NEW PHYSICS IN TOP PRODUCTION AND DECAY

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U. of Cincinnati

Chicago 2012 workshop on LHC physics, May 2-4, Chicago, IL

OUTLINE

- NP in ttbar production
  - mostly about A_{FB}
- NP in top decays

NP IN TTBAR PRODUCTION

THE PROBLEM

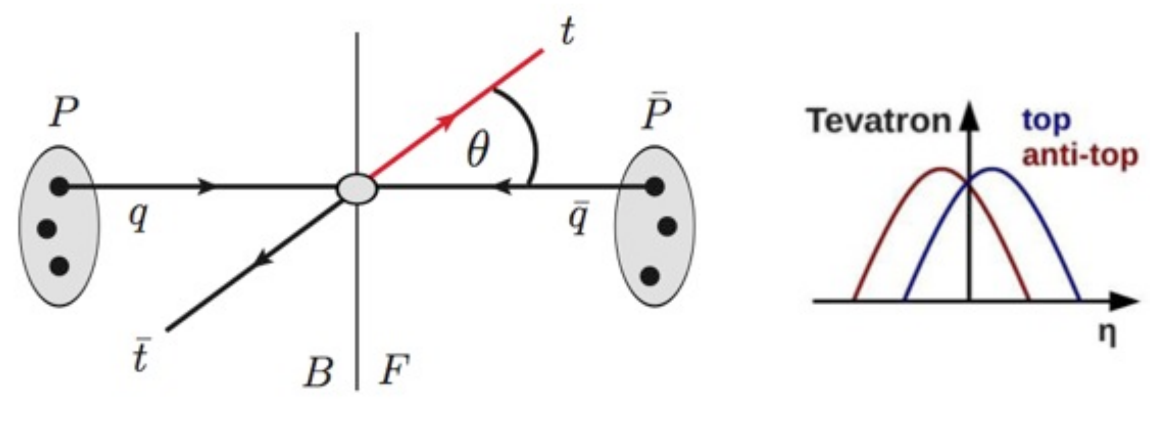
see also talk by Christopher Neu

- indications that $A_{FB}^{t\bar{t}}$ at Tevatron is anomalously large
- charge asymmetry A_C at the LHC in agreement with the SM
  - also other constraints
- does this exclude NP interpretations of A_{FB}^{tt}?

DEFINITIONS

- A_{FB} at Tevatron

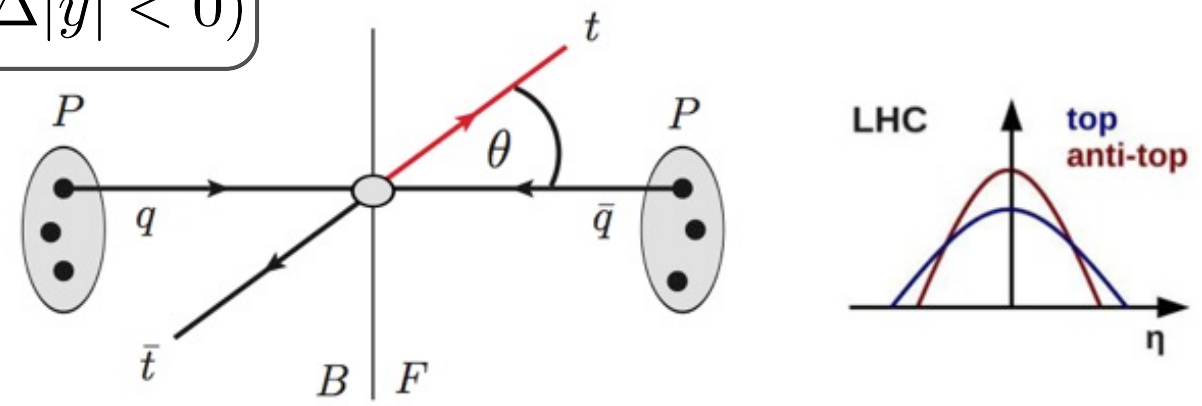
$$A_{FB}^{t\bar{t}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



- A_C at the LHC

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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



ORIGIN OF THE ASYMMETRIES

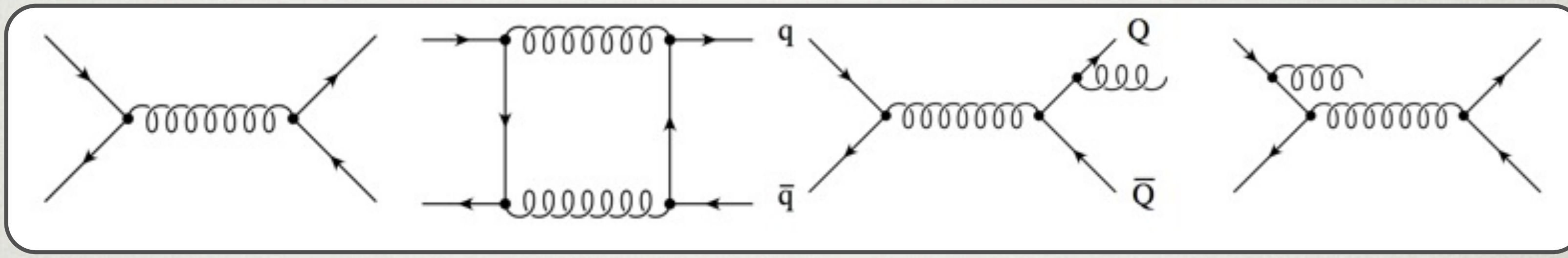
- nonzero A_{FB} and A_C from $(\hat{u}\text{-}\hat{t})$-odd contributions

$$\hat{t}, \hat{u} = m_t^2 - \frac{\hat{s}}{2}[1 \mp \beta_t \cos\theta]$$

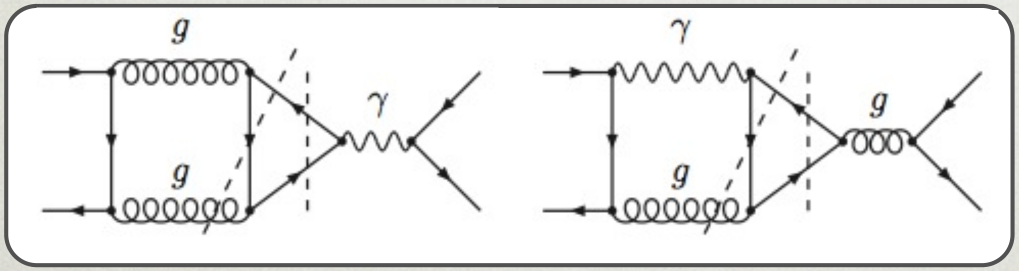
$$\beta_t = \sqrt{1 - \frac{4m_t^2}{\hat{s}}}$$

Kuhn, Rodrigo hep-ph/9802268; hep-ph/9807420
Ahrens et al, 1106.6051

- in QCD at $O(\alpha_S{}^3)$



- additional EW contribs.



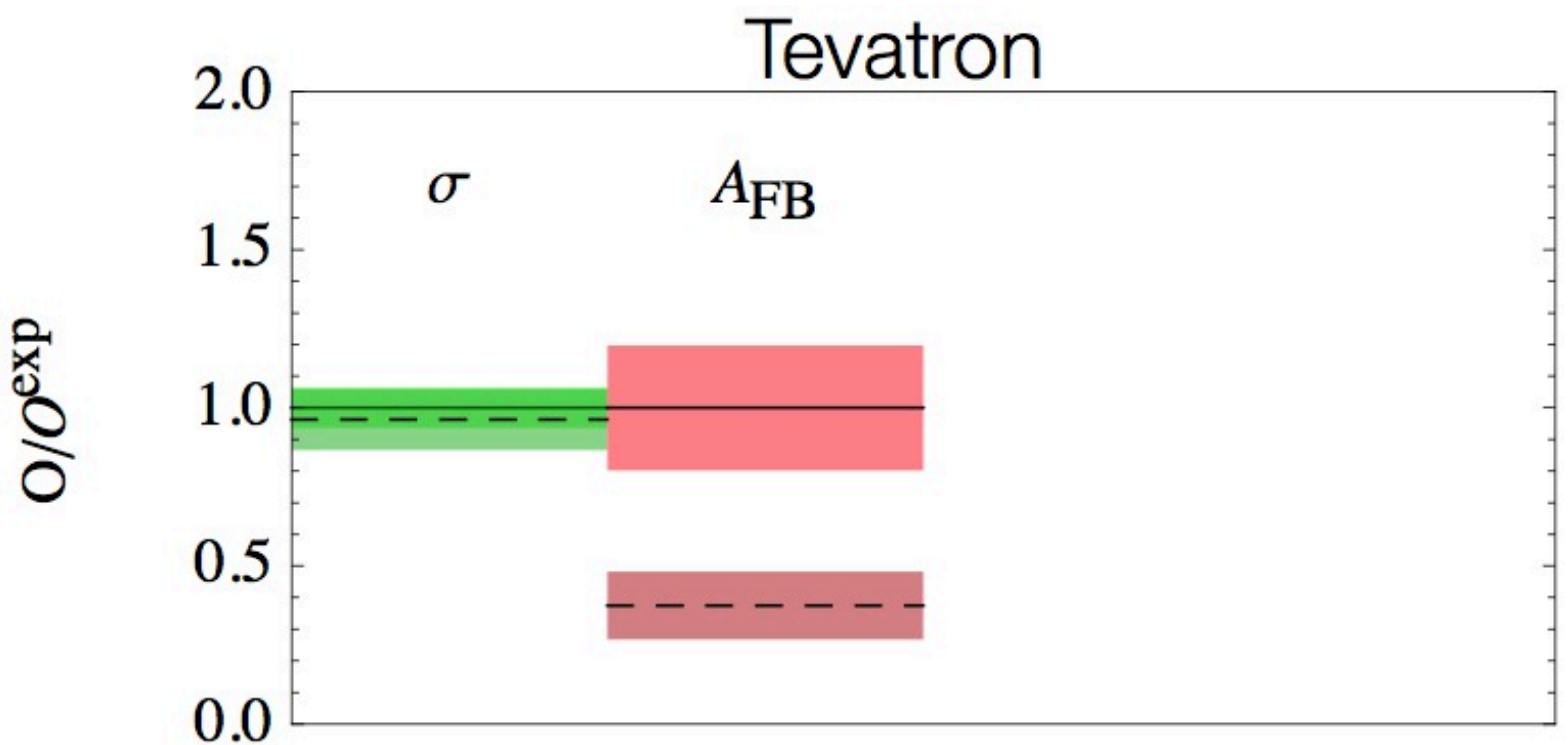
Hollik, Pagani, 1107.2606
Kuhn, Rodrigo, 1109.6830

- SM predictions
  - Tevatron: $(A_{FB})^{SM}$~7-9% ($\bar{q}q$ init. state dominates)
  - LHC: $(A_C)^{SM}$~1% (gg init. state dominates)

MEASUREMENTS

- precisely measured inclusive observables

Kidonakis, 1009.4935; 1105.3481
Beneke et al., 1109.1536



J.Kamenik, talk at DIS2012

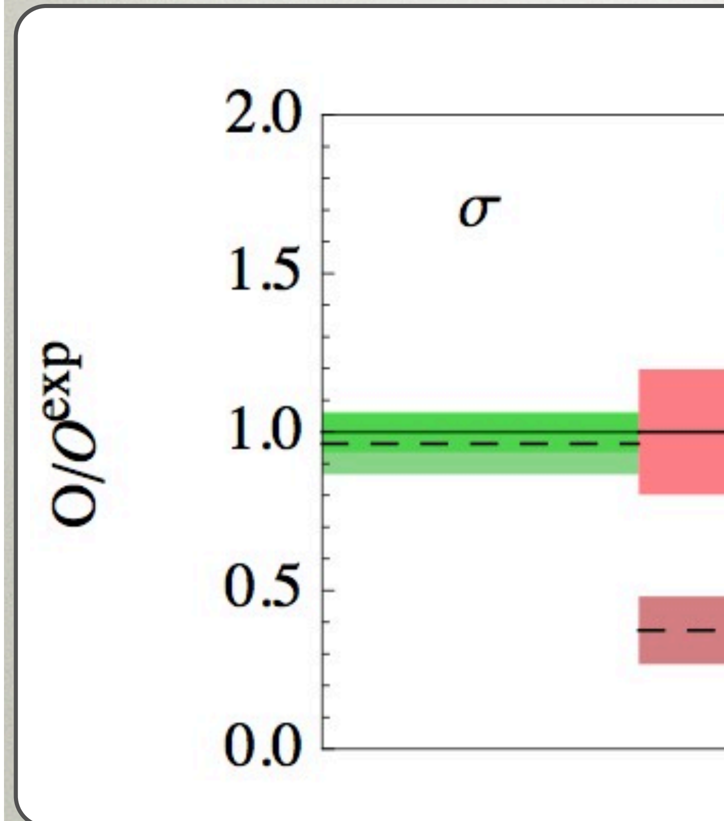
CDF, Public Notes 9913, 10398, 10807
D0, 1107.4995

