



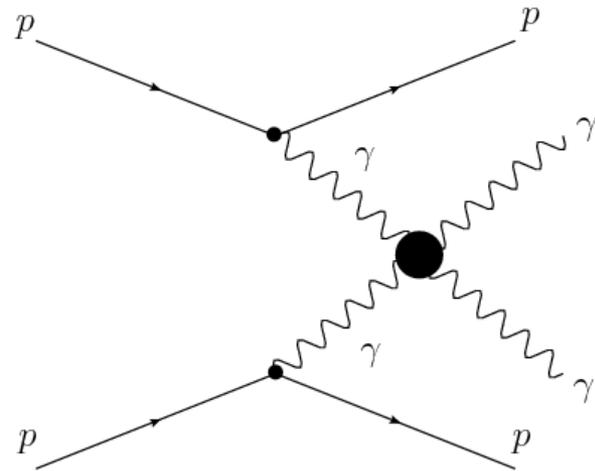
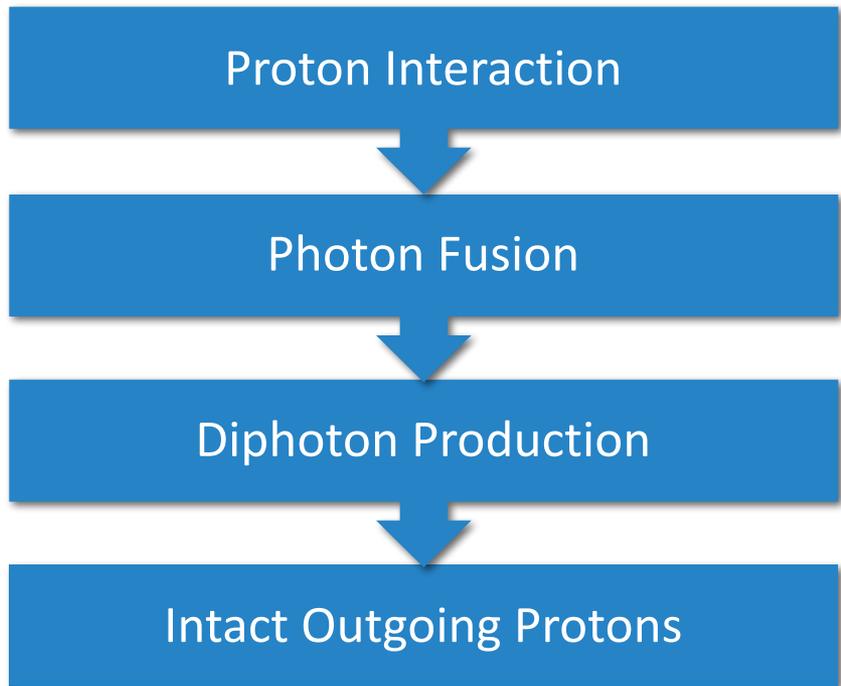
Anomalous Quartic 4γ Couplings

