Test beam experiment of the large prototype of high granularity calorimeter for future electron-positron colliders

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On behalf of the CERN beam test team

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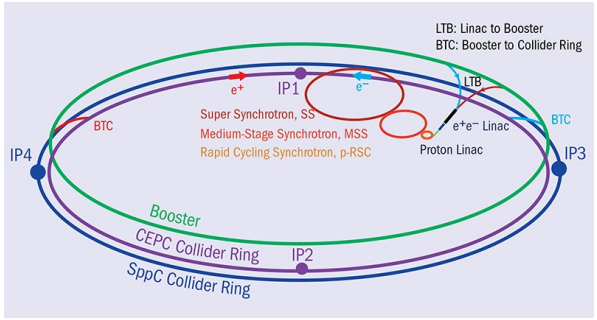
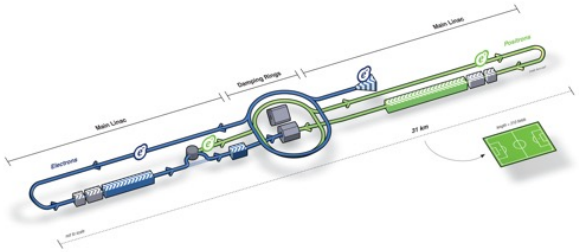
Introduction

- Future electron positron collider
  - Precision measurements of the Higgs/EW/QCD
  - Calorimeter system requirement
    - High granularity for both ECAL and HCAL
      - 5 mm for ECAL, few cm for HCAL
    - Jet resolution ~30%/E

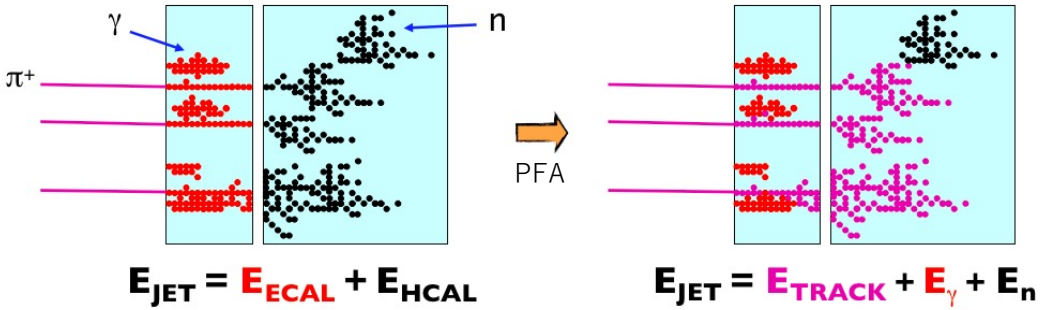
CEPC

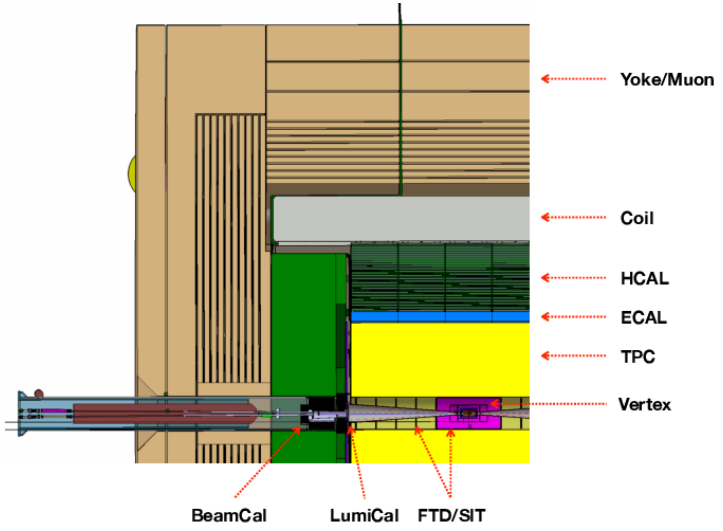


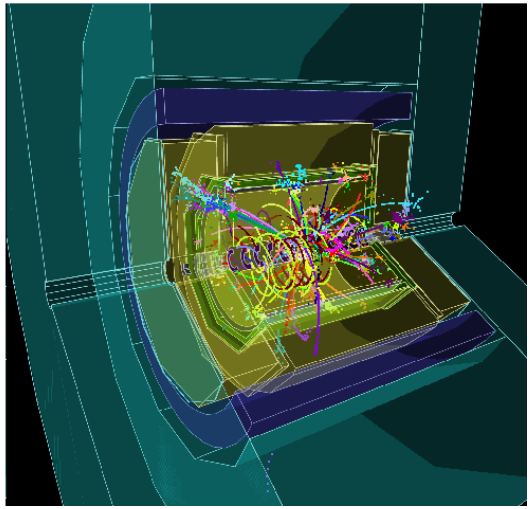
ILC



- Particle Flow Algorithm (PFA) oriented Detector
  - SiWECAL, Sci-ECAL, DECAL, etc…

