Measurement of the Mass of the W Boson at LEP

and

Determination of Electroweak Parameters

Arno Straessner

RWTH Aachen

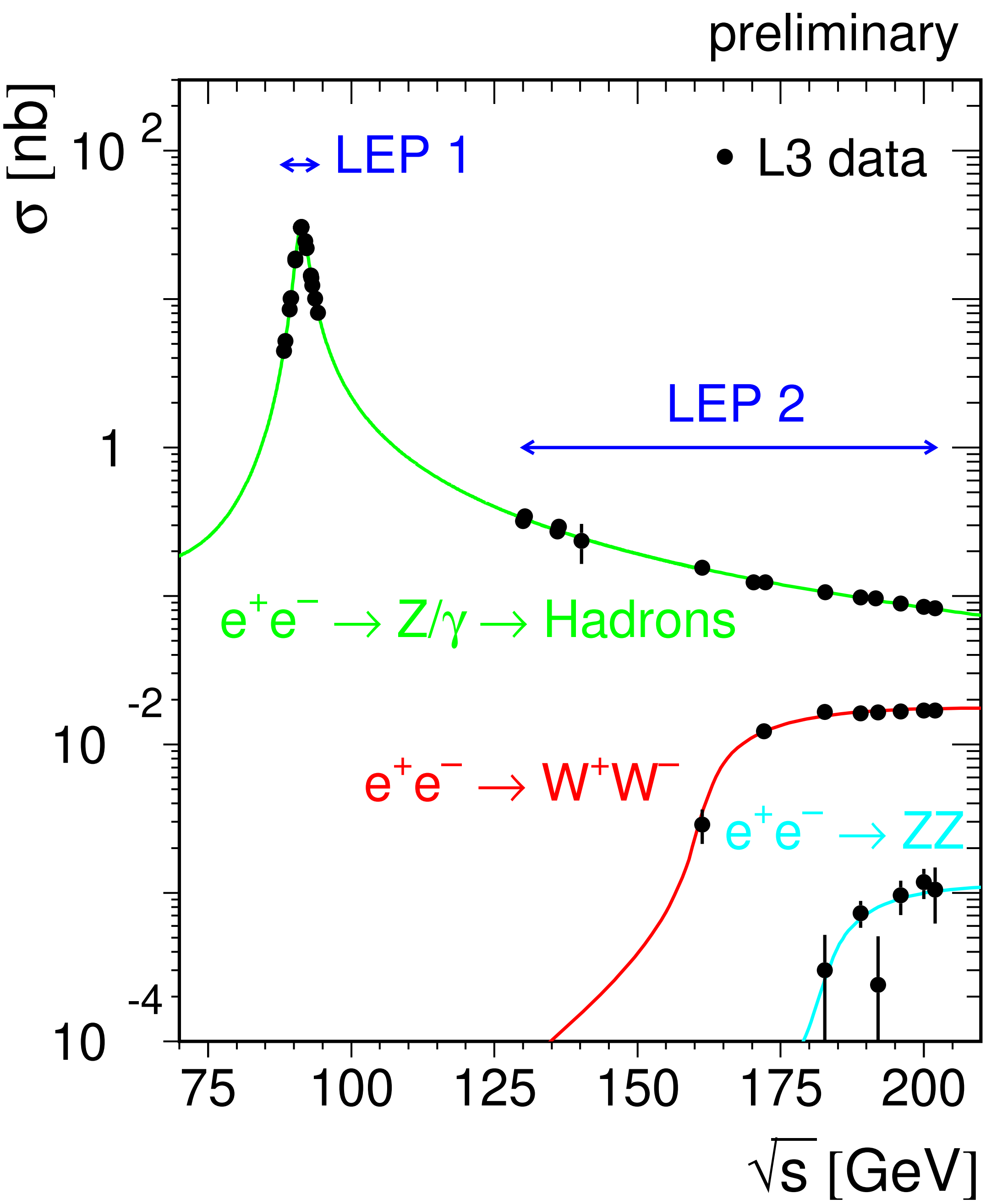
L3 Experiment, CERN

XXXVth Rencontres de Moriond

Electroweak Interactions and Unified Theories

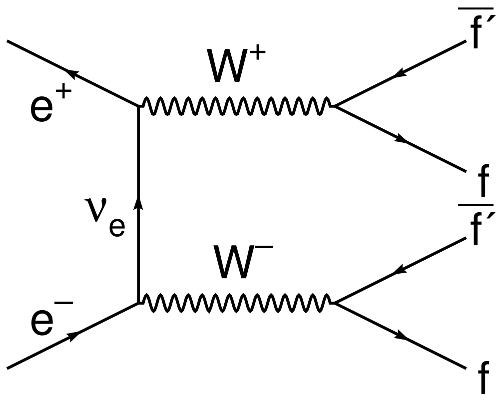
Les Arcs 1800

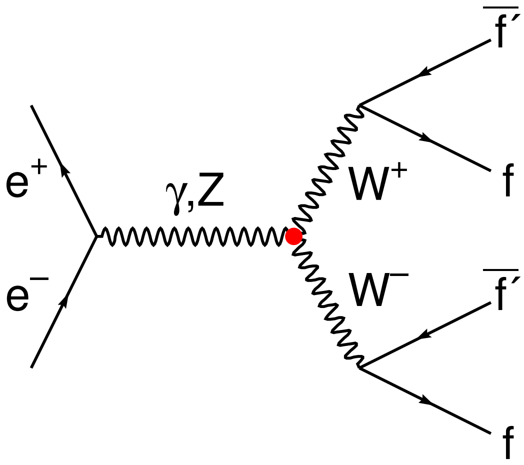
11.-18. Mar. 2000



- large data statistics at the Z pole:
  15 million hadronic and 2 million leptonic events
- above W-pair threshold:
  luminosity 460 – 500 pb^{-1} per experiment
- more than 7000 W-pair events per experiment
- most W results include new 192 – 202 GeV data

