Neutral Triple and Quartic Gauge Couplings at LEP

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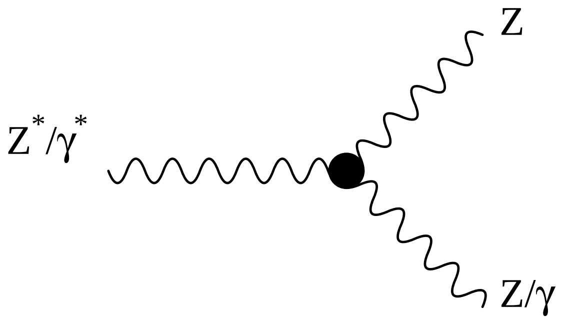
- Neutral Triple Gauge Couplings
  - Theoretical Framework
  - Processes at LEP
  - Results
- Neutral Quartic Gauge Couplings
  - Theoretical Framework
  - Processes at LEP
  - Results
- Summary

Neutral Triple Gauge Couplings

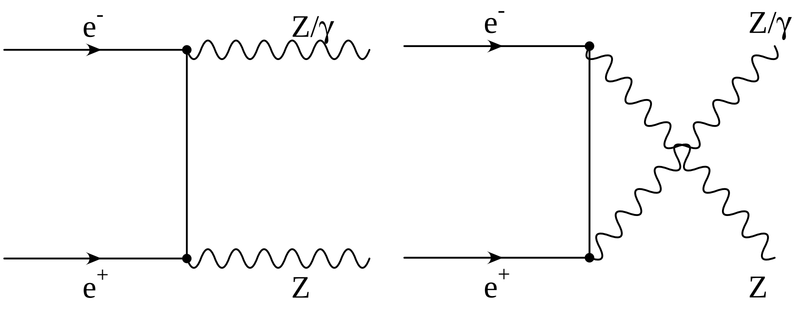


Couplings vanish at tree level in SM.

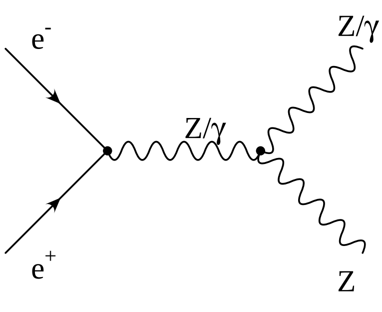
One-loop level: couplings are of order $\mathcal{O}(10^{-4})$, below experimental sensitivity.

New Physics $\Rightarrow$ enlargement of neutral TGC's.

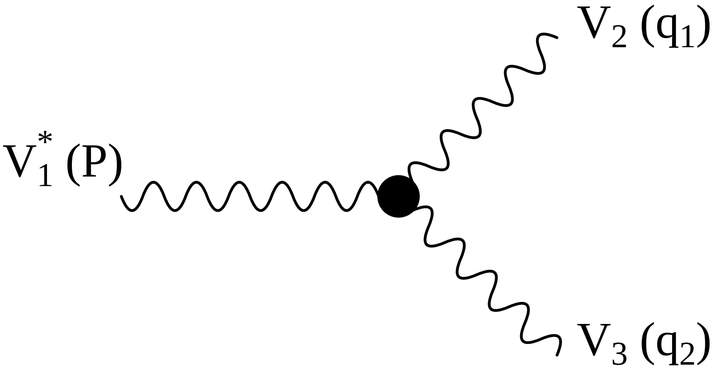
Standard Model



neutral TGC



Theoretical Framework (neutral TGC)



$$= ie\Gamma^{\alpha,\beta,\mu}_{V_1V_2V_3}(q_1, q_2, P)$$

Vertex parametrisation:

(Lorentz, U(1)$_{em}$ gauge invariance + Bose symmetry)

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

$$\Gamma^{\alpha\beta\mu}_{Z\gamma V}(q_1, q_2, P) = \frac{i(P^2 - m_V^2)}{m_Z^2}\left\{h_1^V(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^V}{m_Z^2}P^\alpha[(Pq_2)g^{\mu\beta} - q_2^\mu P^\beta]\right.$$
$$\left. - h_3^V\epsilon^{\mu\alpha\beta\rho}q_{2\,\rho} - \frac{h_4^V}{m_Z^2}P^\alpha\epsilon^{\mu\beta\rho\sigma}P_\rho q_{2\,\sigma}\right\}.$$

(Gounaris et al, hep-ph/0003143,
Hagiwara et al, Nucl.Phys. B282, 253)

f_4, h_1, h_2: CP-violating,
amplitudes do NOT interfere with SM

f_5, h_3, h_4: CP-conserving,
amplitudes interfere with SM

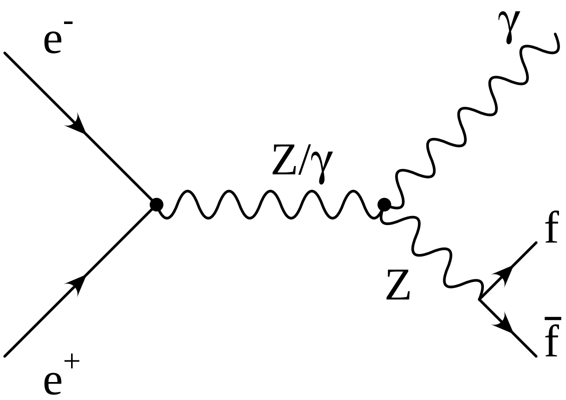
For nonvanishing contribution: V_1 off-shell.

Neutral Triple Gauge Couplings at LEP

can be tested in Zγ and ZZ production.

Experimental NTGC signatures:

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

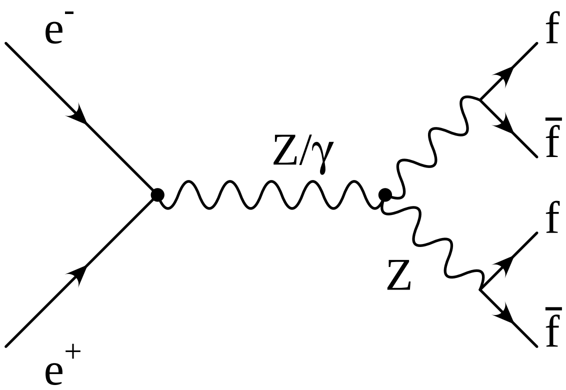


$\boxed{\text{test } h_i^V}$

SM background:

2 fermion processes with ISR

$e^+e^- \to ZZ \to 4f$



$\boxed{\text{test } f_i^V}$

SM background:

