Charged Triple Gauge Coupling at LEP

$WW\gamma - WWZ$ and W polarisation

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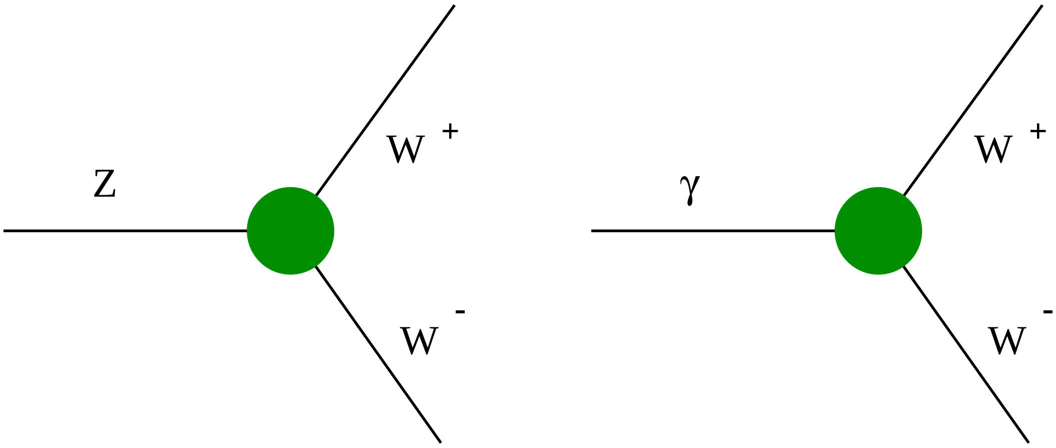
- ▷Bases on Charged bosons Triple Gauge Couplings ($WW\gamma$ and WWZ)
- ▷Standard analysis
  - ▷W^+W^- channel
  - ▷Single W channel
- ▷Combinations of TGC results (LEP=ADLO)
- ▷W polarisation
- ▷Conclusion



– Due to the non-abelian nature of the $SU(2)_L \times U(1)_Y$

– The most general Lagrangian of interactions between WWV (V=Z or γ) contains 2×7 terms

$$\frac{i\mathcal{L}_{eff}^{WWV}}{g_{WWV}} = \left[\begin{array}{lcl} g_V^1 & V^\mu(W^-_{\mu\nu}W^{+\nu} - W^+_{\mu\nu}W^{-\nu}) + & C, P \\ \kappa_V & W^+_\mu W^-_\nu V^{\mu\nu} + & C, P \\ \lambda_V & \frac{1}{M_W^2} V^{\mu\nu} W_\nu^{+\rho} W^-_{\rho\mu} + & C, P \\ ig_V^5 & \epsilon_{\mu\nu\rho\sigma}((\partial^\rho W^{-\mu})W^{+\nu} - W^{-\mu}(\partial^\rho W^{-\nu}))V^\sigma + & \not{C}, \not{P} \\ ig_V^4 & W^-_\mu W^+_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) - & \cancel{CP} \\ \tilde{\kappa}_V & \frac{1}{2} W^-_\mu W^+_\nu \epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - & \cancel{CP} \\ \tilde{\lambda}_V & \frac{1}{2M_W^2} W^-_{\rho\mu} W_\nu^{+\mu} \epsilon\nu\rho\alpha\beta V_{\alpha\beta} & \cancel{CP} \end{array}\right]$$

– Most constrained analysis (C,P and CP conservation , $U(1)_{em}$, $SU(2)_L \times U(1)_Y$) ⇒ 3 terms :

$$\boxed{\begin{array}{c} \Delta g_1^Z = g_1^Z - 1 \qquad \Delta\kappa_\gamma = \kappa_\gamma - 1 \qquad \lambda_\gamma \\ \\ \text{Equal to zero in the S.M.} \end{array}}$$

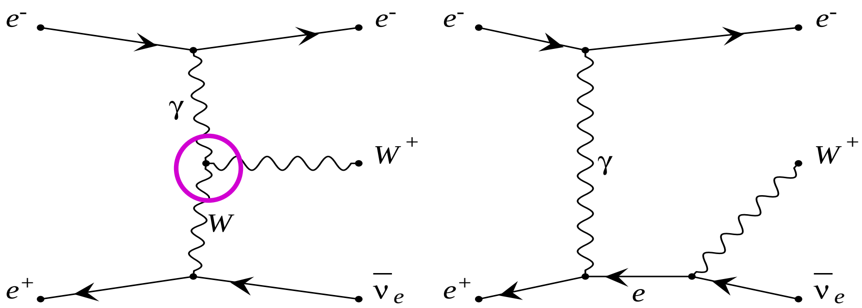
– All other couplings are fixed to S.M. except the 2 constrained ones (assuming $SU(2)_L \times U(1)_Y$ gauge symmetry) :

$$\Delta\kappa_Z = \Delta g_1^Z + \Delta\kappa_\gamma \tan^2\theta_w \quad ; \quad \lambda_Z = \lambda_\gamma$$

