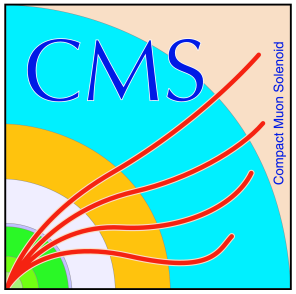
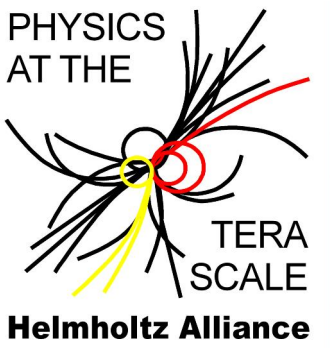
Search for Resonances in Top Quark Pair Production with the CMS Experiment





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on behalf of the CMS Collaboration

3rd Annual Workshop of the Helmholtz Alliance
Physics at the Terascale,
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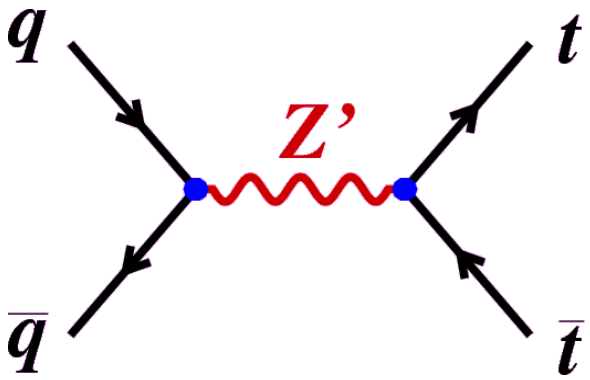
Introduction

Several theoretical models predict contribution to top quark pair production, for instance:

- Axigluons
- Technicolor Z'
- KK excitations of extra dimensional gravitons

→ model independent search for new physics

In all cases M_{tt} spectrum is distorted relative to SM expectation.



Physics question:

- Which cross sections can we exclude?
- At which cross section can we see new signals?

Overview

Three analyses are serching for top pair resonances at CMS:

- High resonance masses O(TeV) in the full hadronic decay mode (CMS PAS: EXO-09-002)
- High masses in the muon+jets decay channel (CMS PAS: EXO-09-008)

  german contribution: Th. Müller, J. Ott, T. Peiffer, J. Wagner-Kuhr (KIT)
- Low masses in the muon+jets decay channel (CMS PAS: TOP-09-009)

  german contribution: M. Erdmann, J. Steggemann (RWTH Aachen)

Assumed scenario:
- 100-200 pb^{-1} integrated luminosity at 10 TeV centre-of-mass energy
- Narrow resonances with Z-like coupling structure

Full Hadronic Channel

Assumption:

Top and anti-top quark originate from the decay of a heavy particle.

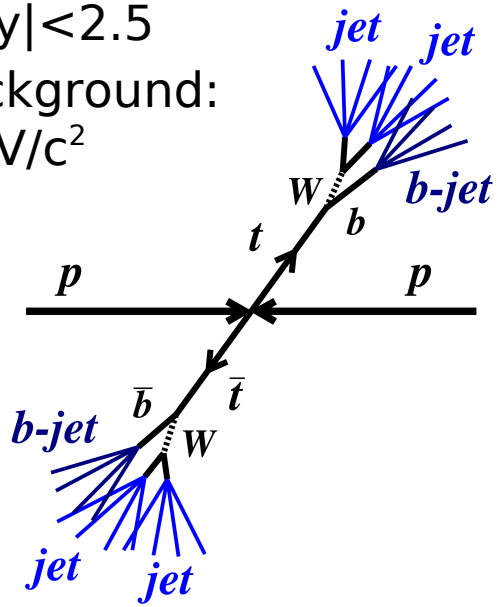
→ Top quarks are boosted.

→ Decay products of hadronically decaying top quarks end up in single fat jets.

→ Fat jets can show substructure.

