Hunting New Physics in Top Pair Production

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Measurements of the forward-backward asymmetry (FBA) in $t\bar{t}$ production at the Tevatron significantly deviate from expectations within the standard model. Several new physics (NP) scenarios have been proposed as explanations of this anomaly. I briefly review the $t\bar{t}$ production observables at the LHC which could shed light on to the origin of the large FBA, whether it is mostly due to NP resonances exchanged in the $s-$, $t-$ or $u-$ channel, or even due to incoherent effects.

1 Introduction

The forward-backward asymmetry (FBA) in $t\bar{t}$ production at the Tevatron has been measured by both the CDF [1, 2] and DØ [3] collaborations and found to be significantly larger than the standard model (SM) predictions. The naïve average of the inclusive FBA, adding the uncertainties in quadrature, is

$$A_{FB} = 0.187 \pm 0.037\,, \tag{1}$$

while the NLO QCD prediction [1, 4] including leading electroweak (EW) contributions [5] is $A_{FB}^{\rm SM} = 0.07(2)$. Both CDF and DØ have also measured the FBA in bins of $m_{t\bar{t}}$ and t-$\bar{t}$ rapidity differences. Only CDF [1, 2], however, unfolds to the partonic ("truth") level obtaining

$$\begin{aligned} A_{FB}^{\rm lo} &\equiv A_{FB}(m_{t\bar{t}} < 450 \text{ GeV}) = 0.078 \pm 0.054\,, \\ A_{FB}^{\rm hi} &\equiv A_{FB}(m_{t\bar{t}} > 450 \text{ GeV}) = 0.296 \pm 0.067\,, \end{aligned} \tag{2}$$

to be compared with the SM (NLO QCD and EW) predictions $(A_{FB}^{\rm lo})^{\rm SM} = 0.05(1)$ and $(A_{FB}^{\rm hi})^{\rm SM} = 0.11(2)$ [1, 4, 5].

A related observable at the LHC is the charge asymmetry (CA) in $t\bar{t}$ production, A_C. In contrast to the FBA, the measurements of the CA at the LHC agree with the SM expectations. The average of ATLAS [6] and CMS [7] results,

$$A_C = 0.001 \pm 0.014\,, \tag{3}$$

agrees within errors with the SM prediction $A_C^{\rm SM} = 0.007(1)$ [6, 4, 5]. Recently, the ATLAS collaboration also presented the first results for the CA binned in $m_{t\bar{t}}$ [8]

$$\begin{aligned} A_C^{\rm lo} &\equiv A_C(m_{t\bar{t}} < 450 \text{ GeV}) = -0.053 \pm 0.088\,, \\ A_C^{\rm hi} &\equiv A_C(m_{t\bar{t}} > 450 \text{ GeV}) = -0.008 \pm 0.047\,, \end{aligned} \tag{4}$$

in agreement with the corresponding SM predictions, $A_C^{\rm lo} = 0.002(2)$ and $A_C^{\rm hi} = 0.009(2)$ [6, 4, 5]. Together with inclusive $t\bar{t}$ production cross-section and $m_{t\bar{t}}$ spectrum measurements at the Tevatron and the LHC, the measured CA already represents a significant constraint on NP models trying to address the anomalously large FBA values.

2 New physics models for the FBA

The large size of the observed non standard contributions to the FBA, points to NP affecting the $t\bar{t}$ production at hadronic colliders at the tree level and typically requires on-shell new degrees of freedom below the TeV scale. A reliable model-independent analysis of NP effects in $t\bar{t}$ production using effective field theory methods is thus not possible [9]. Alternatively, one can consider a single NP amplitude interfering with the SM contributions at a time. Such scenarios can then be classified according to the new resonances coupling to quarks and exchanged in $s-$, $t-$ or $u-$channel. Among the plethora of possible spin, weak isospin, charge and color assignments, only a few of such states can produce a sizable positive FBA at the Tevatron without being in gross conflict with the measurements of the total cross-section and/or the $m_{t\bar{t}}$ spectrum [10]. These include an $s-$channel exchanged (axial-)vector color octet boson (axigluon) [11, 12, 13], neutral (Z') [14] or charged (W') [15] vector bosons, coupling chirally to quarks and exchanged in the $t-$channel, a scalar isodoublet [16] whose neutral component contributes in the $t-$channel, as well as scalar color triplet [17, 18] or sextet [17] bosons coupling chirally to up-type quarks and contributing in the $u-$channel (c.f. [19] for a recent review).