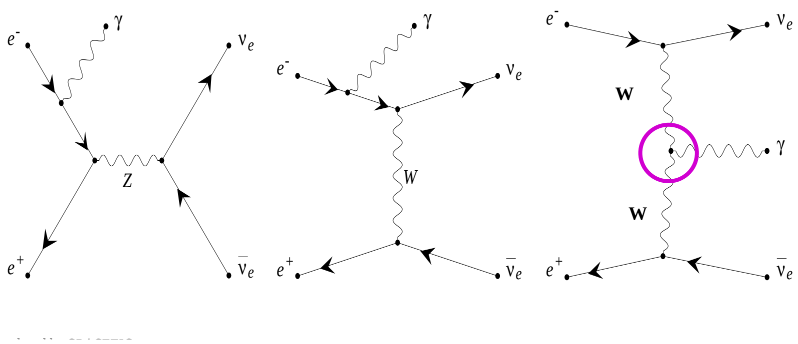
TGCs can be measured through the following processes :

– $e^+e^- \longrightarrow W^+W^- \longrightarrow$ 4 fermions (Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ)

– $e^+e^- \longrightarrow We\nu_e$ (WWγ alone :$\Delta\kappa_\gamma$,λ_γ)

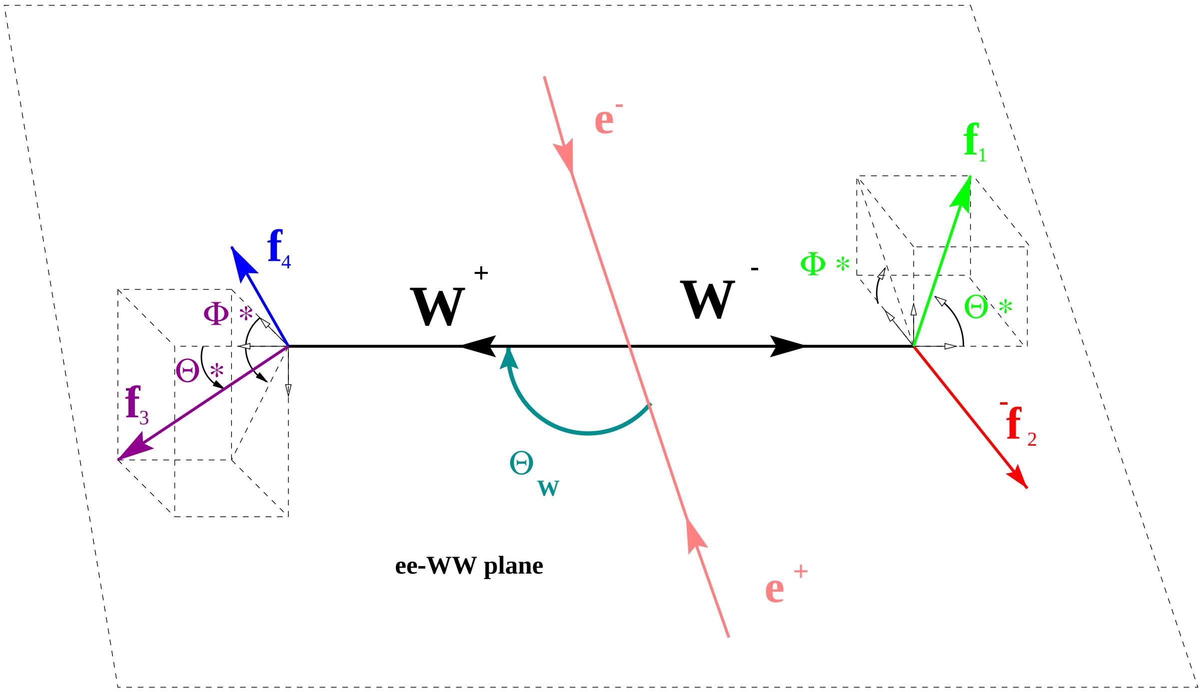


– $e^+e^- \longrightarrow \nu_e\bar{\nu}_e\gamma$ (WWγ alone :$\Delta\kappa_\gamma$,λ_γ)



