Top Theory

Jessie Shelton

Yale University

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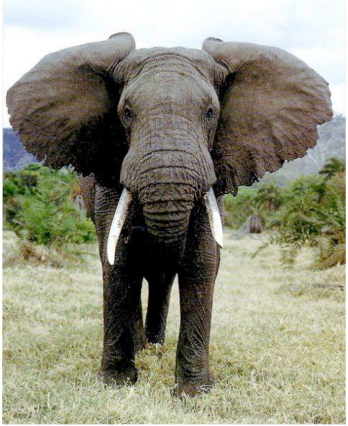
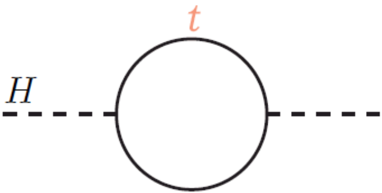
The Top Quark



EWSB

Flavour

The top quark has a privileged role in EWSB



$$\delta m_H^2 = -\frac{3y_t^2}{(4\pi^2)}\Lambda^2$$

- Weak scale new physics leads very generically to top-rich final states.
  - Higgs sectors: elementary or composite
  - Extra-dimensional flavour scenarios
  - Weakly-coupled EWSB stabilisation: top partners
  - MFV color octet scalar
- Understanding and identifying final state tops at LHC in a wide variety of environments will be important to both discover and distinguish models of new physics.

LHC will be the first top factory

- large SM production cross-section: $\sigma(pp \to t\bar{t}) = 830\ \mathrm{pb}$
  - Nearly 1 SM top pair per second at low design luminosity
- also: tops in association with other high-p_T objects
- novel kinematic regime: $\sqrt{s} \gg m_t \gg \Lambda_{QCD}$
- large top data samples, SM and (we hope!) NP: precision measurements
- techniques for analysing top-rich final states are context-dependent and there is still a lot of room for development.

Boosted Top Tagging

- Standard top reconstruction techniques require
  - multiple hard isolated objects
  - *b*-tagged jets
  - *W* and/or *t* mass reconstruction
- For tops produced from very massive parents ($p_{T,top} \gtrsim$ TeV) these techniques begin to break down.
  - collimated: isolation breaks down
  - *b*-tagging resolution degrades at high p_T and in crowded environment
  - *W* not easy to isolate; *t* mass smeared by radiation
- Top-tagging: use jet substructure to distinguish collimated tops from fat QCD jets
  - (broad) *t* mass window
  - a *W*-like object
  - evidence of hard splittings within jet (subjets, energy sharing variables, jet functions)

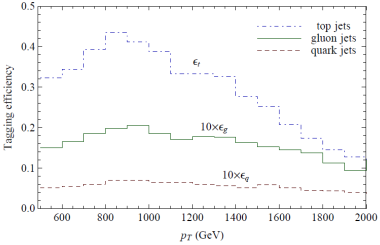
Lillie, Randall, Wang '07; Thaler, Wang '08; Brooijmans '08; Kaplan, Rehermann, Schwartz, Tweedie '08; Almeida *et. al.* '08

The Hopkins top-tagger

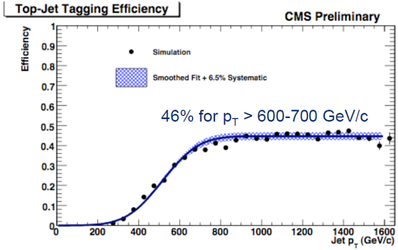
- Developed for $t\bar{t}$ events. Main background: QCD dijet ($\sigma_{QCD} \sim 10^3 \sigma_{t\bar{t}}$)

  1. Cluster the event with a large cone ($R \in (0.4, 0.8)$, depending on event E_T), using the shower-savvy Cambridge-Aachen algorithm
  2. Look for subjets: reverse the cluster sequence, looking for splittings $i \rightarrow jk$ where both p_T fractions $p_{Tj,k}/p_{T,jet}$ exceed a threshold δ_p
  3. Keep jets with 3 or 4 subjets.
  4. Total subjet invariant mass must fall within a top window
  5. Two subjets must fall within a W mass window
  6. W helicity angle $\cos\theta_W < 0.7$

