Model-independent search for the Abelian Z' boson with the LEP2 data in the Bhabha process

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Abstract

Model-independent observables to pick out the Abelian Z' signal in the Bhabha process are introduced at energies $\sqrt{s} \geq 200$ GeV. They measure separately the Z'-induced vector and axial-vector four-fermion contact couplings. The analysis of the LEP2 data constrains the value of the Z'-induced vector four-fermion coupling at the 2σ confidence level, which could correspond to the Abelian Z' boson with the mass of order 1 TeV.

1 Introduction

The LEP2 experiments have successfully confirmed the predictions of the Standard model (SM). At the same time, they inspire numerous estimations of possible new heavy particles beyond the SM. In particular, searching for "new physics" has already become an obligatory part of the reports on modern experiments in high energy physics. To describe possible signals of new physics beyond the SM the LEP2 collaborations apply both the model-dependent and the model-independent analysis of experimental data. The former approach means the comparison of experimental data with the predictions of some specific models, which extend the SM at high energies. In this way a number of Grand Unified theories, the supersymmetry models were discussed and their parameters have been restricted. These model-dependent bounds are adduced in the reports [1].

In the model-independent approach the LEP collaborations have applied a "helicity model fit". In this analysis an effective Lagrangian describing contact interactions of massless fermion states with one specific helicity (axial-axial (AA) model, vector-vector (VV) model, etc.) was introduced and the corresponding couplings have been restricted. This approach, giving a possibility to detect the signals of new physics, does not discern the specific state (its quantum numbers) responsible for them. This is because the particle interactions are described by a number of structures which contribute to different "helicity models". Therefore a specific particle contributes to a number of the "models".

In this regard, it seems resonable to develop an approach giving a possibility to pick out in a model-independent way the parameters of new heavy particles with specified quantum numbers. In the previous papers [2, 3, 4] we established a model-independent search for manifestations of a heavy Abelian Z' boson beyond the SM. The key point of this analysis was the fact that if a theory beyond the SM is renormalizable (but unspecified in other respects) some relations between the unknown Z' couplings hold. In particular, the relations require a universal value of the Z' couplings to the axial-vector fermion currents. Taking into account such model-independent relations as well as the kinematics features of the processes $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$, we introduced a unique sign-definite observable to select the signal of the virtual Z' state [2]. The value of the observable measures the Z'-induced four-fermion coupling of the axial-vector currents. The analysis of the LEP2 data set on $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$ processes has shown that the mean value of the observable is in an accordance with the signal although the accuracy is at the 1σ confidence level (CL). Clearly, this could not be regarded as the actual observation of the particle.

As numerous estimates for various scatering processes showed, the LEP2 data set is not too large to detect the signals of new physics at more then the 1σ CL (see, for instance, Refs. [1]). Such an accuracy is insufficient for a real discovery. However, one may believe that the signals would appear more evidently, if the statistics increases. One of the ways to ensure that within the existing data set is to follow the third of the described approaches and investigate other processes where the virtual states of the chosen new heavy particles contribute and can be identified. If again the observables to single out them are introduced and the data set is treated accordingly, one obtains an independent information about the states. Then, dependently on the results, one is able to conclude about the existence of the states and their characteristics by accounting for both of experiments that increases statistics.

These speculations served as a motivation for investigations carried out in the present paper in order to search for the Abelian Z' gauge boson in the Bhabha processes $e^+e^- \to e^+e^-(\gamma)$. We introduce new model-independent observables sensitive to the vector, v_f, and axial-vector, a_f, Z' couplings to the electron (positron) currents. They can be constructed from differential cross-sections at the LEP2 energies as well as at the energies of future electron-positron colliders ($\geq$ 500 GeV). As an application, we analyse the existing in the literature LEP2 data on the Bhabha process and derive limits on fitted parameters. The comparison with the results obtained already for the $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$ processes is done.

