TRIUMPH OF THE STANDARD MODEL IN THE ALEPH AND OTHER EXPERIMENTS AT LEP*

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Results of the ALEPH and other LEP experiments are presented. Very good agreement with the Standard Model has been found within experimental accuracy of about 1%.

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The study of e^+e^- interactions has contributed greatly to the modern understanding of elementary particle physics. Experiments near the J/ψ resonance were of great importance in proving that quarks are not only mathematical constructions; the measurement of R (ratio of hadronic to $\mu\mu$ cross-section) helped to prove the existence of color; the discovery of τ indicated that there are more than two generations of leptons which implied also the existence of more than two generations of quarks; the discovery of gluons together with spectrum of quarkonium gave strong arguments in favour of QCD, etc...

In the total e^+e^- cross-section above the continuum we observe high resonances ρ, ω, ϕ, ψ's, and Υ's. They are 1^{--} atomic like bound states of all the quarks with mass smaller than the maximum beam energy achieved up to now, *e.g.* u, d, s, c, and b quarks, respectively.

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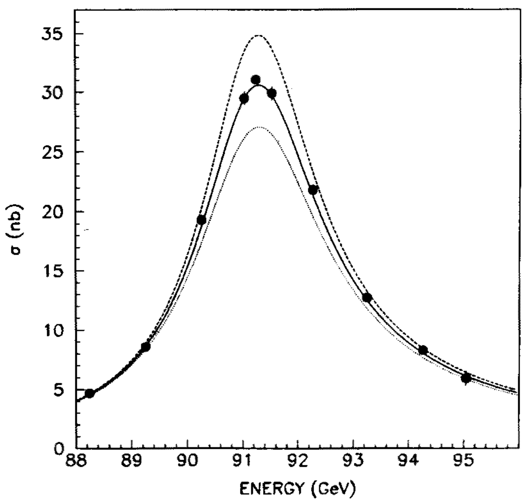

Fig. 1. $Z^0 \to$ hadrons line shape compared to the predictions of the Standard Model for two, three and four neutrino generations.

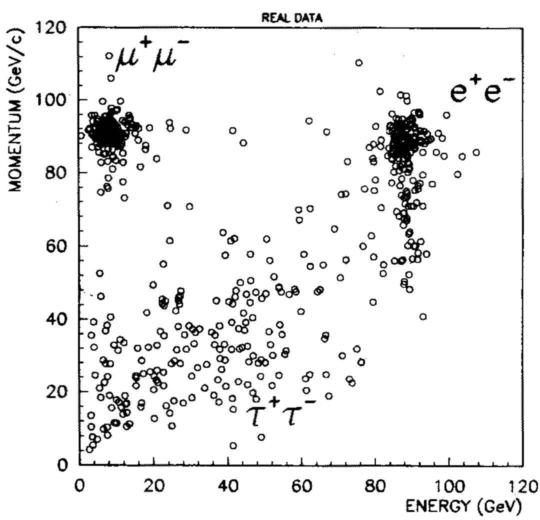

Fig. 2. Energy deposited in the calorimeters compared to the sum of momenta measured by the tracking detectors for the $Z^0 \to$ lepton pair candidates.

When the beam energy rises above 45 GeV a new kind of a resonance is produced, not a quark-antiquark state, but an elementary resonance, Z^0, the carrier of weak interactions.

In order to study the properties of Z^0 resonance, the biggest (27 km)

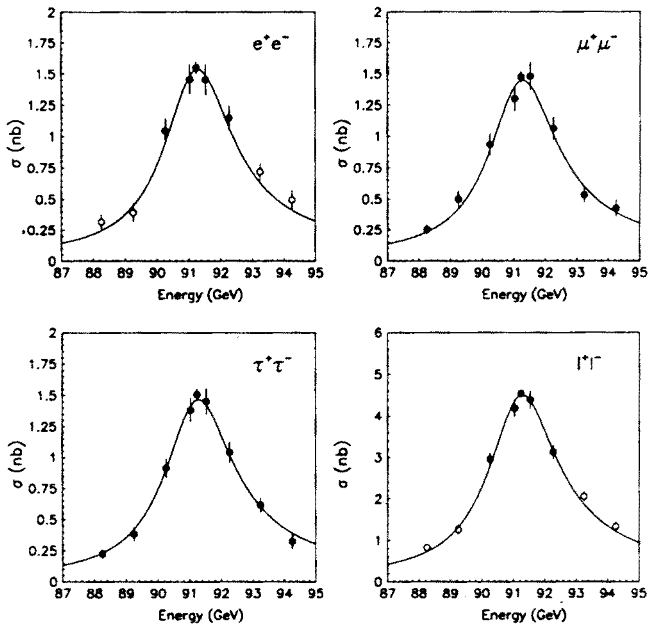

Fig. 3. $Z^0 \to$ leptons pair line shapes compared to the predictions of the Standard Model with three neutrino generations.

e^+e^- storage ring, LEP, has been constructed at CERN near Geneva together with four experiments ALEPH, DELPHI, L3 and OPAL. The first beam circulated there in July 1989, the first Z^0's were produced in August, and the first physics run started in September 1989.