Event Selection:

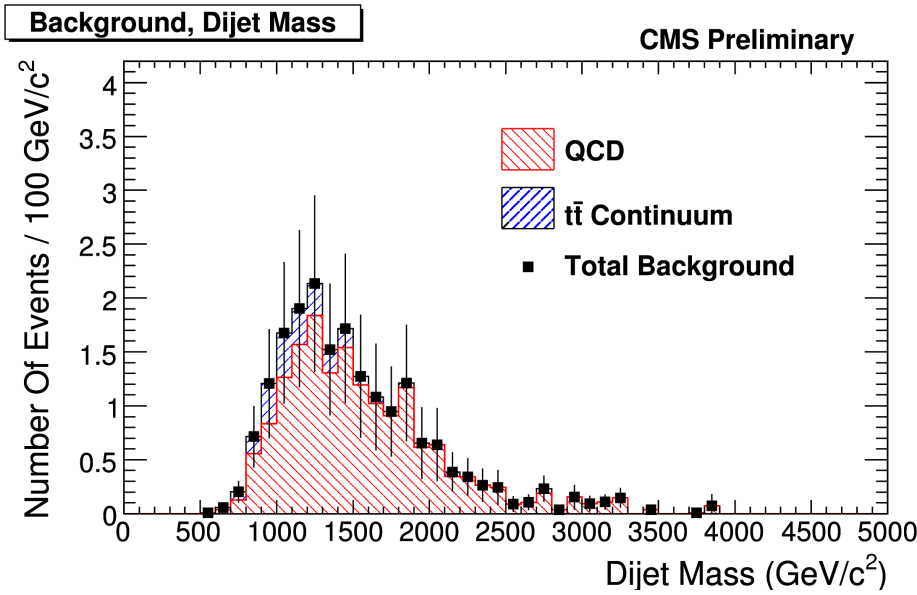
- Two Cambridge-Aachen (CA) jets with p_T>250 GeV/c, |y|<2.5
- Apply 'Top-Tags' to both jets to subpress QCD dijet background:
  - Invariant mass of the jet: 100 GeV/c^2<m_{jet}<250 GeV/c^2
  - Invert the last clustering steps of the CA algorithm to find at least 3 subjets with $p_{T,sub}$>0.05*$p_{T,fat}$
  - Minimal invariant di-subjet mass m_{min}>50 GeV/c^2

