A SiW-ECAL optimized for e+e− collisions

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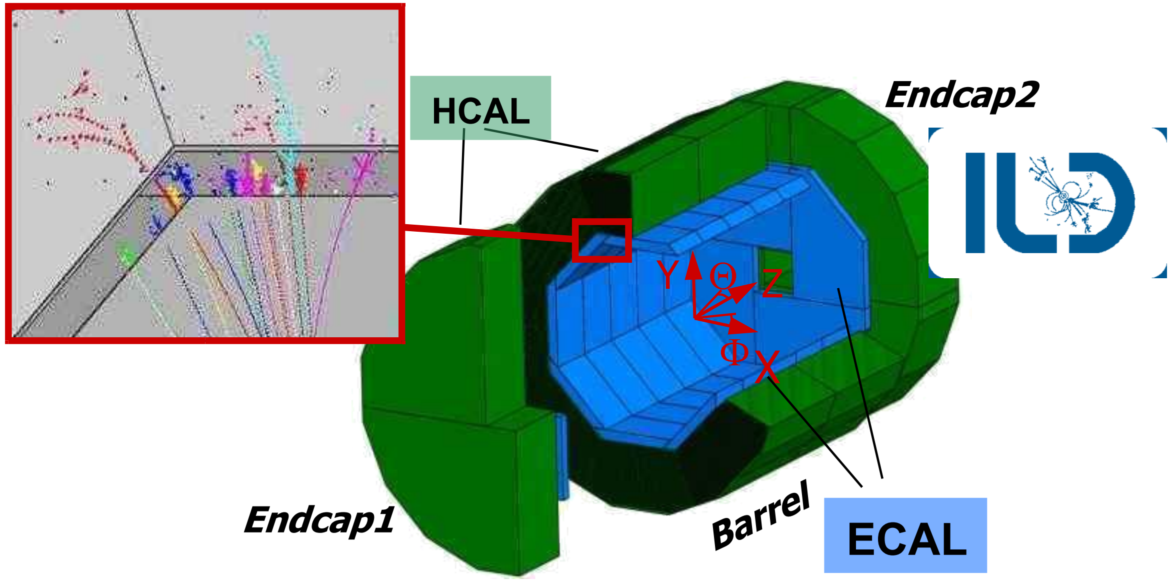
SiW-ECAL: Physics Scope



CALICE ➞ DRDCalo (DRD6)

- Highly-Granular Calorimeters Technologies for Future Higgs Factories Experiments
  - FCC-ee,ILC, CLIC, CEPC

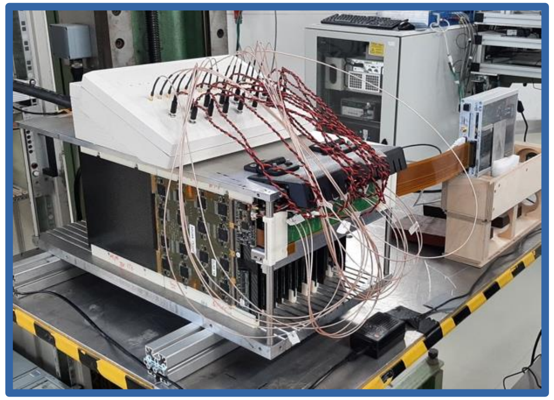
➞ Particle Flow approach:

- Track Charged particles by imaging calorimeters, Measure neutrals (γ, h^0)

Technological prototypes: SiW-ECAL, ScintW-ECAL, AHCAL, SDHCAL

– ⊃ most technological constraints for ILC-calorimeters: Embedded ASICs, Self-Trigger, Delayed RO,
min dead-space, …

➞ LOW DUTY cycle (~10%)



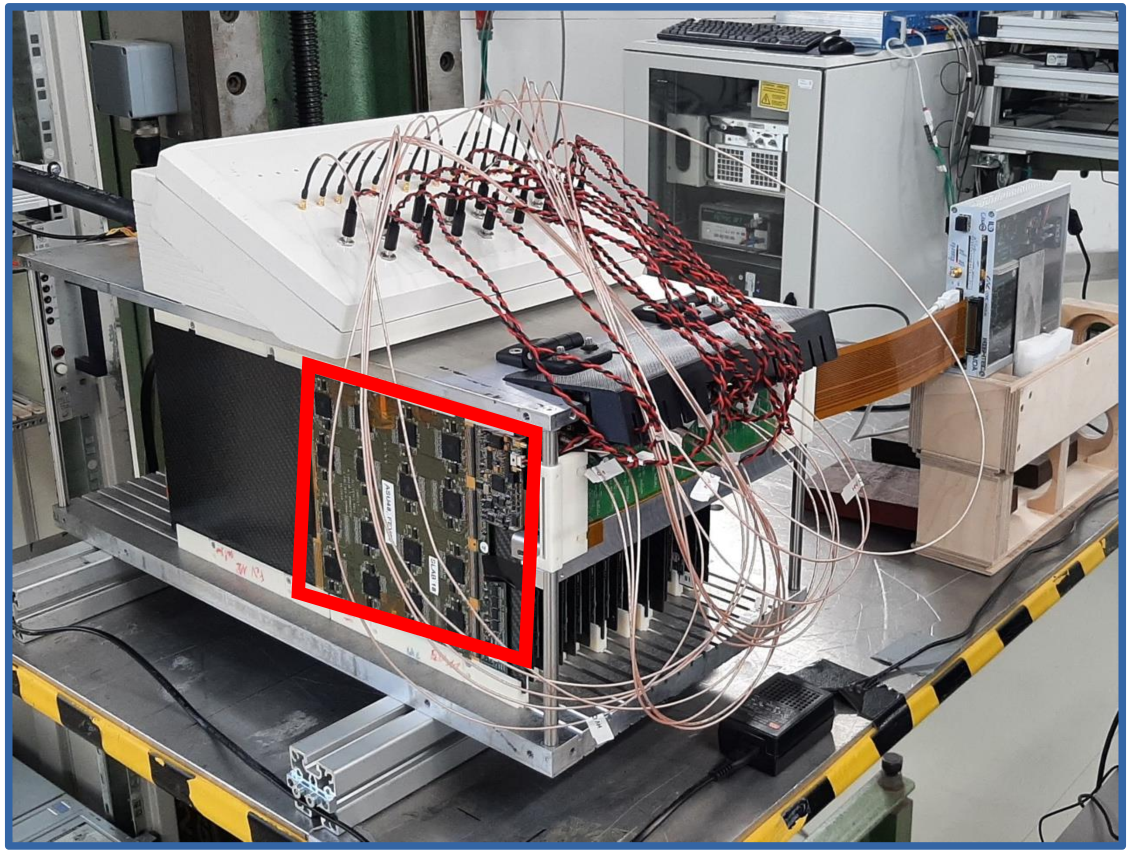
Calorimeter description

A Stack of 15 sensor layers separated by W absorbers

- 1 Sensor layer =
    - 4 wafer [500 µm × (5.5mm)² Si PIN Diodes] ➞ 18×18 cm²
    - 1 PCB (Fev2.1)
    - 16 ASICs (SKIROC2a)
- Tungsten absorbers:
    - 8 × 4.2 mm [1.2 X_0] + 7 × 5.6 mm [1.6 X_0]
    - Total= 20.8 X0
- ~80 kg, 0.4×0.4×80 cm³

Ancillaries:

- Rack ~ 1.5m
- On a stage for (x, y) scans
- HV = 120–150 V.

