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Anomalous di-photon production at LEP: possible consequences at FNAL hadron collider

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Abstract

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The hypothetic R-resonance production (anomalous "$l\bar{l}\gamma\gamma$" events at LEP) with 60 GeV mass at FNAL hadron collider has been considered. The cross-section of this R-resonance production with the consequent decay $R \to \gamma\gamma$ is obtained. Various distributions of leptons and photons in the process $p\bar{p} \to l\bar{l}R(\to \gamma\gamma)X$ are calculated.

Аннотация

Литвин В.А., Слабоспицкий С.Р., Швороб А.В. Аномальные двухфотонные события на LEP: возможные проявления на адронном коллайдере FNAL.: Препринт ИФВЭ 94-69. – Протвино, 1994. – 9 с., библиогр.: 13.

В работе рассмотрено образование гипотетического резонанса R (аномальные "$l\bar{l}\gamma\gamma$" события на LEP) с массой около 60 ГэВ на адронном коллайдере FNAL. Получено сечение образования этого резонанса с последующим распадом по каналу $R \to \gamma\gamma$. Вычислены различные распределения лептонов и фотонов в процессе $p\bar{p} \to l\bar{l}R(\to \gamma\gamma)X$

INTRODUCTION

Nine unusual events of the type $e^+e^- \to f\bar{f}\gamma\gamma$ with the invariant mass of the two photons near 60 GeV were found from the statistics collected by the four LEP experiments [1,2,3,4] (2 – in $e^+e^-\gamma\gamma$, 5 – in $\mu^+\mu^-\gamma\gamma$, 1 – in $q\bar{q}\gamma\gamma$, 1 – in $\nu\bar{\nu}\gamma\gamma$ channels, respectively [11]).

Recent calculations [5,6,7,8] have shown that the Standard Model processes are unlikely to explain the observed accumulation of the events in a narrow $M_{\gamma\gamma}$ band near 60 GeV. Other feasible models (including some common extensions of the Standard Model) also experience considerable difficulties in giving a plausible interpretation of these events (see, for example, [9])

In [10,11] an attempt to account for these events was made by assuming the existence of a scalar (pseudoscalar) resonance R, coupling photons and Z^0-bosons only, with its mass close to 60 GeV. In these papers such a model was shown not to provide a neat explanation of the (possibly observed) phenomenon, its free parameters being effectively restricted by the requirement of the consistency of the model with other experimental data. Nevertheless, presently available low statistics doesn't let us dismiss it confidently and from the phenomenological point of view it appears interesting to find out if other experiments can add something to the limits obtained at LEP. Before the advent of new machines (LEP 200, LHC, NLC, etc.) the hadron collider at FNAL is the most suitable place for such investigations.

In this paper we analyse the implications of the existence of the hypothetical resonance for the physics accessible for center-of-mass energy and luminosity at the FNAL hadron collider. The present–day CDF and D0 detectors [13] allow one to collect some evidence for or against the existence of such resonance.

The paper is organized as follows. Section 1 describes the phenomenological model of resonance interactions with photons and Z–bosons. In Section 2 we discuss possible manifestations of the resonance in $p\bar{p}$ collisions and present calculations results. The results obtained are summarised in Conclusion.

1. THE PHENOMENOLOGICAL MODEL

As has been already mentioned in Introduction we assume the existence of a narrow scalar (pseudoscalar) resonance R with mass of about 60 GeV, coupling photons and Z^0-bosons only.

