W couplings measurements at LEP

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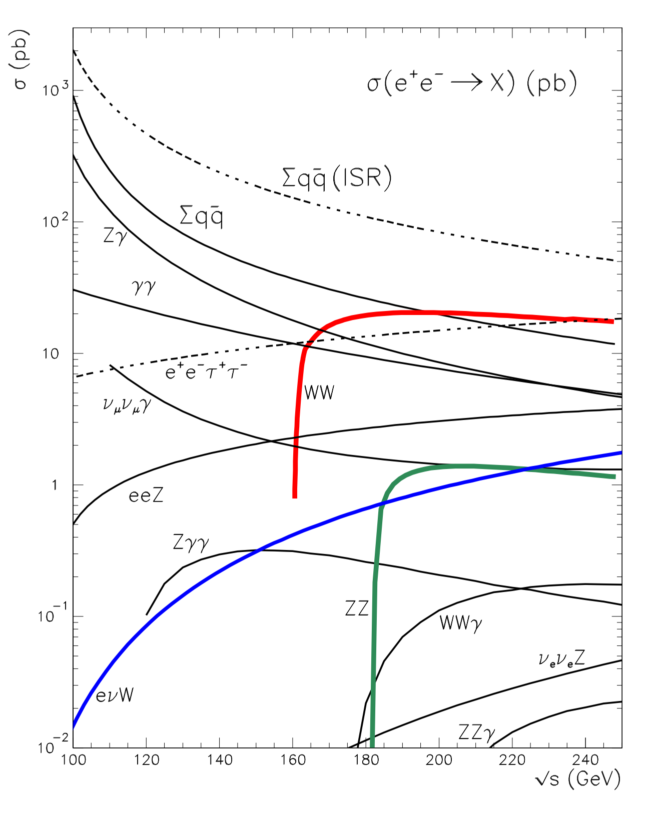
- W pair production cross section
- W decay branching ratios
- γWW and ZWW couplings
- a small detour on ZZγ and Z$\gamma\gamma$

All results from the 1997 run are preliminary

LEP–wide averages provided by
the LEP Electroweak working group

Recorded luminosities above the WW threshold

- $\approx$ 11 pb^{-1} at $\sqrt{s} \approx$161 GeV $\Longleftrightarrow$ 20 W pairs/expt.
- $\approx$ 10 pb^{-1} at $\sqrt{s} \approx$172 GeV $\Longleftrightarrow$ 100 W pairs/expt.
- $\approx$ 57 pb^{-1} at $\sqrt{s} \approx$183 GeV $\Longleftrightarrow$ 800 W pairs/expt.

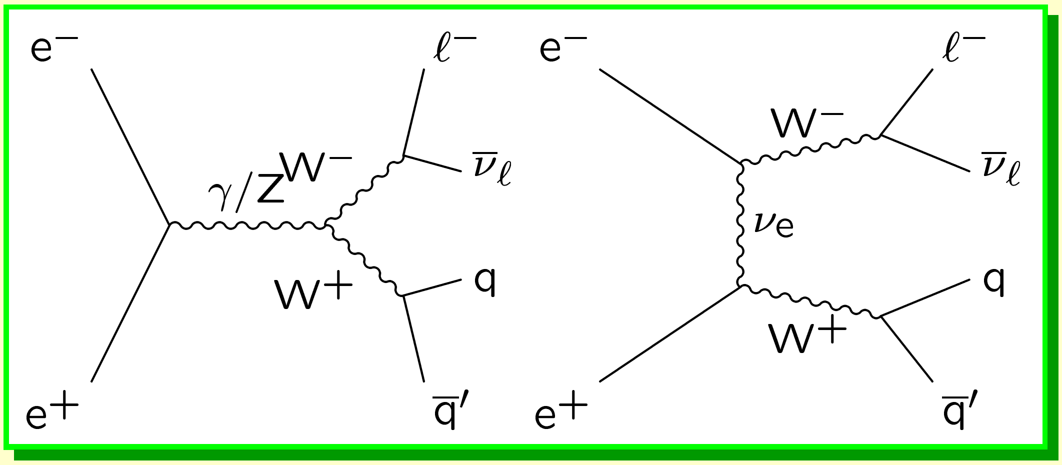


Cross section ratio σ_{WW}/σ_{had}

- $\approx$ 1/40 at threshold
- $\approx$ 1/10 above threshold

4–fermion CC production

WW production proceeds through γ/Z annihilation or t–channel ν_e exchange (3 diagrams – CC03)



Same 4–fermion final state reached through other non–resonant diagrams

$\Longrightarrow$ background and interference effects

Largest in channels with electron among the final state products

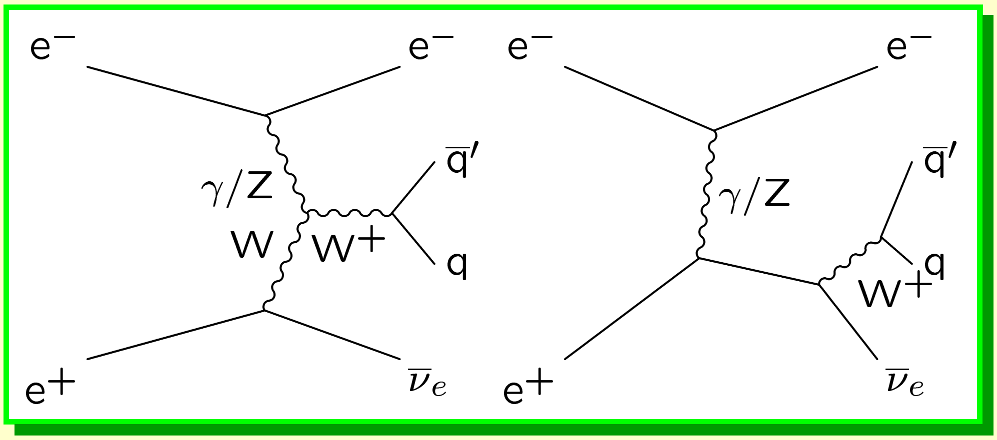
How to obtain the CC03 cross section ?

- DELPHI and L3 apply multiplicative factor 4–fermion $\Longleftrightarrow$ CC03
- ALEPH and OPAL treat non–resonant diagrams and interference as backgrounds to be subtracted

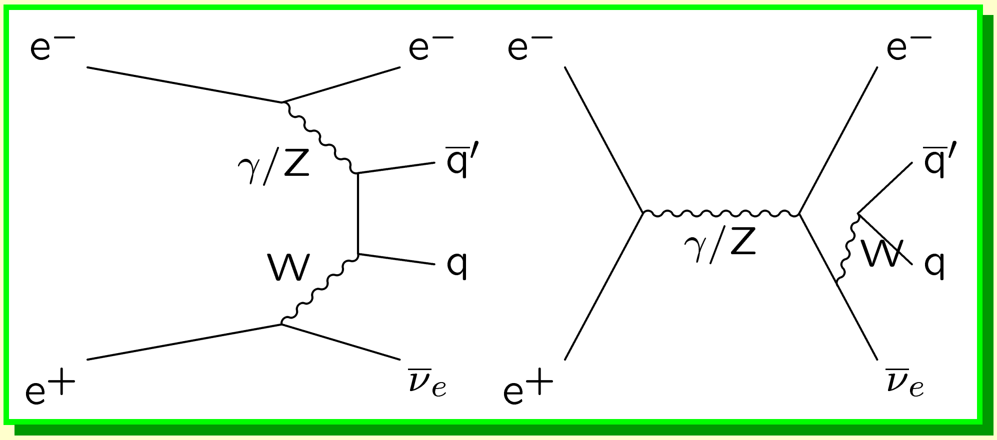
Both procedures give consistent results

Other 4–fermion diagrams

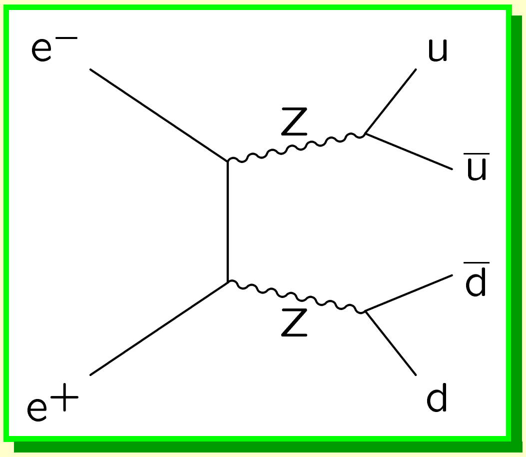
Singly resonating diagrams



Non resonating diagrams

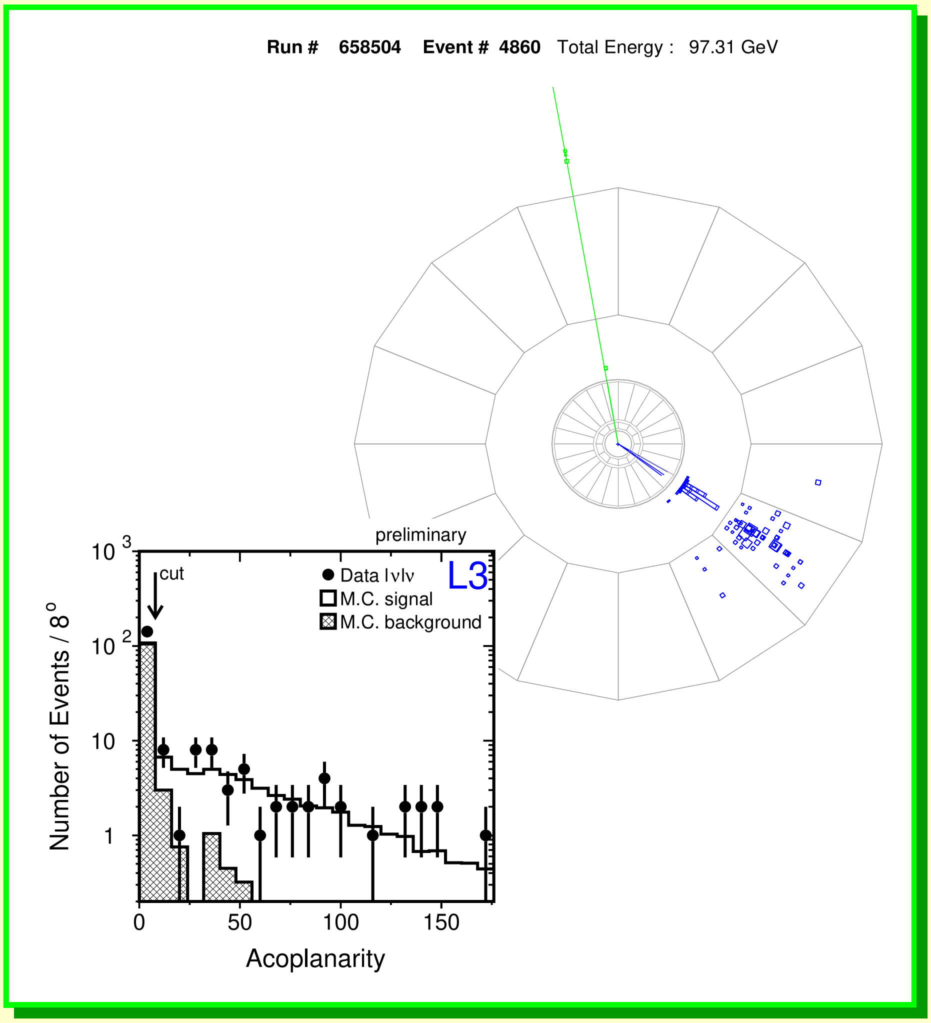


ZZ diagrams



Event selection: leptonic final state(s)

- Branching ratio 10.5%
- e/μ identification, τs identified as narrow jets
- Large $\not{p}_T$ and acoplanarity, veto against $\ell^+\ell^-(\gamma)$ events
- Topological 2 lepton search or dedicated selection of final state
- Event classification



L3 event: $\mathrm{W}^+\mathrm{W}^- \rightarrow \mu^-\overline{\nu}_\mu\tau^+\nu_\tau$

Efficiency and purity at $\sqrt{s} = 183$ GeV

	Average efficiency	Purity	Selected events
ALEPH	71%	89%	60
DELPHI	60%	83%	59
L3	56%	86%	54
OPAL	77%	94%	78

but

- Large cross talk between channels ($\mathrm{e}/\mu \Longleftrightarrow \tau$) taken into account with a correlation matrix (see later...)
- Lower efficiency in channels with 1 or 2 τs

Backgrounds dominated by $\gamma\gamma \to \ell^+\ell^-$ and 4–fermion events (mostly $\mathrm{ZZ} \to \ell^+\ell^-\nu\overline{\nu}$)

Systematic errors (comparison between MC models, MC statistics, veto efficiencies) are small compared to the current statistical ones.

