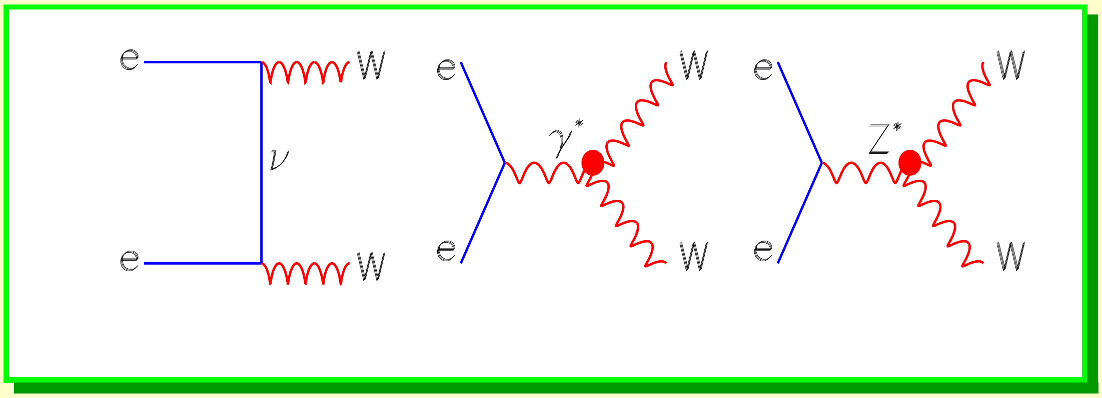
Triple Gauge Couplings in W^+W^- events at LEP

Anna Macchiolo
Université de Montréal
and OPAL Collaboration
representing the LEP Experiments

EPS-HEP99, 15-21 July 1999

- The $\gamma WW/ZWW$ couplings and their parametrisations
- Extraction of TGCs from W^+W^- events: comparison of methods
- Combination of results from the LEP experiments

Triple Gauge Couplings



- 7 independent parameters in a general Lorentz-invariant ZWW or γWW vertex
- 4 are C, P or CP not conserving: assumed to be zero in LEP analyses

$$
\begin{aligned}
i\frac{\mathcal{L}^V_{TGC}}{g_{WWV}} &= g_1^V V_\mu (W^{-\mu\nu}W^+_\nu - W^{+\mu\nu}W^-_\nu) \\
&+\kappa_V V^{\mu\nu}W^-_\mu W^+_\nu \\
&+\frac{\lambda_V}{M_W^2}V^{\mu\nu}W^{+\rho}_\nu W^-_{\rho\mu}
\end{aligned}
$$

with $V=\gamma/Z$ $\quad g_{WW\gamma}=e \quad g_{WWZ}=e\cot\theta_W$
$W_{\mu\nu}=\partial_\nu W_\mu - \partial_\nu W_\mu$ and $V_{\mu\nu}=\partial_\nu V_\mu - \partial_\nu V_\mu$.

- In the SM $\quad g_1^V=1,\ \kappa^V=1$ and $\lambda^V=0$

TGCs parameters used at LEP

We consider deviations from the SM values:

$$\boxed{\Delta g_1^V = (g_1^V - 1), \quad \Delta\kappa_V = (\kappa_V - 1), \quad \lambda_V}$$

Asking for $U(1)_{em}$ invariance:

$$\boxed{Q_W = e g_1^\gamma \quad \Rightarrow \quad g_1^\gamma = 1}$$

Asking for $SU(2)_L \times U(1)_Y$ invariance:

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \cdot \tan^2\theta_W$$

$$\lambda_Z = \lambda_\gamma = \lambda$$

$$\Downarrow$$

Three parameters are left

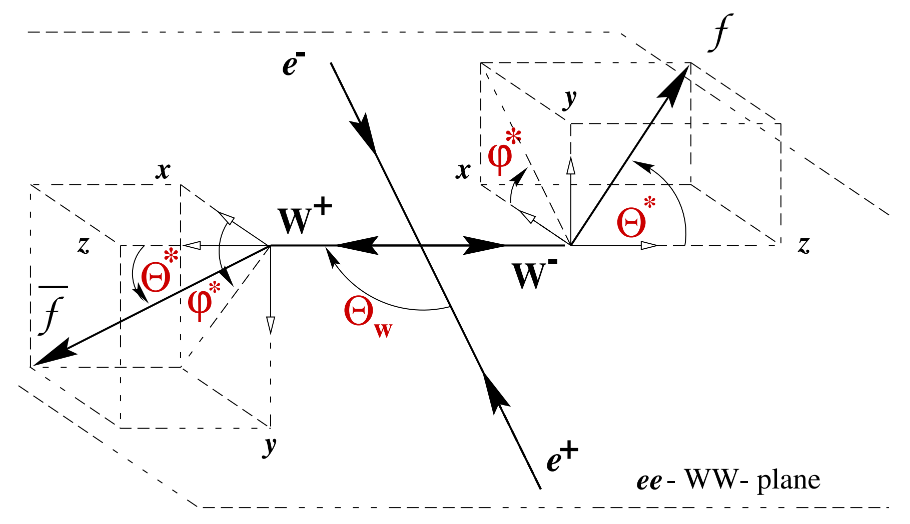
$$\boxed{\Delta\kappa_\gamma, \quad \Delta g_1^Z, \quad \lambda}$$

