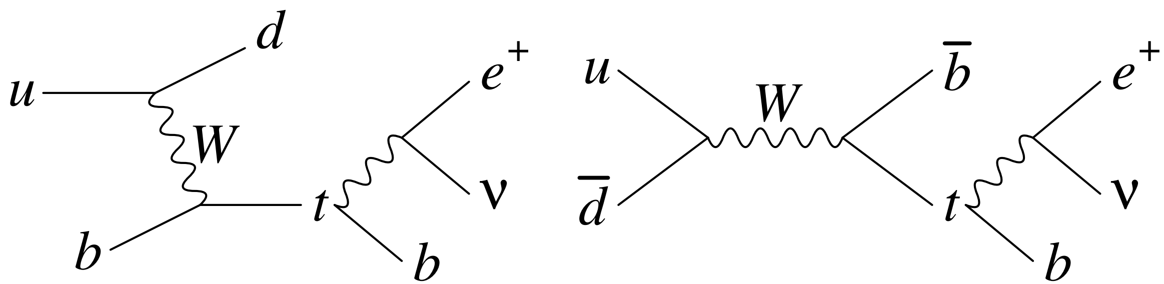
Complete angular correlations in single-top-quark and Wjj at NLO

hep-ph/0510224, submitted to Phys. Rev. D



Zack Sullivan
Visitor at Argonne National Laboratory

October 20, 2005

Recap: December to now

- In December I described the complete status of theory to that point.
- I promised that I would do 2 things if no one else did:
  1. MCFM 4.0 lacked b/non-b jet separation in t-channel single-top.
     $\Rightarrow$ In spring I added this and fixed a bug in t-channel that is present through MCFM 4.1. It *should* be corrected in 4.2. . .
  2. To overcome $W+n$-jet backgrounds, I recommended using information from spin-induced angular correlations.
     $\Rightarrow$ The result appears in hep-ph/0510224, and this talk.

Contents

1. Why the Mahlon-Parke basis works for spin-induced correlations
2. LO vs. NLO: single-top and Wjj
3. Full correlations and results

Mahlon-Parke spin-basis

Both s- and t-channel single-top are matrix elements go like:

$$[p_d \cdot (p_t - m_t s_t)][p_e \cdot (p_t - m_t s_t)]$$

In top rest frame, $p_t = m_t(1,0,0,0)$, and $s_t = (0, \hat{s})$.

Choose top spin projection $\hat{s} = \hat{d}$. $\Rightarrow \sigma \propto (1 + \cos\theta^t_{e^+ d})$

- s-channel 98% of $\bar{d}$ from $\bar{p}$

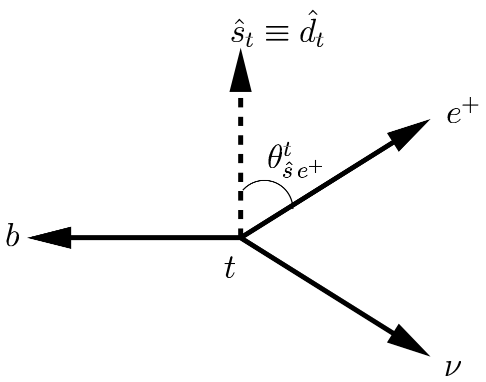
  $\Rightarrow \sigma \propto (1 + \cos\theta^t_{e^+ \bar{p}})$

- t-channel d in highest-E_t non-b-tagged jet j_1

  $3/4$ of the time. $\Rightarrow \sigma \propto (1 + \cos\theta^t_{e^+ j_1})$

  For rest, $\Rightarrow \sigma \propto (1 + \cos\theta^t_{d\,j_1} \cos\theta^t_{e^+ j_1})$

  dilution $\cos\theta^t_{d\,j_1} = 1 - Q^2/(E^t_d E^t_{j_1}) \sim 0.86$



We are saved by kinematically-induced correlations.

i.e., t-channel pole pushes jet forward.

