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On the Leptoquark Interpretation of the High Q^2 Events at HERA

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Abstract. We investigate to which extent an interpretation of the recently observed excess of events in the high Q^2 range at HERA in terms of single leptoquark production is compatible with bounds from other experiments.

INTRODUCTION

Recently both the H1 [1] and ZEUS [2] experiments reported an excess of deep inelastic neutral current events in the range $Q^2 \gtrsim 15000\,\mathrm{GeV}^2$. There is also a slight indication of an excess for charged current scattering in the H1 data, cf. [1]. Various phenomenological and theoretical analyses [3–8] were performed shortly after this finding to seek an interpretation, though the experimental signals have first to stabilize adding in more data in the current runs. One possible interpretation for these events might be single leptoquark production in the e^+q or $e^+\overline{q}$ channels, respectively. In this note we summarize the status of the phenomenological studies which were performed during the last months. [1] Other interpretations, such as a signal for substructure [10], effects due to R–parity violating supersymmetry [11], and others [12], as well as implications for experiments at e^+e^- colliders [13], were also discussed.

$P\overline{P}$ SCATTERING

Leptoquarks may be searched for at hadron colliders both studying single and pair production processes. In the case of the single production processes [14] the reaction cross sections are $\propto \lambda^2$ and amount to $\sigma_{\rm sing} \sim 0.4\ fb ... 1.3\ fb$ at Tevatron energies for $(\lambda/e)\sqrt{Br} \approx 0.075$, eq. (9), only, [5], and are too small to be detected currently.

On the other hand, given the small fermionic couplings, the pair production processes [15–18] depend on the leptoquark–gluon couplings only. In the case of scalar leptoquarks the production cross section is completely predicted,

[1] For surveys on the earlier literature on leptoquarks see e.g. refs. [5,9].

whereas it depends on anomalous couplings, such as κ_G and λ_G, in the case of vector leptoquarks. As was shown in ref. [18], however, there exists a global minimum $\mathsf{min}_{\kappa_G,\lambda_G}\left[\sigma(\Phi_V\overline{\Phi}_V)\right] > 0$ allowing for a model-independent analysis.

The production cross sections for scalar leptoquarks in the partonic subsystem read [15,18]

$$\sigma^{q\overline{q}}_{\Phi_S\overline{\Phi}_S} = \frac{2\pi\alpha_s^2}{27\hat{s}}\beta^3 \tag{1}$$

$$\sigma^{gg}_{\Phi_S\overline{\Phi}_S} = \frac{\pi\alpha_s^2}{96\hat{s}}\left[\beta(41-31\beta^2)-(17-18\beta^2+\beta^4)\ln\left|\frac{1+\beta}{1-\beta}\right|\right], \tag{2}$$

with $\beta=\sqrt{1-4M_\Phi^2/\hat{s}}$. The $O(\alpha_s)$ correction to the production cross section was calculated in ref. [4] and amounts to a K-factor of 1.12 only for the choice $\mu = M_\Phi$ of the factorization scale. The cross sections in the case of vector leptoquark pair production are more complicated, cf. [18], due to the presence of the anomalous couplings κ_G and λ_G and have the general structure

$$\sigma^{q\overline{q}}_{\Phi_V\overline{\Phi}_V} = \frac{4\pi\alpha_s^2}{9M_V}\sum_{i=0}^{5}\chi_i^q(\kappa_G,\lambda_G)\widetilde{G}_i(\hat{s},\beta) \tag{3}$$

$$\sigma^{gg}_{\Phi_V\overline{\Phi}_V} = \frac{\pi\alpha_s^2}{96M_V}\sum_{i=0}^{14}\chi_i^g(\kappa_G,\lambda_G)\widetilde{F}_i(\hat{s},\beta)\ . \tag{4}$$

The functions $\chi^{q,g}, \widetilde{G}_i$ and $\widetilde{F}_i$ are given in ref. [18]. For $\kappa_G = \lambda_G = 0$ one obtains [16,18]

$$\sigma^{q\overline{q}}_{\Phi_V\overline{\Phi}_V} = \frac{\pi\alpha_s^2}{54M_V}\left[\frac{\hat{s}}{M_V^2}+23-3\beta^2\right], \sigma^{gg}_{\Phi_V\overline{\Phi}_V} = \frac{\pi\alpha_s^2}{96M_V}\left\{\beta A(\beta)-B(\beta)\ln\left|\frac{1+\beta}{1-\beta}\right|\right\},$$

$$A(\beta) = \frac{523}{4}-90\beta^2+\frac{93}{4}\beta^4, \qquad B(\beta)=\frac{3}{4}\left[65-83\beta^2+19\beta^4-\beta^6\right]\ . \tag{5}$$

