Status of high granular scintillator calorimeter for future electron positron colliders

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On behalf of the Sc-ECAL working group

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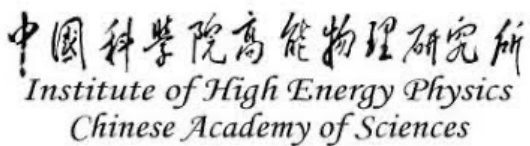
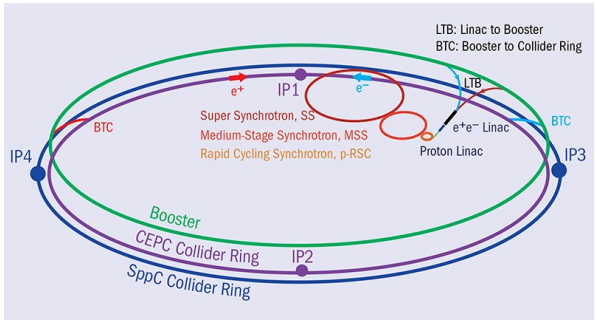


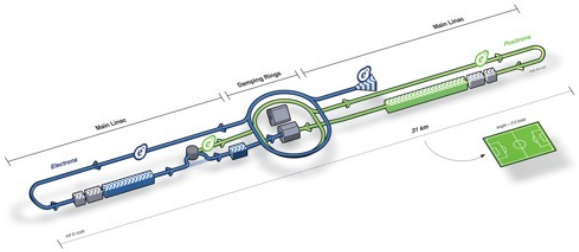
Introduction

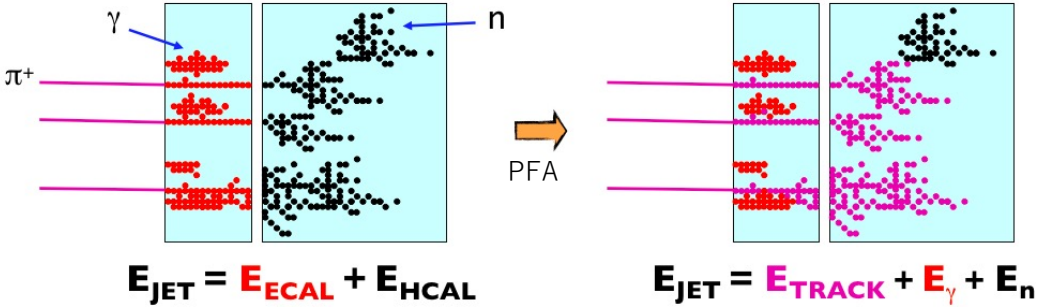
- Future electron positron colliders
  - Precision measurements of the Higgs/EW/QCD
  - Calorimeter system requirement
    - High granularity for both ECAL and HCAL
      - 5 mm for ECAL, few cm for HCAL
    - Jet energy resolution ~30%/E
- Particle Flow Algorithm (PFA) oriented Detector
  - SiWECAL, Sc-ECAL, DECAL, etc…

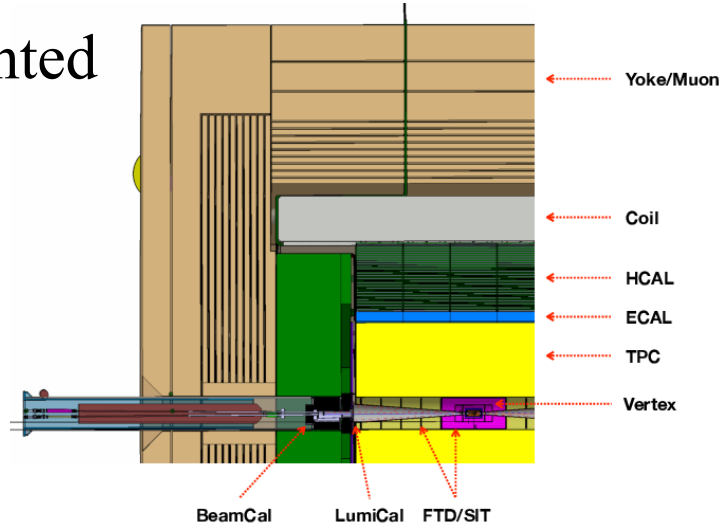
CEPC

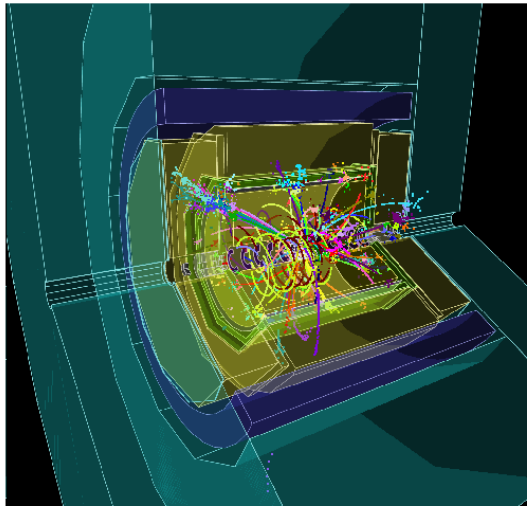


ILC



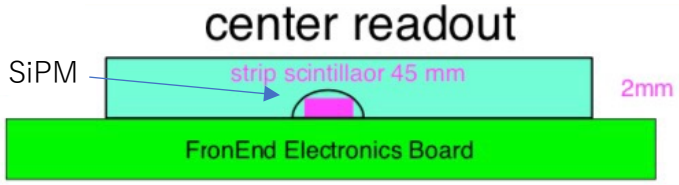






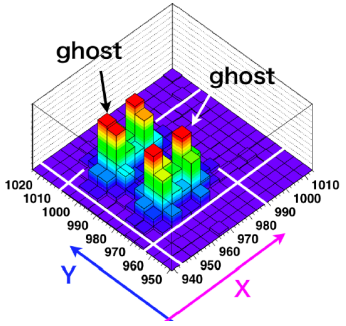
Sc-ECAL

- 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

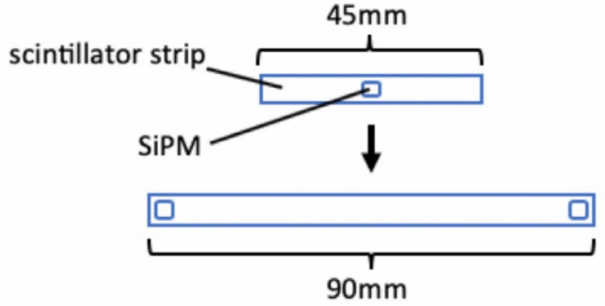


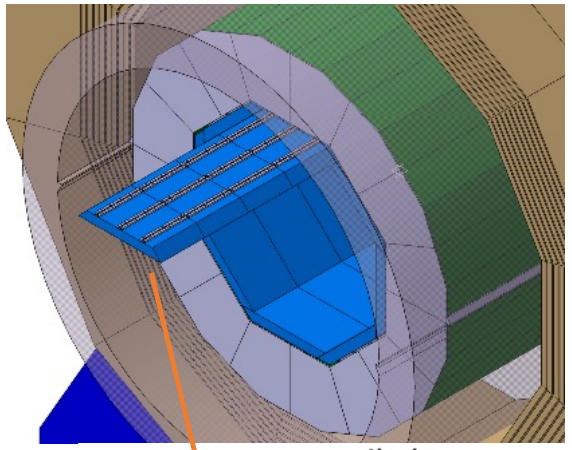
  - Virtual segmentation of 5×5 mm^2 cell can be achieved by x-y configuration of strips with strip splitting algorithm (SSA)

