Production of Z Pairs at LEP2 and Neutral Anomalous Couplings

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representing the LEP collaborations
Aleph, Delphi, L3, Opal

Les Rencontres de la Physique de la Vallée d`Aosta
La Thuile, March 3-9th 2002

Summary

- Theoretical Motivation for ZZ Study
- Experimental data sample
- Results (by experiment, LEP combined)
- Neutral Anomalous Couplings
- Conclusions

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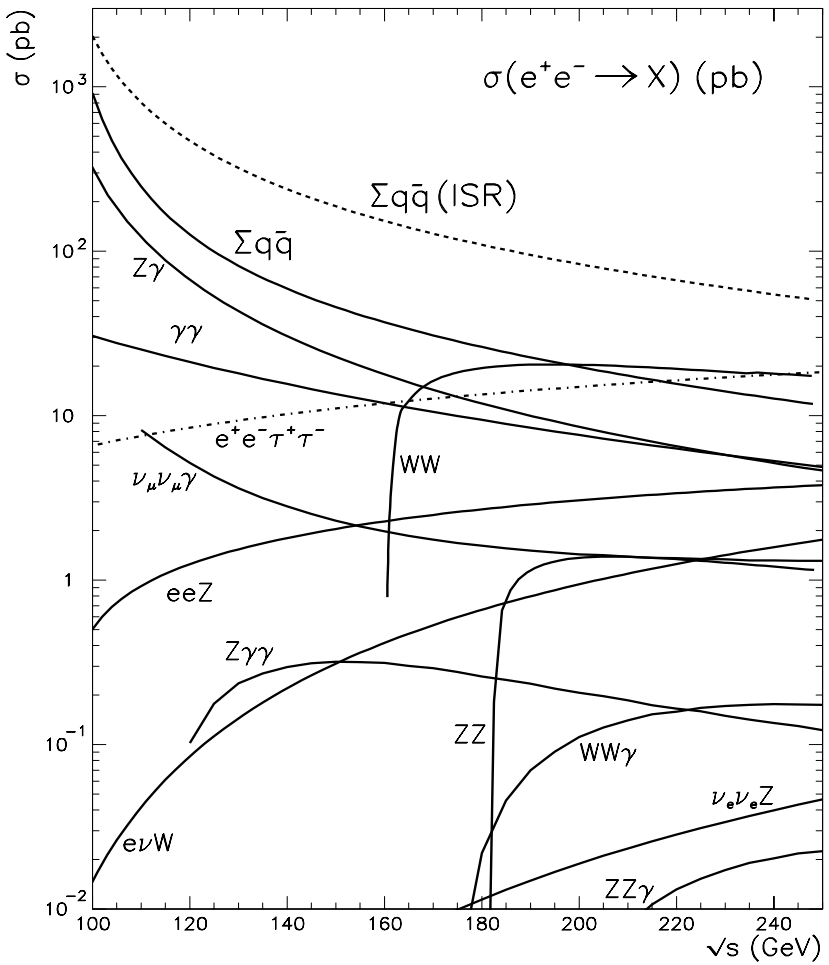
Theoretical Motivation

- Study of SM in the gauge neutral boson sector .
- Test of physics beyond SM (anomalous couplings, extra dimensions, new particles,…)
- Irreducible background for Higgs searches (in particular $m_H \sim m_Z$)



Experimentally, search for ZZ production competes with other more copious proccesses.

At LEP, ZZ seen coming alive.

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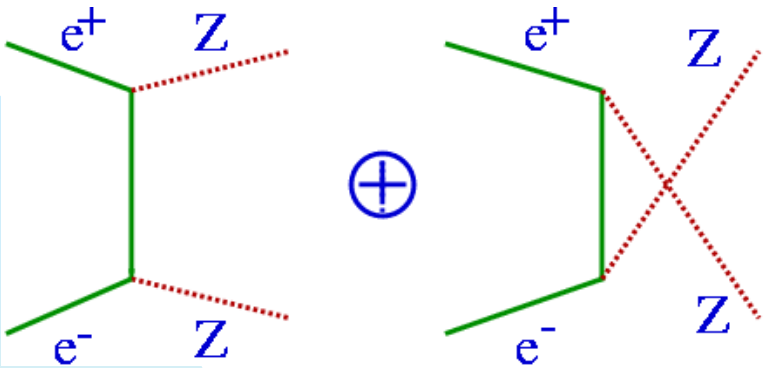
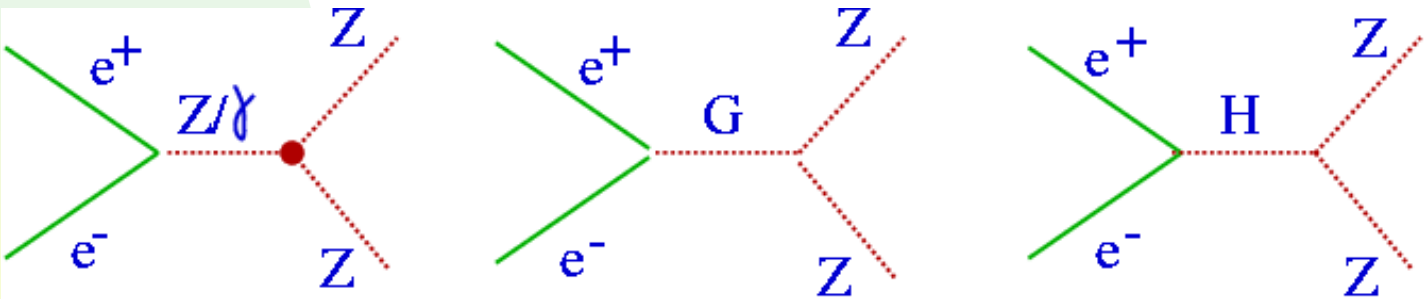
ZZ production



- t-channel exchange.
- no s-channel in SM.
- NC08-NC02 diagrams ($Z \rightarrow \gamma$) are background.
- LEP combination definition (not L3, e.g.)

