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CMS Physics Analysis Summary

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Search for heavy lepton partners of neutrinos in pp collisions at $\sqrt{s} = 7$ TeV, in the context of the Type III seesaw mechanism.

The CMS Collaboration

Abstract

A search for states from fermionic triplet, expected in Type III seesaw model, in pp collisions at $\sqrt{s} = 7$ TeV with three isolated leptons and an imbalance in transverse momentum is presented. The data, collected with the CMS detector at the LHC, correspond to an integrated luminosity of 4.9 fb^{-1}. No excess of events is observed relative to the background predicted by the standard model. The results are interpreted in terms of limits on parameters of the Type III seesaw model.

1 Introduction

Experiments on neutrino oscillations [1–3] demonstrate that neutrinos have mass. This is the first unambiguous evidence for physics which is not foreseen by the standard model of particle physics (SM). However the origin of this mass is still unknown. A possible accommodation of this result is provided by the seesaw mechanism, wherein a small Majorana mass can be generated for each of the known neutrinos by introducing massive fermionic states with Yukawa couplings to leptons and to the Higgs field. The neutrino masses are reduced relative to masses of the charged fermions by factors of v/M, where v is the vacuum expectation value of the Higgs field and M is the mass of the heavy state. Seesaw models called Type I [4, 5], Type II [6–10] or Type III [11] introduce massive states that involve, respectively, fermionic singlets, scalar triplets, or fermionic weak-isospin triplets. The reduction occurs when M is larger than v. However, one can consider extended seesaw mechanism like the Inverse Seesaw [12] in order to obtain the small neutrino mass while keeping the fermionic triplet mass M close to the few hundred of GeV scale. In such framework one introduces small lepton number violating parameters to which the neutrino mass is directly proportional. At the LHC, Type II and III heavy fermions can be produced via gauge interactions, and can be observed if their masses are smaller than ≈ 200 GeV, regardless of the size of their Yukawa couplings. The possibility of discovering a Type III fermion at a center-of-mass energy of $\sqrt{s} = 14$ TeV is discussed in Ref.[13–15]. Recently, a complete evaluation of the signal expected at $\sqrt{s} = 7$ TeV has been made available as computer code for simulating such final states [16].

In particular, given the electric charge of the lepton triplet Σ^+, Σ^0 and Σ^-, the most promising signal for finding a state for $M_\Sigma \approx 100$ GeV is through quark-annihilation $q\bar{q}' \to \Sigma^0\Sigma^+$, followed by the decay $\Sigma^0 \to \ell^\mp \mathrm{W}^\pm$ and $\Sigma^+ \to \mathrm{W}^+\nu$. As there are twice as many u- than d-valence quarks in the proton, the production of $\Sigma^+\ \Sigma^0$ via virtual W^+ boson in the s-channel (Fig. 1) has the highest cross section of all Σ charge combinations. Also, the decay $\Sigma^+ \to \ell^+ \mathrm{Z}^0$ can contribute significantly, especially since its relative yield grows with M_Σ. Selecting $\mathrm{W}^\pm \to \ell^\pm \nu$ decays (where ℓ is an electron or muon), the final state offers a very clean signature of three charged, isolated leptons.

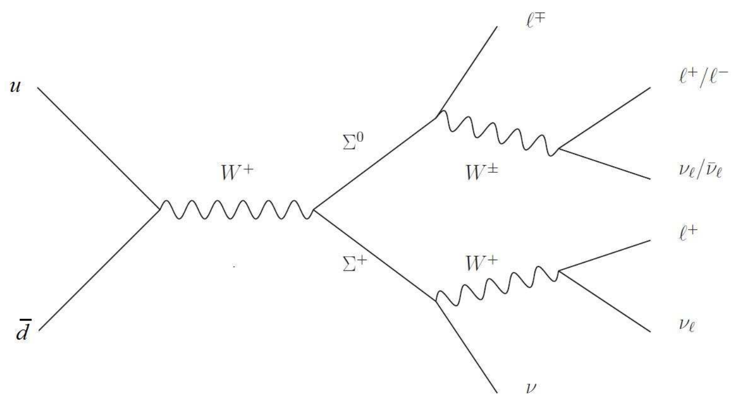

Figure 1: Dominant contribution to three charged lepton final states from pair production of fermionic triplets (Σ) in the Type III seesaw model (the cross section for the charged conjugate intermediary W^- is expected to be smaller).

