The top quark forward-backward asymmetry and new physics contributions*

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* Based on work and discussions with S. Jung, H. Murayama and A. Pierce.

Measurable Properties of the Top Quark

- Total production cross section
- Decay branching fractions and width
- ttbar invariant mass distribution
- Forward-backward asymmetry
- … many other properties

With new physics, all are or can be interrelated.

We will start with forward-backward asymmetry.

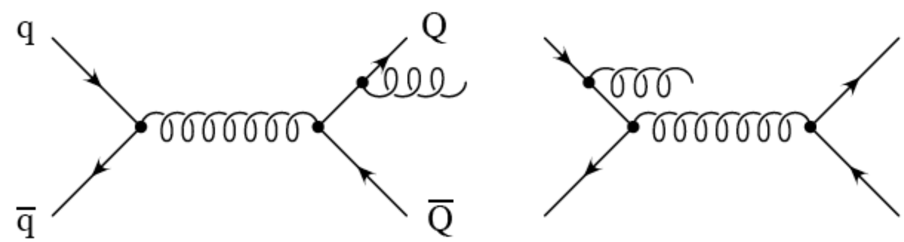
Inspired in part by recent preprint (our main experimental source for this talk):
CDF, "Measurement of the Forward-Backward Asymmetry in ttbar production in 3.2 fb^{-1} of ppbar collisions at 1.96 TeV," CDF Note 9724 (March 17, 2009).

Standard Model Prediction

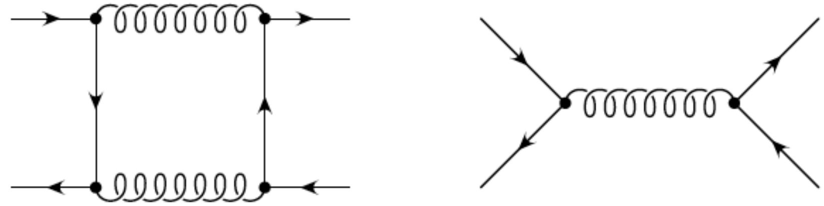
Asymmetry arises at α_s^3 order.

(Close analogy with QED α^3 asymmetry, Berends et al. 1973)

Interference of ISR with FSR:



Interference of box with tree:

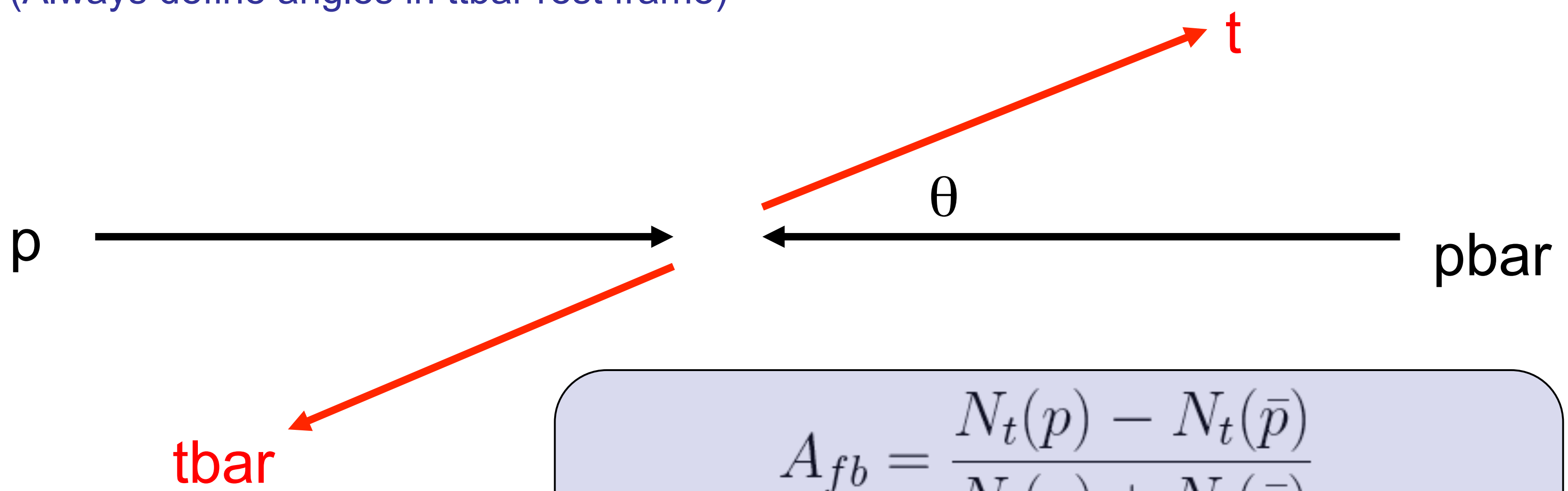


$$A_{FB}^{th} \simeq 0.050 \pm 0.015$$

(Antuñano), Kühn, Rodrigo, PRD '99 (0709.1652)

Top Asymmetry at the Tevatron

(Always define angles in ttbar rest frame)