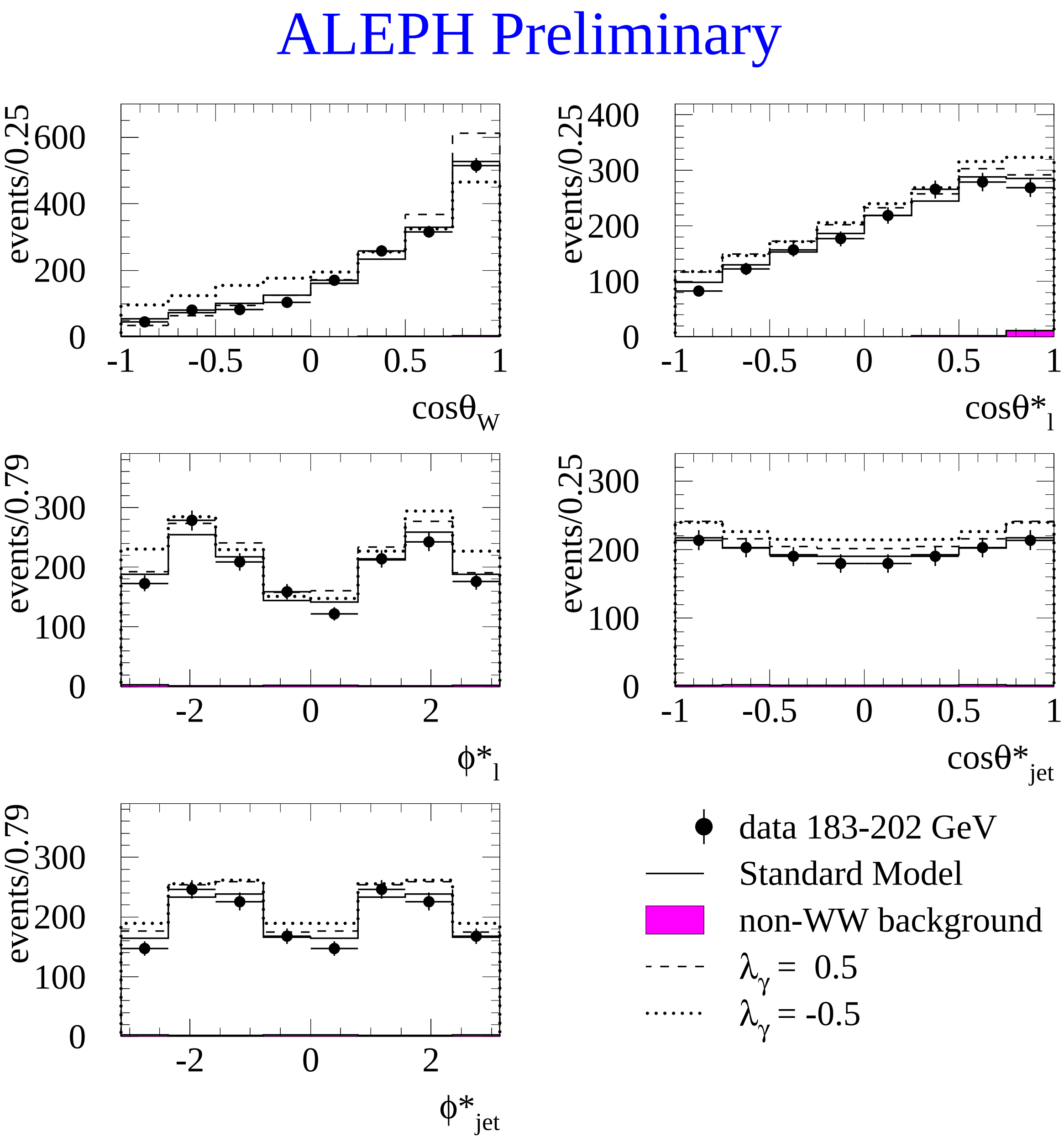
– WW Selection : Same as cross section restricted to well measured four fermion events

▹Kinematic information



– Electrical charge and flavor of individual jet is unknown ⇒ Folded
– $WW \to l\nu qq$: W_1 axis defined by the dijet axis and W_2 charge defined by lepton charge
– $WW \to qqqq$: Pairing of jets (∼ 80% efficiency) ⇒ W_1/W_2 charge estimated from $\mathcal{Q}(W_1)$-$\mathcal{Q}(W_2)$ (∼ 80% efficiency)
– $WW \to l^+\nu l^-\bar{\nu}$: 2 possible solutions for neutrinos (or Ws) which are folded

▹Cross section : Add sensitivity


ALEPH Preliminary
events/0.25
cosθ_W
cosθ*_l
events/0.79
φ*_l
cosθ*_jet
φ*_jet
data 183-202 GeV
Standard Model
non-WW background
λ_γ = 0.5
λ_γ = -0.5

– Angular information

– Problem : Extract the most precise measurement of one/many couplings out of 5 (or less) angles

– Solution 1 : Unbinned likelihood method
▷ALEPH $(e/\mu)\nu qq$: PDF from calculation + detector resolution function
▷L3 : PDF from simulated events

– Solution 2 : Optimal Observables :
Project 5 kinematic variables onto 1 (2) parameter per TGC coupling

$\mathcal{O}^1_i = S^1_i(\Omega)/S^0(\Omega)$ and $\mathcal{O}^2_{ij} = S^2_{ij}(\Omega)/S^0(\Omega)$

with

$$d\sigma(\Omega,\alpha) = S^0(\Omega) + \sum_i \alpha_i.S^1_i(\Omega) + \sum_{ij} \alpha_i\alpha_j S^2_{ij}(\Omega)$$