2 The Abelian Z' couplings to the SM particles

The Z'-boson can be introduced in a phenomenological way by specifying its effective low-energy couplings to the known SM particles [5]. Considering the Z' effects at energies much below the Z' mass, it is enough to parametrize the tree-level Z' interactions of renormalizable types. Such a possibility is provided by the decoupling theorem [6], from which, in particular, follows that the non-renormalizable Z' interactions are produced by loops at higher energies and suppressed by powers of the inverse Z' mass. To investigate the Z' effects in the leptonic processes at the energies of LEP experiments ($\sqrt{s} \sim 200$ GeV) or future electron-positron colliders ($\sqrt{s} \geq 500$ GeV) we use the Lagrangian:

$$\begin{aligned}
\mathcal{L} &= \left| \left(D_\mu^{\mathrm{ew},\phi} - \frac{i\tilde{g}}{2}\tilde{Y}(\phi)\tilde{B}_\mu \right) \phi \right|^2 + \\
& \quad i \sum_{f=f_L, f_R} \bar{f}\gamma^\mu \left(D_\mu^{\mathrm{ew},f} - \frac{i\tilde{g}}{2}\tilde{Y}(f)\tilde{B}_\mu \right) f, \qquad (1)
\end{aligned}$$

where ϕ is the SM scalar doublet, $\tilde{B}_\mu$ denotes the massive Z' field before the spontaneous breaking of electroweak symmetry, and summation over the all SM left-handed fermion doublets, $f_L = \{(f_u)_L, (f_d)_L\}$, and the right-handed singlets, $f_R = (f_u)_R, (f_d)_R$, is assumed. The notation $\tilde{g}$ stands for the charge corresponding to the Z' gauge group, $D_\mu^{\mathrm{ew},\phi}$ and $D_\mu^{\mathrm{ew},f}$ are the electroweak covariant derivatives. Diagonal 2×2 matrices $\tilde{Y}(\phi) = \mathrm{diag}(\tilde{Y}_{\phi,1}, \tilde{Y}_{\phi,2})$, $\tilde{Y}(f_L) = \mathrm{diag}(\tilde{Y}_{L,f_u}, \tilde{Y}_{L,f_d})$ and numbers $\tilde{Y}(f_R) = \tilde{Y}_{R,f}$ mean the unknown Z' generators characterizing the model beyond the SM.

The Lagrangian (1) generally leads to the Z–Z' mixing of order $m_Z^2/m_{Z'}^2$, which is proportional to $\tilde{Y}_{\phi,2}$ and originated from the diagonalization of the neutral vector boson mass matrix. The mixing contributes to the scattering amplitudes and plays an important role at the LEP2 energies.

The Z' couplings to a fermion f are parameterized by two numbers $\tilde{Y}_{L,f}$ and $\tilde{Y}_{R,f}$. Alternatively, the couplings to the axial-vector and vector fermion currents, $a_{Z'}^l \equiv (\tilde{Y}_{R,l} - \tilde{Y}_{L,l})/2$ and $v_{Z'}^l \equiv (\tilde{Y}_{L,l} + \tilde{Y}_{R,l})/2$, are often used. Their specific values are determined by the unknown model beyond the SM. Assuming an arbitrary underlying theory one usually supposes the parameters a_f and v_f are to be independent numbers. However, if a theory beyond the SM is renormalizable one these parameters content some relations. For the Z' boson this is reflected in correlations between a_f and v_f [3]. These correlations are model-independent in a sense that they do not depend on the underlying model:

$$v_f - a_f = v_{f^\star} - a_{f^\star}, \quad a_f = T_{3,f}\tilde{Y}_\phi, \quad \tilde{Y}_{\phi,1} = \tilde{Y}_{\phi,2} \equiv \tilde{Y}_\phi, \qquad (2)$$

where T_f^3 is the third component of the fermion weak isospin, and $f^\star$ means the isopartner of f (namely, $l^\star = \nu_l, \nu_l^\star = l, \ldots$).

The correlations (2) result in important properties of the Abelian Z' couplings. They ensure, in particular, the invariance of the Yukawa terms with respect to the effective low-energy $\tilde{U}(1)$ subgroup corresponding to the Abelian Z' boson. As it follows from the relations, the couplings of the Abelian Z' to the axial-vector fermion currents have the universal absolute value proportional to the Z' coupling to the scalar doublet. So, we will use the short notation $a = a_l = -\tilde{Y}_\phi/2$.

