W Couplings at LEP

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SLAC

For the Four LEP Collaborations ADLO

39th Rencontres De Moriond On Electroweak Interactions And Unified Theories

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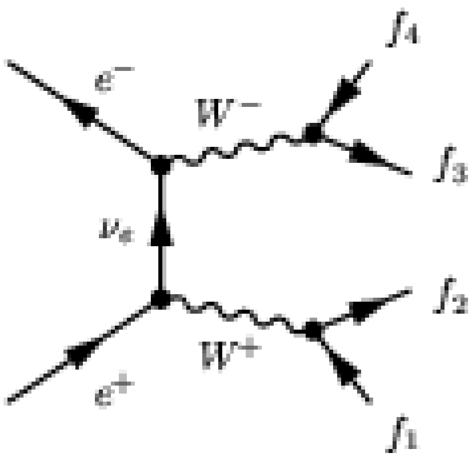
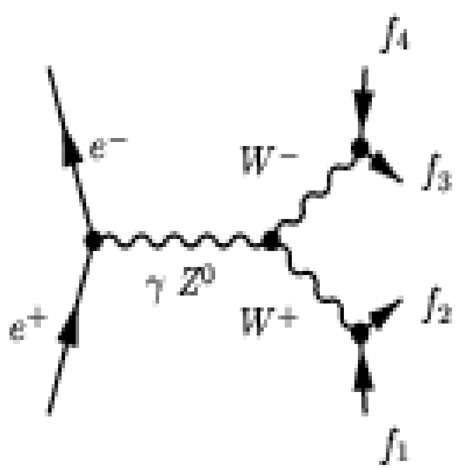
Topics

- W Pair Production Cross Section
- W Branching Fractions
- $WW\gamma$ Cross Section and Limits on Quartic Gauge Boson Couplings
- W Polarization
- Triple Gauge Couplings and Technipion Form Factor

