Reconciliation of A_{FB} and A_C

with s-channel or t-channel NP

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Introduction

- Exploring the $t\bar{t}$ production and possible NP effects.
- The persisting Tevatron $t\bar{t}$ production anomaly in A_{FB}.
- LHC measuring A_C - in agreement with SM.

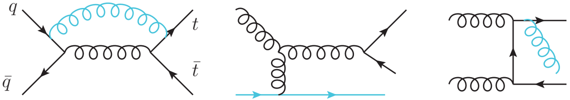
Reconciliation with two examples

1) How correlated are A_{FB} and A_C?
   What kind of NP could accommodate both measurements? JD, Kamenik, Zupan 1205.4721
2) A novel consideration: $t\bar{t}$ observables are based on inclusive samples!
   What if there is considerable $t\bar{t}j$ contribution? JD, Kagan, Kamenik, Perez, Zupan 1205.4721

- Need of consistency with other collider observables
  $m_{t\bar{t}}$ spectrum, $\sigma_{t\bar{t}}$, di-jets, ...

$t\bar{t}$ production asymmetries

- $t\bar{t}$ production is a QCD process



- Only higher order quantum corrections give rise to charge asymmetries

Definition of asymmetries

$$A_{FB} = \frac{N[\Delta y > 0] - N[\Delta y < 0]}{N[\Delta y > 0] + N[\Delta y < 0]}\,, \qquad \Delta y = y_t - y_{\bar{t}}$$

$$A_C = \frac{N[\Delta |y| > 0] - N[\Delta |y| < 0]}{N[\Delta |y| > 0] + N[\Delta |y| < 0]}\,, \quad \Delta |y| = |y_t| - |y_{\bar{t}}|$$

$t\bar{t}$ production asymmetries

- SM at NLO in QCD and EW.

  Frixione et al. hep-ph/0204244, hep-ph/0305252 **Hollik, Pagani** 1107.2606 **Kuhn, Rodrigo** 1109.6830 **Manohar, Trott** 1201.3926

- Comparing SM predictions with averaged Tevatron and LHC results

  JD, Kagan, Kamenik, Perez, Zupan 1209.4872

SM vs Experiment

	SM prediction	Experiment	Discrep.
A_{FB}	0.088 ± 0.006	0.174 ± 0.038	2.3σ
A_{FB}^{high}	$0.129^{+0.008}_{-0.006}$	0.296 ± 0.067	2.5σ
A_C	$(1.23 \pm 0.05)10^{-2}$	$(1.15 \pm 1.25)10^{-2}$	/

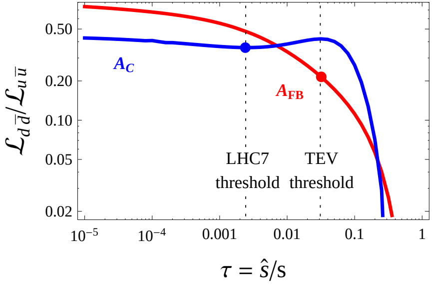
- Models addressing the A_{FB} puzzle typically predict non-negligible A_C in tension with LHC data. **Kamenik et al.** 1107.5257 **Aguilar-Saavedra, Perez-Victoria** 1105.4606
- Should we conclude that observed A_{FB} is not due to NP but a statistical fluctuation?
- Through general considerations we investigate the correlation between A_{FB} and A_C to answer this question.

A_{FB} vs A_C

- At the partonic level A_{FB} and A_C are both due to the same charge asymmetric part of $q\bar{q} \to t\bar{t}$ cross-section (proportional to $\hat{t} - \hat{u}$) (strong positive correlation).
- Different valence structure of $p\bar{p}$ and pp initial states

$$\sigma = \sum_{i,j} \int \frac{\mathrm{d}\hat{s}}{s} \mathrm{d}y \left(\frac{\mathrm{d}\mathcal{L}_{i,j}}{\mathrm{d}\hat{s}\mathrm{d}y} \right) \left(\hat{s}\hat{\sigma}_{ij} \right)$$

- Correlation can be lost if NP couples to both u and d quarks significantly and with opposite sign.



A_{FB} vs A_C [effective theory]

- Interference of the leading order SM amplitudes and NP contributions.
- At $\mathcal{O}(\alpha_S \Lambda^{-2})$ there are only two relevant dimension 6 NP operators.

