Commun. Fac. Sci. Univ. Ank. Series A2-A3
V. 47. pp.7-19 (2003)

SEARCHING FOR COLOR OCTET LEPTONS IN LEPTON-HADRON COLLISIONS

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(Received Aug.15,2003; Revised Dec.26, 2003; Accepted Dec.30, 2003)

ABSTRACT

We study the resonance production of color octet leptons l_8 predicted by composite preon models of leptons and quarks at lepton-hadron colliders such as TESLA × HERA, μp and Linac-LHC with the energy of about 1-10 TeV. The numerical results for l_8 cross sections are obtained from s and t channel diagrams. We also give the discovery contour for l_8 production in the $k \times M_{l_8}$ plane at these machines.

1. INTRODUCTION

Recently, in theoretical and experimental particle physics, many works which explore the answer of a fundamental question: "What is the smallest constituent of matter?" have been made. The present appearance of these works is much more promising. Some experimental results which show the truth of many predictions in particle physics force the physicists rightfully to study in this direction. At present, the high energies and high luminosities to be reached at particle accelerators enable us to some possibilities to research new physics beyond the standard model.

As the fundamental problems of Standard Model such as lepton-quark symmetry, family replication, mass hierarchy problem, charge quantization, etc., it seems to be more natural to go beyond it. Today, SUSY [1,2,3] and compositness [4,5,6] remain alone as the most promising candidates for underlying physics.

Because of too many arbitrary parameters (more than two hundreds in the case of three SM families [7,8,9]), MSSM does not look like a realistic theory. Nowadays, SUGRA could not achieve to give natural description for mass spectrum and mixings of SM fermions and their SUSY partners either. Consequently, the compositness stays alone as a radical candidate for the next scale physics. It is also natural to expect SUSY to be realized at most fundamental, very likely pre-preonic level [10].

Many attempts [4,5,6] and references therein) have been made to search the fundamental building blocks of quarks and leptons. None of the composite models has taken an experimental support yet, although family replication and CKM mixings can be considered as an indirect manifestation of SM fermion's substructure. However, the new experiments with higher energies will provide direct access to shorter distances and composite structures will hopefully be revealed.

At this point, it will be helpful to compare between future collider energy and compositeness scale Λ. There are three options: $i) \sqrt{\hat{s}} << \Lambda$, $ii) \sqrt{\hat{s}} \sim \Lambda$, $iii) \sqrt{\hat{s}} >> \Lambda$. In the first case, compositeness induced contact four fermion interactions of SM particles have usually been considered, since one expects that the masses of new particles lay in the order of Λ. However, as in the flavour democracy approach [11,12,13,14] of SM, the masses of some new particles might be far smaller than Λ. A zoo of the new particles and interactions will appear when $\sqrt{\hat{s}} >> \Lambda$. In the third case, predictions become strongly model dependent. According to recent data taken from CDF and D0 experiments at Tevatron, the lower mass limits for leptogluons is about 86 GeV [15] and for leptogluon neutrinos 110 GeV [16]. These mean that there is no experimental support for lepton compositeness.

2. LEPTON-HADRON COLLIDERS

Nowadays there are many studies on Lepton (Photon)-Hadron Colliders [17,18,19]. The parameters of center of mass energy and luminosities for lepton-hadron colliders which have been planned to design at several countries are given in Table 1.

Table 1. Energy and luminosity parameters of some lepton-hadron colliders [19].

	E_e(TeV	E_p(TeV	$\sqrt{s}$ (TeV)	L(10^{30}cm^{-2}s^{-1})
TESLA × HERA	0.25 0.5 0.8	1.0 0.5 0.8	1.0 1.0 1.6	10 50 25
μp	1.5	1.5	3.0	100
Linac-LHC	1.0	7.0	5.3	500

The investigation of physics phenomena at extremely small x but high Q^2 (>10 GeV^2) is very important for understanding the nature of the fundamental interactions at all levels from atoms to quarks, or more constituent levels like preonic level. At the same time, the results from lepton-hadron colliders are necessary for adequate interpretation physics at future colliders.

Construction of future lepton linacs tangentially to hadron rings (HERA, Tevatron and LHC) will provide a number of additional opportunities to investigate lepton-hadron interactions at TeV scale. As seen in Table 1, Linac-LHC is lepton-hadron collider which has the largest energy and luminosity when compared to the others. It is widely possible to search for new particles predicted by some composite models [20,21,22] at these machines.

