Photoproduction of the charged top-pions at the LHeC

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Abstract

The top triangle moose (TTM) model, which can be seen as the deconstructed version of the topcolor-assisted technicolor (TC2) model, predicts the existence of the charged top-pions $\pi_t^\pm$ in low energy spectrum. In the context of this model, we consider photoproduction of $\pi_t^\pm$ via the subprocesses $\gamma b \rightarrow t\pi_t^-$ and $\gamma \bar{b} \rightarrow \bar{t}\pi_t^+$ at the large hadron-electron collider (LHeC), in which high energy photon beams are generated by using the Compton backscatting method. We find that, as long as the charged top-pions are not too heavy, they can be abundantly produced via $\gamma b$ collision.

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1. Introduction

Although the standard model (SM) is an excellent low energy effective theory, the cause of electroweak symmetry breaking (EWSB) and the origin of fermion masses continue to be outstanding mystery, which has started to be probed at the LHC. Recently, the ATLAS and CMS collaborations have found some hints of a relatively light Higgs boson with a mass somewhere between 120 and 130 GeV [1]. Thus we are now coming into an exciting period of particle physics.

The top quark is the heaviest elementary particle known up to today. Its mass might has a different origin from the masses of other quarks and leptons, a top quark condensate, \( < t \bar{t} > \), could be responsible for at least part of EWSB. Much theoretical work has been carried out in connection to the top quark and EWSB, some specific new physics models are proposed (for review, see [2] and references therein). An interesting model involving a role for the top quark in dynamical EWSB is known as the topcolor-assisted technicolor (TC2) model [3]. In the framework of this model, the topcolor, a new QCD-like interaction, that couples strongly to the third generation quarks, makes small contributions to EWSB and gives rise to the main part of the top quark mass. Technicolor (TC) provides the bulk of EWSB via the vacuum expectation value (VEV) of a technifermion bilinear. The light fermions can get masses from the extended technicolor (ETC). The TC2 model is one of well-motivated new physics models and has all essential features of the topcolor scenario.

Higgsless models [4] have emerged as a novel way of understanding the mechanism of EWSB without the presence of a scalar particle in the spectrum. Recently, combing Higgsless and topcolor mechanisms, a deconstructed Higgsless model was proposed, called the top triangle moose (TTM) model [5, 6]. In this model, EWSB results largely from the Higgsless mechanism while the top quark mass is mainly generated by the topcolor mechanism. The TTM model alleviates the tension between obtaining the correct top quark mass and keeping \( \Delta \rho \) small that exists in many Higgsless models, which can be seen as the deconstructed version of the TC2 model.
The new physics models belonging to the topcolor scenario genetically have two sources of $EW_{SB}$ and there are two sets of Goldstone bosons. One set is eaten by the electroweak gauge bosons $W$ and $Z$ to generate their masses, while the other set remains in the spectrum, which is called the top-pions ($\pi_t^0$ and $\pi_t^\mp$). Topcolor scenario also predicts the existence of the top-Higgs $h_t^0$, which is the $t\bar{t}$ bound state. It is well known that the possible signals of these new scalar particles have been extensively studied in the literature. However, most of works are done in the context of the $TC_2$ model.

More phenomenology analysis about the top-pions and top-Higgs predicted by the $TTM$ model is needed. Although photoproduction of the charged top-pions has been studied in Ref.[7], which proceeds via the subprocess $\gamma c \rightarrow b\pi^+_t$ mediated by the flavor changing couplings. The high energy photon beams are generated by using the Compton backscattering of the initial electron and laser photon beams. However, so far, photoproduction of the charged top-pions via the subprocesses $\gamma b \rightarrow t\pi^-_t$ and $\gamma \bar{b} \rightarrow \bar{t}\pi^+_t$ has not been considered at the large hadron-electron collider ($LHeC$). Furthermore, many popular models beyond the $SM$ predict the existence of the charged scalars. At the $LHeC$, these new particles can be produced via $\gamma b$ collision, which has not been detailed studied in the literature, as we know. Thus, in this paper, we will consider photoproduction of the charged top-pion associated with a top quark in the frameworks of the $TTM$ and $TC_2$ models and compare the numerical results with each other. Our calculation can be easily transformed to other models. We hope that our works will be helpful to test topcolor models and further to distinguish different new physics models at the $LHeC$.

