(Light) t-channel top physics of top asymmetry

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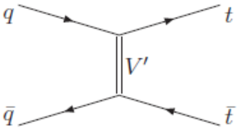
Based on works with H.Murayama, A.Pierce, J.Wells.
Refs: [1108.1802] and [0907.4112], [1103.4835], [1104.3139].

What is t-channel top physics

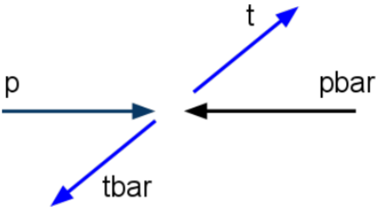


- A class of new physics that produces top pairs at hadron colliders dominantly through t-channel exchange of new particles V'.
- Motivation is provided by anomalously large top quark forward-backward asymmetry (A_{FB}) measured at the Tevatron.
- Most t-channel physics models predict early LHC signatures.

This talk is about

- Summary of A_{FB} data
- Models/characteristic pheno of t-channel top physics
- Emphasis on light V' models: comparison and contrast with heavier V'
  - Relevance of $m_{t\bar{t}}$?
  - Single top phenomena
- Search strategy: Hadronic resonance in association with single top

Top quark forward-backward asymmetry



$$A_{FB} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})},$$

$N_i(j)$ is the number of i in the direction of j

Measured at the Tevatron : A_{FB} = 15.8% +/- 7.4% (l+j, 5.3fb-1 CDF)
A_{FB} = 42% +/- 16% (l+l, 5.1fb-1 CDF)
A_{FB} = 19.6% +/- 6.5% (l+j, 5.4fb-1 D0)

(All these are independently more than 2-sigma away from zero.)

CDF note 10436, 9724 D0 1107.4995

Measurements history

$$A_{FB} = 0.20 \pm 0.11^{stat} \pm 0.047^{sys}\ (0.695 fb^{-1}\ \text{CDF T.Schwarz Thesis})$$

$$A_{FB} = 0.19 \pm 0.09^{stat} \pm 0.02^{sys}\ (0.9 fb^{-1}\ \text{D0 0712.0851})$$

$$A_{FB} = 0.17 \pm 0.07^{stat} \pm 0.04^{sys}\ (1.9 fb^{-1}\ \text{CDF 0806.2472})$$

$$A_{FB} = 0.193 \pm 0.065^{stat} \pm 0.024^{sys}\ (3.2 fb^{-1}\ \text{CDF note 9724, March 2009})$$

$$A_{FB} = 0.08 \pm 0.04^{stat} \pm 0.01^{sys}\ (4.3 fb^{-1}\ \text{D0 note 6062, July 2010})$$

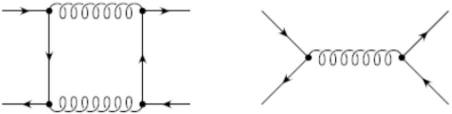
Over a few years, Afb has been consistently large and ~2 sigma away from zero, both at CDF and D0.

What do these imply for SM?

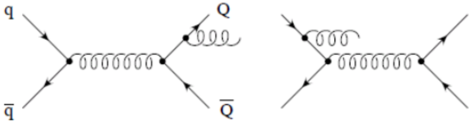
Standard Model prediction

Afb arises at $\mathcal{O}(\alpha_S^3)$
(analogous to QED lepton asymmetry, Berends et al. 1973)

Interference of
box and tree :



Interference of
FSR and ISR :



SM A_{FB} = 5.8 +/- 0.9% (l+j), 6.0 +/- 1.0% (l+l)

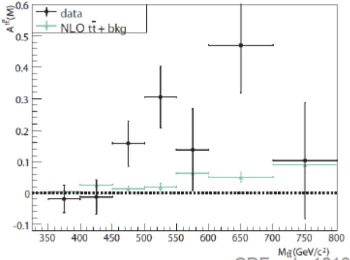
SM prediction is too small to account for data, and is ~2 sigma below data.

Increase at high-energy

- Increasing behavior is natural.

- CDF and D0 observed it.

- Rapid increase may further imply new physics contribution at high-energy region.



