Quartic anomalous couplings: $WW\gamma\gamma$ and $ZZ\gamma\gamma$ in two-photon interactions

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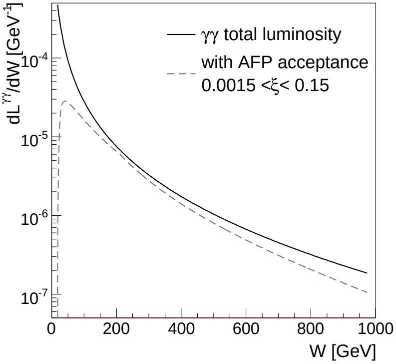
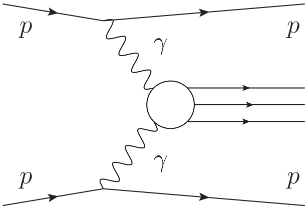
- Two-photon interactions
- Quartic anomalous coupling W, Z to photons
- Sensitivity at the LHC with low and high luminosity

Two-photon interactions at LHC



- pp machine serves as $\gamma\gamma$ collider
- yield depends on $\gamma\gamma$ invariant mass
  - 1% $W > 23$ GeV
  - 0.15% $W > 2 \times m_W$
  - 0.007% $W > 1$ TeV ... probing TeV scale - potential new physics

- clean process - only central object in the detector and nothing else
- very big rapidity gaps
- unaltered very forward protons could be tracked far from IP



Two-photon physics

- largest signal $\gamma\gamma \to \mu\mu$ $\sigma - \doteq 70\,$pb - drops quickly with two-photon mass
- supersymmetric leptons + scalars
  $f^+f^- \doteq 4\,$fb (m=100 GeV) ... (Schul at al. arXiv:0806.1097)
  $s^+s^- \doteq 0.61\,$fb (m=100 GeV) ... charged higgs (limit form LEP $m_H > 80\,$GeV)
- $\gamma\gamma \to W^+W^-$ - $\sigma \simeq 96$ fb
  - $\sigma_{WW}(W > 1$ TeV$) = 5.9\,$fb
  - $\sigma_{WW}(W > 1$ TeV$) = 2.0\,$fb within acceptance $0.0015 < \xi < 0.15$ AFP forward detectors (220+420 m)

- $\to$ with W production probing high two-photon mass ... how much are we sensible to new phenomena
- inspired by T. Pierzchala at al. where no background was considered (Nucl.Phys.Proc.Suppl.179-180:257-264,2008)

Quartic gauge couplings (QGC)

effective lagrangian, parametrized by a_0^W, a_0^Z, a_C^W, a_C^Z (C-,P-even)

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

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

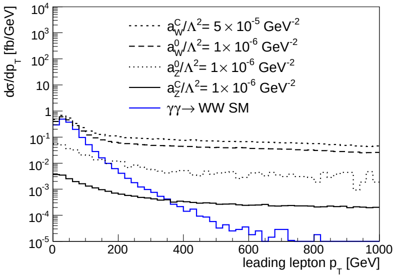
$$F_{\mu\nu} \equiv \partial_\mu A_\nu - \partial_\nu A_\mu$$

- anomalous parameters 0 in SM
- best limits from OPAL (Phys.Rev.**D**70:032005,2004)
  - example: -$0.020 < a_0^W/\Lambda^2 < 0.020$ GeV^{-2}
- no constrain from the Tevatron

- dimension 6 operators $\rightarrow$ violation of unitarity at high energy
- introducing form factors by conventional way:
  $a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W_{\gamma\gamma}/\Lambda_{\text{cutoff}})^2}$ $\quad \Lambda_{\text{cutoff}} = 2$ TeV ... scale of the new physics

Signal of anomalous couplings

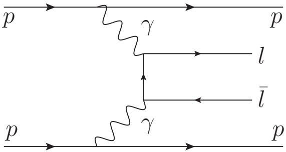
- signal at high $\gamma\gamma$ mass
- focus: leptonic decays of WW, ZZ
  $\rightarrow$ events with two/four leptons in the final state and nothing else



