Measurement of Boson self couplings at LEP

and
search for anomalies

Martin Weber

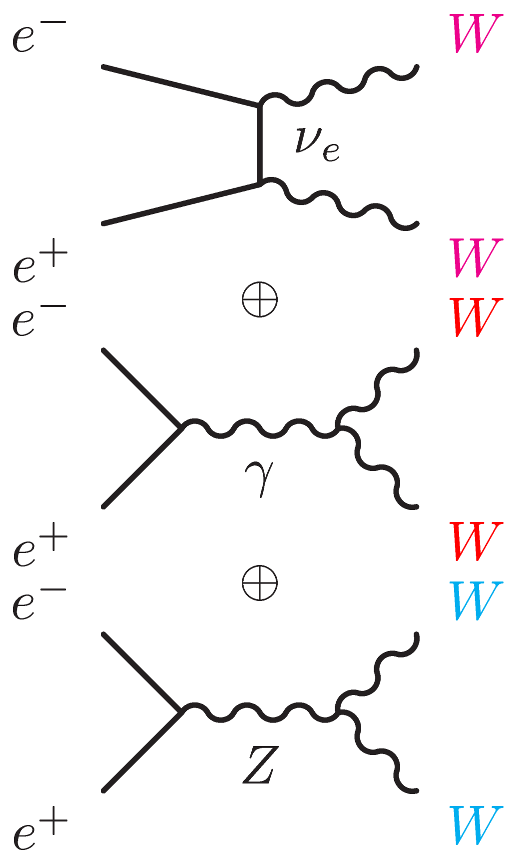
III. Physikalisches Institut, RWTH Aachen and L3 Collaboration, CERN

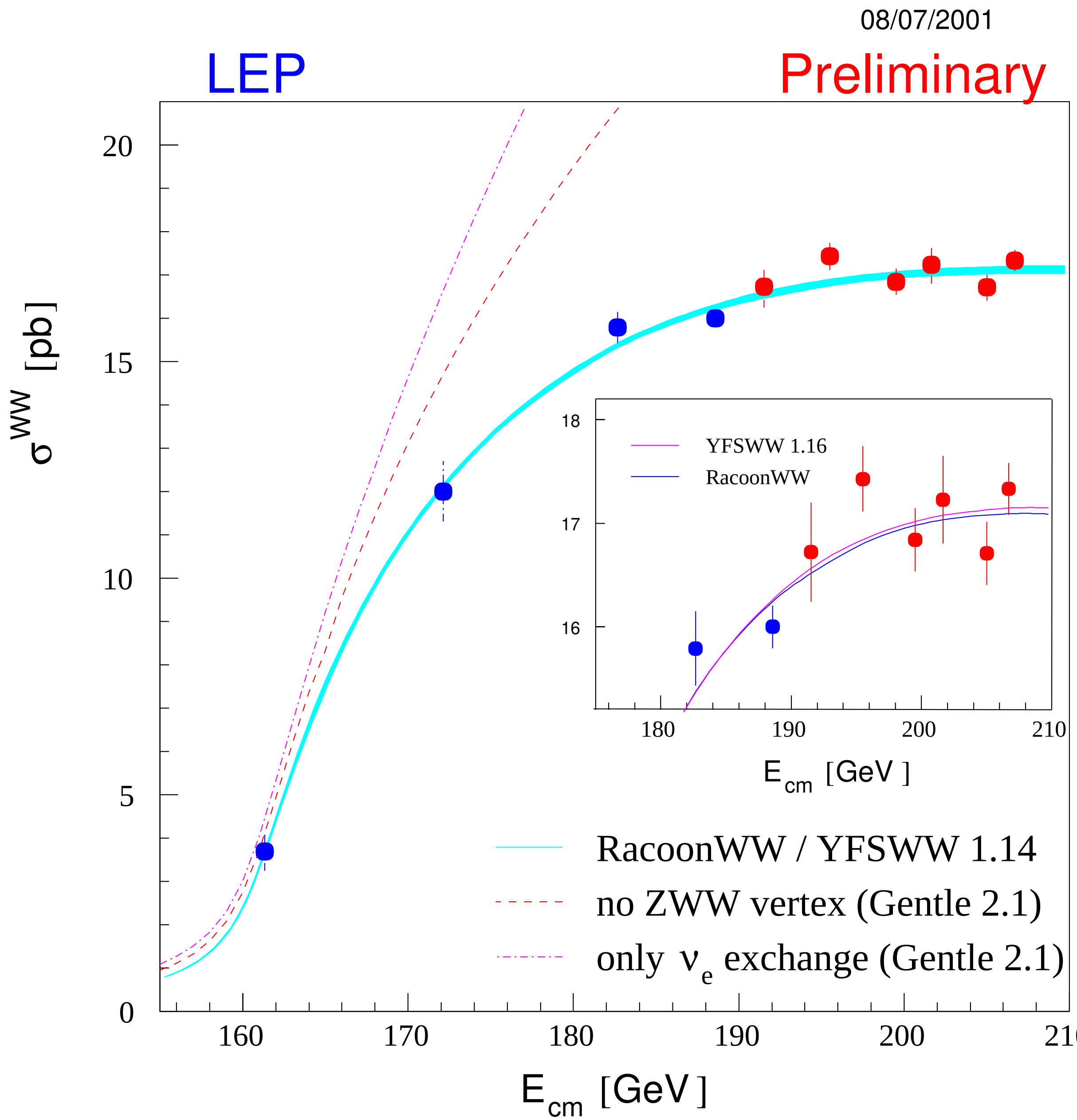
On behalf of the LEP experiments

Original title: “Four Fermion Interactions and Anomalous Couplings”

XXXVIIth Rencontres de Moriond

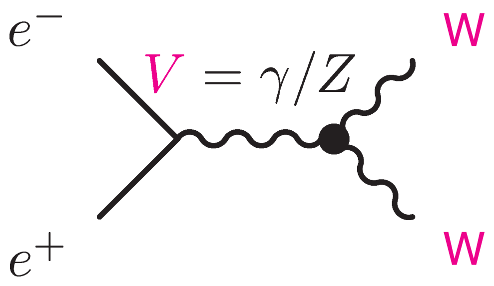
W^+W^- cross section





The non-Abelian structure of the Standard Model is needed to describe the data!

Couplings of the W to other bosons



Vertex described by Lagrangian (only CP conserving terms of lowest dimension (6 couplings):

$$\mathcal{L}^{WWV}/g_{WWV} = g_1^V \left(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}\right) + \kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^\dagger_{\mu\nu} W^\mu_\nu V^{\rho\nu}$$

