Massive Spin-2 States as the Origin of the Top Quark Forward-Backward Asymmetry

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Outline

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2. Spin-2 Effective Field Theory
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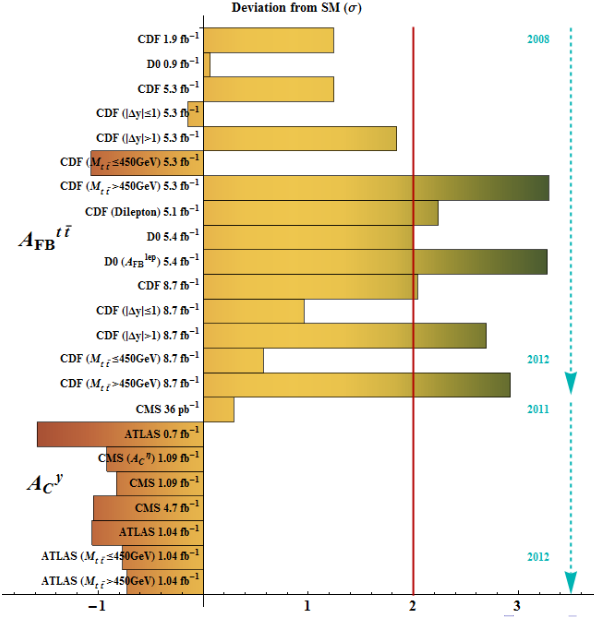
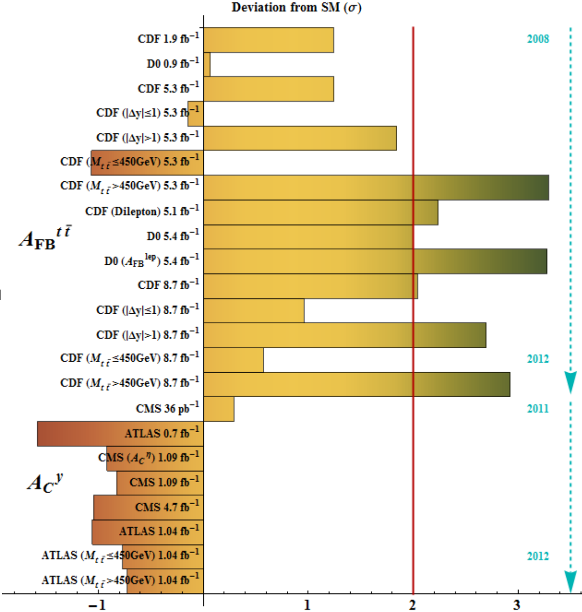
4. Summary

Top Quark Asymmetries Summary



Invariant Mass Dependent Forward-Backward Asymmetry

- Evidence of New Physics?
- Many models involving new spin-0 or spin-1 fields have been proposed
- Difficult to address $A^{t\bar{t}}_{FB}(M_{t\bar{t}} > 450\,\text{GeV})$ while being consistent with existing experimental constraints



Spin-2 Effective Field Theory

We proposed spin-2 particles with flavor-violating couplings quarks.
[Grinstein, Murphy, Pirtskhalava, Uttayarat arXiv:1203.2183]

- Modified Gravity: ADD models, RS models, Massive Gravity
- Resonance from a strongly interacting sector: glueballs

Regardless of its origin, the lowest-order couplings of a spin-2 boson to ferminos are analogous to the couplings of the graviton to energy/momentum.

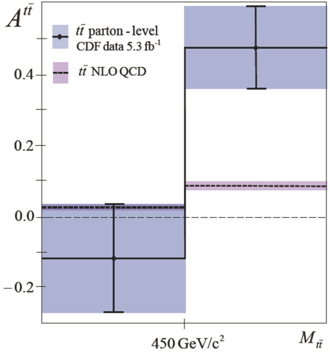
$$\mathcal{L} \supset -\frac{1}{f}\, h^{\mu\nu}\, S_{\mu\nu} + \text{h.c.}$$

$$S_{\mu\nu} = \frac{i\, g^{L}_{jk}}{4}\, \bar{q}_{Lj}\, \gamma_{(\mu}\, \overleftrightarrow{\partial}_{\nu)}\, q_{Lk} + (\text{L} \leftrightarrow \text{R})$$

The derivative interaction leads to strong sensitivity of the energy scales in the problem.

$$S_{\mu\nu} = \frac{i\, g^L_{jk}}{4}\, \bar{q}_{Lj}\, \gamma_{(\mu}\, \overleftrightarrow{\partial}_{\nu)}\, q_{Lk} + (\mathrm{L} \leftrightarrow \mathrm{R})$$

- Observed dependence of $A^{t\bar{t}}_{FB}$ on $M_{t\bar{t}}$ fits nicely into this framework
- [CDF arXiv:1101.0034]