3. RESONANCE PRODUCTION OF LEPTOGLUONS

3.1. Leptogluons

Leptogluons are colour-octet states carrying lepton number which can have dimensionless renormalizable couplings only to gluons. In some works [23,24,25,26,27,28,29], we have seen that leptogluons can be constructed by a global *SU(N)* × *SU(M)* hyperflavour symmetry belonging a preon lagrangian, where *N* is the number of fermionic preons α and *M* is the one of bosonic preons (x, y).

In this section, we want to give their production mechanism and some decay modes. According to our model [30] predicted for lepton and quark compositeness, leptogluons can naturally arise from a bound state of a colour triplet fermionic preon and a colour anti-triplet scalar preon in the fermion-scalar model of leptons and quarks. Therefore, these particles can decay into a lepton and a gluon as

$$\nu_8 \to \nu g \quad e_8 \to eg$$

or a lepton and two quarks as

$$\nu_8 \to \nu d\bar{d},\ u\bar{d}e;\quad e_8 \to \nu\bar{u}d,\ u\bar{u}e$$

In our calculations, we restrict ourselves to two particle decays of leptogluons. Transitions between the colour octet leptons (l_8) and the ordinary lepton (l) may take place via the dimension-5 interactions [31,32,33]

$$L = \frac{1}{2\Lambda}\sum_{l}\left\{\bar{l}_8^{\alpha} g_s G^{\alpha}{}_{\mu\nu}\sigma^{\mu\nu}(\eta_L l_L + \eta_R l_R) + h.c.\right\} \tag{1}$$

where l denotes charged leptons and neutrinos, α runs from 1 to 8. g_s stands for QCD coupling constant and Λ is the compositeness scale. $G^{\alpha}{}_{\mu\nu}$ is the gluon field strenght tensor. η_L and η_R are the chirality factors for left- and right-handed leptons. The leptonic chiral invariance implies that $\eta_L\eta_R = 0$. We choose $\eta_L = 1$ and $\eta_R = 0$ in our calculations. According to this lagrangian the decay width of leptogluons can be easily obtained as

$$\Gamma(l_8 \to \mathrm{lg}) = \frac{\alpha_s M_{l_8}{}^3}{4\Lambda^2}. \tag{2}$$

3.2. Production Cross Section

At TESLA × HERA, e-type leptogluons e_8 will be produced in resonance mode via lepton-gluon fusion in the s-channel as

$$\sigma(ep \to e_8 X) = \int_{x_{\min}}^{x_{\max}} dx \hat{\sigma}(xs) f_g(x) \tag{3}$$

where $f_g(x)$ gluon distribution function in the proton. $x_{\min} = M^2{}_{e_8}/s$ and $x_{\max} = 1$. In the narrow width approximation the cross section of the s-channel leptogluon resonance production can be obtained as

$$\sigma(ep \to e_8 X) \approx \int_{x_{\min}}^{x_{\max}} dx f_g(x) \frac{2\pi^2}{s} \delta(x - \frac{M_{e_8}{}^2}{s}) \tag{4}$$

The total cross section for resonant e-type leptogluon l_8 production at TESLA × HERA is plotted versus the mass of color octet electron in Fig. 1.

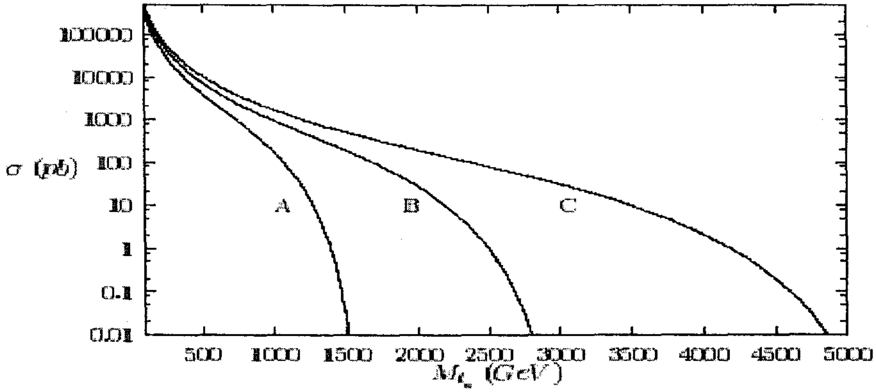

Figure 1. Total cross section for resonance l_8 production at Lepton-Hadron colliders. Curves A, B and C correspond to machines *TESLA × HERA*, *μp* and Linac-LHC, respectively.

