L3 EXPERIMENT AT LEP (CERN)

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Status of the L3 Detector

In the years 1989 to 1995, the LEP has been operating around 45.5 GeV per beam for Z physics. During this period, the four LEP experiments - Aleph, Delphi, L3 and Opal - have recorded 20 million Z decay events. On 31 October, 1995, the LEP, equipped with additional accelerating cavities, registered first events at a collision energy of 130 GeV. After installation of the remaining equipment in 1996, the LEP will boost collision energy to 176 GeV for W physics.

In parallel to the physical runs, the improvement of the L3 detector was continued. The L3 silicon microvertex detector, istalled at the beginning of the 1993 data taking year, significantly improved L3's tracking capability. The coverage of the muon chambers was extended by installation of additional forward/backward chambers. Precision determination of the LEP beam energy by resonant depolarization allowed to improve the measurements of the Z boson mass and resonance width.

This report presents the results of the L3 Collaboration published in 1992 to 1995.

Electroweak Parameters and Test of Standard Model

The electroweak parameters have been determined from the measurements of the reactions $e^+e^- \to$ hadrons(γ), $e^+e^- \to \mu^+\mu^-(\gamma)$, $e^+e^- \to \tau^+\tau^-(\gamma)$, $e^+e^- \to e^+e^-(\gamma)$. All measurements support the hypothesis of lepton universality. The properties of the Z boson were obtained from the hadronic and leptonic cross-section data:

$$m_Z = 91195 \pm 9 \text{ MeV},$$
$$\Gamma_Z = 2494 \pm 10 \text{ MeV},$$
$$\Gamma_{\mathbf{had}} = 1748 \pm 10 \text{ MeV},$$
$$\Gamma_l = 83.49 \pm 0.46 \text{ MeV}.$$

The corresponding invisible width of 496.5 ± 7.9 MeV constrains, within the Standard Model, the number of light neutrino species to be

$$\mathrm{N}_\nu = 2.981 \pm 0.050.$$

A direct determination of the number of light neutrino families N_ν was performed by measuring the cross-section for the radiative process $e^+e^- \to \nu\bar{\nu}\gamma$:

$$\mathrm{N}_\nu = 3.14 \pm 0.24 \text{ (stat)} \pm 0.12 \text{ (syst)}.$$

Including the leptonic forward-backward asymmetries and the average τ polarization, the effective neutral weak current coupling constants for charged leptons were found to be

$$\bar{g}_{Vl} = -0.0378^{+0.0045}_{-0.0042},$$
$$\bar{g}_{Al} = -0.4998 \pm 0.0014.$$

Within the framework of the Standard Model, and including L3 measurements of the $Z \to b\bar{b}$ forward-backward asymmetry and partial decay width, an effective electroweak mixing angle of

$$\sin^2 \bar{\theta}_W = 0.2326 \pm 0.0012$$

was derived. An estimate for the top-quark mass of

$$m_t = 158^{+32}_{-40} \pm 19(\text{Higgs}) \text{ GeV}$$

was also obtained. The mass of the W boson was determined to be

$$m_W = 80.22 \pm 0.22 \text{ GeV}.$$

Analysis of isolated hard photons (direct photons) produced in hadronic Z decays allowed to constrain the effective electroweak couplings of quarks to the Z boson

$$c_{u,d} = 4(\bar{g}_V^2 + \bar{g}_A^2)_{u,d},$$

where the subscripts u and d denote charge +2/3 (u-type) and charge -1/3 (d-type) quarks respectively. Combining obtained result with an independent constraint from L3 measurement of the total hadronic width of the Z, the following values were found:

$$c_u = 0.92 \pm 0.22, \quad c_d = 1.63 \pm 0.15.$$

These results are consistent with Standard Model prediction:

$$c_u = 1.156 \pm 0.014, \quad c_d = 1.486 \pm 0.015.$$

For lepton flavour violating decays of the Z bozon the following limits (95% C.L.) have been obtained:

$$\text{BR}(Z \to e\mu) < 0.6 \times 10^{-5},$$
$$\text{BR}(Z \to e\tau) < 1.3 \times 10^{-5},$$
$$\text{BR}(Z \to \mu\tau) < 1.9 \times 10^{-5}.$$

Search for New Particles

The existence of the Minimal Standard Model Higgs boson H° has been excluded (95% C.L.) in the mass range $0 \leq m_{H^\circ} < 57.7$ GeV. No indication for the production of neutral and charged Higgs bosons predicted in non-minimal models has been found.

