Anomalous $WW\gamma$, $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings in γ-induced processes

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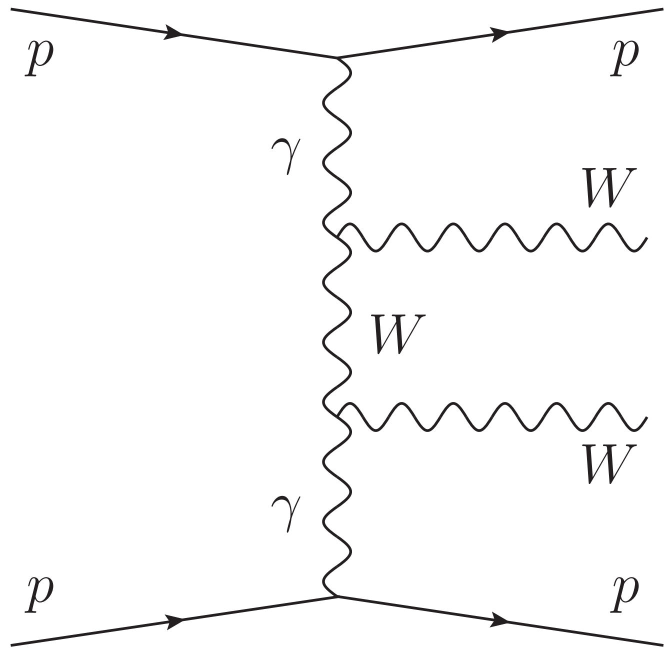
Contents:

- WW production cross section at the LHC
- Trilinear anomalous coupling
- Quartic anomalous couplings

Work in collaboration with E. Chapon, O. Kepka
See arXiv:0808.0322, Phys. Rev. D78 (2008) 073005; arXiv:0908.1061; arXiv:0912.5161 accepted by Phys. Rev. D.
T J. De Favereau et al., arXiv:0908.2020.
Production of SUSY particles: See talk by Nicolas Schul, Trento 2010, http://diff2010-lhc.physi.uni-heidelberg.de/Talks/, and arXiv:0910.0202

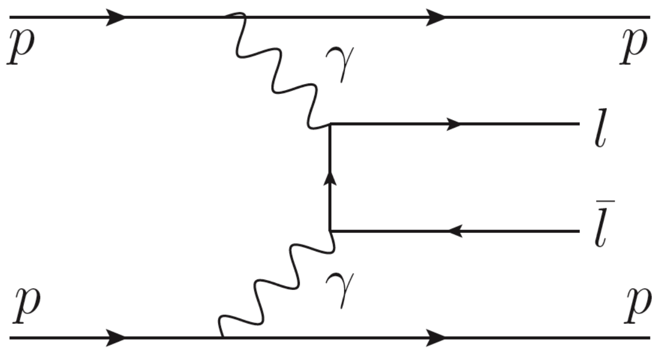
WW production at the LHC



- Study of the process: $pp \to ppWW$
- Clean process: W in central detector and nothing else, intact protons in final state which can be detected far away from interaction point
- Exclusive production of W pairs via photon exchange: QED process, cross section perfectly known
- Two steps: SM observation of WW events, anomalous coupling study (NB: new anomalous couplings predicted by beyond standard model theories) at high luminosities at LHC
- $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W > 1TeV) = 5.9$ fb
- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; arXiv:0912.5161 accepted by Phys. Rev. D; T J. De Favereau et al., arXiv:0908.2020.

WW production at the LHC

- Signal: We focus on leptonic signals decays of WW and ZZ, the protons are tagged in the forward proton detectors; fast simulation of the ATLAS detector (ATLFast++)
- Backgrounds considered:
  - Non diffractive WW production: large energy flow in forward region, removed by requesting tagged protons
  - Two photon dileptons: back-to-back leptons, small cross section for high p_T leptons



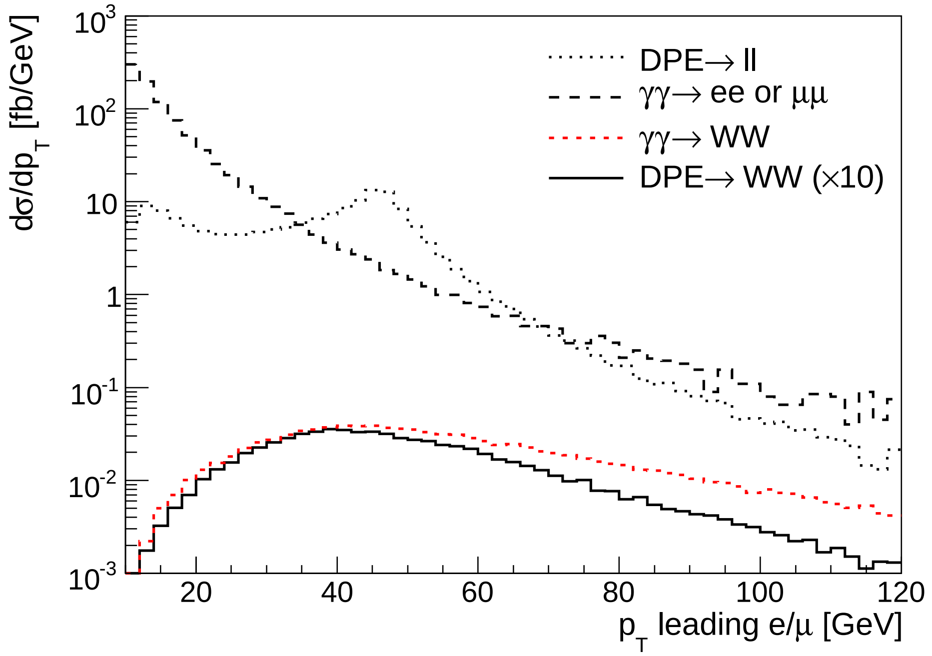
  - Lepton production via double pomeron exchange: activity in the forward region due to pomeron remnants, removed by $\not{E}_T$ cut
  - WW via double pomeron exchange: removed by cut on high diffractive mass

