Search for anomalous $\gamma\gamma \rightarrow \gamma\gamma$ couplings at the LHC and test of the electroweak theory

Workshop on QCD and Diffraction at the LHC

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O. Kepka, B. Lenzi, C. Royon

CEA Saclay - Irfu/SPP

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Forward proton tagging potential to probe anomalous gauge couplings at the LHC energies

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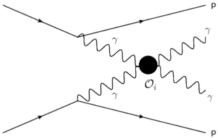
- **High potential** for forward proton tagging in probing aQGC (CMS-TOTEM, AFP)
  - Use of photon induced processes
  - **Dramatic background reduction**: photon flux dominant over pomeron flux at high p_T
  - **Strong kinematics constraints**: all final state particles are detected

$\gamma\gamma \to \gamma\gamma$ couplings



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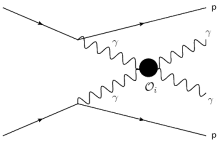

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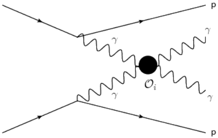

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- **Huge background** in the regular channel (SM $\gamma\gamma$ production + fakes from jets and electrons)
- Requirement of **two intact protons** with forward detectors
- Almost all backgrounds are suppressed
  pile-up effects remain

Operators giving rise to $\gamma\gamma \to \gamma\gamma$ couplings

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

$$L^{\gamma\gamma\gamma\gamma} = \frac{a_1^{\gamma\gamma}}{\Lambda^4} F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \frac{a_2^{\gamma\gamma}}{\Lambda^4} F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu} \text{ with } \Lambda = 1\ TeV$$

- Use of an arbitrary **form factor** at the amplitude level to regularize the new type of production

  We use $f.f = \frac{1}{1+(\frac{W^2_{\gamma\gamma}}{\Lambda^2_{cutoff}})^2}$ with $\Lambda_{cutoff} = 1\ TeV$

  (upper band of the cutoff imposed by unitarity)

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- Only results on $\frac{a_1^{\gamma\gamma}}{\Lambda^4}$ are considered from here

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  - Pile-up backgrounds should dominate: 2 considered scenarios, $\mu = 50$ and 100

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  - Selection on high p_T^{γ}, high diphoton mass, $\Delta\Phi$, match proton missing/$\gamma\gamma$ mass, timing, ...

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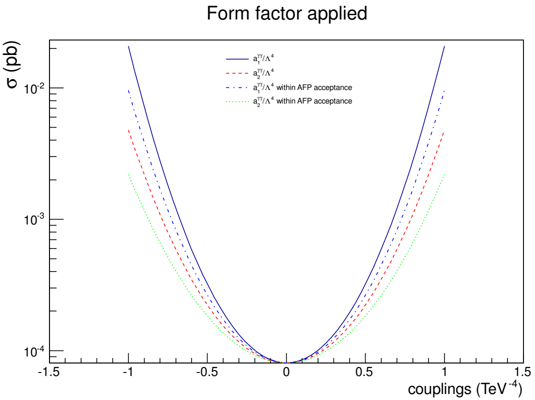
- **Photon fake factors:** electrons 1% (European Strategy studies), use of fake photon efficiency for jets.
- **Fake photon p$_T$ for jets:** gaussian draw (Mean=75%,σ=13%) on the jet p$_T$

Integrated total cross-section against couplings



- Assumption of $\int$ **Ldt** $=$ **300 fb**$^{-1}$ $\rightarrow$ sensitivy potentially down to a few 0.1 TeV^{-4} $=$ $\mathbf{10^{-13}}$ **GeV**$^{-4}$

Sensitivities to new physics (preliminary)