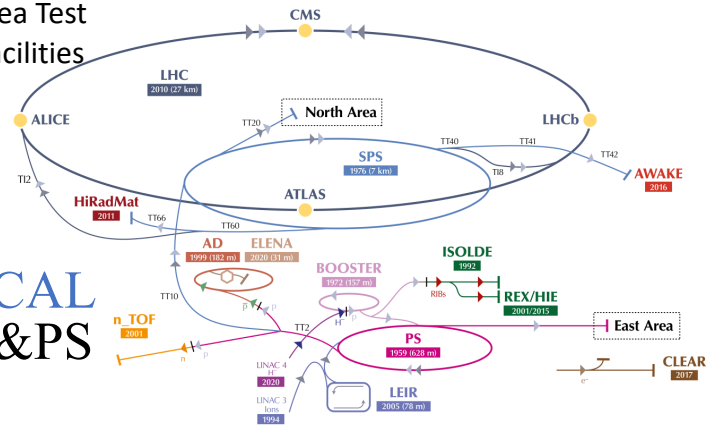


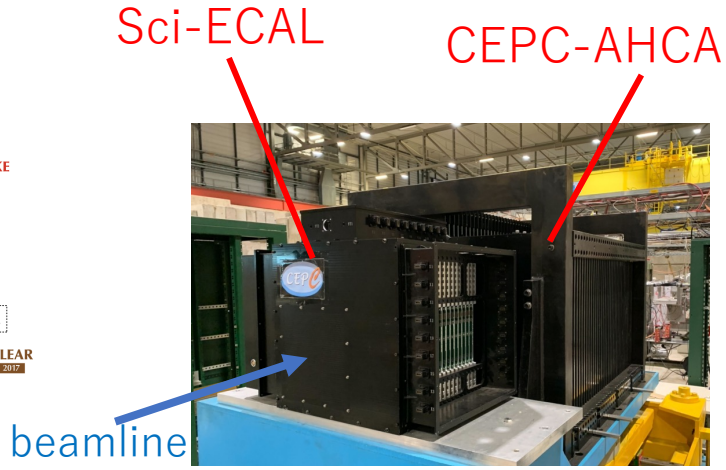




Test beam experiment

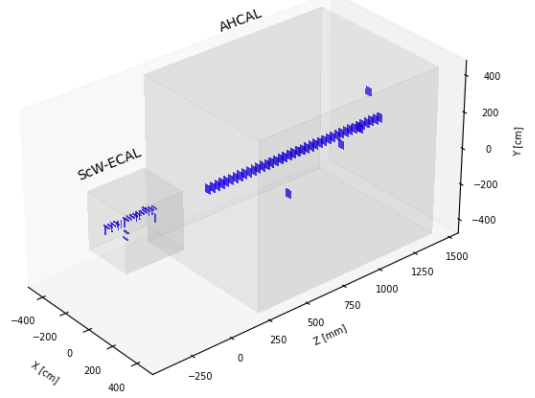
North Area Test Beam Facilities



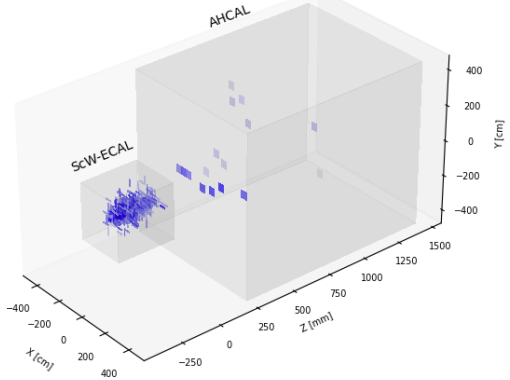


- Test beam experiment for Sci-ECAL and AHCAL combined system is conducted at CERN SPS&PS
  - SPS : site 887, H8 beamline
    - October 19th to November 2nd, 2022
    - High energy beam (10-160 GeV)
    - μ^-, π^-, e^-
  - SPS : Site 887, H2 beamline
    - April 26th to May 10th, 2023
    - High energy beam (10-350 GeV)
    - Higher energy and purity beam than last year's H8 beamline
    - μ^-, π^-, e^-, p^-
  - PS : Site 157, T9 beamline
    - May 17th to 31st, 2023
    - Low energy beam (1-15 GeV)
    - μ^-, π^-, e^-
- Collaborators
  - CALICE, UTokyo, Shinshu university, USTC, IHEP, SJTU

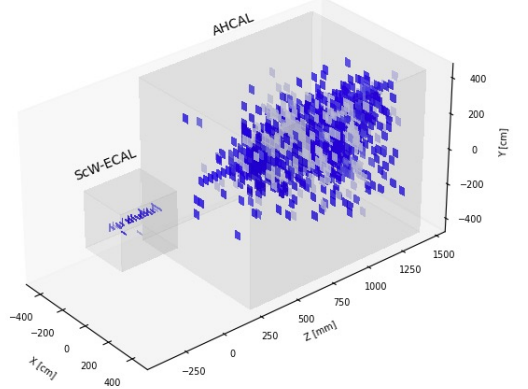
100 GeV muon



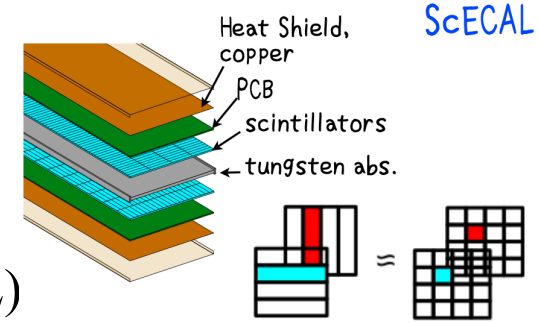
60 GeV electron



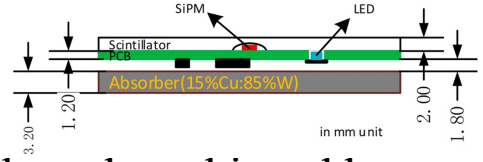
350 GeV pion

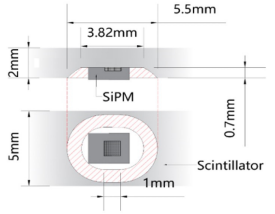


Sc-ECAL



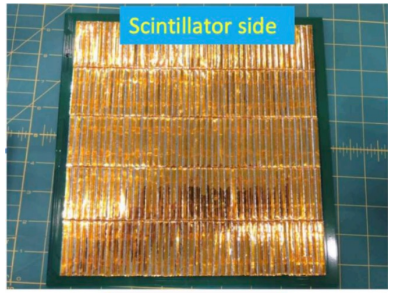
- Scintillator-based Electromagnetic Calorimeter (Sc-ECAL)
  - ECAL concept based on strip-shaped plastic scintillator readout by SiPM
  - Center dimpled readout based on 5×45×2 mm^3 scintillator strip

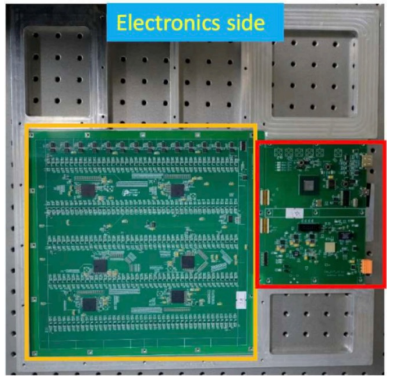


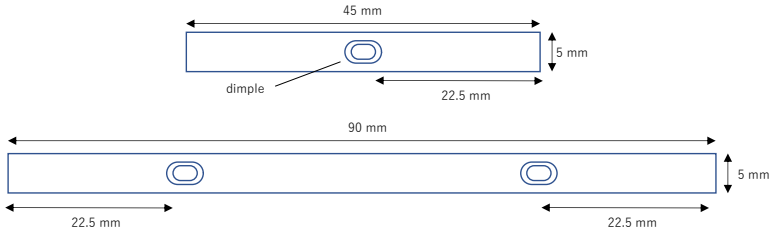


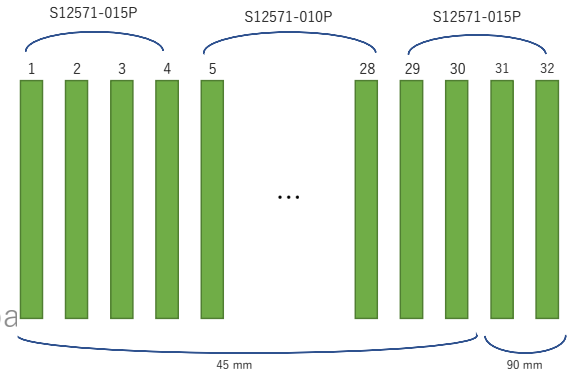
  - Virtual segmentation of 5×5 mm^2 cell can be achieved by x-y configuration of strips with strip splitting algorithm (SSA)

- Sc-ECAL protorype
  - Sampling layers : 32 layers
  - Absorption thickness : tangusten 32×3.2 mm (~23.3 X_0)
  - Electronics : SPIROC2E
  - SiPMs : S12571-010P, -015P
  - Scintillator : injection molding BC408





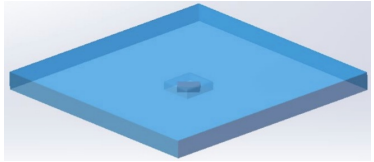


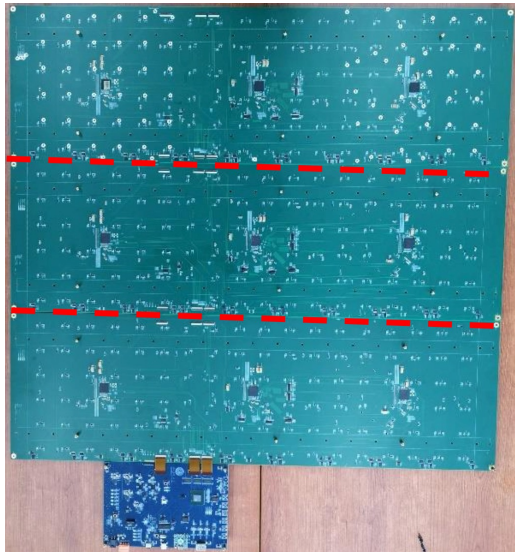


	Pixel size	# of pixel	gain
S12571-010P	10 um	10,000	1.35*10^5
S12571-015P	15 um	4,489	2.3*10^5