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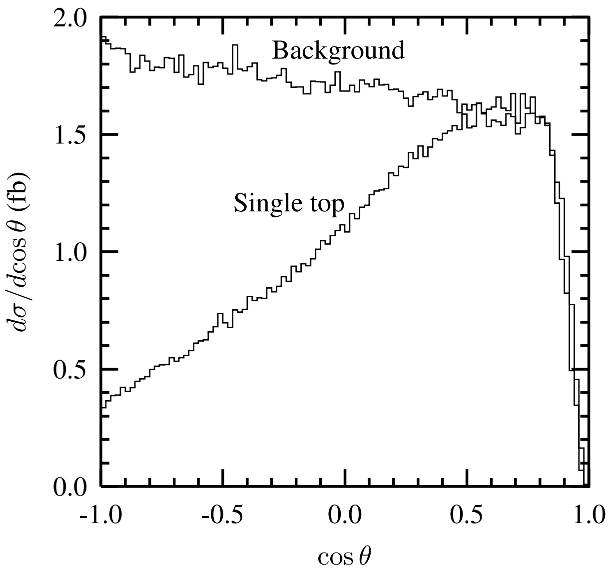


Original comparison of t-channel single-top and Wjj background at LO.

T. Stelzer, Z.S., S. Willenbrock, PRD 58, 094021 (98).

The new paper answers 4 questions:

1. Do spin-induced angular correlations survive higher-order radiation?
2. Is the background really insensitive to the angular distributions that typify the signal? If so, does this survive complex cuts on the data?
3. The angular distributions are properly defined in the top quark rest frame. How much of these correlations is an artifact of that frame?
4. Does this lead to better discriminates between S, B? e.g., ways to avoid b-tagging? Are there other useful particle correlations?

LO vs. NLO

t-channel

- Insensitive to top reconstruction (similar in LAB frame) — top is non-relativistic, so little boost.
- Additional ISR b-jets confuse which jet has the d.

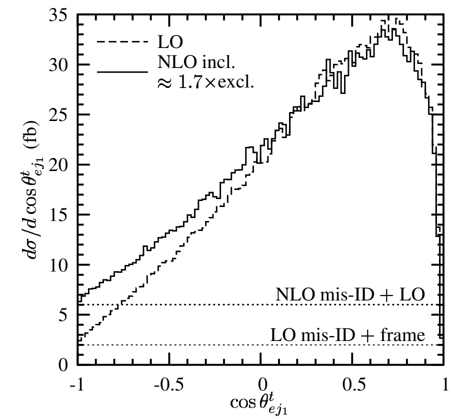
s-channel

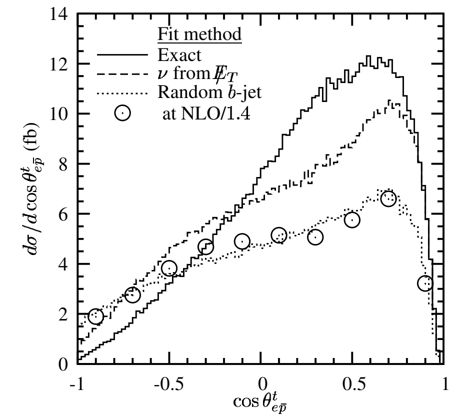
- NLO $=$ LO $\times$ K-factor
- Issue: Dominated by top reconstruction.
  - W fit to $e + \not{E}_T$.
  - I naively assigned a random b jet to top decay.

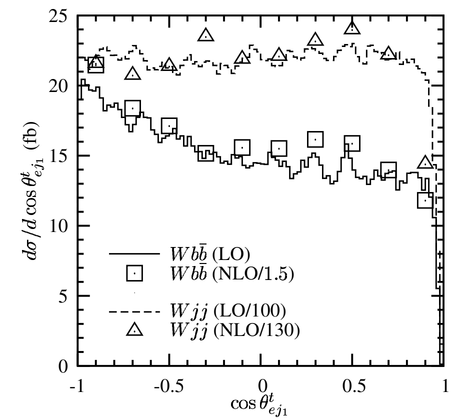
Wjj $(+Wb\bar{b}, Wc\bar{c})$

- NLO $=$ LO $\times$ K-factor

Spin-dependent ME fed into PYTHIA/HERWIG get all correlations (not all shown), as long as NLO-matched ME are used for t-channel.

