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Search for W′ production in the lepton + MET final state at 13 TeV in CMS

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Summary. — This note presents the search for new physics in events with an electron or muon and missing transverse energy, using $2.2\,\text{fb}^{-1}$ of pp collision data at a center-of-mass energy of 13 TeV, collected with the CMS detector during 2015. The focus is set on the potential production of a W′ boson, as described by the Sequential Standard Model. No evidence of an excess relative to the standard model expectation is observed and upper limits at 95% confidence level are set on the production cross section times branching fractions of the W′ boson, which are translated into lower limits for the new boson mass. Masses below 4.4 TeV are excluded when both the electron and muon final decay channels are combined together. These results significantly extend previously published limits.

1. – Introduction

Many extensions of the standard model (SM) predict additional heavy gauge bosons. In particular the Sequential Standard Model (SSM) [1] predicts the existence of a new massive boson, W′, exhibiting the same couplings as the Standard Model (SM) W boson, decaying in final states with a charged lepton and neutrino, or quark pairs.

The analysis presented in this document addresses deviations from the SM prediction in events with a charged lepton (electron or muon) and one (or more) particles that cannot be directly detected (neutrino, dark-matter particle) in the final state. In particular it allows the search for a W′ boson, where the decays to bosons (W, Z, H) are assumed to be suppressed. No interference with the SM W is considered.

Prior to this result, the most stringent limits up-to-date come from the LHC experiments, ATLAS [2] and CMS [3]. Current limits obtained by CMS with an integrated luminosity of $19.7 \pm 0.5\,\text{fb}^{-1}$ of proton-proton collisions at a center-of mass energy of 8 TeV, are 3.22 (2.99) TeV in the electron (muon) channel for SSM W′ bosons. Combining both channels results in an exclusion of masses smaller than 3.28 TeV. The ATLAS combined result at 8 TeV excludes W′ bosons with masses smaller than 3.24 TeV.

This proceeding is based on the Physics Analysis Summary (PAS) associated to this analysis [4] and presents the analysis of $2.2\,\text{fb}^{-1}$ of proton-proton collisions taken by the CMS detector during 2015, at a center-of mass energy of 13 TeV.

2. – CMS detector

A detailed description of the CMS detector and the coordinate system used can be found elsewhere [5]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter providing an axial field of 3.8 T. Within the field volume are located the silicon pixel and strip tracker ($|\eta| < 2.4$) and the barrel and endcap calorimeters ($|\eta| < 3$); a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadronic calorimeter (HCAL). An iron/quartz-fiber calorimeter is located in the forward region ($3 < |\eta| < 5$), outside the field volume. Muons are measured with detection planes made of three technologies: Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers ($|\eta| < 2.4$).

3. – Analysis strategy

The experimental signature in this search is the presence of a high-energy charged lepton and missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, which may flag the presence of a non-interacting particle (neutrino). The quantity $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ is defined as $-\sum \vec{p_T}$ of all reconstructed particles with $E_{\mathrm{T}}^{\mathrm{miss}}$ being the modulus of $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$. The discriminant variable used in the search is the transverse invariant mass, M_{T}, defined from the lepton $\vec{p}_{\mathrm{T}}$, the $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ in the event, and the difference in the azimutal angle between them, as

$$M_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{l} E_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos[\Delta\phi(\vec{p}_{\mathrm{T}}^{\,l}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})])}. \tag{1}$$

Events with at least one high-p_{T} lepton are selected using inclusive lepton triggers. Single-muon triggers (with $p_{\mathrm{T}} > 45\,\mathrm{GeV}$ and restricted in muon pseudorapidity, $|\eta| < 2.1$, or $p_{\mathrm{T}} > 50\,\mathrm{GeV}$ and covering the whole pseudorapidity range, $|\eta| < 2.4$), and single-electron ones (with threshold $E_{\mathrm{T}} > 105\,\mathrm{GeV}$) and loose identification criteria are used.

Electrons with $E_{\mathrm{T}} > 115\,\mathrm{GeV}$ are reconstructed from electromagnetic clusters in the ECAL acceptance region (barrel, $|\eta| < 1.444$, endcaps, $1.566 < |\eta| < 2.5$) matched to a track. The identification, optimized for high p_{T}, includes requirements on isolation and on the shape of the electromagnetic shower.

