New Physics Signatures from Early LHC Single Top Production

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Why Top Quarks?

- Natural new physics models *always* have non-trivial couplings between tops and new physics: Higgsless, LH, RS, SUSY, TC, ...

- 163,000 top quark pairs and 76,000 single top events produced during the 7 TeV, 1 fb^{-1} LHC run.

2

Why Top Quarks?

- QCD corrections to top quark production known beyond leading order!

  E. Laenen, J. Smith, W. L. van Neerven, Nucl. Phys. **B369**,
  E. L. Berger, H. Contopanagos, Phys. Rev. **D54**,
  M. Cacciari, S. Frixione, M. L. Mangano, *et al.*, JHEP **0809**,
  M. Smith, S. Willenbrock, Phys. Rev. **D54**,
  G. Bordes, B. van Eijk, Nucl. Phys. **B435**,
  J.Campbell, R.K.Ellis, Phys. Rev. **D70** ... (much more)

- Top (or top pair) decays with an isolated lepton in the final state is an efficient tag (84-92%).

  ATLAS and CMS TDRs,
  Barger, Han and Walker, Phys. Rev. Lett., **100**,...

Earliest Signatures of New Physics
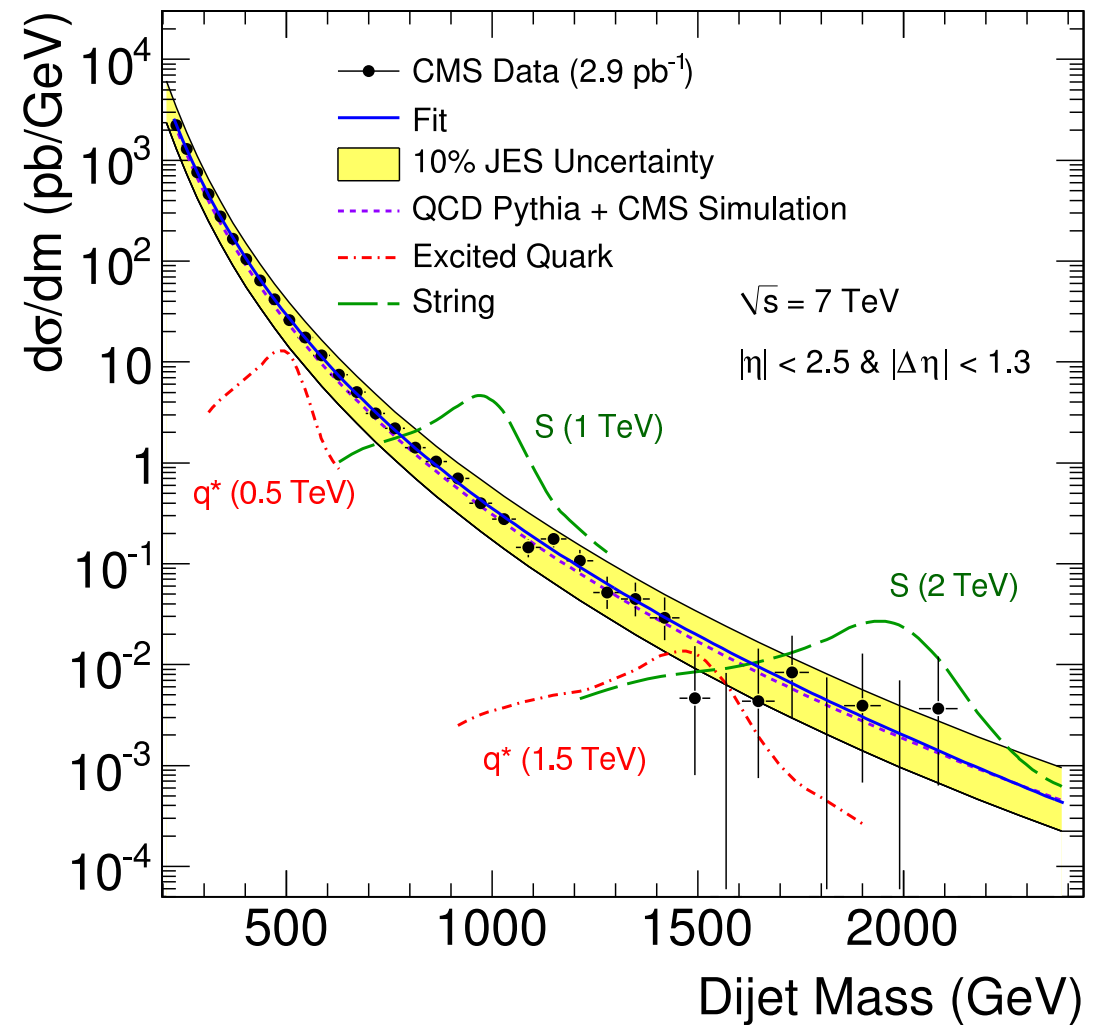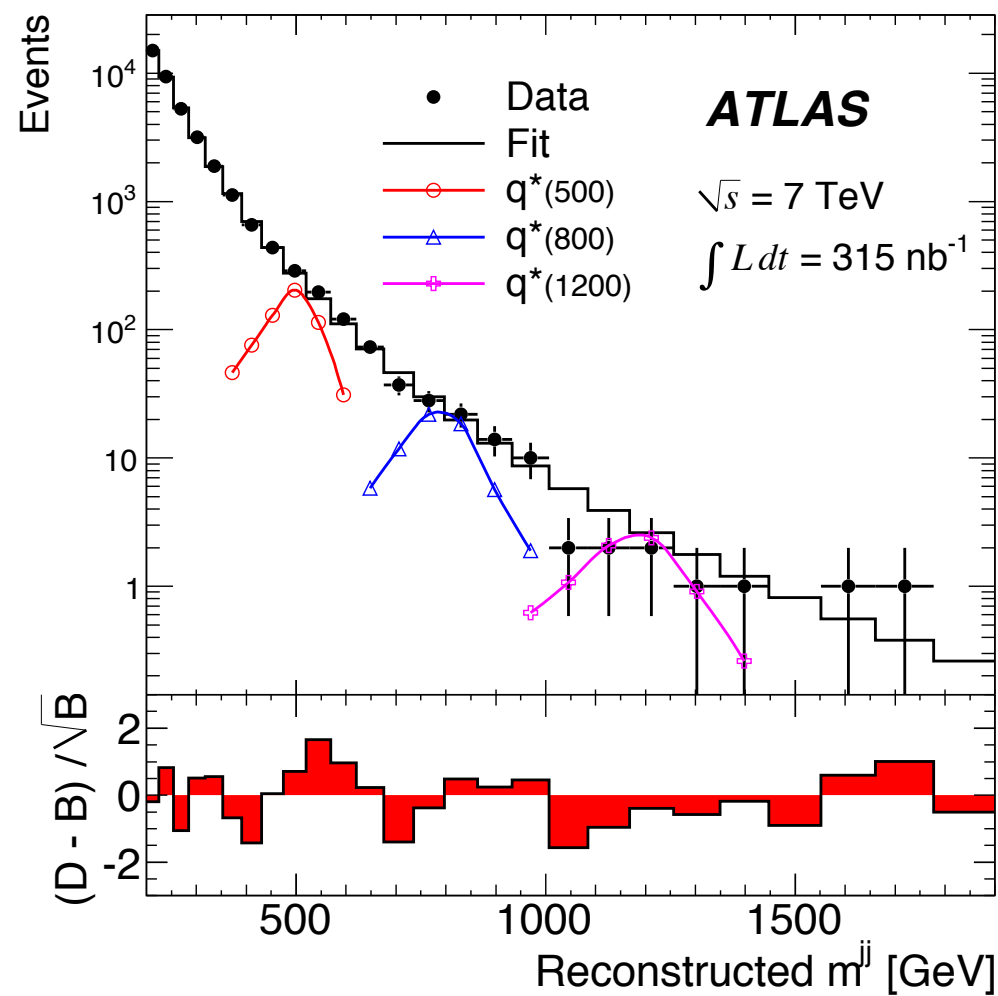
Dijet Invariant Mass Distributions

- Excess number of events above background at high invariant mass.

Plan

- Search for contact operators with invariant mass distributions involving top quarks.

- Today: Focus on single top production.

- Reiterate:

  Backgrounds known beyond leading order.
  Impact electroweak model building.
  Probe events at highest scales.

5

Related Research Efforts

- "Simplified models" for early discovery at LHC

  Bauer, Ligeti, Schmaltz, Thaler and Walker, Phys.Lett. **B690**,
  Barbieri and Torre, Phys.Lett. **B695**,
  Barger, Han, Walker, Phys.Rev.Lett. **100**,
  Schmaltz, Spethman, arXiv:1011.5918 [hep-ph], ...

  SLAC Topologies '10 Workshop: Wacker, Listani, Toro, Tait, Essig,
  Schuster...

- Colored resonances searches with dijets.

  Han, Lewis, Liu, JHEP, **1012**, 085...
  Zhang, Berger, Cao, Chen, Shaughnessy, Phys. Lett. Rev. **105**

6

Similar Research Efforts

- ## Single Top papers
  (not for new physics @ early LHC)

  Tait and Yuan, Phys. Rev. **D63**, 014018
  Gopalakrishna, Han, Lewis, Si and Zhou, Phys. Rev., **D82**,
  Barger, McCaskey, Shaughnessy, Phys. Rev., **D81**, ...

