Top quark forward-backward asymmetry from new t-channel physics

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Top quark

In theories:

In many new physics candidate beyond the Standard Model, top quark plays important roles. (Warped extra dimension - strongly coupled top, SUSY - key role in fine-tuning and little hierarchy, little Higgs, top color, any flavor physics, ...)

Experiment side:

Many properties of top quark has been measured: cross section, decay width, mass, angular distribution, asymmetry... With new physics all or some are correlated.

Let's start with forward-backward asymmetry.

Outline

1. Status of top asymmetry

- Standard Model asymmetry is 5%
- Tevatron measurements has been large.

2. t-channel physics

- t-channel asymmetry can be large.
- What t-channel suffers from.
- Addendum I : Coupling structure
- Addendum II : SU(2) t-channel physics

References :

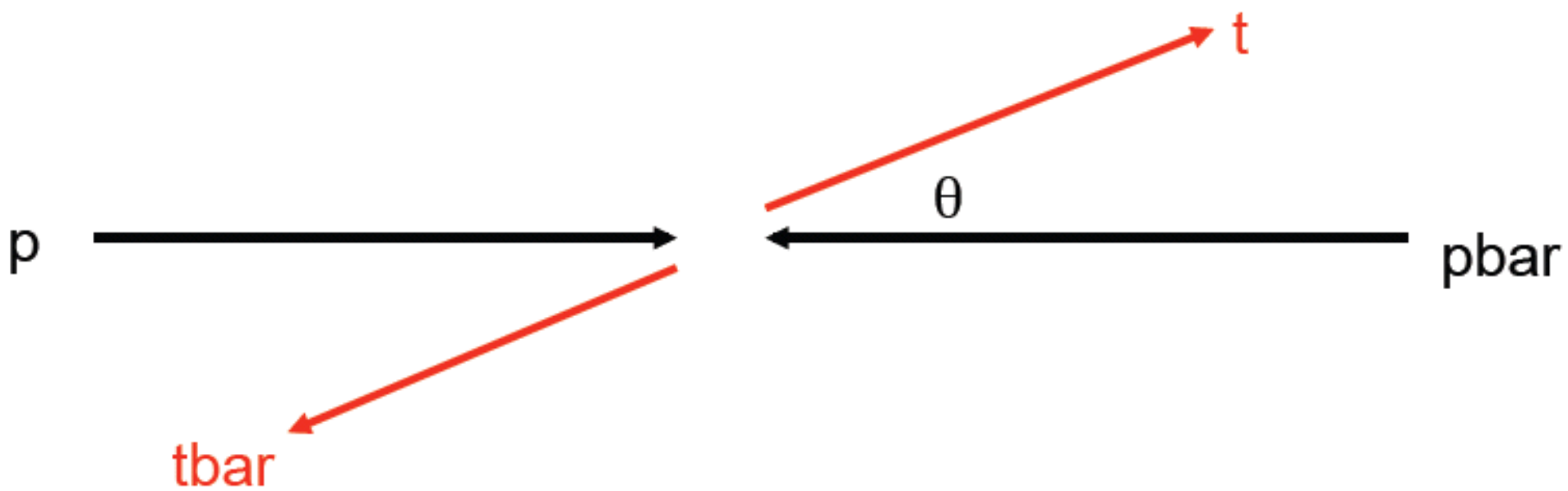
Phys.Rev.D81:015004,2010 by SJ, H.Murayama, A.Pierce, J.Wells.

Experimental discussion is inspired by CDF note 9724 (March 17, 2009)

