ILDハドロンカロリメータ大型試作機テストビーム実験データ解析におけるイベント選別とエネルギー補正

Event selection and energy correction in test beam data analysis for ILD hadron calorimeter large prototype

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Outline

1. International Linear Collider
    - Particle Flow Algorithm
    - Design of ILD HCAL
2. Overview of Test Beam Experiment
    - AHCAL Large Prototype
    - SPS CERN
    - Difference b/w First and Second
    - Typical Events
3. Event Selection
    - Event Selection with Number of Hits
    - Event Selection by Energy
4. Energy Correction
    - Roughly Calculation of Energy Leakage
    - Weight for Energy Correction
    - Linearity
    - An Idea of Better Optimal Weight
5. Current Status and Prospect

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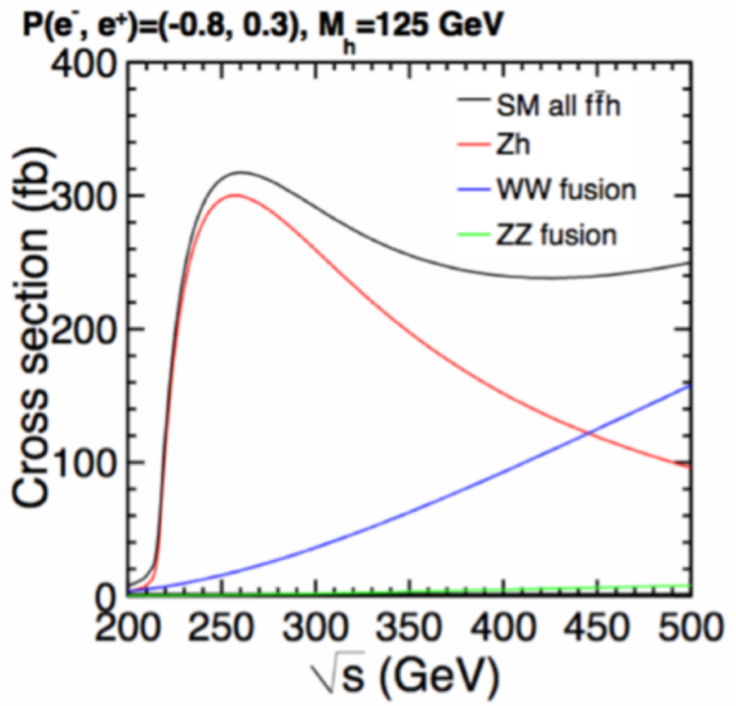
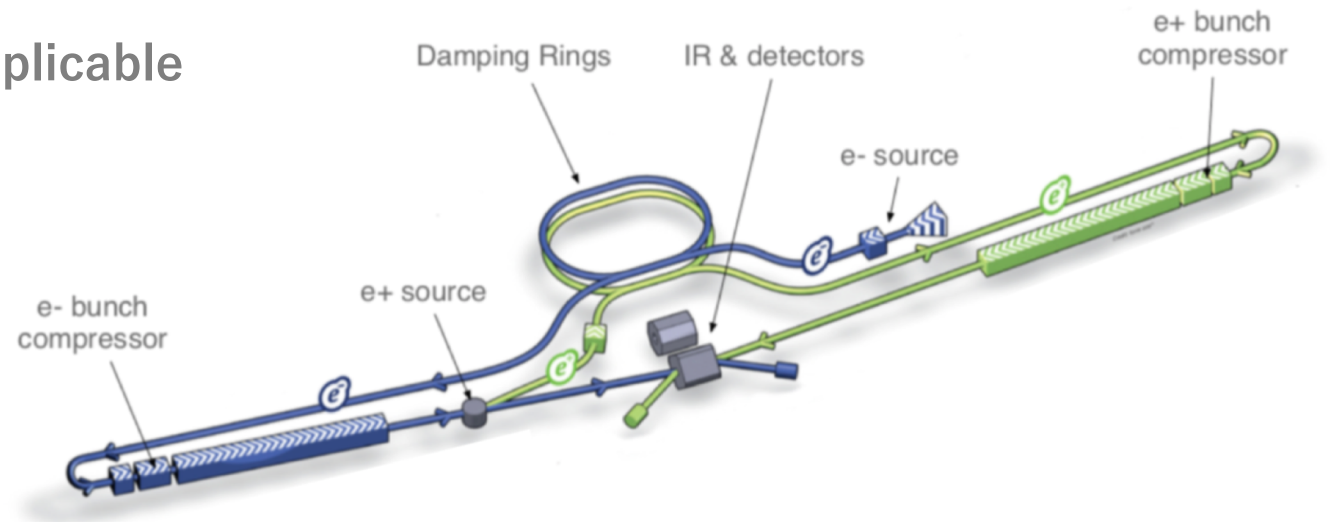
International Linear Collider

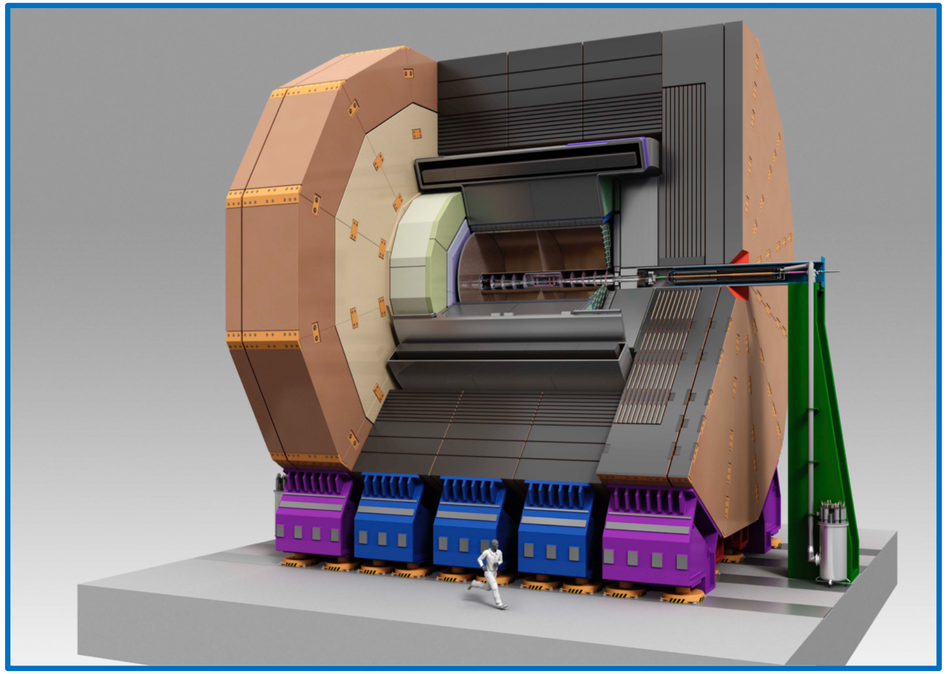
- **ILC is a future e^+e^- linear collider**
- **E_{CM} : 250 – 500 GeV (upgradable to 1 TeV)**
- **Detailed studies on Higgs, top physics, discovery of new particles.**
- **Features**
  - Collisions of accelerated elementary particles
    - Low backgrounds
    - Conservation of 4-momentum is applicable -> Decide the initial state
    - Possible to scan energy
    - Can use polarized beams



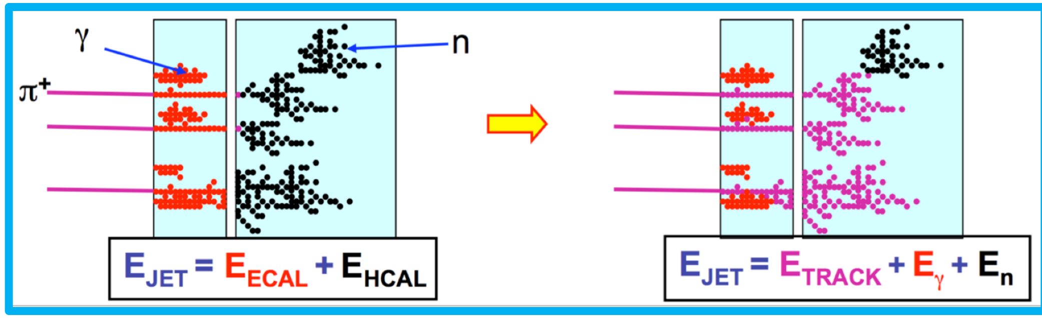


ILD & PFA

- **International Large Detector (ILD)**
  - Europe and Japan promote R&D
  - This design optimized for particle flow calorimetry for the best jet energy resolution -> PFA
- **Particle Flow Algorithm (PFA)**
  - Using this algorithm, we can distinguish each particle in a jet and reconstruct events.
  - Each particle is measured by the suitable detector.
    - charged particle -> tracking detector
    - photon -> ECAL
    - neutral hadron -> HCAL
  - ➢ Necessity of high granularity calorimeter



