Searches for Heavy Lepton Partners of Neutrinos in Proton-Proton Collisions at CMS Experiment in the Context of Seesaw Mechanism

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INTRODUCTION

Ideas beyond the standard model have been proposed to accommodate the finite values of neutrino masses inferred from oscillations among the three neutrino species.

Compact Muon Solenoid (CMS) collaboration at the Large Hadron Collider (LHC) searches for heavy Majorana states predicted in seesaw models. Seesaw mechanisms involve fermionic weak-isospin singlets (type I) or scalar triplets (type II) or fermion triplets (type III). The searches are carried out in different final states containing two jets and two same-sign muons/electrons, or two jets and two muons/electrons without charge requirements, or three charged, isolated leptons and an imbalance in transverse momentum.

The CMS data correspond to integrated luminosities of 5 fb\(^{-1}\) in 2011 and 3.6 fb\(^{-1}\) in 2012 of proton-proton collisions at the center-of-mass energies of 7 TeV and 8 TeV, respectively.

No excess of events is observed above the backgrounds predicted by the standard model, and the results are interpreted in terms of limits on the cross sections and masses of the new heavy particles expected in these models.

CMS EXPERIMENT AND PHYSICS OBJECTS

CMS experiment recorded 21.8 fb\(^{-1}\) of proton-proton collisions at the center-of-mass energies of 8 TeV in 2012 at the LHC.

All three seesaw types are investigated with 5.0 fb\(^{-1}\) of proton-proton collisions at the center-of-mass energies of 7 TeV, collected in 2011. Type II analysis is updated with 3.6 fb\(^{-1}\) of proton-proton collisions at the center-of-mass energies of 8 TeV, collected till June 2012.

The searches involve electron and muon candidates, jets and missing transverse energy (MET). All the physics objects are reconstructed using particle-flow algorithm, that picks up the information from each CMS subdetectors. Jets reconstruction calls anti-\(k_T\) clustering algorithm with a distance parameter of 0.5. MET is the magnitude of the vectorial sum of the transverse momenta of all particles.

Muon candidates leave signal in the outer detectors, Drift Tube in the barrel region and Cathode Strip Chamber in endcap regions or in Resistive Plate Chamber located both in barrel and in endcaps. Electromagnetic calorimeter shows electron candidates signature as an activated tower; jets are identified in electromagnetic and hadronic calorimeters, both installed in the 3.8 T magnetic field.

ANALYSIS AND RESULTS

Signature for type I seesaw searches [1] is two same charge and flavor leptons and two jets. Data come from double electrons or double muons trigger and backgrounds are Z+jets, tt(bar), QCD multijet processes events. The analysis has two channels: muons and electrons. Requirements are two same-sign and same-flavour leptons, leading lepton transverse momentum \(p_T > 20\) GeV and next leading lepton \(p_T > 10\) GeV, leptons in barrel region. Events with a third opposite-sign muon are excluded if the invariant mass is between 76 and 106 GeV; events with any third opposite-sign electron are excluded. The discriminant variable studied is the invariant mass of the second lepton and two jets. Analysis takes in account jet and electron energy scale and resolution, electron reconstruction and isolation and identification, trigger efficiency, pileup, background shape and normalization, QuantumChromoDynamics (QCD) background estimation, as systematic uncertainties. Data collected in 2011 are in agreement with the estimated background. No evidence for excess in the data beyond the SM background is seen; exclusion limits are set on the square of the mixing matrix. For heavy neutrino mass \(m_\nu < 90\) GeV, Large Electron Positron (LEP) experiments limits are more stringent than CMS ones, because of LHC environment in proton-proton collisions. CMS analysis extends direct searches above 90 GeV and sets the first upper limits in these region.

Two leptons and two jets result in final state for type II seesaw search [2]. Trigger is double electron or single muon and backgrounds are Z+jets, tt(bar), QCD multijet processes events. Selection steps require the leading lepton \(p_T > 60\) GeV, and the di-lepton invariant mass \(M_\ell > 200\) GeV. The discriminant variable is the invariant mass of two leptons and two jet \(M(lljj)\). Both in muon and electron channels, a cut on \(M(lljj)\) at 600 GeV is set. Systematic uncertainties are uncertainty on the shape of the \(M(lljj)\), background distribution and normalization, parton distribution function (PDF). The agreement between the observed and the expected limits is good with 2012 data. In the 2D plan (heavy neutrino mass, \(W_R\) mass), a wide region is excluded. The limits extend to roughly \(M_{W_R} = 2.5\) TeV.

Signature for type III seesaw [3] is three isolated charged leptons, jets, and MET. Trigger is two-leptons so the possibilities are two muons, two electrons, electron-muon. Backgrounds are di-bosons (WZ, ZZ), tri-bosons (WWW), vector boson and photon (V), tt(bar), non-prompt leptons,
conversion in materials. The selections are three isolated charged leptons from the same primary vertex, sum of the lepton electric charge = +1, MET > 30 GeV, leptons $p_T$ thresholds respectively 18, 15, 10 GeV, and scalar sum of central jets $p_T$ $H_T < 100$ GeV. Analysis invokes six categories: $\mu e\bar{e}$, $\mu e\mu$, $\mu \mu \mu$, $e\mu\mu$, $e\mu\bar{e}$, $e\mu\bar{e}$. Additional request for di-lepton same-flavor opposite-sign leptons on the invariant mass is put to exclude events in the Z mass peak. Systematic uncertainties are trigger selection, physics objects reconstruction, lepton identification, background normalization, and integrated luminosity. Analysis constraint is related to long life time particle and displacement of vertices: the situation is not considered, so at least one mixing matrix element for the heavy and light leptons is greater than $10^{-6}$. No significant excess of events is observed relative to the SM expectations in any of the six categories. Limits in three different scenarios of the fraction of heavy particle $\Sigma$ decays to a lepton $\alpha (b_\alpha)$ are set on the production cross section times branching fraction and $M_\Sigma$. These are the first limits reported by an experiment at the LHC (Figure 1).

CONCLUSIONS

LHC experiments cannot study neutrinos parameters directly, but they investigate models BSM that give possible explanations for neutrino masses. No excess of events is observed above the backgrounds predicted by the SM.

The CMS results are interpreted in terms of limits on the production cross sections and masses of the new heavy particles expected in the seesaw models. The seesaw mechanism could be investigate deeper through all 2012 data, so it is still live and interesting and exciting.


Figure 1. Type III seesaw model.
The expected (dashed line) and observed (black points) exclusion limits at 95% confidence on $\sigma \times B$ as a function of the fermion mass $M_\Sigma$, assuming three scenarios for the signal ($b_e = b_\mu = b_\tau = 1/3$, $b_e = 0$ $b_\mu = 1$ $b_\tau = 0$, $b_e = 1$ $b_\mu = b_\tau = 0$). The thick theory curve represents the LO Type III seesaw models predictions. The light and dark shaded areas represent respectively the 1 standard deviation (68% CL) and 2 standard deviations (95% CL) limits on the expected results obtained from MC pseudo-experiments. These reflect the combined statistical and systematic uncertainties of the SM contributions.

Table recap limits values coming from plots.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>95% CL: $\sigma \times B$ (fb)</th>
<th>95% CL: $M_\Sigma$ (GeV)</th>
</tr>
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<td>$\mu e\bar{e}$</td>
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<td>20</td>
</tr>
<tr>
<td>$\mu e\mu$</td>
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