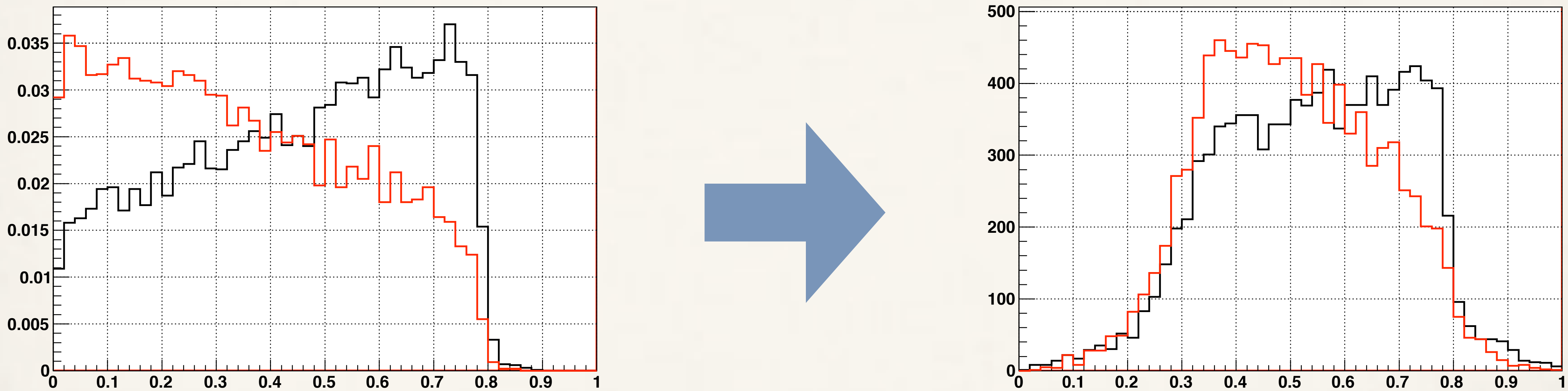

Measuring the Chirality of Boosted Tops in Hadronic Decays

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Giving New Physics A Boost - July 10th, 2009

Based on work in progress with Jessie Shelton (Rutgers) and Lian-Tao Wang (Princeton)

Outline

- Motivations for measuring chirality with hadronic decays
- Subjets & jet shapes
- B-quark energy fraction distributions
- Measuring energy fractions *without* b-tagging or W-reconstruction
- Examples
- Conclusion

Takeaway Points

- We have a new way to measure the chirality of hadronically decaying boosted tops.
- This is done without b-tagging or W-reconstruction.
- Basically, we construct three subjets in a top-jet, use a set procedure to guess which is the b-jet, and look at its energy fraction.
- This seems to be robust against the effects of showering & hadronization.

Measuring the Chirality

- Models of new BSM physics usually involve chiral couplings to the top.
- The top quark decays before hadronization - polarization information is preserved.
- By measuring the chirality of the top we can probe its couplings to new physics.

Hadronic Decay Modes

- Normally we look at semi-leptonic top decays to measure chirality (signal is clean)
- However, there are a number of reasons to look at hadronic decays:
  - We don’t need to assume a production mechanism
  - Chirality information isn’t diluted in more complicated processes
  - No new sources of missing energy are introduced

- We can look at both sides of $X \rightarrow t$ t-bar production (useful in measuring the spin of X)
- No issues with lepton isolation & b-tagging
- Increased statistics
- Could help with top-tagging:
  - A signal with hadronic tops would be more striking if we saw a correlation with chirality
- New discovery channels are always good

Looking Inside Top-Jets

- In general, the chirality of a decaying top will affect most kinematic observables.

- When we investigate a boosted top jet we can try to identify subjets[†] or we can look to jet shapes[*]. Both of these are sensitive to chirality.

- Here we'll focus on using subjets, although jet shapes (like planar-flow) show promise.

[†] See the paper by J. Thaler & L.-T. Wang (0806.0023) and M. Schwartz' talk at this workshop (based on 0806.0848) for more discussion on top subjets.

[*] See G. Perez' talk (based on 0807.0234) for a discussion of jet shapes in boosted tops

B-quark Energy Fraction

- The energy fraction of the top carried by the b-quark is sensitive to the top chirality.

- For a right handed top, the b will decay as

$$P_0(\cos\theta_{bt}) = \frac{1}{2}(1-\cos\theta), \;\; P_-(\cos\theta_{bt}) = \frac{1}{2}(1+\cos\theta)$$

  for the specified W polarization and θ the angle between the b and the top in the top rest frame (for left handed just flip the sign of cos).

