Discovery Potential of New Boson $W_1^{\pm}$ in the Minimal Higgsless Model at LHC

Jian-Guo Bian[1],* Guo-Ming Chen[1], Ming-Shui Chen[1], Hong-Jian He[2],
Zu-Hao Li[1], Song Liang[1], Xiang-Wei Meng[1], Zhi-Cheng Tang[1], Jun-Quan Tao[1],
Jian Wang[1], Jian Wang[3], Hong Xiao[1], Xian-You Wang[4], Min Yang[1],
Yong-Hui Qi[2], Jing-Jing Zang[1], Bin Zhang[2], Zhen Zhang[1], and Zhen-Xia Zhang[1]

[1] *Institute of High Energy Physics, Beijing 100049, China*

[2] *Center for High Energy Physics, Tsinghua University, Beijing 100084, China*

[3] *Physics College, Graduate University of Chinese Academy of Sicences, Beijing 100049, China*

[4] *Theoretical Physics Institute, ChongQing University, ChongQing 400044, China*

(Dated: November 4, 2008)

Abstract

In this paper, we demonstrate the LHC discovery potential of new charged vector boson $W_1^{\pm}$ predicted by the Minimal Higgsless model in the process $pp \to W_1^{\pm} qq' \to W^{\pm} Z^0 qq \to \ell^{\pm}\ell^{+}\ell^{-}\nu qq' (\ell = e, \mu)$ by analyzing the generator level events of the signal and backgrounds. The generator for the signal $pp \to {W_1}^{\pm} qq' \to W^{\pm} Z^0 qq'$ at tree level is developed with the Minimal Higgsless model and then corporated with PYTHIA for the initial and final state radiation and parton hadronization. The backgrounds are produced wih PYTHIA. We give integrated luminosities required to discover 5σ signal as a function of $W_1^{\pm}$ mass.

*Electronic address: `bianjg@mail.ihep.ac.cn`

I. INTRODUCTION

If the Higgs does not exist as predicted by the standard model of electroweak interaction, the unitarity violation will appear in the scattering of massive gauge $W^{\pm}Z^0 \to W^{\pm}Z^0$[1]. To postpone the unitarity, the Higgsless models are proposed, in which new spin-1 gauge bosons play the key role. The typical ones of the models are 5d Higgsless model[1] and the Minimal Higgs model[2]. The former predicts a tower of Kaluza-Klein gauge states, while the latter predicts just one pair of new ($W_1^{\pm}$, Z_1) bosons as light as 400 GeV.

The signature of new boson $W_1^{\pm}$ in the process $pp \to W^{\pm}Z^0qq' \to \nu 3\ell qq'$ and the process $pp \to W^{\pm}Z^0Z^0 \to qq'4\ell$ ($\ell = e, \mu$) were investigated at the parton level, without the initial and final state radiation and parton hadronization for the signal and backgrounds, while the background is only the process $pp \to W^{\pm}Z^0qq'$. Assuming $W_1^{\pm}$ mass within the region of (550, 750)GeV, the integrated luminosity required for 5σ $W_1^{\pm}$ signal detection is from about 12/fb to 25/fb for the first channel, while from about 40/fb to 300/fb for the second channel[2].

This work presents the results on the study of $W_1^{\pm}$ production in the process $pp \to W_1^{\pm}qq' \to W^{\pm}Z^0qq'$ by analyzing the fully hadronized events of the signal and backgrounds at the generator level. The final state is chosen to be $\ell^{\pm}\nu\ell^+\ell^-qq'$ ($\ell = e, \mu$), because electrons and muons are well identified by the LHC detectors. The generator for the signal $pp \to W_1^{\pm}qq' \to W^{\pm}Z^0qq' \to \ell^{\pm}\nu\ell^+\ell^-qq'$ is developed based on the Minimal Higgsless model and corporated with PYTHIA[3] for the initial and final state photon and gluon showers and parton hadronization.