The total width of the new heavy leptons and their decay branching ratios to SM leptons depend on the mixing-matrix element for the heavy and light leptons V_α, where α labels the couplings to each of the e, μ and τ generation of leptons. Constraints on the mixing parameters and their products are reported in Ref.[16]. The maximum allowed values correspond to

$V_e = 0$, $V_\tau = 0$ and $V_\mu = 0.063$. The predicted pair production cross section for the Σ states does not depend on V_α and the production of a lepton α is proportional to the ratios of matrix elements:

$$b_\alpha = \frac{|V_\alpha|^2}{|V_e|^2 + |V_\mu|^2 + |V_\tau|^2}. \quad (1)$$

For very small mixing parameters lower than $\approx 10^{-6}$, the triplets have sufficiently long lifetimes to produce leptons displaced relative to the production vertex. This situation is not considered in this analysis.

The present paper reports a search for the presence of Type III seesaw effects in final states with three charged leptons and an imbalance in transverse momentum (E_T^{miss}), based on 4.9 fb^{-1} of data collected with the CMS detector at LHC in 2011. The search is sensitive to masses $M_\Sigma > 101$ GeV, beyond the lower limits set by L3 at LEP [17].

2 Detector

A detailed description of the CMS detector can be found in Ref.[18]. The central feature of the CMS apparatus is a superconducting solenoid that provides an axial magnetic field of 3.8 T. A silicon tracker, a crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) reside within the field volume. Muons are identified and measured in gas-ionization detectors embedded in the steel return yoke outside of the solenoid.

The particle direction measured by the CMS detector is described using the azimuthal angle (ϕ) and the pseudorapidity (η), which is defined as $\eta \equiv -\ln[\tan\theta/2]$, where θ is the polar angle relative to the counterclockwise circulating proton beam, as measured relative to the interaction vertex.

Jets are reconstructed following a particle-flow (PF) technique [19, 20]. Particles found by the PF algorithm are clustered into jets using the anti-k_T algorithm with a distance parameter of 0.5 [21]. Jet energies are corrected for non-uniformity in calorimeter response and for differences found between jets in simulation and data [22]. The imbalance in transverse momentum is defined as the magnitude of the vectorial sum of the transverse momenta of all particles found by the PF algorithm.

3 Simulation of Signal and Background

To estimate the signal efficiency, signal events are generated using the code described in Ref.[16], and passed through PYTHIA (v6.420) [23] for implementation of parton showering and hadronization. Detector simulation is performed using GEANT4 [24]. Given the large number of mass points to be generated, part of the detector simulation is performed using CMS Fast Simulation. Several background sources are considered in this analysis; the most relevant is the WZ production, with both bosons decaying into leptons. The background also includes a smaller contribution from the diboson ZZ production channel, where one of the leptons is either outside of the detector acceptance or is misreconstructed. These diboson background events are generated with the PYTHIA Monte Carlo (MC) program. Backgrounds of three EW bosons are generated with MADGRAPH 5 [25]. Instrumental backgrounds from jets and photons that are misidentified as leptons are also studied. They include Drell Yan+jets [26], W+jets, $t\bar{t}$, Drell Yan+γ conversions.

4 Selection Criteria

The online trigger and the offline selection criteria are similar to those used in previous CMS analyses [27–29]. The selected events must contain at least two charged lepton candidates (ee, $\mu\mu$ or eμ) at the trigger level, a well reconstructed primary interaction vertex with at least 10 tracks, and at least two lepton candidates with trajectories that have a transverse impact parameter of < 0.2 mm relative to the interaction vertex. Muon candidates are reconstructed from a fit performed to hits in both the silicon tracker and the muon detectors, thereby defined a global μ. The specific selection requirements for a muon are:

- $p_T^\mu >$10 GeV;
- $|\eta| < 2.4$;
- > 10 valid hits in the silicon tracker ;
- a global μ fit with $\chi^2/dof < 10$;

Electron candidates are reconstructed using clusters of energy deposition in the ECAL that match to a reconstructed track extrapolated from the tracker. The trajectory of the electron is fitted using a Gaussian-Sum Filter (GSF) [30], with the algorithm taking into account the emission of Bremsstrahlung photons in the silicon tracker. The specific selection cuts for an electron are:

- $p_T^e >$10 GeV;
- $|\eta| < 2.5$, and within the fully instrumented part of the central barrel ($|\eta| < 1.44$) or endcap ($1.57 < |\eta| < 2.5$) regions;
- not rejected as candidate for photon conversion;
- a consistent sign of electric charge, as reconstructed using three independent algorithms [20].

