Status and plan for SiW ECAL

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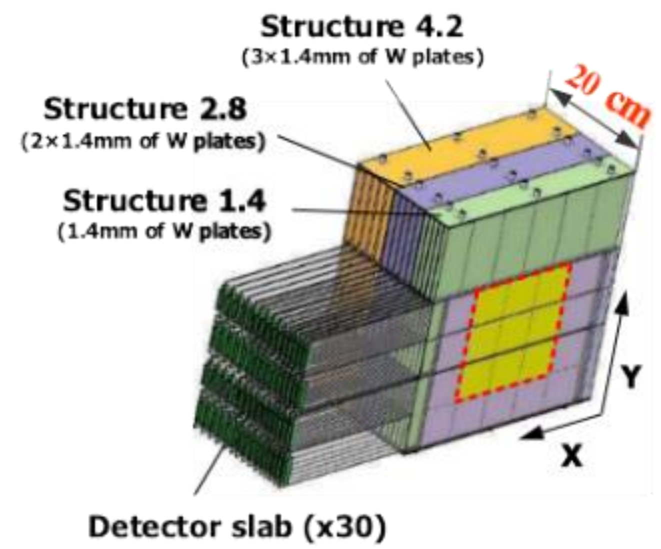
Out Line

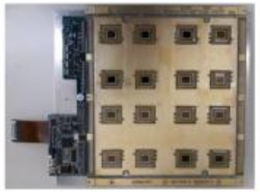
- Overview
- Beam test and time digitization
- Energy reconstruction and detector optimization
- Summary and outlook

History of SiW ECAL: from ILC to FCC



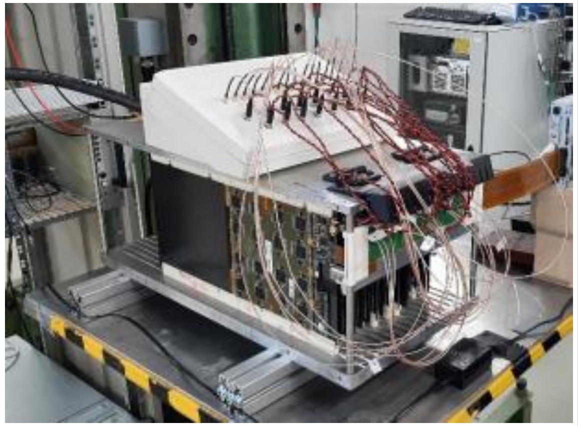
FEV10, 11, 12

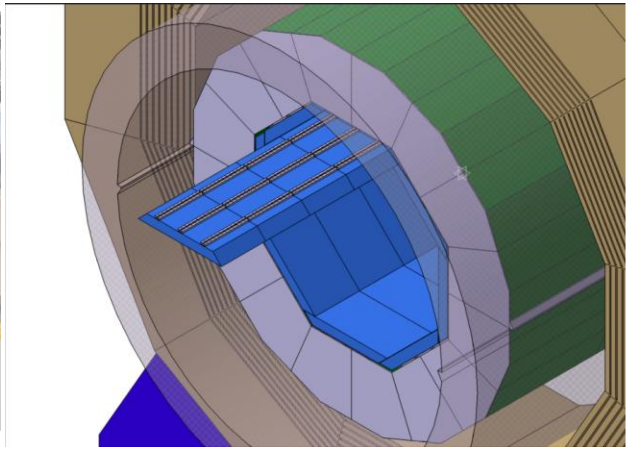
- BGA packaging
- Incremental modifications
- From v10 -> v12
- Main "Working horses" since 2014



FEV-COB

- Chip-On-Board : ASICs wirebonded in cavities
  - Thinner than FEV with BGA
- Based on FEV11
  - External connectivity compatible





Physical(2005-11)

- 1×1 cm² on 500µm 6×6 cm² Pad glued on PCB Floating GR
- 30 layers (10k chan).
- External readout
- Proof of principe
- SKIROC2 chips

Technological (now)

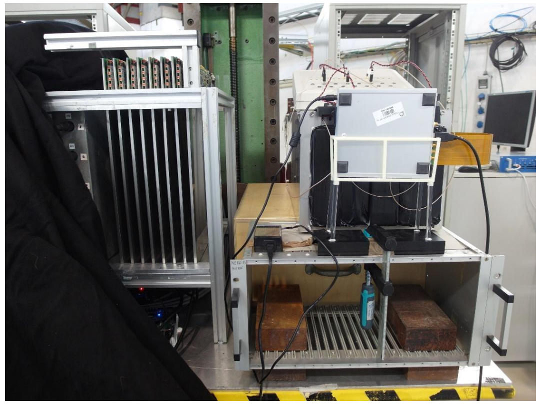
- Embedded electronics
  - Power-Pulsed, Auto-Trig, delayed RO
  - S/N = (MPV/σNoise) ≥ ~12 (trig)
- Compatible w/ 8+ modules-slab
- 0.5×0.5 cm² on 320–650µm 9×9 cm²
- 26–30 layers, 8k (slab) ~ 30k (calo) channels

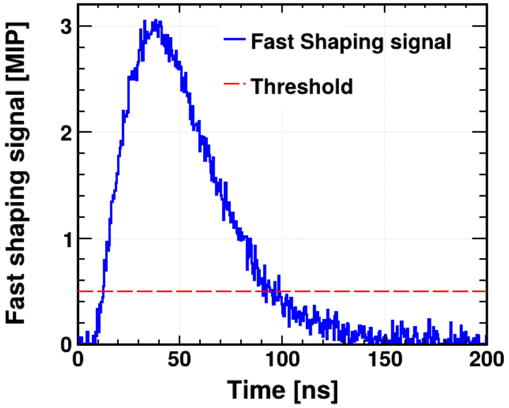
Full Detector(future)

- 1M ➞70M channels
- on 725µm 12×12 cm² 8'' Wafers ?
- Pre-industrial building
- Full integration (⊃ cooling)
- Final ASIC