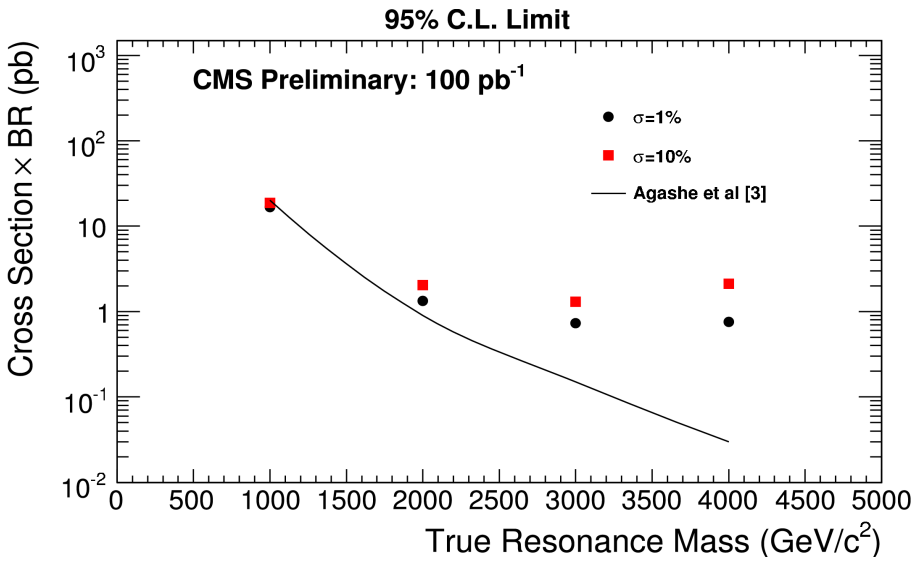


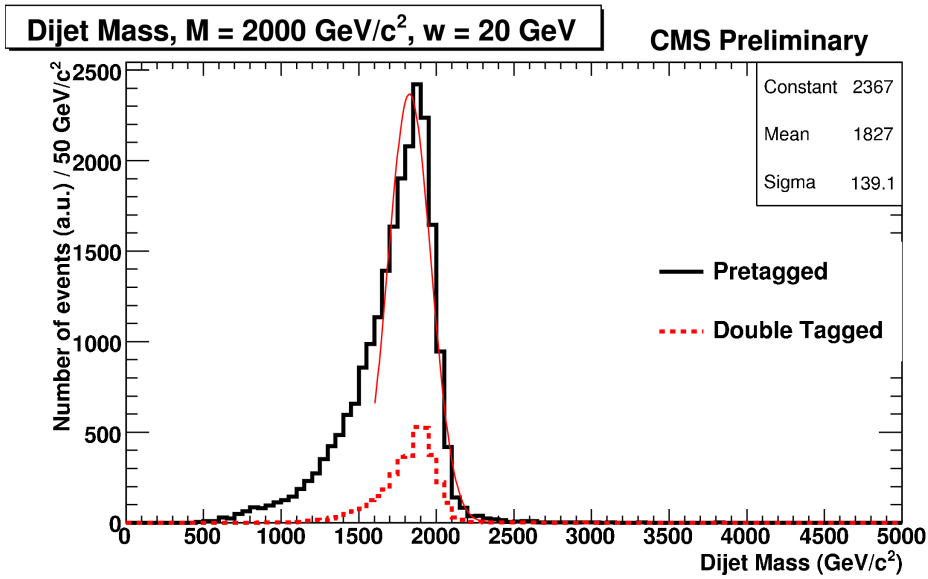
Full Hadronic: Results

Significance estimation:

- Perform a counting experiment in a mass window around the expected mass peak.
- Construct likelihood function and fold in systematics with gaussians.
- Estimate expected 95% C.L. upper limit from averaging individual limits in pseudo experiments.





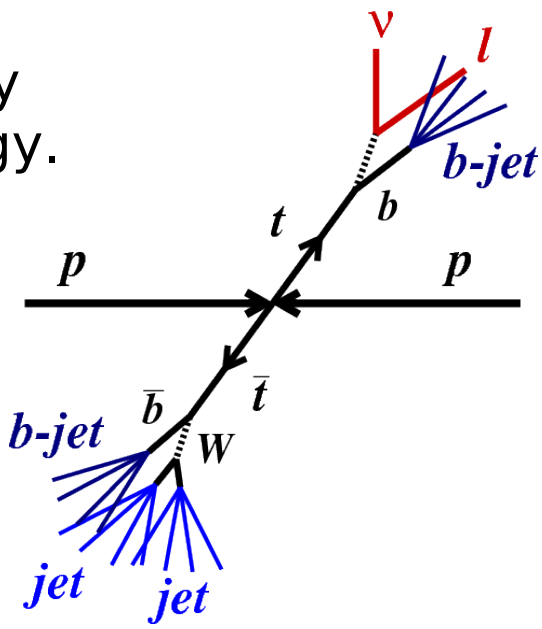


Muon+Jets Channels

Event kinematic differs for the decay of low and high mass resonance particles:

- Low mass particles (several 100 GeV/c^2):
  - Decay of the resonance particle to tt leads to similar event kinematic as SM tt production:
    4 jets, one (mostly isolated) muon, missing transverse energy.

- High mass particles (several TeV/c^2):
  - Top quarks from resonance decay are highly boosted, top quarks in back-to-back topology.
  - Decay products of the top quarks merge:
    Muon often not isolated, #jets≥2.