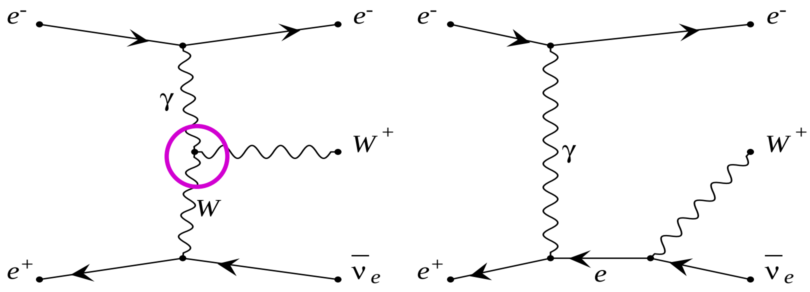
▷Binned maximum likelihood fit to $\mathcal{O}^1_i$ and $\mathcal{O}^2_{ij}$ (DELPHI)

▷χ^2 fit to $\mathcal{O}^1_i$ and $\mathcal{O}^2_{ij}$ averages (OPAL)

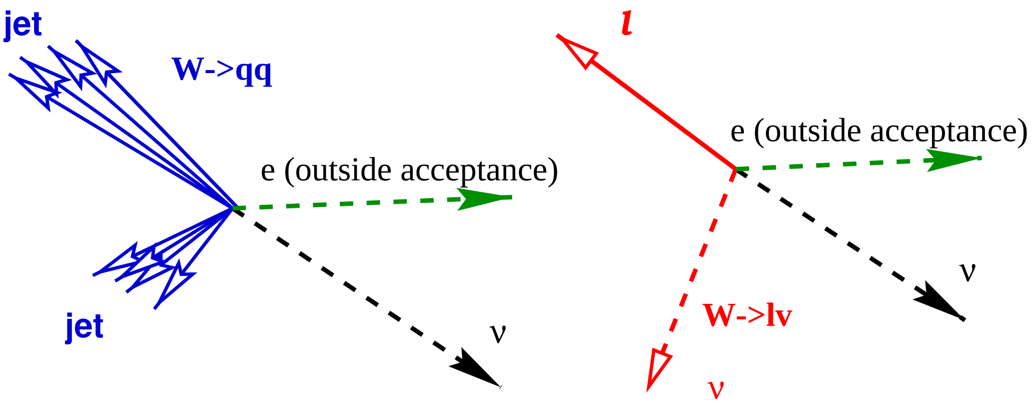
▷χ^2 fit to $\mathcal{O}^1_i$ and $\mathcal{O}^2_{ii}$ averages (ALEPH)

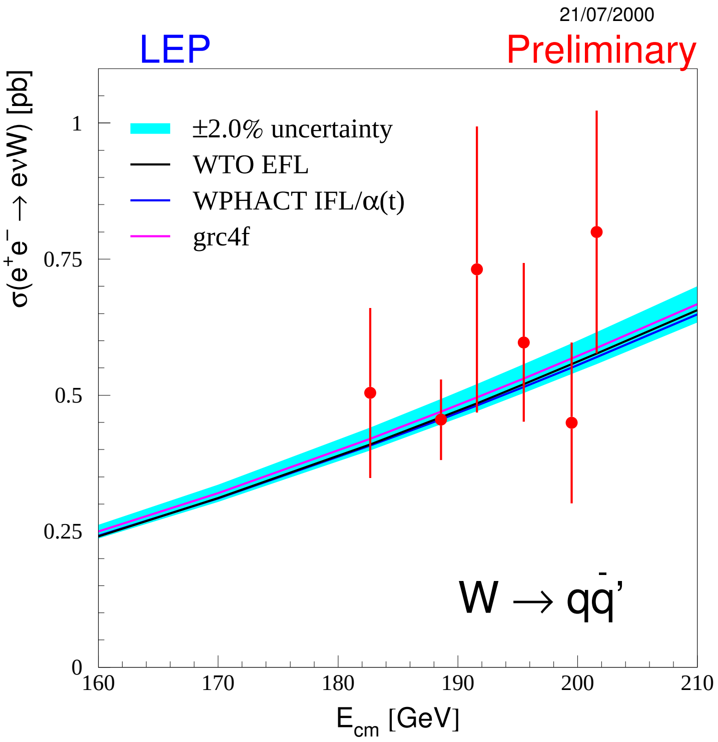
– Cross Section : Adjust expected cross section from simulation to the number of observed data

Cross-Section of single W events (Weν)



Many
s and t channels





WW = Main background

Aleph @ 183-202 GeV

L3 @ 189-202 GeV

Delphi @ 189-202 GeV

Opal @ 189 GeV

– Sensitivity to $WW\gamma$ alone $\Rightarrow$ Sensitive to $\Delta\kappa_\gamma$ and λ_γ

