Probing $\gamma\gamma XX$ anomalous gauge couplings with proton tagging at the LHC

IV Workshop on QCD and Diffraction at the LHC

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December, 16th 2014

C. Royon, O. Kepka, Phys. Rev. D ***78*** *(2008)*

E. Chapon, C. Royon, O. Kepka, Phys. Rev. D ***81*** *(2010)*

S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert, Phys. Rev. D **89** (2014)

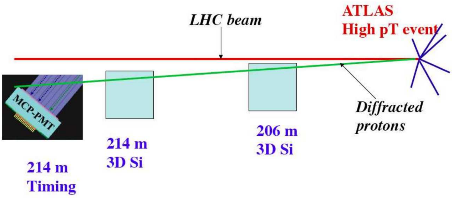
S. Fichet, G. von Gersdorff, B. Lenzi, C. Royon, M. Saimpert, arXiv:1411.6629

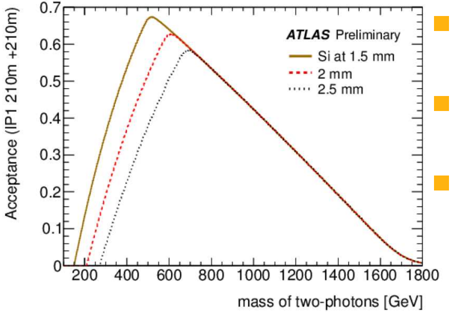
Summary of the presentation

1. **Motivations and description of the proposed measurements**
   What and why are we measuring?
2. The $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings cases in short
3. The $\gamma\gamma\gamma\gamma$ couplings case in details
4. Conclusion and plans

Forward proton detectors at the LHC

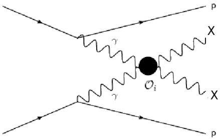
- The ATLAS Forward Physics (AFP) and the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) upgrade projects





- $\xi_{1,2}$ proton momentum loss
- **missing proton mass** $m_{pp}^{miss} = \sqrt{\xi_1 \xi_2 s}$
- **mass acceptance** limited by the LHC beam and optics (low β^* case displayed)

Exclusive production via photon induced processes



- **All particles at the final state are detected:** two protons in the forward detectors and two high energy particles in the central detector → **full reconstructed kinematics**
- Comparison between the forward and the central particles kinematics → **strong background reduction**

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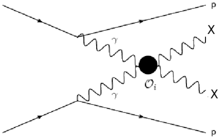

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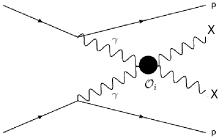
- $\gamma\gamma$, WW, ZZ final states ideal to study **anomalous quartic gauge couplings (aQGC)**
- aQGC important for various physics topics: **electroweak symmetry breaking, extra-dimension models, ...**

Exclusive production via photon induced processes



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- Comparison between the forward and the central particles kinematics $\rightarrow$ **strong background reduction**
- $\gamma\gamma$, WW, ZZ final states ideal to study **anomalous quartic gauge couplings (aQGC)**
- aQGC important for various physics topics: **electroweak symmetry breaking, extra-dimension models, ...**
- Drawback: smaller cross-sections

  (intact protons must be in the acceptance of the forward detectors)

Summary of the presentation

1. Motivations and description of the proposed measurements

2. **The $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings cases in short**
   Brief overview of the two studies published in 2008 and 2010.
   Comparison on the predicted sensitivies with the latest measurements.
   (they do not use proton tagging)

3. The $\gamma\gamma\gamma\gamma$ couplings case in details

4. Conclusion and plans

$WW\gamma\gamma$ and $ZZ\gamma\gamma$ anomalous couplings

C. Royon, O. Kepka, Phys. Rev. D ***78*** *(2008)*

E. Chapon, C. Royon, O. Kepka, Phys. Rev. D ***81*** *(2010)*

- **Effective Field Theory (EFT): dimension 6 operators** parametrized with 4 different parameters

$$\mathcal{L}_6^0 \sim \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$\mathcal{L}_6^C \sim \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

- **Only the leptonic decays** of the heavy bosons are considered as final states (clean signal experimentally)
- **Background considered:** ND WW/ZZ production, di-lepton photoproduction, DPE dilepton, DPE WW/ZZ
- Generation and simulation performed with the **Forward Physics MC generator (FPMC)** interfaced with the fast simulation of the ATLAS detector (ATLFast++ package)

ATLAS full simulation also performed to probe pile-up effects and gave similar results

