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Z lineshape and leptonic forward-backward asymmetries

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ABSTRACT: This talk summarises the results of the precison measurements of the cross sections and the leptonic forward-backward asymmetries at the Z resonance peak, based on the data collected at LEP between 1989 and 1995.

1. Introduction.

Between 1989 and 1995 the four LEP experiments took data at different centre of mass energies, in the region $\pm$ 3 GeV around the Z resonance peak. The decay channels $Z \to$ hadrons, $Z \to e^+e^-$, $Z \to \mu^+\mu^-$, $Z \to \tau^+\tau^-$ were studied reaching an accuracy at the permill level. A total statistics of 15.5×10^6 hadronic Z decays and 1.7×10^6 decays of the Z into charged leptons was recorded. The relevant measurements for the study of the Z parameters are the hadronic and leptonic cross sections and the leptonic forward-backward asymmetry. For each LEP experiment the full data set consists of about 200 individual cross section and asymmetry measurements [1].

To lowest order the Z resonance peak is described by:

$$\sigma_f(s) = \frac{12\pi}{M_Z^2}\frac{\Gamma_e\Gamma_f}{\Gamma_Z^2}\frac{s\Gamma_z^2}{(s-M_Z^2)^2+s\Gamma_Z^2/M_Z^2}$$

and can be completely defined by three parameters: the position of the resonance peak (M_Z), its total width (Γ_Z) and the pole cross section (σ^o_{ff}).

The effective vector (g_V^ℓ) and axial (g_A^ℓ) couplings of the charged leptons to the Z can be unfolded from the measured Z partial widths and forward-backward asymmetries:

$$A_{FB}^{o\ell} = \frac{3}{4}A_eA_\ell \quad ; \quad A_\ell = \frac{2g_V^\ell g_A^\ell}{(g_V^\ell)^2+(g_A^\ell)^2}$$

$$\Gamma_{\ell\ell} = \frac{G_FM_Z^3}{\sqrt{2}\pi}((g_V^\ell)^2+(g_A^\ell)^2)$$

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2. Results of the Model Independent Fit.

The LEP Electroweak Working Group [2] combines all the data in order to extract, with a model independent fit, five psuedo-observables: the Z mass (M_Z), the Z total width (Γ_Z), the hadronic pole cross section (σ_h^o), the ratio of hadronic to leptonic partial widths (R_ℓ) and the pole leptonic forward-backward asymmetry ($A_{FB}^{o\ell}$). These parameters have been chosen in order to minimize their correlations. If lepton universality is not assumed, there are nine pseudo-observables.

A particular care is taken in the treatment of the systematics common between various experiments, which are mainly due to to uncertainties in the normalization of the cross sections, in the LEP absolute scale energy and in the radiative corrections to the lineshape.

The integrated luminosity is measured by counting Bhabha scattering events ($e^+e^- \to e^+e^-(n\gamma)$) at low polar angle ($\theta < 200$ mrad). The large cross section and the clear signature of this process make the experimental error very small, between 0.033% and 0.090% for the different experiments. The theoretical error of the luminosity measurement, due to the uncertainty on the Bhabha cross section calculated by BHLUMI [3], is between 0.054% and 0.060%.

The LEP beam energy is measured for separated beams by means of the resonant depolarization method. A detailed model which tracks in time the properties of the magnets and the geometry of the LEP ring, and has been carefully checked with NMR probes, allows to extrapolate the energy measurement to colliding beams. A precision of about 20×10^{-6} on the absolute energy scale is achieved, which propagates to systematics of 1.5 MeV for M_Z and 1.7 MeV for Γ_Z.

In order to extract the electroweak parameters, accurate theoretical predictions are as important as precise measurements. The $Z - \gamma$ and γ contributions to the cross section are fixed to the Standard Model values, while the Z contribution is fitted to the α^3 radiatively corrected Breit Wigner resonance. The program used by the LEP collaboration are TOPAZ0 [4] and ZFITTER [5], which show an agreement at the level of 10^{-4}. For the e^+e^- final state, the t-channel contribution is evaluated by ALIBABA [6] and the uncertainty on its subtraction is taken into account in the common systematics.

The results of the 5 parameter fit are summarised in table 2 and shown in fig. 1,2.

