Status of high granular Sc-ECAL for future electron positron colliders

May 20th, 2024

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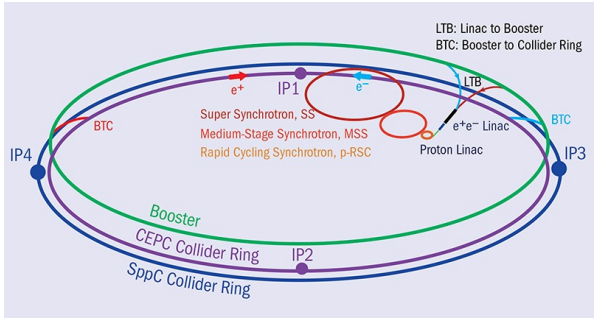
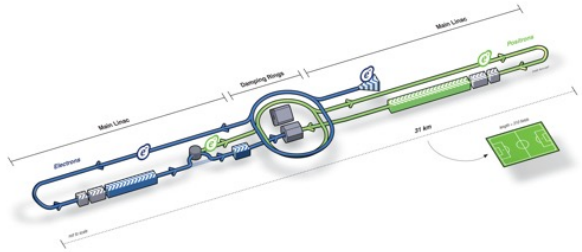
Introduction

- 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

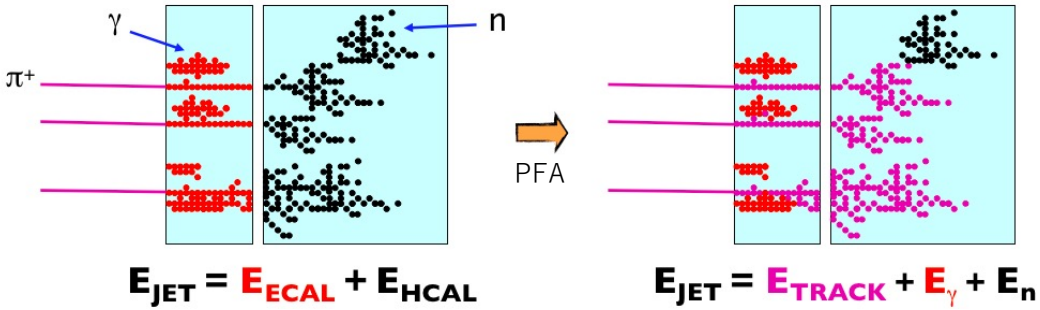
CEPC

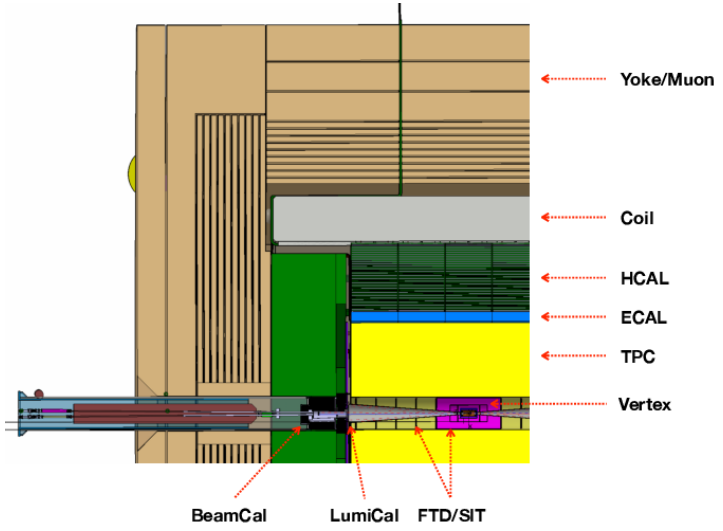


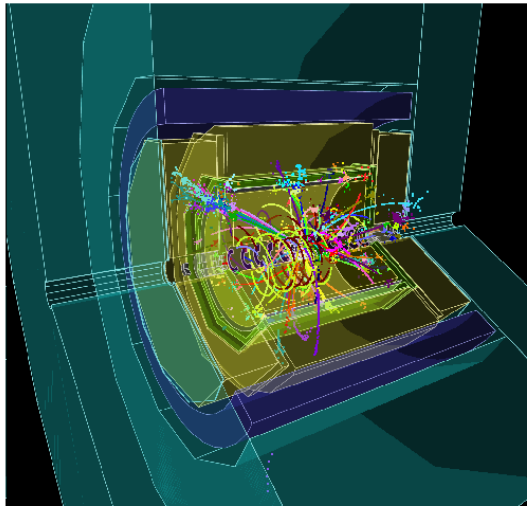
ILC



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



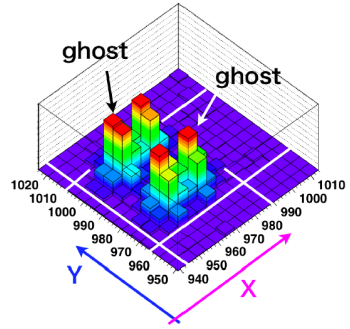




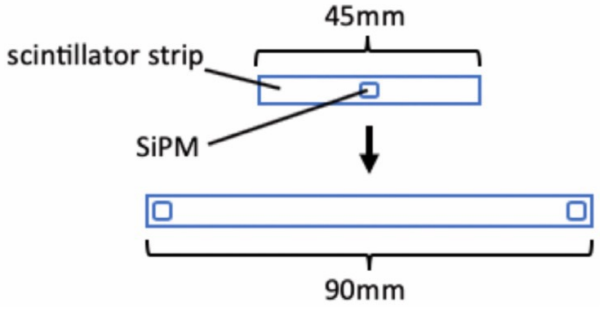
Sc-ECAL

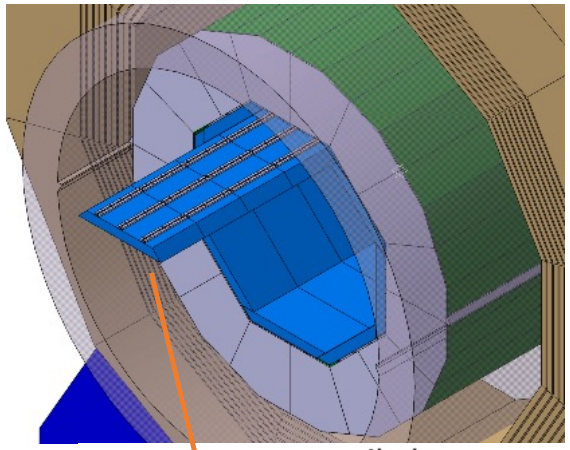
- Scintillator-based Electromagnetic Calorimeter (Sc-ECAL)
  - ECAL concept based on strip-shaped plastic scintillator readout by SiPM
  - Center dimpled readout based on $5\times45\times2$ mm^3 scintillator strip

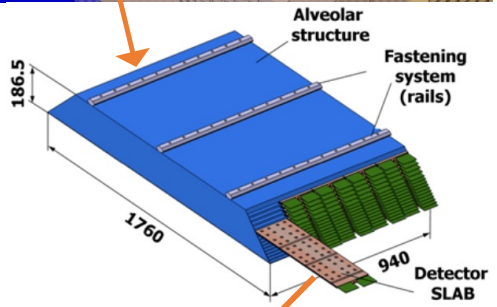
  - Virtual segmentation of 5×5 mm^2 cell can be achieved by x-y configuration of strips with strip splitting algorithm (SSA)

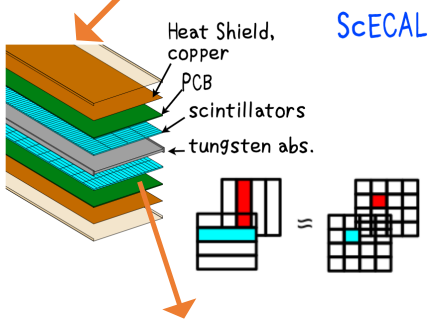


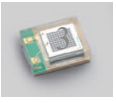
- Ghost hit problem
  - False signal from simultaneous hits
  - Expected to be eliminated by double SiPM readout
- Double SiPM readout
  - readout by two SiPMs at strip ends





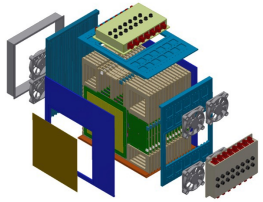


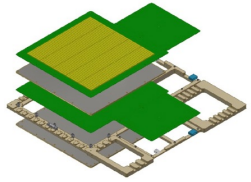


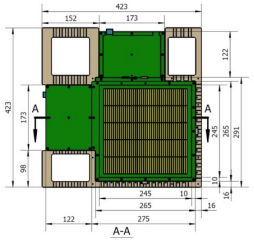


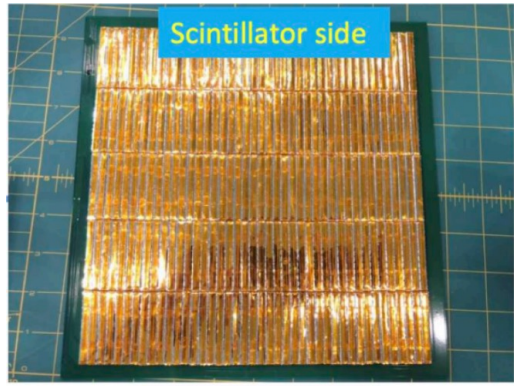
Sc-ECAL large technological prototype

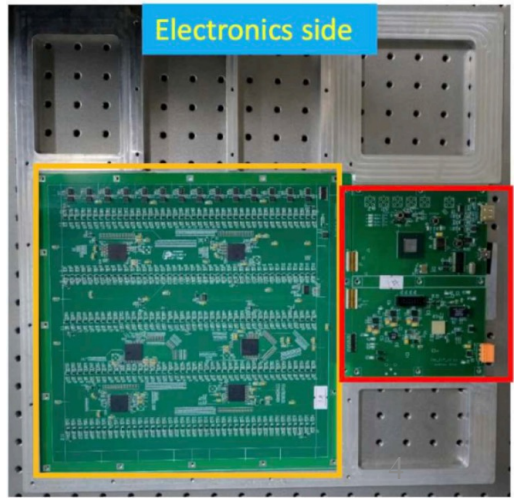
- The prototype consists of 32 absorber(W) and detection layer (EBU)
  - Total absorption layer thickness : 32×3.2 mm (~23.3 X_0)
  - Two absorber layers and two detection layers are integrated on a braced frame (super layer)
  - 16 super layers are mounted on the prototype



