CALICE ScW-ECAL prototype development and commissioning

Yazhou Niu, University of Science and Technology of China

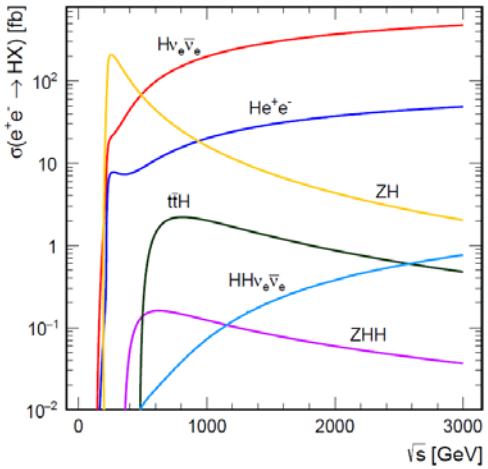
On behalf of the ScECAL group in CALICE and CEPC

Joint Workshop of CEPC
25/5, 2022

Future Higgs factory

- Future e^+e^- collider offer unique physics possibilities
  - Precise mode-independent Higgs coupling measurement
  - Precise measurements of W, Z and top quark properties
  - Direct and indirect search for BSM physics
- Proposed future Higgs factory projects
  - Linear collider : ILC, CLIC
  - Circular collider : CEPC, FCC
- The main physics program require for calorimeters
  - Jet energy resolution $\sim 30\%/\sqrt{E}$

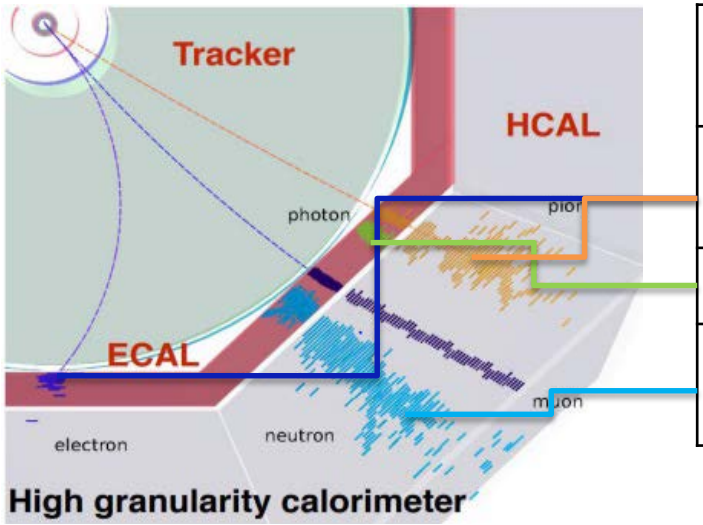
From CEPC CDR



Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Particle Flow Calorimetry

- Each individual particle in one jet is reconstructed and identified, measured with the most suitable subdetector
- High granularity calorimetry
  - Fine segmentation in both transverse and longitudinal
  - Energy resolution requirements not that stringent