Proceeding from the requirement of the Lorentz and gauge invariance, the most general form of the $R\gamma\gamma$, $R\gamma Z$ and RZZ vertices will read as follows:

$$\begin{aligned}
R^+\gamma\gamma &: \frac{g_{\gamma\gamma}}{M_R}(g^{\mu\nu}(k_1k_2) - k_1^\nu k_2^\mu)e_1^\mu e_2^\nu, \\
R^-\gamma\gamma &: \frac{g_{\gamma\gamma}}{M_R}\varepsilon^{\mu\nu\alpha\beta}k_1^\mu k_2^\nu e_1^\alpha e_2^\beta, \\
R^\pm\gamma Z &: \frac{g_{\gamma z1}}{M_R}(g^{\mu\nu}(k_1k_2) - k_1^\nu k_2^\mu)e^\mu V^\nu + \frac{g_{\gamma z2}}{M_R}\varepsilon^{\mu\nu\alpha\beta}k_1^\mu k_2^\nu e^\alpha V^\beta, \\
R^\pm ZZ &: g_{zz1}M_{Z^0}g^{\mu\nu}V_1^\mu V_2^\nu + \frac{g_{zz2}}{M_R}k_1^\nu k_2^\mu V_1^\mu V_2^\nu + \frac{g_{zz3}}{M_R}\varepsilon^{\mu\nu\alpha\beta}k_1^\mu k_2^\nu V_1^\alpha V_2^\beta,
\end{aligned}$$

where $R^+(R^-)$ denotes scalar (pseudoscalar) resonance; k_1 and k_2 are momenta of two photons (photon and Z-boson); e^ν (V^ν) is photon (Z^0-boson) polarization vector. The factor $1/M_R$ is introduced to render the coupling constants dimensionless.

In [10,11] a number of experiments has been analysed, in which hypothetic resonance R can decay into $\gamma\gamma$. As a consequence the following bounds on the couplings (in fact, on the values $g \cdot \sqrt{Br(R \to \gamma\gamma)}$, see [10,11]) are obtained:

$$\begin{aligned}
&g_{\gamma\gamma} \leq (2.92 \pm 2.1)\cdot 10^{-3}, g_{\gamma z1} \leq (3.0 \pm 6.8)\cdot 10^{-3}, g_{\gamma z2} \simeq 0. \pm 0.02, \\
&g_{zz1} \leq 0.220 \pm 0.1, \qquad |g_{zz2}| \leq 0.571 \pm 1.1, \qquad g_{zz3} \simeq 0 \pm 1.6. \qquad (1)
\end{aligned}$$

The processes of R production followed by the photon pair decay are considered. Thus all cross-sections will also depend on the couplings, multiplied by $\sqrt{Br(R \to \gamma\gamma)}$.

2. CROSS-SECTION OF THE R–RESONANCE PRODUCTION

In this Section we consider the R–resonance production in the $p\bar{p}$-collisions at the FNAL hadron collider ($\sqrt{s}$ = 1.8 TeV). In the frames of the considered model (see Section 2), the R–resonance production takes place due to $q\bar{q}$ annihilation to the virtual γ^* or Z^* (see Fig.1):

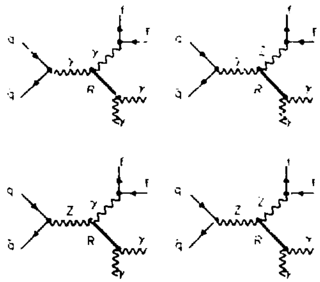

Fig.1. The Feynman diagrams for the process $q\bar{q} \to l\bar{l}\, R$ $(\to \gamma\gamma)$ are presented.

$$q\bar{q} \to \gamma^*(Z^*) \to l\bar{l}\, R(\to \gamma\gamma). \tag{2}$$

We concentrate our attention on the decays Z^* (or γ^*) to the lepton pair ($l\bar{l}$ = e^+e^-, $\mu^+\mu^-$, $\nu\bar{\nu}$) in the final state. It is obvious, that Z^* (or γ^*) decay to the $q\bar{q}$-pair (i.e. process $q\bar{q} \to \gamma^*(Z^*) \to q\bar{q}\, R(\to \gamma\gamma)$) will be dominant. However, the existing QCD background in this channel essentially exceeds the signal. Thus we limit ourselves to considering that kind of processes:

$$p\bar{p} \to l^+l^-\, R\, X \to l^+l^-\gamma\gamma\, X, \tag{3}$$

$$p\bar{p} \to \nu\bar{\nu}\, R\, X \to \nu\bar{\nu}\gamma\gamma\, X. \tag{4}$$

In the framework of the parton model the cross-section of processes (2) and (3) has the following form:

$$\sigma(p\bar{p} \to l^+l^-(\nu\bar{\nu})\gamma\gamma X) =$$
$$\sum_{q=u,d,s,c} \int dx_1 dx_2 \left[f_q(x_1,Q^2) f_q(x_2,Q^2) + f_{\bar{q}}(x_1,Q^2) f_{\bar{q}}(x_2,Q^2)\right] \times$$
$$\hat{\sigma}(q\bar{q} \to l^+l^-(\nu\bar{\nu})R) Br(R \to \gamma\gamma) \cdot N_l, \tag{5}$$

where $f(x,Q^2)$ are quark structure functions from [12], the evolution parameter Q^2 is chosen to be equal to the parton center-of-mass energy squared $\hat{s} \equiv x_1 x_2 s$, and $N_l = 1(3)$ for l^+l^- ($\nu\bar{\nu}$).

Here we must note that the phenomenological model introduced in the previous Section, being an effective one, eventually violates unitarity, but the smallness of the couplings (and, probably, the greatness of the scale of the new physics possibly involved) pushes up the unitary limit to energies as high as tens of TeV. Thus, the model is still working at the FNAL collider energies.

Table 1. The cuts used in the calculations.

Cut	1	2	3	4	5	6	7
$P_{t\ min}^{l^+(l^-)}$, GeV/c	—	5	10	15	5	10	15
$P_{t\ min}^{\gamma}$, GeV/c	—	10					
$\lvert\eta^\gamma\rvert_{max}$	—	3.0			1.5		

Furthermore, to ensure good experimental efficiency we require that the photons be detected in the central η interval and that they have sufficient P_t, which compensates for the lepton pair. The set of cuts on the phase space of final particles, that we applied integrating (4), is summarized in Table 1 (naturally, only the final photons cuts were used in the $\nu\bar{\nu}\gamma\gamma$ analysis).

The total cross-sections of processes (2) and (3) (kinematical cuts from Table 1 are taken into account) are presented in Table 2.

Table 2. The cross sections of process (2).

Cut	1	2	3	4	5	6	7
$\sigma(p\bar{p} \to l^+l^-\gamma\gamma\ X)$, pb	0.076	0.068	0.067	0.065	0.062	0.061	0.060
$\sigma(p\bar{p} \to \nu\bar{\nu}\gamma\gamma\ X)$, pb	0.42	0.39			0.35		

One can expect about 10 events in process (2) and about 40 events in process (3) for the total integrated luminosity $\int Cdt = 100$ pb^{-1}.

The distributions over the various variables for final leptons and photons from processes (2) and (3) are presented on Fig.2 and 3. As we can see from Fig.2(c) and 2(d) the final leptons and photons are produced with rather large transverse momenta ($< p_T^l > \simeq 50$ GeV and $< p_T^\gamma > \simeq 30$ GeV). It is necessary to note, that the final leptons and photons have a good separation from each other (see Fig.3(d)). Thus, all the events of that kind must contain photons with high transverse momenta p_T and $m_{\gamma\gamma} = 60$ GeV. This is the most characteristic feature of these events.

Hence, a pronounced topology of the investigated events will allow the background of these events to be strongly suppressed and make their investigation in the CDF and D0 detectors quite a real problem.

CONCLUSIONS

The limits that low energy e^+e^- experiments set on the couplings of the hypothetical (pseudo)scalar resonance R with photons and Z–bosons from the LEP low energy experiments data, still offer an opportunity to investigate these events at FNAL hadron collider energies. The processes of the R–resonance production in

$$p\bar{p} \rightarrow l^+l^- \; R \; X \rightarrow l^+l^-\gamma\gamma \; X \text{ and}$$
$$p\bar{p} \rightarrow \nu\bar{\nu} \; R \; X \rightarrow \not{E}_T\gamma\gamma \; X$$

modes have the cross-sections of 0.05 – 0.08 pb (depending on experimental cuts) and 0.3 - 0.5 pb, respectively. The high luminosity (10^2 pb^{-1}/year), supposed to be available at Fermilab in the nearest future, will allow one to obtain a noticeable number of events corresponding to these cross–sections. About 10 $l^+l^-\gamma\gamma$ and 40 $\nu\bar{\nu}\gamma\gamma$ events could be observed under these experimental conditions.

