COMPOSITE SCALARS IN e^+e^- COLLISIONS AND RADIATIVE Z DECAYS

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Received 13 February 1984

Starting point is the hypothesis that the observed $Z \to e^+e^-\gamma$ decays are mediated by a (composite) spin 0 boson X with $40 \lesssim m_X \lesssim 50$ GeV. The consequences for $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons at PETRA are explored. PETRA experiments turn out to be sensitive up to masses $m_X \approx 50$ GeV; the best indicator for $m_X \gtrsim 48$ GeV is the angular distribution of Bhabha scattering.

The discovery of the $W^\pm$ and Z vector bosons at the CERN collider [1] appears to confirm the standard Glashow–Salam–Weinberg (GSW) model of electroweak interactions [2]. However, among the 12 Z decay events 2 involve besides the e^+e^- pair a hard photon [1] which exceeds the expectations from the standard model by a factor of order 10. Even though an interpretation as statistical fluctuation is by no means ruled out, the result has led to speculations about dynamical schemes deviating from the GSW model.

There is indeed a candidate scenario available which so far only relied on theoretical motivation: the scenario where quarks, leptons, $W^\pm$ and Z are composite [3] and have short range effective interactions among each other which mimick the GSW interactions for energies $E \lesssim G_F^{-1/2} \sim 300$ GeV. In such a framework one would of course expect, in analogy to strong interactions, a rich spectrum of further bosonic and fermionic bound states well *above* the $W^\pm$ and Z and possibly scalar and/or pseudoscalar particles X *below* the W and Z. An interpretation of the $Z \to e^+e^-\gamma$ collider events in this framework [4–8] is near at hand [‡1]

$$Z \to X\gamma, \quad X \to e^+e^- . \tag{1}$$

The kinematics of the few events furthermore suggests a mass range [1]

$$40\ \text{GeV} \lesssim m_X \gtrsim 50\ \text{GeV} \tag{2}$$

for the X boson(s). The lack of experimental evidence for comparable $W \to e\nu\gamma$ rates [1] at the CERN collider points towards an isoscalar particle X.

The large overlap of the prospective mass range (2) with the highest PETRA energies is of course striking. The aim of this paper is to explore the consequences of the hypothetical presence of such a spin 0 state for PETRA experiments. In particular we shall evaluate its influence on Bhabha scattering which has not been discussed in the literature. Bhabha scattering turns out to be sensitive to a spinless particle with mass well above 45 GeV, since the X contribution is strongly enhanced through interference with photon exchange in the crossed channel. Furthermore it is distinguished by little model dependence and high rates, i.e. good statistics. By combining our results for $e^+e^- \to e^+e^-$ with those for $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons (see also refs.

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[7,8]) we are led to conclude that PETRA experiments are sensitive to a spinless particle with couplings as inferred from the $Z \to e^+e^-\gamma$ events up to masses of order 50 GeV. Even if no evidence for a scalar or pseudoscalar particle were to be found at PETRA our analysis allows to put tight bounds on the resonance parameters such as mass, total width and branching ratios into e^+e^-, $\gamma\gamma$ and hadrons from PETRA data.

Let us first collect the expectations for the parameters of a composite spin 0 particle which have been largely worked out in refs. [4–8]. The strategy is as follows. According to the interpretation (1) of the $Z \to e^+e^-\gamma$ events, the decays $X \to e^+e^-$ as well as $Z \to X\gamma$ exist. Vector dominance allows to predict the mode $X \to \gamma\gamma$ in terms of $Z \to X\gamma$. Finally the quantity $\Gamma(X \to e^+e^-)\Gamma(X \to \gamma\gamma)/\Gamma_{tot}(X)$ is determined from the decay chain (1) in terms of the UA1/UA2 value for $\Gamma(Z \to e^+e^-\gamma)$.

