

Second year report

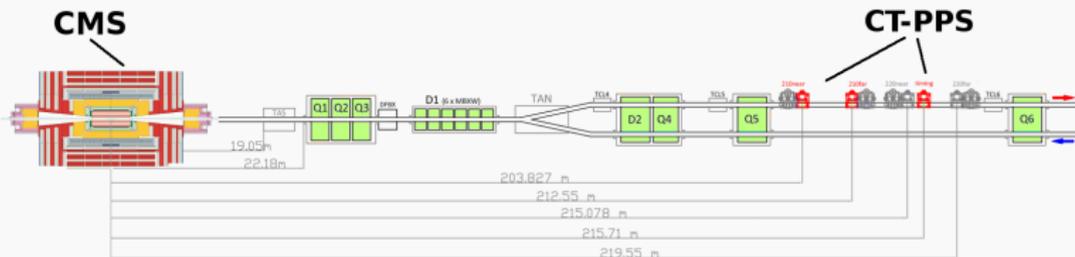
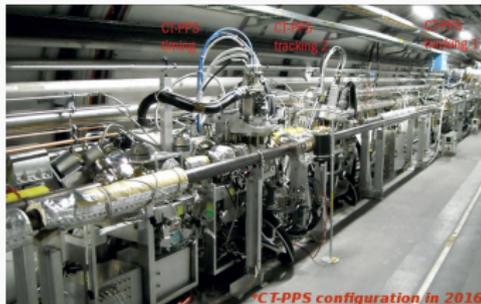
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Torino PhD School seminar
Nov 23, 2017

CT-PPS in a nutshell

- Joint CMS and TOTEM project at CERN
<http://cds.cern.ch/record/1753795>
- Near-beam detector designed for operation at highest LHC intensities
- **Measurement of processes in which proton(s) stay(s) intact after interaction**



(One arm in 2016 configuration shown. The other arm is symmetric with respect to the CMS IP.)

- CMS provides measurement of centrally produced system
- CT-PPS completes this measurement by tagging scattered protons on both sides of CMS

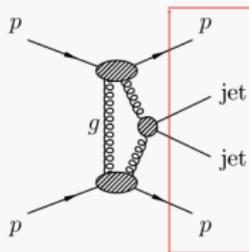
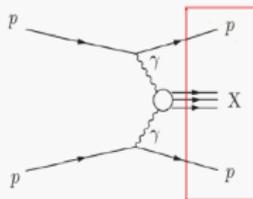
2016: CT-PPS started taking data. First analysis ready (this talk)!

CT-PPS physics motivation

Primary goal: study central exclusive production in $\gamma\gamma$ or gg collisions

► proton tag advantages:

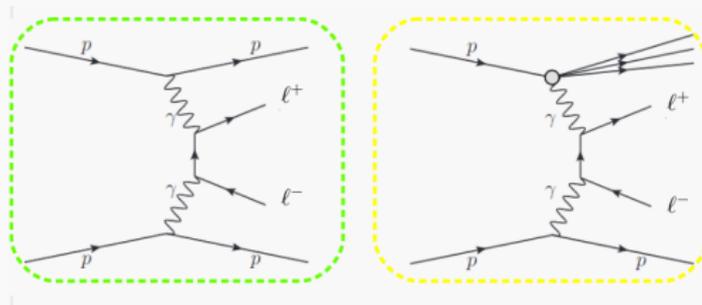
- closure of event kinematics
- effective background rejection
- reduced theory uncertainties related to proton dissociation



Opportunity to access a variety of topics: from diffraction to beyond the Standard Model physics

- proton structure (generalized parton distributions)
- anomalous couplings with high sensitivity
- new resonances in very clean final state

First physics: $\gamma\gamma \rightarrow \ell^+\ell^-$ with proton tag



Selecting double- (green) and single-tagged (yellow) dilepton events

- ▶ Idea: look at "simple" Standard Model process, explore correlation between kinematics of the dilepton system and that of the forward proton(s)
 - ⇒ Validation of the detector sensors alignment and procedure for reconstruction of the scattered proton momentum
 - ⇒ Observation of the first proton-tagged $\gamma\gamma$ collisions

Key proton variable: relative momentum loss $\xi = \Delta p/p$

- Defines kinematics of dilepton system – mass and rapidity

Strategy

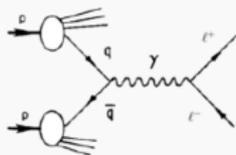
Look for correlation between

- direct proton ξ measurement by CT-PPS
- dimuon system measured by CMS

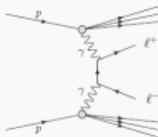
ξ can be derived from lepton's transverse momentum p_T and pseudorapidity η :

$$\xi^{\pm} = \frac{1}{\sqrt{s}} \times (p_T(\ell_1)e^{\pm\eta(\ell_1)} + p_T(\ell_2)e^{\pm\eta(\ell_2)})$$