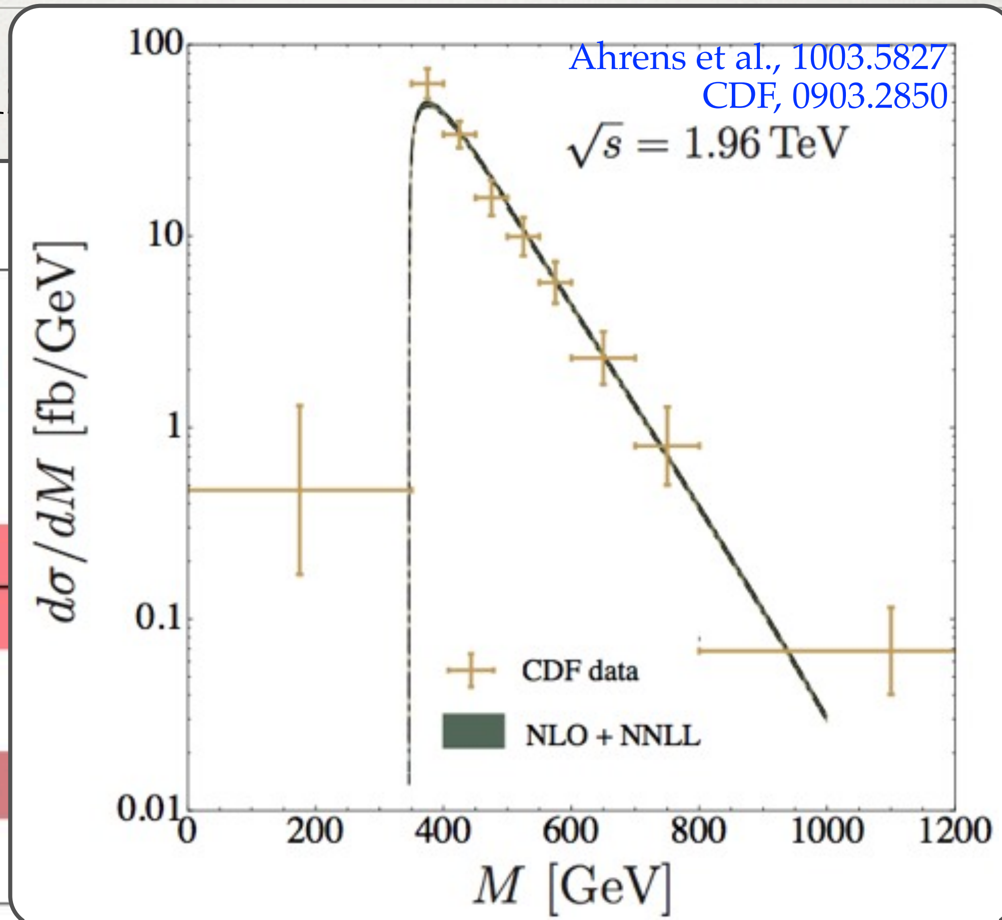
- σ=(7.50±0.48)pb A_{FB}=0.187±0.037*

*naive average of CDF&D0

MEASUREMENTS

- precisely mea





Ahrens et al., 1003.5827
CDF, 0903.2850

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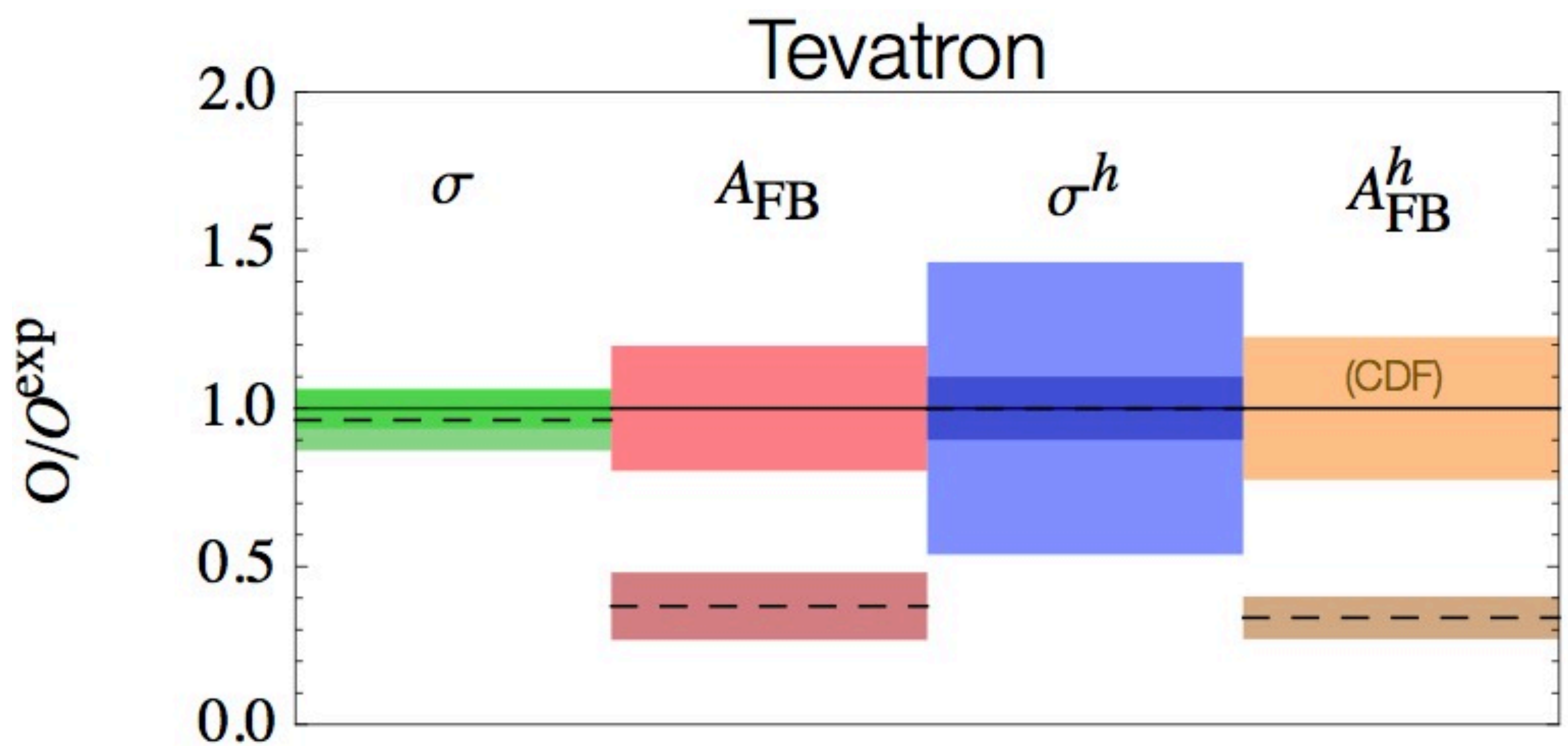

J.Kamenik, talk at DIS2012

- exclusive m_{tt} observables sensitive to NP
  - $\sigma^h = \sigma(700\mathrm{GeV} < m_{tt} < 800\mathrm{GeV})$ $\quad A_{FB}{}^h = A_{FB}(m_{tt} > 450\mathrm{GeV})$

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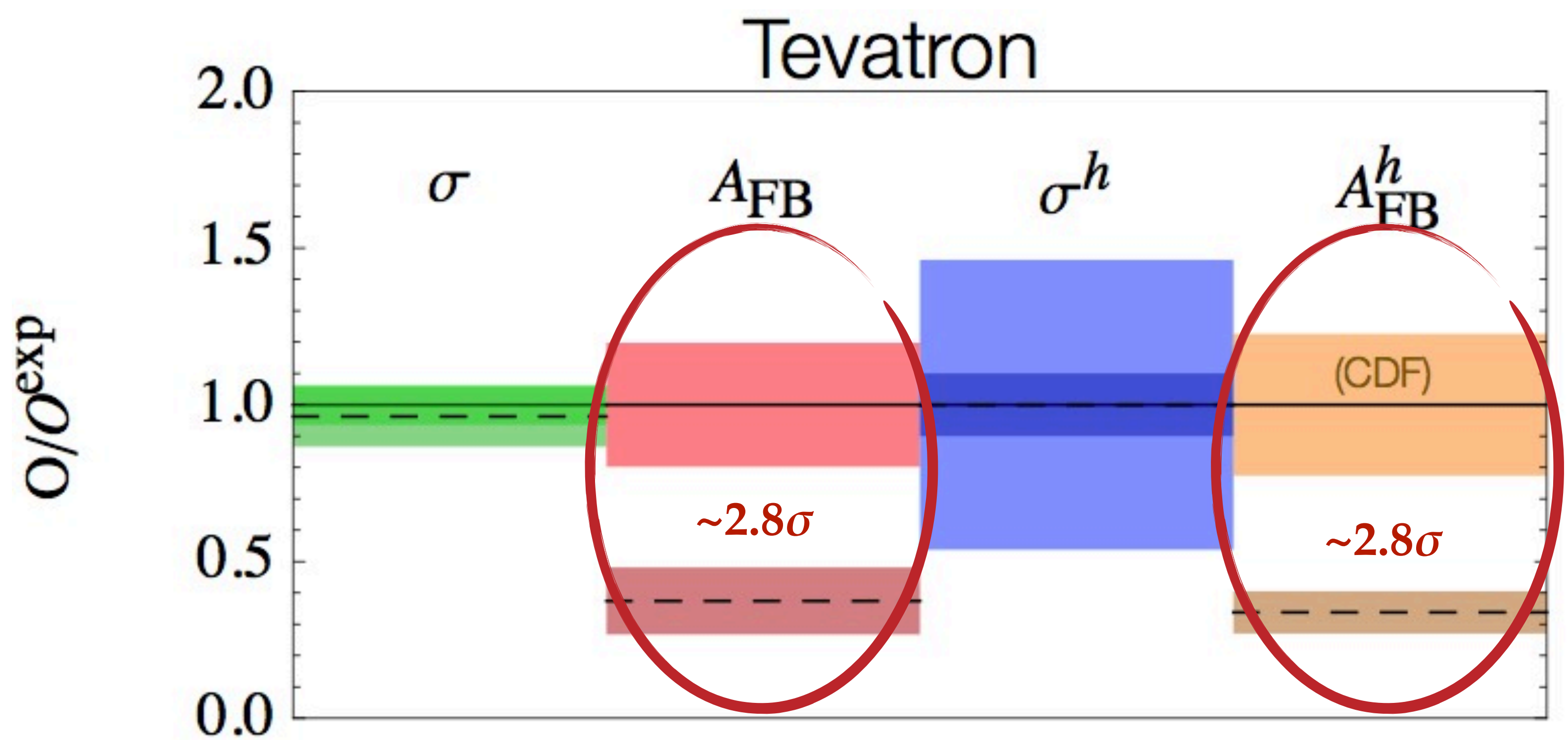

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MEASUREMENTS

- charge asymmetries at Tevatron vs. LHC

Kidonakis, 1009.4935; 1105.3481
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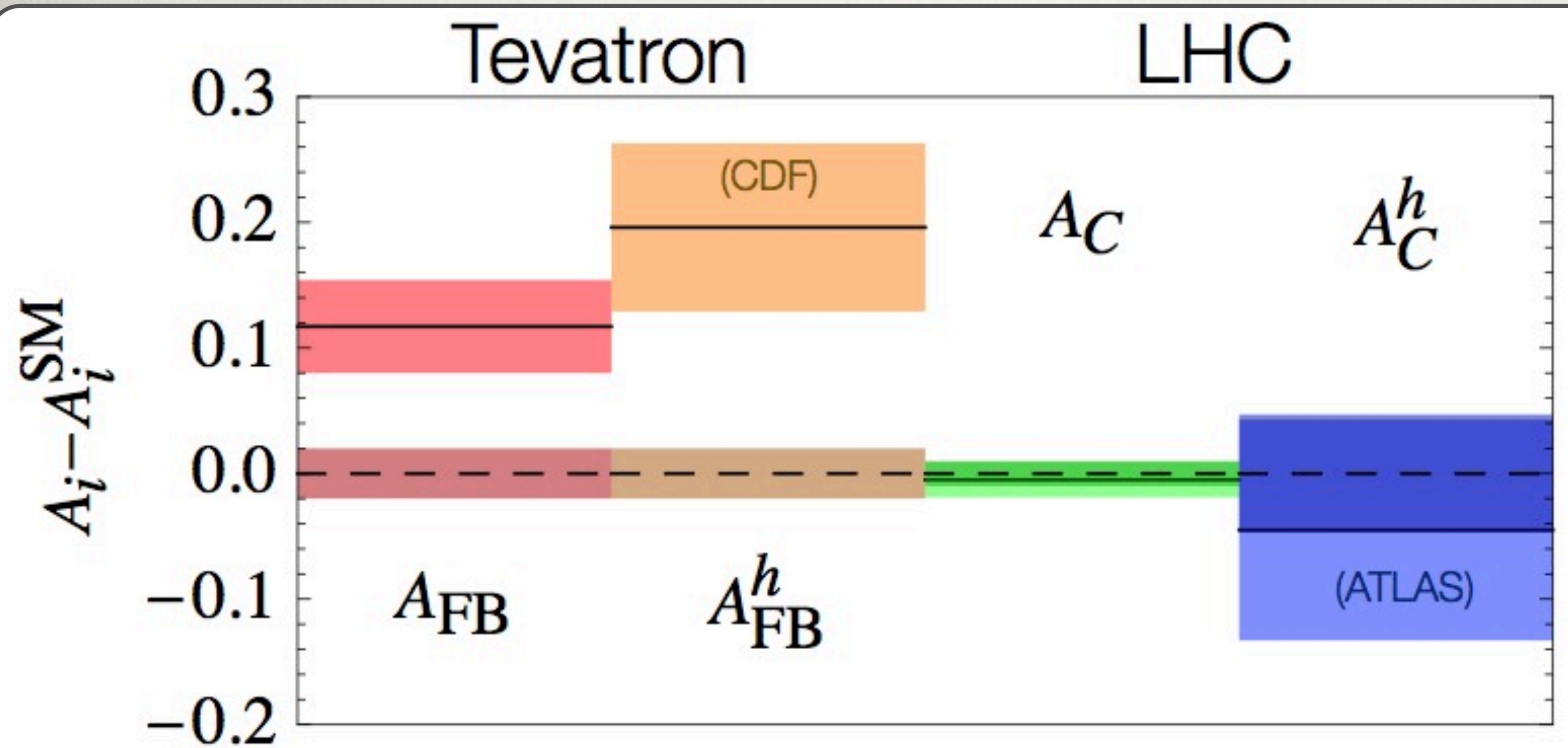