  Schwienhorst, Cao, Yuan and Mueller, arXiv:1012.5132 [hep-ph]
  Alioli, Nason, Oleari, JHEP **0909**, 111, ...

- ## Single top early LHC studies

  Etesami, M. Mohammadi Najafabadi, Phys. Rev. **D81**,
  (SM production of single tops with FCNC couplings)

Similar Research Efforts

- ## Single Top papers
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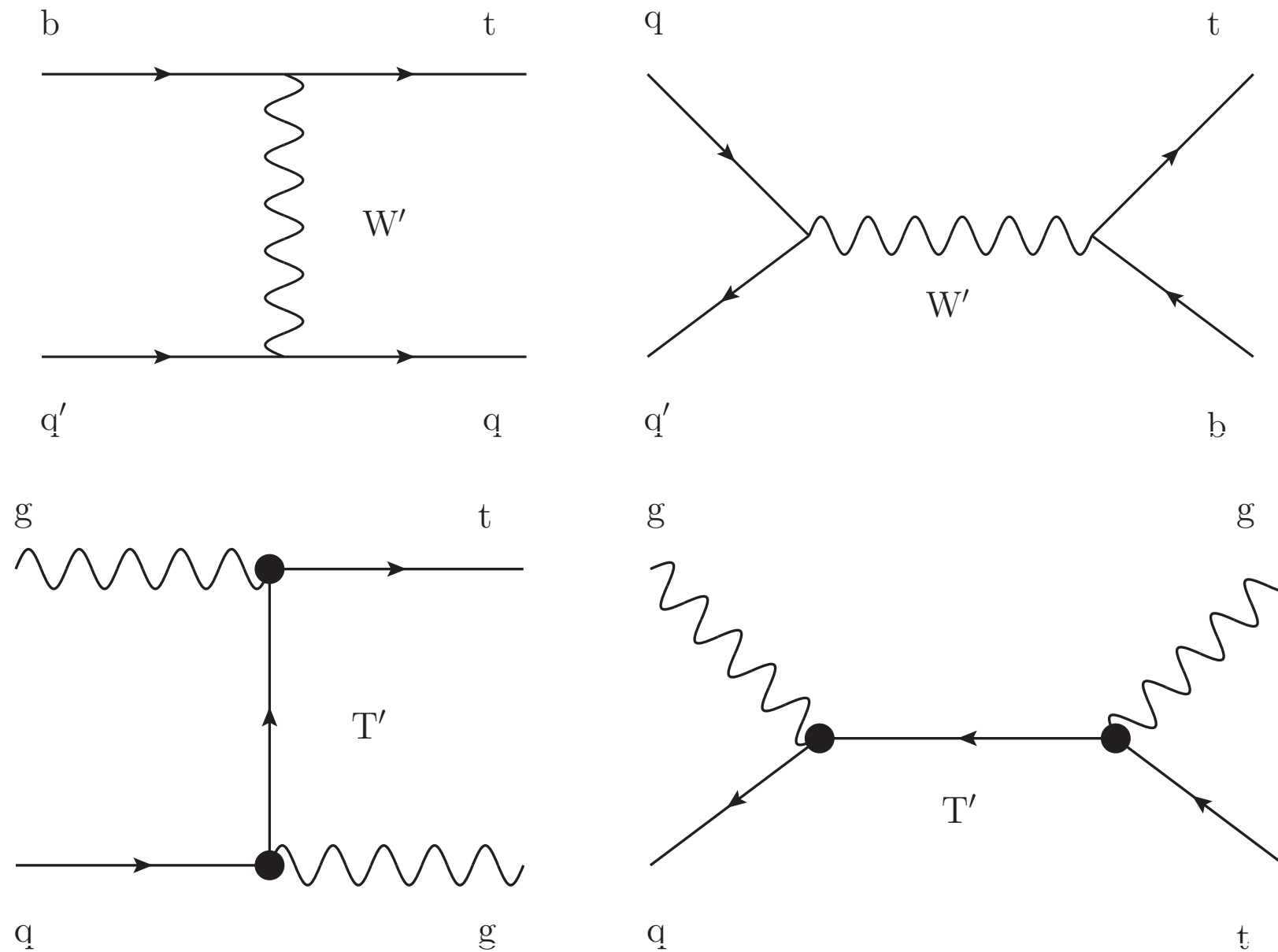- ## Single top early LHC studies

  Etesami, M. Mohammadi Najafabadi, Phys. Rev. **D81**,
  (SM production of single tops with FCNC couplings)

  This work: Model independent search
  to maximize reach to the highest scales.
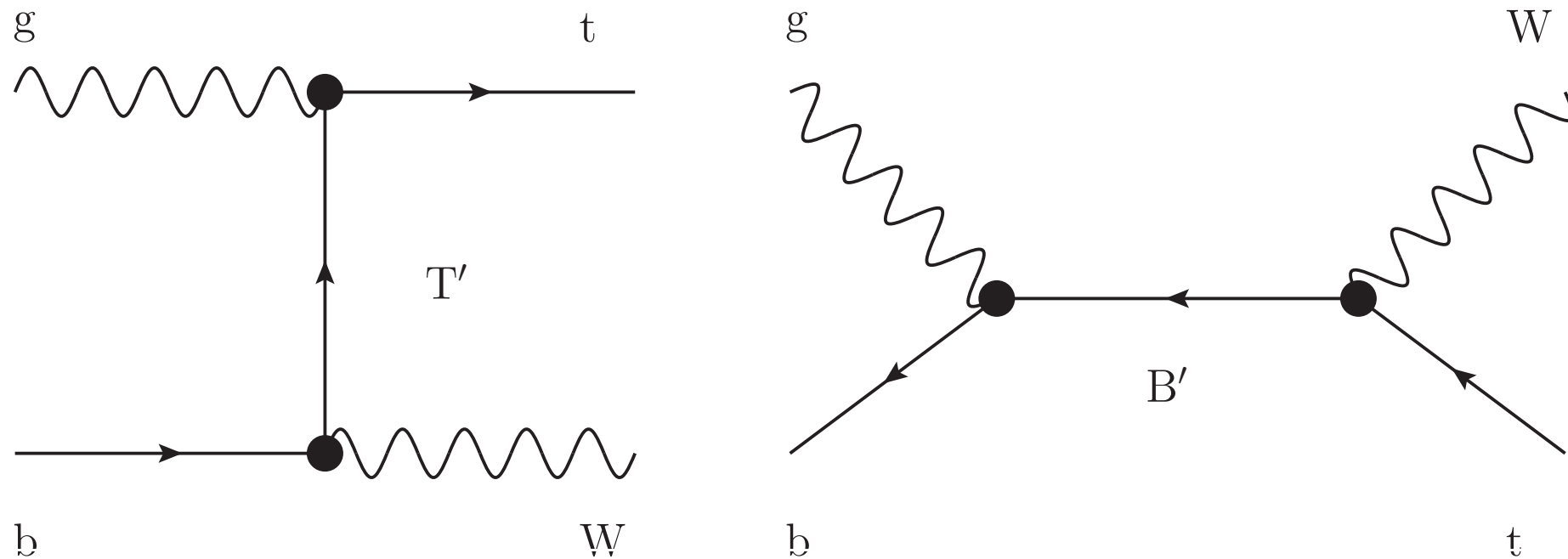
  (fermionic/bosonic resonances)

