CMS Draft Analysis Note

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Search for a heavy partner of the top quark with charge 5/3 in same-sign leptonic events

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Abstract

The search for the production of heavy partners of the top quark with charge 5/3 in same sign leptonic events in pp collision at at $\sqrt{s} = 7$ TeV collected with the CMS detector at the LHC is reported. The data sample corresponds to an integrated luminosity $\mathcal{L} = 4.7\,\mathrm{fb}^{-1}$. The events surviving the kinematical selection are compared with the expectation from Standard model background sources and no excess is found. Exclusion limits are set.

1 Introduction

Many theories predict the existence of heavy partners for the top quark. One model, by Contino and Servant, proposes the $T_{5/3}$, an exotic top partner with charge 5/3, and the B quark (with charge -1/3) as a means of preserving LR custodial parity invariance [1]. The masses of these particles range from about 400 GeV to a TeV so it should be possible to observe them at the LHC. While Ref. [1] focuses on pair production (Fig. 1), single production is also considered by other models [2]. The inclusion of the latter production mode would help in distinguishing the top partner from a generic colored heavy fermion and would also permit a simple measurement of its coupling. Moreover, the single production greatly enhances the cross section for the high masses (up to about 1.5 TeV) and makes discovery possible in the entire range of interest. This note presents a search for such exotic top quark partners using the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC).

In this study we focus on the lepton+jets channels (single and pair production) wherein two of the W bosons decay into same-sign leptons and the other two decay into jets. The leptons used for this analysis are electrons and muons. The presence of same-sign leptons distinguishes this process from $t\bar{t}$, leaving only backgrounds with much smaller cross sections: $t\bar{t}WW$, $t\bar{t}W$, $t\bar{t}Z$, WWW, and WW. The $t\bar{t}$ background still contributes to the overall background due to its large cross section. In addition to instrumental effects such as charge misidentification in dilepton signatures, $t\bar{t}$ events where the W boson from one top quark decays leptonically and the second lepton arises from a b-quark contribute to the same sign dilepton signatures. Due to instrumental effects, QCD multi-jets and Z+jets also contribute to the background.

This analysis is an update of the 2008 Monte Carlo based analysis which considered the pair production of top partners [3].

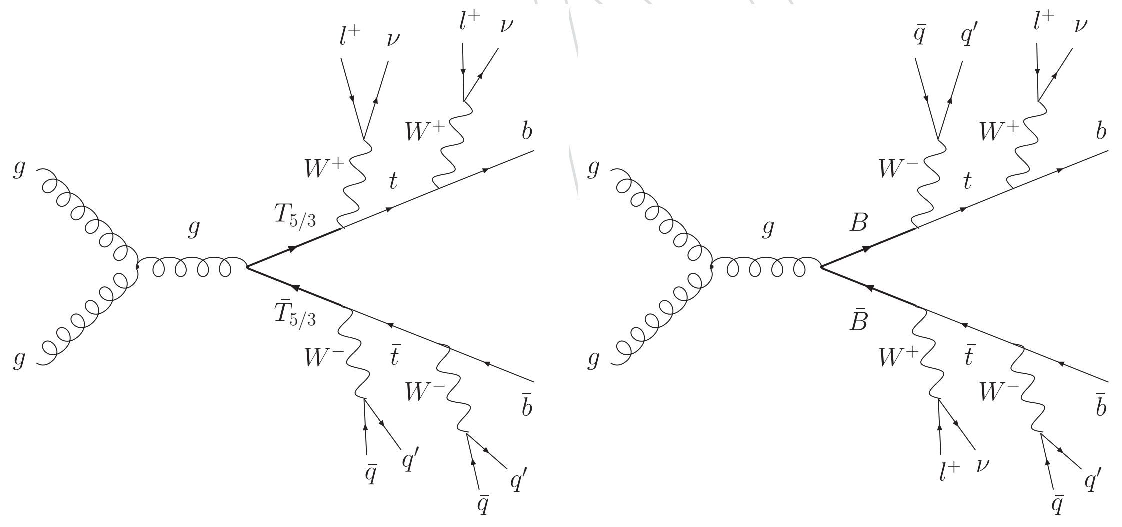

Figure 1: Pair production of $T_{5/3}$ and B quarks and decay to same-sign dilepton final states. Figures taken from Ref. [1].

2 Data and simulation samples

The official "TLBSM" PAT-uples (version 9) have been used for this analysis. Of the total integrated luminosity collected in 2011, 4.7 fb^{-1} has been analyzed. The standard CMS selection of good runs and luminosity sections has been applied.

Dataset	Run range
/DoubleMuon/Run2011A-May10ReReco-v1/AOD	160329-163869
/DoubleMuon/Run2011A-PromptReco-v4/AOD	165071-168437
/DoubleMuon/Run2011A-05AugReReco-v1/AOD	170053-172619
/DoubleMuon/Run2011A-PromptReco-v6/AOD	172620-175770
/DoubleMuon/Run2011B-PromptReco-v1/AOD	175832-180296
/DoubleElectron/Run2011A-May10ReReco-v1/AOD	160329-163869
/DoubleElectron/Run2011A-PromptReco-v4/AOD	165071-168437
/DoubleElectron/Run2011A-05AugReReco-v1/AOD	170053-172619
/DoubleElectron/Run2011A-PromptReco-v6/AOD	172620-175770
/DoubleElectron/Run2011B-PromptReco-v1/AOD	175832-180296
/MuEG/Run2011A-May10ReReco-v1/AOD	160329-163869
/MuEG/Run2011A-PromptReco-v4/AOD	165071-168437
/MuEG/Run2011A-05AugReReco-v1/AOD	170053-172619
/MuEG/Run2011A-PromptReco-v6/AOD	172620-175770
/MuEG/Run2011B-PromptReco-v1/AOD	175832-180296

Table 1: Data samples used for the analysis

The signal and background samples have been produced using the 42X CMSSW release ("Summer11"). They are listed in Tables 2 and 3 respectively. Signal samples have been generated with the MadGraph [4] event generator. The hadronization and fragmentation of quarks and gluons is then performed by PYTHIA [5].