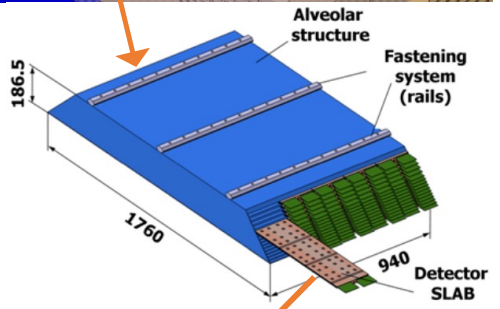
- Ghost hit problem
  - False signal from simultaneous hits
  - Expected to be eliminated by double SiPM readout

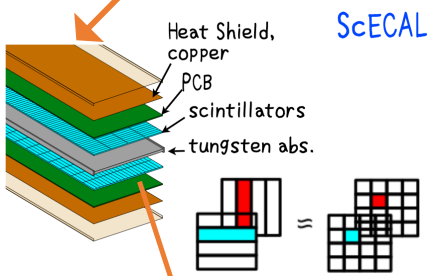


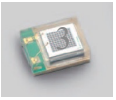
- Double SiPM readout
  - readout by two SiPMs at strip ends



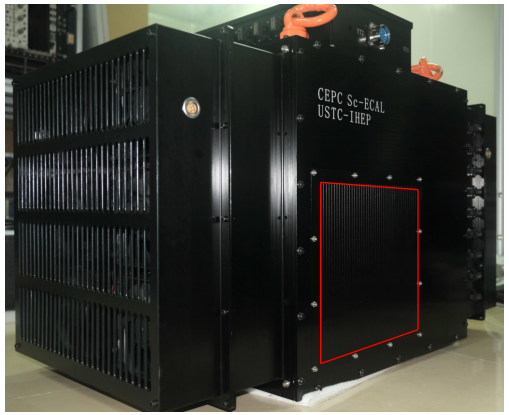




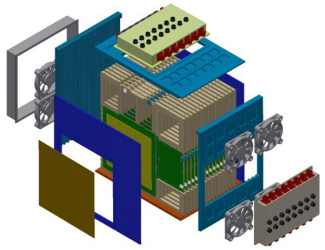


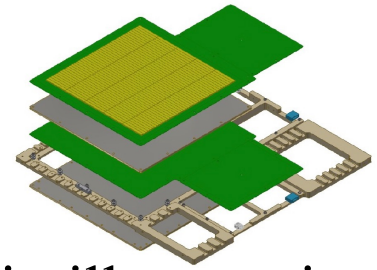


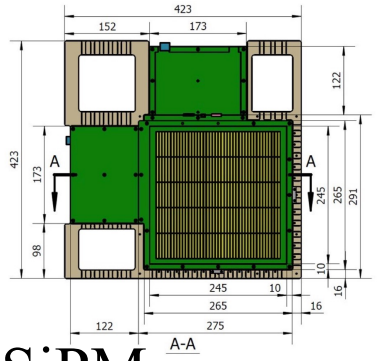
Sc-ECAL large technological prototype

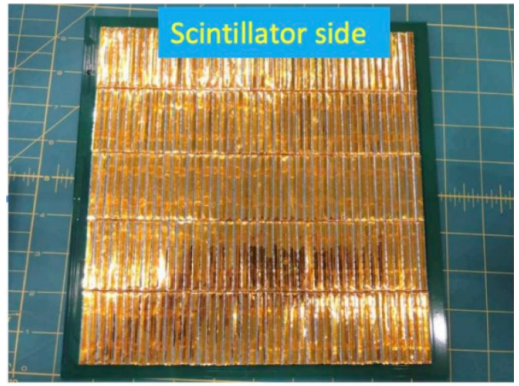


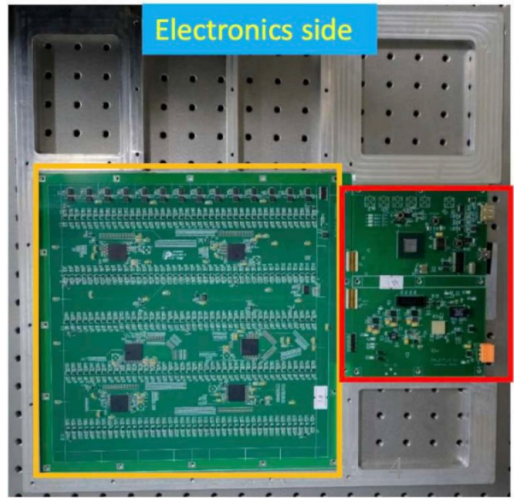
- The prototype consists of 32 absorber(W) and detection layer (EBU)
  - Total absorption layer thickness : 32×3.2 mm (~23.3 X_0)
  - Two absorber layers and two detection layers are integrated on a braced frame (super layer)
  - 16 super layers are mounted on the prototype



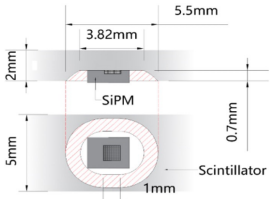


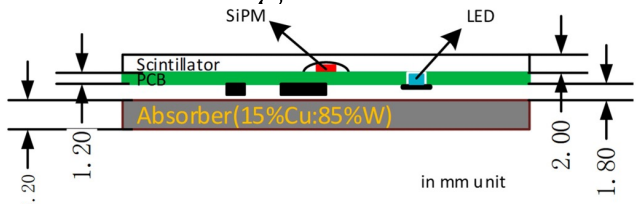




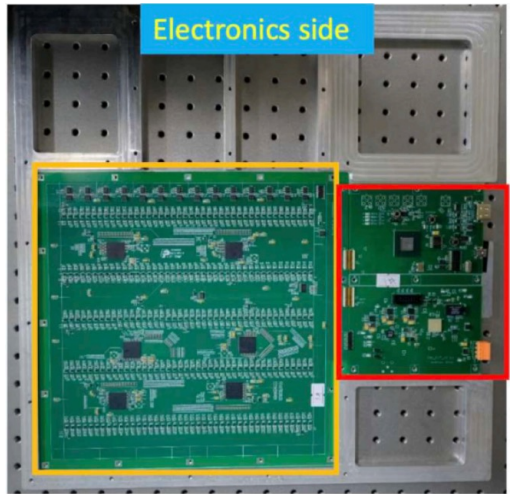


- ECAL Base unit (EBU) and scintillator strips + SiPM readout unit for a detection layer
  - 42 (columns) × 5 (rows) strip readouts per EBU
  - Each channel have LED for calibration of SiPM gain

