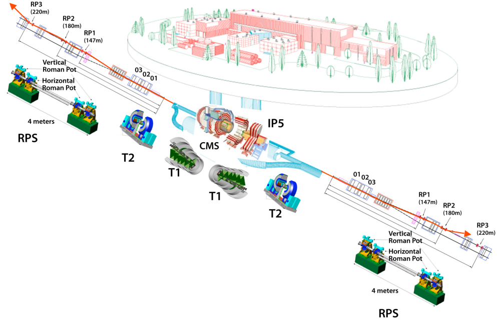
Prospects For Photon-Photon Measurements with CMS PPS

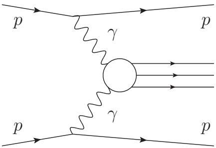
Justin Williams

On behalf of the CMS collaboration



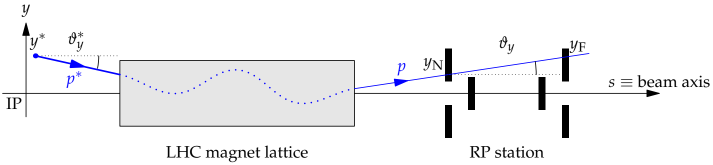
Introduction

The LHC was built as a discovery machine, but we've found a way to do precision physics



- The CMS Precision Proton Spectrometer (PPS) provides an opportunity for new searches and measurements
- Possibility of a very strong background suppression using intact protons
- Outline
  1. Short description of PPS
  2. First physics results
  3. Prospects: Anomalous Couplings, Axion-Like Particles, etc.

CMS Precision Proton Spectrometer

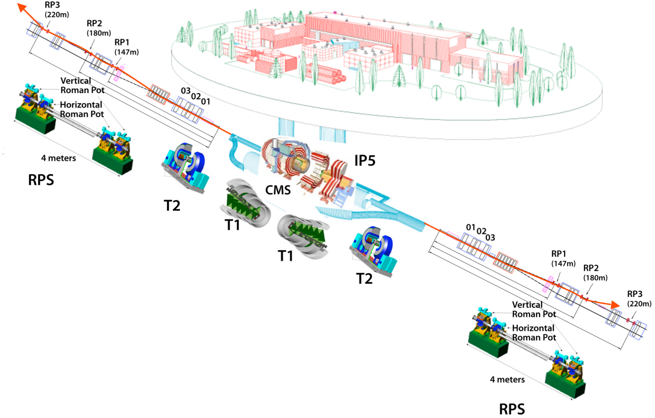


- LHC magnets bend scattered protons outside of the beam envelope
- Detect protons at about $\pm$ 200 m from IP5
- Near and far stations on both sides
- Reconstruct $\xi = 1 - p_f/p_i$
- Central system mass acceptance 350 GeV $< M_X <$ 2 TeV
- Collected $\sim$ 10 fb^{-1}, 40 fb^{-1}, 58 fb^{-1} in 2016, 2017, 2018 respectively

---

https://cds.cern.ch/record/1753795

Layout of PPS



Detectors - Year By Year

2016

TOTEM silicon strip detectors

- Single track capability

2017

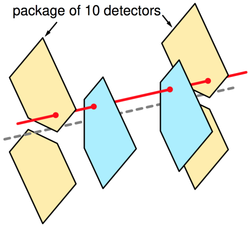
One station with silicon strips, one station with 3D pixels

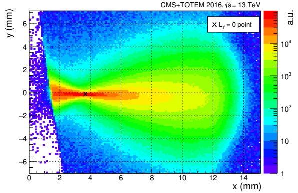
- Pixel detectors with multi-tracking capability
- UFSD timing (one per side)