CEPC-AHCAL

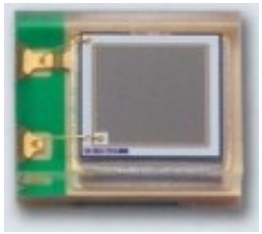
- CEPC-Analog Hadron Calorimeter (AHCAL)
  - HCAL concept based on scintillator cell readout by SiPM with center dimple
  - tile size : 40×40×3 mm^3
  - AHCAL barrel consists of 32 super modules, a super module has 40 sampling layers
  - PFA oriented design



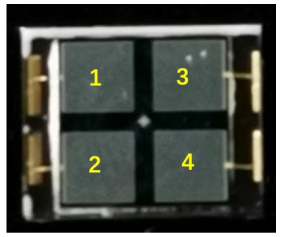


- CEPC-AHCAL prototype
  - Absorption material : Fe
  - Absorption 40×20 mm (steel) ~4.7 λ_n, ~3.9 λ_π
  - Electronics : SPIROC2E
  - SiPMs : MPPC S14160-1315PS, NDL 22-1313-15-S(last two layers)
  - Scintillator : injection molding

MPPC



NDL



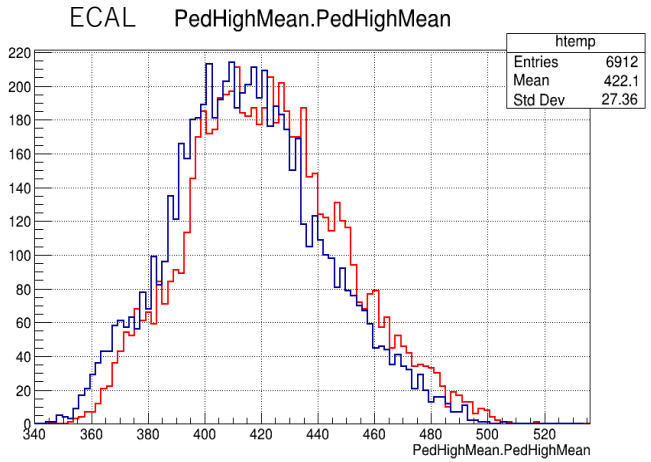
	Pixel size	Sensor area	# of pixels
S14160-1315PS	15 um	1.3×1.3 mm^2	7,284
22-1313-15-S	15 um	4.45×3.65 mm^2	7,396 × 4

Preliminary results

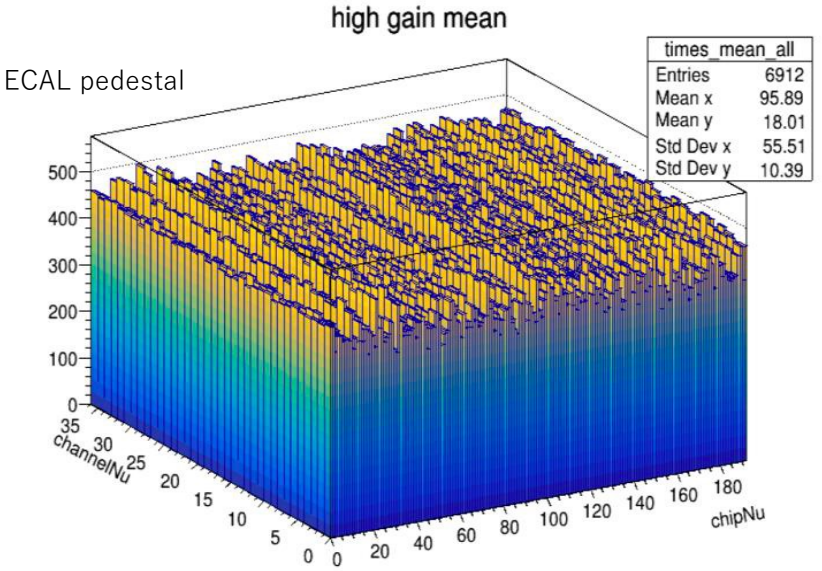
- Pedestal
- Gain calibration
- MIP calibration
- High gain and low gain intercalibration
- Energy reconstruction
- Simulation and validation

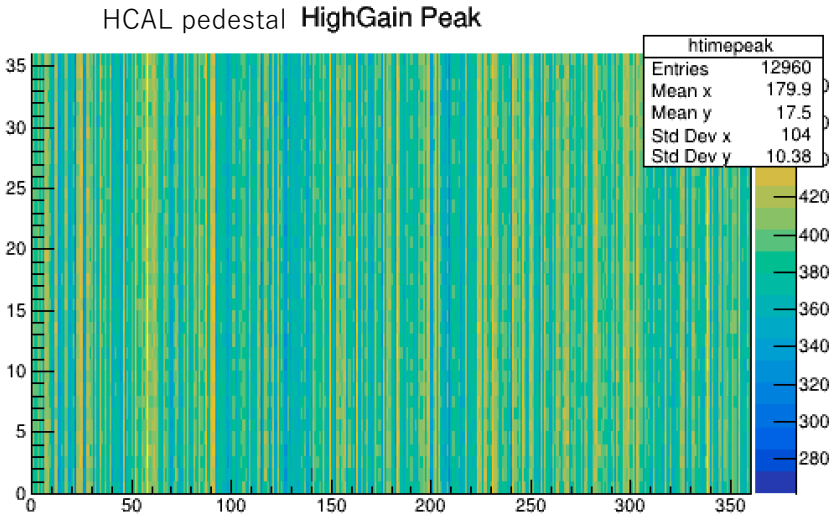
Pedestal calibration

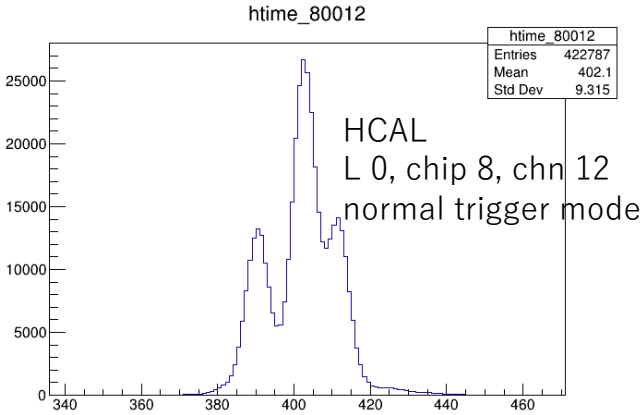
- Pedestal was obtained from events that did not exceed threshold
  - Some channels had multi-peaks due to electronics problem at last years data
- Pedestal is obtained from forced trigger mode

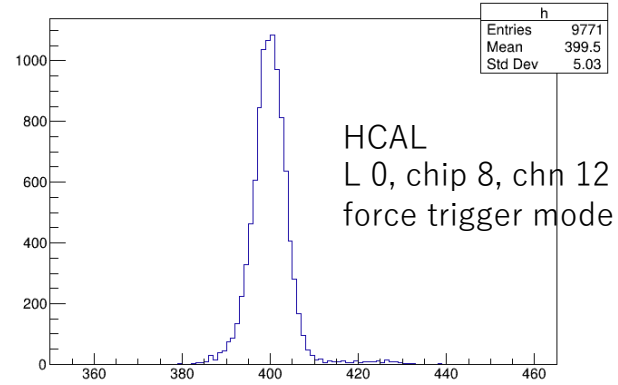


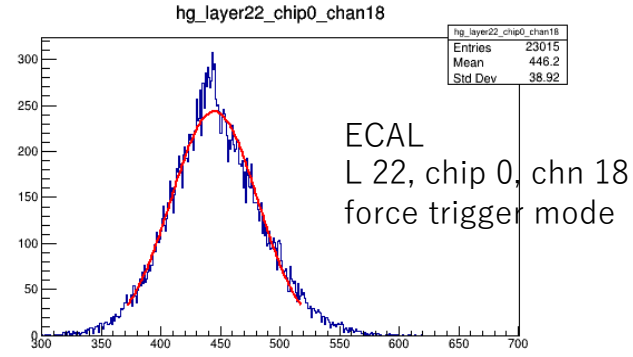
Blue histogram stands for pedestal from force-trigger-mode file
Red stands for pedestal from beam data file