Extraction of TGC information from WW events

Sensitivity to anomalous couplings in:

- total cross section σ_{tot}
- W scattering angle distribution θ_W
- W polarisation $\rightarrow$ angular distribution of the decay fermions in the W rest frame $(\theta^*_{f(\bar{f})}, \phi^*_{f(\bar{f})})$

accessibility of $\Omega = (\theta_W, \theta^*_f, \phi^*_f, \theta^*_{\bar{f}}, \phi^*_{\bar{f}})$ depends on the W decay channel



Linear dependence of $\mathcal{L}$ from TGCs $\rightarrow$ quadratic dependence of total and differential cross section from the couplings

Data sample

Analysis mainly based on W pairs collected at:

183 GeV	$\mathcal{L} \approx 55\, pb^{-1}$	per exp.
189 GeV	$\mathcal{L} \approx 170\, pb^{-1}$	per exp.

N.B. All results @ 189 GeV still preliminary

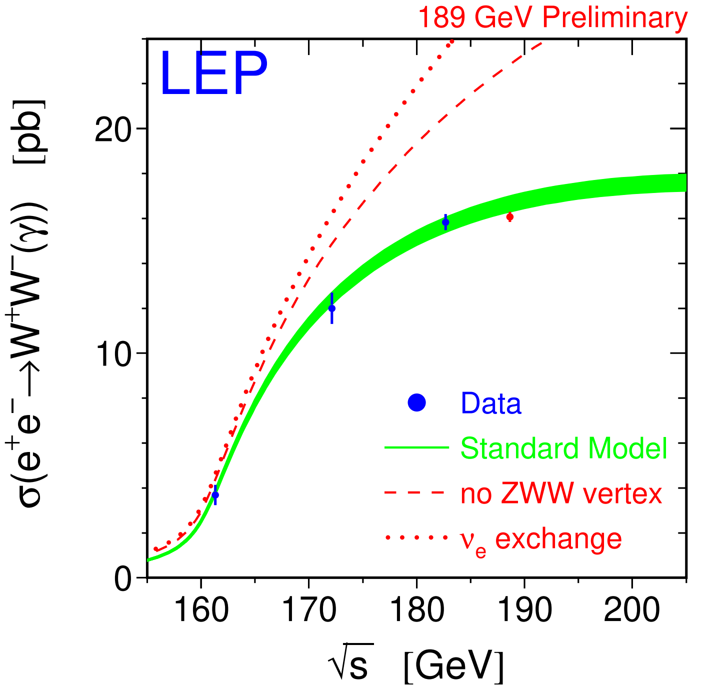
Decay Channels

Channel	BR	
$WW \to ql\nu$	BR= 43 %	analysed by all experiments @ 183/189 GeV
$WW \to qqqq$	BR= 46 %	
$WW \to l\nu l\nu$	BR= 11 %	$d\sigma/d\Omega$ analysed by OPAL @ 183 GeV, ALEPH @ 183/189 GeV

- Event Selection: apply additional cuts to the samples used in the M_W analysis to improve reconstruction of the event kinematic
- Combination of results from WW production with limits on TGCs parameters from $e^+e^- \to We\nu$ and $e^+e^- \to \nu\nu\gamma$ events

