Standard Model Physics measurements at LEP2

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on behalf of the LEP Collaborations

Les Rencontres de Physique de la Vallée d'Aoste

4 - 10 March 2001, La Thuile (Italy)

Outline

- ✓ Two fermions / two photons processes discussed in Burilkov's talk (Session 8)
- ✓ 4 fermions related electroweak physics

- ✓ The LEP2 data sample
- ✓ W pair production
  - ☞ $\mathcal{O}(\alpha)$ radiative corrections
  - ☞ Cross section, Branching ratios, $|V_{cs}|$
- ✓ Single W cross section
- ✓ Charged Triple Gauge Couplings
- ✓ Z pair cross section
- ✓ Neutral Triple Gauge Couplings
- ✓ Quartic Gauge Couplings
- ✓ W mass and width

All the results are preliminary

The LEP2 data sample

✓ November 2000: end of LEP data taking

Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
1996	161	$\simeq 10$
1996	172	$\simeq 10$
1997	183	$\simeq 50$
1998	189	$\simeq 170$
1999	192	$\simeq 30$
1999	196	$\simeq 80$
1999	200	$\simeq 80$
1999	202	$\simeq 40$
2000	205*	$\simeq 100$
2000	207*	$\simeq 120$

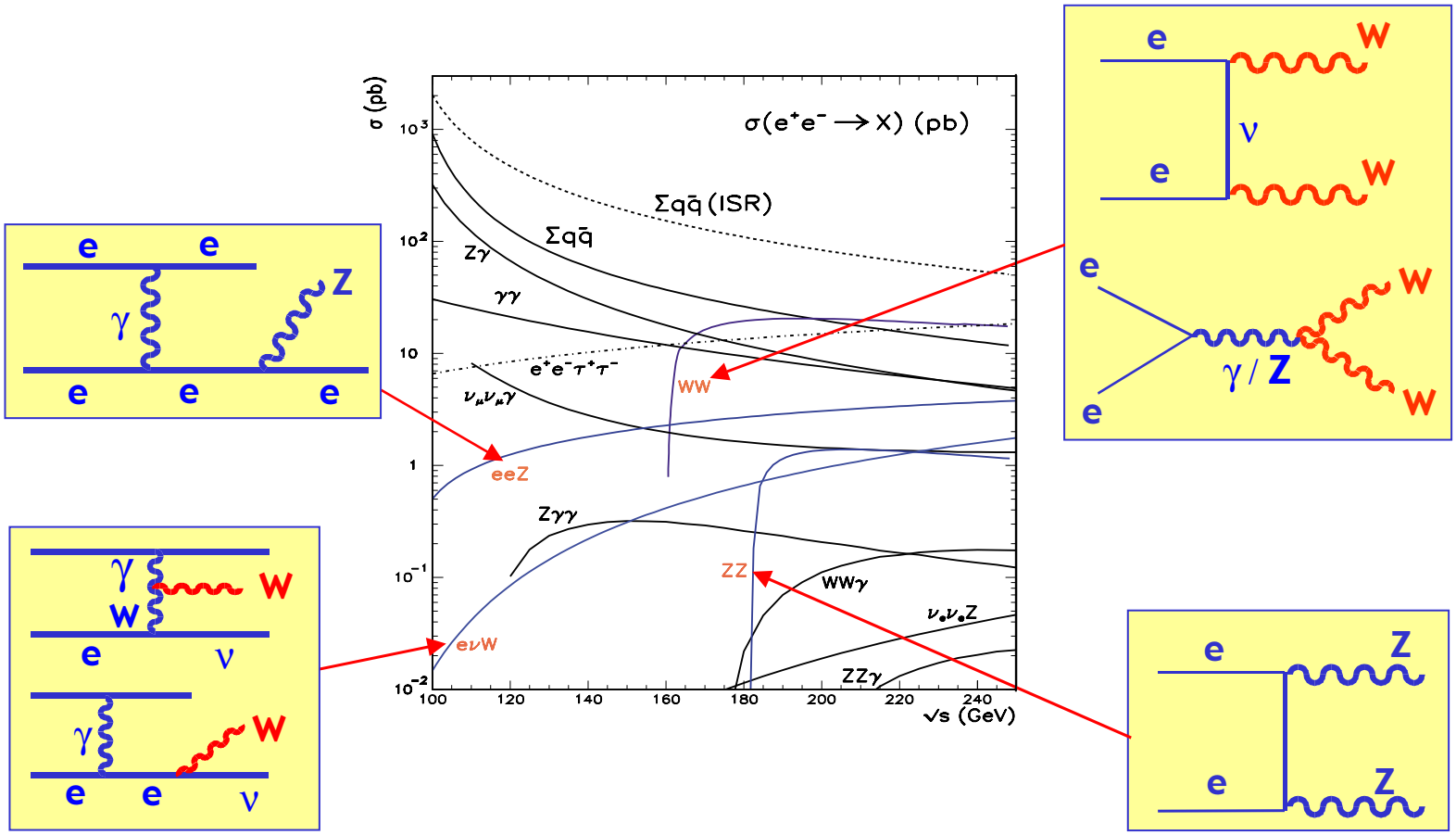
*: average value in a continuous range

✓ $\simeq 10\,\mathrm{pb}^{-1}$ at the WW threshold

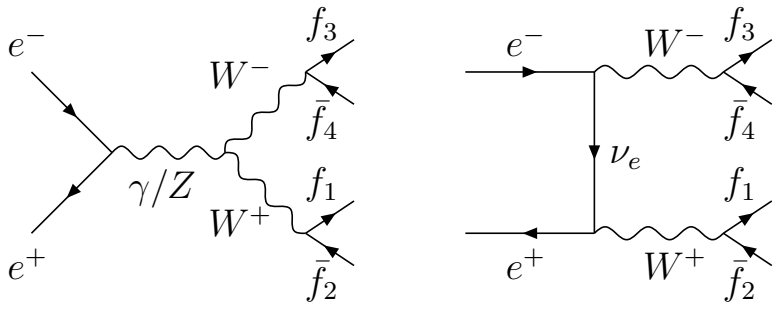
✓ $\simeq 680\,\mathrm{pb}^{-1}$ at $172\,\mathrm{GeV} \leq \sqrt{s} \leq 209\,\mathrm{GeV}$

✓ $\simeq$ 9400 WW pairs / experiment

4 fermion processes at LEP2



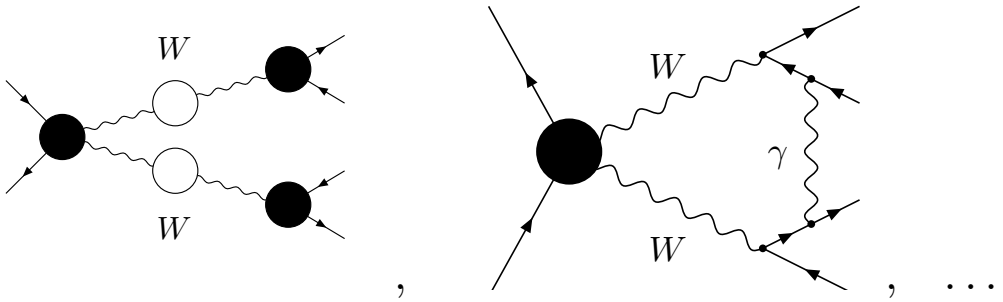
$e^-e^+ \rightarrow W^-W^+$



- ✓ CC03 $\Rightarrow$ correct for other 4 fermions diagrams
- ✓ TGC foreseen by the SM at Born level
- ✓ According to the W decays 3 topologies:

Final State	SM $\mathcal{BR}$	Topology	Bkg. / Eff.
$qqqq$	45.6%	≥ 4 hadronic jets high $\sqrt{s'}$	$Z/\gamma \rightarrow q\bar{q}$ $ZZ \rightarrow q\bar{q}q\bar{q}$ P $\simeq$ 90%, $\epsilon \simeq$ 90%
$qql\nu$	43.9%	energetic charged lepton, missing p_t 2 jets	$q\bar{q}l\bar{l}$ P $\simeq$ 90%, $\epsilon \simeq$ 50% - 90%
$l\nu l\nu$	10.5%	2 isolated acoplanar charged leptons missing energy and p	$Z/\gamma \rightarrow l\bar{l}$ 2γ, Zee, ZZ, $We\nu$ P $\simeq$ 90% $\epsilon \simeq$ 60% - 80%

$e^-e^+ \to W^-W^+$: $\mathcal{O}(\alpha)$ radiative corrections



✓ Full correction not available: Double Pole Approximation

RacoonWW: full $4f + \gamma$ matrix element, massless, full virtual DPA, higher order ISR with Structure Functions, W spin correlations, full non factorizable corrections

YFSWW: CC03 matrix element, LPA with $\mathcal{O}(\alpha)$ EW+QED on shell, W spin correlations, ISR/W radiation with YFS exponentiation, FSR LL calculation, screened Coulomb ansatz

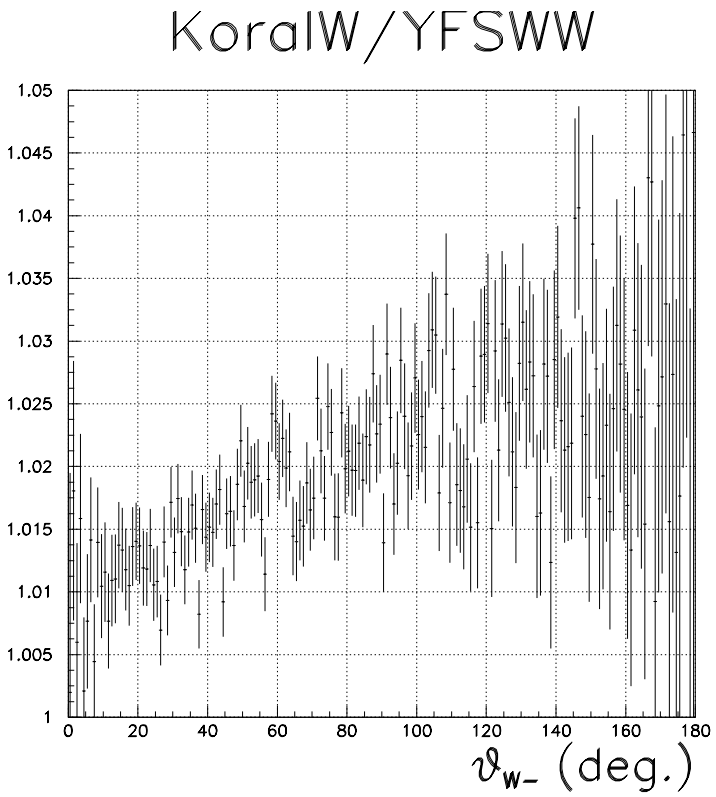
✓ Agreement between the 2 codes:
$\Delta\sigma_{CC03}/\sigma_{CC03} \leq 0.4\%$

