ELECTROWEAK MEASUREMENTS AT LEP BETWEEN 130 AND 140 GeV

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Abstract

The lepton–pair and hadron production in e^+e^- annihilations at centre–of–mass energies between 130 and 140 GeV are presented as measured by the LEP experiments. The measurements of cross sections and leptonic forward–backward asymmetries of the LEP experiments are in good agreement and also agree with the Standard Model predictions.

At these energies a large fraction of the events radiate an initial–state photon which lowers the effective centre–of–mass energy, $\sqrt{s'}$, close to the Z–boson mass. By introducing a cut on $\sqrt{s'}$ events which annihilate close to the full centre–of–mass energy are separated. These events are used for an improved determination of the γZ interference contribution to the cross section which is difficult to measure at the Z resonance.

Introduction

Until October 1995 the LEP collider was operated at centre–of–mass energies around the Z resonance, LEP phase 1, and about 4 million Z decays were collected by each of the four LEP experiments. This large data sample allows a precise determination of the Z–boson properties.

In November 1995 LEP was operated for the first time at energies well above the Z resonance. During this period, LEP phase 1.5, each experiment has collected an integrated luminosity of about 5.5 pb^{-1} at centre–of–mass energies, $\sqrt{s}$, between 130 and 140 GeV. The electroweak measurements of the reactions:

$$\mathrm{e^+e^-} \to \mathrm{hadrons}(\gamma),\quad \mathrm{e^+e^-} \to \mu^+\mu^-(\gamma),\quad \mathrm{e^+e^-} \to \tau^+\tau^-(\gamma),\quad \mathrm{e^+e^-} \to \mathrm{e^+e^-}(\gamma),$$

are presented here[1]. Cross sections are measured for all reactions and forward–backward asymmetries for the leptonic final states.

For a large fraction of the events, initial–state radiation (ISR) photons lower the effective centre–of–mass energy, $\sqrt{s'}$, of the annihilation process to values close to the Z–boson mass, m_Z, which is referred to as *radiative return to the Z*. Requiring a large $\sqrt{s'}$ allows to determine the exclusive cross sections and forward–backward asymmetries for high energy events, $\sqrt{s'} > m_\mathrm{Z}$. All measurements are compared to the predictions of the Standard Model as calculated by the ZFITTER program [1].

Together with the measurements in the vicinity of the Z pole, they are used to determine the properties of the Z boson in the framework of the S–Matrix ansatz [2].

Reconstruction of the Effective Centre–of–Mass Energy

To reconstruct the effective centre–of–mass energy, $\sqrt{s'}$, a three body final state is assumed which consists of the final–state fermion and anti–fermion and the initial–state photon. The $\sqrt{s'}$ is reconstructed using one of the two following relations:

$$s' = s - 2E_\gamma\sqrt{s}\,, \tag{1}$$

$$s' = s\,\frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1+\theta_2)|}\,, \tag{2}$$

where E_γ is the photon energy and θ_1 and θ_2 are the azimuthal angles of the final state fermion and anti–fermion.

In most of the cases the initial–state photon is radiated along the beampipe and not detected. Equation 2 is applicable by measuring the direction of the final state–fermion pair. To use Equation 1 the photon energy is determined by assuming conservation of energy and measuring the energy of the final–state fermions. The determination of the photon energy is refined by performing a kinematic fit to the measured angles and energies of the fermion and anti–fermion. The direction of the photon is assumed along the beampipe and four momentum conservation is imposed as constraint. If the photon energy is measured in the detector Equation 2 applies as before while in Equation 1 the measured photon energy is used.

In Figure 1 the reconstructed effective centre–of–mass energy is shown for events of the processes $\mathrm{e^+e^-} \to \mathrm{hadrons}(\gamma)$ and $\mathrm{e^+e^-} \to \mu^+\mu^-(\gamma)$ at 136 GeV. The ratio of the genuine high energy events and the radiative return to the Z is different for hadronic and muonic final states since the coupling to the photon of quarks and leptons is different.

[1] The (γ) indicates the possible presence of additional photons.

