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

Christophe Royon

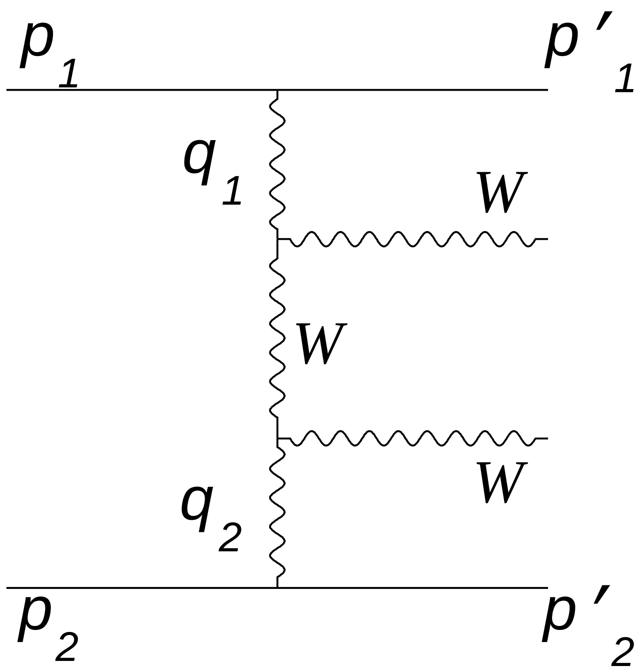
IRFU-SPP, CEA Saclay

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

## $WW$ production at the LHC




- Study of the process: $pp \rightarrow ppWW$
- 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 $\sigma$

| $\xi_{max}$ | 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 $a_0^W$, $a_0^Z$, $a_C^W$, $a_C^Z$

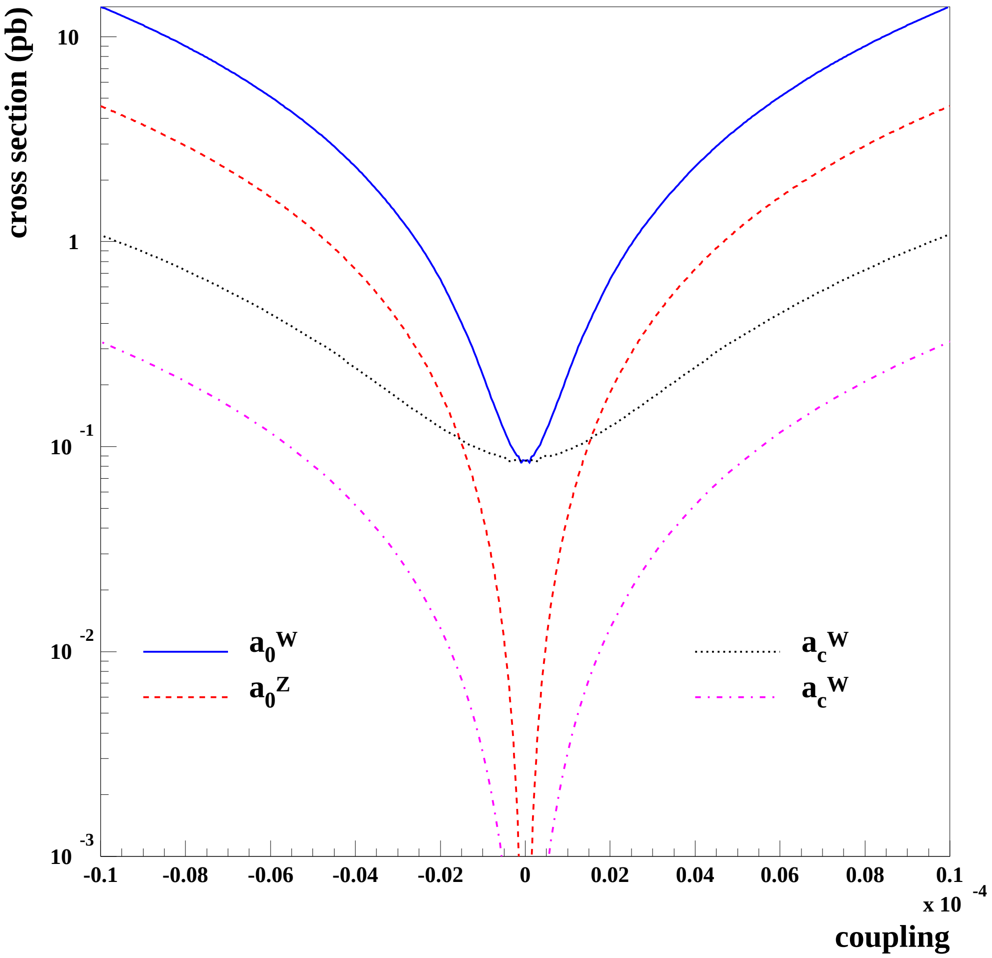
$$\mathcal{L}_6^0 \sim \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