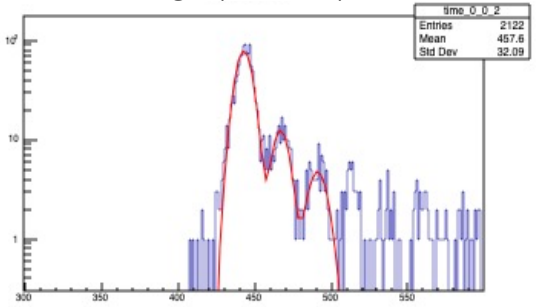


Gain calibration

- LED is mounted in EBU and HBU to measure gain for each channel
  - LED data are fitted with triple gaussian to find gain
  - Fitting is not good for some channels
    - ~15% for ECAL ~70% for HCAL

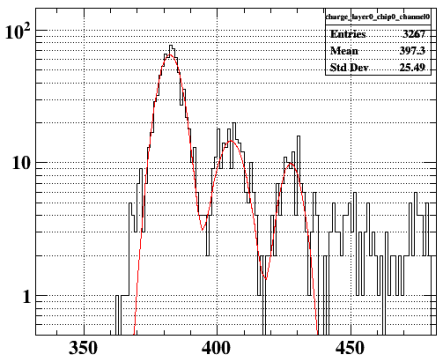
ECAL

15 um single photon spectrum



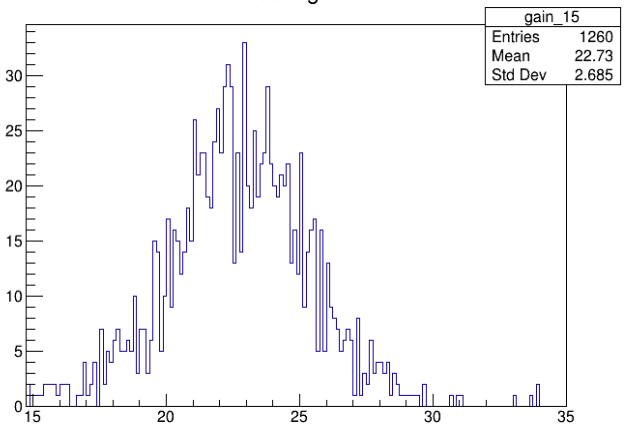
HCAL

charge_layer0_chip0_channel0



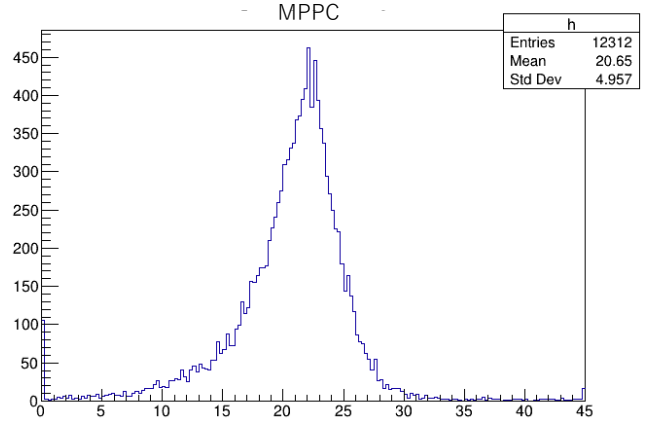
ECAL gain

15um gain

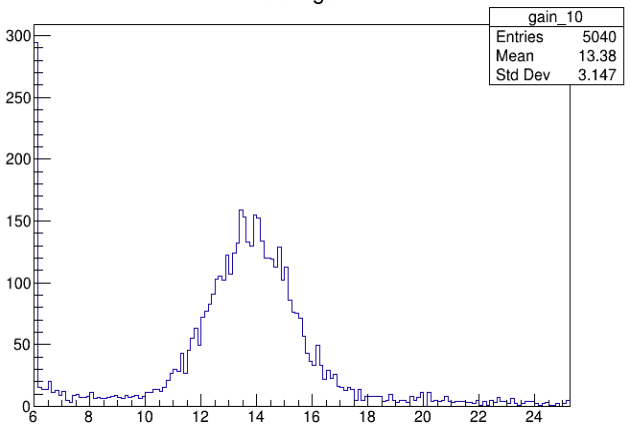


HCAL gain

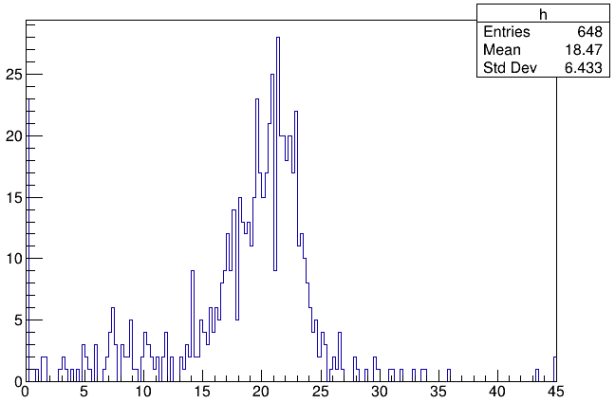