All accepted lepton candidates are required to be isolated from other particles and using PF-based relative isolation criteria. In particular, selected muons must have $(\sum p_{\mathrm{T}})/p_{\mathrm{T}}^{\mu} < 0.15$, where the sum includes all PF particles surrounding the axis defined by the muon track, within a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$, where $\Delta\eta$ and $\Delta\phi$ are the differences in pseudorapidity and azimuthal angle between the lepton and the other particles. Similarly, an electron candidate is accepted if $(\sum p_{\mathrm{T}})/p_{\mathrm{T}}^{\mu} < 0.20$, within a cone of $\Delta R = 0.3$.

The candidate events chosen for performing the search for the Σ fermions must have

- three isolated leptons, as defined above;
- sum of the lepton charges $= +1$;
- $E_{\mathrm{T}}^{miss} > 30$ GeV;
- $p_T^\ell > 18, 15, 10$ GeV for the lepton of highest, next highest and lowest p_{T};
- $\mathrm{H_T}$ <100 GeV,

where $\mathrm{H_T}$ is the scalar sum of the transverse momenta of jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.4$.

The selected events are classified into six categories depending on the lepton flavor and electric charge: $\mu^-e^+e^+$, $\mu^-e^+\mu^+$, $\mu^-\mu^+\mu^+$, $e^-\mu^+\mu^+$, $e^-e^+\mu^+$ and $e^-e^+e^+$. Except the first and fourth categories, such configurations can result from W^+Z events and can have one or two possible combinatorial contributions to the $\ell^+\ell^-$ mass. As shown in Fig. 2, a clear Z peak is evident in both the simulated and measured events. To reduce the background from W^+Z events, a Z veto is added to the selection requirements for the corresponding categories as follows. Events with at least one $\ell^+\ell^-$ mass combination in the range $82 < m_{\ell^+\ell^-} < 102$ GeV are rejected. To reject lepton pairs from decays of heavy-flavour quarks , events with $m_{\ell^+\ell^-} < 12$ GeV are also discarded.

Additional sources of background in final states with three leptons are asymmetric conversions of virtual radiated photons (γ^*) in $Z \to \ell^+\ell^-\gamma^*$ transitions. If one of the additional leptons carries most of the γ^* momentum, the final state could appear as a three lepton event. In such cases, the invariant mass of the $\ell^+\ell^-\ell$ state peaks close to the mass of the Z boson. Since the probability of a γ^* conversion to electrons is higher than to muons, additional Z vetos are applied to the categories $\mu^-e^+\mu^+$ and $e^-e^+e^+$ by rejecting events with $82 < m_{\ell^+\ell^-e^+} < 102$ GeV.

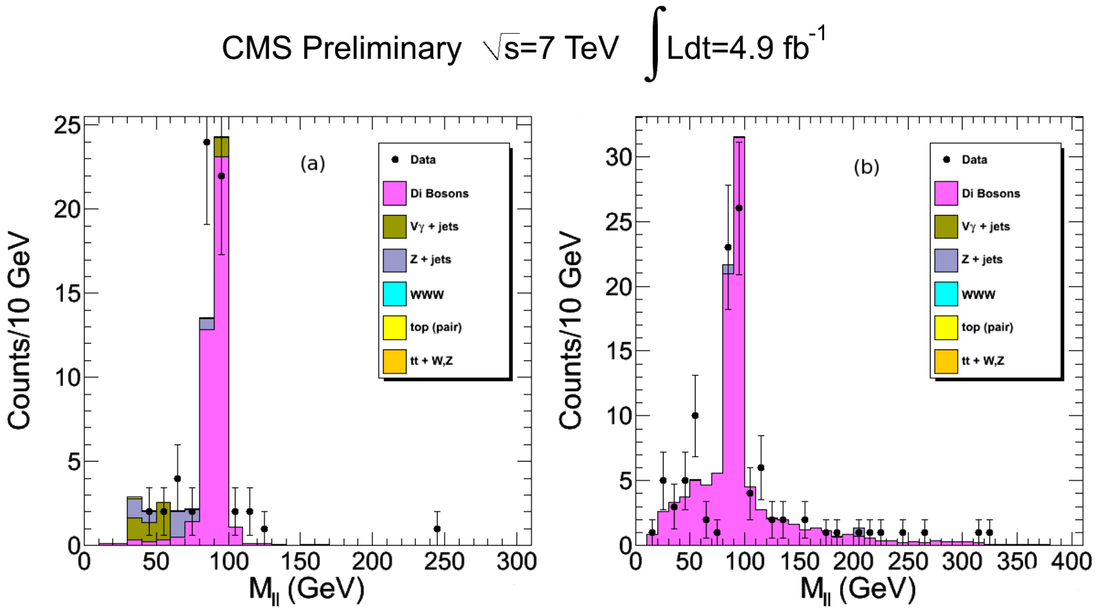

Figure 2: Distributions in $\mu^-\mu^+$ invariant mass for (a) $\mu^-e^+\mu^+$ and (b) $\mu^-\mu^+\mu^+$ events in data, before applying any cuts on the mass $\mu^-\mu^+$ to reject Z bosons, compared to the sum of SM background contributions.