Fig. 1 is Feynman diagram for the process $pp \to W_1^{\pm}qq' \to W^{\pm}Z^0qq' \to \ell^{\pm}\ell^+\ell^-\nu qq'$. The intermediate state $W_1^{\pm}$ proceeds thought $W^{\pm}Z^0$ fusion. The typical cross sections (assuming m_{W_1} to be 700 GeV) are 2.828 fb and 1.538 fb for $pp \to W_1^+qq' \to W^+Z^0qq' \to \ell^+\nu\ell^+\ell^-qq'$ and $pp \to W_1^-qq' \to W^-Z^0qq' \to \ell^-\nu\ell^+\ell^-qq'$ respectively.

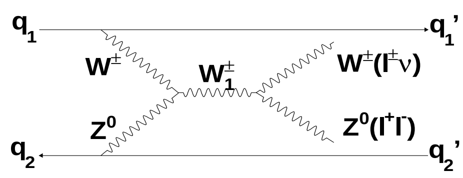


FIG. 1: Feynman diagram

The advantage of the study is that the hadronized events are more realistic than the parton events at the original work[2] for both of the signal and backgrounds. Besides, more backgrounds will be discussed in this work.

II. SIGNAL AND BACKGROUND PRODUCTION

A. Signal cross section and sample

The generator for the signal is developed by the authors of ref.[2] based on the matrix element calculation of the LHC process $pp \to W_1{}^{\pm}qq' \to W^{\pm}Z^0qq' \to \ell^{\pm}\ell^{+}\ell^{-}\nu qq'$ at a full tree level in the Minimal Higgsless model. The Parton Distribution Function CTEQ6L[5] is used. In this work the loose pre-selections at parton level are used to replace the original ones[2] to increase the cross section:

jets satisfy $\quad pt_j > 25\ GeV, \quad \mid \eta_j \mid < 7.0,$

leptons satisfy $\quad pt_\ell > 5\ GeV, \quad \mid \eta_\ell \mid < 2.5.$

The weighted parton level events from the generator are fed into PYTHIA for sampling. PYTHIA adds the initial and final state radiation and parton hadronization to the events automatically. The output from PYTHIA is the unweighted events.

The cross section for the preselection and the number of events and the normalization factor are listed in Table. 1. The luminosity is set to be 20/fb. The W_1^+ signal and W_1^- signal are produced separately with 1000 events each. The normalization factor is $(cross\ section) \times 20(fb^{-1})/events$. The uncertainties of the cross section is discussed in the paragraph of IV.

B. Background cross sections and samples

There are three leptons ($\ell = e^{\pm}, \mu^{\pm}$) and two forward quarks in the signal process. Therefore the contamination to the signal process comes from processes including multiple ℓ events in the final state. In this work, the generators for backgrounds are from PYTHIA with all the default parameters.

In view of the final state of the signal process, the irreducible backgrounds are $pp \to W^{\pm}Z^0 \to \ell^{\pm}\nu\ell^{+}\ell^{-}$ and $pp \to W^{\pm}Z^0qq' \to \ell^{\pm}\nu\ell^{+}\ell^{-}qq'$. Their lepton components are identical to that of the signal process. The first process is a leading order process. The initial and

Table 1 Production of Sample

$W_1^\pm$ mass	$W_1^+qq' \to W^+Z^0qq' \to \ell^+\nu\ell^+\ell^-qq'$			$W_1^-qq' \to W^-Z^0qq' \to \ell^-\nu\ell^+\ell^-qq'$		
(GeV)	cross section (fb)	events	norm	cross section (fb)	events	norm
550	$6.303 \pm 0.364 \pm 0.076$	1000	0.126	$3.674 \pm 0.248 \pm 0.896$	1000	0.073
600	$4.844 \pm 0.260 \pm 0.440$	1000	0.097	$2.728 \pm 0.156 \pm 0.056$	1000	0.054
650	$3.685 \pm 0.192 \pm 0.264$	1000	0.074	$2.101 \pm 0.124 \pm 0.080$	1000	0.042
700	$2.828 \pm 0.152 \pm 0.164$	1000	0.056	$1.538 \pm 0.072 \pm 0.012$	1000	0.031
750	$2.215 \pm 0.124 \pm 0.056$	1000	0.044	$1.176 \pm 0.060 \pm 0.048$	1000	0.023

final gluon radiations will add jets to the final states at the hadron level. The second is a next leading order process, in which there are two forward quarks $qq\prime$. The cross section of the second process is about 0.06% of that of the first process. The first process is a major contamination source.

