Physics prospects with the
CMS-TOTEM Precision Proton Spectrometer

L. Forthomme (Univ. of Kansas),
on behalf of the CMS and TOTEM Collaborations

DIS 2017 – 3-7 Apr 2017 – Birmingham, UK
Central exclusive processes at the LHC

- Production of the central system through the exchange of colour-singlets (photons, pomerons). For instance:
  - Photoproduction of resonances (e.g. $\gamma p \rightarrow Zp$)
  - Two-pomeron exchange (tests of the non-perturbative behaviour of QCD)
  - Two-photon processes
    $(pp \rightarrow p^{(*)}(\gamma\gamma \rightarrow X)p^{(*)})$, with $X = l^+l^-, W^+W^-, ZZ, \gamma\gamma, \ldots$
  - Clear geometrical separation between the central system and scattered forward protons

- “The LHC as a photon collider”
  - Relatively high photon fluxes expected from proton scattering for LHC’s $x-Q^2$ ranges

CMS-TOTEM Precision Proton Spectrometer in a nutshell

- Joint project of the CMS and TOTEM collaborations (CERN-LHCC-2014-021)

- **Roman pots** technique to reduce the distance of approach between the beam and detectors ($d \sim 15 \sigma_{\text{beam}}$ in the horizontal direction)
  - Low-impedance RF shield designed for high-luminosity operations

- Tracking in 2016: **TOTEM silicon strips**

- Extra tracking capability with **diamond detector** (after LHC’s 2nd technical stop, Summer 2016)

---

04/04/17

DIS 2017 - Physics prospects with the CMS-TOTEM Precision Proton Spectrometer

L. Forthomme (KU)
2016 operations

- Fully integrated in CMS data acquisition system
- Operational since run-II /~mid-2016
- More than 15 fb$^{-1}$ collected at $\sqrt{s} = 13$ TeV during 2016 data taking
- Two early analyses developed with the CT-PPS 2016 data:
  - Search for exclusive $\gamma\gamma$ production of lepton pairs
  - Search for $\gamma\gamma$ production of photon pairs
CT-PPS mass and rapidity acceptance

- Two-dimensional **missing mass-rapidity acceptance** determined by the $\xi$ acceptance for each station:
  - Detectors’ distance of approach (lower limit)
  - Upper limit: determined by the position of forward collimators (TCL4) and spatial extension of the detectors
  - $m_{\text{miss}} = \sqrt{s} \xi_1 \xi_2$, $y_{pp} = \frac{1}{2} \log \frac{\xi_2}{\xi_1}$

- Overall sensitivity with double tags to missing mass range between 385 and 1950 GeV (for low-rapidity of the central system)
  - **Lower masses** can be reached in proton dissociative events

Plot courtesy by M. Deile
Detectors commissioning & calibration

- Two-step alignment and calibration procedure:
  - “Data-driven” TOTEM silicon strips alignment with special, low-intensity calibration fills:
    - Relative fill-by-fill detectors alignment
    - Matching of vertical and horizontal hits positions between high-luminosity “physics fills” and special fills (CERN-TOTEM-NOTE-2017-001)

- Optics parameters determination using a MAD-X simulation of the whole beamline lattice (quadrupoles position, kickers strength, ...) and beam parameters (crossing angle) (CERN-TOTEM-NOTE-2017-002)
  - Measurement of dispersion $D_x$ allowing to extract the x-to-$\xi$ calibration curves for each station
  - Relative precision for 2016 data collection (before the 2nd technical shutdown): $\Delta\xi/\xi \sim 5\%$
    See F. Nemes’ talk this afternoon for more details
Exclusive two-photon production of lepton pairs

- **Previously covered** at LHC run-1 by multiple “central” studies from the CMS (e.g. JHEP 1307 (2013) 116, JHEP 1608 (2016) 119) and ATLAS (Phys.Rev. D94 (2016) 3.032011) collaborations

- Search for a pair of **opposite-sign muons** or electrons with “exclusive” (or “semi-exclusive”) features

- **Kinematic matching** between the dilepton and forward tracks information: can obtain the scattered proton momentum both directly (CT-PPS) and indirectly from the lepton pair

- Major benefits of this study:
  - Evaluation of **detectors performance** and background mitigation power
  - Study of the exclusive and single-dissociative production of lepton pairs given the observation of two or one proton track(s) in CT-PPS
    - Exclusive case: precisely known (QED process); can be used as a Standard candle for detector calibration
Search for exclusive two-photon production of photon pairs

- Multiple extensions of the Standard model predict larger yields / different kinematics: e.g.
  - s-channel exchange of new neutral particles (spin-2 gravitons, scalars, composite Higgs, ...), $\zeta_1 \propto 1/|g_{\gamma\gamma X}m|^{4}$ with $g_{\gamma\gamma X}$ the coupling between the new particle X and the photons
  - Exchange (box) of heavier charged particles: model-independent approach, coupling $\zeta_1 \propto \left|Q/m\right|^{4} \rightarrow \zeta_1 \approx 10^{-14} - 10^{-13}$
  - Effective dimension-6 ("LEP-like") or dimension-8 extensions

- Direct probe of anomalous couplings through the observation of $\gamma\gamma \rightarrow \gamma\gamma$ production rates
  - Low-mass diphoton spectrum dominated by QCD production (~10s of fb)

- Photon-induced processes become dominant at higher-masses
  - Very low background after central detector + forward tracking selection (even with no timing requirements!)

- Also extendable to other final states ($\gamma\gamma \rightarrow W^{+}W^{-}, ZZ$)
  - Highest sensitivity achieved for the $\gamma\gamma W^{+}W^{-}$ coupling using only the central CMS detector (JHEP 08 (2016) 119)
  - ~2 orders of magnitude improvement expected with the addition of tracking and timing information of the forward proton tracks (CERN-LHCC-2014-021)
(Near) future operations for CT-PPS

- For **2017 data taking**, several improvements in the apparatus:
  - New **clock distribution system** for precise time synchronisation between both arms (< 1 ps jitter expected)
    - Will unlock the high-precision timing detectors’ capabilities for the 2017 data collection
    - Allows **pileup suppression**: the difference of the times of flight of the two protons gives the coordinate of the vertex, which can then be matched with the information from the central apparatus. Resolution of order few tens of ps.
  - Installation of a **new pixel tracking station** in stations at 220 m (best acceptance)
    - Stations at 210 m will contain TOTEM silicon strips
  - **Optimisation of optics** to improve acceptance
Conclusions and perspectives

• High interest for the central exclusive processes at the LHC (in particular for the γγ production processes)
  • Good tool for high-precision physics studies

• Started data taking in 2016 (one year earlier than initially foreseen) with high-luminosity proton-proton runs
  • Successfully collected > 15 fb⁻¹ of low-β* (0.4 m) data at √s = 13 TeV; ready to proceed with the 2017 collision program
  • With its 2016 operation, CT-PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at a high luminosity hadron collider on a regular basis
  • Multiple challenging physics cases currently being studied; new public results to be released (very) soon.

Stay tuned...