OBSERVATION OF (SEMI)EXCLUSIVE DILEPTON PRODUCTION WITH PROTON TAG IN THE CMS-TOTEM PRECISION PROTON SPECTROMETER (CT-PPS)

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1. A FEW WORDS ABOUT CT-PPS

- **CT-PPS operated for the first time in 2016**
- **Spectrometer allows measurement of processes in which incoming proton(s) escapes intact after interaction at IP**
- Goal: study of central exclusive production in $\gamma\gamma$ or gg collisions by combining CMS and PPS information
- **Access to topics from BSM to diffraction**

Operation principle: Protons scattered at IP are bent out from beam envelope by LHC magnets. CT-PPS detectors housed along the beamline **measure protons a few mm from beam, on both sides of CMS.**

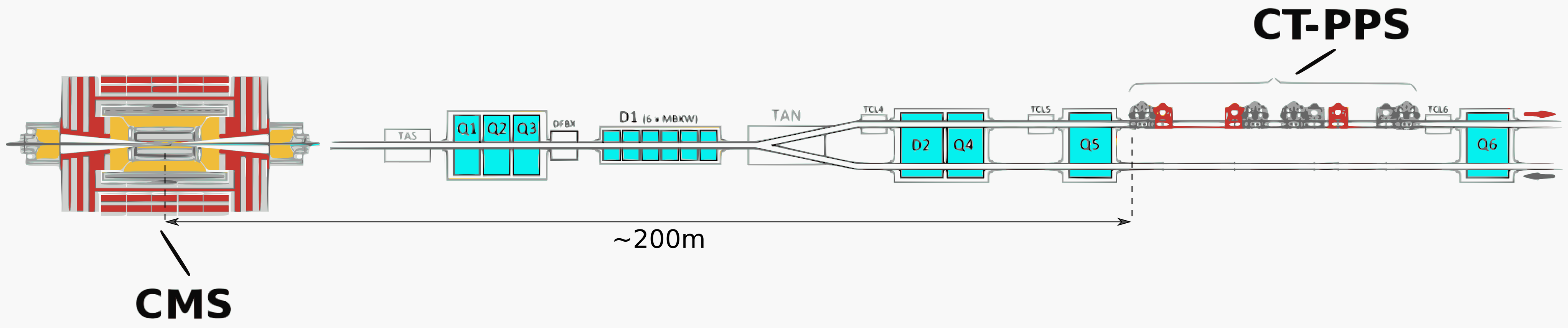


Fig. 1: Schematic layout of one arm in 2016 configuration. The other arm is symmetric wrt the CMS IP. LHC magnets are in cyan.

2. IDEA AND STRATEGY

Analysis of the first data (9.4 fb^{-1}) collected in standard high-luminosity runs.
Study production of lepton pairs by $\gamma\gamma$ fusion.

Two goals:

- **Technical:** validation of CT-PPS performance and reconstruction
- **Physics:** first observation of proton-tagged $\gamma\gamma$ collisions at the EWK scale

Key proton variable: relative momentum loss $\xi = \Delta p/p$. ξ can **also** be derived from leptons p_T and η:

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

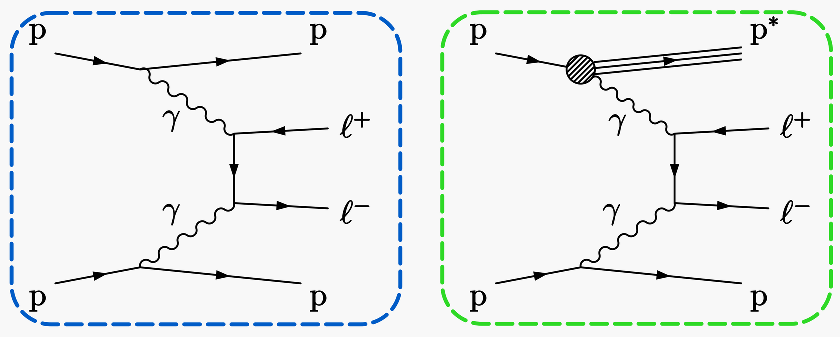
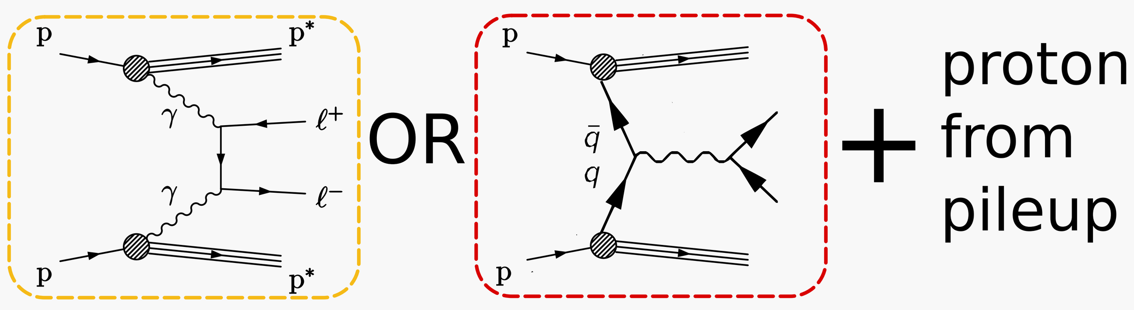


Fig. 2: Signal processes: central exclusive (blue) and semiexclusive (green) dilepton production.