Because additional leptons may come from the decays of q and q' or those quarks introduced by the QCD interaction, there is possibility that the two lepton process $pp \to W^+W^- \to 2\ell 2\nu$ and the corresponding next leading process $pp \to W^+W^-qq' \to 2\ell 2\nu qq'$ may construct a state of 3 leptons. The second process includes $Z^0Z^0 \to W^+W^-(0.003\%)$ and $W^+W^- \to W^+W^-(99.997\%)$.

If a lepton goes beyond the detection region where $|\eta| > 2.5$, the four lepton process $pp \to Z^0Z^0 \to 4\ell$ and the corresponding next leading process $pp \to Z^0Z^0qq' \to 4\ell qq'$ possibly construct a final state of 3 leptons. If an additional lepton comes from a quark decay, the two lepton process $pp \to Z^0Z^0 \to 2\ell q_i\overline{q}_i$ and the corresponding next leading process $pp \to Z^0Z^0qq' \to 4\ell q_i\overline{q}_i qq'$ also construct a final state of 3 leptons. The second process includes $Z^0Z^0 \to Z^0Z^0(0.1\%)$ and $W^+W^- \to Z^0Z^0(99.9\%)$. In PYTHIA Z^0 denotes Z^0/γ^*. The processes include Z^0Z^0, $Z^0\gamma^*$, $\gamma^*\gamma^*$ and their interference. Therefore, one of the two Z^0 is chosen to decay into a pair of electrons or muons and another is allowed to decays free in this work.

The multiple leptons processes that have very large cross sections are $pp \to Z^0b\overline{b} \to 2\ell 2\nu b\overline{b}$ and $pp \to t\overline{t} \to W^+bW^-\overline{b} \to 2\ell 2\nu b\overline{b}$ including $q\overline{q} \to t\overline{t}(13.9\%)$ and $gg \to t\overline{t}(86.1\%)$. b quark are left free to decay according to its branching factions as the default parameters in PYTHIA. There are two leptons in the final state. The third ℓ production may come from the direct or cascade decay of b quark.

The cross sections, the numbers of the events and the normalization factors for the background samples are given in the Table 2. It is worth noting that all normalization factors are less than 1.

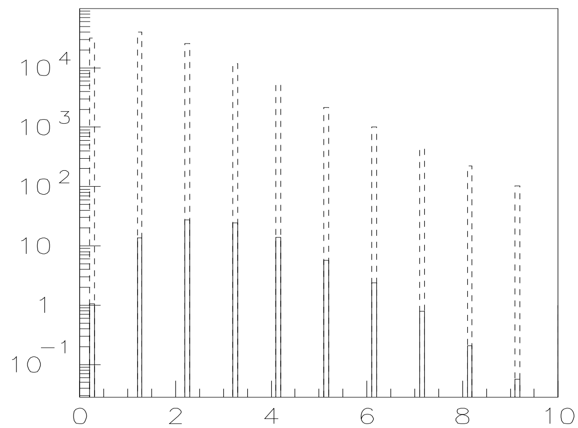
Table 2 production of backgrounds

Process	cross section (fb)	*events*	norm. factor
$f\overline{f}', W^{\pm}Z^0 \rightarrow W^{\pm}Z^0 \rightarrow 3\ell\nu$	389.70+0.24	6E4	0.130
$f\overline{f}, W^+W^-, Z^0Z^0 \rightarrow W^+W^- \rightarrow 2\ell 2\nu$	3295+5673+0.14	54E4	0.332
$f\overline{f}, W^+W^-, Z^0Z^0 \rightarrow Z^0Z^0 \rightarrow 2\ell X$	1676+0.54+7.4E-4	140000	0.240
$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow 2\ell 2\nu b\bar{b}$	22980	2.16E6	0.213
$Z^0b\bar{b} \rightarrow 2\ell b\bar{b}$	3.244E+5	2.7E+7	0.240

f represents a fundamental fermion of flavour d, u, s, c, b, t, e^-, ν_e, μ, ν_μ, τ, ν_τ.

