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ABSTRACT

By definition, leptoquarks resonate in lepton-quark channels and hence ep collisions provide ideal reactions to search for these exotic particles. I describe some principal properties of leptoquark signals in collisions of an e beam of LEP with a p beam of the LHC. Estimates are given for the sensitivity of inclusive neutral current measurements to the coupling and mass of a particular scalar leptoquark.

1. INTRODUCTION

In the Standard Model leptons and quarks coexist as independent degrees of freedom. On the other hand, their electromagnetic charges are quantized in the same units, their weak SU(2) properties are basically identical, and also their family structure matches. These similarities strongly suggest that in a more fundamental theory leptons and quarks should be interrelated. Correspondingly, one expects new particles which mediate lepton-quark transitions. Such states are generically called leptoquarks and occur naturally in Superstring [1] and Grand-Unified Models [2] as well as in Technicolor Theories [3] and Composite Models [4,5].

Leptoquarks may exist with various spin and $SU(3)_c \times SU(2)_L \times U(1)_Y$ quantum numbers. A general classification [6] is given in Table 1. Furthermore, one can distinguish leptoquarks according to their couplings to fermion pairs. For example, in technicolor and composite scenarios global symmetry breaking gives rise to J=0 leptoquarks which are pseudo-Goldstone bosons and thus couple to fermion pairs proportionally to the fermion masses. Other models predict J=0 leptoquarks with non-derivative couplings. Interesting examples are the leptoquarks expected in the low-energy limit of the compactified heterotic $E_8 \times E_8'$ superstring. Finally, leptoquarks may be very massive or relatively light. Those which have baryon and lepton number violating couplings must be extremely heavy in order to avoid rapid proton decay or large neutrino masses. However, leptoquarks with B and L conserving couplings have to satisfy only much weaker bounds [7,8]. Particularly, leptoquarks which mediate flavor-diagonal transitions are permitted with couplings as large as electroweak gauge couplings and with masses of order 100 GeV [8].

TABLE 1

Quantum numbers of scalar and vector leptoquarks with $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariant couplings to quark-lepton pairs ($Q_{em} = T_3 + Y$)

	Spin	F=3B+L	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
S_1	0	2	3	1	-1/3
$\tilde{S}_1$	0	2	3	1	-4/3
$\vec{S}_3$	0	2	3	3	-1/3
V_2	1	2	3	2	-5/6
$\tilde{V}_2$	1	2	3	2	1/6
R_2	0	0	3*	2	-7/6
$\tilde{R}_2$	0	0	3*	2	-1/6
U_1	1	0	3*	1	-2/3
$\tilde{U}_1$	1	0	3*	1	-5/3
$\vec{U}_3$	1	0	3*	3	-2/3

Such low mass leptoquarks could be produced copiously at future particle accelerators. Especially ep collisions provide ideal reactions to search for leptoquarks because of the possible occurrence of resonances in direct eq channels. I have investigated principal properties of leptoquark production in collisions of an electron (or positron) beam of LEP with a proton beam of

LHC, the hadron collider in the LEP Tunnel. In the ep mode LEP and LHC would provide the following typical c.m. energies and luminosities [9]:

$$\text{(I)}\quad \sqrt{s} = 1.4\ \text{TeV and } L = 10^{32}\ \text{cm}^{-2}\text{s}^{-1},$$
$$\text{(II)}\quad \sqrt{s} = 1.8\ \text{TeV and } L = 10^{31}\ \text{cm}^{-2}\text{s}^{-1}. \qquad (1)$$

My main concern have been complete theoretical calculations for the signals of leptoquarks in inclusive neutral current (NC) distributions and asymmetries. From the results one can roughly infer the range of leptoquark couplings and masses which would be accessible in such inclusive searches. More elaborate estimates of detection limits taking into account experimental resolutions etc. are presented in ref. [10]. The conclusions are summarized in the report by J. Ellis and F. Pauss [11].