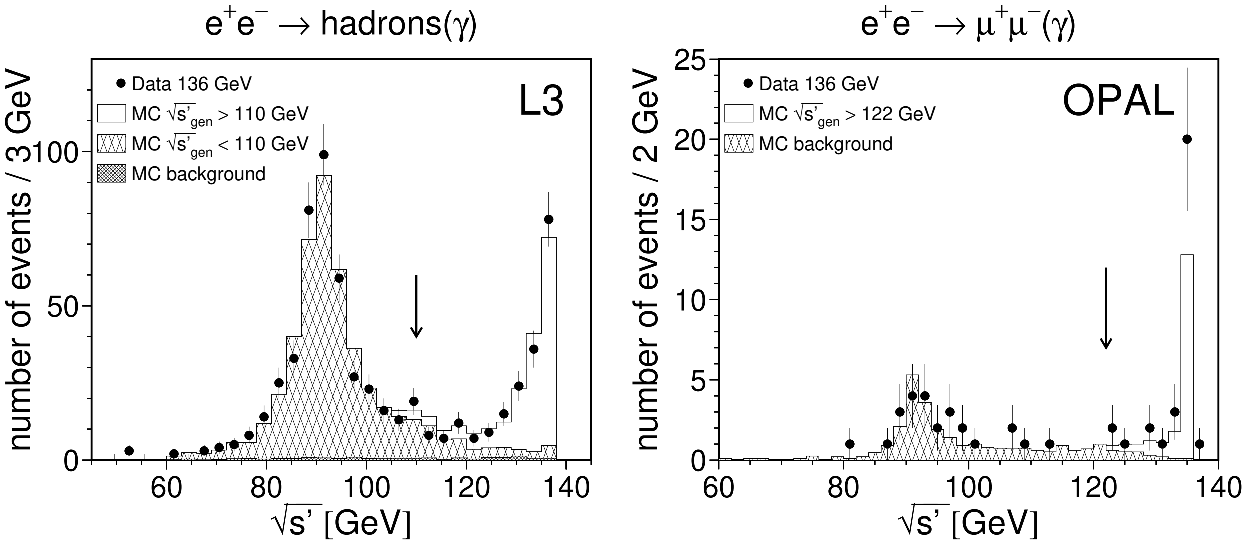

Figure 1: The distribution of the reconstucted effective centre–of–mass energy, $\sqrt{s'}$ in events of the processes $\mathrm{e^+e^-} \rightarrow$ hadrons(γ) and $\mathrm{e^+e^-} \rightarrow \mu^+\mu^-(\gamma)$. The arrows indicate the position to seperate the high energy sample. The Monte Carlo prediction is split by applying a cut on the generated effective centre–of–mass energy, $\sqrt{s'_{\mathrm{gen}}}$.

Cross Sections and Forward–Backward Asymmetries

The most precise measurement is given by the hadron cross section, where per experiment in total about 1600 events were selected which corresponds to a statistical uncertainty of 2.5%. The separation of the high energy events yields about 350 events of the reaction $\mathrm{e^+e^-} \rightarrow$ hadrons(γ) per experiment corresponding to 5.3% statistical uncertainty. Compared to the statistical errors the systematic uncertainties are small.

The measurements of cross sections and forward–backward asymmetries for all processes considered by the LEP experiments [3] are in good agreement with each other and also agree with the Standard Model prediction.

In Figure 2a the ratio of the measured to the Standard Model hadron cross section for the different LEP experiments is compared for the total and the high energy event samples. In Figure 2b the weighted LEP averages of the hadron cross section are shown. The different cut values applied by the LEP experiments have been corrected before the combination. The total event sample refers to the full phase space while the high energy event sample is defined by $\sqrt{s'} > 110$ GeV. Also shown are the LEP measurements at the Z resonance and the measurement of the hadron cross section of the TOPAZ collaboration at 57.77 GeV [4].

