Flavor and $A_{FB}^{t\bar{t}}$: Flavored Colorons and Composite t''s

Alex Kagan

University of Cincinnati

Plan

- Flavor and the top-antitop forward-backward asymmetry with B. Grinstein, M. Trott, J. Zupan, arXiv:1102.3374
  - MFV, flavor octet vectors, t-channel dominance
- New strong interaction realizations with M. Trott and J. Zupan, in progress
  - composite (u', c', t') weak singlet up quarks, composite flavor octet vectors,....
  - identification with technicolor: electroweak symmetry breaking
    - $W + jj$?

Flavor and the top-antitop forward-backward asymmetry

Issues for NP explanations of $A_{FB}^{t\bar{t}}$

For $M_{t\bar{t}} > 450$ GeV CDF measures:

$$A_{FB}^{t\bar{t}} = \frac{\sigma_F^{SM} + \sigma_F^{NP} - \sigma_B^{SM} - \sigma_B^{NP}}{\sigma_F^{SM} + \sigma_F^{NP} - \sigma_B^{SM} - \sigma_B^{NP}} = 0.475 \pm 0.114$$

$$\sigma^{t\bar{t}} = 1.9 \pm 0.5 \;\; \text{pb}$$

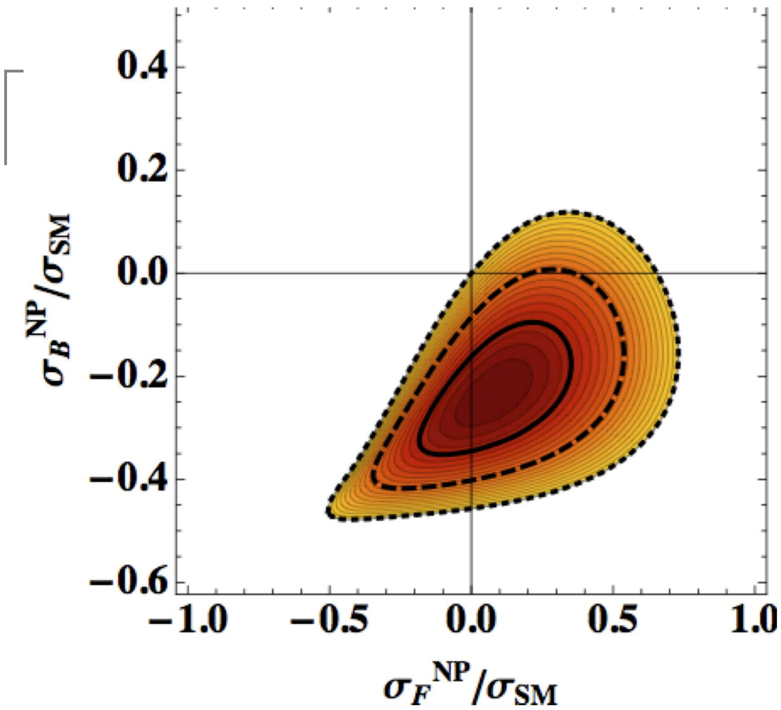
SM theory predictions for $M_{t\bar{t}} > 450$ GeV:

$$A_{\text{NLO}}^{t\bar{t}} = 0.088 \pm 0.013 \;\; (3.4\sigma \text{ discrepancy})$$

$$\sigma_{\text{NLO+NNLL}}^{t\bar{t}} = 2.26 \pm 0.18 \;\; \text{pb} \quad \text{Ahrens et al}$$

Can study

$$\sigma_B^{NP}/\sigma^{SM} \;\; \text{vs.} \;\; \sigma_F^{NP}/\sigma^{SM} \;\; \text{for } M_{t\bar{t}} > 450 \text{ GeV}$$



$\sigma_B^{NP} < 0 \Rightarrow \text{NP interferes with SM}$

Therefore, s-channel explanation requires color octet vector

- $A_{FB}^{t\bar{t}} \neq 0$ requires $g_L^t \neq g_R^t$, $g_L^q \neq g_R^q \Rightarrow$ "Axigluon" or "Chiral gluon"
- FCNC's are an issue, e.g., $D^0 - \bar{D}^0$ mixing
- no s-channel $M_{t\bar{t}}$ bump, no excess in high $M_{t\bar{t}}$ bins, dijets $\Rightarrow$ large $M_V \sim 2$ TeV -see Susanne Westhoff's talk
  - moderate $A_{FB} \lesssim 0.2$ achievable

