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

Tatsuki Murata

On behalf of the Sc-ECAL working group

May 20th, 2024

CALOR 2024

Introduction

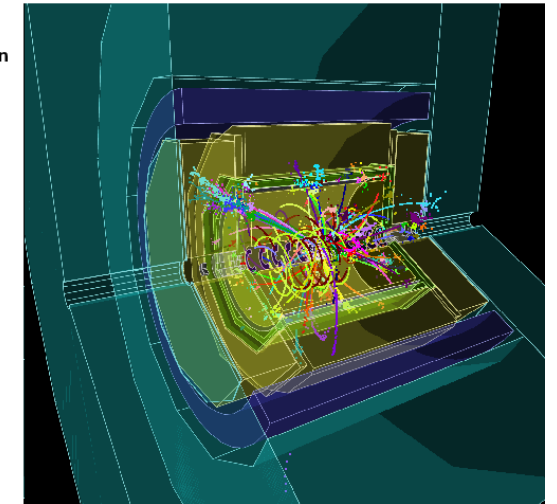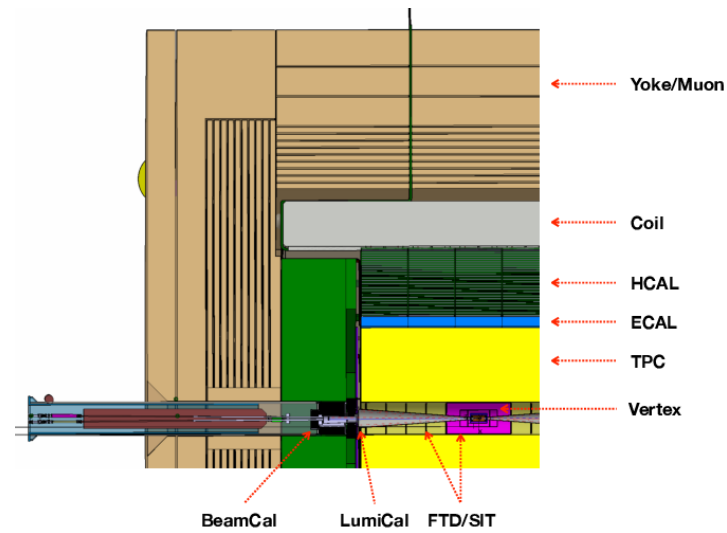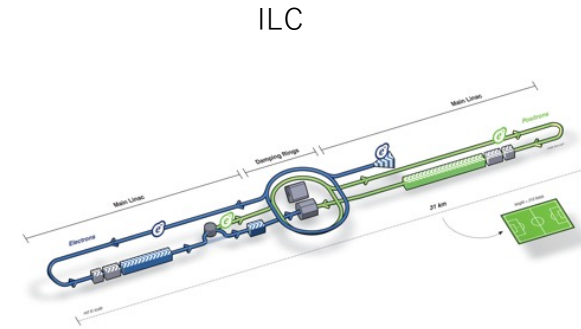- Future electron positron colliders
  - Precision measurements of the Higgs/EW/QCD
  - Calorimeter system requirement
    - High granularity for both ECAL and HCAL
      - 5 mm for ECAL, few cm for HCAL
    - Jet energy resolution ~30%/E

CEPC

ILC

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

$E_{JET} = E_{ECAL} + E_{HCAL}$

PFA

$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

Yoke/Muon
Coil
HCAL
ECAL
TPC
Vertex

BeamCal   LumiCal   FTD/SIT
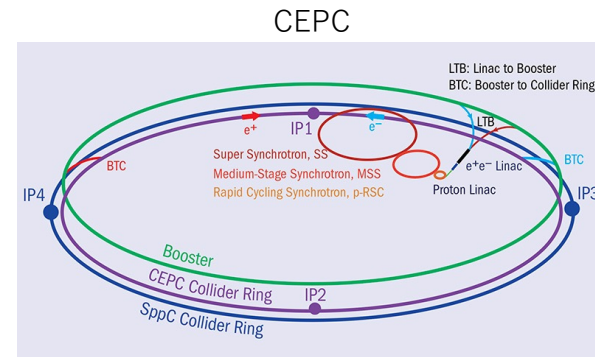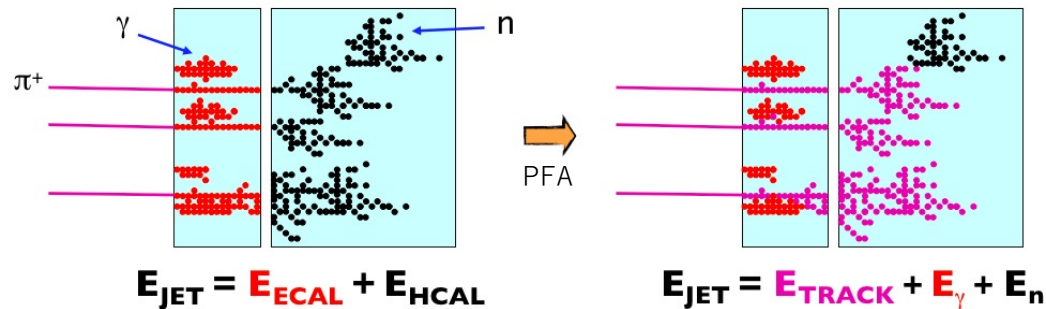
Sc-ECAL

- Scintillator-based Electromagnetic Calorimeter (Sc-ECAL)
  - ECAL concept based on strip-shaped plastic scintillator readout by SiPM
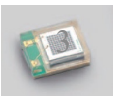 - Center dimpled readout based on $5 \times 45 \times 2$ mm^3 scintillator strip
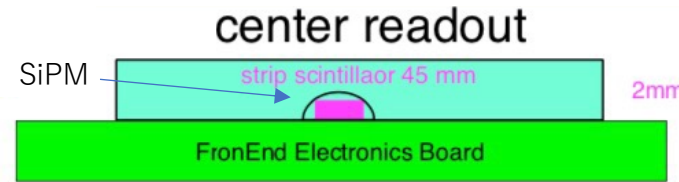
- Virtual segmentation of 5×5 mm^2 cell can be achieved by x-y configuration of strips with strip splitting algorithm (SSA)

