

Anomalous Triple Neutral & Quartic Gauge Boson Couplings

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for the LEP collaborations**

31st International Conference on High Energy Physics
Amsterdam – July 24th-31st 2002

Introduction

- Non-abelian structure of Standard Model
→ couplings between gauge bosons
- Triple couplings
 - $\gamma WW, ZWW$ real EW-3-4
 - $ZZZ, ZZ\gamma, Z\gamma\gamma$ don't exist (at tree level)
- Quartic couplings
 - $WW\gamma\gamma, WWZ\gamma,$ negligible at LEP
 - $ZZ\gamma\gamma,$ don't exist (at tree level)
 - $WWZZ, WWWW$ not at LEP

Introduction (2)

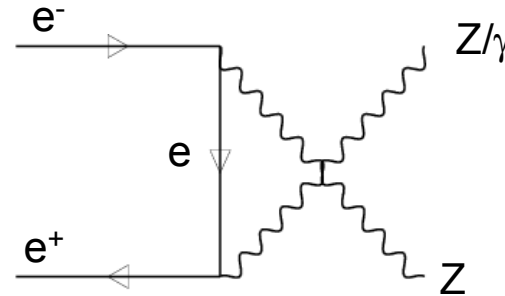
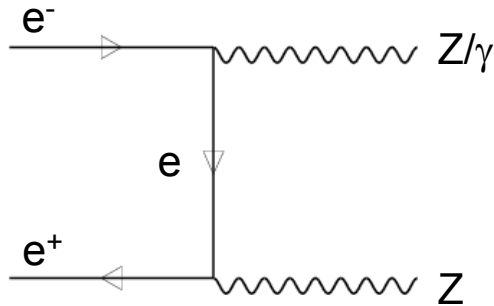
- Standard Model – nothing to expect
- New Physics parameterized with effective Lagrangian
 - ❑ enhancing existing couplings
 - ❑ introduce non-SM couplings

Anomalous Couplings

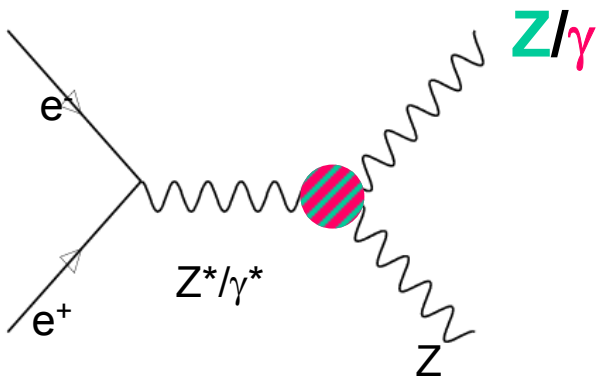


Neutral Triple Gauge Couplings

Standard Model



Anomalous Couplings



- Vertex described by 12 parameters
- Most general Lagrangian assuming
 - Lorentz invariance
 - $U(1)_{em}$ invariance
 - Bose symmetry

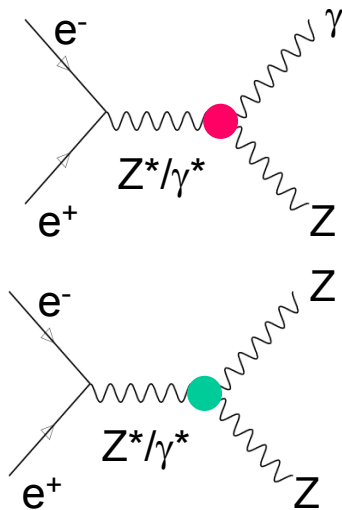
Neutral Triple Gauge Couplings (2)

$$\Gamma_{ZZV}^{\alpha\beta\mu}(q_1, q_2, P) = \frac{i(s - m_V^2)}{m_Z^2} [f_4^V (P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) - f_5^V \epsilon^{\mu\alpha\beta\rho} (q_1 - q_2)_\rho] ,$$

$$\Gamma_{Z\gamma V}^{\alpha\beta\mu}(q_1, q_2, P) = \frac{i(s - m_V^2)}{m_Z^2} \left\{ h_1^V (q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^V}{m_Z^2} P^\alpha [(P q_2) g^{\mu\beta} - q_2^\mu P^\beta] \right. \\ \left. - h_3^V \epsilon^{\mu\alpha\beta\rho} q_{2\rho} - \frac{h_4^V}{m_Z^2} P^\alpha \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma} \right\} ,$$

