



JSR Fellowship

Development of scintillator electromagnetic calorimeter

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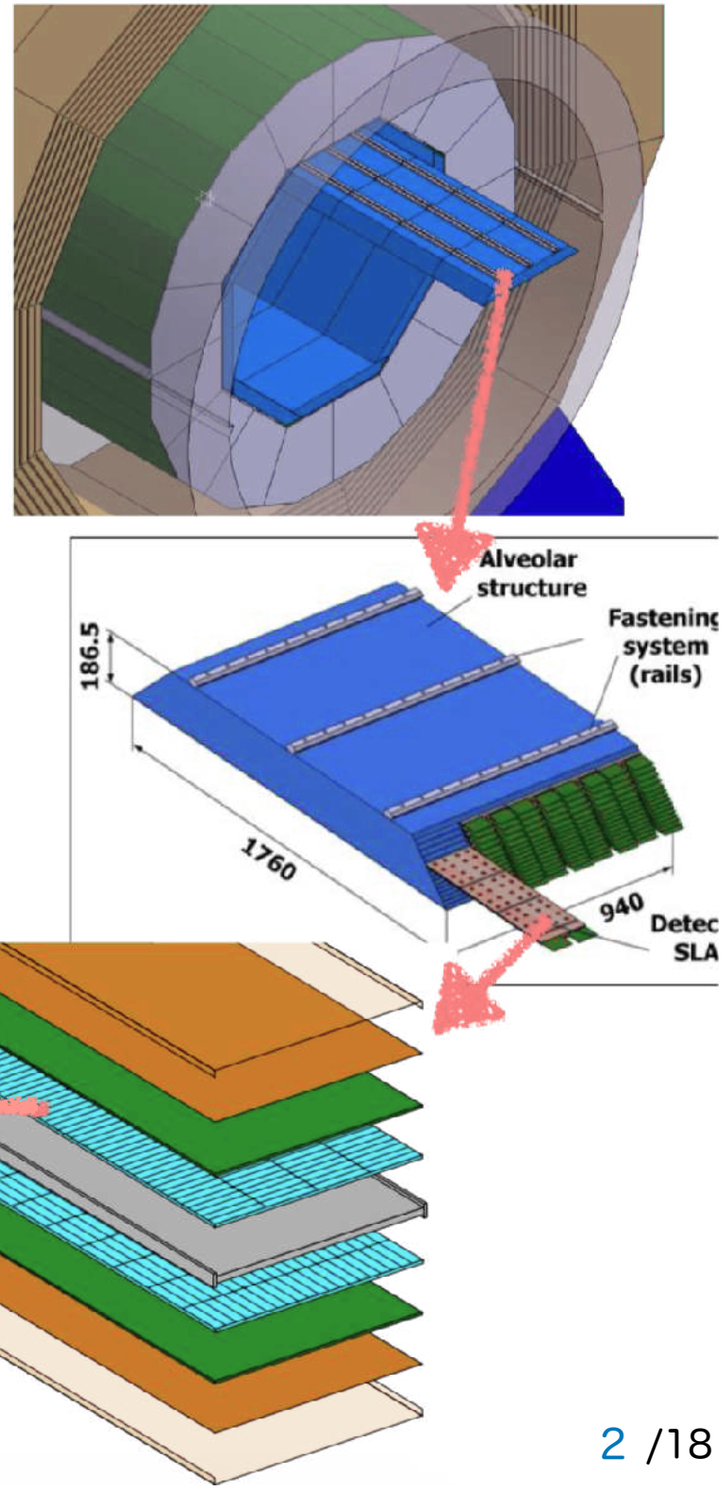
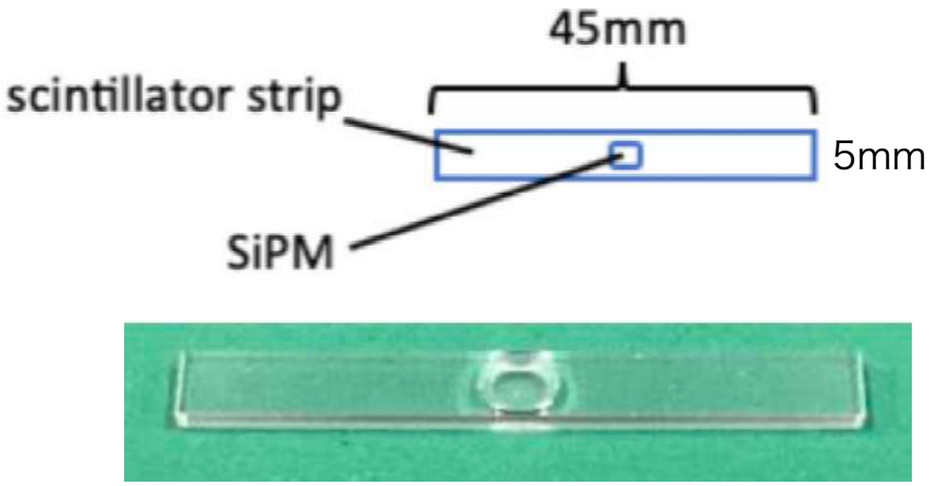
Sc-ECAL

- Scintillator Electromagnetic CALorimeter (Sc-ECAL)
  - Technology option of EM calorimeter for ILC and CEPC
- Based on scintillator strips readout by SiPM
  - 5 × 45 × 2 mm^3 scintillator strip
- Virtual segmentation : 5 × 5 mm^2 with strips in x-y configuration
  - # readout channels significantly reduced ($10^8 \rightarrow 10^7$)
    →Low cost
  - Retaining performance comparable to real 5 × 5 mm^2 segmentation
- Timing resolution < 1 ns

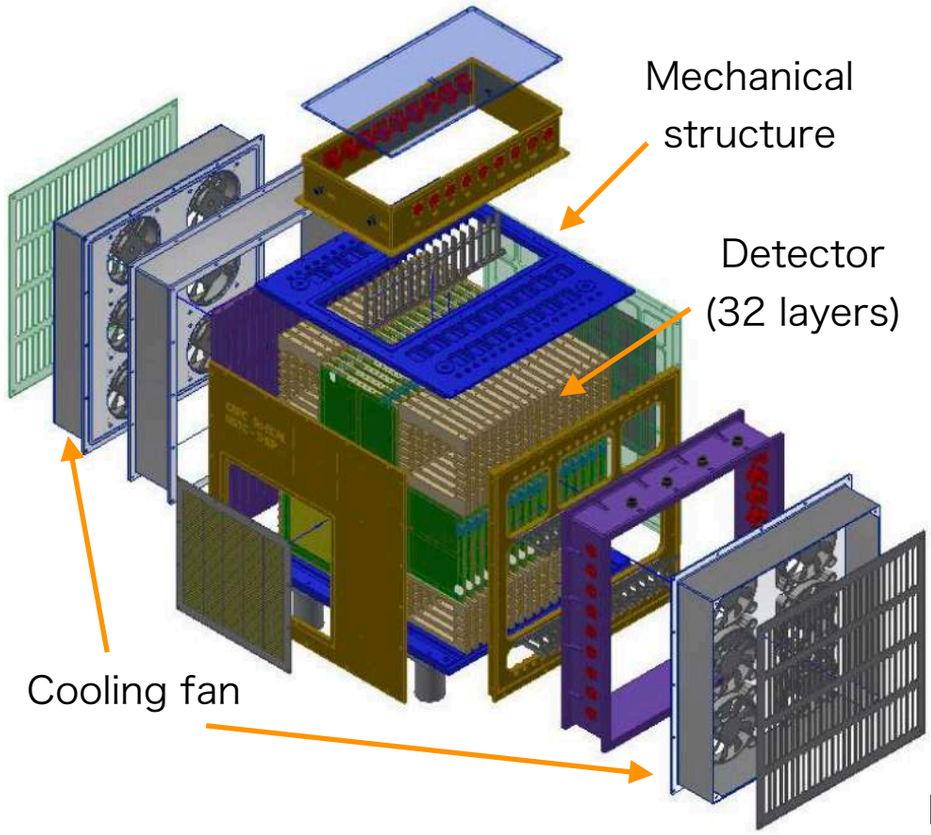




Technological prototype

- **Technological prototype for Sc-ECAL has been constructed as a joint effort by R&D groups for ILC-ILD and CEPC-ECAL**
  - Use the same technology as foreseen in the full scale detector
  - Evaluate the performance using full layers (32 layers)
- Two detection layers with double SiPM readout have been installed in the prototype
- Two additional layers developed with new type of SiPM are also tested

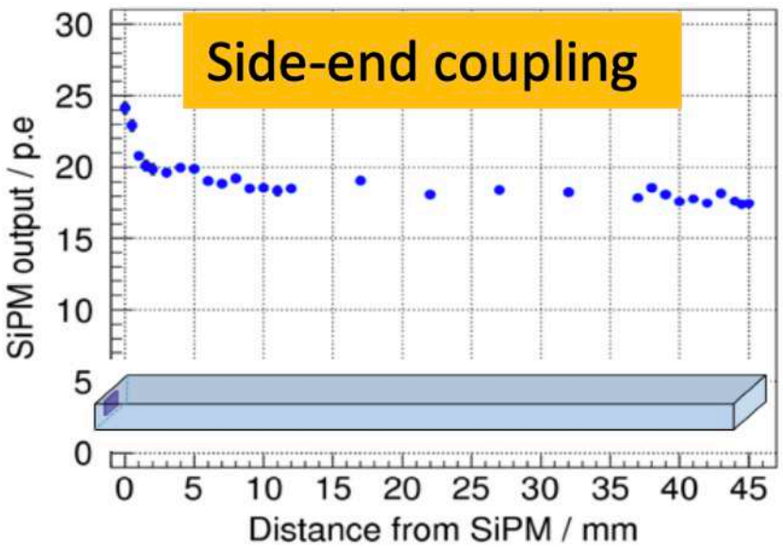
- Test beam in DESY
  - Originally scheduled in Aug. 2020, but postponed to Mar. 2021, which was again canceled due to COVID-19
  - Hoping to have it later this year

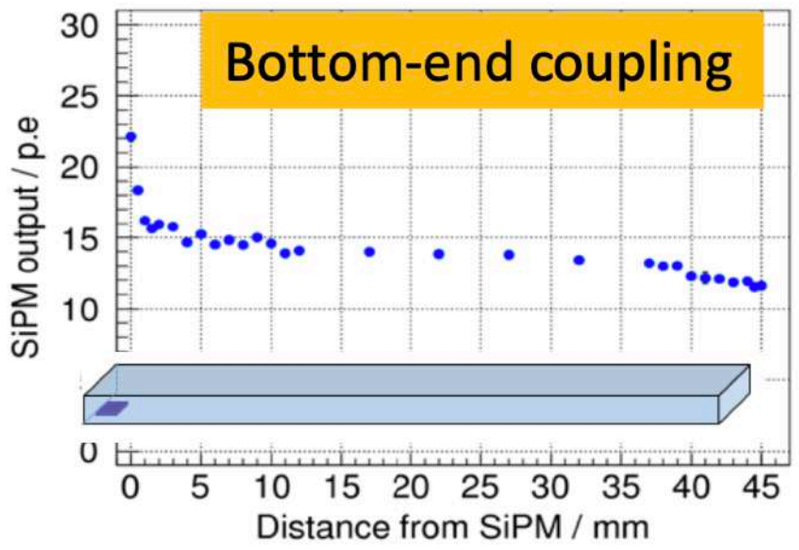


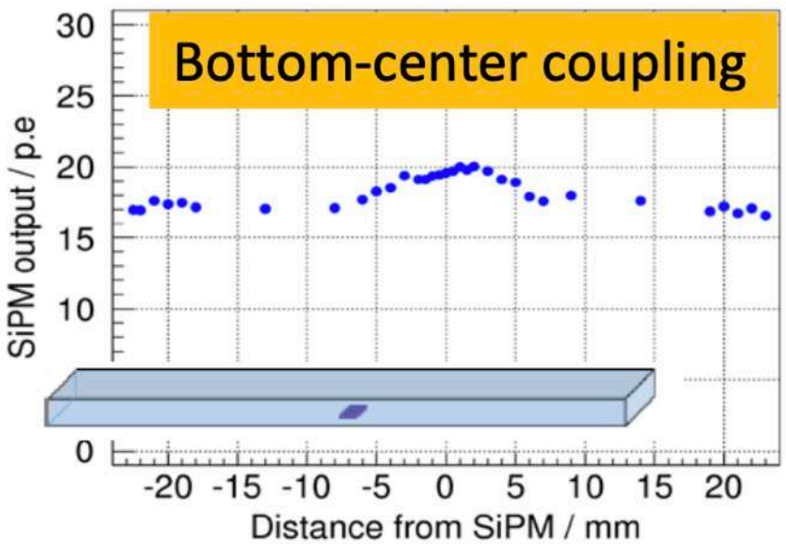
SiPM Coupling optimization

- Three coupling models investigated
  - side-end, bottom-end and bottom-center
- Uniformity of light yield along the strip is important to the ECAL energy resolution
- **Bottom-center coupling gives the best uniformity with additional advantages:**
  - Avoiding the dead area between scintillators introducing by SiPMs
  - Simplifying sensitive layer assembly
  - Allowing for large-size SiPM
- Adopt bottom-center coupling as default design of detection layer

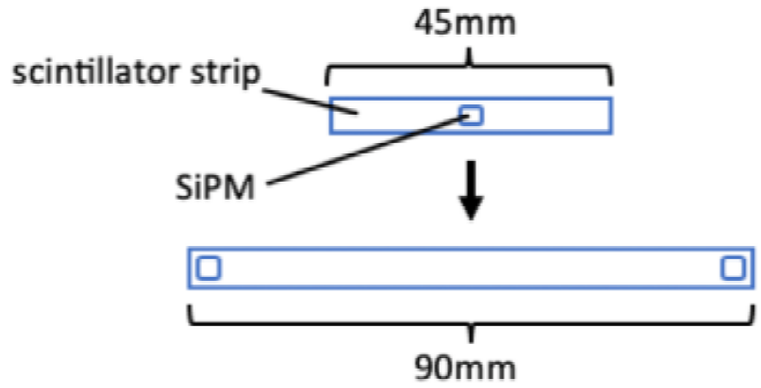
・Commercial PVT scintillator
・MPPC S12571-010P



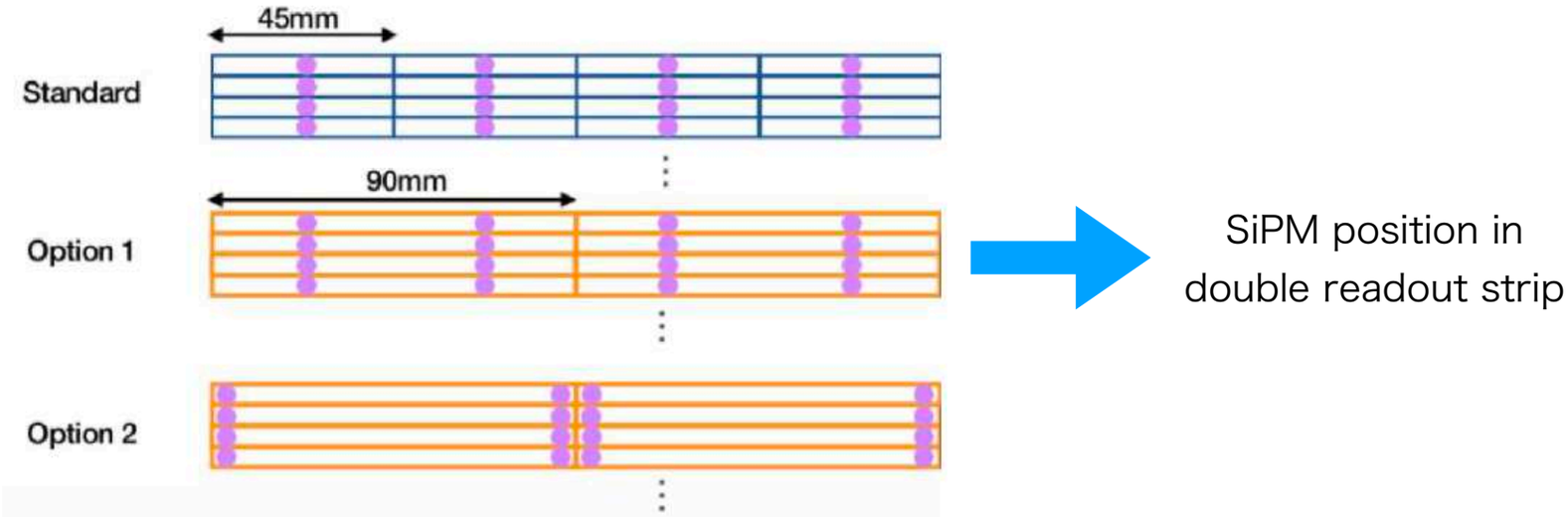




Double SiPM readout (See 15aSE-8)