The relations (2) give a possibility to reduce the number of independent parameters of new physics. As a consequence, these a few parameters can be fitted by an analysis of experimental data. The leading-order differential cross-section depends on five different combinations of Z' couplings: a_e^2, v_e^2, $a_e v_e$,

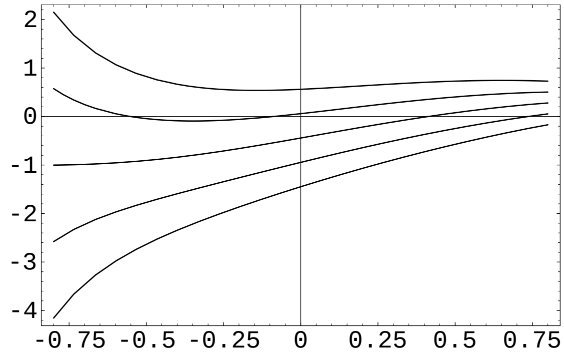

Figure 1: The ratio of the factors at $\bar{a}^2$ and $\bar{v}^2$ in the differential cross-section $\Delta\, d\sigma/dz$, $\mathcal{F}_a(z)/\mathcal{F}_v(z)$, at various hypotetic values of $\tilde{Y}_\phi/a$. The plots coorespond to $\tilde{Y}_\phi/a = -4(\text{top}), -2, 0, 2, 4(\text{bottom})$. The center-of-mass energy is $\sqrt{s} = 200$ GeV.

$a_e\tilde{Y}_\phi$, and $v_e\tilde{Y}_\phi$. Taking into account the correlations between the couplings, this number is reduced to three products: a_e^2, v_e^2, and $a_e v_e$. As it will be shown, the factors at a_e^2 and v_e^2 are dominant. So, with a high accuracy the differential cross-section is a two-parametric function.

3 Cross-section

The leading-order contributions to the cross-section of the process $e^+e^- \to e^+e^-(\gamma)$ are described by the tree-level amplitudes with a neutral vector boson exchange in the s and t channels. The virtual states of the Abelian Z' boson cause the differential cross-section to differ from its SM value:

$$\Delta\frac{d\sigma}{dz} = \frac{d\sigma}{dz} - \frac{d\sigma^{\rm SM}}{dz} = \mathcal{F}_v(\sqrt{s}, z)\bar{v}^2 + \mathcal{F}_a(\sqrt{s}, z)\bar{a}^2 + \mathcal{F}_{av}(\sqrt{s}, z)\bar{a}\bar{v} + \ldots, \quad (3)$$

where $z = \cos\theta$, θ is the scattering angle, and:

$$\bar{a} = a\sqrt{\frac{\tilde{g}^2}{4\pi}\frac{m_Z^2}{m_{Z'}^2}}, \quad \bar{v} = v\sqrt{\frac{\tilde{g}^2}{4\pi}\frac{m_Z^2}{m_{Z'}^2}}. \quad (4)$$

Due to the correlations (2) the leading-order differential cross-section contains only three different combinations of the Z' couplings a_e^2, v_e^2, and $a_e v_e$. The corresponding factors $\mathcal{F}(\sqrt{s}, z)$ depend on the SM couplings and particle masses. For the purposes of the present investigation they are calculated in the improved Born approximation with the values of running couplings at $\sqrt{s} \sim 200$ GeV. The dots in eq. (3) mark the contributions of box diagrams and IR-collinear diagrams, which are inessential for what follows.

As it was mentioned above, the Z–Z' mixing is expressed in terms of the axial-vector coupling, so it is incorporated in the factors $\mathcal{F}_a(\sqrt{s}, z)$ and $\mathcal{F}_{av}(\sqrt{s}, z)$.

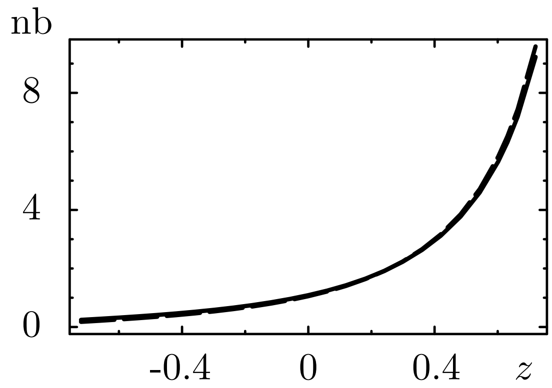

Figure 2: Factor $\mathcal{F}_v(z)$ at the vector-vector four-fermion coupling $\bar{v}^2$ in the deviation of the differential cross-section of the Bhabha process from the SM value, $\Delta\, d\sigma/dz$, for $\sqrt{s} = 200$ GeV (solid) and 500 GeV (dashed).

