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

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1 Introduction

The Tevatron top forward backward asymmetry $\mathcal{A}^{t\bar{t}}$ has been consistently measured to exceed SM predictions by both CDF and D0 [1, 2] at a $\gtrsim 2\sigma$ level. Its status as the largest outstanding collider anomaly requires careful investigation of related signals. In the present proceedings we propose measurements at the LHC and the Tevatron which can help establish the existence and nature of a potential signal. In section 2 we discuss strategies for measuring a top charge asymmetry at the LHC, and demonstrate that a BSM asymmetry consistent with the Tevatron signal can be seen in 5 fb^{-1} of 7 TeV data. In section 3 we point out the utility of lepton charge asymmetries in top pair events at the Tevatron for characterizing the source of the asymmetry.

2 Top charge asymmetries at the LHC

The top forward-backward asymmetry is a vital but challenging measurement at the LHC. In this section we discuss prospects for measuring a BSM charge asymmetry in dileptonic tops at the 7 TeV LHC [3]. The aim is twofold: first, to present strategies for enhancing charge asymmetry signals to a size observable at the early LHC independent of the channel (semileptonic or dileptonic), and second, to provide the first study of the LHC charge asymmetry in dileptonic tops.

At the LHC, the difference between q and $\bar{q}$ PDFs turns a positive partonic forward-backward charge asymmetry translates into a positive *forward-central* charge asymmetry [4]. We define and study the observable

$$\mathcal{A}^{t\bar{t}} = \frac{N(0 < \hat{\theta}_t < \pi/2) - N(\pi/2 < \hat{\theta}_t < \pi)}{N(0 < \hat{\theta}_t < \pi/2) + N(\pi/2 < \hat{\theta}_t < \pi)}, \tag{1}$$

where $\hat{\theta}_t$ is the production angle of the top quark in the $t\bar{t}$ center of mass frame with respect to the direction of the boost of the $t\bar{t}$ system.

The LHC $\mathcal{A}^{t\bar{t}}$ of eq. 1 is a much more difficult signal to observe then the analogous asymmetry at the Tevatron, as symmetric gg-initiated events dominate top pair production, and the correlation between the partonic incoming quark direction is not as strong as the correlation between the proton direction and the partonic quark direction at the Tevatron. The intrinsic size of any SM or BSM top charge asymmetry at the LHC is reduced relative to its value at the Tevatron. The situation is improved by considering $t\bar{t}$ pairs with large invariant masses, where the size of the signal is intrinsically larger. The measurement also becomes cleaner, as the rapid falloff of the gluon PDF with x reduces the proportion of symmetric gg-initiated events. Since different models for the top charge asymmetry will predict different functional dependence on $m_{t\bar{t}}$, the optimal kinematic cuts will also differ between models. We impose $m_{t\bar{t}} > 450$ GeV, which is loosely optimized for a range of BSM reference models. In this regime the typical top p_T is ~ 150 GeV, below the threshold for the boosted top reconstruction techniques considered in [5].

By considering the high invariant mass bin, BSM contributions to the top charge asymmetry can be seen in dileptonic tops at a $\geq 3\sigma$ level after 5 fb^{-1}. We illustrate this in table 1 using two representative BSM models for the Tevatron charge asymmetry, (i) a flavor non-universal axigluon G_A with mass $m_{G'} = 2$ TeV, and axial couplings to first and third generation quarks $g_{A1} = -2.3$ and $g_{A3} = 3.35$ respectively, and (ii) a flavor-off diagonal W' coupling via $\mathcal{L} = g_R/\sqrt{2}W'^{-}_{\mu}\bar{d}\gamma^{\mu}P_R t + \text{H.c.}$, with mass $m_{W'} = 400$ GeV and coupling $g_R = 1.8$ [6]. Top events are fully showered and reconstructed using a realistic procedure after imposing selection cuts following [7]; for further details, see [3].

Table 1: Reconstructed top forward-backward asymmetry ($\mathcal{A}^{t\bar{t}}$) at a 7 TeV LHC, and in parentheses the 1σ statistical uncertainties, (i.e. $1/\sqrt{N}$) assuming 5 fb^{-1} of data.

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

Table 1 shows in addition the effect of requiring large rapidity for the $t\bar{t}$ system, $|y(t) + y(\bar{t})| > 2$, after which the contributions of $q\bar{q}$ and gg initial states are comparable. This condition increases the intrinsic signal size by suppressing the symmetric gg background and improving the correlation between the $t\bar{t}$ boost direction and the incoming q direction. In the dileptonic channel, the acceptance price for this cut is too severe and the measurement becomes statistically limited. However, semileptonic tops offer better statistics and will be more sensitive; the invariant mass and rapidity cuts introduced here will be equally effective at enhancing the intrinsic size of the asymmetry in the semileptonic channel. The 7 TeV LHC therefore has good prospects for measuring a BSM charge asymmetry.

