Non-Abelian models of t-channel top physics

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Based on SJ, A.Pierce, J.Wells [1103.4835]

What was discussed last Friday

- Regarding Tevatron measurements of Afb and Wjj.

- Light V' (mV' < mt) can contribute to both Afb and Wjj.

- Demonstration of important unfolding issue.

- Summary of hadron collider phenos of t-channel physics models (mostly for mV' > mt)

- Hadron collider phenos for the light V'.

- Direct asymmetry observbales at the LHC.

Today, a non-Abelian model and pheno

- Focus on one specific model : non-Abelian model of V'-u-t coupling.

- Issues in Model buildings.

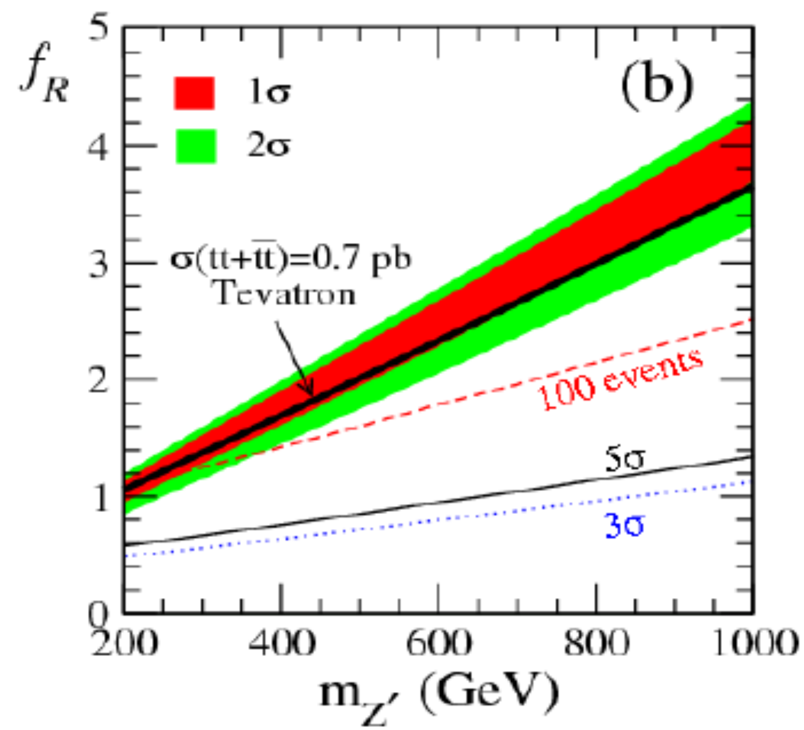
- Hadron collider phenomenology (some are for this model, some are for general t-channel models).

Abelian model suffers

Abelian Z'-u-t model is a simple implementation of t-channel physics idea.

$$\mathcal{L} \ni g_X Z'_\mu \bar{u}\gamma^\mu P_R t + h.c.$$

But, Z' couples both to top and anti-top. Like-sign dileptons from like-sign top pairs are already strong for most of parameter space except for the light Z'. LHC will probe there as well.



Lagrangian for non-Abelian Zut model

SU(2) model. (t_R, u_R) is a doublet.

$$\mathcal{L} = \frac{g_X}{\sqrt{2}} W'^-_\mu \left\{ \bar{t}_R \gamma^\mu t_R(-cs) + \bar{u}_R \gamma^\mu u_R(cs) + \bar{t}_R \gamma^\mu u_R(c^2) + \bar{u}_R \gamma^\mu t_R(-s^2) \right\}$$
$$+ \frac{g_X}{\sqrt{2}} W'^+_\mu \left\{ \bar{t}_R \gamma^\mu t_R(-cs) + \bar{u}_R \gamma^\mu u_R(cs) + \bar{t}_R \gamma^\mu u_R(-s^2) + \bar{u}_R \gamma^\mu t_R(c^2) \right\}$$
$$+ \frac{g_X}{2} Z'_\mu \left\{ \bar{t}_R \gamma^\mu t_R(c^2 - s^2) + \bar{u}_R \gamma^\mu u_R(s^2 - c^2) + \bar{t}_R \gamma^\mu u_R(2cs) + \bar{u}_R \gamma^\mu t_R(2cs) \right\}.$$

If gauge boson couples to mass eigenstate fermions, mixing between t_R and u_R will be induced, parametrized by cos theta = c.