✓ DPA theoretical uncertainty:
$\alpha/\pi \times \Gamma_W/m_W \times \ln(\dots) \leq 0.5\%$

✓ Effect of DPA on total CC03 cross section:
lower by $\simeq 1.5\%$ (up to 3% for Gentle LEP settings)

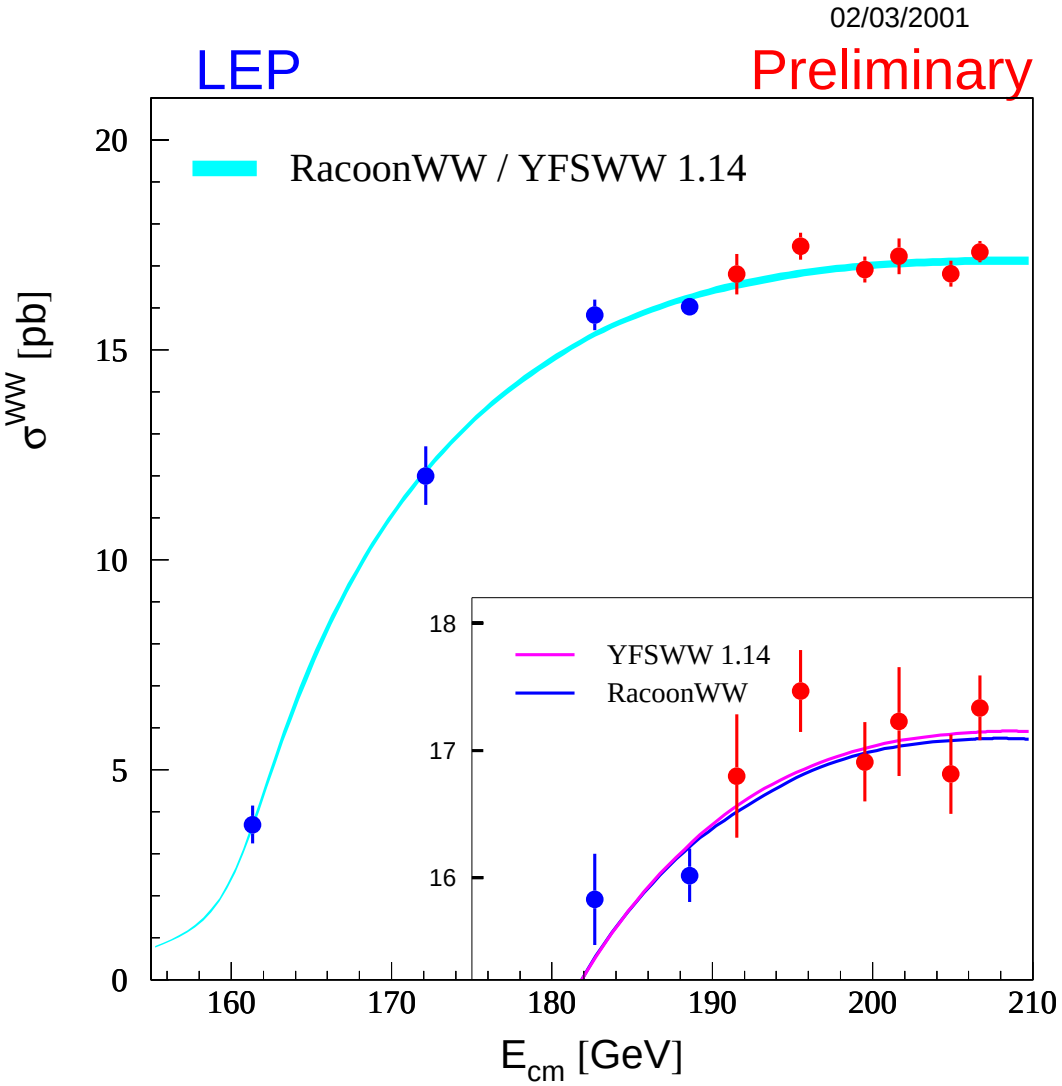
$e^-e^+ \to W^-W^+$: $\mathcal{O}(\alpha)$ radiative corrections

- ✓ Next step: effect of DPA in analysis ⇒
  - ☞ changes in differential distributions
  - ☞ error on differential distributions
- ✓ from preliminary generator level studies
  - ☞ W peak position shift $\simeq 5$ MeV
    (W shape slightly modified)
  - ☞ W boost shifted (non factorizable corrections)
  - ☞ W angular distribution affected ⇒ effect on TGC



- ✓ Add hadronisation + detector effects ⇒ effect on the final measurements: work in progress

$e^-e^+ \to W^-W^+$ cross section



NEW

- ADLO: preliminary at 205 - 207 GeV
- LO: final at 189 GeV
- L: updates at 192 - 202 GeV

Main experimental uncertainty: statistics

Effect of $\mathcal{O}(\alpha)$ (DPA) on selection under study

$e^-e^+ \to W^-W^+$ cross section

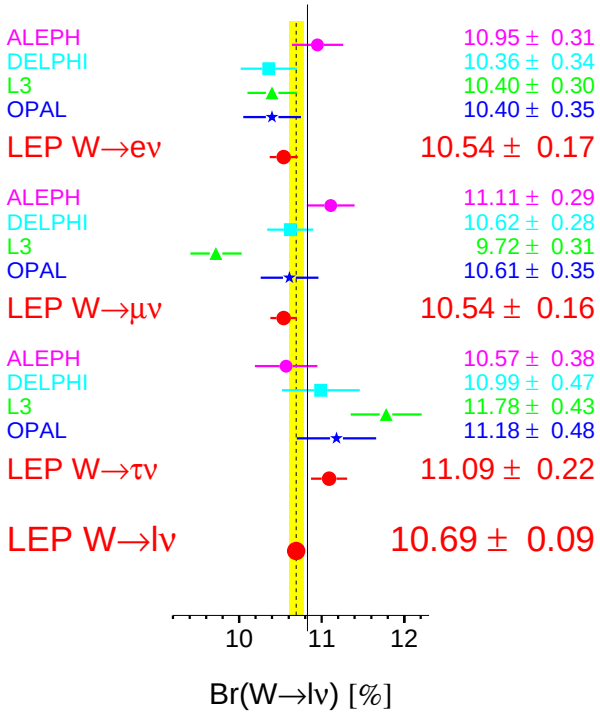
$\sqrt{s}$ (GeV)	ALEPH	DELPHI	L3	OPAL	LEP
189	$15.710 \pm 0.340 \pm 0.180$	$15.830 \pm 0.380 \pm 0.200$	$16.240 \pm 0.370 \pm 0.220$	$16.300 \pm 0.340 \pm 0.180$	$16.018 \pm 0.178 \pm 0$
192	$17.230 \pm 0.890 \pm 0.180$	$16.900 \pm 1.000 \pm 0.220$	$16.430 \pm 0.910 \pm 0.240$	$16.600 \pm 0.880 \pm 0.420$	$16.798 \pm 0.458 \pm 0$
196	$17.000 \pm 0.540 \pm 0.180$	$17.860 \pm 0.590 \pm 0.220$	$16.890 \pm 0.560 \pm 0.240$	$18.590 \pm 0.600 \pm 0.430$	$17.466 \pm 0.285 \pm 0$
200	$16.980 \pm 0.530 \pm 0.180$	$17.350 \pm 0.560 \pm 0.220$	$16.870 \pm 0.570 \pm 0.240$	$16.320 \pm 0.540 \pm 0.380$	$16.910 \pm 0.275 \pm 0$
202	$16.160 \pm 0.740 \pm 0.180$	$17.670 \pm 0.810 \pm 0.230$	$17.020 \pm 0.860 \pm 0.240$	$18.480 \pm 0.810 \pm 0.420$	$17.227 \pm 0.401 \pm 0$
205	$16.570 \pm 0.520 \pm 0.180$	$17.440 \pm 0.600 \pm 0.220$	$17.350 \pm 0.590 \pm 0.240$	$15.970 \pm 0.520 \pm 0.370$	$16.813 \pm 0.277 \pm 0$
207	$17.320 \pm 0.410 \pm 0.180$	$16.500 \pm 0.430 \pm 0.210$	$17.960 \pm 0.450 \pm 0.240$	$17.770 \pm 0.420 \pm 0.380$	$17.333 \pm 0.213 \pm 0$

W branching ratios

02/03/2001

Winter 01 - Preliminary - [161-207] GeV

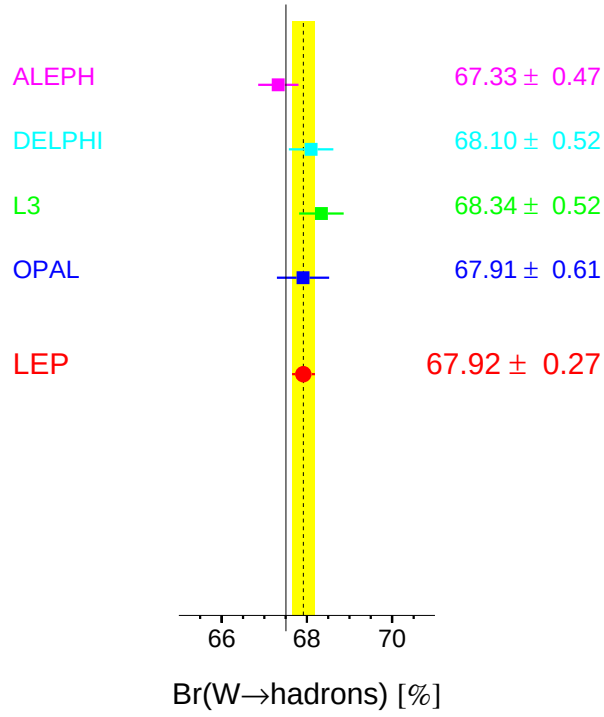
W Leptonic Branching Ratios



02/03/2001

Winter 01 - Preliminary - [161-207] GeV

Br(W→hadrons) [%]