Choosing the factorization and renormalization scales by $\mu = M_\Phi$ the pair production cross sections for scalar and vector leptoquarks (minimizing for κ_G and λ_G) at Born level and using the parametrization [19] for the parton densities are [5] :

$$\sigma_S(M_\Phi = 200\,\mathrm{GeV}) = 0.16\ pb \qquad \sigma_V(M_\Phi = 200\,\mathrm{GeV}) = 0.29\ pb. \tag{6}$$

EXCLUDED MASS RANGES

The most stringent limits on leptoquark masses, which are independent of the fermionic couplings, were derived by the Tevatron experiments, see [20], searching for leptoquark pair production [15–18,4]. The following mass ranges are excluded for scalar leptoquarks associated to the first fermion generation :

$$\begin{array}{llll} M < & 210 \ \mathrm{GeV} & \mathrm{CDF} & Br(eq) = 1 \\ M < & 176\ (225)\ \mathrm{GeV} & \mathrm{D0} & Br(eq) = 0.5\ (1) \end{array} \tag{7}$$

at 95% CL. The mass bounds for vector leptoquarks are correspondingly higher because of the larger production cross section, eq. (6), but have not yet been presented by the Tevatron experiments for the general case [18].

THE HERA EVENTS

If the observed high-Q^2 excess is interpreted in terms of single leptoquark production [21–23] constraints on the fermionic coupling λ of the leptoquarks Φ, which may be either scalars or vectors, may be derived. Due to the location of the excess found by H1 in the range $M = \sqrt{xS} \sim 200$ GeV we assume this scale in the estimates given below. In the narrow width approximation the production cross section reads

$$\sigma = \frac{\pi^2}{2}\alpha \left(\frac{\lambda}{e}\right)^2 q(x, \langle Q^2 \rangle) \left\{ \begin{array}{ccc} 2 & : & V \\ 1 & : & S \end{array} \right. \times Br(\Phi \to eq)\ . \tag{8}$$

For the observed excess in the $e^+ + jet$ channel at H1

$$\frac{\lambda_S}{e}\sqrt{Br} \sim 0.075 \quad (0.15) \qquad u \quad (d), \qquad \Phi = S \tag{9}$$

is derived [5] using the parametrization [19] of the quark densities, while $\lambda_V = \lambda_S/\sqrt{2}$ and $\lambda_{\mathrm{ZEUS}} = 0.55\lambda_{\mathrm{H1}}$. These couplings are well compatible with the limits derived from low energy data [24]. For the production cross section of scalar leptoquarks the QCD corrections were calculated in [7]. They amount to +23%. Both for the measurement of the total cross section and differential distributions, such as the mass distribution $M = \sqrt{xS}$ or the y distribution, a precise treatment of the QED radiative corrections is of imortance, because these corrections can be very large depending on the way in which the kinematic variables are measured, see ref. [25] for a general discussion. The universal QED corrections due to initial and final state radiation can be calculated in the leading log approximation, accounting also for higher orders using the code `HECTOR` [25]. A similar study was performed in [6].

An information on the spin of the produced state can be derived from the y distribution of the events. The statistics is yet to low to allow for such an analysis. The average value $\langle y \rangle_{\mathrm{H1}} = 0.59 \pm 0.02$ is still compatible with both the expectation for a scalar $\langle y \rangle_S = 0.65$ or a vector $\langle y \rangle_V = 0.55$, cf. [5]. One also may consider the scattering process $eq \to \Phi g$ both for scalar and vector leptoquarks Φ [21,8][2]. For this process the angular distributions are different in the case of scalars and vectors, cf. ref. [8] for details.

A severe constraint on the leptoquark states which may be produced in e^+q scattering is imposed by the $SU(2)_L \times U(1)_Y$ quantum numbers[3]. If besides the e^+q final states the indication of also νq final states becomes manifest, scalar leptoquarks are **not** allowed since low energy constraints demand either $\lambda_L \ll \lambda_R$ or $\lambda_R \ll \lambda_L$. For the vector states $U^0_{3\mu}$ or $U_{1\mu}$, which may be produced in the e^+d channel, on the other hand, the branching ratios are $Br(e^+d) = Br(\nu u) = 1/2$.

The bounds in eq. (7) exclude both a scalar and a vector leptoquark with a mass of $M \sim 200\,\mathrm{GeV}$ and $Br(eq) = 1$ at 95% CL. These bounds are widely model independent. If $Br(eq) = 0.5$, the limits derived at the Tevatron and the interpretation of the excess of events in the high Q^2 range at HERA in terms of single leptoquark production are still compatible. It will be interesting to see, whether also an excess of νjet final states is observed by the ZEUS experiment in the high Q^2 range. If the excess of events persists in the data taken throughout this year, a first determination of the $\nu jet/e^+jet$ ratio will be possible.

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[2] A few events with $e + 2jet$ final states have been already observed in the high Q^2 range at HERA [26].

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