Low mass t-channel explanations have appealing features:

- vectors, e.g., Z' and W', with masses of a few hundred GeV yield large $A_{FB}^{t\bar{t}}$, increases with $M_{t\bar{t}}$, as observed -Jung, Murayama, Pierce, Wells '10
- simultaneously, good agreement with measured spectrum at large $M_{t\bar{t}}$ -Gresham, Kim, Zurek '11; Jung, Pierce, Wells '11
  - for large $M_{t\bar{t}}$, NP t-channel top production more forward
  - CDF's acceptance decreases rapidly at large rapidity
    - smaller impact on $A_{FB}^{t\bar{t}}$ due to courser $M_{t\bar{t}}$ binning

Low mass Z', W' have some problems

- Z': same sign top production
- W': single top production
- large $Z' - u - t$ or $W' - d - t$ couplings $\Rightarrow$ FCNC's are an issue

Minimal Flavor Violation: Flavor Symmetric Models

Quark sector formally invariant under the flavor group

$$G_F = U(3)_Q \times U(3)_u \times U(3)_d$$

if Yukawas promoted to spurions, $Y'_{u,d} = V_Q Y_{u,d} V^{\dagger}_{u,d}$.

To address problems mentioned above consider models for $A^{t\bar{t}}_{FB}$

- that do not contain additional breaking of the SM flavor group G_F
- new fields can be in non-trivial representations of G_F
- they have $O(1)$ couplings to the top and light quarks

Vectors in MFV

- Motivated by nice features of vector t-channel models
- There are 22 vector representations satisfying the MFV hypothesis (not all relevant to $A_{FB}^{t\bar{t}}$)

Case	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_{U_R} \times SU(3)_{D_R} \times SU(3)_{Q_L}$	Couples to
$\mathrm{I}_{s,o}$	1,8	1	0	(1,1,1)	$\bar{d}_R \gamma^\mu d_R$
$\mathrm{II}_{s,o}$	1,8	1	0	(1,1,1)	$\bar{u}_R \gamma^\mu u_R$
$\mathrm{III}_{s,o}$	1,8	1	0	(1,1,1)	$\bar{Q}_L \gamma^\mu Q_L$
$\mathrm{IV}_{s,o}$	1,8	3	0	(1,1,1)	$\bar{Q}_L \gamma^\mu Q_L$
$\mathrm{V}_{s,o}$	1,8	1	0	(1,8,1)	$\bar{d}_R \gamma^\mu d_R$
$\mathrm{VI}_{s,o}$	1,8	1	0	(8,1,1)	$\bar{u}_R \gamma^\mu u_R$
$\mathrm{VII}_{s,o}$	1,8	1	-1	($\bar{3}$,3,1)	$\bar{d}_R \gamma^\mu u_R$
$\mathrm{VIII}_{s,o}$	1,8	1	0	(1,1,8)	$\bar{Q}_L \gamma^\mu Q_L$
$\mathrm{IX}_{s,o}$	1,8	3	0	(1,1,8)	$\bar{Q}_L \gamma^\mu Q_L$
$\mathrm{X}_{\bar{3},6}$	$\bar{3}$,6	2	-1/6	(1,3,3)	$\bar{d}_R \gamma^\mu Q_L^c$
$\mathrm{XI}_{\bar{3},6}$	$\bar{3}$,6	2	5/6	(3,1,3)	$\bar{u}_R \gamma^\mu Q_L^c$

- Simplest possibilities are the $SU(3)_{U_R}$ flavor octet color octet or color singlet vectors coupling only to RH up quarks

$$\mathcal{L} = \lambda \bar{u}_R \gamma^\mu V_\mu^{o,s} u_R + \text{MFV corrections}$$

