W,Z couplings and cross-sections at LEP2

- WW cross-section and Branching Ratios
- Single W cross-section
- Trilinear Gauge Coupling
- ZZ cross-section
- ZZZ and ZZγ Anomalous coupling

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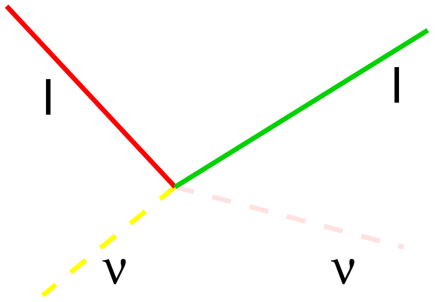
(L3 Collaboration)

W pair identification at LEP2

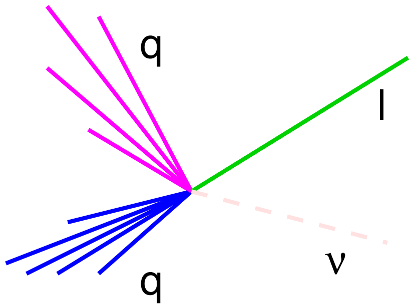


2 acoplanar leptons and large missing energy

photon veto against di-lepton events

efficiency $\simeq$ 64%, σ_{BG} $\simeq$96 fb

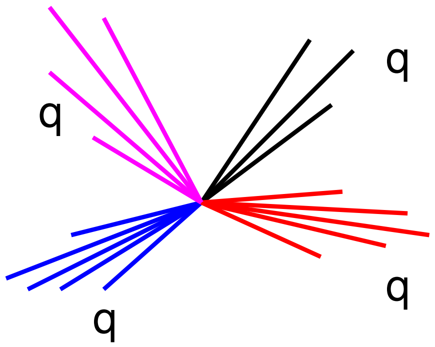
main BG: $\gamma\gamma \rightarrow ll$, $ZZ \rightarrow ll\nu\nu$



1 isolated lepton, 2 jets, missing energy

efficiency (e,μ,τ) $\simeq$ 84,86,65%, σ_{BG} $\simeq$150,60,340 fb

main BG: $Z/gamma \rightarrow q\bar{q}(\gamma)$, ZZ



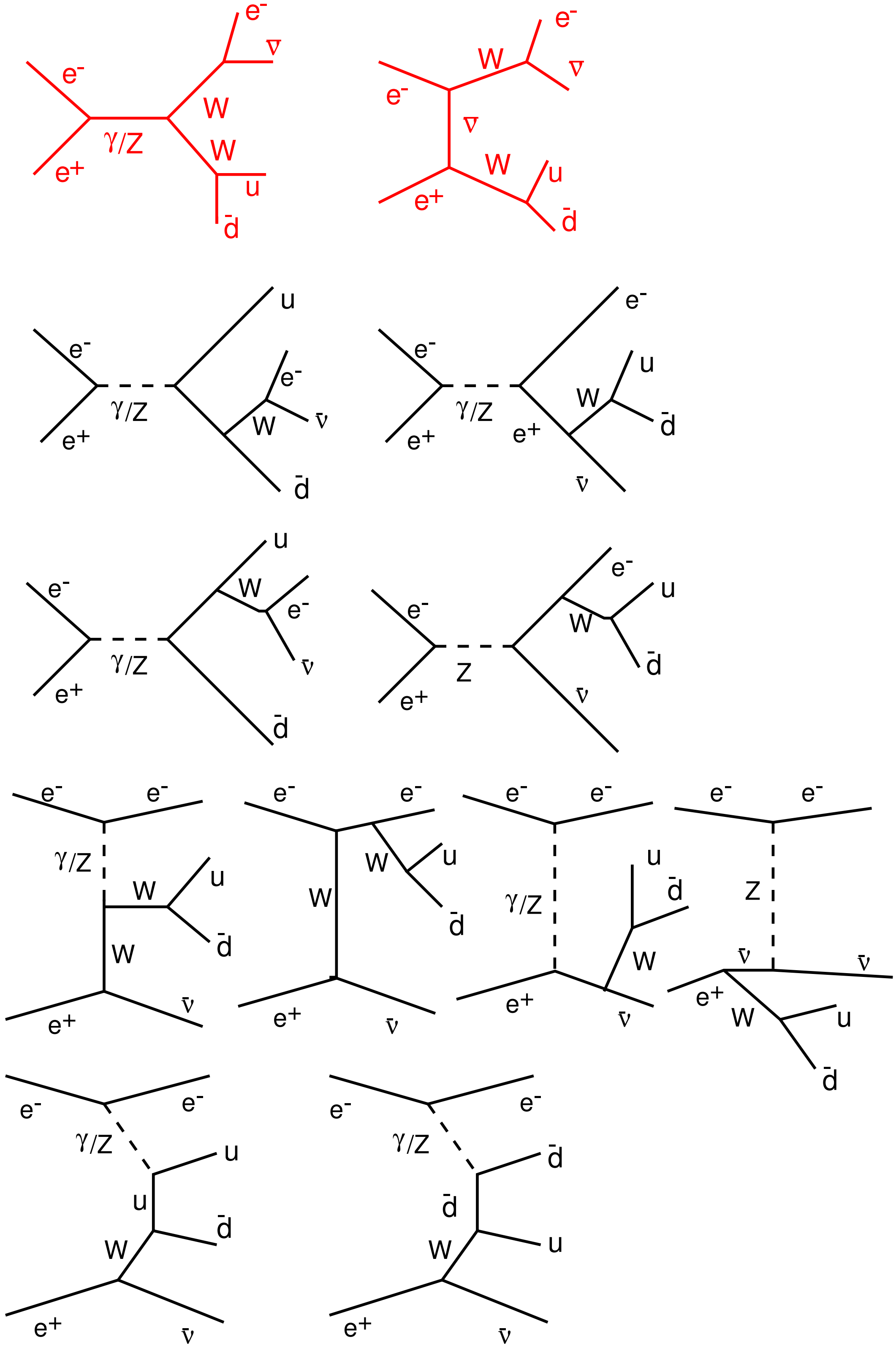
Preselection for high multiplicity and full energy