- 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
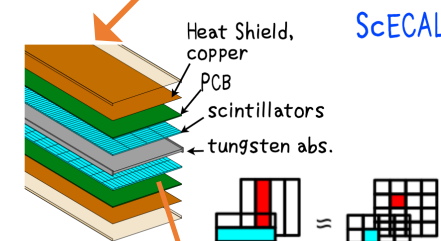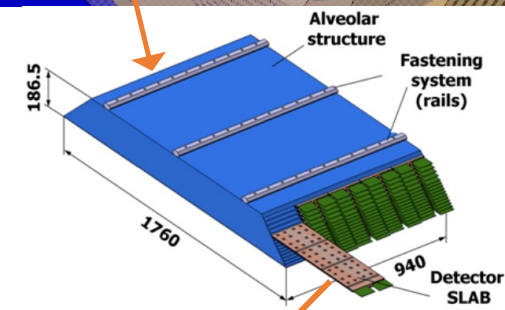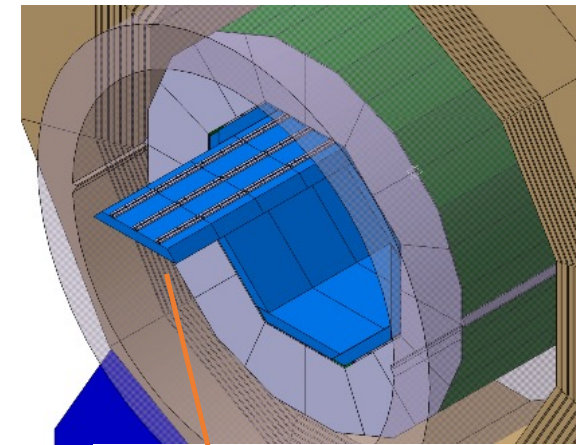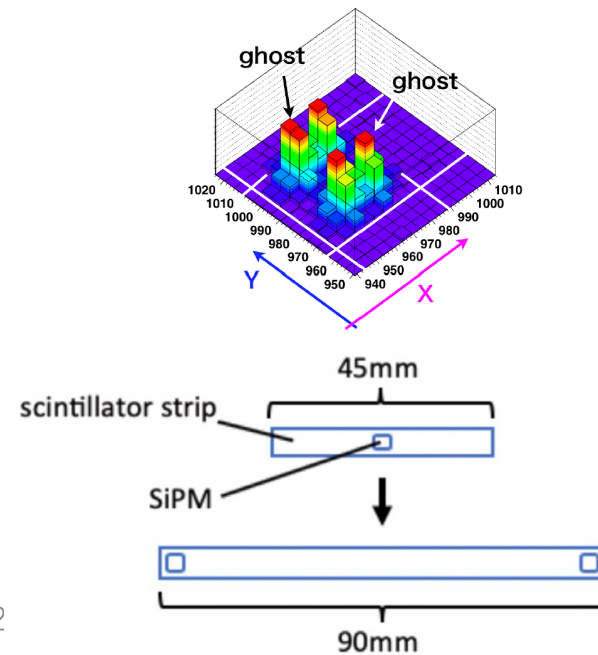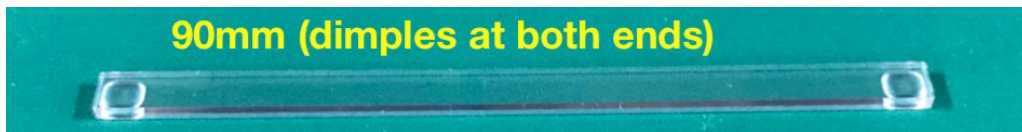
Sc-ECAL large technological prototype

- The prototype consists of 32 absorber(W) and detection layer (EBU)
  - Total absorption layer thickness : 32×3.2 mm ($\sim 23.3\ X_0$)
  - Two absorber layers and two detection layers are integrated on a braced frame (super layer)
  - 16 super layers are mounted on the prototype
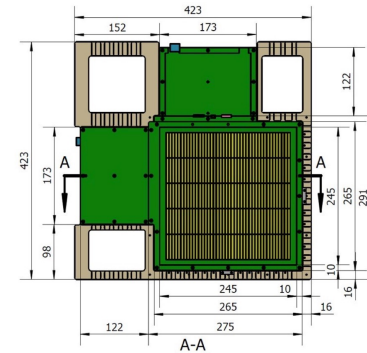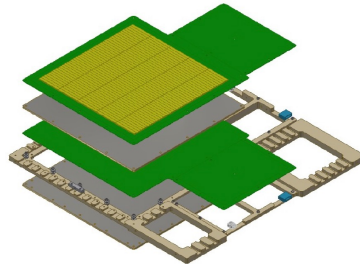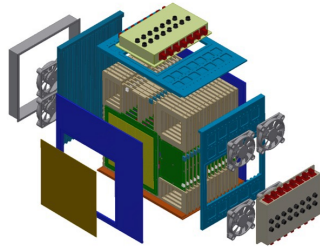
- ECAL Base unit (EBU) and scintillator strips + SiPM readout unit for detection layer
  - 42 (columns) $\times$ 5 (rows) strip readouts per EBU
  - Each channel have LED for calibration of SiPM gain
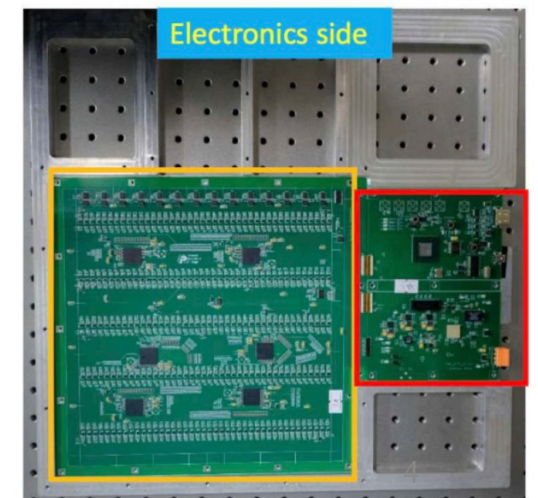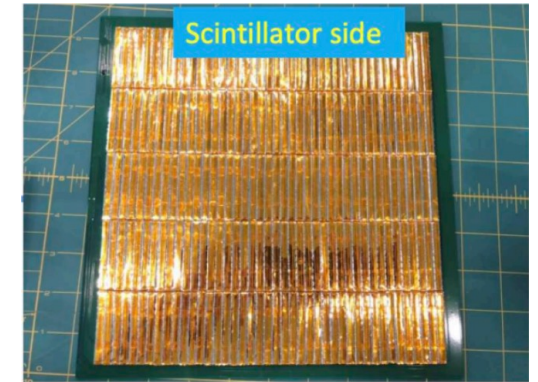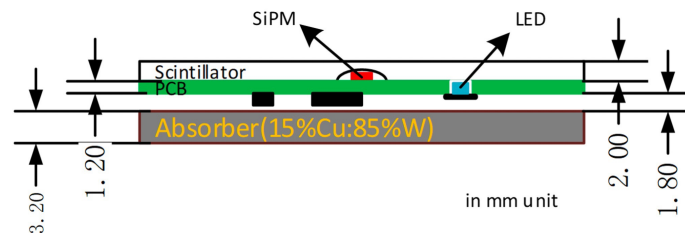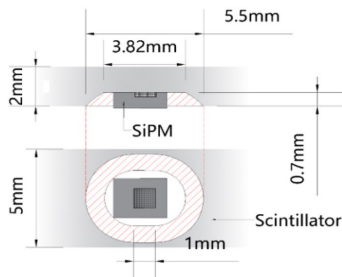
Sc-ECAL large technological prototype

