Measurement of high-mass dimuon production with the CMS-TOTEM Precision Proton Spectrometer

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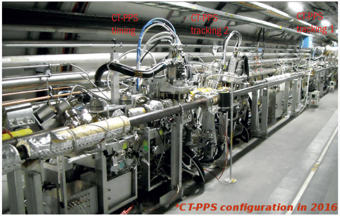
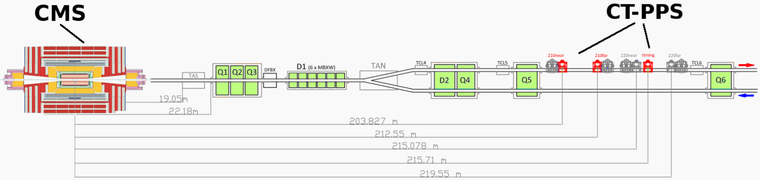
CT-PPS in a nutshell

- Joint CMS and TOTEM project at CERN
  http://cds.cern.ch/record/1753795
- **Proton spectrometer 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.)

Operation principle:

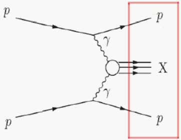
- LHC magnets bend scattered protons out of the beam envelope
- CT-PPS detectors housed in Roman Pot (RP) stations along the beamline

$\Rightarrow$ **detect scattered protons a few mm from beam, on both sides of CMS**

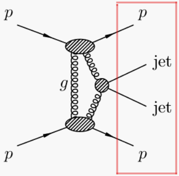
2016: first CT-PP data taking (15 fb^{-1}). Results with 10 fb^{-1} public (this talk)!

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

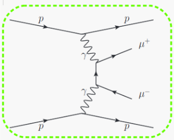


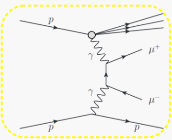
Opportunity to access a variety of topics: from diffraction to BSM physics

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

First physics: $\gamma\gamma \to \mu^+\mu^-$ with proton tag

- Idea: look at "simple" SM process, explore correlation between kinematics of the dilepton system and that of the forward proton(s)





$\Rightarrow$ Validation of the optics and alignment

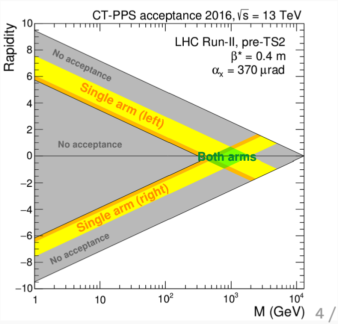
$\Rightarrow$ Observation of the first proton-tagged $\gamma\gamma$ collisions at the EWK scale

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

- Defines dimuon system:

$M = \sqrt{\xi_1 \xi_2}\sqrt{s}$, Rapidity= $Y = \frac{1}{2} ln(\frac{\xi_1}{\xi_2})$

SM contribution in double-tagged region very low — hence consider both double and single-tagged $\mu^+\mu^-$ events



Strategy

Look for correlation between

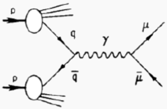
- direct proton ξ measurement by CT-PPS
- dimuon system measured by CMS

ξ can be derived from muon p_T and η:

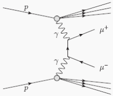
$$\xi^{\pm} = \frac{1}{\sqrt{s}} \times \left(p_T(\mu_1)e^{\pm\eta(\mu_1)} + p_T(\mu_2)e^{\pm\eta(\mu_2)}\right)$$

($\pm\eta$ solutions correspond to the protons in the $+z$ and $-z$ direction.)