- W-pair production at LEP



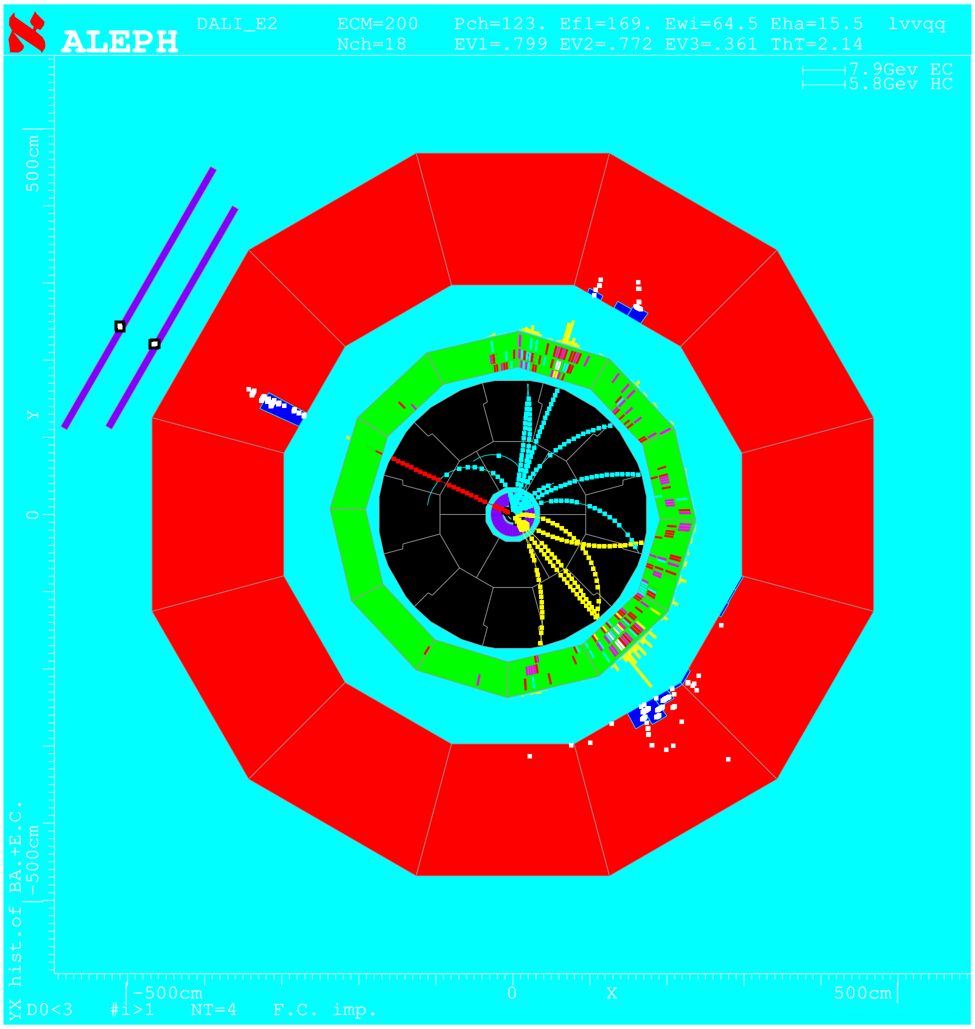


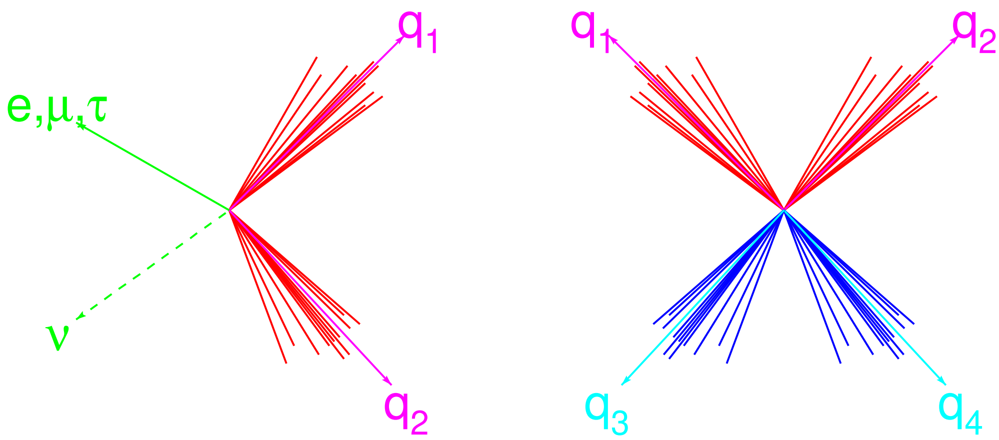
- 4-fermion final states

$$\underbrace{qqqq}_{45\%} \qquad \underbrace{qq\ell\nu}_{44\%} \qquad \underbrace{\ell\nu\ell\nu}_{11\%}$$

- important for mass measurement: qqqq and $qq\ell\nu$

Example:
$e^+e^- \longrightarrow qq\mu\nu$





- reconstruct lepton and jets
- impose kinematic constraints:

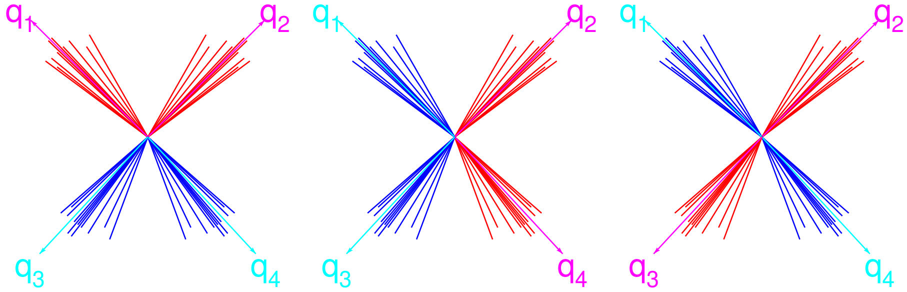
  E and $\vec{p}$ conservation $\longrightarrow$ 1C for $qq\ell\nu$, 4C for qqqq

  equal masses of recontructed W's $\longrightarrow$ +1C

$\longrightarrow$ (M_1, M_2) or $M_{average}$ with improved resolution (A,L,O)

$\longrightarrow$ complete likelihood function (D)

