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Searches Beyond the Standard Model and Flavour Changing Neutral Currents with top quarks in CMS

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Recent searches for new phenomena with the CMS detector are presented, involving top quarks in a wide range of theories beyond the Standard Model. New resonances are searched for as scalar or pseudo-scalar bosons produced in association with a top quark pair, as resonances $W' \to tb$ and as tW resonances. Anomalous couplings are also measured, with flavour changing neutral currents in $t\gamma q$ coupling, and with violation of Lorentz invariance in top pair production. The later analysis was made public at LHCP 2023.

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1. Introduction

Recent searches beyond the Standard Model (SM) performed with CMS [1, 2] are presented in these proceedings, covering a wide range of models where a special role is assigned to the top quark because of its large mass and Yukawa coupling close to 1. Such extensions are introduced to solve the hierarchy problem or provide dark matter candidates, for instance. They are probed either by searching for new resonances (section 2), or measuring anomalous couplings (section 3).

2. Search for new resonances with top quarks

2.1 Search for a (pseudo-)scalar boson associated with a top quark pair

Searches for a (pseudo-)scalar boson Φ, such as predicted within the NMSSM, are especially motivated in the $t\bar{t}\Phi$ production mode if the Φ has Yukawa-like couplings. The analysis presented here [3] covers the range $10 < m_\Phi < 350$ GeV and targets the multilepton final state, with 3 or 4 leptons associated with jets identified as arising from the hadronization of b quarks ("b jets"). Categories are defined according to the flavour of the leptons. Selections on the S_T variable (defined as the scalar sum of p_T of leptons, jets and transverse missing energy), on the invariant mass of all leptons, and on the number of jets and b jets are applied. Control regions for $t\bar{t}Z$ background, mis-identified leptons are defined. The $\phi \rightarrow \mu\mu$ channel provides the best sensitivity at low mass. This analysis presents the first limits in this mass range for $t\bar{t}\Phi, \Phi \rightarrow \tau\tau$ (see Fig. 3). Exclusion limits are improved by a factor 2-3 relative to a previous such analysis at CMS [4] for $m_\Phi < 50$ GeV.

2.2 Search for $W' \rightarrow tb$ in leptonic final state

Searches for W' bosons are motivated by Left-Right symmetric models, Supersymmetry or Universal Extra Dimensions, for instance. This analysis [5] performed in leptonic final states, extends the range of the search to $2 < m_{W'} < 6$ TeV (previously up to 3 TeV). Background from QCD processes is reduced by requiring at least 2 anti-k_T jets with a large radius of 0.8 and $p_T > 170$ GeV, and missing transverse energy $mET > 120$ GeV. The top quark and W' are reconstructed with jets having a radius of 0.4 and $p_T > 300, 150$ GeV instead. Categories are defined with 0, 1 or at least 2 b jets. The background is estimated with an ABCD method. The invariant mass of the final state $l\nu jj$ is employed to set limits at 95% CL on $m_{W'}$, above 4 (2.5) TeV assuming a width of 1% (10%) of the W' mass. An excess over the background hypothesis is observed with a local (global) significance of 2.6σ (2.0σ) for a right-handed signal at $m_{W'} = 3.8$ TeV, as illustrated in Fig. 3.

2.3 Search for tW resonance in semi-leptonic final state

Heavy tW resonances can typically be produced as excited b quarks in composite models. The analysis presented here [6] is targeting the lepton+jets final state, with leptonic top quark decay and hadronic decay of the associated W. The top quark is reconstructed from a non-isolated lepton, at least one b jet and the missing transverse momentum. The associated W is reconstructed as a jet with radius 0.8, using N-subjettiness and soft-drop mass criteria. The main backgrounds are $t\bar{t}$, estimated from simulation, and QCD multi-jets, estimated with a likelihood-based ABCD method. Low- and hig-mass signal regions are defined, as well as a control region using top-tagging. The

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invariant mass of the tW system is used to set exclusion limits on excited b quark mass: $m_{b*} > 2.4$ (left-handed), 2.8 (right-handed), 3.1 TeV (left and right-handed, shown in Fig. 3).

