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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Introduction

- **Simulation results**
  - ◎ Simulation with EM (e^-) and hadron (pi^+) is done
    - 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.)

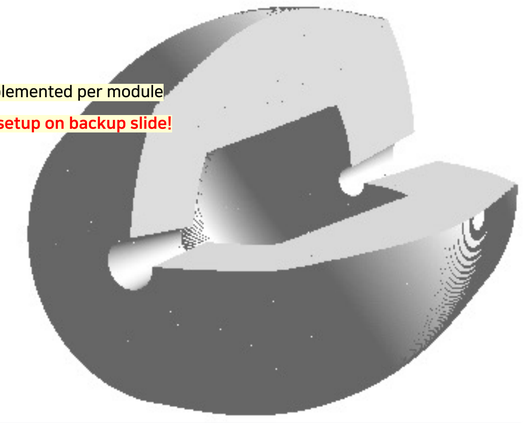
GEANT4 geometry

Cover 4pi, $|\eta|$ <2.4

~ 52000 modules

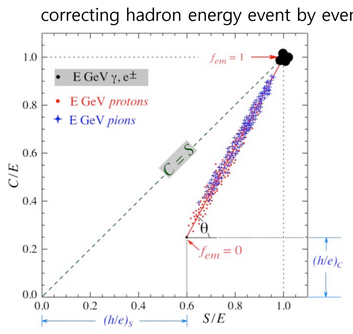
O(3000) fibers implemented per module

Detail simulation setup on backup slide!



Dual-Readout Calorimeter

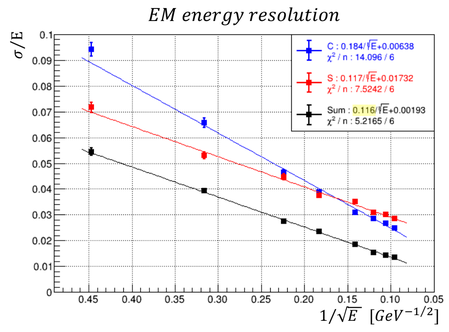
- **What is the IDEA detector**
  - ◎ IDEA detector has been proposed in CDR of FCC-ee and CEPC
  - ◎ DRC is included in the IDEA concept which can detect both EM & hadronic particles
- **What Is The Dual-Readout Calorimeter**
  - ◎ Non-gaussian fluctuations of the EM shower component are a major factor that makes it difficult to measure energy of hadron shower
  - ◎ Outstanding energy resolution can be achieved by measuring EM component and correcting hadron energy event by event

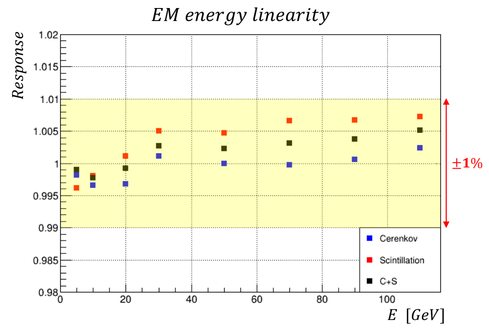


1. $C = E\left[f_{EM} + \frac{1}{(e/h)_C}(1 - f_{EM})\right]$
2. $S = E\left[f_{EM} + \frac{1}{(e/h)_S}(1 - f_{EM})\right]$
3. $f_{EM} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1-(h/e)_S] - [1-(h/e)_C]}$
4. $\chi \equiv \cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C}$
5. $E = \frac{S - \chi C}{1 - \chi}$

Energy resolution via GEANT4 simulation

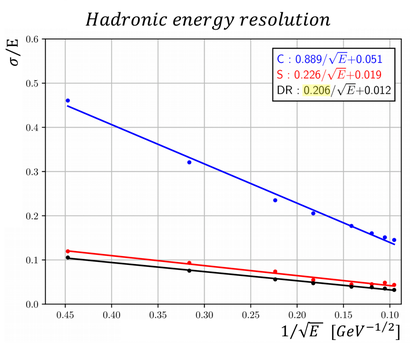
- **EM energy resolution**
  - EM energy resolution is measured with different 8 energy e- beams (5, 10, 20, 30, 50, 70, 90, 110GeV)
  - Resolution is scaled to $1/\sqrt{E}$