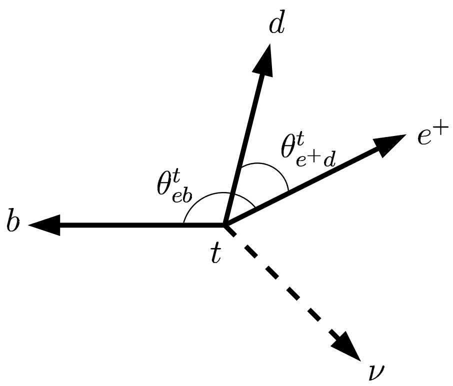






Can you avoid b-tagging? No, but it raises a subtlety...

In the top rest frame, the b recoils against the W (and the e), while j_1 wants to be close to e.



Proposal: Define "b" to be the jet with the largest angle w.r.t. e^+ in the top rest frame.

Correct $b > 80\%$ for s-/t-chan.

Equiv. cut: $\cos\theta^t_{e``b''} < \cos\theta^t_{ej_1}$

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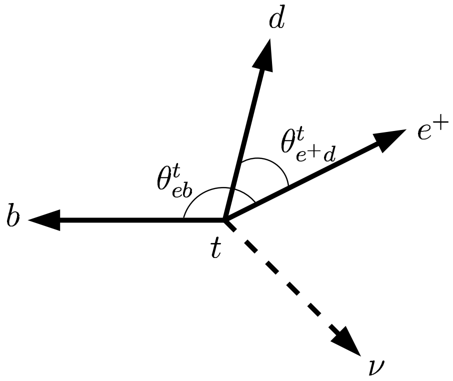

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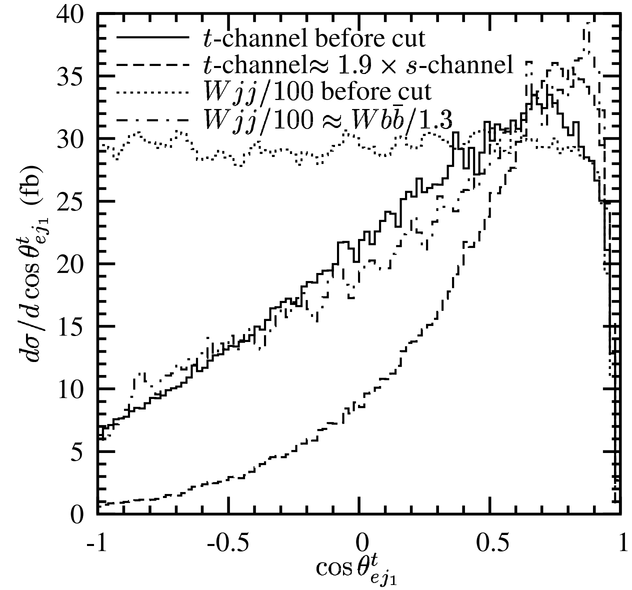

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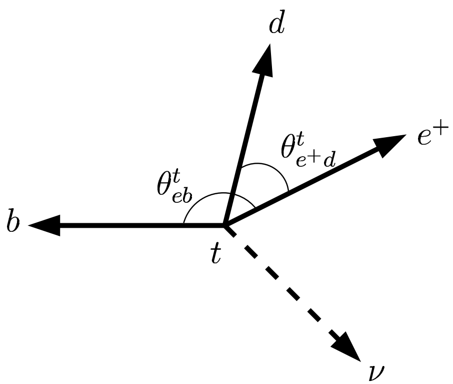

