Searches for resonances in the $tt\bar{t}$ mass spectrum

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for the

CMS collaboration
Physics motivation

- Many new physics models predict extra exchange of massive particles in top quark production
  - Would be observed in a peaked or general excess in the top-antitop invariant mass spectrum
  - Substantial number of theoretical models
    - \( Z' \), colorons, axigluons, Randall-Sundrum/ADD gravitons, Pseudo-scalar Higgs to \( tt\bar{t} \)
    - And many more

- Searches presented can be interpreted in any of these
  - For general comparison, “Topcolor-assisted technicolor” model: hep-ph/991.1288: Hill, Parke, Harris
analysis strategy

- Searches in different top decay channels
  - Dileptons \( t\bar{t} \rightarrow \ell^-\ell^+\nu\bar{\nu}b\bar{b} \)
  - Semileptonic \( \equiv \) lepton+jets \( t\bar{t} \rightarrow \ell \nu q\bar{q}b\bar{b} \)
  - Hadronic \( \equiv \) alljets \( t\bar{t} \rightarrow q\bar{q}q\bar{q}b\bar{b} \)

- And in different regimes
  - Close to 2x(top mass) threshold
    - Sensitive to shape of SM \( M(tt\bar{t}) \) distribution
    - Conventional top physics techniques may be used
  - More boosted
    - Sensitive to more massive \( M(tt\bar{t}) \) BSM physics
    - Dedicated reconstruction techniques may be necessary

[Diagram of top quark decay processes]
Analyses

- All analyses use full CMS pp 2011 dataset: 4.7-5.0 fb$^{-1}$ @ $\sqrt{s} = 7$ TeV
  - **TOP-11-010**: dilepton, threshold
    - Physics Analysis Summary (PAS)
  - **TOP-11-009**: semileptonic, threshold
    - Physics Analysis Summary (PAS)
  - **EXO-11-093**: semileptonic, boosted
    - Physics Analysis Summary (PAS)
  - **EXO-11-006**: hadronic, boosted
    - arXiv: 1204.2488 [hep-ex], submitted to JHEP
Dilepton, threshold

Selection requirements:

ee/e\(\mu\)/\(\mu\mu\) final state

• two isolated leptons, opp.charge, \(p_T>20\) GeV, \(|\eta|<2.5\)

• Missing \(E_T>30\) GeV

• Veto on DY at low/Z peak

• \(\geq 2\) jets, one b-tag (Secondary vertex) 
  \(p_T>30\) GeV, \(|\eta|<2.5\)

Analysis uses Bayesian NN to gain more sensitivity
Dilepton, threshold

- After selection dominated by ttbar production (75%)
- Good agreement between MC (Madgraph) and data.
- BNN trained for 750 GeV Z’
- Input variables: all available four-vectors and angles wrt mE_T, b-tag multiplicity and angles wrt b-jet
- Systematic uncertainty on rates and shapes of SM contribution total: 18%

M(Z’) < 1.1 TeV excluded (expected: 1.1 TeV)
Semileptonic, threshold

- Same lepton & jet selection as di-lepton result
  - But require only one lepton, >= 4 jets and split in b-tag multiplicity
- $\chi^2$ sorting used to select best jet combination
- Using data-driven estimates
  - W+jets (control region)
  - QCD multijet (invert isolation)
- Single top/ttbar/Z+jets from MC (Madgraph)
- Systematic uncertainties take into account rate and shape changes for signal and background model
Semileptonic, threshold

- Simultaneous fit in different b-tag multiplicities and electron/muon final states used to set limits (CLs, ‘LHC style’)
- Narrow (1.2%) $Z'$ limit: $M(Z') > 1.3\text{ TeV}$ excluded
- Wide (10%) $Z'$ limit: $M(Z') > 1.7\text{ TeV}$ excluded
- KK Gluons limit: $M(KKG) > 1.4\text{ TeV}$ excluded

![Graph showing upper limit on $\sigma Z' \times BR(Z' \rightarrow t \bar{t})$ as a function of $m_{Z'}$ for narrow and wide $Z'$ models.](image)

Ref: CMS TOP-11-009
Semileptonic, non-isolated

- Alternate analysis: Loosened lepton isolation criteria allow jet/lepton overlap
- Focus on mass tail: require harder cuts on leptons ($p_T > 70$ GeV) and jets ($p_T > 250$ GeV for leading jet, dependent on channel)
- Only at least 2 jets+lepton required
- $\chi^2$ sorting used to select best jet combination
- Simultaneous fit to $M(t\bar{t})$ in different $b$-tag multiplicities and electron/muon final states used to set limits
- Backgrounds normalized to control region where SM $t\bar{t}$ is dominant