Point	$T_{5/3}$ Mass (GeV)	σ (pb)	Number of events
P1	388	0.011	83,237
P2	509	0.003	84,832
P3	339	0.022	82,586
P4	540	0.002	83,539
P5	350	0.028	81,989
P6	470	0.008	82,805
P7	400	0.010	82,773
P8	430	0.010	42,213
P9	370	0.022	82,669
P10	320	0.037	82,593

Table 2: Details of the signal Monte Carlo samples used for the analysis.

3 Triggers

The events are required to satisfy the trigger requirements listed in Table 4.

4 Object Reconstruction

The data sample used in this analysis corresponds to 4.7 fb^{-1} collected in 2011 and reconstructed with the version CMSSW_4_2_X of the CMS software. The analysis relies on the reconstruction of three types of objects: electrons, muons and jets. The events are reconstructed using a full Particle Flow approach (PF2PAT) [6, 7] and the details of the object selection are provided below.

Process	MC Generator	σ (pb)	Number of events
Background Samples:			
$t\bar{t}$	MADGRAPH	164.4 (NNLO)	3,701,947
$W(\to)\ell\nu$+jets	MADGRAPH	31314 (NNLO)	77,105,816
Drell Yan - $Z/\gamma^*(\to \ell\ell)$+jets	MADGRAPH	3048 (NNLO)	36,277,961
multijet QCD sample (μ+jets)	PYTHIA	296600000	24,324,525
multijet QCD sample (e+jets)	PYTHIA	binned	—
WW	MADGRAPH	3.78	1,197,558
WZ	MADGRAPH	0.72	1,221,134
ZZ	MADGRAPH	0.04	1,185,188
$W\gamma \to e\nu\gamma$	MADGRAPH	114.7	524,503
$W\gamma \to \mu\nu\gamma$	MADGRAPH	114.6	521,774
$W^{\pm}W^{\pm}$	MADGRAPH	0.006	99,307
WWW	MADGRAPH	0.01	60,469
$t\bar{t}W$	MADGRAPH	0.01	99,199
$t\bar{t}Z$	MADGRAPH	0.004	73,521

Table 3: Details of the background Monte Carlo samples used for the analysis.

HLT_DoubleMu7_v1,2 or HLT_Mu13_Mu8_v2,3,4,6,7 or HLT_Mu17_Mu8_v10,11
HLT_Ele17_CaloIdL_CaloIsoVL_Ele8_CaloIdL_CaloIsoVL_v1,2,3,4,5,6 or HLT_Ele17_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_Ele8_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_v2,3,4,5 or HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v5,6,7,8,9,10
HLT_Mu10_Ele10_CaloIdVL_v2,3,4,or HLT_Mu17_Ele8_CaloIdVL_v1,2,3,4,5,6,8 or HLT_Mu17_Ele8_CaloIdT_CaloIsoVL__v4,7,8 or HLT_Mu8_Ele17_CaloIdL_v1,2,3,4,5,6 or HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_v3,4,7,8

Table 4: List of triggers used in the analysis

4.1 Event cleanup and vertex selection

The events are cleaned up by requiring:

- No scraping: the event is rejected if the fraction of high purity tracks is $< 25\%$ in events with at least 10 tracks.
- Require at least one good primary vertex (PV); the PV must have more than 4 degrees of freedom and must be less than 24 cm away from the nominal interaction point in z and less than 2 cm away radially
- HBHE event-level noise filtering

4.2 Electron selection

Electron candidates are reconstructed from a collection of electromagnetic clusters with matched pixel tracks. The momentum of the electron track is fitted using a Gaussian-Sum Filter (GSF) algorithm along its trajectory with the algorithm taking into account the possible emission of Bremsstrahlung photons in the silicon tracker.

- $p_T(\text{elec}) > 30\,\text{GeV}$

- $|\eta(\text{elec})| < 2.4$; we also exclude the barrel and endcap transition region ($1.4442 < |\eta_{sc}| < 1.566$).
- The "Cut in Categories" (CiC) approach to electron identification is used. This method classifies an electron in a number of categories (barrel versus endcap, fbrem versus E/p, and transverse energy) which are optimized to select electrons from W or Z decays and reject fakes from jets or conversions. Electrons are required to pass the "HyperTight" CiC selection.
- Particle Flow based relative isolation is required to be less than 0.15.
- Conversion rejection cuts: we reject an electron if the number of missing expected inner hits is equal to zero and the electron is flagged as conversion using the partner track conversion veto (0.02, 0.02).
- Transverse impact parameter of the electron with respect to the beamspot < 0.02 cm.
- Require Gsf-Ctf-ScPix charge consistency:require that all three charge measurements for a GSF electron agree; one from the charge of the GSF track, one from the charge of the CTF track associated to the GSF track and one, the so-called supercluster charge, determined from the relative position of the supercluster with respect to the projected track from the pixel seed;

4.3 Muon definition

- $p_T > 30\,\text{GeV}$
- $|\eta| < 2.1$
- Classified as GlobalMuon and TrackerMuon
- Number of valid Silicon hits $\geq$11
- Transverse impact parameter of the electron with respect to the beamspot < 0.02
- $\chi^2/ndof < 10$
- Number of Muon hits > 0
- Number of Pixel Hits > 0
- Number of chambers with matched segments > 1
- Particle Flow based relative isolation is required to be less than 0.15.

4.4 Jets

- Jets are reconstructed using the Anti-kT algorithm
- Charged hadron subtraction, L1FastJet corrections and L2L3Jet-EnergyScale corrections
- $P_T > 30\,\text{GeV}$
- $|\eta| < 2.4$
- Loose jet Id (see TopLikeBSMSpring2011#Jets wiki for more info)

5 Signal Selection

The signal selection requires:

- Exactly two isolated same sign leptons as defined above with $p_T > 30\,\text{GeV}$. Reject events with three such leptons.

