MEASUREMENT of NEUTRAL TRIPLE GAUGE BOSON COUPLINGS at LEP2

$Z\gamma\gamma$, $ZZ\gamma$ and ZZZ

Clara Matteuzzi

Milano University and I.N.F.N.

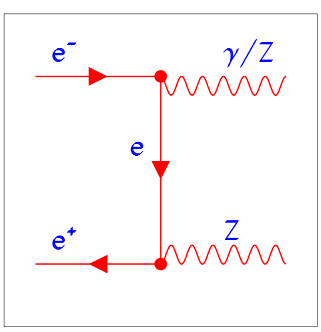
on behalf of LEP experiments

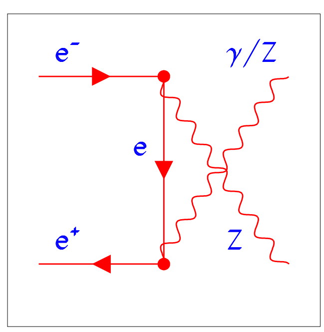
Outline of the talk

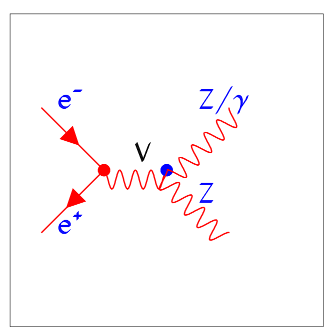
- Introduction
- $Z\gamma$, ZZ vertices
  . NTGC parametrization
  . Properties
- Measurement of $Z\gamma$
- Measurement of ZZ
- Conclusions

INTRODUCTION

- In the STANDARD MODEL interactions between neutral gauge bosons Z and γ are NOT allowed at tree level. Loop corrections are unobservably small (10^{-4}).
- Physics beyond the SM (heavy fermions, compositeness,....) in $Z\gamma\gamma$, $ZZ\gamma$ and ZZZ couplings (NTGC).
- At LEP2 NTGC can be probed through $Z\gamma$ and ZZ production:

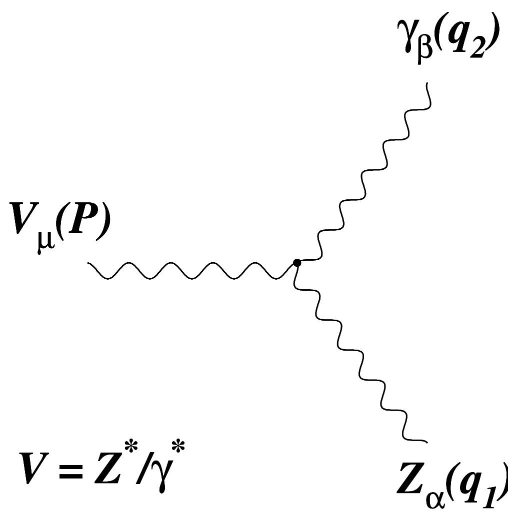






$Z\gamma$ coupling

vertex parametrization



$$= ie\Gamma_{Z\gamma V}^{\alpha\beta\mu}(q_1, q_2, P)$$

Lorentz and $U(1)_{em}$ gauge invariance:

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

$Z\gamma$ coupling

vertex parametrization

- Needs a form factor not to violate unitarity:

$$h_i^V = \frac{h_{0i}^V}{(1+s/\Lambda^2)^n}$$

Λ = scale of new physics

An alternative choice of parameters:

$$\frac{\sqrt{\alpha}h_{1,3}^V}{m_Z^2} = \frac{1}{\Lambda_{1,3V}^2}, \qquad \frac{\sqrt{\alpha}h_{2,4}^V}{m_Z^4} = \frac{1}{\Lambda_{2,4V}^4}$$

- $h_{1,2}^V$ are CP violating
  $\longrightarrow$ NOT interfere with SM

  $h_{3,4}^V$ are CP conserving
  $\longrightarrow$ amplitudes interfere with SM

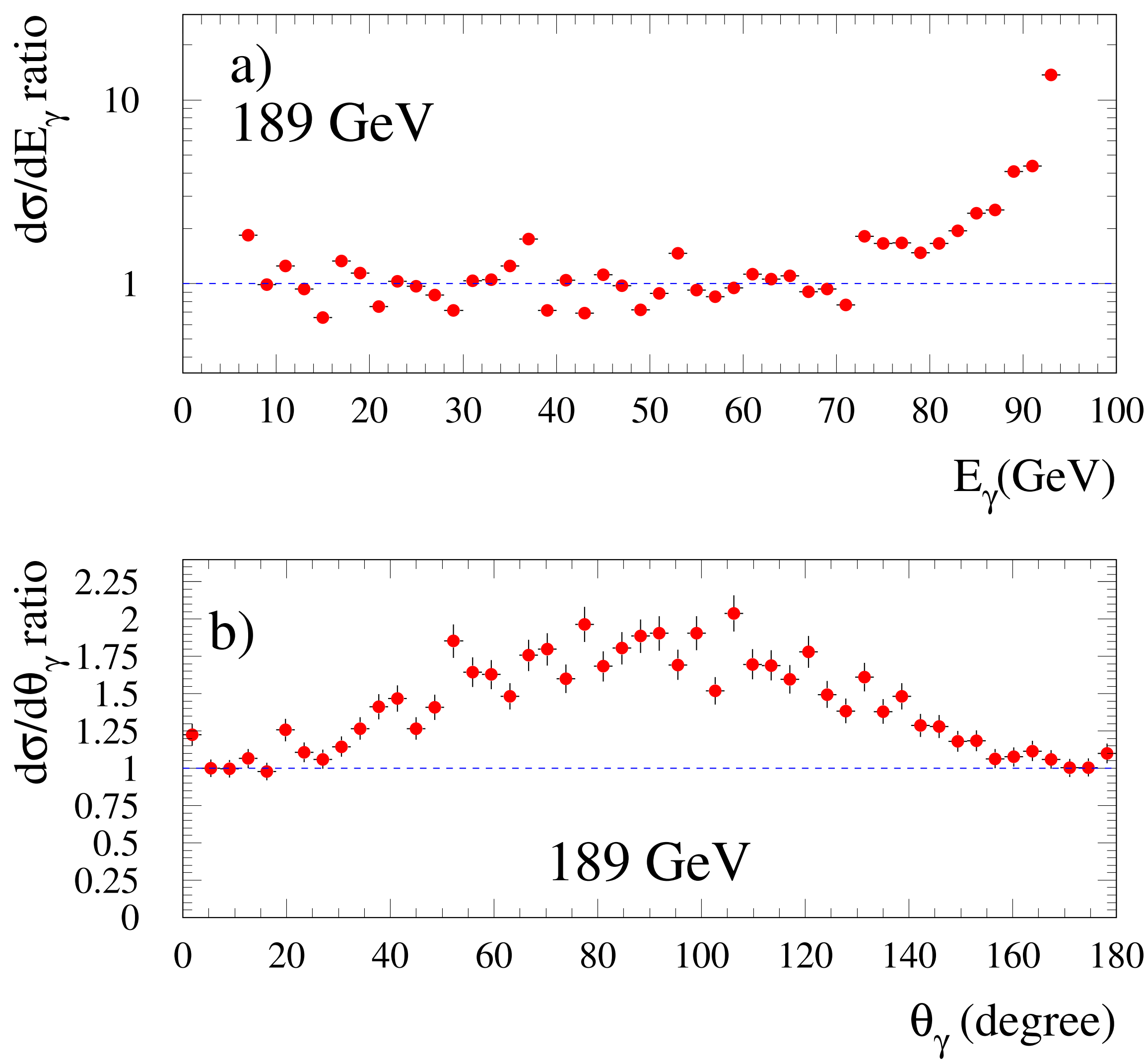
- $h_{1,3}^V$ are dimension 6
  $h_{2,4}^V$ are dimension 8

$Z\gamma$ coupling

Properties

The sensitivity to the couplings is mainly
at large photon polar angle and large photon energy

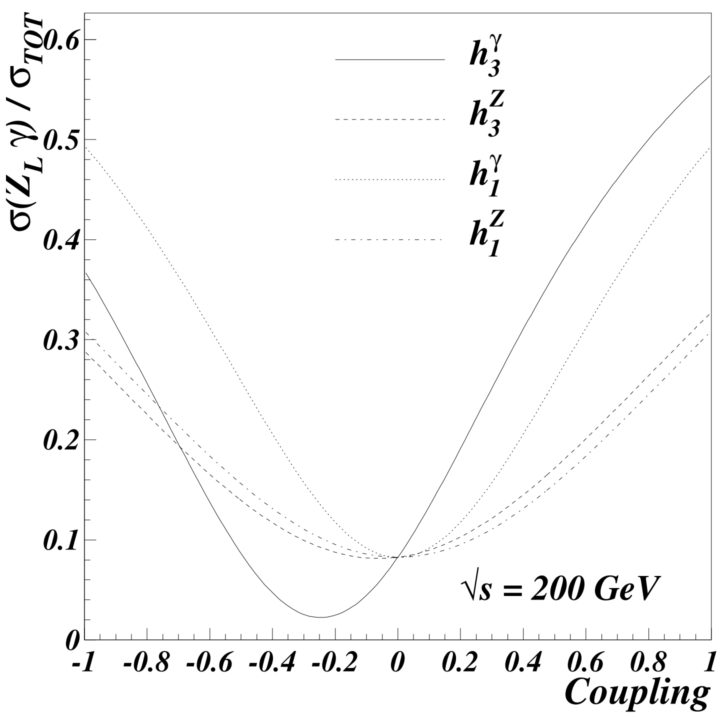
MONTECARLO $\nu\bar{\nu}\gamma$ channel

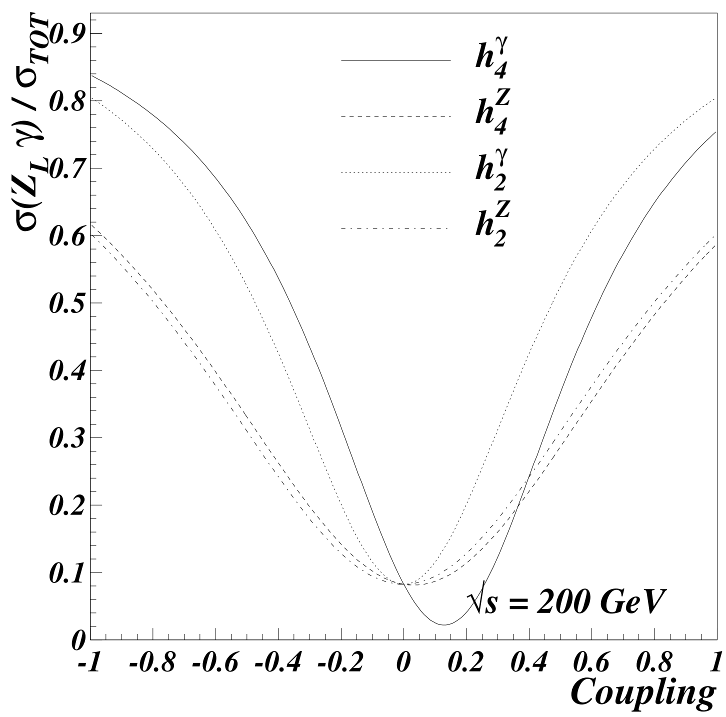


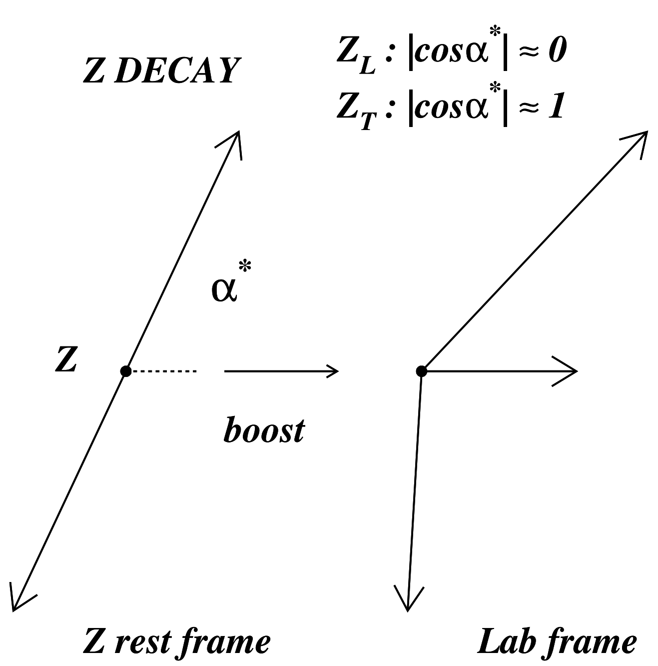
$Z\gamma$ coupling

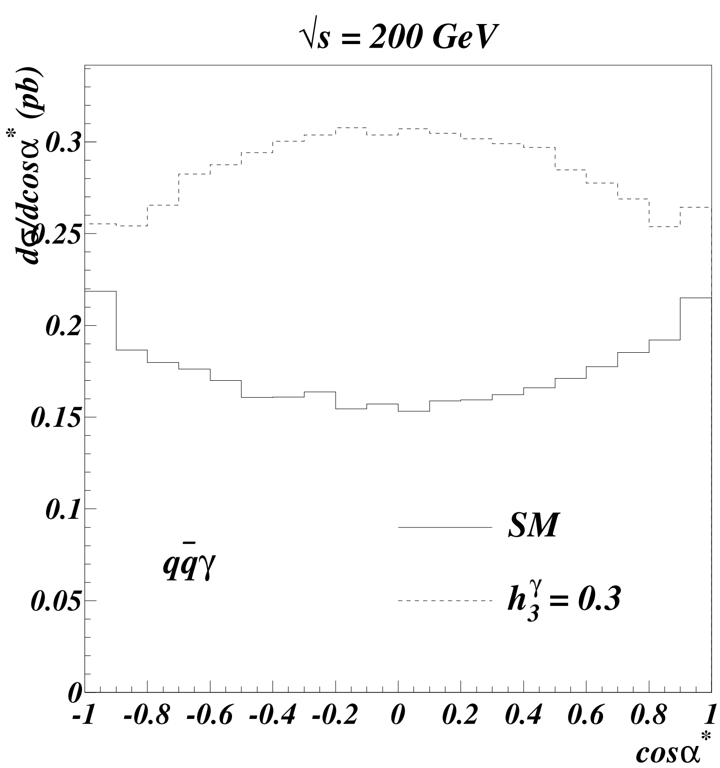
Properties

Enhancement of longitudinal Z's



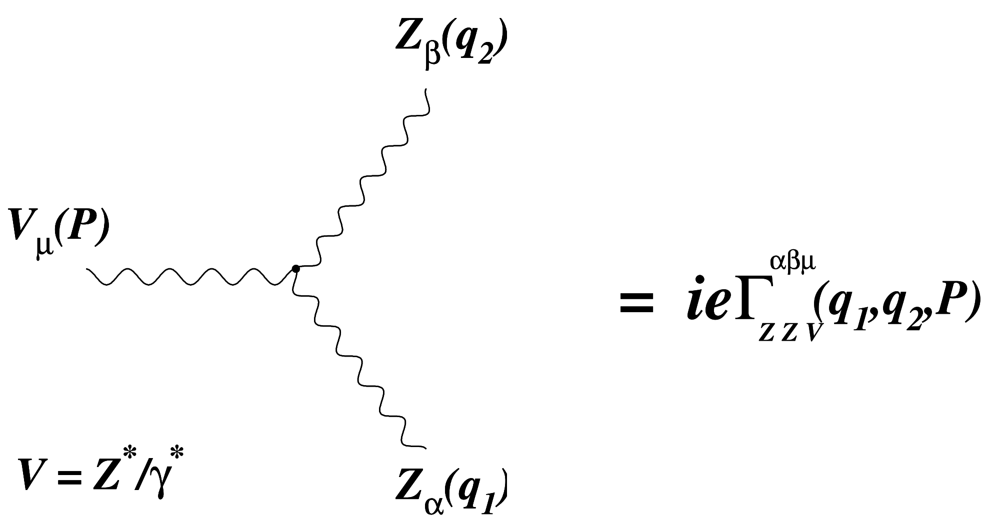






ZZ coupling

parametrization



Lorentz and $U(1)_{em}$ gauge invariance + Bose symmetry $\Rightarrow$ only 4 independent couplings:

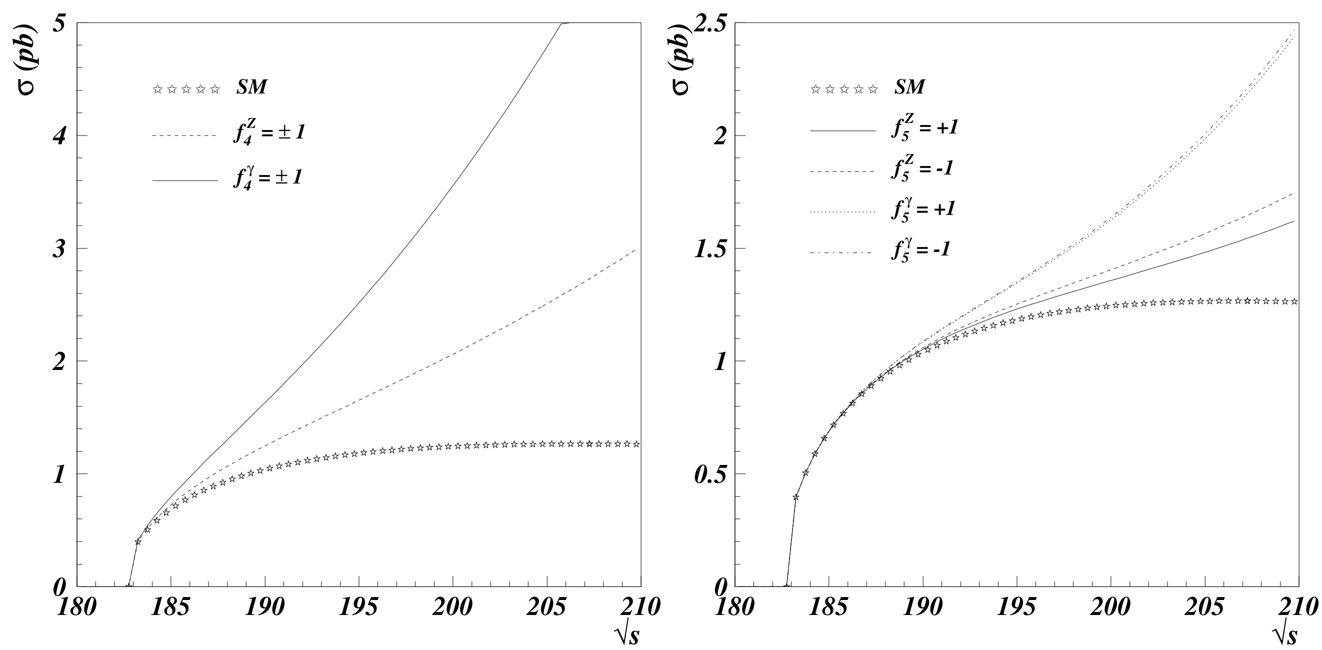
$$\Gamma^{\alpha\beta\mu}_{ZZV}(q_1, q_2, P) = \frac{i(P^2 - m_V^2)}{m_Z^2} \left[f_4^V (P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) - f_5^V \epsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho \right]$$

	f_4^V	f_5^V
CP	-1	1
dim. oper. $\geq$	6	6

ZZ coupling

properties

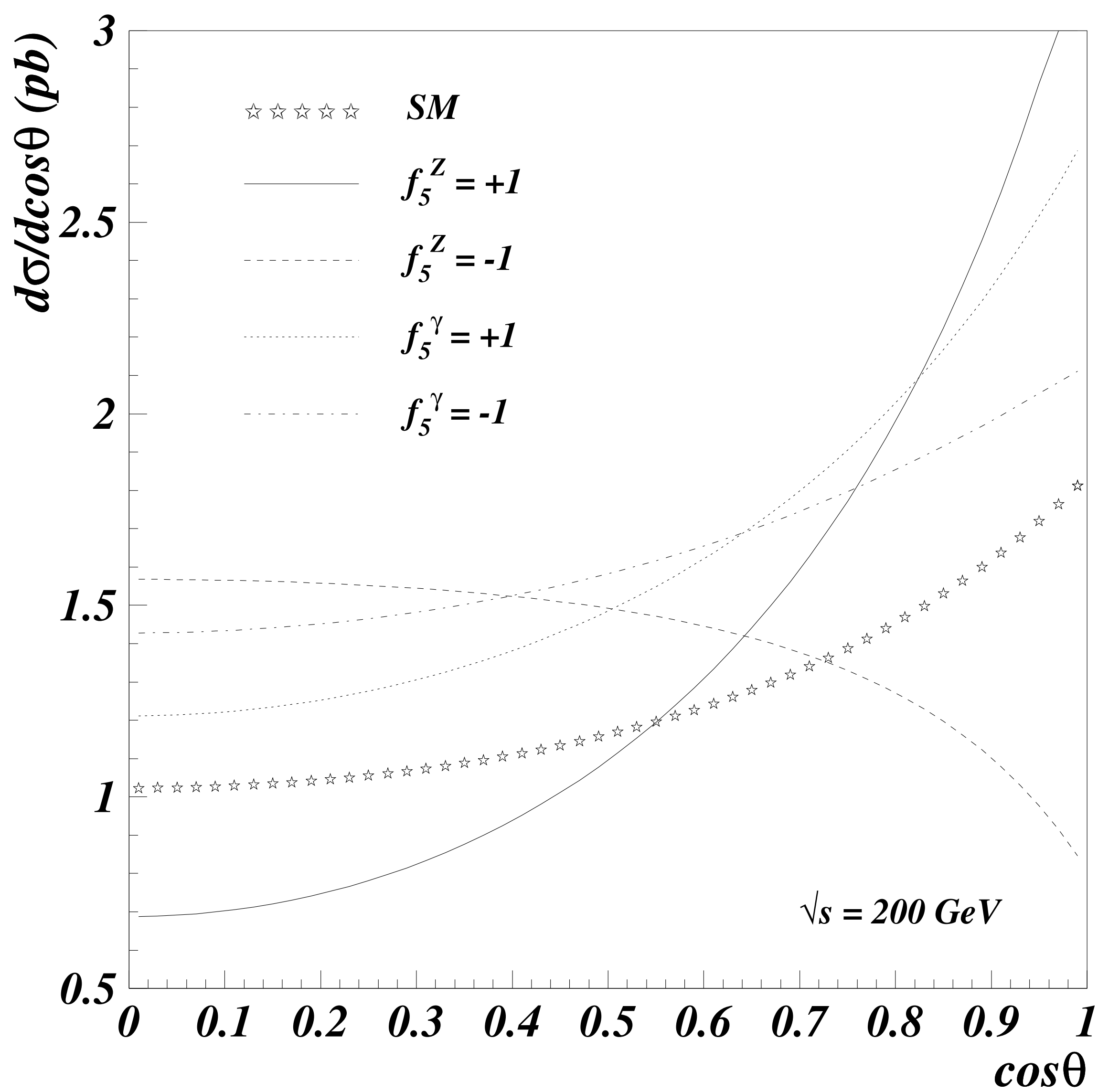
The cross section is strongly affected by the couplings and the sensitivity strongly increases with $\sqrt{s}$



ZZ coupling

properties

The shape of $d\sigma/d\cos\theta_Z$ is strongly modified by f_5^Z



$Z\gamma$, ZZ couplings

Experimental signatures

AT LEP 2 :

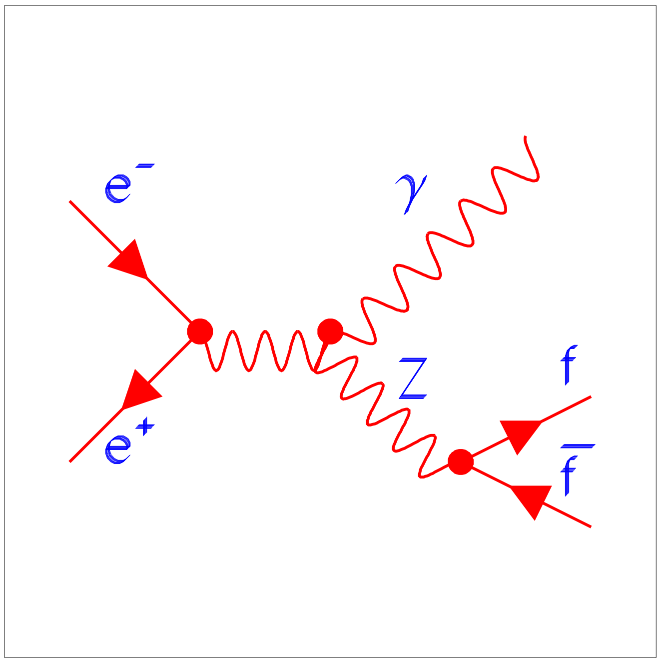
- $e^+e^- \rightarrow \nu\overline{\nu}\gamma$, $q\bar{q}\gamma$

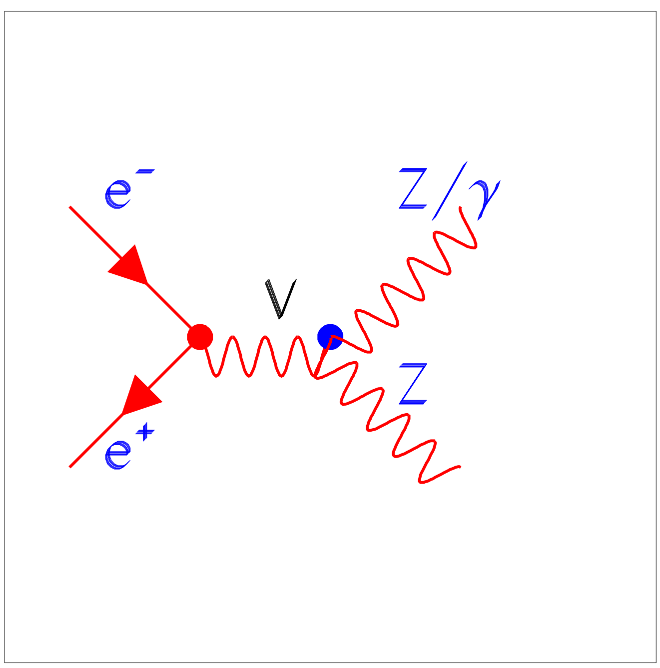
  with a visible γ

  are sensitive to h_i^V

- $e^+e^- \rightarrow 4f$

  are sensitive to $f_{4,5}^V$


e⁻
γ
Z
f
f̄
e⁺


e⁻
Z/γ
V
Z
e⁺

$Z\gamma$ coupling

RESULTS

RESULTS PRESENTED TO THIS CONFERENCE from DELPHI, L3,OPAL

- DELPHI
  - $\nu\bar{\nu}\gamma$: fit the cross section
  - $q\bar{q}\gamma$: fit of $d\sigma/d\cos\alpha^{\star}$
- L3
  - 'Optimal Variables' approach
  - $(E_{\gamma}, \theta_{\gamma}, \phi_{\gamma}, \theta_f^Z, \phi_f^Z)$ in the $q\bar{q}\gamma$ channel
  - $(E_{\gamma}, \theta_{\gamma}, \phi_{\gamma})$ in the $\nu\bar{\nu}\gamma$ channel
- OPAL
  - $\nu\bar{\nu}\gamma$: fit the cross section
  - $q\bar{q}\gamma$: fit of $d\sigma/d\cos\theta_{\gamma j}$

ZZ coupling

RESULTS

RESULTS WERE PRESENTED TO THIS CONFERENCE from DELPHI, L3 and OPAL up to 202 GeV

All the visible channels used

$q\overline{q}q'\overline{q}'$, $q\overline{q}\nu\overline{\nu}$, $q\overline{q}l^-l^+$, $l^-l^+\nu\overline{\nu}$, $l^-l^+l'^-l'^+$

- DELPHI

  Fit the cross section calculated with DELTGC.

- L3

  Fit the most significant variables to distinguish signal and background. The impact of anomalous couplings is obtained with an extension of Excalibur generator.

- OPAL

  Fit the $\cos\theta_Z$ distributions and use an extended YFSZZ generator.

$Z\gamma$ coupling

EXPERIMENTAL RESULTS

STATISTICS of EACH EXPERIMENT

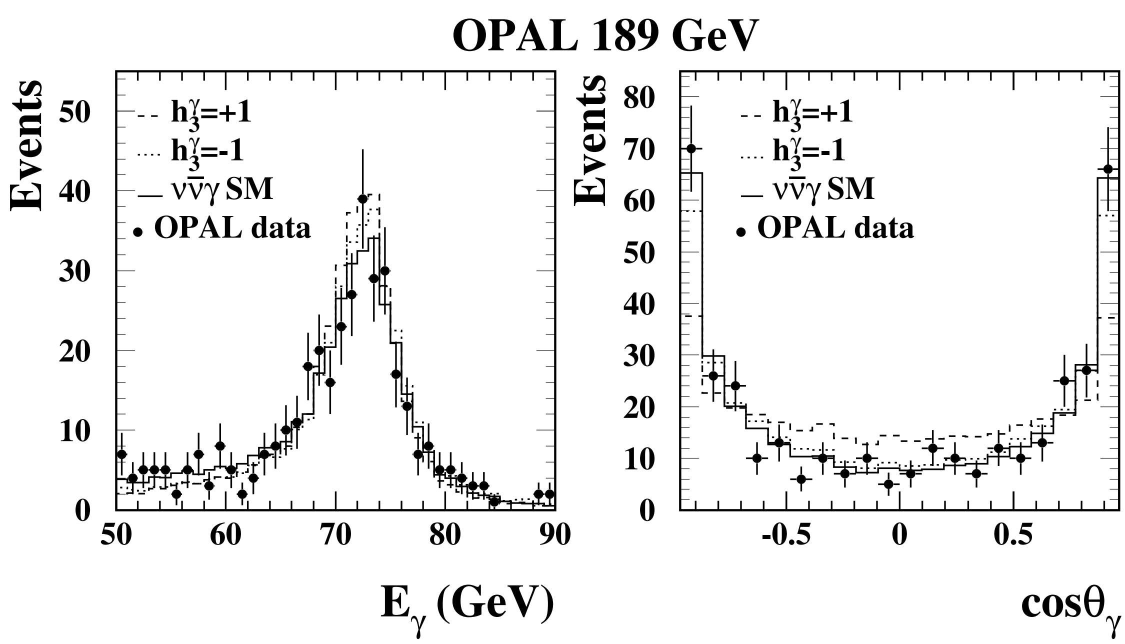
	DELPHI	L3	OPAL
$\nu\bar{\nu}\gamma$	198	267	370
expected	196.5	294	412
$q\bar{q}\gamma$	1074	956	1525
expected	1086	978	1577
Luminosity(pb^{-1})	380	230	176
$\sqrt{s}$ GeV	189-202	192-202	189

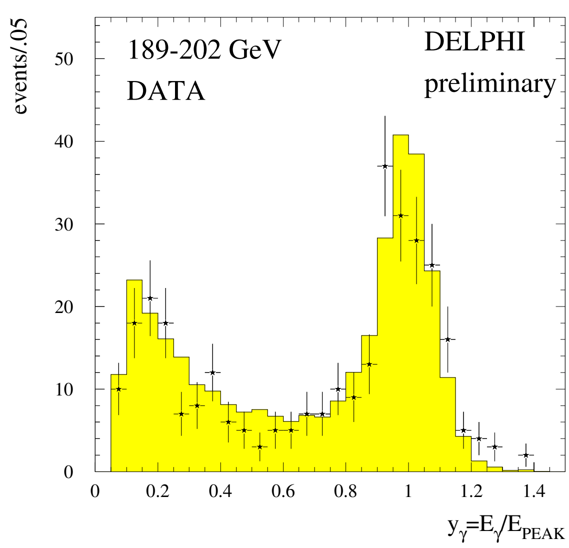
Selection criteria different $\rightarrow$ determine different acceptances in each experiment

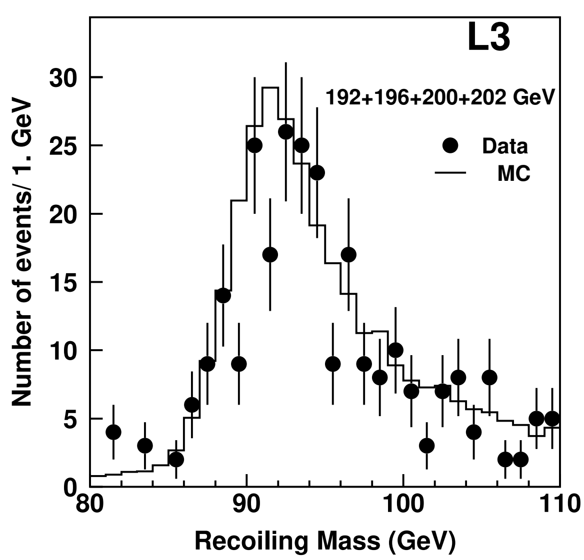
$Z\gamma$ coupling

RESULTS

$\nu\bar{\nu}\gamma$ channel



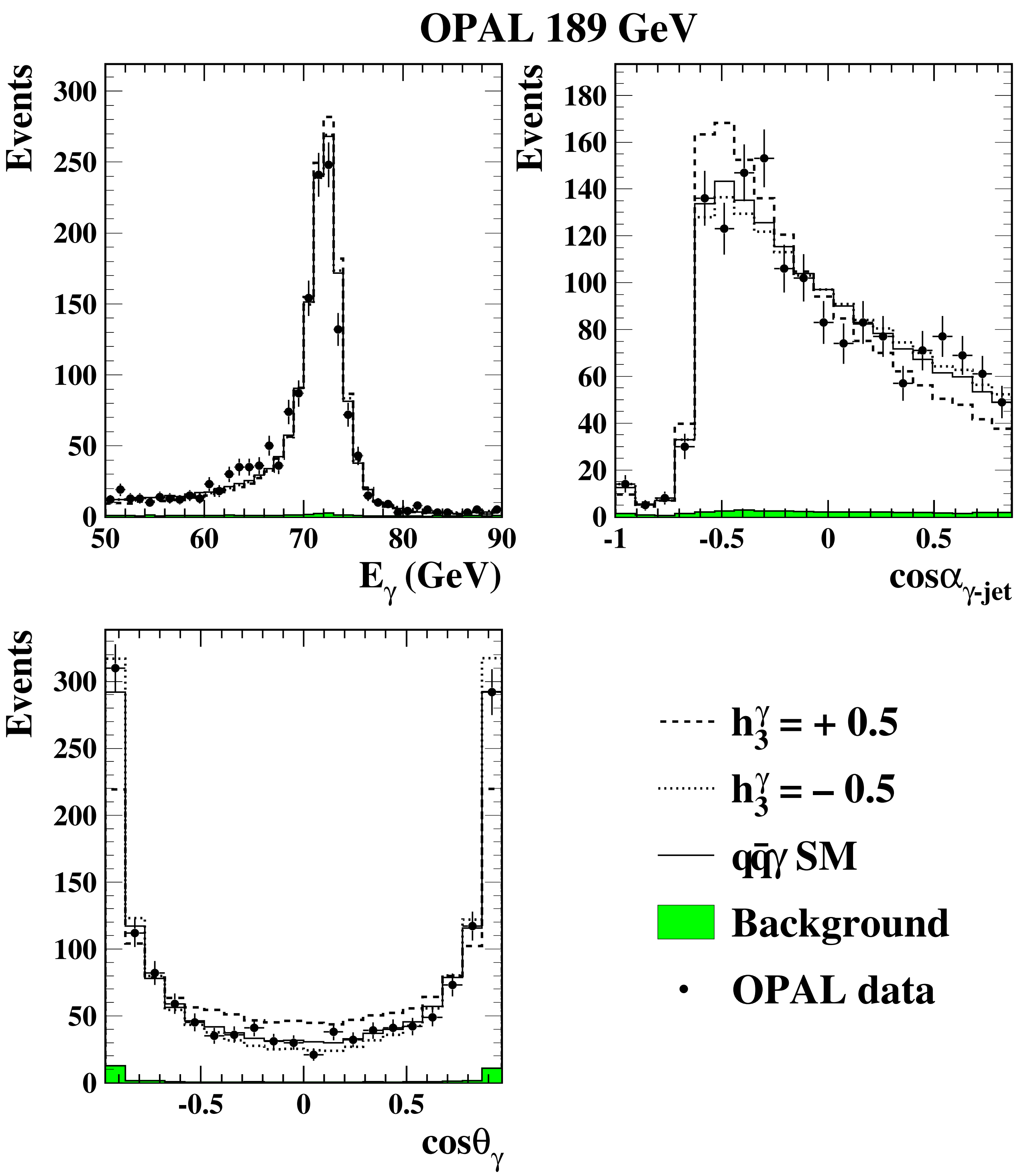




$Z\gamma$ coupling

RESULTS

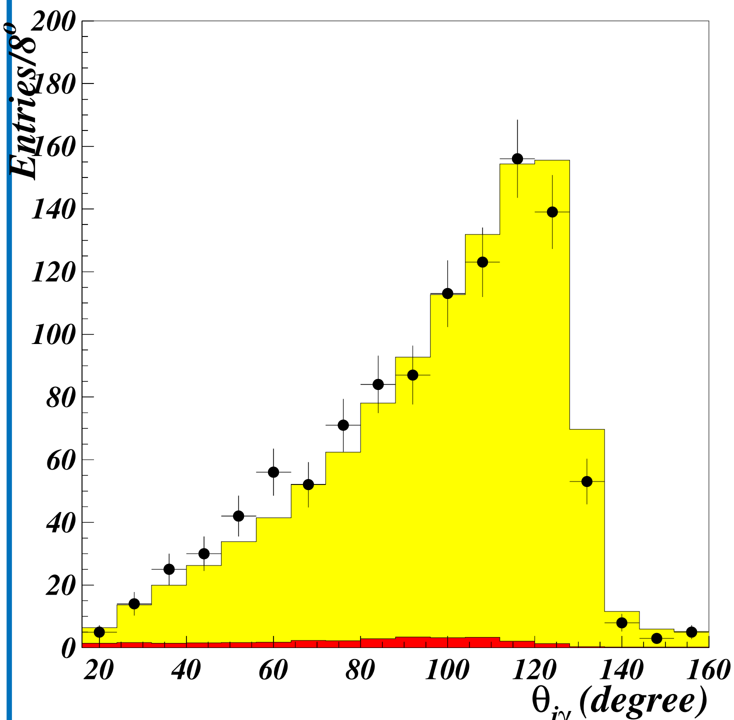
$q\bar{q}\gamma$ channel

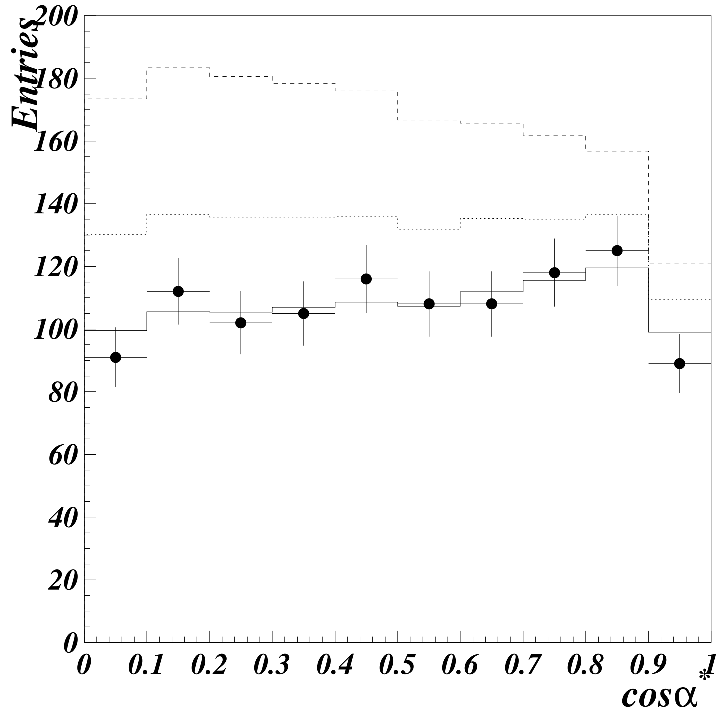


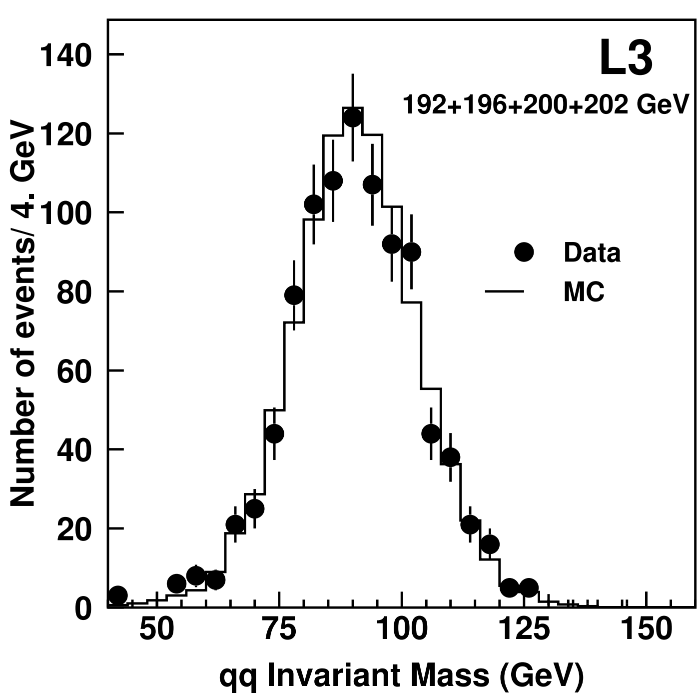
$Z\gamma$ coupling