NN based on topological and kinematic variables

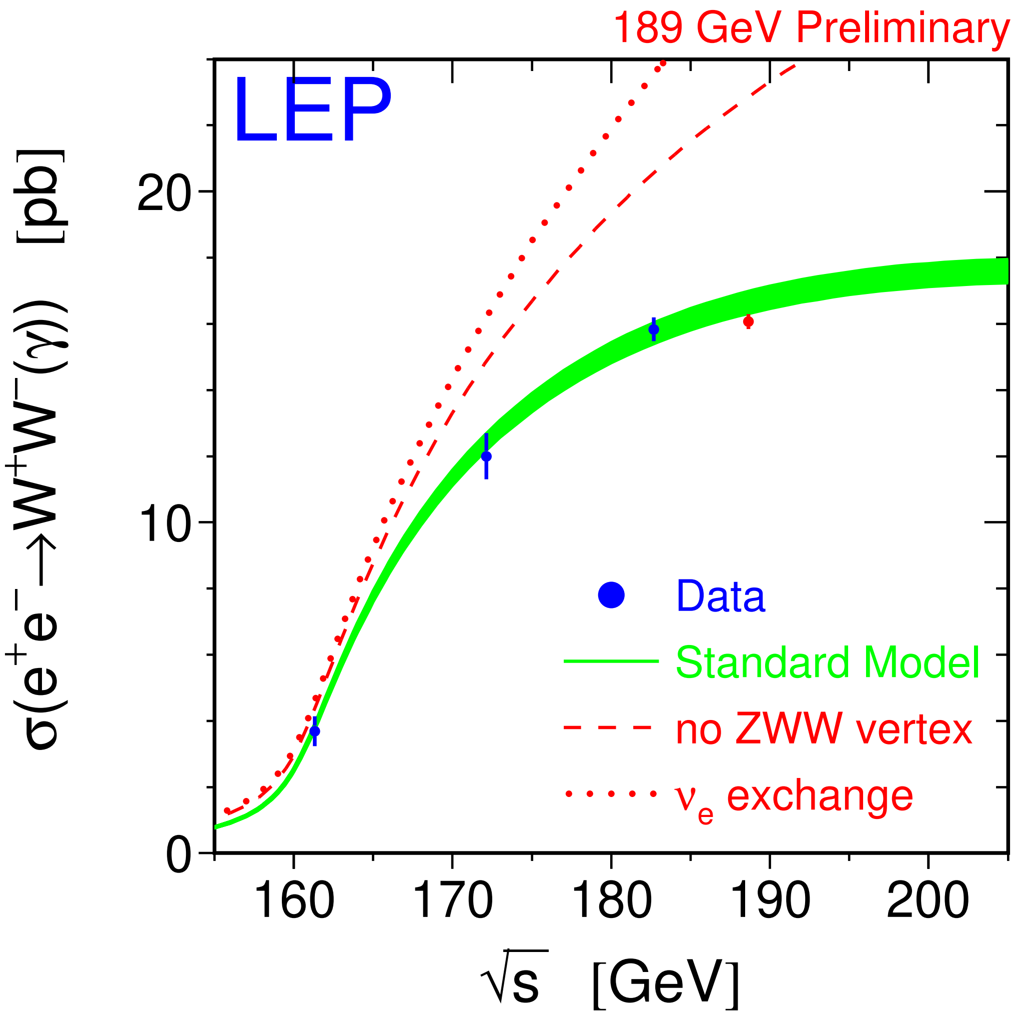
NN cut $\rightarrow$ efficiency $\simeq$ 87.5%, σ_{BG} $\simeq$1.46 pb

main BG: $Z/gamma \rightarrow q\bar{q}(\gamma)$, ZZ

WW versus 4-fermions production

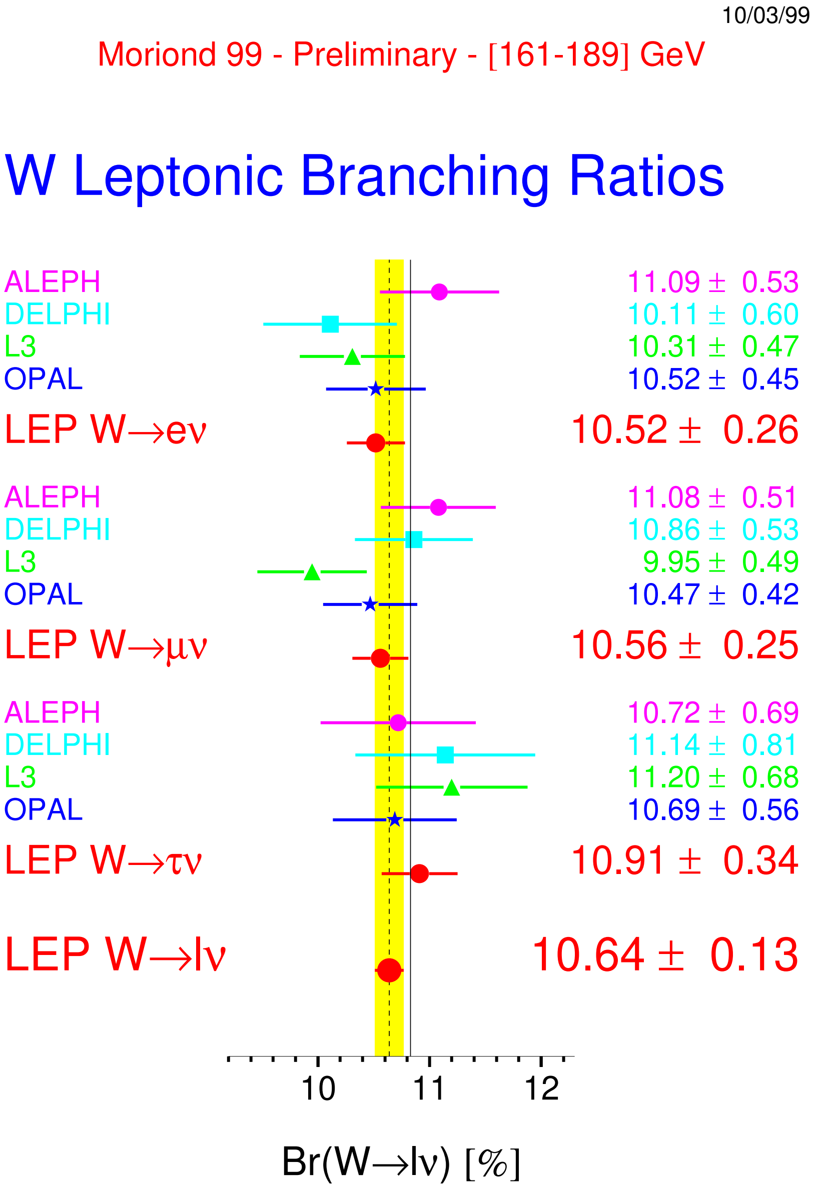


WW Cross-section

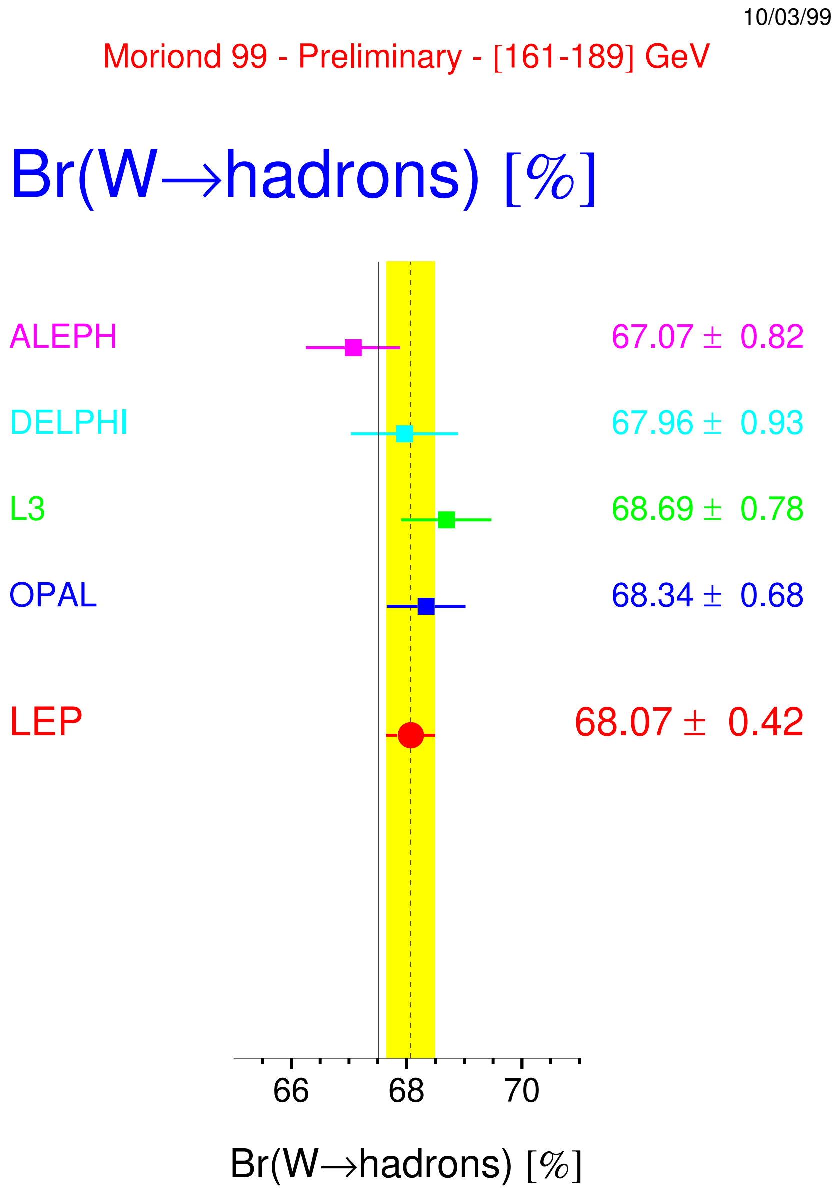


Cross-section σ_{CC03} (pb)		
Experiment	$\sqrt{s}$ =183 GeV	$\sqrt{s}$ =189 GeV
ALEPH	15.57 ± 0.68^n	*15.64 ± 0.43*
DELPHI	15.86 ± 0.74^n	*15.79 ± 0.49*
L3	16.53 ± 0.72^p	*16.20 ± 0.46*
OPAL	15.43 ± 0.66^p	*16.55 ± 0.40*
LEP	15.83 ± 0.36	*16.07 ± 0.23*
SM	*15.70 ± 0.31*	*16.65 ± 0.33*
^{p} **Published** ^{n} **New** *Preliminary*		