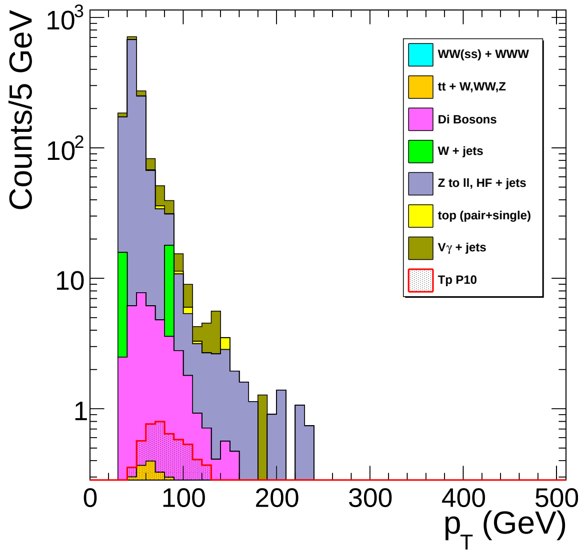

Figure 2: p_{T} leading lepton after SS cut (*ee* channel)

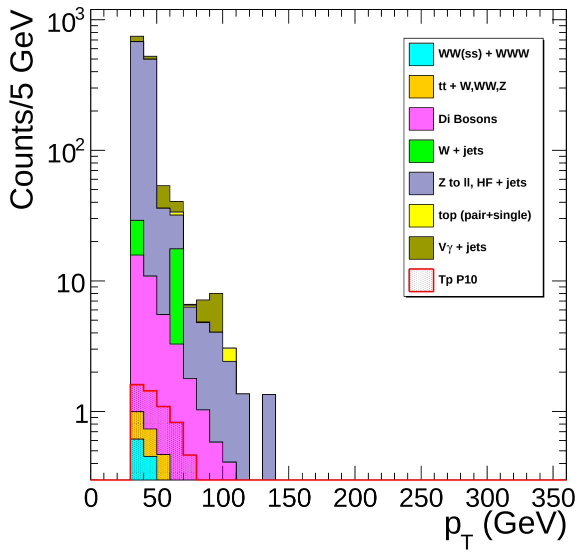

Figure 3: p_{T} second lepton after SS cut (*ee* channel)

- Quarkonia veto: $M(\ell\ell) > 20\,GeV$.
- Z Veto: $M(\ell\ell) < 76\,GeV$ or $M(\ell\ell) > 106\,GeV$.
- $N(jets) \geq 4$
- $H_T > 300$, where H_T is summed over the selected jets only.

To avoid double counting events that are found in multiple datasets, events for the double muon, double electron and muon-electron channels are required to come from the respective primary datasets. The distributions of the properties used to derive the selection are shown in Figures 2 to 13. Figures 2 and 3 illustrate the p_{T} of the leading and second leading leptons (respectively) in events with two same sign electrons. Figure 4 shows the jet multiplicity in same sign dielectron events and Figure 5 shows the H_T in the same events. Figures 6 to 13 display the same quantities as Figures 2 to 5, but in the dimuon and electron-muon channels.

5.1 Event Yields

The event yields for the signal in the *ee*, $\mu\mu$ and $e\mu$ channels are shown in Tables 5, 6 and 7 respectively. Similar events yields for data and backgrounds (exclusively from Monte-Carlo) are shown in Tables 8, 9 and 10.

6 Background Estimation

The backgrounds associated with this analysis fall into three main categories:

- Same-sign di-leptons: Standard Model processes leading to prompt, same-sign di-lepton signatures. The cross sections for these processes are small and hence their contribution is small as well.
- Opposite sign prompt-prompt: prompt leptons could be mis-reconstructed with the wrong charge leading to a same-sign di-lepton final state.
- Same-sign prompt-fake and fake-fake: this is the primary instrumental background arising from jets faking leptons, non-prompt leptons passing tight isolation selection

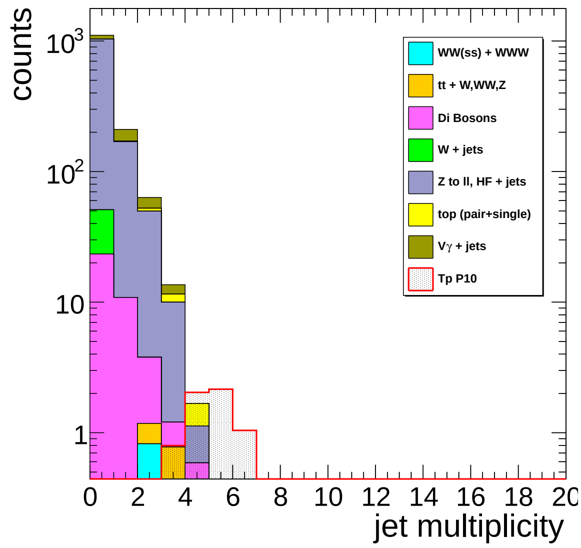

Figure 4: Jet Multiplicity after SS cut (*ee* channel)

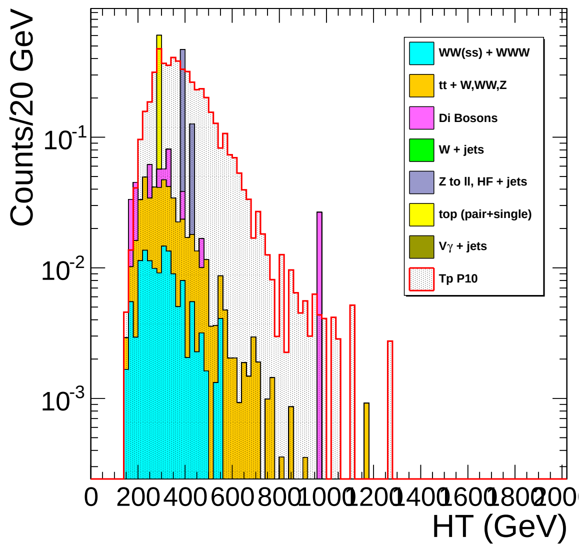

Figure 5: H_T after after jet multiplicity cut (*ee* channel)

