The CMS and TOTEM Precision Proton Spectrometer

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Abstract

The design and physics potential of the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) are discussed.

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The CMS and TOTEM Precision Proton Spectrometer

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1 Introduction

The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) [1] is a magnetic spectrometer that uses the LHC magnets between the Interaction Point (IP) and detector stations at about 210m from the IP on both sides, to bend protons that have lost a small fraction of their momentum out of the beam envelope so that their trajectories can be measured. Two precision proton tracking stations with 144 pixel detectors and one station with 200 timing channels are placed in the very forward region on both sides of CMS to study central exclusive production (CEP) in proton-proton collisions.

Figure 1. On the top the layout of CT-PPS. On the left the two horizontal cylindrical Roman Pots (RPs) equipped with timing detectors, for PU rejection. On the right the two horizontal box-shaped RPs equipped with tracking detectors to measure the displacement of the scattered protons with respect to the beam.
Figure 2. On the left the exploded view of one pixel module. Each station comprises six pixel modules. On the right the assembly of two Cherenkov timing modules in Roman pot. The beam comes from the left.

Figure 3. Schematic diagram of the Central Exclusive Production process.

2 Central Exclusive Production : $pp \rightarrow p \oplus X \oplus p$

- CEP provides a unique method to access a variety of physics topics at high luminosity LHC, such as new physics via anomalous production of W and Z boson pairs, high-pT jet production, and possibly the production of new resonances.
- $q_\alpha$ (four-momentum of the X system) is constrained by proton’s momentum loss $\xi$ and the four momentum transfer squared at the proton vertex, $t$ (Mandelstam variable). See Fig. 4.
- “⊕” indicates rapidity gaps between state X and the protons.

3 Physics Motivation

- Search for new resonances in CEP: clean events (no underlying pp event); independent mass measurement from pp system; JPC quantum numbers 0++ , 2++ .
- Exclusive two and three jet events with mass up to around 700-800 GeV;
- Test of pQCD mechanisms of exclusive production;
- Gluon jet factory: gluon jet samples with small contribution of quark jets;
- LHC as photon collider : Measurement of central production of $W^+W^-, e^+e^-, \mu^+\mu^-$ and $\tau^+\tau^-$ pairs via photon-photon collisions.
- High sensitivity to anomalous quartic gauge couplings (aQGC), including the $\gamma\gamma ZZ$ and $\gamma\gamma\gamma\gamma$ SM-forbidden vertices [2].

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Figure 4. Hit distributions for centrally produced WW events at the tracking detectors at $z=204$ m. The black squared line shows the boundaries of the tracking detectors in $x$ and $y$, when located at $15\sigma$ (elliptical line) from the beam center. Beam energy and vertex smearing, as well as detector resolution are accounted for.

4 CP-PPS design and challenges

The stations will be installed along the beam-line, between 204 and 215 m from the IP, the region already used by TOTEM. See Fig. 1.

The main challenges of the CT-PPS project are:

• Operating the detectors at distances of few mm from the full intensity LHC beam. Detectors will be housed in Roman Pots. A moving beam pipe option is also being studied.
• At high luminosity, several protons will be present in the spectrometer because of pile-up (PU). In order to suppress this background and select the proton pair corresponding to the relevant interaction vertex, the difference in the time of flight of the two protons will be used. A 10 ps resolution leads to a 2 mm resolution on the vertex.

Hence the necessity of combining a set of tracking Si pixel detectors with timing detectors (see Fig. 2). The baseline for the latter is a quartz Cherenkov detector, read out by SiPMs.

5 Physics Performance: Central exclusive WW production and aQGC sensitivity

The performance of CT-PPS was quantified in terms of the ability to measure the exclusive production of W pairs, $pp \rightarrow p W W p$, and the sensitivity to the aQGC coupling $\gamma\gamma WW$. The $pp \rightarrow p W W p$ process is characterized by a primary vertex from the two leptons from the W bosons decays, no other track, a large transverse momentum of the dilepton system and a large invariant mass of the centrally produced system.

The acceptance as a function of the WW mass is shown in Fig. 5. The lower mass reach depends strongly on the distance of closest approach of the detector (acceptances for distances of 15 and 20 sigmas from the beam are shown).
Figure 5. Mass acceptance as a function of centrally produced mass for exclusive $\gamma\gamma \rightarrow WW$ processes.

The WW mass reconstructed from the momenta of the scattered protons for a sample of Standard Model events and one of events with anomalous couplings is shown in Fig. 6.

Figure 6. Kinematical distribution of the missing mass $M_X$ (indicated by $W_{\gamma\gamma}$), estimated from the reconstructed $\xi$ values of the two leading protons.
Fig. 7 shows the sensitivity to the aQGC. The resulting limits are of the order of

\[ a_W^0 / \Lambda^2 = 2 \times 10^{-6} (3 \times 10^{-6}) \quad \text{and} \quad a_C^W / \Lambda^2 = 7 \times 10^{-6} (10 \times 10^{-6}), \]

for a 10ps (30ps) time resolution. This is more than two orders of magnitude better than achieved so far.

![Figure 7](image.png)

**Figure 7.** 95% C.L. excluded regions for the anomalous parameters. In the left panel the expected limits are shown for 10ps and 30ps timing resolution. In the right the comparison with previous CMS results [2]. The expected limits are for an integrated luminosity of 100 fb\(^{-1}\).

**References**