Expected backgrounds:



Drell-Yan



Double dissociation

+ **pileup proton**

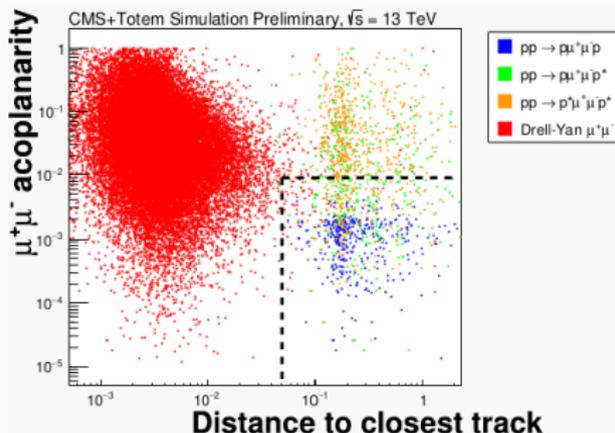
- will fake signal by overlapping with pileup or beam halo protons
- developed method for data-driven estimate (event mixing)

Event selection

- ▶ Pair of opposite sign leptons with $p_T(\ell) > 50$ and $M(\ell^+\ell^-) > 110$ GeV (above Z-peak)

- ▶ To suppress background:

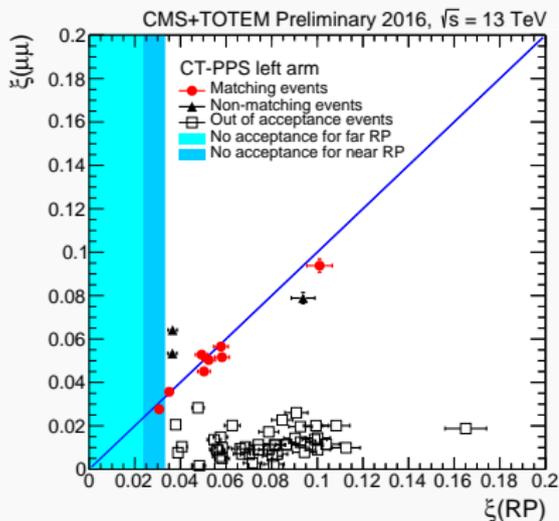
- Veto additional tracks around dilepton vertex (within 0.5mm)
- Require back-to-back leptons: $|1 - \Delta\phi/\pi| < 0.009$



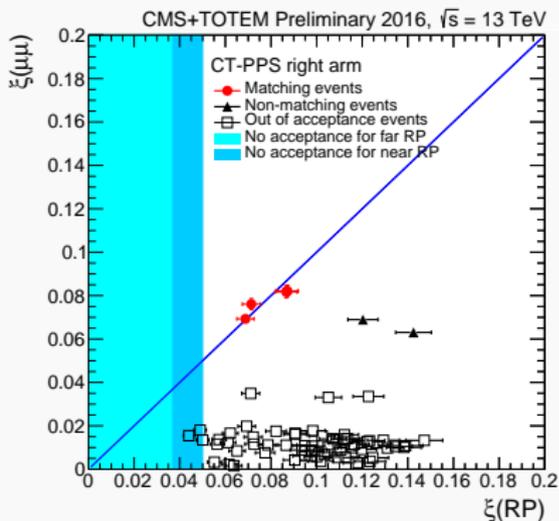
Signal candidates required to have $\xi(\ell^+\ell^-)$ and $\xi(\text{proton})$ matching within 2σ of resolution

Final result for $\mu^+\mu^-$ channel: ξ correlations

Left arm



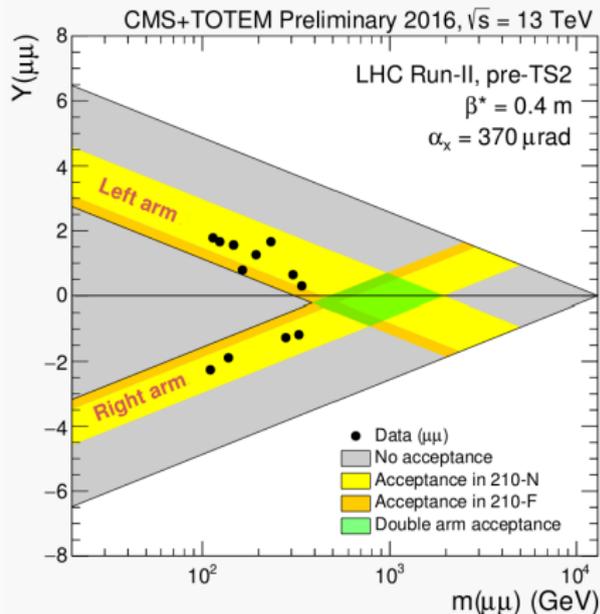
Right arm



- Total 17 events with $\xi(\mu^+\mu^-)$ within acceptance
- **12 with matching $\xi(\mu^+\mu^-)$ and $\xi(\text{RP})$ (red points)**