Lepton coupling universality test

$|V_{cs}|$

✓ From the leptonic branching ratio $\mathcal{BR}(W \to l\bar{\nu})$ of the W assuming lepton universality:

$$1/\mathcal{BR}(W \to l\bar{\nu}_l) \quad = \quad 3\{1 + [1 + \alpha_s(m_W^2)/\pi] \sum_{i=u,c,\, j=d,s,b} |V_{ij}|^2\}$$

with $\alpha_s(m_W^2) = (0.121 \pm 0.002)$ and $\sum |V_{ij}|^2$ from PDG 2000:

$$|V_{cs}| \quad = \quad 0.996 \pm 0.013$$

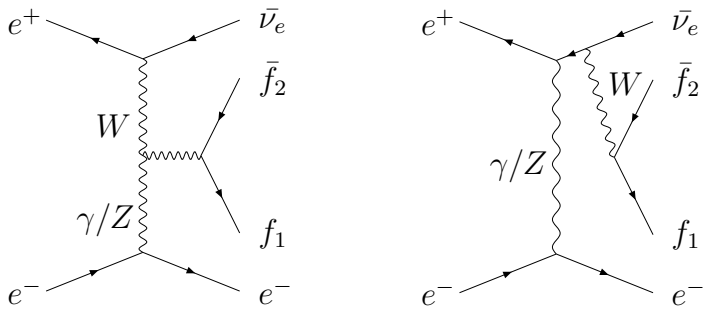
✓ Error dominated by $\mathcal{BR}(W \to l\bar{\nu}_l)$

✓ in agreement with the direct LEP2 measurements (charm jet rate):

$$|V_{cs}| \quad = \quad 0.95 \pm 0.08$$

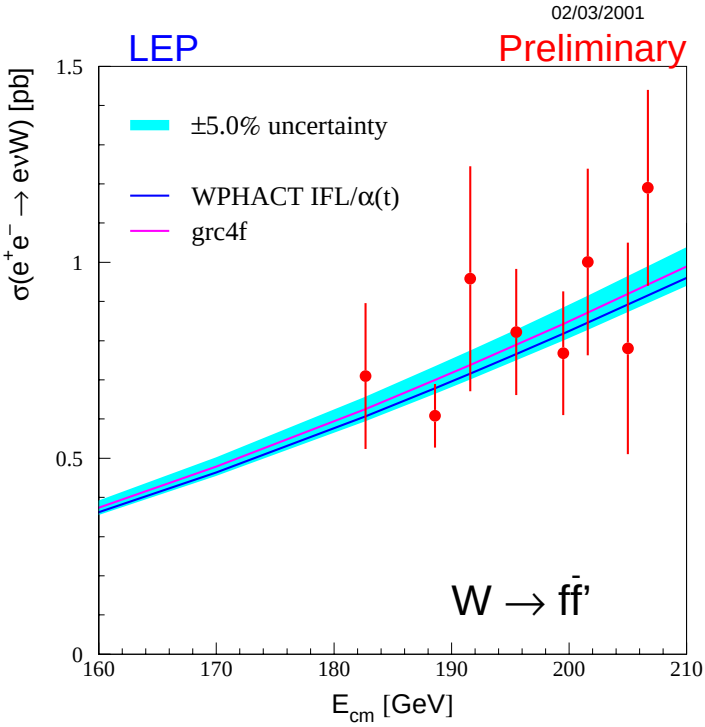
(Gurtu, OSAKA 2000)

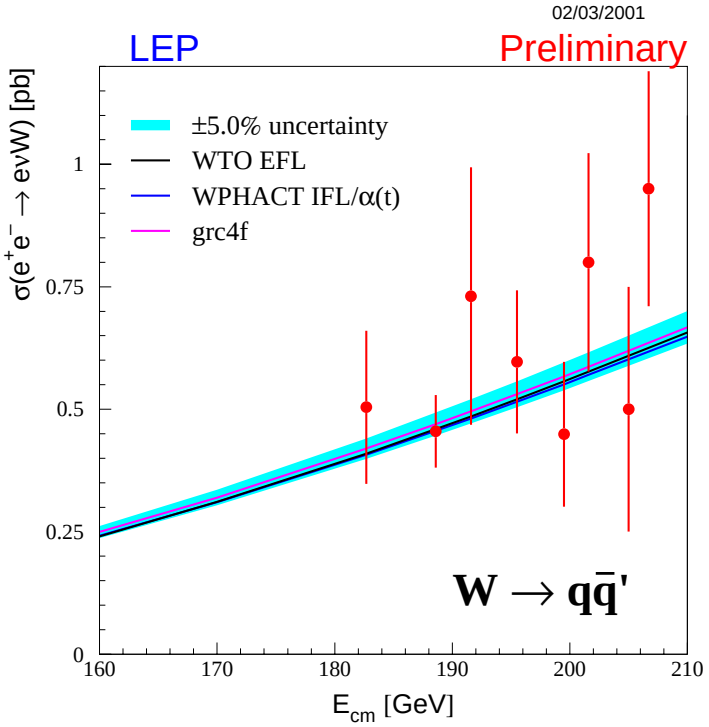
Single W



LEP WG definition: t-channel contributions

$M_{q\bar{q}} > 45\,\mathrm{GeV/c^2}$, $E_l > 20\,\mathrm{GeV}$, if $e\nu e\nu$: $|\cos\theta_e| > 0.95$





NEW A: preliminary at 205 - 207 GeV

(no other results for 2000 data)

Charged Triple Gauge Couplings

- ✓ $SU(2)_L \bigotimes U(1)_Y$ gauge theory: 3 and 4 bosons vertices
- ✓ Charged triple couplings: WWV $(V = \gamma, Z)$, enters at tree level at LEP2 (W^+W^-, single W, $\nu\bar{\nu}\gamma$)
- ✓ Anomalous couplings $\Rightarrow$ physics beyond the Standard Model
- ✓ Lorentz invariant parametrization of the WWV part of the Lagrangian, operators with dimension up to 6 $\Rightarrow$ 7 couplings for each V
- ✓ Ask for electromagnetic gauge invariance, C, P, CP conservation, study the couplings not constrained by low energy measurements:

$$\Delta g_Z^1, \quad \Delta\kappa_\gamma, \quad \lambda_\gamma \qquad (= 0 \quad \text{in SM})$$

$$\Delta\kappa_Z = \Delta g_Z^1 - \Delta\kappa_\gamma \tan^2\theta_W \quad , \quad \lambda_Z = \lambda_\gamma$$

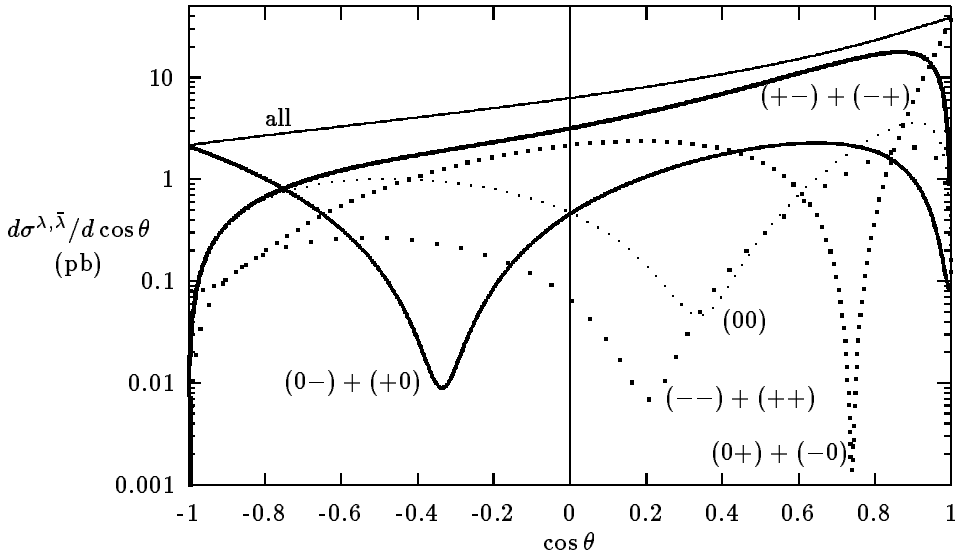
$(\Delta X = X - 1)$

- ✓ Directly linked to W electric charge, magnetic dipole moment, electric quadrupole moment

Charged TGCs measurement

✓ $e^-e^+ \to W^-W^+$:

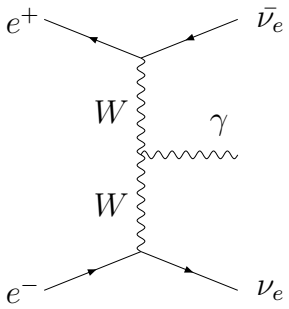
- ☞ total cross section
- ☞ W helicities combinations $\Rightarrow$ W decay angle θ and fermions decay angles in W rest frame $\theta_+, \phi_+, \theta_-, \phi_-$
  - ❖ Maximum Likelihood
  - ❖ Optimal observables