There are no indications for the existence of an additional heavy gauge boson Z'; the fitted $Z - Z'$ mixing angle is compatible with zero for all models considered.

The sample of events with one or two hard isolated photons was used to search for new processes involving photon emission. In the case of production of excited quarks, the following limits (95% C.L.) were found:

$$\sigma(e^+e^- \to Z \to q^*q) \times \text{BR}(q^* \to q\gamma) < 10 \text{ pb},$$
$$\sigma(e^+e^- \to Z \to q^*q^*) \times \text{BR}^2(q^* \to q\gamma) < 2 \text{ pb}.$$

No signal has been observed in the search for neutralinos. This leads to upper limits of a few times 10^{-5} on the branching ratios $Z \to \chi\chi'$ and $Z \to \chi'\chi'$. In the framework of the Minimal Supersymmetric Standard Model the lightest neutralino χ was excluded with m_χ less than 18 GeV, if either $\tan\beta > 2$ or the gluino mass $m_{\tilde{g}} > 100$ GeV.

Three types of isosinglet neutral heavy leptons N_e, N_μ, N_τ, that are expected in many extensions of the Standard Model, have been directly searched for. No evidence for a signal has been found. The limit

$$\text{BR}(Z \to \nu_l N_l) < 3 \times 10^{-5}$$

at the 95% C.L. was set for the mass range from 3 GeV up to m_Z.

The hadronic lineshape of the Z has been analyzed for evidence of signals of new, narrow vector resonances in the Z-mass range. No evidence for new states was found, and it was

thus possible to exclude (95% C.L.) a quarkonium state in the mass range from 87.7 to 94.7 GeV.

Four-fermion events were used to search for new particles coming from process $e^+e^- \rightarrow Z \rightarrow XZ^*$, where X or Z^* decay into ll or qq pair. The number of observed events and their kinematical distributions were found to be consistent with calculations based on the Standard Model. No significant structure was seen in the dilepton invariant or recoil mass spectra.

No signal was observed in the search for single-photon events with $E_\gamma > \frac{1}{2}E_{beam}$. From this result it was found that the parameter β, used to characterize the strength of the Z electric dipole transition, is less than 0.80 (95% C.L.) and that the existence of a superlight gravitino with mass less than 1×10^{-14} GeV is ruled out in a wide region of supersymmetric parameter space.

A lower mass limit of 510 GeV was obtained for a magnetic monopole coupling to the Z.

Test of QED

The total and differential cross sections of the reaction $e^+e^- \rightarrow \gamma\gamma(\gamma)$ have been measured at the center-of-mass energies around 91 GeV. The improved results are in good agreement with QED predictions. Lower limits (95% C.L.) were set on a contact interaction energy scale parameter $\Lambda > 602$ GeV, on the mass of an excited electron $m_{e^*} > 146$ GeV and on the QED cut-off parameters $\Lambda_+ > 149$ GeV and $\Lambda_- > 143$ GeV.

The following upper limits (95% C.L.) were also set for radiative decays of the Z:

$$\begin{aligned} \mathrm{BR}(Z \rightarrow \gamma\gamma) &< 5.2 \times 10^{-5}, \\ \mathrm{BR}(Z \rightarrow \pi^0\gamma) &< 5.2 \times 10^{-5}, \\ \mathrm{BR}(Z \rightarrow \eta\gamma) &< 7.6 \times 10^{-5}, \\ \mathrm{BR}(Z \rightarrow \gamma\gamma\gamma) &< 3.3 \times 10^{-5}. \end{aligned}$$

Determination of α_s

The strong coupling constant α_s has been determined from the study of the global event shape variables thrust and heavy jet mass and of energy-energy correlations. The combined result was found to be

$$\alpha_s(91.2\mathrm{GeV}) = 0.125 \pm 0.003(\mathrm{exp}) \pm 0.008(\mathrm{theor}).$$