Let us now fill in the details. We follow ref. [6] where the presence of a pair of spin 0 particles, a scalar and a pseudoscalar one,

$$X = \{N, S\} \tag{3}$$

is required with

$$N \text{ for scalar}, \quad S \text{ for pseudoscalar}. \tag{4}$$

This pair couples to fermion pairs $\bar{f}f$ (f = lepton or quark) as

$$\mathcal{L}_{\text{eff}}^{\bar{f}fX} = h\bar{f}(N + i\gamma_5 S)f$$

$$= h[\bar{f}\tfrac{1}{2}(1+\gamma_5)fX + \bar{f}\tfrac{1}{2}(1-\gamma_5)fX^*], \tag{5}$$

with the *complex* field

$$X = N + iS \tag{6}$$

behaving like

$$X \to e^{-2i\alpha}X \tag{7}$$

with respect to chiral transformations

$$f \to e^{i\alpha\gamma_5}f. \tag{8}$$

This coupling is distinguished by preserving a *chiral* symmetry which, following 't Hooft [11], is needed to protect the composite quarks and leptons from acquiring a mass of order $m_{W,Z}$. The bosons N and S have the *same* coupling h to a given fermion pair and this coupling is independent of the fermion (quark or lepton) mass in contradistinction to the Yukawa couplings in the GSW model. The coupling h is of course bound to be small due to the absence of a scalar or pseudoscalar contribution to the neutral current data. The width $\Gamma(X \to e^+e^-)$ is related to the coupling h in eq. (5) as follows

$$\Gamma(X \to e^+e^-) = \tfrac{1}{2}\alpha_h m_X, \tag{9}$$

where

$$\alpha_h = h^2/4\pi \tag{10}$$

and X stands for N *or* S. In the chiral limit N and S are mass degenerate,

$$m_e, m_q \to 0: m_N = m_S. \tag{11}$$

In view of the fact that the top quark mass has to be larger than 22 GeV, a considerable mass splitting between N and S can occur. In the following analysis we shall consider two extremes, described by the appearance of a *discrete* parameter ϵ counting the number of effectively contributing spin 0 particles

$\epsilon = 2$: $m_N = m_S$,

$\epsilon = 1$: only one particle, either N or S, contributes in the PETRA energy range, the other one having a much higher mass (cf. ref. [7]). (12)

Next let us discuss the decay mode $X \to \gamma\gamma$. By means of vector dominance it is related [4,6–8] to the decay $Z \to X\gamma$ appearing in eq. (1). Let us remember that the concept of vector dominance (VDM) has already played a crucial rôle in establishing [12] the composite scenario as a viable alternative to the GSW model as concerns the properties of the $W^\pm$, Z and their couplings to fermion pairs. We consider a WWX coupling [4,6–8] [‡2] of the type

$$\mathcal{L}_{\text{eff}}^{WWX} = (k/\Lambda_{\text{eff}})(2W_{\mu\nu}W^{\mu\nu}N$$

$$+ \epsilon^{\mu\nu\rho\sigma}W_{\mu\nu}W_{\rho\sigma}S), \tag{13}$$

where $W_{\mu\nu}$ is the Yang–Mills field strength tensor for the isotriplet vector bosons and Λ_{eff} the compositeness scale with $m_Z \lesssim \Lambda_{\text{eff}} \lesssim 1$ TeV. Using the VDM prescription [‡3], appropriate for the language of effective la-

‡2 In principle each term has an independent, unknown coupling. We chose, for simplicity, their relative weight such that $\Gamma(N \to \gamma\gamma) = \Gamma(S \to \gamma\gamma)$, provided $m_N = m_S$. Here we deviate from ref. [7].

