Study on energy resolution of the dual-readout calorimeter for future e+e- colliders using GEANT4 simulation and the first test-beam data

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Saga-Yonsei Joint Workshop XIX

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Introduction

● Simulation results

◎ Simulation with EM (e^-) and hadron (pi^+)

- Geometry setup : 4pi full wedge geometry
- Optical physics for each Cerenkov and scintillation fiber is implemented
- Calibration is done with 20 GeV e^-
- Energy resolution for each EM and hornic particle is measured.

● Prompt analysis with TB data

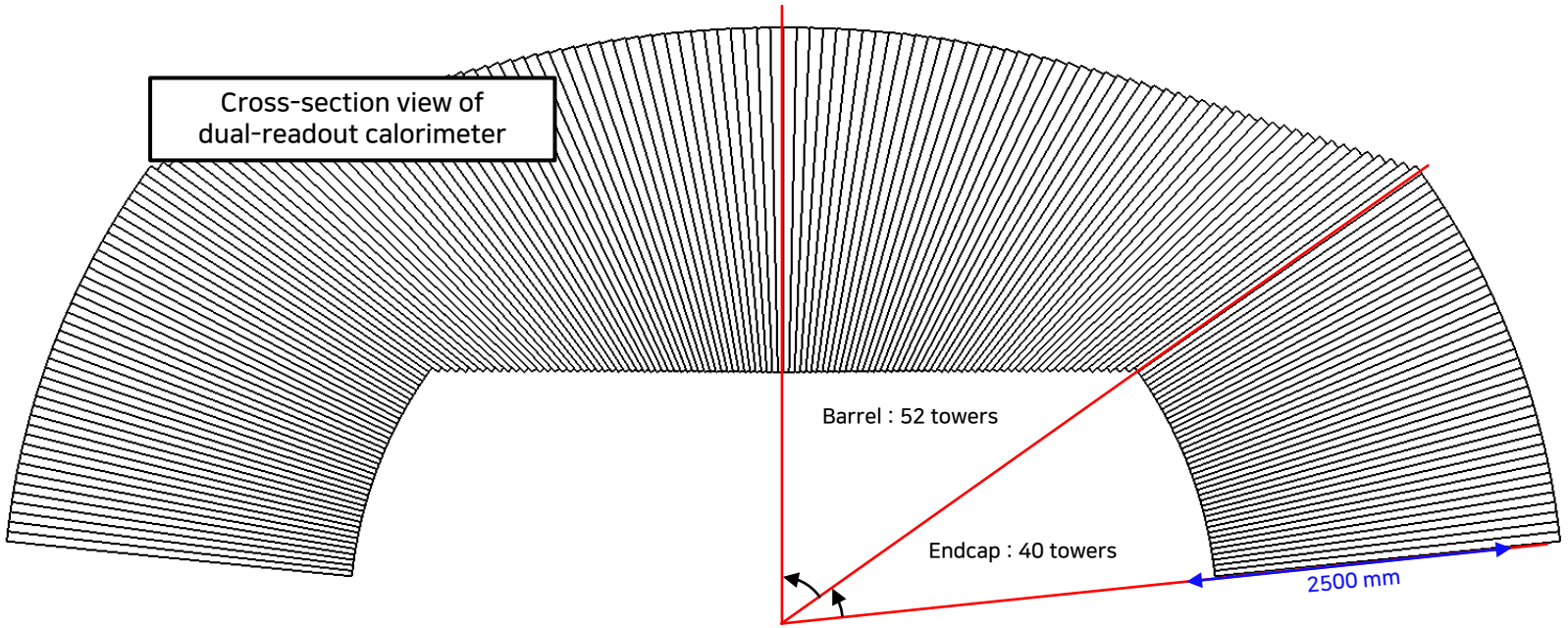
◎ ”Very preliminary” result will be presented.

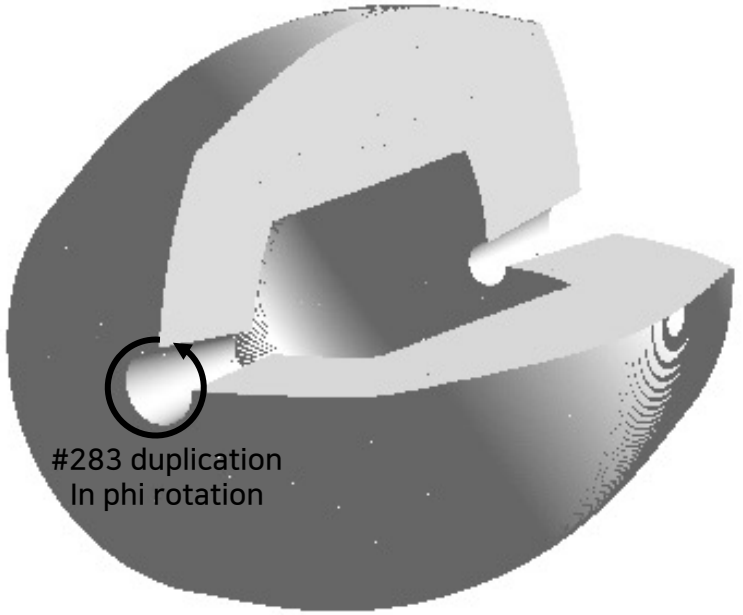
◎ To get energy resolution we have to do PID at the very first stage.

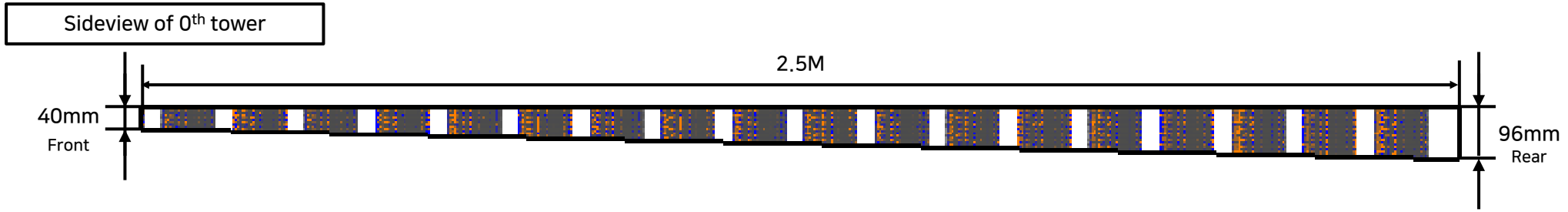
- PID is done with auxiliary detector. (Pre-shower, Muon counter, Delayed wire chamber and etc.)

GEANT4 simulation setup

- **Geometry setup**

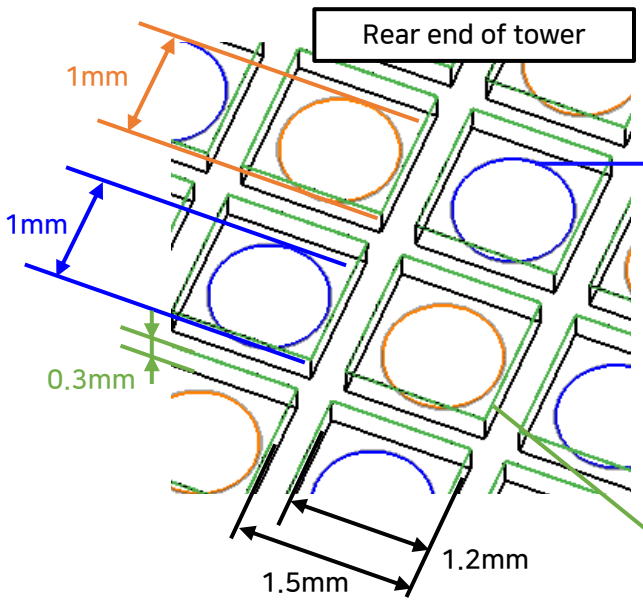




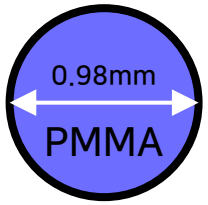


GEANT4 simulation setup

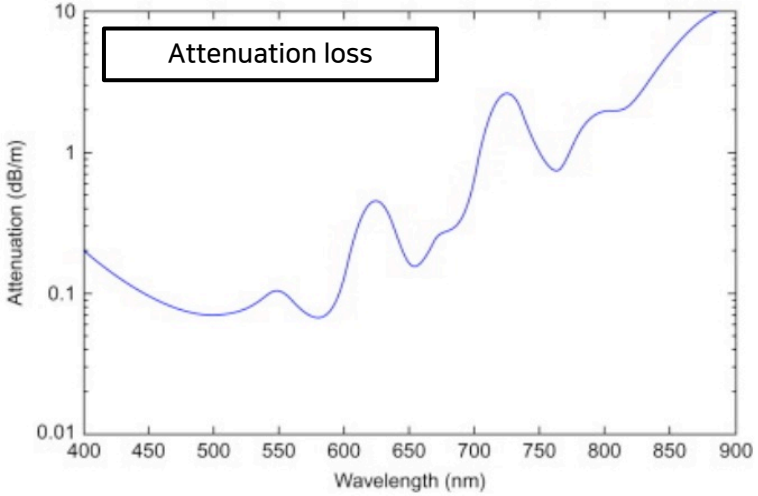
- **Optical setup**



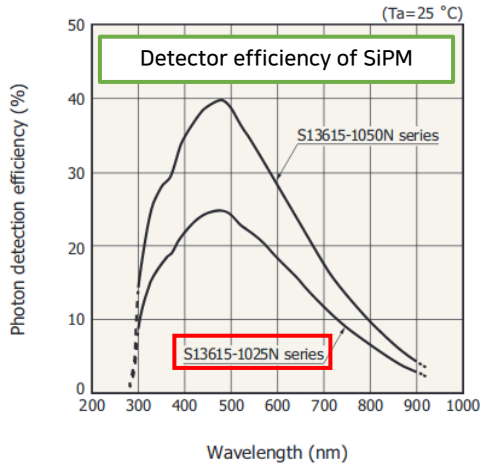
Cerenkov channel



- Eska SK40 (Mitsubishi)



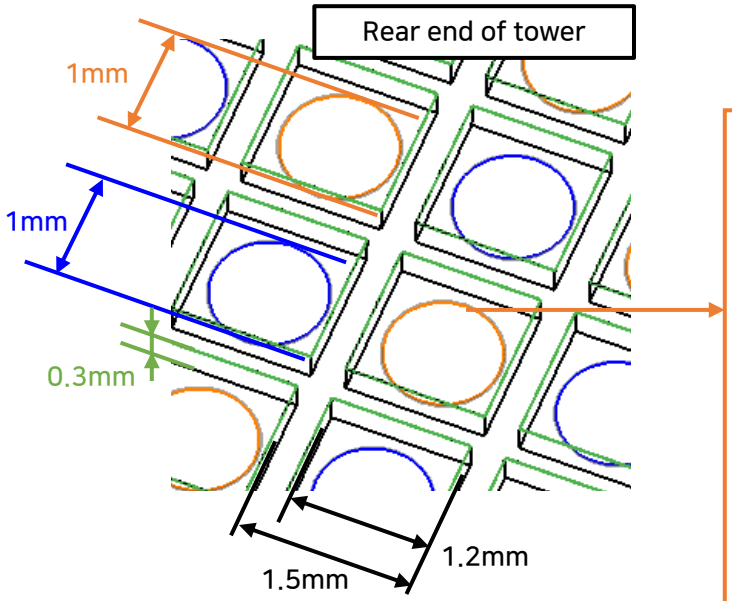
SiPM



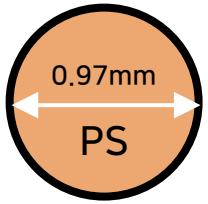
- S13615-1025N (Hamamatsu)

