On New Physics Models for Top AFB

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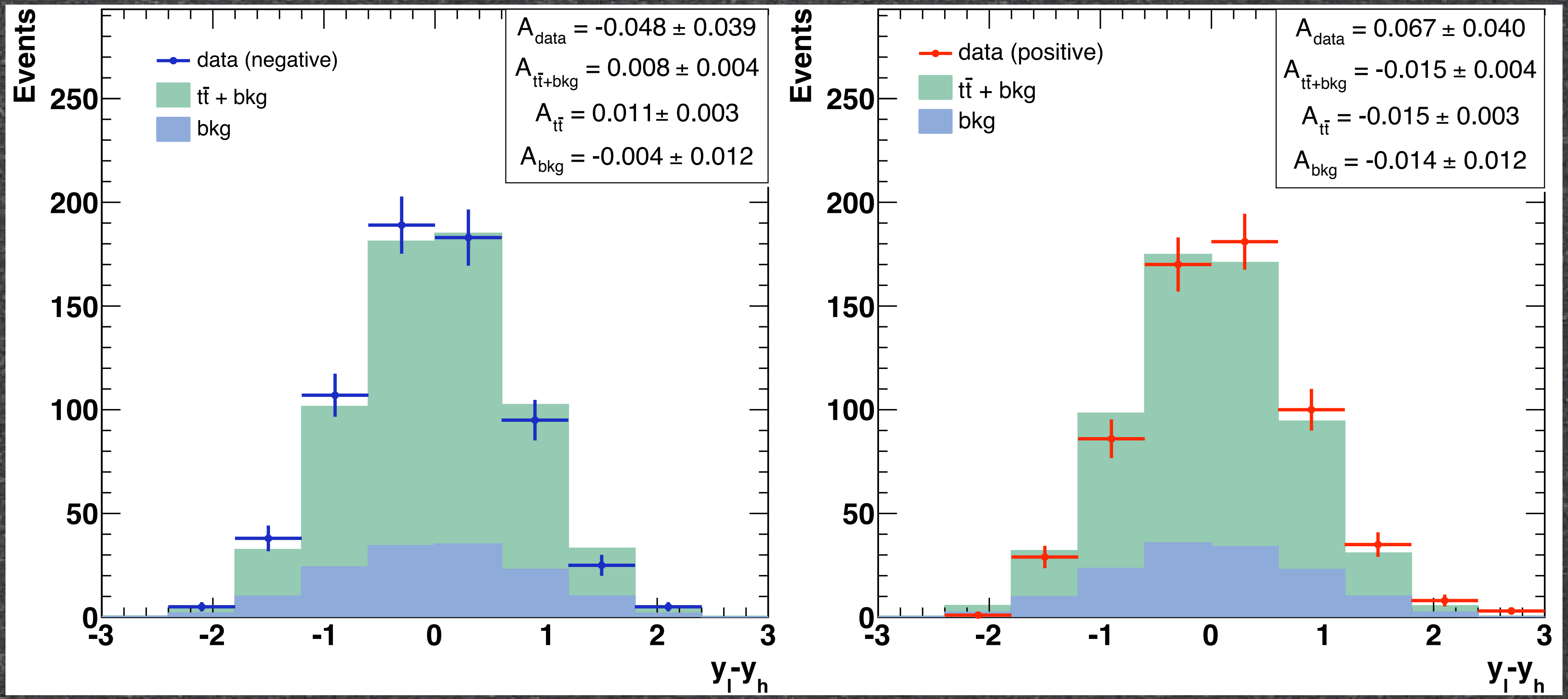
Why this anomaly now?

- CDF 5.3 fb^-1, January 2011



$$A_{FB}^{t\bar{t}} = 0.475 \pm 0.114 \qquad A_{FB}^{t\bar{t}} = 0.088 \pm 0.013$$

$$M_{t\bar{t}} > 450 \text{ GeV}$$

Questions to Ask about the anomaly

- Is it systematic?
- Is it statistical?
- Is it QCD?
- How difficult is it to simultaneously fit the anomaly and other constraints?

- Probably not
- Maybe -- though growing statistics
- Probably not
- Not so easy, but can be done. Not supersymmetry!

Summary

- Experimental evidence
- SM process
- New Physics processes
  - Tevatron analysis
  - LHC analysis
  - Models of flavor

Moira Gresham, Ian-Woo Kim, KZ 1103.3501

Moira Gresham, Ian-Woo Kim, KZ 1102.0018

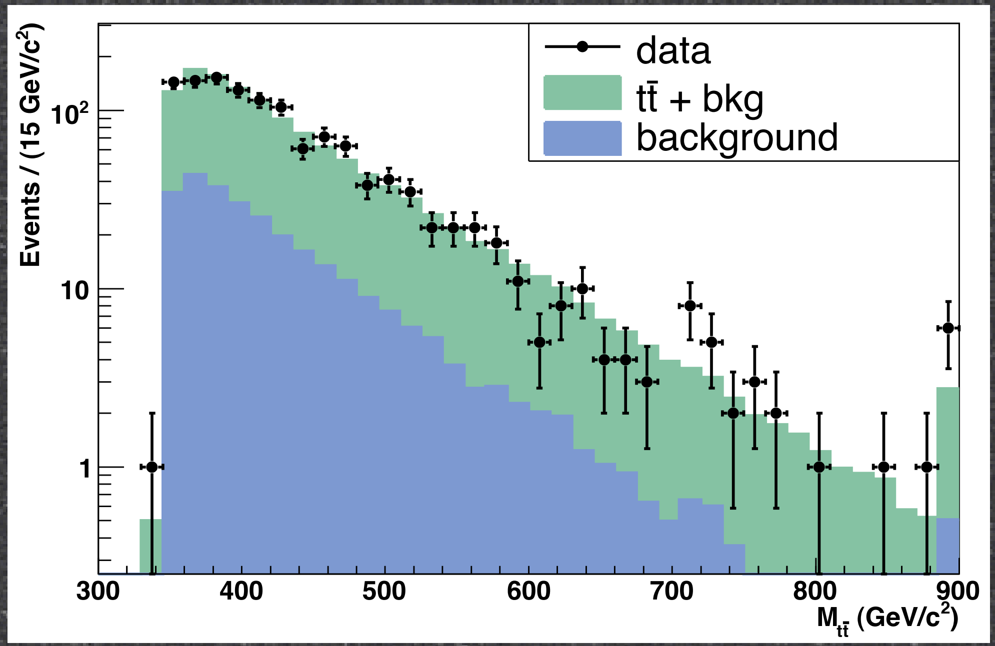
Jessie Shelton, KZ 1101.5392

Measures of Top AFB

- 2008:
- CDF 1.9 fb^-1 $A_{FB}^{t\bar{t}} = 0.17 \pm 0.08$
- D0 0.9 fb^-1 $A_{FB}^{t\bar{t}} = 0.12 \pm 0.08 \pm 0.01$
- Both measurements one leptonic and one hadronic top

Measures of top AFB

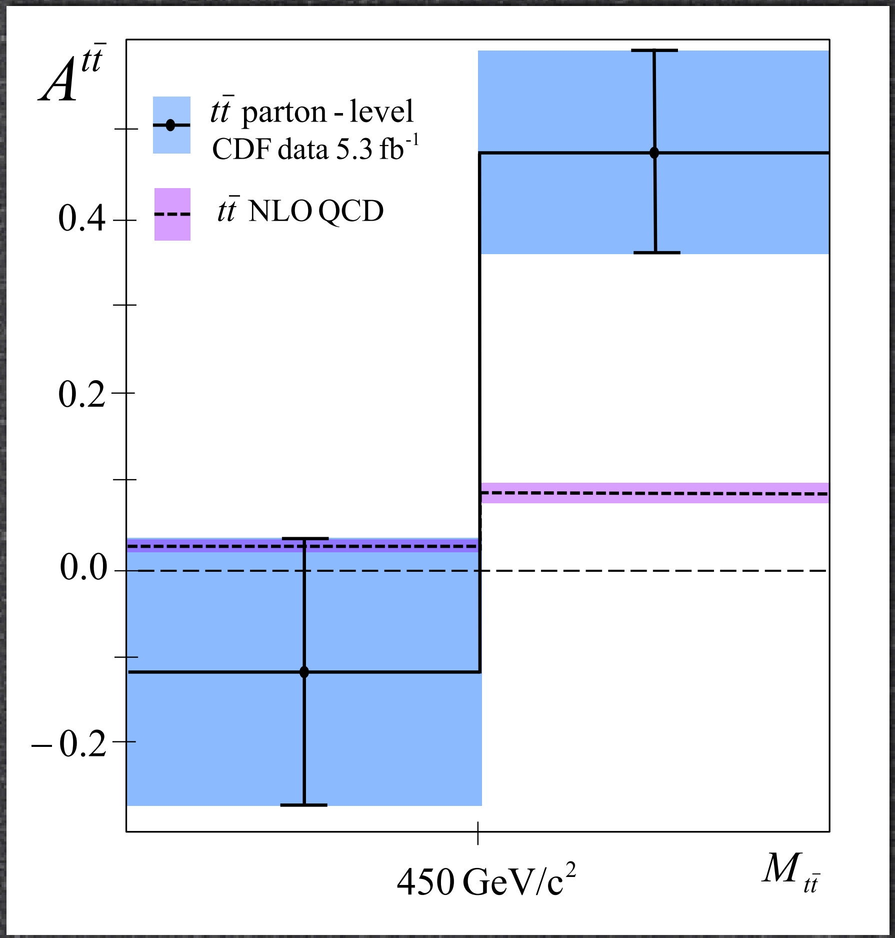
- 2011:
- 5.3 fb^-1
- Enough data to give mass and rapidity dependent asymmetry in mixed leptonic/ hadronic top system!

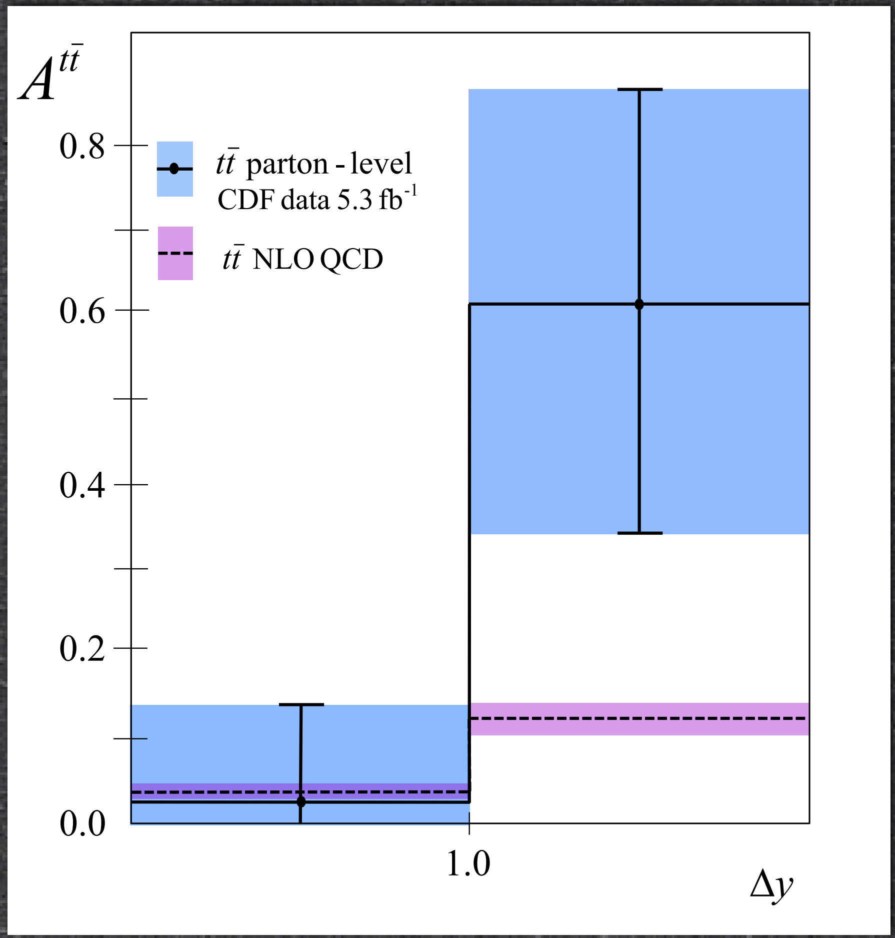


CDF 2011

Measures of top AFB

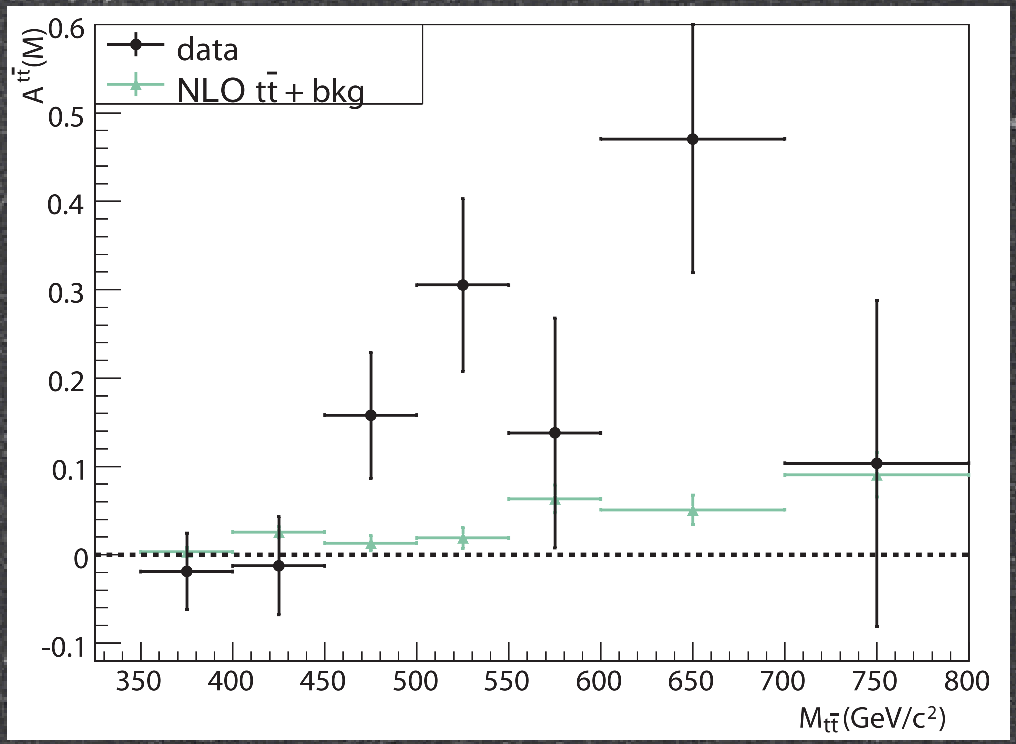
- 2011:5.3 fb^-1, mixed case
- “Parton level” = unfold detector