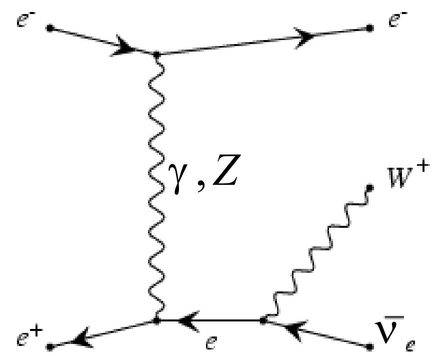
W Boson Production at LEP2

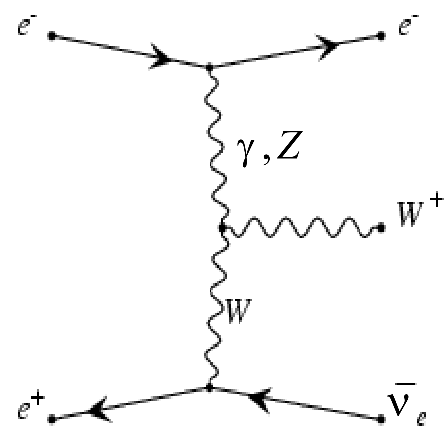
- $e^+e^- \rightarrow W^+W^-$





- $e^+e^- \rightarrow We\nu_e$



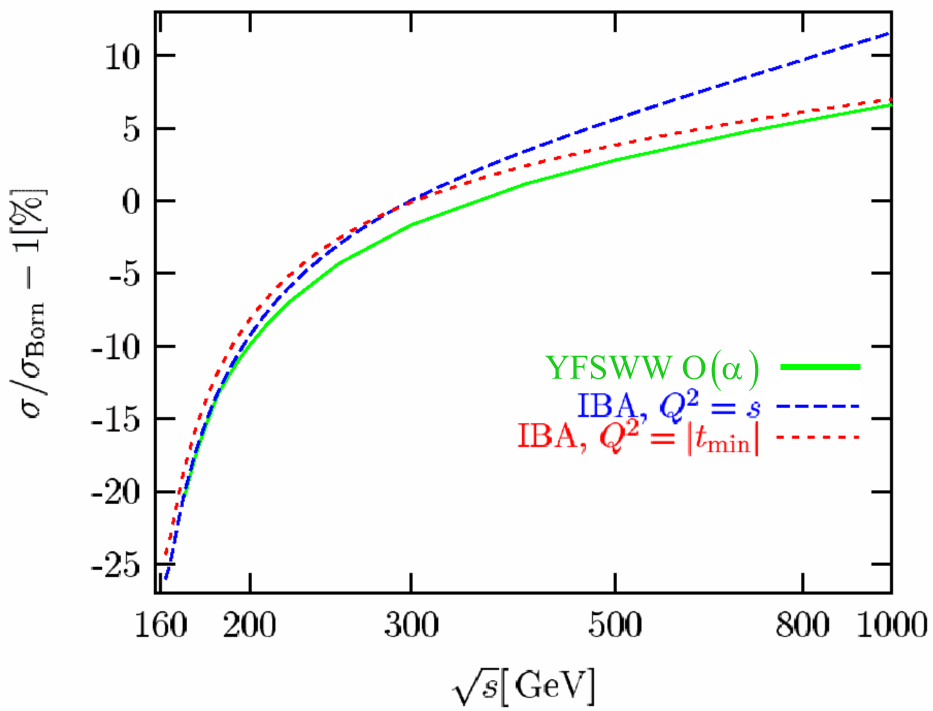


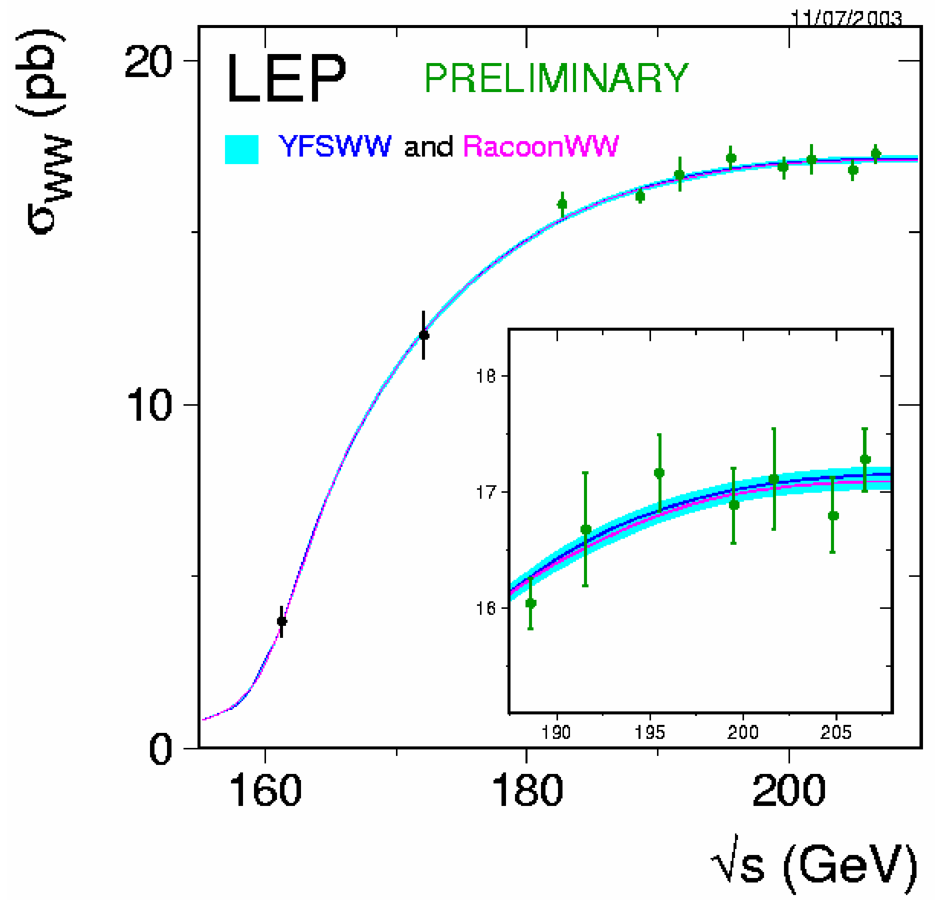
WW Cross Section

LEP Combination

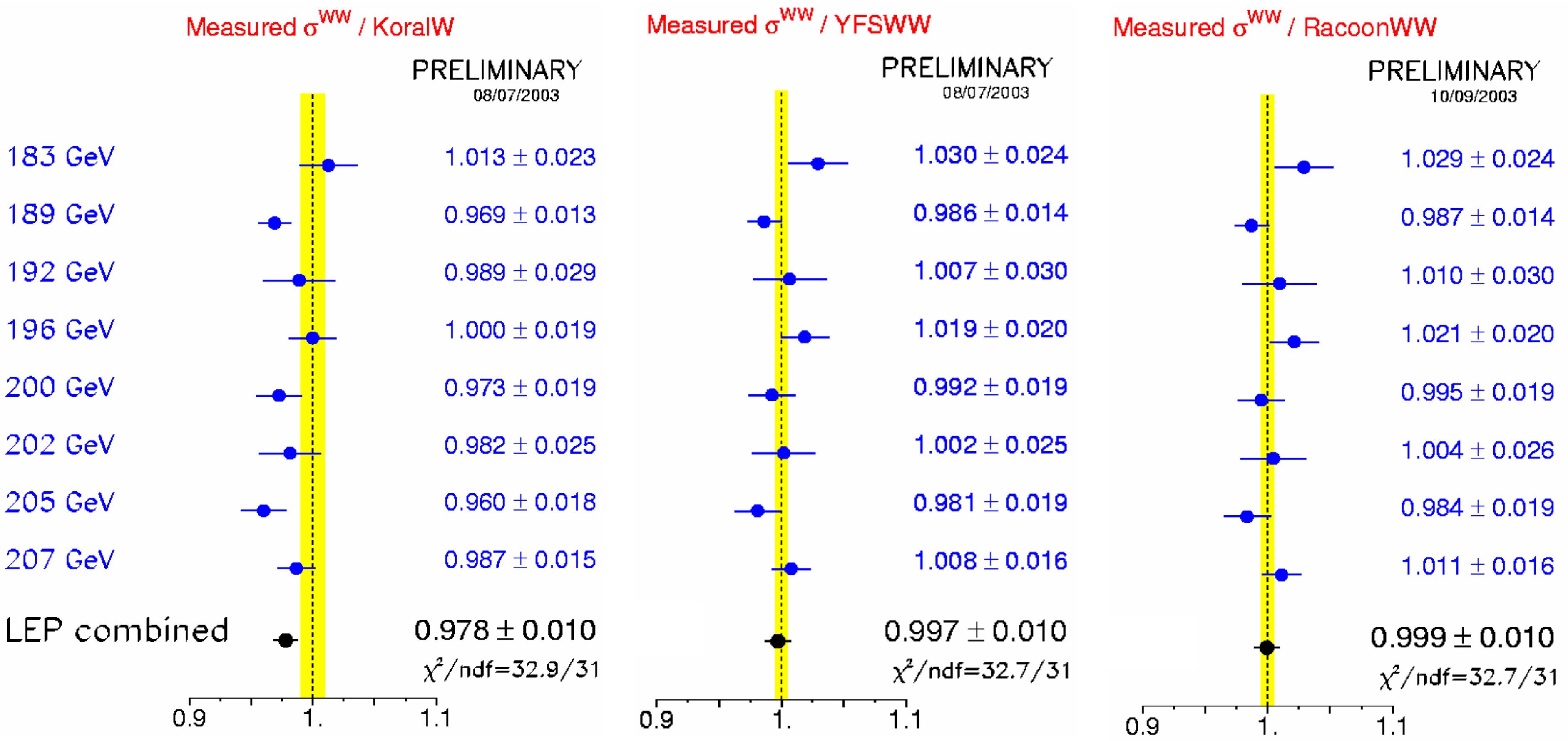
Theory cross sec with and without $O(\alpha)$ corrections:

DELPHI results are final



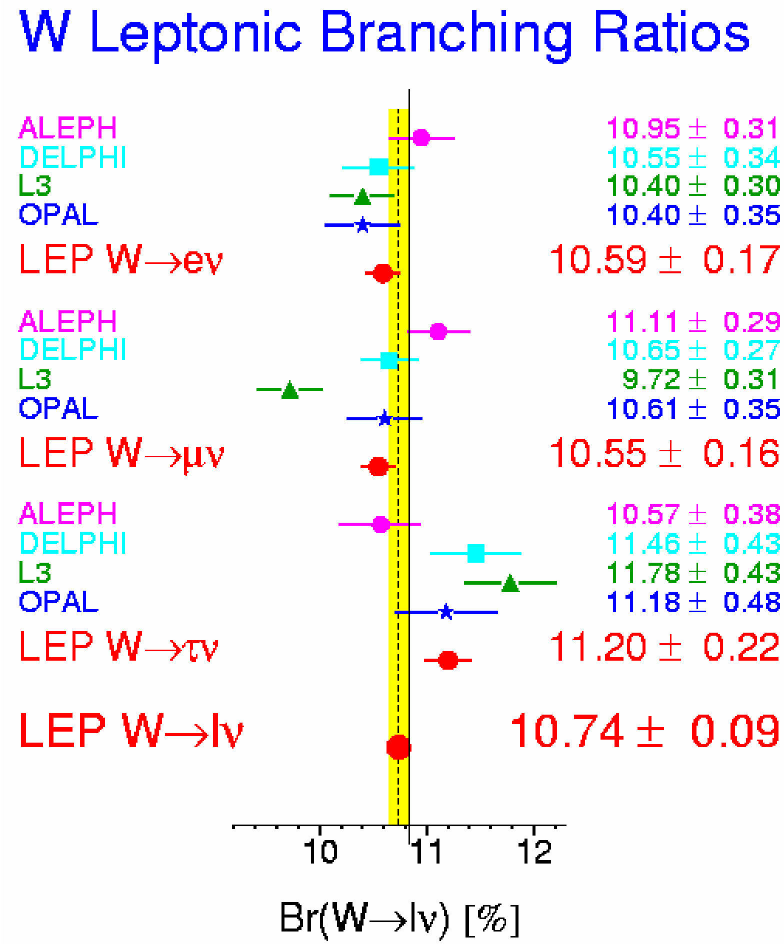


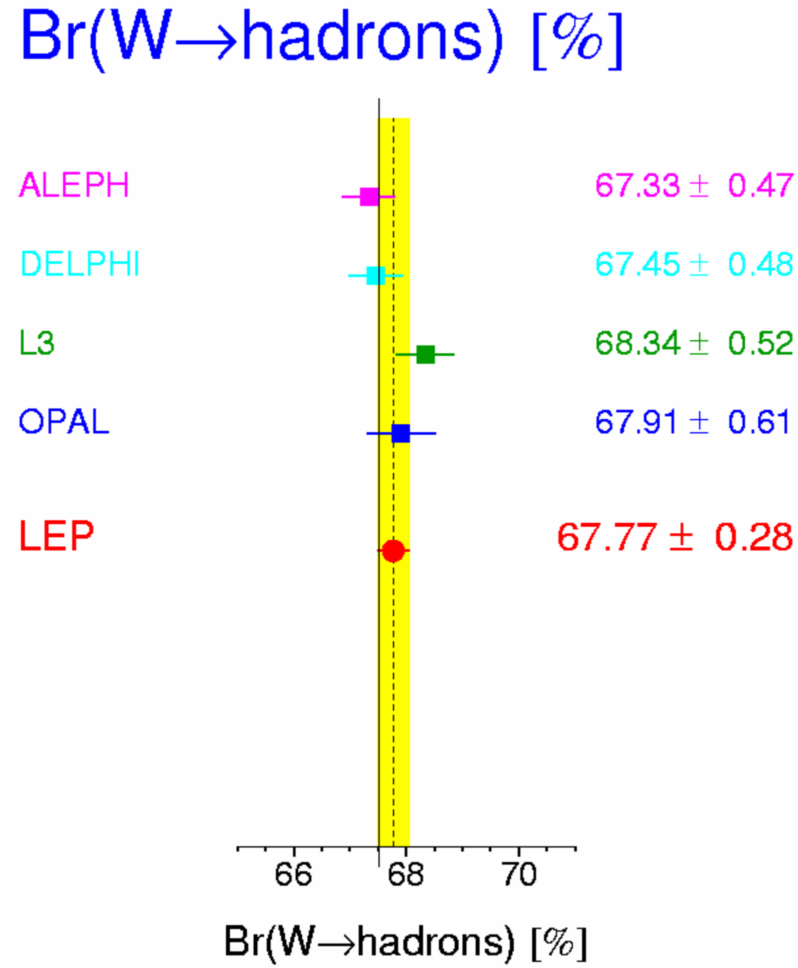
WW Cross Section



W Branching Fractions

SM: $Br(W \to l\upsilon) = 10.83\%$ $Br(W \to hadrons) = 67.51\%$





$$|V_{cs}| = 0.989 \pm 0.014$$

$$e^+e^- \rightarrow W^+W^-\gamma$$

LEP Combination Signal Defn:

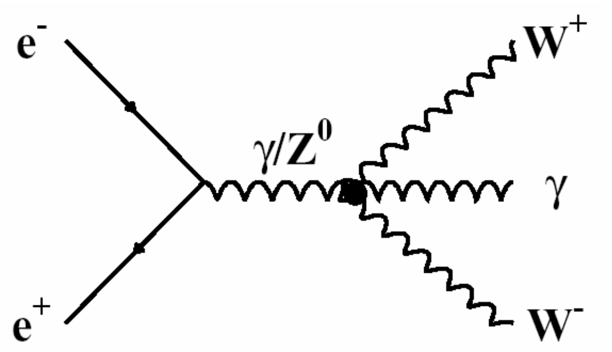
$$E_\gamma > 5\ GeV$$

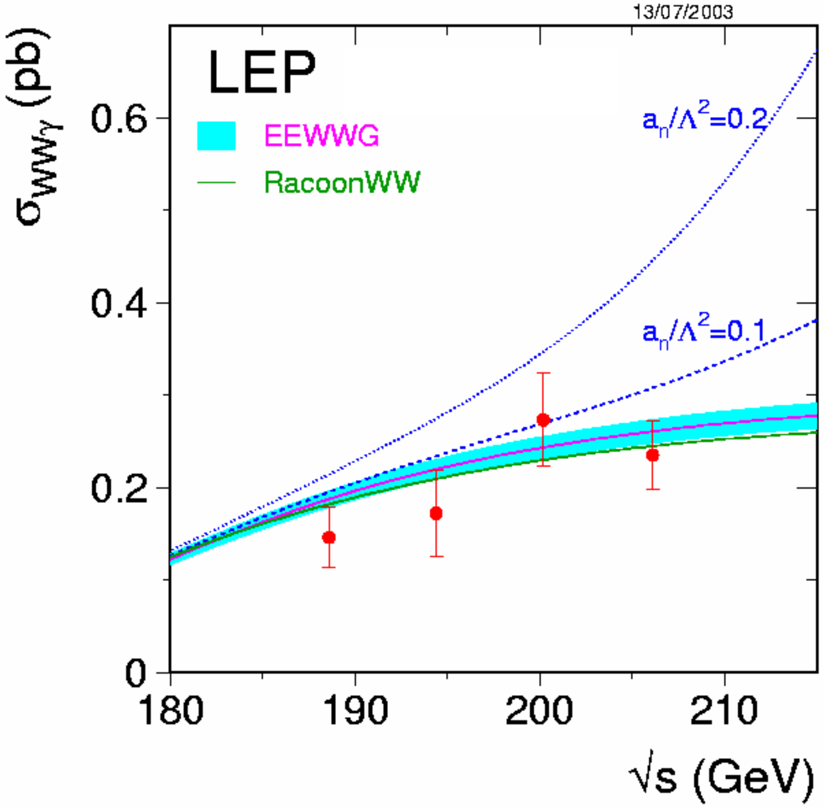
$$|\cos\theta_\gamma| < 0.95$$

$$|\cos\theta_{\gamma,f}| < 0.90$$

$$|M_{f,f'} - M_W| < 2\Gamma_W$$

- Tests real photon radiative corrections to $e^+e^- \rightarrow W^+W^-$
- Probes very anomalous 4 gauge boson couplings $\gamma\gamma W^+W^-$ and $\gamma Z W^+W^-$





