CT-PPS the program and its possible developments

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Abstract

The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) has the goal of studying central exclusive production processes in proton-proton collisions at LHC. Such processes are characterized by the presence of two protons scattered at small angles and detected inside the LHC beam pipe with CT-PPS, along with one or more particles produced at small rapidity values and detected by the central CMS detector. This gives access to a variety of interesting subjects, including the study of quartic gauge couplings and searches for new resonances produced in photon-photon or gluon-gluon fusion. A description of the experimental set-up will be presented, along with the current status of the project.

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CT-PPS: The Program and its Possible Development

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Abstract. The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) has the goal of studying central exclusive production processes in proton-proton collisions at LHC. Such processes are characterized by the presence of two protons scattered at small angles and detected inside the LHC beam pipe with CT-PPS, along with one or more particles produced at small rapidity values and detected by the central CMS detector. This provides access to a variety of interesting subjects, including the study of quartic gauge couplings and searches for new resonances produced in photon-photon or gluon-gluon fusion. A description of the experimental set-up is presented, along with the current status of the project.

INTRODUCTION

CT-PPS [1] is a joint project of the CMS [2] and TOTEM [3] Collaborations that adds precision proton tracking and timing detectors in the very forward region on both sides of CMS. Its aim is to study central exclusive production in proton-proton collisions, namely the process $pp \rightarrow pXp$, in which the protons remain intact and a unique state $X$ is produced. CT-PPS is a magnetic spectrometer that uses the LHC magnets between the Interaction Point 5 of LHC (IP5) to bend protons that have lost a small fraction of their momentum out of the beam envelope, so that their trajectories can be measured. In order to access the LHC primary vacuum and to approach the beam, the detectors are installed in dedicated movable devices called Roman Pots (RP) in both sides of IP5. The experimental layout is shown in Fig. 1. The CT-PPS detectors consist of a silicon tracking system to measure the position and direction of the protons and a set of timing counters to measure their arrival time. This allows the reconstruction of the mass and momentum as well as the longitudinal position of the primary vertex of the centrally produced system, irrespective of its decay mode.

FIGURE 1. Layout of the LHC region where the Roman Pots hosting the CT-PPS detectors are installed.
EXPERIMENTAL APPARATUS

The Roman Pot system

After the so-called *consolidation* [4] of the TOTEM experiment and the start of the CT-PPS project, the beam line in the LHC region at ±200 m from IP5 includes the Roman Pots stations at 220 m (RP220-Near, RP220-Far), the stations at 210 m (RP210-Near, RP210-Far), formerly at 147 m, and a new RP timing station downstream of the 220 m near station. The RP210-Far units are rotated by 8 degrees around the beam line with respect to RP210-Near in order to improve the multi-track resolution. During the Long Shutdown 1 (LS1) the vertical 210 m RPs and all the 220 m RPs have been equipped with new ferrites and improved mechanical support frames to compensate for thermal expansion and allow mechanical stress release. A cylindrical RP has been newly designed to house timing detectors and has been optimized with respect to material budget and radio frequency (RF) interaction with the LHC beam.

During the last few months several insertion tests have been performed to check the effect of the RPs on the LHC beam in different running scenarios and at different distances of approach to the beam. Several parameters were monitored during the tests, so as to quantify the effect of the insertions in terms of beam losses, interplay with the collimators and impact on the impedance (heating, vacuum stability, beam orbit stability). The results of the tests showed that the goal of approaching the RPs to a minimum distance of $15 \sigma_{beam}$ in nominal running conditions was achieved.

The 3D pixel tracker

The CT-PPS tracking system will consist of two stations installed on each side of the CMS experiment at ~210 m from IP5. Each station will have six planes of 3D pixel detectors, tilted by 18.4° to increase the resolution. Because of the small distance from the beam, the silicon modules are foreseen to face an irradiation of $5 \times 10^{15}$ proton/cm$^2$ for 100 fb$^{-1}$ of collected luminosity. This corresponds to a fluence between 1 and $3 \times 10^{15}$ neq/cm$^2$. Besides the radiation hardness, another requirement is the reduction of the insensitive area at the edge of the sensor in order to increase the acceptance for high-momentum protons. Finally, a tracking resolution of $\sim 10 \mu$m on both x and y coordinates (with z the beam direction) is necessary to measure with good resolution the proton kinematic variables.

