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Some New Particles beyond the Standard Model

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Abstract

In this work a simulated B-L model at Large Hadrons Collider is presented using Monte Carlo simulation software. B-L model is one of the scenarios proposed to add an extension of the standard models. B-L model predicts the existence of three new particles at the LHC. They are a new neutral massive gauge boson, three heavy neutrinos and a heavy Higgs boson.

Keywords

Monte Carlo Simulation, Production Cross Section, Particles beyond the Standard Model

1. Introduction

There are many attempts to understand the world around us in terms of fundamental building blocks of matter. The question here is what the world is made of? Now we can say that the behavior of all known subatomic particles can be described within a single theoretical framework called the Standard Model (SM). The Standard Model of fundamental particles and their interactions is one of the most successful theories in physics. In particular, up to the weak scale (a few hundreds of GeV) it agrees to a great degree with a large set of experimental data. However, there are several theoretical reasons, such as the so-called "Hierarchy Problem", as well as experimental ones, such as the neutrino masses and the evidence for dark matter in the Universe, to expect that something new (Particles and/or interactions) could lie at the TeV scale. Hints and/or answer(s) to these fundamental questions will be provided by the Large Hadrons Collider (LHC), a proton-proton collider which is running at high energies. In this work, Monte Carlo simulations [1-6] of new physics scenario B-L model are used to simulate the phenomenological consequences of this model. In the present work a B-L model extension of Standard Model is proposed and the results of simulation of gauge sector of B-L model (new neutral massive gauge boson) are presented. Also the results of the simulation of fermions sector of B-L model (new heavy neutrino—Right handed neutrino) are presented along with the results of simulation of scalar sector of B-L model (new heavy Higgs boson). Generators are used to set detector requirements, to formulate analysis strategies, or to calculate acceptance corrections. The simulation process of the whole proton-proton collision at CMS is performed through steps, event generator, GEANT4 simulation, digitization, event filter, reconstruction, and then the physics analysis. There are many appropriate Monte Carlo (MC) event generators like PYTHIA and AlpGen that produce events of proton-proton collision, and they also provide highly accurate statements of event properties: parton shower, hadronization, and underlying events. The events generators are interfaced to the CMS