Electronics side

- 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
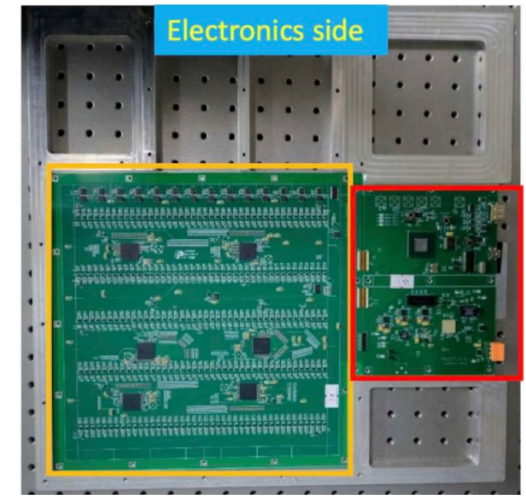
- Two types of MPPC are used for SiPM on detection layer (manufactured by Hamamatsu K. K.)
  - S12571-010P, & -015P
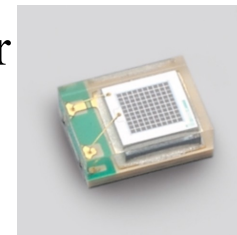
	Pixel size	# of pixel	gain
S12571-010P	10 um	10,000	1.35×10^5
S12571-015P	15 um	4,489	2.3×10^5

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

45 mm
5 mm
dimple
22.5 mm

90 mm
5 mm
22.5 mm   22.5 mm

S12571-015P   S12571-010P   S12571-015P
1 2 3 4 5   28 29 30 31 32
...
45 mm   90 mm

#32

Test beam experiment

North Area Test Beam Facilities
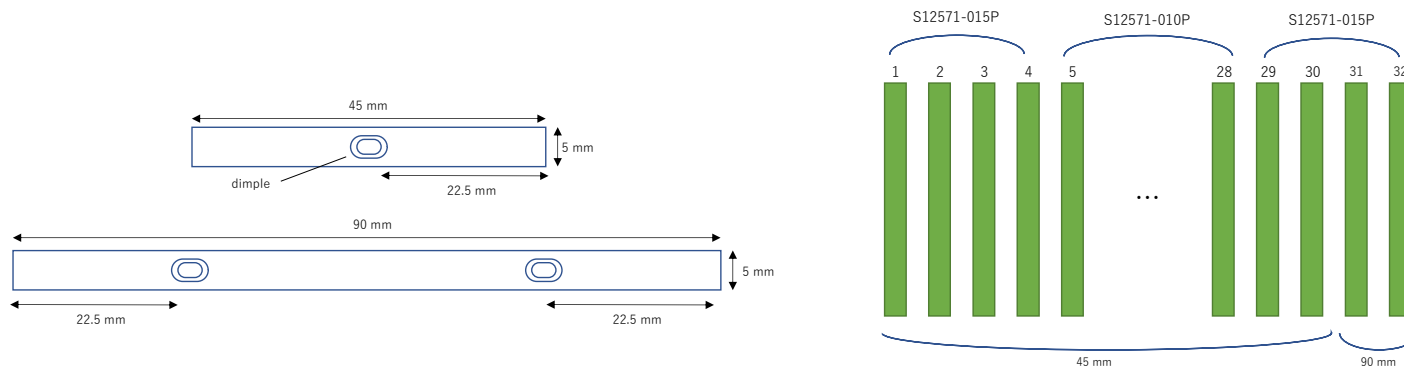
Sc-ECAL   AHCAL

beamline

- 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, <u>2022</u>
    - High energy beam (10-160 GeV)
    - μ^+, π^+, e^+
  - SPS : Site 887, H2 beamline
    - April 26th to May 10th, <u>2023</u>
    - 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, <u>2023</u>
    - Low energy beam (1-15 GeV)
    - μ^-, π^-, e^-
- Collaborators
  - UTokyo, Shinshu university, USTC, IHEP, SJTU
    AHCAL talk by Hongbin Diao on Friday

100 GeV muon

60 GeV electron

350 GeV pion

Pedestal calibration

- Pedestals were originally obtained for the channels that did not exceed threshold (0.5 MIP)
  - Some channels had multi-peaks due to electronics problems a last years

- 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

Times_layer9_chip0_chan0

Times_layer9_chip0_chan0	
Entries	14761
Mean	422.3
Std Dev	9.556

2022

hg_layer9_chip0_chan0

hg_layer9_chip0_chan0	
Entries	82176
Mean	418.8
Std Dev	4.131

2023

htemp	
Entries	6912
Mean	422.1
Std Dev	27.36

Beam data
Force-trigger

All channel's pedestal value [ADC]

Pedestal stability

layer31_chip3_chan1
layer31_chip3_chan2
layer31_chip3_chan3
layer31_chip3_chan4
layer31_chip3_chan5
layer31_chip3_chan6
layer31_chip3_chan7