The processes under study possess pronounced features, which make observation of such events possible.

Thus, the FNAL hadron collider gives a good opportunity to check independently the model based on the LEP data. All data, which will be obtained from CDF and D0 detectors may increase the constraints, received from the LEP data, and allow one to draw a final conclusion about the existence of that kind of resonance.

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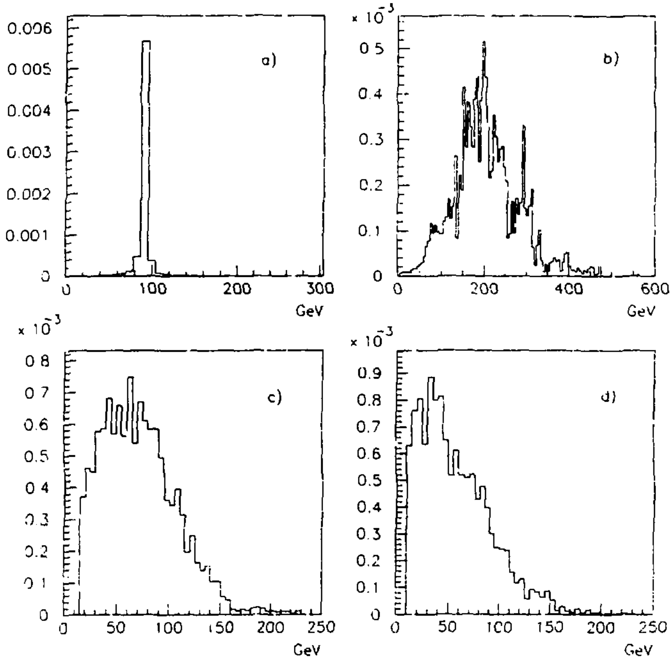

Fig.2. The differential cross-sections of processes (2) and (3): a) – the invariance mass dilepton distribution; b) – the transverse momentum distribution for resonance; c) – the transverse momentum distribution of final leptons; d) – the transverse momentum distribution of final photons.

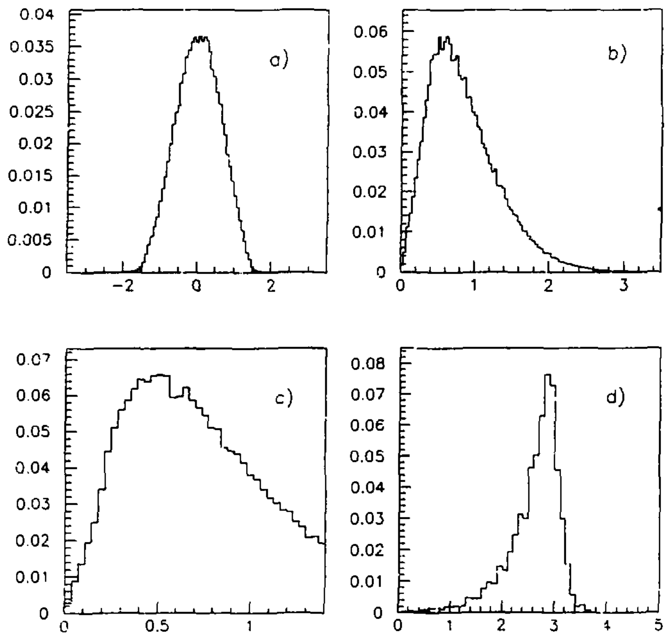

Fig.3. The differential cross-sections of processes (2) and (3): a) – the resonance rapidity distribution; b) – the maximum rapidity distribution from the ones both final leptons; c) – the maximum rapidity distribution from the ones both final photons; d) – the δR distribution between leptons and photons.

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