

Measurement of Boson self couplings at LEP and search for anomalies

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On behalf of the LEP experiments

Original title: "Four Fermion Interactions and Anomalous Couplings"

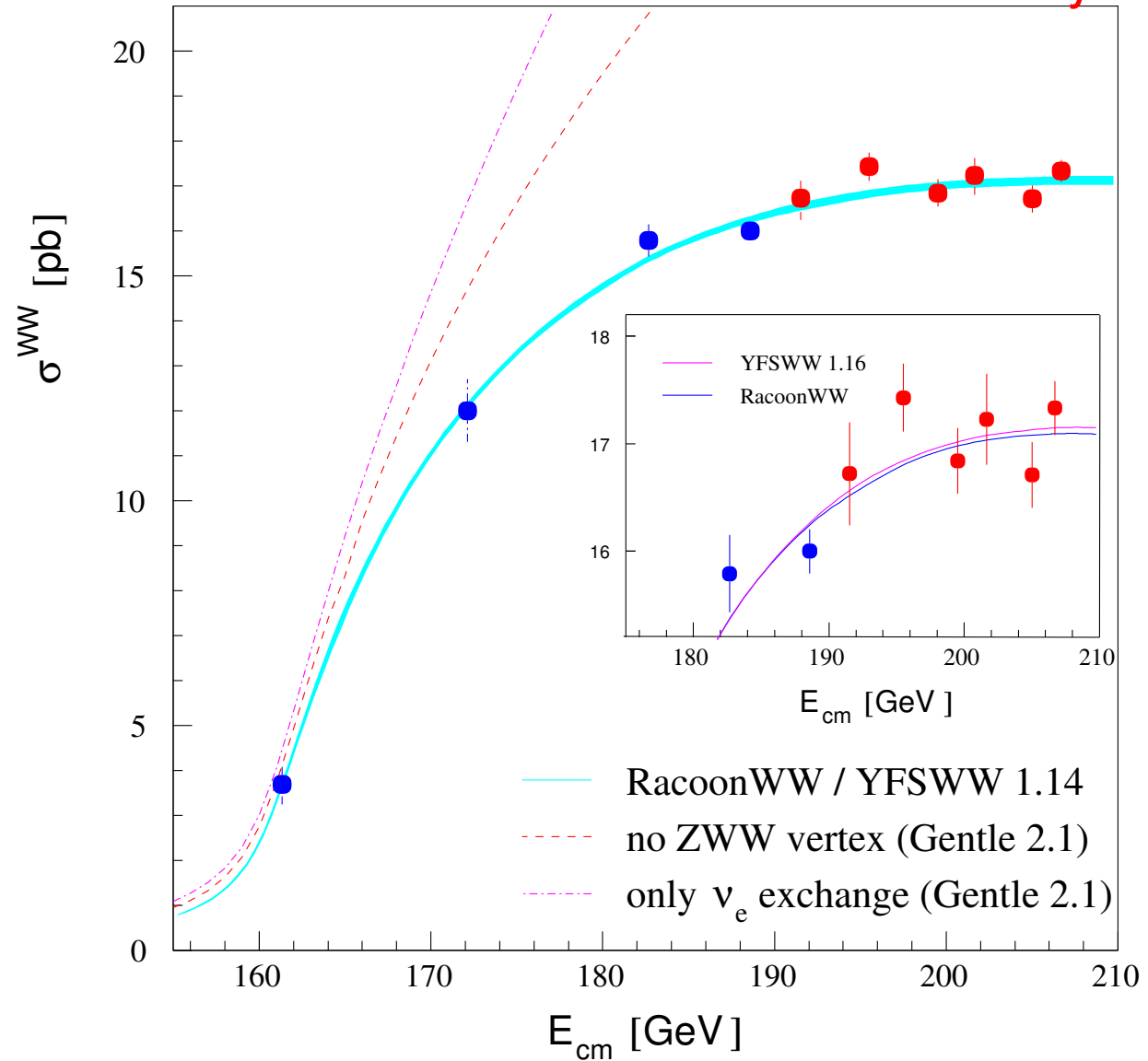
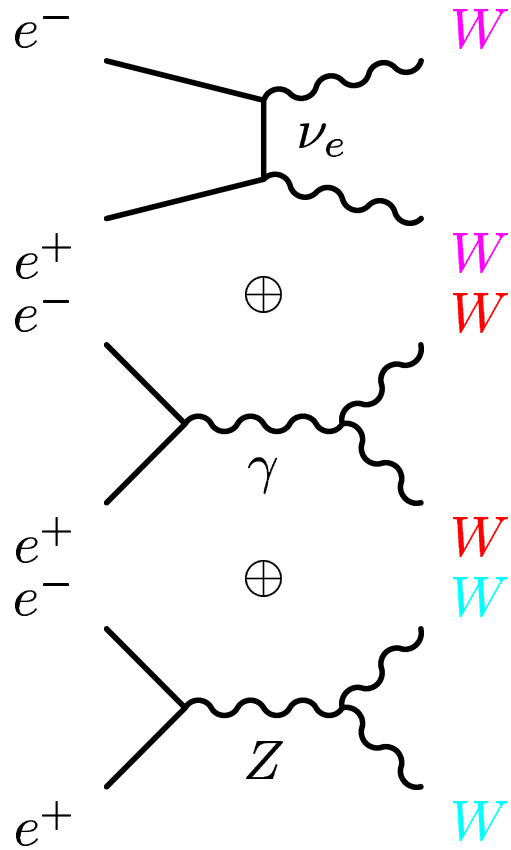
XXXVIIth Rencontres de Moriond

W^+W^- cross section

08/07/2001

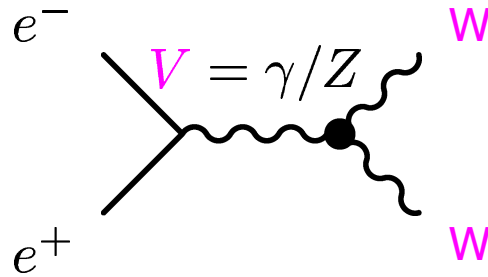
LEP

Preliminary



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**):