CDF note 10185

A_{FB}(M_{ttbar}<450GeV) --> A_{FB}(M_{ttbar}>450GeV)

-2.2 +/- 4.3 % --> 26.6 +/- 6.2 % (CDF)
7.8 +/- 4.8 % --> 11.5 +/- 6.0 % (D0)

(1.3 +/- 0.6 % --> 4.3 +/- 1.3 % (SM))

LHC asymmetry

More directly correlated with Tevatron Afb, but hard to measure.

With respect to ttbar boost direction, [1103.4835] SJ, A.Pierce, J.Wells

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

A_{boost}	no cuts (unfolded)	after cuts (background subtracted)
Model A	4.5%	2.5%
CMS [4]	$-1.3 \pm 3.8\%$	$-0.7 \pm (\lesssim 3.8)\%$
SM	$1.1 \pm 0.1\%$	–

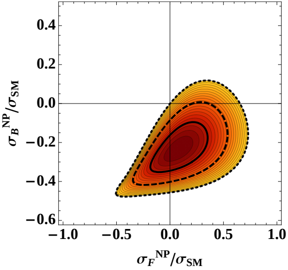
Why is A_{FB} important?

- $\sim 2\ \sigma$ deviations are observed in several independent measurements.

But, not just because of the deviation...

- A_{FB} is a third generation observable that is expected to be somewhat special in many BSM.
- A_{FB} results from small higher-order effects in the SM.
  - is sensitive to LO new physics contribution,
  - helps/facilitates better understanding of QCD.

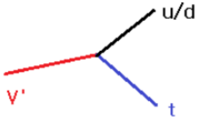
Model independent best fit



(Ref: B.Grinstein et.al. [1102.3374])

- Interference with QCD is preferred.
- New physics possibilities: *s*-channel color-octet and *t*-channel exchange can interfere with QCD.

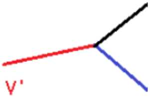
Models of t-channel physics

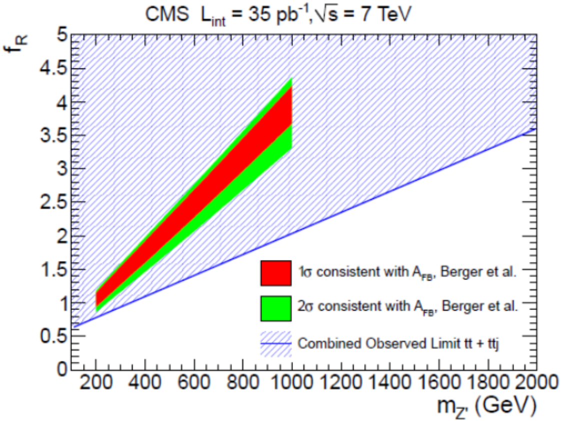


$$\mathcal{L}_{eff} = i g_X \bar{t} \gamma^\mu P_R q V'_\mu$$

- Abelian Z' with Z'-u-t coupling
- W' with W'-d-t coupling from non-Abelian left-right asymmetric model
- W' with W'-u-t coupling from non-Abelian horizontal symmetry under with (u_R, t_R) forms a doublet
- Scalar V' in various color representations
- .....

Models of t-channel physics





- Abelian Z' wi
- W' with W'-d-
  asymmetric r
- W' with W'-u-
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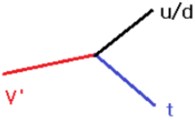
Models of t-channel physics



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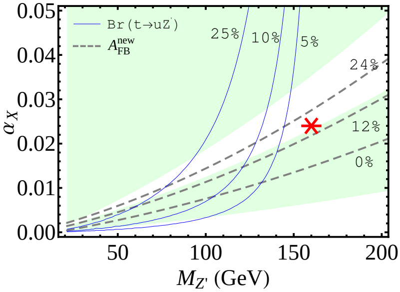
Simplified model

For the purpose of qualitative discussion, free parameters are

$$\{M_{V'}\,,\,\alpha_X\}.$$

Favored parameter space:



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

Characteristic phenomenology

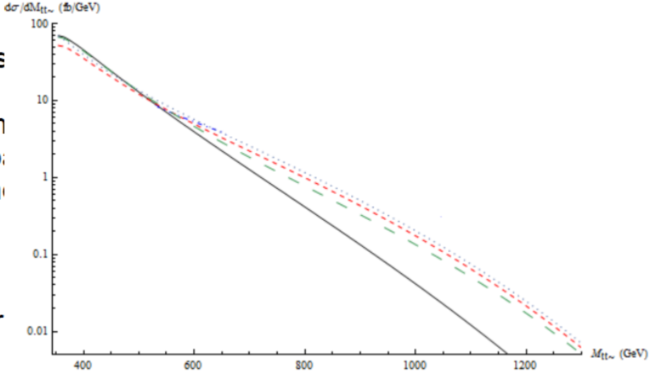
Important observables are:

- invariant mass distribution of top pair
- total top pair production cross section
- tj resonance of V'
- ...

generically arising from:

- t-channel scattering Rutherford enhancement
- direct production of V' from gu -> tV' (-> ttbar j)

Characteristic phenomenology



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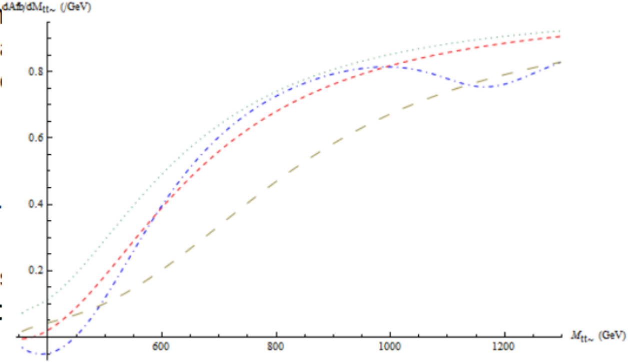

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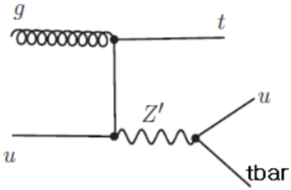

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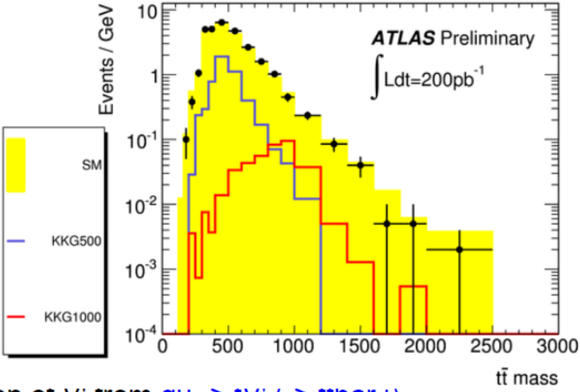

generically arising

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Now, light t-channel V' ($M_{V'} \lesssim M_{top}$) ...

Light t-channel mediator V'

Refs: [0907.4112], [1104.3139] SJ et al.

We add a new free parameter $\epsilon \ll 1$:

$$\{M_{V'}\,,\,\alpha_X\,,\,\epsilon\} \quad , \quad \left(\mathcal{L}_{eff} \ni i\epsilon g_X \sum_{i=1}^{3} \bar{q}_i \gamma^\mu P_R\, q_i\, V'_\mu\right)$$

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Drastically different pheno arises:

- New decay mode $V' \to jj$ dominates over $V' \to tj$.
- $tV' \to tjj$ would contribute to single top sample rather than top pair.
- Important generic signatures ($\sigma(t\bar{t})$, tj resonance) discussed previously do not arise.

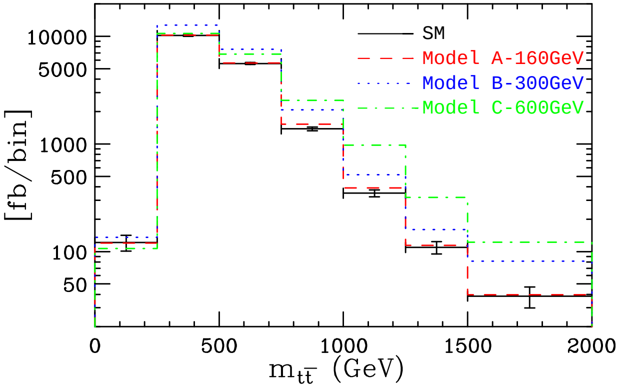
Light t-channel mediator V'

What about

- $m_{t\bar{t}}$?
- single top data?

