New physics results with the CMS Precision Proton Spectrometer

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Abstract

The Precision Proton Spectrometer of the CMS experiment (PPS) collected more than 110 fb^{-1} of data over the course of the LHC Run 2. The present contribution gives an overview of some recent results based on these data. The observation of semi-exclusive dilepton production with the full Run 2 dataset and the search for exclusive two-photon production via photon exchange are presented, along with results on the PPS timing resolution.

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1 Introduction

PPS [1] is a new CMS [2] subdetector that extends the forward coverage of CMS to protons scattered at small angles. The scattered protons remain inside the beam pipe, displaced from the central beam orbit, and can be measured by detectors placed inside movable beam pipe insertions, called Roman pots (RP), which approach the beam down to a few mm. The PPS detector setup in each arm consists of two RPs housing tracking stations to measure the proton track coordinates, and one timing RP for proton time of arrival measurement (Fig. 1). PPS was commissioned in Run 2, and collected more than 110 fb^{-1} of data during regular, high-luminosity LHC runs. For central exclusive production (CEP) events, PPS allows to reconstruct the full collision energy, providing a useful tool for background suppression and characterisation of the measured processes.

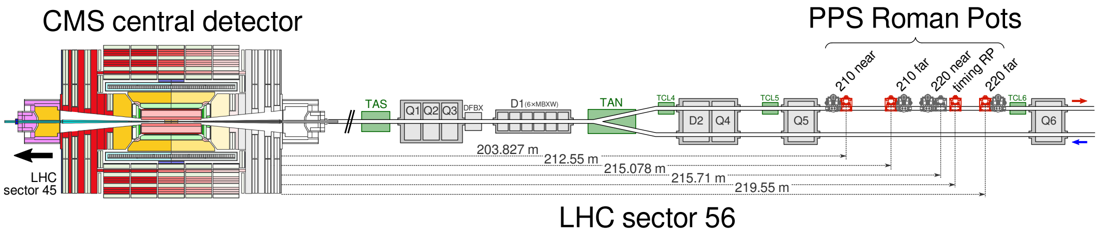

Figure 1: Schematic layout of the beam line between the interaction point and the RP locations in LHC sector 56, corresponding to the negative z direction in the CMS coordinate system and the outgoing proton in the clockwise beam direction.

2 Semi-exclusive dilepton production

This study with PPS targeted the process $\gamma\gamma \rightarrow l^+l^-$ production events, using 10 fb^{-1} of data collected during 2016 [3]. The analysis was later extended to the 2017 and 2018 datasets [4], which allowed to increase the candidate statistics by an order of magnitude compared to the first 2016 study.

In this analysis, only one proton is required to be detected in PPS in order to extend acceptance to the lower masses. This results in a signal sample containing of a mix of both $pp \rightarrow p + ll + p$ and $pp \rightarrow p + ll + p^*$ events, in which one of the protons dissociates into an undetected system p^*.

Events are required to have a dilepton vertex with no additional tracks within a veto region of 0.5 mm. Both leptons are required to have a transverse momentum $p_T > 40$ GeV, and invariant mass > 110 GeV. In addition, the acoplanarity $1 - |\Delta\varphi|/\pi$ of the leptons is required to be less than 0.009. The selection criteria are chosen to obtain a signal to background ratio > 1 after applying the central detector requirements. The selection is based on reconstructed track information and no calorimeter data because of the high rate of multiple collisions within the same bunch crossing ("pileup").

The signal events are defined as those having the fractional momentum loss calculated from the dilepton kinematics ($\xi(ll)$) and that measured directly using protons in PPS (ξ(RP)) matching within 2σ of their combined experimental resolution, which reflects momentum conservation for a fully constrained system. The values of $\xi(ll)$ and ξ(RP) for the selected events are plotted in Fig. 2 for the 2016 dilepton dataset, and for the 2017 and 2018 dimuon datasets in Fig. 3.

For the 2016 analysis, 20 candidate events are found, corresponding to a 5.1 σ excess over the background prediction. The extra data from 2017 and 2018, thanks to the larger statistics, allow to verify the PPS reconstruction and calibration performance with high precision: as expected, a clear peak centered around zero is observed.

