Anomalous gauge couplings in W/Z exclusive pair production at the LHC

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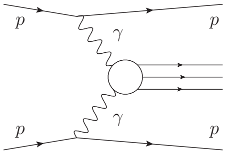
Outline

Diffraction at the LHC

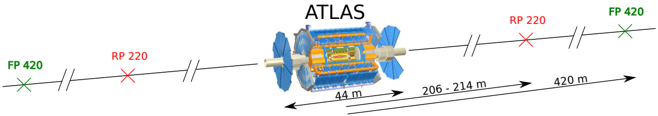
We study exclusive diffractive processes at the LHC.

- Exclusive: events with an object produced in the central detector, two protons and nothing else (no energy loss or remnants).
- We use FPMC (Forward Physics Monte-Carlo), a generator implementing diffractive or photon induced processes.



ATLAS Forward Physics project (AFP):

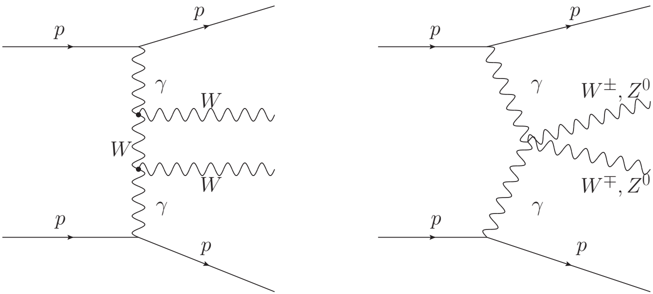
- Upgrade of the ATLAS experiment.
- Forward proton detectors to be installed on both sides of the ATLAS detector, at $\sim 220\,\mathrm{m}$ in the LHC tunnel, in movable beam pipes: both silicon and timing detectors.



Two-photon interaction at the LHC

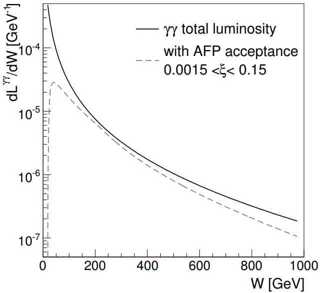
Study of the QED process $pp \to ppWW$

- Fairly large cross section in the Standard Model ($\sigma_{pp\to ppWW} = 95.6$ fb at $\sqrt{s} = 14$ TeV, $\sigma_{pp\to ppWW}(W = M_X > 1\,\text{TeV}) = 5.9$ fb)
- High sensitivity to beyond standard model effects, especially anomalous couplings.



Photon flux

Using photon equivalent approximation (Budnev flux) : low photon virtuality Q^2 but possibly high photon energy. In particular we can have high missing mass $M_{\gamma\gamma} = \sqrt{s\xi_1\xi_2}$ (where ξ is the momentum fraction loss of the proton).



Lagrangian

Lagrangian for anomalous quartic gauge couplings:

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

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

All anomalous parameters a_0^W, a_C^W, a_0^Z and a_C^Z are 0 in the SM.
Many more anomalous couplings possible ($\gamma\gamma$, Higgs, ...)

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Previous results

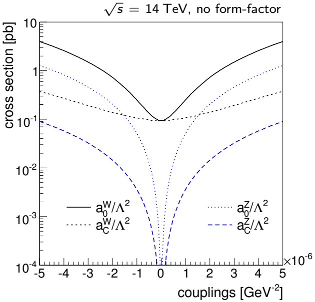
OPAL Collaboration (Phys. Rev. D **70**, 032005 (2004)):

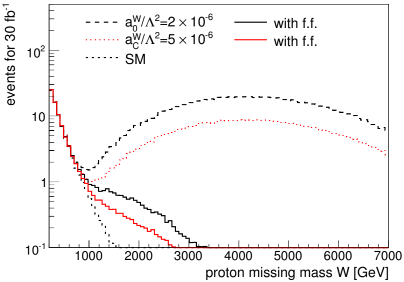
$$\begin{aligned}
-0.020 < \; & a_0^W/\Lambda^2 < 0.020\,\text{GeV}^{-2} \\
-0.052 < \; & a_C^W/\Lambda^2 < 0.037\,\text{GeV}^{-2} \\
-0.007 < \; & a_0^Z/\Lambda^2 < 0.023\,\text{GeV}^{-2} \\
-0.029 < \; & a_C^Z/\Lambda^2 < 0.029\,\text{GeV}^{-2}
\end{aligned}$$

Also recent results from DØ and CMS.

