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QED AND QCD CORRECTIONS TO LEPTOQUARK PRODUCTION AT e^+e^- COLLIDERS*

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ABSTRACT

Relevant QED and QCD radiative corrections are calculated for the pair production cross section of leptoquarks in e^+e^- annihilation. The corrections for the production near threshold are found to be large. For $\beta = 0.1$ the QED corrections of -30 to -45% are obtained, while QCD corrections may reach $\mathcal{O}(+100\%)$.

1. Introduction

The expectations for leptoquark pair production in e^+e^- annihilation at $\sqrt{s} = M_Z$, in the energy range of LEP200, and at future linear colliders have been investigated in detail recently [1, 2] calculating the production cross sections at the Born level. For the class of leptoquarks which was considered rather general assumptions were made demanding that their couplings to fermions and gauge bosons are *i)* dimensionless, *ii)* baryon and lepton number conserving, *iii)* family diagonal, and *iv)* $SU(3)_c \times SU(2)_L \times U(1)_Y$ invariant. Because the cross sections both for scalar and vector leptoquark pair production contain s–channel contributions for which all couplings are known, only a minor uncertainty exists for the prediction of lower bounds due to the unknown leptoquark–fermion couplings. As shown in [2] for almost all leptoquarks classified above the expected production rates are sufficient to discover or definitely exclude these states in the energy range up to 1 TeV.

As known from other processes large QED and QCD radiative corrections may emerge in the case of pair production at thresholds, a typical situation met in the search for new particles. In this letter we will summarize the dominant corrections for leptoquark pair production extending the calculations done in [2]†.

The dominant contribution to the radiative corrections comes from initial state QED and beamstrahlung corrections (section 2), and final state QCD and QED corrections (section 3). For initial state radiation also the inclusion of $\mathcal{O}(\alpha^2)$ QED corrections turns out to be important. Finally, we investigated also the prospects of leptoquark pair production in $\gamma\gamma$–fusion (section 4) ‡. The results are summarized in section 5.

*Contribution to the Proceedings of the 2nd Workshop 'Physics and Experiments with Linear e^+e^- Colliders', Waikoloa, HI, April 26–30, 1993, eds. F.A. Harris, S. Olsen, S. Pakvasa, and X. Tata, (World Scientific, Singapore, 1993).

†An extended version of the present paper will be published elsewhere [3].

‡Studies on leptoquark production in $e\gamma$ [4] and e^-e^- [5] were also discussed during this workshop.

2. Initial State Corrections

2.1. QED Corrections

As shown also for other processes [6] the leading log approximation (LLA) yields accurate results for $L_m = \log(s/m_e^2) \ll 1$. The QED initial state corrections in LLA to 2nd order, including also all order soft exponentiation, is given by

$$\Delta\sigma_{tot}^{QED,is}(s) = \sigma_{tot}^{(1,\gamma)}(s) + \sigma_{tot}^{(2,2\gamma)}(s) + \sigma_{tot}^{(2,e\gamma e)}(s) + \sigma_{tot}^{(2,f\bar{f})} + \sigma_{tot}^{(>2,soft)} \qquad (1)$$

The different contributions refer to the 1st order correction (1γ), 2nd order bremsstrahlung (2γ), e^+e^- pair production ($e\gamma e$), fermion pair production ($f\bar{f}$), and soft exponentiation (3rd order terms and higher). The single terms may be represented by the convolutions

$$\sigma_{tot}^{(i,X)} = \left(\frac{\alpha}{\pi}L_m\right)^i \int_0^1 dz P_X(z) \left[\sigma_{tot}^{(0)}(zs)\theta\left(z - \frac{4M_\Phi^2}{s}\right) - C_X\sigma_{tot}^{(0)}(s)\right] \qquad (2)$$

The different splitting functions $P_X(z)$ are given in [3], $C_X = 0$ for $\sigma_{tot}^{(2,e\gamma e)}(s)$ and 1 otherwise, and $\sigma_{tot}^{(0)}$ denotes the Born cross section. The relative correction $\delta_{QED,\gamma}$ due to bremsstrahlung is shown in figure 1 both for scalar and vector leptoquarks§. Here, the 2nd order terms yield a positive contribution of about ~ 10 %. The corrections due to e^+e^- and $f\bar{f}$ production amount to only 2–4 % in the energy range between 200 GeV and 1 TeV (see [3]). In the threshold range $\beta \approx 0.1$ initial state QED corrections in the range of -30 to -45 % are obtained.

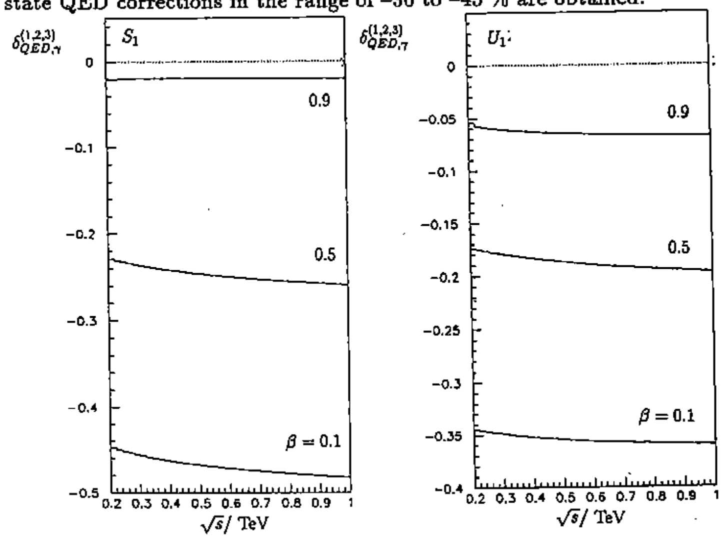

Figure 1: QED initial state corrections for the scalar and vector leptoquarks due to bremsstrahlung.