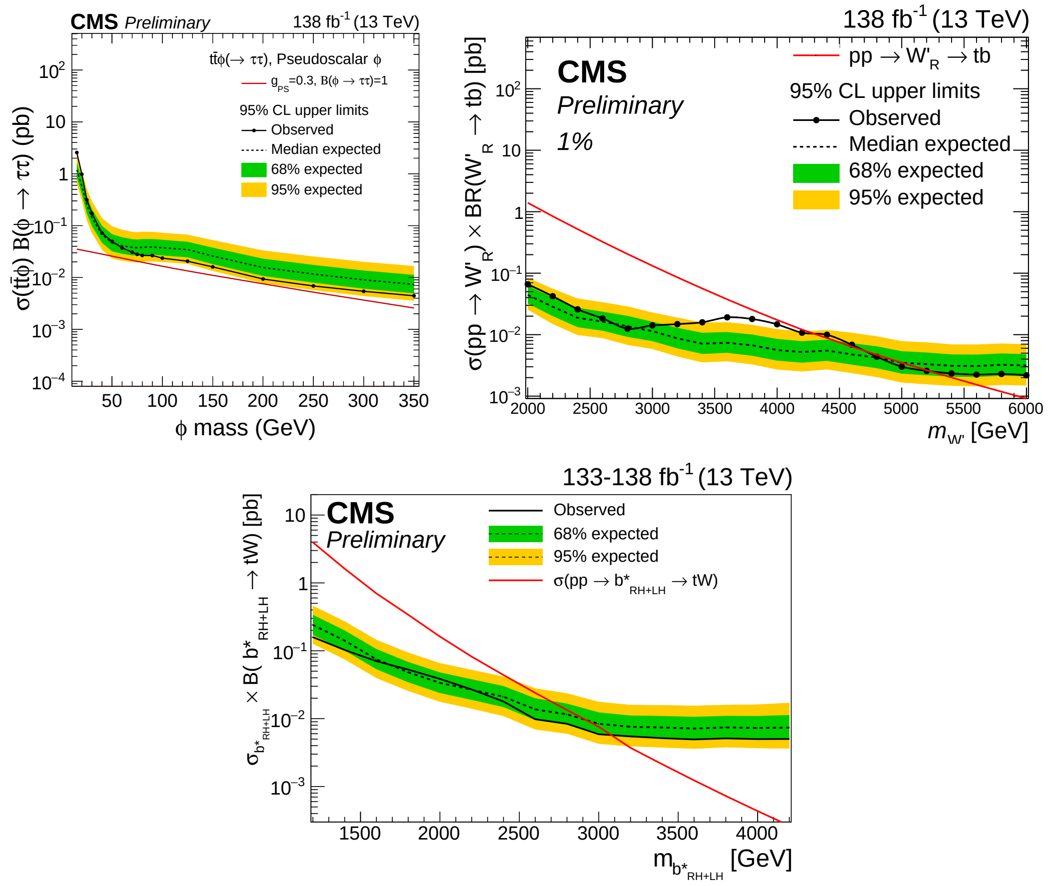

Figure 1: Exclusion limits at 95% CL for $t\bar{t}\Phi, \Phi \to \tau\tau$ for pseudoscalar Φ [3] (top left); for $W' \to tb$ in leptonic final state assuming right-handed W' with a width of 1% of its mass [5] (top right); for $b^* \to tW$ in semileptonic final state forleft- and right-handed b^* [6] (bottom).

3. Search for top quark couplings beyond the Standard Model

3.1 Search for flavour changing neutral currents in $t\gamma q$ coupling

Flavour changing neutral currents (FCNC) are suppressed by the GIM mechanism in the SM, however they can be enhanced in extensions such as the two-Higgs doublet model or supersymmetric models. The analysis presented here [7] requires one electron or muon, and one photon with $p_T > 30$ GeV in the ECAL barrel. Two regions are defined, targeting single top quark in association with one photon, and top quark pair with subsequent decay of one top quark to an up or charm quark and a photon. The former requires exactly one b tagged jet, and the latter at least two jets, among which exactly one b jet. Control regions for $t\bar{t}\gamma$, $W\gamma$ and $Z\gamma$ backgrounds are defined. Backgrounds of jets mis-identified as photons or electrons, and electrons mis-identified as photons are measured from data. Boosted decision trees are trained, setting exclusion limits on $tq\gamma$ FCNC coupling at the level of 10^{-5} as shown in Fig. 2, with best limits to date obtained for $tc\gamma$ coupling.

