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$W^{\pm}\pi^{\mp}$ Associated Production in TOPCMTC Model at LHC *

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Abstract In this paper we calculate the production of a charged technipion in association with a W boson at the CERN Large Hadron Collider(LHC) in the context of the topcolor assisted multiscale technicolor(TOPCMTC) model. We find that the cross section of $pp\to b\bar{b}\to W^{\pm}\pi^{\mp}$ is roughly corresponding to the result of the process $pp\to b\bar{b}\to W^{\pm}H^{\mp}$ in the minimal supersymmetric standard model, and for reasonable ranges of the parameters, the cross section can reach some dozens or even more than one hundred fb. The $W^{\pm}\pi^{\mp}$ signal may be clearly visible at LHC.

Key words topcolor assisted multiscale technicolor model, charged technipion, cross section, Large Hadron Collider

1 Introduction

Despite the successful confirmation of the standard model (SM) of elementary particle physics by experimental precision tests during the past few years, the structure of the Higgs sector has been unconfirmed, the mechanism of electroweak symmetry breaking (EWSB) is still a open question. Technicolor theory[1,2] is one of the important candidates to probe new physics beyond the SM. Especially the topcolor assisted technicolor models including the original topcolor assisted technicolor (TOPCTC) model[3] and the topcolor assisted multiscale technicolor (TOPCMTC) model[4], they combine technicolor or multiscale walking technicolor with topcolor, with the former mainly responsible for EWSB and the latter for generating a major part of the top quark mass. Since these models could give a rational interpretation to answer the questions, they have aroused people's great interest. Lots of signals of these models have already been studied in the work environment of linear colliders and hadron-hadron colliders[5—7], but most of the attention was focused on the neutral pseudo Goldstone bosons (PGBs) and new gauge bosons. Here we wish to discuss the prospects of charged PGBs.

The search for Higgs bosons and new physics particles and the study of their properties are among the prime objectives of LHC, a proton-proton colliding-beam facility with the centre-of-mass (c.m.) energy $\sqrt{s}=14$ TeV presently under construction at CERN[8]. For the production of charged Higgs boson in association with a W boson in the minimal supersymmetric standard model, Ref. [9] investigates $b\bar{b}\to W^{\pm}H^{\mp}$ at the tree level and $gg\to W^{\pm}H^{\mp}$ at one loop, and the electroweak corrections and QCD corrections to $b\bar{b}\to W^{\pm}H^{\mp}$ have already been calculated in Ref. [10], which shows that a favorable scenario for $W^{\pm}H^{\mp}$ associated production would be characterized by the conditions that $m_H > m_t - m_b$ and that $\tan\beta$ is either close to unity or of order m_t/m_b, then the $H^{\pm}$ bosons could not spring from on-shell top quarks and could be so copiously produced at hadron colliders. In this paper we shall calculate $W^{\pm}\pi^{\mp}$ associated production in the framework of the TOPCMTC model ($\pi^{\pm}$ denotes the lighter color singlet and isotriplet charged PGBs) to search for new physics particles.

2 Topcolor assisted technicolor models

First we discuss the original TOPCTC model by C. T. Hill[3]. The model assumes[3,11] that: (ⅰ) Electroweak symmetry is broken mainly by extended technicolor (ETC); (ⅱ) The top quark mass is large because it is the combination of a dynamical condensate component, $(1-\varepsilon)m_t$, generated by a

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new strong dynamics, together with a small fundamental component, $\varepsilon m_t(\varepsilon \approx 0.03-0.1)$, generated by ETC; (ⅲ) The new strong dynamics is assumed to be chiral critically strong but spontaneously broken by technicolor at the scale ~1 TeV, and it generally couples preferentially to the third generation. This needs a new class of technicolor models incorporating "topcolor" (TOPC). The dynamics at ~1TeV scale involves the following gauge structure

$$SU(3)_1 \times SU(3)_2 \times U(1)_{Y_1} \times U(1)_{Y_2} \rightarrow SU(3)_{QCD} \times U(1)_{EM}, \quad (1)$$

where $SU(3)_1 \times U(1)_{Y_1}[SU(3)_2 \times U(1)_{Y_2}]$ generally couples preferentially to the third (first and second) generation, and is assumed to be strong enough to form chiral $\langle \bar{t}t \rangle$ but not $\langle \bar{b}b \rangle$ condensation by the $U(1)_{Y_1}$ coupling. A residual global symmetry $SU(3)' \times U(1)'$ implies the existence of a massive color-singlet heavy Z′ and an octed B_μ^A. A symmetry-breaking pattern onlined above will generically give rise to three top pions, neutral π_t^0 and charged $\pi_t^\pm$, near the top mass scale.