5 Estimates of backgrounds

Two types of SM processes can produce a three-lepton final state:

- events containing three or more prompt leptons from leptonic decays of two or three electroweak (EW) bosons produced in the collisions, and referred to as irreducible backgrounds, as they correspond to the same final states as the signal from Σ production;
- events with one or two prompt leptons and additional non-prompt leptons that arise from leptonic decays of hadrons within jets.

The irreducible backgrounds from three or more leptons are dominated by SM WZ production, but also include ZZ and three EW boson events. The diboson contribution, which is reduced substantially by the Z veto, is evaluated from simulation and normalized using the cross sections measured by CMS [27]. The contribution from three EW bosons is dominated by the WWW channel, and it is quite small.

Photon conversions, in the presence of W or Z bosons, produce isolated leptons that form a source of background for searches for physics beyond the SM in three-lepton events that have characteristics similar to WZ and ZZ backgrounds.

External conversions, where a real photon interacts with the material in the detector, primarily produce e^+e^- pairs. The residual contribution from this background, after applying the cut on the e^+e^- mass around the Z mass, is evaluated from simulation. Internal conversions, where a virtual photon converts to a lepton pair at the interaction vertex, can produce muons and electrons ($\gamma^* \rightarrow \ell(\ell)$). External and internal conversions are sources of background, if one of the two final state leptons carries off most of the photon energy, and the second lepton is soft and not detected (Table 1). The contribution of internal conversions to electrons is removed by the additional three lepton mass veto applied to the $\mu^- e^+ \mu^+$ and $e^- e^+ e^+$ categories. The contribution from photon conversions to muons is evaluated using $\ell^+\ell^-\gamma$ events in data that pass all selections, except the three lepton requirements. The ratio of the number of $\ell^+\ell^-\mu^\pm$ to the $\ell^+\ell^-\gamma$ (real photon) events on the Z peak gives a conversion factor for muons $C_\mu = 0.32\% \pm 0.08\% \pm 0.32\%$ where the first uncertainty is statistical and the second is systematic [29]. A 100% systematic uncertainty was assigned to this ratio, based on the assumption that the number of isolated photons is proportional to the number of leptons from asymmetric internal and external γ conversions. An additional check of this result is obtained from selecting events in a control region, using the same selection criteria as described in section 4, except the $E_{\mathrm{T}}^{miss} > 30$ GeV cut, that is replaced with $E_{\mathrm{T}}^{miss} < 20$ GeV, and no constraint on the sum of the lepton charges. Events from Z decay into two muons or two electrons, containing an additional muon from internal photon conversion, produce a peak in the three-lepton invariant mass distribution close to the Z mass. The number of entries expected in our final sample is estimated from the ratio of simulated events for Z production with $E_{\mathrm{T}}^{miss} > 30$ GeV to that with $E_{\mathrm{T}}^{miss} < 20$ GeV. This estimate differs from the previous one by $\approx 30\%$. From the statistical precision of both estimates, and possible additional contribution from the choice of the normalization criteria, an overall uncertainty of $\pm$ 50% can be assumed for this source of background.

The largest remaining background besides the irreducible backgrounds, comes from the Z+jets process (including Drell Yan production), in which the Z boson decays leptonically, and a third lepton is generated from a misidentified jet in the event. Processes with non-prompt leptons from heavy-flavour decays are not simulated properly with the MC generators and we therefore use a data-driven procedure to estimate this contribution. The yield of such background in data is estimated using a sample of leptons that pass less restrictive selection criteria than the ones described previously. The leptons chosen with the full selection criteria are defined 'tight' leptons, while those that pass the above defined selection criteria, except for the isolation requirement, are called 'loose' leptons. The probability for a loose lepton to pass tight selection in samples, where the presence of prompt isolated leptons is suppressed, gives the misidentification rate.