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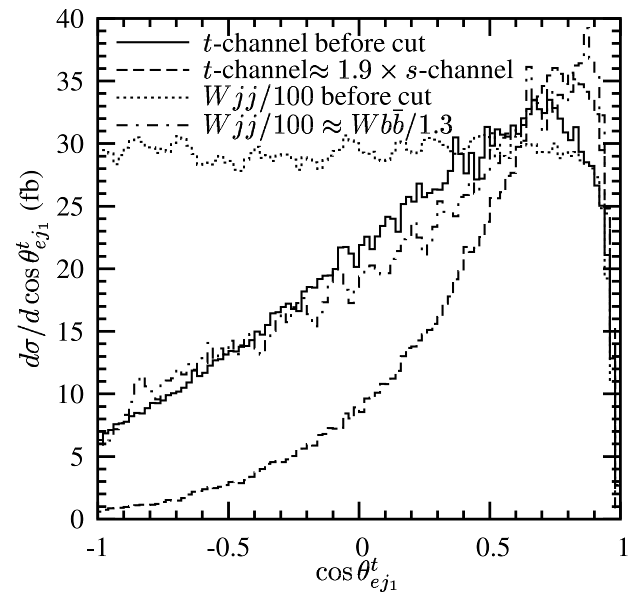
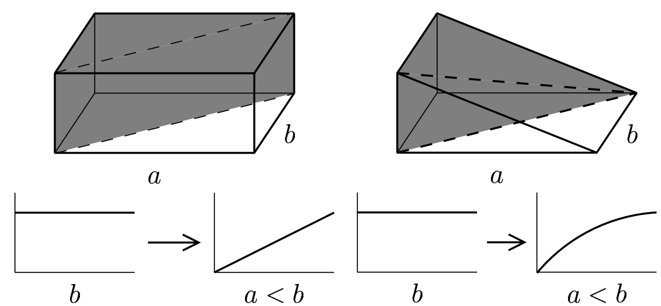


Angular cuts generically induce correlations.

This is why we need reliable predictions.



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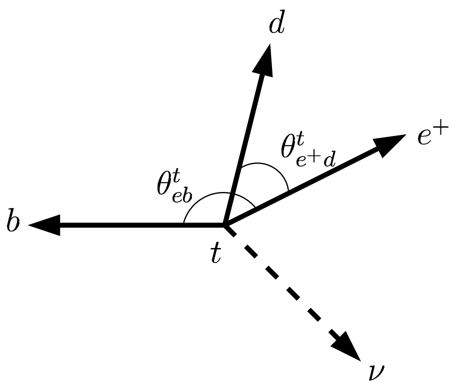

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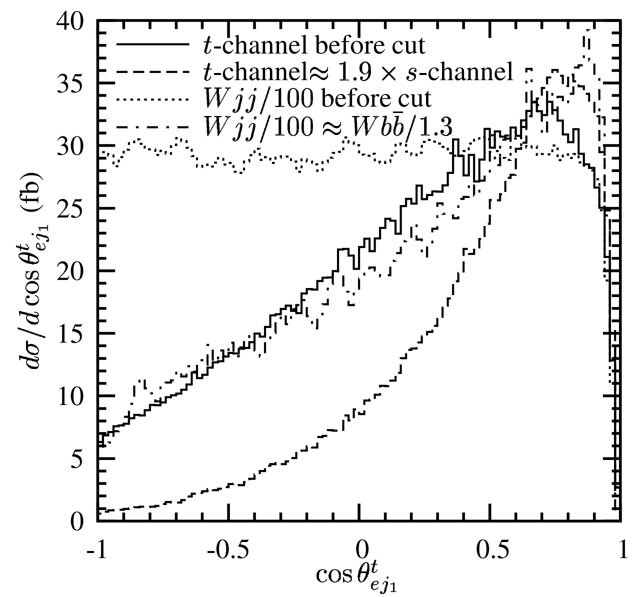