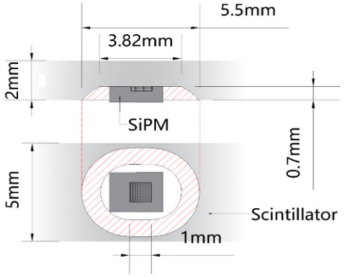


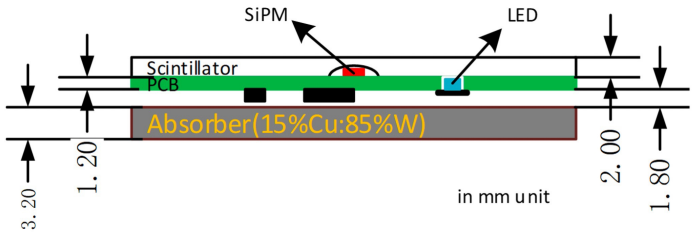




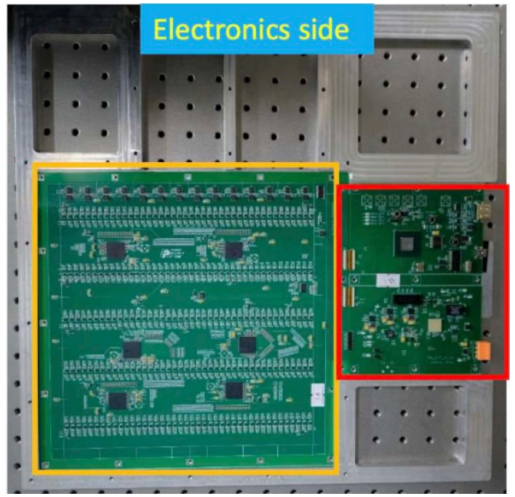


- ECAL Base unit (EBU) and scintillator strips + SiPM readout unit for detection layer
  - 42 (columns) × 5 (rows) strip readouts per EBU
  - Each channel have LED for calibration of SiPM gain

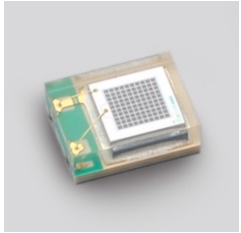




Sc-ECAL large technological prototype



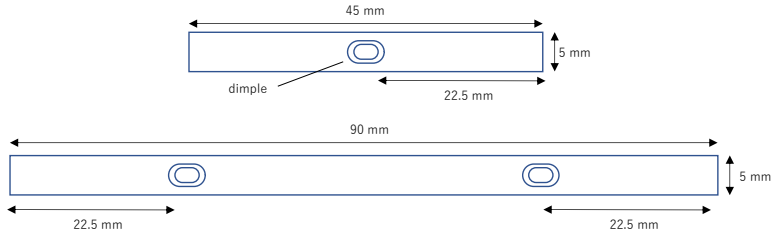
- All channels on each EBU can be individually readout by 6 SPIROC2E chips developed by OMEGA lab and CALICE collab
  - High and low gain mode for wide dynamic range
  - 16 temperature sensors are implemented

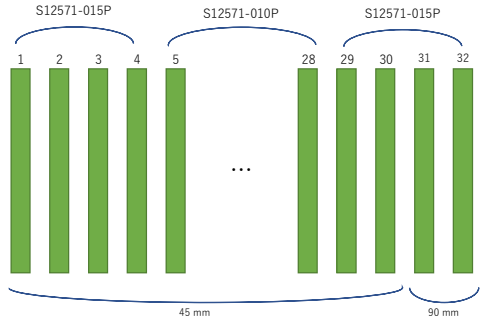


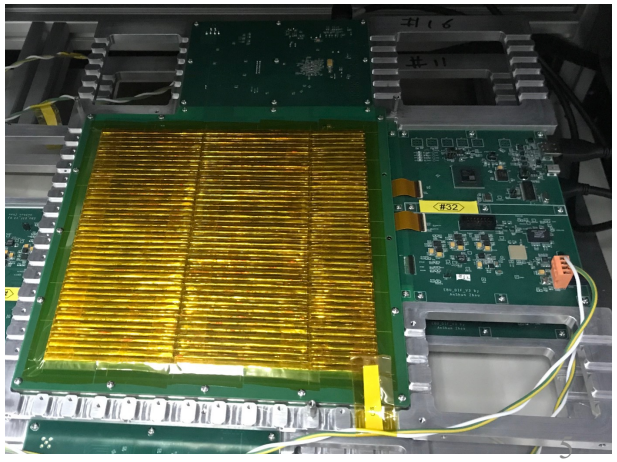
	Pixel size	# of pixel
S12571-010P	10 um	10,000
S12571-015P	15 um	4,489

- Two types of MPPC are used for SiPM on detection layer (manufactured by Hamamatsu K. K.)
  - S12571-010P, -015P

- Last 2 layers have double SiPM readout part
  - Using 90 mm length strip instead of standard 45 mm strip

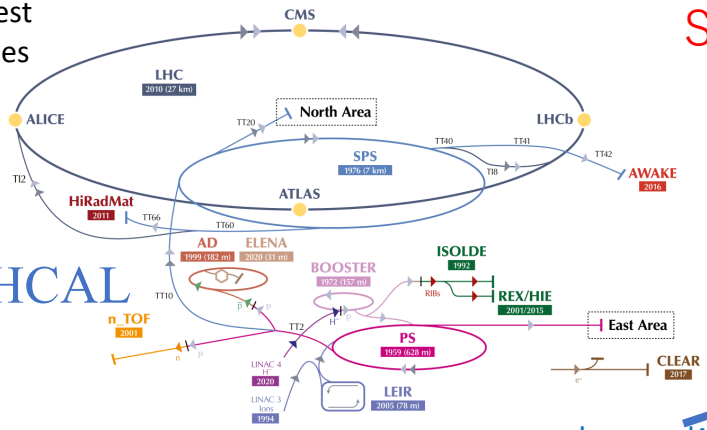


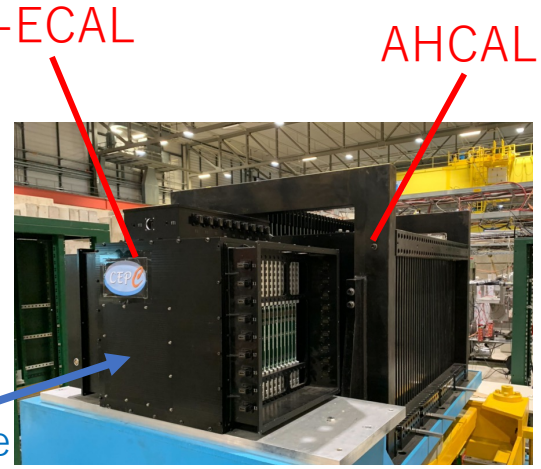




Test beam experiment

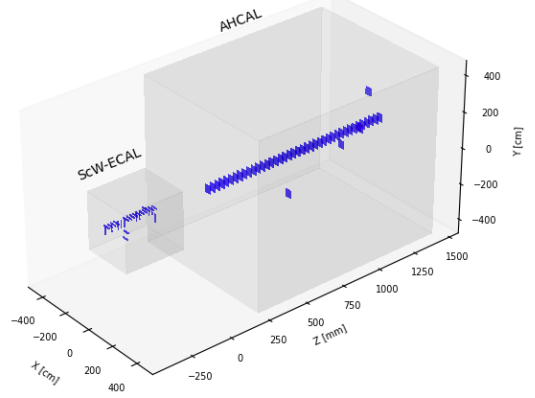
North Area Test Beam Facilities



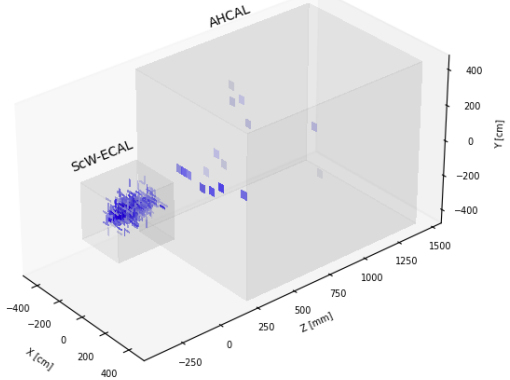


- Test beam experiment for Sc-ECAL and CEPC-AHCAL combined system is conducted at CERN SPS&PS
  - SPS : site 887, H8 beamline
    - October 19th to November 2nd, 2022
    - High energy beam (10-160 GeV)
    - μ^-, π^-, e^-
  - SPS : Site 887, H2 beamline
    - April 26th to May 10th, 2023
    - High energy beam (10-350 GeV)
    - Higher energy and purity beam than 2022'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