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

- Not affect the $t\bar{t}$ cross-section, while they do generate shifts in inclusive A_{FB} and A_C

$$\Delta A_{FB} = -10\% \times \left(0.84 C_A^{ut} + 0.12 C_A^{dt}\right)\left(1{\rm TeV}/\Lambda\right)^2$$
$$\Delta A_C = -1\% \times \left(1.4 C_A^{ut} + 0.52 C_A^{dt}\right)\left(1{\rm TeV}/\Lambda\right)^2$$

- A large A_{FB} and small or negative A_C are possible, if C_A^{dt} and C_A^{ut} have opposite signs and $|C_A^{dt}| \gtrsim |C_A^{ut}|$.

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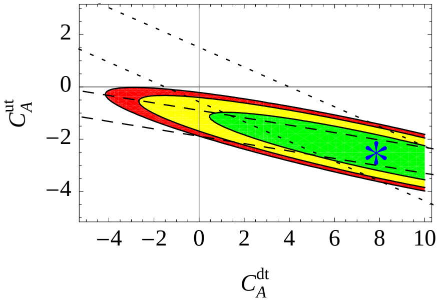


Asymmetric Axigluon

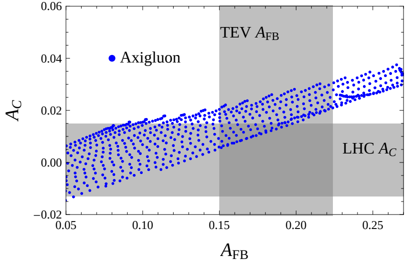
- We present a study of a model that indeed resembles the presented EFT conditions.
- Simple modification of light axigluon model introduced by Tavares and Schmaltz Tavares, Schmaltz 1107.0978 .
- $SU(3)_L \times SU(3)_R$ gauge symmetry broken spontaneously via $\phi_{3,\bar{3}}$ scalar to diagonal $SU(3)_{\text{color}}$.

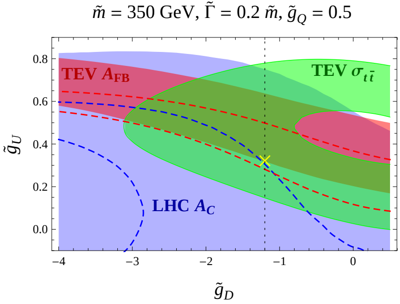
$$\begin{aligned}\mathcal{L} &= -\frac{1}{4}(G^a_{\mu\nu})^2 - \frac{1}{4}(\tilde{G}^a_{\mu\nu})^2 + \frac{\tilde{m}^2}{2}\tilde{A}^2_\mu + \bar{Q}(i\not{D} - \tilde{g}_Q \tilde{\not{A}})Q \\ &\quad + \bar{U}(i\not{D} + \tilde{g}_U \tilde{\not{A}})U + \bar{D}(i\not{D} + \tilde{g}_D \tilde{\not{A}})D + \dots ,\end{aligned}$$

Asymmetric Axigluon

$$\mathcal{L} = \cdots + \bar{Q}(i\not{D} - \tilde{g}_Q \tilde{\not{A}})Q + \bar{U}(i\not{D} + \tilde{g}_U \tilde{\not{A}})U + \bar{D}(i\not{D} + \tilde{g}_D \tilde{\not{A}})D + \cdots$$

- Scan over the $\tilde{g}_U$ and $\tilde{g}_D$ shows points within 1σ experimental intervals (left).
- Further considerations reveal regions compatible with A_{FB}, A_C and σ_{tt} (right).
- Anticipated decorrelation indeed realized!





Asymmetric Axigluon

Compliance with other observables

- $m_{t\bar{t}}$ spectrum **CDF** 0903.2850
- Dijet production **CDF** 0812.4036
- Dijet pair production **CMS** PAS EXO-11-016

Asymmetric Axigluon

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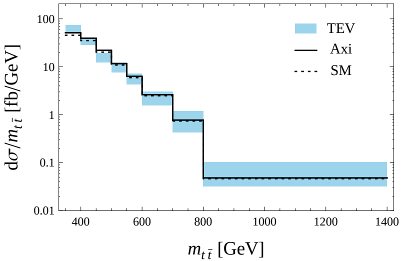

- Axigluon is light, $\tilde{m} = 350$ GeV - below the $t\bar{t}$ threshold!

