Asymmetric Dark Matter

Kathryn Zurek
University of Michigan

Forward-Backward Asymmetry: Status and Updates

Kathryn Zurek
University of Michigan

Coin Toss

ADM -- at 5 GeV

AFB

Coin Toss

ADM -- at 5 GeV

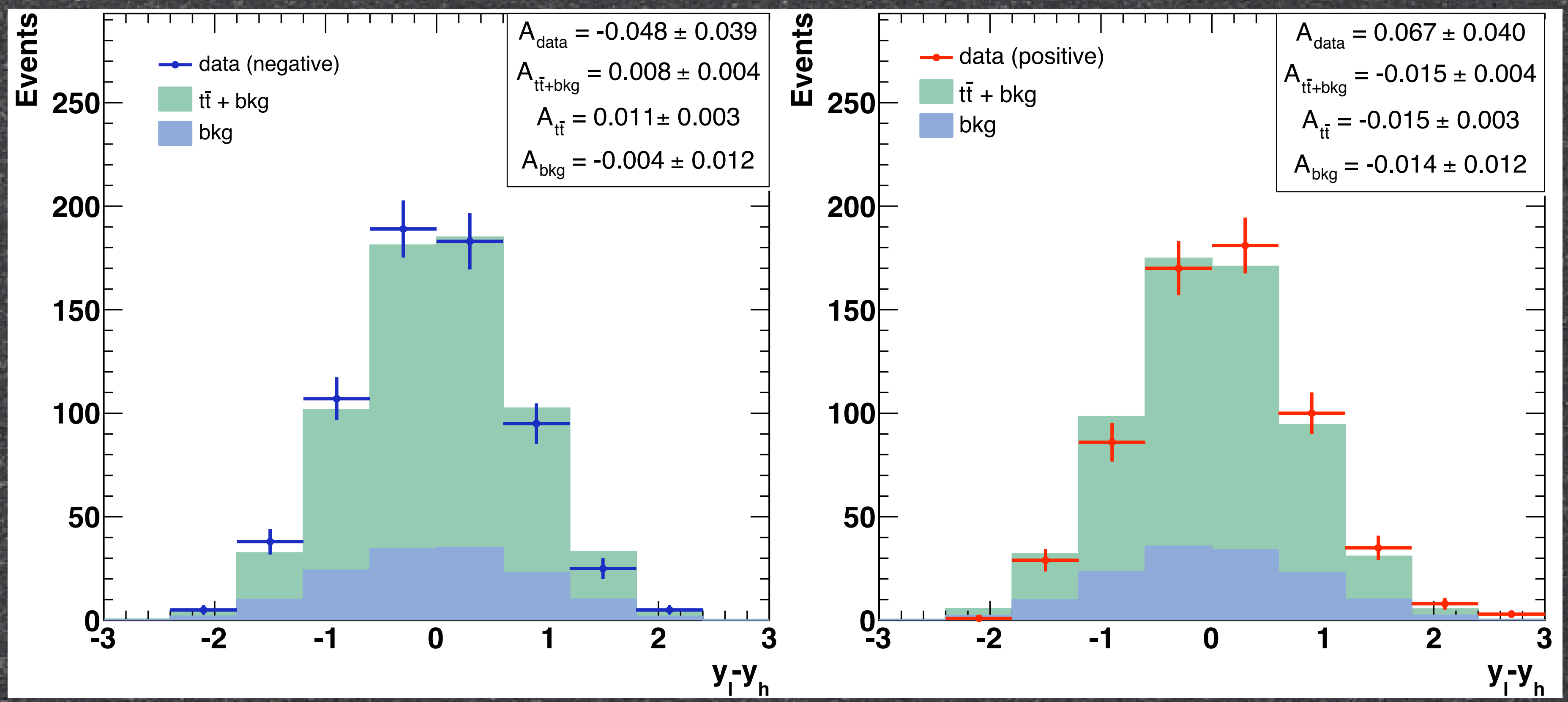
AFB

Forward-Backward Asymmetry: Status and Updates

Kathryn Zurek
University of Michigan

Why this anomaly now?

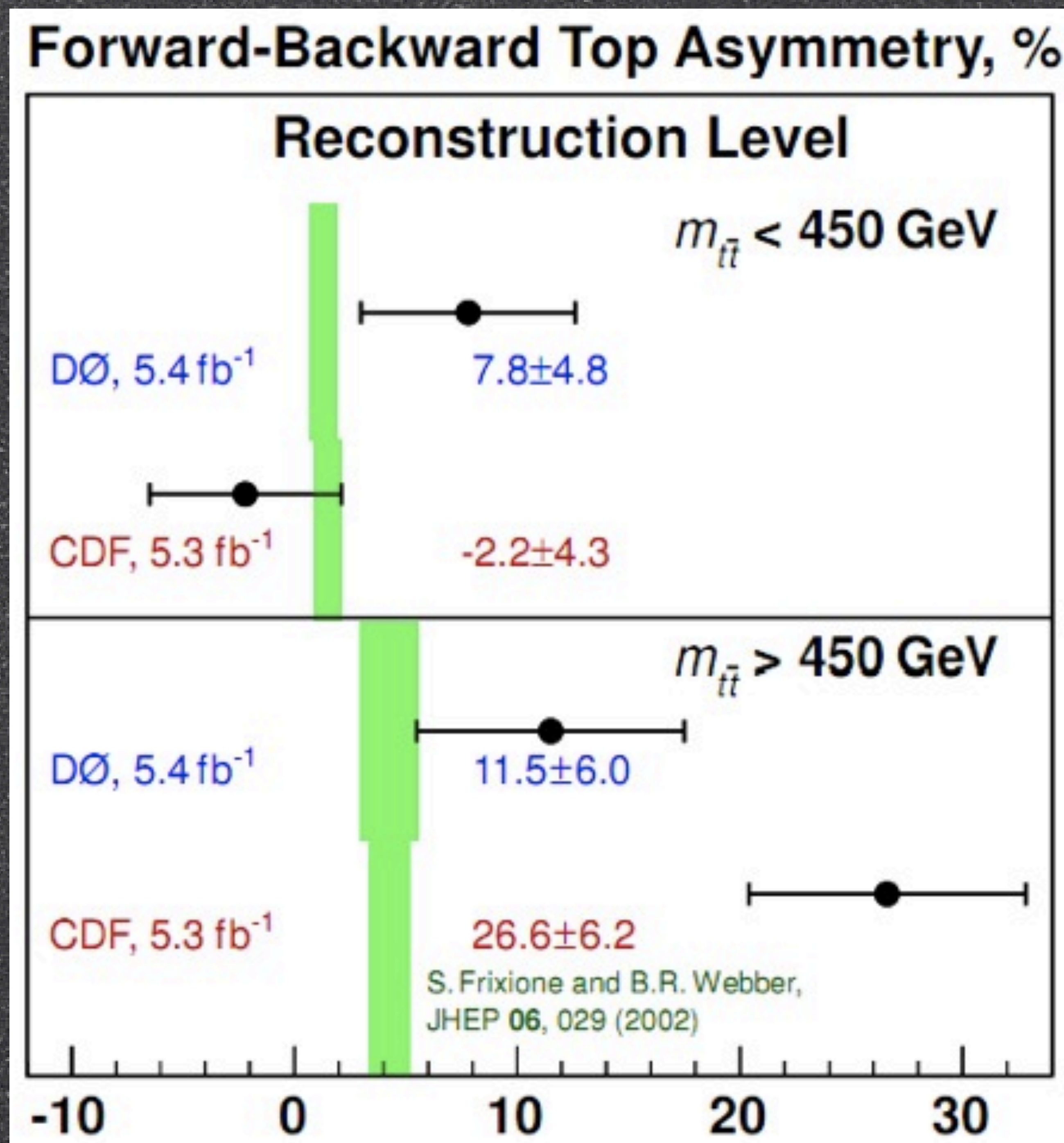
- CDF 5.3 fb^-1, January 2011



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

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

Why this anomaly now?



Why this anomaly, now?

Data level

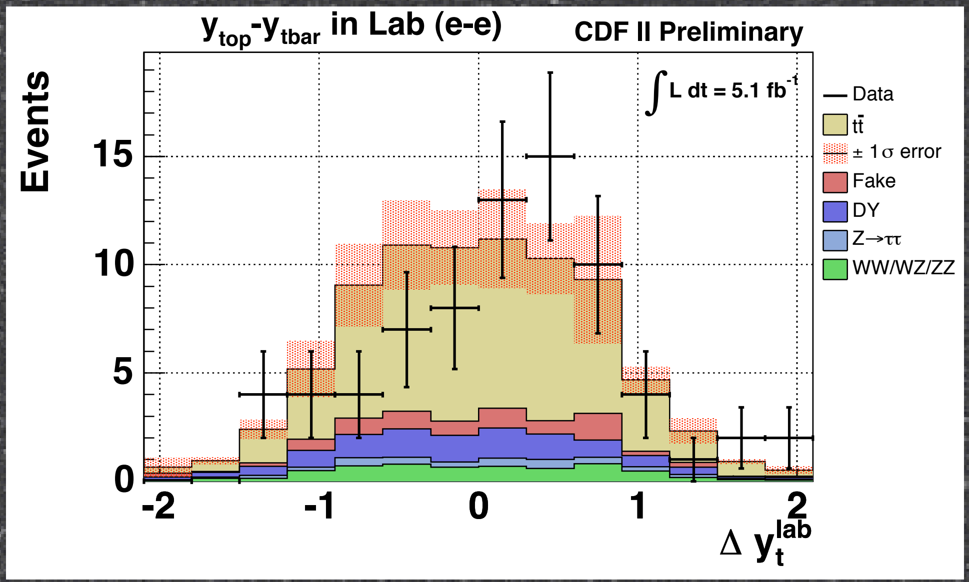
Selection	NLO (QCD+EW)	CDF, 5.3 fb^{-1}	D0, 5.4 fb^{-1}	CDF, 8.7 fb-1
Inclusive	6.6	15.8 ± 7.4	19.6 ± 6.5	16.2 ± 4.7
$M_{tt} < 450$ GeV/c^2	4.7	−11.6 ± 15.3	7.8 ± 4.8 (Bkg. Subtracted)	7.8 ± 5.4
$M_{tt} \geq 450$ GeV/c^2	10.0	47.5 ± 11.2	11.5 ± 6.0 (Bkg. Subtracted)	29.6 ± 6.7
$\|\Delta y\| < 1.0$	4.3	2.6 ± 11.8	6.1 ± 4.1 (Bkg. Subtracted)	8.8 ± 4.7
$\|\Delta y\| \geq 1.0$	13.9	61.1 ± 25.6	21.3 ± 9.7 (Bkg. Subtracted)	43.3 ± 10.9

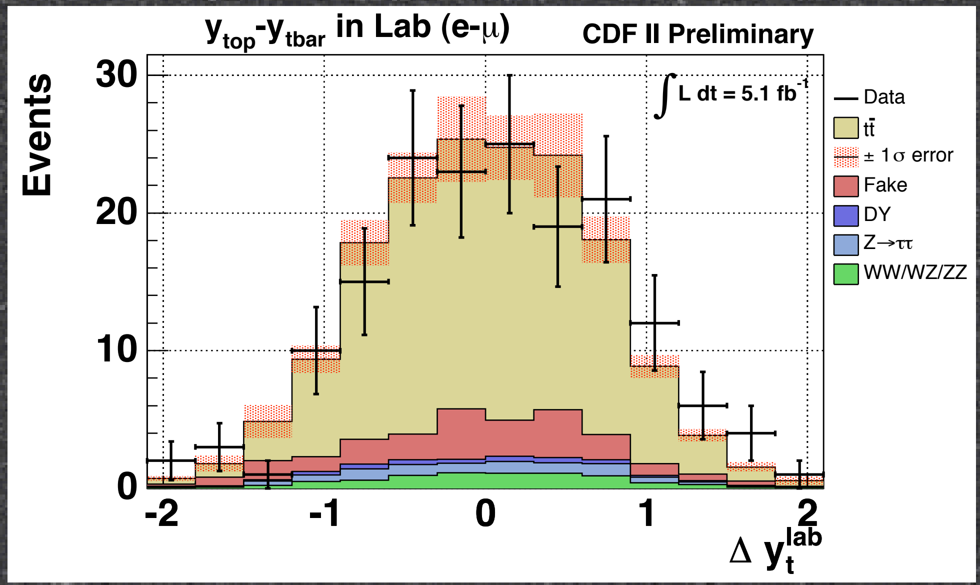
D. Mietlicki, Moriond

Measures of top AFB

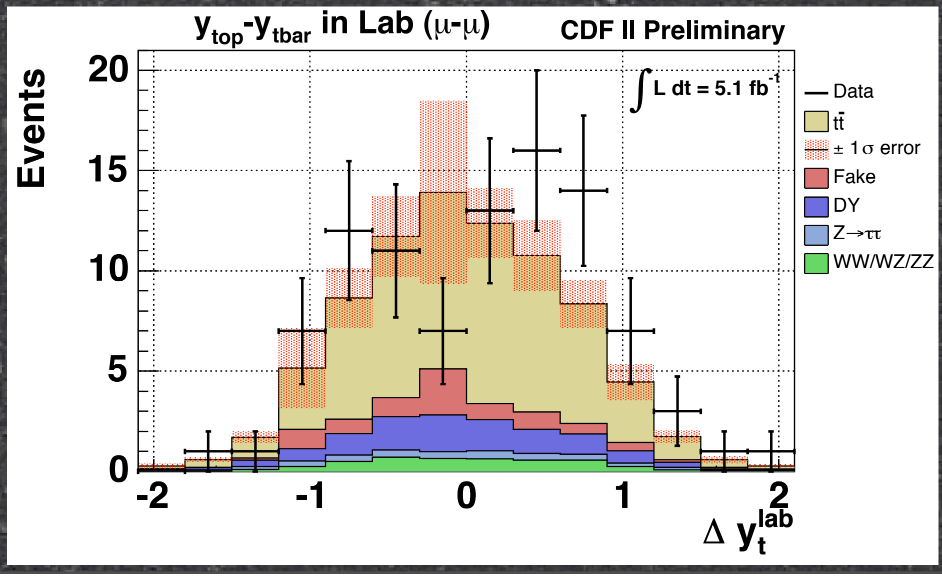
- Asymmetry much larger in ee, mu-mu than in e-mu