TGCs from σ_{WW}

- ZWW and γWW couplings are necessary for good high-energy behaviour of σ_{WW}



- anomalous couplings tend to increase σ_{WW}

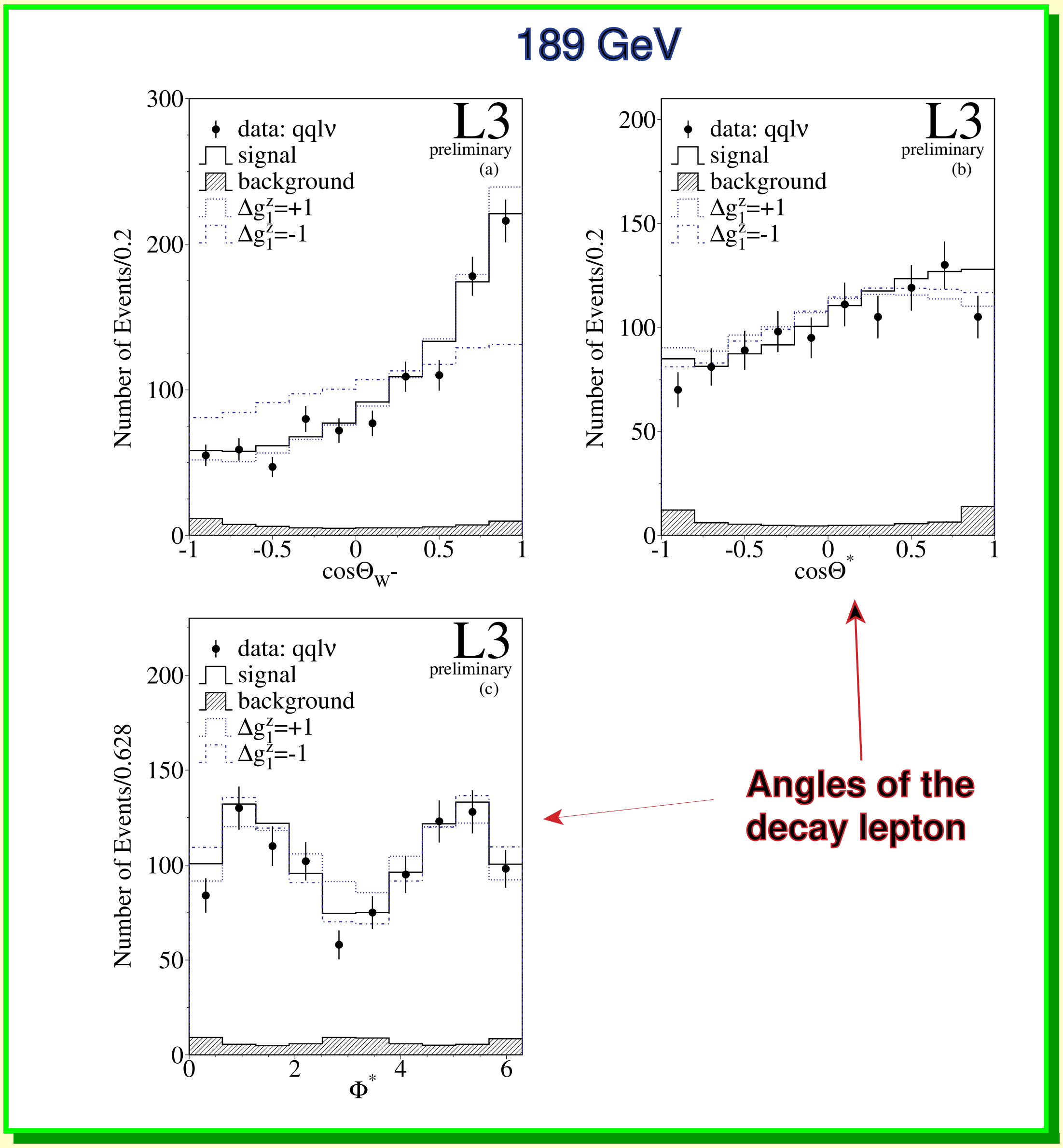
no ZWW vertex

$$\Delta\kappa_\gamma = 0,\ \Delta g_1^Z = -1,\ \lambda = 0$$

- LEP experiments use the event rate in the three decay channels to set limits on TGCs

TGCs in $W^+W^- \to qql\nu$ events

- All angles known for the leptonic W
  improve resolution on the Ω set with kinematic fits
  (E-p conservation + constraints on reconstructed M_W)
  W charge known from the decay lepton



- folding over the angles of the hadronic system:
  ambiguity in quark flavor
  $(\cos\theta^*_{jet},\ \phi^*_{jet}) \leftrightarrow (-\cos\theta^*_{jet},\ \phi^*_{jet}+\pi)$

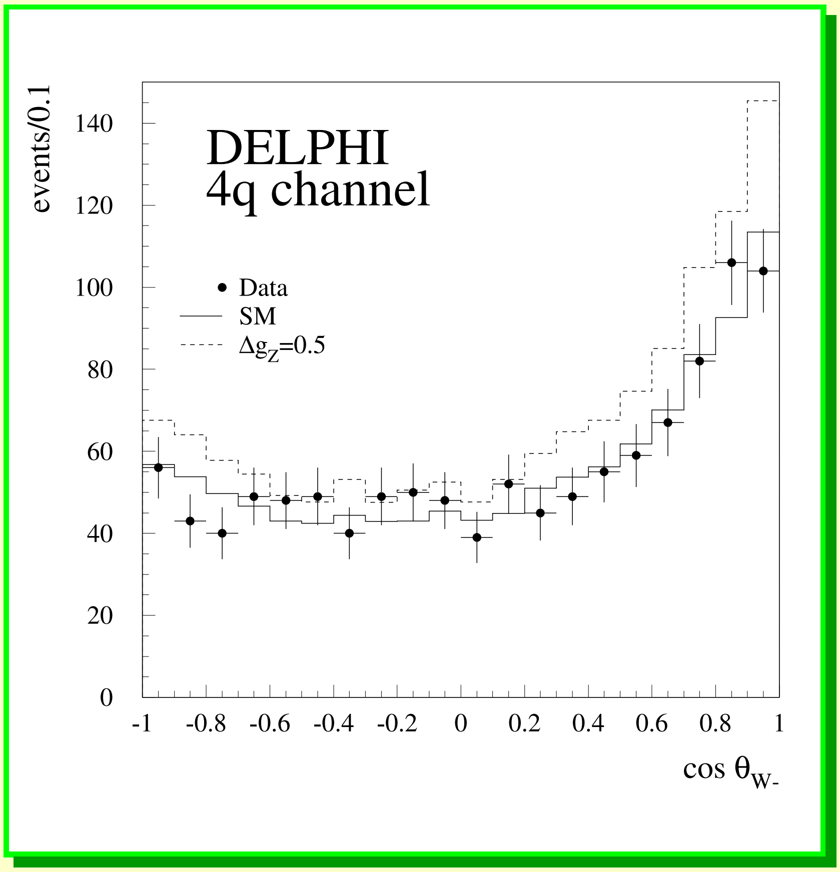
TGCs in $W^+W^- \to q\bar{q}q\bar{q}$ events

