Results from the CMS-TOTEM Precision Proton Spectrometer (PPS)

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on behalf of the CMS and TOTEM collaborations

Diffraction and Low-x 2018
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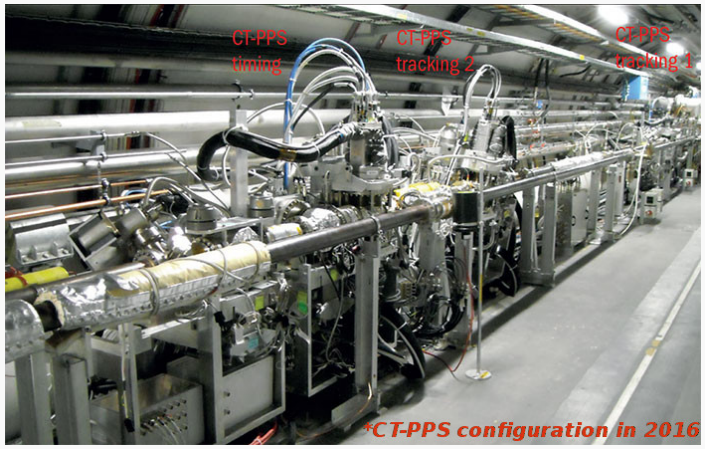
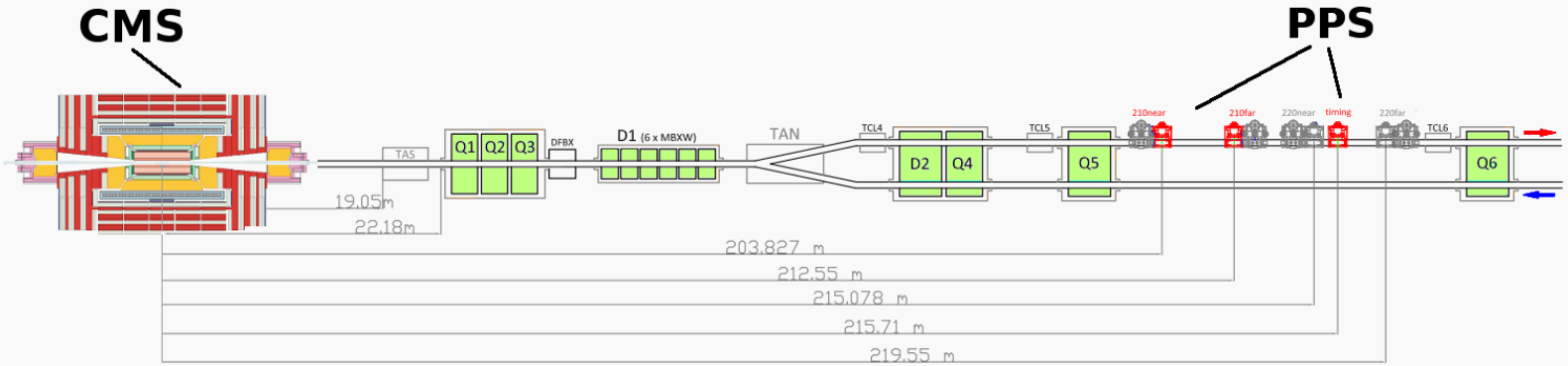
PPS in a nutshell

- **Proton spectrometer designed for operation at highest LHC intensities**
- **Measurement of processes in which proton(s) stay(s) intact after interaction**





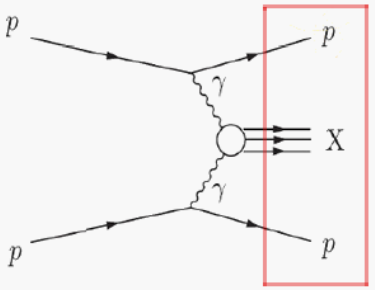
(One arm in 2016 configuration shown. The other arm is symmetric with respect to the CMS IP.)