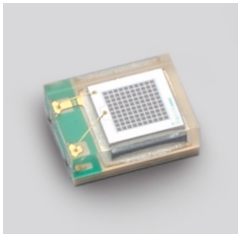




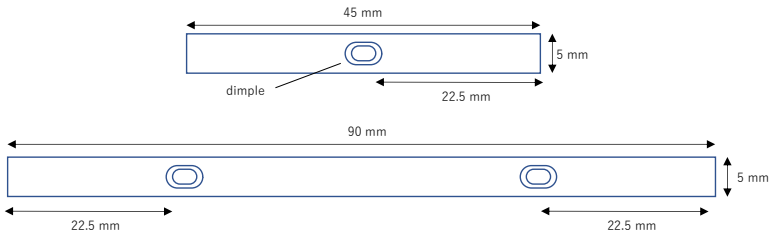
Sc-ECAL large technological prototype

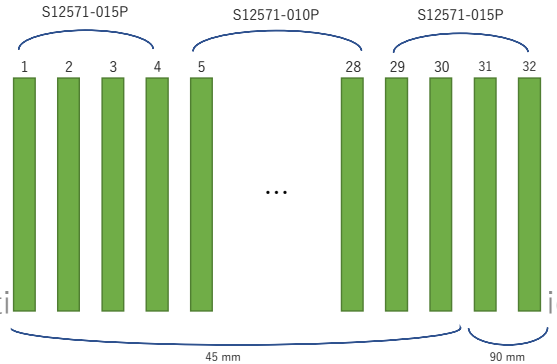


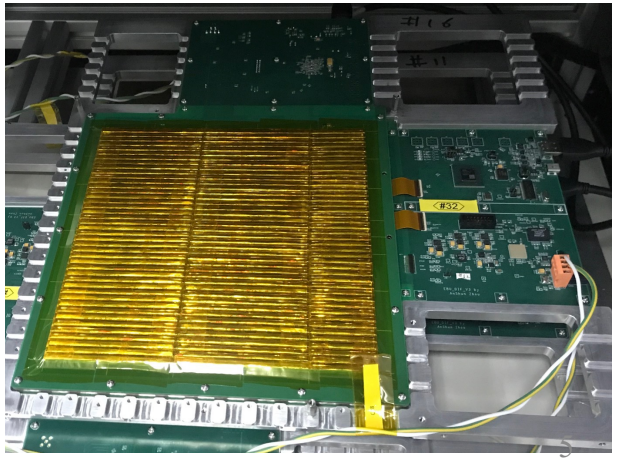
- All channels on each EBU can be individually readout by 6 SPIROC2E chips developed by OMEGA lab and CALICE collab.
  - High and low gain mode for wide dynamic range
  - 16 temperature sensors are implemented
- Two types of MPPC are used for SiPM on detection layer (manufactured by Hamamatsu K. K.)
  - S12571-010P, & -015P
- Last 2 layers have double SiPM readout part
  - Using 90 mm length strip instead of standard 45 mm strip



	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



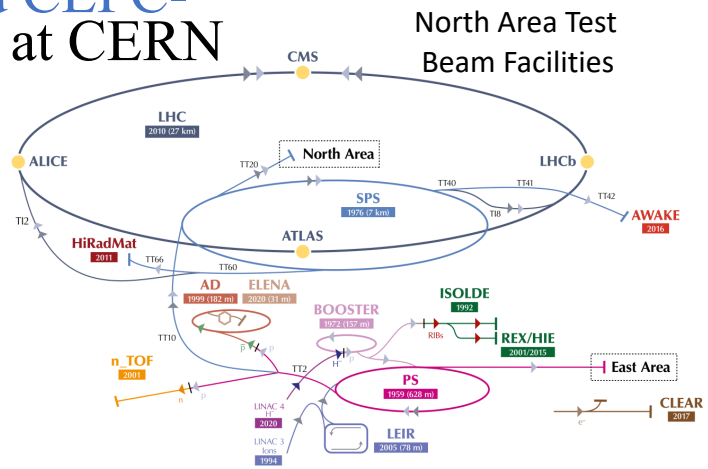


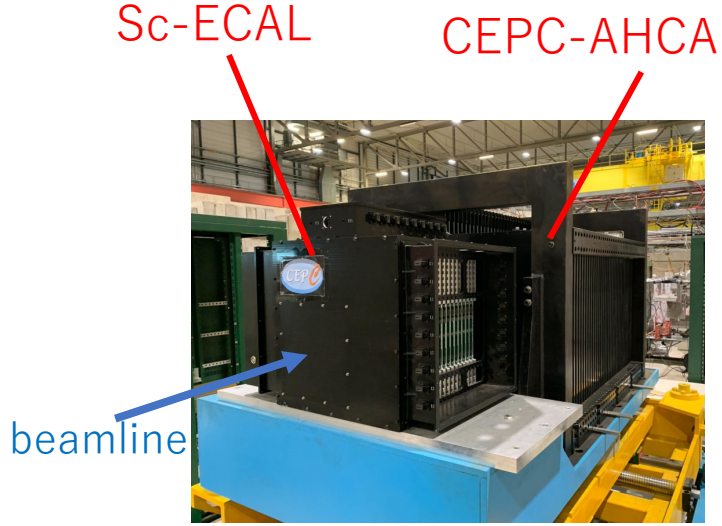


Test beam experiment

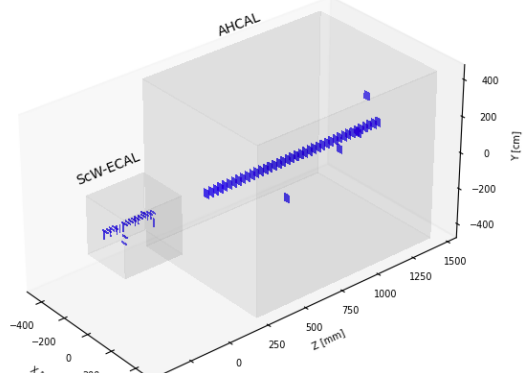
CEPC-AHCAL analysis progress is talked by Taisei

- 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
  - UTokyo, Shinshu university, USTC, IHEP, SJTU