- Jet pairing to identify correct combination
  E-p conservation + constraints on reconstructed M_W
  ϵ (correct pairing) =74% -84%

- W charge assignment

$$\left.\begin{aligned} Q_{jet} &= \frac{\sum q_i |p_i|^\kappa}{\sum |p_i|^\kappa} (\kappa = 0.5) \\ Q_W &= Q_{jet1} + Q_{jet2} \end{aligned}\right\} \epsilon = 71\% - 79\%$$

- Complete folding over the decay angles
  ambiguity in quark flavor
  $(\cos\theta^*_{jet},\ \phi^*_{jet}) \leftrightarrow (-\cos\theta^*_{jet},\ \phi^*_{jet} + \pi)$

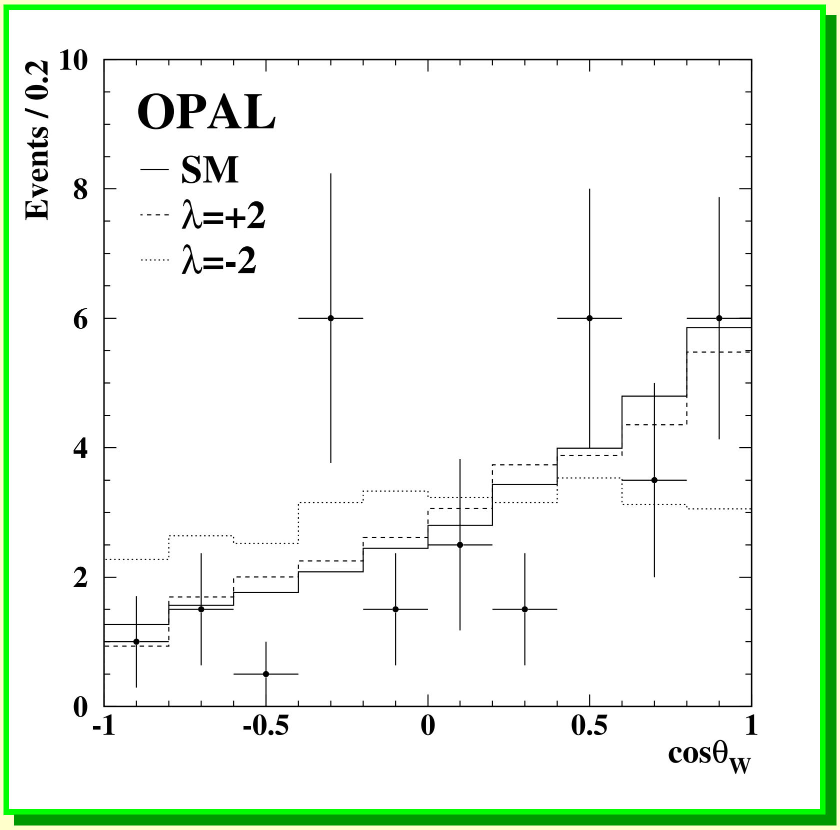


$\oplus$
high statistics
$\ominus$
only $\approx$ 60 % efficiency of correct reconstruction

TGCs in $W^+W^- \to l\nu l\nu$ events

- All angles accessible ...
  ... in the approximation of zero W width and no ISR ...
  ... selecting only events with $l = e, \mu$
- quadratic constraint on M_W results in two-fold ambiguity in $(\cos\theta_W, \phi_1^*, \phi_2^*)$
- 2 entries for event in the distributions for these kinematics variables

183 GeV



⊕ the only channel where both θ_1^* and θ_2^* can be determined

⊖ low statistics

Extraction of TGCs from $d\sigma/d\Omega$

Limits on the TGCs are set using:

L3

Unbinned maximum likelihood fit to

$\theta_W, \theta_l^*, \phi_l^*$ in $qql\nu$ events

θ_W in $qqqq$ events

Aleph, Delphi, Opal

Optimal Observable Method

Project 5 kinematic variables onto 1 observable

Cross-checks between the two methods allow to:

- test their reliability
- compare their sensitivity to anomalous couplings

Opal also compares with a fit to

Spin Density Matrix elements

visualisation of W polarisation

Optimal Observable method

$$d\sigma(\Omega,\alpha) = S^0(\Omega) + \sum_i \alpha_i \cdot S_i^{(1)}(\Omega) + \sum_{ij} \alpha_i\alpha_j \cdot S_{ij}^{(2)}(\Omega)$$

$$\mathcal{O}_i^{(1)} = S_i^{(1)}(\Omega)/S_i^{(0)}(\Omega) \qquad \mathcal{O}_{ij}^{(2)} = S_{ij}^{(2)}(\Omega)/S_i^{(0)}(\Omega)$$

Aleph & Delphi ($qqqq$ channel)

- maximal sensitivity for couplings near to the expansion point
- $d\sigma(\Omega,\alpha)$ expanded around the value measured in data using an iterative procedure
- fit only to $\mathcal{O}_i^{(1)}$

Delphi ($ql\nu$ channel) & Opal

- $d\sigma(\Omega,\alpha)$ expandend around the SM values
- fit to $\mathcal{O}_i^{(1)}$ and $\mathcal{O}_{ij}^{(2)}$

Spin Density Matrix elements

Summing over all possible helicities of the second W....

$$\rho_{\tau\tau'}(\cos\theta_W) = \frac{\sum_\lambda \mathcal{F}_\tau^{(\lambda)} (\mathcal{F}_{\tau'}^{(\lambda)})^*}{\sum_{\lambda\tau} |\mathcal{F}_\tau^{(\lambda)}|^2}$$

helicity of $W^\pm$

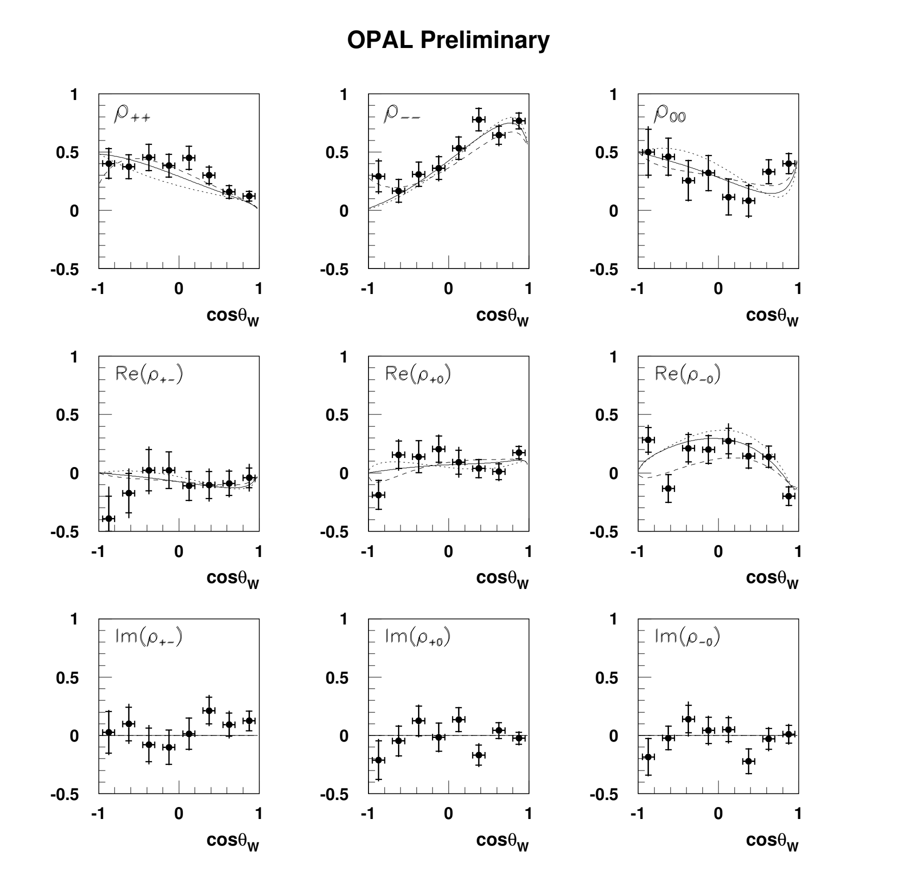
$\Rightarrow$ $\tau = 1$

$\Uparrow$ $\tau = 0$

$\Leftarrow$ $\tau = -1$

λ: e^- spin

- $\rho_{\tau\tau'}$ is a 3×3 hermitian matrix
- Practically the SDM elements are extracted in bins of $\cos\theta_W$ with projection operators that are functions of θ^* and ϕ^*
- $\rho_{\tau\tau}$ (diagonal elements)= probability to produce a boson with helicity τ
- imaginary part of off-diagonal elements: vanish in CP-conserving theories