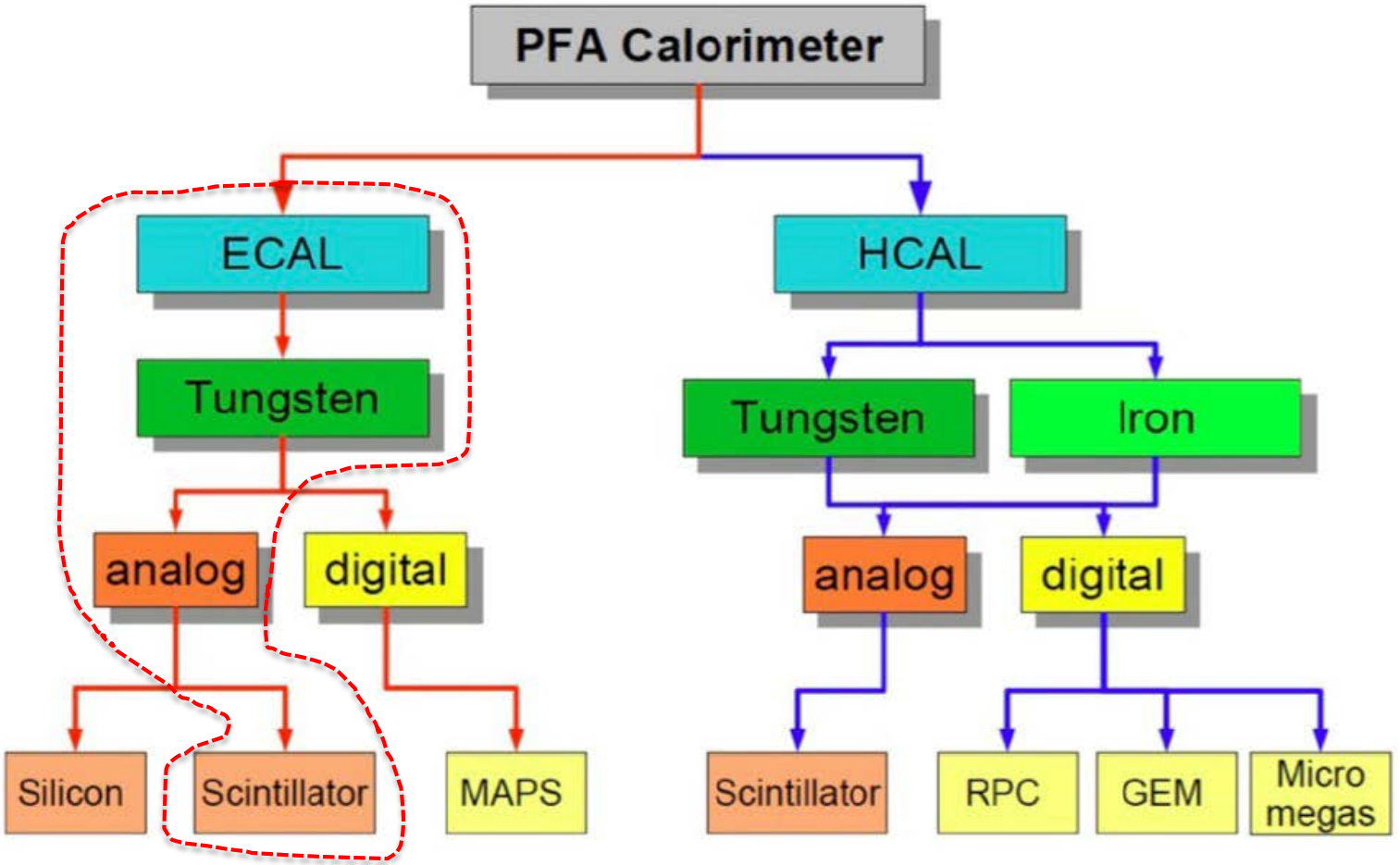


Particles	Energy fraction	Subdetector	Typical resolution
Charged particles	~65%	Tracker	$< 5 \times 10^{-5} p_T$
Photons	~25%	ECAL	$\sim 15\%/\sqrt{E}$
Neutral hadrons	~10%	ECAL+HCAL	$\sim 55\%/\sqrt{E}$

$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{EM} + \sigma^2_{Had} + \sigma^2_{Confusion}}$$

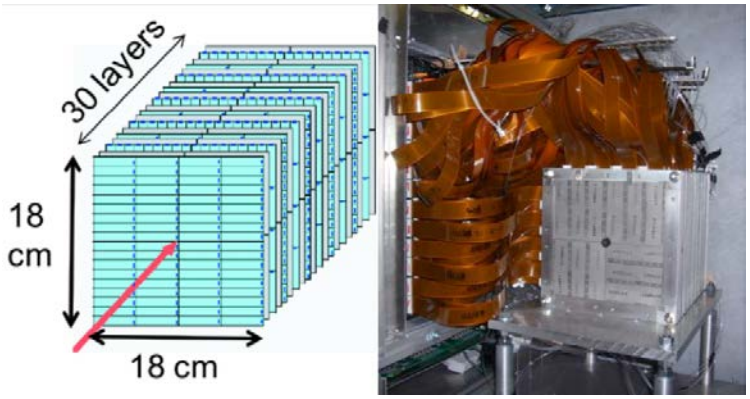
Technologies for highly granular calorimeter

- Mainly organized within the CALICE collaboration



Progress of ScECAL R&D

- Physical Prototype 2007 - 2013



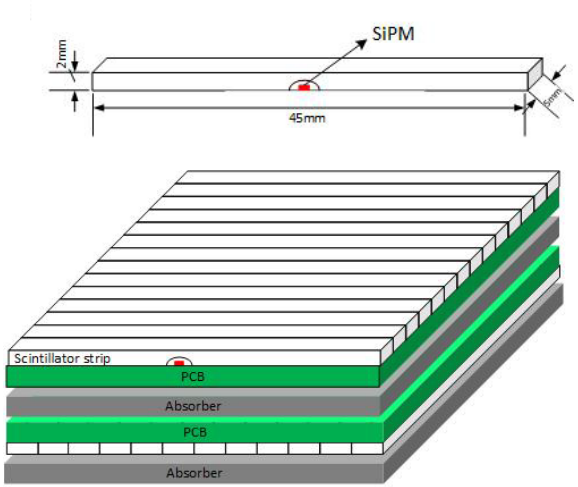
  - Proof-of-principle of scintillator & SiPM for granular calorimeters
  - Beam tests for ScW-ECAL

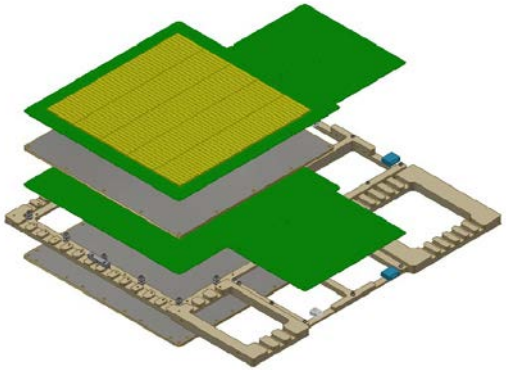
- Technological Prototype 2013 - … Ongoing

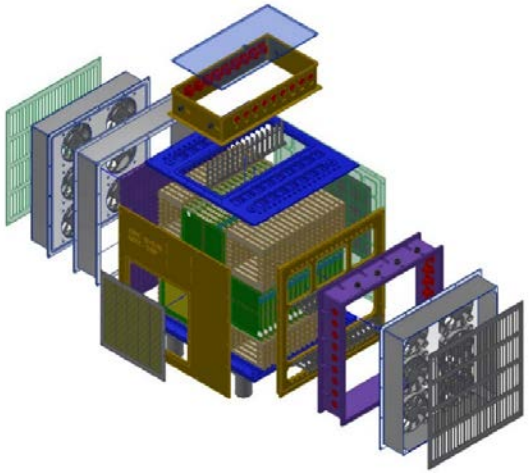
  - Engineering challenges
  - Embedded front-end readout
  - Higher granularity
  - Temperature compensation, gain calibration, …

ScECAL technological prototype

- ScECAL technological prototype consisting of ~ 6,700 channels
  - Scintillator strips readout with SiPMs as sensitive cell
  - Embedded front-end readout electronics integrated with detector
  - 32 active layer (Ecal Base Unit), $22 \times 22\ \mathrm{cm}^2$, ~22 X_0
  - Two EBU layers perpendicular and inserted by two absorber layers
  - Voltage supply, LED calibration system, temperature monitor, …
  - Scalable to full detector (the expected 10^7~10^8 channels)

