PROCEEDINGS OF SCIENCE

Search for a W' boson decaying to a τ lepton and a neutrino in proton-proton collisions at $\sqrt{s} = 13$ TeV with CMS

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A search for a new high-mass resonance decaying to a τ lepton and a neutrino is reported. The analysis uses proton-proton collision data collected by the CMS experiment at the LHC at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 35.9 fb^{-1}. The search utilizes hadronically decaying τ leptons. An interpretation of results is shown in the context of a W' boson predicted in the sequential standard model (SSM), and also nonuniversal gauge interaction model (NUGIM), in which the W' boson decays preferentially to fermions of the third generation. In addition, a model-independent limit is shown, allowing the results to be interpreted in other models giving the same final state with similar kinematic distributions.

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1. Introduction

New charged heavy gauge bosons, generically referred to as W' bosons, are predicted by many extensions of the standard model (SM); for example, the sequential standard model (SSM), and the nonuniversal gauge interaction models (NUGIMs). The SSM, which is often used as a benchmark model, features an extended gauge sector, and the W' boson in this model is a heavy analog of the W boson. NUGIMs exhibit a $SU(2)_l \times SU(2)_h \times U(1)$ symmetry, and often called $G(221)$ models. Here the indices l and h refer to light and heavy, respectively. These two $SU(2)$ groups mix, resulting in an SM-like $SU(2)_W$ and an extended group $SU(2)_E$. The $SU(2)_E$ extended gauge group gives rise to additional gauge bosons. The mixing of the two gauge groups involves a mixing angle, θ_E, which modifies the couplings to the heavy boson. The analysis presented in this proceeding searches for $W' \to \tau\nu$ events, where the τ lepton decays hadronically [1]. The hadronic decays of the τ lepton are experimentally distinctive because they result in low charged-hadron multiplicity, unlike jets originating from the hadronization of quarks and gluons produced in the hard scattering process, which have higher charged-hadron multiplicity. The signature of a W' boson event is similar to that of a W boson event in which the W boson is produced "off-shell" with a high mass. The leading order Feynman diagram is presented in Fig. 1.

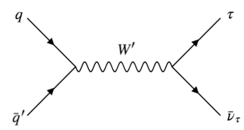

Figure 1: Feynman diagram of the expected signal process.

2. Analysis strategy

In this search, the dominant SM background is the W+jets process. Other important background processes are $Z/\gamma^* \to ll$ and top quark production. Background from jets that are misidentified as τ_h candidates is dominated by $Z \to \nu\nu$ + jets events. The discriminating variable used in this analysis is the transverse mass. The main strategy of this analysis is to select a heavy W' candidate decaying almost at rest to a τ_h and neutrinos, which are detected as p^T_{miss} in the CMS detector. Signal events are selected online with a $\tau_h + p^T_{miss}$ high level trigger that requires the p_T of the τ_h candidate to be greater than 50 GeV and the value of p^T_{miss} to be greater than 90 GeV. To ensure that the trigger is maximally efficient for selected events, the offline selection requires exactly one isolated τ_h candidate to have $p_T > 80$ GeV and $p^T_{miss} > 200$ GeV. Although there are two neutrinos in the final state, p^T_{miss} and the isolated τ_h candidate are largely produced in opposite directions, which helps to distinguish signal from background events especially those coming from QCD multijet production. Two selection criteria exploit this behavior to reduce the background: the ratio of the p^τ_T to p^T_{miss} is required to satisfy $0.7 < p^\tau_T / p^T_{miss} < 1.3$ requirement; and the angle $\Delta\phi$ between the direction of τ p_T and p^T_{miss} has to be greater than 2.4 radians. Consequently, the lowest m_T value is about 300 GeV. To avoid an overlap with the W' boson search in the electron channel, events are rejected if they contain a loosely identified electron with $p_T > 20$ GeV and $|\eta| < 2.5$, where the loose working point is around 90% efficient for real electrons. For similar reasons, events containing a loosely identified muon with $p_T > 20$ GeV and $|\eta| < 2.4$ are not considered in this analysis, where the loose working point is >99% efficient for real muons. After all selections, the m_T distributions for the observed data and expected background events are presented in Fig. 2 (left). The cumulative distribution is shown in Fig. 2 (right), which is formed by filling each bin of the histogram with the sum of that bin and all following bins. The transverse mass