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

- 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 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

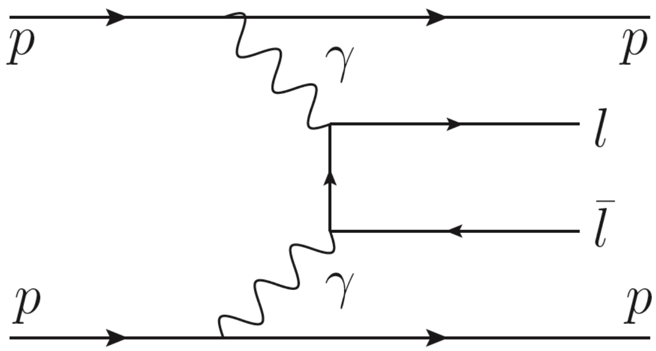
# Anomalous $WW\gamma\gamma$ quadric gauge coupling

- High cross sections at LHC even for an anomalous coupling much smaller than LEP limits ($\sim 0.01$), 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

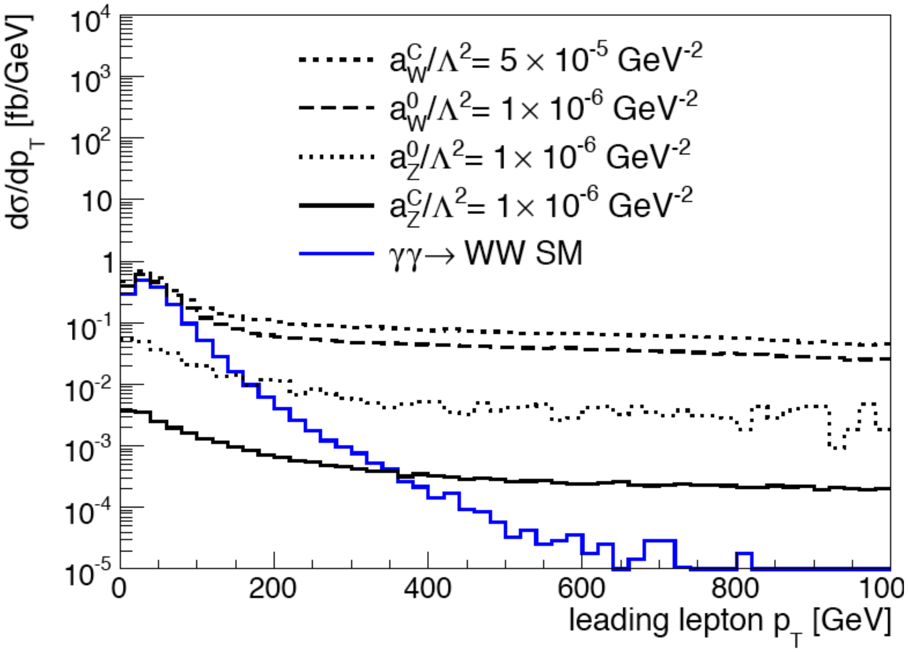
- Signal: We focus on leptonic signals decays of $WW$ and $ZZ$ (typically at least two leptons and nothing else (no jet) in the detector): request two high $p_T$ leptons, exclusivity requirements
- Backgrounds considered:
  - Non diffractive $WW$ production: large energy flow in forward region, removed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

