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Pair production of color octet muons at high energy $\mu^+\mu^-$ and pp colliders

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ÖZET

Bu çalışmada renk sekizlisi müonların sözgelimi 4, 8 ve 12 TeV enerjili, TESLA-μ×CLIC (TESLA-μ, TESLA'nın müon versiyonu) gibi yüksek enerjili $\mu^+\mu^-$ çarpıştırıcılarında ve 14 TeV enerjili LHC (Büyük Hadron Çarpıştırıcısı), 28 TeV enerjili VLHC (Çok Büyük Hadron Çarpıştırıcısı) ve 40 TeV enerjili SSC (Süperiletken Süper Çarpıştırıcı) gibi yüksek enerjili pp çarpıştırıcılarında, çift üretimlerini ve bozunum kanallarını araştırmaktayız. Üç farklı makine grubu için (hem $\mu^+\mu^-$ hem de pp çarpıştırıcıları) renk sekizlisi müonların toplam tesir kesiti hesaplanmakta ve kütlesine göre grafiği çizilmektedir. Bu parçacıklar için sinyal olayları tesir kesitine bağlı olarak analiz edilmektedir. Ayrıca bu parçacıkların gözlenebilme koşulları istatistiksel anlamlı olay sayılarıyla birlikte, keşfedilme sınırları ayarlanarak çalışılmıştır.

Anahtar Kelimeler: Tesir kesiti, Işınlılık, Olay sayısı Standart Model,

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ABSTRACT

In this study we search for pair production of color octet muons and their decay modes at high energy $\mu^+\mu^-$ colliders such as TESLA-μ×CLIC (TESLA-μ, the muon version of TESLA) with the energy of 4, 8 and 12 TeV and pp colliders such as LHC (Large Hadron Collider) with the energy of 14 TeV, VLHC (Very Large Hadron Collider) with the energy of 28 TeV and SSC (Superconducting Super Collider) with the energy of 40 TeV. The total cross sections of color octet muons for the three different machines group (at both $\mu^+\mu^-$ and pp colliders) are calculated and plotted versus its mass. The signal events for color octet muons are analyzed by means of the cross section. The observation conditions of color octet muons are performed by setting the discovery limits with the statistical significant event numbers.

Key Words: Cross section, Luminosity, Number of events, Standard model.

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1. Introduction

The inflation of the numbers of leptons and quarks has increased the speculations that they could be composite structures, i.e. bound states of more fundamental constituents often called "preons". On the other hand, the disability of the Standard Model (SM) to explain the most important fundamental problems such as lepton-quark-symmetry, family replication, mass hierarchy problem, divergences at Higgs mass, charge quantization, etc. forces the physicists to go beyond it. At this point, some approximations beyond SM such as compositeness, supersymmetry (SUSY), etc. might be the most promising candidates to search new physics [1,2,3,4,5,6]. At the future colliders with high center of mass energy and luminosity we may have large physics potential in order to explore the TeV or multi-TeV scale physics. So far, no obviously correct or compelling model has yet emerged. It is hoped that at the LHC the particles predicted by some composite models will be discovered.

In this study, we aim to give a realistic composite model for leptons and quarks which contains scalar and fermionic preons. In order to test our model, we suggest experimental researches on color octet muon productions. Color octet muons will be pairly produced in $\mu^+\mu^-$ and pp collisions. If we may observe these particles at the future high energy collider experiments, then it might be a signature of the compositeness of leptons and quarks. At high energy $\mu^+\mu^-$ and pp colliders, we hope that there will be so much physics potential to search a new scale physics, or so called TeV scale physics.

2. Composite models of leptons and quarks

At present there are many ideas on compositeness [7,8,9,10,11]. These ideas start from the compositeness of Higgs particle to all particles of the Standard Model. In these models, all the SM particles are consist of more fundamental constituents so called preons. Unfortunately, there is no experimental evidence on the existence of lepton and quark compositness at moment. To make a model we have some assumptions to restrict the number of parameters.

There are two assumptions to our preon model,

i) There is no parastatistics,

ii) Preons are colored object.

According to the first assumption, the SM fermions should contain odd number of fermionic preons, which lead to fermion scalar models [12,13,14,15,16,17] or three fermion models [18,19]. The second assumption means that all preons are color triplets.

