Resolved Photon Contributions to
Leptoquark Production in $e^+e^-$ and $e\gamma$ Collisions

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We calculate the resolved photon contribution to leptoquark production at $e\gamma$ colliders for the center of mass energies $\sqrt{s} = 500$ GeV and 1 TeV. We also calculate the resolved photon contribution to leptoquark production at $e^+e^-$ colliders for the center of mass energies $\sqrt{s} = 1$ and 2 TeV. In both cases we find that these contributions are considerably larger than the standard contributions considered in the literature.

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With the prospect of a high energy linear $e^+e^-$ collider [1], there has been much interest in searching for physics beyond the Standard Model [2]. Additionally, there is a growing interest in the physics that can be accomplished at high energy $e\gamma$ colliders. High energy, high luminosity photon beams can be achieved by backscattering a low energy laser against a high energy electron beam [3]. The luminosity is comparable to that of the original electron beam with only a small decrease in energy from the initial electron beam energy. Some of the physics that has been explored at $e\gamma$ collisions are measurement of the $WW\gamma$ coupling [4], Higgs production [5], supersymmetric particle production [6], $t$-quark production [7], and leptoquark production [8,9,10,11]. With this interest, there is the growing realization that contributions from the hadronic content of the photon are important and cannot be neglected [12,13].

Recently, leptoquark production at $e\gamma$ colliders [8] and at $e^+e^-$ colliders [9,10,11] has been studied. Leptoquarks appear in a large number of extensions of the standard model such as grand unified theories, technicolour, and composite models. In this brief report we examine the resolved photon contribution to leptoquark production in $e\gamma$ collisions and find that they are considerable, totally overwhelming the standard, direct, contributions.

The most general $SU(3) \times SU(2) \times U(1)$ invariant scalar leptoquarks satisfying baryon and lepton number conservation have been written down Buchmüller et al. [14]. However, only those leptoquarks which couple to electrons can be produced in $e\gamma$ collisions and for real leptoquark production the chirality of the coupling is irrelevant. For this case the number of leptoquarks reduces to four which can be distinguished by their electromagnetic charge; $Q_{em} = -1/3$, $-2/3$, $-4/3$, and $-5/3$. In our calculations we will follow the convention adopted in the literature [8] where the leptoquark couplings are replaced by a generic Yukawa coupling $g$ which is scaled to electromagnetic strength $g^2/4\pi = \kappa\alpha_{em}$ and allow $\kappa$ to vary.

The process we are considering is shown if Fig. 1. The parton level cross section is trivial, given by:

$$\sigma(\hat{s}) = \frac{\pi^2\kappa\alpha_em}{M_s}\delta(M_s - \sqrt{\hat{s}}).$$  (1)
Convoluting the parton level cross section with the quark distribution in the photon one obtains the expression

\[ \sigma(s) = \int f_{q/\gamma}(z, M_s^2) \hat{\sigma}(\hat{s}) dz = f_{q/\gamma}(M_s^2/s, M_s^2) \frac{2\pi^2 \kappa \alpha_{em}}{s}. \]  

(2)

We would like to point out here that the interaction Lagrangian used in Ref. [9] associates a factor \( 1/\sqrt{2} \) with the leptoquark-lepton-quark coupling. Thus, one should compare our results with \( \kappa \) to those in Ref. [9] with \( 2\kappa \).

In Fig. 2 the cross sections are shown for \( \sqrt{s} = 500 \) GeV and 1 TeV \( e\gamma \) colliders. The cross section for leptoquarks coupling to the \( u \) quark is larger than those coupling to the \( d \) quark. This is due to the larger \( u \) quark content of the photon compared to the \( d \) quark content which can be traced to the larger \( Q^2_q \) of the \( u \)-quark. For all four of the leptoquark types we show curves for three different distributions functions: Drees and Grassie (DG) [15], Glück, Reya and Vogt (GRV) [16], and Abramowicz, Charchula and Levy (LAC) set 1 [17]. Although the cross sections vary, they are qualitatively the same and agree in order of magnitude. Comparing the resolved photon contributions to the direct contributions we find that the former cross sections are roughly two orders of magnitude larger than the latter. Clearly they are important and cannot be ignored.

