The Run 3 timing detector of the CMS Precision Proton Spectrometer: status and performance

Milla-Maarit Rantanen[1,2] for the CMS collaboration
[1] Helsinki Institute of Physics (HIP), University of Helsinki, Helsinki, FINLAND
[2] Department of Physics, University of Helsinki, Helsinki, FINLAND
E-mail: milla-maarit.rantanen@helsinki.fi

INTRODUCTION

The CMS Precision Proton Spectrometer (PPS) detector system measures the time-of-flight (ToF) and position of protons (p) that remain intact in p-p collisions at the interaction point (IP) of CMS at the Large Hadron Collider (LHC). PPS consists of movable tracking and timing stations (Roman Pots) about 200 m from the CMS IP (**Figure 1**). Detectors can be moved close to the outgoing beam (to a distance of a few mm). Precise ToF measurements are needed for reconstruction of the longitudinal vertex position of the p-p collision.[1, 3]

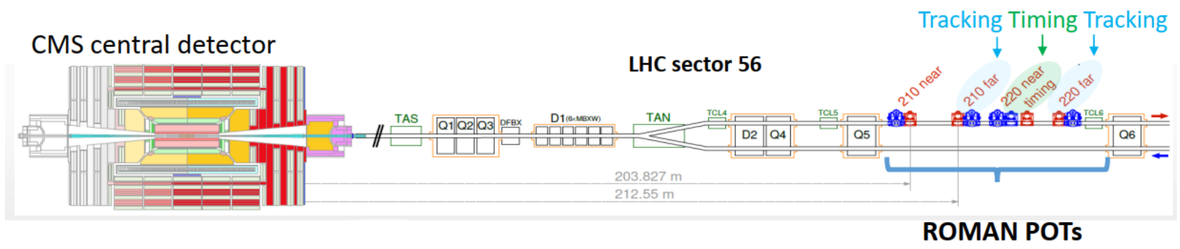

Figure 1. Layout of one arm of the CMS PPS.

TIMING STATION UPGRADE FOR RUN 3

Detectors of PPS are exposed to high and highly non-uniform irradiation, and must have excellent radiation tolerance and good timing resolution. For the LHC Run 3 (2022-2025), the PPS timing stations were upgraded to reach a timing resolution of 30 ps (~1 cm vertex resolution). A second timing station was added to each arm. Each station was equipped with four detector planes with 500 μm thick single crystal diamond detectors in double-diamond configuration (**Figure 2**). Also the operation parameters of the detectors and electronics were optimised.[1, 2]

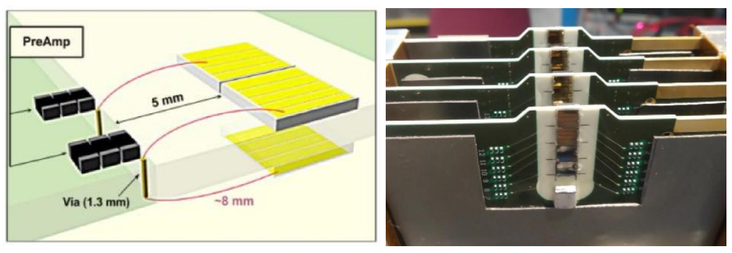

Figure 2. Double-diamond configuration (left) used in PPS in Run 3, in which two diamond detectors with the same segmentation are glued on both sides of the readout board. The detector planes of one timing station (right).

DETECTOR TESTING PROCEDURE

Before installation, the quality of the detectors was checked through visual inspection and electrical measurements. Detectors were metallised in two steps; the first step consisted of deposition of single large electrodes on both sides and the second deposition of segmented electrodes on the top side. The characterisation was done before and after metallisation steps.

VISUAL INSPECTION

Cross-polarised light microscopy (**Figures 3a-b**) was used to visualise defects and strain in the crystal. Optical microscopy was used to visualise surface defects, to check the electrode quality and to measure the detector dimensions. **Figures 3c-d** show optical microscope images of detectors with the two electrode segmentations used (2-strip and 4-strip pattern).

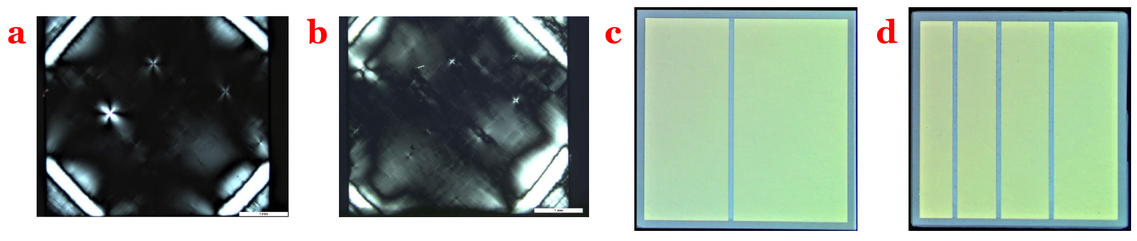

Figure 3. Cross-polarised light microscope images (a and b) of two bare diamond crystals and optical microscope images (c and d) of metallised diamonds.

ELECTRICAL MEASUREMENTS

Leakage currents and amplitude of signals induced by electrons from a ^{90}Sr radiation source were measured. The leakage current was measured between -700 V and 700 V (**Figure 4**) and included 1 hr stability tests. The signal amplitude was measured between 50 V and 700 V, and compared to the amplitude measured with a reference diamond detector (**Figure 5**).