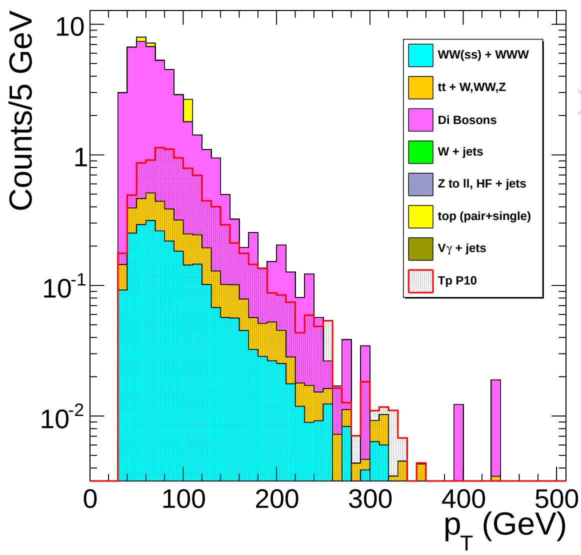

Figure 6: p_T leading lepton after SS cut ($\mu\mu$ channel)

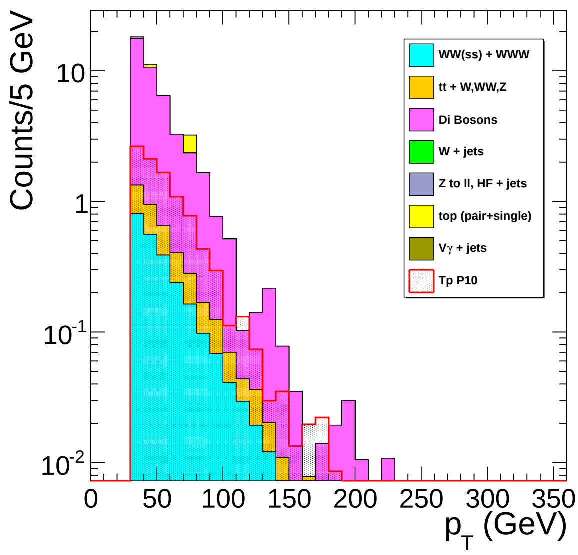

Figure 7: p_T second lepton after SS cut ($\mu\mu$ channel)

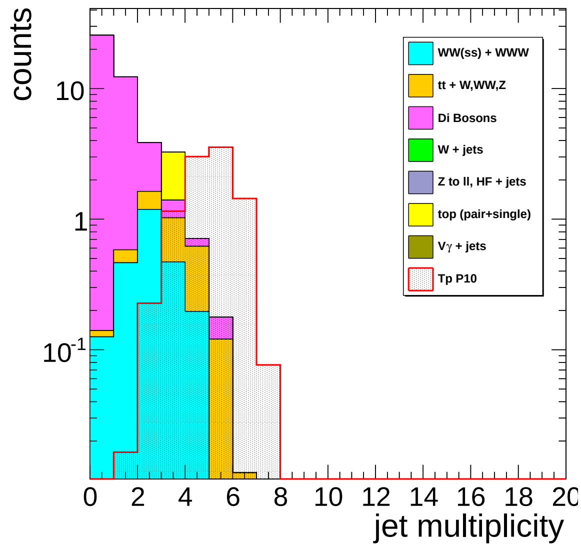

Figure 8: Jet Multiplicity after SS cut ($\mu\mu$ channel)

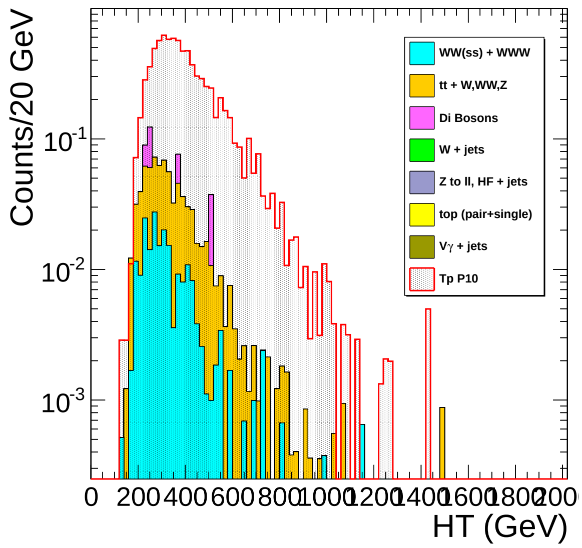

Figure 9: H_T after after jet multiplicity cut ($\mu\mu$ channel)

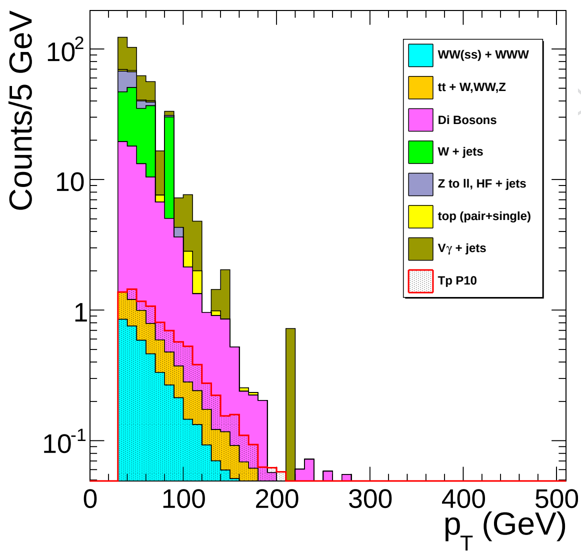

Figure 10: p_T leading lepton after SS cut ($e\mu$ channel)

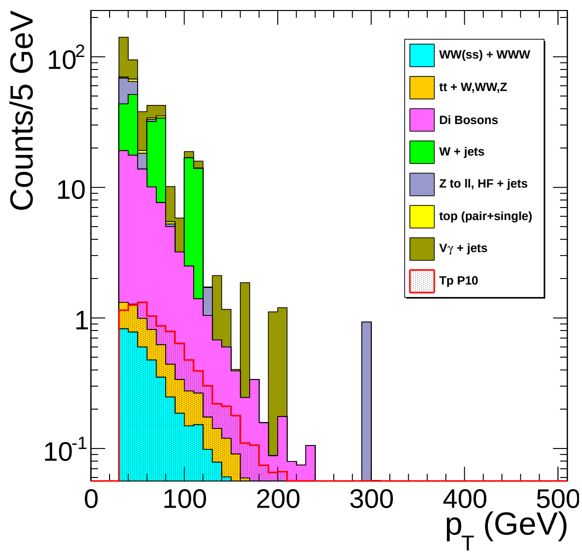

Figure 11: p_T second lepton after SS cut ($e\mu$ channel)

