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Top Quark FB Asymmetry And Flavor Physics

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Abstract

CDF and D0 have reported a deviation from the predicted SM forward-backward asymmetry in $t\bar{t}$ production at the Tevatron. BSM models that accommodate this observation must incorporate flavor physics and can lead to unacceptable levels of FCNC. We describe recent work on incorporating flavor naturally into these models, both for new physics mediated by scalars and by vectors, using the Minimal Flavor Violation principle. We then describe a new class of models that address the asymmetry, that use derivatively coupled spin-2 mediators. This type of interaction naturally suppresses FCNC.

1. INTRODUCTION

The SM predictions for the inclusive $t\bar{t}$ asymmetries at the Tevatron are[1, 2]

$$A_{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} = 0.087(10) \quad (1)$$

$$A_{t\bar{t}} = \frac{N(y_t > 0) - N(y_{\bar{t}} > 0)}{N(y_t > 0) + N(y_{\bar{t}} > 0)} = 0.056(7) \quad (2)$$

where $\Delta y \equiv y_t - y_{\bar{t}}$. These figures include a correction of about 1.2 from QCD-EW interference. The leading contribution to the antisymmetric cross section is a 1-loop effect while the cross section starts at tree level; the asymmetry is normalized to LO cross section. The result is stable to NNL threshold re-summations, about one per mil shift [3]. NNNL threshold re-summations have been performed while the full NNLO (NLO for the asymmetry) on-going [4]. The Moriond 2012 experimental figure for the inclusive parton-level asymmetry is [5]

$$A_{t\bar{t}} = 0.162 \pm 0.041 \pm 0.022 \quad (3)$$

in agreement with previous CDF and D0 results. Moreover, CDF observes $A_{t\bar{t}}$ to increase linearly between $M_{t\bar{t}}$ = 350 GeV and 800 GeV with a slope of about 8.2×10^{-4} GeV^{-1}.

New physics (NP) that explain this face a basic problem: $A_{t\bar{t}} = (\sigma_F - \sigma_B)/(\sigma_F + \sigma_B)$ is enhanced relative to the SM while $\sigma_T = \sigma_F + \sigma_B$ is consistent with the SM. Writing $\sigma_{F,B=} = \sigma^{SM}_{F,B} + \sigma^{NP}_{F,B}$, where σ^{NP} may be negative as it includes SM-NP interference, the best fit has σ^{NP}_F negligible but σ^{NP}_B about $-1/3$ of the SM; see Fig. 1 [6].

NP models that explain the asymmetry by s-channel exchange require the mediator to be a color octet to allow interference with the SM, and the coupling to be through an axial current to produce a FB asymmetry at tree level, an "axigluon" (colored scalars do not generate an asymmetry in the s-channel). If the coupling constant of this axigluon, of mass m_A, to the (axial-)current $\bar{q}\gamma_\mu\gamma_5 q$ is g^q_A, then $A_{t\bar{t}} \propto g^q q^t(\hat{s} - m_A^2)$ (with $q = u, d$). In order to enhance the (positive) asymmetry, one can have either a light axigluon ($\hat{s} - m_A^2 > 0$), so that g^q and g^t have opposite sign, or a heavy one ($\hat{s} - m_A^2 < 0$) which requires sign$(g^q g^t) = +1$ [7–15]. The light axigluon runs into difficulties with natural suppression of FCNC since the coupling g^q_A cannot be universal (since sign$(g^q g^t) = -1$). Moreover, the axigluon needs to be hidden from resonance in $m_{t\bar{t}}$ spectrum by, say, enhancing its width by giving it multiple new decay channels. Alternatively the squared BSM amplitude may dominate and produce an asymmetry if the axigluon contains