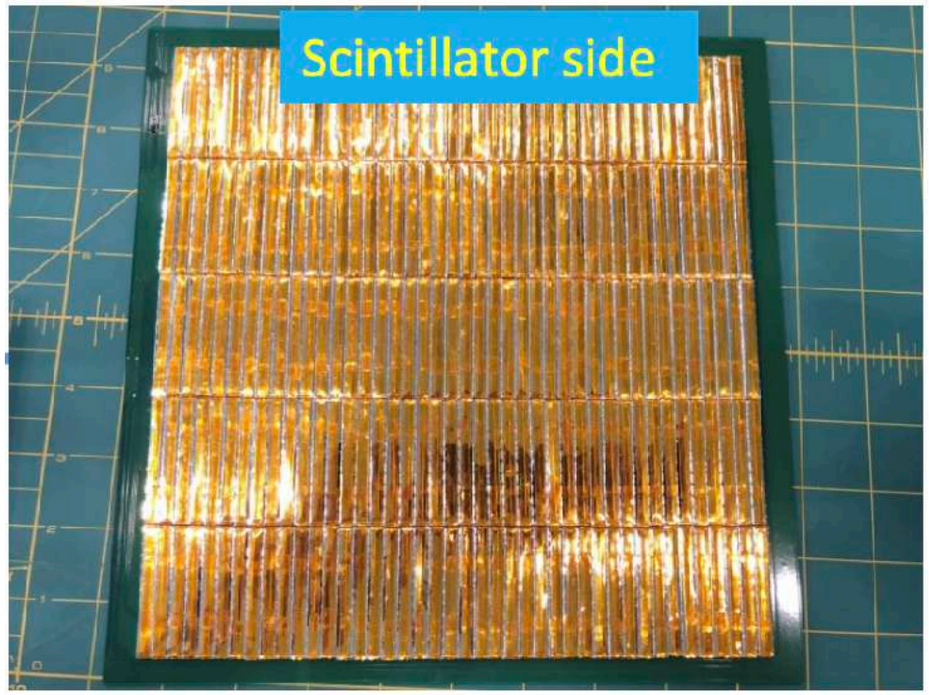


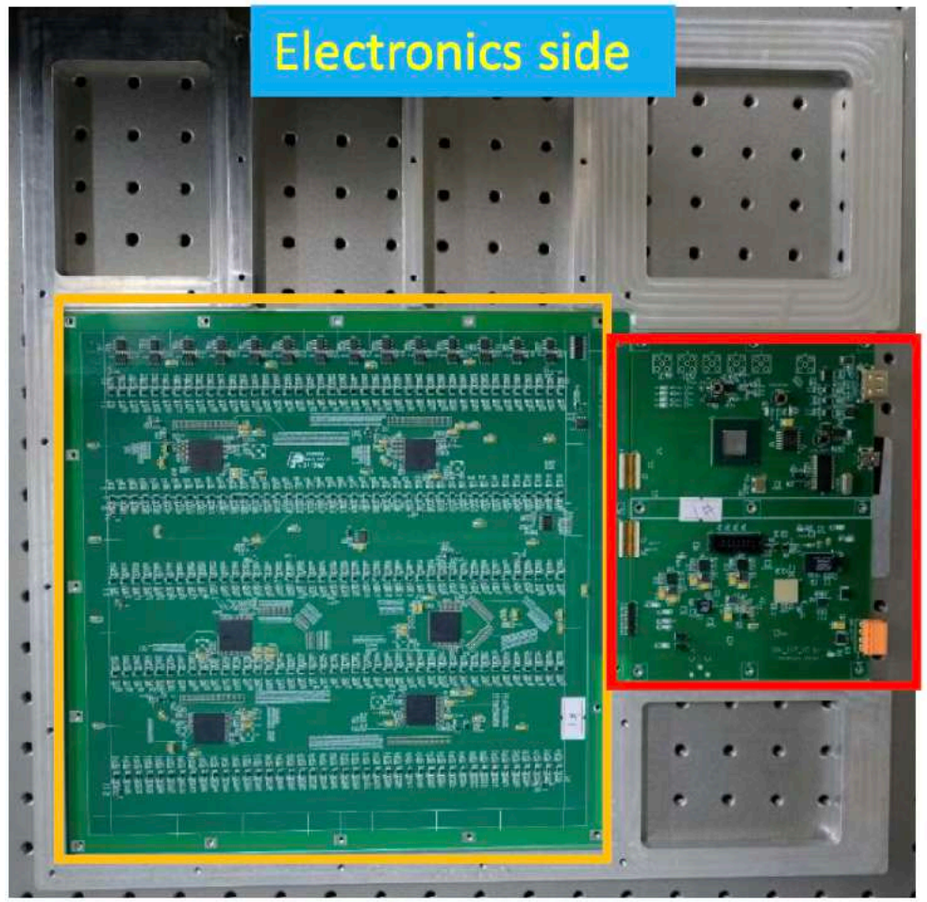
- **Readout by 2 SiPMs at strip ends**
- Twice longer strip (L=90mm) to keep the number of SiPMs
- Possible advantages
  - Eliminating noise by taking coincidence
  - Higher light yield by summing 2 SiPM readouts
  - Even lower light yield for each SiPMs (→less saturation)
  - Position reconstruction by charge and/or timing difference between two readouts (→ reduce ghost hits)
- Two detection layers with double readout tested
  - SiPMs in the middle of the strips instead of the strip ends
    - To be compatible with standard EBU PCB design
    - Not possible to test position reconstruction



ECAL Base Unit (EBU)

- Fully integrated electronics for high granularity
  - 210 channels readout with 6 × ASIC (SPIROC2E) chips divided into 5 rows and 42 columns
  - Electronics calibration and SiPM operation voltage adjustment realized
  - LED calibration and temperature monitoring circuits
  - Total layer: 6 mm / layer





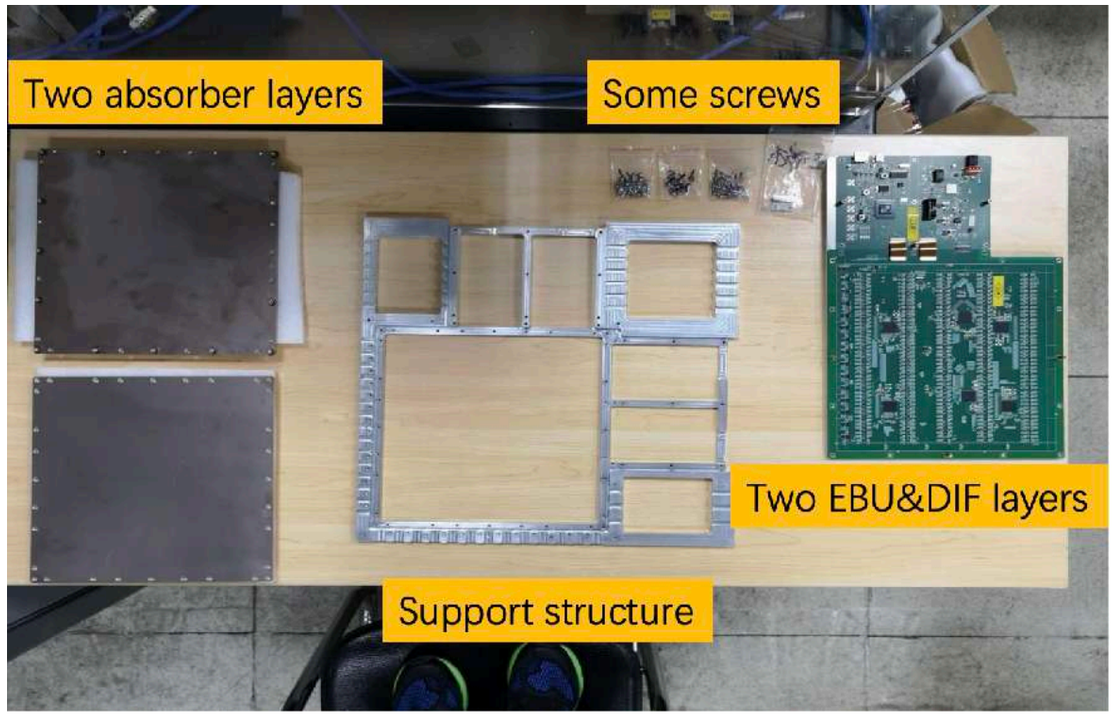
- 24 layers of EBU with 10μm-pixel SiPMs
- 6 layers of EBU with 15μm-pixel SiPMs

	Active area	Pixel pitch	#pixel	#layer
S12571-010P	1×1 mm^2	10 μm	10000	24
S12571-015P	1×1 mm^2	15 μm	4489	6

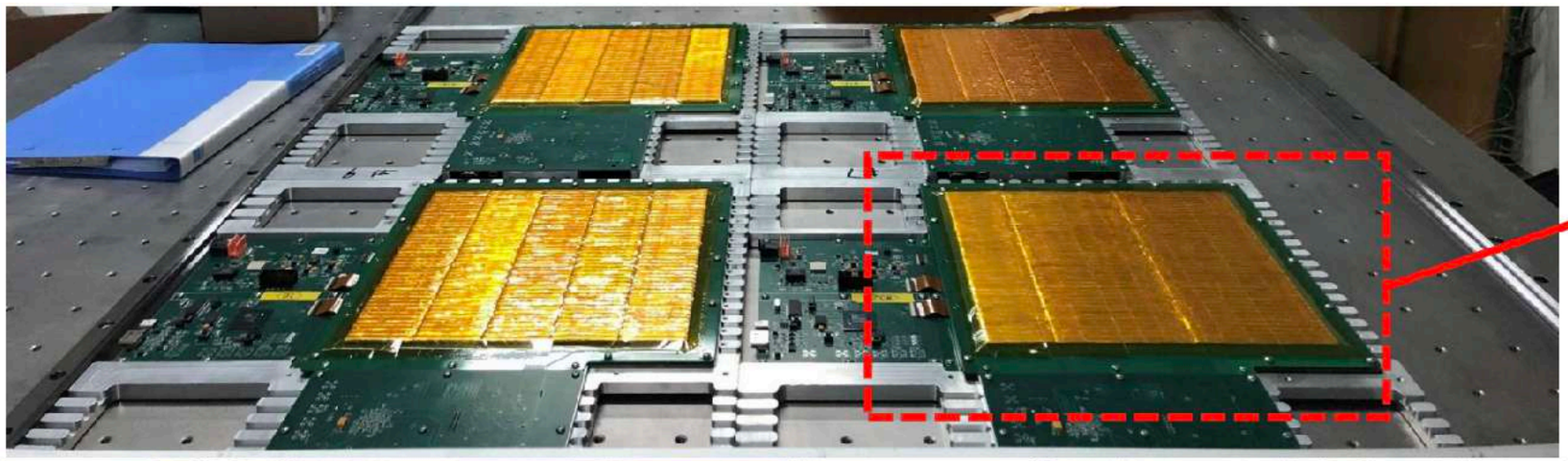
- Scintillator strips were wrapped with ESR film and assembled on EBU boards by Shanghai Institute of Ceramic

Assembly & mounting

- 16 super-modules (32 EBUs) completed
- One super-module consists of two sets of EBU and absorber layer
  - 2 EBUs in x-y configuration
  - Absorber layer: 3.2 mm, 15%-85% Cu-W

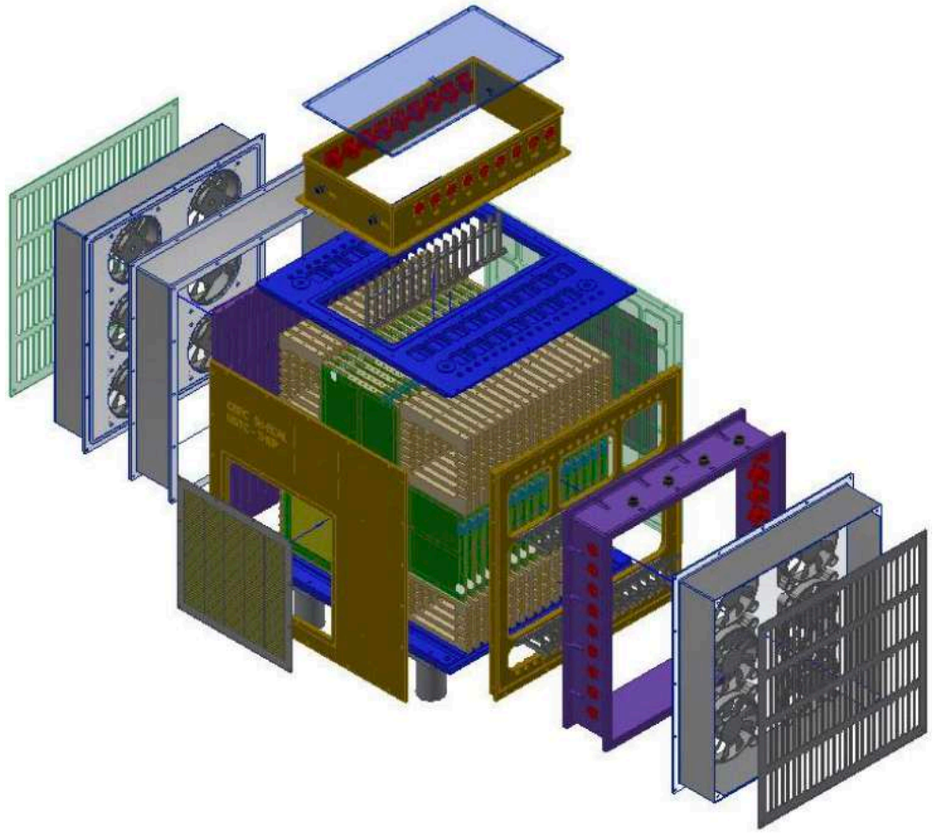


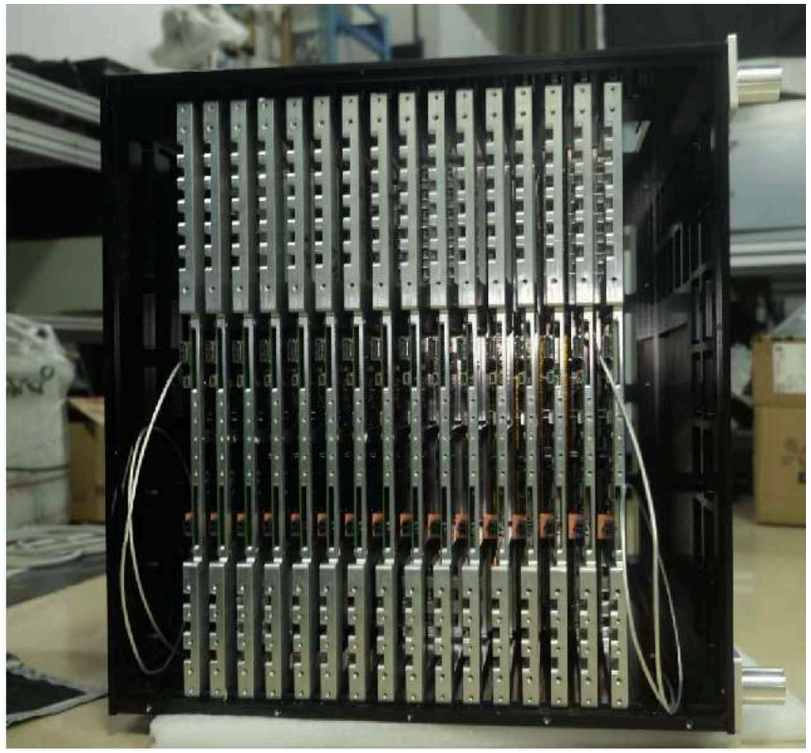
Super-module	#module (EBU)	SiPM	Strip length	Strip material (process)
Single-readout 1	12 (24)	S12571-010P	45 mm	PVT (casting)
Single-readout 2	3 (6)	S12571-015P	45 mm	PVT (casting)
Double-readout	1 (2)	S12571-015P	90 mm	PS (injection moulding)
Shinshu	1 (2)	S14160-1315PS	45 mm	PVT (casting)



Mechanical structure

- The mechanical structure with 17 slots for super-modules
- **Assembly of full Sc-ECAL prototype finished**

