

Highly granular scintillator-strip electromagnetic calorimeter for future Higgs factories

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Abstract: Several future Higgs factories are planned for precision Higgs physics to search for the new physics. The highly granular calorimeters play a crucial role on the precision Higgs measurement. The highly granular Sc-ECAL is based on a scintillator strip readout by a SiPM to realize the 5 mm × 5 mm cell size by aligning the strips orthogonally in x-y configuration. In order to demonstrate the performance of the Sc-ECAL and the scalability to the full-scale detector, the technological prototype has been developed with full 30 layers. The per-channel calibrations and performance demonstration are successfully done by the long-term commissioning test with LED and cosmic-ray. The Sc-ECAL is found to be a promising and mature technology for the highly granular calorimeter to achieve the precision physics at the future Higgs factories.

Higgs factories (e.g. International Linear Collider (ILC), Circular Electron-Positron Collider (CEPC))

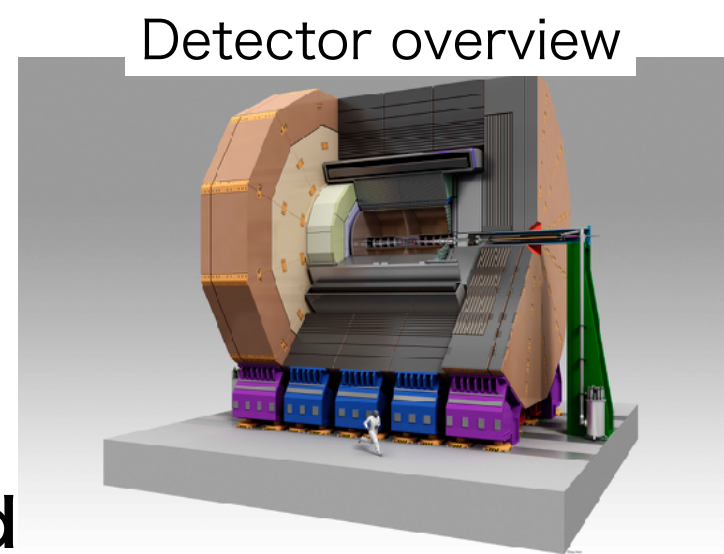
- ✓ Electron-positron colliders
- ✓ Produce many Higgs bosons to investigate new physics

Detector concept

- ✓ Vertex detector, central tracker, electro-magnetic calorimeter, hadron calorimeter, and muon tracker
- ✓ R&D for ILC and CEPC

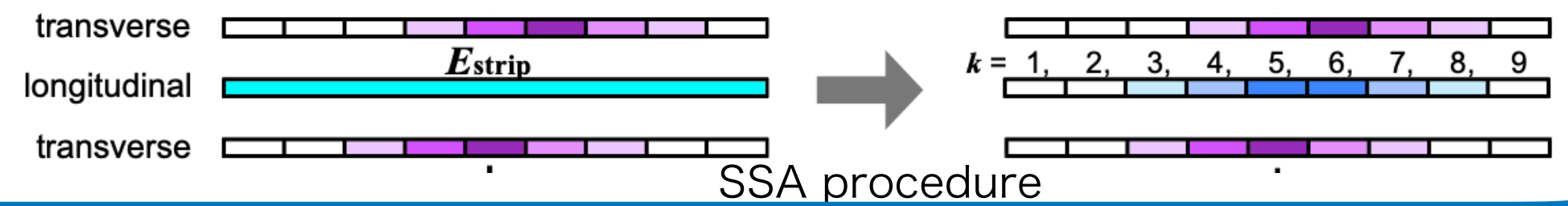
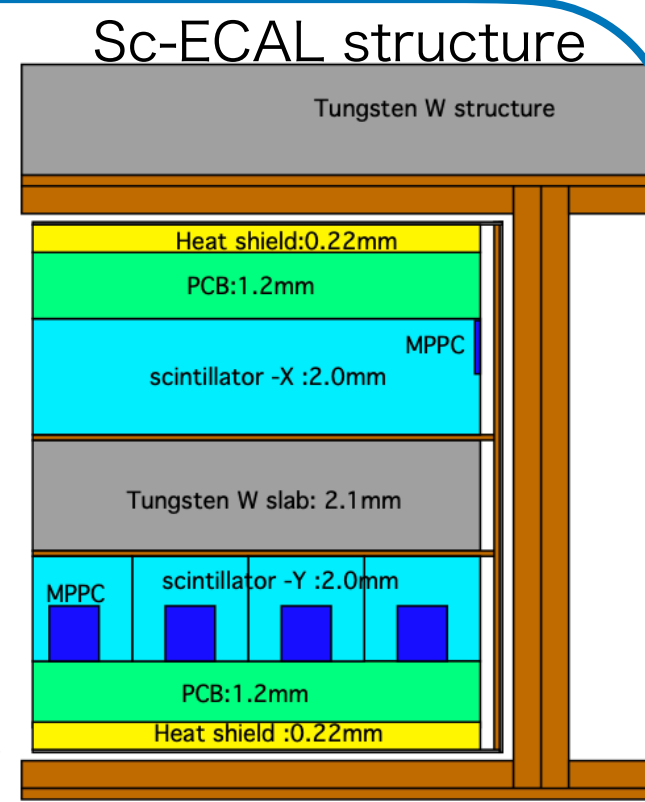
Particle Flow Algorithm (PFA)