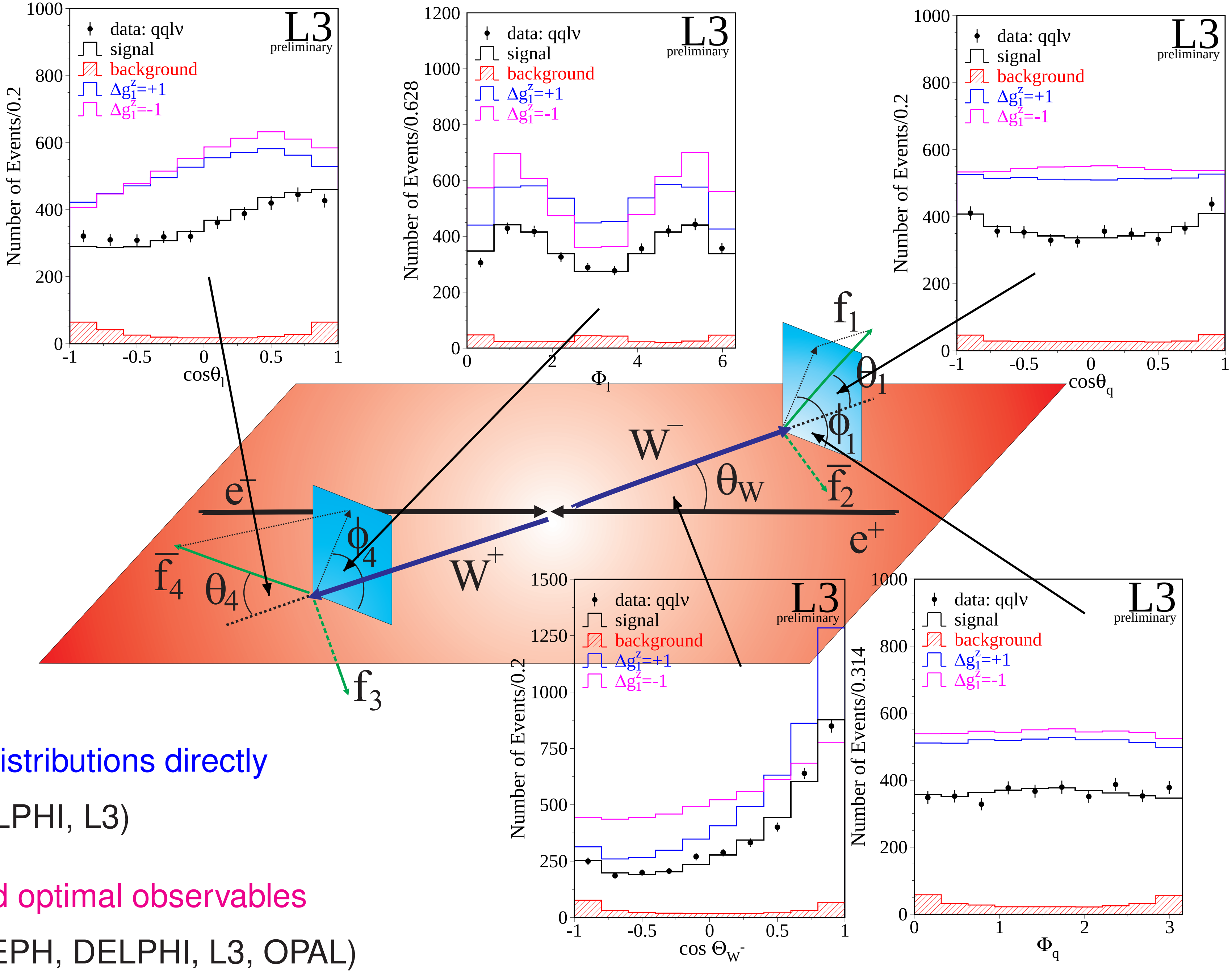
Require U(1)$_{em}$ gauge invariance and SU(2) $\times$ U(1) symmetry (fix 3 couplings):

$$g_1^\gamma = 1 \qquad (q_W = \pm 1)$$
$$\kappa_Z = g_1^Z - (\kappa_\gamma - 1)\tan^2\theta_W$$
$$\lambda_Z = \lambda_\gamma$$

Remaining 3 couplings are fitted:

$$\begin{array}{llcll} g_1^Z & (\text{SM}: 1) & & \Delta g_1^Z = g_1^Z - 1 & (\text{SM}: 0) \\ \kappa_\gamma & (\text{SM}: 1) & \rightarrow & \Delta\kappa_\gamma = \kappa_\gamma - 1 & (\text{SM}: 0) \\ \lambda_\gamma & (\text{SM}: 0) & & \lambda_\gamma & (\text{SM}: 0) \end{array}$$

Couplings of the W to other bosons: measurement method



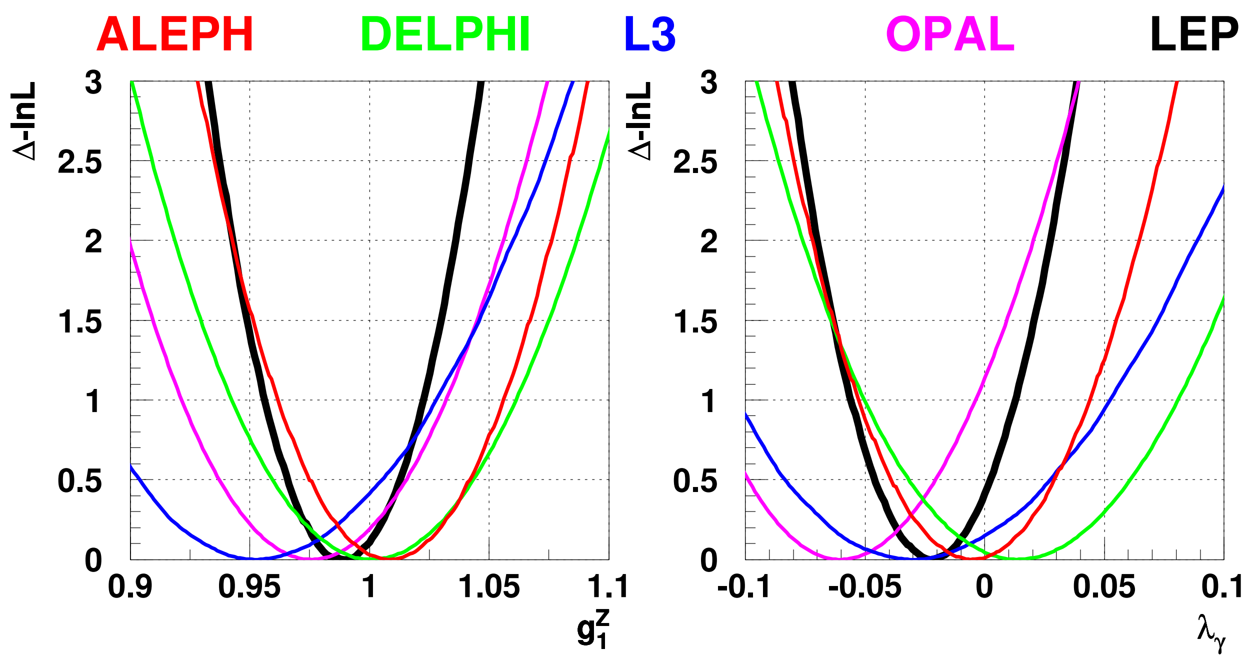
- Fit distributions directly

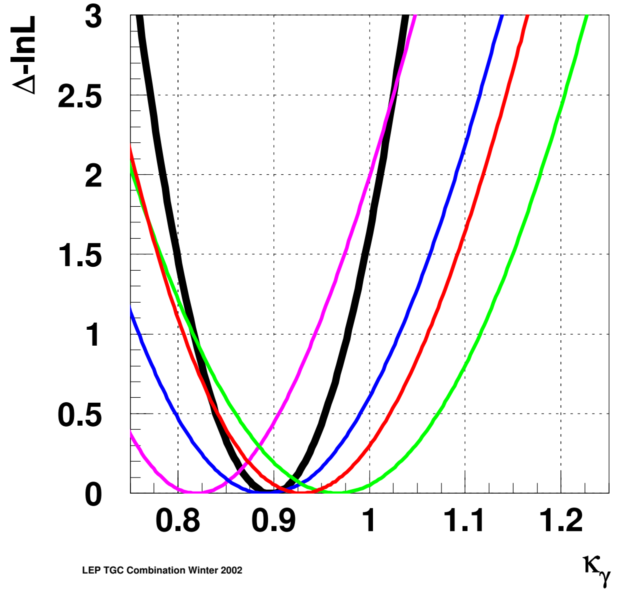
  (DELPHI, L3)