Event Selection

Low mass analysis:

- At least 4 cone jets with E_T>35 GeV, |η|<2.4
- One muon with p_T>35 GeV/c, |η|<2.1
- Di-lepton veto

High mass analysis:

- At least 2 cone jets with p_T>50 GeV/c, |η|<2.4
- Leading jet with p_T>260 GeV/c
- One muon with p_T>25 GeV/c, |η|<2.1
- Z veto
- H_T^{lep}:=p_T(muon)+MET>200 GeV

Common selection:

Apply 2D cut to reduce fake muons from QCD events:
reject events with p_T^{rel}<35 GeV/c and ΔR(muon,jet)<0.4

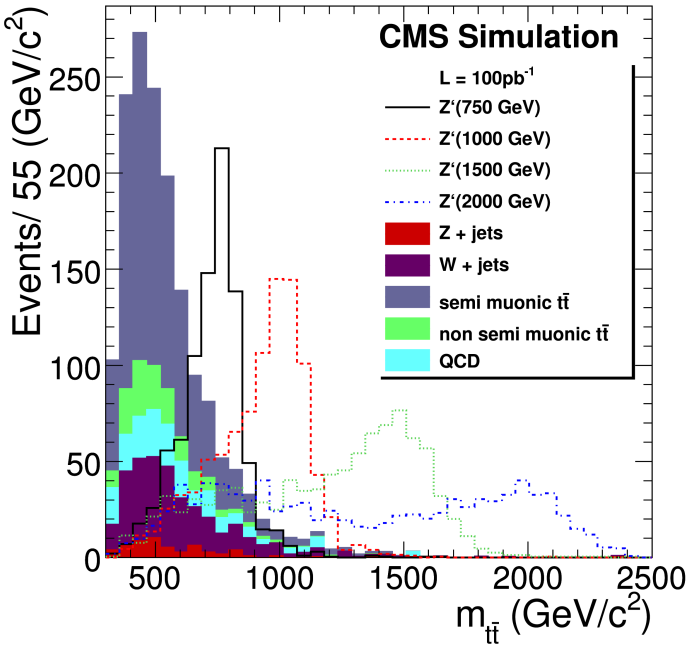
p_T^{rel}: Transverse momentum of μ relative to the direction of of the closest jet

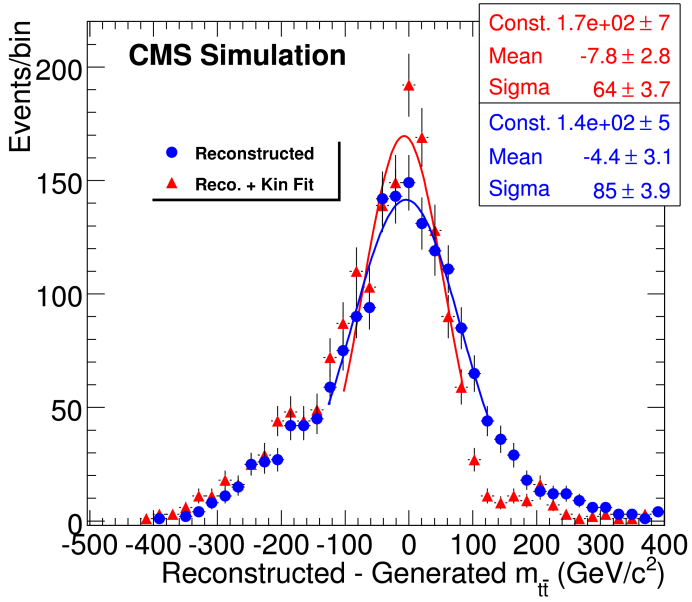
Reconstruction

Invariant mass of top pair system is sensitive variable for resonances.
→ reconstruction of the top 4-momenta required.

Low mass analysis:

- Create list of hypotheses for jet assignment.
- Perform kinematic fit for each jet combination:
  Vary 4-momenta of jets, muon and neutrino to minimize a χ^2 which contains top and W mass constraints.
- Take hypothesis with best χ^2.