We have also plotted μ_8 cross section versus its mass at μp collider represented curve B and e_8 cross section versus its mass at Linac-LHC collider represented curve C. Hereafter, we use parton distributions from the ref. [34].

C. Signal and Background

The differential cross section of leptogluons can be easily obtained as

$$\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{\mathrm{lg}\to\mathrm{lg}}^{Signal}=\frac{1}{16\pi\hat{s}^{2}}\left\{-\frac{k^{2}g_{s}^{4}}{4\Lambda^{4}}\left(\frac{\hat{s}^{3}\hat{t}}{\left[(\hat{s}-M_{l_8}{}^{2})^{2}+M_{l_8}{}^{2}\Gamma^{2}\right]}+\frac{\hat{s}\hat{t}^{3}}{(\hat{t}-M_{l_8}{}^{2})^{2}}\right)\right\} \quad (5)$$

where $\hat{s}, \hat{t}$ and $\hat{u}$ (seen in Eq.(7)) are Mandelstam variables for the subprocess. By choosing $k=1$, we set the value of $\Lambda = M_{l_8}$ in some of our calculations, which means that we concenrate ourselves in the region of compositeness scale Λ. We also calculate the discovery contour of leptogluons as k running from 0.0001 to 1.

There won't be any interference terms to lepton-gluon interaction from SM background processes. On the other hand, there are main contributions from the standard model background processes in lepton-jet channel such as $l+q\to l+q, l+q\to \nu+q'$. The differential cross section of SM background processes in the lepton-jet channel is given by

$$\begin{aligned}\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{lj\to lj}^{SM}=\frac{1}{16\pi\hat{s}^{2}}\Bigg\{&\frac{2g_{e}{}^{4}Q_{u}Q_{l}}{\hat{t}^{2}}\left(2\hat{s}^{2}+2\hat{s}\hat{t}+\hat{t}^{2}\right)+\frac{g_{Z}{}^{4}}{8(\hat{t}-M_{Z}{}^{2})^{2}}\Bigg[\left(\left|C_{V}{}^{e}\right|^{2}+\left|C_{A}{}^{e}\right|^{2}\right)\\ &\times\left(\left|C_{V}{}^{u}\right|^{2}+\left|C_{A}{}^{u}\right|^{2}\right)\left(2\hat{s}^{2}+2\hat{s}\hat{t}+\hat{t}^{2}\right)-4C_{V}{}^{e}C_{A}{}^{e}C_{V}{}^{u}C_{A}{}^{u}\left(2\hat{s}\hat{t}+\hat{t}^{2}\right)\Bigg]+\frac{g_{W}{}^{2}\left|Q_{ij}\right|^{2}}{4(\hat{t}-M_{W}{}^{2})^{2}}\hat{s}^{2}\\ &+\frac{g_{e}{}^{2}g_{Z}{}^{2}Q_{u}Q_{l}}{\hat{t}(\hat{t}-M_{Z}{}^{2})}\left[C_{V}{}^{e*}C_{V}{}^{u*}\left(2\hat{s}^{2}+2\hat{s}\hat{t}+\hat{t}^{2}\right)-2C_{A}{}^{e*}C_{A}{}^{u*}\left(2\hat{s}\hat{t}+\hat{t}^{2}\right)\right]\\ &+\frac{g_{e}{}^{2}g_{W}{}^{2}Q_{u}Q_{l}Q_{ij}{}^{*}}{\hat{t}(\hat{t}-M_{W}{}^{2})}\hat{s}^{2}+\frac{g_{Z}{}^{2}g_{W}{}^{2}Q_{ij}{}^{*}}{4(\hat{t}-M_{Z}{}^{2})(\hat{t}-M_{W}{}^{2})}\left[\left(C_{V}{}^{e}+C_{A}{}^{e}\right)\left(C_{V}{}^{u}+C_{A}{}^{u}\right)\hat{s}^{2}\right]\Bigg\} \quad (6)\end{aligned}$$

where Q_q, Q_l are the charges of u and d quarks and leptons, respectively. ${C_{V,A}}^l$ and ${C_{V,A}}^q$ are the vector and axial vector couplings in the GWS Model. g_e is the coupling constant of electromagnetic interactions, g_Z and g_W are the coupling constants of the weak interactions. M_Z and M_W become the masses of the Z and W bosons, respectively. Γ stands for the decay width of leptogluon, Q_{ij} is the element of CKM matrix for *i* and *j* quarks.