G.J.Gounaris, J.Layssac, F.M.Renard
Phys.Rev. D62(2000) 073013

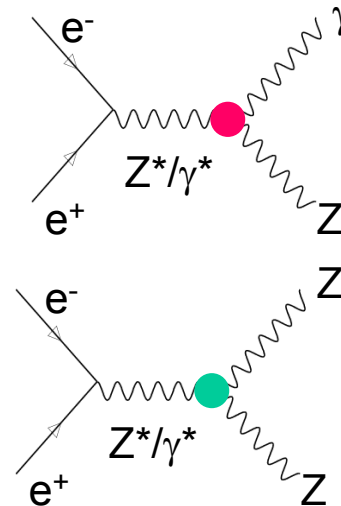
CP - violating



h_1^γ h_2^γ
 h_1^Z h_2^Z

f_4^γ f_4^Z

CP - conserving



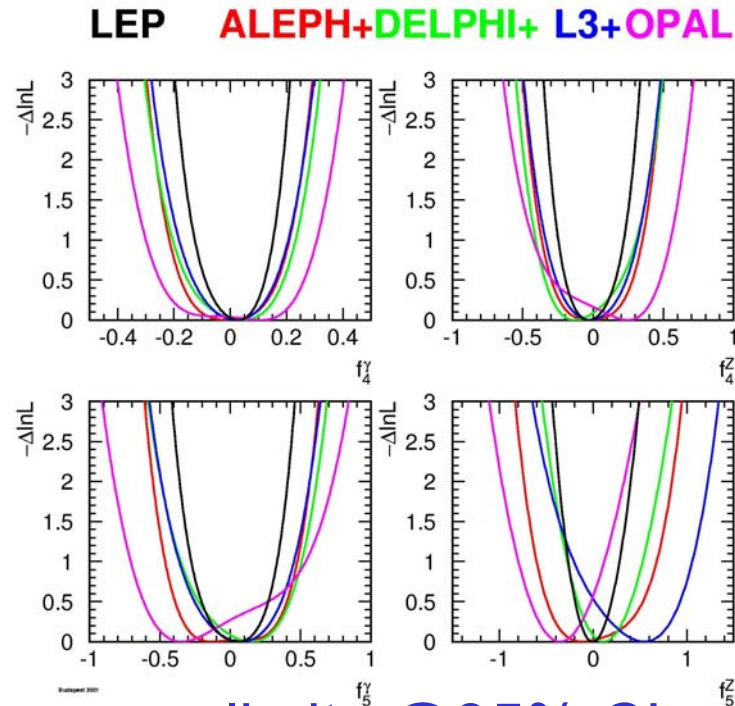
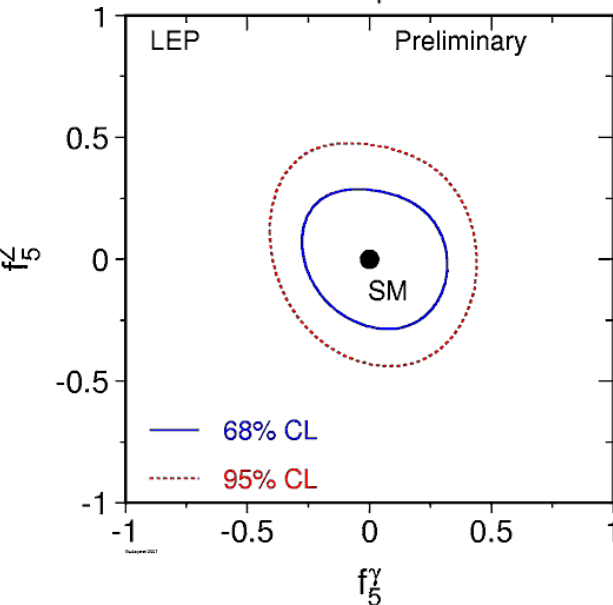
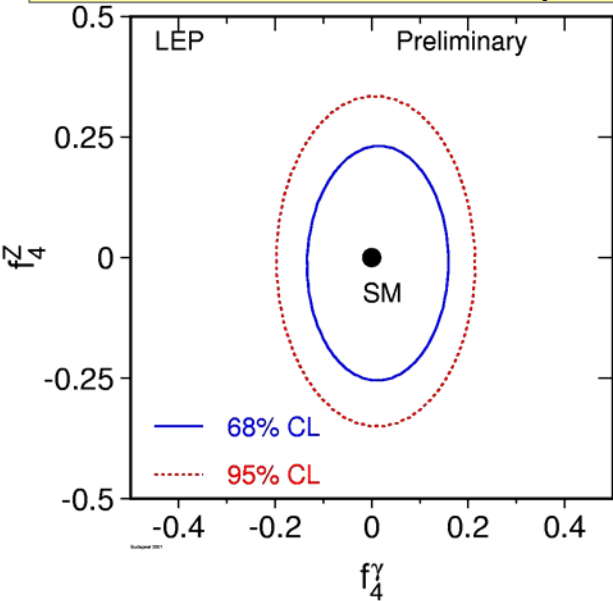
h_3^γ h_4^γ
 h_3^Z h_4^Z

f_5^γ f_5^Z

all values zero at tree level in Standard Model

$$e^+e^- \rightarrow \gamma^* \rightarrow ZZ, e^+e^- \rightarrow Z^* \rightarrow ZZ$$

Use σ , $|\cos \theta_Z|$, Neural Net, Optimal Observ.
 new since summer 2001
Preliminary



limits @95% CL

$$f_4^\gamma$$

$$f_4^Z$$

$$f_5^\gamma$$

$$f_5^Z$$

[-0.17;0.19]

[-0.30;0.28]

[-0.34;0.38]

[-0.36;0.38]

$$e^+e^- \rightarrow \gamma^* \rightarrow Z\gamma, e^+e^- \rightarrow Z^* \rightarrow Z\gamma$$

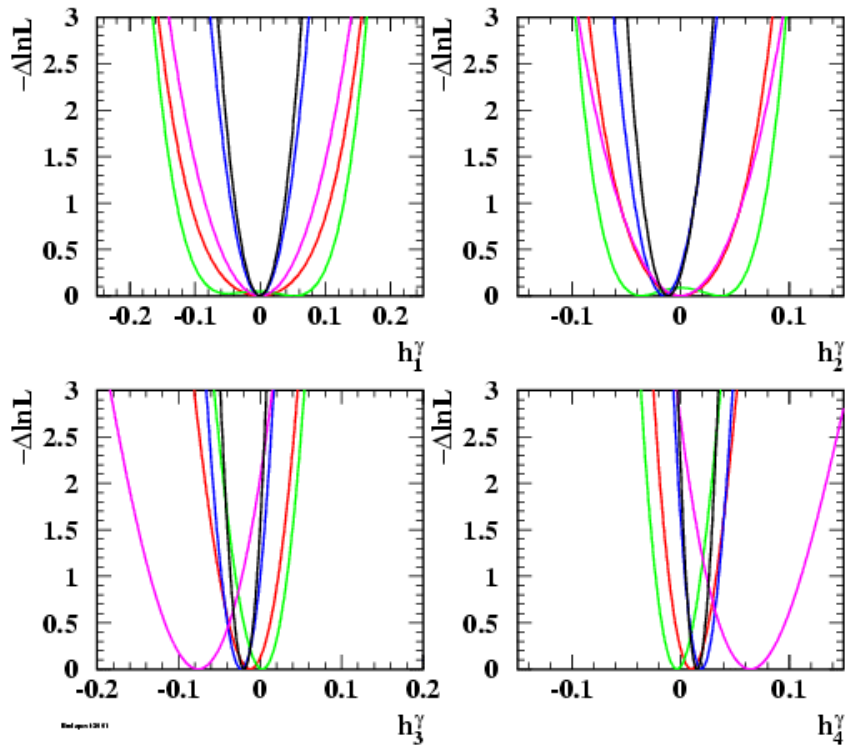
Use σ , $|\cos \theta_\gamma|$, E_γ , Optimal Observ.

$$e^+e^- \rightarrow q\bar{q}\gamma, \nu\bar{\nu}\gamma$$

Preliminary

LEP ALEPH+DELPHI+ L3+OPAL

unchanged since summer 2001



limits @95% CL

h_1^γ

h_2^γ

$[-0.06; 0.05]$ $[-0.05; 0.02]$

h_3^γ

h_4^γ

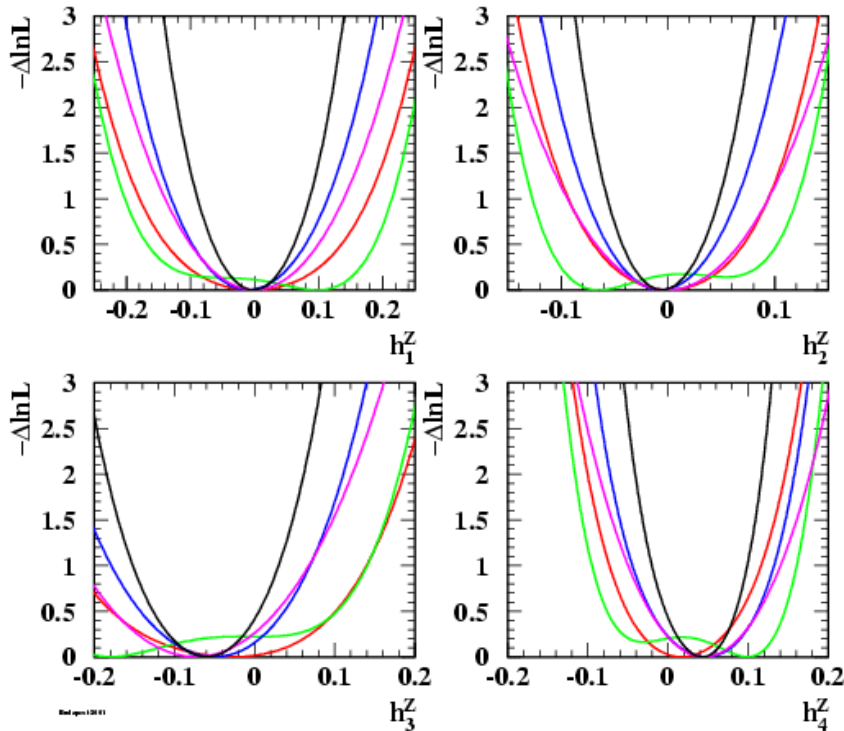
$[-0.05; 0.00]$ $[-0.00; 0.04]$



$\gamma^*Z\gamma, Z^*Z\gamma$ Measurements (2)