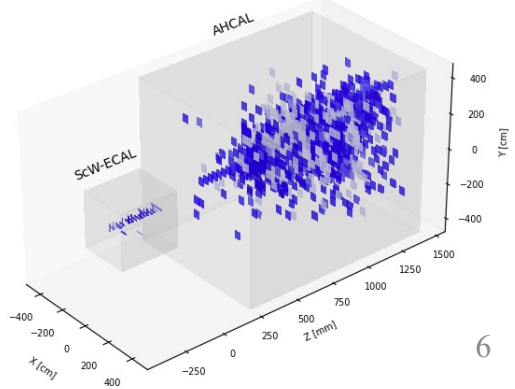
100 GeV muon



60 GeV electron

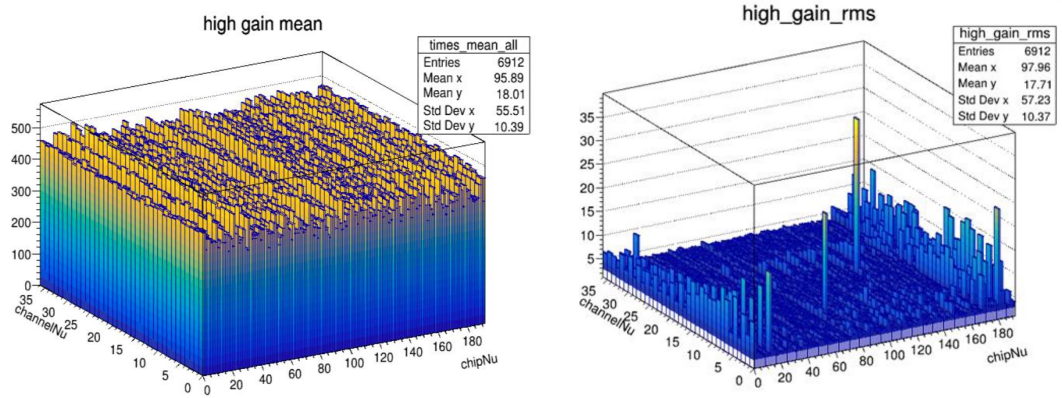


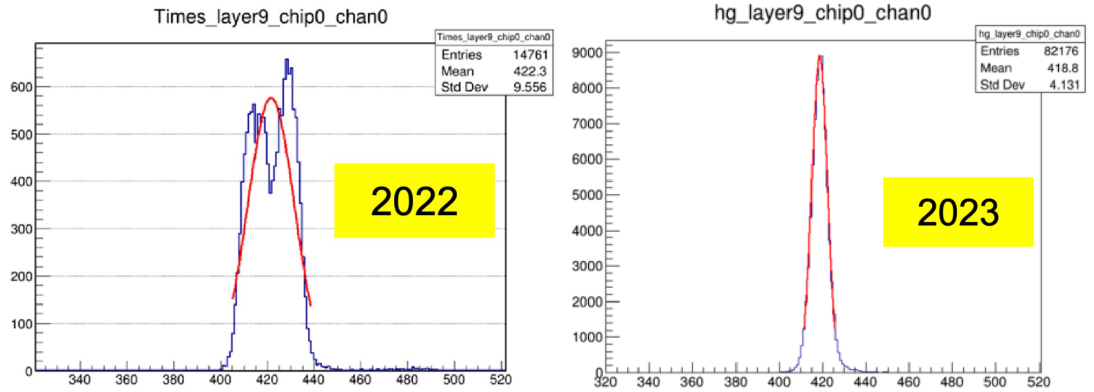
350 GeV pion

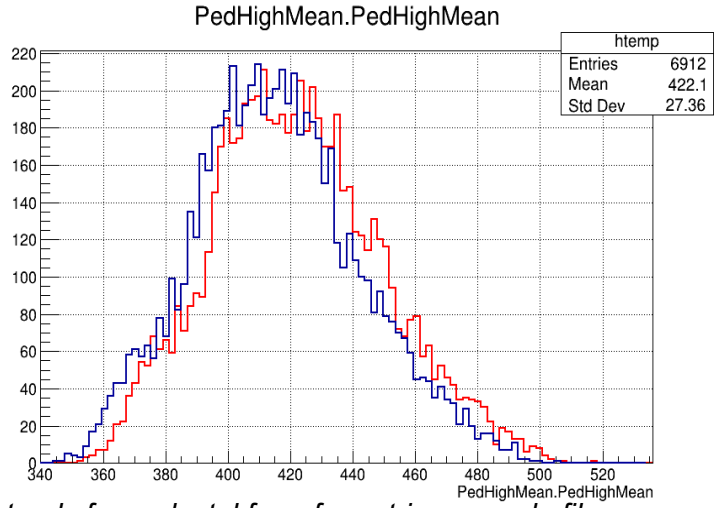


Pedestal calibration

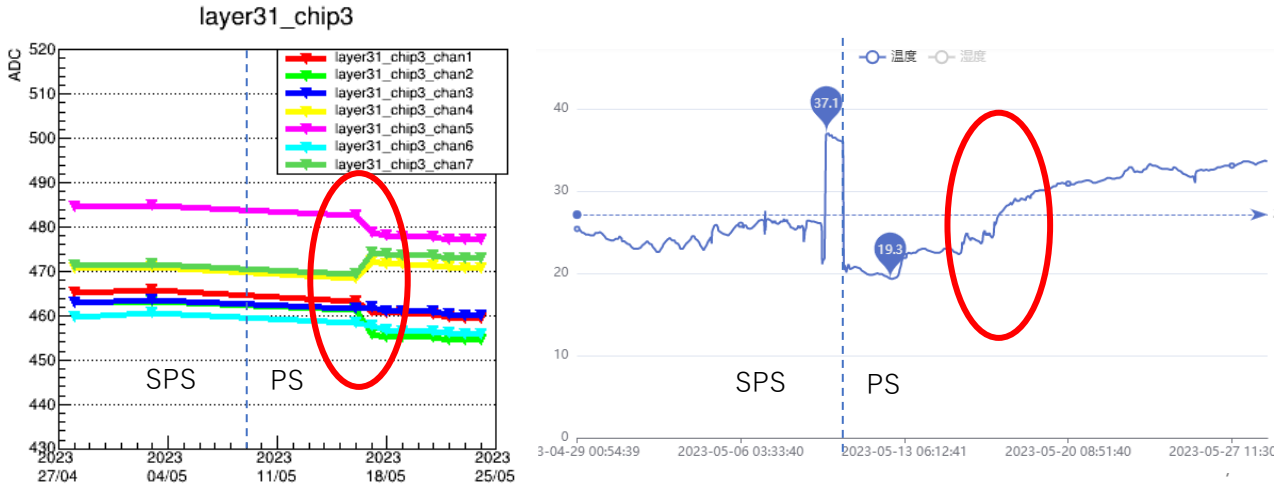
- Pedestals were originally obtained from events that did not exceed threshold
  - Some channels had multi-peaks due to electronics problem at last years data
- Pedestals are obtained from force-trigger-mode to prevent the problem in 2023
- Pedestals were stable during the beam test in SPS or PS respectively within a 2~3 ADC fluctuation when temperature did not change significantly







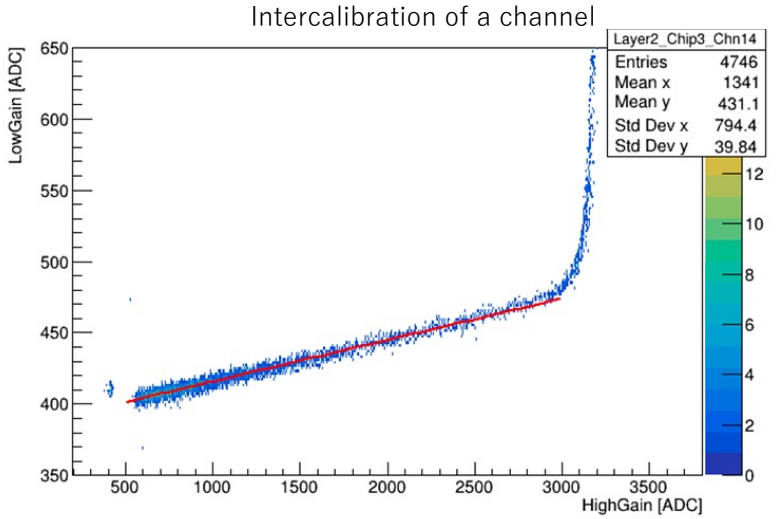
Blue histogram stands for pedestal from force-trigger-mode file
Red histogram stands for pedestal from beam data file

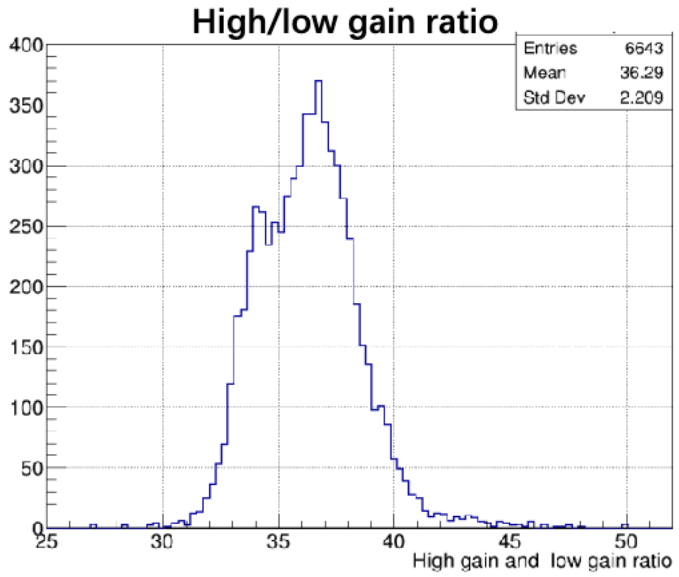


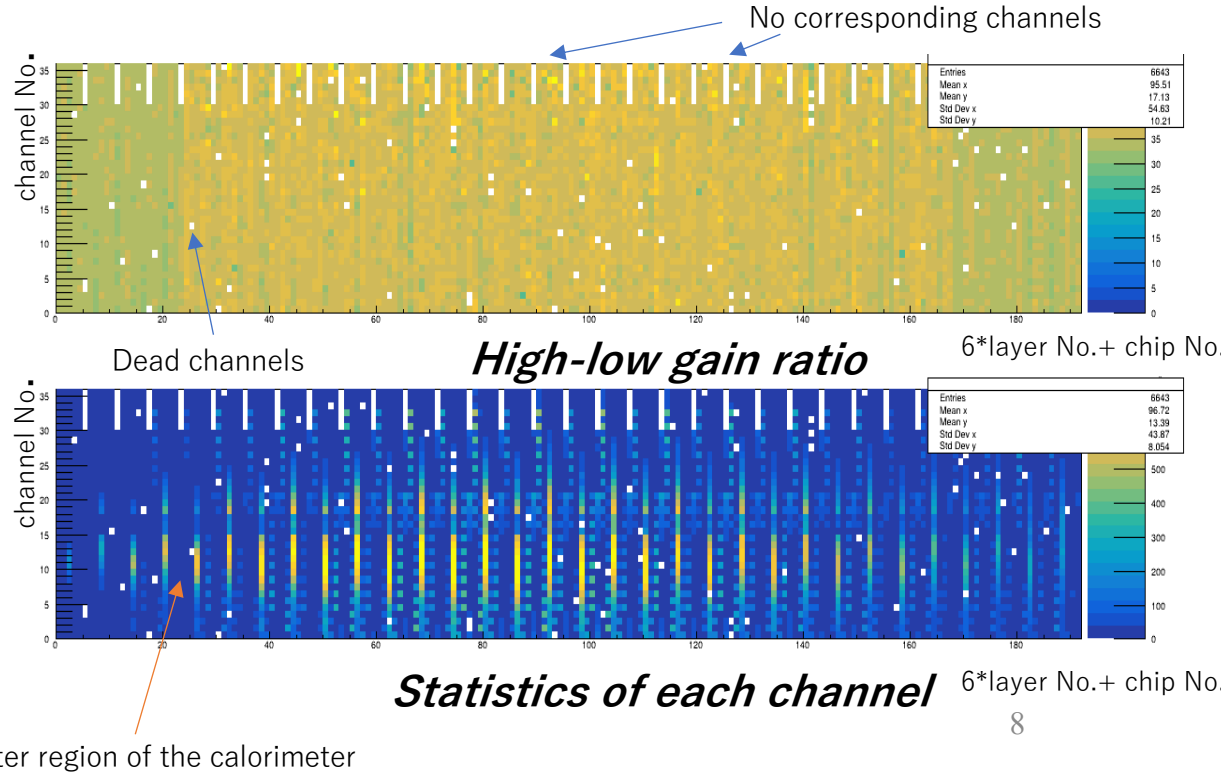
High gain and low gain intercalibration

- SPIROC2E chip records both two gains (high gain and low gain) to cover a large dynamic range
  - Ratio of high and low gain is calculated using electron beam data
  - Many statistics at the center region of the calorimeter
- High gain ADC saturates at different value among channels
- The result is consistent with the gain difference

