

Search for heavy fermionic top partners decaying to same-sign dileptons at 13 TeV

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With the discovery of the Higgs Boson during Run 1 of the Large Hadron Collider, one of the most important questions to answer during Run 2 is the naturalness problem. Composite Higgs theories answer the naturalness problem by regulating the quadratic divergences to the mass of the Higgs boson via fermionic top partners. Often predicted in such models is a top partner with charge $5e/3$ which can decay to the extremely clean same-sign dilepton final state. Further, such a particle is typically the lightest of the top partners predicted and hence represents a very well motivated search. Results using 2.2 fb^{-1} of data from the CMS experiment at 13 TeV will be presented.

1 Introduction

The discovery of the Higgs boson with a mass of 125 GeV^{1,2} has rendered the Standard Model (SM) complete. However, it is not a complete theory of nature. The SM has no mechanism for accounting for dark matter, does not incorporate gravity, and, most relevant to the discussion here, cannot account for the mass of the Higgs boson being so light without relying on tuning to one part in 10^{34} . This latter problem, referred to as the Naturalness Problem, is a main motivation for physics Beyond the Standard Model (BSM). Many BSM theories incorporate new particles whose interactions reduce the reliance on fine tuning for controlling the mass of the Higgs. The search presented here is for such a new particle, predicted by Composite Higgs Theories, and referred to as $X_{5/3}$ ³, decaying to same-sign dileptons. In this document lepton refers to either an electron or a muon, and while the analysis considers each channel separately this report will focus on the combination of all channels. Previously the Compact Muon Solenoid (CMS) experiment⁴ has excluded the existence of the $X_{5/3}$ with a mass less than 800 GeV⁵ using Run 1 data from the Large Hadron Collider (LHC). The previous search was also conducted using the same-sign dilepton final state. However, as there exists strong discovery potential for these particles up to masses of 1.5 TeV, there is a clear motivation to continue the search using recent Run 2 data from the LHC. Presented here are details of the 2015 CMS search for the $X_{5/3}$ ⁶ using proton-proton collision data at a center-of-mass energy of 13 TeV.

2 Signal Topology

The analysis searches for production of pairs of $X_{5/3}$ particles generated via QCD, and hence model independent, interactions. With its exotic charge of $5e/3$, the $X_{5/3}$ decays wholly to tW^+ , giving it a complicated and active topology and allowing for decays to same-sign dileptons. This topology can be exploited to distinguish the signal from background processes. The most striking characteristic of the signal is the same-sign dilepton decay, a process which occurs only extremely rarely via SM processes. Additionally, the large number of extra jets and leptons in the event gives a useful handle for distinguishing signal from background.

3 Background Modelling

3.1 Prompt Same-Sign Background

The SM processes which can give rise to events with two same-sign leptons from the hard scattering process (referred to as 'prompt leptons') fall into two categories: $t\bar{t} + X$ and multi-boson. The latter, which contains processes such as WZ, ZZ, WWW, etc., often involve a Z-boson and hence their contribution can be reduced by requiring that no pair of leptons in the event have an invariant mass consistent with the mass of the Z. The former, i.e. $t\bar{t} + X$, are very similar in topology to signal events, and even with their smaller cross sections than di-boson processes are the majority of the SM background, with $t\bar{t}W$ being the largest single contributor.

The contributions of SM processes with two prompt same-sign leptons are estimated using Monte Carlo (MC). Corrections are applied to account for differences in lepton reconstruction, triggering, and isolation efficiency. Jet reconstruction is modified to match the p_T resolution found in data.

