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

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Sakura meeting, 24-26 August 2009, Tokyo, Japan

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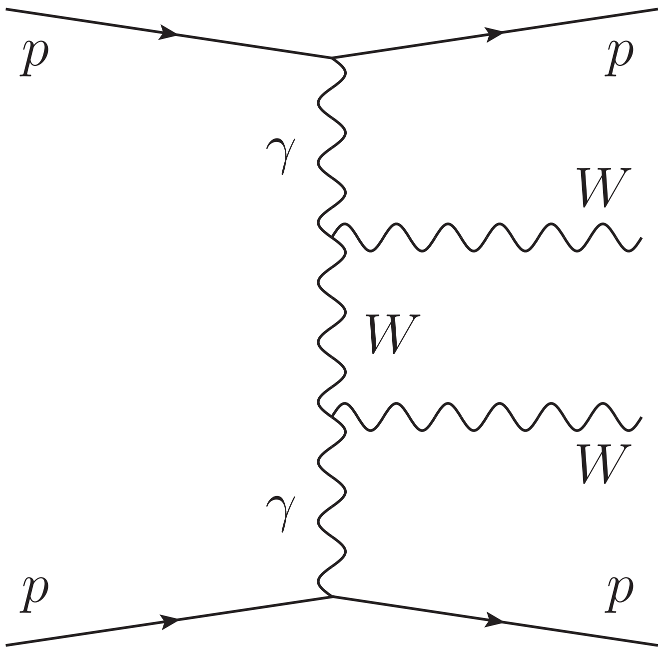
- Trilinear anomalous coupling
- Quartic anomalous couplings
- Motivation: exchange of heavy particles beyond the SM modifying the quartic couplings and higgs-less models modifying the SM quartic couplings, this might be the first evidence for physics beyond the SM

Work in collaboration with E. Chapon, O. Kepka
See arXiv:0808.0322, Phys. Rev. D78 (2008) 073005; arXiv:0908.1061

WW production at the LHC



- Study of the process: $pp \longrightarrow ppWW$
- 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 low and high luminosities at LHC
- $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W > 1TeV) = 5.9$ fb
- Rich $\gamma\gamma$ physics at LHC, supersymmetric particle production see T. Pierzchala, K. Piotrzkowski, Nucl. Phys. Proc. Suppl., 179 (2008))

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

- Forward detectors assumed for ATLAS/CMS experiments allowing to detect protons in the final state: $0.0015 < \xi < 0.15$ (proton fraction momentum carried by the photon)
- Signal and double pomeron exchange background cross section
- Clean signal: 2 W decaying in central detector, and proton detected in forward detectors
- 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

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

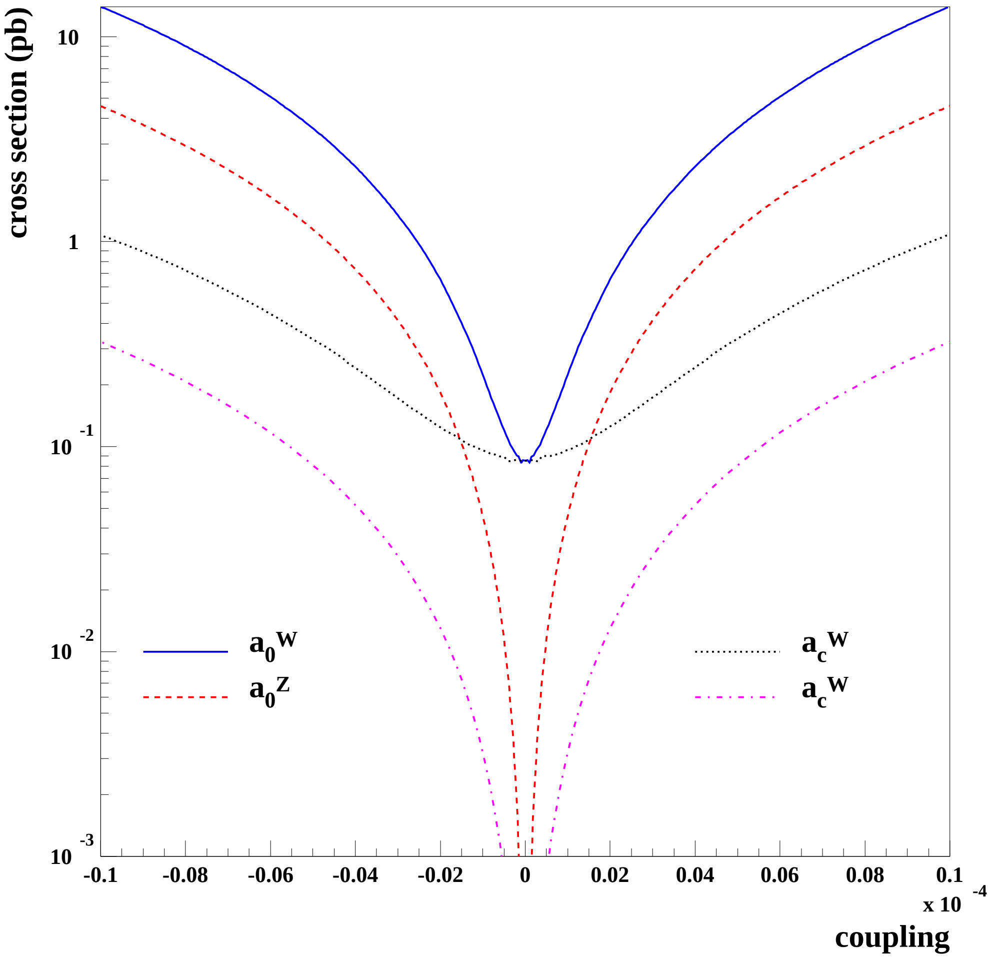
$$\mathcal{L}_6^0 \sim \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