J.Kamenik, talk at DIS2012

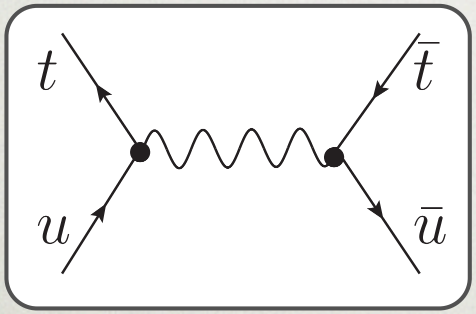
- no deviations seen at the LHC!
  - A_C=0.001±0.014 A_C^h =-0.008±0.047

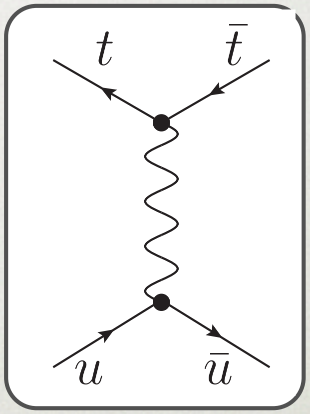
ATLAS, 1203.4211
CMS, PAS-TOP-11-306
ATLAS-CONF-2011-106

*naive average of CDF&D0

THE NEW PHYSICS MODELS

- Working hypothesis: A_{FB} is due to New Physics
- since the effects are large ⇒ tree level
  - *t*-channel or *s*-channel?





  - "light NP" ~ O(300-500 GeV)
  - or "heavy NP" ~ O(2TeV)

NEW PHYSICS MODELS

for review see Kamenik, Shu, JZ,1107.5257

- light NP (~300-400 GeV) models
  - *t*-channel

    Jung, Murayama, Pierce, Wells, 0907.4112
    Cheung, Keung, Yuan, 0908.2589

    - vectors: Z' : $\bar{u}u \to \bar{t}t$, W': $\bar{d}d \to \bar{t}t$

    Blum, Hochberg, Nir, 1107.4350

    - scalar: H': $\bar{u}u \to \bar{t}t$

    Grinstein, Kagan, Trott, JZ, 1102.3374;1108.4027

    - colored and flavor multiplet variants
  - *u*-channel

    Shu, Tait, Wang, 0911.3237; Arhrib, Benbrik, Chen, 0911.4875; Ligeti, Tavares, Schmaltz,1103.2757;. Dorsner, Fajfer, Kamenik, Kosnik, 0912.0972; Cao,McKeen, Rosner, Shaughnessy, Wagner , 1003.3461

    - scalars: color triplet, sextet diquarks: $\bar{u}u \to \bar{t}t$
  - s-channel

    Ferrario ,Rodrigo, 0906.5541; Frampton, ShuWang, 0911.2955
    Tavares, Schmaltz, 1107.0978; Aguilar-Saavedra, Perez-Victoria, 1107.2120

    - axigluon: $\bar{u}u \to \bar{t}t$ and $\bar{d}d \to \bar{t}t$

NEW PHYSICS MODELS

Blum, Delaunay, Gedalia, Hochberg, Lee, Nir, Perez, Soreq,1102.3133;
Delaunay, Gedalia, Hochberg, Perez, Soreq,1103.2297;
Aguilar-Saavedra, Perez-Victoria,1103.2765

- heavy NP (~2TeV)
  - perturbative bounds at ~10TeV
  - usually can apply EFT
  - realizations: some type of axigluon
- word of caution ("light" and "heavy" NP):
  - mostly these are just "effective models"
  - assume one low lying resonance, complete UV model usually not specified

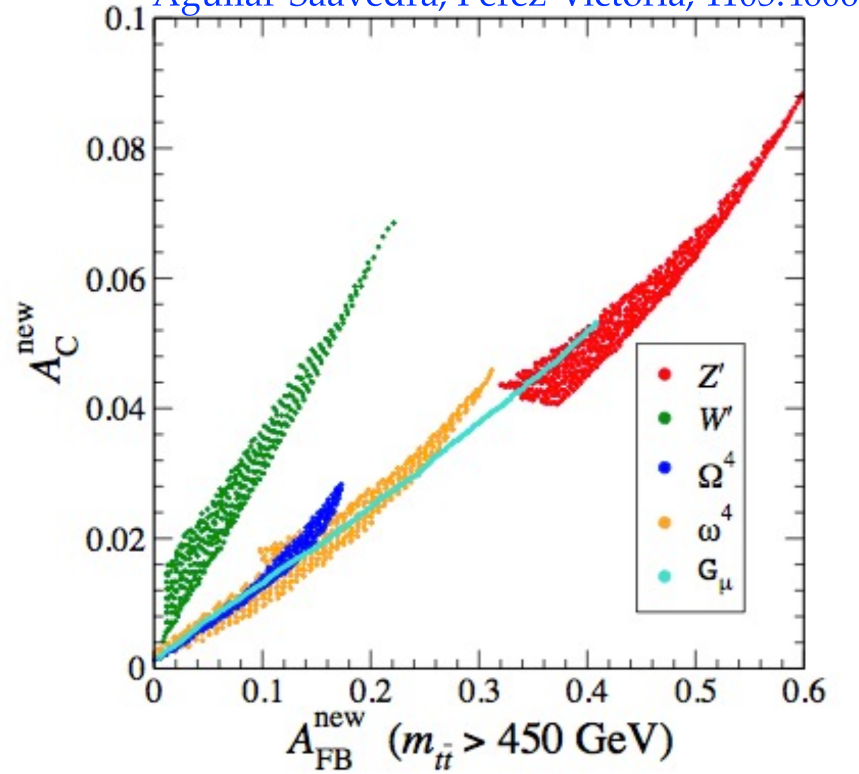
NONTRIVIAL MODELS

- Models have to be nontrivial
  - no significant effect in $d\sigma/dM_{tt}$
  - large A_{FB}, but small A_C
  - constraints from dijets
  - same sign tops
  - atomic parity constraints
  - single top production
  - flavor constraints

RELATING A_{FB} TO A_C

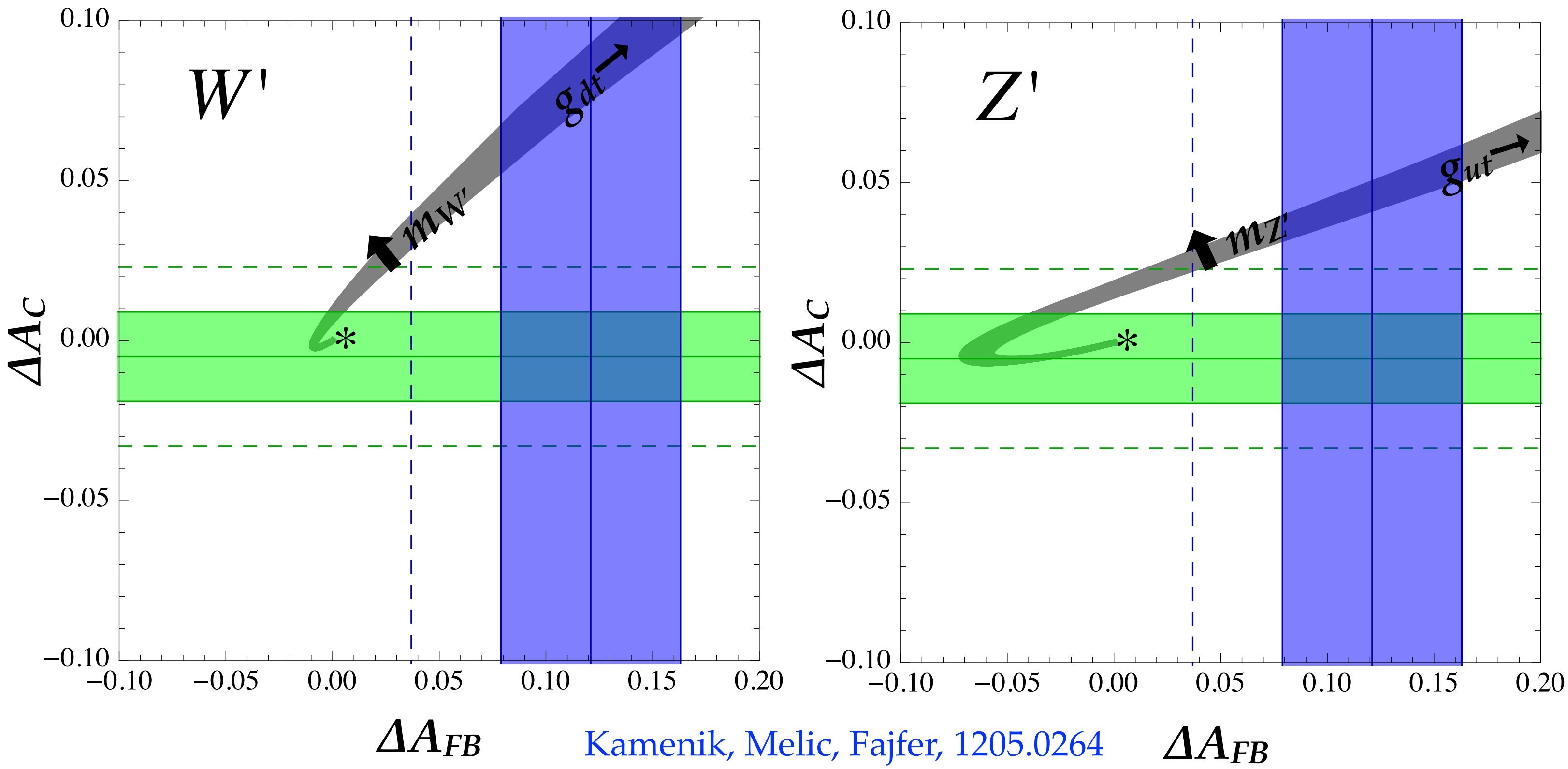
- A_C and A_{FB} both arise in charge asymmetric part of $\sigma(q\bar{q}\to t\bar{t}) \propto \ldots + \ldots(\hat{u}-\hat{t})$
- rigid positive correlation of A_{FB} and A_C for two cases
  - if NP couples flavor universally
  - or if dominated by only u or d in initial state

Aguilar-Saavedra, Perez-Victoria, 1105.4606



A_{FB} present constraints

- LHC measurements of A_{FB} have an impact
  - Z' and W' are incompatible with A_{FB}



  - some tension for other light NP models

A_{FB} DOES NOT IMPLY A_C

- in relating A_{FB} and A_C crucial assumption of universality or dominance

Drobnak, Kamenik, JZ, in preparation

- if coupling to u and d different, but comparable
  - the correlation can be lost
- an example: simple change to axigluon model of Tavares and Schmaltz
  - introduce parity violation in extra vectorlike fermion sector
  - A_{FB} and A_C completely independent
  - A_C can be zero (if cancelations) or even negative
  - possible to be (almost) at central values of top observables at LHC and Tevatron simultaneously