The layout of the present paper is as follows. After reviewing the essential features of the $TTM$ model in section 2, we calculate the production cross section of the subprocess $\gamma b \rightarrow t\pi^-_t$ at the $LHeC$ in section 3. To compare our numerical results with those of the $TC_2$ model, we further consider photoproduction of the charged top-pions predicted by the $TC_2$ model in section 4. Our conclusion and discussion are given in section 5.

2. The essential features of the $TTM$ model
The detailed description of the TTM model can be found in Refs. [5, 6], and here we just want to briefly review its essential features, which are related to our calculation.

The electroweak gauge structure of the TTM model is $SU(2)_0 \times SU(2)_1 \times U(1)_2$. The nonlinear sigma field $\Sigma_{01}$ breaks the group $SU(2)_0 \times SU(2)_1$ down to $SU(2)$ and field $\Sigma_{12}$ breaks $SU(2)_1 \times U(1)_2$ down to $U(1)$. To separate top quark mass generation from EWSB, a top-Higgs field $\Phi$ is introduced to the TTM model, which couples preferentially to the top quark. To ensure that most of the EWSB comes from the Higgsless side, the VEVs of the fields $\Sigma_{01}$ and $\Sigma_{12}$ are chosen to be $<\Sigma_{01}> = <\Sigma_{12}> = F = \sqrt{2}\nu\cos\omega$, in which $\nu = 246\text{GeV}$ is the electroweak scale and $\omega$ is a new small parameter. The VEV of the top-Higgs field is $f = <\Phi> = \nu\sin\omega$.

From above discussions, we can see that, for the TTM model, there are six scalar degrees of freedom on the Higgsless sector and four on the top-Higgs sector. Six of these Goldstone bosons are eaten to give masses to the gauge bosons $W^\pm, Z, W'^\pm$ and $Z'$. Others remain as physical states in the spectrum, which are called the top-pions ($\pi^\pm_t$ and $\pi^0_t$) and the top-Higgs $h^0_t$. In this paper, we will focus our attention on photoproduction of the charged top-pions at the LHeC. The couplings of the charged top-pions $\pi^\pm_t$ to ordinary particles, which are related our calculation, are given by [6]

$$L_{\pi^\pm tb} = i\lambda_t \cos\omega \left\{ 1 - \frac{x^2[a^4 + (a^4 - 2a^2 + 2)\cos2\omega]}{8(a^2 - 1)^2} \right\} (\pi^+_t\bar{b}P_L + \pi^-_t\bar{t}P_R)$$  \hspace{1cm} (1)

with

$$\lambda_t = \frac{\sqrt{2}m_t}{\nu\sin\omega} \frac{M_D^2(\varepsilon_L^2 + 1) - m_t^2}{M_D^2 - m_t^2}, \quad a = \frac{\nu\sin\omega}{\sqrt{2}M_D}, \quad x = \sqrt{2}\varepsilon_L = \frac{2\cos\omega M_W}{M_{W'}}$$  \hspace{1cm} (2)

Here $P_{L(R)} = \frac{1}{2}(1 \mp \gamma_5)$ is the left(right)-handed projection operator, $M_D$ is the mass scale of the heavy fermion and $M_{W'}$ is the mass of the new gauge boson $W'$. Since the top quark mass depends very little on the right-handed delocalization parameter $\varepsilon_{tR}$, we have set $\varepsilon_{tR} = 0$ in Eq.(1). The parameter $\varepsilon_L$ describes the degree of delocalization of the left-handed fermions and is flavor universal, the parameter $x$ presents the ratio of gauge couplings. The relationship between $\varepsilon_L$ and $x$, which is given in Eq.(2), is imposed by ideal delocalization.
Reference [8] has shown that $M_{W'}$ should be larger than 380 GeV demanded by the LEP II data and smaller than 1.2 TeV by the need to maintain perturbative unitarity in $W_L^* W_L$ scattering. It is obvious that the coupling $\pi_t t b$ is not very sensitive to the parameters $M_{W'}$ and $M_D$. Thus, the production cross sections of the subprocesses $\gamma b \to \pi^- t$ and $\gamma t \to \pi^+ t$ are not strongly dependent on the values of the mass parameters $M_{W'}$ and $M_D$. In our following numerical calculation, we will take the illustrative values $M_{W'} = 500 GeV$ and $M_D = 650 GeV$. In this case, there is $[M_D^2 (\varepsilon_L^2 + 1) - m_t^2] / (M_D^2 - m_t^2) \approx 1$ and Eq.(1) can be approximately written as