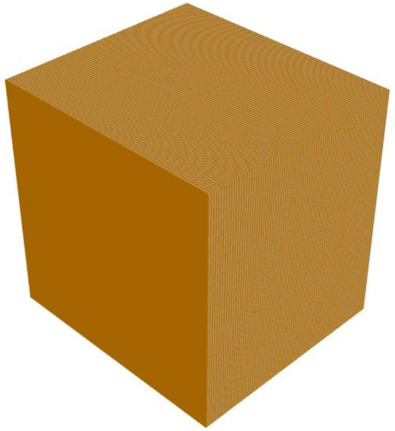
The development of 5D SiW ECAL

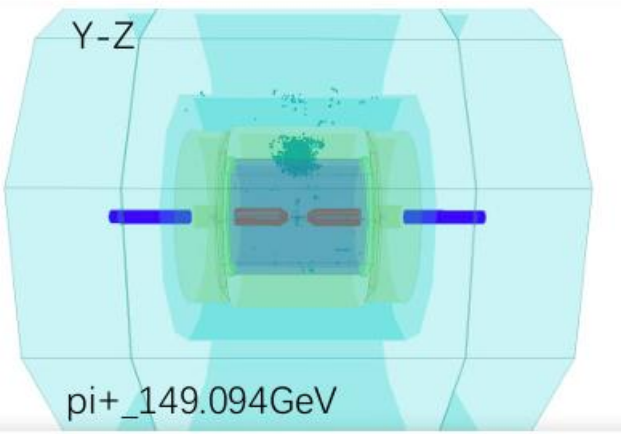
Time: digitization and beam test



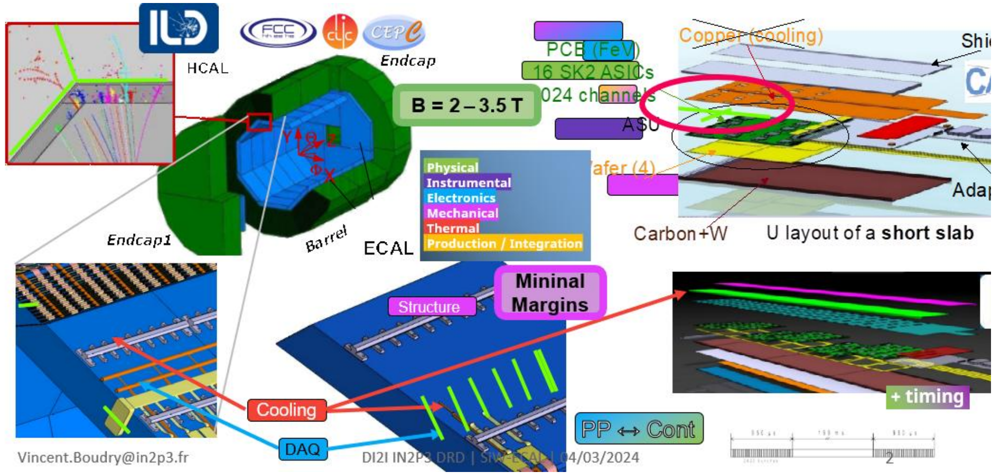


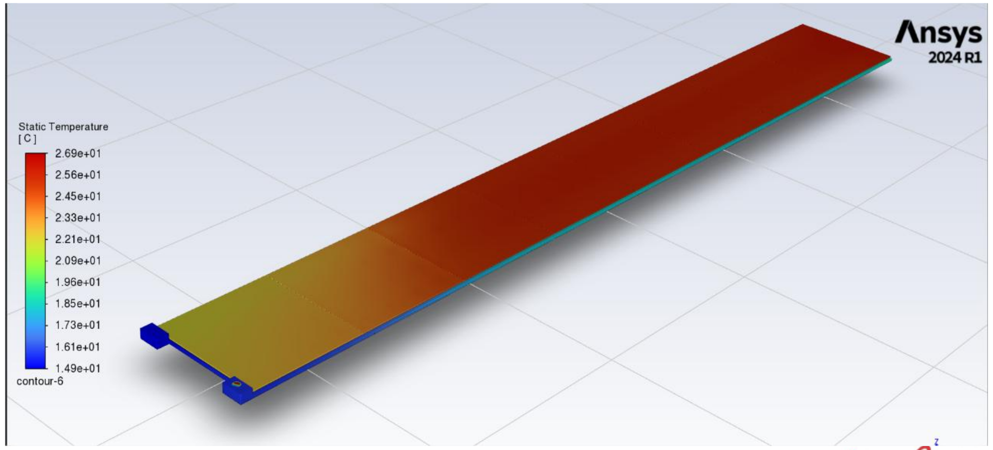
Energy: reconstruction and optimization





Electronics and mechanics: from prototype towards full detector





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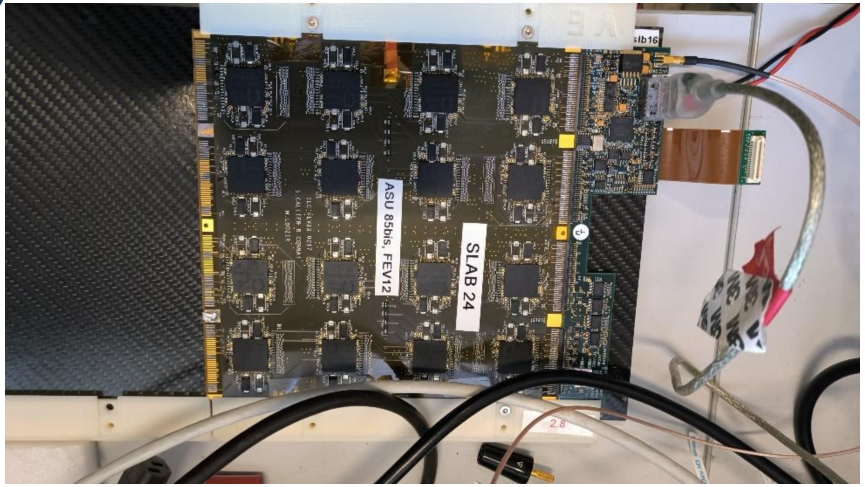
Beam test at DESY

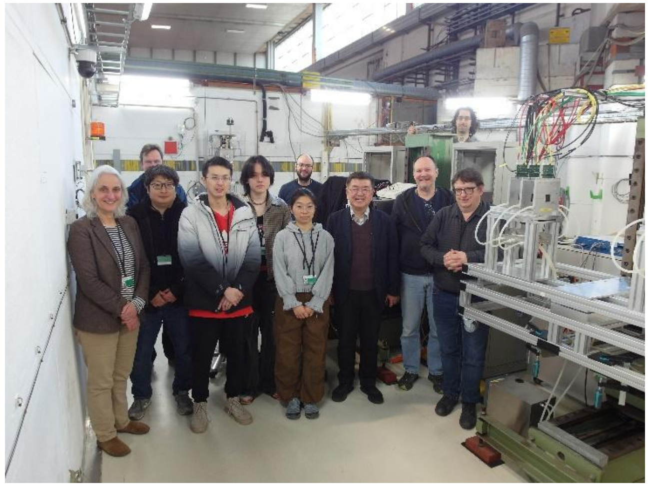
ECAL geometry

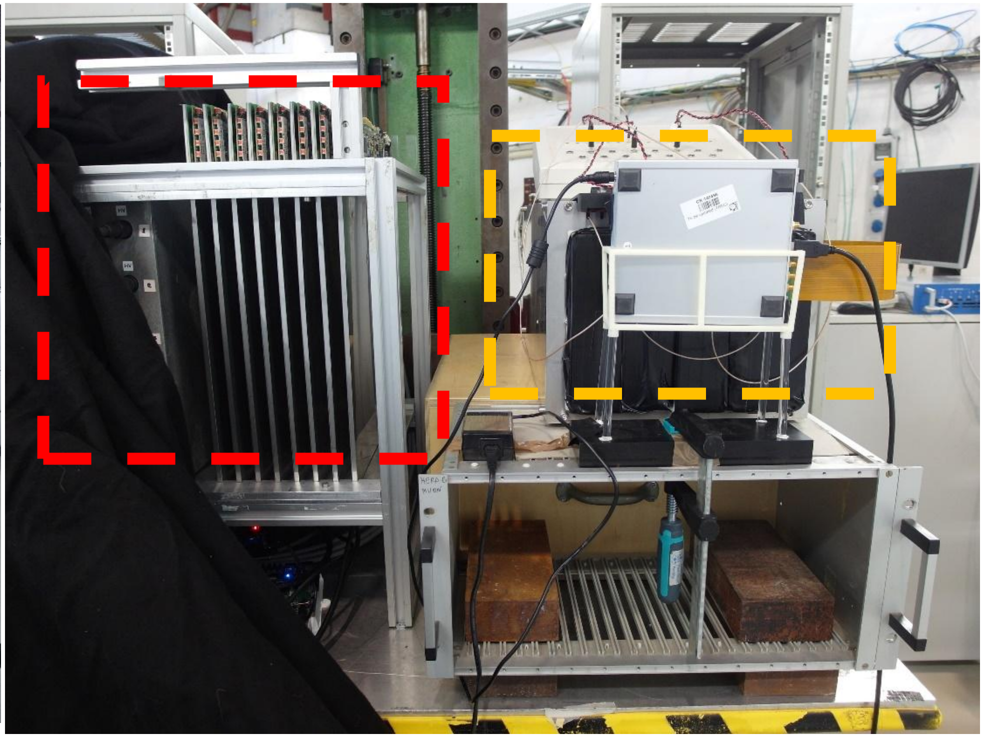
- 3 layers
  - 1 chip on board,2 produced recently
  - 16 SKIROC ships
  - 32×32 cells: $5.5 \times 5.5\ mm^2$
  - No absorbers

Data Taking

- ECAL: Mar 4th - Mar 6th 2025
  - Configuration and calibration
  - Position scan
  - a blown fuse identified and replaced
- ECAL+HCAL: Mar 7th – Mar 8th 2025
  - Configuration and calibration
  - Position scan
  - **TDC test for the first time!**







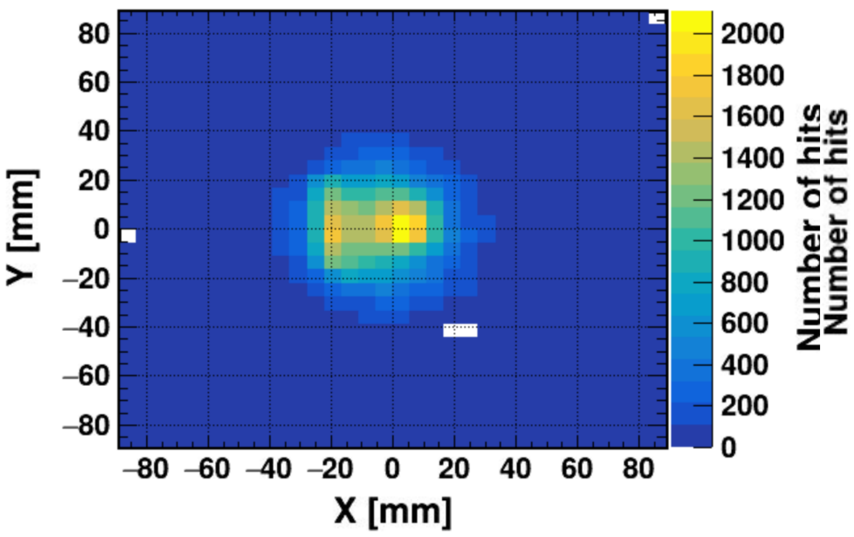
ECAL

ECAL+AHCAL

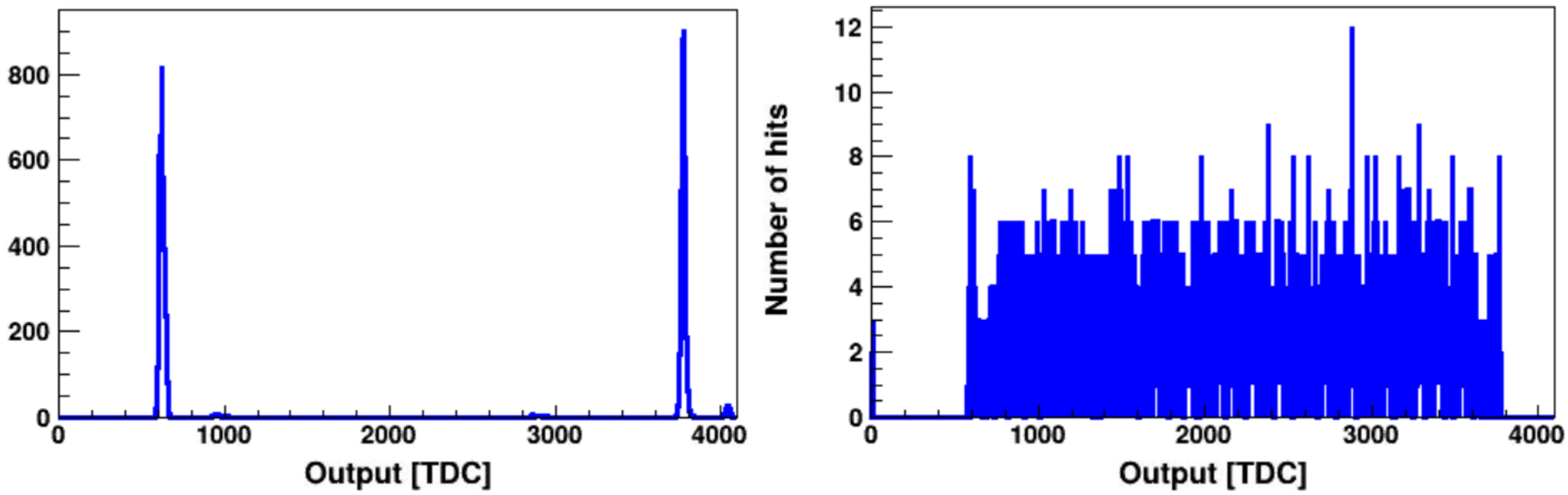
Beam

TDC Calibration

- The range of the TDC distribution corresponds to the time of one bunch crossing
- Bunch crossing time = 200 ns
- The triggered TDC distribution lacks sufficient statistics; however, the untriggered TDC distribution appears suitable for calibration as well. We are currently consulting with our electronics colleagues to confirm this.