GEANT4 simulation setup

- **Optical setup**

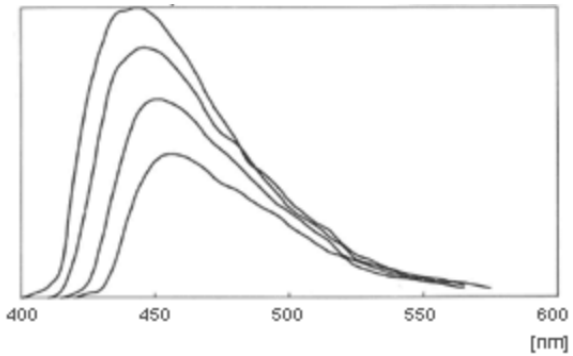


Scintillation channel

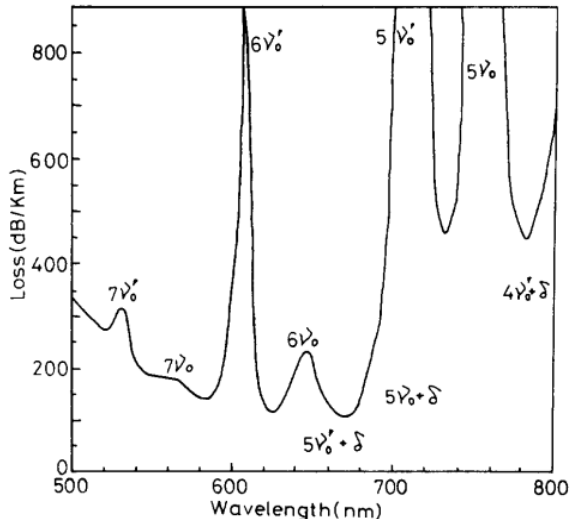


- SCSF-78 (Kuraray)

Scintillation spectra

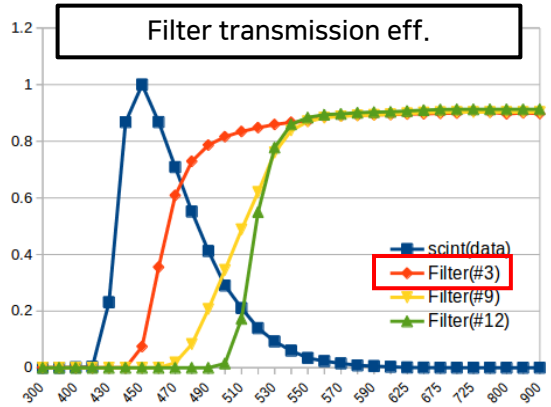


Attenuation loss



- Attenuation diverges under 500nm – to moderate it, filter is applied to scintillation fiber

Filter transmission eff.

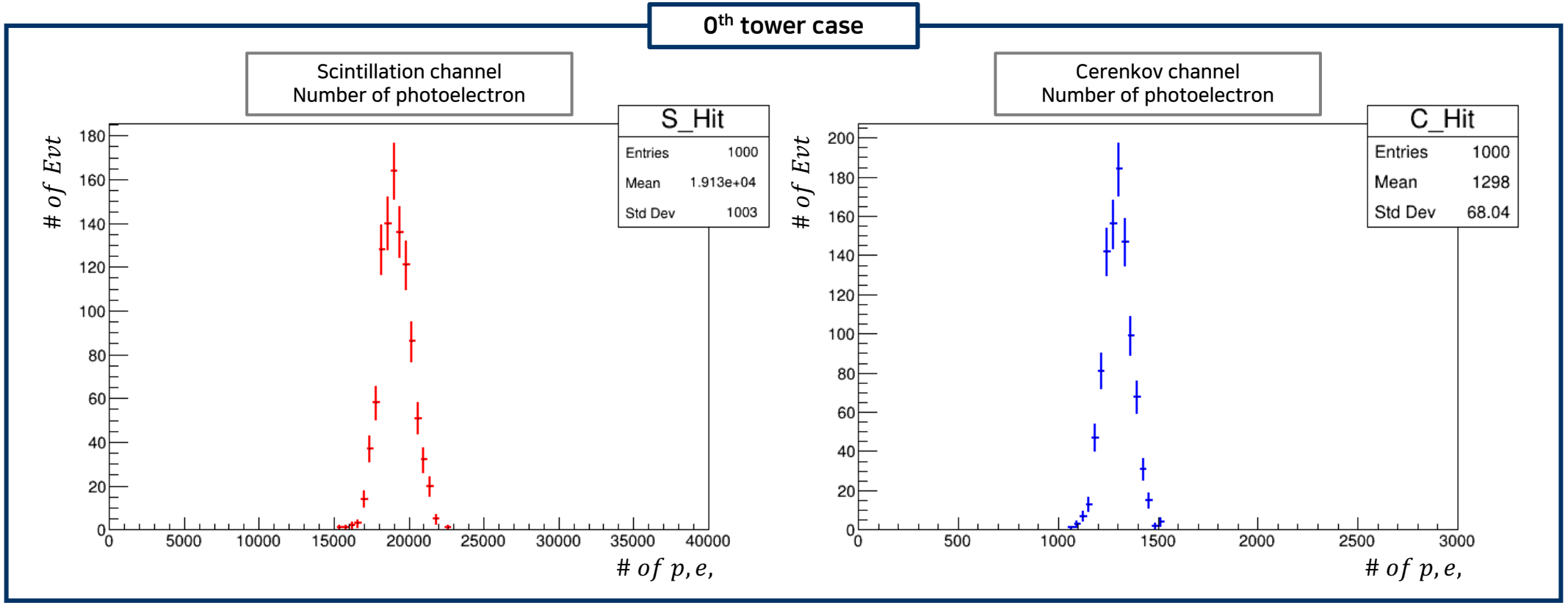


- Wratten#3 filter (yellow filter) is applied

Calibration

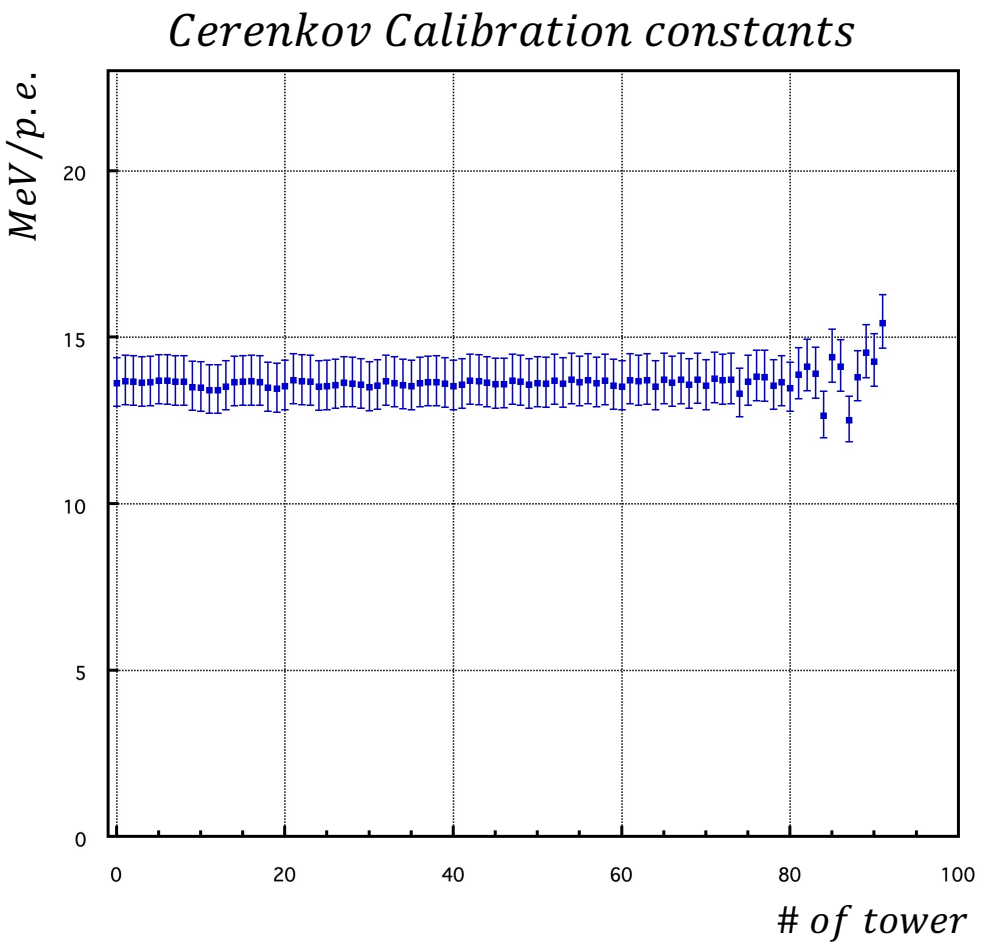
Calibration procedure using 20GeV e- with Full Simulation

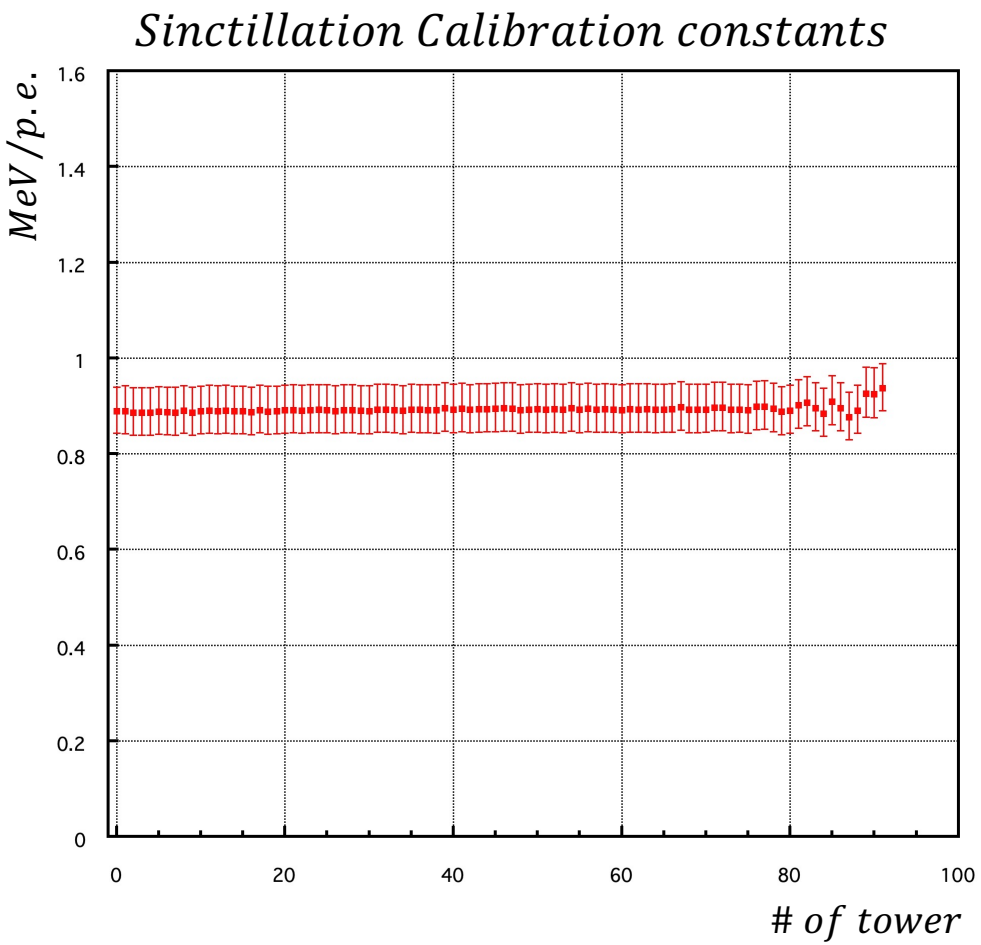
- By the symmetrical shape, towers (modules) can be categorized by 92 components
- Each tower (0~91st tower) simulated with 1 * 1 cm^2 beam which has (θ,ϕ) = (1.5° , 1.0°) angle w. r. t. tower axis
- With each event, estimate # of p.e. counted from each channel in the tower