- The fraction of the top decaying into each W polarization is

$$f_\pm = \frac{2m_w^2}{2m_w^2 + m_t^2} \approx 38\%, \;\; f_0 = \frac{m_t^2}{2m_w^2 + m_t^2} \approx 62\%$$

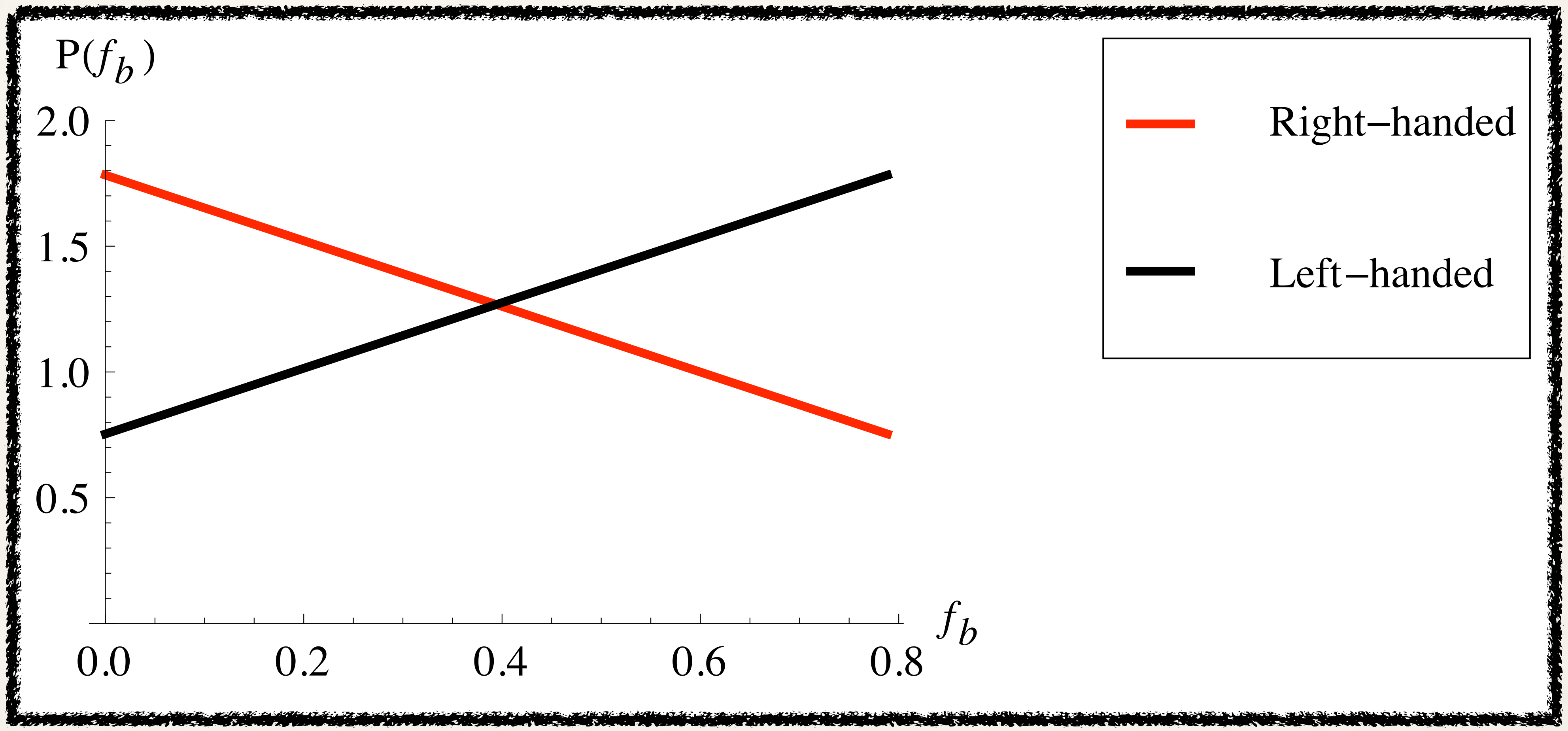
(you can see this from the Goldstone equivalence theorem - the longitudinal mode couples as the mass of the top)

- Finally, we convert from angular distributions to energy fractions f_b (in the boosted frame) via

$$\cos\theta_{tb} = \frac{f_b m_t - E_b}{E_b}$$

- The result is that

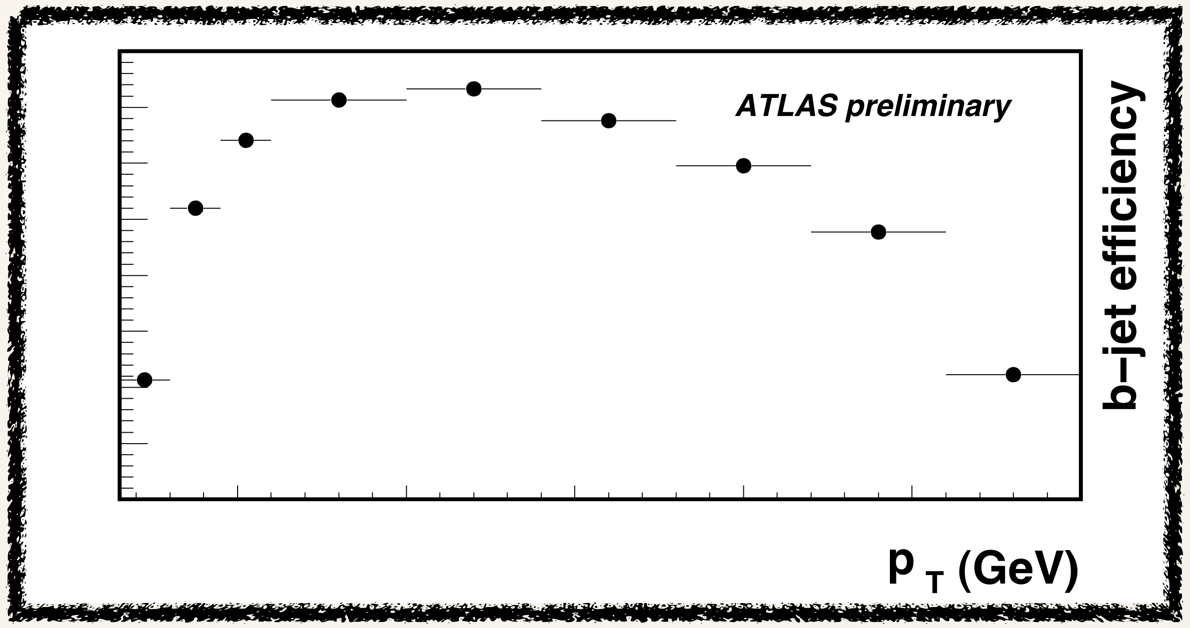
$$P_{r/l}(f_b) \propto \left(2 + \frac{m_t^2}{m_w^2}\right) \pm \left(\frac{f_b m_t - E_b}{E_b}\right)\left(2 - \frac{m_t^2}{m_w^2}\right)$$