Unitarity

- The lagrangians for anomalous quartic gauge couplings $\mathcal{L}_6^0$ and $\mathcal{L}_6^C$ are dimension 6 operators: violation of unitarity at high energies.
- Need form factors to avoid quadratical divergences of scattering amplitudes: $a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W_{\gamma\gamma}^2/\Lambda^2)^2}$ where $\Lambda \sim 2\,\text{TeV}$, scale of new physics





Signal and backgrounds to *WW*

Signal

Two-photon *WW* events with two leptons in the final state, two tagged protons in the forward detectors, and nothing else associated to the primary vertex.

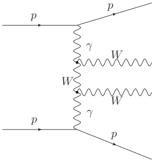
Possible backgrounds:

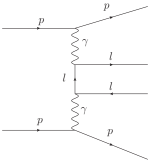
Inelastic *WW*: Characterized by large energy flow in forward regions

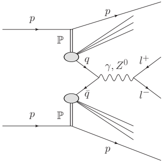
Dilepton through photon exchange: Leptons produced back to back, no missing E_T

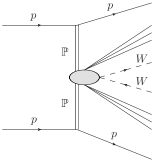
Dilepton through double pomeron exchange (DPE): Characterized by energy flow in the forward regions and higher number of tracks due to pomeron remnants

***WW* through double pomeron exchange:** Same as before



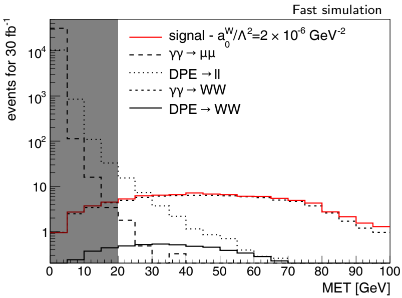


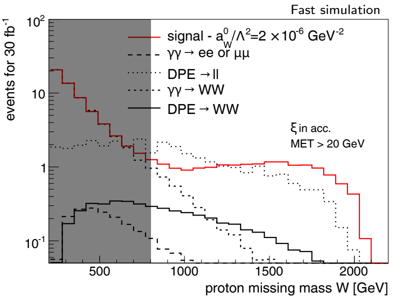




Background rejection

- Preselection: 2 reconstructed leptons (ee, $e\mu$ or $\mu\mu$) with $|\eta^{e,\mu}| < 2.5$ and $p_T^{e,\mu} > 10$GeV, two tagged protons, and nothing else associated to the primary vertex.
- Rejection of dilepton production:
  - Cut on missing E_T and on $\Delta\phi_{ll}$
- Reject DPE WW, increase the sensitivity to anomalous couplings:
  - Cut on the mass W of the central system and on the leading lepton p_T





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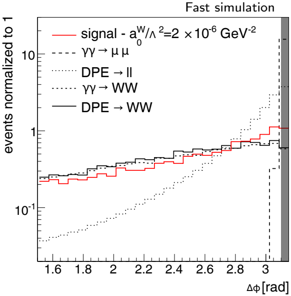
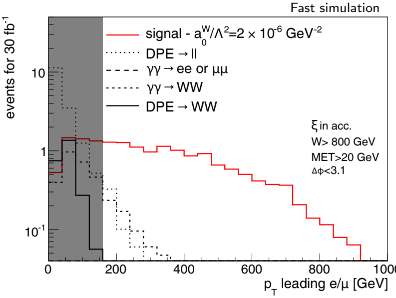




Cutflow

events for 30fb^{-1} (fast simulation ATLFAST++)

cut / process	$\gamma\gamma \to ll$	$\gamma\gamma \to WW$	DPE $\to ll$	DPE $\to WW$
$p_T^{\text{lep1,2}} > 10$ GeV	50619	99	18464	8.8
$0.0015 < \xi < 0.15$	21058	89	11712	6.0
$\not{E}_T > 20$ GeV	14.9	77	36	4.7
$W > 800$ GeV	0.42	3.2	16	2.5
$M_{ll} \notin [80, 100]$	0.42	3.2	13	2.5
$\Delta\phi < 3.13$ rad	0.10	3.2	12	2.5
$p_T^{lep1} > 160$ GeV	0	0.69	0.20	0.024