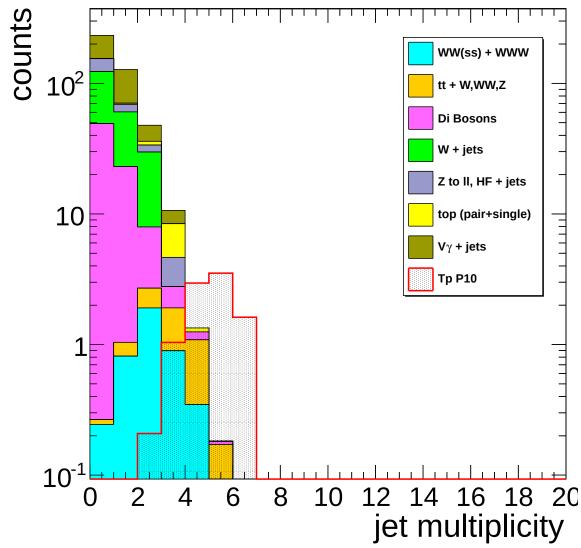

Figure 12: Jet Multiplicity after SS cut ($e\mu$ channel)

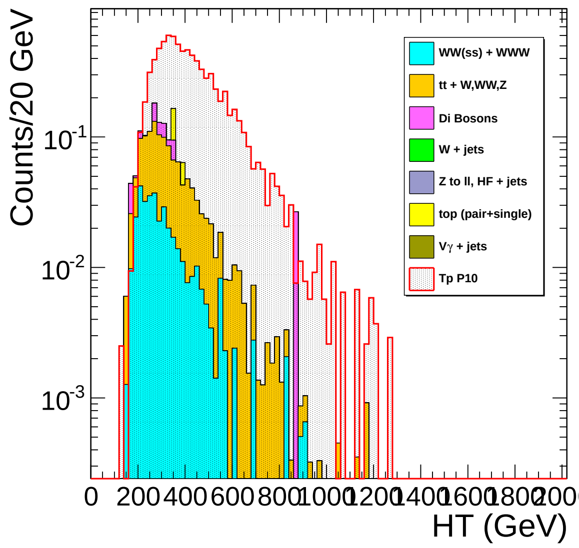

Figure 13: H_T after after jet multiplicity cut ($e\mu$ channel)

Sample	2SS leptons	N(jet)$\geq$ 4	$H_T \geq 300$	Zveto
P1	3.19	2.8	2.52	2.09 $\pm$ 0.042
P2	0.812	0.713	0.686	0.641 $\pm$ 0.0109
P3	5.67	4.92	3.93	3.01 $\pm$ 0.0707
P4	0.589	0.489	0.459	0.421 $\pm$ 0.00806
P5	7.14	6.18	5.31	4.28 $\pm$ 0.0965
P6	2.17	1.8	1.66	1.49 $\pm$ 0.0295
P7	2.41	2.09	1.9	1.54 $\pm$ 0.0338
P8	2.91	2.57	2.41	2.16 $\pm$ 0.0406
P9	5.79	5.03	4.48	3.73 $\pm$ 0.0787
P10	8.74	7.51	5.85	4.3 $\pm$ 0.109

Table 5: Summary table of expected events from signal events in the ee channel

Sample	2SS leptons	N(jet)$\geq$ 4	$H_T \geq 300$	Zveto
P1	3.85	3.45	3.1	2.54 $\pm$ 0.0462
P2	0.985	0.865	0.827	0.776 $\pm$ 0.012
P3	6.73	5.9	4.75	3.66 $\pm$ 0.078
P4	0.712	0.602	0.563	0.513 $\pm$ 0.00886
P5	8.8	7.62	6.59	5.39 $\pm$ 0.109
P6	2.74	2.29	2.14	1.96 $\pm$ 0.0339
P7	2.97	2.61	2.36	1.91 $\pm$ 0.0376
P8	3.49	3.13	2.9	2.55 $\pm$ 0.0442
P9	7.06	6.07	5.35	4.44 $\pm$ 0.0862
P10	10.7	9.23	7.31	5.48 $\pm$ 0.124

Table 6: Summary table of expected events from signal events in the $\mu\mu$ channel

Sample	2SS leptons	N(jet)$\geq$ 4	$H_T \geq 300$	Zveto
P1	3.68	3.25	2.94	2.94 ± 0.0499
P2	0.953	0.841	0.802	0.802 ± 0.0122
P3	6.36	5.52	4.4	4.4 ± 0.0853
P4	0.686	0.578	0.542	0.542 ± 0.00914
P5	9.76	8.49	7.43	7.43 ± 0.127
P6	3.25	2.73	2.56	2.56 ± 0.0388
P7	2.82	2.49	2.24	2.24 ± 0.0408
P8	4.33	3.81	3.59	3.59 ± 0.0524
P9	8.08	7.04	6.39	6.39 ± 0.103
P10	11.4	9.9	8.1	8.1 ± 0.15

Table 7: Summary table of expected events from signal events in the $e\mu$ channel

Sample	2SS leptons	N(jet)$\geq$ 4	$H_T \geq 300$	Zveto
$t\bar{t}$	5.9	1.4	0.295	0.295 ± 0.295
Z+Jets	1.06e+03	1.19	0.676	0 ± 0
W+Jets	23	0	0	0 ± 0
Di Bosons	36.948	0.193	0.097	0.056
$W^{\pm}W^{\pm}$	0.588	0.000572	0.000403	0.000403 ± 0.000285
WWW	1.54	0.218	0.112	0.0915 ± 0.0111
$t\bar{t}$ W	1.27	0.376	0.201	0.163 ± 0.0109
$t\bar{t}$ Z	0.302	0.101	0.0562	0.0454 ± 0.00392
Total MC	1.09e+03	3.28	1.34	0.596 ± 0.296
Data	1177	6	4	2

Table 8: Summary table of expected events from MC background and observed data in the ee channel