W Branching-Ratios



W Branching-Ratios



$$\frac{1}{1-B(W\to hadr.)} = 1 + \left(1 + \frac{\alpha_s(m_W)}{\pi}\right) \sum_{i=u,c\ j=d,s,b} |V_{i,j}|^2$$

with $\alpha_s(m_W^2)$**=**(0.121 ± 0.002) **we have:**

$$|V_{cs}| = (1.002 \pm 0.016_{stat} \pm 0.012_{syst})$$

Single W production

Preliminary results for $\sigma_{We\nu}(\sqrt{s} = 189\ GeV)$ from L3:

Signal Definition:

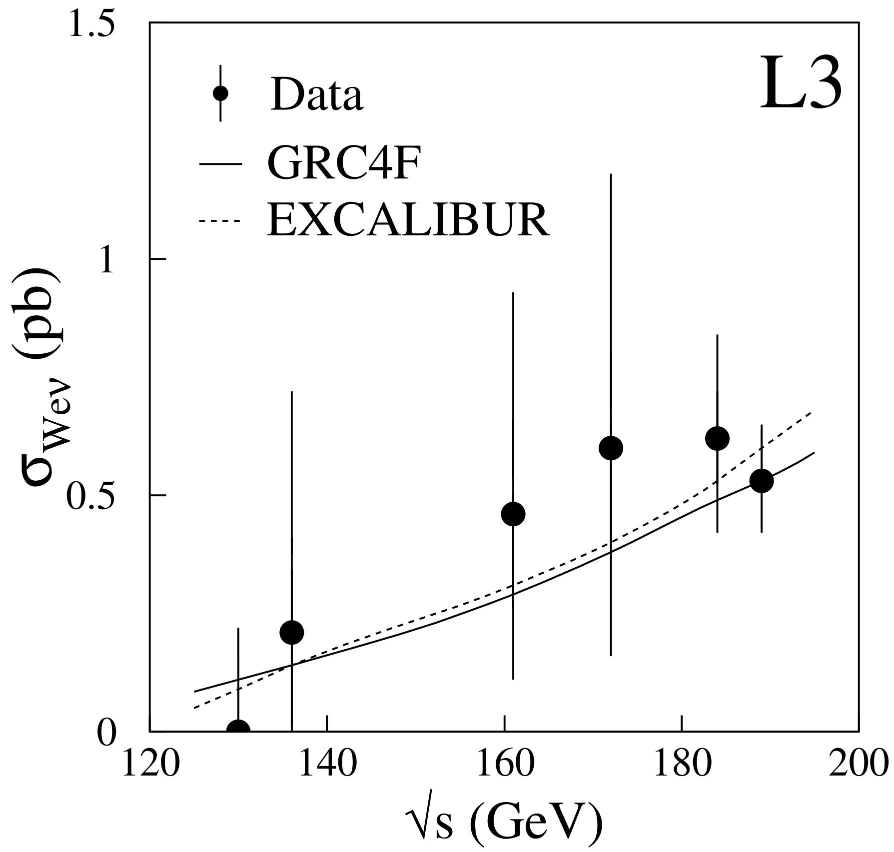
$|\cos\theta_{e^+}| > 0.997$

$min(E_f, E_{\bar{f}'}) > 15$ GeV

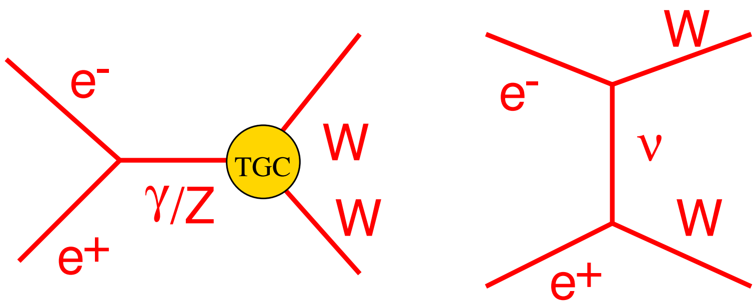
$|\cos\theta_{e^-}| < 0.75$, **for events $e^+\nu_e e^-\bar{\nu}_e$ only**

$$\sigma(e^+e^- \to We\nu) = (0.53^{+0.12}_{-0.11} \pm 0.03)\ \text{pb}$$

$$\sigma_{GRC4F} = 0.53\ \text{pb},\ \sigma_{EXC} = 0.60\ \text{pb}$$



Trilinear Gauge Coupling in WW events



The most general Lorentz-invariant WWγ and WWZ vertices give a Lagrangian with 7 + 7 = 14 parameters.

$$
\begin{aligned}
i\mathcal{L}_{eff}^{WWV} = g_{WWV}\Big(& g_1^V V^\mu (W^-_{\mu\nu} W^{+\nu} - W^+_{\mu\nu} W^{-\nu}) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \\
& + \frac{\lambda_V}{M_W^2} V^{\mu\nu} W^{+\rho}_\nu W^-_{\rho\mu} + i g_4^V W^-_\mu W^+_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) + \\
& + i g_5^V \varepsilon_{\mu\nu\rho\sigma}\big((\partial^\rho W^{-\mu}) W^{+\nu} - W^{-\mu}(\partial^\rho W^{+\nu})\big) V^\sigma + \\
& - \frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - \frac{\tilde{\lambda}_V}{2M_W^2} W^-_{\rho\mu} W^{+\mu}_\nu \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}\Big)
\end{aligned}
$$

with $g_{WW\gamma} = e$, $g_{WWZ} = e\cot\theta_W$, $W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$, **and** $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$.

κ_γ, κ_Z, g_1^Z, λ_γ, λ_Z **are C and P conserving.**

(These terms in the WWγ coupling correspond to the lowest terms of a multipole expansion of the W-photon interaction:

$Q_W = e g_1^\gamma$, $\mu_W = \frac{e}{2M_W}(g_1^\gamma + \kappa_\gamma + \lambda_\gamma)$, $q_W = -\frac{e}{M_W^2}(\kappa_\gamma - \lambda_\gamma)$ **)**

Trilinear Gauge Coupling in WW events

We introduce deviations from the Standard Model:

$$\Delta g_1^Z = (g_1^Z - 1),\ \Delta\kappa_\gamma = (\kappa_\gamma - 1),\ \Delta\kappa_Z = (\kappa_Z - 1),\ \lambda_\gamma,\ \lambda_Z\ .$$