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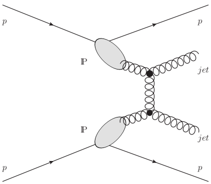
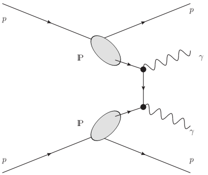
- Sensitivy potentially down to a few $0.1\ \text{TeV}^{-4} = \mathbf{10^{-13}\ GeV^{-4}}$
- Corresponds to a **KK graviton** of 3.4 TeV in brane gauge field scenarios
- **Current sensitivity at the LHC** $>$ **1 TeV** (to be precised)
- For bulk gauge field scenarios and composite Higgs, sensitivities of 10^{-14},10^{-15} GeV^{-4} required

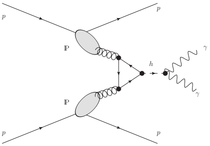
(S. Fichet and G.von Gersdorff, *Anomalous gauge couplings from composite Higgs and warped extra dimensions*, paper in preparation)

Considered backgrounds (FPMC+ExHuME)

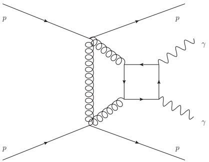
$\mathbb{P}$ backgrounds (FPMC)



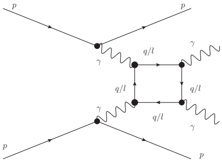


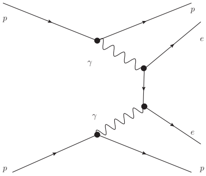


Exclusive QCD (ExHuME)



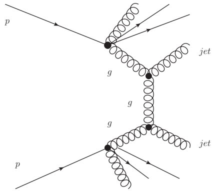
Exclusive QED (FPMC)



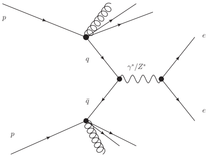


Considered Backgrounds (HERWIG 6.5)

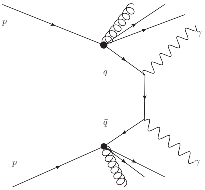
Dijet



Drell-Yan



Diphoton

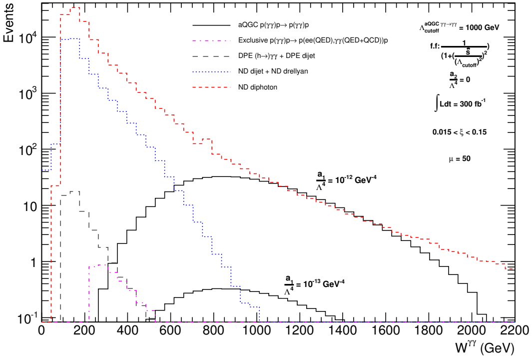


+ protons from minimum bias events (Pythia 8)

transported to the forward detectors with FPTracker (O. Kepka)

Mass distribution of signal and backgrounds

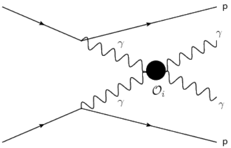
- $0.015 < \xi < 0.15$, $|\eta| < 2.37$, $p_{T1,2} > 50 GeV$



- By requesting $W^{\gamma\gamma} > 600\ GeV$, Only pile-up backgrounds remain

Kinematic cuts

1. $p_{T1} > 200\ GeV, p_{T2} > 100\ GeV$
2. $W > 600\ GeV$



Selection

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- Selection of **exclusive events**
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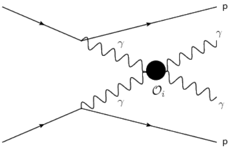

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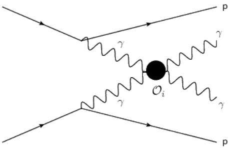