Another variable that is often used in studies of single jet production is the lepton-jet invariant mass *m*. In resonance case, this is easily shown to be given by

$$\left(\frac{d\sigma}{dm}\right)^{SM} = \frac{2m}{s}\hat{\sigma}(\hat{s})\left\{f_u(\frac{m^2}{s}) + f_d(\frac{m^2}{s})\right\} \tag{7}$$

for the SM background processes and

$$\left(\frac{d\sigma}{dm}\right)^{Signal} = \frac{2m}{s}\hat{\sigma}(\hat{s})f_u(\frac{m^2}{s}) \tag{8}$$

for the signal processes.

The subprocess cross section $\hat{\sigma}(\hat{s})$ for the SM and signal processes can be easily obtained from Eqs. (4) and (5) as

$$\sigma(s) = \int_{t_{\min}}^{t_{\max}} \frac{d\hat{\sigma}}{d\hat{t}}(\hat{s},\hat{t},\hat{u})d\hat{t}. \tag{9}$$

4. NUMERICAL RESULTS

According to the results from our calculations, it is posibble to see some signals that the leptons could be composite objects. Particularly, if the compositeness scale for leptons is about 1 TeV, we can most probably see this at *TESLA* × *HERA* collider when it starts running. The total cross section for leptogluon production versus the mass of leptogluon is plotted in Fig. 1. In Fig. 1 curve A tells us the e-type leptogluons can be investigated up to the mass value of

1.43 TeV at *TESLA × HERA* collider with the integrated luminosity of $5\times10^{2}\,pb^{-1}$ by taking 100 events per year for the discovery of leptogluons. Similarly, we can expect the same behaviour for μp (curve B) collider up to the mass value of 2.69 TeV with the integrated luminosity of $10^{3}\,pb^{-1}$ and for LHC-Linac (curve C) collider up to the mass value of 4.79 TeV with the integrated luminosity of $5\times10^{3}\,pb^{-1}$. In Figs. 2, 3 and 4, we plot the invariant mass distributions for leptogluons at different leptogluon mass values.

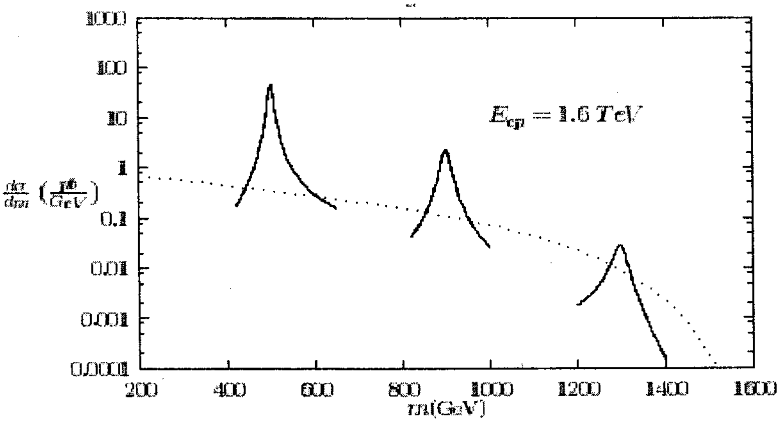

Figure 2. At *TESLA × HERA*, invariant mass distribution $ep \rightarrow ljX$. Resonance peaks are shown for $M_{e8} = 500, 900$ and 1300 GeV, respectively. Dotted line denotes the SM backgrounds.