How can we measure this?

No b-tagging

- B-tagging at high energies can be inefficient, and it will probably take a while for efficiencies to be well understood (especially b-tagging in collimated jets).



Taken from 0809.4896

- We will try to get as far as we can without b-tagging.

No W Reconstruction

- Distinguishing the two subjets from the W is hard.
- Often, another invariant mass formed is close to m_W, and the effects of ISR/FSR & hadronization can make choosing the right pair of subjets difficult†.
- Again, we'll see how far we can go without this.

†Pruning (discussed in S. Ellis' talk on 0903.5081) might help with this.

Robust Subjet Measurements

- So, what can we do well?
- If we identify subjets within a top-candidate usually pretty easy to identify the softest of the three (ISR/FSR & hadronization don't change the ordering too much).
- Also, it's relatively simple to identify the jet centers.

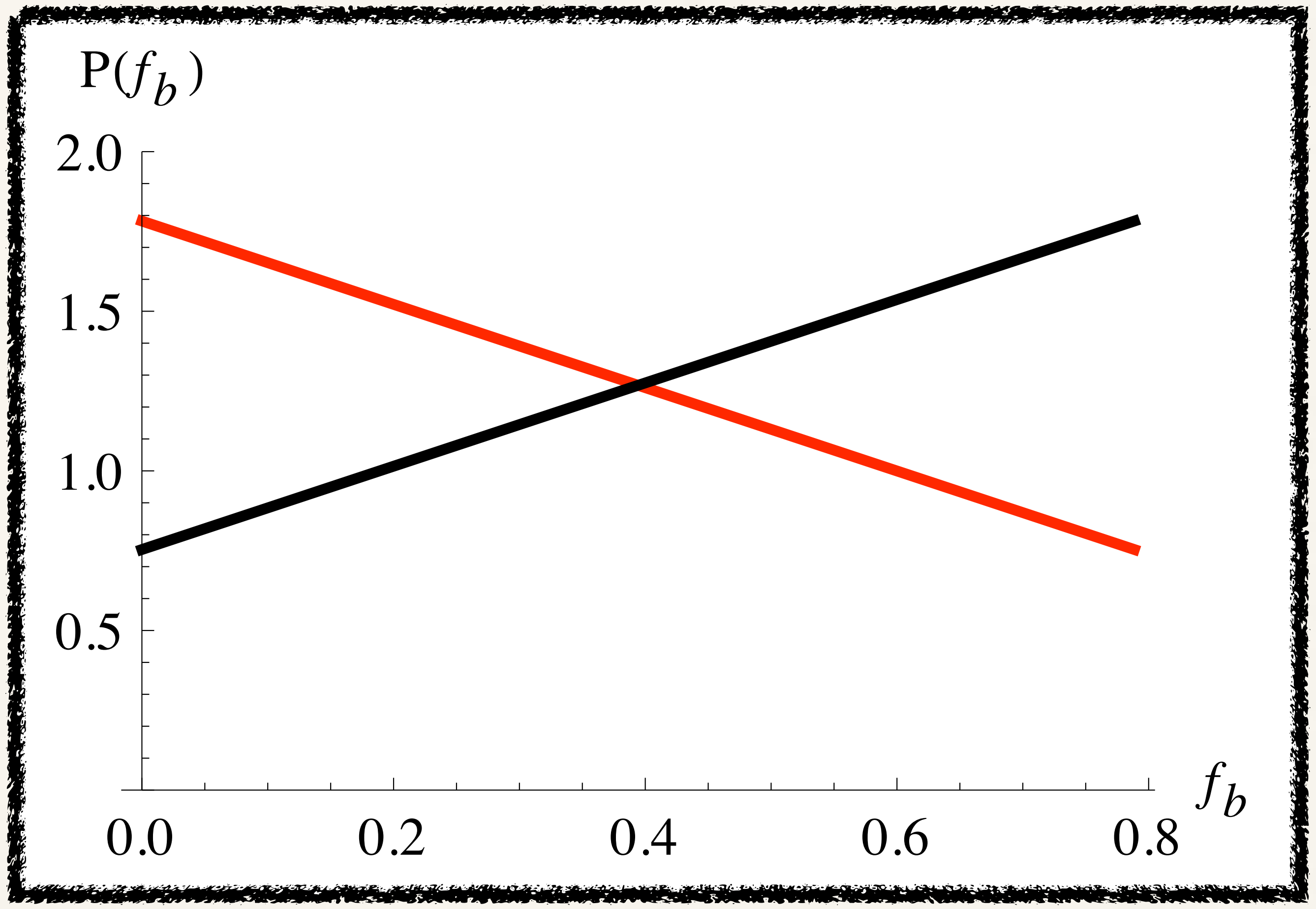
New Procedure

- Take a top jet and form three subjets
  - If this results in a very soft jet, discard it and split the hardest jet (unwind with k_T)
- Consider the three k_T-distances (d_{ij}) between the subjets:

$$d_{ij} = \min\left(p_{Ti}^2, p_{Tj}^2\right) \Delta R_{ij}^2$$

- Identify the smallest k_T distance (which is determined by relatively robust quantities) and consider the energy fraction of the top jet in the harder subjet.

- Part of the time (~ 2/3) this will pick out the b-quark and we will see roughly the distribution we saw before:



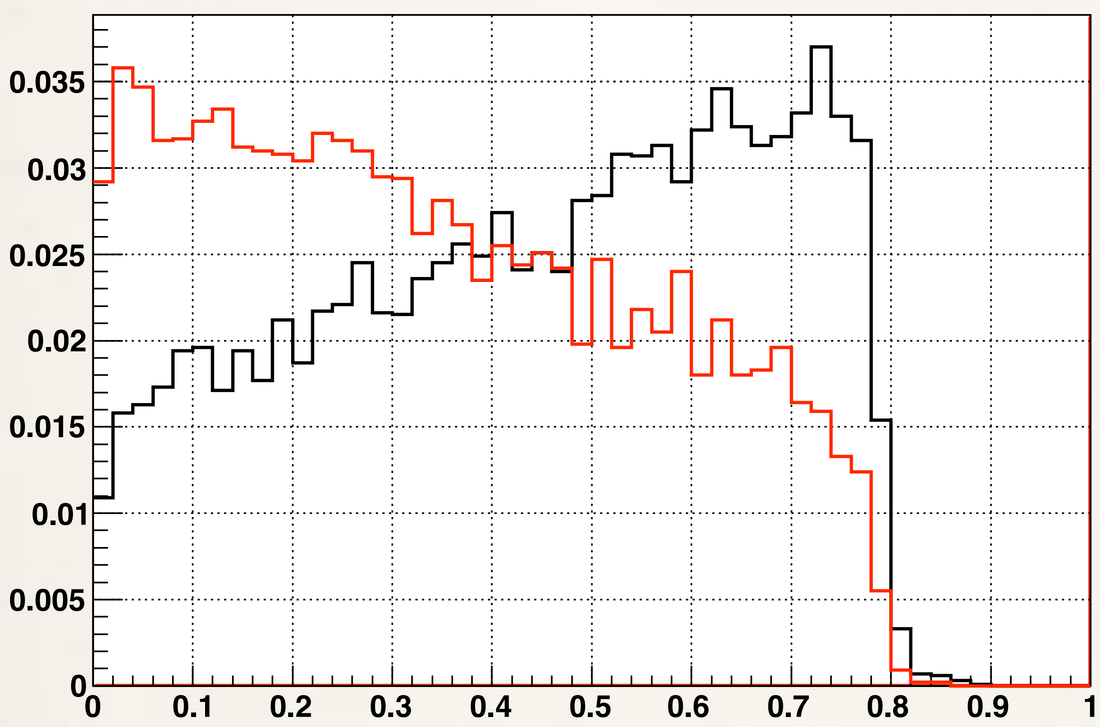
- Remarkably, the chance of getting the wrong jet is roughly the same regardless of the top's chirality, and the distribution coming from incorrectly chosen jets doesn't vary much between polarizations.