$A_{FB} = 0.06 \pm 0.077$



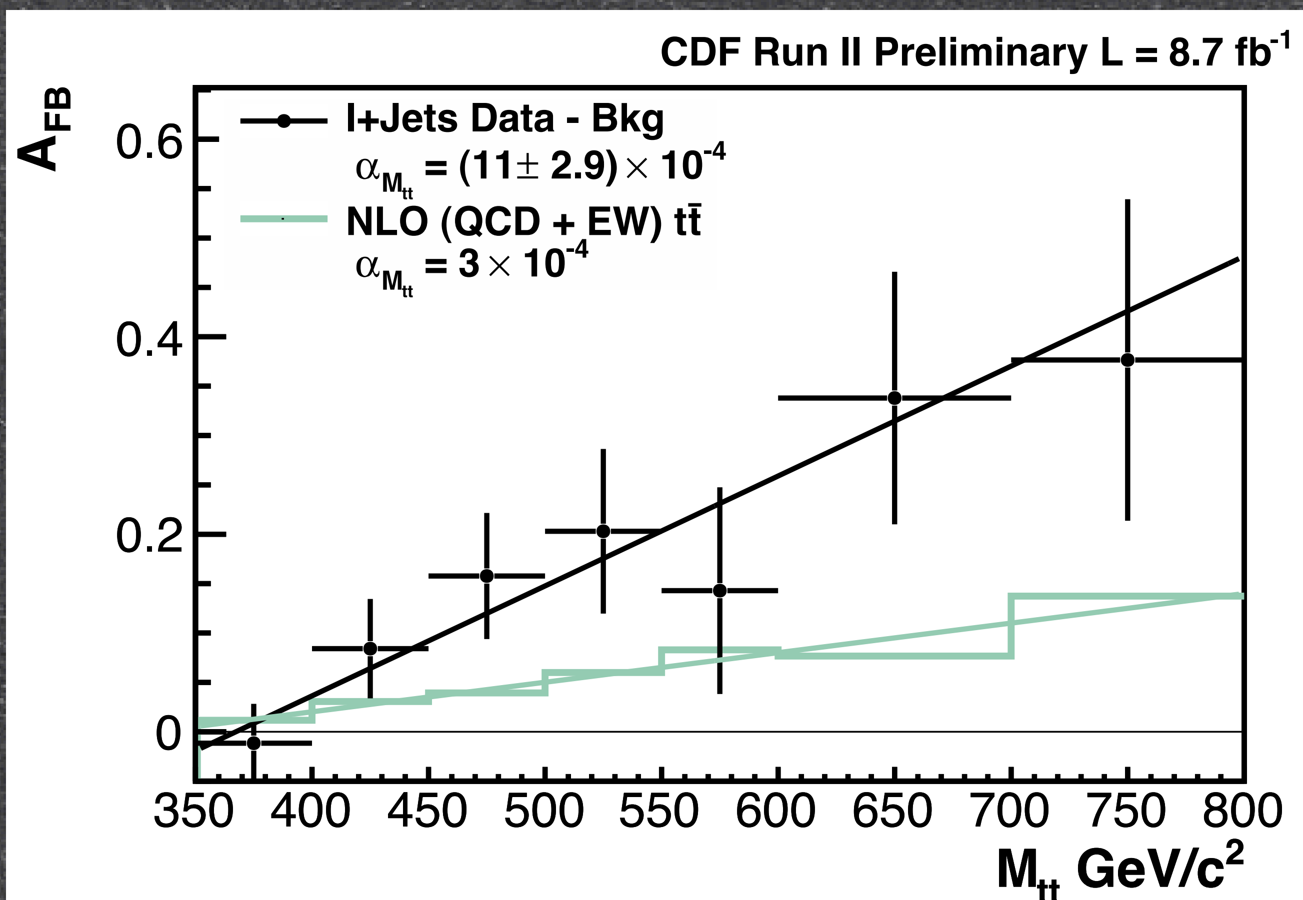


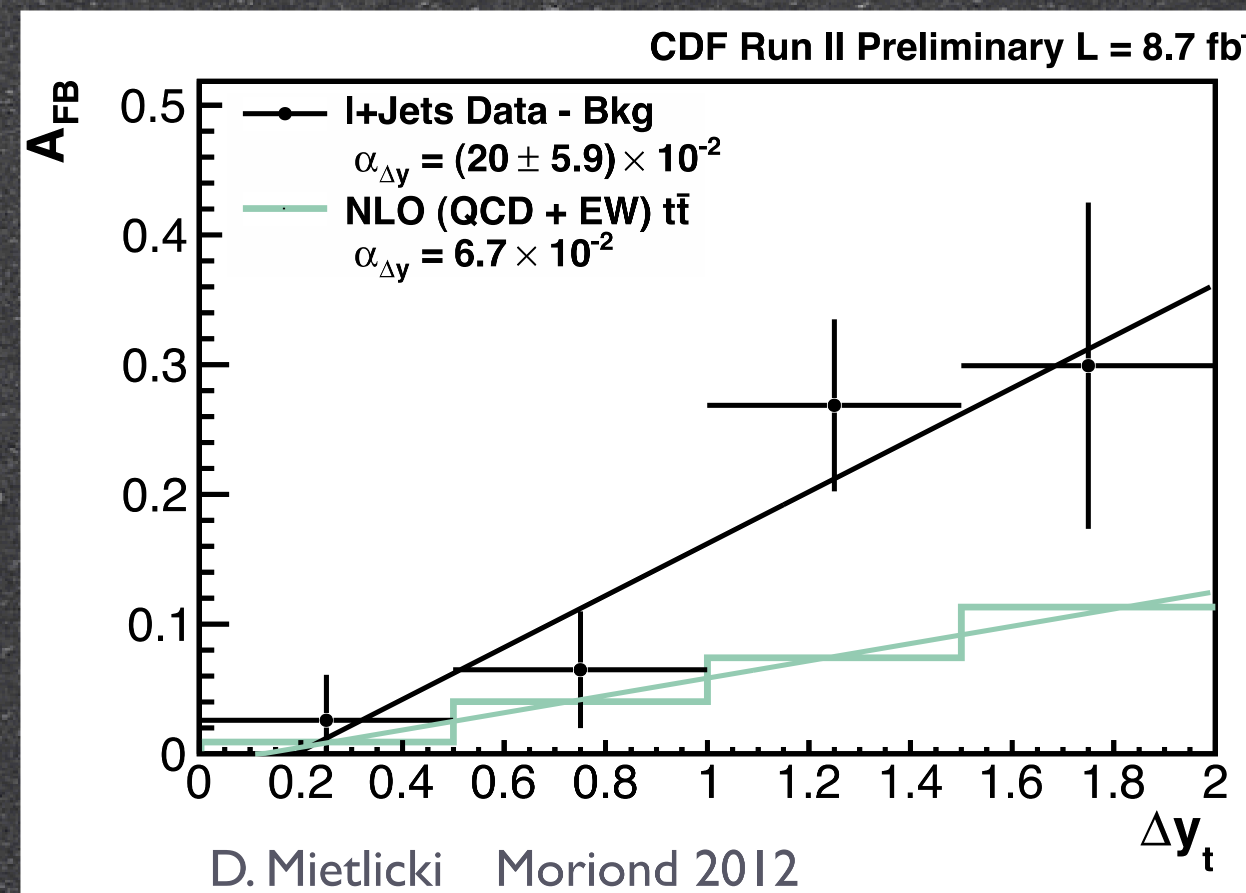
$A_{FB} = 0.27 \pm 0.112$



$A_{FB} = 0.17 \pm 0.102$

CDF Update

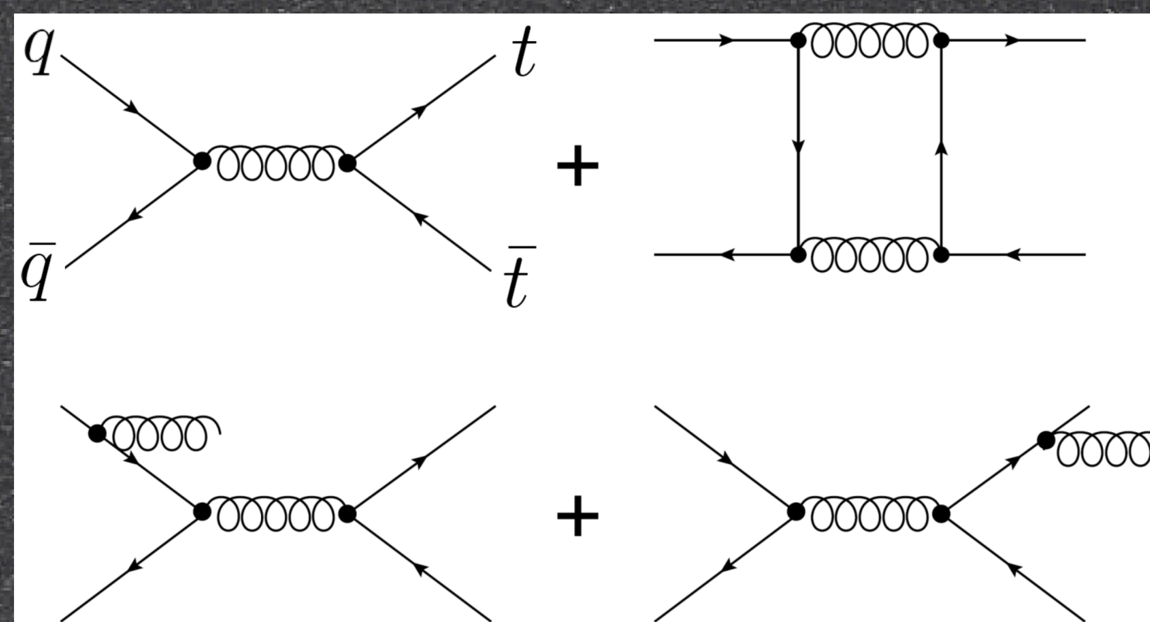




No reconstruction level yet

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

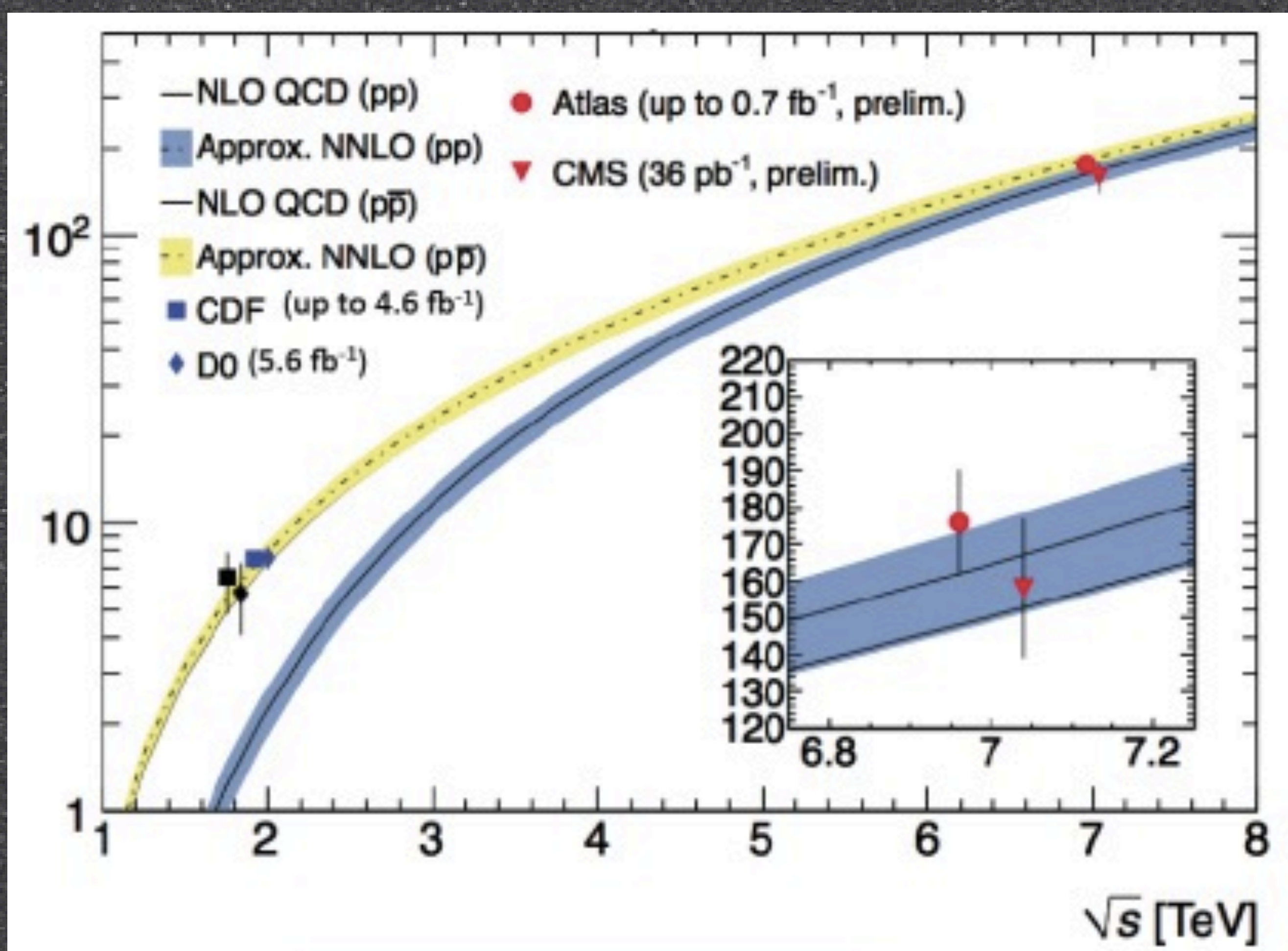
Questions to Ask about the anomaly

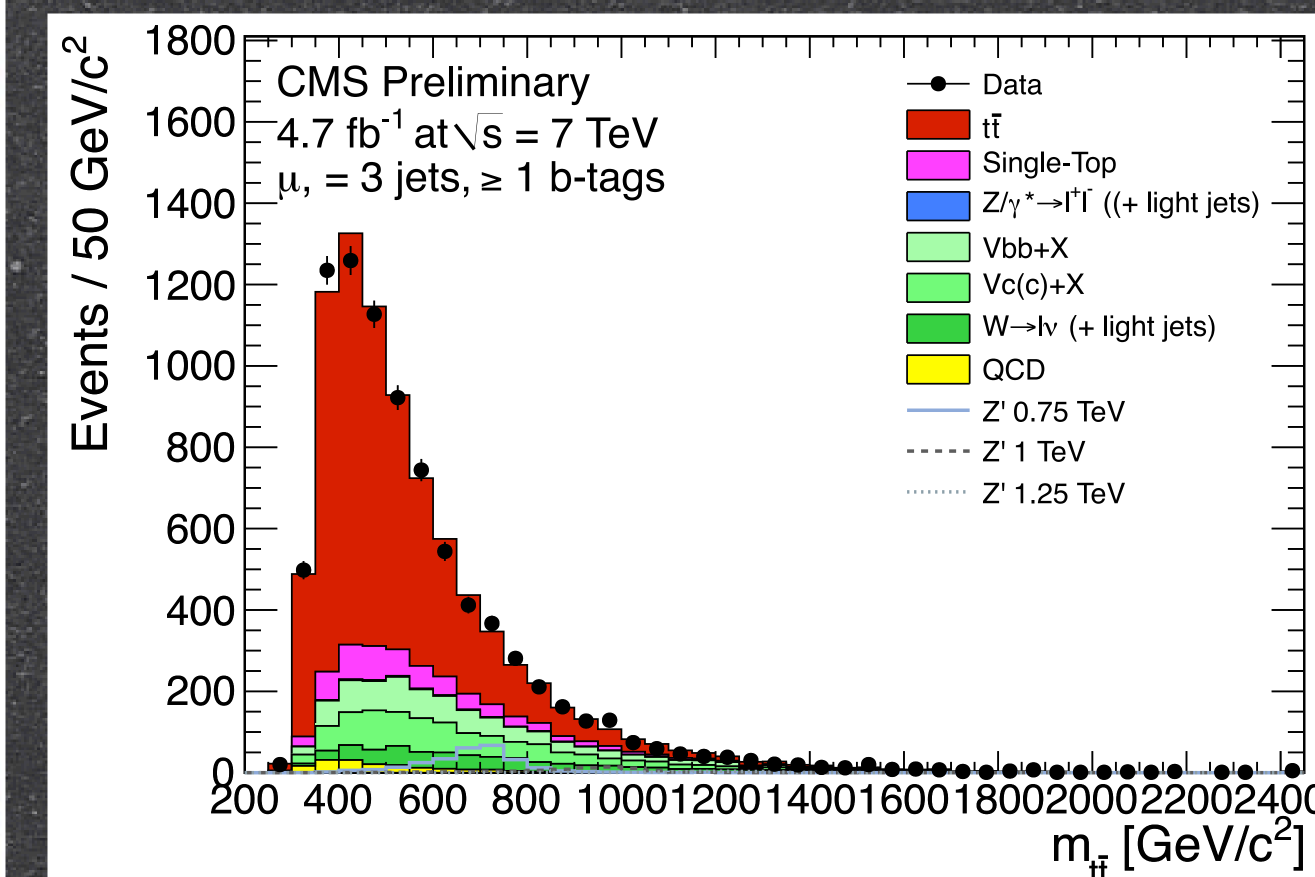
- Is it systematic?
- Is it statistical?
- Is it QCD?
- How difficult is it to simultaneously fit the anomaly and other constraints?

