Anomalous Coupling Studies with Intact Protons at the LHC

Particle Physics On The Plains

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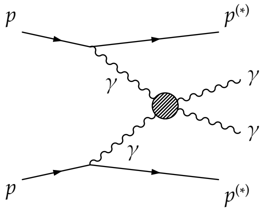
Introduction

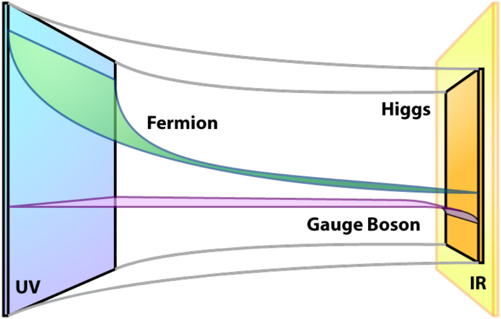
Using the LHC as a photon collider, we can study the photoproduction of exclusive photon pairs



- Proton tagging increases the sensitivity of standard LHC diphoton searches
- BSM effects can have contributions to the Ligh By Light cross-section
- Anomalous Couplings are motivated by many BSM theories

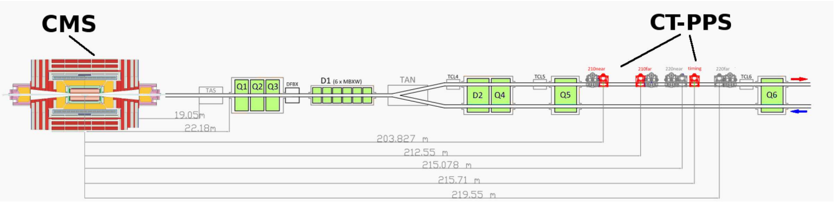
Motivations For Anomalous Couplings

- 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[1]



[1] Anomalous gauge couplings from composite Higgs and warped extra dimensions JHEP 1403 (2014) 102

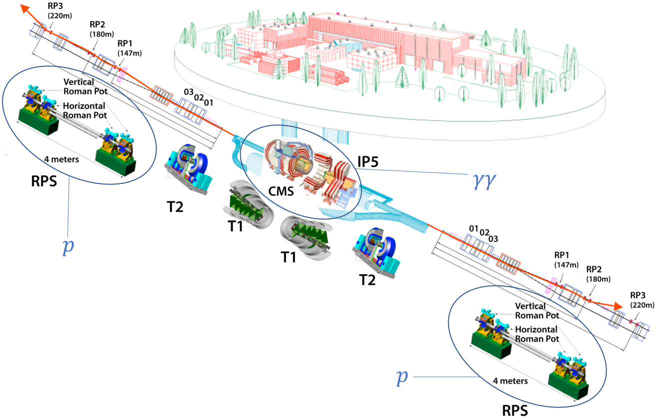
CMS Precision Proton Spectrometer



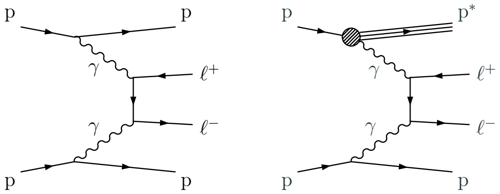
- Joint CMS and TOTEM project[2]
- LHC magnets bend scattered protons outside of the beam envelope
- Intact protons are detected by Roman Pots $\pm$ 200m from IP
- Calculate ξ which is the fractional momentum loss of the protons

[2] https://cds.cern.ch/record/1753795

Layout of PPS



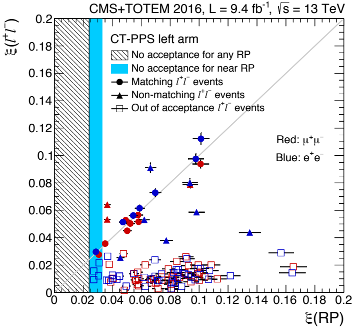
Dilepton Analysis With PPS



First observation ($> 5.1\sigma$) of the process at high mass using intact protons[3]