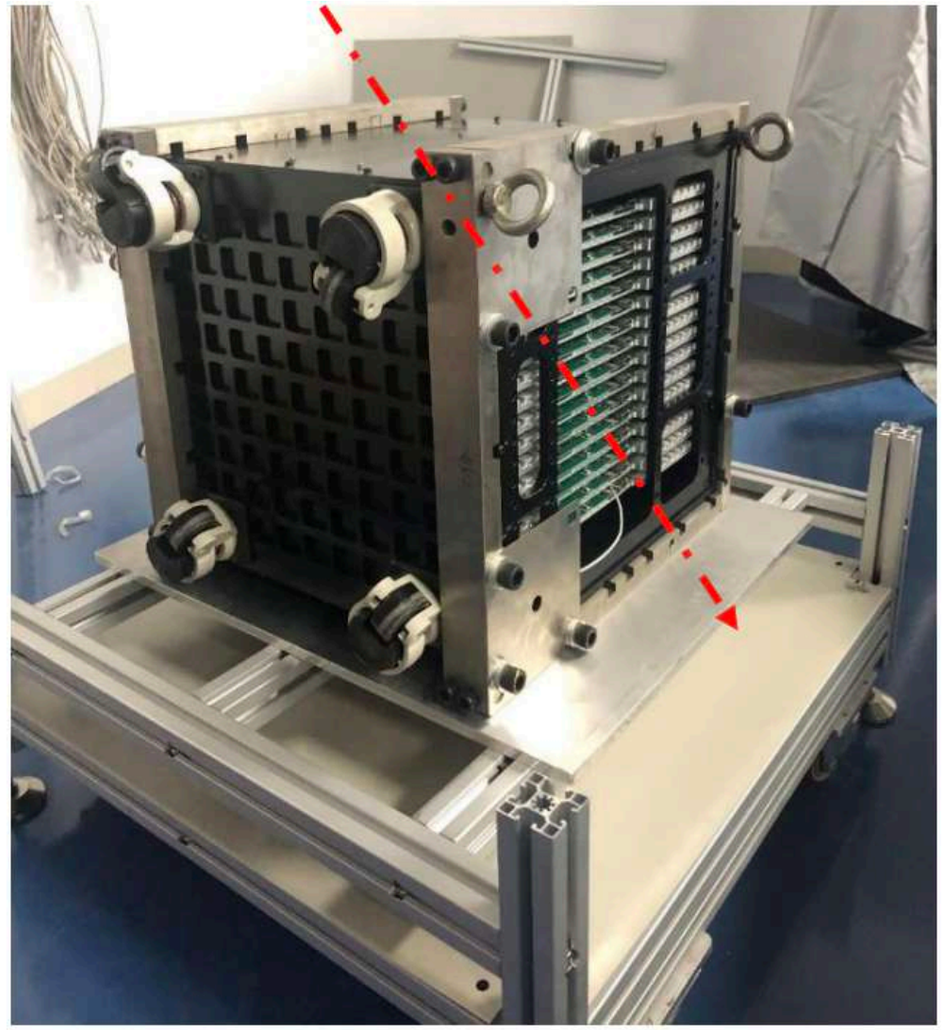


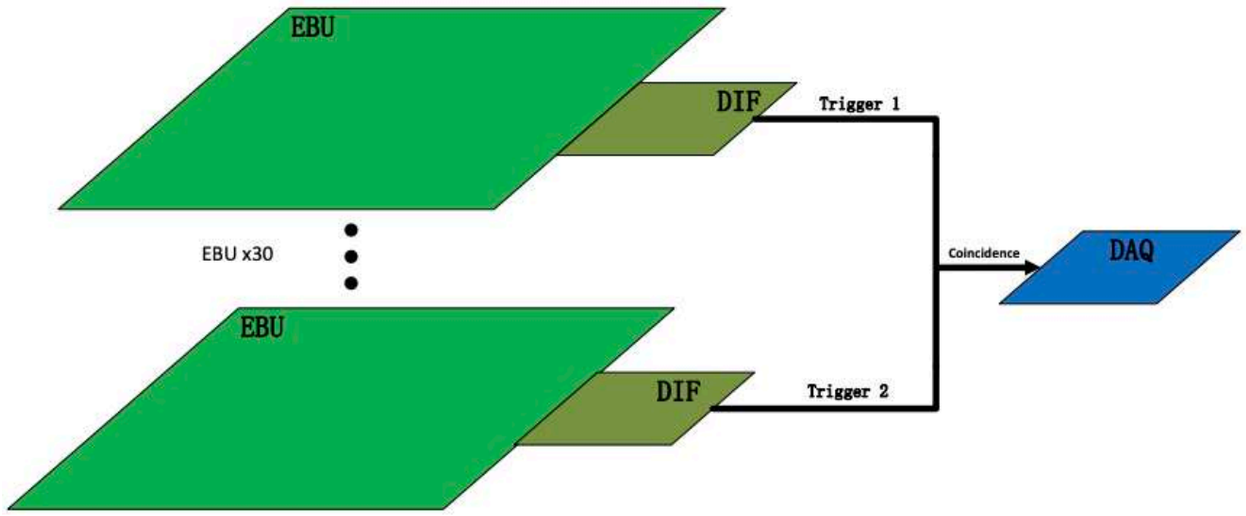


Cosmic-ray test

- Purpose
  - Perfomance evaluation
    - Track finding
    - Efficiency & position resolution
  - **Cell-to-cell MIP calibration**

- Longterm test in 1.5 month
  - Coincidence trigger of top and bottom layers
  - Event rate: ~16 events per minute
  - Collect ~2000 events at each channel

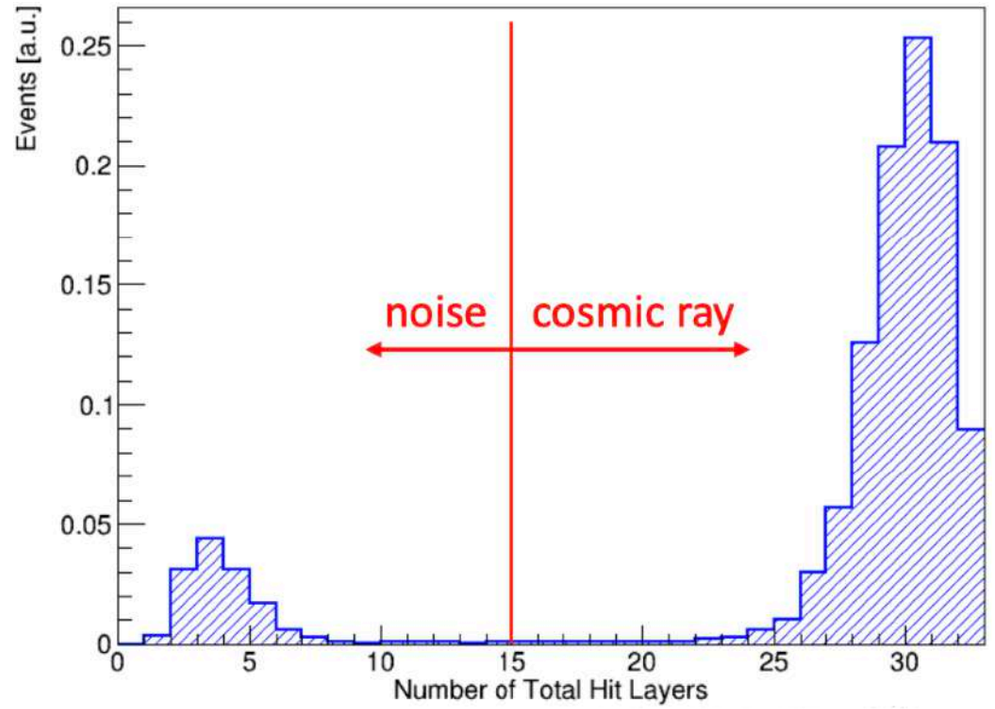


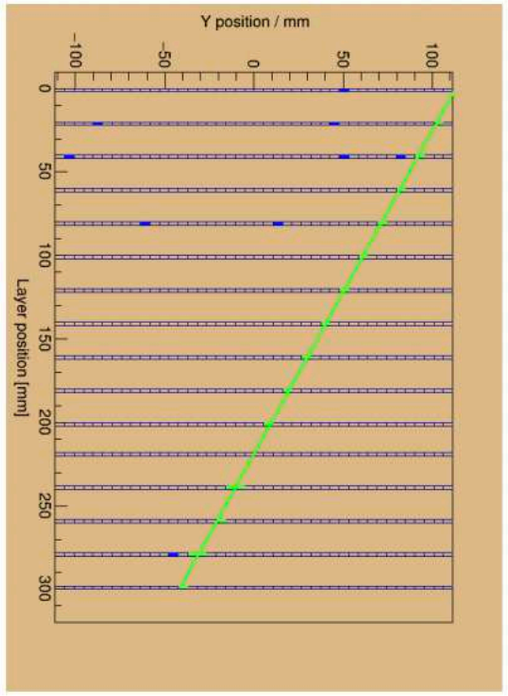


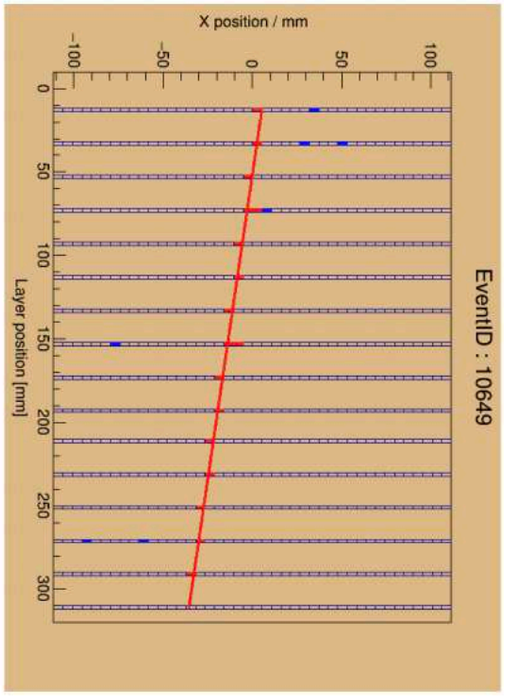
Track finding and fitting

- Some preselections are needed
  - Get rid of noise
  - Find the precise hit track
- A preliminary algorithm performed

	Cut	Efficiency
preSelections	$TotalHitLayer \geq 22$	92%
	$TotalHitStrips \leq 64$	99.6%
	$ADC \geq 5\sigma$	99%
Iteration Fitting	All hits	
	$\lvert Pos_{x/y} - tracking \rvert \leq (47.5, 5, 7.5)$	
Track Selections	$\lvert Intercept_{x/y} \rvert \leq 114$ $\lvert \varphi_{x/y} \rvert \leq 0.7$	98.2%
	$\sigma^2_{x/y} \leq 9.6$	98.3%
	$TotalHitLayer_{x/y} > 6$	99.8%
Alignment	$Pos_{x/y} - track\ fitting$	