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

- Anomalous parameters equal to 0 for SM
- 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
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics

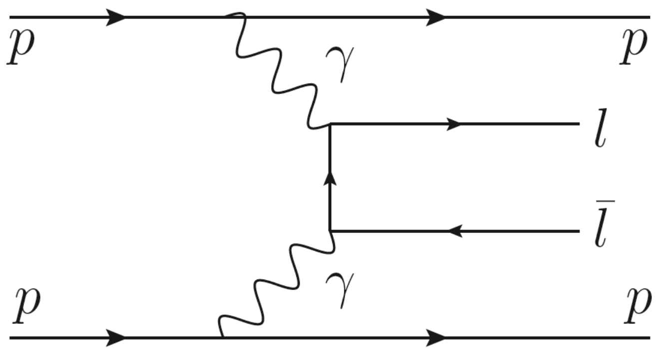
Anomalous $WW\gamma\gamma$ quartic gauge coupling

- High cross sections at LHC even for an anomalous coupling much smaller than LEP limits (~ 0.01), given the expected luminosity ($\sim$ fb^{-1})
- Strategy: Look for W pair events even at low luminosity at the beginning of the LHC (10 pb^{-1} at $\sqrt{S} = 10$ TeV) and at higher luminosity when forward detectors to tag the protons are installed



