PROCEEDINGS OF SCIENCE

ATLAS and CMS searches beyond inclusive resonances in leptonic final states

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Non-resonant final states containing leptons can be used to probe for physics beyond the Standard Model. Searches for new physics models with these signatures are performed using the ATLAS and CMS experiments at the LHC. The results of the most recent searches on 13 TeV pp data will be presented.

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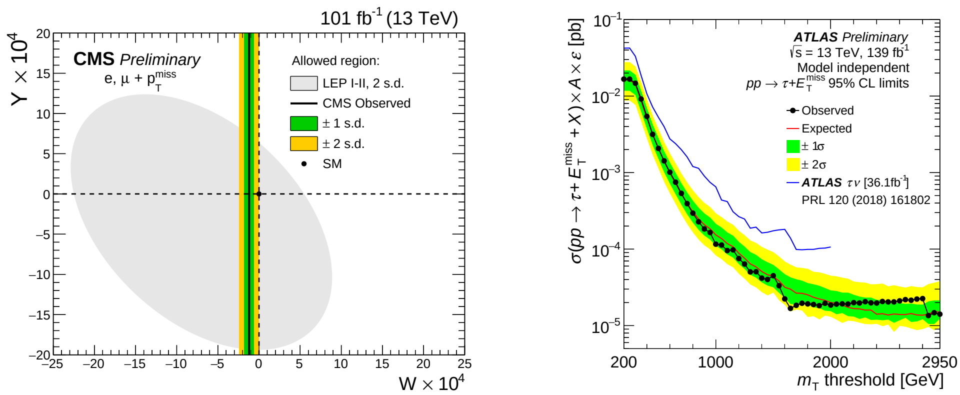
1. Introduction

Searches for physics beyond the Standard Model (BSM) can be performed in various final state topologies at collider experiments. In this document, several searches using full Run 2 dataset of proton–proton collisions collected by the ATLAS [1] and CMS [2] detectors at the Large Hadron Collider (LHC) will be presented. With the increasing amount of data collected non-resonant final states involving leptons can be used to probe for rare processes.

2. Processes with one charged lepton and missing transverse momentum

Events with exactly one isolated high-p_{T} lepton, an electron or a muon, and high missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ can be used for non-resonant searches, especially the tails of transverse mass[1] M_{T}. Effective field theory (EFT) interpretations quantify potential deviations from SM expectations through the oblique electroweak parameters W and Y as a correction to the propagator $qq \to W \to \ell\nu$ [3]. Contributions from this channel would manifest as either an excess or deficit in the M_{T} distribution, especially in the high M_{T} region.

The data taken by CMS during 2017 and 2018, amounting to 101 fb^{-1}, are used to constrain the W parameter separately in electron and muon channels [4]. A combined binned negative log-likelihood fit gives a fit value of $W = -12^{+5}_{-6} \times 10^{-5}$. The outcome of the fit with one and two standard deviation bands in the $Y - W$ parameter is compared to the LEP results [5] in Figure 1a. The result is consistent with the SM value of $W = 0$ at the $2\,\sigma$ level.



(a) **(b)**

Figure 1: (a) Region in the $Y - W$ parameter phase space allowed by the analysis at the $2\,\sigma$ level. Taken from Ref. [4]. (b) Model-independent 95% C.L. upper limit on the visible $\tau + E_{\mathrm{T}}^{\mathrm{miss}}$ cross section as a function of the transverse mass thresholds. Taken from Ref. [6].

Events with τ-leptons in the final state yield wide resonances due to secondary (hadronic) τ decays. Sequential Standard Model (SSM) W' boson [7] has been searched for by ATLAS [6]. W' masses are excluded up to 5.0 TeV. Additionally model-independent limits are set on signal yields above certain transverse mass thresholds, $m_{\mathrm{T}}^{\mathrm{thresh}}$ as shown on Figure 1b.

[1]Transverse mass can be defined as $M_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos\left[\Delta\phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}})\right]\right)}$, where p_{T}^{ℓ} is the transverse momentum of the lepton.

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3. Processes with two leptons

Deviations in the dilepton spectrum could be indicators of new physics. A search for lepton flavour universality violations has been performed by CMS [8]. The ratio of the dimuon to dielectron differential cross section would differ from 1 in such case [9]. The dominant background process, the Drell–Yan process, is estimated using simulation, while jets misidentified from electrons are estimated from data. The combined background is then normalised to data around Z boson peak. No significant deviation from 1 is observed.

The same dataset is used to also probe for the effective four-fermion contact interaction [10, 11]. This analysis has also been performed by ATLAS [12], where a data-driven parametric fit is used to estimate the background. Lower limits on the contact interaction scale Λ are set, ranging from 22.3 to 35.8 TeV for ATLAS and from 23.9 to 36.4 TeV for CMS. The same analysis regions have also been used by both experiments to search for extra dimensions in ADD models [8, 13].