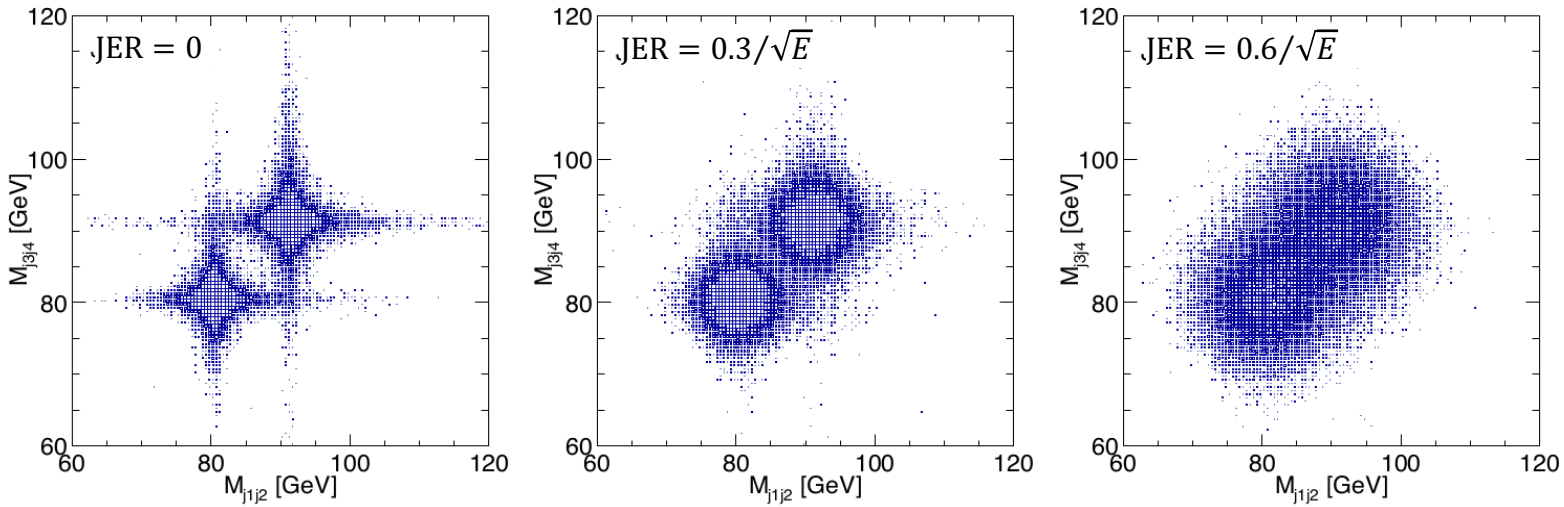
Calibration

- **Calibration procedure using 20GeV e- with Full Simulation**





Energy resolution

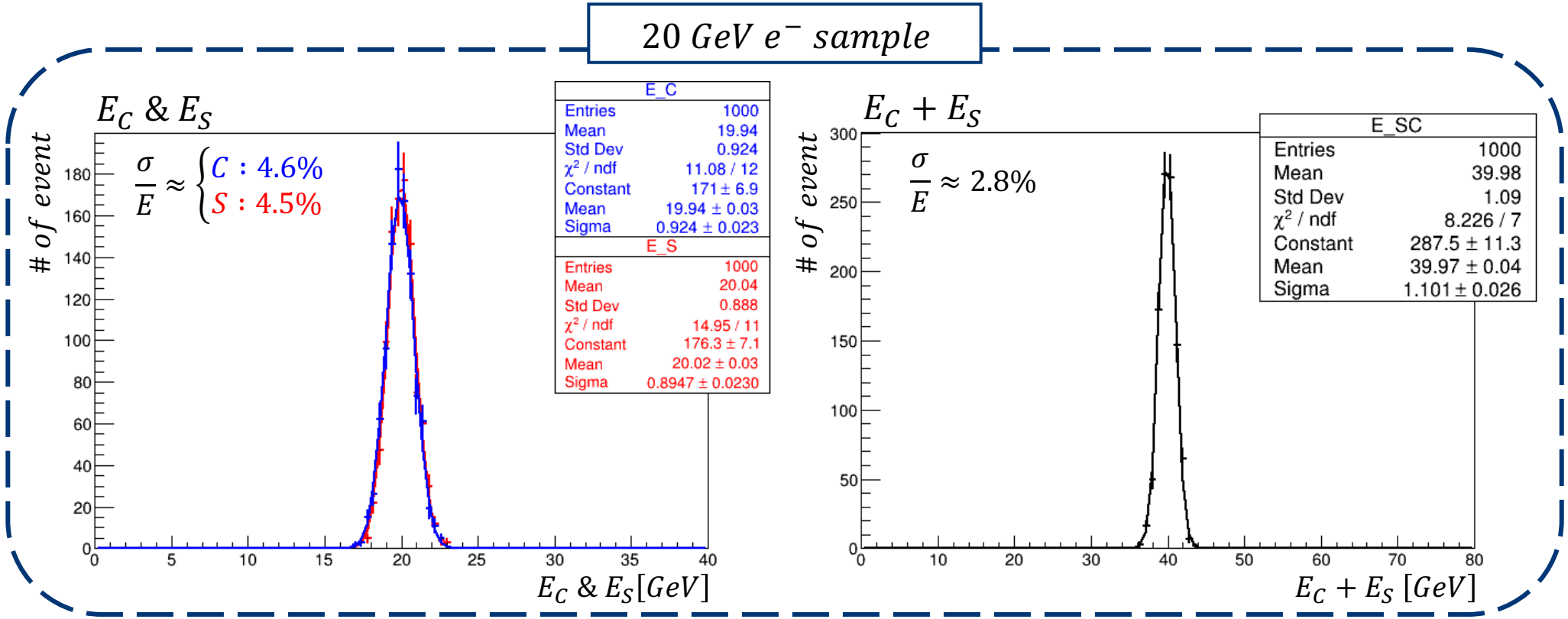


- **What is the energy resolution?**
  - Energy resolution means how much precisely it can measure the energy
  - With high resolution we can get precise result and distinguish each deposition accurately
  - Resolution can be expressed as a function of $\boldsymbol{1/\sqrt{E}}$, stochastic term represents resolution itself

$$\delta E/E = \frac{\boldsymbol{stochastic\ term}}{\sqrt{E}} \oplus constant\ term$$

  - The constant term arises from the different responses depending on impact points for high energy EM showers

Energy resolution

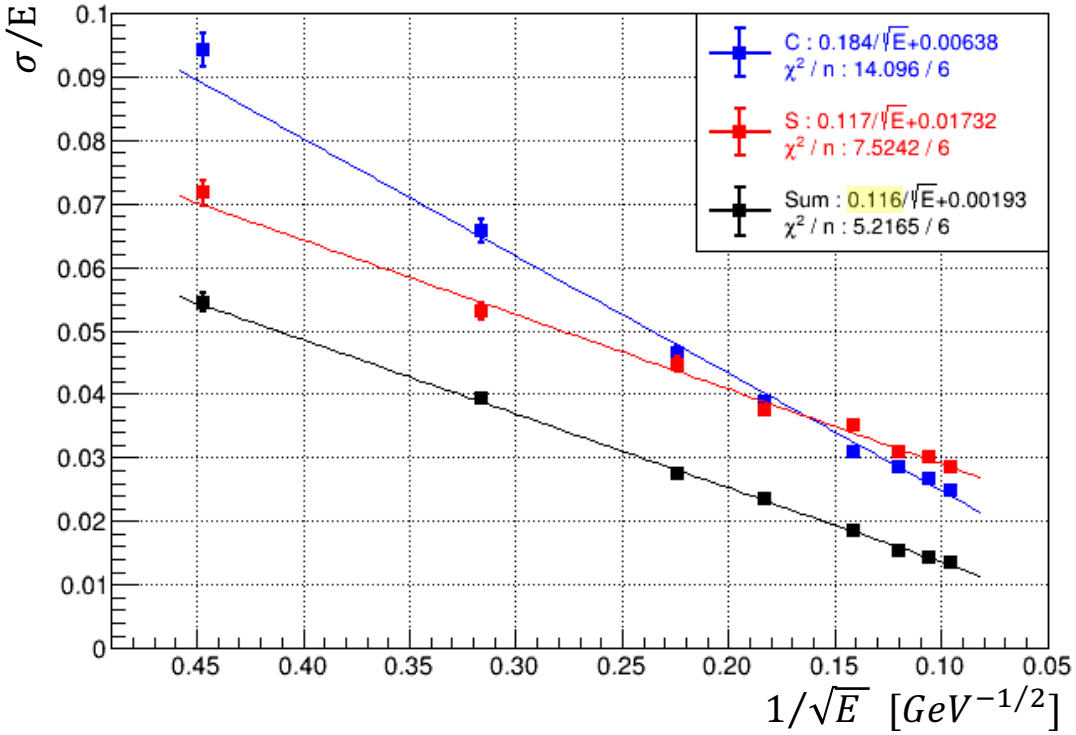


- **20 GeV e- resolution**
  - ~4.5% for both channel and 2.8% for combined channel.

