Search for a di-photon resonance using CT-PPS: Introduction

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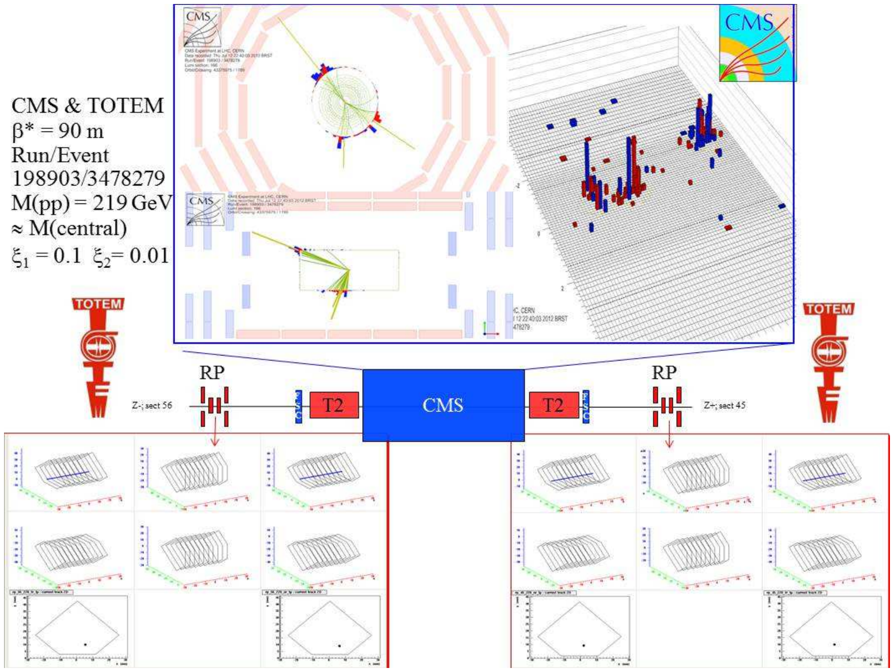
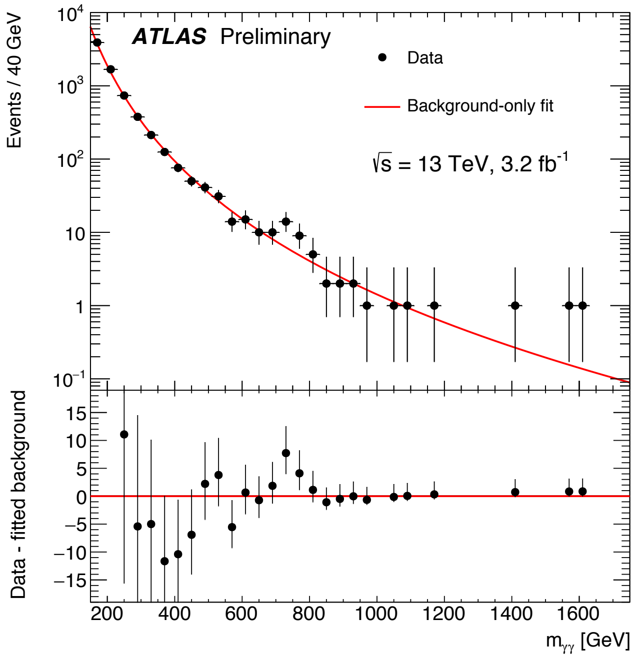
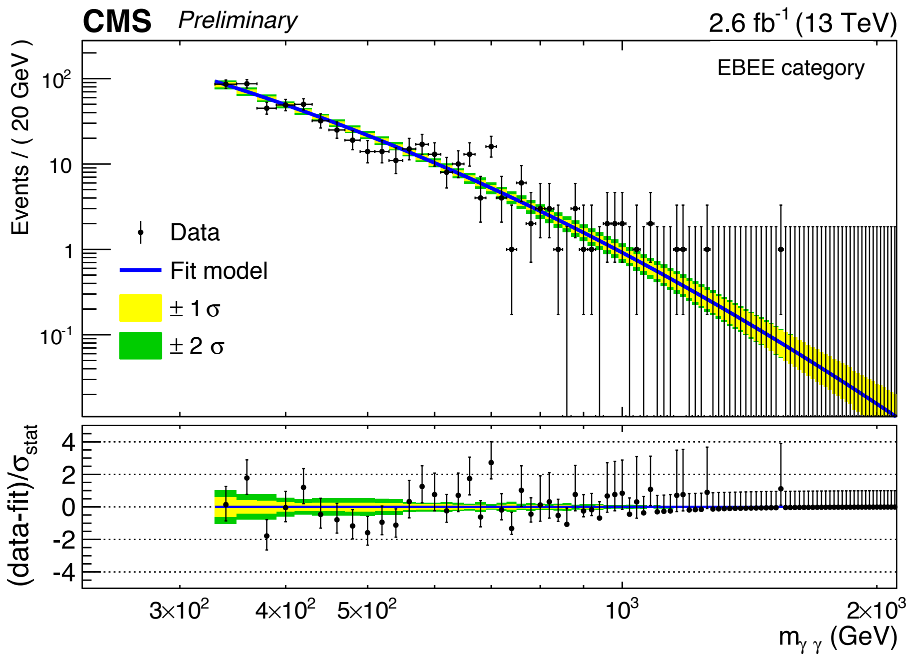