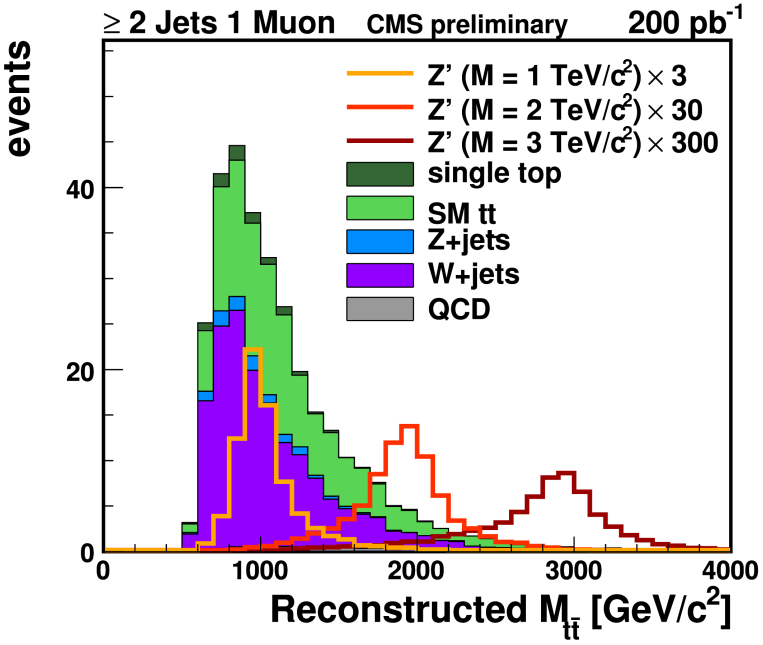


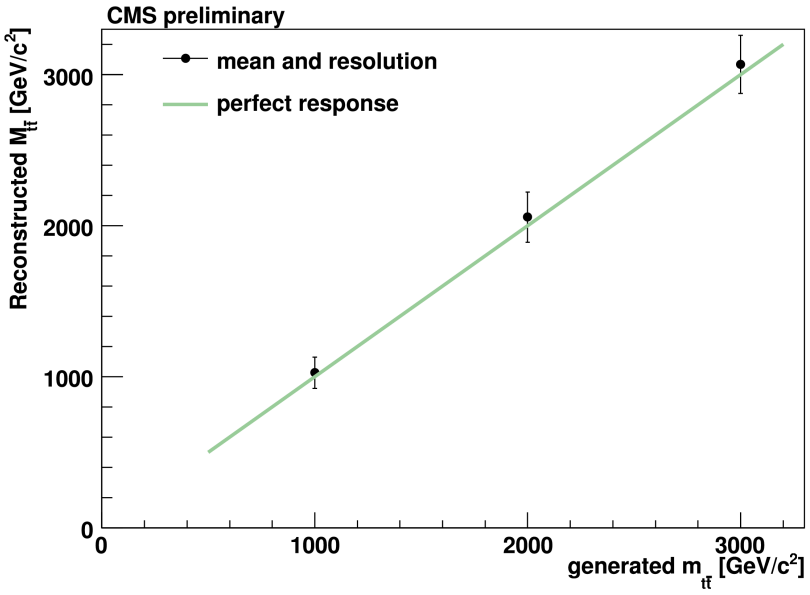
Mass resolution for a Z' with M=500 GeV/c^2 width=5 GeV/c^2

Reconstruction

High mass analysis:

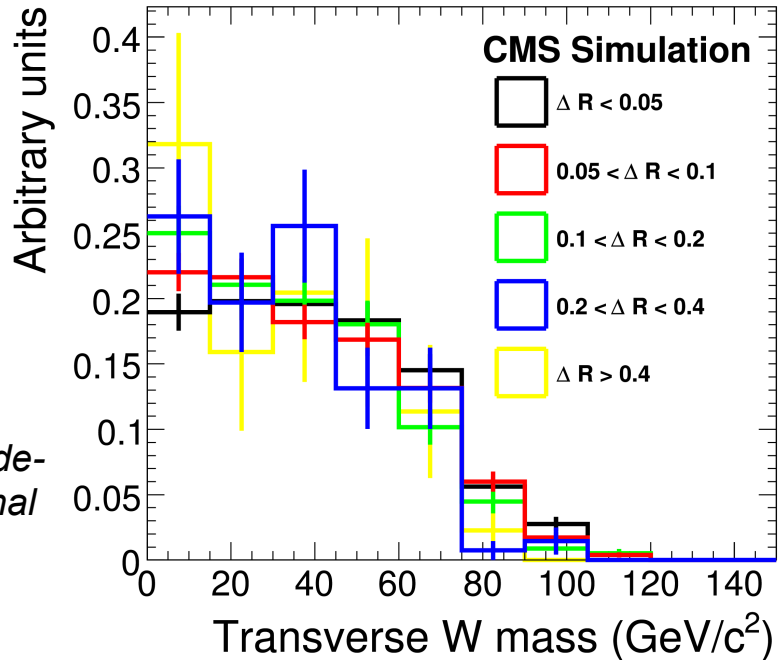
- Less than 4 jets: full reconstruction of each decay product not possible.
- Reconstruct neutrino from MET and W mass constraint.
- Choose jet assignment such, that reconstructed top quarks have expected back-to-back topology.





Background Estimation

- W/Z+jets and SM top shapes are modelled with Monte Carlo.
- Top production rate is also taken from Monte Carlo.
- For QCD background a data driven modelling has been developed:
  - Take data from QCD dominated sideband as QCD model in signal region. **Here:** invert 2D muon cut.
  - Estimate QCD rate from a template fit to an appropriate variable in another sideband region and extrapolate to signal region.
  - Take W/Z+jets and QCD rate as free fit parameters.



QCD models from various sidebands compared to the original QCD template (yellow)

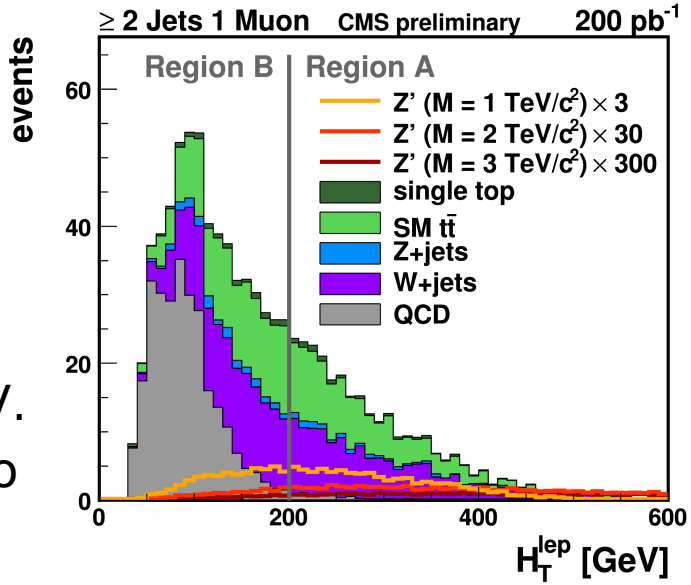
Background Estimation

Low mass analysis:

- Fit to H_T distribution in region H_T<350 GeV.
- Yields 35% uncertainty (syst.+stat.) on QCD and W+jets rates.

High mass analysis:

- Fit to H_T^{lep} distribution in region H_T^{lep}<200 GeV.
- Fit is performed simultaneously with final fit to top pair mass M_{tt}.