The contribution to the background is obtained from the lepton misidentification rate and the events that pass the full kinematics selection of the analysis, except for lepton isolation criteria. The misidentification rate depends on p_T and $|\eta|$ of the lepton. However, we only use the average and therefore assign an uncertainty as large as 50% to this background estimate. Several cross checks of the method used to evaluate this background contribution have been performed using data and Monte Carlo events. They show agreement between the number of observed leptons and the number of leptons predicted on the basis of the lepton misidentification rates. Events from $t\bar{t}$ production with leptonic W decay and an additional lepton are reduced by PF isolation requirements on leptons and the selection on H_{T}. From simulation $t\bar{t}$ background is negligible and its contribution is included in the estimate from non-prompt leptons.

The SM contributions to the background expectations in each of the six categories of lepton channels are shown in Table 1.

Table 1: Summary of the number of SM background events expected in each analysis channel, after final selection cuts. V represents Z or W bosons, Vγ is the contribution from external photon conversions, misidentified jets column includes backgrounds with non-prompt leptons, γ^* shows background values from internal photon conversions, where a virtual photon converts to a muon pair. The contribution of $\gamma^* \to$ e(e) is removed by the additional three lepton mass veto. Only statistical uncertainties are given.

	VV	VVV	Vγ	Misidentified jets	$\gamma^* \to \mu(\mu)$
$\mu^-e^+e^+$	0.28±0.07	0.09±0.01	-	0.38±0.38	-
$\mu^-e^+\mu^+$	3.7±0.27	0.19±0.01	-	3.1±1.2	-
$\mu^-\mu^+\mu^+$	4.6±0.3	0.11±0.01	-	5.7±1.9	0.69± 0.20
$e^-\mu^+\mu^+$	0.26±0.07	0.09±0.01	-	0.76±0.54	-
$e^-e^+\mu^+$	4.6±0.3	0.21±0.02	-	3.0±1.2	0.38± 0.11
$e^-e^+e^+$	2.35±0.21	0.06±0.01	1.4±1.0	1.07±0.62	-

6 Systematic uncertainties

Systematic uncertainties can be divided into those related to the extraction of the signal and those relevant to the sources of background. The first group includes efficiencies of trigger settings, reconstruction of produced objects, and lepton identification. The trigger efficiency for signal, in the kinematic region defined by the analysis, is very high, because it is based on three combinations of dilepton triggers. Each of the dilepton triggers is found to be 92% $\div$ 100% efficient. We estimate an overall efficiency of $(99 \pm 1)\%$. Uncertainties on lepton selection efficiencies are determined using a the tag-and-probe method [31], both in data and in simulations, and the differences between the two are taken as the systematic uncertainties on the efficiencies. For the different event categories considered in this analysis, we use the uncertainties given in Ref. [27]. They were obtained from a full GEANT 4 simulation. As mentioned in Section 3, full GEANT 4 simulations of signal were restricted to several discrete masses M_Σ (in fact, the largest available value for these full simulations is 140 GeV). The efficiency is therefore extrapolated using fast detector simulation to the higher mass points.

The difference between the efficiency evaluated with the Full and the Fast simulation at 140 GeV is taken as additional contribution to the overall uncertainty. Statistical uncertainties in the extrapolation are also taken into account. The overall uncertainty on the integrated luminosity is 2.2% [32]. The values of uncertainties attributed to the expected signal are reported in Table 2.

The uncertainties on background are estimated through simulation or using control samples in data. For the dominant irreducible background WZ production we use the measured cross section that has an overall uncertainty of 16% [27], and normalize the other irreducible backgrounds to LO Monte Carlo cross sections, for which the uncertainties are dominated by next-to-leading order (NLO) K-factor corrections [33]. For very small backgrounds as WWW, we assume a normalization uncertainty of 50%. The systematic uncertainty from the determination of the luminosity is correlated between signal and the Monte Carlo backgrounds.

Uncertainties on the yield from data-driven background estimates were discussed in Section 5. All statistical uncertainties are summarized in Table 1, and the systematic contributions in Table 3.

Table 2: Uncertainties on signal efficiency for each event category.

Source of uncertainty	Uncertainty for each event category (%)					
	$\mu^- e^+ e^+$	$\mu^- e^+ \mu^+$	$\mu^- \mu^+ \mu^+$	$e^- \mu^+ \mu^+$	$e^- e^+ \mu^+$	$e^- e^+ e^+$
Trigger	1 %	1 %	1 %	1 %	1 %	1 %
Signal efficiency (Fullsim)	6.3%	4.5%	3.9%	4.5%	6.3%	7.6%
(Full/Fast) systematics	2.9%	6.8%	11%	8.5%	4.1%	2.8%
Total systematics in quadrature	7.0%	8.2%	12%	9.7%	7.6%	8.0%
(Full/Fast) statistics	3.0%	2.3%	3.3%	2.9%	2.4%	4.2%
Total syst.+stat. in quadrature	7.6%	8.5%	12%	10%	7.9%	9.1%
Luminosity	2.2%	2.2%	2.2%	2.2%	2.2%	2.2%

Table 3: Systematic uncertainties for different significant sources of background.

