Effects produced by superstrings in the e^+e^- annihilation

I. V. Polyubin
Institute of Theoretical and Experimental Physics

(Submitted 16 April 1987)
Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 12, 553–556 (25 June 1987)

The cross section of e^+e^- annihilation in $SU(3)\times SU(2)\times U(1)\times U(1)$ model is calculated. The infrared and QCD corrections, which markedly affect the Born cross section, are taken into account. The effects produced by the additional Z_E boson can already be seen at LEP energies.

The model with the gauge group $SU(3)\times SU(2)\times U(1)\times U(1)$ is now assumed to be the most probable low-energy limit of the superstring theory. This model gives rise to an additional Z_E boson, which mixes with a standard Z_0 boson by means of the mixing matrix

$$m_0^2\,(Z_0 Z_E)\begin{pmatrix}1 & a\\ a & b\end{pmatrix}\begin{pmatrix}Z_0\\ Z_E\end{pmatrix} \tag{1}$$

where

$$m_0 = \frac{38{,}65}{\sin\theta_W\cos\theta_W}\ \mathrm{GeV},\quad a = \frac{\sin\theta_W}{3}\ \frac{4-\lambda^2}{1+\lambda^2},\quad b = \frac{\sin^2\theta_W}{9}\ \frac{25x^2+16+\lambda^2}{1+\lambda^2},$$

$\sin\theta_W$ is the Weinberg angle, and $x = \langle N\rangle/\langle H\rangle$ and $\lambda = \langle \overline{H}\rangle/\langle H\rangle$ are the ratios of the vacuum expectation values of the scalar components of the chiral superfields N, $\overline{H}$, and H of the $\underline{27}$-plet of E_6. As a result of diagonalization of (1), we obtain the physical mass states Z_1 and Z_2,

$$\begin{aligned} Z_1 &= \cos\alpha Z_0 + \sin\alpha Z_E\,,\\ Z_2 &= -\sin\alpha Z_0 + \cos\alpha Z_E\,, \end{aligned} \tag{2}$$

with the masses

$$m_{1,2}^2 = \frac{m_0^2}{2}\left(1 + b \pm\sqrt{(b-1)^2 + 4a^2}\right)$$

and with the coupling constants for the coupling with the fermions

$$\begin{aligned} g_{fi}^1 &= \cos\alpha g_{fi}^0 + \sin\alpha g_{fi}^E\,,\\ g_{fi}^2 &= -\sin\alpha g_{fi}^0 + \cos\alpha g_{fi}^E\,. \end{aligned} \tag{3}$$

Here ($i = L, R{:}\,f = u, d, e, \nu\ldots$), and g_{fi}^0 and g_{fi}^E are the coupling constants for the coupling of Z_0 and Z_E, respectively, with the fermion f. The quantities g_{fi}^E are determined uniquely.[1]

In discussing e^+e^- annihilation into hadrons it is customary to use the quantity $R=\sigma(e^+e^-\to\text{hadr})/\sigma(e^+e^-\to\mu^+\mu^-)$, where $\sigma(e^+e^-\to\mu^+\mu^-)$ has the form[2]

$$\sigma_{\mu^+\mu^-}(s) = \frac{4\pi\alpha^2}{3s}\sum_{j=L,R}\left|1+\frac{(g_{ej}^1)^2}{X_1(s)}+\frac{(g_{ej}^2)^2}{X_2(s)}\right|^2 \tag{4}$$

Here

$$X_{1,2}=\frac{s-m_{1,2}^2+im_{1,2}\Gamma_{1,2}}{s}\,;\quad \Gamma_{1,2}=\sum_f\Gamma(Z_{1,2}\to f\bar f)+\sum_{\tilde f}\Gamma(Z_{1,2}\to\tilde f\tilde{\bar f}),$$

where

$$\Gamma(Z_{1,2}\to f\bar f)=\frac{G_FM_{1,2}^3}{3\sqrt{2}\pi}N_c\left((g_{fL}^{1,2})^2+(g_{fR}^{1,2})^2+2g_{fL}^{1,2}g_{fR}^{1,2}\frac{m_f^2}{M_{1,2}^2}\right)\sqrt{1-\frac{4m_f^2}{M_{1,2}^2}}\,,$$

$$\Gamma(Z_{1,2}\to\tilde f_i\tilde{\bar f}_i)=\frac{G_FM_{1,2}^3}{12\sqrt{2}\pi}N_c(g_{fi}^{1,2})^2\left(1-\frac{4m_{\tilde f_i}^2}{M_{1,2}^2}\right)^{3/2}$$

and N_c is the number of colors of the width of the decay to a pair of fermions and their superpartners, respectively. The cross section σ for the reaction $e^+e^-\to$hadrons is described by the equation