Quartic anomalous coupling signal at low luminosity at LHC

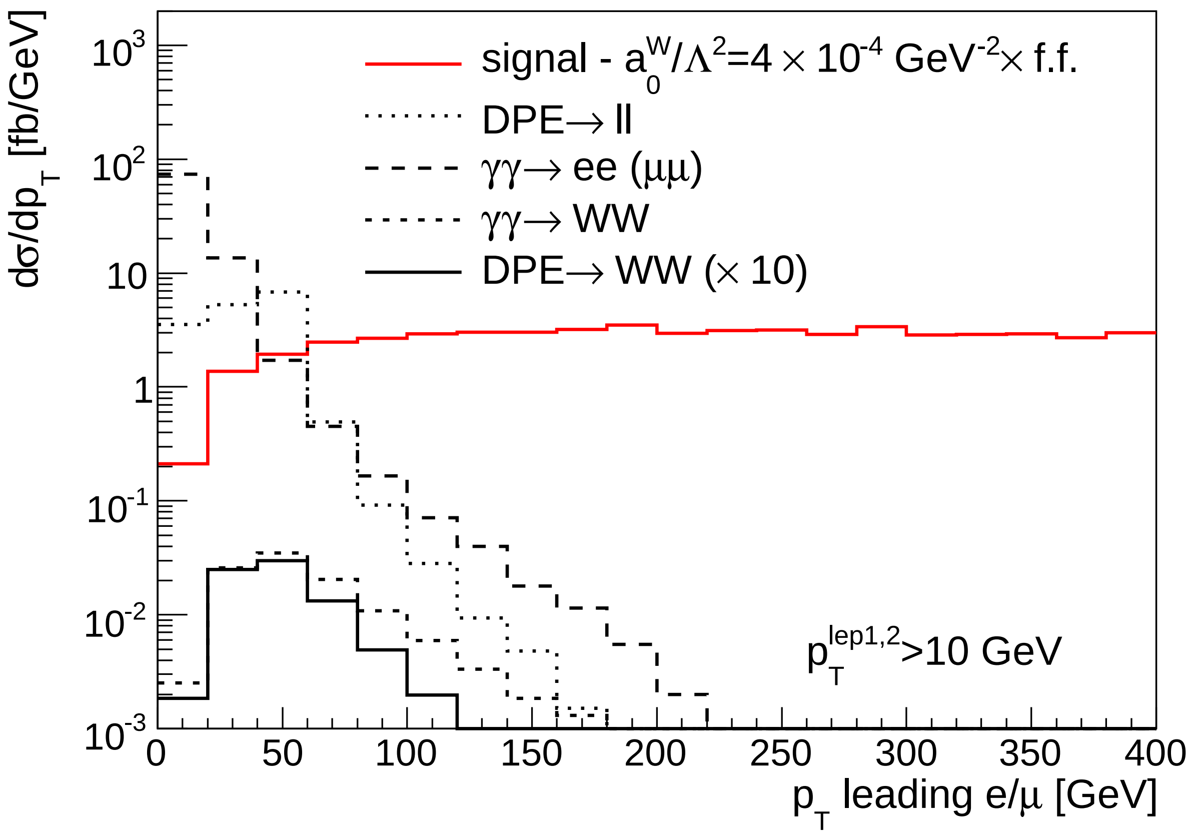
- Signal: We focus on leptonic signals decays of WW and ZZ (typically at least two leptons and nothing else (no jet) in the detector): request two high p_T leptons, exclusivity requirements
- Backgrounds considered:
  - Non diffractive WW production: large energy flow in forward region, removed by "exclusivity cut"
  - Two photon dileptons: back-to-back leptons, small cross section for high p_T leptons



  - Lepton production via double pomeron exchange (high mass): activity in the forward region due to pomeron remnants, removed by "exclusivity cut"
  - WW via double pomeron exchange: Idem
  - Standard model WW production via photon exchange: small cross section, removed partly by requesting a high p_T lepton