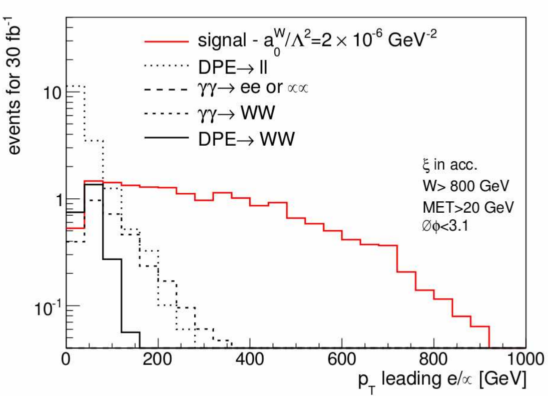
$WW\gamma\gamma$ and $ZZ\gamma\gamma$ anomalous signal

*→ATLAS **fast** simulation study*

*E. Chapon, C. Royon, O. Kepka, Phys. Rev. D **81** (2010)*

- Anomalous signal appears at high energy w.r.t. SM

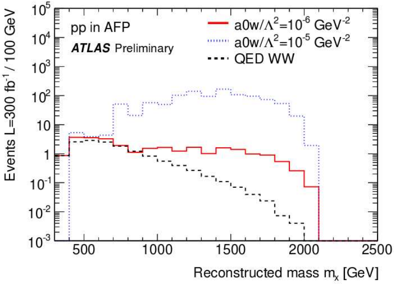
  $WW\gamma\gamma$ signal and background composition passing all the selection but the p_T cut on the leading lepton

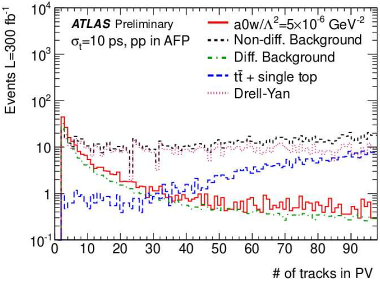


Dealing with pile-up at the LHC

→*ATLAS **full** simulation study*

- The LHC is operated at **very high luminosity** → **high event multiplicites** in a single bunch-crossing (pile-up)
- Use of the **forward timing detectors** to constrain the vertex z-position of the interaction
  dependance on the timing detectors resolution
- Cut on **the number of tracks fitted to the primary vertex**
  very efficient to remove remaining pile up after requesting a high mass object to be produced





$WW\gamma\gamma$ and $ZZ\gamma\gamma$ sensitivities

*E. Chapon, C. Royon, O. Kepka, Phys. Rev. D **81** (2010)*

- **Limits from LEP (OPAL)**, $\simeq$ 0.1-0.2 GeV^{-2}
  *Phys. Rev. D **70** (2004) 032005* (for each coupling)
- **Recent papers from DØ** for $WW\gamma\gamma$ with reach of the order of 10^{-2}-10^{-3} GeV^{-2}
  *Phys. Rev. D **88** (2013) 012005*
- **Recent papers from CMS** for $WW\gamma\gamma$ with reach of the order of 10^{-4}-10^{-5} GeV^{-2}
  *Phys. Rev. D **90** (2014) 032008*
- **Sensitivities predictions with AFP** (30 and 200 fb^{-1})
  reach up to 10^{-6} GeV^{-2}, improvement up to a factor $\simeq$ 100

	form factor	limits [10^{-6} GeV^{-2}]				limits [10^{-6} GeV^{-2}]			
		$\lvert a_0^W/\Lambda^2\rvert$	$\lvert a_C^W/\Lambda^2\rvert$	$\lvert a_0^Z/\Lambda^2\rvert$	$\lvert a_C^Z/\Lambda^2\rvert$	$\lvert a_0^W/\Lambda^2\rvert$	$\lvert a_C^W/\Lambda^2\rvert$	$\lvert a_0^Z/\Lambda^2\rvert$	$\lvert a_C^Z/\Lambda^2\rvert$
95% c.l	$\Lambda_{cut} = \infty$	1.2	4.2	2.8	10	0.7	2.4	1.1	4.1
	$\Lambda_{cut} = 2\,\text{TeV}$	2.6	9.4	6.4	24	1.4	5.2	2.5	9.2
3σ evidence	$\Lambda_{cut} = \infty$	1.6	5.8	4.0	14	0.85	3.0	1.6	5.7
	$\Lambda_{cut} = 2\,\text{TeV}$	3.6	13	9.0	34	1.8	6.7	3.5	13
5σ discovery	$\Lambda_{cut} = \infty$	2.3	9.7	6.2	23	1.2	4.3	4.1	8.9
	$\Lambda_{cut} = 2\,\text{TeV}$	5.4	20	14	52	2.7	9.6	5.5	20

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3. **The $\gamma\gamma\gamma\gamma$ couplings case in details**

   Review of the study published in 2014 and latest developments. Ideas for further developments.