It is worth noticing that taking into account the Z–Z' mixing plays an important role because the factor $\mathcal{F}_a(\sqrt{s}, z)$ depends essentially on the ratio $\tilde{Y}_\phi/a$. The Abelian Z' signal is charachterized by the value $\tilde{Y}_\phi/a = -2$. As is shown in Fig. 1, the corresponding function $\mathcal{F}_a(\sqrt{s}, z)$ distinguishes qualitatively among factors at other hypothetic values of $\tilde{Y}_\phi/a$. As a consequence, it is impossible to search for a signal of the Abelian Z' boson omitting the Z'–scalar coupling $\tilde{Y}_\phi$. Putting $\tilde{Y}_\phi$ to zero, one obtains the factor $\mathcal{F}_a(\sqrt{s}, z)$, which behaviour does not correspond in general to the particle under consideration.

The differential cross-section of the Bhabha process (as well as each factor $\mathcal{F}$) increases infinitely at $z \to 1$. In order to study the deviations from the SM cross-section inspired by the heavy virtual state of the Abelian Z' boson, we introduce the functions, which are finite at all values of the scattering angle. This is provided by the normalization of the differential cross-section by using some known positive monotonic function.

The factor $\mathcal{F}_v(z)$ is a positive monotonic function of z, which is presented in Fig. 2 for the cases of the center-of-mass energies $\sqrt{s} = 200$ and 500 GeV. Such a property allows one to choose $\mathcal{F}_v(z)$ as a normalization factor for the differential cross section. Then, the normalized differential cross-section reads:

$$\frac{d\tilde{\sigma}}{dz} = \mathcal{F}_v^{-1}(\sqrt{s}, z)\Delta\,\frac{d\sigma}{dz} = \bar{v}^2 + F_a(\sqrt{s}, z)\bar{a}^2 + F_{av}(\sqrt{s}, z)\bar{a}\bar{v} + \ldots, \qquad (5)$$

where the normalized factors are shown in Fig 3.

As is seen, the normalized factors are finite at $z \to 1$. Each of them has a special influence on the deviation of the differential cross-section from the SM value. The factor at $\bar{v}^2$ is just the unity. Thus, the four-fermion contact coupling between vector currents, $\bar{v}^2$, determines the level of the deviation above the SM value. The factor at $\bar{a}^2$ depends on the scattering angle in a non-trivial way. It

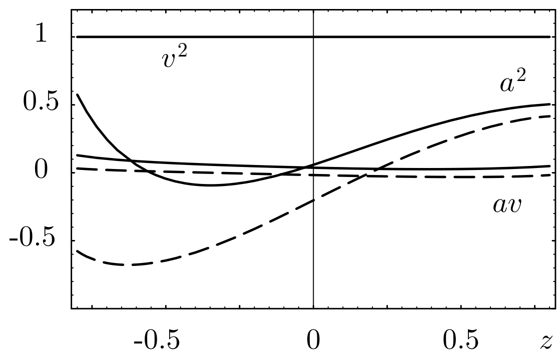

Figure 3: Factors at various couplings in the normalized differential cross-section $\Delta\, d\tilde{\sigma}/dz$ for $\sqrt{s} = 200$ (solid) and 500 GeV (dashed).

allows to recognize the Abelian Z' boson, if the experimental accuracy is quite sufficient. The factor at $\bar{a}\bar{v}$ leads to small corrections. Thus effectively, the obtained normalized differential cross-section is a two-parametric function of $\bar{v}^2$ and $\bar{a}^2$. In the next sections we introduce the observables to fit separately each of these parameters.

4 Observables to pick out v^2

The deviation of the normalized differential cross-section (5) is effectively the function of two parameters, $\bar{a}^2$ and $\bar{v}^2$. We are going to introduce integrated observables to pick separately four-fermion couplings $\bar{a}^2$ and $\bar{v}^2$.