The dominant contribution of $\pm$ 1.7 MeV to the Z mass systematics arises from the calibration of the LEP beam energy, while the dominant contribution of $\pm$ 0.025 nb to the hadronic cross section systematics comes from the theoretical error in the luminosity measurement.

M_Z	$=$	91187.5	$\pm$	2.1 MeV
Γ_Z	$=$	2495.2	$\pm$	2.3 MeV
σ^o_{had}	$=$	41.540	$\pm$	0.037 nb
R_ℓ	$=$	20.767	$\pm$	0.025
$A^{o\ell}_{FB}$	$=$	0.0171	$\pm$	0.0010

Table 1: results of the 5 parameters model independent fit.

3. Derived results.

From the measured decay width of the Z to invisible particles ($\Gamma_{inv} = \Gamma_Z - \Gamma_{had} - 3\Gamma_\ell = 498.8 \pm 1.5$ MeV) the number of light neutrino families coupled to the Z can be derived:

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

Assuming three neutrino families a 95% C.L. limit on the Z decay to non-standard invisible particles can be calculated to be $\Delta\Gamma_{inv} < 2.0$ MeV.

Fig. 3.a shows $A^{o\ell}_{FB}$ versus R_ℓ, while fig. 3.b shows the vector versus the axial couplings to the Z, for the three lepton species. Data are in good agreement with the hypothesis of lepton universality.

From the measured R_ℓ it is possible to estimate the strong coupling constant:

$$\alpha_s = 0.1224 \pm 0.0038 \pm 0.0033$$

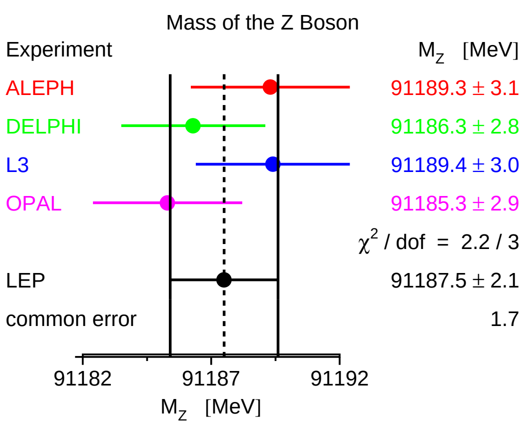

Figure 1: Z mass from the 5 parameter model independent fit.