MPPC

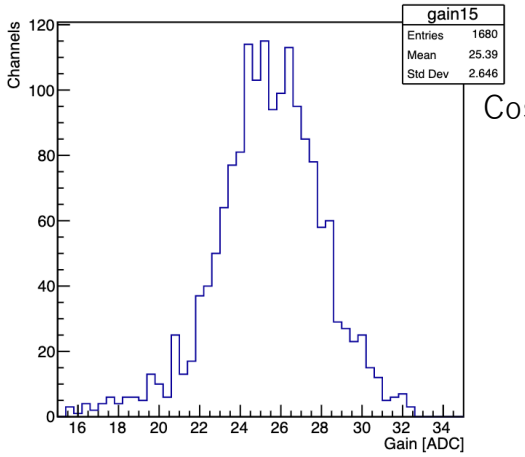


10um gain

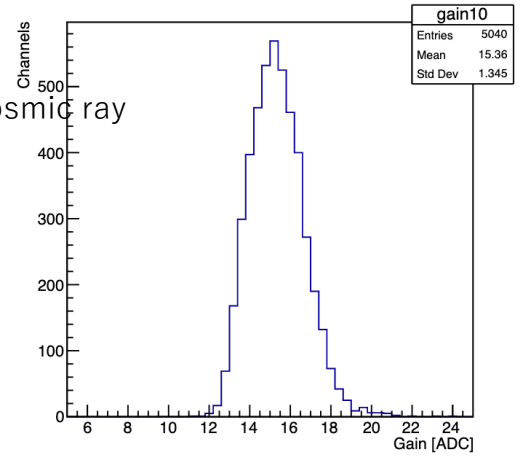


NDL





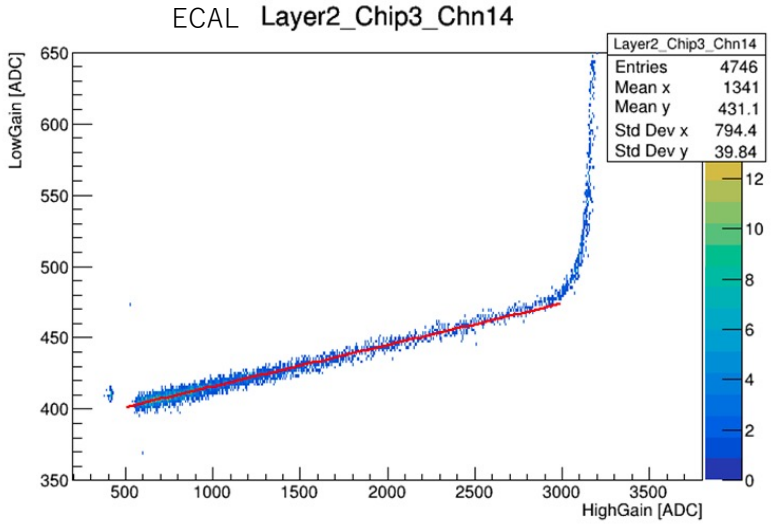
Cosmic ray

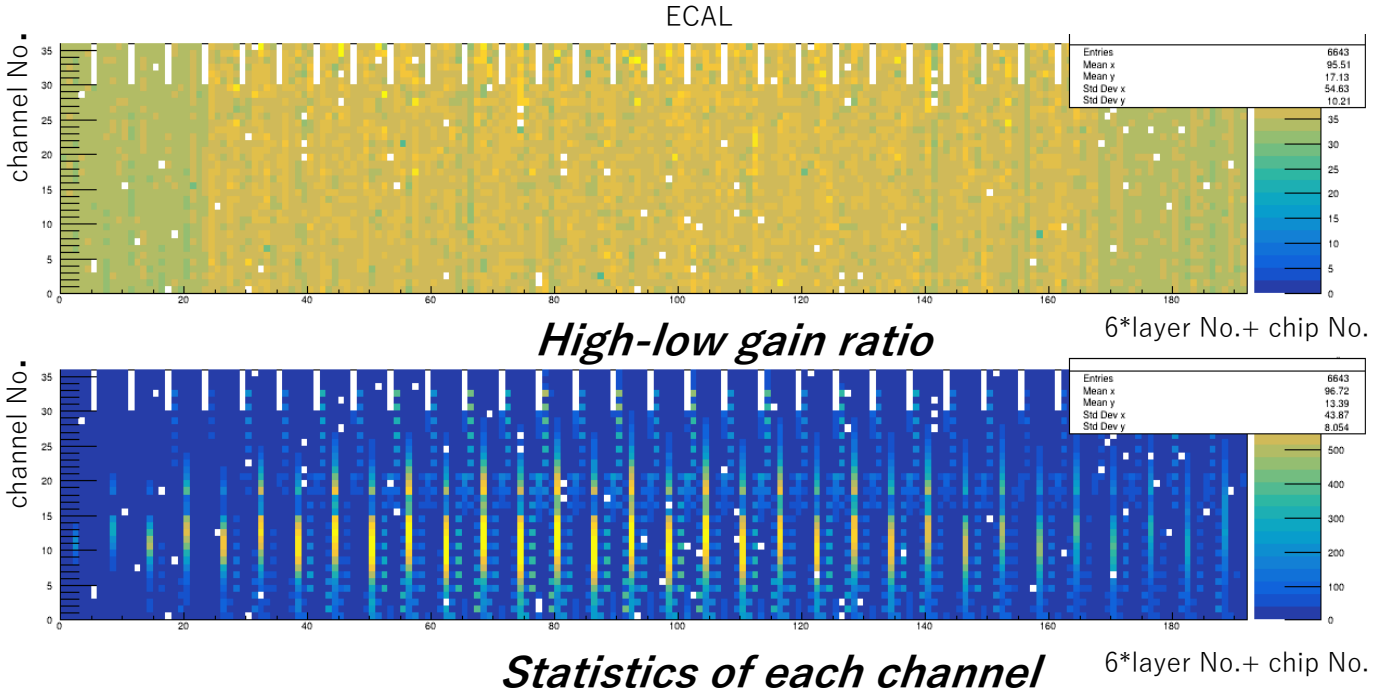


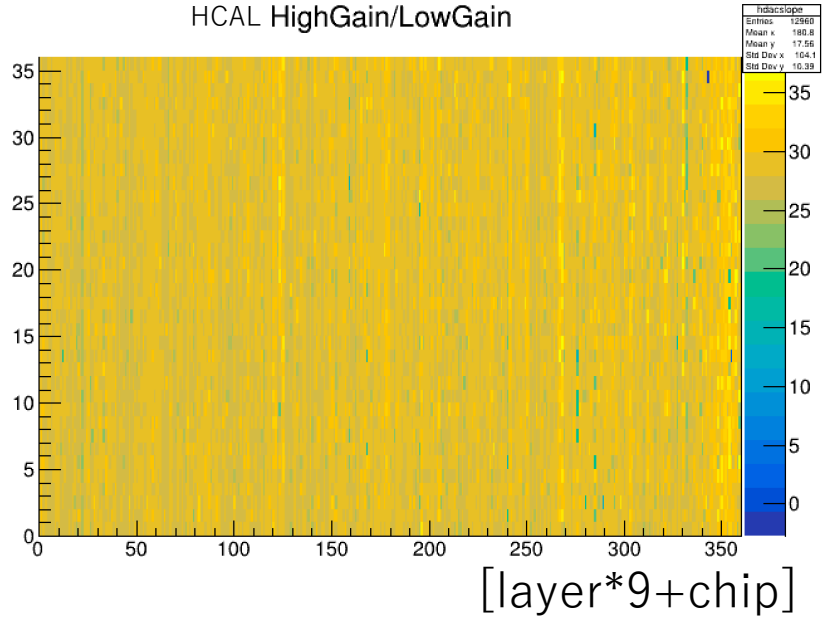
ECAL	CR	Beam test
temperature	~20 C	25~29 C
Bias voltage	-	+0.5 V

High gain and low gain intercalibration

- SPIROC2E chip has two gains (high gain and low gain) to cover a large dynamic range
- High gain ADC saturates at different value among channels
- The result is consistent with the gain difference