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

$N_i(j) = \#$ of particle i in direction of particle j

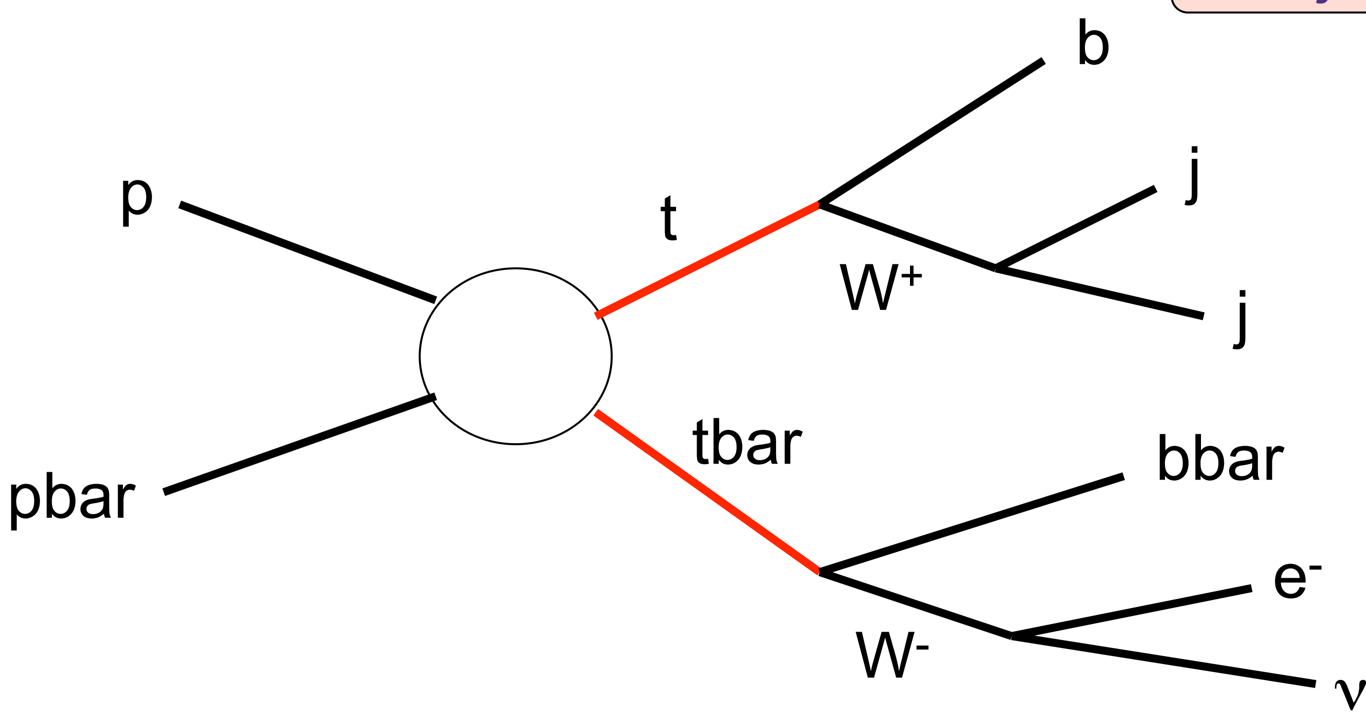
Assuming CP

$N_{\bar{t}}(p) = N_t(\bar{p})$ which implies $A_c = A_{fb}$ where $A_c = \frac{N_t(p) - N_{\bar{t}}(p)}{N_t(p) + N_{\bar{t}}(p)}$

What they measure

Actual measurement is made on collection of ttbar events that have one top decaying leptonically and the other hadronically.

2b+2j+lepton+MET



Event Selection

•Single lepton with p_T > 20 GeV and $|\eta|$ < 1.1

•Missing E_T from neutrino: MET > 20 GeV

•4 or more ‘tight jets’ E_T > 20 GeV, $|\eta|$ < 2.0

•At least one jet has ‘two tracks that form a secondary vertex (a ‘tagged jet’)’ This is the b jet selection

Surviving events in 3.2 fb^{-1}

From CDF Note 9724

Process	==4 Jets	$\geq$ 5 Jets
W + HF Jets	70.08 ± 21.99	16.48 ± 5.41
Mistags (W+LF)	22.52 ± 5.72	4.91 ± 1.98
Non-W (QCD)	25.04 ± 20.53	8.40 ± 7.53
Single Top	6.62 ± 0.42	1.20 ± 0.08
WW/WZ/ZZ	6.00 ± 0.57	1.57 ± 0.17
Z+Jets	3.89 ± 0.48	0.89 ± 0.11
Top	425.02 ± 58.86	144.06 ± 19.95
Total Prediction	559.15 ± 66.99	177.49 ± 22.23

Remaining top sample → Top

Tops/Background ~ 3.4 ratio

(Total number of ttbar produced in 3.2 fb^{-1} is about 20k, meaning only about 3% of ttbar events survived the selection.)

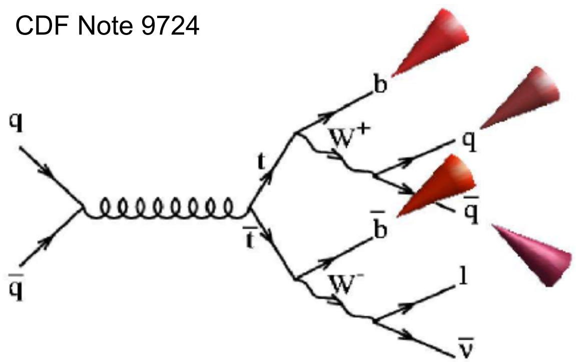
Constructing the asymmetry

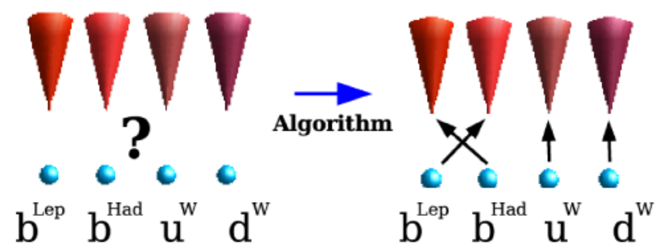
Some constraints and assumptions are applied to sample:

- Assume that highest 4 energy jets come from the 4 quarks in ttbar process [tagged b quark(s) are b quark(s)], with significant matching ambiguity
- Reconstruct p_z(neutrino) by $(p_l+p_\nu)^2=m_W^2$, with 2-fold ambiguity
- Two jets must reconstruct mW ($W \rightarrow jj$)
- $M_{l\nu j} = M_t$ and $M_{j(jj)} = M_t$

Matching Algorithm

CDF Note 9724





$$\chi^2 = \Sigma_{i=l,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \Sigma_{j=x,y} \frac{(p_j^{UE,meas} - p_j^{UE,fit})^2}{\sigma_j^2}$$

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{lv} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{blv} - M_{fit})^2}{\Gamma_t^2}$$

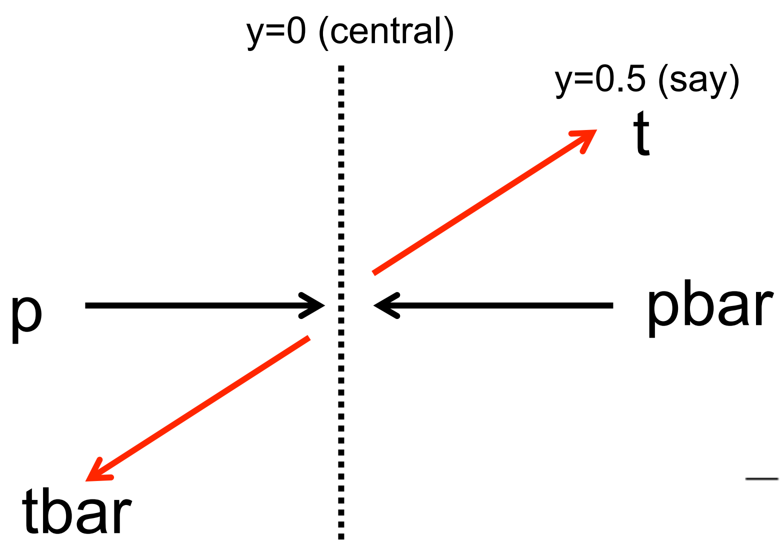
Use MINUIT to minimize χ^2 of each event. Monte Carlo studies say the constrained fit algorithm yields correct match for 60% of the events.

What they measure…

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

y_{had} = rapidity of the hadronically decaying t or $\bar{t}$

Q_l = lepton charge from the leptonically decaying t or $\bar{t}$



$$N_t(p) = N(-Q_l \cdot y_{had} > 0)$$
$$N_t(\bar{p}) = N(-Q_l \cdot y_{had} < 0)$$

$$-Q_l \cdot y_{had} = -(-1) \cdot (0.5) = 0.5 \text{ (positive)}$$

Raw Asymmetry

Applying all this to the data they get

$$A_{FB}^{raw} = 0.098 \pm 0.036$$

But this is “raw asymmetry” from data, which has several problems that must be unfolded to get the correct/true asymmetry.

1. Background pollution (W+jets, etc.). This can be understood, measured and subtracted by much larger set of “antitagged” events (events without b quarks).
2. Kinematic fitter smears true top quark rapidities (only dilutes asymmetry, but does not generate it)
3. Event selection cuts out some ttbar events -- concern is that acceptance may be biased w.r.t. top rapidity (small effect).

Forward-Backward Asymmetry Measurement

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

Why is this so interesting?

- 3σ away from zero -- nonzero, measured property of the top quark.
- About 2σ above Standard Model prediction.
- The actual measurement -- the asymmetry seen by events -- is persistently large at CDF and D0.

$A_{FB}^{th} \simeq 0.05$

Previous Measurements

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

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

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

$$A_{FB} = 0.193 \pm 0.065^{stat} \pm 0.024^{syst}\ (3.2\ fb^{-1}\ \mathrm{CDF}\ 9724,\ 17\ \mathrm{Mar}\ 2009)$$

New Physics?