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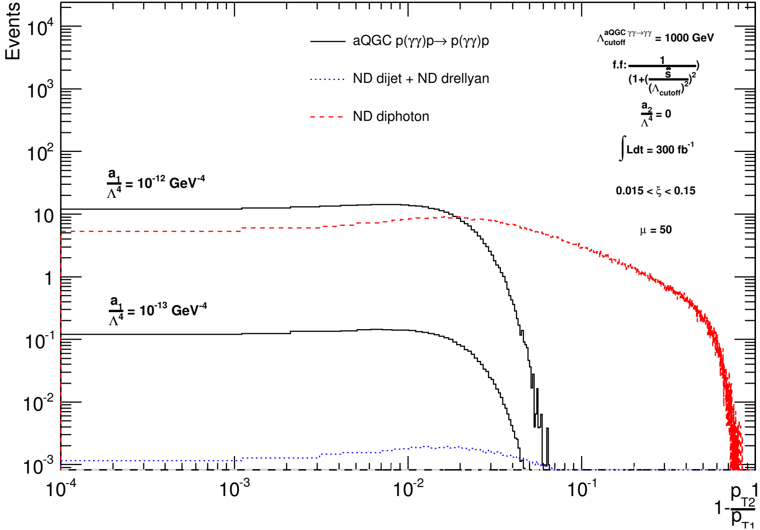
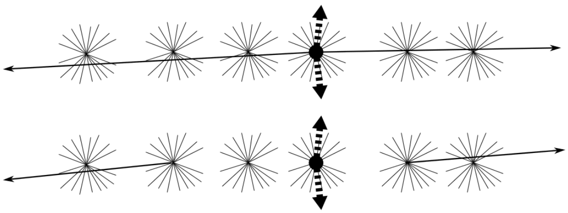
- **Forward detectors** cuts
  1. $\sqrt{\xi_1 \xi_2 s} = W^{\gamma\gamma} \pm 3\%$
  2. Proton timing measurement with forward detectors
  3. $|\eta^{\gamma\gamma} - \eta^{pp}| < 0.03$ $(0.5 * ln(\frac{E_1+E_2+p_{z1}+p_{z2}}{E_1+E_2-p_{z1}-p_{z2}}))$

Exclusive signal: p_T ratio



- p_T ratio distribution after p_T and W cuts

Forward detectors measurement



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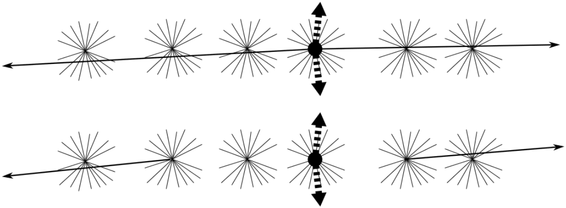

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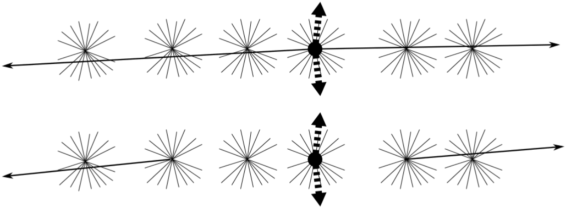

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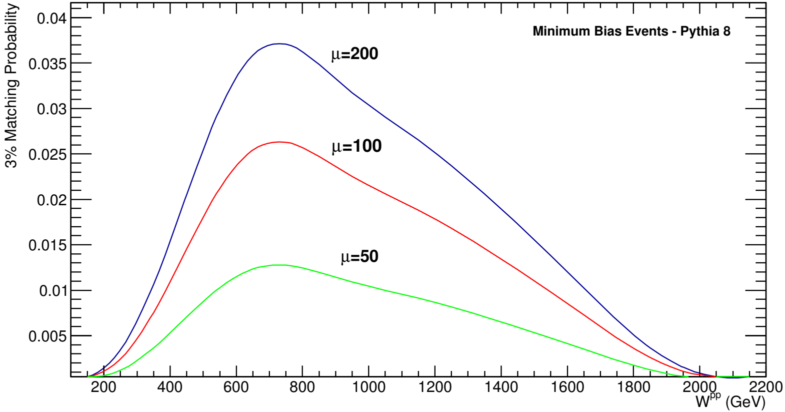
- Double tag probability from pile-up protons on forward detectors (no mass requirement) :
  0.32 ($\mu = 50$)   0.66 ($\mu = 100$)   0.93 ($\mu = 200$)

Mass matching and pile-up



- Probabiliy for forward protons to match a given mass within 3% for different pile-up