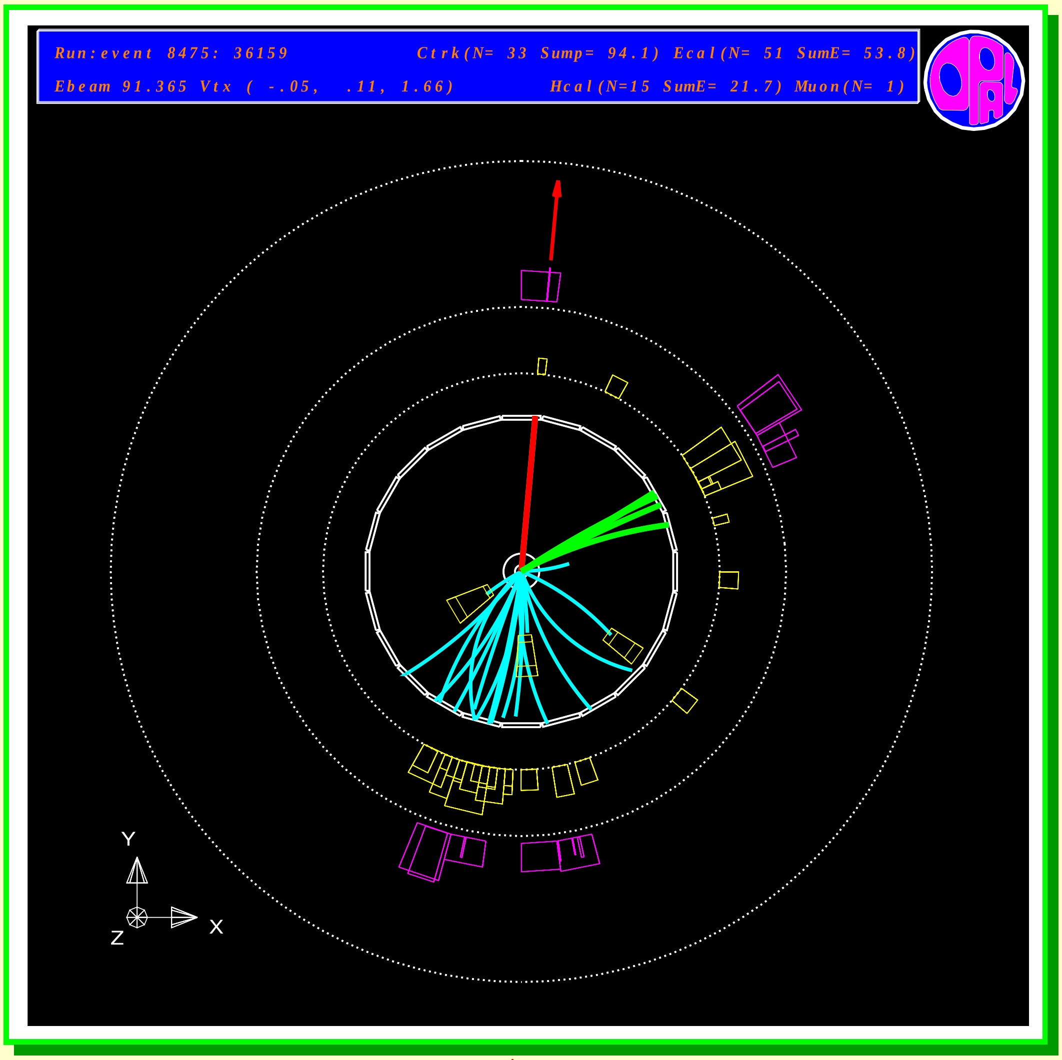
$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{W}^+\mathrm{W}^- \to \ell^-\overline{\nu}_\ell\ell'^+\nu_{\ell'})$ at $\sqrt{s} = 183$ GeV

ALEPH	$1.34 \pm 0.20 \pm 0.05$ pb
DELPHI	$1.64 \pm 0.26 \pm 0.09$ pb
L3	$1.53 \pm 0.24 \pm 0.05$ pb
OPAL	$1.69 \pm 0.20 \pm 0.06$ pb

assuming the SM branching ratios

Event selection: $W^+W^- \rightarrow q\overline{q}'\ell^-\overline{\nu}_\ell$

- Branching ratio 43.9%
- Identify high energy lepton candidate
- Form 2 jets with the rest of the event
- Vetoes on isolated γs and $q\overline{q}\ell^+\ell^-$
- Cuts on $\not{p}_T$, lepton energy and isolation (DELPHI and L3)
- or on a likelihood built using the same variables (ALEPH and OPAL)

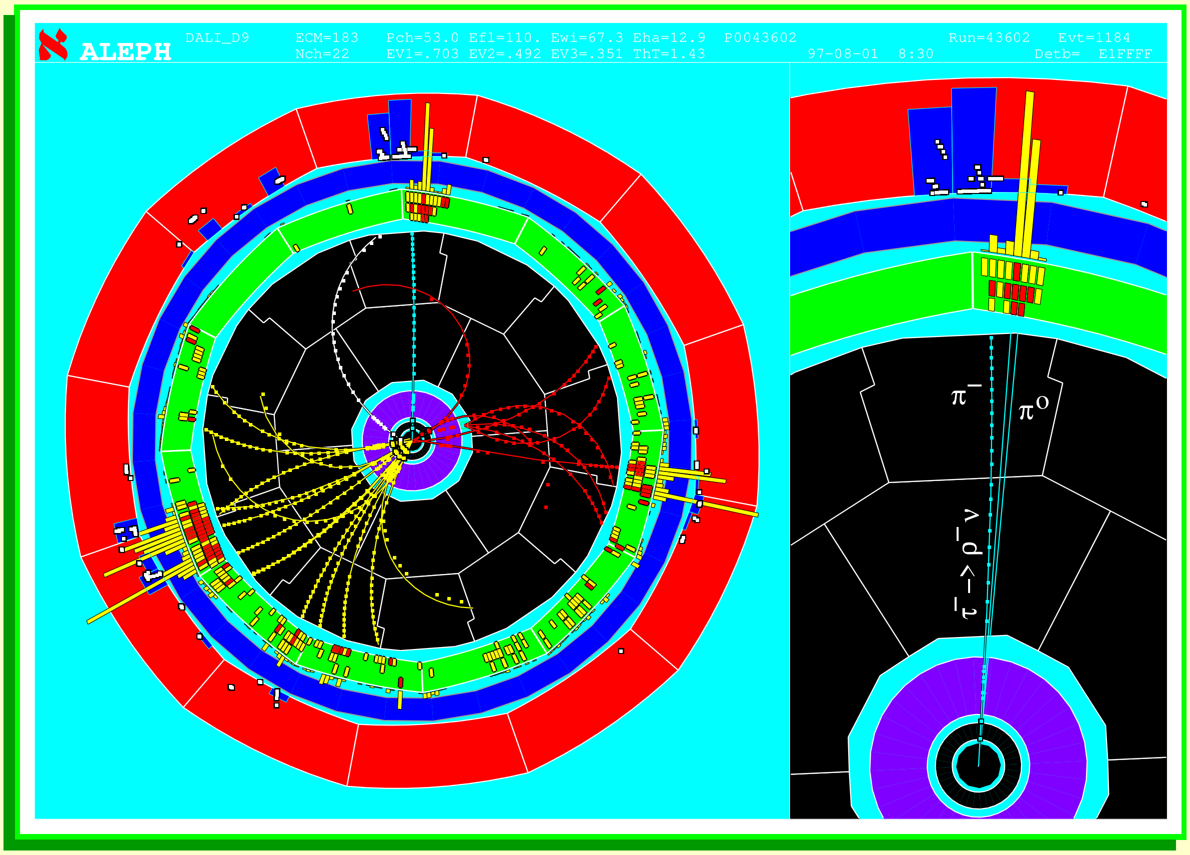


OPAL event: $W^+W^- \rightarrow q\overline{q}'\mu^-\overline{\nu}_\mu$

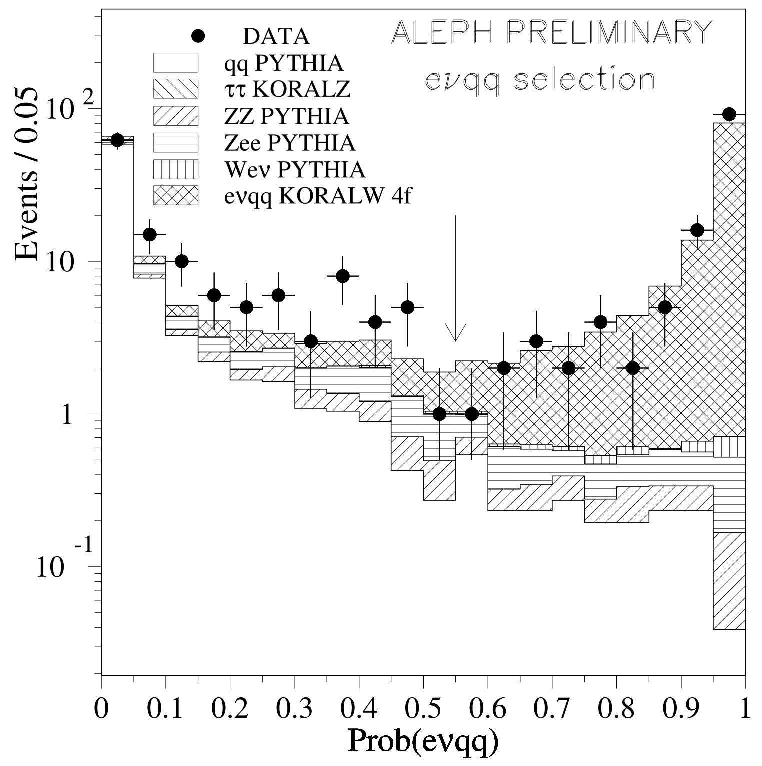
Event selection: $W^+W^- \to q\overline{q}'\tau^-\overline{\nu}_\tau$

- Selection depends on the τ decay channel
- Leptonic τ decays identified with e/μ analysis
- Hadronic τ decays: narrow, low multiplicity and low mass jet
- Similar analysis, but tighter cuts

$\Longrightarrow$ lower efficiency, higher backgrounds



ALEPH event: $W^+W^- \to q\overline{q}'\tau^-\overline{\nu}_\tau$, with $\tau^- \to \rho^-\nu_\tau$



Backgrounds dominated by $q\overline{q}(\gamma)$ and non CC03 4–fermion final states

Systematic errors:

- Signal efficiency
  - Differences data–MC (mainly for the lepton identification variables)
- Accepted background cross section
  - Difference data–MC for $q\overline{q}(\gamma)$ events
  - Difference between different MC models for 4–fermion backgrounds

Efficiency and purity at $\sqrt{s} = 183$ GeV

	Average efficiency	Purity	Selected events
ALEPH	80%	95%	322
DELPHI	73%	89%	288
L3	78%	93%	311
OPAL	86%	90%	362

Same caveats as for the fully leptonic channel apply

$\sigma(e^+e^- \to W^+W^- \to q\overline{q}'\ell^-\overline{\nu}_\ell)$ at $\sqrt{s} = 183$ GeV

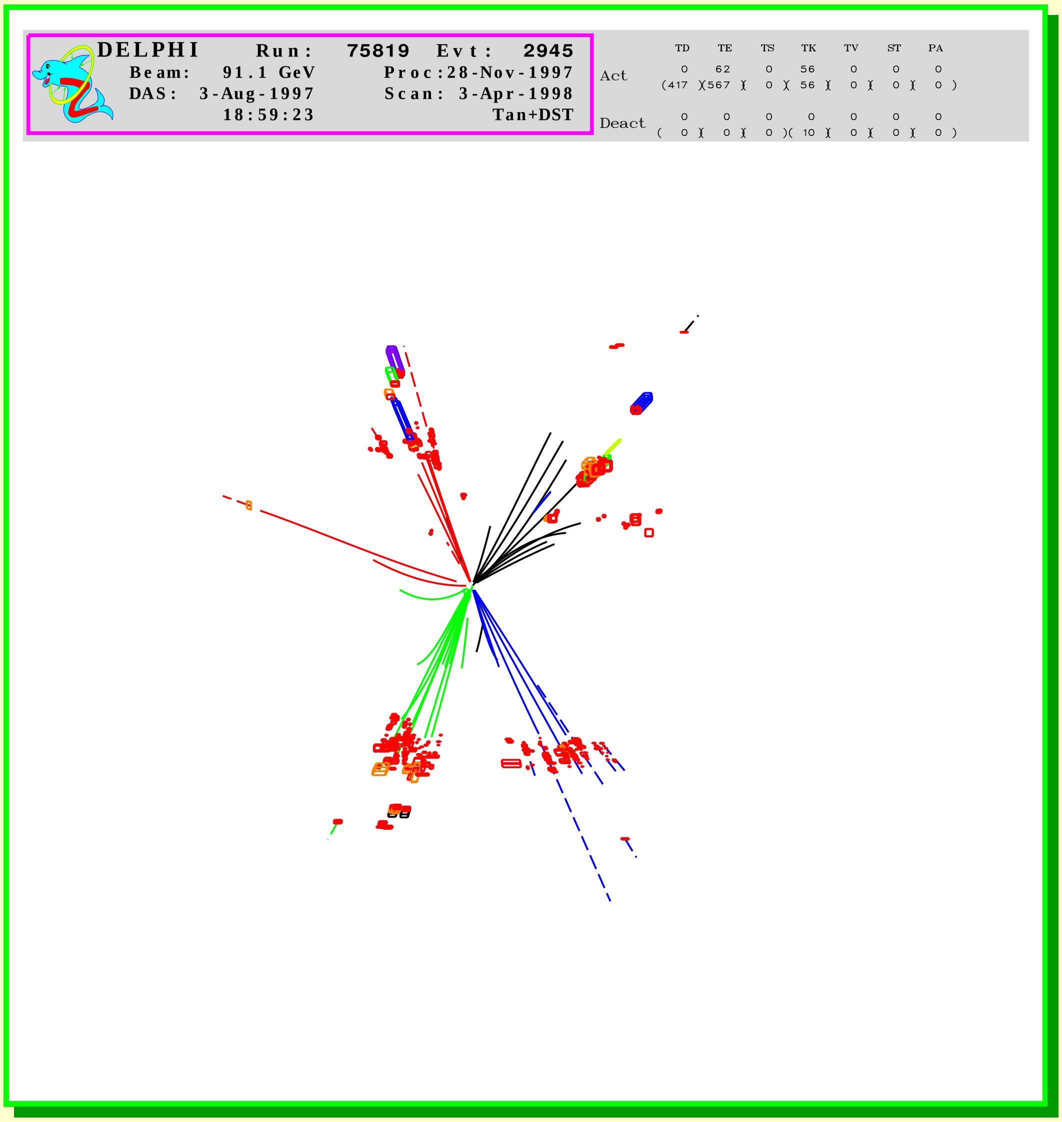
ALEPH	$6.79 \pm 0.40 \pm 0.14$ pb
DELPHI	$7.04 \pm 0.47 \pm 0.28$ pb
L3	$6.82 \pm 0.42 \pm 0.11$ pb
OPAL	$6.65 \pm 0.39 \pm 0.13$ pb

assuming the SM branching ratios

Event selections used for the W mass determination and for TGC analyses may be slightly different

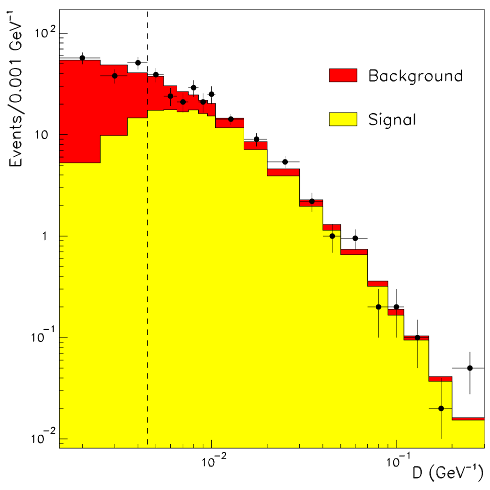
Event selection: $W^+W^- \to q\overline{q}'q\overline{q}'$

- Branching ratio 45.6%
- At least 4 well separated jets
- Little missing energy (γ_{ISR})
- Preselection requires large visible energy and mass
- Different jet energies and jet–jet angles in the $q\overline{q}(\gamma)$ background

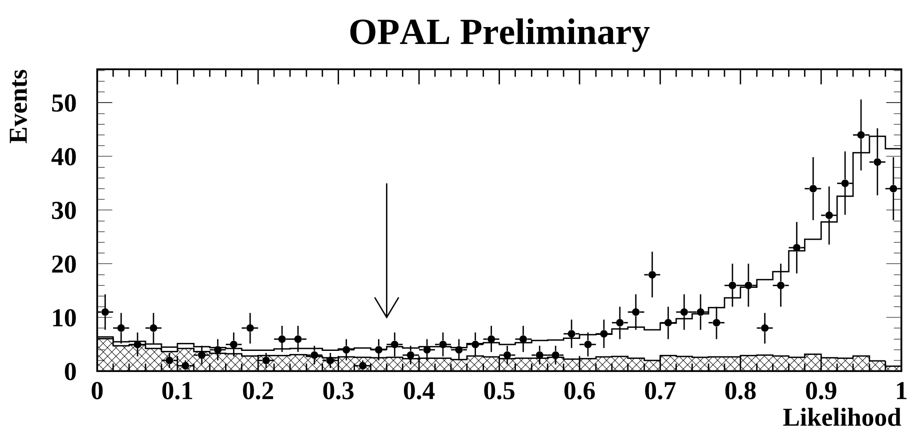


DELPHI event: $W^+W^- \to q\overline{q}'q\overline{q}'$

- Neural networks (ALEPH: 21 inputs), (L3: 10 inputs) or likelihood (OPAL: 4 variables) using global event properties, jet related quantities and in some cases also the mass related informations.
- DELPHI uses $\mathcal{D} = \frac{E_{min}}{E_{max}} \cdot \frac{\Theta_{min}}{(E_{max}-E_{min})}$



- Fit to the neural net output (ALEPH and L3) or event counting (DELPHI and OPAL) to determine the cross section.