2018

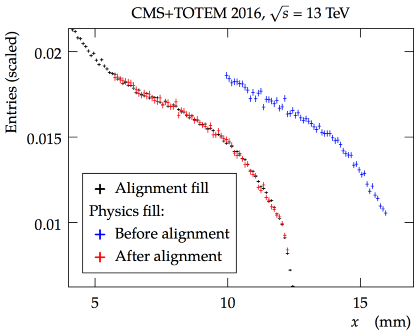
All stations with 3D pixel detectors

- 3D pixel detectors
- Diamond timing detectors (one per side)





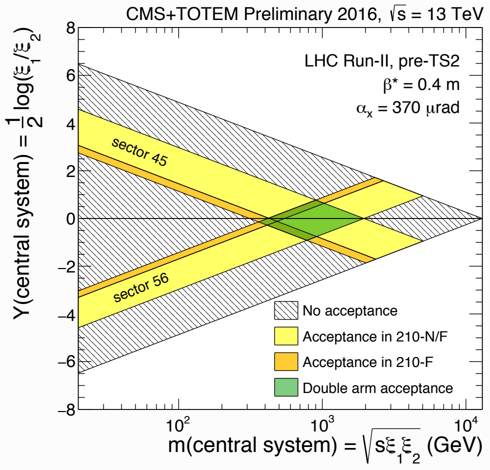
PPS Alignment



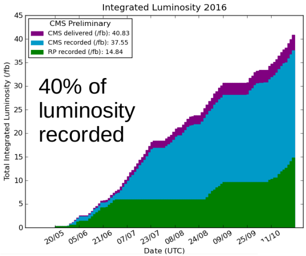
Alignment Procedure

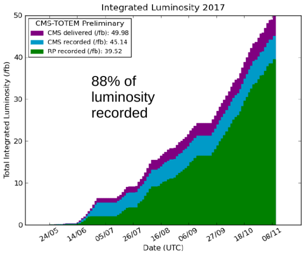
- RP moved very close to beam for alignment fill
- Use low luminosity, elastic runs for reference
- Correct physics run to reference runs
- Full documentation at CERN-TOTEM-NOTE-2017-001

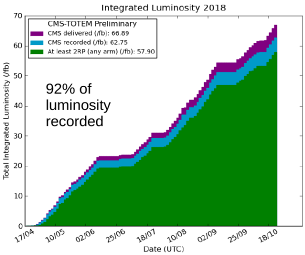
Available Phase Space



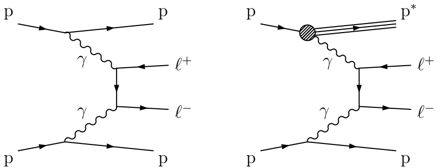
Luminosity


Integrated Luminosity 2016
CMS Preliminary
CMS delivered (/fb): 40.83
CMS recorded (/fb): 37.55
RP recorded (/fb): 14.84
40% of luminosity recorded
Total Integrated Luminosity (/fb)
Date (UTC)
20/05 05/06 21/06 07/07 23/07 08/08 24/08 09/09 25/09 11/10

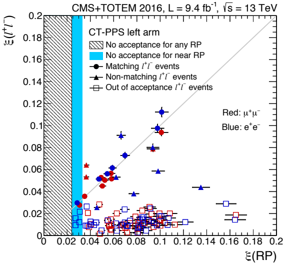

Integrated Luminosity 2017
CMS-TOTEM Preliminary
CMS delivered (/fb): 49.98
CMS recorded (/fb): 45.14
RP recorded (/fb): 39.52
88% of luminosity recorded
Total Integrated Luminosity (/fb)
Date (UTC)
24/05 14/06 05/07 26/07 16/08 06/09 27/09 18/10 08/11


Integrated Luminosity 2018
CMS-TOTEM Preliminary
CMS delivered (/fb): 66.89
CMS recorded (/fb): 62.75
At least 2RP (any arm) (/fb): 57.90
92% of luminosity recorded
Total Integrated Luminosity (/fb)
Date (UTC)
17/04 10/05 02/06 25/06 18/07 10/08 02/09 25/09 18/10

