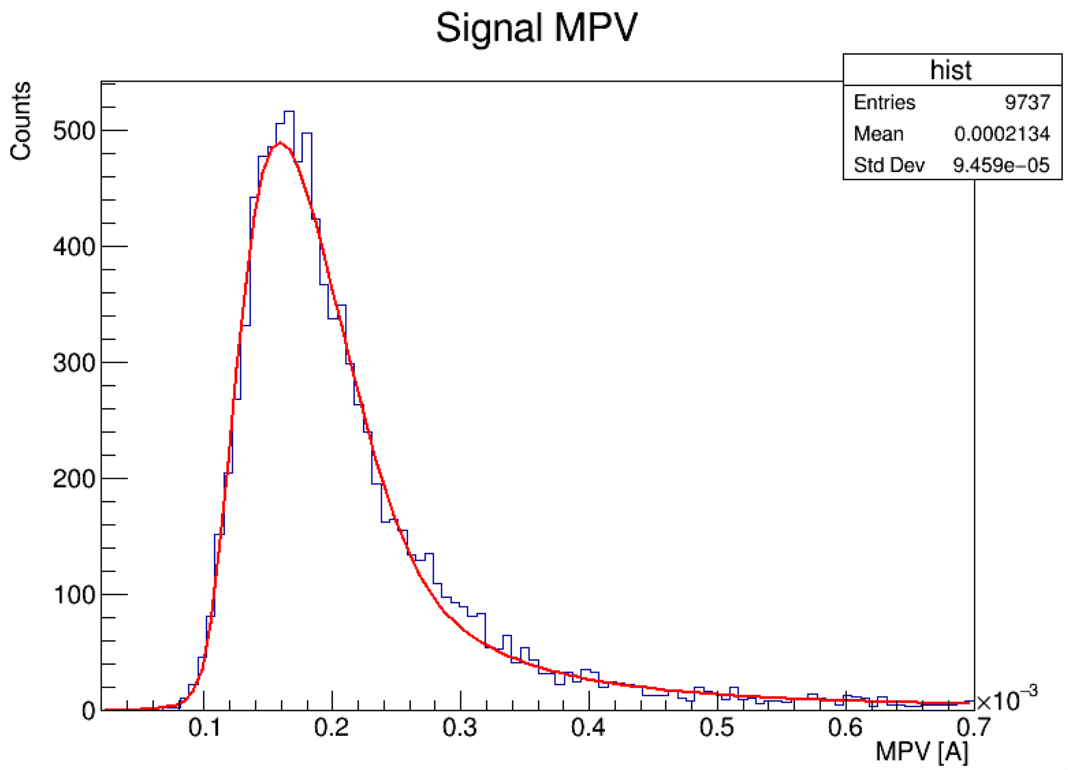
Results(TCAD&Geant4)

20um proton

右下図：右上図のPulse Shape から得られるMPVを histに詰め、landau +gausで fit

MPV = 0.159041 +- 0.00118928 [A]

MPV = 159.0+- 1.2mA



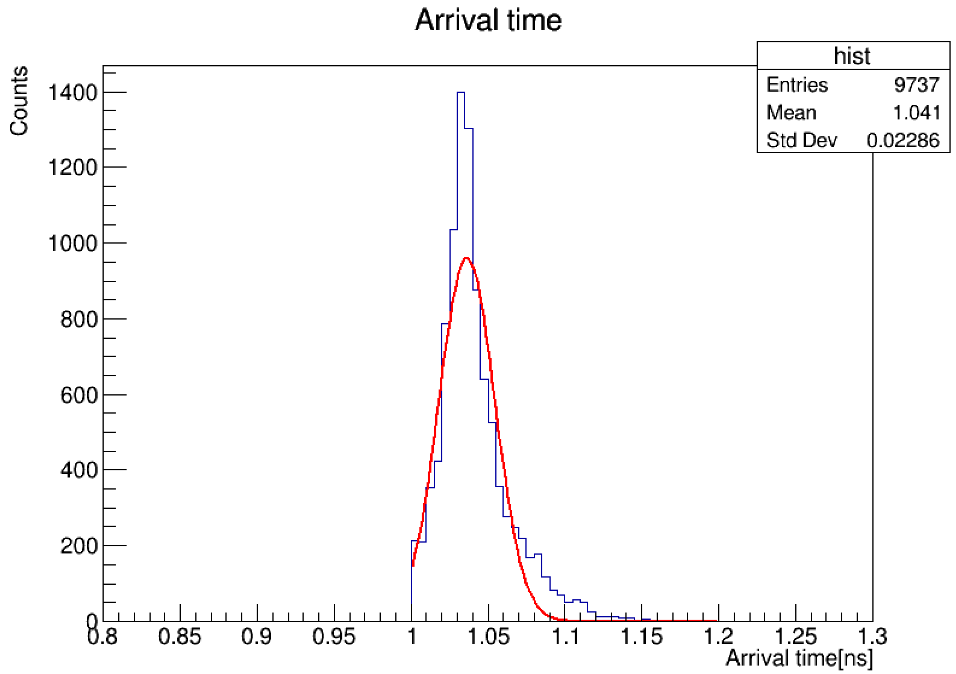
Results(TCAD&Geant4)