Standard Model Proccess

Signal Definition: Neutral Current 02 diagrams (NC02)



New physics (may affect SM ZZ production)

Anomalous couplings, extra dimensions, Higgs exchange

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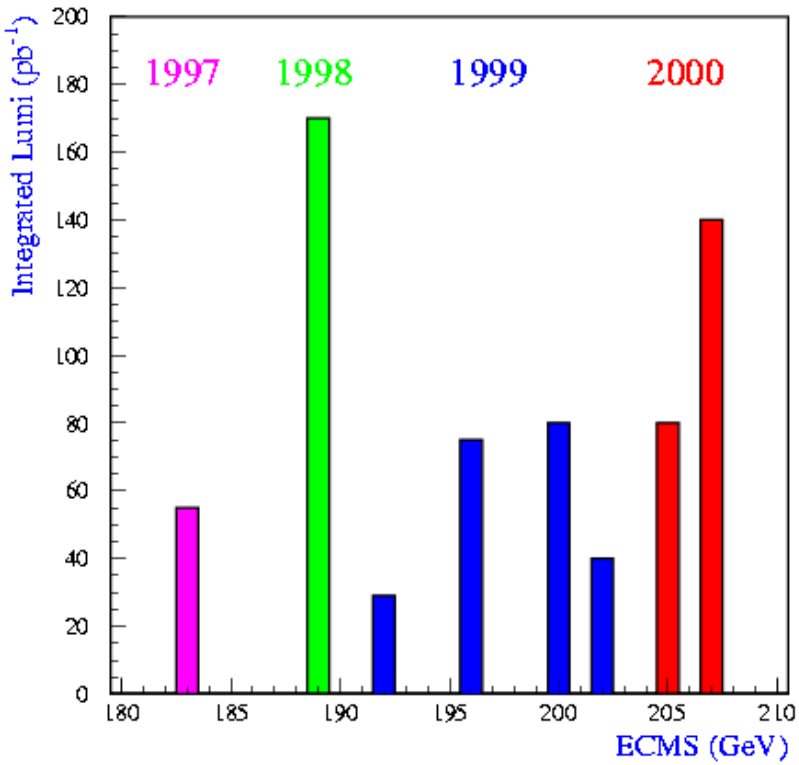
LEP Experimental Data

LEP experimental data sample amounts to ~660 pb^{-1} per experiment, taken during 1997 - 2000, at $\sqrt{s}$ = 183, 189, 192, 196, 200, 202, 205, 207 GeV.



Remark: Results from data at $\sqrt{s}$ > 202 GeV are preliminary for all 4 LEP experiments.

LEP combined results are those presented for summer conferences. Delphi has updated preliminary results since then.

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ZZ decays and Final States

Decay Channel	Br (%)	Effic (%)	Bkgd.	Signature
qqqq	49	30 – 40	WW, qqγ	4 jets, No energy imbalance
bbqq	20	20	WW, qqγ	4 jets, No energy imbalance, b-tagging
qqll l=(e, μ, τ)	14	60	Zee, Zγ, WW $\rightarrow$ qqlν	2 jets + 2 leptons
qq$\nu\nu$	28	40	Weν, WW $\rightarrow$ qqlν, qqγ	2 jets, E_{miss}
ll$\nu\nu$ l=(e, μ)	2.7	40	WW $\rightarrow$ lνlν, rad. Bhabha	2 leptons, E_{miss}
llll	1	50	Non reson. 4f	4 leptons
$\tau\tau\nu\nu$	1.3			
$\nu\nu\nu\nu$	4			

Hermeticity of detectors allows reconstruction of E_{miss} momentum

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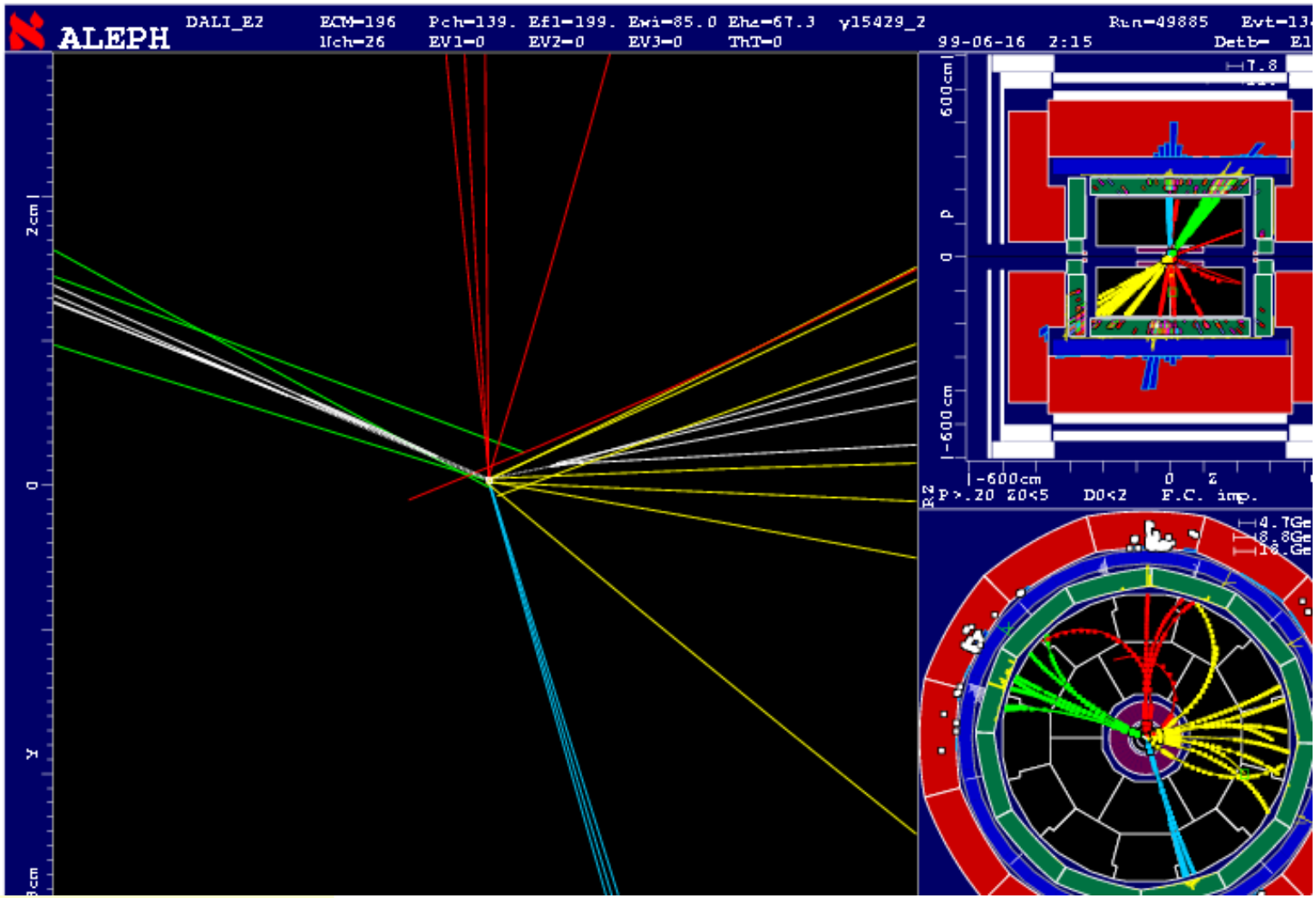
Aleph: ZZ → bbqq at √s = 196 GeV



