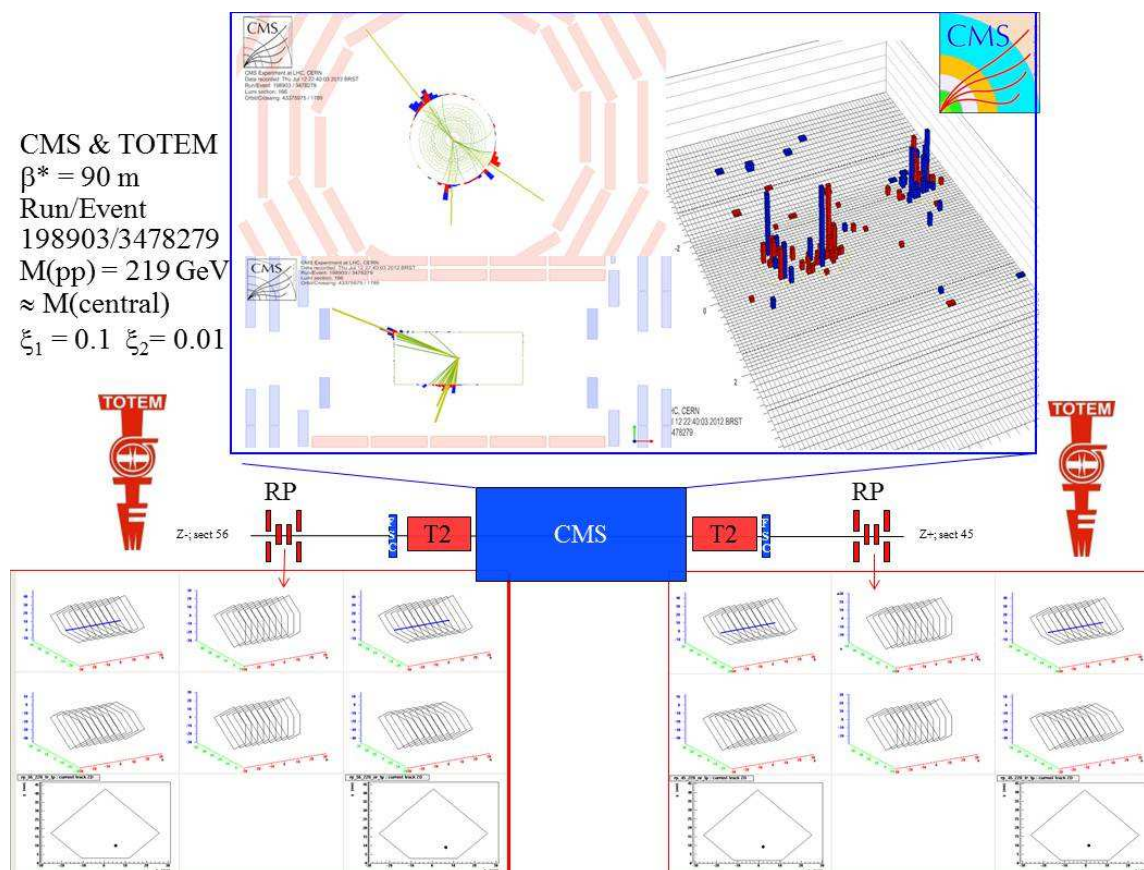# Forward physics with proton tagging at the LHC and the 750 GeV di-photon resonance

Christophe Royon
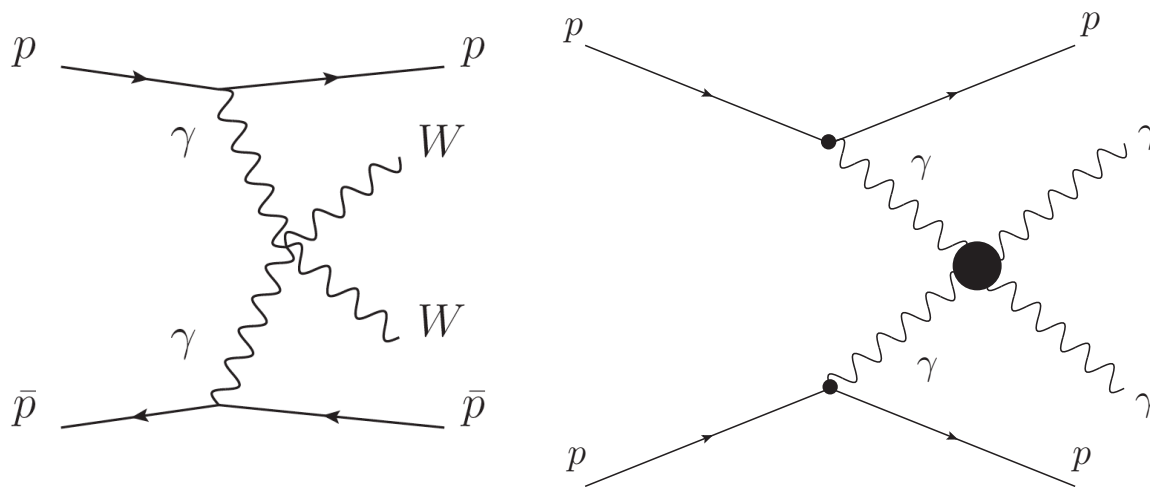University of Kansas, Lawrence, USA