We search for correlation between

- direct proton $\xi(p)$ measurement by CT-PPS
- dilepton system $\xi(\ell^+\ell^-)$ measured by CMS

Main background sources are Drell-Yan and double-dissociative dilepton production. They fake signal signature by overlaying with protons from pileup/beam halo:



3. SELECTION

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

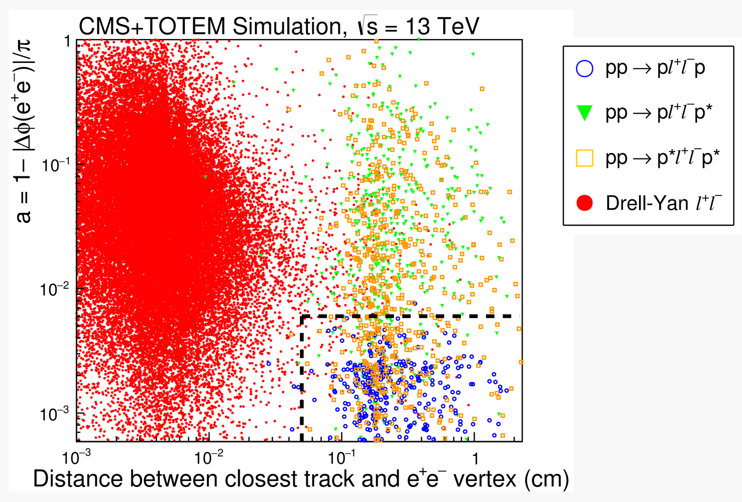


Fig. 6: Lines show analysis cuts.

- **Veto additional tracks** around dilepton vertex (within 0.5mm)
- Require **back-to-back** muons(electrons): $|1 - \Delta\phi/\pi| < 0.009(0.006)$

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

4. PROTON RECONSTRUCTION

Two key components: alignment and optics

- **Alignment of CT-PPS detectors:**
  - Step 1: use elastic scattering events from special run to define reference distribution of proton impact positions
  - Step 2: calibrate distribution from each fill in physics run

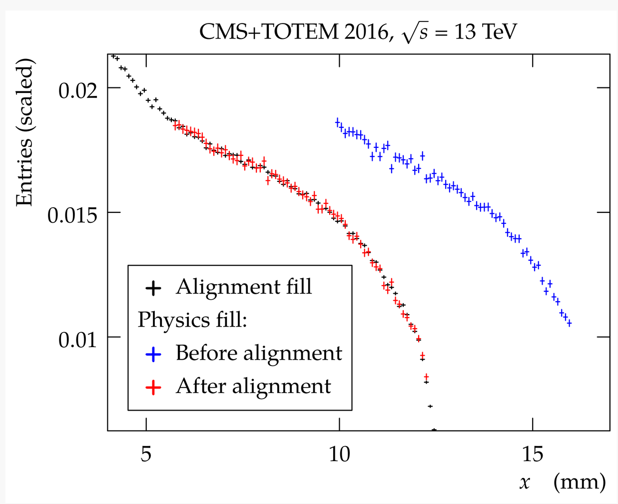


Fig. 3: Distribution of the track impact points before and after alignment.

- **Optics:**
  - Precise knowledge of proton trajectory is necessary to derive $\xi(p)$
  - Determined by combining knowledge of machine parameters (e.g. magnet strenghts, crossing angles) and data from beam position monitors

6. SYSTEMATICS

Sources of uncertainty	$\mu^+\mu^-$ Drell–Yan	$\mu^+\mu^-$ Double-diss.	e^+e^- Drell–Yan	e^+e^- Double-diss.
Statistics of Z sample	5%	5%	4%	4%
$\xi(\ell^+\ell^-)$ reweighting	25%	-	11%	-
Track multiplicity modeling	28%	-	14%	-
Survival probability	-	100%	-	100%
Luminosity	-	2.5%	-	2.5%

5. BACKGROUND ESTIMATE

- Mean pileup in considered data is ~27
- **Main question:** how often pileup protons will **by accident** have $\xi(p)$ matching with $\xi(\ell^+\ell^-)$?
- **Typically pileup/beam halo protons have low ξ values**, and thus are well separated from signal
- To estimate remaining contribution we **we mix signal and background events**
- Sample of background forward protons is obtained from Z-peak events: $80 < M(\ell^+\ell^-) < 110$ GeV
- **Background protons are mixed with LPAIR MC/data** dileptons to estimate background