Sample	2SS leptons	N(jet)$\geq$ 4	$H_T \geq 300$	Zveto
$t\bar{t}$	3.52	1.52	0.619	0.297 ± 0.297
Z+Jets	0	0	0	0 ± 0
W+Jets	0	0	0	0 ± 0
Di Bosons	39.917	0.148	0.057	0.057
$W^{\pm}W^{\pm}$	0.756	0.000576	0.000576	0.000576 ± 0.00056
WWW	1.75	0.264	0.118	0.0954 ± 0.0115
$t\bar{t}$ W	1.53	0.478	0.273	0.226 ± 0.0131
$t\bar{t}$ Z	0.269	0.0786	0.0455	0.0359 ± 0.00346
Total MC	47.7	2.34	1.06	0.655 ± 0.298
Data	87	4	2	2

Table 9: Summary table of expected events from MC background and observed data in the $\mu\mu$ channel

Sample	2SS leptons	N(jet)≥ 4	$H_T \geq 300$	Zveto
$t\bar{t}$	11.5	1.59	0.651	0.651 ± 0.378
Z+Jets	21.4	0	0	0 ± 0
W+Jets	31.2	0	0	0 ± 0
Di Bosons	77.323	0.200	0.091	0.091
$W^{\pm}W^{\pm}$	1.22	0.00193	0.000588	0.000588 ± 0.000588
WWW	2.91	0.493	0.209	0.209 ± 0.0169
$t\bar{t}$ W	2.49	0.845	0.466	0.466 ± 0.0187
$t\bar{t}$ Z	0.455	0.176	0.108	0.108 ± 0.00606
Total MC	148.4	3.1	1.44	1.44 ± 0.378
Data	208	7	5	5

Table 10: Summary table of expected events from MC background and observed data in the μe channel

criteria, etc.

6.1 Same-sign prompt-prompt background

The same-sign prompt-prompt background consists of contributions from di-boson production (WW, WZ and ZZ) and rarer processes like $t\bar{t}W$, $t\bar{t}Z$, $W^{\pm}W^{\pm}$ etc. Many of these processes have not been observed at the LHC or well-measured. Hence we obtain their contribution from simulation (see Tables 8, 9 and 10).

6.2 Opposite sign prompt-prompt background

Processes with two prompt leptons that have opposite sign can contribute to the top partners background if the charge of one of these leptons is incorrectly identified. The magnitude of this contribution can be derived from the data by using the Z-boson resonance. The fraction of misidentified leptons is obtained by considering events with two leptons of the same flavor in which the invariant mass of the leptons falls inside the Z-mass window: 76 GeV $< M(ll) <$ 106 GeV. These events must pass all cleaning and trigger requirements and the leptons are likewise required to pass all quality cuts, but the selection based on jets and H_T is not applied. As can be seen in the Tables 11 and 12, this sample is expected to be dominated by Z+Jets. For electrons, Z+Jets dominates both the overall sample and the same sign sub-sample whereas for muons, the simulation predicts the rate of charge misidentification to be negligible.

Electrons								
	Total Bckd	$t\bar{t}$	Z+Jets	W+Jets	$W^{\pm}W^{\pm}$	WWW	$t\bar{t}$ W	$t\bar{t}$ Z
In Z-Window	8.69e+05	600	8.68e+05	32.4	0.0929	0.536	0.456	1.48
Same Sign	992	1.01	981	9.38	0.0929	0.343	0.264	0.0717
Muons								
	Total Bckd	$t\bar{t}$	Z+Jets	W+Jets	$W^{\pm}W^{\pm}$	WWW	$t\bar{t}$ W	$t\bar{t}$ Z
In Z-Window	1.08e+06	723	1.08e+06	0	0.130	0.600	0.500	1.68
Same Sign	2.19	1.37	0	0	0.130	0.332	0.308	0.0474

Table 11: Expected events yields within the Z invariant mass window (76 GeV $< M(ll) <$ 106 GeV) for backgrounds.

The results of applying the same method to data are shown in Table 13. The probability of misidentifying the charge of each lepton is computed by assuming that the entirety of the same sign contribution is due to misidentified Z+Jets events. To confirm that this upper limit is close

Electrons										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
In Z-Window	0.511	0.052	1.27	0.0455	1.39	0.213	0.449	0.311	0.929	2.34
Same Sign	0.509	0.052	1.27	0.0454	1.39	0.213	0.449	0.311	0.927	2.34
Muons										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
In Z-Window	0.682	0.0587	1.48	0.059	1.61	0.229	0.552	0.403	1.19	2.82
Same Sign	0.682	0.0587	1.48	0.059	1.61	0.229	0.552	0.403	1.19	2.82

Table 12: Expected events yields within the Z invariant mass window (76 GeV $< M(ll) <$ 106 GeV) for the ten signal points.

to the true probability, we consider the dilepton invariant mass spectrum shown in Figure 14. In the case of electrons, both the simulation and the mass spectrum suggest that the upper limit is close to the true probability (within approximately 1% according to the simulation). For muons, the charge misidentification probability is so small that we use the upper limit in its place.

	In Z-Window	Same Sign	Mis-ID Probability
Electrons	857241	1010	5.89E-4
Muons	1107821	27	1.22E-5

Table 13: Events yields within the Z invariant mass window (76 GeV $< M(ll) <$ 106 GeV) for electrons and muons in data and the estimated charge misidentifcation probability based on these events.

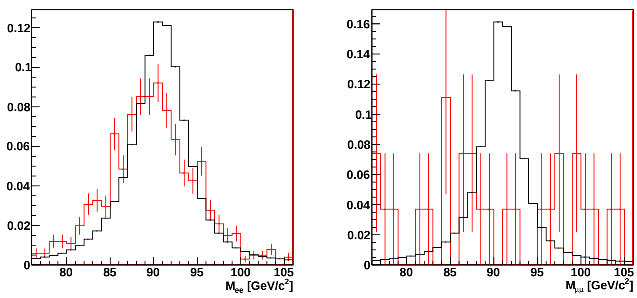

Figure 14: Dilepton invariant mass spectrum in data for electrons (left) and muons (right). The opposite sign distributions are shown in black and the same sign ones are in red. All distributions are normalized to unit area.

The number of expected same sign events due to charge misidentification can be estimated by considering the total number of events passing the full selection (including the jet and H_T requirements as well as the Z-veto), but having oppositely charged leptons. The result of this estimate for each lepton channel are shown in Table 14.

