Anomalous triple and quartic gauge couplings involving photons at the LHC

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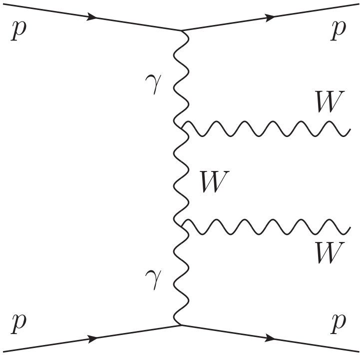
E. Chapon, O. Kepka and C. Royon, Phys.Rev.D81:074003, 2010

Exclusive production

New physics at the LHC

- using hadron accelerator as a photon collider
- exclusive QED process - induced by two photon
- same process possible at e^+e^- at the ILC, electron point like, photon beams intensive
- can study anomalous coupling of γ to W

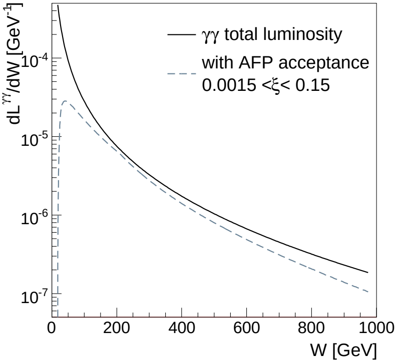


- gaps in rapidity - regions devoid of particles, exchange of a photon
- only WW system produced and nothing else
- fractional momentum loss of the proton $\xi_i = (|\mathbf{p}_{bi}| - |\mathbf{p}_i|)/|\mathbf{p}_{bi}|$
- ξ measured with forward detectors installed far away from IP
- mass measured with excellent resolution ($\sim$ GeV)
- $M^2 \sim s\xi_1\xi_2$

Equivalent Photon Approximation (EPA)

- exchange of almost real ($Q^2 \approx 0$) photons (Budnev flux)
- protons scatter at very small angles ($< 100\,\mu$rad)
- cross section factorizes
- $\rightarrow W^2 = 4E_{\gamma 1}E_{\gamma 2}$

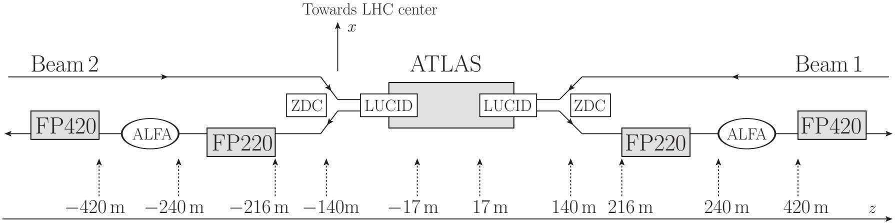
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \int \frac{\mathrm{d}\sigma_{\gamma\gamma\rightarrow X}(W)}{\mathrm{d}\Omega}\frac{\mathrm{d}L^{\gamma\gamma}}{\mathrm{d}W}\mathrm{d}W$$



- for $\mu\bar{\mu}$ - 2.2 pb - $p_T^\mu > 10$ GeV
- for WW^+ - 95.6 fb, 5.9 fb $W > 1$ TeV
- small x-section, but luminosity in first 3 years 30 fb^{-1}, important signal
- other production: sfermion pairs, charged Higgs pairs

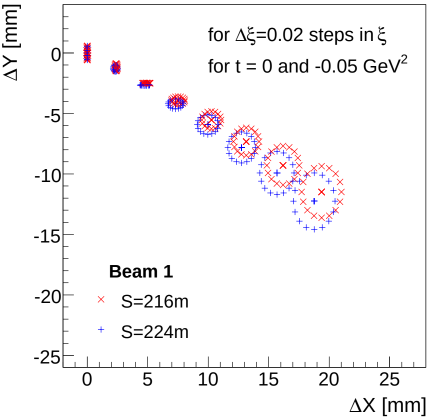
Atlas Forward Proton (AFP) detectors

- existing forward detectors: LUCID, ALFA, ZDC - not sensitive to hard diffraction
- new project: FP220 and FP420 detectors (similar project at CMS)
- scattered protons detected by silicon pixel detectors few mm from beam
- timing detectors few ps resolution