Single Top + Jet Final States

(b-tagging will be applied in later analysis.)
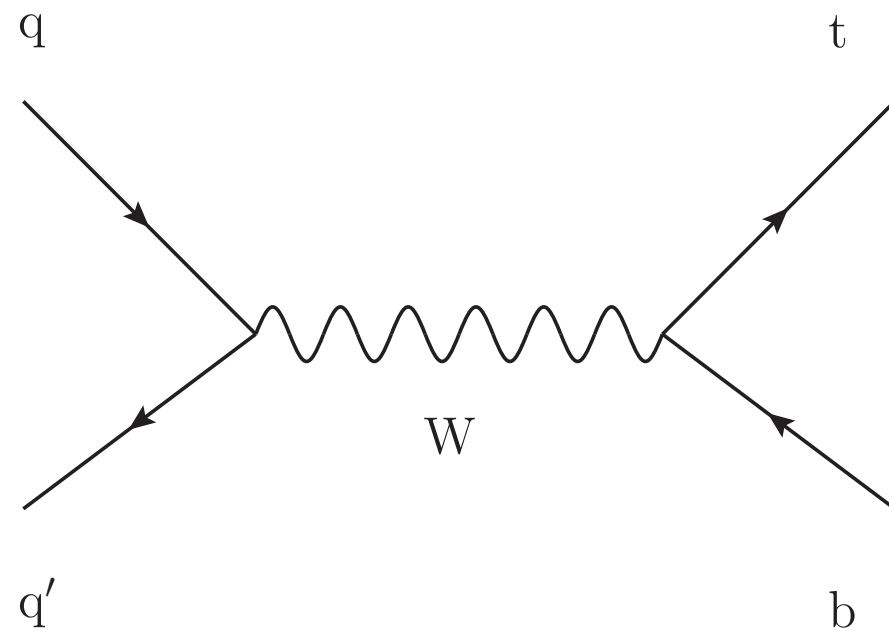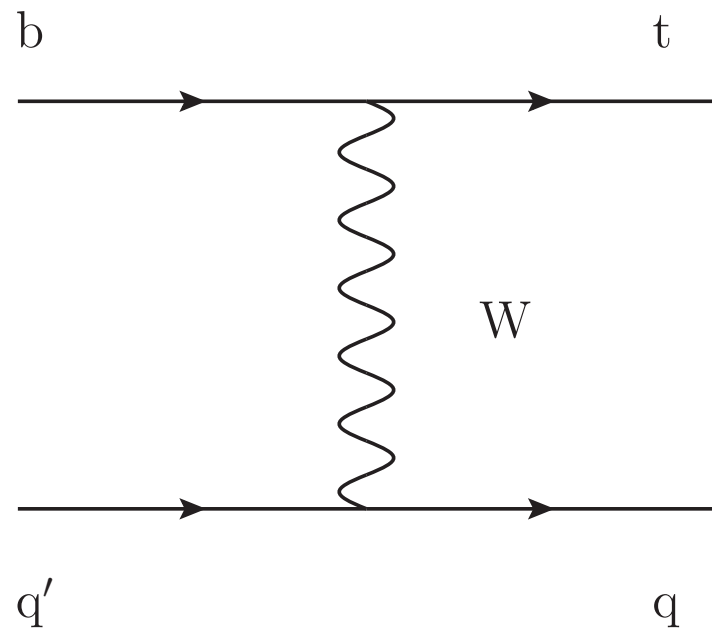
- Today: Probe W's and excited T's.

8

Single Top + W Final States

(b-tagging will be applied in later analysis.)

- **Today:** Excited T's and B's.

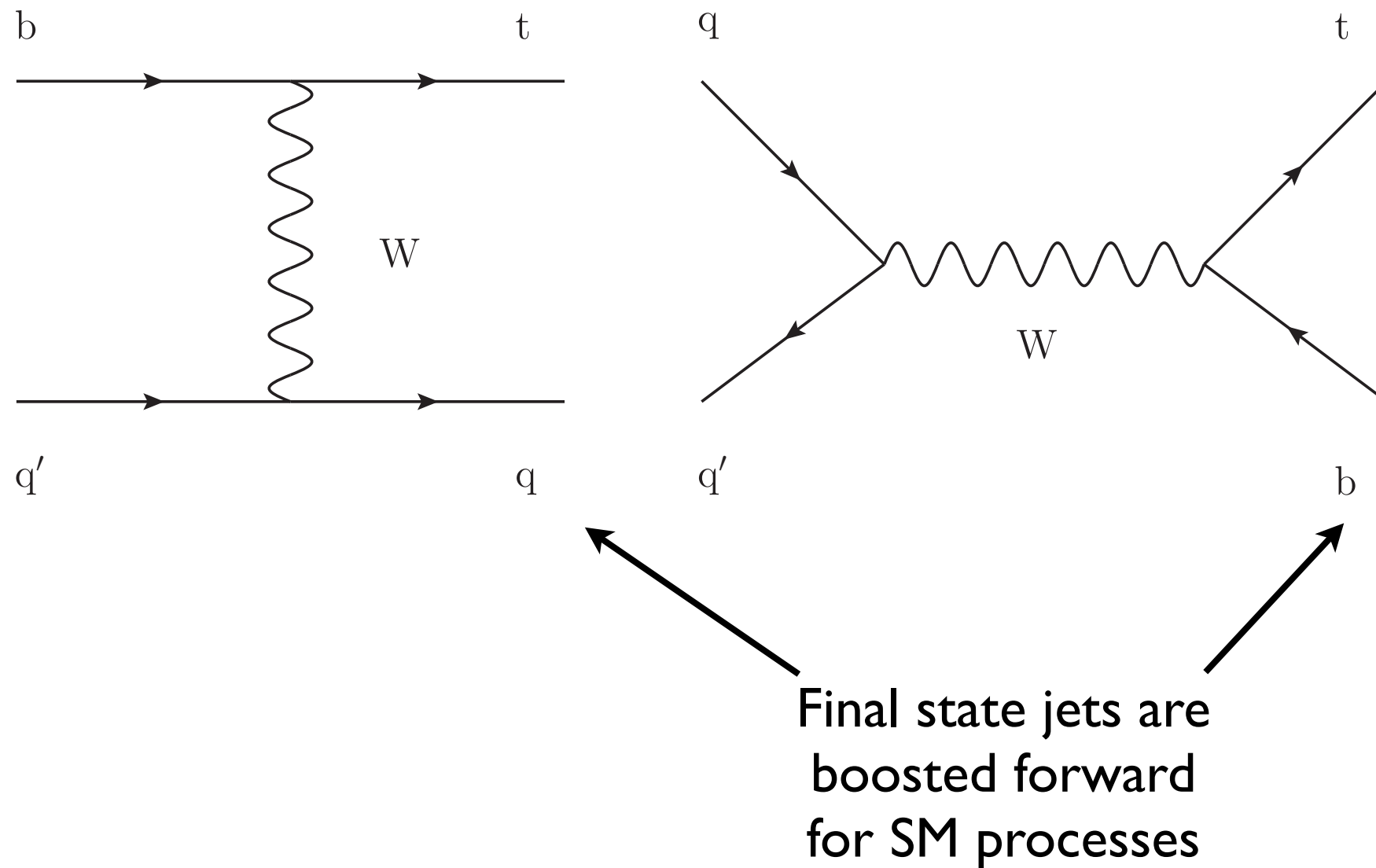- More final states w/top possible. Corresponds to different physics to probe.

9

Why Single Top is Good for New Physics Searches
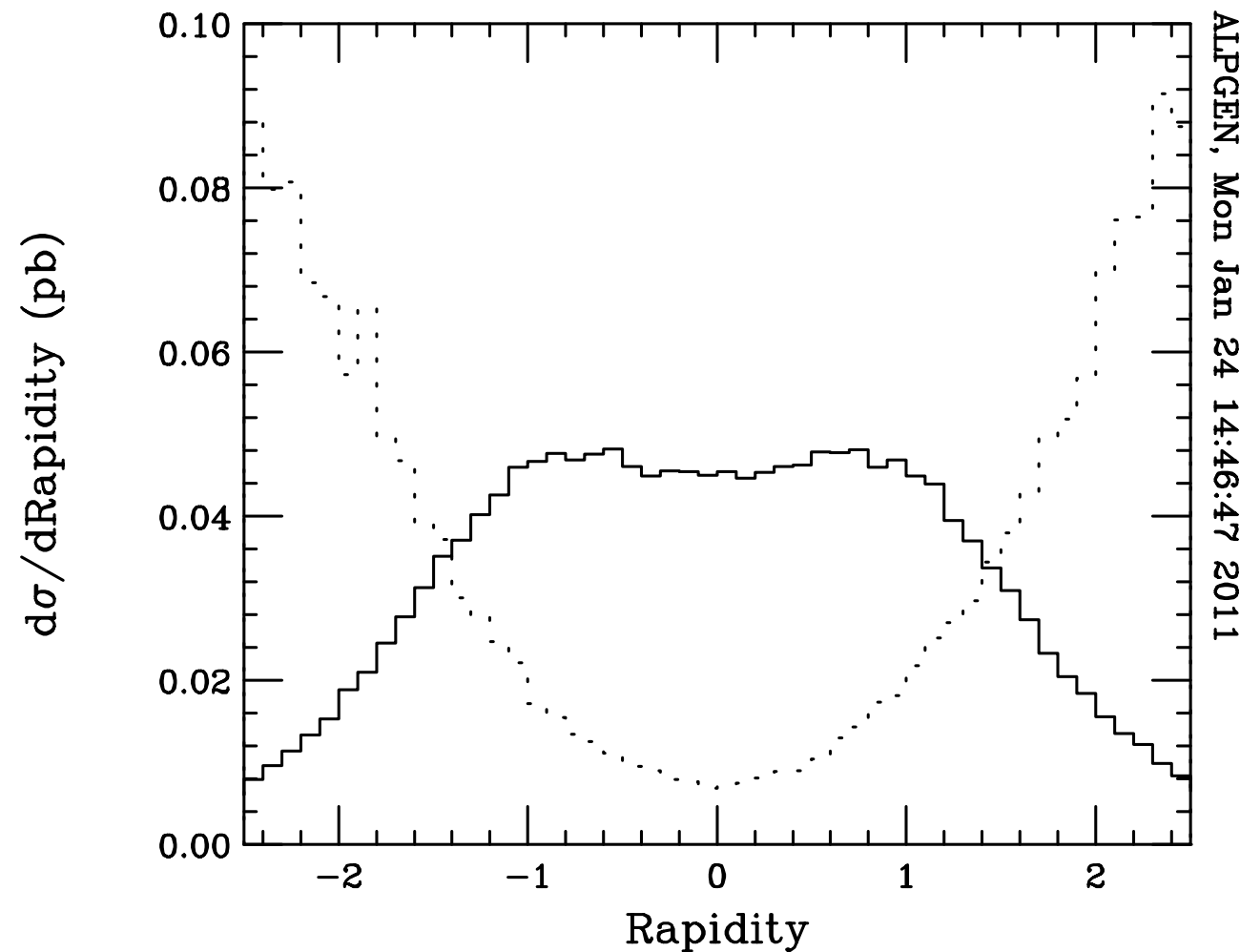
Why Single Top is Good for New Physics Searches