Mixing angle c

For c=1,

W'+ couples only to t-ubar and W'- to u-tbar.

For c < 1,

All sorts of couplings are induced : W'+ to t-ubar, u-tbar, t-tbar, u-ubar.

It's possible only when there exists non-doublet Higgs.

We will work in a region around c=1 to avoid like-sign top pairs.

Top number : convenient for memory

Top number = +1 for top and W'+.
Top number = -1   for anti-top ant W'-.

Each top number breaking by a unit 1 accompanies sin theta suppression (amplitude).

ex1) ttbar production preserves top number. propto s^0

ex2) single top production is propto s^1

ex3) like-sign top pair is propto s^2

Thus, dangerous contributions are suppressed by s.

Many diagrams, but qualitatively t-channel exchange of W'

$$\frac{d\sigma_{(sG-tV)}}{d\cos\theta} = 2\cdot\frac{\pi\beta}{18s}\alpha_S\alpha_X\xi_{tV}\cdot\frac{4(u_t^2+sm_t^2)+2\frac{m_t^2}{m_V^2}(t_t^2+sm_t^2)}{s\cdot t_V}$$

$$\frac{d\sigma_{(tV-tV)}}{d\cos\theta} = \frac{\pi\beta}{8s}\alpha_X^2\xi_{tV}^2\cdot\frac{4u_t^2+\frac{m_t^4}{m_V^4}(t_t^2+4sm_V^2)}{t_V^2}$$

$$\frac{d\sigma_{(tX-tY)}}{d\cos\theta} = 2\cdot\frac{\pi\beta}{8s}\alpha_X^2\xi_{tX}\xi_{tY}\cdot\frac{4u_t^2+\frac{m_t^4}{m_X^2m_Y^2}t_t^2+2\frac{m_t^4}{m_X^4}sm_X^2+2\frac{m_t^4}{m_Y^4}sm_Y^2}{t_X\cdot t_Y}$$

$$\frac{d\sigma_{(sX-tY)}}{d\cos\theta} = 2\cdot\frac{\pi\beta}{24s}\alpha_X^2\xi_{sX}\xi_{tY}\cdot\frac{4u_t^2+2\frac{m_t^2}{m_Y^2}sm_t^2}{s_X\cdot t_Y}$$

$$\frac{d\sigma_{(sV-sV)}}{d\cos\theta} = \frac{\pi\beta}{8s}\alpha_X^2\xi_{sV}^2\cdot\frac{4u_t^2}{s_V^2}$$

$$\frac{d\sigma_{(sX-sY)}}{d\cos\theta} = 2\cdot\frac{\pi\beta}{8s}\alpha_X^2\xi_{sX}\xi_{sY}\cdot\frac{4u_t^2}{s_X\cdot s_Y}$$

Masses of gauge boson W' and Z'

We want (light) W'. Can we heavy-decouple Z'? Not likely.

$$M_{W'}^2 = g_X^2 v_T^2 \frac{T(T+1) - T_3^2}{2}, \qquad M_{Z'}^2 = g_X^2 v_T^2 T_3^2,$$

For the vacuum with <T3=T> and T >>1,
MW'^2 is propto T
MZ'^2 is propto T^2

So possible to decouple Z' with a very large rep. But not beautiful. ==> We consider light W' and Z'.

Masses of gauge boson W' and Z'

Effective Yukawa from Doublet Higgs phi_D.

$$\Delta\mathcal{L} \ni \frac{(\lambda_u')_i}{M}(\bar{Q}_i \cdot h_{SM})(\phi_D \cdot q).$$