For muon reconstruction, information from both the inner tracker and the outer muon system is used. Each muon is required to have at least one hit in the pixel detector, hits in at least four layers of the strip tracker, and segments in two or more muon detector layers. Isolated muons are selected with $p_{\mathrm{T}} > 53\,\mathrm{GeV}$ and $|\eta| < 2.0$ and in order to suppress muons with mismeasured p_{T}, an additional requirement $\sigma_{p_{\mathrm{T}}}/p_{\mathrm{T}} < 0.3$ is applied, where $\sigma_{p_{\mathrm{T}}}$ is the uncertainty from the track reconstruction. Cosmic-ray muons contamination is reduced by requiring the muons to be consistent with the primary vertex.

Once events containing a high-p_{T} charged lepton are selected, the two-body decay kinematics of the $\mathrm{W}' \to l\nu$ process is exploited for background suppression, applying the following two relatively loose kinematic cuts:

- The difference in the azimutal angle between the charged lepton transverse momentum and $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ is required to be $|\Delta\phi(\vec{p}^{\,l}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})| > 2.5$, which ensures a back-to-back configuration between the lepton and $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$.
- The ratio of the charged lepton transverse momentum and $E_{\mathrm{T}}^{\mathrm{miss}}$ must lie in the region $0.4 < p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}} < 1.5$.

Finally, events with an additional second lepton of the same flavour are vetoed.

4. – Backgrounds

The dominant and irreducible background of this search is $W \to \ell\nu$. Other background processes are Drell-Yan, $t\bar{t}$, single top and dibosons production. The contribution from these processes is estimated from simulation. The QCD multijet background, mostly affecting the electron channel, is largely rejected by the analysis selection criteria and the remaining contribution is estimated from data as decribed in [3].

The evaluation of the dominant SM W background is achieved using two different samples, one inclusive in mass generated with MADGRAPH5_aMC@NLO [6] and several exclusive others, covering the boson high-mass region, generated with PYTHIA8.2 [7], tune CUETP8M1 [8, 9] and NNPDF3.0 parton distribution functions (PDF) [10]. A mass-dependent K-factor is applied to take into account contribution from higher order corrections.

Simulation of signal samples (SSM $W' \to l\nu$) is performed with PYTHIA8.2, tune CUETP8M1 and using the NNPDF3.0 PDF. Signal cross sections are normalized to next-to-next-to-leading order (NNLO) QCD cross sections, calculated using FEWZ 3.1β2 [11]. All generated signal and background events are processed through a full simulation of the CMS detector based on GEANT4 [12], a trigger emulation, and the event reconstruction chain.

The signal acceptance times efficiency, defined as the fraction of simulated signal events passing the event selection, is about 75% for a W′ at 3 TeV in both the electron and muon channels.

5. – Systematic uncertainties

In the muon decay channel, the dominant uncertainties come from the preliminary knowledge of the alignment of the tracker and muon chambers, affecting both the muon p_T resolution and scale measurement. These sources of uncertainty translate directly into the E_T^{miss} determination, which is mainly given by the high-p_T lepton, and propagate to a 6%(21%) effect on the yields at $M_T = 1(2)$ TeV. Mismeasurements of the electron energy scale and resolution are typically small [13] and do not change the M_T shape in a sizable way. Uncertainties on the scale factors derived as the ratio of data to simulation efficiencies for triggering and identification when extrapolated to high E_T are 4% (6%) in the barrel (endcaps) in the electron channel and in the muon channel vary between 3%–8% depending on the p_T of the muon.

Other relevent uncertainties common to both channels concern the total integrated luminosity (4.6%) and a 5% flat on the K-factor accounting for higher-order corrections. The theoretical uncertainty related to the choice of the PDF set is estimated following [14] and is the dominant source of uncertainty at high M_T in the electron channel.

6. – Results

The transverse mass, M_T, defined in sect. **1**, is reconstructed for each selected event in data and simulated samples. Signal events are expected at high M_T values, while the several background contributions, and particularly the SM W boson decays appear as a tail as the transverse mass increases, due to the falling cross section. Figure 1 shows the transverse mass (left) and cumulative M_T (right) distributions for the electron channel for $M_T > 200$ GeV. The same distributions are presented for the muon channel in fig. 2 for values $M_T > 120$ GeV.