20um proton

右下図：得られた arrival time を histに詰め、gausで fit

σ = 0.0182402 +- 0.000338450

Landau noise = 18.2+- 0.3ps



Other

Set up (Geant4)

Threshold and Cut-off

- Threshold Secondary particles producted → Cuts below 0.0um
- Cut-off energy deposit → 0.0 mV
- Limits of step → depl 0.1um , wafer 1mm , respectively
- Only interactions involving charged particles
- Plotted the only events of hits in LGAD ly0 and LGAD ly1
  → Only using events when both were hit in the actual experiment

Set up (Geant4)

タイムウォークの軽減

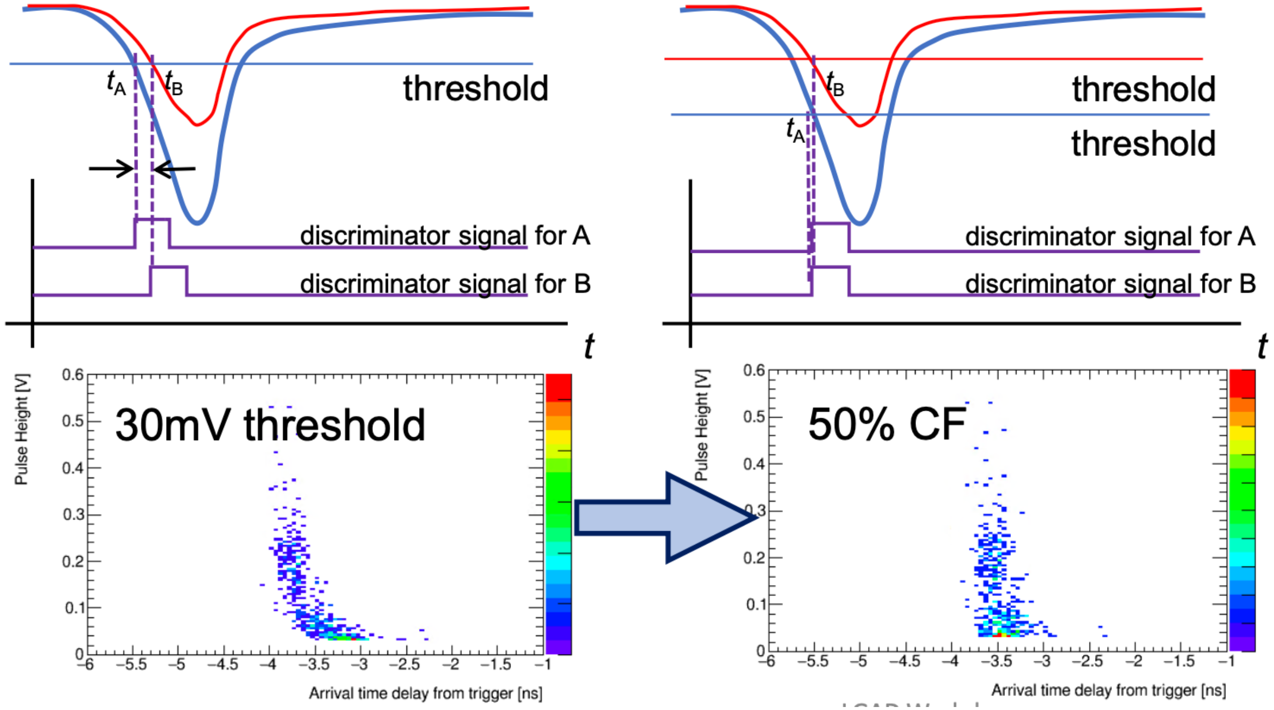
時間分解能

$$\sigma_t^2 = \sigma_{tw}^2 + \sigma_j^2 + \sigma_L^2$$

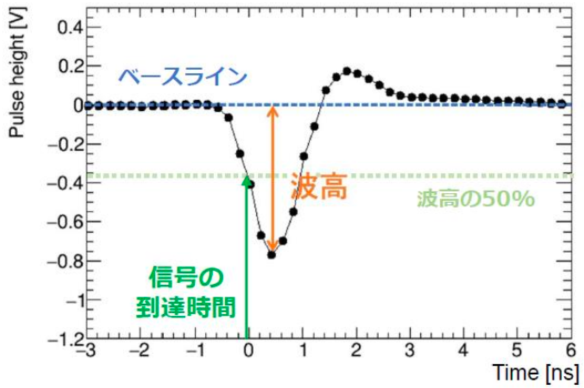
Constant Fraction (CF) 閾値を利用

例えば50%CFなら…

Fixed threshold　　CF threshold



波高ごとに信号の到達時間のthresholdを変える



信号の大きさによるArrivalTimeの影響が減少？