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

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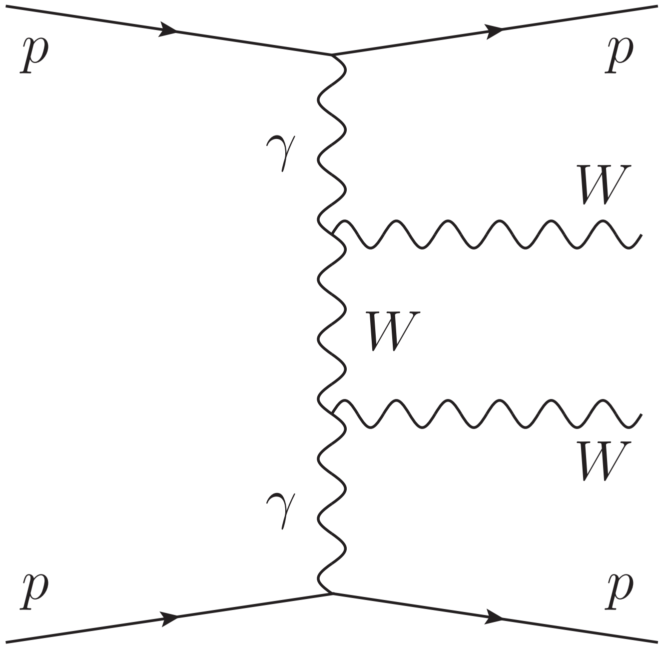
Contents:

- $WW$ production cross section at the LHC
- 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 Phys. Rev. D81 (2010) 074003
T J. De Favereau et al., arXiv:0908.2020.
Production of SUSY particles: See talk by Nicolas Schul

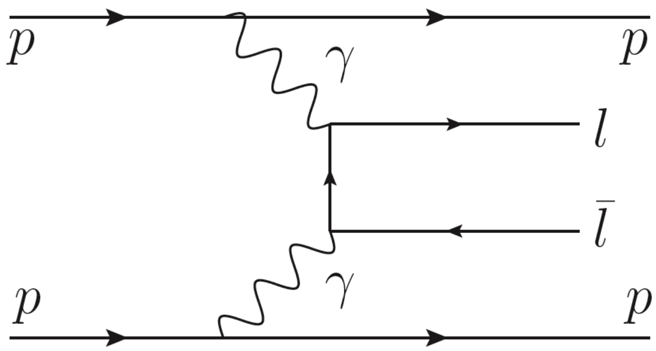
## $WW$ production at the LHC




- 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 high luminosities at LHC
- $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W > 1TeV) = 5.9$ fb
- Rich $\gamma\gamma$ physics at LHC

# $WW$ 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



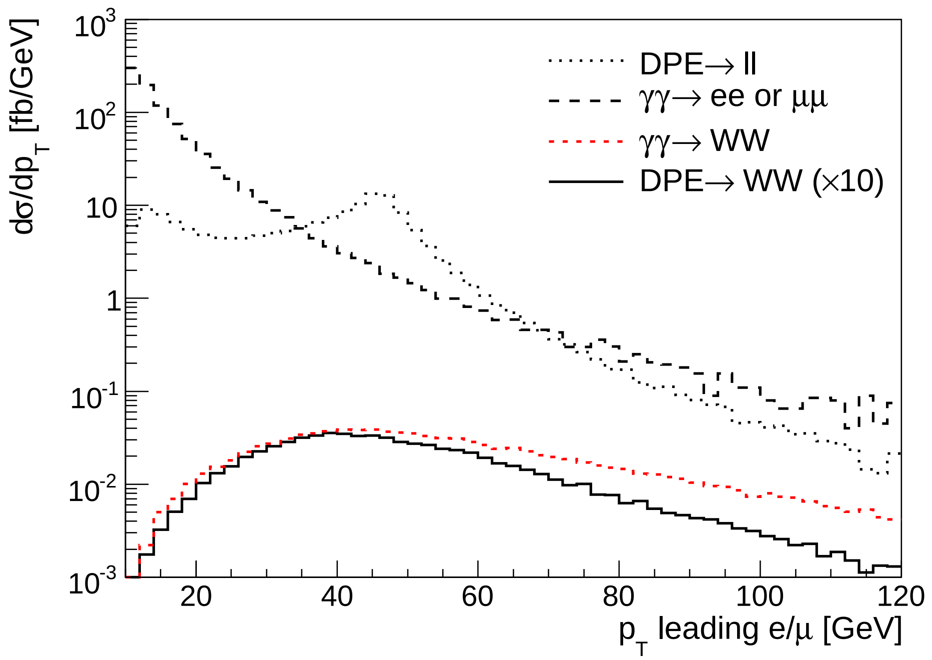

  - Lepton production via double pomeron exchange: activity in the forward region due to pomeron remnants, removed by $\not{E}_T$ cut
  - WW via double pomeron exchange: removed by cut on high diffractive mass