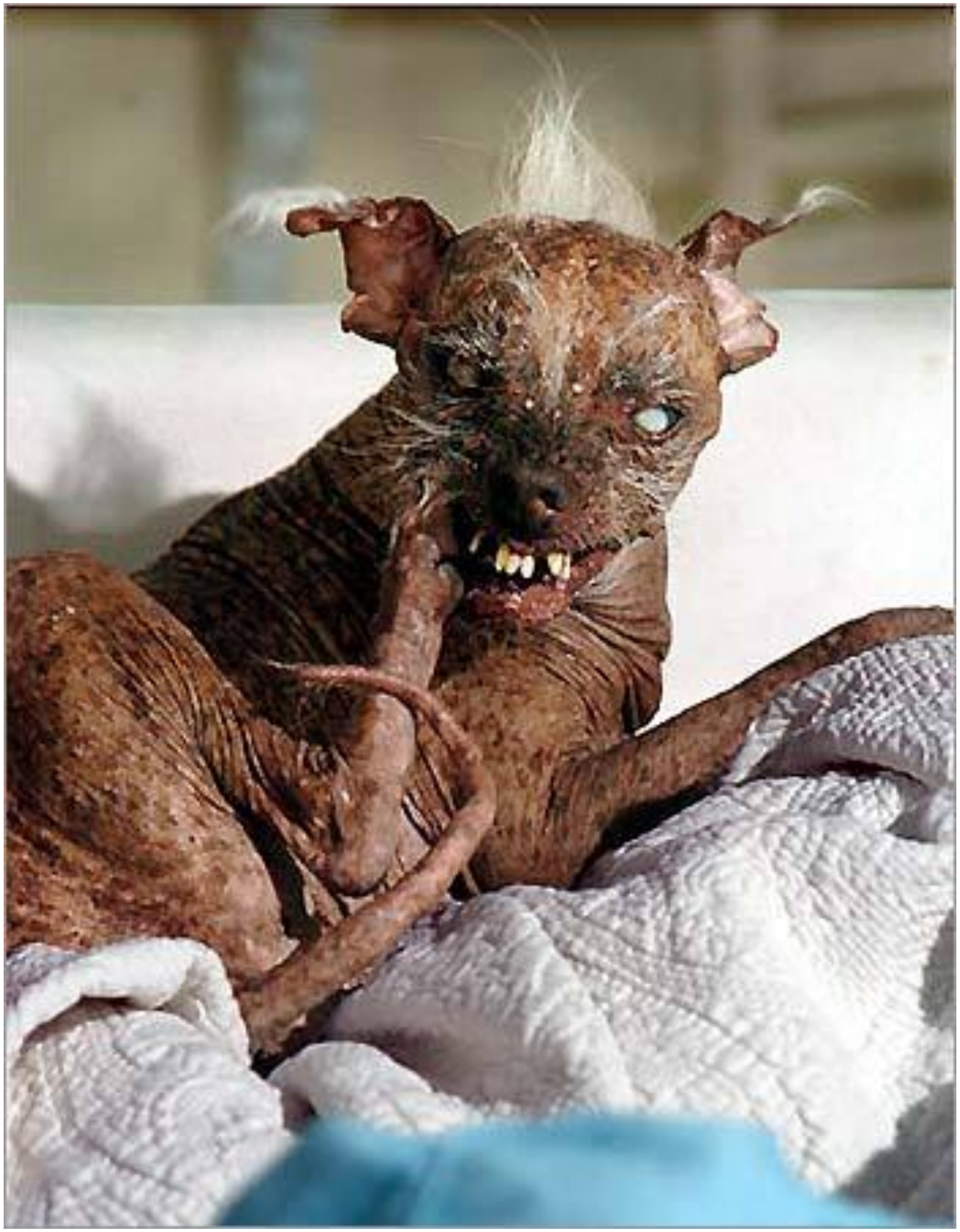
Interesting to ask what new physics could cause this.

Is it possible to have large asymmetry but not affect other observables too much (e.g., top cross section)?

WARNING!!

The models and theories you are about to see may be disturbing to some viewers.

Going forward: if you ever think nature could not be *that ugly*, just remember it produced these (next slide):

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Axigluons

So-called chiral color theories of various origins.
Frampton, Glashow, ‘87, and others….

$SU(3)_L$ x $SU(3)_R$ breaks to $SU(3)_c$
Leaving 8 massive axigluons.
Coupling is QCD strength but with γ^5

Maximal charge asymmetry as tree-level $\bar{t}\gamma^\mu\gamma^5 t$ is relative C odd to $\bar{t}\gamma^\mu t$.

Axigluon limitology

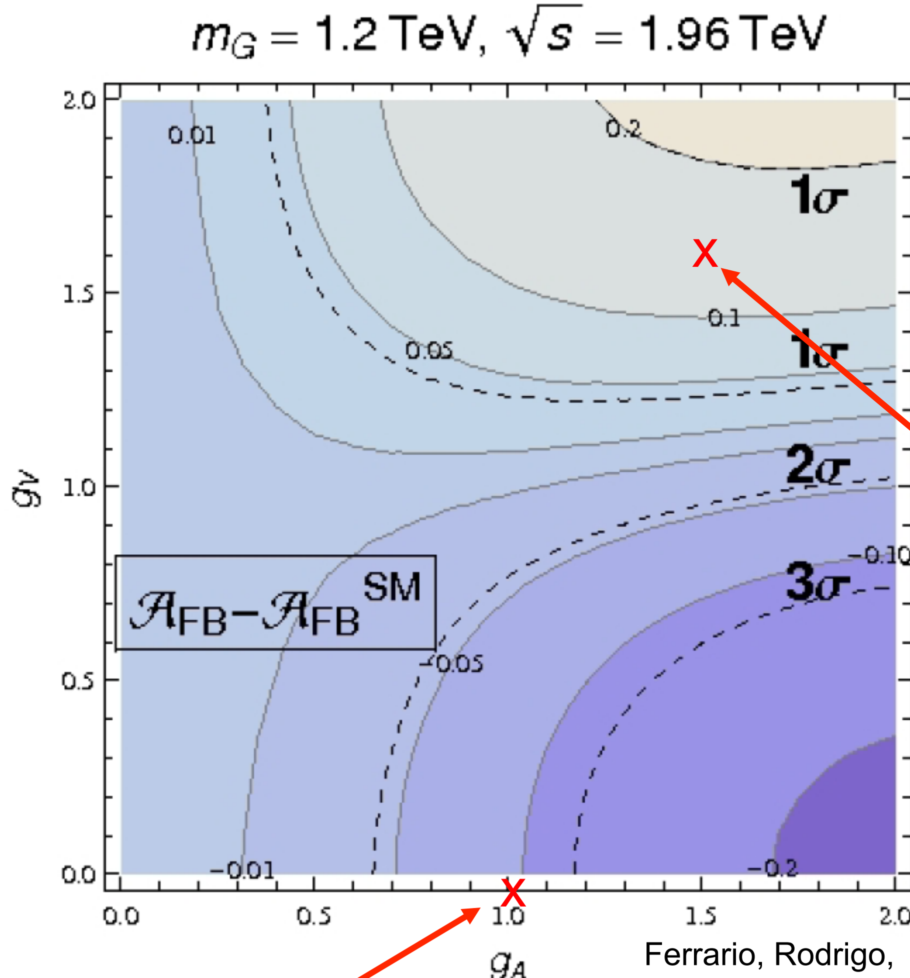
Problem is the asymmetry goes wrong way!