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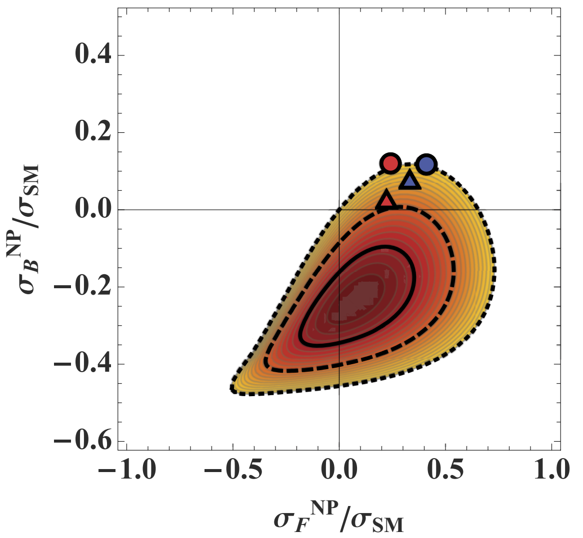


Figure 1: Best fit of new physics contribution to F/B cross section, σ_F^{NP}, relative to SM values. The circles and triangles correspond to the models described in the text.

also vector couplings g_V^q so that the amplitude is proportional to $g_V^t g_V^q g_A^t g_A^q$ [16]. In all cases this models are severely constrained by dijet cross section at the LHC.

Explaining $A_{t\bar{t}}$ by NP models with t-channel are not severely constrained by dijet cross section, but require by construction flavor non-diagonal couplings and again do not generically naturally suppress FCNCs [15, 17–30]. The t-channel mediator needs be relatively light, 200–700 GeV if vector and less than about 1 TeV if scalar. These models are severely constrained by like sign tt production both at Tevatron and LHC.

2. MINIMAL FLAVOR VIOLATING MODELS

Since for either light axigluon or t-channel NP models flavor violating couplings introduce unnatural FCNC constrains, we search for models that accommodate flavor violation in a natural setting. Minimal Flavor Violating (MFV) models are a natural setting. Absent Yukawa couplings, the SM has large flavor symmetry $G_F = \mathrm{SU(3)}_{\mathrm{U_R}} \times \mathrm{SU(3)}_{\mathrm{D_R}} \times \mathrm{SU(3)}_{\mathrm{Q_L}}$ where the first(second) factors act on quark up- (down-)type singlets ($U(D)$) and the last on doublets (Q). An additional factor $\mathrm{SU(3)_L} \times \mathrm{SU(3)_E}$ where the first factor acts on lepton doublets (L) and the second on singlets (E) will be ignored in the remainder as it plays no role. We introduce new field(s) with couplings that respect this symmetry, and assume all flavor violation is from Yukawa couplings. For massive vector fields the couplings are non-

Case	$\mathrm{SU(3)_c}$	$\mathrm{SU(2)_L}$	$\mathrm{U(1)_Y}$	G_F	Couples to
$\mathrm{S_I}$	1	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R\ \ Q_L$
$\mathrm{S_{II}}$	8	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R\ \ Q_L$
$\mathrm{S_{III}}$	1	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R\ \ Q_L$
$\mathrm{S_{IV}}$	8	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R\ \ Q_L$
$\mathrm{S_V}$	3	1	-4/3	$(3,1,1)$	$u_R\ \ u_R$
$\mathrm{S_{VI}}$	$\bar{6}$	1	-4/3	$(\bar{6},1,1)$	$u_R\ \ u_R$
$\mathrm{S_{VII}}$	3	1	2/3	$(1,3,1)$	$d_R\ \ d_R$
$\mathrm{S_{VIII}}$	$\bar{6}$	1	2/3	$(1,\bar{6},1)$	$d_R\ \ d_R$
$\mathrm{S_{IX}}$	3	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R\ \ u_R$
$\mathrm{S_X}$	$\bar{6}$	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R\ \ u_R$
$\mathrm{S_{XI}}$	3	1	-1/3	$(1,1,\bar{6})$	$Q_L\ \ Q_L$
$\mathrm{S_{XII}}$	$\bar{6}$	1	-1/3	$(1,1,3)$	$Q_L\ \ Q_L$
$\mathrm{S_{XIII}}$	3	3	-1/3	$(1,1,3)$	$Q_L\ \ Q_L$
$\mathrm{S_{XIV}}$	$\bar{6}$	3	-1/3	$(1,1,\bar{6})$	$Q_L\ \ Q_L$
$\mathrm{S_{H,8}}$	1, 8	2	1/2	$(1,1,1)$	$\bar{Q}_L u_R,\ \ \bar{Q}_L d_R$