Initial data taking in 2016

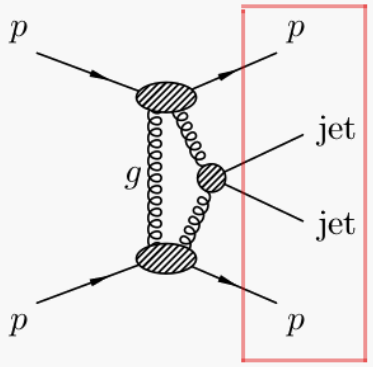
- Using existing TOTEM Si-strips for tracking, integrated with CMS DAQ
- First data to establish proton reconstruction and start physics analyses
- Results with 9.4 fb^{-1} public (this talk)

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

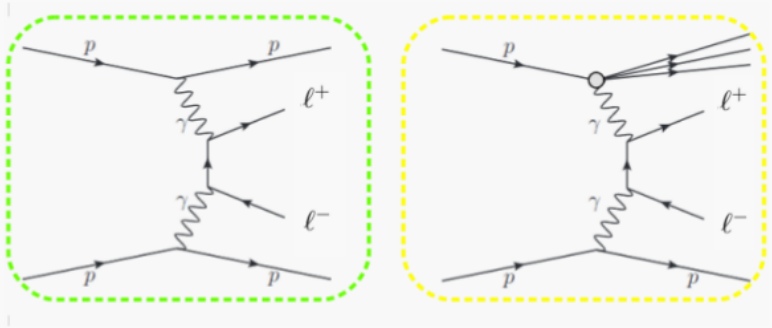


Opportunity to access a variety of topics: from diffraction to BSM physics

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

First physics: $\gamma\gamma \to \ell^+\ell^-$ 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

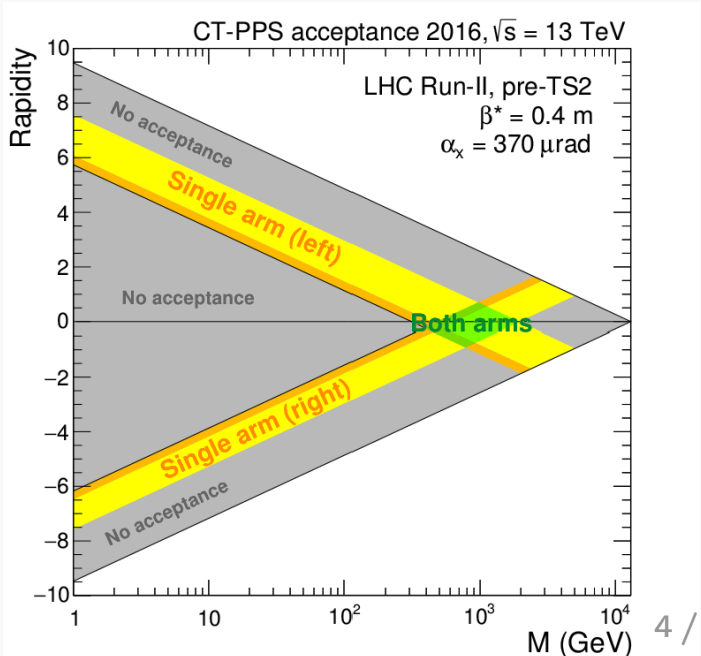
$\Rightarrow$ Observation of the first proton-tagged $\gamma\gamma$ collisions at the EWK scale

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

- Defines dilepton 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 $\ell^+\ell^-$ events



Strategy

Look for correlation between

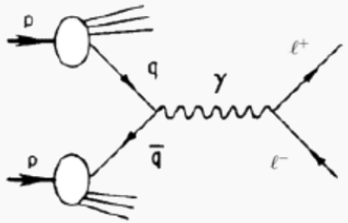
- direct proton ξ measurement by CT-PPS
- dilepton system measured by CMS