A_{FB} does not imply A_C

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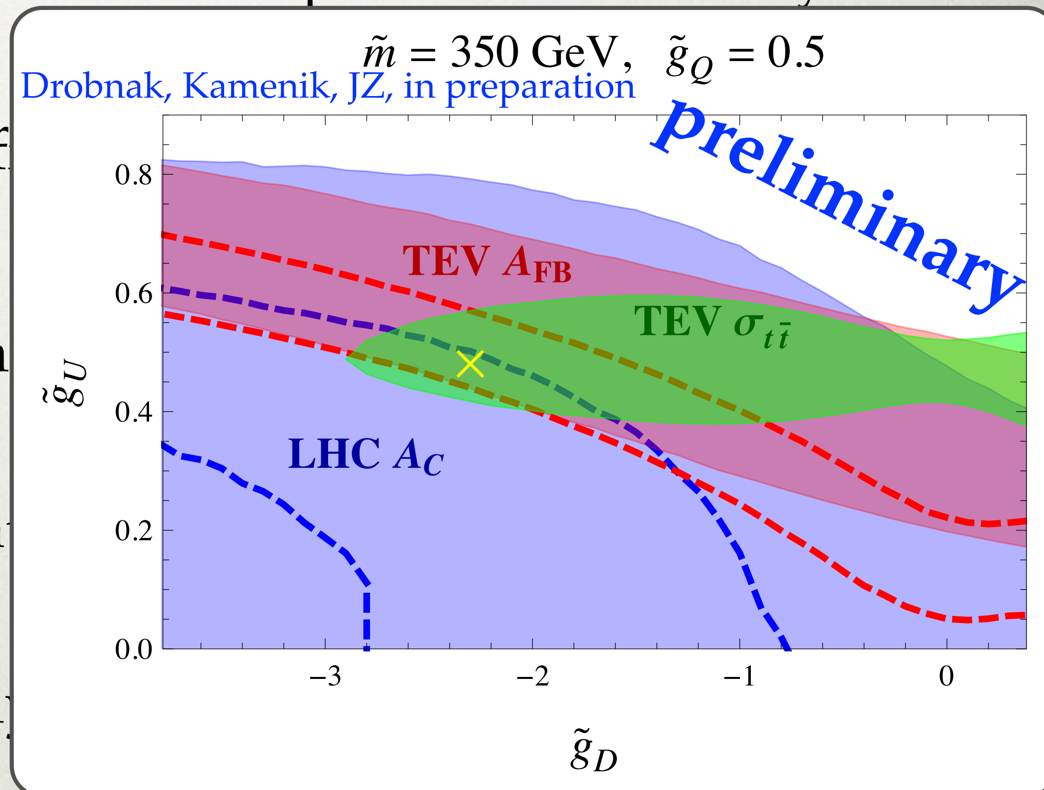
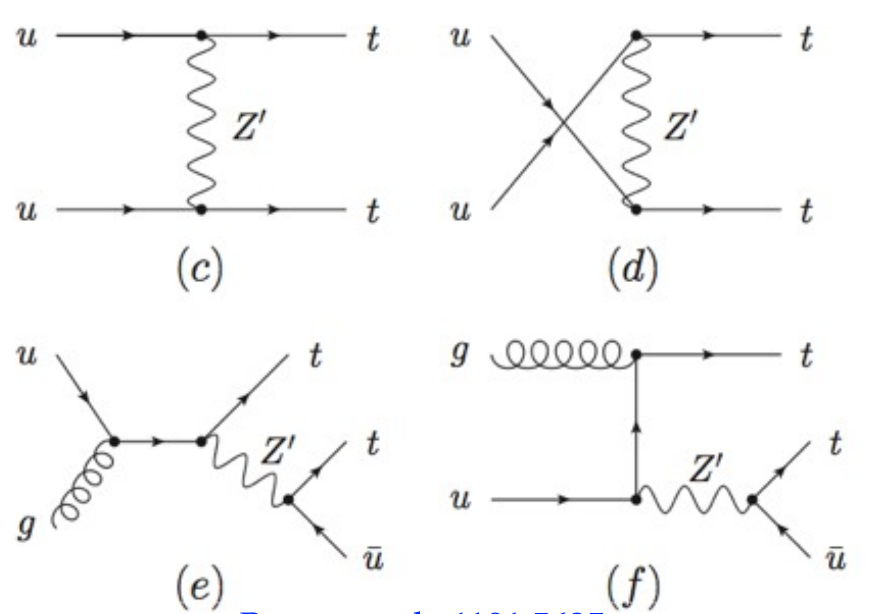


SAME SIGN TOPS

see also talk by Tobias Golling

- Z′ also problems with same sign top production
- not a problem for flavor multiplet models



Berger et al., 1101.5625

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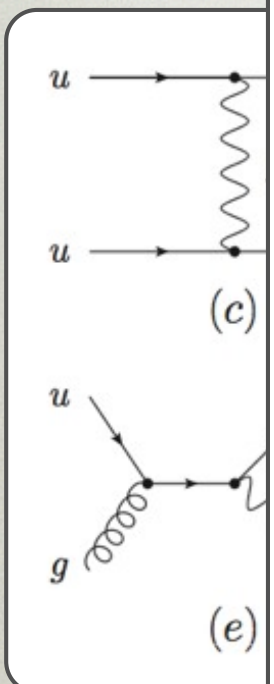
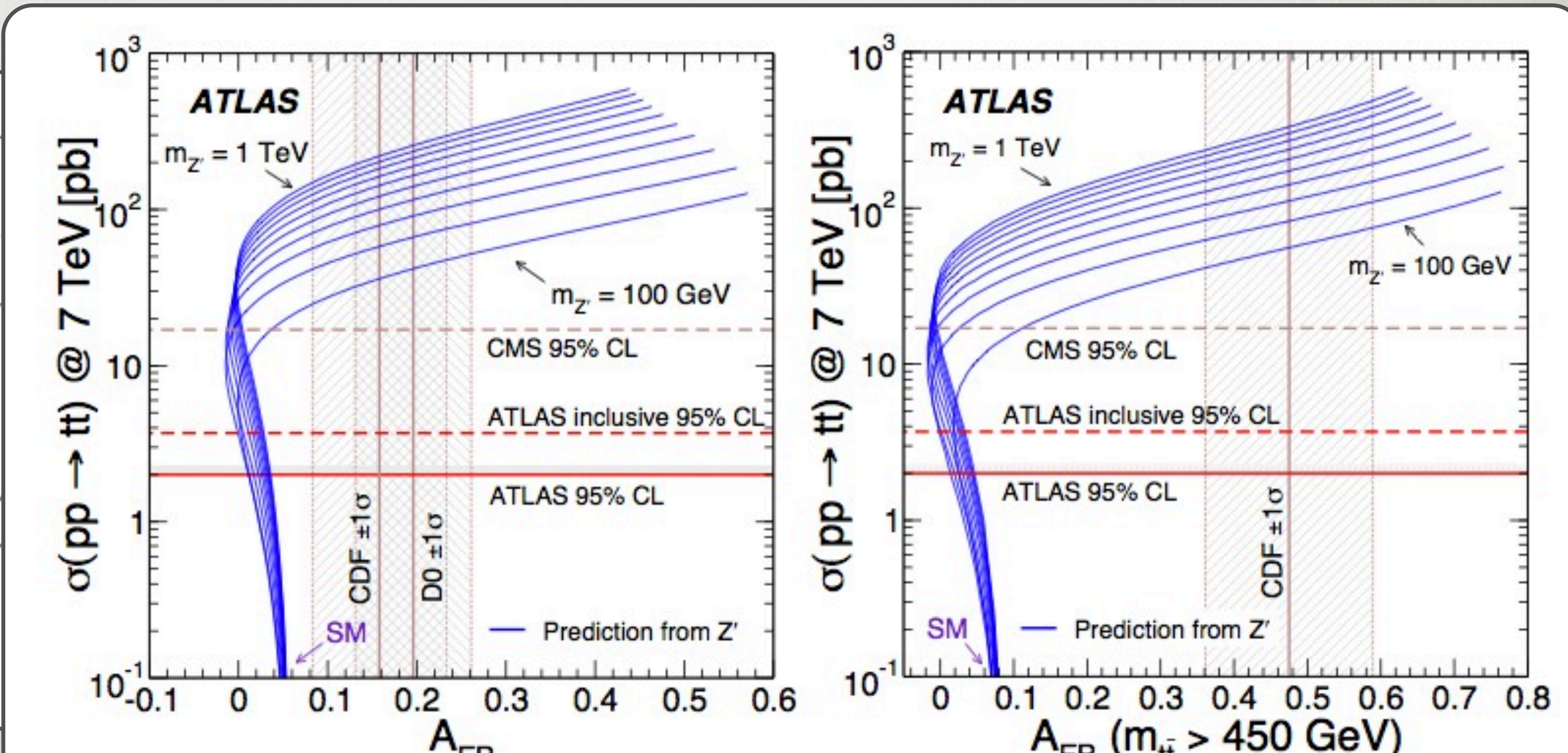




ATLAS, 1202.5520

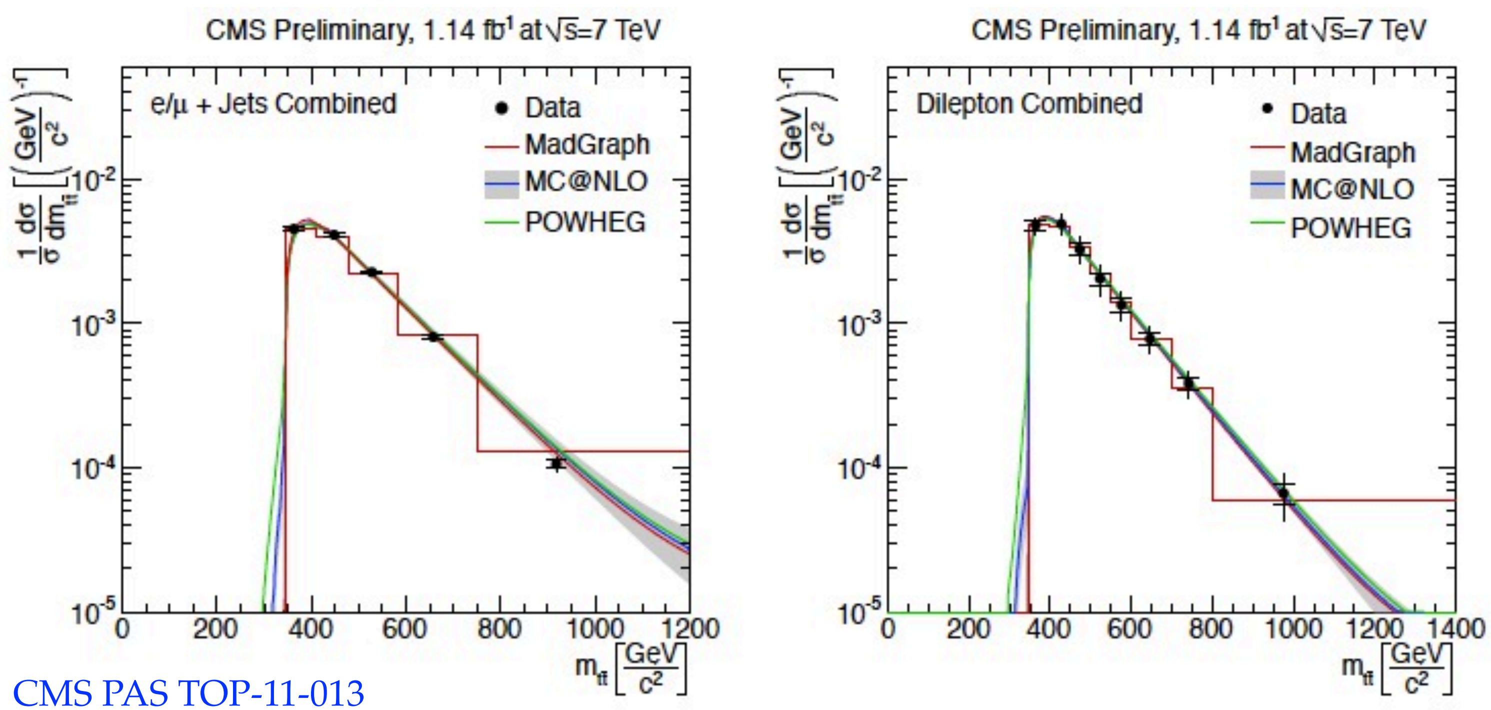
LHC CONSTRAINT ON TTBAR SPECTRUM

- note: EW Sudakov logs reduce the tail by ~10%

  Trott, Manohar, 1201.3926

  - in principle more room for NP
- on the border of being constraining for heavy NP models (axigluon of EFT)

  see also ATLAS-CONF-2012-029



CMS PAS TOP-11-013

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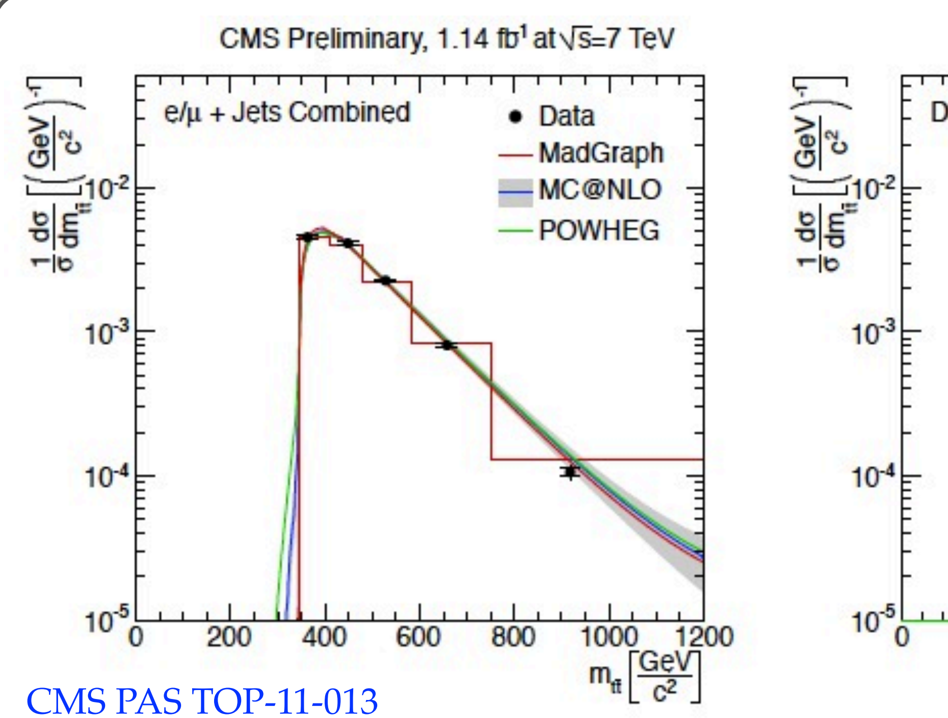

