The Top Forward-Backward Asymmetry and the LHC

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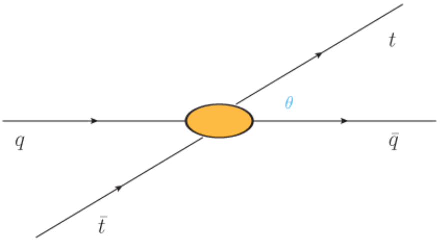
J. Hewitt, JS, M. Spannowsky, M. Takeuchi, T. Tait, arXiv:1103.4618
D. Krohn, T. Liu, JS, L.-T. Wang, arXiv:1105.3743

Boost 2011,
Princeton University
May 24, 2011

The top forward-backward asymmetry

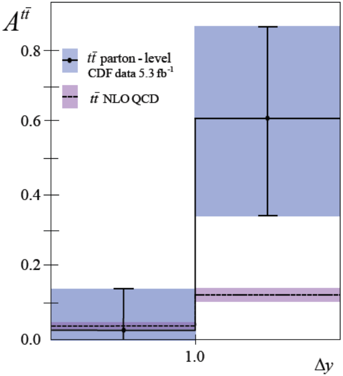


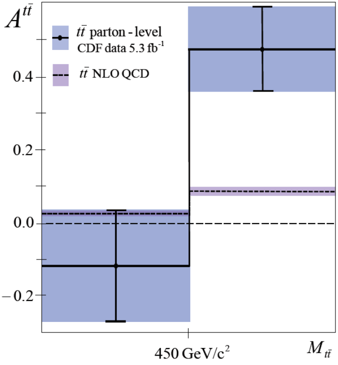
- The SM predicts a small but non-zero asymmetry in $p\bar{p} \to t\bar{t}$:

$$A^t_{SM} = 0.05 \pm 0.015 \text{ Antuñano, Kühn, Rodrigo '07},$$
$$= 0.066 \pm 0.015 \text{ Almeida, Sterman, Vogelsang '08}$$

The top asymmetry at the Tevatron

- D0, CDF have consistently observed anomalously large values for A^t_{FB} at $\gtrsim 2\sigma$ level
- Recent CDF measurements of asymmetry in different kinematic regions:

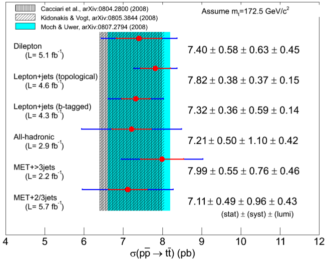


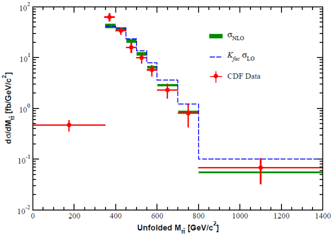


High-mass asymmetry $A^t_{hi} = 0.475 \pm 0114$, 3.4σ from SM (MC@NLO)

The pair production cross-section

- Other top properties – in particular the top cross-section – are in very good agreement with the SM





CDF measurements of $\sigma(p\bar{p} \to t\bar{t})$

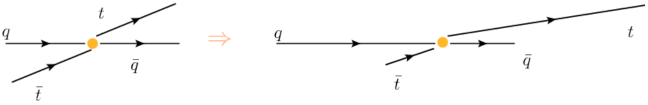
from Cao, McKeen, et al. ’10

- At the LHC: (1) look for new states and (2) verify partonic asymmetry
- (At the Tevatron: add statistics and measure additional observables)

Asymmetries at the LHC

- A more challenging measurement:
  - symmetric *pp* initial state: no global forward direction
  - larger *gg* contribution to top pair cross-section increases background

- *pp* is symmetric...



...but $q\bar{q}$ is not.

- LHC sensitivity to A^t_{FB} limited but not eliminated

(Kuhn, Rodrigo; Antunano, Kuhn, Rodrigo)

Asymmetries at the LHC

- Valence-sea kinematics translate a positive forward-backward partonic charge asymmetry into a positive forward-central charge asymmetry
- Translate this into an observable:

Net forward charge asymmetry

$$\mathcal{A}_F(y_0) = \frac{N_t(y_0 < |y| < y_m) - N_{\bar{t}}(y_0 < |y| < y_m)}{N_t(y_0 < |y| < y_m) + N_{\bar{t}}(y_0 < |y| < y_m)}$$

Xiao, Wang, Zhou, Zhu; Hewett, JS, Spannowsky, Tait, Takeuchi

Asymmetries at the LHC

- Valence-sea kinematics translate a positive forward-backward partonic charge asymmetry into a positive forward-central charge asymmetry

- Translate this into an observable:

Event-by-event forward-central charge asymmetry

$$\mathcal{A}_\eta = \frac{N(|\eta_t| > |\eta_{\bar{t}}|) - N(|\eta_t| < |\eta_{\bar{t}}|)}{N(|\eta_t| > |\eta_{\bar{t}}|) + N(|\eta_t| < |\eta_{\bar{t}}|)}$$

CMS, TOP-10-010

Asymmetries at the LHC

- Valence-sea kinematics translate a positive forward-backward partonic charge asymmetry into a positive forward-central charge asymmetry
- Translate this into an observable:

Event-by-event forward-backward charge asymmetry

$$\mathcal{A}_{FB} = \frac{N(\cos\hat{\theta}_t > 0) - N(\cos\hat{\theta}_t < 0)}{N(\cos\hat{\theta}_t > 0) + N(\cos\hat{\theta}_t < 0)}$$

where $\hat{\theta}$ is defined relative to event boost axis

Krohn, Liu, JS, Wang

Optimizing the kinematic regime

- Sensitivity to underlying asymmetry is greatest for tops at high invariant mass and high rapidity
- The signal is larger:
  - The partonic asymmetry (whether SM or BSM) grows with both invariant mass and and rapidity
- The background is smaller:
  - The symmetric $gg \to t\bar{t}$ falls off faster than $gq, q\bar{q} \to t\bar{t}$
  - The correlation between valence q direction and CM boost direction improves
- Reach can be enhanced by careful choice of kinematic cuts: sensitivity vs statistics

Measuring the top AFB with dileptonic tops

- Outline of the analysis:
  - Select dileptonic top events using basic selection cuts: isolated leptons, jets, MET
  - Reconstruct the tops by solving for the neutrino four-vectors
  - Require high mass: $m_{t\bar{t}} > 450$ GeV
    typical top $p_T \sim 150$ GeV
  - Require large rapidity, $|y_t + y_{\bar{t}}| > 2$
  - Measure the forward-backward asymmetry relative to the CM boost: $\mathcal{A}_{FB} = \frac{N(\cos\hat{\theta}_t > 0) - N(\cos\hat{\theta}_t < 0)}{N(\cos\hat{\theta}_t > 0) + N(\cos\hat{\theta}_t < 0}$

Measuring the top AFB with dileptonic tops

- We studied a set of reference models which give a large $t\bar{t}$ asymmetry at the Tevatron*:
  - a flavor-off-diagonal W' Gresham, Kim, Zurek
  - an axigluon G_A
  - closely related "axigluons" $G_{L,R}$ that couple chirally to tops

*: the axigluon-type models are conservatively chosen to underpredict the Tevatron asymmetry

- Events are generated using MadGraph for the full $2 \to 6$ partonic process, then showered in Pythia, binned into 0.1×0.1 massless cells, and clustered in FastJet.

Results at the 7 TeV LHC

	G_A(%)	G_L(%)	G_R(%)	W'(%)	SM(%)
Selection cuts	3	2	4	14	1 (±1.2)
$m_{t\bar{t}} > 450$ GeV	5	3	6	20	0 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	8	5	12	36	1 (±3.2)

$\mathcal{A}_{FB}$ and 1σ statistical uncertainties assuming $5\ \mathrm{fb}^{-1}$ of data.
The contribution from the Standard Model is LO only
and no K-factors have been applied.

A few words about leptons

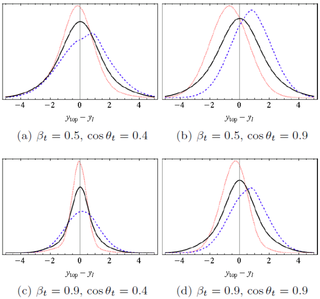
- Charged leptons from the decay of the top are highly sensitive to top spin (→ Brock's talk)
- The distinct chiral structures of models for the top $\mathcal{A}_{FB}$ give rise to distinctive signatures in leptonic and dileptonic distributions. (Godbole, Rao, Rindani, Singh; Jung, Ko, Lee; Choudhury, Godbole, Rindani, Saha; Cao, Wu, Yang; Krohn, Liu, JS, Wang)
  - These signatures contain new information beyond parent top kinematics
- For instance: top polarization

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{1}{2}\left(1 + \mathcal{P}\cos\theta\right)$$

  - t-channel models like the W' in particular have sizable new coupling to t_R and not to t_L: predict substantial top polarization

A few words about leptons

- Charged lepton rapidities are also measuring polarization:
  - lepton rapidity depends on parent top β_t, $\cos\theta_t$, and lepton angle $\cos\theta_\ell$
  - can be important for understanding acceptance



- Relation between top asymmetry and lepton asymmetry $\mathcal{A}^{\ell}_{FB}$ depends on model and is a powerful tool for discriminating between models

A few words about leptons

- At the Tevatron:
  - lepton charge asymmetries particularly useful
  - Discrimination between W' and G_A at $\sim 3\sigma$
- At the LHC:
  - polarization for W' visible within 1 fb^{-1}
  - Will have statistics to ask about many dileptonic observables: charge asymmetries, azimuthal correlations, spin correlations, and so on
  - Leptonic observables, like cross-sections, important for constraining or identifying physics responsible for top $\mathcal{A}_{FB}$

Conclusions

- LHC can measure a top $\mathcal{A}_{FB}$ by exploiting the event-by-event axis determined by the CM boost
  - Can measure large BSM asymmetries at $\gtrsim 3\sigma$ level within the 7 TeV run using dileptonic tops
  - Method has an obvious extension to semileptonic tops
- Meanwhile Tevatron can make additional measurements which could clarify the picture
  - suite of leptonic and dileptonic observables at the LHC add to the set of measurements which will help pin down the source of the top asymmetry
- Single top polarization is a potentially large signal indicating BSM physics in top events