Examples

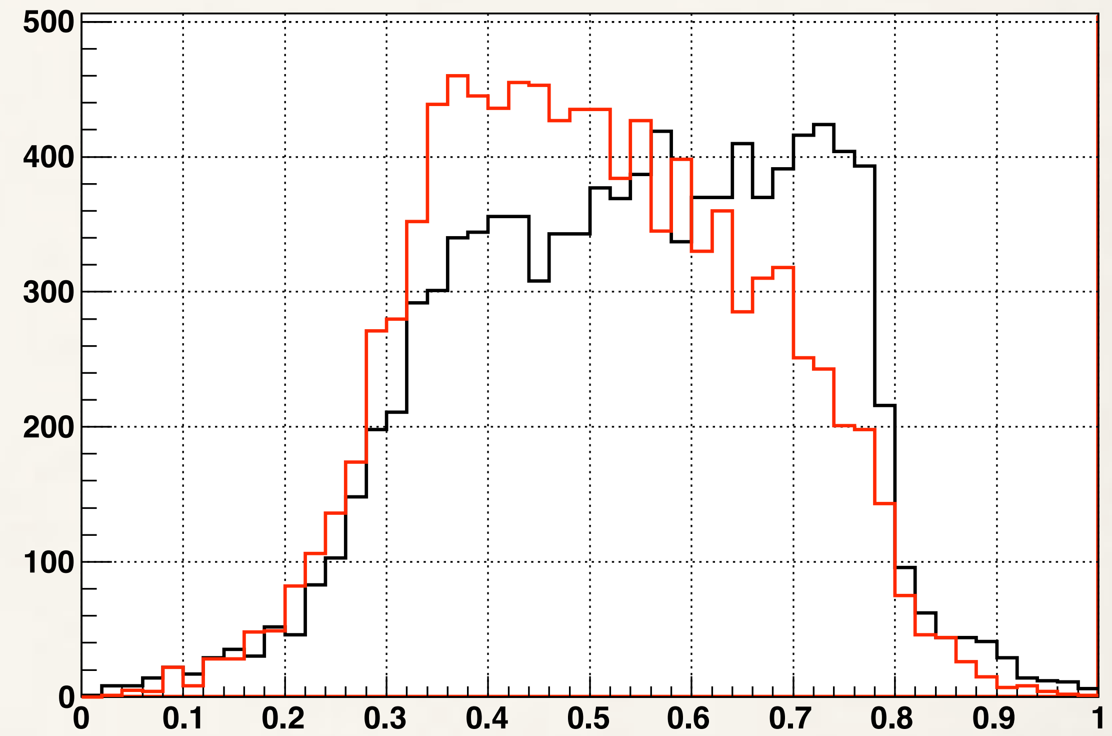
- Our examples are:
  - Generated at parton level by MadGraph
  - Showered in Pythia
  - Merged into 0.1×0.1 cells
  - Clustered with Fastjet (using anti-k_T with ΔR=0.7 or 1.0)

3TeV Spin-1 Color Octet

- Here's the resulting distribution (at parton level):