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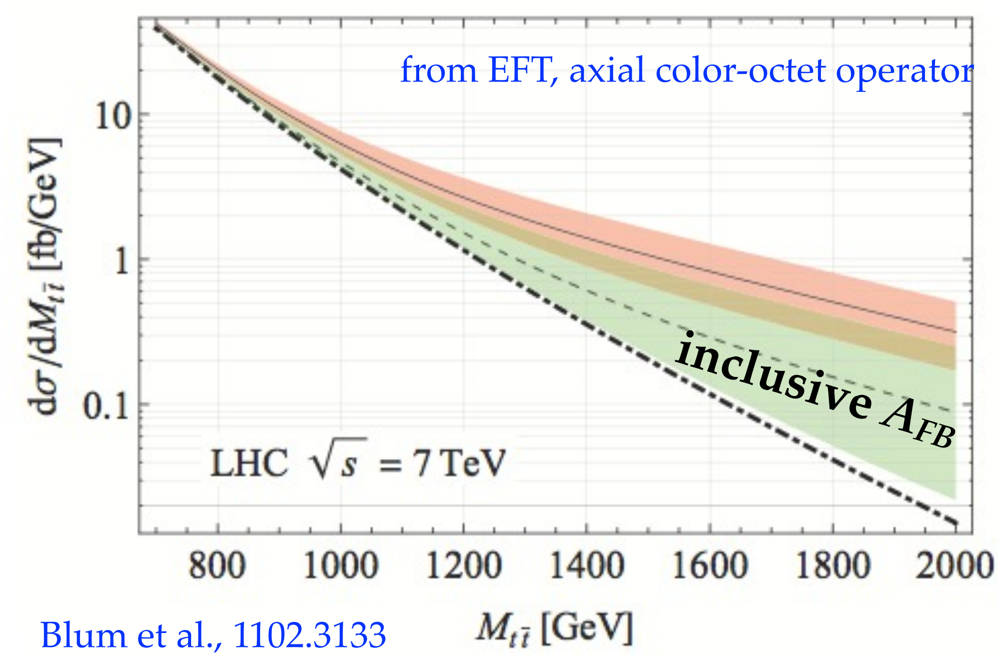
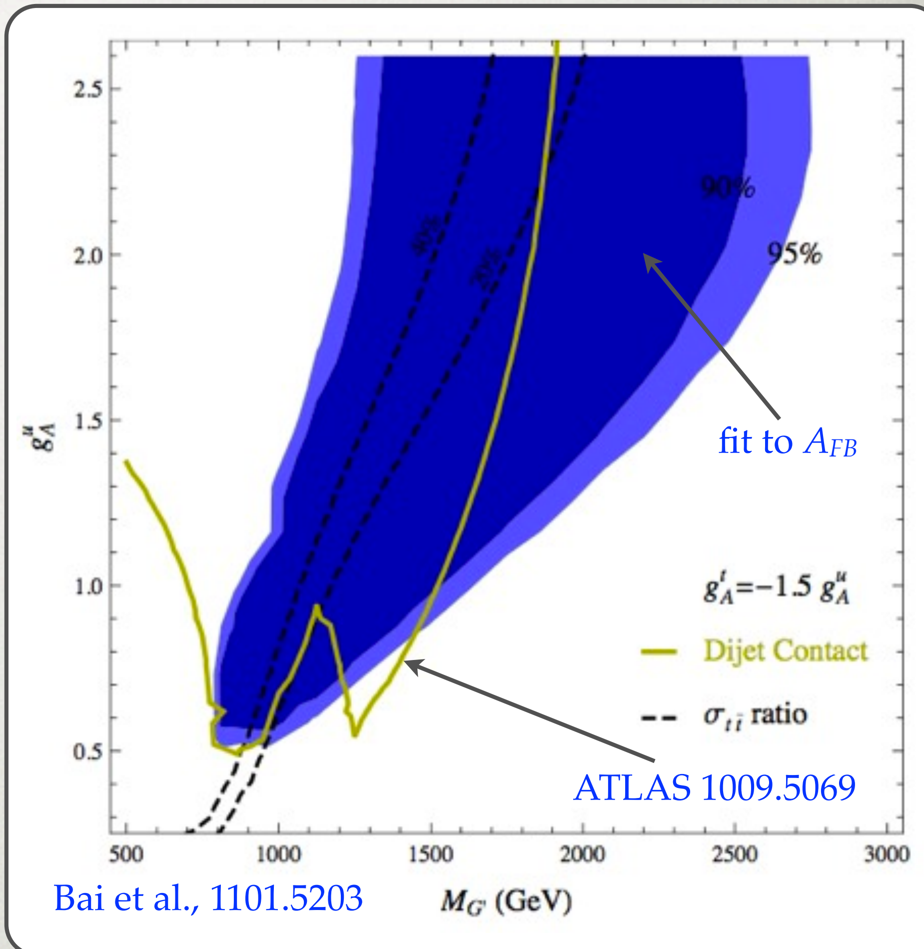


Blum et al., 1102.3133

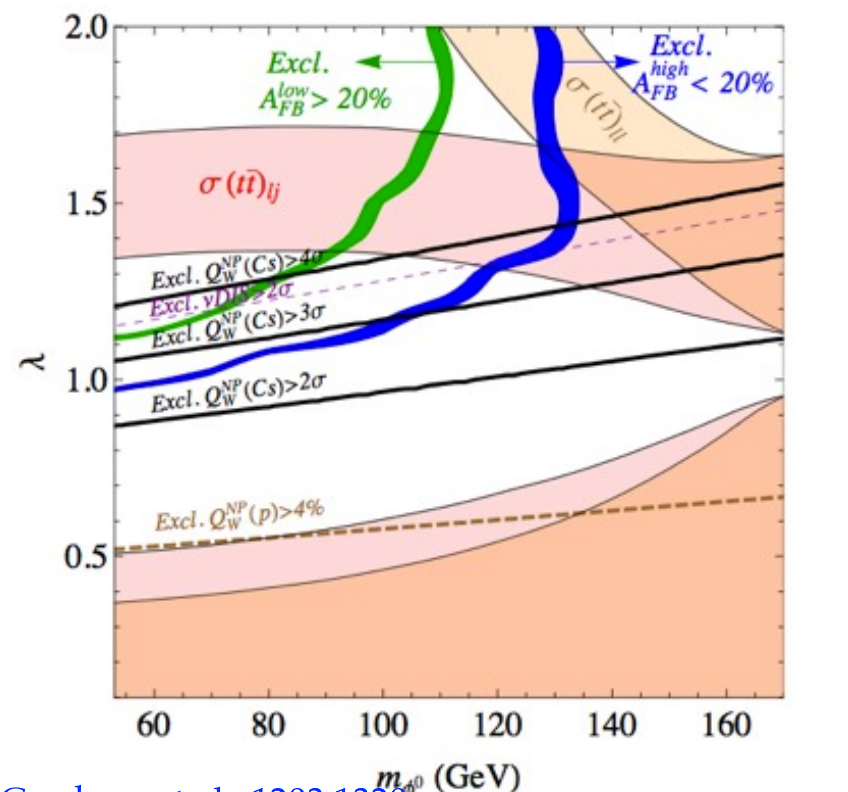
DIJET CONSTRAINTS

- dijet constraints
  - search for narrow resonances
  - angular distributions
- very constraining
  - go away for wide resonances
  - or when $g_u \ll g_t$

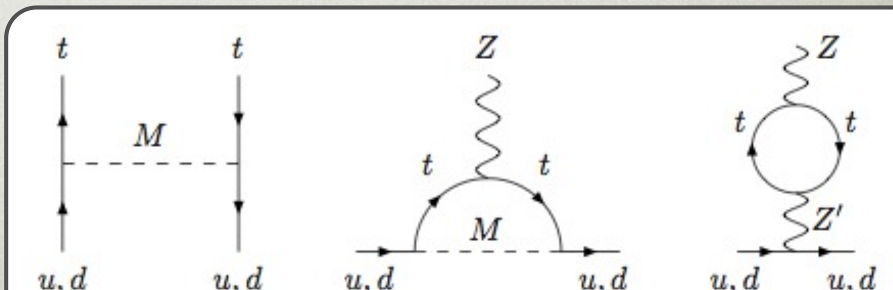


ATOMIC PARITY VIOLATION

- in order to have large A_{FB} NP axial currents
  - will also show in atomic PV exps.
  - for scalars calculable
  - for vectors need a complete UV model
- the models H', Z' tried by Gresham et al. are in tension with atomic PV



Gresham et al, 1203.1320

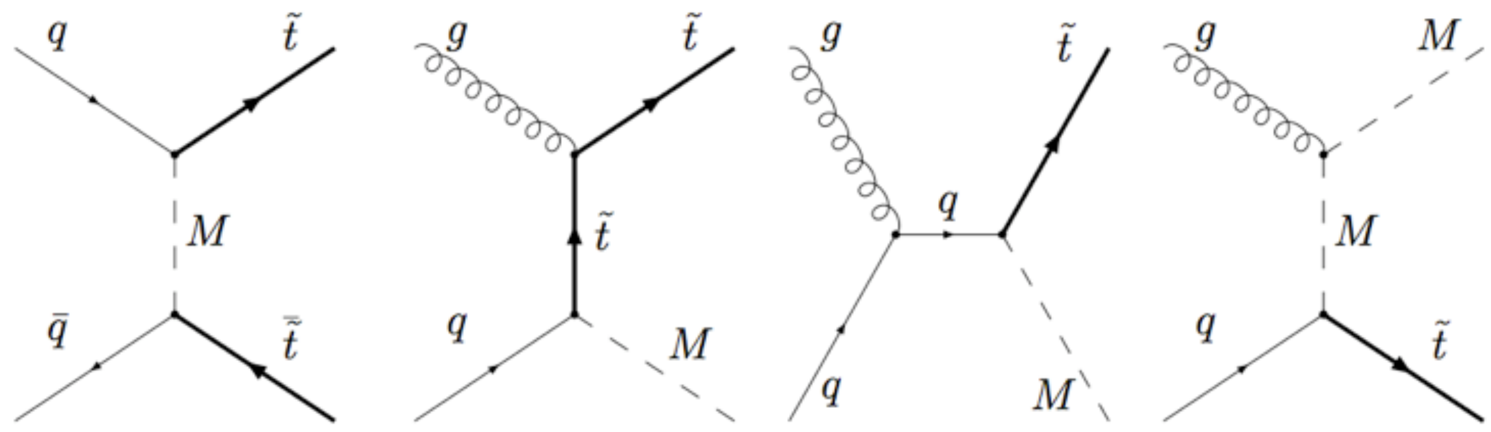


Gresham et al, 1203.1320

ADDITIONAL SIGNALS AT COLLIDERS

- some signals are quite generic for many *t*-channel models
  - a *t+j* resonance in *pp→t tbar+j*
  - in addition use also distrib. in $cos\theta_{tj}$

Dorsner, Fajfer, Kamenik, Kosnik, 0912.0972
Gresham, Kim, Zurek, 1102.0018



(a) $t\bar{t}$ production (b) t-channel (c) s-channel (d) u-channel

Gresham, Kim, Zurek, 1102.0018

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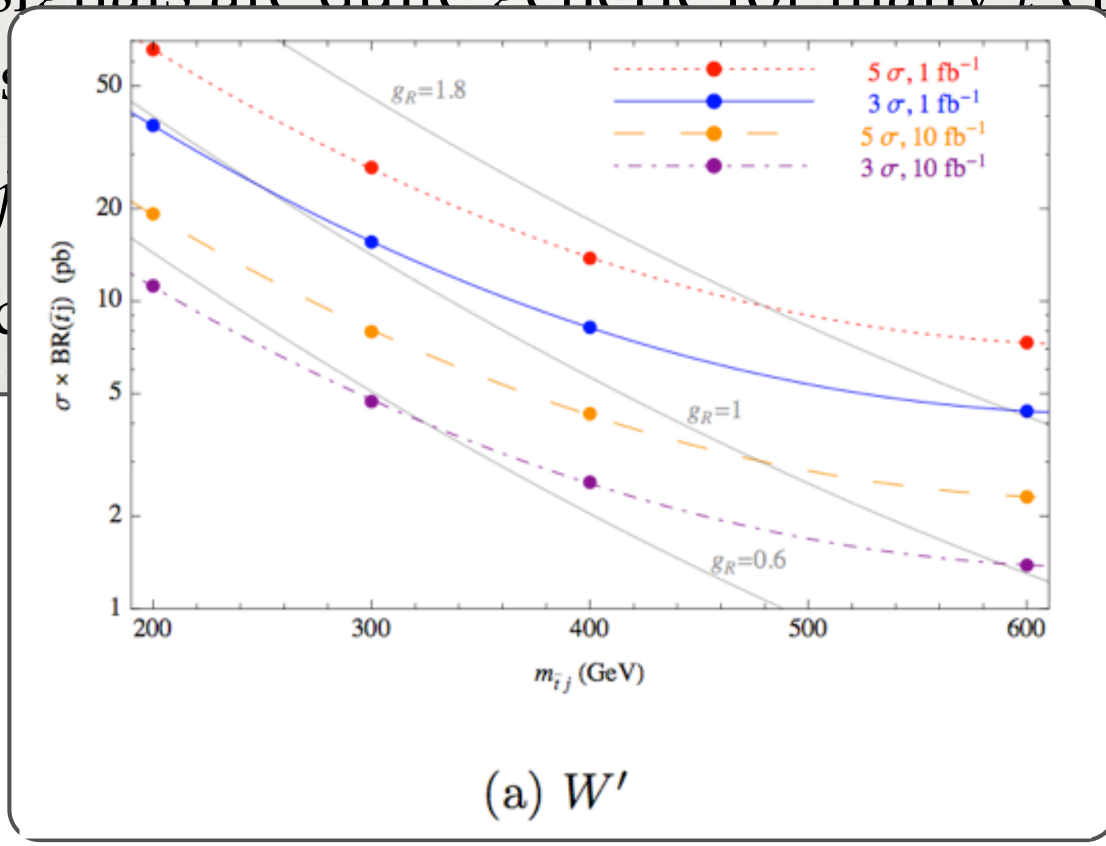
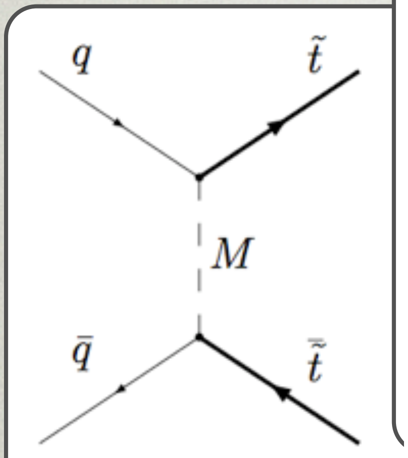