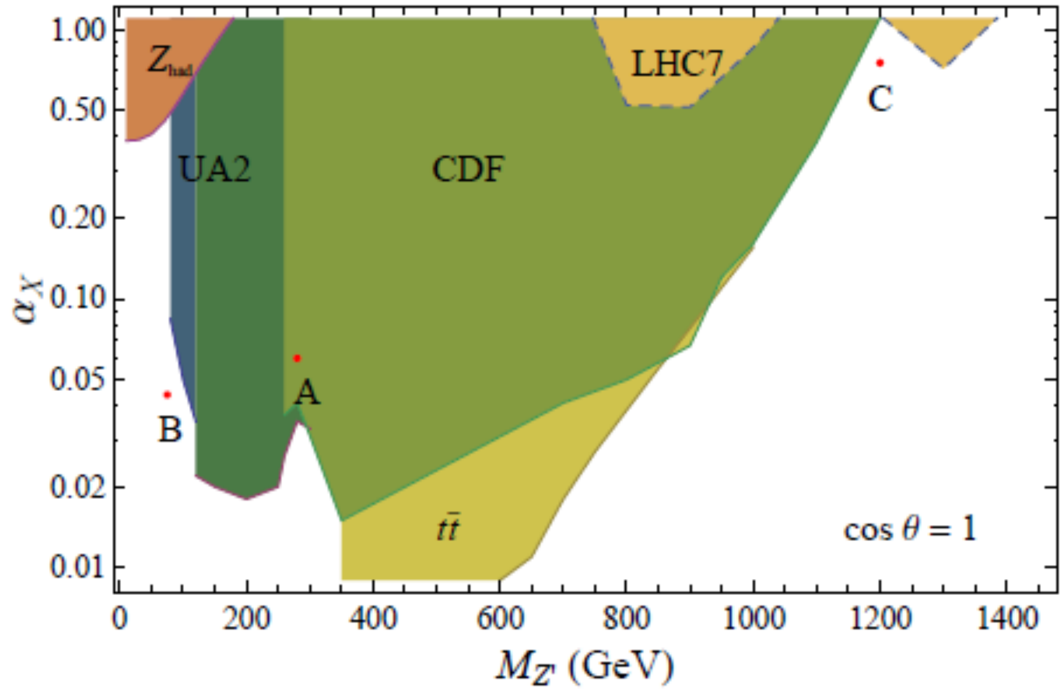
- Other Higgs rep does not allow this low-dimension Yukawa.
- Top Yukawa (v_D/M) comes from this doublet Higgs.

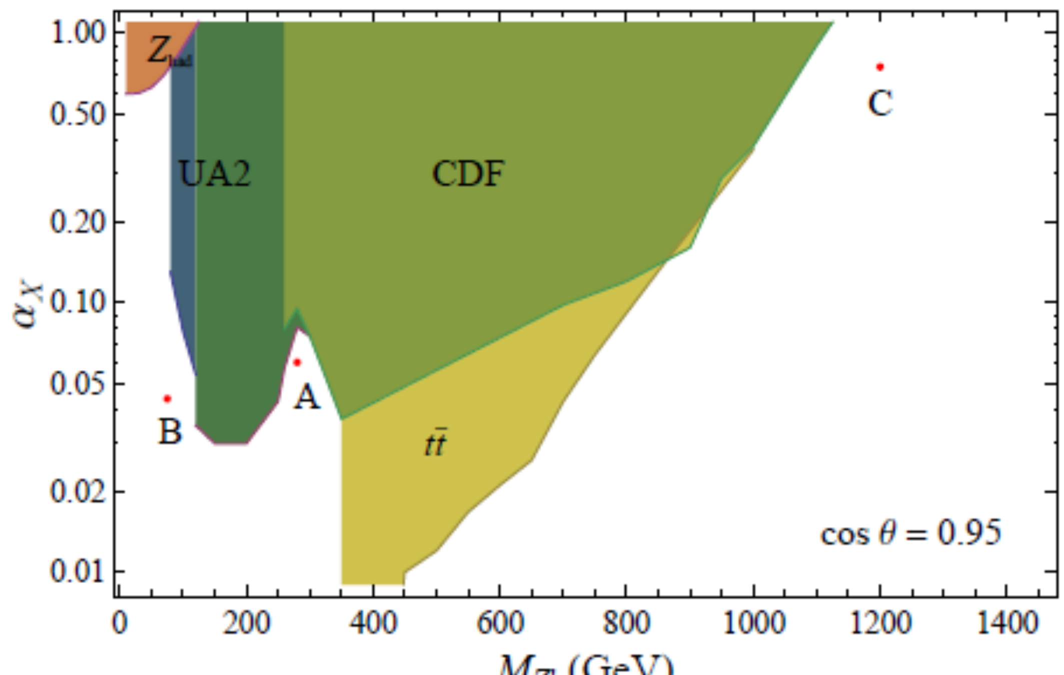
- M can't too above W'/Z' masses.

- Doublet vev gives common masses to all W' and Z'.