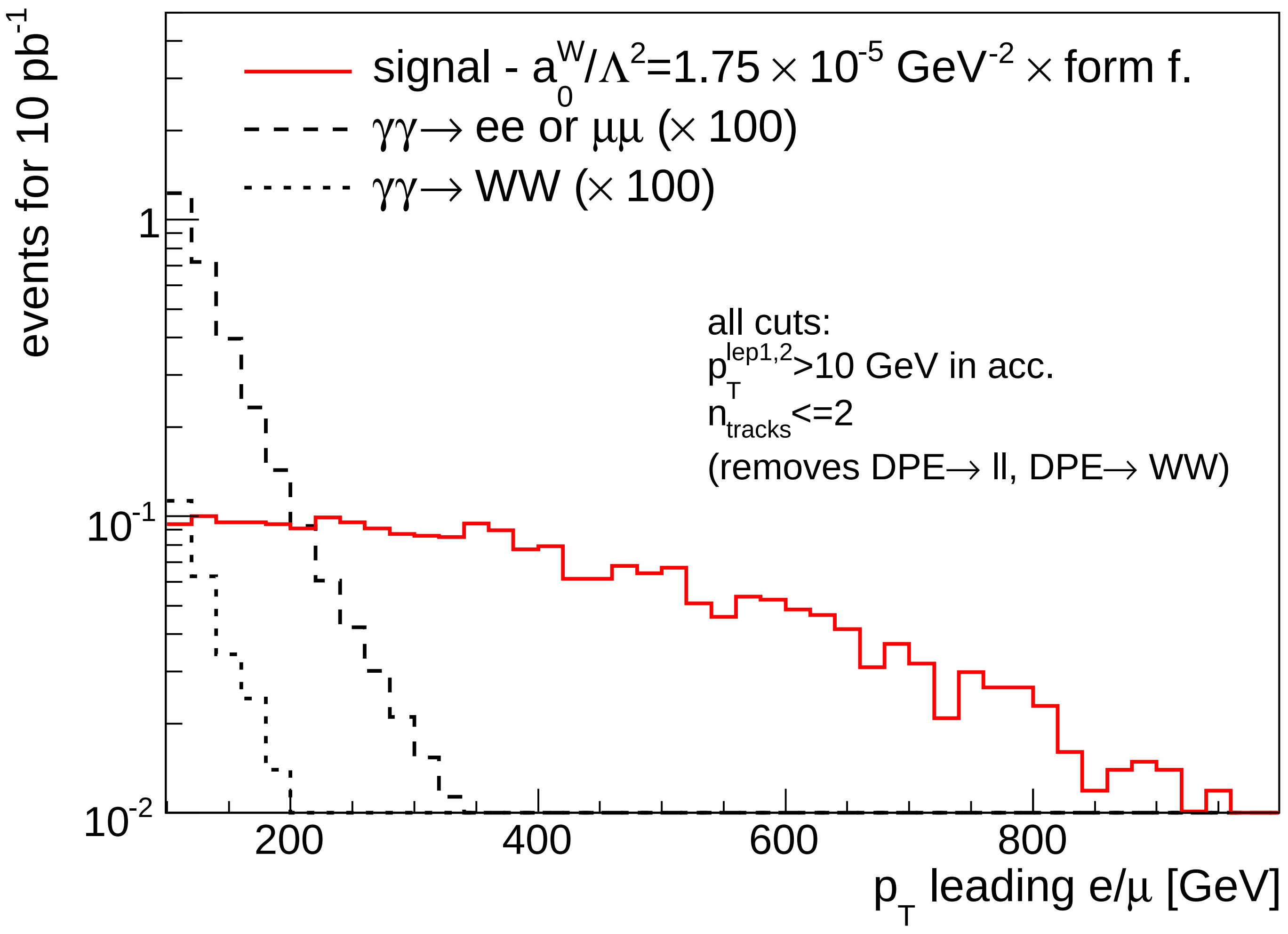
Quartic anomalous coupling signal at low luminosity at LHC

- P_T distribution of leading lepton (e or μ): removes SM background with a cut $p_T > 160$ GeV
- List of cuts for WW events: leading lepton $p_T > 160$ GeV, exclusivity, MET > 20 GeV
- All backgrounds negligible after cuts (all implemented in FPMC Monte Carlo)
- NB: cuts for Z production: 2 like-sign leptons, 3 leptons, leading one with $p_T > 100$ GeV



Event distribution for 10 pb^{-1}

After cuts, no background, sensivity comes mainly for WW or ZZ production cross section with anomalous coupling



Reach at low luminosity

Reach at low luminosity on quartic anomalous coupling

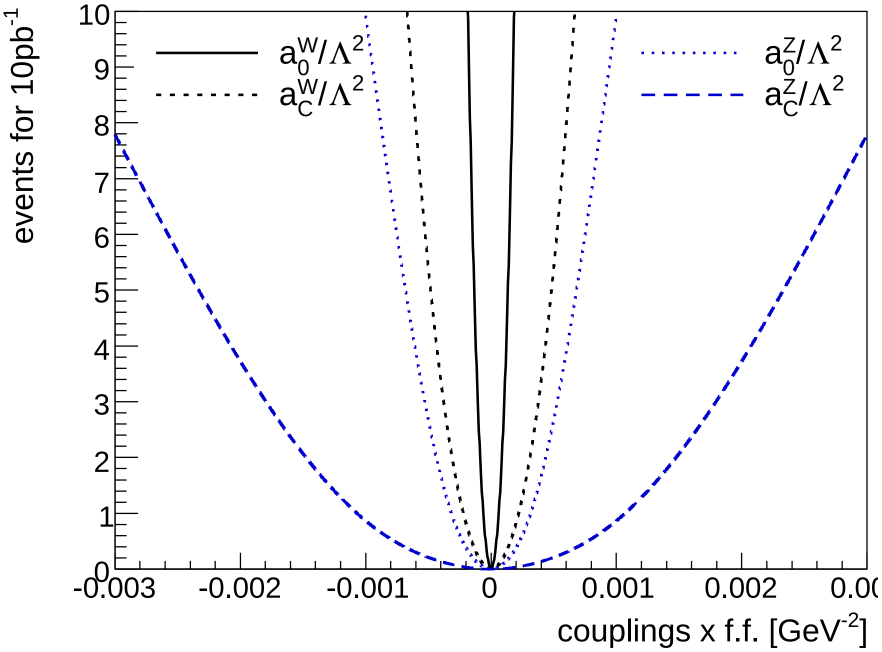
Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 10$ (100) pb^{-1} 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$2.2\ 10^{-4}$ ($7.3\ 10^{-5}$)	$1.0\ 10^{-4}$ ($3.3\ 10^{-5}$)
a_C^W/Λ^2	[-0.052, 0.037]	$5.9\ 10^{-4}$ ($2.4\ 10^{-4}$)	$3.5\ 10^{-4}$ ($1.1\ 10^{-4}$)
a_0^Z/Λ^2	[-0.007, 0.023]	$1.0\ 10^{-3}$ ($3.7\ 10^{-4}$)	$5.2\ 10^{-4}$ ($1.7\ 10^{-4}$)
a_C^Z/Λ^2	[-0.029, 0.029]	$3.0\ 10^{-3}$ ($1.3\ 10^{-3}$)	$1.8\ 10^{-3}$ ($5.9\ 10^{-4}$)