Table 1: Different scalar representations that are not singlets under the flavour group that are $\mathrm{G_F}$ symmetric [33] (the upper rows). The two flavor singlet representations are in the last row and were discussed in [34].

renormalizable, and we take the model as an effective field theory below some scale of further new physics. Table 1 shows all possible scalar field representations under G_F that couple to quark bilinears, and Table 2 is the corresponding classification for vector fields. Examining the table 1 shows, *e.g.*, that cases $\mathrm{S_{I,\,II,\,V,\,VI,\,XI–XIV}}$ and $\mathrm{S_{H,8}}$ include tt couplings for s-channel exchange $A_{t\bar{t}}$ as well as uc couplings that may contribute to tree level D-mixing. Cases $\mathrm{S_{III,\,IV,\,VII,\,VIII,\,XI–XIV}}$ and $\mathrm{S_{H,8}}$ include sd, bd and bs couplings and can give rise to tree level B and K-mixing. And cases $\mathrm{S_{I–IV,\,IX,\,X,\,VIII,\,XIII,\,XIV}}$ and $\mathrm{S_{H,8}}$ include dt coupling for t-channel $A_{t\bar{t}}$ as well as charged currents that give box diagram that contribute to meson mixing.

Cases $\mathrm{S_{V,\,VI}}$ may produce an asymmetry without contributing to K or B mixing. Fig. 2 shows the cross section (upper panel) and FB asymmetry (second panel) for case $\mathrm{S_V}$ for various values of the coupling η of the scalar to the quark bi-linear as a function of scalar mass. $m_{t\bar{t}}$ distributions for the parameter point $*$ of the first two panels are shown in the last two panels (for both cases $\mathrm{S_{V,\,VI}}$). The asymmetry is in better agreement with the experimental results of the CDF 8.7 fb^{-1} data set (not shown).

2.1. LOW ENERGY CONSTRAINTS

Since the focus of this conference is on flavor, let's focus on low energy experimental flavor physics constraints on these MFV models. For additional constraints from LEP, electroweak precision measurements, LHC/Tevatron single top and dijet production, etc, see Refs. [31, 32]. Neutral meson mixing gives the most severe constraints. Use the parametrization

$$h_{s,d}e^{i2\sigma_{s,d}} \equiv \frac{\langle B_{s,d}|\Delta\mathcal{H}_{\rm eff}^{\rm NP}|\bar{B}_{s,d}\rangle}{\langle B_{s,d}|\mathcal{H}_{\rm eff}^{SM}|\bar{B}_{s,d}\rangle}, \tag{4}$$

$$h_K e^{i2\sigma_K} \equiv \frac{M_{12}^{NP}}{\Delta m_K} = \frac{1}{\Delta m_K}\cdot\frac{\langle K^0|\Delta\mathcal{H}_{\rm eff}^{\rm NP}|\bar{K}^0\rangle}{2m_K} \tag{5}$$

and

$$h_D e^{i2\sigma_D} \equiv \frac{M_{12}^{NP}}{\Delta m_D} = \frac{1}{\Delta m_D}\cdot\frac{\langle D^0|\Delta\mathcal{H}_{\rm eff}^{\rm NP}|\bar{D}^0\rangle}{2m_D}. \tag{6}$$

