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Diagnosing top-quark Forward-Backward asymmetry

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Introduction

Recently the two experiments at the Fermilab-Tevatron reported that the top-quark forward-backward asymmertry, $\mathcal{A}^t_{FB}$ to be

$\mathcal{A}^t_{FB}(\texttt{ D}\varnothing) = 0.19 \pm 0.065$, and,

$\mathcal{A}^t_{FB}(\texttt{ CDF}) = 0.158 \pm 0.074$

which are clearly consistent with each other within experimental errors.

But these are about 2.5σ higher than the best available SM predictions of 0.058 ± 0.009, and, $0.072^{+0.011}_{-0.007}$ at the NLO and NLO + NNLL levels respectively.

Also, the top-pair production cross-section has been found to be consistent within the limits of theoretical predictions for the SM.

This creates a tension in the new physics model that was constructed to explain the enhanced $\mathcal{A}^t_{FB}$ as the new interactions would contribute to the top-pair production cross-section.

Introduction ...

Depending upon whether the additional contribution to the $\mathcal{A}^t_{FB}$ is due to a s-channel exchange or due to a t-channel exchange several suggestions (e. g. an extra Z', axi-gluons, color-sextet, octet, W' ...) have been made to explain this effect.

The former category of models require processes where the exchaned particle have flavor diagonal couplings to the SM-quarks.
This is severely constrained from the direct searches on non-observation of any weakly coupling non-standard under-TeV resonance at the Tevatron or at the LHC.

The later possibility requires processes in which an up- or charm-quark can transit into the top-quark or vice versa. Interestingly such (flavor-violating) interactions would also be responsible for the production of same-sign top pairs ($\rightarrow$ same-sign dilepton) at the hadron collider.

The A^t_{FB} Operators

We approached studying this effect in a more general way by starting with the most general form of Lagrangian containing flavor-violating interactions of the top quark with a scalar, vector or even a tensor particle and the up-type quark.

We do not even impose $SU(2) \times U(1)$ unlike Grojean et al [arxiv:1104.1798[hep-ph]].

This gives us the following basis of operators,

$$Q^{V1}_{AB} = (\overline{u}\gamma^{\mu} P_A t)\,(\overline{u}\gamma_{\mu} P_B t) \qquad Q^{V8}_{AB} = (\overline{u}\gamma^{\mu} P_A T^a t)\,(\overline{u}\gamma_{\mu} P_B T^a t)$$

$$Q^{S1}_{AB} = (\overline{u} P_A t)\,(\overline{u} P_B t) \qquad Q^{S8}_{AB} = (\overline{u} P_A T^a t)\,(\overline{u} P_B T^a t)$$

$$Q^{T1}_{A} = (\overline{u}\sigma^{\mu\nu} P_A t)\,(\overline{u}\sigma_{\mu\nu} P_A t) \qquad Q^{T8}_{A} = (\overline{u}\sigma^{\mu\nu} P_A T^a t)\,(\overline{u}\sigma^{\mu\nu} P_A T^a t)$$

Where $P_A = \frac{1}{2}(a_1 + a_5\gamma_5)$, and, $P_B = \frac{1}{2}(b_1 + b_5\gamma_5)$.

For practical purposes we considered the following six realistic possibilities to each of these with a coupling constant g_X;

- $P_A = P_L = P_B$,
- $P_A = P_L, P_B = P_R$ or vice-versa,
- $P_A = P_R = P_B$,
- $P_A = I = P_B$,
- $P_A = I, P_B = \gamma_5$ or vice-versa, and,
- $P_A = \gamma_5 = P_B$.

This thus leads to $6 \times 6 = 36$ independent cases.

The SM and NP contributions to the top-quark forward-backward asymmetries $\mathcal{A}_{FB}^{t,SM}$ and $\mathcal{A}_{FB}^{t,NP}$ are correlated to the $t\bar{t}$ cross-section in the following manner

$$\mathcal{A}_{FB}^{t,Total} = \left(\frac{\sigma_{t\bar{t}}^{SM}}{\sigma_{t\bar{t}}^{Total}}\right)\mathcal{A}_{FB}^{t,SM} + \left(\frac{\sigma_{t\bar{t}}^{NP}}{\sigma_{t\bar{t}}^{Total}}\right)\mathcal{A}_{FB}^{t,NP}, \qquad (1)$$

$$\mathcal{A}_{FB}^{t,SM} = \frac{\sigma_{t\bar{t}}^{SM}(\cos\theta>0) - \sigma_{t\bar{t}}^{SM}(\cos\theta<0)}{\sigma_{t\bar{t}}^{SM}};$$

where $\sigma_{t\bar{t}}^{Total} = \sigma_{t\bar{t}}^{SM} + \sigma_{t\bar{t}}^{NP}$.

θ is the the angle of the top quark in the $t\bar{t}$ center-of-mass frame.

Numerical Analysis and Results

For our numerical studies we implemented aforementioned interaction terms into the `MadGraph5` using `FeynRules`.

We also reproduced some of the existing results for a check.

`CTEQ6L1` was used to evaluate the parton densities at $\mu_R = \sqrt{\hat{s}} = \mu_F$.

Ranges of paramter scanned:

Mass of the exchanged particle, m_X : $0.2 - 4$ TeV.
The Coupling constant, g_X: $0.01 - 1$

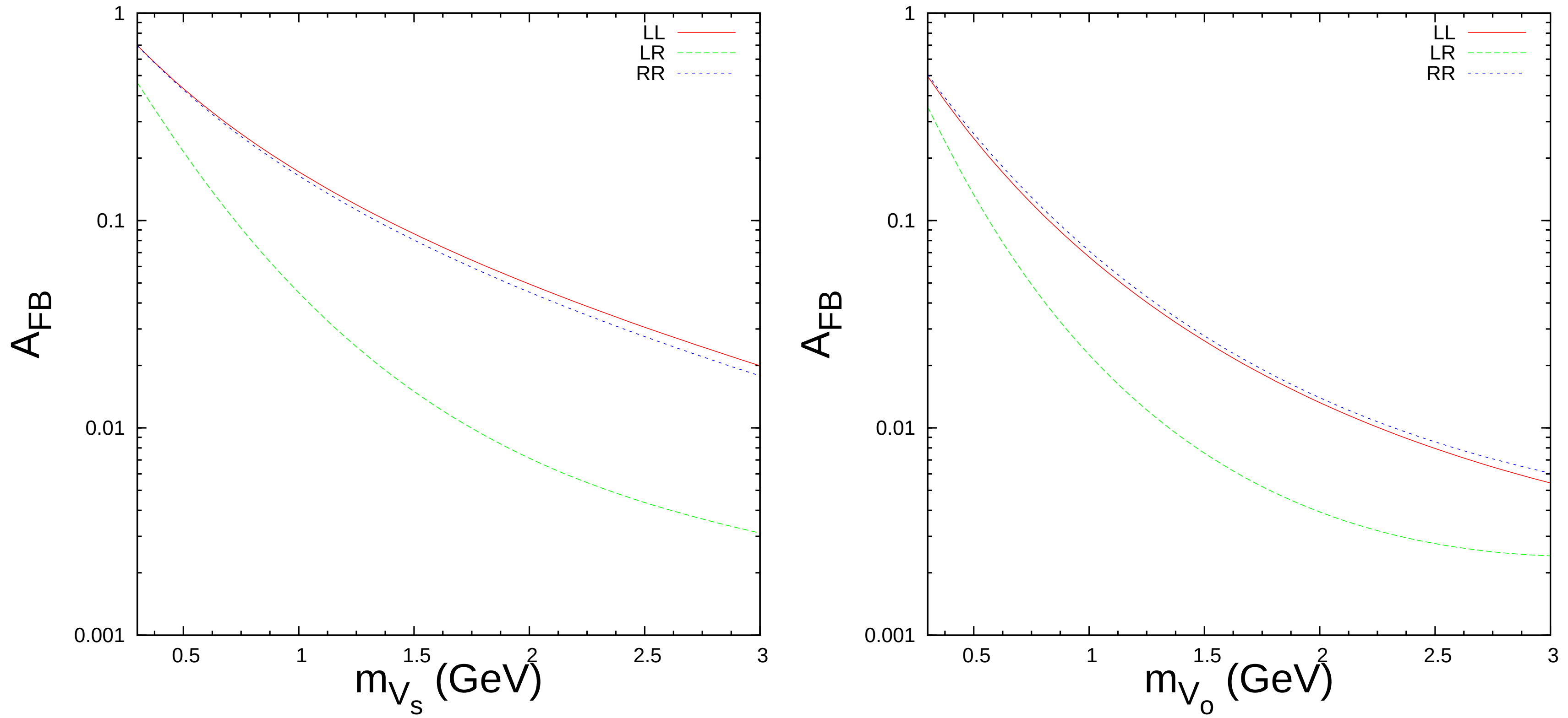
Numerical Analysis and Results ...

In order that a paramter space point qualifies to be part of the allowed region, we demand,

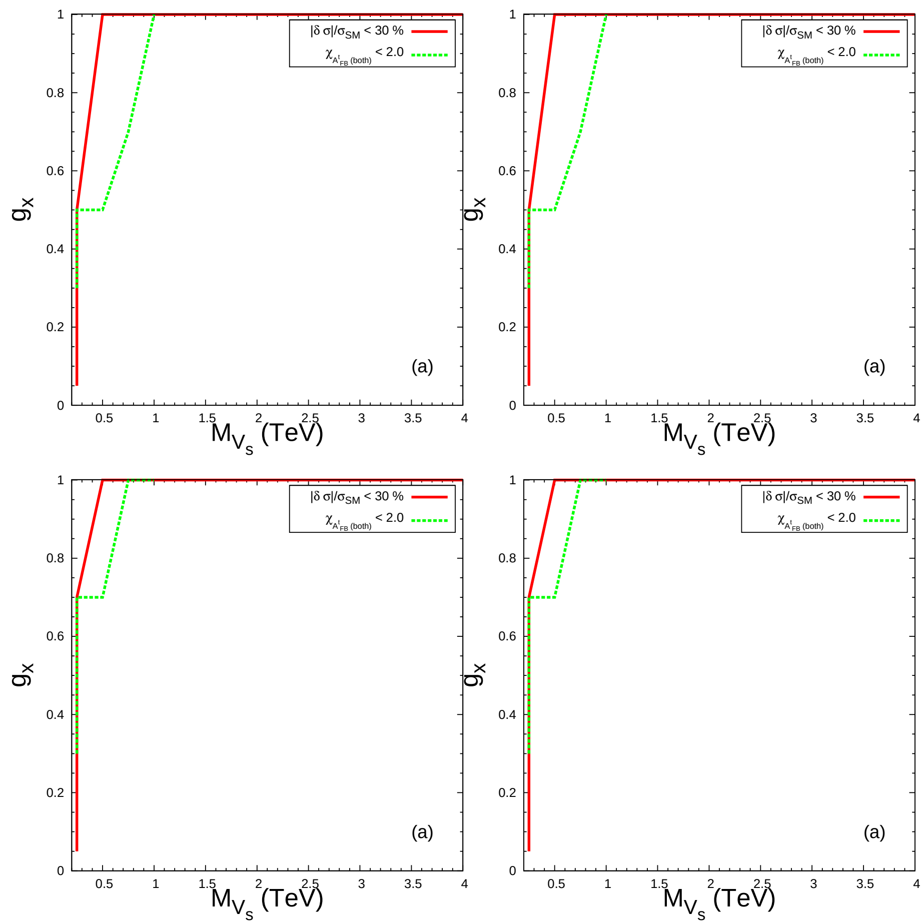
1. The new physics contribution to the $t\bar{t}$ should be below 30% compared to the SM $t\bar{t}$ cross-section,

2. The integrated A^{t}_{FB} for the (a) low mass region ($m_{tt} < 450$ GeV), and the high mass region ($m_{tt} > 450$ GeV) must be well within the 2σ standard deviations from the experimentally measured values.

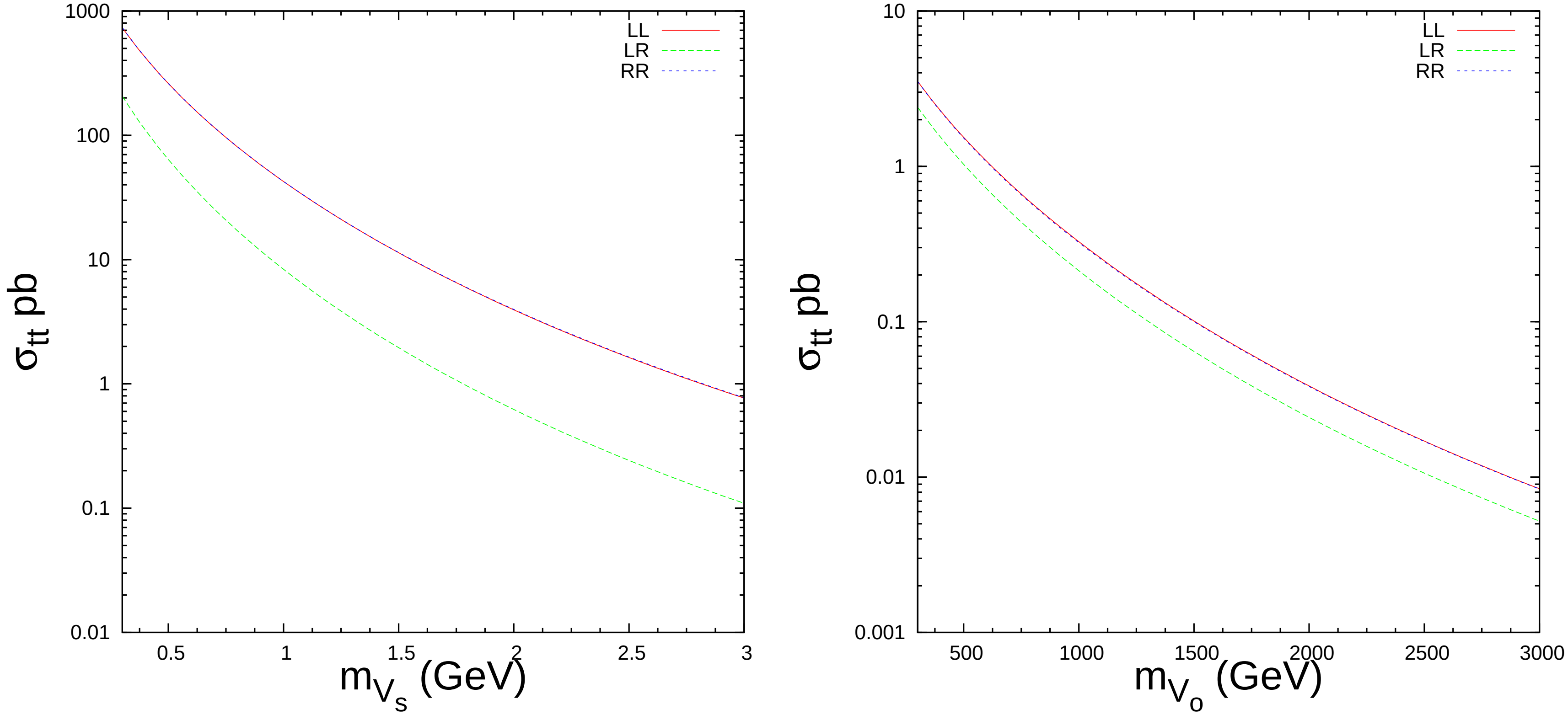
3. The same-sign lepton cross-section at the LHC with $\sqrt{\hat{s}} = 7$ TeV should not exceed 1 fb^{-1} which is equivalent of observing < 5 same-sign lepton events in the 5 fb data.



High mass $\mathcal{A}_{FB}$ vs m_X for the singlet and octet vector cases for $g_X = 1$



Allowed parameter space for the singlet vector cases with LL, RR, 11, 55 operators by the $t\bar{t}$ cross-section and the low and high mass $\mathcal{A}_{FB}$ requirements.



The same-sign top cross-section for the singlet and octet vector cases for $g_X = 1$.

Operator	**Observables**			
	$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}^{SM}}$	$+\chi_{A_{FB}^{t,low}}$	$+\chi_{A_{FB}^{t,high}}$	$+\sigma_{l^{\pm}l^{\pm}}$
Case 1: Singlet Scalar				
$Q_{LL}^{S_s} = (\overline{u}P_L t)\,(\overline{u}P_L t)$	✓	✓	✓	✗
$Q_{LR}^{S_s} = (\overline{u}P_L t)\,(\overline{u}P_R t)$	✓	✓	✗	✗
$Q_{RR}^{S_s} = (\overline{u}P_R t)\,(\overline{u}P_R t)$	✓	✓	✓	✗
$Q_{11}^{S_s} = (\overline{u}It)\,(\overline{u}It)$	✓	✓	✗	✗
$Q_{15}^{S_s} = (\overline{u}It)\,(\overline{u}\gamma_5 t)$	✓	✓	✗	✗
$Q_{55}^{S_s} = (\overline{u}\gamma^5 t)\,(\overline{u}\gamma_5 t)$	✓	✓	✗	✗
Case 2: Octet Scalar				
$Q_{LL}^{S_o} = (\overline{u}P_L T^a t)\,(\overline{u}P_L T^a t)$	✓	✓	✗	✗
$Q_{LR}^{S_o} = (\overline{u}P_L T^a t)\,(\overline{u}P_R T^a t)$	✓	✓	✗	✗
$Q_{RR}^{S_o} = (\overline{u}P_R T^a t)\,(\overline{u}P_R T^a t)$	✓	✓	✗	✗
$Q_{11}^{S_o} = (\overline{u}IT^a t)\,(\overline{u}IT^a t)$	✓	✓	✗	✗
$Q_{15}^{S_o} = (\overline{u}IT^a t)\,(\overline{u}\gamma_5 T^a t)$	✓	✓	✗	✗
$Q_{55}^{S_o} = (\overline{u}\gamma^5 T^a t)\,(\overline{u}\gamma_5 T^a t)$	✓	✓	✗	✗
Case 3: Singlet Vector				
$Q_{LL}^{V_s} = (\overline{u}\gamma^\mu P_L t)\,(\overline{u}\gamma_\mu P_L t)$	✓	✓	✓	✗
$Q_{LR}^{V_s} = (\overline{u}\gamma^\mu P_L t)\,(\overline{u}\gamma_\mu P_R t)$	✓	✓	✗	✗
$Q_{RR}^{V_s} = (\overline{u}\gamma^\mu P_R t)\,(\overline{u}\gamma_\mu P_R t)$	✓	✓	✓	✗
$Q_{11}^{V_s} = (\overline{u}\gamma^\mu It)\,(\overline{u}\gamma_\mu It)$	✓	✓	✓	✗
$Q_{15}^{V_s} = (\overline{u}\gamma^\mu It)\,(\overline{u}\gamma_\mu\gamma_5 t)$	✓	✓	✗	✗
$Q_{55}^{V_s} = (\overline{u}\gamma^\mu\gamma^5 t)\,(\overline{u}\gamma_\mu\gamma_5 t)$	✓	✓	✓	✗
Case 4: Octet Vector				
$Q_{LL}^{V_o} = (\overline{u}\gamma^\mu P_L T^a t)\,(\overline{u}\gamma_\mu P_L T^a t)$	✓	✓	✗	✗
$Q_{LR}^{V_o} = (\overline{u}\gamma^\mu P_L T^a t)\,(\overline{u}\gamma_\mu P_R T^a t)$	✓	✓	✗	✗
$Q_{RR}^{V_o} = (\overline{u}\gamma^\mu P_R T^a t)\,(\overline{u}\gamma_\mu P_R T^a t)$	✓	✓	✗	✗
$Q_{11}^{V_o} = (\overline{u}\gamma^\mu IT^a t)\,(\overline{u}\gamma_\mu IT^a t)$	✓	✓	✗	✗
$Q_{15}^{V_o} = (\overline{u}\gamma^\mu IT^a t)\,(\overline{u}\gamma_\mu\gamma_5 T^a t)$	✓	✓	✗	✗
$Q_{55}^{V_o} = (\overline{u}\gamma^\mu\gamma^5 T^a t)\,(\overline{u}\gamma_\mu\gamma_5 T^a t)$	✓	✓	✗	✗
Case 5: Singlet Tensor				
$Q_{LL}^{T_s} = (\overline{u}\sigma^{\mu\nu}P_L t)\,(\overline{u}\sigma_{\mu\nu}P_L t)$	✓	✓	✗	✗
$Q_{LR}^{T_s} = (\overline{u}\sigma^{\mu\nu}P_L t)\,(\overline{u}\sigma_{\mu\nu}P_R t)$	✓	✓	✗	✗
$Q_{RR}^{T_s} = (\overline{u}\sigma^{\mu\nu}P_R t)\,(\overline{u}\sigma_{\mu\nu}P_R t)$	✓	✓	✗	✗
$Q_{11}^{T_s} = (\overline{u}\sigma^{\mu\nu}It)\,(\overline{u}\sigma_{\mu\nu}It)$	✓	✓	✗	✗
$Q_{15}^{T_s} = (\overline{u}\sigma^{\mu\nu}It)\,(\overline{u}\sigma_{\mu\nu}\gamma_5 t)$	✓	✓	✗	✗
$Q_{55}^{T_s} = (\overline{u}\sigma^{\mu\nu}\gamma^5 t)\,(\overline{u}\sigma_{\mu\nu}\gamma_5 t)$	✓	✓	✗	✗
Case 6: Octet Tensor				
$Q_{LL}^{T_o} = (\overline{u}\sigma^{\mu\nu}P_L T^a t)\,(\overline{u}\sigma_{\mu\nu}P_L T^a t)$	✓	✓	✗	✗
$Q_{LR}^{T_o} = (\overline{u}\sigma^{\mu\nu}P_L T^a t)\,(\overline{u}\sigma_{\mu\nu}P_R T^a t)$	✓	✓	✗	✗
$Q_{RR}^{T_o} = (\overline{u}\sigma^{\mu\nu}P_R T^a t)\,(\overline{u}\sigma_{\mu\nu}P_R T^a t)$	✓	✓	✗	✗
$Q_{11}^{T_o} = (\overline{u}\sigma^{\mu\nu}IT^a t)\,(\overline{u}\sigma_{\mu\nu}IT^a t)$	✓	✓	✗	✗
$Q_{15}^{T_o} = (\overline{u}\sigma^{\mu\nu}IT^a t)\,(\overline{u}\sigma_{\mu\nu}\gamma_5 T^a t)$	✓	✓	✗	✗
$Q_{55}^{T_o} = (\overline{u}\sigma^{\mu\nu}\gamma^5 T^a t)\,(\overline{u}\sigma_{\mu\nu}\gamma_5 T^a t)$	✓	✓	✗	✗

Summary

We studied the most general basis of flavor-violating operators those can explain the A_{FB}^t at the tree-level.

Although some of the operators can consistently explain the low and high mass A_{FB}^t and can be well within the limits of $t\bar{t}$ cross-section, same-sign tops results for the LHC rules out them as well and hence turns out to be an effective tool.