- Build optimal observables

  (ALEPH, DELPHI, L3, OPAL)

Couplings of the W to other bosons: Single parameter fit





LEP preliminary

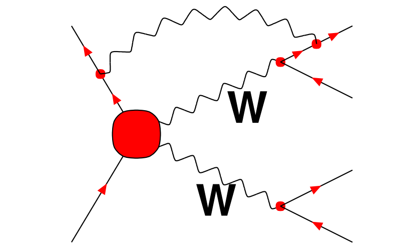
$$\kappa_\gamma = 0.896^{+0.058}_{-0.056}$$

$$\lambda_\gamma = -0.023^{+0.025}_{-0.023}$$

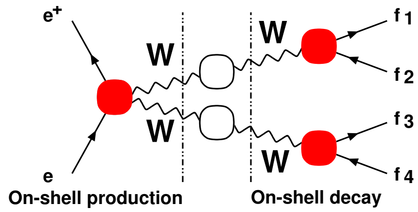
$$g_1^Z = 0.990^{+0.023}_{-0.024}$$

Theoretical improvements:

$\mathcal{O}(\alpha)$ corrections



DPA



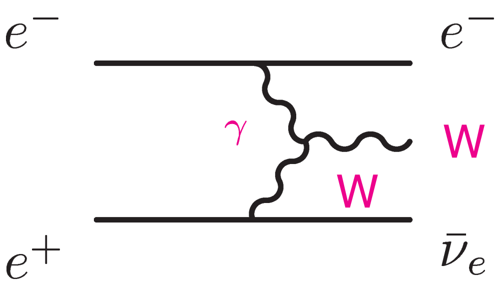
- Not all channels are included

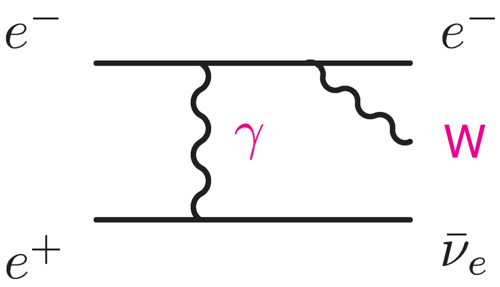
→ Statistical error will improve

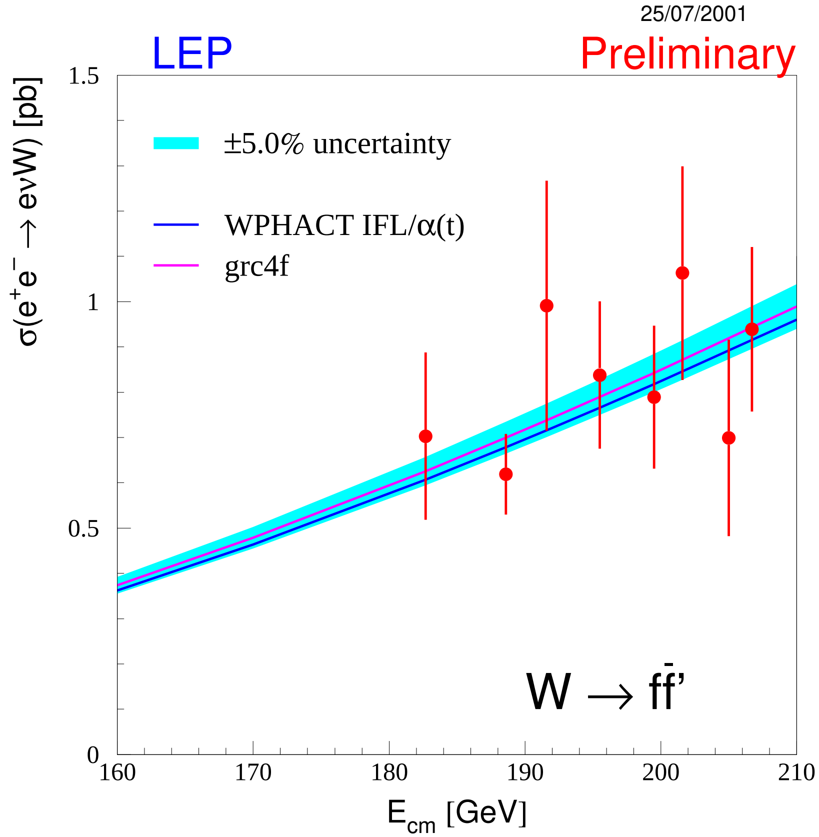
- Largest correlated systematic: $\mathcal{O}(\alpha)$ corrections

→ Need better understanding of theory error

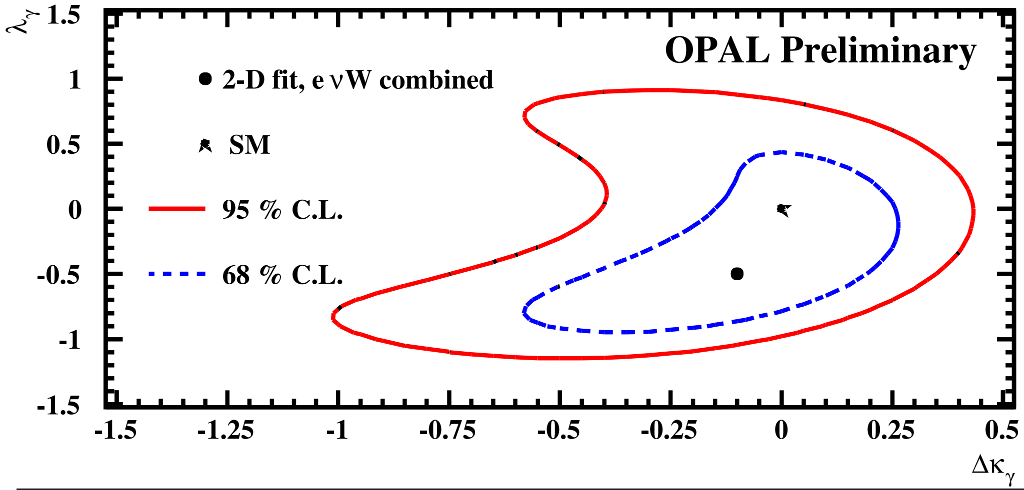
Couplings of the W to other bosons: Single-W





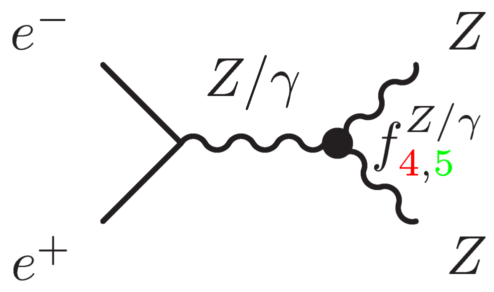


- Smaller sensitivity than WW
- WWγ vertex gives access to $\Delta\kappa_\gamma$ and λ_γ
- Single-W events are most sensitive to $\Delta\kappa_\gamma$

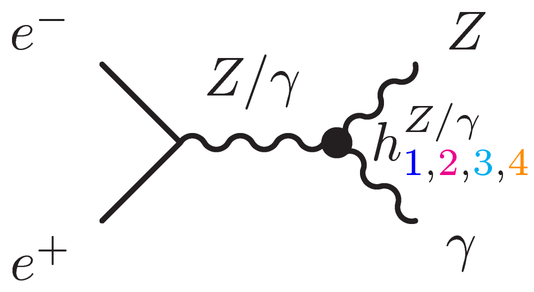


These results are included in the combined fits.