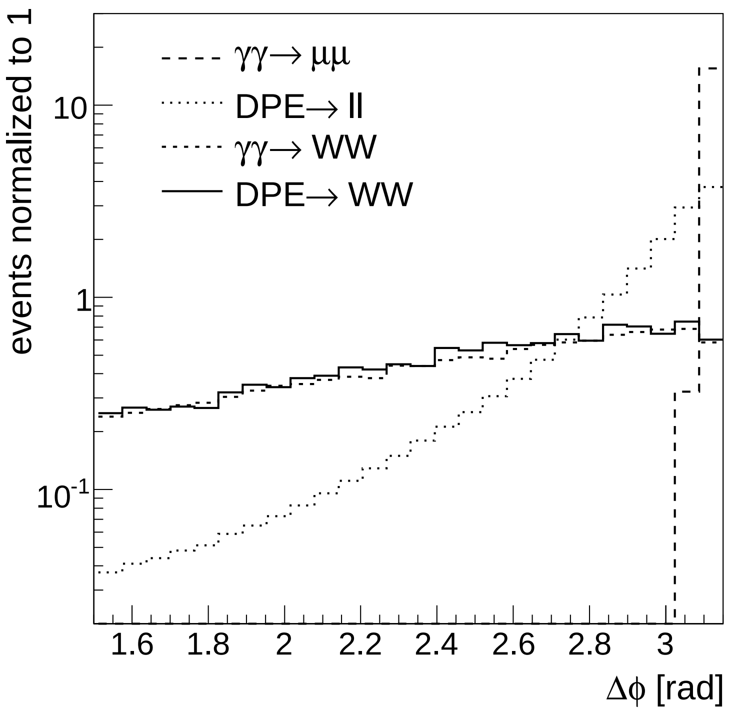
Forward Physics Monte Carlo (FPMC)

- FPMC (Forward Physics Monte Carlo): implementation of all diffractive/photon induced processes
- List of processes
  - two-photon exchange
  - single diffraction
  - double pomeron exchange
  - central exclusive production
- Inclusive diffraction: Use of diffractive PDFs measured at HERA, with a survival probability of 0.03 applied for LHC
- Survival probability for photon exchange events: 0.9
- Central exclusive production: Higgs, jets... for Khoze Martin Ryskin or Dechambre Cudell models as an example; Szczurek et al. model to be implemented (See talk by Rafal Staszewski)
- FPMC manual in preparation (M. Boonekamp, O. Kepka, V. Juranek, C. Royon, R. Staszewski...)
- Output of FPMC generator interfaced with the fast simulation of the ATLAS detector in the standalone ATLFast++ package

Strategy to measure the $\gamma\gamma \to WW$ SM cross section

- Require both Ws to decay leptonically (as a starting point to avoid jet background) with p_T of leading (2nd leading) lepton above 25, 10 GeV
- Require both protons in the ATLAS Forward Proton (AFP) detector
- $\not{E}_T > 20$ GeV, natural for W decays (get rid of dilepton background produced by photon exchange
- $\Delta\Phi$ between leading leptons allows to remove dilepton background



