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OBSERVABILITY OF SAME-CHARGE LEPTON TOPOLOGIES IN FULLY LEPTONIC TOP QUARK PAIR EVENTS IN CMS *

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At the Large Hadron Collider dileptonic $t\bar{t}$(+jets) events can be selected with a relatively high signal-to-noise ratio and efficiency, with background events produced via Standard Model diagrams. Within the clean sample of these events, both isolated leptons have an opposite electric charge. In several models beyond the Standard Model $tt/\overline{tt}$(+jets) topologies are predicted, kinematically similar to the Standard Model $t\bar{t}$(+jets) signature, where both leptons have an equal electric charge. Such a signal of new physics can be diluted by the mis-identification of the leptons or their electric charge in Standard Model $t\bar{t}$(+jets) events. The observability of an excess of same-charge dilepton signals above the mis-reconstruction of the Standard Model background is presented, assuming the same topology. With an integrated luminosity of 30 fb^{-1}, a same-charge dilepton signature of $pp \to tt/\overline{tt}$ events with a cross section larger than 1.2 pb is visible in the measurement of the ratio between same-charge and opposite-charge lepton pair events [J. D'Hondt, S. Lowette, G. Hammad, J. Heyninck, P. Van Mulders, "Observability of same-charge lepton topology in dileptonic events $t\bar{t}$", CERN-CMS-NOTE-2006-065.]

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1. Introduction

In the Compact Muon Solenoid (CMS) experiment [2] at the Large Hadron Collider (LHC) millions of $t\bar{t}$ events will be produced. The branching fraction of the top quark is dominated by the $t \to Wb$ decay. When both W bosons decay leptonically, the so-called dilepton channel, a clear signal of two leptons and two b-quarks is produced. This topology can be distinguished with a high purity from other Standard Model processes, yielding a clean sample to search for deviations from Standard Model predictions.

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The Standard Model (SM) predicts that only $t\bar{t}$ events will be produced in proton collisions and no tt or $\overline{tt}$ should be observed. Therefore the two leptons in the dilepton final state should have an opposite electric charge. Lepton identification and the reconstruction of the electric charge of a track is not fully efficient, however, and hence the SM $t\bar{t}$ events can induce a fake signal of same-sign tt or $\overline{tt}$ events. In this article the Standard Model estimation is performed of the ratio of the amount of events with leptons with same-sign versus opposite-sign electric charge. From this ratio the minimal cross-section for the inclusive $pp \to tt/\overline{tt}$ process is determined, needed for a 5σ excess above the Standard Model expectation, as a function of the integrated luminosity collected by the CMS experiment [1].

2. Same-charge top quarks in the Standard Model and beyond

The LHC will be a "top factory", with $t\bar{t}$ production reaching a cross section of 830 pb. At the low LHC luminosity expected in the first years of operation, corresponding to an integrated luminosity of 10 fb^{-1}/y, over 8 million $t\bar{t}$ pairs will be produced each year. Contrary to the situation at the Tevatron collider, top events at the LHC suffer from lower SM backgrounds, because $\sigma_{\rm LHC}(t\bar{t})/\sigma_{\rm TeV}(t\bar{t}) \sim 100$ while $\sigma_{\rm LHC}(W/Z)/\sigma_{\rm TeV}(W/Z) \sim 10$.

The decay of the top quark $t \to Wb$ has a branching fraction of $\sim 100\%$ in the SM. The signature of a $t\bar{t}$ pair is hence given by the decay topology of the W pair in addition to the two b-quarks in the final state. This study focuses on the dilepton final states. Each of the ee and $\mu\mu$ final states take 1.2% of the total $t\bar{t}$ cross section, the $e\mu$ final state twice as much.

The Standard Model predicts that no tt or $\overline{tt}$ should be observed. Still a same-charge final state can be faked due to wrong charge determination and muon and electron identification inefficiencies. Certain models beyond the Standard Model, on the other hand, predict direct production of tt or $\overline{tt}$, *e.g.* from gluino pairs in supersymmetry with light stop and $\tilde{g}\tilde{g} \to \tilde{t}\tilde{t}X \to ttX$ decays [3], from FCNC with Z in the SM or Z' or top-Higgs in technicolour models [4], or from technipion production $t\pi_t^{\pm} \to tt\bar{b}$ or $t\pi_t^0 \to tt\bar{c}$ [5].

3. Event reconstruction and selection

The key component of this analysis concerns the reconstruction and identification of the isolated leptons in the final state. Standard CMS offline electron and muon reconstruction is followed by the identification method described in [6]. A channel-dependent likelihood ratio $\mathcal{L}$ is determined for each lepton. This likelihood ratio is conceived to efficiently identify the correct lepton from the leptonic $t \to Wb \to \ell\nu b$ decay.

The following observables are combined:

- the lepton's transverse momentum;
- the isolation energy, calculated with calorimeter deposits near the lepton, at the azimuthal side where neutrals in jets are expected;
- the isolation p_{T}, being the sum of transverse track momenta around the lepton;
- the isolation angle, defined as the angle to the closest jet;
- the association significance to the primary vertex;
- a reconstruction quality variable for electrons.

