The CMS Precision Proton Spectrometer: precision timing with scCVD diamond crystals

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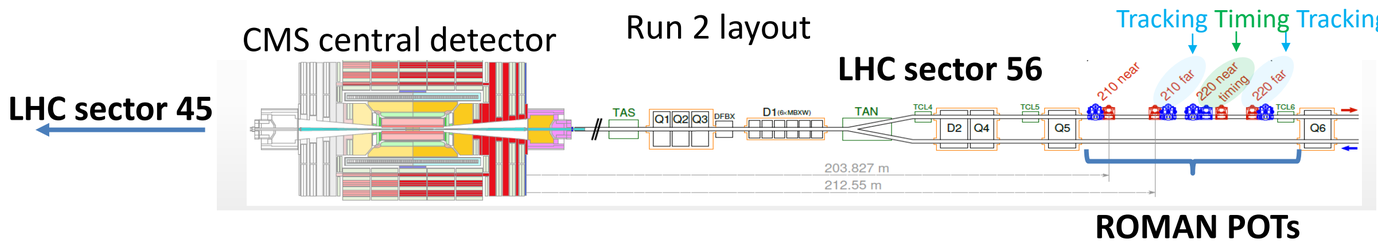
1.Introduction

The PPS detector extends the physics program of CMS to Central Exclusive Production (CEP) processes, where both protons remain intact after the interaction.

The primary vertex is reconstructed by means of the protons time of flights difference in the two sectors ($Z_{PP} = c\Delta t/2$), providing pile-up background suppression. Goal is ~**30 ps precision per sector on MIP**, with **particle rate above 1 MHz/channel.**

Timing RP(4 detection planes/station):
in 2018 each station was equipped with 2 single- (SD) and 2 double-sided (DD) diamond detector planes [1].

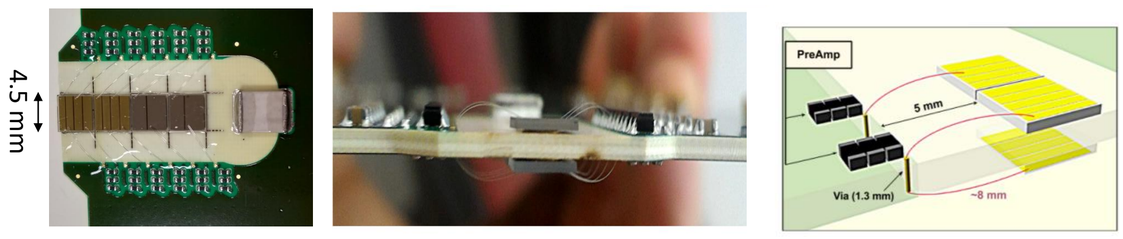
Symmetric experimental setup w.r.t. the interaction point to detect leading protons

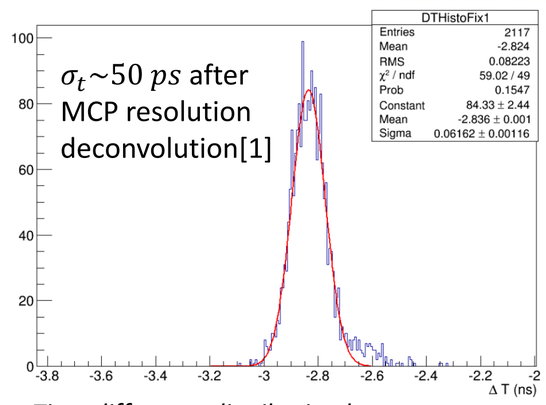


Detectors are hosted inside Roman Pots (RP), movable vacuum insertions which bring the detectors at **12 σ_{beam}+ 0.3 mm (~1.5 mm) from the LHC beams, in a secondary vacuum**

→ Very high non-uniform irradiation field, with a **peak of ~5x10^{15} p/cm^2** in Run 2

2. Double-sided Diamond detector





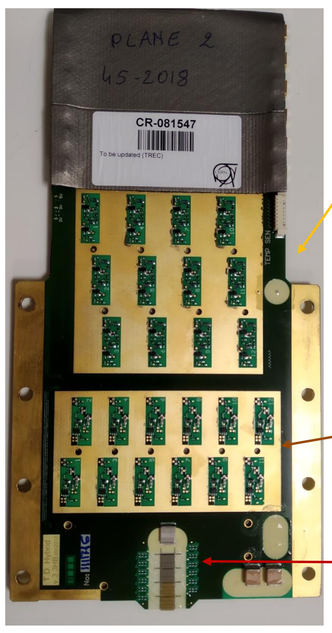
Time difference distribution between DD and reference MCP ($\sigma_{t,MCP}$~40 ps)