$$L_{\pi t b} \approx i \frac{\sqrt{2} m_t C}{\nu} \cot \omega (\pi_L^+ \bar{t} b P_L + \pi_R^- t \bar{b} P_R)$$

(3)

with

$$C = 1 - \frac{x^2 [a^4 + (a^4 - 2a^2 + 2) \cos 2\omega]}{8(a^2 - 1)^2}.$$ 

(4)

It is obvious that constant $C$ is not sensitive to the value of $\sin \omega$ and its value close to 1.

3. Photoproduction of the charged top-pions at the LHeC within the TTM model

Recently, the high-energy $ep$ collision has been considered at the LHC, which is called the LHeC [9, 10]. At the LHeC, the incoming proton beam has an energy $E_p = 7 TeV$ and the energy $E_e$ of the incoming electron is in the range of $50 \sim 200 GeV$, corresponding to the center-of-mass (c.m.) energy of $\sqrt{s} = 2\sqrt{E_p E_e} \approx 1.18 \sim 2.37 TeV$. Its anticipated integrated luminosity is at the order of $10 \sim 100 fb^{-1}$ depending on the energy of the incoming electron and the design. The LHeC can be used to accurately determine the parton dynamics and the momentum distributions of quarks and gluons in proton. Furthermore, it can provide better condition for studying a lot of phenomena comparing to the high energy linear $e^+ e^-$ collider (ILC) due to the high c.m. energy and to the LHC due to more clear environment [10, 11]. Thus, it may play a significant role in the discovery of new physics beyond the SM. An other advantage of the LHeC is the opportunity to construct $\gamma p$ collider [12] with the photon beam generated by the backward
Compton scattering of incident electron- and laser-beams. The energy and luminosity of the photon beam would be the same order of magnitude of the parent electron beam.

$$\gamma \rightarrow t \pi^-$$

Figure 1: Feynman diagrams for the subprocess $\gamma b \rightarrow t \pi^- t$.

From the discussions given in section 2, we can see that the charged top-pion $\pi^-$ can be produced via the subprocess $\gamma(k_1)b(p_1) \rightarrow t(p_2)\pi^-(k_2)$ at the LHeC. The relevant Feynman diagrams are depicted in Fig. 1. With the relevant couplings, the invariant production amplitude can be written as

$$M = M_a + M_b$$

$$= A \bar{u}(p_2) P_R \frac{i}{k_1 + p_1} (-\frac{1}{3} e \gamma^\mu) u(p_1) \varepsilon_\mu(k_1)$$

$$+ A \bar{u}(p_2) (\frac{2}{3} e \gamma^\mu) \frac{i}{p_2 - k_1 - m_t} P_R u(p_1) \varepsilon_\mu(k_1)$$

with

$$A = \frac{\sqrt{2} m_t C}{\nu} \cot \omega.\ (6)$$

Here $\varepsilon_\mu(k_1)$ is the polarization vector of the photon. In above equation, we have taken $m_b \approx 0$. Using the amplitude $M$, we can directly obtain the cross section $\hat{\sigma}(\hat{s})$ for the subprocess $\gamma b \rightarrow t \pi^- t$.

