Search for new particles in $t\bar{t}$ production

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

Introduction

- Top quark is heaviest known elementary particle
- Only accessible in hadron collisions
- Mass of the order of the EW breaking scale
- New Physics might be connected to top quark sector

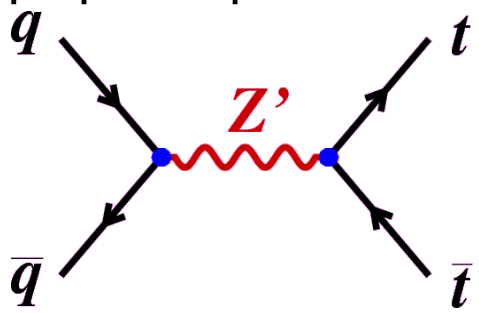
Presented here: Resonance searches in $t\bar{t}$ events:

- Search for resonant $t\bar{t}$ production (arXiv:1309.2030, accepted by PRL)
- Search for excited top quarks (CMS-PAS-B2G-12-008 and CMS-PAS-B2G-12-014, submitted arXiv and JHEP)
- Both analyses based on full 2012 dataset with 8 TeV, ~20 fb^{-1}.

Possible Signatures

New particles in $t\bar{t}$ production:

Heavy new particles could show up as resonance in top quark pair production

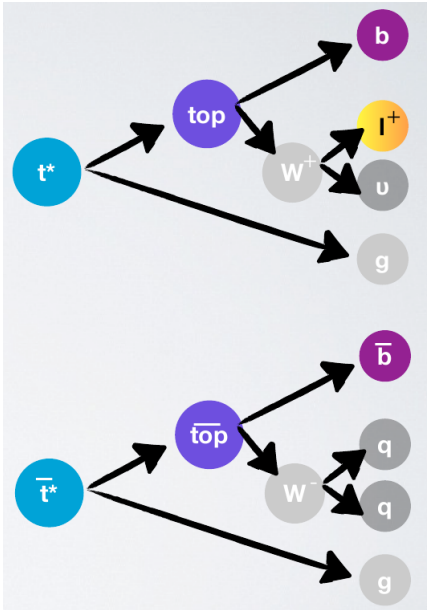


Many models predict such resonances:

topcolor Z', Kaluza Klein excitations, heavy Higgs bosons, etc.

Excited top quark:

- Spin 3/2 or 1/2 excitation t* decaying to top+gluon
- Search for pair produced $t^*\bar{t}^*$
- Expected in Randall-Sundrum models
- Sbottom pair production has same signature

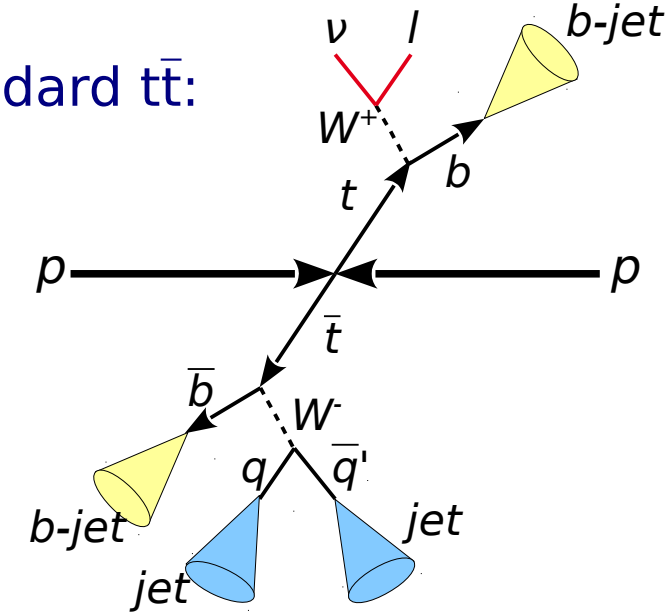


Search for $t\bar{t}$ resonances

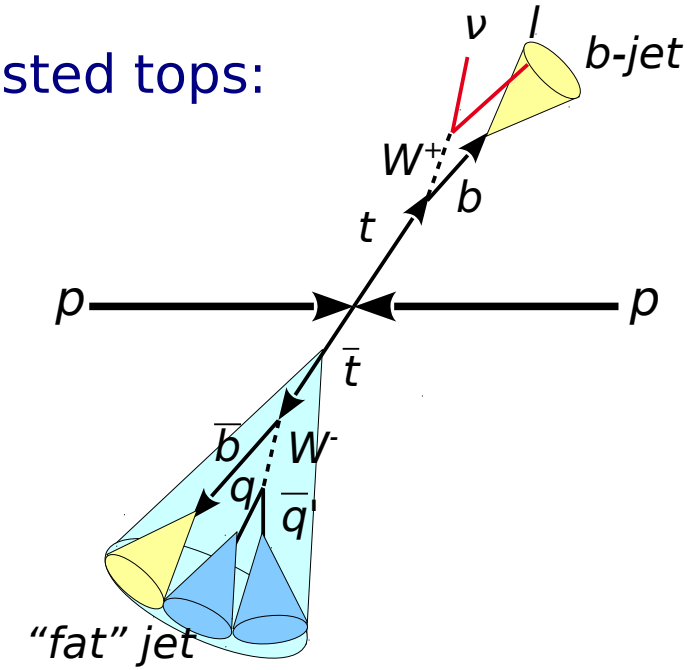
Resonance Signature

Top quarks originating from a heavy resonance decay are produced with large boost

Standard $t\bar{t}$:



Boosted tops:



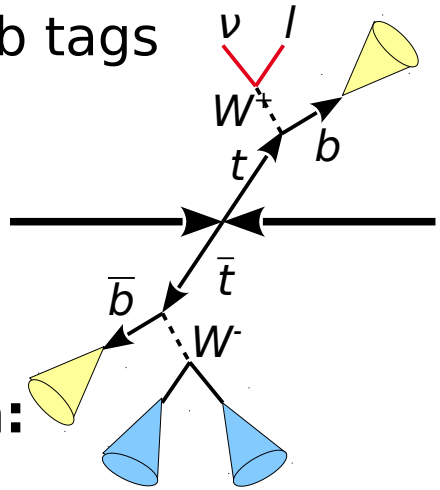
3 analysis channels:

- **Lepton+jets resolved:** one top quark to *b*, *l*, *ν*, other top quark to hadrons, all decay products resolved
- **Lepton+jets boosted:** decay products are allowed to overlap
- **Hadronic boosted:** both top quarks decay to hadrons and can build fat jets

Lepton+jets

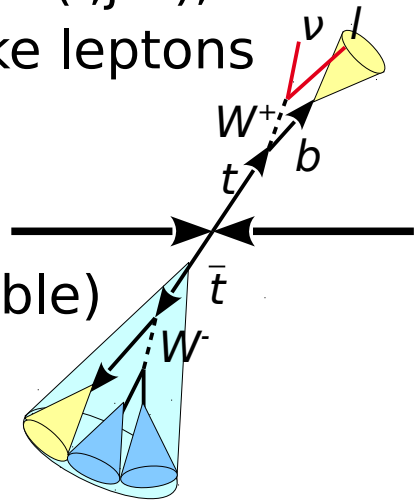
Mass threshold analysis

- 1 isolated e(μ) with p_T>30 (26) GeV
- 4 or more jets (with 70, 50, 50, 30 GeV), 1 or more b tags
- Missing E_T>20 GeV



Boosted analysis

- 1 **non**-isolated e(μ) with p_T>35 (45) GeV
- 2 or more jets with 50 GeV, leading jet with 150 GeV
- Missing E_T>50 GeV, H_T^{lep}>150 GeV
- Cuts on p_T^{rel}(l,jet), ΔR(l,jet), Δφ(l,jet) against fake leptons



Event reconstruction:

- Neutrino momentum from missing E_T
- Assign jets to quarks (in 2 or 3 jet events: not fully resolvable)
- Choose best hypothesis by χ^2 including top and W masses
- Cut on χ^2

Lepton+jets results

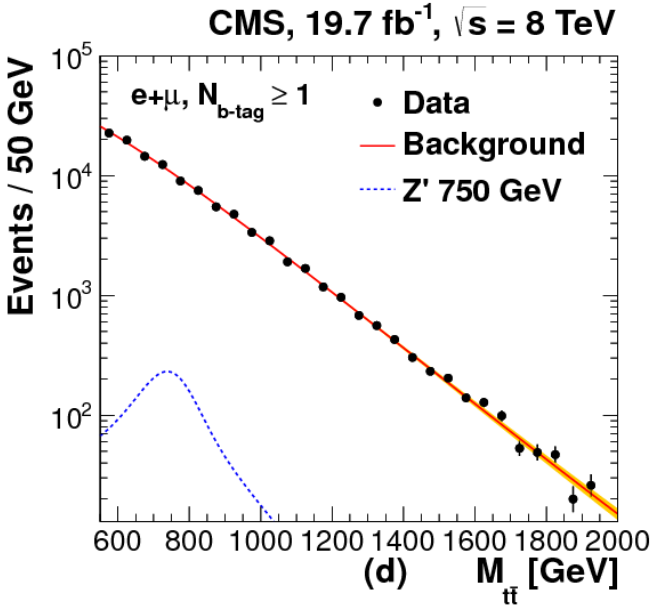
Mass threshold analysis:

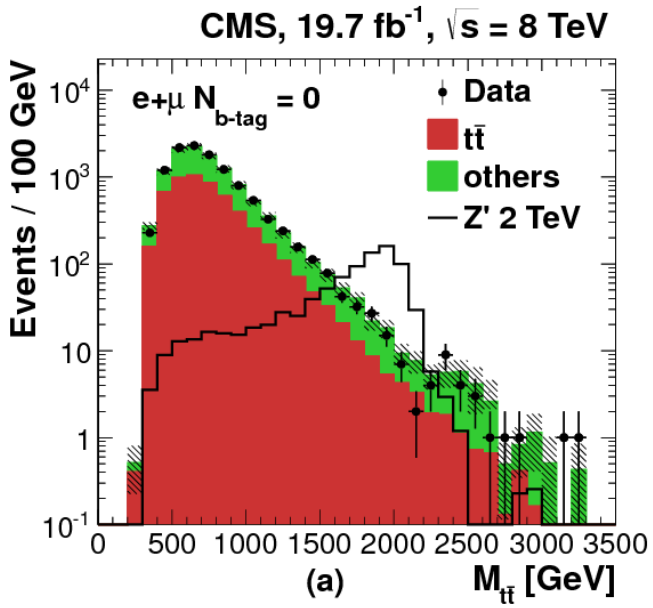
Signal parametrized with Breit-Wigner shape

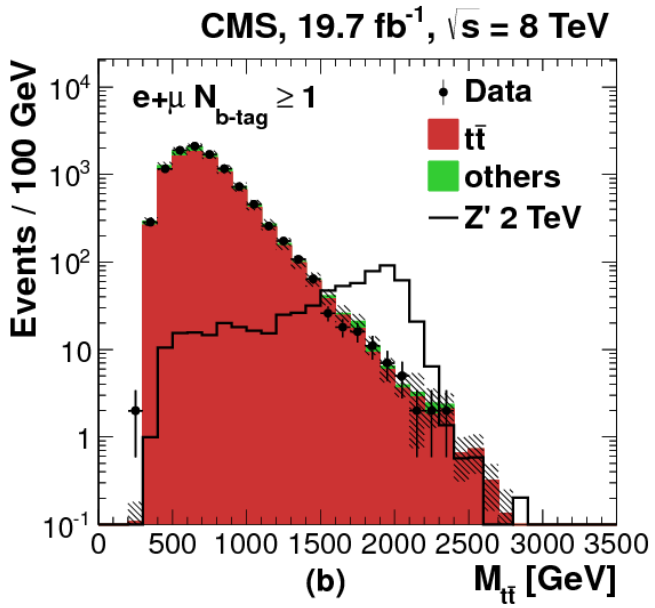
Background modeled with smoothly falling probability density function

Boosted analysis:

Signal and background templates from MC simulation





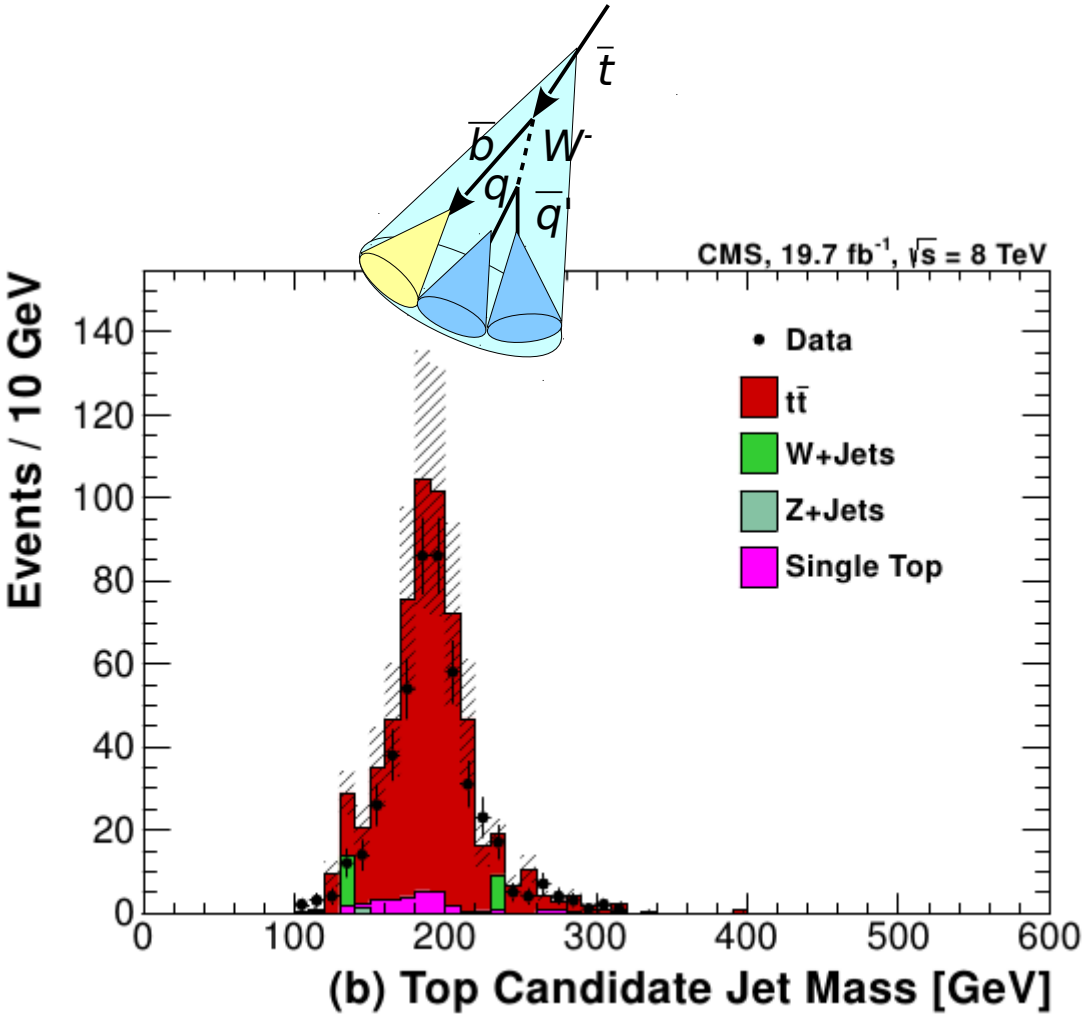


Hadronic channel

No leptons: huge QCD multi-jet background

→ apply **top tagging**:

- Reverse jet clustering steps → sub-jets
- Cuts on jet and sub-jet masses to match top and W masses
- Validate tagging on l+jets top events



Selection:

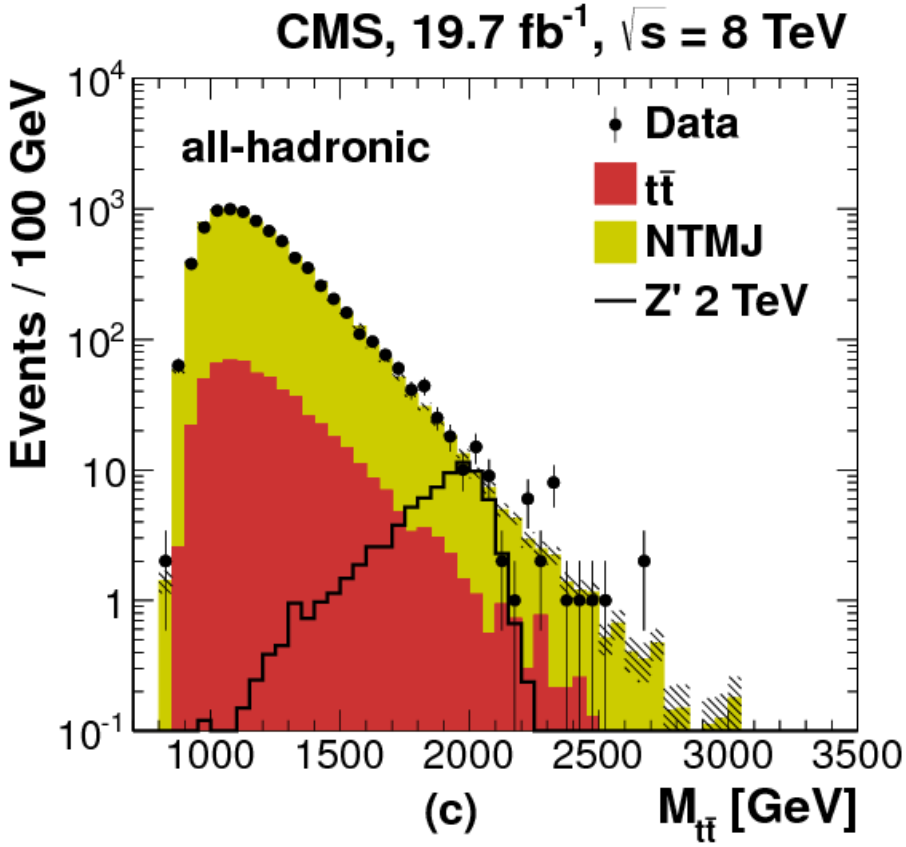
- trigger with H_T>750 GeV
- Two Cambridge-Aachen jets with R=0.8 and p_T>400 GeV
- Both jets top tagged

Hadronic channel

- Non-top multi jet (NTMJ) background modelled from data sideband
- Top background and signal from simulation

No excess observed in all channels

→ set limits on resonance models



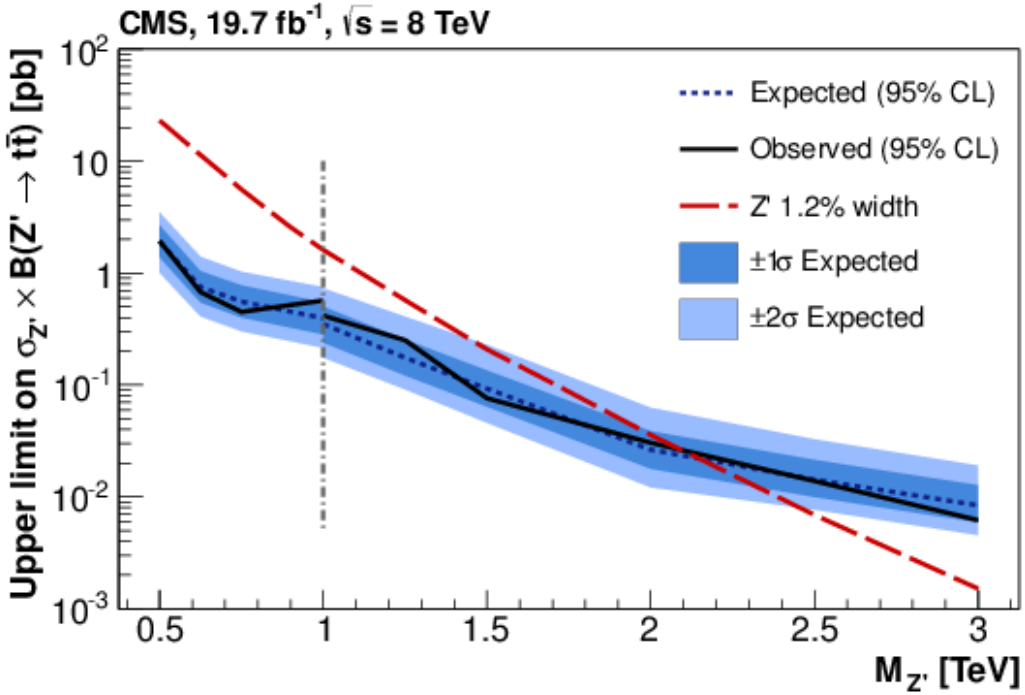
Combined Limits

Low mass analysis:

- Limits from pdf fit

High mass region:

- Template fit to $m_{t\bar{t}}$ distribution
- Combine l+jets and hadronic channels



Limits:

- Narrow Topcolor Z': m>2.1 (2.1 expected) TeV
- Topcolor Z' with 10% width: m>2.7 (2.6) TeV
- RS Kaluza-Klein gluon: m>2.5 (2.4) TeV
- S=σ(SM+BSM)/σ(SM) <1.2 at 95% CL for $m_{t\bar{t}}$>1 TeV

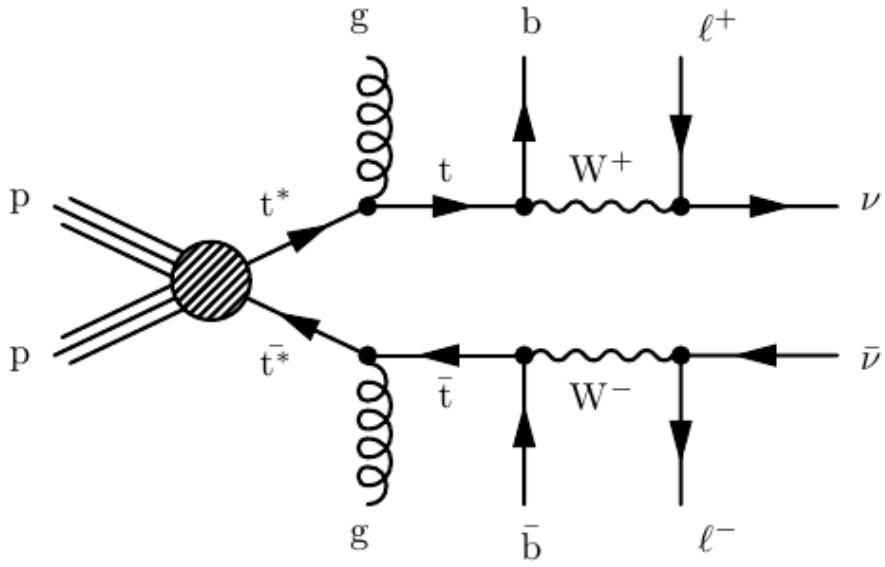
Search for excited top quarks

Analysis Overview

Signature:

- $t\bar{t}$ signature + 2 additional jets:
- Main background:

  SM $t\bar{t}$ production with additional radiation



Event selection lepton+jets:

- Exactly one isolated electron (muon) with p_T>30 (26) GeV
- At least 6 jets with p_T>30 GeV, leading 3 jets with p_T up to 55 GeV
- At least one b tag

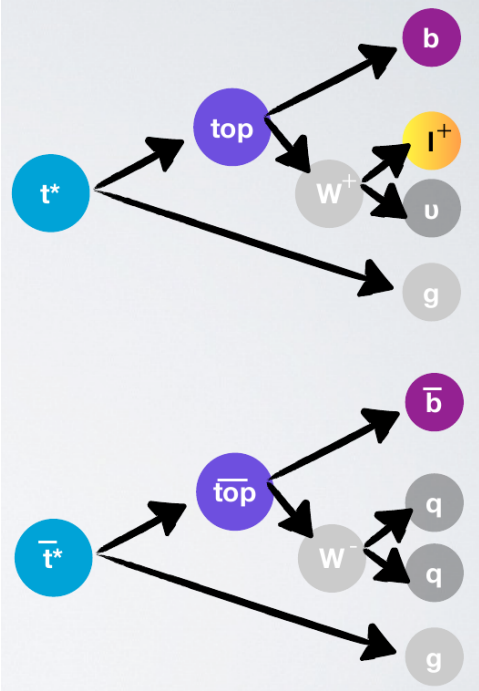
Event selection di-lepton:

- At least two isolated electrons or muons with p_T>20 GeV
- Two b tagged and two non-b tagged jets with p_T>30 GeV

Mass Reconstruction

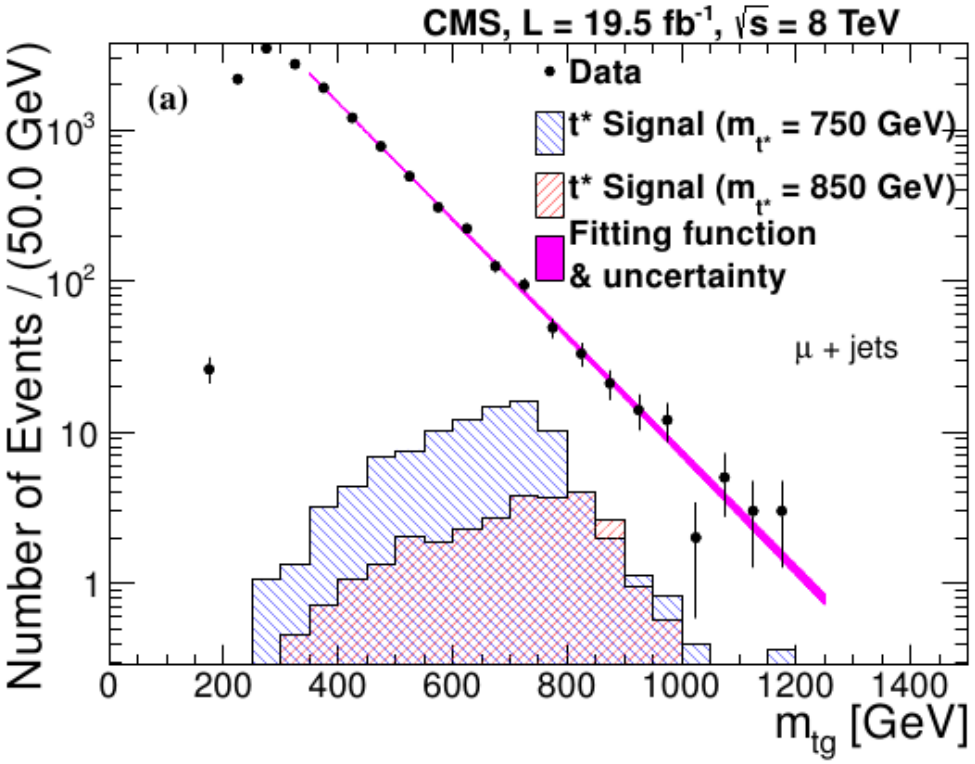
Reconstruct t* mass from kinematic fit:

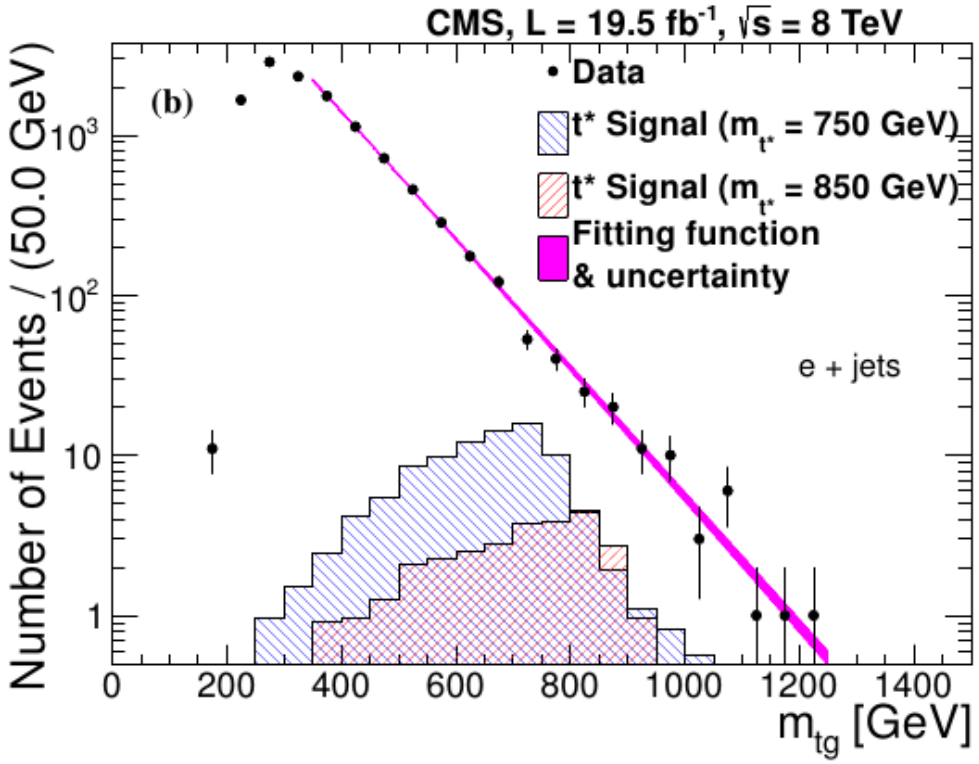
- Neutrino(s) reconstructed from missing transverse energy
- Assign jets to final state partons
- Smear jets within resolution
- Consider all jet/lepton assignments/neutrino solutions
- Constrain masses:
  - $m(l\nu)=m(q\bar{q})=m_W=80.4$ GeV
  - $m(l\nu b)=m(q\bar{q}b)=m_t=173.5$ GeV
  - $m(l\nu bg)=m(q\bar{q}bg)=m_{t^*}$ with free parameter m_{t^*}



Results: L+Jets

- Parametrize $M_{t,jet}$ shape of background with falling function
- Perform likelihood fit to extract t* cross section/limits
- No excess seen in data





Results: Di-Lepton

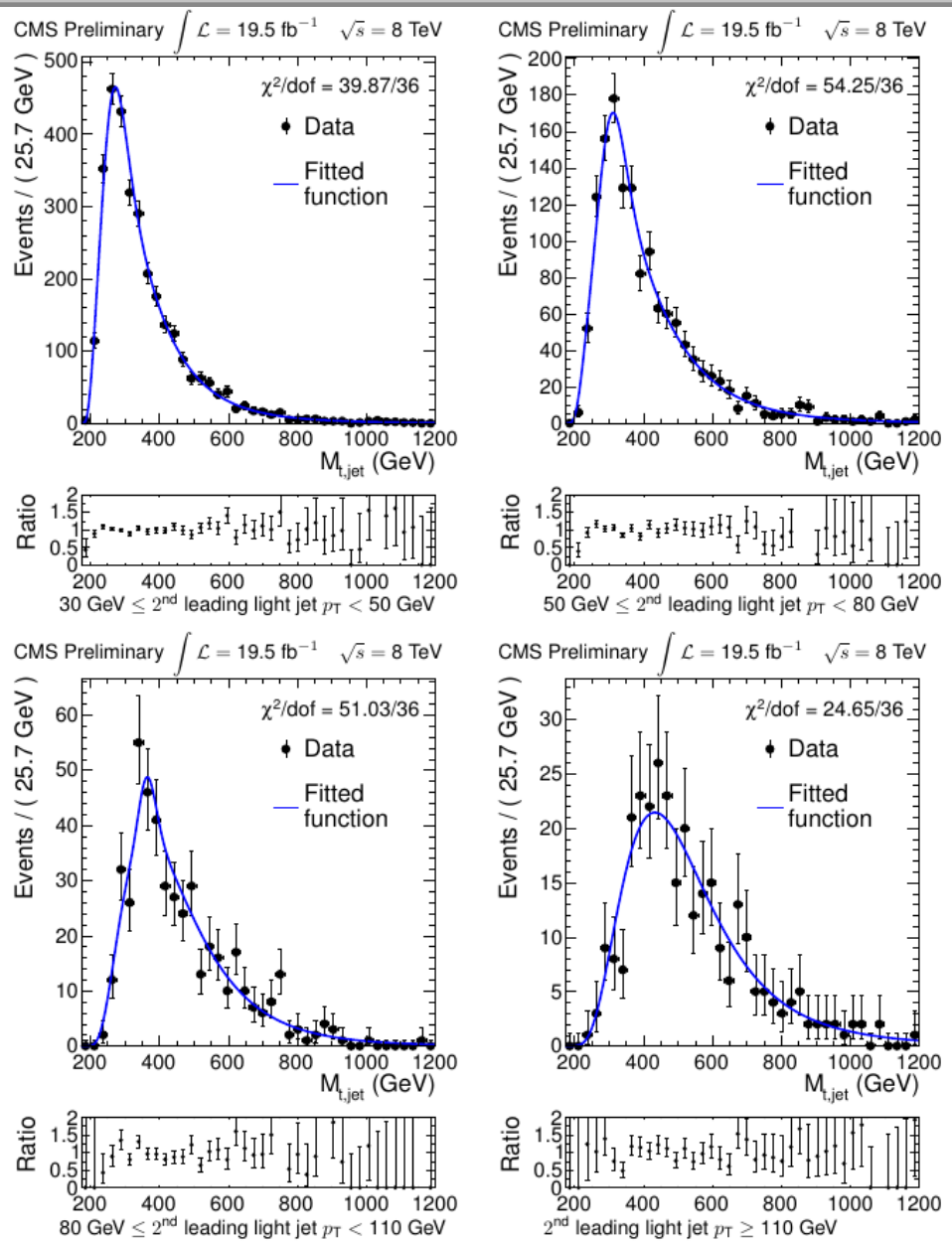
Parametrize $M_{t,jet}$ shape with fit function in bins of 2nd jet p_T

Perform 3D likelihood fit of:

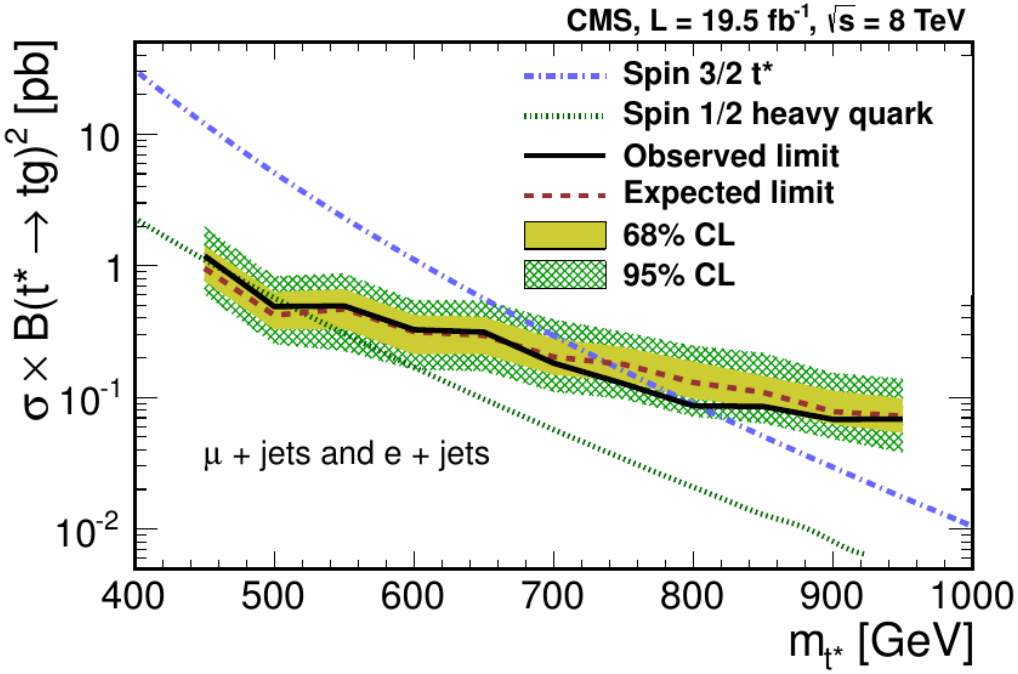
- $M_{t,jet}$
- p_T of leading jet
- p_T of 2nd leading jet

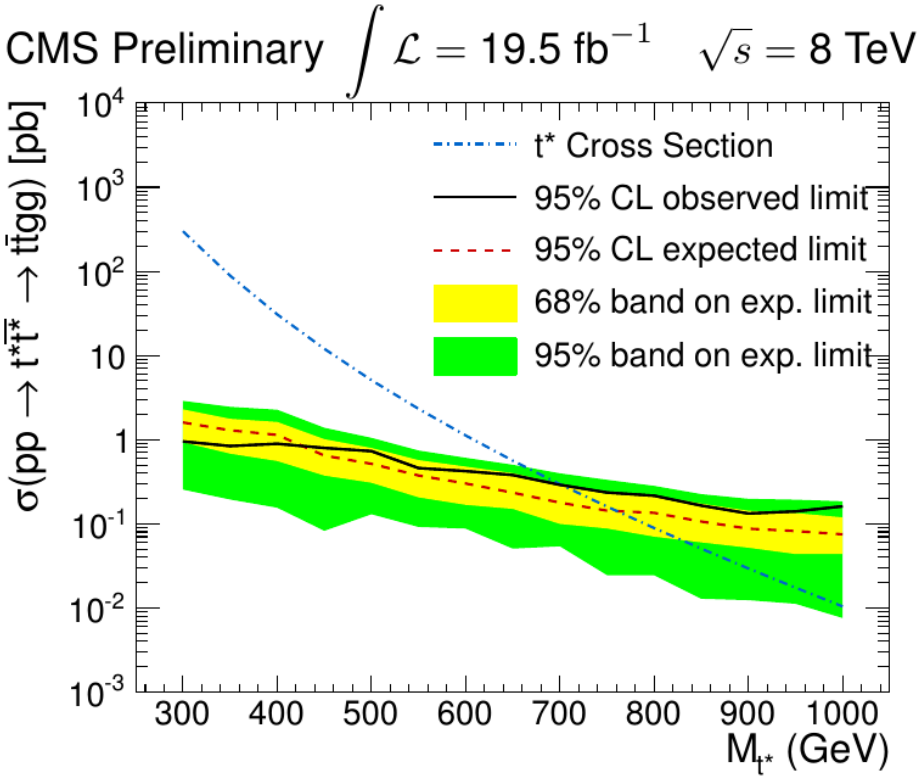
Also no significant excess seen

→ set limits on t* signal



Limits





- **Lepton+jets:** spin 3/2: exclude $m_{t^*} < 803$ GeV (739 GeV expected)
  spin 1/2: excl. $465 < m_{t^*} < 512$ GeV ($m_{t^*} < 521$ GeV)
- **Di-lepton:** spin 3/2: exclude $m_{t^*} < 703$ GeV (763 GeV)
  Sbottom: $m_b < 326$ GeV (298 GeV)

Conclusion

- Top quark sector candidate for new physics searches
- Rich program ongoing at CMS in beyond-2nd-generation group
- Presented two exemplary analyses on resonances in $t\bar{t}$ production
- No hint for new physics in top quark pair production at CMS, yet