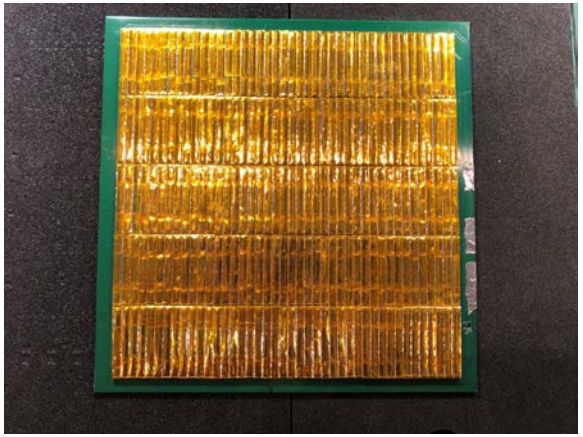


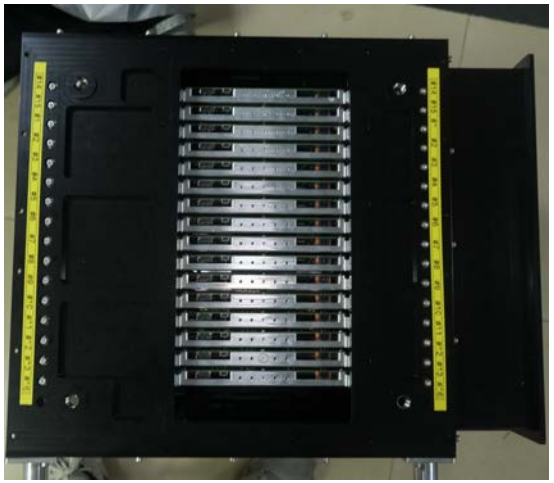




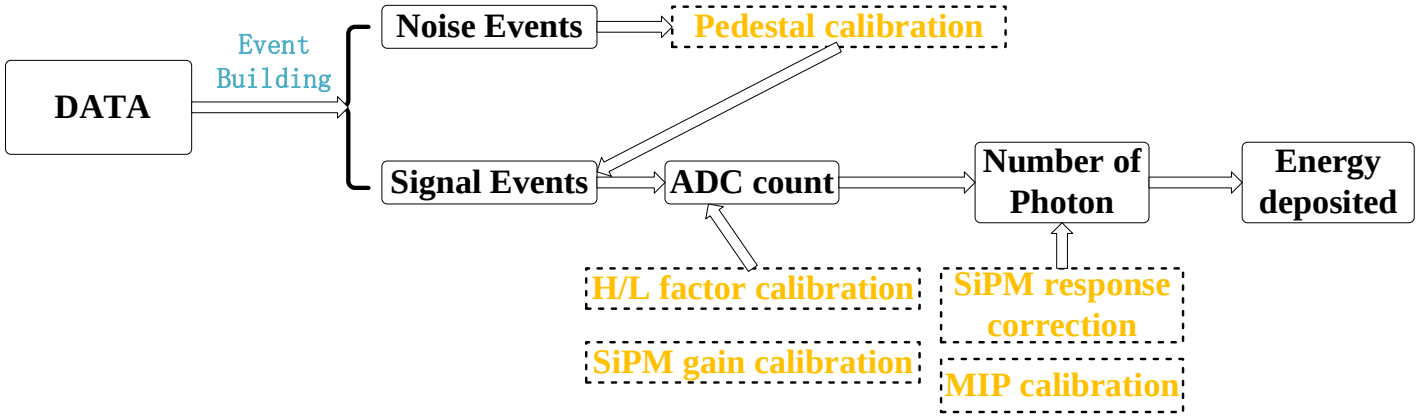
Construct of ScECAL technological prototype

- Large ScECAL technological prototype was constructed within the CALICE framework and CEPC calorimeter group
  - ~ 80 ×43 ×54 cm^3 in dimensions and over 200 kg in weight



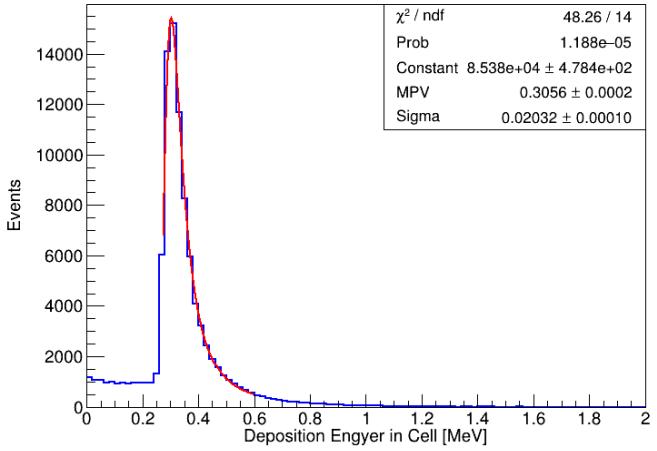


Calibration and energy reconstructed



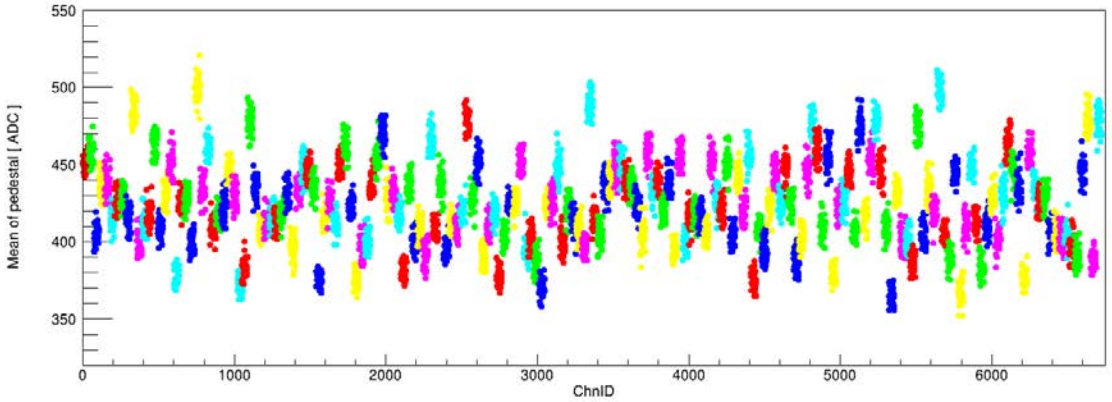
$$E_{reco} = \sum_{all\ strips} E_i = \sum_{all\ strips} F^{-1}((A_i^{ADC}(T) - c_i^{ped}) \cdot \frac{c_i^{inter}(T)}{c_i^{p.e.}(T)}) \frac{c_i^{p.e.}(T) \cdot \mathrm{E}_{MIP}}{c_i^{MIP}(T)}$$