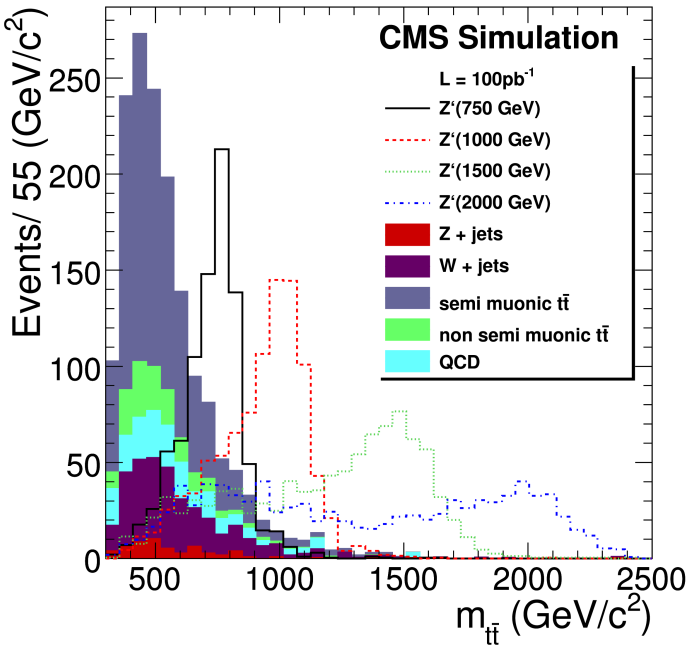


→ Method gives in-situ estimation of main backgrounds QCD and W+jets.

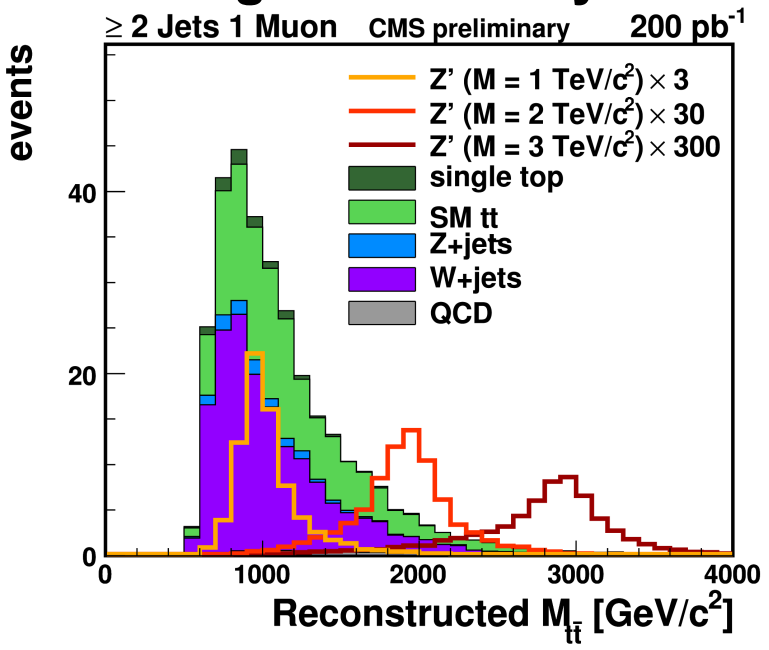
Likelihood Fits

- To estimate upper limits or expected discovery reach a template likelihood fit to the reconstructed M_{tt} is performed.