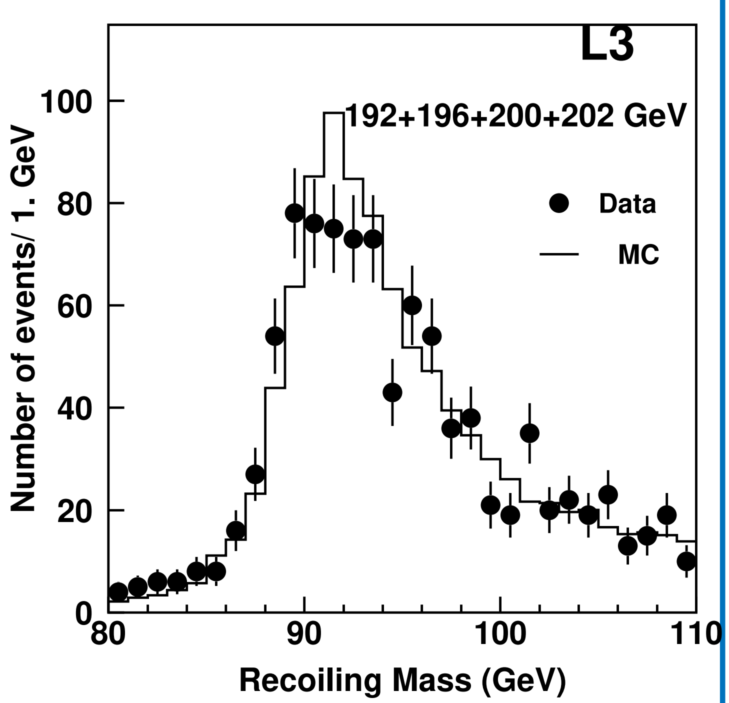
RESULTS

$q\bar{q}\gamma$ channel









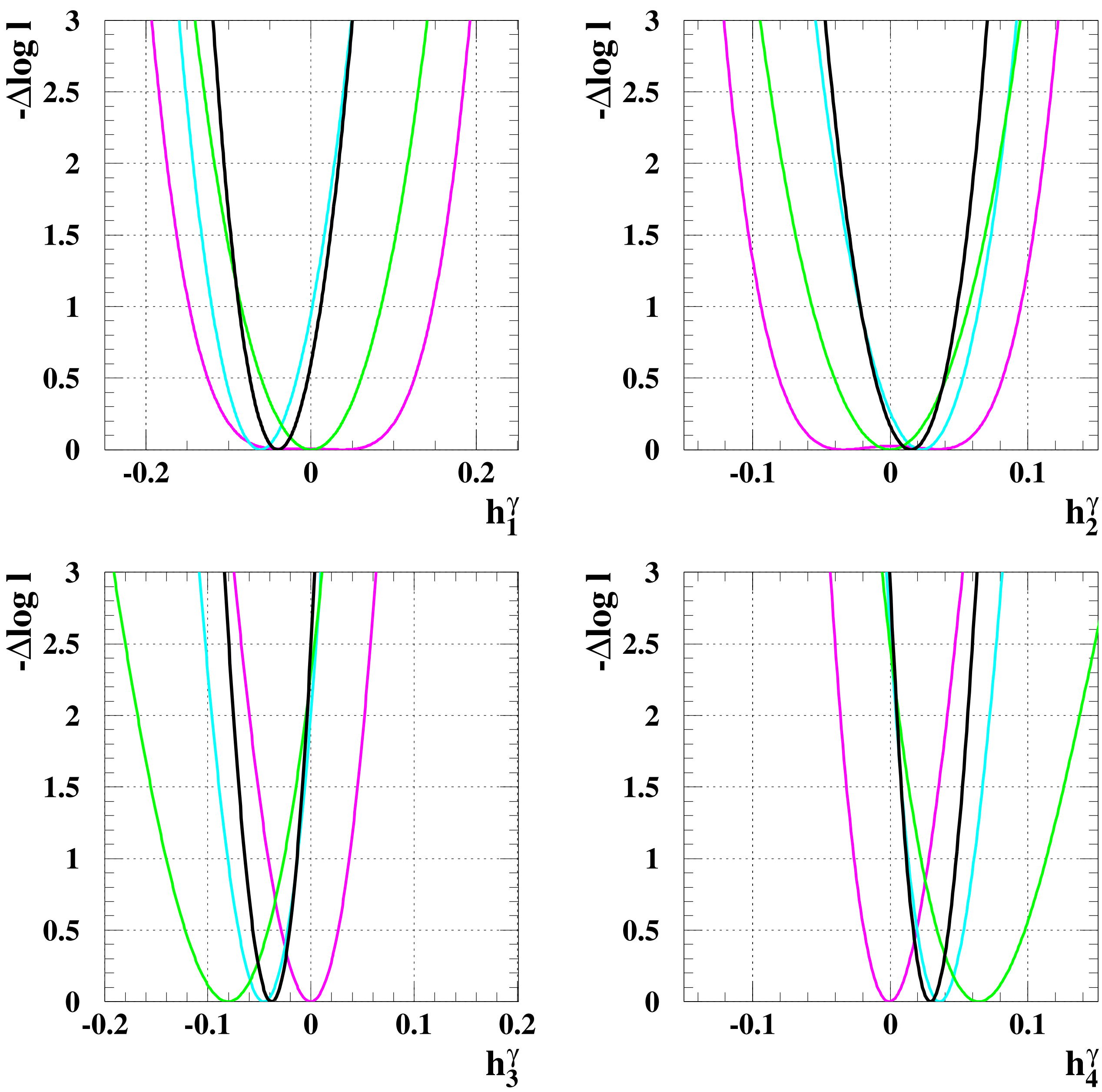
RESULTS

$$h_i^\gamma$$

LEP combined limits (95% CL)

h_1^γ	h_2^γ	h_3^γ	h_4^γ
[-0.10,+0.03]	[-0.04,+0.06]	[-0.075,+0.004]	[0.005,+0.056]

Preliminary DELPHI+L3+OPAL



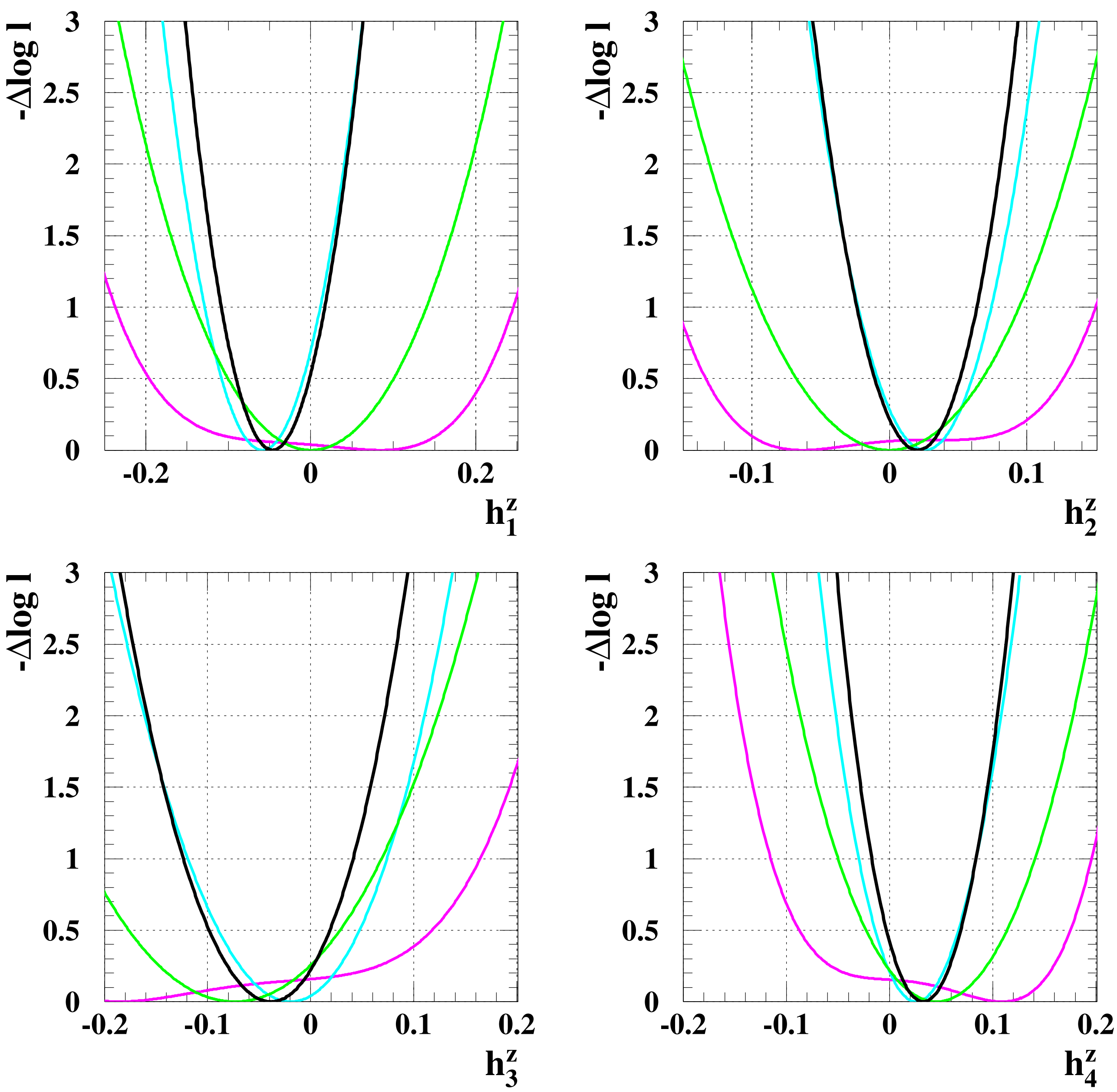
RESULTS

h_i^Z

LEP combined limits (95% CL)