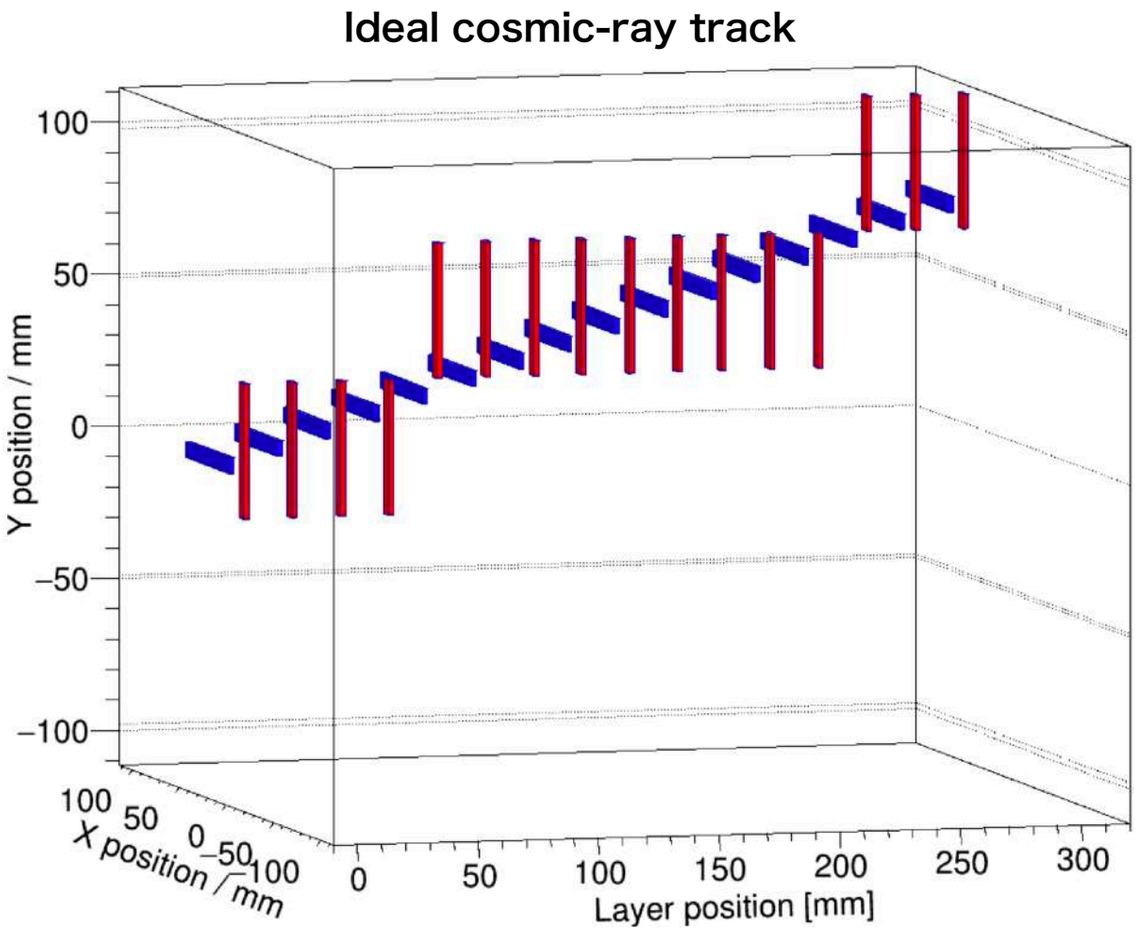


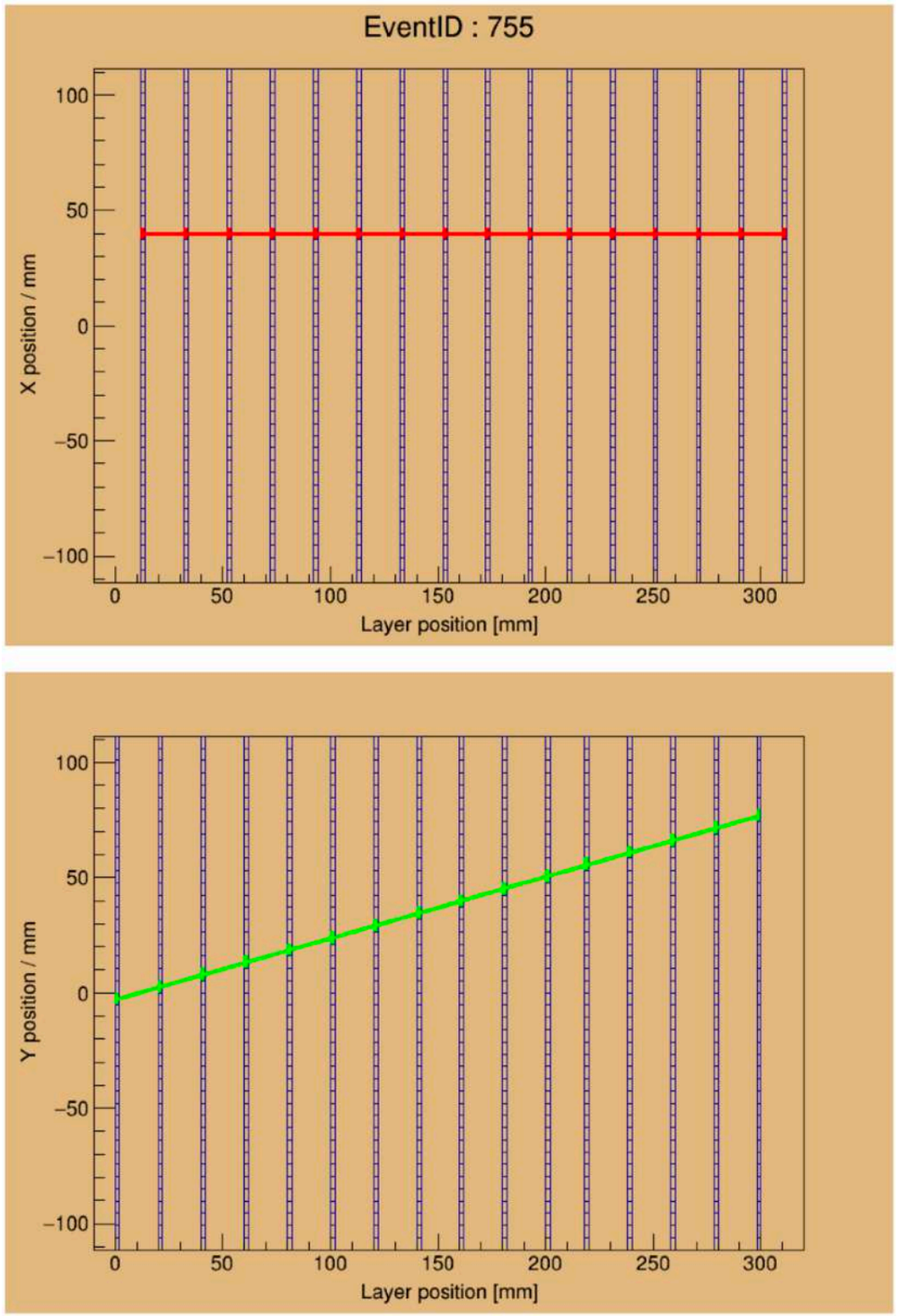




Hit track

- Precise hit track obtained

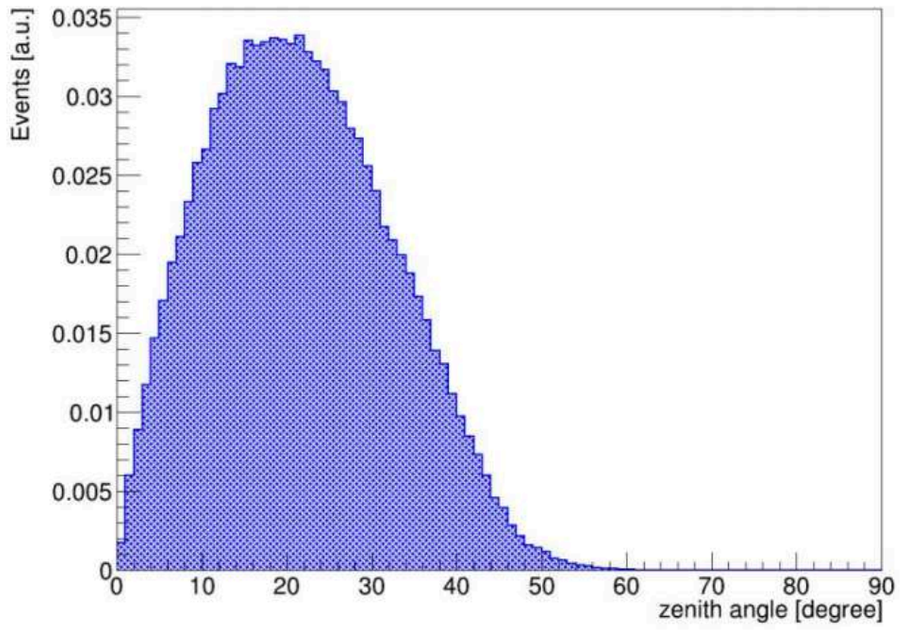




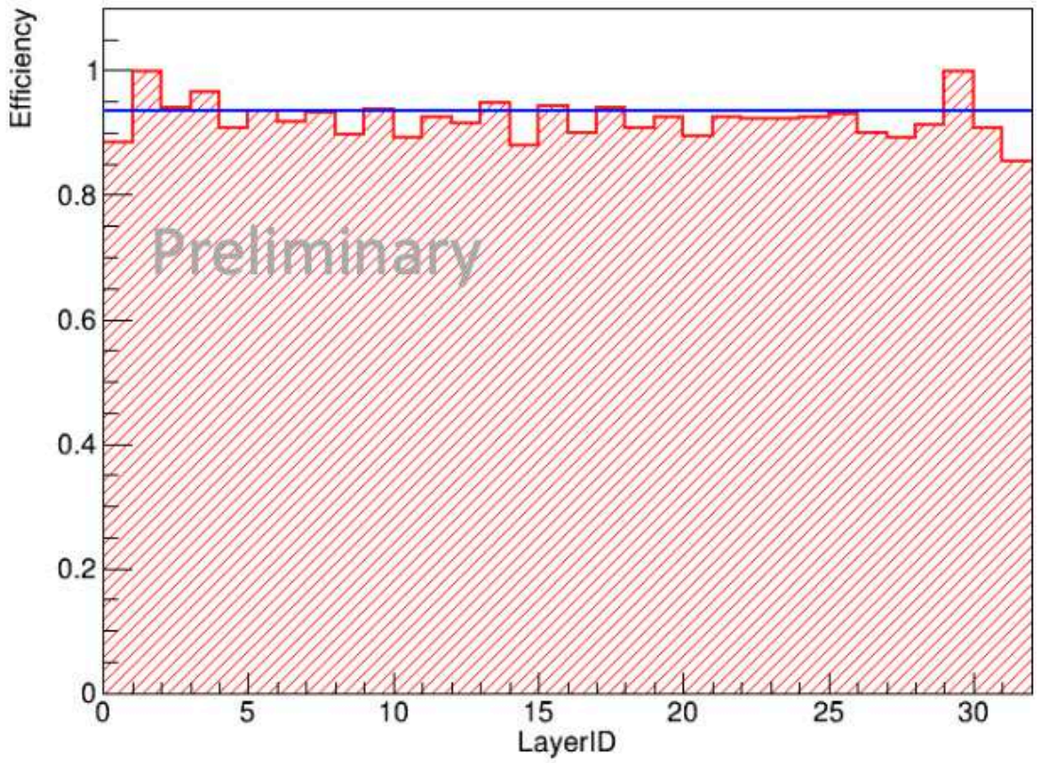
Performance

- Efficiency achieves 95% for all layers
  - Layer 1 & 29 are trigger
  - Affected by MIP threshold
- Position resolution: ~2 mm
  - Difference b/w hit position and fit track for a given layer
  - Achieve the requirement for Sc-ECAL

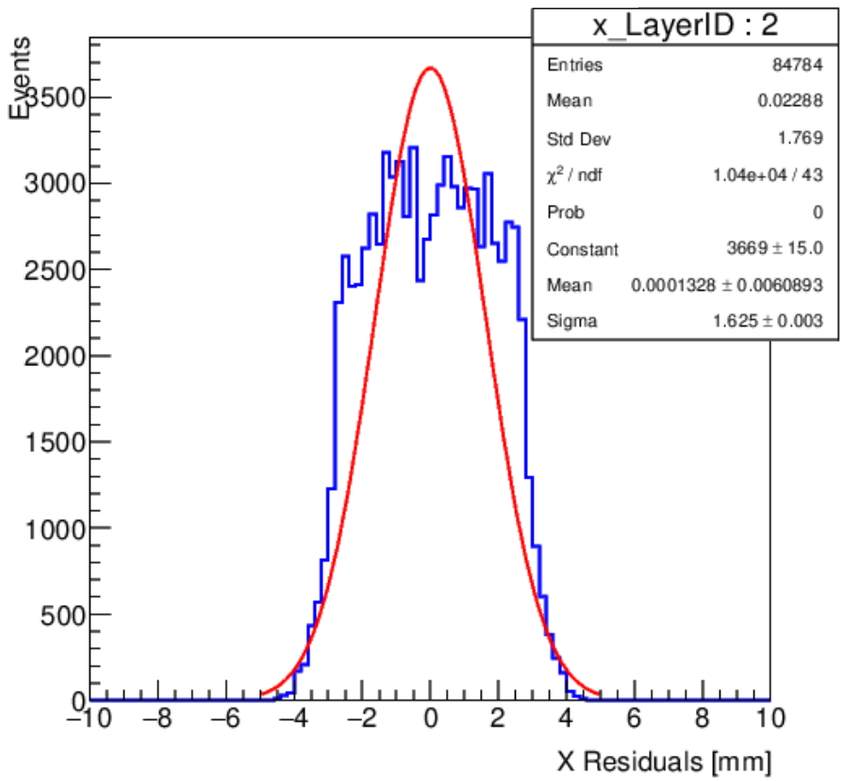
Zenith angle of injection particle



Efficiency per layer

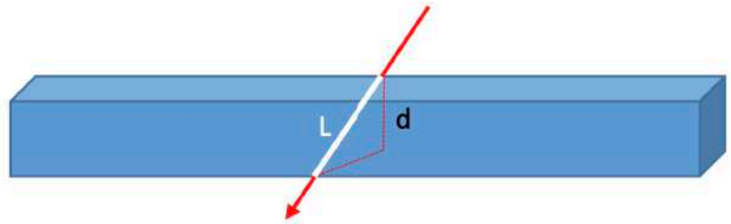


Position difference

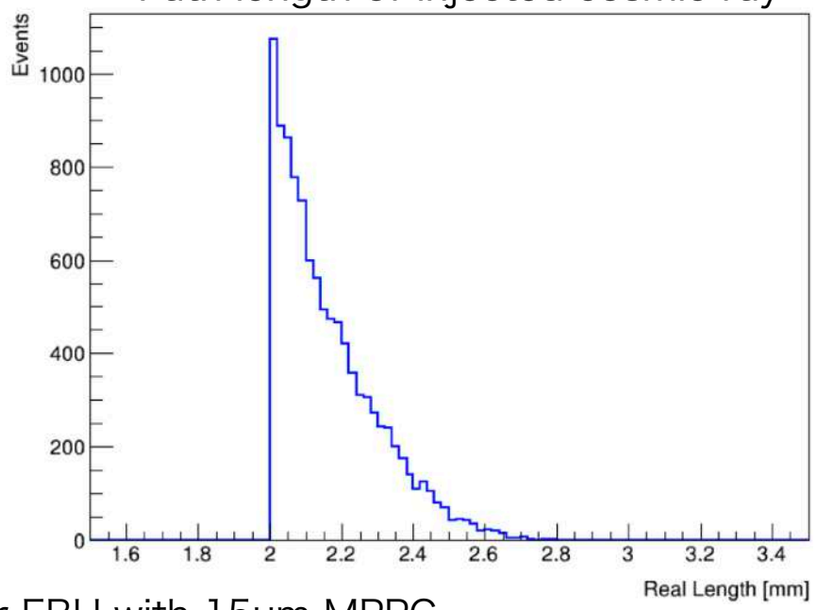


Angular correction for ADC

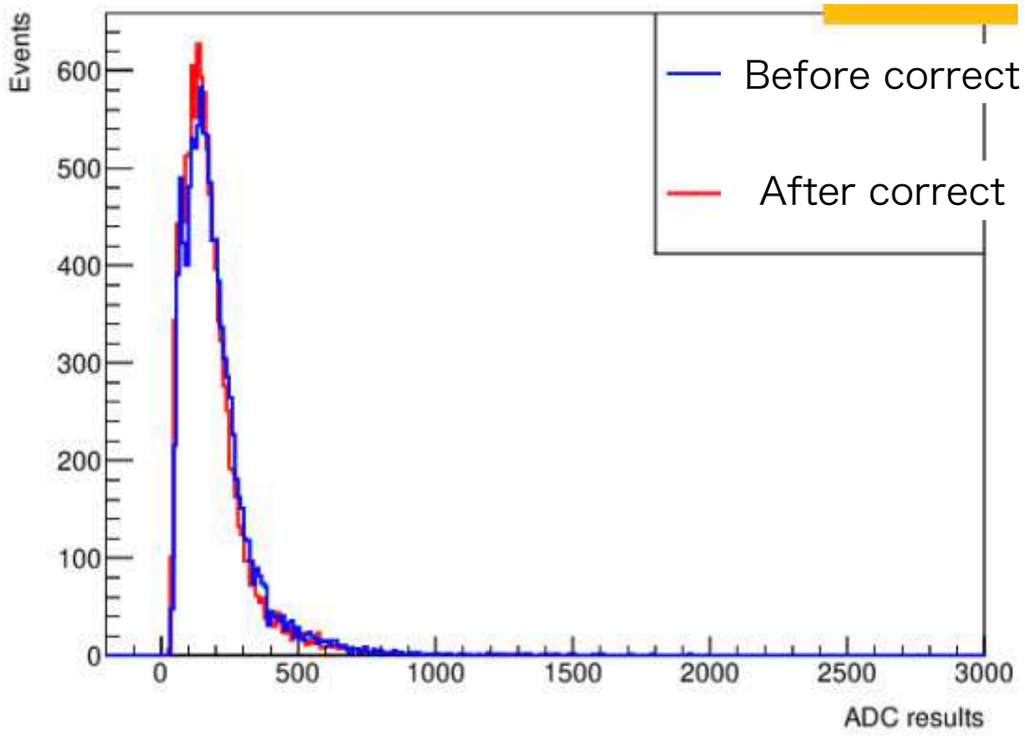
- ADC value should be corrected by the path length in the strip
  - If the path length is longer than 2 mm, the output ADC value shifts larger
- Correction of incident angle is implemented



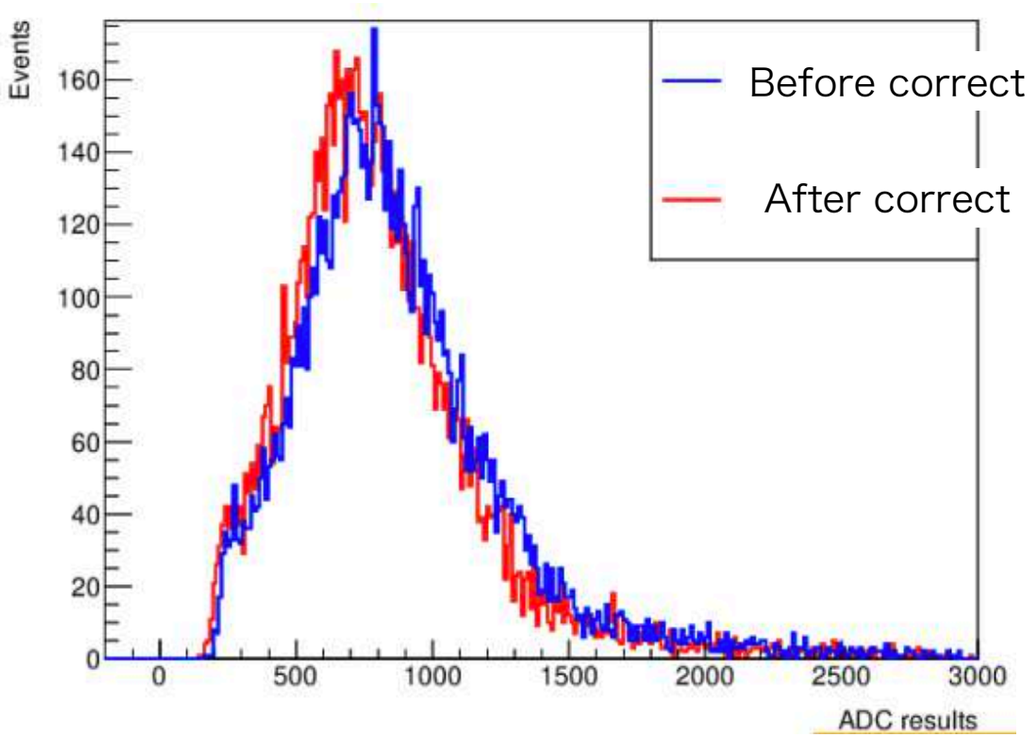
Path length of injected cosmic-ray



MIP for EBU with 10um MPPC

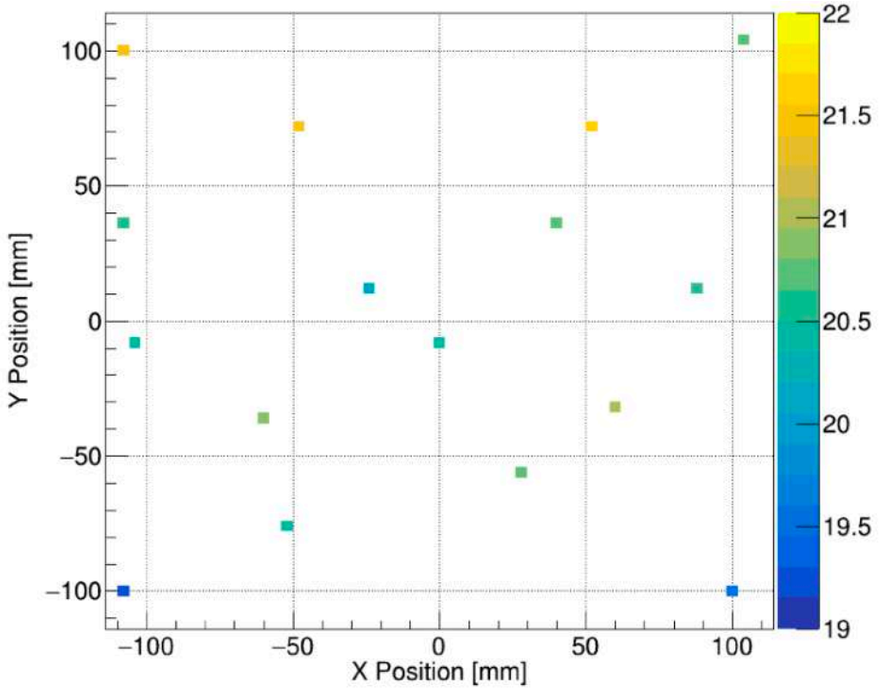


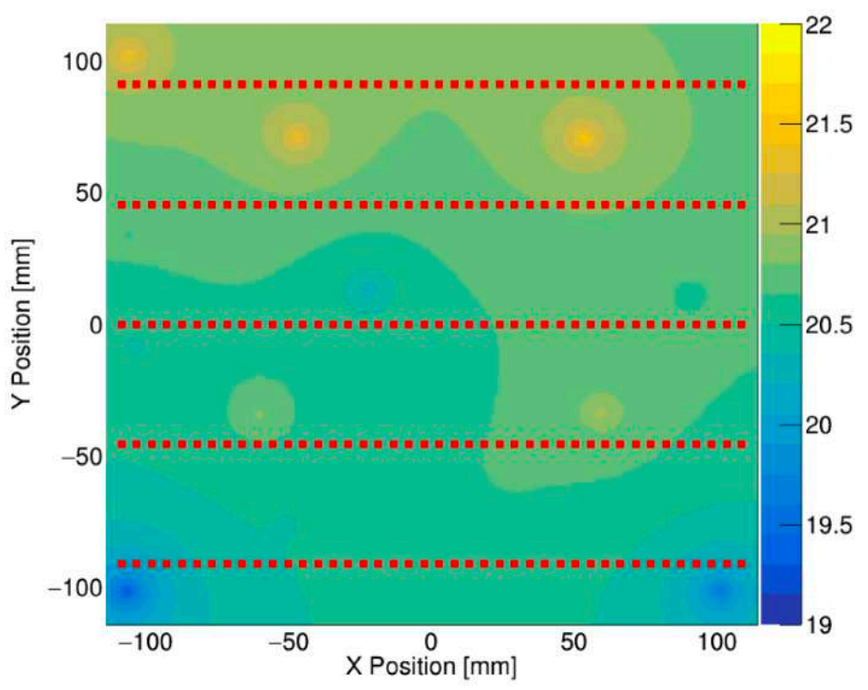
MIP for EBU with 15um MPPC



Temperature monitoring

- Each layers equipped 16 temperature sensors (0℃~85℃, ±0.1℃)
  - Temperature difference in one layer ~3℃
- Distribution on layer reconstructed by inverse distance weighted