Let us proceed with the observable for v^2. The factor at the vector-vector four-fermion coupling is a dominant quantity. After the normalization it becomes the unity function of the cosine of the scattering angle. Alternatively, the factor at $\bar{a}^2$ is a sign-varying quantity. As it is seen from Fig. 3, for the center-of-mass energy 200 GeV it is small over the backward scattering angles. To measure the value of $\bar{v}^2$ the normalized differential cross-section has to be integrated over the backward angles. For the center-of-mass energy 500 GeV the factor at $\bar{a}^2$ is already a non-vanishing quantity for the backward scattering angles. However, since it is a sign-varying quantity, the interval of z can be chosen to make the integral to be zero.

Thus, to measure the Z' coupling to the electron vector current $\bar{v}^2$ we introduce the integrated cross-section (5):

$$\sigma_V = \int_{z_0}^{z_0+\Delta z} (d\tilde{\sigma}/dz) dz, \tag{6}$$

where the interval of integration $[z_0, z_0 + \Delta z]$ is chosen to suppress the con-

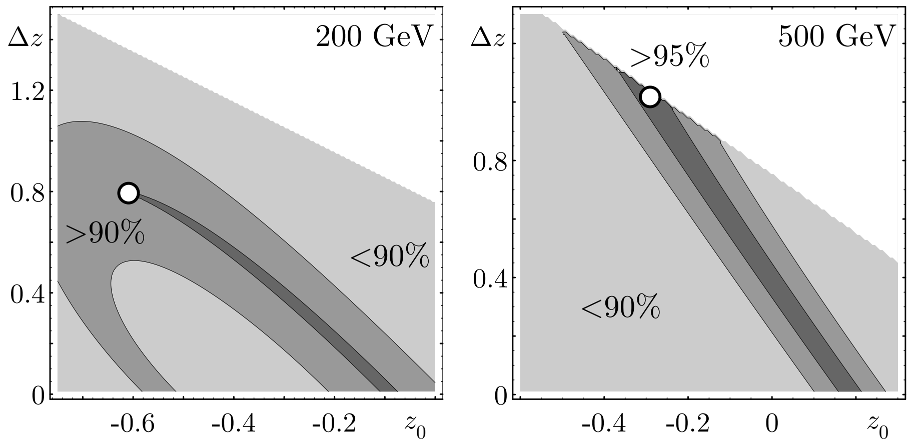

Figure 4: Relative contribution of the factor at $\bar{v}^2$ as the function of the left boundary of the angle interval, z_0, and the interval length, Δz, at the center-of-mass energies 200 GeV and 500 GeV. The shaded areas correspond to the contributions $> 95\%$ (dark), from 90% to 95% (midtone), and $< 90\%$ (light).

tribution of the factor at $\bar{a}^2$. The most effective interval for the analysis of experimental data is the interval of maximal length, since it includes the largest number of bins.

Relative contribution of the factor at $\bar{v}^2$ to the observable (6) is shown in Fig. 4 as the function of the left boundary of the angle interval, z_0, and the interval length, Δz. The dark region correspond to observables, which values are determined by $\bar{v}^2$ with the accuracy $> 95\%$. Within this region we choose the observable, which includes the largest number of bins (largest Δz). This observable is marked by the white dot in the plot.

As it is seen from Fig. 4, the observable (6) with

$$-0.6 < z < 0.2, \quad (200\ \mathrm{GeV}), \qquad -0.3 < z < 0.7, \quad (500\ \mathrm{GeV}). \tag{7}$$

allows one to measure the Z' coupling to the electron vector current $\bar{v}^2$ with the efficiency $> 95\%$.

5 Observables to pick out a^2

In order to pick the axial-vector coupling $\bar{a}^2$, one needs to eliminate the dominant contribution from $\bar{v}^2$. Since the factor at $\bar{v}^2$ in the normalized differential cross-section $d\tilde{\sigma}/dz$ is equal to 1, this can be done by summing up equal number of bins with positive and negative weights. In particular, the forward-backward normalized differential cross-section appears to be sensitive mainly to $\bar{a}^2$:

$$\tilde{\sigma}_{\rm FB} = \int\limits_{0}^{z_{\max}} dz\, \frac{d\tilde{\sigma}}{dz} - \int\limits_{-z_{\max}}^{0} dz\, \frac{d\tilde{\sigma}}{dz} = \tilde{F}_{a,\rm FB}\bar{a}^2 + \tilde{F}_{av,\rm FB}\bar{a}\bar{v} \qquad (8)$$