2. DEFINITION OF MODEL

A systematic study of all leptoquarks listed in Table 1 has been performed in ref. [6]. Here, I shall concentrate on the scalar leptoquark S_1 which will be called D_o further on in order to unify notation with other studies in these Proceedings [11]. The D_o couples to e^-u and $\nu_e d$ pairs as described by the effective, $SU(3)_c \times SU(2)_L \times U(1)_Y$ invariant lagrangian

$$\mathcal{L}_{eff} = \lambda_L(\overline{u}^c_L e_L - \overline{d}^c_L \nu_L)D^c_0 + \lambda_R \overline{u}^c_R e_R D^c_0 + c.c., \qquad (2)$$

where $f_{L,R} = 1/2(1 \mp \gamma_5)f$ are the left- and right-handed components of a fermion and $f^c = C\bar{f}^T$ is the charge conjugated fermion field. The coupling constants λ_L and λ_R in eq. (2) are constrained by low-energy experiments. The limit $B(\pi^+ \to e^+\nu_e) < 1.2 \times 10^{-4}$ implies [8]

$$\sqrt{\lambda_L \lambda_R} < m_{D_0}/10\ TeV, \qquad (3)$$

while quark-lepton universality or, more specifically, the identity of the Fermi constants in μ- and β-decays requires [8]

$$\lambda_L < m_{D_0}/1.7\,TeV. \tag{4}$$

For definiteness, I shall assume

$$\lambda_R = 0; \quad \lambda_L^2/4\pi = F\alpha, \quad F \leq 1, \tag{5}$$

where α is the electromagnetic finestructure constant. This choice is certainly compatible with the above constraints in the mass range of interest, i.e. for m_D = O(1 TeV). In the following, the model defined by eqs. (2) and (5) is used to illustrate possible searches for leptoquarks at LEP-LHC.

3. D_0 DECAY WIDTH AND PRODUCTION CROSS-SECTIONS

From eq. (2) one easily derives the total decay width Γ_{D_0} for $D_o \to e^- u$ and $D_o \to \nu_e d$ [6]:

$$\Gamma_{D_0} = (2\lambda_L^2 + \lambda_R^2) m_{D_0}/16\pi. \tag{6}$$

Using in addition assumption (5) one finds, numerically,

$$\Gamma_{D_0} = F\alpha m_{D_0}/2 \simeq 3.6\,GeV \left(\frac{F m_{D_0}}{1\,TeV}\right) \tag{7}$$

with the branching ratios $B(D_o \to e^- u) = B(D_o \to \nu_e d) = 50$ %. This shows that leptoquarks accessible in ep collisions at TeV energies will be very narrow!

The cross-sections for resonance production in $ep \to D_o X$ are also readily calculated from eq. (2). In the narrow width approximation one has [6]

$$\sigma(ep \to D_0 X) = \pi(\lambda_L^2 + \lambda_R^2)\, \overset{(-)}{u}\, (m_{D_0}^2/s, Q^2)/4s$$

$$= \frac{\pi^2 F\alpha}{m_{D_0}^2} \begin{cases} xu(x,Q^2), & e^- u \to D_0 \\ x\overline{u}(x,Q^2), & e^+ \overline{u} \to D_0, \end{cases} \tag{8}$$

where the second equation follows again from assumption (5).

Furthermore, $\overset{(-)}{u}(x,Q^2)$ describes the probability of finding an u-quark ($\bar{u}$-quark) with momentum fraction $x = m_{D_o}^2/s$ inside the proton. Using set I of ref. [12] for the quark distribution functions and taking $Q^2 = m_{D_o}^2$ for the evolution scale, one obtains the numerical cross-sections plotted in Fig. 1. As anticipated, the D_o leptoquark could be copiously produced in ep collisions at LEP-LHC. For instance, if the D_o exists with m_{D_o} = 1 TeV and F = 1, an e^-p run of roughly one year would yield

2000 D_o's at $\sqrt{s}$ = 1.4 TeV, $\int Ldt = 1\ fb^{-1}$, and

700 D_o's at $\sqrt{s}$ = 1.8 TeV, $\int Ldt = 100\ pb^{-1}$.

Conversely, for m_{D_o} = O(1 TeV) the D_o can still be discovered for couplings hundred times smaller than the e.m. coupling α, i.e. for $F = O(10^{-2})$. Similar results have been obtained in ref. [13].

A few comments on the last assertion may be desirable. Although the D_o decay modes $D_o \rightarrow e^- + \text{jet}$ and $D_o \rightarrow \nu_e + \text{jet}$ (and their charge conjugates) lead to events which at first sight look like conventional NC and CC events, the angular distributions of the D_o decay products are very different from the normal lepton and jet distributions [10,14]. Similarly, the inclusive distributions in $y = Q^2/xs$ ($Q^2 = -(p_e - p_l)^2$ denoting the squared momentum transfer in $ep \rightarrow lX$) are flat for leptoquark events, in contrast to the steeply falling distributions of the NC and CC background [10]. Therefore, it should be rather easy to separate signal from background. Moreover, leptoquarks such as the D_o may give rise to narrow peaks in the inclusive x-distributions centred at $x = m_{D_o}^2/s$. This signature distinguishes leptoquarks of the kind considered here from other possible new phenomena and can thus provide the clearest evidence.