h_1^Z	h_2^Z	h_3^Z	h_4^Z
[-0.13,+0.04]	[-0.04,+0.08]	[-0.16,+0.07]	[0.04,+0.10]

Preliminary DELPHI+L3+OPAL

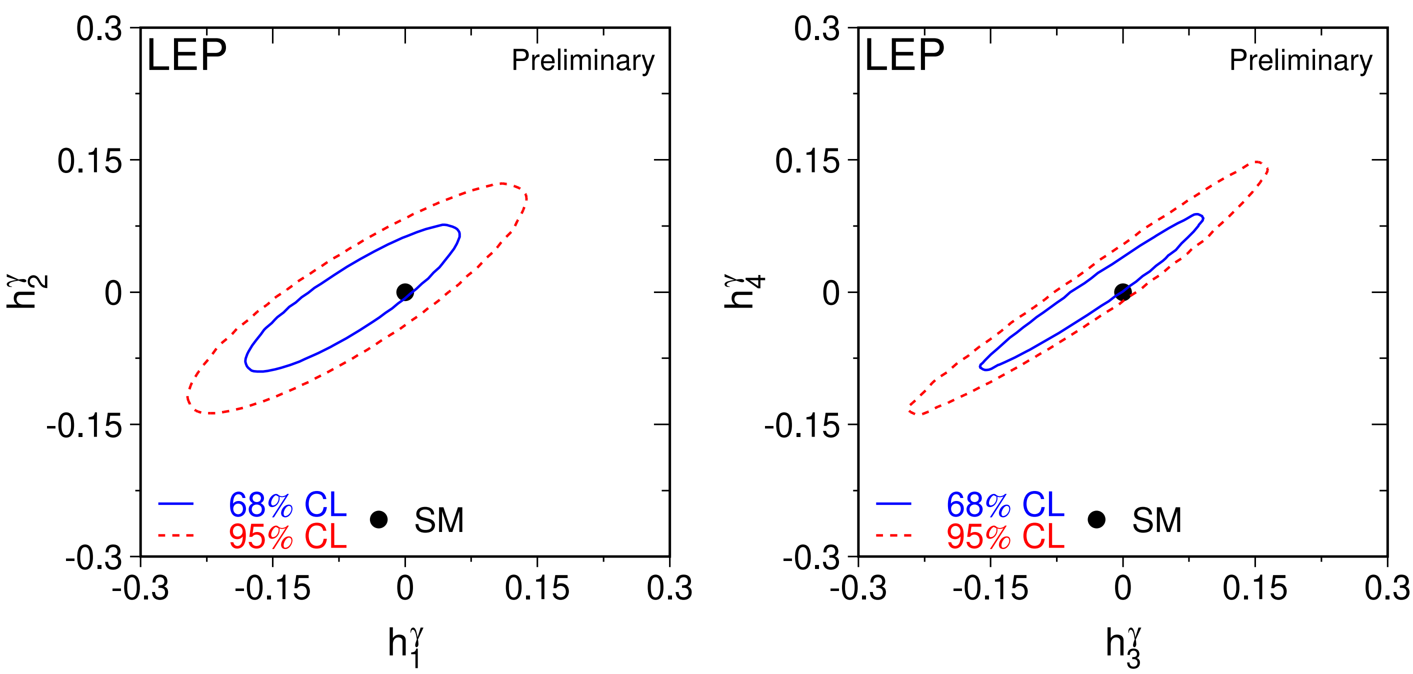


RESULTS

$h^{\gamma}_{1,2}, h^{\gamma}_{3,4}$

LEP combined limits (95% CL)

$h^{\gamma}_1 vs h^{\gamma}_1$	$h^{\gamma}_3 vs h^{\gamma}_4$
[-0.21,+0.10]	[-0.20,+0.13]
-0.11,+0.10]	[-0.11,+0.12]

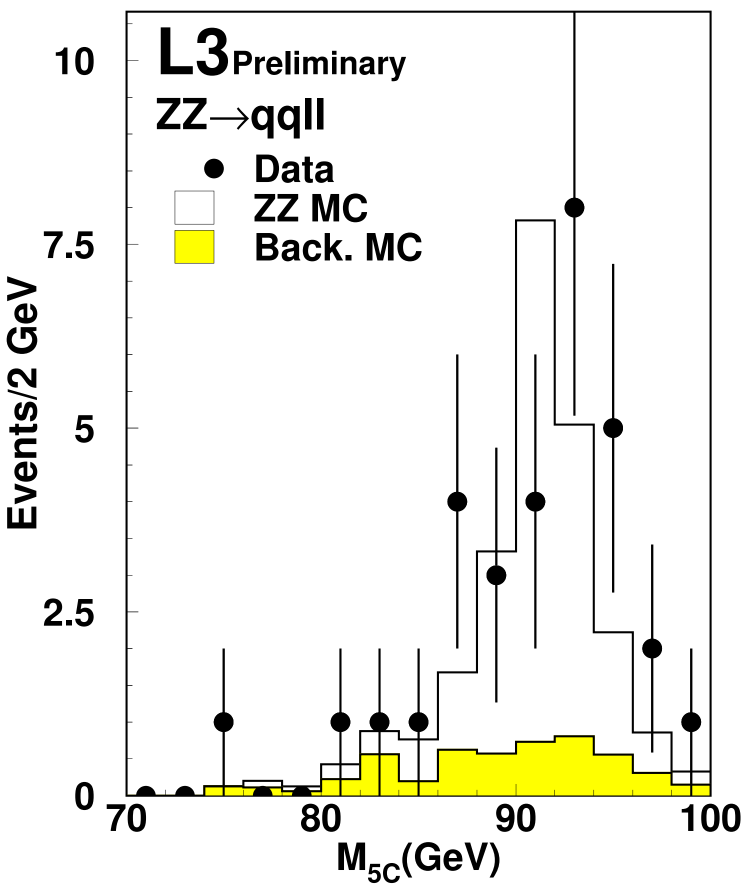


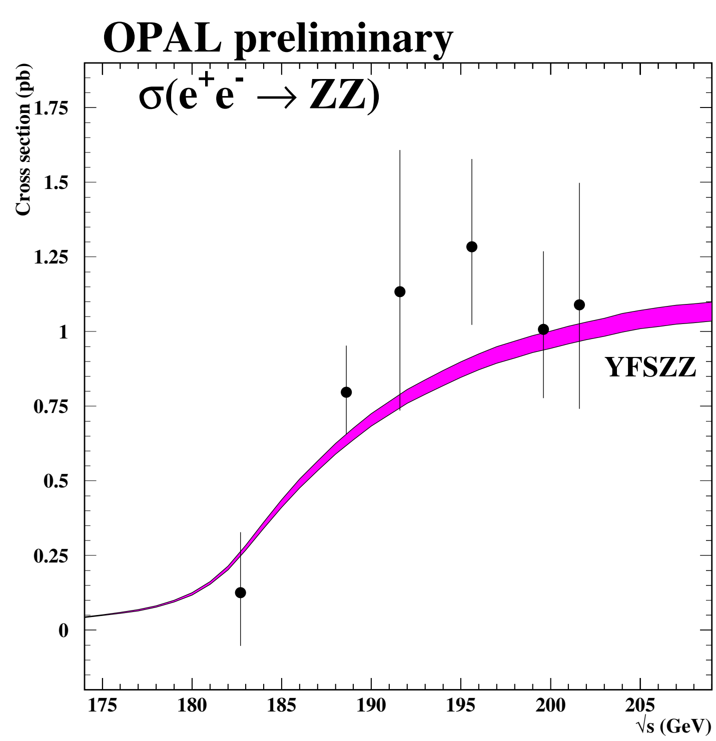
ZZ coupling

EXPERIMENTAL RESULTS

STATISTICS of EACH EXPERIMENT

(See Salvatore Mele talk)





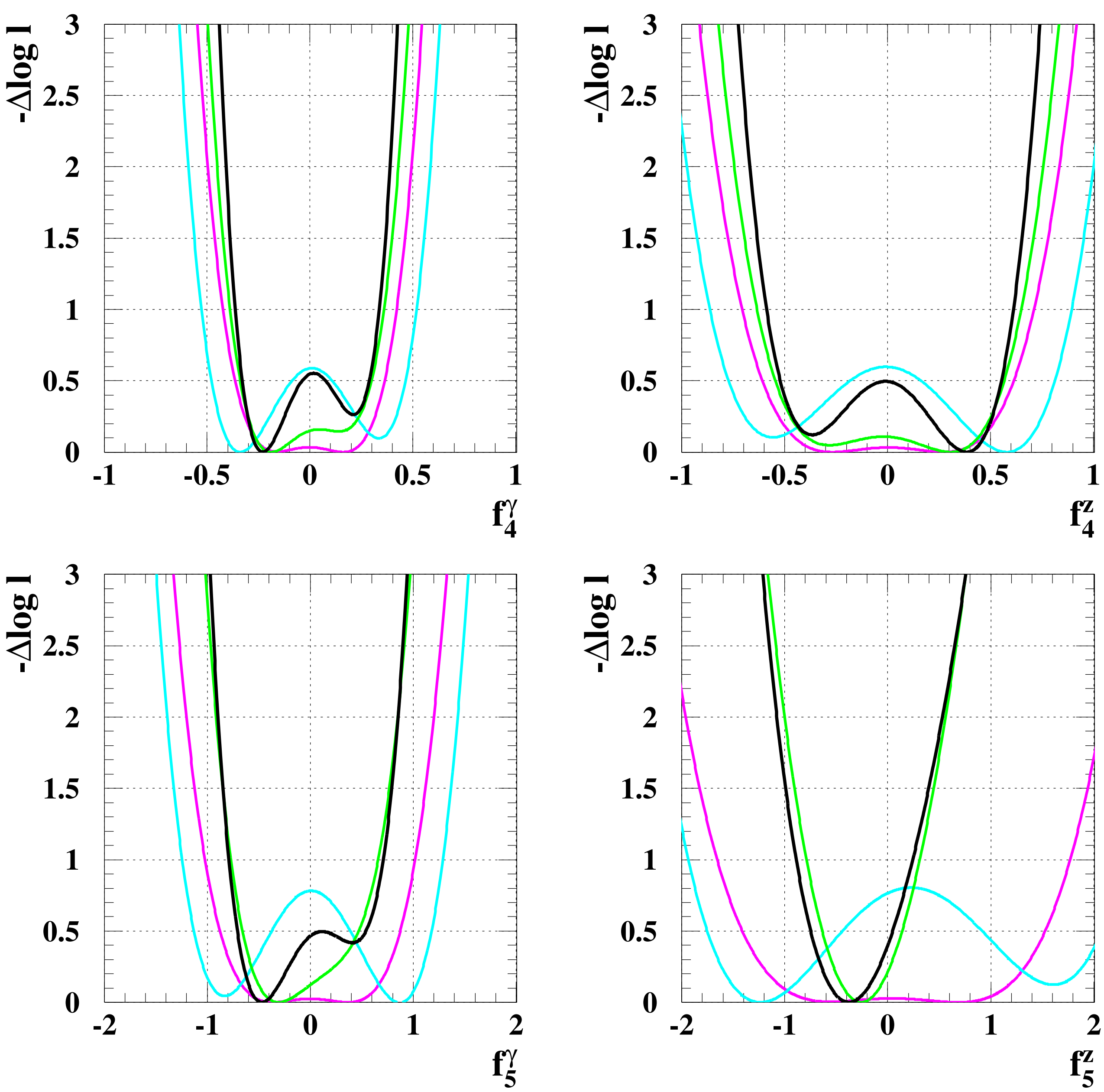
RESULTS

$f^{\gamma}_{4,5}, f^{Z}_{4,5}$

LEP combined limits (95% CL)

f^{γ}_{4}	f^{Z}_{4}	f^{γ}_{5}	f^{Z}_{5}
[-0.41,+0.39]	[-0.66,+0.68]	[-0.89,+0.84]	[-1.06,+0.51]

Preliminary DELPHI+L3+OPAL

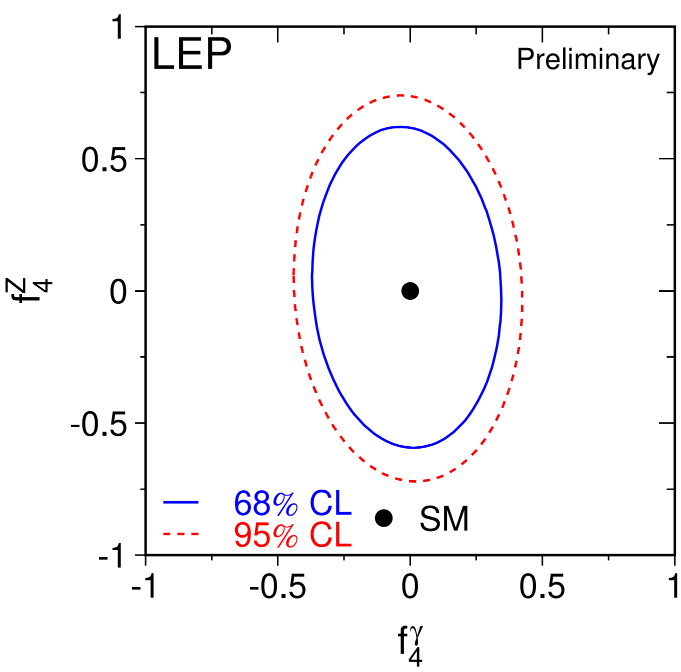


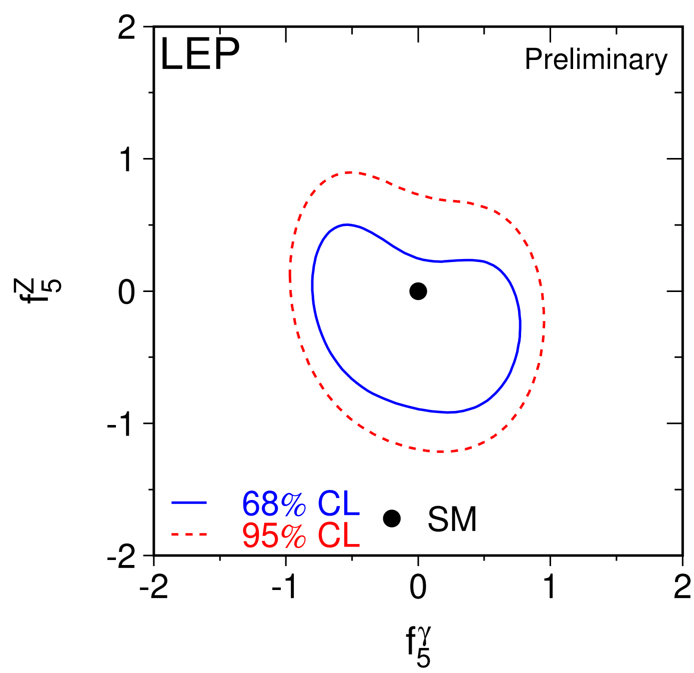
RESULTS

$f^{\gamma}_{4,5}, f^{Z}_{4,5}$

LEP combined limits (95% CL)

$f_4^\gamma vs f_4^Z$	$f_5^\gamma vs f_5^Z$
[-0.40,+0.38]	[-0.89,+0.86]
-0.66,+0.68]	[-1.06,+0.69]





CONCLUSIONS

- No evidence of NTGC at LEP 2
- LEP 2 (DELPHI+L3+OPAL) combination:
  1. $Z\gamma$ couplings (h_i^V) from $\nu\bar{\nu}\gamma$ and $q\bar{q}\gamma$
  2. ZZ couplings $(f_{4,5}^V)$ from 4f
  3. Scale of new physics
- Systematic studies were done in each experiment and included in the combinations.
- In the future include 'off=shell' bosons (new coupling parameters)