Top-tagging efficiencies



from Kaplan, Rehermann, Schwartz, Tweedie '08, `arxiv:0806.0848`, PRL 101:142001 (2008). Top tagging efficiencies for background and signal.



from Salvatore Rappoccio's talk at Washington's Jet Substructure workshop. CMS top tagging efficiencies for signal. QCD dijet rejection 98% at $p_T = 600$ GeV, still unclear at higher p_T (statistics)

- Top tagging promising for high p_T $t\bar{t}$ events: outlook for $t\bar{t}$ resonances is promising.
- Still challenging: moderate p_T top ID in high multiplicity events
  - for instance: $\tilde{g}\tilde{g} \to t\,\bar{t}\,b\,b\,\chi^0\,\chi^0$
  - combinatorics can be overwhelming!
  - other issues: geometric acceptance, multiple (and possibly unknown) signal contributions as well as known SM backgrounds
  - Hisano, Kawagoe, Kitano, Nojiri '08; Acharya, Grajek, Kane, Kuflik, Suruliz, Wang '09
- top-tagging in SM ttH (Plehn, Salam, and Spannowsky '09):
  - moderate boosts address b combinatorics
  - large cone requires sophisticated jet cleanup techniques

Precision top physics

- Precision characterisation of the top will be a critical part of the LHC physics program
- Can tell us directly as well as indirectly about properties of new physics
- Rare top decays:
  - Parameterise BSM contributions to charged and neutral current decays: e.g.,

$$\mathcal{L}_{cc} = \frac{g}{\sqrt{2}} W^-_\mu \bar{t}\gamma^\mu \left((1+\delta_L)P_L + \delta_R)P_R\right) q + \mathrm{H.c.}$$

  - decay directly to on-shell new physics: $t \to H^+ b,\ \pi_T^+ b,\ \tilde{t}\chi_0,\ u(Z' \to u\bar{u})$ Jung, Murayama, Pierce, Wells '09,...
- CP violation, $t\bar{t}$ spin correlations, ...
- Top polarization from new physics

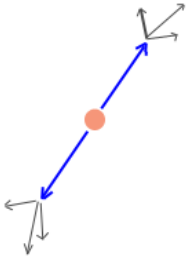
Top polarization from new physics

- new physics generically couples differently to t_R, t_L
  - $\Rightarrow$ tops produced from new physics are typically polarized
  - a degree of polarization dependent on kinematics as well as chiral couplings
- Since top decays before hadronization, distributions of decay products contain information about parent top polarization
- Angular distribution of daughter particles in top decays:

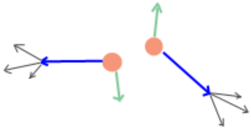
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_f} = \frac{1}{2}\left(1 + \mathcal{P}_t\,\kappa_f\cos\theta_f\right)$$

- ‘spin analyzing power’ κ_f depends on particle identity:
  - $\kappa_b = -\frac{m_t^2 - 2m_W^2}{m_t^2 + 2m_W^2} \simeq -0.4$
  - $\kappa_W = -\kappa_b$
  - $\kappa_\ell = 1, \qquad \kappa_\nu \simeq -0.3$

Top polarization from new physics



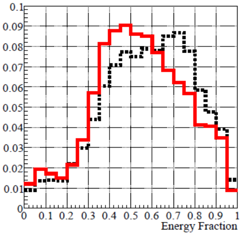
- natural axis of polarization: helicity in parent frame
- solve for parent rest frame, *t* rest frame
- hadronic, semileptonic decay modes both useful



- event is not fully reconstructible
- require hadronic tops: fully reconstructible on their own
- natural axis of polarization: helicity in lab frame

Top polarization from new physics

- Since polarization signals maximised at large top boost, develop tools for polarised boosted tops (Krohn, Shelton, Wang '09)
- Distributions of subjet energy fractions z_k sensitive to polarization.
- Subjet selection algorithm depending on k_T distances between subjets:
  - no reliance on b or W tagging
  - sensitive to multiple aspects of underlying top matrix element
  - uses quantities which are robust under showering, hadronization, binning, reclustering



Conclusions

- Very exciting time for top physics!
- Expect tops to be a key signal and diagnostic of physics beyond the standard model
- Now entering “polytopia”: lots of room left for improving our toolkit for multi-top final states