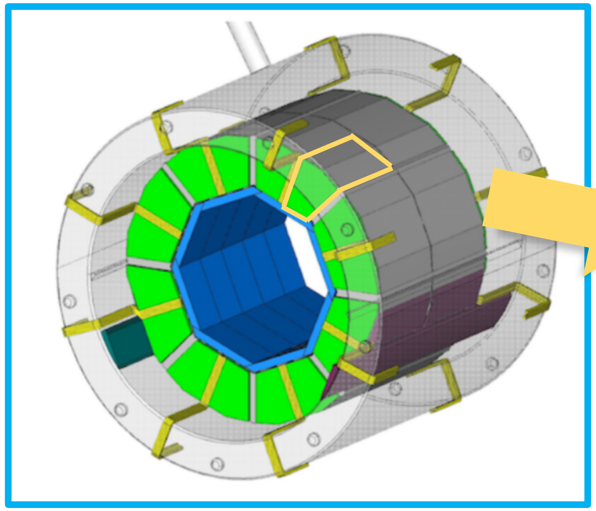
ILD



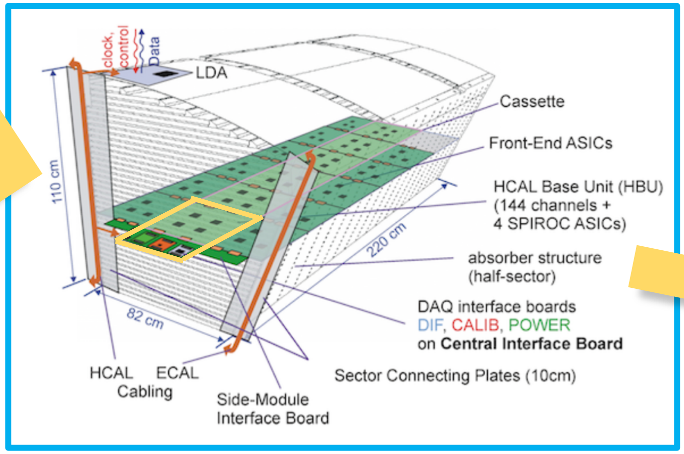
Conventional method PFA

Design of ILD HCAL

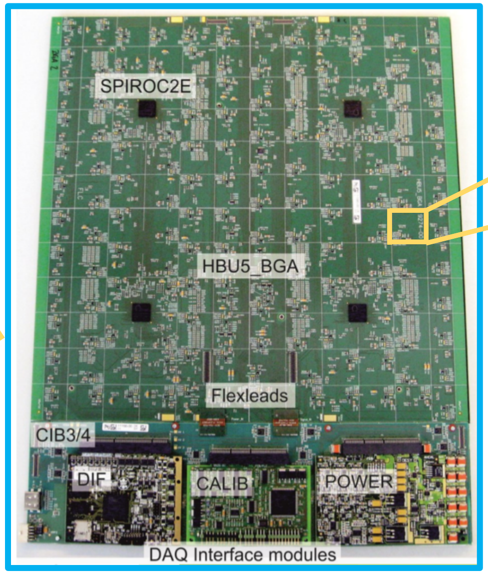
- **AHCAL(Analogue Hadron Calorimeter) is high-granularity calorimeter based on SiPM-on-tile technology.**
  - **8×10^6 scintillator tiles($30\times30\times3$ mm^3) read out by SiPMs**
  - **A barrel has 48 layers(active layer + steel absorber layer).**
  - **Each HCAL Base Unit(HBU) has 144 readout channels with 4 ASICs.**



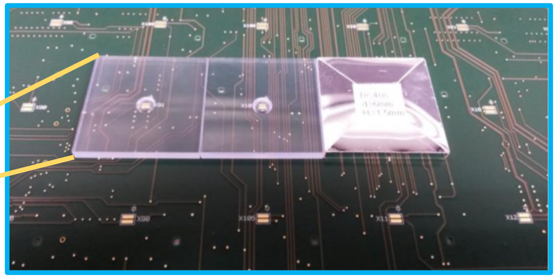
32 barrels

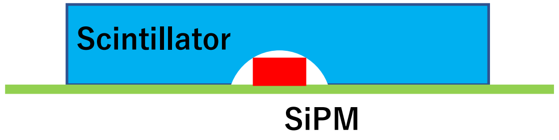


Each barrel



HBU board





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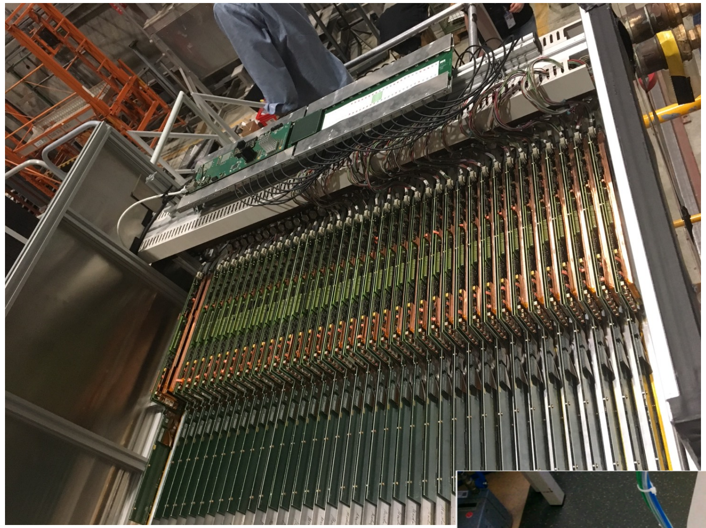
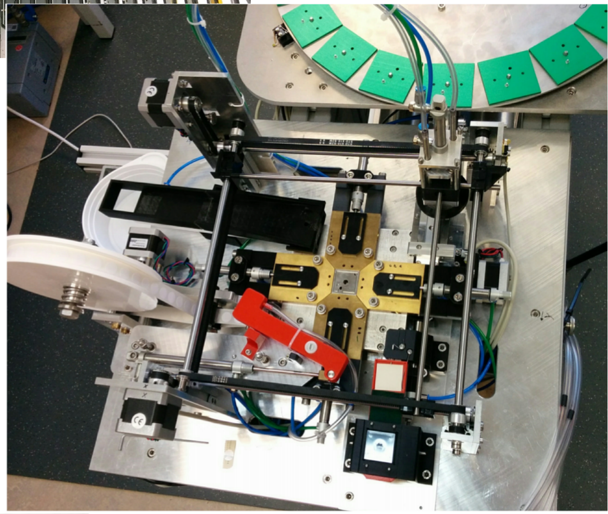
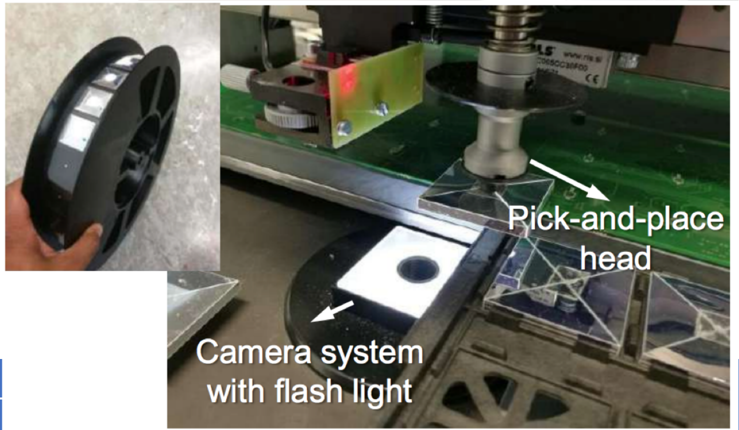
AHCAL Large Prototype