3 Leptonic asymmetries at the Tevatron

It has long been appreciated that the charged lepton in top decay is maximally sensitive to the top spin. Measuring the lepton properties in top pair events probes the spin structure of the top production amplitude and provides additional information beyond the top kinematics. In particular, models for the Tevatron $\mathcal{A}^{t\bar{t}}$ often predict substantial top polarization. We emphasize that the charged lepton rapidity y_ℓ (in either the lab or the CM frame) is also sensitive to top polarization, as shown in Fig. 1.

The leptonic charge asymmetry in semileptonic top events

$$\mathcal{A}^{\ell}_{FB} = \frac{N(q_\ell y_\ell > 0) - N(q_\ell y_\ell < 0)}{N(q_\ell y_\ell > 0) + N(q_\ell y_\ell < 0)}, \tag{2}$$

as well as the generalization $\mathcal{A}^{\Delta\ell}_{FB}$ to the dileptonic channel, is an especially interesting observable. We emphasize that the relationship between $\mathcal{A}^{\ell}_{FB}$ and the parent $\mathcal{A}^{t\bar{t}}$ depends on the model generating the top asymmetry, and provides a valuable tool to distinguish between models at the Tevatron. This is demonstrated in table 2 for the two BSM reference models, together with two "axigluons" $G_{R,L}$ which are identical to the axial G_A model except for having their couplings adjusted to couple only to right- (left-) handed tops in order to highlight the polarization dependence of the lepton distributions. The characteristic relationships between the top and lepton asymmetries in different models allow good discrimination with the full Tevatron data set.

The leptonic charge asymmetry is relatively insensitive to top reconstruction, provides an important additional piece of information about top events, should not be assumed to be SM-like in experiment, and can provide support for and discrimination between BSM interpretations of the Tevatron measurements.

It is a pleasure to thank J. Hewett, M. Spannowsky, T. Tait, M. Takeuchi, and K. Zurek for collaboration on related matters, and in particular D. Krohn, T. Liu, and L.-T. Wang for collaboration on the results presented here.

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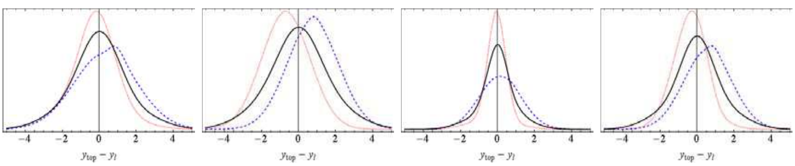
	frame and mass range	$t\bar{t}$ asymmetry	Lepton asymmetry	stat. sig. (5.3 fb^{-1})
G_A	lab, $m_{t\bar{t}} > 450$ GeV	17 %	9 %	1.9
	CM, $m_{t\bar{t}} > 450$ GeV	19 %	12 %	2.4
G_L	lab, $m_{t\bar{t}} > 450$ GeV	14 %	-1 %	0.2
	CM, $m_{t\bar{t}} > 450$ GeV	20%	-3 %	0.6
G_R	lab, $m_{t\bar{t}} > 450$ GeV	14 %	18 %	5.0
	CM, $m_{t\bar{t}} > 450$ GeV	15 %	22 %	4.4
W'	lab, $m_{t\bar{t}} > 450$ GeV	26 %	22 %	4.9
	CM, $m_{t\bar{t}} > 450$ GeV	31 %	26 %	5.3

Table 2: BSM contributions to the parton level $t\bar{t}$ and leptonic asymmetries after imposing CDF semileptonic acceptance cuts. Statistical significances of the leptonic asymmetries are based on the number of events observed in [2].



(a) $\beta_t = 0.5$, $\cos\theta_t = 0.4$ (b) $\beta_t = 0.5$, $\cos\theta_t = 0.9$ (c) $\beta_t = 0.9$, $\cos\theta_t = 0.4$ (d) $\beta_t = 0.9$, $\cos\theta_t = 0.9$

Figure 1: Distributions of the rapidity difference $y_{top} - y_\ell$ for right-handed (red, dotted), left-handed (blue, dashed) and unpolarized (black, solid) tops, for fixed top kinematics as determined by the top boost β_t and CM frame production angle $\cos\theta_t$.

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