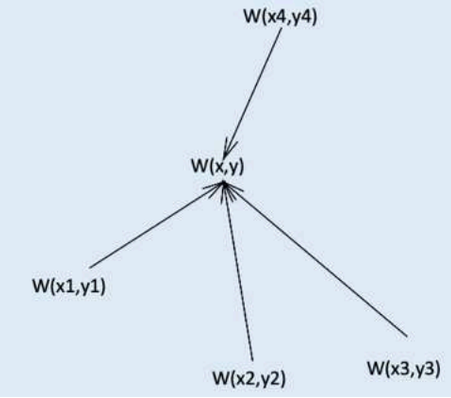


- Inverse Distance Weighted

$$W(x,y) = \sum_{i=1}^{n} Q_i W_i$$

$$Q_i = \frac{\frac{1}{L_i}}{\sum \frac{1}{L_i}}$$

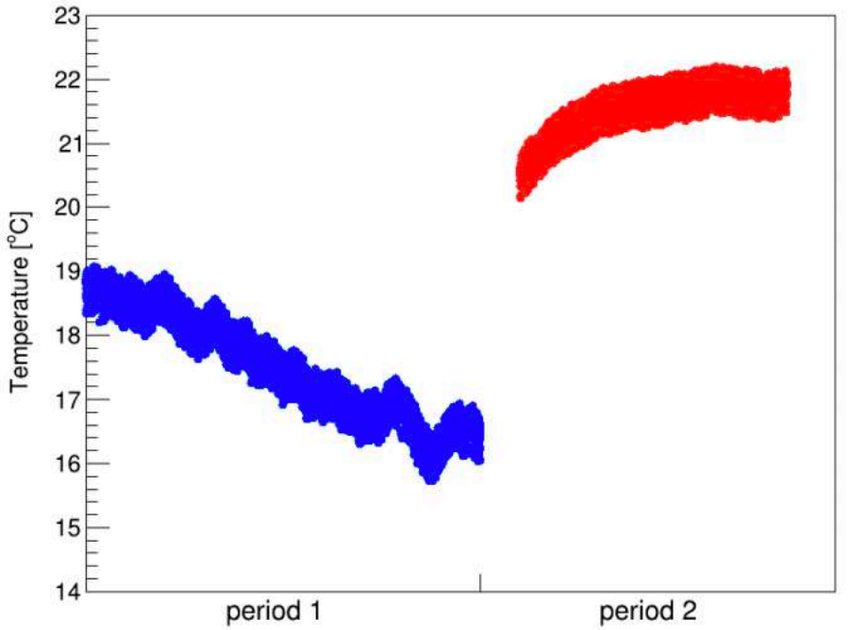
(W: temperature, Q: weight, L: length)

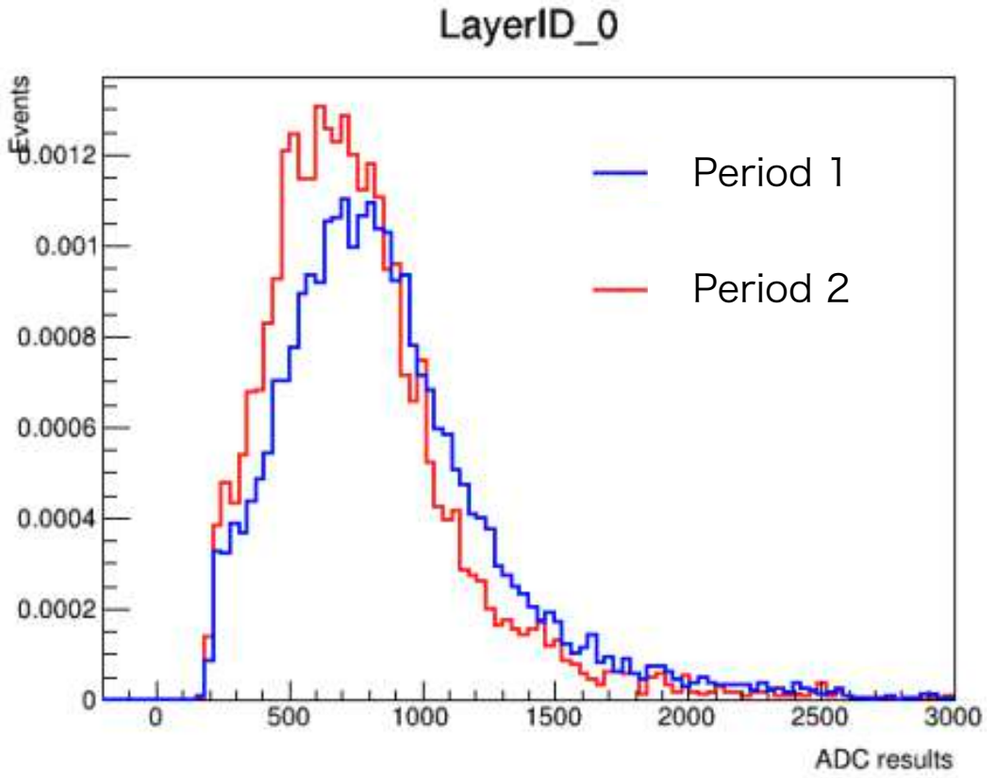


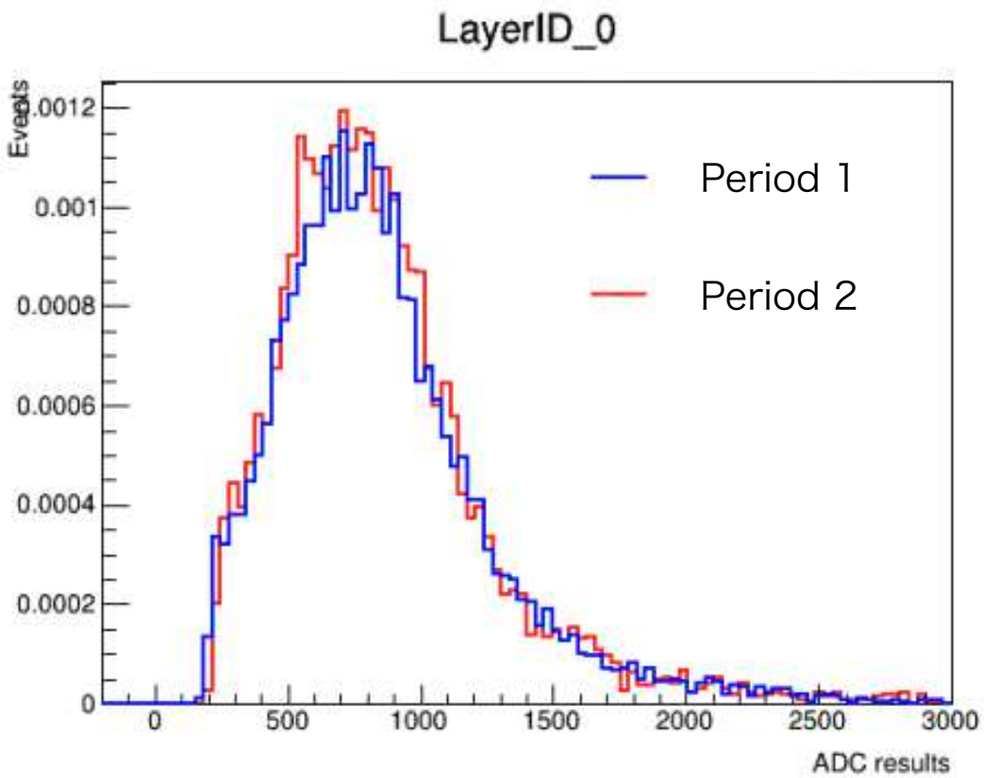
Temperature and gain correction

- Temperature dependence of SiPM gain
  - -2%/℃
- Gain correction according to temperature is implemented
  - Setting 18 ℃ as reference temperature

Two period with large temperature difference



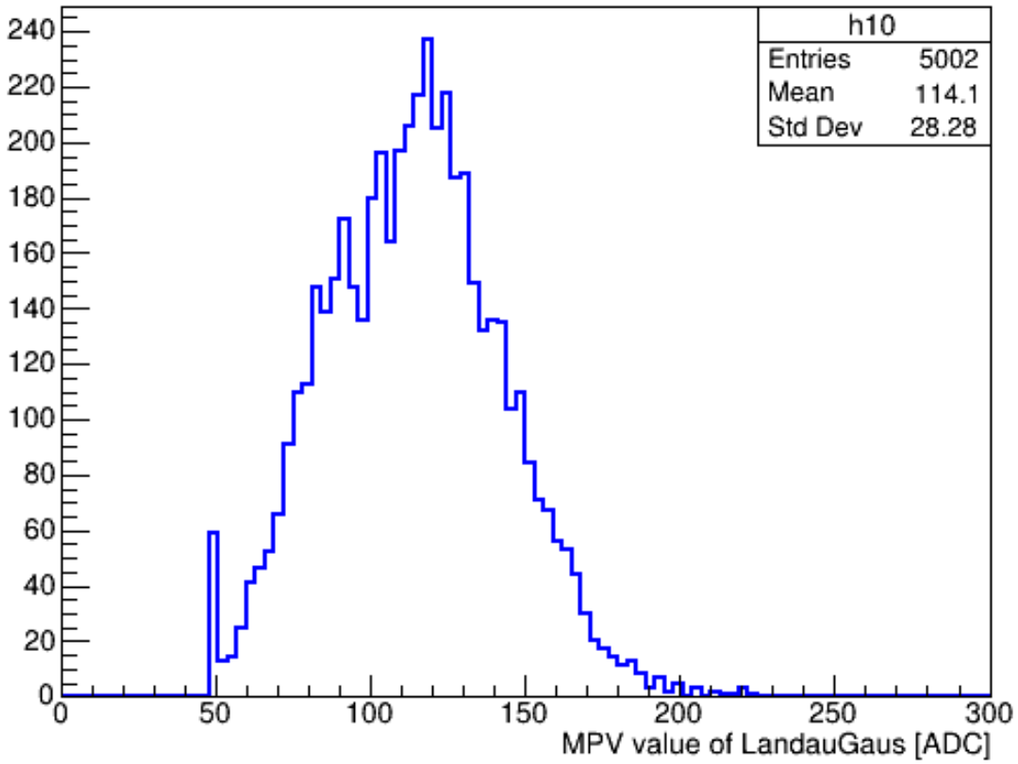




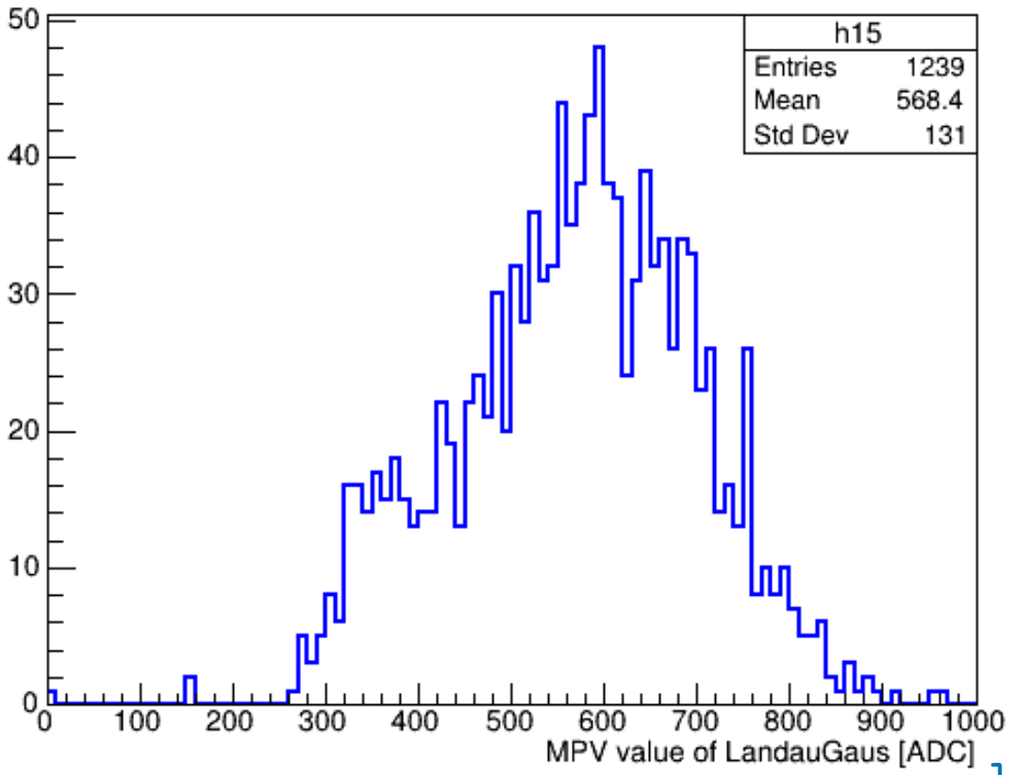
MIP calibration

- **Preliminary Cell-to-cell MIP calibration succeeded**
  - After the angle and gain correction
- MIP values widely spread
  - MIP value is different channel to channel and chip to chip
- Dead channels ~1%
  - 66 / 6720(32*210)

MIP for EBU with 10um MPPC

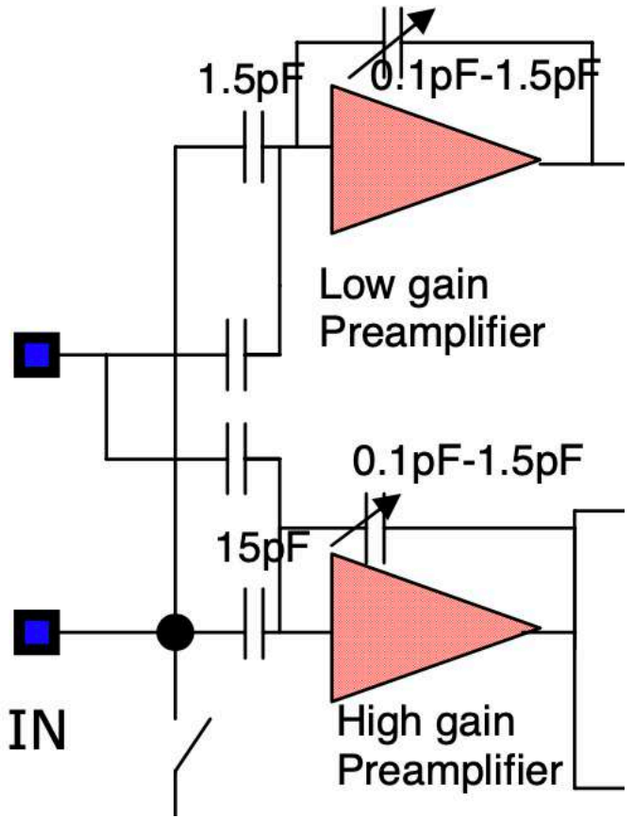


MIP for EBU with 15um MPPC

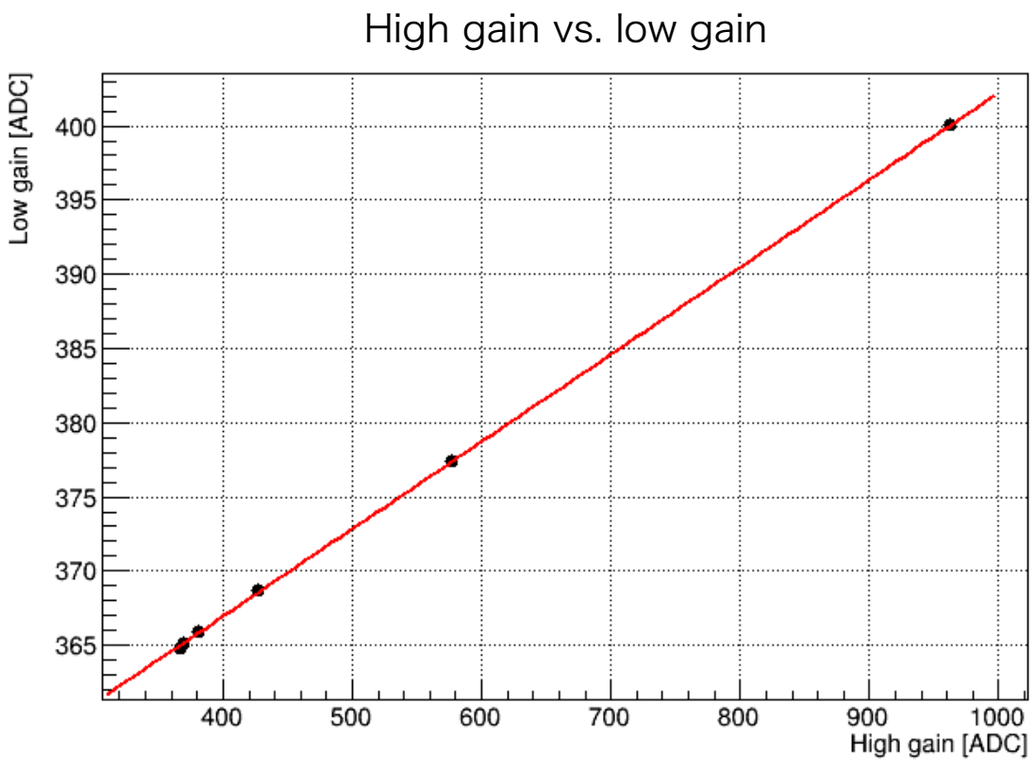


LED calibration (Inter-calibration)