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  - **Pixels may be required for $\mu > 100$**
    M. Saimpert. Search for new states of matter wih the ATLAS experiment at the LHC, Master Thesis MINES ParisTech (2013)

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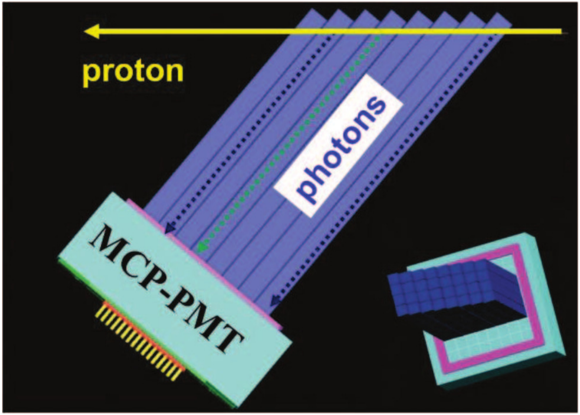
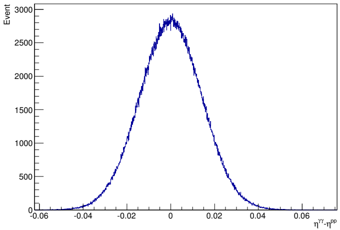
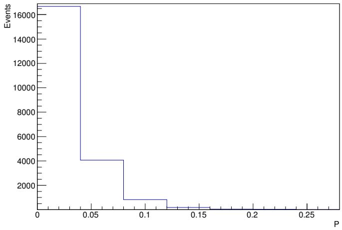


Inefficiencies - 2mm bar detector										
Bar	1	2	3	4	5	6	7	8	9	10
$\mu = 50$	0.129	0.085	0.067	0.057	0.049	0.046	0.043	0.040	0.036	0.011
$\mu = 100$	0.185	0.122	0.097	0.082	0.071	0.066	0.062	0.057	0.051	0.016
$\mu = 300$	0.226	0.149	0.118	0.100	0.087	0.081	0.077	0.071	0.063	0.020

Rapidity cut potential (preliminary)

- $|\eta^{\gamma\gamma} - \eta^{pp}| < 0.03 \quad (0.5 * ln(\frac{E_1+E_2+p_{z1}+p_{z2}}{E_1+E_2-p_{z1}-p_{z2}}))$





- Rapidity variable for signal (left)

- Probability to get this variable within the good range for ND diphotons + pile-up protons which pass the rest of the selection

Signal Events - Preliminary Summary

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

cut/ a_1/Λ^4 coupling with f.f. (GeV^{-4})	10^{-12}	5.10^{-13}	4.10^{-13}	3.10^{-13}	2.10^{-13}	10^{-13}
$p^{\gamma}_{T\,1,2} > 50\ GeV$, $\|\eta\| < 2.37$, $0.015 < \xi < 0.15$	519.3	129.8	83.1	46.7	20.8	5.2
$p^{\gamma}_{T,1}$ 200 GeV,$p^{\gamma}_{T,2} > 100\ GeV$	438.9	109.7	70.2	39.5	17.6	4.4
$W^{\gamma\gamma} > 600\ GeV$	415.8	103.9	66.5	37.4	16.6	4.2
$p^{\gamma}_{T,2}/p^{\gamma}_{T,1} > 0.95$	415.7	103.9	66.5	37.4	16.2	4.2
$\Pi - \Delta\Phi < 0.01$ (no p_T ratio cut)	415.8	103.9	66.5	37.4	16.6	4.2
$\Pi - \Delta\Phi < 0.01$ (with p_T ratio cut)	415.7	103.9	66.5	37.4	16.6	4.2
$W^{pp} = W^{\gamma\gamma} \pm 3\%$	391.7	98.0	62.7	35.2	15.7	3.9
Vertex requirement	391.7	98.0	62.7	35.2	15.7	3.9
$\|\Delta\eta^{pp} - \Delta\eta^{\gamma\gamma}\| < 0.03$	378.3	94.6	60.5	34.0	15.1	3.8