The relative contribution of the factor $\tilde{F}_{a,\rm FB}$ to the observable is estimated as 90% for the center-of-mass energy 200 GeV and 96% for 500 GeV ($z_{\max} = 0.7$). Thus, the observable

$$\begin{aligned} \tilde{\sigma}_{\rm FB} &= 0.224\bar{a}^2 - 0.024\bar{a}\bar{v}, \quad \sqrt{s} = 200 \text{ GeV}, \\ \tilde{\sigma}_{\rm FB} &= 0.472\bar{a}^2 - 0.020\bar{a}\bar{v}, \quad \sqrt{s} = 500 \text{ GeV} \end{aligned} \qquad (9)$$

is mainly sensitive to the Z' coupling to the axial-vector current $\bar{a}^2$.

Consider the usual situation when experiment is not able to recognize the angular dependence of the differential cross-section deviation from its SM value with the proper accuracy due to a loss of statistics. Nevetheless, a unique signal of the Abelian Z' boson can be defined in this case. For this purpose the observables $\int_{z_0}^{z_0+\Delta z}(d\tilde{\sigma}/dz)dz$ and $\tilde{\sigma}_{\rm FB}$ have to be measured (in fact, they are derived from the normalized differential cross-section). As we showed, if the deviation from the SM is inspired by the Abelian Z' boson, both the observables are to be positive quntities simulteneously. This property serves as the signal of the Abelian Z' virtual state in the Bhabha process for the LEP2 energies as well as for the energies of future electron-positron colliders (≥ 500 GeV).

6 LEP II data analysis

Let us apply the above introduced observables to analysis the experimental data on differential cross-sections of the Bhabha process. The LEP2 experiments have measured, in particular, the differential cross-section of the Bhabha process at a number of energy points. Both the final and preliminary data are available in the literature [7]. These data provide an opportunity to estimate possible Abelian Z' virtual states.

In the present paper we analyze the differential cross-sections measured by the L3 Collaboration at 183-189 GeV, by the OPAL Collaboration at 189-207 GeV, as well as the cross-sections obtained by the DELPHI Collaboration at energies 189-207 GeV.

First, we estimate a possible value of the vector coupling $\bar{v}^2$ by means of the observable (6). At the LEP2 energies the appropriate interval of the angular integration of the normalized differential cross-section is $-0.6 < z < 0.2$. The results are shown in Table 1 as 'Fit 1'. The L3 and OPAL Collaborations demonstrate positive values of $\bar{v}^2$ at the 1σ CL, whereas the DELPHI Collaboration shows the 2σ positive deviation. The mean values are a little larger than those obtained for $\bar{a}^2$ for $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$ processes [4]. The combined value of the four-fermion contact coupling corresponds to $m_{Z'} = 0.7 - 1.2$ TeV, if one assumes $\tilde{g}^2/(4\pi) \simeq 0.01 - 0.03$.

Table 1: Fits of the LEP2 data on the Bhabha process. Fit 1 represents the value of v^2 derived with the observable σ_V integrated in the angular interval $z \in (-0.6, 0.2)$. In Fit 2 the axial-vector coupling a^2 is fitted by the analysis of the observable $\tilde{\sigma}_{\rm FB}$. In Fit 3 the value of $a^2 = 0.000036$ from the analysis of the $e^+e^- \to \mu^+\mu^-$ scattering process is taken, and the value of vector coupling v^2 is found by fitting the total cross-section ($|z| < 0.72$).

Collaboration	$\bar{v}^2$, $\times 10^{-4}$, Fit 1	$\bar{a}^2$, $\times 10^{-4}$, Fit 2	$\bar{v}^2$, $\times 10^{-4}$, Fit 3
DELPHI	2.39 ± 1.35	-12 ± 7	1.2 ± 0.9
OPAL	1.33 ± 1.14	-2 ± 6	1.6 ± 0.8
L3	2.36 ± 2.82	-2 ± 16	-0.4 ± 2.3
Combined	1.82 ± 0.83	-6 ± 4	1.3 ± 0.6

The second fit ('Fit 2') concerns the observable (9) associated with the value of $\bar{a}^2$. Since the effects of the axial-vector couplings in the Bhabha process are suppressed comparably to the effects of the vector coupling, we could expect much larger experimental uncertainties for $\bar{a}^2$. Indeed, the LEP2 data lead to the significant errors on $\bar{a}^2$ of order $10^{-3} - 10^{-4}$ (See Table 1). The mean values are negative quantities which are too large to be interpreted as a manifestaion of some heavy virtual state beyond the energy scale of the SM.

