Implications of the CDF $t\bar{t}$ Forward-Backward Asymmetry for Hard Top Physics

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The CDF collaboration has recently reported a large deviation from the standard model of the $t\bar{t}$ forward-backward asymmetry in the high invariant mass region. We interpret this measurement as coming from new physics at a heavy scale Λ, and perform a model-independent analysis up to $\mathcal{O}(1/\Lambda^4)$. We find that a large asymmetry can only be accommodated by heavy new physics that interfere with the standard model. In addition, the new physics induces a minimal enhancement of boosted jets. We show that a smoking gun test for the heavy new physics hypothesis is a significant deviation from the standard model prediction for the $t\bar{t}$ differential cross section at large invariant mass.

Experimental Data (see the table)

- Evidence for an anomalous forward-backward $t\bar{t}$ production asymmetry was observed for large invariant mass of the $t\bar{t}$ system ($M_{t\bar{t}}$).
- Hint for an excess in highly boosted jets, $p_T > 400\,\mathrm{GeV}$.
- Good agreement between other measurements and SM prediction.

Effective Field Theory (EFT)

- A model independent description.
- The new physics (NP) is at heavy scale - $\Lambda \gg M_{t\bar{t}}$.

EFT Description

- The dominant EFT operators are dimension 6 and lead from initial state $u\bar{u}$ to a final state $t\bar{t}$. The effective Lagrangian beyond the SM is

$$\mathcal{L}_{\rm eff} = \sum_i \frac{c_i}{\Lambda^2}\left(\bar{u}\Gamma^i_u u\right)\left(\bar{t}\Gamma^i_t t\right)\ ,\qquad \begin{array}{l} c_i - \text{real coefficients} \\ \Gamma^i_{u/t} - \text{all possible Lorentz/color structures}\end{array}$$

- The two operators which interfere with the SM are the most important:

$$\mathcal{O}^8_V = \left(\bar{u}\gamma_\mu T^a u\right)\left(\bar{t}\gamma^\mu T^a t\right)\ ,\qquad \mathcal{O}^8_A = \left(\bar{u}\gamma_\mu\gamma^5 T^a u\right)\left(\bar{t}\gamma^\mu\gamma^5 T^a t\right)\ .$$

- All the other operators can be approximately described by two parameters (which replace the c_i's except for c^8_V and c^8_A):
  - $R^2 \sim \sum(c_i)^2$ - the total amplitude.
  - θ - the projection on the asymmetry.
- To reduce sub-leading effects we normalize the NP contribution by the SM.

Observable	Data
$A^{t\bar{t}}_{450} \equiv A^{t\bar{t}}(M_{t\bar{t}} \geq 450\ )$	$+0.48 \pm 0.11$ (SM predict. $+0.09 \pm 0.01$)
$\sigma_{700} \equiv \sigma^{t\bar{t}}(700\,\mathrm{GeV} < M_{t\bar{t}} < 800\,\mathrm{GeV})$	$80 \pm 37\,\mathrm{fb}$
$\sigma_{450} \equiv \sigma^{t\bar{t}}(M_{t\bar{t}} > 450\,\mathrm{GeV})$	$1.9 \pm 0.3\,\mathrm{pb}$
$\sigma_{boosted} \equiv \sigma^{t\bar{t}}(p_T > 400\,\mathrm{GeV})$	$11 \pm 4\,\mathrm{fb}$ (SM predict. $2 \pm 0.2\,\mathrm{fb}$)

⇨

NP Goal/Constraints
$A^{t\bar{t},\mathrm{NP}}_{450} = +0.4 \pm 0.1$
$\lvert N_{700}\rvert \equiv \lvert\sigma^{\mathrm{NP}}_{700}/\sigma^{\mathrm{SM}}_{700}\rvert \lesssim 0.5$
$\lvert N_{450}\rvert \equiv \lvert\sigma^{\mathrm{NP}}_{450}/\sigma^{\mathrm{SM}}_{450}\rvert \lesssim 0.2$
$N_b \equiv \sigma^{\mathrm{NP}}_{boosted}/\sigma^{\mathrm{SM}}_{boosted} = 5 \pm 2$

NP forward-backward asymmetry goal

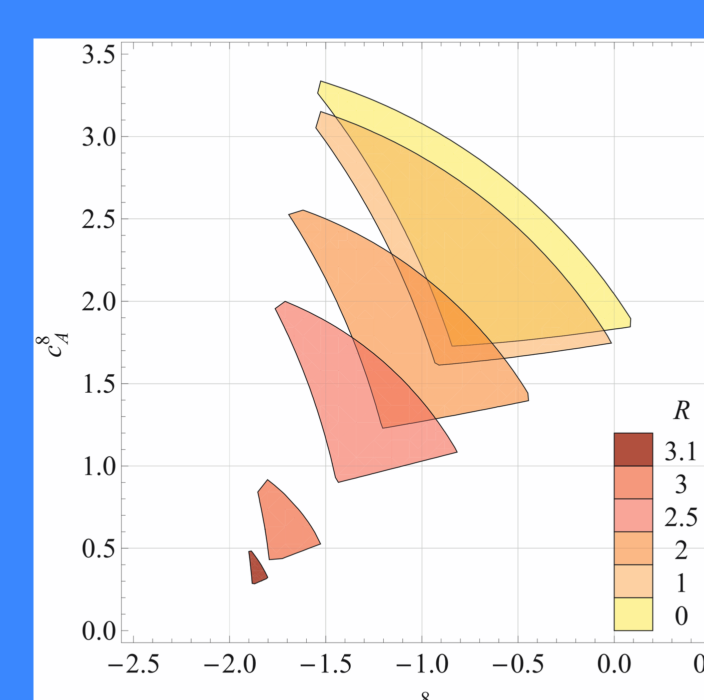
Constrains the NP

The required contribution of the NP to boosted cross section

Conclusions

The constraints on the NP lead to

- $A^{t\bar{t},\mathrm{NP}}_{450} \pm 1\sigma = 0.4 \pm 0.1$ ⇨ **Minimal** interference is needed $c^8_A/\Lambda^2_{\rm TeV} > 0.3$
 Minimal enhancement of boosted tops production $N_b \gtrsim 0.5$
- $N_b \lesssim 4$, it is consistent within $A^{t\bar{t},\mathrm{NP}}_{450} \pm 1\sigma$.
- In case that only operators with definite chirality are included $A^{t\bar{t},\mathrm{NP}}_{450} \lesssim 0.1$.
- $R \lesssim 3.1$.