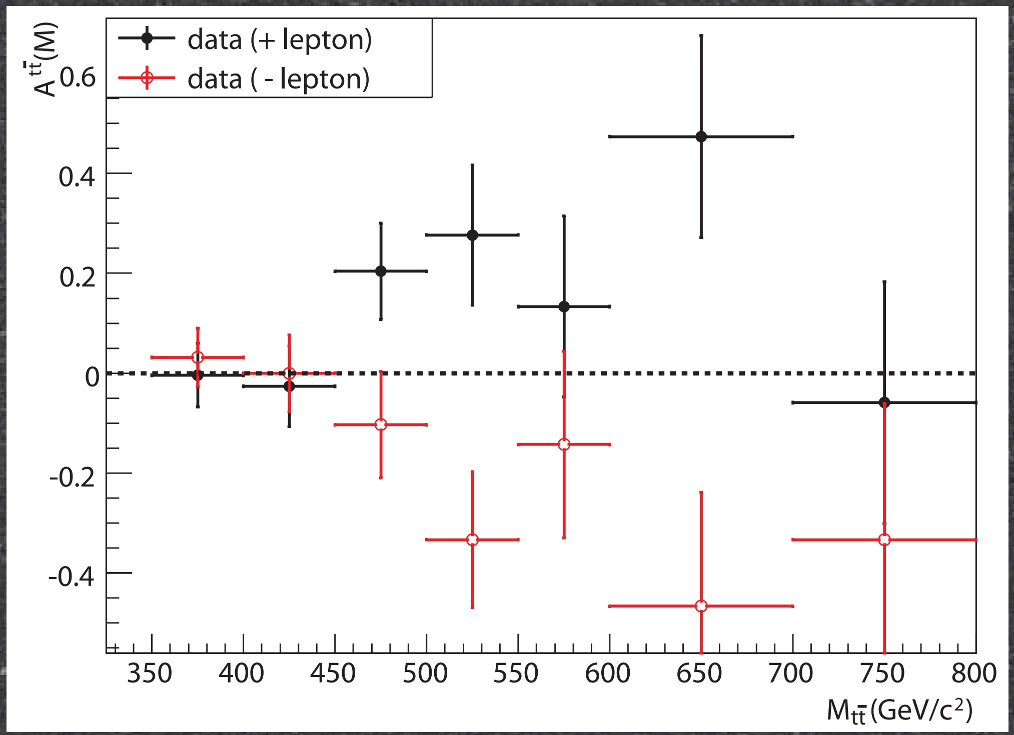




Measures of top AFB

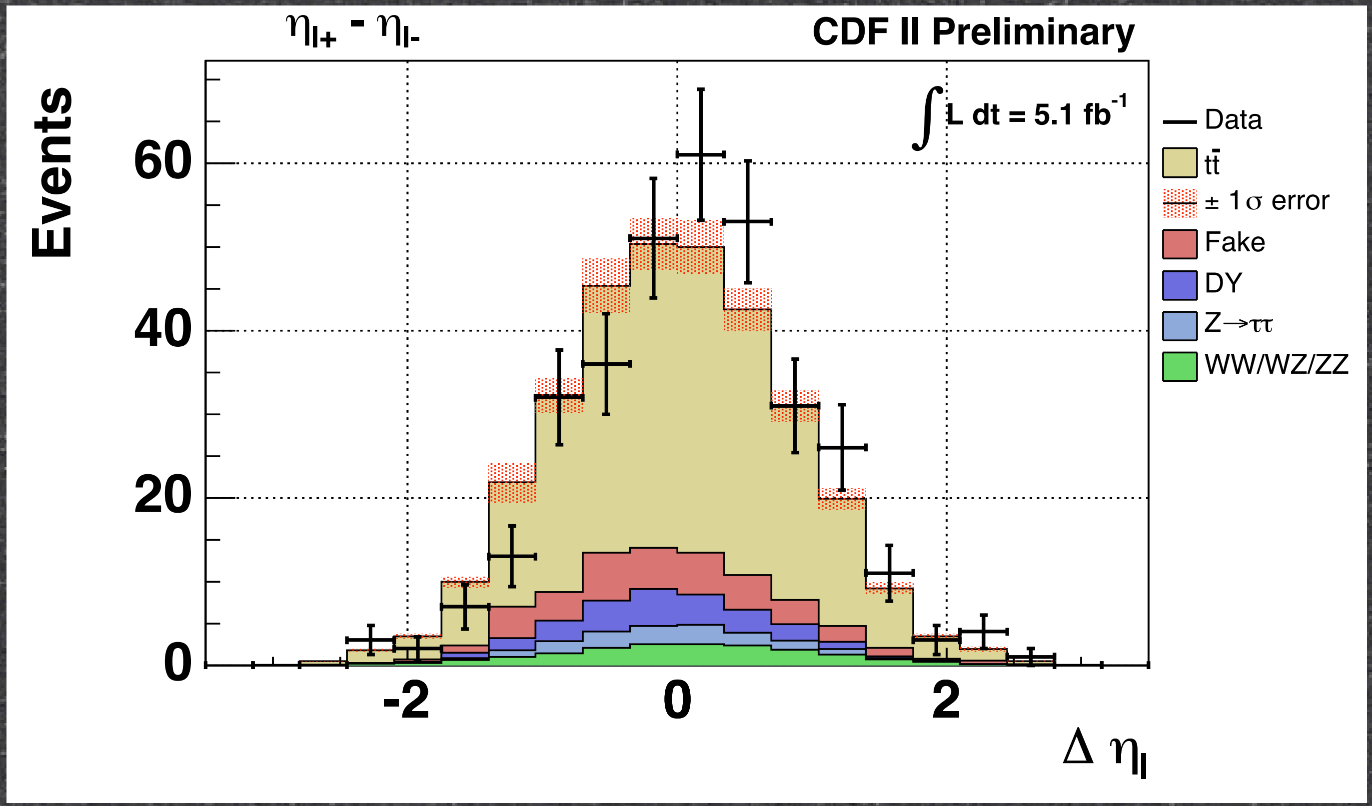
- 2011: 5.3 fb^-1, mixed case
- Detector level





Measures of top AFB

- 2011: 5.3 fb^-1
- Enough data to look at two leptonic tops

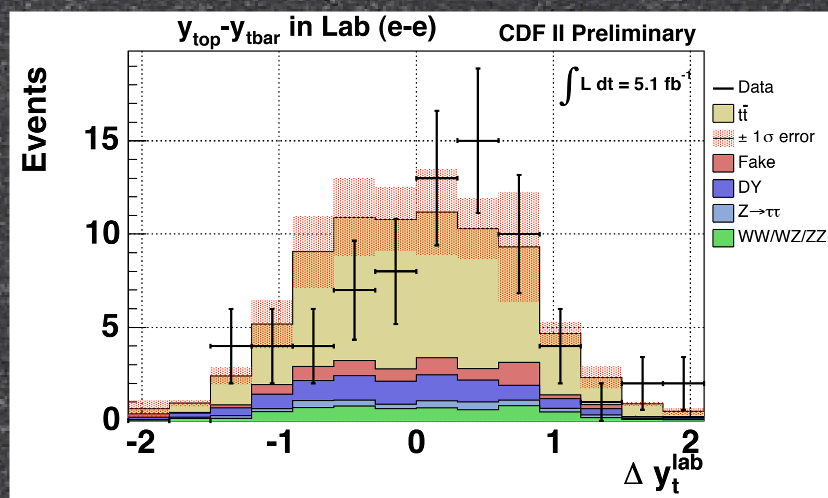


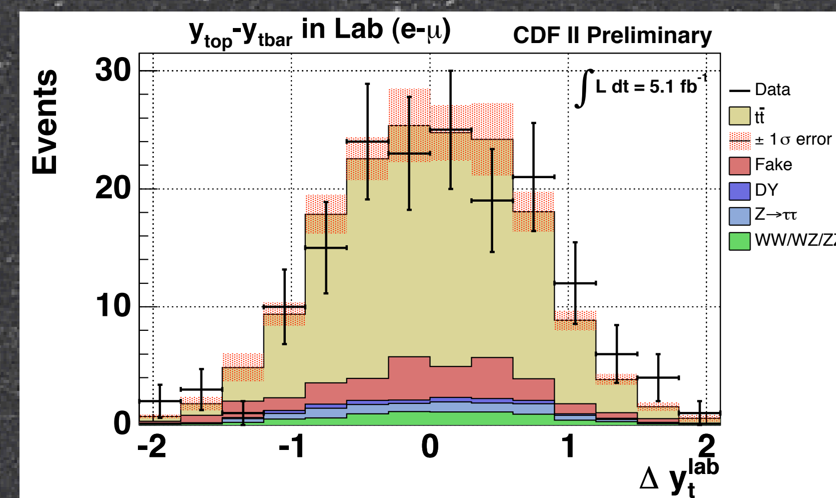
$$A_{FB} = 0.14 \pm 0.05$$

Measures of top AFB

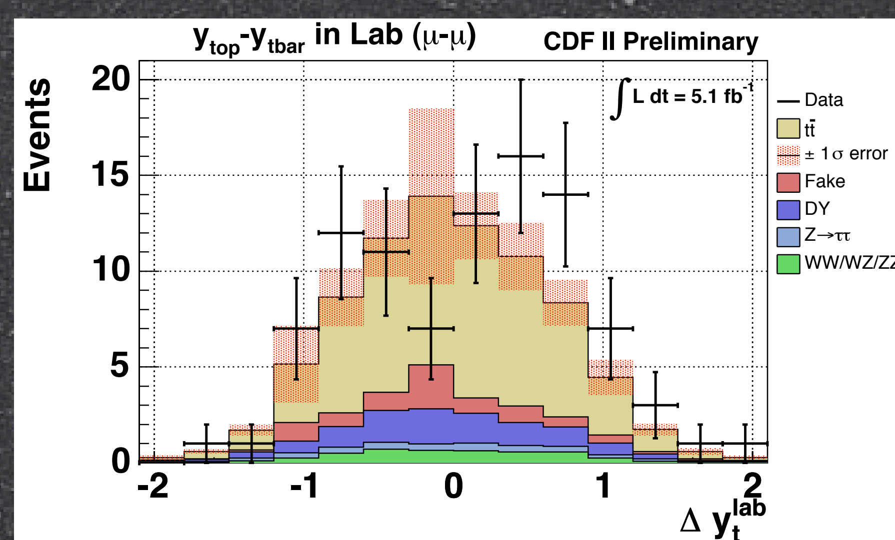
- Asymmetry much larger in ee, mu-mu than in e-mu

$A_{FB} = 0.06 \pm 0.077$





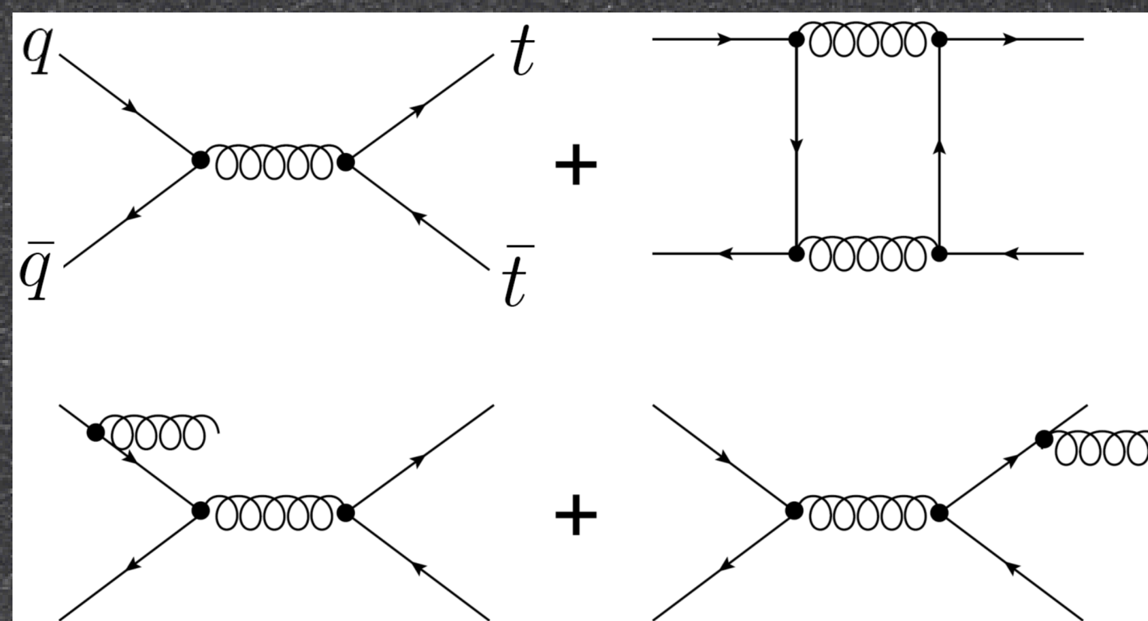
$A_{FB} = 0.27 \pm 0.112$



$A_{FB} = 0.17 \pm 0.102$

Can QCD Generate This?