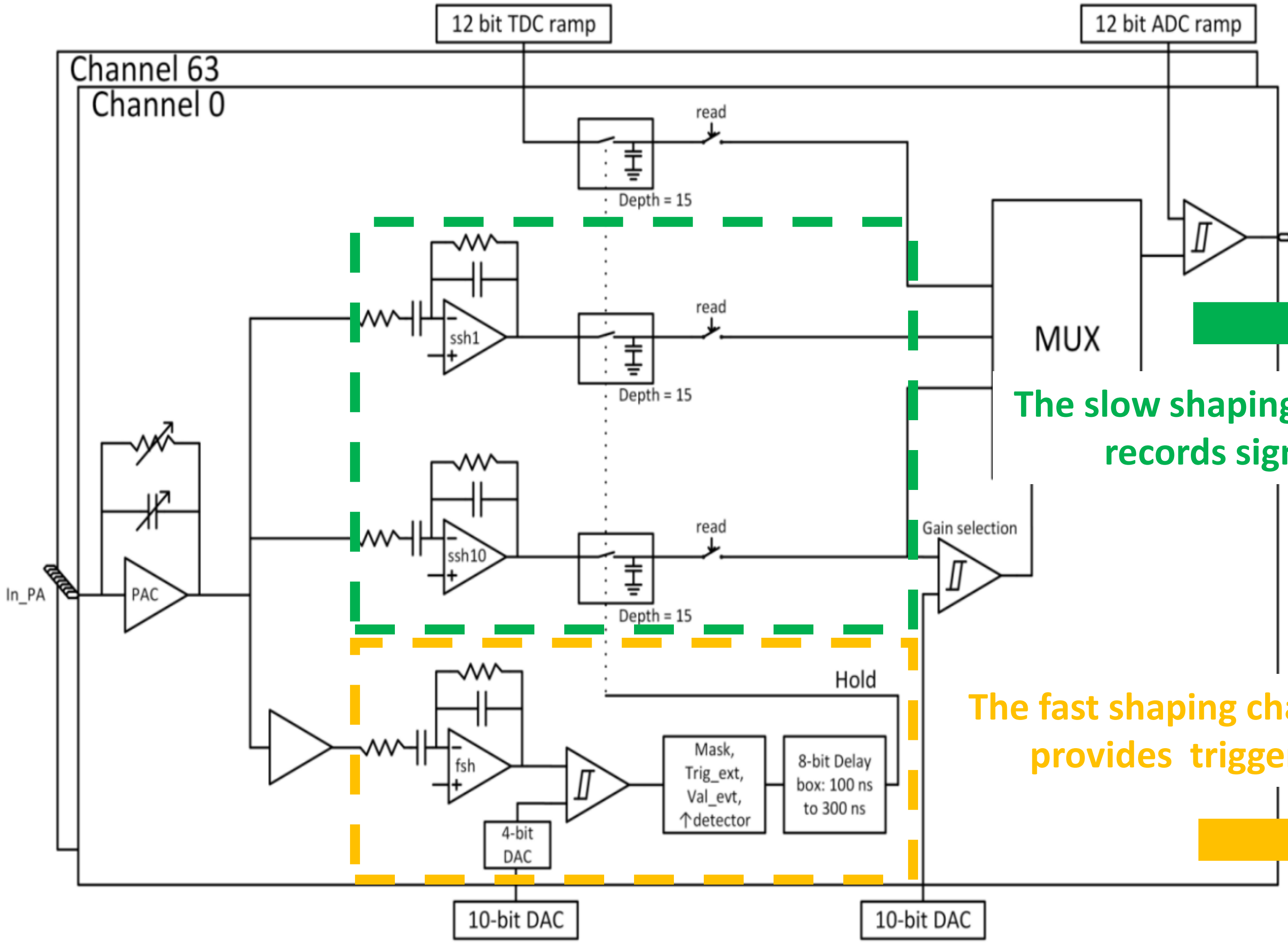


Hit map for TDC data

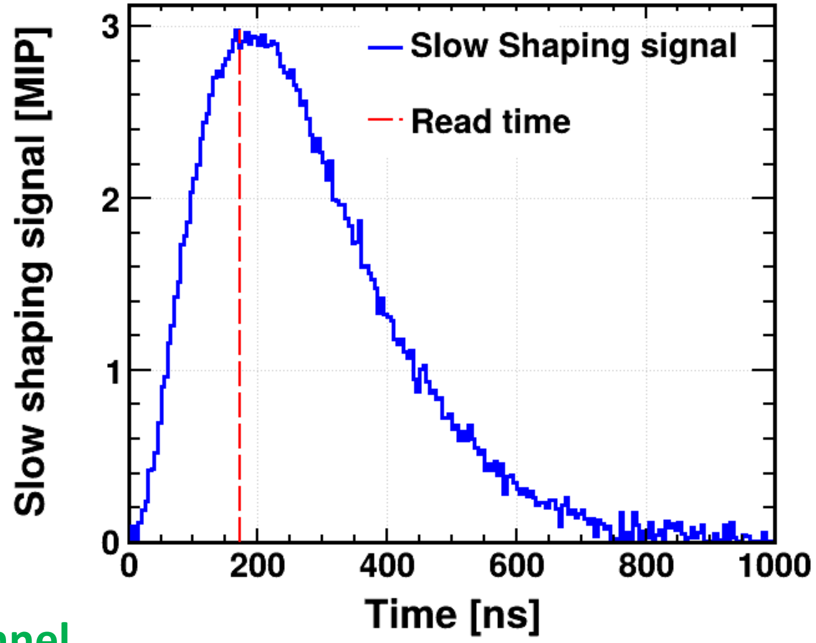


TDC distribution: left(untriggered) and right(triggered)