- LED calibration
  - Inter-calibration of low gain and high gain for electronics
  - Gain calibration of SiPMs (going to study)
- SPIROC2E has high gain and low gain preamplifier
  - Record both data



- Inter-calibration factor obtained by the gradient of the relation
  - Check ADC counts of high gain and low gain, and these relation
    - Turn on LED at different voltages



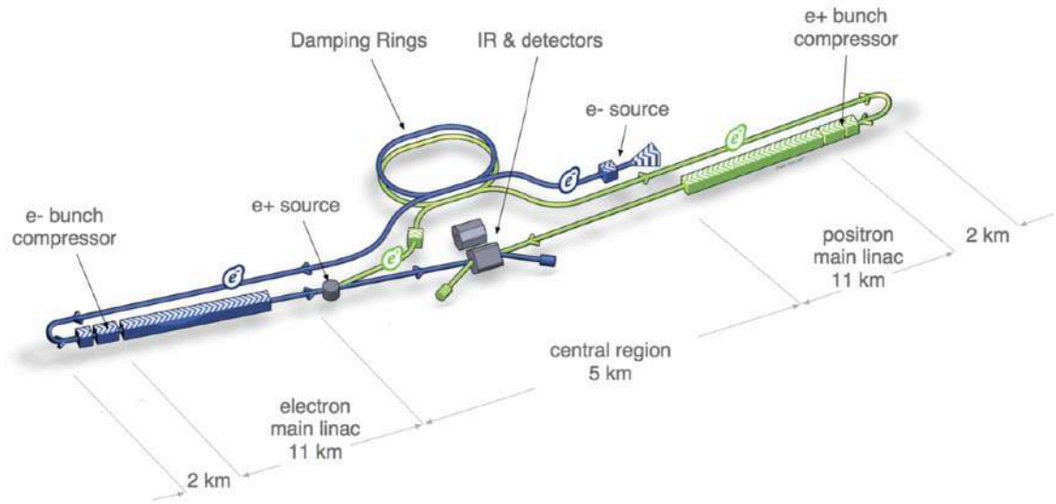
Summary and Prospects

- Sc-ECAL technological prototype
  - Strip assembly on EBU and mounting on mechanical structure completed
- Cosmic-ray test
  - 2 mm position resolution achieved
  - Correction of incident angle and temperature effect implemented
  - Cell-to-cell MIP calibration implemented
- LED calibration
  - Inter-calibration of high gain and low gain is on going
- IHEP test beam
  - Under analysis of event building and particle ID
- Prospects
  - Calibration and data analysis are ongoing
  - Beam test at DESY planned in 2021

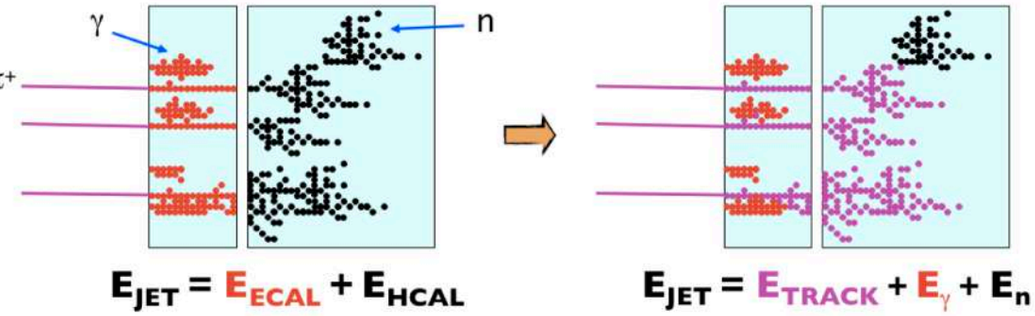
Backup

ILC (International Linear Collider)

- Future high energy frontier machine
  - Electron-positron linear collider
  - Ecm : 250-500 GeV (extendable to 1 TeV)
- Precise measurements in low background environment



- ILD (International Large Detector)
  - vertex detector, central tracker, EM calorimeter, hadron caloriemeter, and muon tracker.
- PFA (Particle Flow Algorithm)
  - Each particle is detected by the best suited detectors.
  - Improved jet energy resolution

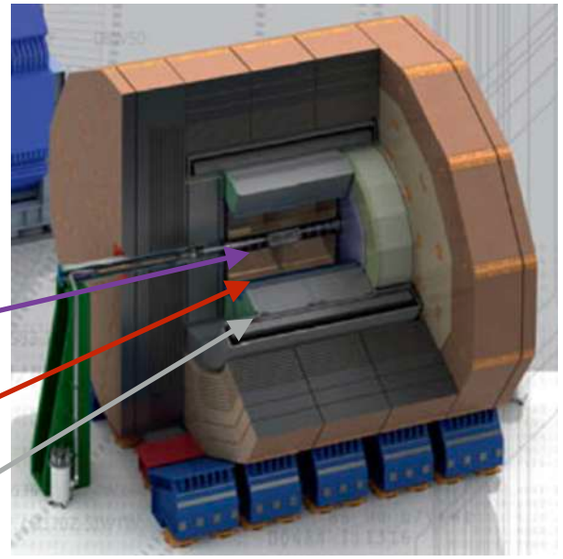


- In order to realize the PFA, high granularity calorimeter is required.

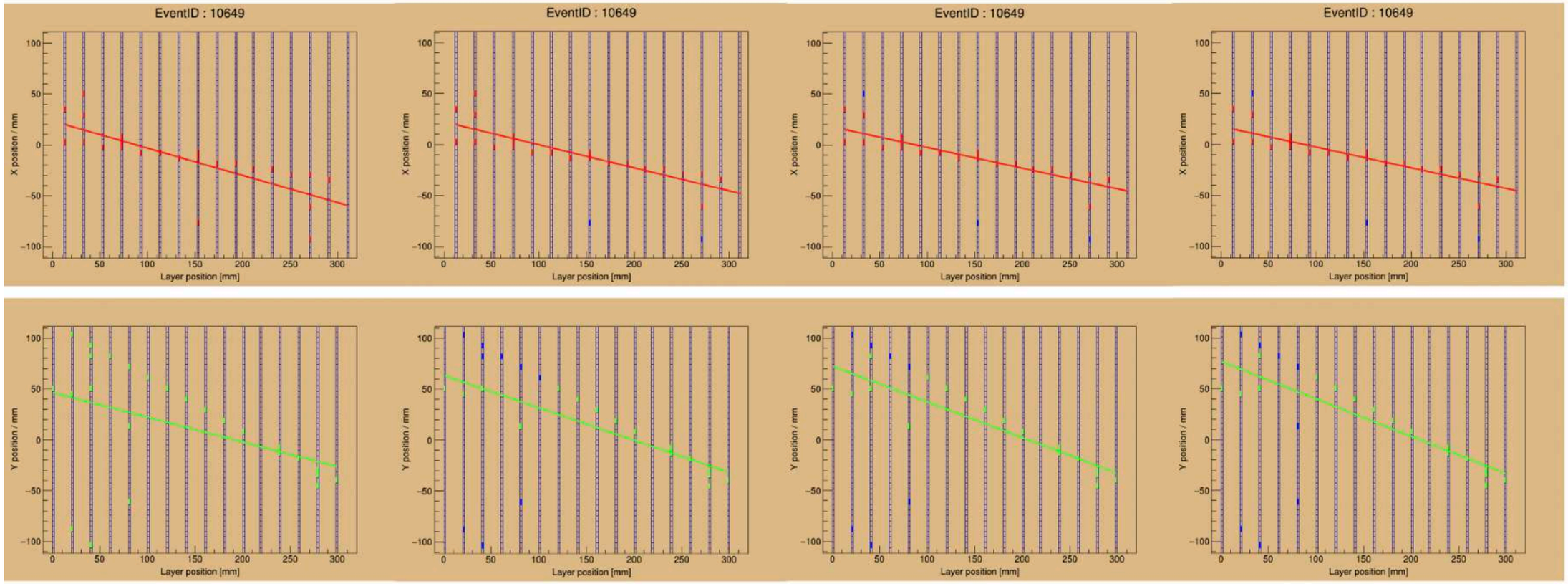
Charged particle → inner tracker

Gamma → ECAL

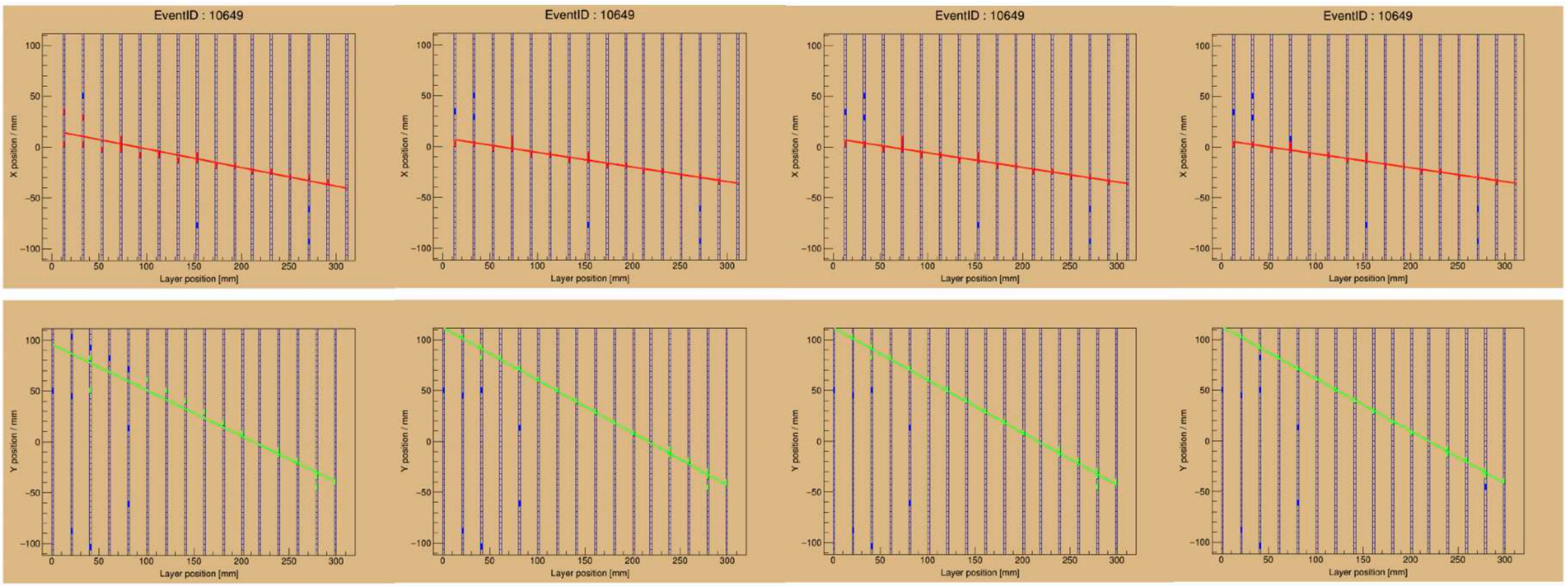
Neutral hadron → HCAL



Iterative fitting

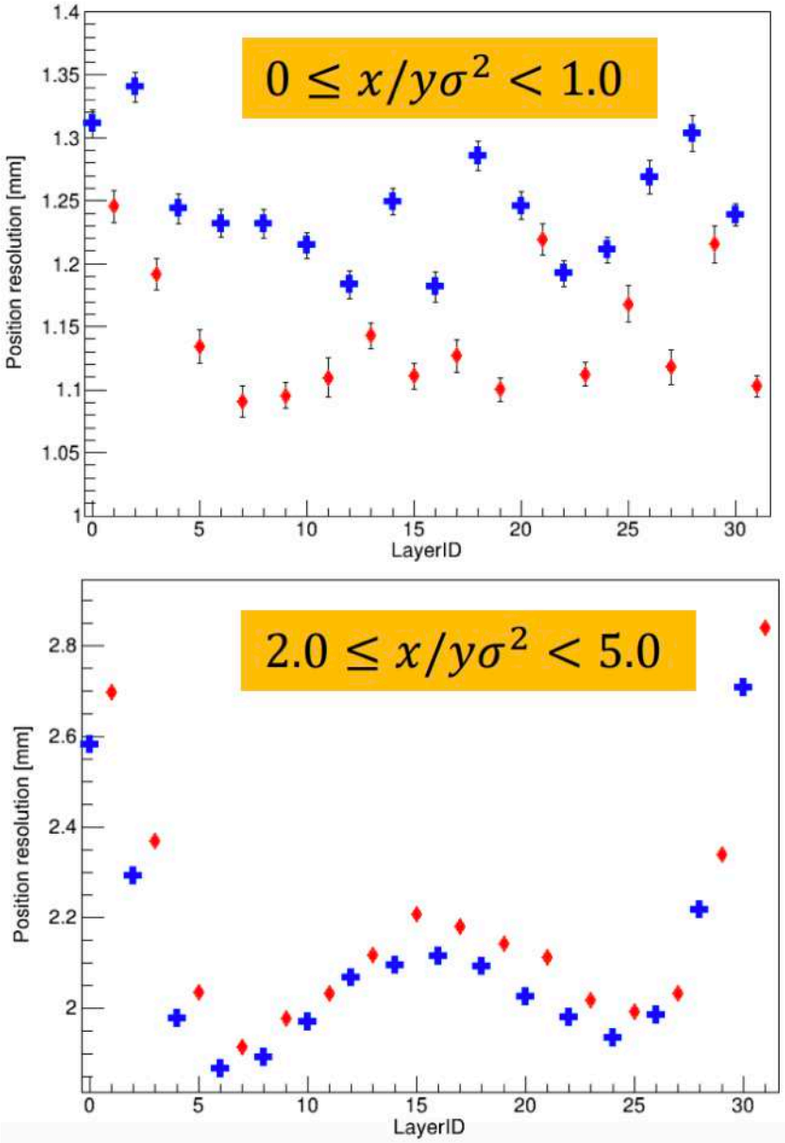


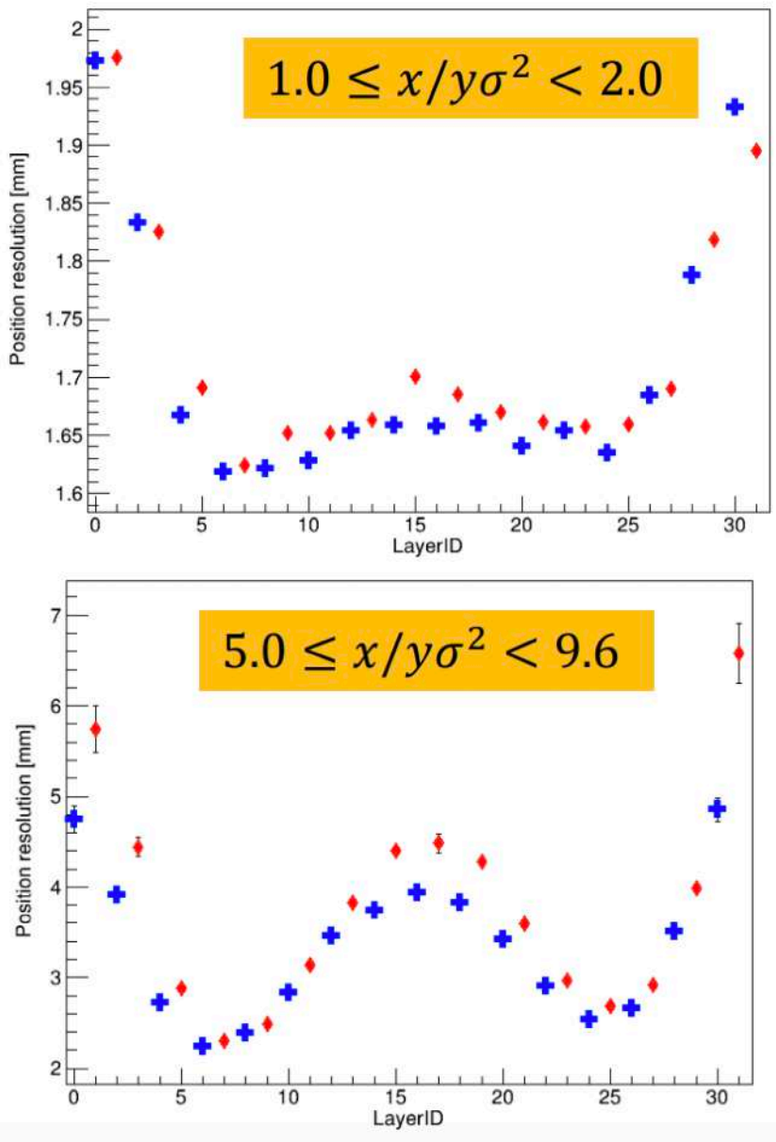
all hits | $|x/y - tracking| \leq 37.5$ | $|x/y - tracking| \leq 32.5$ | $|x/y - tracking| \leq 27.5$