Relevance of $m_{t\bar{t}}$?

Refs: [1108.1802] SJ, A.Pierce, J.Wells



Model A 160GeV vs. Model B 300 GeV

- Model B predicts abundant $\sigma(gu \to tV' \to t\bar{t}j) \sim 20pb$ while Model A does not.
- True $t\bar{t}$ and tV' have different distributions.

This faking $t\bar{t}$ contribution shows up as an overall excess in every bins of Model B.

Relevance of $m_{t\bar{t}}$?

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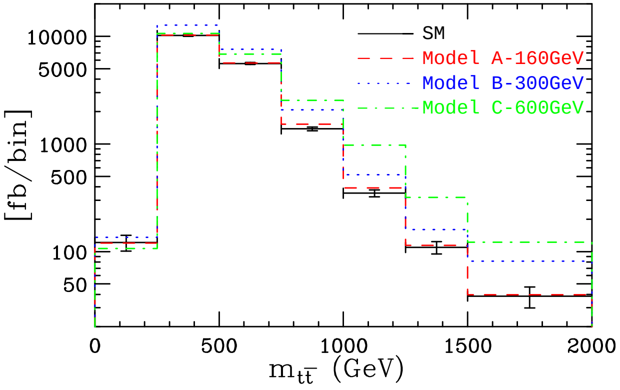


Pitfalls in interpreting unfolded $d\sigma/dM_{t\bar{t}}$ and $dAfb/dM_{t\bar{t}}$

Ref: [1103.4834] SJ, A.Pierce, J.Wells, [1103.3501] M.Gresham, I.Kim, K.Zurek

Unfolding procedure is to correct selection acceptances, detector effects, etc, to facilitate comparison with theory predictions.

However, acceptances can be very different due to very forward top quarks:

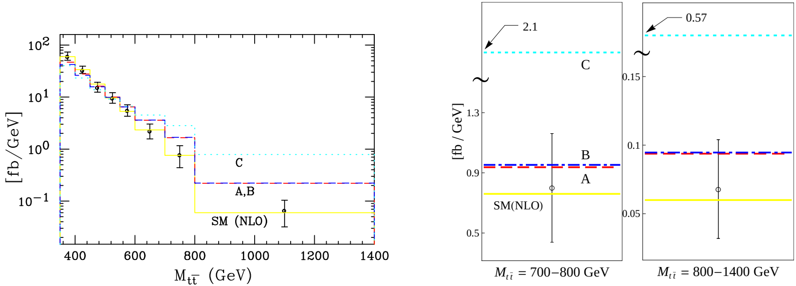
$M_{t\bar{t}}$ (GeV)	350-500	500-600	600-700	700-800	800-1400
SM	7.8 %	7.6	7.8	8.0	8.5
t-channel V'	7.6 %	6.7	5.9	5.0	4.0
color octet	7.8 %	7.8	7.9	8.0	8.8

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

Model independent CDF unfolding *underestimates* t-channel effects, especially at high-energy region (with a lighter V').

Demonstration: theory vs. MC with unfolding.

Our parton-level methodology: Derive SM acceptances. → Form a unfolding matrix. → Apply the same SM matrix to every physics samples.



([1103.4834] SJ, A.Pierce, J.Wells)

This effect is greater for a lighter V', i.e. lower acceptances.

Relevance of $m_{t\bar{t}}$?

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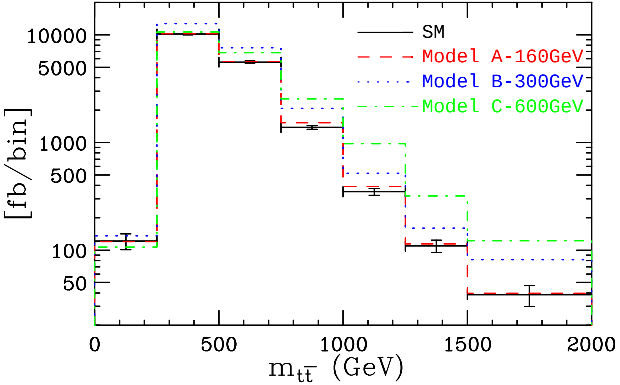