- special for qqqq events: jet pairing problem

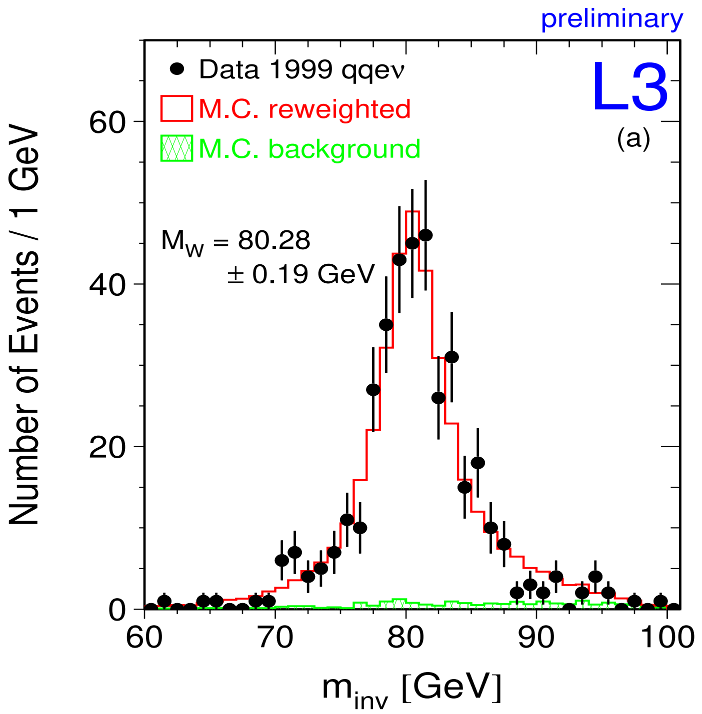


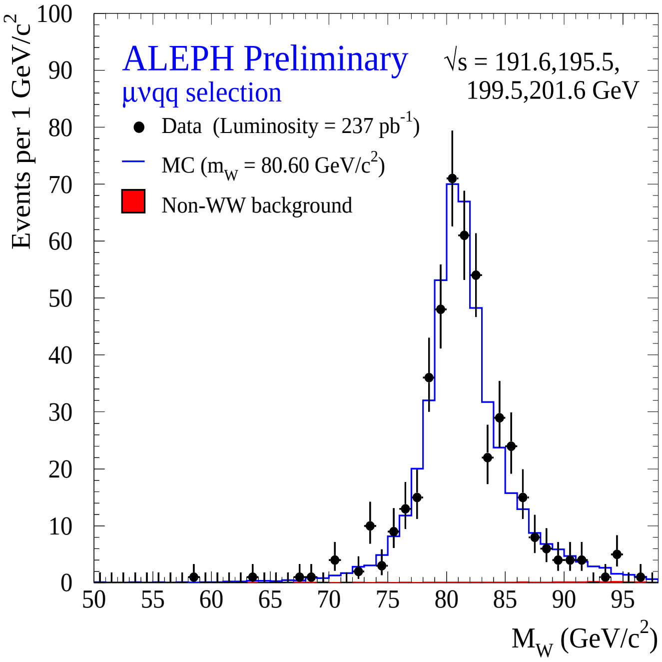
$\longrightarrow$ best from χ^2 fit (L) or best pairing algorithm (A) or jet pairing likelihood (O) or all pairings (D)

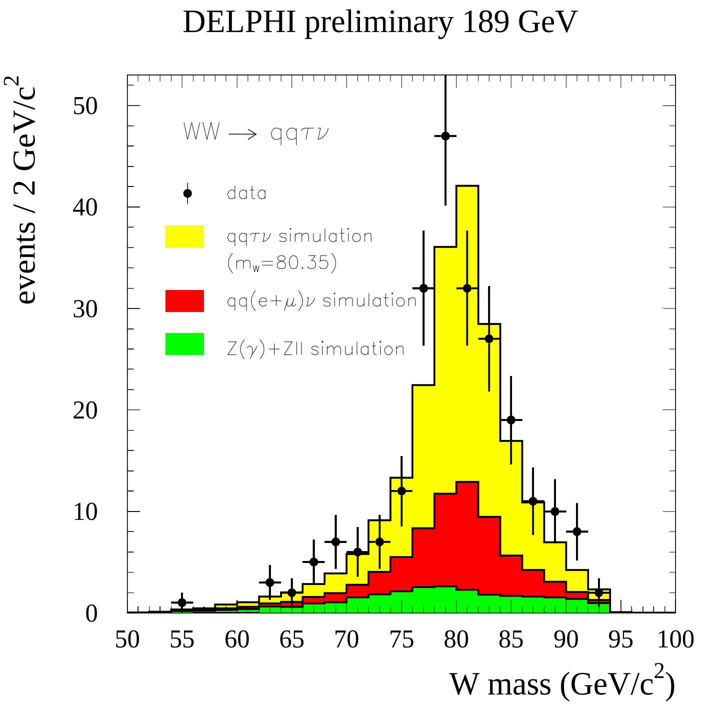
- also gluon radiation is taken into account

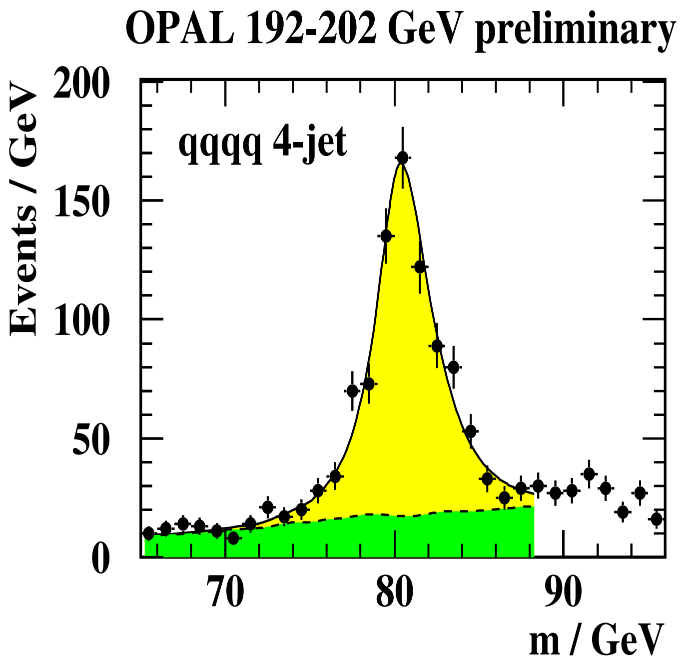
$\longrightarrow$ split into 4 and 5 jet sample (D,O)

W Mass Extraction









→ compare reweighted Monte Carlo to data (A,L,O)

→ convolute differential cross-section with resolution function (D)

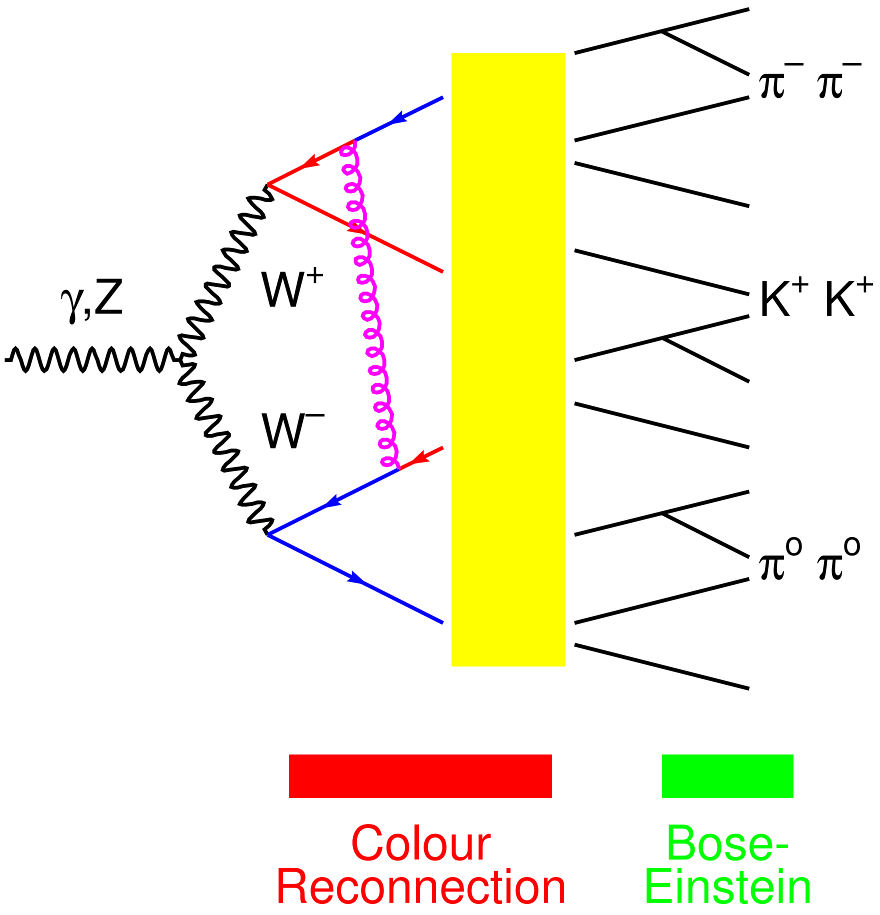
→ fit Breit-Wigner curve to measured mass spectrum (O)