Either ZZ in the final state



or $Z\gamma$ in the final state



- $h_1^{Z/\gamma}$, $h_2^{Z/\gamma}$ and $f_4^{Z/\gamma}$ are $\not{C}\not{P}$
- $h_3^{Z/\gamma}$, $h_4^{Z/\gamma}$ and $f_5^{Z/\gamma}$ conserve CP

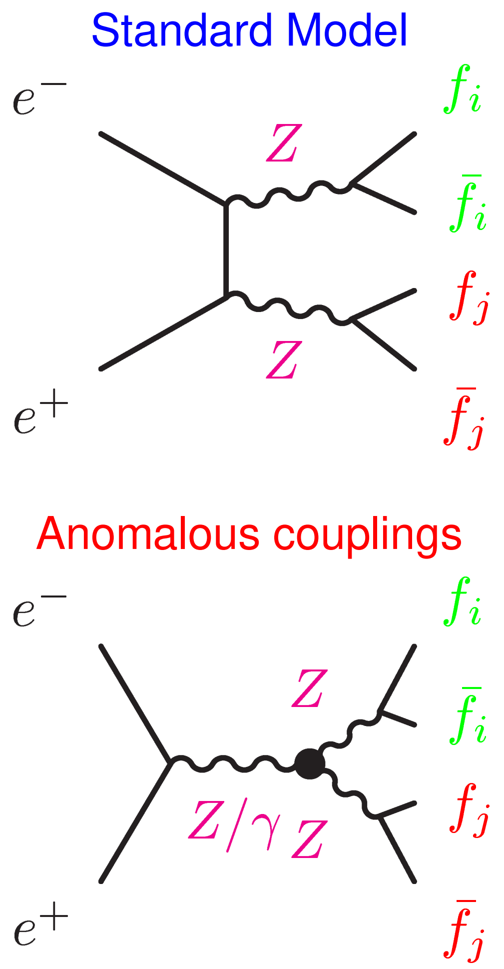
$\rightarrow$ All these couplings vanish in the Standard Model at tree level

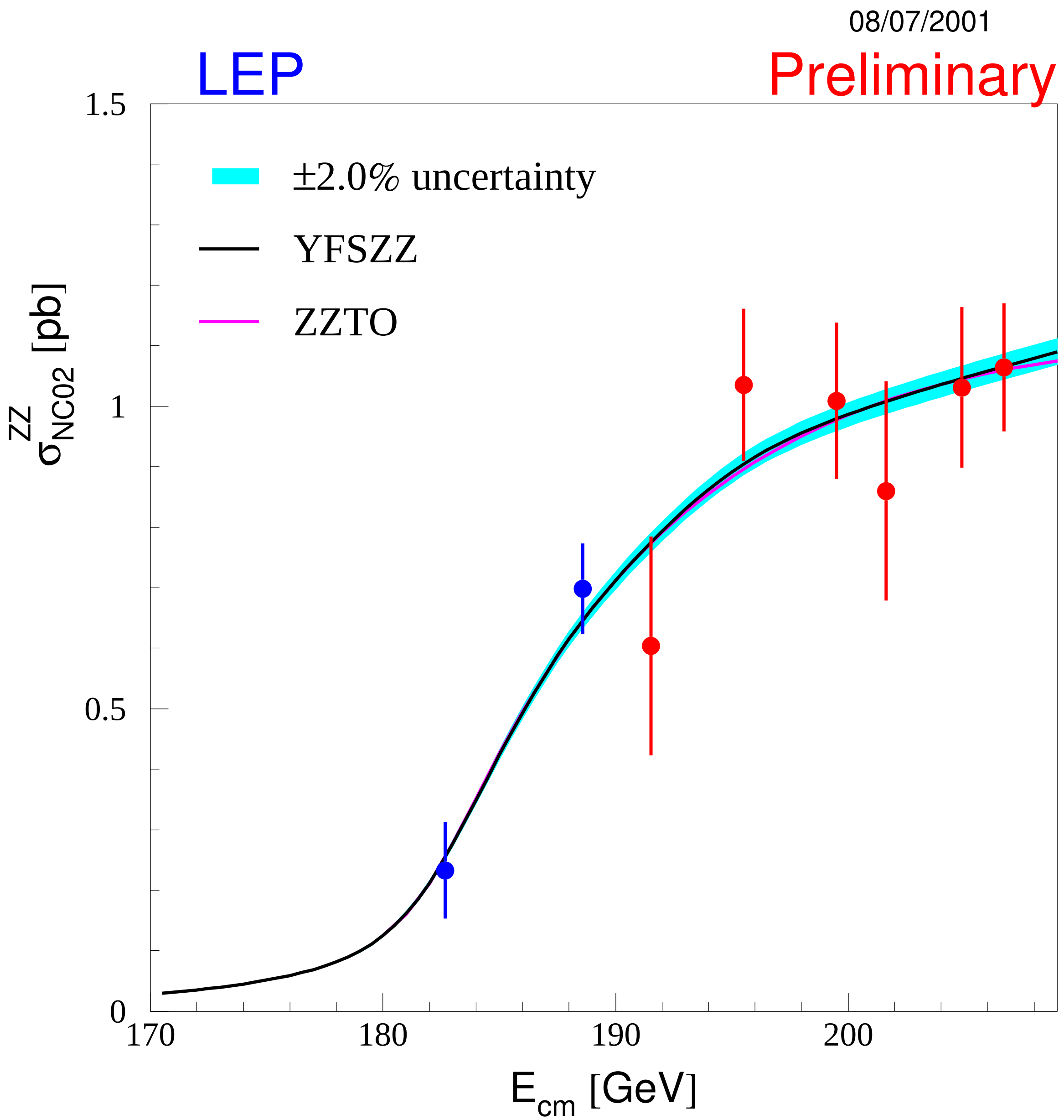
Similar to couplings of W, SU(2)×U(1) symmetry (hep-ph/0111283):