Efficiency and purity at $\sqrt{s} = 183$ GeV

	Efficiency	Purity	No. of events
ALEPH	82%	84%	423
DELPHI	82%	76%	391
L3	88%	80%	475
OPAL	84%	80%	433

$q\overline{q}(\gamma)$ main background, some 4–fermions (ZZ)

$\sigma(e^+e^- \rightarrow W^+W^- \rightarrow q\overline{q}'q\overline{q}')$ at $\sqrt{s} = 183$ GeV

ALEPH	$7.44 \pm 0.41 \pm 0.30$ pb
DELPHI	$7.33 \pm 0.48 \pm 0.29$ pb
L3	$8.25 \pm 0.45 \pm 0.25$ pb
OPAL	$7.15 \pm 0.43 \pm 0.31$ pb

assuming the SM branching ratios

Main systematic error: QCD modelling of fragmentation (jet rates, shape variables), assessed through comparison PYTHIA–HERWIG, variation of MC tuning parameters, and/or by reweighting the MC distributions to match the data

Cross section and branching ratio fits

Maximum likelihood fit to the number of observed events N^i_{obs}

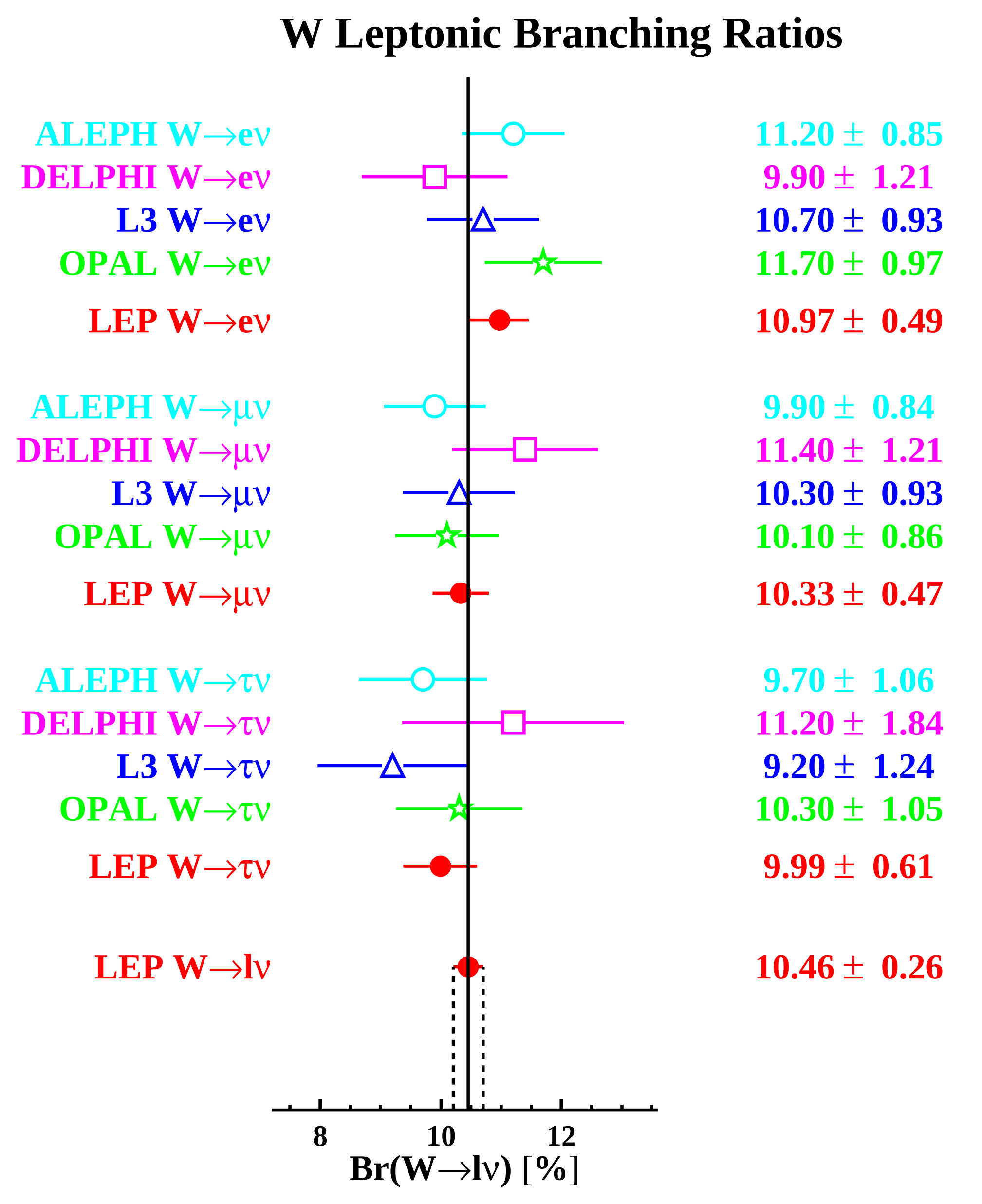
Number of expected events N^i_{exp} obtained with 10 by 10 “cross–talk” matrix

$$\begin{pmatrix} N^{qqe\nu}_{exp} \\ N^{qq\mu\nu}_{exp} \\ \vdots \\ N^{qqqq}_{exp} \end{pmatrix} = \begin{pmatrix} N^{qqe\nu}_{backp} \\ N^{qq\mu\nu}_{back} \\ \vdots \\ N^{qqqq}_{back} \end{pmatrix} + \mathcal{L}\sigma_{WW} \begin{pmatrix} \varepsilon^{qqe\nu}_{qqe\nu} & \varepsilon^{qqe\nu}_{qq\mu\nu} & \dots & \varepsilon^{qqe\nu}_{qqqq} \\ \varepsilon^{qq\mu\nu}_{qqe\nu} & \varepsilon^{qq\mu\nu}_{qq\mu\nu} & \dots & \varepsilon^{qq\mu\nu}_{qqqq} \\ \vdots & \vdots & \ddots & \vdots \\ \varepsilon^{qqqq}_{qqe\nu} & \varepsilon^{qqqq}_{qq\mu\nu} & \dots & \varepsilon^{qqqq}_{qqqq} \end{pmatrix} \begin{pmatrix} 2Br(qq)Br(e\nu) \\ 2Br(qq)Br(\mu\nu) \\ \vdots \\ Br(qq)^2 \end{pmatrix}$$

Each experiment performs several fits:

- σ and 3 leptonic branching ratios
- σ and 1 leptonic branching ratio (assuming lepton universality)
- σ assuming SM branching ratios

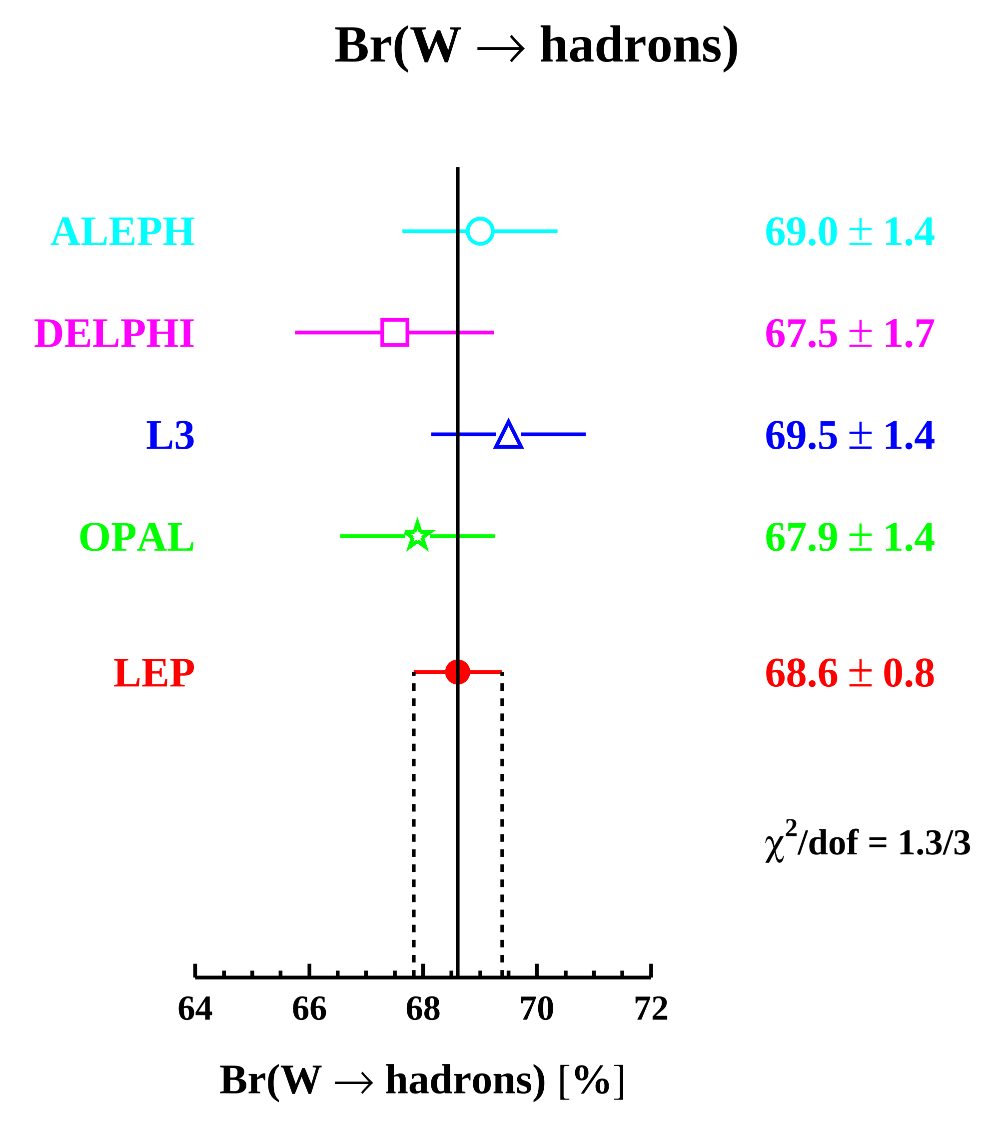
W Leptonic branching ratio(s)