   S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert, Phys. Rev. D **89** (2014)

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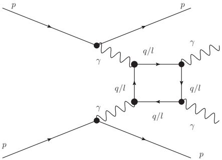
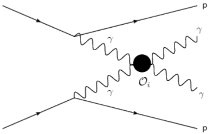
$\gamma\gamma\gamma\gamma$ SM and anomalous couplings





- **Direct coupling absent from the SM**
  Loop induced production strongly suppressed in the SM, measurable at the LHC in Pb-Pb (d'Enterria et al. Phys. Rev. Lett. **111** *(2013) 080405)*
- **Never measured in collider experiments**

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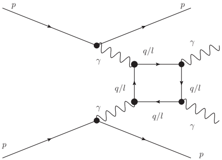

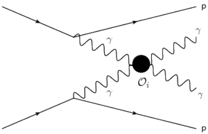

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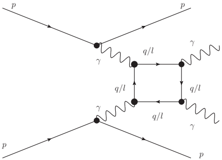
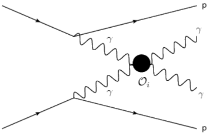
- New Physics search $\rightarrow$ high integrated luminosity required **(so high pile-up!)**
  300 fb^{-1} of data expected at the LHC at $\sqrt{s} = 14$ TeV with $\boldsymbol{\mu} > \mathbf{50}$
- **Huge background** if only 2 high energy γ required
  (SM $\gamma\gamma$ production + fakes from electrons and jets)

$\gamma\gamma\gamma\gamma$ SM and anomalous couplings





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- **Huge background** if only 2 high energy γ required
  (SM $\gamma\gamma$ production + fakes from electrons and jets)
- Additional requirement of **two intact protons** with forward detectors highly suppresses the background
  (All particles at the final state are detected)

Operators of the anomalous $\gamma\gamma\gamma\gamma$ couplings

*R.S. Gupta, Phys. Rev. D **85** (2012) 014006*

*S. Fichet and G. von Gersdorff, JHEP **1403** (2014) 102*

- $\sqrt{\hat{s}_{\gamma\gamma}} << \Lambda$, effective field theory assumption

  $L_{4\gamma} = \zeta_1^{\gamma} F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2^{\gamma} F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu}$ (dimension 8)

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- For low new physics masses, threshold effect to be taken into account $\rightarrow$ **use of a form factor (f.f.) at the amplitude level**

  We use $f.f = \frac{1}{1+(\frac{\hat{s}_{\gamma\gamma}}{\Lambda'^2})^2}$ with $\Lambda' = 1\ TeV \simeq \sqrt{\hat{s}_{\gamma\gamma,max}}/2$

  (Unitarity requires $\zeta_i < 10^{-10}\ GeV^{-4}$, $\simeq 10^4$ higher than our sensitivity limit, so we are safe on this side)

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- The signal showed in the plots of this presentation are for a signal with $\boldsymbol{\zeta_1 \geq 0}$ **and** $\boldsymbol{\zeta_2 = 0}$ **and with f.f.**

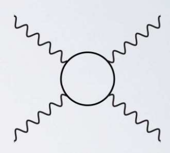
  ζ_1 and ζ_2 have a very similar angular behaviour

- A table of final sensitivities for both ζ_1 and ζ_2, **with and without f.f** are given at the end of the presentation

New physics contributions to 4γ couplings

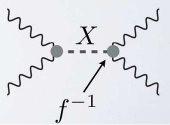
1 New charged particles via loops

- Effective coupling only depends on the mass, charge and spin : $\zeta_i^\gamma \propto c_i^s Q^4 m^{-4}$
- Example: top partners

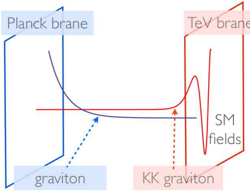


2 New neutral particles at tree level

- Effective coupling depends on mass, spin and the non-renormalizable $\gamma\gamma X$ coupling $\zeta_i^\gamma \propto b_i^s f^{-2} m^{-2}$
- Example: KK gravitons, dilaton (warped extra-dimension)



if coupling $\simeq$ TeV and $m_{KK} \simeq$ few TeV, $\zeta_i^\gamma \simeq 10^{-14}$-$10^{-13}$ GeV^{-4} achievable, which we are sensitive



$\gamma\gamma\gamma\gamma$ phenomenological study

- Evaluate the LHC potential to probe 4γ couplings using proton tagging and **effective field theory**
  - 4γ aQGC operators implemented in the **FPMC generator**
  - Simulation of the detector effects
  - Pile-up simulation with Pythia8 minimum bias events
  - Background estimation, **expected to be very small** thanks to the fully constrained kinematics
  - Sensitivities calculation: significance σ = S $/\sqrt{B}$
  - **2 scenarios were considered**
    - LHC full stat (ATLAS or CMS) : 300 fb^{-1}, $<\mu>=50$
    - HL-LHC (ATLAS) : 3000 fb^{-1}, $<\mu>=200$