- simple analysis:
  $\rightarrow$ look for high p_T leptons and some kind of exclusivity requirement
- triggers for high p_T e/μ without prescale at early running

Background processes

- non-diffractive WW: large energy flow in the forward region
- two-photon dileptons: leptons exactly back-to-back

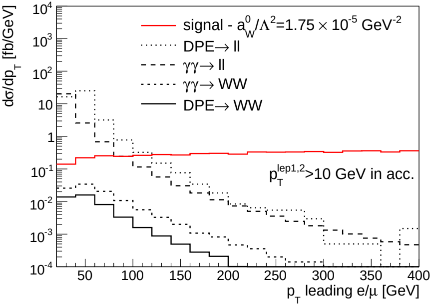


- leptons via double pomeron exchange (DPE): some energy flow in the forward region due to pomeron remnants, higher number of tracks
- WW via double pomeron exchange: same

$\sqrt{s} = 10$ TeV

- at 14 TeV, ll final state, $l = e, \mu$

$\gamma\gamma \to WW$	4.4×0.9 fb
$\gamma\gamma \to ll (p_T > 20$ GeV$)$	340×0.9 fb
DPE $\to ll$ (same)	124×0.03 pb
DPE $\to WW$	0.1×0.03 pb
non-diffractive WW	5.2 pb

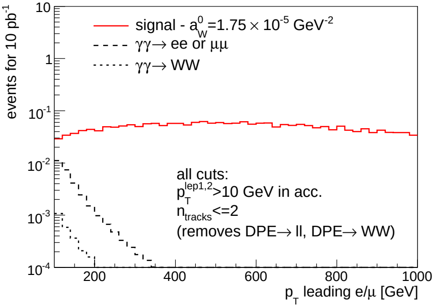


- survival probability (Khoze at al., Eur.Phys.J.**C**23:311-327,2002) :
  - two-photon exchanges - 0.9
  - double pomeron exchange - 0.03

- all processes implemented in FPMC (Forward Physics Monte Carlo), events reconstructed with standalone root ATLFAST++

Sensitivity using low luminosity

- low luminosity - 10-100 pb^{-1}
- one interaction / bunch crossing - exclusivity of two-photon events
  - two leptons and nothing else
  - true approx. up to $\sim 10^{32}\,\text{cm}^{-2}\text{s}^{-1}$ - collect $10\,\text{pb}^{-1}$
  - for higher luminosity ask only one primary vertex



WW analysis

- exclusivity: small number of tracks
  - removes DPE and non-diffractive background
- $p_T^{lep1} > 160\,\text{GeV}$ - to select signal only
- no other cuts needed

ZZ analysis

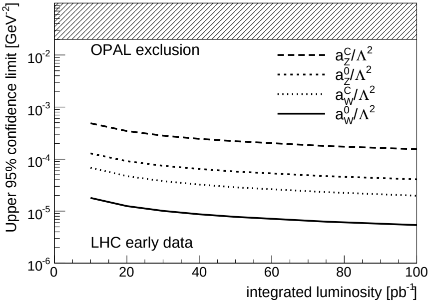
- 2 (e/μ) of the same charge or more than three leptons
- no jet above 20 GeV

Limits low luminosity

- 5σ discovery upper limits at 10 TeV, lower limits similar - negative

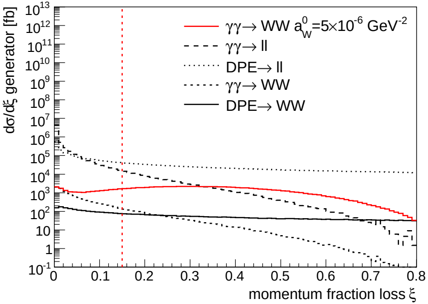
coupling	OPAL limits	limits $\mathcal{L}$=10 pb^{-1}	$\mathcal{L}$=100 pb^{-1}
a_0^W	0.020	2.2×10^{-5}	7.1×10^{-6}
a_C^W	0.037	8.4×10^{-5}	2.7×10^{-5}
a_0^Z	0.023	1.7×10^{-4}	5.3×10^{-5}
a_C^Z	0.029	6.3×10^{-4}	2.0×10^{-4}