To reduce further these parameters, we consider a SU(2)×U(1) gauge-invariant Lagrangian of dimension d=6. Some of these couplings would affect the bosons propagators, others give anomalous Higgs coupling, only 3 remain:

$$\mathcal{L} = ig' \frac{\alpha_{B\phi}}{M_W^2}(D_\mu\Phi)^+ B^{\mu\nu}(D_\nu\Phi) + ig\frac{\alpha_{W\phi}}{M_W^2}(D_\mu\Phi)^+ \vec{T} \cdot \vec{W}^{\mu\nu}(D_\nu\Phi) + \\ + g\frac{\alpha_W}{6M_W^2}\vec{W}_\nu^\mu \cdot (\vec{W}_\rho^\nu \vec{W}_\nu^\rho).$$

which give:

$$\Delta g_1^Z = \frac{\alpha_{W\phi}}{\cos^2\theta_W},$$

$$\Delta\kappa_\gamma = \frac{\cos^2\theta_W}{\sin^2\theta_W}(\Delta\kappa_Z - \Delta g_1^Z) = \alpha_{W\phi} + \alpha_{B\phi},$$

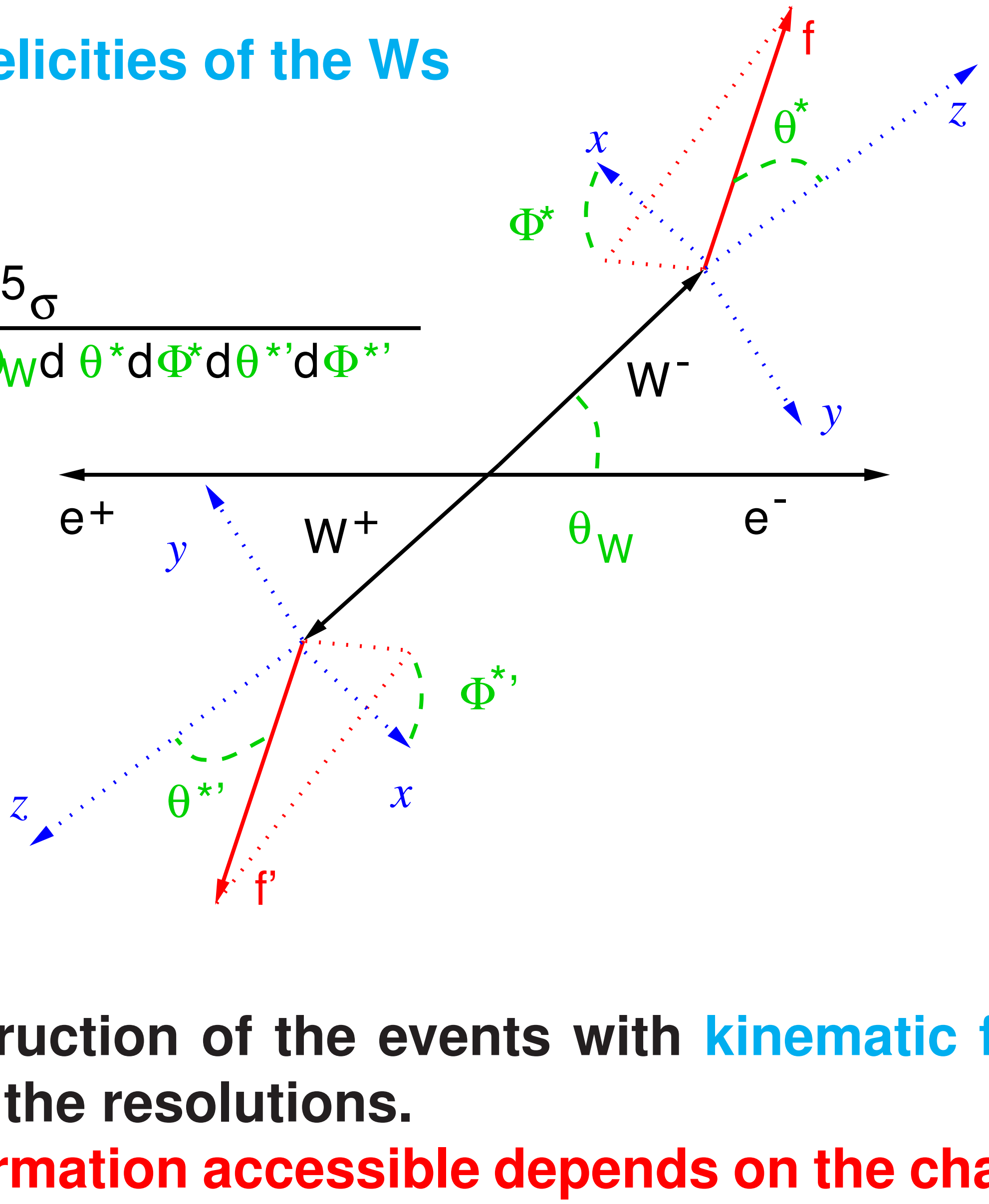
$$\lambda_\gamma = \lambda_Z = \alpha_W$$

Trilinear Gauge Coupling in WW events

The anomalous coupling affects:

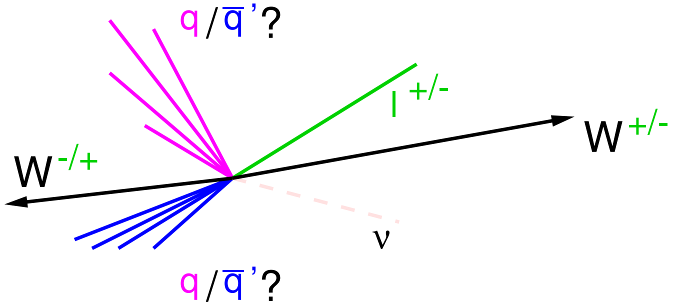
- **the total cross-section σ_{WW}**
- **the W production angle**
- **the helicities of the Ws**

$$\frac{d^5\sigma}{d\,\theta_W\, d\,\theta^*\, d\Phi^*\, d\theta^{*\prime}\, d\Phi^{*\prime}}$$



Reconstruction of the events with kinematic fits to improve the resolutions.
The information accessible depends on the channel: qqqq, qq$l\nu$, $l\nu l\nu$.

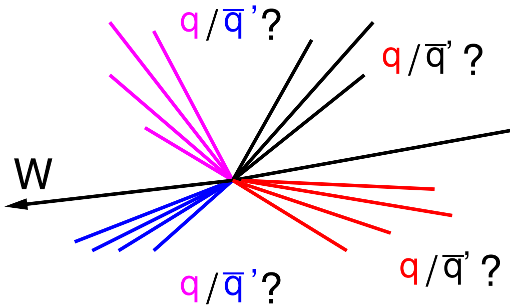
Trilinear Gauge Coupling in WW events



$\boldsymbol{cos\theta_{W^-}}$, $\boldsymbol{cos\theta^*_{l}}$, ϕ^*_{l}, $\boldsymbol{cos\theta^*_{jet}}$, ϕ^*_{jet},

$(\boldsymbol{cos\theta^*_{jet}}, \phi^*_{jet}) \leftrightarrow (-\boldsymbol{cos\theta^*_{jet}}, \phi^*_{jet} + \pi)$

jet-charge or flavour tagging could be used to resolve this ambiguity

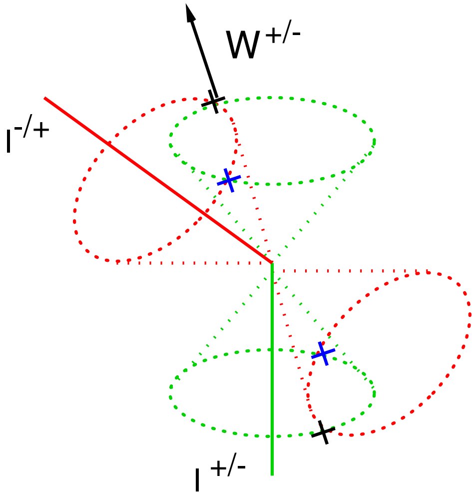


$\boldsymbol{cos\theta_{W^-}}$, $\boldsymbol{cos\theta^*_{jet}}$, ϕ^*_{jet}, $\boldsymbol{cos\theta^*_{jet'}}$, $\phi^*_{jet'}$

kin. fit and jet-charge are used for jet $\rightarrow$ to Ws

jet-charge is used for W^- charge assignement

$(\boldsymbol{cos\theta^*_{jet}}, \phi^*_{jet}) \leftrightarrow (-\boldsymbol{cos\theta^*_{jet}}, \phi^*_{jet} + \pi)$ **and jet'**