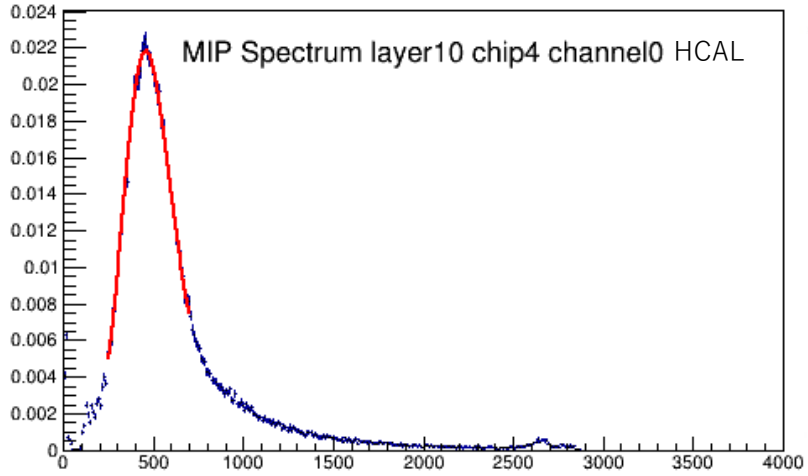


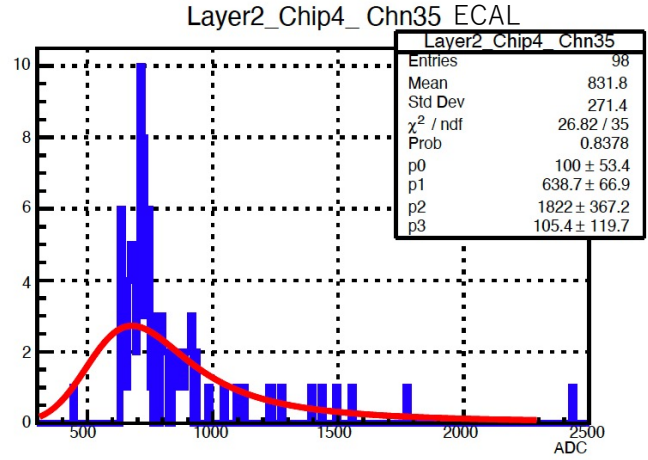


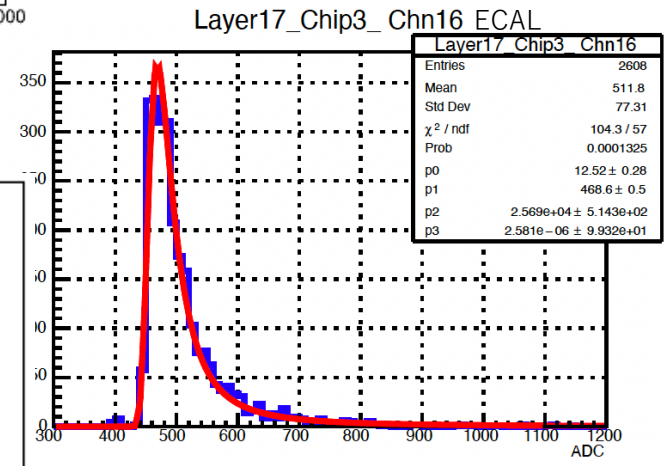
up

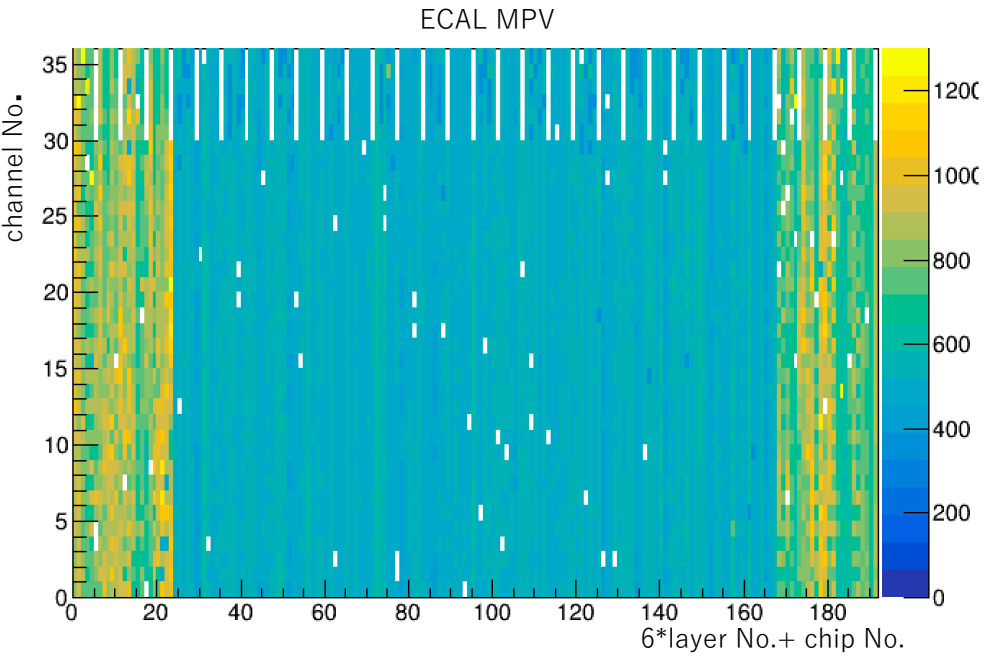
MIP calibration

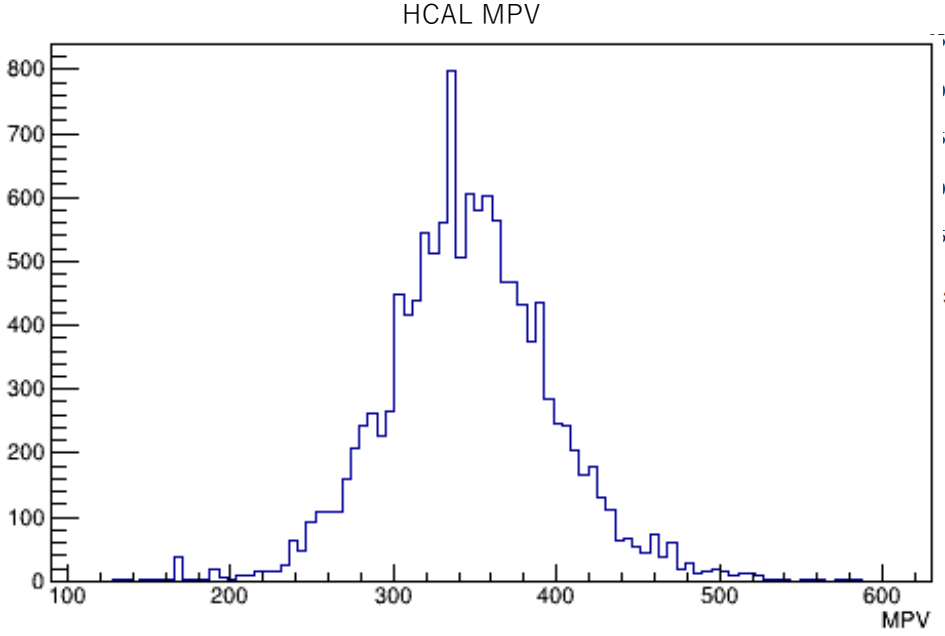
- MIP peak value is calculated from fitting muon events' ADC distribution by Langaus function
- Some channels are not well fitted due to lack of statistics and bad SN ratio
  - ~20% for ECAL and HCAL