ξ can be derived from lepton p_T and η:

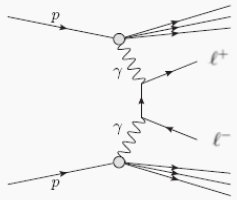
$$\xi^{\pm} = \frac{1}{\sqrt{s}} \times (p_T(\ell_1) e^{\pm\eta(\ell_1)} + p_T(\ell_2) e^{\pm\eta(\ell_2)})$$

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

Expected backgrounds:



Drell-Yan



Double dissociation

+ pileup proton

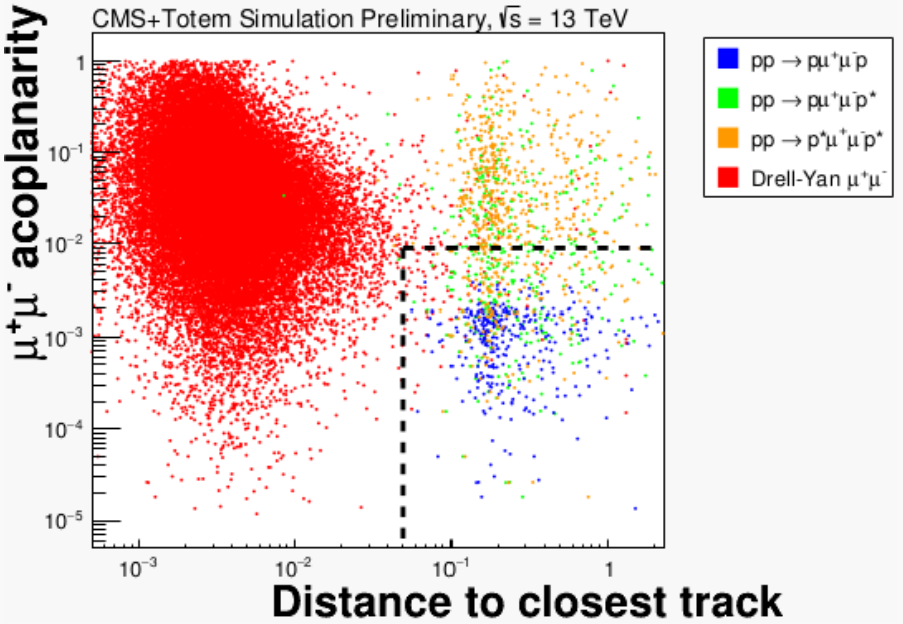
- will fake signal by overlapping with pileup or beam halo protons
- can be largely suppressed by selection cuts

Event selection

- **Pair of opposite sign 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: $|1 - \Delta\phi(\mu^+\mu^-)/\pi| < 0.009$ (<0.006 for e^+e^-)



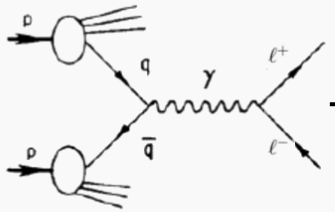
Signal candidates required to have $\xi(\ell\ell)$ and $\xi(proton)$ matching within 2σ of resolution

Data-driven background estimate

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

Drell-Yan contribution:

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

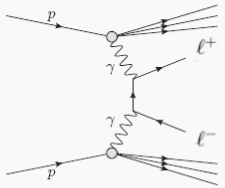


+ pileup proton

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

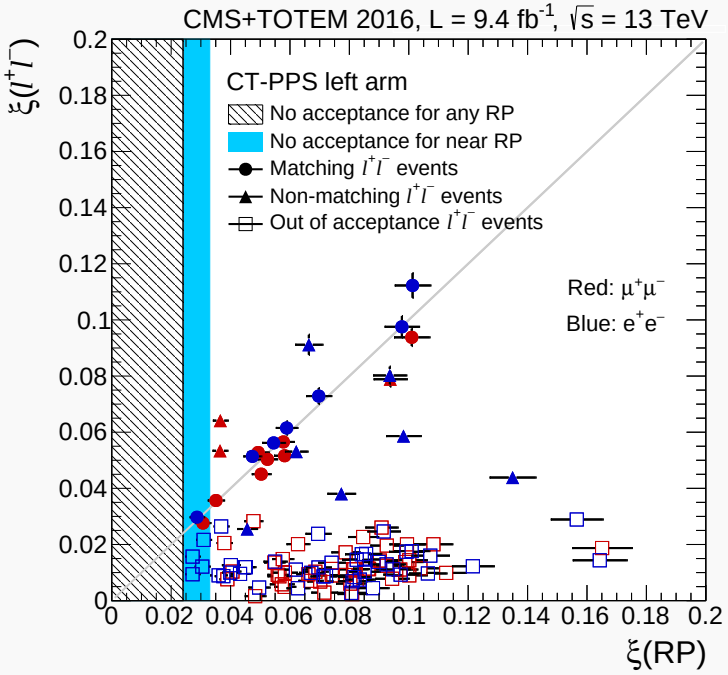
Total number of expected matching background events:

$\mu^+\mu^-$: 1.49 ± 0.07 (stat) ± 0.53 (syst)

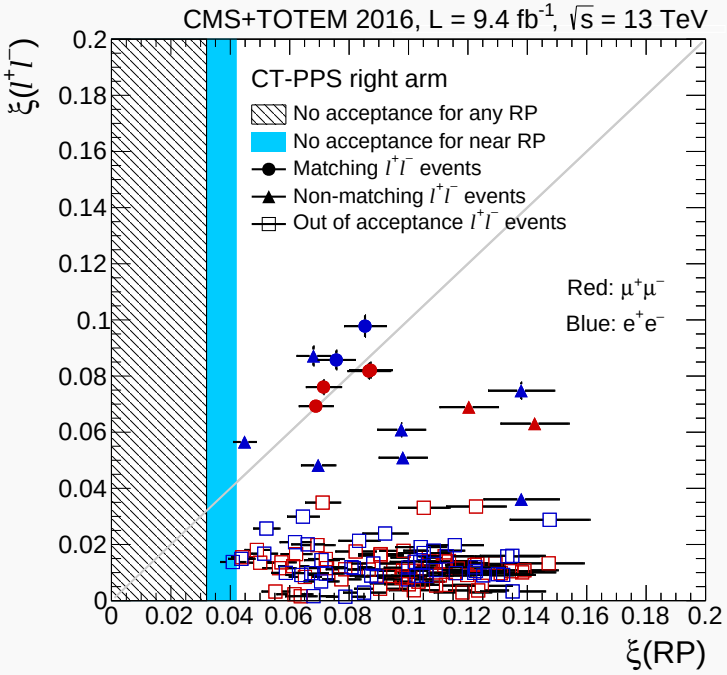
e^+e^-: 2.36 ± 0.09 (stat) ± 0.47 (syst)