- First contribution appears at NLO

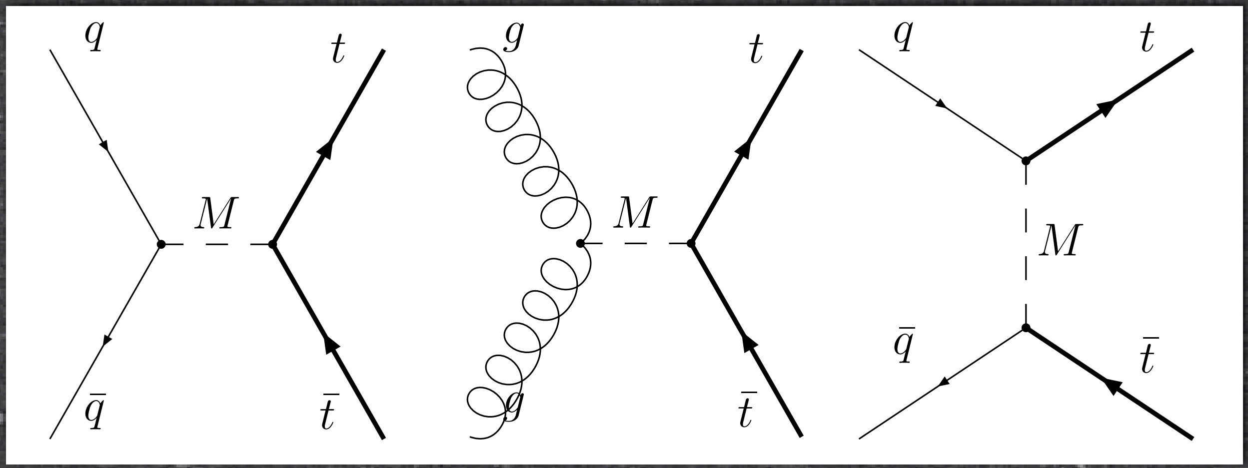


- Stable against higher order corrections? Claim: yes. Threshold resummed results give same asymmetry as fixed order calculation

Almeida, Sterman, Vogelsang 2008

Models to generate top AFB

- s-channel or t-channel
  - s-channel: axigluon



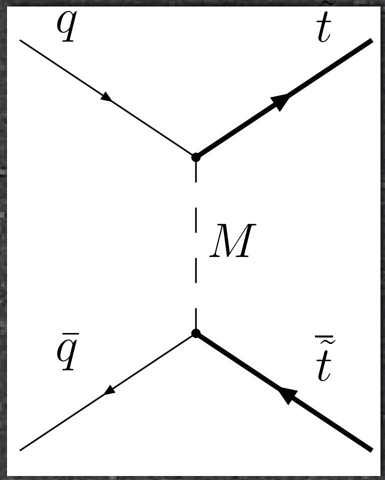
Ferrario and Rodrigo

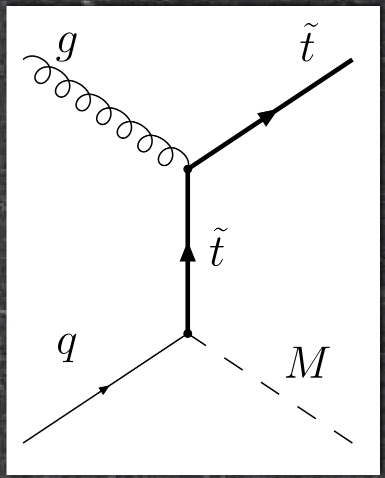
  - t-channel: flavor violating gauge boson (Z’, W’) or scalar color triplet or sextet

Jung, Murayama, Pierce, Wells
Shu, Tait, Wang
Ligeti, Schmaltz, Tavares
Grinstein, Kagan, Trott, Zupan

Challenges

- s-channel models: large AFB, but small change in tt-bar x-section
- t-channel models
  - same sign tops
  - single top
  - invariant mass distribution





Challenges

- s-channel: particular couplings. Opposite charges for light quarks and top

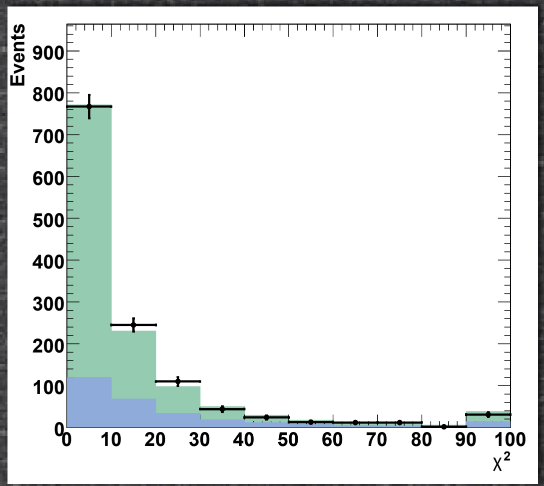
$$\mathcal{A}_{int} = \frac{g_s^4}{9}\frac{\hat{s}(\hat{s}-m_{G'}^2)}{(\hat{s}-m_{G'}^2)^2+m_{G'}^2\Gamma_{G'}^2}(g_L^q+g_R^q)(g_L^t+g_R^t)$$
$$\left[(2-\beta^2)+2\frac{(g_L^q-g_R^q)(g_L^t-g_R^t)}{(g_L^q+g_R^q)(g_L^t+g_R^t)}c_\theta+c_\theta^2\right],$$

- t-channel: high invariant mass spectrum can become skewed

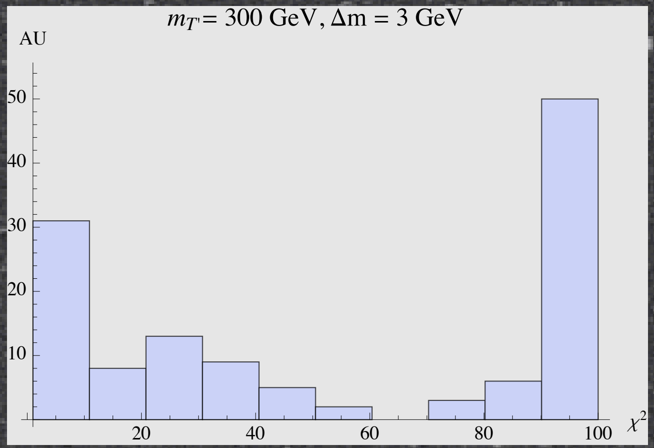
$$\mathcal{A}_{int} = \frac{2g_s^2}{9}\frac{(g_L^2+g_R^2)}{\hat{s}\hat{t}_{Z'}}\left[2\hat{u}_t^2+2\hat{s}m_t^2+\frac{m_t^2}{m_{Z'}^2}(\hat{t}_t^2+\hat{s}m_t^2)\right],$$

Exotic decays are out

- Goodbye SUSY! Or 4th generation!
- Top chi^2 looks good $\tilde{t} \to t\chi$



CDF 2011



T. Volansky

- Any additional MET dramatically changes top chi^2

Models of top AFB

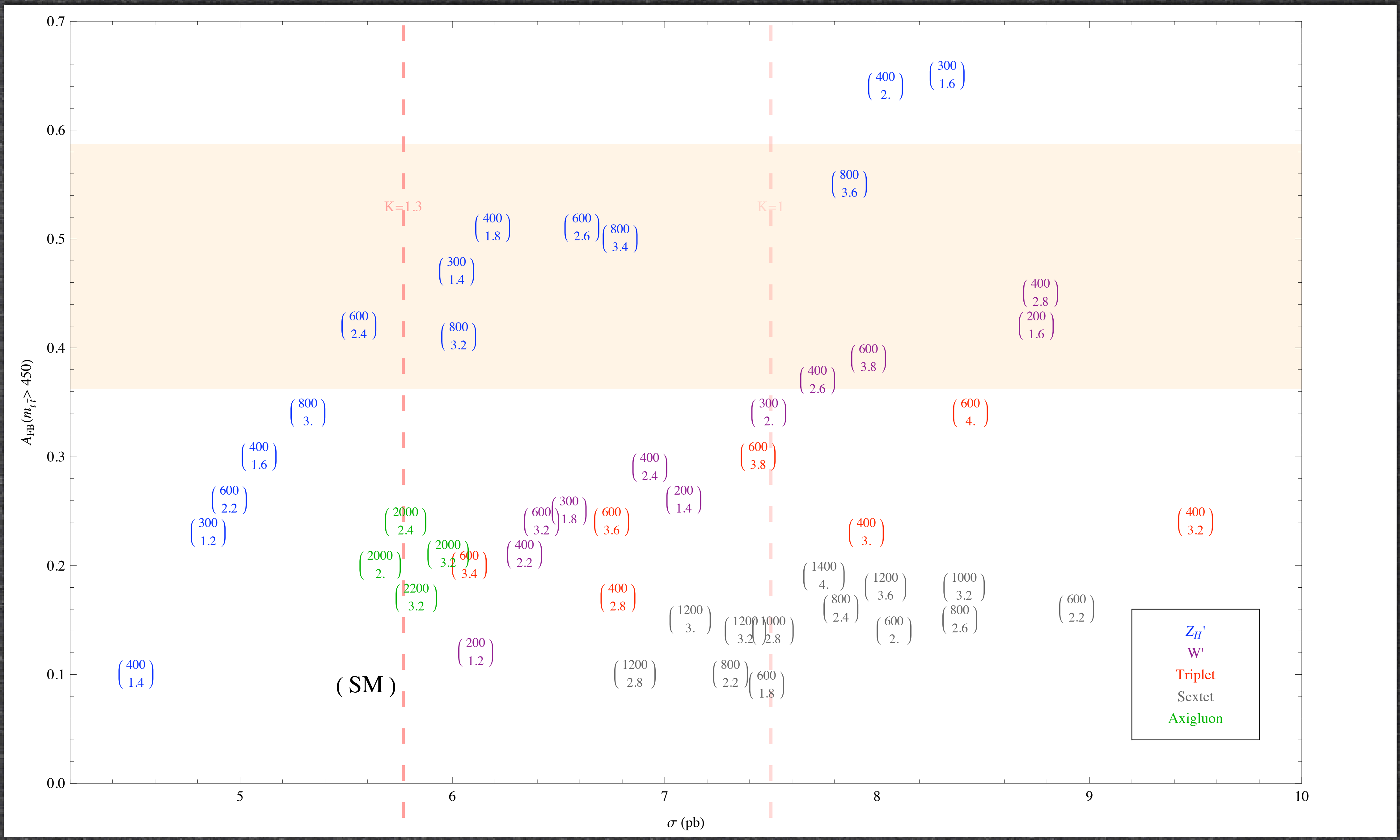
- Carry out phenomenological comparison of feasibility of models -- models of flavor discussed later
- Unfolding detector level -> parton level -- Highly model dependent?
  - Efficiencies (?)
  - Requires top reconstruction

A Comprehensive Analysis

- Generate ttbar events with MG/MadEvent, shower with Pythia, pipe through PGS
- Mixed leptonic/hadronic tops; replicate CDF cuts
  - e or mu with pT > 20 Gev, eta < 1; 4 jets with pT > 20, eta < 2, 1 having b-tag; Etmiss > 20 GeV; photon and tau veto
- Reconstruct top

Parton Level Results

Moira Gresham, Ian-Woo Kim, KZ 1103.3501



Parton Level Results

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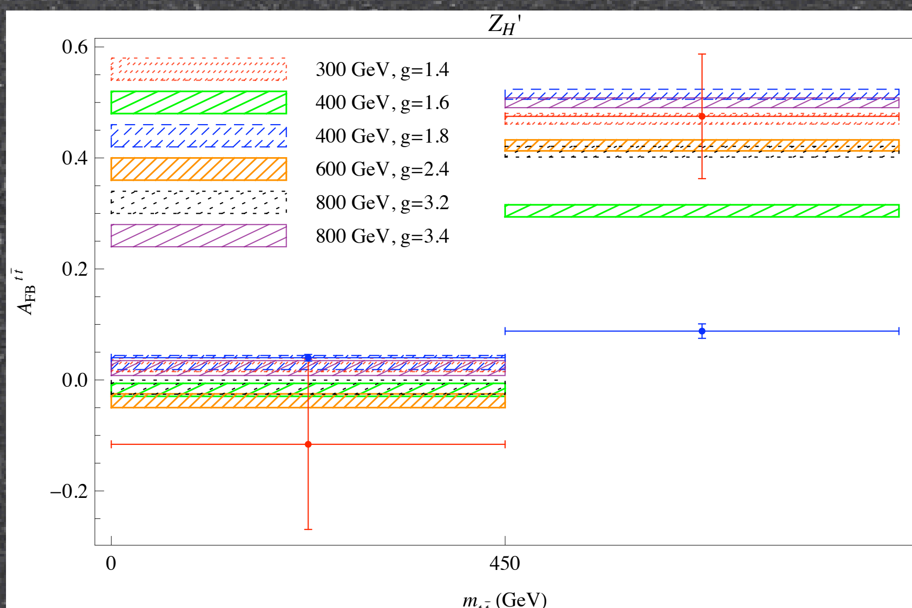
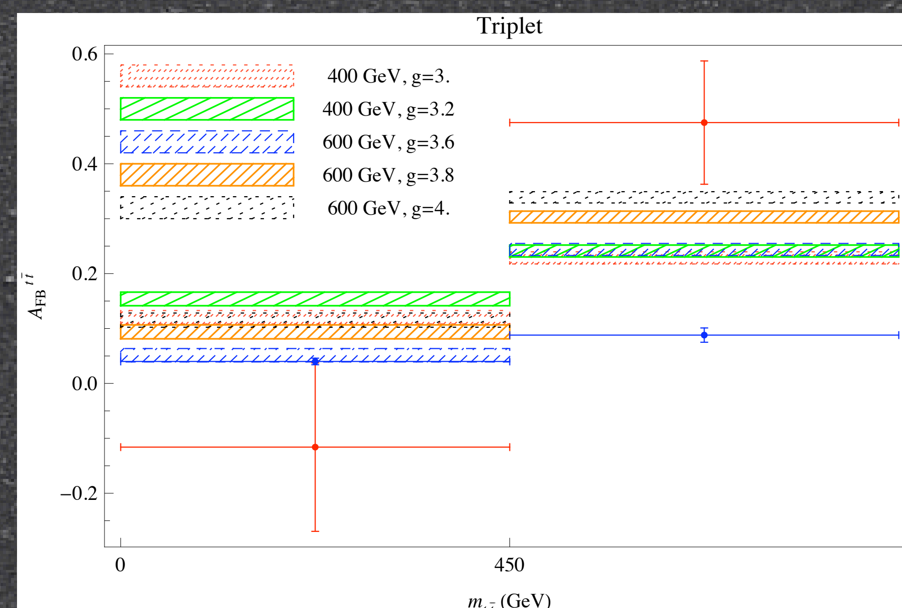
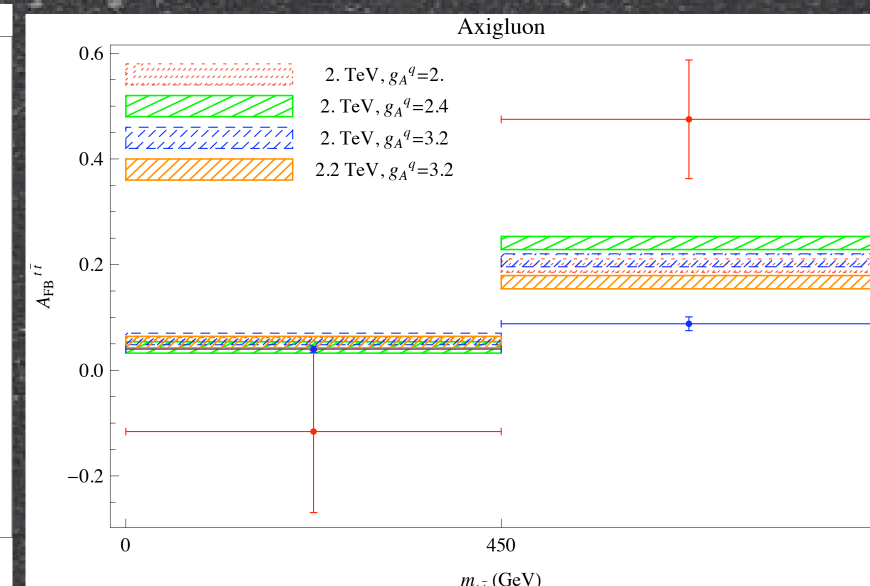
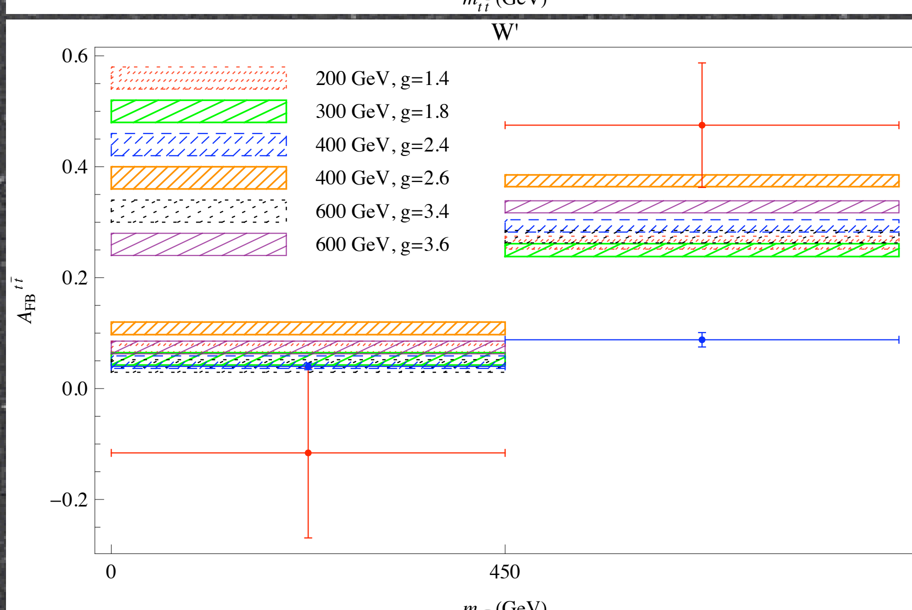
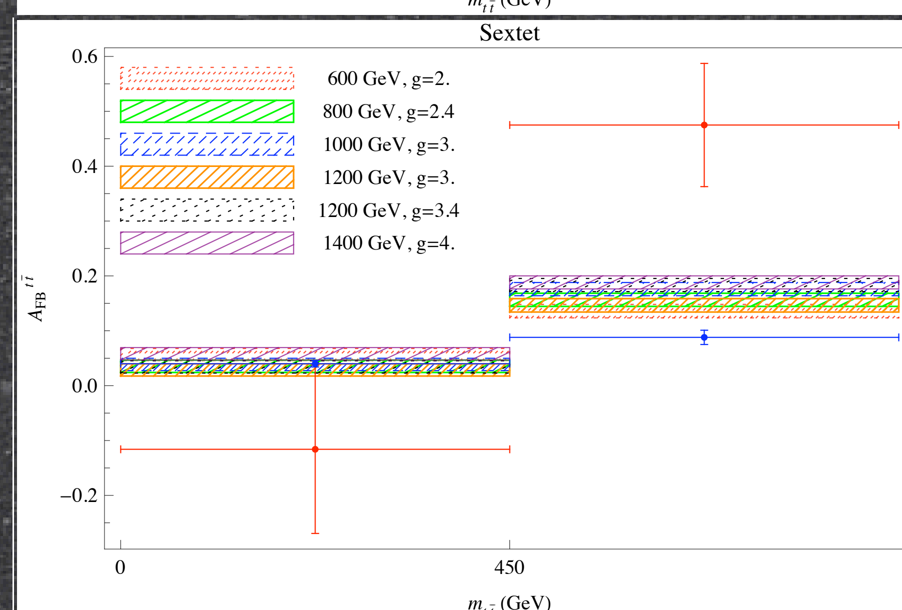