A_{FB} = - 0.13 for m_A = 1 TeV

From asymmetry measurement,
m_A > 1.2 TeV at 90% CL (2 yrs old limit now and based on 695 pb^{-1} of data)

Direct limits from LEP1 (Z to q qbar A) and Tevatron Resonance hunting:
m_A > 1.13 TeV at 95% CL

More general g_V-g_A couplings



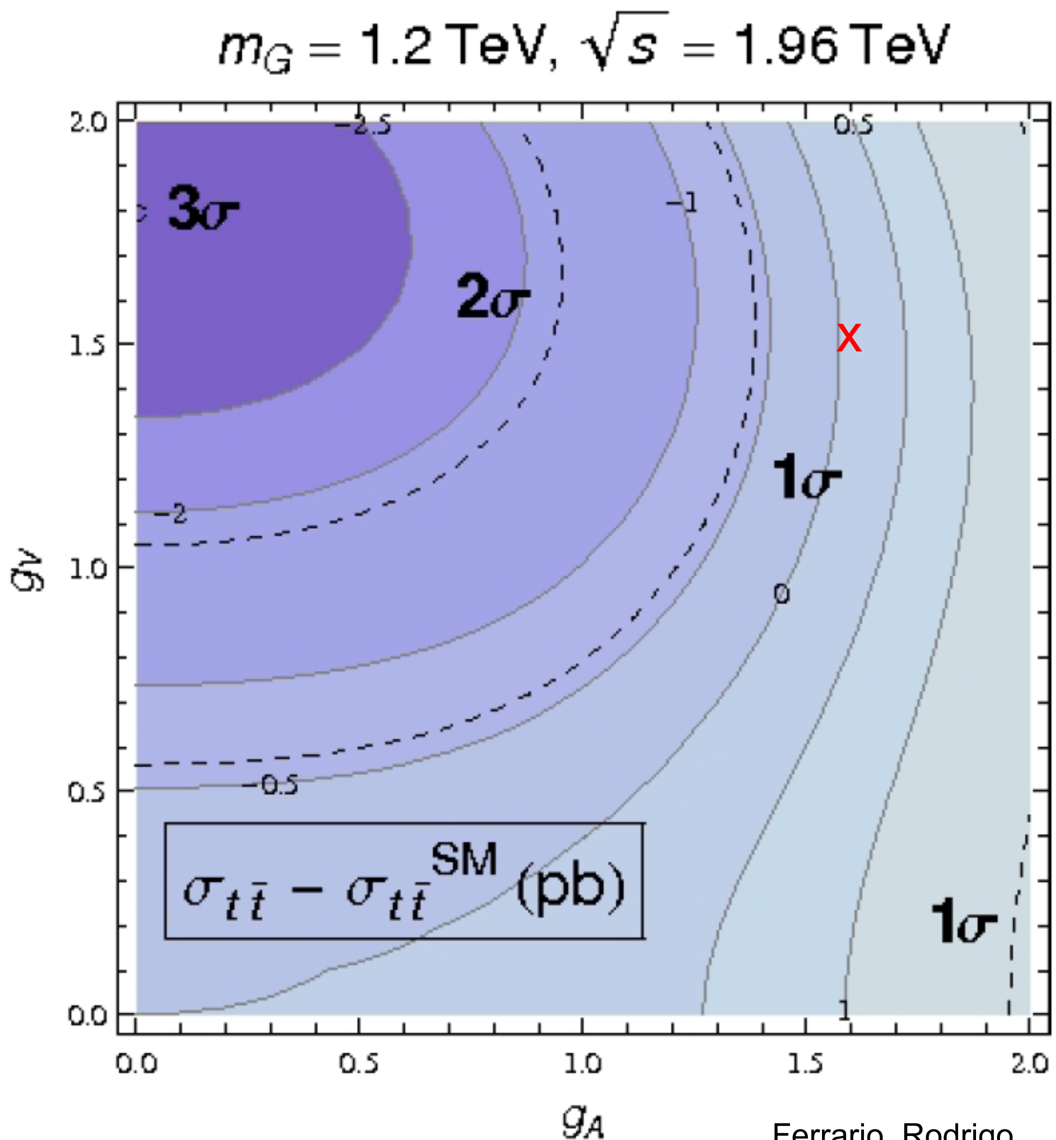
Ferrario, Rodrigo, 0809.3354

Couplings are with respect to the QCD gauge coupling.

This point looks good!

Pure axigluon coupling (large negative contribution to A_{FB})