low mass analysis



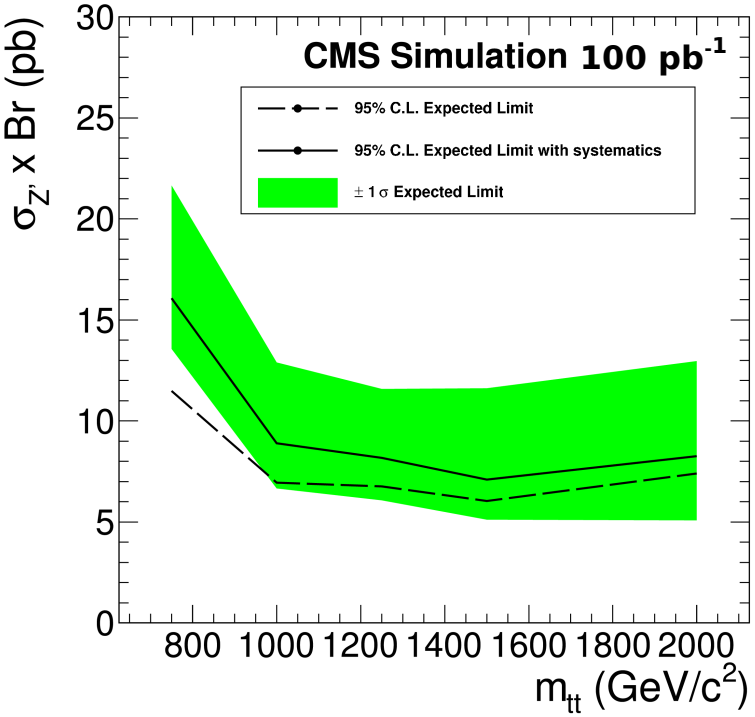
high mass analysis



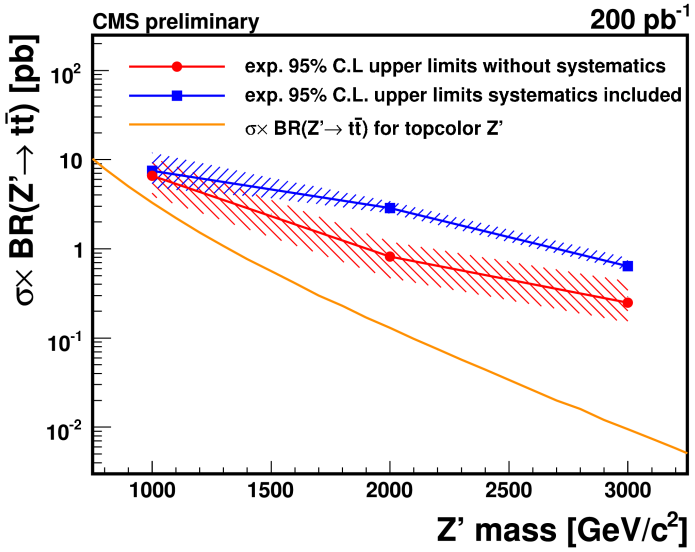
- Systematic uncertainties are incorporated into the fit.
- Main systematic uncertainty arises from jet energy scale uncertainty.
- Estimate expected limits from likelihood ratio in pseudo experiments.

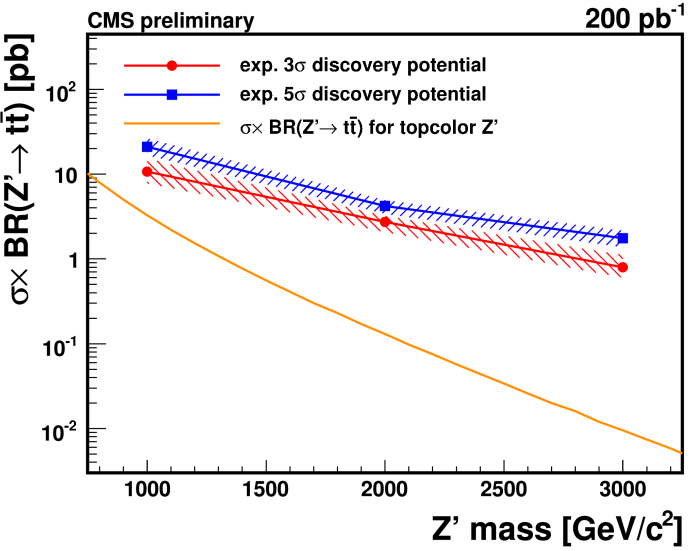
Results

low mass analysis



high mass analysis





- For the first time limits on heavy resonances decaying to top pairs can be given in the multi-TeV range.
- Cross section limits in reach are at the level of a few picobarn.
- The two analyses complement the full mass range.

Conclusion

- Search for resonances in top pair production is universal search for many kinds of new physics.
- Three analyses are actually developed to account for different decay channels and kinematic regions.
- With one year of data taking at CMS first direct limits in the TeV range of the order of several pb might be extracted.

Backup

Top Tagging

Fake rate and tagging efficiency of the Top-Tagger: