New physics results with the CMS Precision Proton Spectrometer

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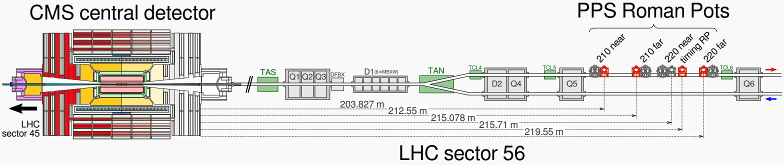
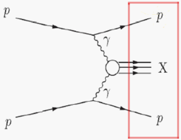
Intro

- **Precision Proton Spectrometer (PPS): forward proton spectrometer designed for operation in regular, high-intensity LHC runs**
- **Collected > 110 fb^{-1} in Run 2, extending forward coverage of CMS on both sides of IP5**



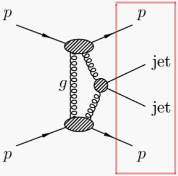
- Unique opportunity to probe $\gamma\gamma$ and gluon-gluon collisions at hadron collider
- In central exclusive production (CEP) events, **addition of PPS allows to reconstruct the full 13 TeV collision energy**
- For details of reconstruction, see talk by Fabrizio Ferro

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

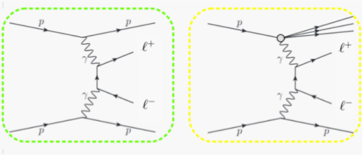


Opportunity to access a variety of topics: from diffraction to BSM physics

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

Dilepton production $\gamma\gamma \to \ell^+\ell^-$ with proton tag

(Semi-)exclusive dilepton production via photon exchange in proton-proton collisions



Final state: one (two) forward protons + dilepton

Physics:

- Look for "simple" SM process, explore correlation between kinematics of the dilepton system and that of the forward proton(s)
- **Consider both double and single-tagged $\ell^+\ell^-$ events**
- Validation of the optics and alignment
- Observation of the first proton-tagged $\gamma\gamma$ collisions at the EWK scale

Strategy

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

Look for correlation between

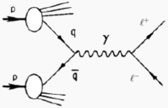
- direct proton ξ measurement by PPS
- dilepton system measured by central subdetectors of CMS

ξ can be derived from lepton p_T and η:

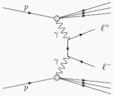
$$\xi^{\pm} = \frac{1}{\sqrt{s}} \times \left(p_T(\ell_1)e^{\pm\eta(\ell_1)} + p_T(\ell_2)e^{\pm\eta(\ell_2)}\right)$$

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

Expected backgrounds:



Drell-Yan

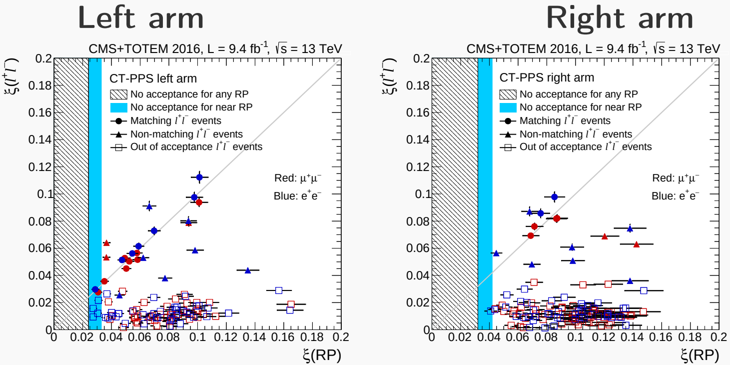


Double dissociation

+ pileup proton

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

Final result: ξ correlations



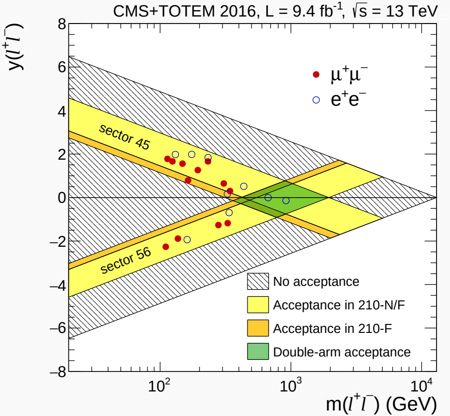
- 20 events with matching kinematics $(12\mu^+\mu^- + 8e^+e^-)$
- $\mu^+\mu^-$ background: 1.49 ± 0.07 (stat) ± 0.53 (syst)
- e^+e^- background: 2.36 ± 0.09 (stat) ± 0.47 (syst)

