# TOP-QUARK CHARGE ASYMMETRY

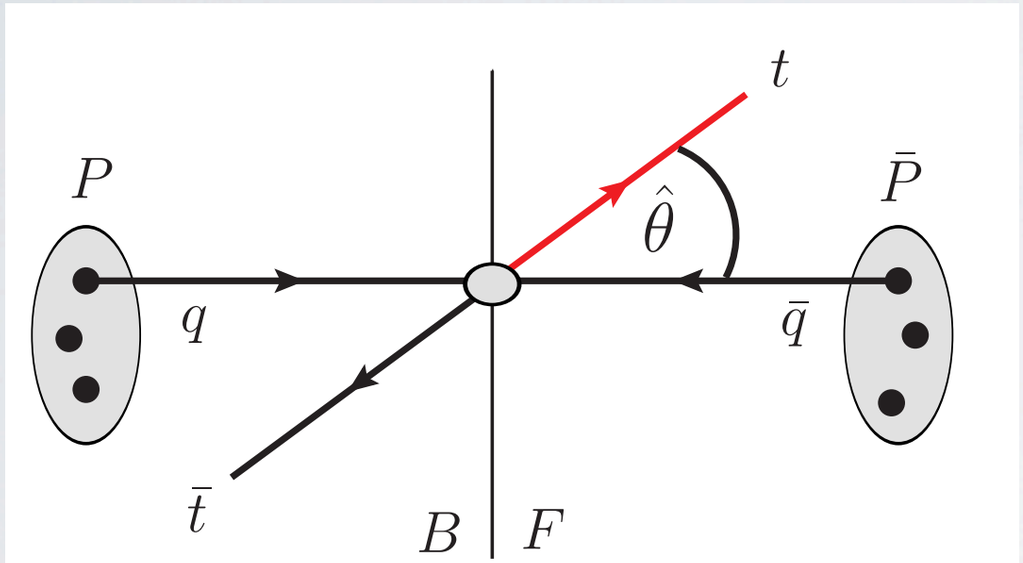
Dante Amidei, Jessie Shelton, George Sterman,
Bryan Webber, Susanne Westhoff, Jure Zupan

presented by Susanne Westhoff, University of Pittsburgh

Snowmass Top Meeting --- January 30, 2013

# TOP-QUARK CHARGE ASYMMETRY

$$A_C = \frac{\sigma_a}{\sigma_s}, \quad \sigma_{s,a} = \int_0^1 d\cos\hat{\theta}\, \frac{d\sigma_{t\bar{t}}}{d\cos\hat{\theta}} \pm \frac{d\sigma_{\bar{t}t}}{d\cos\hat{\theta}}$$




Measure asymmetry
in terms of rapidity differences:

$$A_C^{exp} = \frac{\sigma(\Delta y > 0) - \sigma(\Delta y < 0)}{\sigma(\Delta y > 0) + \sigma(\Delta y < 0)}$$

Tevatron

forward-backward:

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

$$A_C^{exp} = A_{\rm FB}^t = A_C \approx 8\,\%$$

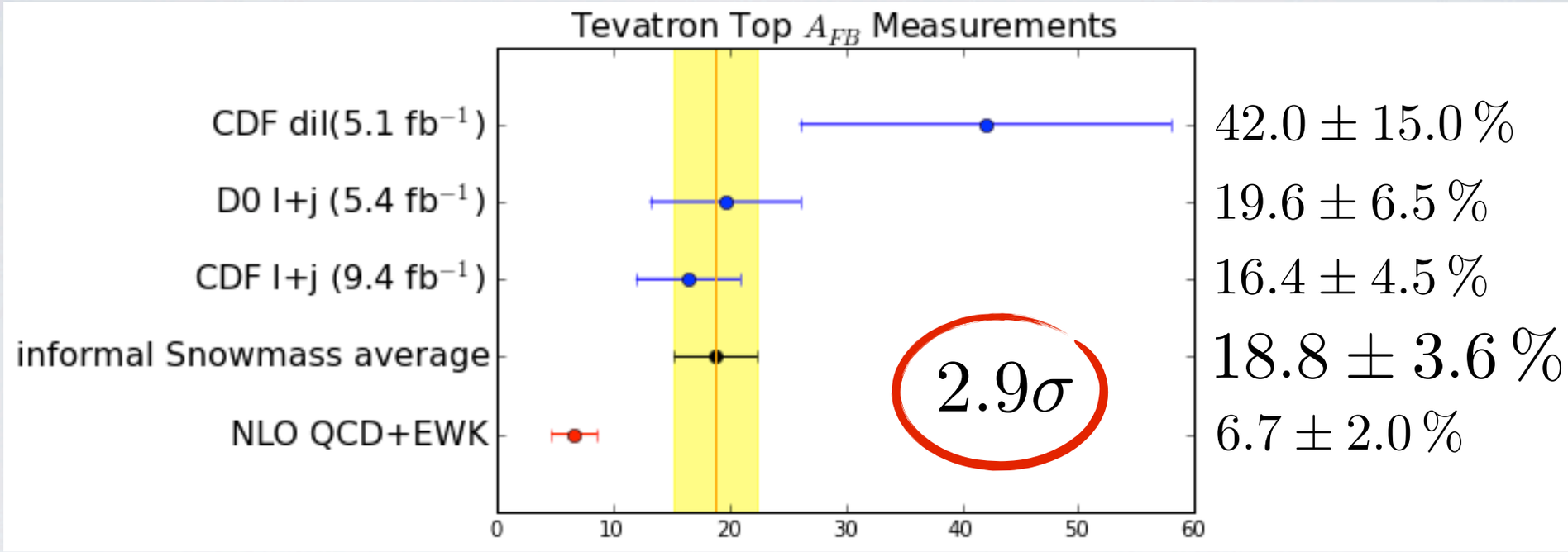
LHC

beamward-central:

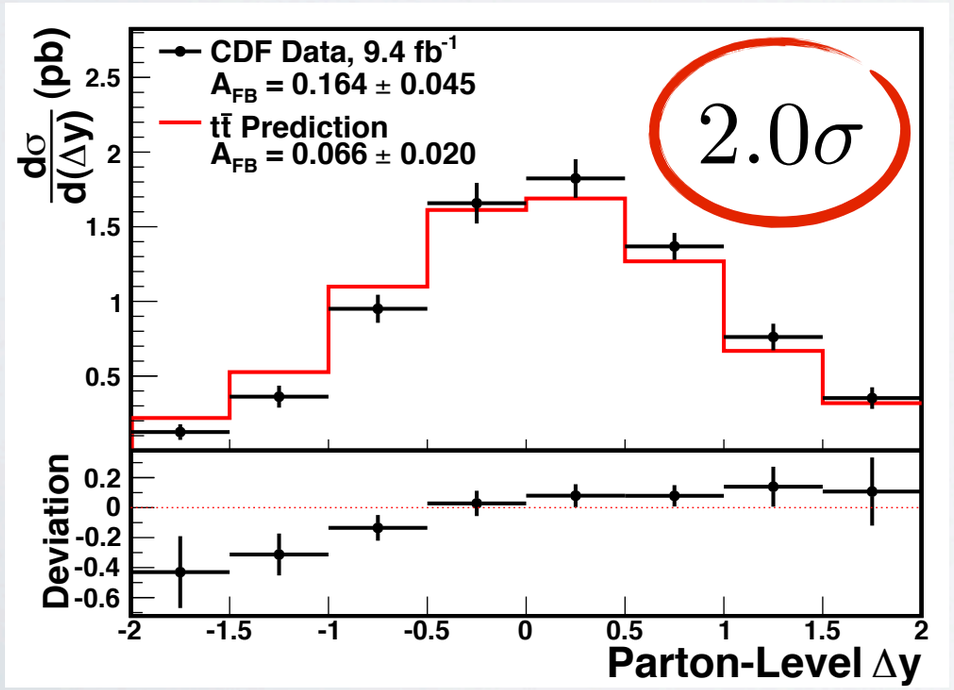
$$\Delta y = |y_t| - |y_{\bar{t}}|$$

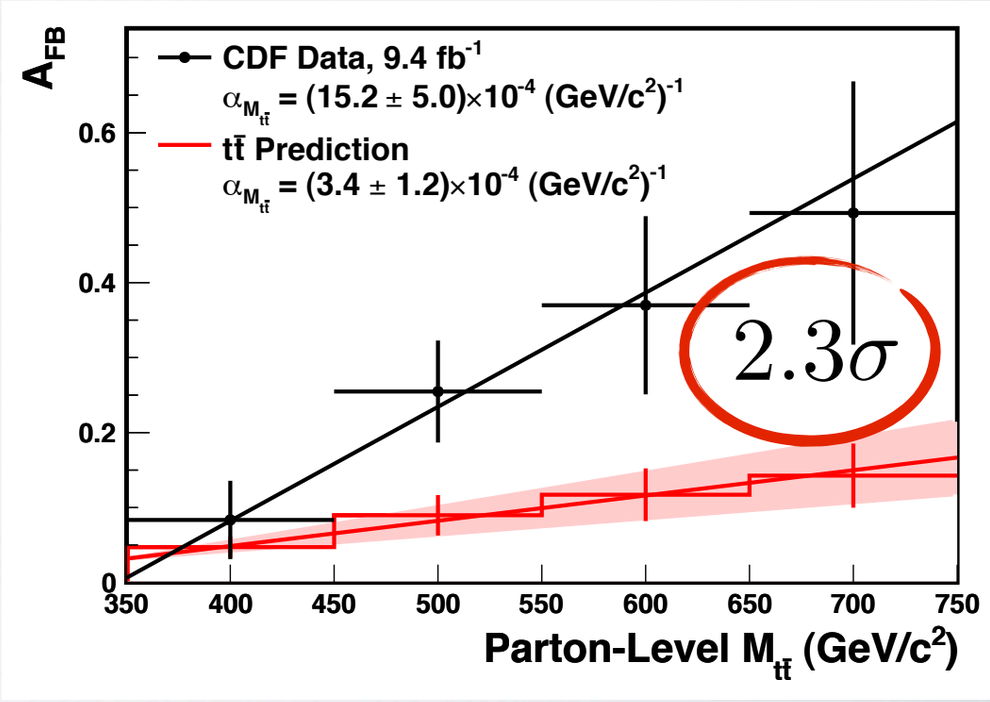
$$A_C^{exp} = A_C^{|y|} \approx 1\,\% \ll A_C$$