In this talk, results from the ALEPH experiment at LEP are presented and compared to results from other LEP experiments, and to the Standard Model predictions. ALEPH has collected about 200 000 hadronic Z^0 decays during the 1989 and 1990 data taking runs.

Each generation of quarks and leptons gives the following contribution to the Z^0 total width:

$$\begin{aligned} \Gamma(Z^0 \to \nu\bar{\nu}) &\leadsto 2 \quad \Gamma^0, \\ \Gamma(Z^0 \to e^+e^-) &\leadsto 1.01 \quad \Gamma^0, \\ \Gamma(Z^0 \to u\bar{u}) &\leadsto 3.45 \quad \Gamma^0, \\ \Gamma(Z^0 \to d\bar{d}) &\leadsto 4.44 \quad \Gamma^0, \end{aligned}$$

where $\Gamma^0 \leadsto 85$ MeV.

For three generations of quarks and leptons (without the top quark), the Z^0 total width Γ_{tot} is expected to be around 2500 MeV, with partial width into hadrons of about 70%, and about 10% and 20% for charged and neutral leptons, respectively.

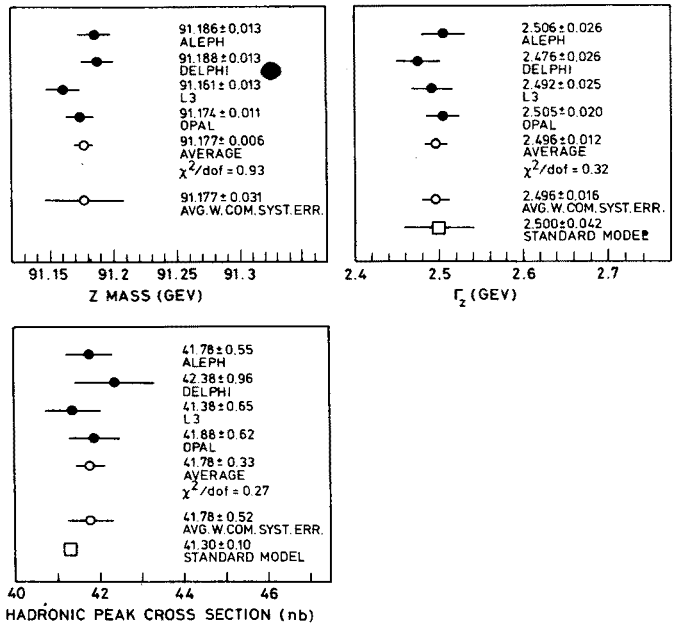

Fig. 4. Comparison of the results of four LEP experiments with the Standard Model predictions for the Z^0 mass, width Γ_Z and hadronic peak cross-section.

If higher (above three) generations of quarks and leptons exist, we expect phenomenologically that the Z^0 should not decay into heavy quarks and charged leptons from additional generations, but the Z^0 should still decay into neutrinos from those generations since, phenomenologically, neutrinos are light. Each additional generation of light neutrinos should add about 170 MeV into the Z^0 width ($\rightsquigarrow$ 6.6%). The peak cross-section depends quadratically on the total width so its value depends twice stronger ($\rightsquigarrow$ 13%) on the existence of each other additional generation:

$$\sigma_{\mathrm{ff}} = \frac{12\pi}{m_Z^2} \frac{\Gamma_{\mathrm{ee}}\Gamma_{\mathrm{ff}}}{\Gamma_{\mathrm{tot}}^2},$$

$$\Gamma_{\mathrm{tot}} = 3\Gamma_{\mathrm{ee}} + \Gamma_{\mathrm{had}} + 170\ \mathrm{MeV} * N_\nu .$$

ALEPH could determine already on October 13, 1989 [1] that only three light neutrino species exist. The measurement of this basic parameter of nature alone justifies the enormous effort in construction of the accelerator and four experiments.

Fig. 1 shows $Z^0 \rightarrow$ hadrons line shape measured in the ALEPH experiment together with the Standard Model predictions for two, three and four neutrino generations. Clearly, only three light neutrino generations can