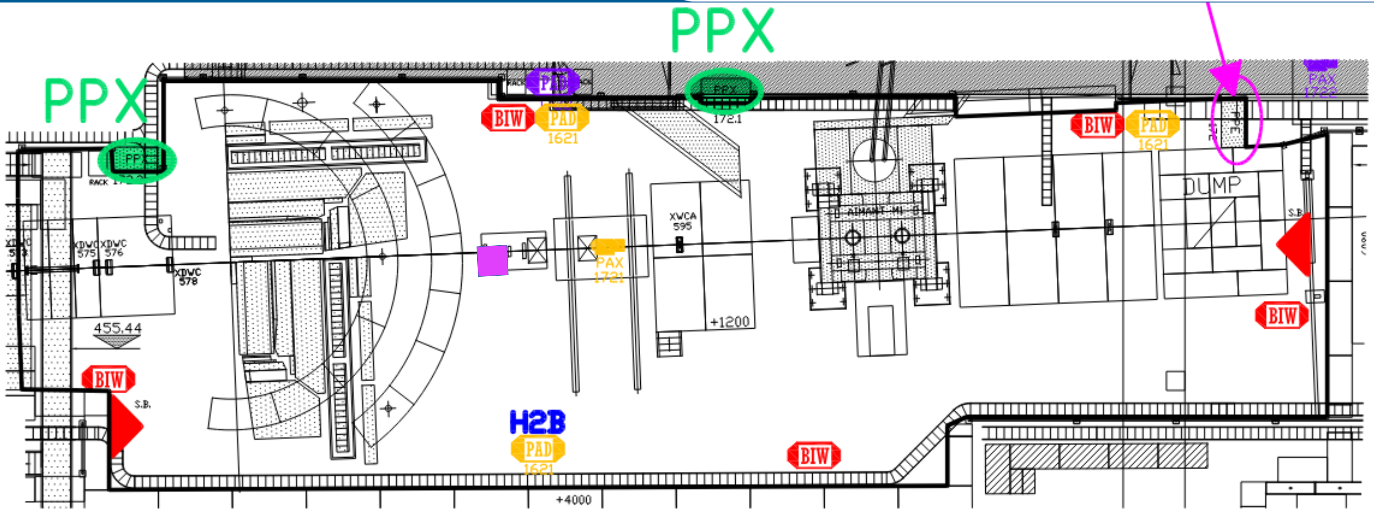


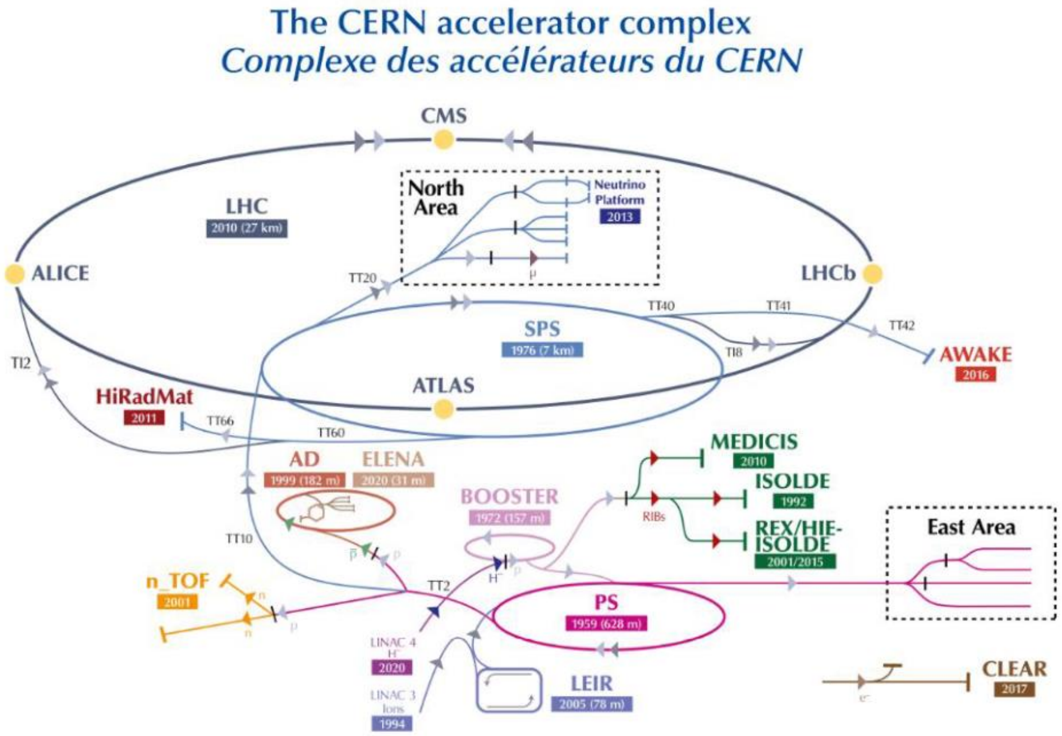
Beam site

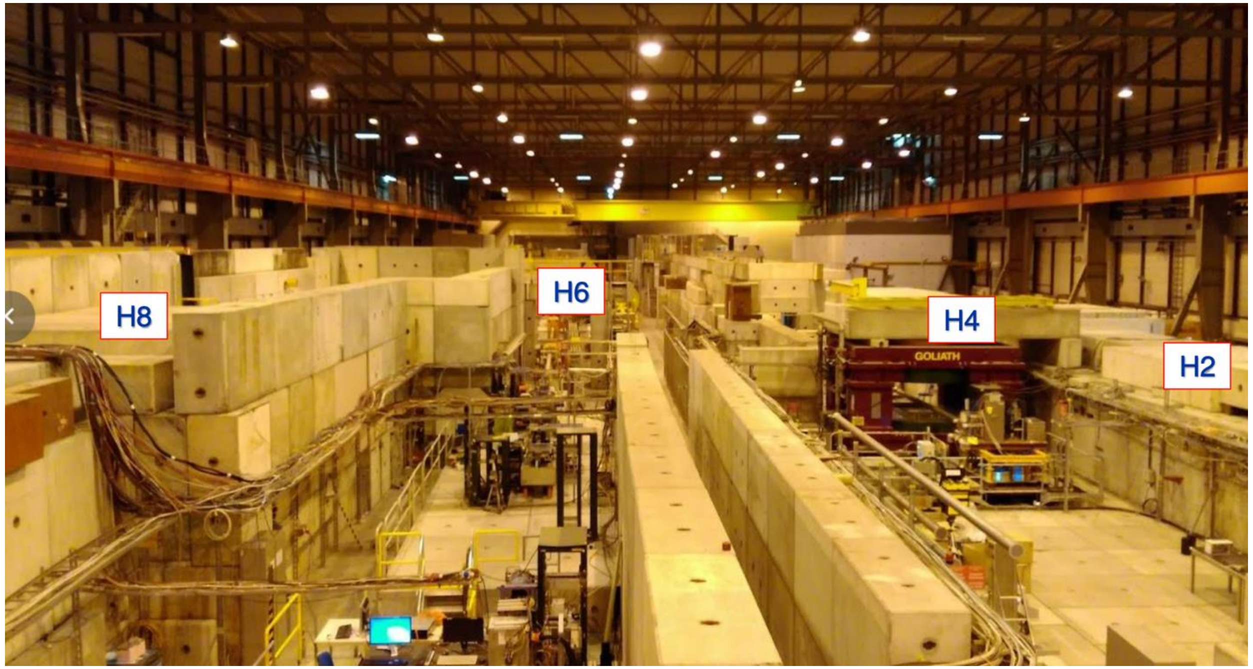
Beam test in June 17th-25th

Beam site: H2 @SPS

Up to 400 GeV particles are provided







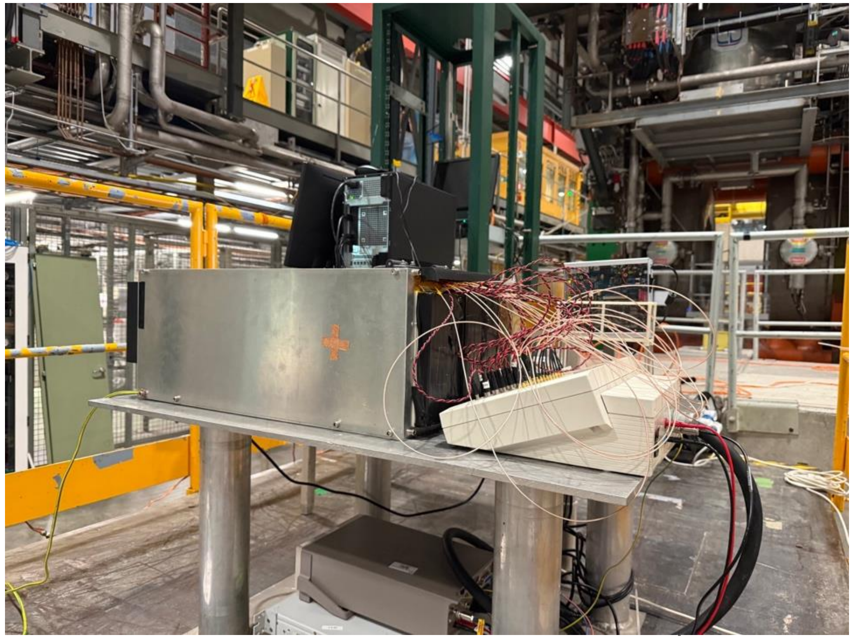
Beam test overview

An international group

- France, China, Germany, Spain, Mexico and South Africa were involved

Data taken in 10 days: more than 300 runs

- 150 GeV muon data
  - Large statistics for calibration
  - fine position scan
- electron/positron data ranging from 7.5 to 99 GeV