Agreement of measured and predicted values of ϵ_K we obtain the bound $|h_K \sin(2\sigma_K)| \lesssim 1.3\times10^{-3}$ at 95% C.L. The CP violation in $D-\bar{D}$ mixing is well constrained and so $|h_D \sin(2\sigma_D)| \lesssim 0.3$, at 95 % C.L. [37]. For B_s mixing a 3.9σ deviation from the negligible SM prediction has been measured in the like-sign dimuon charge asymmetry by the DØ collaboration [38, 39]. This result is in agreement [40, 41] with a hint for nonzero weak phase in B_s mixing (measured through flavour tagged decays [42, 43]). The two preferred solutions [40], $h_s \sim 0.5, \sigma_s \sim 130^\circ$ and $h_s \sim 2, \sigma_s \sim 100^\circ$. hint at NP in B_s mixing. These results use the older measurement of the dimuon asymmetry [39]. There is also a slight preference for $h_d \sim 0.2$, $\sigma_d \sim 100^\circ$, but h_d is consistent with zero at $\sim 1\sigma$. At 3σ one finds $h_d < 0.5$, for all σ_d [40].

Because of space constraints we only give a few examples; see Ref. [31] for a more complete account. The effective Hamiltonian for mixing for vector models I-IX can be parametrized as
$\mathcal{H}_{\rm eff}^{{\rm NP},B_s} = \frac{\kappa_s}{M_V^2}(y_t^2 V_{tb}V_{ts}^*)^2\eta'\eta_{RG}(\bar{b}_L\gamma^\mu s_L)^2$,
$\mathcal{H}_{\rm eff}^{{\rm NP},B_d} = \frac{\kappa_d}{M_V^2}(y_t^2 V_{tb}V_{td}^*)^2(\bar{d}_L\gamma^\mu b_L)^2$,
$\mathcal{H}_{\rm eff}^{{\rm NP},K} = \frac{\kappa_K}{M_V^2}(y_t^2 V_{ts}V_{td}^*)^2(\bar{d}_L\gamma^\mu s_L)^2$ and
$\mathcal{H}_{\rm eff}^{{\rm NP},D} = \frac{\kappa_D}{M_V^2}(y_b^2 V_{ub}^*V_{cb})^2(\bar{c}_L\gamma^\mu u_L)^2$. Numerically,

$$h_{d,s}e^{2i\sigma_{d,s}} \approx 20\times\kappa_{d,s}y_t^4\left(\frac{1\ \text{TeV}}{M_V}\right)^2,$$

$$h_K e^{i2\sigma_K} \approx 0.1\times\kappa_K e^{i2\beta}y_t^4\left(\frac{1\ \text{TeV}}{M_V}\right)^2,$$

$$h_D e^{i2\sigma_D} \approx (0.3\cdot10^{-2})\times\kappa_D e^{i2\gamma}y_b^4\left(\frac{1\ \text{TeV}}{M_V}\right)^2.$$