- White bins
  - Dead channels
  - No corresponding channels



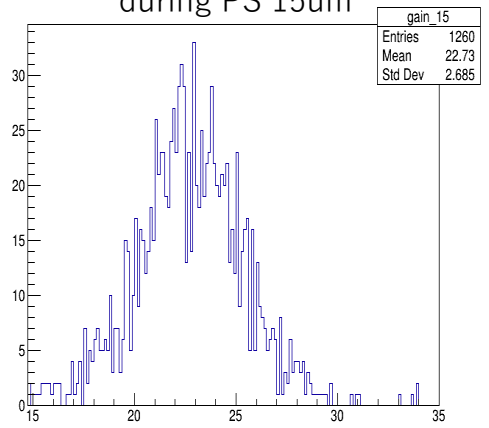




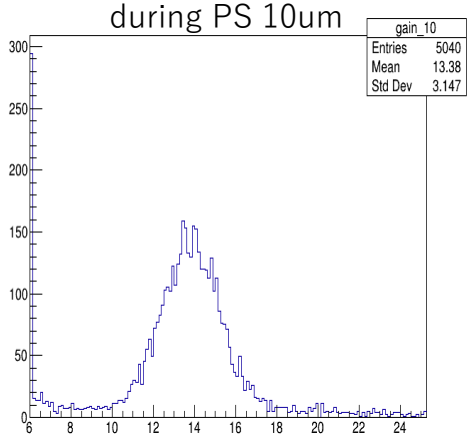
LED calibration

- LED data are taken during the 2023 beam test
  - SPS : 3 times (at the beginning and the middle of the beam test)
  - PS : every day
- LED data are fitted with multi-gaussians to calculate gain for each channel
- Increased the bias voltage of all channels at the beam test to compensate temperature difference from the CR test
  - The gains still decreased compared to the cosmic ray test

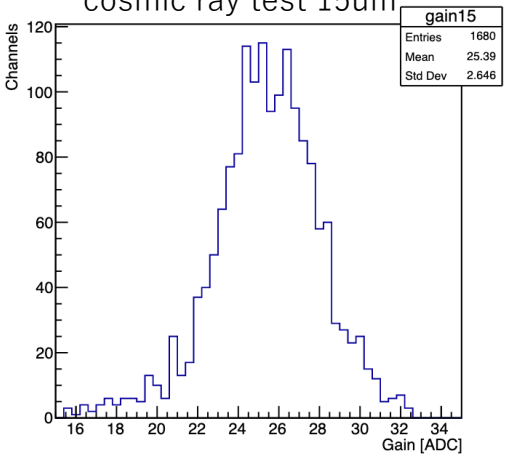
Gain distribution during PS 15um



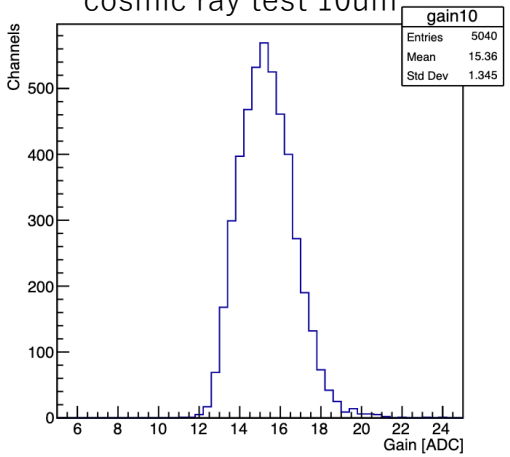
Gain distribution during PS 10um



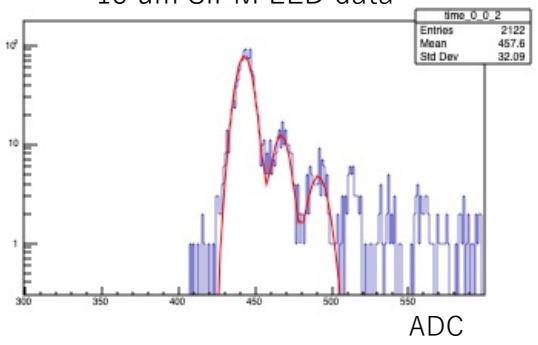
Gain distribution during cosmic ray test 15um



Gain distribution during cosmic ray test 10um



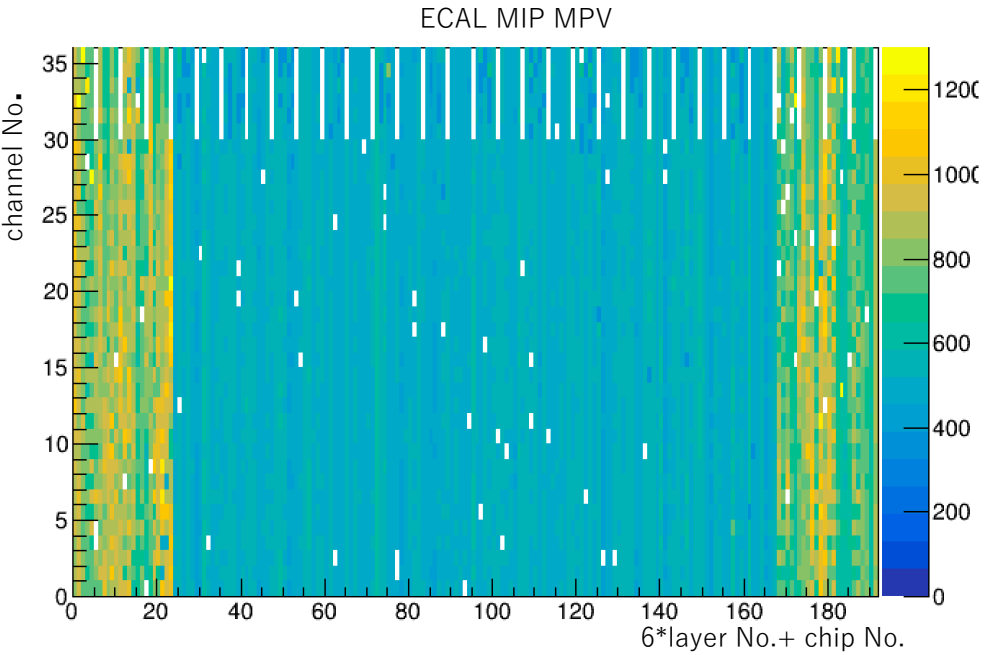
15 um SiPM LED data

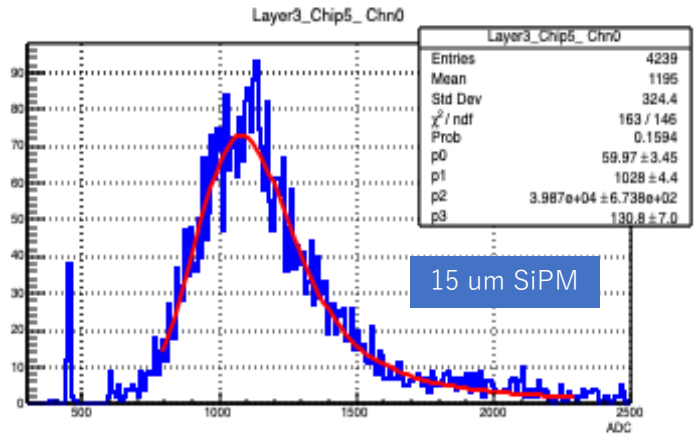


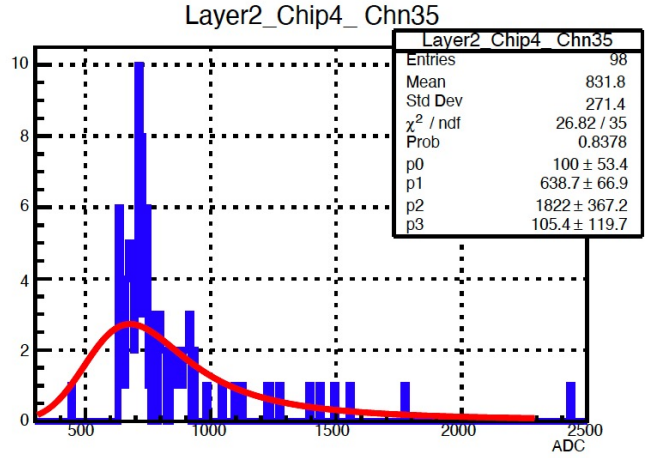
ECAL	CR	Beam test
temperature	~20 C	25~29 C
Bias voltage	-	+0.5 V

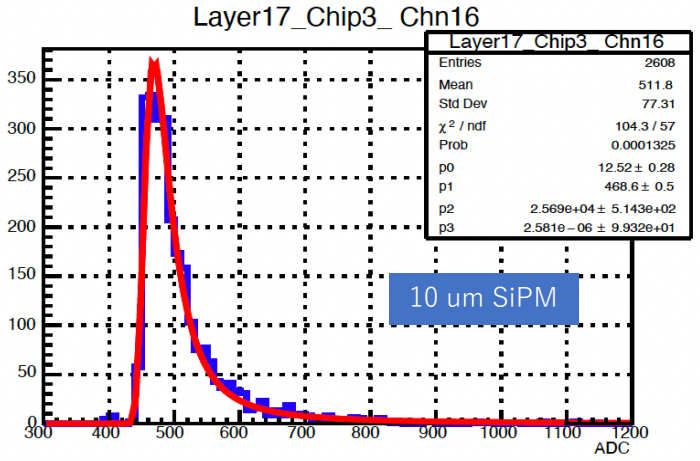
MIP calibration

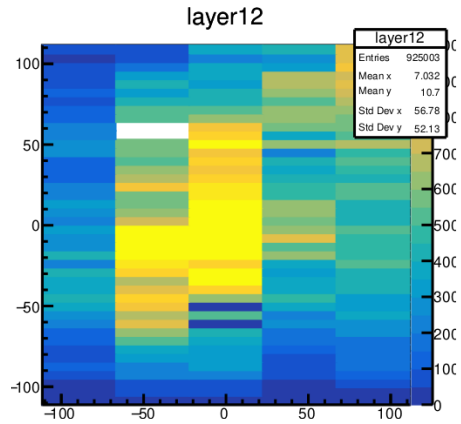
- MIP peak value is obtained from fitting 100 GeV/c muon events' ADC distribution by Langaus function
- Threshold and SiPM voltage are optimized
- Track restriction s are used to improve fit result
- A small part of channels are not well fitted due to lack of statistics