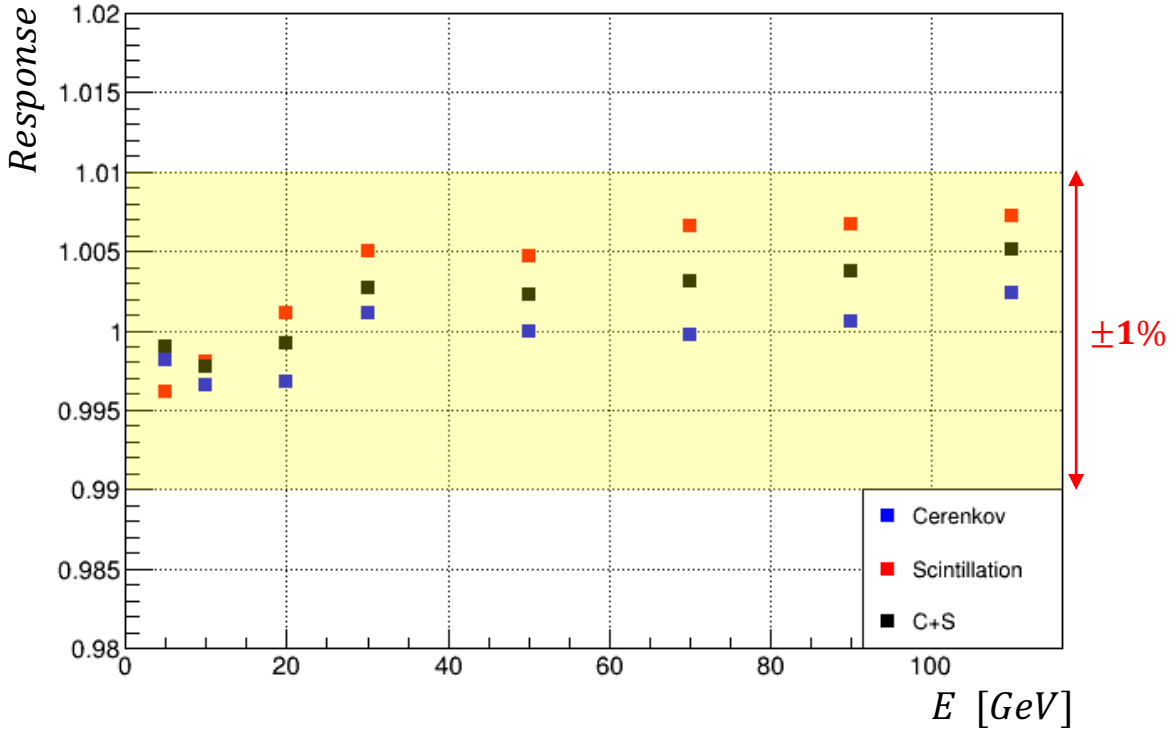
EM energy resolution

- EM energy resolution is measured with different 8 energy e- beams (5, 10, 20, 30, 50, 70, 90, 110GeV)
- Resolution is scaled to $1/\sqrt{E}$

EM energy resolution



EM energy linearity

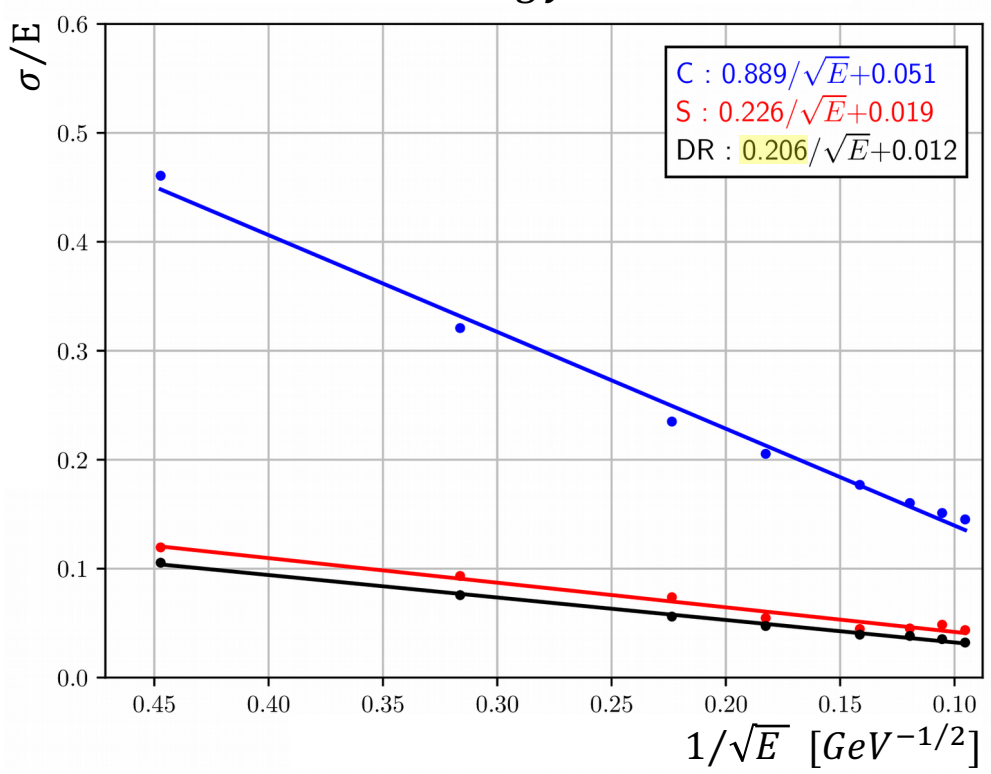


- Stochastic term for EM energy resolution is ~12%
- Measured EM energy satisfies linearity within ±1% level at Cerenkov, scintillation and combined signal

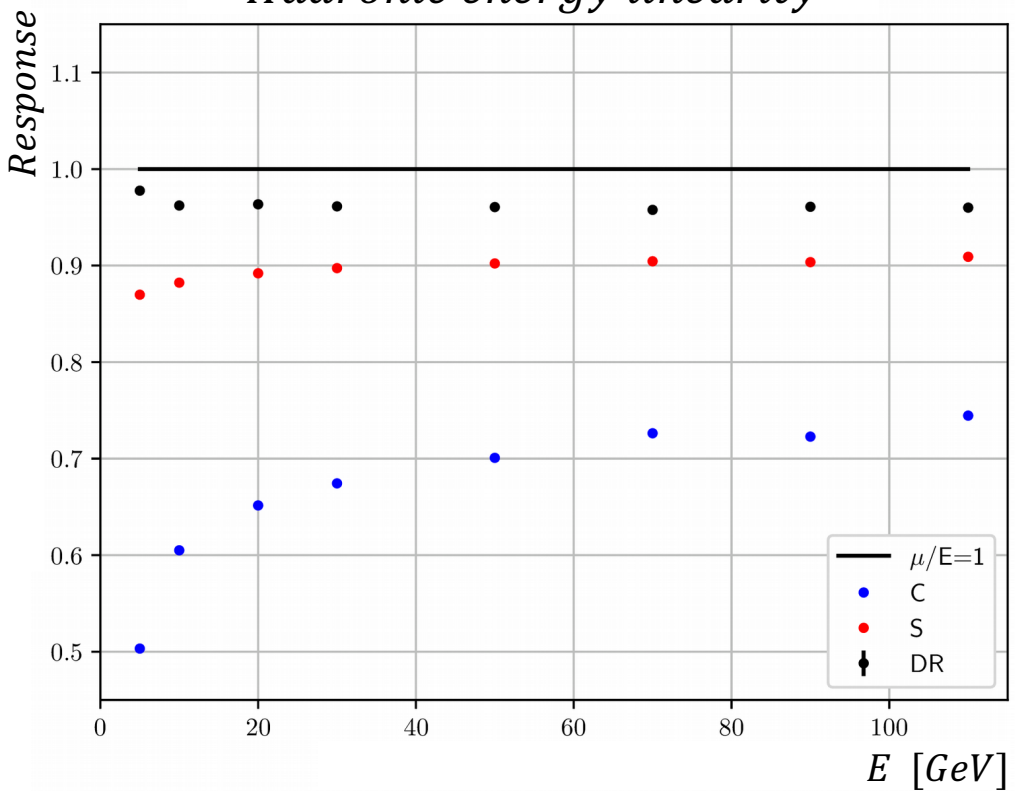
Hadronic energy resolution

- Hadronic energy resolution is measured with different 8 energy pi+ beams (5, 10, 20, 30, 50, 70, 90, 110GeV)
- Both light attenuation correction and dual-readout correction are applied

Hadronic energy resolution



Hadronic energy linearity



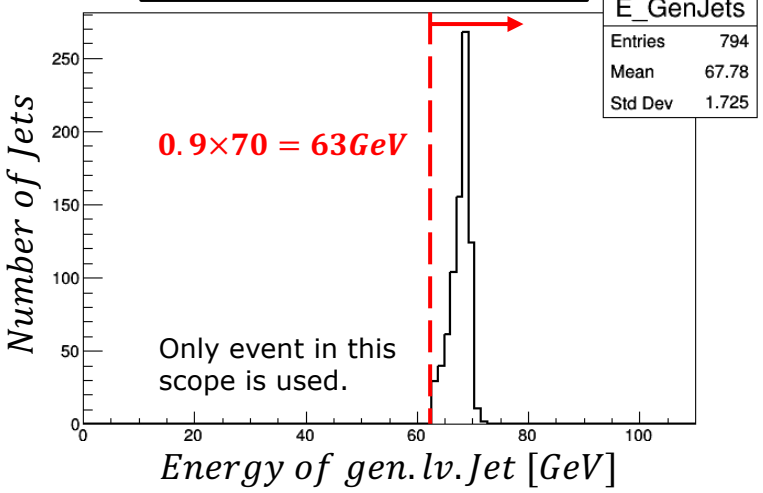
- Stochastic term for hadronic energy resolution is ~21%
- Dual-readout correction improved the linearity of energy response

Jet Energy Resolution

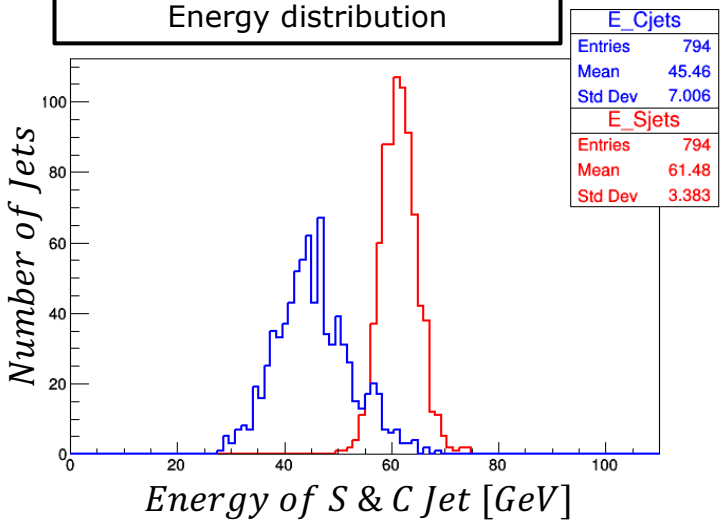
- Jet energy resolution is measured with 4 different energy u quark. (50, 70, 90, 110 GeV)
- Jet is reconstructed with anti-kt algorithm(R=0.8) and chi value for DR correction is 0.221.