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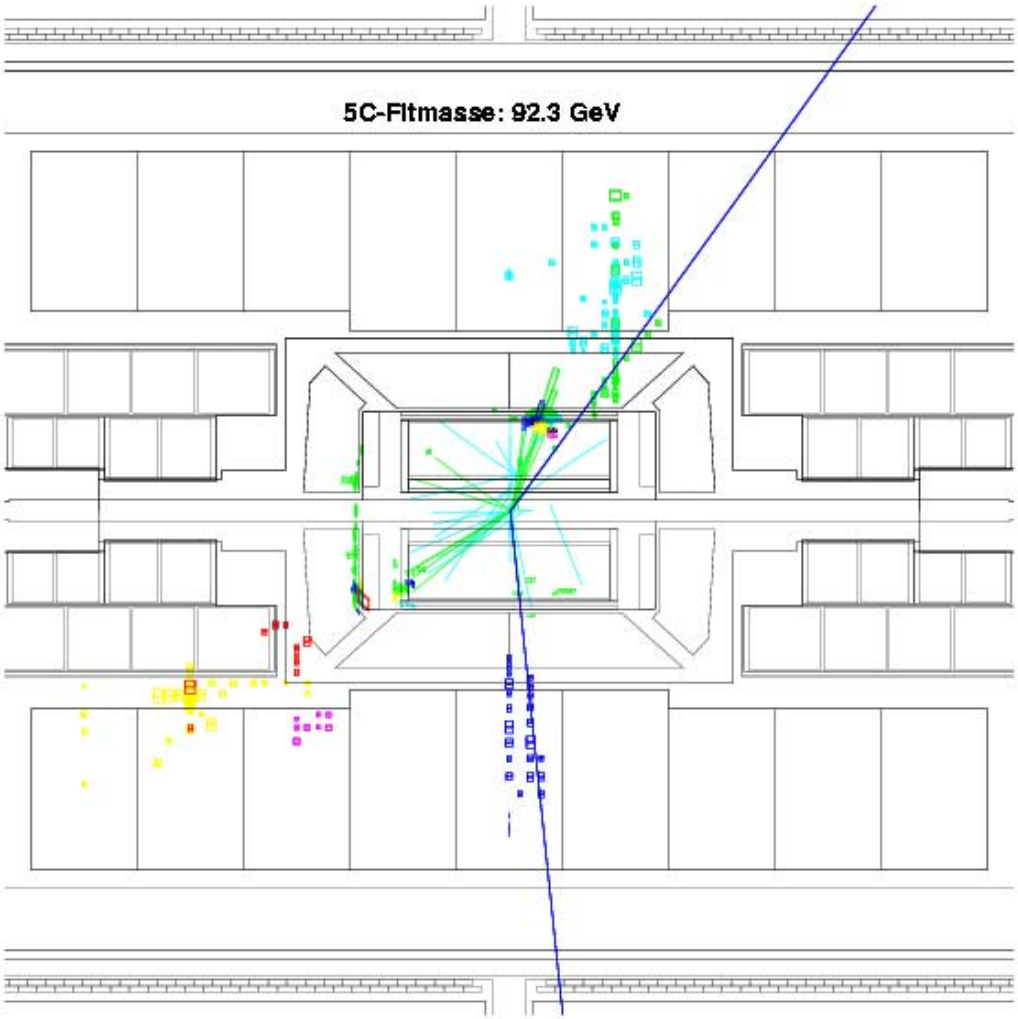
L3: $ZZ \rightarrow qq\mu\mu$