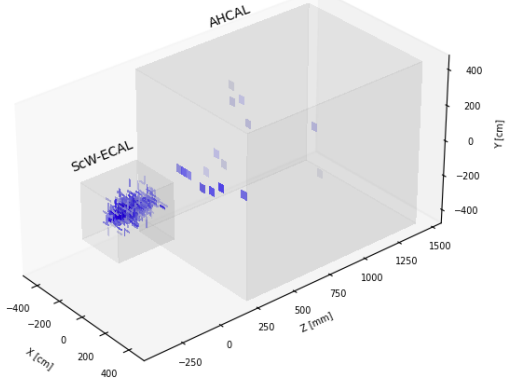




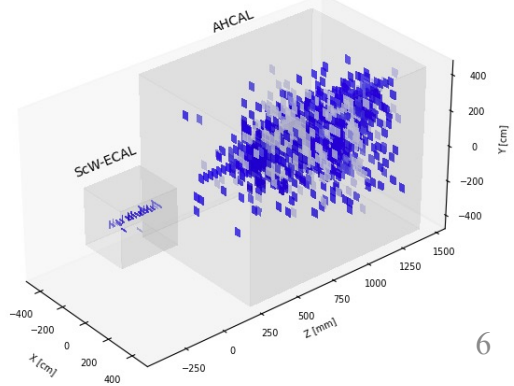
100 GeV muon



60 GeV electron

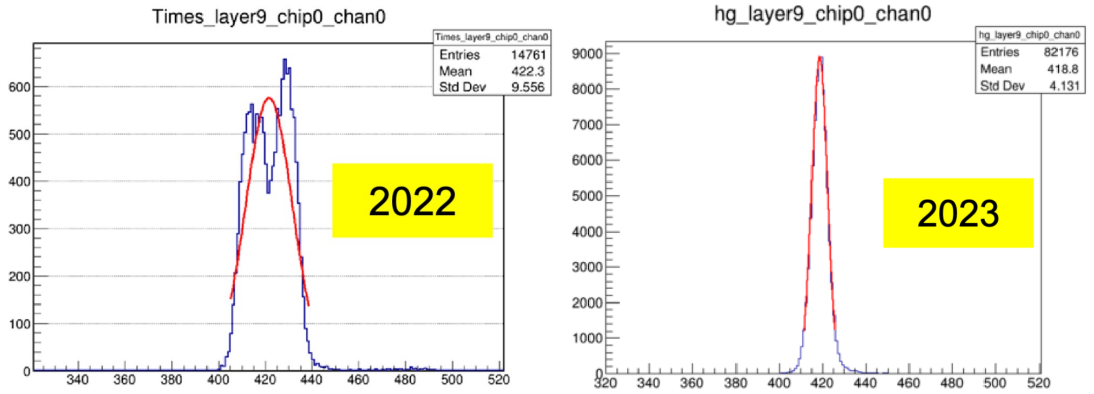


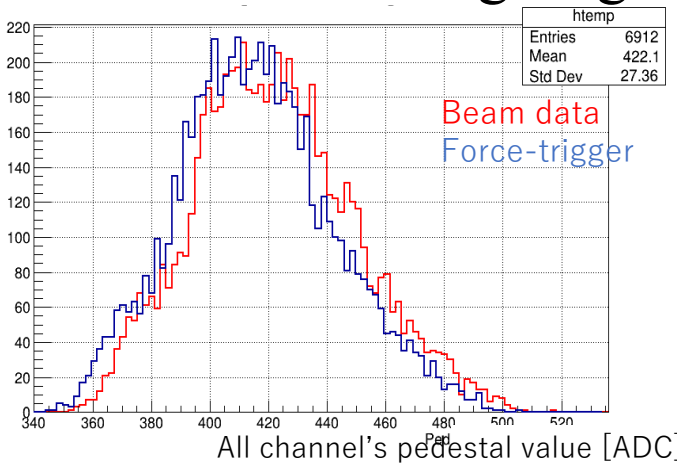
350 GeV pion

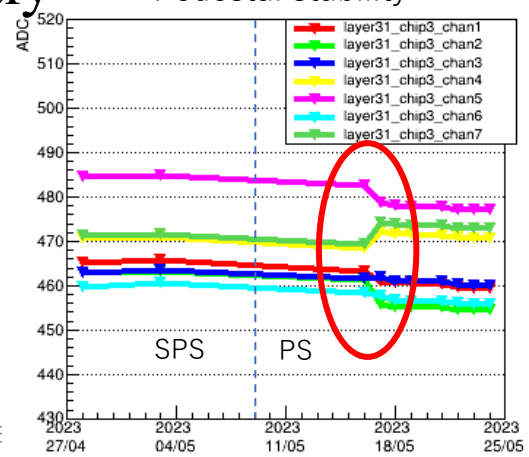


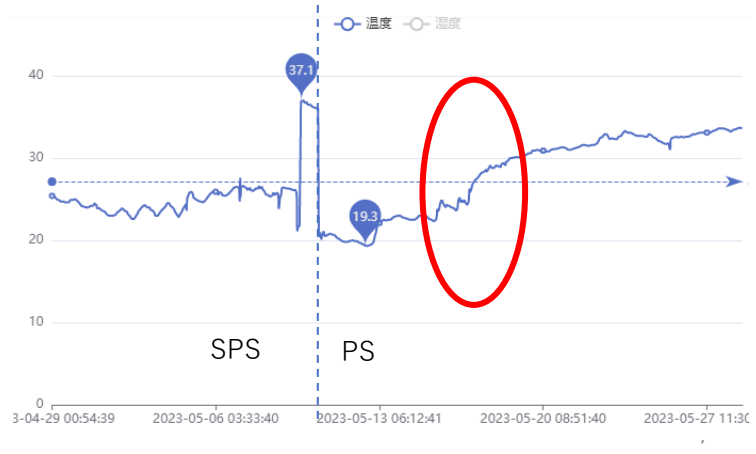
Pedestal

- Pedestals were originally obtained for the channel that did not exceed threshold
  - Some channels had multi-peaks due to electronics problems in 2022 beam test
- <u>Pedestals are obtained from force-trigger-mode</u> to prevent the problem in 2023
- <u>Pedestals were stable</u> during the beam test in SPS or PS respectively within a 2~3 ADC fluctuation when temperature did not change significantly