- **Objective**
  - Measure the detector response to the hadron event
  - Confirm if the design energy resolution can be achieved
  - Understand how the hadron shower evolves in the detector
  - Prove scalability to full AHCAL
  - Operate fully integrated system
- **38 large layers(2×2 HBUs) with new SiPMs, individually wrapped tiles and SPIROC2E**
  - ~ 2.2×10^4 channels
- **Steel absorber stack (~ 17 mm)**
- **Automated assembly**
- **Modules were tested with DESY testbeam for MIP calibration (3 GeV Electron).**
- **Cosmic ray test of all HBUs and final construction were done in DESY.**

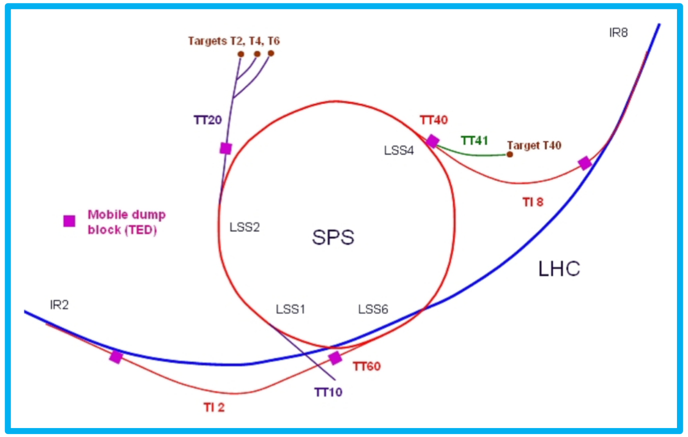




- ☐ AHCAL Large prototype ➚
- ☐ ESR wrapping machine ➚
- ☐ Pick-and-place for tile assembly ➡

Overview of Test Beam @SPS CERN

- **SPS (The Super Proton Synchrotron)**
- **Beam H2 – PPE172**
  - The beam line is a high-energy, high-resolution secondary beam line.
  - Provides hadrons, electrons or muons of energies between 10 and 360 GeV/c.
- **Particle type and energy**
  - Electron : 10 – 100 GeV
  - Pion : 10 – 350 GeV
  - Muon : 40, 120 GeV
- **First beam time in 9 - 23th May, 2018**
  - Check whether the main detector works well.
- **Second beam time in 26th June - 4th July, 2018**
  - Take data with many different beam configurations (particles/energies).
  - Challenge an additional setup.

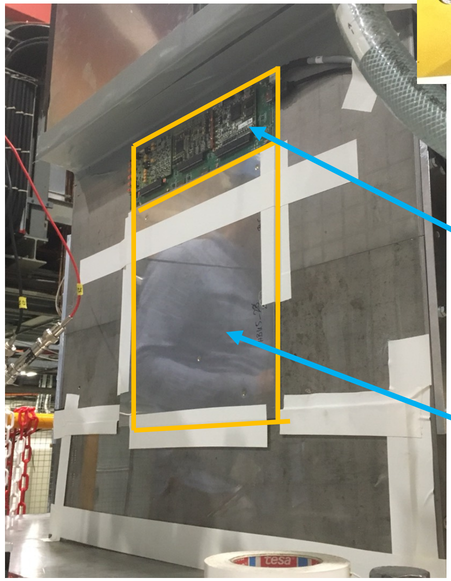


Large Prototype

Difference b/w First and Second

- **The following modules are added in second testbeam.**
  - Module with larger tiles (Tokyo module)
    - ➢ Next N.Tsuji talk
  - Preshower detector
    - 1 × 1 HBU
    - Check if the shower starts before it comes to the AHCAL
  - Tail-catcher
    - 1 × 1 HBU and 12 active layers
    - Steel absorber stack with 74 mm layer thickness
    - Measure the shower which starts later
    - Check how much energy leaks out from the main stacks

