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Physics

Search for the Right-Handed W_R Boson and a Heavy Neutrino at the LHC

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ABSTRACT. We give a brief review of the $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ left-right symmetric gauge model and discuss a possibility to detect the right-handed W_R-boson and a heavy neutrino in *pp* collisions at the LHC. We present bounds on the masses of the W_R-boson and heavy neutrino, obtained at the ATLAS and CMS detectors with a total energy of colliding protons 7–8 *TeV*. *© 2015 Bull. Georg. Natl. Acad. Sci.*

Key words: *heavy neutrino, W_R boson, LHC, ATLAS.*

The discovery of the Higgs boson [1] at the Large Hadron Collider (LHC) using CMS (a Compact Muon Solenoid) [2] and ATLAS (A Toroidal LHC Apparatus) [3] detectors is, undoubtedly, the most outstanding scientific discovery of the 21st century. The existence of the Higgs boson is necessary to renormalize electroweak interactions. After the Higgs boson discovery the main LHC goal is the search for new physics beyond the Standard model (SM). There are a lot of the SM extensions predicting new effects that can be observed at the LHC [4]. Among them, it is worth mentioning supersymmetry, extra dimensions, and the left-right symmetric model [5]. The latter is especially interesting because all the currently existing experimental data were confirmed clearly the hypothesis of neutrino oscillations, therefore neutrinos have nonzero and very small masses. In the SM framework, the so-called "see-saw" mechanism based on the introduction of additional heavy Majorana neutrinos is the most natural way to explain the small values of neutrino masses. It is usually assumed that heavy Majorana neutrinos are singlets of the SM gauge group and have no new interactions. On the other hand, the left-right symmetry is explicitly violated in the SM, which is manifested in the existence of left-handed isodoublets of the electroweak gauge group $SU_L(2) \otimes U(1)$ and of right-handed isosinglets of the same electroweak gauge group. In the light of the fundamental idea of spontaneous symmetry breaking, it seems natural to assume that the explicit violation of the left-right symmetry is related to spontaneous breaking of the left-right symmetry, and the left-right symmetry is restored at large energies or small distances. The minimal left-right gauge model is based on the gauge group $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ [5] which is the most economical realization of the idea of spontaneously broken left-right gauge symmetry. At large energies the $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ gauge group is spontaneously broken to the SM $SU_c(3) \otimes SU_L(2) \otimes U(1)$ gauge group. With respect to the $SU_L(2) \otimes SU_R(2) \otimes U(1)$ gauge group, the left-handed fermions are doublets of the gauge group $SU_L(2)$, and the right-handed fermions are doublets of the $SU_R(2)$ gauge group. The left-right symmetric model includes additional right-handed neutrinos - partners of right-handed charged leptons. The minimal set of the Higgs fields includes a Higgs bi-doublet, which, at the level of the SM is a set of two Higgs isodoublets, one of which interacts with upper fermions of the left-handed isodoublets via nonzero Yukawa couplings and the other isodoublet is related to bottom fermions. In addition, for the breaking of the right $SU_R(2)$ gauge group the model has to contain two triplets Δ_R and Δ_L. The nonzero vacuum expectation value of the right-handed triplet Δ_R leads to the gauge group $SU_L(2) \otimes SU_R(2) \otimes U(1)$ breaking to the SM electroweak gauge group $SU_L(2) \otimes U(1)$, while the nonzero vacuum expectation value of the Higgs doublets is responsible for the spontaneous symmetry breaking of the SM $SU_L(2) \otimes U(1)$ gauge group to the electromagnetic $U(1)$ gauge group. The left-right symmetric model predicts the existence of a new heavy charged right-handed W_R-boson, a heavy neutral Z'-boson and right-handed neutrinos N_k (k = 1,2,3) for each generation of quarks and leptons. Calculations based on the estimation of the W_R-boson contribution to the difference between the $K_L - K_S$ masses lead to the bound $M_{W_R} > 2.5\ TeV$ on the W_R-boson mass [6].