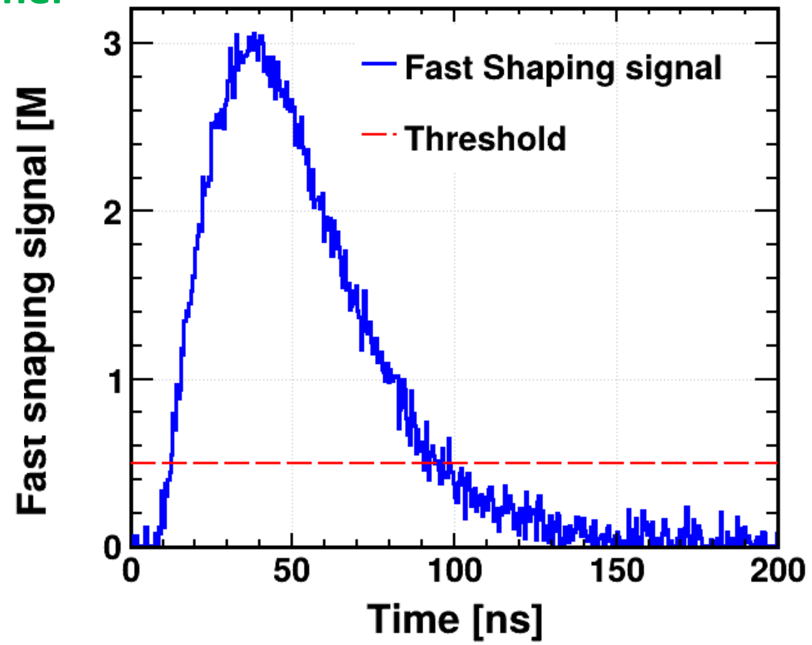
SKIROC chips



The slow shaping channel records signals

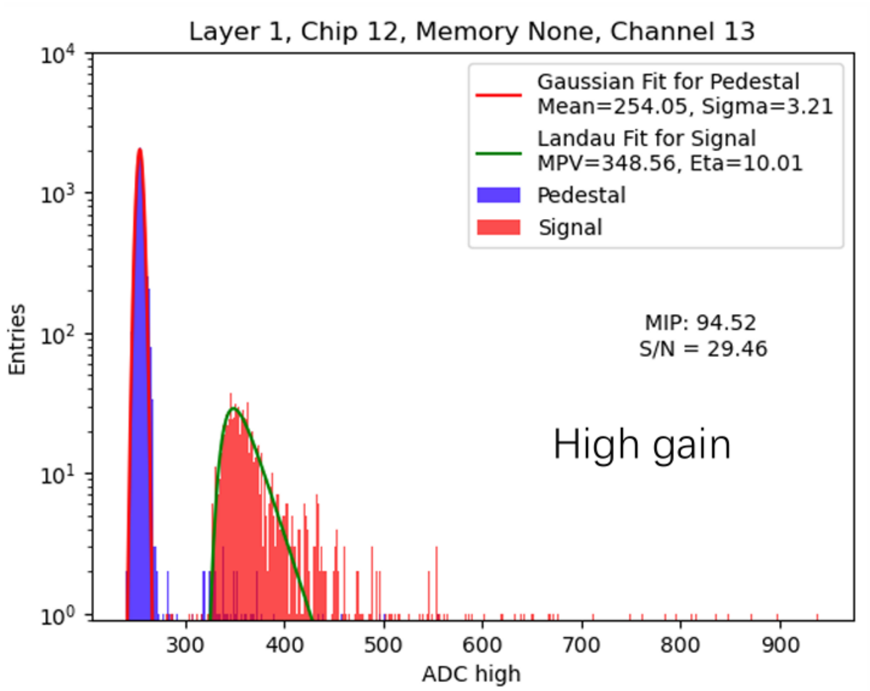


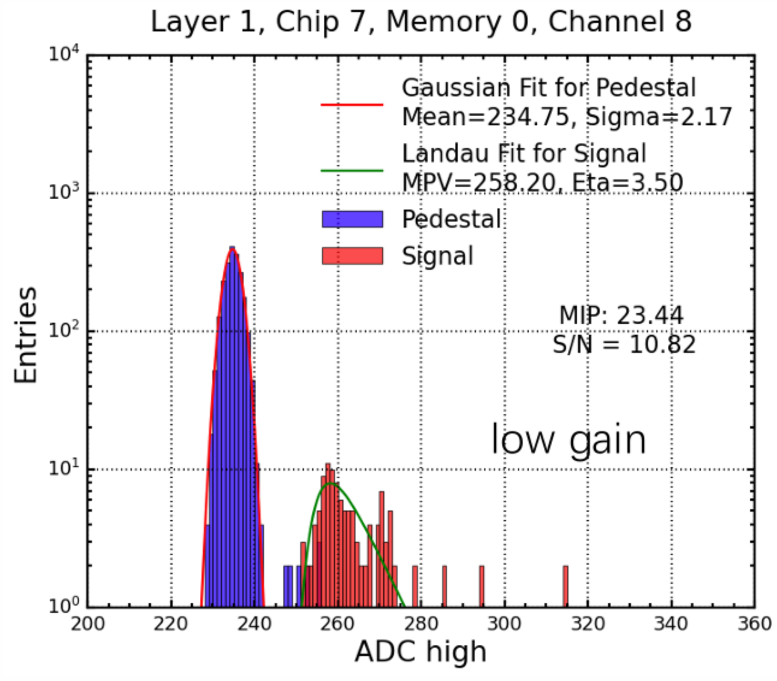
The fast shaping channel provides triggers

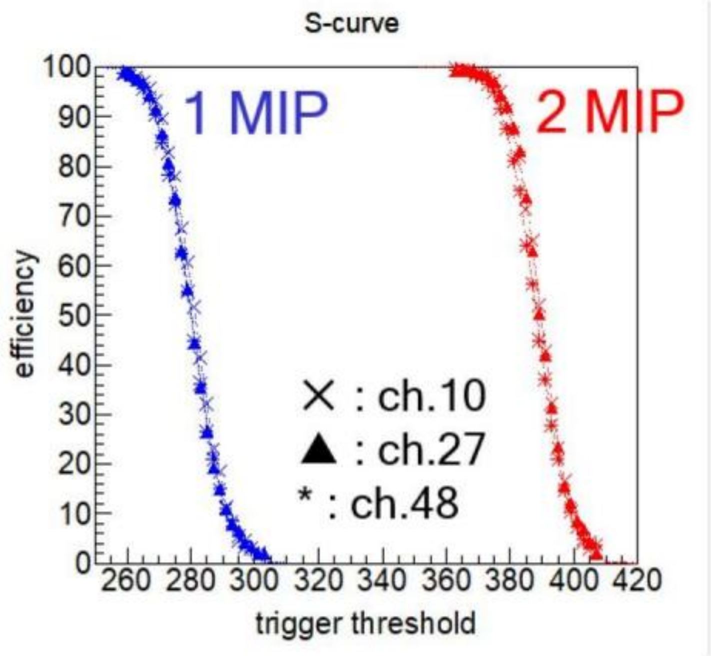


Signal Noise Ratio(S/N)

- Slow shaper: the signal channels
  - High gain S/N ~ 30 according to test beam result @DESY 2025
  - Low gain S/N~ 11 according to test beam result @DESY 2025
- Fast shaper: the trigger channels
  - S/N ~12 according to a charge injection test (CHEF 2017)





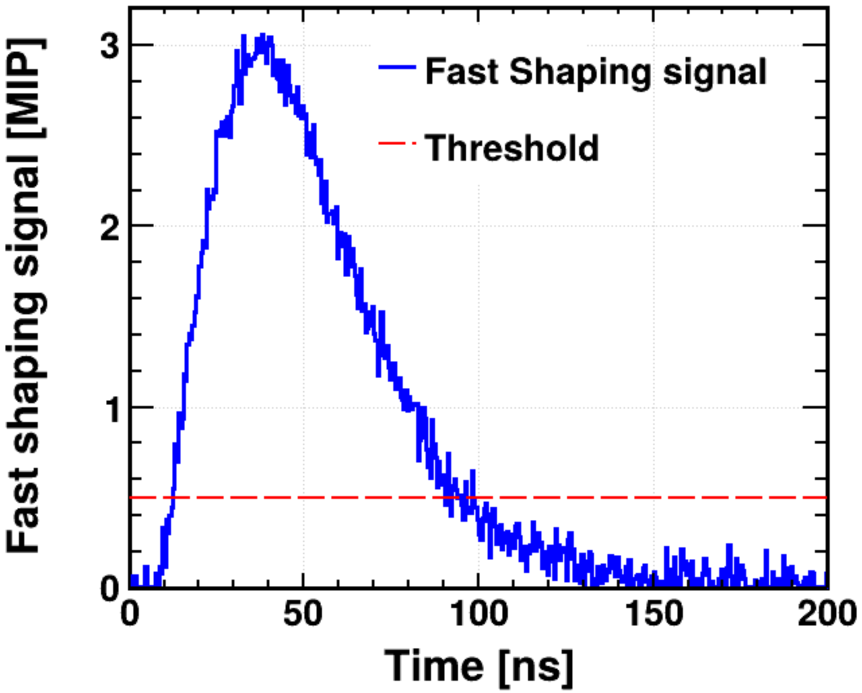


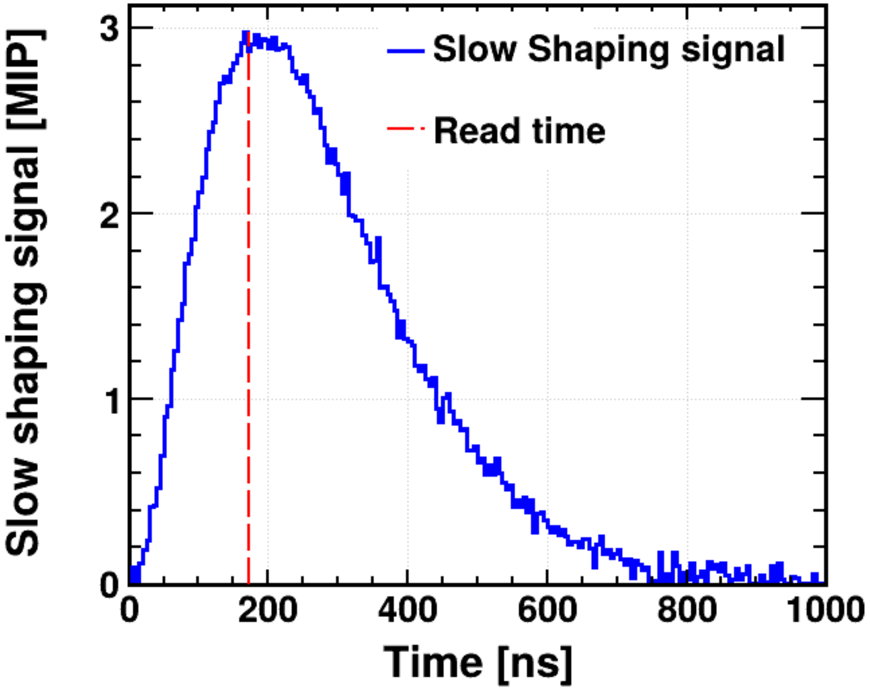
Single channel's S/N for high gain, low gain and fast shaper

Digitization

Shaping signal function

- $S(t) = \sum_i^{subhits} f_{scale} \frac{E_i \cdot T_i^n(t) \cdot e^{-T_i(t)}}{n!} \otimes gauss(0, noise)$
- f_{scale}=4
- $T_i(t) = (t - t_i^{hit})/\tau$





Digitization for Fast shaping(left) and slow shaping(right)

Parameters derived from TB

- Shaping time
  - $\tau_{fast} = 30$ ns, $\tau_{slow} = 180$ ns
- Order of CR_RC filter
  - $n_{fast} = 2, n_{slow} = 2$
- Noise
  - Fast shaping: 1/12 MIP
  - Slow shaping low gain: 1/11 MIP
  - Slow shaping high gain: 1/30 MIP
- t_{Digi}: the threshold is applied
  $S_{fast}(t_{Digi}) = 0.5\text{MIP}$
- E_{Digi} : consider the delay time
  $E_{Digi} = S_{slow}(t_{Digi} + t_{delay})$
  $t_{delay} = 160$ ns