Top Forward-backward asymmetry

At Tevatron

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

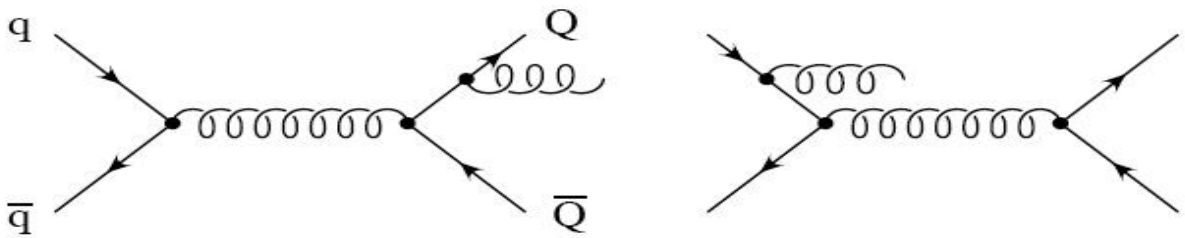


Standard Model Prediction

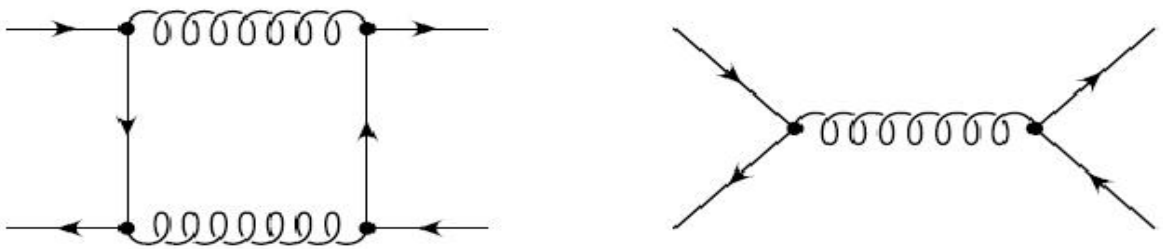
At Tevatron, $$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

5% +/- 1.5% asymmetry arises at α_s^3 order (Kuhn et al. 1995).

ISR / FSR interference :



Box / tree interference :



Top asymmetry at the Tevatron

3.2 fb^{-1}, CDF 9724, March 2009 (most recent measurement)

$$A_{FB} = 0.193 \pm 0.065^{stat} \pm 0.024^{syst}$$

(SM 5% +/- 1.5%)

Previous measurements

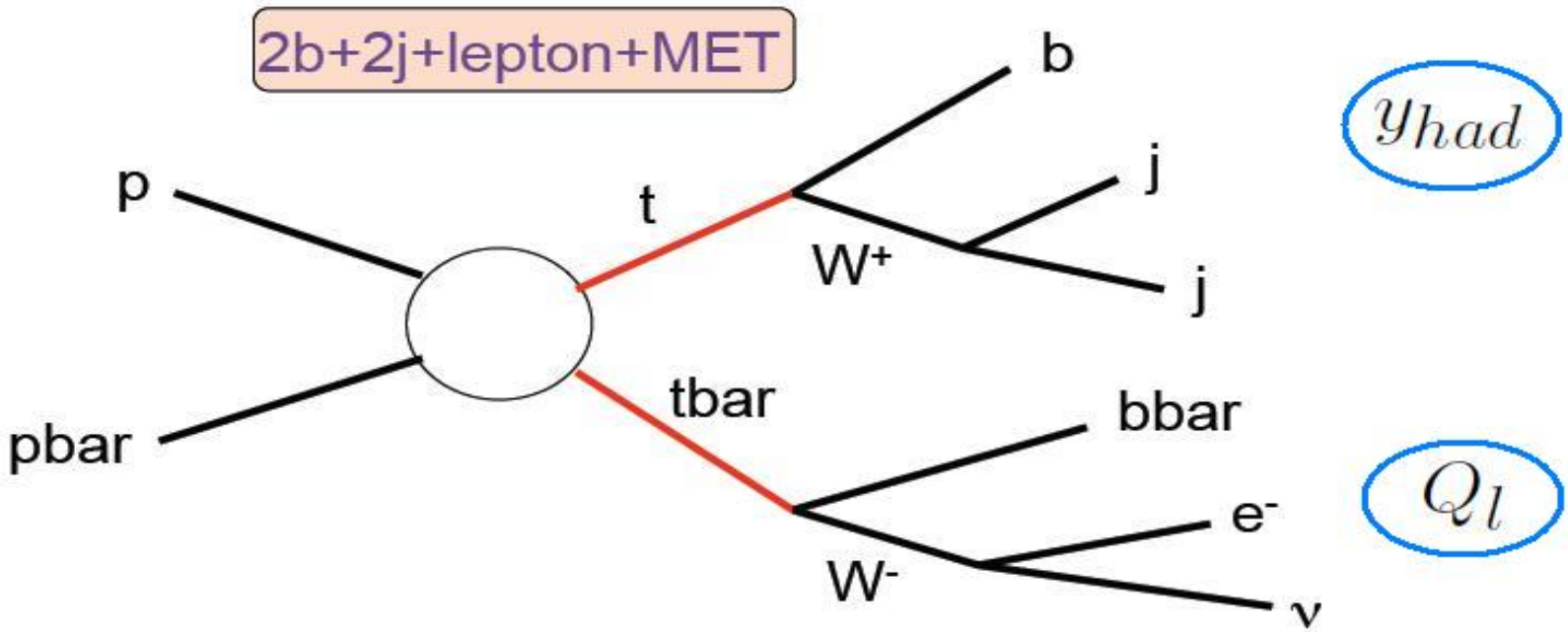
$$A_{FB} = 0.20 \pm 0.11^{stat} \pm 0.047^{syst} \; (0.695\, fb^{-1}\, \text{CDF}\, \text{T. Schwarz Thesis})$$