cut / couplings (with f.f.)	$\lvert a_0^W/\Lambda^2 = 5.4 \cdot 10^{-6}$ GeV^{-2}	$\lvert a_C^W/\Lambda^2\rvert = 20 \cdot 10^{-6}$ GeV^{-2}
$p_T^{\text{lep1,2}} > 10$ GeV	202	200
$0.0015 < \xi < 0.15$	116	119
$\not{E}_T > 20$ GeV	104	107
$W > 800$GeV	24	23
$M_{ll} \notin [80, 100]$	24	23
$\Delta\phi < 3.13$ rad	24	22
$p_T^{lep1} > 160$ GeV	17	16

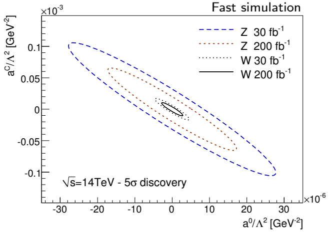
Almost no background at final selection.

Results (using fast simulation ATLFAST++)

Couplings	OPAL limits $[\mathrm{GeV}^{-2}]$	95% limits @ $\mathcal{L} = 30\,(200)\,\mathrm{fb}^{-1}$ $\Lambda = \infty$	$\Lambda = 2\,\mathrm{TeV}$
a_0^W/Λ^2	$[-0.020, 0.020]$	$1.2 \cdot 10^{-6}$ $(0.7 \cdot 10^{-6})$	$2.6 \cdot 10^{-6}$ $(1.4 \cdot 10^{-6})$
a_0^Z/Λ^2	$[-0.052, 0.037]$	$4.2 \cdot 10^{-6}$ $(2.4 \cdot 10^{-6})$	$9.4 \cdot 10^{-6}$ $(5.2 \cdot 10^{-6})$
a_C^W/Λ^2	$[-0.007, 0.023]$	$2.8 \cdot 10^{-6}$ $(1.1 \cdot 10^{-6})$	$6.4 \cdot 10^{-6}$ $(2.5 \cdot 10^{-6})$
a_C^Z/Λ^2	$[-0.029, 0.029]$	$1.0 \cdot 10^{-5}$ $(4.1 \cdot 10^{-6})$	$2.4 \cdot 10^{-5}$ $(9.2 \cdot 10^{-6})$

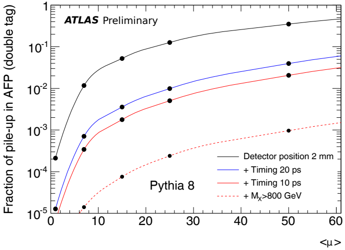
Up to 4 orders of magnitude more sensitive than LEP limits

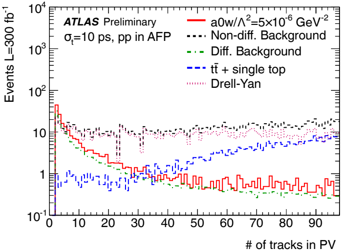
- Reaches values predicted by models with extra-dimensions.
- > 1 order of magnitude more sensitive than "standard" searches using $pp \rightarrow l^{\pm}\nu\gamma\gamma$ (J.P. Bell, Eur. Phys. J. C **64**, 25 (2009)).



Full simulation

- Previous slides assume that pile-up and non-diffractive backgrounds are perfectly rejected.
- Exclusivity of the event defined thanks to the proton time of flight but also tracks fitted to the vertex: need full simulation to study them.
  - For signal, only two tracks expected from the vertex (two charged leptons from the decay of the Ws).
  - Backgrounds considered: previously mentioned diffractive processes, single-diffractive WW, non-diffractive backgrounds ($t\bar{t}$, diboson, W/Z+jets, Drell-Yan, single top).
- Assume 10 ps resolution for the proton timing detectors, and two scenarios: $\mathcal{L} = 40(200)\,\text{fb}^{-1}$, $\mu = 23(46)$ interactions per bunch crossing.