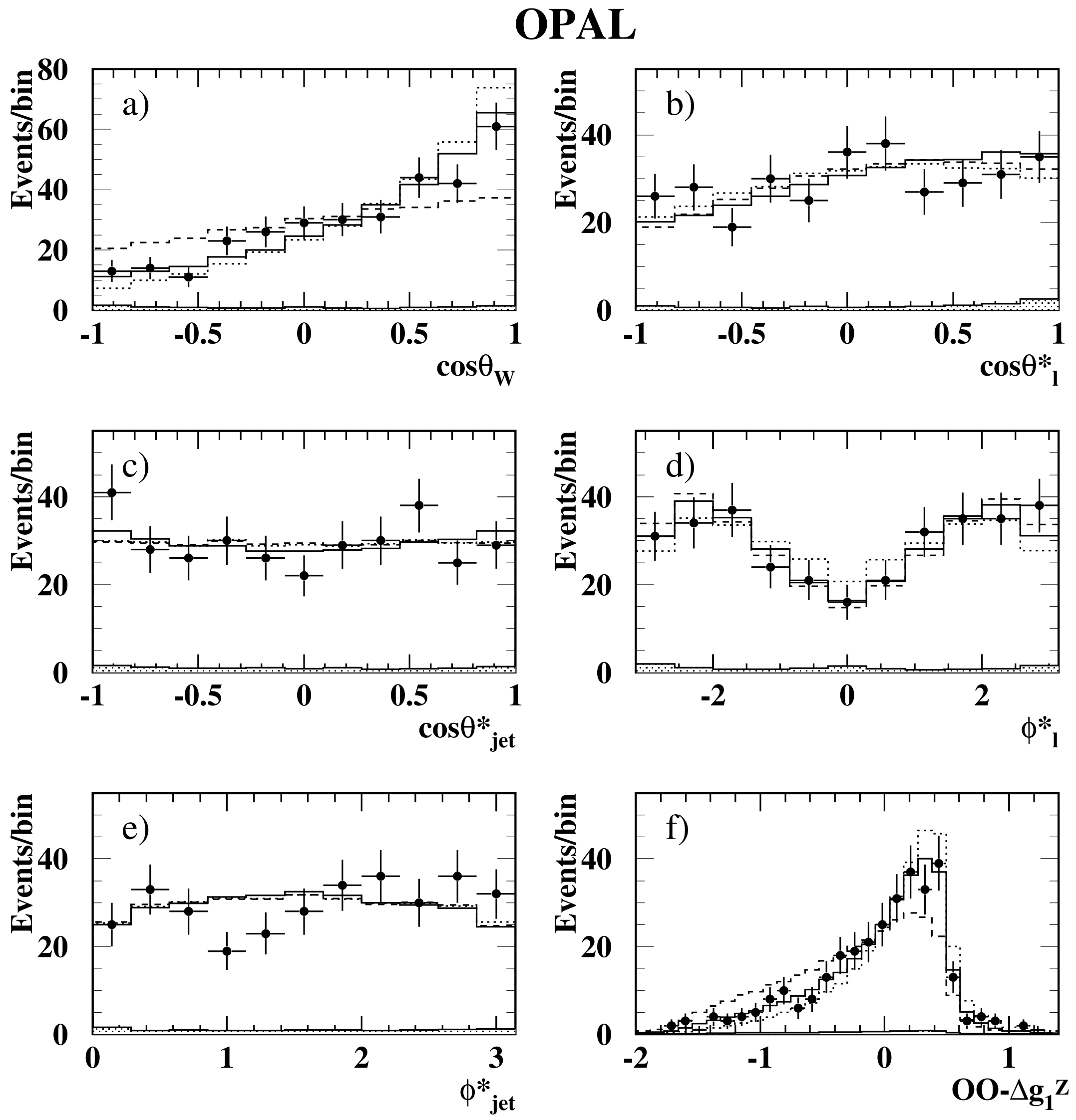


$\boldsymbol{cos\theta_{W^-}}$, $\boldsymbol{cos\theta^*_{l}}$, ϕ^*_{l}, $\boldsymbol{cos\theta^*_{l'}}$, $\phi^*_{l'}$

NO-ISR and small-width approximation allows angle reconstruction

$(\boldsymbol{cos\theta_{W^-}}, \phi^*_{l}, \phi^*_{l'})$ **2 solutions**

Variables used in TGC Analysis



Optimal Observables

The Optimal Observables Analysis projects the 5 observables of the events into 1 variable only:

$$OO_i^{\alpha} = \frac{1}{\sigma_i^{SM}} \left(\frac{d\sigma_i(\alpha)}{d\alpha} \right)_{\alpha=0}$$

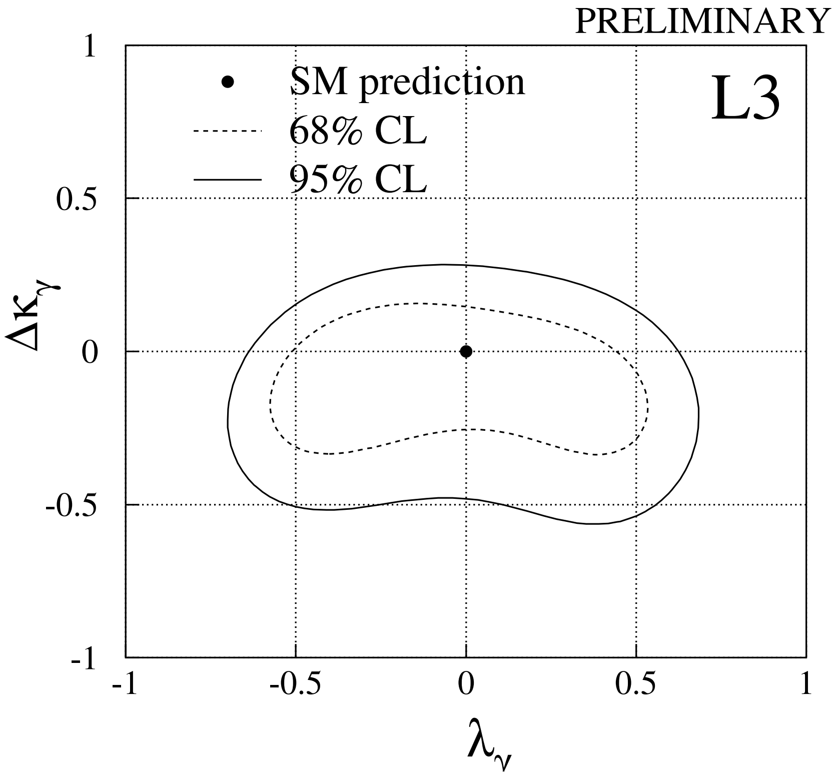
$$\sigma_i(\alpha) = \left(\frac{d\sigma(\Omega, \alpha)}{d\Omega} \right)_{\Omega=\Omega_i}$$

For cross-sections linear in the parameters to be fitted, the sensitivity of the OO is the same as a multi-dimensional fit.