70GeV case

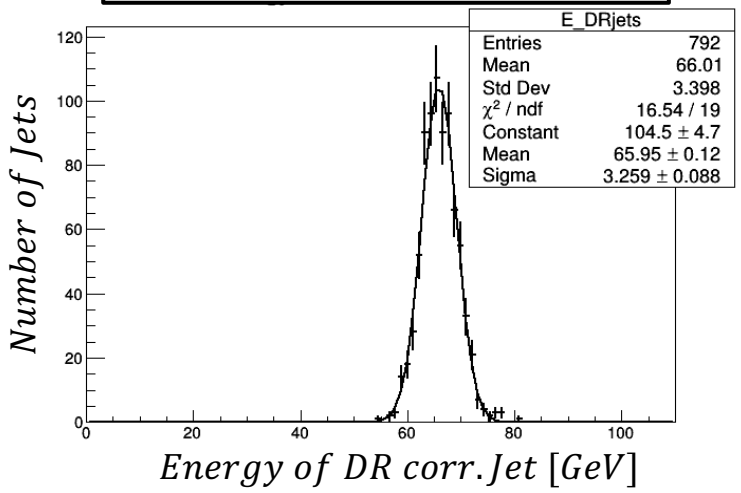
Generator level Jet energy distribution



S & C Jets of each channel Energy distribution

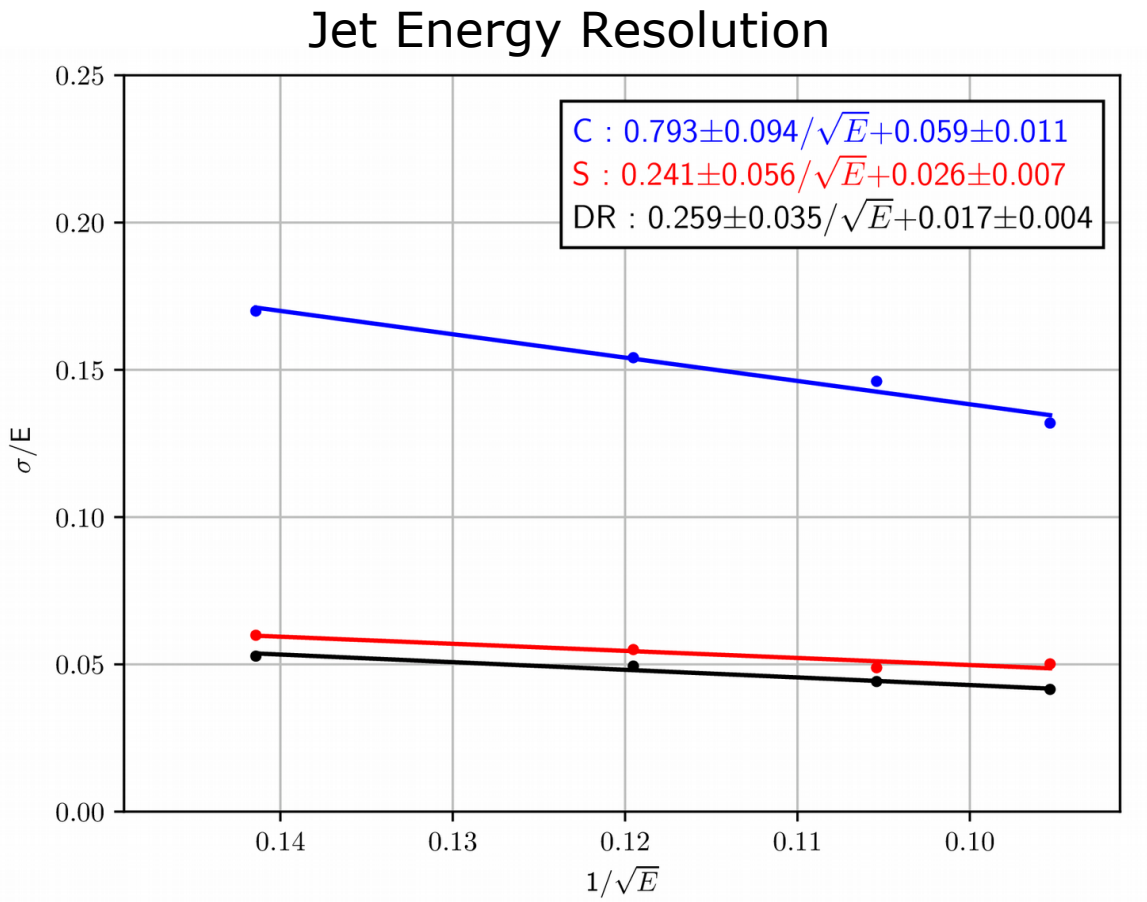


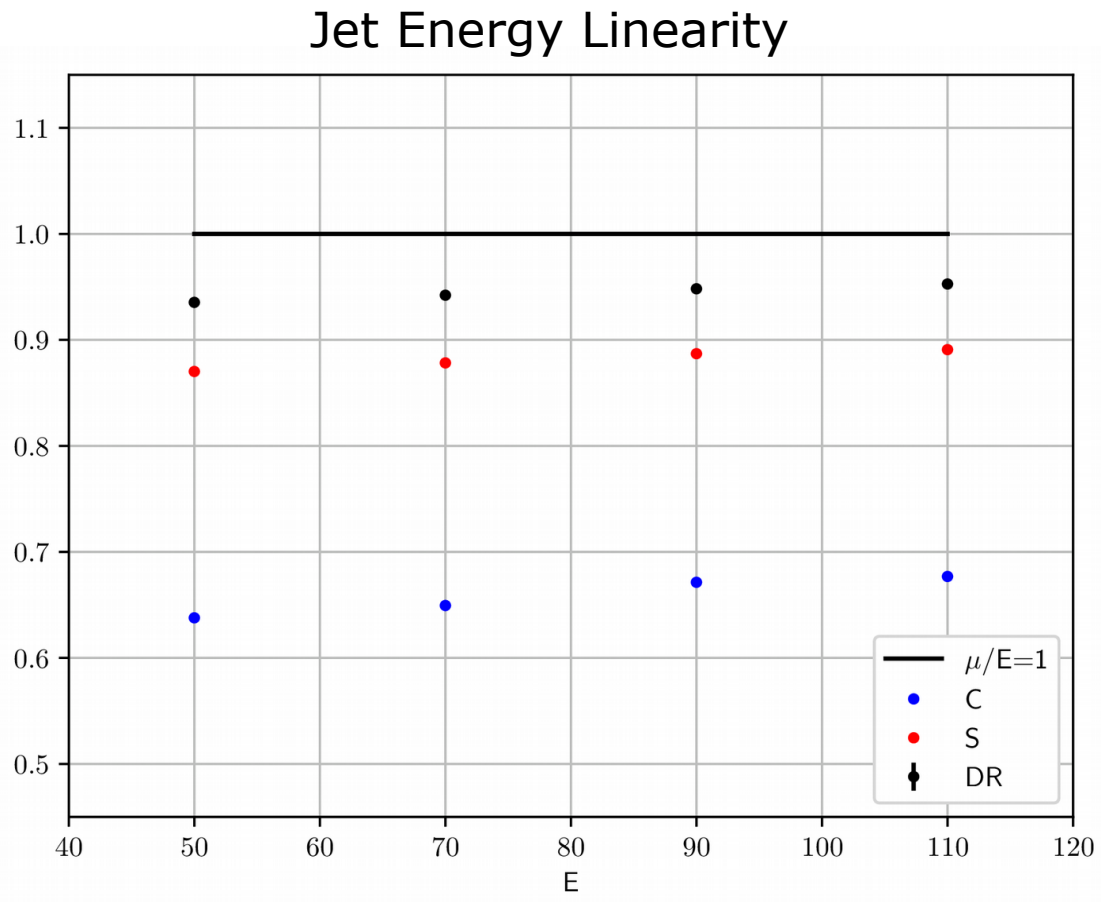
DR corrected Jet energy distribution



- Missing energy from neutrino and neutron during simulation makes resolution worse.
- Only events are used for jet energy resolution measurement whose Gen. lv. Jet has an energy over 90% of generated jet.

Jet Energy Resolution





- Stochastic term for jet energy resolution is ~26%.
- Measured jet energies follow linearity well.

Aug2022 TB

● Successful Test Beam

◎ ~84 hours data taking, 28M data.

Total wave	Total Fast	Total Time (min)	Total Time (hour)
4,657,849	23,248,704	5,046	84

GeV	Total wave e+/e-	Total fast e+/e-	Total wave pion	Total fast pion	Total wave mu	Total fast mu
20	3,014,502	3,044,800	141,339	471,424	-	-
30	111,453	111,360	-	-	-	-
40	181,690	181,504	-	-	-	-
60	150,952	571,584	109,825	439,232	-	-
80	471,194	1,451,968	110,209	220,416	-	-
100	110,317	882,496	-	-	-	-
125	100,060	800,448	-	-	-	-
160	-	-	-	-	30,966	30,848
180	-	-	125,342	15,042,624	-	-
SUM	4,140,168	7,044,160	486,715	16,173,696	30,966	30,848

e^+ extraction

Why we need pure e^+ data?

◎ Beam from H8 is not pure single particle beam, has a lot of contamination.

- SPS coordinate comments : ~ 15% purity

◎ Dual-readout methodology need EM events to do calibration.

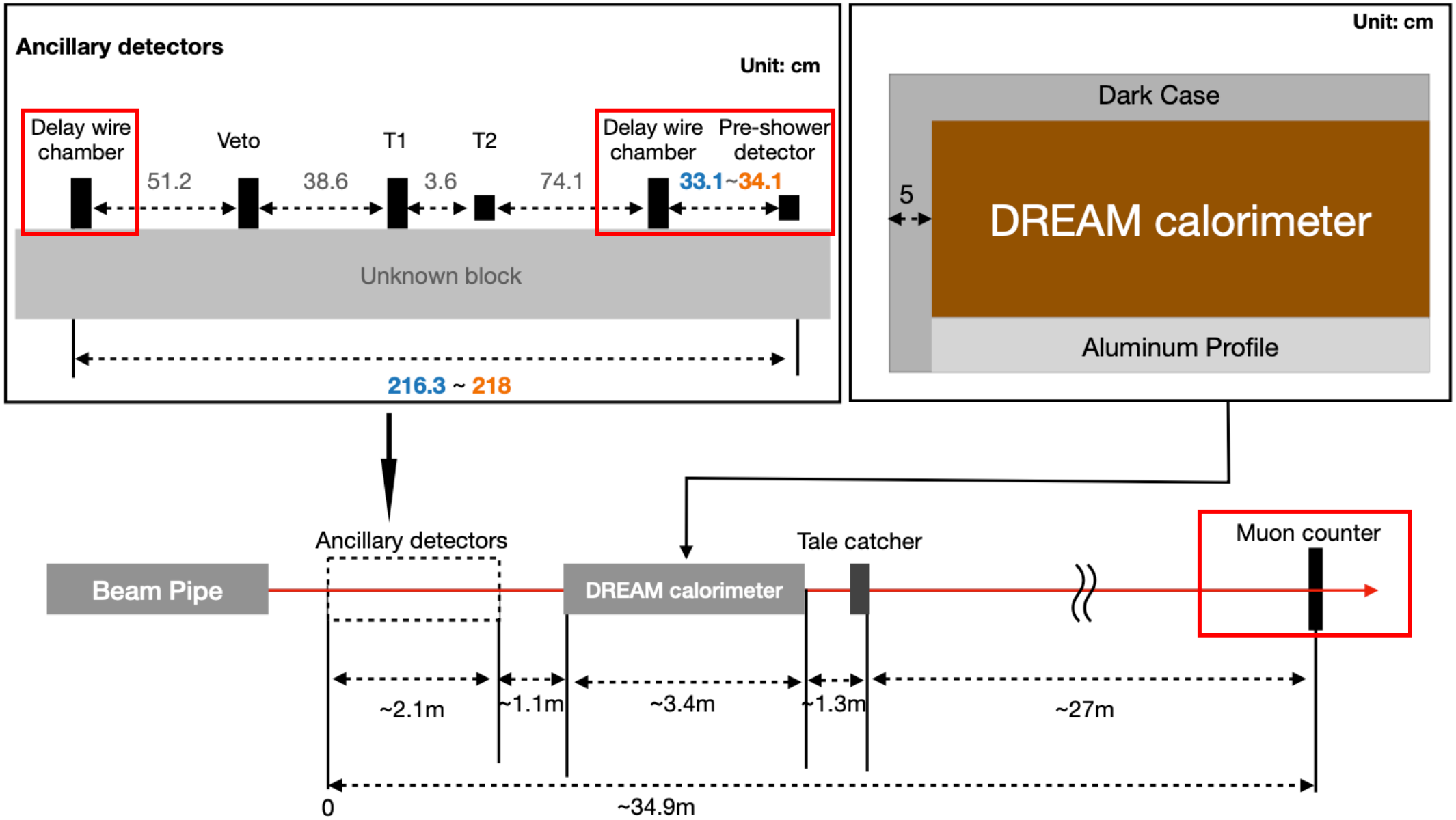
- EM showser : same response at scintillation and Cerenkov channel.

