**What is the context?**

The **H-LHC** (starting in 2027) is the future phase of the LHC and aims to accumulate 10 times more of luminosity. But, this will lead to 5 times more pile-up and a higher radiation dose compared to current dose at LHC. The **High Granularity Calorimeter (HGCAL)** will replace the existing endcap calorimeters of CMS. It will be a sampling calorimeter measuring (k+2.1E), composed of:

- Silicon-based modules (CE-E) for the electromagnetic part (= 25 X0 \( \times 1.3 \lambda_p \))
- Silicon-based modules (CE-H-Si) + Scintillator tiles for the hadronic part (= 8.5 \( \lambda_p \))

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 were tested in the SPS beam in order to validate the timing performance.

**How were the prototypes tested?**

Prototype modules are hexagonal boards composed of a silicon sensor divided in 135 channels of hexagonal shape. On the boards, four chips read the signals from 32 cells. These modules are mounted on a copper-tungsten baseplate for the electromagnetic part and with a steel plate for the hadronic one.

In 2018, HGCAL prototype was exposed to beams of electrons, pions and muons with energy varying from 20 to 300 GeV, produced at the CERN SPS.

**Where is the timing information from?**

<table>
<thead>
<tr>
<th>ToA in SKIROC2cms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time of Arrival (ToA)</strong> is measured from a fast shaper (5 ns). When the trigger is activated, ToA is measured with a Time to Amplitude Converter (TAC). The voltage ramp of the TAC is stopped by clock edge.</td>
</tr>
</tbody>
</table>

**How is the timing information calibrated?**

- **ToA calibration (ToA)**
  - Time Walk (TW) calibration allows to correct for the non-linearity of the ToA distribution due to the ramp saturation in the TAC. This plot shows the non-linear delay depending on the normalised ToA Rise from a single channel.

- **TW calibration (fTW)**
  - This calibration step is a layer energy dependent TW calibration. It corrects the systematic pedestal shifts for high energy densities. This plot shows the TW depending on the energy sum of a layer.

- **TW-layer calibration (fTW-layer)**
  - ToA is measured with respect to two reference points:
    - ToA Rise \( \rightarrow \) TAC ramp is stopped at the next rising clock edge
    - ToA Fall \( \rightarrow \) TAC ramp is stopped at the next clock falling edge

**What is the timing performance?**

- **Single cell timing resolution as given below was measured in data. It has a stoch term of 10-20 ns.MIP and a constant term ~ 50 ps.**

- **Shower timing determination**
  - Per channel combination of ToA Rise & Fall (12.5 ns are added to ToA Fall to match ToA Rise)
  - Outlier removal (keep only timing values within the shortest 68% interval of timing values per event)
  - Energy weighting (for each event \( \sum_i (E_i) \) where \( i \) is cell index)

T Timing resolution taken from a gaussian fit to the combined time distributions. Plots for 28 CE-E layers and electron beams.

**Conclusion**

- Beam tests were performed at CERN of HGCAL prototypes silicon modules
- Time calibration was done for the ToA measurement of the prototype ASIC
- Resolution from the Geant4 simulation (~10 ps constant term) was achieved with assumption of ideal calibration and absence of systematic effects
- Constant term from data ~ 50 ps \( \rightarrow \) Further understanding of systematic effects needed