SPS   PS

温度 温度

SPS   PS

High gain and low gain intercalibration

Intercalibration of a channel

- 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

No corresponding channels

Dead channels

High-low gain ratio

6*layer No.+ chip No.
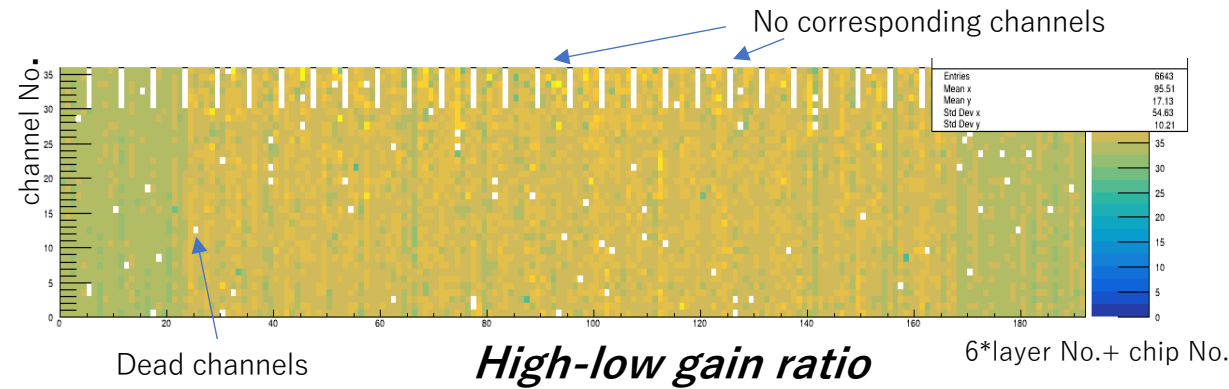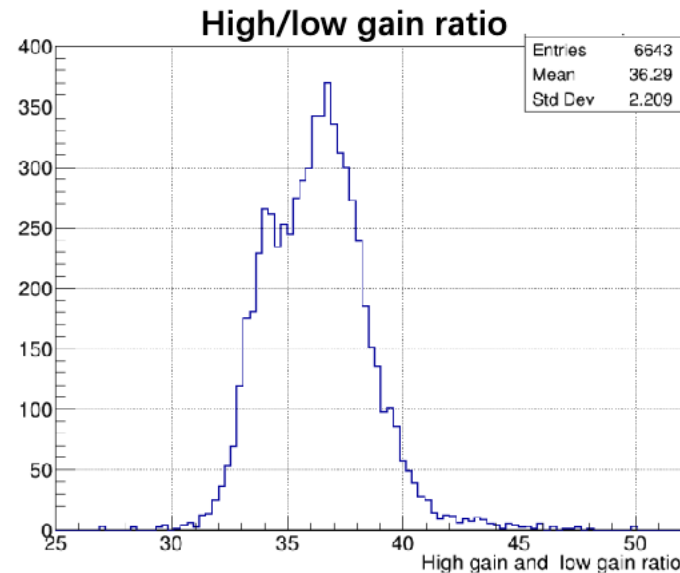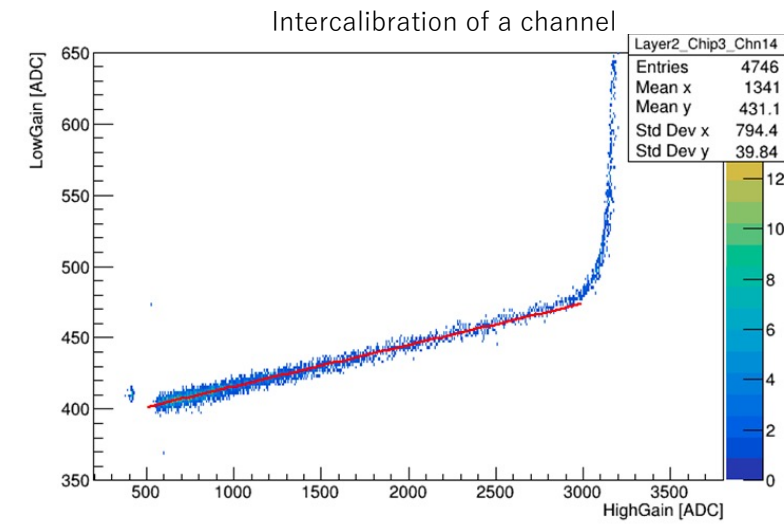
LED calibration

- 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_15	
Entries	1260
Mean	22.73
Std Dev	2.685

Gain [ADC/p.e.]

Gain distribution during PS 10um

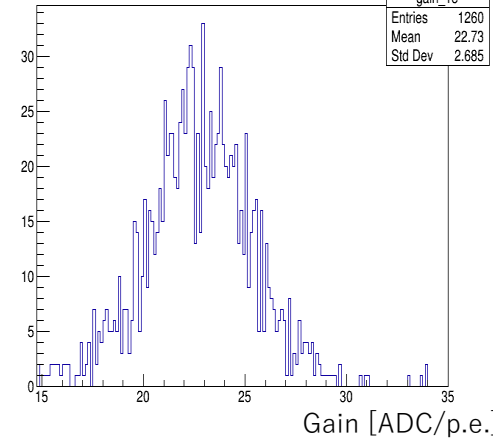| gain_10	
Entries	5040
Mean	13.38
Std Dev	3.147

Gain [ADC/p.e.]
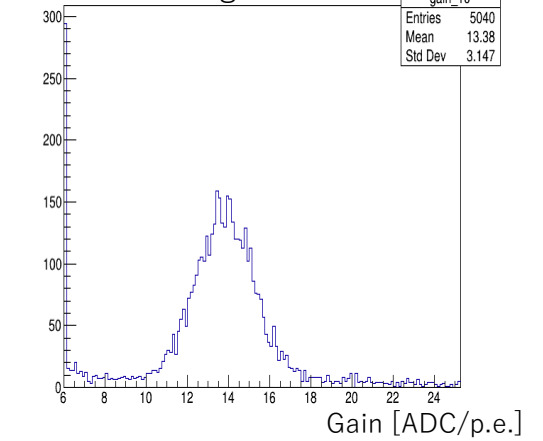
Gain distribution during cosmic ray test 15um

gain15	
Entries	1680
Mean	25.39
Std Dev	2.646

Gain [ADC/p.e.]

Gain distribution during cosmic ray test 10um

gain10	
Entries	5040
Mean	15.36
Std Dev	1.345

Gain [ADC/p.e.]

15 um SiPM LED data

time_0_0_2	
Entries	2122
Mean	457.6
Std Dev	32.09

ADC
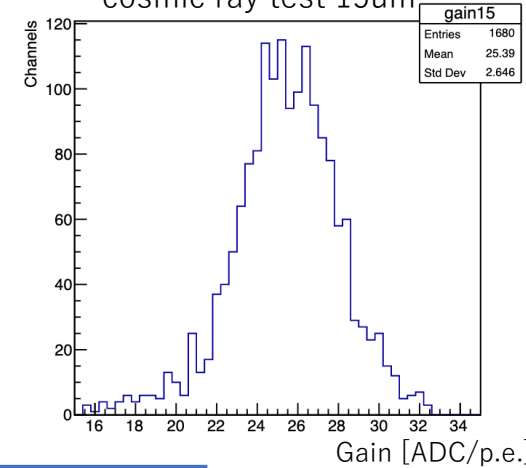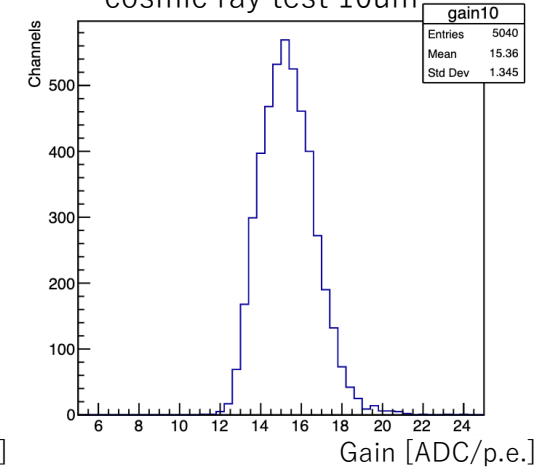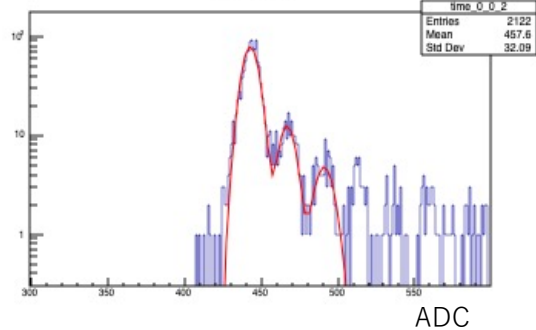
ECAL	Cosmic Ray test	Beam test
temperature	~20 C	25~29 C
Bias voltage	-	+0.5 V