  - Fine angular and position scan
- pion data ranging from 10-30 GeV
- Exploration of electronics: TDC runs



Assembly and recovery

Assembly

- The ECAL prototype was assembled layer by layer.
- After inserting each layer, a power-on test was immediately performed.

Recovery

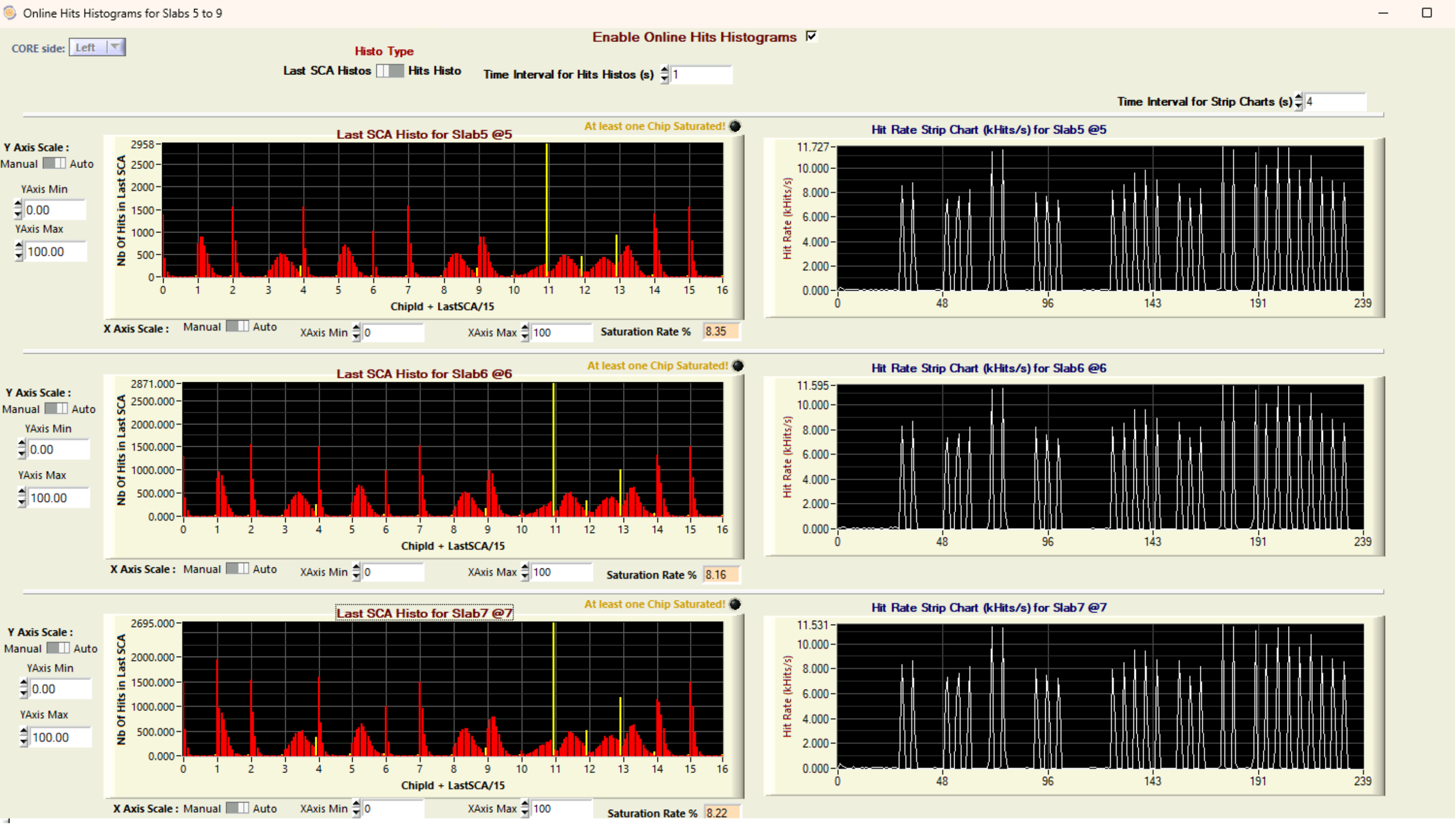
- A connector issue was found in one layer
- The issue was quickly diagnosed and repaired.

The full assembly, debugging, and validation were completed within one afternoon!

This was the best start of beam test in my life!