4. D_o RESONANCE IN INCLUSIVE DISTRIBUTIONS

Whether or not the D_o leptoquark exists can be decided experimentally for a rather large range of masses $m_{D_o} < \sqrt{s}$ and couplings $F \leq 1$ by measuring the usual x-distributions in the process $ep \rightarrow eX$ and $ep \rightarrow \nu_e X$. In the following, I shall briefly describe the NC case. The diagrams contributing to $e^-p \rightarrow e^-X$ are shown in Fig. 2. One should note that in $e^-p(e^+p)$ collisions the

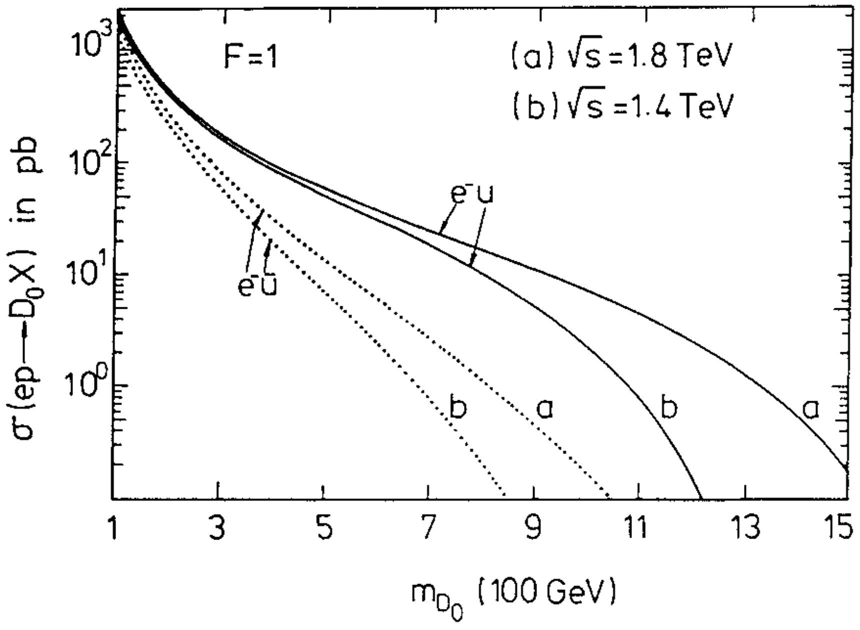

FIG. 1 Resonance production cross-sections in ep collisions for $e^-u \to D_o$ and $e^+\bar{u} \to D_o$, assuming F=1.

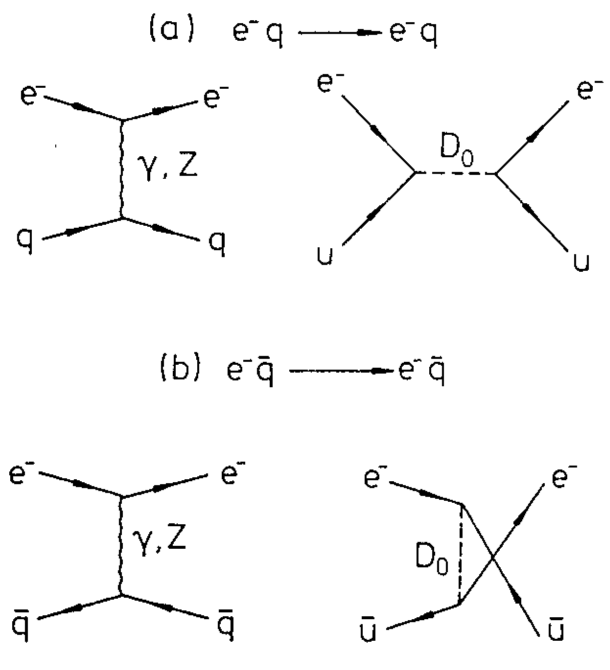

FIG. 2 Diagrams contributing to the inclusive neutral current process $e^-p \to e^-X$.

D_o not only resonates in the $e^-u(e^+\bar{u})$ channel, but also contributes in a crossed channel to $e^-\bar{u}(e^+u)$ scattering.