- LEP energy error $\Delta E_{beam} = 20 - 21$ MeV

$$\Rightarrow \Delta M_W = \frac{\Delta E_{beam}}{E_{beam}} \cdot M_W = 17 \text{ MeV}$$

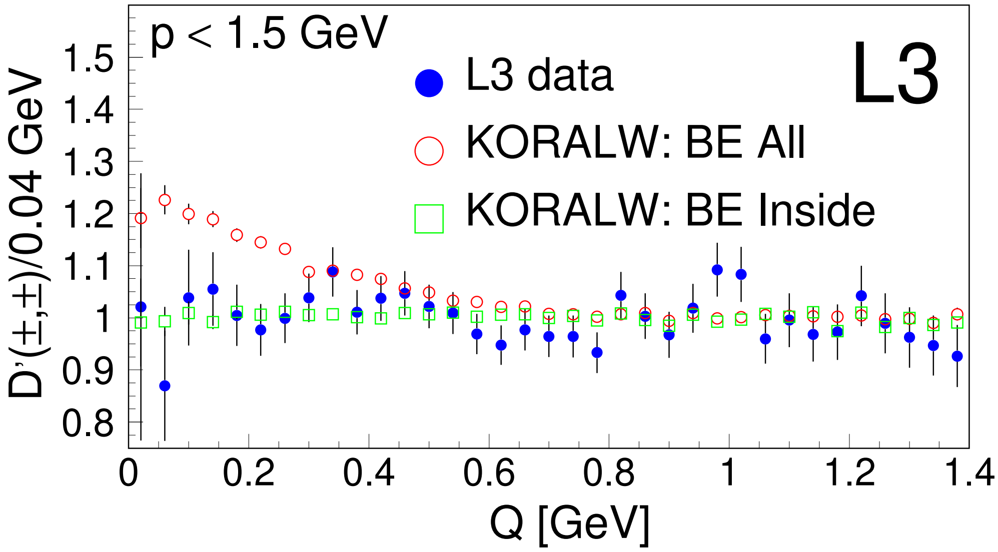
- new LEP spectrometer $\longrightarrow$ precision $\Delta E_{beam} < 15$ MeV

- Final State Interaction in qqqq events:



- cross-talk affects reconstruction of invariant masses

- new studies of FSI effects in hadronic W pairs:



BE correlations only inside each W?

- systematic error is estimated with MC models

  for BE $\longrightarrow$ with and w/o cross-talk

  for CR $\longrightarrow$ SK I, SK II, SK II', ARIADNE I and II, HERWIG, GH

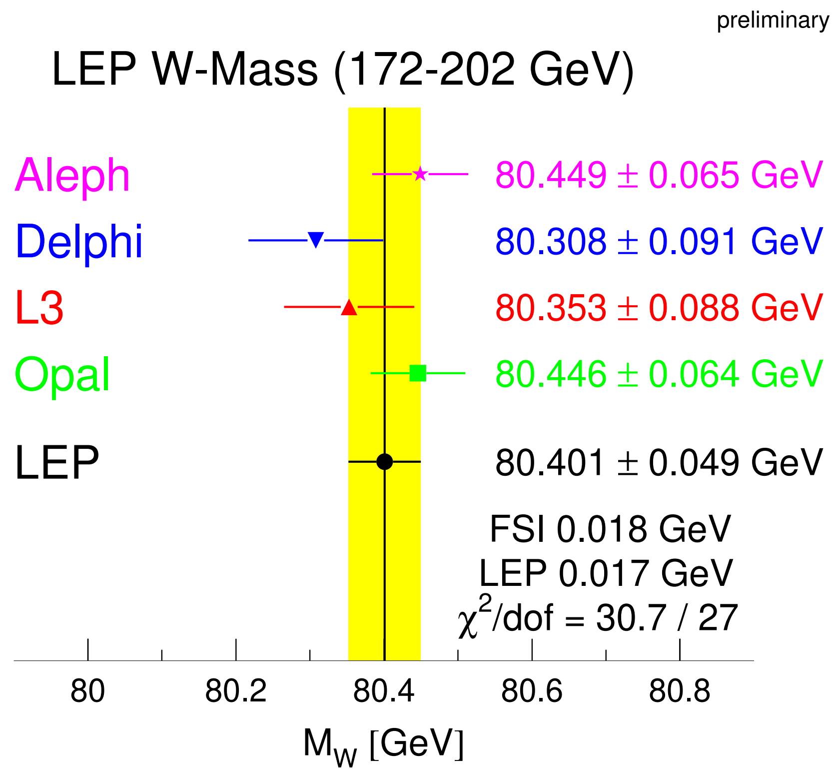
- error due to FSI: 52 MeV on qqqq and 18 MeV on ffff