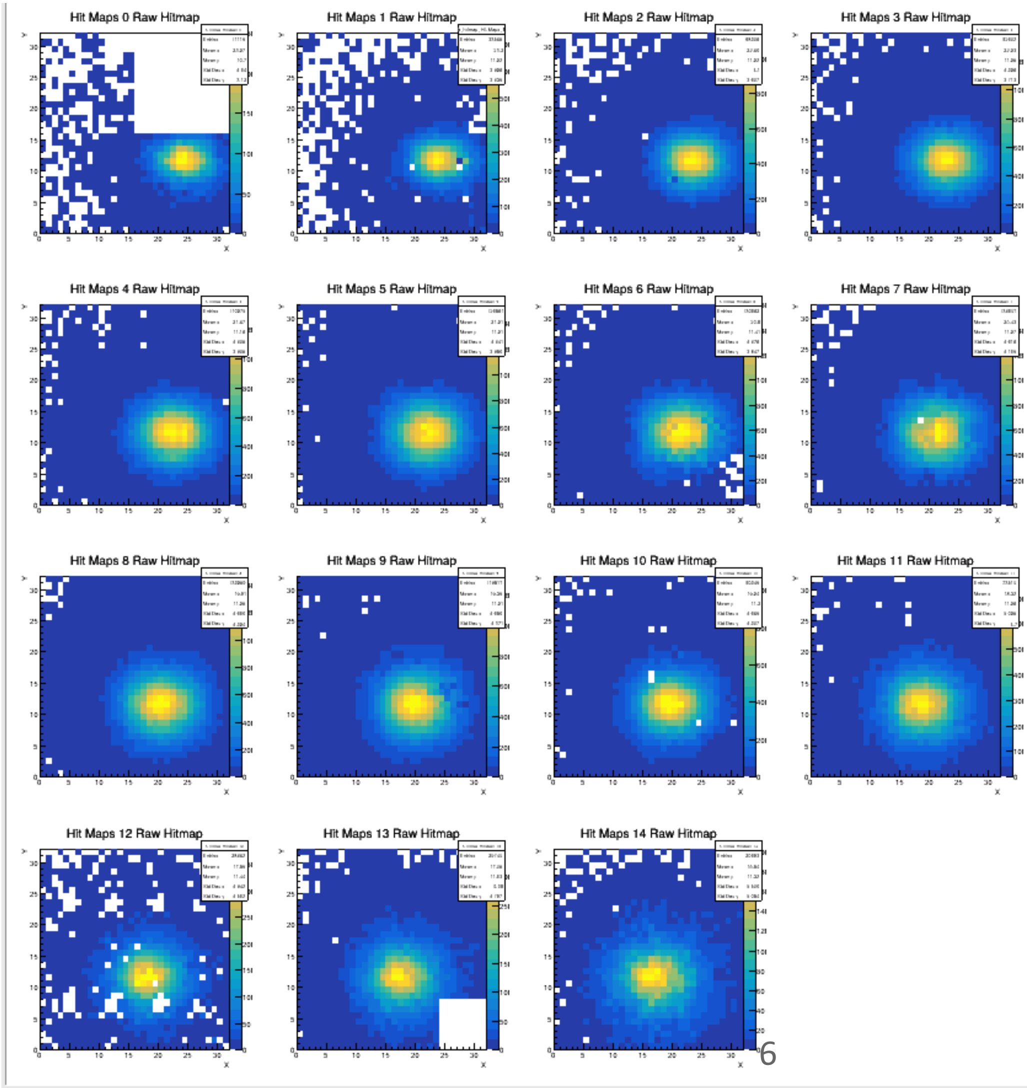
Online monitoring

- Hit map: monitor beam position and development
- Chip memory usage: ensure data quality