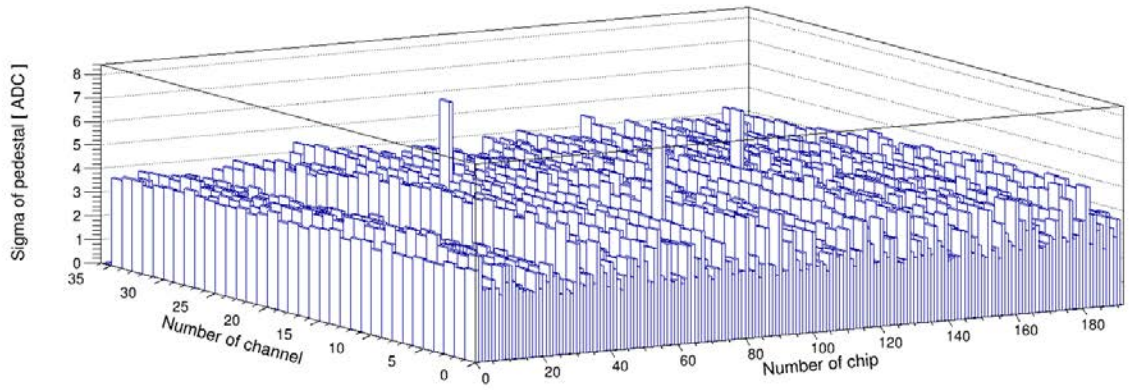
- F^{-1}: correction of SiPM response function
- $A_i^{ADC}(T)$: pedestal subtracted
- c_i^{ped}: pedestal for each channel
- $c_i^{p.e.}(T)$: SiPM gain calibration
- $c_i^{inter}(T)$: ASIC gain calibration
- $c_i^{MIP}(T)$: MIP response calibration



Calibration

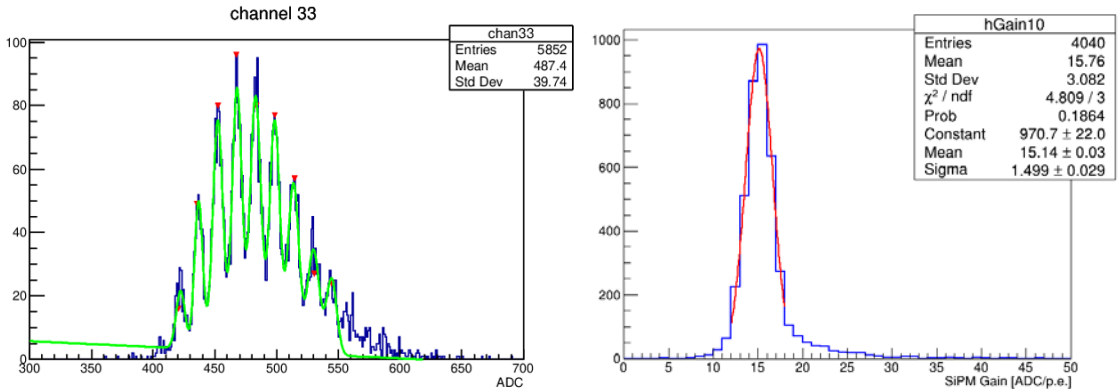
- Pedestal calibration
  - Subtracted for each channel

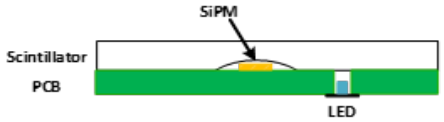




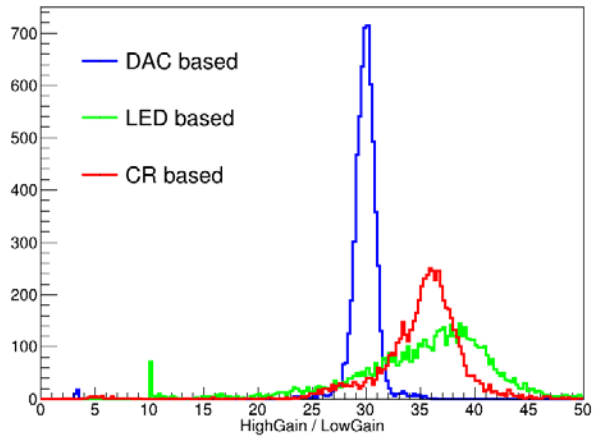
Calibration

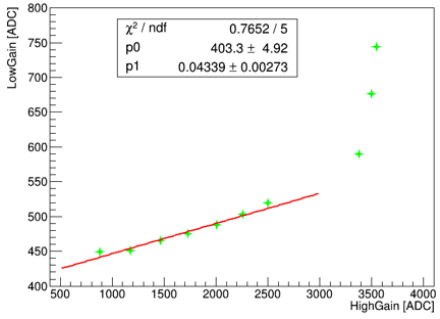
- SiPM gain: LED-based calibration system

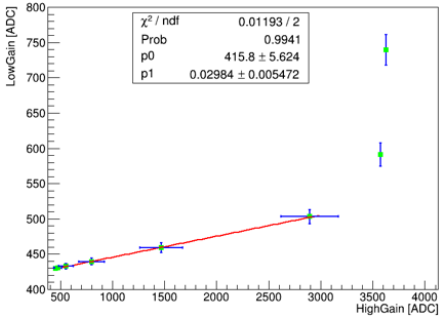


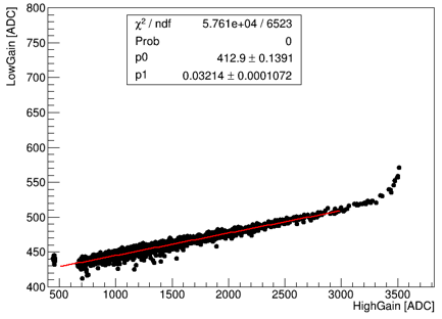


- ASIC inter-factor calibration
  - DAC-based : charge injected into ASIC pin
  - LED-based : SiPM response to LED light
  - Cosmic ray –based : the real signal



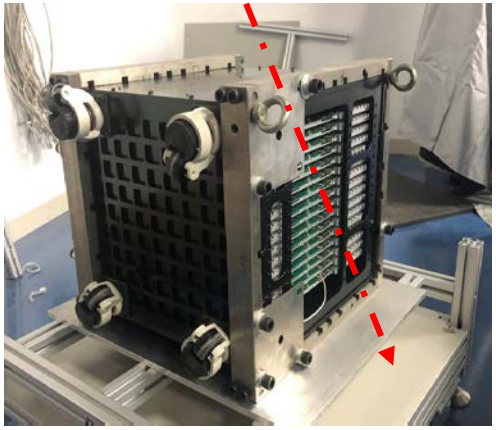


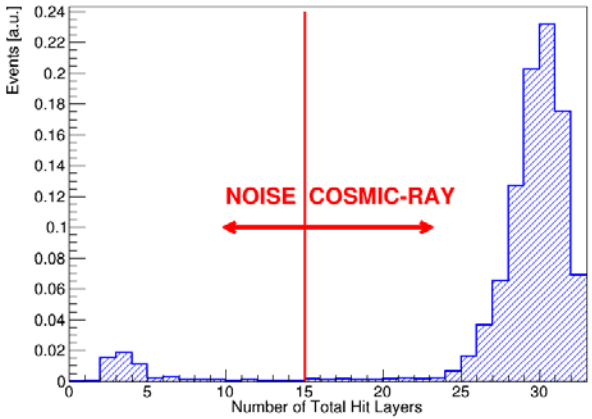


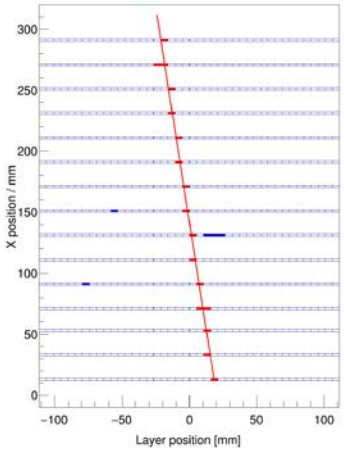


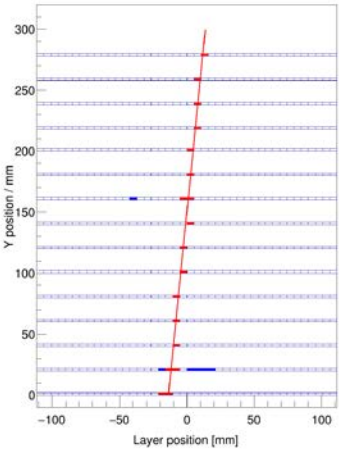
Cosmic Ray test

- Long-term cosmic ray test ~ 3 months
  - Coincidence trigger of Layer 1 & Layer 29
  - 1.4 million effective cosmic ray events collected
- Two methods are performed to reconstruct the track of cosmic-ray events
  - Per-selections to eliminated the noise events
  - w/o SSA: only use the 5 mm width direction of $45mm \times 5mm$ strip in one layer
  - w/ SSA: split the $45mm \times 5mm$ strip into $5mm \times 5mm$ cells firstly
  - Fit the cosmic-ray track and select events with good track