7. RESULTS

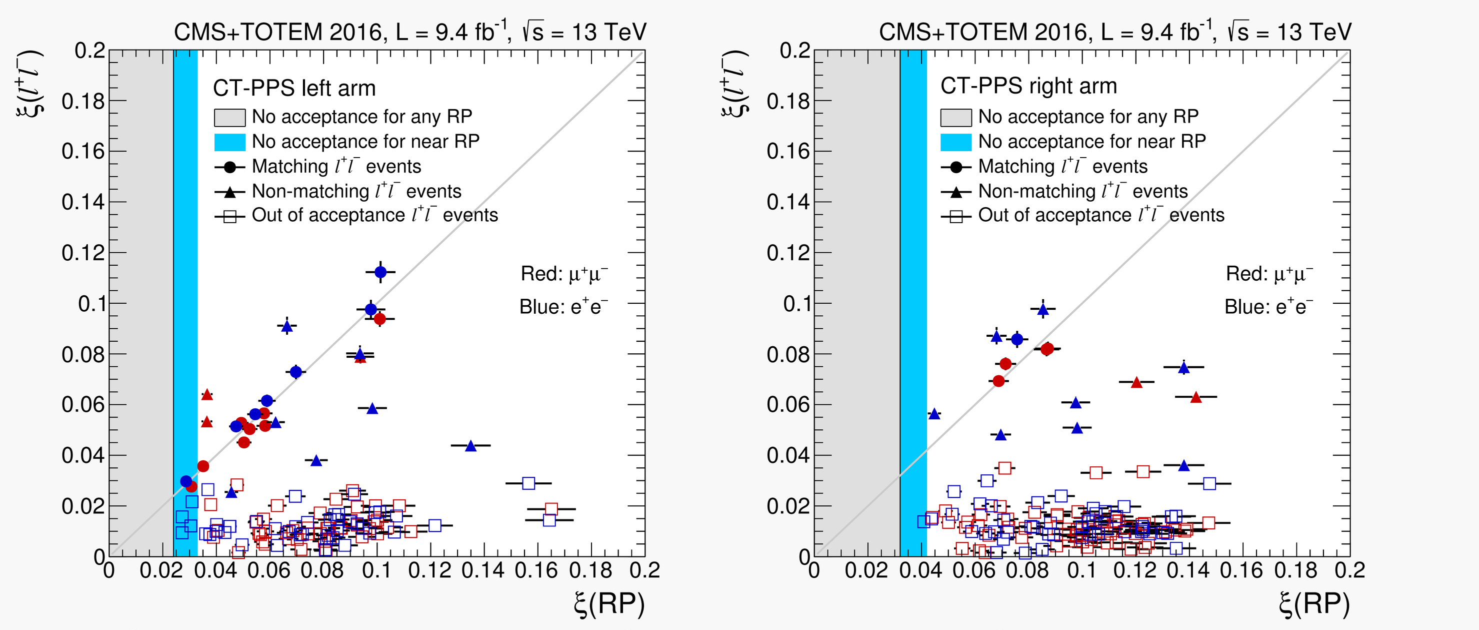


Fig. 4: Correlation between the fractional values of the proton momentum loss measured in the central dilepton system, $\xi(\ell^+\ell^-)$, and in the CT-PPS, ξ(RP), **for each arm.**

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

Combined significance $>$**5.1** σ

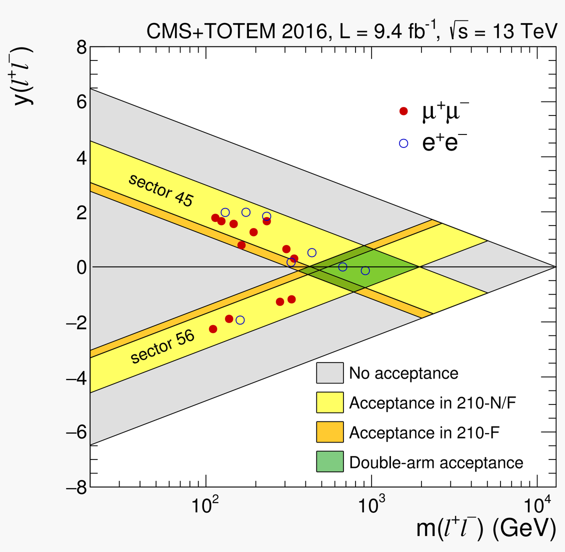


Fig. 5: Expected acceptance regions in the rapidity vs. invariant mass plane overlaid with the observed dimuon and dielectron signal candidate events.

Fractions of the exclusive and semiexclusive contributions obtained by comparing acoplanarity distribution with LPAIR MC expectations: **~ 70% semiexclusive, 30% exclusive**

Summary:

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