Background source	Uncertainty on normalization
WZ	16%
ZZ	7.5%
$V\gamma$	13%
WWW	50%
Misidentified jets	50%
$\gamma^* \to \mu(\mu)$	50%

7 Results

In Table 4, we provide the expected number of seesaw signal events, the expected number of events from SM background, and the number of observed events in each of the six categories, assuming equal branching ratios ($b_e = b_\mu = b_\tau = 1/3$) case.

Table 4: Summary of the expected number of events for signal, as a function of M_Σ, and SM background, and the observed number of events in data, after implementing all analysis selections. Equal ratios $b_e = b_\mu = b_\tau = 1/3$ are assumed for the signal.

	Expected signal for M_Σ (GeV)					Expected SM background	Data
Channel	100	120	130	140	180		
$\mu^- e^+ e^+$	12.32	7.91	6.02	4.49	1.73	0.75±0.44	2
$\mu^- e^+ \mu^+$	20.74	12.31	8.95	6.97	2.97	7.1±2.1	9
$\mu^- \mu^+ \mu^+$	13.57	7.80	5.16	3.59	1.41	11.1±3.6	7
$e^- \mu^+ \mu^+$	13.68	8.25	6.24	4.75	1.75	1.11±0.67	0
$e^- e^+ \mu^+$	21.83	13.20	9.49	6.85	2.73	8.2±2.1	7
$e^- e^+ e^+$	6.47	3.90	2.80	2.00	0.96	4.8±1.4	4

Since no significant excess of events is observed relative to SM expectations in the three-lepton channels, we set 95% confidence level (CL) limits on the product of the cross section and the branching ratio (BR) of $\Sigma^+\Sigma^0$ to three lepton final states for all of the six channels combined. Hereafter BR refers to final states including electrons, muons or tau leptons. Limits on the mass of the seesaw-mediator mass are inferred from the limits on the cross sections. We extrapolate yields for signal to $M_\Sigma > 180$ GeV using the results given in Ref.[16].

The cross section limits as function of the mass of the fermionic triplet Σ are shown in Fig. 3 for $b_e = b_\mu = b_\tau = 1/3$, in Fig. 4 for $b_\mu = 1$, $b_e = b_\tau = 0$, and in Fig. 5 for $b_e = 1$ and $b_\mu = b_\tau = 0$. The solid blue line corresponds to the seesaw-triplet production cross section multiplied by BR.

The observed limits are computed following a Bayesian and a CLs approach [26]. In the former, a flat prior is taken for the seesaw fermionic triplet mass, and, in both calculations, the uncertainties on the efficiencies for detection of signal, on the integrated luminosity, and on the expected SM background are parameterized in terms of Gaussian functions, called 'nuisance' parameters. The RooStats software [34], and the package developed to combine results from searches for the Higgs boson [35], are used to evaluate the limits. The two sets of results are shown in Figs. 3, 4, 5, and they indicate general agreement between the two methods. The expected and observed limits obtained with the Bayesian method are given in Table 5.