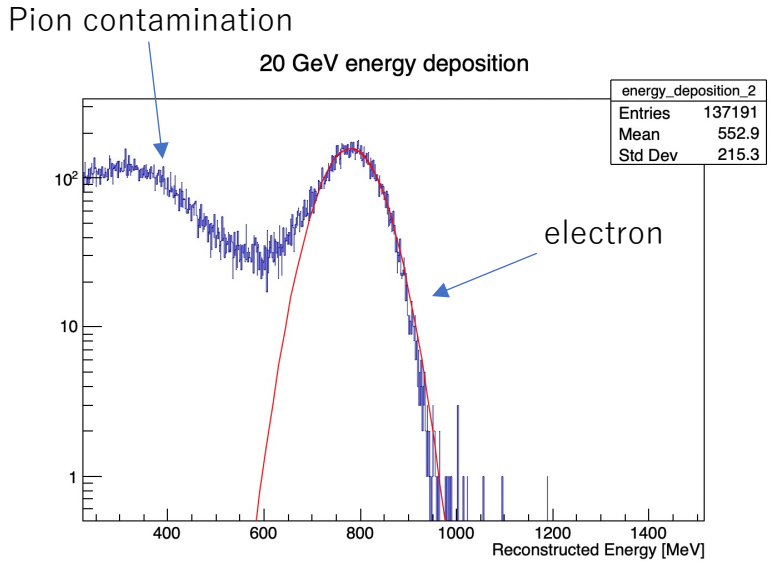


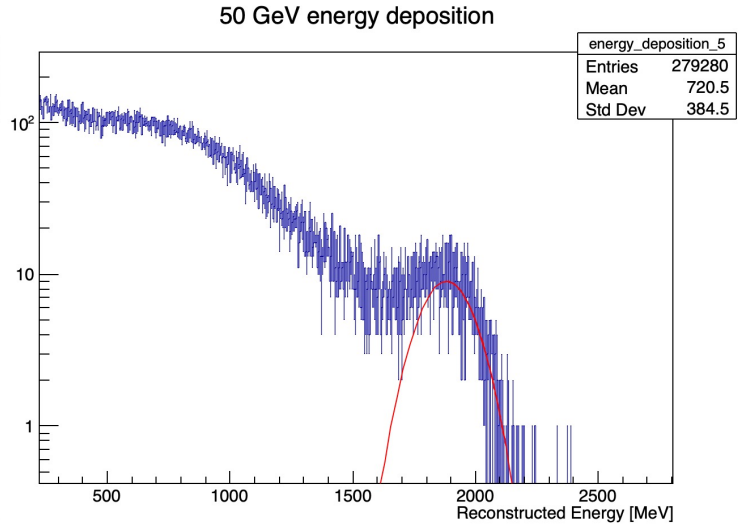


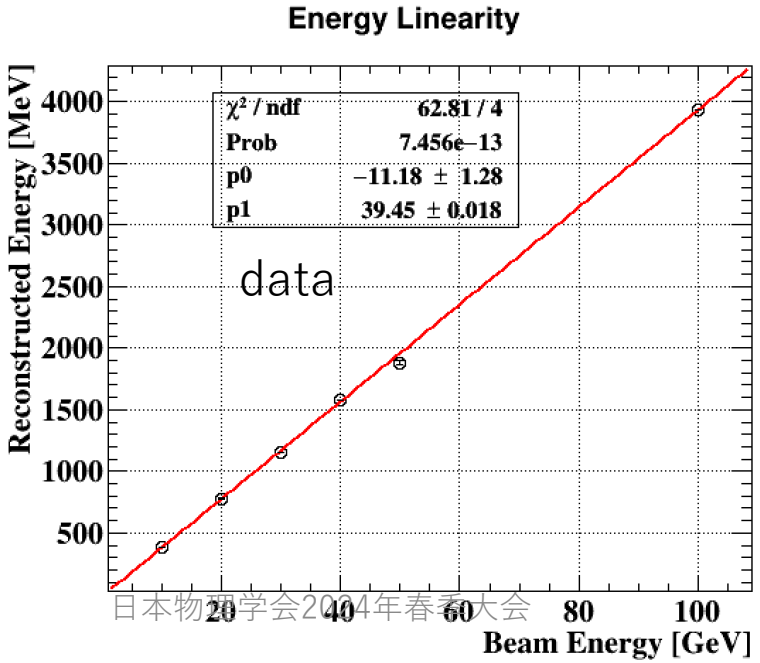
Statistics of each channel in layer2

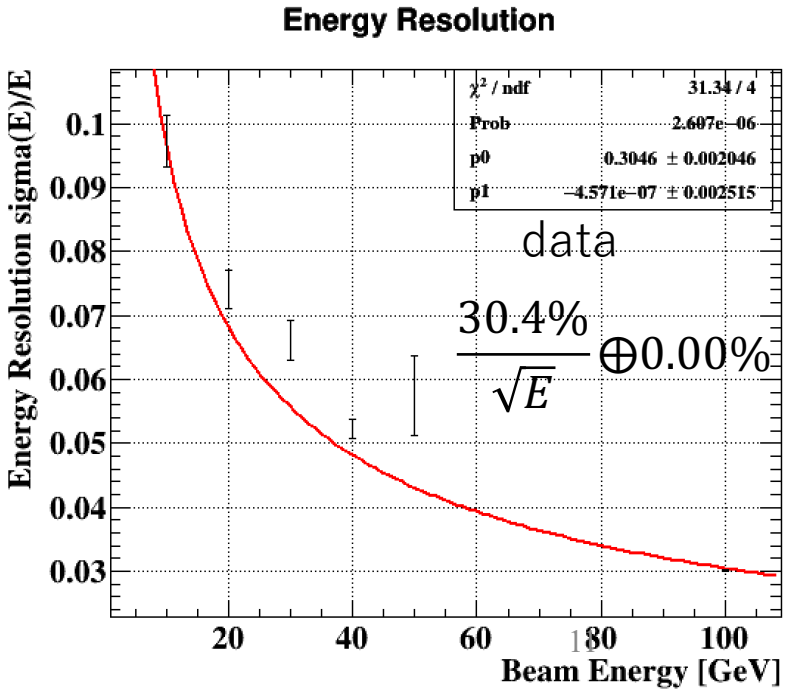
Energy resolution -2022data-

- Used 2022 SPS e+ beam
  - 10,20,30,40,50, 100 GeV
  - lower purity at 2022 beam
- Used calibration parameters
  - Temperature correction 3%
  - No electronics and SiPM saturation correction
- No selection of event
  - Mu, pi contaminations are still included
  -



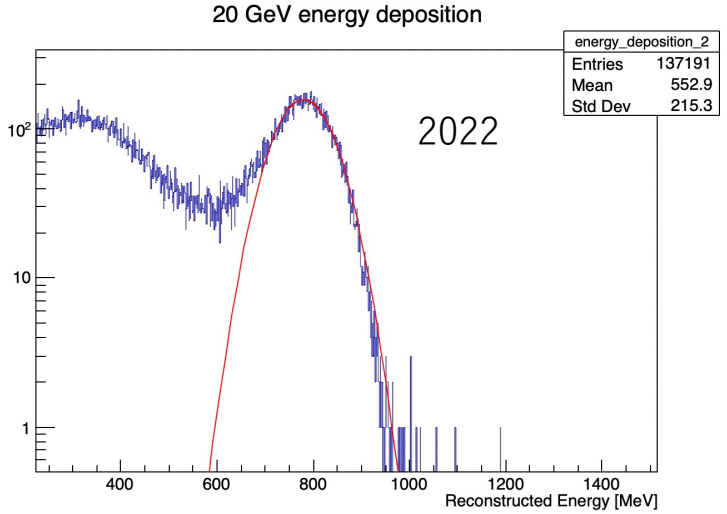


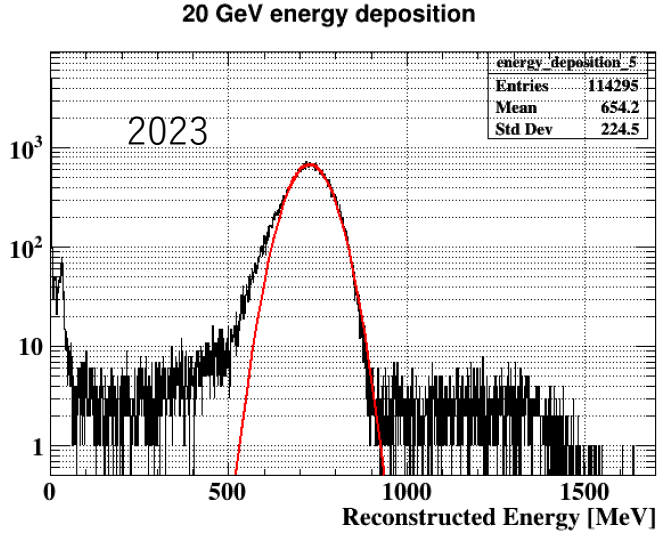


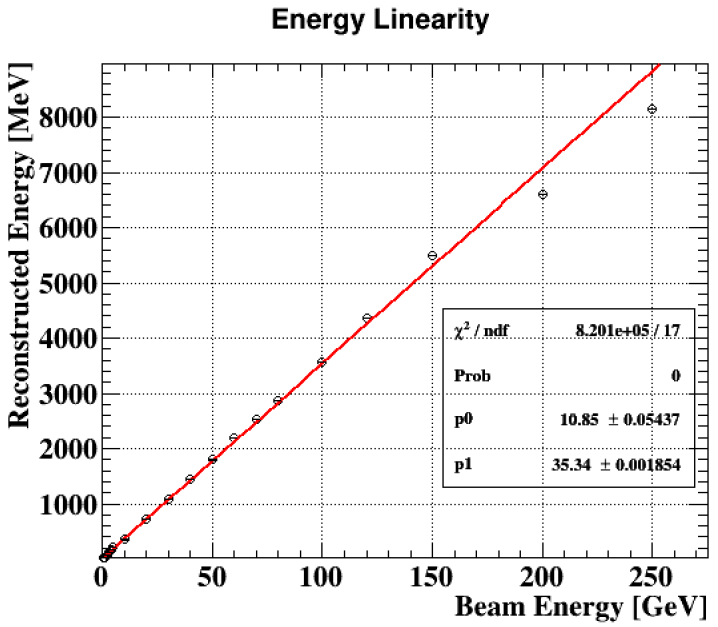


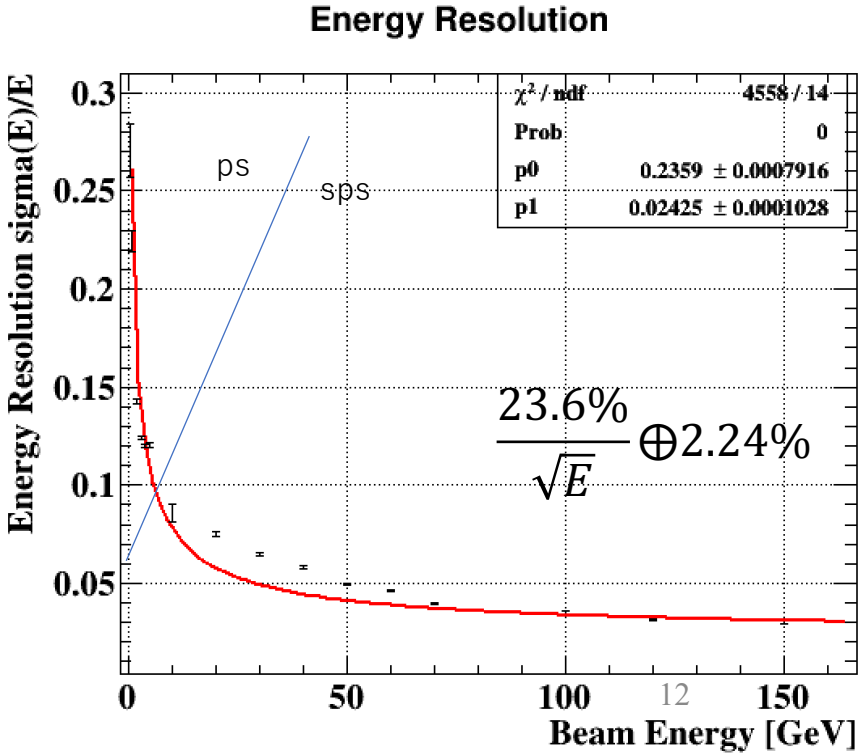
Energy resolution -2023data-

- Used 2023 SPS, PS e- beam
  - 0.5,1,2,3,4,5, (PS) 10,20,30,40,50,60,70,80, 100,150,(200,250) (SPS) GeV
  - Higher purity beam
- Used calibration parameters
  - Temperature correction 3%
  - No electronics and SiPM saturation correction
- Bad linearity above 200 GeV due to saturation of low gain
- No selection of event
  - Mu, pi contaminations are still included