Interpretation within the S–Matrix Framework

The S–Matrix ansatz [2] represents a model which makes a minimum of theoretical assumptions. The scattering matrix is calculated for the hard scattering process of fermion–pair production in $\mathrm{e^+e^-}$ annihilations by assuming the s–channel exchange of two spin–1 bosons, a massless photon and a massive Z boson. In this ansatz the lowest–order total cross section, σ^0_{tot}, and the forward–backward asymmetry, $\mathrm{A^0_{FB}}$, are:

$$\sigma^0_a(s) \quad = \quad \frac{4}{3}\pi\alpha^2 \left[\frac{\mathrm{g}^a_f}{s} + \frac{\mathrm{j}^a_f(s-\overline{m}^2_{\mathrm{Z}})}{(s-\overline{m}^2_{\mathrm{Z}})^2 + \overline{m}^2_{\mathrm{Z}}\overline{\Gamma}^2_{\mathrm{Z}}} + \frac{\mathrm{r}^a_f s}{(s-\overline{m}^2_{\mathrm{Z}})^2 + \overline{m}^2_{\mathrm{Z}}\overline{\Gamma}^2_{\mathrm{Z}}} \right] \qquad \text{for } a = \mathrm{tot,fb}$$

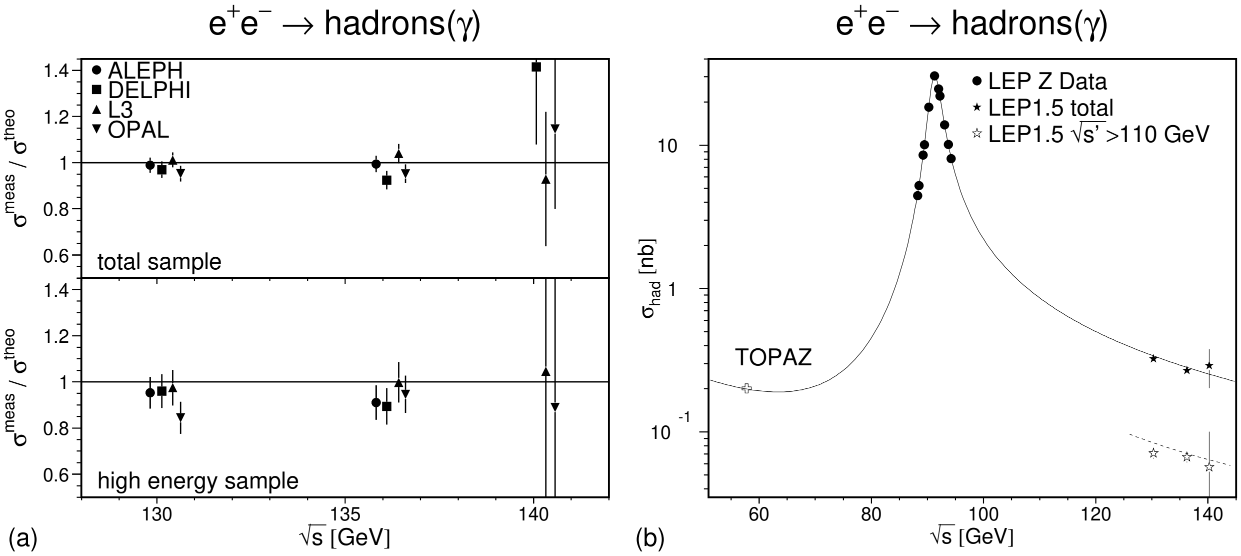

Figure 2: The ratio of the measured to the Standard Model hadron cross section from the LEP experiments for the total and the high energy event samples, (a). The combined measurements are shown in (b).

$$\mathrm{A}^0_{\mathrm{FB}}(s) \;=\; \frac{3}{4}\frac{\sigma^0_{\mathrm{fb}}(s)}{\sigma^0_{\mathrm{tot}}(s)}\,.$$

The parameters r_f, j_f and g_f scale the contributions of Z exchange, γZ interference and γ exchange. The term of the γ exchange is fixed to its QED value. QED radiative corrections are included as usual by convolution with a radiator function.