Estimated significance for observing 12 events for a background of 1.47 ± 0.06 (stat.) ± 0.52 (syst.): **4.3 σ**

Properties of dimuon signal candidates



- No double-tagged events (consistent with SM \times efficiency)
- Mass range up to 342 GeV
- e^+e^- results ready as well, to be public soon

- First observation of proton-tagged $\gamma\gamma$ collisions at the electroweak scale
- Proving for the first time the feasibility of operating a near-beam spectrometer at a high-luminosity hadron collider

Outlook:

CT-PPS:

- Dilepton analysis with proton tag:
 - $\mu^+\mu^-$ channel results published
 - e^+e^- channel analysis finished, approved

⇒ Paper with combined results under CMS and TOTEM collaboration-wide review before publication
- Contributions to the CT-PPS subsystems commissioning:
 - 3D pixel tracking data unpacker, now part of CMS SW
 - Timing detector performance study with its first data

CMS-only data analysis:

- Jet-gap-jet events at $\sqrt{s} = 7\text{TeV}$
 - Paper finalized recently, published on arXiv/submitted to EPJC

Publications and talks

Publications (personal contribution):

- Evidence for proton-tagged, central semi-exclusive production of high-mass muon pairs at $\sqrt{s} = 13$ TeV with the CMS-TOTEM Precision Proton
<http://cds.cern.ch/record/2265781>
- Study of dijet events with a large rapidity gap between the two leading jets in pp collisions at $\sqrt{s} = 7$ TeV
<https://arxiv.org/abs/1710.02586>

CMS author since 2016, full list under the [link](#)

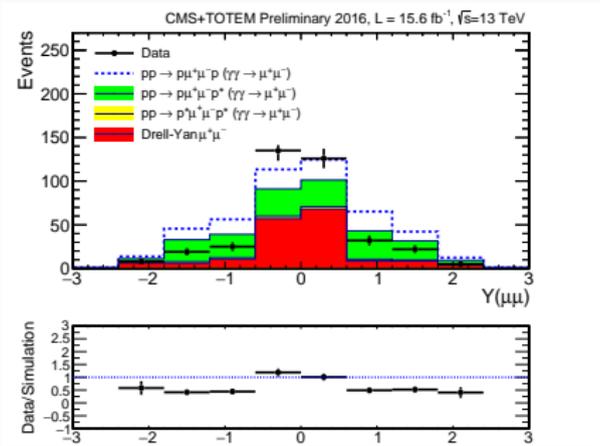
Talks:

- **Measurement of high-mass dilepton and diphoton production with the CT-PPS**
Talk at the European Physics Society Conference on High Energy Physics, Venice, Italy, July 2017
- **Recent CMS results on diffractive and exclusive processes**
Invited talk at the 3rd Elba Workshop on Forward Physics at LHC Energy, Isola d'Elba, Italy, May 2016
- **Search for jet-gap-jet events at CMS**
Seminar at the Rockefeller University, New York, USA, December 2015

Next: finalize the dilepton paper, continue work on the timing detector and 2017 data analysis.

Backup

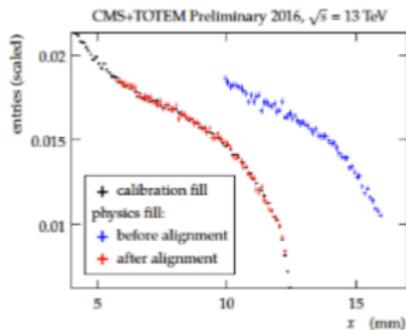
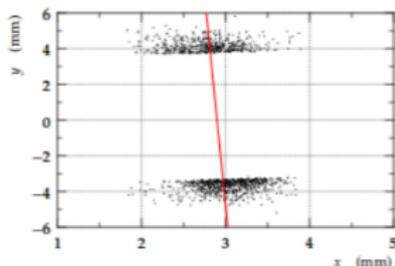
Survival probability



- ▶ Using suppression factors by Durham model [arXiv:1601.03772](https://arxiv.org/abs/1601.03772)
- ▶ Good description of the data at $Y=0$, but values too large for non-zero rapidities.
- ▶ A Y dependence of the rapidity gap survival probability is expected in several models, see e.g. [arXiv:1410.2983](https://arxiv.org/abs/1410.2983), [arXiv:1508.02718](https://arxiv.org/abs/1508.02718), [arXiv:1502.03323](https://arxiv.org/abs/1502.03323)