According to the idea of TOPCTC, the masses of the first and second generation quarks are all generated by ETC interactions. Then, the difference between ξ_U and ξ_D reflects the mass difference between the charm and strange quarks[4,12]. So we have $m'_t=(m_c/m_s)m'_b$, where m'_t and m'_b are the top- and bottom-quark masses generated by ETC interactions, respectively. For $m_s=0.18$ GeV, $m_c=1.5$ GeV, we have $m'_t \simeq 10 m'_b$.

In this model, there are 60 technipions in the ETC sector with decay constant $f_\pi=123$ GeV and three top pions $\pi_t^0, \pi_t^\pm$ in the TOPC sector with decay constant $f_{\pi_t}=50$ GeV. The ETC sector is one generation technicolor model[2]. In 60 technipions the color-singlets π and color-octets π_8 are extensively and universally studied. The color-singlets π include the isosinglet π^0 and the isotriplets $(\pi^\pm, \pi^3)$, while the color-octets π_8 involve the isosinglet π_8^0 and the iso-octets $(\pi_8^\pm, \pi_8^3)$. The coupling of these PGBs to top(bottom) quark are given by[2,13]

$$\frac{i\sqrt{2}c_t}{f_\pi}[m_t\bar{t}\gamma_5 t\pi^0 + m_b\bar{b}\gamma_5 b\pi^0 + m_t\bar{t}\gamma_5 t\pi^3 + m_b\bar{b}\gamma_5 b\pi^3 + \sqrt{2}V_{tb}\bar{t}(m_bR - m_tL)b\pi^+ + \sqrt{2}V_{tb}\bar{b}(m_tR - m_bL)t\pi^-], \quad (2)$$

$$\frac{i\sqrt{2}\lambda^a}{f_\pi}[m_t\bar{t}\gamma_5 t\pi_8^0 + m_b\bar{b}\gamma_5 b\pi_8^0 + m_t\bar{t}\gamma_5 t\pi_8^3 + m_b\bar{b}\gamma_5 b\pi_8^3 + \sqrt{2}V_{tb}\bar{t}(m_bR - m_tL)b\pi_8^+ + \sqrt{2}V_{tb}\bar{b}(m_tR - m_bL)t\pi_8^-], \quad (3)$$

where $L, R = (1 \mp \gamma_5)/2$ are the left-and right-handed projectors, the coefficient $c_t = 1/\sqrt{6}$, λ^a is a Gell-Mann matrix acting on ordinary color indices. In this model $m_t \rightarrow m'_t = \varepsilon m_t$, $m_b \rightarrow m'_b = 0.1 m'_t$. That the color-singlets $\pi^\pm$ predicted are the lighter will be studied in this paper.

The interaction of the top pions with the top and bottom quarks has the form

$$\frac{i}{f_{\pi_t}}\left[\frac{1}{\sqrt{2}}m_t^*\bar{t}\gamma_5 t\pi_t^0 + \frac{1}{\sqrt{2}}m_b^*\bar{b}\gamma_5 b\pi_t^0 + V_{tb}\bar{t}(m_t^*L + m_b^*R)\cdot b\pi_t^+ + V_{tb}\bar{b}(m_t^*R + m_b^*L)t\pi_t^-\right], \quad (4)$$

where $m_t^* = (1-\varepsilon)m_t$, $m_b^* = m_b - m'_b$ denote the masses of top and bottom generated by TOPC interaction, respectively. More detailed Feynman rules needed in the calculations can be found in Refs. [3,13].

For the topcolor assisted multiscale technicolor model[4], it is different from the original TOPCTC model mainly by the ETC sector. In the original TOPCTC model, the ETC sector is the one generation technicolor model with $f_\pi = 123$ GeV and $c_t = 1/\sqrt{6}$ in Eq. (2), and in TOPCMTC model the ETC sector is the multiscale walking technicolor model[14] with $f_\pi = 40$ GeV and $c_t = 2/\sqrt{6}$.

3 The cross section of $pp \rightarrow b\bar{b} \rightarrow W^\pm \pi_t^\mp$

As a rough estimate, we only consider $W^\pm\pi^\mp$ associated production at the tree level. The Feynman diagrams for the color-singlet charged technipion production via $b(p_1)\bar{b}(p_2) \rightarrow W^\pm(k_2)\pi_t^\mp(k_1)$ are shown in Fig. 1.