3.2 Background from Opposite-Sign Dilepton Events

A different way in which events with two prompt leptons can enter the final selection is if, in an event containing oppositely charged leptons, the charge of one of the leptons is mis-measured. This can happen for example in Drell-Yan to ee events. The contribution of this type of background is estimated by measuring the rate of charge misidentification and applying it to opposite sign events that pass all other event selection requirements. The charge misidentification rate for electrons is measured in $Z \rightarrow ee$ events, while the rate for muons is assumed to be zero. In order to suppress Drell-Yan events, a requirement is made on the invariant mass of the same-sign lepton pair (di-electron channel only) such that it is inconsistent with the mass of the Z-boson. As there is potentially a difference, due to different event topologies, between the charge misidentification rate in those events where it is measured and those where it is applied, the overall rate is measured in both Drell-Yan and $t\bar{t}$ MC samples using MC truth information. The percent difference between these two measurements drives the systematic uncertainty associated with this background.

3.3 Background Events from Non-Prompt Leptons

The final type of event which can pass the signal selection requirements are events where one or both of the same-sign leptons is 'non-prompt'. An example of a non-prompt lepton is a muon from a b-quark hadronizing. However, the term is meant to be quite broad and also includes for instance, jets faking leptons, photon conversions, and the like. The simplest example of a non-prompt event passing signal selection requirements is a semi-leptonic $t\bar{t}$ event accompanied by a non-prompt lepton. The contribution of non-prompt events is estimated using a data-driven technique referred to as the Tight-Loose Method⁷. The idea behind the method is that the events containing two high quality reconstructed leptons can be broken into three categories: events with two prompt leptons, events with one prompt and one non-prompt lepton, and events with two non-prompt leptons. The relative sizes (and hence contributions) of each of these categories depends on two things: the rate at which prompt leptons pass your high quality lepton requirements (referred to as the prompt rate) and the rate at which non-prompt leptons pass your high quality lepton requirements (referred to as the fake rate). In order to measure these rates, one first defines a loose set of lepton identification requirements which is used to select a suitable control sample, and then measures the proportion that pass the high quality (or tight) lepton identification requirements of the full analysis. The prompt rate is measured using Drell-Yan events with a tag-and-probe method and found to be 0.940 ± 0.001 for muons and 0.873 ± 0.001 for electrons. The fake rate is measured using a QCD enriched control region and found to be 0.371 ± 0.002 for muons and 0.298 ± 0.003 for electrons. The dominant uncertainty of

this background method prediction arises from the differences in fake rate between QCD events (where the fake rate is measured) and $t\bar{t}$ -like events (where it is applied). These differences result from the different flavor composition of the source of the non-prompt leptons (with b-jets, for example, giving a larger muon fake rate than light-quark hadronization).

4 Analysis Event Selection

The analysis relies on the clean same-sign final state and hence requires two high quality, isolated, same-sign leptons as a starting point. The leading lepton in the pair is required to have a transverse momentum (p_T) of at least 40 GeV while the sub-leading lepton is required to have a p_T above 30 GeV. After the same-sign dilepton selection, the following requirements are placed on the event:

- Quarkonia Veto: invariant dilepton mass (M_{ll}) > 20 GeV
- Associated Z-boson Veto: veto any event where either of the leptons in the same-sign pair reconstructs to within 15 GeV of the mass of the Z-boson with any other lepton in the event not in the same-sign pair.
- Primary Z-boson Veto: $M_{ll} > 106.1$ or < 76.1 GeV for di-electron channel only.
- Number of Constituents ≥ 5
- $H_T^{\text{lep}} > 900$ GeV

The ‘‘Number of Constituents’’ is defined as the number of jets in the event together with the number of other leptons (i.e. not in the same-sign pair) passing our selection requirements. The H_T^{lep} used in this analysis is the scalar sum of the p_T of all jets and high quality leptons in the event.