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

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

$$g_1^\gamma = 1 \quad (q_W = \pm 1)$$

$$\kappa_Z = g_1^Z - (\kappa_\gamma - 1) \tan^2 \theta_W$$

$$\lambda_Z = \lambda_\gamma$$

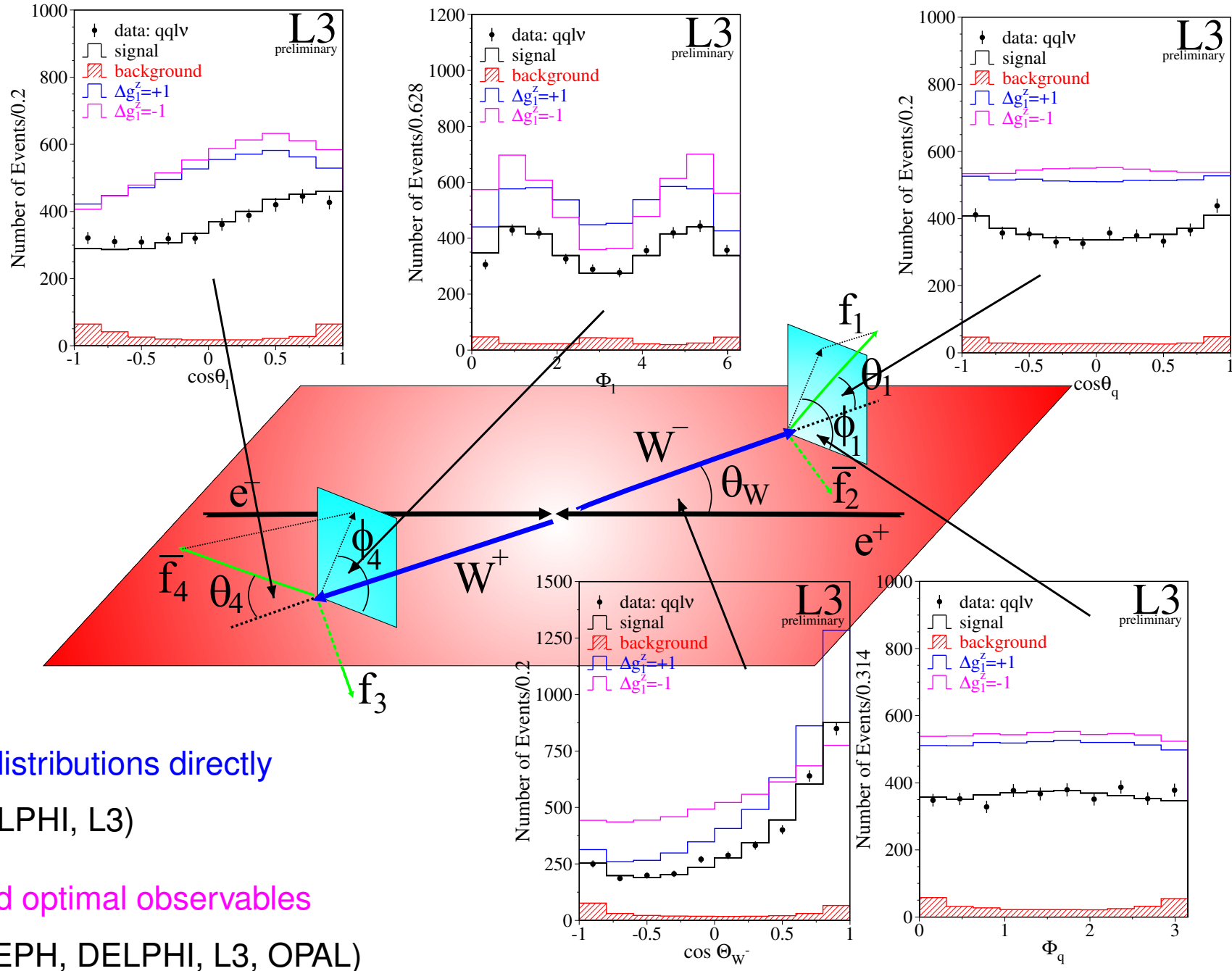
Remaining **3 couplings** are fitted:

$$g_1^Z \quad (\text{SM} : 1) \quad \Delta g_1^Z = g_1^Z - 1 \quad (\text{SM} : 0)$$

$$\kappa_\gamma \quad (\text{SM} : 1) \quad \rightarrow \quad \Delta \kappa_\gamma = \kappa_\gamma - 1 \quad (\text{SM} : 0)$$

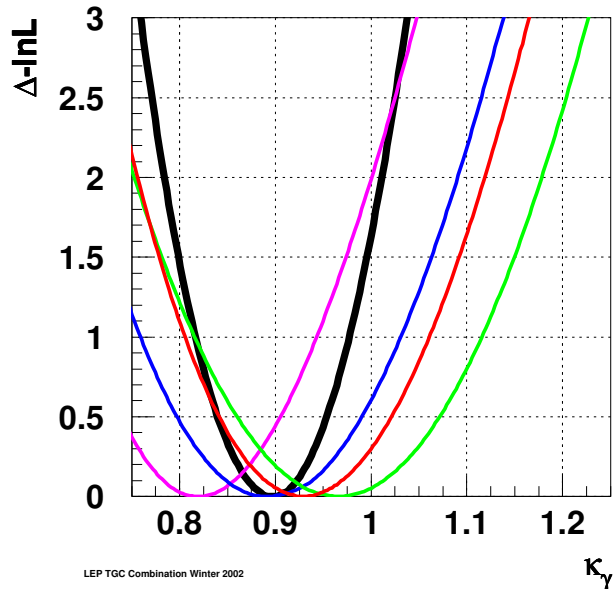
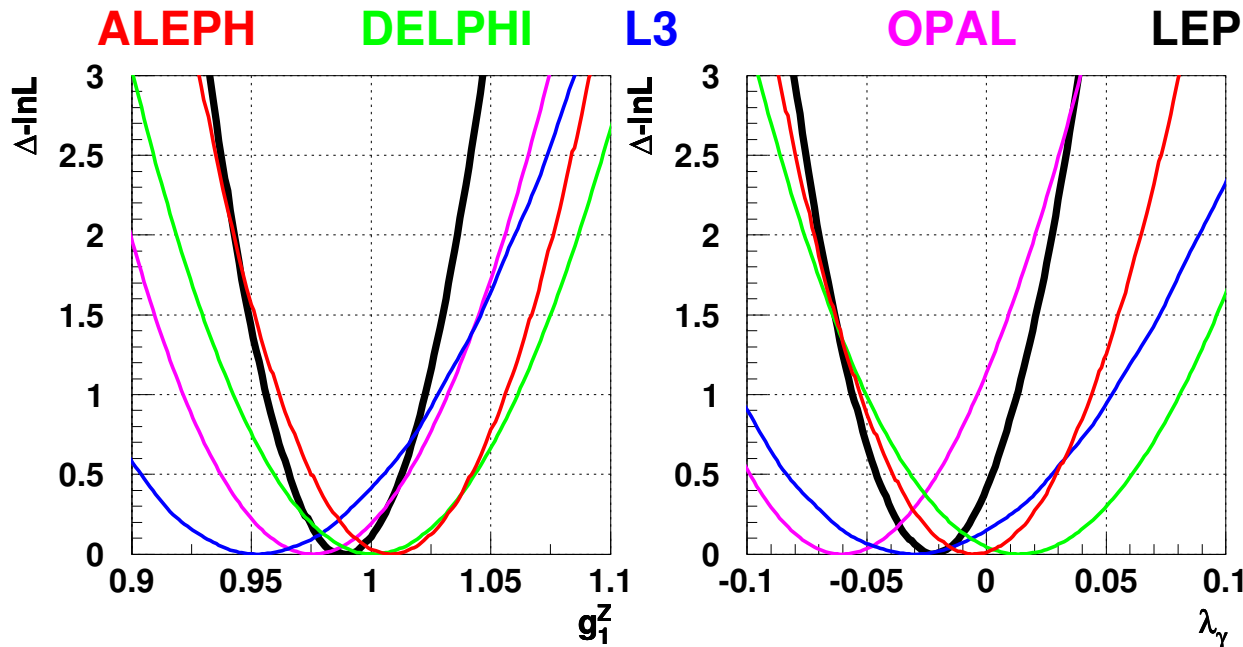
$$\lambda_\gamma \quad (\text{SM} : 0) \quad \lambda_\gamma \quad (\text{SM} : 0)$$