- ✓ Each particle is detected by the best suited detectors
- ✓ **Improved jet energy resolution**
 - **Highly granular calorimeter required**



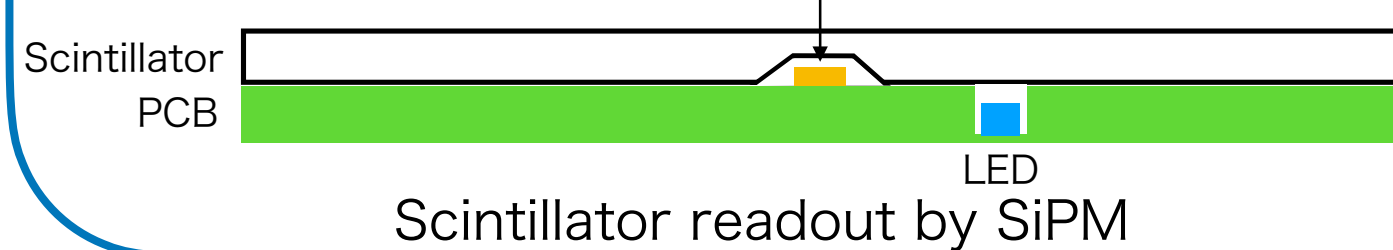
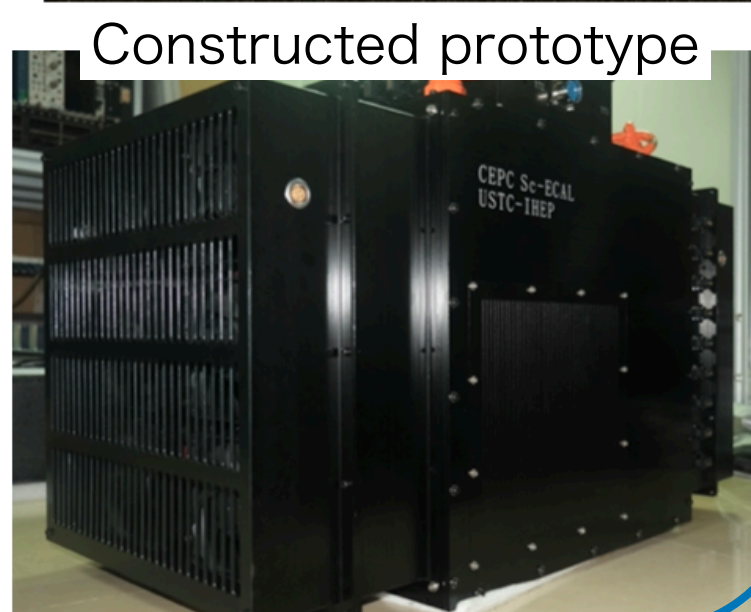
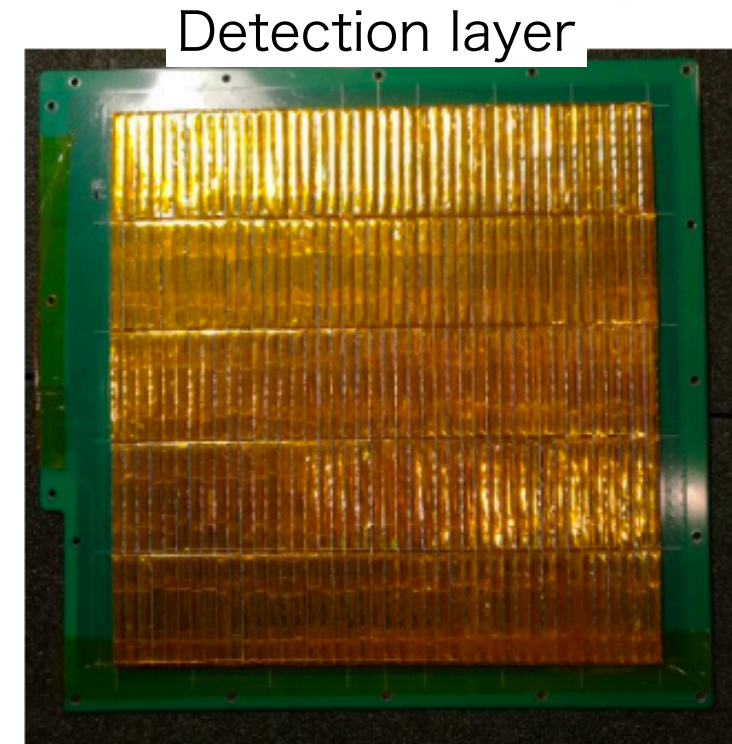
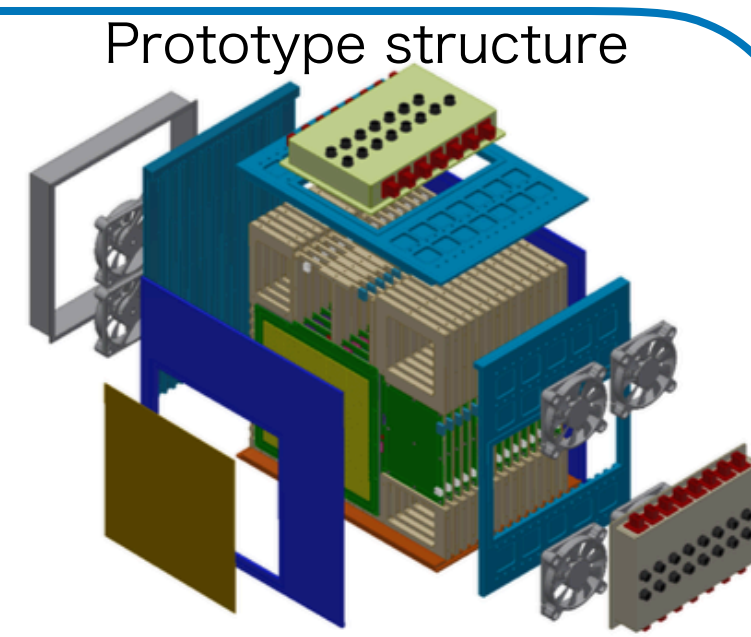
Scintillator ECAL (Sc-ECAL)

- ✓ Sampling calorimeter
 - 30 detection and absorber layers
- ✓ Based on scintillator strips readout by Silicon Photomultiplier (SiPM)
- ✓ **Virtual segmentation: 5 × 5 mm² with strips in x-y configuration**
 - Strip Splitting Algorithm (SSA)
 - 45 mm strip is split by 9 cells using the hit and energy of upper and lower layers



Large technological prototype

- ✓ Target
 - Use the same technology as foreseen in full scale detector
 - Evaluate the performance of Sc-ECAL using full 30 layers
- ✓ **Construction completed**
- ✓ **Detection layer**
 - ✓ 45 × 5 × 2 mm³ strip (BC-408)
 - Wrapped in ESR film
 - Readout by Hamamatsu MPPC S12571-010P/015P
 - Good uniformity with bottom-center coupling
- ✓ ECAL Base Unit (EBU)
 - Fully integrated electronics for high granularity
 - 210 channels, 6 ASIC (SPIROC2E)
 - Temperature monitoring system, LED calibration system