This method greatly suppresses leptons arising from fake leptons and from real leptons in heavy flavour jets. The combined likelihood ratio distributions are shown in Fig. 1 for electrons and muons respectively. Three classes of leptons are distinguished: correctly identified leptons (according to a matching with the generated truth), with either correct or wrong charge determination, and mis-identified leptons.

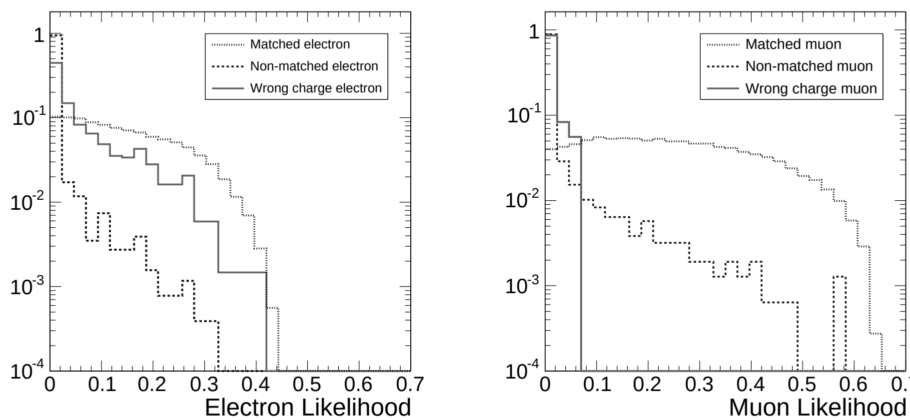

Fig. 1. Combined likelihood ratio distribution for muons (left) and electrons (right).

Apart form the leptons, the event selection consists of simple sequential cuts. First the CMS single or double electron or muon trigger criteria are applied. Next, 2 jets with $E_{\mathrm{T}} > 25$ GeV are demanded, loosely b-tagged to suppress Z+jets, WW+jets, *etc.* Finally, 2 leptons are requested ($\mu\mu$, ee or $e\mu$) with $p_{\mathrm{T}} > 25$ GeV/c and likelihood ratio $\mathcal{L} > 0.05$. The results for this selection are shown in Table I in the three considered final states, for the main SM processes. Contributions from WZ and ZZ production were checked to be negligible. All analyzed samples were generated with PYTHIA, and processed with the detailed GEANT4-based CMS detector simulation and reconstruction.

TABLE I

Overview of the selection applied on the considered SM background processes. The expected number of events are rescaled to an integrated luminosity of 1 fb^{-1}.

	$t\bar{t} \to \mu\mu$	$t\bar{t} \to \mu e/ee$	$t\bar{t} \to \tau + X$	$t\bar{t} \to$ other	WW	$Z+$jets
Before selection	6915	20745	34606	485973	189952	578033
Trigger	6115	16315	17416	100137	41288	266367
2 jets $E_{\mathrm{T}} > 25$ GeV	4398	11983	13561	93858	20594	66147
b-Tag criteria	990	2485	2290	8785	134	240
2 leptons identified	888	30	376	803	1.7	73
2 leptons selected	481.5	0.07	48.4	3.01	0.4	53.3
Efficiency (in %)	6.96	0.0003	0.14	0.0006	0.00022	0.0092
Opposite charge	481.3	0	48.3	2.19	0	53.3
Same charge	0.2	0.07	0.1	0.82	0.4	0
	$t\bar{t} \to ee$	$t\bar{t} \to \mu\mu/\mu e$	$t\bar{t} \to \tau + X$	$t\bar{t} \to$ other	WW	$Z+$jets
Before selection	6915	20745	34606	485973	189952	578033
Trigger	5355	17075	17416	100137	41288	266367
2 jets $E_{\mathrm{T}} > 25$ GeV	3961	12420	13561	93858	20594	66147
b-Tag criteria	803	2672	2290	8785	134	240
2 leptons identified	725	35	454	2284	73	127
2 leptons selected	285.0	0.3	37.5	5.2	0.8	53.3
Efficiency (in %)	4.12	0.0013	0.11	0.0011	0.00044	0.0092
Opposite charge	279.6	0.3	36.8	4.1	0.4	46.7
Same charge	5.4	0	0.7	1.1	0.4	6.7
	$t\bar{t} \to e\mu$	$t\bar{t} \to ee/\mu\mu$	$t\bar{t} \to \tau + X$	$t\bar{t} \to$ other	WW	$Z+$jets
Before selection	13830	13830	34606	485973	189952	578033
Trigger	10960	11470	17416	100137	41288	266367
2 jets $E_{\mathrm{T}} > 25$ GeV	8022	8359	13561	93858	20594	66147
b-Tag criteria	1683	1793	2290	8785	134	240
2 leptons identified	1501	66	822	3002	30.2	20
2 leptons selected	722.7	0.9	85.2	6.3	0.4	0
Efficiency (in %)	5.23	0.0065	0.25	0.0013	0.00022	0
Opposite charge	715.5	0.9	83.8	4.9	0	0
Same charge	7.2	0	1.3	1.4	0.4	0