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

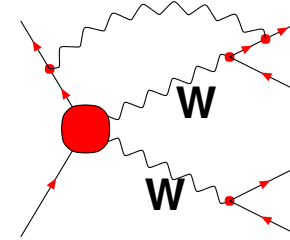


LEP preliminary

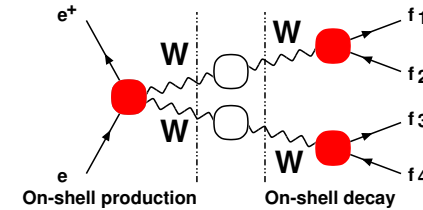
$$\begin{aligned} \kappa_\gamma &= 0.896 & +0.058 & -0.056 \\ \lambda_\gamma &= -0.023 & +0.025 & -0.023 \\ g_1^Z &= 0.990 & +0.023 & -0.024 \end{aligned}$$

Theoretical improvements:

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



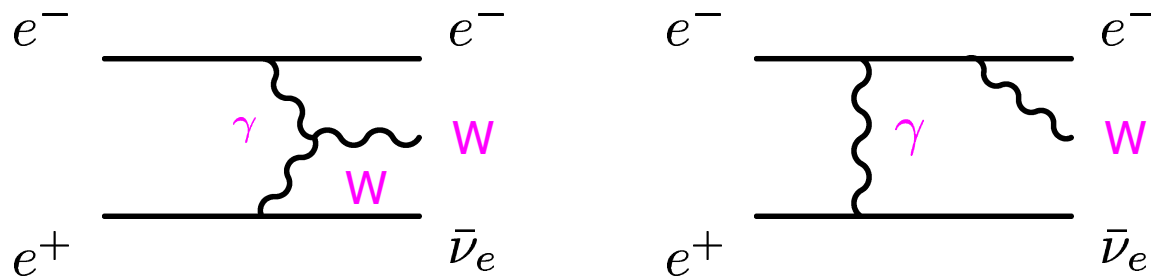
DPA



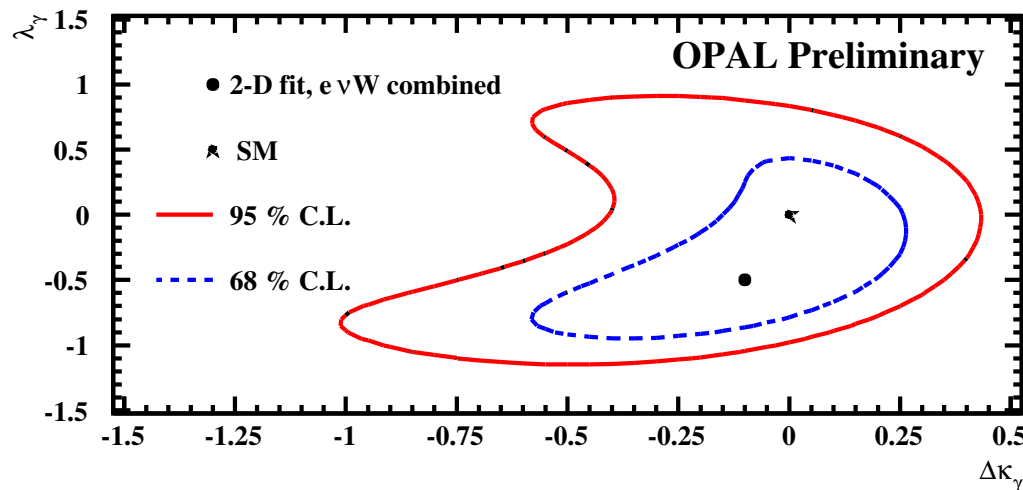
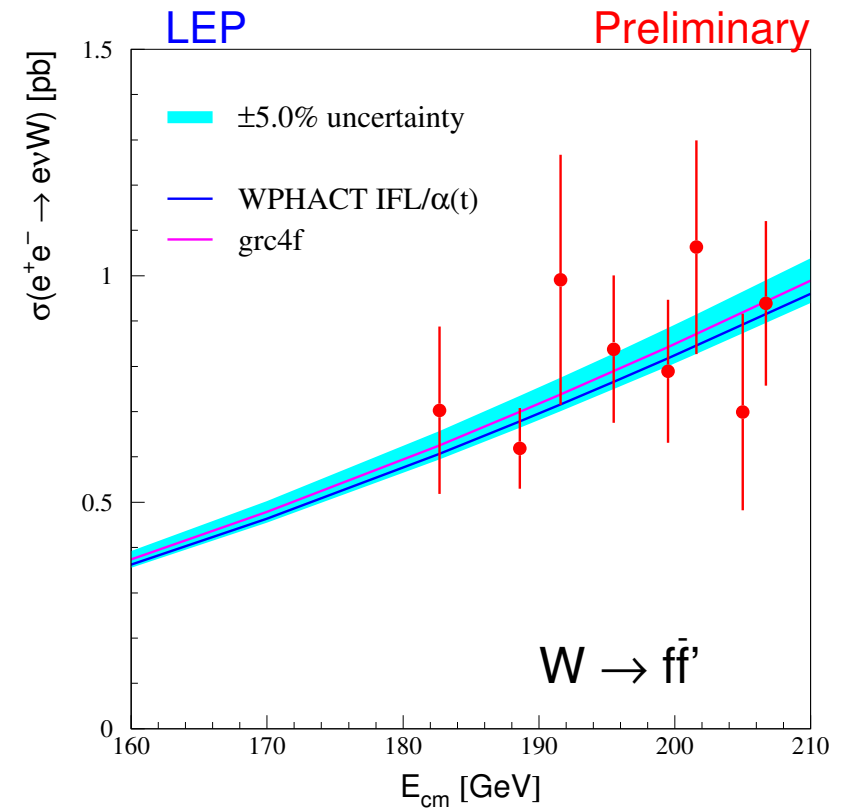
- Not all channels are included
- Statistical error will improve
- Largest correlated systematic: $\mathcal{O}(\alpha)$ corrections
- Need better understanding of theory error

Couplings of the W to other bosons: Single-W

25/07/2001



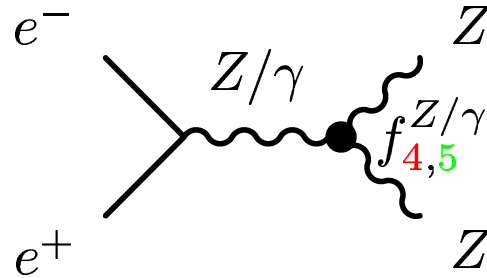
- Smaller sensitivity than WW
- WW γ vertex gives access to $\Delta\kappa_\gamma$ and λ_γ
- Single-W events are most sensitive to $\Delta\kappa_\gamma$



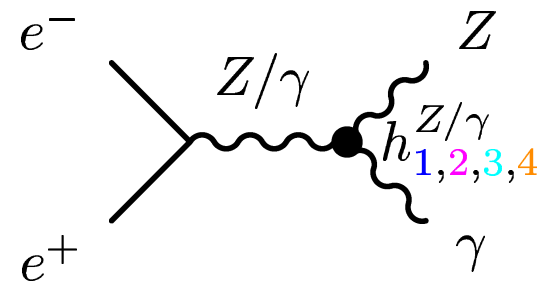
These results are included in the combined fits.