(Phys. Lett. B306 (1993) 219; Z. Phys. C62 (1994) 397)

Trilinear Gauge Couplings from Single W

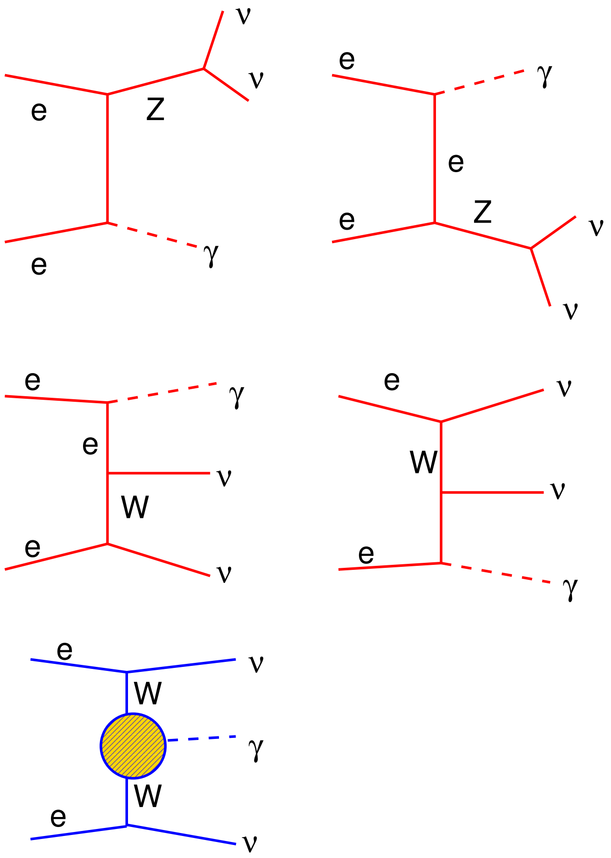
Maximal sensitivity to WWγ couplings: $\Delta\kappa_\gamma$, λ_γ

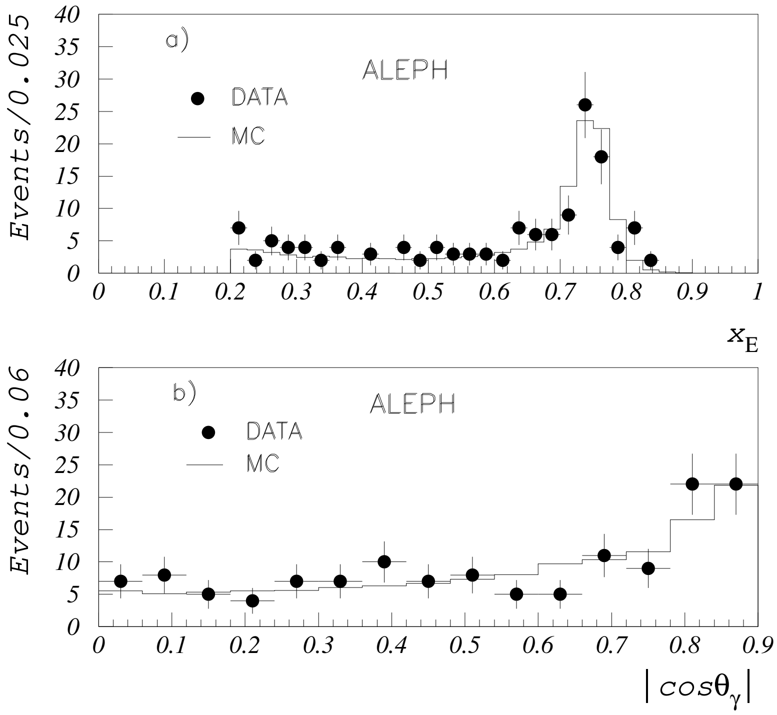


$$-0.42 \leq \Delta\kappa_\gamma \leq 0.22 \quad -0.64 \leq \lambda_\gamma \leq 0.61$$

(L3 95%CL Preliminary)

Trilinear Gauge Couplings from single photon



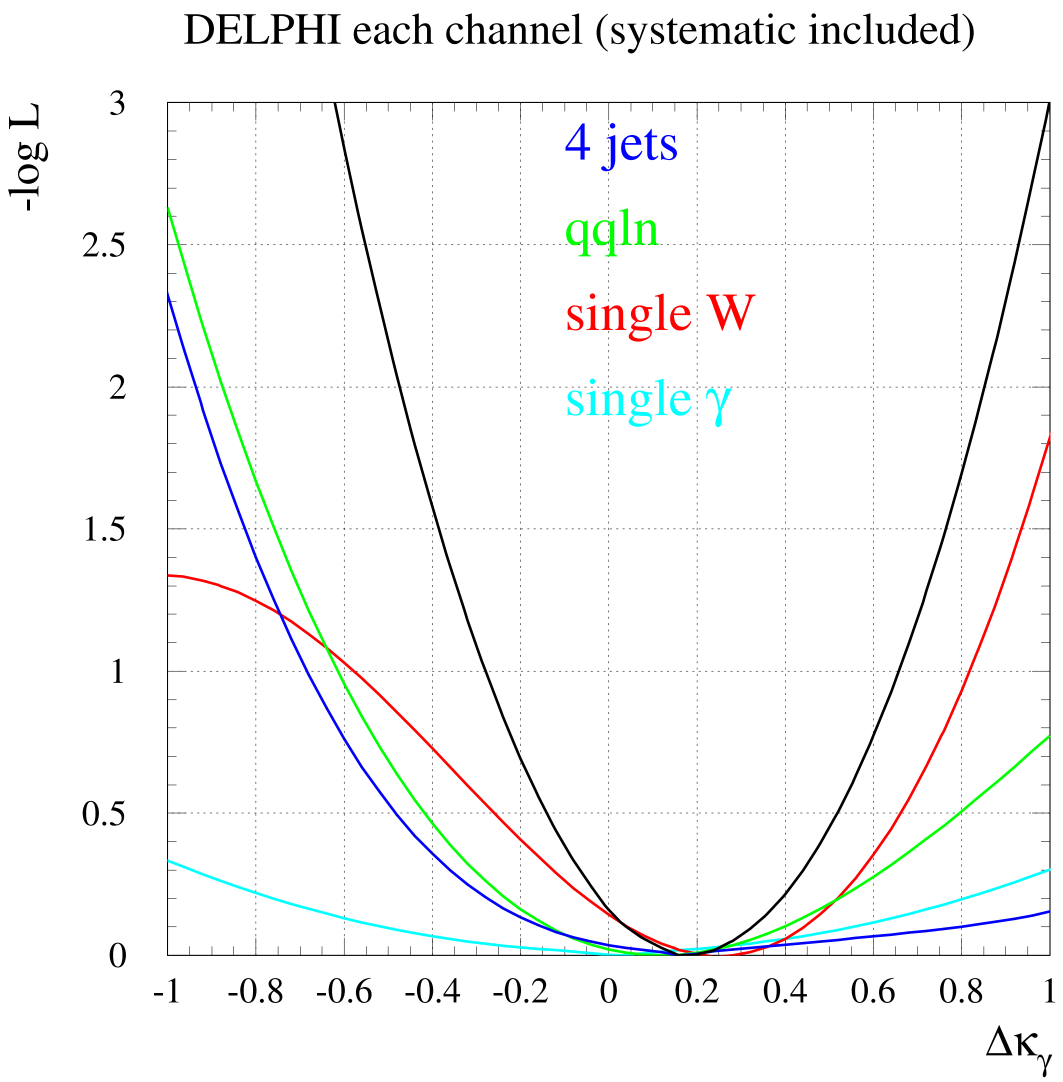


A global fit is performed to the total number of events and the angular and energetic γ spectra. The analysis of data from 161 to 183 GeV gives:

$$-2.1 \leq \Delta\kappa_\gamma \leq 2.2 \qquad -3.0 \leq \lambda_\gamma \leq 3.1$$

(ALEPH 95%CL)