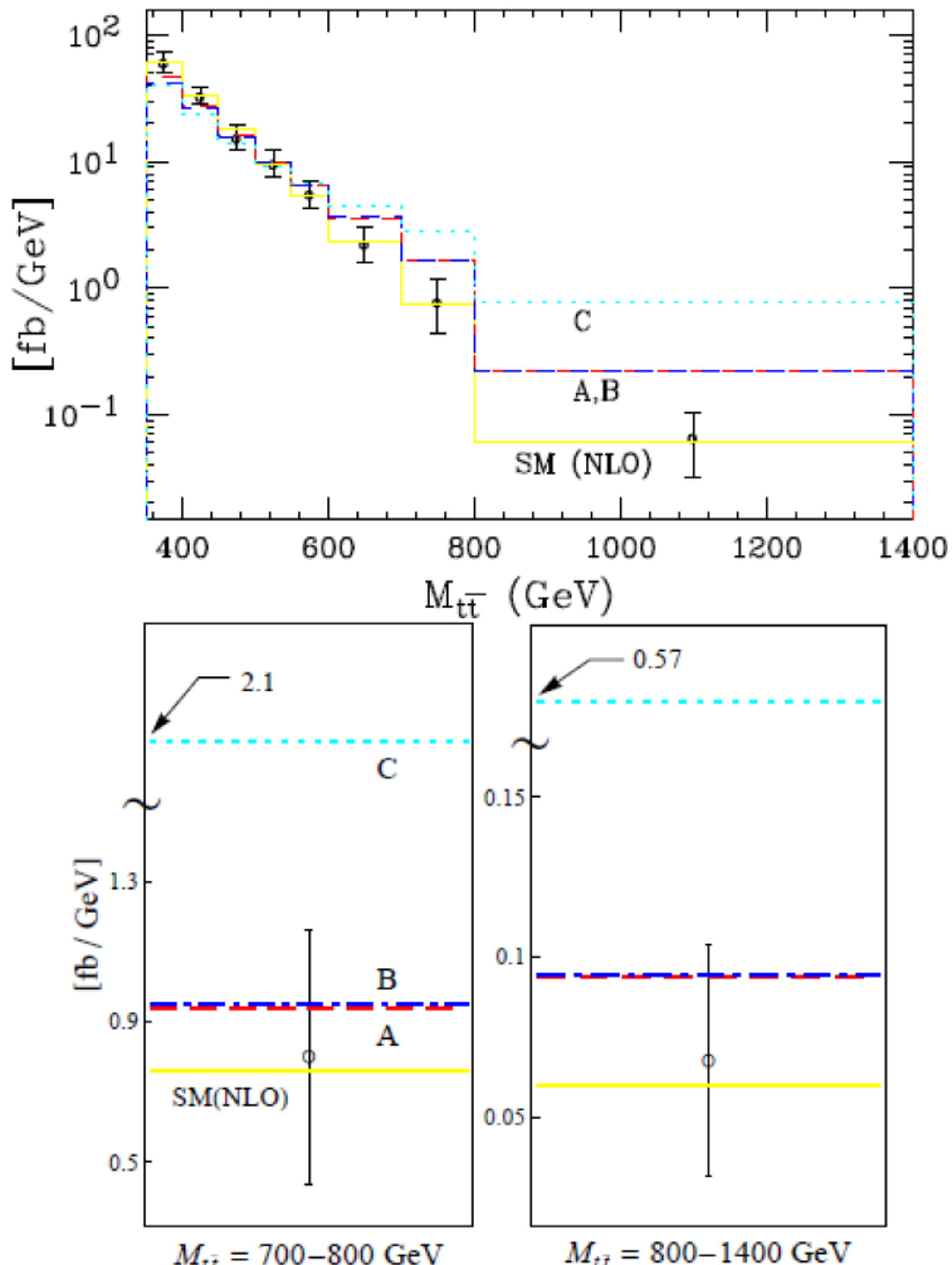
==> We consider light W' and Z' s.