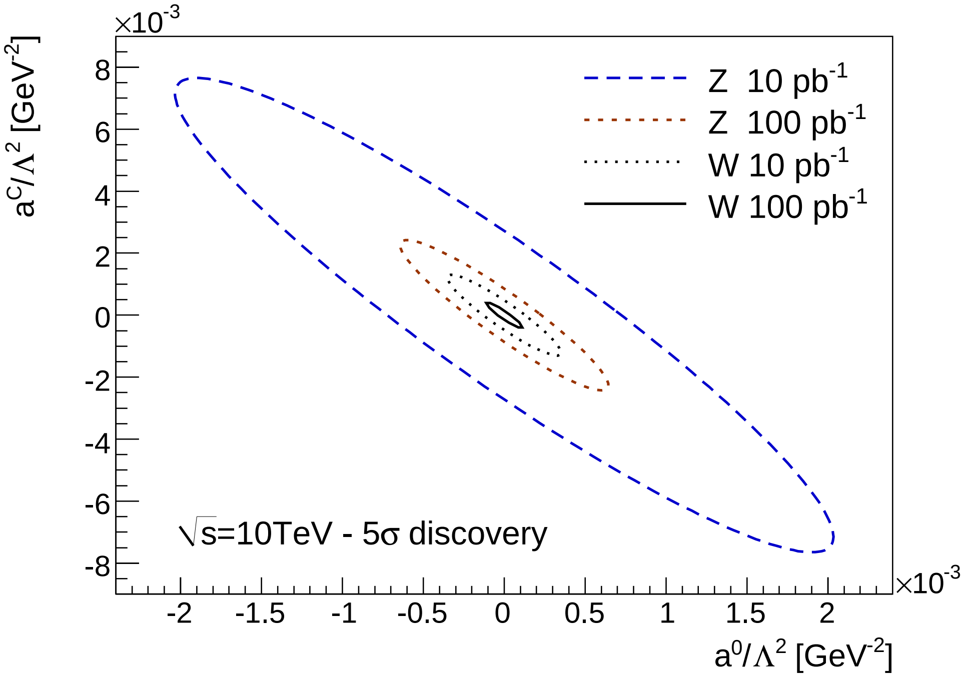
- Improvement of LEP sensitivity by more than 2 orders of magnitude with 10 pb^{-1} at LHC!!!
- NB: Effect of cutoff to avoid the violation of unitarity: reduces the sensitivity by a factor 4-5