3 LHC constraints

In $t-$ and $u-$channel models, the new FBA contributions are mainly driven by kinematics. In particular, they exhibit a forward Rutherford scattering peak. Due to the resulting strong correlations between the FBA and CA, the existing LHC CA measurements alone already exclude the Z' and W' models from addressing the FBA puzzle [20]. Another consequence is an enhanced $t\bar{t}$ production cross-section in the forward region, which could be probed with dedicated analyses at ATLAS and CMS [21] or even at the LHCb [22]. On the other hand, while same-sign top pair production [23] as well as electroweak [24, 25] and precision flavor observables [24, 26, 27] can be a problem, the relevance of such constraints is model-dependent and dangerous effects can be suppressed systematically e.g. by use of symmetries [27]. Similarly, if the new resonances are massive enough and not too broad, sizable flavor violating t+jet resonance production can be expected in $t\bar{t}$+jet final states [18, 28].

With $s-$channel NP, the FBA is essentially due to spin interference effects. Close to threshold, top quark spins effectively probe initial parton chiralities and possible non-standard contributions can be tested for using angular lepton asymmetries in leptonic top decay channels [29]. In general one expects strong correlations with $t\bar{t}$ spin correlation observables (c.f. [20] and references therein). On the other hand the singular features in the $m_{t\bar{t}}$ spectrum expected from $s-$channel NP (resonance in the cross-section and a flip in sign of the FBA and CA) can be suppressed if the resonance appears below $t\bar{t}$ production threshold [12, 13] and/or if it is very broad, as also required by dijet (resonance) constraints [13, 30, 31]. Another interesting related channel is (resonant) four top production at the LHC [32] which already provides a significant constraint [33].

4 Incoherent NP $t\bar{t}$ production

At present, the $t\bar{t}$ production cross-section at the Tevatron and the LHC is still subject to significant $\mathcal{O}(10\%)$ uncertainty. Thus, inclusive $t\bar{t}$ production observables like the FBA and CA could also be affected by NP contributions not interfering with the leading QCD $t\bar{t}$ amplitudes. An example is the production of "top partners" ($\tilde{t}$) decaying to top quarks and additional light invisible particles (χ^0) [34]. In order to pass experimental $t\bar{t}$ reconstruction and escape searches for $t\bar{t}+$ MET (missing transverse energy) $\tilde{t}$ should be almost degenerate with the top and χ^0 approximately massless. This puts strong preference for scalar $\tilde{t}$ candidates whose QCD production cross-section is mostly p-wave and is thus suppressed close to threshold [35]. The FBA is in this case driven by strongly asymmetric $t-$channel χ^0 mediated contributions [34]. Since the relevant interactions are flavor violating and involve couplings to light quarks, one would generically also expect effects in jets+MET final states.

5 Conclusions

The most significant hints of physics beyond the standard model at the Tevatron have been reported in the top sector. The large observed value of the FBA could still be due to new $\mathcal{O}$(TeV) ($s-$channel) resonances, in which case one generically expects excesses in the $t\bar{t}$ and di-jet (pair) spectra. Alternative interesting possibilities are represented by sub TeV NP contributions in the $u-$ or $t-$channel, in which case one predicts interesting signatures in $t\bar{t}$+jets final states. At the LHC, the FBA is manifested in terms of a rapidity dependent CA. Presently measured inclusive values are well consistent with SM predictions, introducing some tension in almost all existing NP proposals (see however [31]). In the near future top spin correlation and polarization observables could provide more complementary constraints. Finally, an enhanced $t\bar{t}$ production cross-section in the forward region in such NP scenarios represents an opportunity for an interesting top physics program at the LHCb.

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References

[1] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. D **83**, 112003 (2011);

[2] Y. Takeuchi *et al.* [CDF Collaboration] (2011), http://www- cdf.fnal.gov/physics/new/top/2011/DilAfb/, Note10398; T. Schwarz *et al.* [CDF Collaboration] (2011), CDF Note 10584; S. Leone [CDF Collaboration], Talk given at Moriond EWK, March 9, 2012.

[3] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **84**, 112005 (2011).

[4] S. Frixione and B. R. Webber, JHEP **0206**, 029 (2002); S. Frixione, P. Nason and B. R. Webber, JHEP **0308**, 007 (2003).

[5] W. Hollik and D. Pagani, Phys. Rev. D **84**, 093003 (2011); J. H. Kuhn and G. Rodrigo, JHEP **1201** (2012) 063; A. V. Manohar and M. Trott, Phys. Lett. B **711** (2012) 313.

[6] [ATLAS Collaboration], (2011), ATLAS-CONF-2011-106; [arXiv:1203.4211 [hep-ex]].

[7] [CMS Collaboration], (2011), CMS-PAS-TOP-11-030.

[8] A. Krasznahorkay, [ATLAS Collaboration], presented at ASPEN 2012 Winter Conference, 12 February, 2012.

[9] C. Delaunay, O. Gedalia, Y. Hochberg, G. Perez and Y. Soreq, JHEP **1108** (2011) 031.

[10] J. A. Aguilar-Saavedra and M. Perez-Victoria, JHEP **1105**, 034 (2011); J. A. Aguilar-Saavedra and M. Perez-Victoria, Phys. Rev. D **84**, 115013 (2011).