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Software (CMSSW) via associated package developed by the CMS PH Generator group. In the current work all the produced results are via using Monte Carlo (MC) programs, FEYNRULES program for the implementation of the new model beyond the Standard Model. Our model here will be the B-L model which is based on a Lagrangian for calculation of Feynman rules in momentum space for any QFT physics mode. We also use PYTHIA8 event generator for proton-proton collision and partons showers (PS), MadGraph5/Madevent is a Matrix Element Monte Carlo Generator, CALCHEP for computation of Feynman diagrams and for effective evaluation and simulation of high energy physics collider processes at parton level, COMPHEP is a Matrix Element Monte Carlo (MC) Generator (MEG). As for MEG, it generates partons based on a Lagrangian also the programs ROOT, Physical Analysis Works station (PAW) and MADANALYSIS are used for physical analysis and to draw the results, in addition to Mathematica, C++, FORTRAN and Python programming languages, all this works on Scientific Linux. Does the Standard Model of particles physics need an extension? The standard model of electroweak and strong interactions is once again going to be severely tested as well as many of its extensions that have been proposed to cure its flaws. The observed pattern of neutrino masses the existence of dark matter and the observed matter-antimatter asymmetry are the most severe evidences where the SM fails to explain. It is widely accepted that the SM ought to be extended but no one knows if the proper way has already been explored in the literature. A joint collaboration is therefore needed between the experimental and the theoretical communities. The aim of this work has been guided by these principles. The aim is to fill some of the gaps in the overall preparation towards real data, as well as to interact with the experimentalists. An extension of the SM has been systematically studied, from the definition of its parameter space to the collider signatures, leading to some new and exciting possibilities for the LHC to shed light on. Within the ambition of a complete study, in all its aspects, the experimental help has been fundamental to efficiently concentrate on aspects of actual interest in a way which is useful for both communities. The main motivations for the extension of the SM that we will describe concern the lack of a natural explanation for the observed pattern of neutrino masses, the unknown origin of a global and not anomalous accidental U(1) symmetry in the SM (related to the baryon minus lepton (B-L) quantum numbers), and the absence of any observation of a fundamental scalar degree of freedom (the Higgs boson). B-L model is a triply-minimal extension of the SM. It is minimal in the gauge sector, in which a single U(1) factor is added, related to the B-L number, by simply promoting to local the already existing U(1) B-L global symmetry of the SM. It is minimal in the fermions sector, in which a SM singlet fermions per generation. These fermions can naturally be interpreted as the Right Hand neutrinos (RH). It is minimal in the scalar sector, in which a complex neutral scalar singlet is added to spontaneously break the new U(1) symmetry, and at the same time to give to the new gauge boson a mass. The two latter points, once the U(1) symmetry is spontaneously broken; naturally provide a dynamical implementation of the see-saw mechanism explaining the neutrino masses. As we will see, the remnant degree of freedom of the new complex scalar severely impinges in the phenomenology of the scalar sector. The general model we introduce is a one-dimensional class of U(1) extensions of the SM, in which each element is characterized by the properties of the new gauge boson associated to the extra U(1) factor. The “pure” B-L model is identified by the fact that the extra gauge boson, or Z′B-L, couples to fermions proportionally to their B-L number only. On the one side, this directly implies a vanishing of Z-Z′ mixing (at the tree-level), that is consistent with the existing tight constraints on such mixing, compatible with a negligible value. Moreover, the B-L charge does not distinguish the chirality, *i.e.*, the LH and the RH degrees of freedom of the same fermion which has the same B-L quantum numbers. It is important to emphasize that this is a TeV scale extension of the SM. This means that the U(1) B-L breaking vacuum expectation value (VEV) is of O (TeV). Hence, the new particles will have masses at the TeV scale. We are mainly concerned with the impact of the model at Large Hadrons Collider, on which the above phases do not play any role. We will show that the Z′ new neutral massive boson in this model, with TeV scale heavy neutrinos, can decay into pairs of the heavy neutrinos. The presence of new coupled matter, the heavy neutrinos, has important phenomenological consequences. The possibility of the Z′ boson (and of the Higgs bosons, as we will show) to decay into pairs of them, will provide new and exciting signatures. It is worth to briefly mention that the peculiar decays of the Higgs bosons into pairs of heavy neutrinos, or into pairs of Z′ bosons, is a distinctive signature of this model, offering the chance to distinguish it from the plethora of the otherwise identical, concerning the scalar sector, singlet extensions of the SM in the literature. We will consider all the heavy neutrinos as degenerate and with masses that are free parameters. In this work we study the details of the gauge and fermion sectors. Their mutual interactions are fully included in the Z′ decay into pairs of heavy neutrinos. Altogether, this decay provides new and spectacular multi-lepton signatures of the Z′ boson. One of the main results of this work is the study of one of them, the tri-lepton decay mode (*i.e.*, when the Z′ decays into exactly 3 charged leptons and other particles, such as jets and/or missing energy), together with the related backgrounds. We will present a parton level strategy for reducing the latter in order to isolate the signal that will be validated at the detector level.

2. Gauge Sector-New Neutral Massive Gauge Boson Z'_{B-L}

In the B-L extension of the SM model, the extra Z'_{B-L} boson and SM fermions are coupled through the non-vanishing B-L quantum numbers. Searching for Z'_{B-L} is accessible via a clean dilepton signal at LHC. We will simulate B-L extension of the SM at LHC which is based on the gauge group $G_{B-L} = SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$ using MC programs then search for the Z'_{B-L} boson in the dielectron events $Z'_{B-L} \rightarrow l^+ + l^-$ provides the most distinctive signature for observing the Z'_{B-L} signal at the Large Hadrons Collider. The results in this paper were produced by using simulation events generator PYTHIA8 and other software tools as CalcHep, Mad Graph/Madevent, FeynRules, ROOT data analysis, Physics Analysis Workstation (PAW), ROOFIT package to fit any resulted histogram in order to get P.D.F. (Probability density function) and Mathematica production of Z'_{B-L} at LHC which includes production cross section. **Figure 1** gives the cross section for Z'_{B-L} at LHC as a function of Z'_{B-L} mass for various g" values (where g" is the $U(1)_{B-L}$ gauge coupling constant) at CM energy of LHC = 14 TeV.