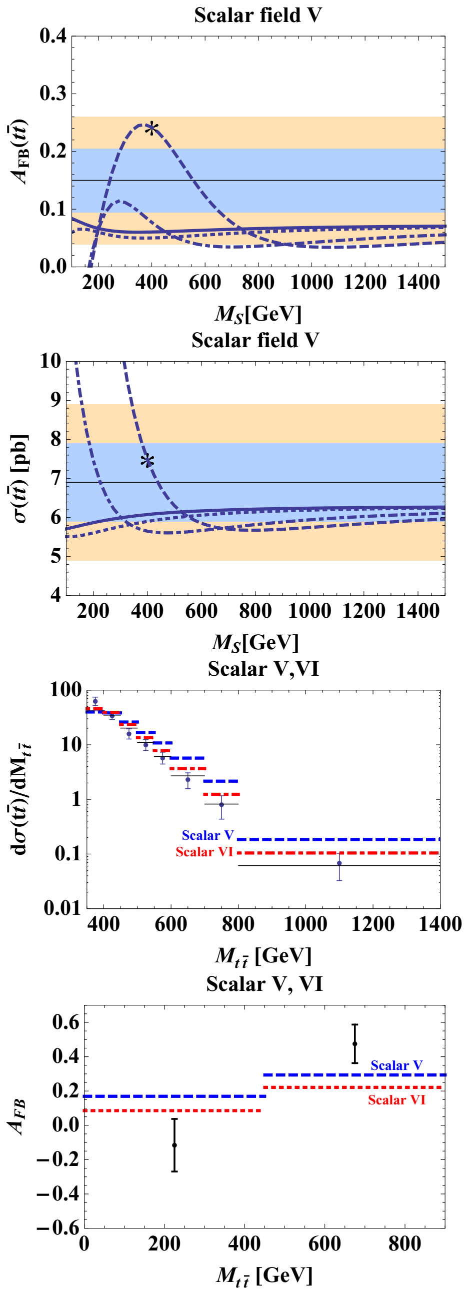


Figure 2: Predictions for inclusive cross sections $\sigma(t\bar{t})$ and inclusive forward-backward asymmetry $A_{FB}(t\bar{t})$ as a function of scalar mass m_S for models S_V, S_{VI} and couplings $\eta = 1/4$ (solid line), $1/2\sqrt{2}$ (dotted), $1/\sqrt{2}$ (dot-dashed), 1 (dashed) compared to 1σ and 2σ experimental (shaded) bands. The predictions for A_{FB} with $m_{t\bar{t}}$ below and above 450 GeV and for $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ are shown in the last row for benchmark points labeled with a $\star$ in the inclusive predictions. The experimental data points are from [35, 36] .

Case	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	G_F	Couples to
$I_{s,o}$	1,8	1	0	(1,1,1)	$\bar{d}_R\,\gamma^\mu\,d_R$
$II_{s,o}$	1,8	1	0	(1,1,1)	$\bar{u}_R\,\gamma^\mu\,u_R$
$III_{s,o}$	1,8	1	0	(1,1,1)	$\bar{Q}_L\,\gamma^\mu\,Q_L$
$IV_{s,o}$	1,8	3	0	(1,1,1)	$\bar{Q}_L\,\gamma^\mu\,Q_L$
$V_{s,o}$	1,8	1	0	(1,8,1)	$\bar{d}_R\,\gamma^\mu\,d_R$
$VI_{s,o}$	1,8	1	0	(8,1,1)	$\bar{u}_R\,\gamma^\mu\,u_R$
$VII_{s,o}$	1,8	1	-1	$(\bar{3},3,1)$	$\bar{d}_R\,\gamma^\mu\,u_R$
$VIII_{s,o}$	1,8	1	0	(1,1,8)	$\bar{Q}_L\,\gamma^\mu\,Q_L$
$IX_{s,o}$	1,8	3	0	(1,1,8)	$\bar{Q}_L\,\gamma^\mu\,Q_L$
$X_{\bar{3},6}$	$\bar{3}$,6	2	-1/6	(1,3,3)	$\bar{d}_R\,\gamma^\mu\,Q_L^c$
$XI_{\bar{3},6}$	$\bar{3}$,6	2	5/6	(3,1,3)	$\bar{u}_R\,\gamma^\mu\,Q_L^c$

Table 2: The flavor and gauge representations for vector fields that can couple directly to quarks through G_F symmetric dimension four interactions. Q_L^c denotes the right handed conjugate representation of the left handed SM doublet.

The coefficients κ can be computed for each model. For example, from table 2 it is immediate that $\kappa_D = 0$ for cases I and V, $\kappa_{s,d,K} = 0$ for cases II and VI, while in model VII $\kappa_{s,d,K,D}$ arise only through a box-diagram exchange of charged vectors. Models III, IV, VIII and IX have $\kappa_s \approx \kappa_d \approx \kappa_K$ unsuppressed by small Yukawas, implying $h_s \approx h_d$, while for models I and V $\kappa_{s,d} \propto y_{s,d}^2 y_b^2$ and $\kappa_K \propto y_d^2 y_s^2$, so $h_s \gg h_d$.

