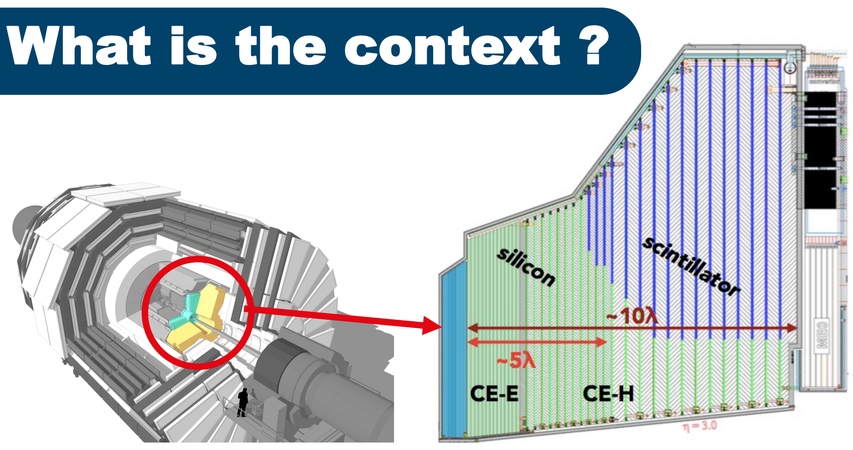
Timing performance analysis of CMS HGCAL prototypes in beam tests

Axel Buchot Perraguin on behalf of the CMS Collaboration — 11th LHCC students poster session

What is the context ?



The **HL-LHC** (starting in 2027) is the future phase of the LHC and aims to **accumulate 10 times more of integrated luminosity** than the LHC. But, this will lead to 5 times **more pile-up** and significantly **higher radiation levels** compared to current ones at LHC.

The **High Granularity Calorimeter (HGCAL)** will replace the existing **endcap calorimeters of CMS**. It will be a sampling calorimeter measuring (x,y,z,t,E), composed of :

- Silicon-based modules (CE-E) for the electromagnetic part (≈ 25 X_0 | 1.3 λ)
- Silicon-based modules (CE-H-Si) + Scintillator tiles for the hadronic part (≈ 8.5 λ)

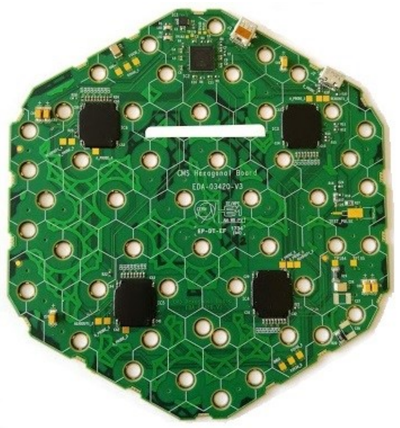
In order to efficiently reject particles originating from pile-up, **precision timing information of the order of 30 ps** for a full shower will be of great benefit. Silicon module prototypes using SKIROC2-CMS were tested in the SPS beam in order to validate the timing performance, even if the foreseen chip for HL-LHC (HGCROC) is different.

Prototype

Prototype modules are hexagonal boards composed of a **128-channels silicon sensor** of hexagonal shape. On the boards, four chips read the signals from 32 cells. The board and sensor are mounted on copper-tungsten or PCB baseplates.

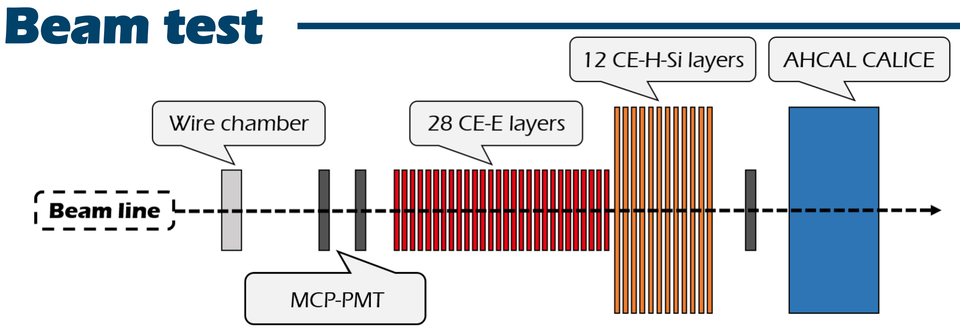
In 2018, the HGCAL prototype composed of 96 modules and corresponding to 12k channels in total, was exposed to beams of **electrons, pions and muons** with energy varying from **20 to 300 GeV**, produced at the CERN SPS.

The prototype was equipped with SKIROC2-CMS chips which measure the **Time-of-Arrival** of particles.