Since the photon beam in $\gamma b$ collision is generated by the Compton backscattering of the incident electron- and the laser-beams, the effective cross section $\sigma_1(s)$ at the LHeC can be obtained by folding $\hat{\sigma}(\hat{s})$ with the bottom quark and photon distribution functions. For this purpose, we define the variables: $\hat{s} = x_1 x_2 s$ with $x_1 = E_\gamma/E_e$ and $x_2 = E_b/E_p$. $\sqrt{s}$ is the c.m. energy of the LHeC. The cross section $\sigma_1(s)$ for the process
\[ \text{ep} \rightarrow \gamma b + X \rightarrow t\pi^- + X \] can be given by
\[
\sigma_1(s) = \int_{(m_e + m_f)^2/s}^{x_{\text{max}}} dx_1 \int_{(m_e + m_f)^2/x_1 s}^{1} dx_2 f_{\gamma/e}(x_1) f_{b/p}(x_2) \hat{\sigma}(\hat{s}). \quad (7)
\]
For unpolarized initial electron and laser beams, the energy spectrum of the backscattered photon is [13]
\[
f_{\gamma/e}(x) = \frac{1}{D(\xi)} \left\{ 1 - x + \frac{1}{1 - x} \left[ 1 - \frac{4x}{\xi} \left( 1 - \frac{x}{\xi(1 - x)} \right) \right] \right\} \quad (8)
\]
with
\[
D(\xi) = (1 - \frac{4}{\xi} - \frac{8}{\xi^2}) \ln(1 + \xi) + \frac{1}{2} + \frac{8}{\xi} - \frac{1}{2(1 + \xi)^2}. \quad (9)
\]
Where \( \xi = 4E_eE_0/m_e^2 \) in which \( m_e \) denotes the incident electron mass, \( E_0 \) denotes the initial laser photon energy. \( x \) is the fraction of energy taken by the backscattered photon beam moving along the initial electron direction. \( f_{\gamma/e}(x) \) vanishes for \( x > x_{\text{max}} = E_{\text{max}}/E_e = \xi/(1 + \xi) \). In order to get rid of the background effects in the Compton backscattering, particularly \( e^+e^- \) pair production in the collision of the laser with the backscattered photon, it is required \( E_0 x_{\text{max}} \leq m_e^2/E_e \) which implies \( \xi \leq 2 + 2\sqrt{2} \approx 4.83 \) [13]. For the choice \( \xi = 4.8 \), one can obtain \( x_{\text{max}} \approx 0.83 \) and \( D(\xi) \approx 1.84 \). In Eq.(7), the bottom quark is directly taken from the proton in a five flavor scheme. For the bottom quark distribution function \( f_{b/p}(x_2) \), we will use the form given by the CTEQ6L [14] parton distribution functions (PDFs). The renormalization and factorization scales are taken as the \( t\pi^- \) invariant mass.

Except for the SM input parameters \( \alpha_e = 1/128 \), \( m_t = 172 GeV \), and \( M_W = 80.4 GeV \) [14], the production cross section for the process \( \text{ep} \rightarrow t\pi^- + X \) is dependent on the free parameters \( \sin \omega \) and \( m_{\pi_t} \). The parameter \( \sin \omega \) indicates the fraction of \( EWSB \) provided by the top condensate. The top-pion mass \( m_{\pi_t} \) depend on the amount of top-quark mass arising from the \( ETC \) sector and on the effects of electroweak gauge interactions [2], and thus its value is model-dependent. In the context of the \( TTM \) model, Ref.[6] has obtained the constraints on the top-pion mass via studying its effects on the relevant experimental observables. Similarly with Refs.[6, 16], we will assume that the values of
the free parameters $\sin \omega$ and $m_{\pi_t}$ are in the ranges of $0.2 \sim 0.8$ and $200 \sim 600 GeV$, respectively.

Our numerical results are summarized in Fig.2, in which we have plotted the production cross section $\sigma_1(s)$ as a function of the charged top-pion mass $m_{\pi_t}$ for $E_e = 70 GeV$, $150 GeV$ and $200 GeV$, and various values of the parameter $\sin \omega$. One can see that, for $70 GeV \leq E_e \leq 200 GeV$, $200 GeV \leq m_{\pi_t} \leq 600 GeV$, and $0.2 \leq \sin \omega \leq 0.8$, the value of the cross section $\sigma_1(s)$ for the process $ep \rightarrow t\pi^- + X$ is in the range of $2.8 \times 10^{-3} fb \sim 1.6 \times 10^3 fb$, which is sensitive to the free parameters $\sin \omega$ and $m_{\pi_t}$. If we assume that the yearly integrated luminosity $\mathcal{L}_{\text{Lint}} = 50 fb^{-1}$, than there will be several

Figure 2: The cross section $\sigma_1(s)$ as a function of the mass parameter $m_{\pi_t}$ for $E_e = 70 GeV$ (a), $150 GeV$ (b) and $200 GeV$ (c).
and up to ten thousands of $t\pi^-_t$ events to be generated at the LHeC per year.