III. EVENT SELECTION

Event selection is based on the feature of the signal process. There are 3 leptons with high momentum and two hard forward quarks in the final state at the parton level. Two of 3 leptons come from the Z^0 decay and one from the $W^{\pm}$ decay. The two forward quarks are supposed to evolve into hard forward jets. Events are accepted if there are three leptons in the final states at hadron level and total charge of three leptons is equal to 1 or -1. Each lepton satisfies $\mid \eta_\ell \mid < 2.5$, $p_\ell > 10\ GeV$. Then number of jets is required to be equal to or larger than 2, see Fig. 2. Each jet is reconstructed with Cone of $\Delta R = \sqrt{\Delta\eta^2 + \phi^2} = 0.7$ and satisfies $\mid \eta_j \mid < 4.5$ and $p_j > 25\ GeV$ and $\Delta R(j, \mu) > 0.3$ to suppress fake jets. The jet reconstruction algorithm is one provided with PYTHIA[3], in which a detector grid is assumed, with the pseudorapidity range $\mid \eta \mid < \eta_{max}(4.5)$ and the full azimuthal range each divides into 50 equally large bins, giving a rectangeular grid; the cell with largest ET is taken as a jet initiator; a candidate jet is defined to consist of all cells which are within $(\eta_{-}\eta_{initiator})^2 + (\phi - \phi_{initiator})^2 < \Delta R$; the candidate jet is accepted if the summed ET is above 7 GeV and its all cells are removed from futher consideration; The sequence is now repeated within the remaining cell of highest ET and so on. The cut is powerful to remove the background $W^{\pm}Z^0 \to 3\ell\nu$, $WW \to 2\ell 2\nu$,$Z^0Z^0 \to 4\ell$, because there are not quarks in the final states at the parton level.



Number of jets

FIG. 2 The solid line is jet number distribution for the signal process. The dashed line is for the backgrounds.

To suppress the backgrounds, the highest one of 3 ℓ's momenta is required to be larger than 150 GeV, see Fig. 3. For the signal process, the threshold of the momentum distribution is 150 GeV, thanks to that the three leptons come from $W_1^{\pm}$ with large mass. The thresholds are 60 GeV for background processes. Out of the same reason, the scalar sum of pt of 3 ℓs and missing E_t is required to be larger than 700 GeV. The distribution is between 200 and 1500 GeV for the signal, but it is between 200 and 600 GeV for the irreducible background $W^{\pm}Z^0 \to \ell^{\pm}\nu\ell^+\ell^-$.

The reconstruction of Z^0 and $W^{\pm}$ using 3 ℓs and one missing neutrino is a prerequisite for the signal event selection. The remaining events are required to satisfy $\mid m_{Z^0} - 91.18 \mid < 15\ GeV$ and $mt_{W^{\pm}} < 200\ GeV$.

To suppress the background $pp \to W^{\pm}Z^0,\ Z^0 b\bar{b}$ further, the ratio of the scalar sum of jets' transverse momenta and the scalar sum of jets' momemta is larger than 0.1. Finally, the transverse mass of $W^{\pm}Z^0$ denoted as mh for the remaining events is shown in Fig. 2. The definition of mh is

$$mh = \sqrt{E^2 - p^2},$$

where

$$E = \sum_{i=1}^{3} E_{\ell i} + \sqrt{px_{miss}^2 + py_{miss}^2})^2,$$

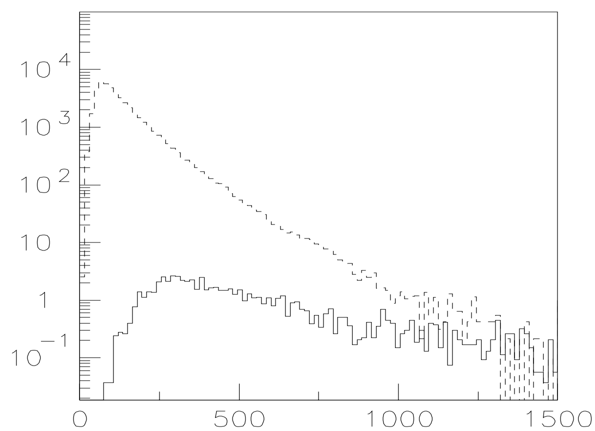
$$p = \sqrt{(\sum_{i=1}^{3} px_{\ell i} + px_{miss})^2 + (\sum_{i=1}^{3} py_{\ell i} + py_{miss})^2 + (\sum_{i=1}^{3} pz_{\ell i})^2}.$$