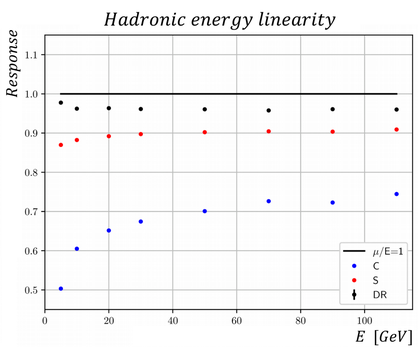




- Stochastic term for EM energy resolution is ~12%
- Measured EM energy satisfies linearity within ±1% level at Cerenkov, scintillation and combined signal

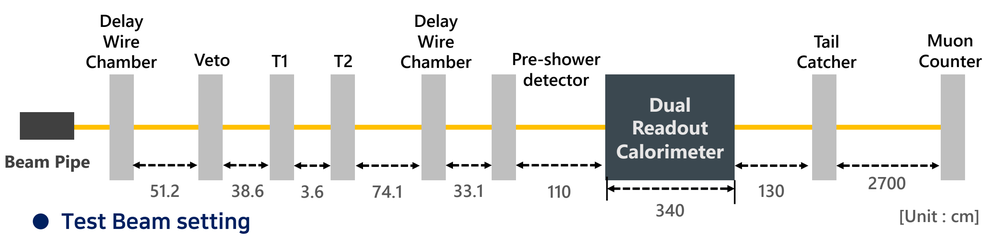
- **Hadronic energy resolution**
  - Hadronic energy resolution is measured with different 8 energy pi+ beams (5, 10, 20, 30, 50, 70, 90, 110GeV)
  - Both light attenuation correction and dual-readout correction are applied





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

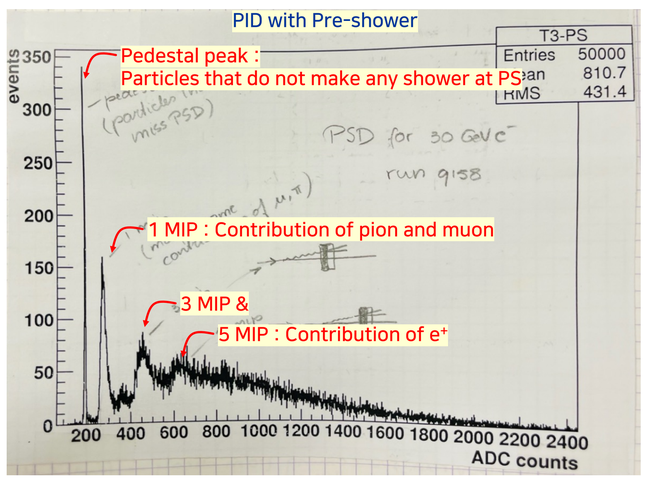
Test Beam setting



- **Test Beam setting**
  - ◎ 2022 Aug. we got test-beam at CERN north area H8 beam.
    - e^+, pi^+ and μ data is taken during test beam period. (mainly e^+ for EM performance estimation)
    - To get unbaised data, we installed a lot of auxiliary detectros in front of and behind DRC.
    - All signal processed with data acquisition system covering 480 independent channels.
    - DAQ system designed to match time resolution under O(100) pico seconds. (details on C05, C07, C08)
  - ◎ 2 Modules with different tower structure
    - We built two modules with different structure to test responses differences betweend various setting.
    - Details can be checked at C09.

First step of TB data analysis : PID

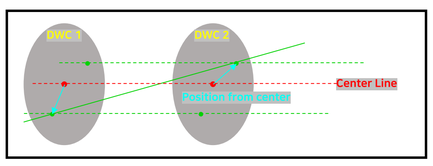
- **Why we need PID?**
  - ◎ Beam from H8 is not pure single particle beam, has a lot of contamination.
    - Beam purity from SPS coordinate : 10 ~ 20%
- **PID with auxiliary detector**
  - ◎ To do PID, we used auxiliary detector.
    1. DWC : Selection on beam position and angle.
    2. Muon counter : Selection on muon signal
    3. Pre-shower : Discrimination on (pion, muon) vs. electron
- **Dataset**
  - ◎ Run570 – 573 is used for prompt analysis.
    - The biggest data set which has same setup.