In Fig. 3 the cross sections are shown for \( \sqrt{s} = 1 \) TeV and 2 TeV \( e^+e^- \) colliders. This cross section is obtained by convoluting the expression for the resolved photon contribution to \( e\gamma \) production of leptoquarks, Eqn. (2), with the Weizsäcker-Williams effective photon distribution

\[ \sigma(e^+e^- \rightarrow XS) = \frac{2\pi^2 \alpha_{em} \kappa}{s} \int_{M_s^2/s}^{1} \frac{dx}{x} f_{\gamma/e}(x, \sqrt{s}/2)f_{q/\gamma}(M_s^2/(xs), M_s^2) \]  

(3)

with the Weizsäcker-Williams effective photon distribution given by

\[ f_{\gamma/e}(x, E) = \frac{\alpha_{em}}{2\pi} \left\{ \frac{[1 + (1 - x)^2]}{x} \ln \left[ \frac{E^2 (1 - 2x + x^2)}{m_e^2 (1 - x + x^2/4)} \right] + x \ln \left( \frac{(2 - x)}{x} \right) + \frac{2(x - 1)}{x} \right\}. \]  

(4)

As is the case for Fig. 2, the cross section for \( Q = -1/3 \) and \(-5/3 \) leptoquarks is larger due to the larger \( u \) quark distribution in the photon. We show curves for the four different
leptoquark charges, using the same three resolved photon distribution functions as in Fig. 2. Again, although the cross sections vary somewhat, they are qualitatively in good agreement. Our results are about an order of magnitude larger than those of Ref. [9]. Ref. [10] also present results for leptoquark production at $e^+e^-$ colliders. Those authors calculate the contribution from $\gamma + e \rightarrow q + S$, regulating the collinear divergence with the quark mass, which in some ways is similar to including the resolved photon contribution. However, this method introduces uncertainty into the problem (constituent or current quark mass?) and misses completely the vector meson dominance contribution to the resolved photon.

There are a number of issues we did not consider in this paper. Because we wanted to make a direct comparison with previous calculations of leptoquark production we assumed, as did the previous calculations, that the photon energy is equal to the beam energy and did not include the backscattered laser photon spectra. The main effect of including the photon spectrum would be to scale the photon spectrum by about a factor of 0.8. The second issue to consider is that if one is not careful there is a double counting in the resolved and direct contributions to the cross section. One has to be careful in matching the low $Q^2$ $p_T$ cut to the resolved photon contributions. Finally, we did not perform a sophisticated analysis of the signature, including leptoquark decays, detector acceptances, and backgrounds expected in a realistic situation. It is possible that once these effects are taken into account, the resolved contributions could be suppressed far more than the unresolved contributions. The answer to these questions awaits a more detailed analysis than is relevant to the main point of this paper.

In conclusion, we have calculated the resolved photon contribution to single leptoquark production in $e\gamma$ and $e^+e^-$ collisions. We find that these contributions are significantly larger than the direct contributions and should be included in any realistic study of leptoquark production in $e\gamma$ and $e^+e^-$ collisions.
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FIGURES

FIG. 1. The resolved photon contribution for leptoquark production in $e\gamma$ collisions.

FIG. 2. The cross sections for leptoquark production due to resolved photon contributions in $e\gamma$ collisions. (a) is for $\sqrt{s} = 500$ GeV and (b) for $\sqrt{s} = 1$ TeV. In both cases the solid, dashed, dotdashed line is for resolved photon distribution functions of Abramowicz, Charchula and Levy [17], Glück, Reya and Vogt [16], Drees and Grassie [15], respectively.

FIG. 3. The cross sections for leptoquark production due to resolved photon contributions in $e^+e^-$ collisions. (a) is for $\sqrt{s} = 1$ TeV and (b) for $\sqrt{s} = 2$ TeV. In both cases the solid, dashed, dotdashed line is for resolved photon distribution functions of Abramowicz, Charchula and Levy [17], Glück, Reya and Vogt [16], Drees and Grassie [15], respectively.
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