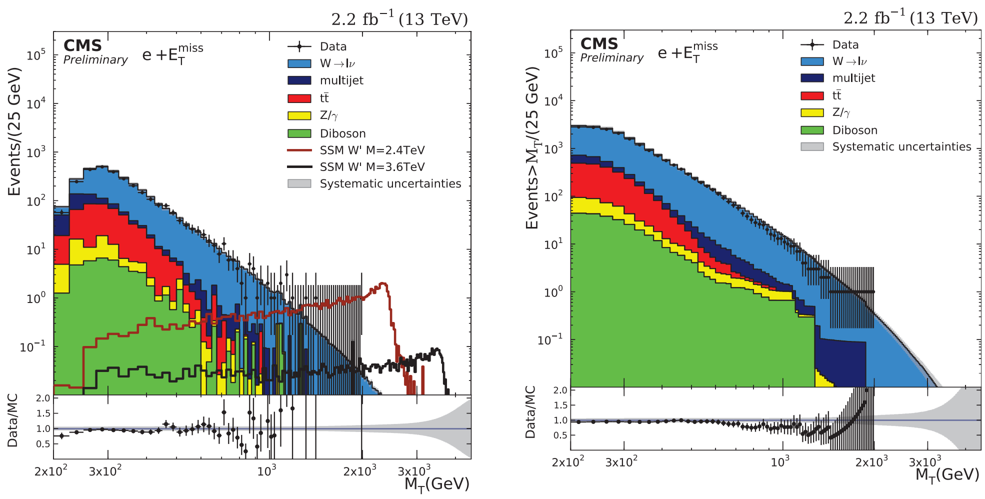

Fig. 1. – Distributions for data and expected SM backgrounds after kinematic selection in the electron channel: transverse mass M_{T} (left) and M_{T}-cumulative (right). The expected signal from the decay of two W′ bosons with masses $M(\mathrm{W}') = 2.4$ and 3.6 TeV is also shown. The bottom panels in both figures show the ratio of observed data to SM predictions where the band centred around unity accounts for the systematic uncertainty on the background prediction, without including the 4.6% uncertainty in the luminosity.

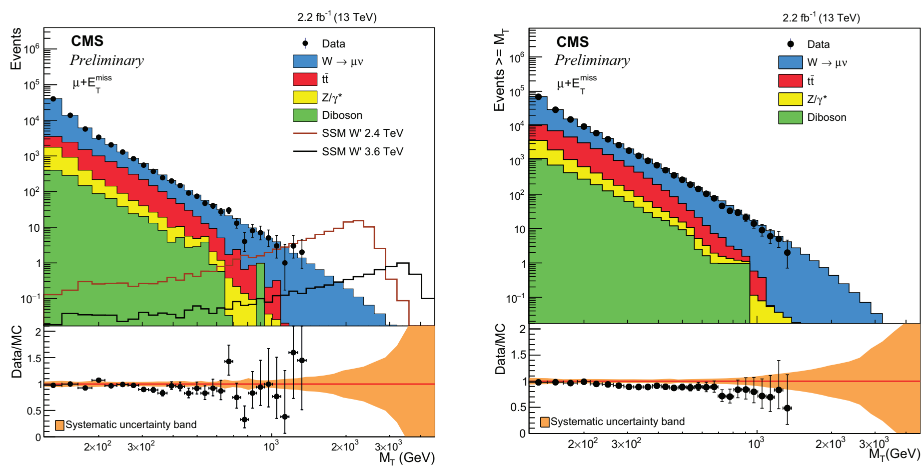

Fig. 2. – Distributions for data and expected SM backgrounds after kinematic selection in the muon channel: transverse mass M_{T} (left) and M_{T}-cumulative (right). The expected signal from the decay of two W′ bosons with masses $M(\mathrm{W}') = 2.4$ and 3.6 TeV is also shown. The bottom panels in both figures show the ratio of observed data to SM predictions where the band centred around unity accounts for the systematic uncertainty on the background prediction, without including the 4.6% uncertainty in the luminosity. The increasing bin size at high M_{T} is chosen to take into account the degradation of the muon p_{T} resolution.