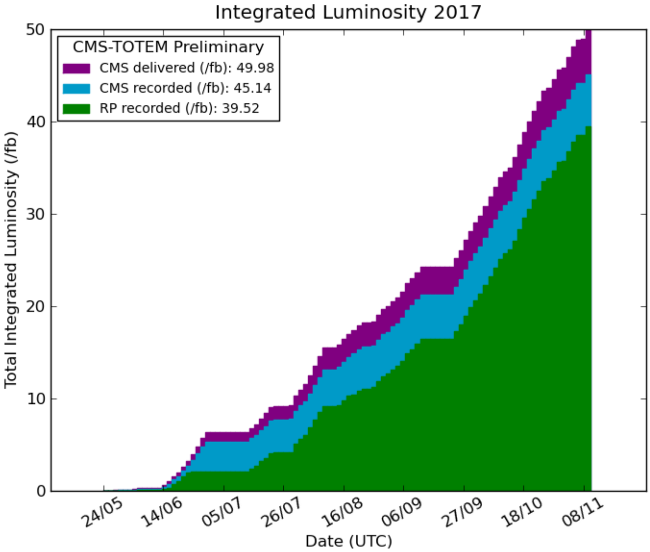
Performed at normal optics and pileup conditions

Proof that the alignment, optics, trigger, proton tagging, etc are working



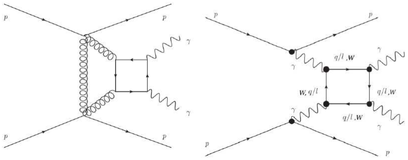
[3] *JHEP 1807 (2018) 153*

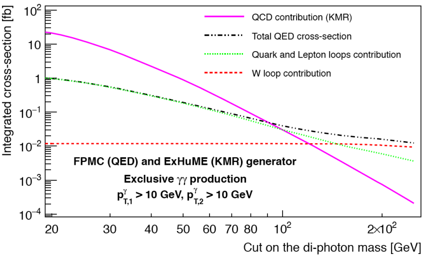
Luminosity Comparison - 2017



Standard Model $\gamma\gamma$ Exclusive Production

- QED process dominates at high $m_{\gamma\gamma}$[4]
- Cross section is well known
- W boson loop is the most significant at high $m_{\gamma\gamma}$

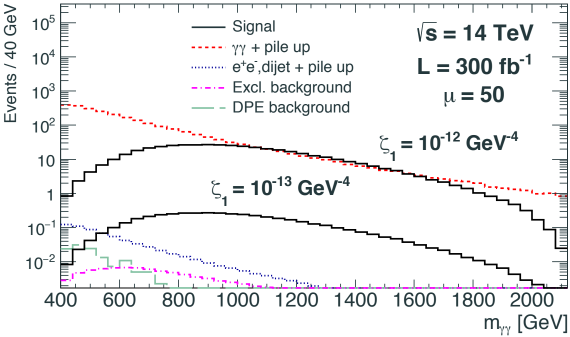




[4] *Light by light scattering with intact protons at the LHC: from Standard Model to new physics. 10.1007/JHEP02(2015)165*

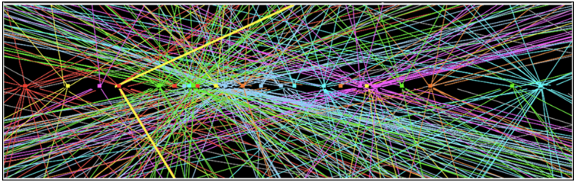
Other backgrounds

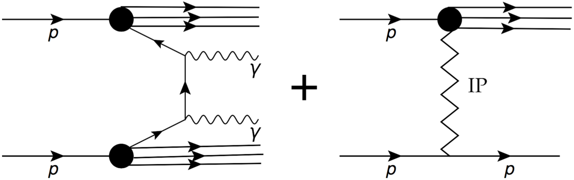
- Requesting two protons identified in forward detectors and two photons in central detector
- All backgrounds considered (DPE diphoton production, H$\to \gamma\gamma$, exclusive $\gamma\gamma$ production, dilepton + dijet misidentification, PU, Drell-Yan, ...)
- Pile up is the main source of background[5]



[5] *Light by light scattering with intact protons at the LHC: from Standard Model to new physics. 10.1007/JHEP02(2015)165*