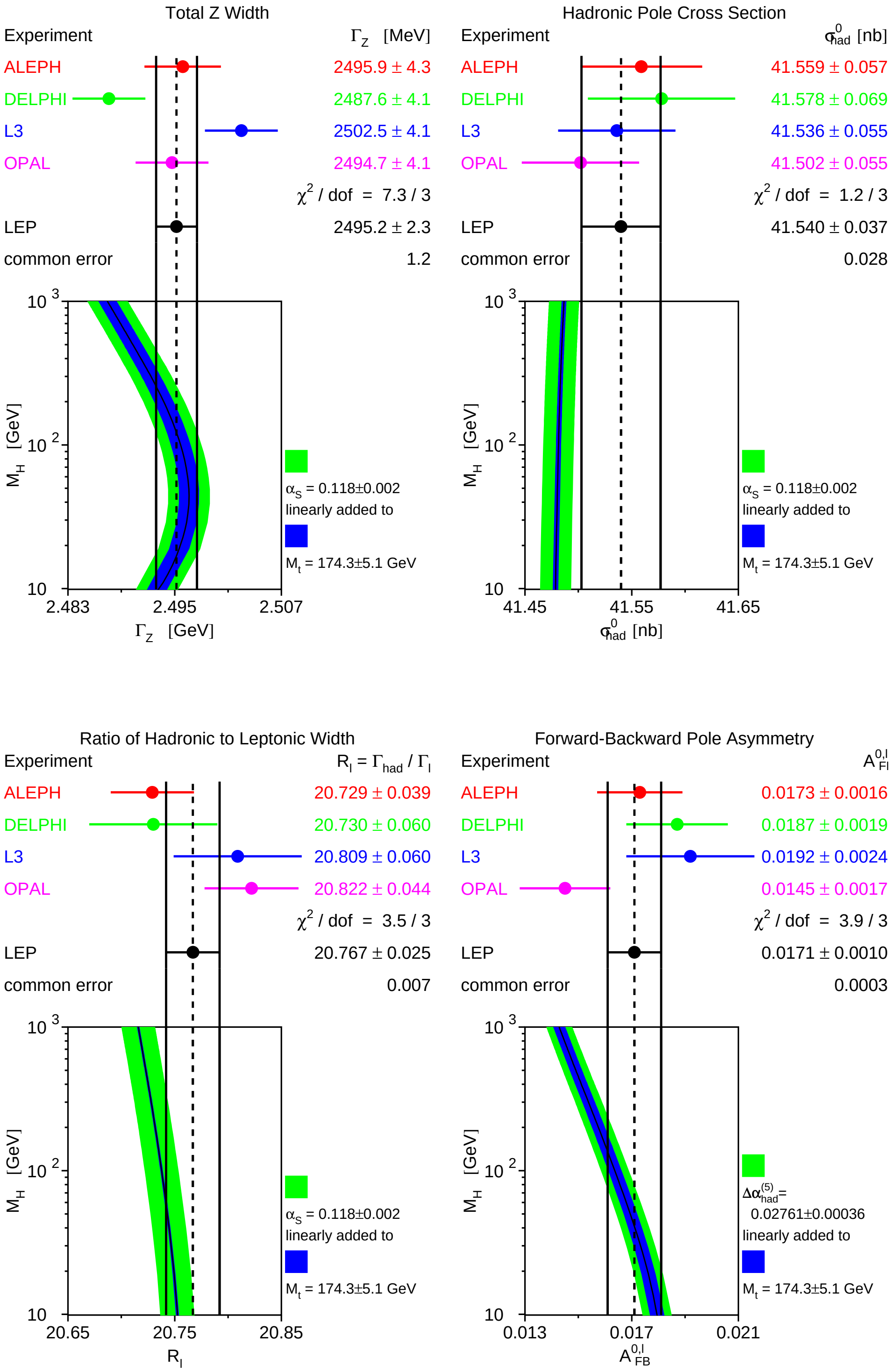

Figure 2: total Z width, hadronic pole cross section, hadronic to leptonic cross section ratio and pole leptonic forward backward asymmetry from the 5 parameter model independent fit.

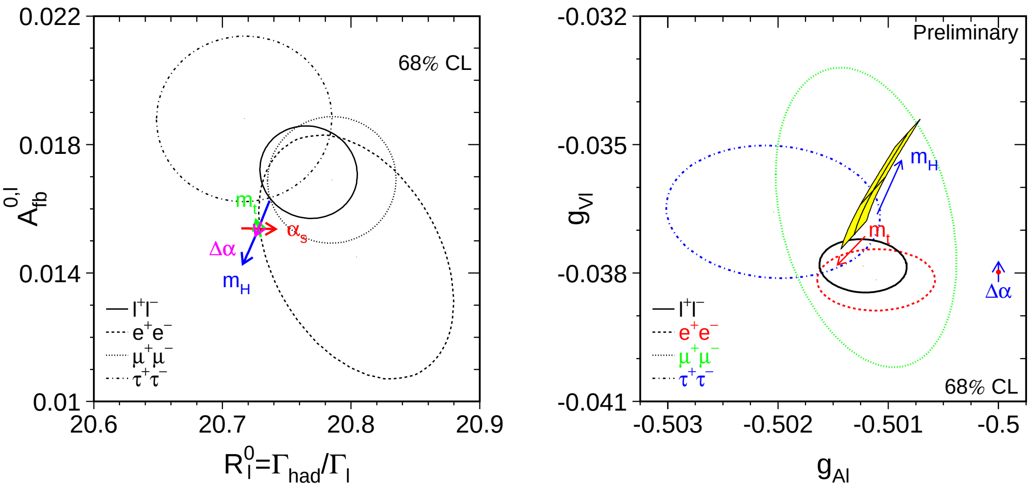

Figure 3: couplings to the Z of the three lepton species: (a) $A_{FB}^{o\ell}$ versus R_ℓ; (b) vector versus axial couplings to the Z.

4. Conclusions.

Both the Z lineshape parameters and the leptonic forward-backward asymmetries have reached at LEP an unprecedented precision.

While the calibration of the LEP beam energy is the limiting factor for the Z mass, the leptonic forward-backward asymmetries are still statistically limited.

These results provides an unique test of the gauge structure of the electroweak interaction, beyond the tree level.

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