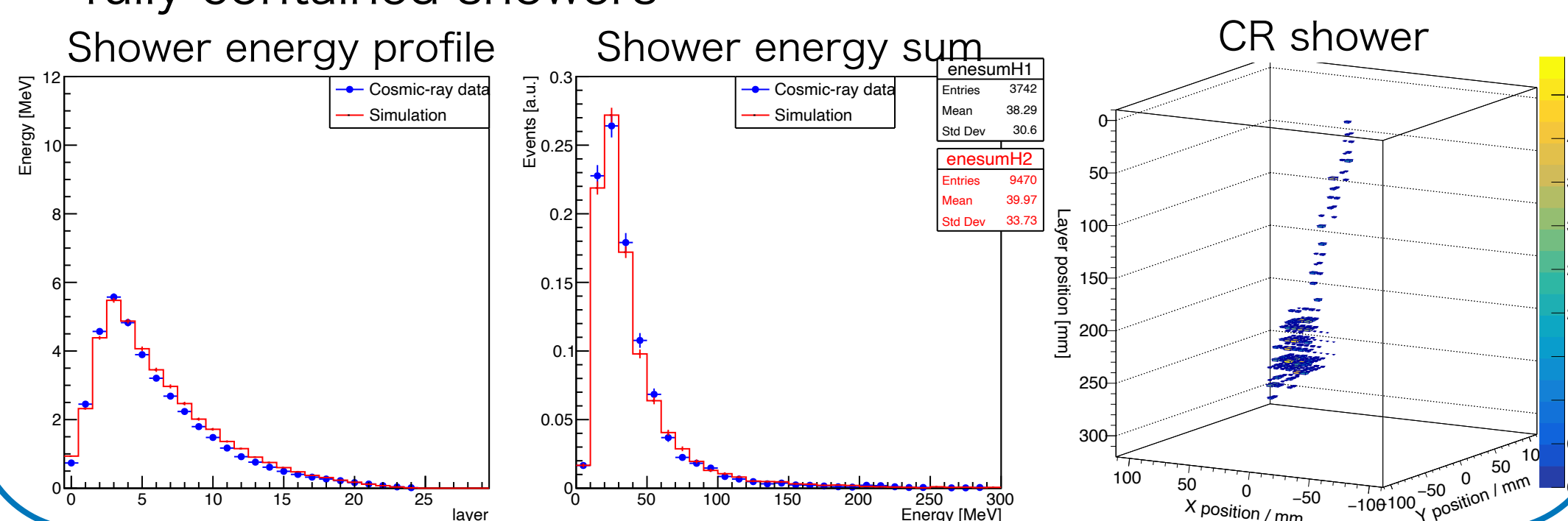


Performance evaluation by cosmic-ray muon

- ✓ **~84% detection efficiency**
 - Agree with Monte Carlo simulation
- ✓ **Good position resolution**
 - Short-side direction: 1.5-1.7 mm → ~5 mm uniform distribution
 - Long-side direction: ~2.3 mm → a bit worse due to the SSA
 - Achieve granularity requirement

