The Top Forward-Backward Asymmetry at the Tevatron and the LHC

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JS and K. Zurek, arXiv:1101.5392
J. Hewitt, JS, M. Spannowsky, M. Takeuchi, T. Tait, arXiv:1103.4618
D. Krohn, T. Liu, JS, L.-T. Wang, arXiv:1105.3743

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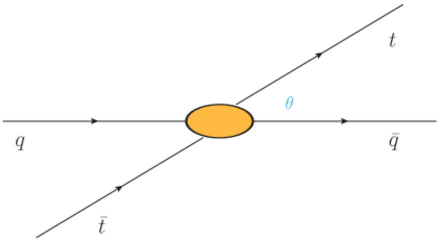
The top forward-backward asymmetry

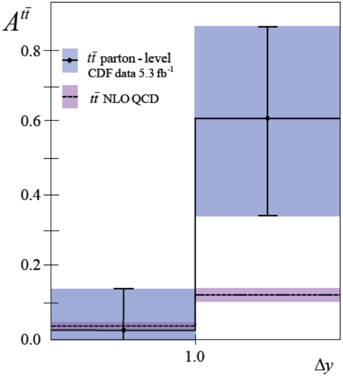


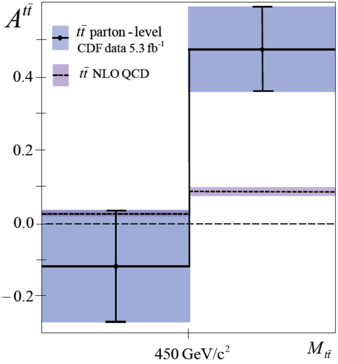
- The SM predicts a small but non-zero asymmetry in $p\bar{p} \to t\bar{t}$:

$$A_{SM}^{Tev} = 0.05 \pm 0.015 \text{ (Antuñano, Kühn, Rodrigo)},$$
$$= 0.066 \pm 0.015 \text{ (Almeida, Sterman, Vogelsang)}$$

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:

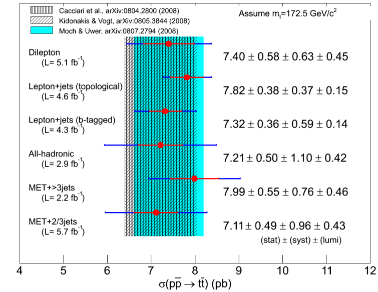




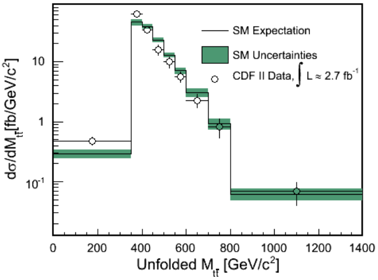
High-mass asymmetry $A^t_{hi} = 0.475 \pm 0114$, 3.4σ from SM (MC@NLO)

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 $\sigma(p\bar{p} \to t\bar{t})$

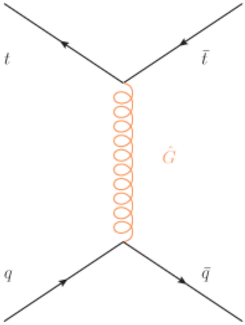


CDF measurements of $d\sigma/dm$

- Must explain large asymmetry without significant change to cross-section

Strategies to generate large A_{FB}^t

- To successfully explain all top measurements, generate asymmetry from interference of new physics with SM
- In particular, must interfere with $q\bar{q} \to t\bar{t}$, which restricts to 2 possibilities:



- *s*-channel exchange of spin 1 octet

  (Djouadi, Moreau, Richard, Singh; Frampton, Shu, Wang; Chivukula, Simmons, Yuan; Bai, Hewett, Kaplan, Rizzo)

- asymmetry $\propto -g_A^{u,d} g_A^t$: to get positive asymmetry, require flavor nonuniversal couplings

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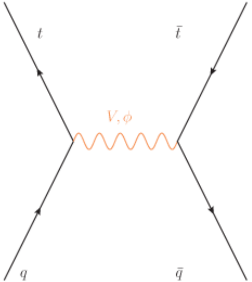