$$\begin{aligned}\sigma_{\text{hadr}}(s)=\frac{4\pi\alpha^2}{s}\Bigg(&\sum_{i,j=L,R}\sum_{f=1}^{5}\left|-Q_f+\frac{g_{fi}^1g_{ej}^1}{X_1(s)}+\frac{g_{fi}^2g_{ej}^2}{X_2(s)}\right|^2\\&+\sum_{i,j=L,R}\left|-2/3+\frac{g_{ti}^1g_{ej}^1}{X_1(s)}+\frac{g_{ti}^2g_{ej}^2}{X_2(s)}\right|^2\left(1-\frac{m_t^2}{s}\right)\sqrt{1-\frac{4m_t^2}{s}}\\&+\frac{3}{8}\sum_{i=L,R}\text{Re}\left[\left(-\frac{2}{3}+\frac{g_{tL}^1g_{ei}^1}{X_1(s)}+\frac{g_{tL}^2g_{ei}^2}{X_2(s)}\right)\left(-\frac{2}{3}+\frac{g_{tR}^2g_{ei}^2}{X_1(s)}\right.\right.\\&\left.\left.+\frac{g_{tR}^2g_{ei}^2}{X_2(s)}\right)\right]\frac{m_t^2}{s}\sqrt{1-\frac{4m_t^2}{s}}\Bigg).\end{aligned}\tag{5}$$

Figure 1 shows the functional dependence $R(s)$ for $x=9$, 6, 3 and $\lambda=1/2$, in agreement with $m_2=205$, 394, and 593 GeV and $\Gamma_2=2.2$, 4.8, and 6.7 GeV; m_1 varies less than 1 GeV. The maximum of $R(s)$ near Z_2, which is an order of magnitude larger than the maximum near Z_1, is shifted to the left by 10–15 GeV. A functional dependence $R(s)$ of this sort is determined by the destructive interference of the resonant and nonresonant terms of the amplitude $e^+e^-\to\mu^+\mu^-$. A more severe restriction on the mass of Z_2 was found from the analysis of the data of the "Charm" collaboration[3]: $m_2>500$–700 GeV. Figure 2 shows plots of the cross sections $\sigma_{\text{hadr}}/\sigma_0$ and $\sigma_{\mu^+\mu^-}/\sigma_0$, where $\sigma_0=4\pi\alpha^2/3s$, and also the $R(s)$ curves for $m_2=593$ GeV. The calculations

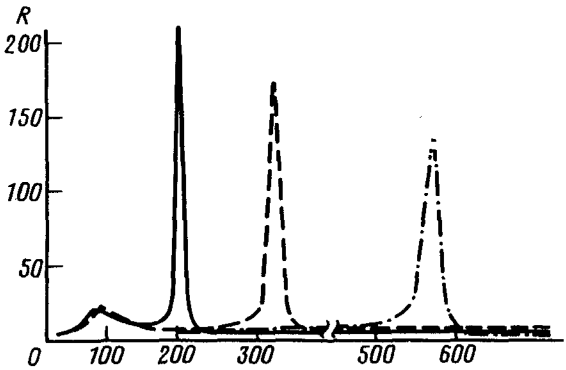

FIG. 1. $R(s)$ for $m_2 = 205$ GeV (solid curve), $m_2 = 394$ GeV (dashed curve), $m_2 = 593$ GeV (dot-dashed curve); $\sin^2\theta_W = 0.23$.

were carried out for three generations with $m_t = 40$ GeV and $m_{\tilde{f}} = 80$ GeV. The mass of the $SU(2)_L$ singlet g quark is large. The resonances occurring at $\sqrt{s} \sim 2m_t$ were disregarded in all equations. The deviations of the σ_{hadr} from the standard-model predictions due to the Z_E of the boson amount to 5% and 38% at $\sqrt{s} = 100$ GeV and $m_2 = 593$ and 205 GeV and 5% and 30% at $\sqrt{s} = 180$ GeV, respectively.

Calculation of the electroweak radiative corrections to these processes is a task that should be undertaken separately. It is known,[4] however, that in the total cross section the corrections associated with the emission of soft photons are large, while the rest of the corrections are on the order of $\alpha/\pi \sim 10^{-3}$. These corrections are as follows.[5] If Eqs. (5) and (6) are written near the resonance in the form