PID with auxiliary detector

◎ To do PID, we used auxiliary detector.

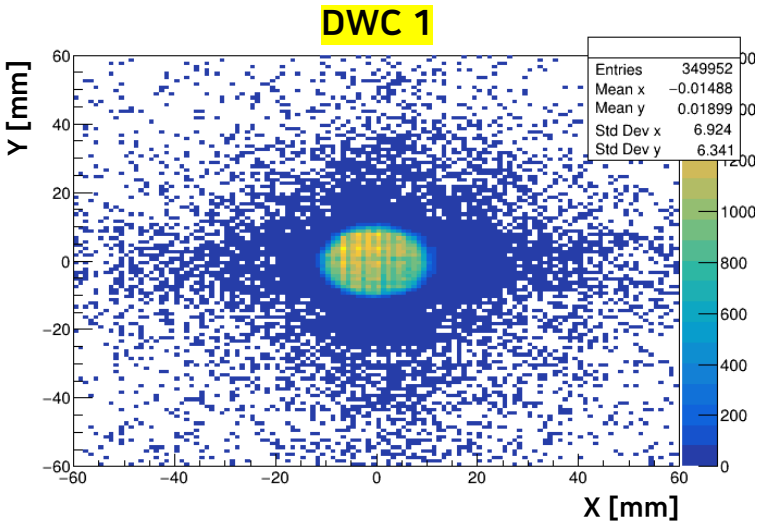
1. DWC : Selection on beam position and angle.
2. Muon counter : Selection on muon signal
3. Pre-shower : Discrimination on pion, muon vs. electron

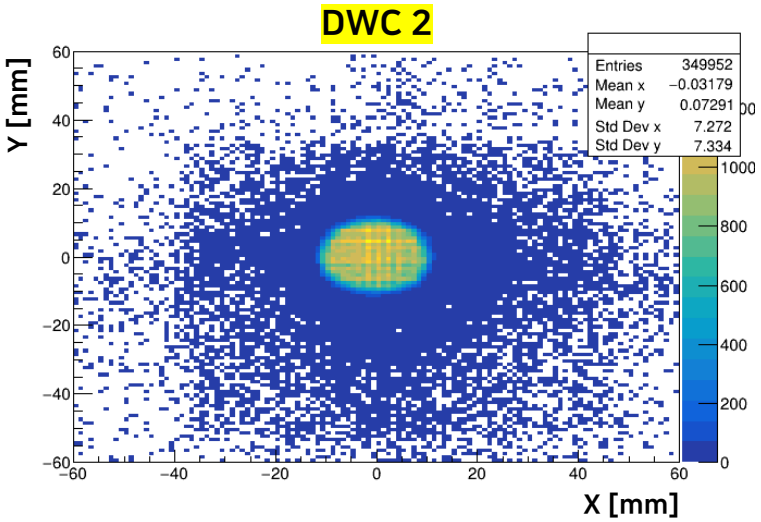
Auxiliary Detectors



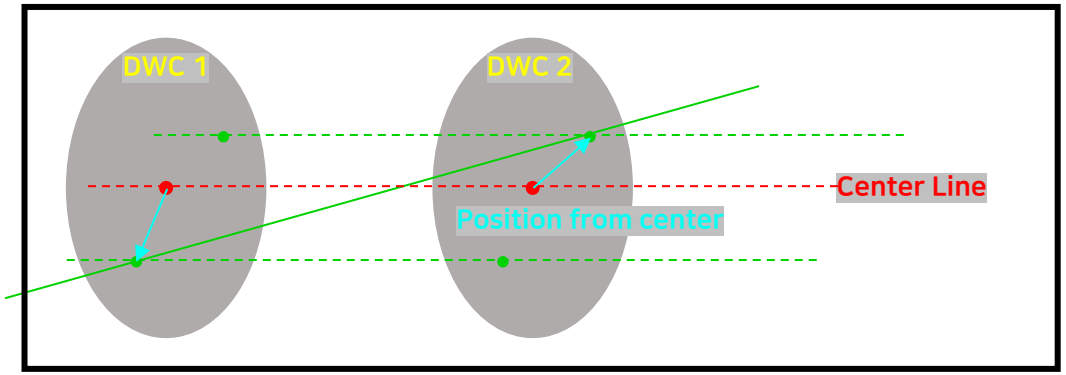
DWC and Beam angle

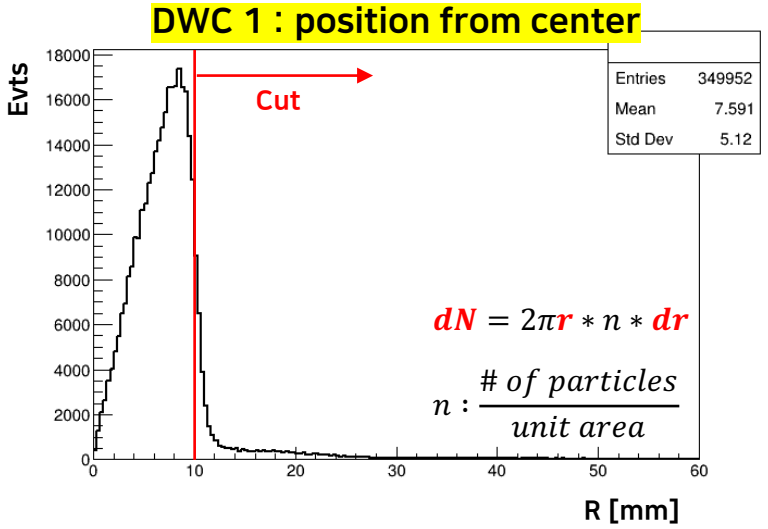
Beam position

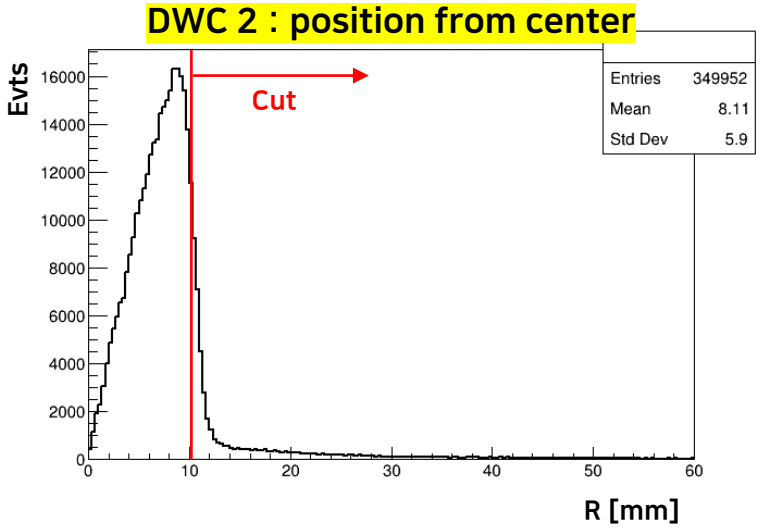




- From DWC calibration result, we can see that the position is well calculated.
- But we have to check the angle of the beam with DWC1 and 2 data.







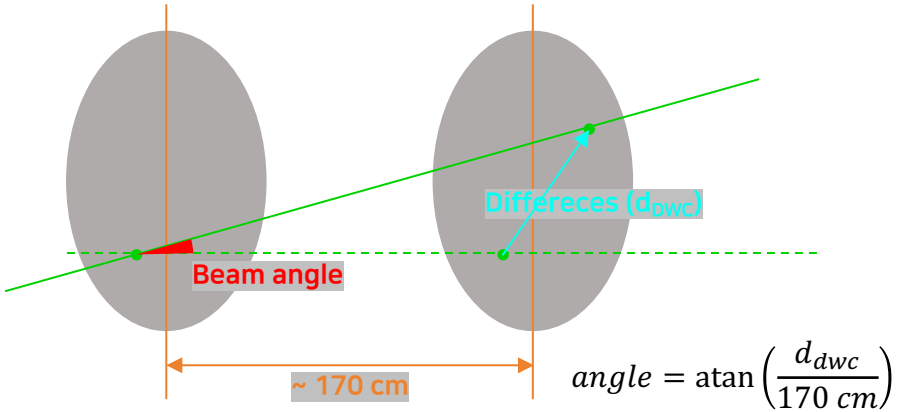
- Frist selection : R < 10 mm for both DWC1 and DWC2

DWC and Beam angle

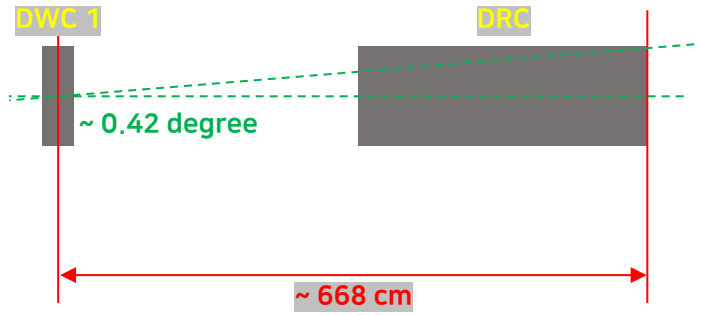
● Beam angle

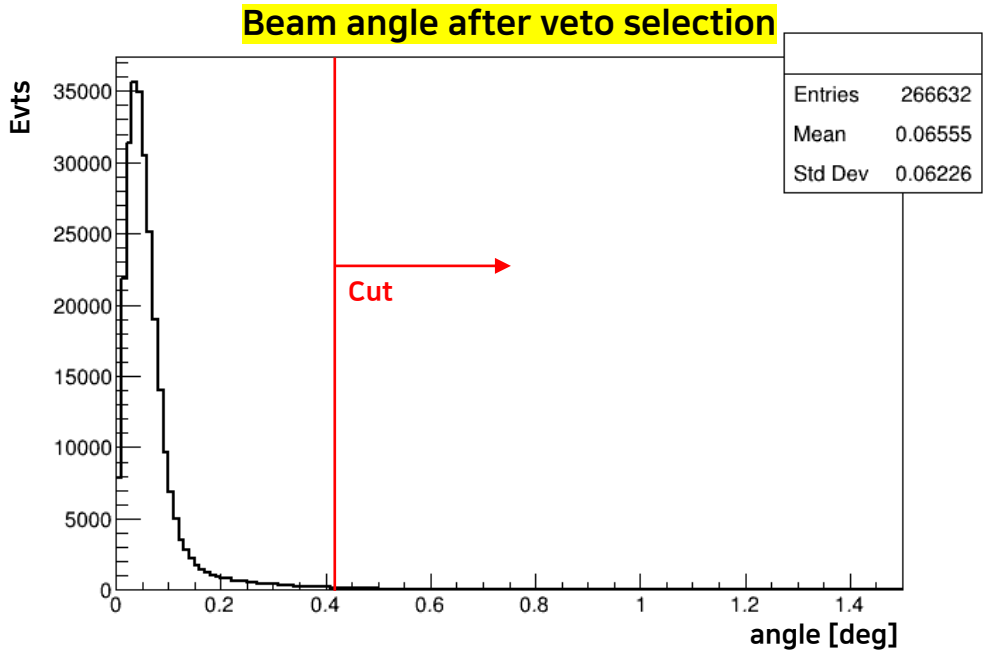
◎ Why we should take care about angle?