- Probably not
- Maybe -- though growing statistics
- Hard to see how ... but maybe likely given the constraints
- Not so easy.

On the LHC Side

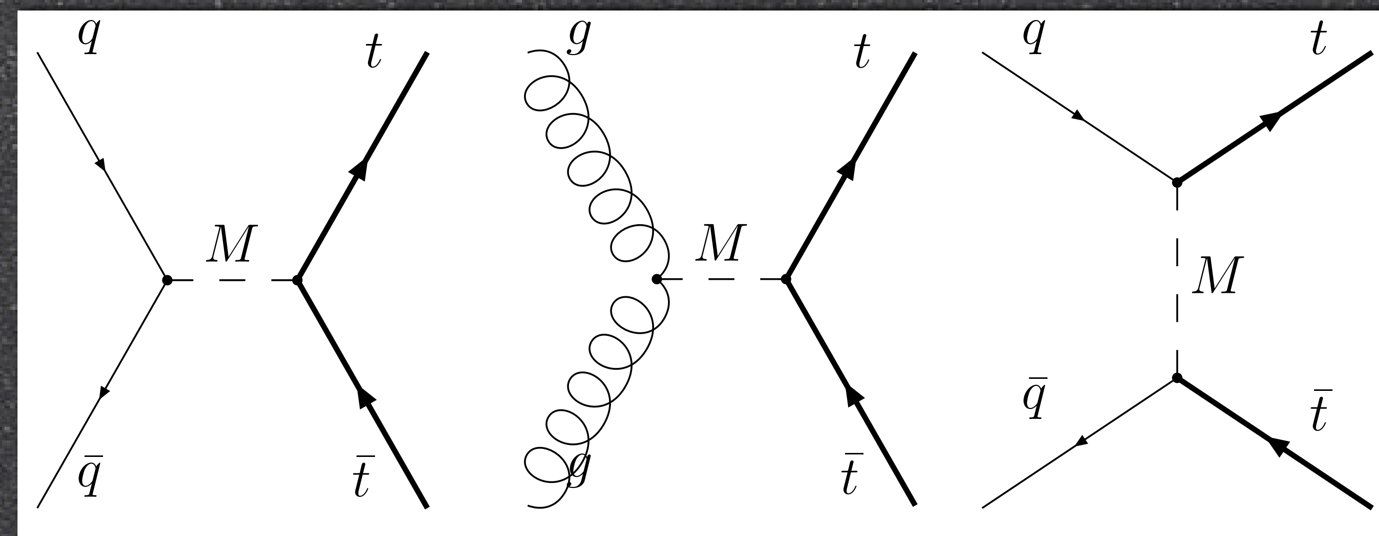
Cross-section and Invariant Mass Distribution Looks like SM





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

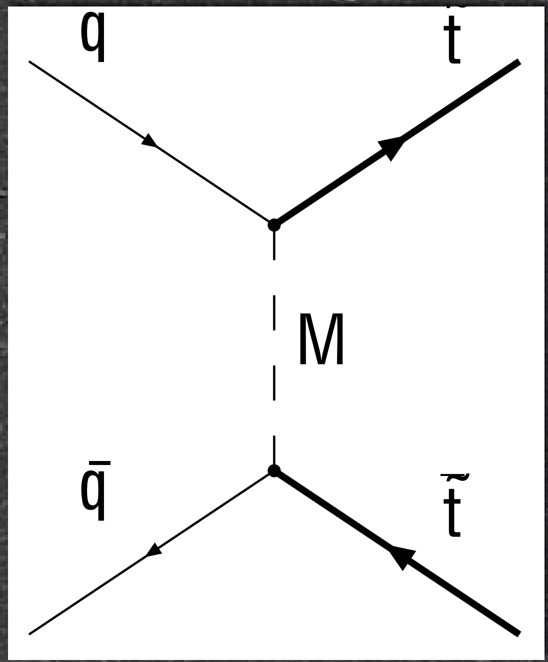
Jung, Murayama, Pierce, Wells
Shu, Tait, Wang
Ligeti, Schmaltz, Tavares
Grinstein, Kagan, Trott, Zupan

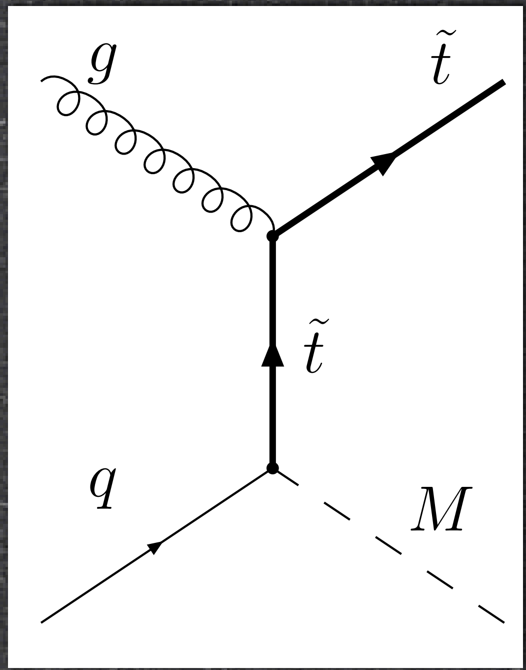
You can also refer to....

Sehgal, Wanninger(1988), Bagger, Schmidt, King (1988), Ferrario, Rodrigo (2009), Frampton, Shu Wang (2009), Chivukula, Simmons, Yuan (2010), Djouadi, Moreau, Richard, Singh (2010), Bauer, Goertz, Haisch, Pfoh, Westhoff (2010), Alvarez, Da Rold, Szynkman (2010), Chen, Cvetic, Kim (2010) Bai, Hewett, Kaplan, Rizzo (2011), Foot (2011), 1103.1266, 1103.1940, Zerwekh (2011) , Shu, Wang, Zhu (2011), Alvarez, Da Rold, Vietto, Szynkman (2011), 1103.0956, Tavarez, Schmaltz (2011), Aguilar-Saavedra (2011), Jung, Murayama, Pierce, Wells (2009), Cheung, Keung, Yuan (2009) Shu, Tait, Wang (2010), Arhrib, Benbrik, Chen (2010), Dorsner, Fajfer, Kamenik, Kosnik (2009), Barger, Keung, Yu (2010), Xiao, Wang, Zhu (2010), Cheung, Yuan (2010), Shelton, Zurek (2011), Berger, Cao, Chen Li, Zhang (2011), Grinstein, Kagan, Trott, Zupan (2011), Patal, Sharma (2011), Craig, Kilic, Strassler (2011), Ligeti, Tavares, Schmaltz (2011), Jung, Pierce, Wells (2011), Nelson, Okui, Roy (2011), Duraisamy, Rashed, Datta (2011), Gabrielli, Raidal (2011), Jung, Ko, Lee, Nam (2009), Cao, Heng, Wu, Yang (2010), Cao, McKeen, Rosner, Shaughnessy, Wagner (2010), Jung, Ko, Lee (2010), Choudhury, Godbole, Rindani, Saha(2010), Jung, Ko, Lee, Nam (2010), Delaunay, Gedalia, Hochberg, Perez, Sereq (2011), Gresham, IWK, Zurek (2011), Grinstein, Kagan, Zupan, Trott (2011) ...

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

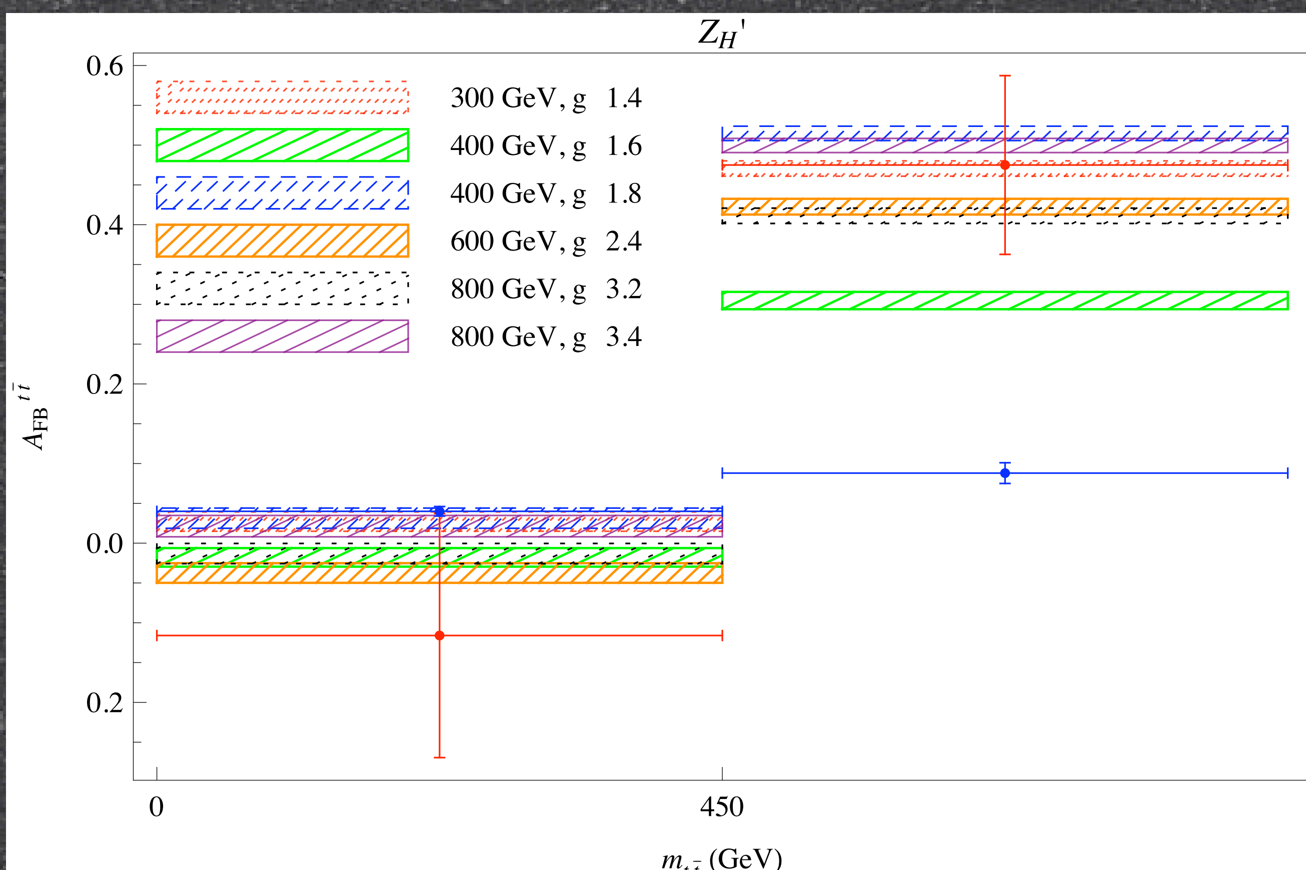
$$\mathcal{A}_{int} = \frac{2g_s^2}{9}\frac{(g_L^2+g_R^2)}{\hat{s}\hat{t}_{Z'}}\left[2\hat{u}_t^2+2\hat{s}m_t^2+\frac{m_t^2}{m_{Z'}^2}(\hat{t}_t^2+\hat{s}m_t^2)\right],$$