Reach at low luminosity

Reach at low luminosity on quartic anomalous coupling

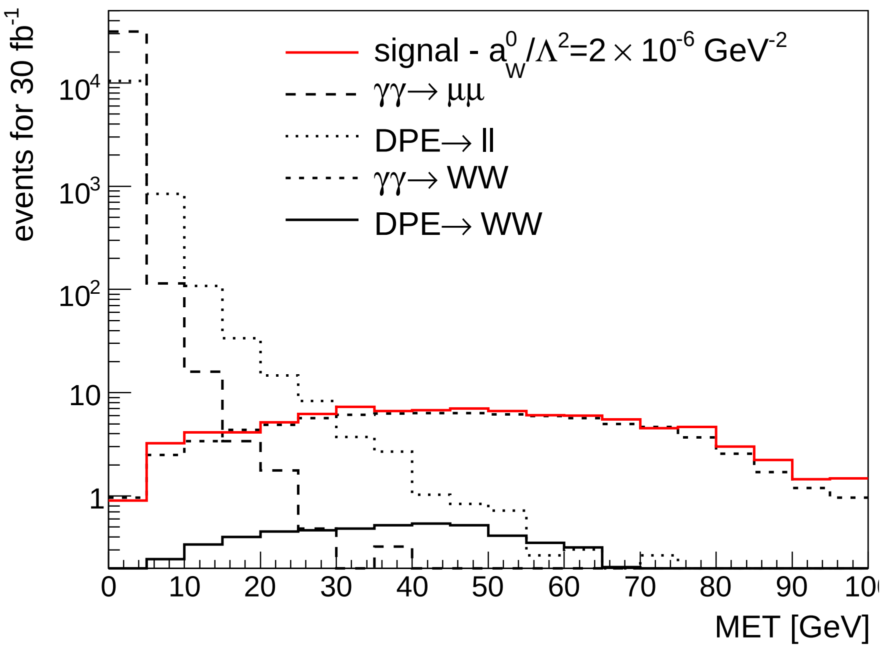
- Number of events for signal after all cuts for a luminosity of 10 pb^{-1}
- 5σ discovery contours for all WW and ZZ anomalous couplings for 10 and 100 pb^{-1}

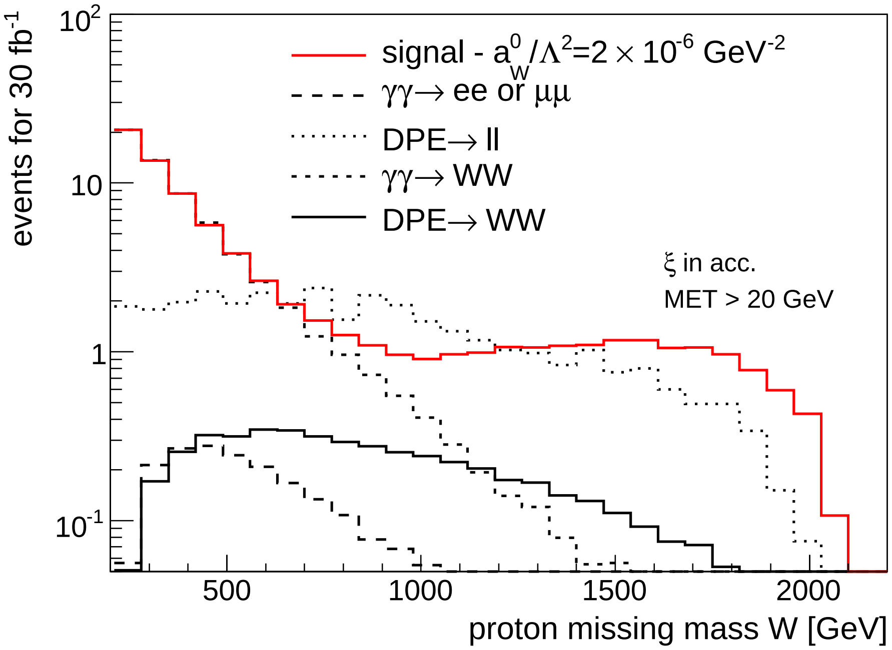




Reach at high luminosity

- Exclusivity cut impossible because of pile up events
- Request protons tagged in forward detectors with $0.0015 < \xi < 0.15$
- Additional cuts to remove background: p_T(leading lepton) > 160 GeV, proton missing mass $\sqrt{\xi_1 \xi_2 S} > 800$ GeV, MET>20 GeV





- Reach: (5σ discovery sensitivities for different luminosities)

Coupling	OPAL limits	10 pb^{-1}	30 fb^{-1}	200 fb^{-1}
a_0^W	[-0.020,0.020]	2.2 10^{-5}	5.4 10^{-6}	2.7 10^{-6}
a_C^W	[-0.052,0.037]	5.9 10^{-4}	2.0 10^{-5}	9.6 10^{-6}
a_0^Z	[-0.007,0.023]	1.0 10^{-3}	1.5 10^{-5}	5.9 10^{-6}
a_C^Z	[-0.029,0.029]	3.0 10^{-3}	5.5 10^{-5}	2.2 10^{-5}

Improvement by more than 3 orders of magnitude with respect to LEP!

