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Preparations for BSM Searches using the Top-Antitop Invariant Mass Distribution

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Many new physics models beyond the Standard Model predict heavy new particles that preferentially decay to top-antitop pairs. New particles with high invariant masses will produce boosted top quarks, and these top quarks will have collimated decay products, requiring the development of new methods for selection and reconstruction of such events. Searches for resonances in the invariant mass spectrum of these $t\bar{t}$ pairs are examined for both the semileptonic μ + jets and the all-hadronic channels, and the expected sensitivity to observe these resonances is analyzed as a function of mass.

The Xth Nicola Cabibbo International Conference on Heavy Quarks and Leptons,
October 11-15, 2010
Frascati (Rome) Italy

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PoS(HQL 2010)033

1. Event selection for top quark pairs

Top quarks predominantly decay to a b quark and W boson, so analyses are characterized by the decay modes of the W, which have branching ratios $\mathrm{BR}(W \to l\nu) \approx 2/9$ ($l = e, \mu$), and $\mathrm{BR}(W \to q\bar{q}') \approx 2/3$. Thus, for the corresponding $t\bar{t}$ channels: $\mathrm{BR}(t\bar{t} \to l + \text{jets}) \approx 30\%$ (semileptonic) and $\mathrm{BR}(t\bar{t} \to \text{jets}) \approx 44\%$ (all-hadronic).

The greater the invariant mass of the top pair, $M_{t\bar{t}}$, the more boosted the top quarks, and the smaller the angle between decay products. For leptonic W decays, this can produce leptons close to or inside the b-jet. For hadronic W decays, jet overlapping may cause the jet algorithm to reconstruct 1 or 2 jets instead of 3.

2. μ + jets analysis: expected sensitivity

The major backgrounds to boosted $t\bar{t}$ production come from several Standard Model processes: internal $t\bar{t}$, W production in association with jets, and QCD multijet events, as shown in Figure 1. For comparison, the expected spectra for potential $Z' \to t\bar{t}$ signal events are also shown for various possible Z' masses, with the cross section for each Z' assumed equal to the semi-muonic $t\bar{t}$ cross section [2]. The reconstructed signal peaks show non-Gaussian effects, particularly for high mass Z'.

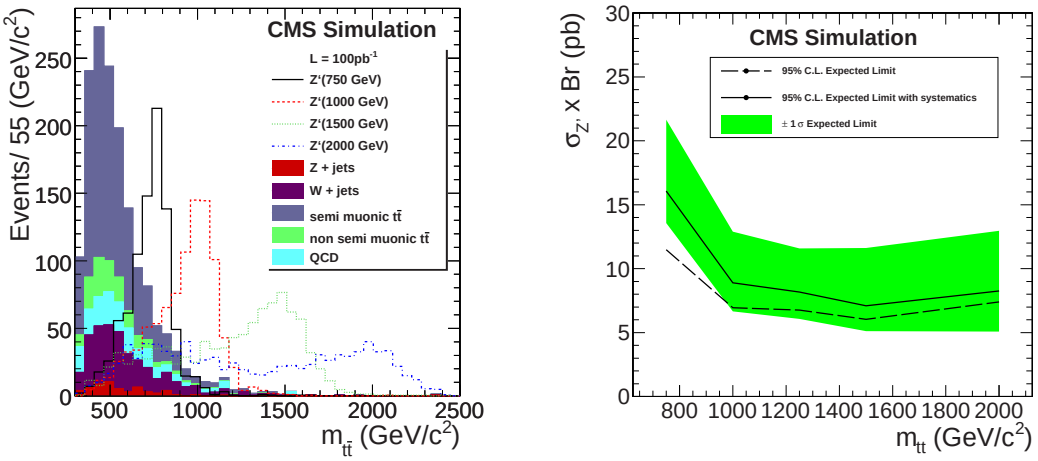

Figure 1: $M_{t\bar{t}}$ spectrum from SM, with potential $Z' \to t\bar{t}$ signals superimposed (left) and expected limits on $\sigma_{Z'} \times \mathrm{BR}(Z' \to t\bar{t})$ at 95% C.L. (right)

3. All hadronic analysis: expected sensitivity

For the all-hadronic analysis, CMS uses a modified top-tagging algorithm[4] that clusters input particles (calorimeter clusters) into a jet that contains all top decay products. These jets are

then decomposed into constituent subjets. The efficiency for tagging top jets with this algorithm, estimated from MC, is $\varepsilon \approx 46\%$ for jet $p_T \gtrsim 600$ GeV/c, as shown in Figure 2. The analysis requires two tagged jets with $p_T > 250$ GeV/c, $|\eta| < 2.5$, either 3 or 4 subjets, and an invariant mass between 100 GeV/c^2 and 250 GeV/c^2. For these selection criteria, background is dominated by QCD dijet events, with small contributions from internal $t\bar{t}$.

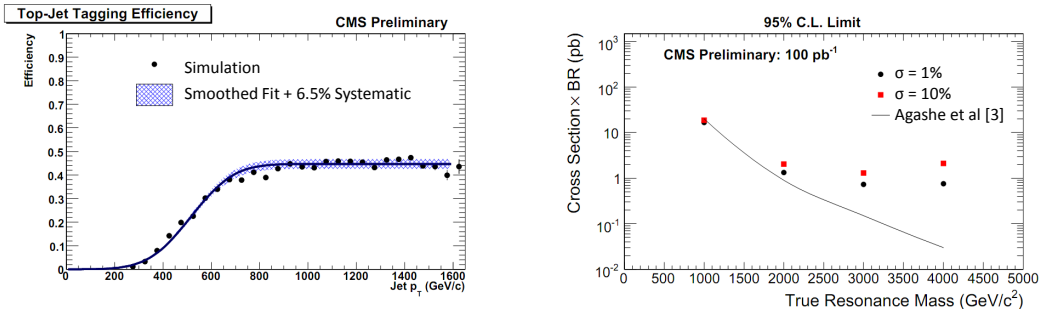

Figure 2: Efficiency for matched top-jets (left) and expected limits on $\sigma \times$ BR at 95% C.L. for $\sqrt{s} = 10$ TeV (right)

4. Experimental outlook

First data collected by CMS at pp center-of-mass energy 7 TeV were analyzed using μ + jets selection requirements and compared to predictions from Monte Carlo simulation. For this initial sample, the predicted yields are in good agreement with the observed yields in data.

The event selection criteria for early semileptonic and all-hadronic $t\bar{t}$ analyses is designed to efficiently select signal events while suppressing contributions from background. Due to the boosted nature of the top quarks in these analyses, techniques have been developed to accurately determine contributions from possible new physics sources.

The μ + jets analysis is well adapted for observing $t\bar{t}$ resonance production from new physics in an intermediate mass range up to about 2 TeV. The all-hadronic analysis uses a top-tagging algorithm to identify boosted top quarks, giving good sensitivity to resonances at higher values of $M_{t\bar{t}}$.

References

[1] CMS Collaboration, "Selection of Top-Like Events in the Dilepton and Lepton-plus-Jets Channels in Early 7 TeV Data", CMS PAS TOP-2010-004 (2010)

[2] CMS Collaboration, "Search for narrow resonances in top-pair production close to threshold in the semileptonic muon channel at sqrt(s) = 10 TeV", CMS PAS TOP-2009-009 (2009)

[3] CMS Collaboration, "Search for heavy narrow t-tbar resonances in muon-plus-jets final states with the CMS detector", CMS PAS EXO-2009-008 (2009)

[4] CMS Collaboration, "Search for High Mass tt Resonances in the All-Hadronic Mode", CMS PAS EXO-2009-002 (2009)