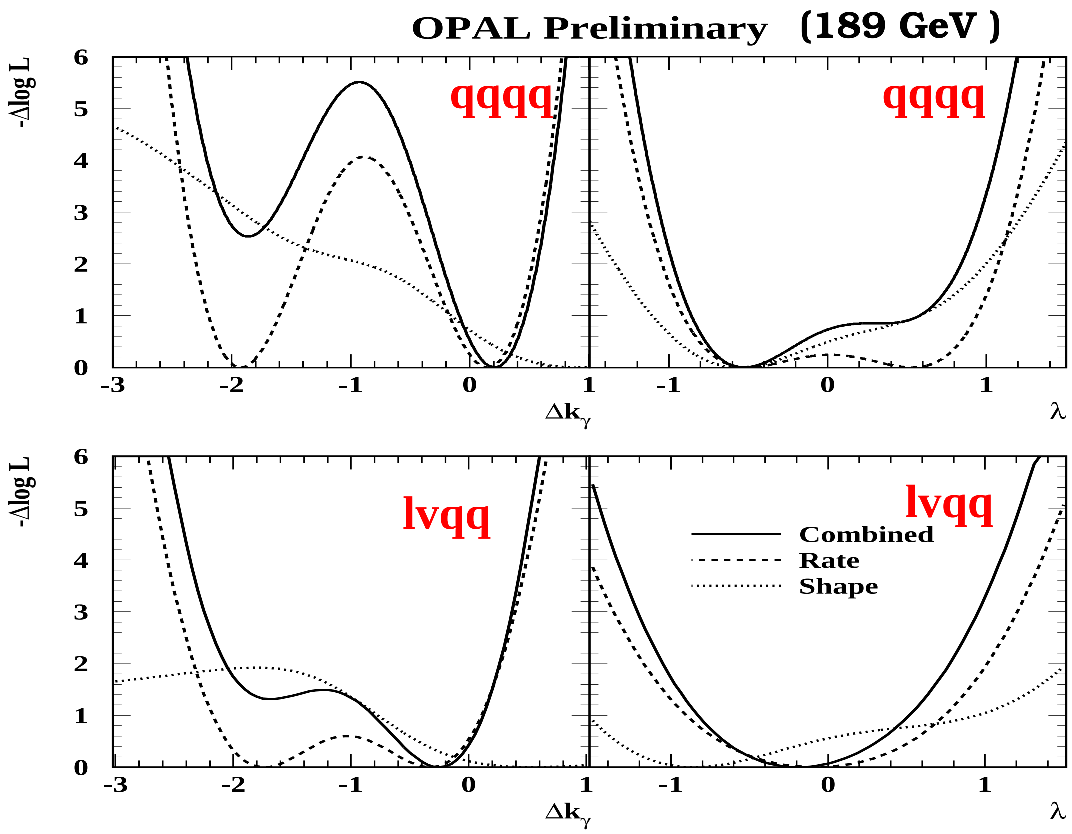
– Main sensitivity through cross section

– the double minima structure is removed with the kinematic information

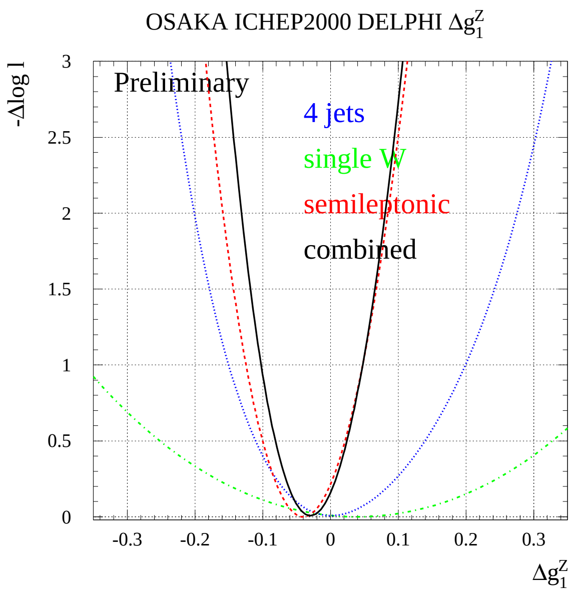
 – Pt_W (ALEPH)

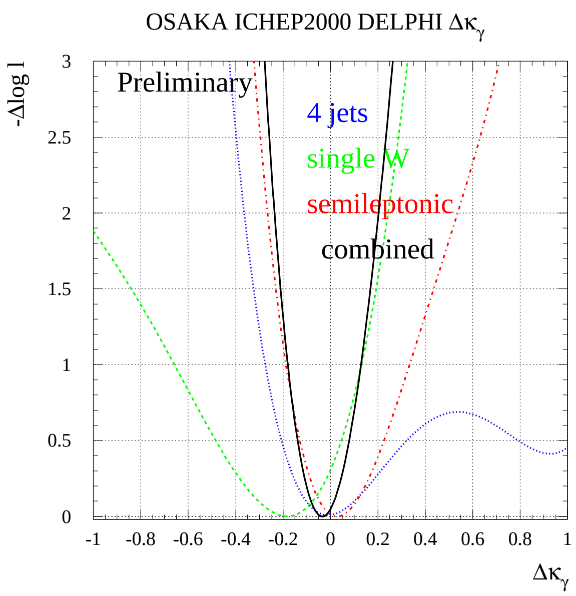
 – ($Pt_W, |\cos\theta_{jet1} - \cos\theta_{jet2}|$) for W$\longrightarrow$ 2 jets (OPAL)