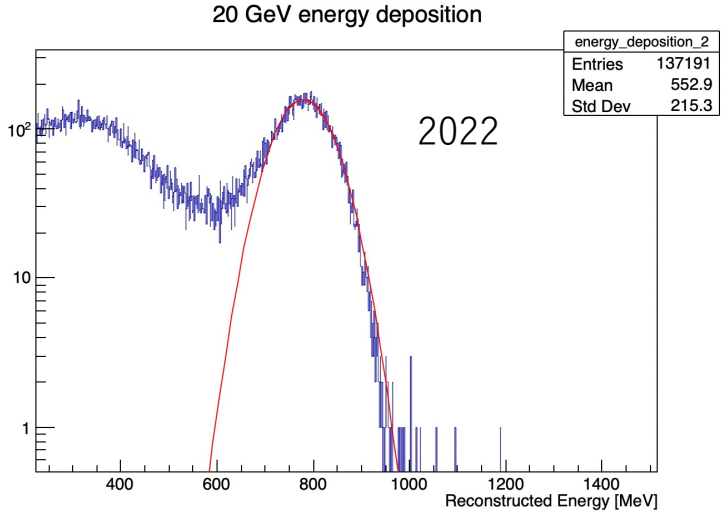


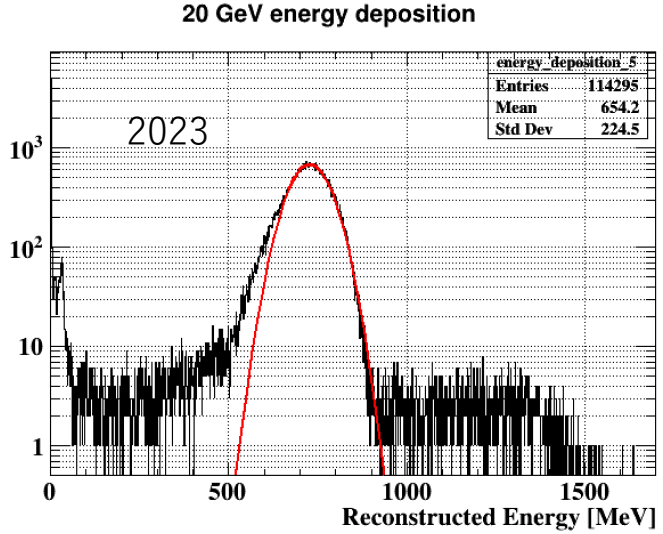


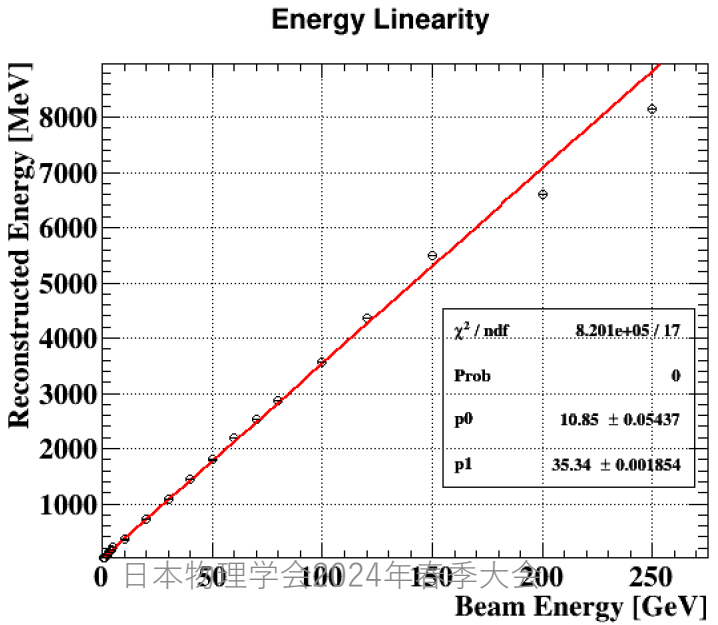


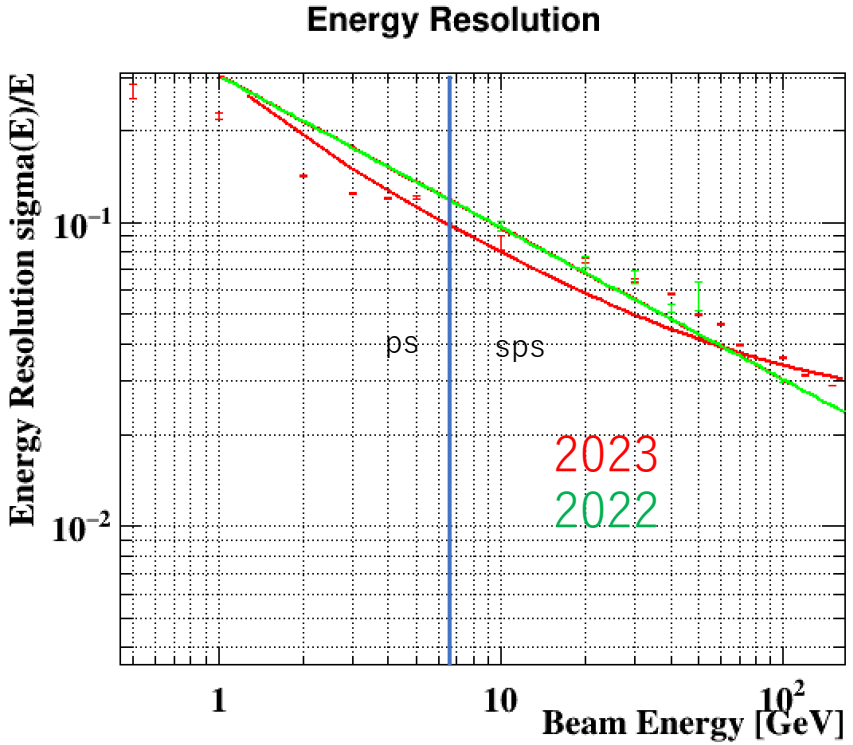
Energy resolution -2023data-

- Used 2023 SPS, PS e- beam
  - 0.5,1,2,3,4,5, (PS) 10,20,30,40,50,60,70,80, 100,150 (SPS) GeV
  - Higher purity beam
- Used calibration parameters
  - Temperature correction 3%
  - No electronics and SiPM saturation correction
- No selection of event
  - Mu, pi contaminations are still included
- Resolutions are consistent with 2022 data
  - Contamination is not the major reason
  - Still need investigation









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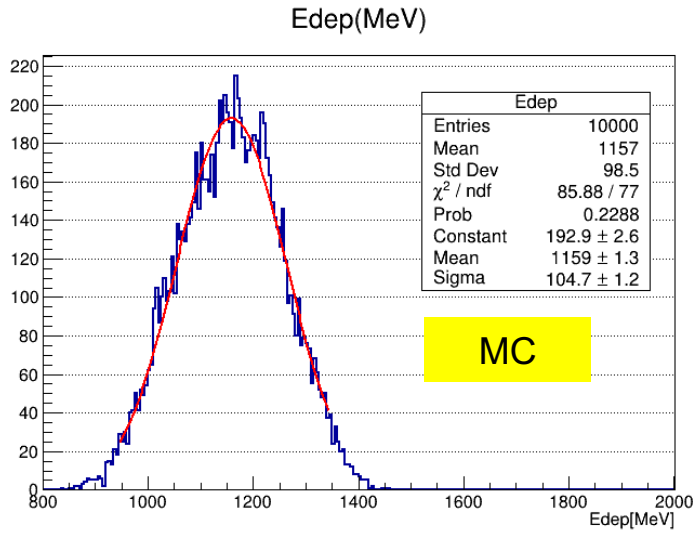
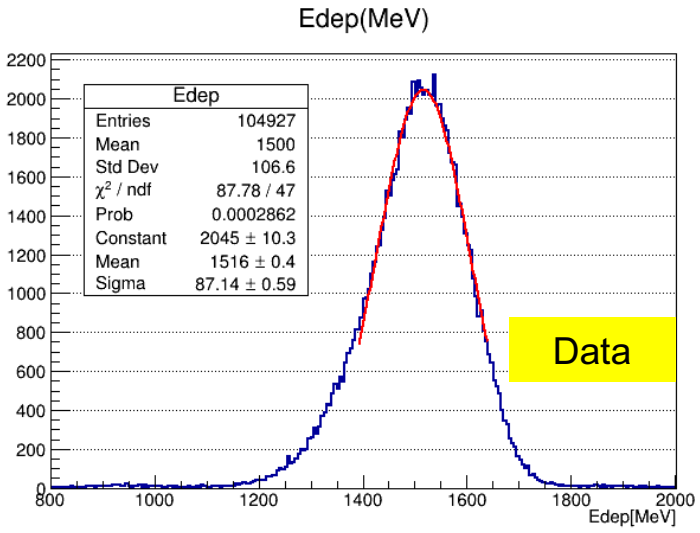
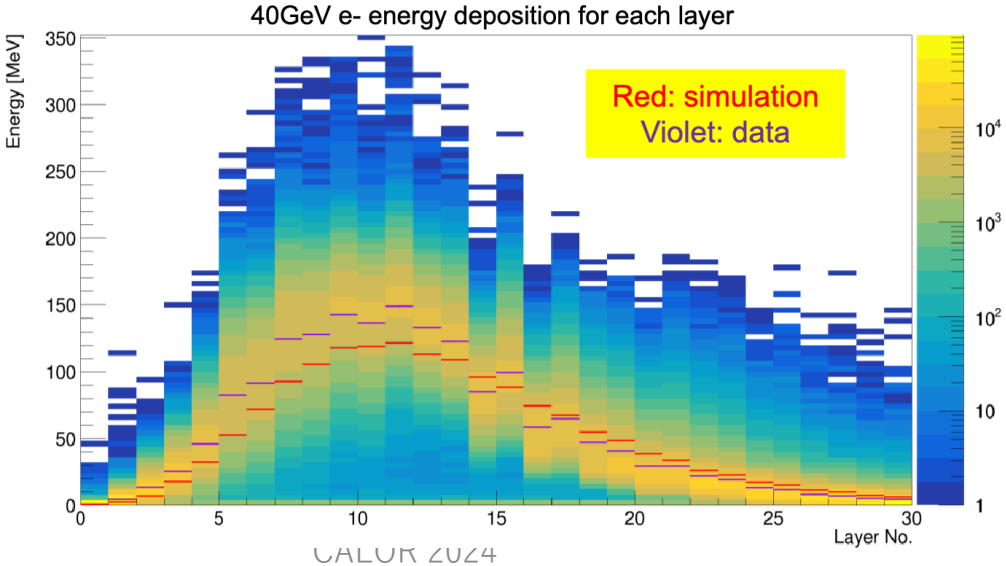
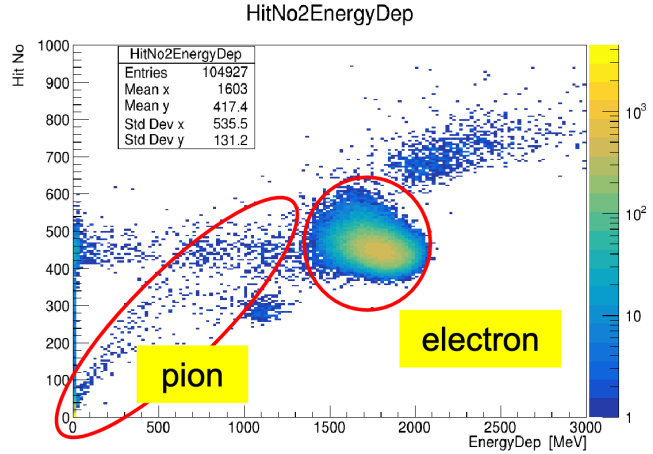
Simulation and validation