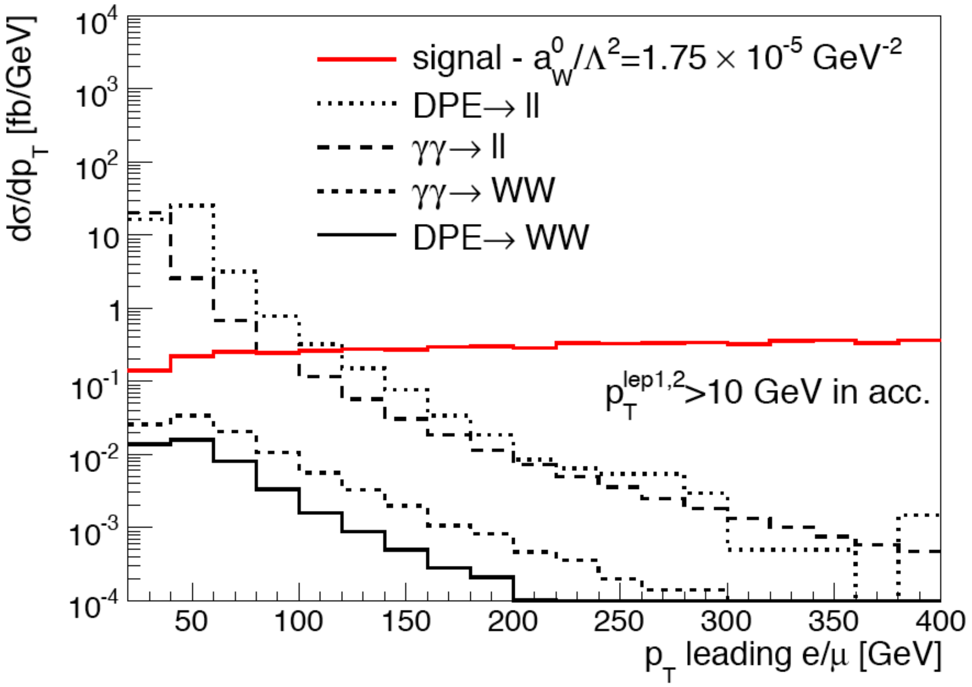



  - Lepton production via double pomeron exchange (high mass): activity in the forward region due to pomeron remnants, removed by "exclusivity cut"
  - WW via double pomeron exchange: Idem
  - Standard model $WW$ production via photon exchange: small cross section, removed partly by requesting a high $p_T$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

## Quartic anomalous coupling signal at low luminosity at LHC

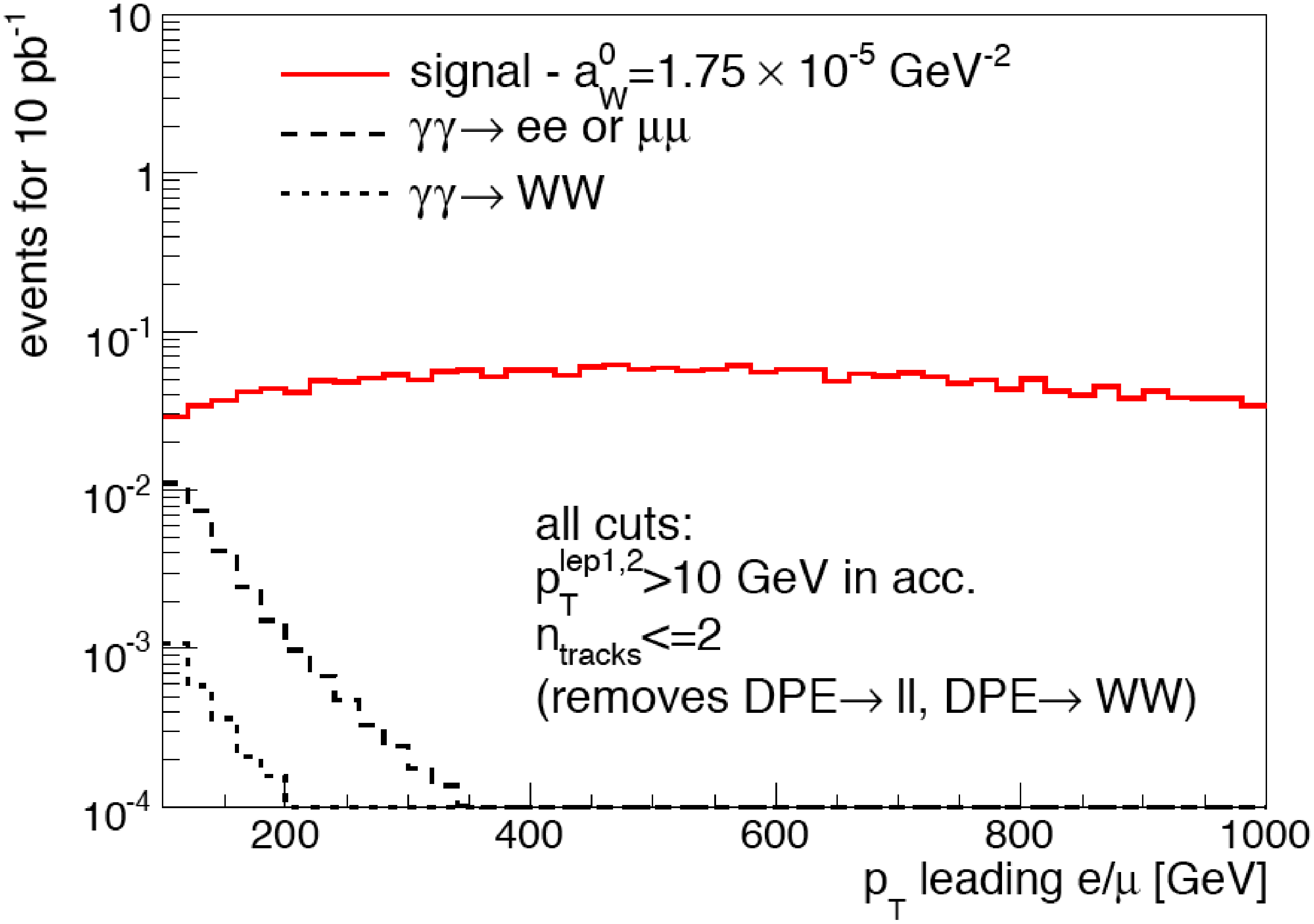
- $P_T$ distribution of leading lepton ($e$ or $\mu$): removes SM background with a cut $p_T > 160$ GeV
- Other backgrounds very small after cuts (all implemented in FPMC Monte Carlo)