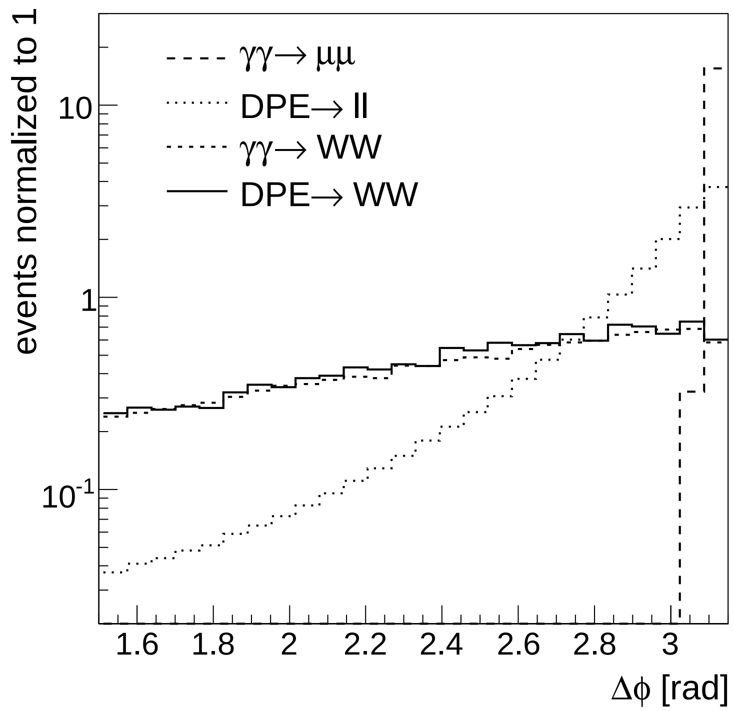
# Forward Physics Monte Carlo (FPMC)

- 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 $\gamma\gamma \rightarrow WW$ SM cross section