- Geant4 full simulation is established
  - Geometry : for both Sci-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
- 40 GeV/c electron data from SPS H2
  - Calibrated with 100 GeV muon data
  - Threshold: 0.5 MIP
  - No obvious energy leakage
  - Contamination is not yet eliminated
- More effort to match data and simulation



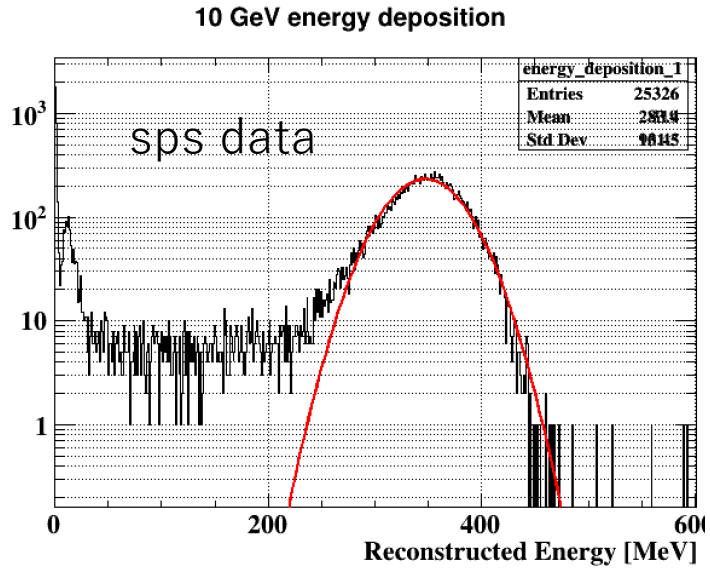


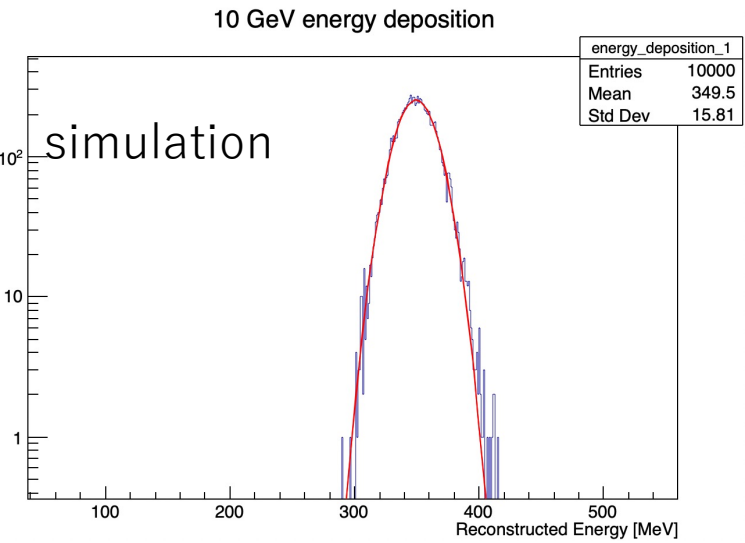


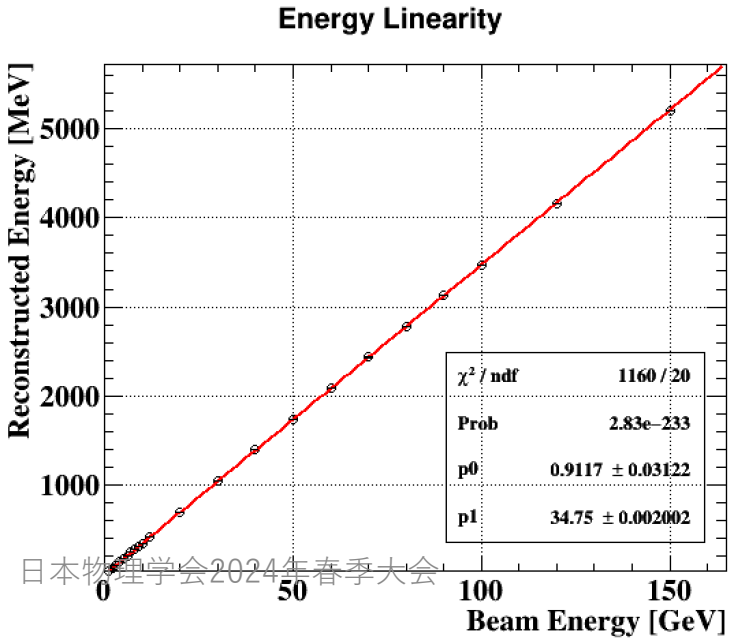


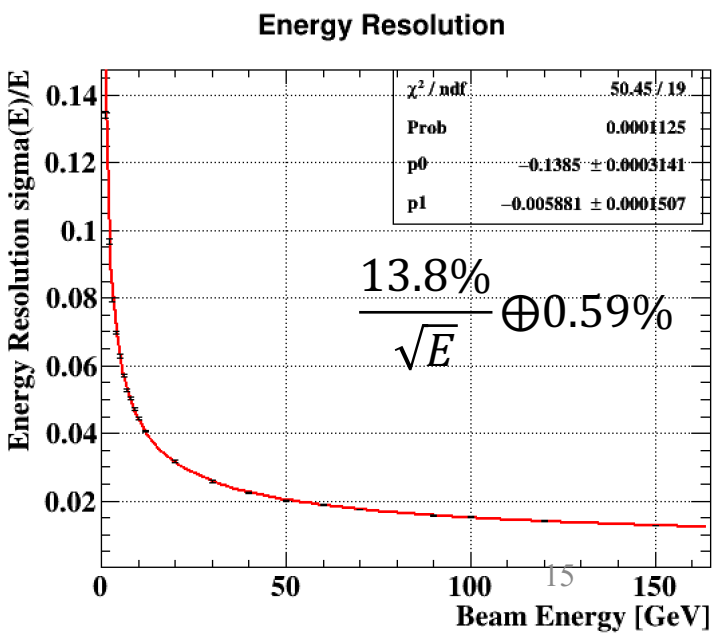
Energy resolution -Simulation-

- Injected e- beam
  - 1,2,3,4,5,6,7,8,9,10, 12, 20,30,40,50,60,70,80,90,100, 120,150 GeV
- Fit energy distribution by gaussian
  - Errors are calculated from fitting parameters' error
  - Means are almost same between data and simulation
  - StdDev are different
- Still needs some modification
  - SiPM saturation
  - Dead cells
  -