The differential cross-sections $d\sigma\,(e^{\mp}p \to e^{\mp}X)/dxdQ^2$ including D_o resonance and exchange, standard NC background and interferences have been calculated in ref. [6]. It is convenient to use the Mandelstam variables

$$\hat{s} = (p_e + p_q)^2 = xs, \quad t = (p_e - p_e')^2 = -Q^2, \quad u = (p_e - p_q')^2 = -\hat{s} + Q^2, \qquad (9)$$

where $p_e(p_e')$ and $p_q(p_q')$ are the initial (final) electron and quark momenta. The total squared amplitude for $e^-_{L,R}q \to e^-_{L,R}q$ (and $e^+_{R,L}\bar{q} \to e^+_{R,L}\bar{q}$), averaged over the quark spin, takes the form

$$|A|^2_{L,R} = |A_\gamma + A_Z|^2_{L,R} + 2Re[(A_\gamma + A_Z)A^*_{D_0}]_{L,R} + |A_{D_0}|^2_{L,R}, \qquad (10)$$

where A_γ, A_Z and A_{D_0} denote the photon, Z-boson and leptoquark amplitudes, respectively, depicted in Fig. 2a. The Standard Model contribution is given by [6]

$$|A_\gamma + A_Z|^2_{L,R} = \frac{2e^4Q_q^2}{t^2}(\hat{s}^2 + u^2) - \frac{4e^2g^2Q_q}{t(t-m_Z^2)}(v_e \pm a_e)[v_q(\hat{s}^2 + u^2) \pm a_q(\hat{s}^2 - u^2)]$$
$$+\frac{2g^4}{(t-m_Z^2)^2}(v_e \pm a_e)^2[(v_q^2 + a_q^2)(\hat{s}^2 + u^2) \pm 2v_qa_q(\hat{s}^2 - u^2)]\,. \qquad (11)$$

The notation is as follows: $g = e/\cos\theta_W \sin\theta_W$ is the gauge coupling of the Z-boson in terms of the e.m. coupling e and the Weinberg angle θ_W, Q_f are the electric fermion charges with the convention $Q_e = -1$, T_{3f} is the third component of the weak isospin with the convention $T_{3e} = -1/2$, and $v_f = T_{3f}/2 - Q_f\sin^2\theta_W$ and $a_f = T_{3f}/2$ denote the NC vector and axial vector couplings. Furthermore, the upper (lower) signs in eq. (11) and in the subsequent formula correspond to $e^-_Lq(e^-_Rq)$ and $e^+_R\bar{q}(e^+_L\bar{q})$ subprocesses. The interference and resonance terms of eq. (10) obtained with the effective lagrangian eq. (2) read [6]

$$2Re[(A_\gamma + A_Z)A^*_{D_0}]_{L,R} = 2[\frac{e^2Q_q}{t} - \frac{g^2(v_e \pm a_e)(v_q \pm a_q)}{t-m_Z^2}]a(D_0)_{L,R} \qquad (12)$$

with

$$a(D_0)_{L,R} = \frac{\lambda^2_{L,R}\hat{s}^2(\hat{s}-m^2_{D_0})}{(\hat{s}-m^2_{D_0})^2+m^2_{D_0}\Gamma^2_{D_0}}\ \delta_{qu}, \qquad (13)$$

and

$$|A_{D_0}|^2_{L,R} = \frac{1}{2}\ \frac{\lambda^2_{L,R}(\lambda^2_L+\lambda^2_R)\hat{s}^2}{(\hat{s}-m^2_{D_0})^2+m^2_{D_0}\Gamma^2_{D_0}}\ \delta_{qu}. \qquad (14)$$

Here, the Kronecker symbol δ_{qu} is introduced to project on the $\overset{(-)}{u}$-quark when summing later over the quark flavors present in the proton. The decay width Γ_{D_0} is given by eq. (6). The corresponding expressions for $e^-_{L,R}\bar{q} \rightarrow e^-_{L,R}\bar{q}$ (and $e^+_{R,L}q \rightarrow e^+_{R,L}q$) can directly be inferred [6] from the above results and the diagrams of Fig. 2b: $|A_\gamma + A_Z|^2_{L,R}$ follows from eq. (11) by simply changing the sign of a_q, $2Re[(A_\gamma + A_Z)A^*_{D_0}]_{L,R}$ reads as in eq. (12) with $a(D_0)_{L,R}$ replaced by

$$\bar{a}(D_0)_{L,R} = \frac{\lambda^2_{L,R}u^2}{u-m^2_{D_0}}\ \delta_{qu}\,, \qquad (15)$$

and

$$|A_{D_0}|^2_{L,R} = \frac{1}{2}\ \frac{\lambda^2_{L,R}(\lambda^2_L+\lambda^2_R)u^2}{(u-m^2_{D_0})^2}\ \delta_{qu} \qquad (16)$$

results from eq. (14) by interchanging $\hat{s}$ and u and dropping the irrelevant decay width Γ_{D_0}.