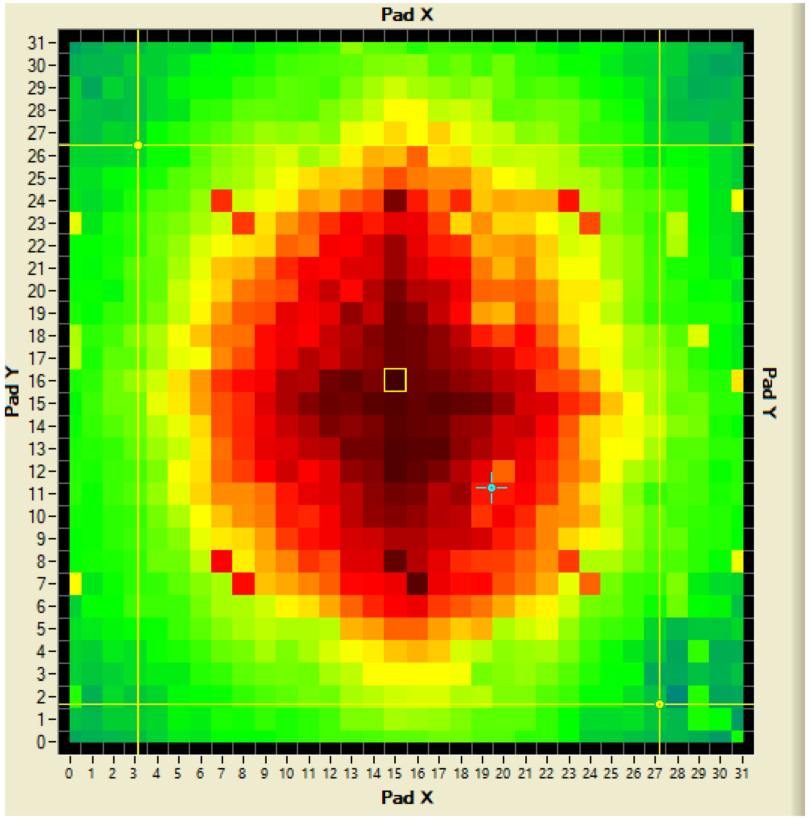
Chip memory usage for 20 GeV electrons

Hit maps for 20 GeV electrons

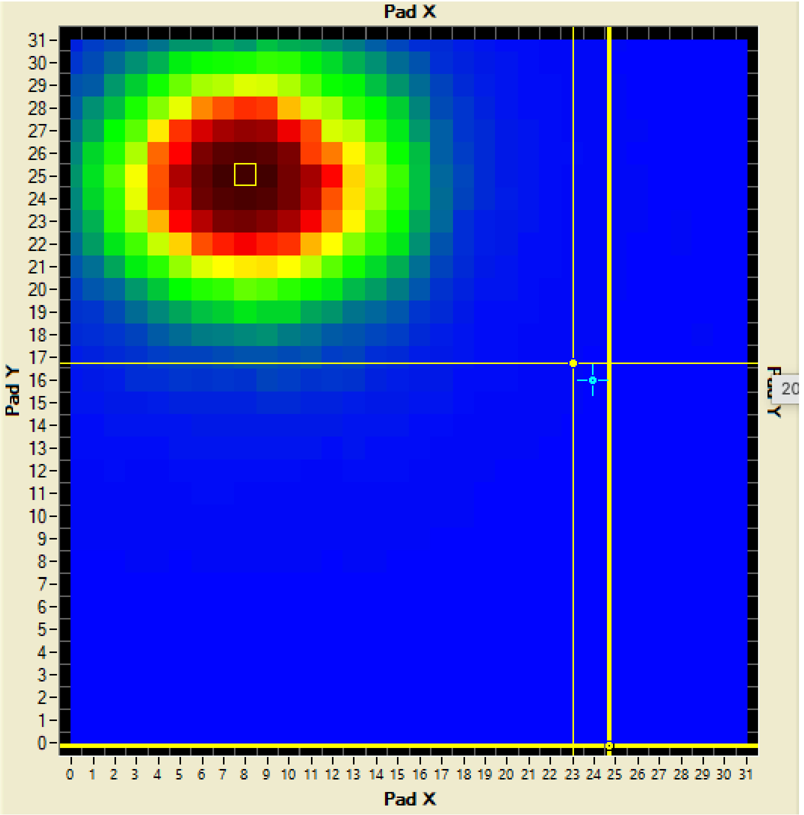


Online monitoring

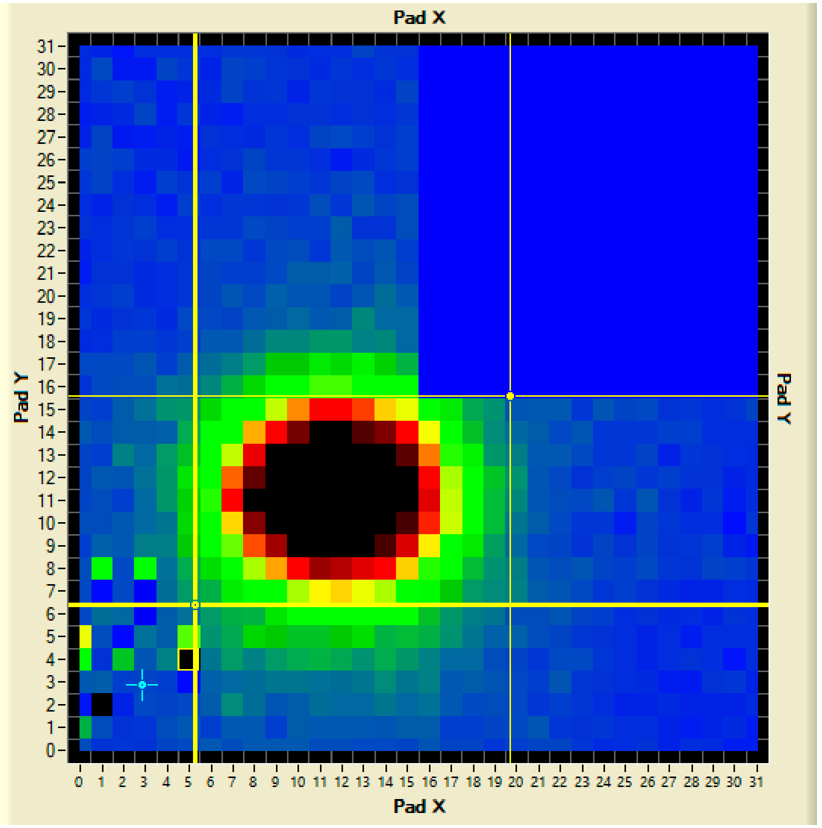
Muon beam was configured to have large beam size to make it easier to calibrate all channels in SiW ECAL prototype



150 GeV muons



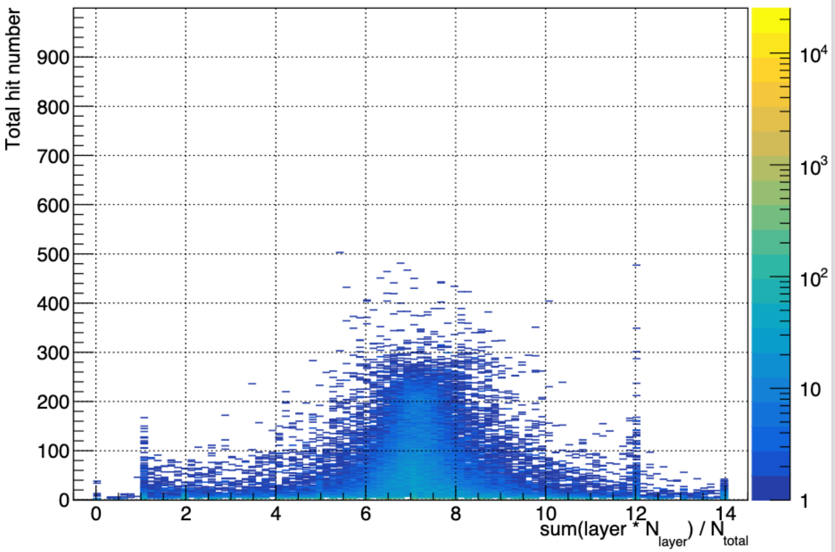
20 GeV electrons



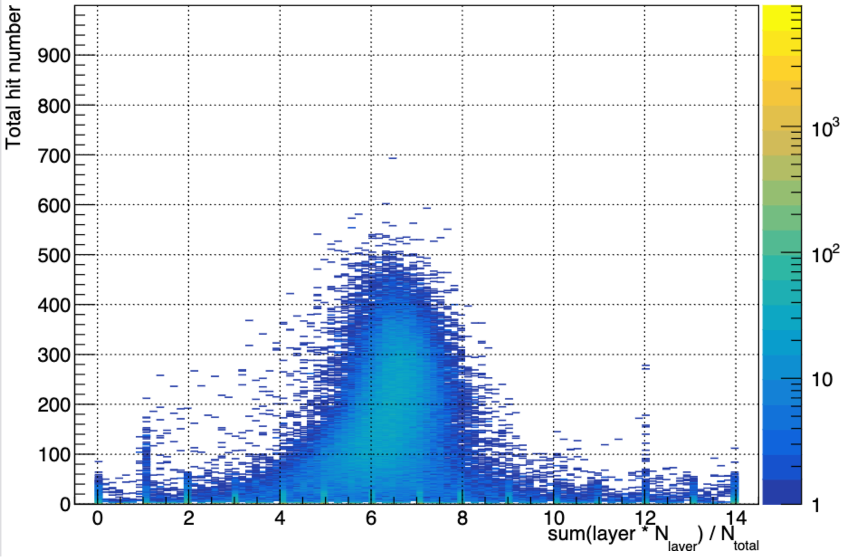
20 GeV pions

Simple PID

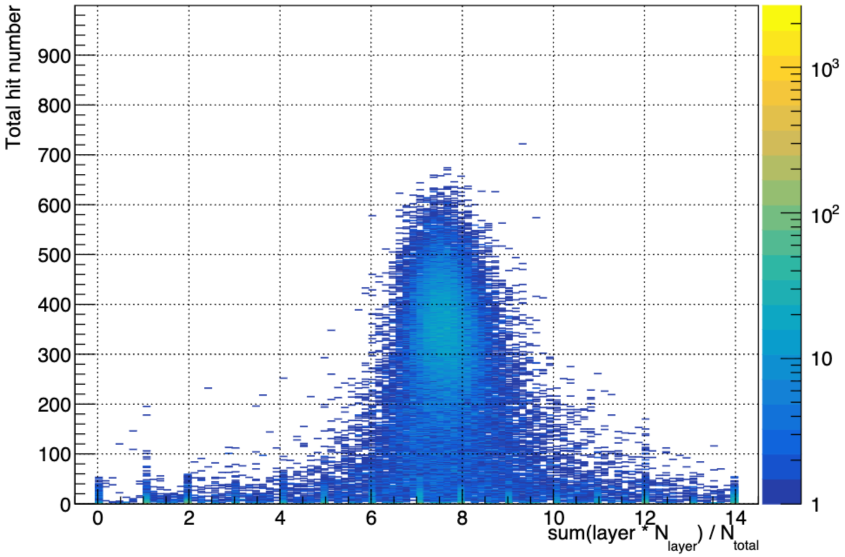
- Electron beam purity at 74 GeV and 99 GeV ~70%
- Use N^{hit}_{total} VS $\sum \text{layer} \times N^{hit}_{\text{layer}} / N^{hit}_{total}$ for simple PID
- Provides only a preliminary indication of the beam purity; further dedicated studies are needed.