$M_{qq} = M_{\mu\mu} = M_{fit} =$ 92.3 GeV



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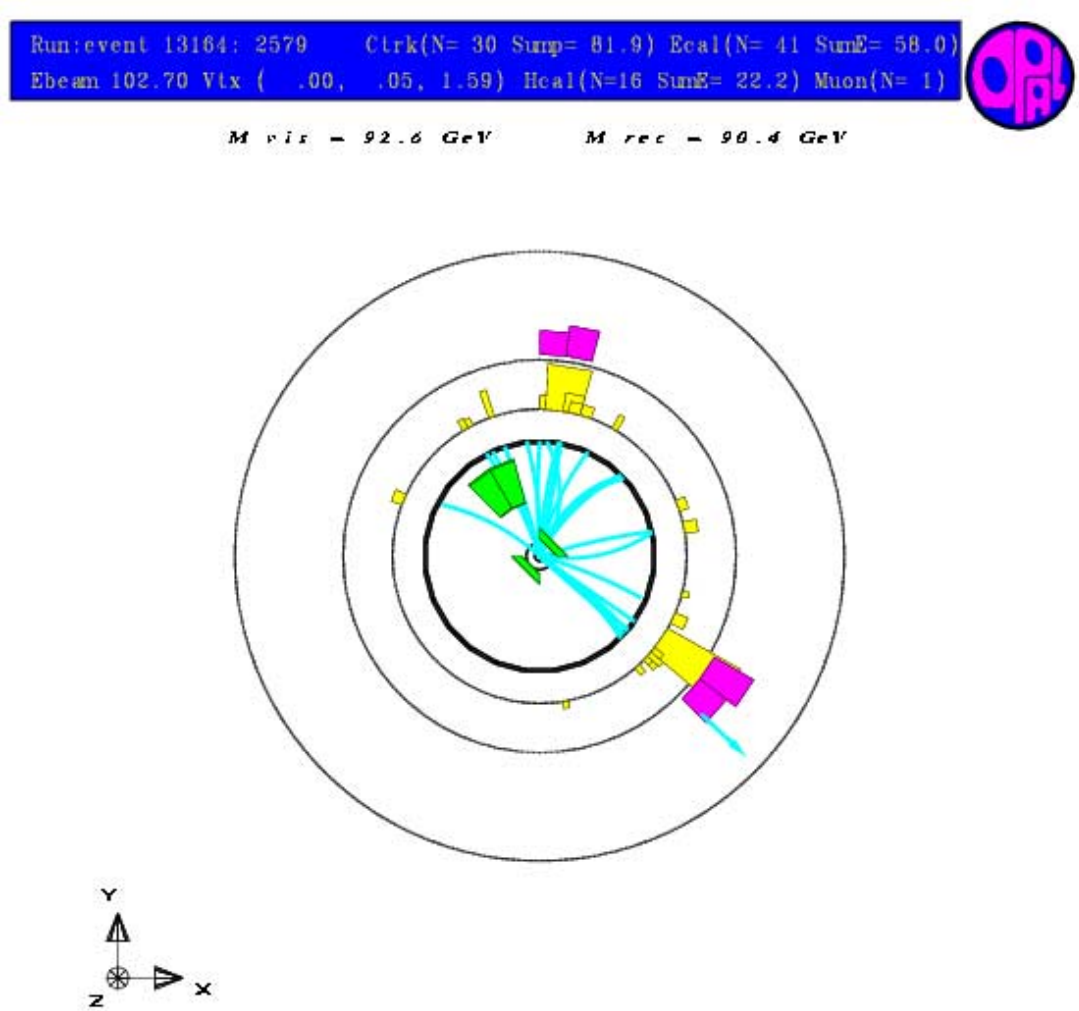
Opal: $ZZ \rightarrow qq\nu\nu$ at $\sqrt{s} = 205$ GeV

M_{vis} = 92.6 GeV

M_{rec} = 90.4 GeV



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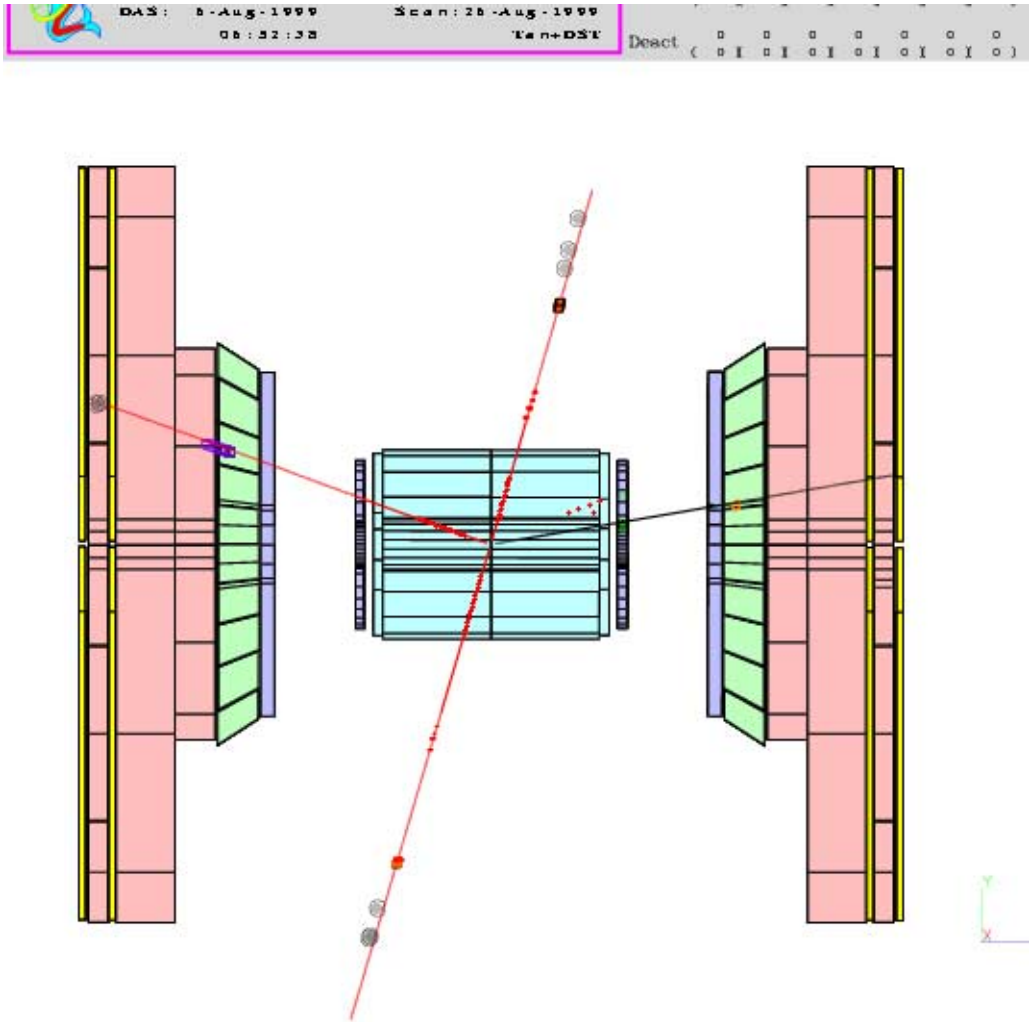
Delphi: $ZZ \rightarrow llll$ at $\sqrt{s} = 200$ GeV

$ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-$



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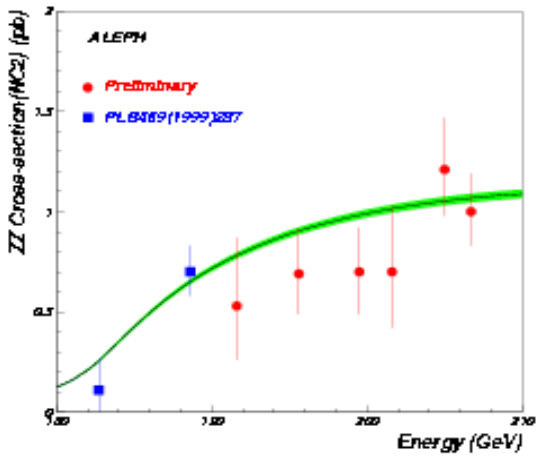
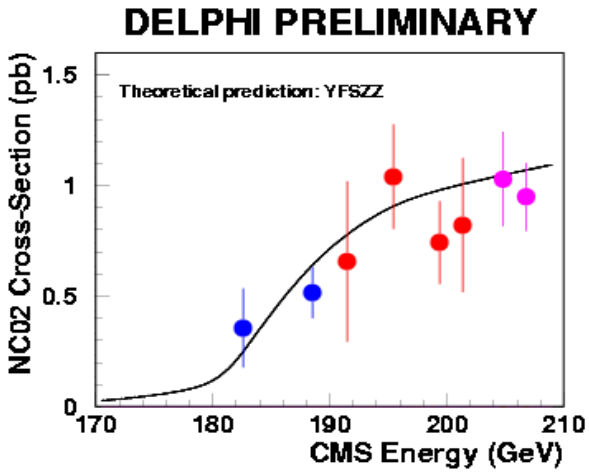
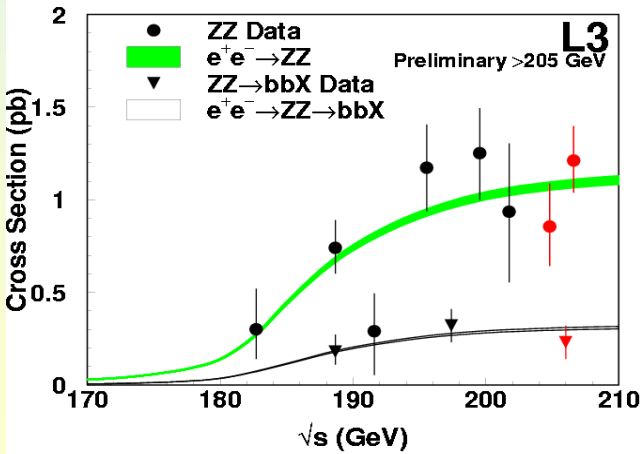
Cross section for ZZ production

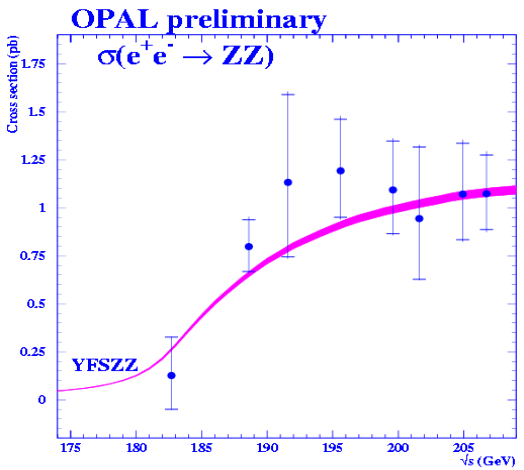
Determination of σ_{ZZ} from a global likelihood fit, including all channels,

- Binned discriminant variable (qqqq, qqνν)
- Poisson probabilities of number of events observed and expected (qqll, llll, llνν)









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Cross section for ZZ production
LEP Combination

σ_{ZZ} from each experiment combined using symmetrized expected statistical errors

Systematic errors:

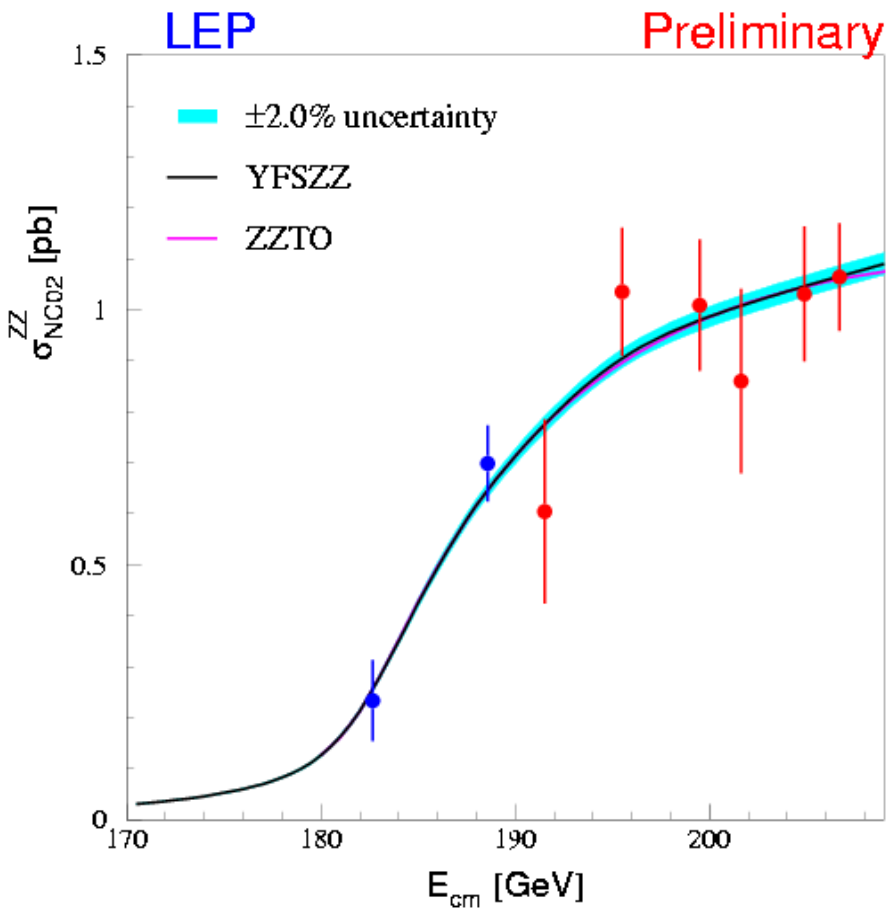
Correlated: 0.01-0.07 pb

- Uncertainty on backgrounds (qq, WW, Zee, Wev),
- Uncertainty on b-quark modelling.