‡3 Approximating $\cos\theta_W$ by 1.

grangians [13],

$$W^3_\mu \to Z_\mu + \lambda A_\mu, \quad (14)$$

with

$$\lambda = e/g \sim \sin\theta_W \quad (15)$$

one obtains the widths ‡4

$$\Gamma(Z \to X\gamma) = \tfrac{2}{3}\pi^{-1}(k/\Lambda_{eff})^2\lambda^2(m_Z^2 - m_X^2)^3/m_Z^3, \quad (16)$$

$$\Gamma(X \to \gamma\gamma) = \pi^{-1}(k/\Lambda_{eff})^2\lambda^4 m_X^3. \quad (17)$$

Again X stands for N *or* S. Only the ratio of the two widths,

$$r_{VDM} = \Gamma(X \to \gamma\gamma)/\Gamma(Z \to X\gamma)$$
$$= \tfrac{3}{2}\lambda^2(m_X m_Z)^3/(m_Z^2 - m_X^2)^3, \quad (18)$$

as a function of m_X, will enter the following discussion. It is of order 0.1.

Nothing is known about the coupling of X to hadrons. In principle X can couple to quark pairs as well as to gluons. Disregarding the latter and assuming (for simplicity and not for good reason) quark–lepton universality, one expects [5–7]

$$\Gamma(X \to \text{hadrons}) \approx n_q\Gamma(X \to e^+e^-), \quad (19)$$

with the number of contributing quarks $n_q = 15$. We shall try to stay as independent of assumptions for $\Gamma(X \to \text{hadrons})$ as possible.

Let us finally implement the constraint (1) which now reads

$$\epsilon\,\Gamma(X \to e^+e^-)\Gamma(X \to \gamma\gamma)/\Gamma_X = r_{VDM}\Gamma(Z \to e^+e^-\gamma), \quad (20)$$

where Γ_X is the total width of N *or* S. We shall base all our following estimates on a typical UA1/UA2 value [1,6,7]

$$\Gamma(Z \to e^+e^-\gamma) \sim 20\ \text{MeV}. \quad (21)$$

From this constraint, using the obvious inequality $\Gamma_X > \Gamma(X \to \gamma\gamma)$, one obtains a lower bound for $\Gamma(X \to e^+e^-)$

$$\epsilon\Gamma(X \to e^+e^-) > r_{VDM}\Gamma(Z \to e^+e^-\gamma) \approx O(2\ \text{MeV}). \quad (22)$$

which implies

$$\epsilon\alpha_h > (2/m_X)r_{VDM}\Gamma(Z \to e^+e^-\gamma)$$
$$\sim O(0.8 \times 10^{-4}). \quad (23)$$

In all our ensuing calculations we shall be conservative and use this lower bound or a value close to it for α_h.

Now we are ready to explore the consequences of a hypothetical scalar and/or pseudoscalar state X for PETRA physics in the energy range $40 \lesssim \sqrt{s} \lesssim 45$ GeV. For our purpose the most interesting e^+e^- reactions ‡5 are

(i) $e^+e^- \to e^+e^-$ (Bhabha scattering),

(ii) $e^+e^- \to \gamma\gamma$,

(iii) $e^+e^- \to$ hadrons

[provided $\Gamma(X \to \text{hadrons})$ is sufficiently large].

Starting from the effective lagrangian (5) for the $X - e^+e^-$ interaction, we have calculated

$$\frac{d\sigma}{d\Omega_{e^+e^-\to e^+e^-}} = \frac{d\sigma^{QED}}{d\Omega}(1 + \delta_{GSW} + \delta_X),$$

$$\frac{d\sigma^{QED}}{d\Omega} = \frac{\alpha^2}{4s}\left(\frac{3+\cos^2\theta}{1-\cos\theta}\right)^2. \quad (24)$$

$(d\sigma/d\Omega)^{QED}\delta_{GSW}$ is the well-known standard model contribution [14] due to Z exchange in the *s* and *t* channels. Analogously, $(d\sigma/d\Omega)^{QED}\delta_X$ is the contribution due to the additional X exchanges in the *s* and *t* channels. Our result is

‡4 We agree on both widths with refs. [4,6] and deviate by a factor of 4 in $\Gamma(Z \to X\gamma)$ from ref. [7]. We thank H.D. Dahmen for informative discussions on this point.