The Breit–Wigner denominator uses an s–independent width to parametrise the Z resonance, while commonly an s–dependent width is used. Therefore the Z–boson mass, $\overline{m}_{\mathrm{Z}}$, and width, $\overline{\Gamma}_{\mathrm{Z}}$, in the S–Matrix framework have different numerical values. The transformations yield $m_{\mathrm{Z}} = \overline{m}_{\mathrm{Z}} + 34.2$ MeV and $\Gamma_{\mathrm{Z}} = \overline{\Gamma}_{\mathrm{Z}} + 0.9$ MeV. The fit results within the S–Matrix framework are quoted with s–dependent width.

Using the cross section and forward–backward asymmetry measurements at the Z resonance [5] and the values measured for the high energy sample the hadronic γZ interference term $\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}}$ is determined to [6]:

$$\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}} \;=\; -0.22 \,\pm\, 0.25\,.$$

By including the small data sample taken between 130 and 140 GeV the error on the hadronic γZ interference term has improved by a factor of 1.4 compared to the measurements from the Z resonance alone. The application of the cut on the effective centre–of–mass energy is important since it rejects events which are due to Z exchange. The percentage of the γZ interference term to the total hadron cross section is shown in Figure 3a for the total cross section and after the application of the $\sqrt{s'}$ cut.

Including also the recently published measurements of the hadron cross section at 57.77 GeV of the TOPAZ collaboration further improves the error on $\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}}$:

$$\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}} \;=\; -0.06 \,\pm\, 0.18\,.$$

The results for $\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}}$ from the different LEP experiments and the TOPAZ collaboration are summarised in Figure 3b. The improvement from the LEP1.5 data from all LEP experiments together is about the same as the improvement due to the TOPAZ measurement.

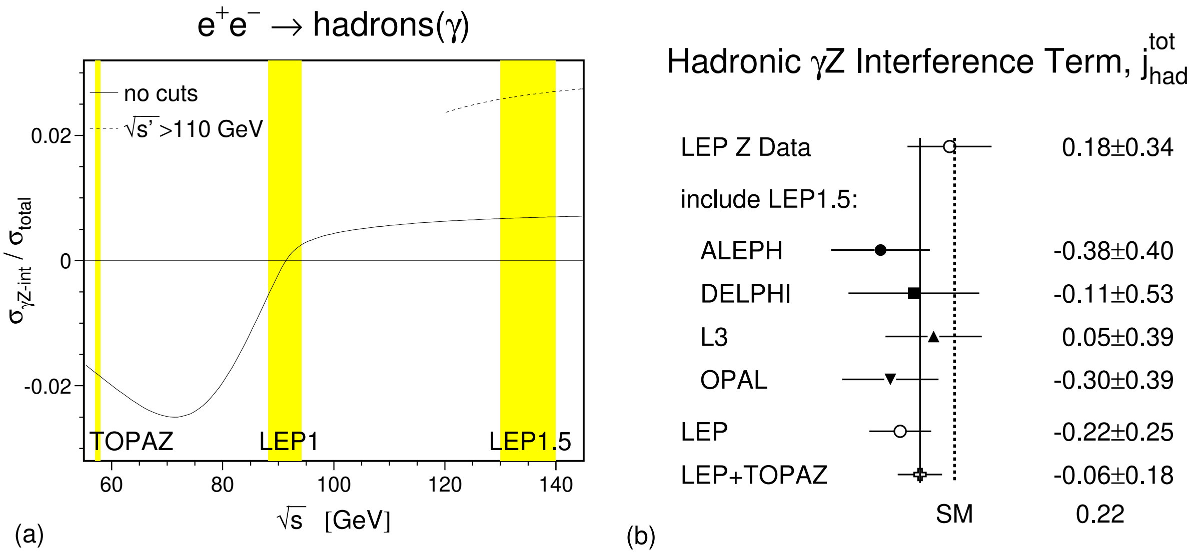

Figure 3: The percentage of the γZ interference to the total cross section, (a), and the measurements of $j_{\rm had}^{\rm tot}$ from the different LEP experiments, (b). The LEP average is also combined with the measurement of the TOPAZ collaboration.