Preliminary

LEP ALEPH+DELPHI+ L3+OPAL



unchanged since summer 2001

limits @95% CL

h_1^Z

h_2^Z

$[-0.17;0.15][-0.10;0.09]$

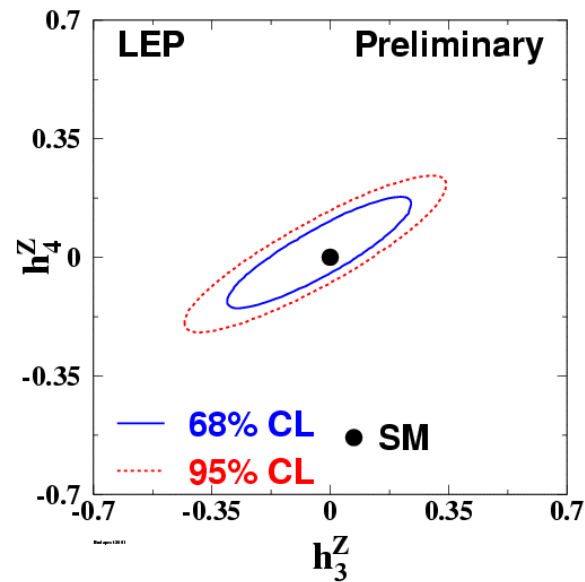
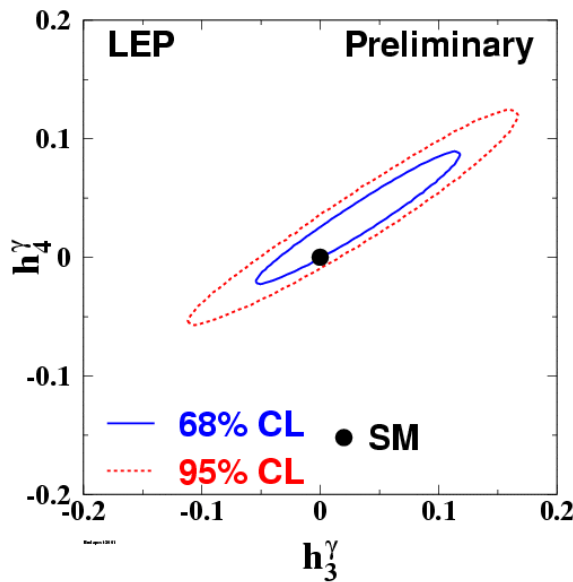
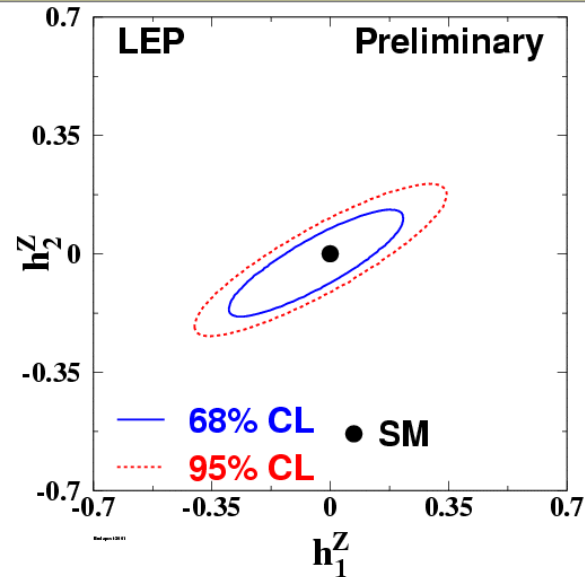
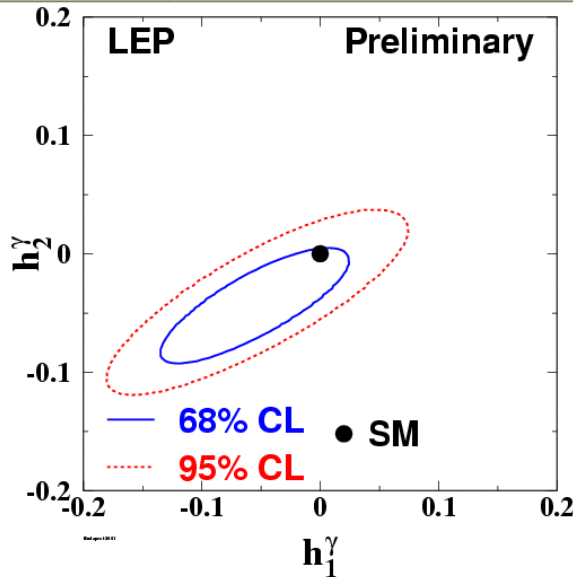
h_3^Z

h_4^Z

$[-0.23;0.11][-0.07;0.15]$

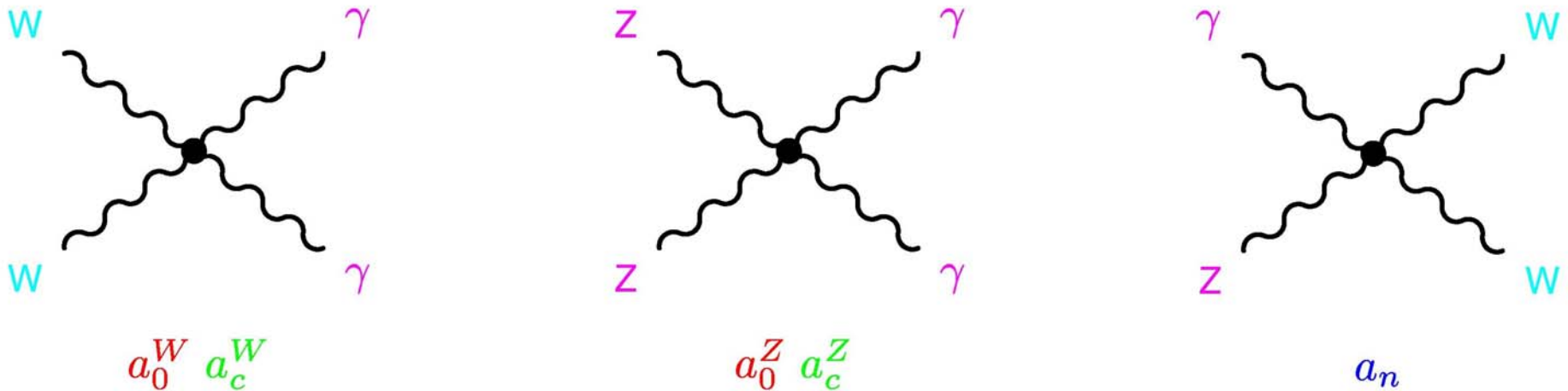
$\gamma^*Z\gamma, Z^*Z\gamma$ Measurements (3)

unchanged since summer 2001



Quartic Gauge Couplings

Non-abelian structure:



Effective Lagrangian to parameterize New Physics

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

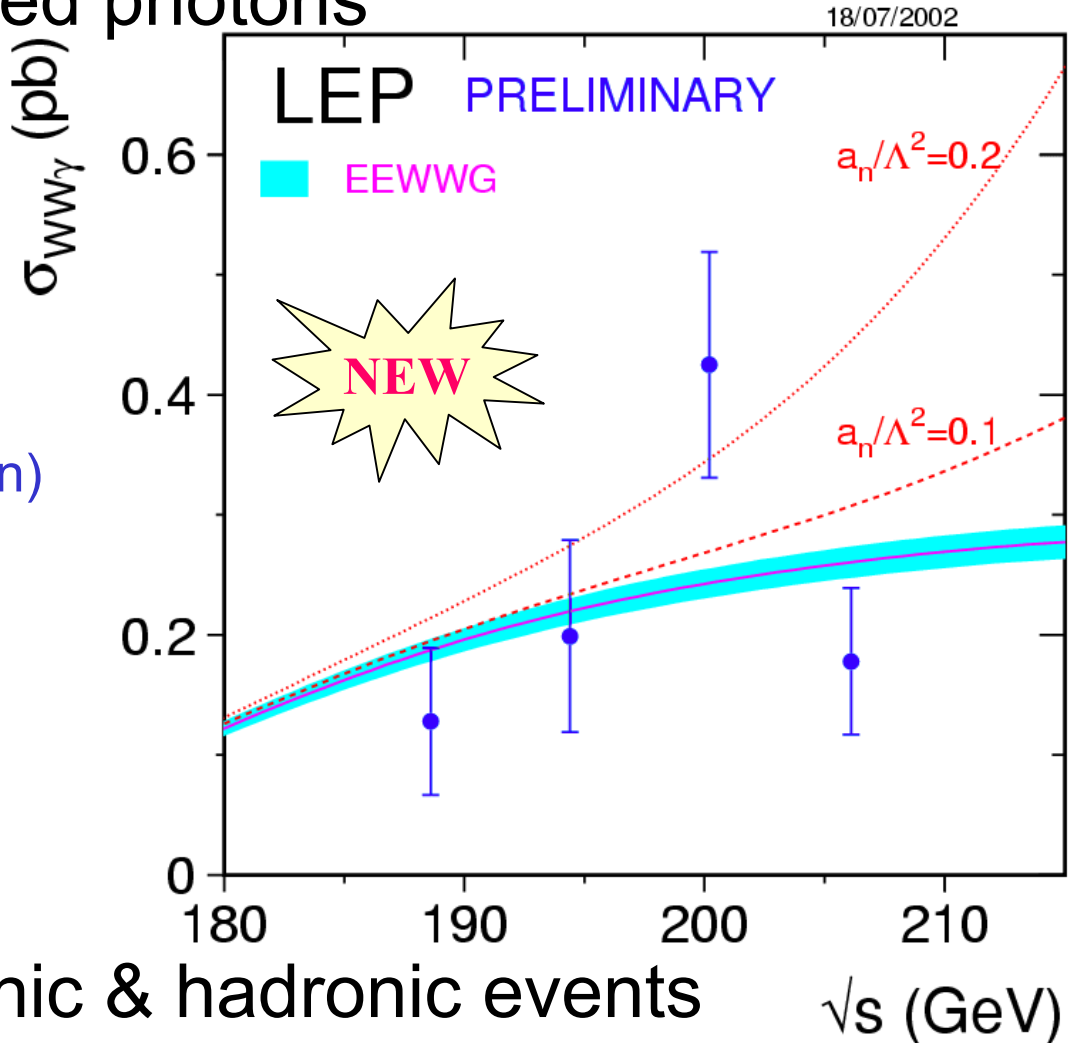
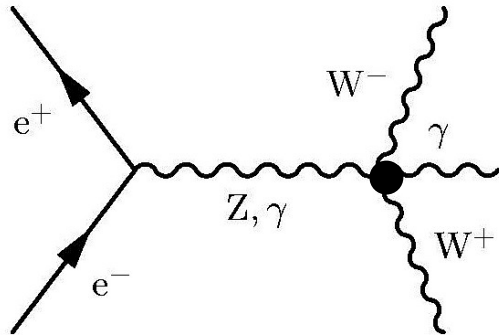
Λ – energy scale for New Physics

$$e^+ e^- \rightarrow WW\gamma$$

W-pairs & hard, isolated photons

Signal definition

- $E_\gamma > 5 \text{ GeV}$
- $|\cos(\theta_\gamma)| < 0.95$
- $\cos(\alpha) < 0.90$
(angle γ – charged fermion)
- $|m(f, f') - m_W| < 2\Gamma_W$



Delphi, L3: Semi-leptonic & hadronic events

\sqrt{s} (GeV)