The main characteristic of 3D sensors is that the electrodes are etched in a column shape perpendicular to the surface, thus decoupling the sensor thickness from the distance between electrodes. This is unlike the planar case, where the electrodes are on the sensor surface. The main advantages are low depletion voltage and high signal collection efficiency after irradiation. 3D pixel detectors have been chosen because of their intrinsic radiation hardness and for the possibility to implement slim edges.

Test results on prototype detectors match the project requirements. Mechanics and electronics are under test yielding good results. The detector is foreseen to be completed for installation during the 2016-17 extended winter LHC shutdown.

The timing detectors

The primary task of the timing detectors is to measure the time of flight of the scattered protons in order to reconstruct the longitudinal position of the primary vertex and compare it with that reconstructed in the central system, thus enhancing the pile-up rejection capability. The ultimate goal is to measure the arrival time with a precision of $\sim 10$ ps, which corresponds to a longitudinal spatial resolution of $\sim 2$ mm.

The detectors currently installed are based on diamond sensors that, using a customized front-end and read-out electronics, are capable of a resolution of $\sim 80$ ps. Every cylindrical RP is equipped with four planes of sensors to obtain an overall timing resolution of $\sim 40$ ps. The timing detectors need to be segmented to cope with the expected pile-up: simulations were done to find the best geometry of the segmentation, while keeping relatively low (<16) the number of channels to simplify the read-out electronics. In particular, the pixel geometry has been studied in order to minimize the probability of multiple hits in the same channel [5].

In addition to the diamonds, the R&D of ultra fast silicon detectors (UFSD) [6] is also being pursued. The basic feature of these detectors is the presence of a large volume within the bulk of the silicon where the electric field is high enough so that the drifting electrons will generate a controlled, low gain avalanche. With a dedicated sensor design, the effect of charge multiplication can be exploited to obtain a silicon detector that can concurrently measure time and position with high accuracy. Preliminary test-beam results on prototype detectors show a resolution of $\sim 30$ ps per plane.
Central exclusive production (CEP) provides a unique method to access a variety of physics topics, such as new physics via anomalous production of W and Z boson pairs, high transverse momentum ($p_T$) jet production, and the production of new resonances. These studies can be carried out in particularly clean experimental conditions thanks to the absence of proton remnants. The detection of the two final state protons, scattered at almost zero degrees, in the very forward near-beam detectors, provides a striking signature. The measurement of the leading protons allows to fully determine the kinematics of the central system. Well defined final states in the CMS central detector matching the protons kinematics can then be selected and precisely reconstructed.

The exclusive production of pairs of photons, W and Z bosons provides a novel and unique testing ground for the electroweak gauge boson sector. The virtualities of the exchanged photons are on average very small, which makes the LHC a quasi-real photon collider with centre-of-mass energy approaching 1 TeV, a region so far unexplored. The detection of $\gamma\gamma \rightarrow W^+W^-$ events allows to measure the quartic gauge coupling $WW\gamma\gamma$ with high precision. CT-PPS expects to achieve of the order of $10^{3-4}$ times better sensitivity to anomalous quartic gauge couplings than LEP or Tevatron.

A number of physics studies will be aimed at the understanding of the QCD mechanisms involved in CEP. Exclusive di-jet production with $M(jj)$ up to $\sim 700 - 800$ GeV allows the study of pure gluon-jet samples with small contamination of quark jets. The detailed characterization of gluon jets in this data sample relative to quark jets may improve the efficiency of gluon vs. quark jets separation, which is of particular interest for Vector Boson Fusion (VBF) forward jet tagging. One of the reasons that make CEP very attractive is that if the outgoing protons remain intact and scatter through small angles then, to a very good approximation, the di-gluon system obeys a $J_z = 0$, C-even, P-even, selection rule. This selection rule readily permits a clean determination of the quantum numbers of any new resonance.

