Precision Timing Capabilities of Silicon Pad Sensors in the CMS HGCAL

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Introduction & Summary

Excellent time resolution will be an essential tool for pile-up mitigation and vertex identification at the HL-LHC.

The CMS experiment is currently building highly granular calorimeter endcaps **(CMS HGCAL)** with silicon pad sensors as active material in the high radiation region [1].

The results presented here show that these sensors have **intrinsic timing capabilities down to 10 ps** and that the capabilities are **uniform across the sensor**. It is further shown that the **time resolution can be well modelled by 2 parameters**, accounting for jitter and constant contributions. Both are **dominated by the front-end electronics**.

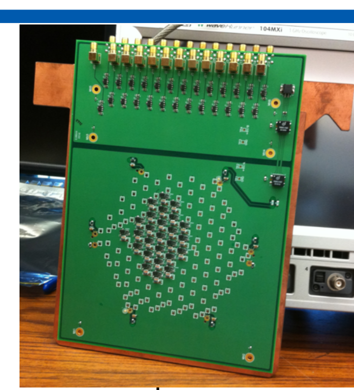
Experimental Setup

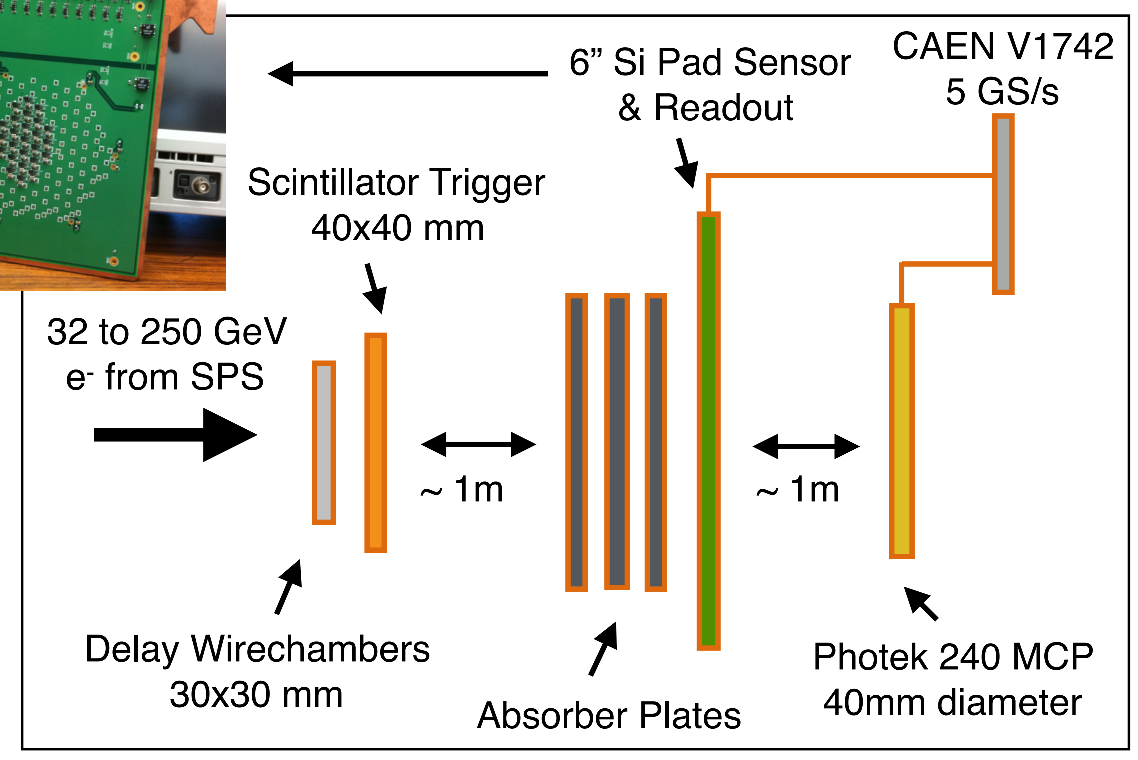
A **6" HGCAL prototype sensor samples EM showers** after 5.7 X_0 W and 10 X_0 W+Pb.

The sensor is wire-bonded to a custom readout board and the **waveform is sampled with 5 GS/s**.