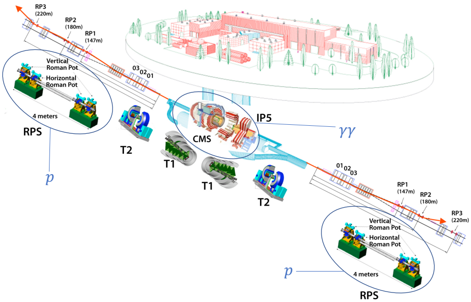
Pile Up at the LHC

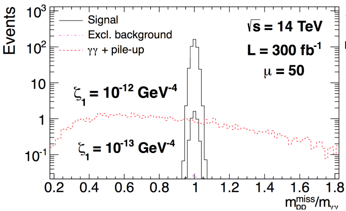


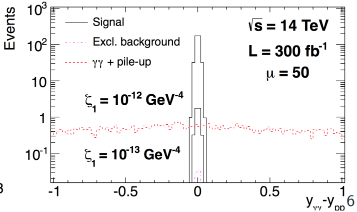


- The LHC collides packets of protons
- PU causes additional proton tracks from unrelated interactions
- For conditions of the LHC in 2016, can have up to 50 PU

Dealing With Pile Up







Dealing With Pile Up

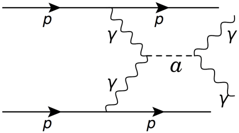
Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15,$ $p_{\mathrm{T}1,(2)} > 200, (100)$ GeV]	65	18 (187)	0.13	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	64	17 (186)	0.10	0	0.2	1023
$[p_{\mathrm{T}2}/p_{\mathrm{T}1} > 0.95,$ $\lvert\Delta\phi\rvert > \pi - 0.01]$	64	17 (186)	0.10	0	0	80.2
$\sqrt{\xi_1\xi_2 s} = m_{\gamma\gamma} \pm 3\%$	61	16 (175)	0.09	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	60	12 (169)	0.09	0	0	0

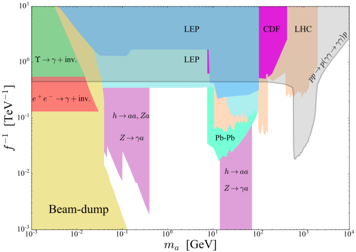
- Virtually no background after selection cuts for 300 fb^{-1}
- Gain 2 orders of magnitude in sensitivity compared to standard CMS/ATLAS searches[7]

[7] *Light by light scattering with intact protons at the LHC: from Standard Model to new physics. 10.1007/JHEP02(2015)165*

Search For Axion-Like Particles

Study the production of axion-like particles via photon exchange with proton tagging





- CT-PPS provides a new sensitivity at high ALP mass
- Existing limits on the Axion Like Particle from [8]

[8] arXiv:1708.00443v2

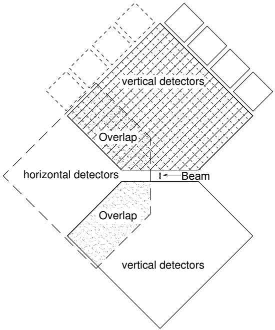
Summary

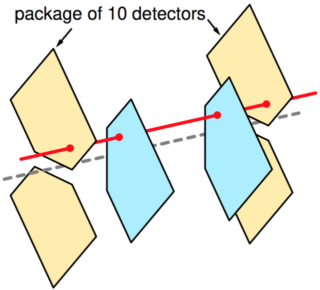
- PPS operated a near beam proton spectrometer for the 1st time at a HL collider
- The use of proton tagging can increase the sensitivity of CMS to anomalous couplings
- The analysis has a background free selection after exclusivity cuts
- We can also probe WW, Zγ, and ZZ final states[9]
- Potential for strongest limits to be placed on the 4-photon anomalous coupling

[9] Phys.Rev.D81 (2010) 074003

Questions?

Roman Pots





- Both horizontal and vertical Roman Pots
- Using silicon strips (2016), silicon pixels, and timing detectors
- Multiple planes to deduce tracks
- Susceptible to radiation damage

ξ calculations

Diphoton

$$\xi_{+} = \frac{pT_1 * exp(\eta_1) + pT_2 * exp(\eta_2)}{\sqrt{s}}$$

$$\xi_{-} = \frac{pT_1 * exp(-\eta_1) + pT_2 * exp(-\eta_2)}{\sqrt{s}}$$

Diproton

$$m_{pp} = \sqrt{s}\sqrt{\xi_1 \xi_2}$$

$$y_{pp} = \frac{1}{2} \log\left(\frac{\xi_1}{\xi_2}\right)$$

Background estimation