A strong correlation of -89% between the Z–boson mass and the hadronic γZ interference term is observed. In Figure 4a the correlation is depicted as the 68% confidence level contour in the $m_{\rm Z} - j_{\rm had}^{\rm tot}$ plane.

The large error on the $j_{\rm had}^{\rm tot}$ introduces via the correlation an additional error on the Z–boson mass. The measurements of the Z–boson mass and the combination of the different experiments is summarised in Figure 4. Combining all LEP and TOPAZ measurements the Z–boson mass is determined to:

$$m_{\rm Z} \;=\; 91188.4 \,\pm\, 2.2 \pm 3.1 \text{ MeV}\,,$$

where the second error is due to the uncertainty of the γZ interference. Fixing the γZ interference the first error of 2.2 MeV is obtained. In the S–Matrix framework the error on the Z–boson mass is thus dominated by the uncertainty of the γZ interference. The quoted error on $m_{\rm Z}$ does not include effects which are discussed in [7].

Conclusion

The LEP1.5 run at centre–of–mass energies between 130 and 140 GeV was a success:

- The LEP machine provided the foreseen integrated luminosity under clean running conditions which constitutes a large step in direction of LEP phase 2 starting June, 1996.
- The LEP experiments measure cross sections and forward–backward asymmetries in good agreement with each other and also with the Standard Model prediction.
- Requiring a high effective centre–of–mass energy makes the cross section measurements particularly sensitive to the γZ interference term. The uncertainty on the hadronic γZ interference term $j_{\rm had}^{\rm tot}$ is significantly improved by this small data sample and will further be decreased by the data taken in the LEP phase 2 at energies of 161 GeV and beyond.

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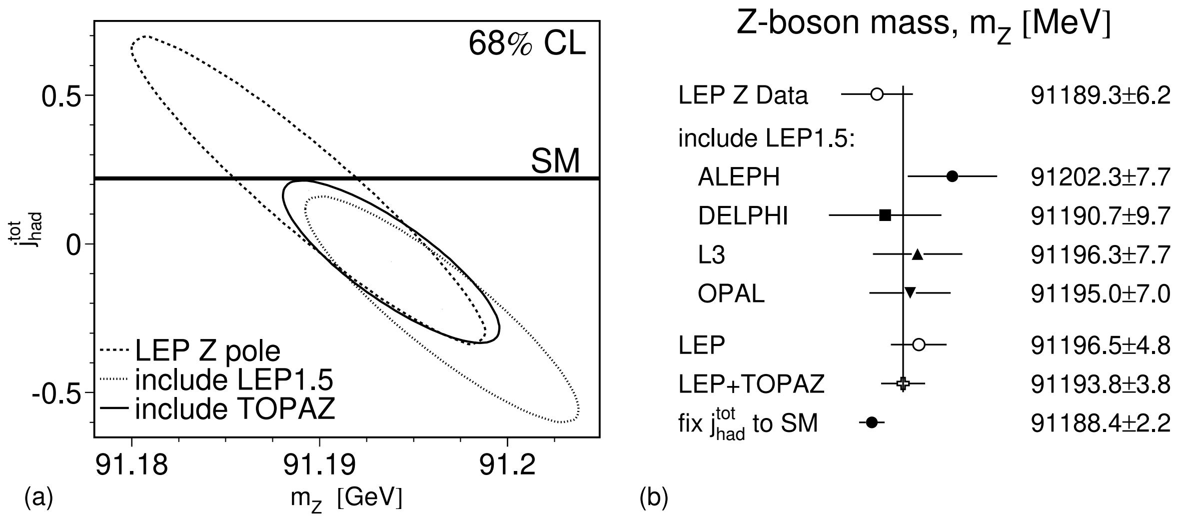

Figure 4: The 68% confidence level contour in the $m_Z - j^{tot}_{had}$ plane, (a). Comparison of the Z–boson mass from the LEP experiments within the S–Matrix framework, (b).

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