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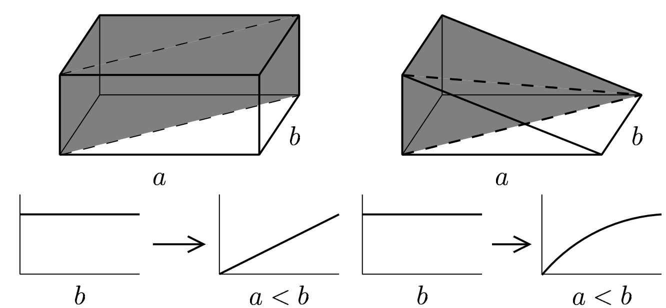
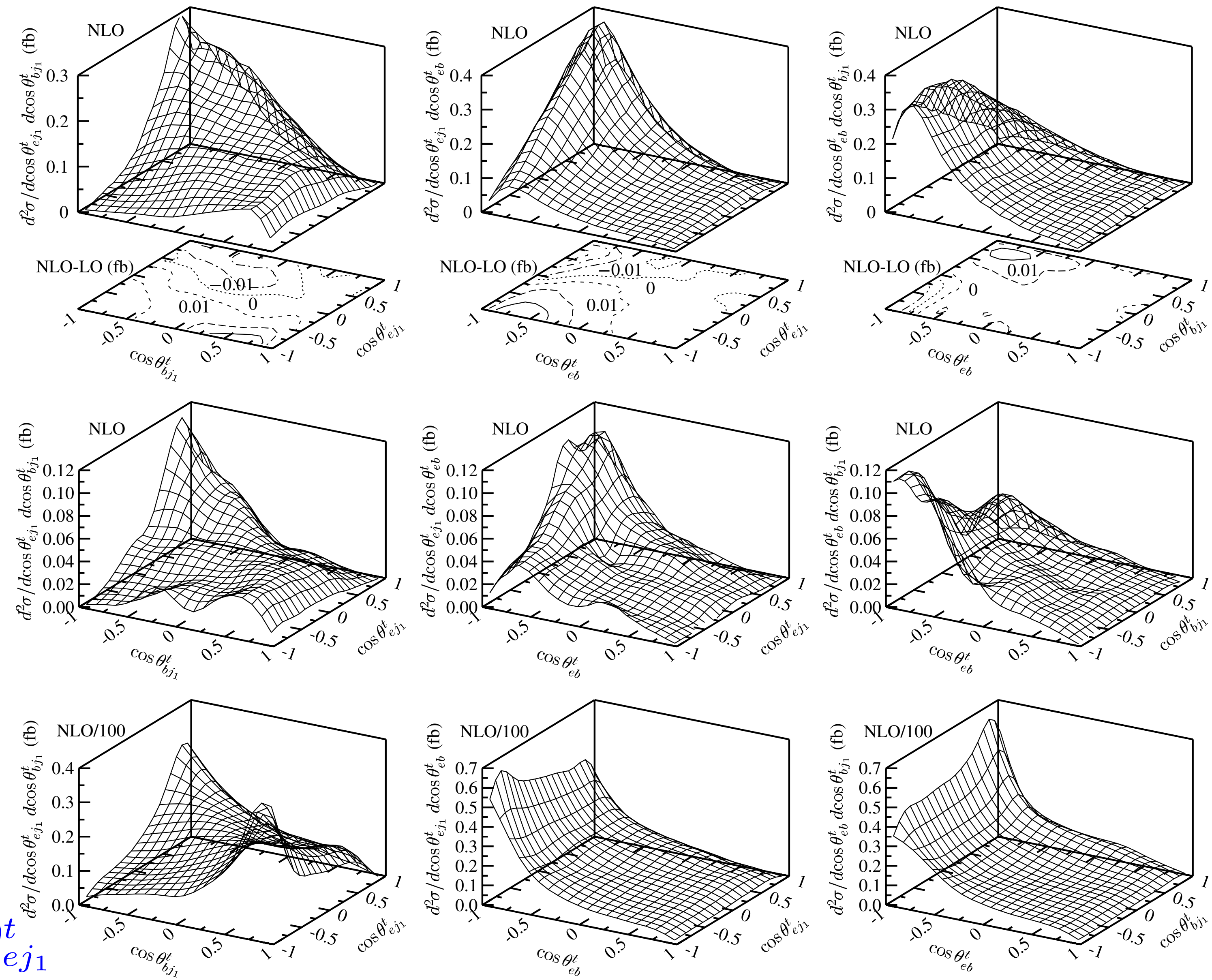
Warning: Two experimental biases select the largest angle jet (this cut):

1. b-tagging $\propto E_{Tb}$, picks jet recoiling vs. W.
2. Top-mass cut, also picks jet recoiling vs. W.