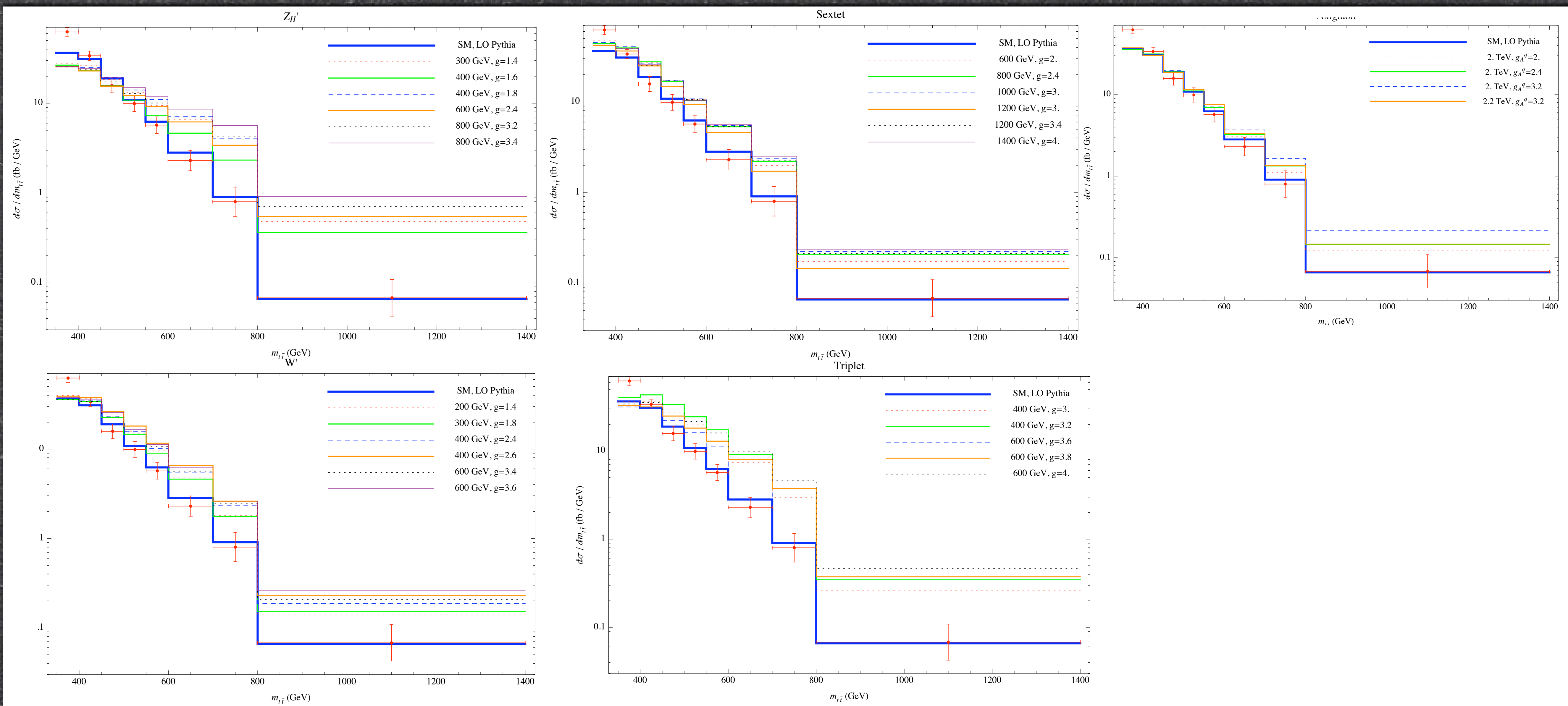






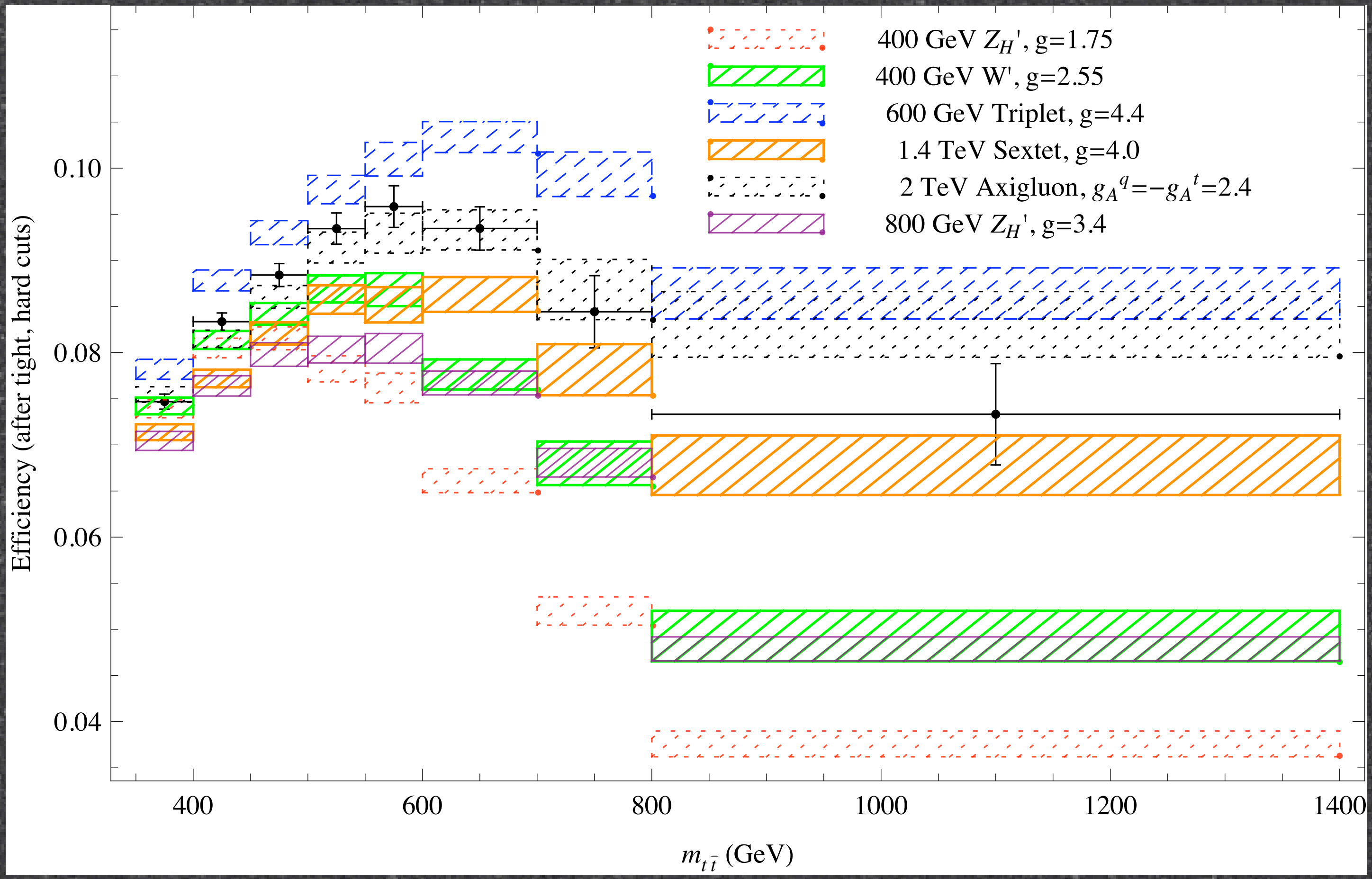
Invariant Mass Distribution

- Looks disfavored for most models



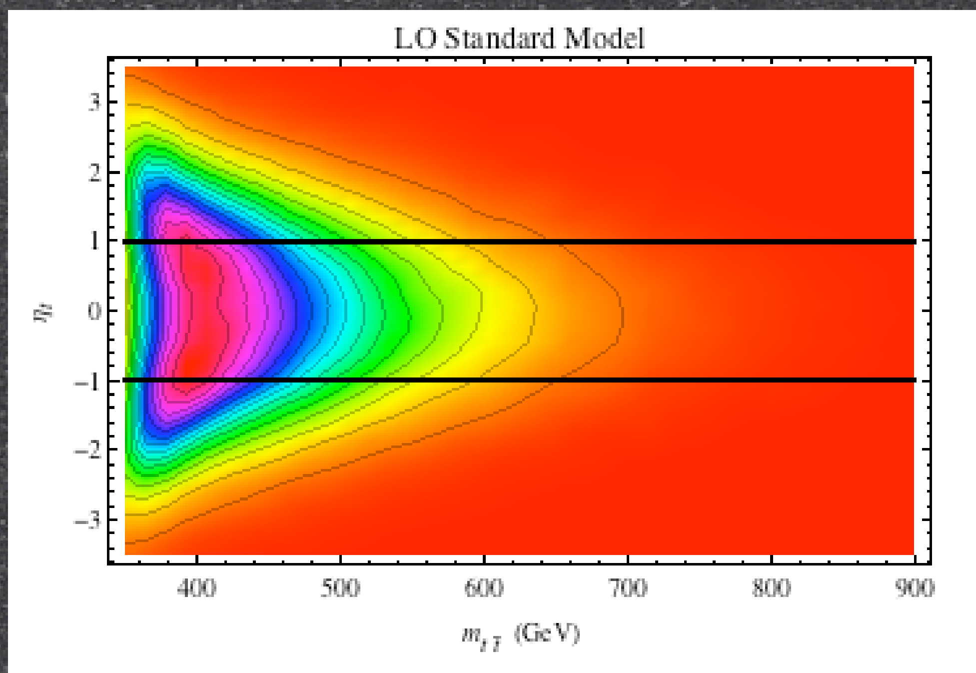
Assumed Efficiencies

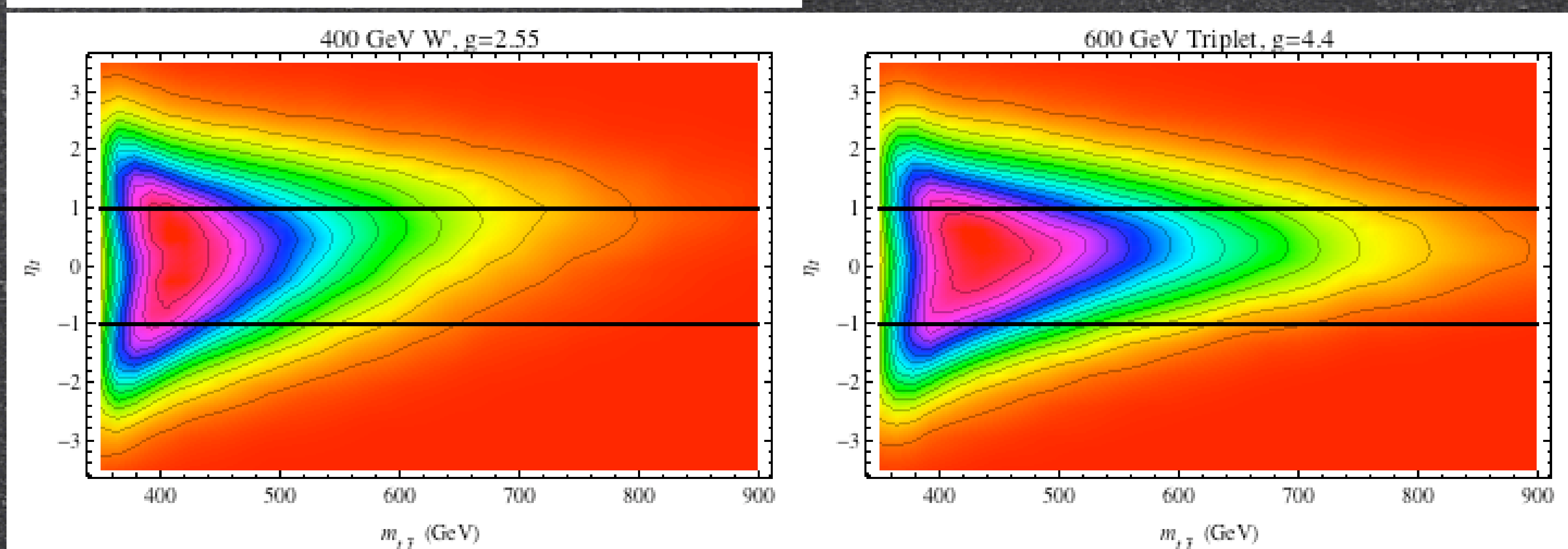
- Highly model dependent



- Save the day!