	Opposite Sign	Expected Same Sign
ee	203	0.201 ± 0.017
$e\mu$	287	0.173 ± 0.012
$\mu\mu$	203	0.005 ± 0.001

Table 14: The numbers of opposite sign events passing the full selection and the expected contribution of charge to same sign events due to charge misidenfication.

6.3 Same sign Prompt-Fake background

Here we consider the case of the non-prompt leptons that come from heavy flavor decays, deacys in flight, or conversions. Since we are requiring two same sign leptons in the final state we will consider both the case of a true and a fake lepton but also the fake-fake contribution. In general the largest source of the true-fakes contribution is semileptonic top or W/Z plus jets events where the second lepton comes from a heavy flavor decay. The fake-fake contribtution is dominated by pure multijet QCD events. The data driven calculation of the fake contribution is done with the Tight-Loose method described in Ref. [8]. The procedure is in two steps: first the average fake rate is determined using control samples enriched in non-prompt leptons. Secondly the fake rate is applied to the events selected by the analysis. The fake rate is defined as follows: it is the probability for a Loose lepton to pass the Tight identification selection. In formula: $Fr = N(TL)/N(L)$ in samples where the presence of prompt isolation leptons is suppressed.

The following assumptions are made:

- The probability of a lepton to be fake is independent from the presence of another lepton
- No correlation is included for the fake-fake lepton case
- the fake rate as measured in an inclusive QCD sample as described in Ref.[8] is applicable to the case of a QCD object in a lepton plus jet event
- Ref. [8] assigns a 50% systematic uncertainty to this procedure, we would like to evaluate the systematic comparing different primary datasets and selections used to determine the fake rate itself.

The data samples used to determine the fake rate are selected with the following cuts:

- at least one loose lepton ($E_T > 30$ GeV,$\eta < 2.10$)
- $E_{\mathrm{T}}^{\mathrm{miss}} < 20\,\mathrm{GeV}$
- $M_T < 25\,\mathrm{GeV}$
- Z veto: reject events if $71 < M(\ell\ell) < 111$

Two different approaches have been used: the first one(A) consists only of the selection above, the second(B) requires also exactly one jet with $p_T > 40\,\mathrm{GeV}$ and $\Delta R(\ell, jet) > 1.0$. The results obtained for the various primary datasets with the two methods are reported in Tab.xx. The values used for the final calculation are those obtained with method B in the MultiJet sample. The other values are used to determine the systematic uncertainty on the FR itself.

The Tight lepton definition is the one already described, while the Loose selection is as follows. For muons:

- $\chi^2/\mathrm{ndof} < 50$ (for tight is 10)
- $d0 < 2$mm (tight $d0 < 0.02\,\mathrm{mm}$)
- Iso< 0.4 (tight< 0.15)

For Electrons:

- $d0$ cut removed (tight$< 0.02\,\mathrm{mm}$)
- Iso< 0.6 (tight < 0.15)

In order to predict the final contribution to the background we use the technique described in

Dataset	$FR(A)^{\mu}$	$FR(B)^{\mu}$	$FR(A)^{e}$	$FR(B)^{e}$
/MultiJet/Run2011A-PromptReco-v4	0.45	0.27	0.37	0.24
/MuHad/Run2011A-PromptReco-v4	0.48	0.43	0.25	0.22
/ElectronHad/Run2011A-PromptReco-v4	0.46	0.37	0.37	0.34
/SingleMu/Run2011A-PromptReco-v4	0.48	0.35	0.45	0.26
/SingleElectron/Run2011A0-PromptReco-v4	0.62	0.49	0.42	0.35

Table 15: Primary datasets used for the analysis and values of the fake rates obtained for electron and muons with the A and B method

Ref. [9] and [8]. The idea is to count the number of events that pass the full kinematical selection and contain one lepton passing all the tight selection and a second lepton passing a looser set of requirements but not tight (LnoT). For the fake-fake(N_{ff}) case we start from events passing the full selection but where both leptons satisfy the Loose-no-Tight conditions ($N_{2LnTLnT}$):

$$FRweight = FR/1 - FR$$

$$N_{ff} = FRweight * FRweight * N_{2LnTLnT}$$

For the true-fake(N_{tf}) case we start from events passing the full kinematical selection, with one lepton satisfying the full selection while the second is Loose-No-Tight:

$$N_{tf} = FRWeight * N_{LnT} - 2 * N_{ff}$$

Selection	SS	N(jets)	H_T	Z_{veto}
		$\mu\mu$ channel		
N(2LnT)	23	5	3	3
N(LnT)	71	20	7	6
N(fakes)	43±8.9	13±4.3	3±2.5	2±2.3
		ee channel		
N(2LnT)	544	2	1	0
N(LnT)	2591	14	7	5
N(fakes)	1334±56	8±2.3	4±1.6	2±1.3
		$e\mu$ channel		
N(2LnT)	94	6	2	n.a.
N(LnT)	414	24	6	n.a.
N(fakes)	183±18.3	11±3.8	3± 2.0	n.a.

Table 16: Summary of the estimate for the fake contribution in the various channels

7 Results

The Monte-Carlo samples are only used for estimating backgrounds with two prompt, same sign leptons. For instrumental backgrounds, we use the data driven methods described above. The final estimates of observed and expected event yields are shown in Table 17.

7.1 Limits

Exclusion limits are computed at the 95% C.L. by using the RooStats CL95 tool [10]. The event yields from all channels are combined when setting the limits. Limits from two models that include the $T_{5/3}$ are shown in Fig. 15.

	PSS MC	Fake Leptons	Charge Mis-ID	Total Expected	Observed
ee	0.45 ± 0.02	2.0 ± 1.3	0.201 ± 0.017	2.65 ± 1.3	2
$e\mu$	1.23 ± 0.04	3.0 ± 2.0	0.173 ± 0.012	4.45 ± 2.0	5
$\mu\mu$	0.50 ± 0.02	2.0 ± 2.3	0.005 ± 0.001	2.51 ± 2.3	2
All	2.23 ± 0.06	7.0 ± 3.31	0.379 ± 0.021	9.61 ± 3.31	9

Table 17: Summary table of expected and observed events for all channels. The expected yield is composed of the prompt, same sign (PSS) MC the contribution due to fake leptons and that due to charge mis-ID.