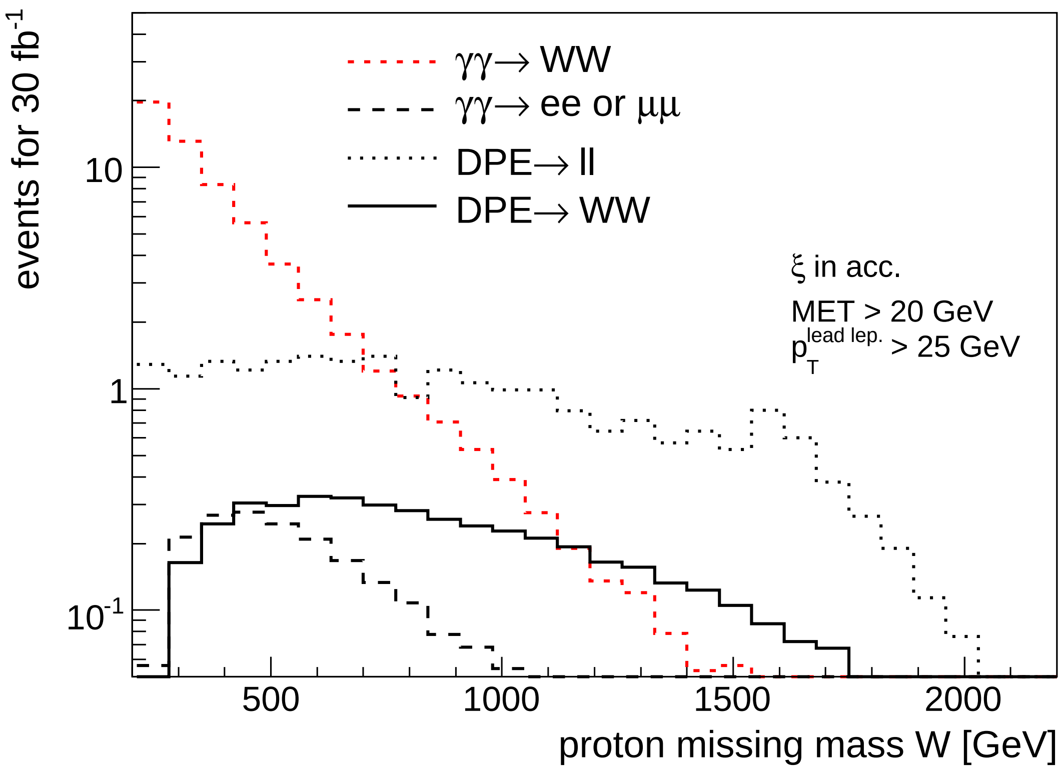


Measuring the $\gamma\gamma \to WW$ SM cross section

Number of events for 30 fb^{-1} after successive cuts

cut / process	$\gamma\gamma \to ll$	DPE$\to ll$	DPE$\to WW$	$\gamma\gamma \to WW$
$p_T^{lep1,2} > 10$ GeV	50620	17931	8.8	95
$0.0015 < \xi < 0.15$	21059	11487	5.9	89
$\not{E}_T > 20$ GeV	14.9	33	4.7	78
$W > 160$ GeV	9.2	33	4.7	78
$\Delta\phi < 2.7$	0	14	3.8	61
$p_T^{lep} > 25$ GeV	0	7.5	3.5	58
$W < 500$	0	1.0	0.67	51

5 σ discovery possible after 5 fb^{-1} (pure leptonic decays of Ws)



Measuring the $\gamma\gamma \rightarrow WW$ SM cross section: semi-leptonic decays

- Consider both leptonic and semileptonic decays of Ws
- Fast generator level study: For a luminosity of 200 pb^{-1}, observation of 5.6 W pair events for a background less than 0.4, which leads to a signal of 8 σ

ξ_{max}	signal (fb)	background (fb)
0.05	13.8	0.16
0.10	24.0	1.0
0.15	28.3	2.2

- Study needs to be redone considering the simulation of all backgrounds: especially when one of the quarks radiates a W boson, which is being implemented in FPMC

Quartic anomalous gauge couplings

- Quartic gauge anomalous $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings parametrised by a_0^W, a_0^Z, a_C^W, a_C^Z

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

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

- Anomalous parameters equal to 0 for SM
- Non zero anomalous couplings motivated by Higgsless and extra dimension models (under study: Christophe Grojean et al.)
- Best limits from LEP, OPAL (Phys. Rev. D 70 (2004) 032005) of the order of 0.02-0.04, for instance $-0.02 < a_0^W < 0.02$ GeV^{-2}
- Dimension 6 operators $\rightarrow$ violation of unitarity at high energies

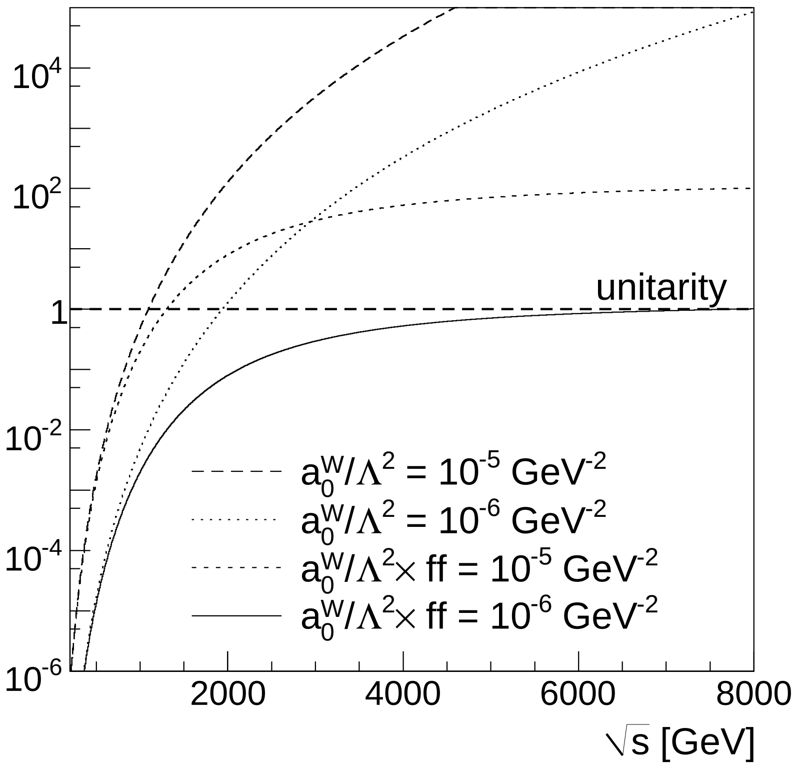
Quartic anomalous gauge couplings: form factors