Final result: ξ correlations

Left arm



Right arm



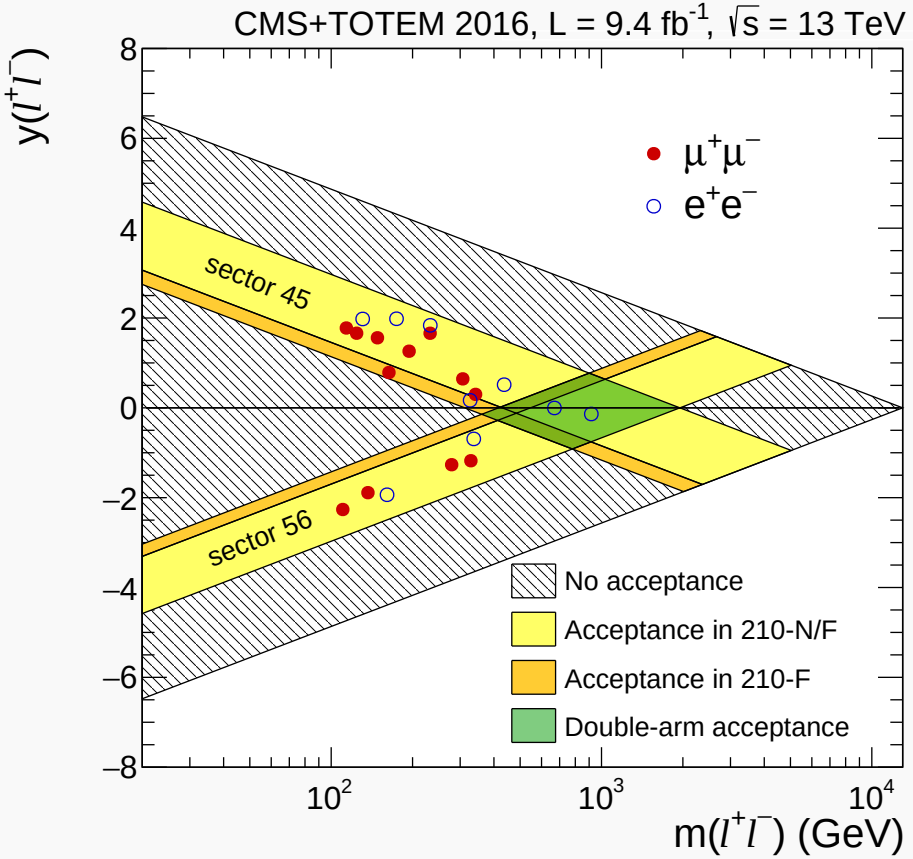
- **20 events with matching kinematics ($12\mu^+\mu^- + 8e^+e^-$)**
- $\mu^+\mu^-$ background: 1.49 ± 0.07 (stat) $\pm$ 0.53 (syst)
- e^+e^- background: 2.36 ± 0.09 (stat) $\pm$ 0.47 (syst)

Combined significance: $> 5.1\sigma$

arXiv:1803.04496

JHEP07(2018)153

Signal candidates properties



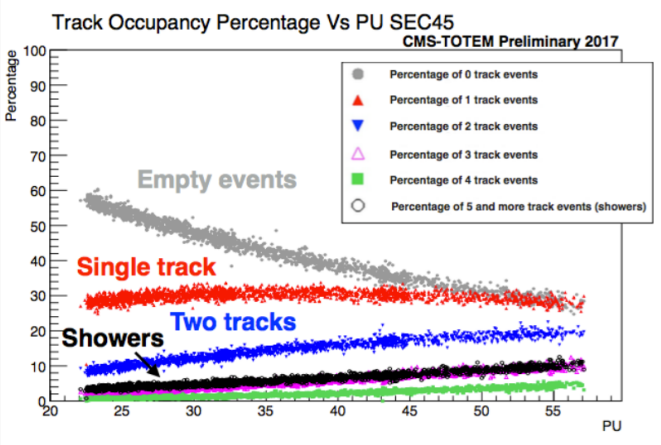
- Dilepton M and Y consistent with single arm acceptance
- No double-tagged events observed, consistent with SM xsection*efficiency

Mass extends up to ∼900 GeV – first tagged $\gamma\gamma$ collisions at EWK scale!

Prospects with the new data

2017-2018: successful data taking after major upgrade

- 3D Si pixels for tracking $\rightarrow$ capability of resolving multiple tracks in high pileup conditions
- Operation of diamond detectors $\rightarrow$ timing measurements



Total integrated luminosity:
15 fb^{-1} (2016)
40 fb^{-1} (2017)
$\sim$35 fb^{-1} (2018) – so far

Rich physics program ahead:
exclusive diphotons, $t\bar{t}$, quartic gauge couplings with photons(Z/ZZ/WW), search for dark matter, axion-like particles and more.