Leptons: In the framework of fermion scalar models, leptons would be a bound state of one fermionic preon and one scalar anti-preon,

$$l = (F\bar{S}) = 1 \oplus 8 \tag{1}$$

then each SM lepton has one color octet partner. In a three fermion, the color decomposition

$$l = (FFF) = 1 \oplus 8 \oplus 8 \oplus 10 \tag{2}$$

predicts the existence of two color octet and one color decouplet partners.

Quarks: In fermion scalar models, anti-quarks are made of one fermionic and one scalar preons which means that each SM anti-quark has one color sextet partner,

$$\bar{q} = (FS) = \bar{3} \oplus 6 \tag{3}$$

In three fermion models,

$$q = (F\bar{F}F) = 3 \oplus \bar{3} \oplus \bar{6} \oplus 15 \tag{4}$$

$$\begin{aligned} \nu_e &= (F_1\bar{S}_1), e = (F_2\bar{S}_1), \\ \bar{d} &= (F_1 S_2), \bar{u} = (F_2 S_2) \end{aligned} \tag{5}$$

3. Pair production of color octet muons

a. $\mu^+\mu^-$ colliders

Composite models of leptons and quarks may have a number of new exotic particles such as leptogluons, leptoquarks, excited leptons, etc., The interaction Lagrangian between a lepton, a gluon and a leptogluon may be [22]

$$L = \frac{g_s}{2\Lambda} \sum_l [\bar{l}_8{}^{\alpha} \sigma^{\mu\nu} F^{\alpha}{}_{\mu\nu} (\eta_L l_L + \eta_R l_R) + h.c] \tag{6}$$

According to Eq. (6) it is possible to produce color octet muons pairly in the t-channel at $\mu^+\mu^-$ colliders as

$$\mu^+\mu^- \rightarrow \mu_8{}^+\mu_8{}^- \rightarrow 2l + 2jet \tag{7}$$

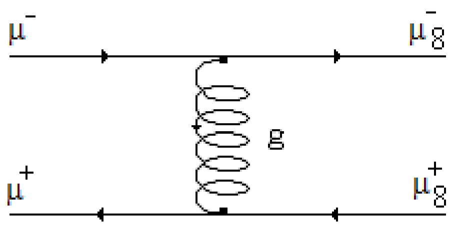

Figure 1. Feynman diagram for the pair production of color octet muons coming from the t-channel at $\mu^+\mu^-$ colliders.

In addition to this channel, an extra contribution coming from the contact interactions will be as [23]

$$L_{cont} \approx \frac{g^2}{2\Lambda^2} \mu_8{}^+ \mu_8{}^- \mu^+ \mu^- \qquad (8)$$

and its Feynman diagram as

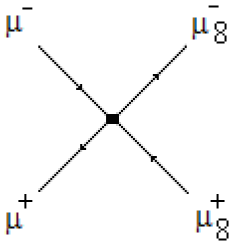

Figure 2. Feynman diagram for the pair production of color octet muons coming from the contact interactions at $\mu^+\mu^-$ colliders.

From the diagrams seen in Fig. 1 and Fig. 2 we can easily calculate the differential cross section for color octet muon production as

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{\pi\alpha_s^2}{16\Lambda^4\hat{s}^2}\left\{\hat{s}(\hat{s}-2m^2)+16k^2(\hat{t}-m^2)^2\right\} \qquad (9)$$

where k is the new interaction parameter seen in the contact interactions, $g^2 = kg_s^2$, and g is the new coupling constant for the four vertex interaction, Λ is compositeness scale. If $k=1$, namely taking $\Lambda = m$, the contact interactions will be order of QCD coupling constant α_s, but we don't know what will be. The total cross section for color octet muon production is plotted versus its mass in Fig. 3. for and $k=1$. As seen in Fig. 3, color octet muon cross section is potentially large, then we might expect the number of events so large in $\mu^+\mu^-$ collisions. On the other hand, there will be very clean signals without background events at $\mu^+\mu^-$ colliders. Because we expect that color octet muons will decay into two muons and two jets. For the various values of k, for example, 0.1, 0.01 and 0.001, we obtained that the total cross section curves behave same compared to Fig. 3.

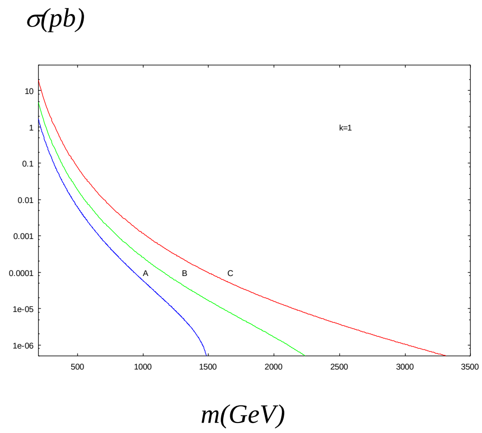

Figure 3. Total cross section for color octet muons versus its mass m setting to three different machines taking $k=1$, curve A with $\sqrt{s}=4\,\text{TeV}$, curve B with $\sqrt{s}=8\,\text{TeV}$ and curve C with $\sqrt{s}=12\,\text{TeV}$ at $\mu^+\mu^-$ colliders.

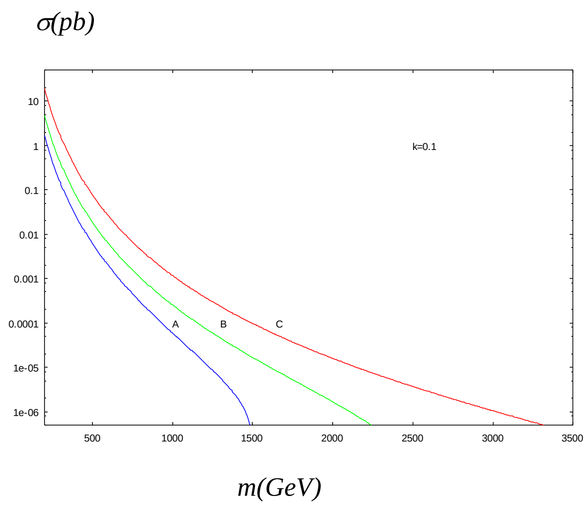

Figure 4. Total cross section for color octet muons versus its mass m setting to three different machines taking $k=0.1$, curve A with $\sqrt{s}=4\,\text{TeV}$, curve B with $\sqrt{s}=8\,\text{TeV}$ and curve C with $\sqrt{s}=12\,\text{TeV}$ at $\mu^+\mu^-$ colliders.

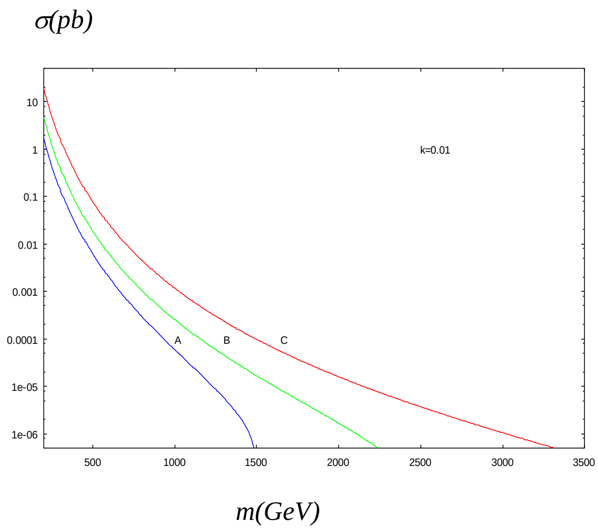

Figure 5. Total cross section for color octet muons versus its mass m setting to three different machines taking $k = 0.01$, curve A with $\sqrt{s} = 4\,\text{TeV}$, curve B with $\sqrt{s} = 8\,\text{TeV}$ and curve C with $\sqrt{s} = 12\,\text{TeV}$ at $\mu^+\mu^-$ colliders.