Some more details on the setup:

- MCP gives reference timestamp
- Delay wirechambers determine the impact position
- Large trigger counter allows illumination of multiple cells





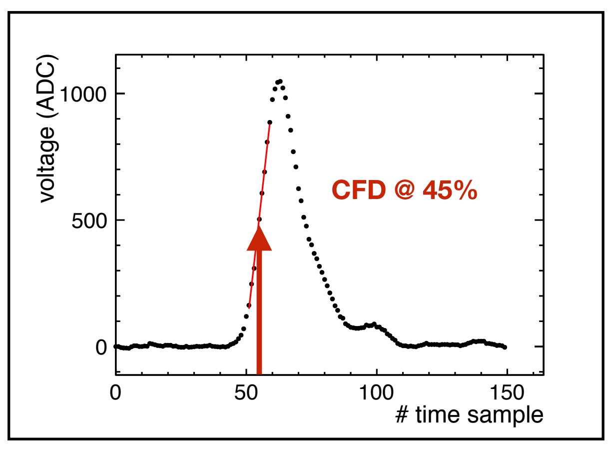
Experimental Setup: A silicon pad sensor with custom read-out optimised for timing tasks samples EM showers. Time differences between pads and relative to the MCP are analysed.

Analysis

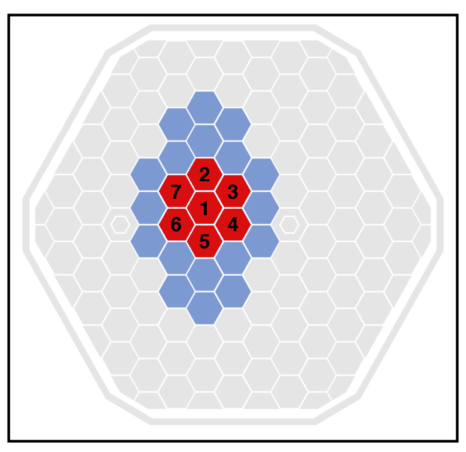
Waveforms are analysed offline

- Timestamp via constant fraction @ 45%
- **Time differences between adjacent pads and relative to the MCP** as well as single pad and cluster timestamps are analysed

To compare different pads, **offset** in time between pads & **timewalk** has to be corrected.



Example silicon waveform: Timestamp extracted at 45% of peak height.



Silicon pad sensor: Only red cells are used for the presented data.

More Details

Some details on the sensor

- HGC 300 µm thick silicon pad sensor
- DC coupled n-type planar FZ
- Hexagonal cells with 1.1 cm² (40 pF)

Some details on the electronics

- DRS4 ASIC with 8 channels at 5 GS/s and f_u = 500 MHz
- 1:2 transformer to lower rise time
- Rise time of t_r^{si} ~1.8 ns, t_r^{mcp} ~0.7 ns

Some details on the analysis

- Effective S/N is the relevant quantity
- Cluster timestamp via weighting of effective S/N with inverse variance

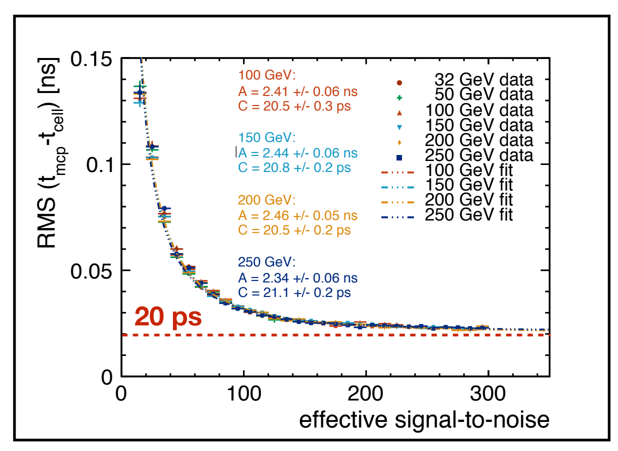
$$(S/N)_{\mathrm{eff}} = \frac{(S/N)_{\mathrm{ref}}(S/N)_{\mathrm{dut}}}{\sqrt{(S/N)^2_{\mathrm{ref}} + \alpha^2 \cdot (S/N)^2_{\mathrm{dut}}}} \qquad \alpha \approx \frac{t_{\mathrm{rise,ref}}}{t_{\mathrm{rise,dut}}}$$