JUSTIN WILLIAMS

SEPTEMBER 28, 2016



Search For Quartic Anomalous Couplings

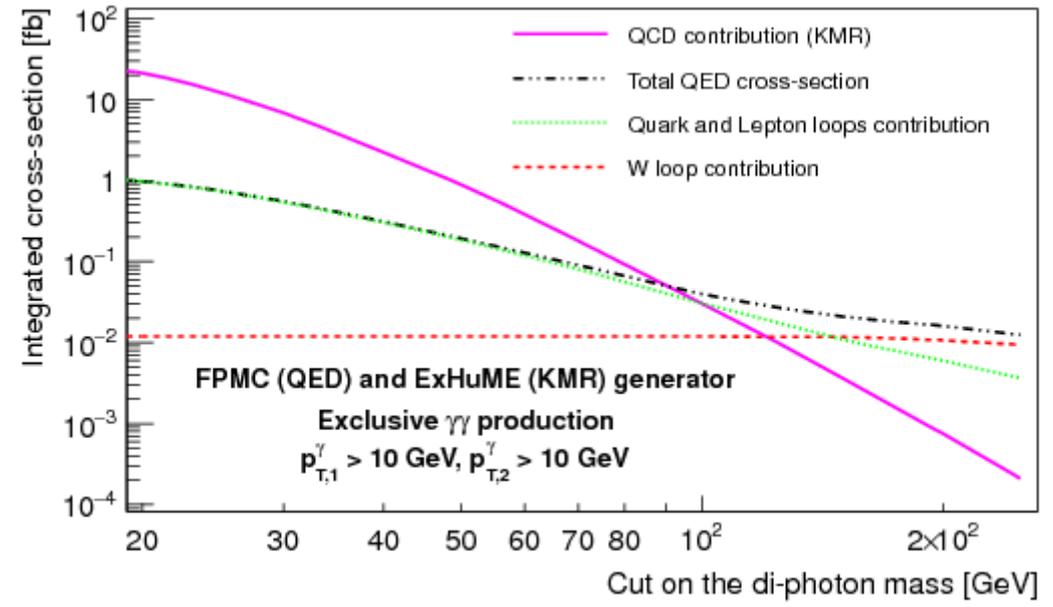
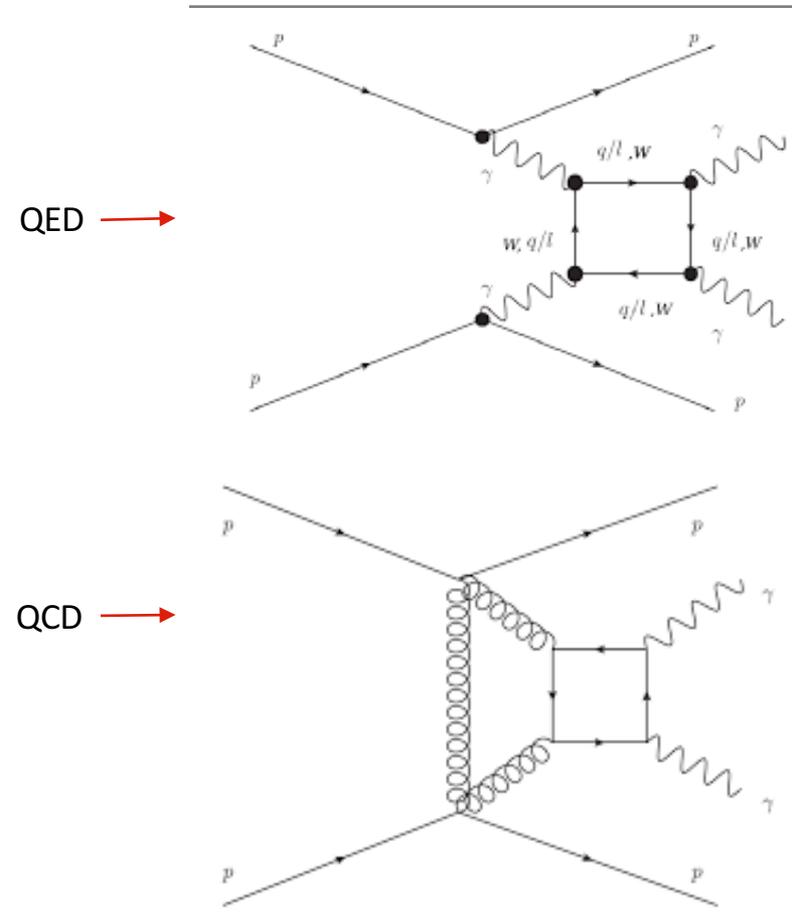




Why is this significant?