Footprint of $\xi \neq 0$ events

- $\xi \neq 0$ - beam proton losing momentum, $\xi_i = (|\mathbf{p}_{bi}| - |\mathbf{p}_i|)/|\mathbf{p}_{bi}|$



FP220

- positive ΔX - protons scattered outside the cryogenic ring
- most of the physics covered with a detector of the size 2 cm - 10 μm resolution in x
- reconstruction
  - from proton track in two stations 216 m and 224 m
  - reconstruct ξ, t, ϕ

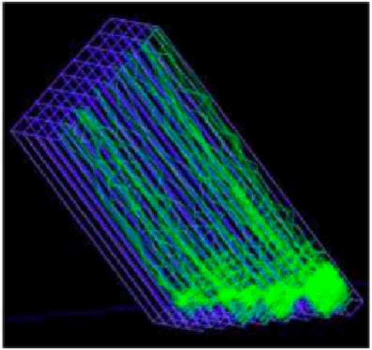
FP420

- protons scattered to negative ΔX
- but detector must be placed in between two beam pipes

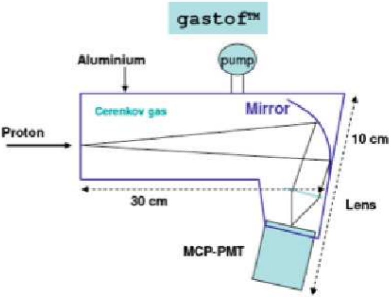
Fast Timing

- up to 32 interactions/bunch crossing
- measure time of arrival of the proton precisely $\sim 10\,\mathrm{ps} \sim 3\,\mathrm{mm} \rightarrow$ constrain the position of vertex from which the proton originates
- achieved in lab: Gastof $\sim 5\,\mathrm{ps}$, Quartic $\sim 15\,\mathrm{ps}$

Quartic (FNAL, Alberta, UTA)



GASTOF (Louvain)



$\gamma\gamma \to WW/ZZ$ at high lumi

Focusing on two application of two-photon production:

- Measurement of two-photon WW production
- Search for anomalous W/Z couplings to photon

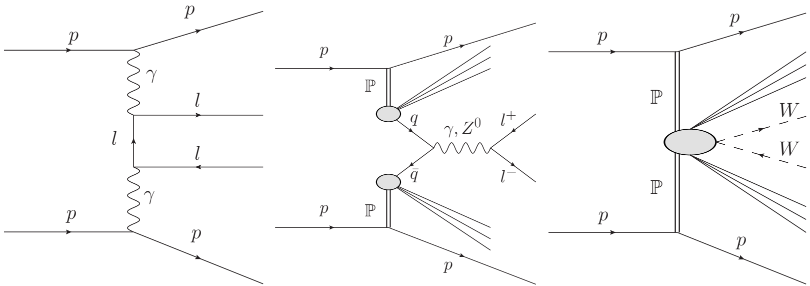
Phenomenological study: considered processes

signal

- two-photon WW/ZZ: two leptons e/μ from leptonic WW/ZZ decays

background

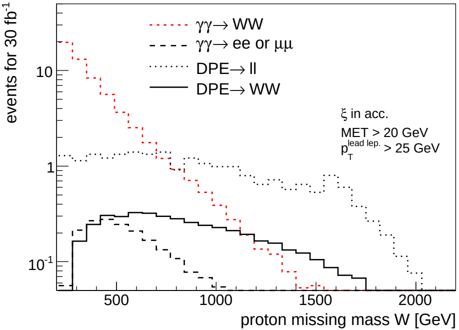
- two-photon dileptons: leptons exactly back-to-back
- leptons via double pomeron exchange (DPE): hard diffraction, probing structure of the pomeron
- WW via double pomeron exchange: same