- Unitarity bounds can be computed (Eboli, Gonzales-Garcia, Lietti, Novaes):

$$4\left(\frac{\alpha a s}{16}\right)^2\left(1-\frac{4M_W^2}{s}\right)^{1/2}\left(3-\frac{s}{M_W^2}+\frac{s^2}{4M_W^4}\right)\leq 1$$

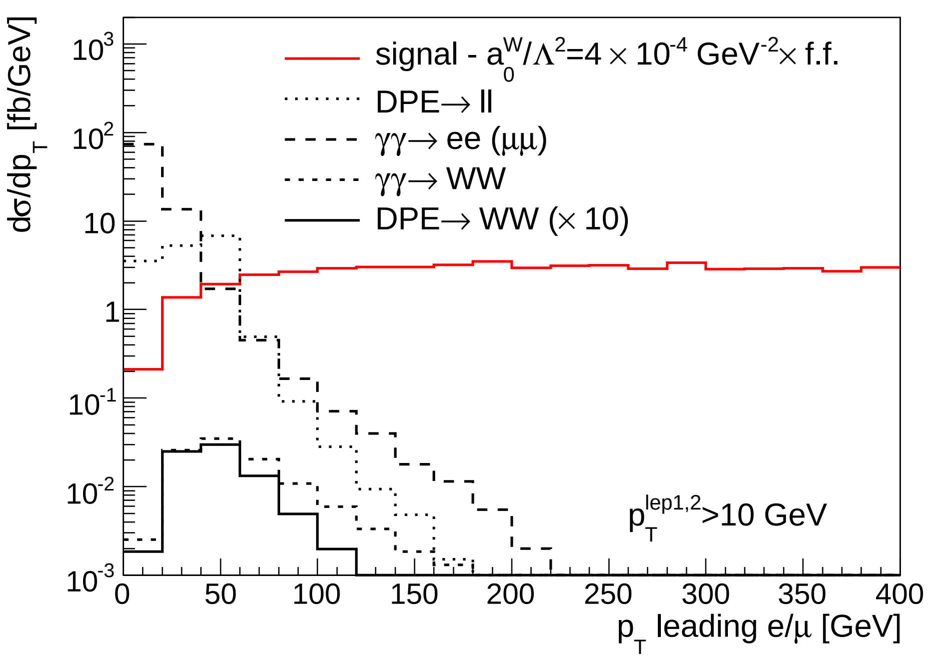
where $a = a_0/\Lambda^2$

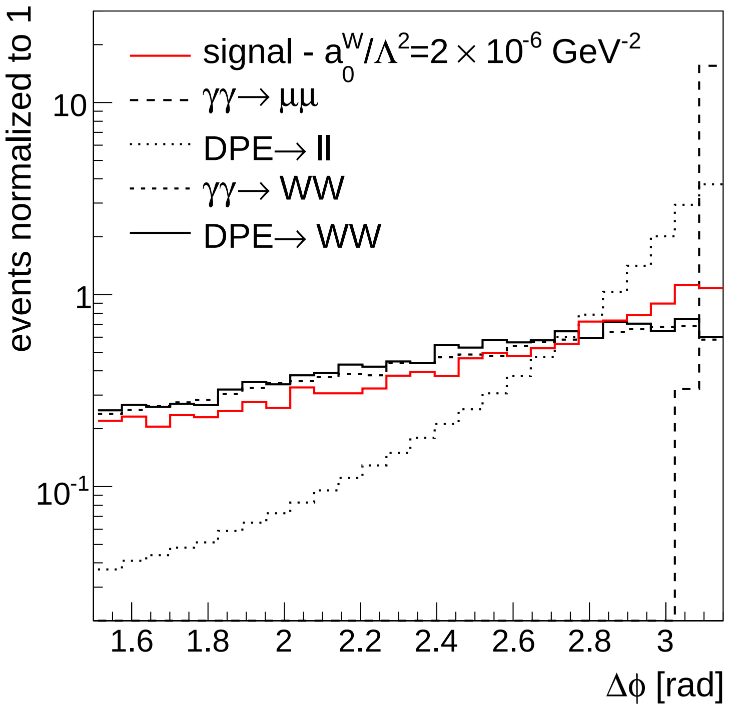
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics
- For $a_0^W \sim 10^{-6}$ GeV^{-2}, no violation of unitarity