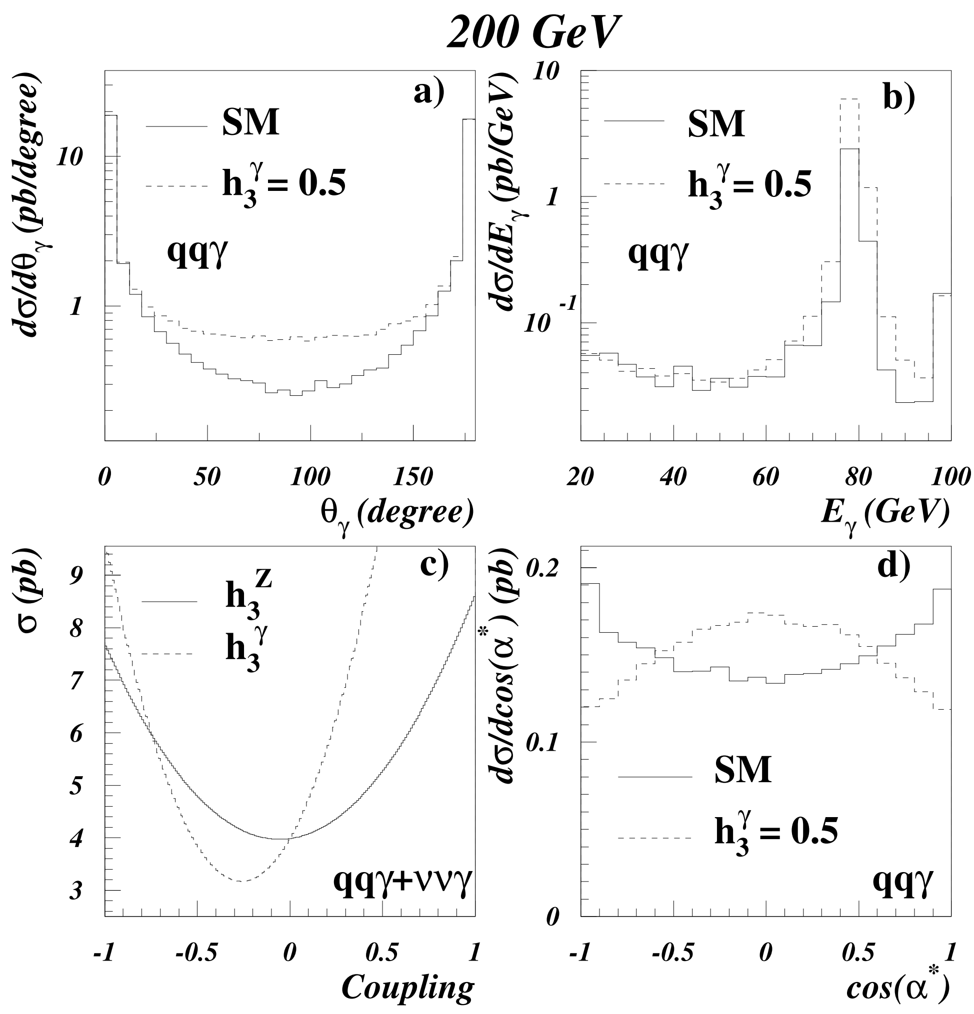
other 4 fermion processes

$e^+e^- \to Z\gamma$ ($Z\gamma Z^*$, $Z\gamma\gamma^*$ couplings)

Main effects of anomalous NTGC:

- increase of total cross-section,
- modification of differential spectrum of photon (mainly at large polar angles),
- enhancement of production of longitudinally polarised Z.

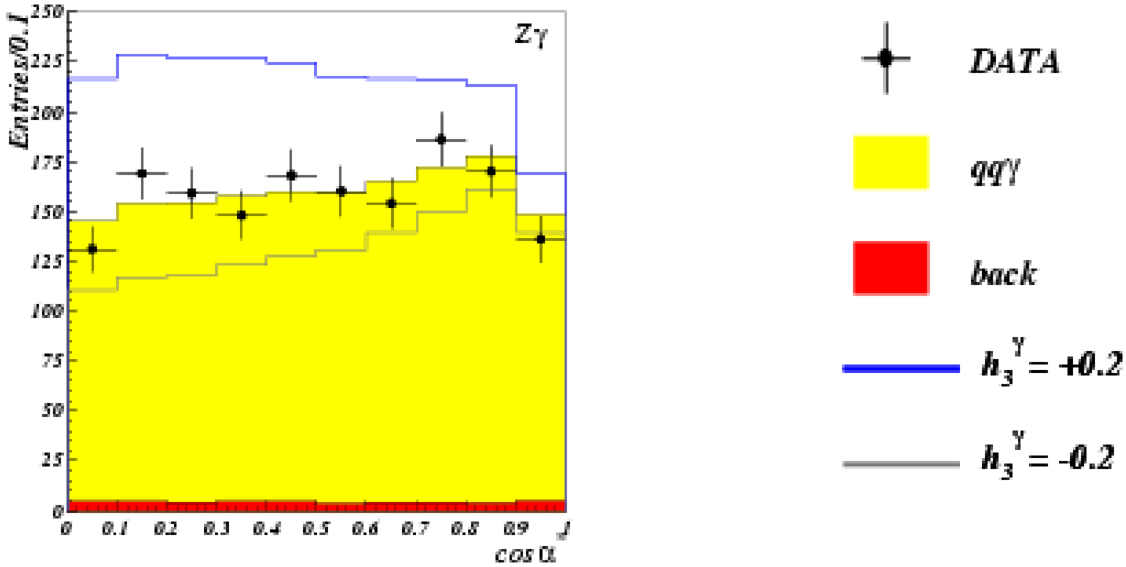
DELPHI / U.Baur



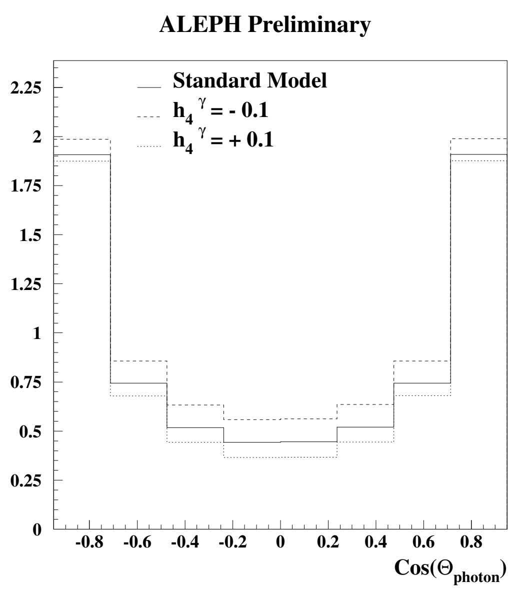
$e^+e^- \to Z\gamma$ ($Z\gamma Z^*$, $Z\gamma\gamma^*$ couplings)

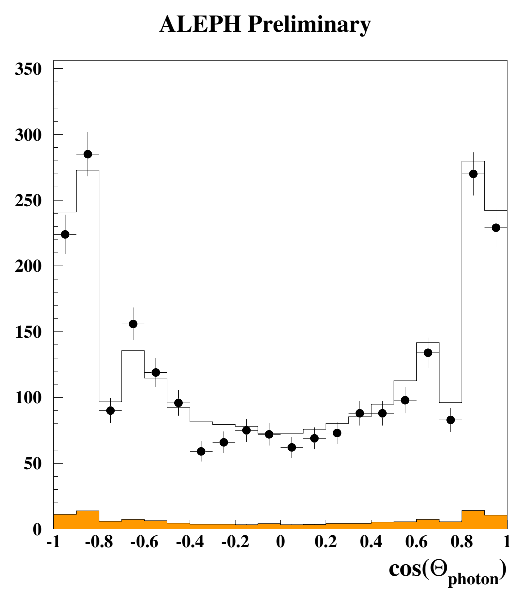
DELPHI Preliminary:

Decay angle of Z in its rest frame in hadronic $Z\gamma$ events



ALEPH Preliminary:

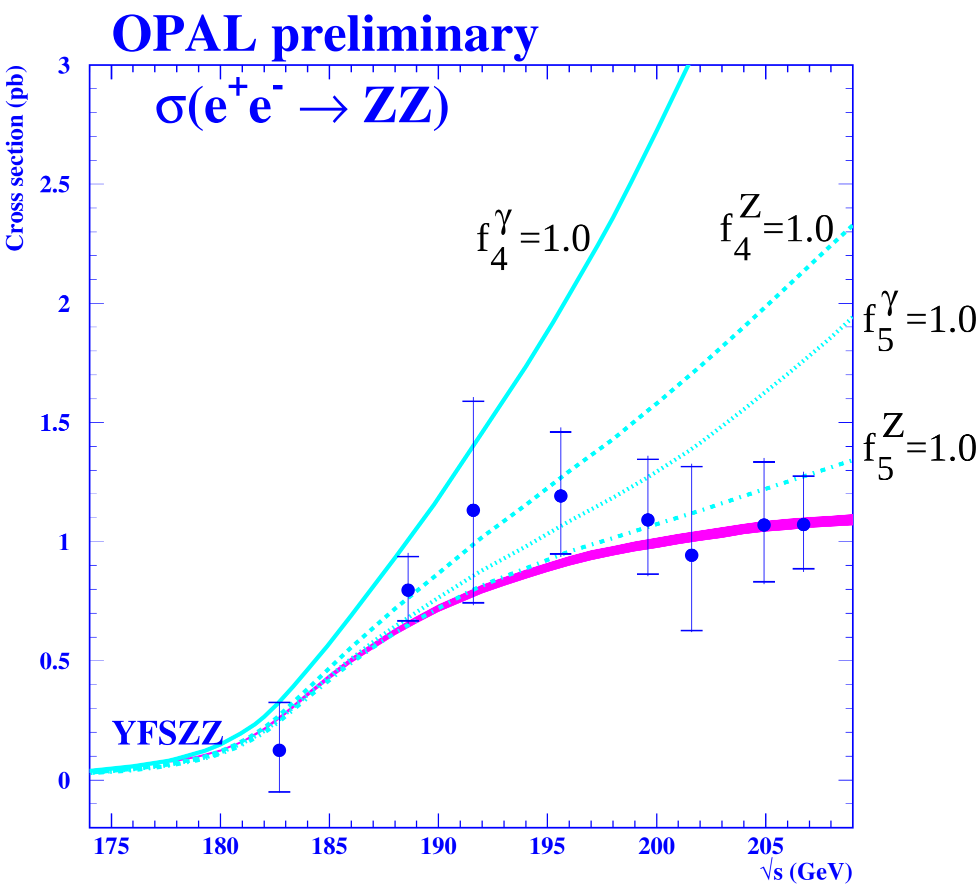




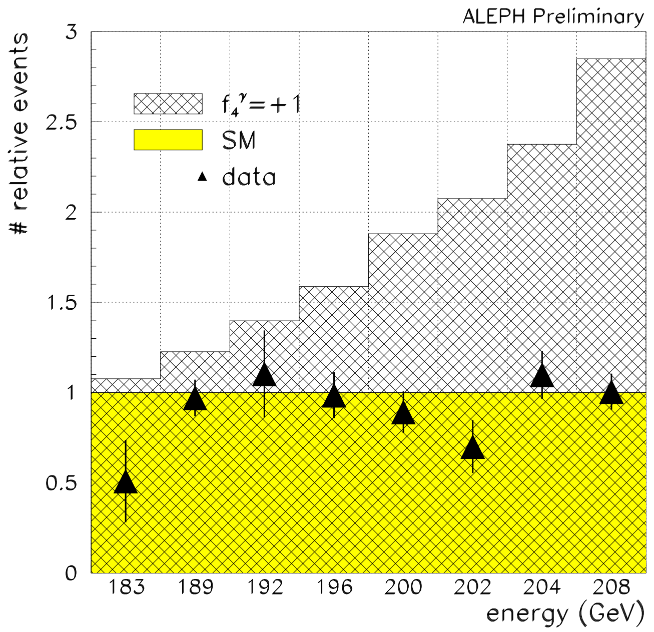
$e^+e^- \to$ ZZ (ZZZ*, ZZγ* couplings)

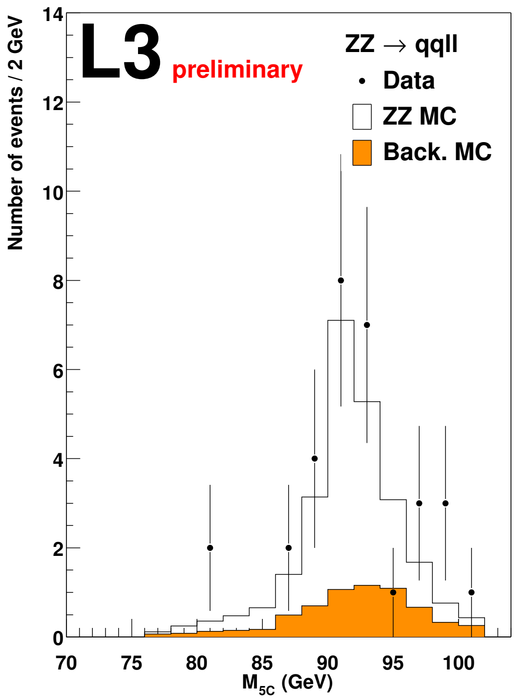
Main effects of anomalous NTGC:

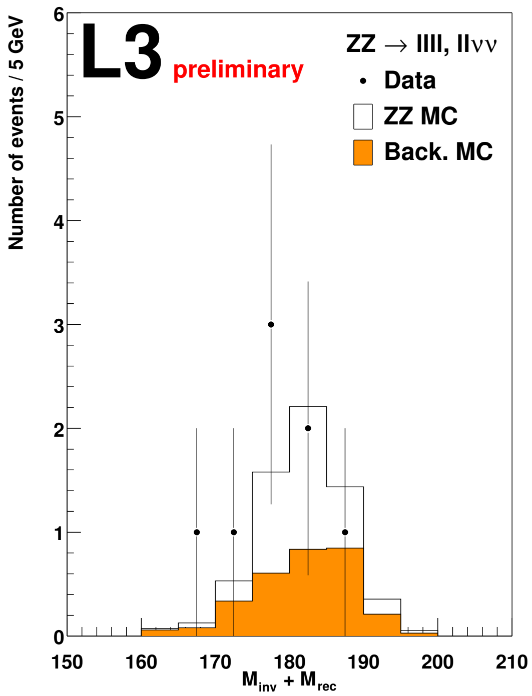
- change in observed total cross-section
- modification of angular distribution of Z
- change in average polarisation of Z



$e^+e^- \rightarrow$ ZZ (ZZZ*, ZZγ* couplings)







NTGC Results: Zγ Process

ALEPH, DELPHI, L3 use data up to 208GeV (OPAL only 189GeV)