Final state jets are boosted forward for SM processes

Why Single Top is Good for New Physics Searches
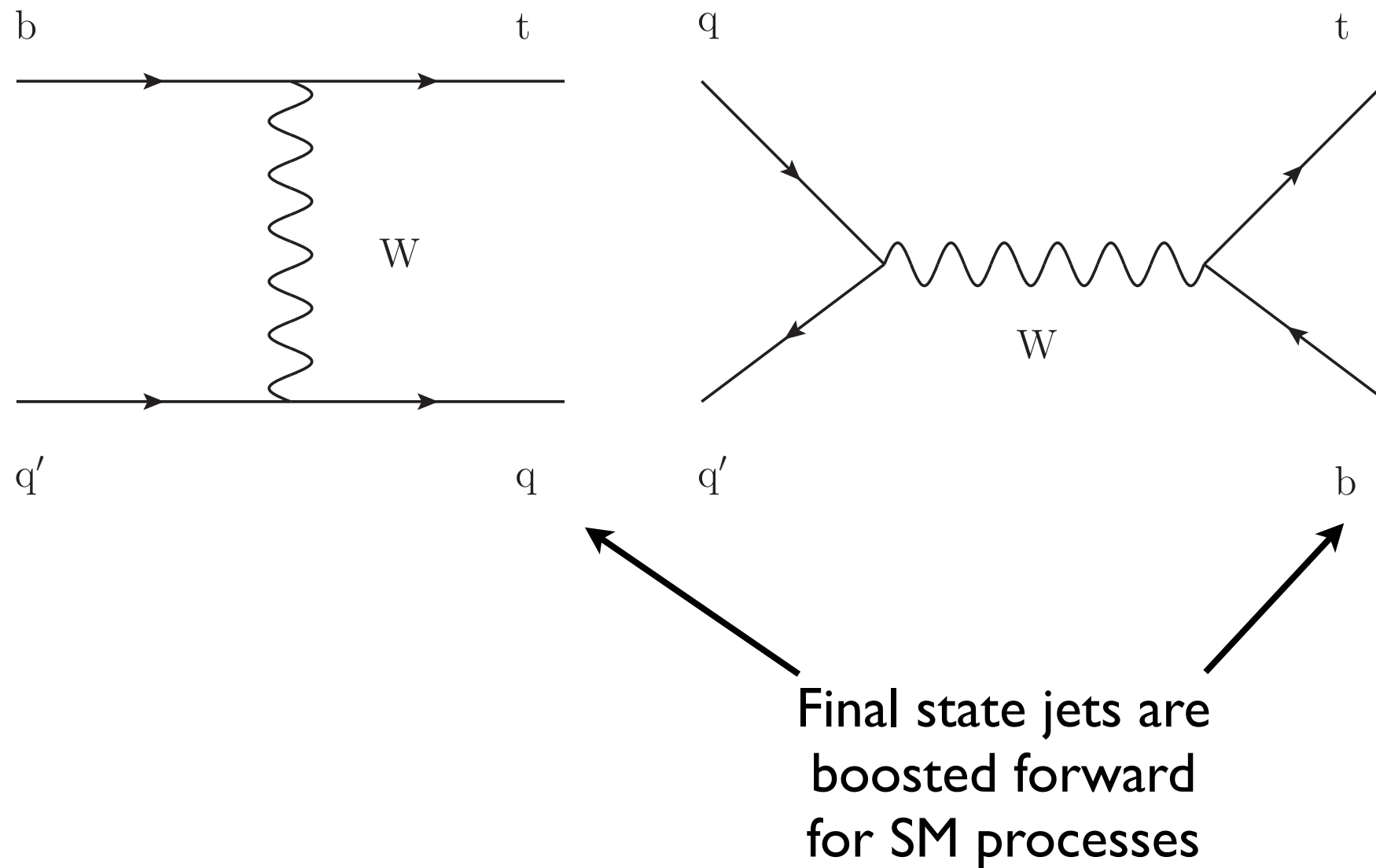
Final state jets are boosted forward for SM processes

- Signal jets are central.

Why Single Top is Good for New Physics Searches

SM single top production: Jet not associated with top (dotted)
1.5 TeV W' signal x 10: Jet not associated with top (solid)

- Can potentially see new physics before SM single top observation!

11

Rest of the Talk

- Current Bounds on B', T' and W'.

- Top + X Backgrounds

  - Event Selection
    (minimize the backgrounds)

- Preliminary Results

- Future Efforts

12

Bounds on B', T' and W's

Current Bounds on W'

- Benchmarks: TeVatron direct searches.

$$m_{W'} > 1.1 \text{ TeV}$$

(CDF result: LR Symmetric Model. W' decay to e nu.)

$$m_{W'} > 690 \text{ GeV}$$
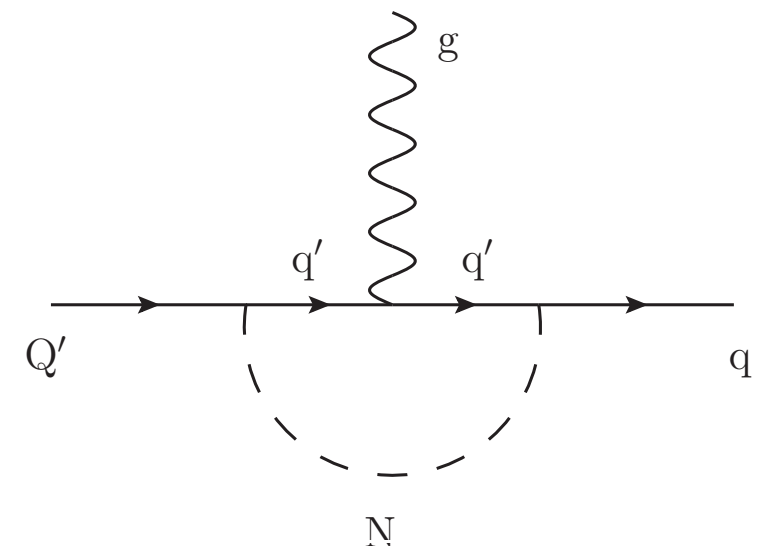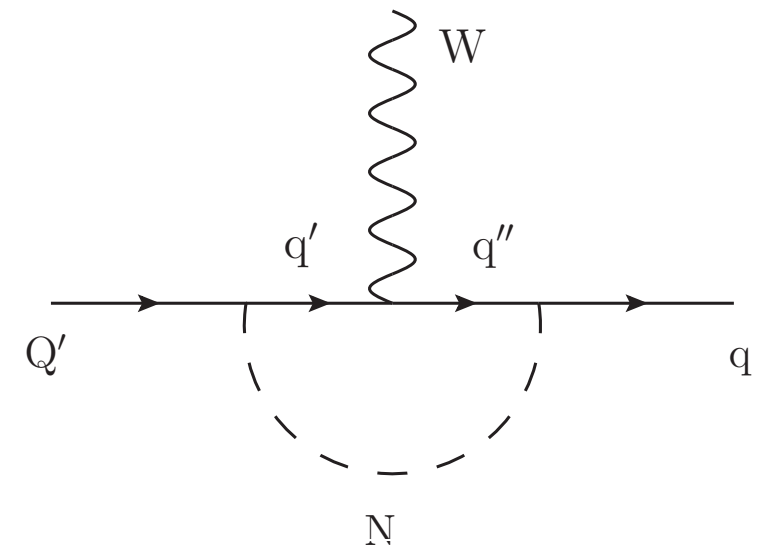
(D0 result: Sequential SM.)

- Aim for the current analysis to place stronger bounds.