The new definition is different from the conventional transverse mass

$$mt = \sqrt{(\sum_{i=1}^{3} Et_{\ell i} + \sqrt{px^2_{miss} + py^2_{miss}})^2 - (\sum_{i=1}^{3} px_{\ell i} + px_{miss})^2 - (\sum_{i=1}^{3} py_{\ell i} + py_{miss})^2}.$$

We call it half transverse mass temporarily, because it take all available components of momenta into account so that the number of components of momenta involved is larger than that of the transverse mass and less than that of the mass.

The number of remaining events and efficiency after each cut are shown in Table 3 where $W_1^{\pm}$ mass is 700 GeV. The significance is 7.8 σ using significance=$\sqrt{2ln(Q)}$, $Q = (1 + N_s/N_b)^{N_{obs}} exp(-N_s)$, which corresponds to 5.0 σ for the luminosity of 8.3 fb^{-1}.



Highest one of three leptons' momenta (GeV)

FIG. 3 The solid line is th distribution of highest one three leptons' momenta. The dashed line is for the backgrounds.

Varying m_{W_1} to be 550, 600, 650, 750 GeV, the signal process for luminosity of 20/fb can be processed with the same criteria with 700 GeV. The remaining events and significances and the luminosity for 5σ signal detection are shown in Table 4.

IV. SYSTEMATIC UNCERTAINTIES

For the generator level events, the resources of uncertainties on the signal significance and the luminosity to find 5σ signal are the uncertainties of both the signal and background cross sections.

Table 3 Remaining Events and Efficiency(%) for Each Cut

	Signal of W_1^+	Signal of W_1^-	WZ	WW	ZZ	$t\bar{t}$	$Z^0 b\bar{b}$
$CR \times 20fb$	56.6	30.8	7794.0	179380.0	33540.0	459600.0	6.48E6
	100.00	100.00	100.00	100.00	100.00	100.00	100.00
number of	54.0	29.5	3312.3	682.3	1097.2	58412.6	55663.2
leptons = 3	95.40	96.00	42.50	0.32	3.22	12.71	0.86
number of	46.3	23.7	30.1	521.5	135.9	25147.1	21114.5
jets $\geq$ 2	81.80	77.20	0.39	0.29	0.41	5.47	0.33
maximum mon of	45.8	23.4	17.1	207.6	67.8	7994.7	5251.0
3 leps. > 150 GeV	81.0	76.10	0.22	0.2	0.20	1.74	0.08
scalar sum p of 3 leps.	24.3	11.1	0.5	7.3	1.3	73.6	19.4
and $pt_{missing}$ > 700 GeV	43.00	36.20	0.006	4.1E-3	3.8E-3	0.016	3.0E-4
$\mid M_{\mu^+\mu^-} - M_{Z^0} \mid$	23.4	10.6	0.4	0.3	1.3	7.0	16.1
< 15 GeV	41.30	34.3	0.005	1.9E-4	3.8E-3	1.5E-3	2.5E-4
$0 < M_{wt}$	22.8	910.3	0.4	0.3	1.3	5.1	16.1
< 200 GeV	40.30	33.50	0.005	1.9E-4	3.8E-3	1.1E-4	2.5E-4
Jets' pt/p	20.1	9.6	0.3	0	1.2	4.9	1.0
> 0.1	35.50	31.30	3.3E-3	0	3.5E-3	1.1E-4	1.5E-5
total	29.7		7.4				

The mass of $W_1^\pm$ is set to be 700 GeV in the table.

The cross section uncertainty for the signal process here includes the statistical error and the difference between two PDFs cteq6l[5] and cteq6m141[6] listed in Table 2 as the first and second errors respectively. The uncertainty of the background cross sections are assumed to be 100%. The uncertainties on number of signal events, number of background events for luminosity of 20/fb and the uncertainty of luminosity to find 5σ signal caused by the uncertainty are listed on Table 4.