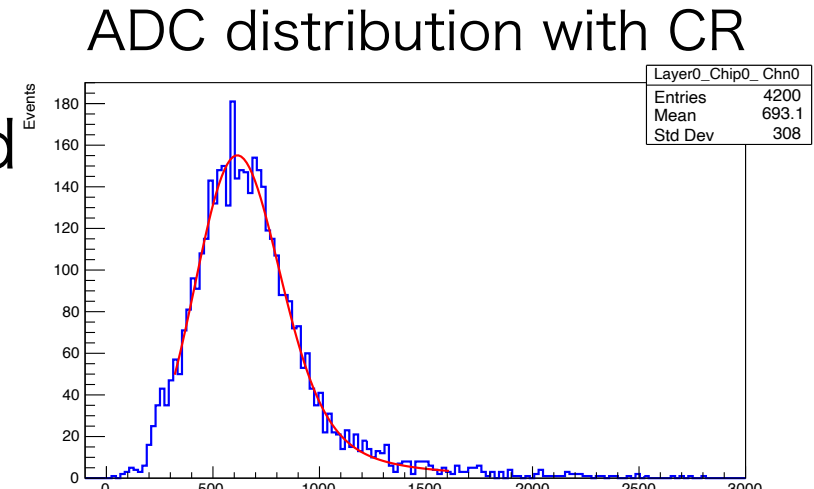
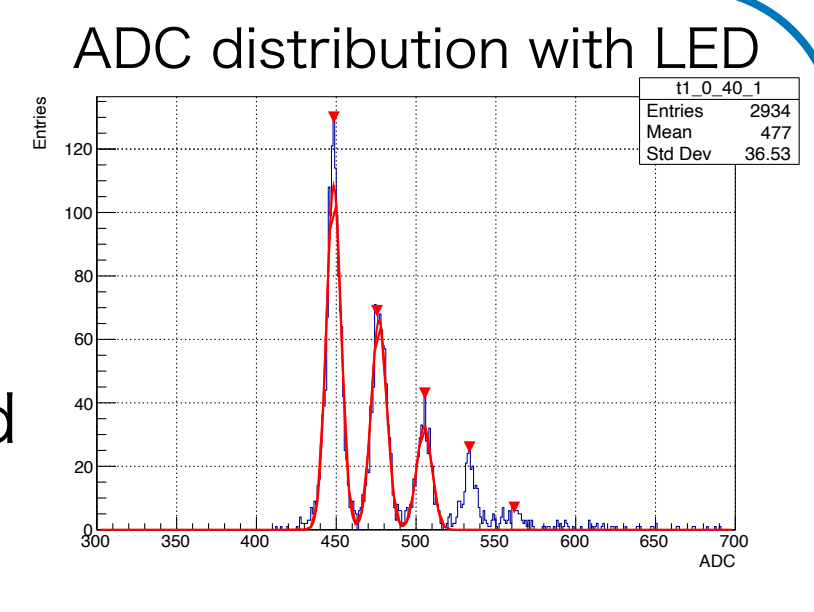
Cosmic-ray shower analysis

- ✓ Performance for electromagnetic showers is evaluated using cosmic-ray showers (instead of test beam)
- ✓ **Data and simulation match well** when comparing the properties of fully-contained showers



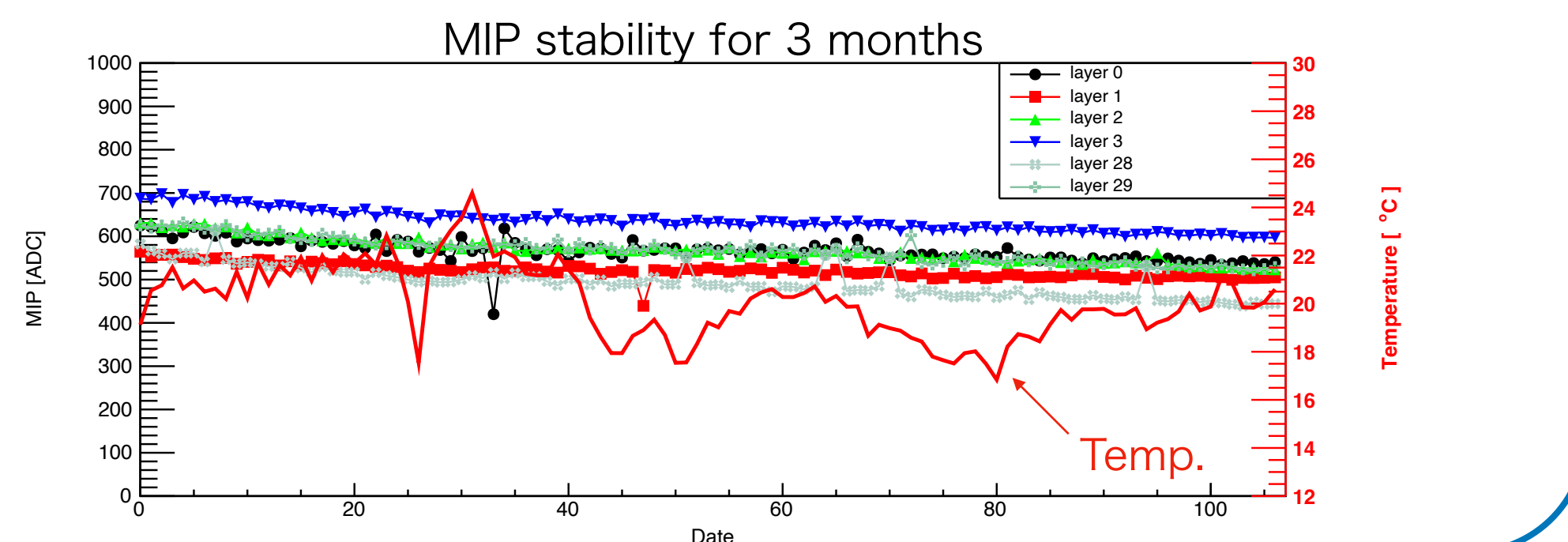
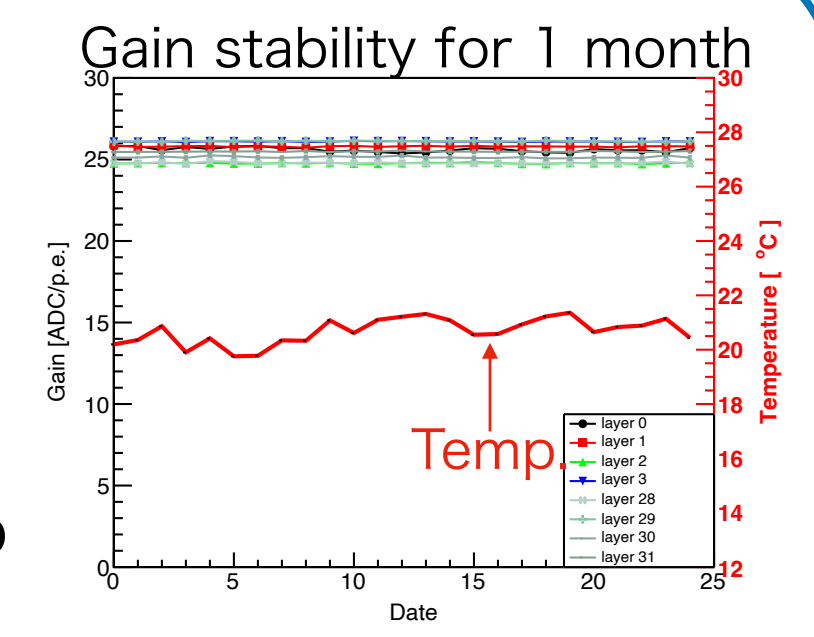
Calibration

- ✓ **Single photo-electron gain**
 - Clear separation of peaks of 0, 1, 2 photons using LED
 - Per-channel calibration succeeded
- ✓ **MIP calibration**
 - Obtained by Landau MPV of ADC distribution of cosmic-ray hits
 - Per-channel calibration succeeded after angler & temperature correction
- ✓ Pedestal, high-gain vs. low-gain, cross-talk and after-pulse
 - Per-channel calibration succeeded



Stability

- ✓ **Gain is quite stable** during 1 month LED test
- ✓ MIP has some continuous decline during 3 months cosmic-ray test
 - Reason is under investigation
- ✓ The other calibration factors are also stable during long-term test



Conclusion

- ✓ Highly granular ECAL is required for the Higgs factories to search for the new physics
- ✓ **Sc-ECAL**
 - Large technological prototype has been constructed
 - First demonstration of Sc-ECAL performance using full-scale prototype
- ✓ Performance evaluation
 - Per-channel calibration succeeded for all calibration parameters, and good stability achieved
 - Sufficient efficiency, position resolution
 - Achieve the requirement for Sc-ECAL
 - Shower events can be detected as expected at the simulation
- ✓ **Sc-ECAL is found to be a promising and mature technology for highly granular calorimeter to achieve precision physics at future Higgs factories**