SM prediction 10.8%

All data (161–183) GeV included

W hadronic branching ratio



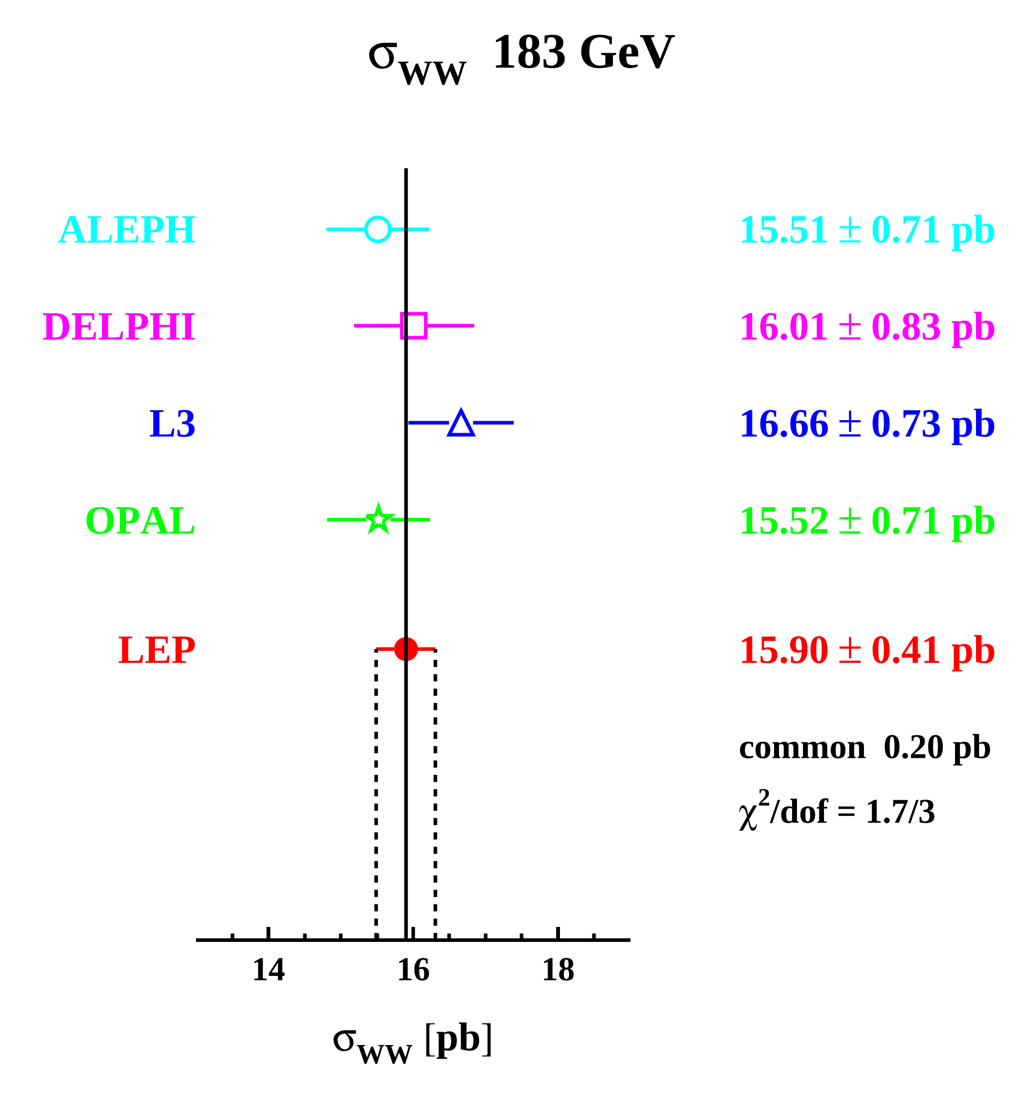
SM prediction 67.5%

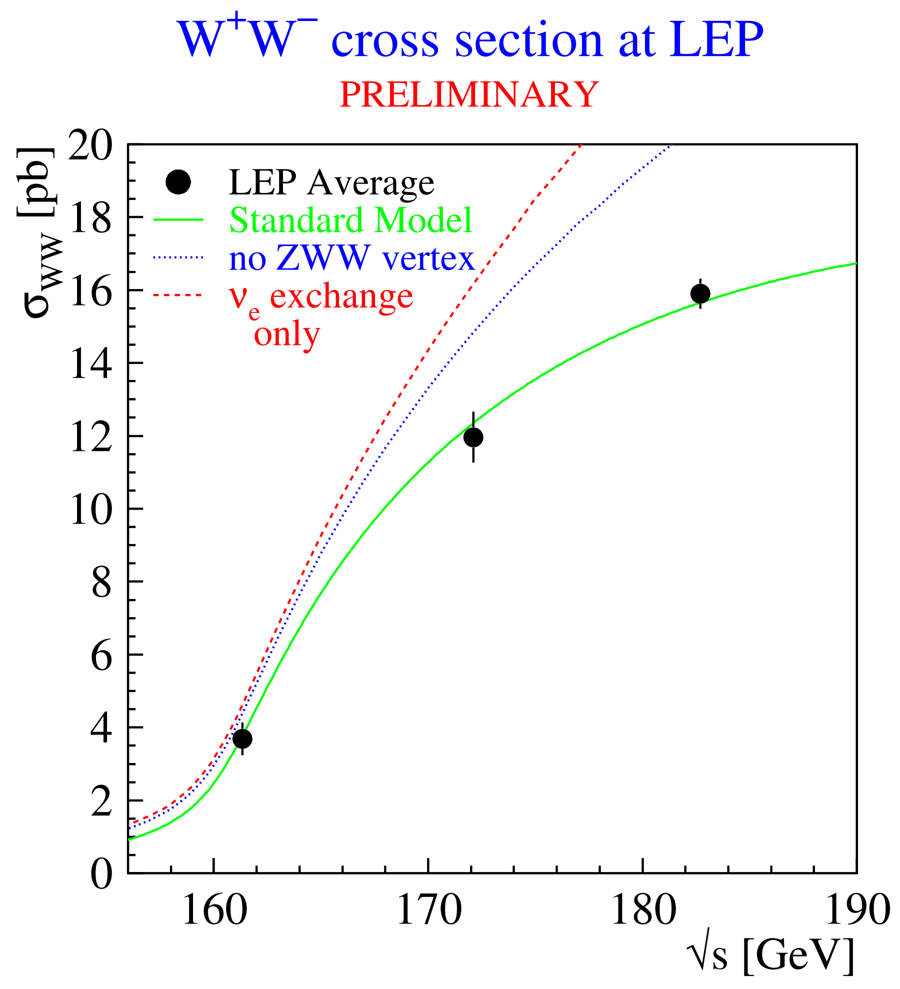
All data (161–183) GeV included

QCD modelling of fragmentation is the only systematic error considered as correlated among experiments

The CC03 cross section

	$\sigma(WW)$ at $\sqrt{s} = 183$ GeV
ALEPH	$15.51 \pm 0.61 \pm 0.36$ pb
DELPHI	$16.01 \pm 0.71 \pm 0.43$ pb
L3	$16.66 \pm 0.66 \pm 0.30$ pb
OPAL	$15.52 \pm 0.62 \pm 0.35$ pb





Measurements in good agreement with SM expectations (here GENTLE 2.0 with m_W =80.35 GeV/c^2)

Models without γWW and ZWW vertices ruled out

Interpreting the results

- Check the unitarity of the CKM matrix:

$$\frac{\mathrm{Br}(\mathrm{W} \to \mathrm{q\bar{q}'})}{1 - \mathrm{Br}(\mathrm{W} \to \mathrm{q\bar{q}'})} = (1 + \frac{\alpha_s}{\pi}) \sum_{i=u,c;\, j=d,s,b} |V_{ij}|^2$$

From the hadronic branching ratio measurement:

$$\sum_{i=u,c;\, j=d,s,b} |V_{ij}|^2 = 2.10 \pm 0.08$$

Least well known matrix element: $|V_{cs}|$
Derive it from the branching ratio!

Use PDG values of others $|V_{ij}|$	$|V_{cs}| = 1.03 \pm 0.04$
$|V_{cs}|$ from D meson decay	$|V_{cs}| = 1.04 \pm 0.16$
Unitarity of CKM matrix	$|V_{cs}| = 0.9745 \pm 0.0008$

Possible improvements?

- Include charm tagging and measure:

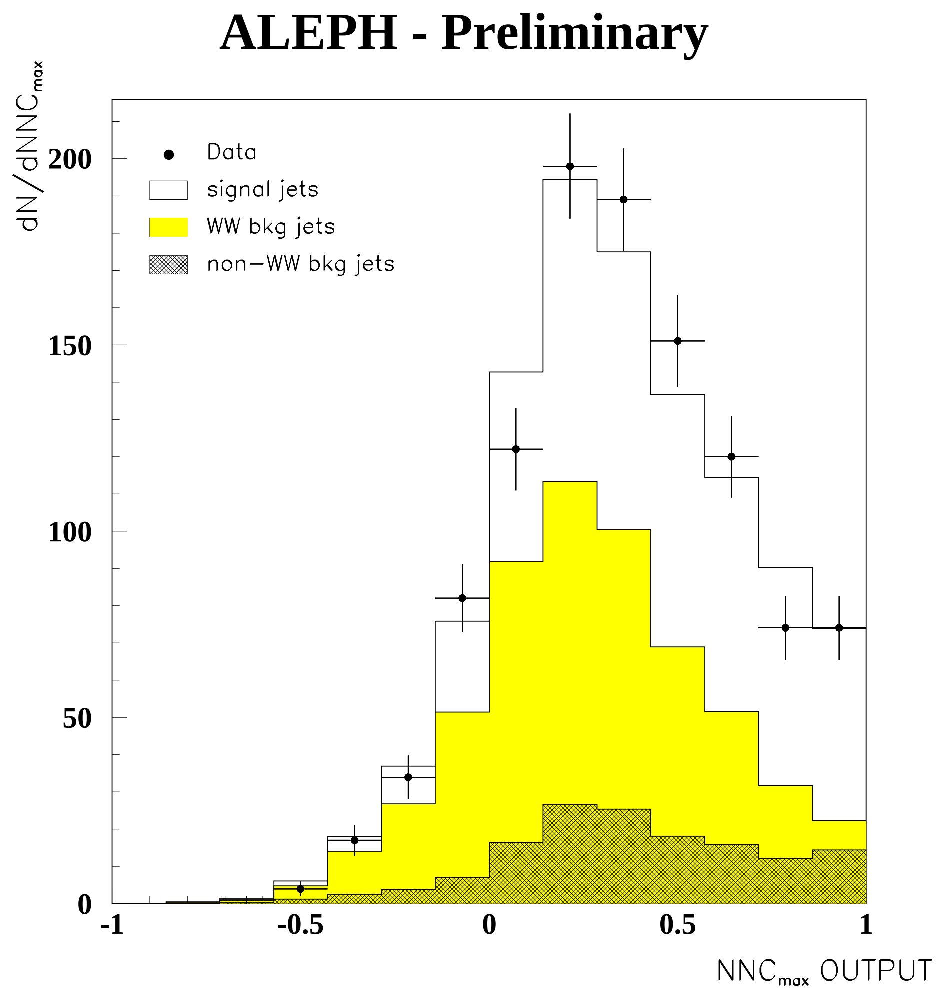
$$\mathcal{R}_c = \frac{\Gamma(\mathrm{W} \to \mathrm{cX})}{\Gamma(\mathrm{W} \to \mathrm{q\bar{q}'})} = \frac{|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2}{\sum_{i=u,c;\, j=d,s,b} |V_{ij}|^2}$$

- Tag both charm and strange quarks
$\Longrightarrow$ measure directely $|V_{cs}|$

See B. Golob talk later for the DELPHI analysis involving charm and strange tagging

Charm tagging not easy, even in absence of b quarks

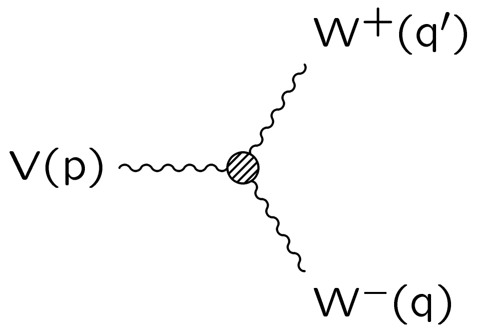
Combine informations on leptons, secondary vertices, π_{soft} from D^*, jet shape and kinematic variables using multivariate analyses



	$\mathcal{R}_c$	$\lvert V_{cs} \rvert$
ALEPH	$0.51 \pm 0.05 \pm 0.03$	$1.00 \pm 0.10 \pm 0.06$
L3	$0.50 \pm 0.11 \pm 0.04$	$0.98 \pm 0.22 \pm 0.08$

Triple gauge boson vertices

- SM: non abelian gauge theory ($SU(2)_L \otimes U(1)_Y$)
  $\Longrightarrow$ vertices with 3 and 4 gauge bosons



$$= -ieg_{VWW}\Gamma_V^{\alpha\beta\mu}(p, q, q')$$

- TGC or anomalous couplings of the triple gauge bosons: parameters of the triple–gauge boson part of the electroweak Lagrangian
- For each VWW vertex ($V = \gamma, Z$) introduce general Lorentz invariant form
- Consider only operators with dimension ≤ 6
  $\Longrightarrow$ 7 independent terms for γ and Z
- Require C,P and CP conservation
- Require $U(1)_{em}$ gauge invariance ($q_W = \pm 1$)

Only 5 parameters to describe the vertices:

$$g_1^Z, \kappa_\gamma, \lambda_\gamma, \kappa_Z, \lambda_Z$$

In the SM: $g_1^Z, \kappa_\gamma, \kappa_Z = 1$ and $\lambda_\gamma, \lambda_Z = 0$

Relation with physical quantities

$$
\begin{aligned}
q_W &= e \cdot g_1^\gamma &&\overset{SM}{=} e \\
\mu_W &= \frac{e}{2M_W}(g_1^\gamma + \kappa_\gamma + \lambda_\gamma) &&\overset{SM}{=} \frac{e}{2M_W} \\
Q_W &= -\frac{e}{M_W^2}(\kappa_\gamma - \lambda_\gamma) &&\overset{SM}{=} -\frac{e}{M_W^2}
\end{aligned}
$$

similarly for the "weak moments"

- Still too many parameters (5) to measure
- Impose $SU(2)_L \otimes U(1)_Y$ gauge invariance
- Consider only operators not constrained from lower energy measurements (radiative corrections to the Z/γ propagator)
- Only 3 anomalous couplings remain

$$
\begin{aligned}
\alpha_{W\phi} &= \Delta g_Z^1 \cos^2\theta_w \\
\alpha_W &= \lambda_\gamma \\
\alpha_{B\phi} &= \Delta\kappa_\gamma - \Delta g_Z^1 \cos^2\theta_w
\end{aligned}
$$

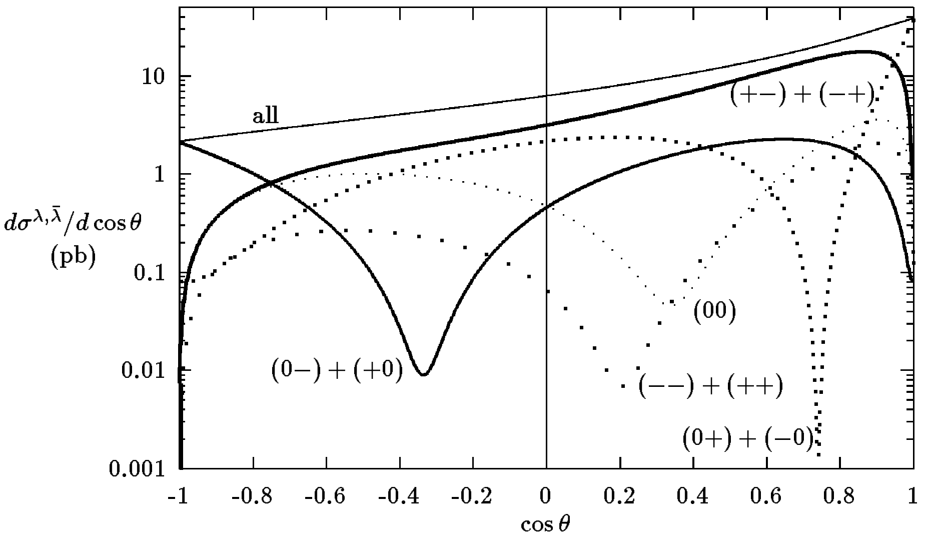
Δ is the deviation from the SM value 1

- All α are zero in the SM
- The remaining parameters are obtained through gauge invariance:

$$
\begin{aligned}
\Delta\kappa_Z &= \Delta g_Z^1 - \Delta\kappa_\gamma \tan^2\theta_w \\
\lambda_Z &= \lambda_\gamma
\end{aligned}
$$