Delphi 2002-059

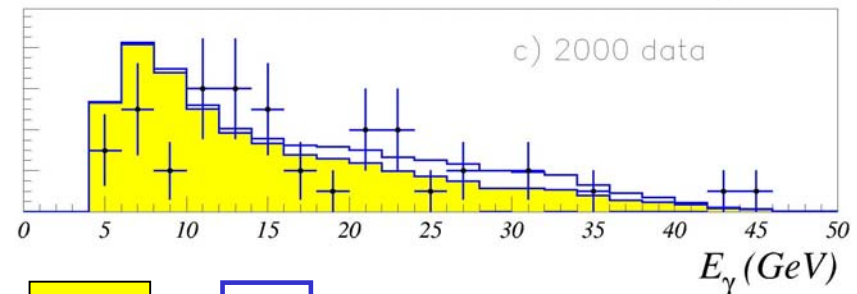
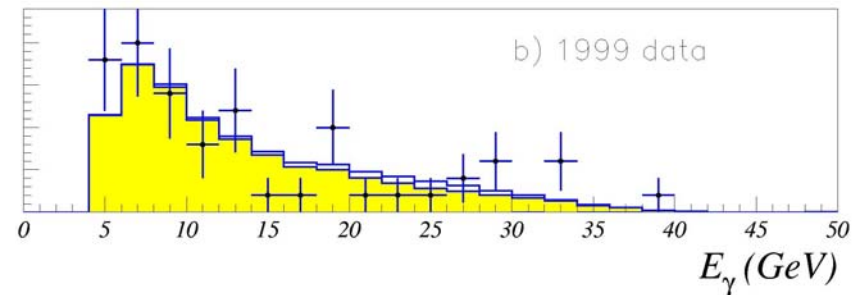
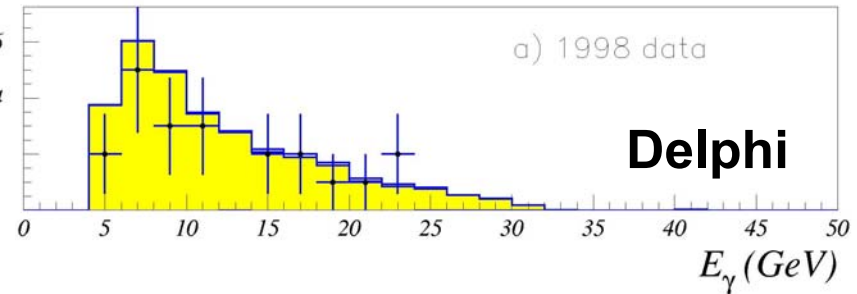
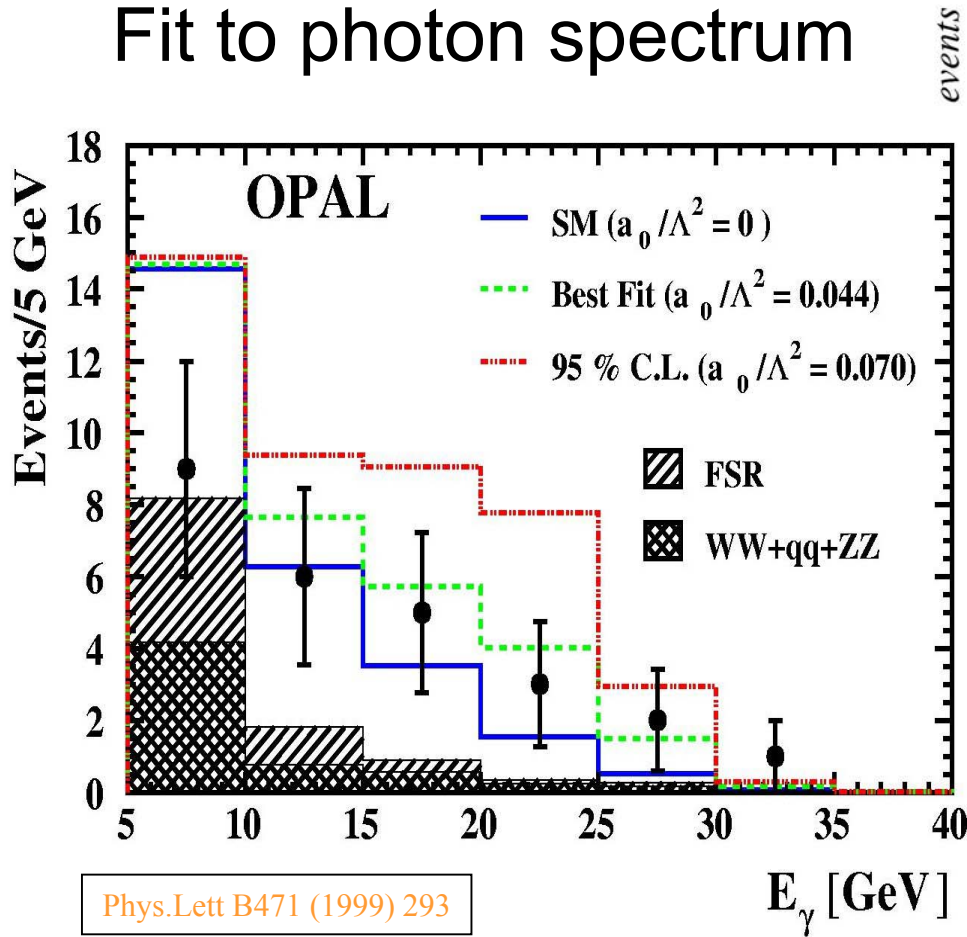
Phys.Lett. B527/1-2 (2000) 29



WW γ Measurements

Determination of anomalous couplings

Fit to photon spectrum



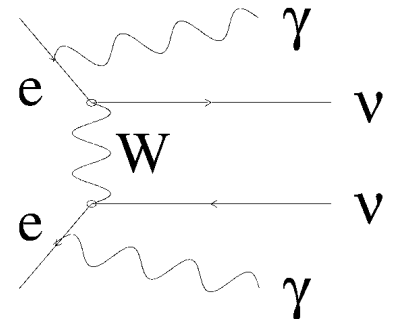
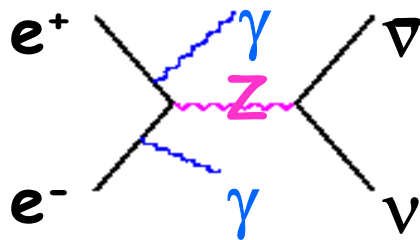
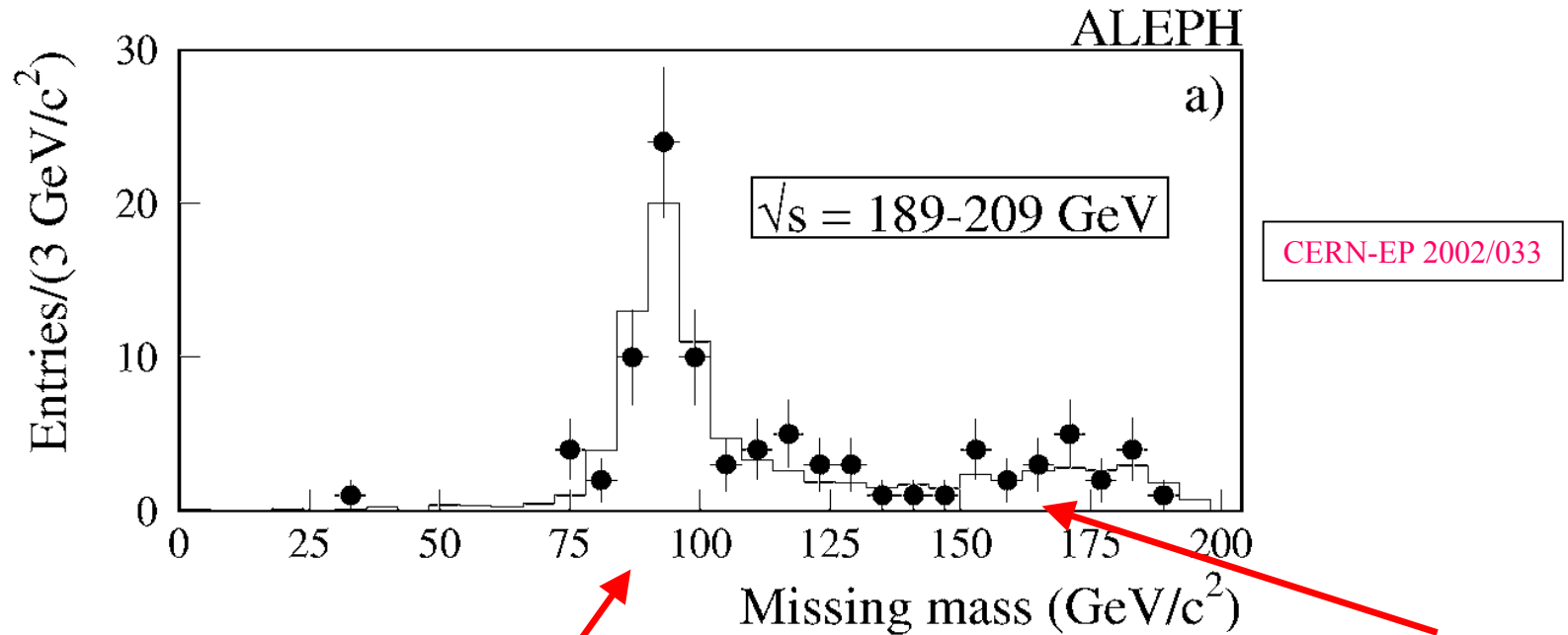
SM