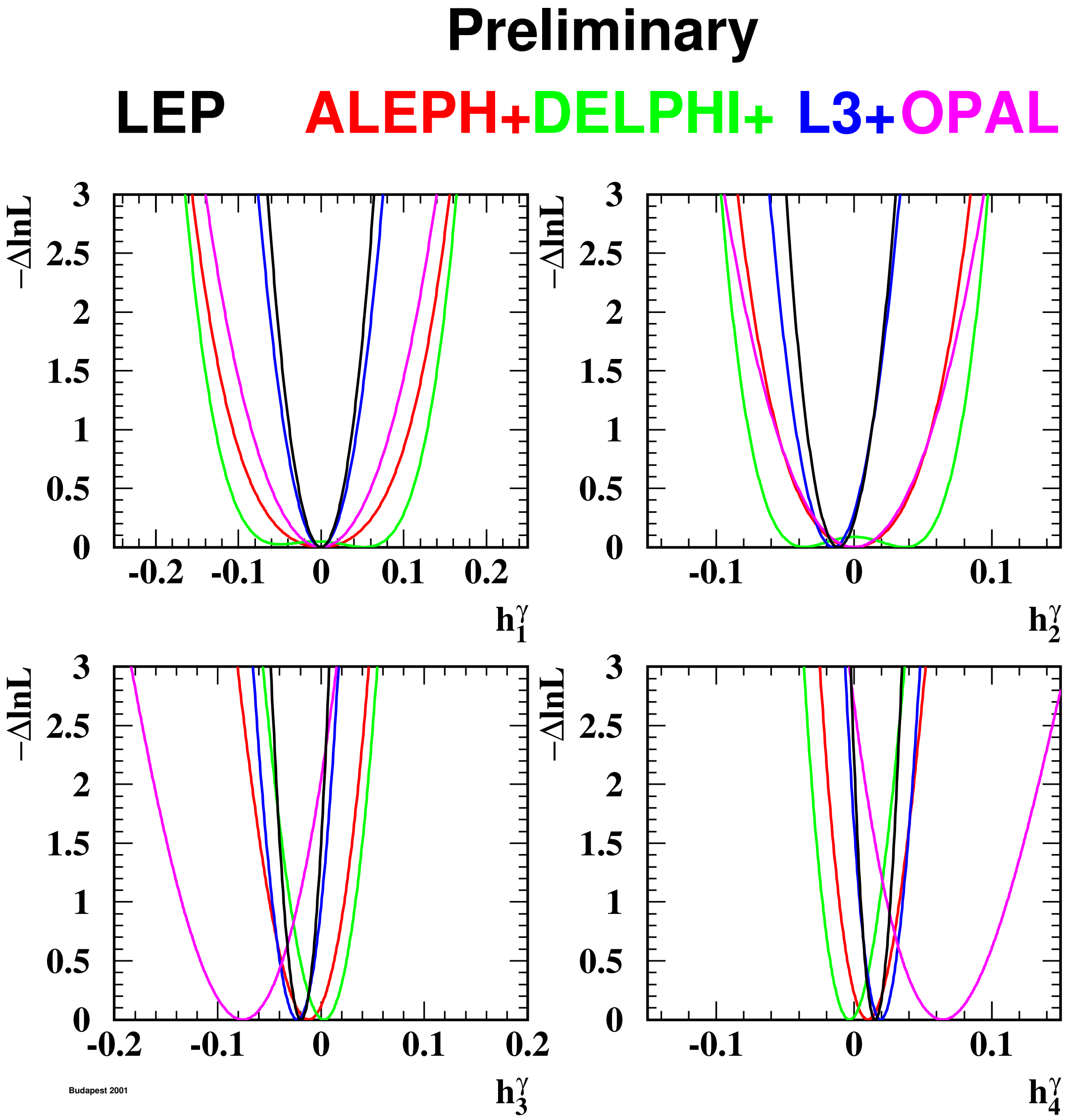
- ALEPH: (605pb^{-1})
  q$\bar{\text{q}}\gamma$: fit using cross-section
  + angular information

- DELPHI: (638pb^{-1})
  q$\bar{\text{q}}\gamma$: fit of $d\sigma/d\cos\alpha^*$
  $\nu\bar{\nu}\gamma$: fit cross-section

- L3: (620pb^{-1})
  Optimal Observables:
  q$\bar{\text{q}}\gamma$: $(E_\gamma, \theta_\gamma, \phi_\gamma, \theta_f^Z, \phi_f^Z)$
  $\nu\bar{\nu}\gamma$: $(E_\gamma, \theta_\gamma, \phi_\gamma)$

- OPAL: (176pb^{-1})
  q$\bar{\text{q}}\gamma$: fit cross section $(E, \cos\theta_\gamma, cos\alpha)$
  $\nu\bar{\nu}\gamma$: fit cross section $(E, \cos\theta_\gamma)$

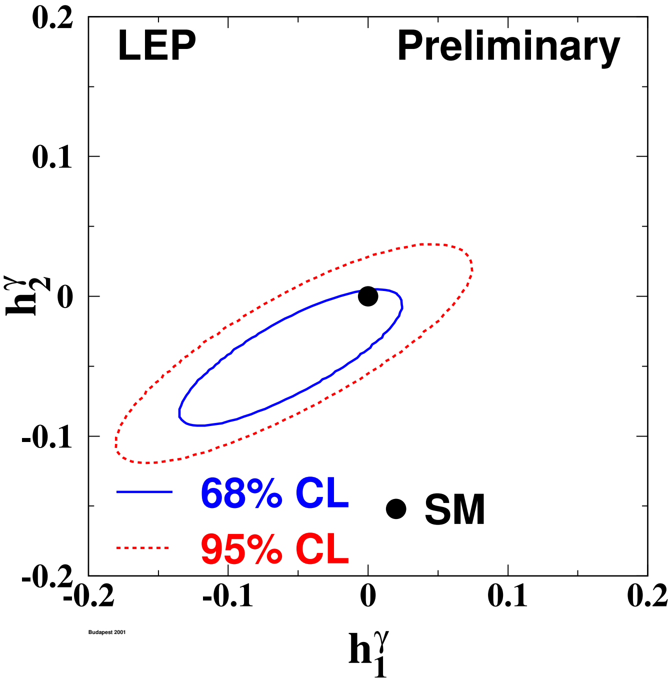
Results on h_i^γ ($Z\gamma\gamma^*$ coupling)



LEP combination (95% CL limits)

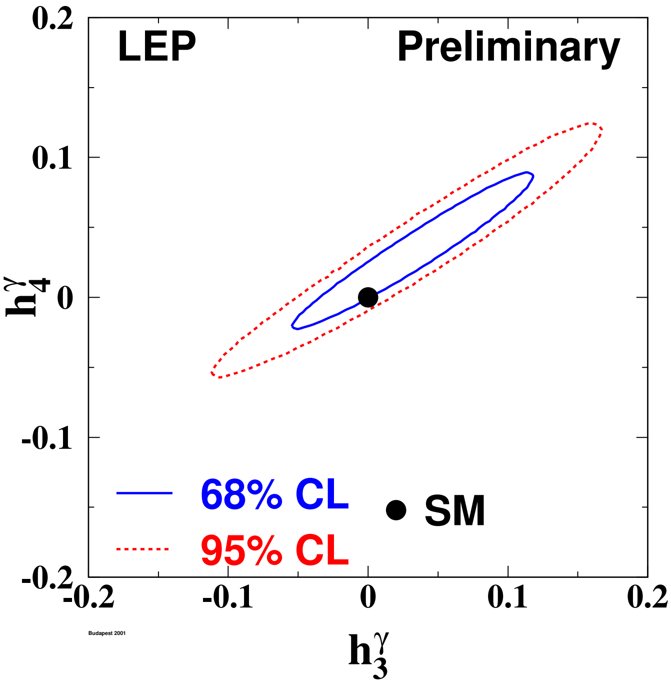
h_1^γ	h_2^γ	h_3^γ	h_4^γ
-0.056	-0.045	-0.049	-0.002
$+0.055$	$+0.025$	-0.008	$+0.034$

Results on h_i^γ (2-dim.)