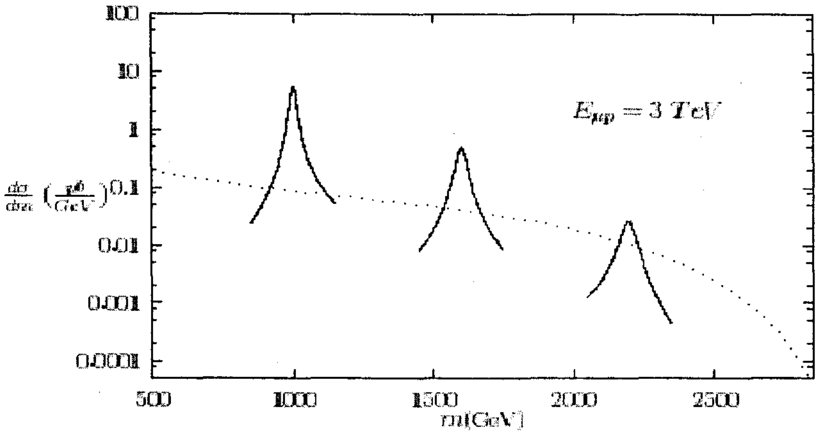

Figure 3. At μp collider, invariant mass distribution $\mu p \to ljX$. Resonance peaks are shown for $M_{\mu_8} = 1000, 1600$ and 2200 GeV, respectively. Dotted line denotes the SM backgrounds.

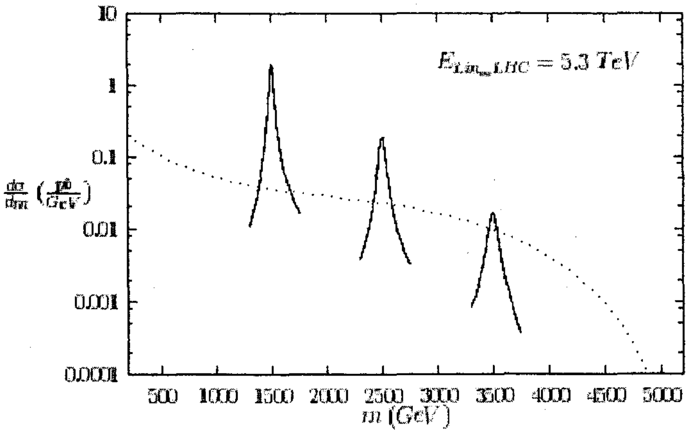

Figure 4. At Linac-LHC, invariant mass distribution $ep \to ljX$. Resonance peaks are shown for $M_{e_8} = 1500$, 2500 and 3500 GeV, respectively. Dotted line denotes the SM backgrounds.

In our calculations, we ignore the contributions coming from t-channel diagram because of the leptogluon propagator term, and only take into account the term coming from s-channel diagram. The peaks appearing in the figures show that the expected number of events for signal will be more when compared to the background events.

Finally, we give the discovery contour for leptogluons in terms of its mass and a new coupling parameter k for the machines $TESLA \times HERA$, μp and Linac-LHC in Fig. 5.

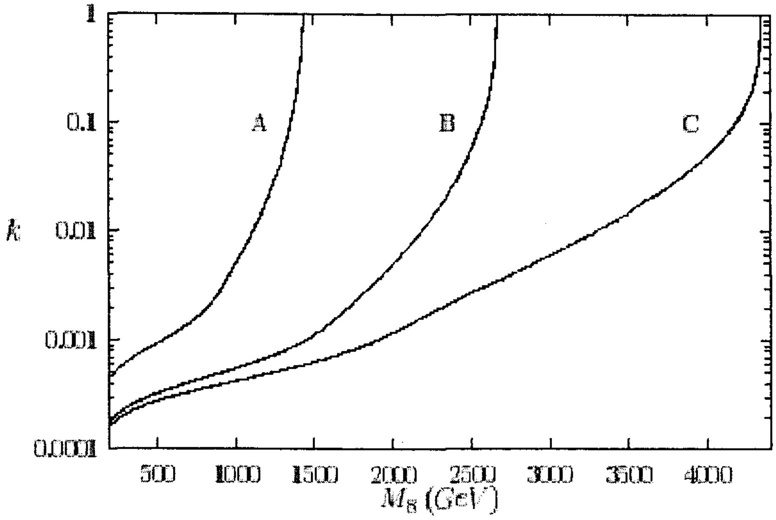

Figure 5. Discovery contour in the plane $k \times M_{l_8}$ for the resonance production $l + j \to l_8 \to l + j$. Curves A, B and C correspond to machines mentioned in Fig. 1.

5. CONCLUSION

In conclusion, in this work we have shown that the $TESLA \times HERA$, μp and Linac-LHC will be more promising machines for color octet lepton searches, namely lepton compositeness. Particularly, the resonance production of leptogluons will give clean signal at these machines with the energy of TeV scale. Detailed analysis of signal and background for leptogluons remain us for future investigations.

ACKNOWLEDGEMENTS

I am so grateful to S. Atağ and O. Çakır for useful discussions. I also thank S. Sultansoy and his group at Gazi University for their contributions to this work.

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