Strategy to select quartic anomalous gauge couplings events

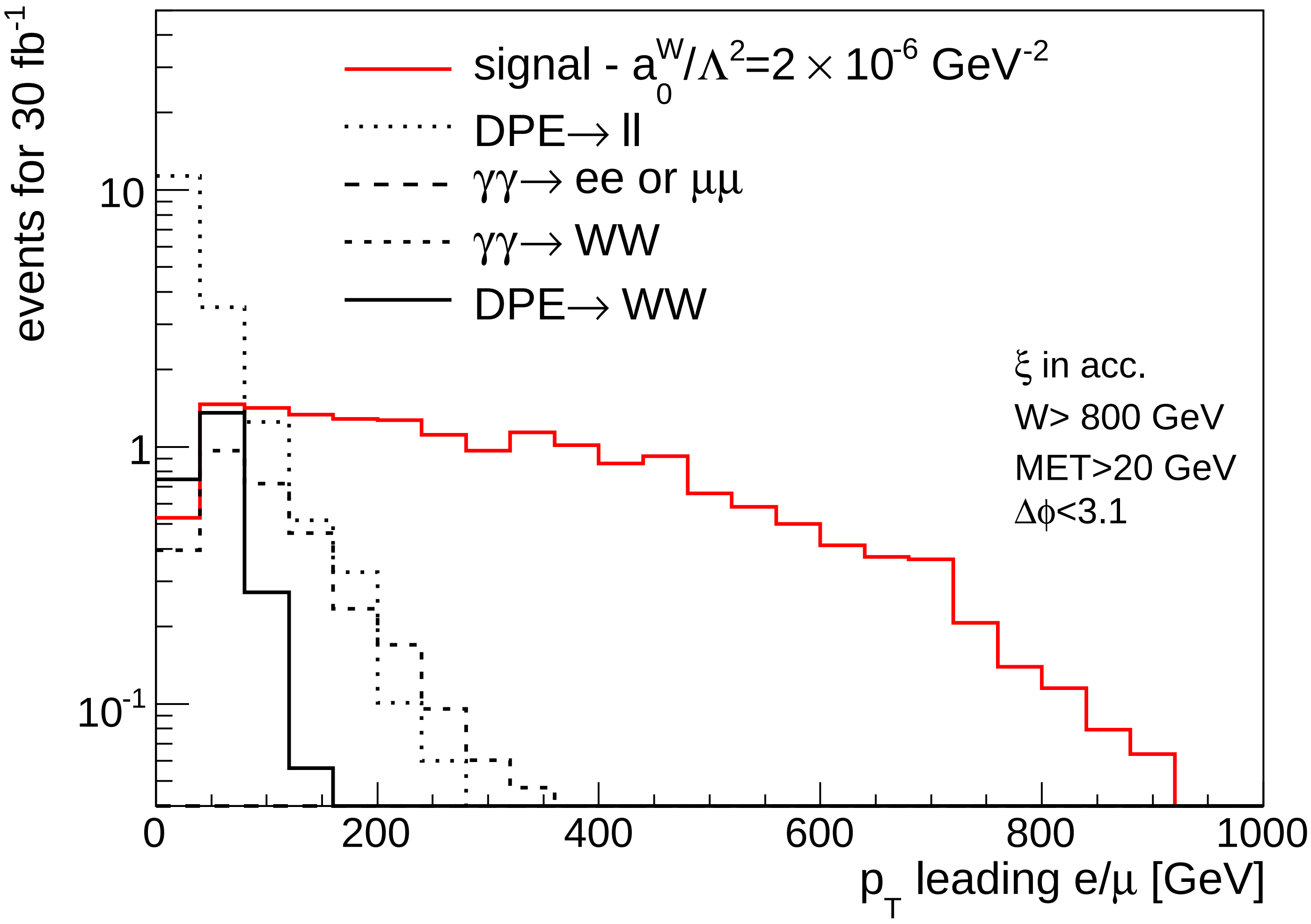
- p_T of the leading lepton: request high p_T lepton to remove background
- Missing E_T distribution: natural to be requested for W pair production
- Diffractive mass computed using the forward proton detectors $\sqrt{\xi_1 \xi_2 S}$: request high mass objects to be produced
- $\Delta\Phi$ between both leptons: avoid back-to-back leptons





Quartic anomalous gauge couplings

Distribution of the leading lepton p_T after all cuts (proton tagged, $\not{E}_T$, diffractive mass, $\Delta\Phi$) except the cut on leading lepton p_T