Spin-2 Effective Field Theory: Nice Features

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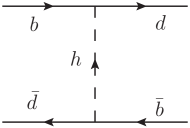
$$S_{\mu\nu} = \frac{i\, g^L_{jk}}{4}\, \bar{q}_{Lj}\, \gamma_{(\mu} \overleftrightarrow{\partial}_{\nu)}\, q_{Lk} + (\mathsf{L} \leftrightarrow \mathsf{R})$$

- Suppresses low-energy phenomena, such as FCNCs

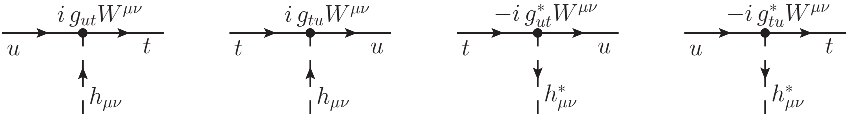


- This diagram contributes to the 4-quark operator of the form $(\bar{d}_L \gamma_\mu b_L)(\bar{d}_L \gamma^\mu b_L)$. Dimensional analysis yields

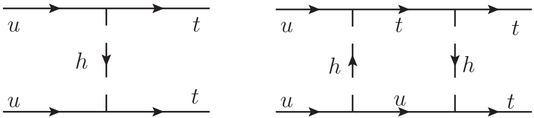
$$\frac{g^L_{ut} g^{L*}_{tu}}{f^2} \frac{m_b^2}{M^2}.$$

Problem: Same-Sign Top Production

To avoid bounds from same-sign top production, any neutral, t-channel NP must not be self-conjugate.



- $g_{tu} \lesssim g_{ut}/26$ to avoid bounds at tree level
- $g_{tt} \lesssim 0.9$ to avoid bounds at 1-loop level (assuming $g_{tu} = 0$)
- g_{uu} more strongly constrained by dijet searches and single-top production



Binned Forward-Backward Asymmetry

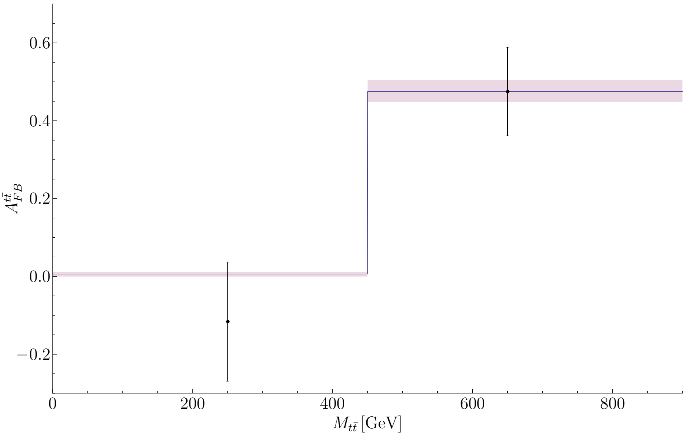


Figure: Prediction from the spin-2 model for $A_{FB}^{t\bar{t}}$ with $M = 350$ GeV and $g_{ut}/f = 2.36\,\text{TeV}^{-1}$. The purple band represents the theoretical uncertainty from varying the factorization scale in the range $\mu = \{m_t/2,\, 2m_t\}$.

We Fit the Spin-2 Model to Tevatron Observables

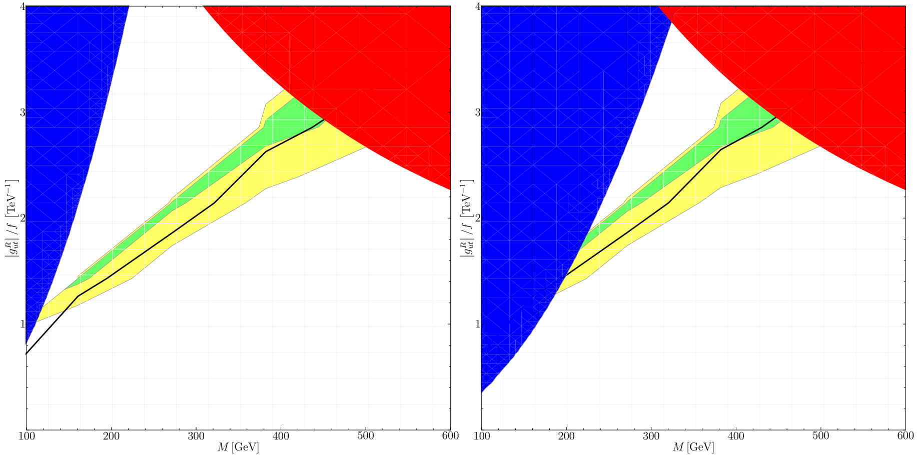


Figure: Results of a global fit of the spin-2 model to Tevatron observables. $A^{t\bar{t}}_{\text{high}} = 47.5\%$ is shown in black. The 1 and 2σ confidence regions of allowed parameters are shown in green and yellow respectively. The blue and red regions are disfavored by constraints from same-sign tops and EWPD respectively

