Phenomenology of t-channel top physics regarding Tevatron anomalies

Sunghoon Jung

University of Michigan

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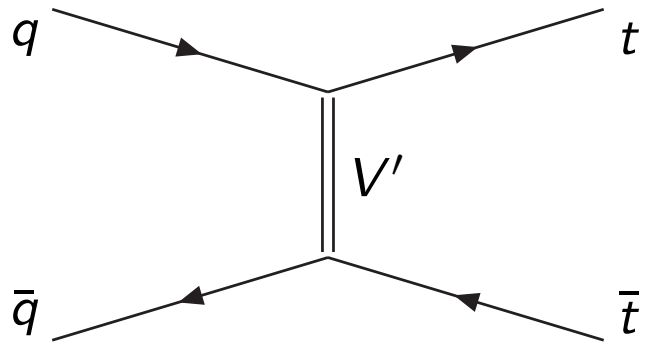
Based on SJ, H.Murayama, A.Pierce, J.Wells [0907.4112], SJ, A.Pierce, J.Wells [1103.4835, 1104.3139, another in progress]

What is t-channel top physics



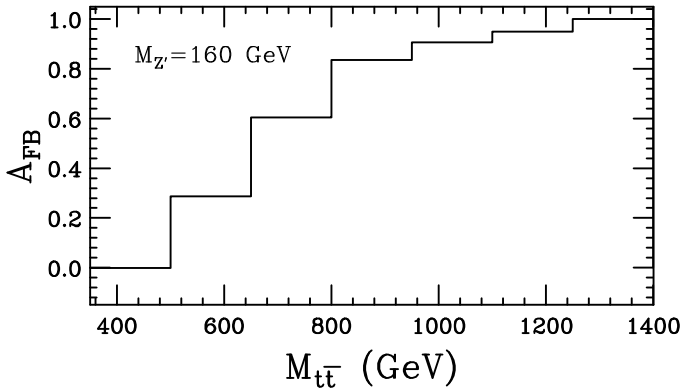
- t-channel top physics is a class of new physics that produces top pairs dominantly through t-channel exchange of new particles V'.
- Motivation for such new physics is provided by anomalously large top quark forward-backward asymmetry (Afb) measured at the Tevatron.
- Also, if new particle is light ($M_{V'} \lesssim M_t$), it can unavoidably contribute to Wjj events in the Tevatron excess region.

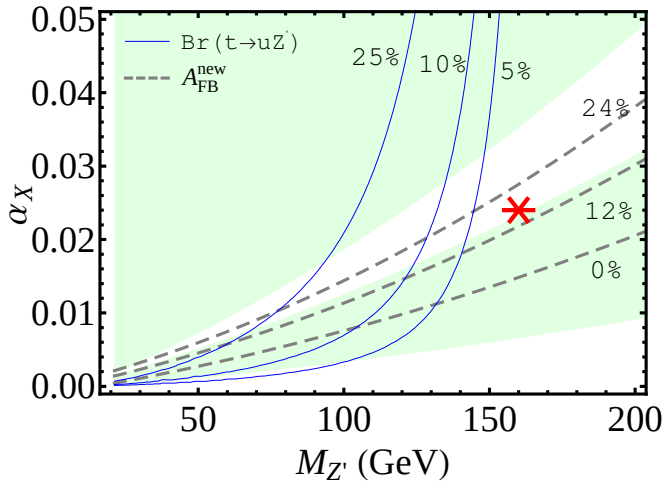
This talk is about

- How t-channel top physics contributes to Afb and Wjj excess.
- Given these motivations, various phenomenologies of the light new boson V' (reviews and new studies for unconstrained relevant parameter space):
  - Pitfalls in comparison with current measurements of $d\sigma/dM_{t\bar{t}}$ and $dAfb/dM_{t\bar{t}}$.
  - V' resonance in association with single top at the Tevatron and the LHC.
  - Single lepton charge asymmetry at the LHC.

Afb from *t*-channel physics

- One way to explain a large positive *Afb* is to introduce a new (vector) boson V' that couples mainly to up (or down) and top quarks in a flavor-violating way: $V' - t - u$ (or $V' - t - d$).
- A large positive *Afb* is analogous to classical Rutherford scattering.
- Rutherford enhancement is more apparent at high-energy region resulting in large cross sections at high-energy.
- A wide range of V' mass can explain *Afb* measurements. In particular, a light V' of $M_{V'} \lesssim M_t$ is allowed.