- diffractive and exclusive processes in FPMC + fast ATLAS standalone simulation

Measurement of SM two-photon WW

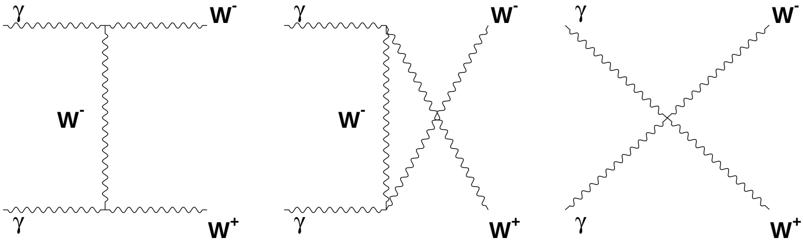
- high lumi used, $\gamma\gamma \to WW$ can be measured, pure leptonic decays
- $0.0015 < \xi < 0.15$, $160 < W < 500$ GeV
- $p_T^{lep1} > 25$ GeV, $p_T^{lep2} > 10$ GeV, $\not{E}_T > 20$ GeV, $\Delta\phi < 2.7$



- discovery with $\mathcal{L}$=5 fb^{-1} (8 events, 1 background)
- big advantage, missing mass reconstructed with AFP: $W = \sqrt{s\xi_1\xi_2}$

cut / process 30 fb^{-1}	$\gamma\gamma \to ee$ $(\mu\mu)$	$\gamma\gamma \to \tau\tau$	DPE$\to ll$	DPE$\to WW$	$\gamma\gamma \to WW$
$p_T > 10$ GeV	24896	177	17931	8.8	95
after cuts	0	0	1.0	0.67	51

Effective Lagrangian - quartic couplings

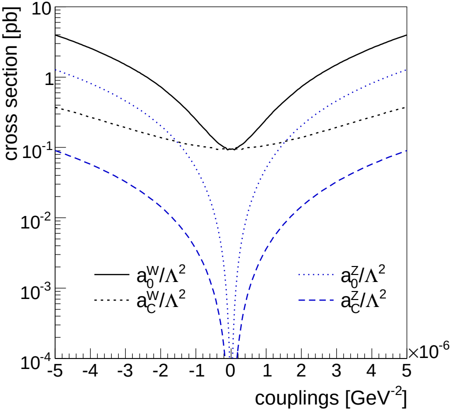


$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

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

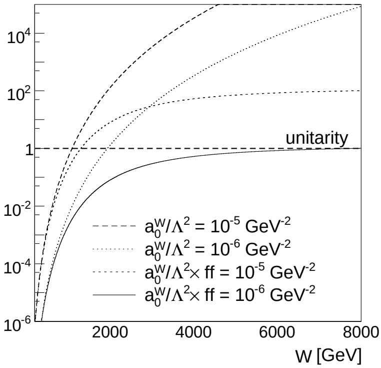
- modifying the direct quartic amplitude
- in $\mathcal{L}_6^0$ - indices of F and W,Z decoupled, term can be interpreted as effective exchange of a scalar
- appears naturally in Higgs-less theories

Total WW and ZZ cross sections



- enhancement of the SM cross section - WW: 95.6 fb, ZZ: 0
- notice coupling scale 10^{-6} GeV^2, OPAL limits $\sim 10^{-2}$ GeV^2
- any (non)observation can give important constraints on the couplings