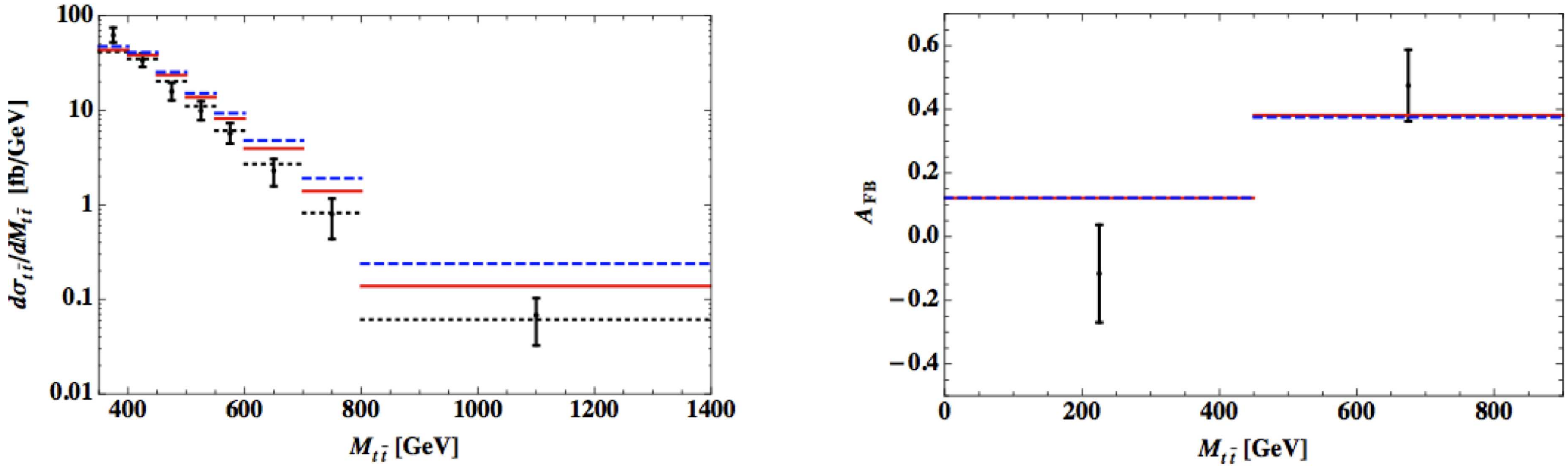
  - color octet: $V_\mu^o = V_\mu^{A,B} \mathcal{T}^A T^B$
  - color singlet: $V_\mu^s = V_\mu^A T^A$

$$\text{t} - \text{channel} \qquad (V_\mu^4 - iV_\mu^5)(\bar{t}_R \gamma^\mu u_R) + ...$$

$$\text{s} - \text{channel} \qquad V_\mu^8 (\bar{u}_R \gamma^\mu u_R + \bar{c}_R \gamma^\mu c_R - 2\bar{t}_R \gamma^\mu t_R)$$

- color octet: $t\bar{t}$ production t-channel dominated
- color singlet: s-channel larger than for color octet $\Rightarrow$ problematic for $M_{t\bar{t}}$ bump and dijets at Tevatron
- MFV corrections split $\bar{t}t$, $\bar{t}q$, and $\bar{q}q$ couplings, preserve $SU(2)_{U_R}$ symmetry
- Flavor symmetry $\Rightarrow$ no like sign top or single top production;
  negligible FCNC's: $D^0 - \bar{D}^0$ mixing

$A_{FB}^{t\bar{t}}$ and $d\sigma/dM_{t\bar{t}}$ for the octet of color and flavor



$\mathrm{A}_{\mathrm{FB}}^{\mathrm{t\bar{t}}}$ and $d\sigma(t\,\bar{t})/dM_{t\bar{t}}$, for two different values of $(m_V, \sqrt{\lambda_{qq}\lambda_{33}}, \lambda_{q3}, \Gamma_V/m_V)$: solid red $(300\,\mathrm{GeV}, 1, 1.33, 0.08)$; dashed blue $(1200\,\mathrm{GeV}, 2.2, 4.88, 0.5)$, that give approximately the same $\mathrm{A}_{\mathrm{FB}}^{\mathrm{t\bar{t}}}$ in the high mass bin

- CDF rapidity acceptance corrections (in progress) should eliminate $M_{t\bar{t}} > 600$ GeV spectrum excesses for light vector example
- Dijet constraints: require moderate flavor symmetry breaking for light vectors; large breaking for heavy vectors

Strong interaction realizations:
composite t''s, flavored colorons

The set-up

- can we build models with composite flavor octet vector mesons which naturally only couple to right-handed up quarks?