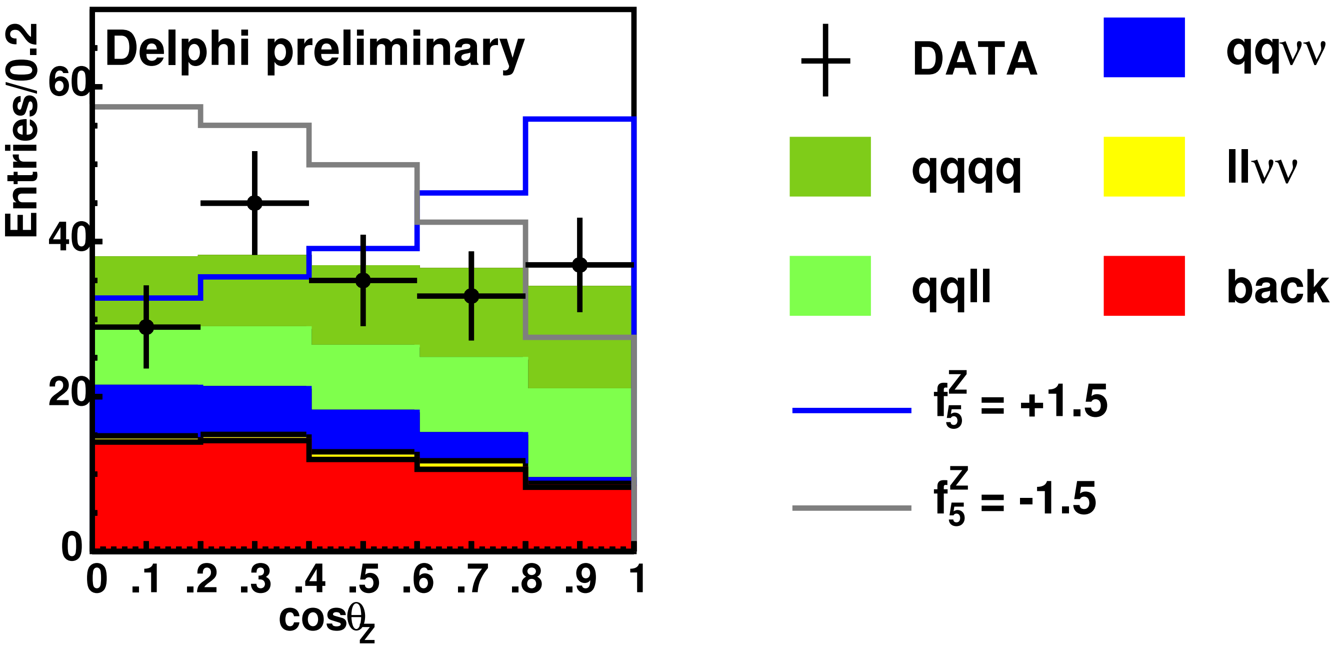
$$f_5^{Z/\gamma} = h_3^{Z/\gamma} \tan\theta_W$$
$$f_4^{Z/\gamma} = h_1^{Z/\gamma} \tan\theta_W$$

(yet to be done)

Couplings of three neutral bosons: ZZ



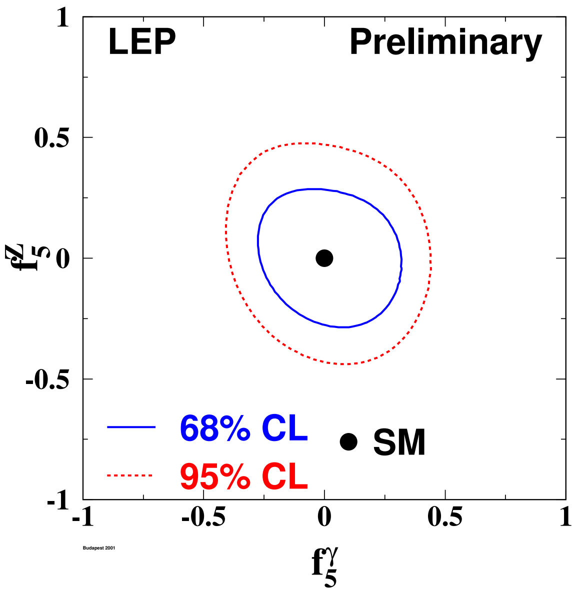


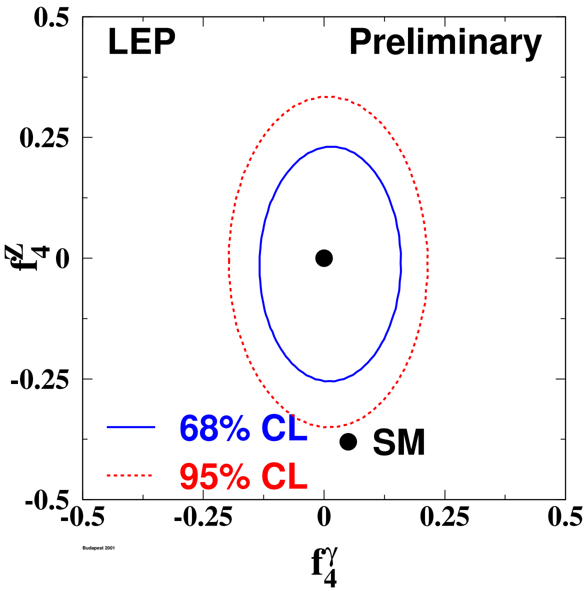


Limits at 95% CL:

CP

f_5^γ	$[-0.34, 0.38]$
f_5^Z	$[-0.36, 0.38]$

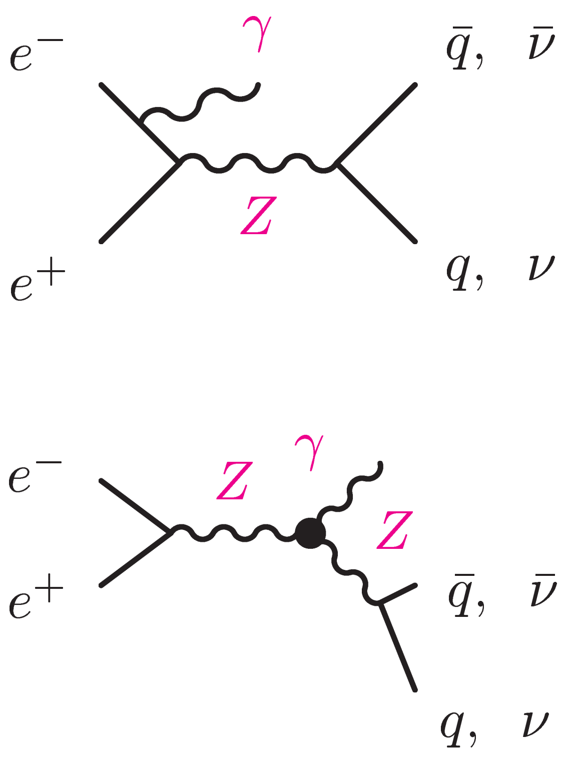


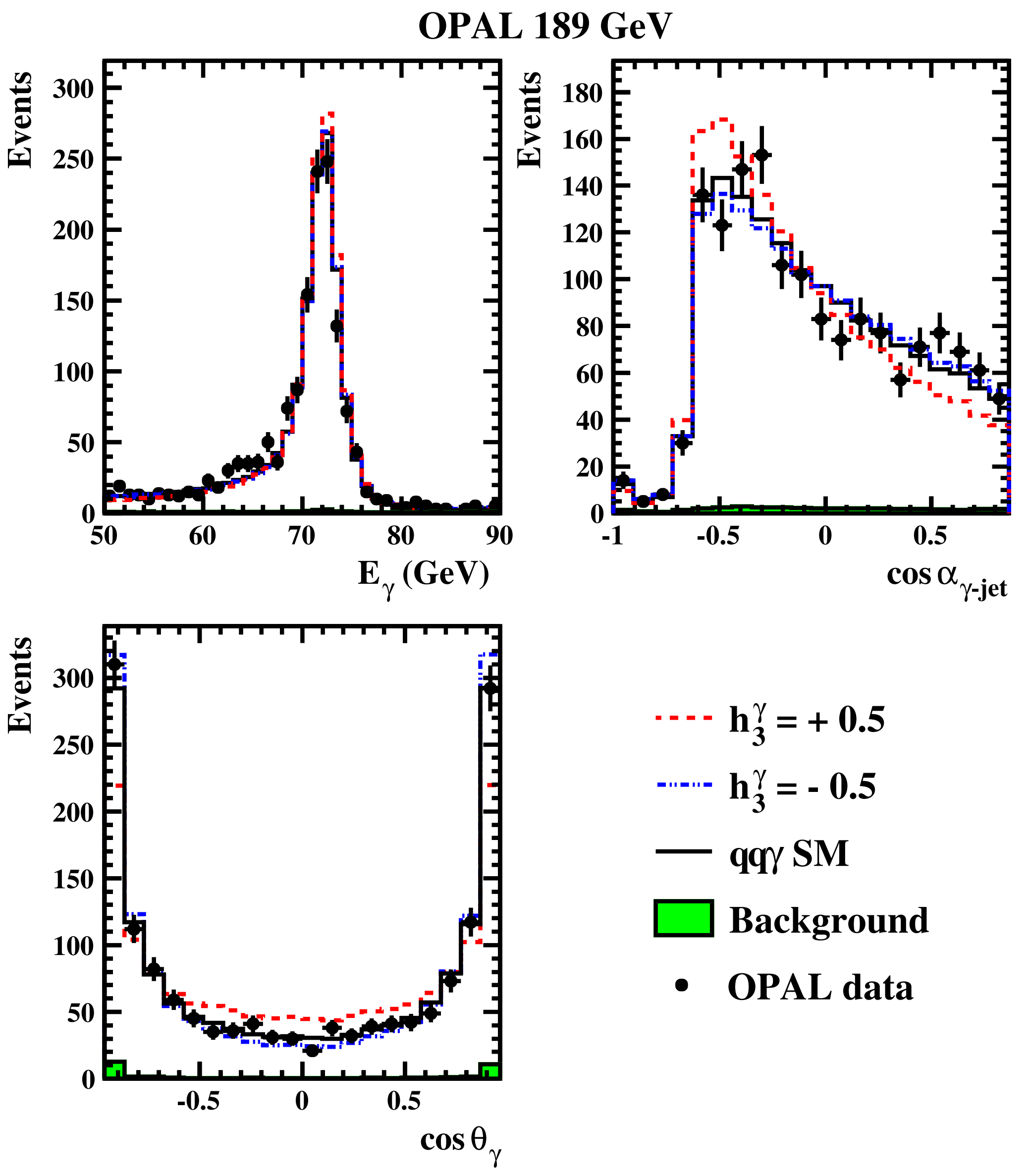


$\not{C}\not{P}$

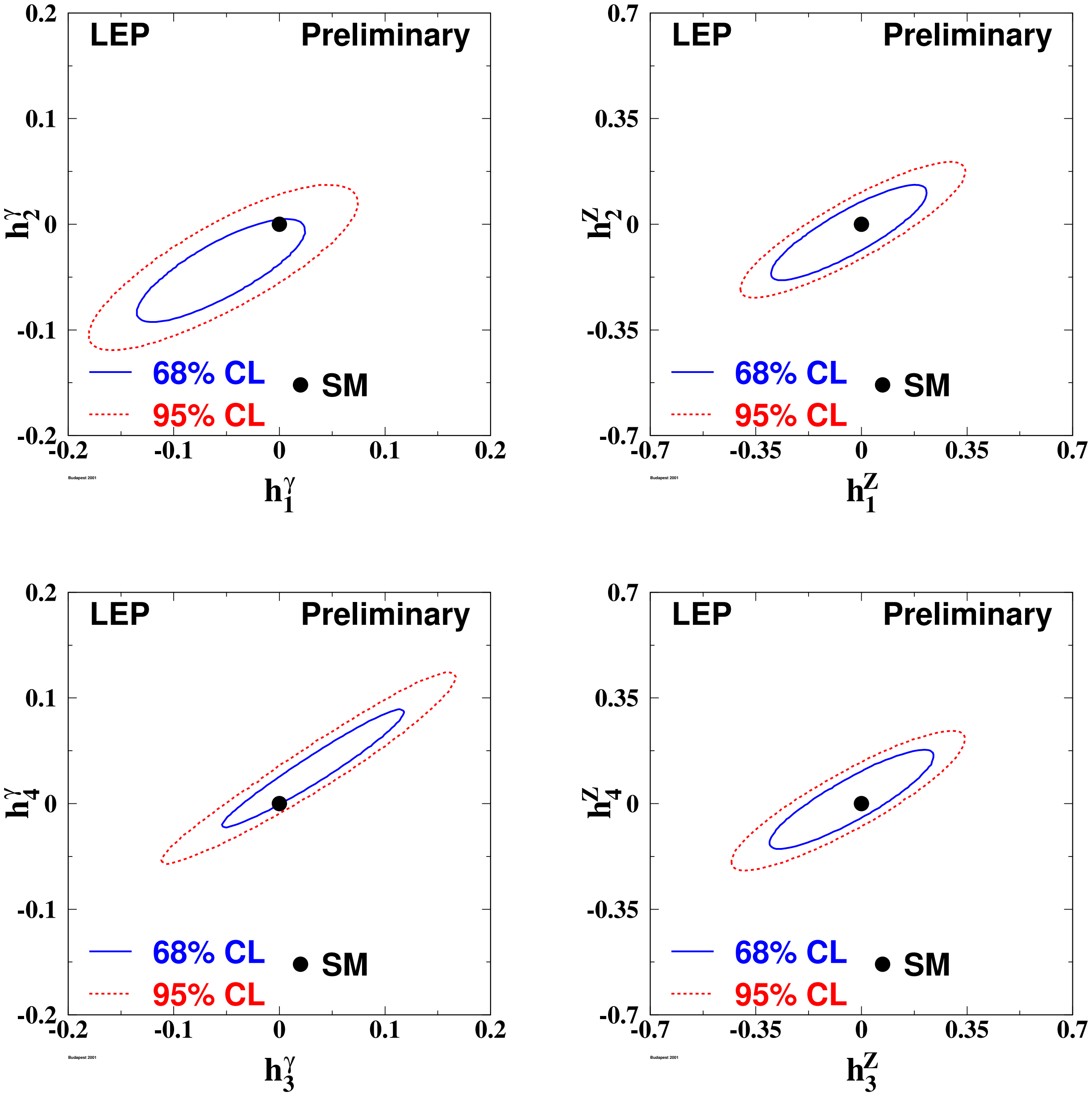
f_4^γ	$[-0.17, 0.19]$
f_4^Z	$[-0.30, 0.28]$

Couplings of three neutral bosons: Zγ





Couplings of three neutral bosons: Zγ

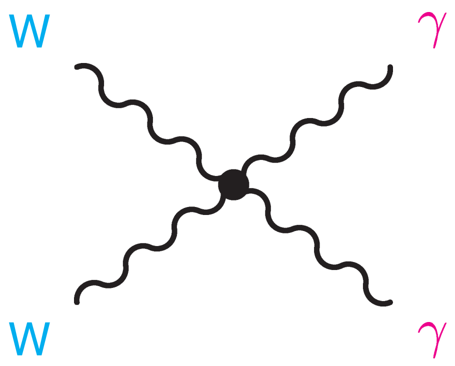


Limits at 95% CL:

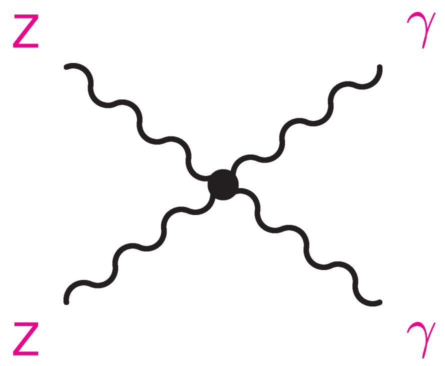
	$\not{C}\not{P}$
h_1^γ	$[-0.056, 0.055]$
h_2^γ	$[-0.045, 0.025]$
h_1^Z	$[-0.13, 0.13]$
h_2^Z	$[-0.078, 0.071]$

	CP
h_3^γ	$[-0.049, 0.008]$
h_4^γ	$[-0.002, 0.034]$
h_3^Z	$[-0.20, 0.07]$
h_4^Z	$[-0.05, 0.12]$

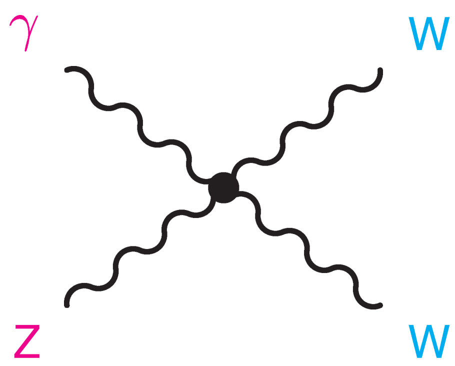
Consider the following vertices:



a_0^W a_c^W



a_0^Z a_c^Z



a_n

The anomalous contributions to these vertices are:

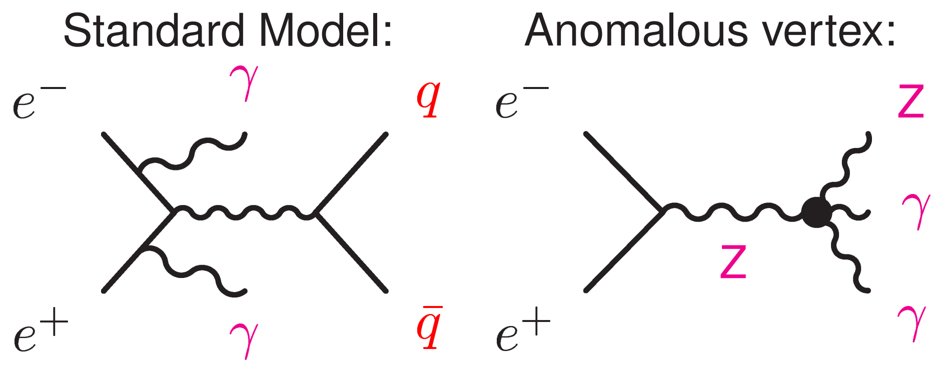
$$\mathcal{L}_0 = -\frac{e^2}{16}\frac{a_0^{W,Z}}{\Lambda^2} F^{\mu\nu} F_{\mu\nu} \vec{W}^\alpha \vec{W}_\alpha \qquad WW\gamma\gamma, ZZ\gamma\gamma$$

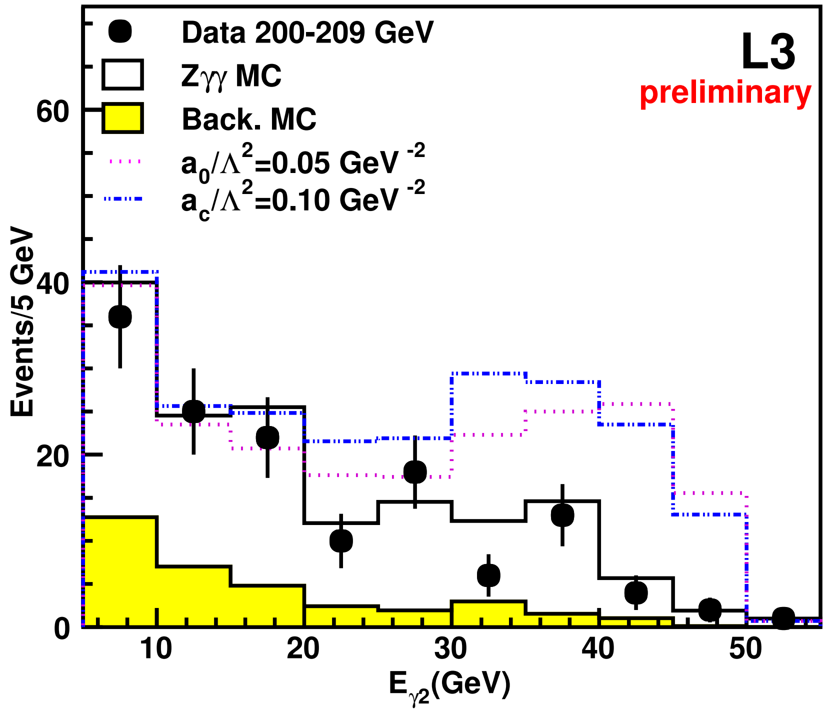
$$\mathcal{L}_c = -\frac{e^2}{16}\frac{a_c^{W,Z}}{\Lambda^2} F^{\mu\alpha} F_{\mu\beta} \vec{W}^\beta \vec{W}_\alpha \qquad WW\gamma\gamma, ZZ\gamma\gamma$$

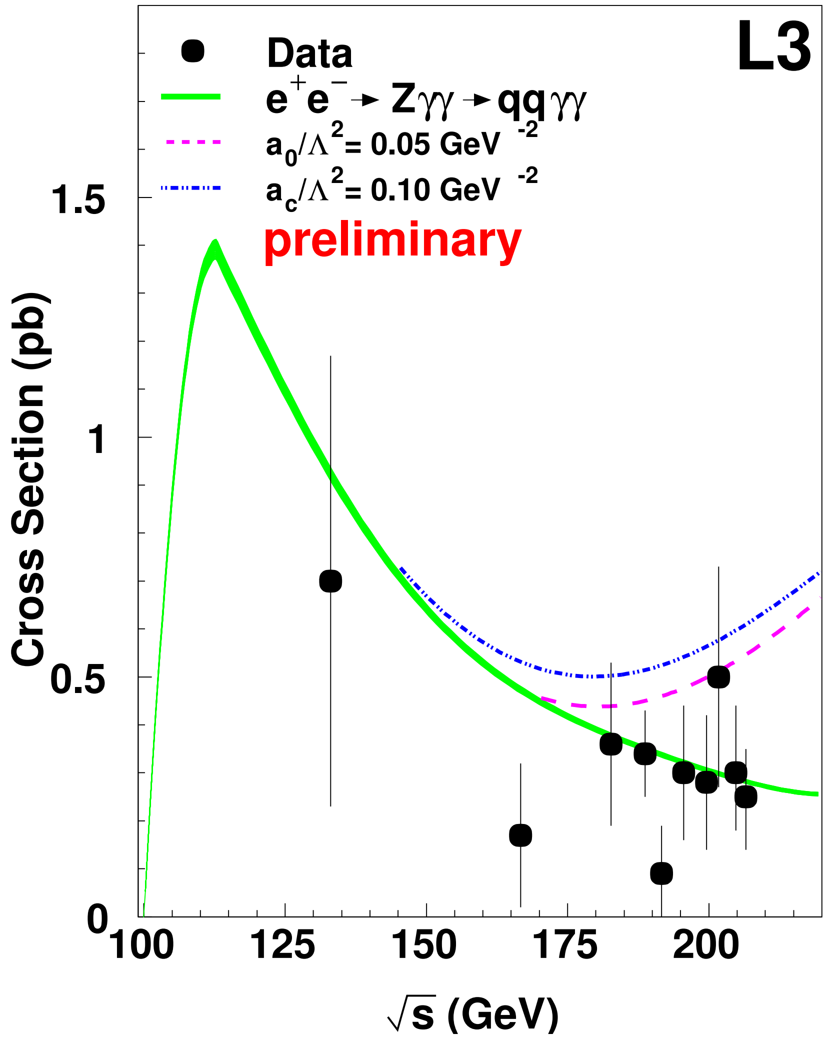
$$\mathcal{L}_n = -\frac{e^2}{16}\frac{a_n}{\Lambda^2} \vec{W}_{\mu\alpha} \cdot (\vec{W}_\nu \times \vec{W}^\alpha) F^{\mu\nu} \qquad WWZ\gamma$$