Single W and $\nu\bar{\nu}\gamma$

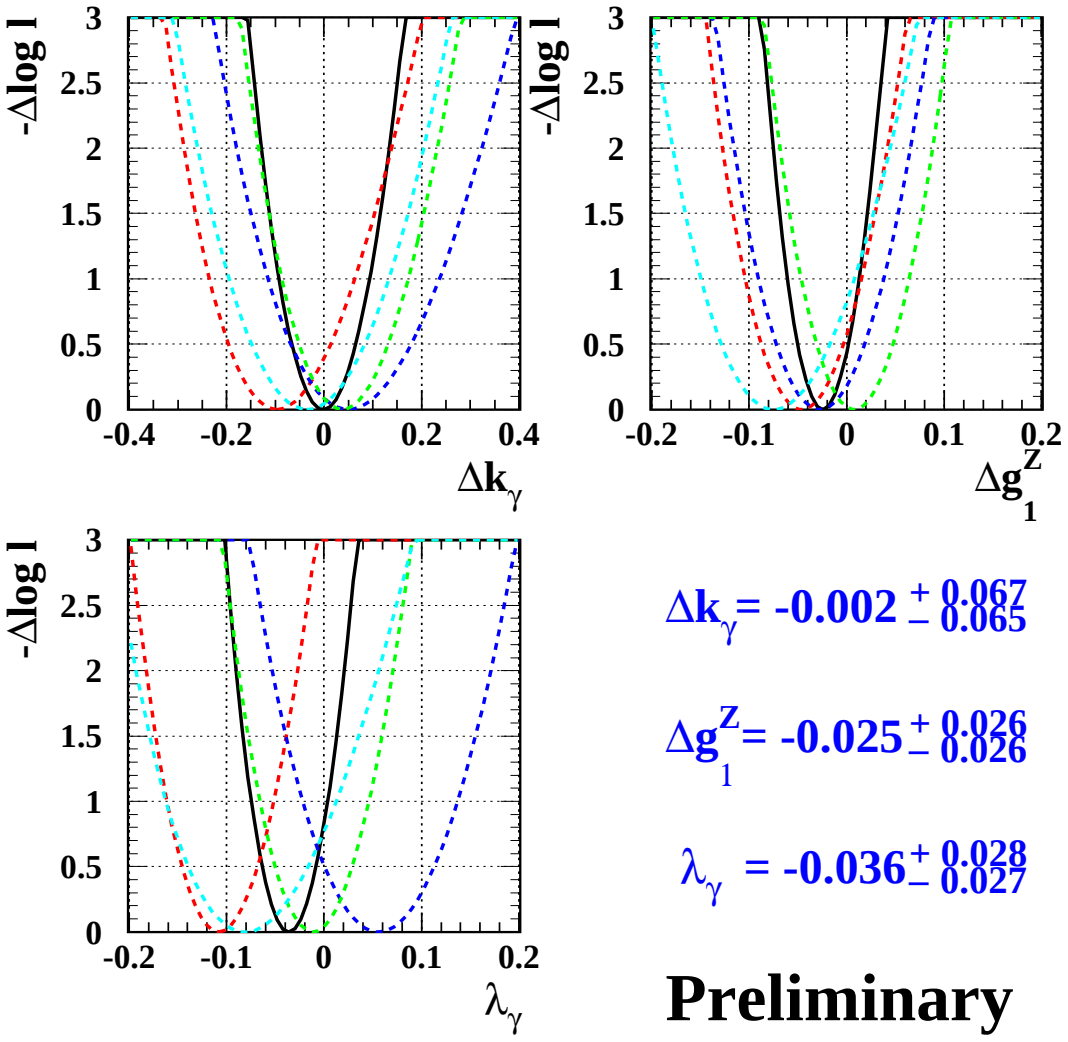
✓ total cross section

✓ differential distributions $(E_\gamma,\ \cos\theta_\gamma)$



Charged TGCs results

ALEPH + DELPHI + L3 + OPAL



$\Delta k_\gamma = -0.002 \pm^{0.067}_{0.065}$

$\Delta g_1^Z = -0.025 \pm^{0.026}_{0.026}$

$\lambda_\gamma = -0.036 \pm^{0.028}_{0.027}$

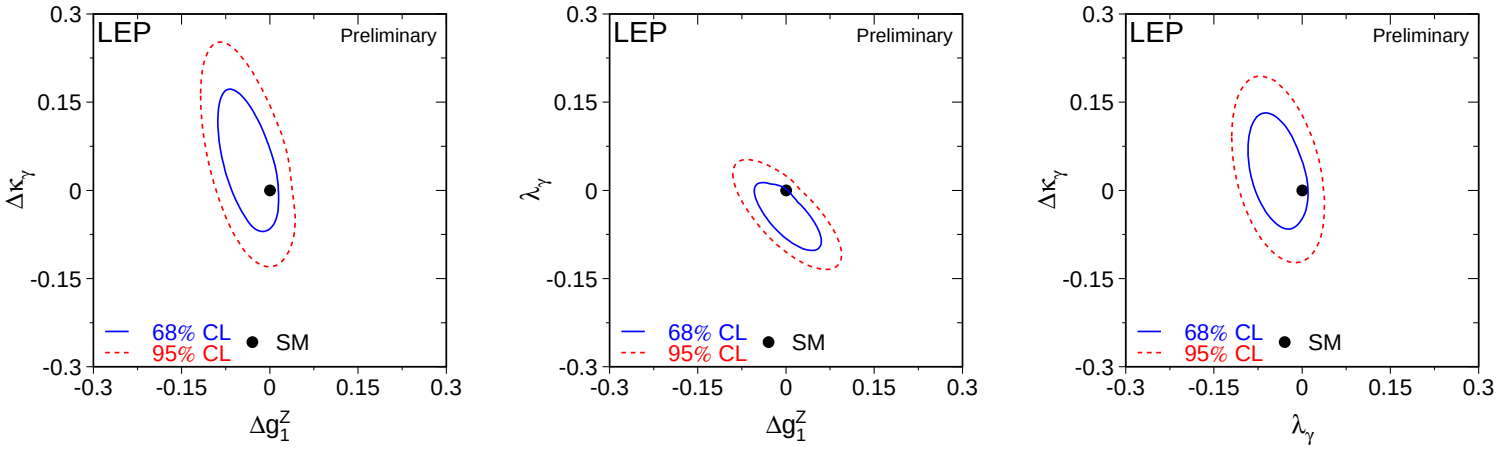
Preliminary

No new result in combination since OSAKA 2000

Studies of effects of $\mathcal{O}(\alpha)$ (DPA) corrections in progress

biases of angular distributions $\Rightarrow$ systematic shifts

Charged TGCs results



- ✓ Precision at the 2% level
- ✓ ALEPH preliminary results on WW data 183 - 207 GeV with DPA effect in cross section and as uncertainty on angular distributions:

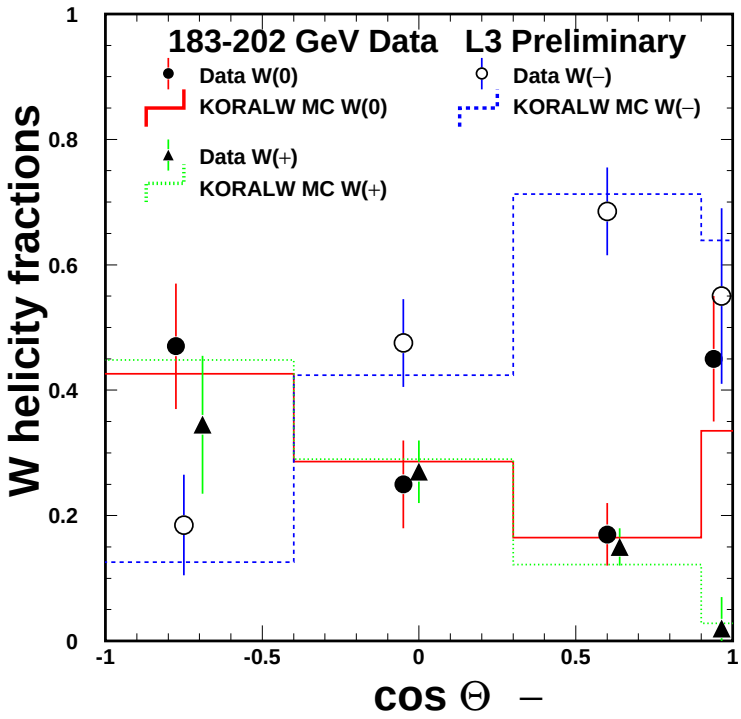
Coupling	Central value	stat. + syst.	$\mathcal{O}(\alpha)$
Δg_Z^1	0.015	0.032	0.013
$\Delta\kappa_\gamma$	0.018	0.124	0.037
λ_γ	0.006	0.034	0.015

Charged TGCs results

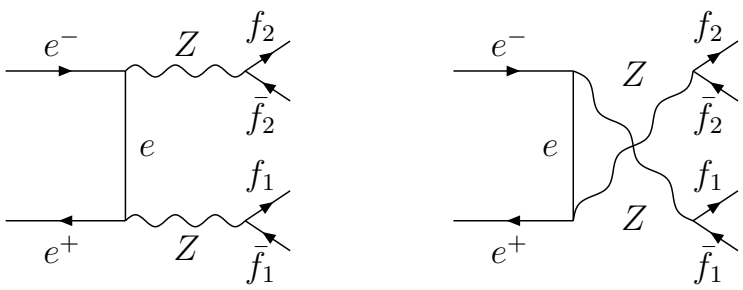
✓ W polarisation: Spin Density Matrix (OPAL)

Pol. frac.	Result	SM
σ_T/σ_{total}	$0.790 \pm 0.033 \pm 0.016$	0.74
σ_L/σ_{total}	$0.210 \pm 0.033 \pm 0.016$	0.26
$\sigma_{TT}/\sigma_{total}$	$0.781 \pm 0.090 \pm 0.033$	0.57
$\sigma_{LL}/\sigma_{total}$	$0.201 \pm 0.072 \pm 0.018$	0.09
$\sigma_{TL}/\sigma_{total}$	$0.018 \pm 0.147 \pm 0.038$	0.34

✓ W helicity fractions (L3)



$e^-e^+ \to ZZ$



✓ NC02 $\Rightarrow$ correct for other 4 fermions diagrams

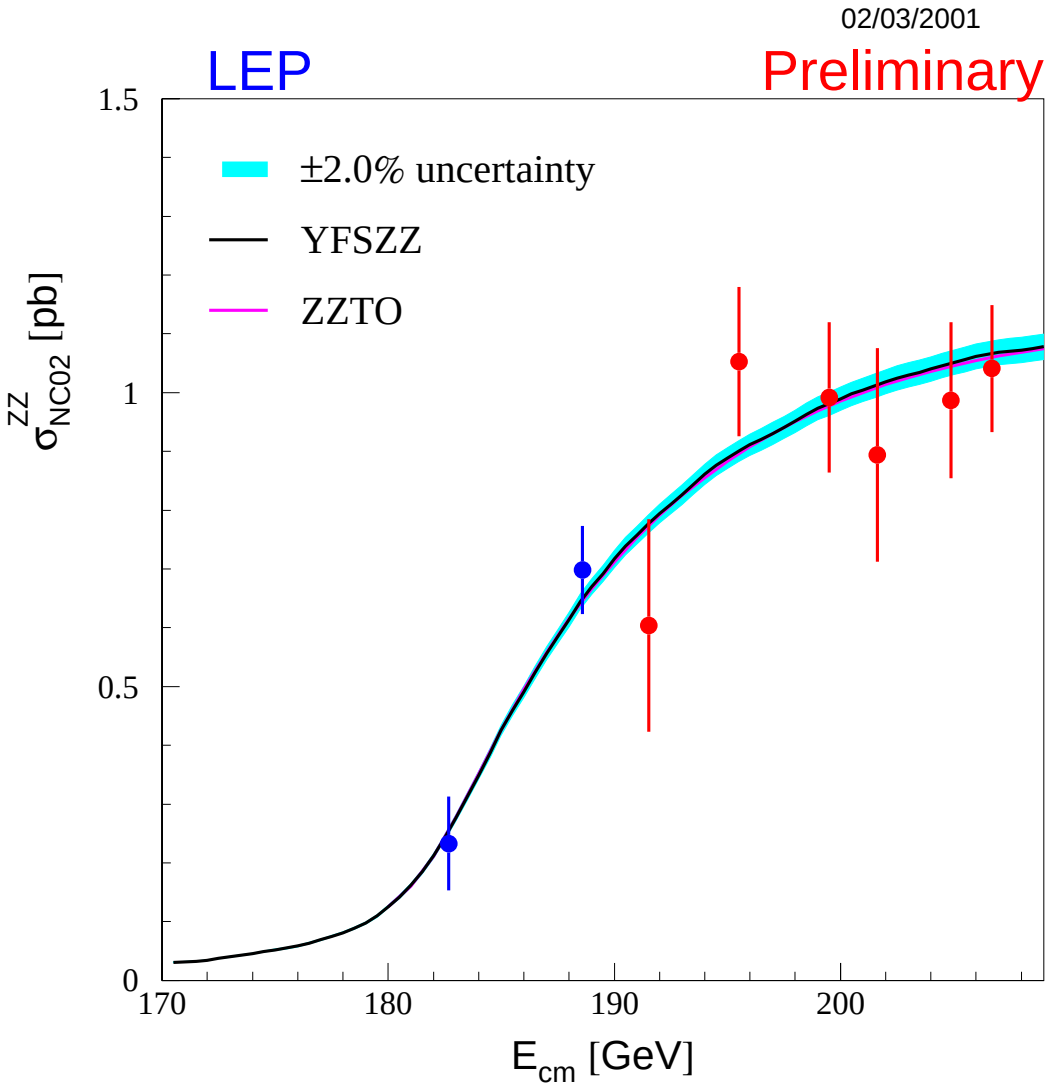
✓ Background to the Higgs searches at LEP2