It is well known that, for a heavy charged scalar, which is heavier than the top quark, the main production channel proceeds via gluon-bottom collision at the LHC. In the context of the TTM model, Ref.[6] has studied production of the charged top-pion $\pi^-_t$ via the subprocess $gb \to t\pi^-_t$ and discussed the possibility of detecting the charged top-pions at the LHC. It is obvious that the $t\pi^-_t$ production cross section at the LHC with $\sqrt{s} = 14 TeV$ is larger than that at the LHeC with $\sqrt{s} = 2.37 TeV$ as shown in Fig.2. However, considering the more clear environment comparing to the LHC, it is needed to consider the subprocess $\gamma b \to t\pi^-_t$ in the near future LHeC experiments.

Reference [6] has shown that, for $m_{h_t} \geq 300 GeV$ and $m_{\pi_t} \leq 600 GeV$, the charged top-pions $\pi^-_t$ dominantly decay into $tb$ and there is $Br(\pi^+_t \to tb) > 90\%$. Thus, photoproduction of the charged top-pion associated a top quark can easily transfer to the $t\bar{t}b$ final state. In order to ensure the clearest event signature, only fully leptonic decay modes of the gauge boson $W$ are considered. Then, photoproduction of the charged top-pions can give rise to the $l^+l^- + bbb + \not{E}$ signature at the LHeC. Its production rate can be easily

Figure 3: The number of the $l^+l^- + bbb + \not{E}$ signal events generated at the LHeC.
estimated by multiplying the overall decay branching ratios to the effective production cross section, which can be approximately written as: 

\[ \sigma_1 (t\pi^+) \times \sigma_1 (\bar{t}\pi^-) \times \text{Br}(t \rightarrow Wb)^2 \times \text{Br}(W \rightarrow l\nu)^2 \approx 2\sigma_1 \times 1 \times 0.9 \times (3 \times 0.108)^2 \approx 0.18\sigma_1. \]

In this estimation, we have assumed that the production cross section of the subprocess \( \gamma\bar{b} \rightarrow \bar{t}\pi^+ \) equals to that for the subprocess \( \gamma b \rightarrow t\pi^- \), and taken \( \text{Br}(t \rightarrow Wb) \approx 1 \) and \( \text{Br}(W \rightarrow l\nu_\ell) \approx \text{Br}(W \rightarrow \tau\nu_\tau) \approx 10.8\% \). The number of the signal events generated at the \( LH\epsilon C \) per year are given in Fig.3, in which we have taken \( E_e = 150 GeV \) and the yearly integrated luminosity \( L_{int} = 50 fb^{-1} \). One can see from this figure that, in wide range of the parameter space of the \( TTM \) model, there will be thousands of the \( l^+l^- + bbb + E \) signal events to be generated at the \( LH\epsilon C \). If the electroweak gauge boson \( W \) decays to \( l\nu \) with \( l \) denoting \( e \) or \( \mu \), the number of the signal events will be reduced. However, this allows the invariant mass of the charged top-pion to be reconstructed, which help separate the signal from the large \( t\bar{t} + jets \) background. Certainly, detailed confirmation of the observability of the signals generated by the process \( ep \rightarrow t\pi^\pm + X \), would require Monte Carlo simulation of the signals and the relevant \( SM \) backgrounds, which is beyond the scope of this paper.

4. Photoproduction of the charged top-pions at the \( LH\epsilon C \) within the \( TC^2 \) model

To solve the phenomenological difficulties of traditional \( TC \) theory, topcolor models [2] were proposed by combining \( TC \) interactions with the topcolor interactions at the scale of about 1\( TeV \). It is well known that the \( TC^2 \) model [3] is one of the phenomenologically viable models, which has almost all essential features of this kind of new physics models.

For the \( TC^2 \) model [3], \( TC \) interaction plays the main role in \( EWSB \). Topcolor interaction makes small contributions to \( EWSB \) and gives rise to the main part of the top quark mass, \( (1 - \varepsilon)m_t \), with the parameter \( \varepsilon \ll 1 \). Thus, there is the relation

\[ \nu_{\pi}^2 + F_t^2 = \nu_W^2. \]  

(10)

Where \( \nu_{\pi} \) represents the contributions of \( TC \) interactions to \( EWSB \), \( \nu_W = \nu/\sqrt{2} = \)
Here $F_t$ is the physical top-pion decay constant, which can be estimated from the Pagels-Stokar formula and written as

$$F_t^2 = \frac{N_c m_{t,dyn}^2}{16\pi^2} \ln\left(\frac{\Lambda^2}{m_{t,dyn}^2}\right). \quad (11)$$

Where $N_c = 3$ is the color factor, $\Lambda$ is the cutoff scale and $m_{t,dyn}$ denotes the portion of the top quark mass generated by the topcolor interaction. In the case of $m_{t,dyn} \approx m_t$ and $1\,TeV \leq \Lambda \leq 20\,TeV$, Ref.[16] has shown that the value of the factor $\sin \omega = F_t/\nu_W$ is in the range of 0.25 and 0.5. Allowing $F_t$ to vary over this ranges does not qualitatively change our conclusion, thus, we will take $F_t = 50\,GeV$ for illustration in our numerical analysis, which corresponds to $\Lambda = 1.59\,TeV$.

In the TC2 model, topcolor interaction is not flavor-universal and mainly couples to the third generation quarks. Thus, the top-pions ($\pi^{\pm}_t, \pi^0_t$) have large Yukawa couplings to the third family. The explicit forms for the couplings of $\pi^+_t$ to the third generation quarks, which are related our calculation, can be written as [3, 17]

$$(1 - \varepsilon) m_t \sqrt{\nu_w^2 - F_t^2/\nu_w} (\pi^+_t \bar{b} P_L + \pi^-_t \bar{t} P_R). \quad (12)$$

Where the factor $\sqrt{\nu_w^2 - F_t^2/\nu_w}$ reflects the effects of the mixing between the top-pion and the electroweak Goldstone boson of the TC sector.

It is obvious that the charged top-pions $\pi^{\pm}_t$ predicted the TC2 model can also be produced via the subprocesses $\gamma b \rightarrow t \pi^-_t$ and $\gamma \bar{b} \rightarrow \bar{t} \pi^+_t$ at the LHeC. The effective production cross section $\sigma_2$ only depends on two free parameters $\varepsilon$ and $m_{\pi_t}$. The parameter $\varepsilon$ parameterizes the portion of the ETC contributions to the top quark mass. From theoretical point of view, $\varepsilon$ with value from 0.01 to 0.1 is favored. The cross section $\sigma_2$ depends on the free parameter $\varepsilon$ only via the factor $(1 - \varepsilon)^2$, thus its value is not sensitive to the free parameter $\varepsilon$ and we will take $\varepsilon = 0.05$ in our numerical estimation. For the top-pion mass, the mass splitting between the neutral top-pion and the charged top-pion is very small, since it comes only from the electroweak interactions [18]. The absence of $t \rightarrow \pi^+_t b$ implies that $m_{\pi^+_t} > 165\,GeV$ [19] and the branch ratio $R_b$ for the decay $Z \rightarrow b \bar{b}$
yields $m_{\pi^+} > 220\text{GeV}$ [20]. In this paper, we will take $m_{\pi^0} = m_{\pi^+} = m_{\pi_t}$ and assume that its value is in the range of 200 ∼ 600 GeV.

The production cross section $\sigma_2$ for the process $e^+p \rightarrow t\pi^- + X$ is plotted in Fig.4 as a function of the mass parameter $m_{\pi^t}$ for the parameters $\varepsilon = 0.05$ and $E_e = 70\text{GeV}$, 150 GeV, 200 GeV. One can see from this figure that the cross section is larger than that for the $TTM$ model with $\sin \omega \geq 0.3$. For $\varepsilon = 0.05$, $200\text{GeV} \leq m_{\pi^t} \leq 600\text{GeV}$, and $70\text{GeV} \leq E_e \leq 200\text{GeV}$, the value of the cross section $\sigma_2$ is in the range of $5 \times 10^{-2} \sim 5.8 \times 10^2 \text{fb}$.