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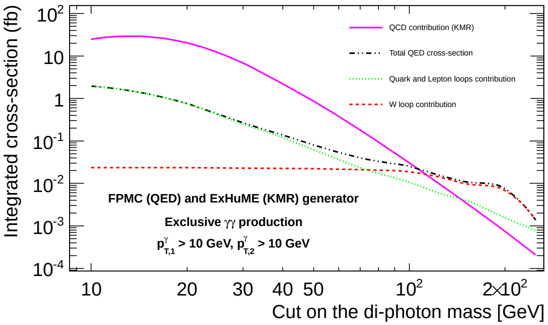
- **Extra:** update of the exclusive $\gamma\gamma$ SM production (FPMC)
  W loop contribution and fermion masses included

SM exclusive $\gamma\gamma$ production



- Mass of the fermions, W loop contribution and related interference taken into account in the QED generation
- W loop non negligible for $m_{\gamma\gamma} > 70$ GeV
- **Irreducible background for $\gamma\gamma\gamma\gamma$ new physics searches**
  Needs to be simulated accurately

SM exclusive $\gamma\gamma$ production: possible measurement at the LHC?

Cut / Process	QCD Exclusive (KMR)	QED Fermion loop	W loop
$m_{\gamma\gamma} > 10$ GeV,$p_{T1,2} > 5$ GeV	372.1 fb	4.71 fb	0.024 fb
$m_{\gamma\gamma} > 10$ GeV,$p_{T1,2} > 10$ GeV	24.2 fb	1.87 fb	0.023 fb
$m_{\gamma\gamma} > 20$ GeV,$p_{T1,2} > 10$ GeV	20.4 fb	0.75 fb	0.023 fb
$m_{\gamma\gamma} > 50$ GeV,$p_{T1,2} > 10$ GeV	0.87 fb	0.061 fb	0.022 fb
$m_{\gamma\gamma} > 100$ GeV,$p_{T1,2} > 10$ GeV	0.030 fb	0.015 fb	0.019 fb
$m_{\gamma\gamma} > 200$ GeV,$p_{T1,2} > 10$ GeV	7.4e-4 fb	$1.5 \cdot 10^{-3}$ fb	9.7e-3 fb
$m_{\gamma\gamma} > 500$ GeV,$p_{T1,2} > 10$ GeV	3.2e-6 fb	$< 5.0 \cdot 10^{-4}$ fb	1.4e-3 fb

Table: Integrated cross sections of the different SM exclusive di-photon production processes at the LHC at $\sqrt{s} = 14$ TeV for various requirements on the di-photon mass ($m_{\gamma\gamma}$) and photon transverse momenta ($p_{T1,2}$).

- No mass acceptance to perform a measurement at low β^* with proton tagging
- Measurement of KMR production possible at high β^* ($\simeq 0.1$ $\mathbf{fb}^{-1}$luminosity expected)
- It will be required to go at p_T^γ down to 5 GeV
- Rapidity gaps detection at the trigger level required?

Modelisation of the detector effects

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- **Analysis performed at particle level** but taking into account dominant detector effects
  - Estimation of γ **conversion rates** (η function), **fake photon rates**, **reconstruction efficiency** (p_T functions) from ECFA ATLAS studies
  - **Smearing** of 1% in γ energies, 0.001 in η and ϕ (absolute), 2% for ξ to mimic detector resolution
  - Requirement of **at least one converted photon** $\rightarrow$ **constraint on the γ vertex**, possibility to combine with forward proton timing measurement
  - Selection on high p_T^γ, high diphoton mass, $\Delta\phi_{\gamma\gamma}$, match proton missing/$\gamma\gamma$ mass (summary S17)

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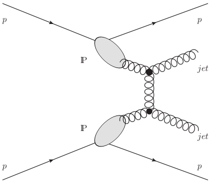
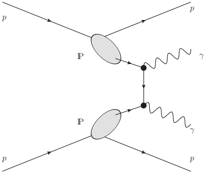
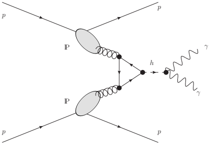
  - Selection on high p_T^γ, high diphoton mass, $\Delta\phi_{\gamma\gamma}$, match proton missing/$\gamma\gamma$ mass (summary S17)
- **Final outputs**
  - 5σ and 95% C.L sensitivities on the $\gamma\gamma\gamma\gamma$ couplings at the LHC
    EFT, valid for m>2(1) TeV for tree-level (loop-induced) production
  - M-Q exclusion plane for generic new fermions/vectors at the LHC
    full amplitude calculation, valid for all masses