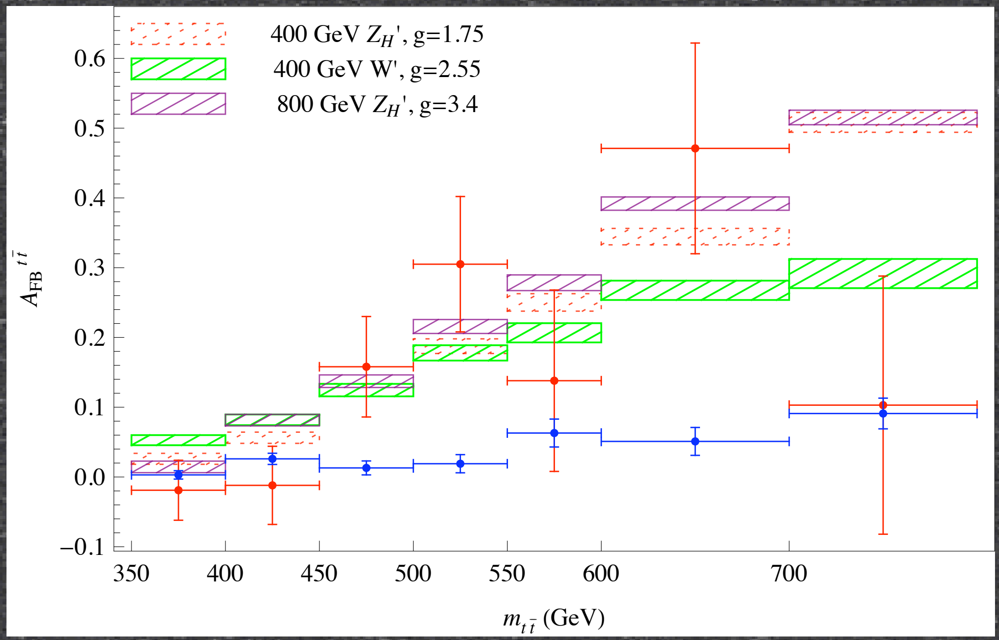
Assumed Efficiencies

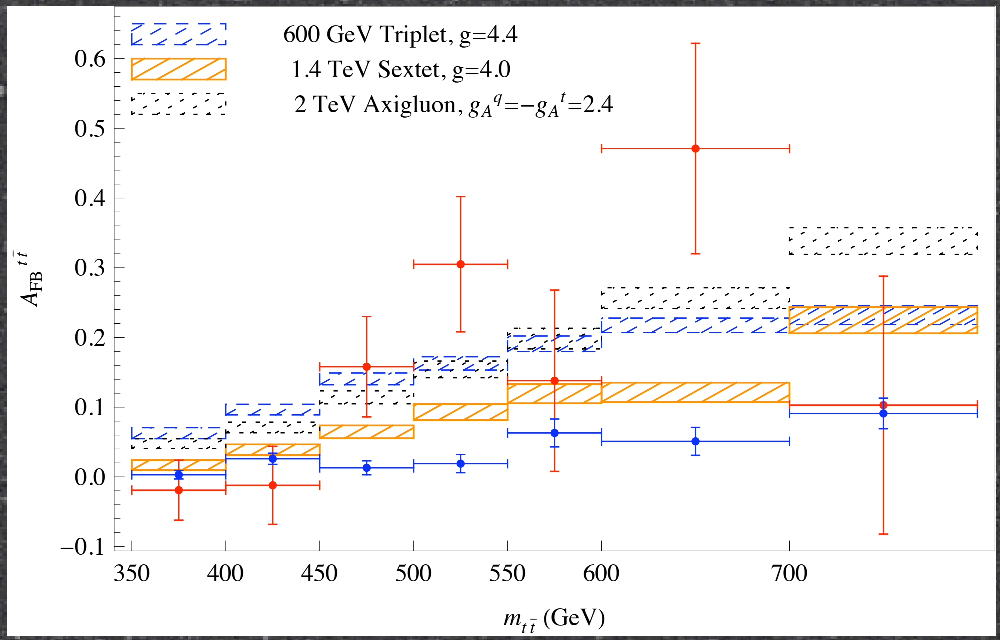




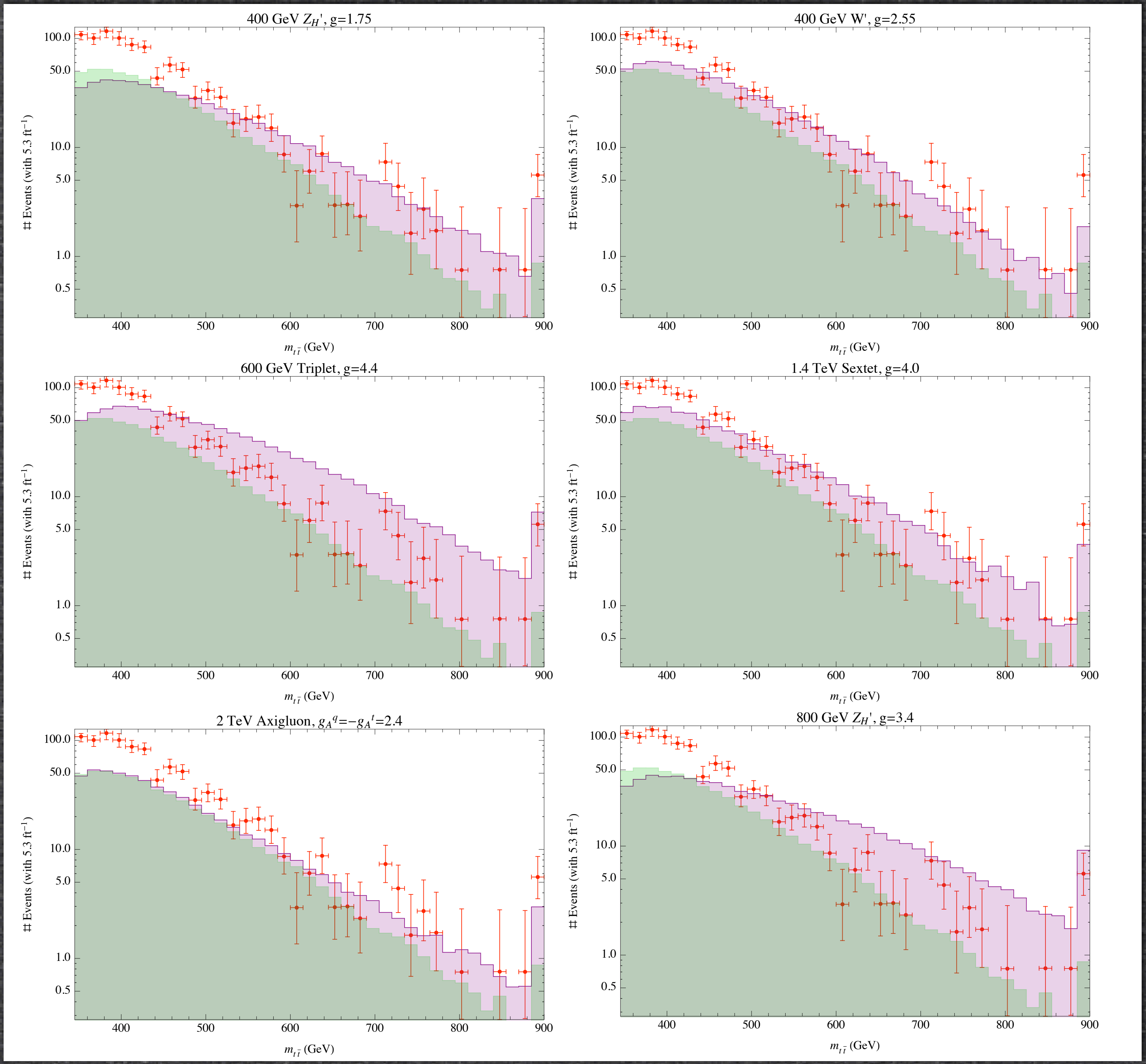
Detector Level

- Efficiencies do not dramatically affect extracted AFB



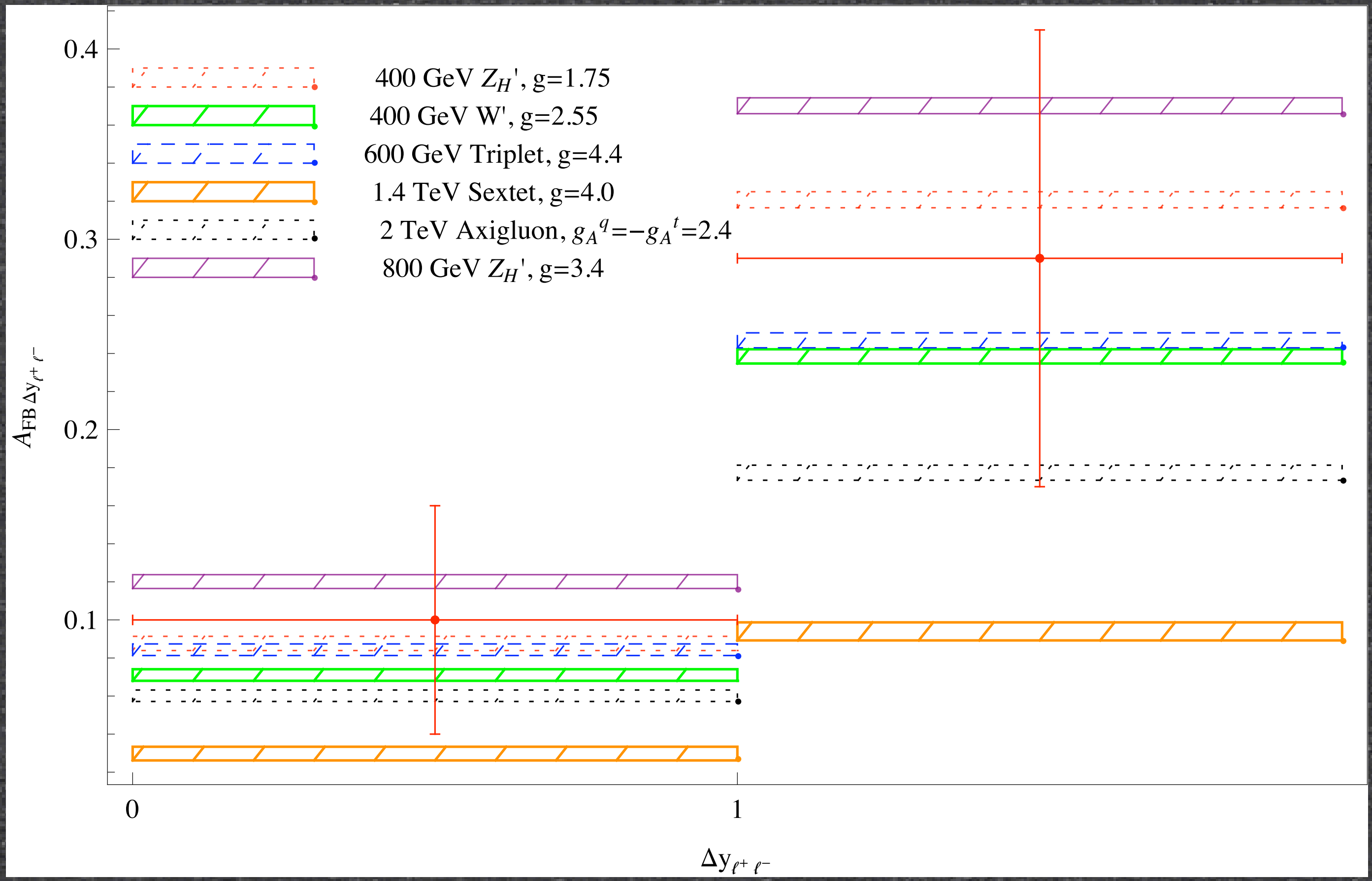


Invariant Mass Distributions



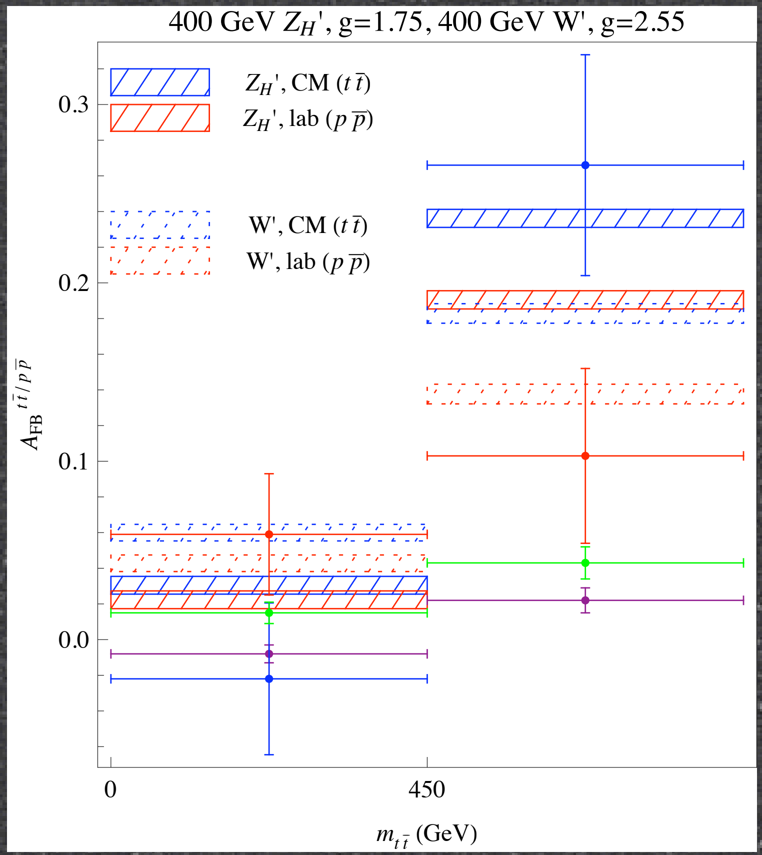
Di-lepton channel

- Also well-produced

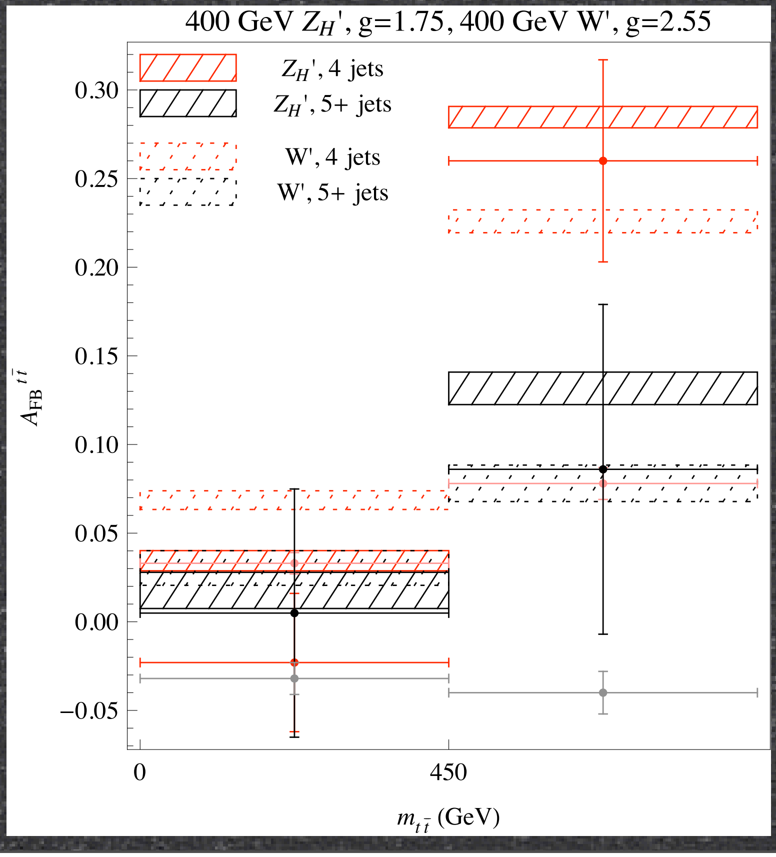


Other Observables

- Lab vs CM



- 4 versus 5 jet

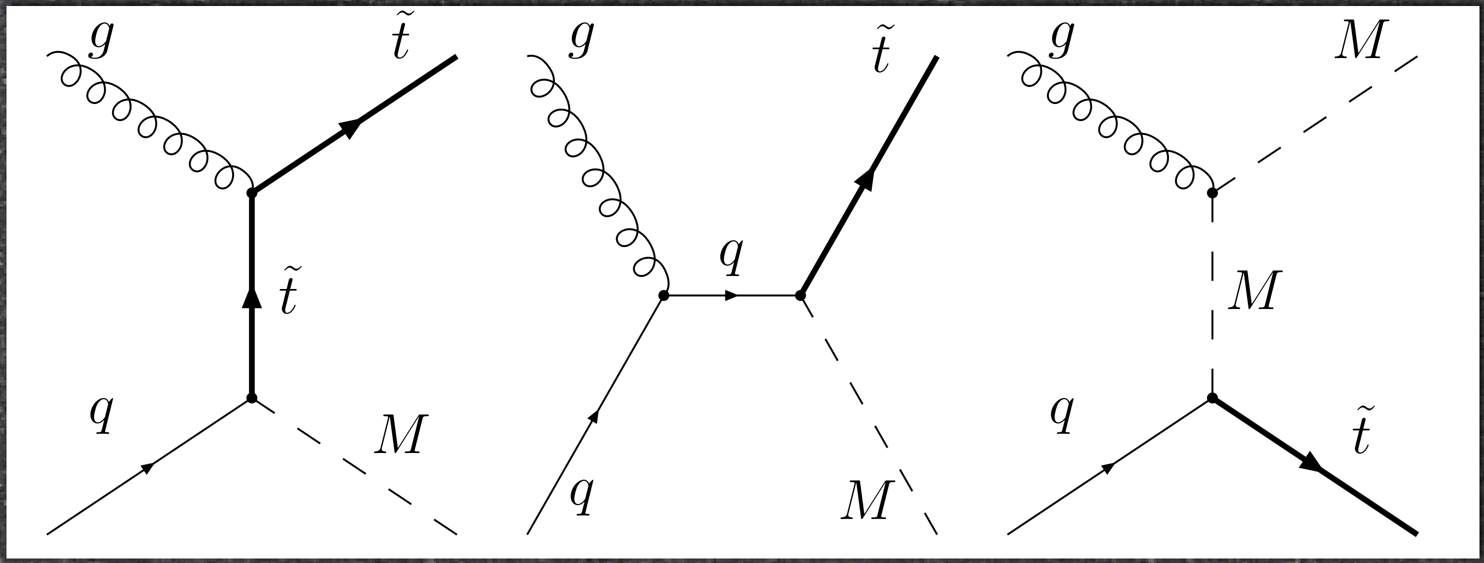


Summary: Tevatron observables

- After taking into account efficiencies, both W' and Z' models can effectively reproduce the asymmetry