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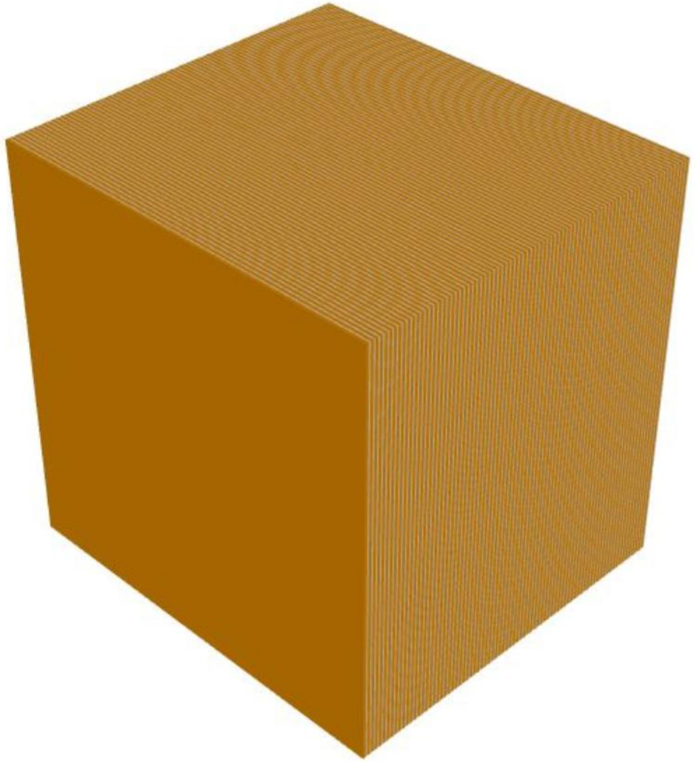
Simulation setup

Geometry

- Sampling Layers: 80
- Absorber: tungsten
  - 1.5 mm per layer
  - ~34 X_0 for 80 layers
- Sensitive material: Silicon
  - 0.75 mm per layer
  - Less than 2% of W
  - Segmentation: $5 \times 5 \times 0.15\ mm^3$
- **This geometry could be easily transformed into different configurations without running the simulation again**



ECAL prototype geometry

- Particles
  - Photons with energy from 0.05 - 60 GeV
  - Position: (2.5 2.5 -200)(mm)
  - Direction: (0 0 1)
- The hits were defined as Si cells which have energies above a certain threshold

Fitting the reconstructed energies

Gaussian

- $f(x) = \frac{1}{\sqrt{2\pi\cdot\sigma}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}$
- Mean: μ
- Peak: μ
- Resolution: $\sigma/\ \mu$

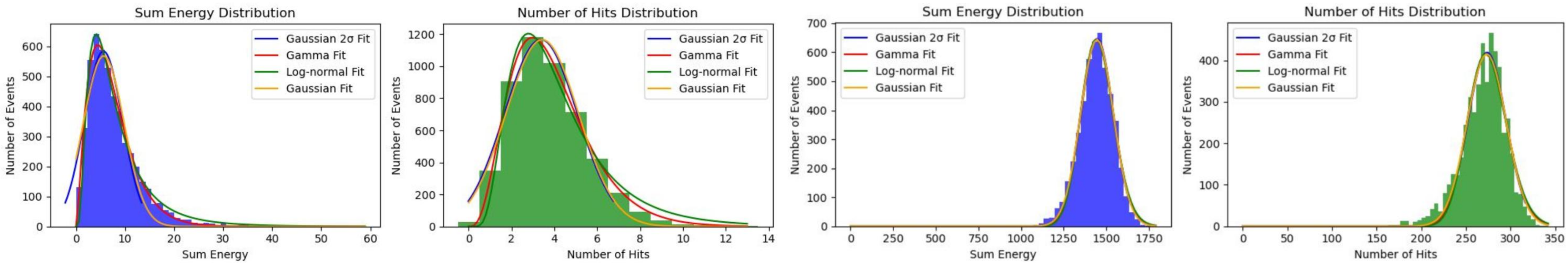
Gamma

- $f(x) = x^{k-1}\ \cdot e^{-\frac{x}{\theta}}/\theta^k \cdot \Gamma(k)$
- Mean: $k\theta$
- Peak: $(k-1)\theta$
- Resolution: $\frac{\sqrt{k}}{k-1}$

Log-Normal

- $f(x) = \frac{1}{\sqrt{2\pi}\cdot x\sigma} \cdot e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$
- Mean : $e^{\mu+\sigma^2/2}$
- Peak: $e^{\mu-\sigma^2}$
- Resolution: $\sqrt{e^{\sigma^2}-1} *\ e^{\frac{3}{2}\sigma^2}$

Distribution of reconstructed energy from Sum Energy(blue) and Number of hits(green)



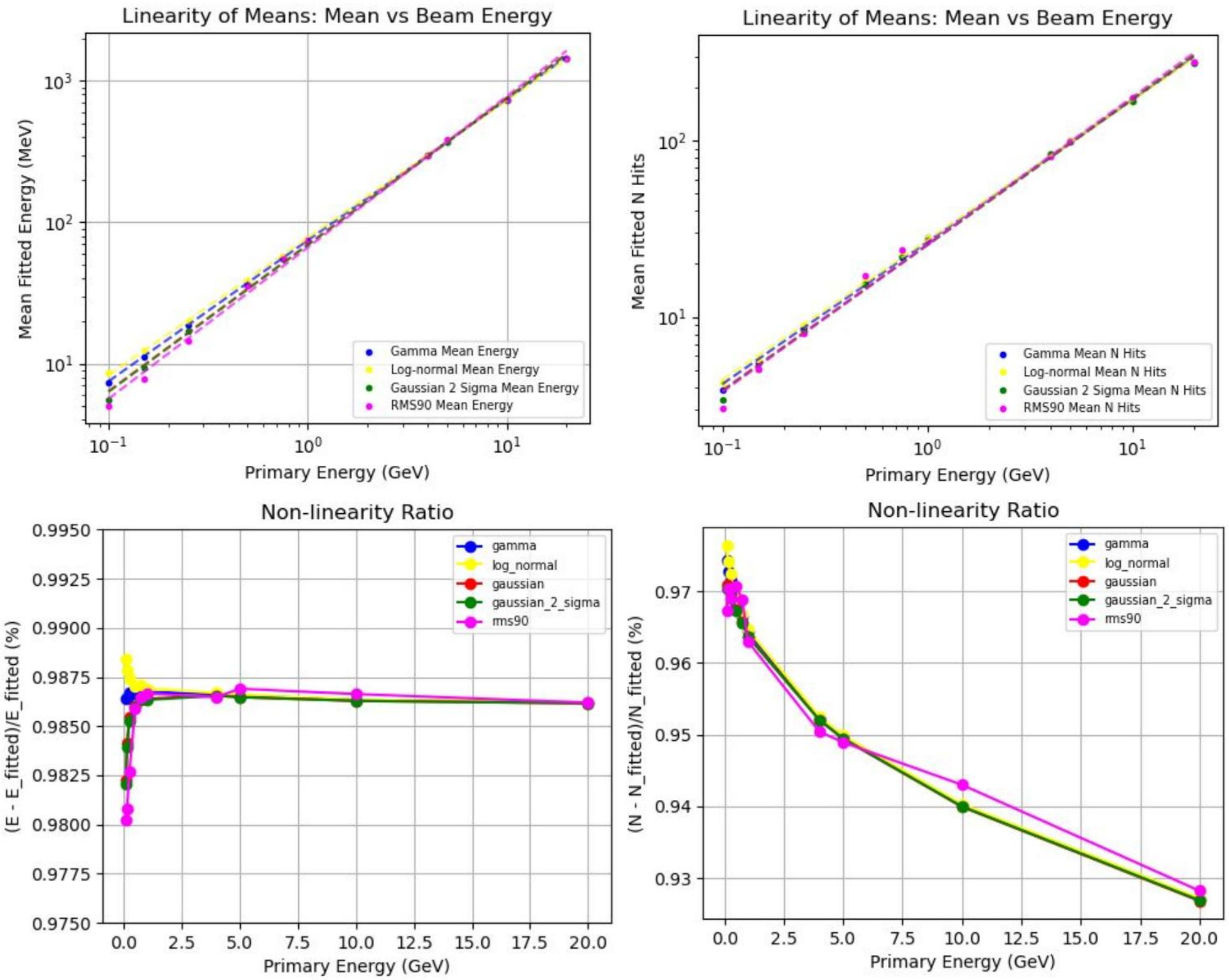
the energy of gamma is 0.5 GeV(left) and 20 GeV(right), these plots were drawn from an old geometry 2022

All functions did well at high energy and will give almost the same result, while they differs at low energy region

Linearity

Linear Fitting

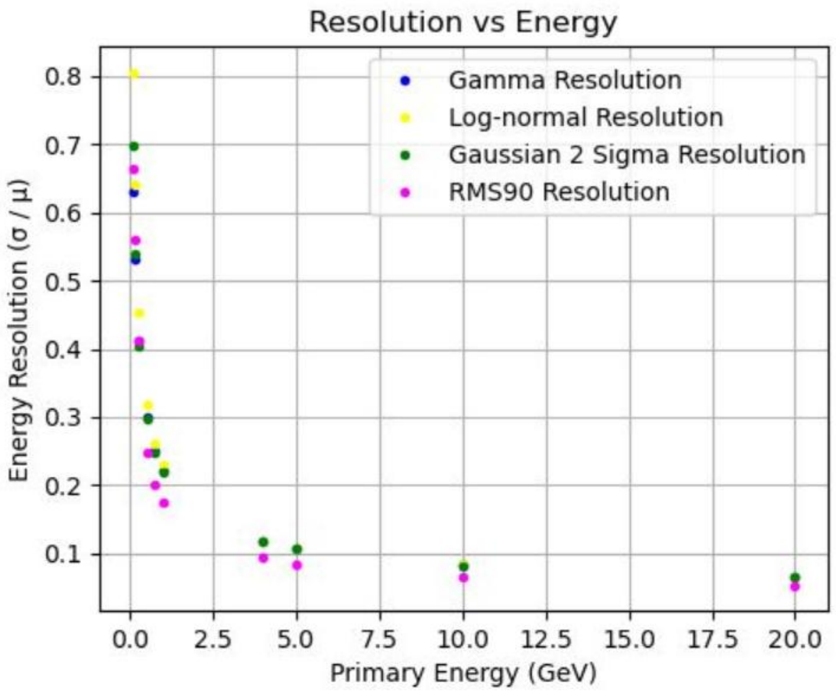
- Non-linearity is defined as
  - $E - E_{fit}/E_{fit}$ for sum E
  - $N - N_{fit}/N_{fit}$ for number of hits
- Different fitting methods give similar result in high energy region
- But in low energy region, different methods have different results