✓ According to the Z decays 5 topologies are studied:

Final state	SM $\mathcal{BR}$	Backgrounds
$q\bar{q}q\bar{q}$	$\simeq$ 49%	WW, $q\bar{q}\gamma$ High
$q\bar{q}l^+l^-$	$\simeq$ 14%	Zee, $Z\gamma^*$ Low
$q\bar{q}\nu\bar{\nu}$	$\simeq$ 28%	WW, $We\nu$, $q\bar{q}\gamma$ High
$l^+l^-\nu\bar{\nu}$	$\simeq$ 3%	WW Medium
$l^+l^-l^+l^-$	$\simeq$ 1%	non res. $e^+e^-l^+l^-$ Medium

✓ Boson(s) reconstructed invariant masses close to m_Z (reject $Z\gamma^*$)

$e^-e^+ \to ZZ$ cross section



NEW

- ADLO: preliminary at 205 - 207 GeV
- A: updates to 192 - 202 GeV syst.
- L: 192 - 202 GeV final

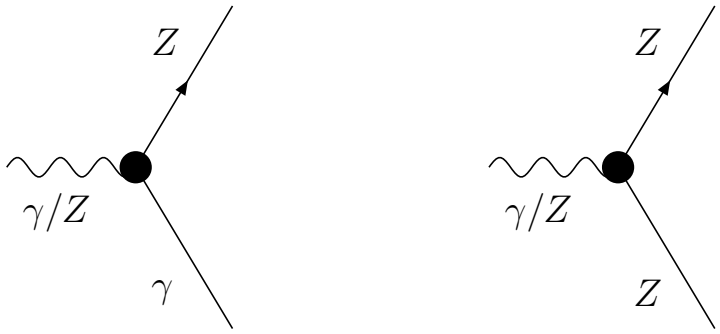
Main experimental uncertainty statistics

$e^-e^+ \to ZZ$ cross section

$\sqrt{s}$ (GeV)	ALEPH	DELPHI	L3	OPAL	LEP
183	$0.110 \pm 0.135 \pm 0.040$	$0.380 \pm 0.146 \pm 0.040$	$0.310 \pm 0.155 \pm 0.050$	$0.120 \pm 0.190 \pm 0.030$	$0.233 \pm 0.076 \pm 0.0$
189	$0.670 \pm 0.130 \pm 0.040$	$0.600 \pm 0.135 \pm 0.070$	$0.730 \pm 0.145 \pm 0.040$	$0.800 \pm 0.140 \pm 0.060$	$0.698 \pm 0.069 \pm 0.0$
192	$0.530 \pm 0.331 \pm 0.020$	$0.550 \pm 0.400 \pm 0.084$	$0.290 \pm 0.340 \pm 0.020$	$1.130 \pm 0.360 \pm 0.110$	$0.604 \pm 0.177 \pm 0.0$
196	$0.690 \pm 0.228 \pm 0.030$	$1.170 \pm 0.239 \pm 0.098$	$1.180 \pm 0.220 \pm 0.090$	$1.280 \pm 0.250 \pm 0.100$	$1.053 \pm 0.117 \pm 0.0$
200	$0.700 \pm 0.232 \pm 0.030$	$1.080 \pm 0.231 \pm 0.105$	$1.250 \pm 0.240 \pm 0.090$	$1.010 \pm 0.250 \pm 0.070$	$0.992 \pm 0.119 \pm 0.0$
202	$0.700 \pm 0.349 \pm 0.020$	$0.870 \pm 0.336 \pm 0.112$	$0.950 \pm 0.350 \pm 0.070$	$1.090 \pm 0.370 \pm 0.090$	$0.894 \pm 0.175 \pm 0.0$
205	$1.210 \pm 0.270 \pm 0.030$	$1.051 \pm 0.232 \pm 0.123$	$0.690 \pm 0.230 \pm 0.060$	$1.080 \pm 0.260 \pm 0.090$	$0.987 \pm 0.123 \pm 0.0$
207	$1.010 \pm 0.180 \pm 0.020$	$0.975 \pm 0.193 \pm 0.115$	$1.170 \pm 0.210 \pm 0.080$	$1.030 \pm 0.210 \pm 0.080$	$1.041 \pm 0.099 \pm 0.0$

Neutral Triple Gauge Couplings

✓ Not foreseen by the Standard Model at the tree level



✓ 2 classes of anomalous neutral TGCs:

✓ $Z\gamma\gamma$, $ZZ\gamma$ couplings in $e^-e^+ \to Z\gamma$:
$h_i^V, V = Z, \gamma, i = 1, \ldots, 4$

☞ h_1^V, h_2^V CP violating, h_3^V, h_4^V CP conserving

- ❖ $\nu\bar{\nu}\gamma$ cross section measurement and differential event observables
- ❖ $q\bar{q}\gamma$ cross section and differential event distributions
- ❖ $\nu\bar{\nu}\gamma$, $q\bar{q}\gamma$ optimal observables

✓ $ZZ\gamma$, ZZZ couplings in $e^-e^+ \to ZZ$:
$f_i^V, V = Z, \gamma, i = 4, 5$

☞ f_4^V CP violating, f_5^V CP conserving

- ❖ ZZ cross section

Neutral Triple Gauge Couplings results

$Z\gamma$ final state

Coupling	95% C.L.
h_1^γ	[-0.09 , +0.05]
h_2^γ	[-0.05 , +0.05]
h_3^γ	[-0.07 , -0.002]
h_4^γ	[+0.002 , +0.05]
h_1^Z	[-0.15 , +0.14]
h_2^Z	[-0.10 , +0.10]
h_3^Z	[-0.22 , +0.07]
h_4^Z	[-0.05 , +0.15]

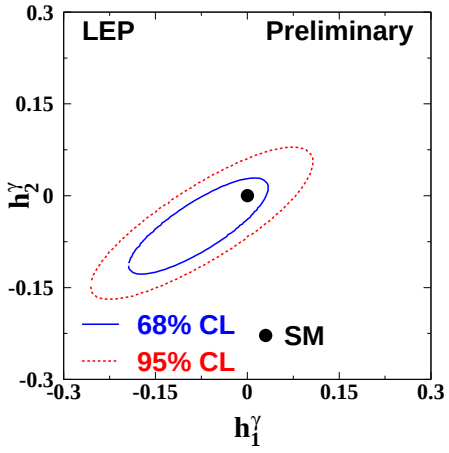
ZZ final state

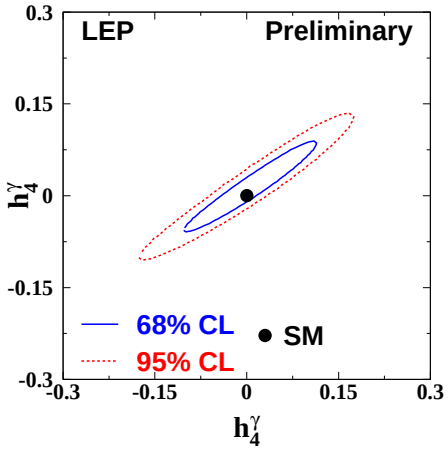
Coupling	Value/Error	95% C.L.
f_4^γ	$0.04^{+0.12}_{-0.17}$	[-0.21 , +0.23]
f_4^Z	$-0.13^{+0.28}_{-0.16}$	[-0.403 , +0.332]
f_5^γ	$0.21^{+0.16}_{-0.35}$	[-0.373 , +0.489]
f_5^Z	$0.00^{+0.15}_{-0.14}$	[-0.27 , +0.29]

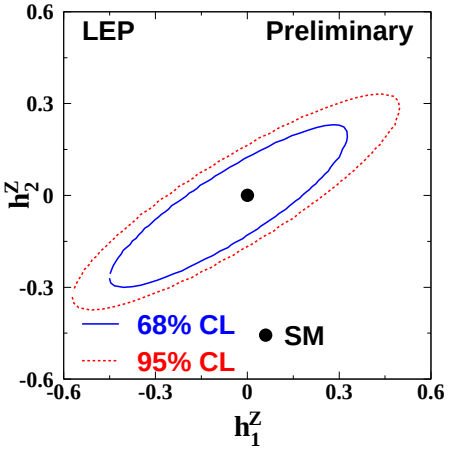
NEW h L: updated analysis

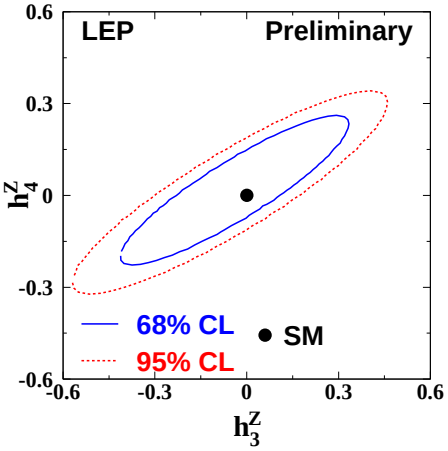
NEW f D: preliminary 2000 data, A: new results