95% CL

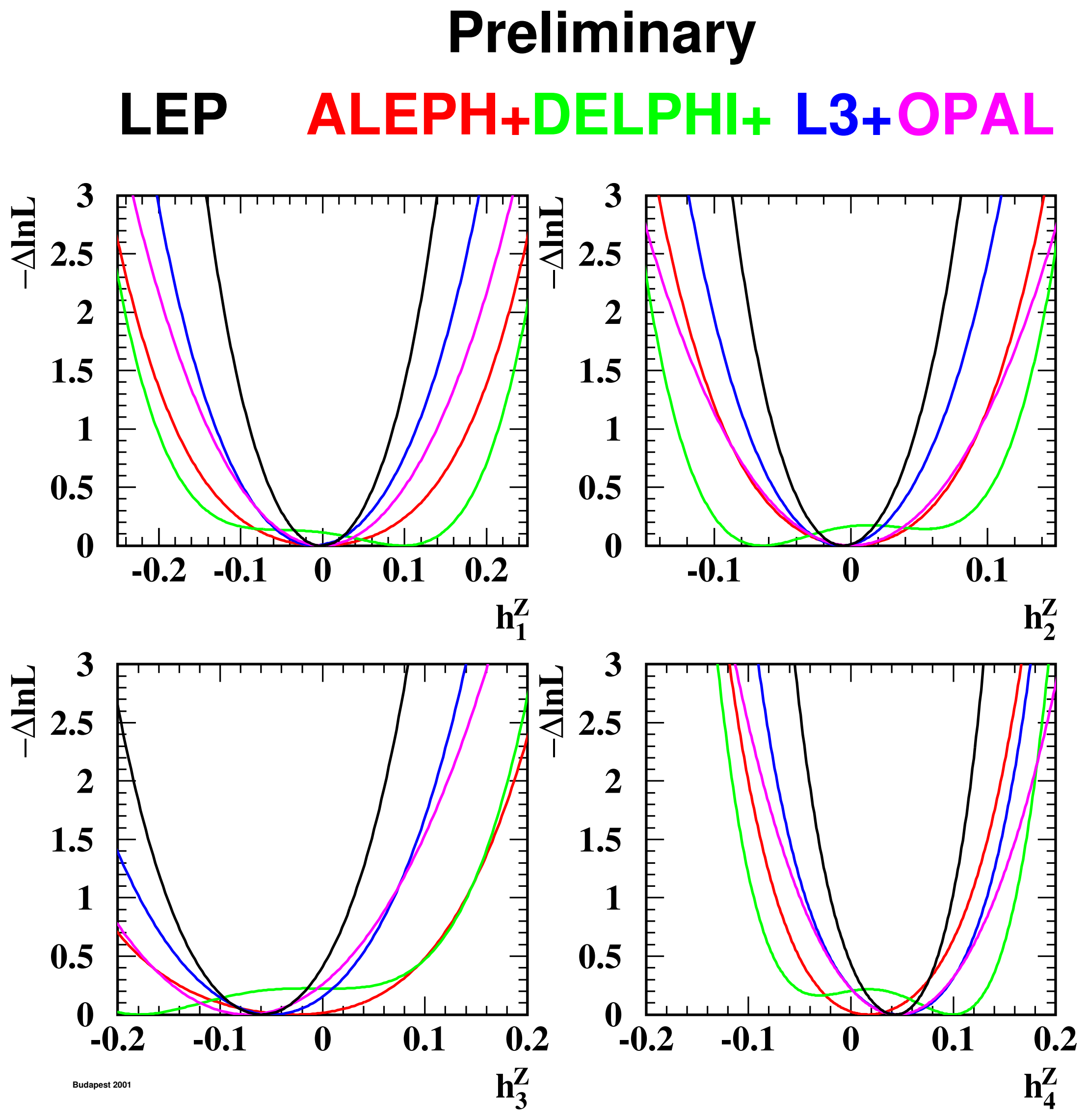
h_1^γ	h_2^γ
-0.16	-0.11
$+0.05$	$+0.02$



95% CL

h_3^γ	h_4^γ
-0.08	-0.04
$+0.14$	$+0.11$

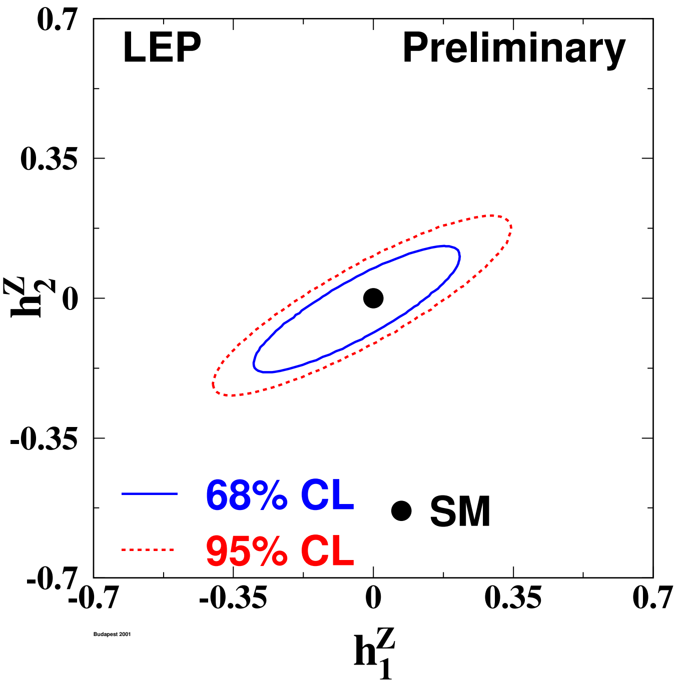
Results on h_i^Z ($Z\gamma Z^*$ coupling)



LEP combination (95% CL limits)

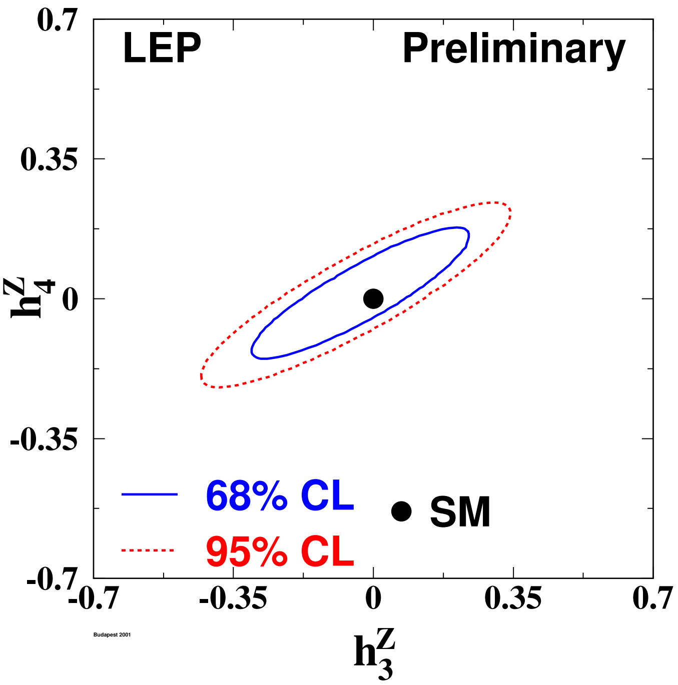
h_1^Z	h_2^Z	h_3^Z	h_4^Z
-0.13	-0.078	-0.20	-0.05
$+0.13$	$+0.071$	$+0.07$	$+0.12$

Results on h_i^Z (2-dim.)