Couplings of three neutral bosons

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 CP
- $h_3^{Z/\gamma}$, $h_4^{Z/\gamma}$ and $f_5^{Z/\gamma}$ conserve CP

→ All these couplings **vanish in the Standard Model** at tree level

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

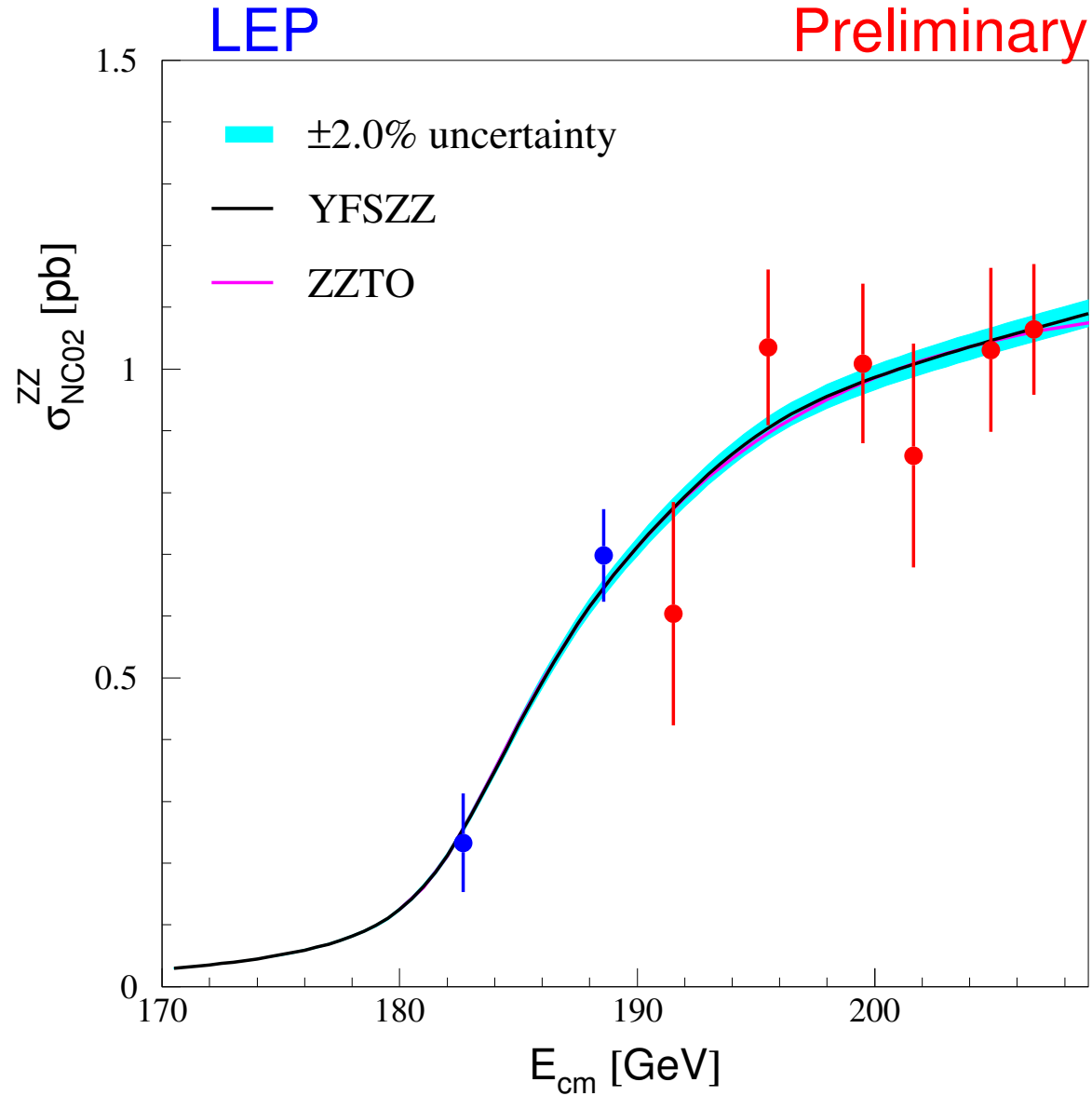
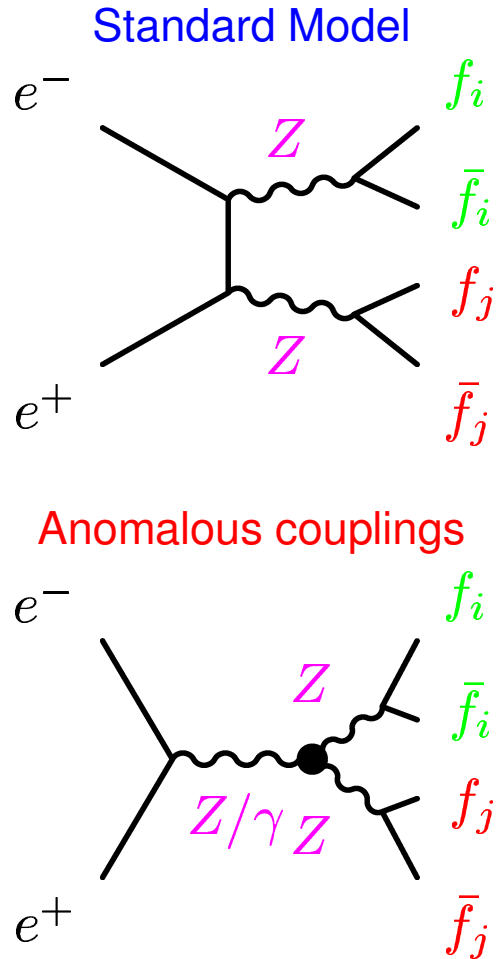
$$f_5^{Z/\gamma} = h_3^{Z/\gamma} \tan \theta_W$$