(a) W'



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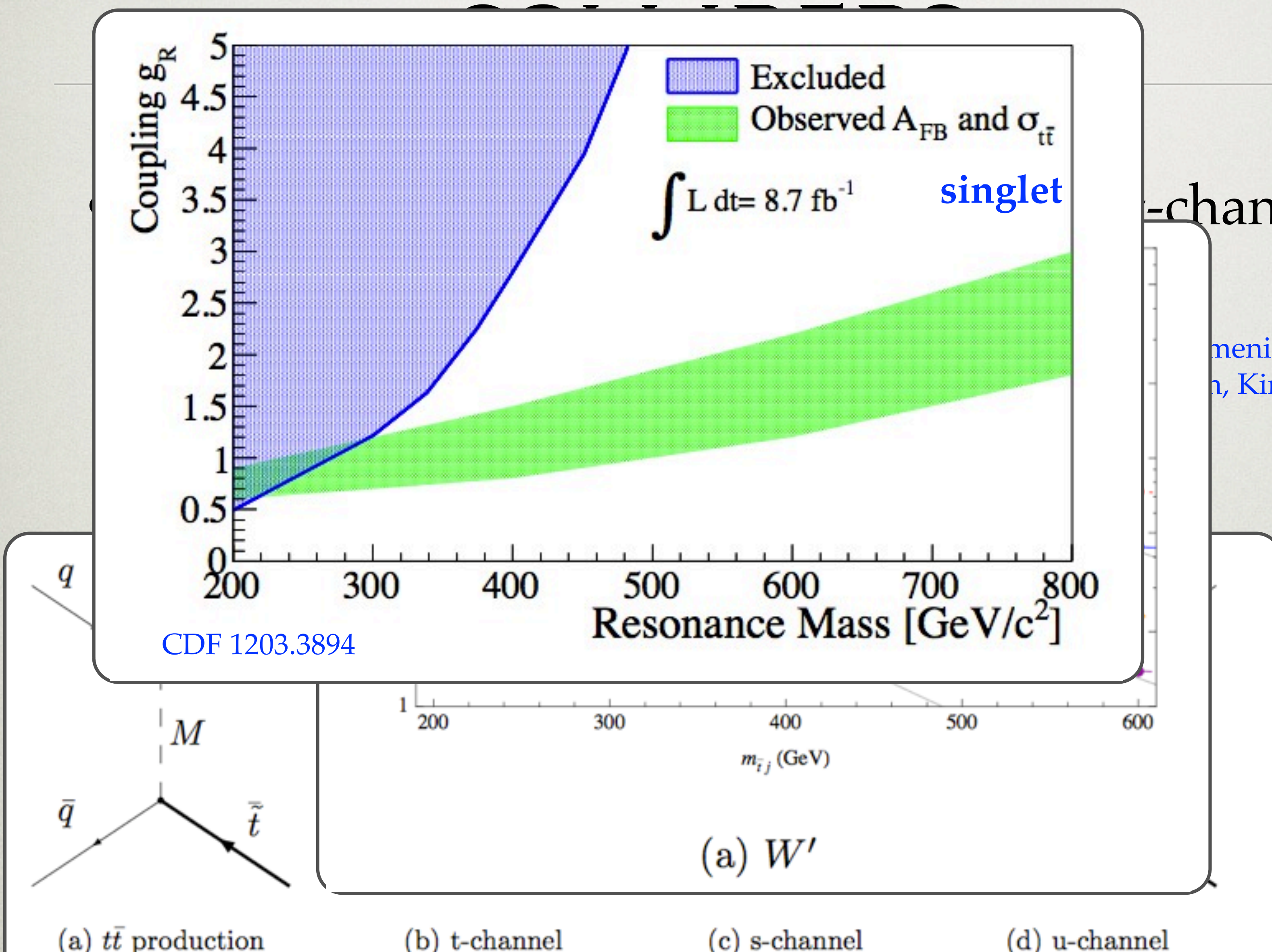
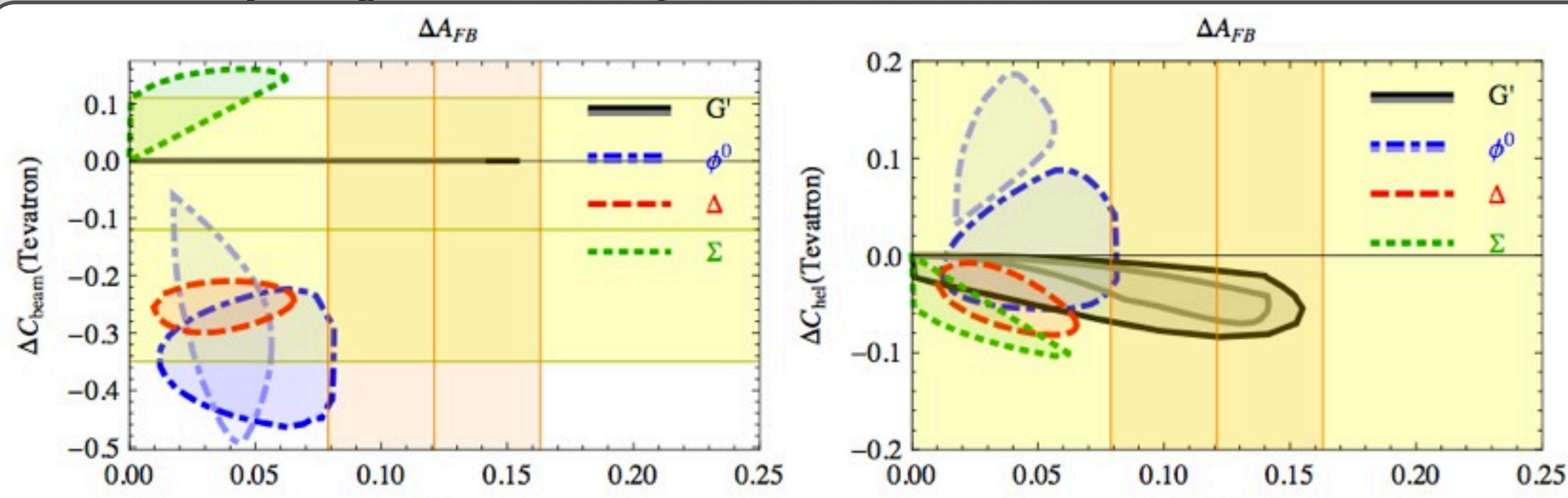


Gresham, Kim, Zurek, 1102.0018

SPIN MEASUREMENTS

- chiral couplings
  - spin correlations between ttbar
  - polarization of t or tbar
- Tevatron and LHC not yet constraining
  - need ~10-20% precision at Tevatron, ~2%-5% at LHC
- very important discriminator
  - only axigluon small spin obs. (~2% at LHC, ~5% at Tevatron)

Krohn, Liu, Shelton,Wang, 1105.3743; Degrande et al.,1010.6304; Godbole, Rao, Rindani, Singh, 1010.1458; Cao, Wu,Yang, 1011.5564; Jung, Ko, Lee, 1011.5976; Choudhury et al., 1012.4750; Cao et al., 1109.6543; Bai, Han,1106.5071; Falkowski, Perez, Schmaltz, 1110.3796 ; Berger et al., 1201.1790 ; Fajfer, Kamenik,Melic, 1205.0264



Fajfer, Kamenik,Melic, 1205.0264

BBAR A_{FB}

- another important obs.: $\bar{b}b$ A_{FB}
- would generically expect effects
- relation to $\bar{t}t$ A_{FB} is model dependent

Strassler, 1102.0736;
Kahawala, Krohn, Strassler, 1108.3301

M_{bb} (GeV)	A_{FB} (in %)
35 - 75	X.YZ ± 0.96 (stat) ± 0.05 (syst)
75 - 95	X.YZ ± 1.15 (stat) ± 0.11 (syst)
95 - 130	X.YZ ± 1.57 (stat) ± 0.1 (syst)
> 130	X.YZ ± 2.56 (stat) ± 0.68 (syst)

Integrated $\mathcal{A}_{\mathcal{FB}}$: $A_{FB} = X.YZ \pm 0.62(\text{stat}) \pm 0.10(\text{syst})$

Bartos for CDF, talk at Top physics workshop, CERN, May 2, 2012

BBAR A_{FB}

- another imp
- would gene
- relation to $t\bar{t}$

M_{bb} (GeV)							
35 - 75	X						
75 - 95	X						
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Integrated $\mathcal{A}_{\mathcal{FB}}$: A_{FB}=X.YZ±0.62(stat)±0.10(syst)

Bartos for CDF, talk at Top physics workshop, CERN, May 2, 2012

Tevatron	$A_{b\bar{b}}$	$m_{b\bar{b}} >$ 100 GeV	$m_{b\bar{b}} >$ 200 GeV	$m_{b\bar{b}} >$ 300 GeV
Inclusive	0.004 (2)	0.011 (3)	0.029 (4)	0.060 (6)
$\lvert\Delta y\rvert > 1.5$	0.004 (2)	0.010 (3)	0.026 (4)	0.057 (6)
$p_\perp^{b\bar{b}} <$ 10 GeV	0.004 (2)	0.014 (5)	0.044 (7)	0.095 (10)

Rodrigo, talk at Top physics workshop, CERN, May 3, 2012

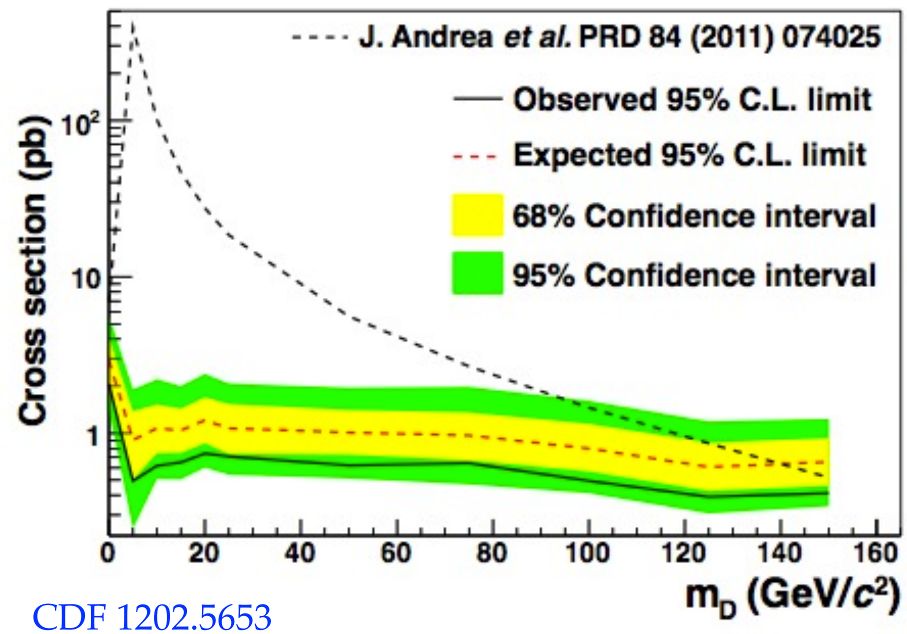
SUMMARY OF A_{FB}

- tight constraints on the models that can explain A_{FB}
- most models are dead = provide an improvement over SM < 1sigma
- preferred model is axigluon
  - light axigluon needs large decay width, $\Gamma \sim 0.2m$
  - heavy axigluon needs $g_u \ll g_t$
  - could be our first sign of strongly coupled EWSB sector or just a mirage...

OTHER NP PHENOMENA IN TOP PRODUCTION

see talks by LianTao Wang, Rick Cavanaugh, Tobias Golling

- heavy ttbar resonances
- enhanced 4top signal
- monotops= single top+MET
  - can be the dominant sign of DM production
  - production through FV vertex $c \to t\chi\chi$
  - dominates for scalar interactions



CDF 1202.5653

Kamenik, JZ, 1107.0623
Andrea et al, 1106.6199

NP IN TOP DECAY

NONSTANDARD TOP DECAYS

see also talk by Kevin Black

- NP can induce nonstandard (rare) top decays
  - FCNC: $t \to qZ$, $q\gamma$, qg ($q=u,c$)
  - charge decays: $t \to bW$, sW, dW
  - exotica: $t \to qX$ (X=invisible,H^+ ...)
- difficulty:
  - top decay width is "large", no CKM suppression
  - compared to *b*, *c* decays probe smaller scales for general FV
- motivation: top is heavy, could directly "feel" NP
  - compositness, extended higgs sector, ...