- Triplet and sextet scalars are ineffective; don't reproduce steep rise and overproduce invariant mass distribution
- Axigluon models also have difficulty

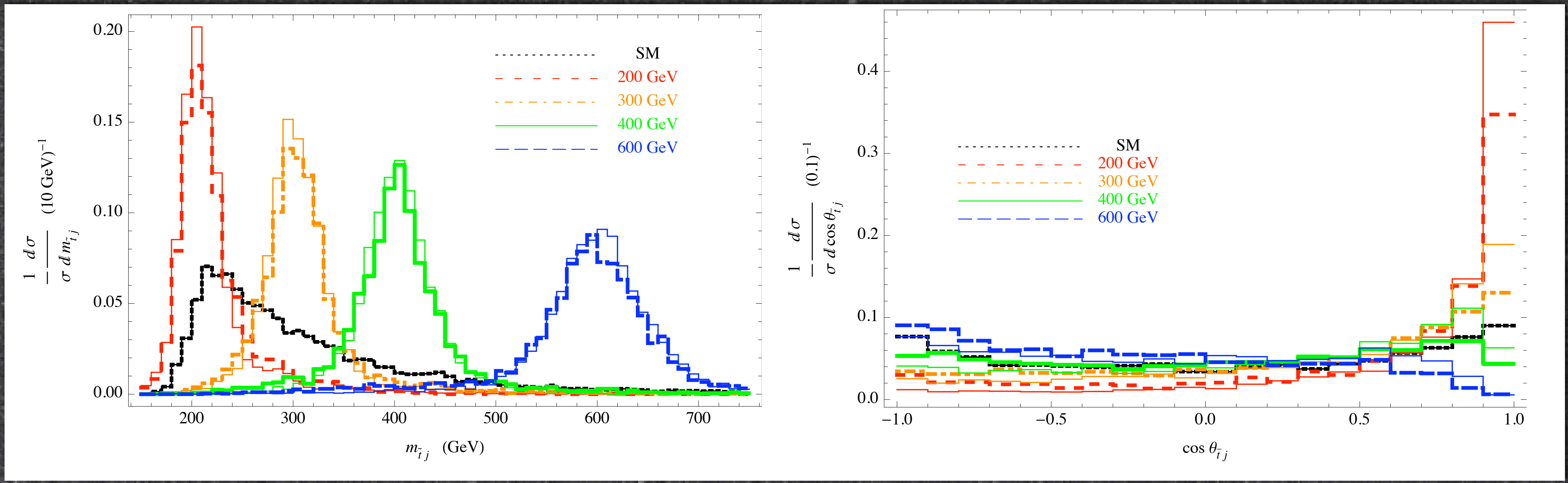
LHC Observables

- Search for O(1) flavor violation!
- Couple strongly; light states; likely observable at LHC7 with 1 fb^-1



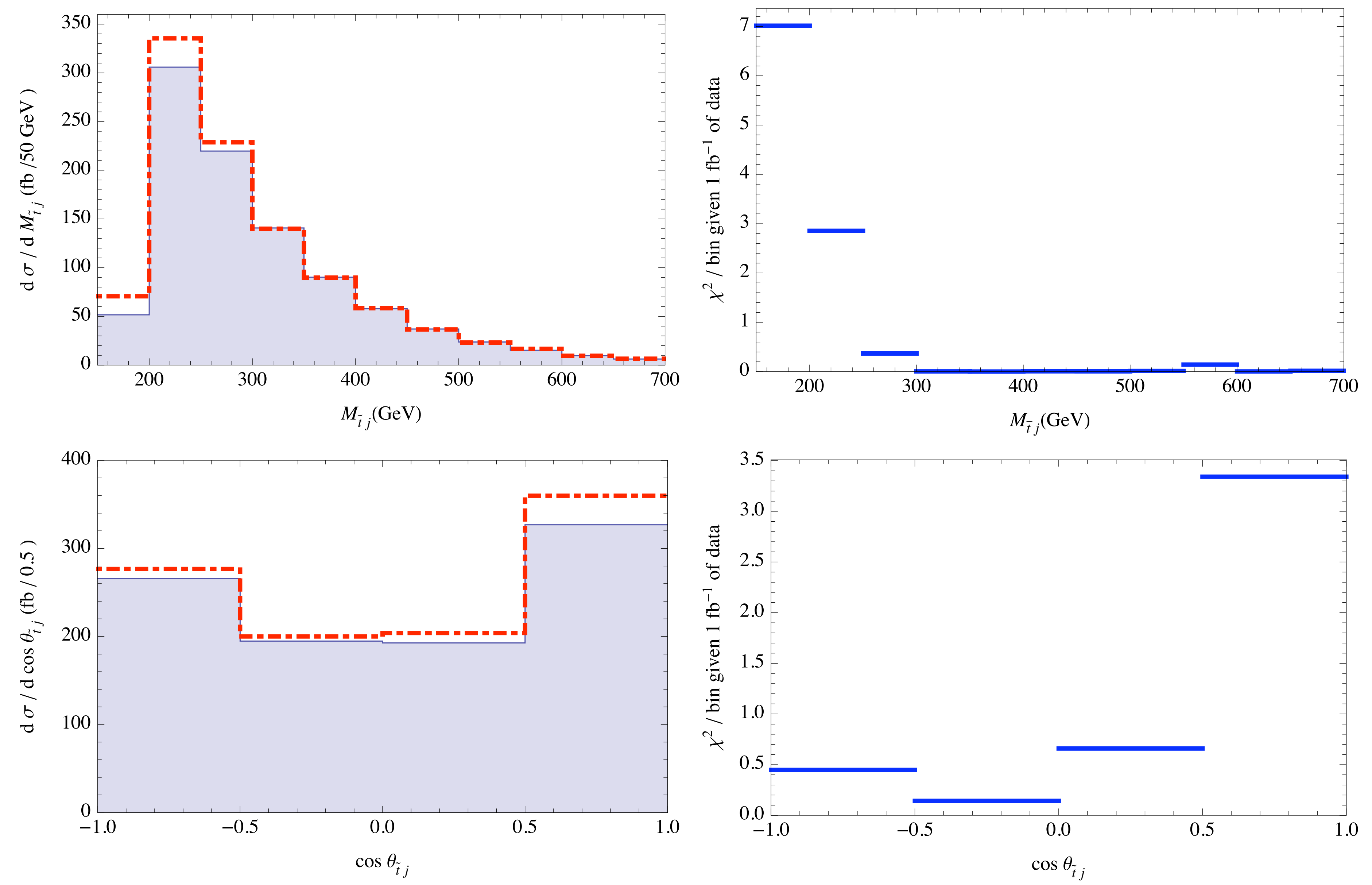
Searching for top-jet resonances

- In tt-bar+jet events, look for resonances in tj



Searching for top-jet resonances

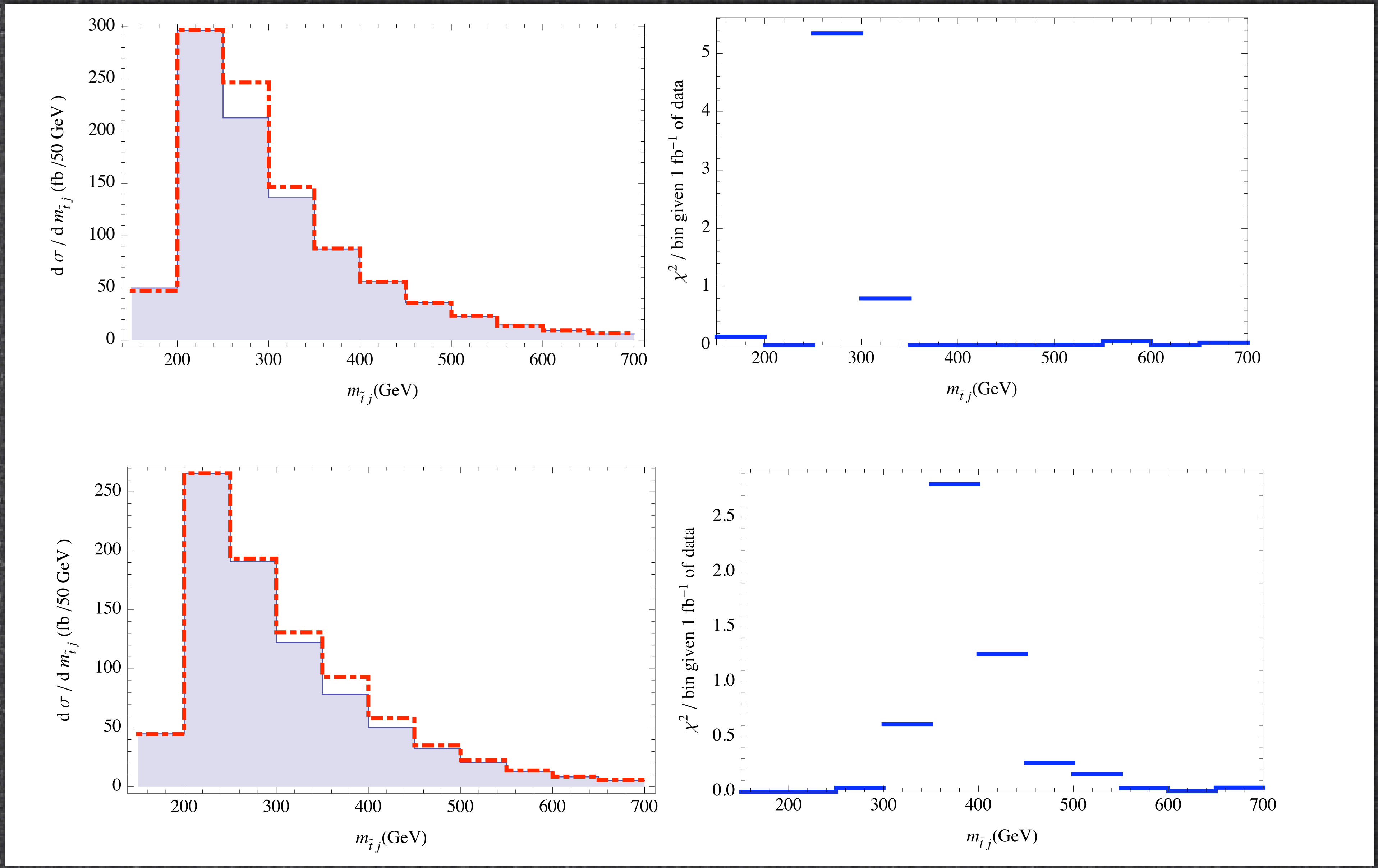
Moira Gresham, Ian-Woo Kim, KZ 1102.0018