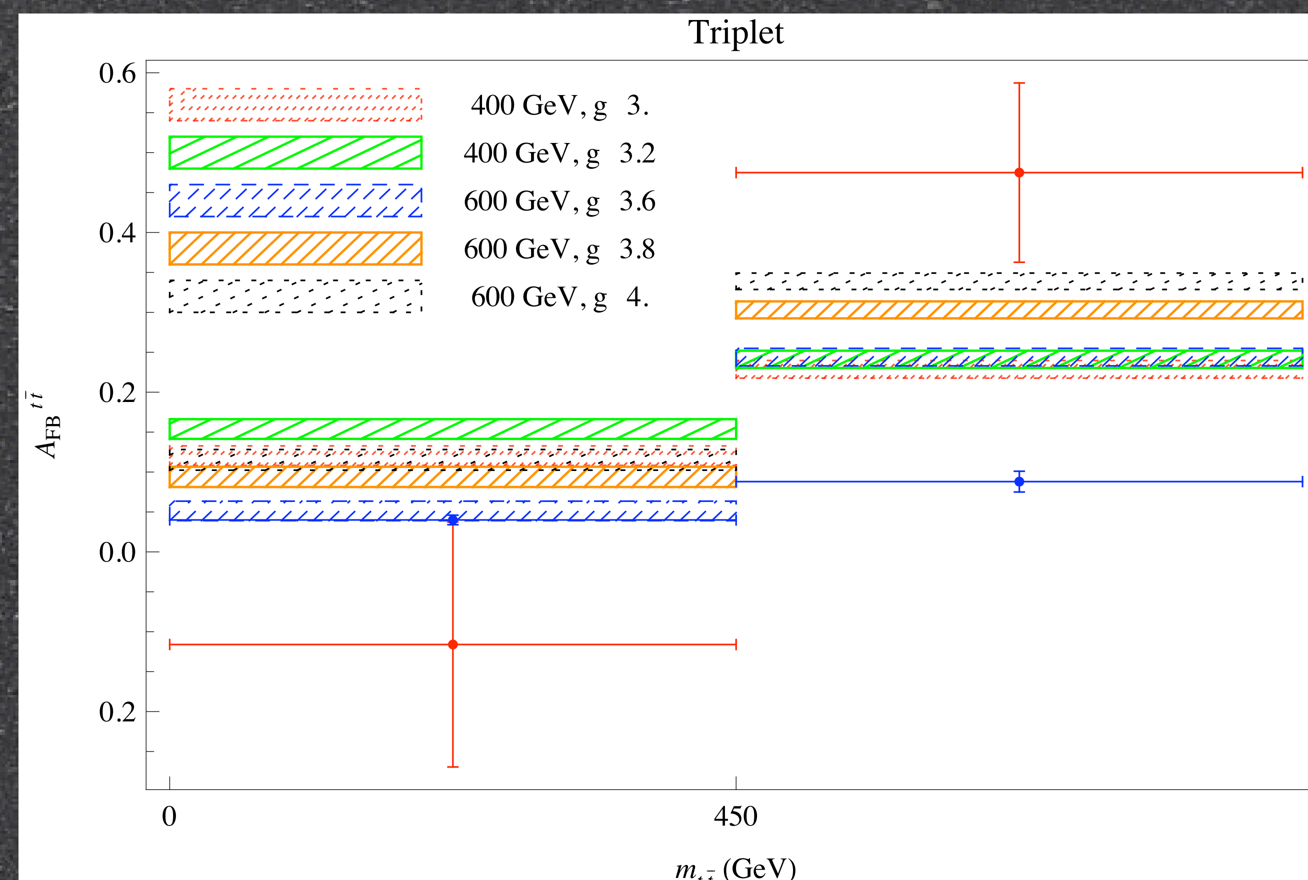
t-channel models

Challenges from the Tevatron

A_{FB}

Gresham, Kim, KZ, 1103.3501



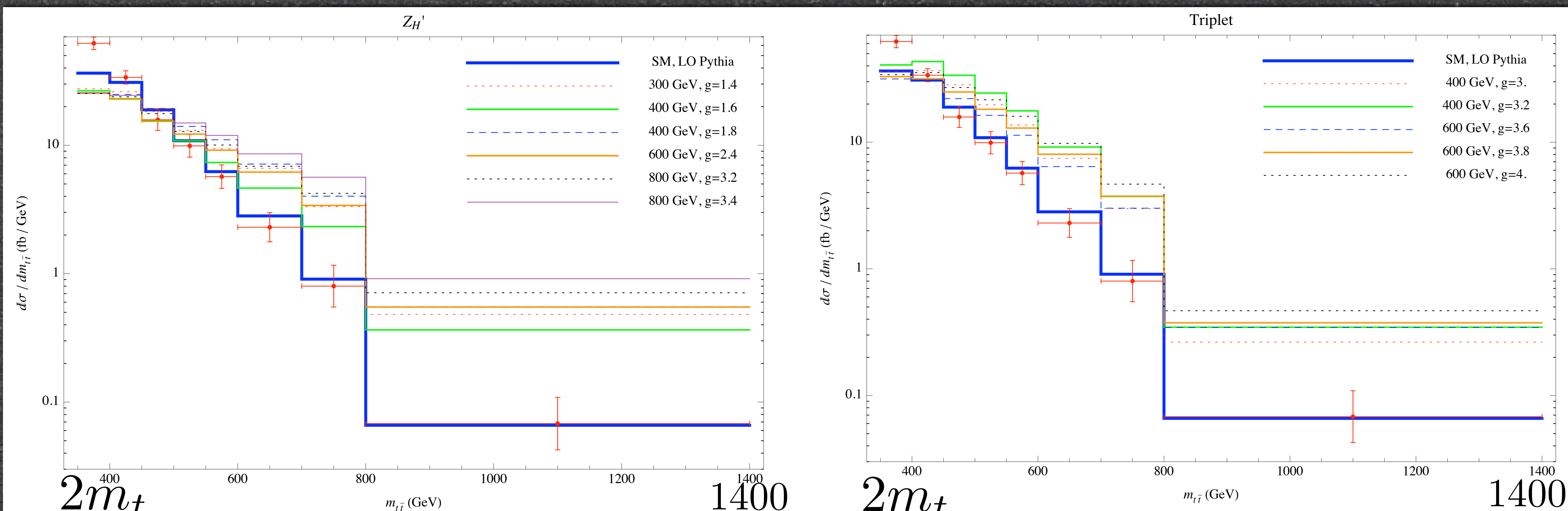


$m_{t\bar{t}}$

Challenges from the Tevatron

$d\sigma/dm_{t\bar{t}}$

Gresham, Kim, KZ, 1103.3501

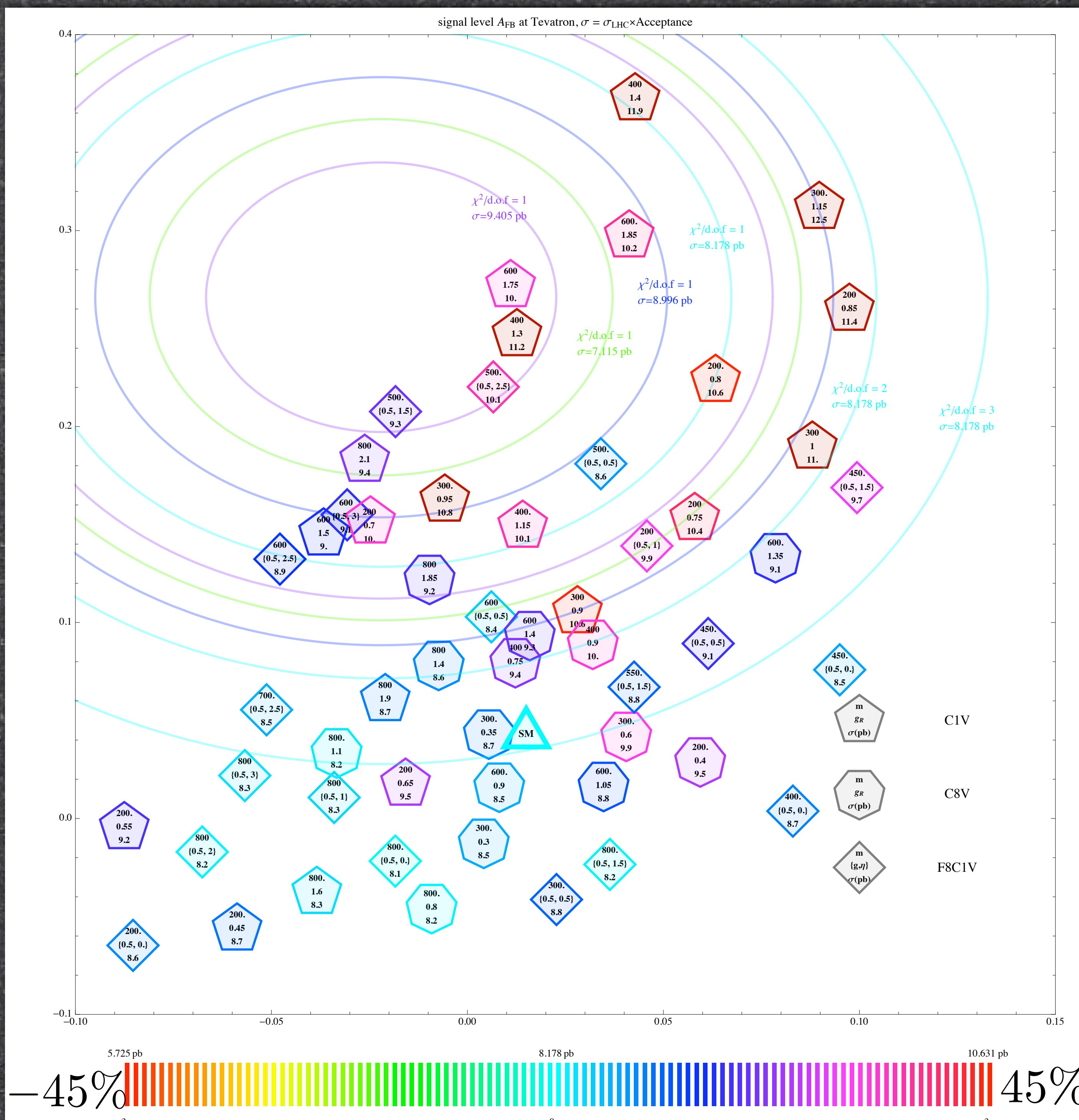


$m_{t\bar{t}}$

More Challenges from LHC

Gresham, Kim, KZ, 1107.4364

$A_{FB}(> 450\ \mathrm{GeV})$



Total Cross-Section

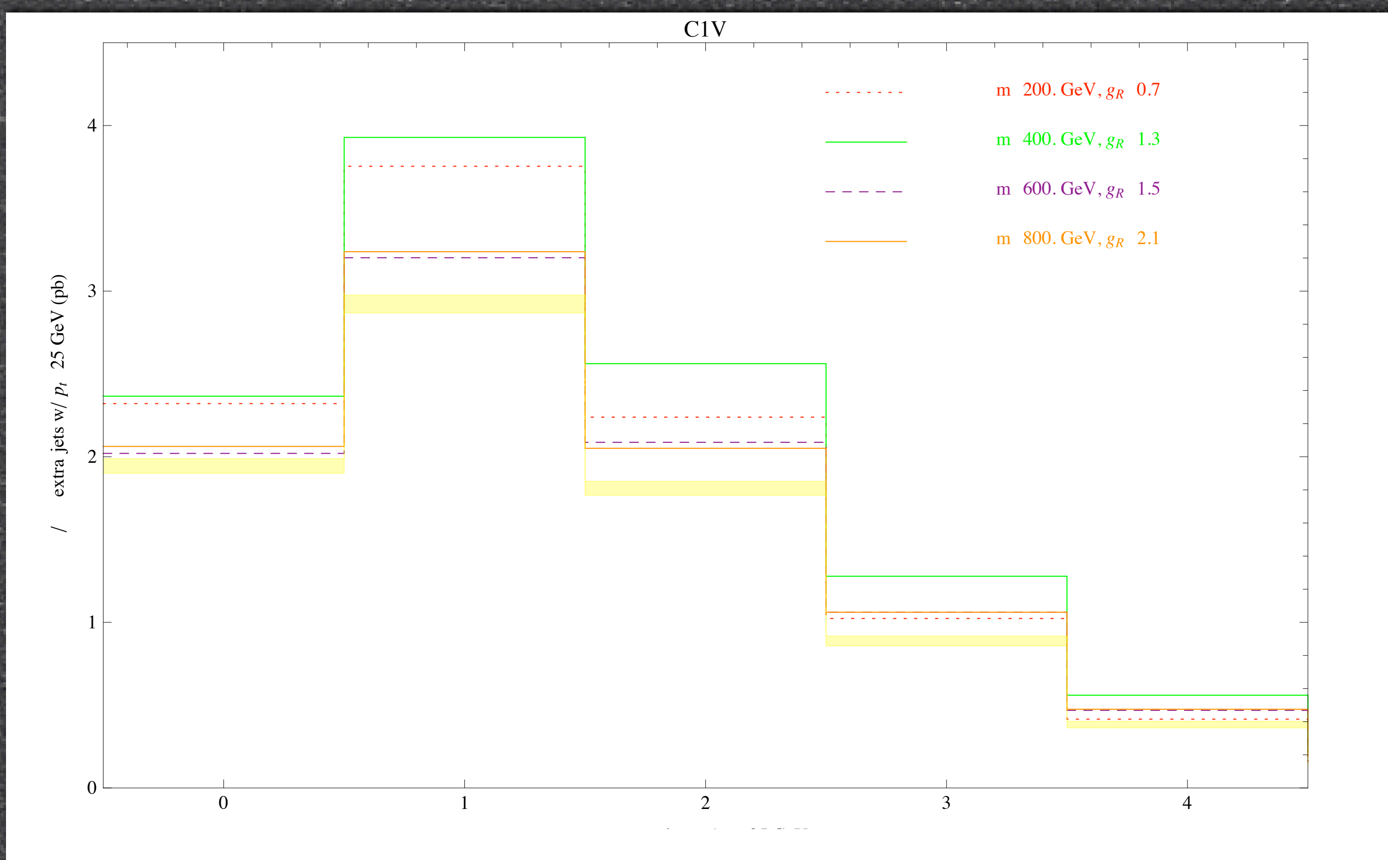
Models which give rise to a large enough AFB for Mtt > 450 GeV also give too large a cross-section