Final LEP Results (DLO) on $W^+W^-\gamma$ Cross Section

Lowest dimension operators involving photons which generate quartic gauge couplings but not triple gauge couplings:

$$\mathcal{L}_6^0 = -\frac{e^2}{16\Lambda^2} a_0 \mathrm{F}^{\mu\nu}\mathrm{F}_{\mu\nu}\, \vec{W}^{\alpha} \cdot \vec{W}_{\alpha} \,, \qquad \gamma\gamma W^+W^-$$

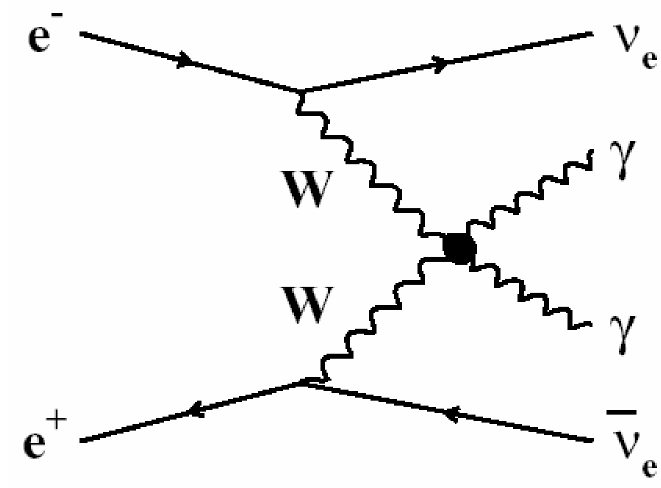
$$\mathcal{L}_6^c = -\frac{e^2}{16\Lambda^2} a_c \mathrm{F}^{\mu\alpha}\mathrm{F}_{\mu\beta}\, \vec{W}^{\beta} \cdot \vec{W}_{\alpha} \,, \qquad \gamma\gamma W^+W^-$$

$$\mathcal{L}_6^n = i\frac{e^2}{16\Lambda^2} a_n \epsilon_{ijk} W_{\mu\alpha}{}^{(i)} W_{\nu}{}^{(j)} W^{(k)\alpha} \mathrm{F}^{\mu\nu} \qquad \gamma Z W^+W^-$$

95% C.L. Limits on quartic couplings in GeV^{-2} from $W^+W^-\gamma$

DELPHI	L3	OPAL
$-0.020 < a_0/\Lambda^2 < 0.020$	$-0.017 < a_0/\Lambda^2 < 0.017$	$-0.020 < a_0/\Lambda^2 < 0.020$
$-0.063 < a_c/\Lambda^2 < 0.032$	$-0.052 < a_c/\Lambda^2 < 0.026$	$-0.053 < a_c/\Lambda^2 < 0.037$
$-0.180 < a_n/\Lambda^2 < 0.140$	$-0.140 < a_n/\Lambda^2 < 0.130$	$-0.160 < a_n/\Lambda^2 < 0.150$

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

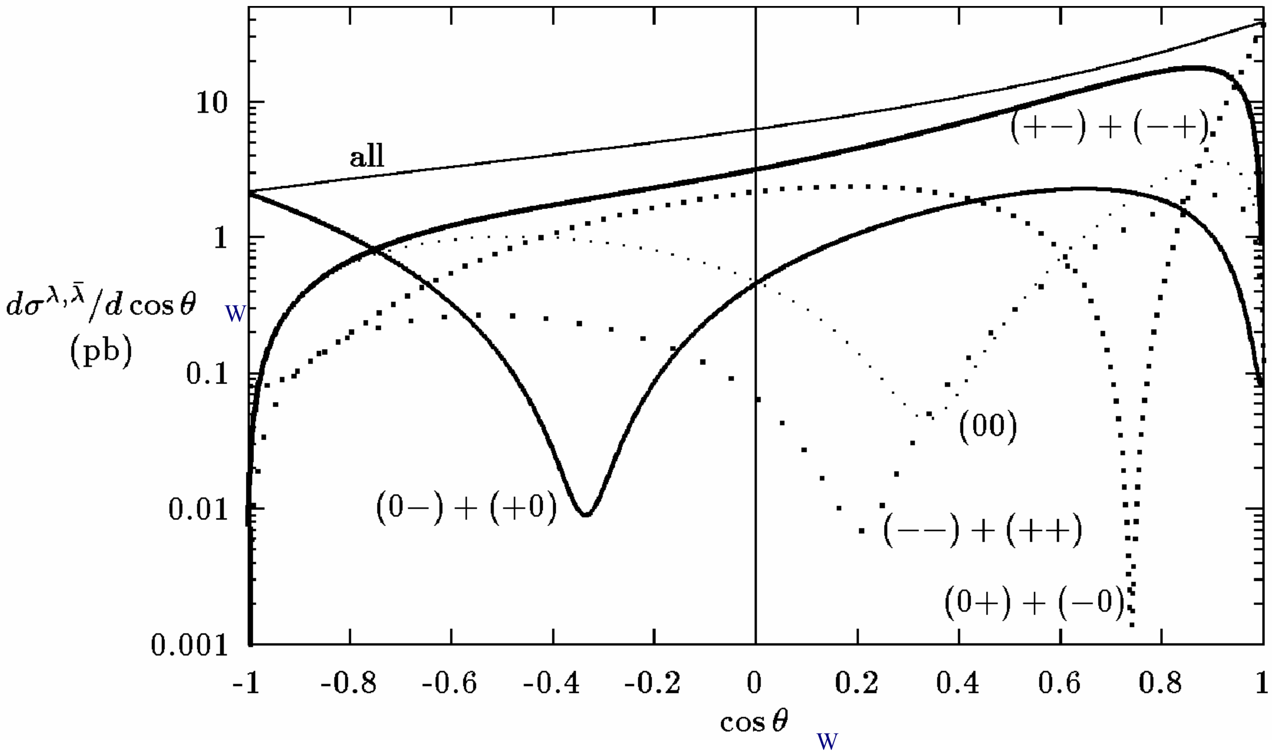


95% C.L. Limits on quartic couplings in GeV^{-2} from combining $W^{+}W^{-}\gamma$ and $\nu\bar{\nu}\gamma\gamma$ measurements:

L3	OPAL
$-0.015 < a_0/\Lambda^2 < 0.015$	$-0.020 < a_0/\Lambda^2 < 0.020$
$-0.048 < a_c/\Lambda^2 < 0.026$	$-0.052 < a_c/\Lambda^2 < 0.037$
$-0.140 < a_n/\Lambda^2 < 0.130$	$-0.160 < a_n/\Lambda^2 < 0.150$

W Polarization in $e^+e^- \to W^+W^-$

Measure spin density matrices $\rho_{kk}(s, \cos\theta_W)$ and extract polarized diff cross sec



$$\frac{d\sigma_L}{d\cos\theta_W} = \rho_{00}\cdot\frac{d\sigma}{d\cos\theta_W}$$

$$\frac{d\sigma_T}{d\cos\theta_W} = (\rho_{++}+\rho_{--})\cdot\frac{d\sigma}{d\cos\theta_W}$$

Fit for ρ_{kk} (L3)

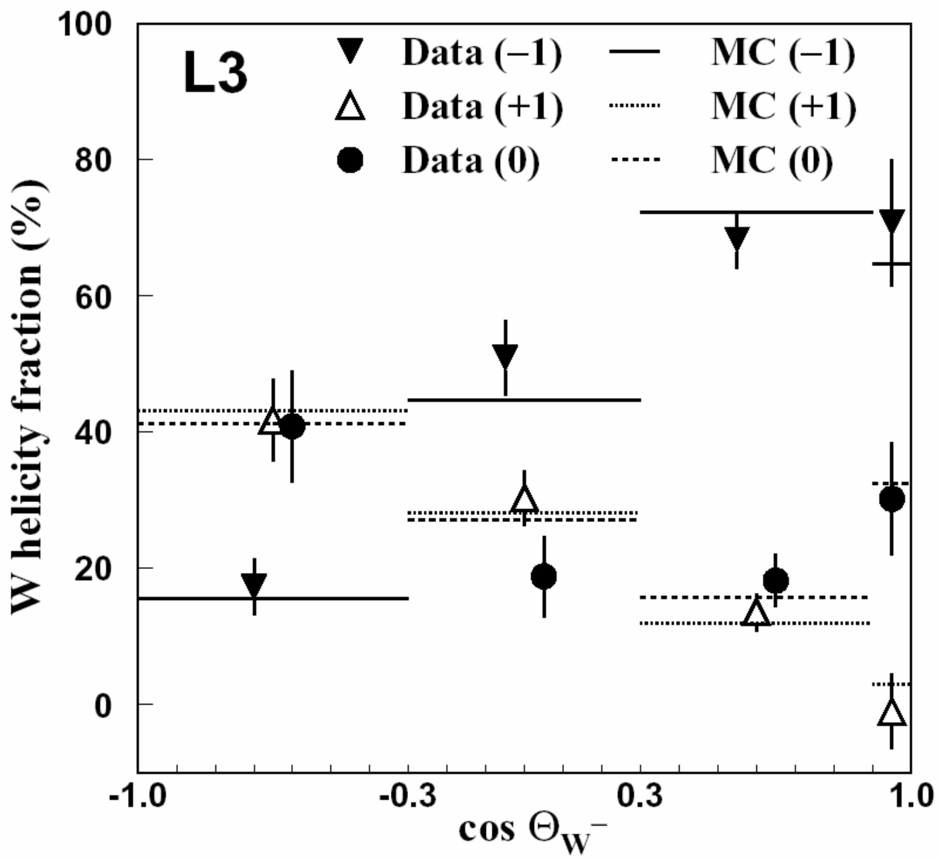
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_f^*} = \rho_{--}\frac{3}{8}\left(1+\cos\theta_f^*\right)^2 + \rho_{00}\frac{3}{4}\sin^2\theta_f^* + \rho_{++}\frac{3}{8}\left(1-\cos\theta_f^*\right)^2 .$$