Measuring the anomalous couplings

The anomalous couplings appear linearly in the lagrangian
$\Longrightarrow$ the cross section is a bilinear function of the α parameters



$\cos\theta_{W^-}$ is defined as the polar angle of the W^- relative to the electron beam

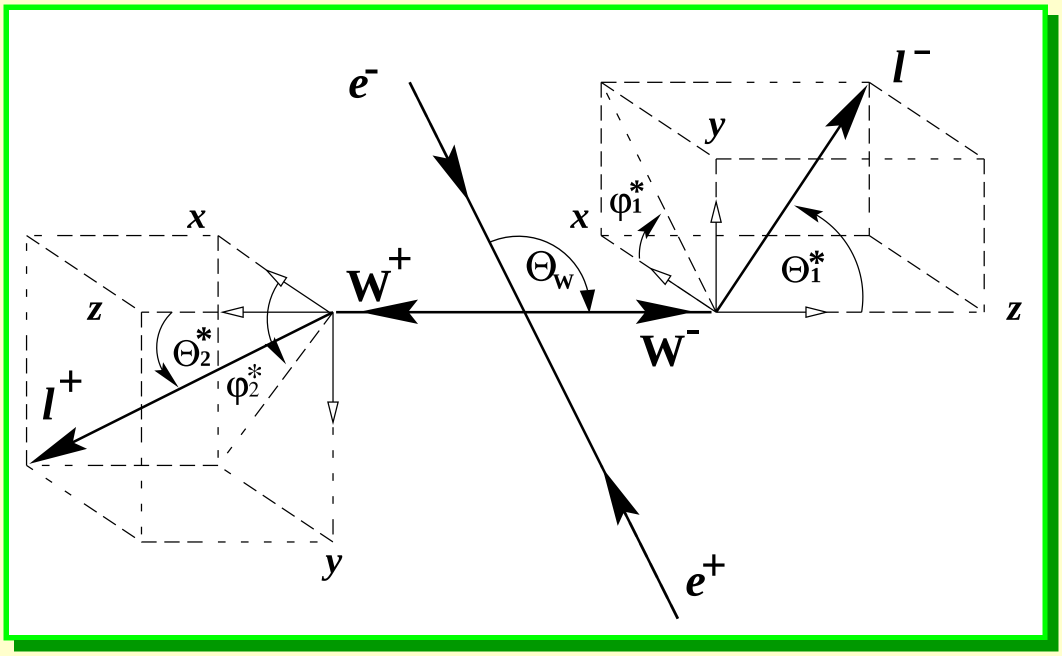
Effects of the couplings

- Changes in the relative contribution of each W helicity state
- Changes in the total cross section and in $d\sigma/d\cos\theta_{W^-}$
- The helicities of the two W also change

Measure the W^- scattering angle and the helicities of the two W bosons

- Use the W decay as a polarimeter

In the $\Gamma_W \to 0$ approximation and neglecting ISR the final state is fully determined by the measurement of 5 angles



but in the real life

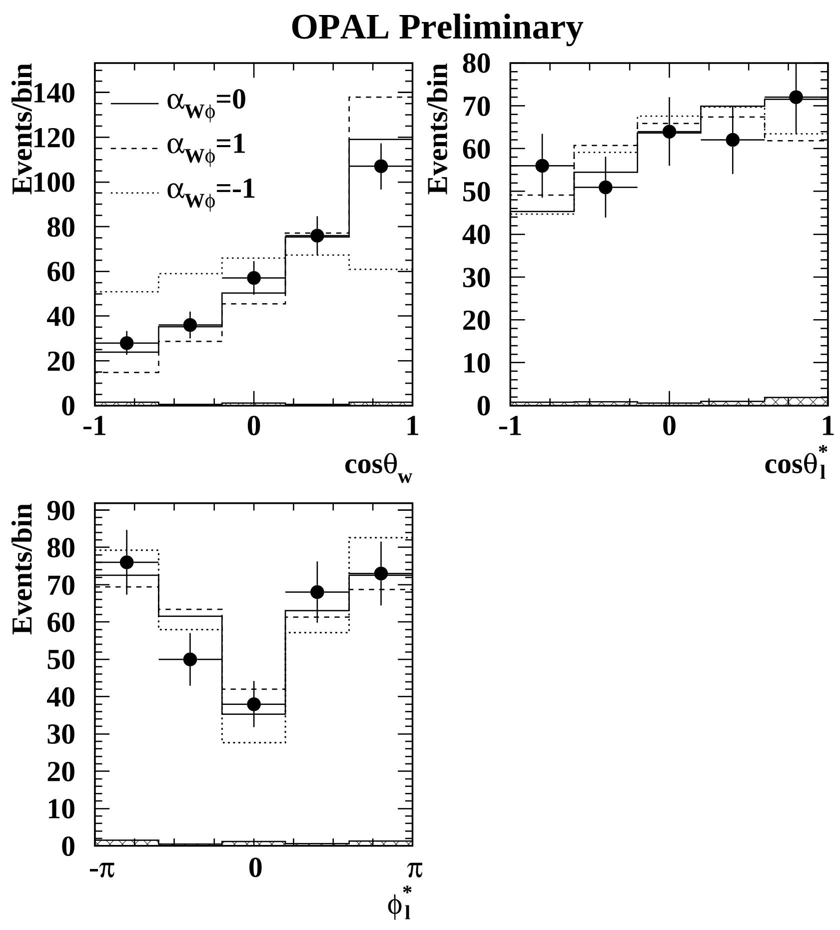
- Cannot neglect the W width
- ISR photons are mostly unmeasured
- Neutrinos are unmeasured (and there are at least 2 in τ events)
- Quark charges cannot be measured (efficiently ?)
- Detector resolution
- Backgrounds

Experimental strategies

- Refine the selection to ensure events are properly measured (mainly for the channels with τs in the final state)
- Improve the resolution with a kinematic fit (equal W masses)

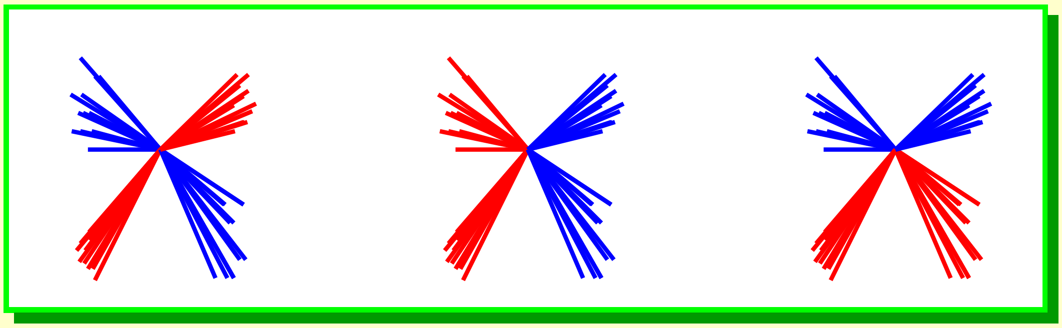
The $W^+W^- \to q\bar{q}'\ell^-\bar{\nu}_\ell$ channel

- Large branching ratio, W charge from the lepton
- Integrate over quark variables (twofold ambiguity)

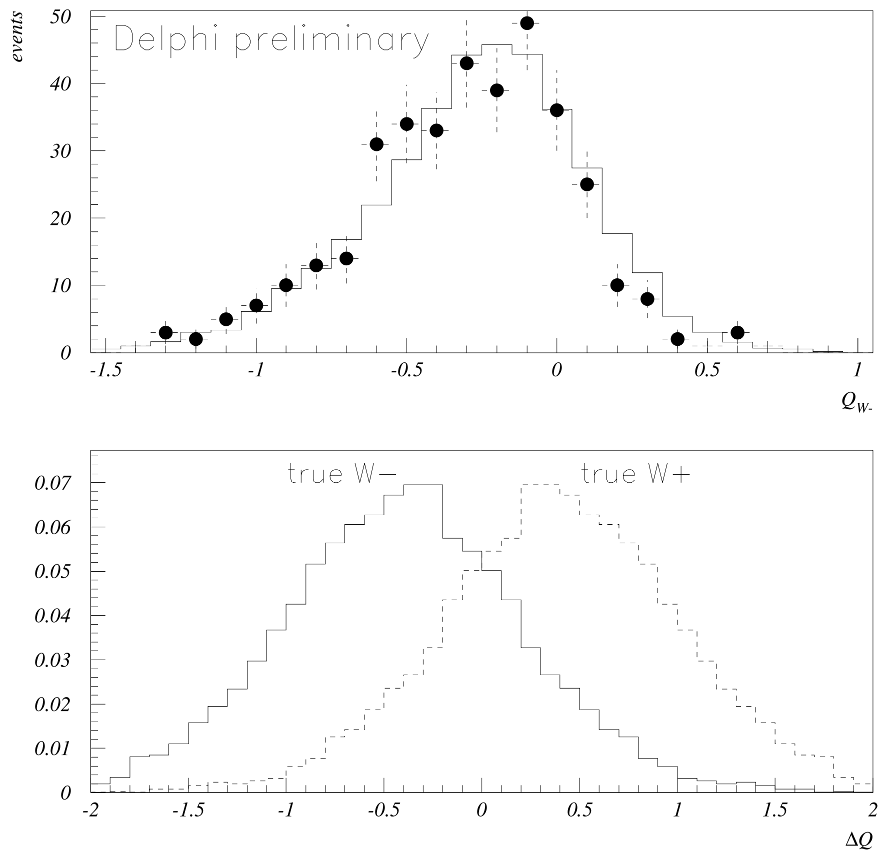


The $W^+W^- \to q\overline{q}'q\overline{q}'$ channel

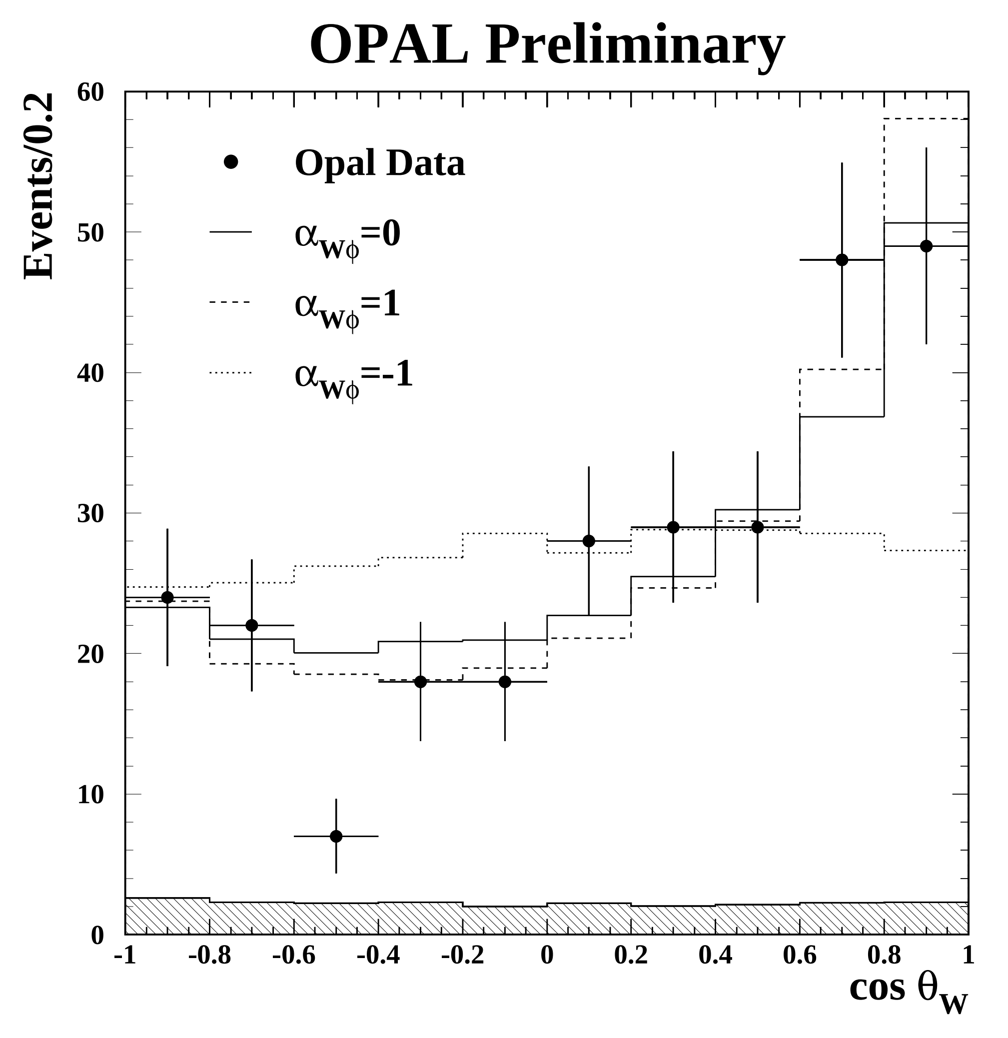
- Correct jet pairing: 3 possibilities



- Quark charges unmeasurable: largest difference is between W^- and W^+ (2 units)
  $\Longrightarrow$ measure only $\cos\theta_{W^-}$ using the jet charge method