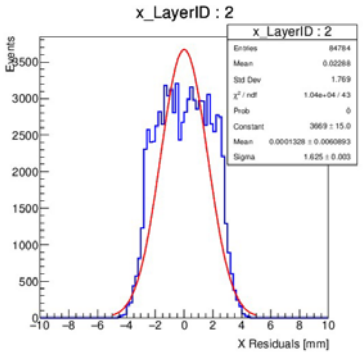


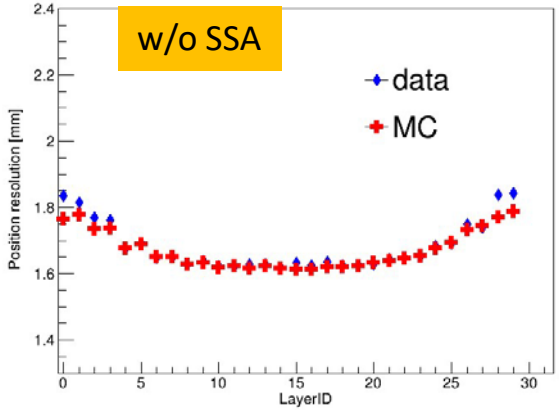


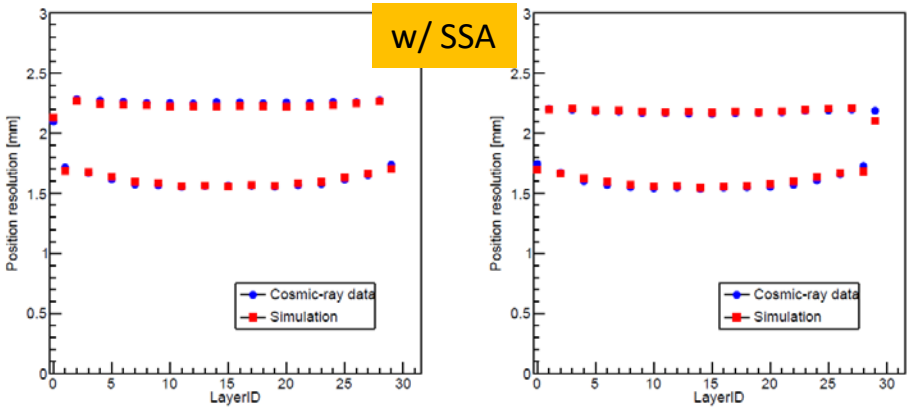


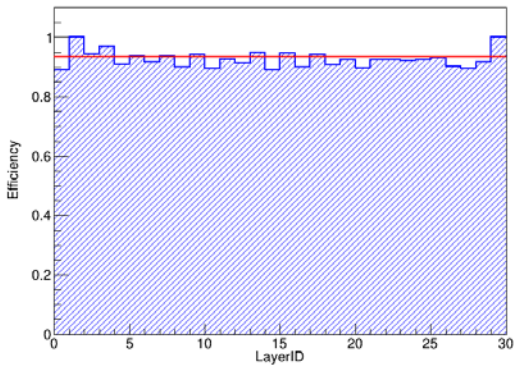
Performance evaluation

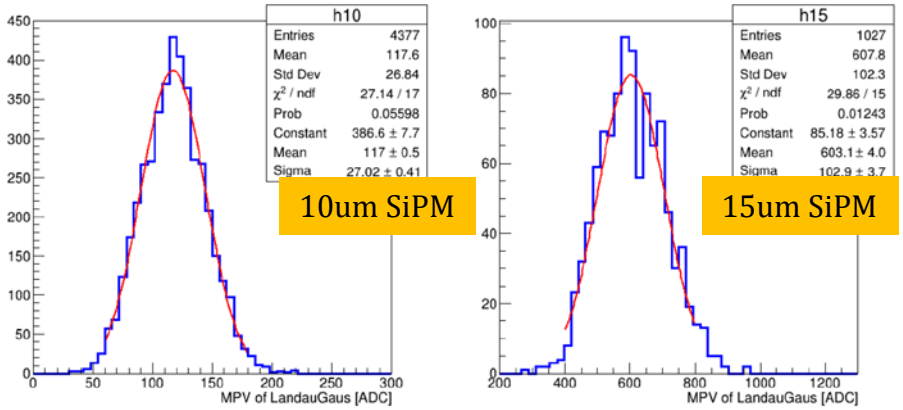
- Cosmic ray events with straight line
  - Position resolution better than $\sim 2\ mm$
  - Detection efficiency above than ~ 90 % for all EBUs
  - MIP response calibration for each sensitive cell