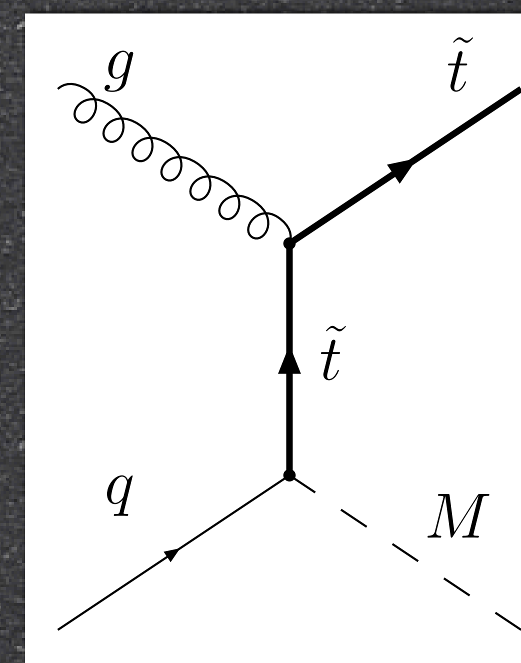
$A_{FB}(< 450\ \mathrm{GeV})$

More Challenges from LHC

Gresham, Kim, KZ, 1107.4364

$d\sigma/dm_{t\bar{t}}$





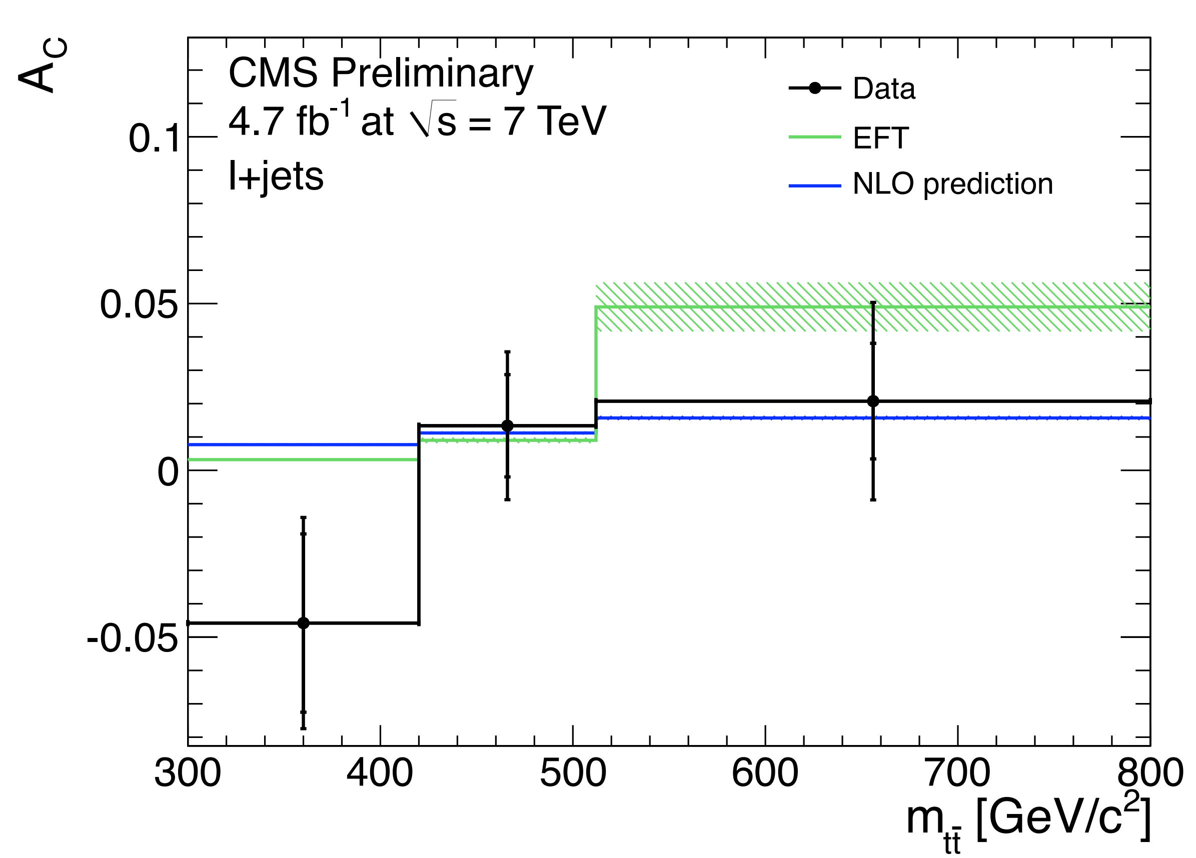
0 4

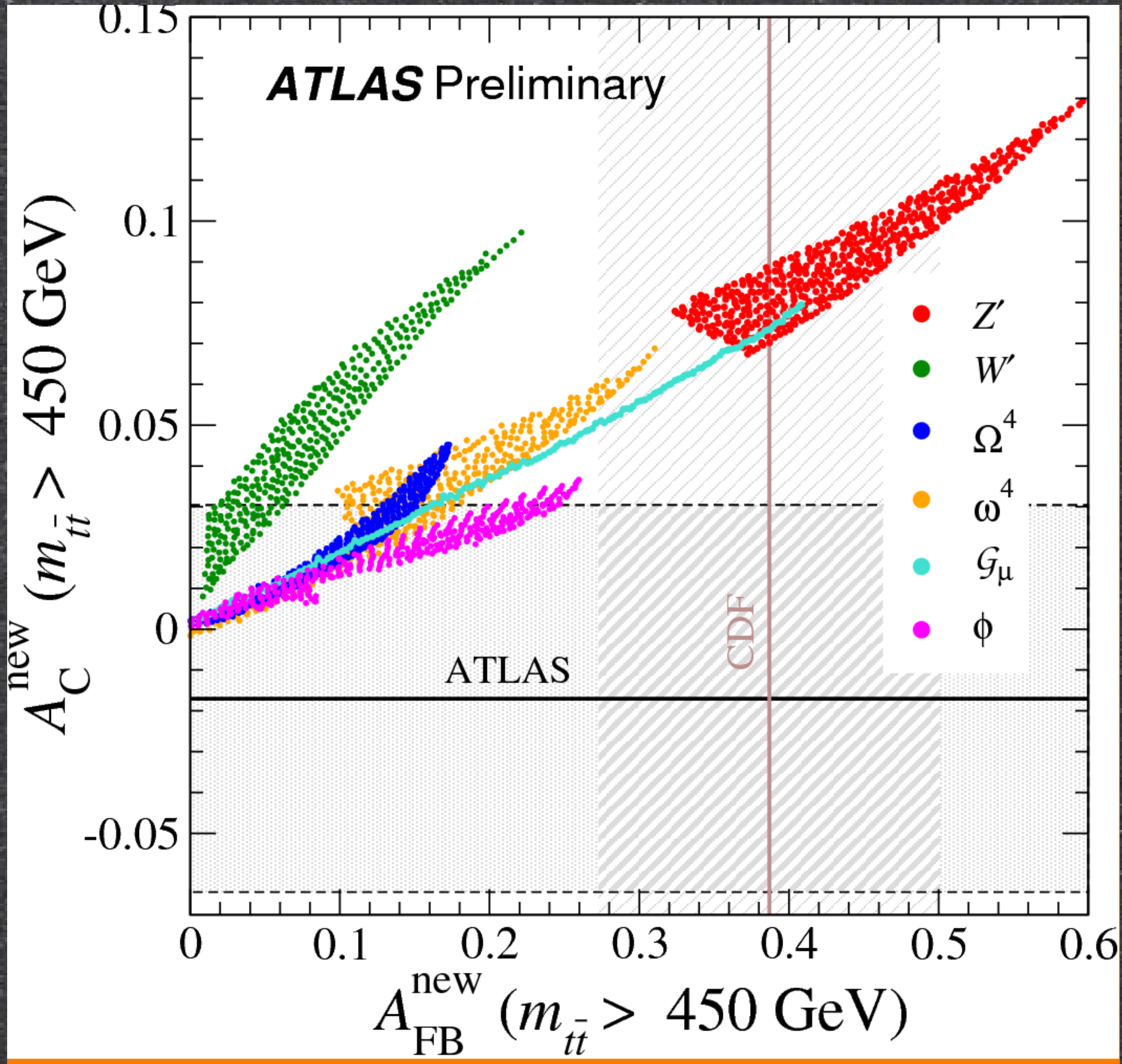
Additional Jets

More Challenges from LHC

Charge Asymmetry

Aguilar-Saavedra and Perez-Victoria



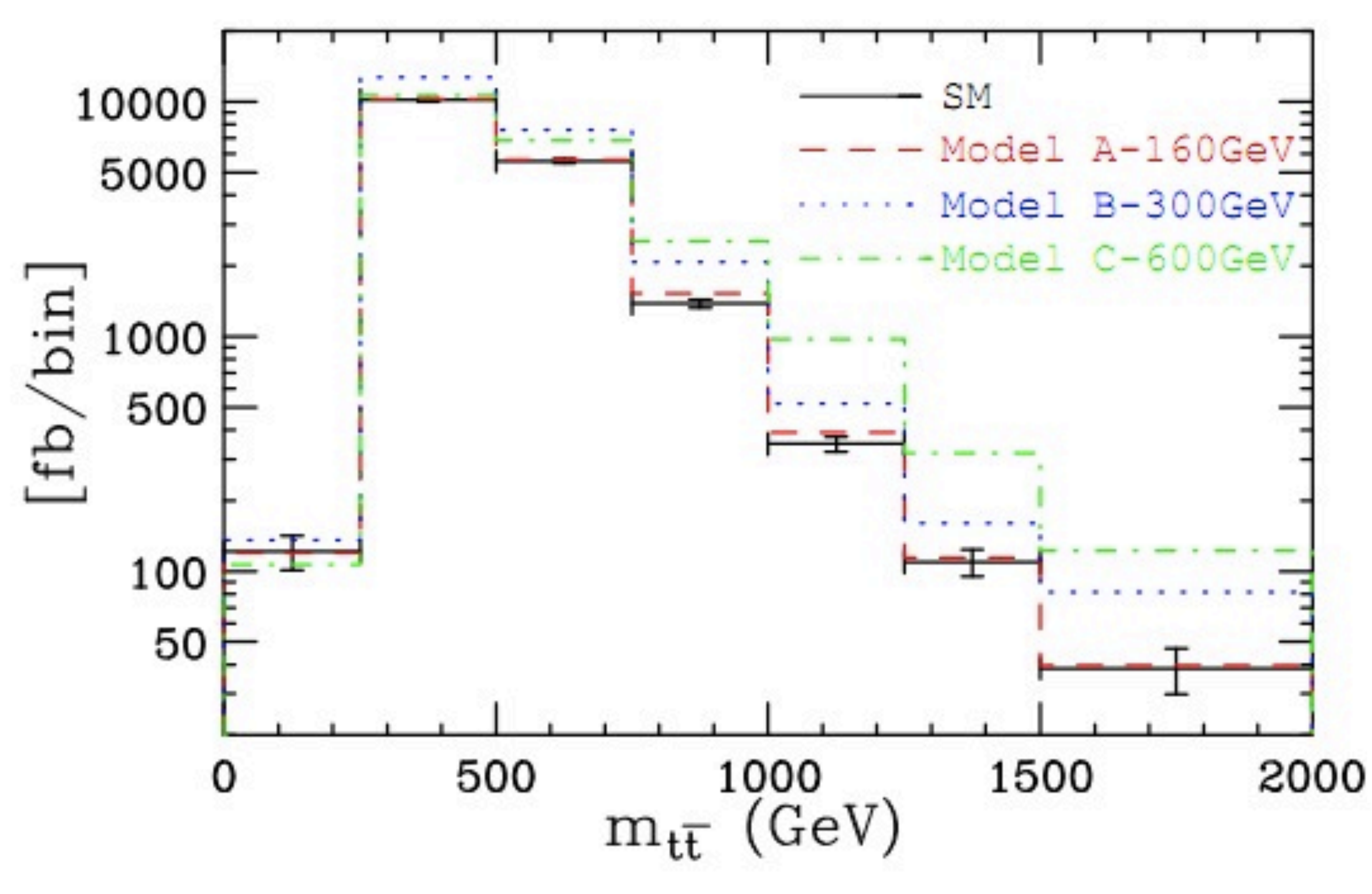


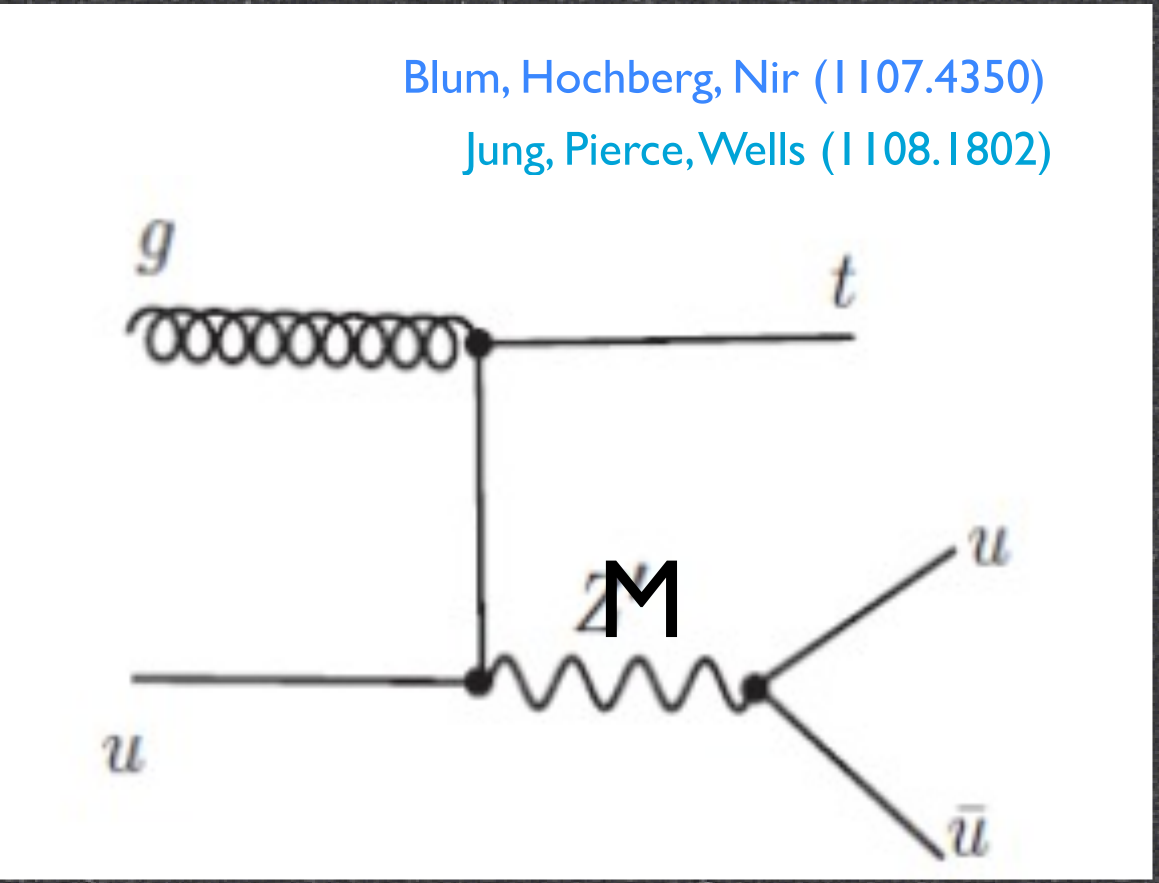
$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$

