Study on the performance of the ScECAL prototype

- ✧ Overview of ScECAL technological prototype
- ✧ Performance evaluation of ScECAL prototype
  - ✓ Cosmic-ray data analysis
  - ✓ Efficiency, position resolution, MIP response, stability
  - ✓ EM shower performance study
- ✧ Summary and prospect

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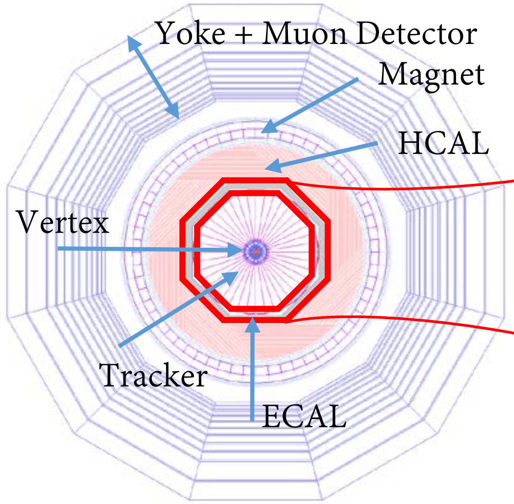
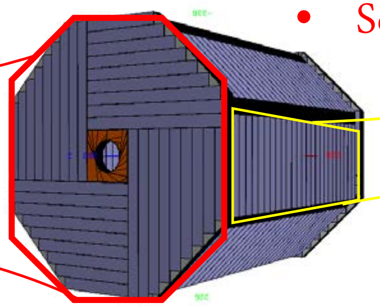
on behalf of the ScECAL Working Group

CALICE Collaboration Meeting
At Valencia, 20 – 22 Apr 2022

ScECAL technological prototype

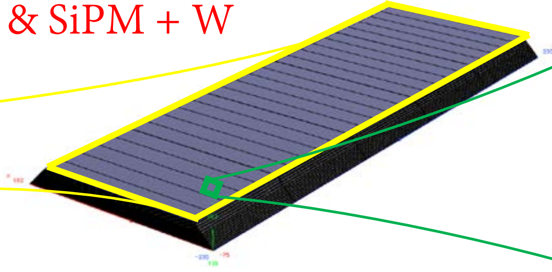
CEPC CDR

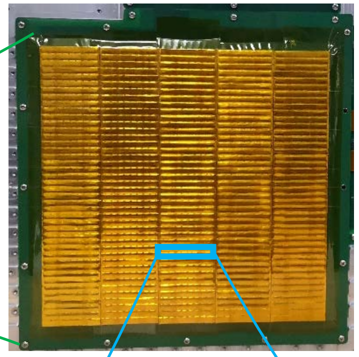


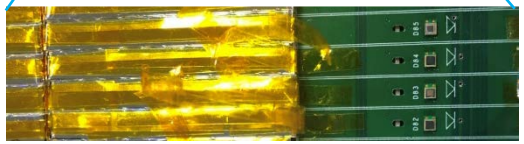


PFA-oriented high granularity ECAL :

- Silicon + W
- Scintillator & SiPM + W



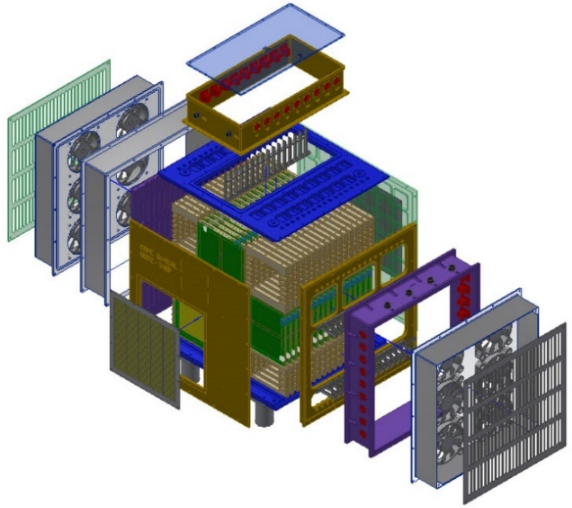




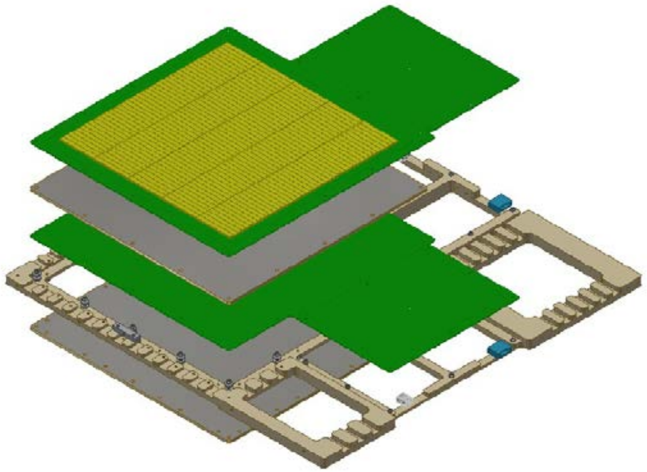
- CEPC ScECAL $10^7 \sim 10^8$ channels (barrel + Endcap)
- ScECAL technological prototype ~ 6,720 channels
  - 32 active layer (Ecal Base Unit), ~22 × 22 cm^2, ~22 X_0
  - Embedded front-end electronics, data acquisition system
  - Voltage supply, LED calibration system, temperature monitor system
  - Scalable to full detector (minor modifications for the EBU)

Development of ScECAL prototype

- A complete ScECAL prototype constructed in mid-2020
- ~ $80 \times 43 \times 54\ cm^3$ in dimensions and over 200 kg in weight
- Two EBU layers perpendicular and inserted by two absorber layers
- All super-layers are interchangeable for different test
- Fans cooling and light shield structure in the outermost

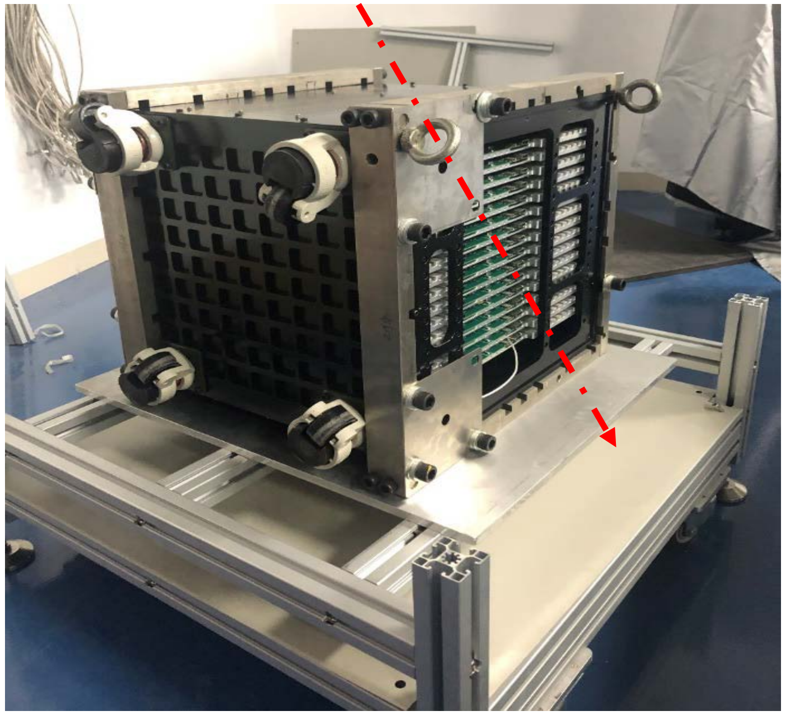


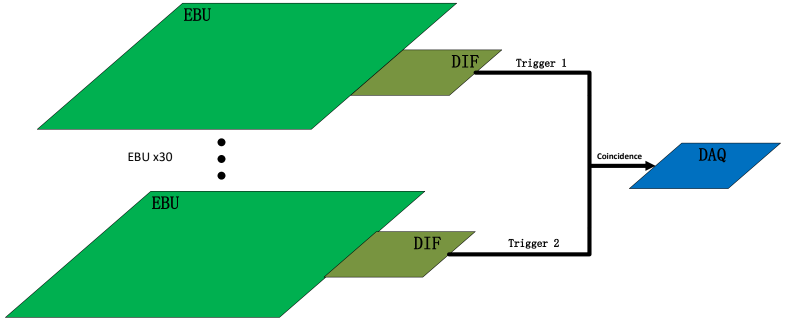
- Fully integrated with electronics
- Scintillator strip + SiPM
- Readout by SPIROC2E ASICs
- LED calibration and temperature monitor
- $2 \times 5 \times 45\ mm^2$, BC408 plastic scintillator
- SiPM operated at 4 V / 4.5 V overvoltage
- Bias voltage compensation with 0 – 4.5 V



Cosmic-ray test

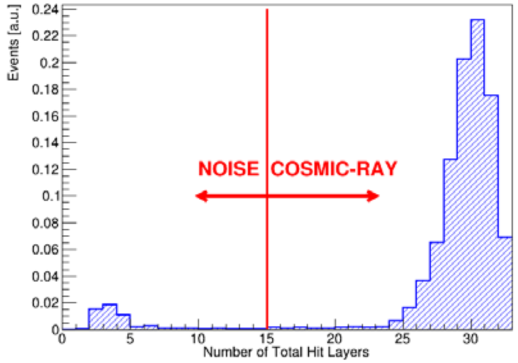
- Long-term cosmic-ray test in ~3 months
  - Coincidence trigger of Layer1 & Layer29
  - Event rate : ~16 events per minute
  - 1.4 million effective events collected
- Goals of long-term cosmic-ray test
  - Technical
    - ☐ demonstrate reliable operation of ScECAL prototype
  - Scientific
    - ☐ track finding
    - ☐ all EBU layers detection efficiency
    - ☐ position resolution
    - ☐ cell-to-cell MIP response calibration
    - ☐ EM shower performance evaluation



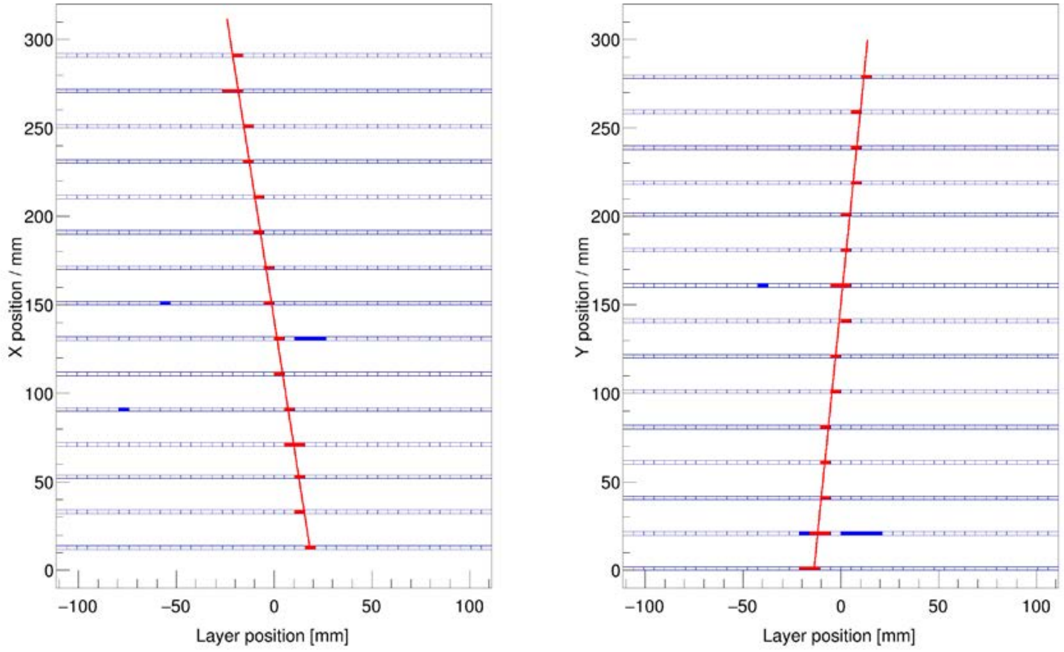


Reconstruction for cosmic-ray track

- Two methods are performed
  - Same pre-selections to eliminated the noise events
  - w/ SSA : split the strip into 5 cm × 5 cm cells firstly
  - w/o SSA: only use the 5 mm width direction in one layer
  - Fit the cosmic-ray track and select events with good straight track

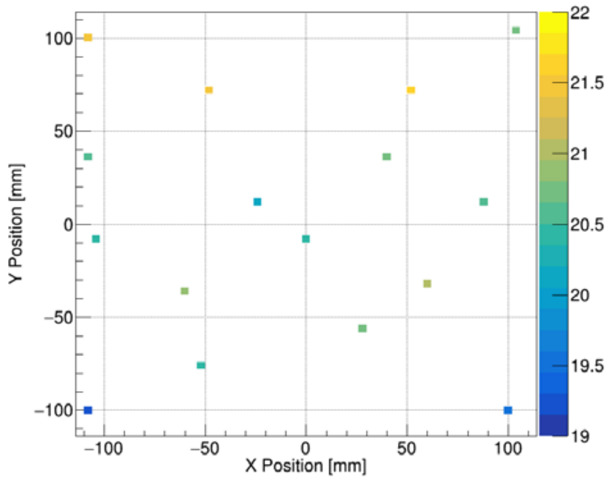


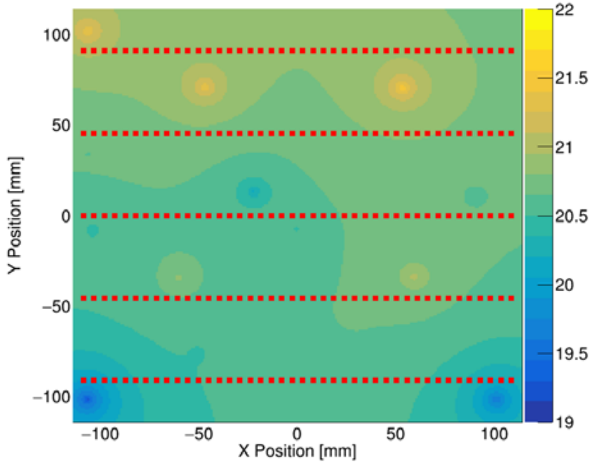
Process	Selection	Efficiency
preSelection	$TotalHitLayer \geqslant 22$	92%
	$TotalHitStrips \leqslant 64$	99.6%
	$ADC \geqslant 5\sigma$	99%
Iteration Fitting	All Hits	
	$Pos - tracking \leqslant (47.5,\ 5,\ 7.5)$	
	Nearest point in one layer	
Track Selection	$\lvert Intercept\rvert \leqslant 114$, $\lvert\varphi\rvert \leqslant 0.7$	98.2%
	$\sigma^2 \leqslant 9.6$	98.3%
	$TotalHitLayer \geqslant 6$	99.8%
Alignment	$Position - trackfittingresidual$	



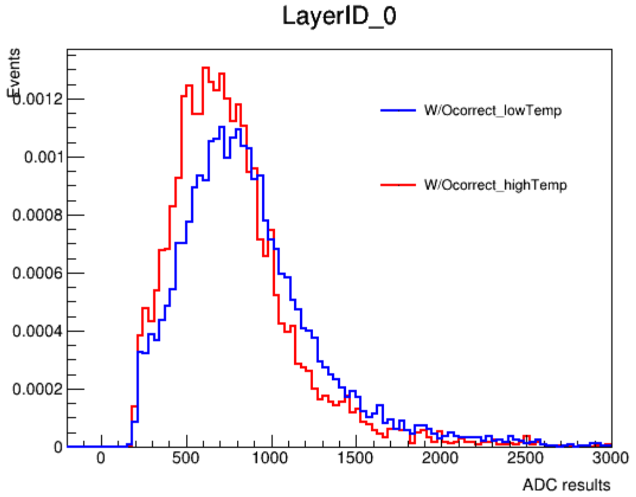
Temperature monitor

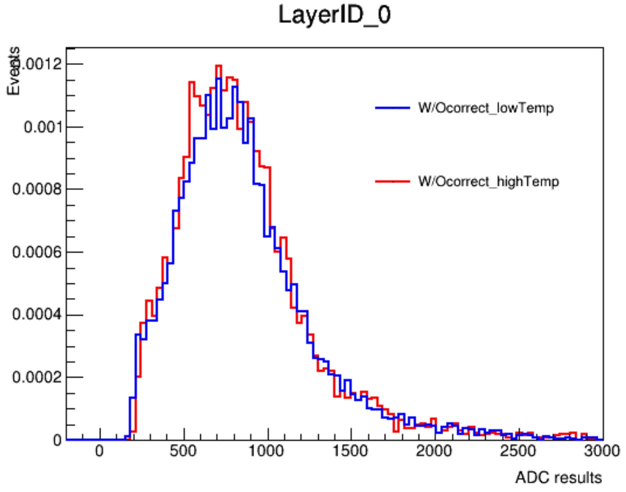
- The temperature is monitored at each event during the prototype
  - 16 temperature sensors ($0\ ^{o}C - 85\ ^{o}C$, $\pm 0.1\ ^{o}C$) equipped in one EBU
- Temperature reconstruction and correction
  - The temperature at each channel is reconstructed by the inverse distance weighting
  - Temperature dependence can be corrected, SiPM gain, CTAP, etc





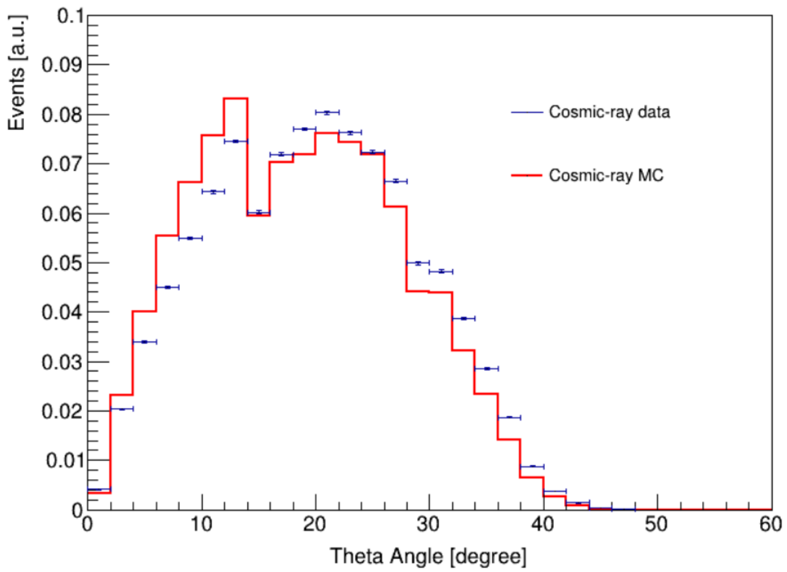
$$W(x,y) = \Sigma_{i=1}^{n} Q_i W_i Q_i = \frac{\frac{1}{L_i}}{\Sigma \frac{1}{L_i}}$$

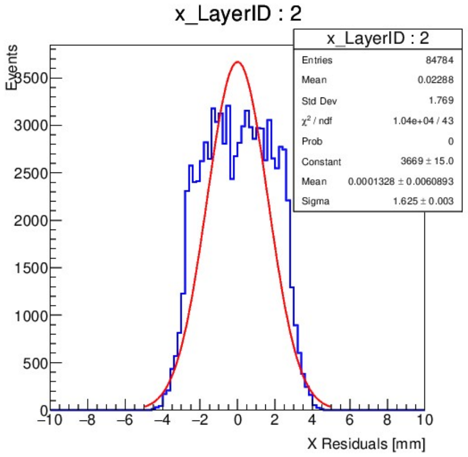


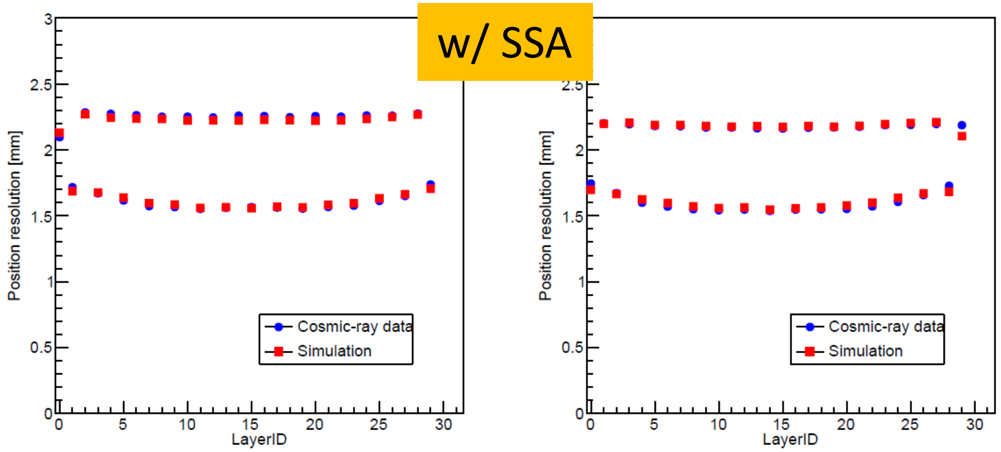


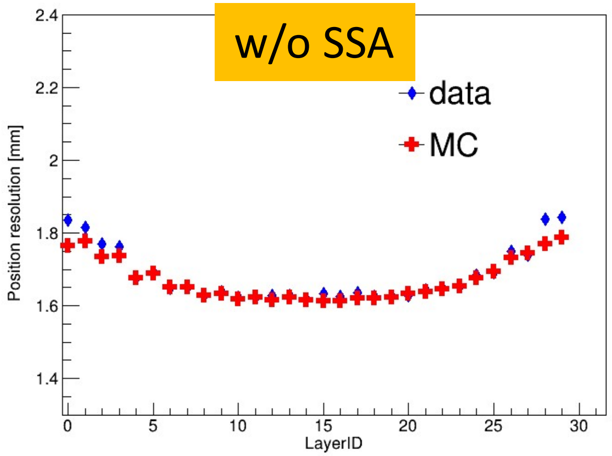
Performance evaluation using straight track

- Cosmic-ray particle incident angle
  - Obtained by the track fit
  - Data matches reasonable well with the simulation
- Position resolution achieves about 1.5 mm ~ 1.8 mm
  - Depend on the layers, due to the track has extensional errors
  - Affected by muon scatter in 22 X_0 depth
  - Achieves the requirement for PFA-oriented ScECAL
  - A litter better position resolution obtained w/ SSA method



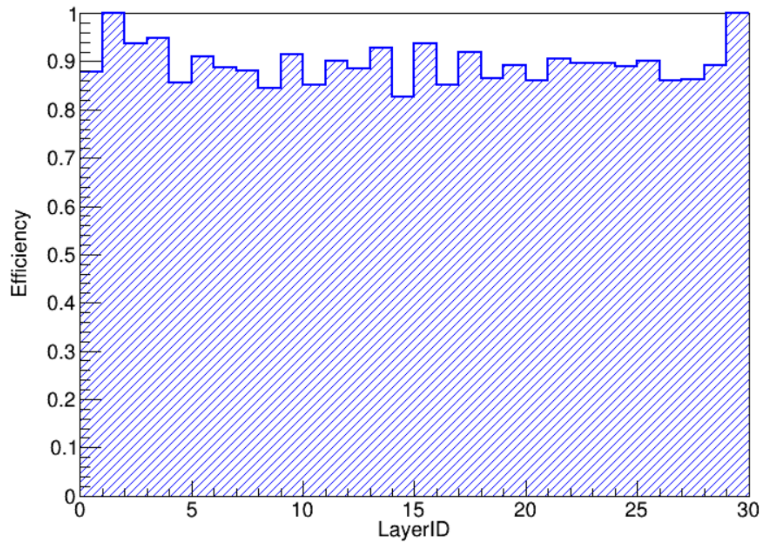


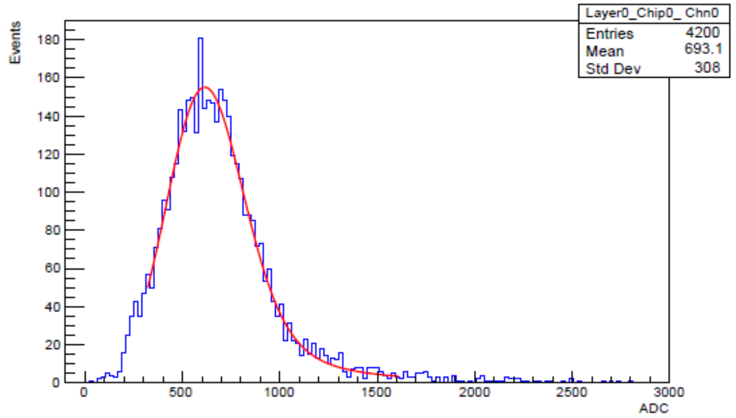


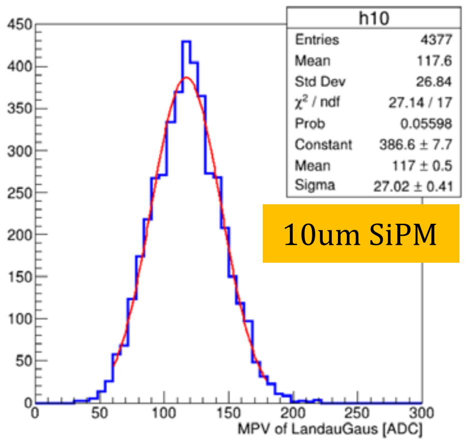


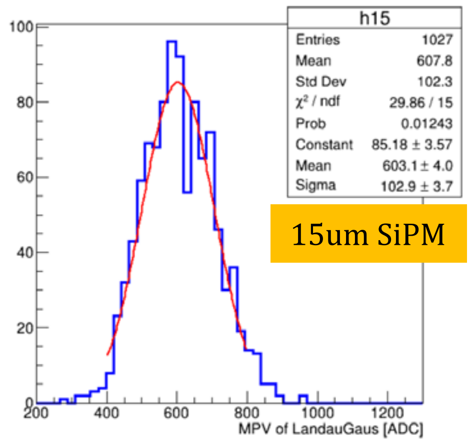
Performance evaluation using straight track

- Detection efficiency achieved ~83% for all layers
  - Layer 1 & 29 are trigger
  - The sensitive area is ~96.5%
  - The thresholds are ~1/2 MIP
- MIP response calibration for almost all strips are obtained
  - Angle correction and SiPMs gain temperature correction performed
  - 66/6720 (~1%) dead channels, still finding any possible reasons
  - MIP response variation ~ 20% between different channels
  - MIP response values are consistent with the beta source results





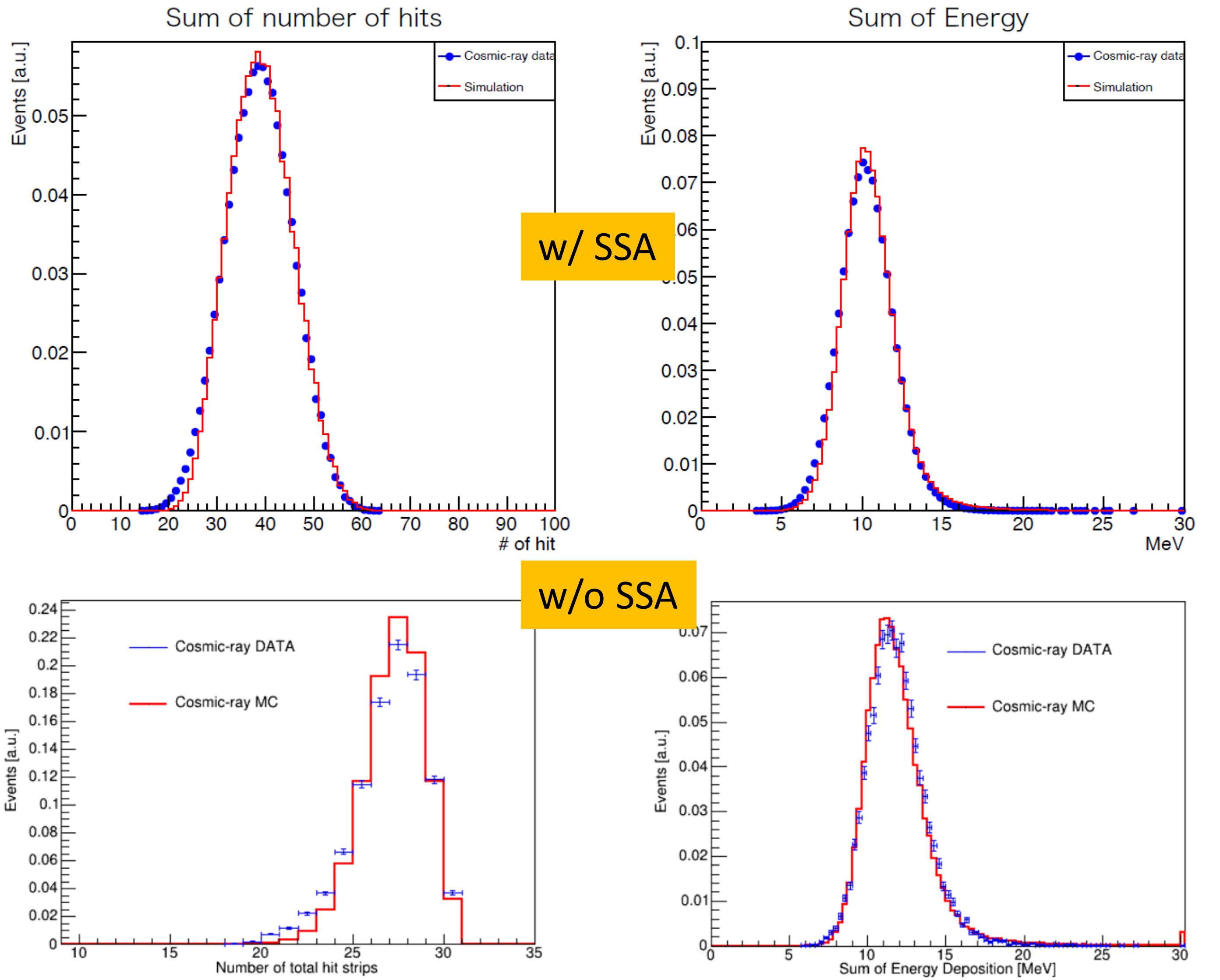




Sum of energy deposition

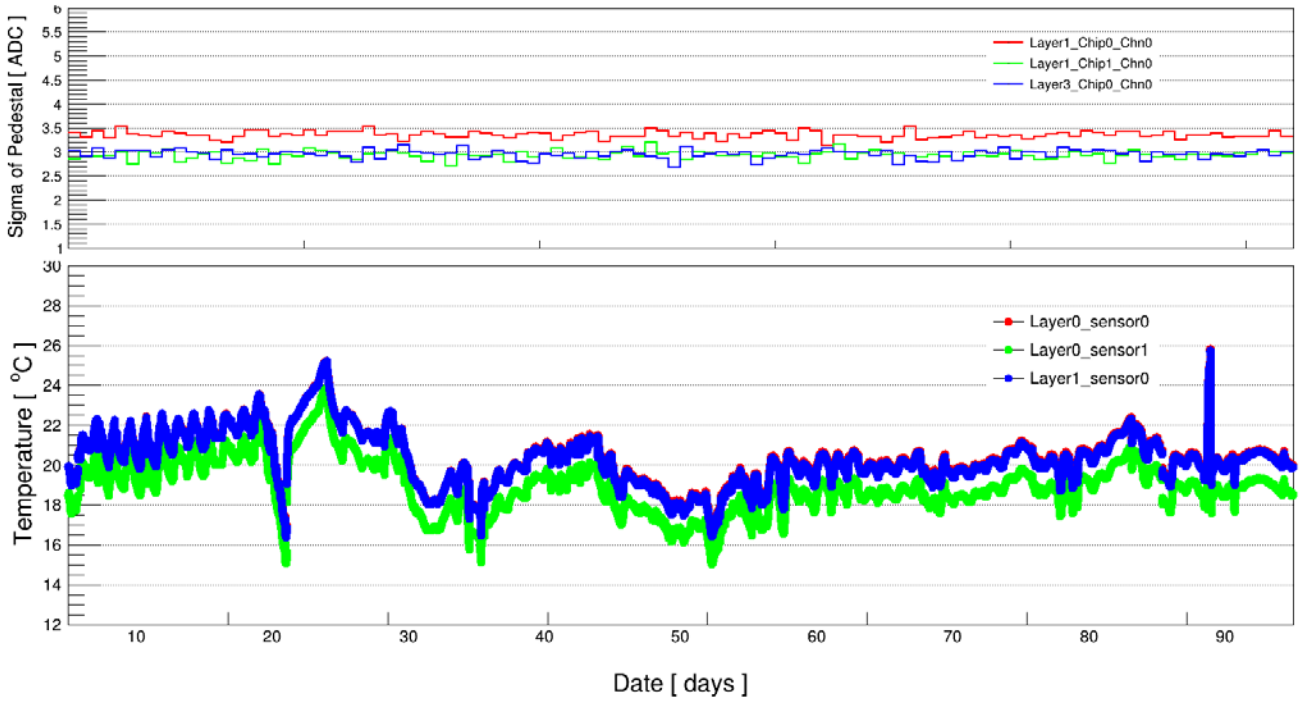
- Sum of cosmic-ray events deposition energy in sensitive layer reconstructed
  - Based on the MIP cell-to-cell calibration
  - Two methods are performed : w/ & w/o SSA
  - Both methods reconstructed sum of deposition energy distribution show good agreement with simulation results
  - SSA will eliminate more low energy cells, lead to the reconstructed deposition energy is underestimated

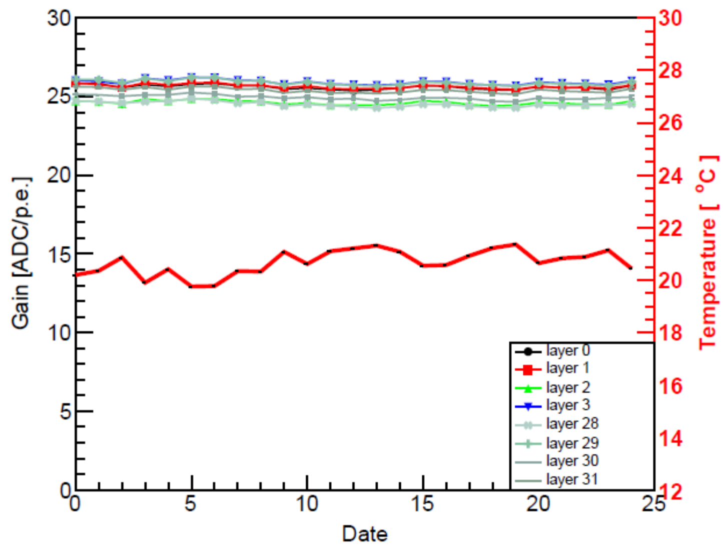
$$E_{sum} = \sum_{all\ strips} E_i \approx \sum_{all\ strips} \frac{(A_i^{ADC}(T) - C_i^{pedestal}) \cdot E_{MIP}}{C_i^{MIP(T)}}$$

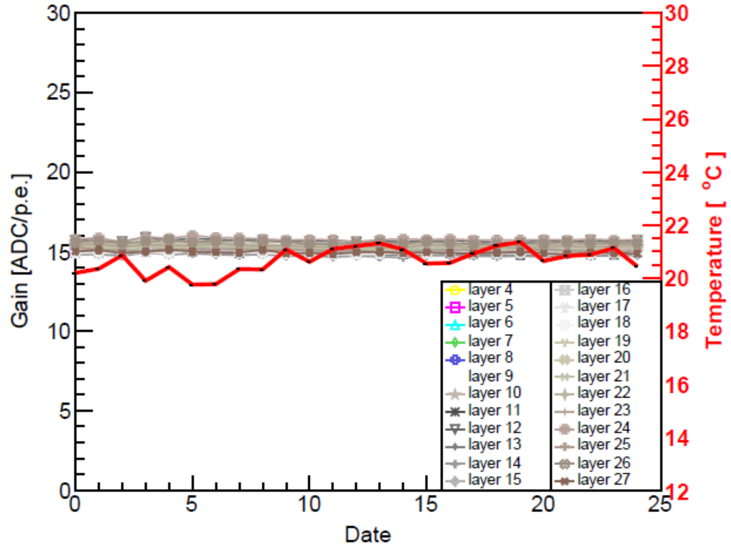


Stability of the ScECAL prototype

- The ScECAL prototype system can be operated stably
  - Pedestal of all channels are stable during 3 month cosmic-ray test
  - Temperature monitor and variation can be corrected
  - SiPM gain of all channels are stable during 1 month LED run





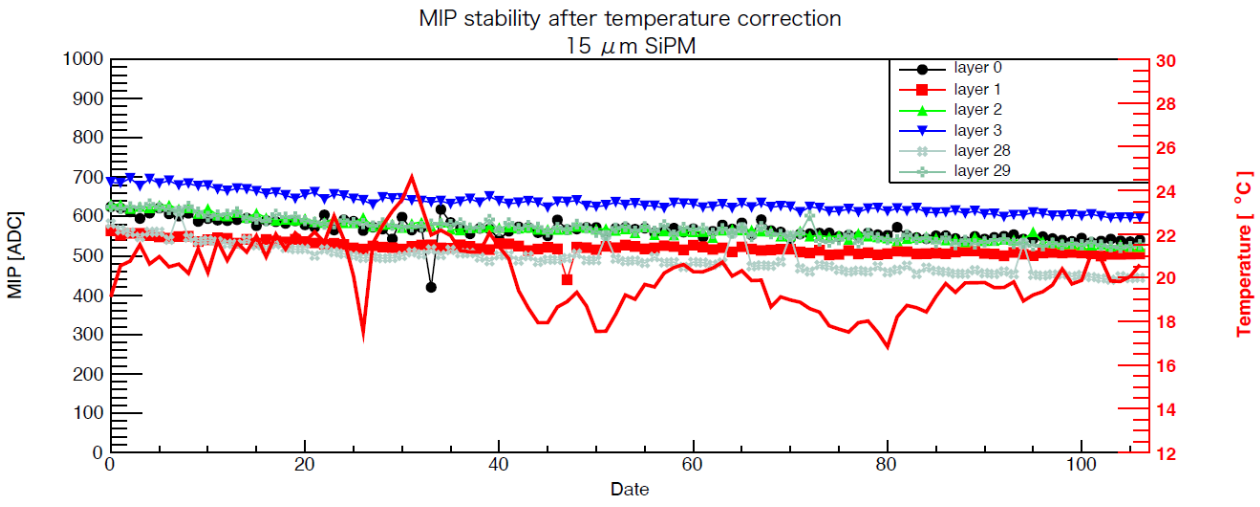


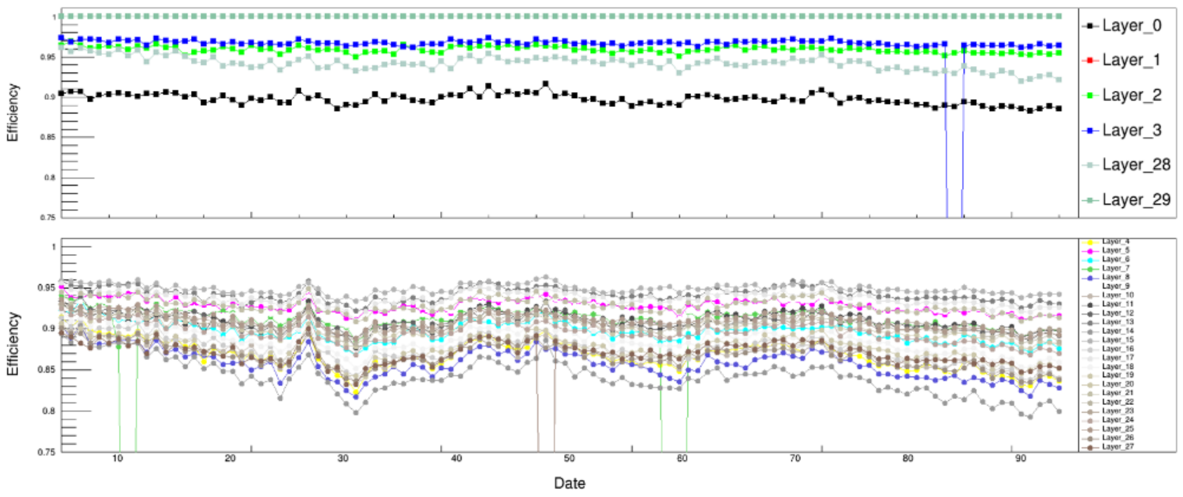
Stability of the ScECAL prototype

† MIP response decrease 5%~15% over 3 months

- The rate of decline various for each channel
  - The rate is relatively large at the beginning and the plateaus
- The detection efficiency decrease accordingly, due to the fixed threshold for each chips
- The reason is under investigation
  - Instability of electronics of SiPM
  - Aging of scintillator light emission

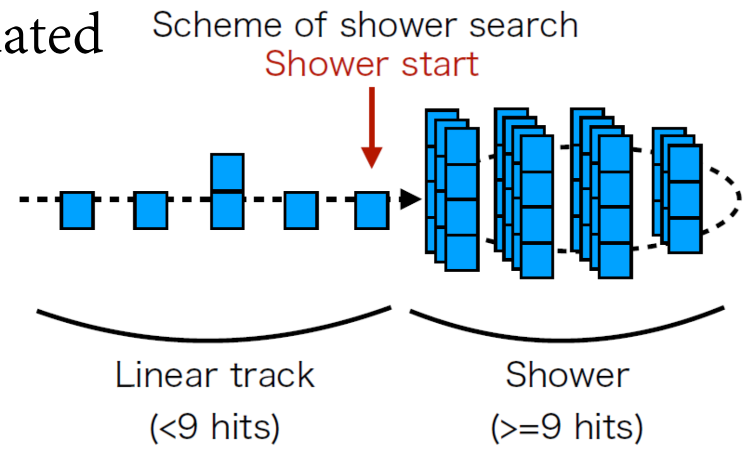
See more detail in Tohru Takeshita's report

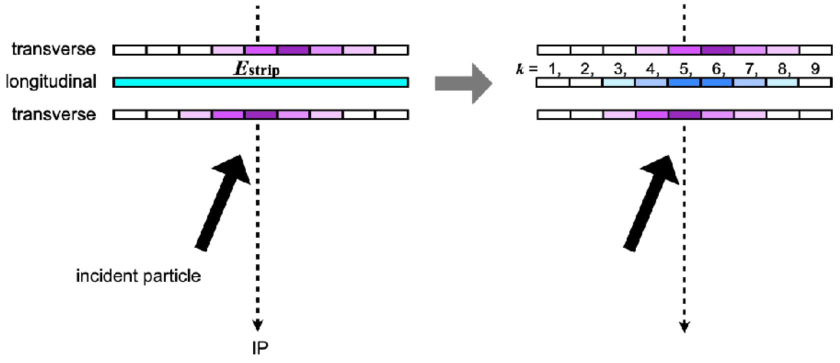


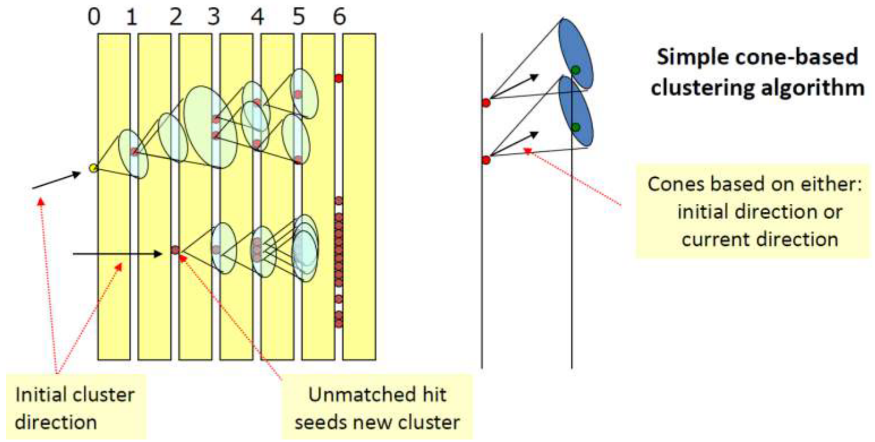


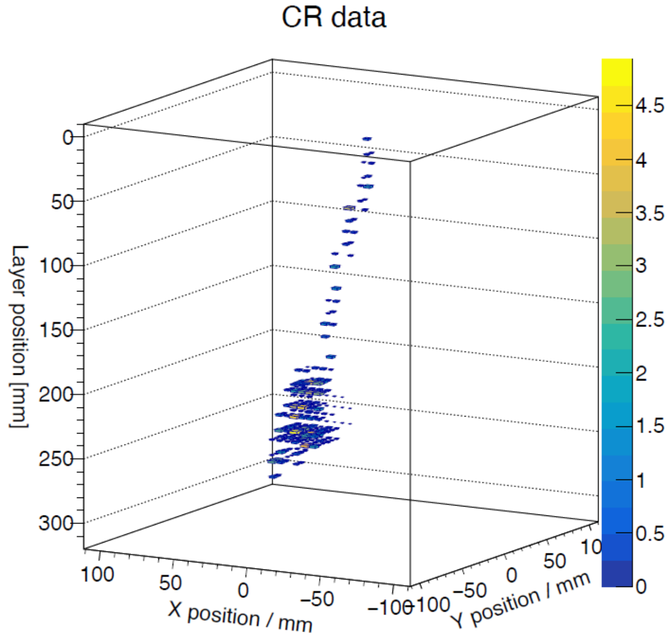
Reconstruction for cosmic-ray shower

- Performance of ScECAL prototype for electromagnetic shower is evaluated using the cosmic-ray events
  - Instead of test beam experiment (due to the COVID around the world)
- Cosmic-ray shower events is searched for:
  - Calibration : ADC counts converts to # of MIPs
  - Strip Splitting Algorithm & clustering
  - Shower search
    - Many hits in three consecutive layers



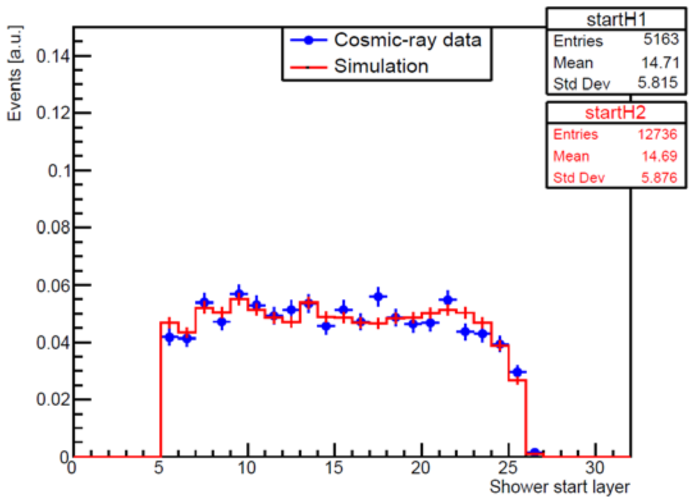


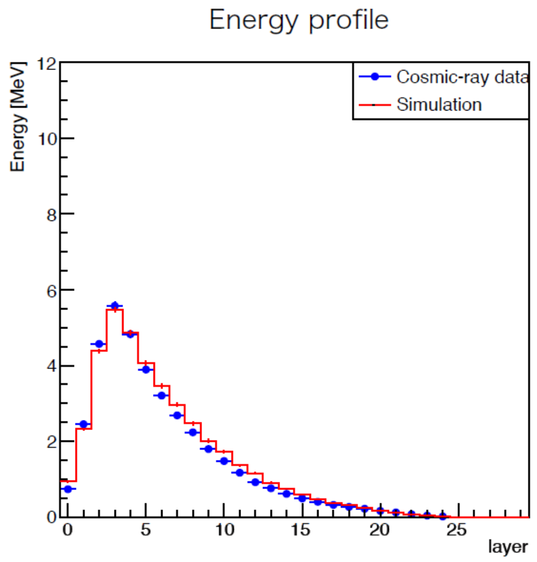


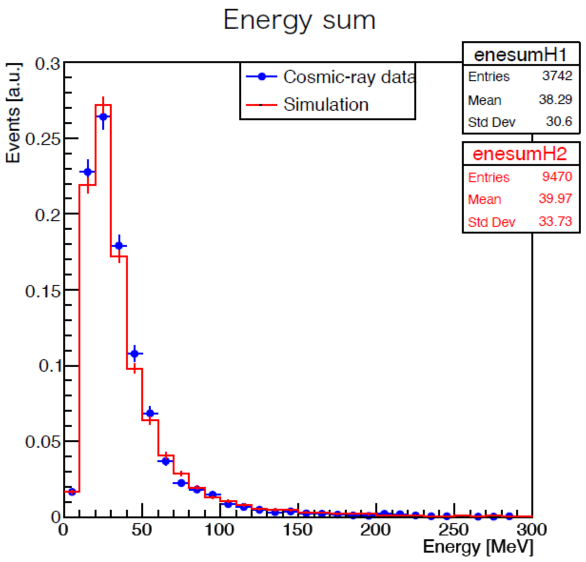


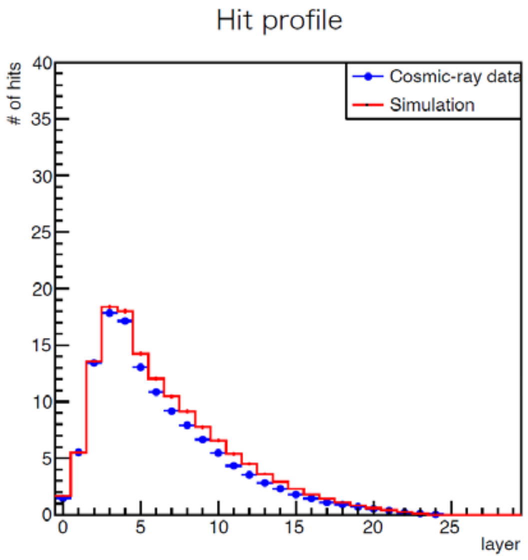
Performance evaluation using CR shower

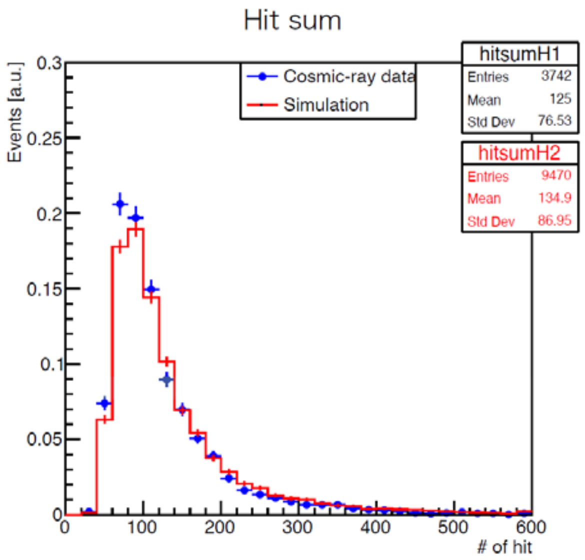
- Study only with SSA performed method
- Comparison using the events with fully contained shower
  - The sum of hits at the last layer is less than 4
- Data and simulation matches reasonably well
  - Simulation reproduces the behavior of the prototype very well for the fully contained cosmic-ray shower events











Summary and prospect

- A complete ScECAL technological prototype constructed in mid-2020
  - Fully integrated front-end readout electronics and detector layer
- Performance evaluation of ScECAL prototype
  - Sufficient detection efficiency & position resolution
  - Good stability, MIP declines is under investigation
  - Sum of deposition energy is reconstructed and agree with simulation
  - Cosmic-ray shower events can be detected as expected at the simulation
- ScECAL prototype is ready to carry further test beam
  - Energy resolution and linearity will be demonstrated
  - EM shower performance can be study

Thank you!

Monte Carlo Simulation

- ScECAL prototype CR test is simulated using Geant4
  - 30 layers of absorbers, detection layers, readout PCBs
  - Aligned in the same as technological prototype
  - Building material corresponding to the simulation with 15 floors above the prototype
- Cosmic-ray shower library (CRY) for events generator
  - Wide energy range: 1 MeV – 100 TeV
  - Several particle types: muon, electron, gamma, hadron
- Channel characteristics obtained in the calibration are applied to each channel
  - MIP response, threshold