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

ECAL MIP MPV

Statistics of each channel in layer2
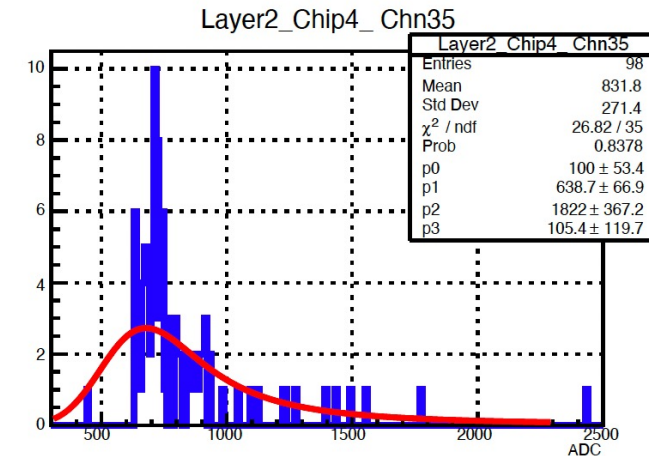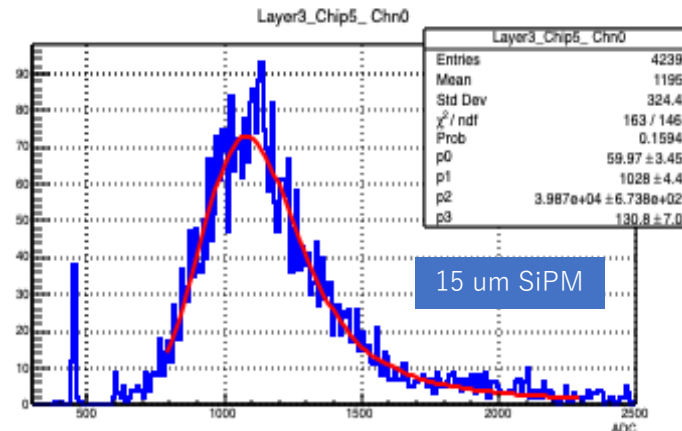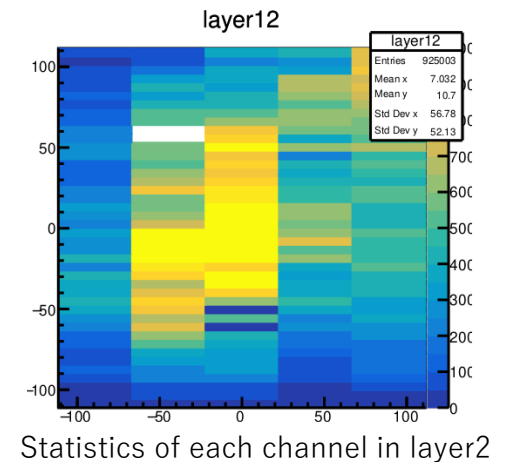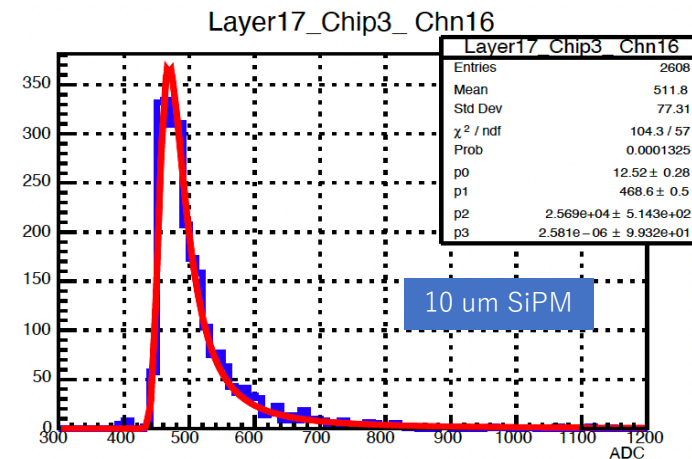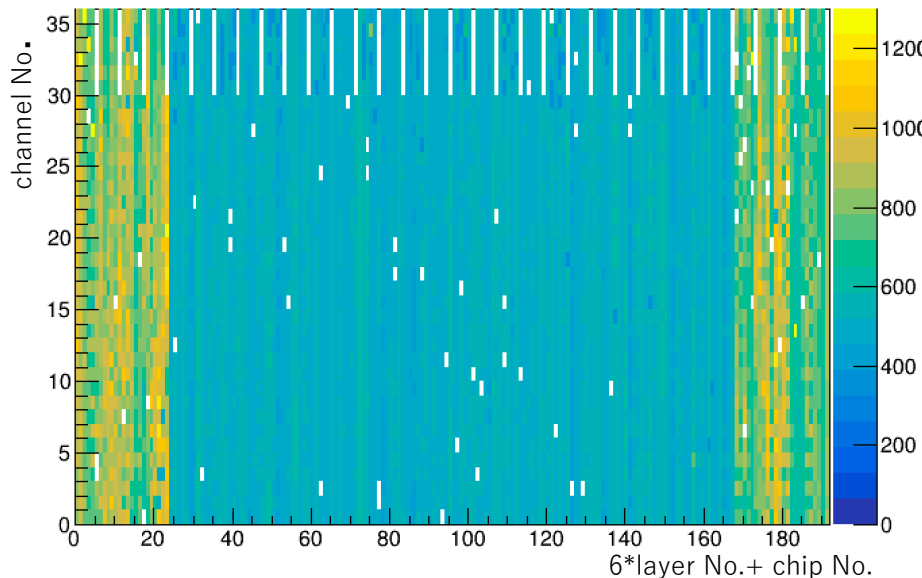
Energy resolution -2023data-

- 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
  - <u>Higher purity</u> beam
- Used calibration parameters

- Bad linearity above 200 GeV due to saturation of low gain
- Mu, pi contaminations are still included