Limits:
- Narrow (1.2%) $Z'$ limit: $M(Z') < 1.58$ TeV (1.55 expected)
- Wide (10%) $Z'$ limit: $M(Z') < 1.98$ TeV (1.98 expected)
All hadronic, boosted

- Using boosted objects and jet pruning to identify substructure
  - Full merged and semi-merged topologies
- Cambridge-Aachen jets
  - ‘top jets’
  - ‘W boson jets’

**Figure 2:** (a) The mass of the highest-mass jet (W-jet), and (b) the mass of the Type-2 top candidate (W\(^+\)b), in the hadronic hemisphere of moderately boosted semimuonic t\(\bar{t}\) events. The data are shown as points with error bars, the t\(\bar{t}\) Monte Carlo events in dark red, the W\(^+\)jets Monte Carlo events in lighter green, and non-W multijet (non-W MJ) backgrounds are shown in light yellow (see Ref. [46] for details of non-W MJ distribution derivation). The jet mass is fitted to a sum of two Gaussians in both data (solid line) and MC (dashed line), the latter of which lies directly behind the solid line for most of the region.

3.3 Background estimate

Since this analysis focuses on signatures with high-\(p_T\) jets, the main backgrounds expected are from SM non-top multijet production and t\(\bar{t}\) production. The background from NTMJ production is estimated from sidebands in the data as described below. For the Z\(^0\) masses considered in this analysis, the irreducible SM t\(\bar{t}\) component is significantly smaller than the NTMJ background contribution, and is therefore estimated from MC simulation using the same correction factors as found for the Z\(^0\) MC described in Sec. 3.2. It is normalized to the approximate next-to-next-to-leading-order (NNLO) cross section for inclusive t\(\bar{t}\) production, taken to be 163 pb [48–50].
All hadronic, boosted

- LLH fit to bumps in mass spectrum used to set limits
  - Narrow (1.2%) Z' limit: $M(Z') > 1.3-1.5$ TeV
  - Intermediate (3%) Z' limit: $M(Z') > 1.6$ TeV
  - Wide (10%) Z' limit: $M(Z') > 2.0$ TeV
  - RS Kaluza-Klein gravitons: $M(KKG) > 1.4-1.5$ TeV

- 95% CL upper limits on increased cross section at high mass:
  - $\sim 1$ pb for intermediate mass (1 TeV)
  - $\sim 50$ fb for higher mass (2 TeV)

Ref: CMS EXO-11-006
Summary

- CMS examined the top pair mass spectrum for possible BSM resonances.
- Multiple ttbar final states were considered, limit for 1.2% width Z’:
  - Di-lepton: 1.1 TeV
  - Lepton+jets: 1.58 TeV (no iso), 1.3 TeV (threshold)
  - All-hadronic: 1.3-1.5 TeV
  - Limits on many other models and Z’ widths also available
5.1 Resonance analysis

Figure 4: The 95% CL upper limits on the product of production cross section ($\sigma Z'$) and branching fraction ($B$) of hypothesized objects into $t\bar{t}$, as a function of assumed resonance mass. 

(a) $Z'$ production with $G_{Z'}/m_{Z'} = 1\%$ (1\% width assumption) compared to predictions based on Refs. [4–6] for $G_{Z'}/m_{Z'} = 1.2\%$ and $3.0\%$. 

(b) $Z'$ production with $G_{Z'}/m_{Z'} = 10\%$ (10\% width assumption) compared to predictions based on Refs. [4–6] for a width of 10\%.

(c) Randall–Sundrum Kaluza–Klein gluon production from Ref. [12], compared to the theoretical prediction of that model. The $\pm 1$ and $\pm 2$ standard deviation (s.d.) excursions are shown relative to the results expected for the available luminosity.

Stay tuned for new results coming soon!
Backup
CMS - the Compact Muon Solenoid

- **SUPERCONDUCTING COIL**
- **ECAL**
  - Scintillating PbWO$_4$
- **CALORIMETERS**
  - HCAL
    - brass
    - Plastic scintillator sandwich
  - IRON YOKE
- **TRACKERs**
- **MUON BARREL**
  - Drift Tube Chambers (DT)
  - Resistive Plate Chambers (RPC)
- **CATHODE STRIP CHAMBERS (CSC)**
- **RESISTIVE PLATE CHAMBERS (RPC)**

- Total weight: 12,500 t
- Overall diameter: 15 m
- Overall length: 21.6 m
- Magnetic field: 4 Tesla

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