‡5 $e^+e^- \to \mu^+\mu^-$ is not discussed; the X contribution to the amplitude is small ($\propto \alpha_h$) and does not interfere with the QED amplitude, in contrast to $e^+e^- \to e^+e^-$.

$$\delta_X = \left(\frac{1-\cos\theta}{3+\cos^2\theta}\right)^2 \frac{\epsilon\alpha_h}{\alpha} \left\{ \frac{s^2}{(s-m_X^2)^2 + m_X^2\Gamma_X^2} \right.$$

$$\times \left[2\frac{s-m_X^2}{t} + \frac{\alpha_h}{\alpha} + 2\frac{g_V^2 - g_A^2}{e^2}\frac{s-m_X^2}{t-m_Z^2}\right]$$

$$+ \frac{t^2}{(t-m_X^2)^2 + m_X^2\Gamma_X^2}$$

$$\times \left[2\frac{t-m_X^2}{s} + \frac{\alpha_h}{\alpha} + 2\frac{g_V^2 - g_A^2}{e^2}\frac{t-m_X^2}{s-m_Z^2}\right]$$

$$+ (2-\epsilon)\frac{\alpha_h}{\alpha}\frac{s}{(s-m_X^2)^2 + m_X^2\Gamma_X^2}$$

$$\times \frac{t}{(t-m_X^2)^2 + m_X^2\Gamma_X^2}$$

$$\left. \times \left[(s-m_X^2)(t-m_X^2) + m_X^2\Gamma_X^2\right] \right\}, \qquad (25)$$

where $\epsilon = 1,2$ is defined in eq. (12) and α_h in eq. (10). X–Z interference effects, leading to the two terms proportional to $(g_V^2 - g_A^2)/e^2 \simeq -0.359$, are of course negligibly small. The last term in eq. (25) results from the interference of X exchange in the direct and the crossed channels. It only contributes for $\epsilon = 1$ and in this case it is negligibly small provided $\Gamma_X/m_X \ll 1$. Essentially the whole contribution to δ_X comes from the first two terms proportional to the Breit–Wigner form $1/[(s-m_X^2)^2 + m_X^2\Gamma_X^2]$ which results from the *interference of the s channel X exchange with the t channel γ exchange* plus the modulus square of the s channel X exchange. The latter contributes only in the resonance peak such that off-resonance δ_X is extremely well approximated by the interference term alone

$$\delta_X \approx 4\frac{1-\cos\theta}{(3+\cos^2\theta)^2}\frac{s}{m_X^2 - s}\frac{\epsilon\alpha_h}{\alpha},$$

$$\text{for } |\sqrt{s} - m_X| \gtrsim 2\Gamma_X. \qquad (26)$$

Clearly, the predictions for off-resonance Bhabha scattering are least model dependent; they involve no theoretical prejudice about $\Gamma(X\to\gamma\gamma)$, $\Gamma(X\to \text{hadrons})$ or Γ_X! The model dependence comes in only mildly through the application of the lower bound (23) for α_h. Notice, furthermore, that formula (26) as well as the bound (23) depend on the product $\epsilon\alpha_h$. Using α_h^{min} thus leads to a result δ_X^{min} in eq. (26) which is independent of whether a pair of states N, S or only one of them contributes!

The angle-integrated cross section is also of interest. For later use we define the convenient ratio

$$\Delta R_{e^+e^-\to e^+e^-} = [\sigma_{pt}(e^+e^-\to\mu^+\mu^-)]^{-1}$$

$$\times \left(\int_0^{2\pi} d\varphi \int_{-\cos\theta_{max}}^{\cos\theta_{max}} d\cos\theta \frac{d\sigma^X}{d\Omega}(e^+e^-\to e^+e^-)\right) \qquad (27)$$

as a function of $\cos\theta_{max}$, with

$$(d\sigma/d\Omega)^X = (d\sigma/d\Omega)^{QED}\delta_X \qquad (28)$$

and

$$\sigma_{pt}(e^+e^-\to\mu^+\mu^-) = 4\pi\alpha^2/3s. \qquad (29)$$

Off resonance we obtain from eq. (26) the approximation

$$\Delta R_{e^+e^-\to e^+e^-} \approx \frac{3}{2}\frac{s}{m_X^2 - s}\frac{\epsilon\alpha_h}{\alpha}\log\frac{1+\cos\theta_{max}}{1-\cos\theta_{max}}$$

$$= \frac{3}{\alpha}\frac{s}{m_X}\frac{\epsilon\Gamma(X\to e^+e^-)}{m_X^2 - s}\log\frac{1+\cos\theta_{max}}{1-\cos\theta_{max}}. \qquad (30)$$

In $e^+e^-\to\gamma\gamma$ there is (for $m_e\to 0$) no interference of the QED with the X contribution. Therefore the X contribution has simply a Breit–Wigner form

$$\Delta R_{e^+e^-\to\gamma\gamma} = [\sigma_{pt}(e^+e^-\to\mu^+\mu^-)]^{-1}$$

$$\times \int_0^{2\pi} d\varphi \int_0^{\cos\theta_{max}} d\cos\theta \frac{d\sigma^X}{d\Omega}(e^+e^-\to\gamma\gamma)$$

$$= \frac{3}{\alpha^2}\cos\theta_{max}\frac{s^3}{m_X^4}\epsilon\frac{\Gamma(X\to\gamma\gamma)\Gamma(X\to e^+e^-)}{(s-m_X^2)^2 + m_X^2\Gamma_X^2} \qquad (31)$$

$$= \frac{3}{\alpha^2}\cos\theta_{max}\frac{s^3}{m_X^4}\frac{\Gamma_X}{(s-m_X^2)^2 + m_X^2\Gamma_X^2}$$

$$\times r_{VDM}\Gamma(Z\to e^+e^-\gamma)$$

by virtue of the constraint (20). This prediction depends on theoretical prejudice, since it involves r_{VDM} and Γ_X. On the other hand this is a neat result, since for a given value of m_X the quantity $\Delta R_{e^+e^-\to\gamma\gamma}$ only depends on the unknown parameter Γ_X. Again the result (31) is independent of ϵ, i.e. of whether one or two spinless particles contribute.

The contribution of the X particle(s) to $e^+e^- \to$ hadrons is strongly model dependent, since it is proportional to $\Gamma(X \to \text{hadrons})$ which in the extreme case could even be zero. We therefore prefer to consider the less model dependent quantity

$$\Delta R_{e^+e^-\to\text{hadrons}}\, n_q \Gamma(X \to e^+e^-)/\Gamma(X \to \text{hadrons})$$

$$= \tfrac{3}{4} n_q \epsilon \left(\frac{\alpha_h}{\alpha}\right)^2 \frac{s^2}{(s - m_X^2)^2 + m_X^2 \Gamma_X^2}\,, \qquad (32)$$

with

$$\Delta R_{e^+e^-\to\text{hadrons}} = \sigma^X(e^+e^- \to \text{hadrons})/\sigma_{\mathrm{pt}}(e^+e^- \to \mu^+\mu^-),$$
$$\text{and } n_q = 15. \qquad (33)$$

The quantity (32) coincides with $\Delta R_{e^+e^-\to\text{hadrons}}$, if quark–lepton universality (19) holds.