- Require both $W$s 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



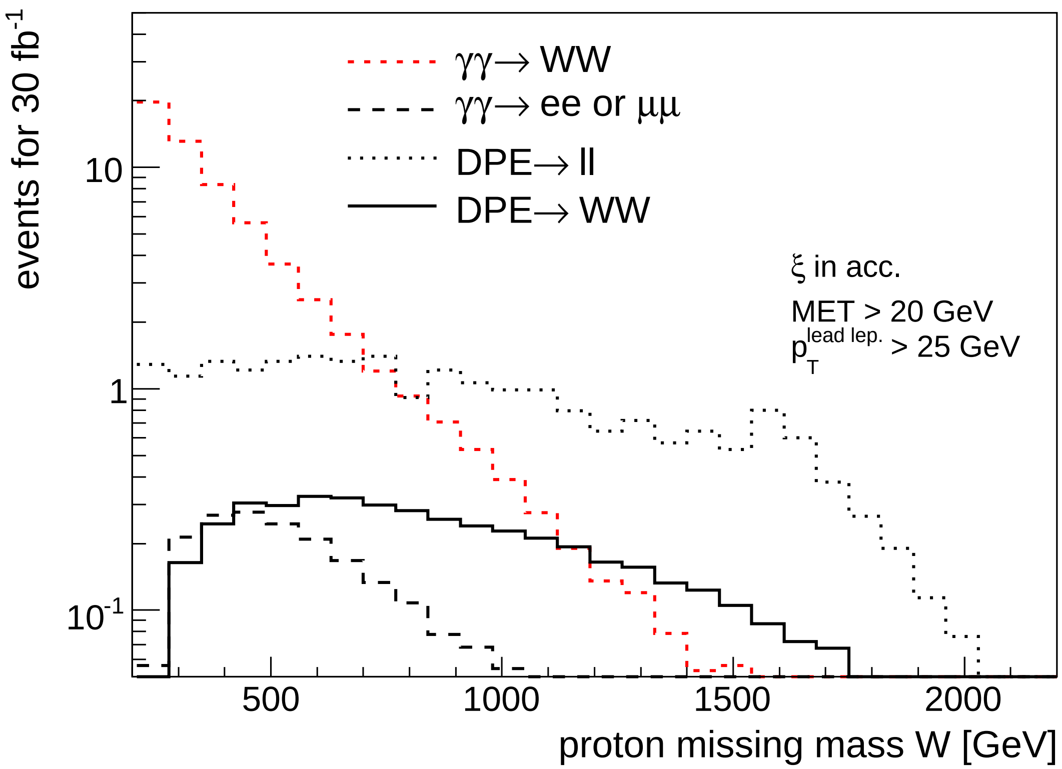



# Measuring the $\gamma\gamma \to WW$ SM cross section

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 $\sigma$ discovery possible after 5 fb$^{-1}$ (pure leptonic decays of $W$s)



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

- Consider both leptonic and semileptonic decays of $W$s
- 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 $\sigma$

| $\xi_{max}$ | signal (fb) | background (fb) |
|---|---|---|
| 0.05 | 13.8 | 0.16 |
| 0.10 | 24.0 | 1.0 |
| 0.15 | 28.3 | 2.2 |

- 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

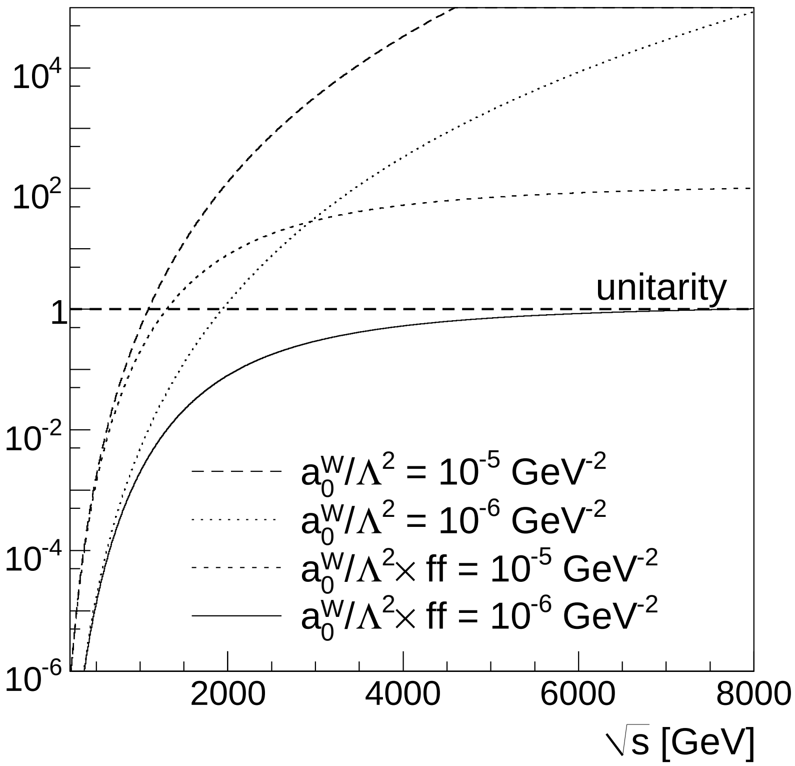
# Quartic anomalous gauge couplings: form factors