200 GeV Resonance

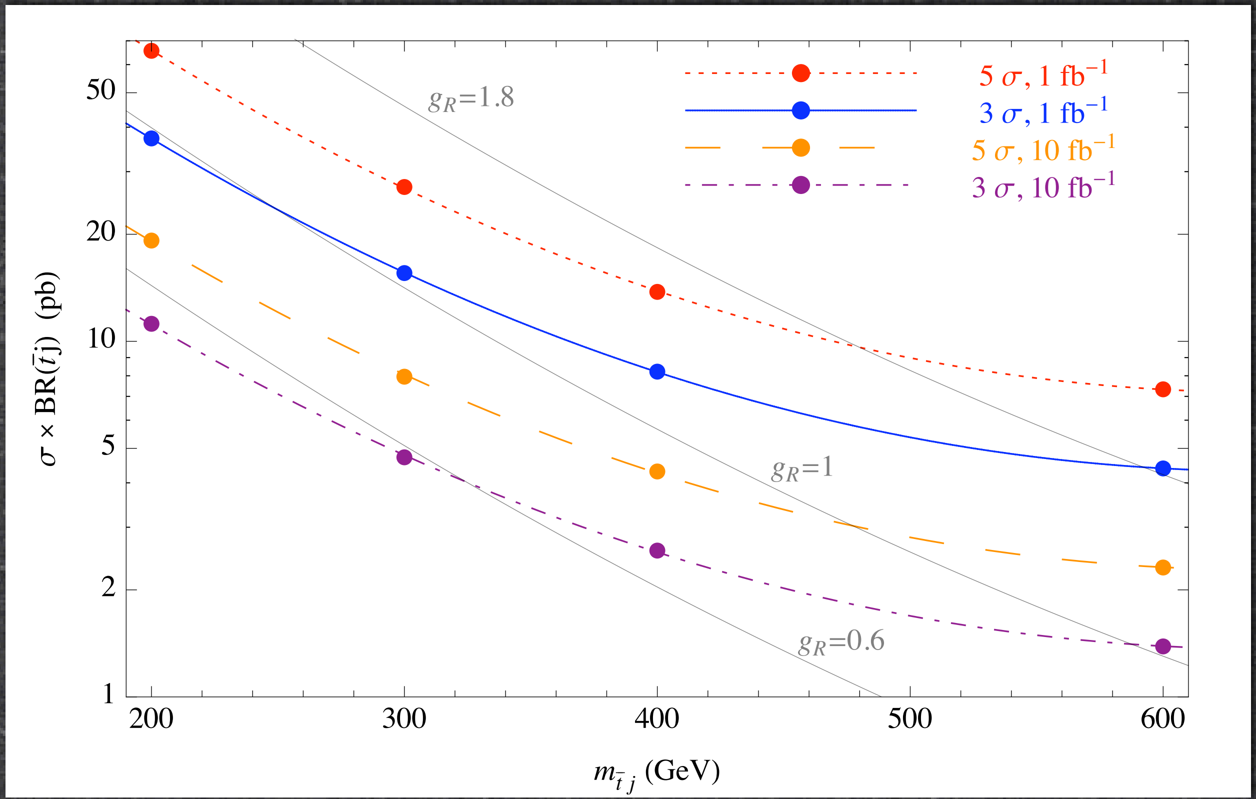
Searching for top-jet resonances

- Bump-anti-bump-bump



LHC7 Reach

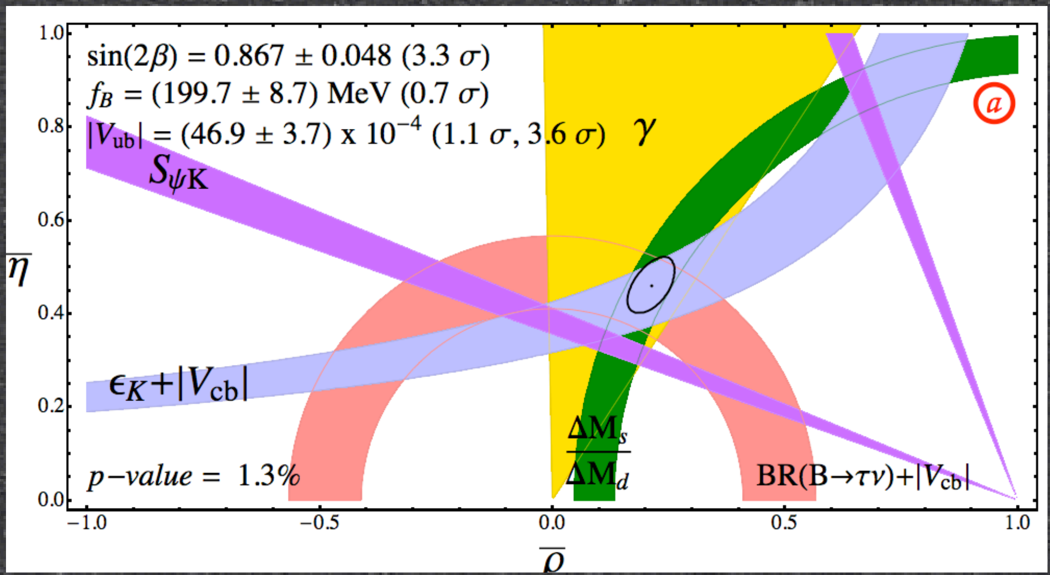
- 3 sigma excess with 1 fb^-1



- Easy extension of tt-bar resonance searches

Models of Flavor

- LARGE flavor violation!!
- Seems seriously constrained

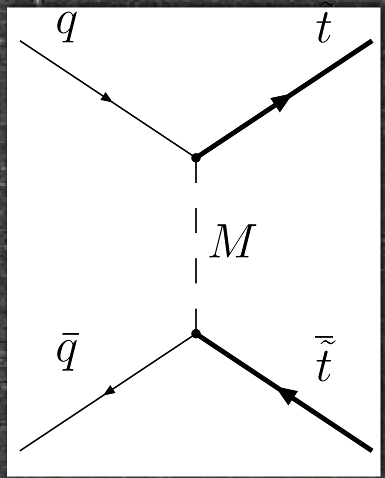


Lunghi, Soni

- Even with no tree level flavor violation in coupling, can enter in loops

Horizontal Symmetry

- Strategy: charge minimal number of quarks required to generate anomaly
- Avoid problem with same sign tops

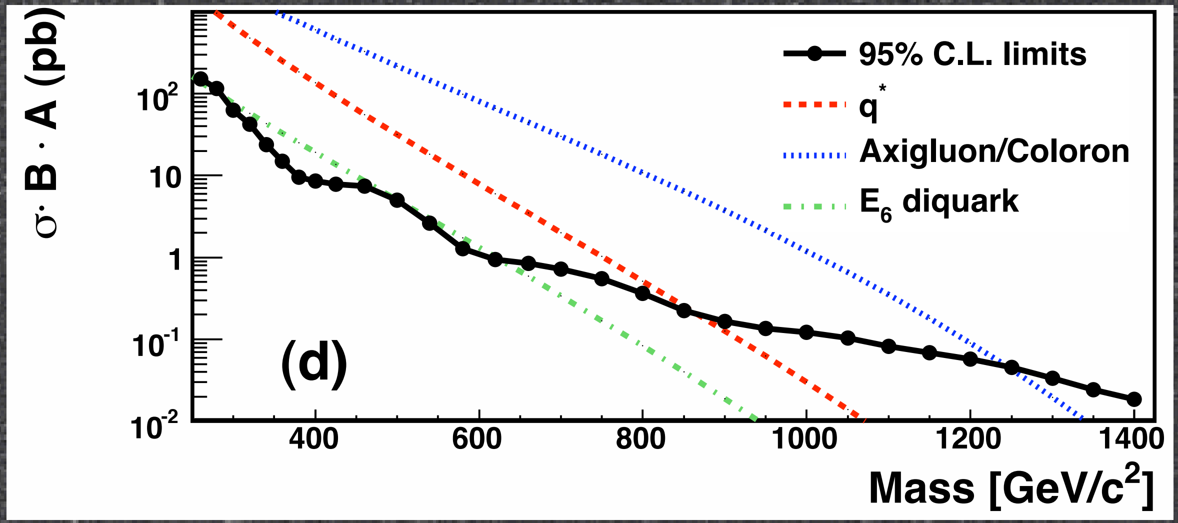


$$(u, t)_R$$

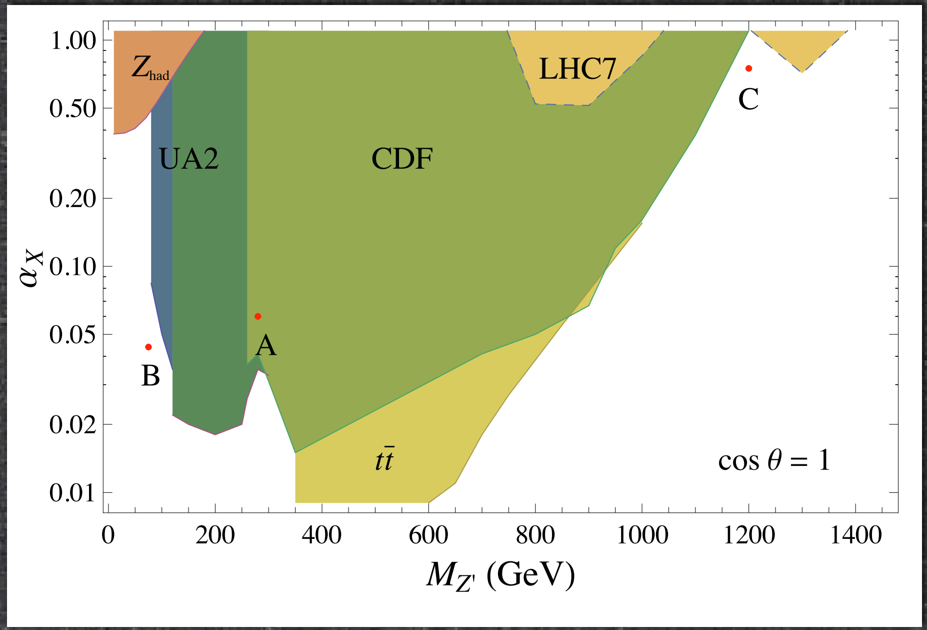
- uu and tt couplings can be tuned via mixings

Constraints on models with more sym

- Flavor conserving Z’ is still there -- dijet constraints, UA2 bounds (sols: higher rep Higgs, light Z’)



CDF 2008



Jung, Pierce, Wells

- Single top production

A Global View Towards Flavor

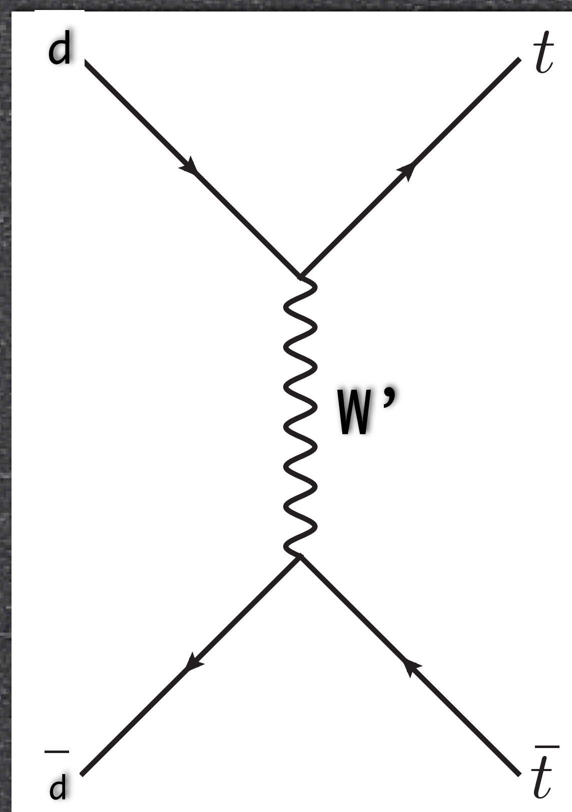
- Try a 1-3 generation gauging

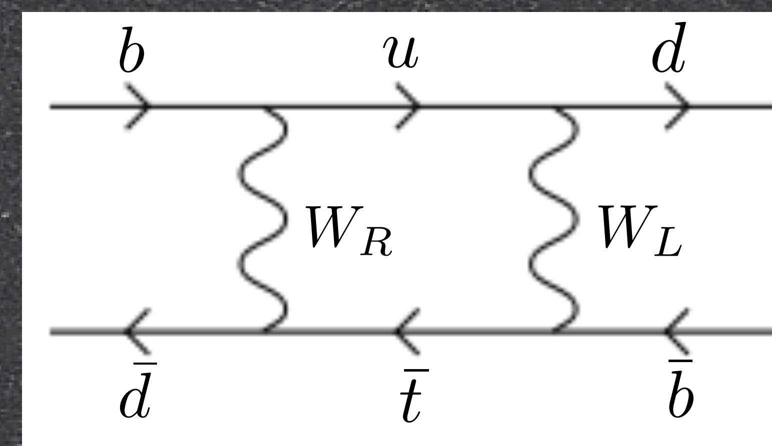
$$\begin{pmatrix} t \\ d \end{pmatrix}_R \quad \begin{pmatrix} u \\ b \end{pmatrix}_R$$