HGCAL hexaboard prototype

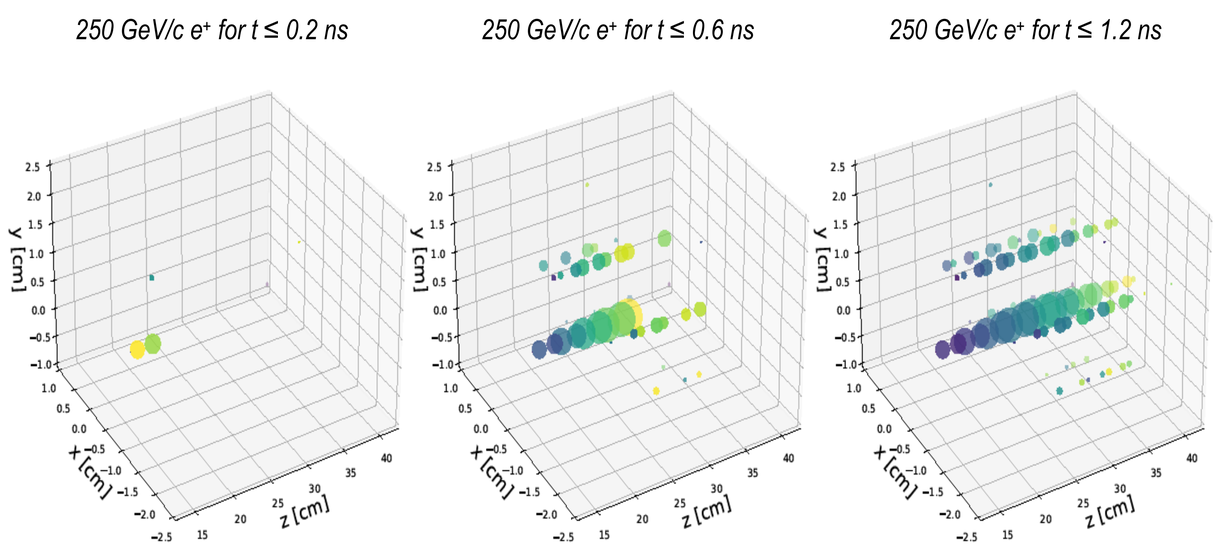
Beam test



The experimental set up is composed of the following elements :

- Wire chamber ⟶ Tracking & position reference
- MCP-PMT ⟶ Timing reference
- 28 layers of 1 hexagonal module ⟶ Electromagnetic calorimeter (CE-E-Si)
- 12 layers of 7 hexagonal modules ⟶ Hadronic calorimeter (CE-H-Si)
- AHCAL CALICE scintillators tiles ⟶ Hadronic calorimeter (CE-H-Sci)

What is the timing performance?



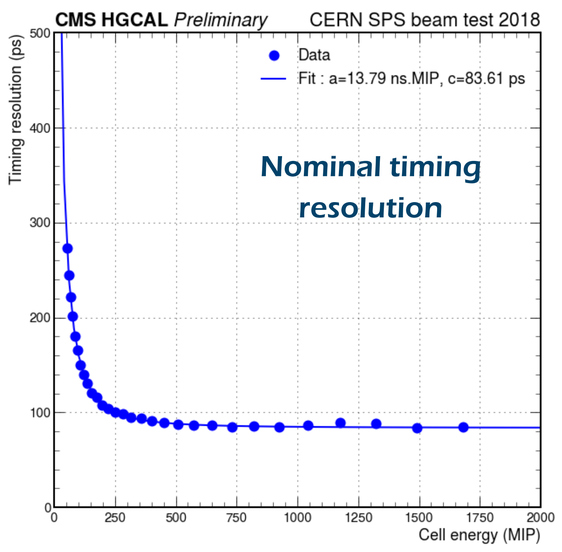
Timing development of an electromagnetic shower in HGCAL prototype

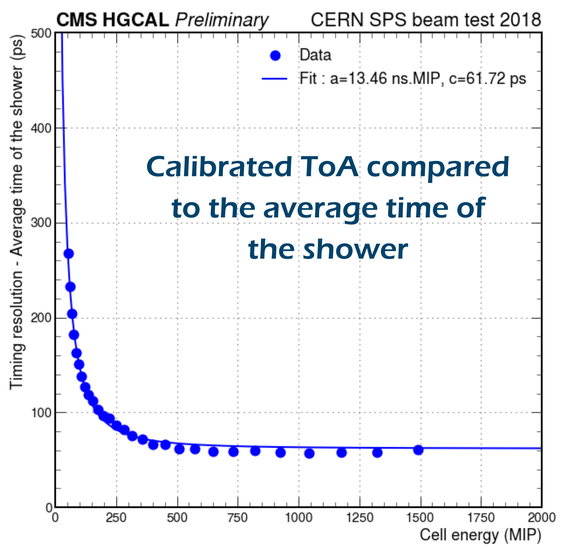
Timing performance analysis procedure

1. **Calibration of the channels** → Harmonize their time-measurement response
   - 134 channels from the CE-E layers could be fully calibrated (~1% of the channels)
   - Calibration done using MCP as reference
   - Linearisation of the ToA, time walk correction & residual correction
2. **Computation of the single channel timing resolution**