Dilepton Analysis

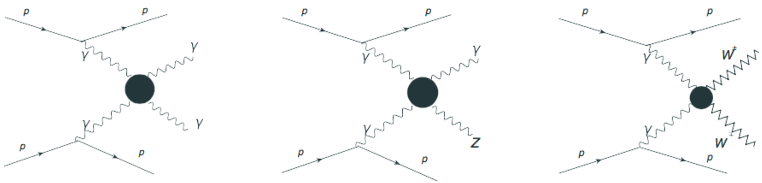


- First observation of the process at high mass using intact protons
- Observed 13 signal events (5.1σ) consistent with the SM expectation
- Performed at normal optics and pileup conditions
- Proof that the alignment, optics, trigger, proton tagging, etc are working



JHEP 1807 (2018) 153

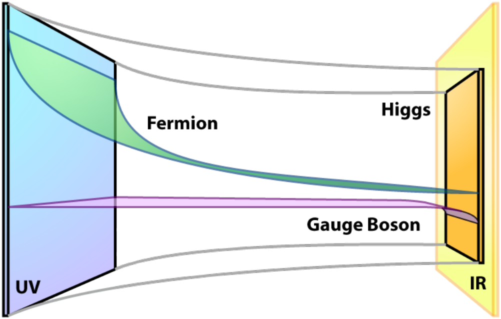
Anomalous Quartic Guage Couplings



- Photon induced processes with intact protons in forward regions
- Exclusive processes with a very clean signal
- PPS provides the best sensitivity to anomalous couplings due to proton tagging

Motivations for AQGC

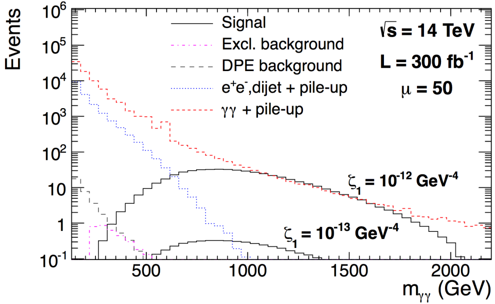
- Warped Extra Dimensions solve hierarchy problem of the SM
- Predicted by Composite Higgs, Kaluza Klein, Extra Dimensional models
- Couplings can be probed independently of models
- Effective 4-photon couplings $\zeta_i \sim 10^{-14}$ - 10^{-13} GeV^{-4} possible



JHEP 1403 (2014) 102

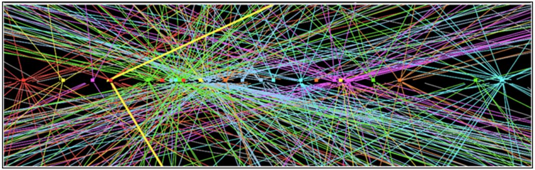
Backgrounds

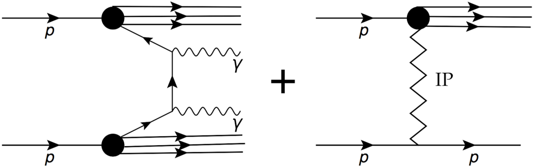
- Requesting two protons identified in forward detectors + two converted photons in central detector
- All backgrounds considered (DPE diphoton production, H$\to \gamma\gamma$, exclusive $\gamma\gamma$ production, dilepton + dijet misidentification, PU, Drell-Yan, ...)
- Pileup is the main source of background



JHEP 02, 165 (2015)