Inclusive Production of Hadrons in Z Decays

From the measurement of inclusive production of J and χ_c in hadronic Z decays the following branching ratios have been determined:

$$\begin{aligned} \mathrm{BR}(Z \rightarrow J + X) &= (3.6 \pm 0.5(\mathrm{stat}) \pm 0.4(\mathrm{syst})) \times 10^{-3}, \\ \mathrm{BR}(b \rightarrow J + X) &= (1.3 \pm 0.2(\mathrm{stat}) \pm 0.2(\mathrm{syst})) \times 10^{-2}, \\ \mathrm{BR}(Z \rightarrow \chi_{c1} + X) &= (7.5 \pm 2.9(\mathrm{stat}) \pm 0.6(\mathrm{syst})) \times 10^{-3}, \\ \mathrm{BR}(b \rightarrow \chi_{c1} + X) &= (2.4 \pm 0.9(\mathrm{stat}) \pm 0.2(\mathrm{syst})) \times 10^{-2}. \end{aligned}$$

An upper limit (90% C.L.) was set on J meson production from excited gluons:

$$\mathrm{BR}(Z \rightarrow q\bar{q}g^*; g^* \rightarrow J + X) < 7.0 \times 10^{-4}.$$

The inclusive production of neutral hadrons π^o, η, K_s^o and Λ from Z decays has also been measured. Comparing obtained results with low energy e^+e^- data, it was shown that QCD describes the shape and energy evolution of the spectra of hadrons.

B Physics

From the sample of the $Z \to q\bar{q}$ events the ratio $R_b = \Gamma_{b\bar{b}}/\Gamma_{had}$ has been measured:

$$R_b = 0.222 \pm 0.003(\text{stat}) \pm 0.007(\text{syst}).$$

Using a sample of $Z \to b\bar{b}$ events, the following quantities have been determined.

The average b hadron lifetime:

$$\tau_b = 1535 \pm 35(\text{stat}) \pm 28(\text{syst}) \text{ fs}.$$

The inclusive production ratio of B^* mesons relative to B mesons:

$$N_{B^*}/(N_{B^*} + N_B) = 0.76 \pm 0.08(\text{stat}) \pm 0.06(\text{syst}).$$

The inclusive $b \to \tau\nu X$ branching ratio:

$$BR(b \to \tau\nu X) = 0.024 \pm 0.007(\text{stat}) \pm 0.008(\text{syst}).$$

The time integrated $B^o - \bar{B}^o$ mixing parameter that corresponds to the composition of the B_s^o and B_d^o states produced in Z decays was determined to be

$$\chi_B = 0.123 \pm 0.012(\text{stat}) \pm 0.008(\text{syst}).$$

Combining this measurement with the B_d^o mixing value measured by the CLEO Collaboration, a value for the B_s^o mixing parameter was extracted:

$$\chi_s = 0.43^{+0.26}_{-0.17}.$$

The $b\bar{b}$ forward-backward asymmetry at the effective center-of-mass energy $\sqrt{s} = 91.30$ GeV was measured to be

$$A_{b\bar{b}} = 0.087 \pm 0.011(\text{stat}) \pm 0.004(\text{syst}).$$

This corresponds to a value of the effective electroweak mixing angle of

$$\sin^2 \bar{\theta}_W = 0.2335 \pm 0.0021.$$

No evidence for a signal was found in the searches for the electromagnetic penguin decay $b \to s\gamma$, for the decays $B_{d,s}^o \to \gamma\gamma$, and for rare charmless decays of $B_{d,s}^o$ mesons in the neutral exclusive channels $\eta\eta$, $\eta\pi^o$ and $\pi^o\pi^o$. The following upper limits (90% C.L.) have been set:

$$\begin{aligned}
BR(b \to s\gamma) &< 1.2 \times 10^{-3}, \\
BR(B_d^o \to \gamma\gamma) &< 3.9 \times 10^{-5}, \\
BR(B_s^o \to \gamma\gamma) &< 14.8 \times 10^{-5}, \\
BR(B_d^o \to \eta\eta) &< 4.1 \times 10^{-4}, \\
BR(B_s^o \to \eta\eta) &< 1.5 \times 10^{-3}, \\
BR(B_d^o \to \eta\pi^o) &< 2.5 \times 10^{-4}, \\
BR(B_s^o \to \eta\pi^o) &< 1.0 \times 10^{-3}, \\
BR(B_d^o \to \pi^o\pi^o) &< 6.0 \times 10^{-5}, \\
BR(B_s^o \to \pi^o\pi^o) &< 2.1 \times 10^{-4}.
\end{aligned}$$