The inclusive differential cross-sections for polarized NC scattering can now be computed from the usual parton model expression

$$\frac{d\sigma(e^\mp_{L,R}p)}{dx dQ^2} = \frac{1}{16\pi x^2 s^2}\sum_q\{q(x,Q^2)|A(e^\mp_{L,R}q)|^2 + \bar{q}(x,Q^2)|A(e^\mp_{L,R}\bar{q})|^2\}, \qquad (17)$$

by substituting the squared amplitudes $|A_{L,R}|^2$ defined in eq. (10) and specified thereafter, for $|A(e^-_{L,R}q)|^2 = |A(e^+_{R,L}\bar{q})|^2$ and

$|A(e^-_{L,R}\bar{q})|^2 = |A(e^+_{R,L}q)|^2$, respectively. The cross-sections eq. (17) have been evaluated numerically, using the following input: eq. (5) with F=1 for the D_o couplings λ_L and λ_R, m_Z = 92 GeV for the Z-boson mass, $\sin^2\theta_W = (1-(1-4\mu^2/m_Z^2)^{1/2})/2$ with μ = 38.65 GeV for the Weinberg angle, and set I of ref. [12] for the quark and antiquark distribution functions, summing over u,d,s and c flavors.

The main points which can be learned from this study are illustrated in Fig. 3. This Figure shows x-distributions at large values of Q^2 for $e^-p \to e^-X$ in the presence of the D_o with m_{D_o} = 700 GeV (Figs. 3a and b) and m_{D_o}= 1.2 TeV (Fig. 3c). On top of the conventional NC background one can nicely see very narrow Breit-Wigner resonances which have the maximum at $x \simeq m^2_{D_o}/s$ and are distorted in the tails by inferences between the γ and Z exchange and the D_o contributions. Since the resonance cross-section eq. (14) is independent of Q^2, apart from small scaling violating effects in the quark structure functions, one can very efficiently suppress the background by applying appropriate cuts in Q^2 (or y [10]) without affecting the signal. This is indicated in Figs. 3a and b. Although in a real experiment the resonance peaks would be broadened by finite detector resolutions etc., one should be sensitive to D_o masses not much below the kinematic limit, at least for couplings F = O(1) [10]. In fact, the signal for m_{D_o} = 700 (1200) GeV illustrated in Fig. 3b(c) contains roughly 1200 (120) events per 100 pb^{-1} as can be estimated from the D_o cross-section at $\sqrt{s}$ = 1.8 TeV plotted in Fig. 1 including the branching fraction $B(D_o \to e^- + jet) = 0.5$. Finally the corresponding D_o resonances in $e^+p \to e^+X$ are considerably less pronounced due to the softness of the $\bar{u}$-density as compared to the u-density in the proton. However, for other species among the leptoquarks characterized in Table 1, the situation would be just reversed.

5. INDIRECT EFFECTS

In case the D_o is too heavy to be produced directly, i.e. if $m_{D_o} \gtrsim \sqrt{s}$, one would have to search for indirect effects of virtual D_o exchange on inclusive ep cross-sections and asymmetries