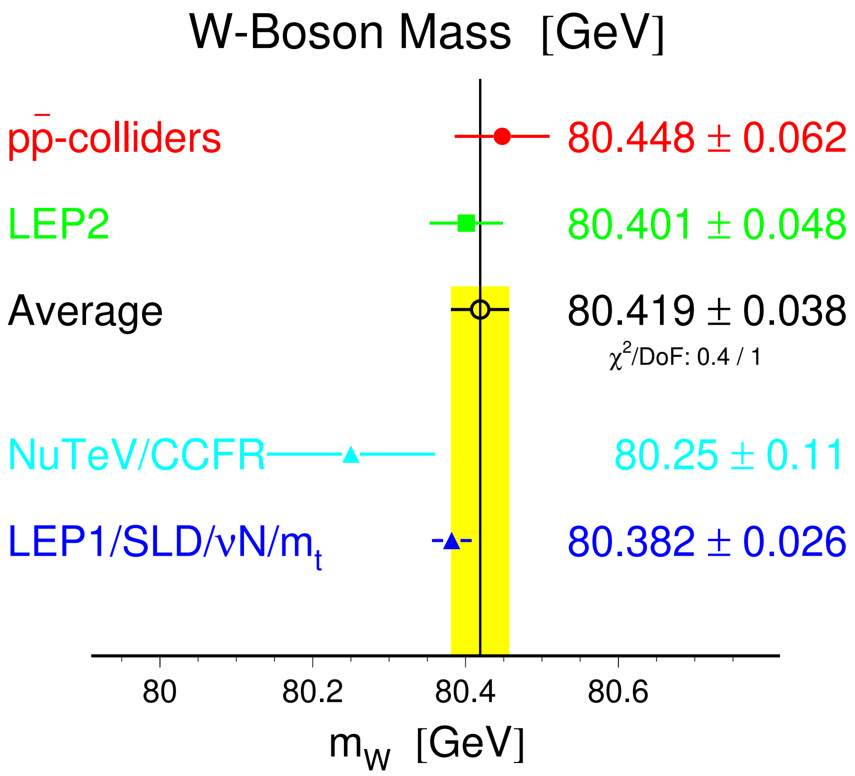
  statistical error: 37 MeV and 27 MeV

- look at mass difference $M_W(4q) - M_W(\text{non } 4q)$

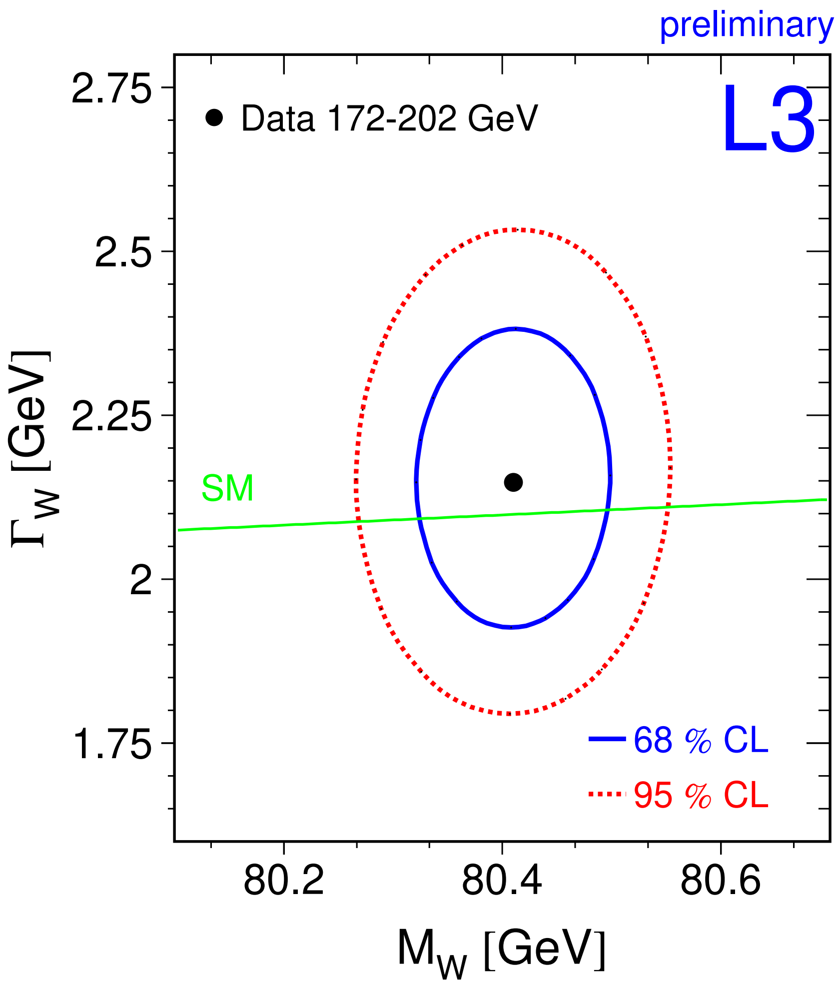
$$\Delta M = 35 \pm 55 \text{ MeV}$$ (LEP combined)

- no significant difference visible





(LEP2 value is a combination with M_W from cross-section measurements)



- W width is measured by

ALEPH	$\Gamma_W = 2.17 \pm 0.20$ GeV	(189-202 GeV)
DELPHI	$\Gamma_W = 2.48 \pm 0.41$ GeV	(183 GeV)
L3	$\Gamma_W = 2.18 \pm 0.22$ GeV	(172-202 GeV)
OPAL	$\Gamma_W = 1.86 \pm 0.37$ GeV	(172-183 GeV)

- all LEP data combined

$$\boxed{\Gamma_W = 2.19 \pm 0.15 \text{ GeV}}$$

- compare direct width determination by CDF

$$\Gamma_W = 2.055 \pm 0.125 \text{ GeV}$$

Results from Z peak data

- mass and width of the Z boson
- hadronic pole cross-section

$$\sigma_h^0 = \frac{12\pi}{M_Z} \frac{\Gamma_{ee}\Gamma_{had}}{\Gamma_Z^2}$$

- ratios of leptonic to hadronic partial widths $R_\ell = \Gamma_{had}/\Gamma_{\ell\ell}$
- leptonic pole asymmetries

$$A_{FB}^{0,\ell} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f \quad \text{with} \quad \mathcal{A}_f = \frac{2g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}$$

- LEP average values (status of summer 1999):

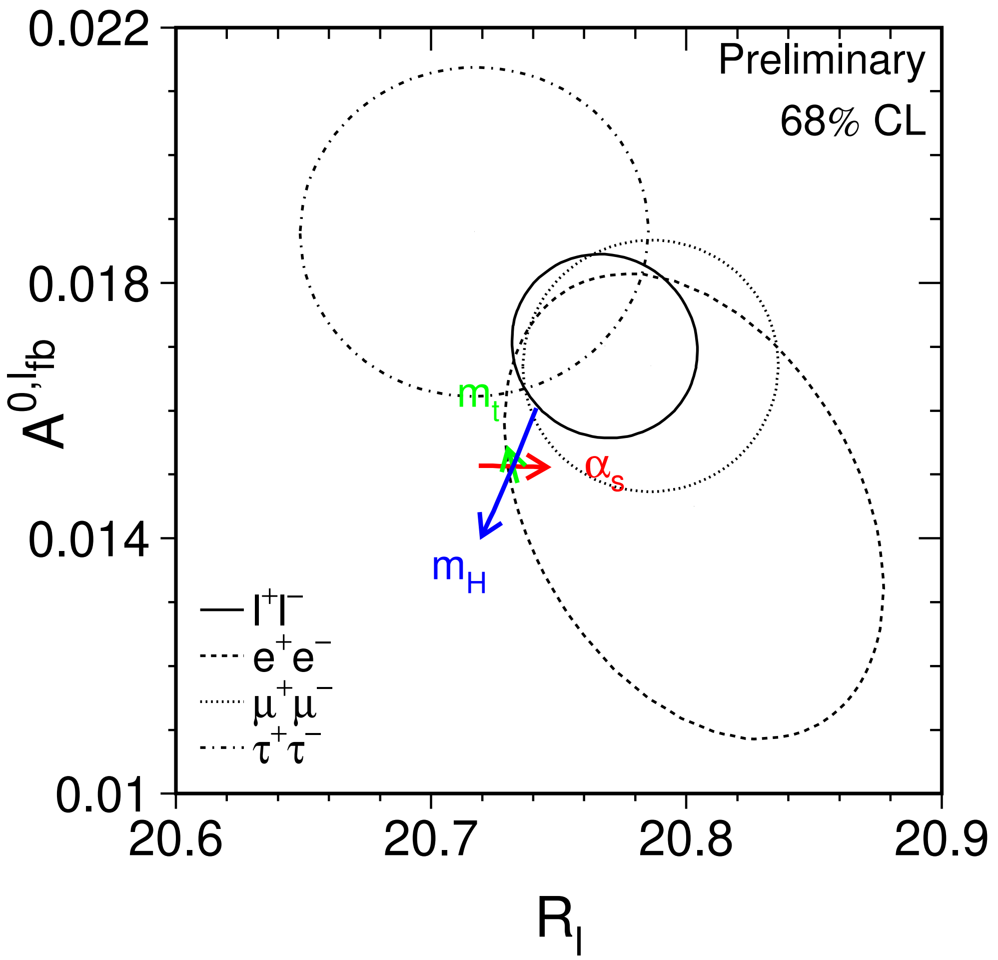
$$\begin{array}{lcrcll}
M_Z & = & 91.1871 & \pm & 0.0021 & \text{GeV} \\
\Gamma_Z & = & 2.4944 & \pm & 0.0024 & \text{GeV} \\
\sigma_{had}^0 & = & 41.544 & \pm & 0.037 & \text{nb} \\
R_\ell & = & 20.768 & \pm & 0.024 & \\
A_{FB}^{0,\ell} & = & 0.01701 & \pm & 0.00095 &
\end{array}$$

- theory programs: ZFITTER 6.21, TOPAZ0 4.4, ALIBABA

3 LEP experiments published their Z peak results

F i n a l Combination is in Progress !!!