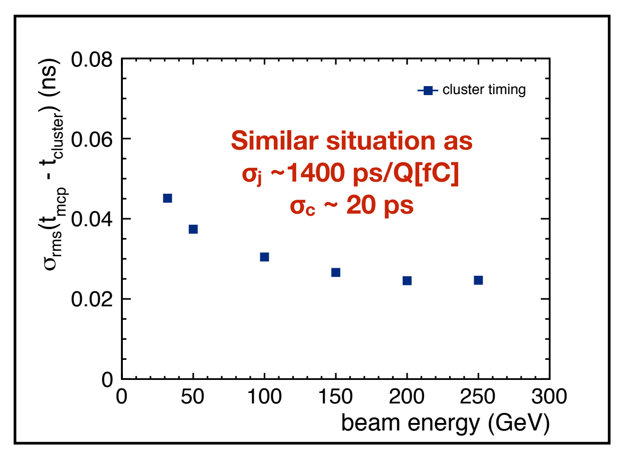
Results Relative to MCP

Resolution of MCP with ~20 ps **larger than silicon**

- Constant term C similar to O(50 ps) TDC
- Jitter term A similar to 1.4 ns/fC
- Final front-end ASIC should do better!

Previous measurements have shown that the **dependence of time resolution on S/N is not affected by irradiation** up to 10¹⁶ neq/cm² [2].





Uncertainty vs S/N and beam energy after 5.7 X_0 W: Results are limited by electronic noise and MCP resolution.