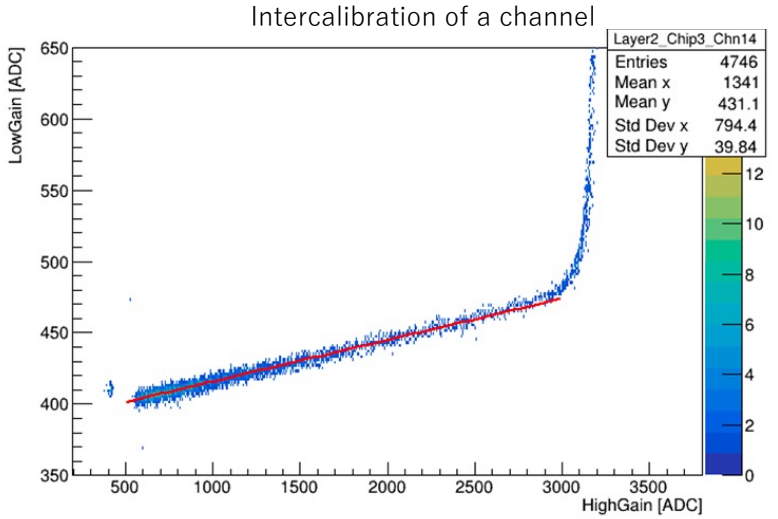


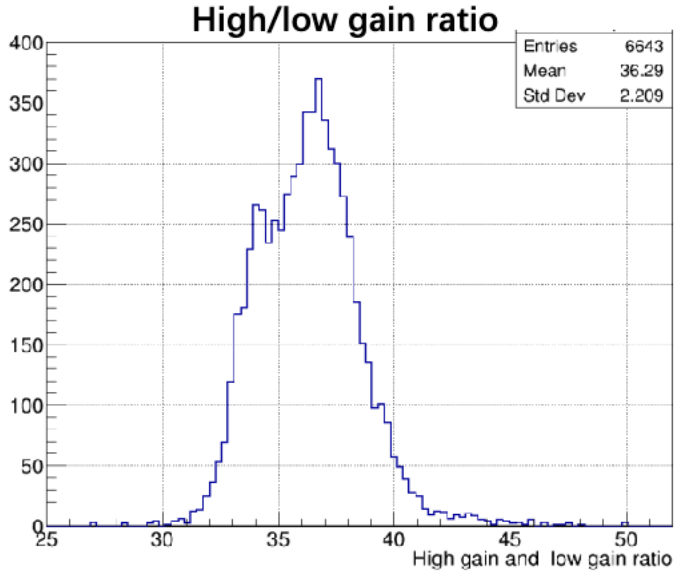


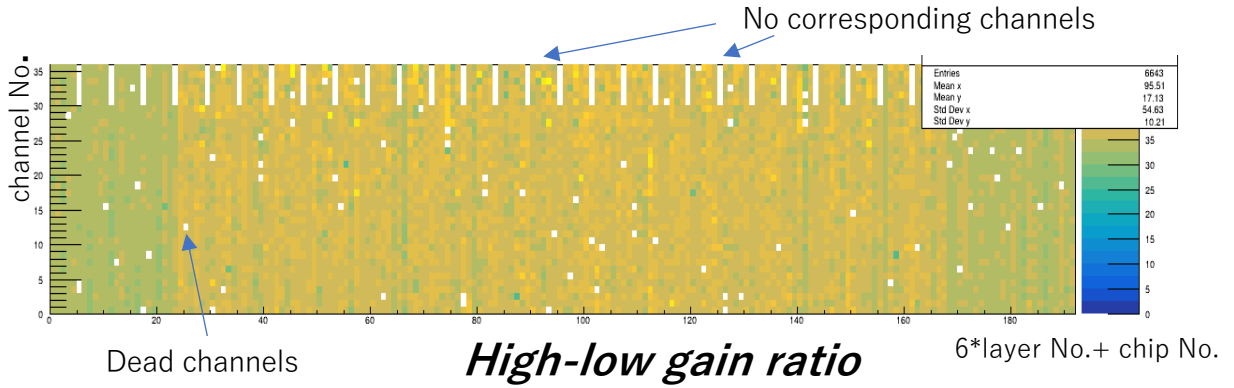


High gain and low gain intercalibration

- 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

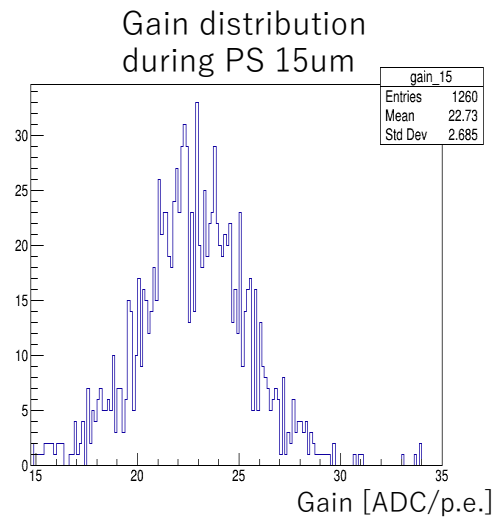


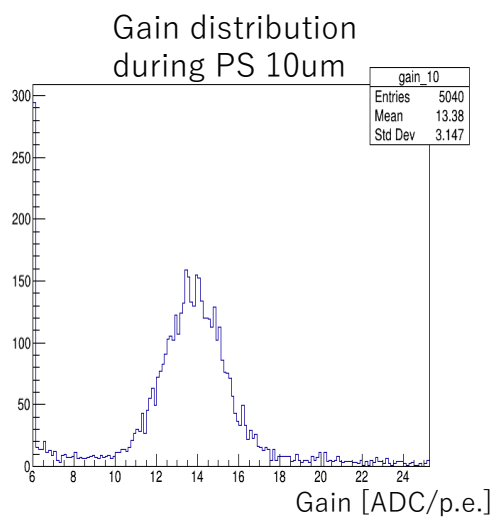


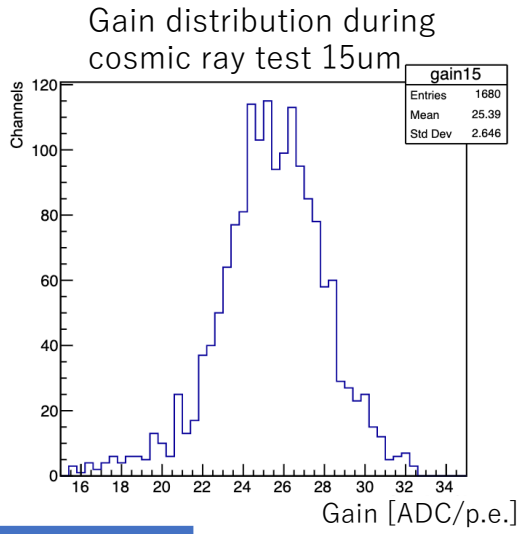


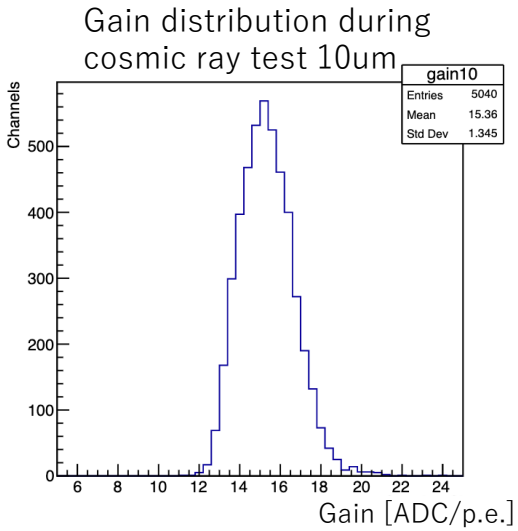
LED calibration

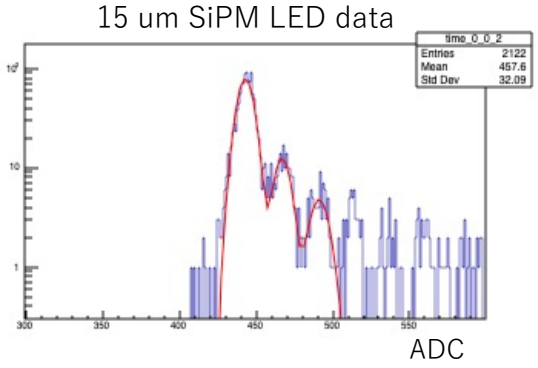
- LED data are taken during the 2023 beam test
  - SPS : 3 times (at the beginning and the middle of the beam test)
  - PS : every day
- LED data are fitted with multi-gaussians to calculate gain for each channel
- Increased the bias voltage of all channels at the beam test to compensate temperature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







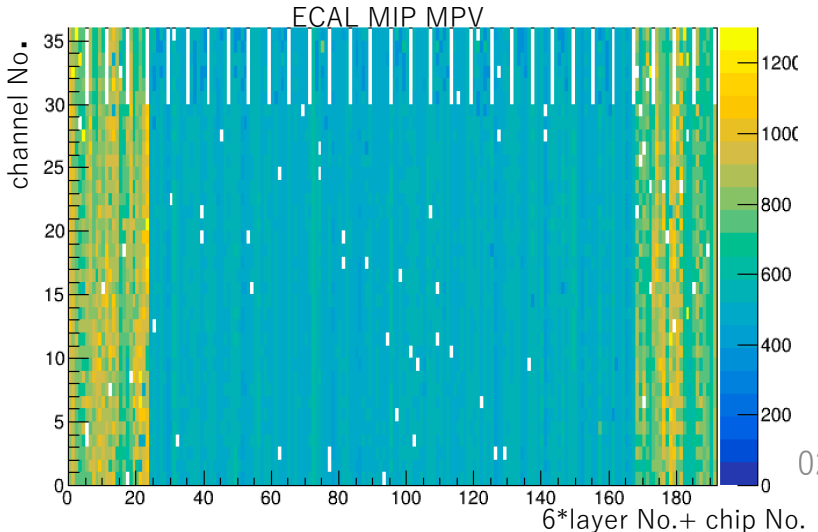


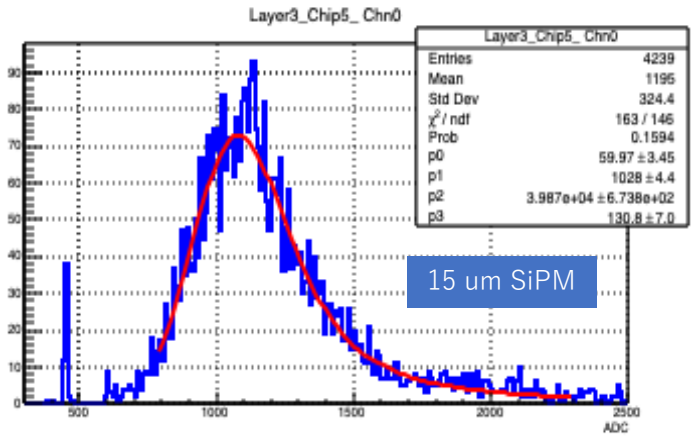


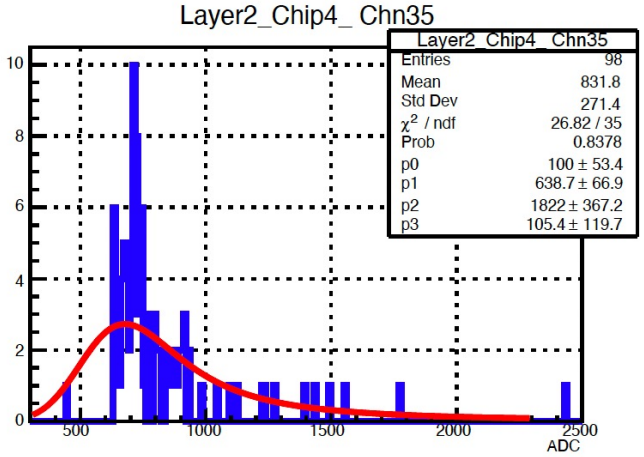
ECAL	Cosmic Ray test	Beam test
temperature	~20 C	25~29 C
Bias voltage	-	+0.5 V

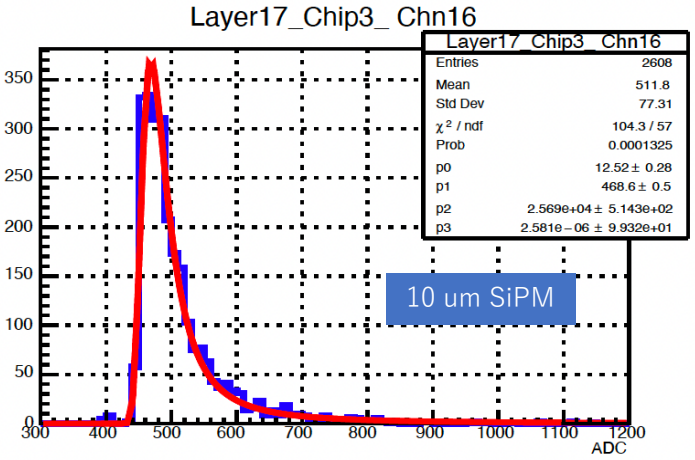
MIP calibration

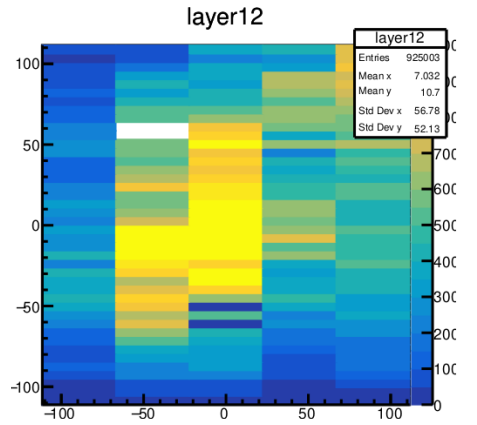
- MIP peak value is obtained from fitting 100 GeV/c muon events' ADC distribution by Langaus function
- Threshold and SiPM voltage are optimized
- Track restriction s are used to improve fit result
- A small part of channels are not well fitted due to lack of statistics