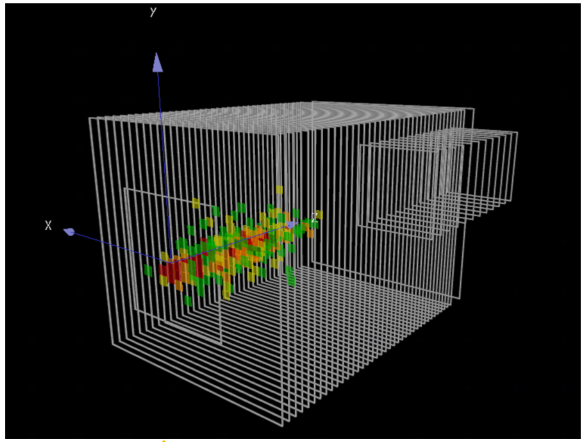

Tail-catcher



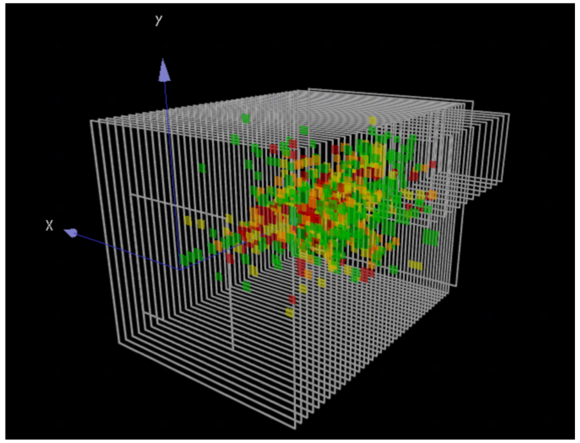
Preshower detector

N.B. very first look with preliminary calibrations

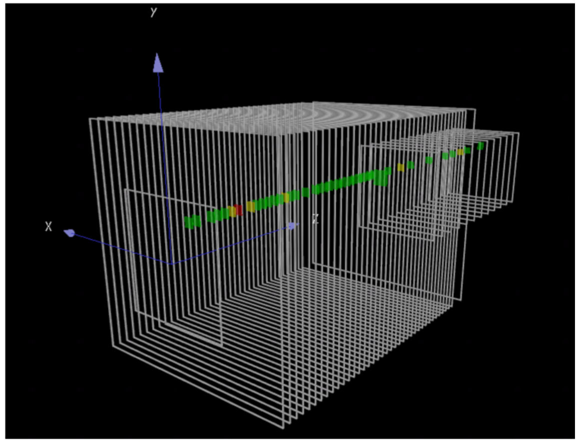
Typical Events



Electron

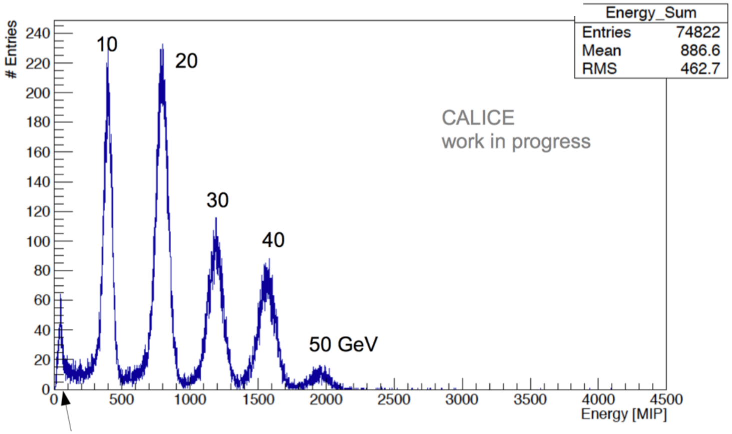


Pion

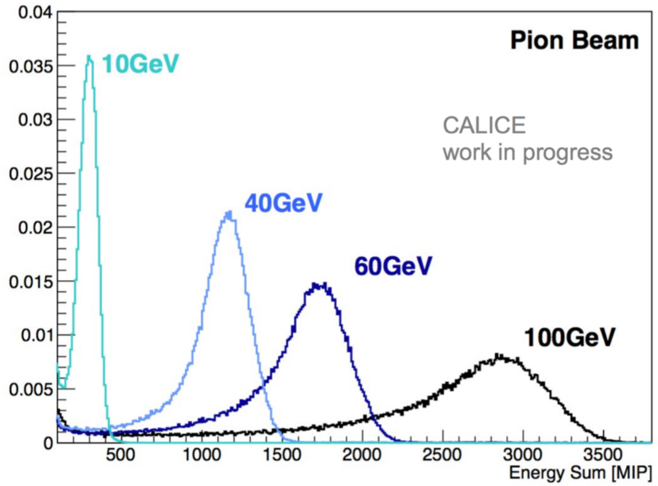


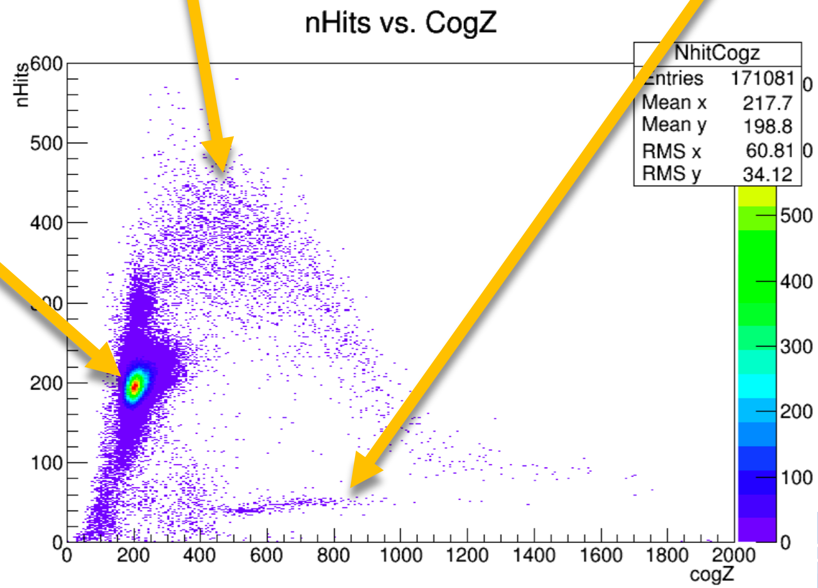
Muon

Electron



Pion





Center of Gravity Z vs. The number of hits

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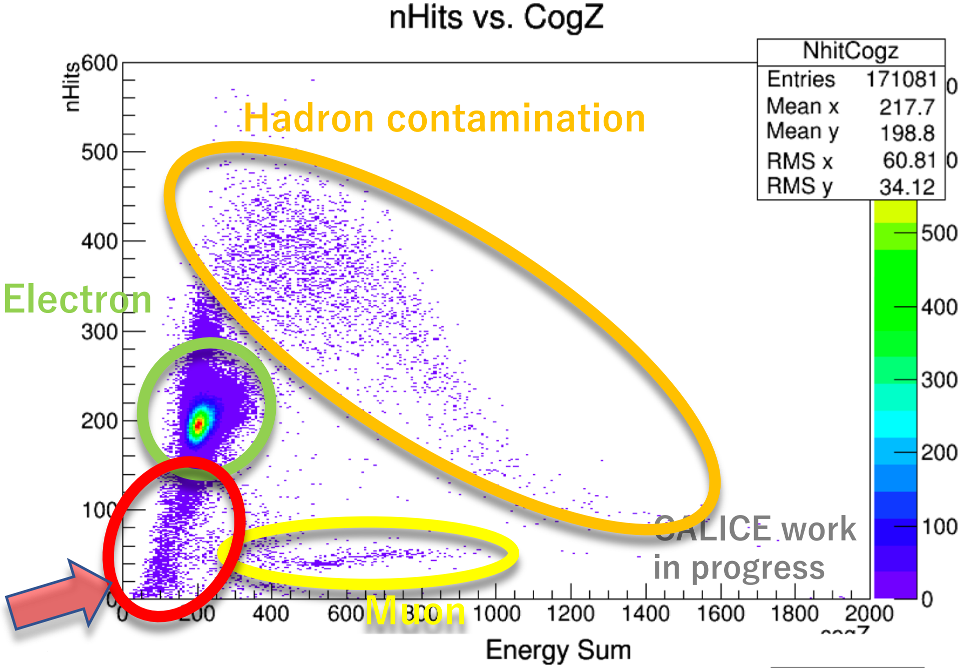
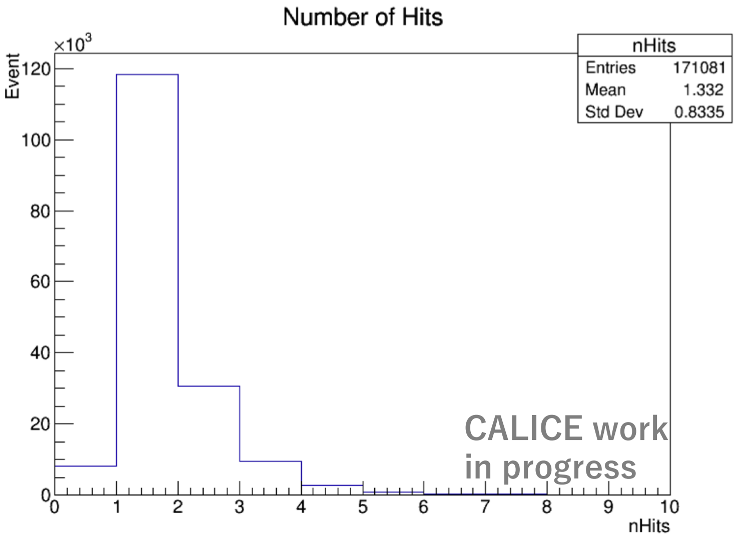
Event Selection with Preshower Detector

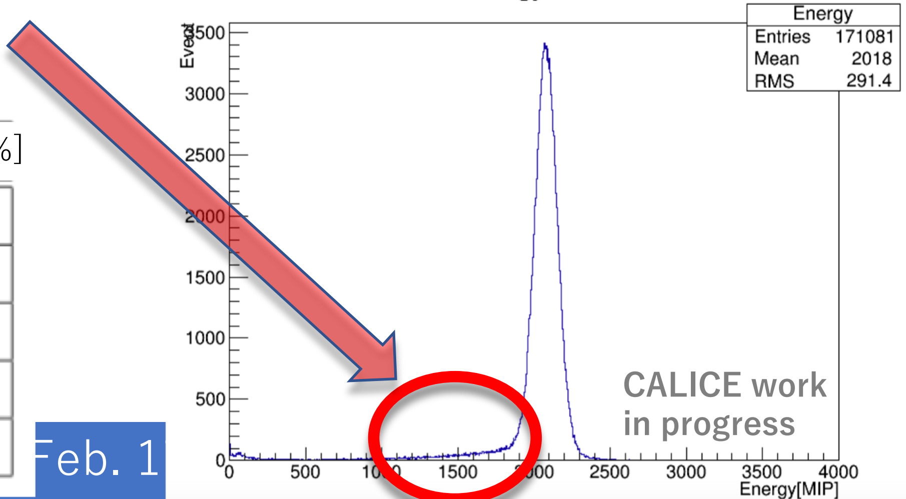
- **X : NHits Y : cogZ(** $\mathrm{cogZ} = \frac{1}{E}\sum_{i=1}^{\mathrm{nHits}} z_i E_i$ **)**
  - cogZ : Center Of Gravity Z
  - Nhits : The Number of Hits
- **The tail in low energy range is most likely to come from preshowers.**
  - Preshowers can be made in the beam line.
  - ➢ They can be removed by PS detector.
- **Electron 50 GeV Run Data**
  - Select events with the number of hits.