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

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

What they measure

Actual measurement is made on collection of ttbar that have one top decaying leptonically and the other hadronically (l+j channel)

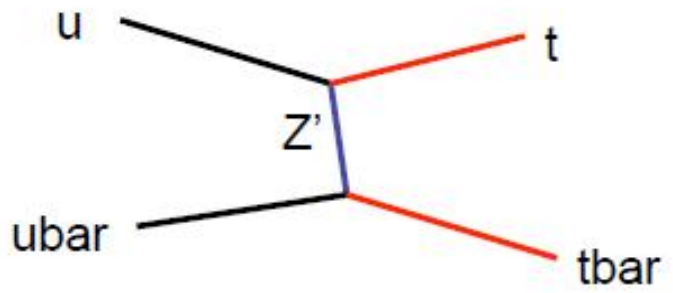


$$A_{fb} = \frac{N(-Q_l \cdot y_{had} > 0) - N(-Q_l \cdot y_{had} < 0)}{N(-Q_l \cdot y_{had} > 0) + N(-Q_l \cdot y_{had} < 0)}$$

NB : Is this observable the same thing as previous naive definition?

Predictions from t-channel physics

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

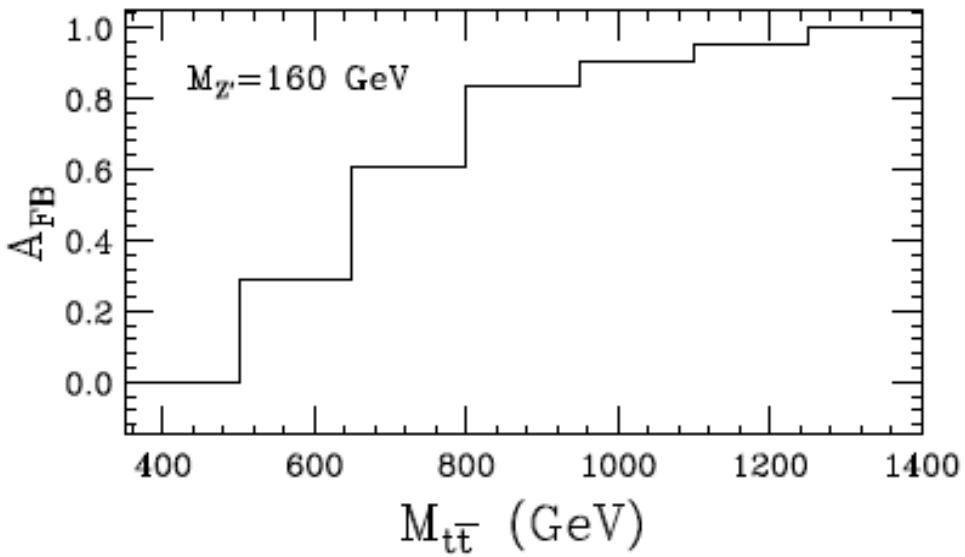


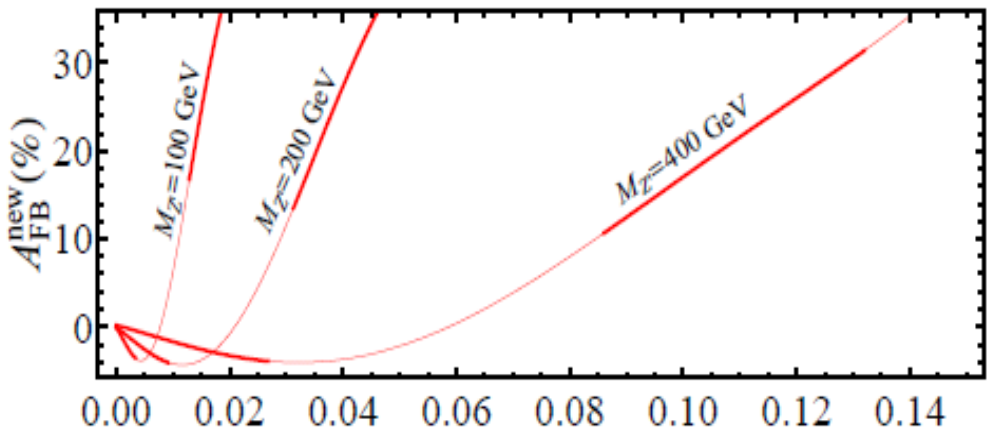
Our model can produce 18% asymmetric tt-bar events at a rate consistent with CDF measurements in the lepton+jet and dilepton channels.