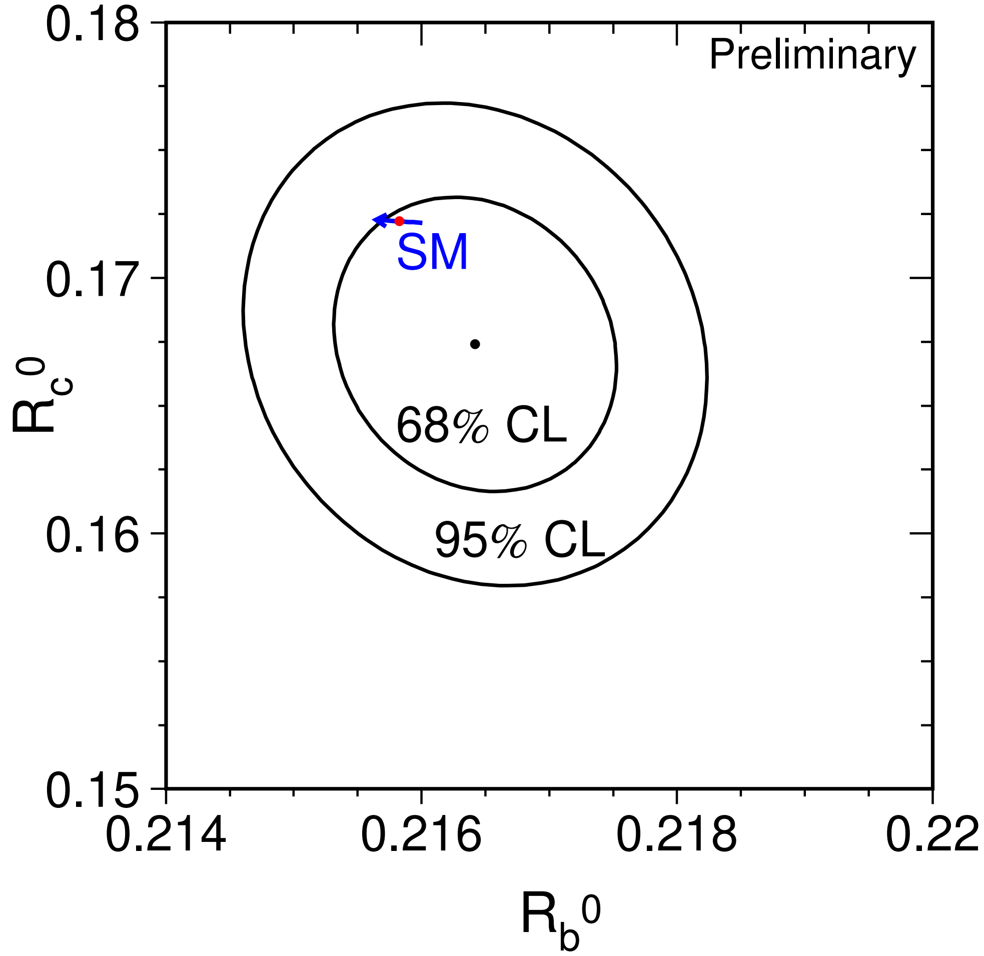
- R_ℓ and $A_{FB}^{0,\ell}$ measurements test lepton universality



- invisible Z decay width $\Gamma_{inv}/\Gamma_{\ell\ell} = 5.941 \pm 0.016$
- use Standard Model calculation for $\Gamma_{\nu\nu}/\Gamma_{\ell\ell}$, then

$$N_\nu = 2.9835 \pm 0.0083$$

- Z partial decay width to $c\bar{c}$ and $b\bar{b}$ (LEP+SLD)



- more heavy flavour results...

$$
\begin{aligned}
R_b^0 &= 0.21642 \pm 0.00073 \\
R_c^0 &= 0.1674 \pm 0.0038 \\
A_{FB}^{0,b} &= 0.0988 \pm 0.0020 \\
A_{FB}^{0,c} &= 0.0692 \pm 0.0037 \\
\mathcal{A}_b &= 0.911 \pm 0.025 \\
\mathcal{A}_c &= 0.630 \pm 0.026
\end{aligned}
$$

- most recent updates of $\mathcal{A}_c$ by SLD are not yet included

- asymmetry measurement with polarised beams

$$A_{LR} = \frac{N_L - N_R}{N_L + N_R} \frac{1}{\mathcal{P}_e}$$

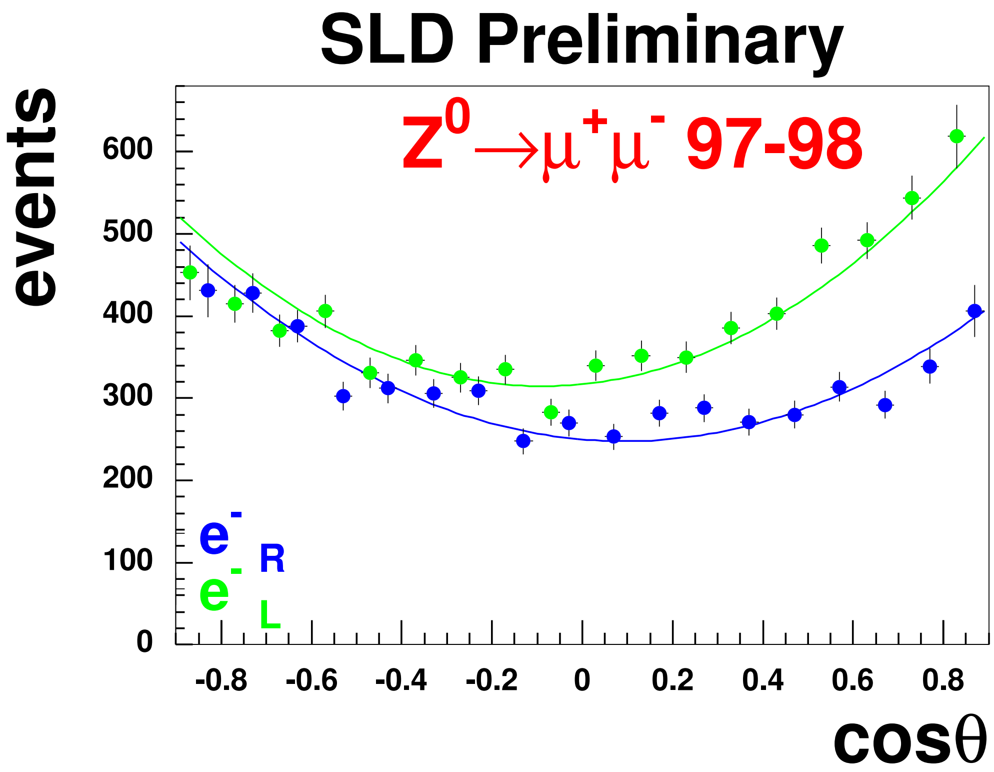
- most precise determination of $\mathcal{A}_e = A^0_{LR}$ (new and final result)

$$\mathcal{A}_e = 0.1514 \pm 0.0022$$

- leptonic forward-backward left-right asymmetry

$\longrightarrow$ improved measurement with larger polar acceptance

- example μ-pairs:



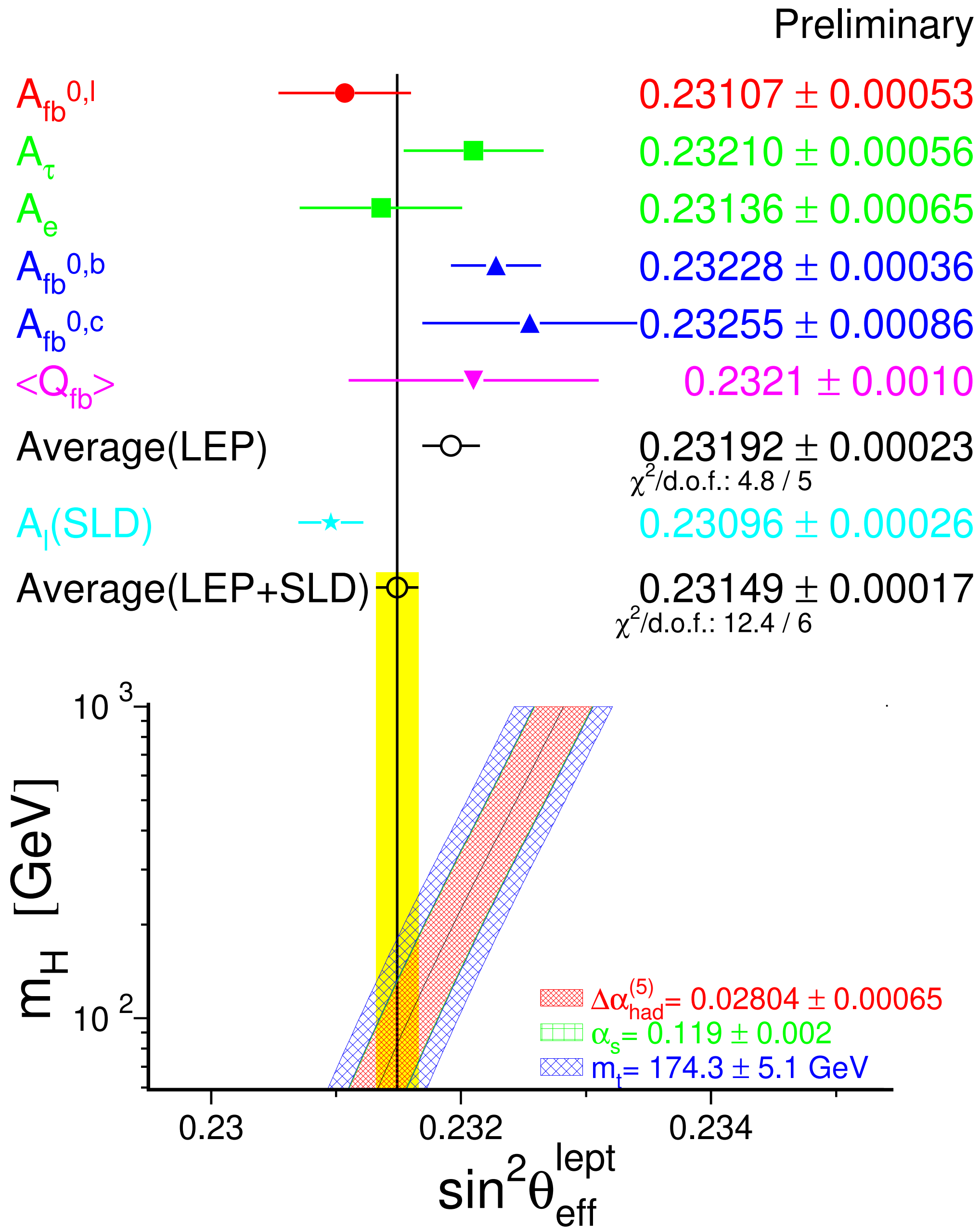
$$\mathcal{A}_e = 0.1548 \pm 0.0058 \quad \text{(preliminary)}$$
$$\mathcal{A}_\mu = 0.142 \pm 0.015 \quad \text{(preliminary)}$$
$$\mathcal{A}_\tau = 0.140 \pm 0.015 \quad \text{(preliminary)}$$

- all combined in

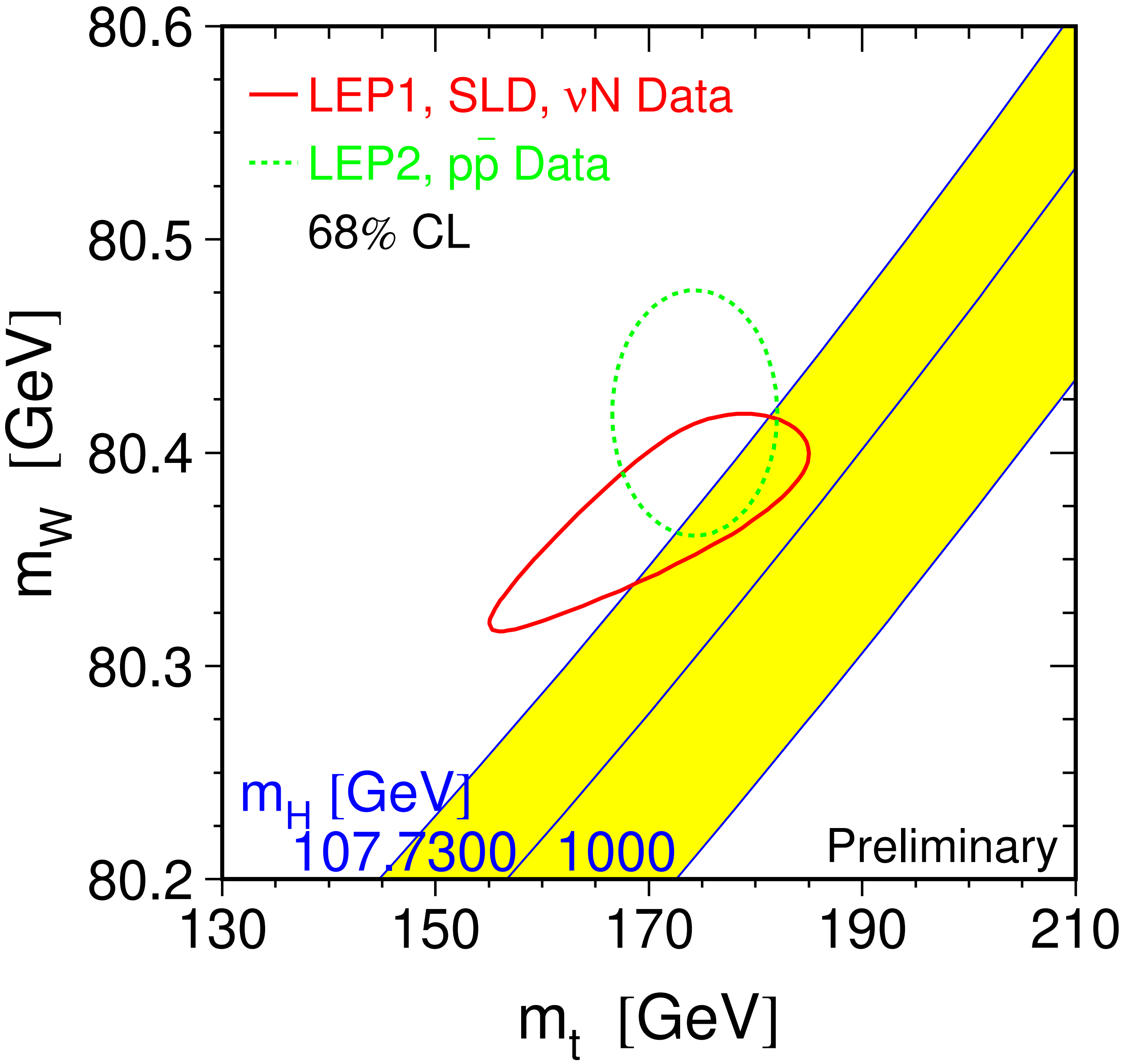
$$\sin^2\theta^{lept}_{eff} = 0.23096 \pm 0.00026 \quad \text{(preliminary)}$$