3. Fermion Sector-New Heavy Neutrinos

B-L model provides also a natural explanation for the presence of three right-handed neutrinos, [7-9] and can account for the current experimental results of the light neutrino masses and their mixings. The heavy neutrinos are rather long-lived particles producing distinctive displaced vertices that can be seen in the detectors. In this section we determine the production cross section of heavy neutrino discovery at LHC for various CM energies, 5,7,10 and 14 TeV using MadGraph5/MadEvent and PYTHIA8 programs. We consider the production channel of heavy neutrino pair production via the Z'_{B-L} boson decay. The distinctive features of the B-L model take place because the heavy neutrinos decay predominantly to SM gauge bosons in association with a lepton (either charged or neutral, depending on the electrical nature of the SM gauge boson). Also, once heavy neutrinos are pair-produced via the Z'_{B-L} boson, they give rise to novel and spectacular multi-lepton decay modes of the intermediate boson. Thus the rate for the pair production of the heavy neutrinos depends on the mass of the Z'_{B-L} and the strength of the B-L coupling g". The process $pp \rightarrow Z'_{B-L} \rightarrow \nu_h \nu_h$ can be tested at the LHC (for $\sqrt{s}$ = 5,7,10 and 14 TeV CM energy). If we take the value of the total integrated luminosity1 fb^{-1} and take the maximum value of the cross section to be 180 fb for mass of Z'_{B-L} = 700 GeV and g" = 0.2. For mass of ν_h = 100 GeV as in **Figure 2** we can say that approx. 180 events are produced according to the relation.

$$N = L\sigma$$

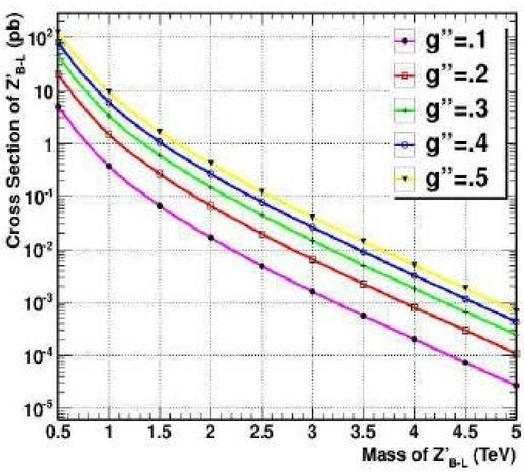

Figure 1. Cross section for Z'_{B-L} as a function of Z'_{B-L} mass for various g" values at fixed CM energy of LHC = 14 TeV.

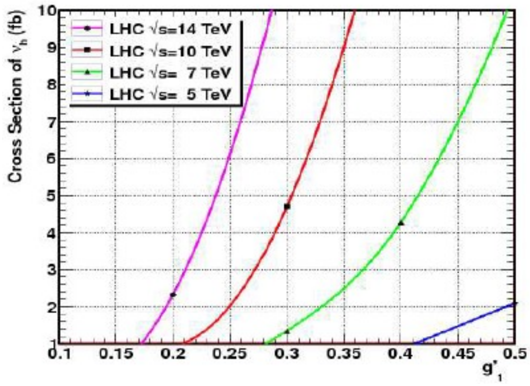

Figure 2. Heavy neutrino pair production cross sections at the LHC for different values of g" (for √s = 5,7,10 and 14 TeV, Z'_{B-L} mass = 1.5 TeV).

where N is the number of events and L is the total integrated luminosity and σ is the production cross section. Also, we can deduce from the figure that the production cross section depends on the Z'_{B-L} mass and the value of the g" coupling in addition to the LHC CM energy.