Expected backgrounds:



Drell-Yan



Double dissociation

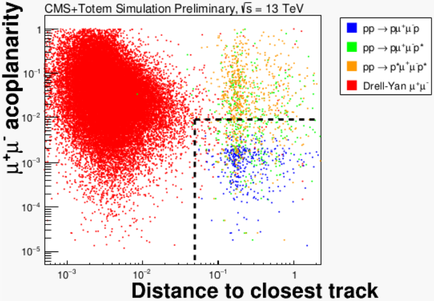
+ pileup proton

- will fake signal by overlapping with pileup or beam halo protons
- can be largely suppressed by selection cuts

Event selection

- **Pair of opposite sign muons** with $p_T(\mu) > 50$ and $M(\mu\mu) > 110$ GeV (above Z-peak)

- To suppress background:
  - **Veto additional tracks** around dimuon vertex (within 0.5mm)
  - Require **back-to-back** muons: $|1 - \Delta\phi/\pi| < 0.009$



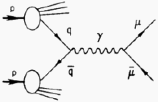
Signal candidates required to have $\xi(\mu\mu)$ and $\xi(proton)$ matching within 2σ of resolution

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 ξ(proton) correlated within 2σ
- use MC to extrapolate to the signal region

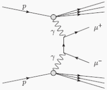


+ pileup proton

Drell-Yan

Double-dissociative contribution:

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



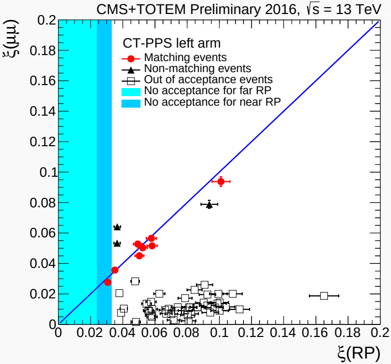
+ pileup proton

Double dissociation

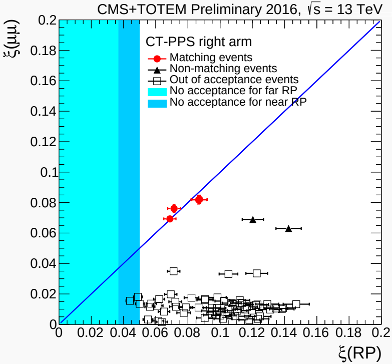
Total number of expected matching background events:
1.47 ± 0.06 (stat.) $\pm\, 0.52$ (syst)

Final result: ξ correlations

Left arm



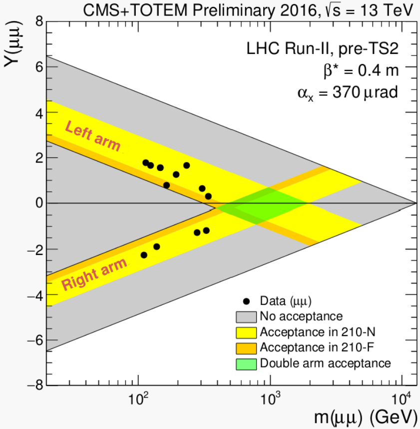
Right arm



- Total 17 events with $\xi(\mu\mu)$ within acceptance
- **12 with matching $\xi(\mu\mu)$ and ξ(RP) (red points)**

Estimated significance for observing 12 events for a background of 1.47 $\pm$ 0.06 (stat.) $\pm$0.52 (syst.): $\boxed{4.3\sigma}$

Signal candidates properties



- Dimuon M and Y consistent with single arm acceptance
- No double-tagged events observed, consistent with SM xsection*efficiency

Mass extends up to 341 GeV – first tagged $\gamma\gamma$ collisions at EWK scale!

Conclusions

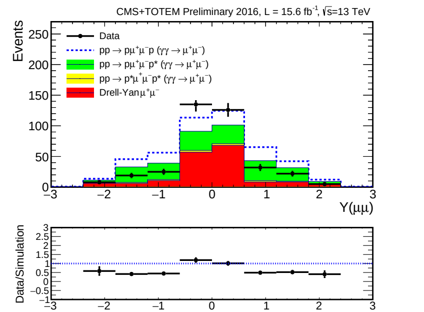
- **Proven for the first time the feasibility of operating a near-beam spectrometer at a high luminosity collider** on a regular basis
- **More than 4σ evidence for electroweak scale single proton-tagged $\gamma\gamma$ collisions** at the LHC
  Ref.: CMS-PAS-PPS-17-001; TOTEM-NOTE-2017-003
- Next: diphoton production, $\gamma\gamma \to \gamma Z/ZZ/WW$ with timing, ...