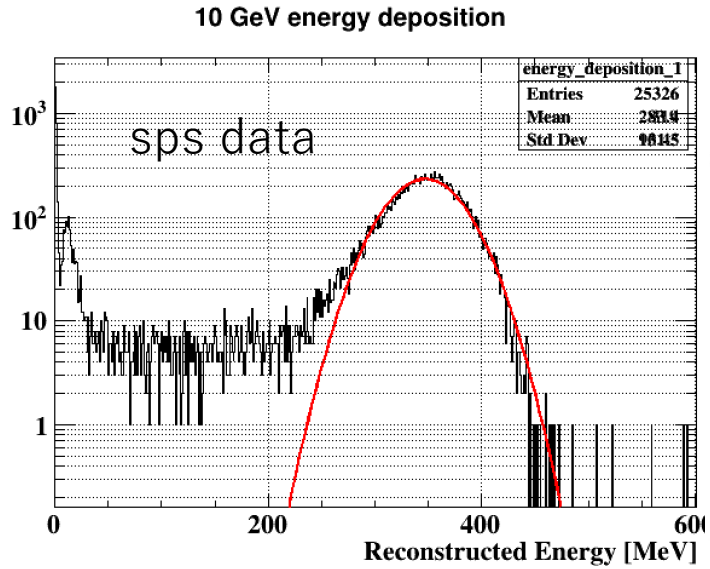


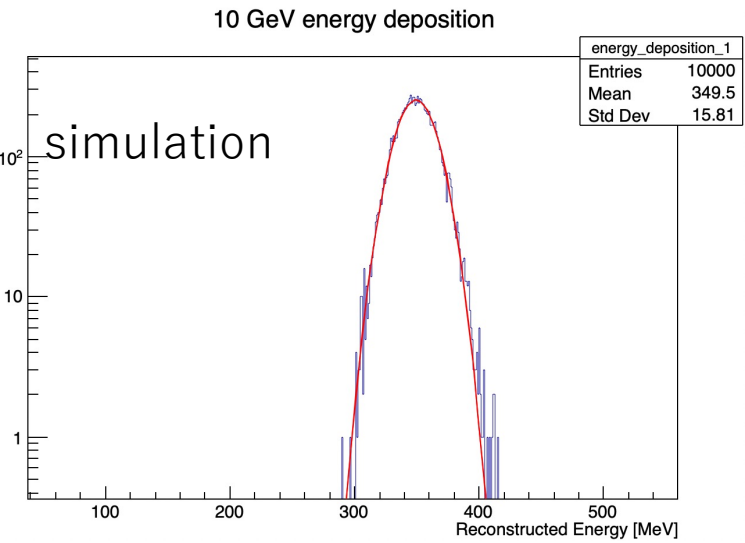


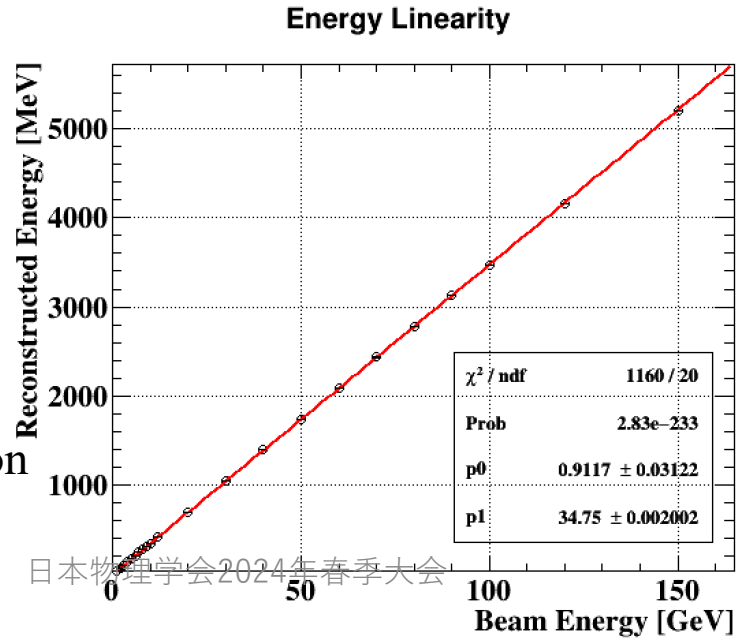


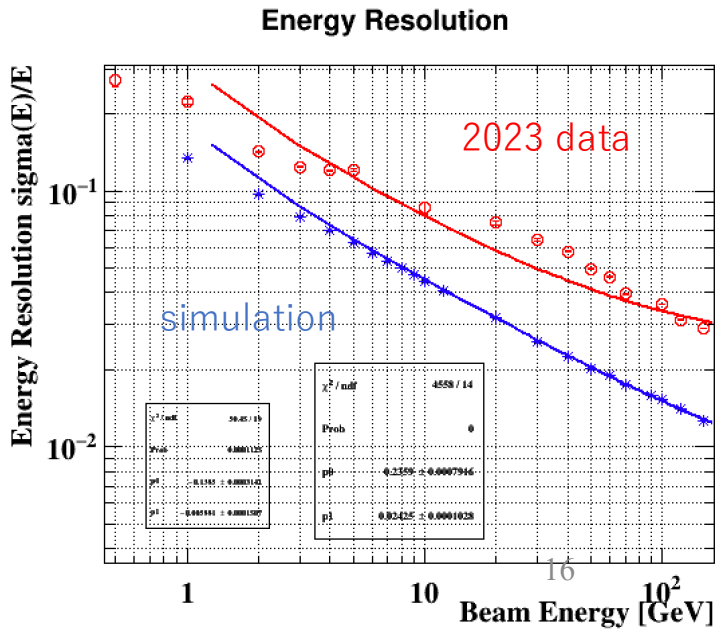
Energy resolution -Simulation-

- Injected e- beam
  - 1,2,3,4,5,6,7,8,9,10, 12, 20,30,40,50,60,70,80,90,100, 120,150 GeV
- Fit energy distribution by gaussian
  - Errors are calculated from fitting parameters' error
  - Means are almost same between data and simulation
  - StdDev are different
- Still needs some modification
  - SiPM saturation
  - Dead cells
- Energy resolution of simulation is 2x smaller than data
  - Need more modification to simulation and data analysis





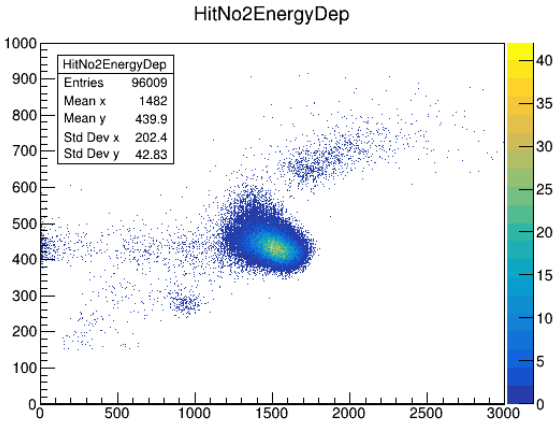


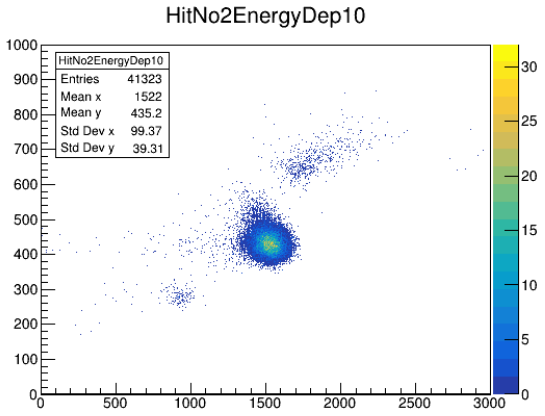


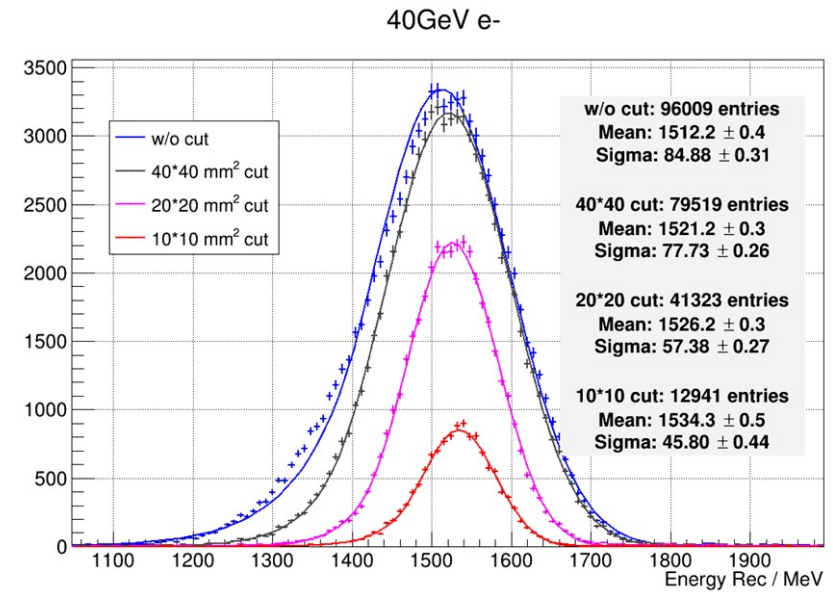
Event Selection

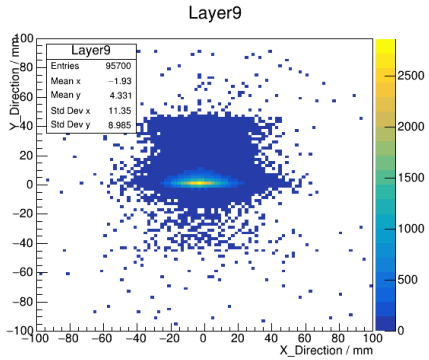
- Event selection
  - Position cut : layer energy gravity position cut
- Energy reconstruction with several cuts
  - (-20,20), (-10,10), (-5,5), contrast (mm)

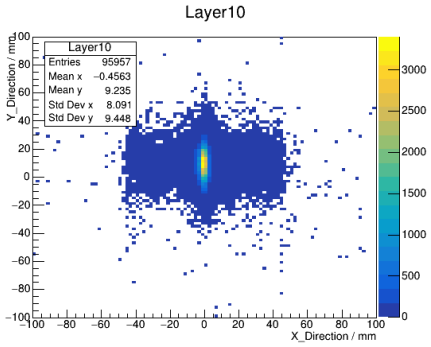
  at layer 9,10
- Same cut will be applied in MC to check whether extra bias get introduced into

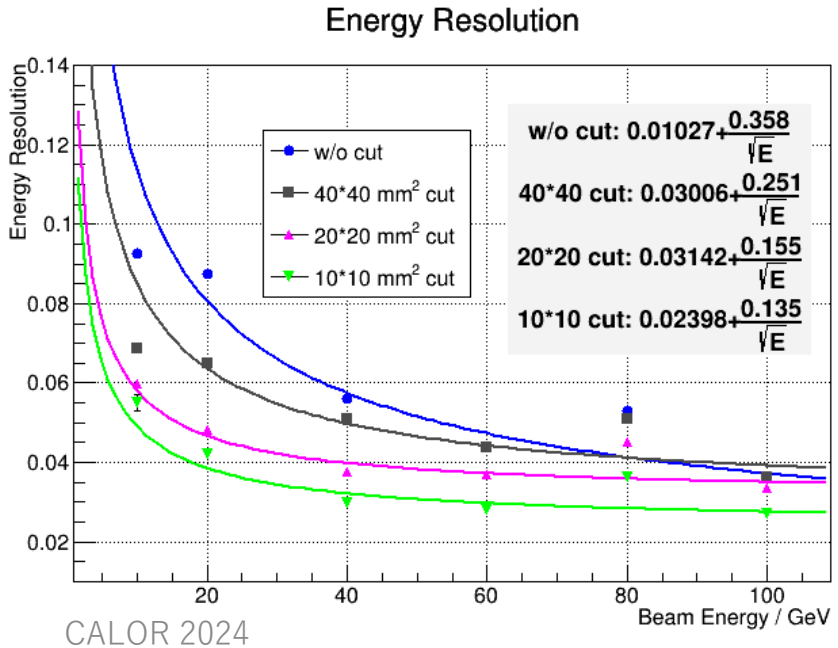


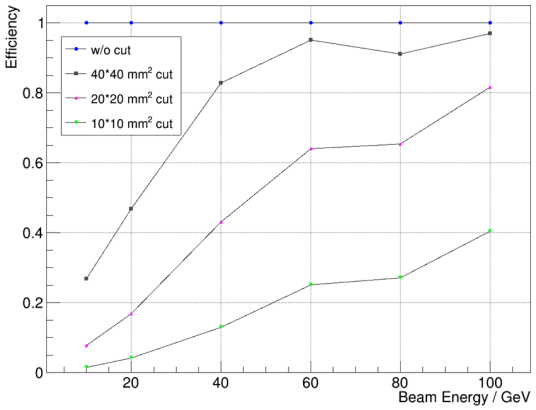












Summary and prospect

- 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 ongoing
- 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

Backup