In this brief review, we discuss bounds on the mass of the right-handed W_R-boson and heavy neutrinos obtained at the CMS and ATLAS detectors at the total energy $E_{tot} = 7 - 8\ TeV$ of colliding protons. The use of two reactions $pp \to W_R \to l + N_l + X$, $pp \to Z' \to N_l + N_l + X$ with the subsequent decays of heavy neutrinos $N_l \to l + j_1 + j_2$ into charged leptons and at least two hadronic jets, is the most promising for the search for the W_R-boson and heavy neutrinos at the LHC. The detection of the right-handed W_R-boson in the decay $W_R^+ \to t\bar{b}$ is also very important because the right-handed heavy neutrinos do not participate in this decay and the W_R-boson can be detected even in the case where the right- handed neutrinos are heavier than the W_R-boson, contrary to the use of the decay mode $pp \to W_R \to l + N_l + X$. In the left-right symmetric model, in view of the specificity of the Higgs sector the mass of the Z'-boson is larger than that of the mass of the W_R-boson, therefore the use of the reaction $pp \to W_R \to l + N_l + X$ with the subsequent decay $Nl \to l + j_1 + j_2$ is more profitable. As a consequence, we expect the appearance of two charged leptons and at least two hadronic jets in the final state. The main SM background is related to the top-antitop quark-antiquark pair $t\bar{t}$ with their subsequent decay into leptons and hadron jets and also to the Drell-Yan process $pp \to (Z^* \to ll) + \geq 2$ *hadronic jets*. In addition, the instrumental background appearing in the case when we confuse the hadronic jet with the charged lepton sector must be taken into account. As a result of the cascade decay $W_R \to lN \to llj_1j_2$ the distribution of the invariant mass of two leptons and two hadronic jets $M_{inv}(llj_1j_2)$ has a resonant structure with the maximum peak near M_{W_R}. In addition, as a result of the decay $N_l \to l + j_1 + j_2$, a resonant structure must be seen in the distribution of the invariant mass of one of the leptons and two hadronic jets $M_{inv}(llj_1j_2)$ with the maximum peak near the heavy neutrino mass M_{N_l}. These facts help one in the search for W_R-boson and heavy neutrino.

For the search for W_R-boson on the base of $W_R^+ \to t\bar{b}$ decay it is convenient to use the chain of decays $W_R^+ \to t\bar{b}$, $t \to bW^+ \to bl^+\nu$. As a result, we have $b\bar{b}l\nu$ in the final state, i.e. the signature with the presence of at least two b-jets, one isolated lepton and nonzero missing transverse energy.

The search for W_R-boson and a heavy neutrino was studied using the CMS detector based on the signature with two charged leptons and two hadronic jets [7]. The experimental data with total energy $E_{tot} = 8\ TeV$ of colliding protons and the integral lumi-

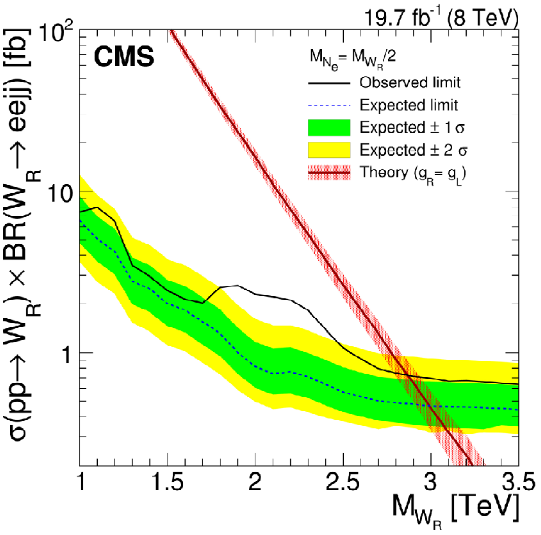

Fig. 1. Upper limit of the cross-section on the production of right-handed W_R-boson vs the mass of the W_R-boson at $M_{N_\mu} = M_{W_R}/2$ in the left-right symmetric model $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ at 95% C.L. in CMS experiment [7].

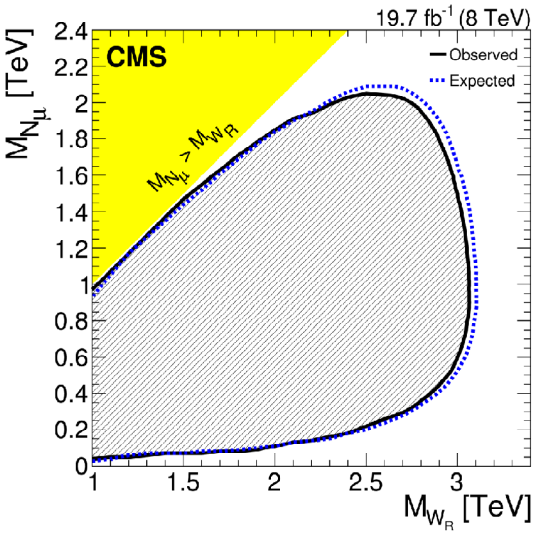

Fig. 2. The lower bound on the mass of W_R-boson in the plane (M_{W_R},M_N) in the left-right symmetric model $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ containing one heavy muonic neutrino.