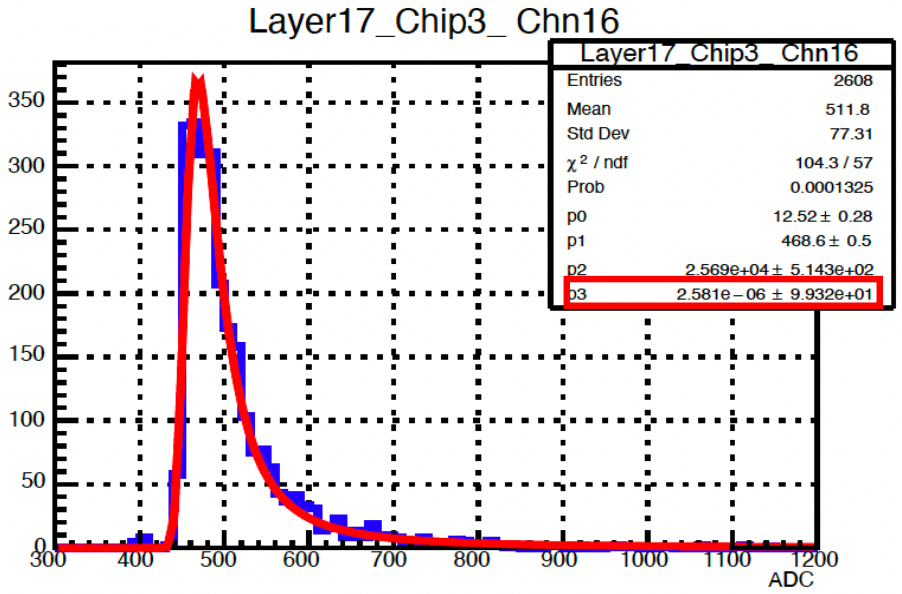




Statistics of each channel in layer2

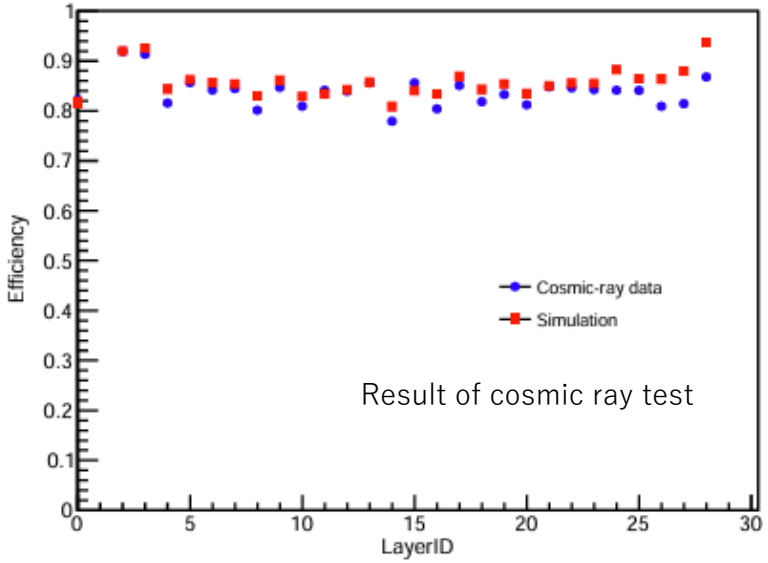
MIP calibration problems

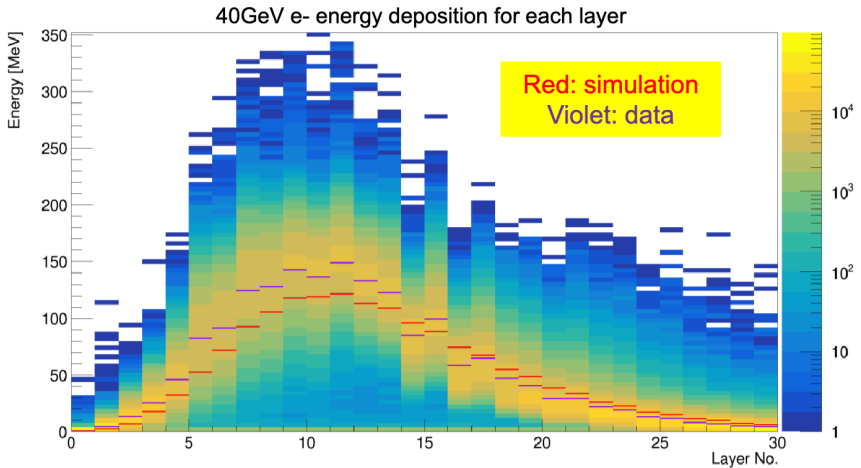
- DAQ threshold might not be set to appropriate values on many channels
  - Too narrow MIP spectrum
  - Very low gaussian component in convoluted Landau and Gaussian function
  - Might be caused by low SPS gain
- MIP calculation failed on high threshold channels
  - Resulting unsuccessful energy reconstructions
- Trying to compensate by cosmic ray test result or other well-fitted channels

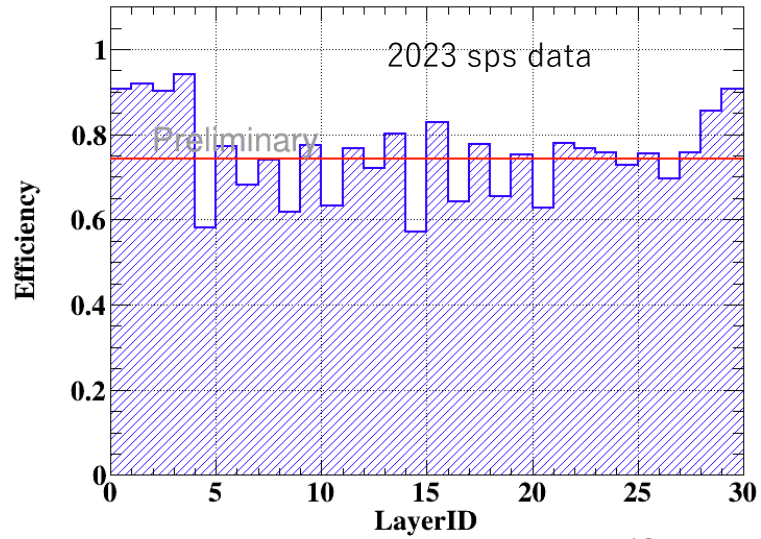


Detection efficiency of strips

- Definition of efficiency :
  - (# of hits which hit exist on the track fitting) / (estimated # of hit from track fitting)
- Detection efficiency of layers is calculated using track fit
  - A layer's hit strips are excluded from the track fitting
  - Efficiency of a layer is the ratio of events that have corresponding hits in the layer to all events
- Detection efficiency is fluctuating among layers
  - Same behavior with the energy distribution