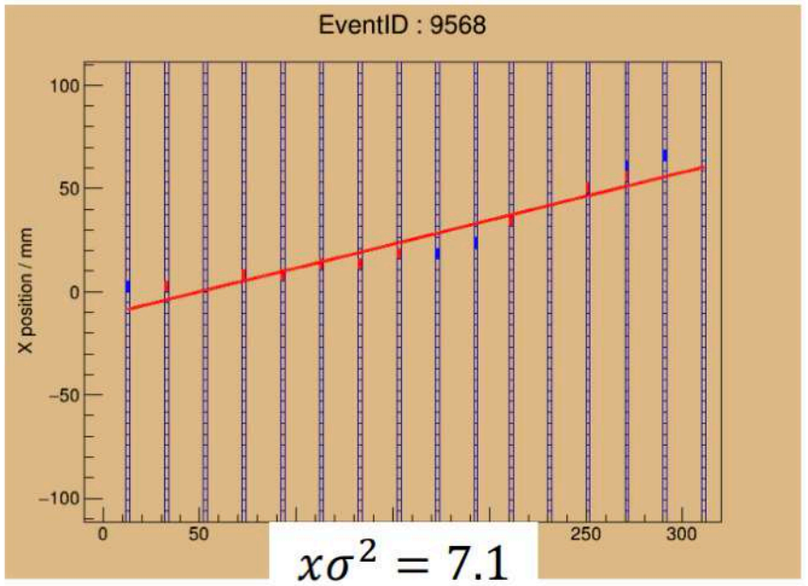


$|x/y - tracking| \leq 22.5$ | $|x/y - tracking| \leq 17.5$ | $|x/y - tracking| \leq 12.5$ | $|x/y - tracking| \leq 7.5$

Large angle scattering

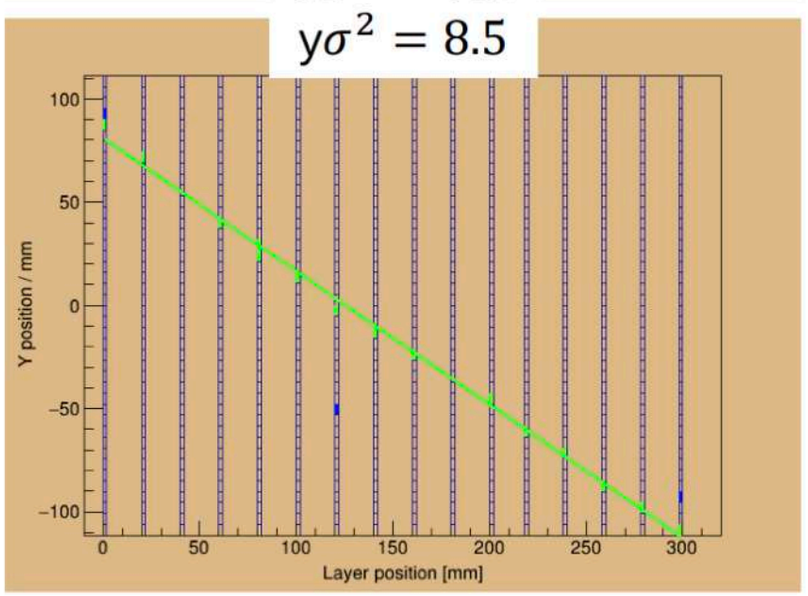




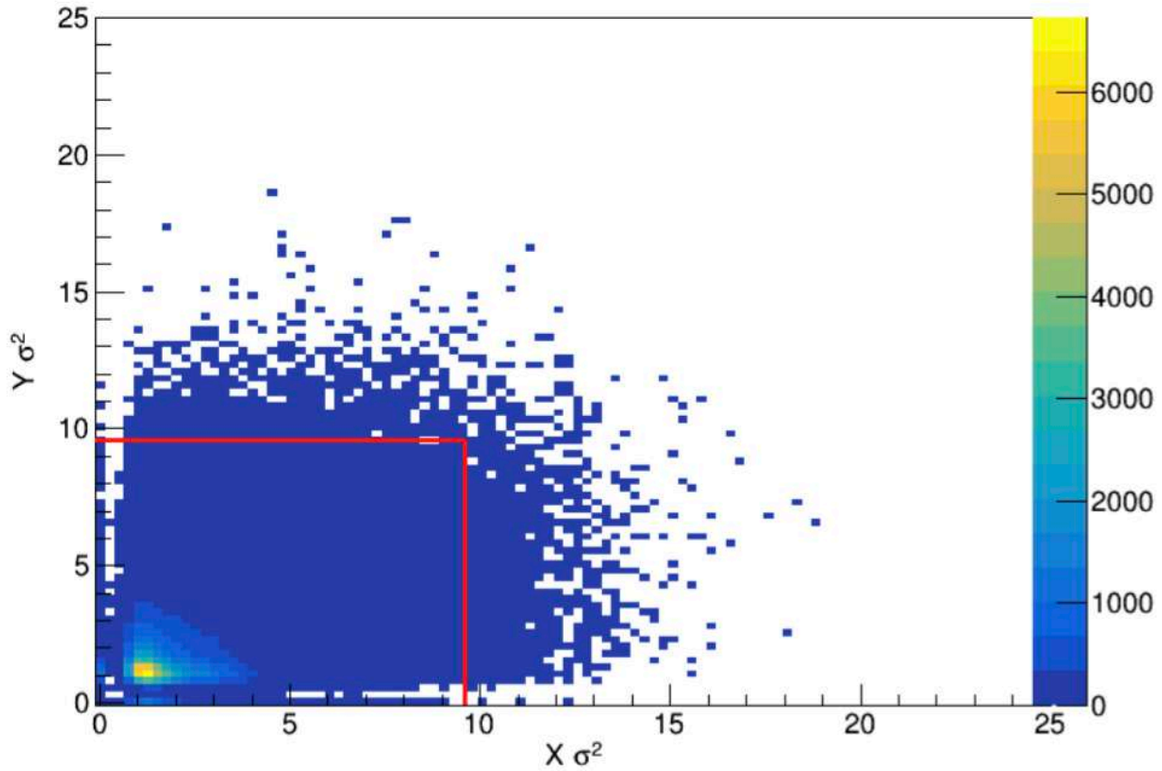


$x\sigma^2 = 7.1$

$y\sigma^2 = 8.5$



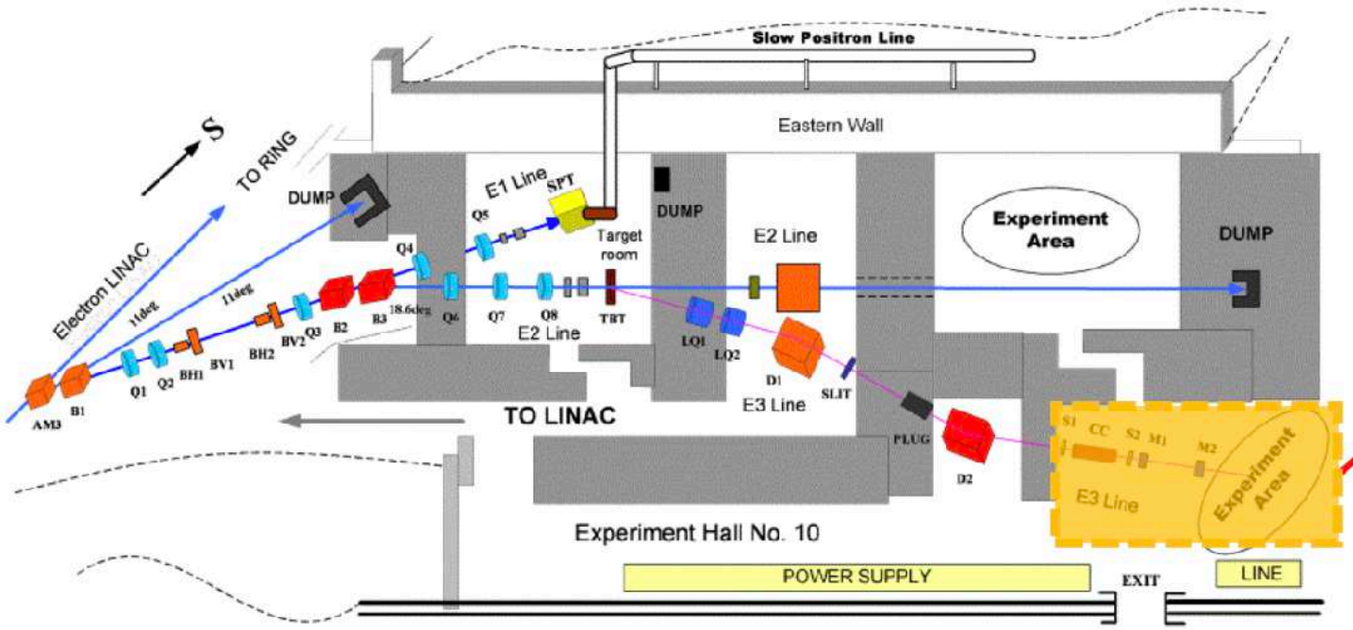
Residual Sum of Squares

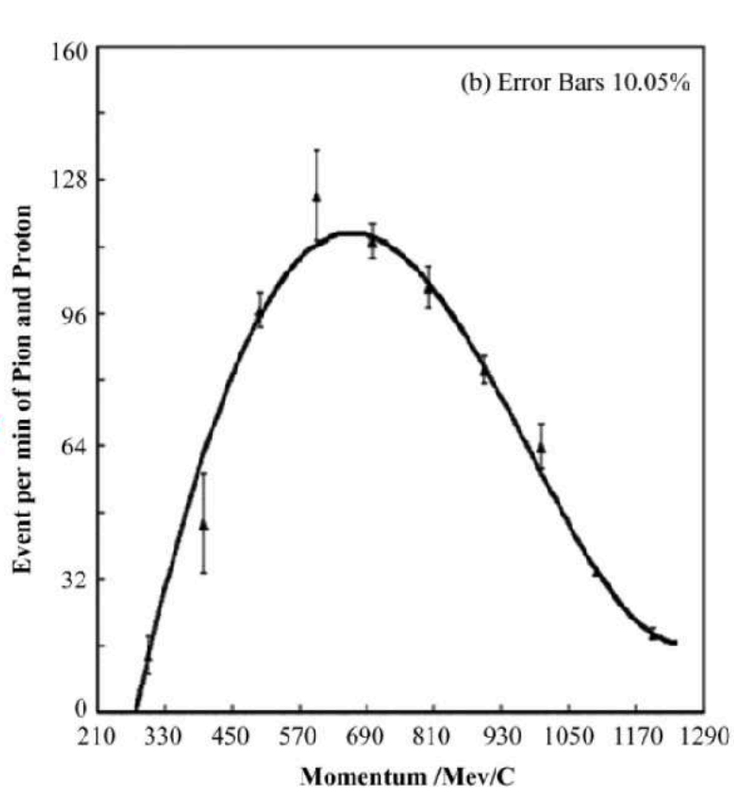


- Residual : $\hat{\varepsilon}_i = Y_i - \hat{Y}_i$
- Residual Sum of Squares : $RSS = \sum_{i=1}^{n} \hat{\varepsilon}_i^2$
- σ^2 unbiased estimation : $\hat{\sigma}^2 = \frac{1}{n-2}\sum_{i=1}^{n} \hat{\varepsilon}_i^2$

Beam test at IHEP

- E3 beam line: secondary particle beam
  - Mixed with proton/pion: proton dominate
  - Energy: 300 MeV - 1.2 GeV
  - Event rate: ~100 per minute
- The beam was not suitable
  - Low momentum, low rate, pre-shower