14

B' and T' Couplings

- Excited B' and T' couplings from effective operators:

$$\mathcal{O}_1 = \frac{g_s \lambda^2}{16\,\pi^2}\,\frac{1}{\Lambda}\,\overline{Q}'\,\sigma^{\mu\nu}\,\frac{\lambda^a}{2}\,G_{\mu\nu}\,q_L$$

$$m_{W'} > 1.1 \text{ TeV}$$

$$\mathcal{O}_1 = \frac{y_s}{4\Lambda_1}\,\overline{Q}'\,\sigma^{\mu\nu}$$

$$\mathcal{O}_1 = \frac{g_s}{4\Lambda_1}\,\overline{Q}'\,\sigma^{\mu\nu}\,\lambda^a\,G_{\mu\nu}\,q_L$$

$$\mathcal{O}_2 = \frac{g_s \lambda^2}{16\,\pi^2}\,\frac{1}{\Lambda}\,\overline{Q}'\,\sigma^{\mu\nu}\,\frac{\vec{\tau}}{2}\,W_{\mu\nu}\,q_L$$

$$\mathcal{O}_2 = \frac{g}{4\Lambda_2}\,\overline{Q}'\,\sigma^{\mu\nu}\,\vec{\tau}\,W_{\mu\nu}\,q_L$$

$$\mathcal{O}_2 = \frac{g}{4\Lambda_2}\,\overline{Q}'\,\sigma^{\mu\nu}$$

$$m_{W'} > 1.1 \text{ TeV}$$

$$\mathcal{O}_1 = \frac{y_s}{4\Lambda_1}\,\overline{Q}'\,\sigma^{\mu\nu}$$

- Assume: Strong/colored physics generates effective operators. Negates loop suppression.

$$\mathcal{O}_1 = \frac{g_s}{4\Lambda_1}\,\overline{Q}'\,\sigma^{\mu\nu}\,\lambda^a\,G_{\mu\nu}\,q_L \longrightarrow 4\pi$$

$$\mathcal{O}_2 = \frac{g}{4\Lambda_2}\,\overline{Q}'\,\sigma^{\mu\nu}$$

$$\mathcal{O}_2 = \frac{g}{4\Lambda_2}\,\overline{Q}'\,\sigma^{\mu\nu}\,\vec{\tau}\,W_{\mu\nu}\,q_L$$

15

B' and T' Bounds

- Direct stringent bounds on the mass of exited quarks from ATLAS and CMS.

$$m_{q^*} > 1.26 \text{ TeV} \qquad m_{q^*} > 1.58 \text{ TeV}$$

ATLAS

Phys. Rev. Lett. **105**:161801

CMS

Phys. Rev. Lett. **105**:211801

- Conventional to set suppression scale to: $\Lambda = 2\, m_{q^*}$

Baur, Hinchliffe, and Zeppenfeld, Int. J. Mod. Phys. **A2**, 1285

16

Top + X Backgrounds

SM Backgrounds

- *Always* require: Top decays to a final state with lepton.

top + jet signal | top + W signal

W + jets   top + W

W+ b bar   top + jets

top + b bar   t tbar

(All backgrounds Alpgen and Madgraph simulated.)

Event Selection

- Require: All background and signal events reconstruct to a single top.
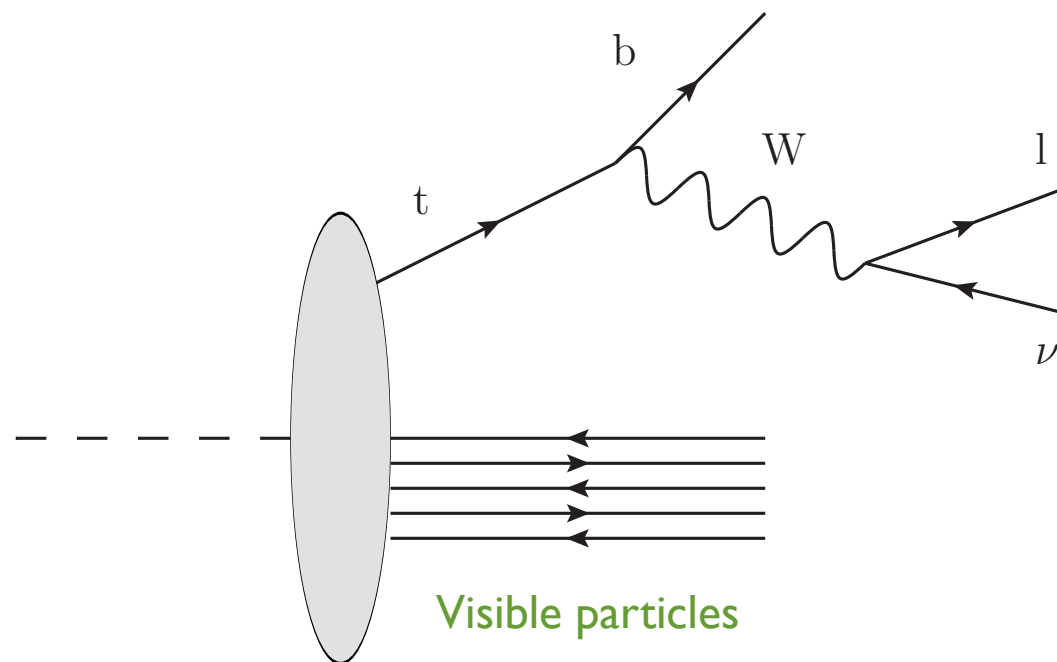
Fully reconstructable system: Use W and top mass.

Accepted reconstructed W and top masses:

$$m_W = 80.4 \pm 2 \text{ GeV} \ \text{(reconstructed)}$$

$$m_t = 172 \pm 5 \text{ GeV} \ \text{(reconstructed)}$$

- Severely reduces W + jet, etc... backgrounds

19

Event Selection

- Require: All leptons and jets separated.

$$\Delta R_{lj} > 0.4 \qquad \Delta R_{jj} > 0.4$$

- Define and implement:

$$M_T = \left(\left(\sum_i p_i \right)^2 + \not{E}_T{}^2 \right)^{1/2} + \not{E}_T > 600 \text{ GeV}$$

Forces tops to be boosted.

- On average: Jet resulting from top decay is closest to lepton.

20

Event Selection

- Require: Simulated calorimetry response with Gaussian smearing:

$$\frac{\Delta E_e}{E_e} = \frac{10\%}{\sqrt{E_e(\text{GeV})}} \oplus 0.7\% \qquad \frac{\Delta E_j}{E_j} = \frac{50\%}{\sqrt{E_j(\text{GeV})}} \oplus 3\%$$

ATLAS and CMS TDRs.

- Simplicity: Do not separately "smear" muons.