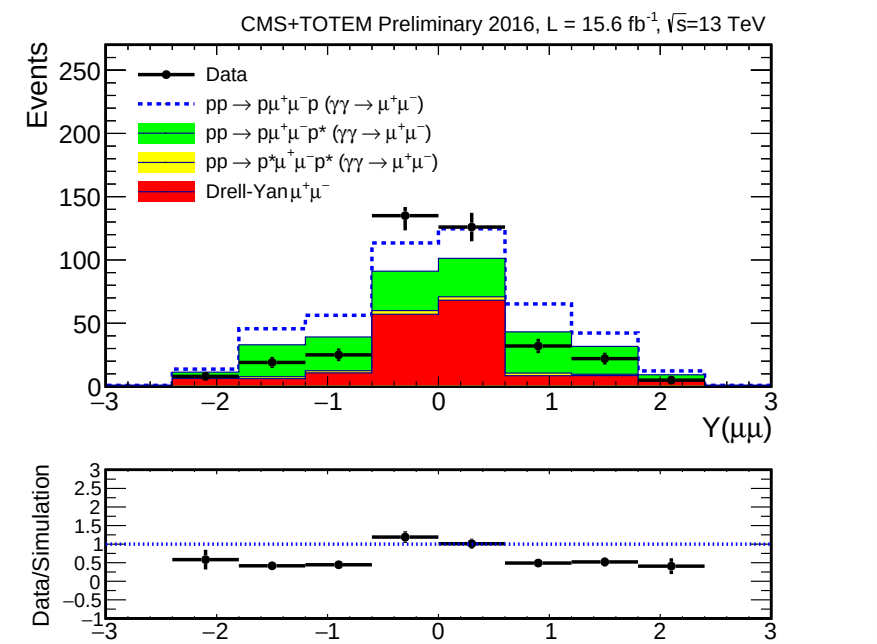
Conclusions

- **Successful operation of CT-PPS Roman Pot detectors in high luminosity runs at the LHC since 2016**
- **First paper** using 2016 data published
- **More than 75 fb^{-1} of good quality data collected during 2017-18 operation**, multiple analyses ongoing

Expect much more physics in 2018-2019.

Backup

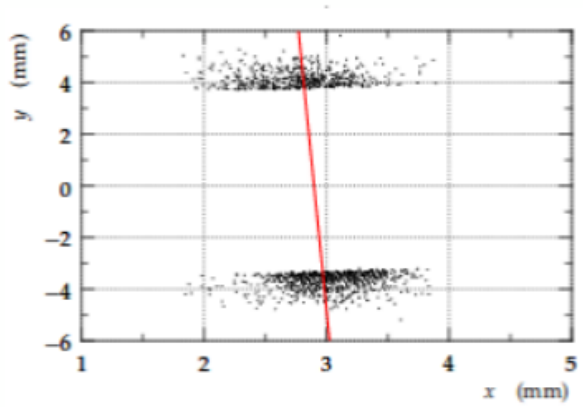
Survival probability

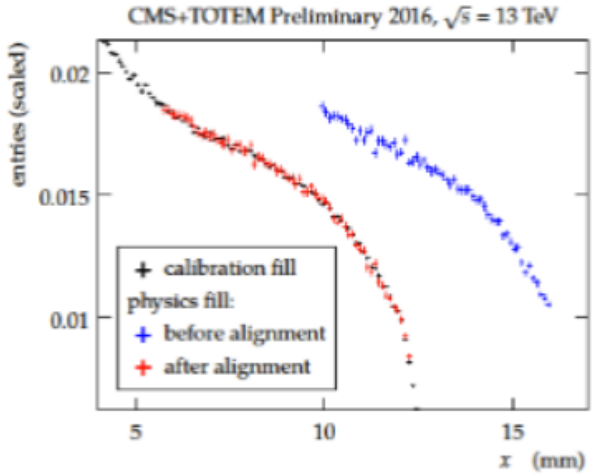


- Using suppression factors by Durham model arXiv:1601.03772
- Good description of the data at Y=0, but values too large for non-zero rapidities.
- A Y dependence of the rapidity gap survival probability is expected in several models, see e.g. arXiv:1410.2983, arXiv:1508.02718, arXiv:1502.03323