$a_n/\Lambda^2 = -0.16 \text{ GeV}^{-2}$



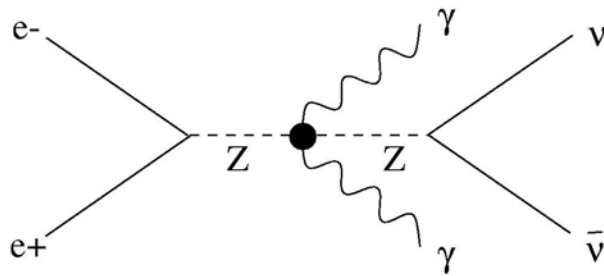
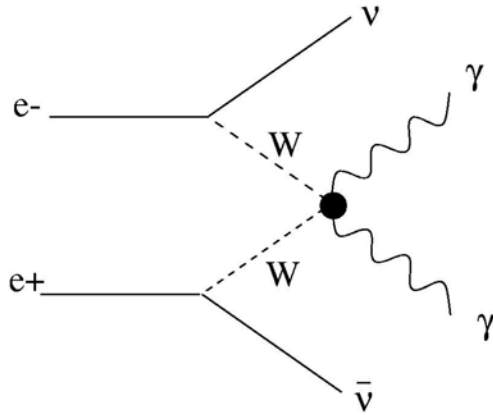
$$e^+ e^- \rightarrow \nu \nu \gamma \gamma$$

Signature: 2 acoplanar photons & missing energy

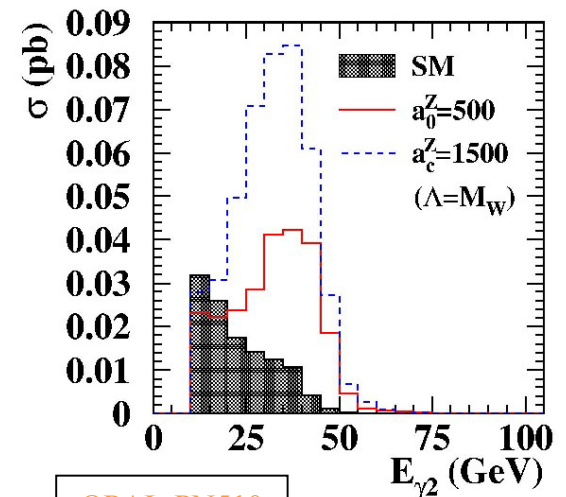
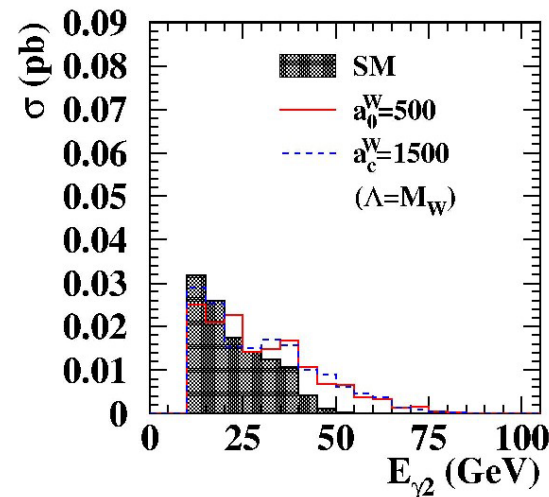
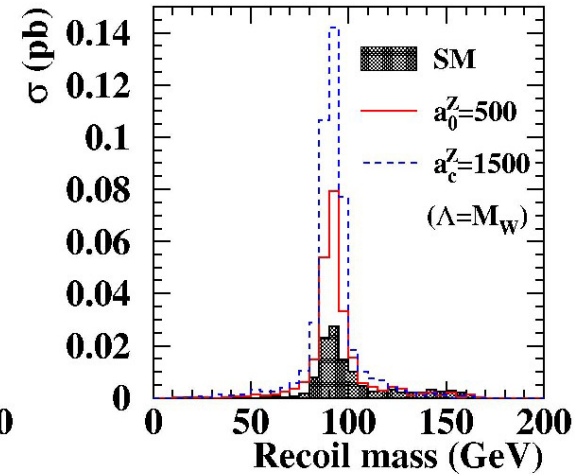
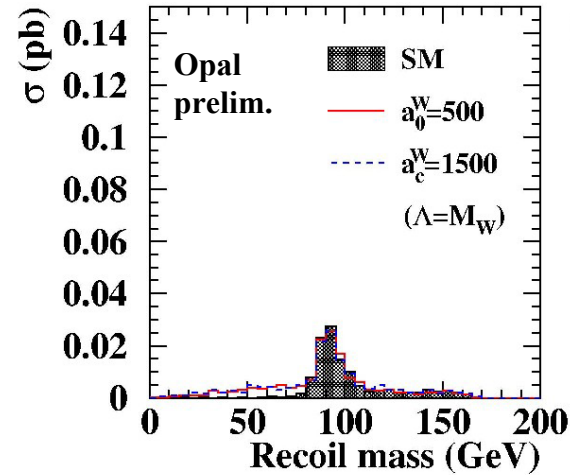


$$e^+ e^- \rightarrow \nu \bar{\nu} \gamma \gamma$$

Opal fits couplings $WW_{\gamma\gamma}$ & $ZZ_{\gamma\gamma}$



Estimations of a_0/Λ^2 , a_c/Λ^2 obtained looking for anomalous increase



$$a_0^W, a_c^W, a_n^W$$

Summer 2001
LEP combination

$$\left\{ \begin{array}{l} -0.031 \text{ GeV}^{-2} < a_0^W/\Lambda^2 < 0.030 \text{ GeV}^{-2} \\ -0.069 \text{ GeV}^{-2} < a_c^W/\Lambda^2 < 0.070 \text{ GeV}^{-2} \\ -0.45 \text{ GeV}^{-2} < a_n^W/\Lambda^2 < 0.41 \text{ GeV}^{-2} \end{array} \right.$$

$$a_0^W/\Lambda^2$$

$$a_c^W/\Lambda^2$$

$$a_n^W/\Lambda^2$$

Delphi $WW\gamma \rightarrow 209\text{GeV}$ [-0.018,0.018] [-0.057,0.030] [-0.16,0.12]