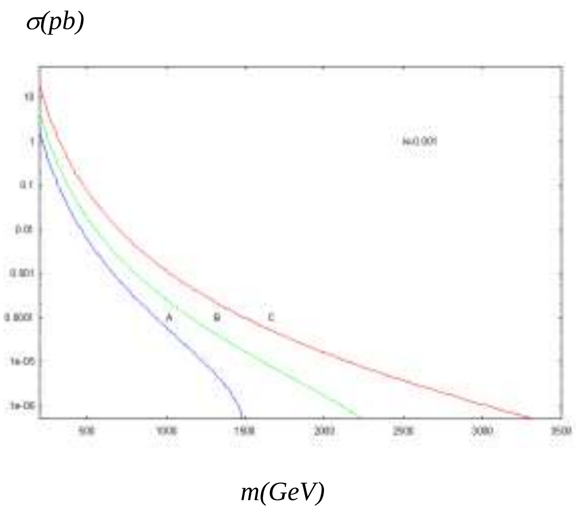

Figure 6. Total cross section for color octet muons versus its mass m setting to three different machines taking $k = 0.001$, curve A with $\sqrt{s} = 4\,\text{TeV}$, curve B with $\sqrt{s} = 8\,\text{TeV}$ and curve C with $\sqrt{s} = 12\,\text{TeV}$ at $\mu^+\mu^-$ colliders.

B. pp Colliders

At LHC (or VLHC, upraged version of LHC) and SSC, leptogluons will be pairly produced in the s-, t- and u- channels as

$$gg \to l_8 \bar{l}_8 \to 2l + 2\,jet,$$
$$q\bar{q} \to l_8 \bar{l}_8 \to 2l + 2\,jet \tag{10}$$

and their Feynman diagrams are given as

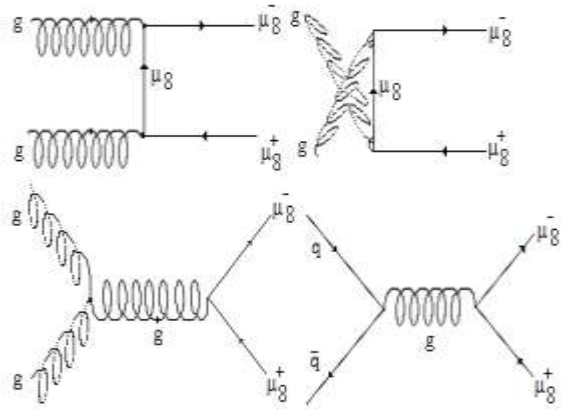

Figure 7. Feynman diagrams for the pair production of color octet muons at pp colliders.

From these diagrams we can easily obtain the differential cross section for color octet muon production coming from gluon-gluon fusion as

$$\begin{aligned}\frac{d\hat{\sigma}}{d\hat{t}} &= d_R C(R)\frac{\pi\alpha_s^2}{32\hat{s}^2}\left\{\frac{6}{\hat{s}^2}(\hat{t}-m^2)(\hat{u}-m^2)\right.\\ &+ C(R)\frac{(\hat{t}-m^2)(\hat{u}-m^2)-2m^2(\hat{t}+m^2)}{(\hat{t}-m^2)^2}\\ &+ \frac{3(\hat{t}-m^2)(\hat{u}-m^2)-2m^2(\hat{s}-4m^2)}{\hat{s}(\hat{t}-m^2)}\\ &+ C(R)\frac{(\hat{u}-m^2)(\hat{t}-m^2)-2m^2(\hat{u}+m^2)}{(\hat{u}-m^2)^2}\\ &+ \frac{3(\hat{u}-m^2)(\hat{t}-m^2)+m^2(\hat{s}-4m^2)}{\hat{s}(\hat{u}-m^2)}\\ &\left.-(3-2C(R))\frac{m^2(\hat{s}-4m^2)}{(\hat{t}-m^2)(\hat{u}-m^2)}\right\}\end{aligned} \tag{11}$$

and quark-antiquark annihilation as

$$\frac{d\hat{\sigma}}{d\hat{t}} = d_R C(R)\frac{\pi\alpha_s^2}{9\hat{s}^2}\left\{\frac{(\hat{t}-m^2)^2+(\hat{u}-m^2)^2+2m^2\hat{s}}{\hat{s}^2}\right\} \tag{12}$$

where d_R is the dimension of the representation and $C(R)$ is the color factor of color octet muons. In our calculations we have taken $d_R = 8$ and $C(R) = \frac{4}{3}$ for gg fusion, $d_R = 8$ and $C(R) = 3$ for $q\bar{q}$ fusion. According to Eq. (11) and Eq. (12) after integrating over $\hat{t}$ we can calculate the total cross section for color octet muon production bye using the parton distribution functions given in Ref. [24] at *pp* colliders.