- compare effective electroweak mixing angle

$$\sin^2\theta_{\rm eff}^{\rm lept} = \frac{1}{4}\left(1 - \left(\frac{g_V^\ell}{g_A^\ell}\right)^2\right)$$



- LEP and SLD averages still different



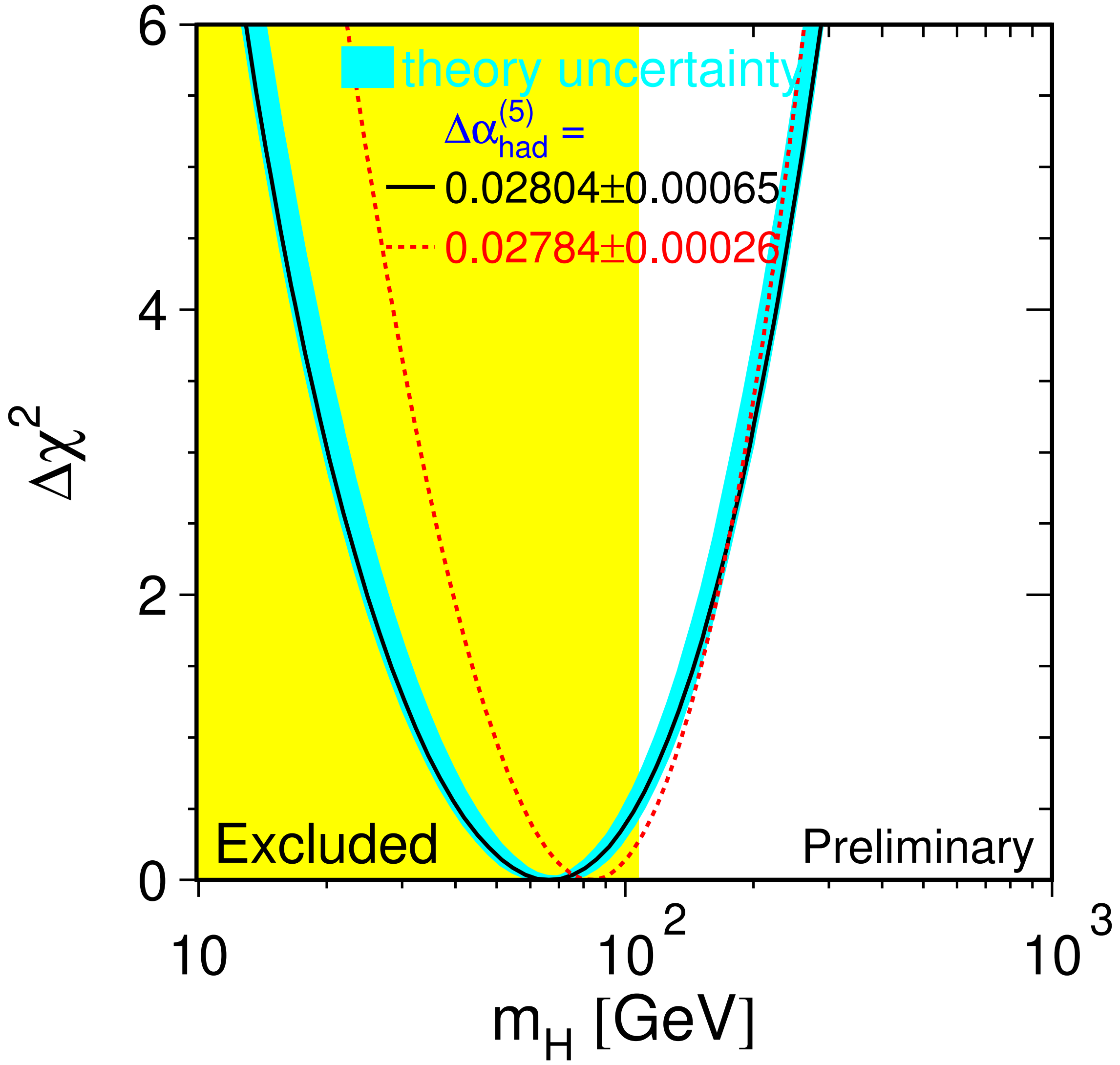
- from electroweak fits

with LEP data: $m_t = 176^{+14}_{-11}$ GeV

all data except direct M_W: $M_W = 80.383 \pm 0.026$ GeV

Standard Model parameter relations confirmed at quantum level

small Higgs masses preferred!



$m_{\mathrm{H}} = 67^{+60}_{-33}$ GeV $\qquad \log(m_{\mathrm{H}}/\text{ GeV}) = 1.82^{+0.28}_{-0.30}$

- with $\Delta\alpha^{(5)}_{\mathrm{had}} = 0.02784 \pm 0.00026 \longrightarrow$ 25% better error on $\log(m_{\mathrm{H}}/\text{ GeV})$
- the more conservative value yields

$m_{\mathrm{H}} < 188$ GeV at 95% CL

$\longrightarrow$ the Higgs boson is light . . . but heavier than

$m_{\mathrm{H}} > 107.7$ GeV at 95% CL

(limit from direct searches at LEP)

- LEP measures W mass and width with increased precision

$$M_W = 80.401 \pm 0.048 \text{ GeV}$$
$$\Gamma_W = 2.19 \pm 0.15 \text{ GeV}$$

. . . in perfect agreement with fit to electroweak data

- for the future:

  analysis of 1999 W-pair data continues

  with 2000 data $\longrightarrow$ statistical error $\times$ 0.85

  $\longrightarrow \delta M_W = 35$ MeV $\oplus$ FSI $\oplus$ LEP

  LEP's final word on the Z

The Standard Model still works

The Standard Model Higgs boson is light