Constraints on light gauge bosons





Before and after the unfolding



Inclusive ttbar cross sections (Tevatron)

	$\sigma(t\bar{t})_{thy}$	A^t_{FB}	$\sigma(t\bar{t})_{lj}$	$\sigma(t\bar{t})_{ll}$
CDF	7.50 ± 0.48 pb [48]	0.158 ± 0.074 [4]	7.22 ± 0.79 pb [49]	7.25 ± 0.92 pb [50, 51]
SM	7.34 pb	0.058 ± 0.009	7.34 pb (normalized)	7.34 pb (normalized)
Model A	6.69 pb	0.14	7.0 pb	6.6 pb

TABLE II: Cross sections for point A at the Tevatron. The theoretical value of exclusive top pair cross section is shown in the column denoted $\sigma(t\bar{t})_{thy}$, where we apply a K-factor found by normalizing the LO SM to the approximated NNLO results 7.34 pb, averaged over three independent results [52–54]. The rest-frame asymmetry A^t_{FB} is also shown. Inclusive top pair cross sections in the semi-leptonic ($\sigma(t\bar{t})_{lj}$) and dileptonic ($\sigma(t\bar{t})_{ll}$) are obtained by applying CDF selection cuts [49–51] and by including other faking contributions, see text for detail.

Inclusive ttbar cross sections (LHC7)

	$\sigma(t\bar{t})_{\ell j}$	$\sigma(t\bar{t})_{\ell\ell}$	$\sigma(t\bar{t})_{thy}$	A_{boost}
ATLAS [58]	142^{+61}_{-46} pb	151^{+86}_{-66} pb	145^{+52}_{-41} pb	—
CMS [59]	—	$194_{\pm 79}$ pb	—	—
Model A	193 pb	177 pb	166 pb	6%

TABLE III: Detailed LHC7 cross section predictions for Point A. Exclusive $pp \to t\bar{t}$ cross section is shown in the column denoted by $\sigma(t\bar{t})_{thy}$, with a $K = 1.89$ normalizing LO SM to the approximate NNLO SM calculation $\sigma(t\bar{t}) = 164.6^{+11.4}_{-15.7}$ pb [58, 60, 61]. The other two columns $\sigma(t\bar{t})_{\ell j}$ and $\sigma(t\bar{t})_{\ell\ell}$ represent predictions for observed inclusive cross-sections in the semi-leptonic and dileptonic channels. Here we have included possible "fake" contributions dominantly from the process $\sigma(gu \to W't) = 47$ pb at the leading order and applied the cuts from the ATLAS analysis [58]. See text for more discussions. A_{boost} observable is defined in Eq. 4.

Why non-zero theta (c<1) considered?

1. To relax dijet bound on Z'.
   (see previous figures)

2. To suppress faking contributions to inclusive xsec.

If instead, $\cos\theta = 1$, the top cross sections would be measured as $\sigma(t\bar{t})_{lj,ll} = 8.0, 7.5$ pb with a (somewhat smaller) asymmetry, $A^t_{FB} = 0.12$. The decrease in the asymmetry is largely a result of contributions from the process $gu \to W'^- t$.

c-dependence and like-sign top pairs again

$\cos\theta$ (Point A)	$\sigma(t\bar{t})_{\ell j}$	$\sigma(t\bar{t})_{\ell\ell}$	$\sigma(tt, \bar{t}\bar{t})$
0.9	175 pb	166 pb	3.90 pb
0.95	193 pb	177 pb	1.34 pb
1.0	233 pb	216 pb	0 pb

TABLE IV: The $\cos\theta$ dependence of two relevant LHC signals (7 TeV) for a mass spectrum corresponding to Point A. Point A is defined with $\cos\theta = 0.95$ but other values in the range of $0.92 \lesssim \cos\theta \lesssim 0.98$ are also allowed. The inferred inclusive $t\bar{t}$ cross-sections are shown in $\sigma(t\bar{t})_{\ell j,\ell\ell}$. Refer to table III for more details and corresponding LHC7 data. The inclusive like-sign top pair production (including tt, $\bar{t}\bar{t}$ and vector boson decays to like-sign tops) is calculated at LO. Current deduced upper bound of $\sigma(tt, \bar{t}\bar{t})$ from heavy exotic quark searches at LHC7 is about 5 pb at 95% CL.

LHC Afb

With respect to the ttbar boost direction,

$$A_{boost} = \frac{N(a>0) - N(a<0)}{N(a>0) + N(a<0)}, \qquad a \equiv (y_t + y_{\bar{t}})(y_t - y_{\bar{t}}).$$

for Mtt>450GeV.
- 25% chance of mismatch of q-direction and boost direction.

- A_boost = 6% is predicted (while Afb = 15%, Afb+=30%).

- Roughly a few fb-1 of data is required to gain statistics.