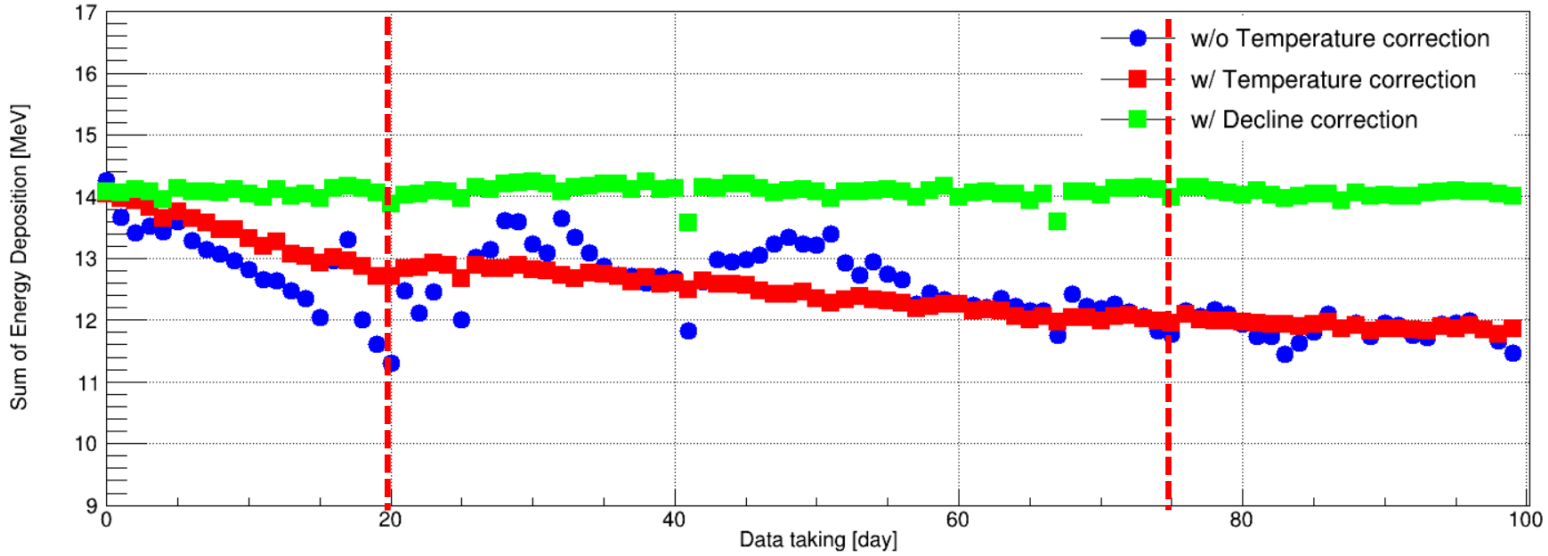




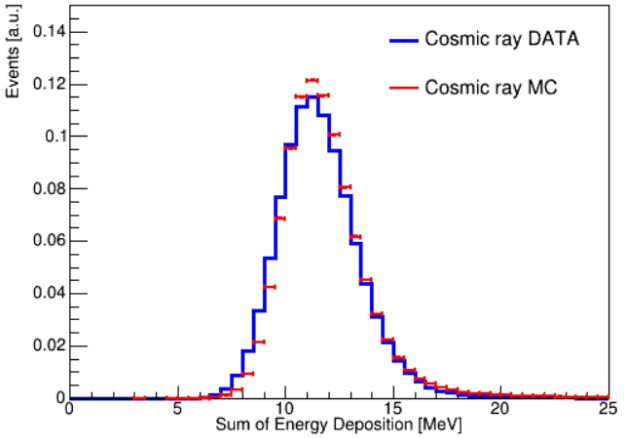


Performance evaluation

- Sum of cosmic-ray events deposition energy in sensitive layer

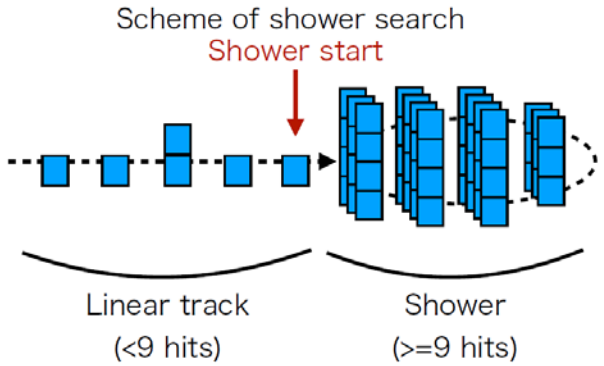


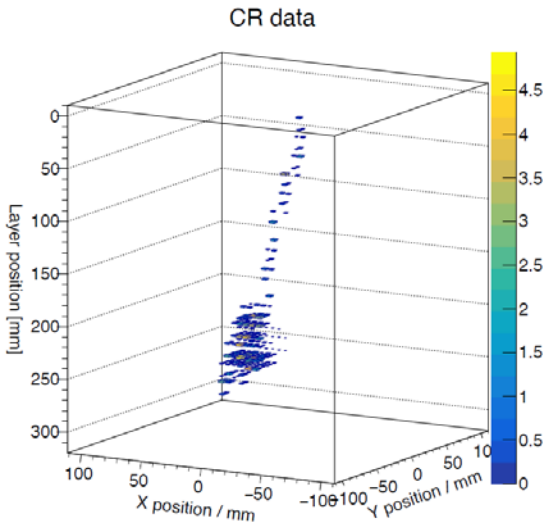
- The reason for MIP decline is under investigation
- Temperature dependence and MIP decline corrected
  - The data shows good agreement with simulation