# ASYMMETRY AT THE TEVATRON




## Differential distributions



# ASYMMETRY AT THE LHC

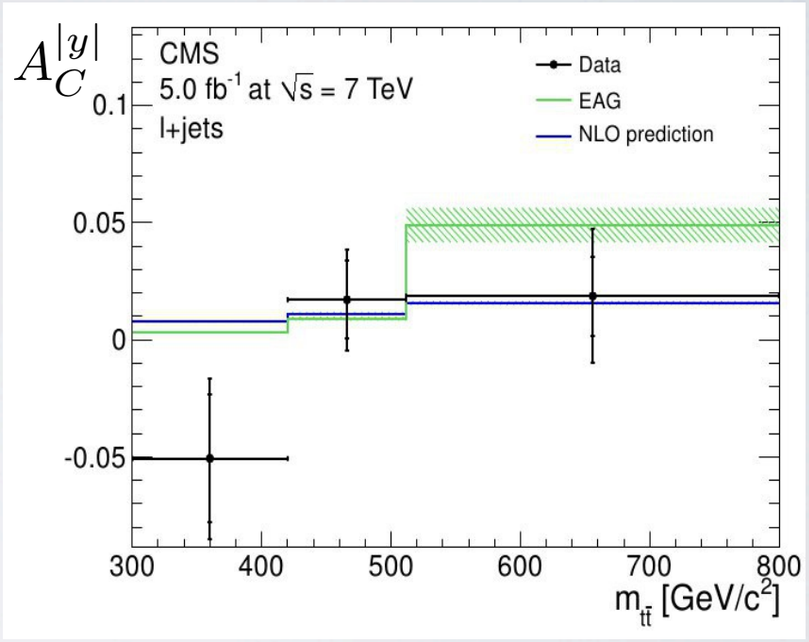
Consistent with SM prediction $A_C^{\mathrm{LHC7}} = 1.15 \pm 0.06\,\%$ :

$$A_C^{\mathrm{CMS}}(\ell j) = 0.4 \pm 1.0 \pm 1.1\,\%$$

[CMS, arXiv:1207.0065]

$$A_C^{\mathrm{CMS}}(\ell\ell) = 5.0 \pm 4.3^{+1.0}_{-3.9}\,\%$$

[CMS-PAS-TOP-12-010]



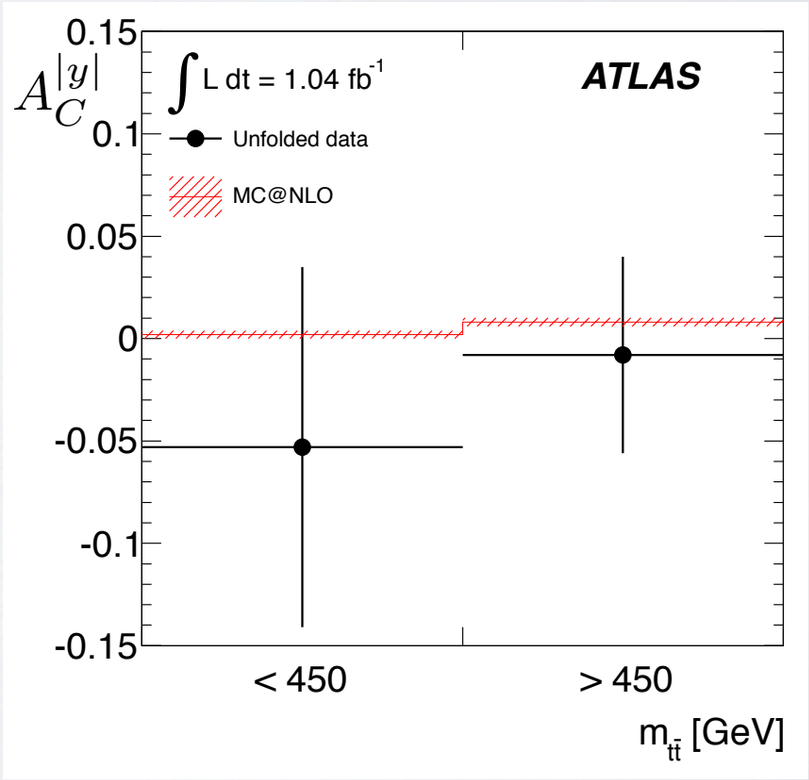

$$A_C^{\mathrm{ATLAS}}(\ell j) = -1.9 \pm 2.8 \pm 2.4\,\%$$

[ATLAS, Eur. Phys. J. C72 (2012) 2039]

$$A_C^{\mathrm{ATLAS}}(\ell\ell) = 5.7 \pm 2.4 \pm 1.5\,\%$$

[ATLAS-CONF-2012-057]

$$A_C^{\mathrm{ATLAS}}(\ell j + \ell\ell) = 2.9 \pm 1.8 \pm 1.4\,\%$$

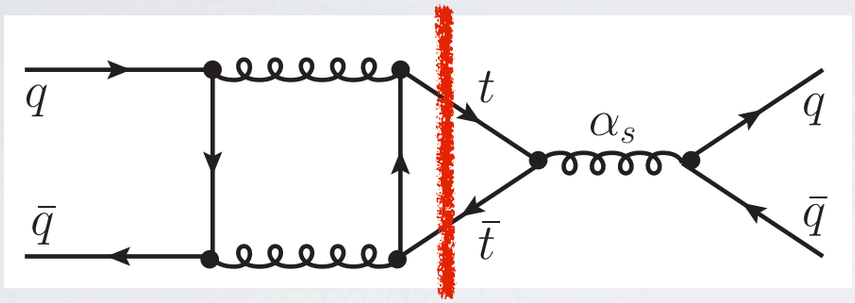


# PERTURBATIVE QCD AND RESUMMATION

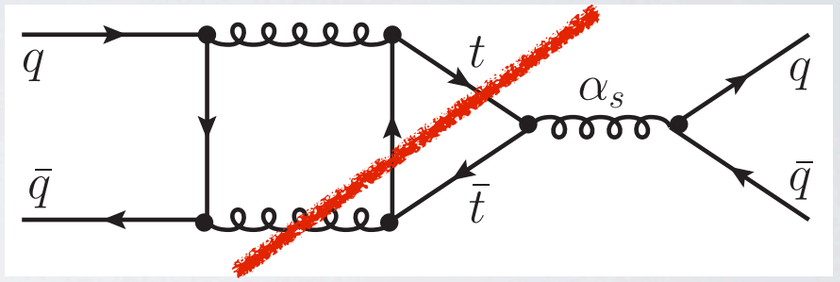
Asymmetry in QCD at NLO from virtual and real gluons:

$\sigma_a > 0$ $\qquad\qquad$ $\sigma_a < 0$

$\sigma_a$ " = "




+




[Ahrens et al., PRD 84 (2011) 074004]

NLO QCD + NNLL + EW:

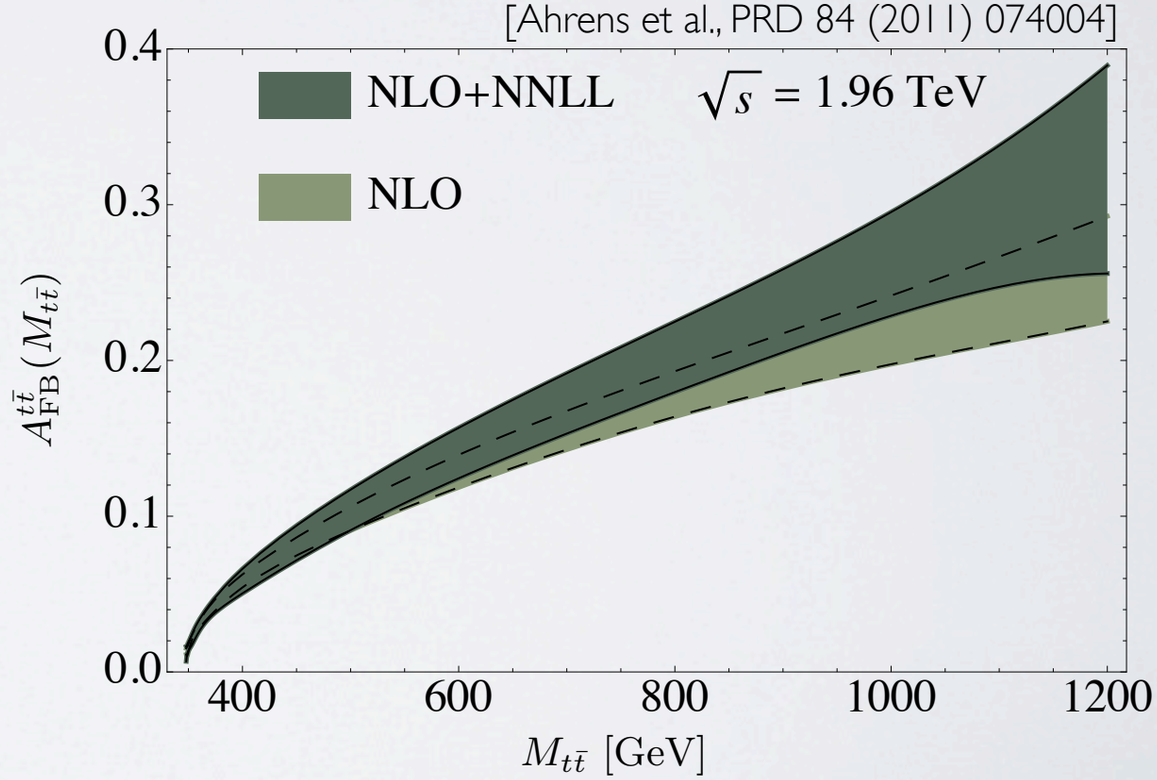
$$A_C^{\mathrm{TEV}} = (7.16^{+1.05}_{-0.68}\,\%) \cdot 1.22_{\mathrm{EW}}$$

[Ahrens et al., PRD 84 (2011) 074004]
[Hollik, Pagani, PRD 84 (2011) 093003]

NLO QCD + EW:

$$A_C^{\mathrm{LHC7}} = 1.15 \pm 0.06\,\%$$

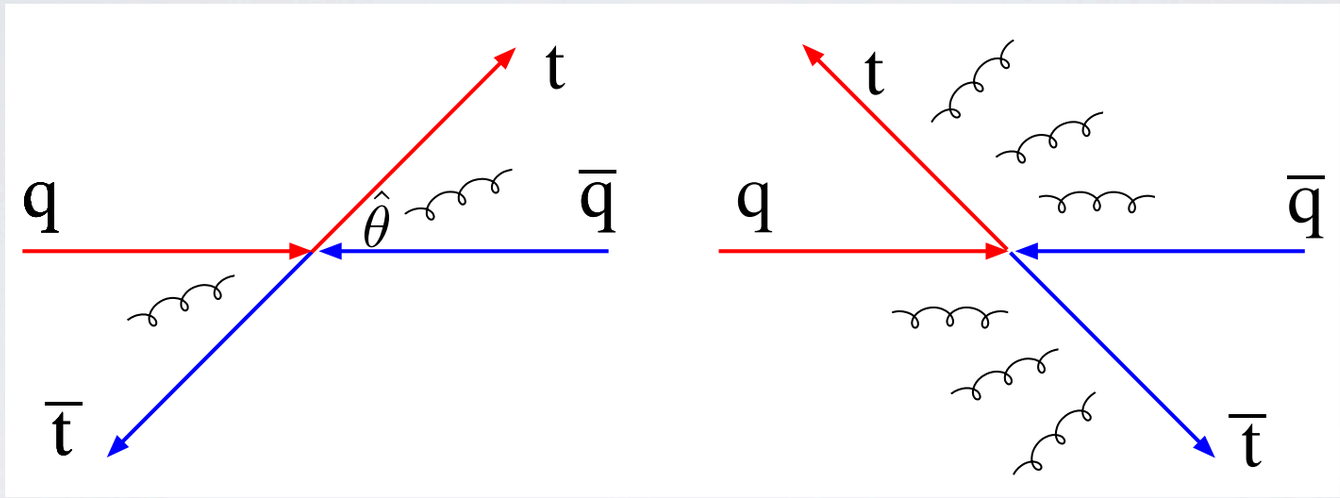
[Kühn, Rodrigo, JHEP 1201 (2012) 063]




Results are stable with respect to soft gluon resummation.