FCNC TOP DECAYS

- FCNC decays of top rare in SM
- already constraints from *B* physics
  - $t \to cZ$: LL operators nothing new from LHC
- LR and RR operators are being constrained by LHC
  - CMS: Br($t \to cZ$)<0.34% (4.6 fb^{-1}) CMS PAS TOP-11-028
  - ATLAS: Br($t \to qZ$)<1.3% (0.70 fb^{-1}) ATLAS-CONF-2011-154

$$O^w_{LR} = g_2 \left[\overline{Q}_3 \sigma^{\mu\nu} \sigma^a \tilde{H}\right] c_R W^a_{\mu\nu} + \text{h.c.}\,,$$

$$O^b_{LR} = g_1 \left[\overline{Q}_3 \sigma^{\mu\nu} \tilde{H}\right] c_R B_{\mu\nu} + \text{h.c.}\,,$$

$$O^u_{RR} = i\, \bar{t}_R \gamma^\mu c_R \left[H^\dagger \overleftrightarrow{D}_\mu H\right] + \text{h.c.}\,.$$

Fox et al, 0704.1482

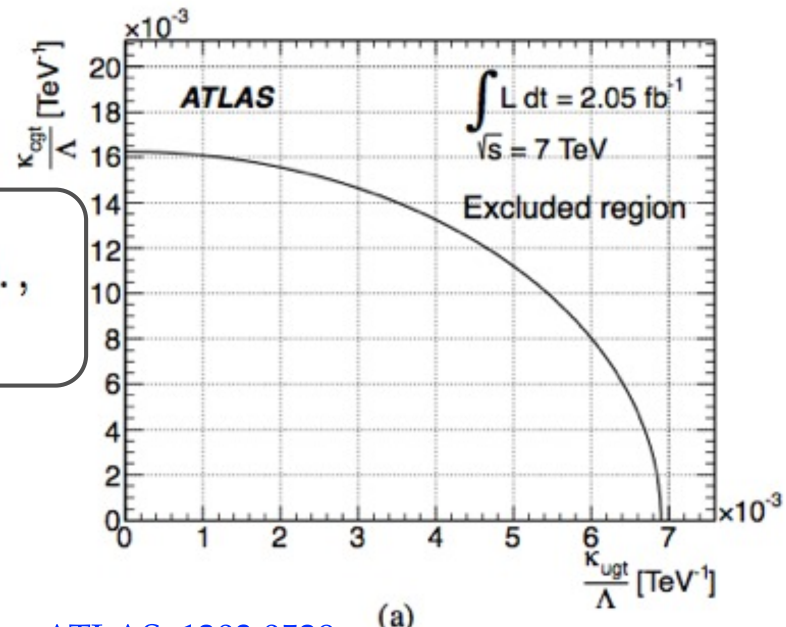
	C^u_{LL}				C^w_{LR}	C^b_{LR}	C^u_{RR}
direct bound	9.0				6.3	6.3	9.0
LHC sensitivity	0.20				0.15	0.15	0.20
Λ for $C_i = 1$ (min)	3.9 TeV	8.3 TeV	2.6 TeV	2.0 TeV	0.8 TeV	0.4 TeV	0.3 TeV
$\mathcal{B}(t \to cZ)$ (max)	7.1×10^{-6}	3.5×10^{-7}	3.4×10^{-5}	8.4×10^{-6}	4.5×10^{-3}	5.6×10^{-3}	0.14
$\mathcal{B}(t \to c\gamma)$ (max)	—	—	1.8×10^{-5}	4.8×10^{-5}	2.3×10^{-3}	3.2×10^{-2}	—
LHC Window	Closed*	Closed*	Ajar	Ajar	Open	Open	Open

CHROMOMAGNETIC DECAYS

- bounds on FV chromomagnetic op

$$\mathcal{L} = g_s \sum_{q=u,c} \frac{\kappa_{tqg}}{\Lambda} \bar{t}\sigma^{\mu\nu}T^a(f_q^L P_L + f_q^R P_R)qG^a_{\mu\nu} + h.c.\,,$$

Gao et al., 1104.4945



ATLAS, 1203.0529

- the bounds translate to
  Λ/κ_{ugt}>140 TeV
  Λ/κ_{cgt}> 60 TeV

- most probably due to loop, then $\Lambda \sim 16\pi^2 m^2/v$ and
  m/g_{ugt}>0.5 TeV
  m/g_{cgt}>0.3 TeV

OTHER DECAYS

- anomalous $t \to Wb$ CC

$$\mathcal{L}_{tWb} = \mathcal{L}_{tWb}^{\rm SM} - \frac{g}{\sqrt{2}}\bar{b}\Big[(V_L P_L + V_R P_R)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{m_W}(G_L P_L + G_R P_R)\Big]tW_\mu$$

  - similar for $t \to Wb$ CC
- constrained from B physics
  - certain ops. are (very!) constrained
  - others not constrained (or weak bounds)
  - complementary to the Tevatron and LHC

OTHER DECAYS

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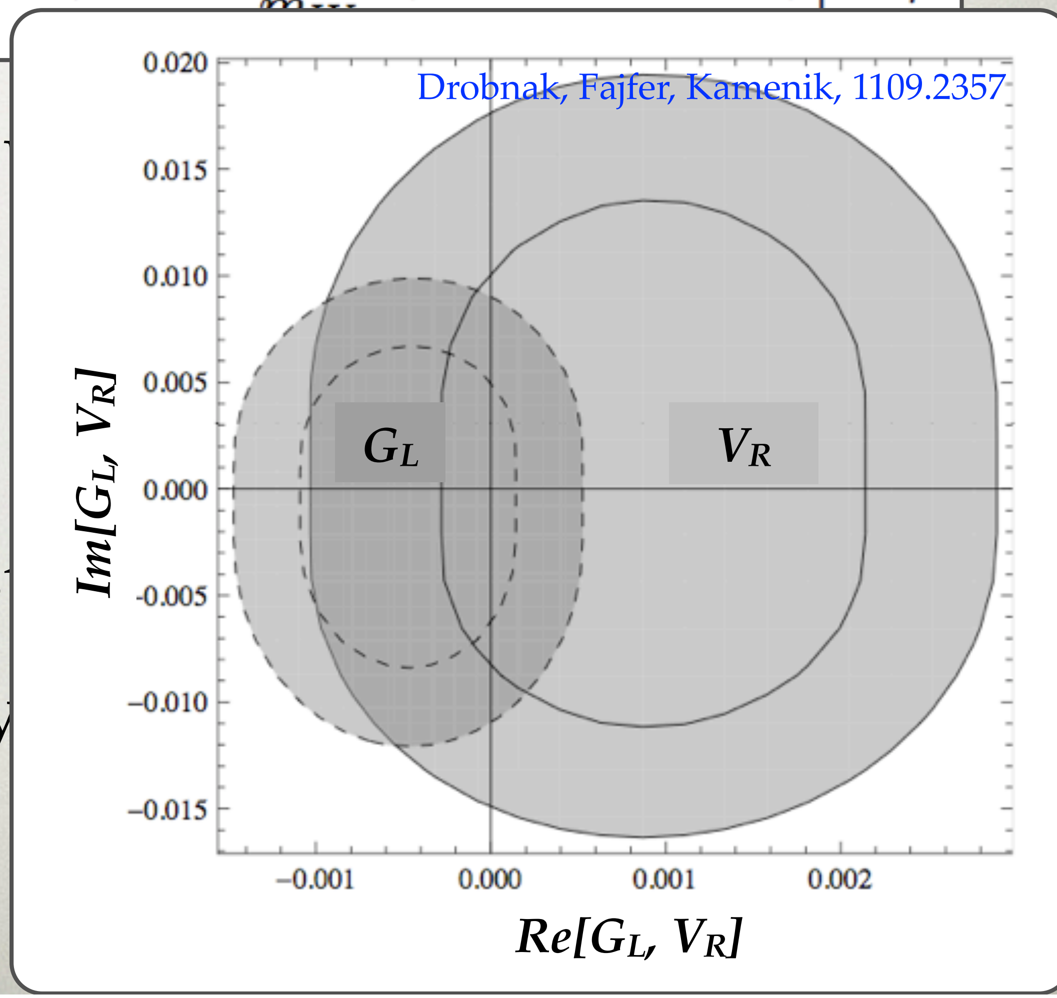

OTHER DECAYS

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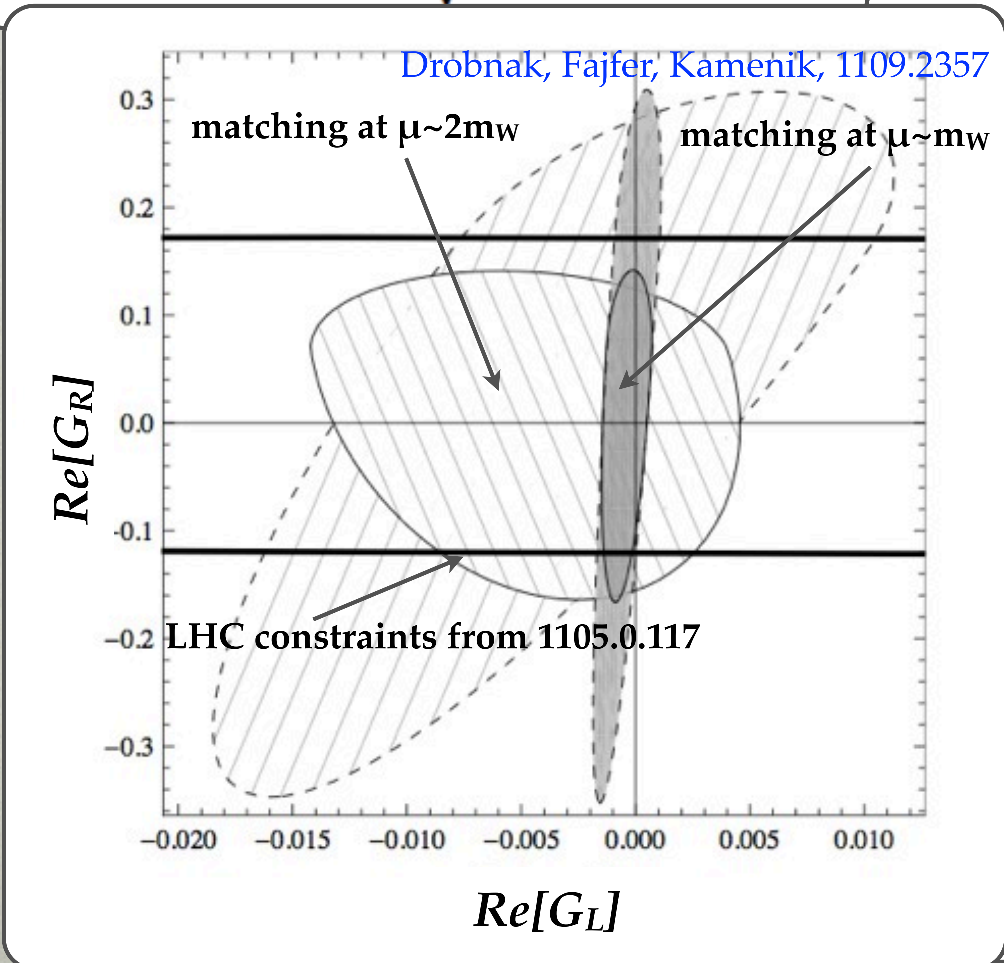
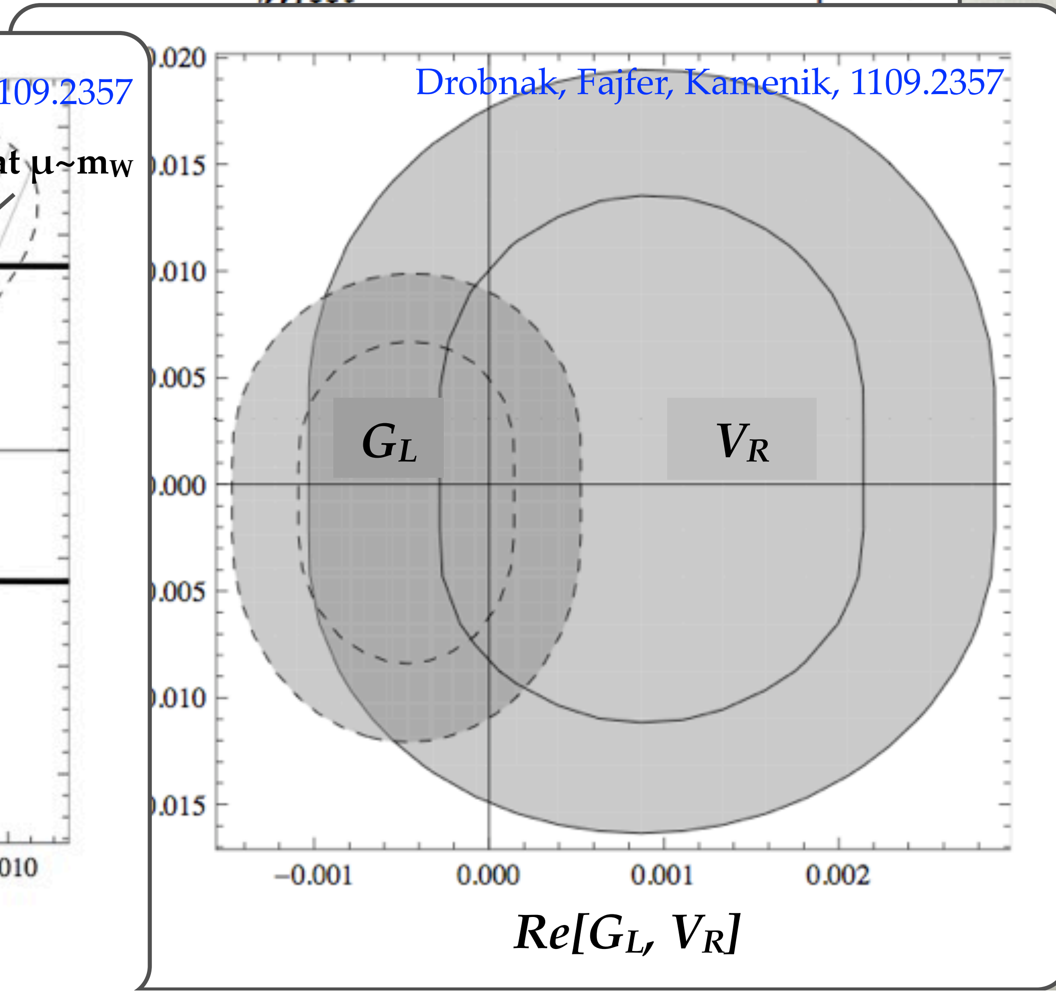