B-quark energy fraction

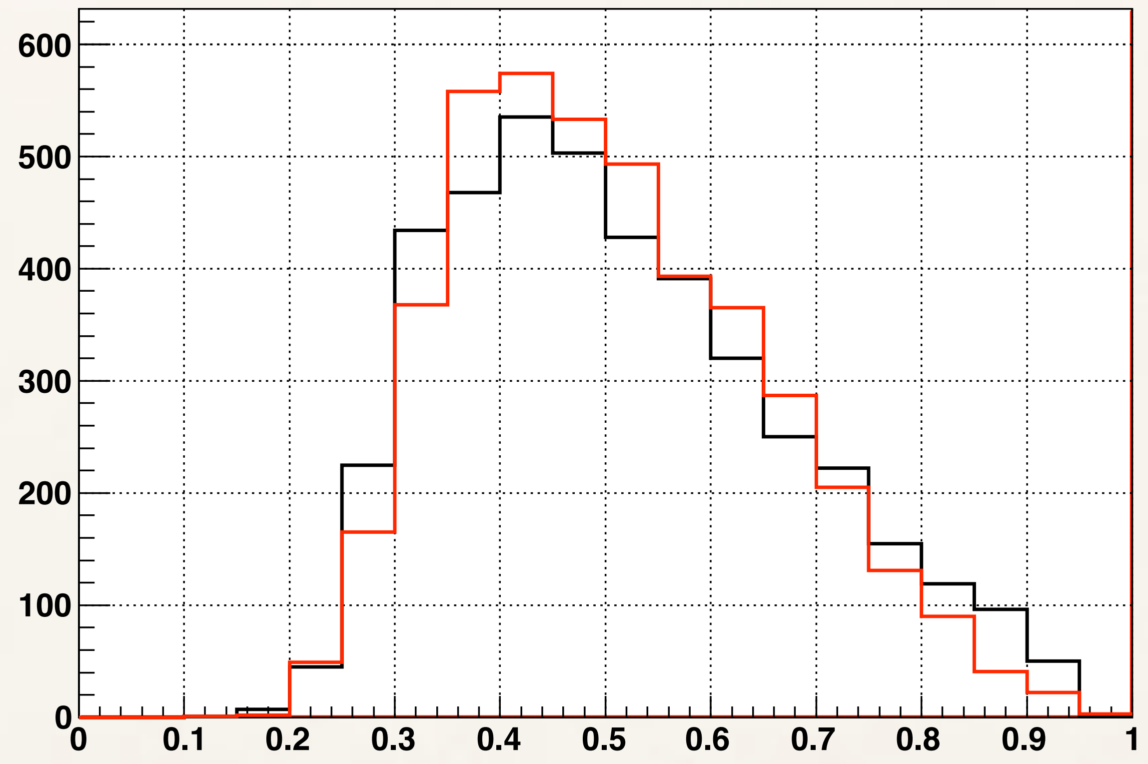


Infered B-quark energy fraction using k_T procedure

- The difference between the two chiralities is striking

Mistags

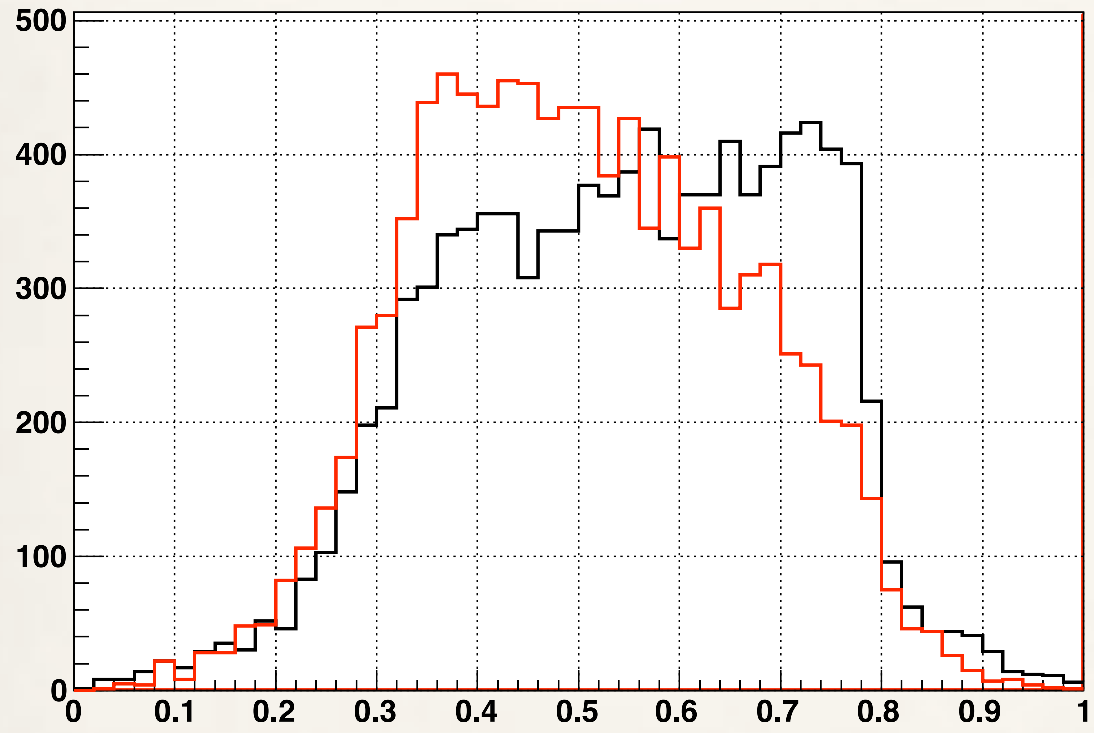
- Here's the distribution resulting from mistags, where you plot the energy fraction of a W decay product (parton level):



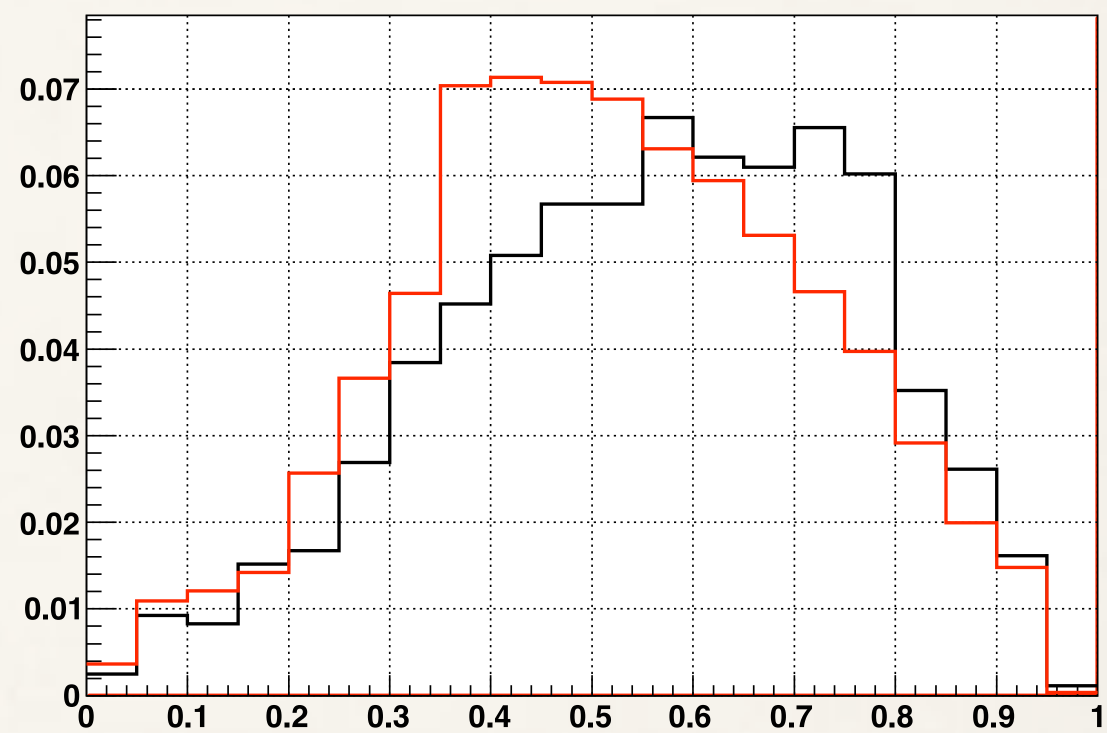
- The distribution resulting from both chiralities are the same.