nosity $L_t = 19.7 fb^{-1}$ were analyzed. The modes with two electrons (muons) and at least two hadronic jets were analyzed. The bounds $p_{T_{j1,j2}} > 40\ GeV$ were imposed on the transverse momenta of hadronic jets. The cut $p_{T_{j1,j2}} > 60\ GeV$ was used for the transverse momentum of the most energetic lepton and the cut $p_{T_{j1,j2}} > 40\ GeV$ was used on that of the second lepton. To attenuate the background associated with the $Z + jets$ production an additional cut on the invariant mass of two leptons $M_{inv}(ll) > 200\ GeV$ was imposed. The additional restriction $M_{inv}(llj_1 j_2) >$ 600 GeV on the invariant mass of two leptons and two hadronic jets was also used. After these cuts, the main background events occur from the $t\bar{t}$ and $Z + jets$ productions. Using these cuts, the CMS collaboration has obtained bounds on the masses of W_R and a heavy neutrino [7]. The best bounds were obtained for the heavy neutrino masses $M_N \sim M_{W_R}/2$ [7]. For small heavy- neutrino masses, the hadronic jets and the lepton produced as a result of the decay $N \to lj_1 j_2$ are mainly inside a narrow cone. This makes it as difficult to identify the lepton and hadronic jets. As a result the bounds on the masses W_R and N become weak.

The obtained bounds are presented in Figs. 1 and 2. The upper limit of the cross-section on the production of right-handed W_R-boson vs the mass of the W_R-boson at $M_{N_\mu} = M_{W_R}/2$ in the left-right symmetric model $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ at 95% C.L. in CMS experiment [7] is given in Fig. 1. The lower bound on the mass of W_R-boson in the plane (M_{W_R}, M_N) in the left-right symmetric model $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ containing one heavy muonic neutrino is presented in Fig. 2. The best bound on the W_R mass is M_{W_R} MWR > 3.0 TeV [7].

The ATLAS collaboration also searched for the W_R-boson and the heavy neutrino using the reaction $pp \to W_R \to l + N_l + X, N \to lj_1j_2$ [8]. Similar bounds on the masses of W_R-boson and the heavy neutrinos were obtained.

In ref. [9] the CMS collaboration used the chain of decays $W_R^+ \to t\bar{b} \to b\bar{b}W^+ \to b\bar{b}l^+\nu$ $(l = c,\ m)$ for the search for W_R-boson. As a result of the chain decays of W_R-boson, we have two hadronic b-jets, one isolated lepton and missing transverse momentum in the final state. The main backgrounds are due to $t\bar{t}$, $W + jets$, tW, $Z/\gamma^* + jets$, WW productions and their subsequent decays into hadrons and leptons. Using the lepton momentum and the missing transverse momentum, the W-boson momentum is restored. The momentum of the t-quark is also restored with the help of one of the b-jets and the momentum of the W-boson. The reconstructed momentum of the t-quark and the momentum of the second b-jet are used to build the invariant mass distribution $m_{inv}(tb)$. The existence of the resonance peak in the spectrum of the $m_{inv}(tb)$ distribution will be the evidence of the W_R-production. The CMS data with the total energy $E_{tot} = 8\ TeV$ and the total integral luminosity $L_t = 19.5\ fb^{-1}$ were used [9]. The obtained results agree with the expectations from the SM backgrounds. The restriction on the product of the W_R cross-section production and the branching ratio of its decay into $W_R^+ \to t\bar{b}$ as a function of the W_R-boson mass has been found [9]. In the left-right symmetric $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ model the bound $M_{W_R} > 2.05\ GeV$ on the mass of the W_R-boson was obtained [9].

The ATLAS collaboration also looked for the W_R-boson using the decay mode $W_R \to tb \to l\nu bb$. For the total energy $E_{tot} = 8\ TeV$ of colliding protons and the integral luminosity $L_{tot} = 20.3\ fb^{-1}$ the bound $M(W_R) > 1.92\ TeV$ on the mass of right-handed W_R-boson was obtained [10].

In this brief review on the example of the search for the right-handed W_R-boson and a heavy neutrino we have demonstrated the LHC potential for the search for physics beyond the SM. We hope that new physics beyond the SM will be discovered at the LHC run with the total energy $E_{tot} = 13\ TeV$ of colliding protons.

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ფიზიკა

მარჯვენივი W_R ბოზონის და მძიმე ნეიტრინოს ძიება დიდ ადრონულ კოლაიდერში (LHC)

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მოცემულია $SU_c(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ მარჯვნივ და მარცხნივ სიმეტრიული კალიბრული მოდელის მოკლე მიმოხილვა და განხილულია მარჯვენივი W_R ბოზონის და მძიმე ნეიტრინოს აღმოჩენის შესაძლებლობა დიდი ადრონული კოლაიდერის pp კოლიზიებში. წარმოდგენილია W_R-ბოზონის და მძიმე ნეიტრინოს მასების ზღვარი ATLAS-ის და CMS დეტექტორებზე, სადაც პროტონების შეჯახების მთლიანი ენერგიაა 7-8 TeV.

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