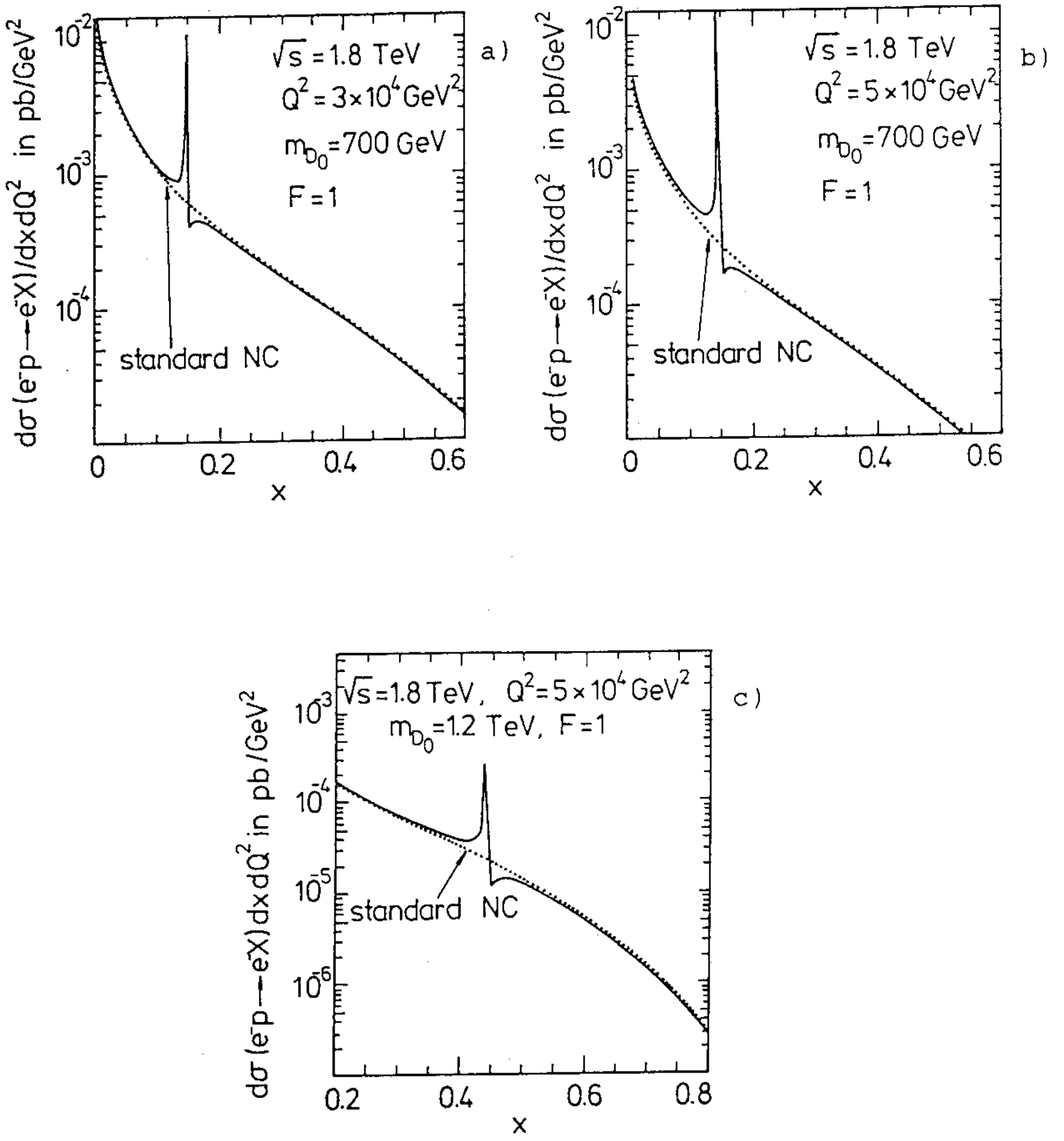

FIG. 3 Inclusive differential cross-sections for unpolarized e^-p scattering in the presence of the D_o leptoquark. The dotted curves represent the Standard Model predictions for $e^-p \to e^-X$.

[6,14]. For NC processes the weak interactions induced by such a heavy D_o are described by the effective lagrangian ($\lambda_R = 0$)

$$\mathcal{L}_{eff} = \frac{\lambda_L^2}{2m_{D_0}^2}(\bar{e}_L\gamma^\mu e_L)(\bar{u}_L\gamma_\mu u_L) \tag{18}$$

which follows from the original lagrangian eq. (2) after Fierz-transformation. Similar contact interactions are expected from lepton and quark substructure [15]. In the latter case, the effective four-fermion couplings are usually parameterized by g_{eff}^2/Λ_{eq}^2 where Λ_{eq} is supposed to be of the order of the binding scale and $g_{eff}^2/4\pi = 1$ by convention. The sensitivity of searches for eq contact interactions in ep collisions at LEP-LHC is discussed in some detail in ref. [16]. From the statistical errors of cross-section and asymmetry measurements one estimates that contact terms of the above type can be probed up to $\Lambda_{eq} \simeq (8\text{-}9)$TeV. Using eqs. (5) and (18) this result translates into the following sensitivity limit for virtual D_o effects:

$$m_{D_0} = \lambda_L \Lambda/\sqrt{8\pi} = \sqrt{F\alpha/2}\,\Lambda \leq 500\ GeV. \tag{19}$$

Although this estimate may not be totally reliable numerically, since the effective lagrangian eq. (18) is obviously not a very good approximation for such light masses, it certainly shows that one cannot probe the existence of the D_o in the mass range beyond the kinematical limit for real production, unless the coupling to the e^-u channel is considerably stronger than the electromagnetic coupling.