Event Selection

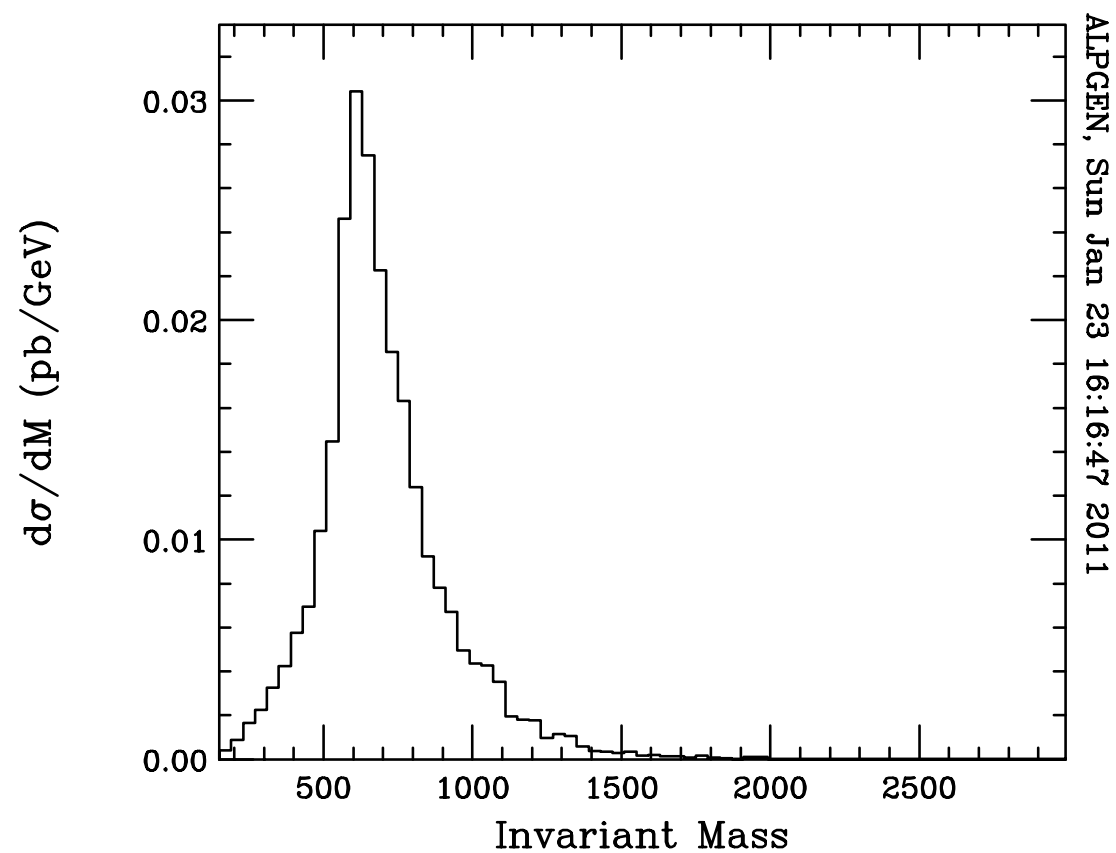- To minimize SM top + jet: $|\eta_{\text{non-top jet}}| < 1.5$
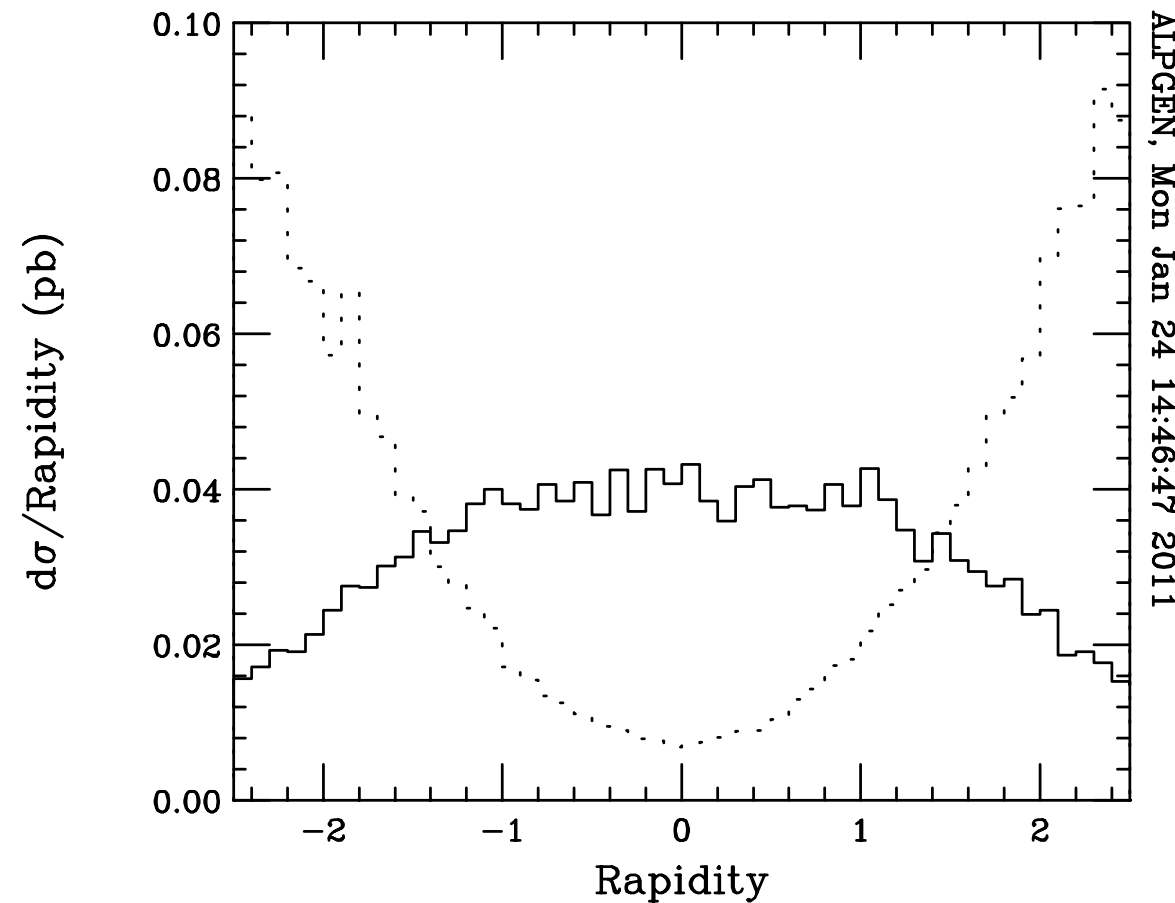
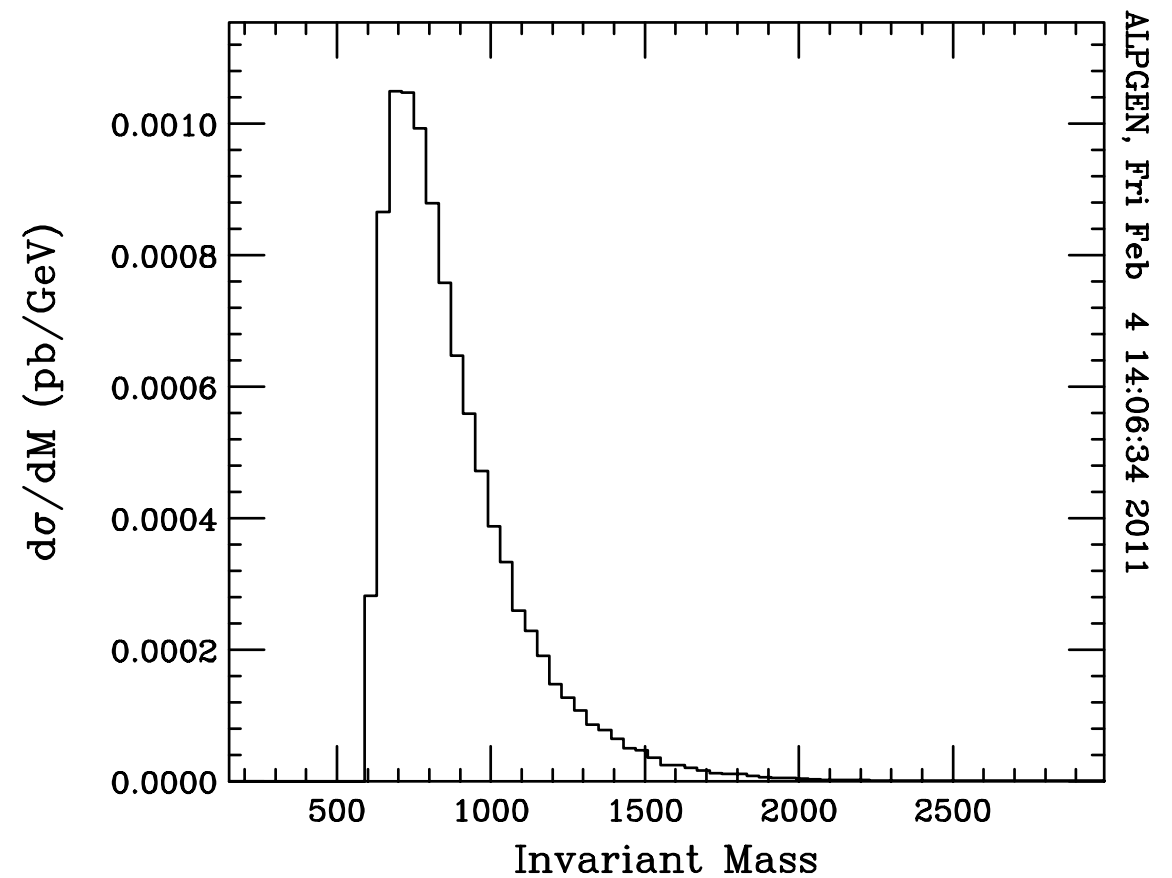SM single top production: Jet not associated with top (dotted)
b-jet from top decay (solid)

- Others: $|\eta_{\text{lepton}}| < 2.5$ $\qquad |\eta_{\text{other jets}}| < 2.5$

22

Backgrounds w/Cuts

top + jets backgrounds with
all cuts and top reconstruction
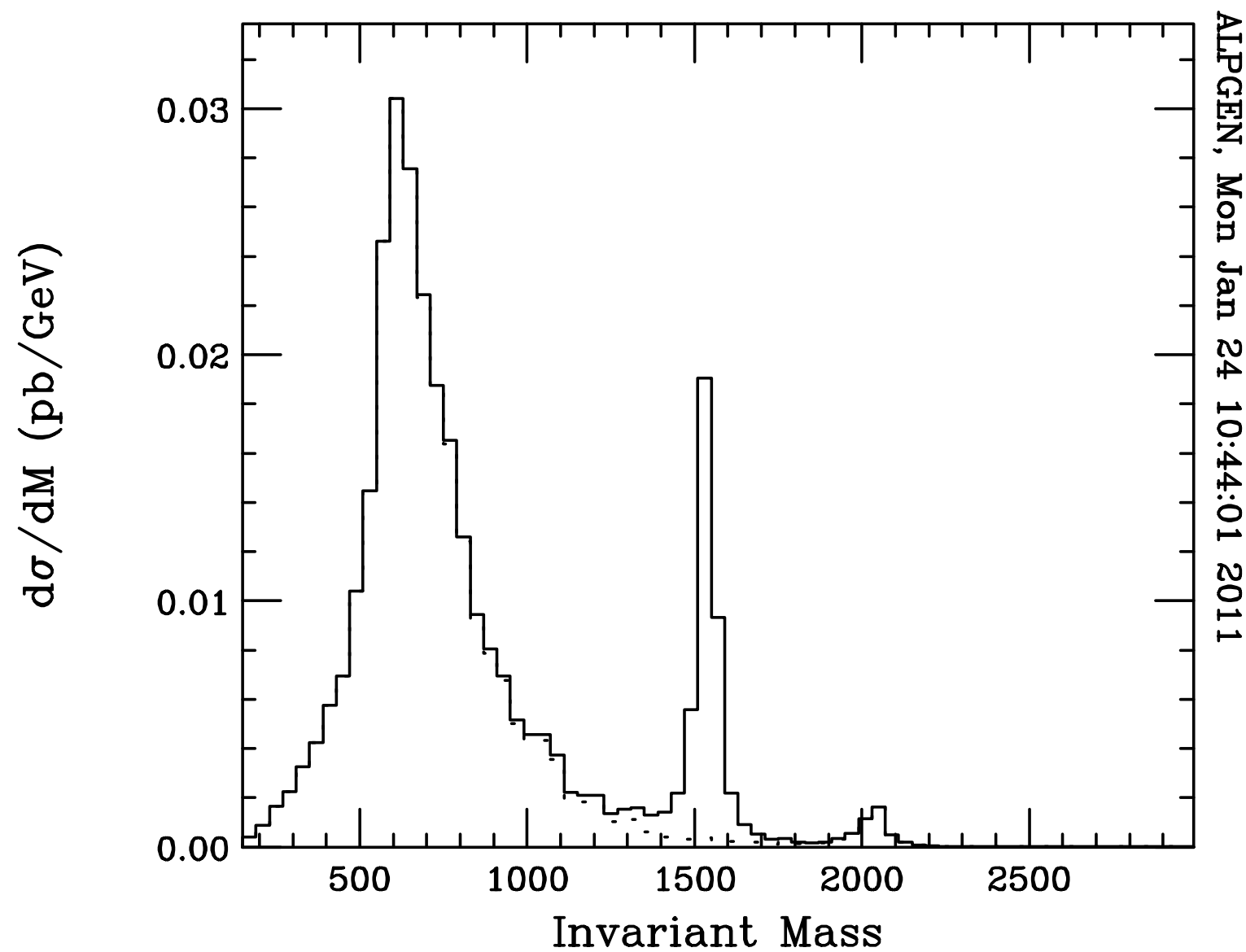
top + W with all cuts, W
and top reconstruction