Trilinear anomalous gauge couplings

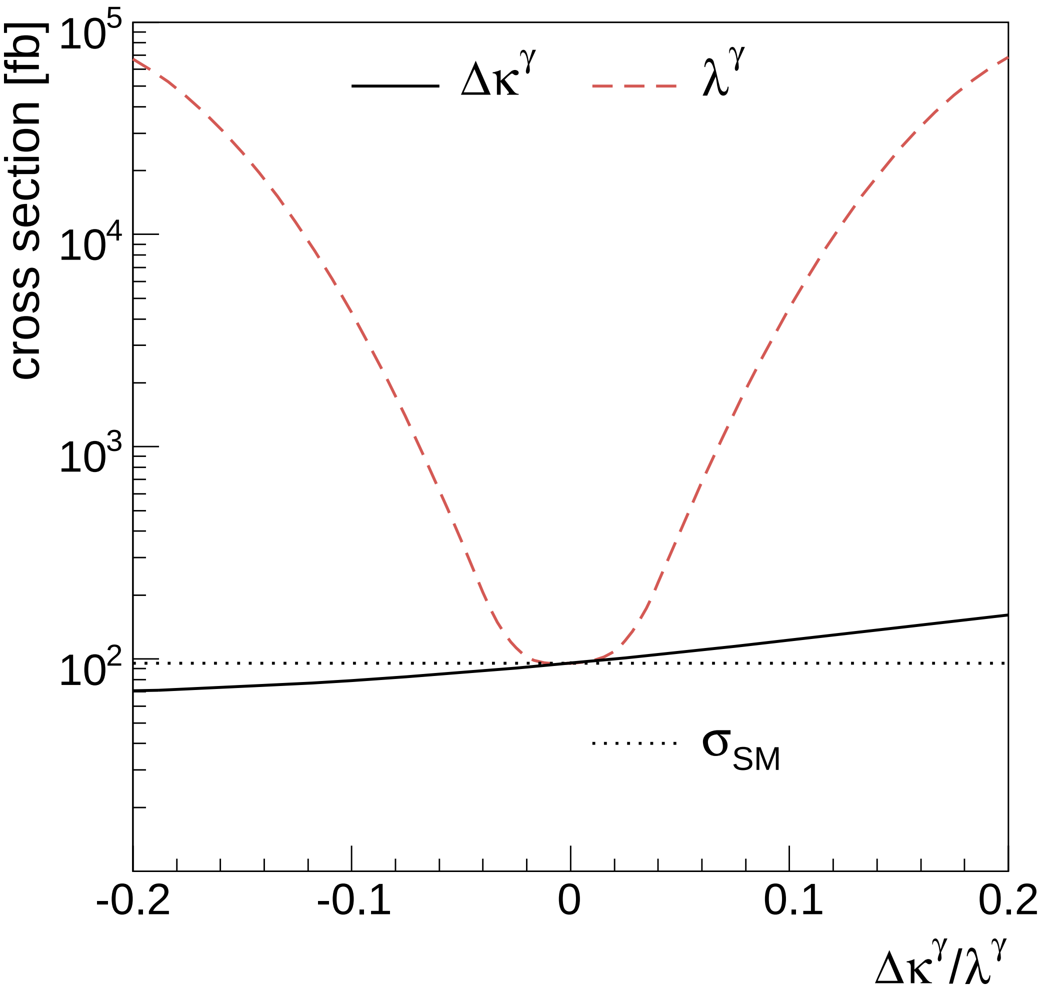
- Lagrangian with trilinear gauge $WW\gamma$ anomalous couplings λ^γ and $\Delta\kappa^\gamma$

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

- 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)