The total cross section for color octet muon production are plotted versus its mass in Fig. 8 for *gg* fusion Fig. 9 for $q\bar{q}$ annihilation.

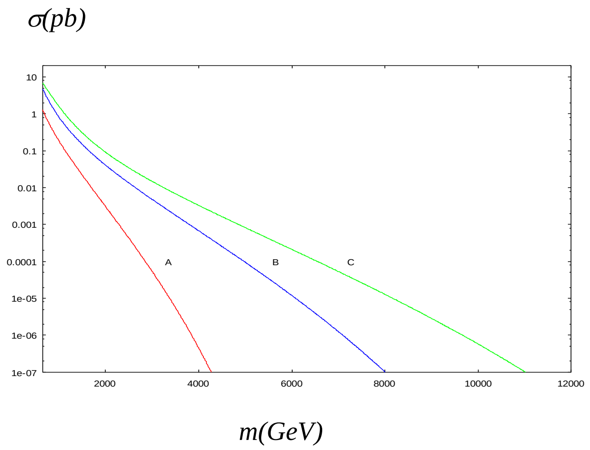

Figure 8. Total cross section for color octet muons coming from the *gg* fusion versus its mass m setting to three different machines, curve A with $\sqrt{s}=14\,\text{TeV}$, curve B with $\sqrt{s}=28\,\text{TeV}$ and curve C with $\sqrt{s}=40\,\text{TeV}$ at pp colliders.

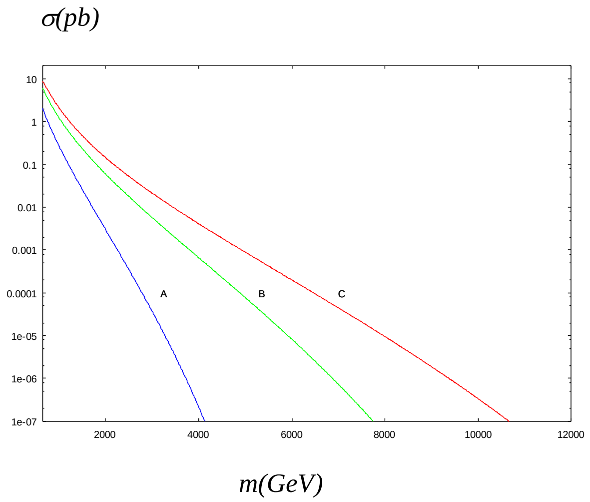

Figure 9. Total cross section for color octet muons coming from the $q\bar{q}$ annihilation versus its mass m setting to three different machines, curve A with $\sqrt{s}=14\,\text{TeV}$, curve B with $\sqrt{s}=28\,\text{TeV}$ and curve C with $\sqrt{s}=40\,\text{TeV}$ at pp colliders.

4. Conclusion

In this work we assumed that leptogluons strongly interact with leptons by exchanging gluon in the t-channel according to effective Lagrangian (6). According to our calculations color octet muons can be explored up to the masses of 0.92 TeV for $\sqrt{s}=4$ TeV, 1.16 TeV for $\sqrt{s}=8$ TeV and 1.42 TeV for $\sqrt{s}=12$ TeV in $\mu^+\mu^-$ collisions (4.56) TeV for $\sqrt{s}=28$ TeV and 6.04 (6.00) TeV and 2.69 (2.64) TeV for $\sqrt{s}=14$ TeV, 4.62 for $\sqrt{s}=40$ TeV in pp collisions. The values in the parenthesis correspond the mass limits coming from the subprocesses $q\bar{q}$. The existence of leptogluons "colored leptons" is an essential feature of a large class of composite models of leptons and quarks. If they exist, both charged and neutral "colored leptons" are produced at appreciable rates and have extremely interesting experimental signatures.

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