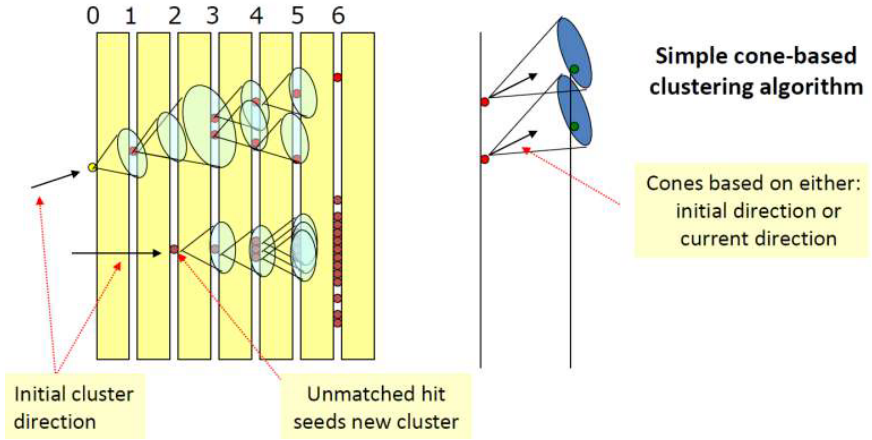


Reconstruction of cosmic-ray shower

- 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

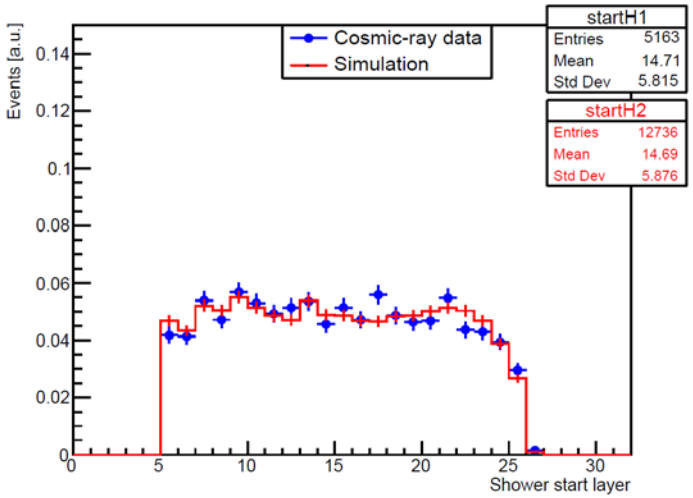


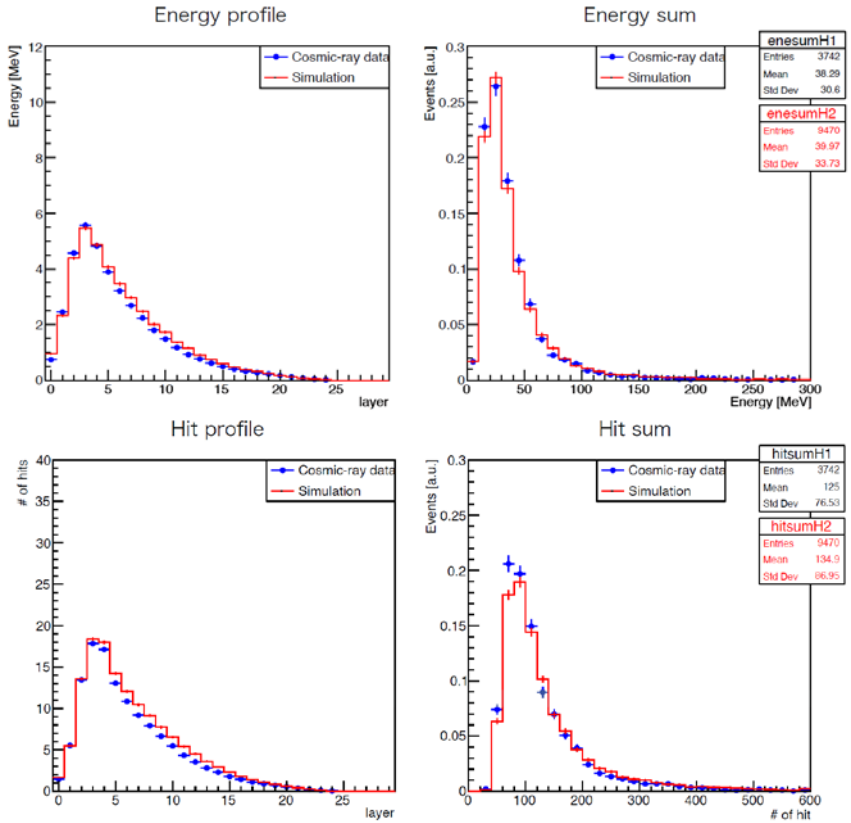




Performance of cosmic-ray shower

- 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





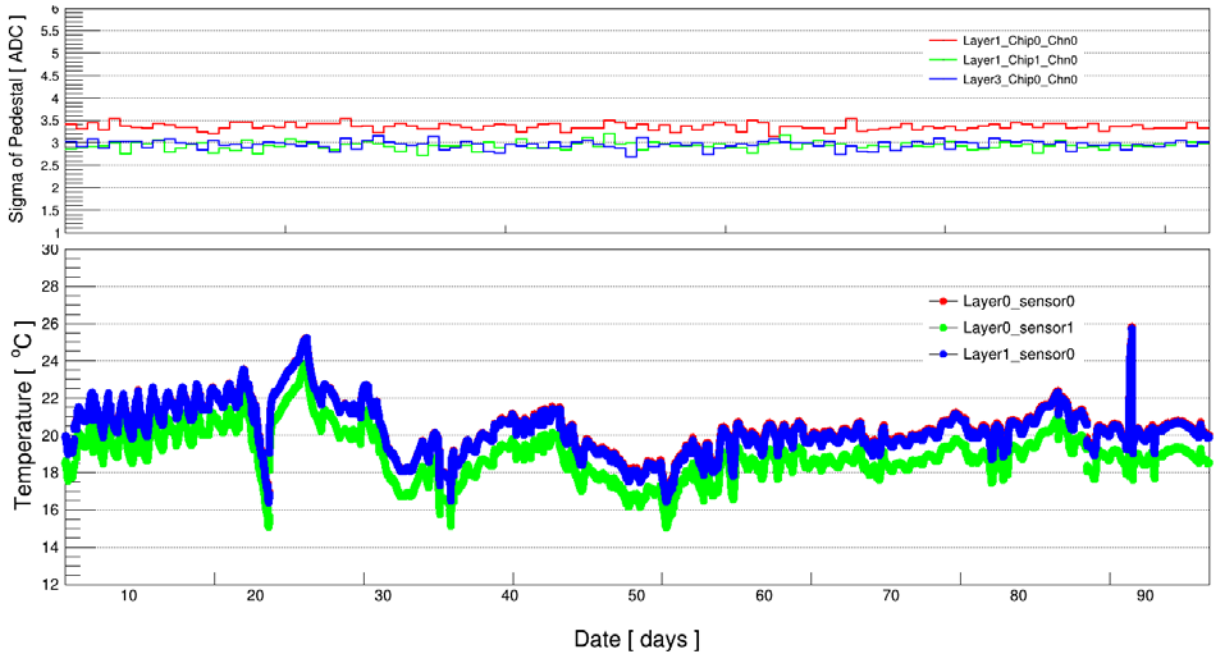
Summary

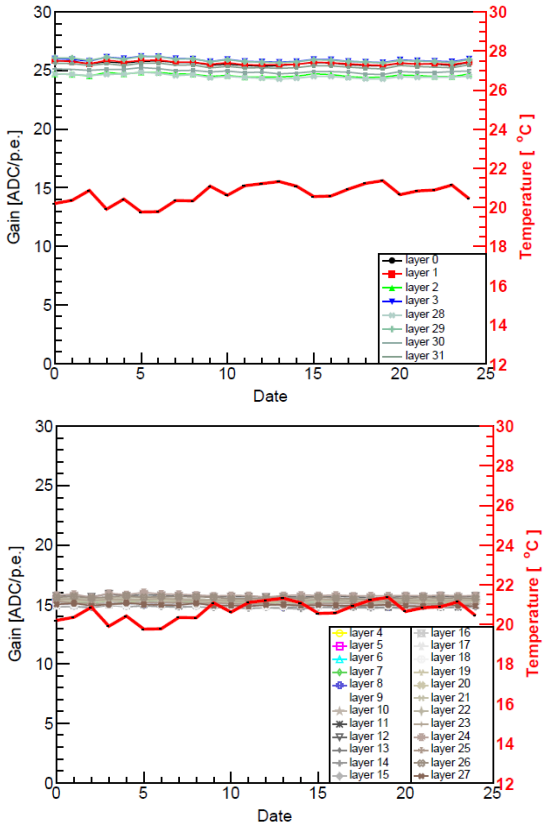
- A large ScECAL technological prototype constructed
  - Fully integrated front-end readout electronics and detector layer
- Performance evaluation
  - Sufficient detection efficiency and position resolution
  - Sum of deposition energy is reconstructed and agree with the simulation
  - Cosmic-ray shower events can be detected as expected at the simulation
- ScW-ECAL is found to be a promising and mature technology for highly granular calorimeter for future Higgs factories
- Prepare the new beam test at CERN SPS in Oct. 2022 within the CALICE collaboration

Additional

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





Beam test

- IHEP E3 beam test in Oct. 2020
  - Mixed with protons/pions: protons dominate
  - Momentum : $0.3\ GeV \sim 1.2\ GeV$
  - Event rate: less than 100 per minute
  - Limited by the poor beam quality
  - The ScECAL prototype is ready for further beam tests
- DESY T24 in 2020: postponed due to the pandemic
- Prepare the new beam test at CERN SPS in Oct. 2022 within the CALICE collaboration