Signal from corresponding pad is connected to the same amplification channel:

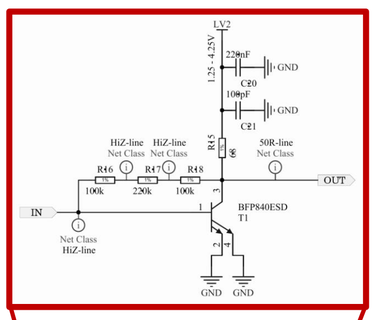
- Higher signal amplitude
- Same noise (pre-amp dominated) and rise time (defined by shaper)
- Higher sensor capacitance

Better time resolution (factor ~1.7) w.r.t single diamond[1]

3. Front End Electronics



Shaper:
2xBFG425 Si BJT matched amplifier for shaping the signal

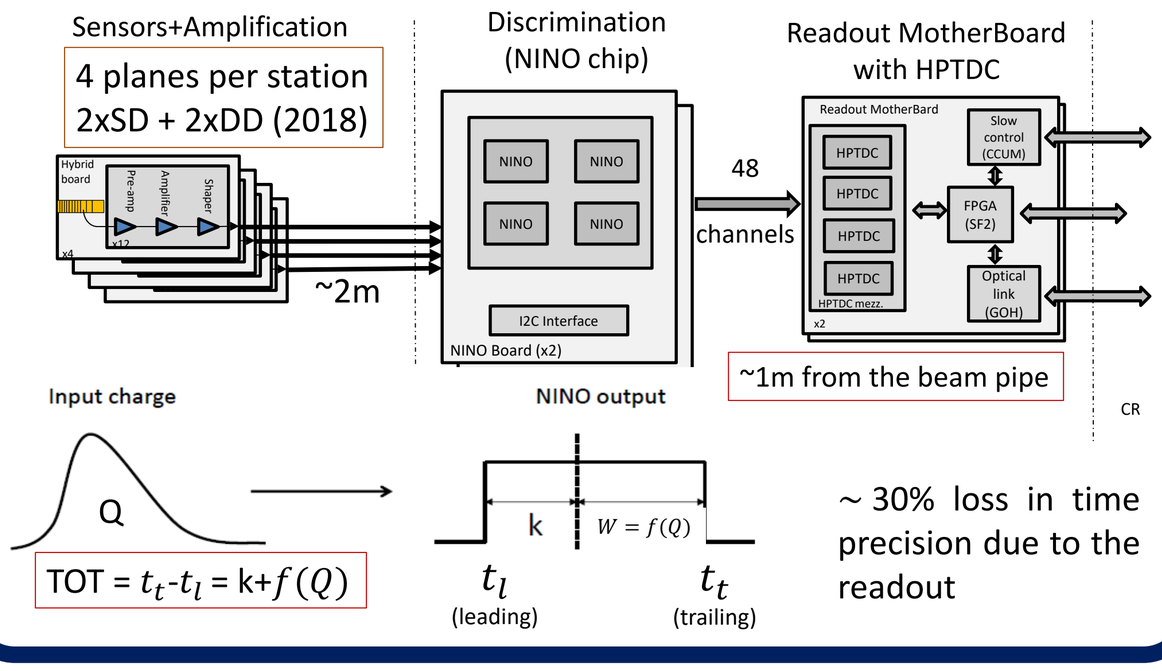


Amplifier:
Monolithic microwave integrated circuit ABA-53563, near linear phase, absolute stable amplifier

Pre-Amplifier:
stage BFP840 SiGe BJT with low-C feedback (~0.4 pF)

Each plane: 12 discrete amplification channels with pre-amp @1mm from crystals[2]