NLO $\cos\theta^t_{ej_1}$ *vs.* $\cos\theta^t_{eb}$ *vs.* $\cos\theta^t_{bj_1}$



t-channel

NLO$-$LO$< 3\%$

s-channel

NLO$-K\times$LO negligible, also true in

all Wjj

$\cos\theta^t_{ej_1}$ looked flat, but sum of 2 peaks + tails.

$\Rightarrow \cos\theta^t_{bj_1} < \cos\theta^t_{ej_1}$

The power of reliable angular cuts

I propose these acceptance cuts as a starting point:

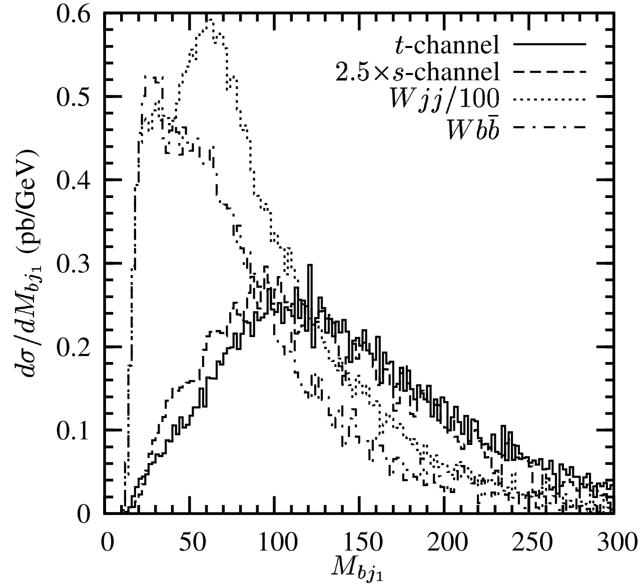
1. $\cos\theta^t_{eb} < \cos\theta^t_{ej_1}$.
2. $\cos\theta^t_{bj_1} < \cos\theta^t_{ej_1}$.
3. $\cos\theta^t_{bj_1} < 0.6$–$0.8$.
4. $\cos\theta^t_{ej_1} > 0$–0.4 or $\cos\theta^t_{eb} > -0.8$.

Result: $S/\sqrt{B} \approx S_0/\sqrt{B_0}$, $S/B \approx 1.5\times S_0/B_0$

I also examined invariant-mass correlations. This leads to the cut:

5. $M_{bj_1} > 80$–120 GeV

Result: $S/\sqrt{B} \approx 1.25\times S_0/\sqrt{B_0}$,
$S/B \approx 3\times S_0/B_0$



Overall $S \sim 0.4\times S_0$, but $B \sim B_0/7$!

Conclusions

1. Angular correlations in single-top-quark production are a composite of spin correlations, and kinematic correlations.
   - The kinematics are different at LHC: top is more relativistic.
   - Experimental reconstructions of the top frame will differ.
2. Huge gains are possible if cuts are made on the reliably predicted angular distributions.
   - $S/B \sim 3 \times S_0/B_0$, $S/\sqrt{B} > 1.25 \times S_0/\sqrt{B_0}$ — refine w/ detector sim.
   - Spin-dependent LO ME are fine, t-channel needs matched ME — already in use!
3. Many analyses depend on strong angular cuts — generically induces correlations. We better check our modeling of all processes.
4. Not in paper: $\bar{t}$ production at the LHC comes from IS d quark. The perfect correlation is in $\cos\theta^t_{ep}$ not $\cos\theta^t_{ej_1}$. This means that $\bar{t}$ is more sensitive to top reconstruction than t.

We must measure and understand these effects at the Tevatron in detail to disentangle the more complicated system at the LHC.