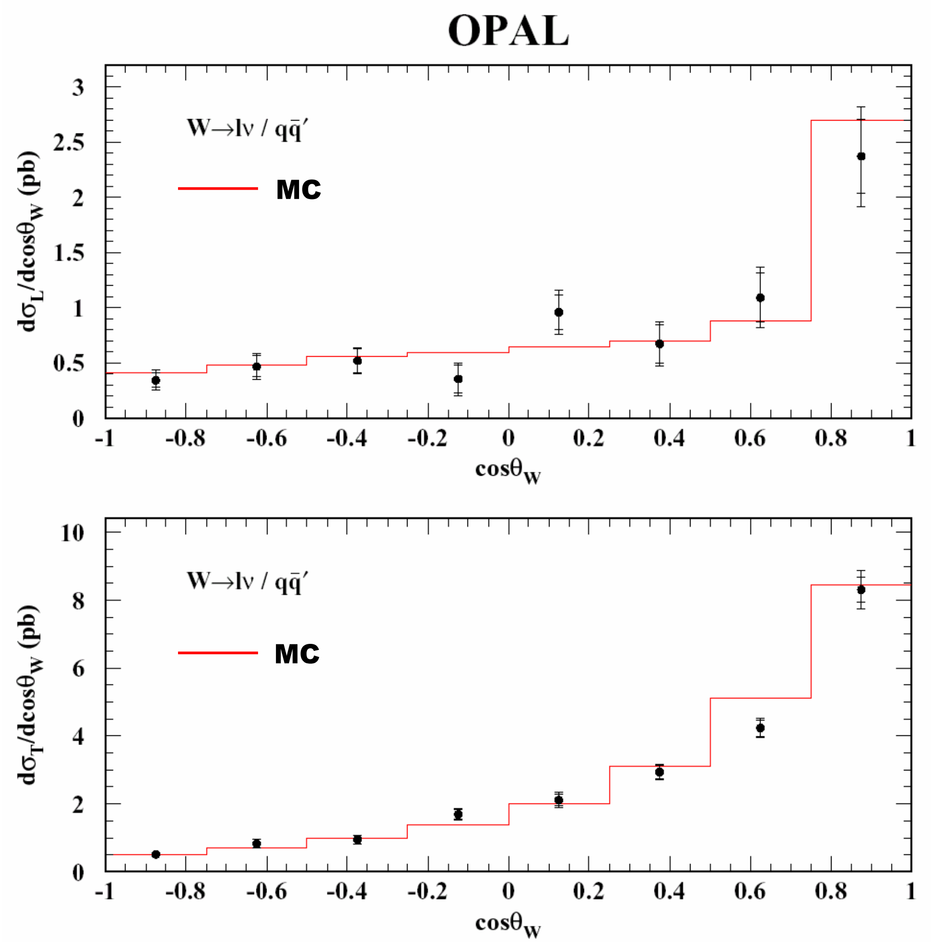
Use avg value of projection op Λ_{kk} (OPAL)

$$\rho_{\tau\tau'}^{W^-}(s,\cos\theta_W) = \frac{\int \frac{d^3\sigma}{d\cos\theta_W\, d\cos\theta_f^*\, d\phi_f^*}\cdot\Lambda_{\tau\tau'}\, d\cos\theta_f^*\, d\phi_f^*}{\frac{d\sigma}{d\cos\theta_W}}$$

W Polarization in $e^+e^- \to W^+W^-$

Polarized Differential Cross Sections





Triple Gauge Couplings

7 Complex Triple Gauge Couplings (TGCs) in Lorentz Invariant WWV Vertex $(V = \gamma, Z)$

	g_1^V	κ_V	λ_V	g_5^V	g_4^V	$\tilde{\kappa}_V$	$\tilde{\lambda}_V$
C	+	+	+	-	-	+	+
P	+	+	+	-	+	-	-
SM	**1**	**1**	**0**	**0**	**0**	**0**	**0**

$$\text{electric charge } Q_W = e g_1^\gamma$$

$$\text{magnetic dipole moment } \mu_W = \frac{e}{2M_W}(1 + \kappa_\gamma + \lambda_\gamma)$$

$$\text{electric dipole moment } d_W = \frac{e}{2M_W}(\tilde{\kappa}_\gamma + \tilde{\lambda}_\gamma)$$

Precision Electroweak Data $\Longrightarrow$ Effective Lagrangian must be SU(2)XU(1) Invariant to a Very Good Approximation

This can be used to constrain allowed TGC values IF assumptions about low energy (< 1TeV) particle content are made:

Assuming effective Lagangian is C and P invariant , a relatively light Higgs boson, and no particles beyond SM at low energy $\Longrightarrow$

$$g_1^Z \;\; \kappa_\gamma \;\; \lambda_\gamma \text{ are free parameters}$$

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

$$\lambda_Z = \lambda_\gamma$$

$$g_1^\gamma = 1$$

$$\text{all other TGCs} = 0$$

This model used for 1d, 2d, 3d fits by all 4 experiments, and for 1d & 2d LEP comb

Assuming effective Lagrangian is C and P invariant ,a heavy (or no) Higgs boson and no particles beyond SM at low energy $\Longrightarrow$

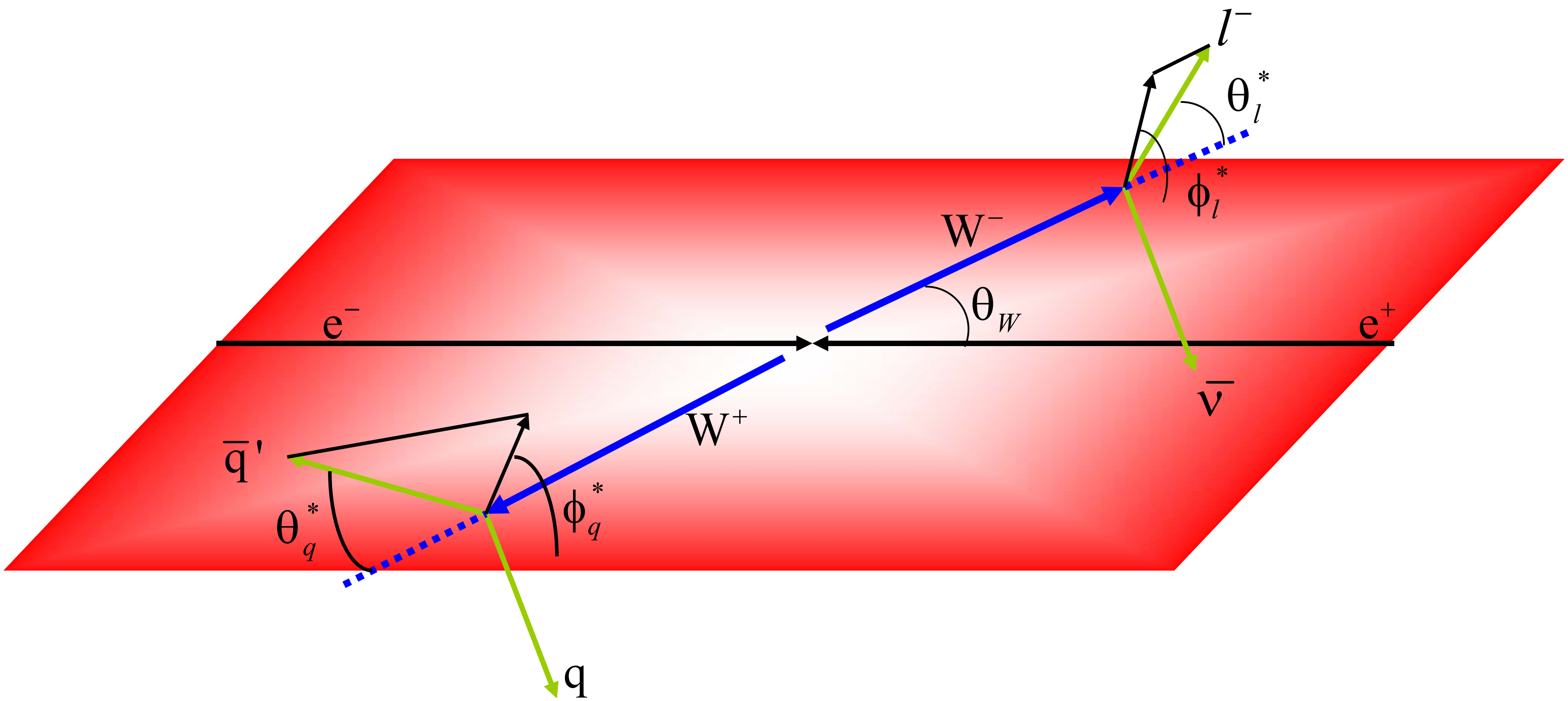
$$g_1^Z \;\; \kappa_\gamma \;\; \kappa_Z \text{ are free parameters}$$

$$g_1^\gamma = 1$$

$$\text{all other TGCs} = 0$$

Triple Gauge Couplings

Most important process for studying TGCs is $e^+e^- \to W^+W^-$



Also some sensitivity to $WW\gamma$ TGCs from

$e^+e^- \to W^+e^-\bar{\nu}_e$ and $e^+e^- \to \nu_e\bar{\nu}_e\gamma$

Triple Gauge Couplings: W^+W^- Analysis

Use angular distributions from all event topologies:

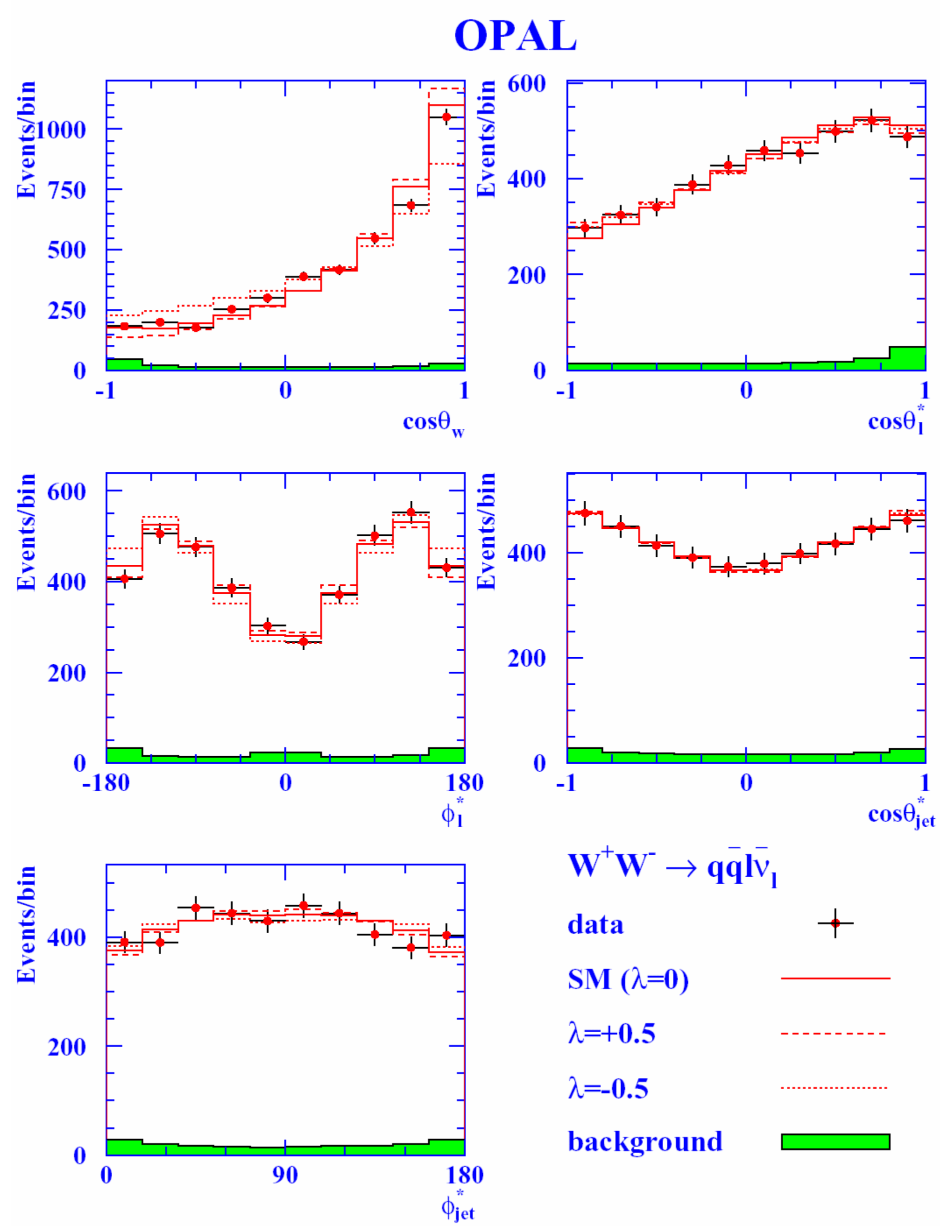
$$W^+W^- \rightarrow l^-\bar{\nu} q\bar{q}$$
$$q\bar{q}q\bar{q}$$
$$l^-\bar{\nu} l^+\nu$$

No jet flavor tagging - average over jet directions in W rest frame.

Do W charge tagging to obtain W^- direction in $q\bar{q}q\bar{q}$ events

Include total cross section

Use Monte Carlo to correct for detector effects and to implement radiative corrections



Triple Gauge Couplings: Systematic Errors

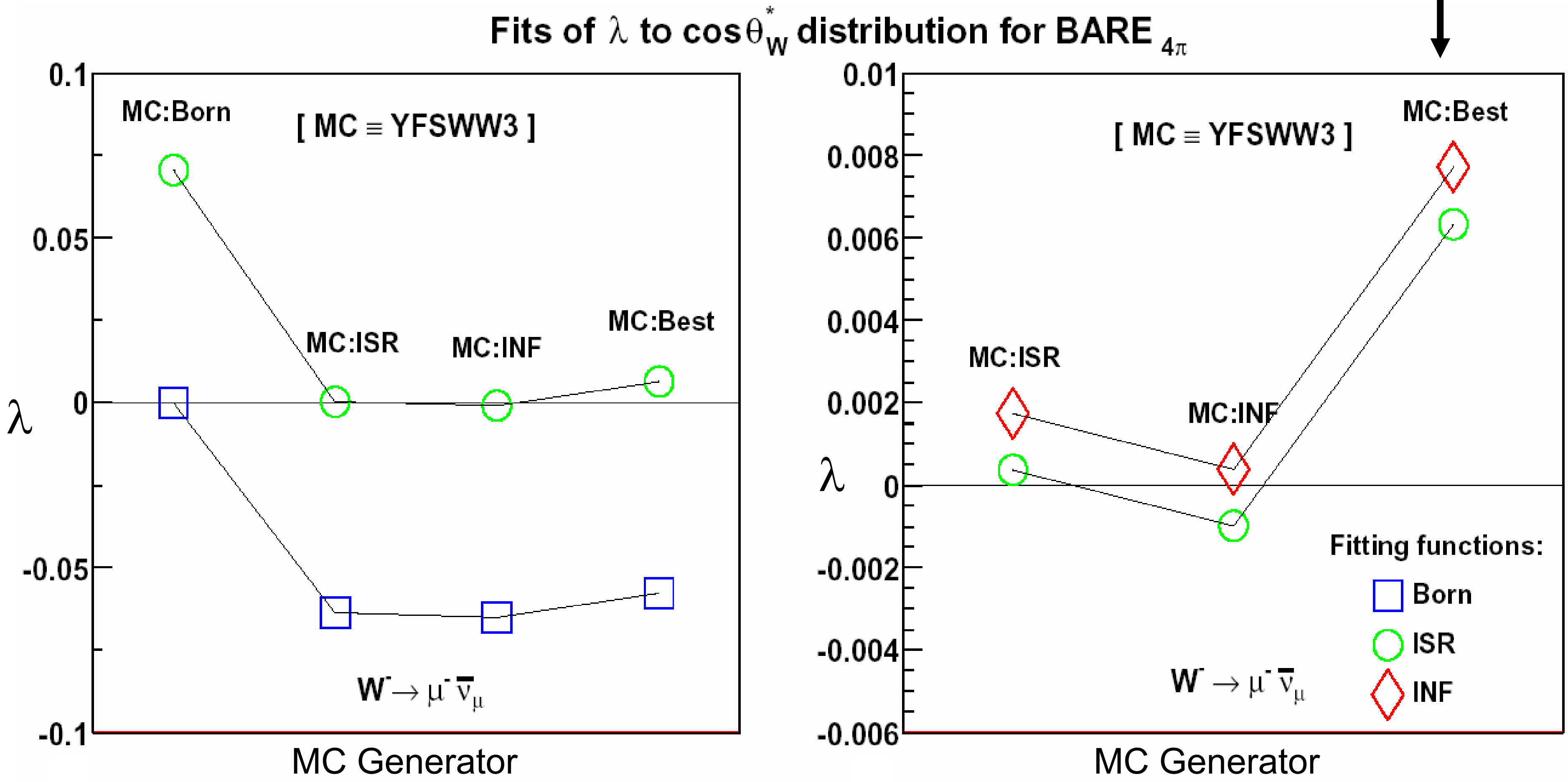
OPAL

	Source	$\Delta\kappa_\gamma$	Δg_1^z	λ	g_5^z
a)	$\mathcal{O}(\alpha)$ correction	0.029	0.011	0.010	0.031
b)	ISR	0.006	0.002	0.003	0.003
c)	Fragmentation	0.038	0.013	0.018	0.047
d)	TGC matrix element	0.011	0.005	0.004	0.005
e)	Detector simulation	0.006	0.003	0.005	0.013
f)	Background	0.015	0.004	0.011	0.012
g)	$\sqrt{s}$, M_W	0.008	0.004	0.005	0.017
h)	Bose-Einstein correlations	0.001	0.000	0.004	0.005
i)	Colour reconnection	0.004	0.003	0.005	0.000
	Total	0.053	0.019	0.026	0.061