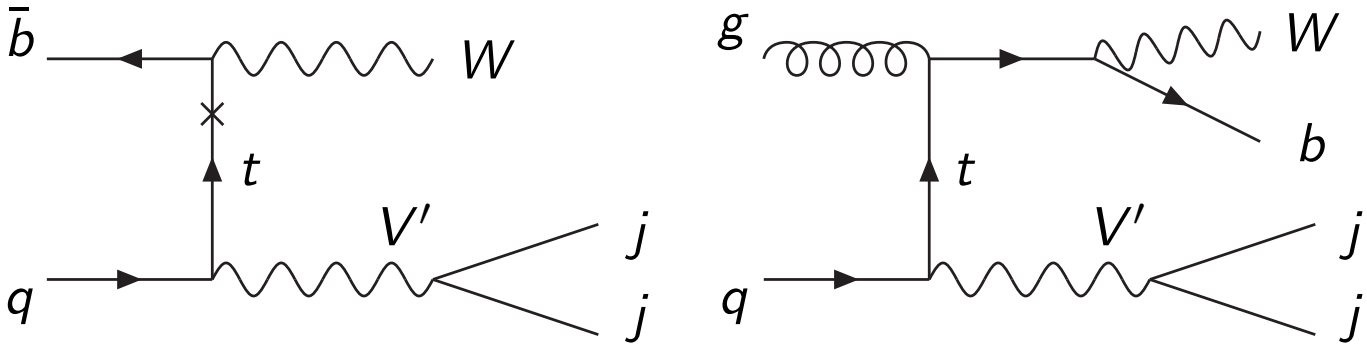


(Ref: SJ, H.Murayama, A.Pierce, J.Wells [0907.4112])

V' contribution to Wjj

Ref: SJ, A.Pierce, J.Wells [1104.3139]

- $M_{V'} \sim 160$ GeV somewhat coincides with the Wjj excess region at the Tevatron. It is natural to speculate on a common origin of Afb and Wjj.
- $V' \to jj$ is kinematically preferred, and it appears as a resonance.
- V' contribution accompanies extra jet, making M_{jj} distribution a bit broad (but a peak exists at around 150-160 GeV).
- Excess is about 40% of the central value of CDF measurement. But there seems unaccounted uncertainties that may overestimate the exess.



Collider constraints on t-channel physics

- Different signatures are predicted from different parameter space and different models of t-channel physics.
- Like-sign top pair production will be constrained by like-sign dilepton events and/or by single lepton charge asymmetry at the LHC.
- V' resonance of tj can be reconstructed from direct productions of V' (e.g. $gu \to tV' \to t\bar{t}j$).
- Deviation of inclusive $t\bar{t}$ cross sections (from the same direct productions) can also be measured. $\ell + j$ measurement is likely larger than $\ell\ell$ one.

✓ However, for complex V' lighter than the top quark (relevant to both *Afb* and *Wjj*), all of the above signatures are absent or small.

✓ On the other hand, generic prediction of t-channel physics is a large enhancement of $t\bar{t}$ cross section at high-energy region (not as a peak structure). But there is a subtlety...

In the rest of the talk, last two check-marked ✓ items will be discussed.

Pitfalls in interpreting unfolded $d\sigma/dM_{t\bar{t}}$ and $dAfb/dM_{t\bar{t}}$

Ref: SJ, A.Pierce, J.Wells [1103.4835], see also M.Gresham's talk.

Unfolding procedure is to correct selection efficiencies, detector effects, etc, so that resulting measurements can be directly compared with parton-level theoretical predictions. CDF unfolding (used for $d\sigma/dM_{t\bar{t}}$ and $dAfb/dM_{t\bar{t}}$) is based on Standard Model (SM) calculation (color octet models were also used to verify this procedure).

- Model independent unfolding procedure of CDF may not be applicable to t-channel top physics.
- Acceptances under event selection are significantly different for the SM and t-channel physics. Consequently, t-channel effects are likely *underestimated*.
- It is especially true and important at high-energy region. Very forward top quarks (high rapidity) from Rutherford scattering are less likely to be selected/reconstructed.

Parton-level unfolding simulation

Our parton-level analysis methodology:

- Derive SM acceptances under CDF cuts using our own parton-level event samples.
- Form a unfolding matrix in four-binned $Q_\ell \cdot \eta(t_h)$ (following CDF procedure).
- Approximate CDF unfolding procedure by applying the same SM unfolding matrix to every physics event samples that are applied to CDF cuts.

$M_{t\bar{t}}$ (GeV)	350-500	500-600	600-700	700-800	800-1400
SM	7.8 %	7.6	7.8	8.0	8.5
t-channel V'	7.6 %	6.7	5.9	5.0	4.0
color octet	7.8 %	7.8	7.9	8.0	8.8

Table: Acceptances under CDF cuts used for $d\sigma/dM_{t\bar{t}}$.