Preshower-like

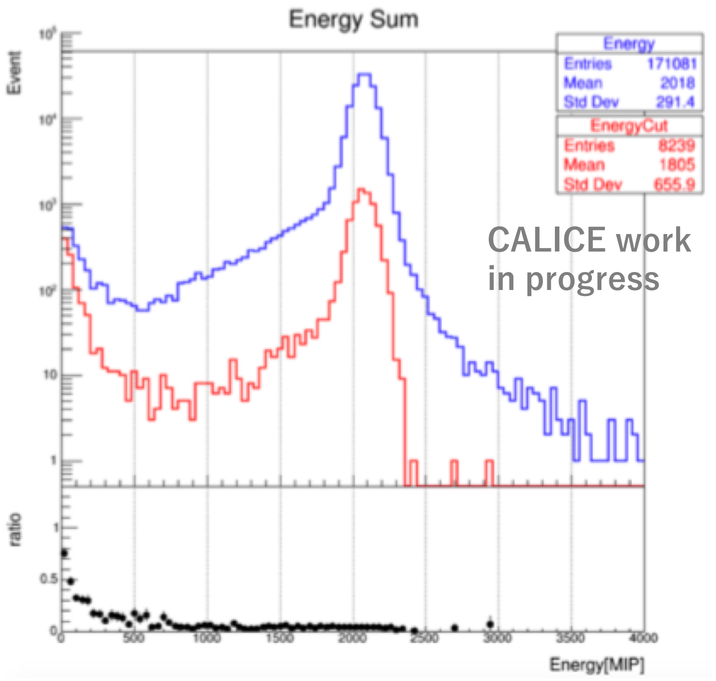


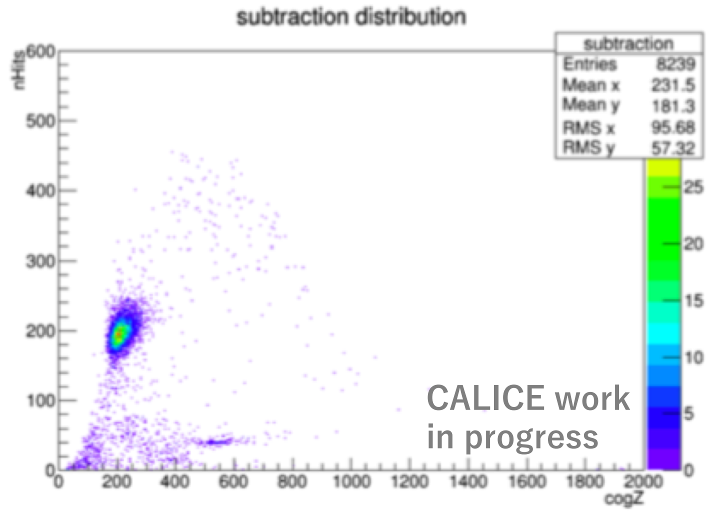
NHits	Events	Fraction[%]
0	8239	4.8
1	116692	69
2	19479	18
3	8896	5.5
4	2685	1.6



Characteristics of Events up to 2 Hits at PS detector

- NHits = 0
  - Probably events below 0.5 MIP threshold
  - There are many events which is likely not related with beams, while are not much tail events.
  - Many events coming from beams

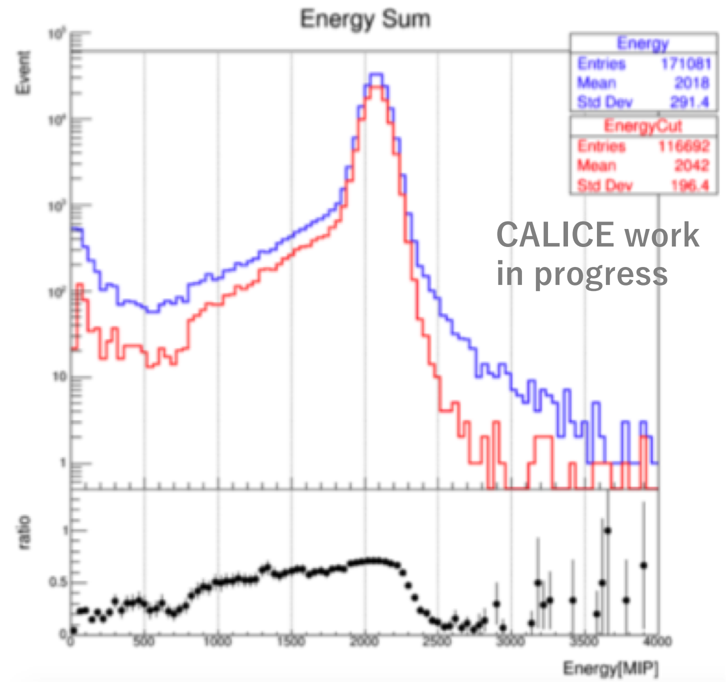




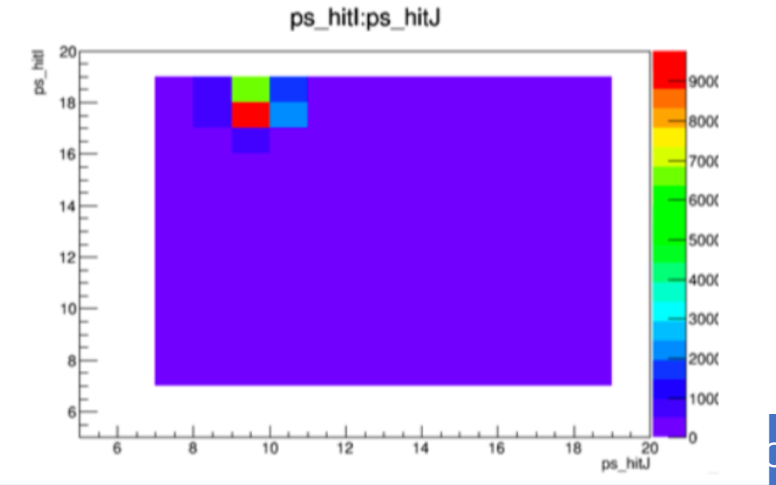
↑ Energy distribution of NHit = 0
← CogZ - NHits distribution

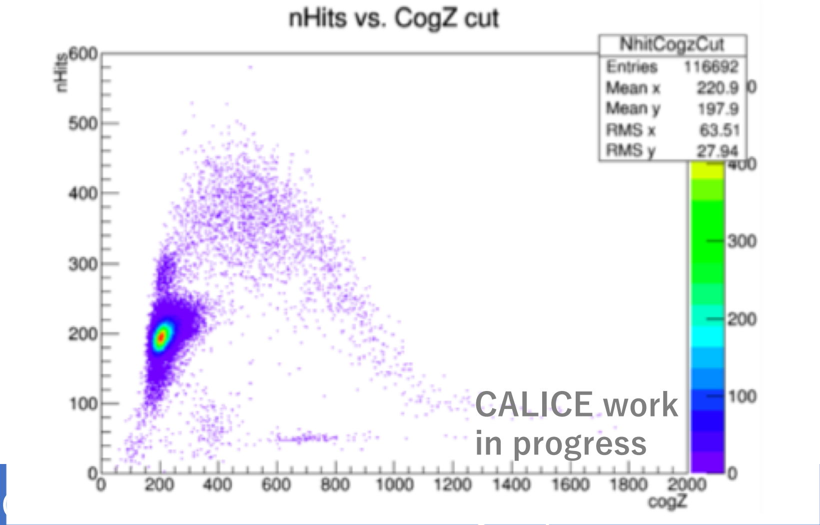
Characteristics of Events up to 2 Hits at PS detector

- **NHits = 1**
  - We want to select only events of this case.
  - Focus on 9 channels into which beams hit mainly
    -> remove backgrounds
  - Many tail events
  - Fraction of tail events is smaller than that of peak events



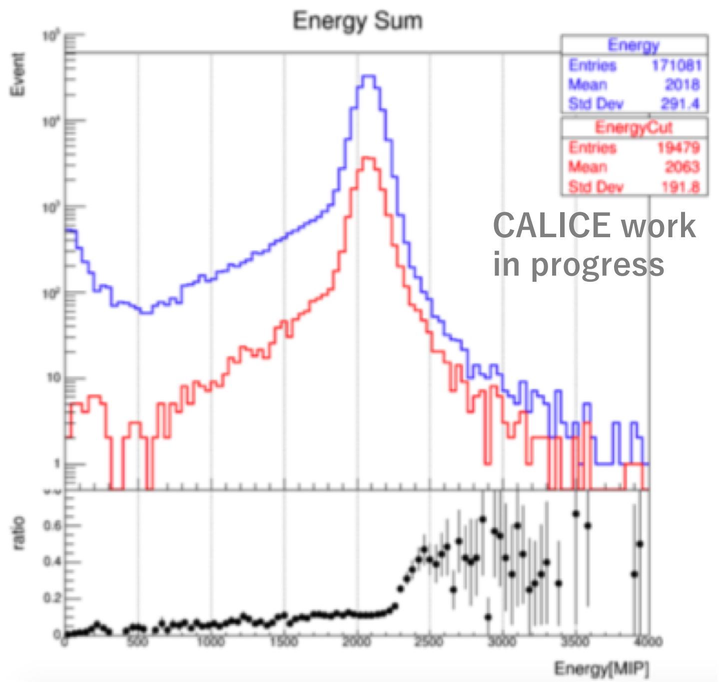
↑ Energy distribution of NHit = 1
← CogZ - NHits distribution