Next, let us ask how strong the signal would be, if the X particle were to lie *within* the PETRA energy range. Fig. 1 illustrates the contribution of a scalar (N) and a pseudoscalar (S) particle with a common mass $m_X = 44$ GeV to the three reactions $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons. We chose a width $\Gamma_X = 35$ MeV which is of the order of the PETRA resolution and the smallest possible value for α_h, $\alpha_h^{\min} = 3.4 \times 10^{-5}$, corresponding to $\epsilon = 2$. The peak values have to be compared to the respective QED or QCD backgrounds also quoted in fig. 1. The effect in all three reactions is enormous, in particular in $e^+e^- \to \gamma\gamma$; it cannot escape detection. From eqs. (25), (27), (31) and (32) one can easily estimate the changes for increasing Γ_X. For instance, for $\Gamma_X = 350$ MeV the peak in $e^+e^- \to \gamma\gamma$ still reaches a value of 192; a value of the order of tens of GeV would be required for Γ_X in order to make the effect only marginally detectable. From the fact that no effect has been reported from PETRA so far we feel safe to discard $m_X \lesssim 45$ GeV.

Let us now discuss the possibility $m_X > 45$ GeV. Whereas Bhabha scattering has turned out to be the least sensitive of all three reactions *on* resonance (see fig. 1), its virtue lies in its sensitivity *off* resonance (see figs. 2 and 3). Its X contribution is dominated by the γ–X interference and correspondingly involves a slow $1/(m_X^2 - s)$ decrease for decreasing energy to be compared with the fast $1/(s - m_X^2)^2$ decrease in $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons. This becomes manifest in fig. 2 where the X = {N, S} contribution to the three reactions is shown for four values of m_X between 46 and 50 GeV. We chose a width of $\Gamma_X = 70$ MeV and α_h rather conservative, $\alpha_h = 10^{-4} \approx 2\alpha_h^{\min}$ for $a = 2$. For this choice of parameters the X signal at $\sqrt{s} = 45$ GeV is significant in all three reactions for $m_X = 46$ GeV; it

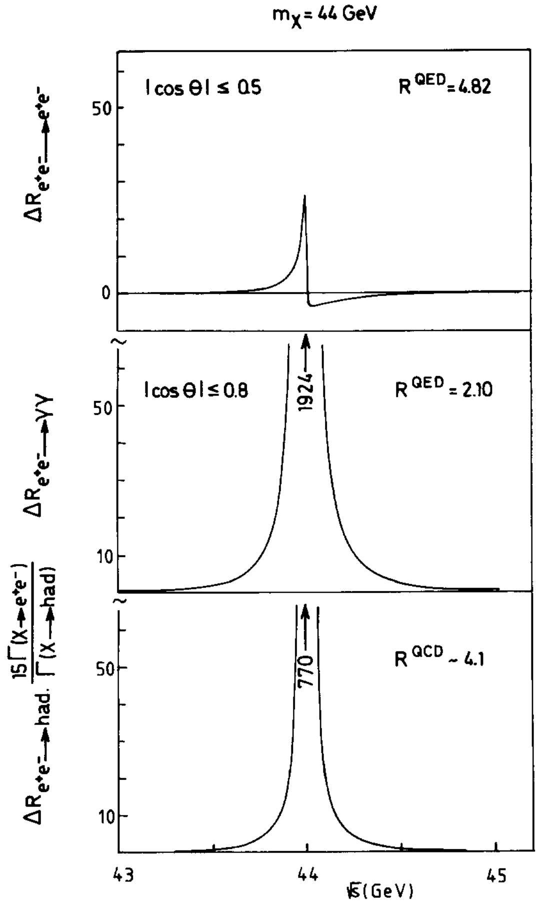

Fig. 1. The energy dependence of the contribution of a pair X of (composite) scalar and pseudoscalar bosons to $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons, normalized by $\sigma_{\mathrm{pt}}(e^+e^- \to \mu^+\mu^-)$, is displayed assuming $m_X = 44$ GeV, $\Gamma_X = 35$ MeV and $\alpha_h = \alpha_h^{\min} = 3.4 \times 10^{-5}$. The angular-integrated ratios ΔR are defined in eqs. (27), (31) and (32). For comparison the values of the corresponding QED or QCD backgrounds are also given.