# QCD PREDICTION FROM EVENT GENERATORS

Asymmetry arises from QCD coherence:




More radiation for backward tops ⟶ large recoil of the $t\bar{t}$ pair.

[Skands, Webber, Winter, JHEP 1207 (2012) 151]

Minimal radiation for large $y_t$ and $m_{t\bar{t}} \approx \hat{s}$

⟶ $A_C$ grows with $\Delta y = y_t - y_{\bar{t}}$ (but less than observed in the data)

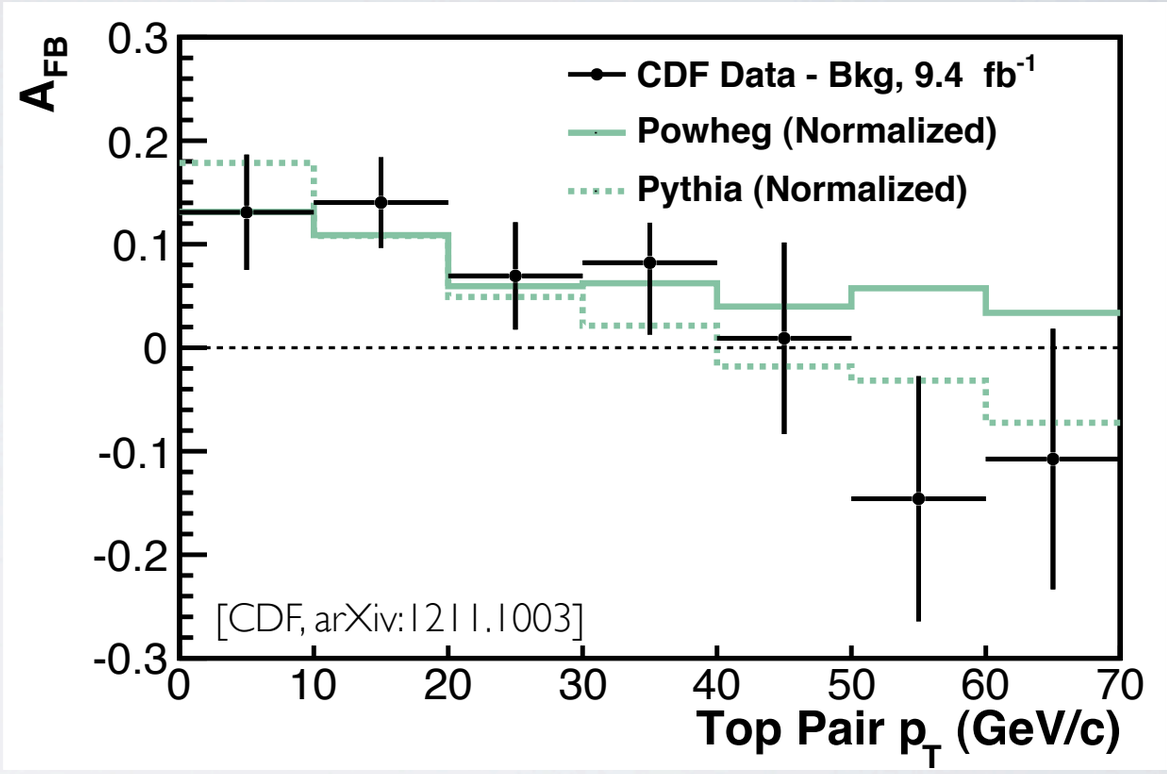
⟶ $A_C$ grows with $m_{t\bar{t}}$

# COMPARISON WITH DATA

Low $p_T^{t\bar{t}}$: $A_C > 0$
virtual contributions dominant.

High $p_T^{t\bar{t}}$: $A_C < 0$
real radiation dominant.

Reconstruction and modelling of $p_T^{t\bar{t}}$ dependence is robust.



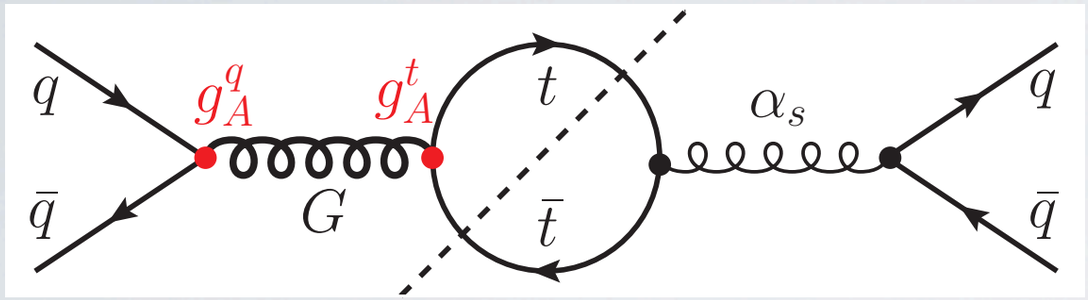

---

Used by CDF & D0:
Monte Carlos matched to NLO QCD + EW corrections

$$A_C^{\mathrm{MC}} = \frac{\sigma_a^{\mathrm{MC@NLO}}}{\sigma_s^{\mathrm{MC@NLO}}} \cdot \frac{\sigma_s^{\mathrm{NLO}}}{\sigma_s^{\mathrm{LO}}} \cdot R_{\mathrm{EW}}$$

Normalize to LO or NLO QCD?