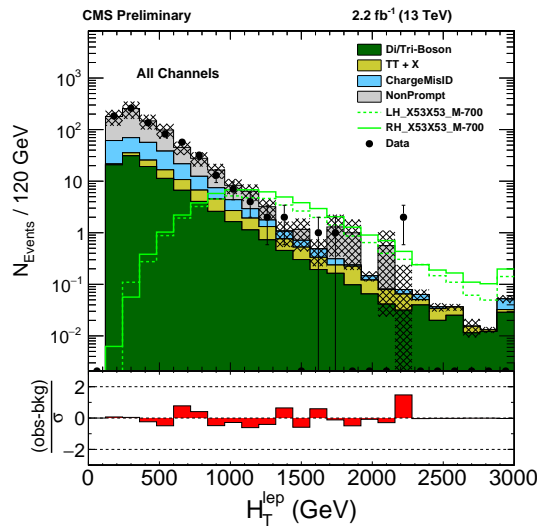


Figure 1 – The H_T^{lep} distribution after the same-sign dilepton selection, lepton invariant mass vetoes, and requiring at least two jets in the event. The bottom histogram shows the difference between the observed and the predicted number of events in that bin divided by the total uncertainty (i.e. combined systematic and statistical).

5 Results

The number of events passing the full analysis selection is summarized in table 1, including background by category, observed events, and the expected number of events for an 800 GeV

Table 1: Summary of background yields from rare standard model Monte Carlo (PSS MC), non-prompt, and charge misidentification backgrounds as well as observed data events after the full analysis selection. Also shown are the number of expected events for a right handed 800 GeV $X_{5/3}$. The errors include both statistical and systematic uncertainties.

Channel	PSS MC	NonPrompt	ChargeMisID	Total Background	800 GeV $X_{5/3}$	Observed
Di-electron	2.41 ± 0.29	2.16 ± 1.91	1.90 ± 0.60	6.47 ± 2.02	4.38	7
Electron-Muon	2.98 ± 0.36	5.20 ± 3.21	0.54 ± 0.18	8.72 ± 3.24	9.14	3
Di-muon	0.70 ± 0.12	2.09 ± 1.69	0.00 ± 0.00	2.80 ± 1.70	3.55	1
All	6.09 ± 0.67	9.45 ± 5.49	2.44 ± 0.76	17.98 ± 5.58	17.06	11

$X_{5/3}$. No significant excess is observed and hence limits are put on $X_{5/3}$ production. These limits are calculated using Bayesian statistics assuming a flat prior for signal production cross section. Systematic uncertainties are treated as nuisance parameters when setting limits. At 95% CL we exclude $X_{5/3}$ with masses less than 950 (910) GeV, expected limits of 860 (820) GeV, for a right (left) handed chirality $X_{5/3}$. Figure 2 shows these results. These limits are the most stringent to date in this channel and the first public results searching for $X_{5/3}$ using 13 TeV data.

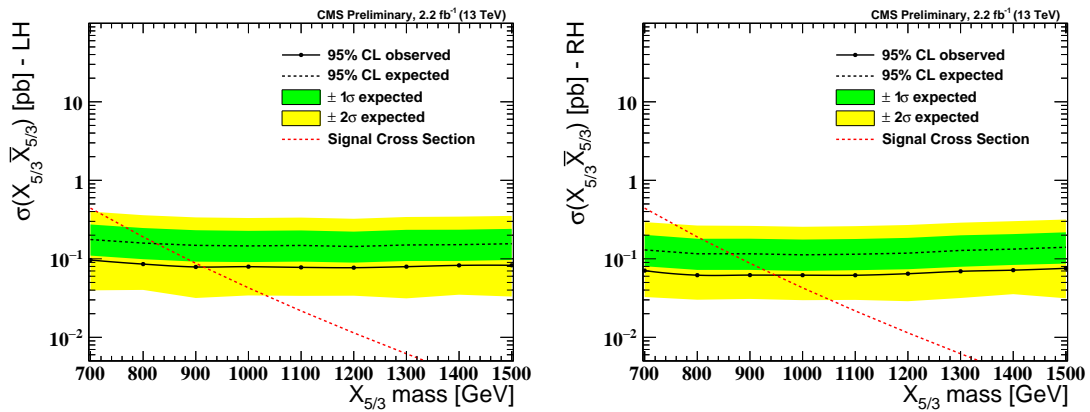


Figure 2 – 95% CL expected and observed limits for a left-handed (left) and right-handed (right) $X_{5/3}$.

References

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