To explain the asymmetries measured in the B-meson decays, the $bs\ell\ell$ interaction would have to be different between electrons and muons [14–16]. This has been probed by ATLAS [17] using four different topologies, opposite-charge electron or muon pairs with 0 or 1 b-jet. Top and multijet backgrounds are estimated from simulation and extrapolated from a region with 2 b-jets. Several signal regions are defined with lower bounds on $m_{\ell\ell}^{\mathrm{min}}$ starting at 400 GeV. The largest observed local significance is 2.6 σ in the dielectron channel with 1 b-jet. Lower limits on the scale are set and range from 1.8 to 2.4 TeV.

The number of leptons of each generation is conserved in weak interactions, and violation of this assumption is known as lepton flavour violation (LFV). Only one in 10^{54} Z bosons would decay into a muon and a τ lepton via neutrino mixing, but with presence of heavy neutrinos the probability would increase to one in 10^5 [18]. ATLAS has also performed searches for such lepton flavour violating Z boson decays with both leptonically [19] and hadronically [20] decaying τ-leptons. Each individual background contribution is estimated using a neural network, which is then used in a combination optimising for the highest signal sensitivity. A combined fit of eight signal regions is used to derive limits on $\mathcal{B}(Z \to e\tau) < 5 \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) < 6.5 \times 10^{-6}$.

4. Multilepton final states

The experimental observation of neutrino oscillation shows that neutrinos have non-zero masses, which are much smaller than those of the charged leptons. ATLAS [21, 22] uses a minimal type-III seesaw model [23] focusing on the lightest fermionic triplet of unknown (heavy) masses with one neutral and two oppositely-charged leptons denoted by (L^+, L^-, N^0). Here L^+ is the antiparticle of L^- and N^0 is a Majorana particle. These heavy leptons decay into a SM lepton and a W, Z or H boson.

Signal regions are first split by light lepton multiplicity. Six dilepton signal regions probe all flavour and charge combinations, and require at least 2 hadronic jets to be present. In the trilepton case, two regions also requiring at least 2 jets are split by the presence of a leptonically decaying Z boson, and one region covers events with 0 or 1 jets. Two four lepton signal regions are defined based on the total sum of lepton charge being either 0 or 2. Two examples of signal regions are

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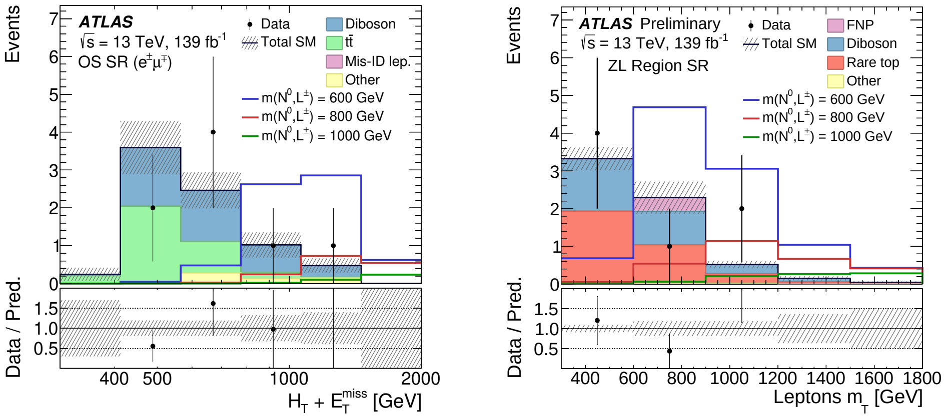
shown in Figure 2. As the signal process contains neutrinos in the final state, one of the most important selection criteria is based on the E_T^{miss} reconstruction significance Sig(E_T^{miss}) [24].



(a) **(b)**

Figure 2: Distributions of (a) $H_T + E_T^{miss}$ in the opposite-sign electron–muon signal region and (b) $m_T(3\ell)$ in the trilepton signal region containing leptonically decaying Z boson. Taken from Refs. [21] and [22].

A binned maximum-likelihood fit of the $H_T + E_T^{miss}$ variable distribution, the sum of the E_T^{miss} and the scalar sum of the transverse momenta H_T of the selected leptons and jets, is used to interpret the observations in dilepton and four lepton signal regions, whereas in trilepton regions the transverse mass of three leptons is used. For type-III seesaw $L^{\pm}$ and N^0, masses below 910 GeV are excluded.

5. Model independent searches

To avoid bias on specific BSM models more generalised searches can be performed. ATLAS looked at 22 signal regions [25], categorised by lepton count (3 or 4 leptons), presence of a leptonically decaying Z boson, magnitude of the invariant mass of all leptons and magnitude of E_T^{miss}. The measured number of signal events is defined as the difference between the estimated background and the data. No significant deviations from the Standard Model are observed.

CMS categorised events in about 60 classes [26] based on the number of light leptons and light jets. Data collected during 2016 corresponding to an integrated luminosity of 35.9 fb^{-1} is used. For each class three distributions of interest are investigated, the scalar sum of p_T of all objects, invariant or transverse mass of all objects, and the missing transverse momentum E_T^{miss}. A global search is then performed by comparing observed deviations in data with pseudo-experiments using the SM-only hypothesis. No significant deviations are found.

6. Conclusions

The ATLAS and CMS experiments at the LHC have performed many non-resonant searches with leptons in the final state. No significant excess from the Standard Model has been observed and limits on production cross sections or other model parameters of various theories beyond the Standard Model have been set.

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