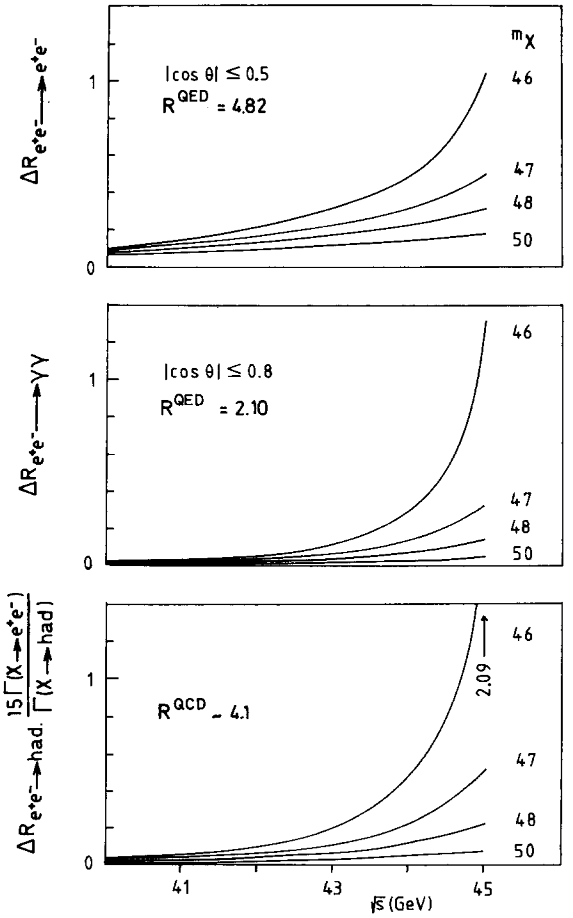

Fig. 2. The same quantities as in fig. 1 are shown for four values of $m_X > 45$ GeV, $\Gamma_X = 70$ MeV and $\alpha_h = 10^{-4}$.

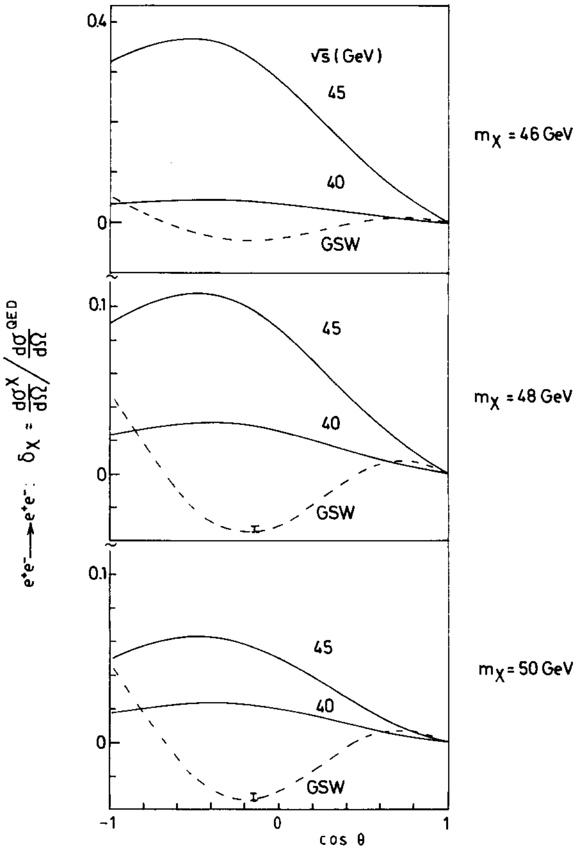

Fig. 3. The angular dependence of a pair X of (composite) scalar and pseudoscalar particles to $e^+e^- \to e^+e^-$ is displayed for $\sqrt{s} = 40$ and 45 GeV and three values of $m_X > 45$ GeV. $\alpha_h = 10^{-4}$ and there is Γ_X independence for $0 \lesssim \Gamma_X \lesssim 500$ MeV. The dashed curve is the standard GSW model contribution $\delta_{GSW} = (d\sigma/d\Omega)^{GSW}/(d\sigma/d\Omega)^{QED}$, the error bar indicating its energy dependence for $40 \leqslant \sqrt{s} \leqslant 45$ GeV.