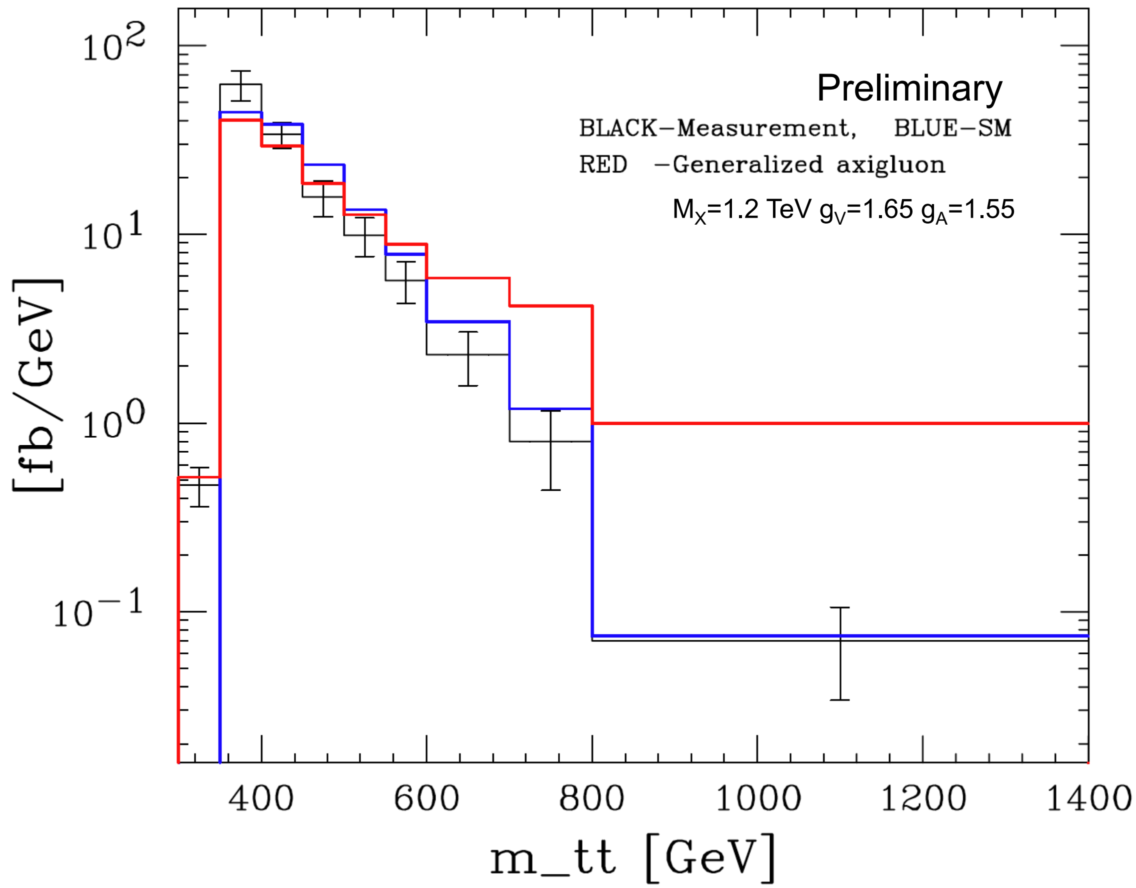
Top cross-section constraint



Consistency with total rate is ok.

Ferrario, Rodrigo, 0809.3354

Difficulty with differential cross-section

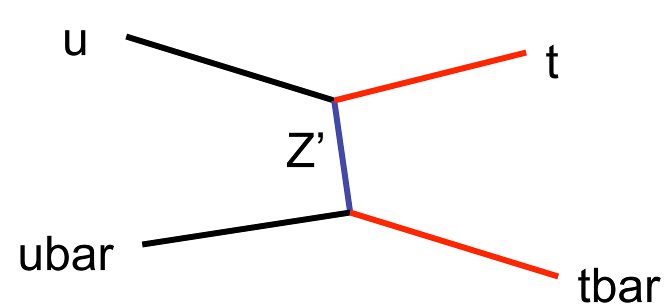


Data from CDF, "Measurement of the ttbar differential cross section … in 2.7 fb^{-1} of CDF II Data", CDF note 9602 (11 Nov 08).

t-channel approach

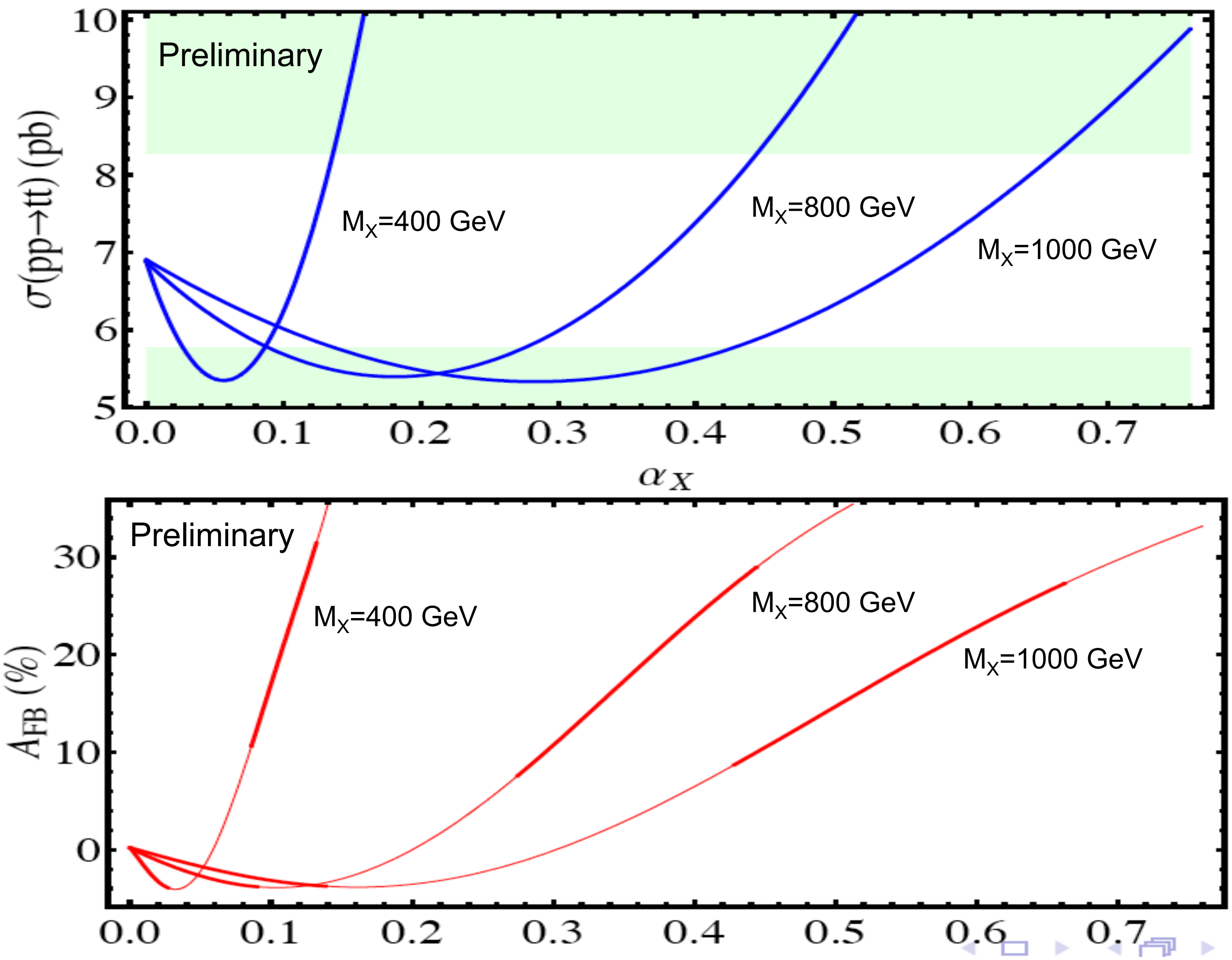
Start with a simple model that can produce top quarks via t-channel exchange, with hopes of less disruption to ttbar invariant mass distribution:

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

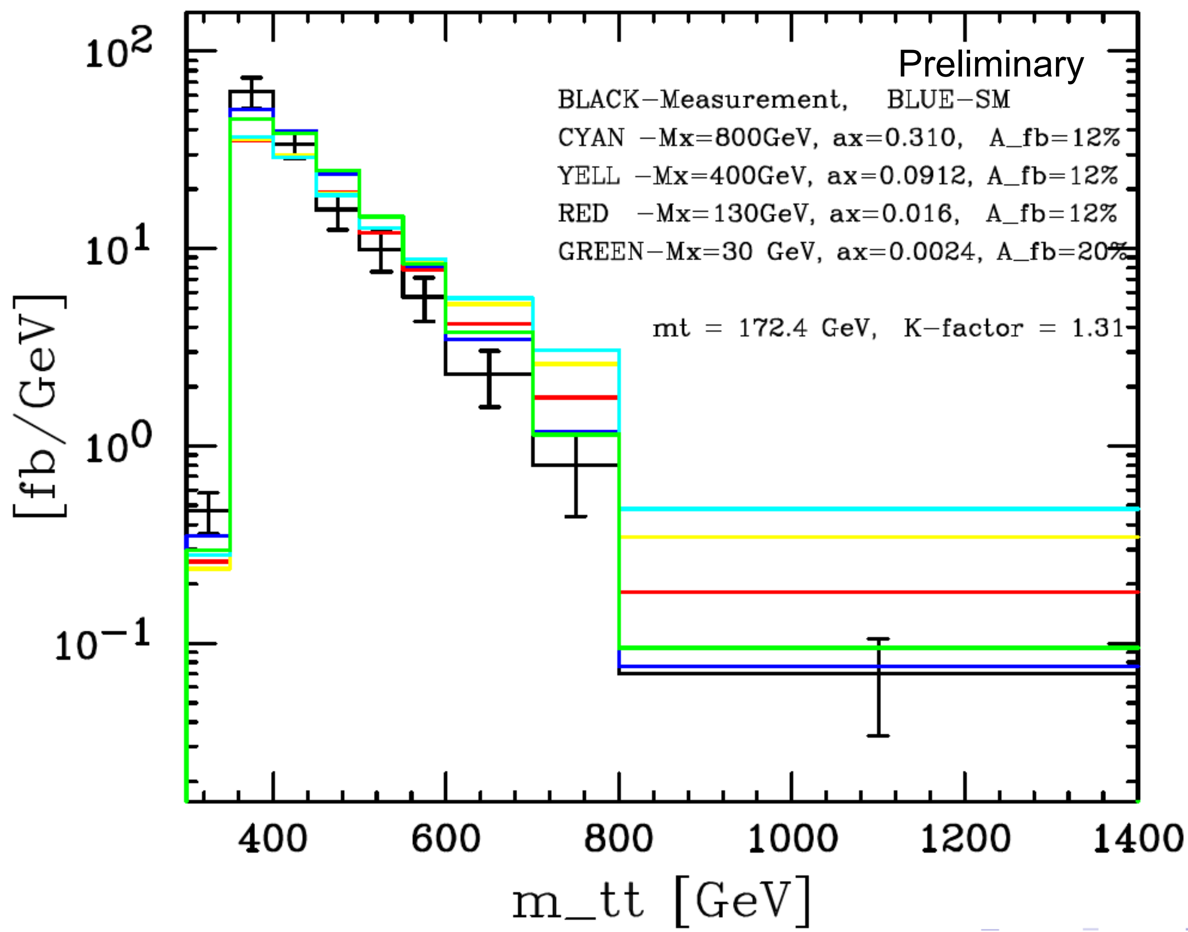


Theory challenges, that can be met, include flavor physics constraints, and an anomaly free model.

Cross-section and Asymmetry



Differential cross-section

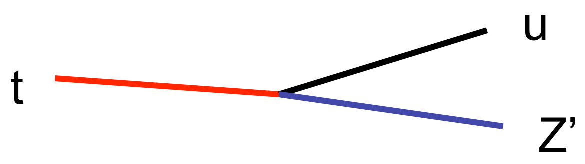


Problem with invariant mass distribution unless $M_X < 200$ GeV

Data from CDF, "Measurement of the ttbar differential cross section … in 2.7 fb^{-1} of CDF II Data", CDF note 9602 (11 Nov 08).