Combined	Obs. limit	Exp. limit	$\pm1\sigma$ (exp. limit)	$\pm2\sigma$ (exp. limit)
$\kappa_{tu\gamma}$	6.2×10^{-3}	6.9×10^{-3}	$(5.9-8.4)\times10^{-3}$	$(5.1-10.1)\times10^{-3}$
$\kappa_{tc\gamma}$	7.7×10^{-3}	7.8×10^{-3}	$(6.7-9.7)\times10^{-3}$	$(5.7-11.5)\times10^{-3}$
$\mathcal{B}(t\to u+\gamma)$	0.95×10^{-5}	1.20×10^{-5}	$(0.89-1.78)\times10^{-5}$	$(0.64-2.57)\times10^{-5}$
$\mathcal{B}(t\to c+\gamma)$	1.51×10^{-5}	1.54×10^{-5}	$(1.13-2.37)\times10^{-5}$	$(0.81-3.32)\times10^{-5}$

Figure 2: Exclusion limits at 95% CL for $tq\gamma$ $(q = u, c)$ [7].

3.2 Search for violation of Lorentz invariance in top quark pair production

Violation of Lorentz invariance is predicted in models of strings or loop quantum gravity. The analysis presented here [8] is searching for a modulation of $t\bar{t}$ cross section with sidereal time, and is using the number of b jets to discriminate $t\bar{t}$ from the main background, tW process. The integrated luminosity, pileup distribution, and trigger efficiencies, with their uncertainties, are computed as a function of sidereal time. A direct fit of $t\bar{t}$ differential normalized cross section yields an uncertainty of 2.2% per time bin, where 0.9% is due to statistical uncertainties. Dominant systematic uncertainties are arising from experimental sources and treated as uncorrelated in time, while other experimental uncertainties (luminosity, pileup and trigger) where treated as correlated and are as negligible as SM theory uncertainties. A set of 16 coefficients of a Lorentz-violating Effective Field Theory called the Standard Model Extension are measured at the $0.1-0.8$% level, showing no deviation larger than 1σ relative to the SM. These results represent an improvement up to a factor 100 relative to a previous such analysis at D0 experiment [9].

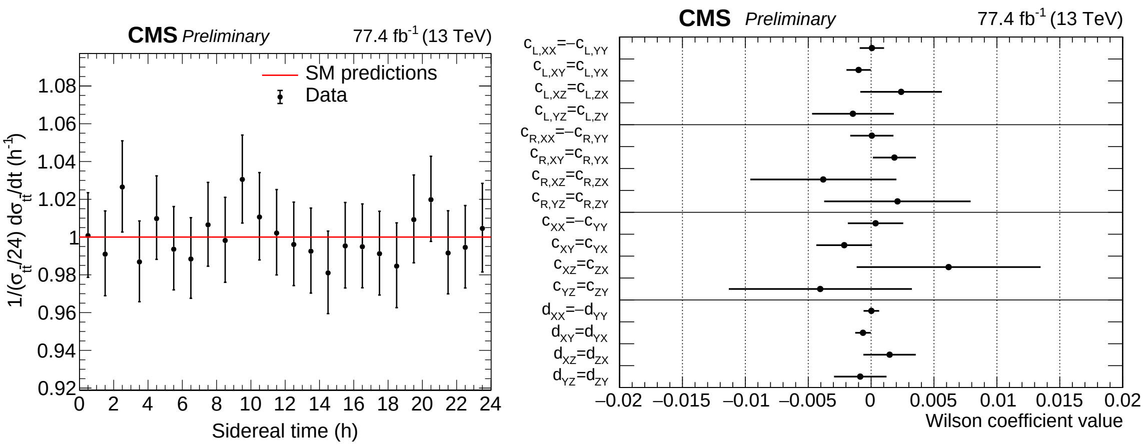

Figure 3: Normalized differential $t\bar{t}$ cross section as a function of sidereal time (left); and measured Lorentz-violating coefficients (right) [8].

4. Conclusions

Recent searches for new phenomena beyond the SM involving top quarks with CMS were presented. The ongoing LHC Run 3 with $\sqrt{s}$ = 13.6 TeV will extend the range where new phenomena are searched for, opening the door to more final states and new scenarios to be tested.

References

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