- Discrepancy between fit and at 20-60 GeV

20 GeV energy deposition

energy_deposition_5	
Entries	114295
Mean	654.2
Std Dev	224.5

Preliminary

60 GeV energy deposition

energy_deposition_10	
Entries	108711
Mean	1974
Std Dev	661.6

Preliminary

Energy Linearity

Preliminary

χ^2 / ndf	8.201e+05 / 17
Prob	0
p0	10.85 ± 0.05437
p1	35.34 ± 0.001854

Energy Resolution

ps   sps

χ^2 / ndf	4558 / 14
Prob	0
p0	0.2359 ± 0.0007916
p1	0.02425 ± 0.0001028

Preliminary

$$\frac{23.6\%}{\sqrt{E}} \oplus 2.24\%$$

11
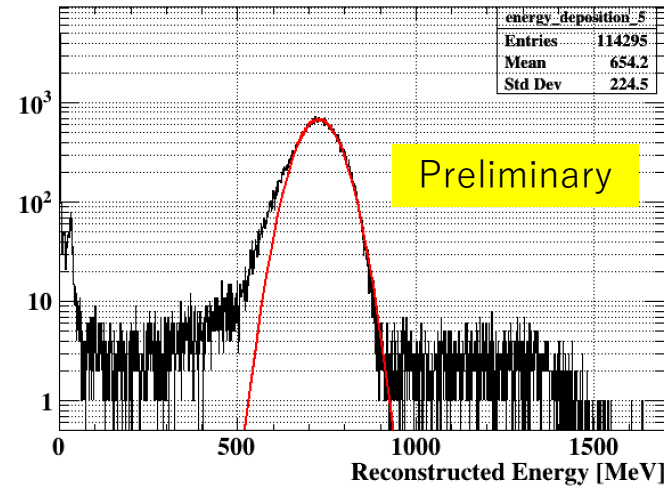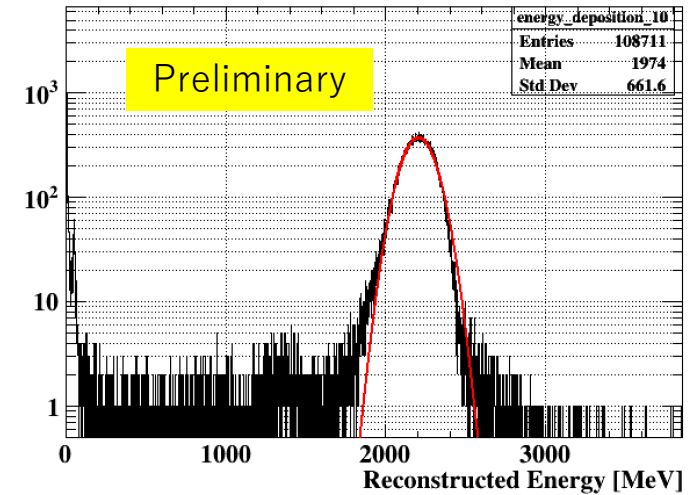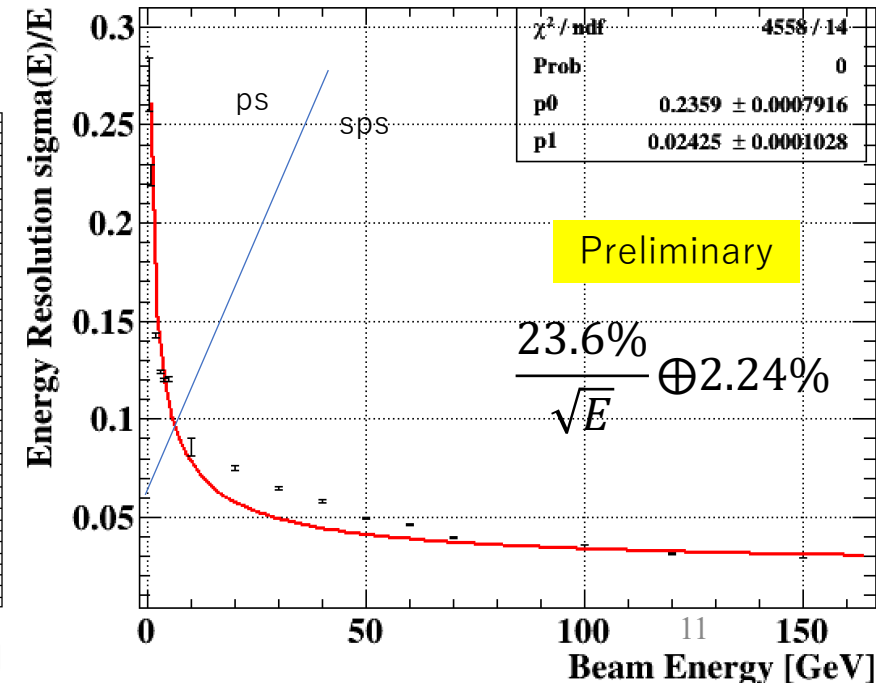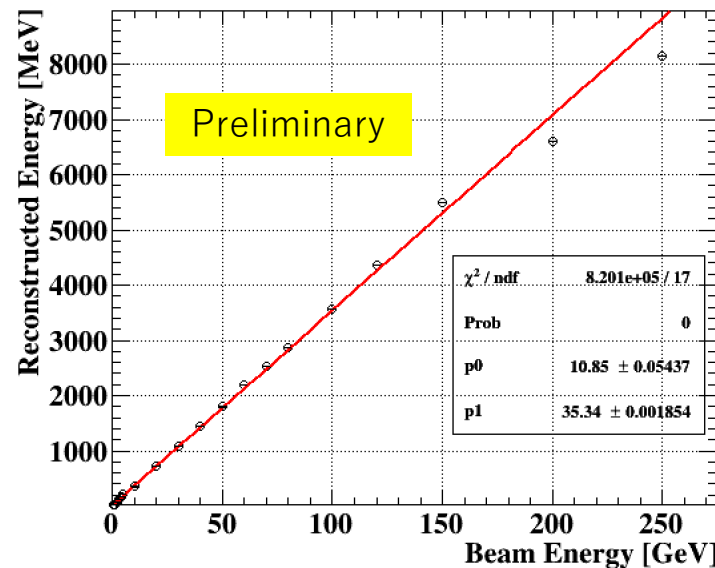
Simulation and validation

- 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

Edep(MeV) — MC

Edep	
Entries	10000
Mean	1157
Std Dev	98.5
χ^2 / ndf	85.88 / 77
Prob	0.2288
Constant	192.9 ± 2.6
Mean	1159 ± 1.3
Sigma	104.7 ± 1.2

Edep(MeV) — Data

Edep	
Entries	104927
Mean	1500
Std Dev	106.6
χ^2 / ndf	87.78 / 47
Prob	0.0002862
Constant	2045 ± 10.3
Mean	1516 ± 0.4
Sigma	87.14 ± 0.59

40GeV e- energy deposition for each layer

Red: simulation
Violet: data

HitNo2EnergyDep

HitNo2EnergyDep	
Entries	104927
Mean x	1603
Mean y	417.4
Std Dev x	535.5
Std Dev y	131.2

pion

electron

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
  - Low gain saturation in the electronics

10 GeV energy deposition

Preliminary

sps data

energy_deposition_1	
Entries	25326
Mean	281.6
Std Dev	96.15

Detected energy [MeV]

10 GeV energy deposition

energy_deposition_1	
Entries	10000
Mean	349.5
Std Dev	15.81

simulation

Preliminary

Detected energy [MeV]

Energy Linearity

Preliminary

χ^2 / ndf	1160 / 20
Prob	2.83e−233
p0	0.9117 ± 0.03122
p1	34.75 ± 0.002002

CALOR 2024

Beam Energy [GeV]

Energy Resolution

χ^2 / ndf	50.45 / 19
Prob	0.0001125
p0	−0.1385 ± 0.0003141
p1	−0.005881 ± 0.0001507

$$\frac{13.8\%}{\sqrt{E}} \oplus 0.59\%$$
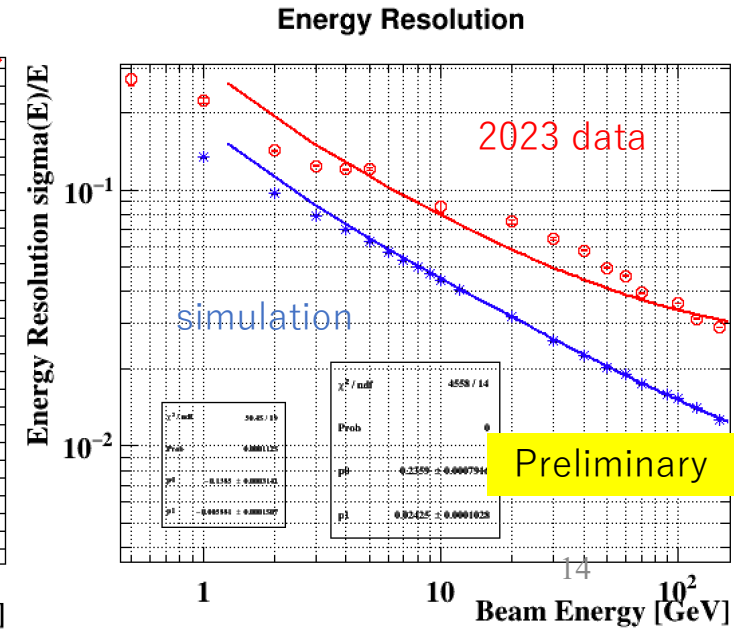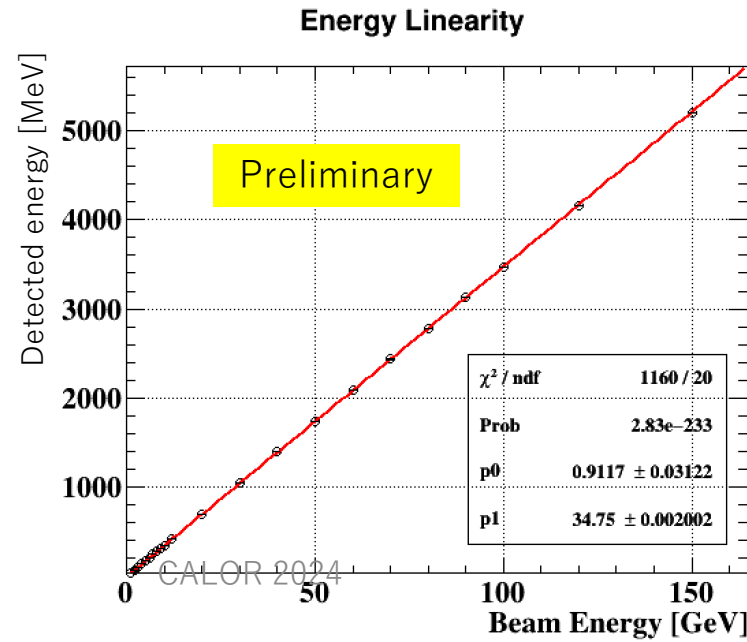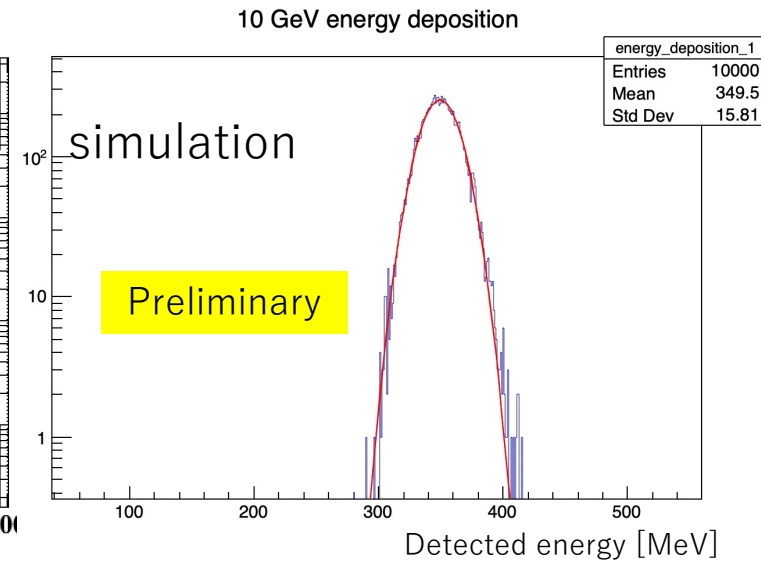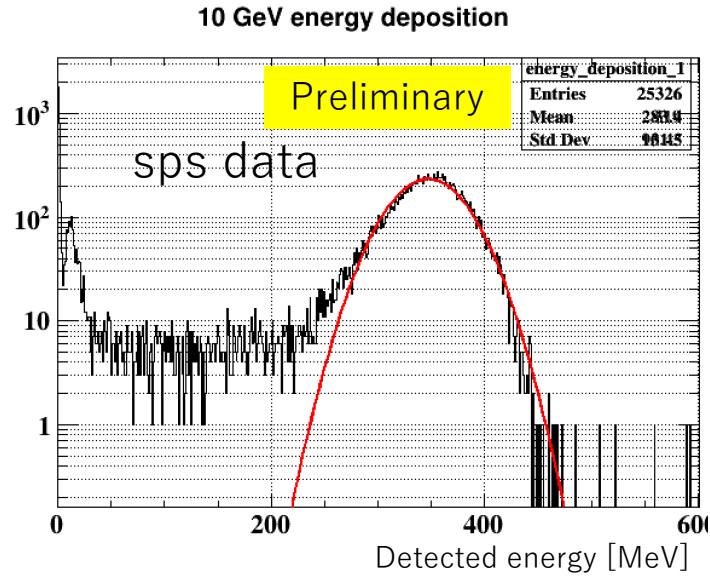
Preliminary

Beam Energy [GeV]

13
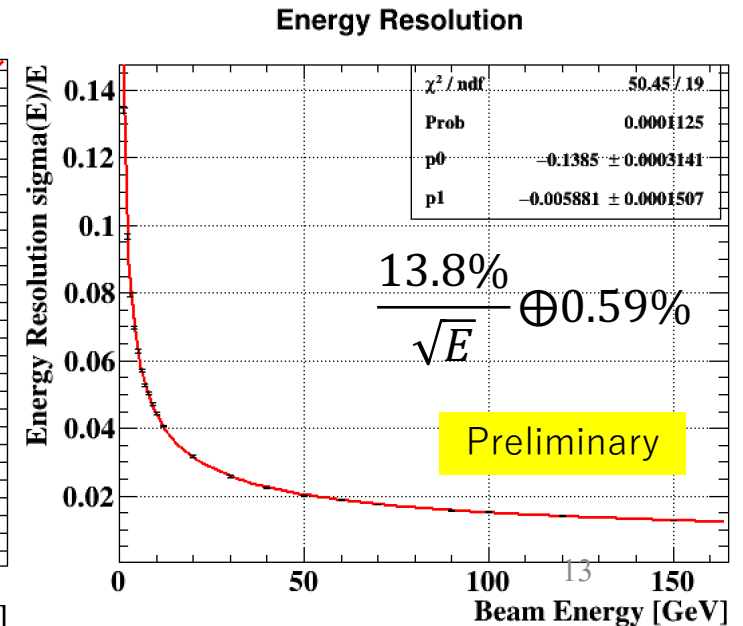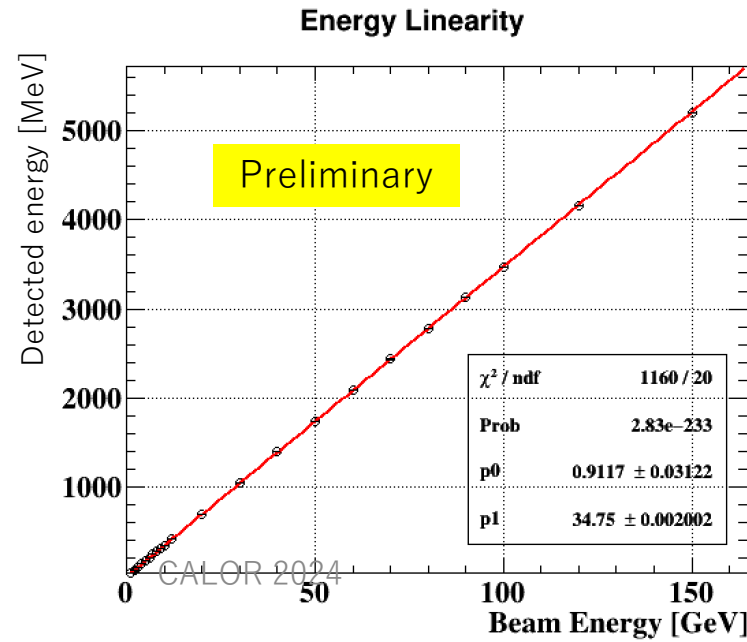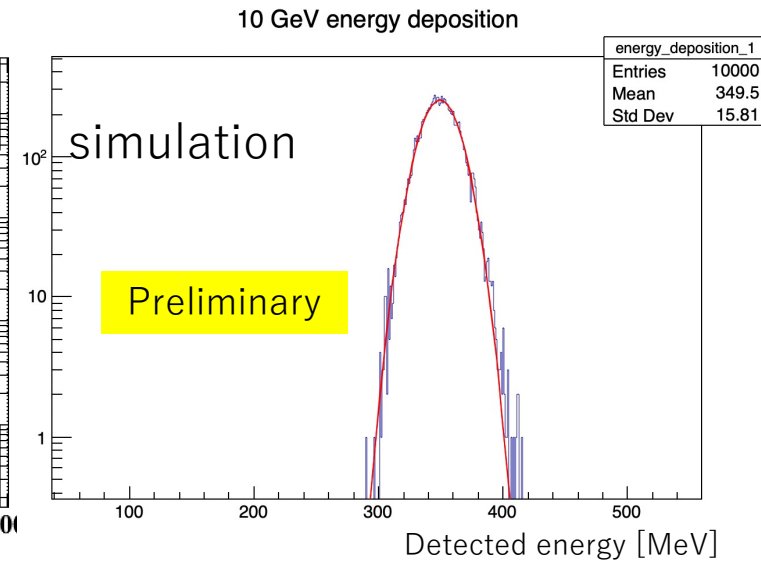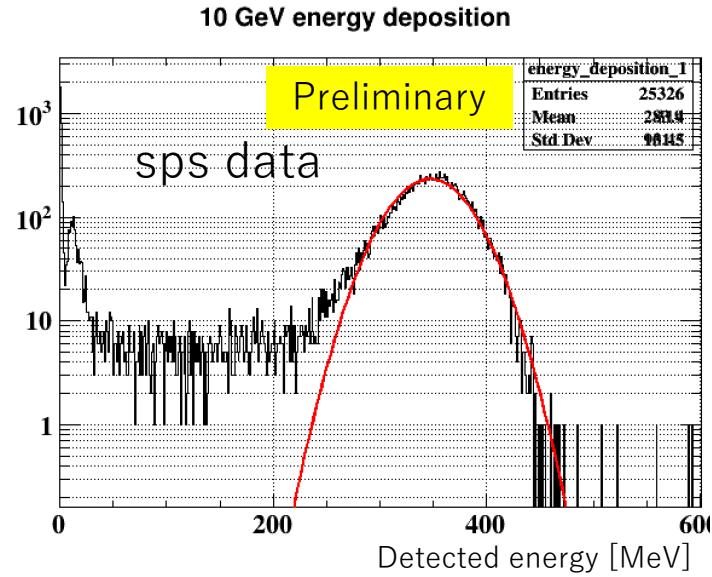
Energy resolution -Simulation-

- Injected e- beam
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- 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
  - Low gain saturation in the electronics

- Energy resolution of simulation is 2x smaller than data
  - Need more modification to simulation and data analysis

10 GeV energy deposition

Preliminary

sps data

energy_deposition_1	
Entries	25326
Mean	281.8
Std Dev	90.15

Detected energy [MeV]

10 GeV energy deposition

simulation

Preliminary

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Entries	10000
Mean	349.5
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Detected energy [MeV]

Energy Linearity

Preliminary

CALOR 2024

χ² / ndf	1160 / 20
Prob	2.83e−233
p0	0.9117 ± 0.03122
p1	34.75 ± 0.002002

Detected energy [MeV]

Beam Energy [GeV]

Energy Resolution

2023 data

simulation

Preliminary

Energy Resolution sigma(E)/E

Beam Energy [GeV]

14

Summary and prospect

- Sci-ECAL and AHCAL combined test beam experiments are conducted at CERN
  - SPS H8 beamline in October 2022
  - SPS H2 beamline in April to May 2023
  - PS T9 beamline in this May 2023
- 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
  - Geant4 MC validation
  - Sci-ECAL and AHCAL combined analysis

Thanks for CERN, CERN staff,
and CALICE collaboration colleagues

Backup