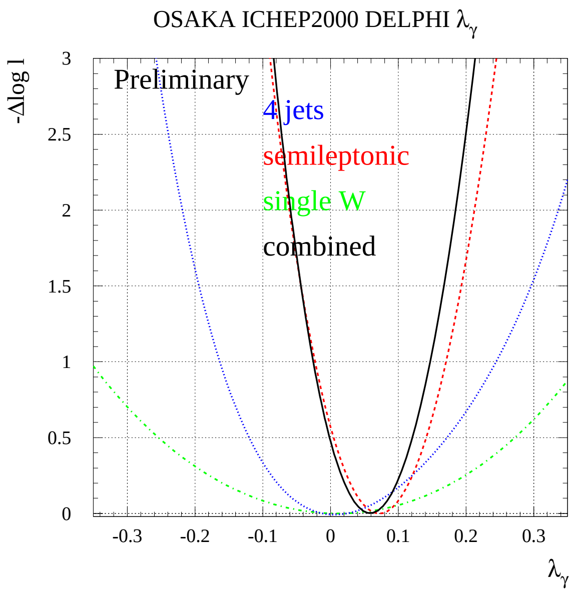
 – ($E_l, \cos\theta_l$) for W$\longrightarrow$ $l\nu$ (OPAL)



Combination of channels : 1D







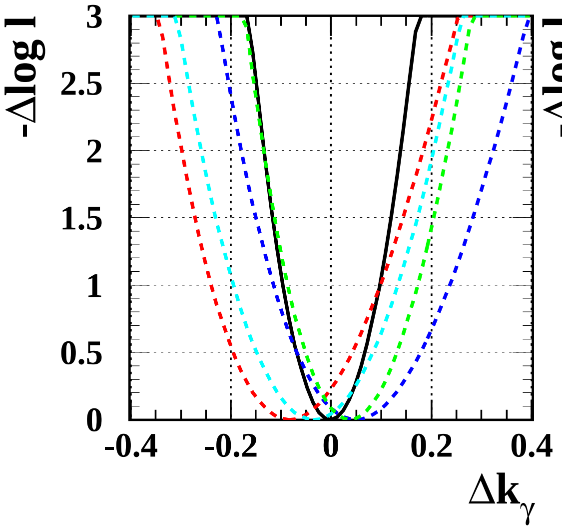
Delphi

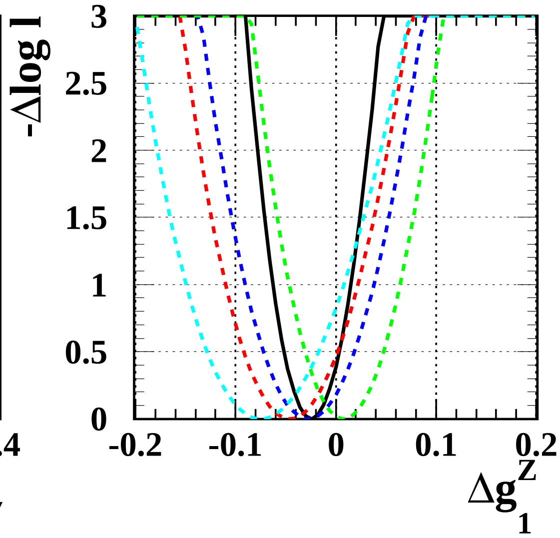
192-202 GeV data

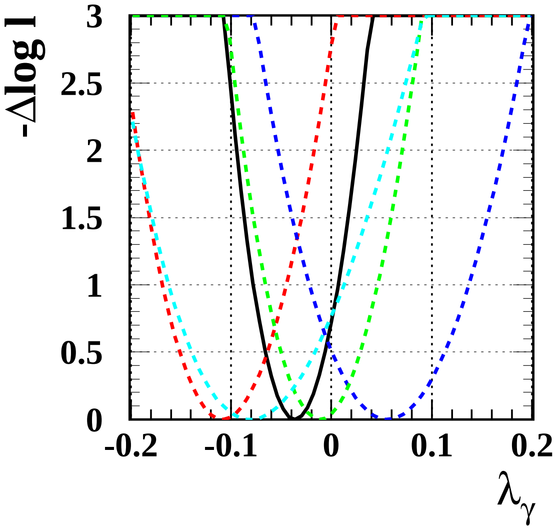
▷WW and single W (LEP2 $\longrightarrow$ 202 GeV in 99)