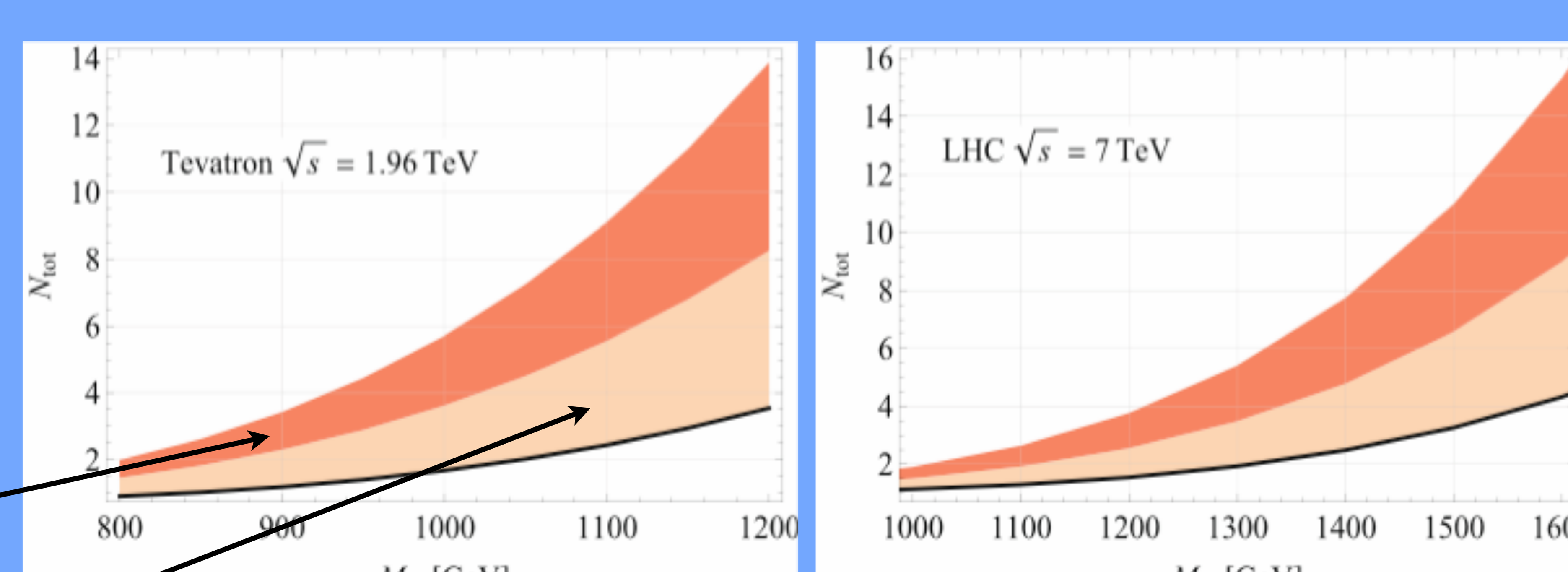


Allowed region for $c^8_V/\Lambda^2_{\rm TeV} - c^8_A/\Lambda^2_{\rm TeV}$ as constrained by $\pm 1\sigma$ for $A^{t\bar{t},\mathrm{NP}}_{450}$, N_{450} and N_{700} for different values of R.

Prediction for the Near Future

Expect that the NP will have a **large** contribution to the differential cross section ratio, $N_{\rm tot} \equiv \frac{d\sigma^{\rm SM+NP}/dM_{t\bar{t}}}{d\sigma^{\rm SM}/dM_{t\bar{t}}}$,at $M_{t\bar{t}} > 1\,\mathrm{TeV}$:

⇨ For the Tevatron - $N_{\rm tot}(M_{t\bar{t}} = 1\,\mathrm{TeV}) \gtrsim 2$.
 For the LHC, at 7 TeV - $N_{\rm tot}(M_{t\bar{t}} = 1.5\,\mathrm{TeV}) \gtrsim 3$.



corresponds to $A^{t\bar{t},\mathrm{NP}}_{450} = 0.4$, ranging over the allowed range for N_{700} and N_{450}.

corresponds to the range of $A^{t\bar{t},\mathrm{NP}}_{450} = 0.4 \pm 0.1$, ranging over the allowed range for N_{700} and N_{450}.

The ratio between the total and SM differential cross sections at top-pair production as a function of $M_{t\bar{t}}$ at the Tevatron (left) and the LHC at 7 TeV (right).

References:
- K. Blum *et al.*, Implications of the CDF $t\bar{t}$ Forward-Backward Asymmetry for Boosted Top Physics, arXiv:1102.3133.
- C. Delaunay, O. Gedalia, Y. Hochberg, G. Perez and Y. Soreq, Implications of the CDF $t\bar{t}$ Forward-Backward Asymmetry for Hard Top Physics, arXiv:1103.2297.