Combined significance: $\boxed{> 5.1\sigma}$

arXiv:1803.04496

JHEP07(2018)153

Signal candidates properties

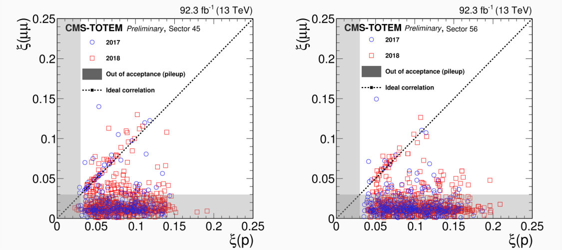


- Dilepton M and Y consistent with single arm acceptance
- No double-tagged events observed, consistent with SM cross section*efficiency

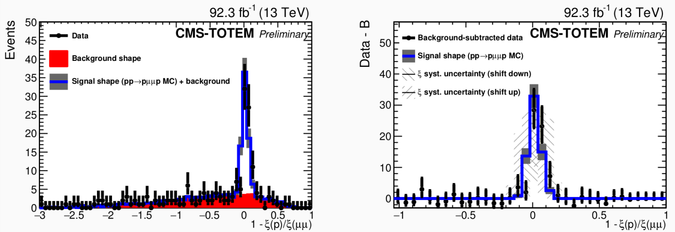
Mass extends up to ~900 GeV – first tagged $\gamma\gamma$ collisions at EWK scale!

Dilepton analysis with 2017 + 2018 data

- 92.3 fb^{-1} of remaining Run 2 data calibrated and analyzed, $\mu\mu$ channel shown



- Excellent reconstruction and MC performance ⇒ full dataset ready for any Run 2 analysis

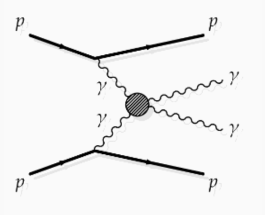


CMS-DP-2020-047

Exclusive di-photon production at high mass

Search for BSM contributions to the light-by-light scattering cross section

Final state: two forward protons + diphoton



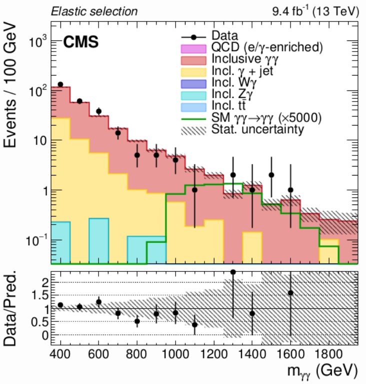
Physics:

- CMS and ATLAS reported[1] the observation of LbL event candidates for diphoton masses of a few GeV. The $m_{\gamma\gamma}$ spectrum above 350 GeV is explored for the first time at a hadron collider in this analysis
- Challenges: low process cross-section (few fb for elastic SM production), large theoretical uncertainties (survival probability, particles in loop)

[1] Phys. Rev. Lett. 123 (2019) 052001, Phys. Lett. B 797 (2019) 134826

Di-photon mass spectrum

- 2016 data, 9.4 fb^{-1}
- $m_{\gamma\gamma} > 350$ GeV,$p_T > 75$ GeV, 1 - $|\Delta\varphi|/\pi < 0.005$
- Di-photon mass spectrum before PPS proton requirement
- Main background from inclusive $\gamma\gamma$ and inclusive $\gamma + jet$



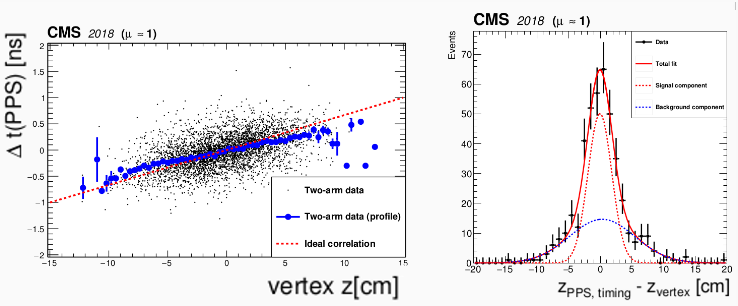
CMS-PAS-EXO-18-014

- No events in signal region found to contain a pair of forward proton tracks, expected background $0.23^{+0.08}_{-0.04}$
- **a 95% confidence level observed frequentist upper limit of 3.0 fb is quoted on the LbyL cross section within the fiducial region**