Quartic anomalous gauge couplings

Background events for 30 fb^{-1}

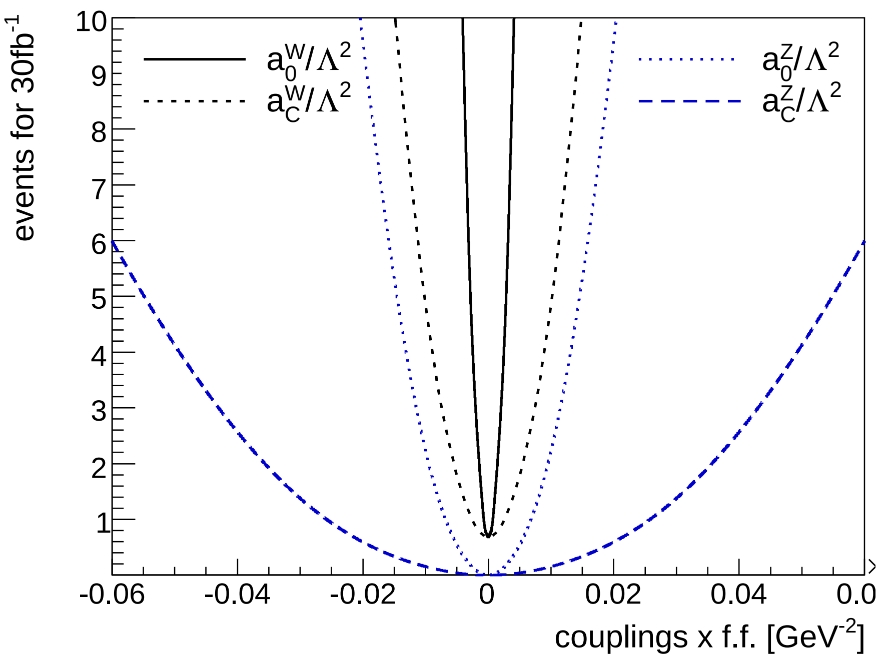
cut / process	$\gamma\gamma \to ll$	$\gamma\gamma \to WW$	DPE$\to ll$	DPE$\to WW$
$p_T^{lep1,2} > 10$ GeV	50619	99	18464	8.8
$0.0015 < \xi < 0.15$	21058	89	11712	6.0
$\not{E}_T > 20$ GeV	14.9	77	36	4.7
$W > 800$ GeV	0.42	3.2	16	2.5
$M_{ll} \notin < 80, 100 >$	0.42	3.2	13	2.5
$\Delta\phi < 3.13$	0.10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

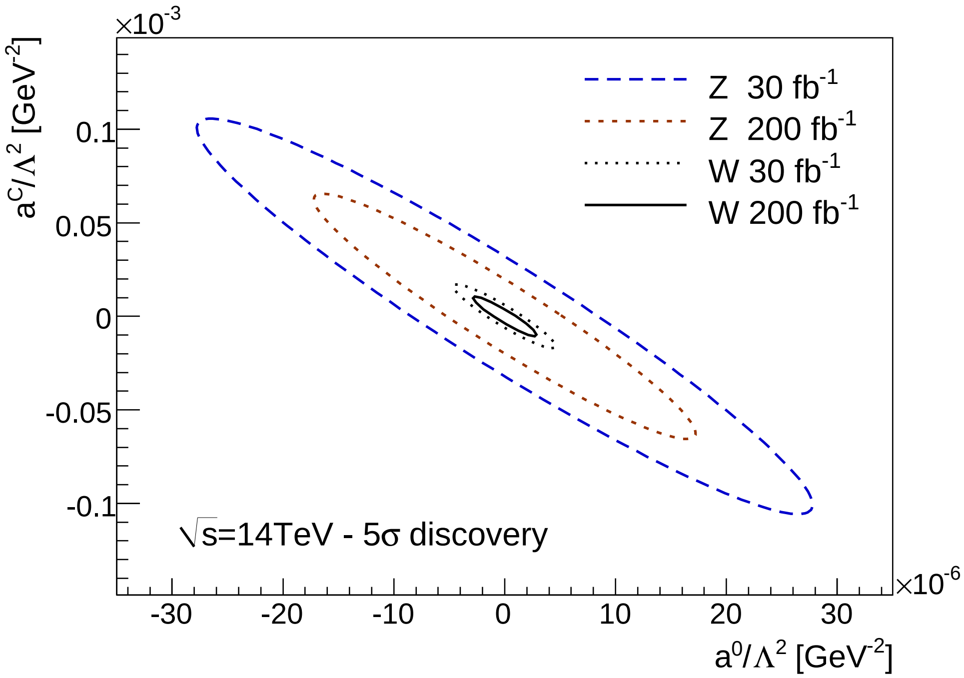
Signal events for 30 fb^{-1}

cut / couplings (with f.f.)	$\|a_0^W/\Lambda^2\| = 5.4 \cdot 10^{-6}$	$\|a_C^W/\Lambda^2\| = 20 \cdot 10^{-6}$
$p_T^{lep1,2} > 10$ 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
$\Delta\phi < 3.13$	24	22
$p_T^{lep1} > 160$ GeV	17	16

Quartic anomalous gauge couplings

- Strategy for ZZ events similar: Request either three leptons or two leptons of the same sign, protons tagged in forward detectors, p_T of leading leptons greater than 160 GeV
- Number of events for 30 fb^{-1} for the different couplings
- 5σ discovery countours for two different luminosities 30 and 200 fb^{-1}
- Present LEP limits can be improved by up to four orders of magnitude





Reach at LHC

Reach at high luminosity on quartic anomalous coupling

Couplings	OPAL limits $[\mathrm{GeV}^{-2}]$	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$5.4\ 10^{-6}$ ($2.7\ 10^{-6}$)	$2.6\ 10^{-6}$ ($1.4\ 10^{-6}$)
a_C^W/Λ^2	[-0.052, 0.037]	$2.0\ 10^{-5}$ ($9.6\ 10^{-6}$)	$9.4\ 10^{-6}$ ($5.2\ 10^{-6}$)
a_0^Z/Λ^2	[-0.007, 0.023]	$1.4\ 10^{-5}$ ($5.5\ 10^{-6}$)	$6.4\ 10^{-6}$ ($2.5\ 10^{-6}$)
a_C^Z/Λ^2	[-0.029, 0.029]	$5.2\ 10^{-5}$ ($2.0\ 10^{-5}$)	$2.4\ 10^{-5}$ ($9.2\ 10^{-6}$)

- Improvement of LEP sensitivity by more than 4 orders of magnitude with 30/200 fb^{-1} at LHC!!!

