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ABSTRACT

New physics at a high scale Λ can affect top-related observables at $\mathcal{O}(1/\Lambda^2)$ via the interference of effective four quark operators with the SM amplitude. The $(\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)$ operator modifies the large $M_{t\bar{t}}$ forward–backward asymmetry, and can account for the recent CDF measurement. The $(\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)$ operator modifies the differential cross section, but cannot enhance the cross section of ultra-massive boosted jets by more than 60%. The hint for a larger enhancement from a recent CDF measurement may not persist future experimental improvements, or may be a QCD effect that is not accounted for by leading order and matched Monte Carlo tools or naive factorization. If it comes from new physics, it may stem from new light states or an $\mathcal{O}(1/\Lambda^4)$ new physics effect.

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1. Introduction

The top quark is unique among the known elementary fermions in that its coupling to the electroweak symmetry breaking sector is not small. There is still much to be explored in both the top quark sector and the electroweak breaking sector. This situation makes the experimental study of top physics interesting as a probe of new physics, and promising in its potential to lead to actual discoveries. The Tevatron experiments, CDF and D0, are now reaching a stage where the precision of their top-related measurements might provide first hints to such new physics.

The CDF Collaboration has recently provided two new intriguing measurements. First, a large forward–backward $t\bar{t}$ production asymmetry was observed for large invariant mass of the $t\bar{t}$ system [1]:

$$A_h^{t\bar{t}} \equiv A^{t\bar{t}}(M_{t\bar{t}} \geq 450 \text{ GeV}) = +0.475 \pm 0.114, \quad (1)$$

to be compared with the Standard Model (SM) prediction [2–4], $A_h^{t\bar{t}} = +0.09 \pm 0.01$.

Second, the CDF Collaboration has recently made progress in studying the mass distribution of highly boosted jets ($p_T > 400$ GeV for the leading jet) [5]. This study led to an upper bound of 20 fb on the corresponding boosted top pair cross section, based on naive QCD background estimation [6]. The analysis included

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two channels, one involving two massive jets (130–210 GeV) and another with one massive jet and large missing energy. An interesting result found was a significant deviation from the estimated background in the first channel, while no excess was found in the second channel or in the combined inclusive search. However, in Ref. [7] it was argued that the hadronic channel is more sensitive to the presence of boosted tops, and accounting for the excess in that channel leads to a tension of less than 1.5 standard deviations in the missing E_T channel. This observation motivates us to consider the possibility that the excess is associated with an enhanced boosted tops cross section, which might also be linked to Eq. (1).

The estimation of the excess depends on a parameter R_{mass} , described below in Eq. (3), which determines the QCD background. Assuming that both the statistical and systematic uncertainties scale linearly with R_{mass}^{-1} , the cross section for ultra-massive boosted jets (not coming from QCD events) can be written as follows

$$\sigma_b \equiv \sigma^{t_h \bar{t}_h}(p_T > 400 \text{ GeV}) \sim [21 - (8.7 \pm 3.1)R_{\text{mass}}^{-1}] \text{ fb}, \quad (2)$$

where t_h stands for a hadronically decaying top. The SM prediction is $\sigma_b^{\text{SM}} = 2.0 \pm 0.2$ fb [8].

It is not unlikely that the differences between either or both of these measurements and the corresponding SM predictions will disappear with improved experimental precision, or will be explained by non-trivial QCD effects. Yet, either or both of these effects might represent hints for new physics. Our approach in this work is the following. We interpret the measurement of $A_h^{t\bar{t}}$ in terms of new physics, checking the consistency of such a scenario with other measurements that do not show any significant deviation from the SM predictions. Then we extract the predictions

of such new physics explanations for ultra-massive boosted jets at the Tevatron, and compare to the recent measurement.

Several works have interpreted the recent CDF measurement of $A_h^{t\bar{t}}$ within specific models of new physics [9–15]. Similarly, new physics models were invoked [16–30] and model-independent studies were performed [31–33] to explain earlier D0 and CDF measurements of the inclusive asymmetry [34,35].

We do not discuss a specific new physics model, but we focus on a large class of models with the following two ingredients:

- The scale of the new physics is well above the scale $M_{t\bar{t}}$ that is relevant to the CDF measurements.
- The dominant contribution to $A_h^{t\bar{t}}$ comes from interference between the new physics contribution and the SM contribution to top pair production.

These assumptions allow us to follow a low energy model independent approach, and lead us to particularly clear and strong conclusions. Ref. [32] has recently presented a comprehensive analysis of top pair production at hadron colliders within the same framework. The novelty in our work is, first, the incorporation of the measurement of the $M_{t\bar{t}}$ -dependent $A_h^{t\bar{t}}$ and, second, the study of the boosted jets.

2. Boosted jets production

The CDF study [6] focused on events with two jets, with a lower bound on the transverse momentum ($p_T > 400$ GeV) and an upper bound on the pseudorapidity ($|\eta| < 0.7$) of the leading jet. As concerns the jet masses, CDF has defined “light” (30–50 GeV) and “massive” (130–210 GeV) jets. The search was divided to four regions. Region A corresponds to events with two light jets, regions B and C to one light and one massive jet, depending on which is the leading jet in terms of p_T , and region D corresponds to two massive jets. The top pairs should contribute to region D. To estimate the QCD contribution to this region, three assumptions were invoked:

1. Events in regions A, B, C come from only QCD;
2. The actual cross section can be factorized into the partonic cross section, which only weakly depends on the masses of the final states, and the jet and soft functions;
3. The masses of the leading and sub-leading jets are largely uncorrelated.

Under these assumptions,

$$R_{\text{mass}} \equiv \frac{n_B n_C}{n_A n_D} = 1, \quad (3)$$

where n_X is the number of QCD events in region X . Assumption 3 above could turn out to be wrong if there is some mechanism in QCD which leads to bias towards two massive jets. In [7] it was shown that R_{mass} is insensitive to the variation of the relative partonic momentum fraction of the parton distribution function (PDF) value due to the variation of the jet masses between regions A to D. Furthermore, it is possible to test this assumption by using various Monte Carlo (MC) tools to extract R_{mass} . We did so with four different tools. The results are summarized in Table 1.

The impressive agreement between Sherpa and MadGraph when matching is employed leads us to use, instead of Eq. (3), the estimate

$$R_{\text{mass}} = 0.87. \quad (4)$$

The estimated number of background events within the data sample of 5.95 fb^{-1} is then

Table 1

The results for R_{mass} [Eq. (3)] from the different MC tools: Sherpa (1.2.3) [36] with matching (jj, jij, jijj), MadGraph/MadEvent (4.4.56) [37] with MLM matching [38] (jj, jij, jijj) to the Pythia package (2.1.4) [39], MadGraph/MadEvent with no matching, and Herwig (6.520) [40] with no matching. We use the CTEQ6M PDF set [41] and FastJet (2.4.2) [42] with anti- k_r algorithm [43] ($\Delta R = 1$). Quoted errors are statistical only.

MC tools	Matching	R_{mass}
Sherpa	Yes	0.88 ± 0.03
MadGraph	Yes	0.86 ± 0.04
MadGraph	No	0.76 ± 0.04
Herwig	No	0.86 ± 0.02

$$\text{QCD: } 15 \pm 5,$$

$$t\bar{t}: 3 \pm 1. \quad (5)$$

The number of observed events was 32 [6], which constitutes a deviation of 2.7σ from the above expectation. Following the exercise performed in Ref. [7], the difference between the 32 observed events and the mean value of Eq. (5) is translated to a cross section of

$$\sigma_b^{\text{NP}} \sim 10 \pm 4 \text{ fb}, \quad (6)$$

or, equivalently,

$$N_b \equiv \sigma_b^{\text{NP}} / \sigma_b^{\text{SM}} \sim 5 \pm 2. \quad (7)$$

Below we obtain predictions from new physics scenarios for N_b , which we will compare against Eq. (7).

3. Additional data

Other top-related CDF and D0 measurements, beyond $A_h^{t\bar{t}}$ and σ_b , do not show significant deviations from the SM predictions. (Interestingly, a recent D0 measurement of the differential p_T distribution of $t\bar{t}$ events hints towards some increase over the NLO SM prediction for $p_T \sim 300$ GeV [44].) When we invoke new physics to account for the large value of $A_h^{t\bar{t}}$, we will have to make sure that such new physics does not violate the constraints from other measurements. Specifically, we consider the following measurements:

- (i) The forward–backward $t\bar{t}$ production asymmetry for small invariant mass of the $t\bar{t}$ system [1]:

$$A_I^{t\bar{t}} \equiv A^{t\bar{t}}(M_{t\bar{t}} \leq 450 \text{ GeV}) = -0.116 \pm 0.153, \quad (8)$$

to be compared with the SM prediction [2], $A_I^{t\bar{t}} = +0.040 \pm 0.006$.

- (ii) The inclusive $t\bar{t}$ production cross section reported by the CDF Collaboration [45,46]:

$$\sigma_i \equiv \sigma_{\text{inclusive}}^{t\bar{t}} = 7.50 \pm 0.48 \text{ pb}, \quad (9)$$

which is consistent with the D0 result [47]. This is to be compared with the SM prediction [48], $\sigma_i = 7.2 \pm 0.4$ pb. We note that the results of [48] agree with other recent evaluations [49,50], but are in some tension with [51]. We conservatively use this result, as that of [51] would be less constraining given our framework.

- (iii) The $t\bar{t}$ differential cross section, which for simplicity we choose to represent by the following large $M_{t\bar{t}}$ bin [52]:

$$\sigma_h \equiv \sigma^{t\bar{t}}(700 \text{ GeV} < M_{t\bar{t}} < 800 \text{ GeV}) = 80 \pm 37 \text{ fb}, \quad (10)$$

to be compared with the SM prediction [2,51], $\sigma_h = 80 \pm 8$ fb. The choice of this specific bin requires some explanation.

- Since we focus on new physics which contributes to the $t\bar{t}$ cross section $\propto (M_{t\bar{t}}/\Lambda)^2$ relative to the SM, the corrections to lower $M_{t\bar{t}}$ bins are less significant.

- In the more recent study of [1], which was based on a larger sample, there is some discrepancy above 800 GeV (note however that the data in [1] is not unfolded to the partonic level and so cannot be directly used). Hence we choose to use the next-to-last bin given in [52].

In order to minimize the impact of NLO corrections to the new physics (NP) contributions, we normalize the new physics contribution to the SM one. We assume that the K -factors are universal, so that the NP/SM ratios at LO and NLO are the same. Since the highly virtual intermediate gluon in the SM process can be integrated out to give \mathcal{O}_V^8 , NP NLO contributions should be similar, up to small corrections of $\mathcal{O}(\alpha_s)$. Moreover, the parity invariance of QCD suggests that the same argument applies to \mathcal{O}_A^8 as well.

Combining in quadrature the experimental and theoretical uncertainties, we represent Eqs. (9) and (10) as follows:

$$\begin{aligned} N_i &\equiv |\sigma_i^{\text{NP}}/\sigma_i^{\text{SM}}| \lesssim 0.1, \\ N_h &\equiv |\sigma_h^{\text{NP}}/\sigma_h^{\text{SM}}| \lesssim 0.5. \end{aligned} \quad (11)$$

4. \mathcal{L}_{eff} for $t\bar{t}$ production

The basic assumption that we aim to test is that the source of the large value of $A_h^{t\bar{t}}$ is new physics that is characterized by a mass scale Λ that is larger than $M_{t\bar{t}}$ in all the measurements that we consider. (In particular, our Tevatron-related calculations are safe for $\Lambda \gtrsim 2$ TeV.) In such a case, the new physics can be represented as a set of effective operators. These operators must lead from an initial $u\bar{u}$ state to a final $t\bar{t}$ state. (The contribution of $d\bar{d} \rightarrow t\bar{t}$ at the Tevatron is at most 15% that of $u\bar{u} \rightarrow t\bar{t}$ for $M_{t\bar{t}}$ above 450 GeV, as relevant for the observables that we consider.) When expanding in inverse powers of the scale Λ , the leading NP contributions to top pair production appear at $\mathcal{O}(1/\Lambda^2)$:

$$|M|^2 = |M_{\text{SM}}|^2 + 2\text{Re}(M_{\text{SM}}M_{\text{NP}}^*) + \mathcal{O}(1/\Lambda^4). \quad (12)$$

Therefore, we should consider dimension-six operators that interfere with the SM amplitude. There are two such four-quark operators:

$$\begin{aligned} \mathcal{L}_{\text{eff}}^{4q} &= \frac{1}{\Lambda^2} (c_A^8 \mathcal{O}_A^8 + c_V^8 \mathcal{O}_V^8), \\ \mathcal{O}_A^8 &= (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t), \\ \mathcal{O}_V^8 &= (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t). \end{aligned} \quad (13)$$

Below, we consider the effects of these two operators on the forward–backward asymmetry and on the differential cross section in top pair production. We work only at leading order, using the MSTW PDF set [53] and running of the strong coupling at leading order. We use factorization and renormalization scales given by the partonic center of mass energy. Note that all other possible Lorentz structures (scalar, pseudoscalar, tensor and pseudotensor) and the other possible color contractions do not interfere with the SM amplitude.

In addition to the four-quark operators, there is a chromomagnetic dipole operator,

$$\mathcal{L}_{\text{eff}}^{tg} = \frac{c_{tg}^V}{\Lambda^2} (\bar{t}\sigma_{\mu\nu} T^a t) G^{a\mu\nu}. \quad (14)$$

Here v is the vacuum expectation value of the Higgs field, reflecting the fact that the operator breaks $SU(2)$. The corresponding chromoelectric dipole operator violates CP and, therefore, does not interfere with the SM amplitude. The interference of the chromomagnetic operator requires a chirality flip. Consequently, the corresponding operator involving the up quark is suppressed by m_u and

therefore negligible. Thus, among the dipole operators, Eq. (14) is the only one that we need to consider.

The interference of the c_{tg} term with the SM amplitude does not contribute to the forward–backward asymmetry. As concerns the contribution to the cross section, it falls like $1/M_{t\bar{t}}^2$ [32]. We learn that while the c_{tg} term can affect the inclusive cross section, it does not affect $A_h^{t\bar{t}}$, and its effect on N_h and N_b is negligible. We therefore focus mainly on the effects of \mathcal{O}_A^8 and \mathcal{O}_V^8 . See, however, additional discussion above Eq. (23).

5. The forward–backward asymmetry

It is convenient to represent the new physics effects on $A^{t\bar{t}}$ as follows:

$$(A^{t\bar{t}})^{\text{NP}} = \frac{\sigma_-^{\text{NP}}}{\sigma_+^{\text{SM}} + \sigma_+^{\text{NP}}}, \quad (15)$$

where $\sigma_\pm \equiv \sigma(\Delta y > 0) \pm \sigma(\Delta y < 0)$ and Δy is the rapidity difference, $\Delta y = y_t - y_{\bar{t}}$. Among the two operators of Eq. (13), only \mathcal{O}_A^8 contributes to σ_- . If this is the only NP operator, the NP contribution to $A_h^{t\bar{t}}$ is

$$(A_h^{t\bar{t}})^{\text{NP}} \simeq 0.17 \frac{c_A^8}{\Lambda_{\text{TeV}}^2}, \quad (16)$$

where $\Lambda_{\text{TeV}} = \Lambda/\text{TeV}$. Requiring that $(A_h^{t\bar{t}})^{\text{NP}} \sim +0.4 \pm 0.1$, we obtain

$$c_A^8/\Lambda_{\text{TeV}}^2 \sim 2.4 \pm 0.7. \quad (17)$$

Eq. (17) implies, in turn,

$$(A_l^{t\bar{t}})^{\text{NP}} \sim +0.10 \pm 0.03 \implies A_l^{t\bar{t}} = +0.14 \pm 0.04, \quad (18)$$

about 1.7σ higher than the experimental result in Eq. (8). In addition, Eq. (17) predicts $(A^{t\bar{t}})^{\text{NP}} \sim +0.21 \pm 0.06$, 1.5σ too large [1], and $(A^{t\bar{t}}(\Delta y > 1))^{\text{NP}} \sim +0.55 \pm 0.15$, within one standard deviation from the measurement [1]. On the other hand, the \mathcal{O}_A^8 operator does not affect the cross section at $\mathcal{O}(1/\Lambda^2)$ and, in particular, cannot enhance the boosted jets cross section. The contribution of the next order in $1/\Lambda^2$ to the forward–backward asymmetry is subdominant, and, using the one sigma lower bound of Eq. (17), saturates the constraint from N_h in Eq. (11).

Eq. (17) provides an upper bound on the scale of new physics. We use naive dimensional analysis (NDA) to derive an upper bound on c_A^8 ,

$$c_A^8 \lesssim 16\pi^2. \quad (19)$$

Combining this upper bound with the one sigma lower bound in Eq. (17), we obtain

$$\Lambda \lesssim 10 \text{ TeV}. \quad (20)$$

The upper bound on Λ in Eq. (20) implies that, if a heavy axigluon is to provide a perturbative explanation to the large asymmetry in Eq. (1), then new physics effects should be observed early on at the LHC. In particular, given that the LHC will directly explore energy scales close to Λ , then the $t\bar{t}$ production cross section should be significantly enhanced at high $M_{t\bar{t}}$ (see [54] for more details).

To substantiate this statement, we perform the following exercise. We note that the \mathcal{O}_A^8 operator does modify the cross section at $\mathcal{O}(1/\Lambda^4)$ via the $|M_{\text{NP}}|^2$ term. We plot in Fig. 1 the differential $t\bar{t}$ cross section as a function of $M_{t\bar{t}}$ at the LHC for the case where the SM is augmented by only the \mathcal{O}_A^8 operator, with the coupling of Eq. (17) (the distribution at the Tevatron is also depicted for comparison). Of course, at this order

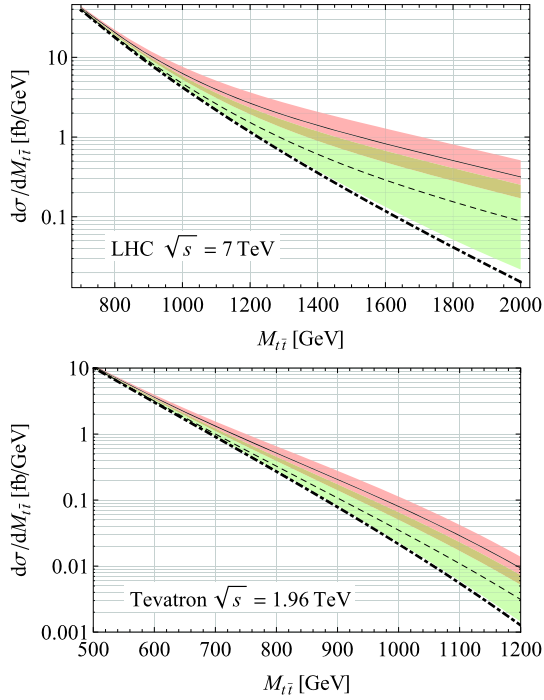


Fig. 1. The differential cross section of top pair production as a function of $M_{t\bar{t}}$ at the LHC at 7 TeV (top) and the Tevatron (bottom), calculated at leading order. The dashed–dotted curve corresponds to $\sigma_{\text{SM}}^{\text{SM}}$. The solid curve corresponds to $\sigma^{\text{SM}+\mathcal{O}_A^8}$, where the new physics coupling is set by the central value of $A_h^{t\bar{t}}$. The dashed curve corresponds to $\sigma^{\text{SM}+\mathcal{O}_A^8}$, where the new physics coupling is set by the central value of the inclusive asymmetry $A^{t\bar{t}}$. The shaded regions around the two upper curves depict the one sigma ranges of the corresponding measurements.

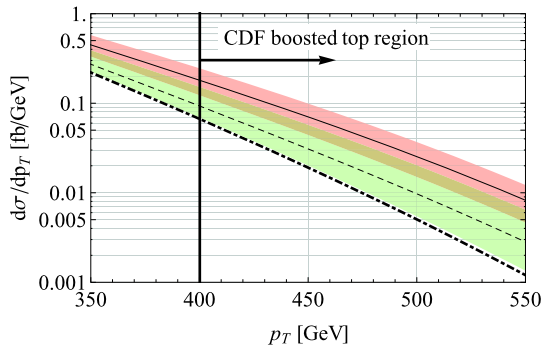


Fig. 2. The differential cross section of top pair production as a function of p_T at the Tevatron, calculated at leading order. The color and curve conventions are the same as in Fig. 1. The vertical line corresponds to the lower p_T cut used in the analysis of [6].

there are many more operators that affect the cross section, either via $|M_{\text{NP}}|^2$ for $\mathcal{O}(1/\Lambda^2)$ operators, or via $\text{Re}(M_{\text{SM}} M_{\text{NP}}^*)$ for $\mathcal{O}(1/\Lambda^4)$ operators. In Ref. [54] it is shown, however, that there can be no fine-tuned cancellations between these other contributions and the one that we consider. Thus our calculation illustrates the size of the effects that should be expected at the LHC. We learn that at $M_{t\bar{t}} \sim 1.5$ TeV, we should expect an enhancement by a factor ~ 5 compared to the SM. When applied to the Tevatron, the same exercise gives an enhanced boosted jets production cross section of $N_b \sim 2$, which is 1.5σ from the mean value in Eq. (7). Fig. 2 depicts the resulting p_T distribution at the Tevatron.

We stress that the recent measurement of the differential $t\bar{t}$ forward–backward asymmetry predicts a more pronounced deviation from the SM at the LHC than the previous inclusive asymmetry measurement. This is illustrated in Fig. 1 by the difference between the solid and dashed curves (and the respective shaded regions) and the dashed–dotted curve representing the SM prediction.

6. The $t\bar{t}$ production cross section

Among the two operators of Eq. (13), only \mathcal{O}_V^8 contributes to the inclusive cross section (σ_i), to the cross section at large $M_{t\bar{t}}$ (σ_h) and to the production cross section of boosted jets (σ_b) at $\mathcal{O}(1/\Lambda^2)$:

$$\begin{aligned} N_i &\simeq 0.24 c_V^8 / \Lambda_{\text{TeV}}^2, \\ N_h &\simeq 0.76 c_V^8 / \Lambda_{\text{TeV}}^2, \\ N_b &\simeq 1.5 c_V^8 / \Lambda_{\text{TeV}}^2. \end{aligned} \quad (21)$$

This equation, where relevant, is consistent with previous results in the literature ([32] and references therein). Independently of the value of the coupling, our framework predicts

$$N_b \sim 2N_h \sim 6N_i. \quad (22)$$

This ordering of the size of the effects reflects the fact that each of these three measurements samples a different $M_{t\bar{t}}$ region; the closer this region is to Λ , the larger the effect.

The relation between N_b and N_i and between N_h and N_i can be modified by the presence of the chromomagnetic dipole operator in Eq. (14), if $|c_{tg}|$ is not much smaller than $|c_V^8|$. However, since the c_{tg} term does not affect the cross section at high invariant mass $M_{t\bar{t}}^2 \gg m_t^2$, the relation between N_b and N_h is insensitive to it. The bound on N_h in Eq. (11) then leads to an upper bound on the enhancement of boosted jets production:

$$N_b \lesssim 0.8, \quad (23)$$

well below our estimate of Eq. (7). We conclude that one of the following must hold:

- The estimate of Eq. (7) is wrong because of either experimental or QCD effects.
- New physics explains Eq. (7), but it is characterized by a scale that is $\lesssim 1$ TeV.
- Heavy new physics explains Eq. (7), but $\mathcal{O}(1/\Lambda^4)$ terms play an important role [54].
- The reported excess in events with two boosted massive jets does not originate from top quarks.

7. Conclusions

The recent CDF measurement of the $t\bar{t}$ forward–backward asymmetry at large $M_{t\bar{t}}$, $A_h^{t\bar{t}}$, shows a deviation higher than 3σ from the SM prediction. The recent CDF measurement of ultra-massive boosted jets, σ_b , shows a deviation of order 2.7σ from a SM calculation augmented with an estimate of QCD background based on data and on several simplifying assumptions that we test with various MC tools.

We investigated whether these effects can be accounted for within a large class of new physics models. This class of models is defined by a mass scale above the scales directly explored by these CDF measurements, and a dominant effect coming from interference between the Standard Model and new physics amplitudes.

Table 2

Effects from new physics of $\mathcal{O}(1/\Lambda^2)$ on top-related observables. The first column gives the list of observables, and the second the equation where they are defined. We use $A_h^{t\bar{t}}$, σ_i and σ_h to fix, or constrain, the new physics parameters. The experimental value quoted for σ_h is based on our theoretical interpretation of the data.

Obs.	Def.	Experiment	Standard Model	New physics
$A_h^{t\bar{t}}$	Eq. (1)	$+0.475 \pm 0.114$	$+0.09 \pm 0.01$	Input
$A_{\bar{t}\bar{t}}^{t\bar{t}}$	Eq. (8)	-0.116 ± 0.153	$+0.040 \pm 0.006$	$+0.16 \pm 0.04$
σ_i	Eq. (9)	7.50 ± 0.48 pb	7.2 ± 0.4 pb	Input
σ_h	Eq. (10)	80 ± 37 fb	80 ± 8 fb	Input
σ_b	Eqs. (2), (4)	12 ± 4 fb	2.0 ± 0.2 fb	< 3.2 fb

Within this framework, we find that there is a single four quark operator that contributes to the asymmetry, which is the axial vector, color octet, operator $\mathcal{O}_A^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)$. There is a different single four quark operator that modifies the differential cross section at high $t\bar{t}$ invariant mass, which is the vector, color octet, operator $\mathcal{O}_V^8 = (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)$. This means in particular that there is no model independent relation between the forward–backward asymmetry and the boosted jets cross section. Note that we focus on these operators at tree level, and so do not discuss their contribution to dijet production at the LHC [12].

Our numerical results are summarized in Table 2. If \mathcal{O}_A^8 accounts for the high value of $A_h^{t\bar{t}}$, then the asymmetry at low invariant mass is about 1.7σ high compared to the CDF measurement. One should expect a striking enhancement of $t\bar{t}$ production at high $M_{t\bar{t}}$ at the LHC.

If \mathcal{O}_V^8 is to be consistent with constraints from the inclusive and differential cross sections, then it cannot enhance the boosted tops cross section by more than 60%. Furthermore, \mathcal{O}_V^8 is restricted to be significantly smaller than the contribution of \mathcal{O}_A^8 implied by the $t\bar{t}$ asymmetry. This means that a chiral model cannot consistently reproduce the asymmetry.

The above conclusions are related to the fact that the interference effects of heavy new physics with the SM scale roughly as $(M_{t\bar{t}}/\Lambda)^2$ relative to the SM. Consequently, they do not differentiate between the low and high $M_{t\bar{t}}$ regions enough to avoid tension with the data.

The conclusion concerning the ultra-massive boosted tops is that $\mathcal{O}(1/\Lambda^2)$ effects do not explain the discrepancy of the data with our theoretical estimate of the SM contribution. Perhaps the explanation does not involve new physics: The deviation is below 3σ and might disappear with better experimental accuracy, or it could be that QCD effects that are unaccounted for in the various MC tools play a role. If the deviation is related to new physics, then either the new physics is below the TeV scale and cannot be represented by effective higher-dimension operators, or the contribution of $|M_{\text{NP}}|^2 \propto 1/\Lambda^4$ is significant, bringing into the analysis a richer set of operators and a sharper distinction between the low and high $M_{t\bar{t}}$ regions.

The LHC will explore $t\bar{t}$ production at higher energy scales. Whether the scale Λ is within its direct reach or just beyond it, new physics effects are expected to be large. The Tevatron, on the other hand, has better access to the $q\bar{q} \rightarrow t\bar{t}$ process which, via observables such as the forward–backward asymmetry, can close in on the detailed structure of new physics. The combination of Tevatron and LHC measurements is likely to shed light on the top-related puzzles very soon.

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