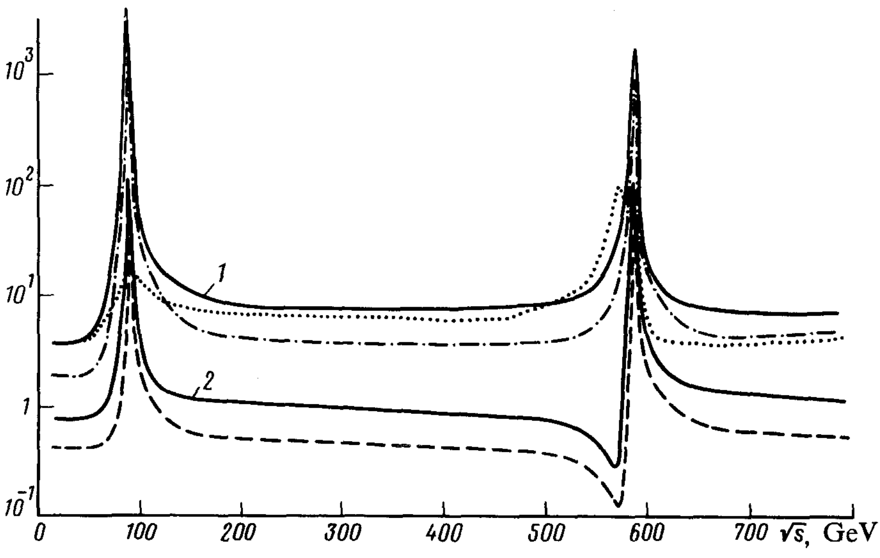

FIG. 2. Cross section 1—$\sigma_{\text{hadr}}/\sigma_0$; 2—$\sigma_{\mu^+\mu^-}/\sigma_0$; $R(s)$—dotted curve for $m_2 = 593$ GeV, dot-dashed curve—$\sigma_{\text{hadr}}/\sigma_0$ with allowance for the corrections; dashed curve—$\sigma_{\mu^+\mu^-}/\sigma_0$ with allowance for the corrections; $\sin^2\theta_W = 0.23$, $\Delta = 10^{-2}$, $\delta = 5\times 10^{-2}$.

$\sigma = \sigma_{res} + \sigma_{int} + \sigma_{nr}$, where σ_{res}, σ_{int}, and σ_{nr} are the resonant, interference, and nonresonant contributions, respectively, we will then have

$$\sigma^{corr} = C^{res}_{infra}\sigma_{res} + C^{int}_{infra}\sigma_{int} + C^{nr}_{infra}\sigma_{nr} \, , \tag{6}$$

where[5]

$$C^{res}_{infra} = \left| \frac{\Delta}{1 + \frac{s\Delta}{M\Gamma} e^{i\delta_R} \sin\delta_R} \right|^{\beta_e} \Delta^{\beta_\delta} \Big(1 - \beta_e \cot\delta_R \, \delta(s, \Delta) \Big),$$

$$C^{int}_{infra} = \Delta^{\beta_\delta} \frac{1}{\cos\delta_R} \operatorname{Re} \left[e^{i\delta_R} \left(\frac{\Delta}{1 + \frac{s\Delta}{M\Gamma} e^{i\delta_R} \sin\delta_R} \right)^{\beta_e} \right] ,$$

$$C^{nr}_{infra} = \Delta^{\beta_e + \beta_\delta}, \ \tan\delta_R = \frac{M\Gamma}{s - M^2}, \quad \beta_e = \frac{2\alpha}{\pi} \left(\ln\frac{s}{m_e^2} - 1 \right), \quad \beta_\delta = \frac{2\alpha}{\pi} Q_f^2 \ln\frac{4}{\delta^2} \quad ,$$

are the resolutions with respect to the energies and angles, and

$$\delta(s,\Delta) = \arctan\frac{s\Delta - (s - M^2)}{M\Gamma} - \arctan\,(s - M^2/M\Gamma)$$

is the radiation tail of the resonance. Allowance for the QCD corrections reduces to the factor[6] $[1 + \alpha_s(s)/\pi]$. Figure 2 also shows σ_{hadr}/σ_0 and $\sigma_{\mu^+\mu^-}/\sigma_0$ with allowance for the corrections. For $\Delta = 10^{-2}$ and $\delta = 1^\circ$ these corrections amount to 30–40%. The infrared corrections, however, cancel out for $R(s)$. In this sense, $R(s)$ is stable with respect to these corrections. In models with a different gauge group, e.g.,[7] $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_L \times (1)_R$, there is no maximum near Z_2 in $R(s)$. These topics will be further discussed in a comprehensive study.

I wish to thank K. A. Ter-Martirosyan for constant interest in this study and V. S. Abadzhev for assistance in the computer calculations.

[1] J. Ellis, Preprint CERN TH 4439/96.
[2] V. D. Angelopoulos *et al.*, Phys. Lett. **B176**, 203 (1986).
[3] N. I. Polyakov, Preprint ITEP 19, 1987.
[4] W. Wetzel, Nucl. Phys. **B227**, 1 (1983).
[5] M. Greco *et al.*, Nucl. Phys. **B171**, 118 (1980).
[6] T. Appelquist and H. Georgi, Phys. Rev. D **8**, 4000 (1973).
[7] M. V. Burova and K. A. Ter-Martirosyan, Preprint ITEP 124, 1986.

Translated by S. J. Amoretty