- Selection of γ-induced processes
- Analysis flow
- Existence of a new particle?

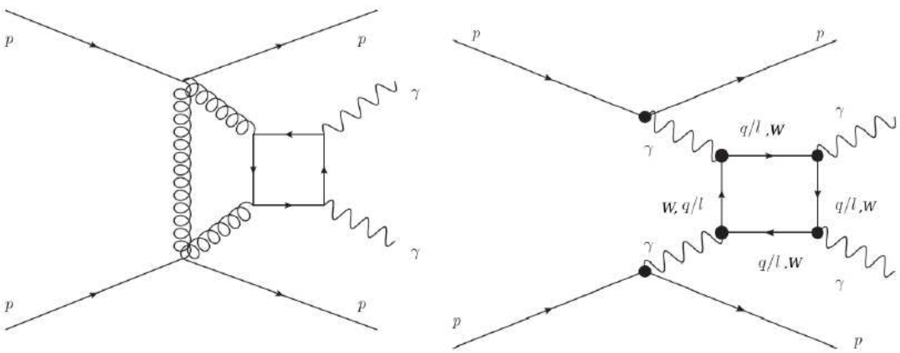
CMS and ATLAS observation

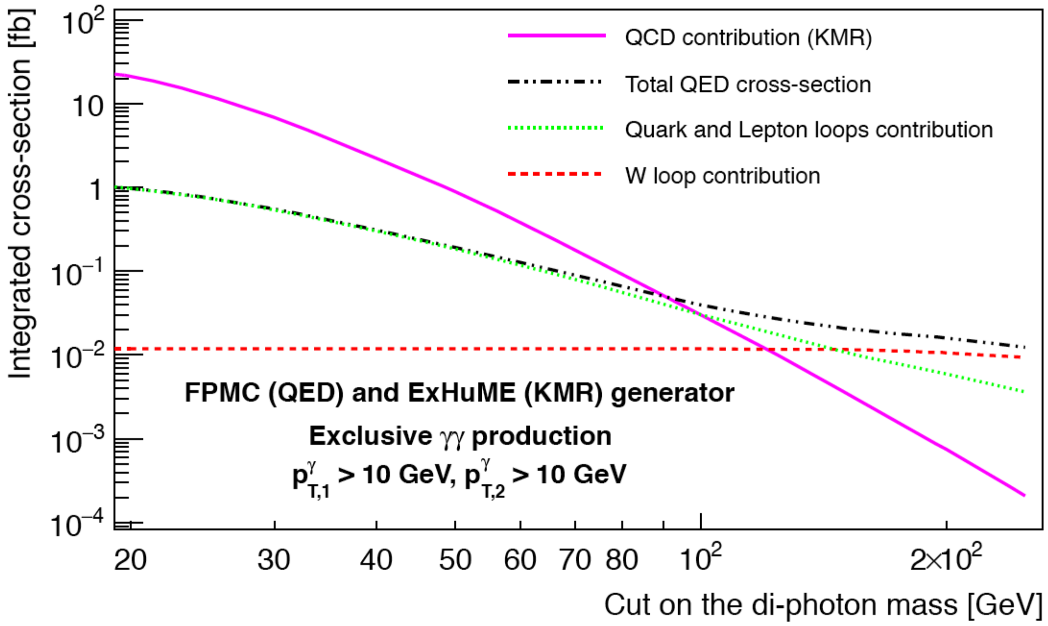




- Potential excess observed by ATLAS and CMS in the diphoton spectrum at 13 TeV
- Can CT-PPS give additional information about this excess if confirmed with more data?
- Specificities of CT-PPS with respect to standard CMS/ATLAS standard searches without tagging the protons
- Do we have a natural explanation for such an excess if confirmed? Many publications on ArXiv...