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

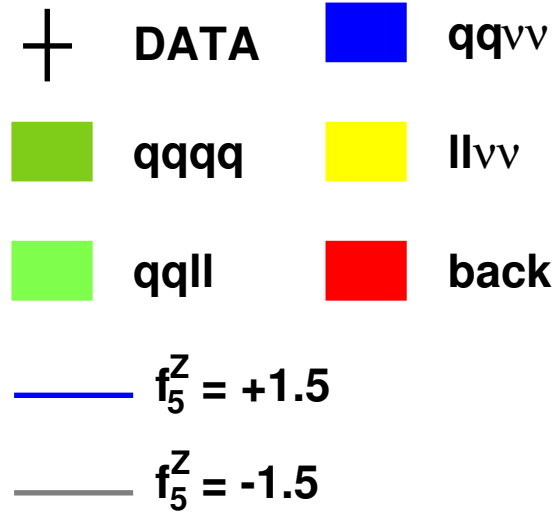
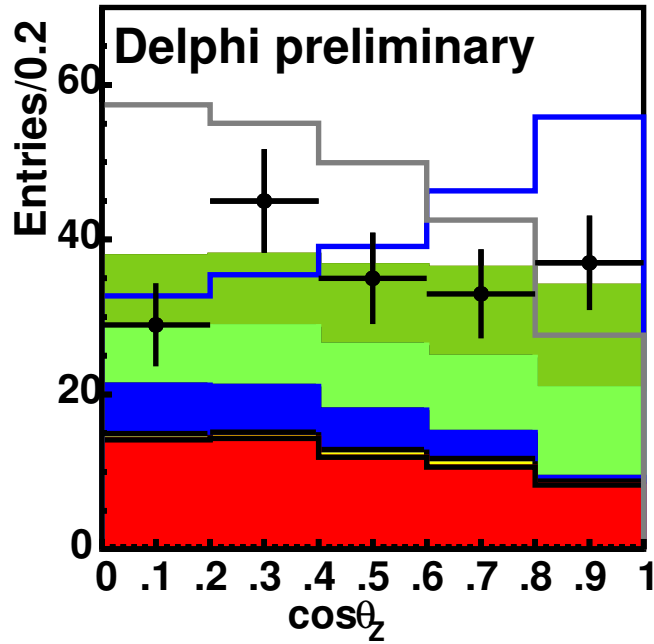
(yet to be done)

Couplings of three neutral bosons: ZZ

08/07/2001



Couplings of three neutral bosons: ZZ and f couplings

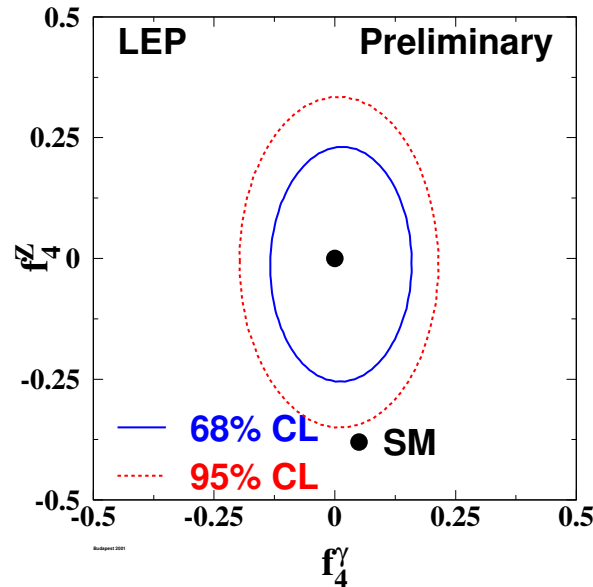
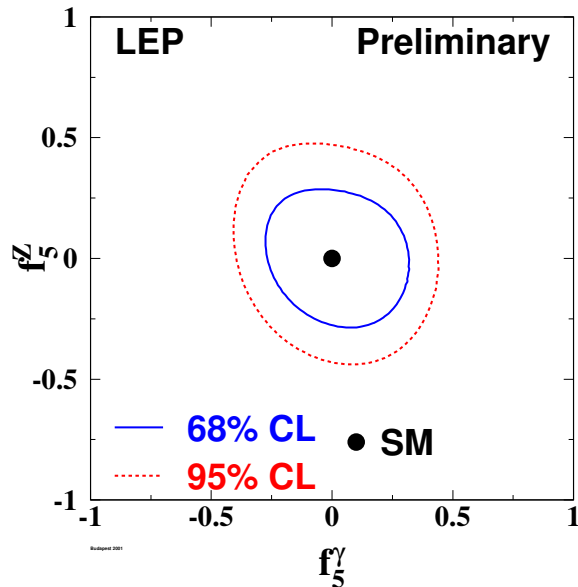


Limits at 95% CL:

CP

$$f_5^\gamma \quad [-0.34, 0.38]$$

$$f_5^Z \quad [-0.36, 0.38]$$

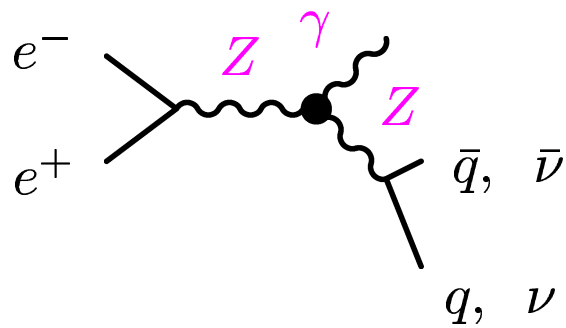
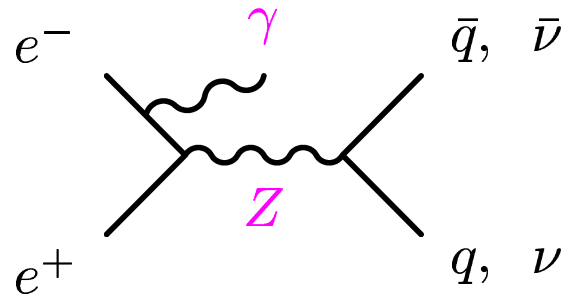