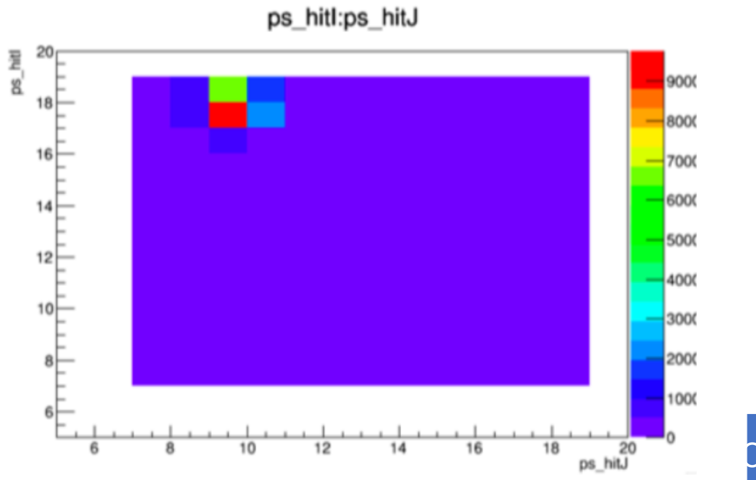


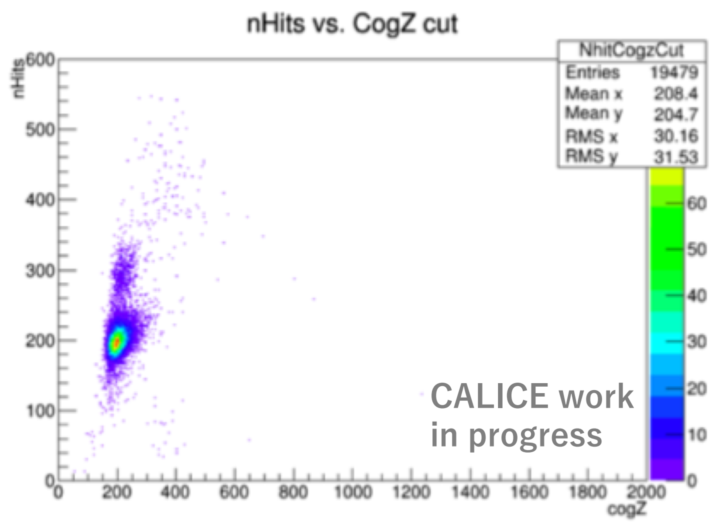


Characteristics of Events up to 2 Hits at PS detector

- **NHits = 2**
  - It is likely that this case means a particle hits between 2 channels.
  - Focus on 9 channels into which beams hit mainly -> remove backgrounds
  - There are almost not tail events.
  - Many peak events







↑ Energy distribution of NHit = 2
← CogZ - NHits distribution

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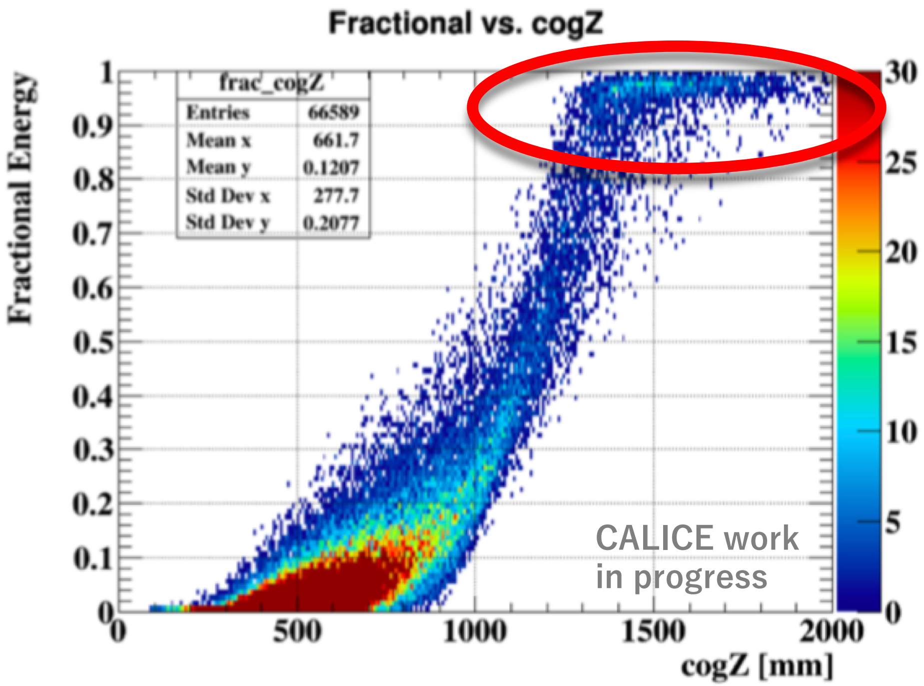
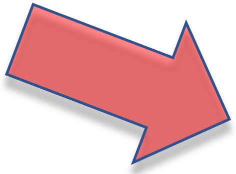
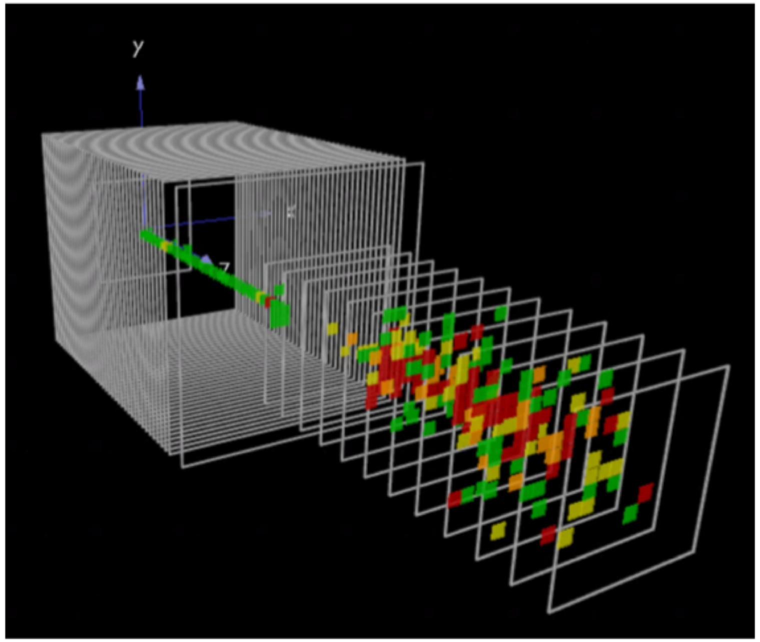
Roughly Calculation of Energy Leakage

- **Energy Leakage from the main stacks**
  - Fractional energy leakage to energy sum
  - Leakage ~ 1 : showers start late
  - Fractions of entries which showers start late are bigger.

Beam Energy [GeV]	All Entries	cogZ > 1070 mm	Fraction [%]
160	75166	4883	6.50
80	91997	5273	5.73
60	89458	4543	5.08
40	117327	5080	4.33
20	96693	2409	2.49