Full Dataset Update

- CDF Note 10807, integrated luminosity 8.7 fb^{-1}
- Slope of best-fit lines $\sim 2.5\sigma$ away from NLO QCD+EW predictions

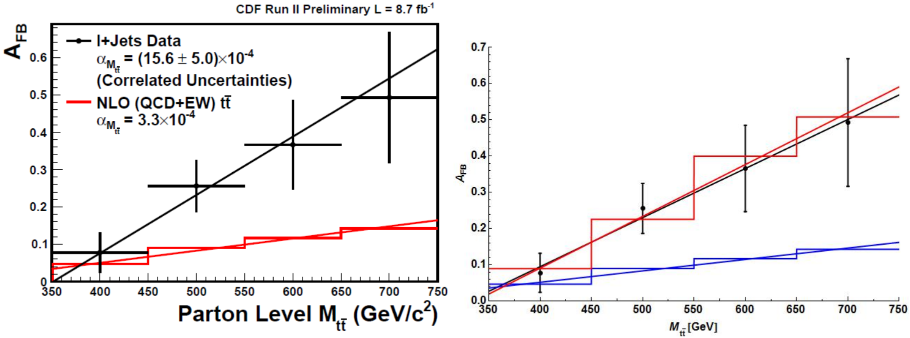


Figure: Prediction from the spin-2 model for $A_{FB}^{t\bar{t}}(8.7\,\text{fb}^{-1})$ with $M = 200$ GeV and $g_{ut}/f = 1.13\,\text{TeV}^{-1}$.

We Fit the Spin-2 Model to Tevatron and LHC Observables

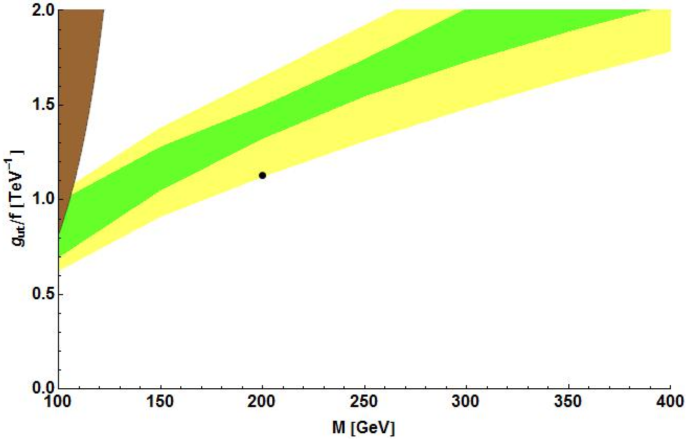


Figure: Results of a fit to A_{FB} (binned & inclusive), A_C, and $\sigma_{t\bar{t}}$ (Tevatron & LHC). Regions of parameter space shown that are allowed at 1- and 2-σ are shown in green and yellow respectively. The black dot is the benchmark point for the binned asymmetry.

Charge Asymmetry

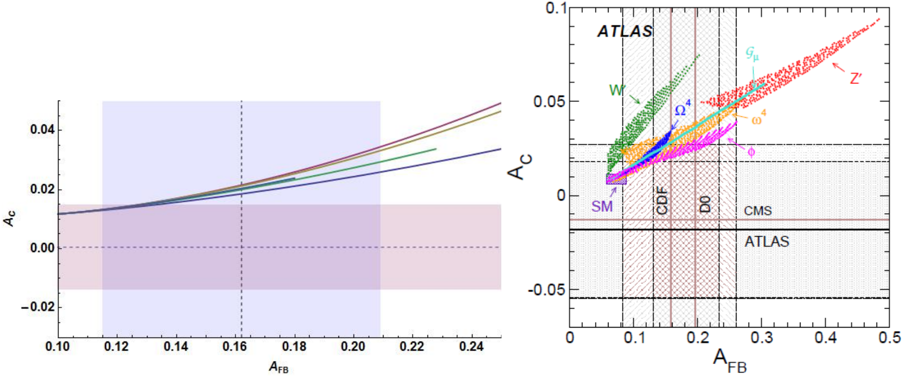


Figure: (left) The effect of the spin-2 model on A_C vs. A_{FB} for $M =$ 100-500 GeV. (right) Various spin-0 and spin-1 model's predictions for A_C vs. A_{FB} from ATLAS arXiv:1203.4211

Summary

- $A_{FB}^{t\bar{t}}$ can be accommodated in models with flavor-violating couplings of a massive spin-2 state to quarks
- We found a vast parameter space leading to the central value of $A_{FB}^{t\bar{t}}(M_{t\bar{t}} > 450\text{GeV})$, while being consistent with existing experimental constraints
- Drawbacks of the spin-2 model are the same as every other neutral, t-channel model