Finally, we performed also a fit of $\bar{v}^2$, assuming the value of the Z'-induced axial-vector coupling from $e^+e^- \to \mu^+\mu^-$ process [4]. In this case, putting $\bar{a}^2 = 0.000037$ and computing the total cross-section ($|z| < 0.72$), we obtain the observable which depends on one parameter $\bar{v}^2$, only. So, this parameter can be easily fitted. As it is seen from Table 1, the results are close to those based on the observable (6) for the vector coupling.

So, the LEP2 data constrain the value of $\bar{v}^2$ at the 2σ CL, which could correspond to the Abelian Z' boson with the mass of the order 1 TeV. In contrast, the value of $\bar{a}^2$ is a large negative number with a significant experimental uncertainty, which can not be interpreted as a manifestaion of some heavy virtual state beyond the energy scale of the SM.

7 Conclusion

It is interesting to compare the results on the Z' search in the Bhabha processes with that of the processes $e^+e^- \to l^+l^-$ investigated already in Ref. [4]. First of all, we note that in the latter case due to a more simple kinematics a one-parametric observable $\Delta_{Z'}$ can be introduced, which is directly related to the coupling a_f^2. Hence, the estimate has been derived:

$$a^2_{\mu\mu} = 0.0000366 \pm 0.0000489, \quad a^2_{\tau\tau} = -0.0000266 \pm 0.0000643. \tag{10}$$

The more precise $\mu^+\mu^-$ data demonstrate the 1σ deviation, whereas the $\tau^+\tau^-$ data do not specify the sign of the observable. As the value of v_f^2 is concerned, it remained completely unrestricted in that case. So, the results derived in the present paper from the analysis of the Bhabha process are complementary. It is of interest that the mean value of v_e^2 is about of the same order of magnitude as a_f^2 in Eq. (10). That is resonable to expect on general grounds. We see also, that the accuracy of the result is of 2σ CL vs. 1σ for $e^+e^- \to l^+l^-$.

As a general conclusion we note that the observables to pick out the Abelian Z' signal in Bhabha process can be introduced at the LEP2 energies ($\sqrt{s} \simeq 200$ GeV) as well as at the energies of future electron-positron colliders ($\sqrt{s} \geq 500$ GeV). They are determined by normalized differential cross-section and measure two sign-definite Z' couplings, v^2 and a^2. The signs of the observables are the characteristic feature of the Abelian Z' virtual state. The corresponding values of the Z' couplings could be compared with those obtained in other independent scattering processes.

The Abelian Z' effects in the Bhabha process are dominated by the vector coupling v^2. Thus, the process $e^+e^- \to e^+e^-$ provides mainly constraints on the Z'-induced vector-vector four-fermion coupling, which are complementary to the constraints on axial four-fermion coupling based on the analysis of $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$. From the carried out analysis one can conclude that the Z' boson is expected to have the mass of order $1 - 1.2$ TeV and has a good chance to be discovered at colliders of next generation.

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References

[1] ALEPH Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration, LEP Electroweak Working Group, SLD Electroweak Group, SLD Heavy Flavor Group, hep-ex/0312023.

[2] A.Gulov and V.Skalozub, Phys. Rev. D **61**, 055007 (2000).

[3] A.Gulov and V.Skalozub, Eur. Phys. J. C **17**, 685 (2000).

[4] V.Demchik, A.Gulov, V.Skalozub, and A.Yu.Tishchenko, Yadernaya Fizika **67**, 1335 (2004) [Physics of Atomic Nuclei **67**, 1312 (2004)].

[5] A.Leike, Phys. Rep. **317**, 143 (1999).

[6] T. Appelquist and J. Carazzone, Phys. Rev. D **11**, 2856 (1975).

[7] OPAL Collaboration (G.Abbiendi et al.), Eur. Phys. J. C **33**, 173-212 (2004); L3 Collaboration (M.Acciarri et al.), Phys. Lett. B **479**, 101-117 (2000);