## 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

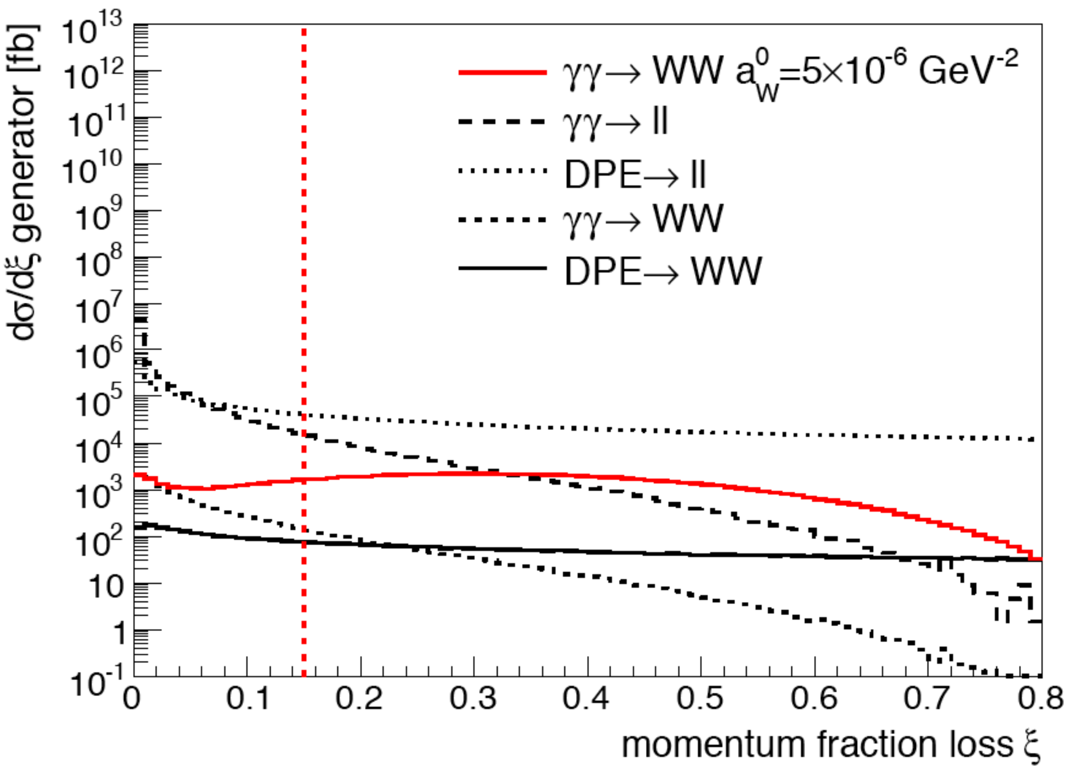
Reach at low luminosity on quartic anomalous coupling