Here is a brief summary of findings for the vector models:

Universal Models: III, IV, VIII and IX. They give $h_s \approx h_d$, so to account for both as NP effects they give somewhat high h_d and low h_s. A large value of h_s is easily accommodated, since κ_s is not Yukawa suppressed. Models VIII and IX can have some deviation from universality form splits in the vector spectrum. Model IX has in addition non-universal box diagram contributions.

Yukawa-square suppressed models: I and V are y_s^2-suppressed. To account for NP require $M_V \lesssim 100$ GeV, with order 1 couplings and $y_b|sim1$ (*i.e.*, two higgs doublets, large $\tan\beta$). They predict negligible $h_d \approx (y_d/y_s)^2 h_s$.

Yukawa-linear suppressed models: X is y_s-suppressed. Non-SM operators contribute to mixing and it accommodates a large h_s with sub-TeV vectors and couplings of order 1. It then gives small but non-negligible $h_d \approx (y_d/y_s)h_s$.

Loop-only models: VII and XI. Here the MFV assumption gives $h_d \approx h_s$. The contribution to h_s can carry a substantial new weak phase.

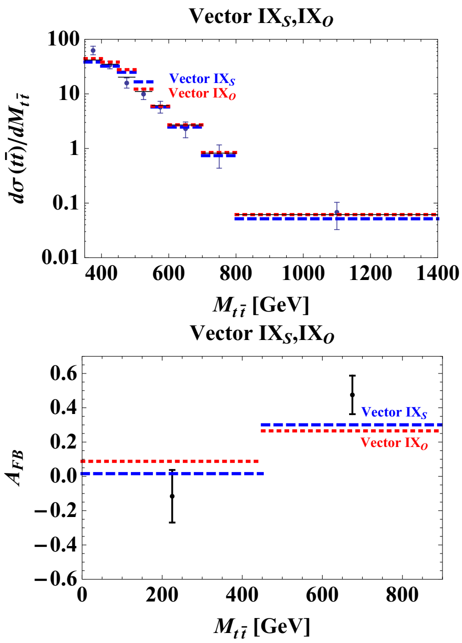
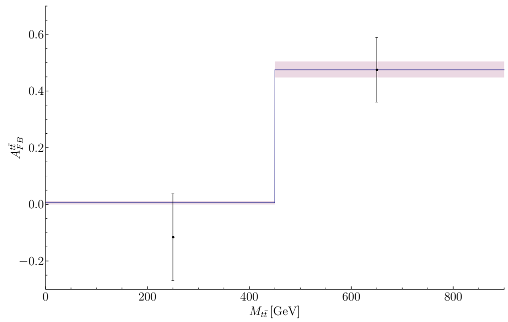


Figure 3: Same as in bottom two panels of Fig. 2 but now for vector model IX.

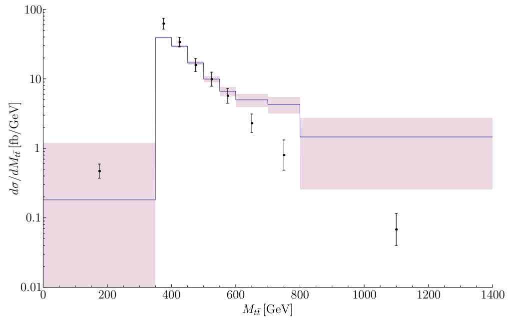
So which of these models can be used to account for the deviations from the SM in both $A_{t\bar{t}}$ and B-mixing? Any such model, with mixing from tree level, must include couplings to both t and d, s, b quarks. This selects Models III, IV, VII, VIII, IX, X. Model X contributes negatively to $A_{t\bar{t}}$. The others have ranges of parameters that can account for $A_{t\bar{t}}$ (for s-channel models only the octet case can produce an interference with the SM; model III_o is the axigluon model, but with additional flavor changing interactions as allowed by the MFV principle). For example, Fig. 3 shows the prediction for the cross section and asymmetry $m_{t\bar{t}}$ distributions for model IX (the acceptable agreement with data is much improved with the more recent data [5]).

