Nuclear Instruments and Methods in Physics Research A 1068 (2024) 169710

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

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

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ARTICLE INFO

Keywords:
Timing detectors
Diamond detectors
Precision timing detector

ABSTRACT

The CMS Precision Proton Spectrometer at the LHC measures protons scattered in the very forward region. Single crystal diamond detectors are used to precisely measure the proton time-of-flights and to reconstruct the longitudinal position of the interaction vertex. For the LHC Run 3 the timing detector was upgraded with the aim to reach a timing resolution of better than 30 ps, corresponding to a vertex resolution of better than 1 cm. An overview of the timing detector upgrade is given and the diamond detector testing procedure before installation is described. Preliminary results of the Run 3 timing detector performance are reported.

1. Introduction

The Precision Proton Spectrometer (PPS) [1] is a subdetector of CMS [2] at the Large Hadron Collider (LHC) designed to extend the physics program of CMS to high mass (>300 GeV) Central Exclusive Processes (CEP). In CEP events the protons remain intact after the proton–proton collision and a central system X is formed. PPS measures the position and time-of-flight (TOF) of the protons scattered in the very forward region.

PPS consists of tracking and timing detectors placed symmetrically on both sides of the interaction point (IP) of CMS at a distance of about 200 m from the IP (layout described in [3] and [4]). The detectors are housed in movable detector units, called Roman Pots (RP), and can be moved to a distance of a few mm from the outgoing beam. The detectors are located after several magnets and reconstruction of the proton tracks relies on good understanding of the proton transport in the magnetic fields between the IP and the RP location. Despite this, the tracking detectors are not able to make a precise determination of the vertex position. Instead precise measurement of TOF of the protons detected in both arms is used to reconstruct the longitudinal position of the vertex. The TOF measurement is also an effective way to reduce pile-up background [1,4,5].

For the LHC Run 3 (2022–2025) the timing detector was upgraded to reach a timing resolution of better than 30 ps. In the upgrade one more timing RP was added to each arm at about 215 m distance, increasing the total number of timing RPs from two to four. Due to their location close to the beam the detectors are exposed to high and non-uniform irradiation. Diamond detectors were chosen because of their radiation tolerance and fast signals. Each RP was equipped with four planes of 500 μm thick diamond detectors in double-diamond (DD) configuration (Fig. 1). The area of each detector is $4.5 \times 4.5\ \text{mm}^2$ [3–5]. In the DD configuration two diamond detectors with the same electrode segmentation are glued on both sides of the readout board and the corresponding electrodes are connected to the same amplifier [4,6]. In addition, a new readout board was designed to improve amplification stability and high voltage isolation, and the operation parameters were optimized [4,5].

2. Detector testing procedure

Before installation the quality of the diamond detectors was checked through visual inspection and electrical measurements. The detectors were metalized in two steps; first single large electrodes were deposited on both sides of the crystal, after which segmented electrodes (strips) were deposited on the top side. Fig. 2 shows the two segmentations used. The detectors were characterized before and after all metalization steps.

The visual inspection included cross-polarized light microscopy (Fig. 2 left) to visualize defects and strain inside the crystal, and optical microscopy to check the quality of the electrodes and to measure the detector dimensions. The electrical measurements included measurement of leakage currents and mean amplitude of signals induced by electrons from a ^{90}Sr source. The leakage currents were measured between −700 V and 700 V, and the measurement included 1-hour-long stability tests at the highest and lowest voltage. The mean signal

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https://doi.org/10.1016/j.nima.2024.169710
Received 28 June 2024; Received in revised form 1 August 2024; Accepted 5 August 2024
Available online 8 August 2024

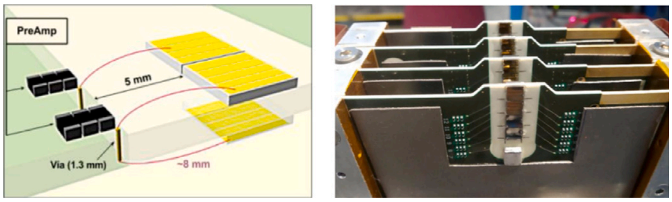

Fig. 1. Picture of the double-diamond configuration (left) used in PPS in Run 3 and the four detector planes of one timing Roman Pot (right).