95% CL

h_1^Z	h_2^Z
−0.35	−0.21
+0.28	+0.17



95% CL

h_3^Z	h_4^Z
−0.37	−0.19
+0.29	+0.21

NTGC Results: ZZ Process

All experiments use data up to 208GeV.
All visible channels used.

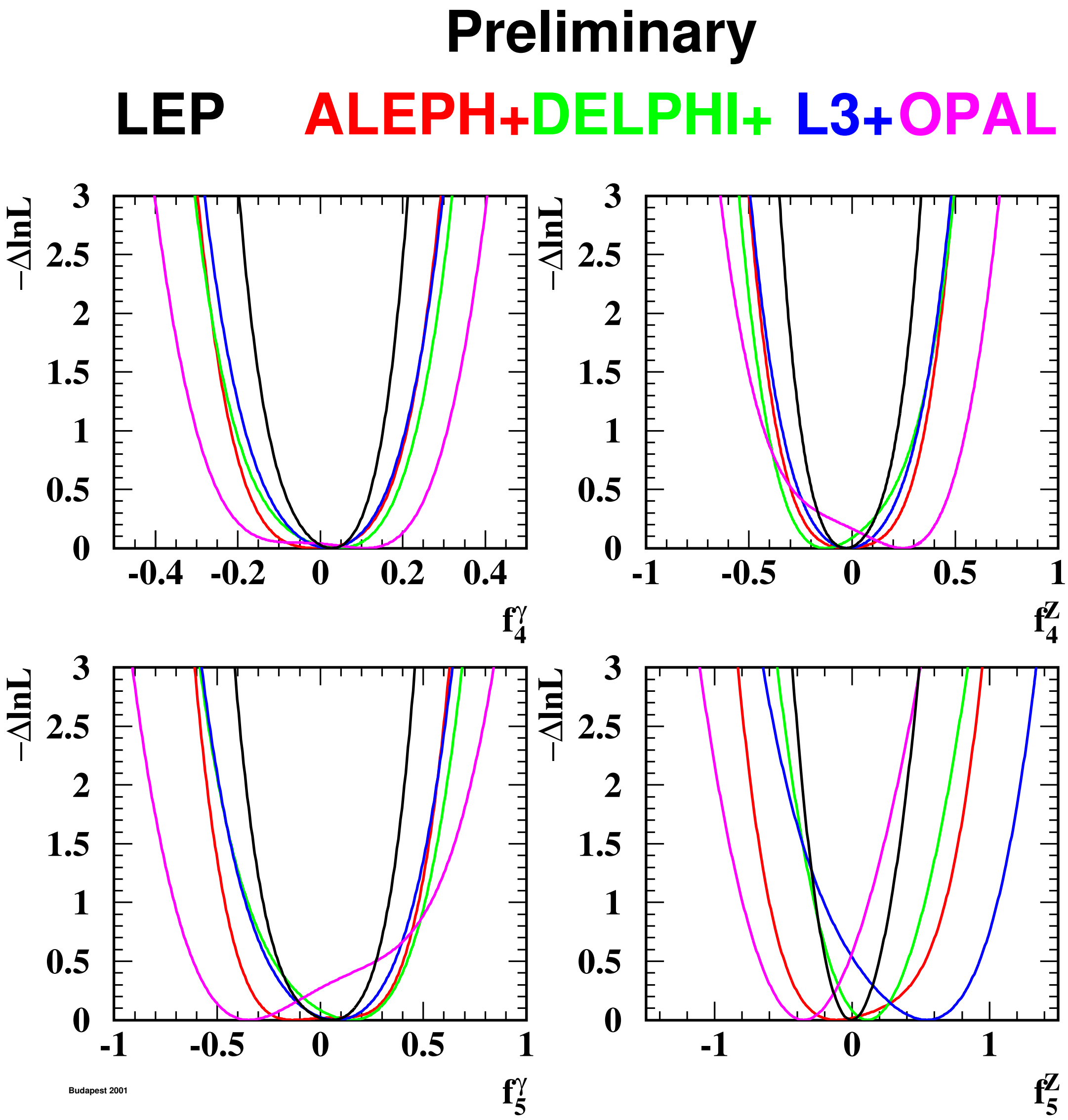
- ALEPH: (660pb^{-1})
  fit with cross-section and $\cos\theta_Z$.

- DELPHI: (638pb^{-1})
  fit cross-section.

- L3: (620pb^{-1})
  fit most significant variables,
  impact of anomalous couplings from
  extension of Excalibur generator.

- OPAL: (609pb^{-1})
  Optimal Observables
  + fit of cross-section

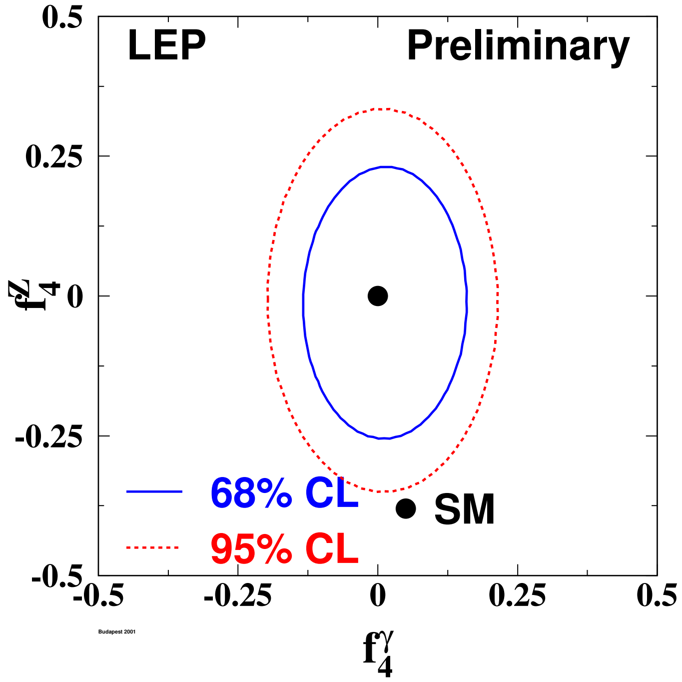
Results on $f_i^{\gamma,Z}$ ($ZZ\gamma^*$, ZZZ^* couplings)



LEP combination (95% CL limits)