Reference [21] has shown that, in most of the parameter space of the $TC2$ model, the charged top-pions $\pi_t^\pm$ mainly decay to the modes $tb$ and $cb$ with the branching ratio about 70% and 30%, respectively. For the decay mode $tb$, photoproduction of the charged top-pions at the $LHeC$ would give rise to the $t\bar{t}b$ final state, which is same as that in the $TTM$ model. For the decay channel $\pi_t^\pm \rightarrow bc$ induced by the flavor changing interactions
Figure 5: The number of the $l^\pm + bb + jet + E_T$ events generated at the LHeC.

[17], it would give rise to the $tbc$ final state, which induces the $l^\pm + bb + jet + E_T$ and $bb+3jets$ signature for $W^\pm$ leptonic decay, $W^\pm \rightarrow l\nu$ and $W^\pm$ hadronic decay, $W^\pm \rightarrow q\bar{q}'$, respectively. The number of the $l^\pm + bb + jet + E_T$ events are shown in Fig.5 as a function of the mass parameter $m_{\pi_t}$ for $E_e = 150GeV$. one can see from this figure that, for $200GeV \leq m_{\pi_t} \leq 500GeV$, there will be $78 \sim 3226$ $l^\pm + bb + jet + E_T$ events to be generated per year at the LHeC with $L_{Lint} = 50fb^{-1}$.

5. Conclusion and discussion

A common feature of the new physics model belonging to the topcolor scenario is the prediction of the charged top-pions in the low energy spectrum, regardless of the dynamics responsible for EWSB and light quark masses. It is well known that, for the heavy charged scalar, which is heavier than the top quark, the subprocesses $gb \rightarrow tS^-$ and $g\bar{b} \rightarrow \bar{t}S^+$ are one kind of important production channels at the LHC. At the LHeC, the charged scalars can be produced via $\gamma b$ collision, which has not been detailed studied
in the literature, as we know. In this paper, we consider photoproduction of the charged top-pions predicted by the TTM and TC2 models, which proceed via the subprocesses $\gamma b \rightarrow t\pi^-_t$ and $\gamma\bar{b} \rightarrow \bar{t}\pi^+_t$ at the LHcC.

Our numerical results show that, in the frameworks of both the TTM model and the TC2 model, the charged top-pions $\pi^\pm_t$ can be abundantly produced via $\gamma b$ collision, as long as they are not too heavy. In the TC2 model, the production cross section is only sensitive to the model-dependent parameter $m_{\pi^t}$, while it is sensitive to the free parameters $\sin \omega$ and $m_{\pi^t}$ in the TTM model. For $\sin \omega < 0.3$, the cross section of the process $ep \rightarrow t\pi^-_t + X$ is larger than that in the TC2 model. For example, for $\sin \omega = 0.2$, $E_e = 150 GeV$ and $200 GeV \leq m_{\pi^t} \leq 600 GeV$, the value of $\sigma_1(t\pi^-_t)$ for the process $ep \rightarrow t\pi^-_t + X$ is in the range of $7.3 \sim 995 fb$, while its value is in the range of $5 \times 10^{-2} \sim 5.8 \times 10^2 fb$ in most of the parameter space of the TC2 model.

The minimal supersymmetric standard model (MSSM) [22] also predicts the existence of the charged scalars, which can also be produced via the subprocesses $\gamma b \rightarrow tS^-$ and $\gamma\bar{b} \rightarrow \bar{t}S^+$ at the LHcC. For the type II two-Higgs doublet models (2HDMs) [23], the tree-level production cross sections are proportional to $(m^2_t \cot^2 \beta + m^2_b \tan^2 \beta)$, while proportional to $\cot^2 \beta$ for the type I 2HDMs. Thus, photoproduction cross sections of the charged scalars predicted by the MSSM are larger or smaller than those of the TTM model or the TC2 model, which depend on the parameter $\tan \beta$.

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