- already have a very nice example of flavor octet composite vector mesons in QCD

- add a new asymtpotically free $SU(N)_{HC}$ "hypercolor" gauge interaction, with strong interaction scale $\Lambda_{HC} \sim 1/2$ TeV

- add a new weak singlet vectorlike "flavor triplet" of left-handed and right-handed hypercolor quarks, $(\omega_{L_i}, \omega_{R_i})$ $(i = 1, 2, 3)$, and a new hypercolored scalar, $\tilde{s}$, transforming under $SU(N)_{HC} \times SU(3)_C \times SU(2)_L \times U(1)_Y$ as

$$\text{model A}: \quad \omega_{L_i,R_i}(N, 1, 1, 2/3), \quad \tilde{s}(\bar{N}, 3, 1, 0)$$

$$\text{model B}: \quad \omega_{L_i,R_i}(N, 3, 1, 2/3), \quad \tilde{s}(N, 1, 1, 0)$$

  with new Lagrangian

$$\mathcal{L}_{NP} = \mathbf{h}_{ij}\, \bar{u}_{Ri}\omega_{Li}\tilde{s} + h.c. + \mu_{ij}\, \bar{\omega}_i\omega_j + m_s^2|\tilde{s}|^2$$

  u_{Ri} are the ordinary right handed quarks (u_R, c_R, t_R)

- could "supersymmetrize" in order to protect the scalar masses, or could imagine that scalars are composites of some yet higher energy interaction,.......

$$\mathcal{L}_{NP} = \mathbf{h}_{ij}\, \bar{u}_{Ri} \omega_{Li} \tilde{s} + h.c. + \mu_{ij}\, \bar{\omega}_i \omega_j + m_s^2 |\tilde{s}|^2$$

- hypercolor sector only couples to the right-handed up quarks
  - consequence of choice of representations for ω, $\tilde{s}$ (hypercharge assignments)
  - $SU(3)_{U_R}$ symmetry of $\mathcal{L}_{NP}$ could be an accidental consequence of $SU(3)_H$ horizontal gauge symmetry at some large UV scale responsible for generating the quark mass and mixing hierarchies via a Frogatt-Nielsen type mechanism

- imposing MFV $\Rightarrow$ $\mathbf{h}_{ij} = h\, \delta_{ij}, \quad \mu_{ij} = \mu\, \delta_{ij}$
- MFV corrections $\Rightarrow$ $\mathbf{h} = \mathrm{diag}(h_1, h_1, h_3), \quad \mu = \mathrm{diag}(\mu_1, \mu_1, \mu_3)$

consider model A: $\omega_{L_i,R_i}(N,1,1,2/3)$, $\tilde{s}(\bar{N},3,1,0)$

- vectors $\rho^{\rm HC}[\bar{\omega}\omega]$, $a_1[\bar{\omega}\omega]$ are flavor "nonets" 8 + 1
  - vector P-wave bound state of the scalars $[\tilde{s}^*\tilde{s}]$, flavor singlet
- $\langle\bar{\omega}\omega\rangle \neq 0$ breaks global chiral symmetry

$$SU(3)_L \times SU(3)_R \to SU(3)_V$$

$\Rightarrow$ flavor octet of hypercolor pions π^{HC}, heavier η'_{HC}

- mass scales: scale up from QCD

$$\frac{f_\pi^{HC}}{f_\pi} \sim \frac{f_\rho^{HC}}{f_\rho} \sim \frac{m_{\rho_{HC}}}{m_\rho}\sqrt{\frac{N_{HC}}{3}}$$

Motivated by vector flavor/color octet analysis of $A_{FB}^{t\bar{t}}$

  - $m_\rho^{HC} \sim 300 - 500$ GeV $\Rightarrow$ $f_\pi^{HC} \sim 30 - 60$ GeV ($N_{HC} = 3$)
  - $\Lambda_{\chi SB} \sim 4\pi f_\pi^{HC} \sim 400 - 700$ GeV