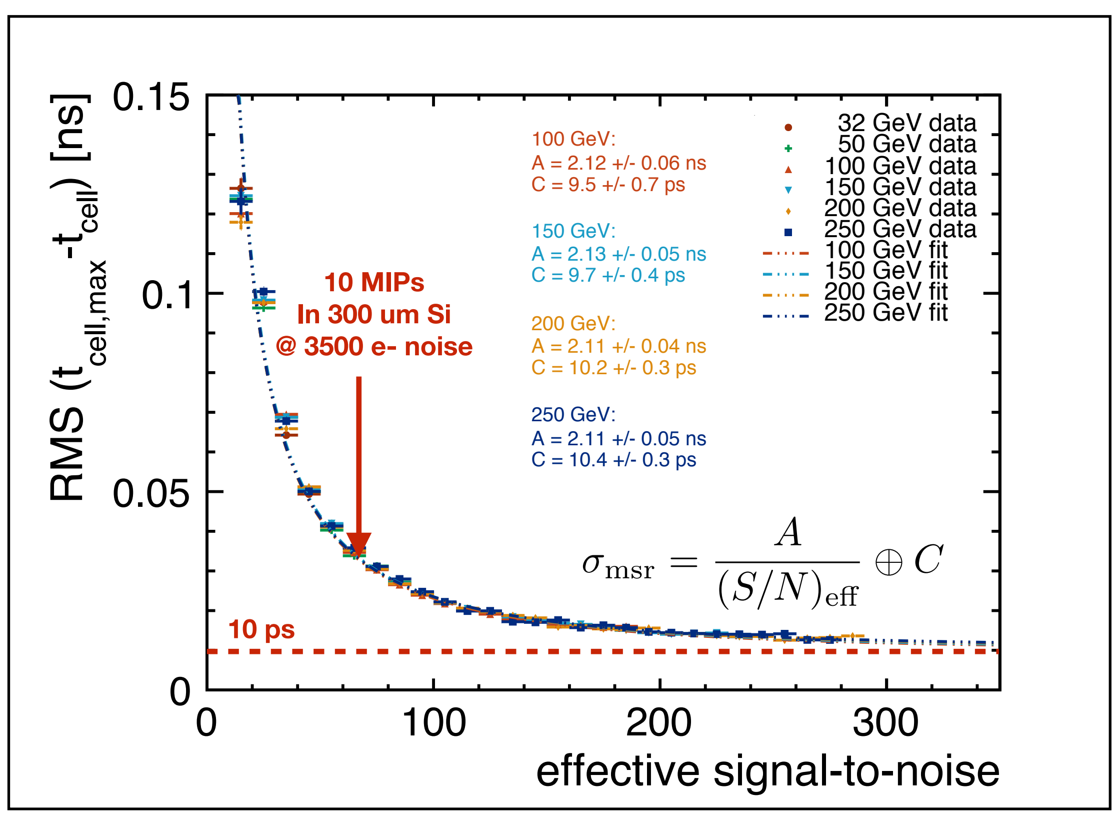
Results Between Adjacent Pads

Results on intrinsic timing

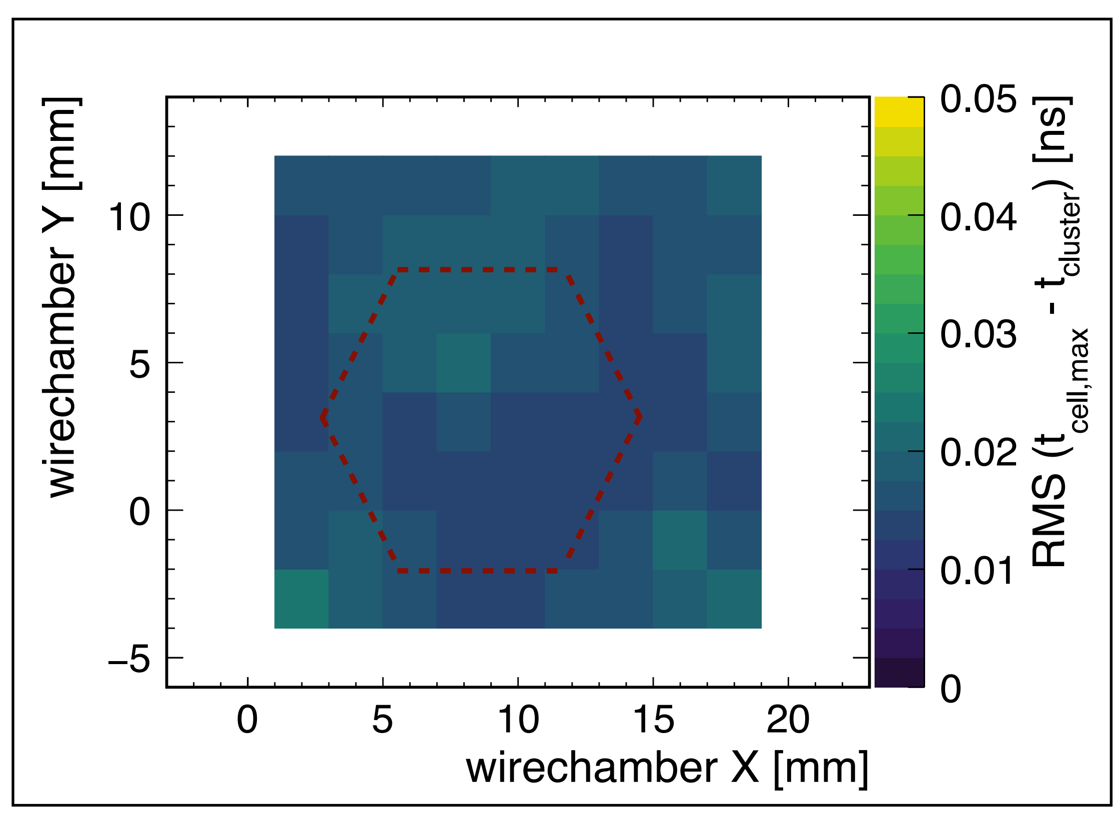
- S/N for MIP is ~ 6.5, noise is 3500 e-
- Data well represented by **2 parameter fit**
- **Jitter term A** fits well with electronics expectations
- **Constant term C around 10 ps** can be partly explained by DRS4 synchronisation uncertainty of 5-7 ps [3] and the offset uncertainty of 2-3 ps

Results on cluster timing

- Cluster timestamp removes dependency on impact position
- **Excellent uniformity** across illuminated area
- Performance increase with larger cluster size depends on exact values of A and C



Uncertainty vs. S/N after 5.7 X_0 W: Uncertainty is well modelled by a two parameter function, accounting for jitter (A) and constant (C) contributions.



Uncertainty vs. impact at 200 GeV, 10 X_0 W+Pb: Results are uniform across the illuminated sensor area. The red hexagon indicates the approximate position of the central pad.

References

[1] CMS-TDR-019
[2] CMS-DN-2017-011
[3] Nucl. Instr. Meth. A 759 (2014) 65–73

Acronyms

MCP … Micro Channel Plate
CFD … Constant Fraction Discriminator
FZ … Float Zone
DUT … Device Under Test

Contact

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