COMMENT ON SPINLESS-BOSON INTERPRETATIONS OF ANOMALOUS $\ell\bar{\ell}\gamma$ EVENTS

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Received 23 October 1984

Scenarios with a spinless boson decaying into $\ell\bar{\ell}\gamma$ have been proposed to explain the anomalous $\ell\bar{\ell}\gamma$ events at the CERN $p\bar{p}$ collider. A simple argument shows that the models fail to reproduce the concentration of the events at low $\ell-\gamma$ invariant masses. The same argument provides a strong constraint upon any other possible interpretation of the events.

The UA1 and UA2 collaborations at the CERN $p\bar{p}$ collider have found [1,2] three $\ell\bar{\ell}\gamma$ events with invariant mass close to the Z^0 mass within seventeen $Z \to \ell\bar{\ell}$ candidates. The rate was much larger than that expected from bremsstrahlung in the standard model. This led to a number of speculations concerning the origin of the events. The scenarios [‡1] with Z^0 as the parent of $\ell\bar{\ell}\gamma$, which was natural because of the proximity of the invariant masses, were shown to be very unlikely [3], for they could not explain the kinematic features of the data. All three events have the lower $\ell-\gamma$ invariant mass $m(\ell\gamma)_L$ below 10 GeV, while all models predict a mild $m(\ell\gamma)_L$ distribution with a peak at 40–50 GeV.

Later several authors proposed different scenarios [4–8]. They attribute the parent particle of $\ell\bar{\ell}\gamma$ to a new spinless boson, which is supposed to couple very weakly to $\ell\bar{\ell}$, and decay into $\ell\bar{\ell}\gamma$ via virtual Z [6,8] or by some higher-dimensional interactions [5] [‡2]. It has been emphasized that the kinematics is consistent with the data, since the models favor a smaller $m^2(\ell\gamma)_L$ The purpose of this note is to demonstrate that their claim cannot be taken at face value. A quantitative study shows the actual $m(\ell\gamma)_L$ distribution (not m^2!) has a broad maximum at the 25–35 GeV region and falls almost linearly to zero at smaller masses, which means the concentration of the data below $m(\ell\gamma)_L \sim$ 10 GeV is hard to understand.

In discussing the kinematics of a spinless boson S decaying into $\ell\bar{\ell}\gamma$, it is most transparent to take invariant kinematic variables:

$$x = m^2(\ell\bar{\ell})/M_S^2\,, \quad x_\ell = m^2(\ell\gamma)/M_S^2\,,$$
$$x_{\bar{\ell}} = m^2(\bar{\ell}\gamma)/M_S^2 = 1 - x - x_\ell\,, \tag{1}$$

with $x, x_\ell \geqslant 0, x + x_\ell \leqslant 1$. A convenient variable is the lower of x_ℓ and $x_{\bar{\ell}}$:

$$x_L = \min(x_\ell, x_{\bar{\ell}}) = m^2(\ell\gamma)_L/M_S^2\,, \tag{2}$$

with $0 \leqslant x_L \leqslant (1-x)/2$.

In the scenarios with the scalar boson S decaying via virtual Z^0, the $S-Z^0-\gamma$ vertex is derived from the effective interaction

$$\mathcal{L} = (f_S/\Lambda) S F_{\mu\nu} \partial^\mu Z^\nu\,, \tag{3}$$

where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, and f_S can in general be a dimensionless function of the virtuality of Z^0; $f_S = f_S(x)$. In the pseudoscalar case just change $F_{\mu\nu}$ into $\tilde{F}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}F^{\rho\sigma}$ in eq. (3). In both cases the differential decay distribution is readily calculated to lead to the same result:

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx\,dx_\ell} = \frac{9x(x_\ell^2 + x_{\bar{\ell}}^2)}{(1-x)^2} \quad \text{(virtual Z)}\,. \tag{4a}$$

Here we have assumed that $M_S = M_Z$ and that f_S is constant, and neglected the Z^0 width according to Marciano [8]. In the scenario of Matsuda and

‡1 See references cited in ref. [3].
‡2 Decay via virtual Z^0 is considered in ref. [7], but their decay distribution is that of higher-dimensional interactions (Z^0 propagator is lacking).

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Matsuoka [6], where $M_S \sim 90$ GeV, the distribution should be very similar.

In the higher-dimensional interaction scenario of Holdom [5], the decay distribution lacks the Z^0 propagator:

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx\,dx_{\ell}} = 30x(x_{\ell}^2 + x_{\bar{\ell}}^2) \quad \text{(higher-dimensional)}. \tag{4b}$$

This result agrees with that in ref. [5] [eq. (6)] after making appropriate substitutions.

The x distribution [or the photon energy distribution noting that $E_\gamma = (M_S/2)(1-x)$] in each case is given by

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx} = 6x(1-x) \quad \text{(virtual Z)}, \tag{5a}$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx} = 20x(1-x)^3 \quad \text{(higher-dimensional)}. \tag{5b}$$

Eq. (5a) reproduces eq. (4b) in ref. [8].