3. SPIN-2

We have tried spin-0 and 1 mediators. Why not spin-2? As we will see there are good phenomenological reasons for trying this, so it is worth studying even in the absence of further theoretical motivation. But we are not lacking in this either: complex massive spin-2 particles could arise from many different contexts including resonances of a new strongly interacting sector, Kaluza-Klein modes of graviton in models with extra-dimensions, or a four-dimensional theory of massive gravity. Consider a phenomenological model of a com-



(a) $A_{FB}^{t\bar{t}}$



(b) $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$

Figure 4: Prediction from the spin-2 model for $A_{FB}^{t\bar{t}}$ and $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ with $M = 350$ GeV. The purple band represents the theoretical uncertainty from varying the factorization scale in the range $\mu = \{m_t/2,\, 2m_t\}$. This example hits the central value of $A_{FB}^{t\bar{t}}$ in the high bin and is within 1σ of the central value in the low bin. Detector acceptance effects and the known increase in the measured value for $\sigma_{t\bar{t}}$ could account for the disagreement in the high mass bins for $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$.

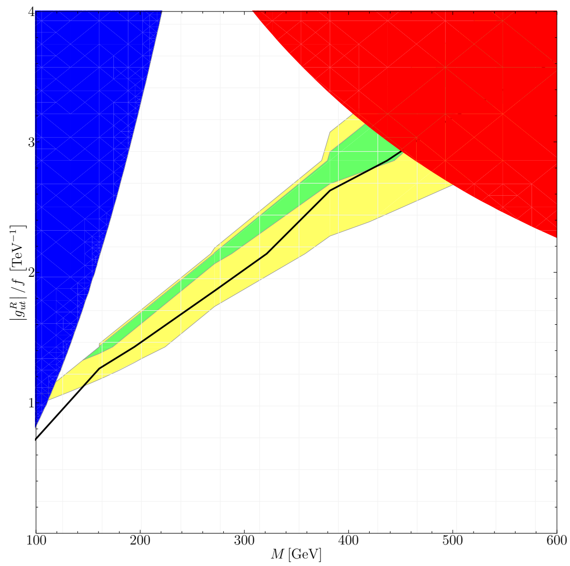


Figure 5: Results of a global fit of the spin-2 model to Tevatron observables. The fit assumes $g_{uu}^R = g_{tt}^R = g_{ut}^R/10 = 3g_{tu}^R$; see Ref. [44] for the global fit under different assumptions. $A_{\rm high}^{t\bar{t}} = 47.5\%$ is shown in black. The 1 and 2σ confidence regions of allowed parameters are shown in green and yellow respectively. The blue, red, and brown regions are disfavored by constraints from same-sign top, EWPD, and the width of the top respectively.

plex spin-2 particle of mass M [44]. It is only an effective theory below some TeV-scale cut-off, higher than M. To see why this may be phenomenologically interesting notice that the propagator for the two index symmetric tensor that describes our particle is

$$\langle h_{\mu\nu} h_{\alpha\beta}\rangle = \frac{i}{k^2 - M^2}\left(\frac{\bar\eta_{\mu\alpha}\bar\eta_{\nu\beta}}{2} + \frac{\bar\eta_{\mu\beta}\bar\eta_{\nu\alpha}}{2} - \frac{\bar\eta_{\mu\nu}\bar\eta_{\alpha\beta}}{3}\right) \quad (7)$$

where $\bar\eta_{\mu\nu} = \eta_{\mu\nu} - k_\mu k_\nu/M^2$. At large momentum the propagator grows with the second power of momentum so it can give rise to more dramatic energy dependence in spectra. It is natural to enquire whether such models may accommodate the sharp rise in $A_{t\bar{t}}$ with $m_{t\bar{t}}$. Moreover, there is additional energy dependence introduced by the interaction. Assuming the trace of the two index tensor does not couple to a quark mass bi-linear (*i.e.*, to $\bar{Q}_L u_R$ or $\bar{Q}_L d_R$), the couplings of the spin-2 tensor are derivative, much like the ones of linearized gravity (but with additional freedom in the coupling constants of various interaction terms).