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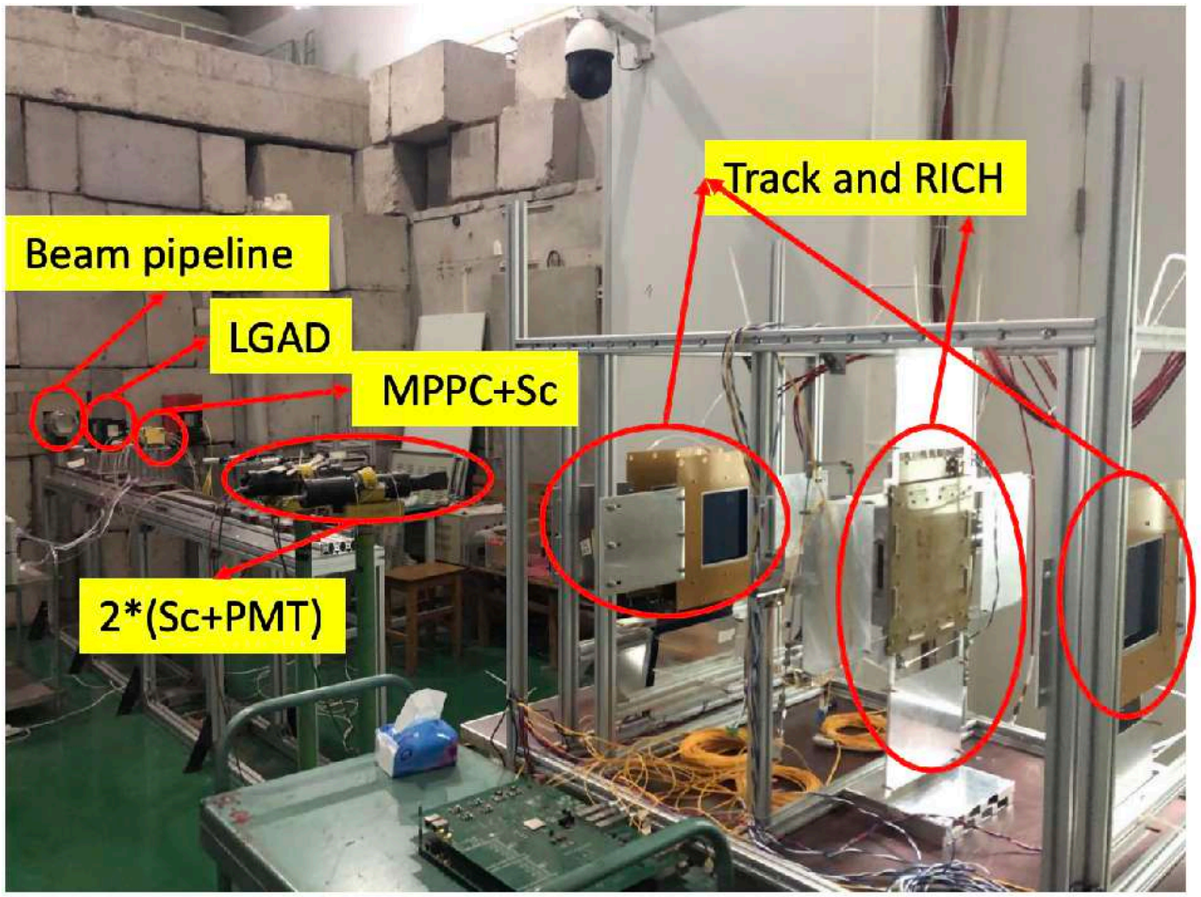
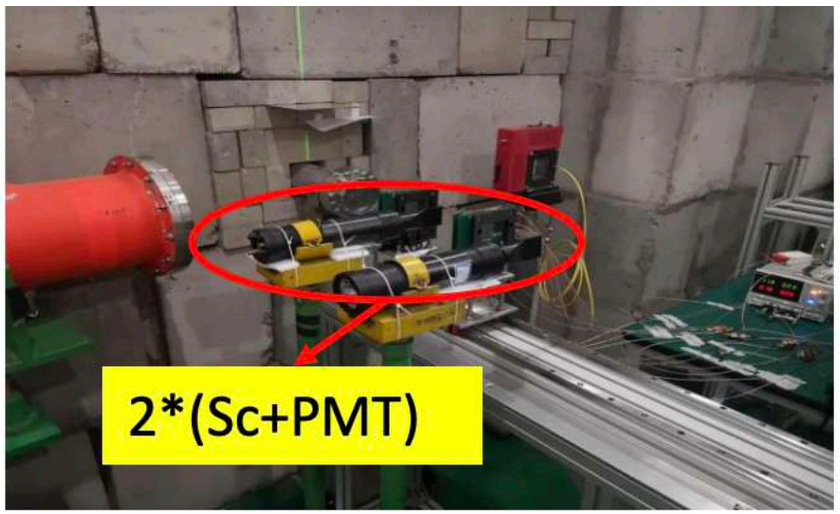
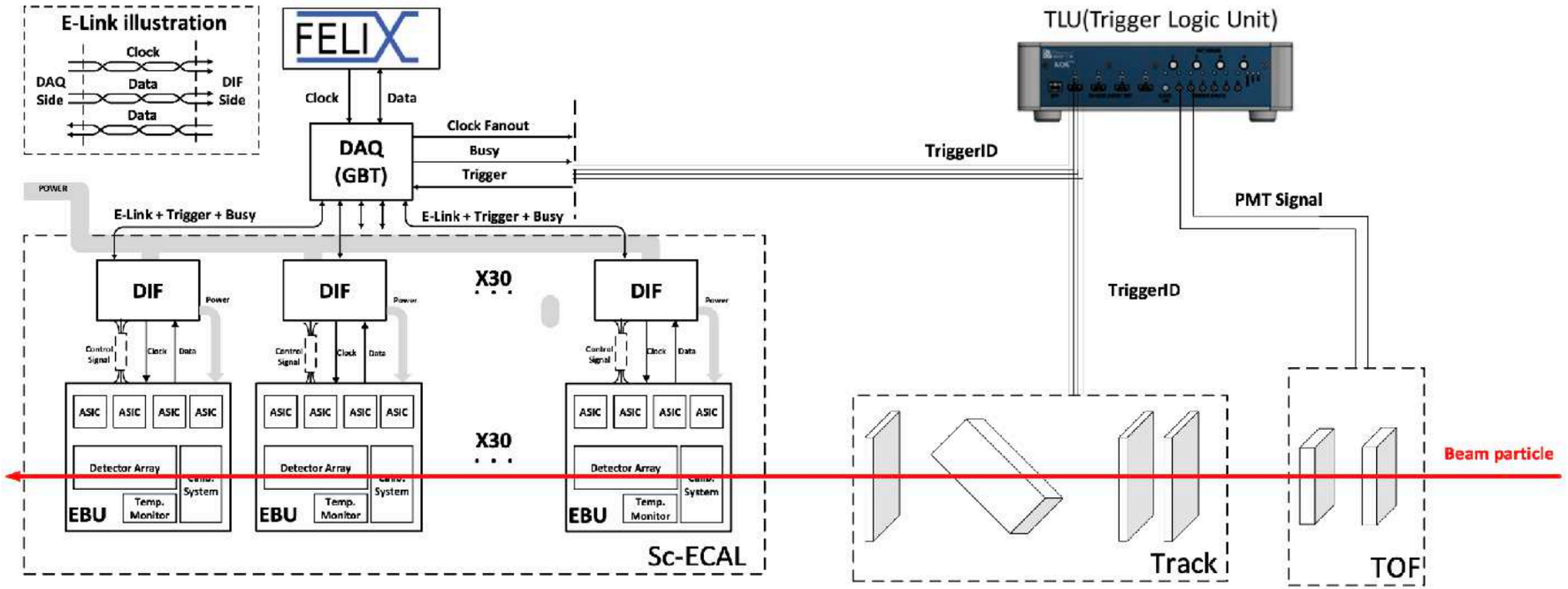
Setup


Beam pipeline
LGAD
MPPC+Sc
2*(Sc+PMT)
Track and RICH

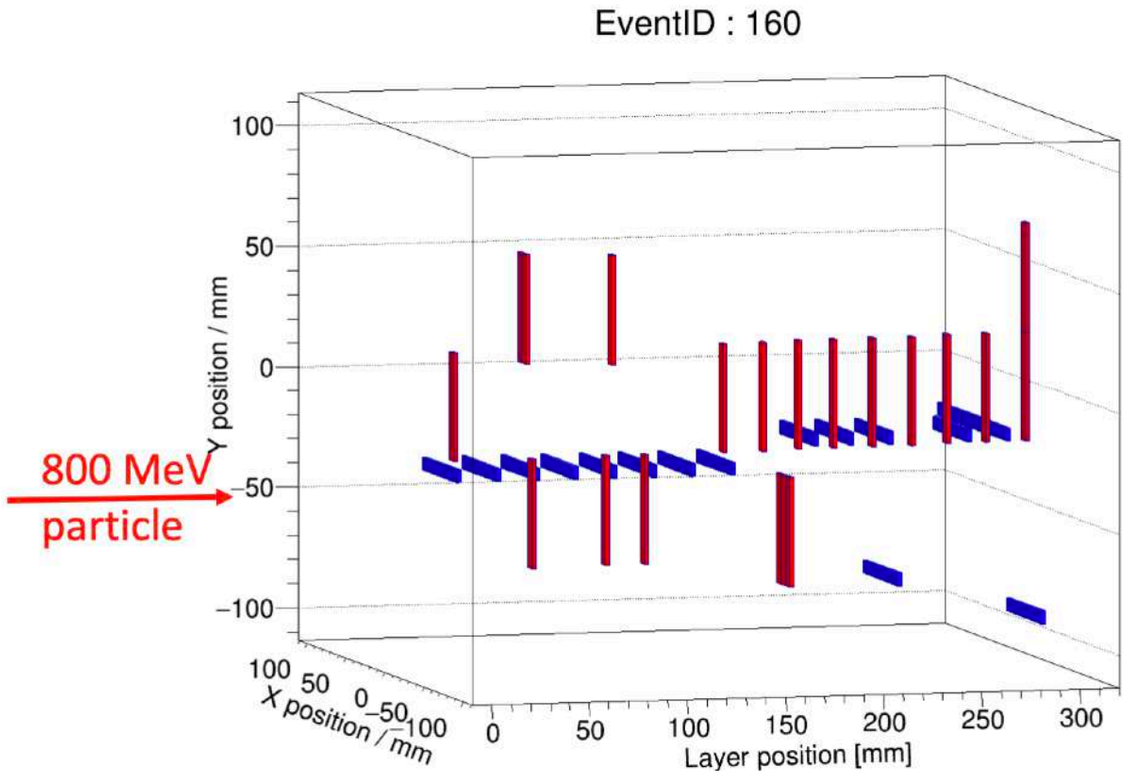

2*(Sc+PMT)

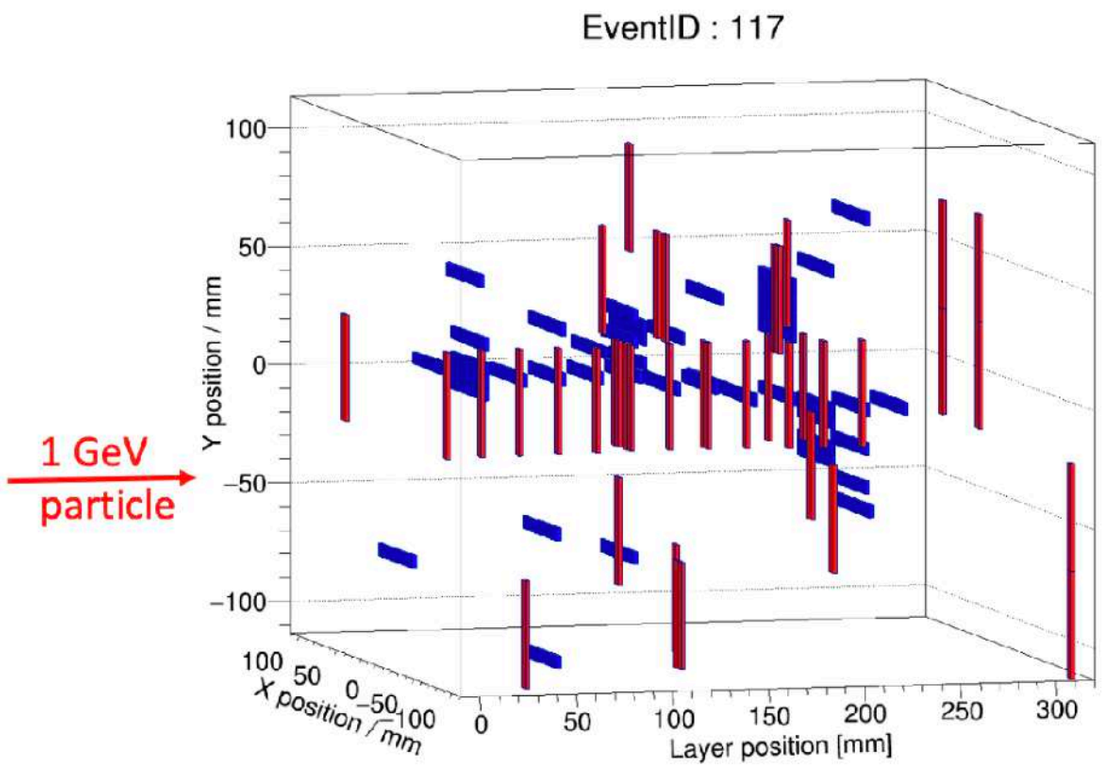

Sc-ECAL prototype


E-Link illustration
Clock
DAQ Side
Data
DIF Side
Data
FELIX
Clock
Data
DAQ (GBT)
Clock Fanout
Busy
Trigger
POWER
E-Link + Trigger + Busy
E-Link + Trigger + Busy
DIF
Power
Control Signal
Clock
Data
ASIC
Detector Array
Calib. System
Temp. Monitor
EBU
X30
Sc-ECAL
TLU(Trigger Logic Unit)
TriggerID
PMT Signal
TriggerID
Beam particle
Track
TOF

Event building

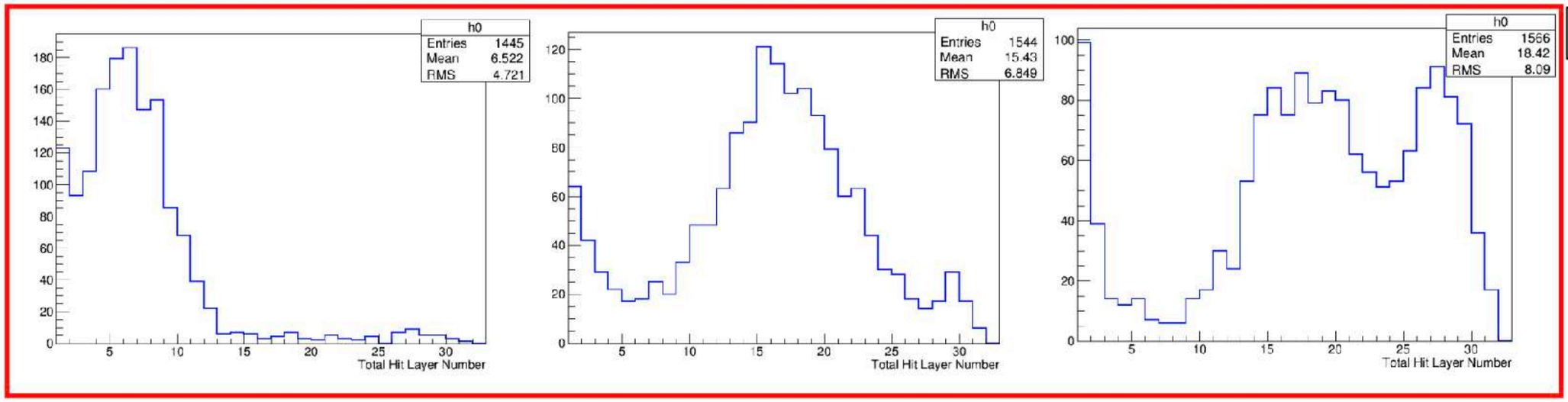
- Event building with track detectors successfully done
- Particle track can be seen at the prototype
  - Not ideal track because of the beam condition
  - Under analysis of event building and particle ID



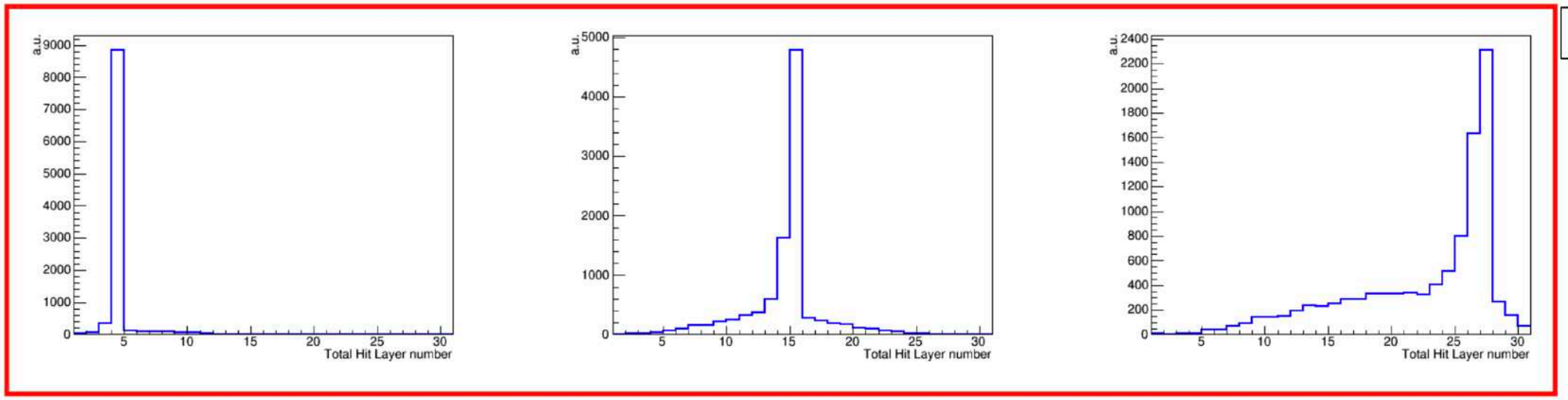


Preliminary results

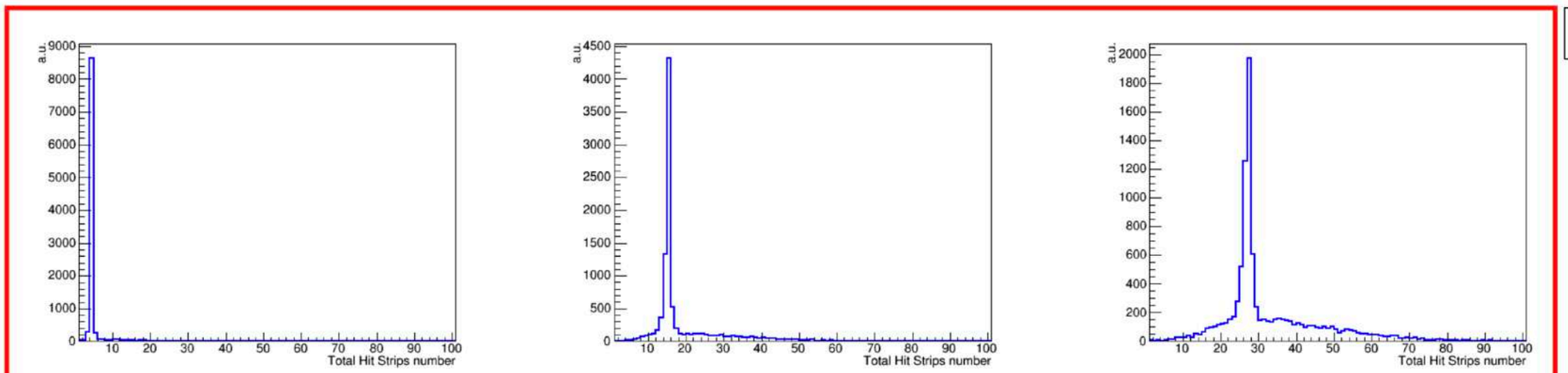
- Hit distribution is widely spread
- Beam was not suitable
  - Large contamination
  - Not well collimated



Sc-ECAL MC results - proton



Total hit Layer number



Total hit Strip number

P = 500 MeV

P = 800 MeV

P = 1000 MeV