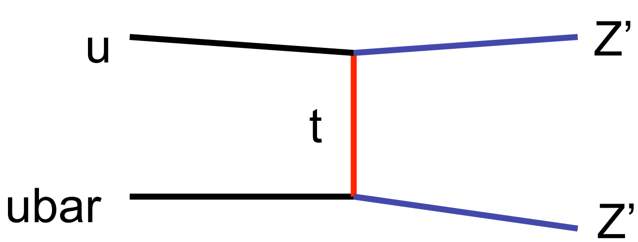
Problem with small Z' mass

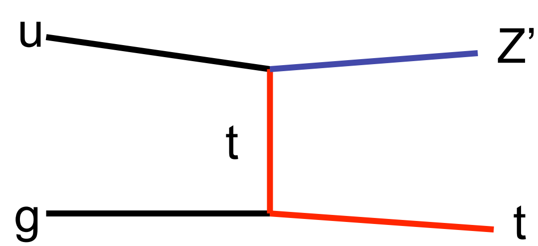
Top quark can decay to Z': t -> Z' u --- limits about 10%



Z' -> t* ubar
Z' -> tbar* u

Z' can be produced efficiently and pollute top sample
and create 'pink elephant' phenomenology

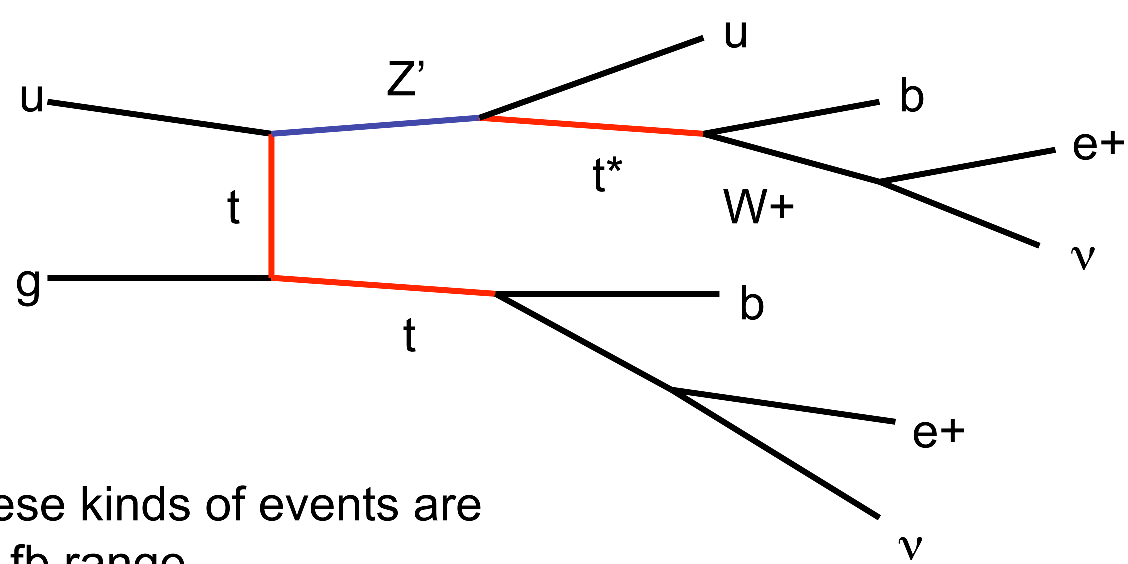




Etc.

Z’ production constraints

Among other things, can produce events of the type: SS Dilepton + b + MET



Limits on these kinds of events are in the 5 - 10 fb range.

Results for Light Z'

Mx=100GeV $(Br(t \to uZ') = 29.8\%)$ A_{FB} = 0.17 (α_x = 0.013)

Preliminary	σ (pb)	measured σ^*	$tt + \bar{t}\bar{t}$	measured†
$p\bar{p} \to t\bar{t}$ (SM)	6.85	7.1±0.8(l+j), 6.7±0.98(l+l)	0	0
$p\bar{p} \to t\bar{t}$	5.85	4.45, 3.18	1.49	1.08
$tZ', \bar{t}Z'$	4.03	1.03, 0.57	2.02	0.57
$t\bar{u}Z', \bar{t}uZ'$	6.98	3.76, 1.99	3.49	1.99
$Z'Z'$	0.73	0.06, 0.019	0.37	0.019
total		9.31, 5.76	7.37pb	2.66pb

σ(SS dilep) ~ 50 fb after br fractions.

Several times too large[&]

Mx=160GeV $(Br(t \to uZ') = 2.8\%)$ A_{FB} = 0.15 (α_x = 0.024)

Preliminary	σ (pb)	measured σ	$tt + \bar{t}\bar{t}$	measured
$p\bar{p} \to t\bar{t}$ (SM)	6.85	7.1±0.8(l+j), 6.7±0.98(l+l)	0	0
$p\bar{p} \to t\bar{t}$	5.85	5.64, 5.18	0.15	0.15
$tZ', \bar{t}Z'$	2.28	2.22, 1.01	1.14	1.01
$t\bar{u}Z', \bar{t}uZ'$	0.71	0.77, 0.31	0.36	0.31
$Z'Z'$	0.64	0.55, 0.25	0.32	0.25
total		9.18, 6.755	1.97	1.725

σ(SS dilep) ~ 35 fb after br fractions.

* Lowering α_x gets ttbar cross-section better/fine, but SS dilepton problem remains.

& if Z' -> uu is allowed then 2^{nd} model is ok, but 1^{st} model is still a problem

Rock and a Hard Place

Rock: Large M_X value means ttbar differential distribution in conflict with data.

Hard Place: Small M_X value means too many exotic events from Z' production.

Intermediate values work best ….

Conclusion

CDF and D0 finding tantalizing large top quark asymmetry.

Very hard to get over 15%, say, by way of new physics without creating stresses and conflicts with other data.