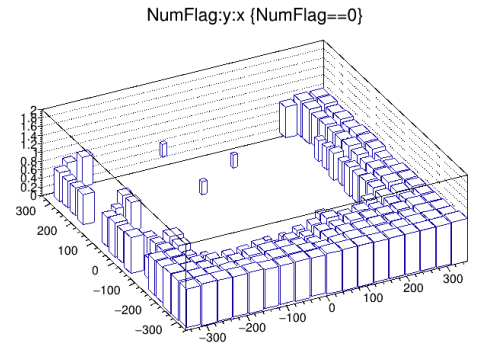






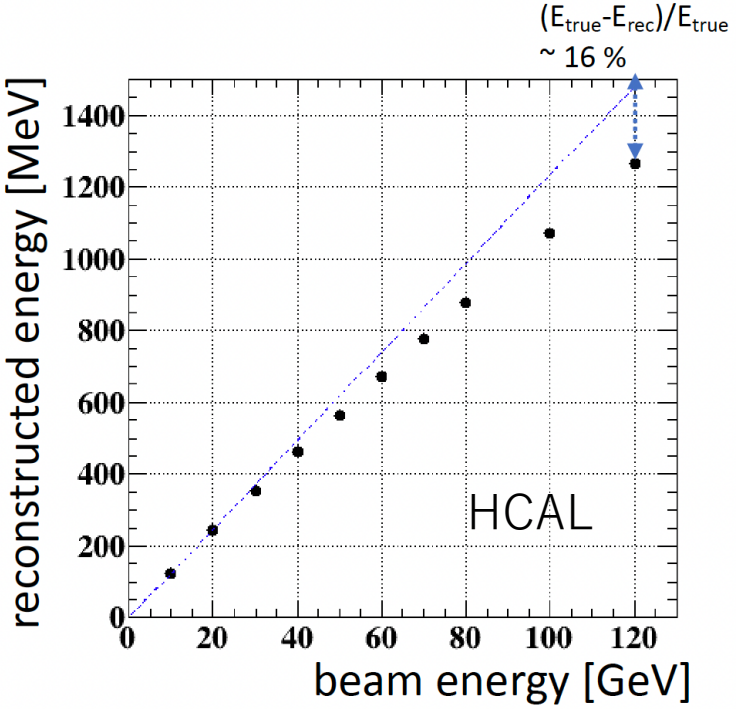


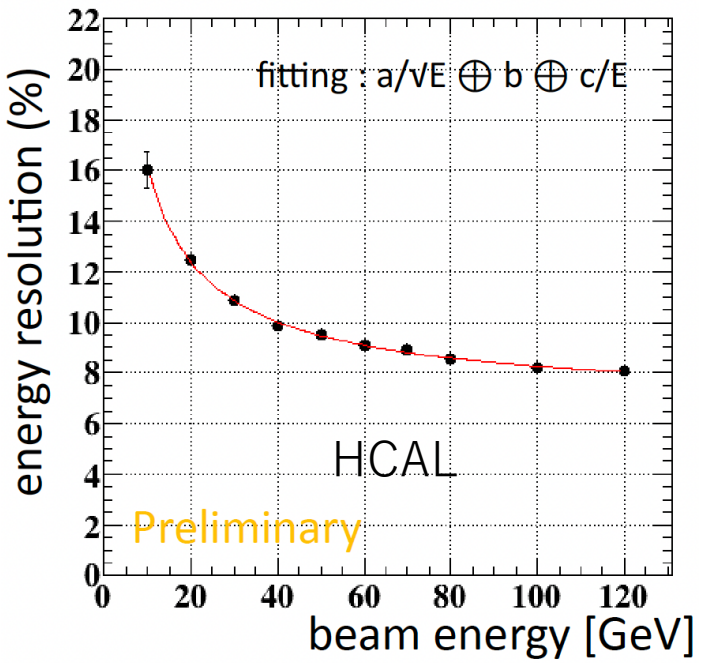


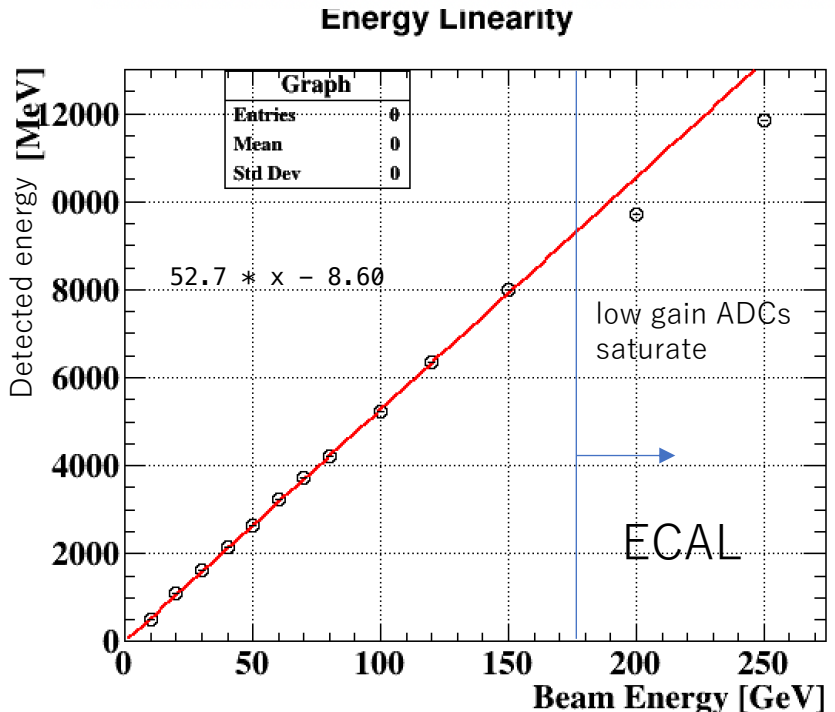


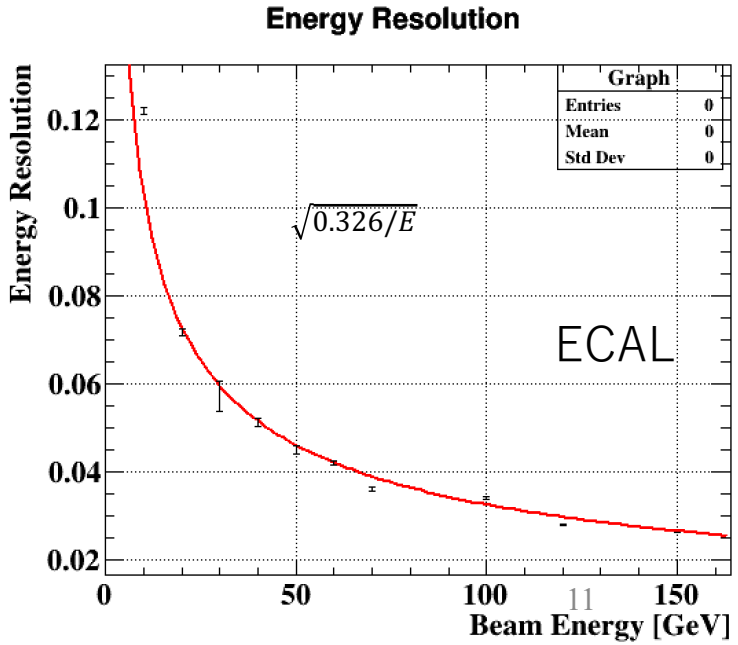
Energy resolution (electron beam)

- Reconstructed energy using new MPV, pedestal, and intercalibration factors
  - MPPC saturation is not corrected
- Linearity of energy get worse above 200 GeV
  - Low gain ADC saturates from 150 GeV
- Resolution is bad at 80 GeV and above 200 GeV
  - Bad beam profile (80 GeV)
  - Saturation of low gain ADC (above 200 GeV)