The x_L distribution is found to be

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_L} = 9[(1-2x_L)(1+4x_L) + 4x_L(1+x_L)\ln 2x_L] \quad \text{(virtual Z)}, \tag{6a}$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_L} = 5(1-2x_L)^2(1+8x_L^2) \quad \text{(higher-dimensional)}. \tag{6b}$$

Eq. (6a) also agrees with eq. (4c) in ref. [8].

The $m(\ell\gamma)_L$ distribution in this case is shown in fig. 1. We can see that both distributions peak at medium value and that the proportion below 10 GeV is quite small.

To make a quantitative assessment, we introduce the integrated x_L distribution

$$F(x_L) = \frac{1}{\Gamma}\int_0^{x_L} dx_L \frac{d\Gamma}{dx_L}. \tag{7}$$

This quantity shows the percentage of the events having x_L below the argument. ($F(\frac{1}{2}) = 1$.) We find

$$F(x_L) = x_L[9 - 28x_L^2 + 12x_L(3+2x_L)\ln 2x_L] \quad \text{(virtual Z)}, \tag{8a}$$

$$F(x_L) = x_L(5 - 10x_L + 20x_L^2 - 40x_L^3 + 32x_L^4) \quad \text{(higher-dimensional)}. \tag{8b}$$

For the region $m(\ell\gamma)_L < 10$ GeV, i.e. $x_L < 0.012$ (!),

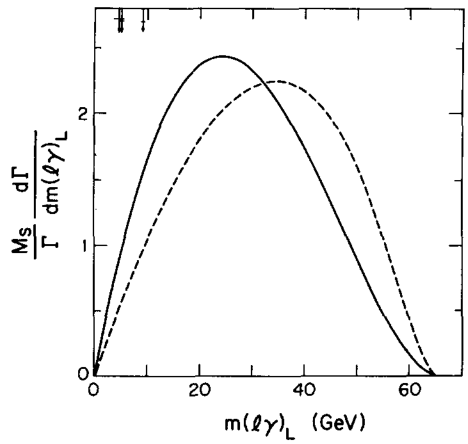

Fig. 1. $m(\ell\gamma)_L$ distribution in the scenario $S \to Z^*\gamma \to \ell\bar{\ell}\gamma$ (solid line), $S \to \ell\bar{\ell}\gamma$ via higher-dimensional interaction (dashed line). The three events are shown by arrows.

we have

$$F(x_L) = 0.095 \quad \text{(virtual } Z^0),$$
$$= 0.057 \quad \text{(higher-dimensional)}.$$

This result implies that the probability of having all three events [‡3] at $m(\ell\gamma)_L < 10$ GeV is less than 10^{-3} for the virtual Z^0 scenario and 2×10^{-4} for the higher-dimensional scenario, thus making these interpretations very unlikely [‡4,5].

Our discussion would not be altered much even if we allow the form factor f_S to vary, because it is a function of x and independent of x_L. In general, any model with regular behavior at $x_L \to 0$ can be excluded in the same manner. Evidently this is true also for other interpretations [3,10] of the events such as anomalous Z^0 decay. Thus a likely explanation of the

[‡3] The values of $m(\ell\gamma)_L$ are [1,2] 4.6 ± 1.0 (UA1, eeγ), 5.0 ± 0.4 (UA1, $\mu\mu\gamma$), and 9.1 ± 0.3 (UA2, eeγ) GeV.

[‡4] A discussion disfavoring the virtual Z^0 scenario is found in ref. [9]. However, the quantity "asymmetry" introduced in ref. [9] does not have clear physical meaning.

[‡5] If we take the $m^2(\ell\gamma)_L$ or x_L distribution instead of $m(\ell\gamma)_L$ as in fig. 1, the distribution peaks at $x_L = 0$, as the authors of refs. [6,5,8] have shown. However, the peaking is not sufficient to explain the observed concentration at the extremely low values of x_L, i.e. $x_L = 0.0024$, 0.0029, and 0.0096. (The allowed region is $0 < x_L < 0.5$.) In any case, a definite conclusion must await larger statistics

data requires some singular behavior at $x_L = 0$ (bremsstrahlung in the standard model) or at very small x_L (excited lepton ℓ^* with mass 5–10 GeV decaying into $\ell\gamma$). However, there is a problem with the latter possibility in that neither e^* nor μ^* has been observed in e^+e^- annihilation experiments [11] up to 45 GeV.

I am grateful to V. Barger and M. Olsson for reading the manuscript, and to K. Hagiwara for extensive discussions. This research was supported in part by the University of Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research Foundation, and in part by the Department of Energy under contract DE-AC02-76ER00881.

Note added. A detailed calculation including experimental cuts has been done by Baer, Hagiwara and Ohnemus [12]. I thank K. Hagiwara and J. Ohnemus for showing me their results prior to publication.

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