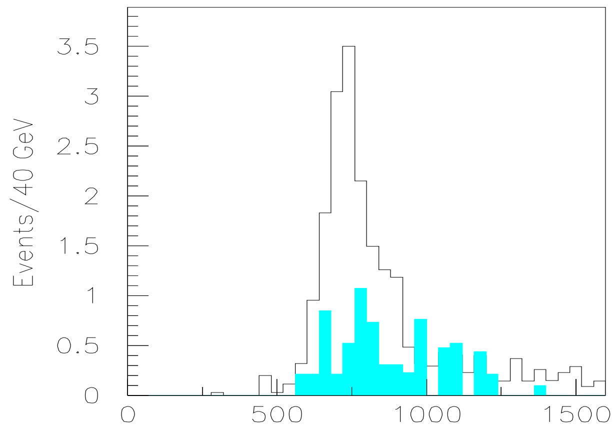
Table 4 Events and Significance for luminosity of $20/fb$ and the luminosity for 5σ signal detection

m_{W_1} (GeV)	Signal	bg	Significance(σ)	luminosity(fb^{-1})
550	$52.3\ ^{+5.2}_{-5.2}$	$7.4\ ^{+7.4}_{-0.0}$	$12.0\ ^{+0.9}_{-2.9}$	$3.5\ ^{+2.5}_{-0.5}$
600	$41.1\ ^{+3.0}_{-3.0}$	$7.4\ ^{+7.4}_{-0.0}$	$10.0\ ^{+0.6}_{-2.3}$	$5.0\ ^{+3.5}_{-0.6}$
650	$35.3\ ^{+2.2}_{-2.2}$	$7.4\ ^{+7.4}_{-0.0}$	$8.9\ ^{+0.4}_{-2.1}$	$6.3\ ^{+4.5}_{-0.6}$
700	$29.7\ ^{+1.6}_{-1.6}$	$7.4\ ^{+7.4}_{-0.0}$	$7.8\ ^{+0.3}_{-1.9}$	$8.3\ ^{+5.9}_{-0.7}$
750	$26.4\ ^{+1.2}_{-1.2}$	$7.4\ ^{+7.4}_{-0.0}$	$7.1\ ^{+0.2}_{-1.7}$	$10.0\ ^{+7.2}_{-0.7}$

V. SUMMARY

We have studied discovery potential of new charged boson $W_1^\pm$ in the process $pp \to W_1^\pm qq' \to W^\pm Z^0 qq\prime \to \ell^\pm \nu \ell^+ \ell^- (\ell = e,\ \mu)$ based on the hadronized events at the generator level. The signal generator is developed with the Minimal Higgsless model. The background processes including multiple muons are discussed. The uncertainty on the luminosity for 5σ signal detection propagated from the uncertainties of cross sections are estimated. Compared with the origanl work[2], the luminosity for 5σ signal detection is lowed by a factor of one third.

The signal cross section decreases with the increase of W_1 mass. Because we do not know what is W_1 mass before analyzing data, the identical selection criteria is used to select the signal and background events for the various assuming mass of W_1 from 550 to 750 GeV. Therefore the contamination from the backgrounds is always 7.4 events. In future, when we contact with data and the LHC detector simulated events, the selection criteria can be optimized according to practical mass of W_1, which will make the luminosity for 5σ signal detection lower than what it is now.



mh(GeV)

FIG. 4 The solid line is the $W^{\pm}Z^0$ mass distribution defined as mh for the signa. The shaded area is the backgrounds.

[1] Phys.Rev.Lett. 94 (2005) 191803, Andreas Birkedal, KonstantinMatchev, et al.

[2] Phys.Rev. D78 (2008) 031701(R), Zhang Bin, Kuang Yuping, et al.

[3] hep-ph/0308153, T. Sjostrand, L. Lonnblad, S.Mrenna and P.S.kands.

[4] CMS Analysis Note 2006/063, V. Brigljevic, D. Ferencek, S. Morovic, M. Planinic

[5] JHEP 0207 (2002) 012 [arXiv:hep-ph/020195], J. Pumplin, D.R. Stump, et al.

[6] Eur. Phys. J.12 (2000) 375, H.L. Lai, et al.