| Coupling | OPAL limits | 95% CL 10 $pb^{-1}$ | 95% CL 100 $pb^{-1}$ |
|---|---|---|---|
| $a_0^W$ | 0.020 | $8.1\ 10^{-5}$ | $2.5\ 10^{-5}$ |
| $a_C^W$ | 0.037 | $4.5\ 10^{-4}$ | $1.4\ 10^{-4}$ |
| $a_0^Z$ | 0.023 | $6.7\ 10^{-3}$ | $2.3\ 10^{-4}$ |
| $a_C^Z$ | 0.029 | $2.7\ 10^{-3}$ | $8.0\ 10^{-4}$ |

- 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 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, $p_T^2/p_T^1 < 0.9$, proton missing mass $\sqrt{\xi_1 \xi_2 S} > 800$ GeV, MET>20 GeV
- Reach: (95% CL limits for different luminosities)

| Coupling | OPAL limits | 10 pb$^{-1}$ | 30 fb$^{-1}$ | 200 fb$^{-1}$ |
|---|---|---|---|---|
| $a_0^W$ | 0.020 | 2.2 $10^{-5}$ | 1.4 $10^{-6}$ | 7.9 $10^{-7}$ |
| $a_C^W$ | 0.037 | 8.4 $10^{-5}$ | 5.7 $10^{-6}$ | 3.6 $10^{-6}$ |

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

## Trilinear anomalous gauge couplings

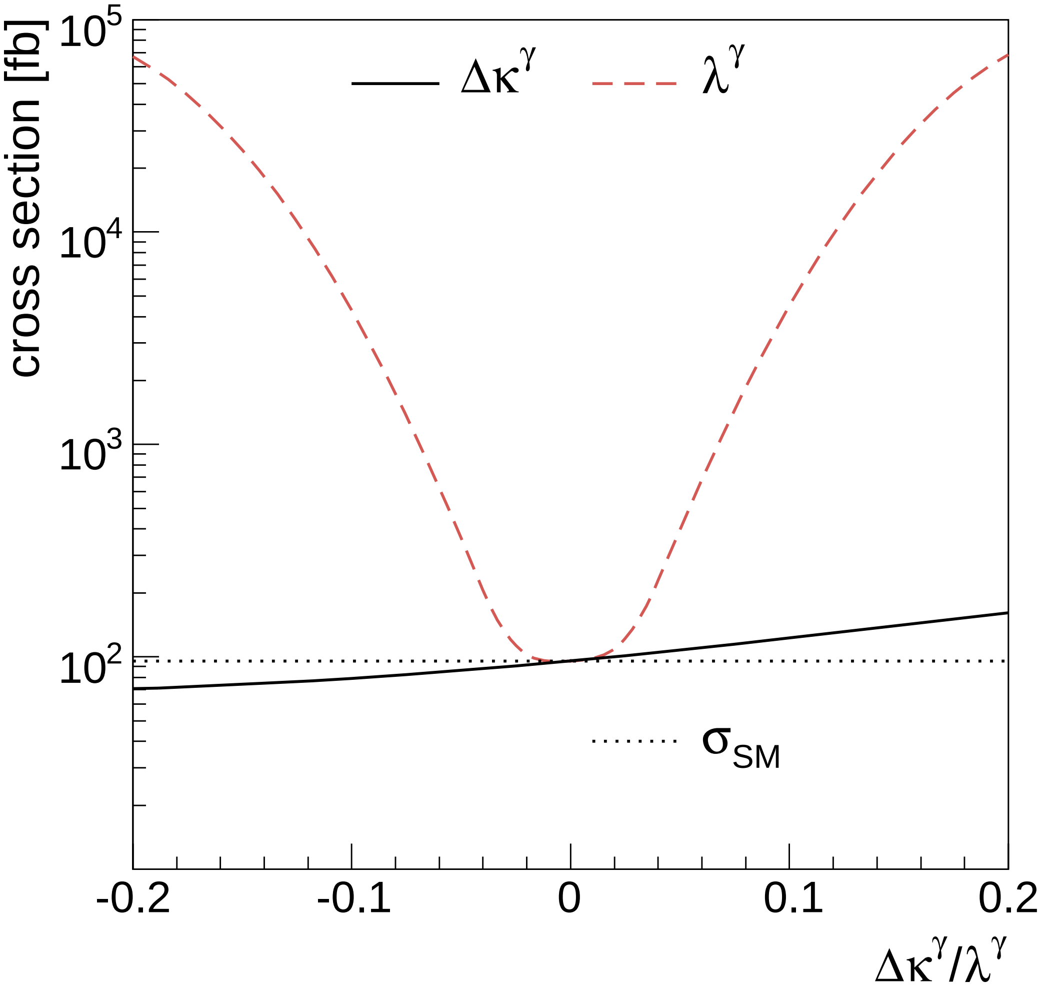
- Lagrangian with trilinear gauge $WW\gamma$ anomalous couplings $\lambda^\gamma$ and $\Delta\kappa^\gamma$