Trilinear anomalous gauge couplings

- Lagrangian with trilinear gauge $WW\gamma$ anomalous couplings λ^γ and $\Delta\kappa^\gamma$

$$\mathcal{L} \sim (W^\dagger_{\mu\nu} W^\mu A^\nu - W_{\mu\nu} W^{\dagger\mu} A^\nu) + (1 + \Delta\kappa^\gamma) W^\dagger_\mu W_\nu A^{\mu\nu} + \frac{\lambda^\gamma}{M_W^2} W^\dagger_{\rho\mu} W^\mu{}_\nu A^{\nu\rho}$$

- Present limits on trilinear gauge anomalous couplings:
  - From LEP: $-0.098 < \Delta\kappa^\gamma < 0.101$; $-0.044 < \lambda^\gamma < 0.047$ (Inconvenient: mixture of γ and Z exchanges in $e^+e^- \to WW$)
  - From Tevatron: $-0.51 < \Delta\kappa^\gamma < 0.51$; $-0.12 < \lambda^\gamma < 0.13$ (direct limits)

- Same strategy as for quartic anomalous couplings with the caveat that the signal appears at high mass for λ^γ, and $\Delta\kappa^\gamma$ only modifies the normalisation and the low mass events have to be retained:
  - for $\Delta\kappa^\gamma$:

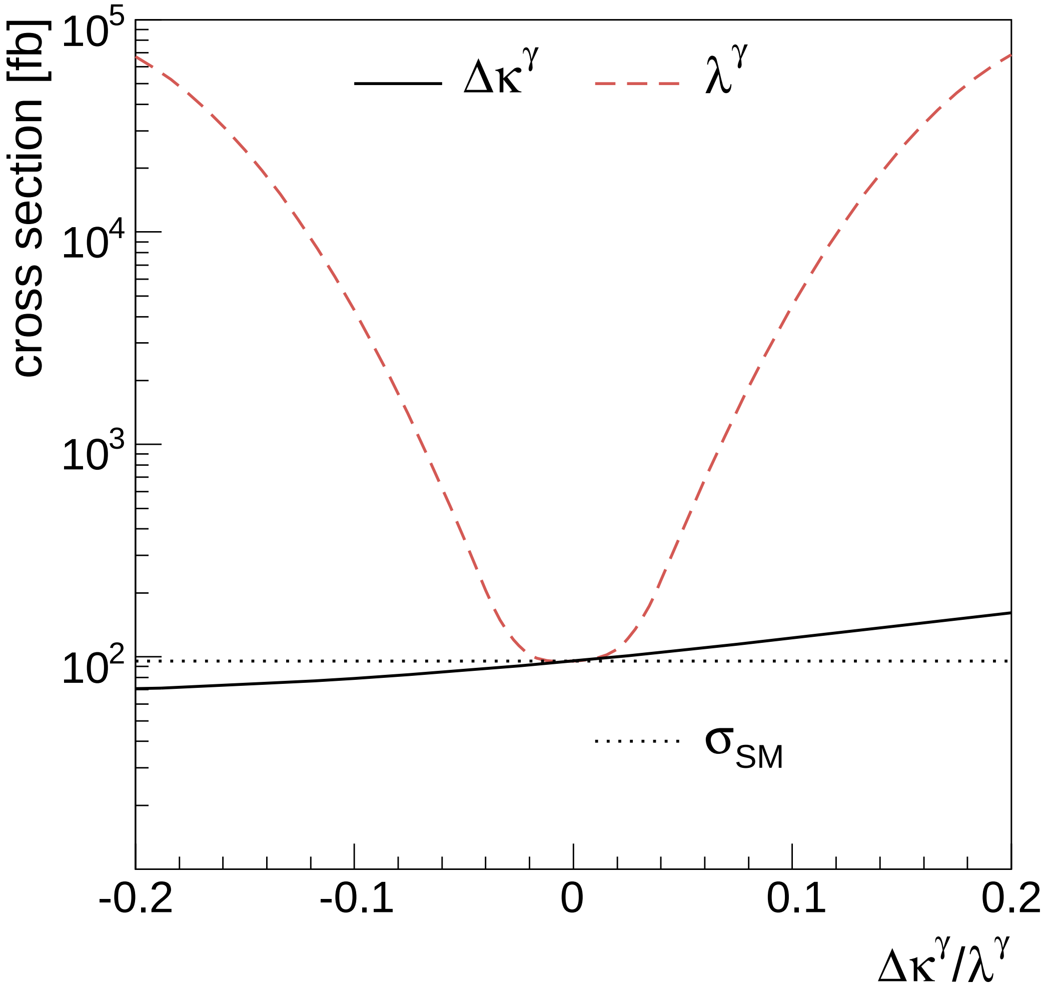
$$p_T^{lep1} > 25 \text{ GeV} , \ p_T^{lep2} > 10 \text{ GeV} , \ 0.0015 < \xi < 0.15, \ \not{E}_T > 20 \text{ Ge}$$
$$W > 160 \text{ GeV} , \ \Delta\phi < 2.7, \ W < 500 \text{ GeV}$$