- BSM Physics
- Couplings predicted by theories ($\zeta_i \sim 10^{-14} - 10^{-13} \text{ GeV}^{-4}$) ¹
- Couplings can be probed independent of models
- Example: Polarizable Dark Particles

QED vs QCD Contributions



arXiv:1606.07675v1



FPMC Signal With Background

- Analysis at hadron level including:

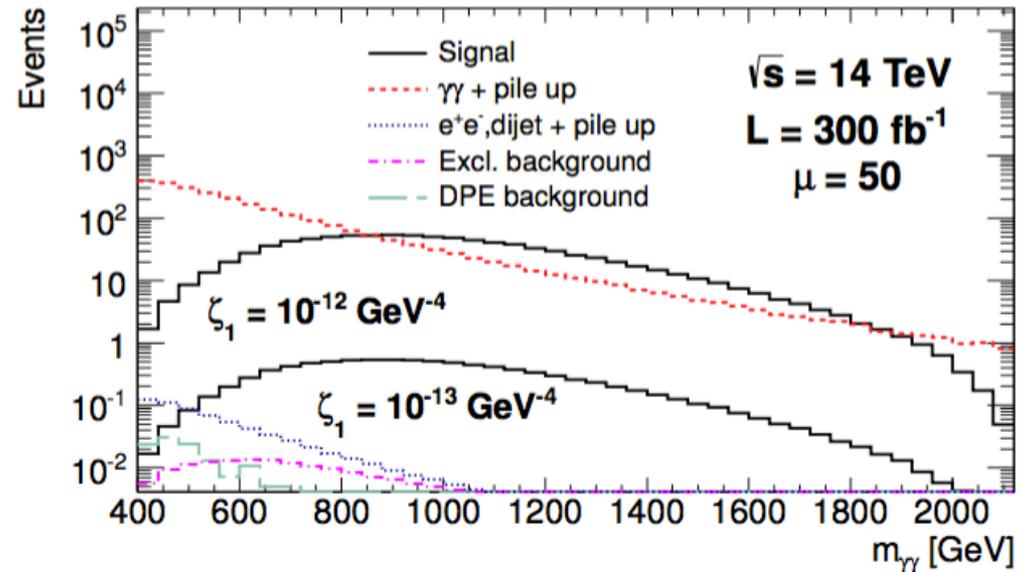
- Detector efficiencies
- Resolution effects
- Pile up

- Requesting:

- 2 protons in forward detectors
- $p_{T_{1,(2)}} > 200, (100)$ GeV
- At least 1 converted proton in the central detector

- Roman Pot Proton Acceptance²

- $\xi > \sim 0.015$

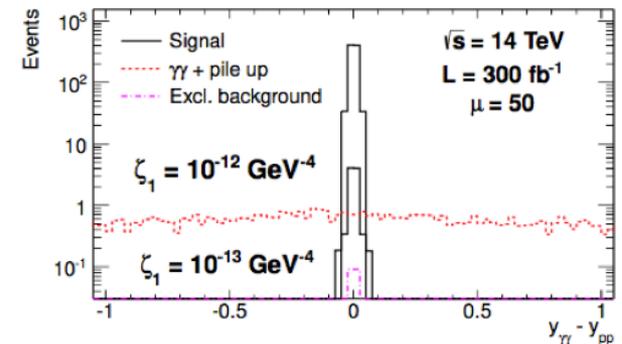
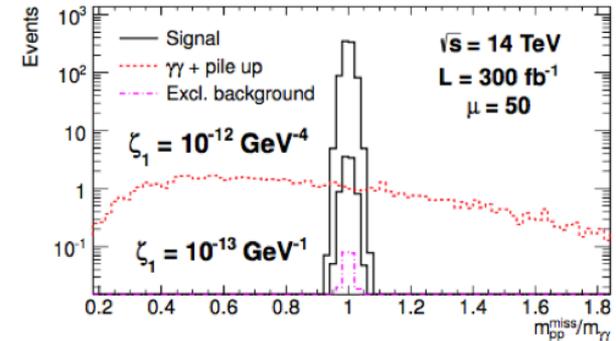


arXiv:1606.07675v1



Mass and Rapidity

- Mass and Rapidity matching
- Background is flat lined
- Cuts
 - 2 high pT photons ($p_{T1} > 200$ GeV, $p_{T2} > 100$ GeV)
 - $m_{\gamma\gamma} > 600$ GeV



arXiv:1606.07675v1

Dealing With Pile Up (PU) Events

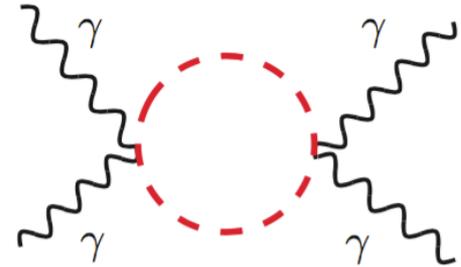
Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15,$ $p_{T1,(2)} > 200, (100) \text{ GeV}]$	65	18 (187)	0.13	0.2	1.6	2968
$m_{\gamma\gamma} > 600 \text{ GeV}$	64	17 (186)	0.10	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95,$ $ \Delta\phi > \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
$ y_{\gamma\gamma} - y_{pp} < 0.03$	60	12 (169)	0.09	0	0	0

No background \rightarrow 5 events = 5σ



Example Application: Polarizable Dark Particles

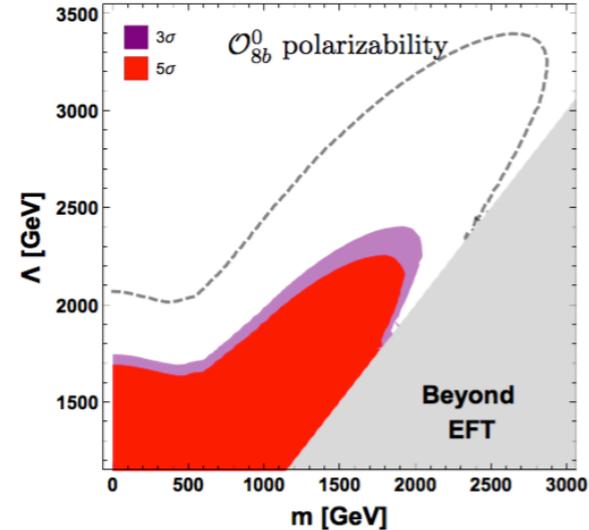
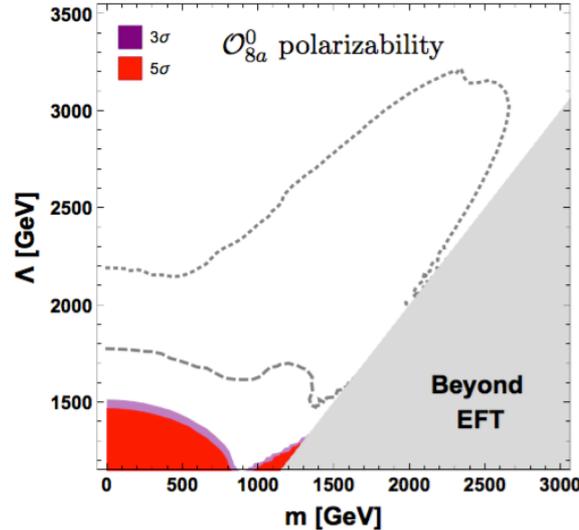
- Paper published Sep. 6 2016
- Polarizable dark particles automatically induce loops with four external photon legs³
- Propose to use this anomalous coupling to search for dark matter candidates





Energy Plots

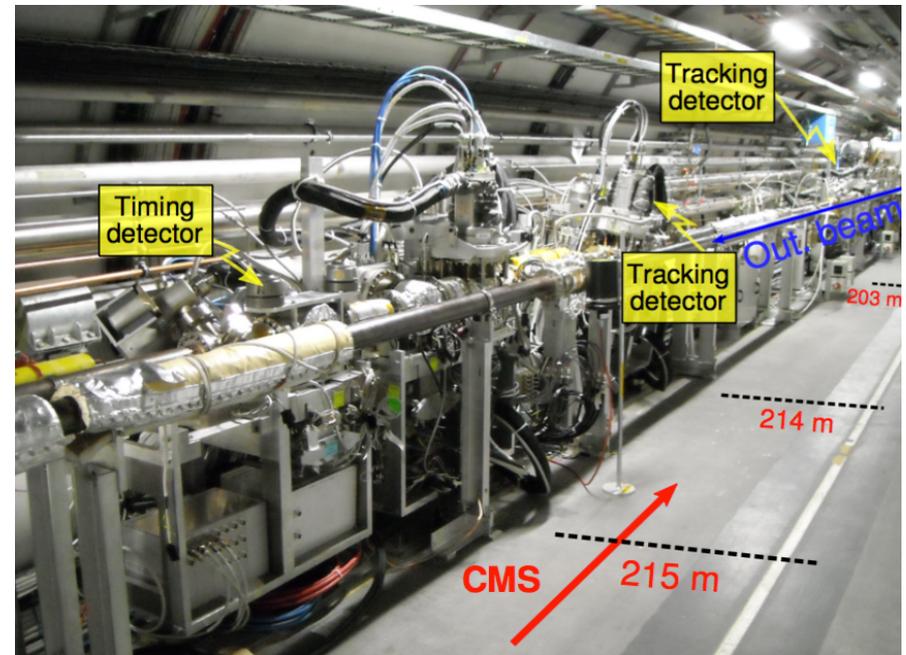
- Sensitivity of the exclusive diphoton channel to a spin-0 dark particle with dimension-8 polarizability
- The dashed lines correspond to the 5σ sensitivity in presence of 5 events of the dark particle
- Possibility of a dark particle being detected at a 5σ significance³



3. Fichet, S. Shining Light on Polarizable Dark Particles. arXiv:1609.01762 [hep-ph] (2016).

CT-PPS

- Intact protons
- Fast timing detector - Proton time of flight
 - Check if compatible with vertex to avoid PU
- Currently running analysis





Summary

- Cross section is well known
- High diphoton mass \rightarrow Photon induced processes
- Background free experiment
- Many applications
- Future: Studies with heavy ions for SM production



Backup Slides



Extra Dimensions

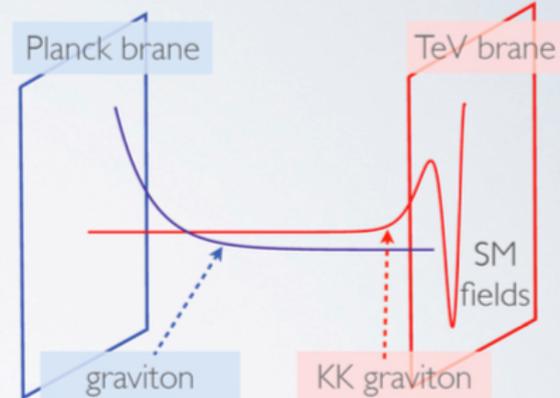
- ✗ Warped Extra Dimensions solve hierarchy problem of SM
- ✗ 5th dimension bounded by two branes
- ✗ SM on the visible (or TeV) brane

- ✗ The Kaluza Klein modes of the graviton couple with TeV strength

$$\mathcal{L}^{\gamma\gamma h} = f^{-2} h_{\mu\nu}^{\text{KK}} \left(\frac{1}{4} \eta_{\mu\nu} F_{\rho\lambda}^2 - F_{\mu\rho} F_{\rho\nu} \right)$$

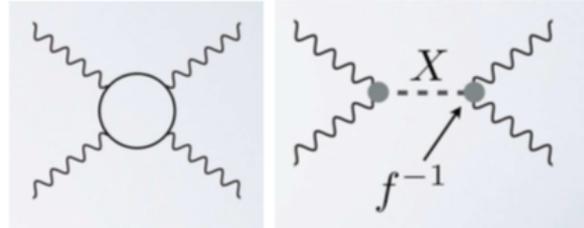
$$f \sim \text{TeV} \quad m_{\text{KK}} \sim \text{few TeV}$$

- ✗ Effective 4-photon couplings $\zeta_i \sim 10^{-14} - 10^{-13} \text{ GeV}^{-2}$ possible
- ✗ The radion can produce similar effective couplings





Motivations to look for quartic $\gamma\gamma$ anomalous couplings



- Two effective operators at low energies

$$\mathcal{L}_{4\gamma} = \zeta_1^\gamma F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2^\gamma F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

- $\gamma\gamma\gamma\gamma$ couplings can be modified in a model independent way by loops of heavy charge particles

$$\zeta_1 = \alpha_{em}^2 Q^4 m^{-4} N c_{1,s}$$

where the coupling depends only on $Q^4 m^{-4}$ (charge and mass of the charged particle) and on spin, $c_{1,s}$ depends on the spin of the particle
This leads to ζ_1 of the order of 10^{-14} - 10^{-13}

- ζ_1 can also be modified by neutral particles at tree level (extensions of the SM including scalar, pseudo-scalar, and spin-2 resonances that couple to the photon) $\zeta_1 = (f_s m)^{-2} d_{1,s}$ where f_s is the $\gamma\gamma X$ coupling of the new particle to the photon, and $d_{1,s}$ depends on the spin of the particle; for instance, 2 TeV dilatons lead to $\zeta_1 \sim 10^{-13}$



Luminosity	300 fb^{-1}	300 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
pile-up (μ)	50	50	50	200
coupling (GeV^{-4})	$\geq 1 \text{ conv. } \gamma$ 5σ	$\geq 1 \text{ conv. } \gamma$ 95% CL	all γ 95% CL	all γ 95% CL
ζ_1 f.f.	$1 \cdot 10^{-13}$	$9 \cdot 10^{-14}$	$5 \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$
ζ_1 no f.f.	$3.5 \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$	$7 \cdot 10^{-15}$
ζ_2 f.f.	$2.5 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$1 \cdot 10^{-13}$	$4.5 \cdot 10^{-14}$
ζ_2 no f.f.	$7.5 \cdot 10^{-14}$	$5.5 \cdot 10^{-14}$	$3 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$

Operators

Spin 0			
Operator	$\phi^2(F)^2$	$\partial^\mu \phi \partial^\nu \phi (F.F)^{\mu\nu}$	$(\partial^\mu \phi)^2 (F)^2$
Dimension	6	8	8
Name	\mathcal{O}_{6a}^0	\mathcal{O}_{8a}^0	\mathcal{O}_{8b}^0

Spin 1/2			
Op.	$\bar{\Psi} \Psi (F)^2$	$i \bar{\Psi} \gamma_\mu \partial^\nu \Psi (F.F)^{\mu\nu}$	$i \bar{\Psi} \gamma_\mu \partial^\mu \Psi (F)^2$
Dim.	7	8	8
Name	$\mathcal{O}_{7a}^{1/2}$	$\mathcal{O}_{8a}^{1/2}$	$\mathcal{O}_{8b}^{1/2}$
	$i \bar{\Psi} \gamma_5 \Psi (F \tilde{F})$	$\bar{\Psi} \gamma_5 \gamma_\mu \partial^\nu \Psi (F \tilde{F})^{\mu\nu}$	$\bar{\Psi} \gamma_5 \gamma_\mu \partial^\mu \Psi (F \tilde{F})$
	7	8	8
	$\mathcal{O}_{7b}^{1/2}$	$\mathcal{O}_{8c}^{1/2}$	$\mathcal{O}_{8d}^{1/2}$

Spin 1					
Op.	$(X_\mu)^2 (F)^2$	$X_\mu X_\nu (F.F)^{\mu\nu}$	$(X.X)^{\mu\nu} (F.F)^{\mu\nu}$	$(X)^2 (F)^2$	$(X.F)^{\mu\nu} (X.F)^{\mu\nu}$
Dim.	6	6	8	8	8
Name	\mathcal{O}_{6a}^1	\mathcal{O}_{6b}^1	\mathcal{O}_{8a}^1	\mathcal{O}_{8b}^1	\mathcal{O}_{8c}^1