- *t*-channel exchange of spin 0,1, several color structures possible

  (Jung, Murayama, Pierce *et al.*; Shu, Tait, Wang; Cheung, Keung, Yuan; Barger, Keung, Yu; JS, Zurek; Grinstein, Kagan, Trott, Zupan; Ligeti, Schmaltz, Tavares)

- right magnitude for asymmetry requires large flavor-off-diagonal couplings

Strategies to generate large A_{FB}^t

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- In particular, must interfere with $q\bar{q} \to t\bar{t}$, which restricts to 2 possibilities:

Both strategies require new flavor structure.
t-channel large flavor violation striking. Is it possible to accommodate this flavor structure elsewhere?

1. MFV: (Grinstein, Kagan, Trott, Zupan; Ligeti, Schmaltz, Tavares)
2. extend Maximally Flavor Violating structure beyond top (JS, Zurek)

Testing models for top A_{FB}

- Models for top $\mathcal{A}_{FB}$ will be testable in the near future:
  - same-sign top pair production and charge asymmetries in single t production (Berger et al; Craig, Kilic, Strassler)
  - Excesses in $t\bar{t}$ and single t production (Aguilar-Saavedra, Perez-Victoria; Gedalia et al; Degrande et al)
  - Top polarization and non-SM spin correlations
  - New states will be produced on shell at LHC with large cross-sections (Kim, Gresham, Zurek; Hewett, JS, et al)
- Measure top asymmetry at the LHC
- Additional measurements at the Tevatron can strengthen case for new physics and help to discriminate between models

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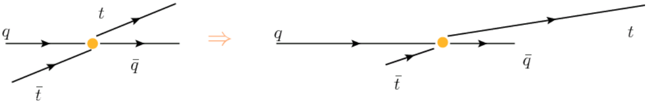
Top asymmetries at the LHC

- 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_{FB}^{t} limited but not eliminated

(Kuhn, Rodrigo; Antunano, Kuhn, Rodrigo)

Top 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)

Top 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)

Top 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 A_{FB} with dileptonic tops

- Outline of the analysis: Krohn, Liu, JS, Wang
  - Select dileptonic top events using basic selection cuts:
    isolated leptons, jets, MET
    remaining background dominantly Drell-Yan, small
  - 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 A_{FB} 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 $2 \rightarrow 6$ 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 ($\pm$1.2)
$m_{t\bar{t}} > 450$ GeV	5	3	6	20	0 ($\pm$1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	8	5	12	36	1 ($\pm$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.

Discrimination with leptonic variables

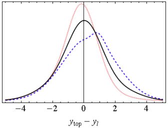
- Charged leptons from the decay of the top are highly sensitive to top spin
- Distinct chiral structures of models for the top $\mathcal{A}_{FB}$ give rise to distinctive signatures in leptonic and dileptonic distributions. (Godbole, Rao, Rindani, Singh; Jung, Ko, Lee; Choudhury, Godbole, Rindani, Saha;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

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

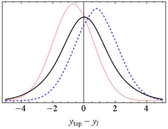
  - t-channel models like the W' in particular have sizable new coupling to t_R and not to t_L: predict substantial top polarization

Lepton rapidity as a polarization probe

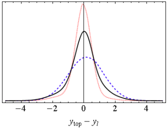
- Charged lepton rapidities are also measuring polarization:
    - lepton rapidity depends on parent top β_t, $\cos\theta_t$, and lepton angle $\cos\theta_\ell$
    - can be important for understanding acceptance



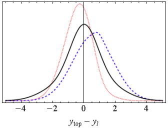
$\beta = 0.5$, $\cos\theta = 0.4$



$\beta = 0.5$, $\cos\theta = 0.9$



$\beta = 0.9$, $\cos\theta = 0.4$



$\beta = 0.9$, $\cos\theta = 0.9$

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

Leptonic observables

- 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
- Individual top polarization is a signal indicating BSM physics in top events which can be large