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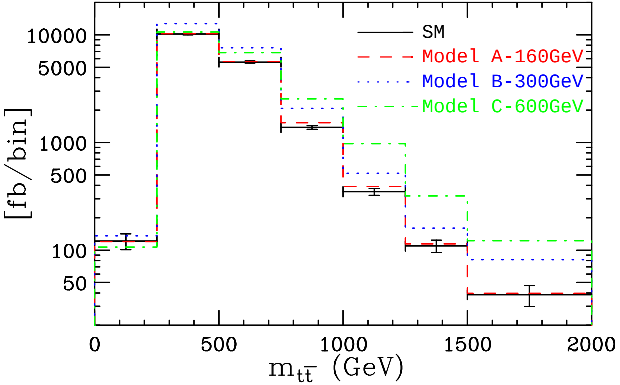

NB: Another issue about inefficient $m_{t\bar{t}}$ reconstruction is discussed in paper and suppl material.

Light V' in current analysis of Single top

- Single top productions:
  - SM single top : dominantly from $ub \to dt(\to dbW)$.
  - Light t-channel : $gu \to tV'(\to bWjj)$.

  $\sigma(\text{SM single top}) \sim \sigma(tV') \sim 60pb \quad < \quad \sigma(t\bar{t}) \sim 160pb$

- Cut based analysis:
  - SM analysis is usually optimized in $W+2j$ topology, while new physics has $W+3j$ topology.

- Distributions:
  - $H_T(j)$: As V' is light, new $H_T(j)$ distribution does not peak at high value above top pair contribution.

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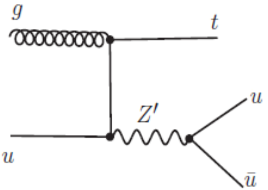
Current SM single top analysis is not that sensitive to light V' model.

Search strategy: hadronic resonance associated with single top

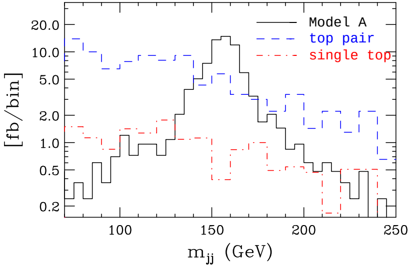
Refs: [1108.1802] SJ et al.



- Signal topology is "$3j$ (1b-tagged) $+1\ell+$ missing energy".
- Two untagged jets are used to calculate m_{jj} distribution.

Search strategy:
hadronic resonance associated with single top

At LHC7,



backgrounds	σ after discovery cuts
$t\bar{t}$	0.20 pb
Single top (t-channel)	0.019 pb
Single top (tW)	0.016 pb
$W+j$	0.080 pb
$Wb\bar{b}$	0.012 pb
Model A	0.33 pb
$S/\sqrt{B}$	$5.7\sqrt{\mathcal{L}/100\,\mathrm{pb}^{-1}}$

Discovery cuts are: $p_T(leadj) > 90GeV$, $H_T(j) > 200GeV$, $\Delta R(j,j) < \pi$ and $135 \le m_{jj} \le 175GeV$ in addition to basic single top selections.

Search strategy: hadronic resonance associated with single top

At Tevatron,

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/B	0.35	$S/\sqrt{B}$	2.0 $\sqrt{\mathcal{L}/1fb^{-1}}$

If this optimized analysis is carried out and systematics are under control, we can tell light V' t-channel models even with current Tevatron/LHC data.

Complementary: Single lepton charge asymmetry

At the LHC, $gu \to tV'$ is more abundant than $g\bar{u} \to \bar{t}V'^*$ (with $V' \to jj$).

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

backgrounds	ATLAS total rate	A_C^ℓ
$t\bar{t}$	1847 events	0
$W+j$	1930 events	0.2
Single top	385 events	0.3
others	668 events	0
tV' (Model A)	780 events	0.75
Total (SM only)	4830 events	0.10 ± 0.014(stat)
Total (Model A)	5610 events	0.19 ± 0.013(stat)

Summary, cross-check advocacy

- The persistence of A_{FB} anomaly begs for a cross check.
- Light t-channel model remains a leading explanation.
- $m_{t\bar{t}}$ might not be the first place to look for it (unlike other ideas, unlike general expectations).
- Search for a jj resonance with single top is a definitive signal, discovering or refuting this model.