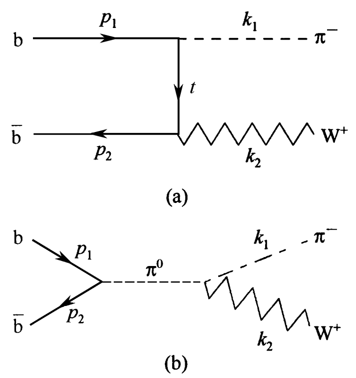

Fig. 1. Feynman Diagrams for $b\bar{b} \rightarrow W^+\pi^-$ at the tree level.

We define the Mandelstam variables as

$$\hat{s} = (p_1+p_2)^2 = (k_1+k_2)^2,$$

$$\hat{t} = (p_1 - k_1)^2 = (p_2 - k_2)^2,$$
$$\hat{u} = (p_1 - k_2)^2 = (p_2 - k_1)^2. \quad (5)$$

The amplitude for $b\bar{b} \to W^+\pi^-$ can be written as

$$M = M_0^{(\hat{s})} + M_0^{(\hat{t})}, \quad (6)$$

where $M_0^{(\hat{s})}$ and $M_0^{(\hat{t})}$ are given by

$$M_0^{(\hat{s})} = \frac{\sqrt{2} g c_t m'_b}{f_\pi} \frac{1}{\hat{s} - m_\pi^2} [M_5 - M_6 + M_9 - M_{10}] , \quad (7)$$

and

$$M_0^{(\hat{t})} = -\frac{g V_{tb}^2}{\sqrt{2} f_\pi} \frac{1}{\hat{t} - m_t^2} [m'_b (2M_9 - m_b M_1 + M_3) - m_t m'_t M_2] . \quad (8)$$

The coupling constant g is defined by $e/\sin\theta_W$, θ_W is the Weinberg angle. M_i is the standard matrix element, which is defined by

$$M_1 = \bar{v}(p_2) \not\varepsilon(k_2) R u(p_1) ,$$
$$M_2 = \bar{v}(p_2) \not\varepsilon(k_2) L u(p_1) ,$$
$$M_3 = \bar{v}(p_2) \not k_2 \not\varepsilon(k_2) R u(p_1) ,$$
$$M_4 = \bar{v}(p_2) \not k_2 \not\varepsilon(k_2) L u(p_1) ,$$
$$M_5 = \bar{v}(p_2) R u(p_1) p_1 \cdot \varepsilon(k_2) ,$$
$$M_6 = \bar{v}(p_2) L u(p_1) p_1 \cdot \varepsilon(k_2) ,$$
$$M_7 = \bar{v}(p_2) \not k_2 R u(p_1) p_1 \cdot \varepsilon(k_2) ,$$
$$M_8 = \bar{v}(p_2) \not k_2 L u(p_1) p_1 \cdot \varepsilon(k_2) ,$$
$$M_9 = \bar{v}(p_2) R u(p_1) p_2 \cdot \varepsilon(k_2) ,$$
$$M_{10} = \bar{v}(p_2) L u(p_1) p_2 \cdot \varepsilon(k_2) ,$$
$$M_{11} = \bar{v}(p_2) \not k_2 R u(p_1) p_2 \cdot \varepsilon(k_2) ,$$
$$M_{12} = \bar{v}(p_2) \not k_2 L u(p_1) p_2 \cdot \varepsilon(k_2) . \quad (9)$$

The cross section for the process $b\bar{b} \to W^\pm\pi^\mp$ is

$$\hat{\sigma} = \int_{\hat{t}_-}^{\hat{t}_+} \frac{1}{16\pi\hat{s}^2} \overline{\sum} |M|^2 d\hat{t} , \quad (10)$$

with

$$\hat{t}_\pm = \frac{m_W^2 + m_\pi^2 - \hat{s}}{2} \pm \frac{1}{2}\sqrt{[\hat{s} - (m_W + m_\pi)^2][\hat{s} - (m_W - m_\pi)^2]} . \quad (11)$$

The total hadronic cross section for $pp \to b\bar{b} \to W^\pm\pi^\mp$ can be obtained by folding the subprocess cross section $\hat{\sigma}$ with the parton luminosity

$$\sigma(s) = \int_{(m_W + m_\pi)/\sqrt{s}}^{1} dz \frac{dL}{dz} \hat{\sigma}(b\bar{b} \to W^\pm \pi^\mp \text{ at } \hat{s} = z^2 s) . \quad (12)$$