  - for λ^γ:

$$p_T^{lep1} > 160 \text{ GeV} , \ p_T^{lep2} > 10 \text{ GeV} , \ 0.0015 < \xi < 0.15, \ \not{E}_T > 20 \text{ G}$$
$$W > 800 \text{ GeV} , \ M_{ll} \notin \langle 80, 100 \rangle \, GeV, \ \Delta\phi < 3.13 rad$$

Anomalous $WW\gamma$ triple gauge coupling

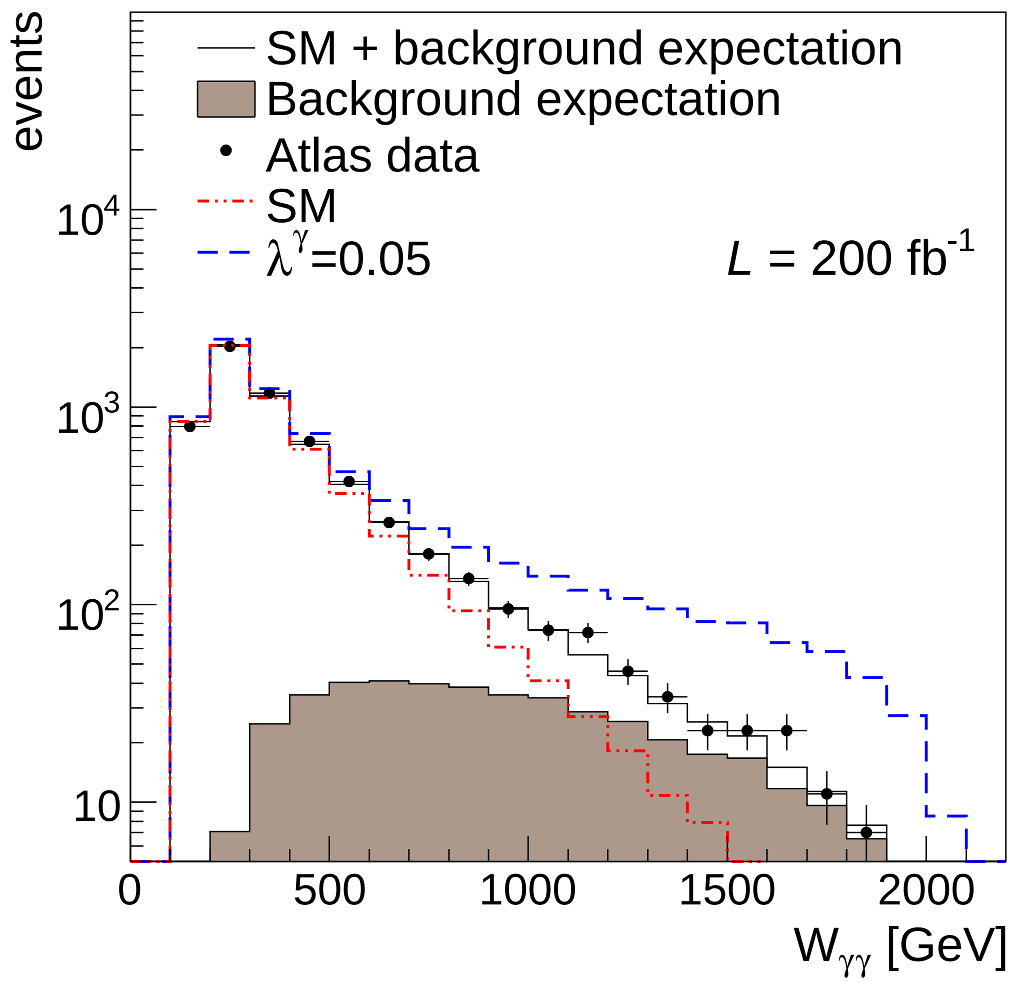
Different behaviour of the cross section as a function of anomalous couplings



Measurement of WW events at high luminosities at LHC, $2W$ events and protons tagged in forward detectors

Reach on anomalous coupling

- Reach on anomalous coupling at the LHC using a luminosity of 200 fb^{-1}
  - 5σ discovery: $-0.26 < \Delta\kappa^\gamma < 0.16$; $-0.053 < \lambda^\gamma < 0.049$
  - 95% CL limit: $-0.096 < \Delta\kappa^\gamma < 0.057$; $-0.023 < \lambda^\gamma < 0.027$,
- One of the best reaches before ILC, which can be improved using semi-leptonic decays of Ws



Conclusion

- Observation of QED WW production at the LHC: easy once forward detectors installed
- Quartic gauge anomalous coupling studies: Easy analysis (2 W or Z decaying in leptons); Improvement of LEP (OPAL) sensitivity by four orders of magnitude with $\sim$ 30-200 fb^{-1}
- Trilinear gauge anomalous coupling at high luminosity: requires forward detectors, gain of a factor 10 compared to Tevatron sensitivity (direct limit), gain of a factor 3 with respect to LEP (indirect limits), best reach before ILC