~~CP~~

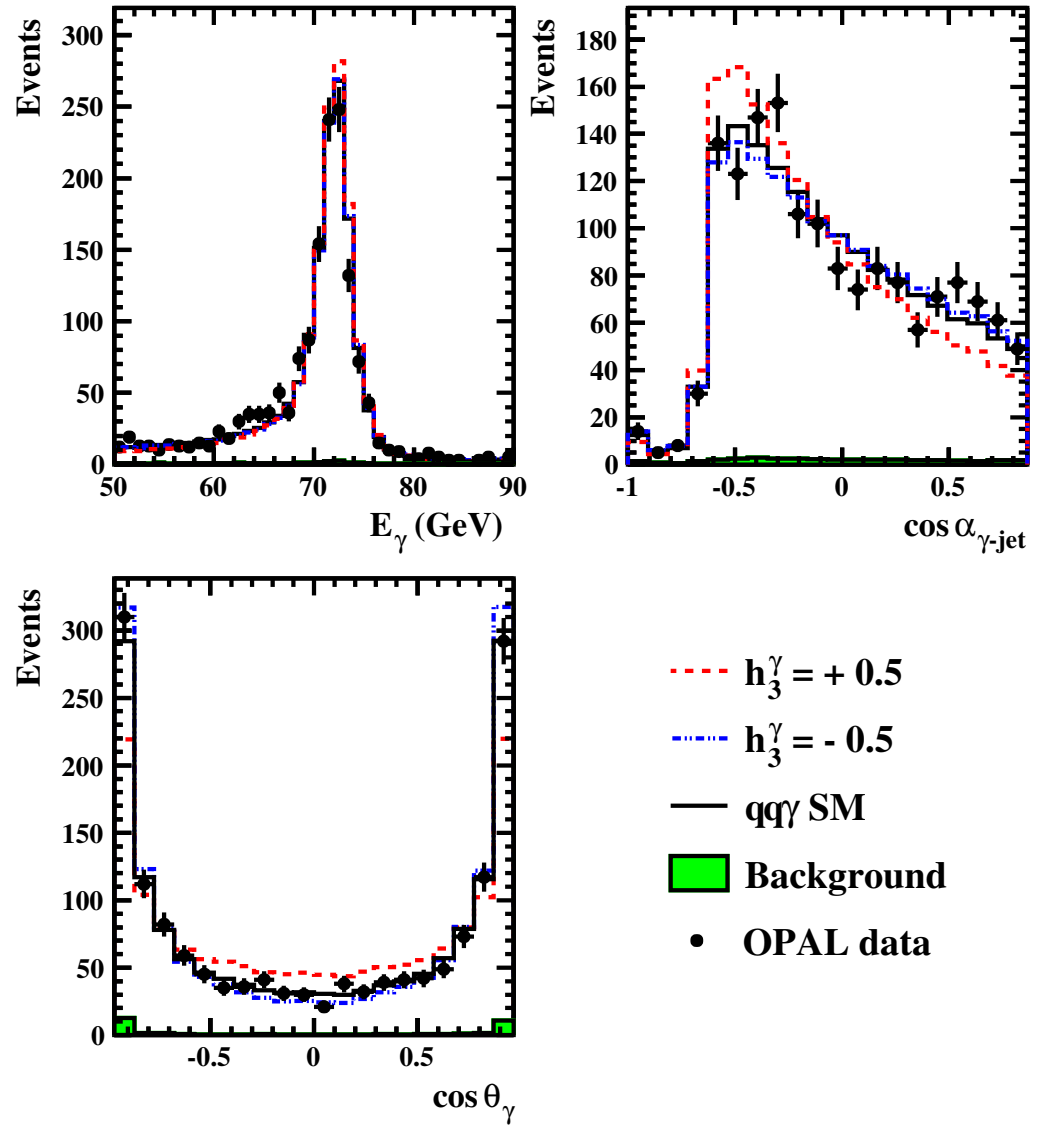
$$f_4^\gamma \quad [-0.17, 0.19]$$

$$f_4^Z \quad [-0.30, 0.28]$$

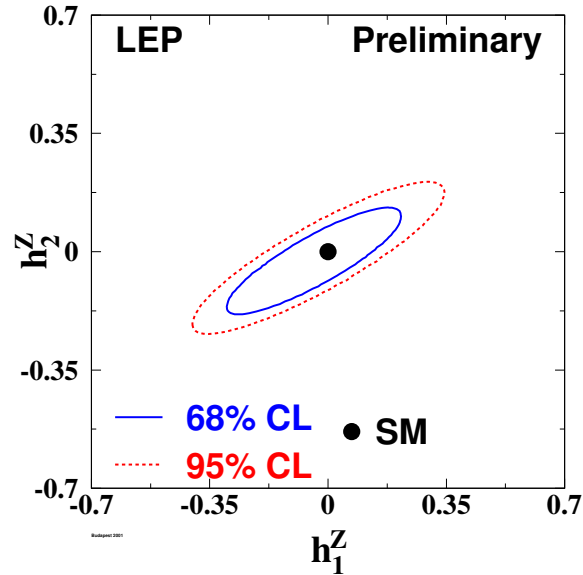
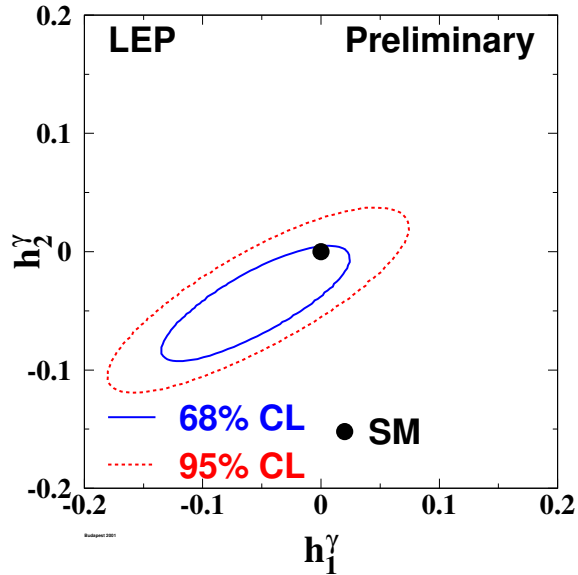
Couplings of three neutral bosons: $Z\gamma$



OPAL 189 GeV



Couplings of three neutral bosons: $Z\gamma$



Limits at 95% CL:

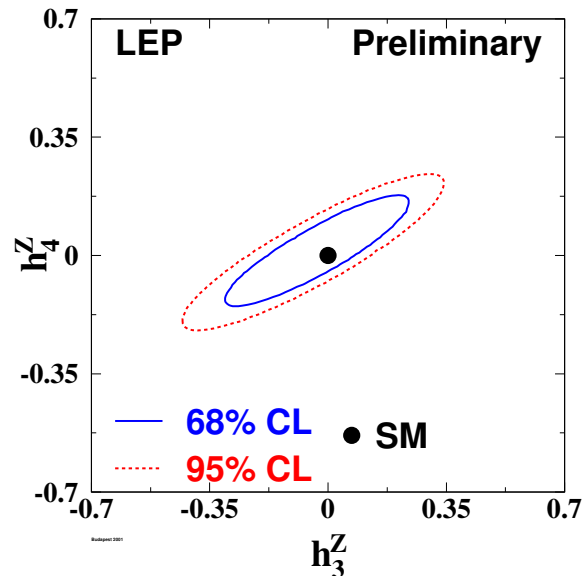
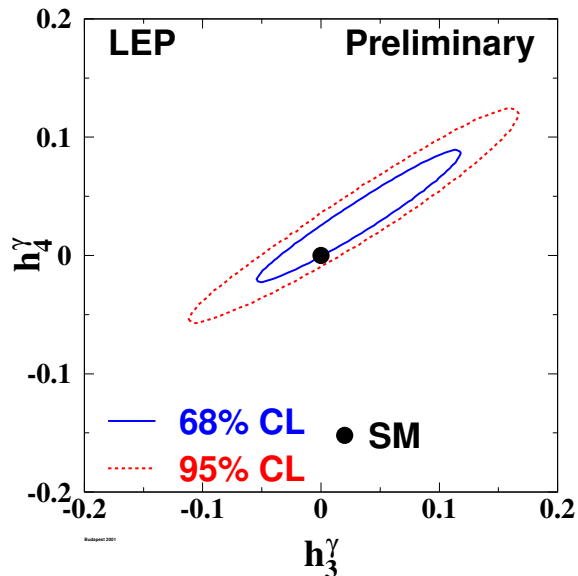
~~*CP*~~