**THE ACCELERATED PROGRAM**

At the end of 2015, the ATLAS and CMS Collaborations reported an excess of events with $\gamma\gamma$ final state [7, 8]. Even though it could have been a statistical fluctuation, as motivated by the new 2016 data, the possibility of a new, unpredicted resonance triggered for a few months the enthusiasm of the scientific community with a few hundred theoretical articles trying to explain this excess. Since CT-PPS has good acceptance at $\sim 750$ GeV (see Fig. 3), the CT-PPS group decided to develop a strategy to enable the project to take data one year in advance with respect to the expected starting date, foreseen for Spring 2017.

The strategy has been to use the already existing silicon strip detectors of TOTEM [3], designed to take data only in special low luminosity runs, and to include them in the global data acquisition system of CMS. The effort was successful and CT-PPS was able to take $\sim 8$ fb$^{-1}$ of data in Spring-Summer 2016, during the nominal LHC high luminosity runs, with the detectors at a distance of 15 $\sigma_{\text{beam}}$ from the beam. As a consequence, the strip detectors have been permanently damaged by the high radiation dose absorbed and needed to be replaced. On the positive side
such instances are thus contributing as a source of inefficiency to the data analysis. Figure 4 shows the resulting occupancies for the two geometries, when pileup and beam-related backgrounds (as discussed in Sections 2.2 and with an average number of pileup interactions $\mu = 25$ are produced. In view of the statistical uncertainties, 50 pileup interactions mixed with the primary interaction is assumed. Here again, an average of 50 pileup interactions are simulated. In the simulation, a coincidence of the tracking detectors placed at $z=204$ m and $z=215$ m is required. The estimated acceptance is shown as a solid blue (red) line when the crossing angle are simulated.

This can be done combining the data taken with the central CMS detector with those taken with a spectrometer built at $\sim 200$ m from the interaction point, which can measure the kinematic parameters and the time of flight of the protons that survived the scattering. Dedicated detectors are being built and will be installed during the 2016-17 year end shutdown. A huge effort by the CT-PPS group to start taking data one year before schedule, during Spring-Summer 2016, exploiting the already existing TOTEM silicon strip detectors has been successful and the CT-PPS project has the main goal of studying CEP processes in high luminosity proton-proton runs at the LHC. This can be done combining the data taken with the central CMS detector with those taken with a spectrometer built at $\sim 200$ m from the interaction point, which can measure the kinematic parameters and the time of flight of the protons that survived the scattering. Dedicated detectors are being built and will be installed during the 2016-17 year end shutdown. A huge effort by the CT-PPS group to start taking data one year before schedule, during Spring-Summer 2016, exploiting the already existing TOTEM silicon strip detectors has been successful and $\sim 8$ fb$^{-1}$ of data have been taken and are currently being analyzed for commissioning and physics purposes. The new tracking and timing detectors are on schedule and are expected to be installed during the coming few months.

CONCLUSIONS

The CT-PPS project has the main goal of studying CEP processes in high luminosity proton-proton runs at the LHC. This can be done combining the data taken with the central CMS detector with those taken with a spectrometer built at $\sim 200$ m from the interaction point, which can measure the kinematic parameters and the time of flight of the protons that survived the scattering. Dedicated detectors are being built and will be installed during the 2016-17 year end shutdown. A huge effort by the CT-PPS group to start taking data one year before schedule, during Spring-Summer 2016, exploiting the already existing TOTEM silicon strip detectors has been successful and $\sim 8$ fb$^{-1}$ of data have been taken and are currently being analyzed for commissioning and physics purposes. The new tracking and timing detectors are on schedule and are expected to be installed during the coming few months.

REFERENCES