# S-CHANNEL NEW PHYSICS: AXIGLUONS




Constructive interference for

$M_G < 2m_t : \; g_A^q \cdot g_A^t > 0$

$M_G > 2m_t : \; g_A^q \cdot g_A^t < 0$

<u>Towards UV completion:</u>

Chiral color breaking $SU(3)_L \times SU(3)_R \xrightarrow{\langle \Phi \rangle} SU(3)_C$

Anomaly cancellation and coupling textures: new fermions.

<u>Axigluon constraints:</u>

- Dijet and top pair production ■■, dijet pair production ■
- LHC charge asymmetry ■■
- Precision electroweak observables (PEW) ■

# CONSTRAINTS ON HEAVY AXIGLUONS

## Dijet resonances at LHC

$g_A^q \lesssim 0.3\, g_s \quad (M_G \lesssim 2\,\mathrm{TeV},\, \Gamma_G/M_G \lesssim 15\,\%)$

## Dijet angular distributions

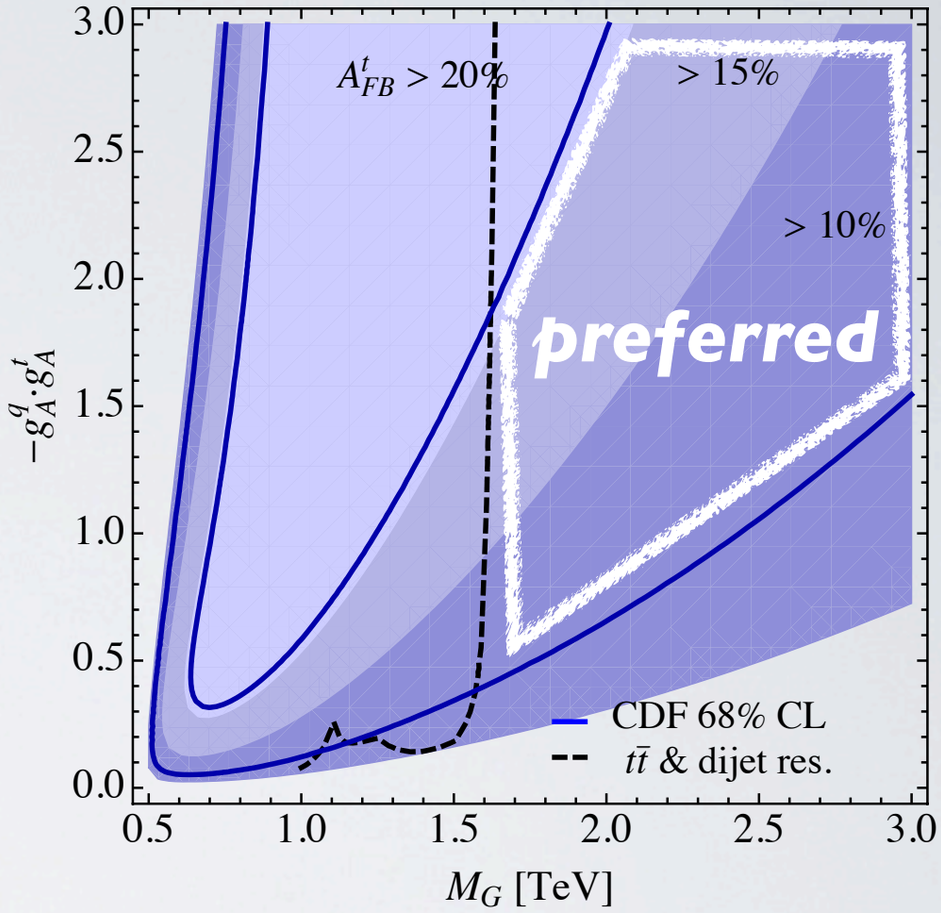
$g_A^q \lesssim 0.7\, g_s$ ($M_G \lesssim 2\,\mathrm{TeV}$, largely width-independent)

## Top pair production

- Top-antitop resonance searches are insensitive to $g_A^t$ for $g_A^q \ll g_A^t$.
- Spectrum $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ probes axigluons with $M_G \approx M_{t\bar{t}} \lesssim 1.6\,\mathrm{TeV}$.

## LHC charge asymmetry

$A_C^{|y|} \lesssim 2\,\%$ o.k. with $A_{\mathrm{FB}}^t$




An axigluon with $M_G \approx 2\,\mathrm{TeV}$ and strong couplings to top quarks can explain the excess in $A_{\mathrm{FB}}^t$.

# CONSTRAINTS ON LIGHT AXIGLUONS

Dijet pair resonance searches rule out *narrow* axigluons with $100 \lesssim M_G \lesssim 500\,\mathrm{GeV}$.