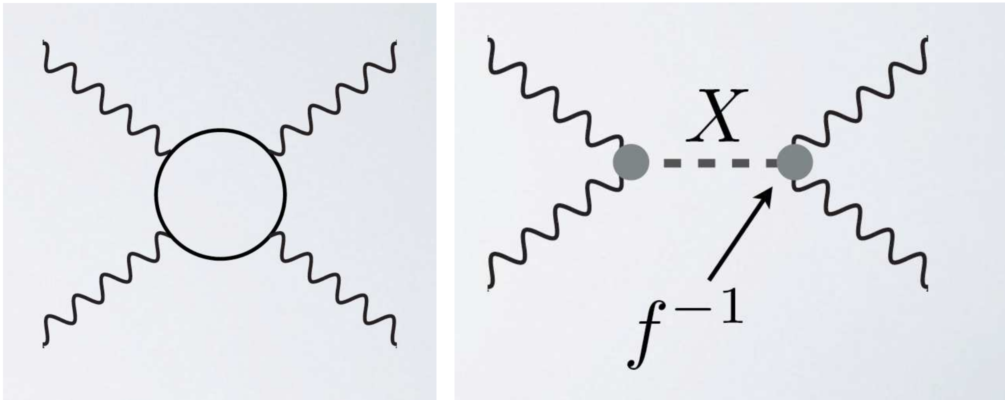
SM $\gamma\gamma$ exclusive production





- QCD production dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$
- Important to consider W loops at high $m_{\gamma\gamma}$
- At high masses (~ 750 GeV), the photon induced processes are dominant

Looking 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

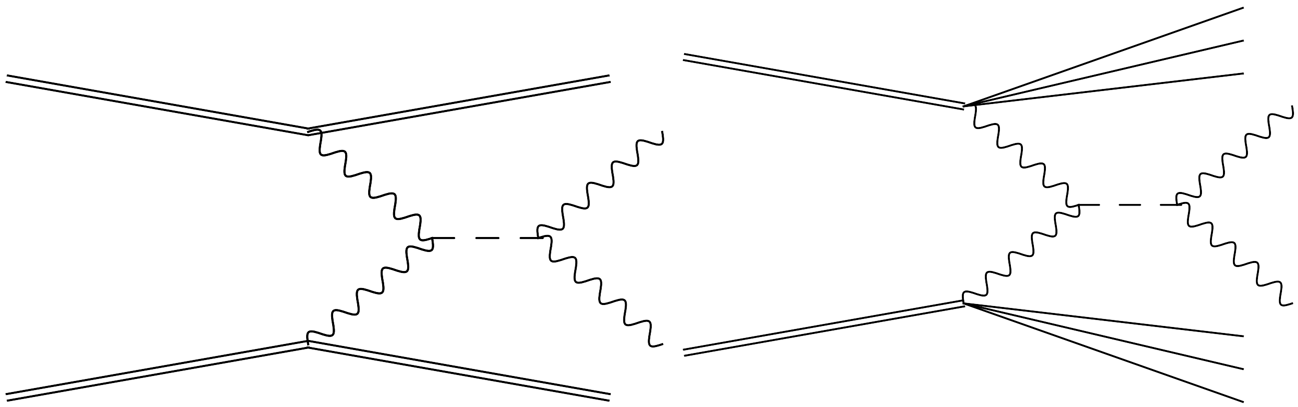
$$\zeta_1 = \alpha_{em}^2 Q^4 m^{-4} N c_{1,s}$$

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 $\zeta_1 \sim 10^{-13}$

Possible explanation of the di-photon excess

- S. Fichet, G von Gersdorff, C. Royon, http://arxiv.org/pdf/1512.05751.pdf
- The ATLAS and CMS collaborations measured the sum of the elastic and inelastic contributions



- Two important points:
  - We can select photon-induced processes in a background free mode by tagging the protons in CT-PPS: model independent
  - We can try to interprete present results in terms of the existence of a new particle
- Let us explore the possibility of a spin 0/ spin 2 resonance