Violation of unitarity



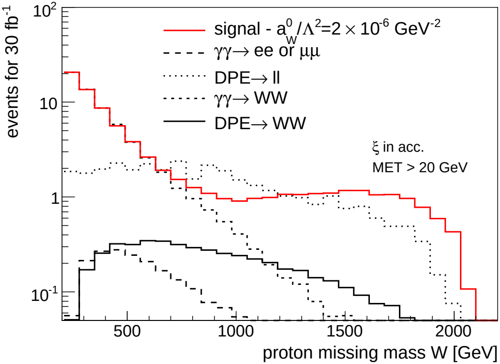
- anomalous coupling – low energy approximation of new theory
- dimension 6 operators → violation of unitarity at high energy
- sensitivities should not be driven by the divergence cause by longitudinal polarization of vector bosons

- introducing form factors by conventional way:

$a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W_{\gamma\gamma}/\Lambda_{\rm cutoff})^2}$ $\quad \Lambda_{\rm cutoff} = 2$ TeV . . . scale of the new physics

Anomalous quartic coupling - high lumi

- looking for high p_T and high mass signal
- $p_T^{lep1} > 160$ GeV, $p_T^{lep2} > 10$ GeV, $M_{ll} \notin \langle 80, 100 \rangle$, $\Delta\phi < 3.13$, $\not{E}_T > 20$ GeV
- $0.0015 < \xi < 0.15$, $W > 800$ GeV



largest backgrounds

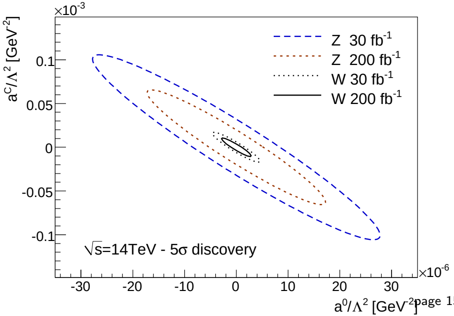
- $\gamma\gamma \rightarrow WW$
- DPE$\rightarrow ll$
- ~ 1 event for 30 fb^{-1}

Sensitivities at high luminosity

Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 95% CL
a_0^W/Λ^2	[-0.020, 0.020]	2.6×10^{-6} (1.4×10^{-6})
a_C^W/Λ^2	[-0.052, 0.037]	9.4×10^{-6} (5.2×10^{-6})
a_0^Z/Λ^2	[-0.007, 0.023]	6.4×10^{-6} (2.5×10^{-6})
a_C^Z/Λ^2	[-0.029, 0.029]	24×10^{-6} (9.2×10^{-6})

- improvement of sensitivities up to 4 orders of magnitude with 30 fb^{-1}

- E. Chapon, O. Kepka and C. Royon, Phys.Rev.D81:074003, 2010



Sensitivity to triple couplings

$$\mathcal{L}/g_{WW\gamma} = i(W^+_{\mu\nu}W^\mu A^\nu - W_{\mu\nu}W^{+\mu}A^\nu) + i\kappa^\gamma W^+_\mu W_\nu A^{\mu\nu} + i\frac{\lambda^\gamma}{M_W^2}W^+_{\rho\mu}W^\mu{}_\nu A^{\nu\rho}$$

$$\Delta\kappa^\gamma = \kappa^\gamma - 1$$

- $\Delta\kappa^\gamma$ signal at low, λ^γ signal at high $W = \sqrt{s\xi_1\xi_2}$ mass
- TGC already well constrained from LEP
- Improvement up to a factor of 10 wrt. Tevatron

Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 95% CL
$\Delta\kappa^\gamma$	[-0.098, 0.1]	[-0.25, 0.16] ([-0.096, 0.057])
λ^γ	[0.044, 0.047]	[-0.052, 0.049] ([-0.023, 0.027])

Summary

- LHC can be used also as a photon-photon collider
- allows to test SM in a unique way in clean exclusive QED process
  - quartic couplings discussed - appears in Higgs-less models
  (little Higgs model, 5D Higgs-less model, holographic composite model, etc. C. Grojean, arXiv:0910.4976)
  - triple gauge coupling also possible (but smaller improvement)

- important step in precision measurement of quartic coupling before ILC
- photon-photon induced processes can be studied at e^+e^-