$$\Delta y = |y_t| - |y_{\bar{t}}|$$

A way out

Make the mediator light

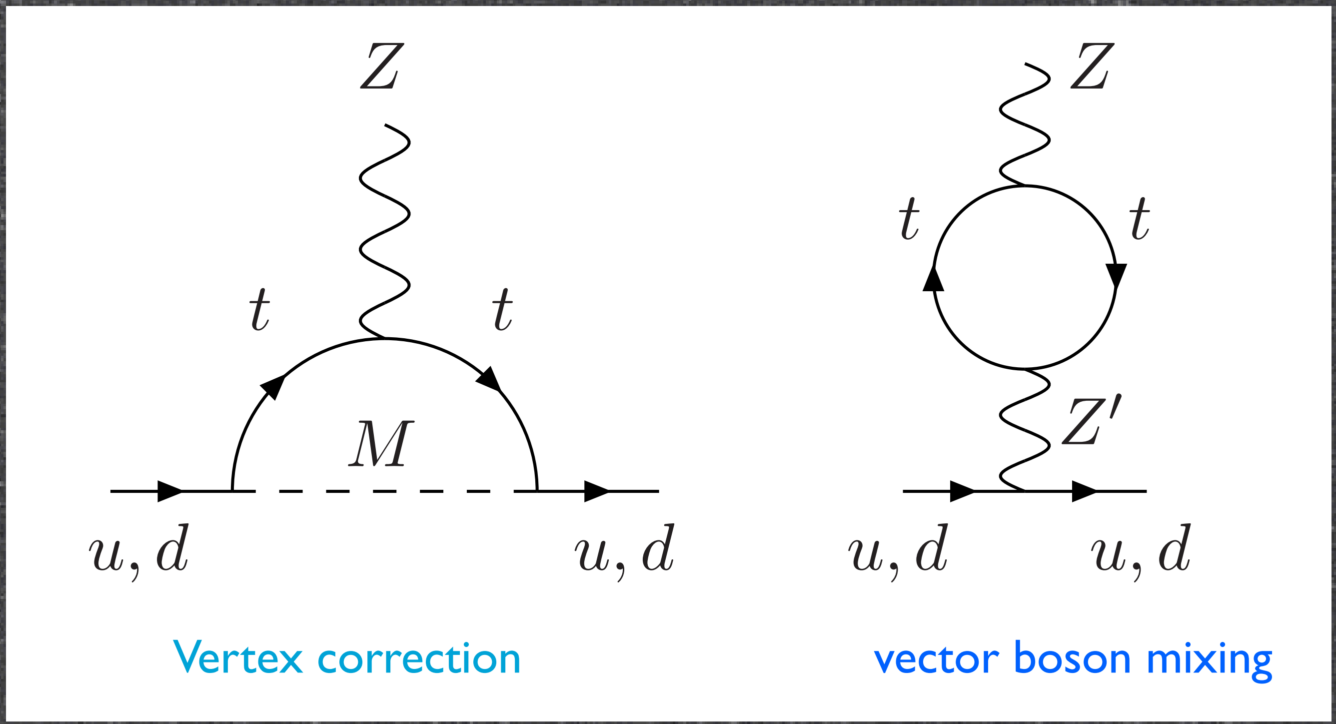


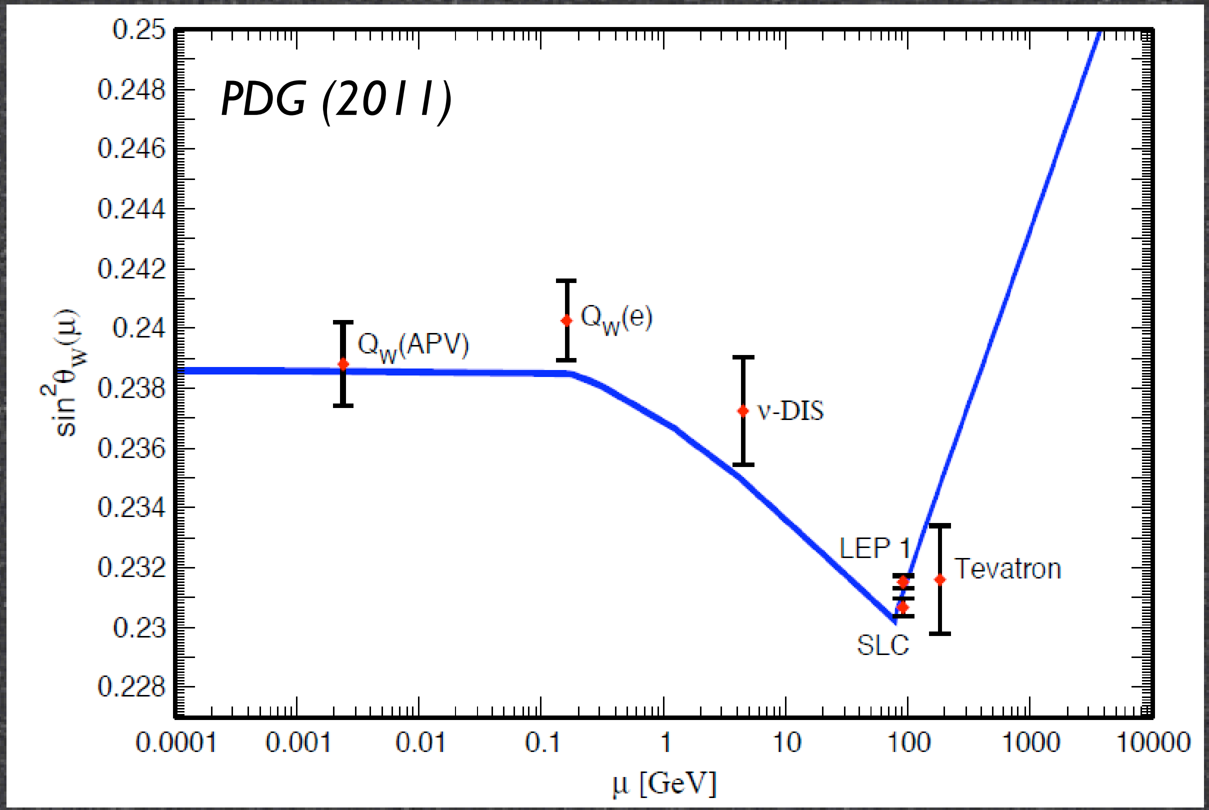


Hidden from ttbar event

Atomic Parity Violation Challenges

Gresham, Kim, Tulin, KZ



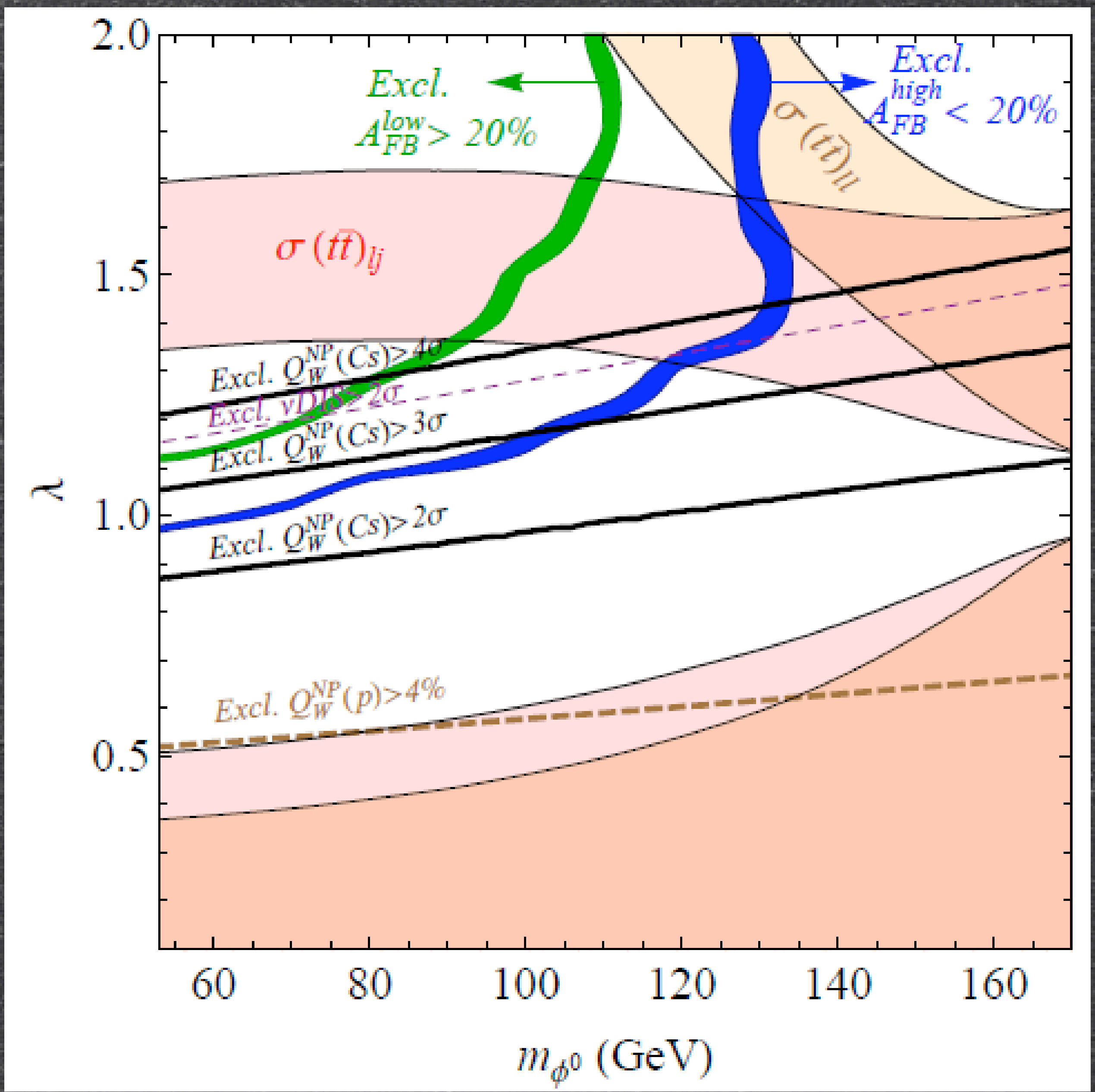


$$\mathscr{L}_{eq}^{PV} = \frac{G_F}{\sqrt{2}} \sum_{q=u,d} \left(C_{1q}\bar{e}\gamma^\mu\gamma_5 e\,\bar{q}\gamma_\mu q + C_{2q}\bar{e}\gamma^\mu e\,\bar{q}\gamma_\mu\gamma_5 q\right)$$

$$Q_W(Z,N) \equiv -2\big[(2Z+N)C_{1u} + (2N+Z)C_{1d}\big]$$

Weak Scalar Doublet Model

Gresham, Kim, Tulin, KZ 1203.1320



$$\lambda\left(\bar{u}_R V_{ib} u_L^i \phi^0 - \bar{u}_R b_L \phi^+\right) + \text{h.c.}$$

Blum, Hochberg, Nir

Provides good fit for mediator mass below 130 GeV

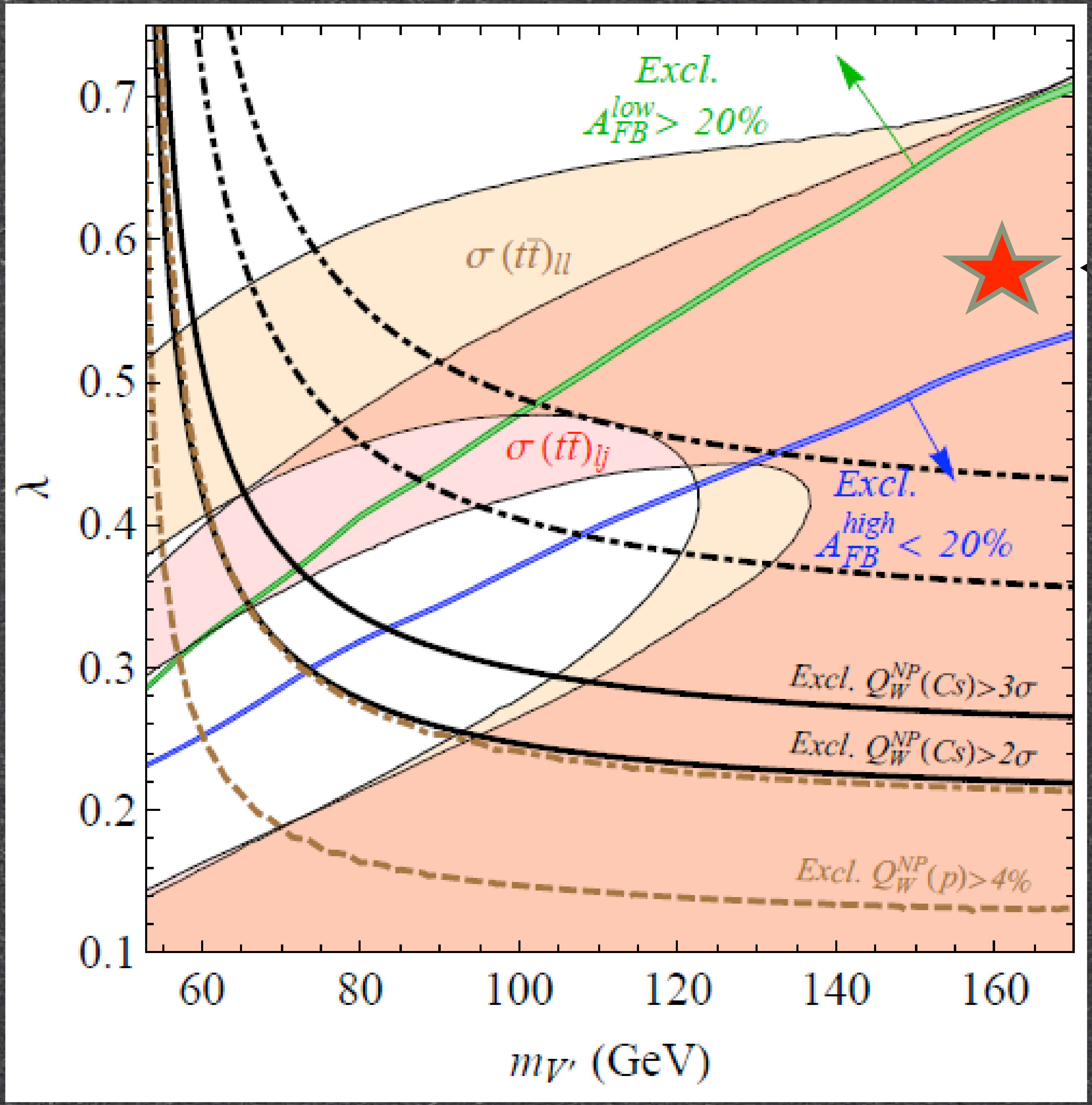
Parity violation at one-loop:

$$a_R^{\rm NP}(u) = \frac{\lambda^2 |V_{tb}|^2 m_t^2}{32\pi^2 \, m_M^2} F(m_t^2/m_M^2)$$

Friday, June 1, 2012

t-channel vectors

Gresham, Kim, Tulin, KZ 1203.1320



Best model point of Jung, Pierce, Wells

Naive calculation

With UV completion

t-channel models conclusion

- Heavy t-channel models challenged by LHC total cross-section and invariant mass distributions
- Light t-channel models challenged by APV
- Easier if asymmetry becomes smaller for Mtt > 450 GeV