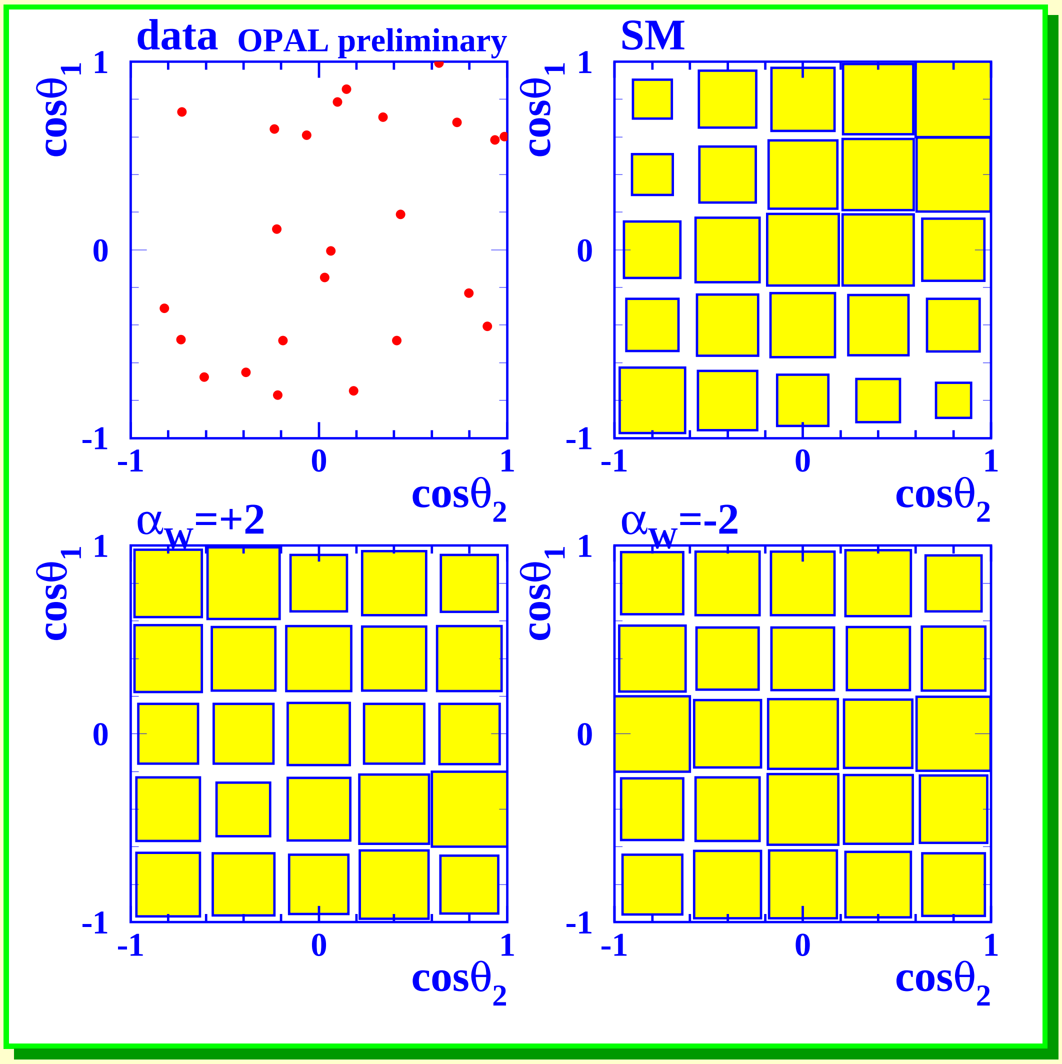


- Jet charge right in $\approx 70\%$ of the cases
  $\Longrightarrow$ distorsion of the angular distribution



The $W^+W^- \to \ell^-\overline{\nu}_\ell \ell'^+\nu_{\ell'}$ channel

- Small useful branching ratio ($\approx 5\%$)
- All 5 angles can be determined (up to a twofold ambiguity)
- Sensitivity to the correlation of the W helicities



Only OPAL has sofar investigated this channel

- Despite low statistics (24 events) helps improving the limits

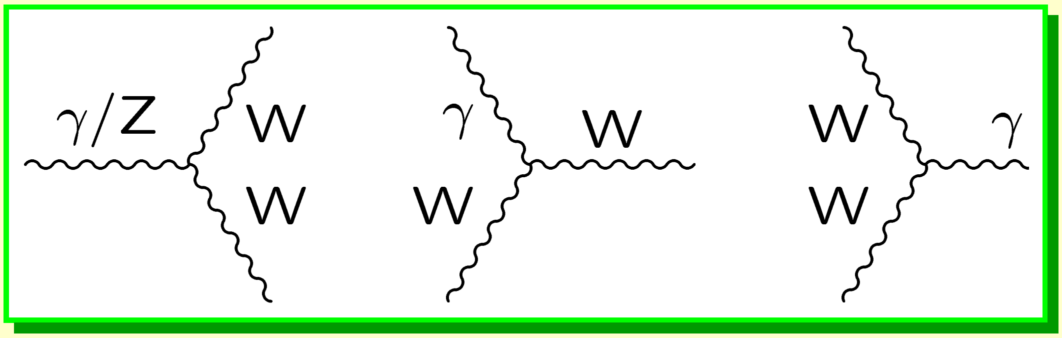
Methods to extract the couplings

- Event counting: fit to the total cross section
- Differential distributions:
  - unbinned ML fit to theoretical distribution
    ISR, Γ_W, backgrounds not taken into account
    requires folding with detector resolution
  - binned ML fit to MC
    take into account all physical and detector effects
    requires large MC samples
    some loss of statistical precision
  - "optimal" observables method
    retain sensitivity of unbinned ML fit for small α
    all informations contained in a single variable
    value of α can be obtained from the mean
    value of the distribution or from a binned fit
- Checks for biases in the procedure using MC events generated with $\alpha \neq 0$
- Small event samples, non gaussian detector resolution
  $\Longrightarrow$ error calibration required
- Multidimensional fits also performed
- Results are presented as 1–dim or 2–dim likelihood curves which are then added when combining the different channels/experiments

DELPHI, L3 and OPAL preliminary results include the 1997 data

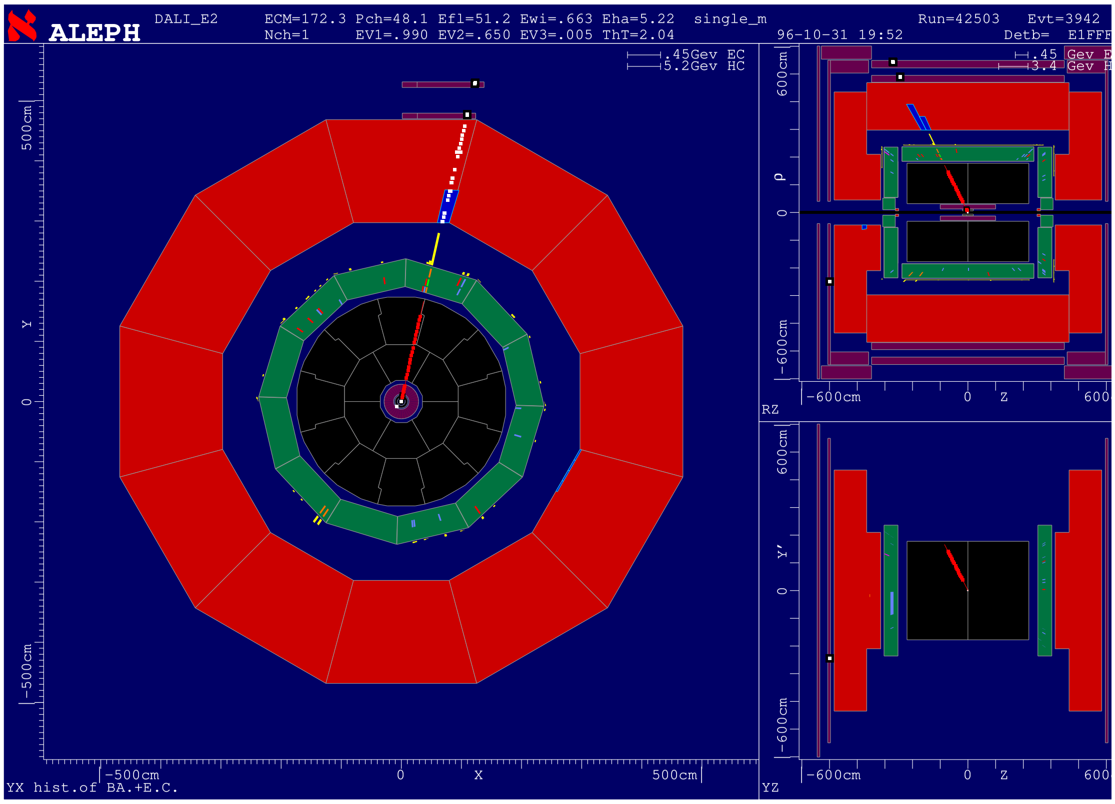
Other ways of measuring the TGCs

The couplings at the γWW vertex can be measured also in the "single W" process and in the $\nu\bar{\nu}\gamma$ final state

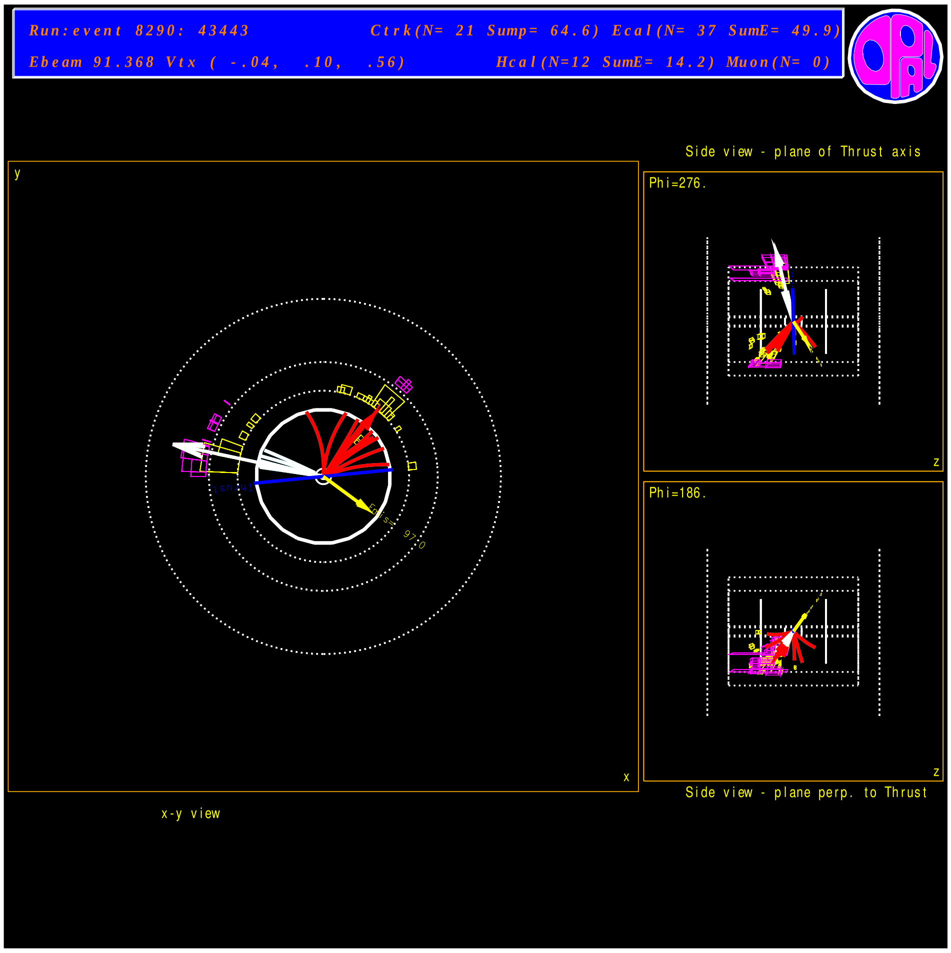


The "single W" process

- 1 electron lost in the beam pipe
- missing transverse momentum from the ν_e
- 1 isolated energetic lepton or ...

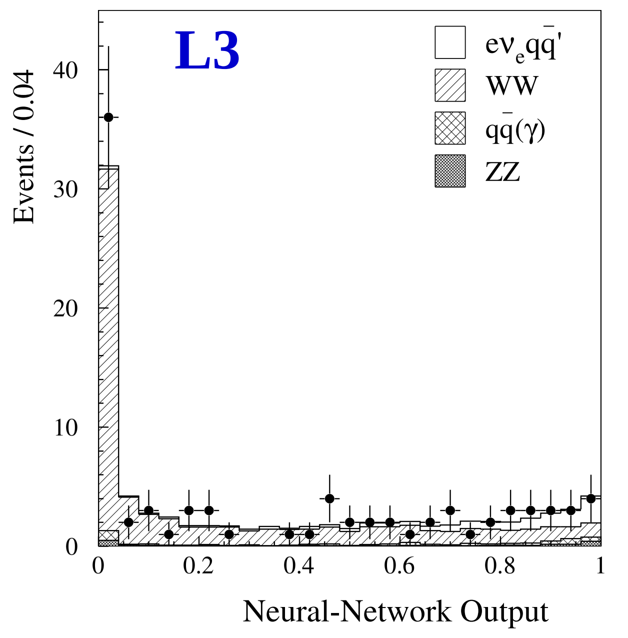


- ... acoplanar jet pair with $\mathrm{M}_{jj} \sim \mathrm{M_W}$



Caveats:

- Signal definition ambiguous
- Retain some sensitivity to the ZWW couplings
- Background (mostly $\mathrm{W^+W^-} \to \mathrm{q\overline{q}'}\tau^-\overline{\nu}_\tau$, $S/N \sim 1$) also depends on the TGCs



All the experiments have looked at this channel:
only ALEPH and L3 have results from the 1997 data

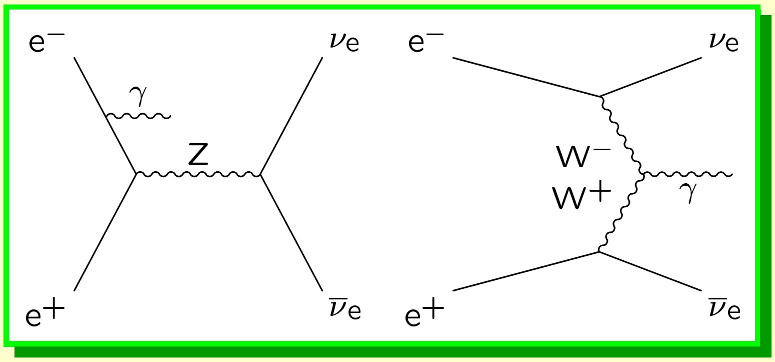
ALEPH	$-2.60 \leq \Delta\kappa_\gamma \leq 0.50$	$-1.60 \leq \lambda_\gamma \leq 1.60$
L3	$-0.86 \leq \Delta\kappa_\gamma \leq 0.38$	$-0.65 \leq \lambda_\gamma \leq 0.76$

$95\% CL$ on the γWW couplings from the "single W" process
Same efficiency and S/N ratio
Different assumptions in the calculation of the limit