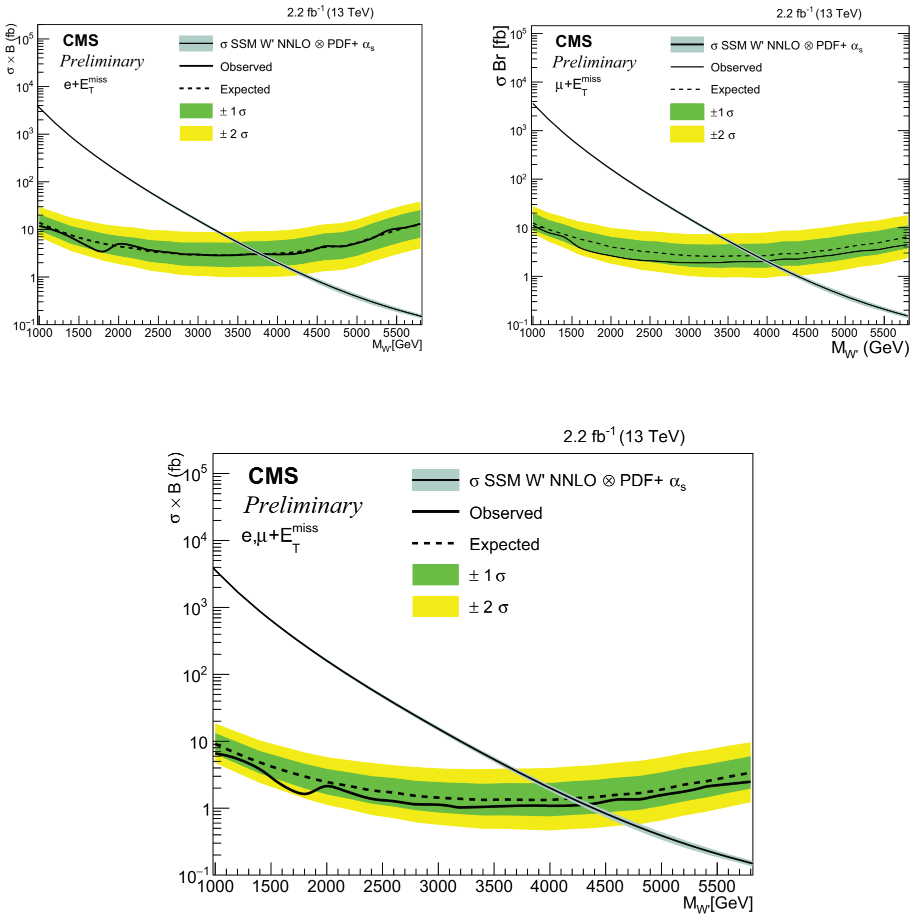

Fig. 3. – Top: expected and observed 95% CL limits for the electron (left) and muon (right) channels. Bottom: expected and observed 95% CL limit for the combined channel assuming lepton universality. The expected (observed) limit is displayed as a dashed (solid) line and the green (yellow) bands represent the one (two) sigma uncertainty bands. The SSM W′ NNLO cross sections are depicted as a function of $M(\mathrm{W}')$.

7. – Exclusion limits on SSM W′ bosons

As no significant deviation from predictions is seen in the M_{T} distributions in neither the electron nor the muon decay channels, exclusion limits on new signals are set in the context of the SSM W′ boson production. Upper limits on the production cross section times branching fraction $\sigma_{\mathrm{W}'}(\mathcal{B} \to \ell\nu)$, with $\ell = e, \mu$, are determined using the modified frequentist prescription for the CLs method [15, 16].

Expected and observed 95% confidence level (CL) limits as a function of W′ mass are shown in fig. 3, in the electron (left) and the muon (right) channels for $M(\mathrm{W}') > 1\,\mathrm{TeV}$. With the present data statistics SSM W′ resonances of masses less than 3.8 TeV (3.8 TeV expected) in the electron channel and 4.0 TeV (3.8 TeV expected) in the muon channel, are excluded at 95% CL. These results provide tighter limits than the ones obtained from Run-I data.

If both channels are combined, SSM W′ bosons with masses below 4.4 TeV (4.2) TeV expected) are excluded at 95% CL as shown in fig. 3.

8. – Conclusions

A search for SSM W′ bosons in final states containing a single high-p_T electron or muon and E_T^{miss}, using $2.2\,fb^{-1}$ of pp collision data at 13 TeV collected with the CMS detector has been performed. No sign of new physics has been observed and exclusion limits at 95% CL were extracted on the mass of the W′ boson. Masses below 3.8 (4.0) TeV are excluded using the individual electron (muon) decay channels analysis. When both channels are combined the limits on the mass exclusion extend to 4.4 TeV.

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