$$h_1^\gamma \quad [-0.056, 0.055]$$

$$h_2^\gamma \quad [-0.045, 0.025]$$

$$h_1^Z \quad [-0.13, 0.13]$$

$$h_2^Z \quad [-0.078, 0.071]$$



CP

$$h_3^\gamma \quad [-0.049, 0.008]$$

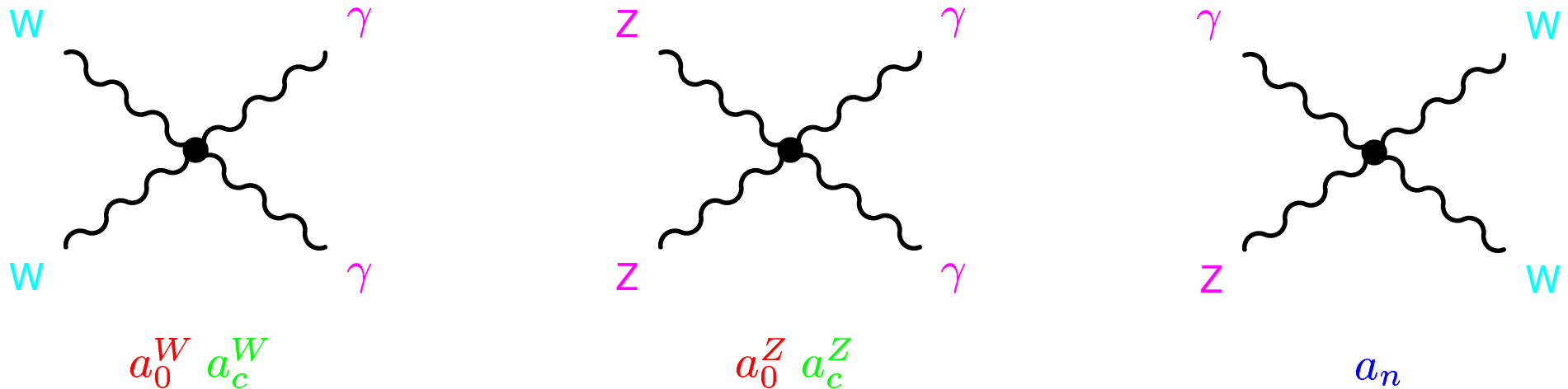
$$h_4^\gamma \quad [-0.002, 0.034]$$

$$h_3^Z \quad [-0.20, 0.07]$$

$$h_4^Z \quad [-0.05, 0.12]$$

Quartic boson self-couplings

Consider the following vertices:

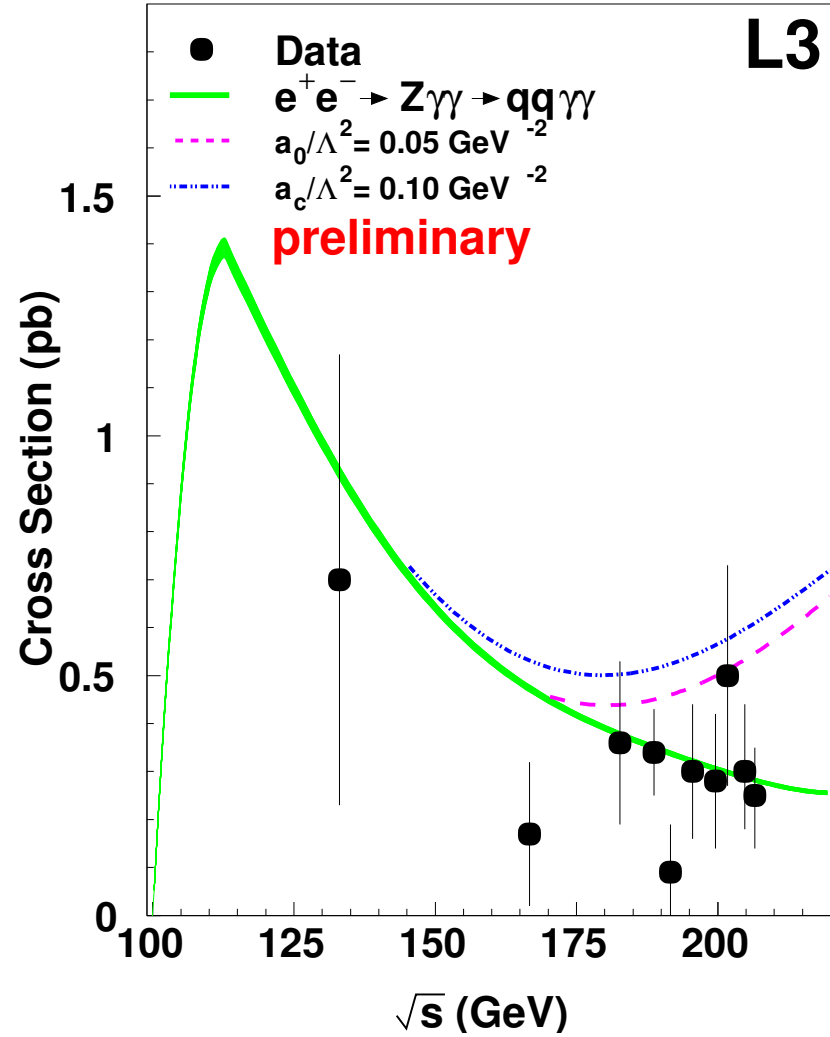
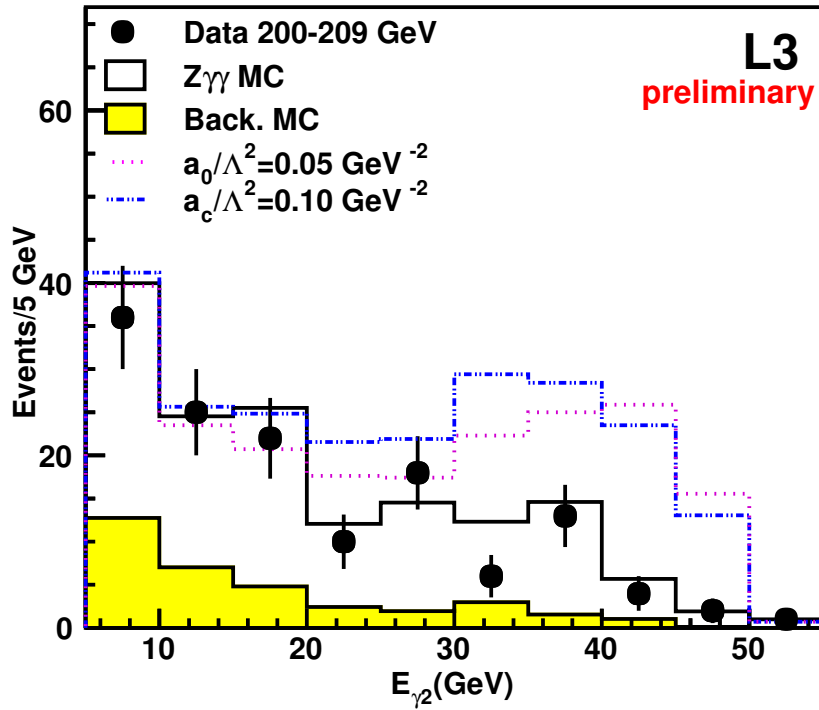
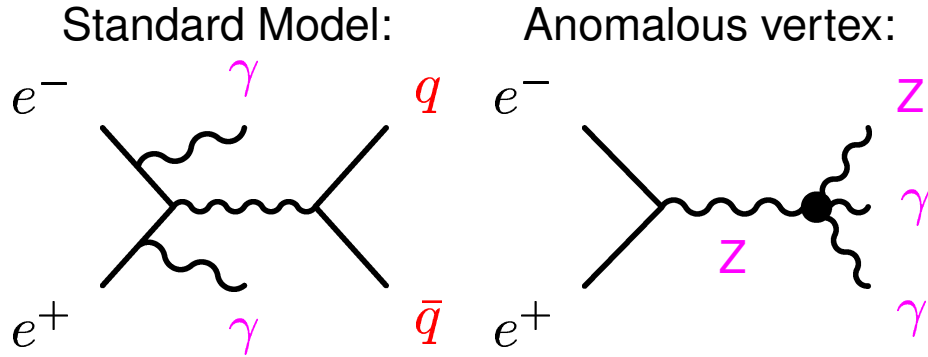