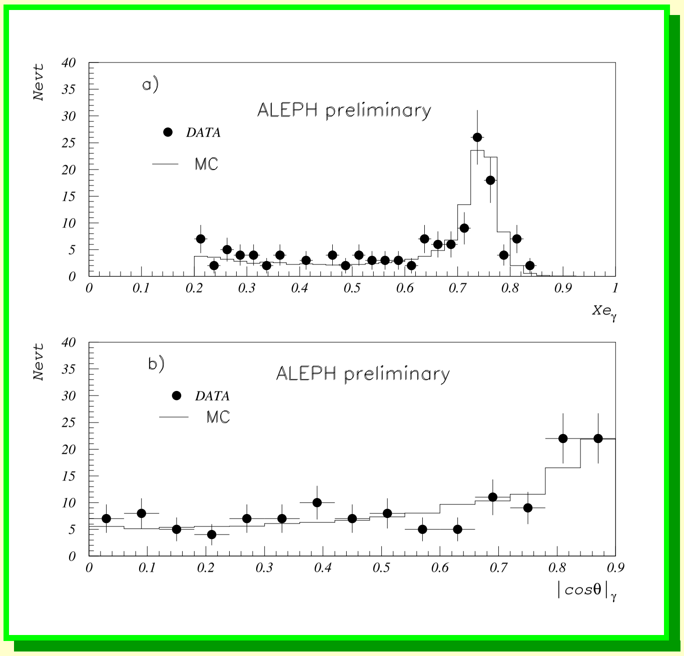
- L3 takes into account the dependency of the background on the TGCs

Helps in improving the $\Delta\kappa_\gamma$ limits ...
... but avoid double counting

The $\nu\overline{\nu}\gamma$ final state



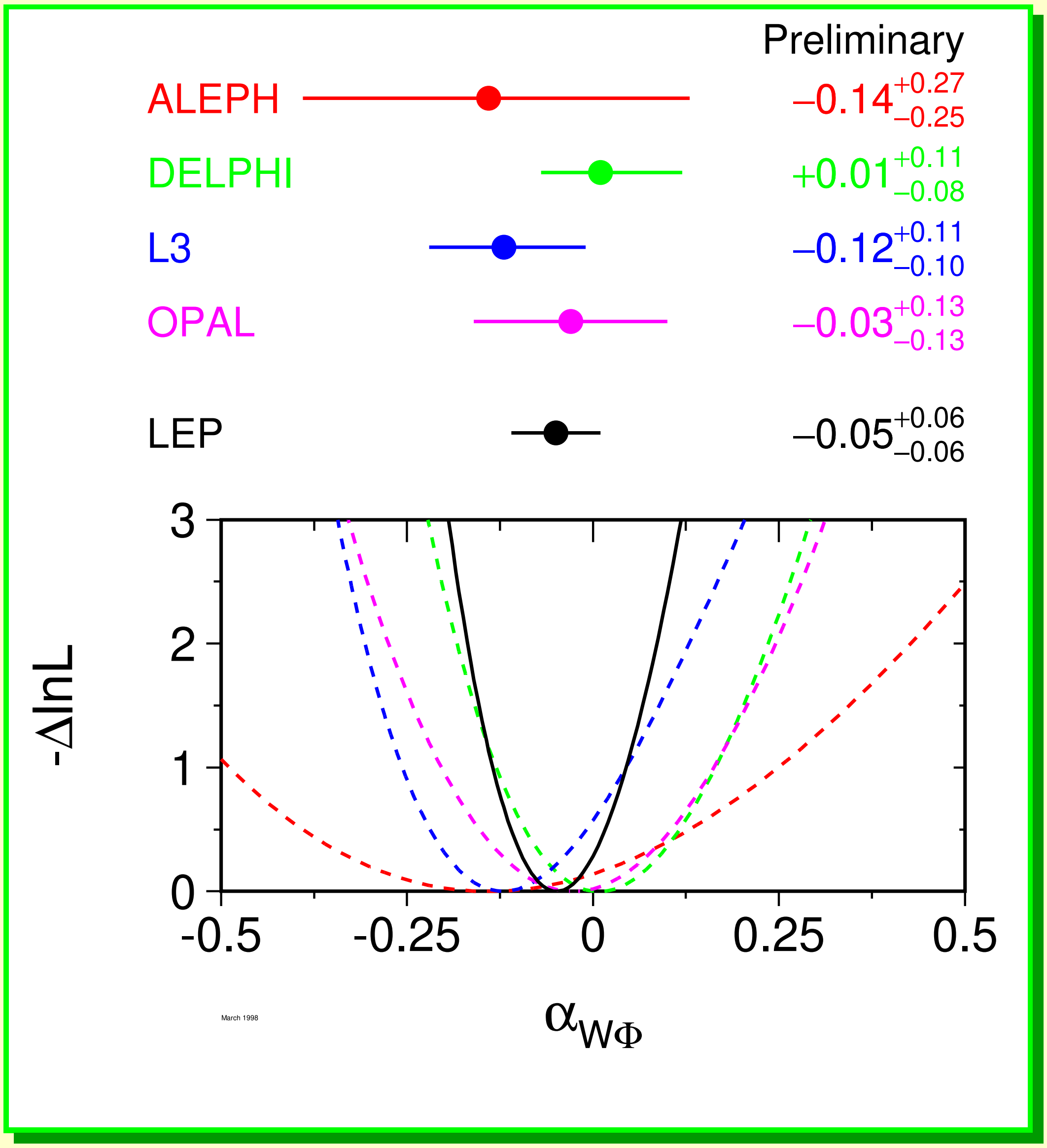
- The $\nu_e\overline{\nu}_e\gamma$ final state is also sensitive to the γWW vertex
- Signature: high energy isolated γ in the detector
- Anomalous couplings change the energy and angular distributions, veto radiative returns to the Z^0
- ALEPH: ML fit to the differential distributions using the KORALZ MC to predict the cross section



95%CL: $|\Delta\kappa_\gamma| \leq 2.2$, $|\lambda_\gamma| \leq 3.2$

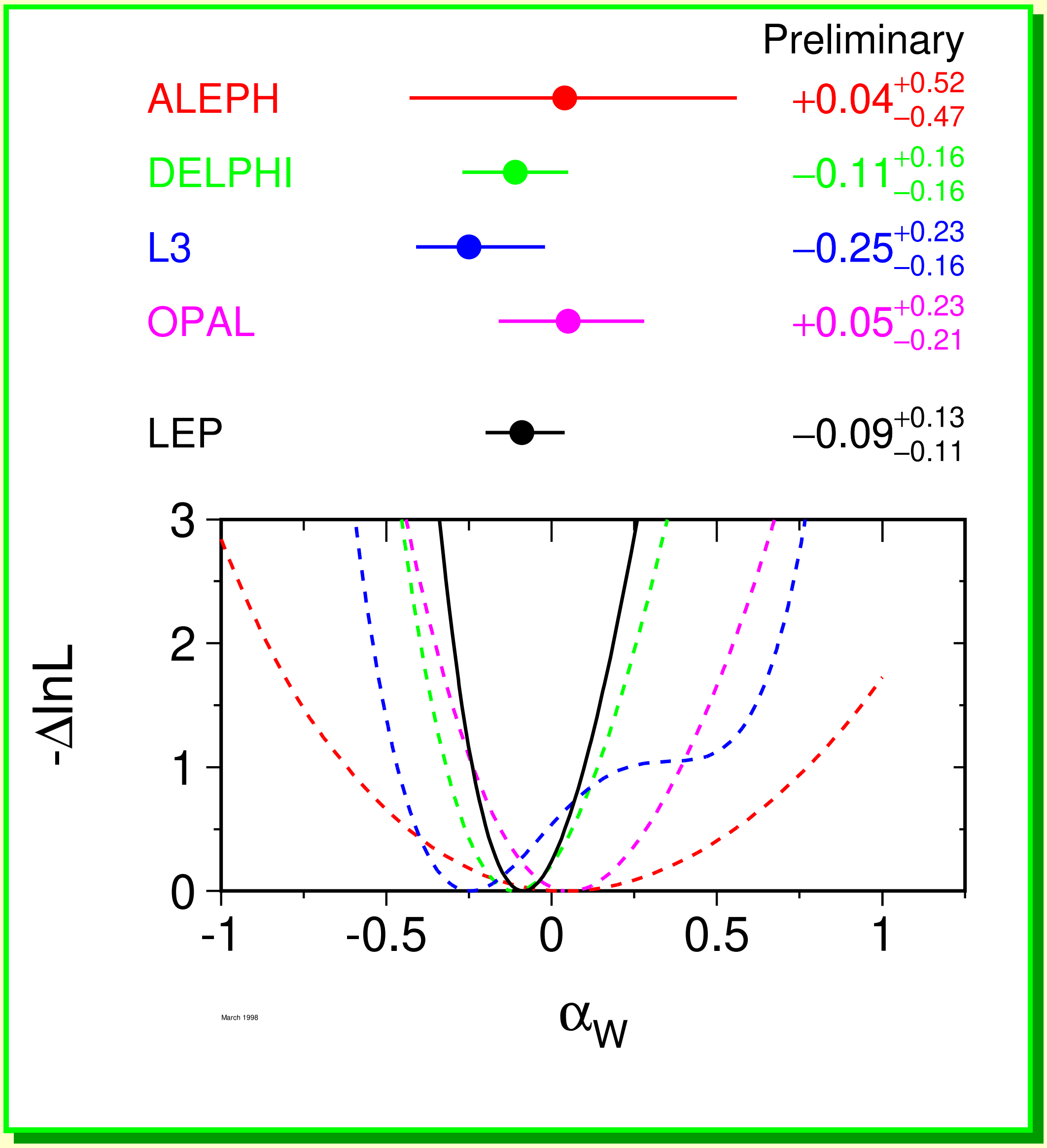
LEP Combined results

- LEP combined results obtained adding likelihood curves from different experiments
- Correlated systematic errors small relative to statistical and uncorrelated ones



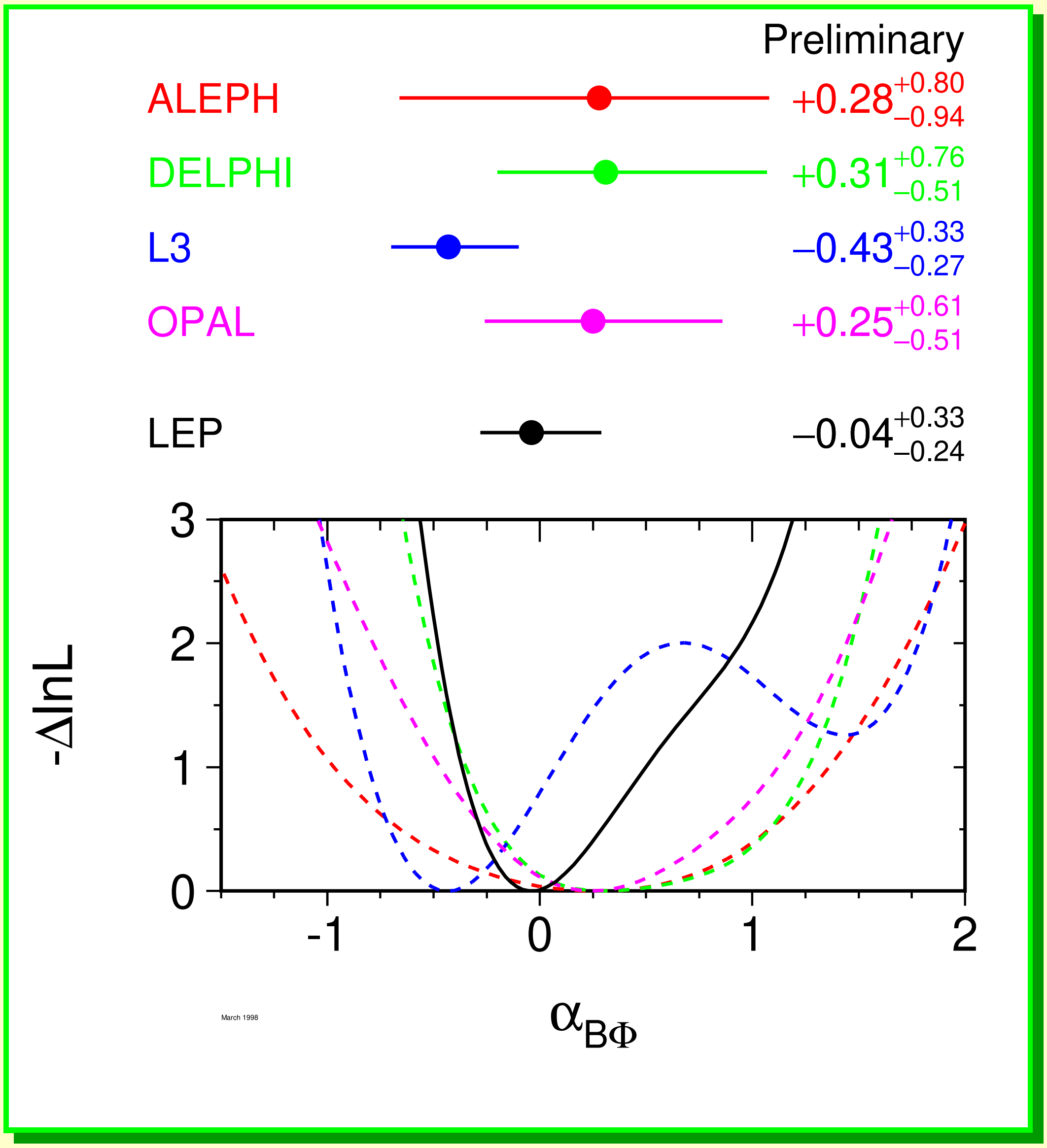
$95\%CL$: $-0.12 \leq \alpha_{W\phi} \leq +0.13$

Limit from DØ: $-0.22 \leq \alpha_{W\phi} \leq +0.44$ for $\Lambda = 2$ TeV



$95\%CL$: $-0.21 \le \alpha_W \le +0.27$

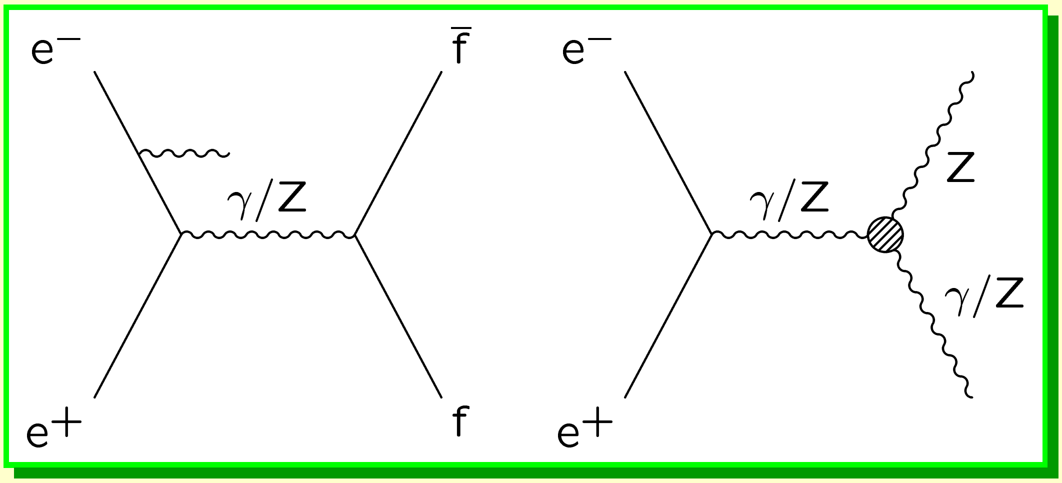
Limit from DØ: $-0.20 \le \alpha_W \le +0.20$ for $\Lambda = 2$ TeV