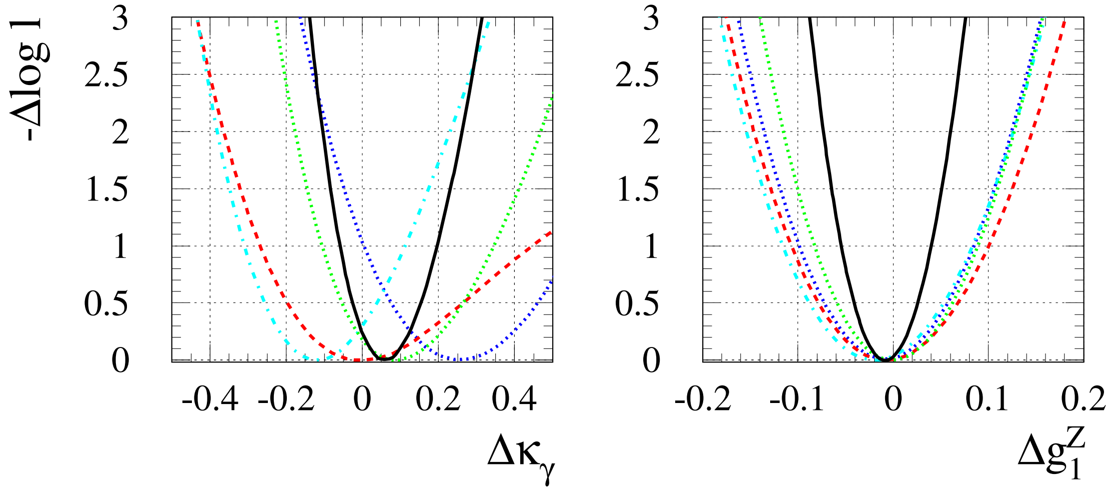
Trilinear Gauge Couplings

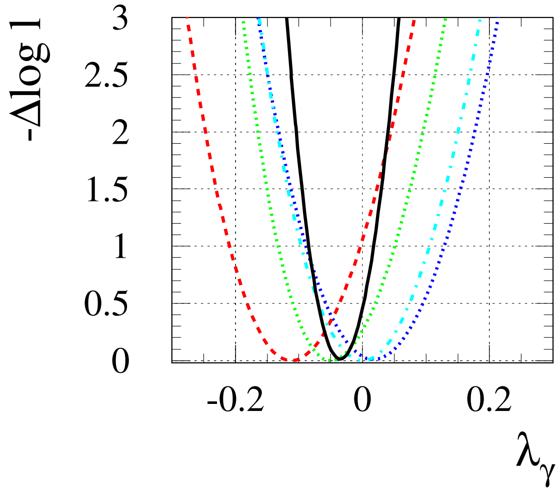


(DELPHI 183 GeV New)

Trilinear Gauge Coupling Results

ALEPH + DELPHI + L3 + OPAL



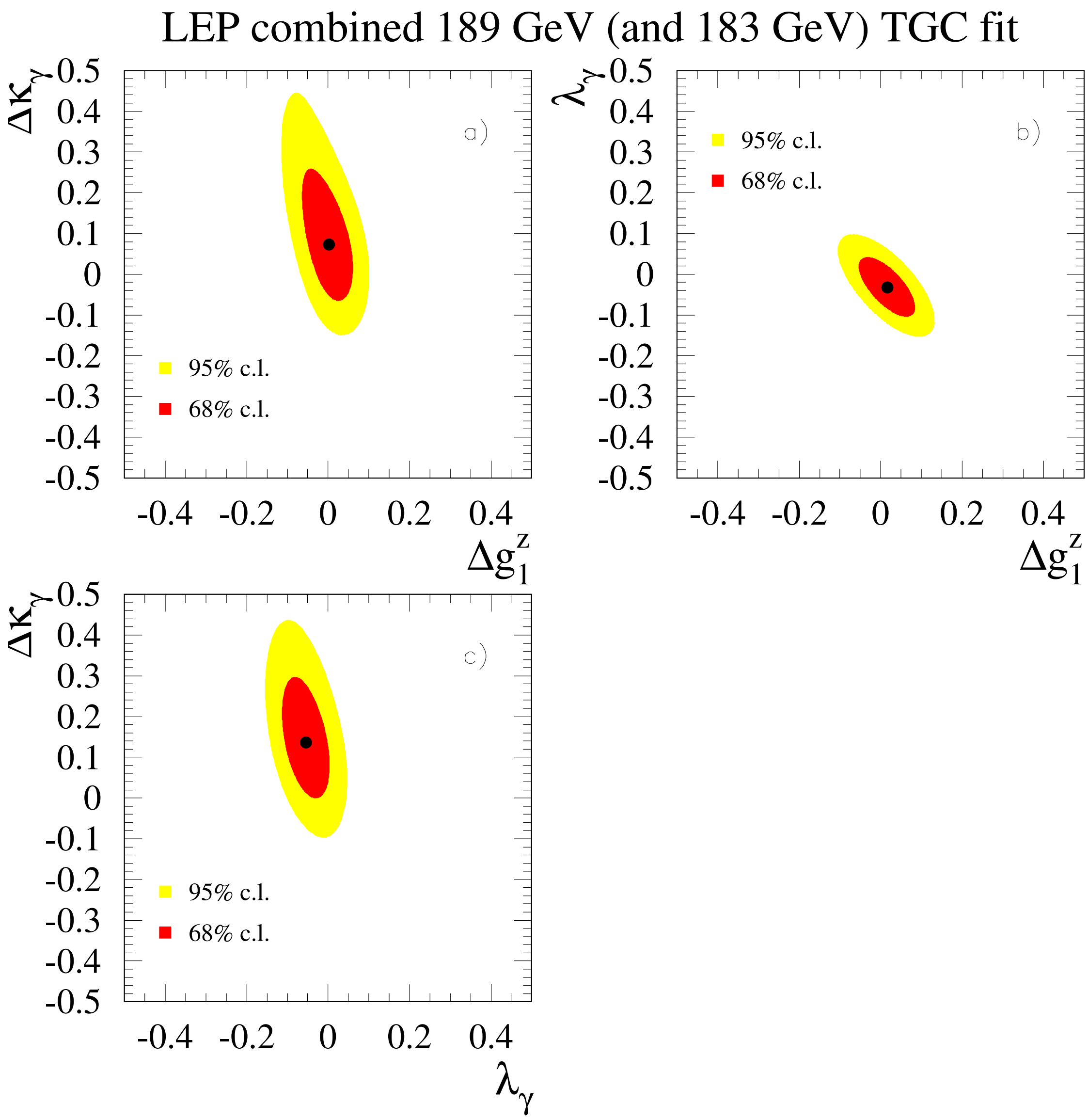


$$\Delta\kappa_\gamma = 0.06^{+0.09}_{-0.09}$$

$$\Delta g_1^Z = -0.01^{+0.03}_{-0.03}$$

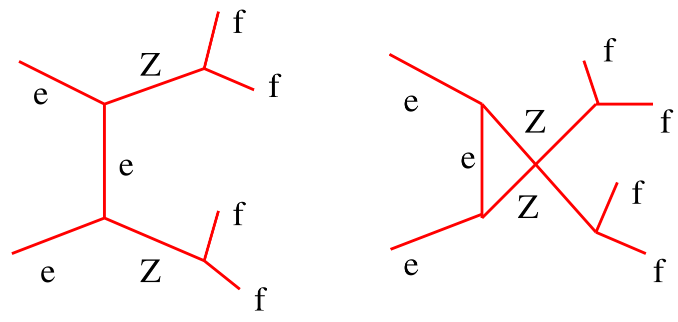
$$\lambda_\gamma = -0.03^{+0.04}_{-0.04}$$