Alignment

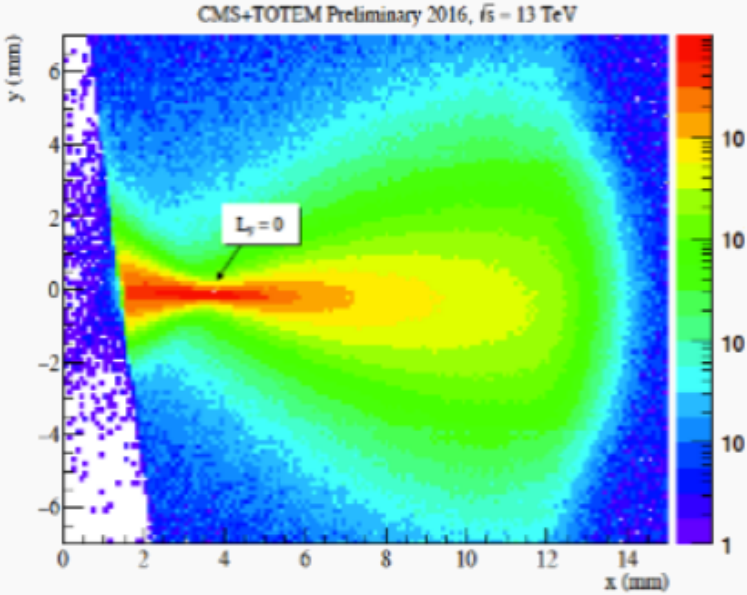
- Alignment procedure performed in 2 steps
  - 1: Absolute alignment
  - 2: Fill-by-fill alignment
- Step 1: Use elastic scattering (pp→pp) events, in special alignment runs where both horizontal and vertical RPs approach very close to the beam
- Step 2: Use inclusive sample of protons triggered by central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