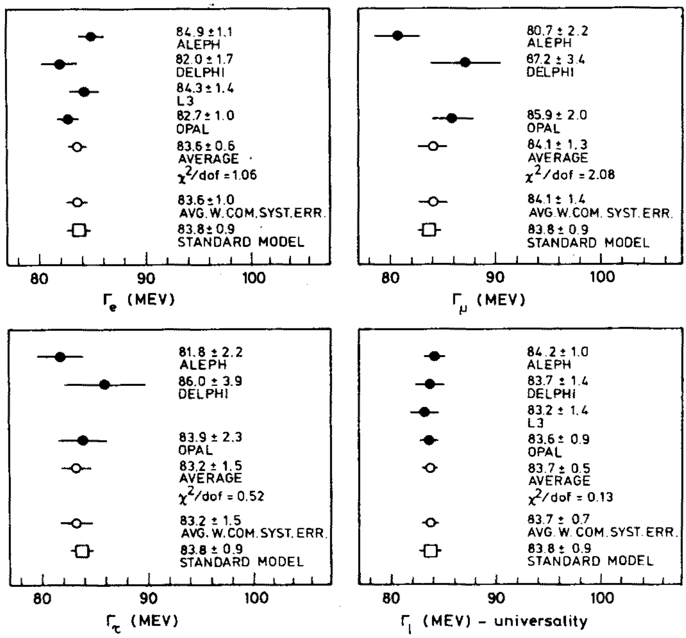

Fig. 5. Comparison of the results of four LEP experiments with the Standard Model predictions for the $Z^0 \to$ lepton pair widths Γ_e, Γ_μ, Γ_τ and Γ_l.

describe the data.

ALEPH measures momenta of charged tracks in its tracking detectors in the 1.5 T magnetic field (vertex detector, ITC, TPC) and energy deposition in the electromagnetic and hadronic calorimeters. Hadronic events are characterized by high energy track multiplicity (above 5) and large energy deposited in the calorimeters or measured by tracking detectors. Leptonic events are "two-jet-like" events with low multiplicity. Three lepton channels can be clearly separated on the plot showing track momenta measured by tracking detectors *vs* energy deposited in the calorimeters (Fig. 2). In order to obtain Z^0 line shapes for different channels, ALEPH has measured the rate of different channels and divided it by the luminosity measurement. Luminosity was determined by measuring small angle $e^+e^- \to e^+e^-$ scattering in the calorimeter where t-channel exchange dominated. More details about experimental procedure can be found in Ref. [2].

The Z^0 line shape measured in the ALEPH detector is presented in Fig. 1 for the Z^0 decays into hadrons and in Fig. 3 for the Z^0 decays into all the leptons and three lepton channels separately. These cross-sections can be fitted, after 30% correction for the initial state radiation, by the formulation [2] containing three terms: Z^0 exchange, photon exchange and

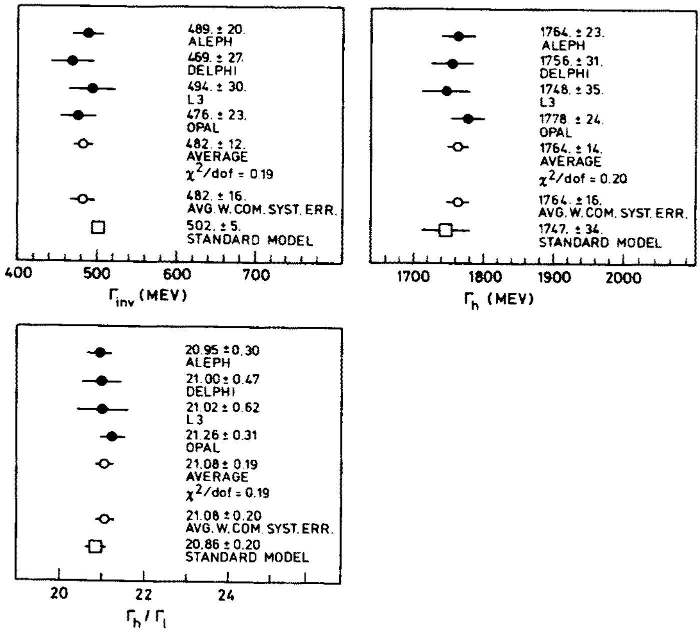

Fig. 6. Comparison of the results of four LEP experiments with the Standard Model predictions for the hadronic width Γ_h, "invisible" width Γ_{inv} and for the ratio of hadronic to leptonic width Γ_h/Γ_l.

the small interference term. The results of the fit are presented in Figs 4, 5, 6 and are compared to the results of other LEP experiments as well as to the predictions of the Standard Model [3]. The agreement between the results of different experiments and the predictions is very good. Predictions of the Standard Model depend on the unknown masses of the Higgs and top quark, which enter through higher order corrections, as well as on the value of α_s. The strongest dependence is on the top mass. The error of the Standard Model prediction reflects variations of the Higgs mass between 40 and 1000 GeV, the top mass between 80 and 220 GeV and α_s between 0.1 and 0.13. The ratios of partial widths, like Γ_{had}/Γ_{ll} or the peak cross-section depend very little on the M_{top} and M_{Higgs} and are therefore very useful to check the validity of the Standard Model. We see from Figs 4 and 6 that the agreement is very good within the the experimental accuracy of about 1%. However, the partial widths themselves depend on the unknown masses, particularly on the top mass. We can therefore estimate the top mass by determining which top mass makes the ALEPH results, $p\bar{p}$ collider results and the low energy ν scattering results compatible with the Standard Model. The answer [2] is

$$M_{\rm top} = 120 \pm 40 \pm 3_{M_Z} \pm 1_{\alpha_s} \pm 20_{M_{\rm Higgs}}\,{\rm GeV}\,.$$

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