Trilinear Gauge Coupling Results

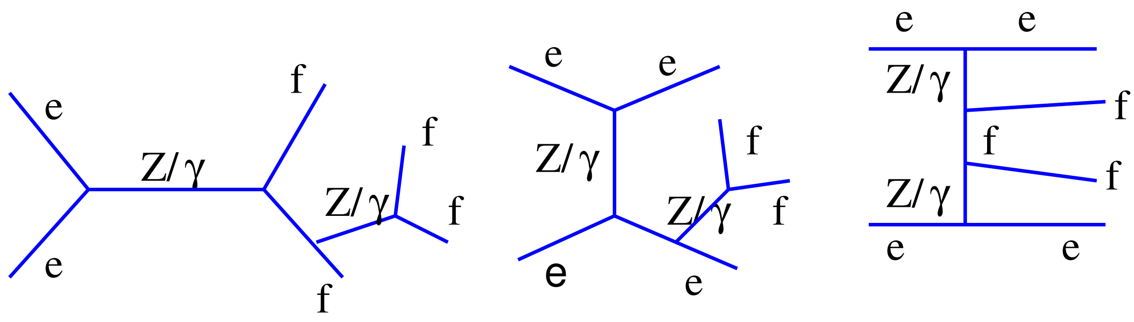


ZZ Production

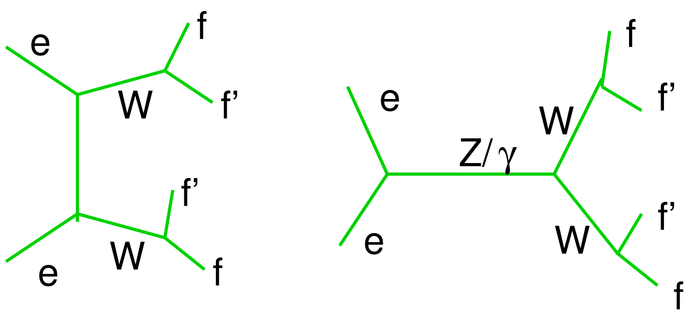
Above threshold for ZZ production (NC02)



+ other non resonant diagrams for the same final states ...



+ other diagrams involving WW production ...



ZZ versus 4-fermions production

The experiments measure the NC02 cross-section:

ALEPH and OPAL calculate:

$$\sigma_{\mathrm{NC02}} = \frac{N_{data} - N_{bg}^{non\ 4f} - N_{4f}^{non\ ZZ\ res.}}{\mathcal{L}\varepsilon_{\mathrm{NC02}}}$$

$$N_{4f}^{non\ ZZ\ res.} = \mathcal{L}\left(\varepsilon_{4f}\sigma_{4f}^{MC} - \varepsilon_{\mathrm{NC02}}\sigma_{\mathrm{NC02}}^{MC}\right)$$

L3 and DELPHI calculate correction factors for "resonant ZZ":

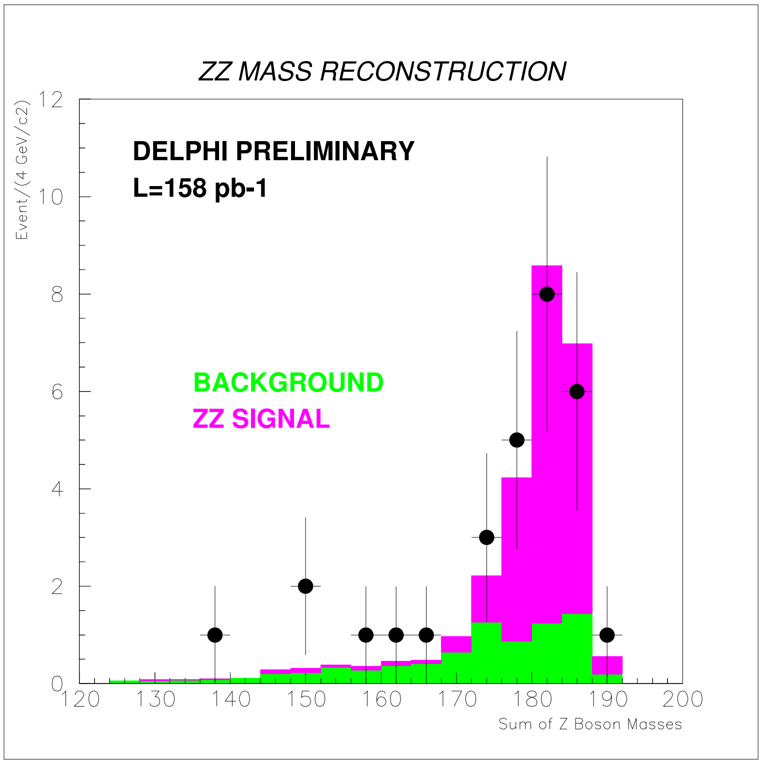
"resonant ZZ" signal is defined through some kinematic cuts:
DELPHI: All 4-f within a mass window: $|M_Z - M_{ff,f'f'}| < 10$ GeV
and channels in common with CC not analyzed
L3: 70 GeV$< |M_{ff,f'f'}| < 105$ GeV, $E_f >$1 GeV, $|cos\theta_e| <$0.95,
exclude 75 GeV$< M_{ff'} <$85 GeV for channels common with WW.

$$\sigma_{\text{``}ZZ''}$$

$$\sigma_{\mathrm{NC02}} = \frac{\sigma_{\mathrm{NC02}}^{MC}}{\sigma_{4f}^{MC\ \text{``}ZZ''}} \cdot \sigma_{\text{``}ZZ''}$$

ZZ Selection

Channel	Statistics	Experimental Signature	Background
$q\bar{q}q'\bar{q}'$	Large	4 hadronic jets	Large
$q\bar{q}\nu\bar{\nu}$	Large	2 jets + missing energy	Medium
$q\bar{q}l^+l^-$	Medium	2 jets + 2 leptons	Low
$l^+l^-\nu\bar{\nu}$	Low	2 leptons + missing energy	Medium
$l^+l^-l'^+l'^-$	Low	4 leptons	Medium
$\nu\bar{\nu}\nu'\bar{\nu}'$		invisible!	

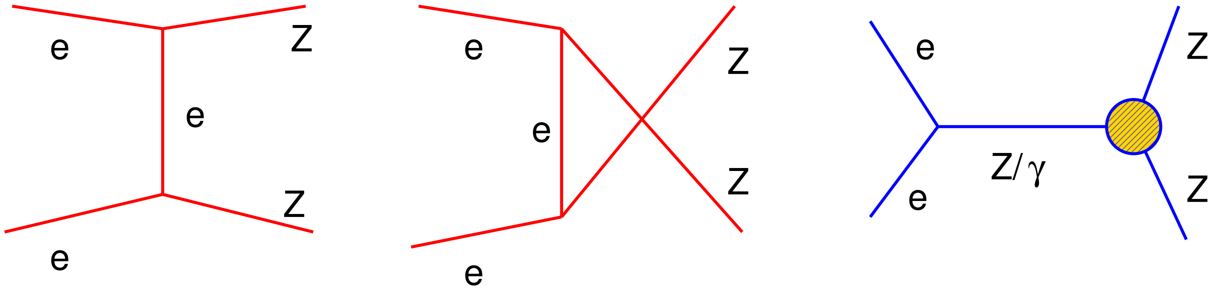


ZZ Cross-section

Cross sections are measured for NC02 processes or Resonant "ZZ" defined through kinematic cuts. Data are corrected for 4f background by multiplicative or subtractive method.

Experiment	$\sigma(\sqrt{s} = 189$ GeV) (pb)	
	NC02	"ZZ within cuts"
ALEPH	0.63±0.12±0.05	
DELPHI	0.58±0.17	
L3	$0.71^{+0.16}_{-0.17}$	$0.68^{+0.15}_{-0.14}$
Priv. Average	*$0.64\pm0.08_{stat}$*	
SM	*$\simeq$ 0.61-0.63*	

ZZ Anomalous Couplings



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

$$-1.7 \leq f_4^Z \leq 1.8 \quad -4.7 \leq f_5^Z \leq 4.7$$
$$-1.0 \leq f_4^\gamma \leq 1.1 \quad -2.8 \leq f_5^\gamma \leq 2.9$$

(L3 95% CL Preliminary)

Conclusions

- Preliminary results for WW cross-sections at LEP at $\sqrt{s}$ =189 GeV have been presented
- Evidence for ZZ signal at LEP200 has been well established
- No deviation from the Standard Model is observed for what concerns the Cross-Sections, Branching Ratio and Couplings.