Searches for New Physics with Jets in the Final State at CMS

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1 Introduction

We present the results of searches for physics Beyond the Standard Model (BSM) with the CMS detector [1] at the LHC using final states containing jets. Unless otherwise noted, we used the entire $\sqrt{s} = 7$ TeV proton-proton collision dataset collected in 2011, which corresponds to about 5 fb^{-1} of integrated luminosity.

2 Summary of the Searches and Results

Highly-Boosted $t\bar{t}$ Decaying Hadronically: Various BSM scenarios predict an enhancement of the $t\bar{t}$ production at high invariant mass in the form of resonances, such as Topcolor Z' and Randall-Sundrum (RS) Kaluza-Klein (KK) gluon, or as a continuum, such as in models proposed to resolve the anomalous forward-backward asymmetry measured at the Tevatron. In 46% of the cases, both top quarks decay to 3 jets, which often merge due to the boost of the mother quark. The last steps of the jet reconstruction algorithm are reversed in order to perform a W-jet and a top-jet tagging based on the jet substructure and mass. Fig. 1-left shows the jet mass of the highest mass jet in a boosted muon-plus-jets data sample. The dominant standard model (SM) background is non-top multi-jet production, which is estimated by computing the probability for non-top jets to satisfy the top-jet selection criteria in data control regions. After the final event selection, the $t\bar{t}$ mass spectrum is consistent with SM expectations and 95% C.L. limits on the cross section times the branching ratio (BR) are set. The Topcolor Z' is excluded in the mass ranges 1.3-1.5, 1.0-1.6 and 1.0-2.0 TeV for a resonance width of 1%, 3% and 10%, respectively. The RS KK gluon is excluded between masses of 1.4-1.5 TeV and in a small region near 1 TeV. A 2.6 upper limit at 95% CL is set on a possible continuum enhancement of the cross section with respect to SM expectation for $t\bar{t}$ masses above 1 TeV [2].

Search For Microscopic Black Holes: A prediction of the Arkani-Hamed, Dimopoulos, and Dvali (ADD) model, which introduces a number of large and flat extra-dimensions of space to solve the hierarchy problem, is the formation of microscopic Black-Holes (BH). Evaporated semiclassical and quantum BH leave a signature

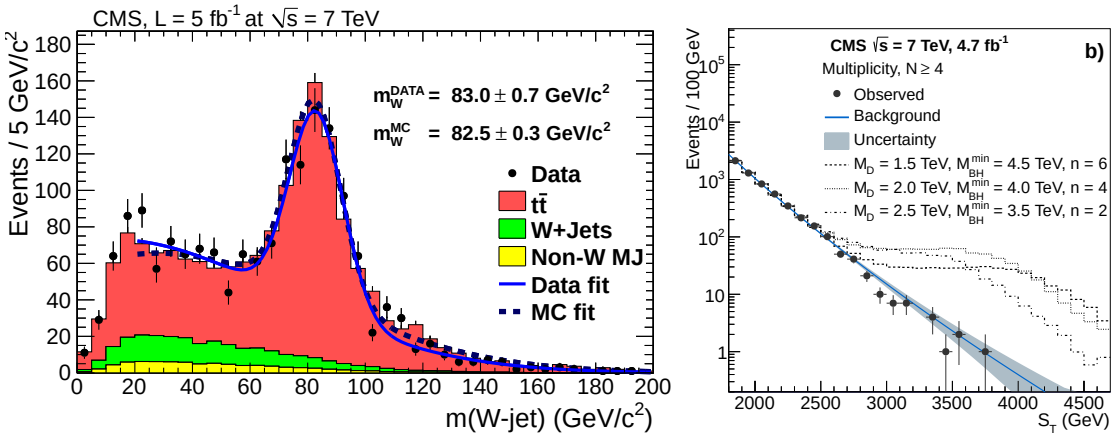

Figure 1: Left: W mass measurement using the jet mass in the boosted $t\bar{t}$ analysis. Right: $S_{\rm T}$ distribution for events with $N \geq 4$ objects in the BH search.

with a large number (N) of particles, most of them jets. The event selection requires large values of $S_{\rm T}$ (Fig. 1-right), defined as the scalar sum of the $p_{\rm T}$ of all reconstructed objects (including $\not\!\!E_{\rm T}$) above a 50 GeV threshold. The dominant background at high $S_{\rm T}$ is QCD multi-jet production, and is determined from data by exploiting the empirically observed $S_{\rm T}$ invariance with respect to N. Model-independent limits are set on new physics processes producing high-multiplicity, energetic final states. Also, limits are set on specific subsets of the several probed models using optimized $S_{\rm T}$ and N selections [3].