Signal Robustness

- The distributions are fairly robust against the effects of ISR/FSR and hadronization:



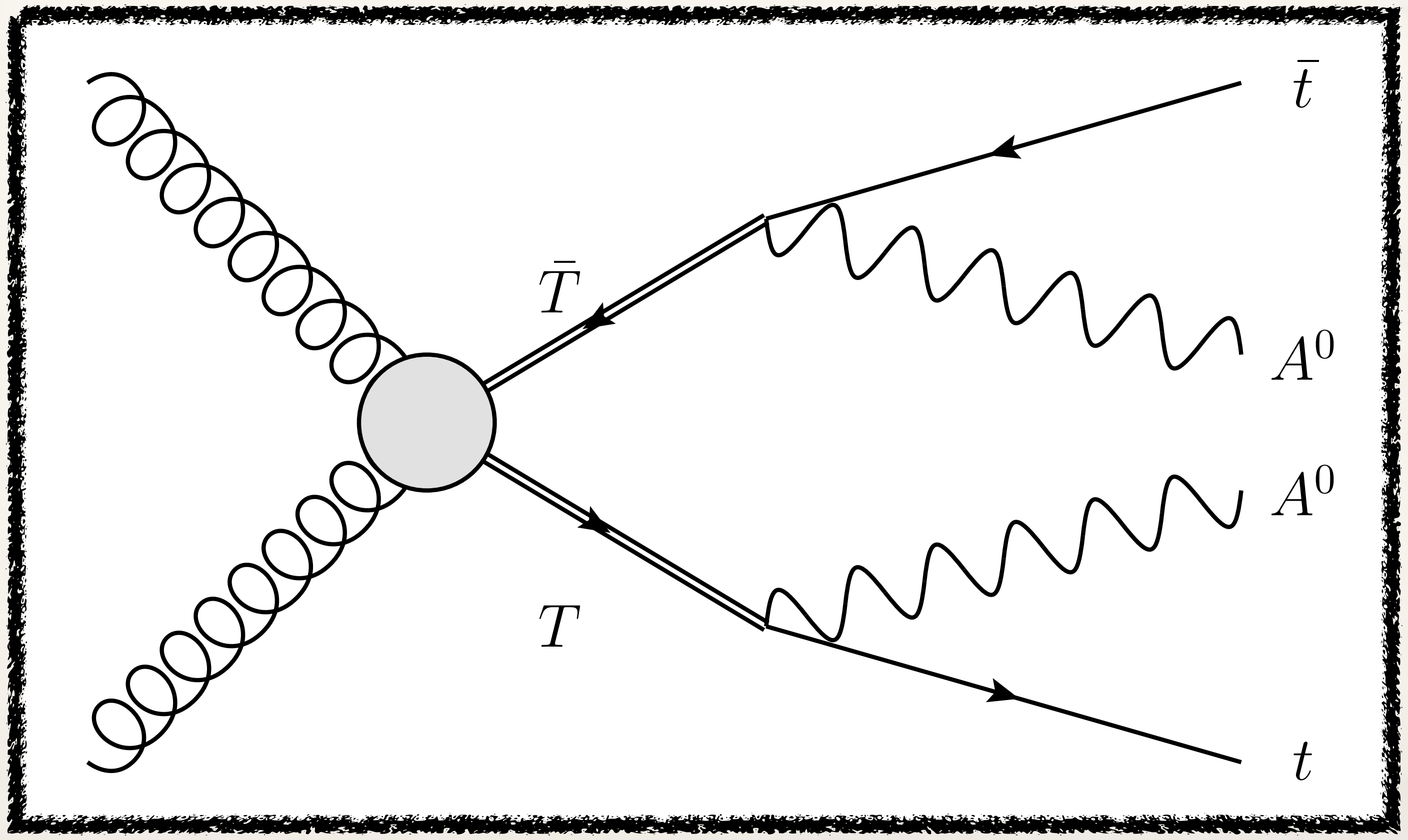
Parton-level truth



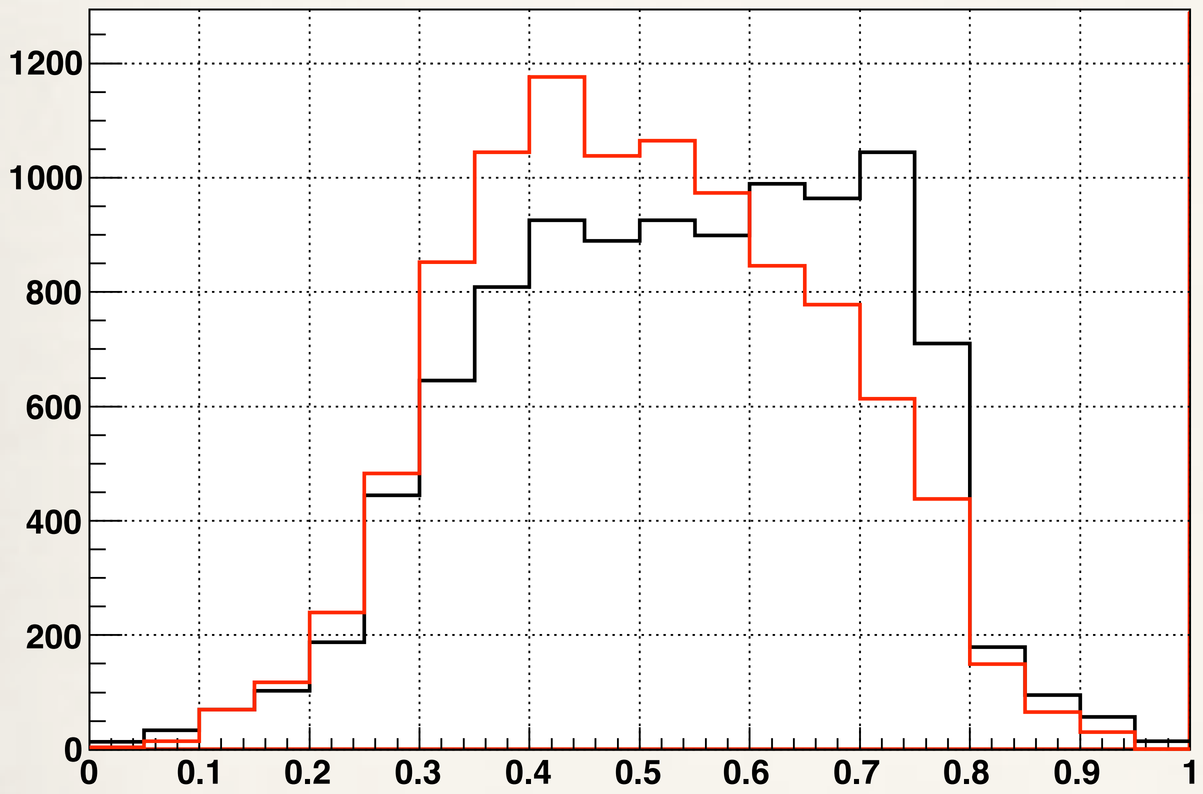
Full simulation (ISR/FSR, hadronization, cells)