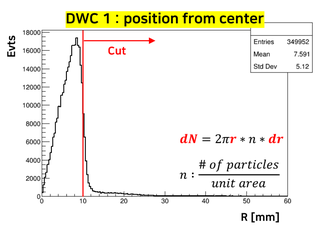


Beam position and angle

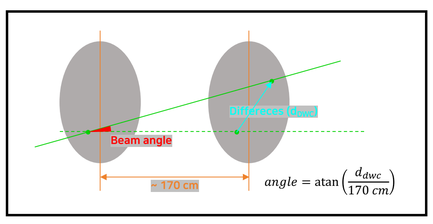
- **Delayed wire chamber**
  - ◎ Beam position and angle can be checked with DWC
    - From DWC calibration result, we can see that the position is well calculated.
    - But we have to check the angle of the beam with DWC1 and 2 data.

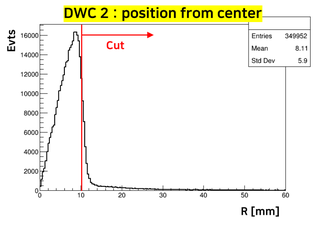
Beam Position



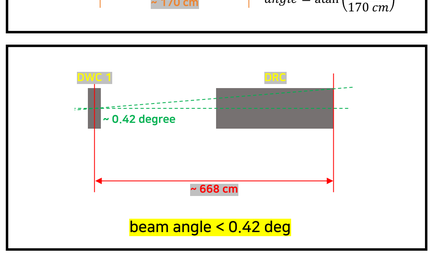


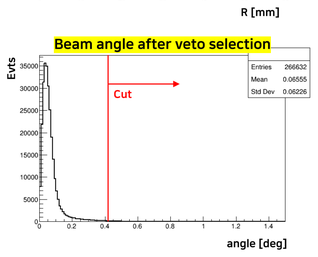
Beam Angle





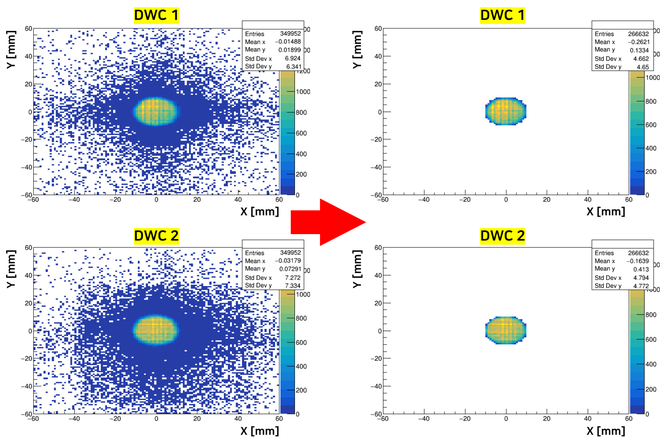
Beam Angle selection





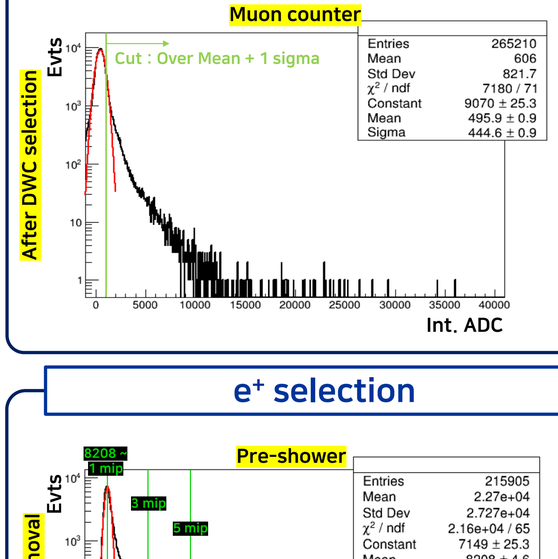
Before DWC selection

After DWC selection

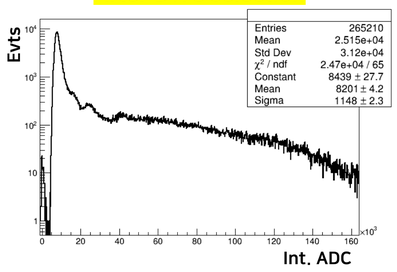


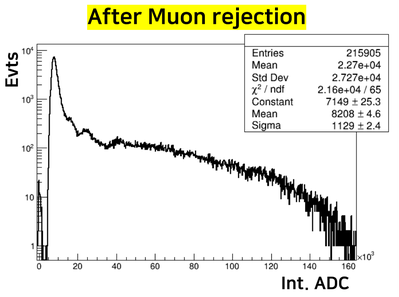
- Events which have the beam position at the center of DRC are selected.