Properties of τ Leptons

For the hadronic one-prong τ decays the following branching fractions have been measured:

$$\begin{aligned}
BR(\tau \to \pi/K\ \nu_\tau) &= 0.1182 \pm 0.0026\ (\text{stat}) \pm 0.0043\ (\text{syst}), \\
BR(\tau \to \pi/K\ \pi^\circ\ \nu_\tau) &= 0.2505 \pm 0.0035\ (\text{stat}) \pm 0.0050\ (\text{syst}), \\
BR(\tau \to \pi/K\ 2\pi^\circ\ \nu_\tau) &= 0.0888 \pm 0.0037\ (\text{stat}) \pm 0.0042\ (\text{syst}), \\
BR(\tau \to \pi/K\ 3\pi^\circ\ \nu_\tau) &= 0.0170 \pm 0.0024\ (\text{stat}) \pm 0.0038\ (\text{syst}).
\end{aligned}$$

The branching fractions for τ decays with neutral kaons have also been obtained:

$$\begin{aligned}
BR(\tau^- \to \nu_\tau \pi^- \bar{K}^\circ) &= 0.0095 \pm 0.0015(\text{stat}) \pm 0.0006(\text{syst}), \\
BR(\tau^- \to \nu_\tau \pi^- \pi^o \bar{K}^\circ) &= 0.0041 \pm 0.0012(\text{stat}) \pm 0.0003(\text{syst}), \\
BR(\tau^- \to \nu_\tau \pi^- K^o \bar{K}^\circ) &= 0.0031 \pm 0.0012(\text{stat}) \pm 0.0004(\text{syst}).
\end{aligned}$$

From the measured polarization of the τ leptons $P_\tau(\cos\theta)$ the quantities

$$A_l = 2g_{Vl}g_{Al}/({g_{Vl}}^2 + {g_{Al}}^2), \quad l = e, \tau$$

were obtained:

$$A_\tau = 0.150 \pm 0.013(\text{stat}) \pm 0.009(\text{syst}),$$
$$A_e = 0.157 \pm 0.020(\text{stat}) \pm 0.005(\text{syst}).$$

This corresponds to a ratio of vector to axial-vector weak neutral couplings for electrons

$$g_{Ve}/g_{Ae} = 0.0791 \pm 0.0099(\text{stat}) \pm 0.0025(\text{syst})$$

and τ's

$$g_{V\tau}/g_{A\tau} = 0.0752 \pm 0.0063(\text{stat}) \pm 0.0045(\text{syst})$$

consistent with the hypothesis of e-τ universality. Assuming universality of the e-τ neutral current, the effective electroweak mixing angle was determined:

$$\sin^2\bar{\theta}_W = 0.2309 \pm 0.0016.$$

The analysis of the sample of energetic single-photon events ($E_\gamma > 15$ GeV) allowed to set an upper limit of $4.1\times10^{-6}\mu_B$ (90% C.L.) on the magnetic moment of the τ neutrino.

Gamma-Gamma Physics

The reaction $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-K^\circ_s K^\circ_s$ has been studied and the formation of the $f'_2(1525)$ resonance was observed. The radiative width times the branching ratio was measured to be

$$\Gamma_{\gamma\gamma}(f'_2)\times\text{BR}(f'_2 \to K\bar{K})=0.093\pm\ 0.018(\text{stat})\pm\ 0.022(\text{syst})\ \text{keV}.$$

The mixing angle of the tensor meson nonet of

$$\theta = (29.4^{+1.4}_{-1.6})^\circ$$

was determined.

A study of twelve distinct decay channels of the η_c produced in two-photon collisions has also been performed. Summing all channels, 28 candidate events have been identified, with an estimated background of 11 events. The two-photon radiative width was evaluated to be

$$\Gamma_{\gamma\gamma}(\eta_c) = 8.0 \pm 2.3(\text{stat}) \pm 2.4(\text{syst})\ \text{keV}.$$

REFERENCES

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