- Trigger only cares veto and external trigger.
- If a incident particle triggered with significantly high angle, then it could pass the detector with just short length.



$$angle = \mathrm{atan}\left(\frac{d_{dwc}}{170\ cm}\right)$$

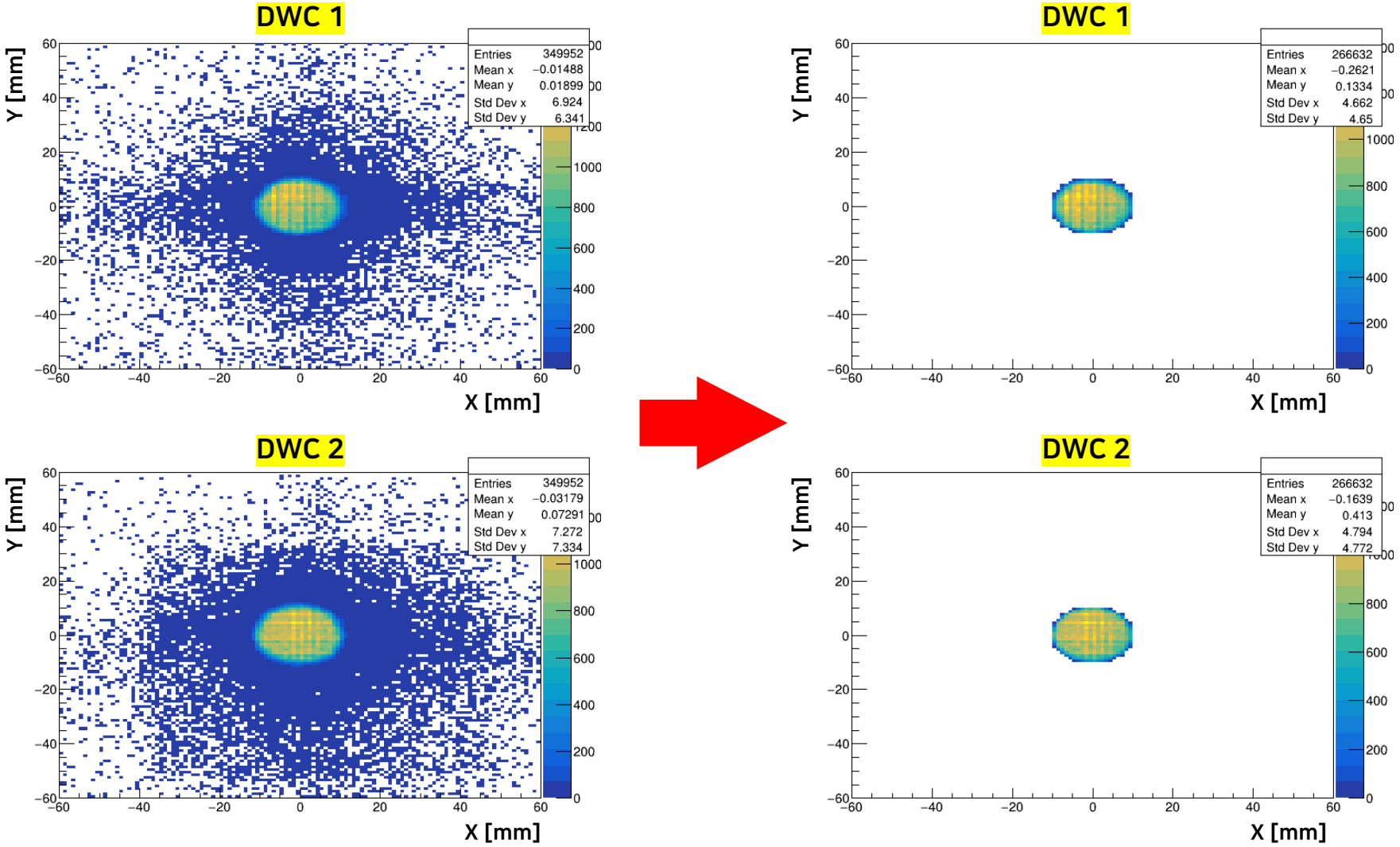




- Second selection : beam angle < 0.42 deg

DWC and Beam angle

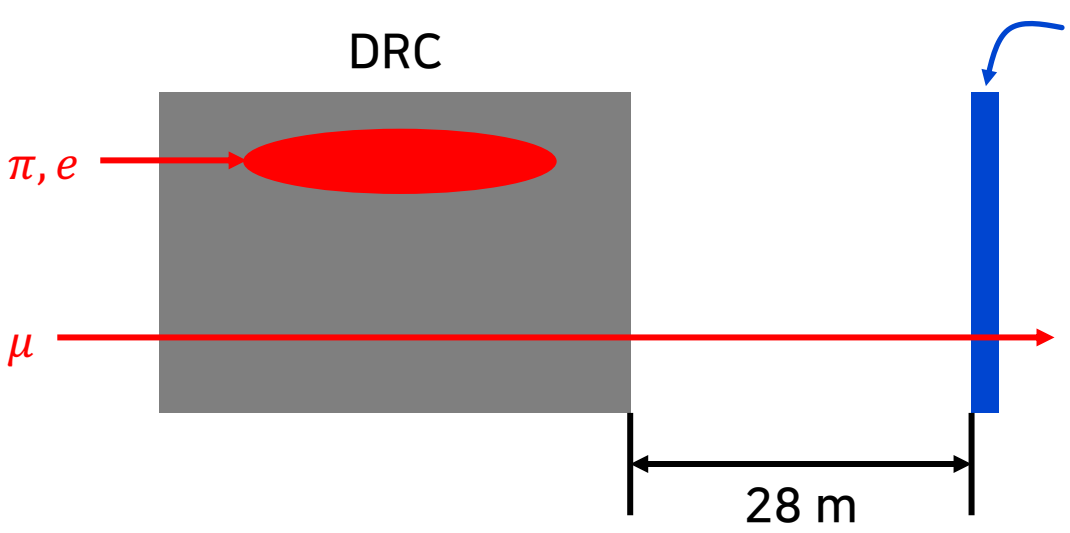
- After selection own DWC selection

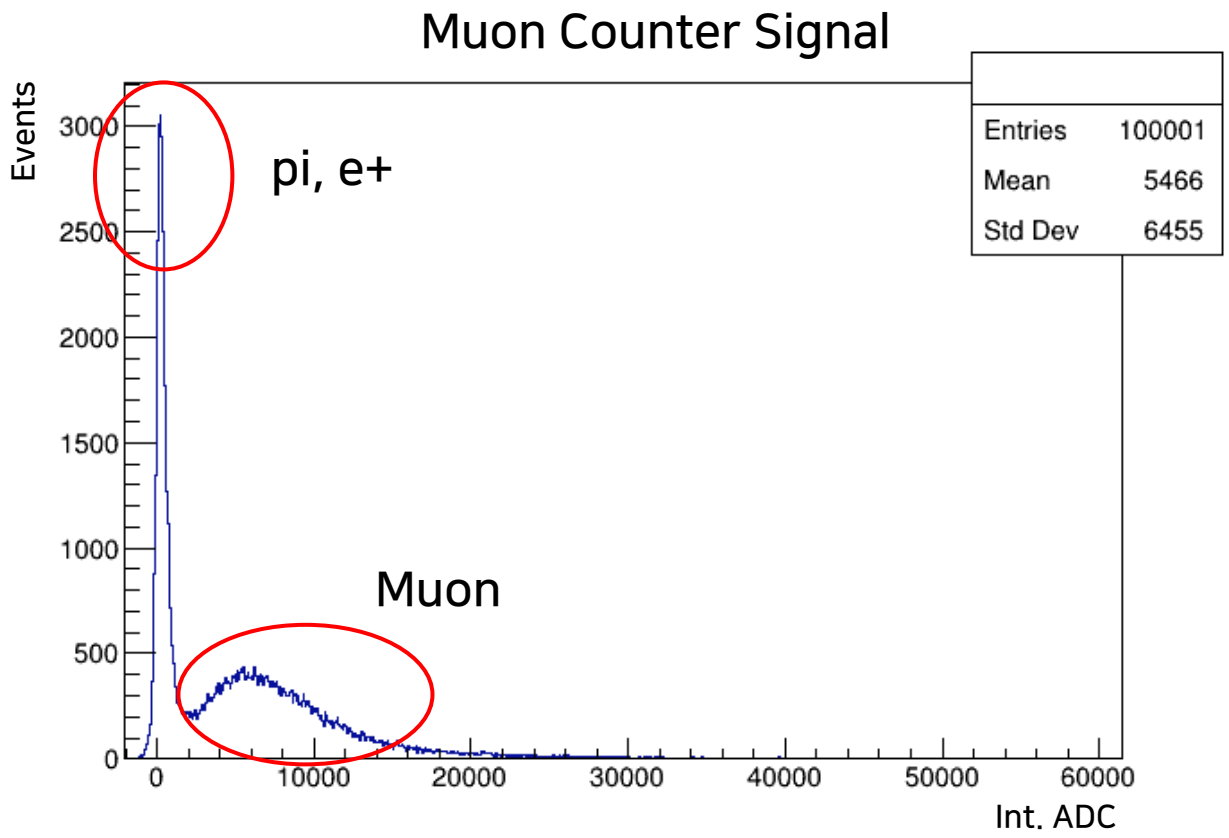


Muon Counter

- **MC response w.r.t. the particle types**

◎ Only muon can leave signal on muon counter.