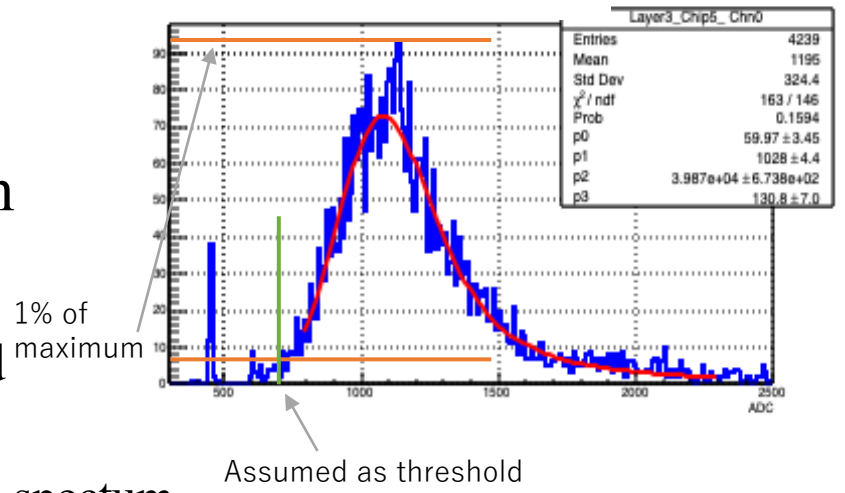




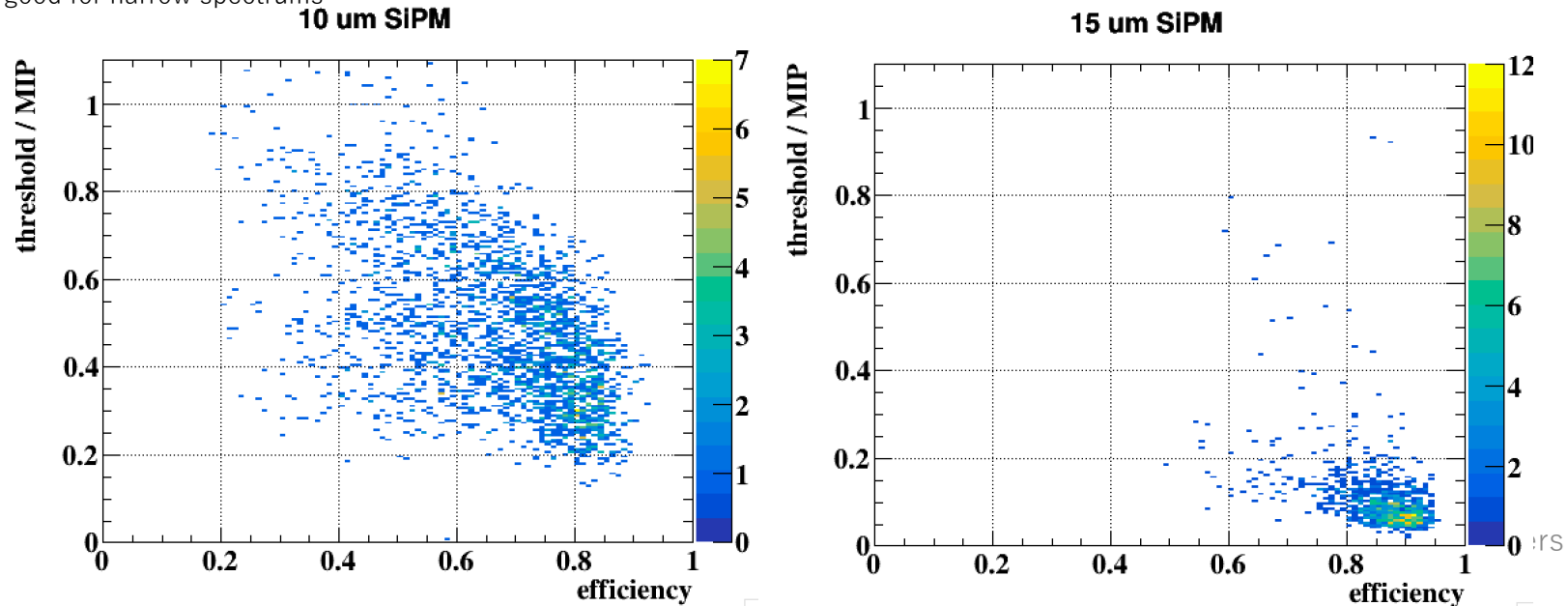
Correlation of threshold and detection efficiency

- Threshold are too high to cut lower edge of MIP spectrum
- Estimated threshold with constant fraction
  - ADC value with 1% of maximum height is assumed as threshold
    - This method might not be true for 15 um SiPMs
    - Might be a good indicator for 10 um SiPMs with rising edge in the spectum
- Lower threshold channels have higher efficiency

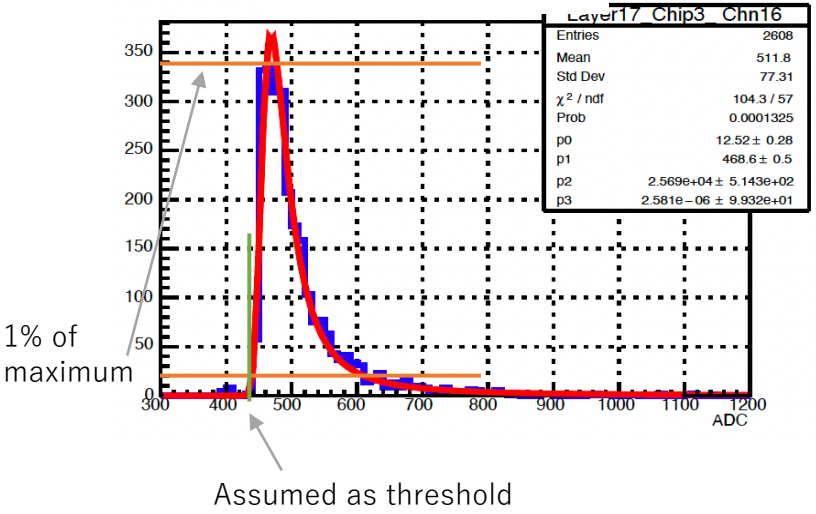
MIP spectrum of a channel (15 um)



This MIP is from the fit
Not good for narrow spectrums



MIP spectrum of a channel (10 um)



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 decent statistics of 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
  - Efficiency
  - etc…
- Plan
  - Geant4 MC validation
  - Sci-ECAL and AHCAL combined analysis

Thanks for CERN, CERN staff,
and CALICE collaboration colleagues