7 TeV COM, CTEQ 5L PDFs

Thursday, February 17, 2011

Preliminary Results
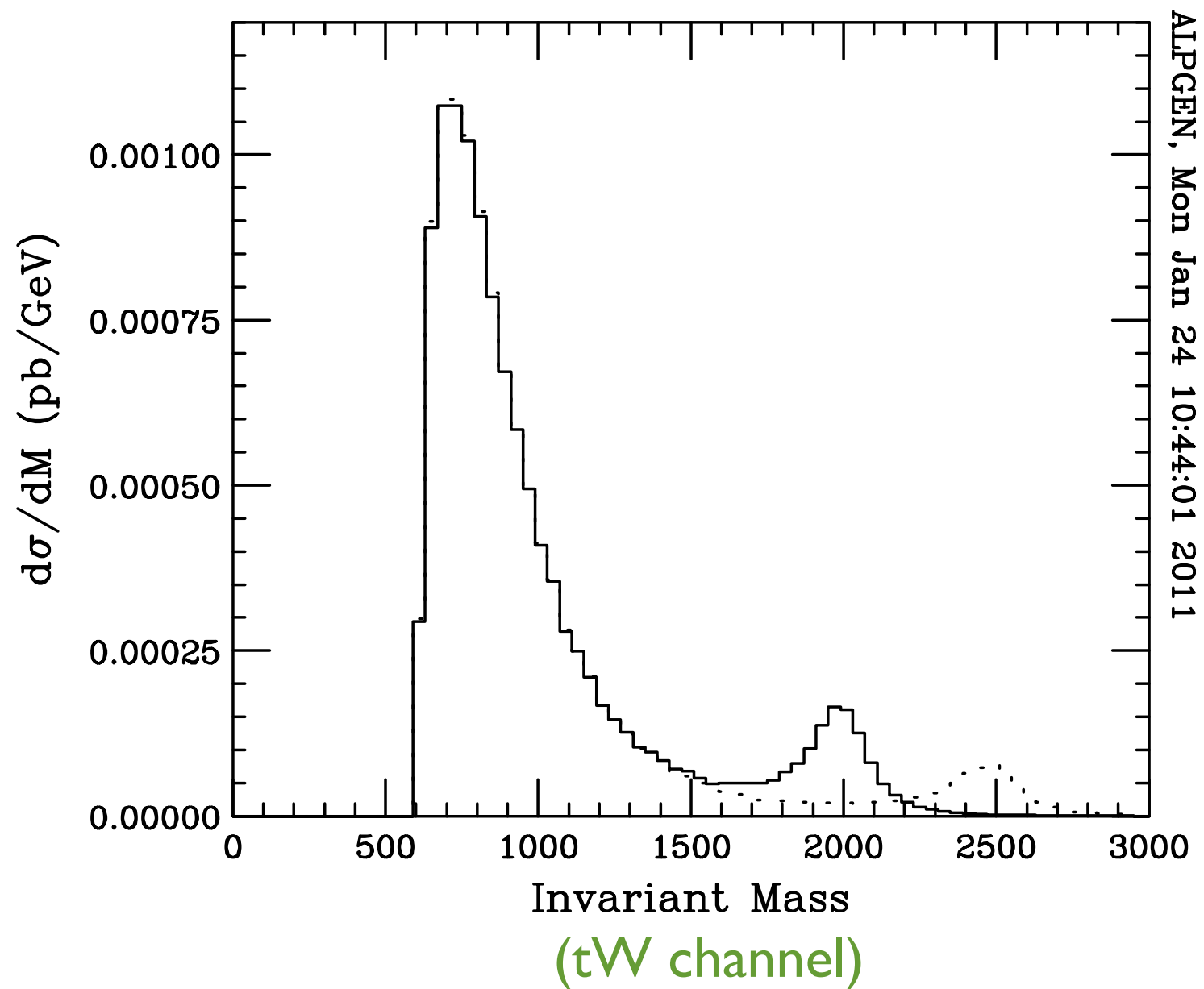
W' Results

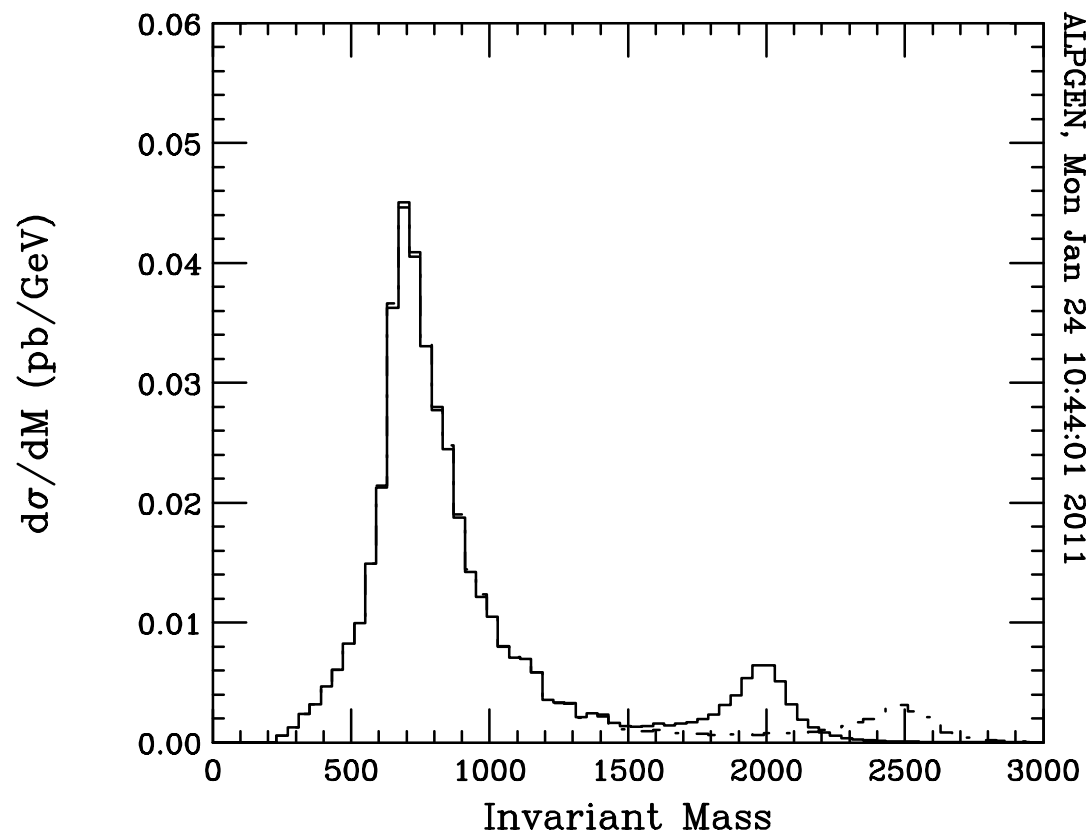Sequential W' at 1.5 and 2 TeV

7 TeV COM, CTEQ 5L PDFs

Future work: Relaxation of M_T cut can potentially extend reach.
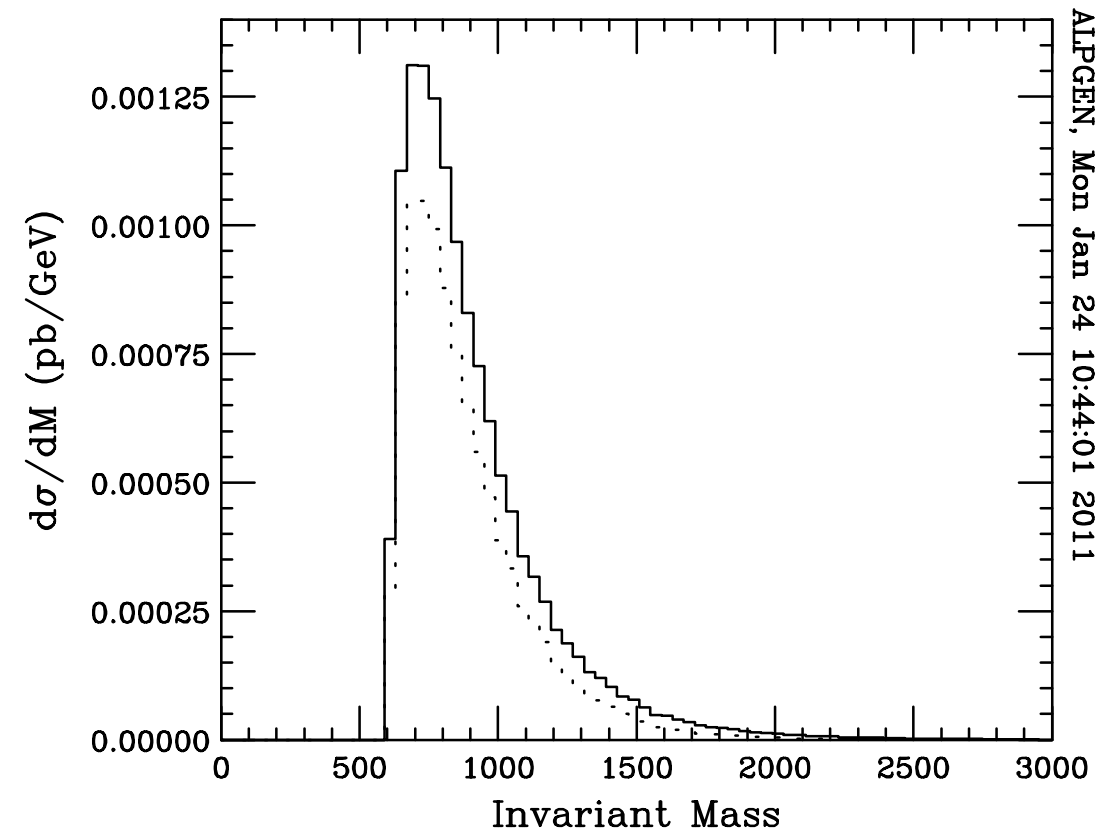
25

B' Preliminary Results

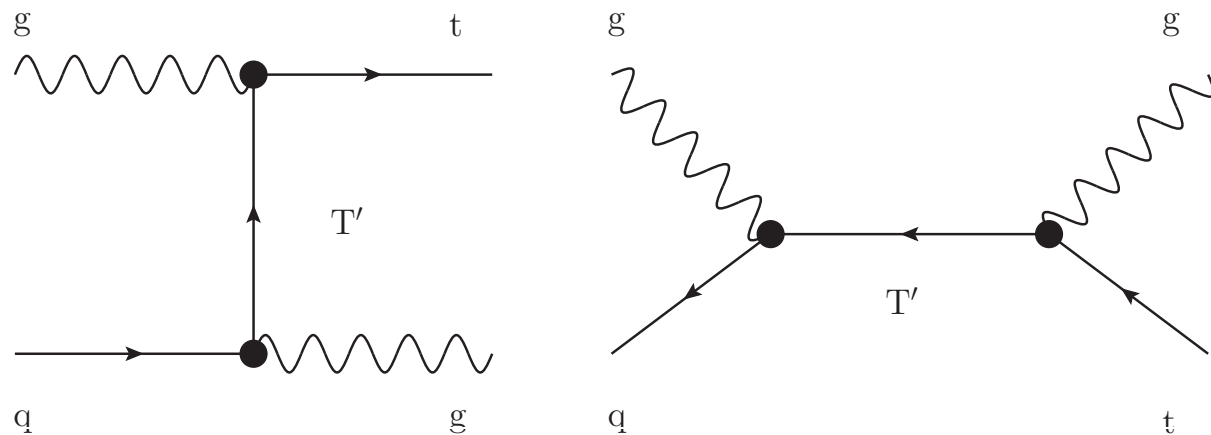B' excited quark at 2 and 2.5 TeV

(tW channel)
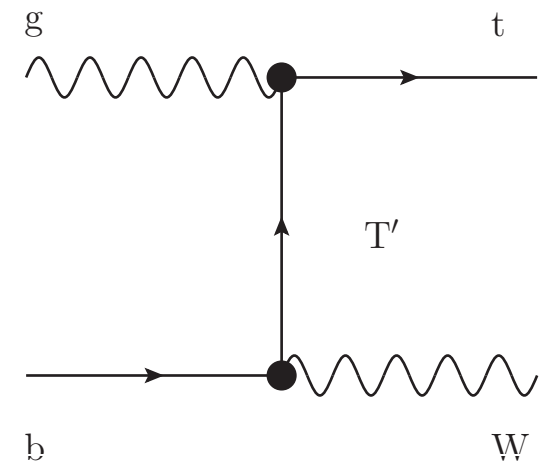
26

Thursday, February 17, 2011

T' Preliminary Results

2 and 2.5 TeV Excited T' (t + jet channel)

2 TeV Excited T' (tW channel)

27

Future Directions

Future Directions

- Count events of single top + large missing energy.

  - Tag: Events for poor top reconstruction.

  - Probes SUSY scenarios.

  Han, Mahbubani, Walker, Wang, JHEP **0905**:117

- Apply b-tagging and additional techniques used in dijet searches such as angular distributions.