150 GeV muons

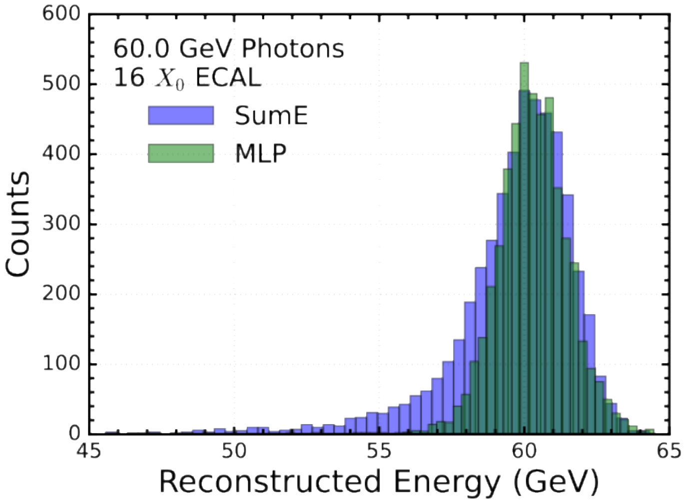


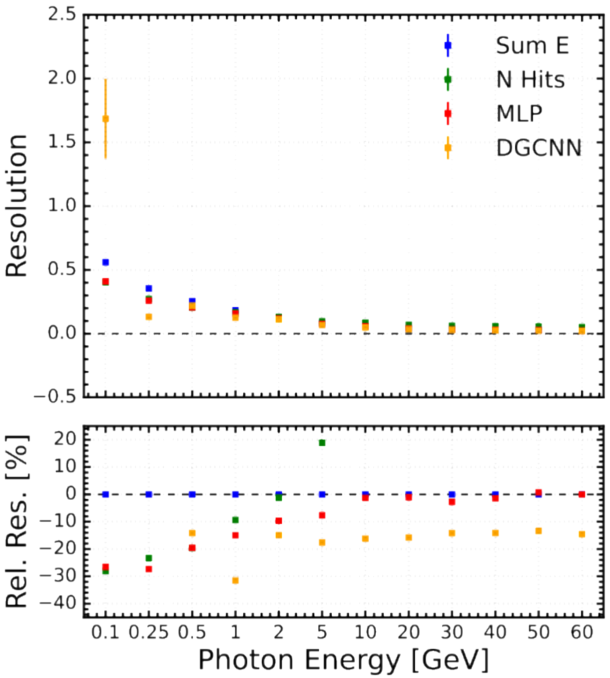
20 GeV pions



74 GeV positrons

Energy reconstruction





Previous work

- ML learning based energy reconstruction algorithm
  - Improves the energy resolution especially for low energy photons
  - Efficiently correct the energy leakage
- Optimisation of a silicon-tungsten electromagnetic calorimeter energy response to photons(arXiv:2604.27853)

Beam data

- Apply current algorithm to beam data
- Tune more powerful models
- Compare electron and pion samples

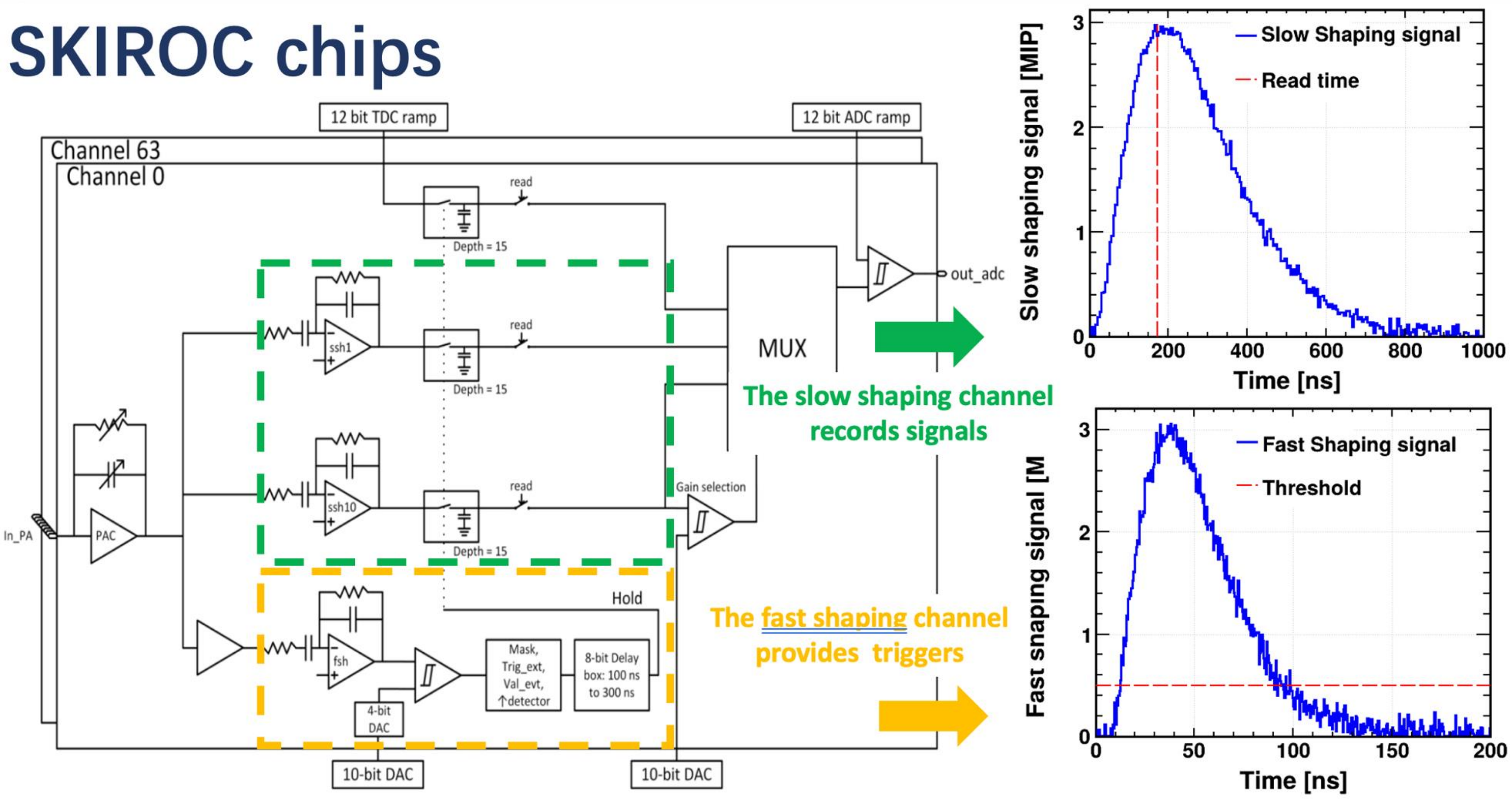
TDC

Previous work

- A digitizer for SKIROC

Beam data

- Different Configurations
  - Gain mode
  - Threshold
  - Shaping time
  - Delay time
- Digitized MC samples will be compared with beam data to evaluate the time resolution



Summary and Plan

Summary

- The whole beam test was quite successful!
- Plenty of data was taken, including muon, pion ,electron and positron.

