Z^0 Lineshape and Asymmetries Measured at OPAL

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The most fundamental measurement performed at LEP1 is the determination of the cross-section for hadrons and lepton pairs at centre-of-mass energies in the vicinity of the Z^0 peak. From the energy dependence of the cross-sections (the Z^0 lineshape) the basic parameters of the Z^0 can be derived, the mass m_Z and total decay width Γ_Z, together with the partial decay widths for the different final states. When combined with the lepton charge asymmetry one can further disentangle the vector and axial vector couplings of the Z^0 and the leptons.

Experimentally, three separate measurements are needed to determine the cross-section for a final-state fermion pair $f\overline{f}$: The event selection counts the number of events at a specific centre-of-mass energy point and must determine precisely the corrections which account for the experimental detection efficiency and the expected background contamination; the integrated luminosity must be determined at this energy point; the centre-of-mass energy of LEP, E_i, must be measured precisely.

The huge data statistics recorded at LEP1 set the scale for the precision required for these measurements. About four million hadronic decays correspond to a statistical precision of 0.05 %. Ideally, this should be matched by the selection and luminosity uncertainties. In order to fully exploit the achievable statistical precision for m_Z and Γ_Z it is required to determine the LEP centre-of-mass energy at the level of 1 MeV.

Owing to the clean operation conditions at the LEP collider and the high redundancy of the detectors, the four final-state categories – hadronic events, and electron, muon and tau pairs – are triggered with essentially 100 % efficiency and show very characteristic signatures. Background from non-Z^0 decays is largely suppressed owing to the large cross-section at the Z^0 resonance. The main challenge is to control the systematic uncertainties at the level of the high statistical precision of around 0.1 % as given by the large event sample at LEP1. In order to reach such an accuracy the analyses, in general, use Monte Carlo simulations as a first iteration step only. Any model-dependent corrections are derived by making best use of the redundancy which is available from different detector components or inherent in the event.

For the luminosity measurement a new detector, based on semiconductor tracking, was installed in 1993 which improved the performance to the requested precision [1]. Similar progress could be achieved for the centre-of-mass energy determination. By employing the method of resonant depolarization the beam energy can be derived from the very precisely known $g-2$ of the electron. Detailed evaluations of the many external sources which potentially affect the time stability of the LEP operation constrained the beam energy to the desired level of 1 MeV [2].

From a fit of a Breit-Wigner curve to the measured cross-sections several fundamental results can be derived. First of all, the mass of the Z^0 boson can be determined with a precision of 3 GeV. Together with the electromagnetic coupling α and the Fermi constant G_F, which are known with similar precision, m_Z completes the tree-level parameters of the electroweak Standard Model (SM).

The number of fermion family generations, which is not constrained in the SM, can be determined from the parameters of the resonance. The total Z^0 width Γ_Z depends on the number of possible decay channels and is therefore sensitive to the number of neutrino species N_ν. The large effect of N_ν as compared with the measured lineshape is illustrated in Fig. 1.

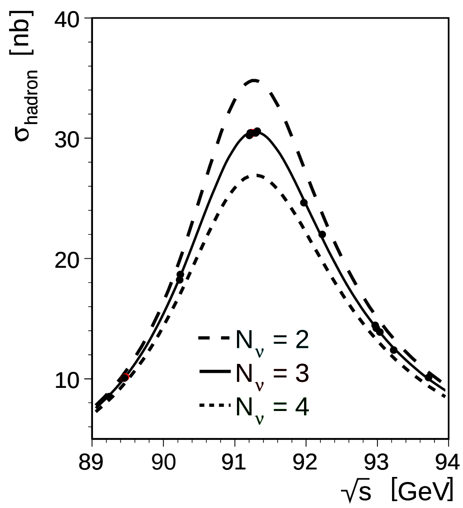

Fig. 1: Hadronic lineshape measured at OPAL *(points)* and the expected curves for 2, 3 and 4 neutrino species

The universality of lepton–boson couplings is another fundamental prediction of the SM, which can be precisely verified using the partial widths and pole-asymmetry results for electrons, muons and taus (Fig. 2).

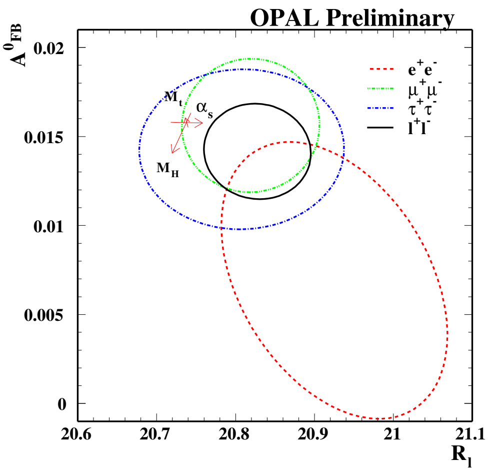

Fig. 2: Contours of 68 % probability in the A^0_{FB}–R_ℓ plane (lepton charge asymmetry and ratio of hadronic to leptonic partial width).

References

[1] OPAL Collaboration, CERN-EP/99-136.
[2] R. Assmann *et al.*, Eur. Phys. J. **C 6** (1999) 187.