Conclusion

Because of high tagging efficiency and known backgrounds, single tops can be used to aggressively probe a variety of new physics beyond the SM.
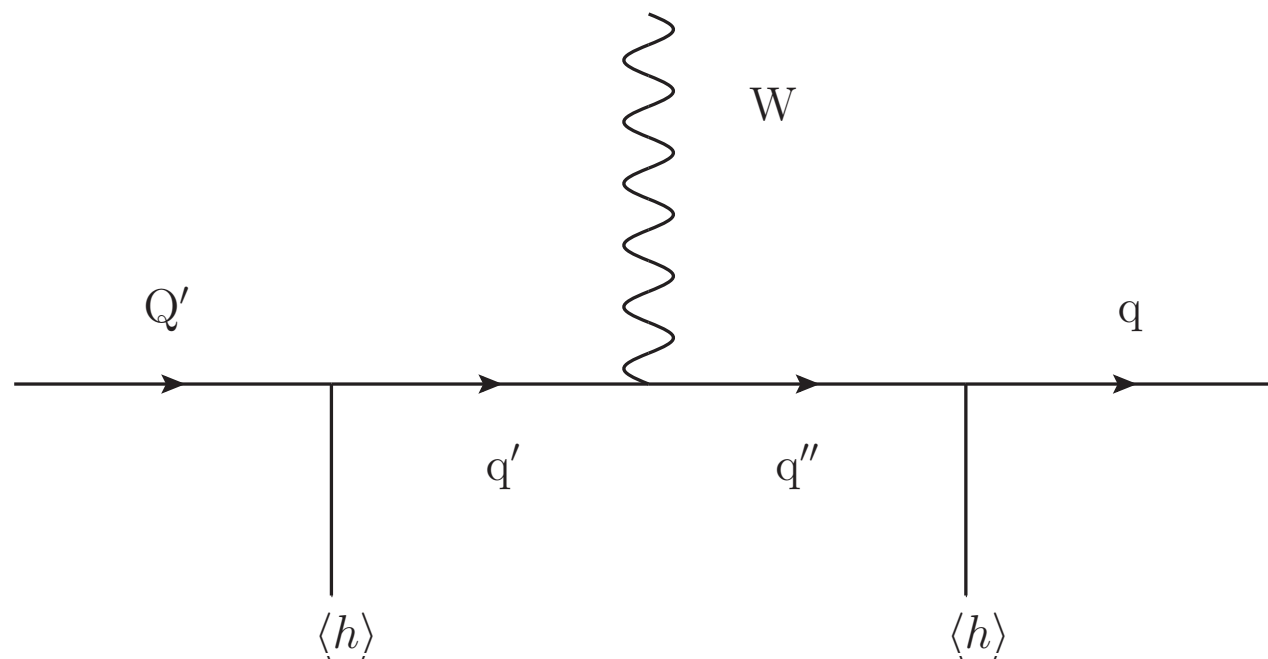
Thank you to the organizers for
an excellent conference!

Additional Slides

B' and T' Couplings

- Excited B' and T' couplings from effective operators:

$$\mathcal{O}_3 = \frac{g_s\,\lambda^2}{2}\,\frac{v^2}{M_{q'}^3}\,\overline{Q}'\,\sigma^{\mu\nu}\,\vec{\tau}\,W_{\mu\nu}\,q_L$$

$$\lambda \to 4\pi\,\lambda$$

Current Bounds on W'

- Suggest: If no observation of W', ATLAS and CMS expresses the bound in ratio of $g/m_{W'}$

$$\mathcal{O}_{W'} = \frac{g^2}{m_{W'}^2} \left(b_L^c \, \sigma^\mu \, t_L \right) \left(q_L^c \, \sigma_\mu \, q' \right)$$

$$m_{W'} > 1.1 \text{ TeV}$$

(CDF result: LR Symmetric Model. W' decay to e nu.)

$$m_{W'} > 690 \text{ GeV}$$

(D0 result: Sequential SM.)