Backgrounds (FPMC, ExHuME)

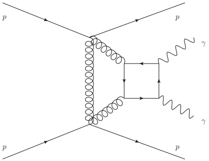
$\mathbb{P}$ backgrounds (FPMC)



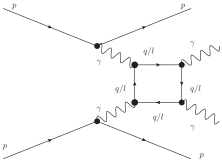


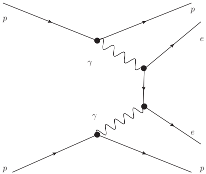


Exclusive QCD (ExHuME)



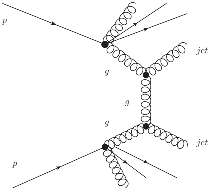
Exclusive QED (FPMC)



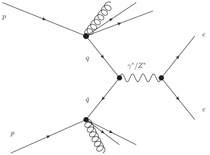


Pile-up backgrounds (HERWIG 6.5)

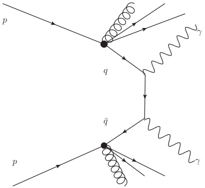
Dijet



Drell-Yan



Diphoton



+ intact protons from pile up generated from minimum bias events (Pythia 8)

transported to the forward detectors through the LHC magnets with FPTracker/MADX

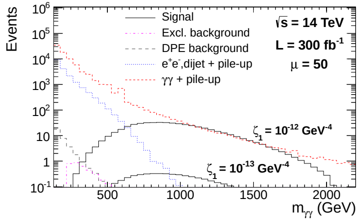
(software developed for the LHC)

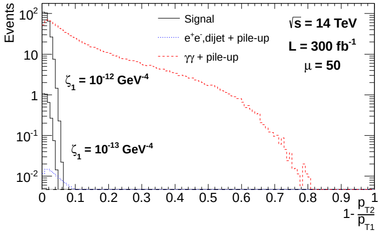
Mass and p_T balance distribution of signal and backgrounds

smearing, fakes and reconstruction factors, $\geq$ 1 converted γ required

$0.015 < \xi < 0.15$, $|\eta| < 2.37$, $p^{\gamma}_{T1,2} > 50$ GeV ONLY

if we request also $m_{\gamma\gamma} > 600$ GeV and $p_{T1,2} > 200, 100$ GeV



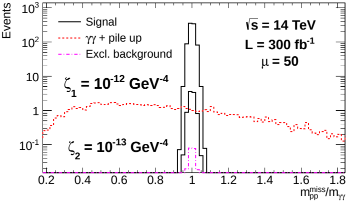


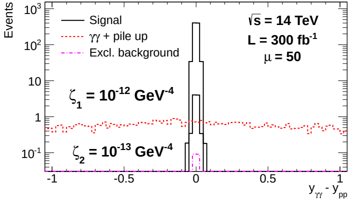
- By requesting $m_{\gamma\gamma} > 600$ GeV (left), **Only pile-up backgrounds remain**
- p_T ratio distribution after p_T and $m_{\gamma\gamma}$ cuts (right) provides another efficient cut **(exclusive process)**
- $\Delta\phi >$ Π-0.01 also applied in the final selection

Use of the forward detector ξ measurement

smearing, fakes and reconstruction factors, $\geq$ 1 converted γ required

$0.015 < \xi < 0.15$, $|\eta| < 2.37$, $m_{\gamma\gamma} > 600$ GeV, $p_{T1,2} > 200$, 100 GeV,
p_T ratio > 0.95, $\Delta\phi > \Pi$-0.01



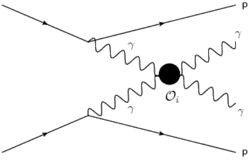


- **Missing proton mass** $\sqrt{\xi_1 \xi_2 s}$ matches $m_{\gamma\gamma}$ for the signal
  A mass window of 3% ($\simeq$ resolution) is required in the event selection
- Same effect with **rapidity variables**
  $|y_{\gamma\gamma} - y_{pp}| < 0.03$ *with* $y_{pp} = (0.5 * ln(\frac{\xi_1}{\xi_2}))$ *is applied*
- The small width of the signal distributions is due to the smearing applied to simulate detector effects

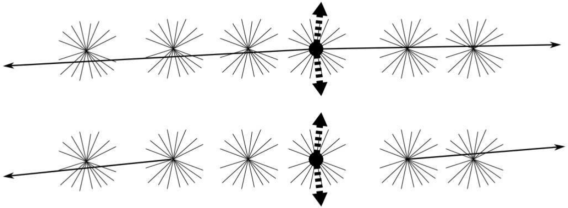
Very efficient cuts due to very good ξ resolution, **absolutely needed in order to suppress the pile-up background**