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

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

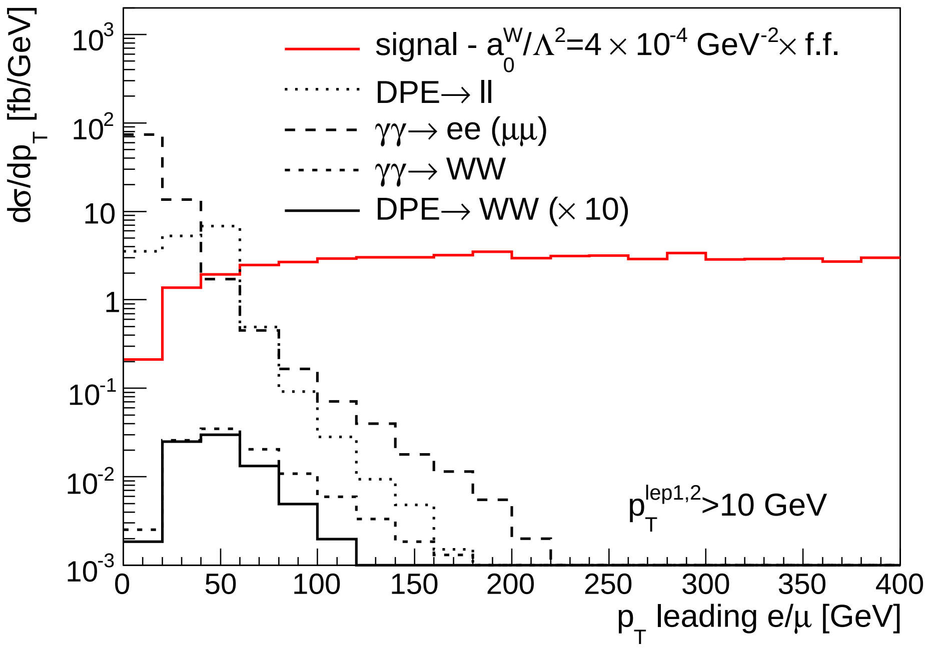
where $a = a_0/\Lambda^2$

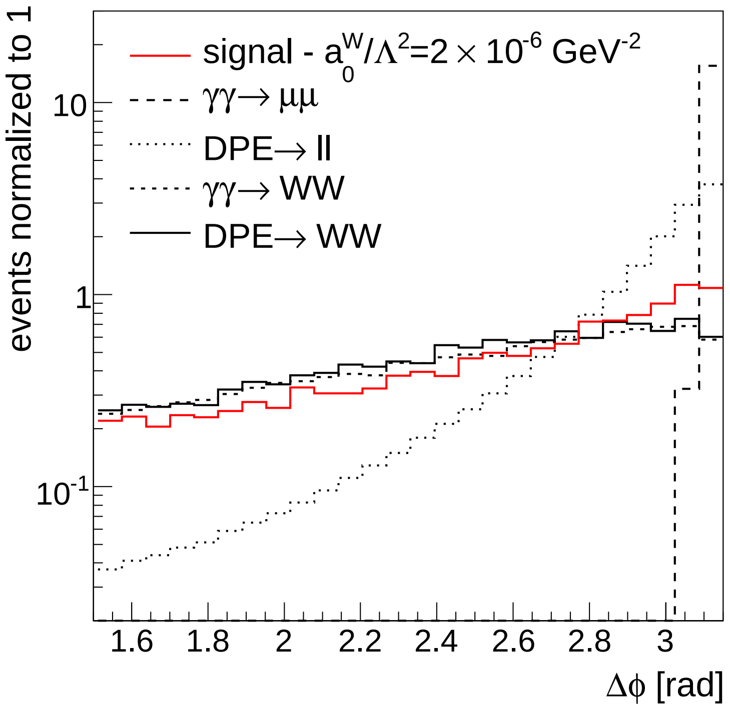
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics
- For $a_0^W \sim 10^{-6}$ GeV$^{-2}$,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