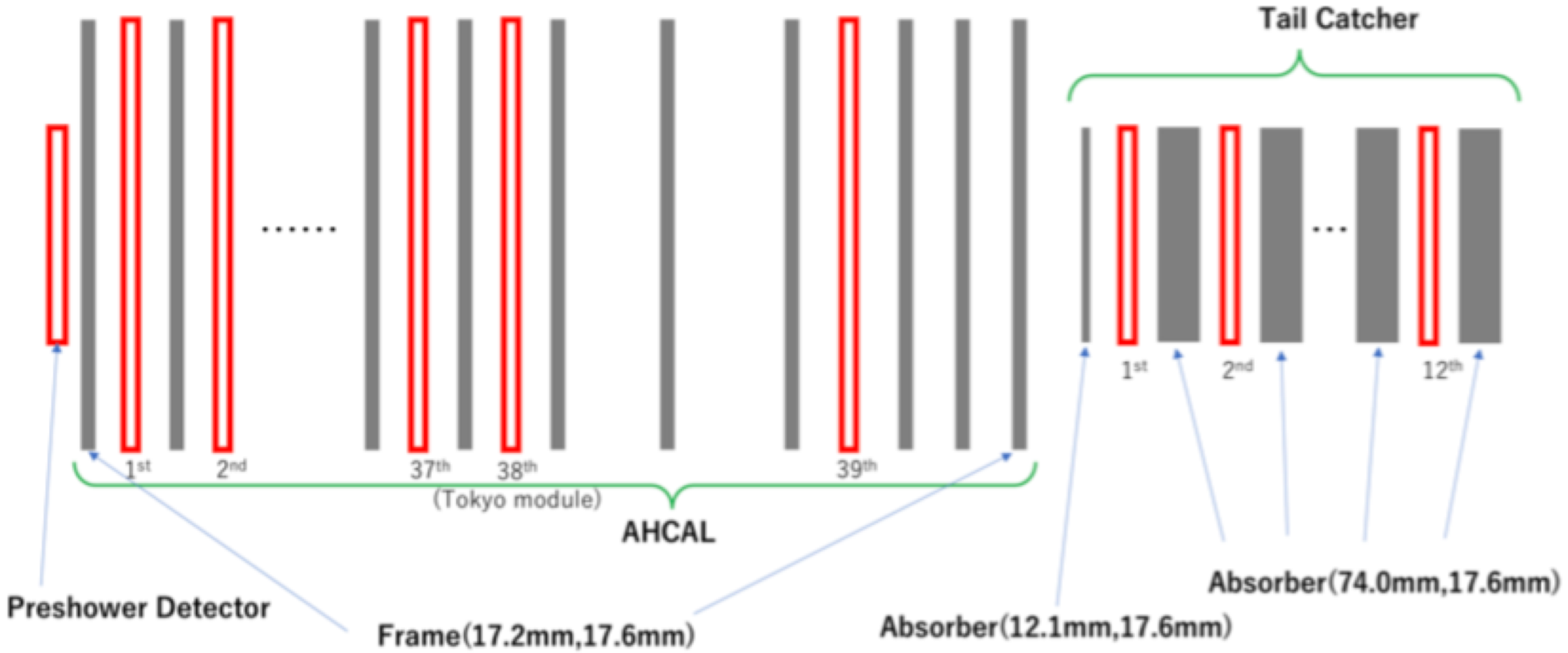






Weight for Energy Correction

- **Weight : Ratio of absorber thickness of Tail Catcher to main stacks**
  - 39^{th} layer in main stacks : three times thicker than other layers
  - First layer in Tail Catcher : $(17.2 \times 3 + 12.1)/17.2$
  - Other layers in Tail Catcher : $74.0/17.2$
- **Correct energy with the above ratio as weight**

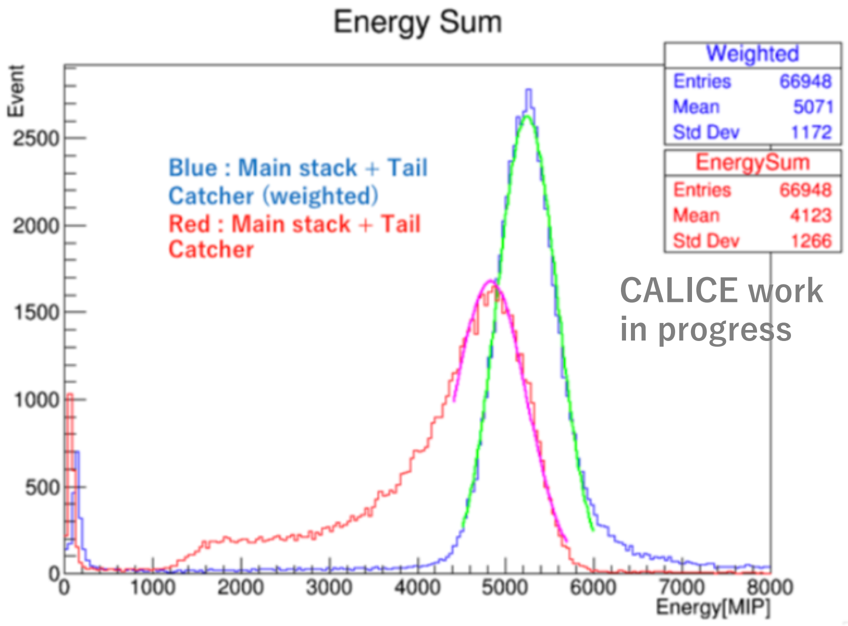


Setup Geometry

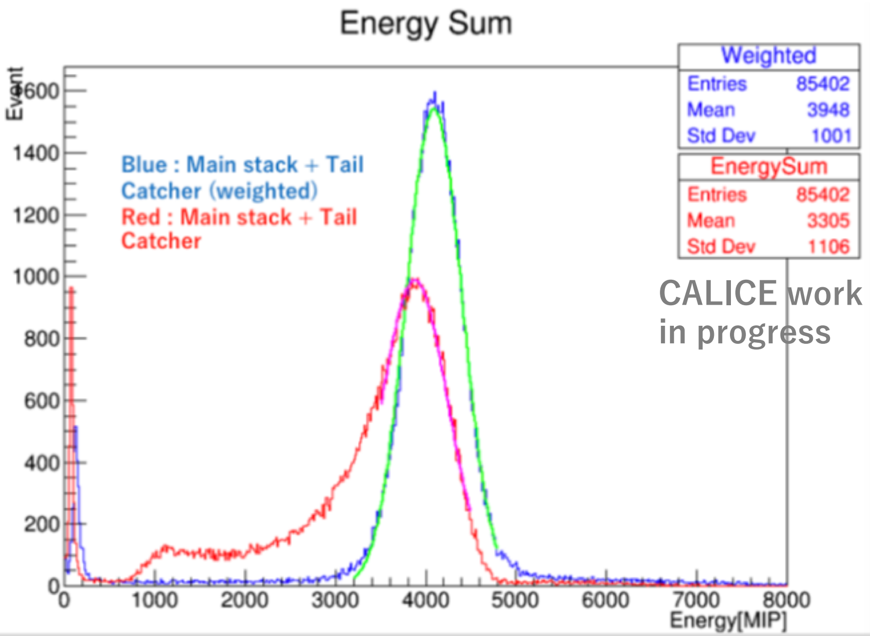
Result of Energy Correction

- Energy distribution
  - Red : before correction
  - Blue : after correction
  - Tail events in low energy range coming from Tail Catcher decrease drastically and width of the peak became narrower.
- A tail arises in high energy range when 160 GeV pion data is corrected.
  - ➢ It is possible to be related to the shower starting points due to high energy beam.