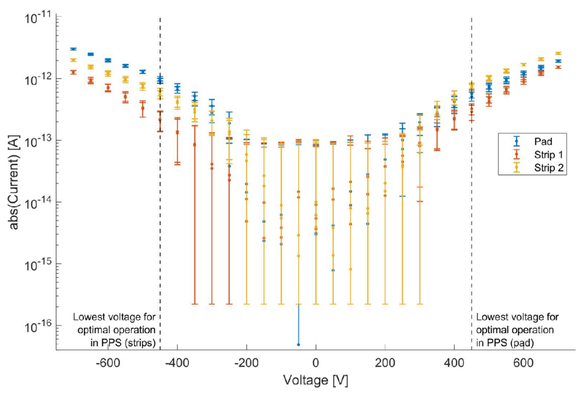

Figure 4. Absolute value of the leakage current as function of voltage measured for all electrodes on a detector.

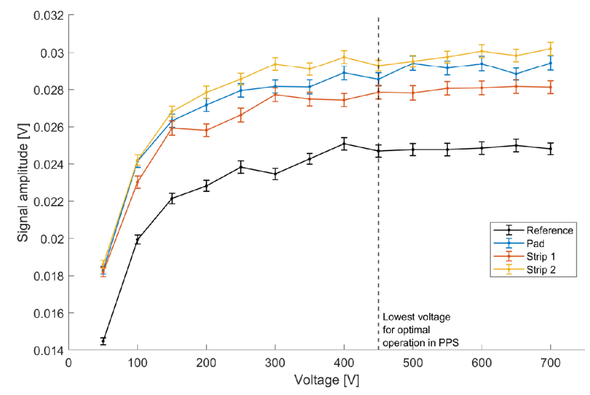

Figure 5. The mean signal amplitude for all electrodes (coloured lines) on a detector under a ^{90}Sr radiation source. The black line shows the signal amplitude for a reference diamond detector.

PERFORMANCE IN RUN 3

The PPS timing detector performance has been validated using central diffractive events from low pile-up data (μ~1), where majority of the detected protons belong to the primary vertex reconstructed with the CMS Tracker. The PPS vertex resolution was determined by fitting a double-Gaussian (signal+background) to the data (**Figure 6**) [3].

Results of the preliminary analysis [3]:

- PPS **vertex resolution** is **~1.9 cm** (**60 ps timing resolution**) with correction and alignment of the arrival time with the signal time over threshold. Resolution is expected to improve significantly by determining the resolution of each timing signal channel.
- The **ToF** difference of the two protons (one in each arm) **correlates with the vertex position** reconstructed by the Tracker. (**Figure 7**).

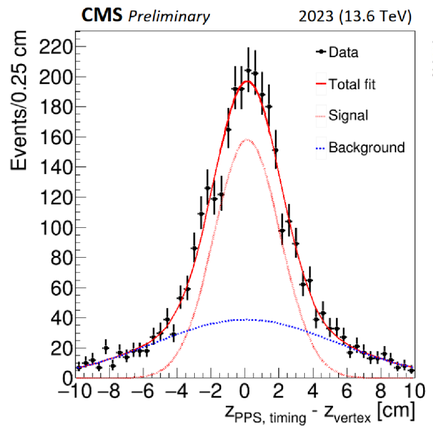

Figure 6. Fit of double-Gaussian of background (events where one or both protons are not associated to the vertex found in the Tracker) and signal to the difference between the PPS and CMS Tracker vertex position.

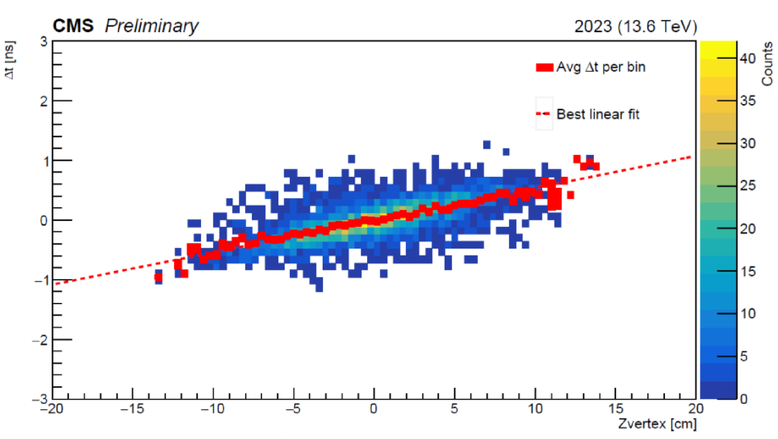

Figure 7. The difference of the ToF of the two protons (Δt) measured by PPS as function of the CMS Tracker vertex position (Z_{vertex}).

CONCLUSIONS

- The CMS PPS **diamond timing detectors** and the procedure used to check their quality and response before installation are presented.
- Preliminary analysis gives a **vertex resolution** of about **1.9 cm (60 ps)** in Run 3 data. The complete calibration is expected to give improved resolution closer to the target resolution of better than 30 ps.
- The difference in proton **ToFs** measured by PPS **correlate with** the CMS Tracker **vertex position**.

REFERENCES

1. Bossini, E. (2020). The CMS Precision Proton Spectrometer timing system: performance in Run 2, future upgrades and sensor radiation hardness studies. *Journal of Instrumentation*, *15*(05), C05054.
2. Bossini, E. (2023). The CMS Precision Proton Spectrometer: Precision timing with scCVD diamond crystals. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *1047*, 167823.
3. CMS collaboration. PPS Performance: first evaluation of the two-arm vertex reconstruction with timing detectors in 2023, https://cds.cern.ch/record/2890103

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