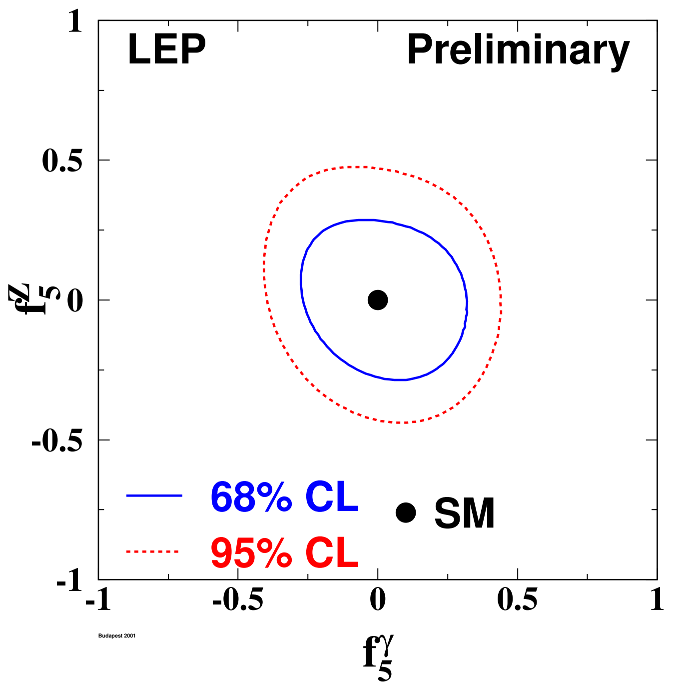
f_4^γ	f_4^Z	f_5^γ	f_5^Z
−0.17	−0.31	−0.36	−0.36
+0.19	+0.28	+0.40	+0.39

Results on $f_i^{\gamma,Z}$ (2-dim.)



95% CL

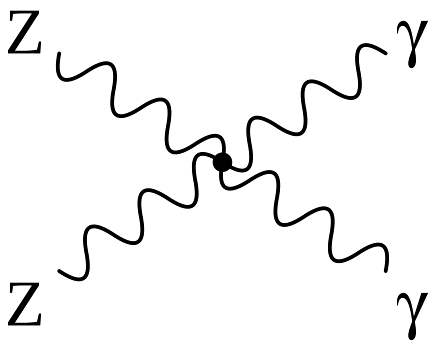
f_4^γ	f_4^Z
-0.17	-0.30
$+0.19$	$+0.28$



95% CL

f_5^γ	f_5^Z
-0.34	-0.36
$+0.38$	$+0.38$

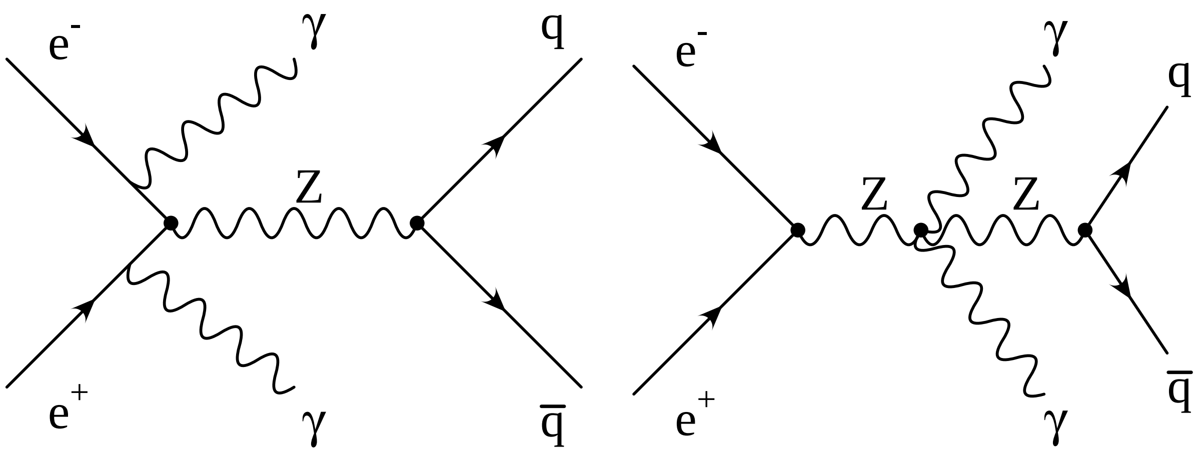
Neutral Quartic Gauge Couplings



Window on Spontanous Symmetry Breaking.
New Physics effects due to heavy new particle exchange.

Standard Model

neutral QGC



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

Theoretical Framework (neutral QGC)

Parametrisation with effective Lagrangian:
(C, P, $U(1)_{em}$, $SU(2)_c$ symmetries)

$$\mathcal{L}^0 = -\frac{\pi\alpha}{4}\frac{a_0}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}Z^\rho \cdot Z_\rho$$

$$\mathcal{L}^c = -\frac{\pi\alpha}{4}\frac{a_c}{\Lambda^2} F_{\mu\rho}F^{\mu\sigma}Z^\rho \cdot Z_\sigma$$

[Belanger et al., Phys.Lett. B288 (1992)

α: fine structure constant,

$F_{\mu\nu}$: field strength tensor,

Z^ρ: physical field of Z boson.

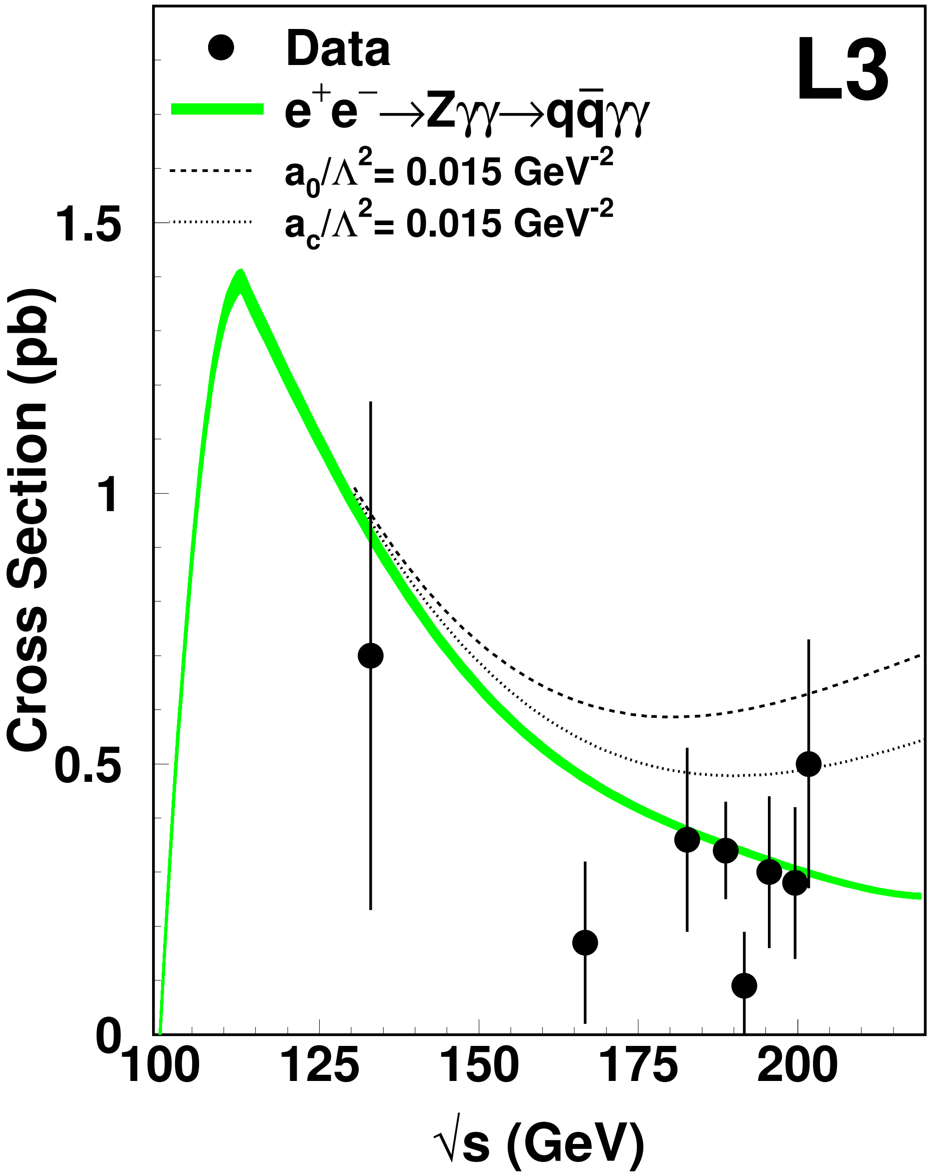
Strength of QGC's described by $\frac{a_0}{\Lambda^2}$ and $\frac{a_c}{\Lambda^2}$.
Scale of new physics represented by Λ.