$95\% CL$: $-0.44 \leq \alpha_{\mathrm{B}\phi} \leq +0.95$

Limit from DØ: $-0.77 \leq \alpha_{\mathrm{B}\phi} \leq +0.58$ for $\Lambda = 2$ TeV

Pairs of neutral bosons



Final state $Z\gamma(\gamma\ldots)$ copiously produced above threshold
The $ZV\gamma$ coupling vanishes at tree level in the SM (V=Z,γ)
It can be parametrised with 4 anomalous couplings:

- h_1^V and h_2^V $\Longrightarrow$ CP violating (angular asimmetries)
- h_3^V and h_4^V $\Longrightarrow$ CP conserving

Deviations from SM proportional to some power of Z velocity
$\Longrightarrow$ better limits at high energy
Unitarity constraint: introduce form factors

$$h_i^V = \frac{h_{i0}^V}{(1+s/\Lambda^2)^3} \quad \text{for}\, i = 1,3$$
$$h_i^V = \frac{h_{i0}^V}{(1+s/\Lambda^2)^4} \quad \text{for}\, i = 2,4$$

Experimental signature: monoenergetic photon with

$$\mathrm{E}_\gamma = \frac{\sqrt{s}}{2}(1 - \frac{m_Z^2}{s})$$

Effects of anomalous couplings

Enhancement of $Z\gamma$ events at large polar angles
Enhancement of longitudinal Z's
$\Longrightarrow$ different angular distribution of fermions in the Z frame

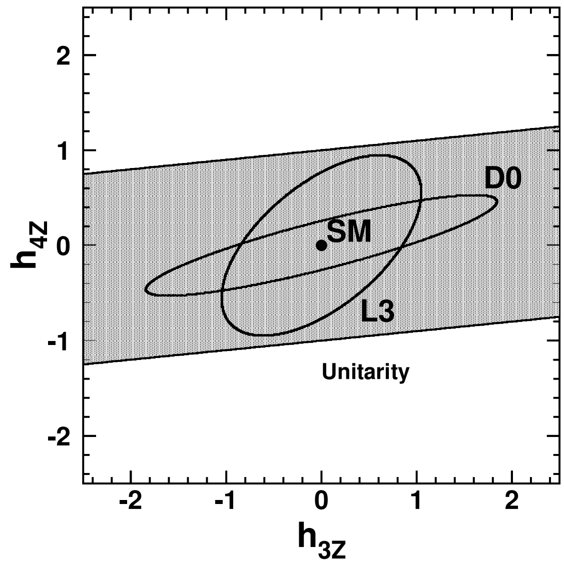
Limits from LEP

- DELPHI uses only the total cross section for the $\nu\bar{\nu}\gamma$ and $q\bar{q}\gamma$ final states using data taken at $\sqrt{s}$ =130–184 GeV
- L3 uses both the cross section and the differential distributions (only for $\sqrt{s}$ =161–184 GeV):
  - Energy and angular distribution of photons for the $\nu\bar{\nu}\gamma$ final state
  - and also θ^{thrust} and ϕ^{thrust} for the $q\bar{q}\gamma$ final state (twofold ambiguity)

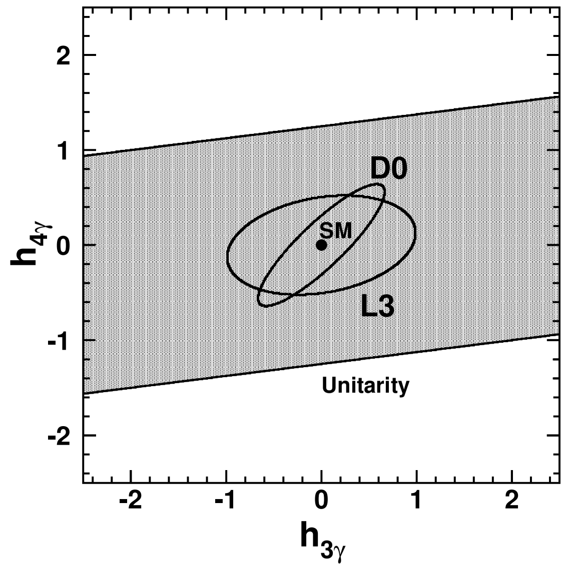
  $\Longrightarrow$ limits also on the CP violating couplings

DELPHI	$\lvert h_{30}^{Z}\rvert < 0.55$ for Λ =1 TeV	
L3	$-0.69 < h_{30}^{Z} < 0.44$	$-0.18 < h_{40}^{Z} < 0.62$
CDF	$\lvert h_{30}^{Z}\rvert < 1.6$	$\lvert h_{40}^{Z}\rvert < 0.4$
DØ	$\lvert h_{30}^{Z}\rvert < 0.78$	$\lvert h_{40}^{Z}\rvert < 0.19$
DELPHI	$\lvert h_{30}^{\gamma}\rvert < 0.34$ for Λ =1 TeV	
L3	$-0.45 < h_{30}^{\gamma} < 0.04$	$-0.05 < h_{40}^{\gamma} < 0.37$
CDF	$\lvert h_{30}^{\gamma}\rvert < 3.1$	$\lvert h_{40}^{\gamma}\rvert < 0.8$
DØ	$\lvert h_{30}^{\gamma}\rvert < 0.81$	$\lvert h_{40}^{\gamma}\rvert < 0.20$

95% CL – All experiments use Λ =0.5 TeV, except DELPHI

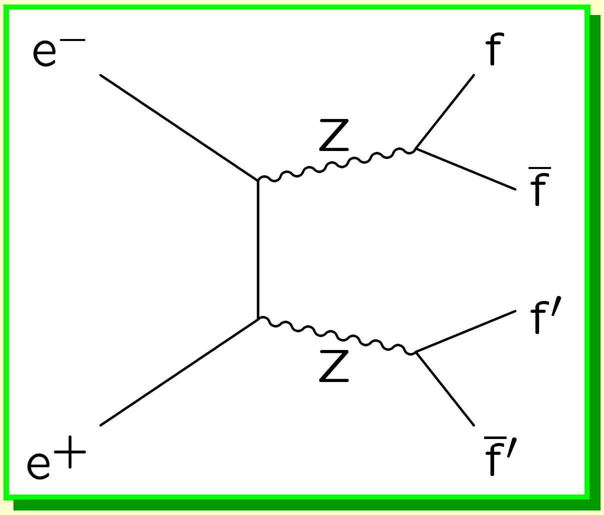


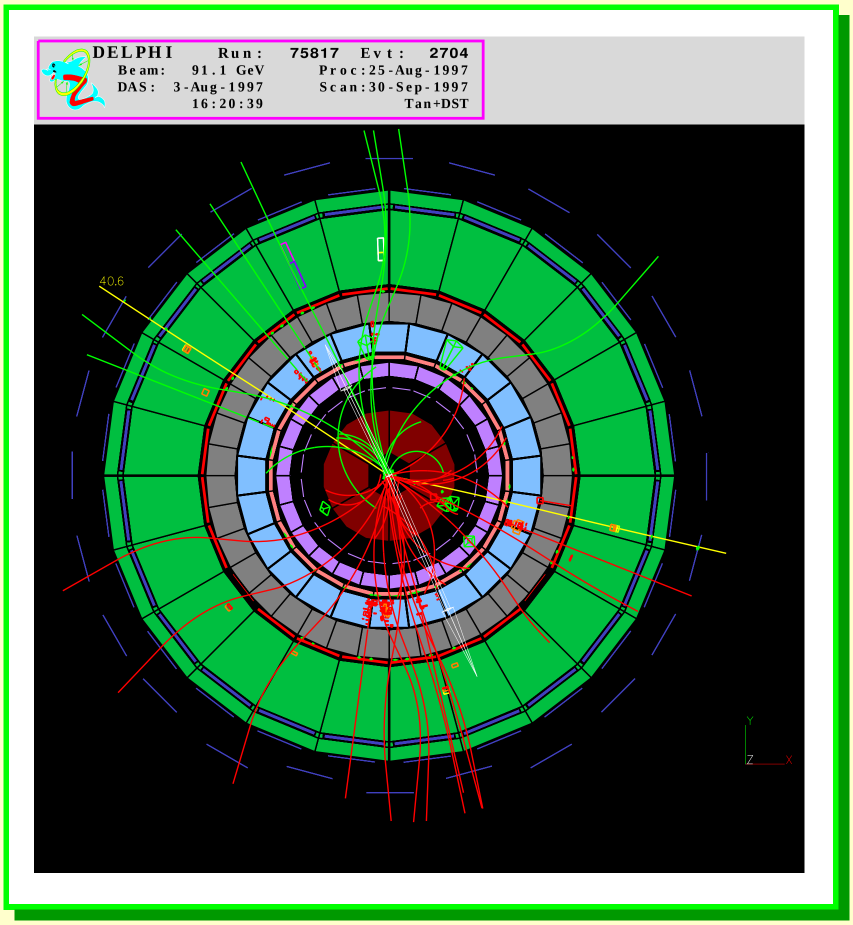
Different parameter correlation in e^+e^- and $p\bar{p}$ experiments



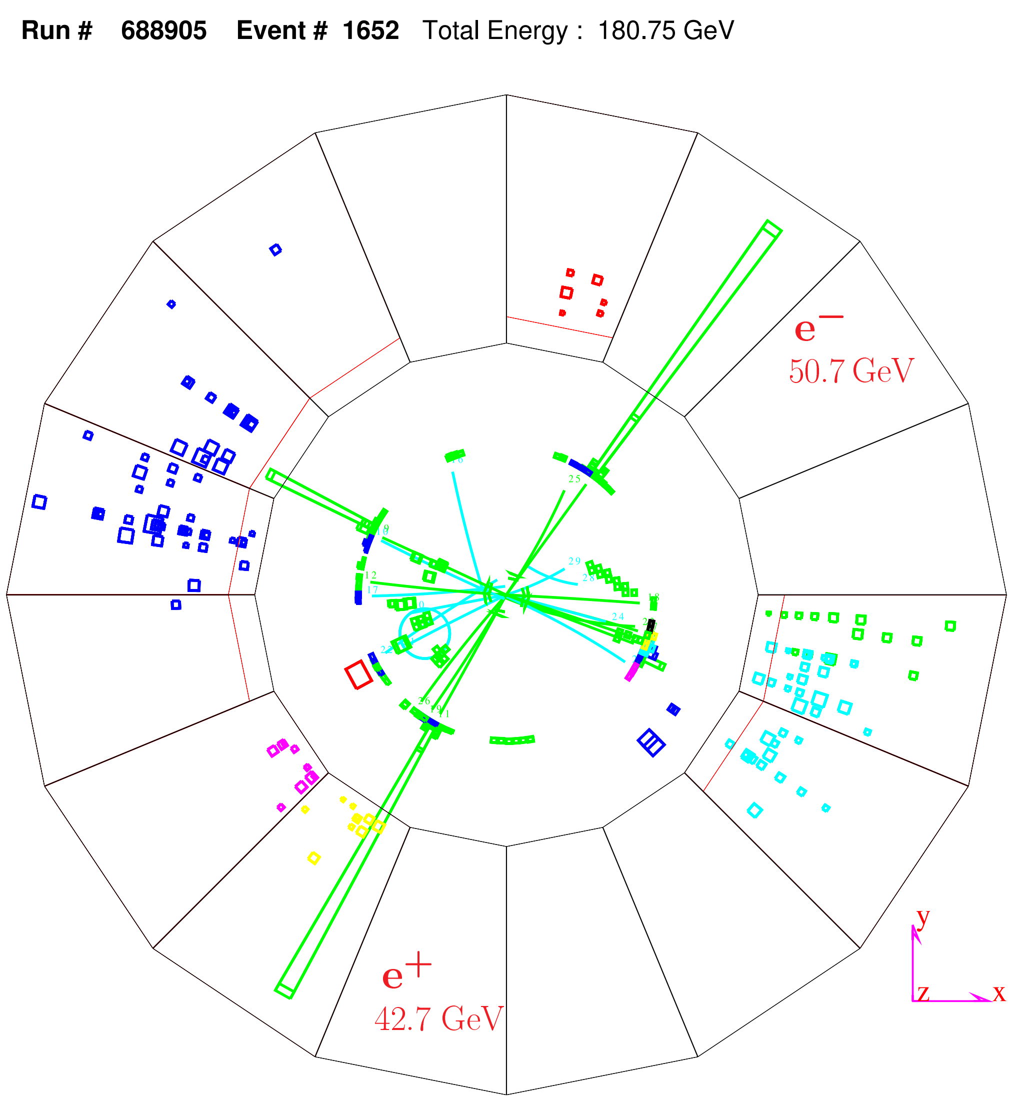
ZZ events

$\sqrt{s} = 183$ GeV: just above the threshold for ZZ production





All LEP experiments observe a few ZZ events.
Easiest channels: $q\bar{q}\ell^+\ell^-$, $\ell^+\ell^-\ell'^+\ell'^-$.



$m_{ee} = 92.8$ GeV $\qquad m_{jj} = 88.8$ GeV

In 1998 gain a factor 4 in cross section (higher $\sqrt{s}$)
and a factor 3 in luminosity

Start looking at anomalous couplings also in the ZZZ vertex

Conclusions and future prospects

- Still 3 years of data to come, hopefully with high $\mathcal{L}$
- Cross section measured to 2.5%, hadronic branching ratio to 1.2%
- All results on TGCs consistent with the SM, sensitivity similar to that of Tevatron Run I
- Still learning the best way to extract all informations from the data
- Improvements on $\Delta\kappa_\gamma$, combined 2–dim and 3–dim fits for the summer conferences

Change of model

- Move to a different set of parameters: $\Delta\kappa_\gamma$, λ_γ and g_Z^1
- $\Delta\kappa_Z$ and λ_Z obtained from gauge invariance
- Combined limits from LEP and Tevatron