L3 $WW\gamma \rightarrow 207\text{GeV}$
 $\nu\nu\gamma\gamma \rightarrow 207\text{GeV}$ [-0.015,0.015] [-0.048,0,026] [-0.14,0,13]

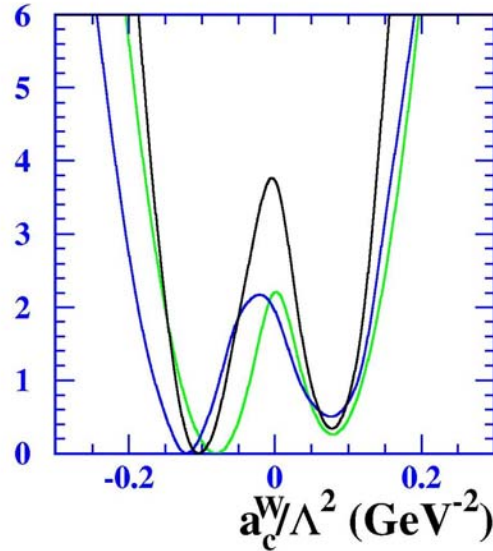
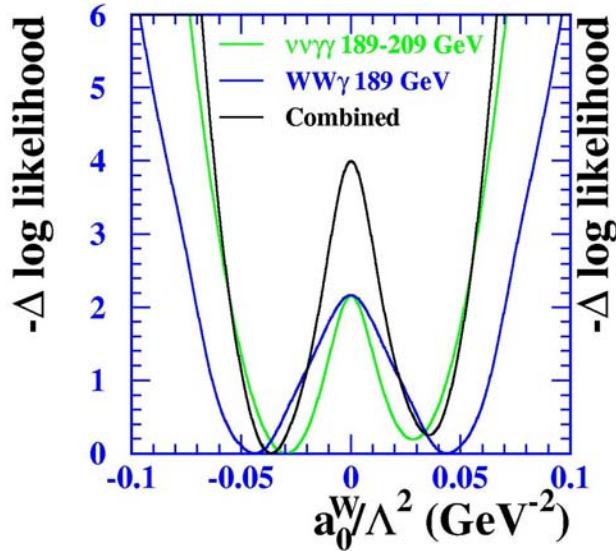
Opal $WW\gamma \rightarrow 189\text{GeV}$
 $\nu\nu\gamma\gamma \rightarrow 209\text{GeV}$ [-0.054,0,052] [-0.15,0.14] [-0.61,0.57]

limits @95% CL all numbers in GeV^{-2}

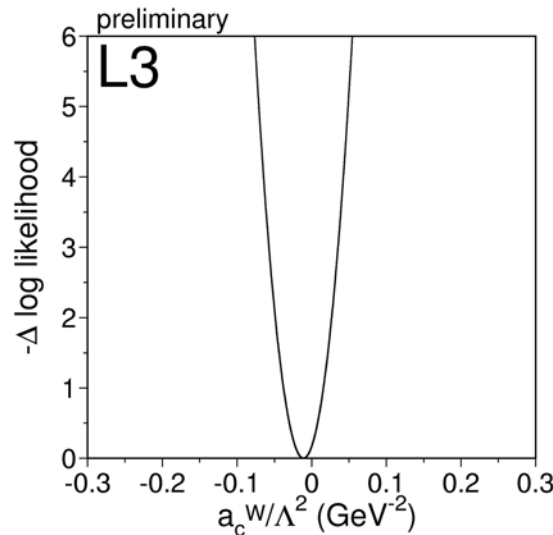
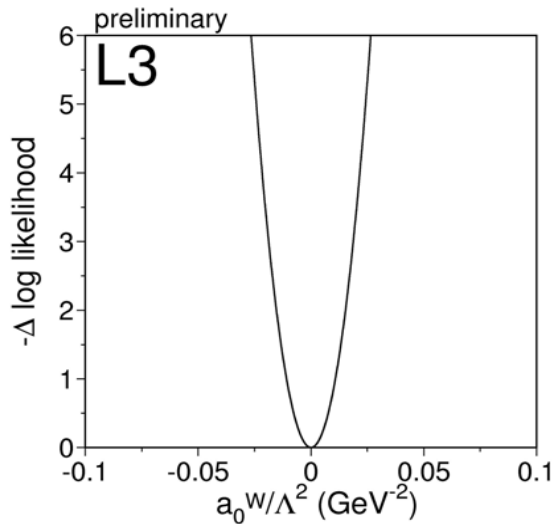


$\overset{W}{a}_0, \overset{W}{a}_c, a_n$

OPAL Preliminary



$WW\gamma \rightarrow 189\text{GeV}$
 $\nu\nu\gamma\gamma \rightarrow 209\text{GeV}$

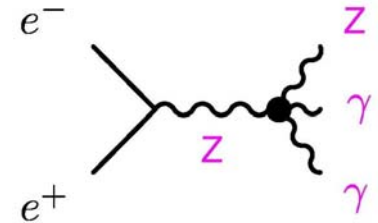


$WW\gamma \rightarrow 207\text{GeV}$
 $\nu\nu\gamma\gamma \rightarrow 207\text{GeV}$



