Standard Model tests and new physics at LEP

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Abstract. The stringent tests of the Standard Model performed with LEP data taken between 1989 and 1995 severely constrain the possible sources of new physics beyond it. The most recent measurements of the Standard Model parameters obtained with more than 20 million Z boson decays are summarized and interpreted from this point of view. The data collected by LEP at higher energies allow to investigate the direct production of new particles. The status of the searches for new particles, other than Higgs bosons and supersymmetric partners is reported.

I INTRODUCTION

In the years between 1989 and 1995, the four LEP experiments collected overall more than 20 million Z bosons. About 100 pb^{-1} were collected per experiment at center of mass energy $\sqrt{\mathrm{s}}\sim\mathrm{M_Z}$, and 40$\mathrm{pb}^{-1}$ approximately two GeV above and below. Since November 1995 the beam energy has been increased. The center of mass energy passed the W pair-production threshold in 1996 and the Z pair one in 1997. The integrated luminosities collected per experiment are approximately 6, 11, 12 and 55 pb^{-1} at $\sqrt{\mathrm{s}}$=130-140, 161, 172 and 183 GeV respectively(LEP2).

The analysis of LEP1 data is almost finalized and it yields a very precise measurement of the Standard Model parameters. The level of accuracy is such that the comparison of the results with the predicted radiative corrections severely limits the existence of new physics.

The LEP2 project is still going on and each upgrade in energy opens new accessible phase space for the production of new particles. Among the possible extensions of the Standard Model that the LEP experiments are able to probe, this article reviews:

- those predicted by compositeness models.
  The possibility to explain the mass hierarchy of the existing particles as a spectrum of particles composed of smaller constituent has appealed physicists for a long time [1]. Most of the models developed have the additional advantage that dynamic symmetry breaking can occur without requiring the existence of the Higgs boson, the major missing piece of the Standard Model [2].
  As far as new particles are concerned, these models predict the existence of

excited states of the known particles that decay in the stable ones emitting a gauge boson. The binding forces (TechniColour, TC) are typically strong enough to give contributions to the electroweak radiative corrections and indeed these models are probed at LEP1. In addition particles carrying both leptonic and barionic number are predicted (leptoquarks [3]).

- models predicting more than four families. The next sequential family can either have a neutral leptonic component (N) lighter than the charged one (C) ore vice-versa. Since the existence of other massless N particles is excluded, in this scenario the mixing between families is very likely so that C and N particles can also decay into ordinary leptons.
- generic contact interaction models. New interactions mediated by bosons with masses well above the center of mass energies can be approximated by four-fermion vertices, resulting therefore in deviations from the Standard Model cross sections and asymmetries of the fermion pair-production ($\mathrm{e^+e^-}\to\mathrm{f\bar{f}}$).

II ELECTROWEAK TESTS AT LEP1

The measurements of the properties of the Z boson decays can be divided in two sets, the cross sections and the asymmetries. Preliminary results based on the full data set collected at LEP1 are discussed here.

The cross section measurements of the processes $\mathrm{e^+e^-}\to\mathrm{Z}\to\mathrm{f\bar{f}}$ are related to the couplings of the Z boson to the fermion f, the Z mass and total width via

$$\sigma^0_{\mathrm{f\bar{f}}} = \frac{12\pi\Gamma_{\mathrm{ee}}\Gamma_{\mathrm{f\bar{f}}}}{\mathrm{M_Z^2}\Gamma_{\mathrm{Z}}^2} \qquad\qquad \Gamma_{\mathrm{f\bar{f}}} \propto (\bar{\mathrm{g}}_{\mathrm{V,f}}{}^2 + \bar{\mathrm{g}}_{\mathrm{A,f}}{}^2)$$

where $\sigma^0_{\mathrm{f\bar{f}}}$ are the peak cross sections, Γ are the decay widths and $\mathrm{g_{A,V}}$ are the axial and vector couplings. Measuring cross sections as a function of the center of mass energy close to $\sqrt{\mathrm{s}}=\mathrm{M_Z}$ allows the determination of $\mathrm{M_Z}$ Γ_{Z} and the individual $\Gamma_{\mathrm{f\bar{f}}}$. To this aim good measurements of the integrated luminosity collected,which has an error smaller than 0.1% since 1994, and of the center of mass energy are both crucial. The current leakage into LEP of some current of the close-by railway (the so called “train effect”) has been understood [4] so that the present error are reduced below all the other experimental systematics. With this improvement the present measurement of the mass and the width of the Z are:

$$\mathrm{M_Z} = 91186.7 \pm 2.0\ \mathrm{MeV} \qquad\qquad \Gamma_{\mathrm{Z}} = 2494.8 \pm 2.5\ \mathrm{MeV}$$

Among the cross section measurements the most sensitive to new physics are those involving heavy quarks since in most of the models the coupling of the new particles is proportional to the masses. While on partial statistics there were indications of deviations of Γ_{cc} and Γ_{bb} from the predictions the analysis of the full data samples shows no significant discrepancy (see figure 1a).