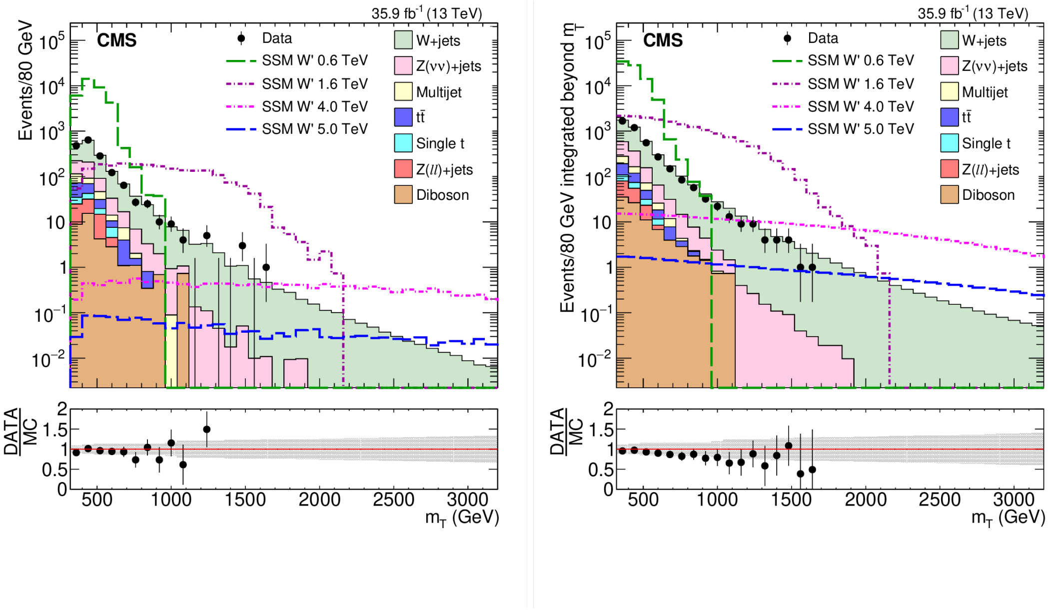

Figure 2: The m_T and cumulative m_T distributions after the final selection. The black symbols with error bars show data, while the filled histograms represent the SM backgrounds [1].

distribution shows no significant deviations from the expected SM background. Signal events are expected to be particularly prominent at the upper end of the m_T distribution, where the expected SM background is vanishingly small.

3. Results

Upper limits on the product of the production cross section and branching fraction are determined using a Bayesian method with a uniform positive prior probability density for the signal cross section. The nuisance parameters associated with the systematic uncertainties are modeled through log-normal distributions for uncertainties in the normalization. For the SSM W', the parameter of interest is the product of the signal cross section and the branching fraction. The branching fraction includes all τ lepton decay modes, to allow a direct comparison with the W' searches in the electron and muon channels. The upper limit on the parameter of interest as a function of the SSM W' boson mass is shown in Fig. 3 (left). The observed limit is consistent with the expected limit. The SSM W' boson is excluded for masses $0.4 < M'_W < 4.0$ TeV at 95% CL where the lower limit is mainly determined by the trigger threshold and the upper one by the available data. The upper limits on the cross section depend not only on the mass of a potential excess, but also on the width. Because of the relation between the coupling of a particle and its width, it was also possible to set a limit on the coupling strength, as depicted in Fig. 3 (right). The phase space above the observed limit contour is excluded. For low masses, $g_{W'}/g_W$ values down to 7×10^{-2} are excluded. Fig. 4 shows expected and observed 95% CL upper limits on the mixing angle $\cot\theta_E$ as a function of the W' boson mass in NUGIM. The region left of the solid black line is excluded. Depending on the value of $\cot\theta_E$, the