amounts to a 20% effect in $e^+e^- \to e^+e^-$, a 60% effect in $e^+e^- \to \gamma\gamma$ and a 50% effect in $e^+e^- \to$ hadrons. For m_X as large as 48 and 50 GeV Bhabha scattering still shows a 7% and a 4% effect, respectively. The effect of a change in the parameters Γ_X and α_h, for a given value of m_X, is very simply inferred from the *off-resonance* behaviours [see eqs. (26), (31) and (32) for $|\sqrt{s} - m_X| \gtrsim 2\Gamma_X$]:

$$\Delta R_{e^+e^-\to e^+e^-} \propto \alpha_h, \quad \text{independent of } \Gamma_X,$$

$$\Delta R_{e^+e^-\to\gamma\gamma} \propto \Gamma_X, \quad \text{independent of } \alpha_h,$$

$$\Delta R_{e^+e^-\to \text{had.}}\, n_q \Gamma(X\to e^+e^-)/\Gamma(X\to \text{had.}) \propto \alpha_h^2, \quad \text{independent of } \Gamma_X. \quad (34)$$

In all three cases it amounts to a simple rescaling of the various curves in fig. 2.

The characteristic and simple off-resonance dependences (34) on the parameters $\alpha_h = 2\Gamma(X\to e^+e^-)/m_X$, Γ_X and $\Gamma(X \to$ hadrons) imply a further important message. The PETRA data on $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ and $e^+e^- \to$ hadrons allow an *independent* determination of the resonance parameters $\Gamma(X\to e^+e^-)$, Γ_X and $\Gamma(X \to$ hadrons), respectively, each one as a function of m_X. If no resonance signal is found, independent *bounds* for the three parameters are obtained instead.

Finally, fig. 3 shows the angular dependence of the

X contribution to Bhabha scattering, normalized by the QED contribution, for $m_X = 46, 48$ and 50 GeV and $\sqrt{s} = 40$ and 45 GeV. we chose $\alpha_h = 10^{-4}$, $\epsilon = 2$, as in fig. 2; the result is independent of Γ_X for $0 \leqslant \Gamma_X \lesssim 500$ MeV. The dashed curves represent the GSW contribution $\delta_{GSW} = (d\sigma/d\Omega)^{GSW}/(d\sigma/d\Omega)^{QED}$, the error bar indicating the small amount of energy variation from $\sqrt{s} = 40$ to 45 GeV. It is interesting to notice that the X contribution has the *opposite sign* of the GSW contribution. For $\alpha_h = 10^{-4}$, the two contributions roughly compensate each other as $\sqrt{s} = 40$ GeV; however, for $\sqrt{s} = 45$ GeV, the X contribution dominates by far. For $-1 \leqslant \cos \lesssim 0$ a 35% effect for $m_X = 46$ GeV, a 10% effect for $m_X = 48$ GeV and still a 6% effect for $m_X = 50$ GeV is predicted. Again the results for any other value of α_h are obtained by simple rescaling. We conclude from fig. 3 that the *large angle behaviour of Bhabha scattering is the most sensitive indicator* for a scalar/pseudoscalar particle with *mass* $m_X \gtrsim 48$ *GeV* in e^+e^- collisions.

Let us summarize. If one takes the measured $Z \to e^+e^-\gamma$ event rate at face value, then PETRA experiments are definitely sensitive to the hypothesis

$$Z \to X\gamma, \quad X \to e^+e^-$$

up to $m_X \sim 47$ GeV and marginally sensitive up to $m_X \sim 50$ GeV.

We wish to thank A. Boehm, W. De Boer, M. Chen and S. Yamada for informative discussions on the PETRA experiments and for useful suggestions. Part of this work was carried out when B.S. was a Heisenberg fellow.

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