Muon rejection



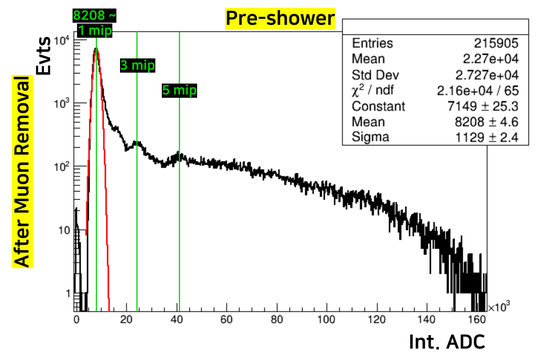
Pre-shower response after muon rejection





◎ Removing Muon
- Simple gaussian fit to the pedestal peak.
- Muon selection : ADC over mean + 1 sigma

e^+ selection

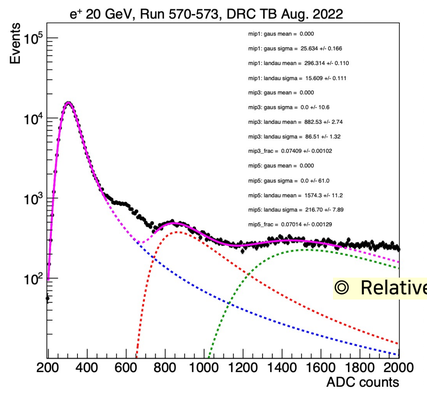


◎ e^+ selection
- 1 mip peak from single gaussian fit : ~ 8208 ADC
- e^+ selection : over 2.5 mip ADC value (20520 ADC)

Beam purity from analytic fit

◎ Full signal PDF = $(1 - f_{3MIP} - f_{5MIP}) \times \mathbf{LanGaus_{MIP}} + f_{3MIP} \times \mathbf{LanGaus_{3MIP}} + f_{5MIP} \times \mathbf{LanGaus_{5MIP}}$

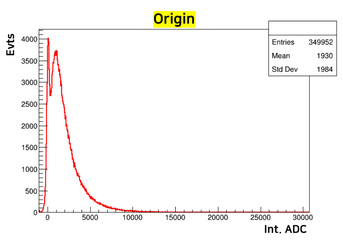
◎ Full range : MIP peak ~ 296, 3 MIP peak ~ 883 and 5 MIP peak ~ 1574

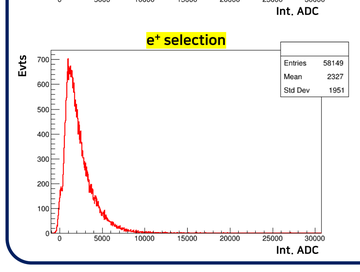


◎ Relative fraction of 3 MIP and 5 MIP contribution : ~ 14.4%

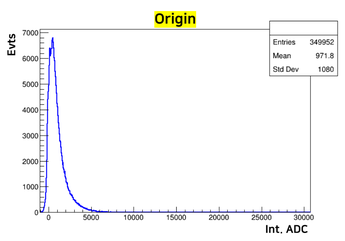
Beam purity from Aux. detector

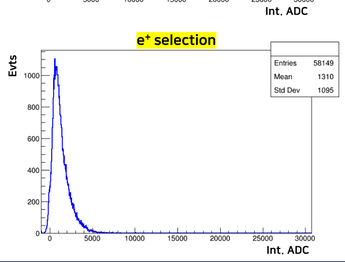
Scintillation





Cerenkov





◎ Estimated beam purity : ~17%

Summary

◎ TB at CERN North area H8 beam is done.

◎ Beam purity from selection of aux. detector : ~17 %

◎ Beam purity from analytic fit : ~14.4 %

◎ Beam purity from SPS coordinate : 10 ~ 20 %

◎ Estimated purity from different method has consistency.