(Except Single-W from OPAL for 192-202 GeV data)

ALEPH + DELPHI + L3 + OPAL







$$\Delta k_\gamma = -0.002^{+0.070}_{-0.067}$$

$$\Delta g_1^Z = -0.024^{+0.028}_{-0.027}$$

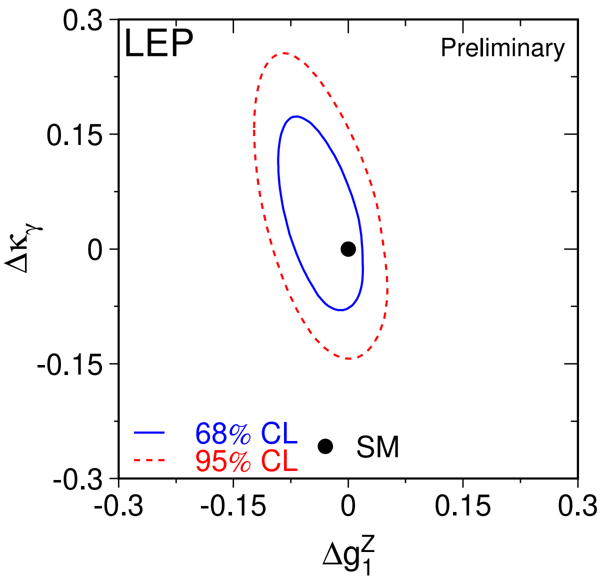
$$\lambda_\gamma = -0.037^{+0.030}_{-0.030}$$

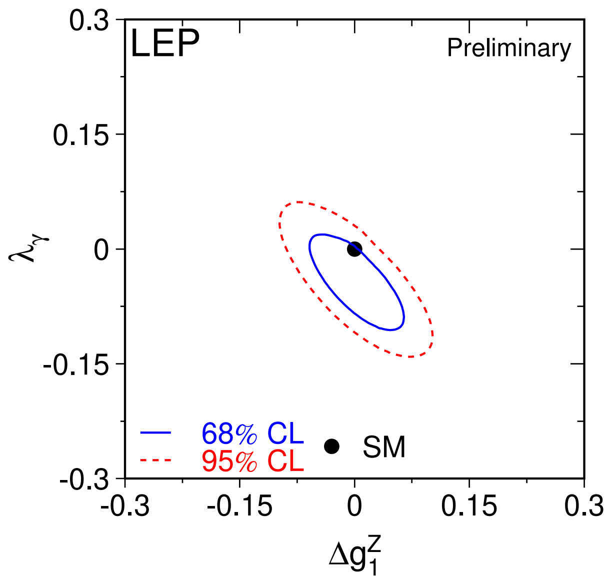
Preliminary

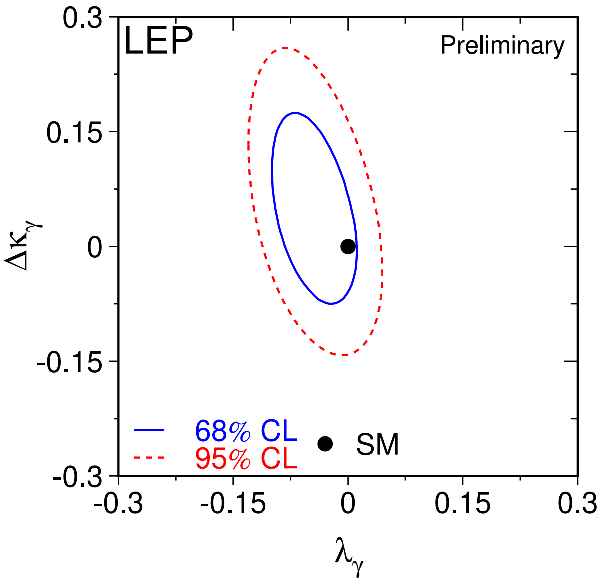
Systematic source	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
σ (WW) ($\pm$ 2%)	$\pm$ 0.012	$\pm$ 0.055	$\pm$ 0.014
Fragmentation	$\pm$ 0.013	$\pm$ 0.051	$\pm$ 0.014
Color Reconnection	$\pm$ 0.003	$\pm$ 0.012	$\pm$ 0.005
Bose-Einstein effect	$\pm$ 0.006	$\pm$ 0.020	$\pm$ 0.006
σ (Weν) $\pm$ 5%)	-	$\pm$ 0.049	$\pm$ 0.067

▷WW and single W (183-202 GeV)

▷2D fits of (Δg_1^Z, $\Delta\kappa_\gamma$) ; (Δg_1^Z, λ_γ) ; (λ_γ, $\Delta\kappa_\gamma$)