Low x Meeting, June 6- 11 2016, Gyongyos, Hungary

- Anomalous $\gamma\gamma\gamma\gamma$ quartic coupling
- The potential 750 GeV resonance (ATLAS/CMS)
- Photon induced processses

Search for $\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous coupling

- Study of the process: $pp \to ppWW$, $pp \to ppZZ$, $pp \to pp\gamma\gamma$

- Standard Model: $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W = M_X > 1 TeV) = 5.9$ fb

- Process sensitive to anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$; motivated by studying in detail the mechanism of electroweak symmetry breaking, predicted by extradim. models

- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003; S.Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert, Phys.Rev. D89 (2014) 114004 ; S.Fichet, G. von Gersdorff, B. Lenzi, C. Royon, M. Saimpert, ArXiv:1411.6629; J. de Favereau et al., arXiv:0908.2020.

- Conentrate here on $\gamma\gamma\gamma\gamma$ anomalous coupling: For $\gamma\gamma WW$, $\gamma\gamma ZZ$, gain of two orders of magnitude with respect to present CMS limits

Motivations to look for quartic $\gamma\gamma$ anomalous couplings
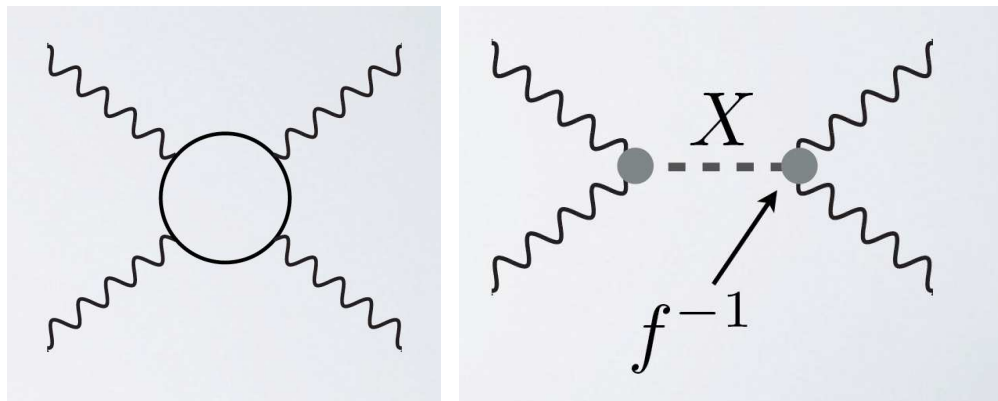
- Two effective operators at low energies

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

- $\gamma\gamma\gamma\gamma$ 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 $\zeta_1 \sim 10^{-13}$
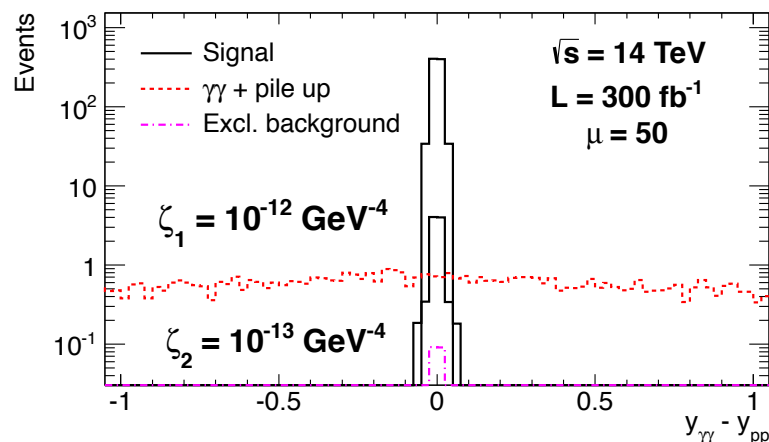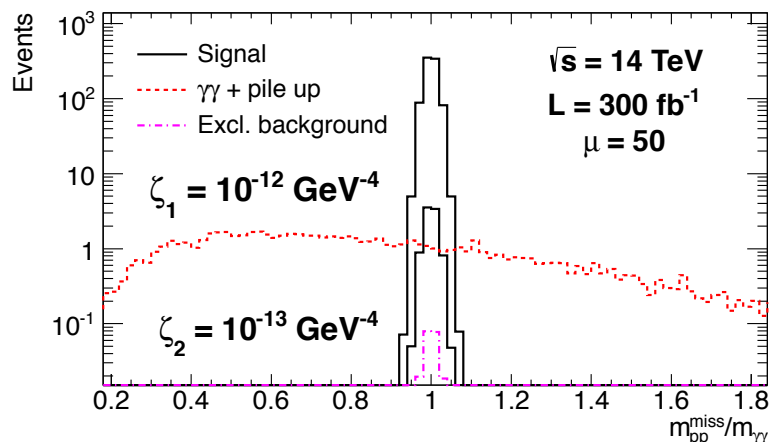
Search for quartic $\gamma\gamma$ anomalous couplings
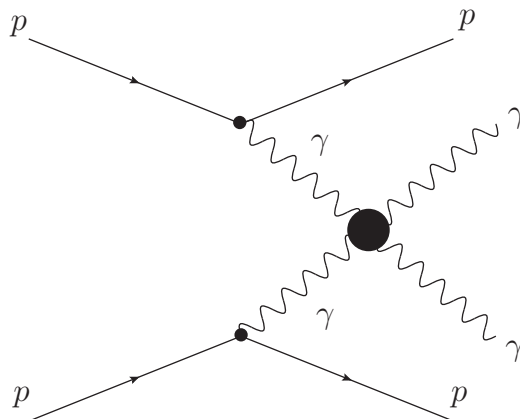
- Search for $\gamma\gamma\gamma\gamma$ quartic anomalous couplings
- Couplings predicted by extra-dim, composite Higgs models
- Analysis performed at hadron level including detector efficiencies, resolution effects, pile-up...
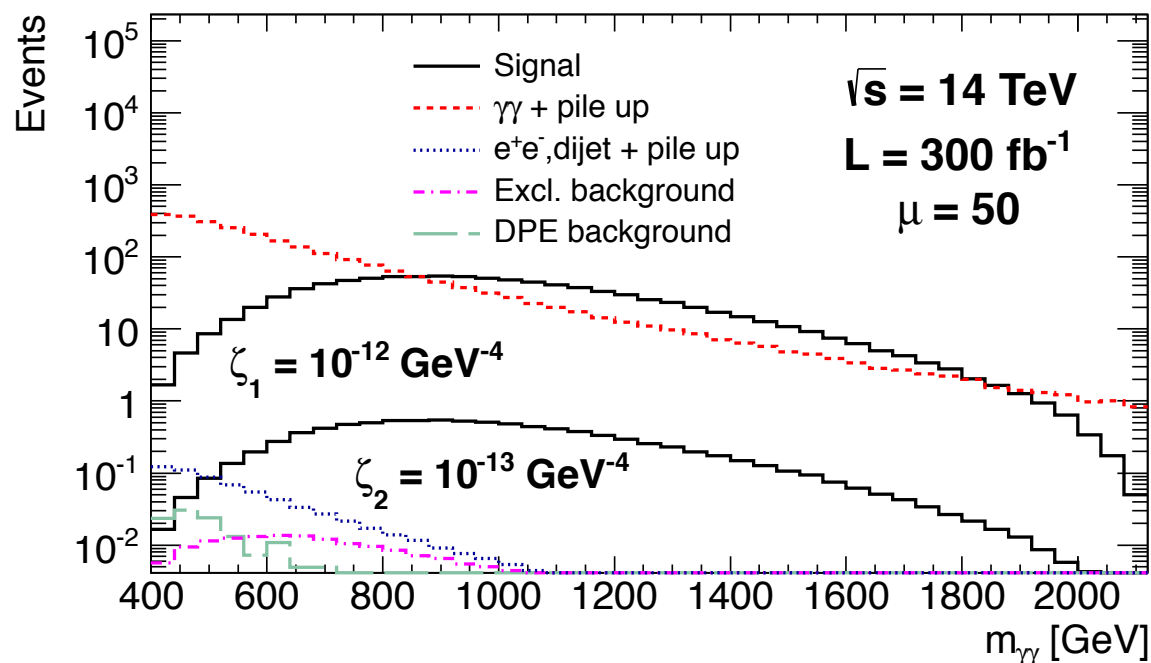
Search for quartic $\gamma\gamma$ anomalous couplings

Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15,$ $p_{T1,(2)} > 200, (100) \text{ GeV}]$	130.8	36.9 (373.9)	0.25	0.2	1.6	2968
$m_{\gamma\gamma} > 600 \text{ GeV}$	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})

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 $5\,\sigma$	≥ 1 conv. γ 95% CL	all γ 95% CL	all γ 95% CL
ζ_1 f.f. ζ_1 no f.f.	$8 \cdot 10^{-14}$ $2.5 \cdot 10^{-14}$	$5 \cdot 10^{-14}$ $1.5 \cdot 10^{-14}$	$3 \cdot 10^{-14}$ $9 \cdot 10^{-15}$	$2.5 \cdot 10^{-14}$ $7 \cdot 10^{-15}$
ζ_2 f.f. ζ_2 no f.f.	$2. \cdot 10^{-13}$ $5 \cdot 10^{-14}$	$1. \cdot 10^{-13}$ $4 \cdot 10^{-14}$	$6 \cdot 10^{-14}$ $2 \cdot 10^{-14}$	$4.5 \cdot 10^{-14}$ $1.5 \cdot 10^{-14}$

- **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 leads to similar results: avoids using a form factor and parameters dependence of the results

CMS and ATLAS observation
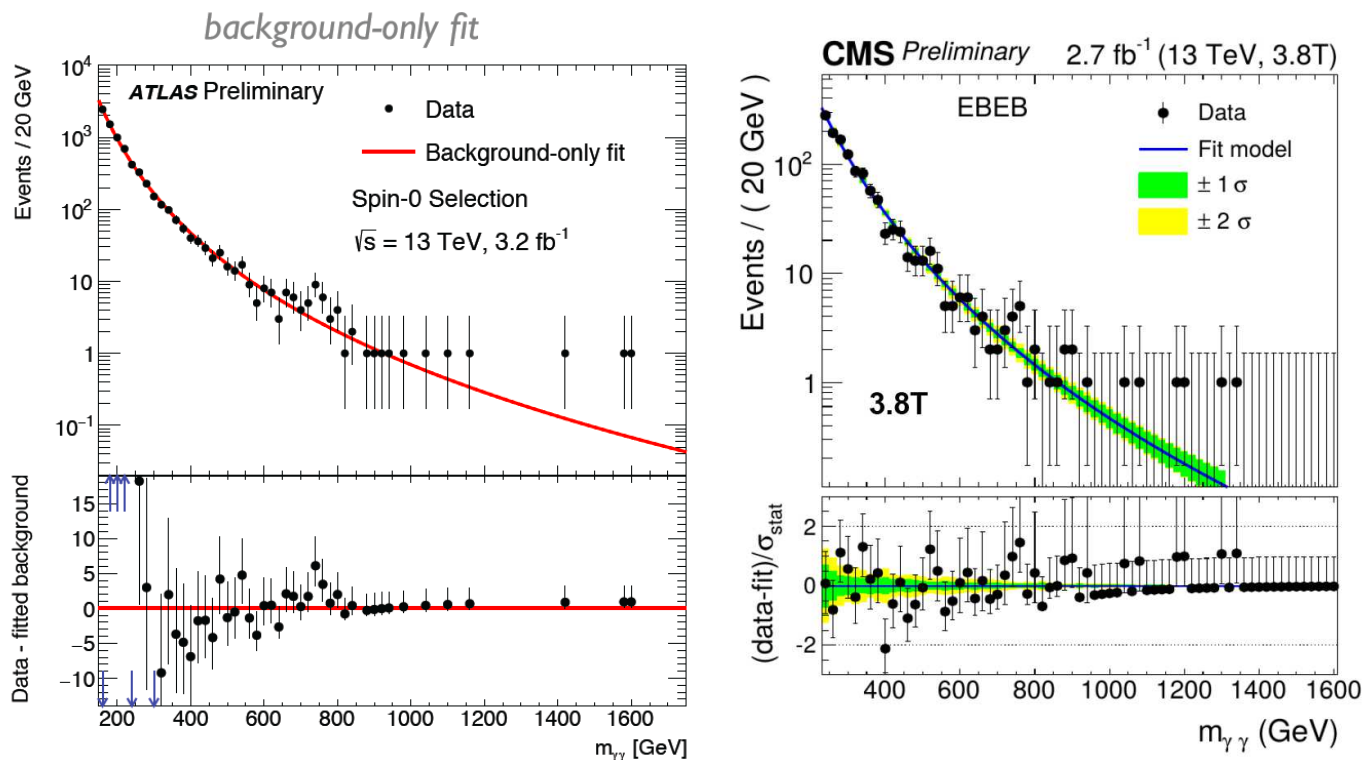
- Potential excess observed by ATLAS and CMS in the diphoton spectrum at 13 TeV

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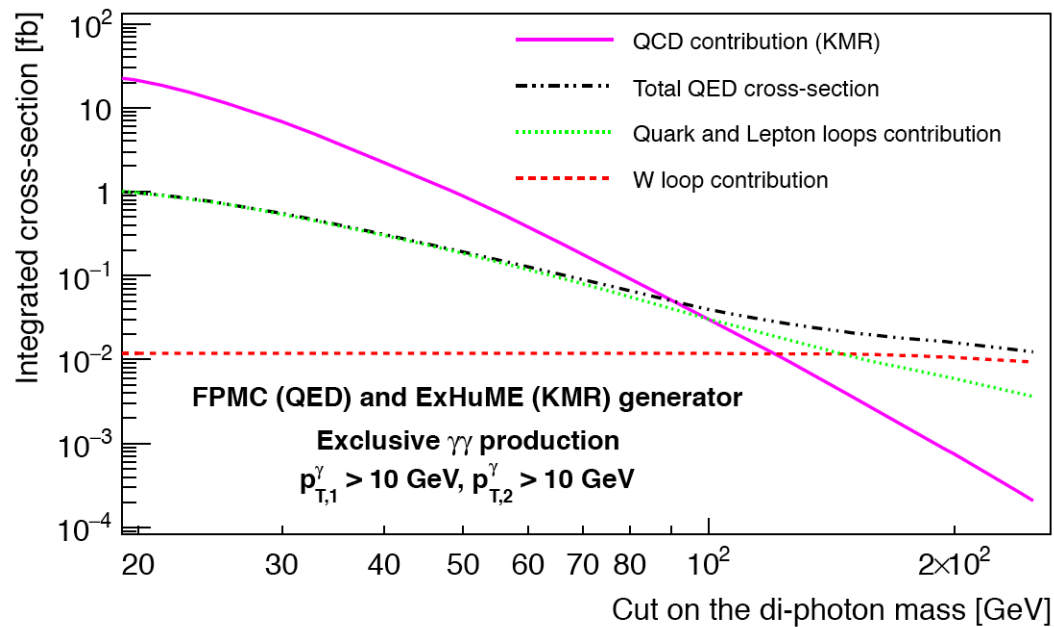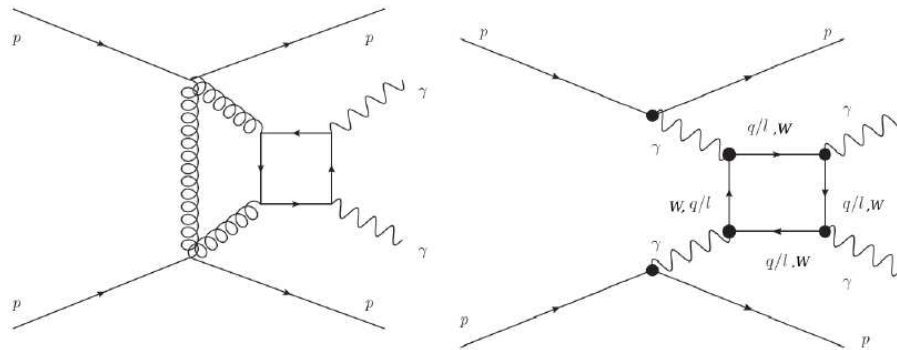
- QCD production dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$
- Important to consider W loops at high $m_{\gamma\gamma}$
- At high masses (~ 750 GeV), the photon induced processes are dominant

Possible explanation of the di-photon excess

- S. Fichet, G von Gersdorff, C. Royon, http://arxiv.org/pdf/1512.05751.pdf, Phys.Rev. D93 (2016) no.7, 075031

- The ATLAS and CMS collaborations measured the sum of the elastic and inelastic contributions
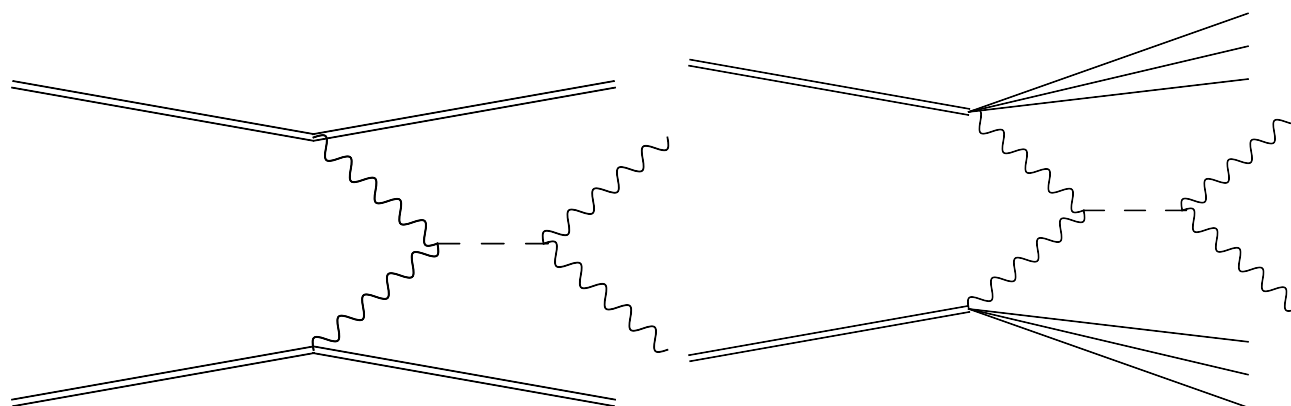
- Two important points:
  - We can select photon-induced processes in a background free mode by tagging the protons in CT-PPS: model independent
  - We can try to interprete present results in terms of the existence of a new particle

- 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

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

- 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). (see talks by Valery/Lucian)

- 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, so $\sim$40 fb^{-1} taking into account efficiencies...

Complementarity between gluon gluon and $\gamma\gamma$ production
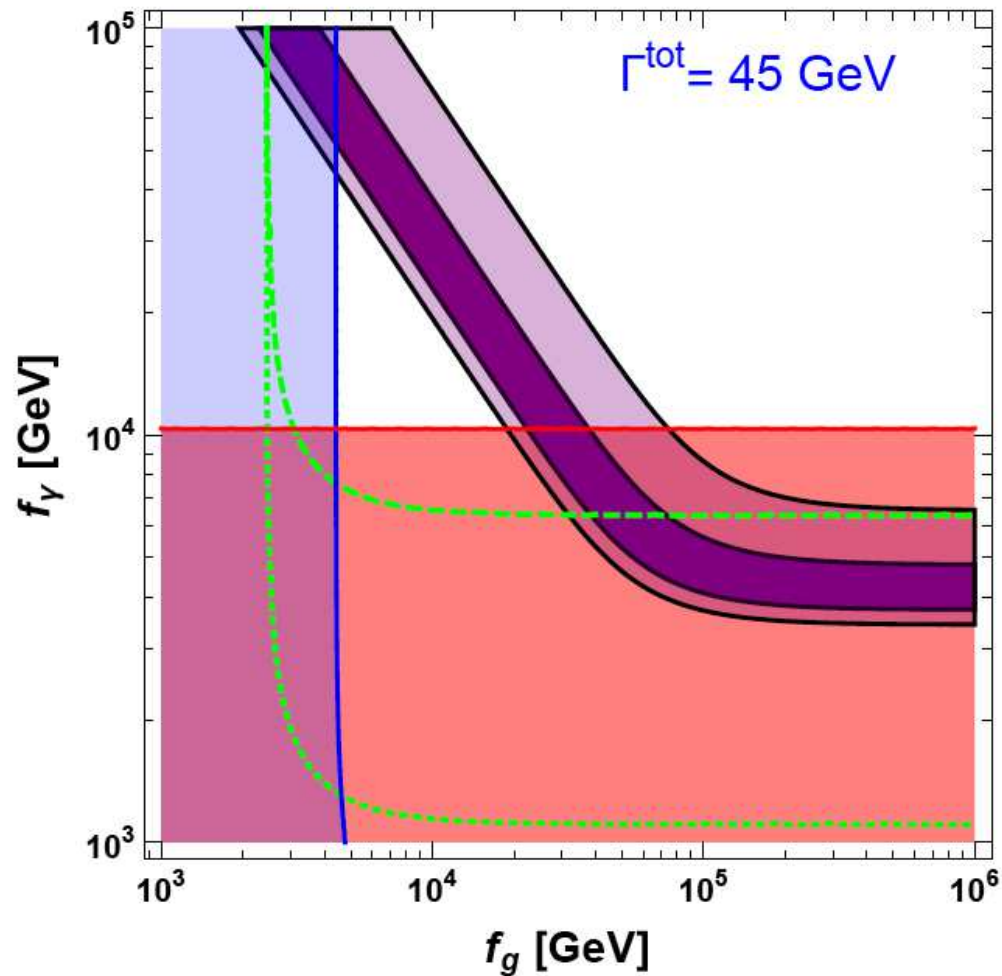
- Complementarity between gg and $\gamma\gamma$ production (the plot is for spin 0 resonance of 45 GeV width purple: allowed region from the resonance, blue: excluded from Run I jets, Red: reach using CT-PPS with 300 fb^{-1}

- Complementarity with decays in Z γ, ZZ, WW...

Looking for potential resonances at higher masses

Potential resonances at higher masses and reach in coupling vs mass plane for luminosities of 15 and 150 fb^{-1} ($0.015 < \xi < 0,15$ and $0.037 < \xi < 0.15$) - Cristian Baldenegro
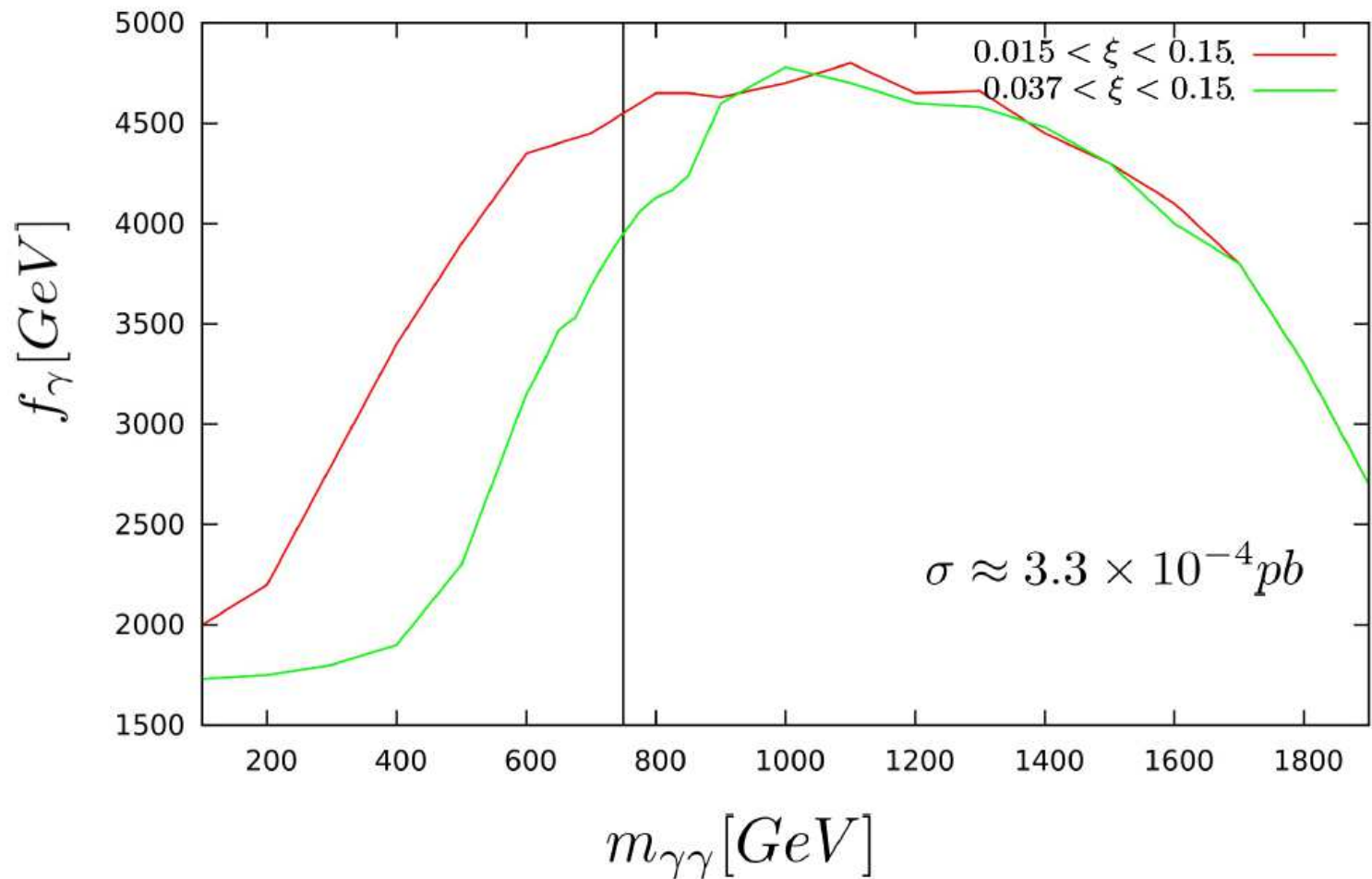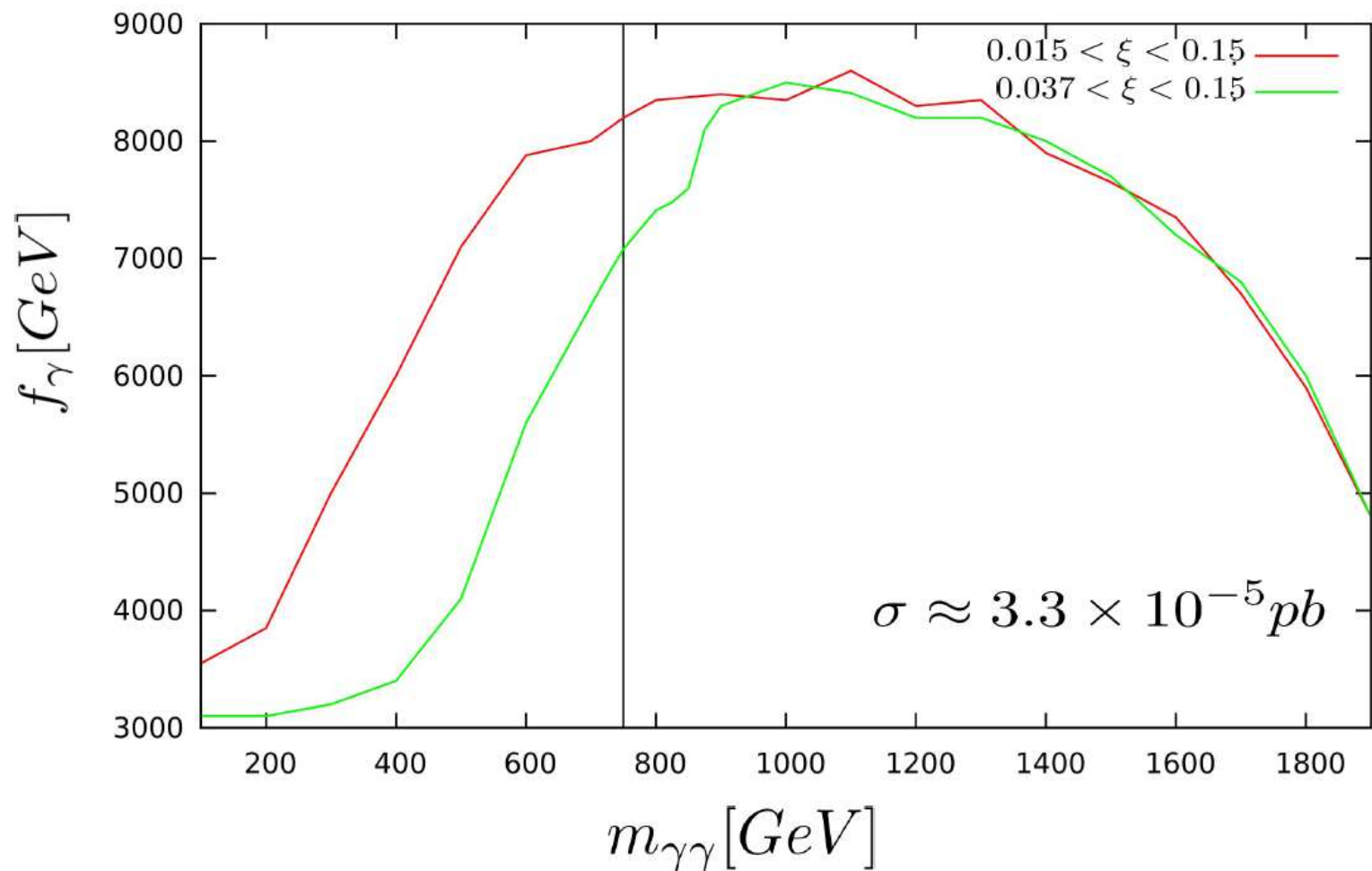
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Consequences for CT-PPS analyses and conclusion

- 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 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, to be published in PRL

- 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 to test γ-induced processes in background free experiments:
  - Fundamental if the resonance is photon-induced
  - if this is not completely the case, measure branching ratio

- If one believes the ATLAS/CMS observation, 40 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)