Improvement of a factor up to 1000 with respect to OPAL limits

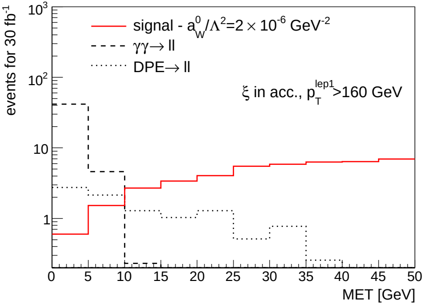


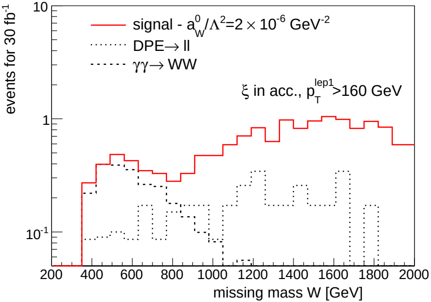
Sensitivity high luminosity

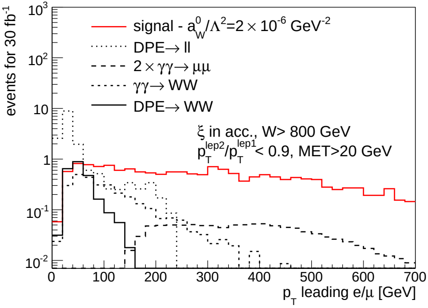
- high luminosity - 30 fb^{-1}- 200 fb^{-1}
- 20-30 multiple interactions / bunch crossing
  - identify unaltered protons by forward taggers
  - acceptance $0.0015 < \xi < 0.15$ Atlas Forward Physics



- removes a lot of signal
- but also removes direct SM $\gamma\gamma \to WW$ background







- two-photon ll removed with MET> 20 GeV, $p_T^{lep2}/p_T^{lep1} < 0.9$
- two-photon WW suppressed with proton missing mass $W > 800$ GeV
- signal selected with $p_T > 160$ GeV

Limits high luminosity

- showing upper 5σ discovery limits at 14 TeV, lower limits similar

coupling	OPAL limits	limits $\mathcal{L}$=30 fb^{-1}	$\mathcal{L}$=200 fb^{-1}
a_0^W	0.020	1.4×10^{-6}	7.9×10^{-7}
a_C^W	0.037	5.7×10^{-6}	3.6×10^{-6}

- a_0^W, a_C^Z - signal cut by ξ acceptance - numbers to come

Improvement by more than 10000 with respect to OPAL limits

- in contrast with TGC where the improvement is only modest

coupling	CDF limits	limits $\mathcal{L}$=30 fb^{-1}	$\mathcal{L}$=200 fb^{-1}
λ^γ	0.51	0.026	0.017
$\Delta\kappa^\gamma$	0.13	0.029	0.012

Conclusion

- no / little multiple interaction at the early data $\rightarrow$ interesting to probe the SM photon couplings with high precision with small collected luminosity
- part of the rich two-photon exchange physics program
- preparation of the analysis in the ATLAS framework

Backup slide

OPAL limits

-0.007 $< a_0^Z/\Lambda^2 < 0.023$ GeV^{-2}

-0.029 $< a_C^Z/\Lambda^2 < 0.029$ GeV^{-2}

-0.020 $< a_0^W/\Lambda^2 < 0.020$ GeV^{-2}

-0.052 $< a_C^W/\Lambda^2 < 0.037$ GeV^{-2}