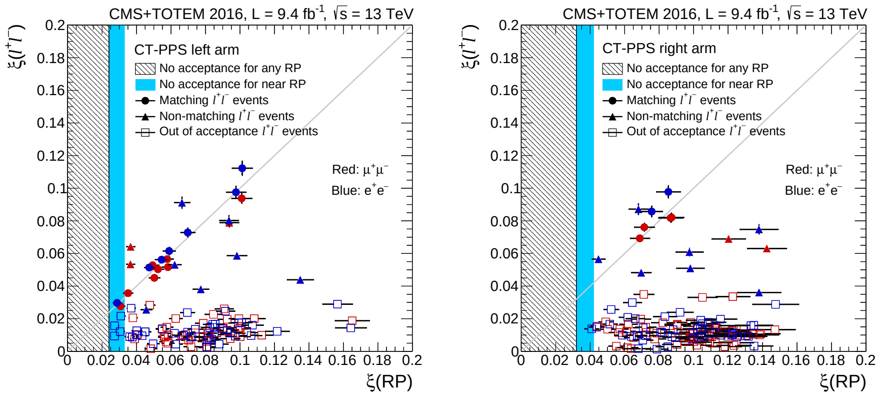

Figure 2: Correlation between the fractional values of the proton momentum loss measured in the central dilepton system, $\xi(ll)$, and in the RPs, ξ(RP), for both RPs in each arm combined. The 45 (left) and 56 (right) arms are shown. The hatched region corresponds to the kinematical region outside the acceptance of both the near and far RPs, while the shaded (pale blue) region corresponds to the region outside the acceptance of the near RP. For the events in which a track is detected in both, the ξ value measured at the near RP is plotted [3].

3 Diphoton production

The focus of the analysis detailed in [5] is the light-by-light (LbL) scattering process, in which the central diphoton system is measured in the central CMS apparatus, and the forward two-proton system is detected with PPS. For the diphoton, selection criteria are defined to retain events consistent with the kinematics of the LbL process. Two photon candidates are required, each having a transverse momentum p_T greater than 60 GeV, $\eta < 2.5$, and passing a multivariate identification selection. The diphoton system is further required to have a mass ($m_{\gamma\gamma}$) greater than 350 GeV and an acoplanarity ($1-|\Delta\varphi|/\pi$) less than 0.005, consistent with two photons produced back-to-back in an exclusive process. This set of criteria defines the “Elastic” selection region. The corresponding mass spectrum is illustrated in Fig. 4.

For the diphoton events passing the Elastic selection, a forward proton is required on each side of CMS. Matching between the mass and rapidity of the diphoton system and those of the two-proton system allows to select protons produced in the signal events, rejecting the ones coming from pileup interactions. Using 9.4 fb^{-1} of data collected by PPS in 2016, no diphoton events are found after imposing the matching criteria. The expected background is $0.23^{+0.08}_{-0.04}$ events.

These data make it possible to set the first collider limits on the four-photon anomalous coupling. Limits are extracted in the context of an Effective Field Theory (EFT) extension with dimension-8 operators, and are set in the plane of the two anomalous coupling parameters ζ_1 and ζ_2:

$$|\zeta_1| < 3.7 \times 10^{-13}\ \text{GeV}^{-4}\ (\zeta_2 = 0) \tag{1}$$

$$|\zeta_2| < 7.7 \times 10^{-13}\ \text{GeV}^{-4}\ (\zeta_1 = 0). \tag{2}$$

4 PPS timing performance in Run2

In addition to the tracking system, timing detectors were installed in 2017 to measure the Time-Of-Flight (TOF) of the protons produced in central exclusive interactions. RPs were equipped