Event selection: summary

- **Kinematic cuts**
  1. $p_{T1}^{\gamma} > 200$ GeV, $p_{T2}^{\gamma} > 100$ GeV
  2. $m_{\gamma\gamma} > 600$ GeV
- Selection of **exclusive events**
  1. $\frac{p_{T2}^{\gamma}}{p_{T1}^{\gamma}} > 0.95$
  2. $|\Delta\phi_{\gamma\gamma}| > \pi$ - 0.01
- **Forward detectors** cuts
  1. $m_{pp}^{miss} = m_{\gamma\gamma} \pm 3\%$
  2. $|y_{\gamma\gamma} - y_{pp}| < 0.03$
     with y_{pp} = $(0.5 * ln(\frac{\xi_1}{\xi_2}))$
  3. Possible proton timing measurement with forward detectors **(Not used)**



Possible extra-cut: proton timing requirement



- **Proton timing will be measured by forward detectors**
  - 10 ps resolution assumed $\rightarrow$ proton vertex constrained within 2.1 milimeters
  - Requirement of 1 converted $\gamma \rightarrow < 1$ mm resolution on the γ vertex
  - **Resolution on the vertex position driven by forward timing detectors**
- Matching the two proton and photon vertices provide an additional background rejection factor of $\simeq 40$ at $\mu = 50$
- No need to use for this study, **robustness of the $\gamma\gamma\gamma\gamma$ analysis** $\rightarrow$ *needed for $WW\gamma\gamma$ (and $ZZ\gamma\gamma$)!*
- can be used for unknown backgrounds (beam-induced)

Expected events for S=1, Q_{eff}=4, m=340 GeV (ζ_1^{γ} = 2 10^{-13}.GeV^{-4})

- $\sqrt{s} = 14$ TeV, L = 300 fb^{-1}, at least one converted γ

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)	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
$(p_{\mathrm{T}2}/p_{\mathrm{T}1} > 0.95$, $\lvert\Delta\phi\rvert > \pi - 0.01)$	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

- **Very high signal selection efficiency**
  - Signal increased by a factor 3-4 when relaxing the $>$1 conv. photon requirement
    (the di-photon vertex not identified accurately anymore from the central detector)

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- **Very high signal selection efficiency**
  - Signal increased by a factor 3-4 when relaxing the $>$1 conv. photon requirement
    (the di-photon vertex not identified accurately anymore from the central detector)
- **Background completely suppressed thanks to forward detectors ξ measurement**
  - Very high significance per observed event
  - $<$ 5 background events expected at μ = 200
    Robust analysis, good background control
  - proton time-of-flight **not used**
    Possible additional rejection factor of 40 at μ = 50

Final discovery (5σ) and exclusion (95% CL) sensitivities on ζ_1 and ζ_2

EFT approach: *S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert, Phys. Rev. D* ***89*** *(2014).*

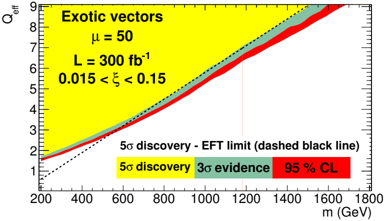
Update of the EFT + full amplitude calculation: *S. Fichet, G. von Gersdorff, B. Lenzi, C. Royon, M. Saimpert, arXiv:1411.6629.*

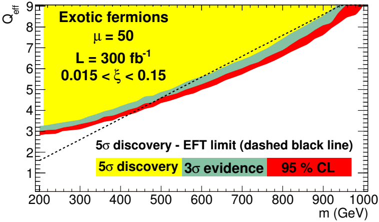
Luminosity	300 fb^{-1}	300 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
pile-up (μ)	50	50	50	200
coupling (GeV^{-4})	$\geq$ 1 conv. γ 5 σ	$\geq$ 1 conv. γ 95% CL	all γ 95% CL	all γ 95% CL
ζ_1 f.f.	$8 \cdot 10^{-14}$	$5 \cdot 10^{-14}$	$3 \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$
ζ_1 no f.f.	$2.5 \cdot 10^{-14}$	$1.5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

- A large panel of extra-dimension models can be probed in **the multi-TeV range**
- The form factor is not needed for any new physics scale **beyond $\simeq$ 2 TeV**
  because of the forward detector acceptance (see slide 9)

Full amplitude computation for generic heavy charged fermions/vectors contributions

- **The existence of new heavy charged particles** will enhance the $\gamma\gamma\gamma\gamma$ coupling at high mass via loops
- This enhancement can be parametrized by **only the mass and the effective charge** $Q_{eff} = Q.N^{1/4}$, N multiplicity (= nb of values taken by the new degree of freedom)
- Generic full amplitude implementation for fermions and vectors implemented in FPMC





Summary of the presentation

1. Motivations and description of the proposed measurements
2. The $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings cases in short
3. The $\gamma\gamma\gamma\gamma$ couplings case in details
4. **Conclusion and plans**

Where does proton tagging do better?

- Proton tagging allows a **very high background rejection** at the cost of a **smaller cross-section**
  - A single observation has **a high significance**
  - Ideal to probe small deviations from the Standard Model like aQGC
    ex: new charged particles via loops, ADD gravity effects, ...
  - Interesting "subleading" constraints on resonances searches at tree level
    ex: new neutral particles at tree level
  - Hard to be more quantitative: no $\gamma\gamma\gamma\gamma$ limits from collider experiments yet (with intact protons or not)

- We reach sensitivities allowing to **probe directly a large class of new models**
  - **Extra-dimensions:** KK gravitons, strongly-interacting heavy dilaton, ...
  - **Strongly-interacting composite states, monopoles:** generic searches of new heavy charged particles

Conclusion

- **Forward proton tagging at the LHC seems promising to probe anomalous $\gamma\gamma XX$ Gauge Couplings**
  - proton tagging associated with high energy object in the central detector allow to highly suppress the background
  - $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings sensitivity improvement by a factor up to 100 compared to latest the CMS measurement
  - $\gamma\gamma\gamma\gamma$ couplings: sensitivities around $10^{-13} - 10^{-14}$ GeV^{-4}, down to $7{\cdot}10^{-15}$ GeV^{-4} $\rightarrow$ allows to probe directly a large panel of new physics models in the multi-TeV range (KK gravitons, strongly-interacting heavy dilaton, ...)
    (no previous constraints from collider experiments)

- **$\gamma\gamma\gamma\gamma$ couplings: a way to probe exotic heavy charged vectors/fermions in a completely model-independant way** $\rightarrow$ *very interesting subleading constraints in addition to direct searches at the LHC*

Conclusion

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    (no previous constraints from collider experiments)
- **$\gamma\gamma\gamma\gamma$ couplings: a way to probe exotic heavy charged vectors/fermions in a completely model-independant way** $\rightarrow$ *very interesting subleading constraints in addition to direct searches at the LHC*
- The cross-section of those potential new contributions seems to be very dependant on the spin value of the new particles $\rightarrow$ **sensitivies to higher sping resonances under study (requires further theoretical developments)**

Probing $\gamma\gamma XX$ anomalous gauge couplings with proton tagging at the LHC

Back-up

Matthias Saimpert[1]
E. Chapon, S. Fichet, G .von Gersdorff,
O. Kepka, B. Lenzi, C. Royon[1]

[1]CEA Saclay - Irfu/SPP

December, 16th 2014

Effective Field Theory cross-section of the 4γ couplings (G. Von Gersdorff)

EFT OF 4 PHOTON INTERACTIONS

- Focus on AAAA (AAZZ and AAWW see [Chapon et al '12])
- EFT for 4-photon interaction contains two dim-8 structures

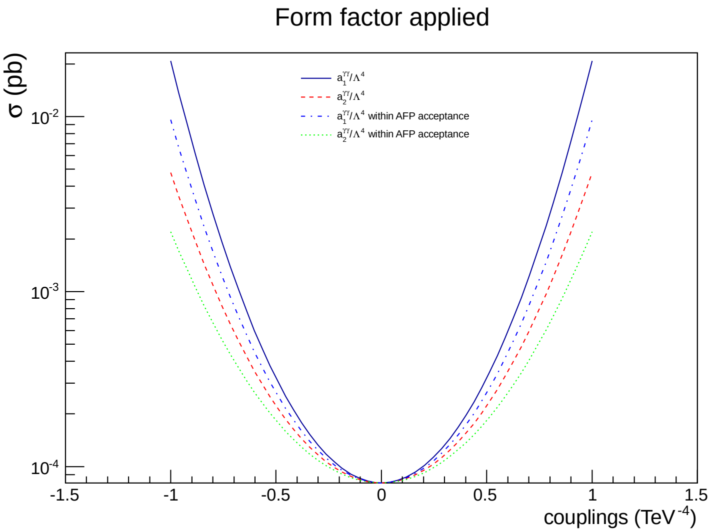
$$\mathcal{L}_{4\gamma} = \zeta_1 \, (F_{\mu\nu}F^{\mu\nu})^2 + \zeta_2 \, F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu}$$

- Cross section has a simple form

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

- Unitarity breaks down for $\zeta_i s^2 \gtrsim 2\pi$
- Demanding unitarity for LHC energies $\Rightarrow$ $\zeta_i \lesssim 10^{-10}\mathrm{GeV}^{-4}$
- In explicit models EFT breaks down before that!
- LHC sensitivities to ζ_i are ~10^{4-5} better than unitarity bound