[11] O. Antunano, J. H. Kuhn and G. Rodrigo, Phys. Rev. D **77**, 014003 (2008); P. Ferrario and G. Rodrigo, Phys. Rev. D **80**, 051701 (2009); P. H. Frampton, J. Shu and K. Wang, Phys. Lett. B **683**, 294 (2010).

[12] R. Barcelo, A. Carmona, M. Masip and J. Santiago, Phys. Rev. D **84** (2011) 014024; R. Barcelo, A. Carmona, M. Masip and J. Santiago, arXiv:1106.4054 [hep-ph].

[13] G. M. Tavares and M. Schmaltz, Phys. Rev. D **84**, 054008 (2011); J. A. Aguilar-Saavedra and M. Perez-Victoria, Phys. Lett. B **705**, 228 (2011).

[14] S. Jung, H. Murayama, A. Pierce and J. D. Wells, Phys. Rev. D **81**, 015004 (2010).

[15] K. Cheung, W. -Y. Keung and T. -C. Yuan, Phys. Lett. B **682**, 287 (2009).

[16] K. Blum, Y. Hochberg and Y. Nir, JHEP **1110**, 124 (2011).

[17] J. Shu, T. M. P. Tait and K. Wang, Phys. Rev. D **81**, 034012 (2010); A. Arhrib, R. Benbrik and C. -H. Chen, Phys. Rev. D **82**, 034034 (2010); K. M. Patel and P. Sharma, JHEP **1104**, 085 (2011); Z. Ligeti, G. M. Tavares and M. Schmaltz, JHEP **1106** (2011) 109.

[18] I. Dorsner, S. Fajfer, J. F. Kamenik and N. Kosnik, Phys. Rev. D **81**, 055009 (2010).

[19] J. F. Kamenik, J. Shu and J. Zupan, arXiv:1107.5257 [hep-ph].

[20] S. Fajfer, J. F. Kamenik and B. Melic, arXiv:1205.0264 [hep-ph].

[21] O. Antunano, J. H. Kuhn and G. Rodrigo, Phys. Rev. D **77**, 014003 (2008); J. L. Hewett, J. Shelton, M. Spannowsky, T. M. P. Tait and M. Takeuchi, Phys. Rev. D **84** (2011) 054005; J. -F. Arguin, M. Freytsis and Z. Ligeti, Phys. Rev. D **84**, 071504 (2011).

[22] A. L. Kagan, J. F. Kamenik, G. Perez and S. Stone, Phys. Rev. Lett. **107**, 082003 (2011).

[23] J. A. Aguilar-Saavedra and M. Perez-Victoria, Phys. Lett. B **701**, 93 (2011); C. Degrande, J. -M. Gerard, C. Grojean, F. Maltoni and G. Servant, Phys. Lett. B **703**, 306 (2011).

[24] U. Haisch and S. Westhoff, JHEP **1108**, 088 (2011).

[25] M. I. Gresham, I. -W. Kim, S. Tulin and K. M. Zurek, arXiv:1203.1320 [hep-ph].

[26] I. Dorsner, S. Fajfer, J. F. Kamenik and N. Kosnik, Phys. Rev. D **82**, 094015 (2010).

[27] B. Grinstein, A. L. Kagan, M. Trott and J. Zupan, Phys. Rev. Lett. **107**, 012002 (2011); JHEP **1110**, 072 (2011).

[28] M. I. Gresham, I. -W. Kim and K. M. Zurek, Phys. Rev. D **84**, 034025 (2011).

[29] A. Falkowski, G. Perez and M. Schmaltz, arXiv:1110.3796 [hep-ph].

[30] R. S. Chivukula, E. H. Simmons and C. -P. Yuan, Phys. Rev. D **82**, 094009 (2010); C. Delaunay, O. Gedalia, S. J. Lee, G. Perez and E. Ponton, Phys. Lett. B **703**, 486 (2011); Y. Bai, J. L. Hewett, J. Kaplan and T. G. Rizzo, JHEP **1103** (2011) 003; A. Djouadi, G. Moreau and F. Richard, Phys. Lett. B **701**, 458 (2011);

[31] J. Drobnak, J. F. Kamenik and J. Zupan, arXiv:1205.4721 [hep-ph].

[32] J. A. Aguilar-Saavedra and J. Santiago, Phys. Rev. D **85**, 034021 (2012).

[33] N. Zhou, D. Whiteson and T. M. P. Tait, Phys. Rev. D **85**, 091501 (2012).

[34] G. Isidori and J. F. Kamenik, Phys. Lett. B **700**, 145 (2011).

[35] W. Beenakker, S. Brensing, M. Kramer, A. Kulesza, E. Laenen and I. Niessen, JHEP **1008**, 098 (2010).