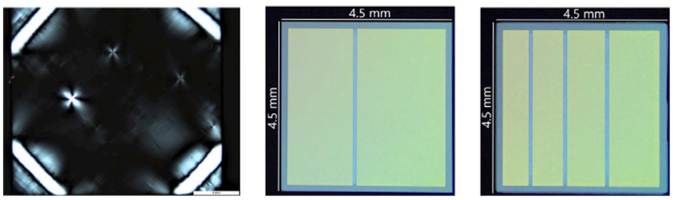

Fig. 2. A cross-polarized light microscope image of a diamond crystal (left) and optical microscope images of metallized diamonds with the two electrode segmentations used in PPS (middle and right).

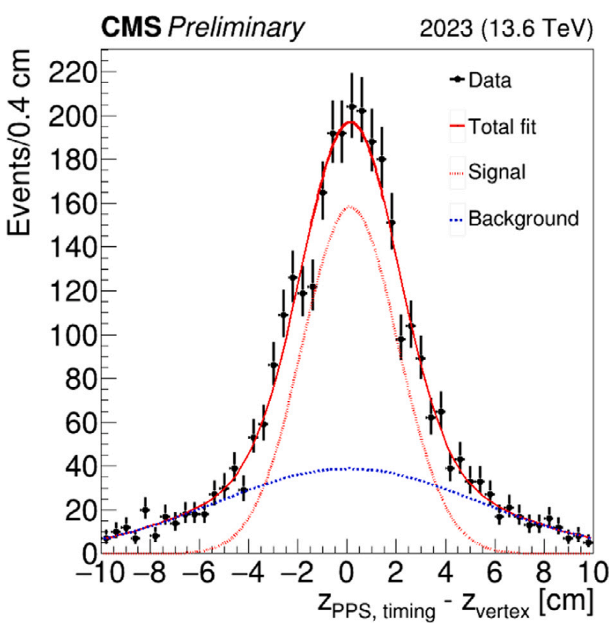

Fig. 3. Distribution of the difference between the longitudinal vertex positions reconstructed by PPS and the CMS Tracker. Dashed curves show the Gaussian fits to the signal and the background.
Source: Figure from [3].

amplitude was measured between 50 V and 700 V, and compared with the signal measured for a reference diamond detector.

3. Performance in Run 3

The detectors are used for data taking in Run 3. Their performance has been validated offline using CEP events selected from low pile-up data ($\mu \approx 1$), in which the majority of the detected protons belong to the primary vertex reconstructed with the CMS Tracker. The calibration of the timing detectors is done in two steps. In the first step the proton arrival times are corrected and aligned with the signal time over threshold. In the second step the resolution of each timing signal channel is determined through an iterative procedure. The resolutions are then used to calculate a weighted average for the proton TOF. The PPS vertex resolution is determined by comparing the PPS vertex position with the position reconstructed with the CMS Tracker. A double Gaussian fit is made to the difference of the vertex positions to describe the signal and the background. The background consists of events in which one or both protons are not associated to the vertex found in the Tracker [3,7].

Fig. 3 shows the result obtained in the analysis including only the first step of the calibration. The PPS vertex resolution is around 1.9 cm, corresponding to a timing resolution of 60 ps. The comparison of the TOF difference of the protons detected by PPS and the vertex reconstructed by the Tracker shows a clear correlation, confirming that the TOF measurements can be used to suppress pile-up background [3].

4. Conclusions

The timing detector of CMS PPS was upgraded for Run 3. PPS uses detectors based on single crystal diamond to precisely measure the TOF of protons scattered in the very forward region and to reconstruct the longitudinal vertex position. A vertex resolution of about 1.9 cm (60 ps timing resolution) is obtained using only partial TOF detector calibration. This demonstrates that TOF measurements can be used to reduce the background from pile-up protons in the analysis of Central Exclusive Processes. An improved vertex resolution closer to the 1 cm target resolution (30 ps timing resolution) is expected to be achieved by including the second step of the TOF detector calibration.

Funding

This research was partially supported by Svenska kulturfonden, Finland [grant number 176403, 2022].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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