Triple Gauge Couplings: $O(\alpha)$ Shape Sys Error

$O(\alpha)$ electroweak corrections to angular distribution shift λ by 0.008

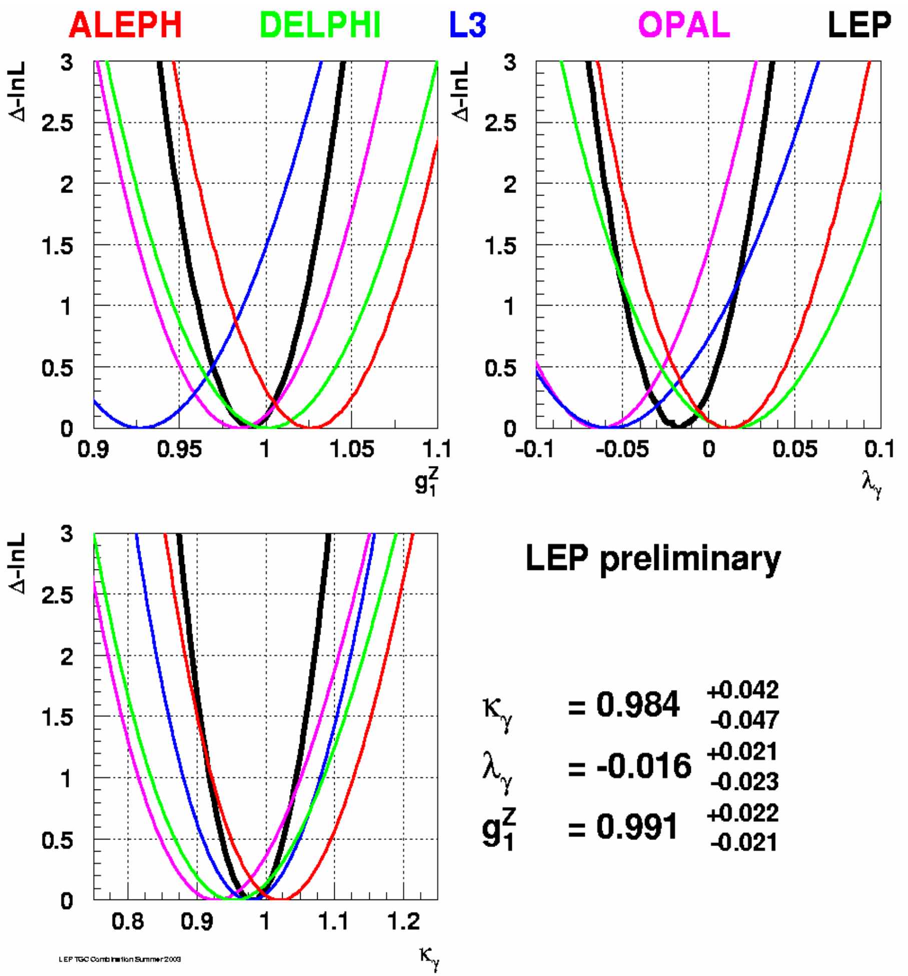
Total theory error estimated to be $\Delta\lambda = 0.005$

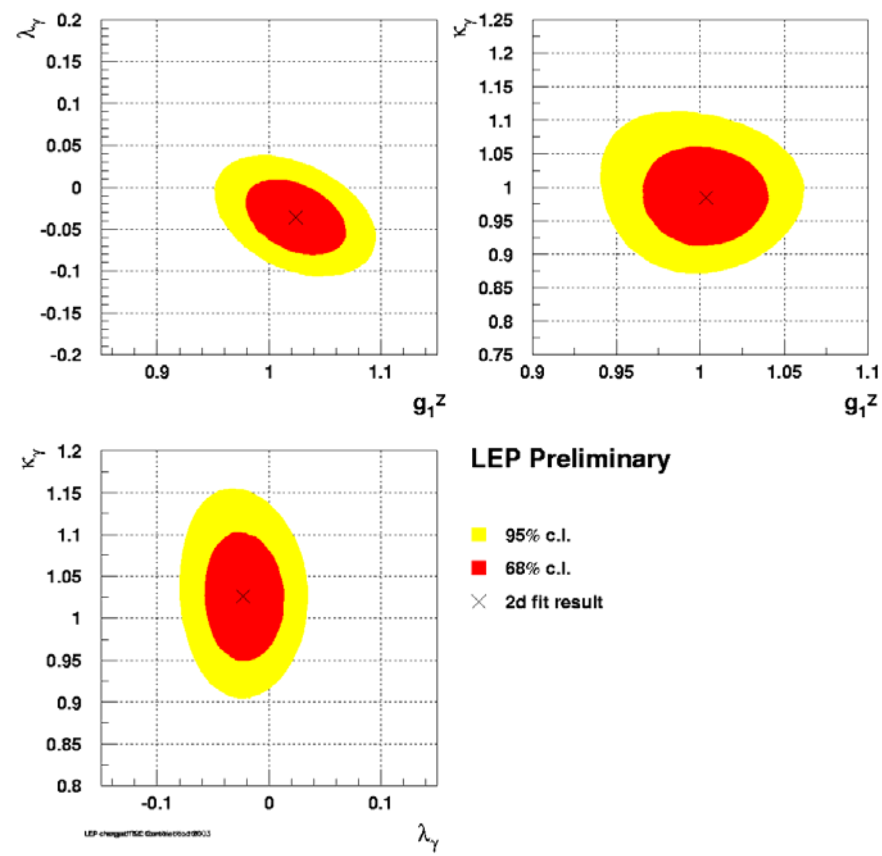


OPAL & DELPHI assign $O(\alpha)$ theory error = total shift in TGC due to $O(\alpha)$ corr.

ALEPH & L3 assign $O(\alpha)$ theory error = 1/2 shift in TGC due to $O(\alpha)$ corr.

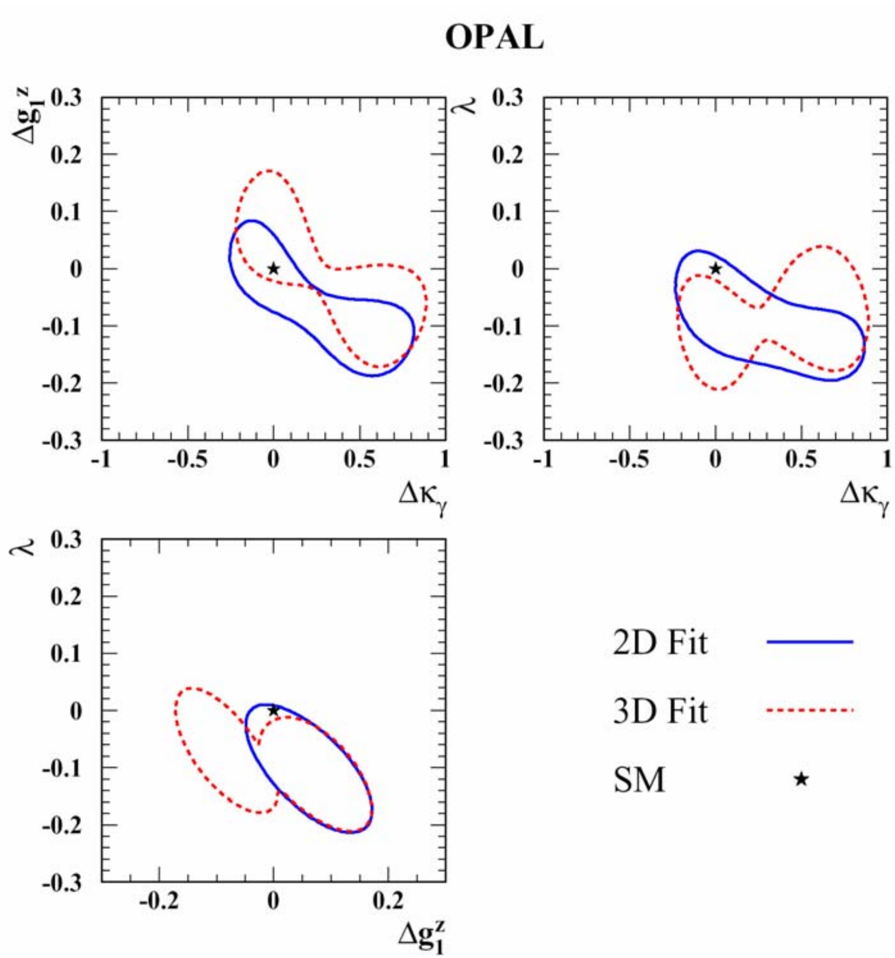
Triple Gauge Couplings: 1d & 2d Fit LEP Results