4. Scalar Sector-New Heavy Higgs

The Standard Model is based on one complex Higgs doublet consisting of four degrees of freedom, three of which, after spontaneous Electro-Weak Symmetry Breaking turn out to be absorbed in the longitudinal polarization component of each of the three weak gauge bosons $W^{\pm}$ and Z. The fourth one gives the physical Higgs state. Minimal extension of the B-L model consists of a further U(1)B-L gauge group in addition to the SM gauge structure, three right-handed neutrinos and an additional complex Higgs singlet which is responsible for giving mass to an additional Z'_{B-L} new gauge boson. Therefore the scalar sector in the B-L model consists of two real CP-even scalars that will mix together. B-L model breaking can take place at the TeV scale far below that of any Grand Unified Theory. In this section, we will present production cross sections for Higgs bosons SM-like Higgs (light Higgs) H^1 and extra Higgs (heavy Higgs) H^2 by analyzing the data produced from simulated collisions between two protons at different center of mass energies by Monte Carlo event generator programs .Also, we find that the independent physical parameters of the Higgs boson in the minimal B-L extension of the Standard Model:

1) Higgs bosons masses MH^1, MH^2 and the scalar mixing angle *α*. Masses and couplings which depend on the Higgs mixing have been tested against the experimental limits obtained at the Large Electron-Positron (LEP) collider and at the Tevatron.

2) g" the new U(1)B-L gauge coupling.

3) The mass of the new gauge boson mass Z'_{B-L}. An indirect constraint on the mass of Z'_{B-L} which comes from the analysis at LEP of the precision EW data:

$$MZ'_{B-L}/g'' \geq 7\text{TeV}$$

4) $\alpha = 0$ is the decoupling limit with H^1 behaving like the SM Higgs.

5) $\alpha = \pi/2$ is called inversion limit where H^2 is the SM Higgs.

Figures 3(a) top and **(b)** low show the production cross section of the light Higgs boson H^1 and the heavy Higgs boson H^2 in B-L model at center of mass energy7 TeV at Large Hadrons Collider for different values of the mass. We notice that the curve is a smooth function of the mixing angle α and maximum cross section is observed at the smallest value of masses.

The cross-section for H^2 at an angle α is equal to that one of H^2 for $\pi/2 - \alpha$. The maximum cross-section for H^2 when $\alpha = \pi/2$ coincides with the cross-section of H^2 for $\alpha = 0$. The minimal B-L context [10] for high value of the mixing angle could lead to important consequences for Higgs boson discovery at the LHC [11]. As in the SM, the main contribution to the production cross section comes from the gluon-gluon fusion mechanism. The next relevant contribution is given by the Higgs production in the weak vector boson mechanism. This contribu-

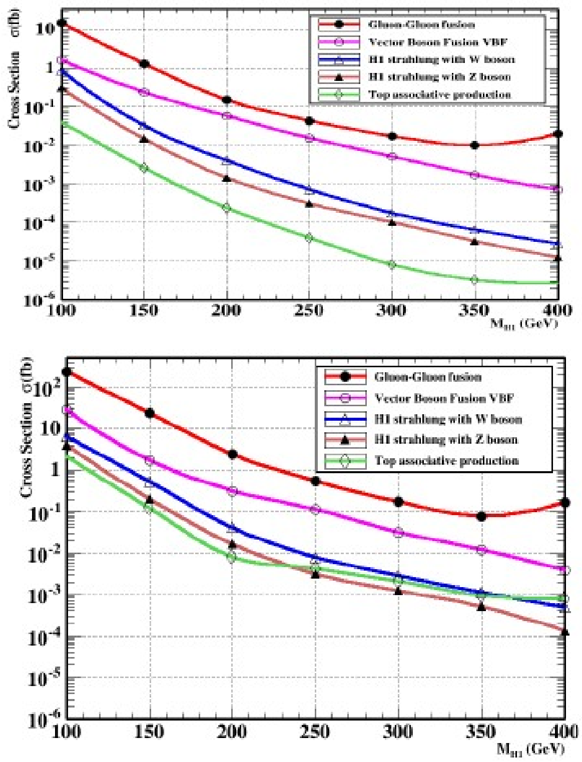

Figure 3. Production Cross-sections at the LHC in the B-L model for light Higgs boson H⁾ by standard methods figure (a) at √s = 7 TeV and figure (b) at √s = 14 TeV using MadGraph5 and Pythia Monte Carlo event Generator.

tion is at the level of a few fb, as estimated above. Furthermore, the production associated with Z/W is dominant over the production associated with Z'_{B-L} [12,13]. When we analyze the production of the heavy Higgs, it turns out that its cross sections are smaller than the light Higgs ones. In the light Higgs scenario, the production associated with Z'_{B-L} is dominant over the Production associated with Z/W which is in agreement with our previous prediction.

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