Searches For Randall-Sundrum Gravitons and W' Decaying to Di-Bosons: We report on the RS graviton searches in 3 channels: **a)** $G^* \to ZZ \to q\bar{q}\nu\bar{\nu}$, where q and $\bar{q}$ are merged into a single jet; **b)** $G^*(W') \to VZ \to q\bar{q}ll$, where V is either a Z or a W boson that decays to a $q\bar{q}$ merged into a single jet (when the V is a W, this analysis is sensitive to the possible existence of a W'); and **c)** $G^* \to ZZ \to q\bar{q}ll$.

In analysis **a)**, events are selected by requiring a jet with $p_{\rm T} > 300$ GeV and invariant mass $m_{\rm jet} > 70$ GeV (the $m_{\rm jet}$ distribution is shown in Fig. 2-left), a missing transverse energy $\not\!\!E_{\rm T} > 300$ GeV, a jet-$\not\!\!E_{\rm T}$ transverse mass $m_{\rm T}({\rm jet},\not\!\!E_{\rm T}) > 900$ GeV, no more than 2 jets with $p_{\rm T}$ >30 GeV, and no isolated leptons. The main surviving background is $Z(\to \nu\bar{\nu})$+jets. As no departure from SM expectation is observed, upper limits on the cross section times BR are set, and the RS graviton is excluded in a mass range between 1.0 and 1.5 GeV for values of the coupling constant of the model, k/M_{Pl}, varying from 0.11 to 0.29 [4].

The search **b)** targets heavy resonances with boosted decay products. The mass of the single jet is required to satisfy $65 < m_{\rm jet} < 120$ GeV, while special isolation requirements are applied to the leptons to allow for small ll opening angles.The shape and overall normalization of the $M_{\rm VZ}$ distributions of the main SM backgrounds (Z/γ^*+jets dominates) are determined from data, and no deviation from SM expec-

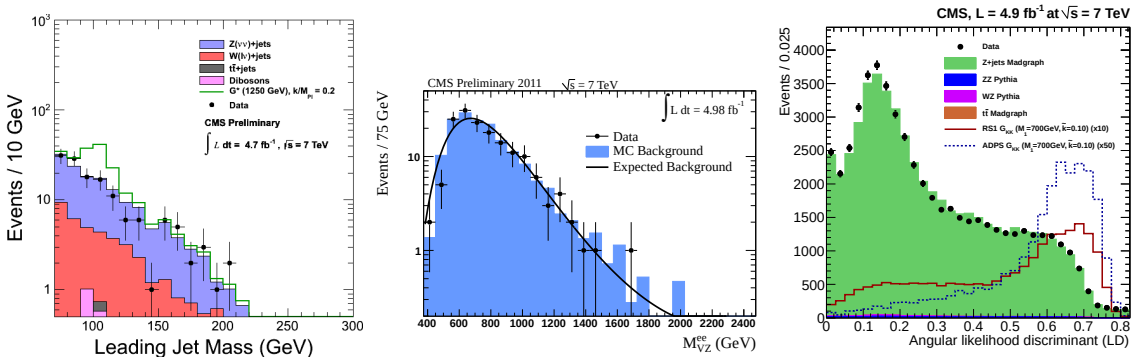

Figure 2: Left: mass of leading jet at final selection in the $G^* \to ZZ \to q\bar{q}\nu\bar{\nu}$ search. Center: $M_{\rm VZ}$ distribution at final selection in the $G^*(W') \to VZ \to q\bar{q}ll$ search. Right: Distributions of the angular likelihood discriminant at pre-selection in the $G^* \to ZZ \to q\bar{q}ll$ search.

tation is observed (Fig. 2-center shows the ee case, similar results are found for $\mu\mu$). The RS graviton is excluded for masses between 700 and 924 GeV for $k/M_{Pl} = 0.05$ while the Sequential Standard Model W' is excluded between 700 and 929 GeV [5].