Uncorrelated:

- Detector,
- Selection procedures (jet kine., lepton id effic.,…)
- Limited MC statistics,...

Very good agreement with SM!



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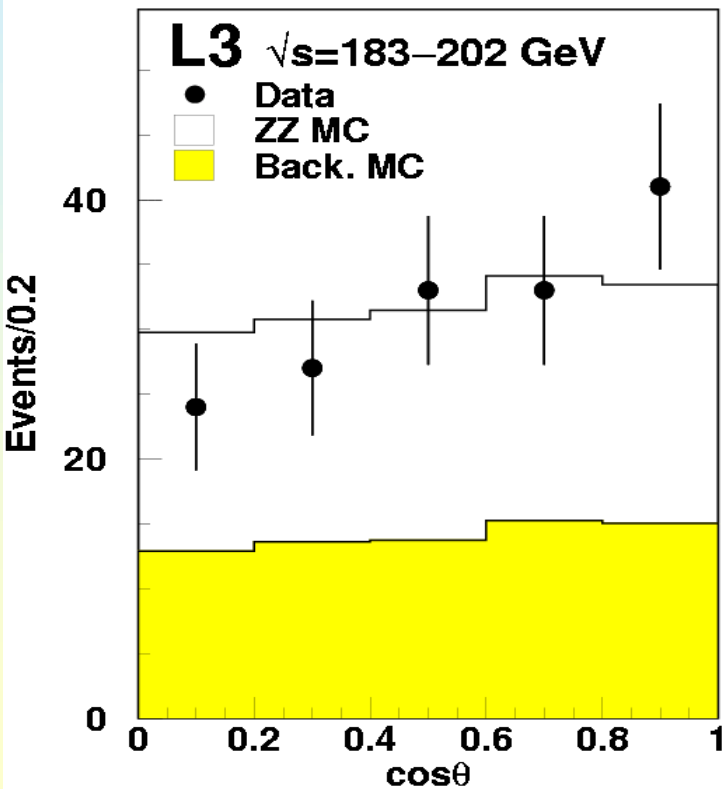
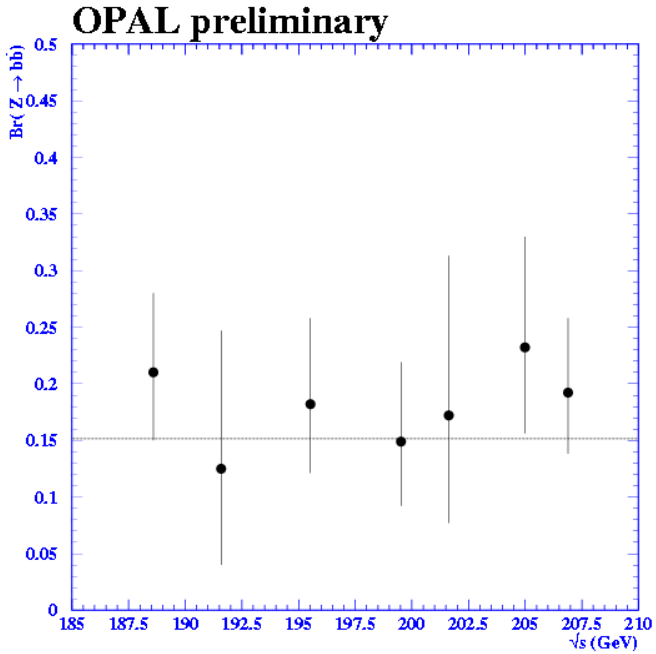
Results from ZZ production

Z Production polar angle, θ





Br ($Z \rightarrow bb$) determination

0.196 ± 0.032

←Lep1 result:

0.151 ± 0.001

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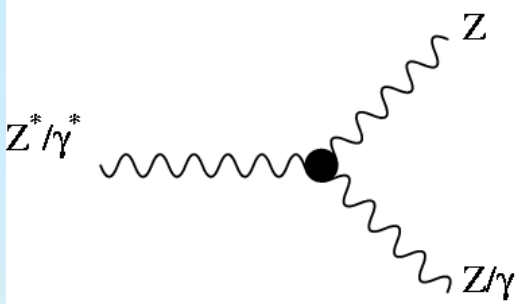
Neutral Anomalous Couplings



Couplings are zero are tree level in SM; at 1 loop, ~10^{-4} (below experimental sensitivity).

New physics may modify SM rates.

Possible deviations from SM can be quantified in terms of an effective Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\left(\sum_i h_i O_i + f_i O_i'\right)$$

Vertex parametrization: Lorentz, gauge $U(1)_{em}$ invariance, Bose symmetry

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

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

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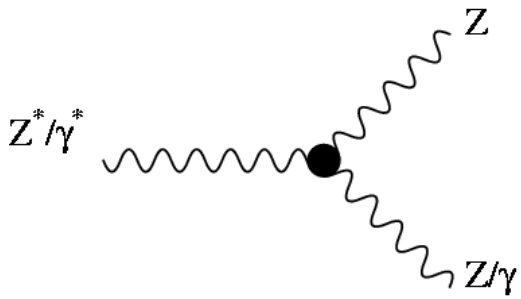
Neutral Anomalous Couplings



2 independent sets of neutral couplings, depending on final state vector bosons:

Final State	Coupling	Parameter (V=Z, γ)
ZZ	ZZ*Z	f_4^V, f_5^V
	Zγ*Z	
Zγ	ZZ*γ	h_1^V, h_2^V, h_3^V, h_4^V
	Zγ*γ	

f_4, h_1, h_2: CP violating, no interference with SM

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

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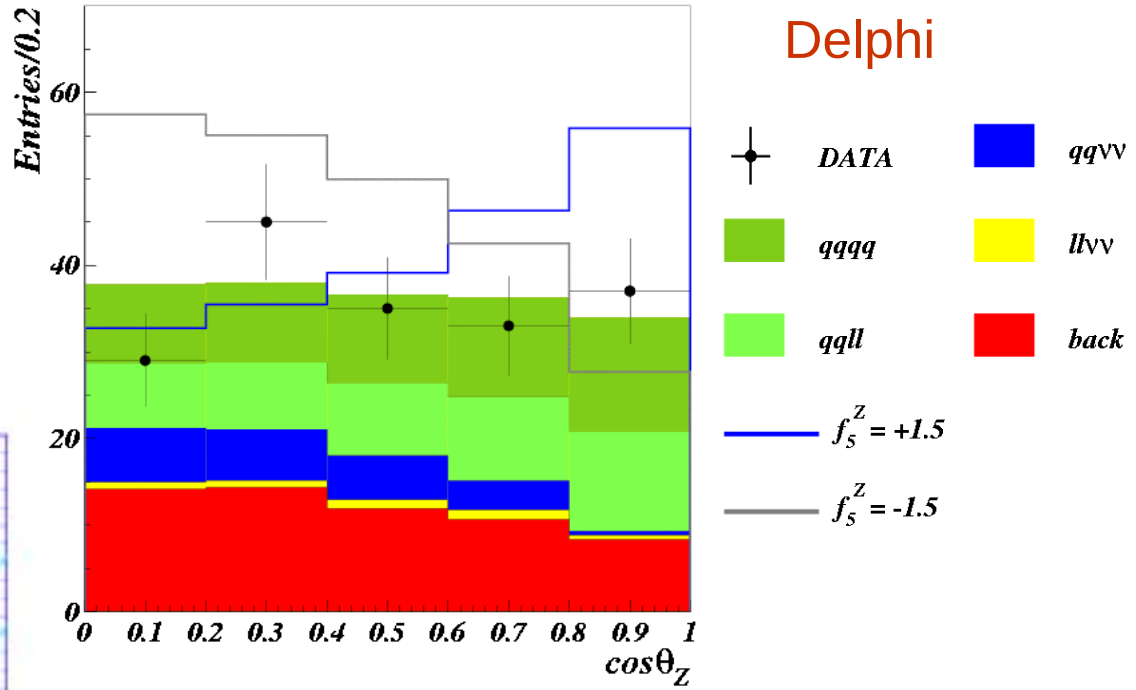
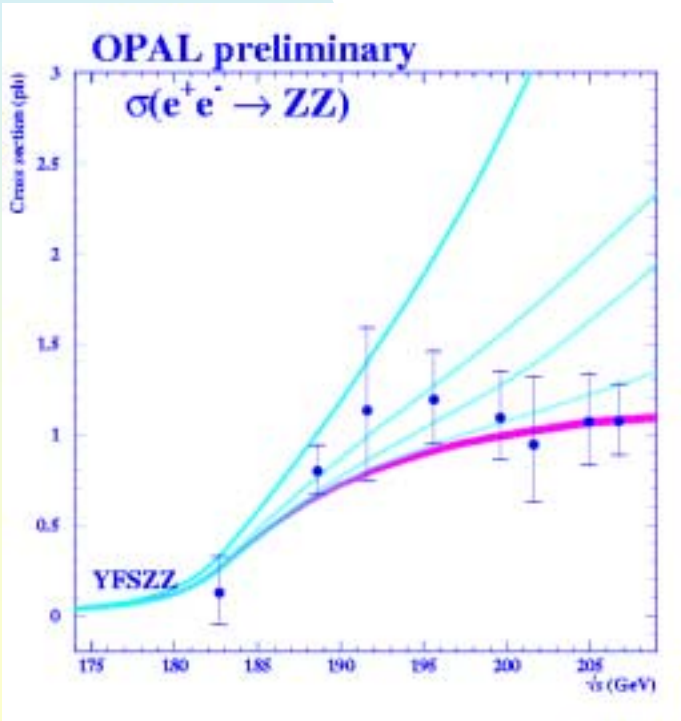
Neutral Anomalous Couplings Signatures

Change in polar angle distribution of Z boson





σ_{ZZ} Enhancement

$f_4^{ZZ\gamma} = 1.0$ $f_5^{ZZ\gamma} = 1.0$

$f_4^{ZZZ} = 1.0$ $f_5^{ZZZ} = 1.0$

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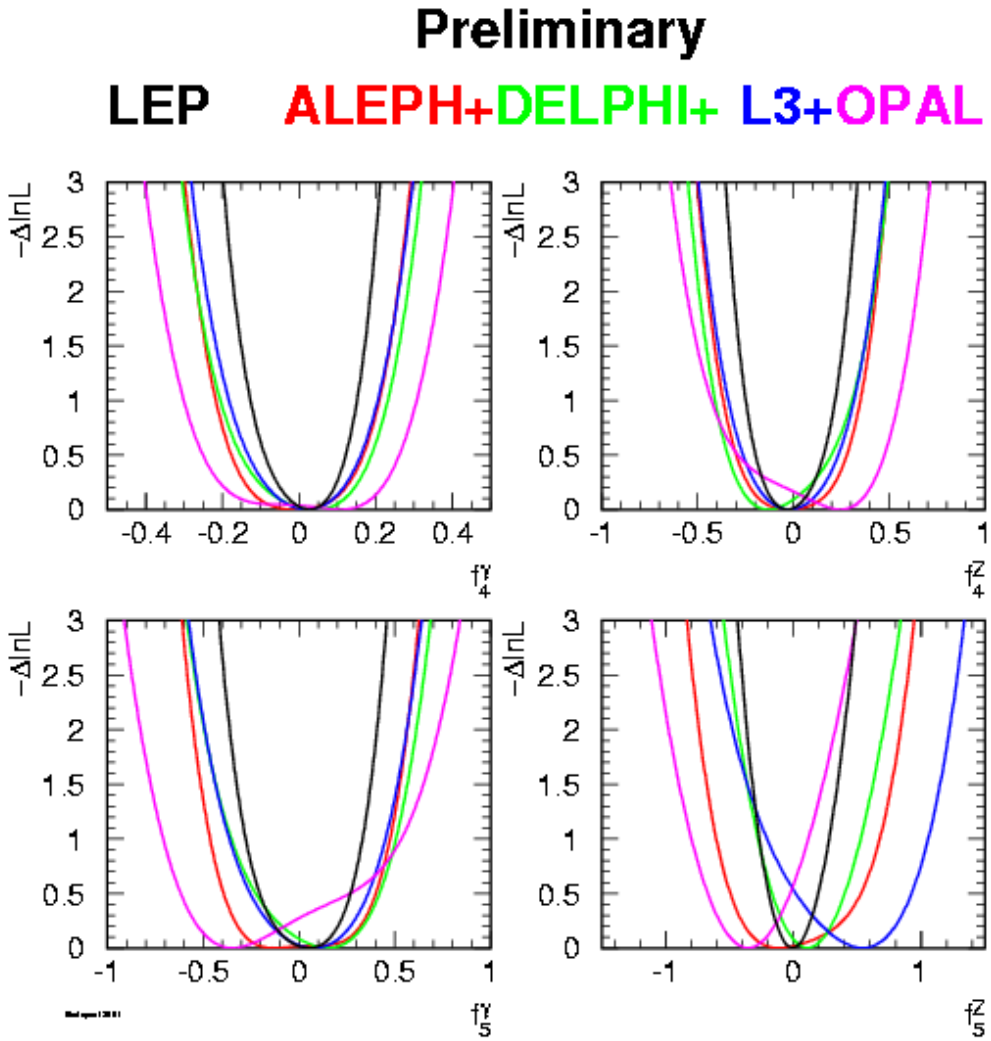
Neutral Anomalous Couplings Limits