Good agreement with Standard Model

▷Analysis extended to all TGC parameters

▷One dimension fit with all other couplings at S.M. value

	fit result	95% confidence limits
ALEPH @ 183-202 GeV ($l\nu qq$)		
$\tilde{\kappa}_\gamma$	$-0.192^{+0.178}_{-0.159}{}^{+0.057}_{-0.057}$	[-0.507, 0.183]
$\tilde{\lambda}_\gamma$	$0.167^{+0.130}_{-0.147}{}^{+0.051}_{-0.051}$	[-0.147, 0.427]
$\tilde{\kappa}_Z$	$-0.085^{+0.115}_{-0.109}{}^{+0.023}_{-0.023}$	[-0.296, 0.144]
$\tilde{\lambda}_Z$	$0.073^{+0.090}_{-0.095}{}^{+0.022}_{-0.022}$	[-0.119, 0.248]
g_4^γ	$0.063^{+0.340}_{-0.347}{}^{+0.053}_{-0.053}$	[-0.619, 0.721]
g_5^γ	$-0.020^{+0.502}_{-0.502}{}^{+0.093}_{-0.093}$	[-1.018, 0.979]
g_4^Z	$0.067^{+0.224}_{-0.228}{}^{+0.039}_{-0.039}$	[-0.384, 0.503]
L3 @ 189-202 GeV (all WW channels)		
$\Delta\kappa_Z$	$-0.013^{+0.08}_{-0.07}\pm0.09$	[-0.34, 0.12]
λ_Z	$-0.014^{+0.11}_{-0.06}\pm0.09$	[-0.34, 0.16]
ALEPH+L3		
g_5^Z	$0.05\pm0.17\pm0.08$	[-0.29, 0.37]

▷ OPAL : Based on Spin Density Matrix analysis

	constraint	fit result
$\tilde{\kappa}_Z$	$\tilde{\kappa}_Z$=-$\tan^2\theta_w\tilde{\kappa}_\gamma$	$-0.20^{+0.10}_{-0.07}$
$\tilde{\lambda}_Z$	$\tilde{\lambda}_Z=\tilde{\lambda}_\gamma$	$-0.18^{+0.24}_{-0.16}$
g_4^Z	$g_4^Z=g_4^\gamma$	$-0.02^{+0.32}_{-0.32}$

Good agreement with Standard Model

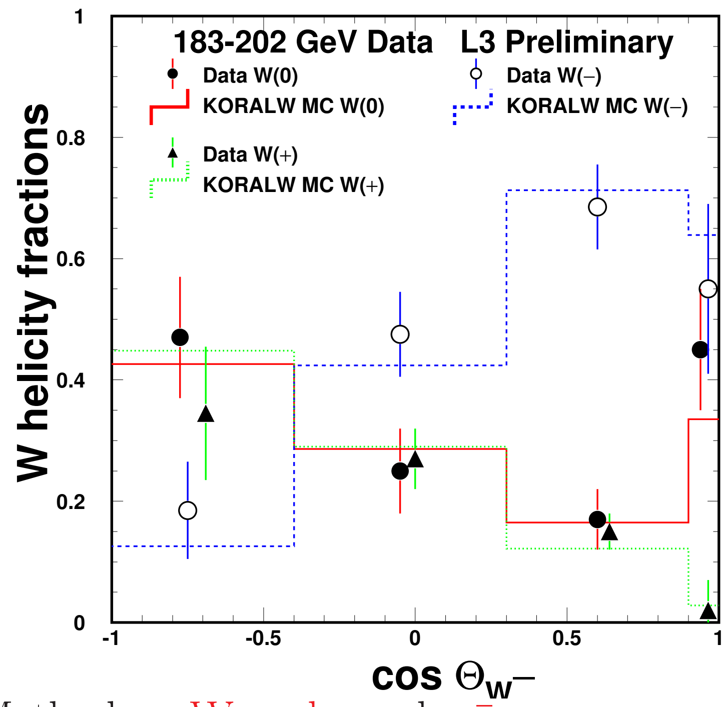
▹W polarisation is an independant measurement of Lagrangian definition

W polarisation is extracted from the $\cos\theta^*$ distributions of $W \to l\nu$ splitted in $\cos\theta_W$ bins

L3 @ 183-202 GeV

$\sigma_L/\sigma_{tot} = 25.9 \pm 3.5$ %

$\sigma_L/\sigma_{tot} = 24.8$ % for S.M.



Spin Density Method on $W \to l\nu$ and $q\bar{q}$

OPAL @ 183-189 GeV

$$\sigma_L/\sigma_{tot} = 21.0 \pm 3.3(stat.) \pm 1.5(Syst.)\%$$

σ_L/σ_{tot}=25.7 % for S.M.

Good agreement with Standard Model

$$-0.077 < \Delta g_1^Z < 0.030$$

$$-0.130 < \Delta\kappa_\gamma < 0.130$$

$$-0.094 < \lambda_\gamma < 0.024$$

95 % C.L.

TGCs in good agreement with S.M. expectation

- Precision of TGC measurement becomes limited by systematics
- Measurements on C, P and CP violating parameters agrees with S.M.
- Measurement of W polarisation in WW events is in good agreement with S.M.