- Λ is the scale of new physics associated with these phenomena.
- a_0 and a_c conserve CP, whereas a_n violates CP.
- Couplings from Z could be different from W (here assumed to be the same)

Quartic couplings: $Z\gamma\gamma$





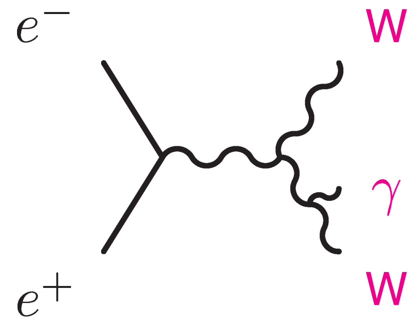


$$-0.02 \leq a_0/\Lambda^2 \times \text{GeV}^2 \leq 0.03$$

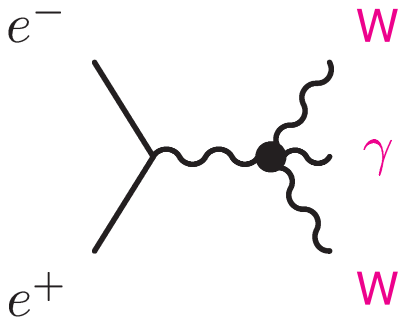
$$-0.07 \leq a_c/\Lambda^2 \times \text{GeV}^2 \leq 0.05$$

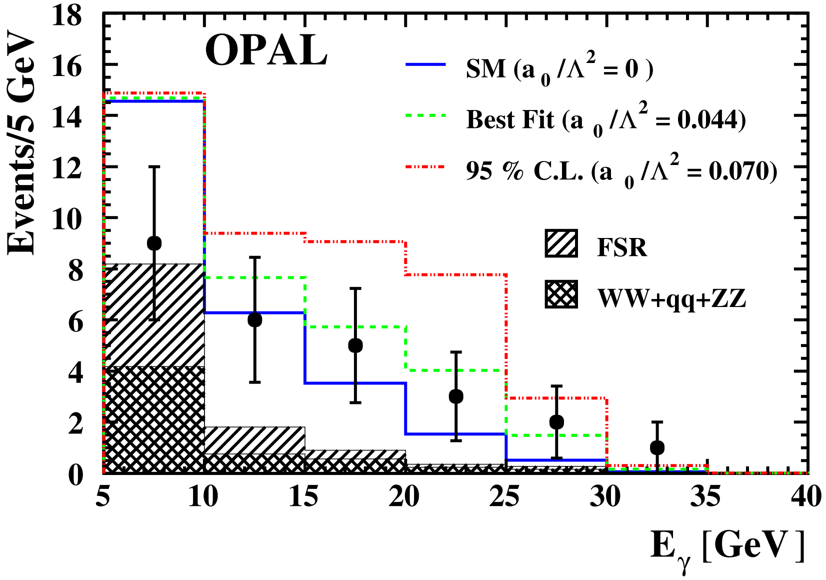
Quartic couplings: W$\gamma\gamma$

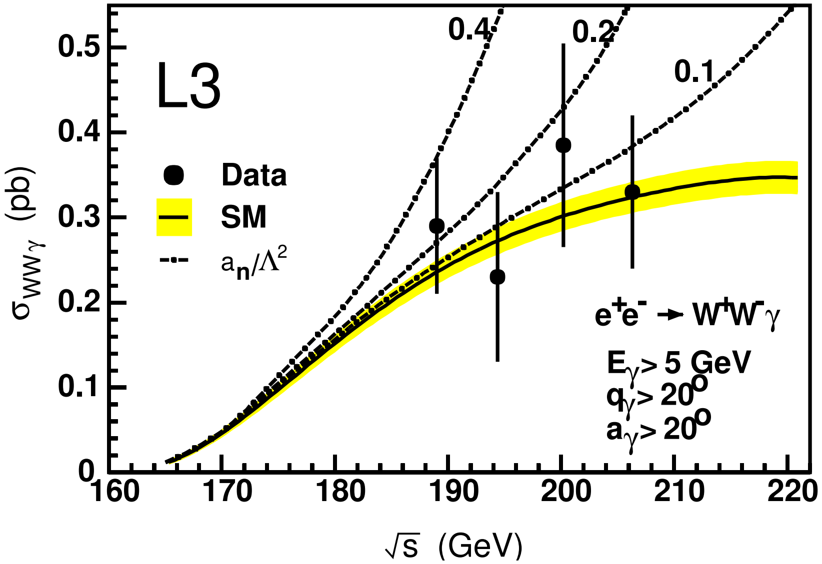
Standard Model:



Anomalous vertex:







LEP Combined limits for quartic couplings:

$$-0.02 \leq a_0/\Lambda^2 \times \mathrm{GeV}^2 \leq 0.02$$

$$-0.03 \leq a_c/\Lambda^2 \times \mathrm{GeV}^2 \leq 0.05$$

$$-0.17 \leq a_n/\Lambda^2 \times \mathrm{GeV}^2 \leq 0.15$$

Conclusions

- The existence of the non-Abelian structure of the Standard Model has been proven by LEP experiments
- The γWW and ZWW couplings are in good agreement with prediction of the Standard Model
- Many other possible boson self-couplings have been studied

$\rightarrow$ No significant deviation from the Standard Model has been found

$\Rightarrow$ The Standard Model continues to describe the data...

Correlated systematic errors

Source	$\Delta\kappa_\gamma$	λ_γ	Δg_1^Z
$\mathcal{O}(\alpha)$ corrections	$^{+0.038}_{-0.040}$	$^{+0.014}_{-0.015}$	$^{+0.012}_{-0.018}$
WW cross-section	$^{+0.014}_{-0.014}$	$^{+0.005}_{-0.006}$	$^{+0.000}_{-0.005}$
Bose-Einstein correlation	$^{+0.009}_{-0.009}$	$^{+0.003}_{-0.004}$	$^{+0.003}_{-0.007}$
Colour-Reconnection	$^{+0.009}_{-0.011}$	$^{+0.003}_{-0.004}$	$^{+0.003}_{-0.004}$
Fragmentation	$^{+0.004}_{-0.004}$	$^{+0.001}_{-0.002}$	$^{+0.002}_{-0.006}$
single-W cross-section	$^{+0.010}_{-0.012}$	$^{+0.000}_{-0.000}$	$^{+0.000}_{-0.000}$

Combination done according to a new proposal: L3 note 2718