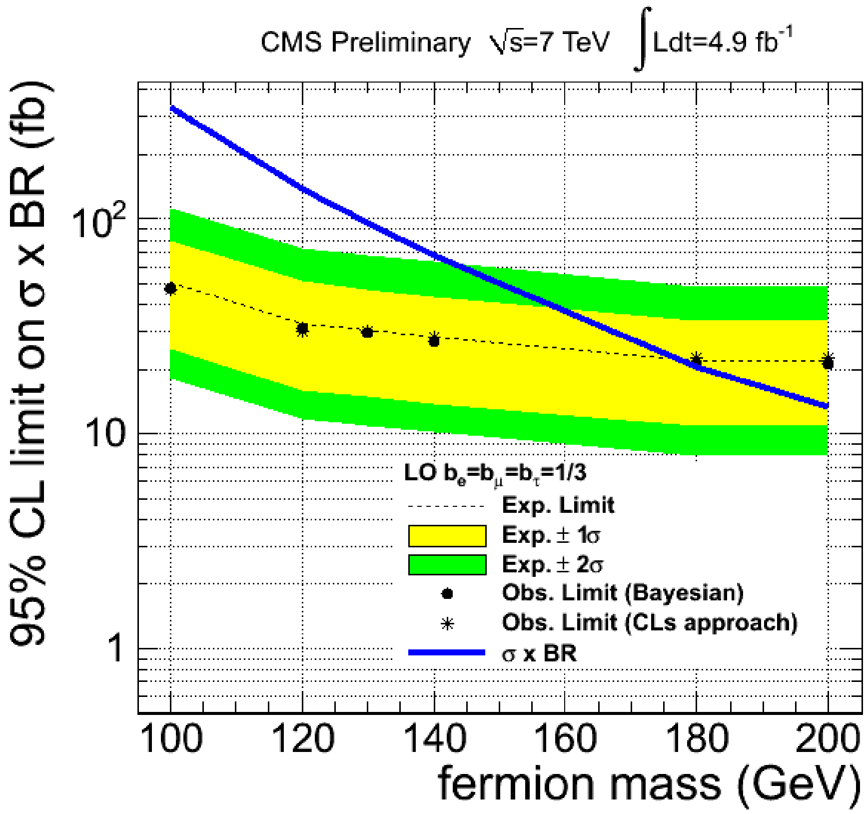

Figure 3: The expected and observed exclusion limits at 95% confidence on $\sigma \times$ BR as a function of the Σ mass. The light and dark shaded areas represent respectively the 1 standard deviation (σ) and 2 standard deviation (σ) limits on the expected results (dashed line) obtained from MC pseudo-experiments. These uncertainties reflect the combined statistical and systematic SM contributions, assuming for the signal $b_e = b_\mu = b_\tau = 1/3$.

The extracted limits are obtained using the leading-order (LO) cross section for the Type III seesaw signal. To estimate the NLO cross section and the normalization K-factor, we use Ref. [36].

As mentioned above, although the predicted seesaw-triplet cross sections do not depend on the mixing value itself, nevertheless, for very small values of the b_α the triplet lifetime is sufficiently long to provide displaced decay vertices, measurable in the CMS detector. In this case, the analysis requires a very different approach, since the leptons can originate from different displaced vertices in an environment with high pile-up. The limits reported here are therefore valid only for mixing values larger than $\approx 10^{-6}$.

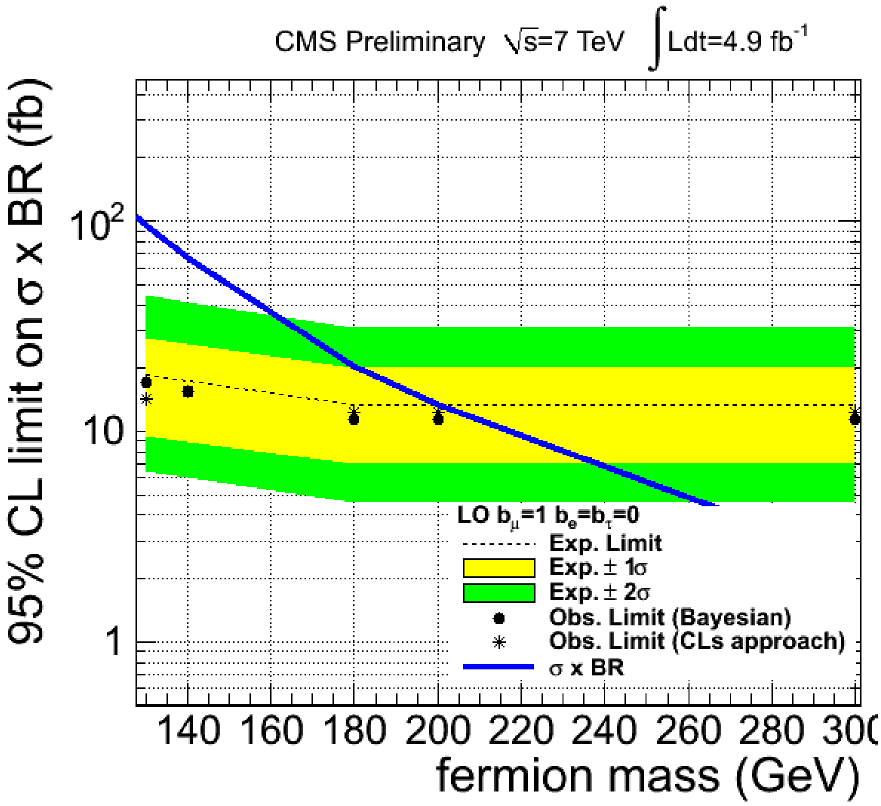

Figure 4: The expected and observed exclusion limits at 95% confidence on $\sigma \times \mathrm{BR}$ as a function of the Σ mass. The light and dark shaded areas represent respectively the 1 standard deviation (σ) and 2 standard deviation (σ) limits on the expected results (dashed line) obtained from MC pseudo-experiments. These uncertainties reflect the combined statistical and systematic SM contributions, assuming for the signal $b_\mu = 1, b_e = b_\tau = 0$.