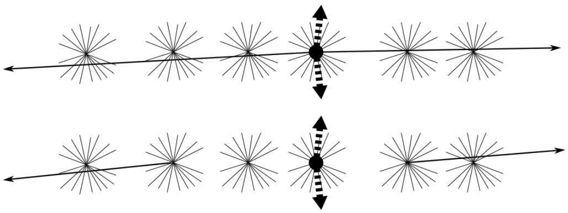
Integrated total cross-section against couplings for anomalous $\gamma\gamma\gamma$ couplings



Conversion, fake and efficiency reconstruction rates

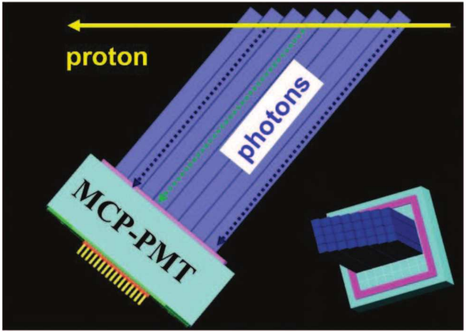
- Inputs from the **ECFA ATLAS studies**
- **Photon conversion factors:** 15% in the barrel, 30% in the end-caps
- **Photon and electron reconstruction efficiency**:
  $Eff(p_T) = 0.76 - 1.98\ exp^{\frac{-p_T}{16.1(GeV)}}$
- **Photon fake factors:** 1% for electron
  European Strategy studies
- **Fake photon p$_T$ for jets:** gaussian draw (Mean=75%,σ=13%) on the jet p$_T$ and use of
  $Eff_{fake}(p_T) = 0.0093\ exp^{\frac{-min(p_T, 200 GeV)}{17.5(GeV)}}$
  almost no fake γ from jets at very high p$_T$

Forward detectors measurements



- **Proton missing mass** measurement with 3% resolution in case of double tag
- **It matches the central $\gamma\gamma$ mass for signal**. Can match as well for pile-up backgrounds as a statisical fluctuation
- **Double tag probability** from pile-up protons on the forward detectors (no missing mass requirement) :
  32% ($\mu = 50$)   66% ($\mu = 100$)   93% ($\mu = 200$)

Forward timing detectors : inefficiencies due to pile-up protons

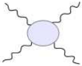


Inefficiencies - 2mm bar detector										
Bar	1	2	3	4	5	6	7	8	9	10
$\mu = 50$	0.129	0.085	0.067	0.057	0.049	0.046	0.043	0.040	0.036	0.011
$\mu = 100$	0.185	0.122	0.097	0.082	0.071	0.066	0.062	0.057	0.051	0.016

M. Saimpert. Search for new states of matter wih the ATLAS experiment at the LHC, Master Thesis MINES ParisTech (2013)

$\gamma\gamma\gamma\gamma$ full amplitude calculation (S. Fichet)

The BSM amplitudes



- Loops of spin 0,1/2, 1 new electric particles contribute to 4γ . Because all vertices are fixed by gauge invariance, the NP contributions depend only on spin, mass and electric charge ! ⇨ Very model-independent

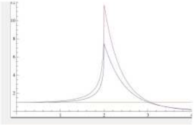
- For example in the effective theory limit : $\zeta_i^\gamma = \alpha_{\rm em}^2 Q^4 m^{-4} N c_{i,s}$

$$c_{1,s} = \begin{cases} \frac{1}{288} & s=0 \\ -\frac{1}{36} & s=\frac{1}{2} \\ -\frac{5}{32} & s=1 \end{cases}, \quad c_{2,s} = \begin{cases} \frac{1}{360} & s=0 \\ \frac{7}{90} & s=\frac{1}{2} \\ \frac{27}{40} & s=1 \end{cases}$$

Scalar loops are smaller !

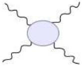
- Full amplitudes for fermions and vectors are now implemented in FPMC.

- Amplitudes get enhanced near the threshold



$\gamma\gamma\gamma\gamma$ full amplitude calculation (S. Fichet)

The SM background



- All electric particles of the SM contribute : leptons, quarks and W bosons

- The imaginary part of certain W helicity amplitudes grows with the energy, while the fermion ampliudes are finite. Background is dominated by the W loop

- When the new particle is real, it interfers with the W loop.
  ⇨ On-shell NP signal enhanced by SM interference

- All SM background amplitudes are implemented in FPMC (+ swiches to separately turn off them)

- One can check that SM fermions contributions are negligible.
  ⇨ Keeping only the W loop provides a huge gain of CPU time !