Top-Parter Production

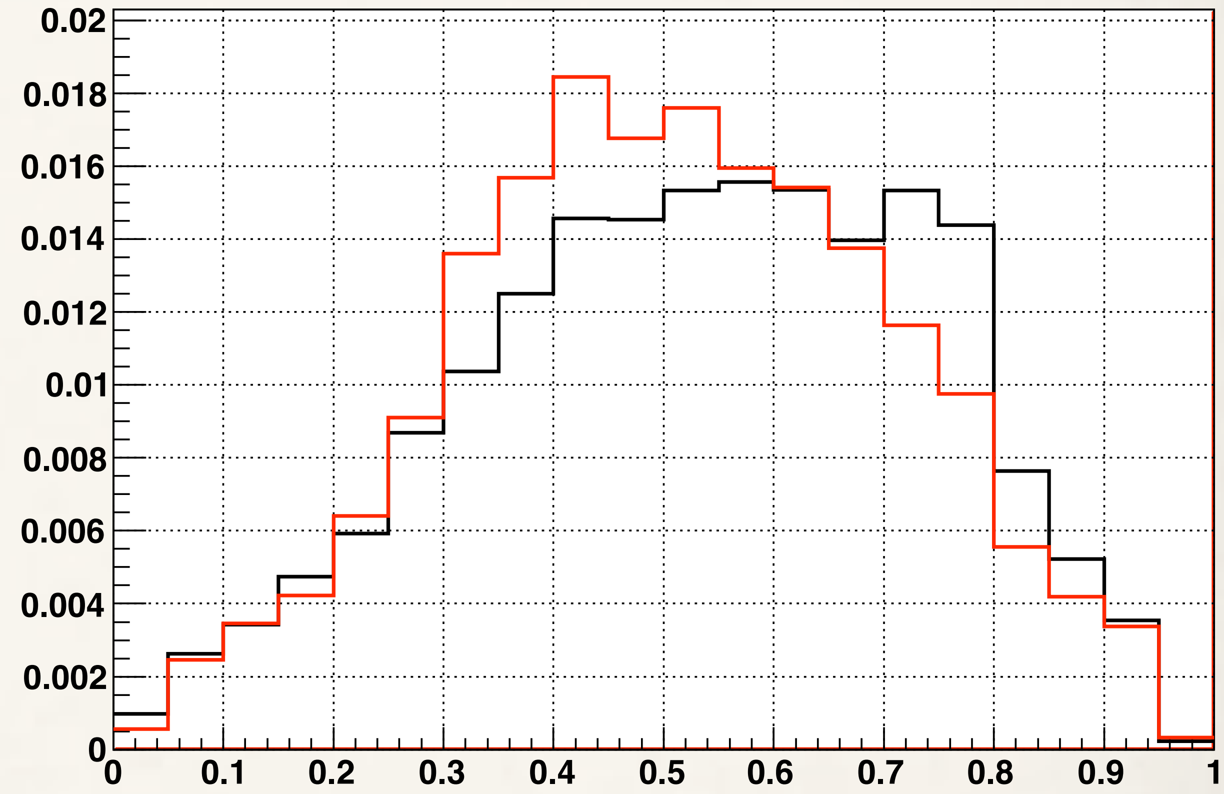
- Consider producing two tops partners (2 TeV) with chiral couplings and looking at their decay products (m_A=100 GeV). Here there are additional transverse boosts.



- The cuts need to be tinkered with, but initial results are promising:



Parton-level truth



Nearly full simulation (ISR/FSR, cells)

Conclusions

- The top quark preserves chirality information in its decays and is useful in studying new physics
- There are many advantages to measuring the chirality in hadronic decays
- We can perform this measurement in boosted tops without using b-tagging or W mass reconstruction through the procedure described herein
- Roughly, this lets you see the b-quark energy fraction on top of a constant background