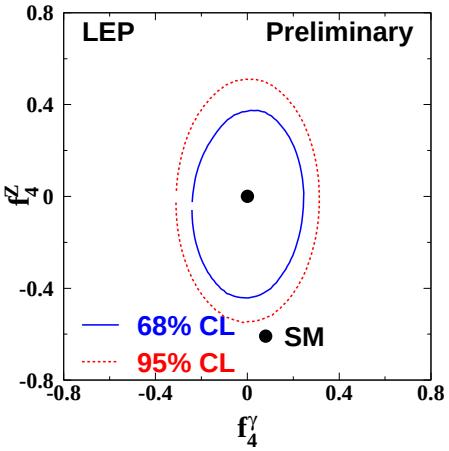
Neutral Triple Gauge Couplings results

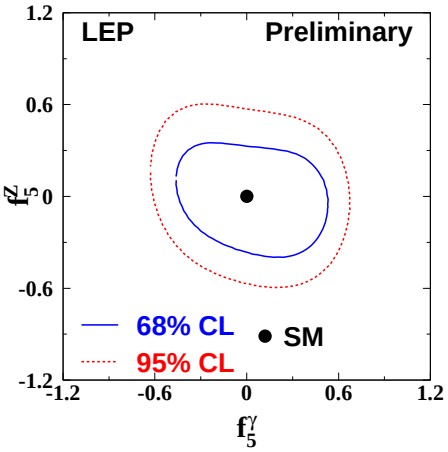




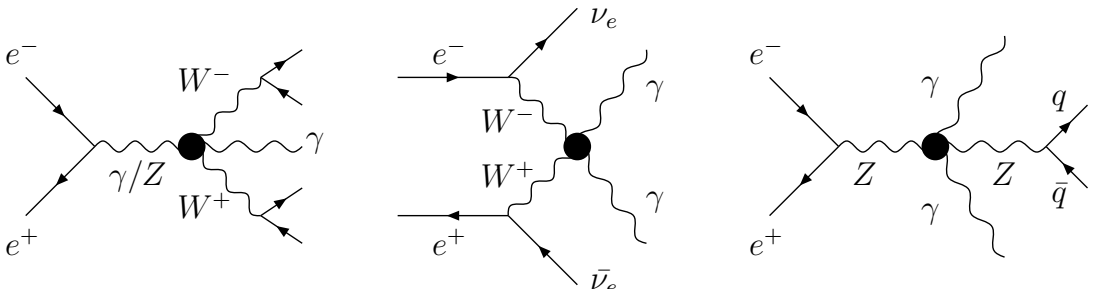








Quartic Gauge Couplings



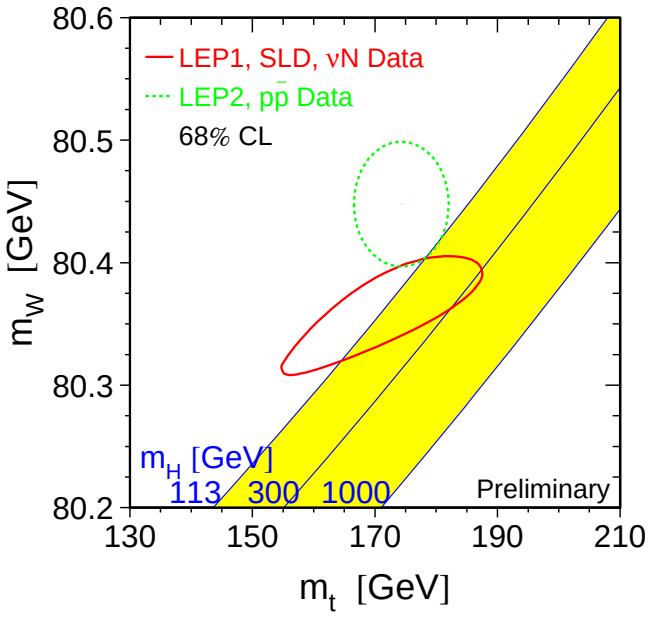
- ✓ Charged QGC: $WWVV$ negligible in the SM
- ✓ Neutral QGC: $ZZ\gamma\gamma$ forbidden in the SM
- ✓ Search for anomalous contributions
- ✓ Parameters not already constrained by the TGCs $\Rightarrow$ $WW\gamma$, $\gamma\gamma$ + missing energy and $q\bar{q}\gamma\gamma$ total cross section and event differential distributions

Final state	a_0/Λ^2	a_c/Λ^2
$WW\gamma$	[-0.054 , +0.054]	[-0.092 , +0.147]
$\gamma\gamma$ + missing energy	[-0.029 , +0.028]	[-0.079 , +0.079]
$Z\gamma\gamma$	[-0.0048 , +0.0056]	[-0.0052 , +0.0099]
All combined	[-0.0049 , +0.0056]	[-0.0054 , +0.0098]

No new result since OSAKA 2000

W mass at LEP2

- ✓ m_W direct measurement:
  - ☞ cfr. indirect measurements ($e^-e^+ \to Z$, νN) $\Rightarrow$ SM consistency test
  - ☞ constraint on Higgs mass



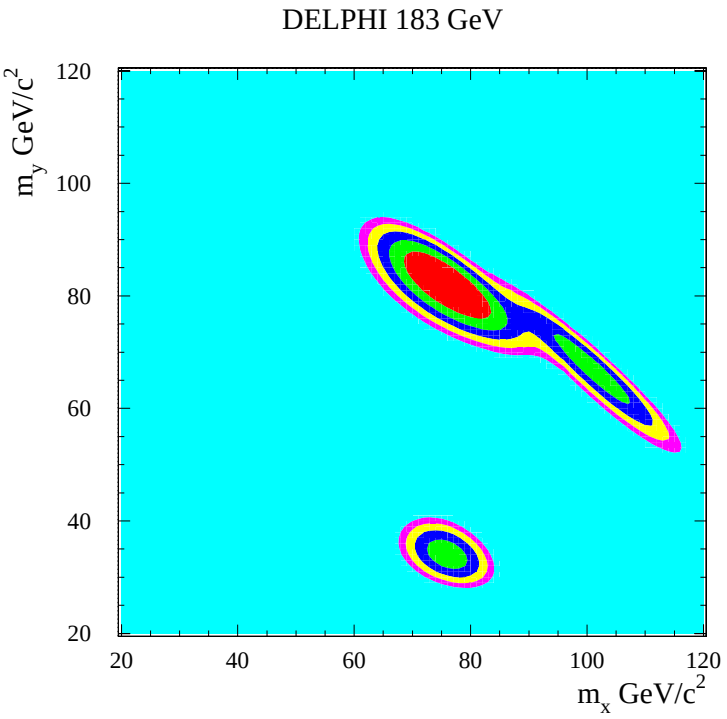
LEPEWWG Winter 2001

- ✓ Measurement at $e^-e^+ \to W^-W^+$ $\Rightarrow$ different systematics than hadronic colliders
- ✓ At the WW threshold exploit $d\sigma/dm_w$ $\Rightarrow$ from the total cross section:

$$m_W = 80.40 \pm 0.20\,(\text{stat.}) \pm 0.07\,(\text{syst.}) \pm 0.03\,(\text{LEP } E_{beam})\ \text{GeV}$$

W mass measurement

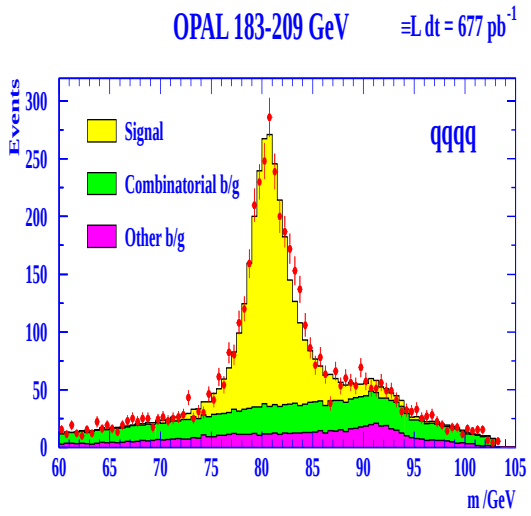
- ✓ m_W direct kinematical reconstruction ⇒
  use only $qqqq$ and $qql\nu$
- ✓ Use also differential distributions from $l\nu l\nu$ (AO)
- ✓ Improve the mass resolution ⇒ Constrained fits:
  - ☞ 4C ⇒ $E_{tot} = \sqrt{s}, \qquad \vec{p}_{tot} = \vec{0}$
  - ☞ solve jet pairing ambiguity in $qqqq$
  - ☞ $m_1 = m_2$,
    $m'_{q\bar{q}} = m_{q\bar{q}} \times \sqrt{s}/(E_q + E_{\bar{q}})$ (A $qqqq$),
    ideograms (D $qqqq$)

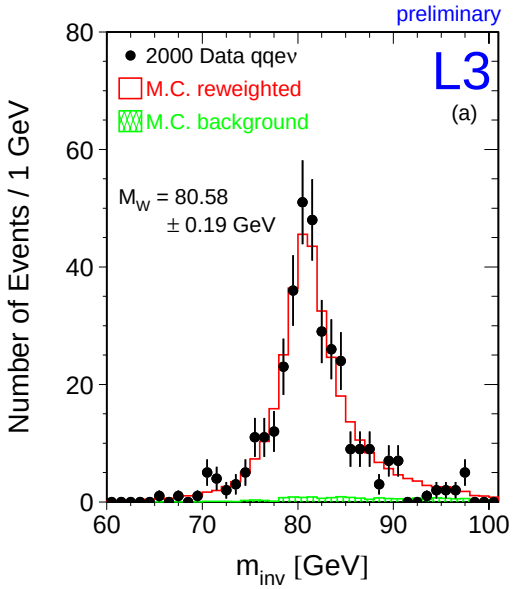


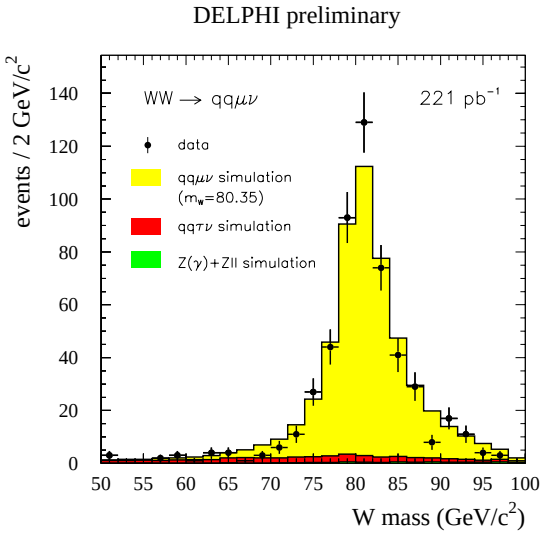
W mass measurement

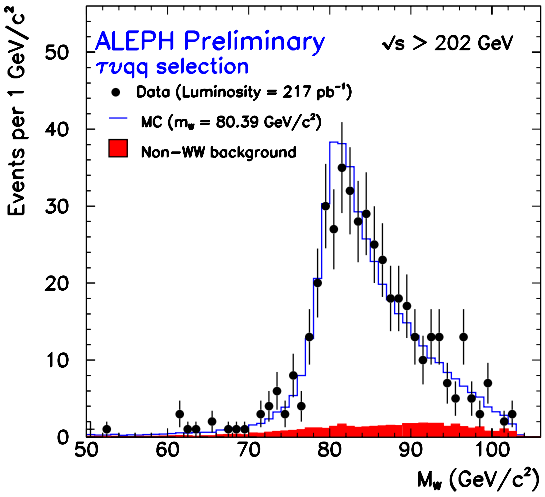
✓ From the mass distributions extract the value:

- ☞ Likelihood fit with Montecarlo reweighting (ALO)
- ☞ Likelihood fit with convolution of W mass distribution and resolution function (D)

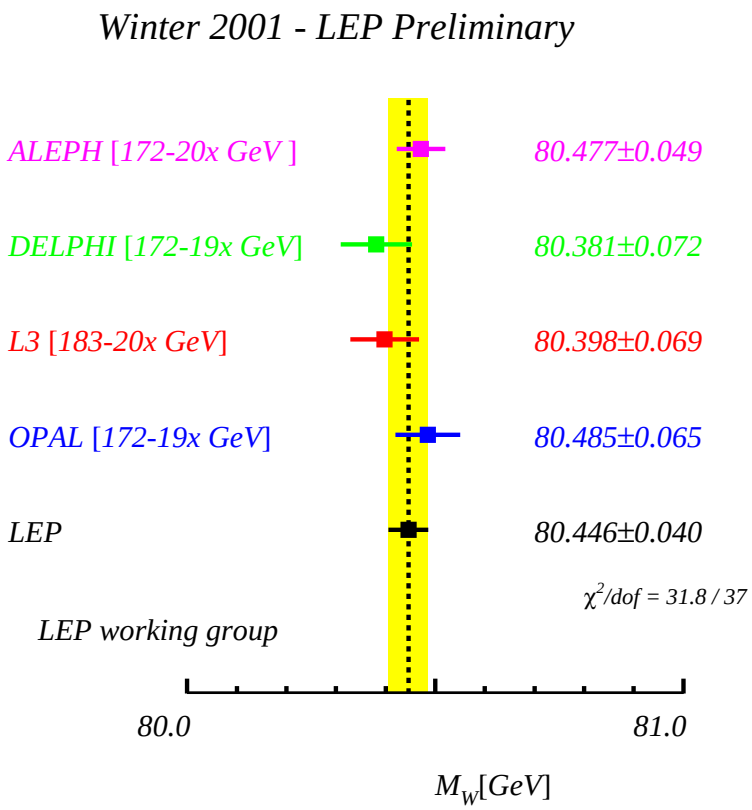


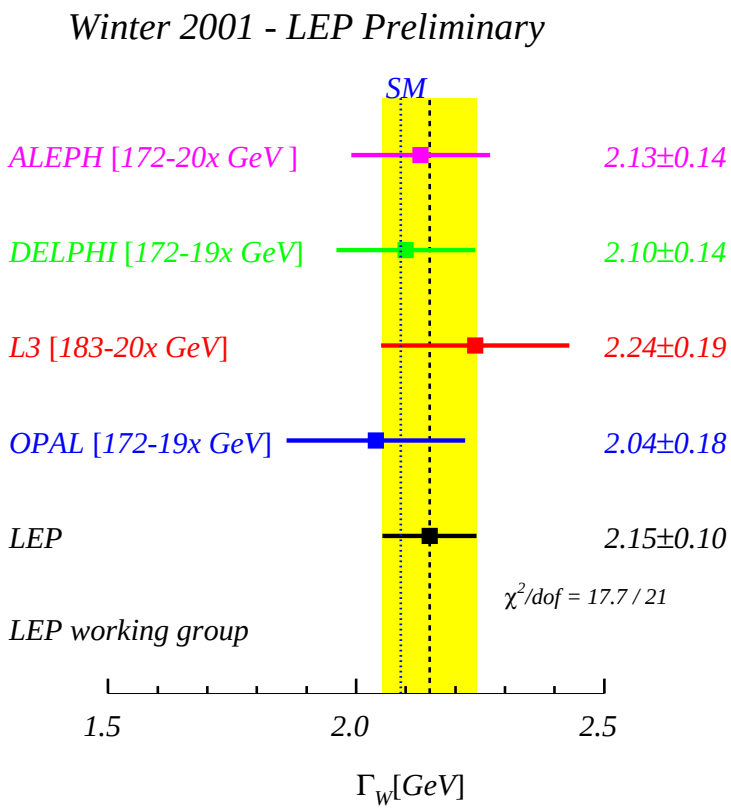






W mass and width results





$$\Delta m_W(qqqq - qql\nu) = +18 \pm 46\,\text{MeV}$$

NEW AL: preliminary 2000 , D: final 1998

W mass results (direct measurement)

Experiment	$m_W(qql\nu)$ (GeV/c^2)	$m_W(qqqq)$ (GeV/c^2)	m_W Combined (GeV/c^2)
ALEPH	$80.456 \pm 0.051 \pm 0.032$	$80.507 \pm 0.054 \pm 0.045$	$80.477 \pm 0.038 \pm 0.032$
DELPHI	$80.381 \pm 0.088 \pm 0.048$	$80.373 \pm 0.065 \pm 0.065$	$80.378 \pm 0.053 \pm 0.049$
L3	$80.314 \pm 0.074 \pm 0.045$	$80.478 \pm 0.063 \pm 0.069$	$80.389 \pm 0.048 \pm 0.051$
OPAL	$80.510 \pm 0.067 \pm 0.031$	$80.408 \pm 0.066 \pm 0.100$	$80.486 \pm 0.053 \pm 0.039$
LEP	$80.442 \pm 0.034 \pm 0.028$	$80.460 \pm 0.031 \pm 0.054$	$80.447 \pm 0.026 \pm 0.030$

$qql\nu$: $\sigma_{stat} \simeq \sigma_{syst}$ $qqqq$: $\sigma_{stat} < \sigma_{syst}$

Study systematics!

(AO: $l\nu l\nu$ in $qql\nu$)

W mass systematics

Error source	$qql\nu$ (MeV)	$qqqq$ (MeV)	Combined (MeV)
ISR/FSR	8	8	7
Hadronisation	19	17	18
Detector systematics	11	8	10
LEP beam energy	17	17	17
Colour reconnection	-	40	11
Bose-Einstein correlations	-	25	7
Other	4	5	3
Total systematics	29	54	30

Final State Interaction effects in $qqqq$: a limiting factor?

(FSI systematics equalized between experiments before the combination)

W mass systematics: hadronisation

- ✓ m_W from constrained fits ⇒
  affected by jet characteristics, particle misassignement
- ✓ information from $Z \to q\bar{q}$ and extrapolate to W jets
  (high statistics from LEP1, precision studies)
- ✓ phenomenological hadronisation models tuned at the Z:
  - ☞ Vary JETSET parameters $\Lambda_{QCD}, Q_0, \sigma_q$ within tuning uncertainties ⇒ fast simulations
  - ☞ Compare JETSET with new HERWIG version
    (good agreement with data)
  - ☞ In both cases: no significant effect within simulation statistics ⇒ preliminary ALEPH estimate:
    $\Delta m_w(qqqq/qql\nu) = 10/15$ MeV
  - ☞ Problem: tuning changes significantly between experiments ⇒ delicate procedure;
    detector effect absorbed?

$$\Delta m_W = 18\,\text{MeV}$$

W mass systematics: LEP beam energy

- ✓ $\sqrt{s}$ enters m_W measurement in constrained fits $\Rightarrow$ $\Delta\sqrt{s}/\sqrt{s} = \Delta m_W/m_W$
- ✓ LEP energy calibration:
  - ☞ Resonant depolarisation up to $\sqrt{s} = 60\,\text{GeV}$
    extrapolation for NMR probes calibration at h.e.
    cross calibrate with Flux Loop: $\oint Bdl \propto E_b$
    $\Rightarrow \delta E_b \simeq 20/25$ MeV (1998 - 1999 / 2000)
  - ☞ LEP spectrometer (1999 - 2000): $\Delta\theta_b \propto \oint Bdl/E_b$
    in 1999 $E_{spect} - E_{NMR} = 0.5 \pm 15$ MeV
    more studies needed for 2000
  - ☞ Syncrotron tune vs V_{RF}:
    $E_{Q_S} - E_{NMR} = -9 \pm 11\,\text{MeV}$
- ✓ $\sqrt{s}$ from radiative return peak data fit
  (m_Z known at 10^{-5}) $\Rightarrow \sqrt{(s)} = m_{f\bar{f}}$

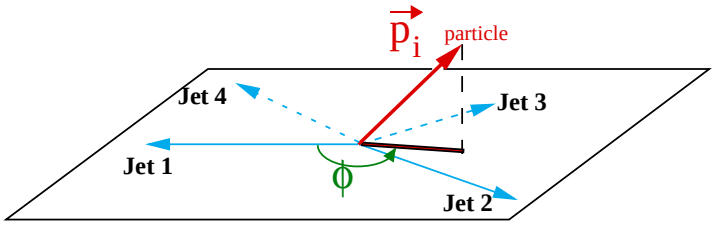
Experiment	final state	$\Delta(E_{\sqrt{s'}} - E_{LEP})$ MeV
ALEPH 97-99	$q\bar{q}$	$-15 \pm 95\,(\text{stat.}) \pm 40\,(\text{syst.})$
DELPHI 97-99	$\mu^-\mu^+$	$80 \pm 101\,(\text{stat.}) \pm 58\,(\text{syst.})$
OPAL 98-99	$\mu^-\mu^+, \tau^-\tau^+, q\bar{q}$	$-88 \pm 44(\text{stat.}) \pm 51(\text{syst.})$