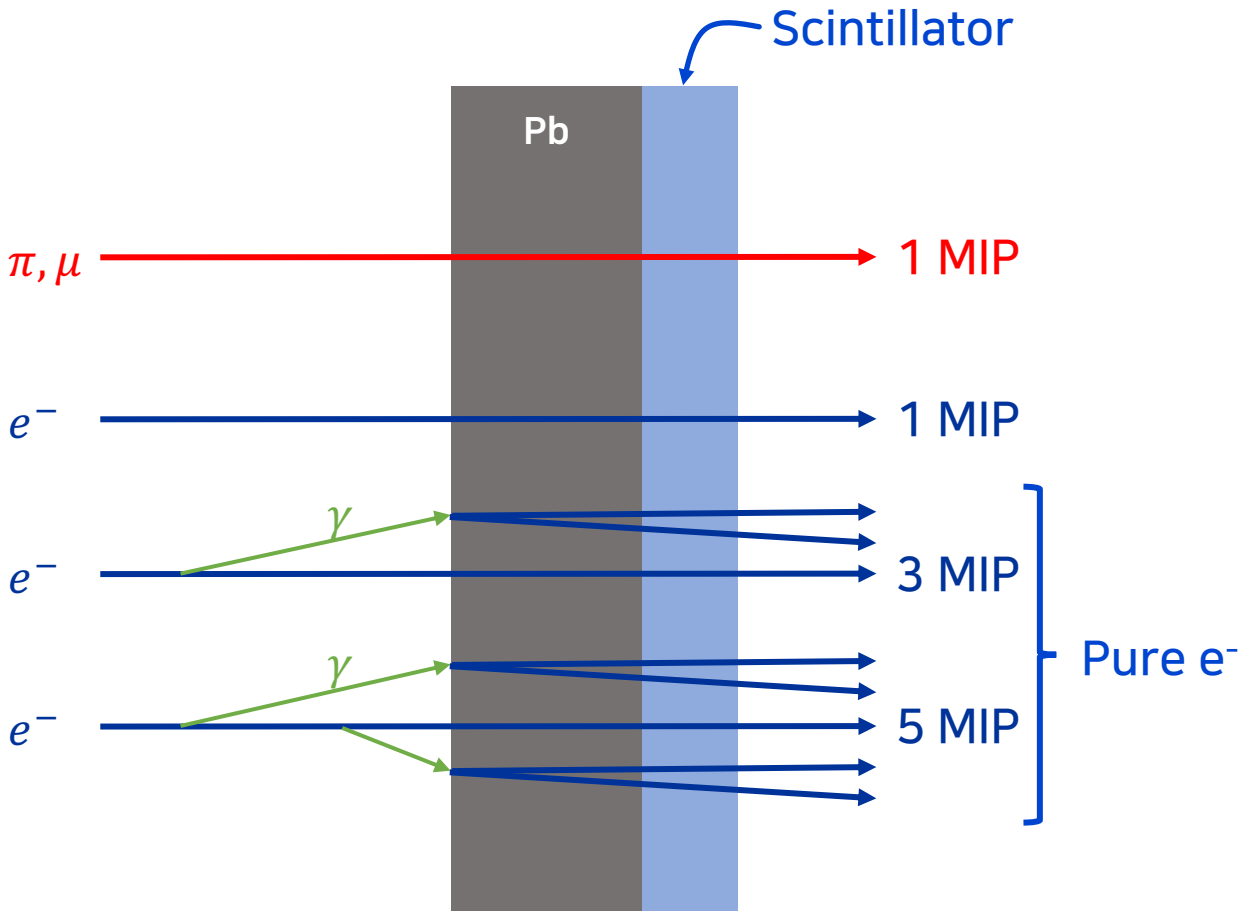


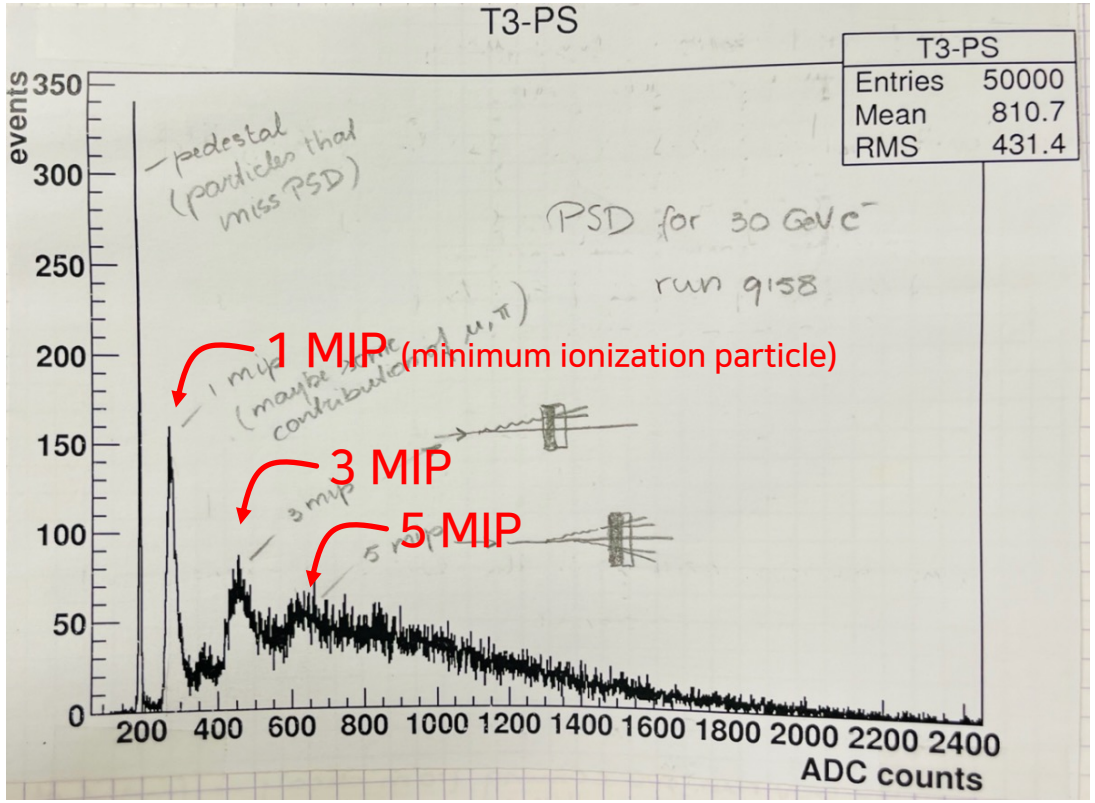


Pre-shower Detector

- **PS response w.r.t. the particle types**

◎ With PS response, particles can be distinguished.



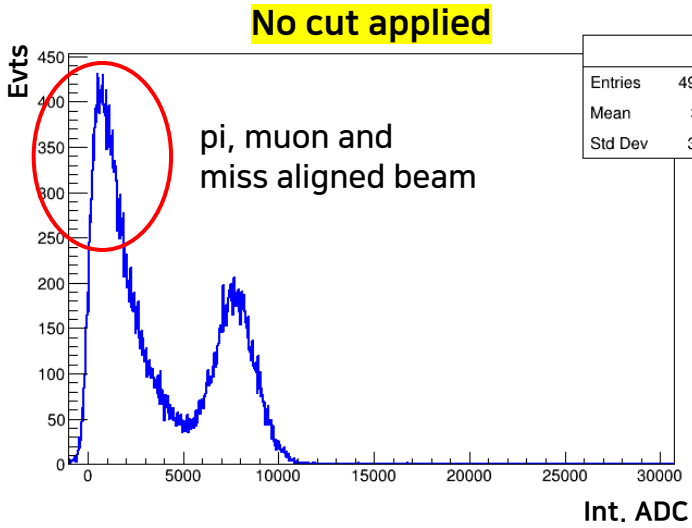


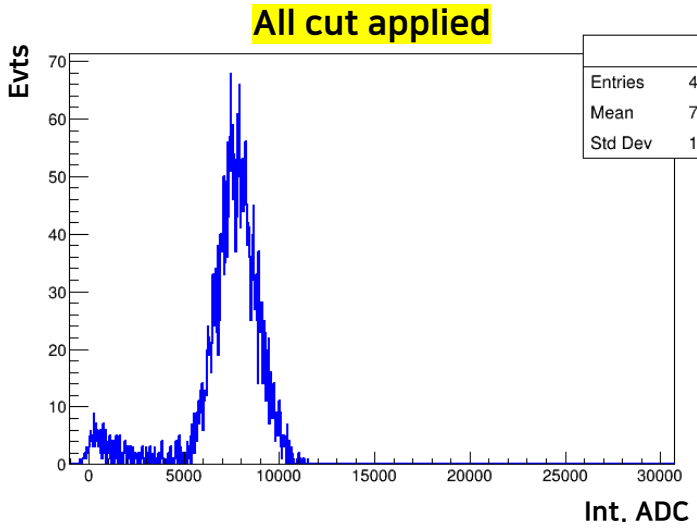
◎ Selecting events who has PS response higher than 3mip data, we can collect pure e+ data

Event Selection

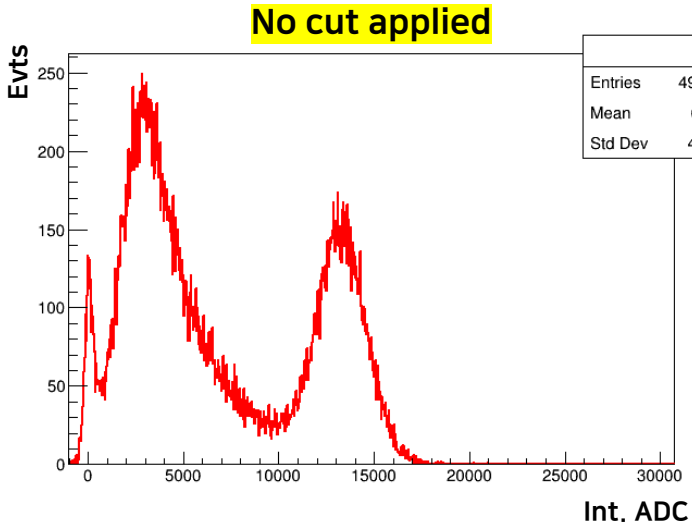
- Selection by aux. detectors

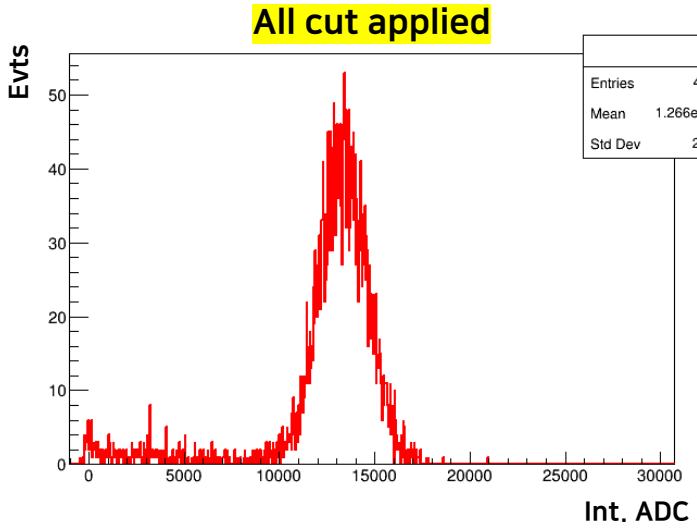
Cerenkov





Scintillation





- Almost pure e^+ events are collected.
- efficiency : ~ 9.25%

Summary

● Simulation results

◎ Resolution : 12% (EM), 21% (Hadronic), 27% (Jet)

● TB results

◎ Purely e^+ events selection is done.

◎ Calibration is on-going.

◎ Energy resolution will be estimated.

Thank you!