Table : Signal

DPE and Exclusive Background Events - Preliminary Summary

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

cut/process	DPE $\gamma\gamma$	DPE Higgs	DPE di-jet	QED Excl. $\gamma\gamma$	QED Excl. ee	QCD Excl. $\gamma\gamma$
$p^{\gamma}_{T\,1,2} > 50\ GeV, \lvert\eta\rvert < 2.37,$ $0.015 < \xi < 0.15$	39.8	6e-02	8.3	7e-01	2e-02	3.0
$p^{\gamma}_{T,1} > 200\ GeV, p^{\gamma}_{T,2} > 100\ GeV$	2e-01	0.	4e-06	3e-02	3e-03	2e-01
$W^{\gamma\gamma} > 600\ GeV$	3e-02	0.	3e-07	2e-02	2e-03	6e-02
$p^{\gamma}_{T,2}/p^{\gamma}_{T,1} > 0.95$	1e-02	0.	2e-08	2e-02	2e-03	6e-02
$\Pi - \Delta\Phi < 0.01$ (no p_T ratio cut)	4e-03	0.	2e-08	2e-02	2e-03	6e-02
$\Pi - \Delta\Phi < 0.01$ (with p_T ratio cut)	3e-03	0.	4e-09	2e-02	2e-03	6e-02
$W^{pp} = W^{\gamma\gamma} \pm 3\%$	0.	0.	0.	2e-02	1e-03	5e-02
Vertex requirement	0.	0.	0.	2e-02	1e-03	5e-02
$\lvert\Delta\eta^{pp} - \Delta\eta^{\gamma\gamma}\rvert < 0.03$	0.	0.	0.	2e-02	1e-03	5e-02

Table : DPE and Exclusive Background

Pile-up Background Events ($\mu = 50$) - Preliminary Summary

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

cut/process	ND dijet	ND DY *ee*	ND $\gamma\gamma$
$p^{\gamma}_{T\,1,2} > 50\ GeV$, $\lvert\eta\rvert < 2.37$, $0.015 < \xi < 0.15$	3e+04	84.2	1.03e+05
$p_{T,1} > 200\ GeV$, $p_{T,2} > 100\ GeV$	1.6e-01	1.46	2968.2
$W^{\gamma\gamma} > 600\ GeV$	3.6e-02	2e-01	1022.7
$p_{T,2}/p_{T,1} > 0.95$	1.2e-03	8.7e-02	413.5
$\Pi - \Delta\Phi < 0.01$ (no p_T ratio cut)	1.3e-03	2.5e-02	115.2
$\Pi - \Delta\Phi < 0.01$ (with p_T ratio cut)	1.3e-04	1.8e-02	80.2
$W^{pp} = W^{\gamma\gamma} \pm 3\%$	4.4e-06	6.4e-04	2.8
Vertex requirement	1.1e-07	1.6e-05	7.0e-02
$\lvert\Delta\eta^{pp} - \Delta\eta^{\gamma\gamma}\rvert < 0.03$	2.5e-09	2.9e-07	1.1e-03

Table : Pile-up Background

Conclusions

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

Conclusions

- Forward proton tagging at the LHC seems promising to probe **aQGC**
  - *WW*$\gamma\gamma$ and *ZZ*$\gamma\gamma$ couplings already studied with positive outputs (constrains improved by a factor > 100)

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  - A first look at the $\gamma\gamma \to \gamma\gamma$ couplings shows that we will be able to probe them down to a few $10^{-13}\ \mathrm{GeV}^{-4}$
  - Waiting for final outputs from theorists (Discussions with S. Fichet and G.von Gersdorff)

Plans

- Form factor effect to evaluate
- $\mu = 100$ scenario

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- Higer luminosity scenarios (300 fb^{-1}) ?

Search for anomalous $\gamma\gamma \to \gamma\gamma$ couplings at the LHC and test of the electroweak theory

Back-up

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