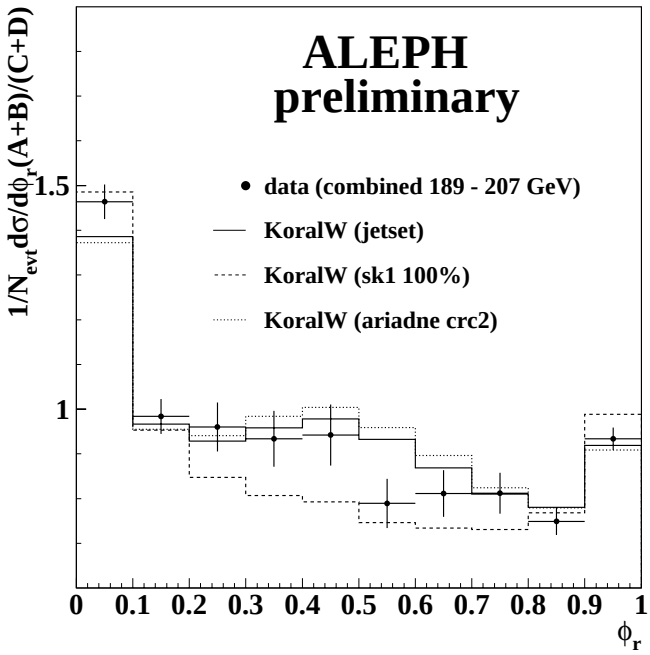
- ✓ with full LEP statistics statistically interesting method
  $\Rightarrow \delta E_{\sqrt{s'}} \simeq 15$ MeV but systematics to be understood

$$\Delta m_W = 17\,\text{MeV}$$

Colour reconnection

- ✓ Perturbative effects $\mathcal{O}(5\,\mathrm{MeV})$, negligible
- ✓ Cross talk in hadronisation between hadronic systems from different Ws $\Rightarrow$ phenomenological models
  - ☞ data exclude only the most extreme models
  - ☞ mass shifts $\mathcal{O}(0-50\,\mathrm{MeV})$ for SK models
- ✓ No measured effect on charged particle multiplicity (even at low energy - heavy hadrons)
- ✓ ALO: study the energy flow between jets from the same and from different Ws (affected if hadronic systems interfere)

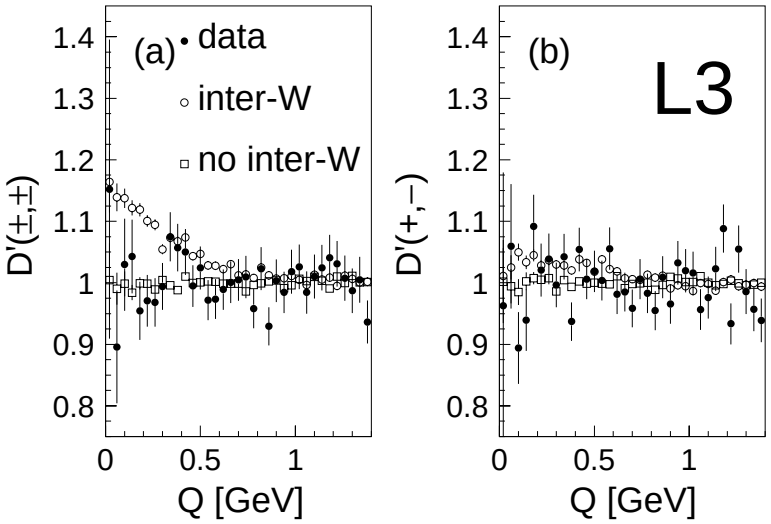




$$\Delta m_W(qqqq) = 40\,\mathrm{MeV}$$

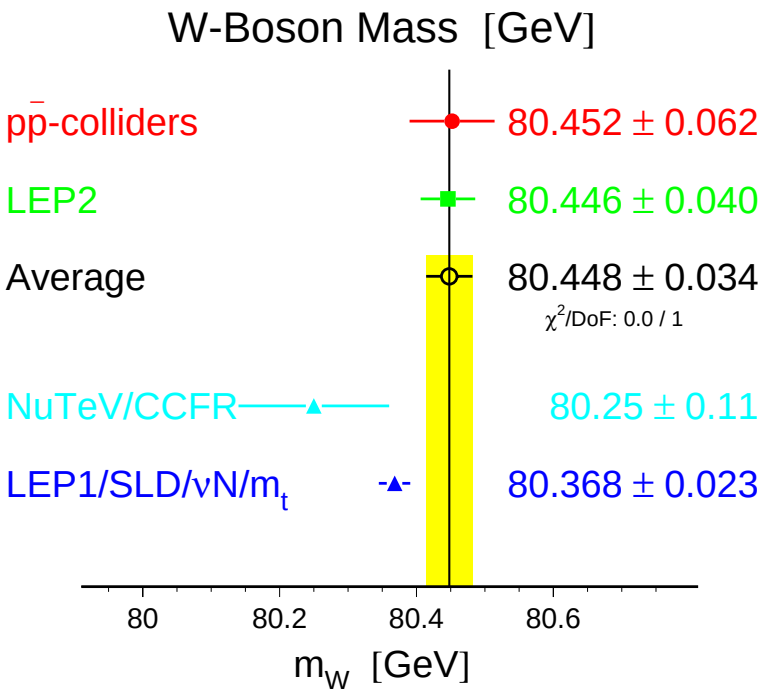
Bose-Einstein correlations

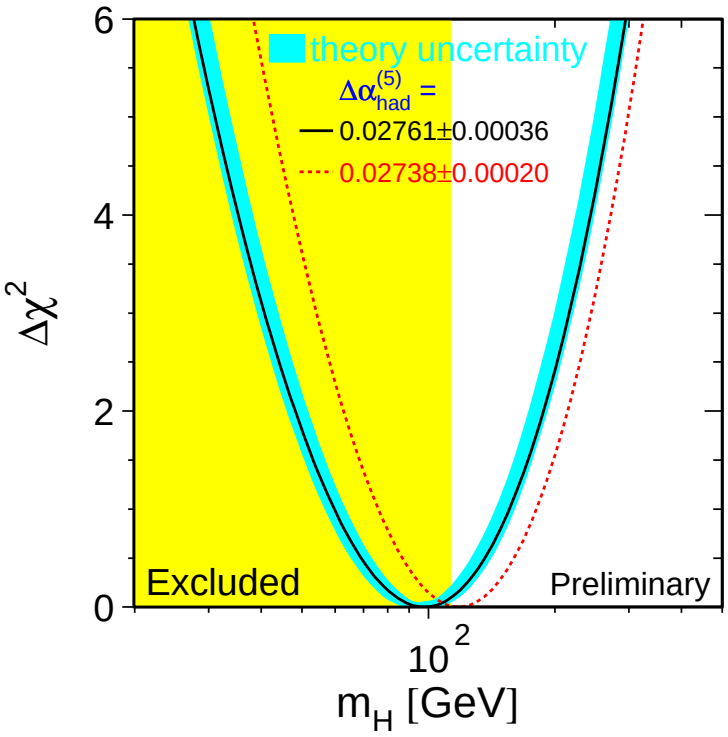
- ✓ Known phenomenon in Z (and W) decays
- ✓ No correct calculation $\Rightarrow$ rely on phenomenological models tuned at the Z peak
- ✓ The problem: correlations between like-sign pions from different Ws ?
  - ☞ if yes the W mass distribution could be distorted
- ✓ Different results from models $\Rightarrow$ try to measure it
- ✓ ratio (or double ratio) of particle correlations functions $R(Q), \quad Q = \sqrt{-(p_1 - p_2)^2}$
  - ☞ double ratio (data / MC) (++,- - / + -) AO
  - ☞ ratio data $qqqq$ / data "mixed $qqqq$" (from $qql\nu$) DL
- ✓ No clear conclusion yet



$$\Delta m_W(qqqq) = 25\,\text{MeV}$$

From m_W to LEPEWWG SM fit



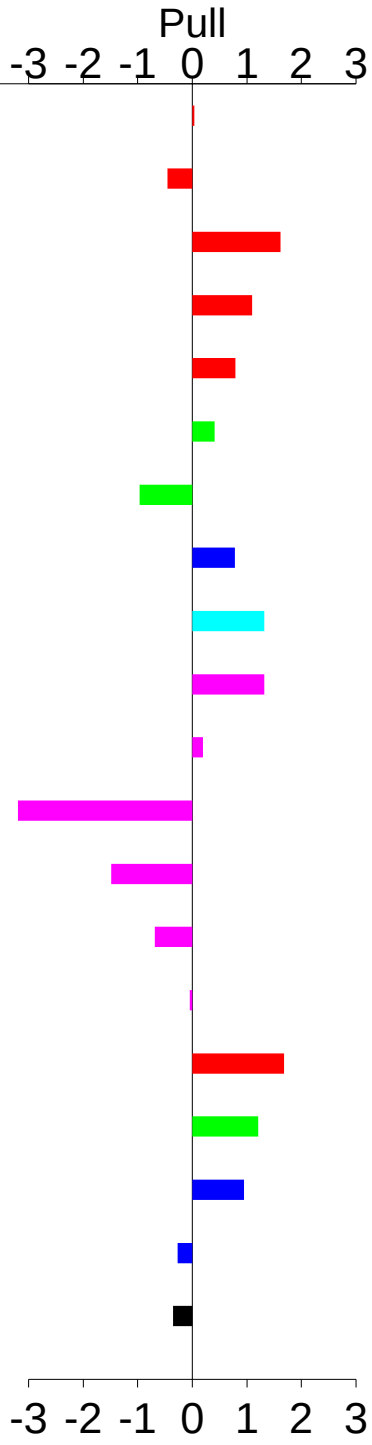


one-sided 95% C.L. $\mathbf{m_H \leq 212\,GeV}$

LEPEWWG SM fit

Winter 2001

	Measurement	Pull
m_Z [GeV]	91.1875 ± 0.0021	.04
Γ_Z [GeV]	2.4952 ± 0.0023	-.46
σ^0_{hadr} [nb]	41.540 ± 0.037	1.62
R_l	20.767 ± 0.025	1.09
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.79
A_e	0.1498 ± 0.0048	.41
A_τ	0.1439 ± 0.0041	-.96
$\sin^2\theta^{lept}_{eff}$	0.2322 ± 0.0010	.78
m_W [GeV]	80.446 ± 0.040	1.32
R_b	0.21664 ± 0.00068	1.32
R_c	0.1729 ± 0.0032	.20
$A^{0,b}_{fb}$	0.0982 ± 0.0017	-3.20
$A^{0,c}_{fb}$	0.0689 ± 0.0035	-1.48
A_b	0.921 ± 0.020	-.68
A_c	0.667 ± 0.026	-.05
A_l	0.1513 ± 0.0021	1.68
$\sin^2\theta_W$	0.2255 ± 0.0021	1.20
m_W [GeV]	80.452 ± 0.062	.95
m_t [GeV]	174.3 ± 5.1	-.27
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.36



Conclusions

- ✓ Several new measurements updated since OSAKA 2000:
  - ☞ WW cross section and branching ratios
  - ☞ Single W cross section
  - ☞ ZZ cross section
  - ☞ Neutral anomalous TGC
  - ☞ W mass and width
- ✓ $\mathcal{O}(\alpha)$ radiative corrections on WW are moving from theoreticians to experimentalists
- ✓ W mass systematics under study
  - ☞ Improvements in systematics
  - ☞ Total error at the 40 MeV threshold
- ✓ Although the data taking has ended

LEP is not yet finished . . .

Still a lot of numbers to come!