The anomalous contributions to these vertices are:

$$\begin{aligned}
 \mathcal{L}_0 &= -\frac{e^2}{16} \frac{a_0^{W,Z}}{\Lambda^2} F^{\mu\nu} F_{\mu\nu} \vec{W}^\alpha \vec{W}_\alpha && WW\gamma\gamma, ZZ\gamma\gamma \\
 \mathcal{L}_c &= -\frac{e^2}{16} \frac{a_c^{W,Z}}{\Lambda^2} F^{\mu\alpha} F_{\mu\beta} \vec{W}^\beta \vec{W}_\alpha && WW\gamma\gamma, ZZ\gamma\gamma \\
 \mathcal{L}_n &= -\frac{e^2}{16} \frac{a_n}{\Lambda^2} \vec{W}_{\mu\alpha} \cdot (\vec{W}_\nu \times \vec{W}^\alpha) F^{\mu\nu} && WWZ\gamma
 \end{aligned}$$

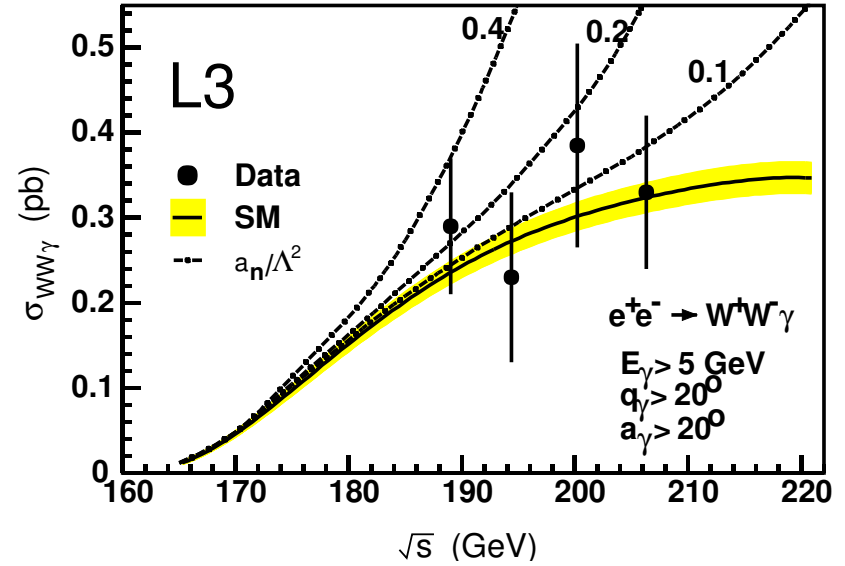
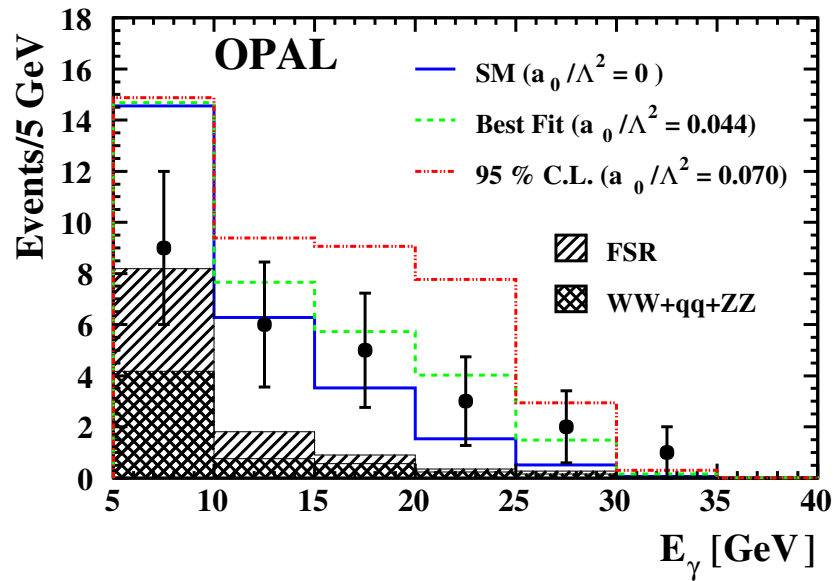
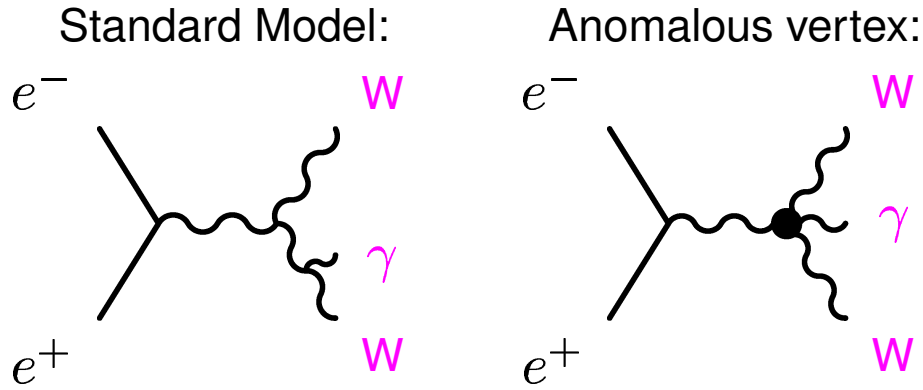
- Λ is the scale of new physics associated with these phenomena.
- a_0 and a_c conserve CP, whereas a_n violates CP.
- Couplings from Z could be different from W (here assumed to be the same)

Quartic couplings: $Z\gamma\gamma$



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

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



LEP Combined limits for quartic couplings:

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

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

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

- 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**
- **No significant deviation** from the Standard Model has been found
- ⇒ **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	+0.014	+0.012
	-0.040	-0.015	-0.018
WW cross-section	+0.014	+0.005	+0.000
	-0.014	-0.006	-0.005
Bose-Einstein correlation	+0.009	+0.003	+0.003
	-0.009	-0.004	-0.007
Colour-Reconnection	+0.009	+0.003	+0.003
	-0.011	-0.004	-0.004
Fragmentation	+0.004	+0.001	+0.002
	-0.004	-0.002	-0.006
single-W cross-section	+0.010	+0.000	+0.000
	-0.012	-0.000	-0.000

Combination done according to a new proposal: L3 note 2718