Anomalous $WW\gamma$ triple gauge coupling

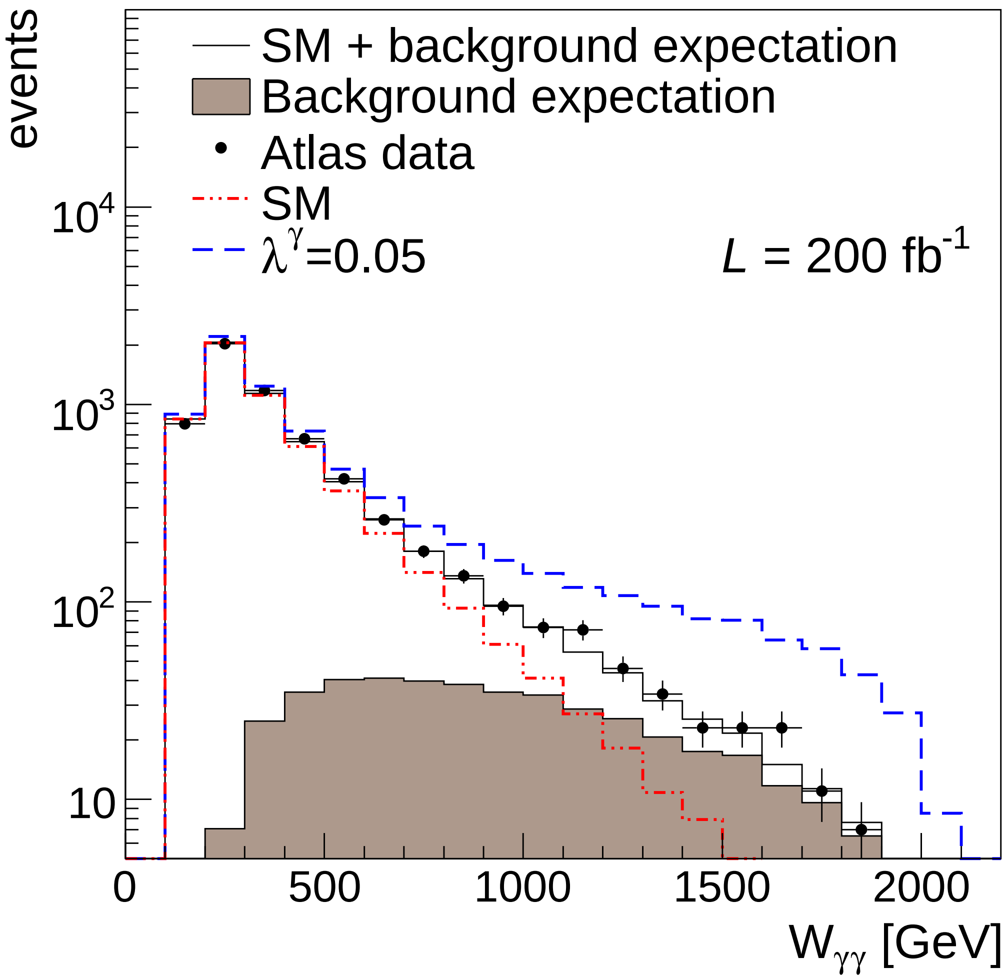
Different behaviour of the cross section as a function of anomalous couplings



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 30 fb^{-1}
  - 5σ discovery: $-0.097 < \Delta\kappa^\gamma < 0.069$; $-0.047 < \lambda^\gamma < 0.038$
  - 95% CL limit: $-0.034 < \Delta\kappa^\gamma < 0.029$; $-0.033 < \lambda^\gamma < 0.026$, about 970 (resp. 65) events expected in the detector acceptance for $\Delta\kappa^\gamma$ (resp. λ^γ)
- Reach on anomalous coupling at the LHC using a luminosity of 200 fb^{-1}: 5σ discovery: $-0.033 < \Delta\kappa^\gamma < 0.029$; $-0.033 < \lambda^\gamma < 0.026$
- Best reach before ILC



Conclusion

- Observation of QED WW production at the LHC: easy even with low luminosity (200 pb^{-1}) once forward detectors installed
- Quartic gauge anomalous coupling studies at low luminosities: Easy analysis (2 W or Z decaying in main detector and nothing else); Improvement of LEP (OPAL) sensitivity by two to three orders of magnitude with ~ 10 pb^{-1}
- Quartic gauge anomalous coupling studies at high luminosities: Requires forward detectors to be installed, further improvement on sensitivity of one order of magnitude
- Trilinear gauge anomalous coupling at high luminosity: requires forward detectors, gain of a factor 30 compared to Tevatron sensitivity (direct limit), gain of a factor 5 with respect to LEP (indirect limits), best reach before ILC
- 400 events expected for 200 fb^{-1} for WW events QED SM production with $W > 1$ TeV: sensitive to beyond standard model effects (SUSY, new strong dysnamics at the TeV scale)