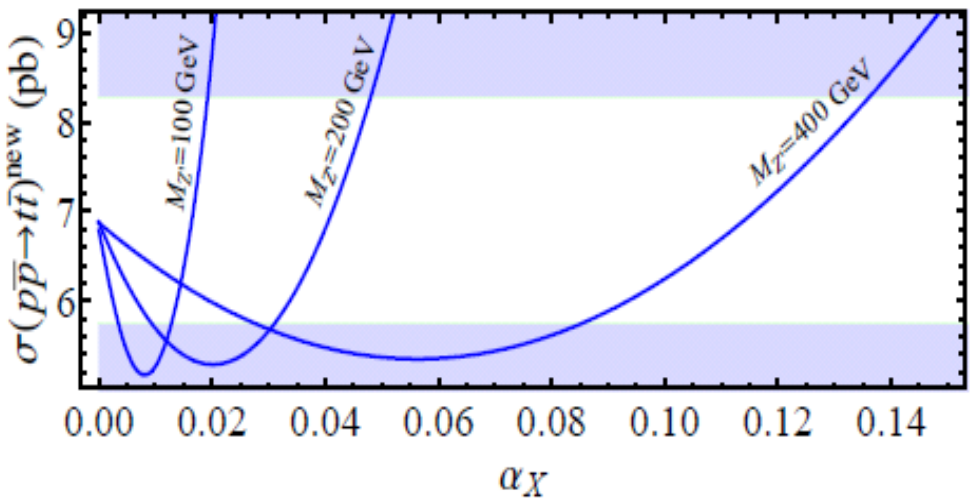
	$l+j$ (pb)	dilepton (pb)	A_{FB}^{tot} %
$M_X = 160$ GeV, $\alpha_X = 0.024$	7.5	5.8	18
Measurements [1, 22, 23]	7.2 ± 0.8	6.7 ± 1.0	19 ± 7

How t-channel obtains large asymmetry

- Rutherford scattering singularity prefers forward scattering.
- Color-singlet t-channel interferes with QCD.