Standard Model: $a_0 = a_c = 0$.

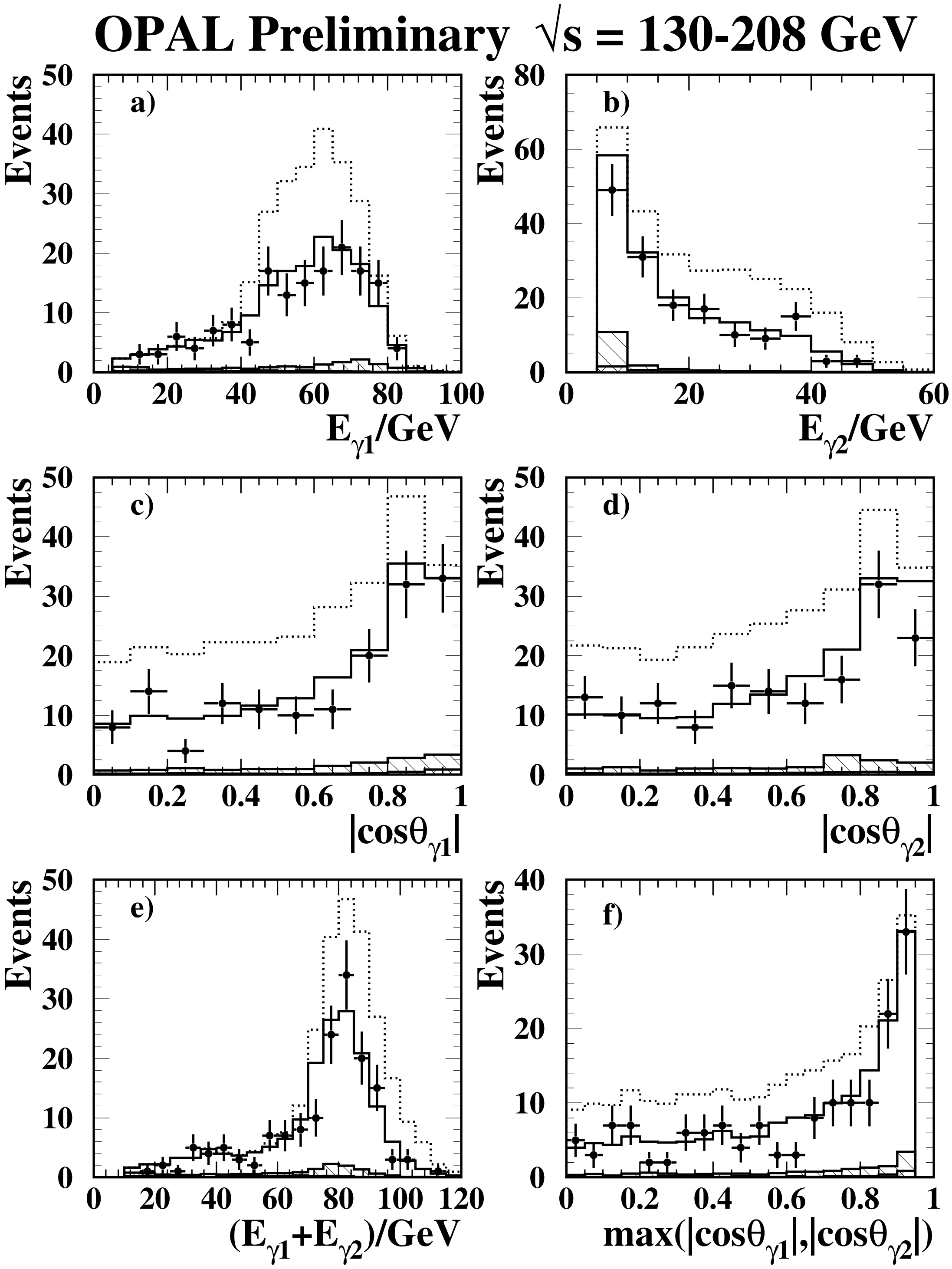
$e^+e^- \rightarrow Z\gamma\gamma$ ($ZZ\gamma\gamma$ coupling)

Main effects of anomalous NQGC:

- deviations in total cross-section,
- less energetic photon gets harder.



$e^+e^- \rightarrow Z\gamma\gamma$ ($ZZ\gamma\gamma$ coupling)



(dotted lines: $a_0/\Lambda^2 = 0.015\ \mathrm{GeV}^{-2}$)

NQGC Results: Z$\gamma\gamma$ Process

Problem: new theoretical program (WRAP generator) differs from old one (Stirling&Werthenbach)

Results from July 2001:

(using EEZGG generator)

- L3: (130 – 202GeV, 500 pb^{-1})
  fit to transverse momentum $Pt_{\gamma 2}$
- OPAL: (130 – 208GeV, 580 pb^{-1})
  fit to distribution of
  $[E_{\gamma 2}, \max(|\cos\theta_{\gamma 1}|, |\cos\theta_{\gamma 2}|)]$

95% CL limits:

	a_0/Λ^2 (GeV^{-2})	a_c/Λ^2 (GeV^{-2})
L3	[−0.008, +0.005]	[−0.007, +0.011]
OPAL	[−0.006, +0.008]	[−0.008, +0.0012]

But: limits are expected to change.

Summary

Neutral Triple Gauge Couplings:

- analyses use $Z\gamma$ and ZZ processes:
- no evidence for neutral TGC's,
- 95% CL limits on $h_i^{\gamma,Z}$, $f_i^{\gamma,Z}$ obtained (LEP combination) of order of 10^{-1}.

Neutral Quartic Gauge Couplings:

- analyses use $Z\gamma\gamma$ process,
- no evidence for neutral QGC's,
- ongoing effort to repeat measurements using WRAP generator.