Plan

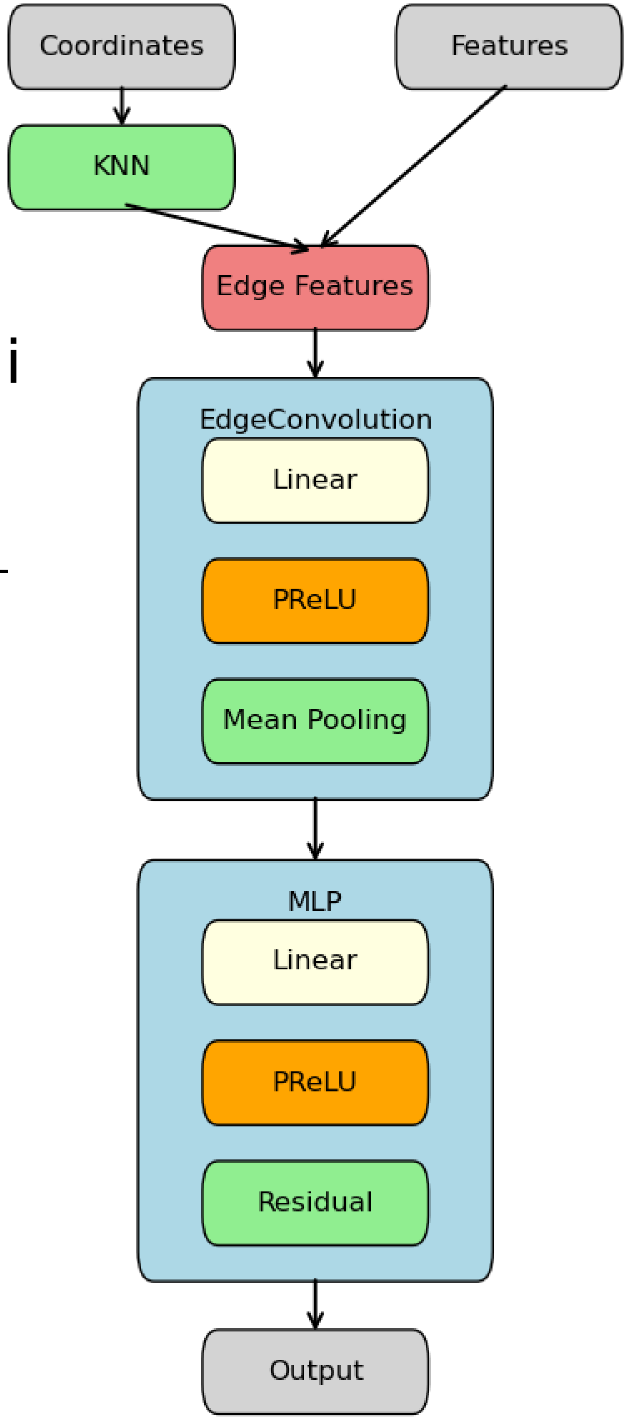
- Channel performance: pedestal, noise, and signal-to-noise ratio
- Channel-wise MIP calibration
- Particle identification using a ML-based PID algorithm
- Energy reconstruction for electrons, positrons, and pions: linearity and resolution
- TDC data analysis and timing resolution

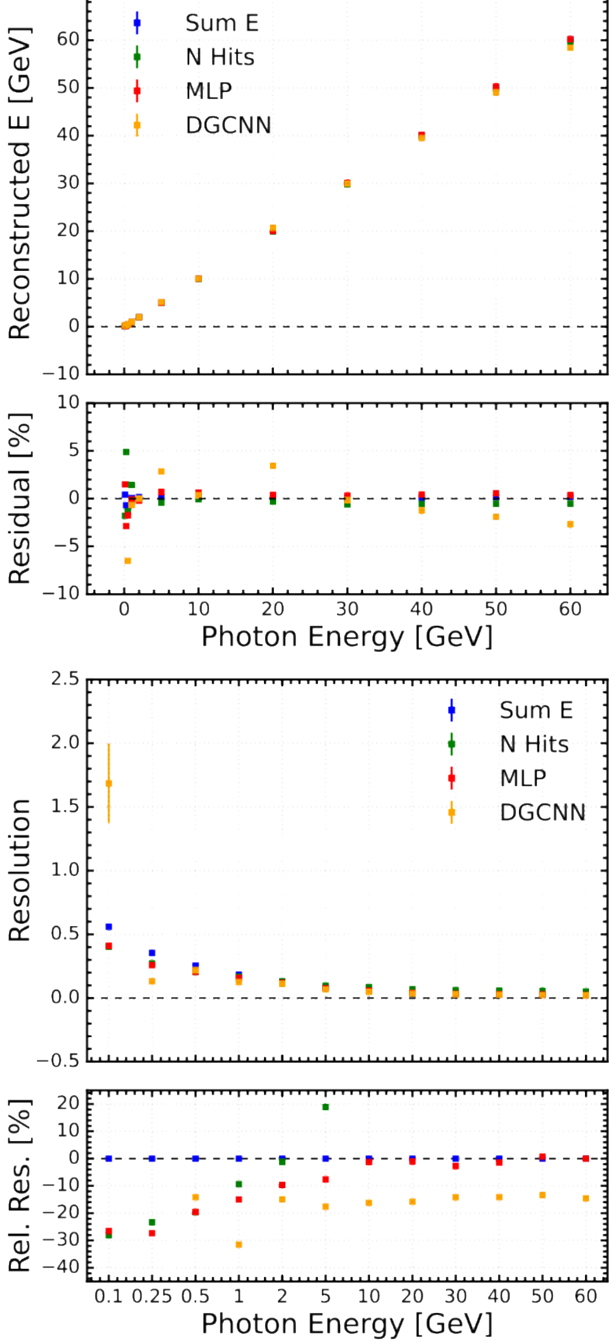
BACK UP

DGCNN model

KNN+EdgeConvolution+MLP

- KNN:Construct edges by connecting layer i with its k nearest neighbors
- Edge features: $[E_i, N_i, Pos_i, E_j - E_i, N_j - N_i, Pos_j - Pos_i]$
- Edge convolution
  - Edge features->NN[[32,32,32],[64,64,64]]
  - Node aggregation: mean
  - Pooling: mean
- MLP: final energy regression