4. Results

From the number of selected events, the ratio

$$R = \frac{N_{++,--}}{N_{+-}}$$

is determined, with $N_{++,--}$ and N_{+-} the amount of remaining events with same-charge and opposite-charge leptons, respectively. For 10 fb^{-1} the Standard Model expectation is

$$\begin{array}{rcccl} R^{\mu\mu} & = & 0.0027 & \pm & 0.0007\,, \\ R^{\rm ee} & = & 0.0389 & \pm & 0.0033\,, \\ R^{\rm e\mu} & = & 0.0128 & \pm & 0.0013\,. \end{array}$$

For each decay channel, using the uncertainty on the ratio R, the inclusive cross-section of the process $pp \to tt/\overline{tt}$ can be determined, needed to obtain a 5σ excess above the SM expectation. It is assumed that a signal beyond the Standard Model has a similar kinematic topology compared to the SM $t\bar{t}$ process. In Fig. 2 the significance of the excess in standard deviations above the Standard Model prediction of the ratio R is shown as a function of the inclusive $pp \to tt/\overline{tt}$ cross-section. It has been shown that the smaller significance with electrons is due to inefficiencies in electron identification that can be further improved.

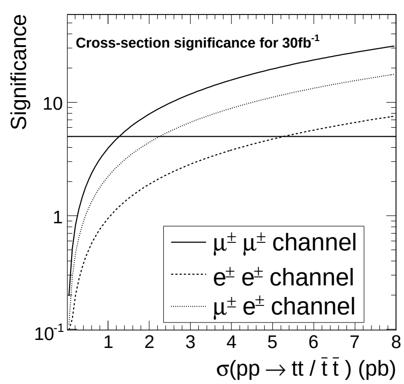

Fig. 2. Significance of a same-charge dilepton excess above the SM expectation, as a function of the inclusive $pp \to tt/\overline{tt}$ cross-section.

5. Systematic uncertainties

The use of the ratio R cancels most of the expected experimental and theoretical systematics. Several possible remaining sources of systematics were investigated. The knowledge of the background cross section was shown to be negligible. A 100% uncertainty on the Z+jets cross section only affects slightly the ee final state. Uncertainties on R due to the WW cross section are also expected negligible. Another possible source of systematics stems from the $t\bar{t} \to \tau + X$ selection efficiency. A 20% variation with respect to the dilepton final state showed no effect, however.

The systematic effect due to uncertainties on the charge determination is possibly dangerous, and requires an accurate measurement of the charge identification efficiency from data. This can be envisaged using the ∼10 M $Z \to \ell^+\ell^-$ events per 10 fb^{-1} after trigger and acceptance cuts. The Z mass distributions can be reconstructed using different (N_{D} events) and same (N_{S} events) charge leptons. For the background an equal amount of events $N_{\mathrm{D}}^{\mathrm{B}} \simeq N_{\mathrm{S}}^{\mathrm{B}} = N^{\mathrm{B}}$ can be assumed around the Z mass. The efficiency of the charge identification is then given by $\epsilon = \frac{N_{\mathrm{S}}+2N_{\mathrm{D}}}{2N_{\mathrm{S}}+2N_{\mathrm{D}}}$. In Fig. 3 the expected relative uncertainty on $(1-\epsilon)$ is shown for this proposed measurement, as a function of ϵ itself, for 10 fb^{-1}. With a 10% background contribution,an uncertainty of 4% is expected on a charge mis-identification efficiency of 0.1%. Such an uncertainty on the charge determination has negligible effect on the measurement of the ratio R.

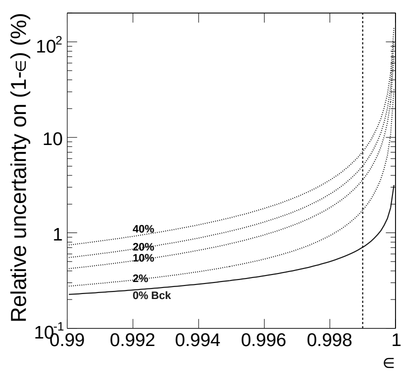

Fig. 3. Relative uncertainty on the charge mis-identification efficiency $(1-\epsilon)$ as a function of ϵ, for 10 fb^{-1}.

6. Conclusions

It is shown that with a measurement of the ratio $R = N_{++,--}/N_{+-}$ in dileptonic top quark pair events, new processes $pp \to tt/\overline{tt}$, kinematically similar to the Standard Model process $pp \to t\bar{t}$, can be observed in CMS with 30 fb^{-1}, if they have a cross section above 1.2 pb. The dimuon channel exhibits the largest sensitivity of the considered decay channels. Most of the experimental and theoretical systematic uncertainties cancel in the ratio. Potential remaining systematic uncertainties were checked to be negligible.

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