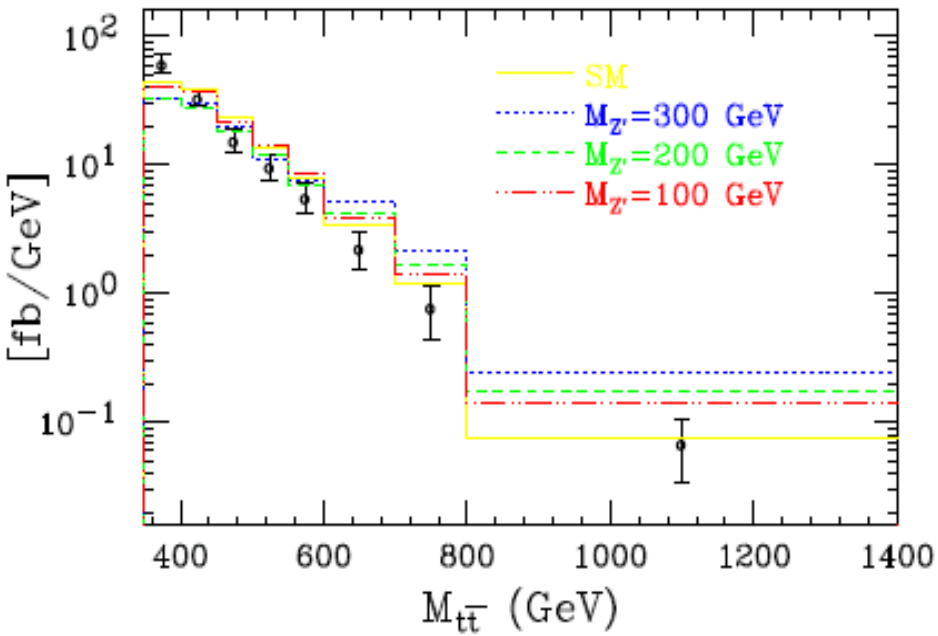


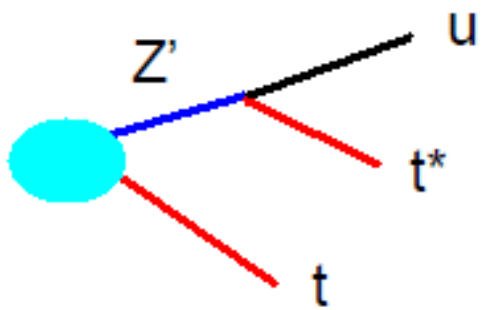


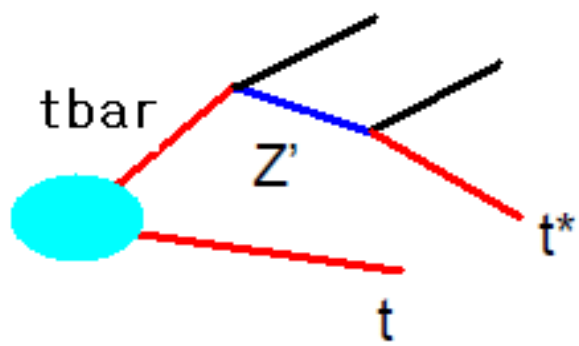
t-channel physics challenges

1. Rutherford singularity distorts differential cross section, especailly M_{ttbar}.

2. Like-sign top production is abundant because Z' equally decays to top or anti-top. (only 3-10 events at CDF, $2fb^{-1}$)







t-channel physics challenges

All those challenges require :

1. Mass range is tight: $140GeV \lesssim M_{Z'} \lesssim M_{top}$
   Dangerous decay modes of Z' and top are suppressed.

2. Flavor diagonal coupling ϵ_U is essential to provide with light quark decay modes of Z'.

$$\begin{pmatrix} \epsilon_U & 0 & 1 \\ 0 & \epsilon_U & 0 \\ 1 & 0 & \epsilon_U \end{pmatrix}$$

t-channel physics phenomena (list)

Many other considerations listed below lead us to our best point.

Extra top or jets from Z' decay :

- ttbar+j / ttbar+0 ratio
- difference in the l+j and dilepton channels
- negative asymmetry from gu -> Z't channel
- effects on single top production
- Z' resonance at dijet channel

Exotic top decays:

- t -> uZ' (if Z' is light) may lose true ttbar events
- t -> ug (one-loop induced FCNC)

Z' can mediate rare processes:

- Hadronic widths of Z boson and Upsilon
- B meson decay (box diagram with W, Z')
- D-Dbar mixing (no flavor changing charm couplings)

Addendum I: Structure of couplings

$$R_u^\dagger C_R R_u = \begin{pmatrix} \epsilon_U & 0 & 1 \\ 0 & \epsilon_U & 0 \\ 1 & 0 & \epsilon_U \end{pmatrix}$$

Is there any solution of Z' charges C_R and unitary mixing matrices R_U giving our desired coupling structure subject to CKM and quark masses?

(CKM : $V_{CKM} = L_u L_d^+$, Yukawa : $L_q Y_q R_q^+ = diag(m_1,m_2,m_3)$)

Yes, such solution C_R always exists because a symmetric matrix can be diagonalized by an orthogonal matix. Z' charges are given by

$$C_R = diag(-1+\epsilon_U, 0+\epsilon_U, 1+\epsilon_U)$$

Addendum II: SU(2) t-channel physics

- W' couples to (t_R', u_R') doublet. $W'^{+/-}$ produce ttbar in t-channel.

- W' (almost) distinguishes top and anti-top (or, carries "top-charge") which greatly avoids like-sign top production. As u_R and t_R mix more, dangerous top-charge breaking increases.

- t_R' is mostly t_R mass eigenstate. Small mixture of u_R is neccessary to provide with W'-u_R-u_R coupling (playing similar roles as abelian Z'-u_R-u_R coupling). Multi-Higgses can achieve such coupling sturcture.

- Best case results in about 20% asymmetry.