$Z\gamma\gamma$

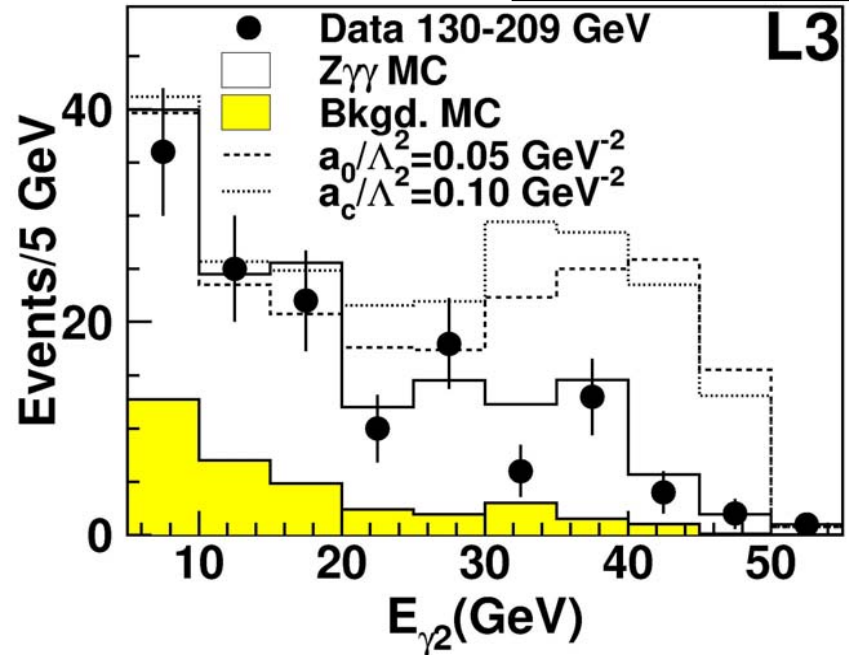
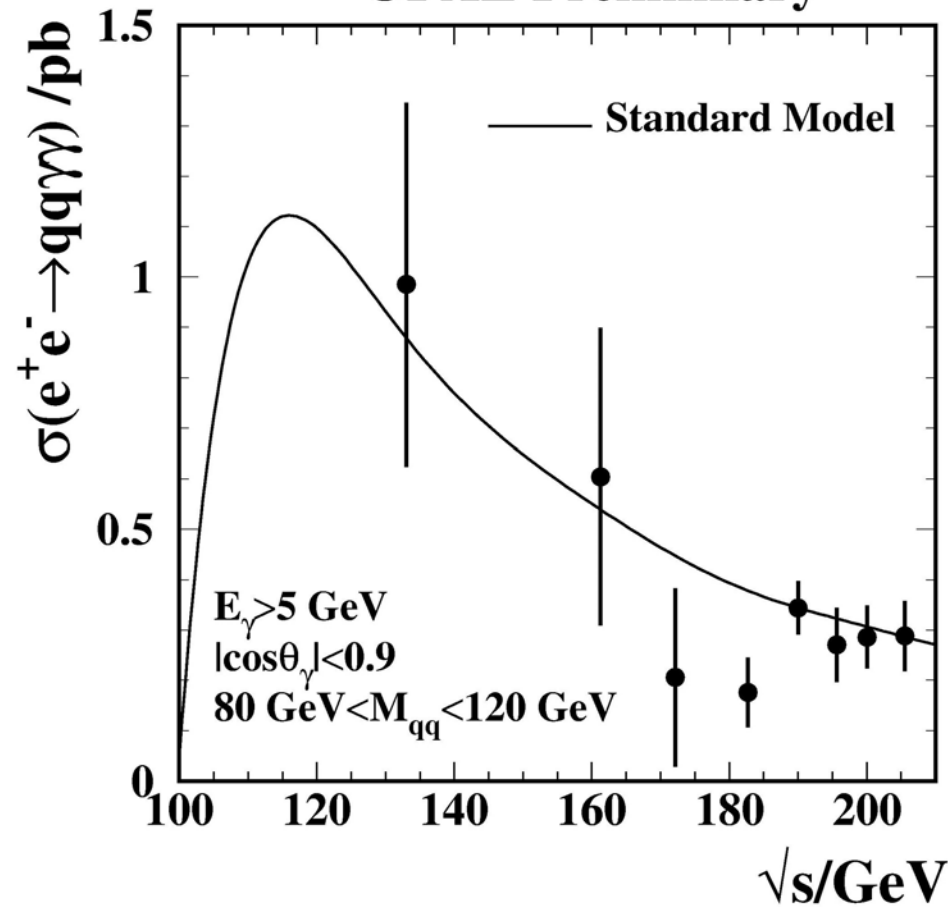
Hadronic events with 2 identified photons



OPAL Preliminary

Fit to energy spectra and angular distributions

Phys.Lett. B540/1-2 (2002) 43



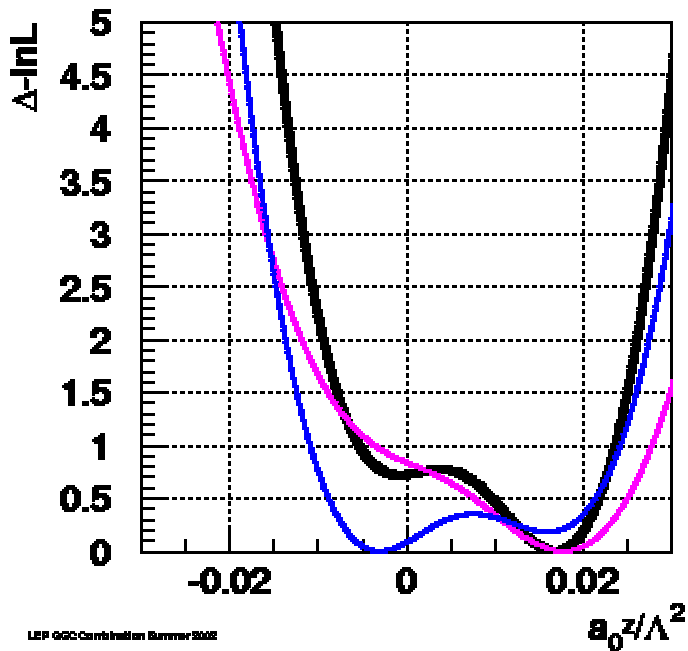
$$a_0^Z, a_c^Z$$

Preliminary

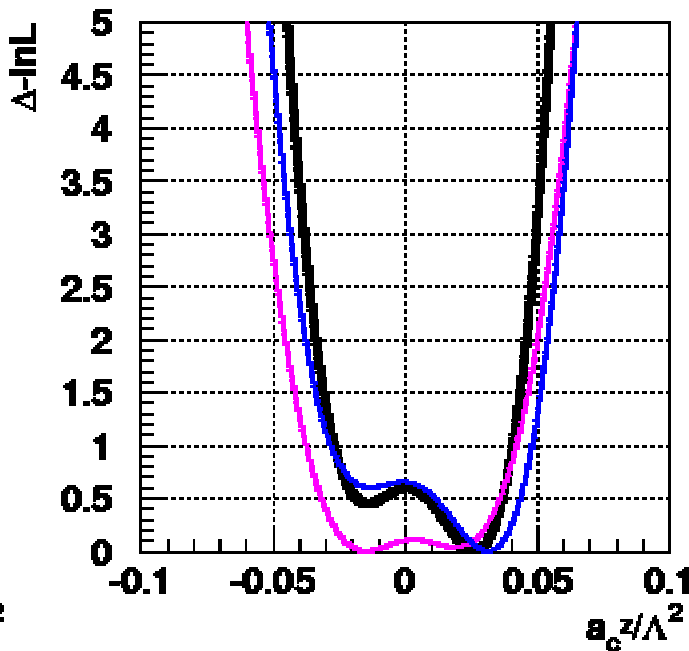
L3

OPAL

LEP



LEP QGC Combination Summer 2002



$$a_0^Z/\Lambda^2 \quad [-0.009, 0.026]$$

$$a_c^Z/\Lambda^2 \quad [-0.034, 0.046]$$

limits @95% CL

Opal: $\nu\nu\gamma\gamma, qq\gamma\gamma$

L3: $qq\gamma\gamma$



Summary

- Triple neutral gauge boson couplings are studied at LEP in $Z\gamma$ and ZZ production
- Quartic gauge boson couplings are studied at LEP looking for $WW\gamma$, $Z\gamma\gamma$ and $\nu\nu\gamma\gamma$ events
- No significant anomaly found
- Wait for
 - final LEP results
 - new Tevatron data
 - LHC
 - Linear collider
 -