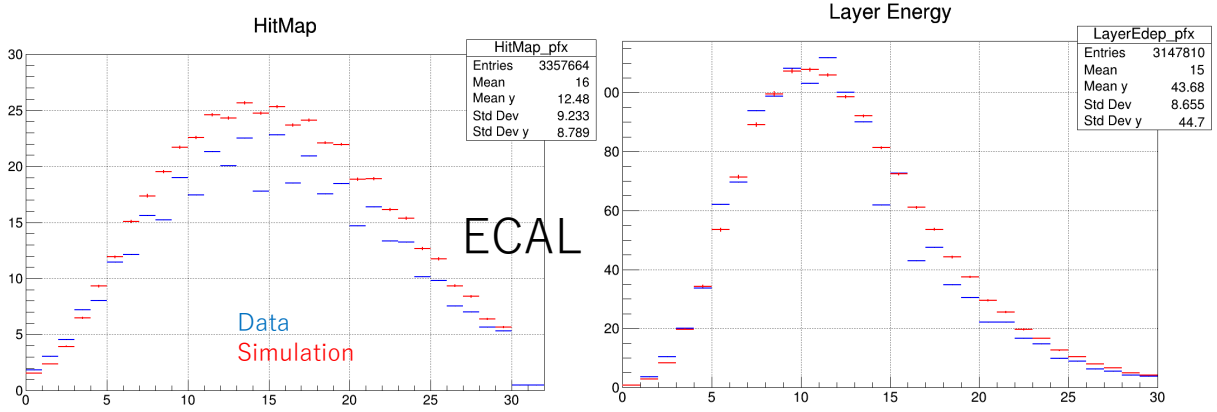


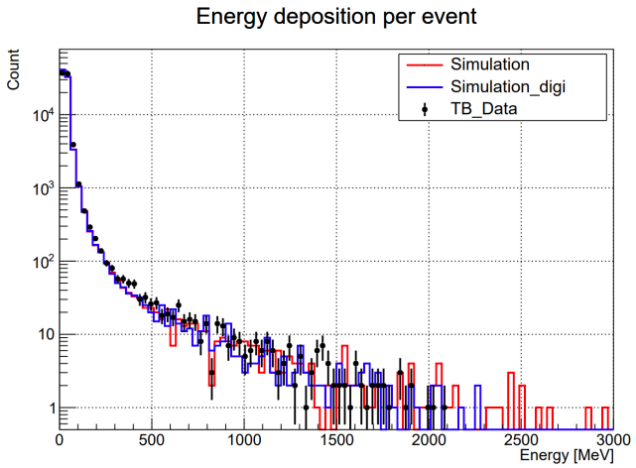


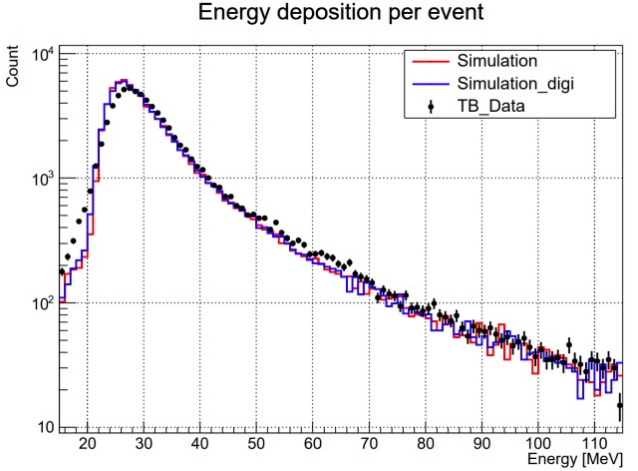


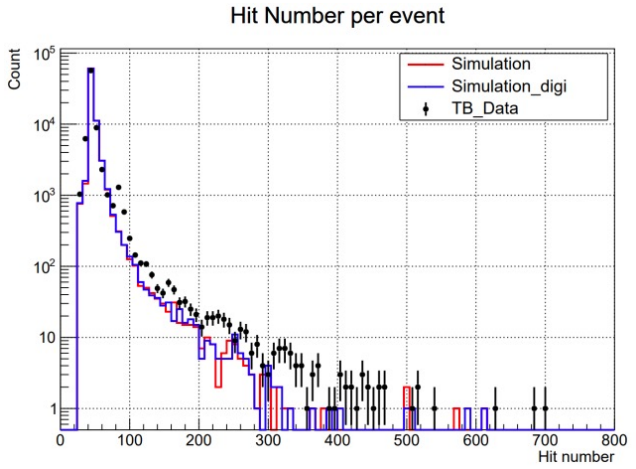
Simulation and validation

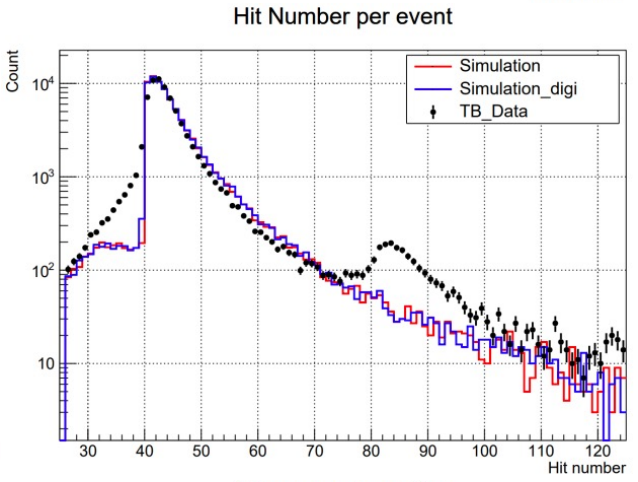
- Geant4 full simulation is established
  - Geometry : for both Sc-ECAL and AHCAL prototype
  - Scintillation : quenching effect (Birks' law) is implemented
  - Assuming perfect response uniformity for each channel
    - MIP calibration of each channel : done in data
  - Digitization
    - Photon statistics, SiPM saturation, ASIC saturation
- There are some discrepancy between data and MC
  - Still working in progress



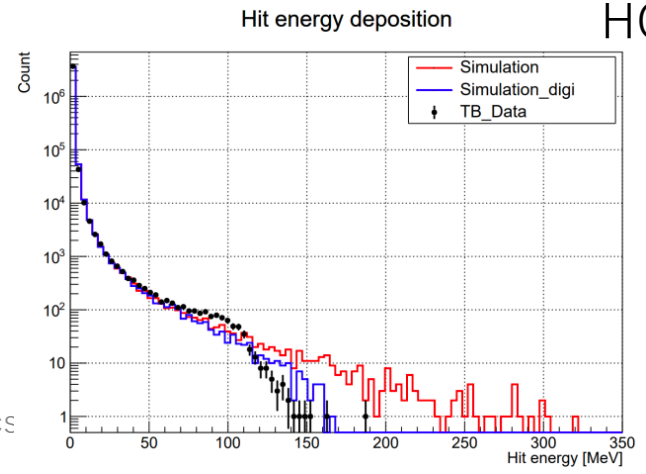


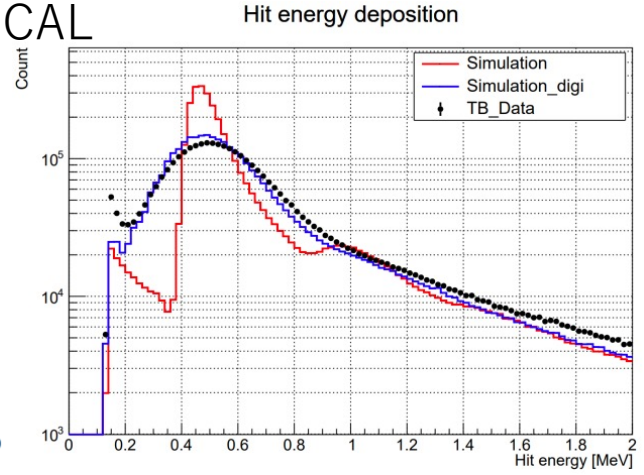






HCAL





Summary and prospect

- Sci-ECAL and AHCAL combined test beam experiments are conducted at CERN
  - SPS H8 beamline in last October
  - SPS H2 beamline in this April to May
  - PS T9 beamline in this May
- Collected data in wide energy range for electrons, pions, and muons

- Analyses of the combined beam test is ongoing
  - Preliminary calibrations are almost finished
- Some detailed analyses are also ongoing
  - shower analysis,
  - PID
  - Test beam simulation
  - etc…
- Plan
  - SiPM saturation, temperature correction
  - Geant4 MC validation
  - Sci-ECAL and AHCAL combined analysis

Thanks for CERN, CERN staff,
and CALICE collaboration colleagues