[CDF, ATLAS, CMS 2012]

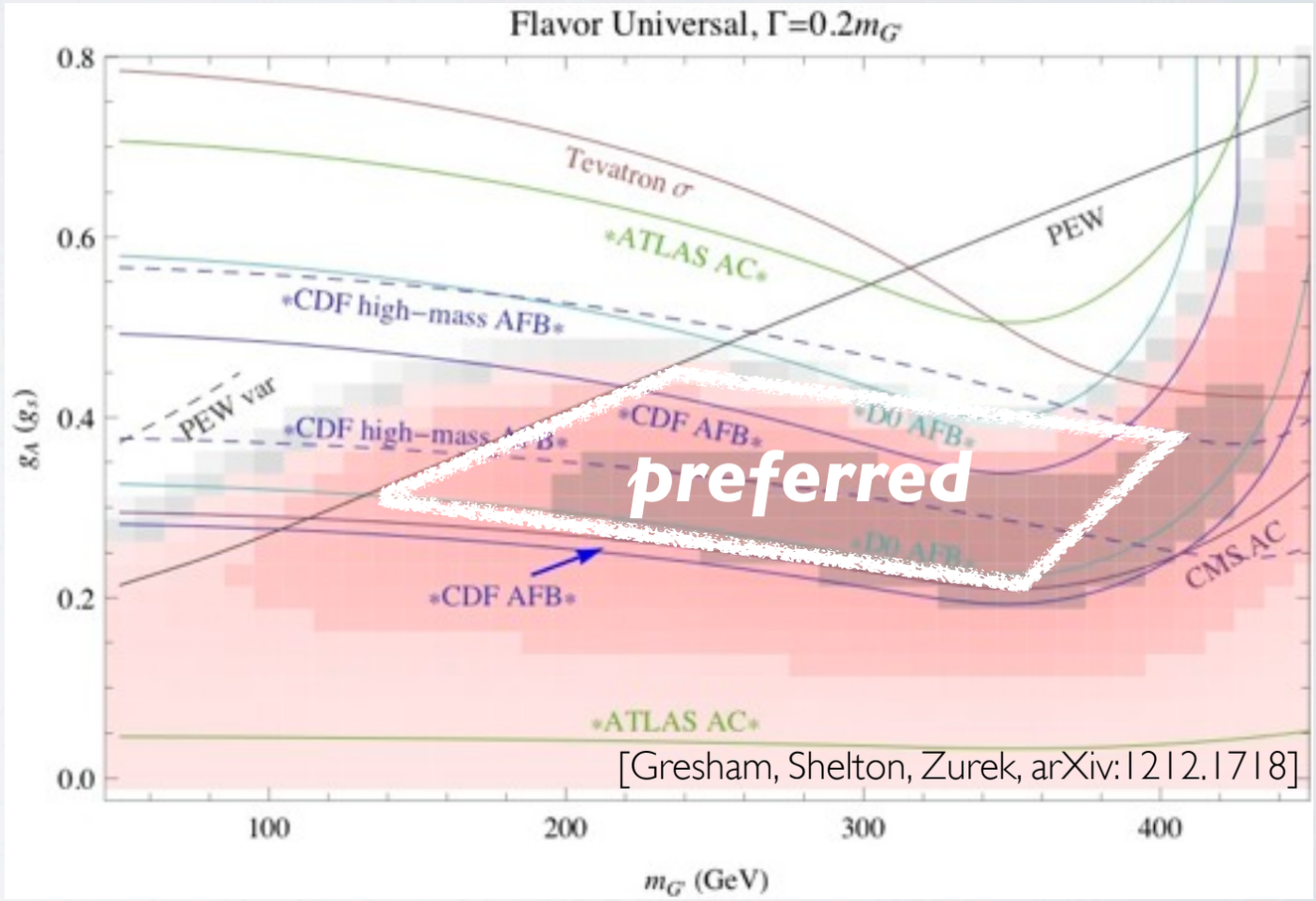
<u>Counter-acting constraints</u>

PEW (mainly $\Gamma_Z$, $\sigma_{\mathrm{had}}$) and LHC asymmetry $A_C^{|y|}$.

- Non-universal $g_R^d < -g_R^u$:
Relax $A_C^{|y|}$, strengthen PEW.

- Increase $g_R^t$:
Relax PEW, but trouble with top observables.

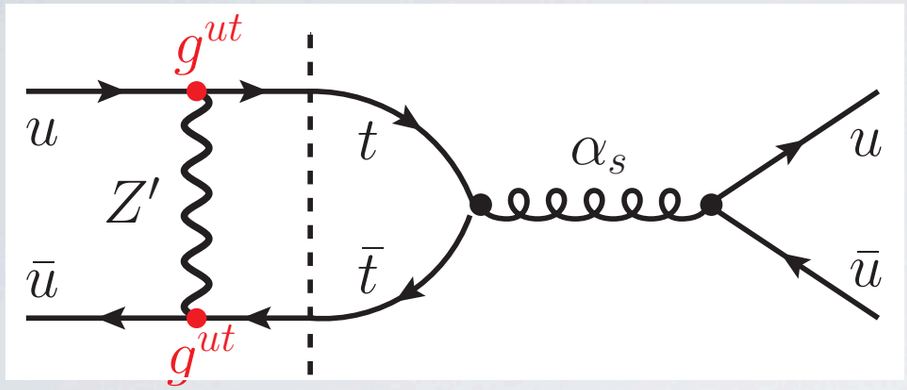
- New fermions strengthen bounds from PEW.




[Gresham, Shelton, Zurek, arXiv:1212.1718]

Preferred: $200 \lesssim M_G \lesssim 450\,\mathrm{GeV}$ and $g_A^q = g_A^t \sim 0.3 - 0.4\,g_s$ .