Model independent measurement of W helicity structure

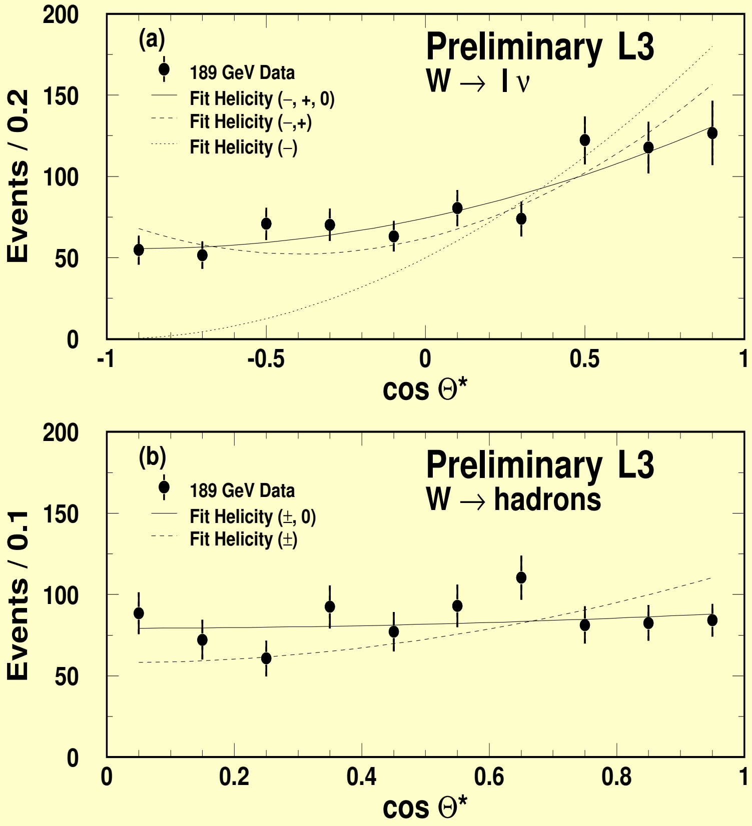
- L3: extract the fractions of longitudinal and transverse polarised W with a fit to the θ^* distribution in $qql\nu$ events
- longitudinally polarized Ws are observed with a statistical significance $> 5\ \sigma$

$$f(\tau = 0) = 27.8 \pm 9.3 \pm 3\% \text{ 183 GeV}$$

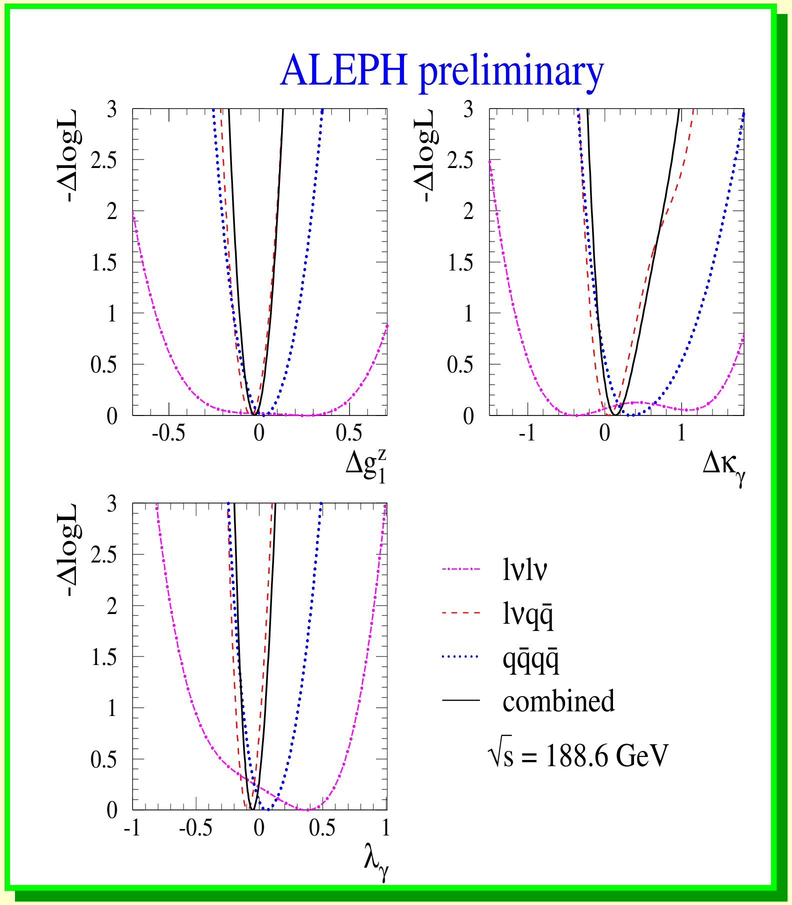
$$f(\tau = 0) = 24.4 \pm 4.8 \pm 3\% \text{ 189 GeV}$$