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

- 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 $\gamma$ 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

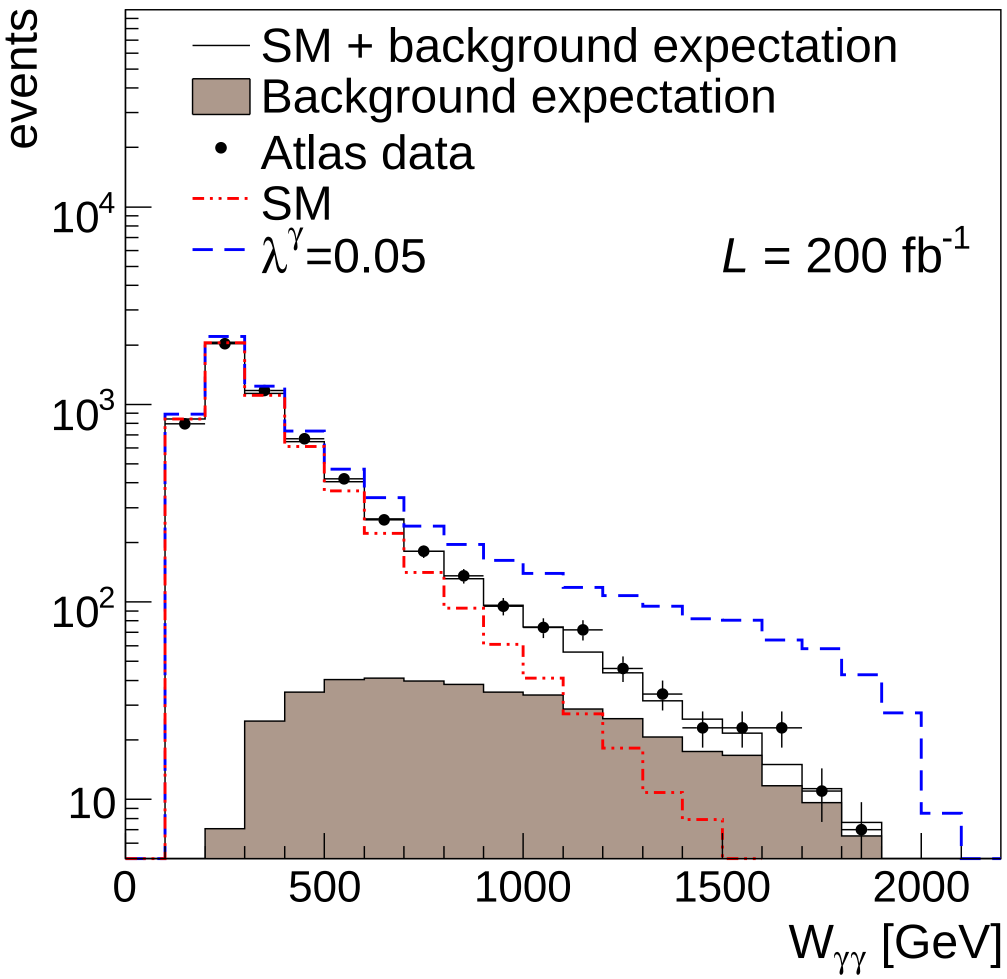
Different behaviour of the cross section as a function of anomalous couplings




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$^{-1}$
  - 5$\sigma$ 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. $\lambda^\gamma$)
- Reach on anomalous coupling at the LHC using a luminosity of 200 fb$^{-1}$: 5$\sigma$ 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 $\sim$ 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)