# T- AND U-CHANNEL: Z´, W´, SCALARS




Flavor constraints

u-c and c-t couplings induce FCNCs

$$\rightarrow g_{ut}\, Z'_\mu \bar{u}_R \gamma^\mu t_R$$

Flavor symmetries

- protect Z´ model from large FCNCs
- avoid same-sign top production ( $uu \rightarrow Z' \rightarrow tt$ )
- imply flavor-diagonal couplings $g_u\, Z'_\mu \bar{U}_R \gamma^\mu U_R$

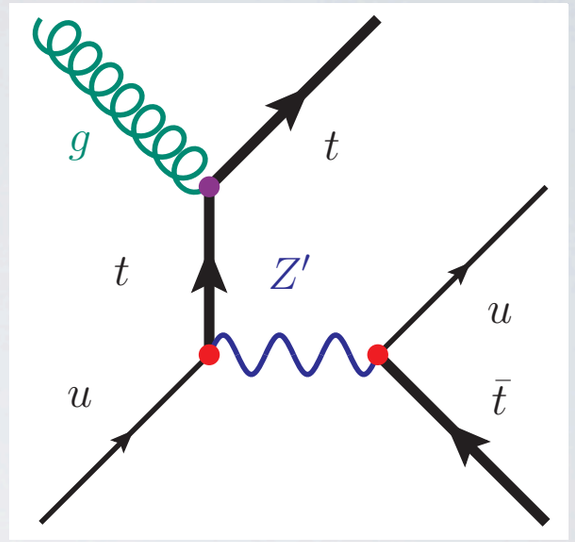
  ⟶ dijet constraints are important

Scalars in u-channel are disfavored by $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ and atomic parity violation.

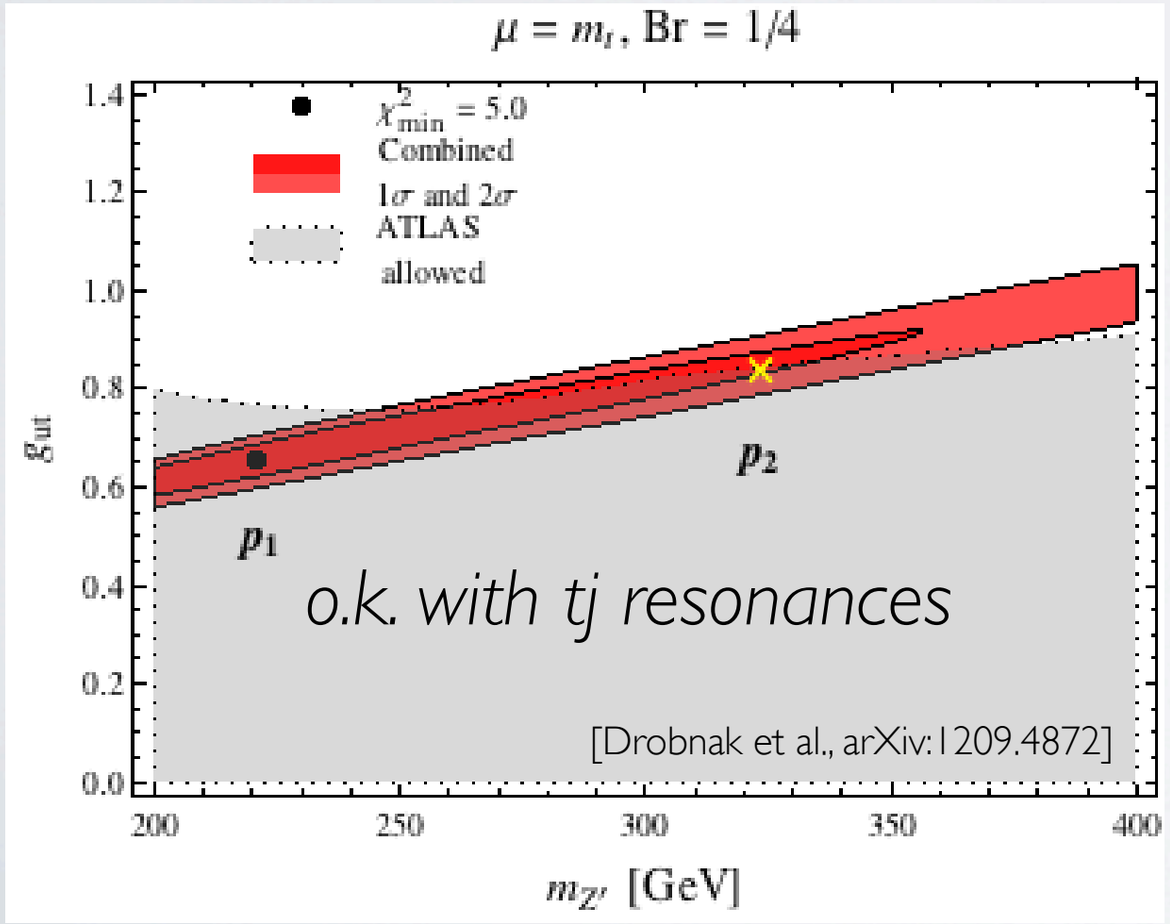
# ASSOCIATED T+Z´ PRODUCTION

Negative contribution of Z´ to $A_C^{|y|}$
reconciles large $A_{\rm FB}^t$ with SM-like $A_C^{|y|}$.

[Alvarez, Coluccio, arXiv:1209.4354] [Drobnak et al., arXiv:1209.4872]




## Fit to inclusive $t\bar{t}$ production




## Top-jet resonances

$$\mathcal{B}(Z' \to \bar{t}u) \lesssim 30\,\%$$

Need other Z´ decay modes.

## Jet multiplicities in $t\bar{t}$ prod.

Rule out u-channel scalars.

[Shelton 2012, unpublished]

No conclusion about $Z' \to jj$.

# OPEN QUESTIONS AND NEXT STEPS

<u>For theorists</u>

- NNLO QCD contributions to charge asymmetry
- Normalization of $A_{\mathrm{FB}}^{t}$ and scale uncertainties

<u>For experimentalists</u>

- Lepton and threshold asymmetries in top pair prod.
- Top-quark spin and polarization measurements

<u>For both</u>

- Dijet angular distributions for heavy and light axigluons
- Asymmetry and distributions in top pair plus hard jet
- Inclusive top + X observables for t-channel candidates