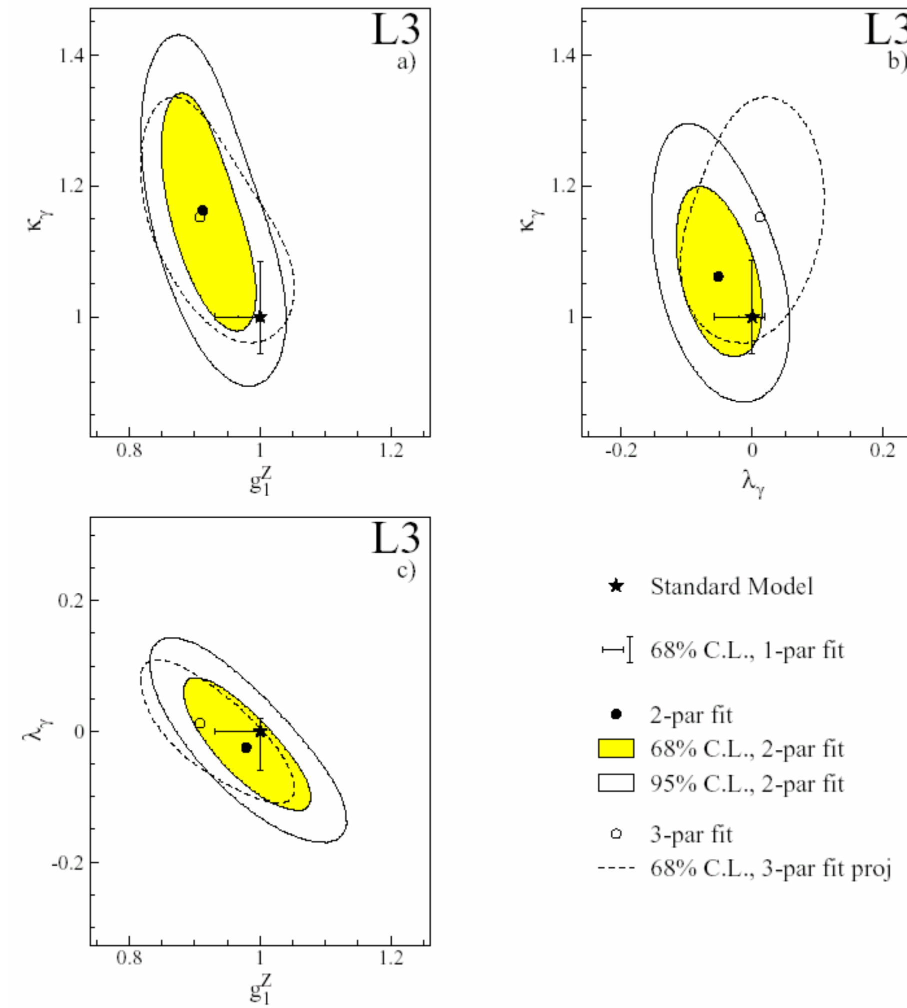




L3 and OPAL results are final

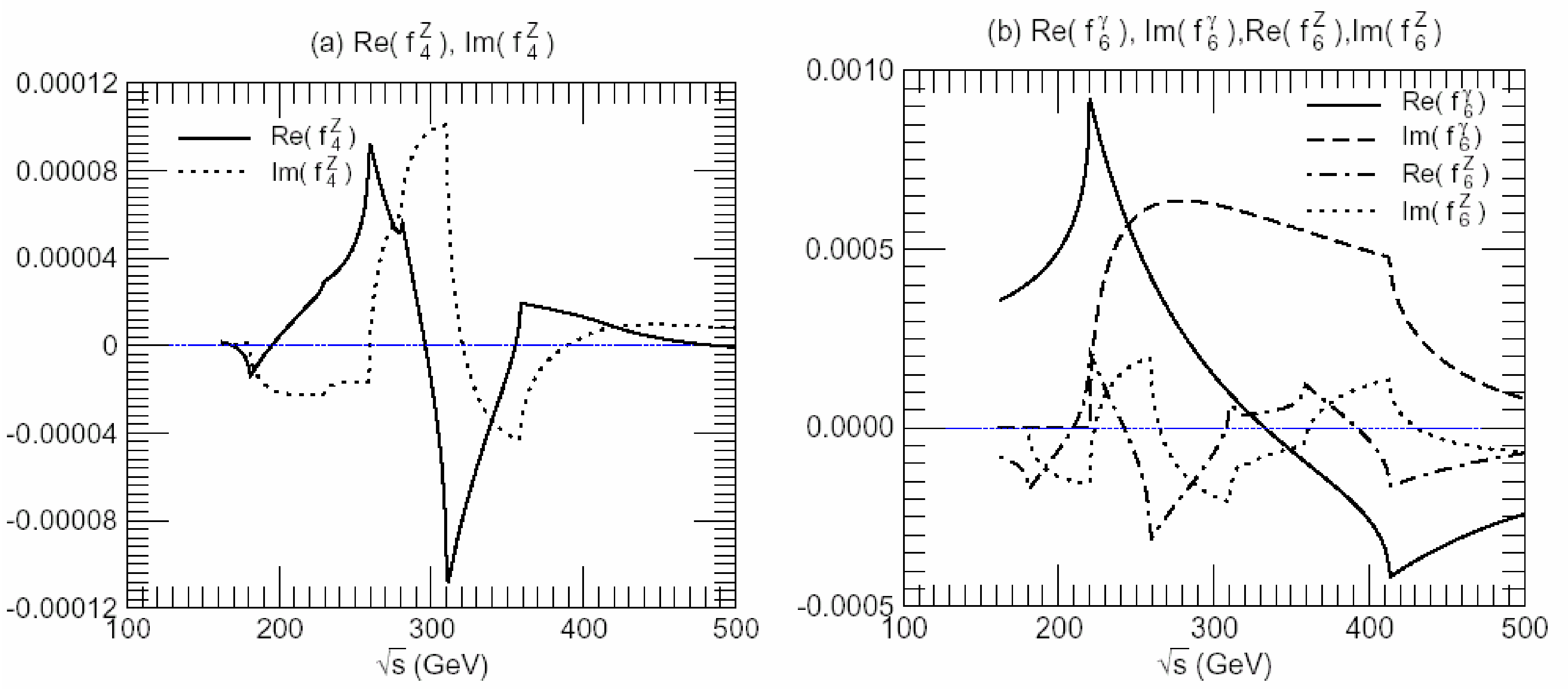
Triple Gauge Couplings: 3d Fit Results





One-Loop SUSY Contribution to CP Violating TGCs

Hagiwara,Kanemura,Klasen,Umeda hep-ph/0212135

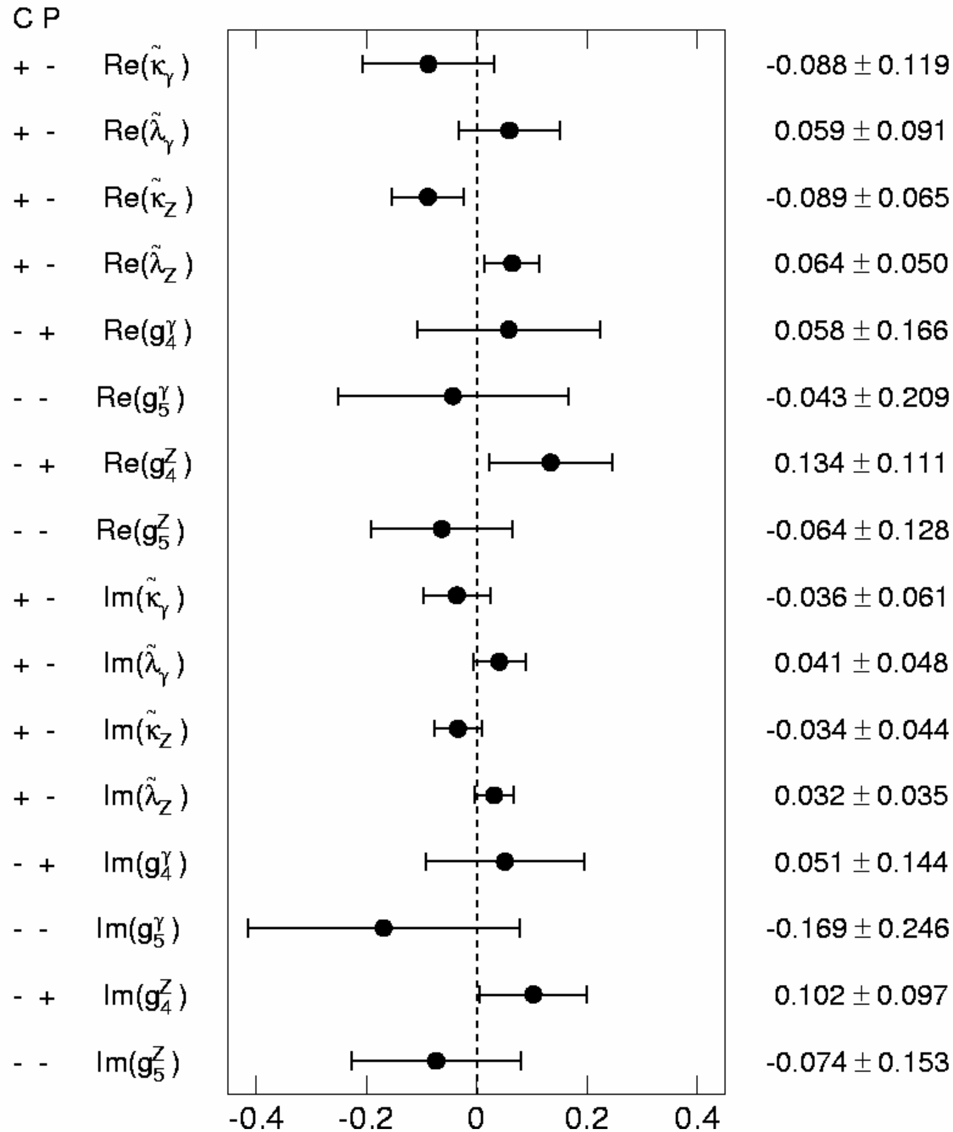


$$f_4^Z = g_4^Z \qquad\qquad f_6^V = \tilde{\kappa}_V - \tilde{\lambda}_V$$

ALEPH Preliminary

C, P Violating TGCs

183-209 GeV Data (684.0 pb^{-1})

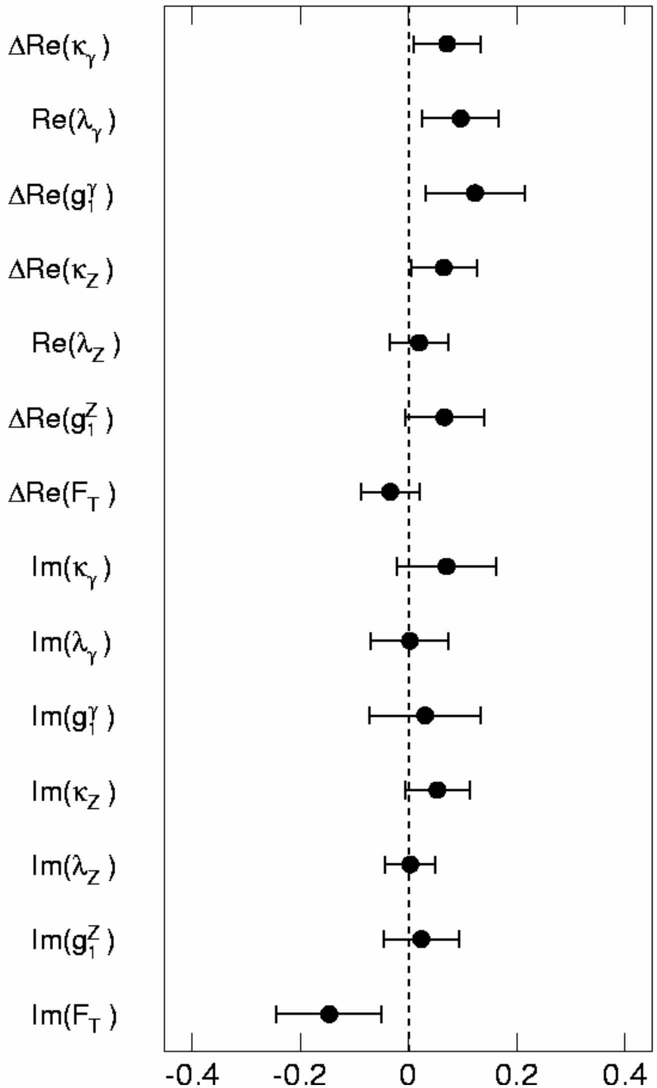


L3 (Final)	OPAL (Final)
0.00 ± 0.139	-0.04 ± 0.125

ALEPH Preliminary

C, P Conserving TGCs, No SU(2) X U(1) Constraints

183-209 GeV Data (684.0 pb^{-1})



$\Delta Re(\kappa_\gamma)$	0.071 ± 0.062
$Re(\lambda_\gamma)$	0.096 ± 0.071
$\Delta Re(g_1^\gamma)$	0.123 ± 0.091
$\Delta Re(\kappa_Z)$	0.065 ± 0.061
$Re(\lambda_Z)$	0.019 ± 0.054
$\Delta Re(g_1^Z)$	0.066 ± 0.073
$\Delta Re(F_T)$	-0.034 ± 0.055
$Im(\kappa_\gamma)$	0.070 ± 0.091
$Im(\lambda_\gamma)$	0.002 ± 0.072
$Im(g_1^\gamma)$	0.030 ± 0.103
$Im(\kappa_Z)$	0.053 ± 0.060
$Im(\lambda_Z)$	0.003 ± 0.046
$Im(g_1^Z)$	0.023 ± 0.069
$Im(F_T)$	-0.147 ± 0.097

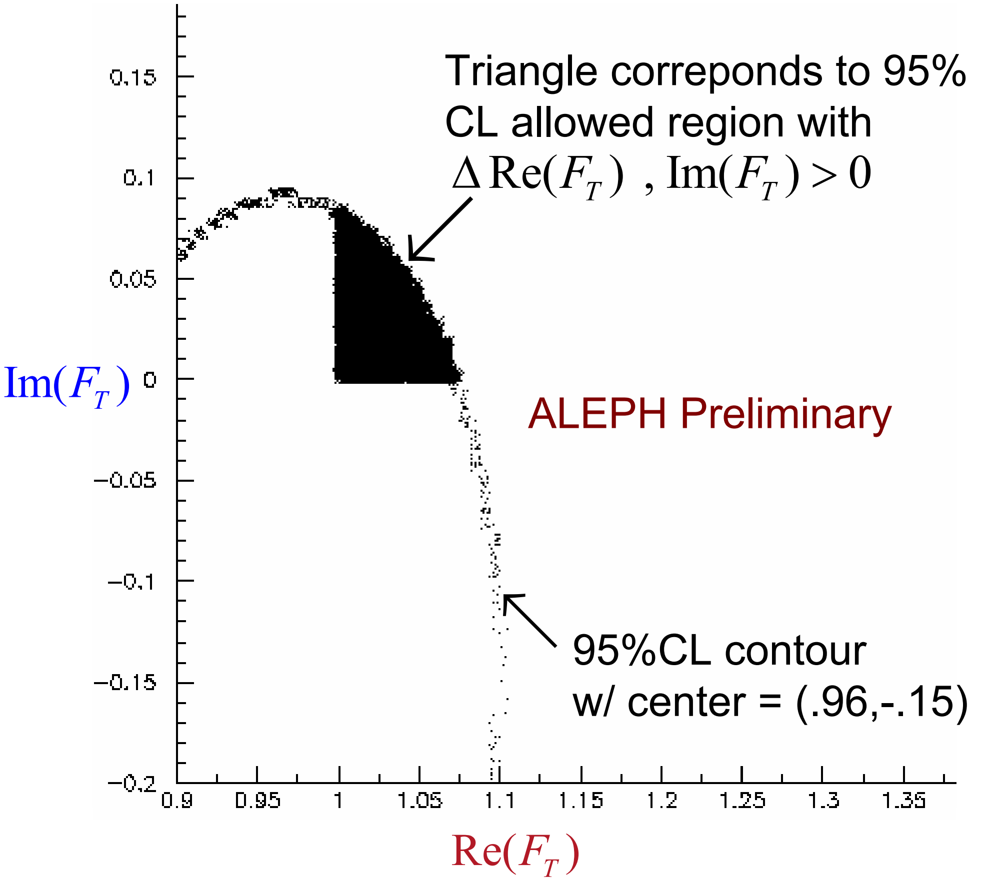
L3 (Final)

-0.076 ± 0.062

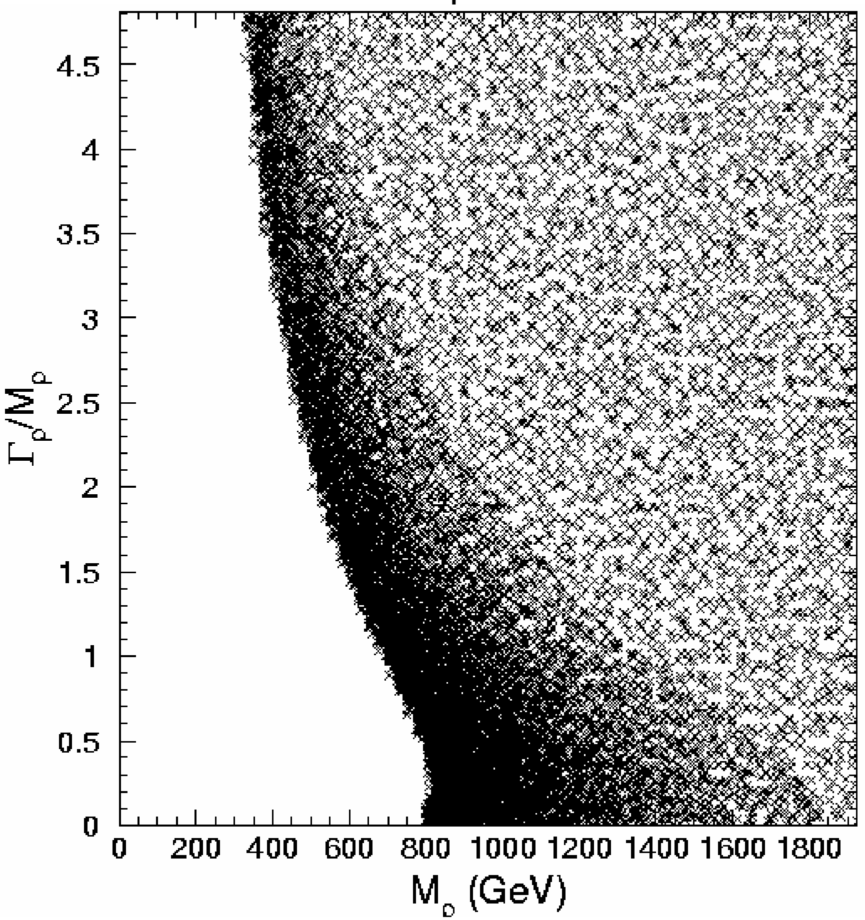
-0.088 ± 0.063

Form Factor F_T for Vector Resonance Enhancement of $e^+e^- \to W_L^{\,+}W_L^{\,-}$

$$F_T = 1 + \left(1 + \frac{\Gamma_\rho^2}{M_\rho^2}\right)^{-1} \frac{s}{M_\rho^2} + i\frac{\Gamma_\rho}{M_\rho}\left(1 + \frac{\Gamma_\rho^2}{M_\rho^2}\right)^{-1} \frac{s}{M_\rho^2}$$



Map triangle onto $(M_\rho, \Gamma_\rho / M_\rho)$ plane



For $\frac{\Gamma\rho}{M\rho} < 1$ the technirho mass $M_\rho > 675\,GeV$ at 95% C.L.

For $\frac{\Gamma\rho}{M\rho} < 0.5$ the technirho mass $M_\rho > 775\,GeV$ at 95% C.L.

Summary

- W Pair Production Cross Section Agrees with SM at all LEP2 energies. Agreement is best when $O(\alpha)$ electroweak rad corr are included.
- W Decay Branching Fractions Agree with SM.
- No Anomalous Quartic Couplings Observed.
- Fraction of Longitudinal and Transverse W Polarizations in Agreement with SM.
- TGCs measured to few percent accuracy. No deviation from the SM is observed.