Analysis **c)** explores the $M_{\rm ZZ}$ region between 400 and 1000 GeV, and all decay products are separately reconstructed. An angular likelihood discriminant between the spin-2 signal and the background hypotheses is constructed using 5 measured angles, see Fig. 2-right. Events are categorized according to having 0, 1 or 2 b-tagged jets, and the di-jet and di-lepton masses are required to be consistent with the Z mass. The kinematics of the jets is corrected using a fit that imposes the $M_{\rm dijet} = M_{\rm Z}$ constraint. The $M_{\rm ZZ}$ distribution is consistent with SM background, Z/γ^*+jets being the dominant source, and graviton masses in the range 400-945 GeV (400-720 and 760-850 GeV) are excluded for $k/M_{Pl} = 0.1$ (0.05) [6].

Searches For Dark Matter and Large Extra Dimension in Monojet Events: A signature with an energetic jet with $p_{\rm T}$ imbalance arises in the ADD model of large extra-dimensions, as well as in dark matter (DM) interactions with SM particles. The event selection requires a jet with $p_{\rm T} > 110$ GeV, $\not\!\!E_{\rm T} > 350$ GeV, no additional jets with $p_{\rm T} > 30$ GeV (but 2-jet events are kept if $\Delta\phi(\text{jet1}, \text{jet2}) < 2.5$) and no isolated leptons. The main SM background are $Z(\to \nu\bar{\nu})$+jets and W+jets, both determined from data using $Z(\to \mu\mu)$+jets and $W(\to \mu\nu)$+jets, and no deviation from SM expectations is observed. 90% CL upper limits on the DM-nucleon cross section are set for spin-independent and spin-dependent models (Fig. 3-left and -center), while 95% CL lower limits on the fundamental mass scale $M_{\rm D}$ of the ADD model are set versus the number of extra-dimension [7].

Searches for Di- and Three-Jet Resonances: A search for pair-produced di-jet resonances in events with at least 4 separated jets [8], and a search for di-jet resonances using the $\Delta\eta$ ratio distribution [9] are performed using the first 2.2 fb^{-1}

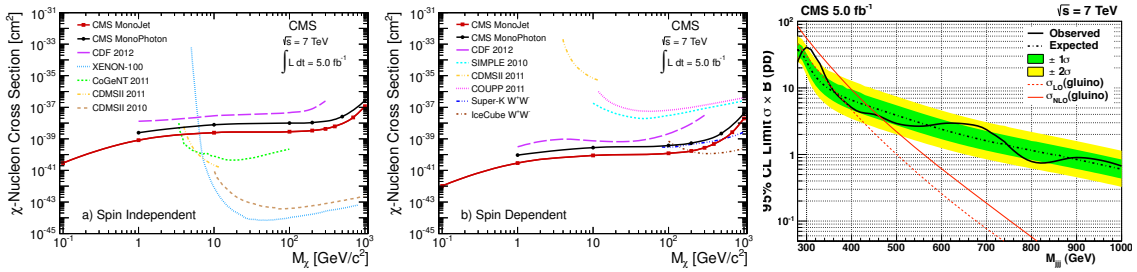

Figure 3: Left and center: 90% CL upper limits on the dark matter-nucleon scattering cross section versus dark matter mass from the CMS monojet analysis and direct detection experiments. Right: 95% CL upper limits on cross section × BR for gluino pair production followed by RPV decay of each gluino to three light-quark jets.

of the 2011 dataset. No deviations from SM background expectations are observed in either cases. 95% CL upper limits on the pair-production of di-jet resonances are set. These are compared with a model of pair-produced colorons, each decaying to $q\bar{q}$, to exclude coloron masses between 320 and 580 GeV. The angular ratio analysis is used to set 95% CL upper limits on the cross sections of new spin-1/2 quark-gluon resonances, and excited quarks of mass less than 3.2 GeV are excluded.

Various extensions of the SM predict resonances that decay to multi-jet states, such as heavy colored fermions and SUSY gluinos with an R-parity violating decay. The pair production of gluinos, each decaying to 3 jets, is used as a benchmark model. Events with high jet multiplicity and large scalar sum of jet p_{T} are selected from the 5.0 fb^{-1} of analyzed data. A jet ensemble technique is used to select jet-triplet combinations out of 6 high-p_{T} jets. The large combinatoric and SM background is fit to a functional form plus a gaussian and, since no excess is observed, gluino masses below 460 GeV are excluded at 95% CL assuming a BR of 100% to 3 jets [10].

References

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