Pion 160 GeV

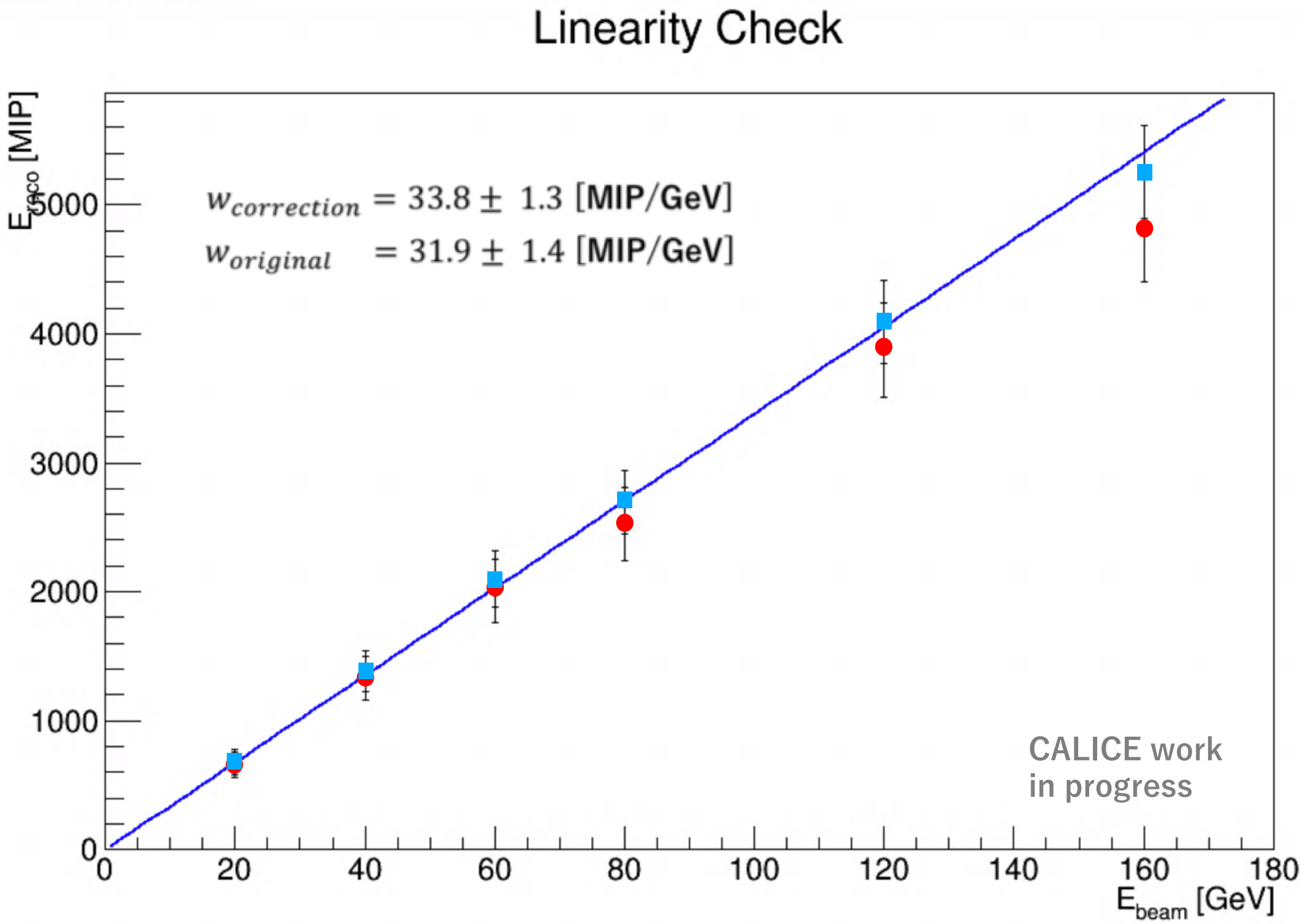


Pion 120 GeV



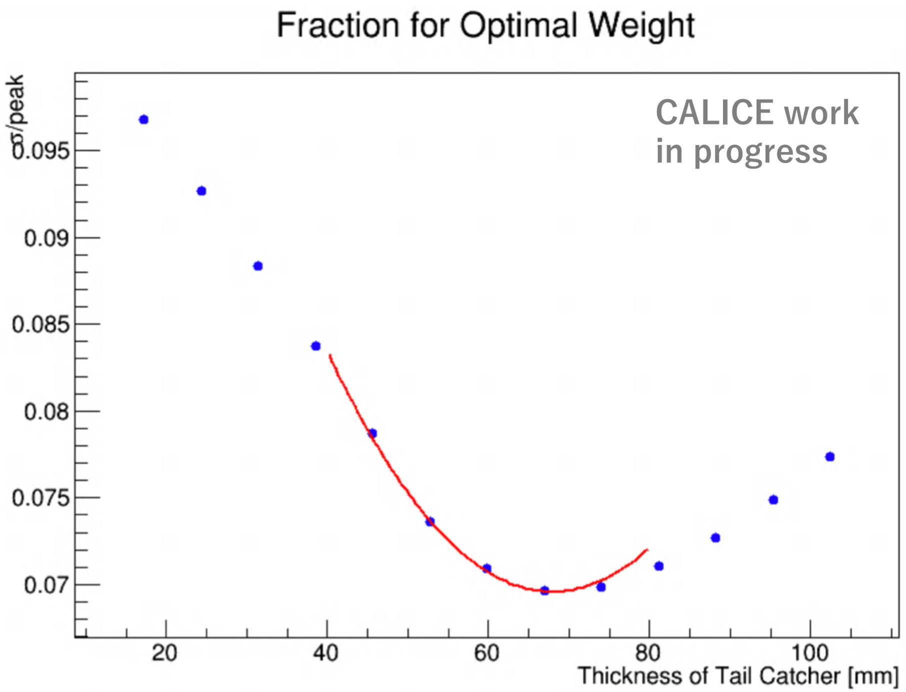
Linearity

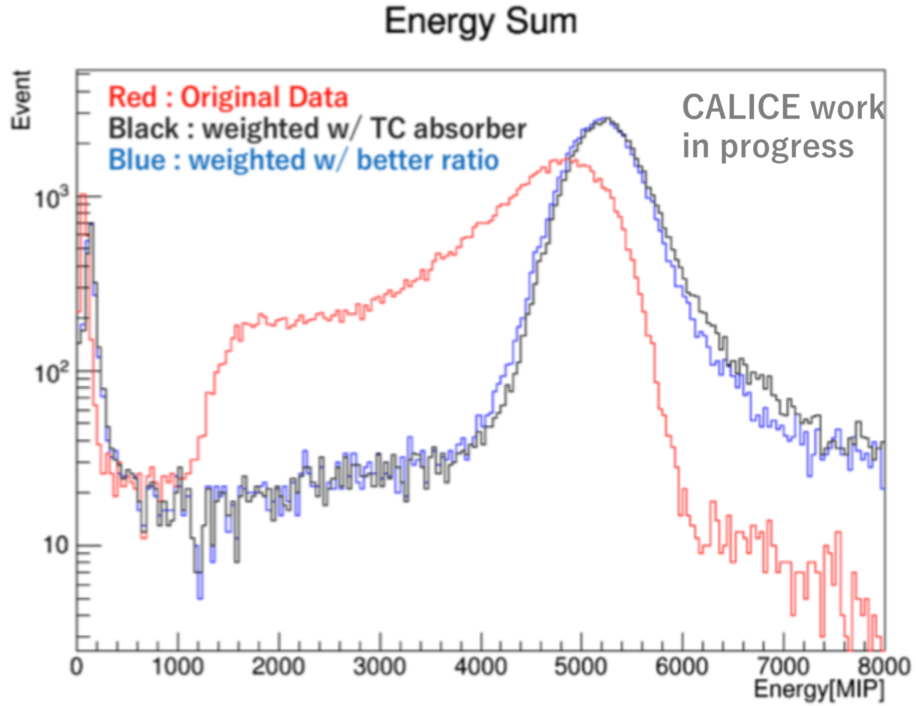
- **Red : before correction**
- **Blue : after correction**
- **Recover the linearity in high energy beams.**



An Idea of Better Optimal Weight

- Consider the problem of tail in corrected pion 160 GeV data.
- Change fraction of an absorber thickness in order to optimize energy resolution.
  - 74.0/17.2 -> x/17.2
- result : 67.2/17.2
- Comparison
  - Red : before correction
  - Black : after correction w/ simple weight
  - blue : after correction w/ the above procedure
- Tail events become smaller a bit.





Current Status and Prospect

- **Current Status**
  - For two testbeam data sets calibration constants are updating and the final version will be completing.
  - Several analysis software are developing and tried for the data sets.
- **Attempt for simulation study**
  - Comparative study of MC simulation to testbeam data is ongoing.
    - There are some gaps.
    - ➢ Wrong calibration constants cause these gaps(?)
- **Prospect**
  - Search for better optimal weight
  - After MC simulation would be consistent with data
    - Expand Tail Catcher to the size of main stacks virtually and calculate energy leakage from them precisely
    - Check whether main stacks obtain the designed energy resolution

Summary

- Constructed AHCAL large prototype in DESY and tested it in SPS, CERN.
- Take data of several particle types and energies.
  - Electron(10 – 100 GeV), Pion(10 – 350 GeV), Muon(40,120 GeV)
- This AHCAL large prototype worked very well and gave high quality data.
- Mostly finished various calibrations for data from both of beam times.
- The best way to select events with the preshower detector decrease preshower-like events moderately.
- We analyzed data with tail-catcher.
  - Roughly energy leakage from main stacks.
  - Energy correction was done by considering simple weight.
  - Linearity was checked.
  - Energy correction with a better optimal weight was tried.
- Simulation study is ongoing in order to compare with data and another studies.

backup

Event Selection by Energy

- Investigate tail events
  - 0<cogZ<300 && 0<NHits<150
  - Number of hits at preshower detector : 1 or 2
- Higher energy deposit at preshower detector would be expected for preshower events.
  - 2 MIP > Energy at preshower detector -> cut
- But it seems that this procedure is not good.