   (fitted with $\sigma(E) = \frac{a}{E} \oplus c$, where a is a stochastic term, c a constant term and E the energy.)
3. **Smearing of the MC** using single channel timing resolution
4. **Computation of the full shower timing resolution**
   - Define a resolution-weighted time per shower for the fitted sigma $\bar{t} = \frac{\sum_{i=1}^{n} w_i t_i}{\sum_{i=1}^{n} w_i}$, where $w_i = \frac{1}{\sigma^2(E_{cell})}$
   - Define an expected sigma $\sigma_{\bar{t}} = \frac{1}{\sqrt{\sum_{i=1}^{n} w_i}}$
5. **Sources of jitters measured** and injected in the MC → More realistic simulation
   - Total jitter between HGCAL prototype and MCP system: ~ 54 ps
   - Intrinsic jitter to the MCP detectors: ~ 25 ps for e^+ and ~100 ps for π^+
   - Remaining extra jitter of unclear origin: ~ 50 ps

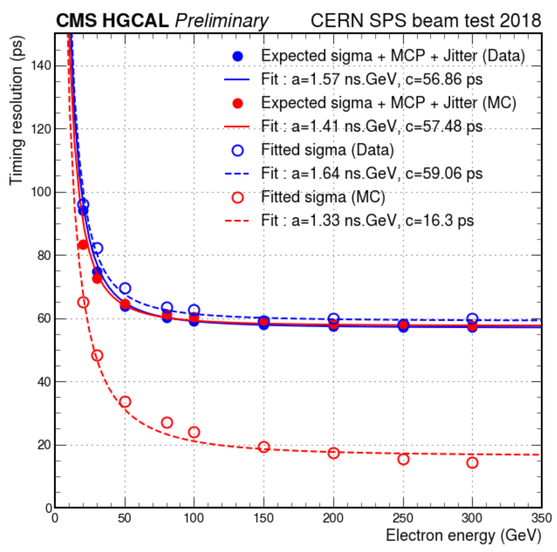
Single channel performance

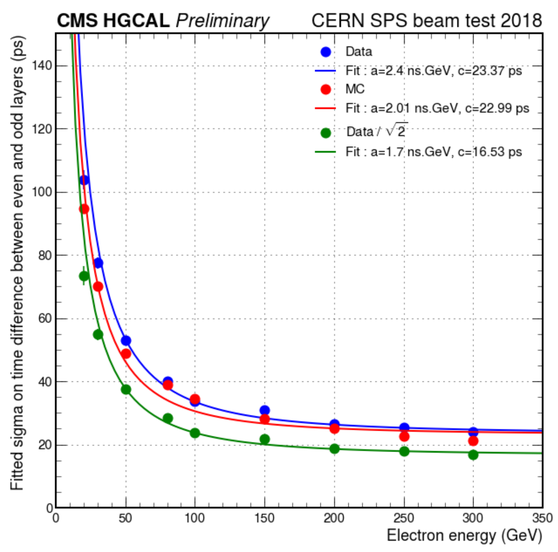




- **Timing resolution constant term ~83ps** when comparing ToA to MCP reference
- **Constant term ~61ps** when comparing the calibrated ToA to the average time of the shower (reference independent from the MCP system)
  → Gauges the performance of the SKIROC2-CMS ToA
- **The comparison between both resolutions reveals the extra jitter between HGCAL and MCP**

Electromagnetic shower





- **Expected and fitted shower resolutions in data are in perfect agreement**
- **Excellent agreement observed between data and MC for the expected sigma**
- Jitter factor of √2 between odd & even layers → **Data / √2 is comparable to MC**
- **Timing resolution constant term ~56ps** (including extra jitter)
- **Timing resolution constant term ~23ps** (odd vs even HGCAL layers)

Conclusion

- Beam tests were performed at CERN of HGCAL prototypes silicon modules & a timing performance analysis was done using CE-E channels
- **Excellent agreement between data & MC simulation**
- An extra jitter is observed and the good agreement between data & MC indicates a good understanding of the timing of electromagnetic showers
- Timing resolution constant term **~61ps for single channel, ~23ps for electromagnetic showers** in an equivalent detector with half of the layers & **~56ps with the extra jitter**
- **The single channel performance is in agreement with the designer's specifications** → This is promising in view of the final HGCROC and HL-LHC