Resulting differential cross sections

	$d\sigma/dM_{t\bar{t}}$ (fb/GeV)	Afb
CDF measurement	0.068 ± 0.036	0.475 ± 0.114
t-channel V'	$0.215 \to 0.091$	$0.30 \to 0.22$
color octet		$0.16 \to 0.14$

Table: For $M_{t\bar{t}} \geq 800, 450$ GeV before cuts $\to$ after CDF cuts and unfolding.

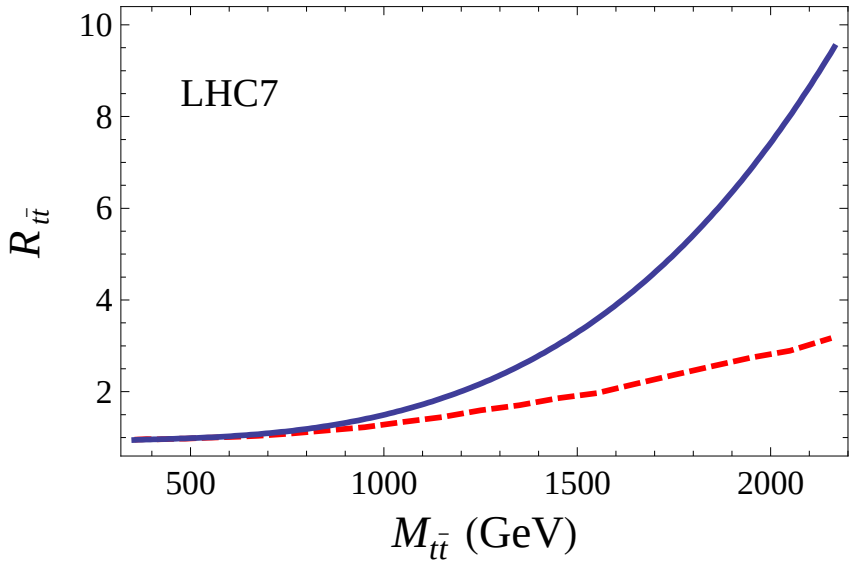


Figure: $R_{t\bar{t}} \equiv \frac{d\sigma(V')/dM_{t\bar{t}}}{d\sigma(SM)/dM_{t\bar{t}}}$ with(red)/without(blue) cuts $\eta(t), \eta(\bar{t}) < 2$.

V' resonance in association with single top

(Ref: SJ, A.Pierce, J.Wells [1105.xxxx] preliminary.)

- Look at jj resonance in the process $gu \to tV' \to tjj$.
- Signal topology is "3 j (1 b-tagged) + 1 ℓ + missing energy".
- Two untagged jets are used to construct m_{jj} distribution.
- Our discovery cuts are based on single top measurements supplemented by additional hard cuts.

Within a narrow range of m_{jj} around V' peak,

backgrounds	After all cuts	backgrounds	After all cuts
$t\bar{t}$	16.7 fb	$W + j$	8.5 fb
$Wb\bar{b}$	2.8 fb	Single top	1.3 fb
V' signal	11.2 fb		
$S/(0.12B)$	2.9	$S/\sqrt{B}$	2.0 $\sqrt{\mathcal{L}/1fb^{-1}}$

More than 3σ evidence is likely possible with current or future top quark data samples at the Tevatron.

Single lepton charge asymmetry

At the LHC, $gu \to tV'$ is more abundant than $g\bar{u} \to \bar{t}V'^*$ (with $V' \to jj$). This can produce single lepton charge asymmetry defined as

$$A_C \equiv \frac{N(tX \to 1\ell^+X) - N(\bar{t}X \to 1\ell^-X)}{N(tX \to 1\ell^+X) + N(\bar{t}X \to 1\ell^-X)}$$

With basic kinematic cuts with "$3j$ ($1b$-tag) + 1ℓ +MET" topology,

- $A_C \sim 0.75$ for V' production associated with single top.
- Two largest bkgds to numerator are $W + j$ and SM single top while $t\bar{t}$ is the largest contributor to denominator.
- We estimate $A_C \sim 0.19$ while the sole SM prediction is $A_C \sim 0.09$.
- We are trying to better understand uncertainty factors. By taking stat. error only, $150(300)pb^{-1}$ of data is enough for $3(5)\sigma$ evidence. $W + j$ is already subdominant.

Summary

- A new light V' physics with flavor-violating couplings of top quarks may be relevant to Tevatron Afb and/or Wjj.
- They can be probed and tested at hadron collider by various observables: like-sign dilepton, single lepton charge asymmetry (from various processes), V' resonance, inclusive xsec, and deviation in differential cross sections.
- We can even go back to Tevatron top quark data to look for light V' resonance of jj.
- To properly use differential cross section measurements to test this new physics, more careful study of unfolding procedure should be preceded.
- Future direction of t-channel physics explanation depends on early results of hadron collider searches.