Consider, for example, the interaction term

$$\mathcal{L}_{\rm int} = \frac{i}{4f} g_{ut}^L h_{\mu\nu}\left[\bar{t}_L\gamma^\mu \overleftrightarrow{\partial}^\nu u_L\right] + (L \leftrightarrow R) + \text{h.c.} \quad (8)$$

where $h_{\mu\nu}$ is the spin-2 field and f is a dimensional parameter characterizing the scale of new physics, with cut-off $\Lambda_{NP} \sim 4\pi f$. LEP four jet measurements severely constrain the coupling g_{ut}^L. This is because since the left handed quarks are in $SU(2)_L$ doublets one has a corresponding coupling $g_{bd}^L = g_{ut}^L$, and one has a sizable contribution to four jets from $e^+e^- \to q\bar{q}^*$ followed by $\bar{q}^* \to \bar{q}q\bar{q}$ mediated by h. It is interesting that the constrain from $B_d - \bar{B}_d$ mixing is naturally suppressed. The exchange of H gives rise to an effective four quark interaction $(\bar{d}_L\gamma^\mu b_L)^2$ with coefficient $g_{ut}^L g_{tu}^{L*}/f^2(m_b^2/M^2)$. The factor (m_b^2/M^2) arises from the derivative interaction and naturally suppresses mixing. The coupling g_{ut}^R is not necessarily related to g_{bd}^R and it is only mildly constrained by precision EW data. At the one-loop level there is a contribution to the dimension-4 operator, $C_{Zu\bar{u}} Z_\mu \bar{u}\gamma^\mu u$. Atomic parity violation gives the best constraint, $|C_{Zu\bar{u}}| < 1.3 \times 10^{-3}$, which translates into

$$|C_{Zu\bar{u}}| \approx \frac{2es_w}{3c_w}\frac{|g^R_{ut}|^2(M^2+m_t^2)}{16\pi^2 f^2} \Rightarrow \frac{|g^R_{ut}|^2(M^2+m_t^2)}{f^2} \lesssim 2.$$

Same sign top-quark pair and dijet production at LHC further constrains g^R_{ut}; see Ref. [44] for details.

Figure 4 shows the prediction for $A^{t\bar{t}}_{FB}$ and $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ with $M = 350$ GeV. We choose for this example parameters consistent with the bounds described above that hit the central value of $A^{t\bar{t}}_{FB}$ in the high bin and is within 1σ of the central value in the low bin. Detector acceptance effects and the known increase in the measured value for $\sigma_{t\bar{t}}$ could account for the disagreement in the high mass bins for $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$. Figure 5 shows a global fit of the spin-2 model to Tevatron observables for the CDF measurements of $A_{t\bar{t}}$ in the low- and high-bins, and $\sigma_{t\bar{t}}$, using least-squares assuming the measurements are uncorrelated. The scale f was fixed to 1 TeV and the relation $g^R_{uu} = g^R_{tt} = g^R_{ut}/10 = 3g^R_{tu}$ was assumed so that the plot only involves two parameters. The black line corresponds to $A_{t\bar{t}} = 0.475$ in the high bin.

I have not shown our results for charge asymmetry for pp collisions at 7 or 8 TeV. In light of the observations made in Refs. [45, 46] our computations (which would show disagreement with LHC data) need be redone. Work on this is under way, as is the calculation of the $b\bar{b}$ FB asymmetry induced by the spin-2 exchange. Also under way is an analysis of spin-2 MFV models, in the spirit for the previous section. One of the novel implications is that flavor symmetry may be sufficient to exclude or naturally suppress the unwanted coupling of the trace of h in a to a fermion mas-like bi-linear. We hope to report on progress by the next Capri meeting!

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