CONCLUSIONS

- it is possible that NP contributions to A_{FB} are large, and A_C is SM-like
- axigluon preferred (only surviving?) model for A_{FB}

BACKUP SLIDES

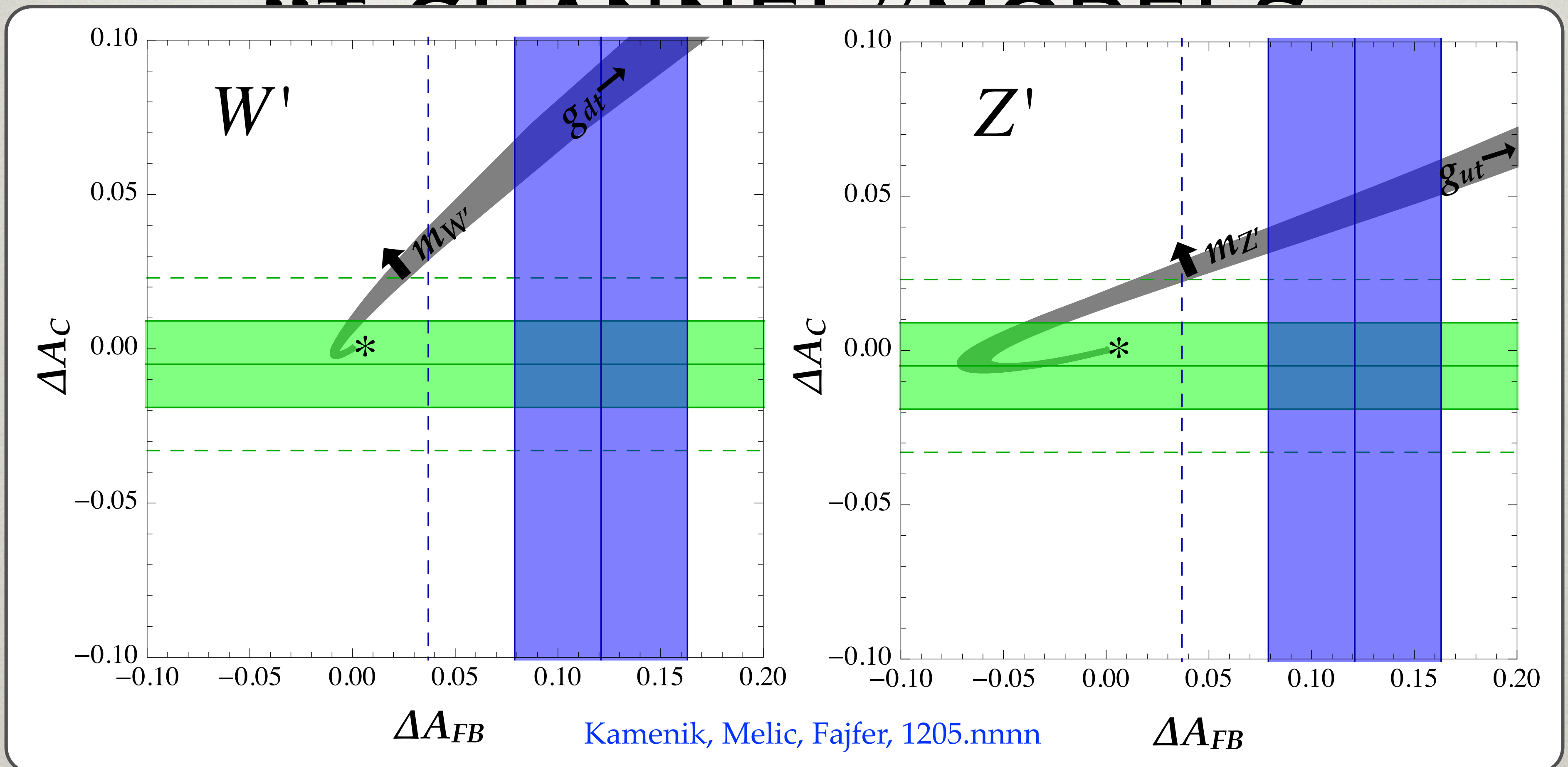
EXPERIMENTAL DATA VS. THE SM

- inclusive A_{FB} at Tevatron (naive average)
  S. Leone [CDF], talk at Moriond EWK 2012; Abazov et al. [DO], 1107.4995
  - A_{FB}=0.187±0.037 *vs* SM: A_{FB}^{SM}=0.066±0.020
    Ahrens et al., 1106.6051
- CDF unfolded
  - $A_{FB}(m_{tt}<450GeV)$=0.078±0.054 *vs* SM: 0.047
  - $A_{FB}(m_{tt}<450GeV)$=0.296±0.067 *vs* SM: 0.100
- A_C at the LHC (naive average)
  [ATLAS] 1203.4211; CMS-PAS-TOP-11-030
  - A_C=0.001±0.014 *vs* SM: A_C^{SM}=0.006±0.001
  - ATLAS also has A_C binned in m_{tt}
    - larger errors, agree with SM

"T-CHANNEL" MODELS

- three sets of "*t*-channel" models
  - large flavor violation: Z′, W′,H′, scalar color sextets, triplets,...
  - flavor conserving: full representations of flavor group $SU(3)^3$
  - not exactly $t\bar{t}$, but $t\bar{t}+X$ (so no interference)
- viable masses ~300-500GeV
- asymmetries driven by Rutherford peak
- LHC measurements have an impact
  - Z' and W' are incompatible with A_{FB}

“T-CHANNEL” MODELS



Kamenik, Melic, Fajfer, 1205.nnnn

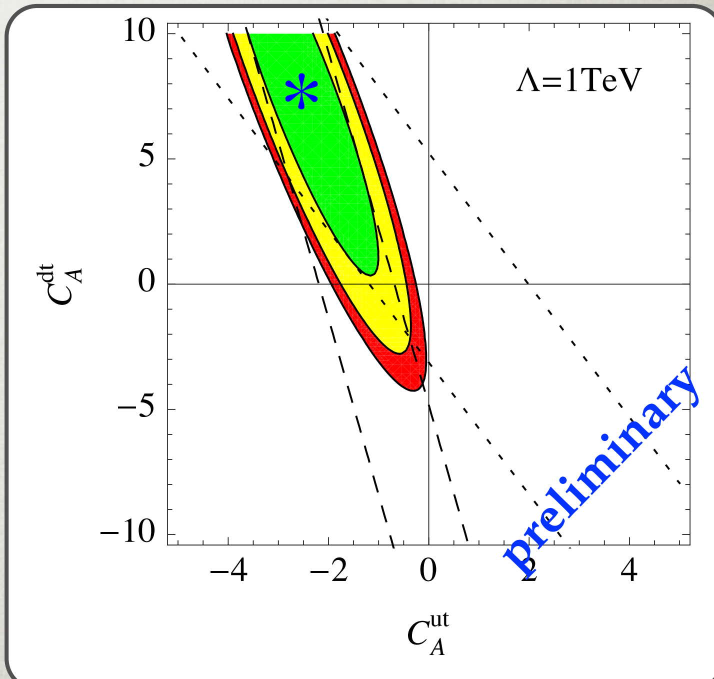
- asymmetries driven by Rutherford peak
- LHC measurements have an impact
  - Z' and W' are incompatible with A_{FB}

DECORELATING A_{FB} AND A_C

- assume NP couples differently to *u* and *d*
- the largest difference due to different valence structure
  - pp̄ at Tevatron, pp at LHC
  - $\bar{u}u:\bar{d}d$ luminosity funct. are 4:1 at Tevatron, 2:1 at the LHC (at large x)
- perform EFT analysis
  - just two operators that can give AFB

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_{q=u,d} \frac{C_A^{qt}}{\Lambda^2} (\bar{q}\gamma^\mu\gamma_5 q)(\bar{t}\gamma_\mu\gamma_5 t)\,.$$

- can have large A_{FB} and small (zero, or even negative) A_C if
  - C_A^{ut} and C_A^{dt} have opposite signs
  - and $|C_A^{ut}| \lesssim |C_A^{dt}|$



Drobnak, Kamenik, JZ, in preparation

ON SHELL MODELS

- the EFT discussion motivates the necessary changes to on-shell models
- an example: asymmetric axigluon model
  - a simple modification of axigluon model of Schmaltz,Tavares
  - SSB of $SU(3)_L \times SU(3)_R \to SU(3)_C$
  - SM fermions $Q \sim (3,1)$, $U,D \sim (1,3)$
  - extra fermions for anomaly cancellation
    - here the only modification - in this sector we allow for parity breaking
  - strong gauge interactions still parity invariant ($g_L = g_R$)
- after SSB:

$$\mathcal{L} = -\frac{1}{4}(G^a)^2 - \frac{1}{4}(\tilde{G}^a)^2 + \frac{\tilde{m}^2}{2}\tilde{A}^2 + \bar{Q}(i\not{D} - \tilde{g}_Q\tilde{\not{A}})Q$$
$$+\bar{U}(i\not{D} + \tilde{g}_U\tilde{\not{A}})U + \bar{D}(i\not{D} + \tilde{g}_D\tilde{\not{A}})D + \dots,$$

Schmaltz, Tavares, 1107.0978

FURTHER COMMENTS ON AXIGLUON COUPLINGS

- from EFT: need sizeable coupling
  - for $g_i \sim O(1)$ sizeable widths $\Gamma \sim 0.1m$
- nonuniversality of $g_{Q,D,U} \Rightarrow$vectorial couplings to quarks
  - increase the ttbar cross section
  - unless below threshold
- there is a solution that has correct AFB, AC, sigma tt
- to avoid paired dijet constraints (constraints onpair production)
  - decay with of $\Gamma \sim 0.2m$ needed
  - a factor of 2 larger than in the considered model
  - generation dependent coupling (or extra channels?)

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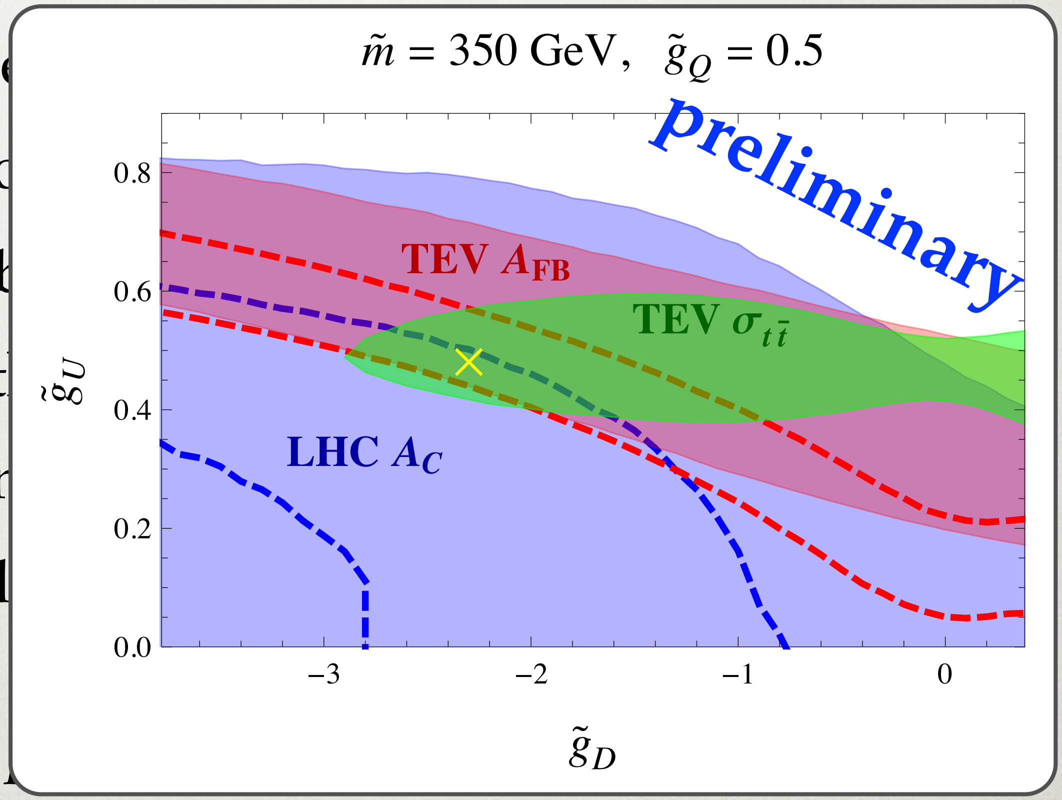

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