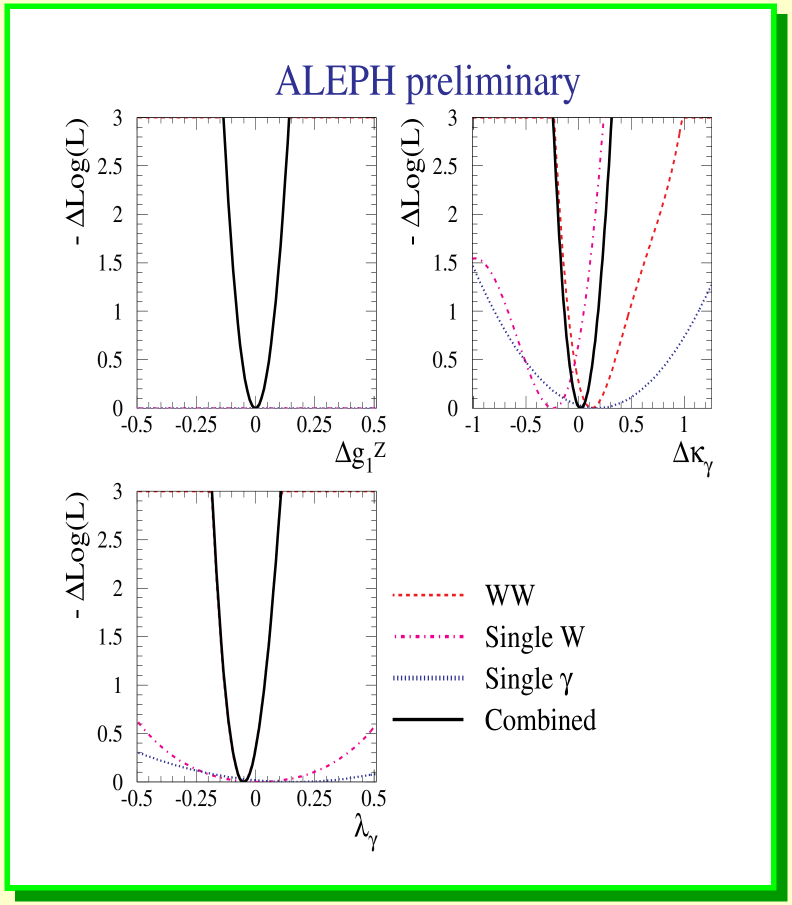
$$f(\tau = 0) = 26\% \qquad \text{in the SM}$$

- measurement of W helicity as function of $\cos\theta_W$ in agreement with SM expectations



Some comparisons ...

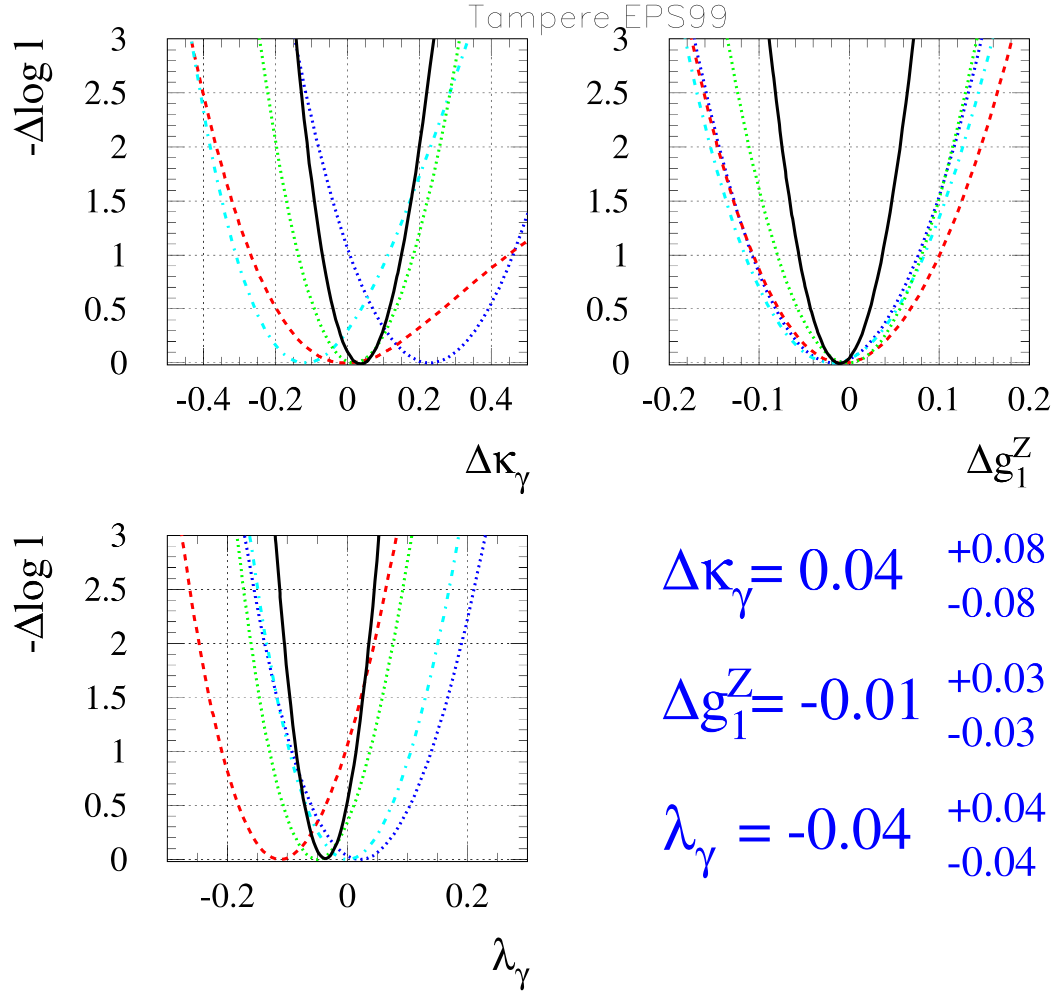




LEP Combination (1-D fit)