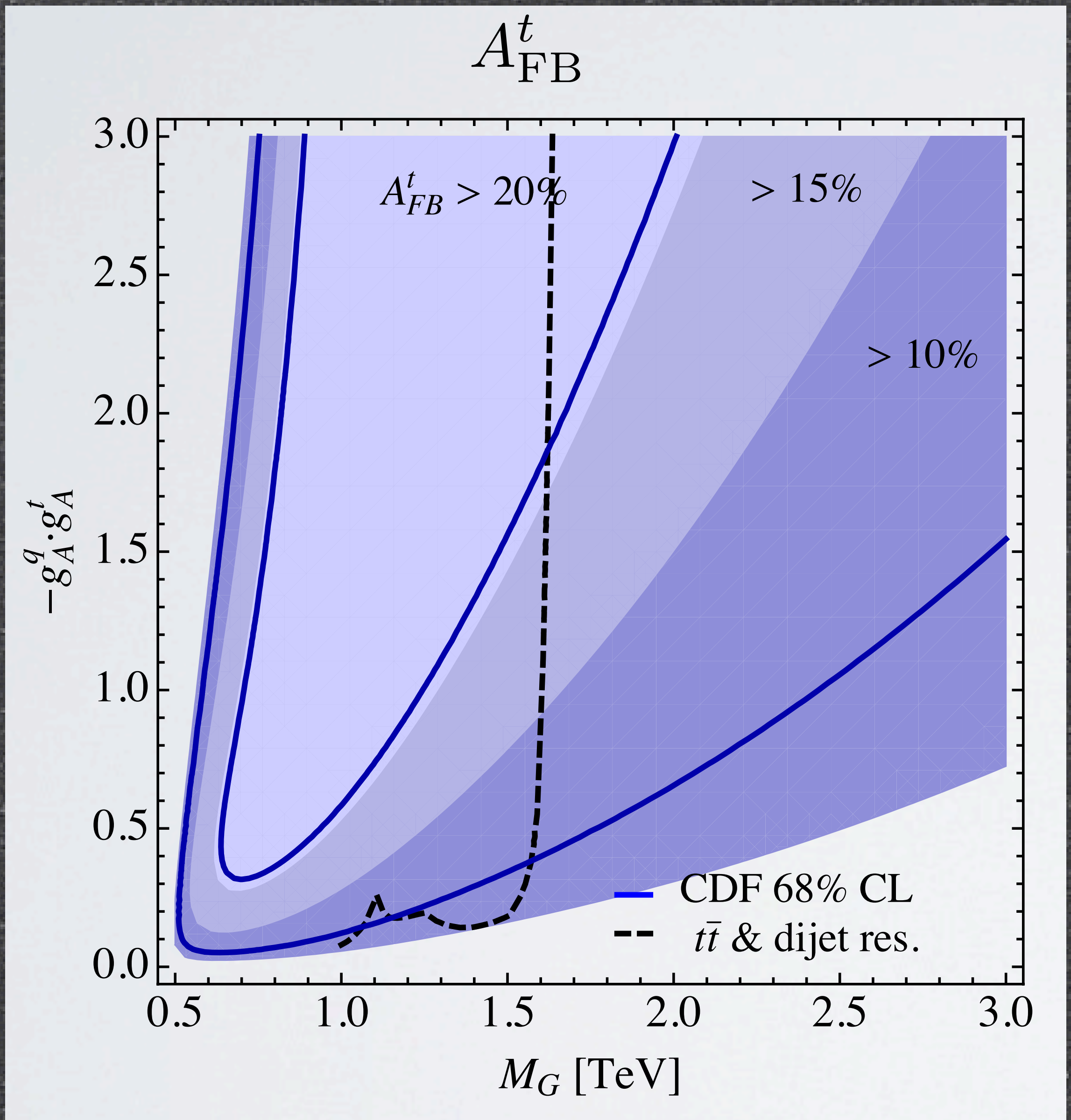
s-channel models

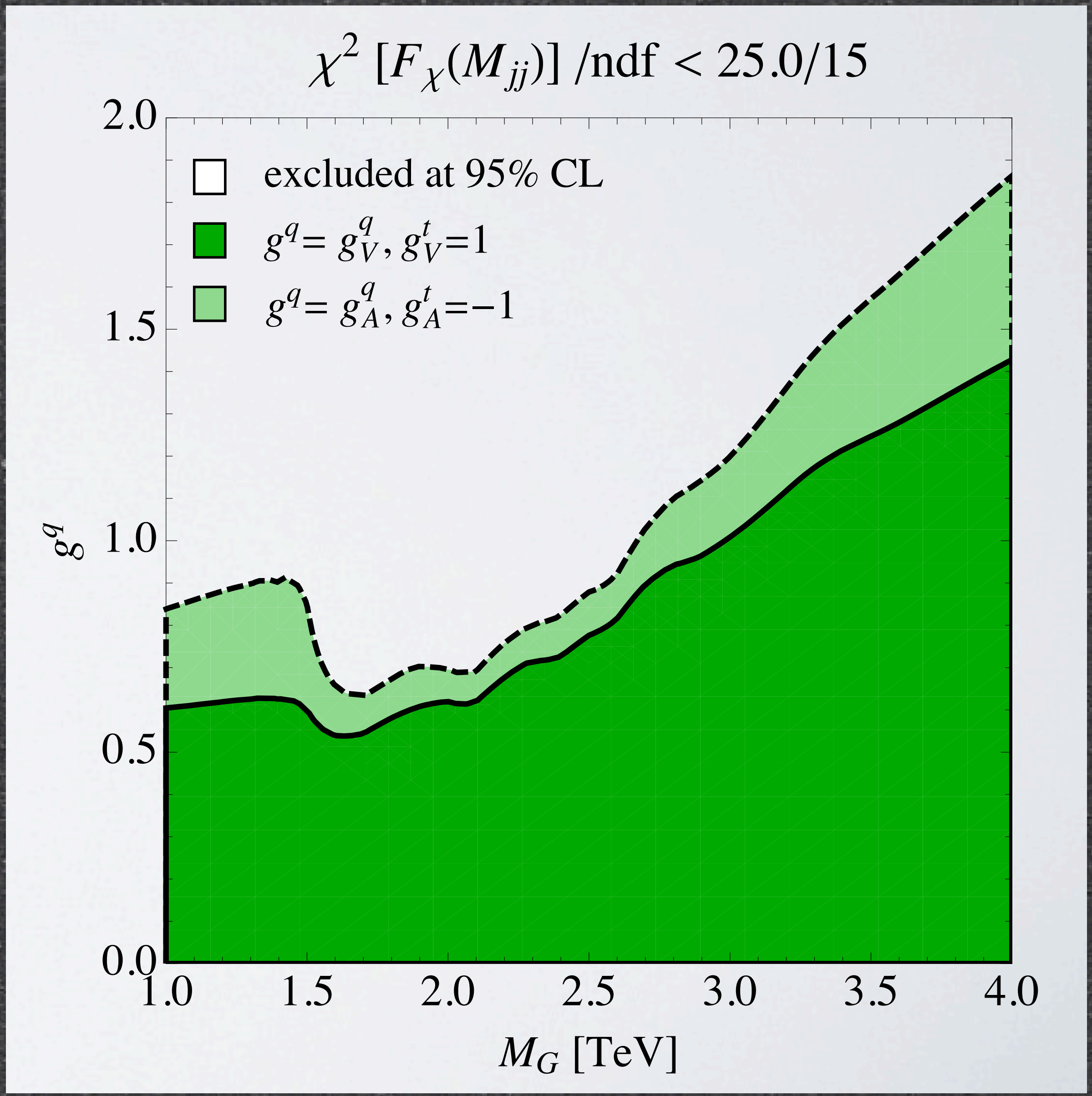
s-channel models

- Again have light-heavy dichotomy
- Opposite sign axial couplings for heavy mediator (m > 2 mt), same sign axial couplings for light mediator