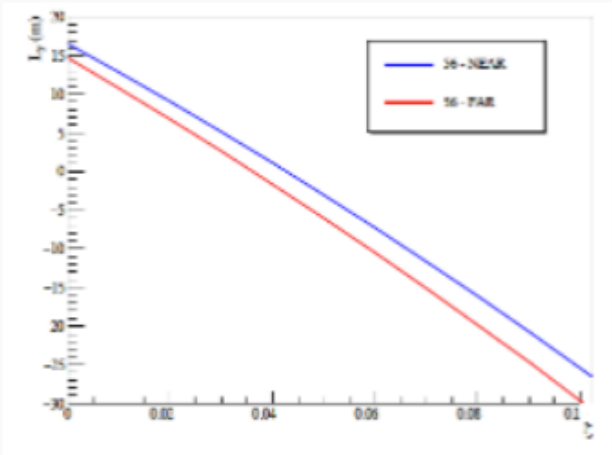




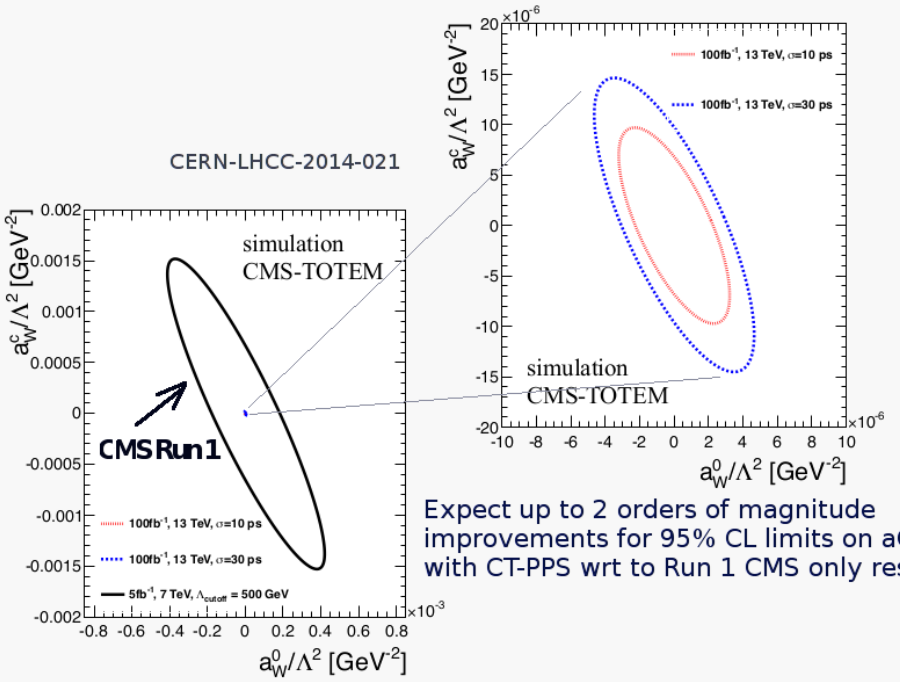
Optics determination

- 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"



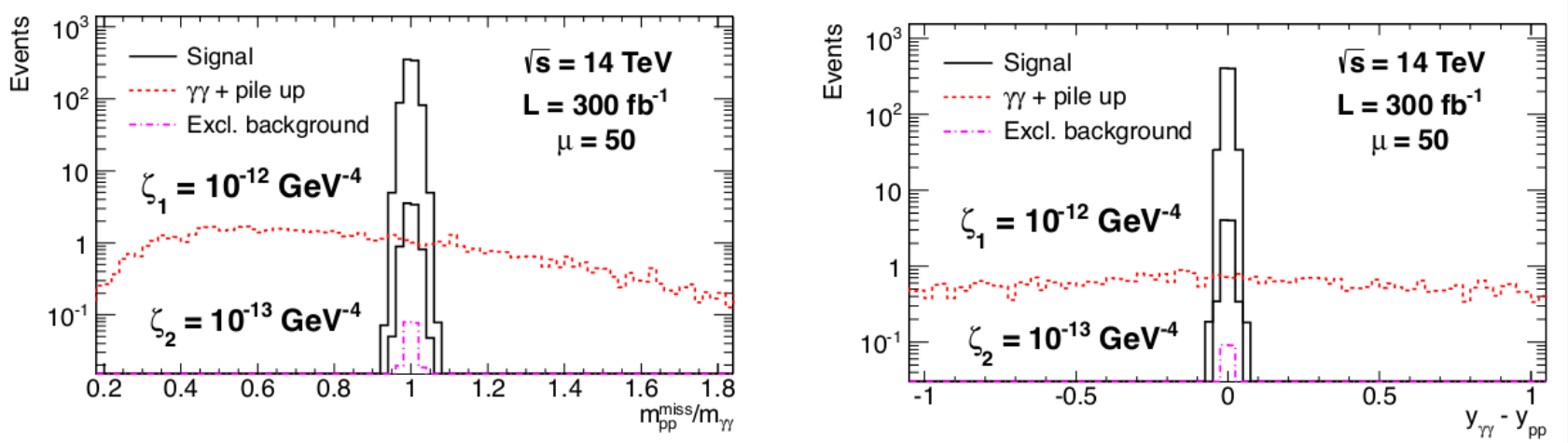


- Final result is a (non-linear) calibration of ξ vs. the measured track x position
- Overall ξ resolution of ~5.5%



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)