Combination provided by the LEP TGC working group

ALEPH + DELPHI + L3 + OPAL



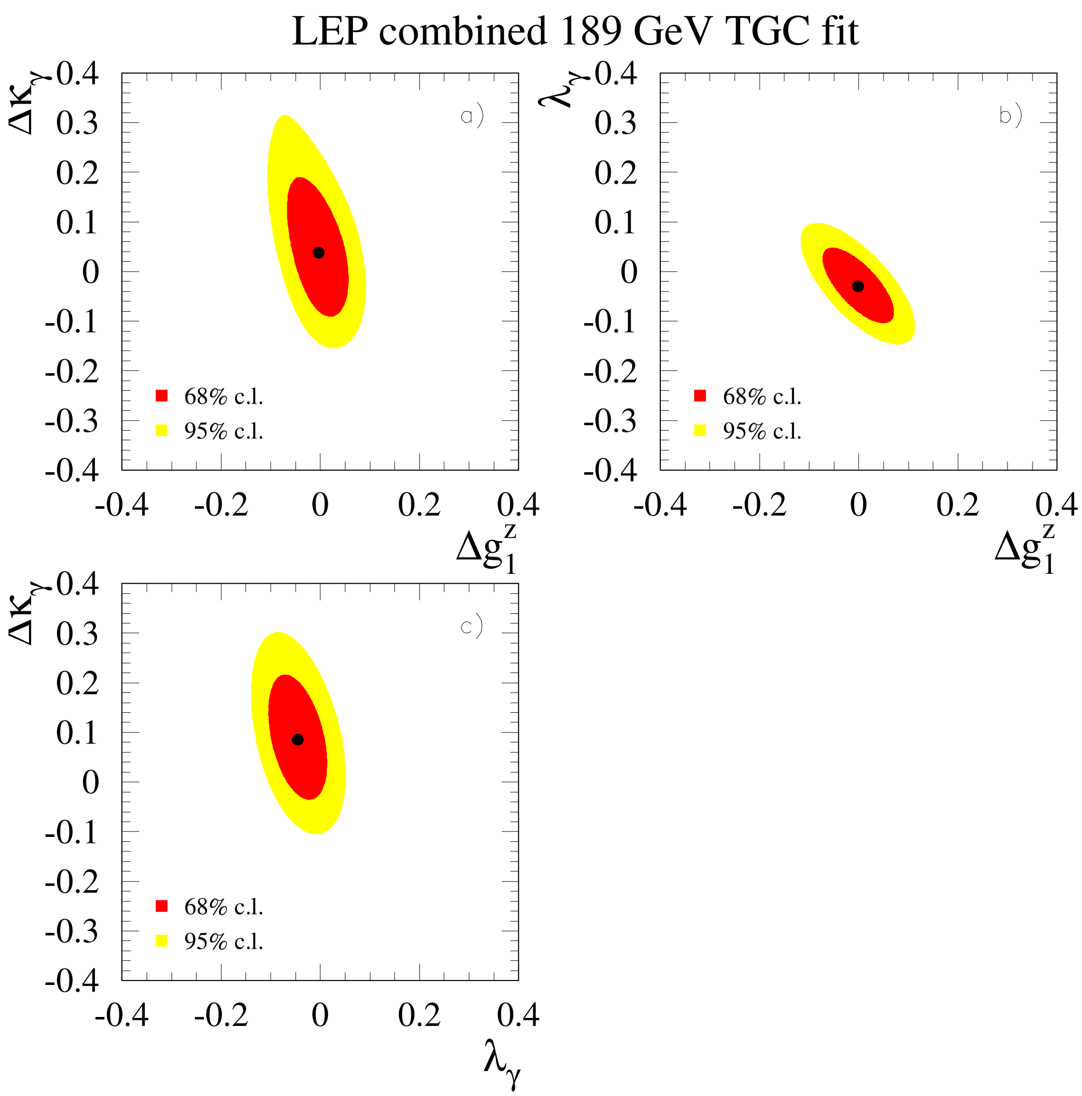
$\Delta\kappa_\gamma = 0.04 \begin{smallmatrix} +0.08 \\ -0.08 \end{smallmatrix}$

$\Delta g_1^Z = -0.01 \begin{smallmatrix} +0.03 \\ -0.03 \end{smallmatrix}$

$\lambda_\gamma = -0.04 \begin{smallmatrix} +0.04 \\ -0.04 \end{smallmatrix}$

LEP Combination (2-D fit)

Combination provided by the LEP TGC working group



Conclusions and Outlook

- Data collected at 183 and 189 GeV have been analysed with a variety of methods by the LEP Collaborations

- Large improvement with respect to the Vancouver results: 189 GeV data have been added and analysis techniques refined

	Vancouver	Tampere
$\Delta\kappa_\gamma$	$0.17^{+0.16}_{-0.16}$	$0.04^{+0.08}_{-0.08}$
Δg_1^Z	$0.00^{+0.08}_{-0.08}$	$-0.01^{+0.03}_{-0.03}$
λ	$-0.05^{+0.08}_{-0.09}$	$-0.04^{+0.04}_{-0.04}$

- No deviations have been found from the Standard Model expectations

- Ready to further investigate the $SU(2)_L \times U(1)_Y$ structure of the SM with the new data ...