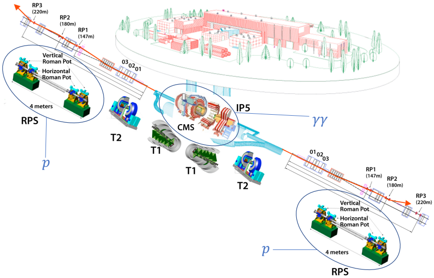
Pile Up In PPS

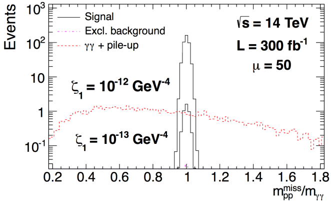


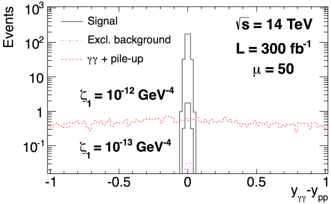


- The LHC collides packets of protons
- PU causes interference from particles generated at unrelated vertices
- For conditions of the LHC in 2016, can have up to 60 PU vertices

Dealing with pileup

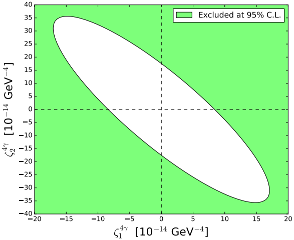






JHEP 02, 165 (2015)

Potential For Limits



Cross section scales as a function of the coupling values ζ_1,ζ_2

$$\frac{d\sigma}{d\Omega} = \frac{1}{16\pi^2 s}\left(s^2 + t^2 + st\right)^2 \left[48\left(\zeta_1\right)^2 + 40\zeta_1\zeta_2 + 11\left(\zeta_2\right)^2\right]$$

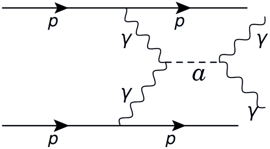
- Based on 9.41 fb^{-1} of data from 2016
- Assume signal and background obey a Poisson distribution
- Assume expected background is 0 and observed events is 0

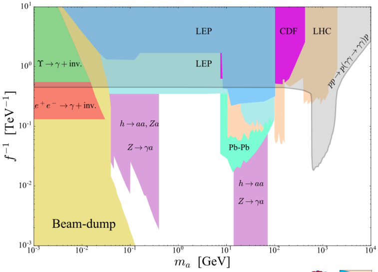
$$\sqrt{48\zeta_1^2 + 40\zeta_1\zeta_2 + 11\zeta_2^2} \geq 5.8 \times 10^{-13} \text{GeV}^{-4}$$

Search For Axion-Like Particles

We can study the production of ALPs via photon exchange with intact protons

- Study the production of ALPs via photon exchange with intact protons
- Sensitivity is enhanced since ALP production rate increases with $m_{\gamma\gamma}$
- PPS provides sensitivity that is competitive and complimentary to other collider searches above 600 GeV
- Existing limits on ALP production[1]





[1] JHEP 1806 (2018) 131

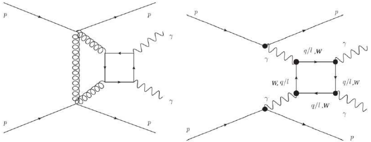
Summary

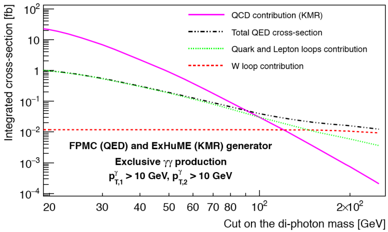
- With its 2016 operation, PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at a high luminosity hadron collider on a regular basis
- First observation of $\gamma\gamma \rightarrow \ell\ell$ with single proton tag
- Prospects for anomalous couplings, ALP searches, and more
- PPS has > 110 fb^{-1} and has plans for Run 3

Questions?

Standard Model $\gamma\gamma$ Exclusive Production

- QED process dominates at high $m_{\gamma\gamma}$
- Cross section is well known
- W boson loop is the most significant at high $m_{\gamma\gamma}$





JHEP 02, 165 (2015)

Dispersion Matrix

measured at RP

values at IP

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \xi \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \xi^* \end{pmatrix}$$