Measured ZZ production agrees with SM $\Rightarrow$ no evidence of AC, but set limits on them.

1-d fit

Parameter	95 (%) CL Limits
f_4^γ	[-0.17, +0.19]
f_4^Z	[-0.31, +0.28]
f_5^γ	[-0.36, +0.40]
f_5^Z	[-0.36, +0.39]



1 parameter different from zero at a time.

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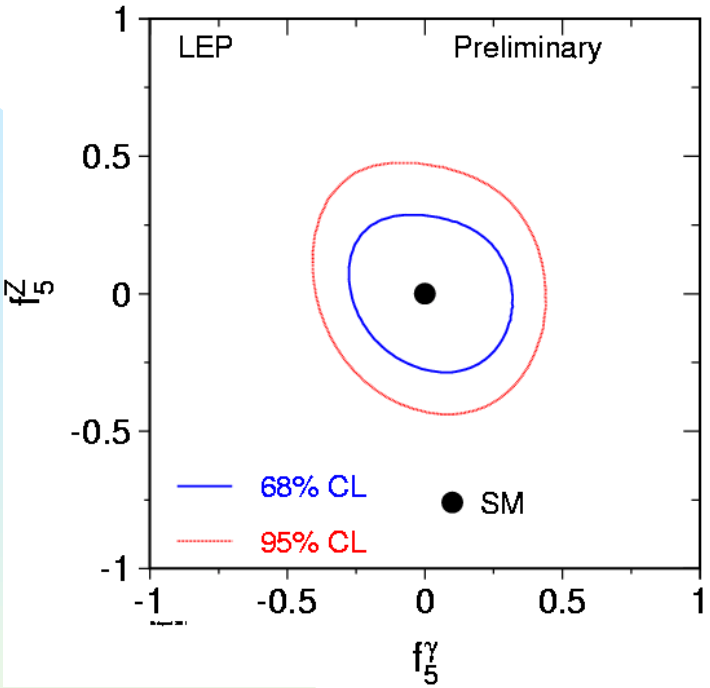
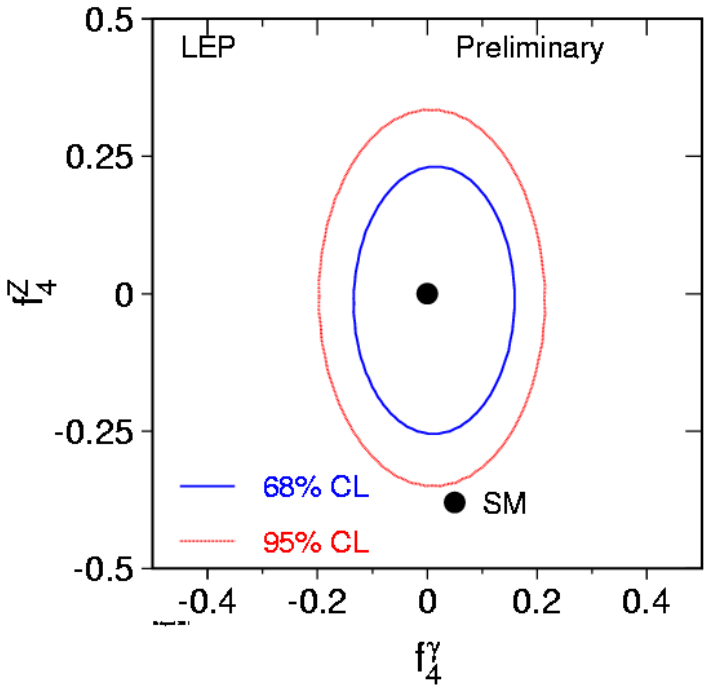
Neutral Anomalous Couplings Limits





2-d fits

2 parameters different from zero at a time.

Parameter	95 (%) CL Limits	Correlations
f_4^γ	[-0.17, +0.19]	1.00 +0.10
f_4^Z	[-0.30, +0.28]	+0.10 1.00
f_5^γ	[-0.34, +0.38]	1.00 -0.18
f_5^Z	[-0.36, +0.38]	-0.18 1.00

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Conclusions

The Standard Model has proved, once more, to work very satisfactorily

- σ_{ZZ} measured agrees with expected,
- no ZZZ, ZZγ anomalous couplings observed, set limits ($|f| \sim 0.3$)

LEP2 has shown to be consistent with LEP1

- Z pair production depends on properties measured at LEP1 ➔ Br($Z \rightarrow bb$)

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