Run 2 timing performance

- In addition to proton ξ, PPS measures time of proton arrival
- Vertex resolution can be obtained from the difference of proton arrival times in two arms

$$\boxed{z_{PPS} - z_{vertex} = (c/2 * \Delta t_{PPS}) - z_{vertex}}$$

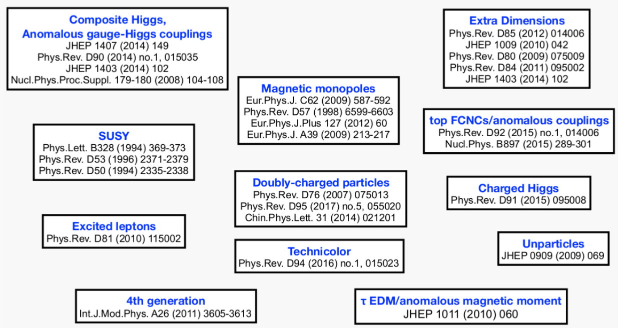


- Vertex resolution of 1.87 $\pm$ 0.21 cm ($\sim$60 ps)
- Resolution dominated by the single-arm detector and electronics performance
- Expected to degrade by $\sim 15 - 25$ ps between this low pileup data and the end of Run 2

CMS-DP-2020-046

PPS in future analyses

- A myriad of accessible topics – here are few examples:



Run 3 prospects:

- Goal to acquire 300 fb^{-1} of data
- New opportunities with introduction of PPS in HLT trigger: for both automatized calibration and physics
- Upgrade of PPS timing system to reach 30 ps resolution – additional tool to combat background

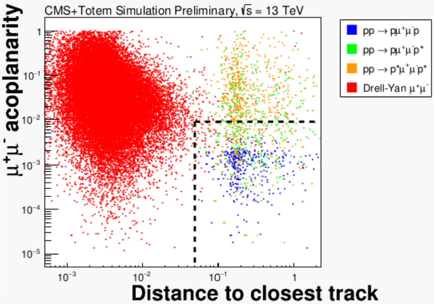
Summary

- Public PPS results based on 2016 data: first observation of tagged $\gamma\gamma$ collisions at the EWK scale, first collider limit on 4-photon AQGC
- Extensive work on full Run 2 analyses, to be released very soon
- Exciting prospects for Run 3: benefit from acquired Run 2 experience, more data, more powerful tools for signal extraction

Backup

Event selection

- **Pair of opposite sign leptons** with $p_T(\ell) > 50$ GeV 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^-)



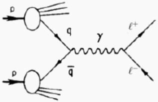
Signal candidates required to have $\xi(\ell\ell)$ and $\xi(proton)$ matching within 2σ of resolution

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 $\xi(\text{proton})$ correlated within 2σ
- use MC to extrapolate to the signal region

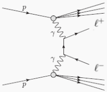


+ pileup proton

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

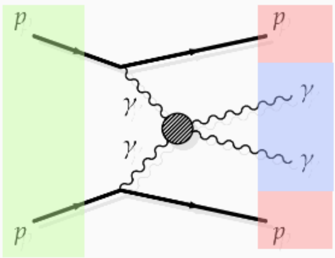
Total number of expected matching background events:

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

e^+e^-: 2.36 $\pm$ 0.09 (stat) $\pm$ 0.47 (syst)

PPS for signal extraction: the principle

- Since the process is exclusive, the energy lost by the protons in the interaction goes into producing the diphoton system
- PPS measures fractional **proton momentum loss** ξ.



$\Rightarrow$ Two independent ways to derive diphoton M and y

a) measure diphoton kinematics directly with CMS

b) Use $\xi = \frac{p_{in} - p_{final}}{p_{in}}$ to predict diphoton M and y from energy conservation:

$M(VV) = \sqrt{s}\sqrt{\xi(p1)\xi(p2)}$ $\qquad$ $y(VV) = \frac{1}{2}\ln(\xi(p1)/\xi(p2))$

For signal events a) and b) will be the same within resolution, for background just random correlation.