## Strategy to select quartic anomalous gauge couplings events

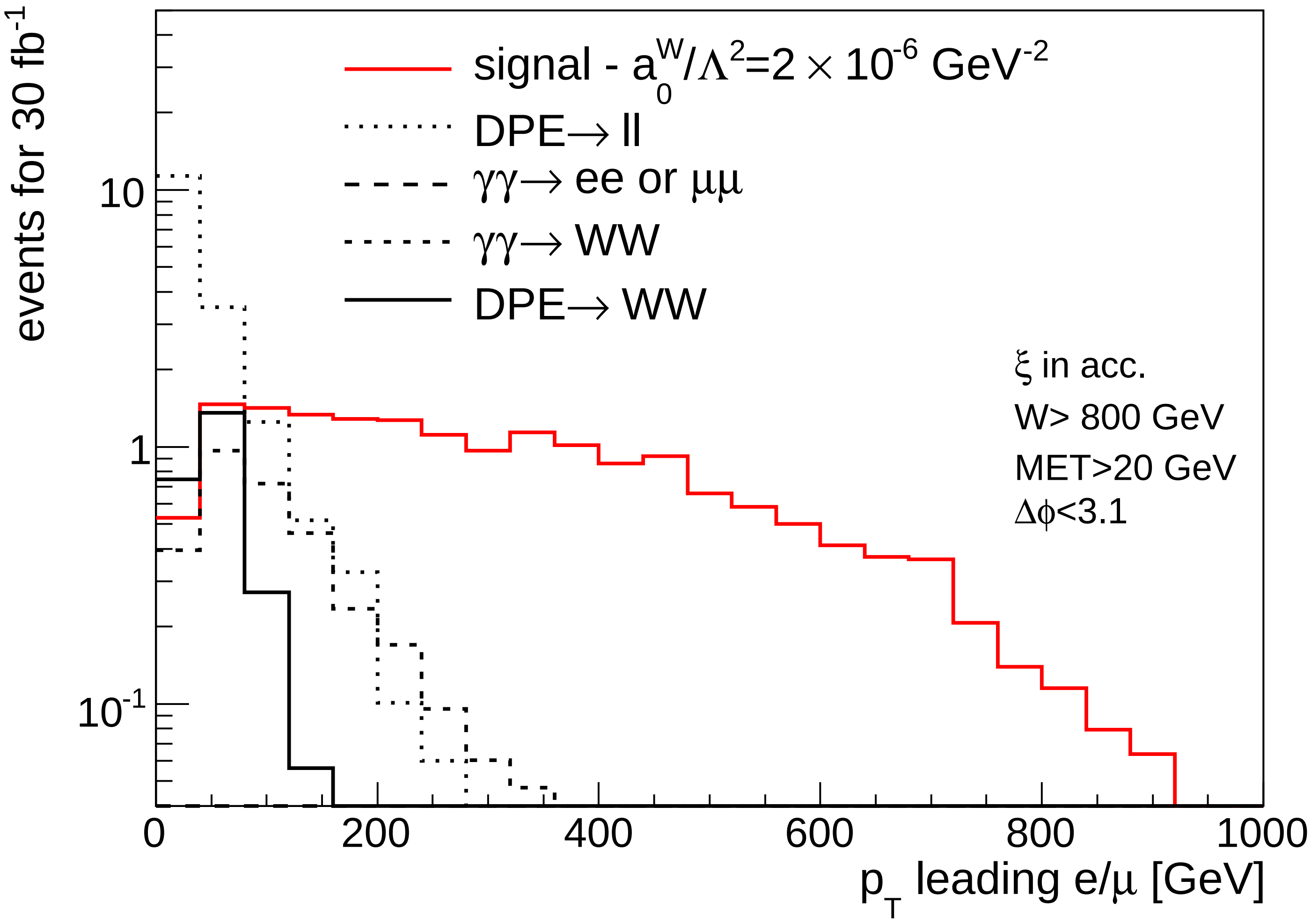
- $p_T$ of the leading lepton: request high $p_T$ lepton to remove background
- Missing $E_T$ distribution: natural to be requested for $W$ pair production
- Diffractive mass computed using the forward proton detectors $\sqrt{\xi_1 \xi_2 S}$: request high mass objects to be produced
- $\Delta\Phi$ between 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$^{-1}$

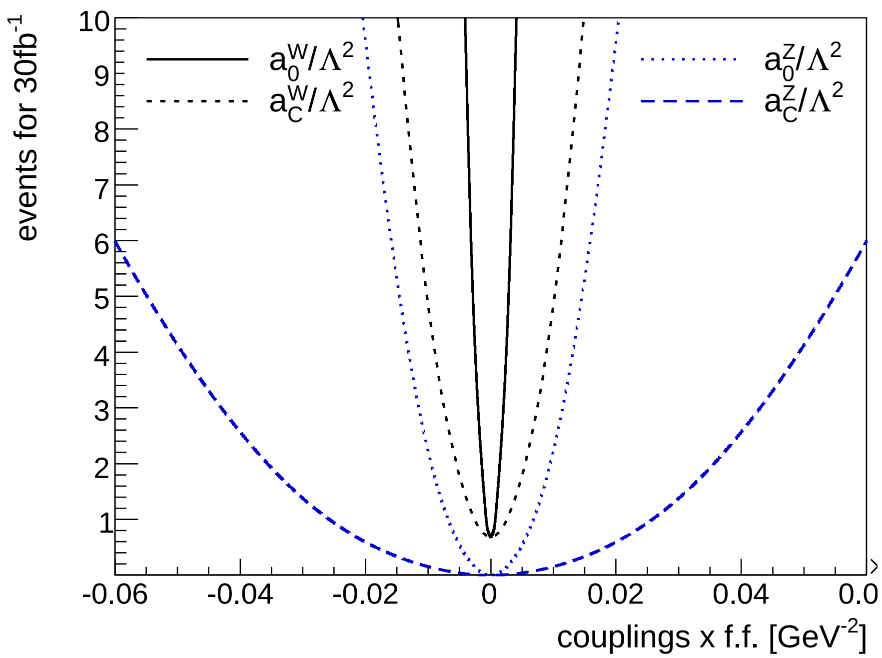
| cut / process | $\gamma\gamma \to ll$ | $\gamma\gamma \to WW$ | DPE$\to ll$ | DPE$\to WW$ |
|---|---|---|---|---|
| $p_T^{lep1,2} > 10$ GeV | 50619 | 99 | 18464 | 8.8 |
| $0.0015 < \xi < 0.15$ | 21058 | 89 | 11712 | 6.0 |
| $\not{E}_T > 20$ GeV | 14.9 | 77 | 36 | 4.7 |
| $W > 800$ GeV | 0.42 | 3.2 | 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 |