4. PPS timing system

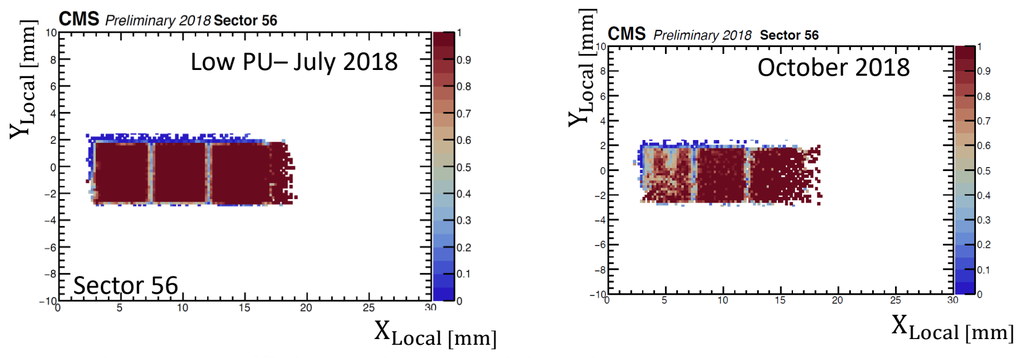


~ 30% loss in time precision due to the readout

5. Run 2: efficiency

The timing system was operated @LHC in Run2. Best performance (section 5-6) was reached in 2018, limited by instabilities in amplification and HV discharges induced by the beam, forcing to operate below nominal bias and amplification level.

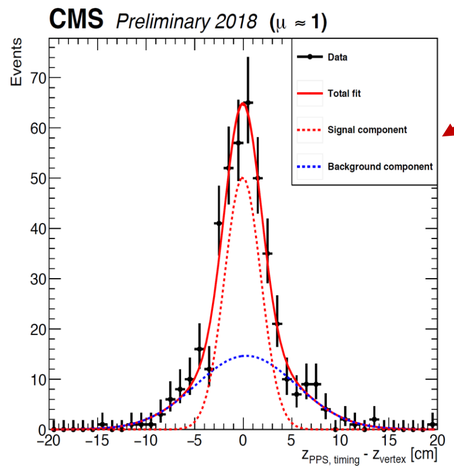
- The time-track efficiency in low pileup data from July 2018 is near 100%
- The evolution at the end of Run 2 (October 2018) shows a degradation of the efficiency. Later investigation in test beam shows that full efficiency is retained when operating the sensor at nominal voltages[3].



Systematic lower efficiency is only visible in the regions between two crystals, not between pads on the same crystal .

6. Run 2: performance

Vertex resolution checked in central exclusive events collected in low pileup conditions[4].



High resolution tracks (hits in all planes):
$\sigma_{Zpp} = 1.87 \pm 0.21$ cm

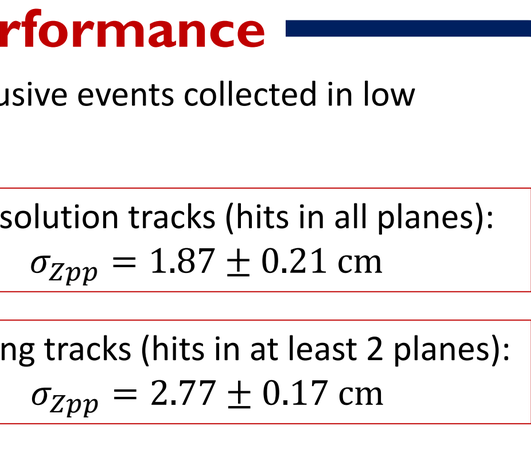
All timing tracks (hits in at least 2 planes):
$\sigma_{Zpp} = 2.77 \pm 0.17$ cm

Timing information can be used in physics analysis to suppress pile-up background.

Correlation observed between the time difference of the protons and the longitudinal vertex position reconstructed in the central CMS tracker

7. Run3 Upgrade & perspective

- Additional timing station in each sector, equipped with 4 DD planes
- New hybrid & NINO boards -> amplification stability and HV isolation improved +signal splitting for secondary readout



- Sensor readout with SAMPIC chip (fast sampler @ 7.8 Gsa/s) possible for commissioning phase and sensor monitoring. Successfully used as CMS-TOTEM timing sensor readout for a special run in 2018[5]

Time precision <30 ps on MIP is the final goal for LHC Run 3 -> vertex resolution < 1 cm

[1] M. Berretti *et al* 2017 *JINST* **12** P03026
[2] G. Antchev *et al* 2017 *JINST* **12** P03007
[3] E. Bossini *et al,* CMS-NOTE-2020-007, https://cds.cern.ch/record/2742383
[4] CMS Collaboration, CMS-DP-2020-046, https://cds.cern.ch/record/2740689
[5] E.Bossini, PoS(TWEPP2018)137

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