Here $\sqrt{s}$ and $\sqrt{\hat{s}}$ are the c. m. energies of the pp and $b\bar{b}$ states, respectively, and dL/dz is the parton luminosity, defined as

$$\frac{dL}{dz} = 2z \int_{z^2}^{1} \frac{dx}{x} f_{b/p}(x, \mu) f_{\bar{b}/p}(z^2/x, \mu) , \quad (13)$$

where $f_{b/p}(x, \mu)$ and $f_{\bar{b}/p}(z^2/x, \mu)$ are the bottom quark and bottom antiquark parton distribution functions, respectively.

4 The numerical results, discussions and conclusions

We are now in a position to explore the phenomenological implications of our results. The SM imput parameters for our numerical analysis are $G_F = 1.16639 \times 10^{-5}$ GeV^{-2}[15], $m_W = 80.41$ GeV, $m_t = 175.6$ GeV, and $m_b = 4.7$GeV. We use the CTEQ5M parton distribution function[16] with $\mu = \sqrt{s}/2$. The parameter ε and the mass of charged technipion $\pi^\pm$ are all model-dependent, we select them as free parameters, $0.03 \leqslant \varepsilon \leqslant 0.1$ and 100 GeV $\leqslant m_\pi \leqslant$ 400 GeV to estimate the total cross section of $W^\pm\pi^\mp$ associated production at LHC.

The final numerical results are shown in Figs. 2 and 3.

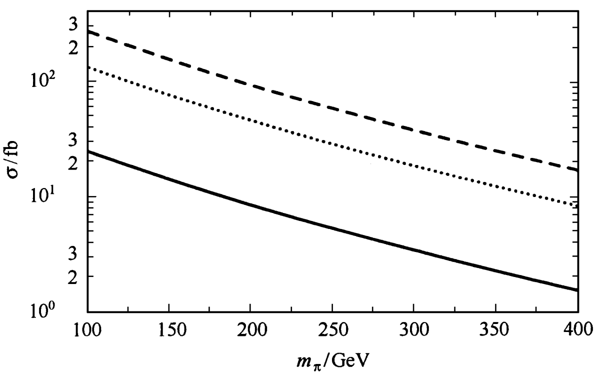

Fig. 2. The total cross section versus m_π for $\varepsilon = 0.03$ (solid), 0.07 (dotted), 0.1 (dashed) in TOPCMTC model.

In Fig. 2, the total cross section as a function of m_π for $\varepsilon = 0.03, 0.07$ and 0.1 at LHC with $L = 100\text{fb}^{-1}$ is given. Fig. 3 is the plot of the fully integrated cross section due to $b\bar{b}$ annihilation versus ε for $m_\pi = 150$ GeV. From these diagrams, we can see that(ⅰ) the cross section increases with ε sensitively; (ⅱ) the cross section σ decreases quickly as m_π increase, changes the values from 132 fb to 8.34 fb with the range of m_π, 100 – 400 GeV for $\varepsilon = 0.07$, this cross section is roughly corresponding to that of the process $pp \to b\bar{b} \to W^\pm H^\mp$ in the

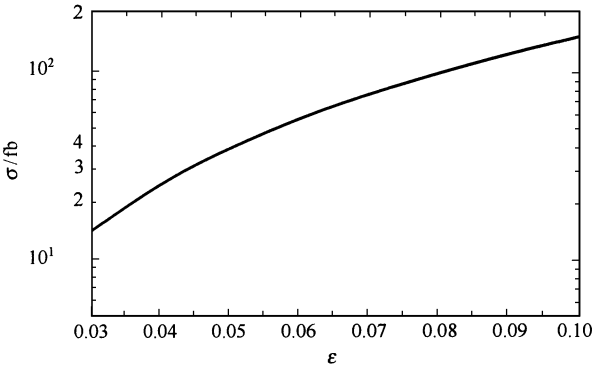

Fig.3. The curve of $\sigma(pp\to b\bar{b}\to W^{\pm}\pi^{\mp})$ vs. ε for $m_\pi = 150$ GeV in TOPCMTC model.