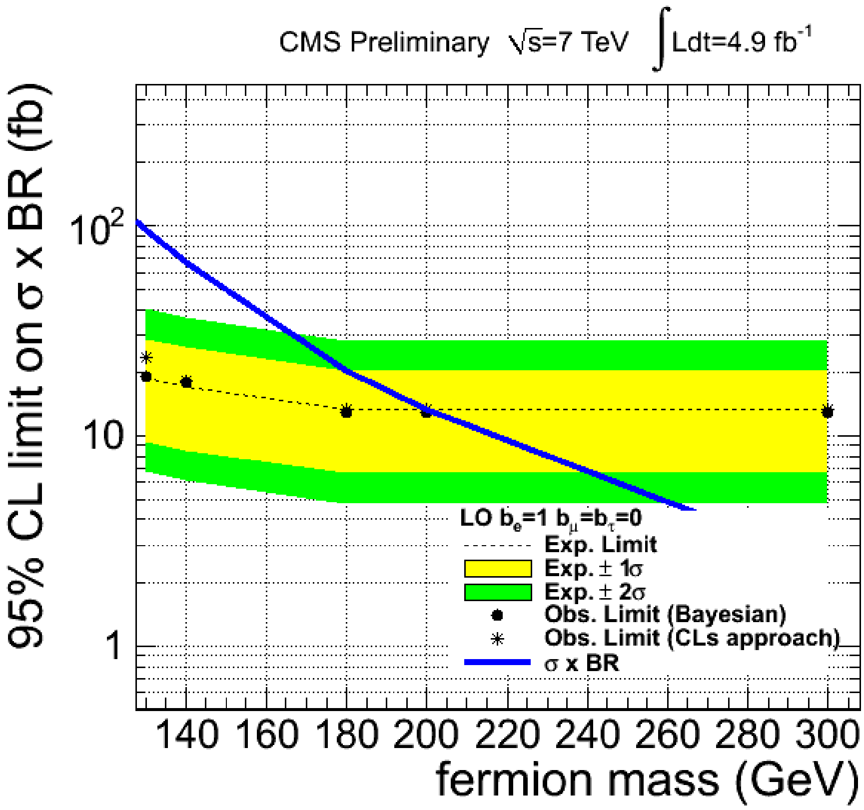

Figure 5: The expected and observed exclusion limits at 95% confidence on $\sigma \times$ BR as a function of the Σ mass. The light and dark shaded areas represent respectively the 1 standard deviation (σ) and 2 standard deviation (σ) limits on the expected results (dashed line) obtained from MC pseudo-experiments. These uncertainties reflect the combined statistical and systematic SM contributions, assuming for the signal $b_e = 1, b_\mu = b_\tau = 0$.

Table 5: Expected and observed lower limits at 95% CL for the triplet Σ mass and in corresponding upper limits on $\sigma \times$BR for different assumptions on the mixing ratios values.

Branching ratio cases	95% on M_Σ GeV		95% on $\sigma \times$ BR (fb)	
	Exp.	Obs.	Exp.	Obs.
$b_e = b_\mu = b_\tau = 1/3$	177	179	22	20
$b_\mu = 1, b_e = b_\tau = 0$	201	211	13	11
$b_e = 1, b_\mu = b_\tau = 0$	202	204	13	13

8 Conclusions

A search for Type III seesaw contributions in $\ell^- \ell^+ \ell^+ + E_T^{miss}$ final states in pp interactions at $\sqrt{s} = 7$ TeV using data recorded in 2011 by the CMS experiment at the CERN LHC, corresponding to an integrated luminosity of 4.9 fb^{-1} is presented.

No evidence for pair production of fermionic triplet $\Sigma^+\Sigma^0$ states is found, and 95% CL lower limits on the product of cross section times branching fraction of $\Sigma^+\Sigma^0$ to final states with three leptons are set. By comparing the results with the predicted cross sections at LO, lower bounds at 95% CL on the mass of the triplet states are derived. Limits, valid for mixing values larger than $\approx 10^{-6}$, are reported for three choices of mixing between the Σ states and the three lepton generations. These are the first limits on the production of seesaw Type III fermionic triplet reported by an experiment at the LHC.

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