Possible explanation of the di-photon excess

- The explanation must explain two experimental facts: The excess was not observed at 8 TeV, and is also not seen in dijets at 13 TeV with the limited statistics
- If processes are gluon-induced, we would expect the dijet cross section to be of the order of 1 pb (the ratio of partial widths is $\Gamma_{gg}/\Gamma_{\gamma\gamma} = \alpha_S^2/\alpha^2 \sim 200$) $\rightarrow$ natural to consider γ-exchange processes
- When protons are not tagged (the present case), one is dominated by inelastic events (inelastic production of diphotons via photon fusion): the ratio between the total (inelastic, inelastic-elastic, elastic) and the elastic contribution is about a factor 20

$$\sigma_{pp\to\gamma\gamma X} = (7.3\ \mathrm{fb}) \left(\frac{5\ \mathrm{TeV}}{f_\gamma}\right)^4 \left(\frac{45\ \mathrm{GeV}}{\Gamma_{\mathrm{tot}}}\right) \left(\frac{r_{\mathrm{inel}}}{20}\right) r_{\mathrm{fs}}$$

- Why do not we observe anything at 8 TeV? This is due to the probability to emit a quasi-real photon. The ξ of the photon has to be much higher at 8 TeV than at 13 TeV and the production is much suppressed (factor estimated to be between 2.4 and 3.9).
- We follow the same strategy as the search for quartic anomalous couplings: same final state
- The resonance production matrix element has been fully implemented in FPMC

A cleaner measurement: $\gamma\gamma$ exclusive production

- The idea is now to consider elastic production:
  - The theoretical calculation is in better control (QED processes with intact protons), not sensitive to the photon structure function
  - This is a "background-free" experiment (see following slides) and any observed event is signal
  - The survival probablity is in better control than in the QCD (gluon) case
  - This is complementary to the search in the jet channel (see following slides)
- Using FPMC and the "resonance" production parameters:

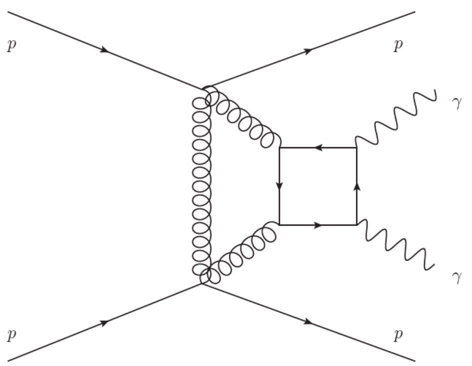
$$\sigma_{pp\to\gamma\gamma pp} = (0.23 \text{ fb}) \left(\frac{5 \text{ TeV}}{f_\gamma}\right)^4 \left(\frac{45 \text{ GeV}}{\Gamma_{\text{tot}}}\right) r_{fs}$$

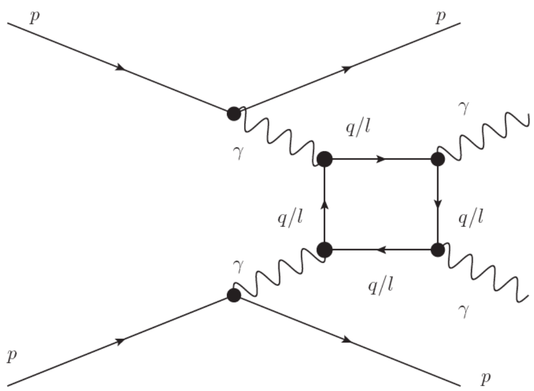
with $f_\gamma \sim 4.6 TeV$

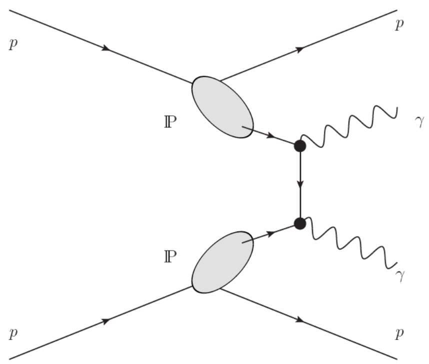
- Since we do not have background in this channel, observing 6 events is a 5 σ discovery: 21 fb^{-1} is needed to reach this number of events

Search for resonance/$\gamma\gamma\gamma\gamma$ anomalous couplings: Analysis flow

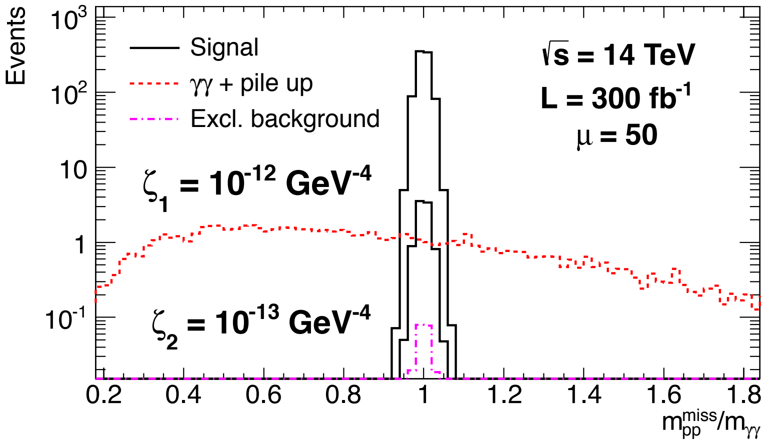
- Studies performed at hadron level but taking into account the main detector/pile-up effects
- By default, $> 1\gamma$ converted is requested (1 mm resolution), but all γ are also considered
- pile-up simulated in AFP/CT-PPS: 50, 100, 200...
- Main detector effects are included (from ATLAS ECFA studies ATL-PHYS-PUB-2013-009), for instance:
  - Photon conversion probability: 15% in barrel, 30% in the end-caps; γ rapidity, Φ, and p_T resolutions taken into account as well as the reconstruction efficiency
  - Misidentification of electron as a γ: 1%
  - Misidentification of jet as a γ: 1/4000,
- All backgrounds were considered: DPE diphoton production, Higgs decaying into photons, exclusive production of diphtoon, dilepton, dijet with lepton/jet misidentified, pile up (ND production of Drell-Yan, dijet, diphoton...)

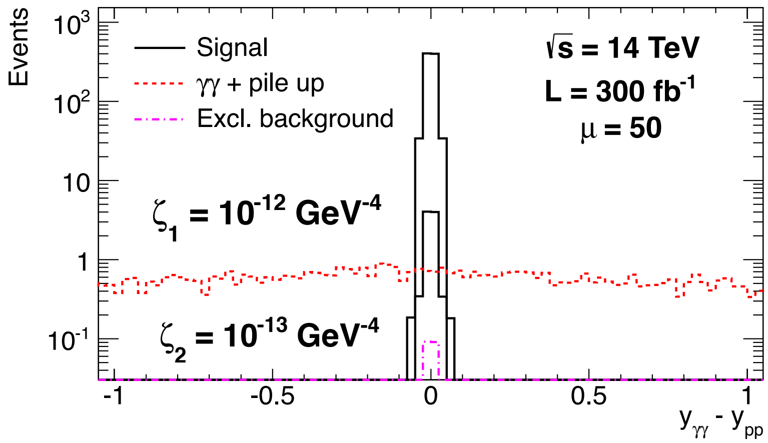






Search for resonance/ quartic $\gamma\gamma$ anomalous couplings





Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15$, $p_{T1,(2)} > 200, (100)$ GeV]	130.8	36.9 (373.9)	0.25	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	128.3	34.9 (371.6)	0.20	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95$, $\|\Delta\phi\| > \pi - 0.01]$	128.3	34.9 (371.4)	0.19	0	0	80.2
$\sqrt{\xi_1\xi_2 s} = m_{\gamma\gamma} \pm 3\%$	122.0	32.9 (350.2)	0.18	0	0	2.8
$\|y_{\gamma\gamma} - y_{pp}\| < 0.03$	119.1	31.8 (338.5)	0.18	0	0	0

- No background after cuts for 300 fb^{-1} **without needing timing detector information**
- Exclusivity cuts using proton tagging needed to suppress backgrounds (Without exclusivity cuts using CT-PPS: background of 80.2 for 300 fb^{-1})

Consequences for CT-PPS analyses and conclusion

- Looking for di-photon production via photon fusion is an ideal case for CT-PPS: this is $\sim$ background free after exclusivity cuts, we can be sure that they are photon induced processes
- Even if the model discussed above (if the "resonance" is real) is not true, many other models predict a non-zero contribution of photon-induced processes that can be probed using CT-PPS in a clean way
- S. Fichet, G. von Gersdorff, C. Royon, http://arxiv.org/pdf/1601.01712.pdf
- CT-PPS allows to probe diphoton production in a model independent way knowing that any observation is a potential signal
- CT-PPS has the possibility the test γ-induced processes in background free experiments:
  - Fundamental if the resonance is photon-induced
  - if this is not compeltely the case, measure brqanching ratio
- If one believes the ATLAS/CMS observation, 20-25 fb^{-1} of data might be enough for a 5 σ discovery in CT-PPS
- We are also going to look into other channels: WW, ZZ, $Z\gamma$ (specially interesting)
- See talks by Gero/Valery

High lumi: Search for quartic $\gamma\gamma$ anomalous couplings: Results from effective theory

Luminosity	300 fb^{-1}	300 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
pile-up (μ)	50	50	50	200
coupling (GeV^{-4})	≥ 1 conv. γ 5 σ	≥ 1 conv. γ 95% CL	all γ 95% CL	all γ 95% CL
ζ_1 f.f.	$8 \cdot 10^{-14}$	$5 \cdot 10^{-14}$	$3 \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$
ζ_1 no f.f.	$2.5 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$	$9 \cdot 10^{-15}$	$7 \cdot 10^{-15}$
ζ_2 f.f.	$2. \cdot 10^{-13}$	$1. \cdot 10^{-13}$	$6 \cdot 10^{-14}$	$4.5 \cdot 10^{-14}$
ζ_2 no f.f.	$5 \cdot 10^{-14}$	$4 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$

- Unprecedented sensitivities at hadronic colliders: no limit exists presently on $\gamma\gamma\gamma\gamma$ anomalous couplings
- Reaches the values predicted by extra-dim or composite Higgs models
- Pile up background rejected using exclusivity cuts: timing detectors not used in this analysis
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a \to \frac{a}{(1+W_{\gamma\gamma}/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics

Full amplitude calculation

- Effective field theory valid if $S << 4m^2$, S smaller than the threshold production of real particles
- Since the maximum proton missing mass is $\sim$ 2 TeV at the 14 TeV LHC, the effective theory needs to be corrected for masses of particles below $\sim$ 1 TeV $\rightarrow$ use of form factor which creates an uncertainty on the results (depends on the exact value of form factors)
- Solution: compute the full momentum dependence of the 4 photon amplitudes: computed for fermions and bosons
- Full amplitude calculation for generic heavy charged fermion/vector contribution
- Existence of new heavy charged particles enhances the $\gamma\gamma\gamma\gamma$ couplings in a model independant way
- Enhancement parametrised with particle mass and effective charge $Q_{eff} = QN^{1/4}$ where N is the multiplicity

Search for quartic $\gamma\gamma$ anomalous couplings: Results from full theory

Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15,$ $p_{T1,(2)} > 200, (100)$ GeV]	130.8	36.9 (373.9)	0.25	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	128.3	34.9 (371.6)	0.20	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95,$ $\lvert\Delta\phi\rvert > \pi - 0.01]$	128.3	34.9 (371.4)	0.19	0	0	80.2
$\sqrt{\xi_1 \xi_2 s} = m_{\gamma\gamma} \pm 3\%$	122.0	32.9 (350.2)	0.18	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	119.1	31.8 (338.5)	0.18	0	0	0

- No background after cuts for 300 fb^{-1} **without needing timing detector information**
- For signal: 119.1 events for $Q_{eff} = 4$, $m =$340 GeV
- Results for full calculation lay between the effective field result with/without form factor as expected since effective calculation not valid in the region of $S \sim m^2$

Full amplitude calculation

- 5 σ discovery sensitivity on the effective charge of new charged fermions and vector boson for various mass scenarii for 300 fb^{-1} and $\mu = 50$

Mass (GeV)	300	600	900	1200	1500
Q_{eff} (vector)	2.2	3.4	4.9	7.2	8.9
Q_{eff} (fermion)	3.6	5.7	8.6	-	-

- Unprecedented sensitivites at hadronic colliders reaching the values predicted by extra-dim models - For reference, we also display the result of effective field theory (without form factor) which deviates at low masses from the full calculation
- For $Q_{Jeff} = 4$, we are sensitive to new vectors (fermions) up to 700 (370) GeV for a luminosity of 300 fb^{-1}