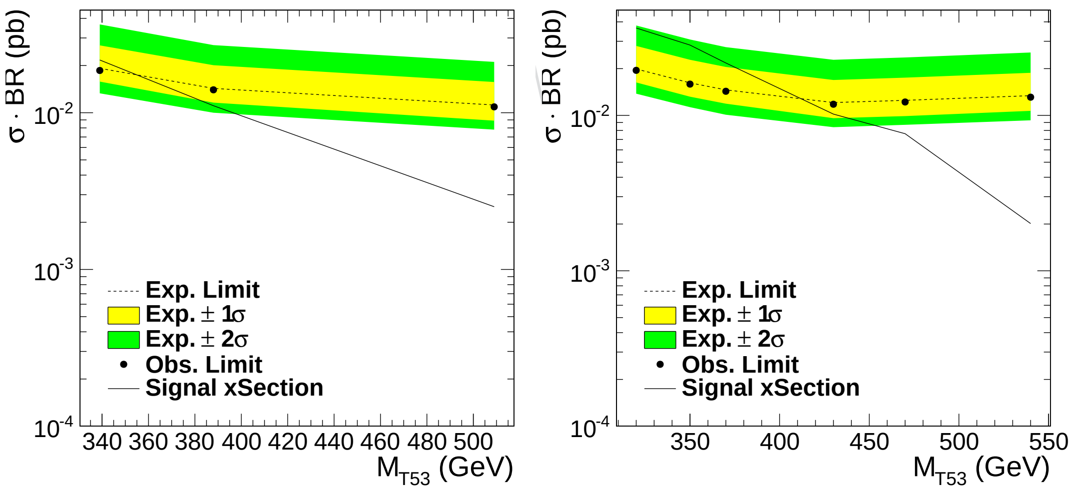

Figure 15: The limits for a model with a pseudo-Goldstone boson Higgs (left) and a generic model with $T_{5/3}$ particles (right) [2].

Effect	Uncertainty (%)
Electron trigger	0.6
Electron reco	0.9
Electron ID and Isolation	1
Electron p_T scale	1
Muon trigger	0.5
Muon reco	0.5
Muon ID and Isolation	0.7
Muon p_T scale	1
Luminosity	4.5

Table 18: Systematic uncertainties.

Sample	JES	Pileup
P1	1.5%	0.18%
P2	0.72%	0.074%
P3	2.9%	0.067%
P4	0.76%	0.18%
P5	1.6%	0.44%
P6	0.97%	0.05%
P7	1.3%	0.47%
P8	0.77%	0.28%
P9	1.5%	0.28%
P10	2.7%	0.14%

Table 19: Systematic uncertainties for signal samples.

8 Systematics

Systematic uncertainties can be due imperfect knowledge of either detector effects or theory. The former include uncertainties in the efficiency of the trigger, lepton reconstruction, lepton ID and isolation and the lepton p_T scale. We take these from [11]. The systematic uncertainties are summarized in Table 18. Additional uncertainties are being incorporated.

The jet energy scale (JES) and pileup uncertainties are calculated by varying the JES and pileup according to the recommended recipes in the samples for which we take the result from Monte-Carlo. The effect of these depends on the topology of the sample. The JES and pileup uncertainties are summarized in Table 19 for the signal and in Table 20 for the backgrounds. Table 20 also contains the overall normalization uncertainty for each background sample. The WZ and ZZ normalization uncertainties are taken from [11]. For the rare backgrounds, we assume a normalization uncertainty of 50%.

Sample	JES	Pileup	Normalization
WZ	6%	1.9%	17%
ZZ	1.9%	1.2%	7.5%
$W^{\pm}W^{\pm}$	23%	21%	50%
WWW	3.9%	0.5%	50%
$t\bar{t}W$	4.2%	0.94%	50%
$t\bar{t}Z$	4.2%	0.25%	50%

Table 20: Systematic uncertainties for backgrounds that are taken from Monte-Carlo.

9 Summary and Conclusions

In summary, we have performed a search for an exotic top partner with charge 5/3 in same-sign leptonic events using 4.7 fb^{-1} of data collected by the CMS experiment at $\sqrt{s} = 7$ TeV. We find no significant excess over the Standard Model expectation and set lower bounds at the 95% C.L. on the masses of these heavy top quark partners.

References

[1] R. Contino and G. Servant, "Discovering the top partners at the LHC using same-sign dilepton final states", *JHEP* **06** (2008) 026, arXiv:0801.1679. doi:10.1088/1126-6708/2008/06/026.

[2] J. Mrazek and A. Wulzer, "A strong sector at the LHC: Top partners in same-sign dileptons", *Phys. Rev. D* **81** (Apr, 2010) 075006. doi:10.1103/PhysRevD.81.075006.

[3] CMS Collaboration, "Search for Exotic Partners of the Top Quark with the CMS Experiment", CMS Physics Analysis Summary CMS-PAS-EXO-08-008, (2008).

[4] J. Alwall et al., "MadGraph/MadEvent v4: The New Web Generation", *JHEP* **09** (2007) 028, arXiv:0706.2334.

[5] T. Sjostrand, L. Lonnblad, S. Mrenna et al., "Pythia 6.3 physics and manual", arXiv:hep-ph/0308153.

[6] CMS Collaboration, "Commissioning of the particle-flow event reconstruction wi th leptons from J/ψ and W decays at 7 TeV", technical report, (2010).

[7] CMS Collaboration, "Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus, and Missing ET", technical report, (2009).

[8] CMS Collaboration, "Fake rates for Dilepton Analyses", CMS Analysis Note CMS AN-2010/257, (2010).

[9] CMS Collaboration, "Inclusive search for new physics with Same-sign Dileptons using early LHC data", CMS Analysis Note CMS-AN-2010-247, (2010).

[10] L. Moneta, K. Belasco, K. Cranmer et al., "The RooStats Project", in *13th International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT2010)*. SISSA, 2010. arXiv:1009.1003. PoS(ACAT2010)057.

[11] CMS Collaboration, "Search for exotic WZ resonances at CMS", CMS Analysis Note CMS AN-2011/333, (2011).