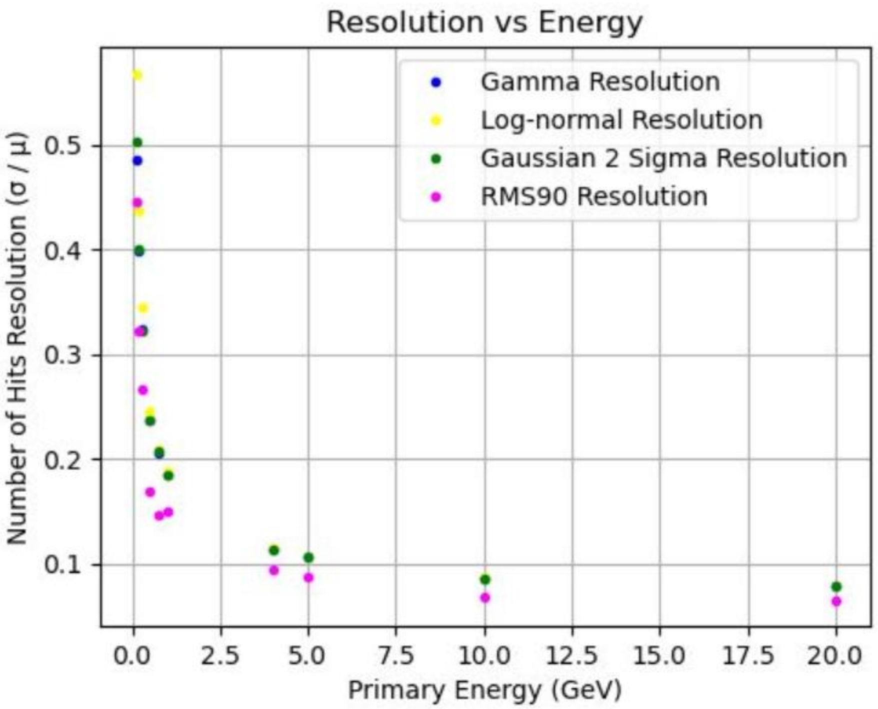


The linear fit(up) and non-linearity(down) for sum of energy(left) and number of hits(right)

Resolution

- RMS90
  - The minimum RMS of a range that contains 90% of the events in the distribution.
- Different fitting methods have different results in low energy region, while they become same at high energy region
- The number of hits method has better resolution and low energy region, while the sum of E method is better at high energy region
- **Gamma function fit best**
- **An new reconstruction method would be the goal**





The energy resolution for sum of energy(left) and number of hits(right)

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Summary and outlook

Time

- Several beam tests were conducted
- A timing digitizer was developed, but more analysis and beam tests are needed

Energy

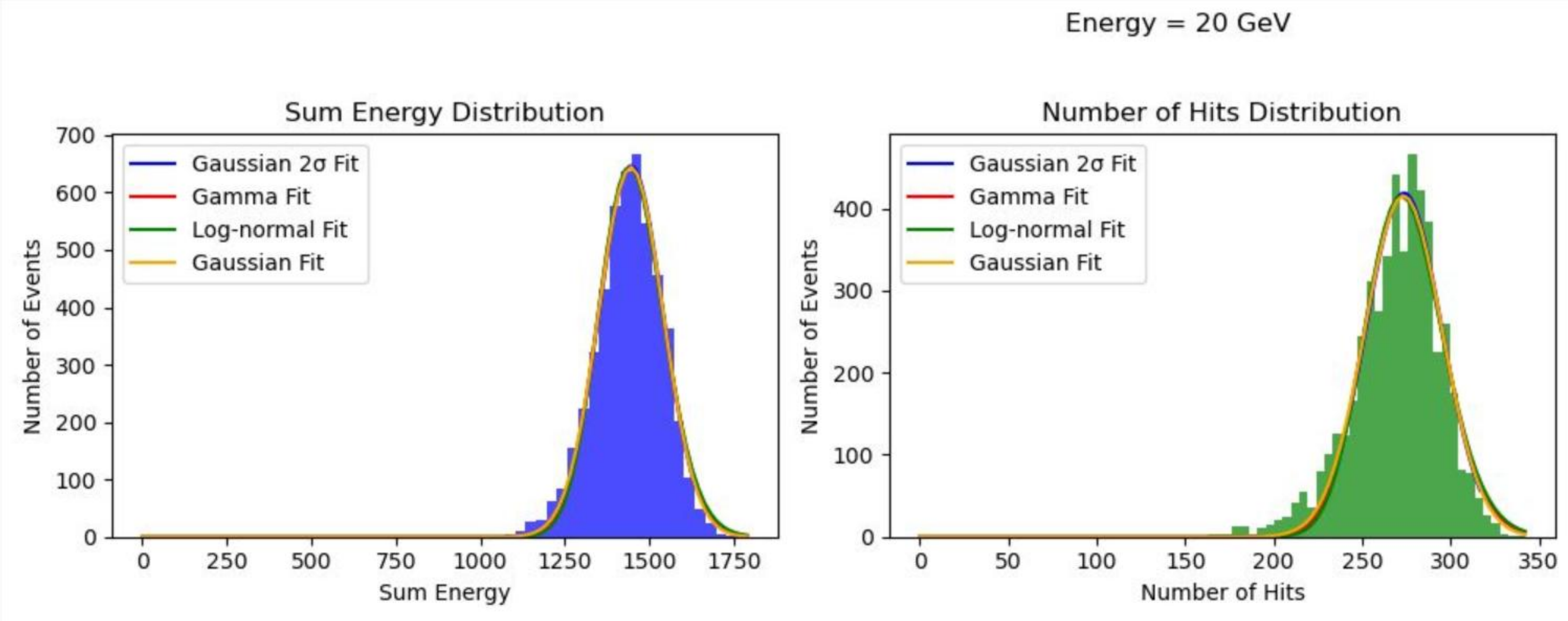
- The full potential of the ECAL, particularly in the low-energy region, has yet to be fully explored

Plan

- Improve the performance of ECAL, and optimize ECAL for the FCC experiment
- New ASIC boards and beam tests are expected in 2026
- Optimize ECAL geometry in terms of time and energy resolution
- Continue the study on time digitizer, implement it into PFA, and perform full simulation with FCC detector

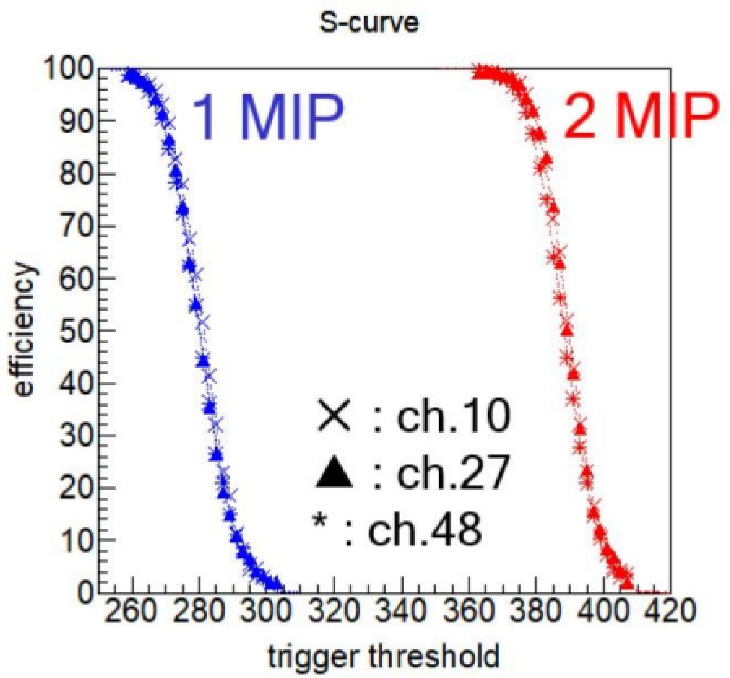
Backup

Meeting Note



S/N in the trigger line

- For the physics prototype, we worked with externally triggered events → the S/N was measured only in the ADC.
- Working in autotrigger, the S/N is defined by the study of the trigger line (fast shaper) → threshold scans (aka scurves)



Injection tests in SK2 testboard by Taikan et al (CHEF2017)

- S/N(trig) = 2MIP(50%) - 1MIP(50%) / width = **12.9**
  - *allows to set the trigger using low energy signals (0.5MIP)*
  - The threshold curve is interpreted as theintegral of the gaussian distribution of the noise. The **width** is **1sigma** of that **gaussian**, i.e.: half the difference between the thresholds for 50±34% of the efficiency.