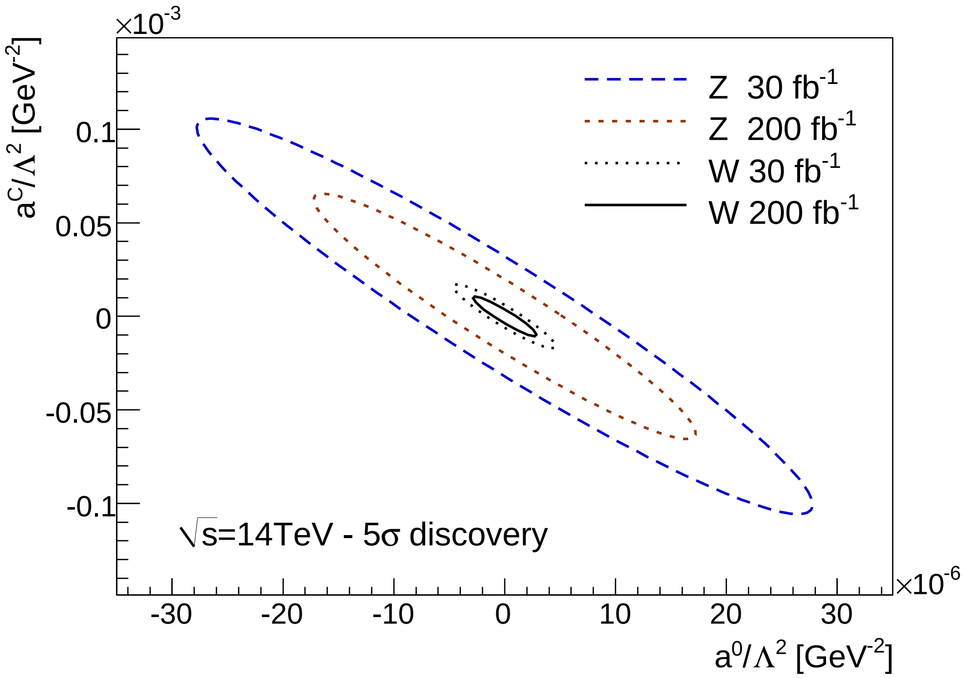
## Signal events for 30 fb$^{-1}$

| 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
- $5\sigma$ 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 [GeV$^{-2}$] | Sensitivity @ $\mathcal{L} = 30$ (200) fb$^{-1}$ 5$\sigma$ | 95% CL |
|---|---|---|---|
| $a_0^W/\Lambda^2$ | [-0.020, 0.020] | 5.4 $10^{-6}$ (2.7 $10^{-6}$) | 2.6 $10^{-6}$ (1.4 $10^{-6}$) |
| $a_C^W/\Lambda^2$ | [-0.052, 0.037] | 2.0 $10^{-5}$ (9.6 $10^{-6}$) | 9.4 $10^{-6}$ (5.2 $10^{-6}$) |
| $a_0^Z/\Lambda^2$ | [-0.007, 0.023] | 1.4 $10^{-5}$ (5.5 $10^{-6}$) | 6.4 $10^{-6}$ (2.5 $10^{-6}$) |
| $a_C^Z/\Lambda^2$ | [-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!!!

# 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