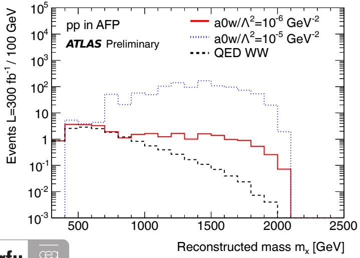




Results from full simulation

events for 300fb^{-1} and $\mu = 46$ (full simulation)

Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{\text{lep1}} > 150$ GeV $p_T^{\text{lep2}} > 20$ GeV	5198	601	20093	1820	190	282
$M_{ll} > 300$ GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV	0.6	0.4	7.3	0	1.1	50
$p_T^{\text{lep1}} > 300$ GeV	0	0.2	0	0	0.2	35



	a_0^W/Λ^2 Sensitivity 5σ	95% C.L.
$\mathcal{L} = 40\ \text{fb}^{-1}$, $\mu = 23$	$5.5 \cdot 10^{-6}$	$2.4 \cdot 10^{-6}$
$\mathcal{L} = 300\ \text{fb}^{-1}$, $\mu = 46$	$3.2 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$

Very similar sensitivity compared to fast simulation.

Summary

Probing new physics in the electroweak sector

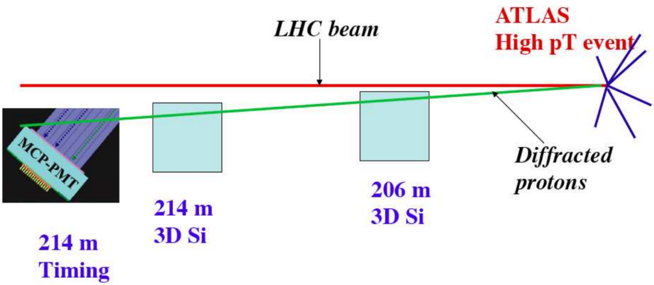
- The LHC as a "photon collider."
- Proton tagging with AFP allows to reject inclusive backgrounds.
- Potential improvement of current limits on anomalous quartic gauge boson couplings (up to 4 orders of magnitude compared to LEP limits).

More information:

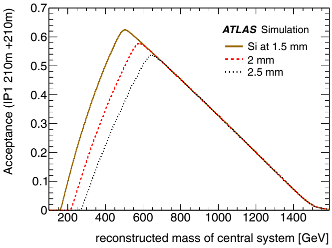
- E. Chapon, C. Royon and O. Kepka, Phys. Rev. D **81**, 074003 (2010)
- ATLAS Collaboration, *Letter of Intent for the Phase-I Upgrade of the ATLAS Experiment*, LHCC-I-020 (2011).

Additional material

ATLAS Forward Physics (AFP)



- Tag and measure protons at ±210 m from the interaction point.
- Trigger: rely on ATLAS high p_T L1 trigger.
- AFP detectors: Radiation hard "edgeless" 3D silicon detectors, 10 ps timing detectors.
- Allows running in high pile up conditions with correct primary vertex: access to rare processes.



What about anomalous triple gauge couplings?

Lagrangian for anomalous triple gauge couplings:

$$\mathcal{L}_{\mathrm{TGC}}/(-ie) = \left(W^{\dagger}_{\mu\nu} W^{\mu} A^{\nu} - W_{\mu\nu} W^{\dagger\mu} A^{\nu}\right) + (1 + \Delta\kappa^{\gamma})\, W^{\dagger}_{\mu} W_{\nu} A^{\mu\nu} + \frac{\lambda^{\gamma}}{M_W^2} W^{\dagger}_{\rho\mu} W^{\mu}_{\nu} A^{\nu\rho}$$

	$\mathcal{L} = 30\text{fb}^{-1}$		$\mathcal{L} = 200\text{fb}^{-1}$	
	$\Delta\kappa^{\gamma}$	λ^{γ}	$\Delta\kappa^{\gamma}$	λ^{γ}
95% c.l	[-0.25, 0.16]	[-0.052, 0.049]	[-0.096, 0.057]	[-0.023, -0.027]
3σ evidence	[-0.39, 0.25]	[-0.066, 0.064]	[-0.136, 0.087]	[-0.037, 0.038]
5σ evidence	[-0.67, 0.40]	[-0.088, 0.094]	[-0.26, 0.16]	[-0.053, 0.049]

	$\Delta\kappa^{\gamma}$	λ^{γ}
$W\gamma, (p_T^{\gamma})$	[-0.11, 0.05]	[-0.02, 0.01]
$WW, (M_T)$	[-0.056, 0.054]	[-0.052, 0.100]