ECAL-BIF Correlation

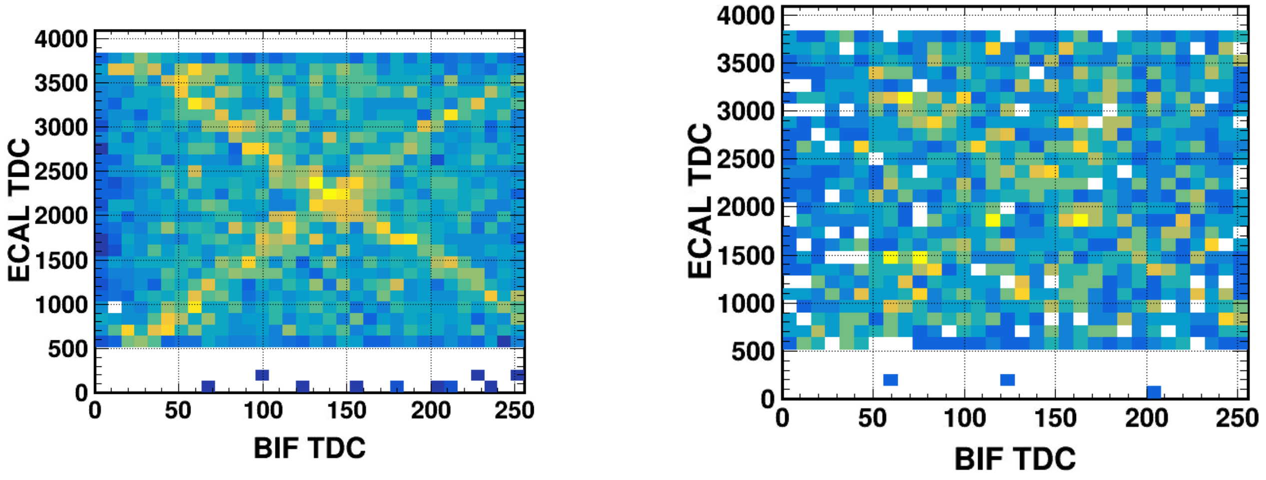
Reverse BCID in memory cells?

Noise hits?

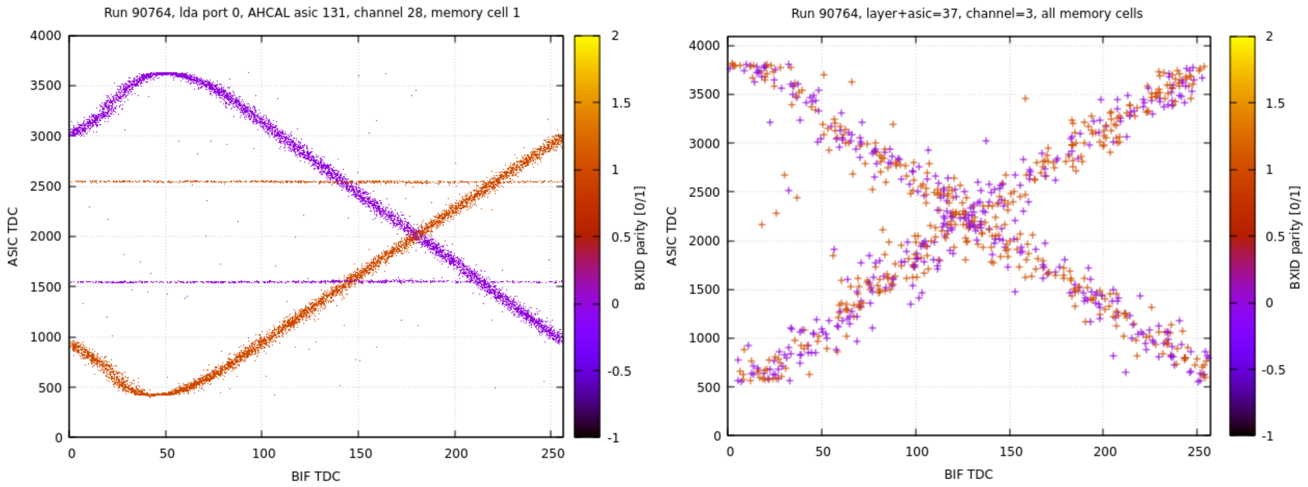
- Differences between channels

AHCAL-BIF correlation

- Red and purple curves represents odd/even bcid events
- The different curves in the ECAL-BIF plot don’t correspond to odd/even bcid events



ECAL – BIF correlations from two different channels



HCAL-BIF correlations(left) and ECAL-BIF correlations(right)

Results from Jiri Kvasnicka

Towards the 5D calorimtry

Detector

- CE-E region
  - $1.1cm^2$ hexagonal **300μm** Si
  - **SKIROC2-CMS** chips

Timing performance

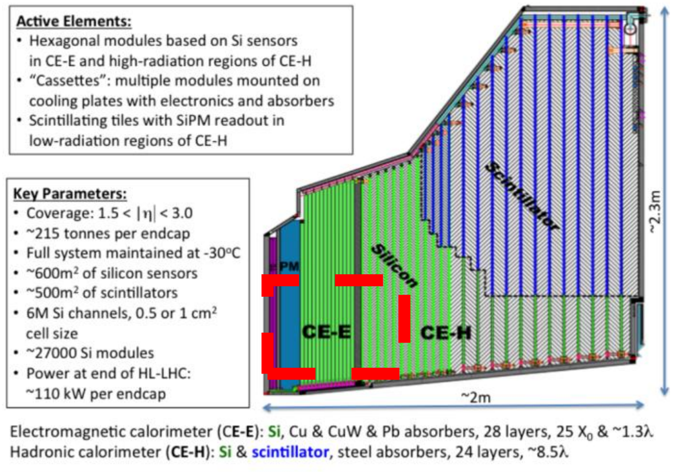
- Single channel

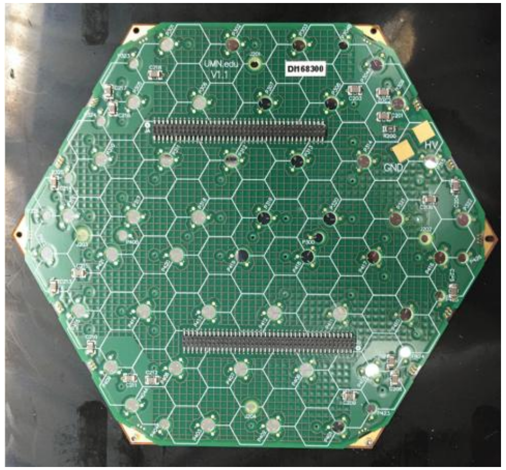
$$\sigma^2(E) \sim \left(\frac{13.5\mathrm{ns}\cdot\mathrm{MIP}}{E}\right)^2 + (62\mathrm{ps})^2$$

- Positron showers

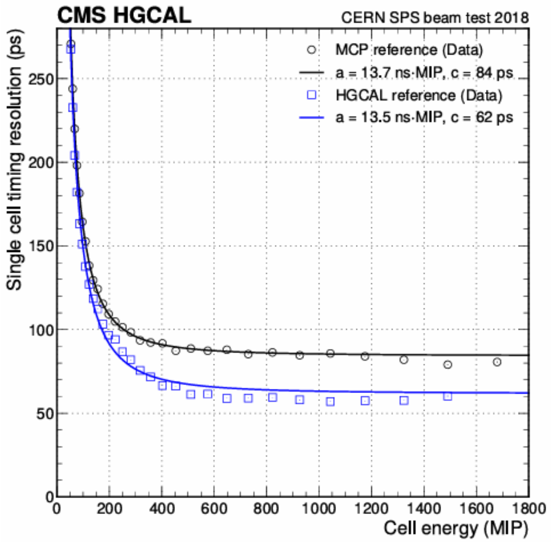
$$\sigma^2(E) \sim \left(\frac{1.9\mathrm{ns}\cdot\mathrm{GeV}}{E}\right)^2 + (16\mathrm{ps})^2$$

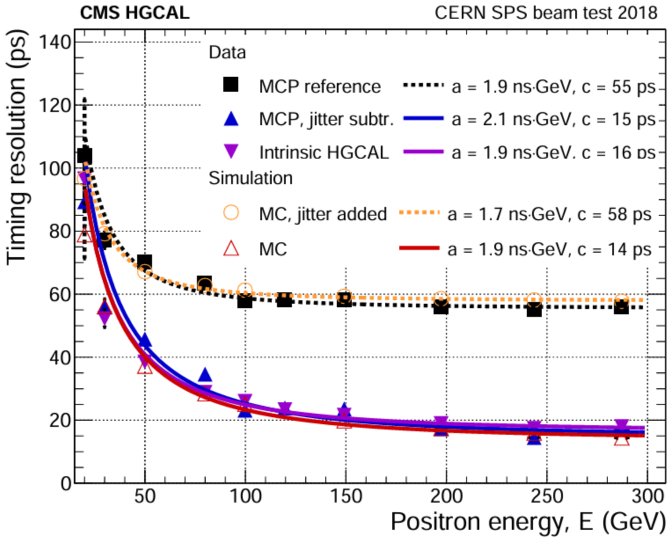
SiW ECAL is expected to have better performance with thicker Si Wafers





Design of the CMS HGCAL





Timing performance of HGCAL Test beam results
Left: single channel, right: positron showers