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

Heavy Axiglue LHC tt-bar constraints



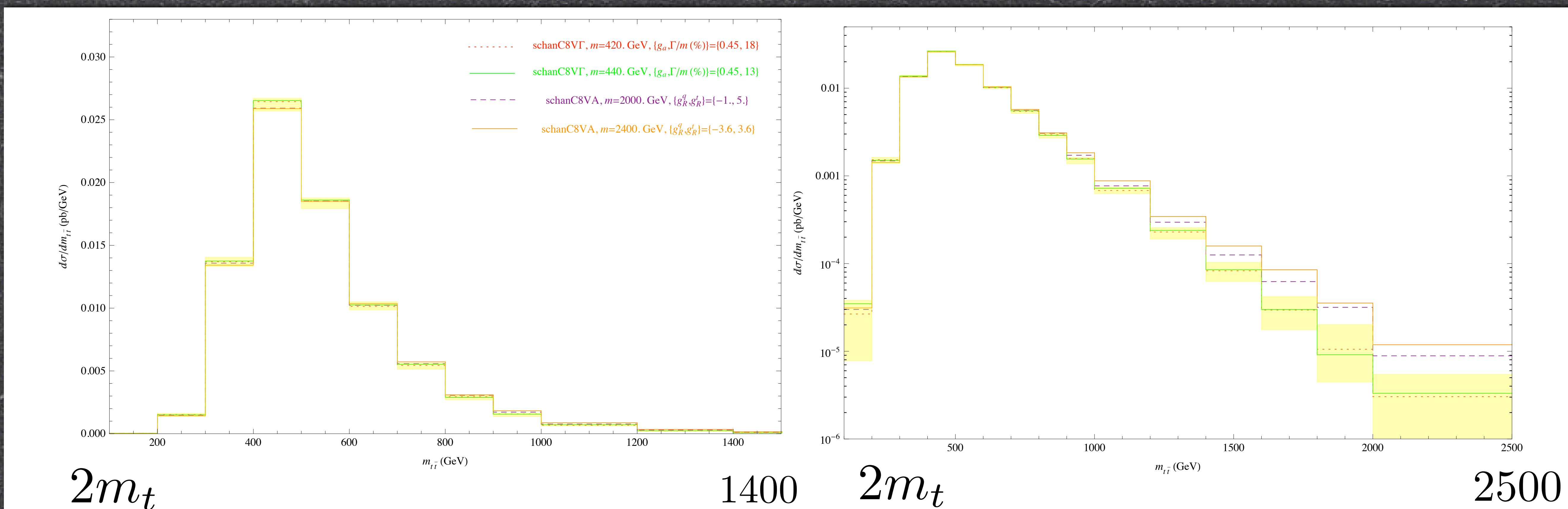


See S. Westhoff talk

Heavy Axiglue LHC tt-bar constraints

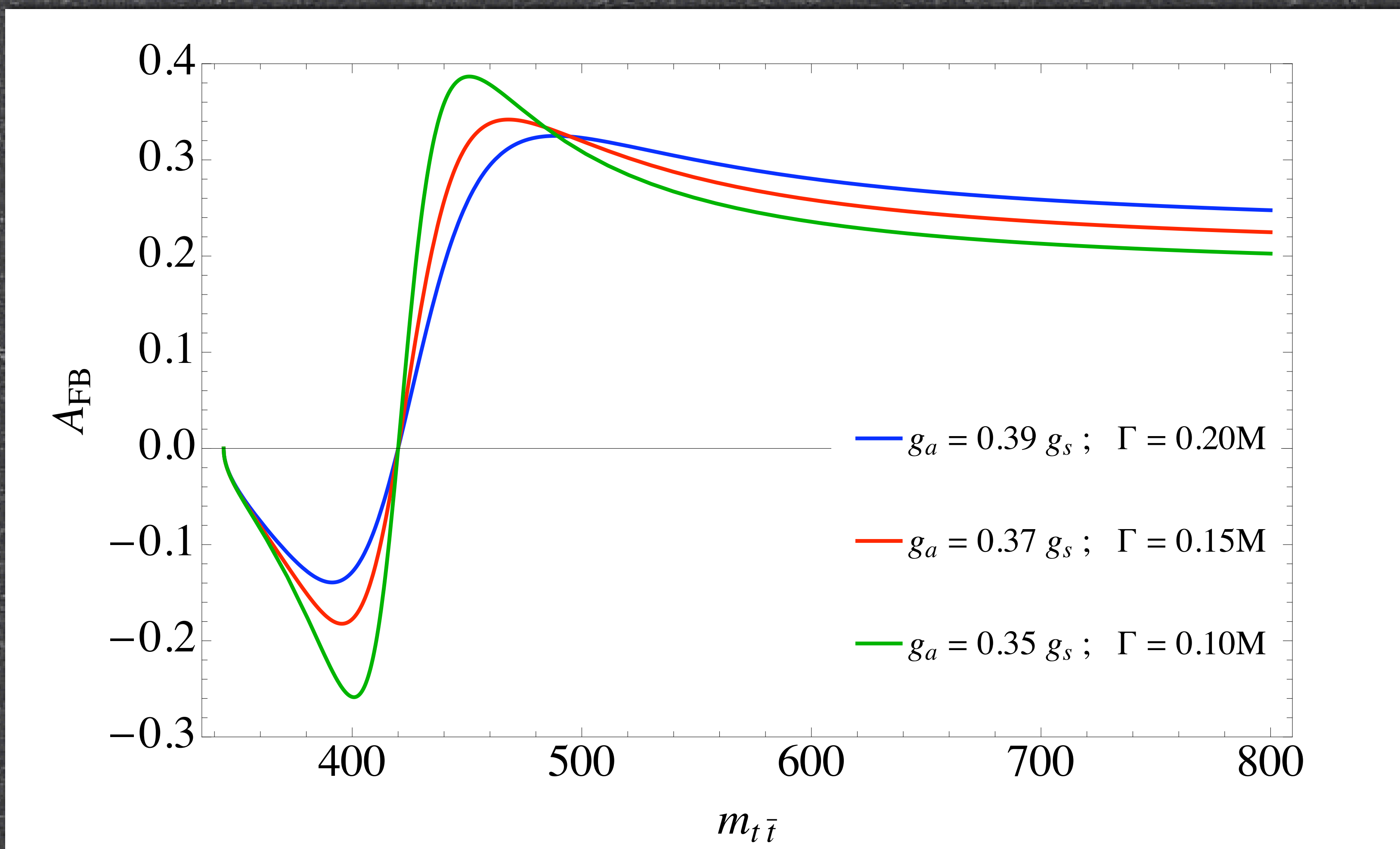
$d\sigma/dm_{t\bar{t}}$

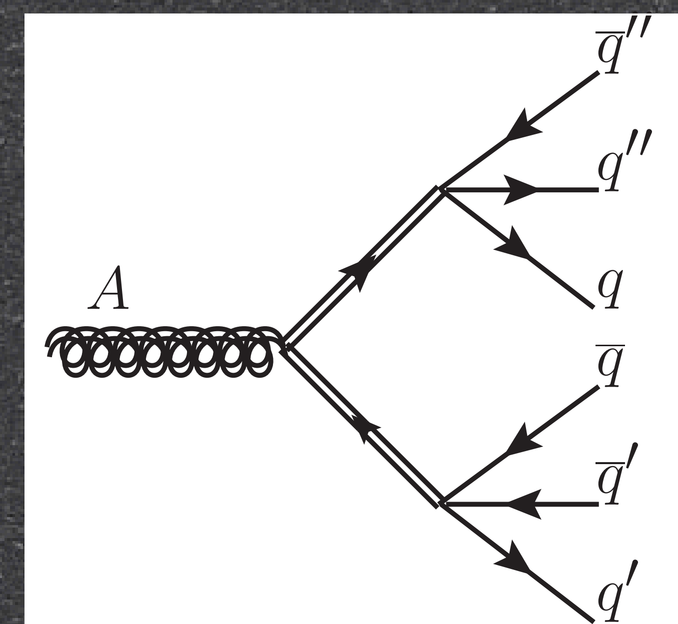
Gresham, Kim, KZ 1107.4364



$m_{t\bar{t}}$

One possible solution: bury it





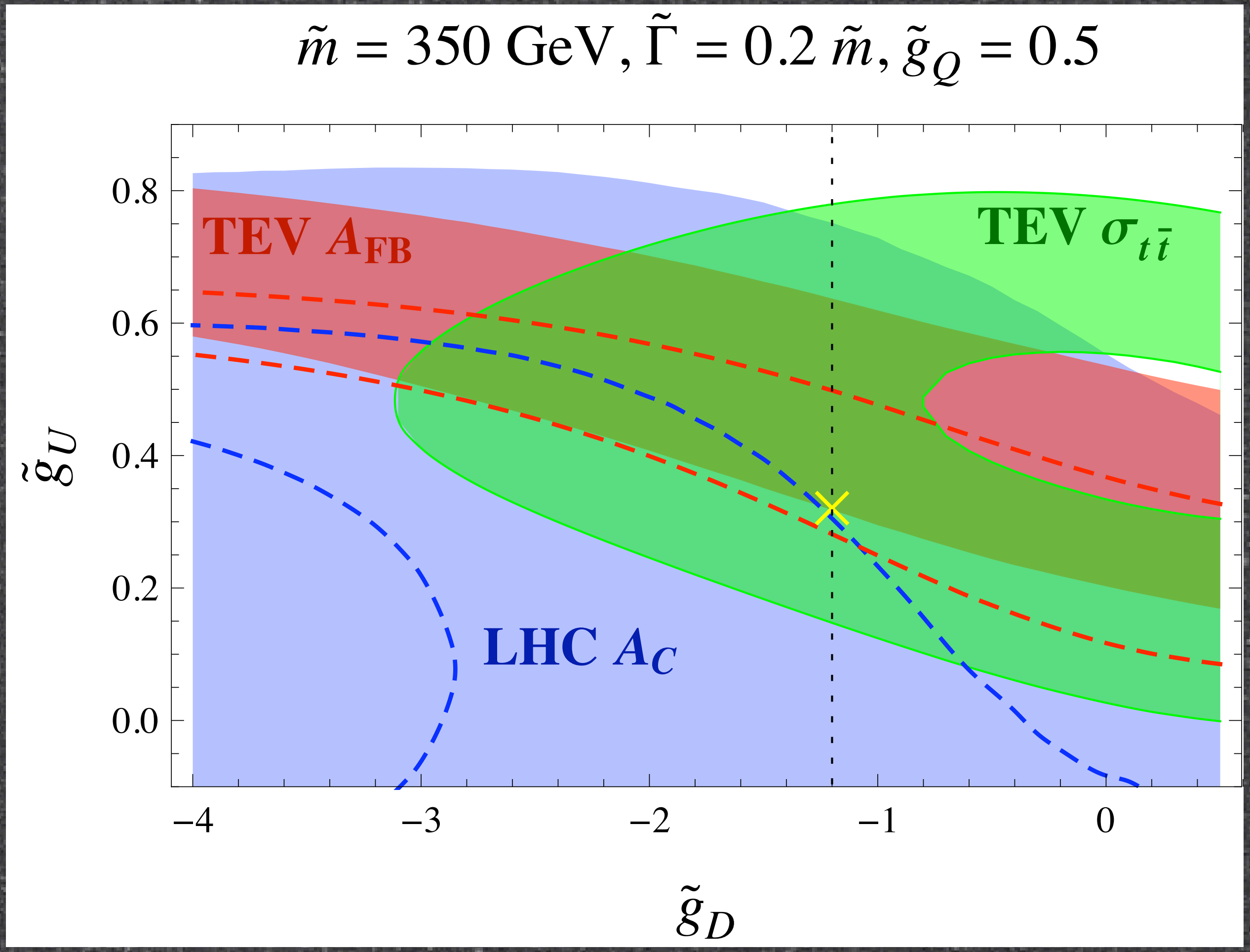
Schmaltz and Tavares

$140\ \text{GeV} < m_D < 170\ \text{GeV}$

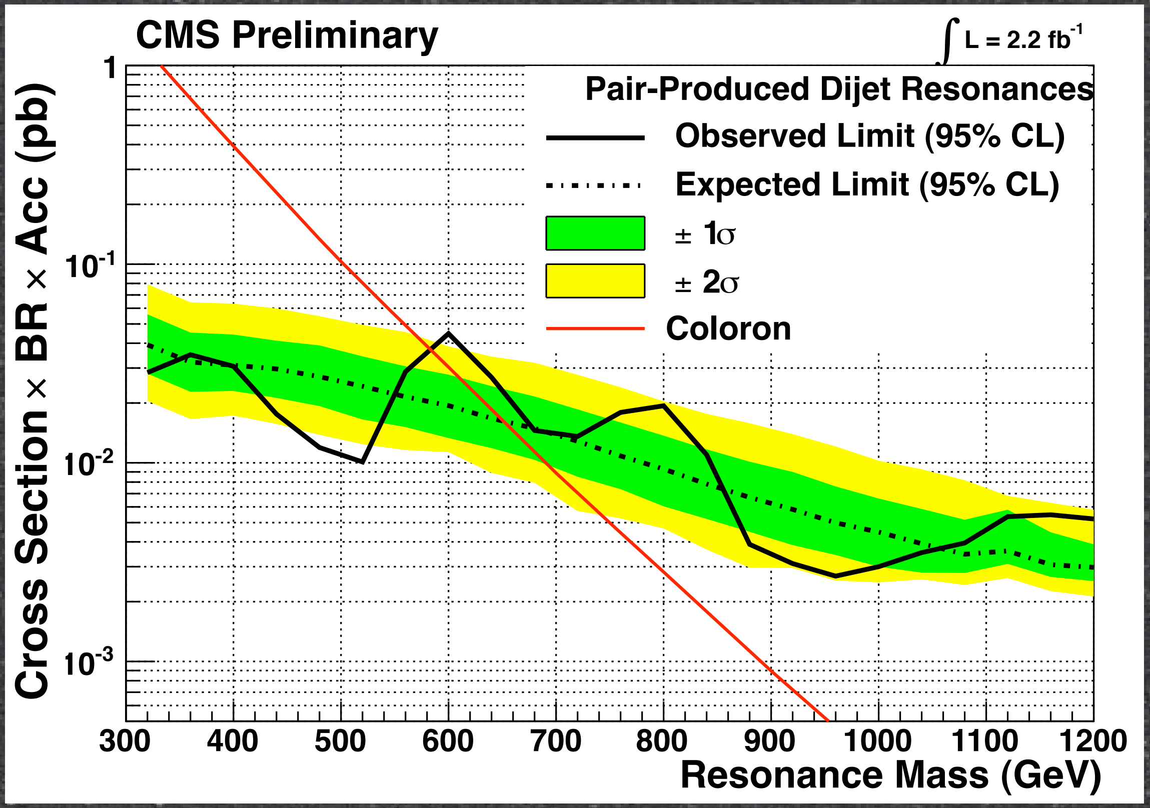
Must reside in particular window to evade RPV searches

Burying it .... continued

Below 2 mt



Can also bury it

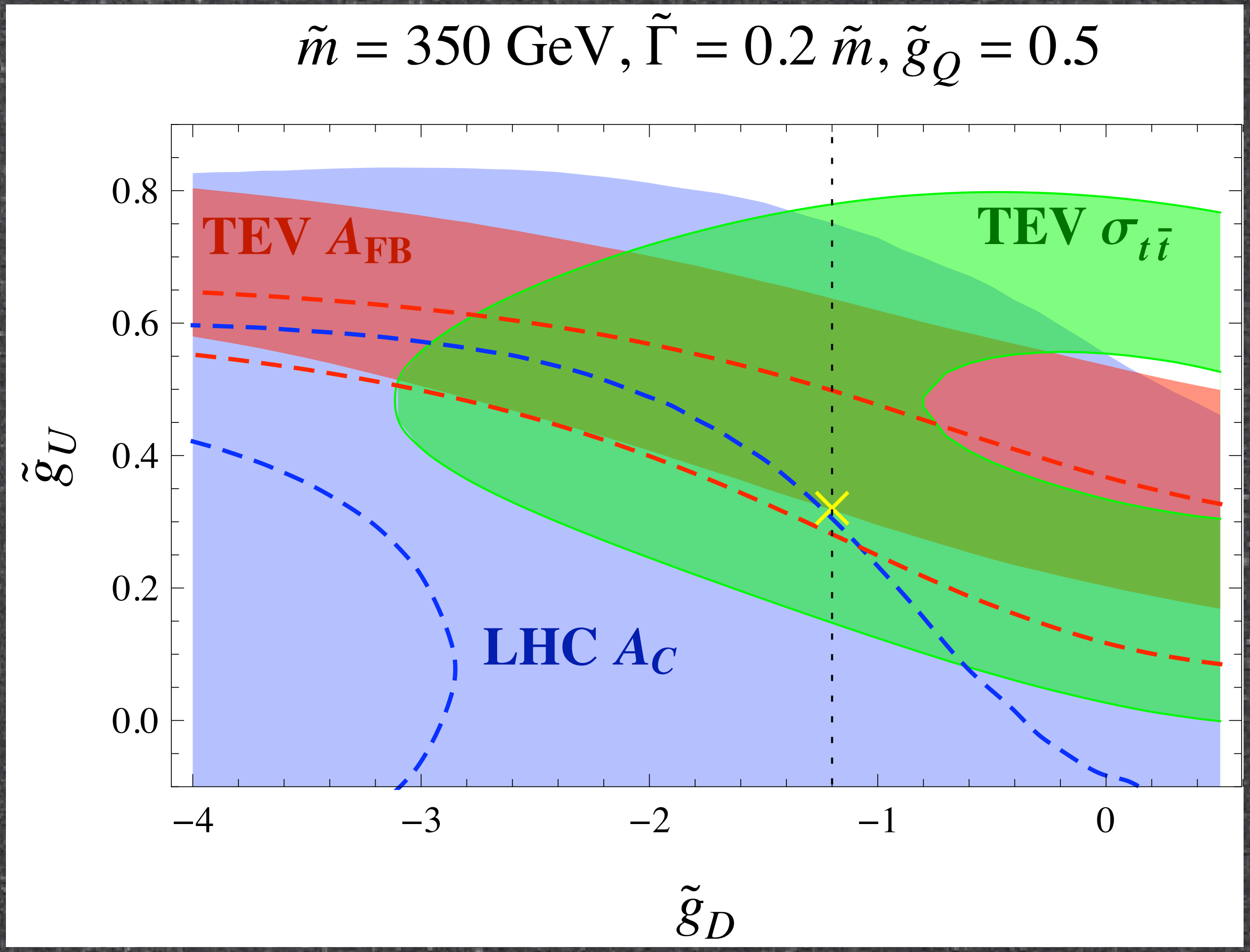


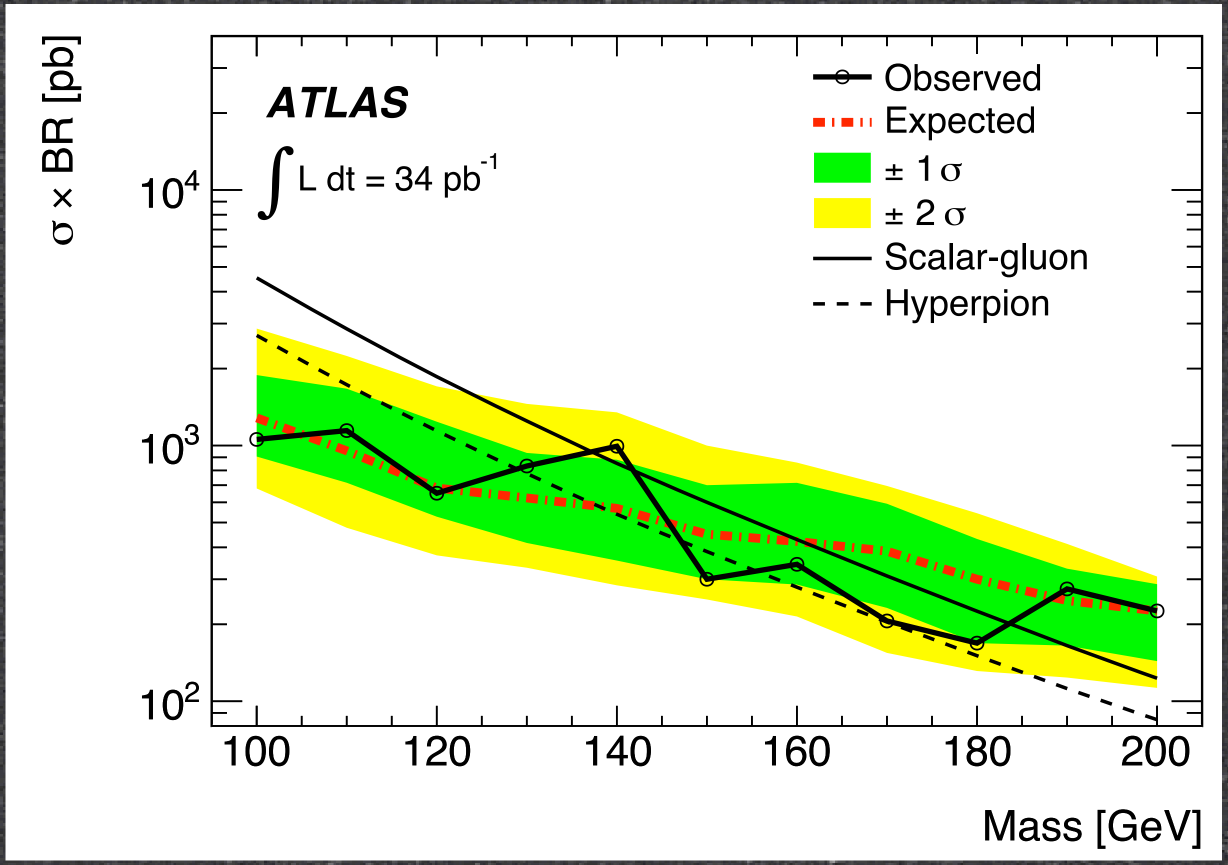
Drobnak, Kamenik, Zupan

Burying it .... continued

Below 2 mt

Can also bury it





Drobnak, Kamenik, Zupan

No current Tevatron limit

Summary

- LHC is squeezing models for AFB
- Seems more favorable to bury models
- In some cases low energy constraints can kill even these models -- for example light t-channel mediator

Summary

- Some window still for light and heavy s-channel states
- Heavy could be excluded by mtt analysis; light could be further constrained by multi-jet analyses
- Need further focus on possible SM explanations