Jessie Shelton, KZ 1101.5392

- Note that it now mixes RH new physics with CKM physics (Danger!)
- Payoff: anomalies in B system for free

Irreducible Consequences



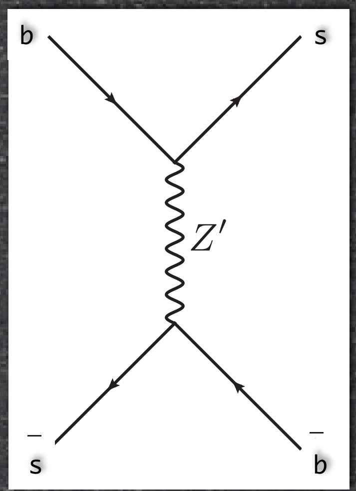


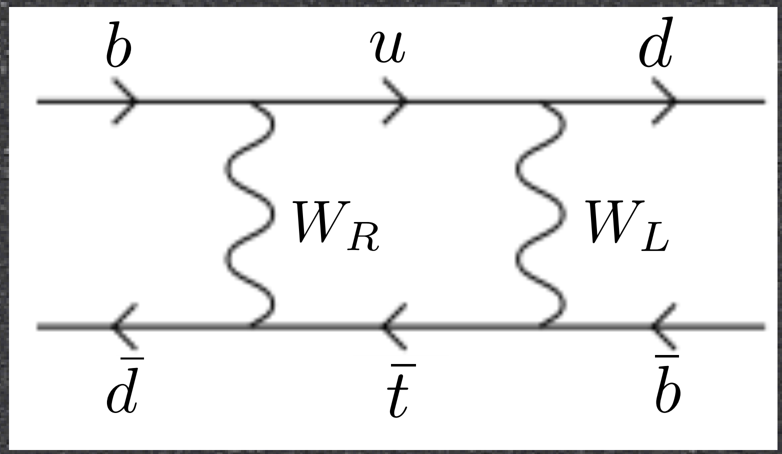
$$\frac{\mathcal{M}_{LR}}{\mathcal{M}_{LL}} \simeq -0.2 \left(\frac{\tilde{g}}{2}\right)^2 \left(\frac{450 \text{ GeV}}{m_{W'}}\right)^4 \frac{G(x_t)}{G(x_t^0)}$$

Anomalies in B mesons -- new CPV

- Tevatron like sign muons
- B) $B_s \to \psi\phi$
- C) $B_d \to \psi K$

$$\begin{pmatrix} t \\ d \end{pmatrix}_R \quad \begin{pmatrix} u \\ b \end{pmatrix}_R$$





$\Delta M_{B_s},\ S_{\psi\phi}$ $\quad$ $\Delta M_{B_d},\ S_{\psi K}$

B physics anomalies

- Tevatron like-sign muons

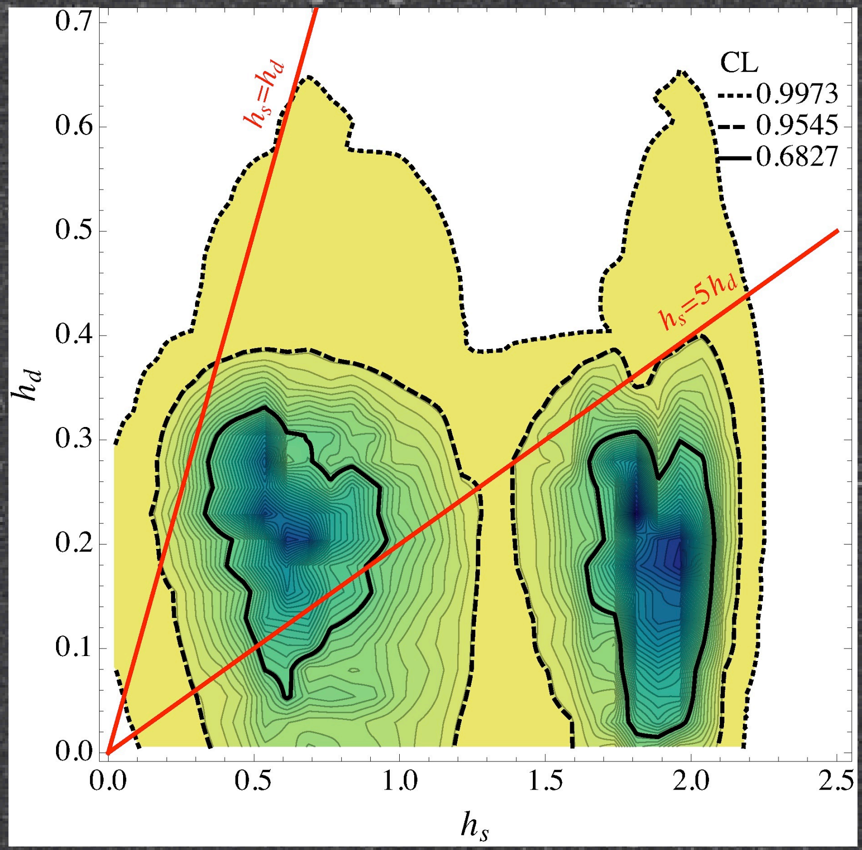
  $a_{sl}^b = -(8.5 \pm 2.8) \times 10^{-3} \qquad b\bar{b} \to \mu^+ \mu^+ X$

- B_s mixing in $\Delta\Gamma_s$ and $S_{\psi\phi}$
- Less significant:
  - measurement of $\sin 2\beta$ in $B_d \to \psi K$ and penguin dominated $b \to sq\bar{q}$

Fit to Tevatron anomalies

$$M_{12}^{d,s} = \left(M_{12}^{d,s}\right)^{\rm SM}\left(1 + h_{d,s}\, e^{2i\sigma_{d,s}}\right)$$

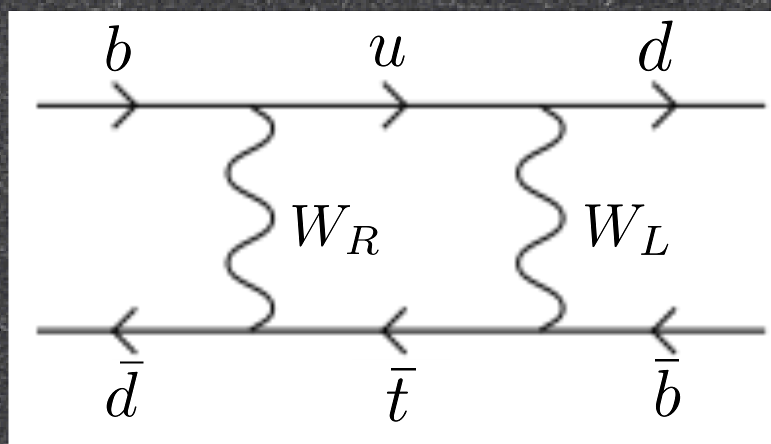
$$\begin{aligned}
\Delta m_q &= \Delta m_q^{\rm SM}\left|1 + h_q e^{2i\sigma_q}\right|,\\
\Delta\Gamma_s &= \Delta\Gamma_s^{\rm SM}\,\cos\left[\arg\left(1 + h_s e^{2i\sigma_s}\right)\right],\\
A_{\rm SL}^q &= {\rm Im}\left\{\Gamma_{12}^q / \left[M_{12}^{q,{\rm SM}}(1 + h_q e^{2i\sigma_q})\right]\right\},\\
S_{\psi K} &= \sin\left[2\beta + \arg\left(1 + h_d e^{2i\sigma_d}\right)\right],\\
S_{\psi\phi} &= \sin\left[2\beta_s - \arg\left(1 + h_s e^{2i\sigma_s}\right)\right].
\end{aligned}$$



Ligeti, Papucci, Perez, Zupan

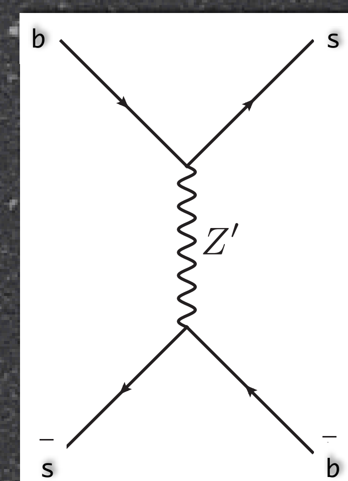
- 3 sigma deviation from SM

Amplitudes



$$\frac{\mathcal{M}_{LR}}{\mathcal{M}_{LL}} \simeq -0.2 \left(\frac{\tilde{g}}{2}\right)^2 \left(\frac{450\ \mathrm{GeV}}{m_{W'}}\right)^4 \frac{G(x_t)}{G(x_t^0)}$$

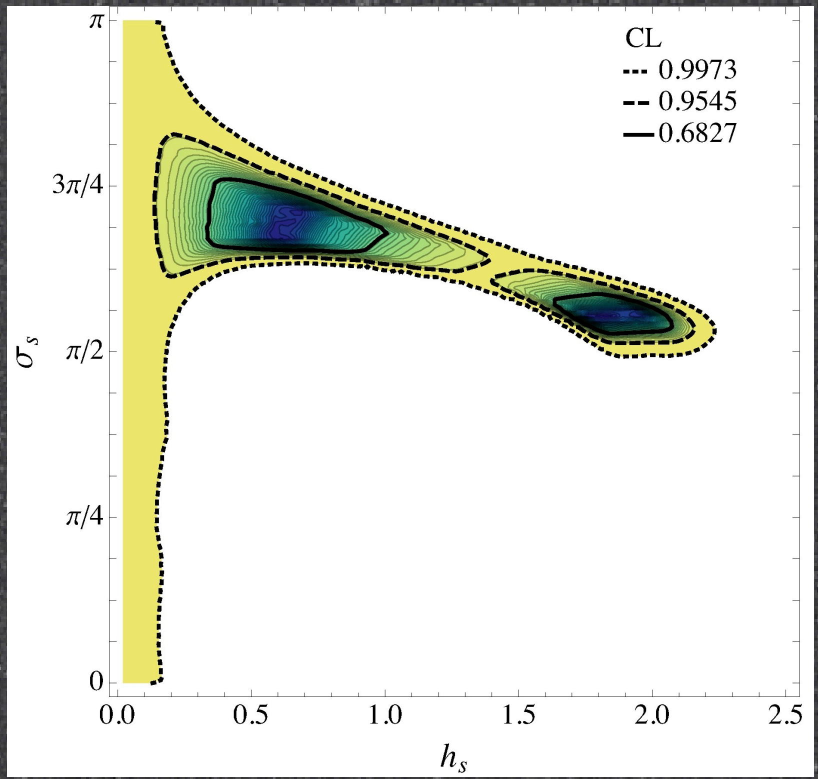
$$\frac{S_{sb}^2 \tilde{g}^2}{m_{Z'}^2}\ \bar{b}_R \gamma^\mu s_R \bar{b}_R \gamma_\mu s_R,$$



$$\Lambda \equiv \frac{m_Z'}{|S_{sb}|\tilde{g}} \sim 0.4 - 1.2\ \mathrm{TeV} \left(\frac{10^{-2.5}}{\tilde{g}|S_{sb}|}\right)$$

Phases

- Same size phase appears in anomalous CKM fits as in the Tevatron anomalies, and the phases needed are around the same size



Ligeti, Papucci, Perez, Zupan

$$S_{\psi K} \;=\; \sin\left[2\beta + \arg(1 + h_d e^{2i\phi_d})\right]$$

$$\pi/2 < \phi_d < 3\pi/4$$

$$\eta_{CP} S_{\psi K} = 0.655 \pm 0.0244$$

$$\sin(2\beta)^{fit} = 0.891 \pm 0.052$$

Constraints

- W' charged state. Z/Z' mixing. Precision EW.
- Mixing matrix

$$\mathcal{M} = \frac{1}{4}\begin{pmatrix} g^2 v^2 & g g' v^2 & 0 \\ g g' v^2 & g'^2(v^2 + 4Y^2 \hat{v}^2) & 4Y T_{3R} g' \tilde{g} \hat{v}^2 \\ 0 & 4Y T_{3R} g' \tilde{g} \hat{v}^2 & 4T_{3R}^2 \tilde{g}^2 \hat{v}^2 \end{pmatrix}$$

$$Z = \begin{pmatrix} \frac{g}{g_Z} \\ \frac{-g' \tilde{g}^2}{(\tilde{g}^2+g'^2) g_Z}(1 + \epsilon_Z^2 \frac{g'^2 g_Z^2}{g^2(\tilde{g}^2+g'^2)}) \\ \frac{-g'^2 \tilde{g}}{(\tilde{g}^2+g'^2) g_Z}(1 + \epsilon_Z^2 \frac{\tilde{g}^2 g_Z^2}{g^2(\tilde{g}^2+g'^2)}) \end{pmatrix}$$

$$\frac{\delta\rho}{\rho} = -\frac{\delta m_Z^2}{m_Z^2} = \frac{(m_Z^2 - m_W^2)\tan^2\theta_R}{m_{Z'}^2 - (m_Z^2 - m_W^2)\tan^2\theta_R}$$

- No serious precision EW constraints for heavy Z'

UV Completions

- 1,3 versus 2nd generation mass terms appear differently

$$\frac{Y^d_{ij}}{M}\bar{q'}^i_R\phi^\dagger_R H_L q'^j_L + \frac{Y^u_{ij}}{M}\bar{q'}^i_R\tilde{\phi}^\dagger_R \tilde{H}_L q'^j_L$$

$$Y^j_d \bar{q'}^2_R H_L q'^j_L + Y^j_u \bar{q'}^2_R \tilde{H}_L q'^j_L$$

- A simple way to generate this is via vector-like quarks $\mu\bar{Q}Q + \bar{Q}H_L q_L + \bar{q}_R H^\dagger_R Q$
- Flavor violation comes down to the couplings of Q to the various generations

Summary

- Top AFB has held up and significance has increased. Await more data from D0 and CDF. Measurement seems clean.
- Phenomenologically viable models require large flavor violation or colored state with exotic couplings

Summary

- Most models which generate top AFB should show up in early LHC data; some worry about light mediators
- While large flavor violation through gauge bosons seems highly constrained, it's less constrained than might be supposed
- May be new physics. Excellent prep for LHC7.