This claim is substantiated by direct calculation of the polarization asymmetry

$$A(e_L^- - e_R^-) = \frac{\tilde{\sigma}(e_L^-)-\tilde{\sigma}(e_R^-)}{\tilde{\sigma}(e_L^-)+\tilde{\sigma}(e_R^-)}\,, \tag{20}$$

where $\tilde{\sigma}(e_{L,R}^-) = d\sigma(e_{L,R}^- p)/dxdQ^2$ are the differential cross-sections obtained in eq. (17). This asymmetry turns out to be particularly sensitive to LL contact interactions [16] such as the one generated by a heavy D_o. Results are shown in Fig. 4 for

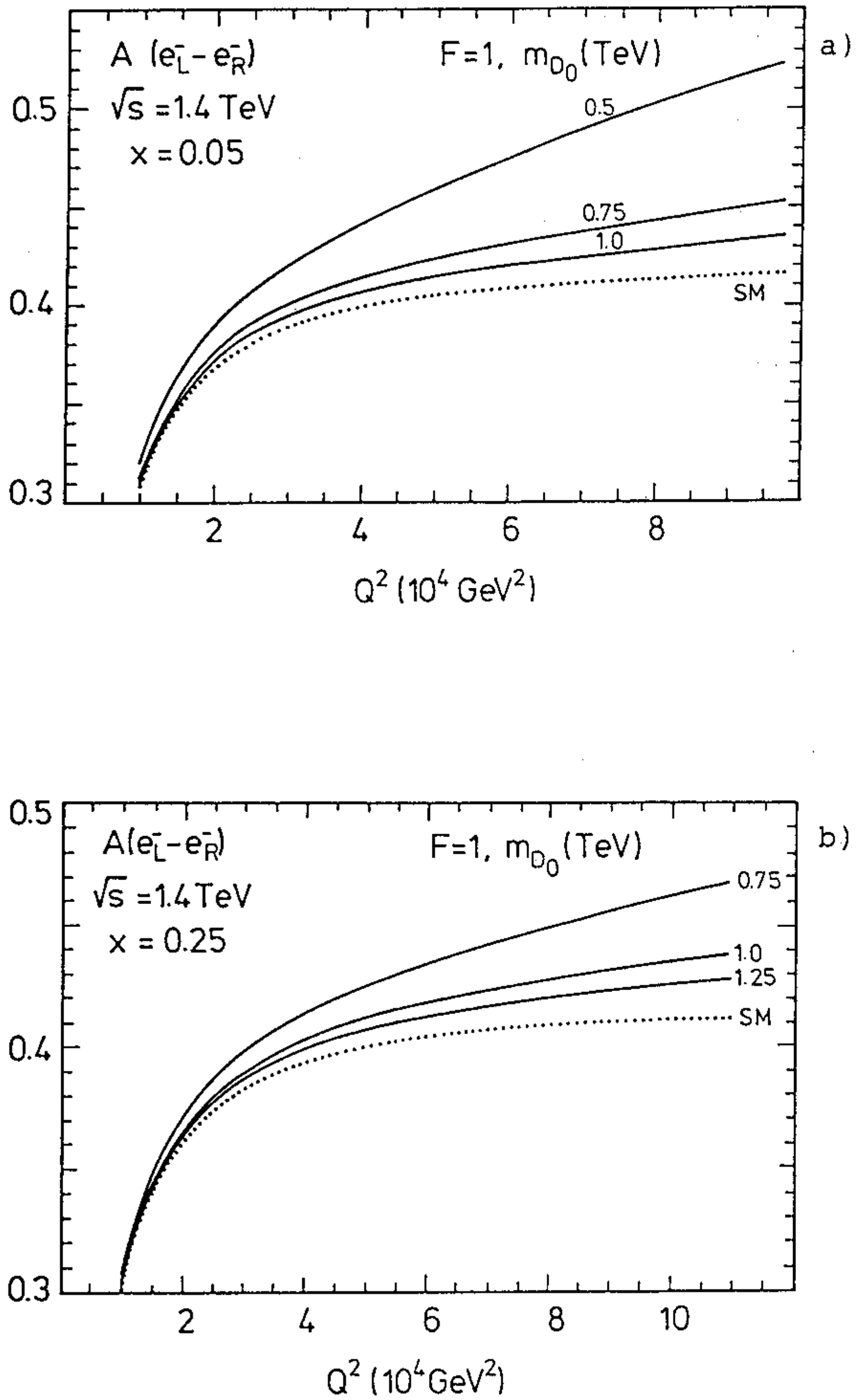

FIG. 4 Deviations of the polarization asymmetry in $e^-_{L,R}p$ NC scattering from the Standard Model predictions (SM) due to D_o exchange off resonance for various values of m_{D_o}.