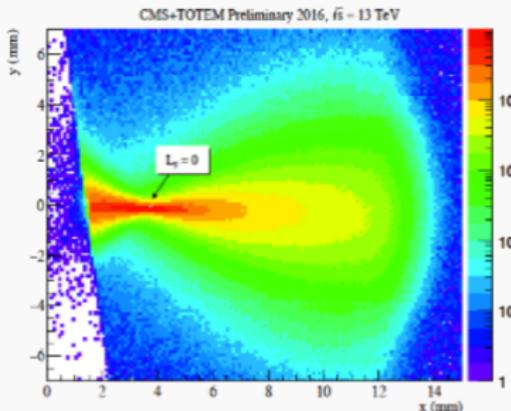
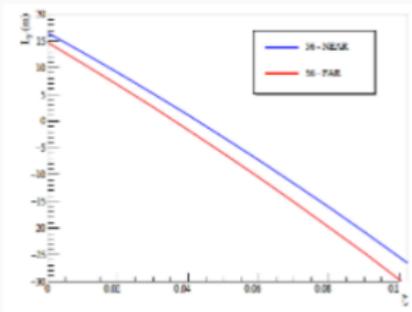
Alignment

- Alignment procedure performed in 2 steps
 - 1: Absolute alignment
 - 2: Fill-by-fill alignment
- Step 1: Use elastic scattering ($pp \rightarrow pp$) events, in special alignment runs where both horizontal and vertical RPs approach very close to the beam
- Step 2: Use inclusive sample of protons triggered by central CMS detectors
 - Match distribution of proton track positions to that of alignment runs



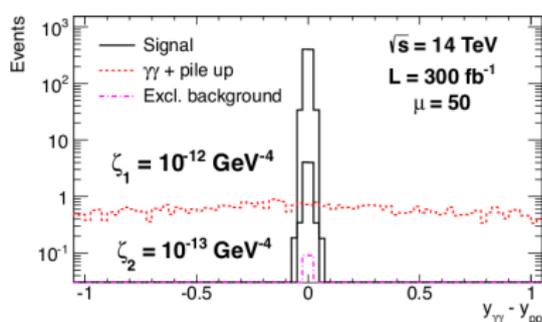
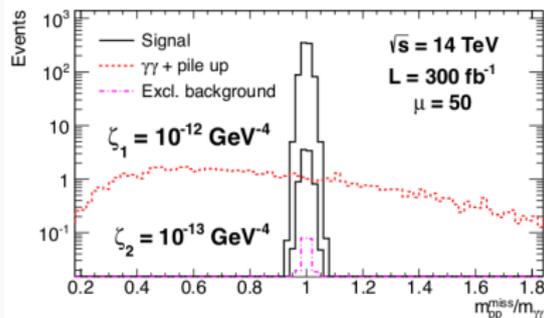
Optics determination

- Final physics variable of interest is the proton momentum loss " ξ "
- Reconstruction from measured RP track position requires precise knowledge of LHC optics & dispersion D_x
 - Standard TOTEM optics matching with elastic events [New J. Phys. 16 (2014) 103041] using measured quadrupole strengths
 - Dispersion calibration using $L_y(x) = 0$ point
 - LHC lattice/optics matching of crossing-angle and quadrupole positions using measured dispersions and the beam position as measured by RPs and BPMs"



- Final result is a (non-linear) calibration of ξ vs. the measured track x position
- Overall ξ resolution of $\sim 5.5\%$

- In particular, search for **exclusive diphoton production**
- Multiple extensions of SM predict extra yields/different kinematic differences wrt SM
- **Very low expected background** after proton tag requirement:



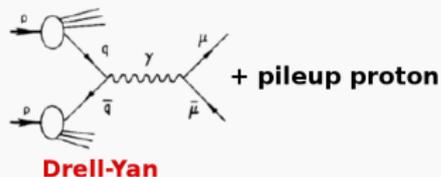
Also, part of program is to explore quartic gauge couplings with photons: $\gamma\gamma \rightarrow \gamma Z/ZZ/WW$ (with timing detector)

Data-driven background estimate

Use sample of **background protons** from Z-peak events (data)

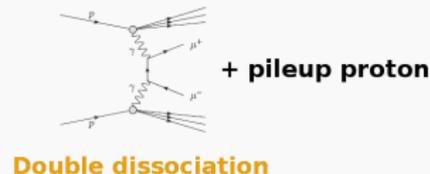
Drell-Yan contribution:

- count number of Z-peak events with $\xi(\mu\mu)$ and $\xi(\text{proton})$ correlated within 2σ
- use MC to extrapolate to the signal region



Double-dissociative contribution:

- mix double-dissociative simulated events (LPAIR) and protons from data to derive number of matching events



Total number of expected matching background events:
 1.47 ± 0.06 (stat.) ± 0.52 (syst)