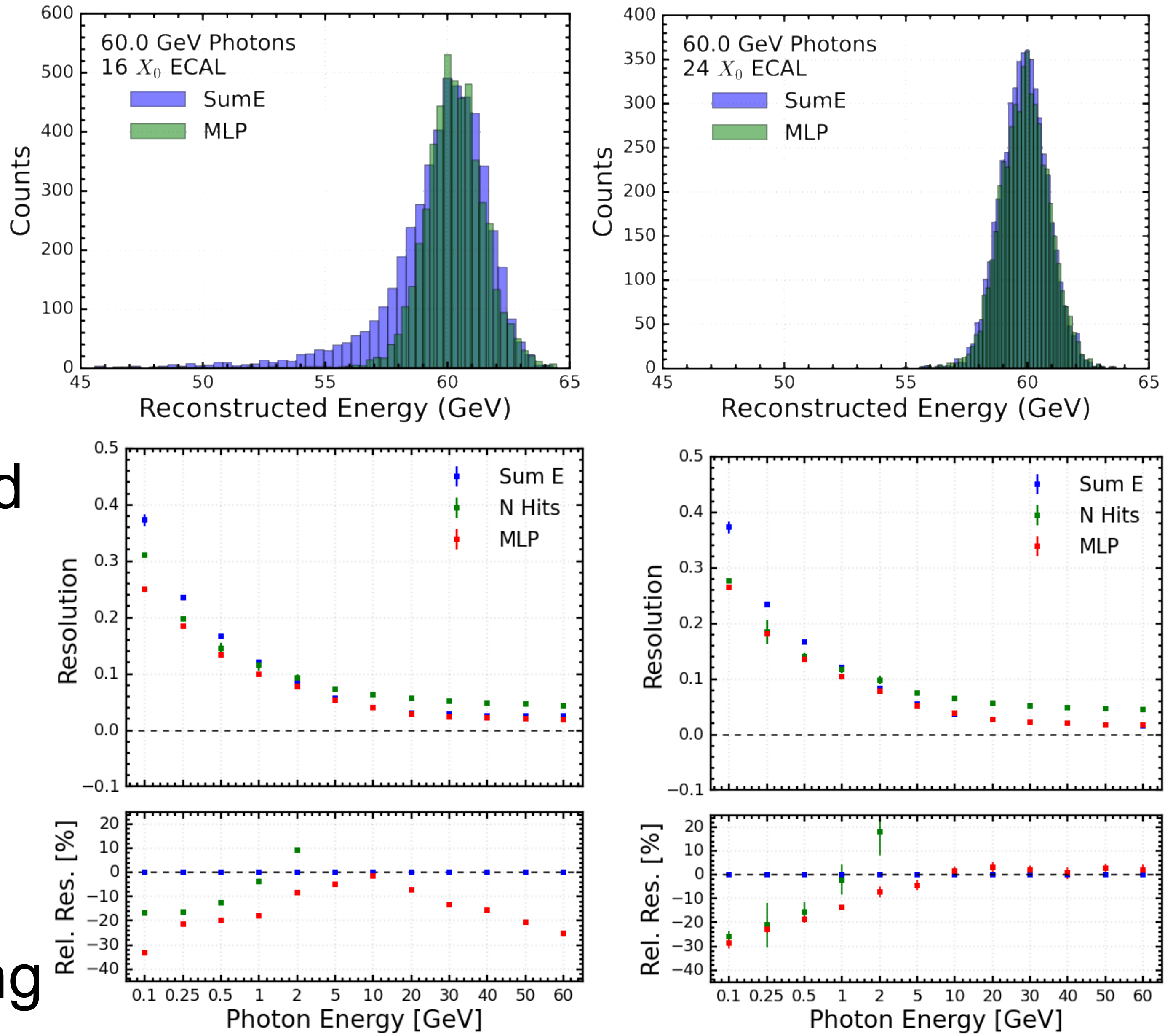
Energy leakage

16-24 X_0 ECAL geometry

- 40,45…60 layers to remain the same sampling ratio
- obvious leakage could be noticed on energy distribution, linearity and resolution

MLP performance

- MLP could correct the energy leakage to **some extent**, resulting in improved linearity and resolution

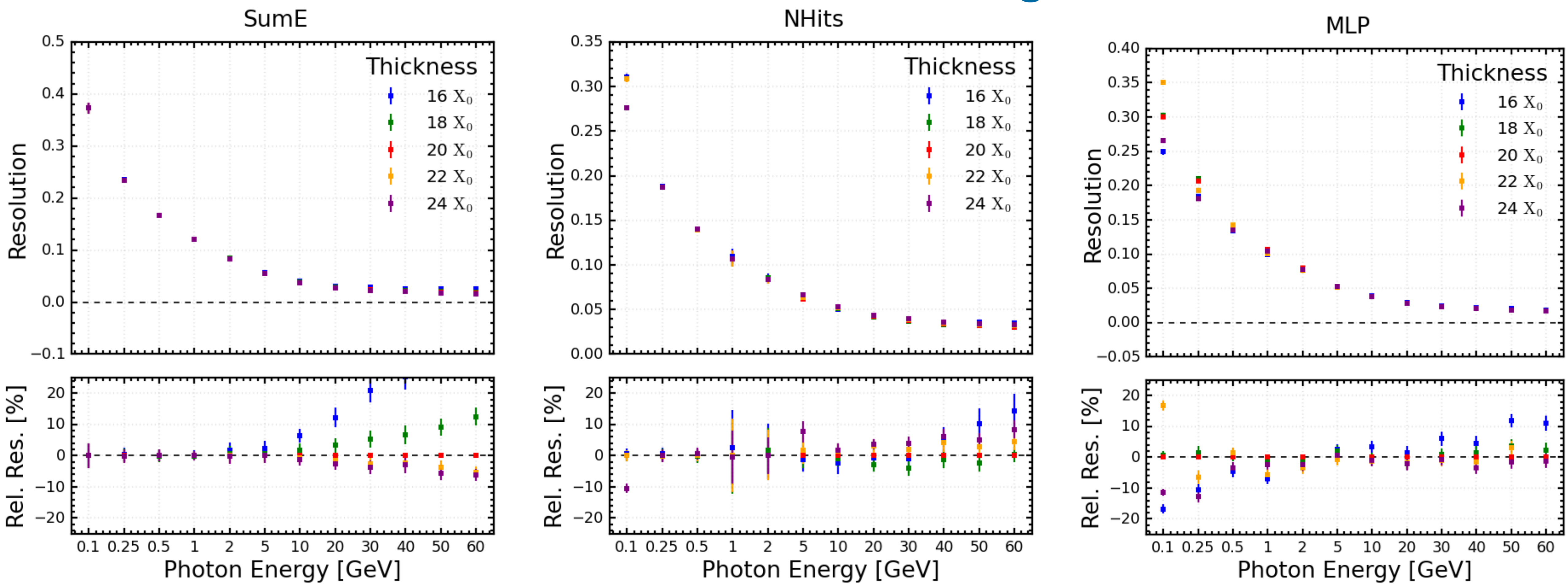


Energy distribution and resolution for 16 X_0(left) and 24 X_0(right) geometries

ECAL radiation length

- For ECAL geometries with different radiation length, the data at low energy is exactly the same, the differences are in
- What MLP learned at high energy also influences what MLP predicted at low energy

Radiation length could be reduced to



Resolutions of ECAL with different radiation length