two typical values of x and various D_o masses in comparison to the Standard Model prediction. One can safely conclude that deviations for $m_{D_o} \gtrsim \sqrt{s}$ are unobservable as already indicated by the limit (19). Moreover, even for $m_{D_o} < \sqrt{s}$, the effects are difficult to discover except at or near the value of x at which the resonance occurs. Examples displayed in Fig. 4 are the deviations for $m_{D_o} = 500$ GeV in which case the resonance occurs at $x \simeq 0.13$, i.e. just above the value of x chosen in Fig. 4a, and the effects for $m_{D_o} = 750$ GeV in which case the resonance is centred somewhat above the value x = 0.25 considered in Fig. 4b. Of course, for $m_{D_o} < \sqrt{s}$ one does not have to rely on searches for indirect effects but one may hope to observe a striking resonance in the x-distributions as illustrated in Fig. 3.

6. SUMMARY

I have studied the production of leptoquarks in ep collisions at LEP-LHC, and the observability of signals in inclusive NC cross-sections and asymmetries, using the scalar, weak isoscalar leptoquark D_o as an illustrative example. Three results are particularly noteworthy. Firstly, the production cross-sections are large. If the D_o couples to e^-u with the strength $(0.01-1)\alpha$, one can expect 10 D_o events for the following masses, c.m. energies and integrated luminosities:

$$m_{D_o} \simeq (1.1-1.2)\ \text{TeV}, \quad \sqrt{s} = 1.4\ \text{TeV}, \quad \int L dt = 1\ \text{fb}^{-1},$$
$$m_{D_o} \simeq (0.9-1.5)\ \text{TeV}, \quad \sqrt{s} = 1.8\ \text{TeV}, \quad \int L dt = 100\ \text{pb}^{-1}.$$

Secondly, clear evidence for leptoquarks would be narrow resonance lines in the x-distributions which should be relatively easy to observe after suppressing the conventional NC and CC background by cutting away events at $Q^2 \lesssim (10^4-10^5)$ GeV. Thirdly, indirect effects of virtual D_o exchange on cross-sections and asymmetries are difficult to detect except near the resonance at $x = m_{D_o}^2/s$. In particular, it does not seem to be possible to probe the existence of leptoquarks at masses $m_{D_o} > \sqrt{s}$, unless the coupling to e^-u is much stronger than the electromagnetic coupling.

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REFERENCES

[1] J. Ellis, CERN-TH. 4439/86 (1986);
V.D. Angelopoulos et al., CERN-TH. 4578/86, MAD/TH/86-26 (1986).

[2] P. Langacker, Phys. Rep. 72 (1981) 185.

[3] E. Farhi and L. Susskind, Phys. Rep. 74 (1981) 277;
R.J. Cashmore et al., Phys. Rep. 122 (1985) 275.

[4] W. Buchmüller, Acta Phys. Austriaca, Suppl. XXVII (1985) 517.

[5] L. Abbott and E. Farhi, Phys. Lett. 101B (1981) 69 and Nucl. Phys. B189 (1981) 547;
M. Claudson, E. Farhi and R.L. Jaffe, Phys. Rev. D34 (1986) 873;
B. Schrempp, Proc. of the 23rd Int. Conf. on High Energy Physics, Berkeley, 1986, ed. S.C. Loken (World Scientific Pub. Co., Singapore, 1987) p. 454

[6] W. Buchmüller, R. Rückl and D. Wyler, Phys. Lett. B191 (1987) 442.

[7] B.A. Campbell et al., CERN-TH. 4473/86, MAD/TH/86-15, LBL-22861, UCB-PTH-87/3 (1986).

[8] W. Buchmüller and D. Wyler, Phys. Lett. 177B (1986) 377.

[9] G. Brianti, Vol. I of these Proceedings, p. 6.

[10] N. Harnew, Vol. II of these Proceedings.

[11] J. Ellis and F. Pauss, Vol. I of these Proceedings, p. 80.

[12] D.W. Duke and J.F. Owens, Phys. Rev. D30 (1984) 49.

[13] V.D. Angelopoulos et al., ref. [1];
A. Dobado, M.J. Herrero and C. Munoz, FTUAM/87-4 (1987).

[14] J. Wudka, Phys. Lett. 167B (1986) 337.

[15] E.J. Eichten, K.D. Lane and M.E. Peskin, Phys. Rev. Lett. 50 (1983) 811;
R. Rückl, Phys. Lett. 129B (1983) 363 and Nucl. Phys. B234 (1984) 91.

[16] F. Cornet and R. Rückl, Vol. II. of these Proceedings.