- $A_{FB}^{t\bar{t}} \Rightarrow O(1)\ \rho - \bar{t} - t$ coupling λ
- perturbative Yukawa couplings h require scalar $m_{\tilde{s}} < \Lambda_{HC}$. Naive dimensional analysis (NDA) implies

$$\lambda \sim h^2 \frac{f_\rho}{\Lambda_{HC}}$$

or $h = O(\mathrm{few})$

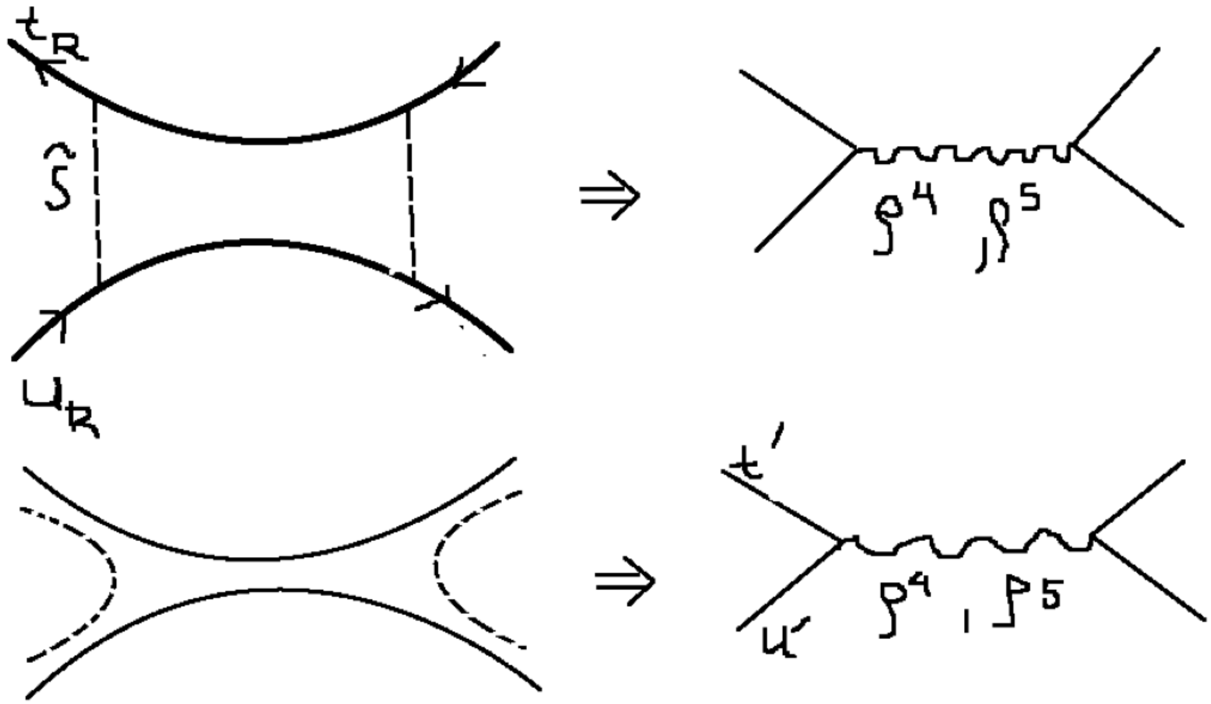
- a modified resonance picture emerges, in which we also have a new flavor triplet of weak singlet vectorlike up quarks,

$$u'[\tilde{s}\omega_1], \quad c'[\tilde{s}\omega_2], \quad t'[\tilde{s}\omega_3]$$

with masses of $O(m_\rho^{\mathrm{HC}})$ or $O(1/2\ \mathrm{TeV})$

$$\langle u_{R_i}|\bar{\omega}_{R_i}\tilde{s}^*|0\rangle \sim f_U \bar{u}_{R_i} \text{ with } f_U \sim f_\rho^{\mathrm{HC}}$$

- $t\bar{t}$ production via exchange of ρ^a, a_1^a and large mixing of the composite u'_{R_i}'s with the ordinary u_{R_i}



t_R
u_R
$\Rightarrow$
ρ^4, ρ^5
t'
u'
$\Rightarrow$
ρ^4, ρ^5

- The new composite quarks can be quite broad! via decays to ordinary RH up quarks and HC pions, π^a, e.g.,

$$u'_i \rightarrow \pi^a + t$$

- using NDA for the couplings of the π^a to the u''s

$$O(4\pi)\,\bar{u}'_{R_i} T^b_{ij} \pi^b u'_{Lj} \Rightarrow$$

$$\Gamma_{u'}/M_{u'} \sim 10 - 30\%$$

is possible, compared with $\approx 1\%$ for the top quark

- detection at LHC via

$$u'_i \rightarrow t + \pi^a$$

  - Model A: the π^a are stable, color neutral
  - Model B: the π^a are color octets, decay to two jets $\pi^a \rightarrow gg$