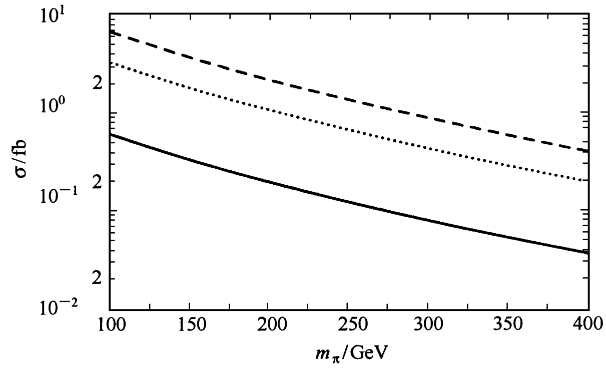

Fig.4. The same as Fig.2 but in TOPCTC model.

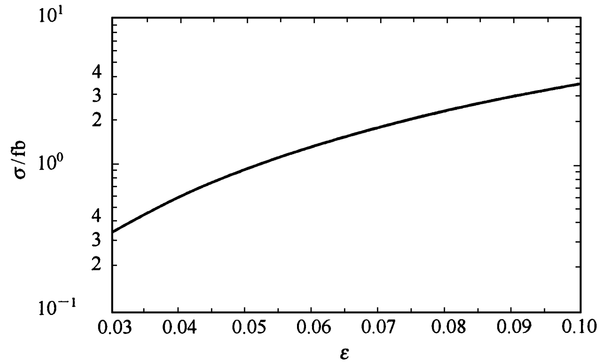

Fig.5. The same as Fig.3 but in TOPCTC model.

minimal supersymmetric standard model[9]; (ⅲ) for $m_\pi = 150$ GeV, the cross section of $W^{\pm}\pi^{\mp}$ associated production due to $b\bar{b}$ annihilation is roughly some dozens or even more than one hundred fb, and is rather large.

At LHC, the integrated luminosity is expected to reach $L = 100\mathrm{fb}^{-1}$ per year, it shows that a cross section of 1 fb could translate into about 60 detectable $W^{\pm}H^{\mp}$ events per year[9,15]. Looking at Fig.3, we thus conclude that, depending on ε, one should be able to collect an annual total of between 9.0×10^3 and 8.2×10^2 events if $m_\pi = 150$ GeV. So the $W^{\pm}\pi^{\mp}$ signal should be clearly visible at LHC.

It is necessary to point out that the calculated results in TOPCMTC model are strongly dependent on important parameters of this model. It is model-dependent and has some uncertainties like the results given out in the other models. For the original TOPCTC model, our calculations show that the cross section is rather small and is only roughly one tenth of the relevant result in TOPCMTC model due to the larger decay constant of the technipions $f_\pi = 123$ GeV (Looking at Figs.4 and 5). So we only give our analyses of the possibility of producing $pp\to b\bar{b}\to W^{\pm}\pi^{\mp}$.

In conclusion, we have calculated the production of a charged technipion in association with a W boson at the CERN LHC in the topcolor assisted multiscale technicolor model. We find that, the cross section of $pp\to b\bar{b}\to W^{\pm}\pi^{\mp}$ is roughly corresponding to that of the process $pp\to b\bar{b}\to W^{\pm}H^{\mp}$ in the minimal supersymmetric standard model, and with reasonable values of the parameters, the cross section can reach some dozens or even more than one hundred fb. It is so large that the $W^{\pm}\pi^{\mp}$ signal may be clearly visible at LHC. Certainly, as a rough estimate, we only calculate the cross section of the process $pp\to b\bar{b}\to W^{\pm}\pi^{\mp}$ at the tree level, the electroweak corrections and QCD corrections to this process remain.

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TOPCMTC 模型中 $\pi^{\mp}$ 介子与 $W^{\pm}$ 规范玻色子在 LHC 上的辅助产生*

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摘要　在顶色辅助多标度人工色(TOPCMTC)模型下计算了大动量强子对撞机(LHC)上 $\pi^{\mp}$ 介子与 $W^{\pm}$ 规范玻色子辅助产生过程 $pp\to b\bar{b}\to W^{\pm}\pi^{\mp}$ 的产生截面.发现这个产生截面与最小超对称模型下 $pp\to b\bar{b}\to W^{\pm}H^{\mp}$ 的相应结果大致相当.在一定的参数范围内,这个过程的产生截面能够达到几十个甚至一百多个 fb. $W^{\pm}\pi^{\mp}$ 的信息可能在 LHC 上被探测到.

关键词　顶色辅助多标度人工色模型　荷电人工色介子　产生截面　大动量强子对撞机

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