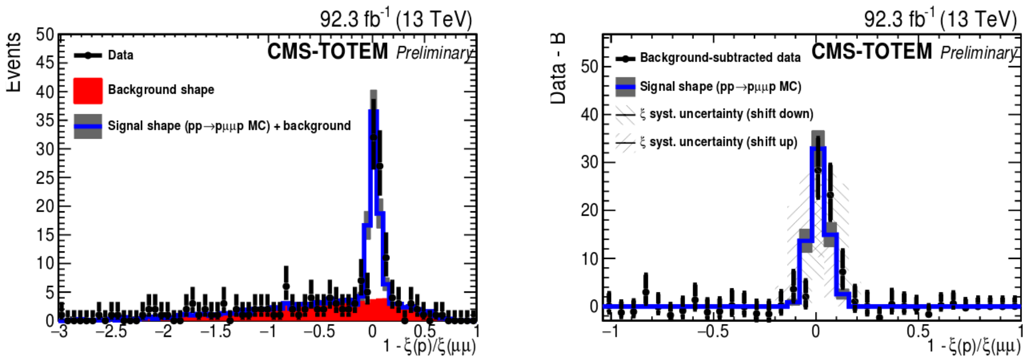

Figure 3: The plots show the 1-dimensional projection used to study proton fractional momentum loss ξ resolution, before (left) and after (right) background subtraction. The correlation peak width is consistent between data and simulation, showing the resolution is well described; the peak position is compatible with the expectation within the systematic uncertainties [4].

with Diamond sensors. In 2018 the TOF system consisted of two single- and two double-diamond planes. Figure 5 illustrates the resolution of the timing system in two-arm events. Using low pileup data (μ = number of interactions per bunch crossing ≈ 1) and selecting central diffractive events, a strong correlation is observed between the time difference of the protons detected in PPS and the longitudinal vertex position reconstructed in the central CMS tracker [6]. Vertex resolution of 1.87±0.21 cm ($\sim$ 60 ps) is observed in a subsample sample of high-resolution tracks.

5 Conclusion

The PPS detector has shown excellent performance in Run 2, allowing to obtain the first physics results already with the data collected shortly after detector commissioning. The analysis of Run 2 data continues in several more channels, and active preparation for the Run 3 data taking is unfolding in parallel. The addition of forward proton tagging to CMS opens up the possibility of studying processes otherwise beyond reach.

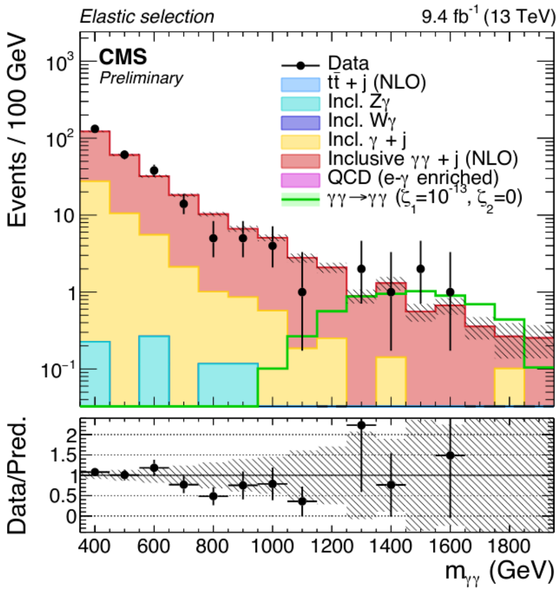

Figure 4: Diphoton mass spectrum for both data (black points) and Standard Model simulated backgrounds (colored histograms) passing the elastic selection described in the text. The lower plot shows the ratio of the number of events in data to the number of total events from simulation [5].

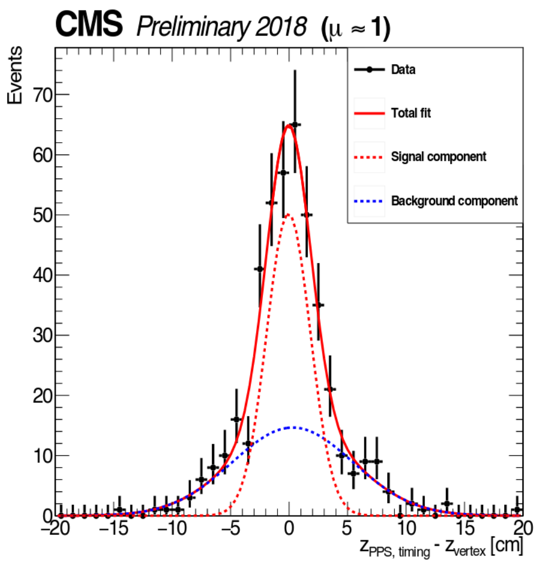

Figure 5: PPS vertex measurement resolution, defined as the difference between vertex position measured by CMS (Z_{CMS}) and that calculated from the protons time of arrival in PPS (Z_{PPS}). The red curve shows the fit to the signal component, the blue curve that to the background shape [6].

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