CMS 18 TB results

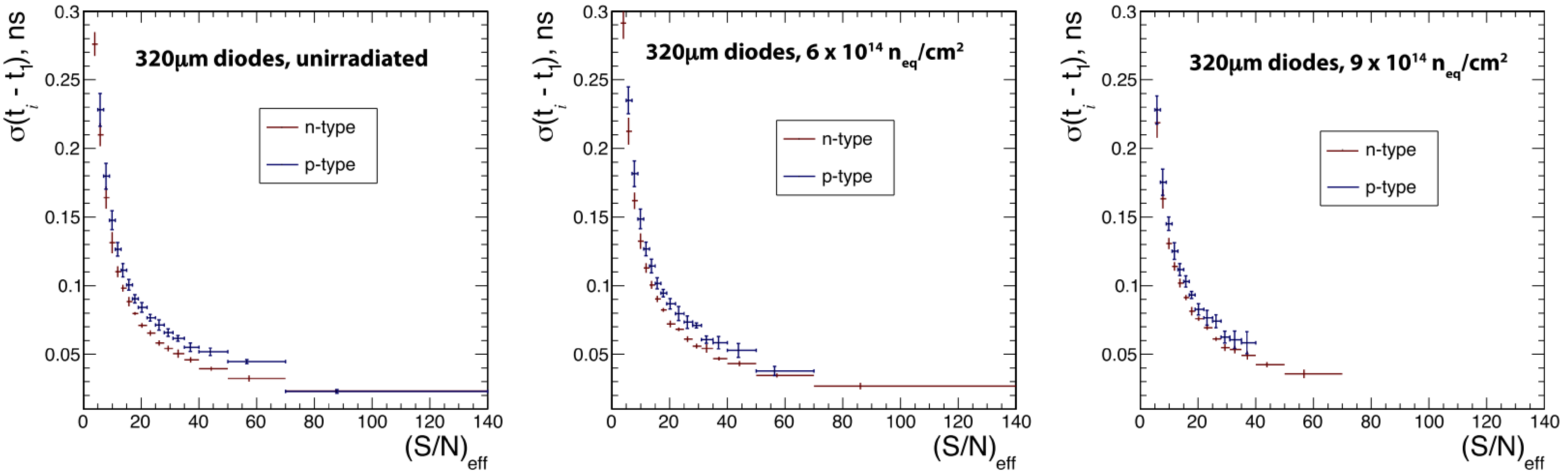


Figure 34. Resolution on the time difference between an unirradiated diode and one irradiated to a fluence level of 0 (left), 6.0×10^{14} (middle) and 9.0×10^{14} (right) neq/cm^2. In black for p-type and red for n-type.

Status: beam test analysis

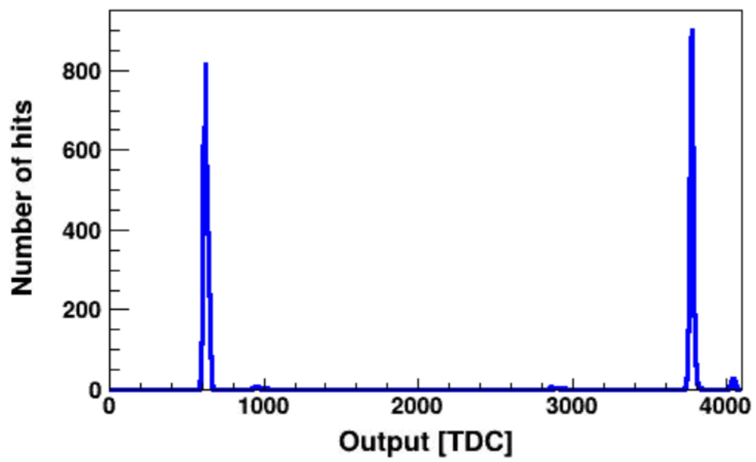
TDC Calibration

- Use the data whose hittag=0
- Multi peaks exsist

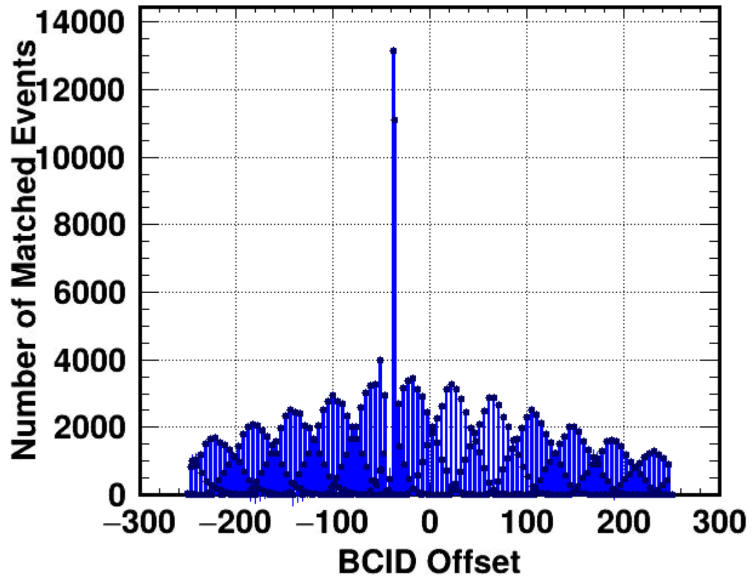
Event matching with BIF and AHCAL

- Cycle ID offset on BIF and AHCAL: scanned
- BCID ID offset on BIF and AHCAL: scanned

Timing performance



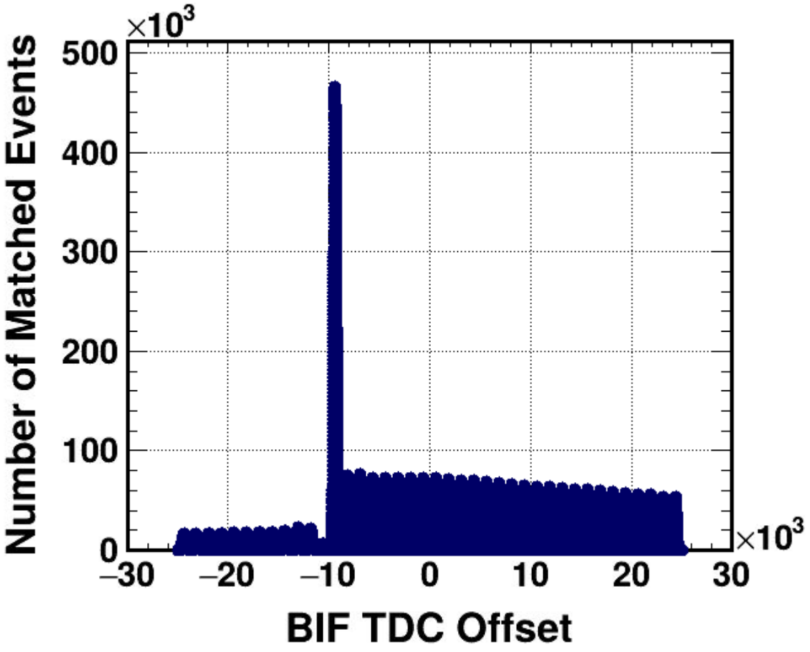
TDC Calibration



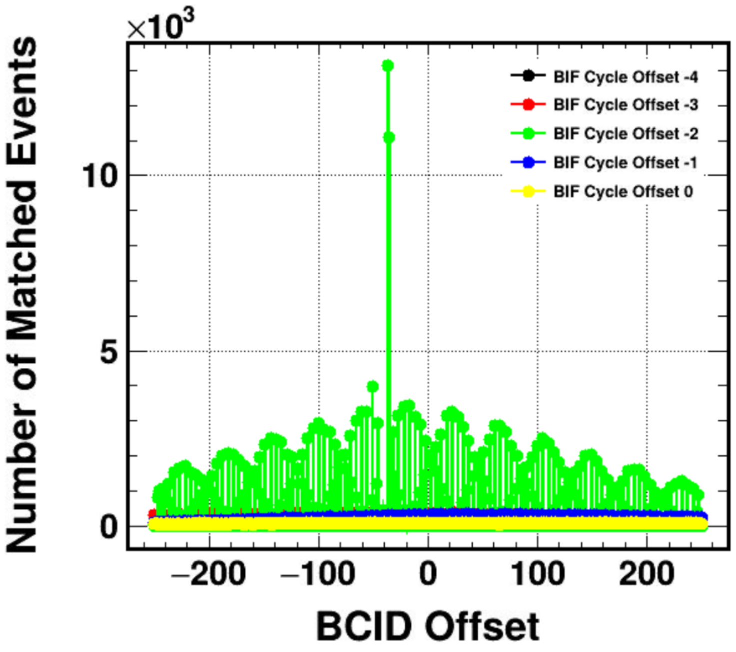
BCID matching with BIF

Synchronization with BIF

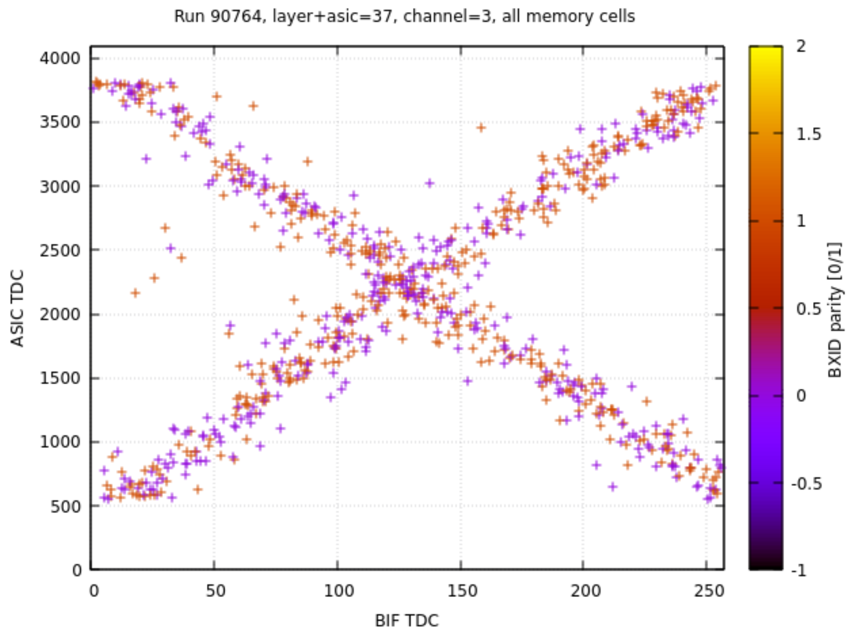
- BIF(Beam InterFace): to provide time reference
- There is offset on cycleIDs and BIF TDC between ECAL and BIF
- There is still something not synchronized now



Scan the BIF TDC offset



Scan the cycle offset



Compare the odd(red) and even(purple) BCID