§For the classification of leptoquarks see [2].

2.2. Beamstrahlung

The beamstrahlung correction may be expressed by

$$\Delta\sigma_{BS}(s) = \int_0^1 dz \frac{1}{\mathcal{L}}\frac{d\mathcal{L}}{dz}(z)\sigma_{tot}^{(0)}(zs)\theta\left(1-\frac{4M_\Phi^2}{s}\right) - \sigma_{tot}^{(0)}(s) \quad (3)$$

The normalized luminosity spectrum $(1/\mathcal{L})d\mathcal{L}/dz$ may in general be determined by Monte Carlo simulations for the particular linear collider type. For narrow band colliders as TESLA or DESY–Darmstadt (NB) the corrections amount to –80 to –70 % for $\beta = 0.1$ and become smaller as β rises.

3. Final State Corrections

For the case that the fermion couplings of the leptoquarks are small, i.e. $\lambda << e$, the QCD and QED final state corrections may be expressed by a single form factor. Here we will restrict us to the case of scalar leptoquarks. The corrections are

$$\sigma_{scalar}^{(1,QCD)} = \sigma_{tot}^{(0)}(s)\left\{1+\frac{4\alpha_s}{3\pi}\mathcal{F}_s(\beta)\right\}, \qquad \sigma_{scalar}^{(1,QED,fs)} = \sigma_{tot}^{(0)}(s)\left\{1+\frac{\alpha}{\pi}\mathcal{F}_s(\beta)\right\} \quad (4)$$

The function $\mathcal{F}_s(\beta)$ (see [3]) was first derived in [7]. In figure 2a the β–dependence of the final state corrections is shown. The strong rise at small β is due to the Coulomb singularity. In this range, similarly to the case of quarkonia, one may expect the formation of exotic bound states – *leptoquarkonia*. However, both for scalar and vector leptoquarks for $\lambda \ll e$ the Born cross sections are proportional to β^3 for $\beta \to 0$ (see [2]). Therefore it will be very difficult to find these states if they exist. A better possibility to detect such bound states is provided by $\gamma\gamma$ fusion where the Born cross section behaves $\propto \beta$.

4. $\gamma\gamma$ Fusion

Leptoquarks can be pair produced in $\gamma\gamma$ fusion also. Photon beams may be derived from the electron beams via laser back–scattering [8]. The corresponding production cross section for scalar leptoquarks is shown in figure 2b for $\sqrt{s}$= 500 GeV. Because the production cross section is $\propto Q_\Phi^4$ leptoquarks with large charges ($R_2^{5/3}$) may be produced at high rates. The Compton spectrum $\Phi_\gamma(z)$ ranges practically only up to values of $z \sim 0.83$. This is the reason for the sharp fall-off of the cross sections at values of $\beta \sim 0.55$ to 0.6.

5. Summary

For the pair production of leptoquarks in the threshold range QED and QCD corrections yield large and partly compensating contributions to the total cross sections. In a search for these states the radiative corrections have to be taken into account. Leptoquarks may be pair produced also via photon–photon fusion. Because of the β–dependence of the Born cross section this reaction may allow to search also for possible bound states of leptoquarks.

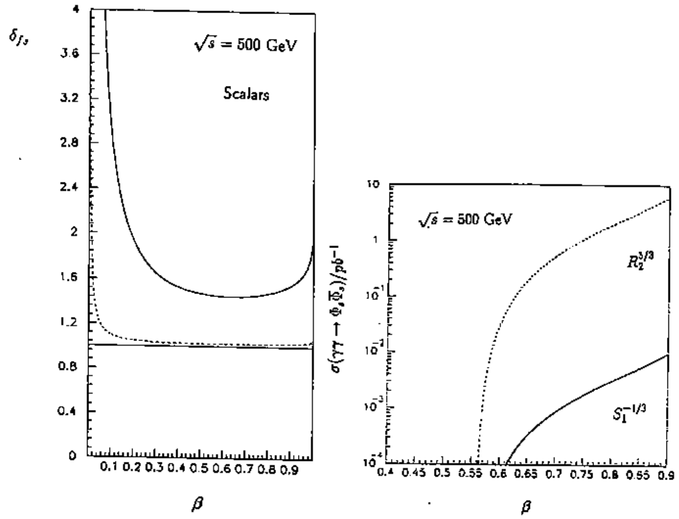

Figure 2: a) Final state corrections for scalar leptoquarks vs β. The full line denotes the QCD corrections in $\mathcal{O}(\alpha_s)$, and the dashed line the full $\mathcal{O}(\alpha)$ QED corrections. b) Pair production cross section of scalar leptoquarks for photon–photon fusion assuming the Compton photon spectrum [8].

6. References

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