- **2017: restarted data taking after major upgrade**
  Tracking: 3D Si pixels & strips
  Timing: Diamonds & Ultra Fast Silicon Detector

Expect much more physics in 2017.

Backup

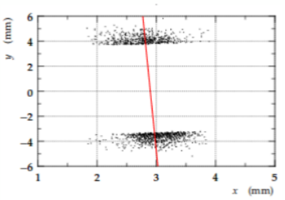
Survival probability

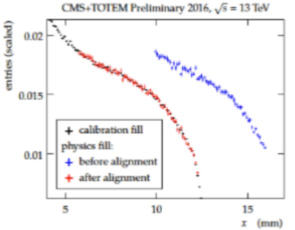


- Using suppression factors by Durham model arXiv:1601.03772
- Good description of the data at Y=0, but values too large for non-zero rapidities.
- A Y dependence of the rapidity gap survival probability is expected in several models, see e.g. arXiv:1410.2983, arXiv:1508.02718, arXiv:1502.03323

Alignment

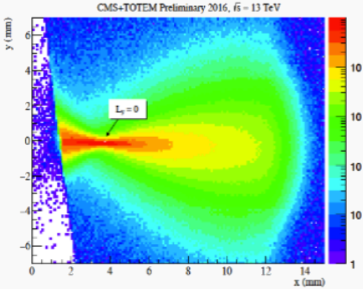
- Alignment procedure performed in 2 steps
  - 1: Absolute alignment
  - 2: Fill-by-fill alignment
- Step 1: Use elastic scattering (pp→pp) events, in special alignment runs where both horizontal and vertical RPs approach very close to the beam
- Step 2: Use inclusive sample of protons triggered by central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

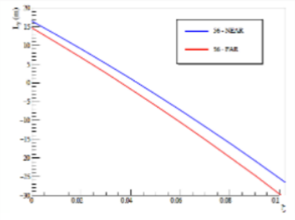




Optics determination

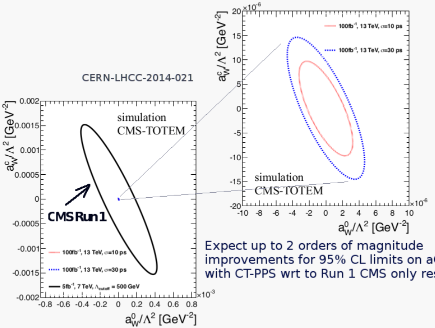
- Final physics variable of interest is the proton momentum loss "ξ"
- Reconstruction from measured RP track position requires precise knowledge of LHC optics & dispersion D_x
  - Standard TOTEM optics matching with elastic events [New J. Phys. 16 (2014) 103041] using measured quadrupole strengths
  - 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"





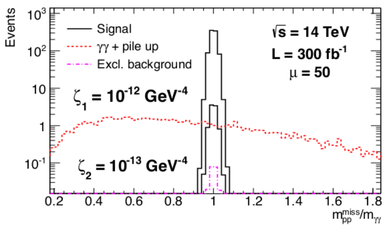
- Final result is a (non-linear) calibration of ξ vs. the measured track x position
- Overall ξ resolution of ~5.5%

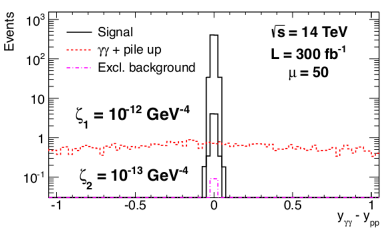
CERN-LHCC-2014-021



Expect up to 2 orders of magnitude improvements for 95% CL limits on aQGC with CT-PPS wrt to Run 1 CMS only results

- 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: $\gamma\gamma \to \gamma Z/ZZ/WW$ (with timing detector)