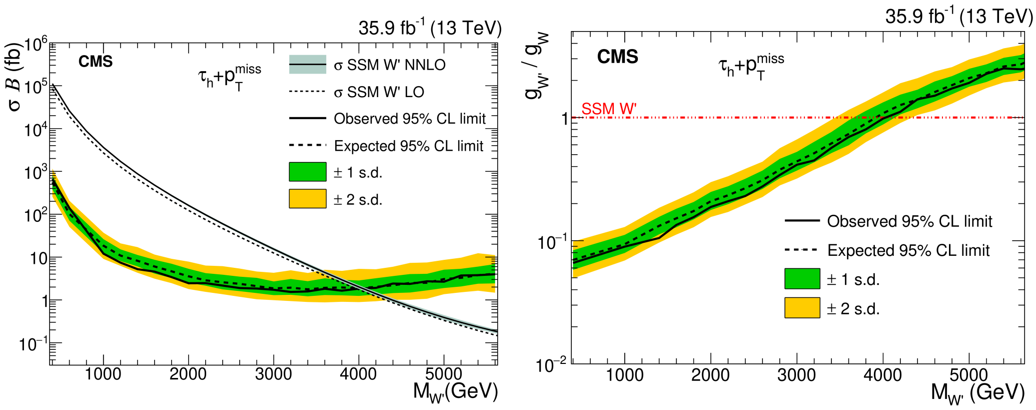

Figure 3: Expected and observed 95% CL upper limits on (left) the cross section for the production of SSM W' boson; and (right) the ratio of couplings [1].

mass of the W' boson can be excluded at 95% CL up to 3.9 TeV in the NUGIM $G(221)$ framework. The previous limit plots are obtained with a shape analysis that assumes a certain signal shape in

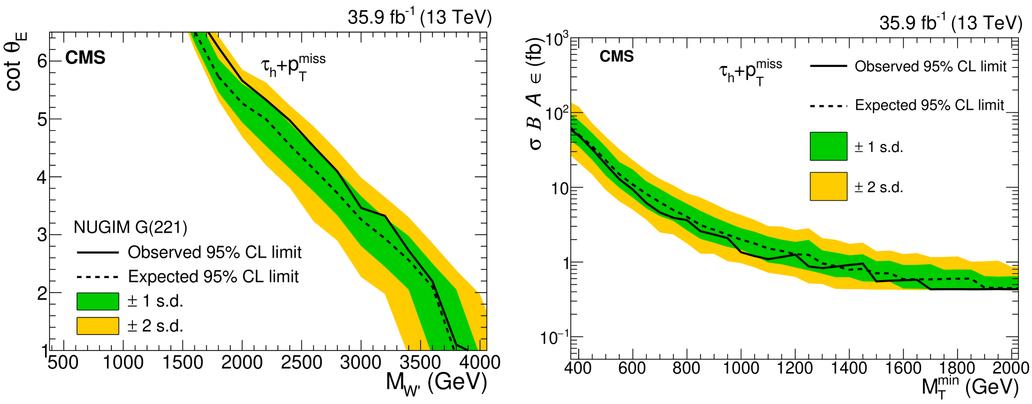

Figure 4: Expected and observed 95% CL upper limits on (left) the mixing angle $\cot\theta_E$; and (right) the product of cross section, branching fraction, and acceptance, obtained in a model independent fashion [1].

m_T. However, alternative new physics processes yielding a $\tau_h + p^T_{miss}$ final state could cause an excess of a different shape. A model-independent cross section limit is determined using a single bin ranging from a lower threshold on m_T to any values higher than that. No assumptions on the shape of the signal m_T distribution have to be made other than that of a flat product of acceptance times efficiency, as a function of W' mass. The resulting cross section limit as a function of m_T^{min} is shown in Fig. 4 (right). The highest m_T event in data was found at 1.65TeV, after which the limit becomes flat.

References

[1] A. M. Sirunyan *et al.* [CMS Collaboration], "Search for a W' boson decaying to a τ lepton and a neutrino in proton-proton collisions at $\sqrt{s} = 13$ TeV," Phys. Lett. B **792**, 107 (2019) doi:10.1016/j.physletb.2019.01.069 [arXiv:1807.11421 [hep-ex]].