Asymmetric Axigluon

Compliance with other observables

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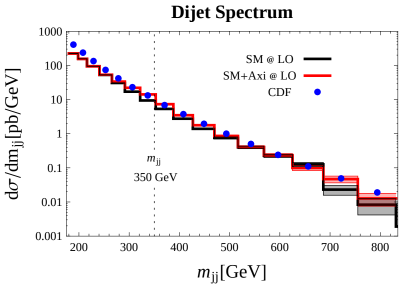

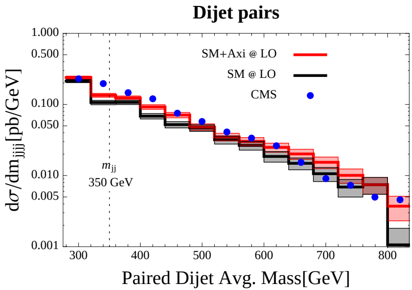

- To pass the test of dijet pairs $\tilde{\Gamma} \sim 0.2\tilde{m}$ is needed. Doable by setting

$$\tilde{g}_D^{(s)} = \tilde{g}_D^{(b)} = -3.7 \quad \text{or} \quad \tilde{g}_D^{(b)} = -5.1$$

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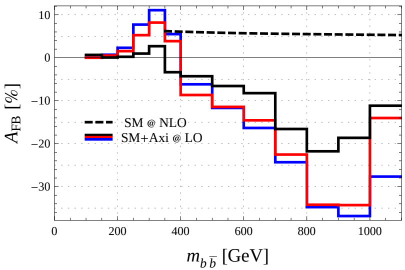
- A direct consequence: prediction of large A_{FB} in $b\bar{b}$!

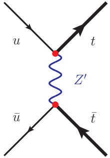


t-channel associated production

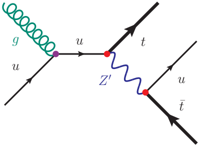
- Illustration of the mechanism with a simple Z' model.

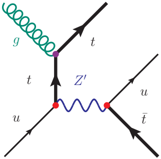
$$\mathcal{L} = g_{ut}\, Z'_\mu\, \bar{u}_R\, \gamma^\mu\, t_R + \text{h.c.} + M_{Z'}^2\, Z'^\dagger_\mu\, Z'^\mu$$

- t-channel exchange leads to increased A_{FB} as well as A_C

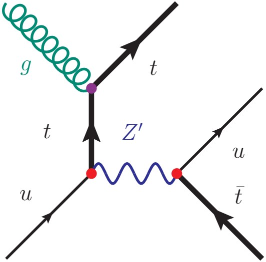


- Additional negative contribution to A_C can be obtained considering associated Z' production!





The mechanism



- The Z' decay yields a $\bar{t}$ quark which tends to be boosted in the same direction as the incoming u quark.
- PDF of u quark "harder" than PDF of the gluon.
- On average, $\bar{t}$ produced with larger rapidity than $t \Rightarrow$ negative contribution to A_C.

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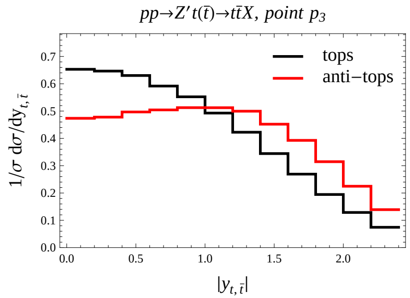

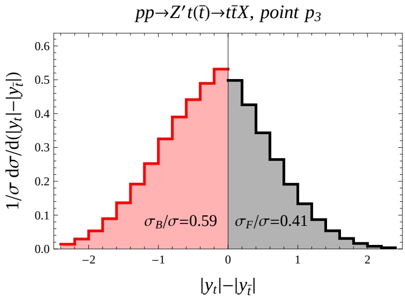

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- PDF of u quark "harder" than PDF of the gluon.
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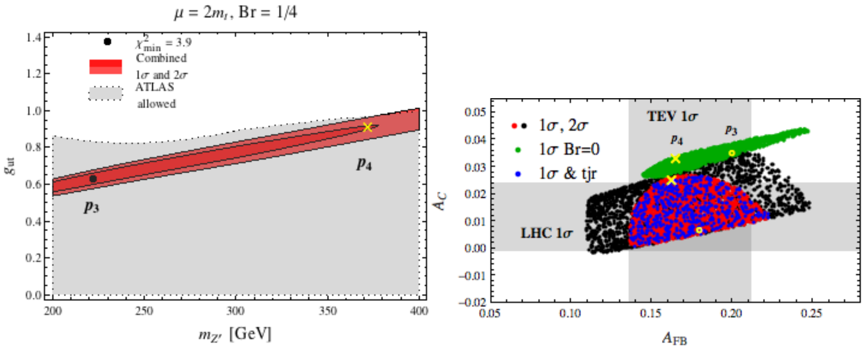
Validity

- Benchmark points: χ^2 including total x-sections and asymmetries.



- Additional checks for compatibility with
  - ◇ $m_{t\bar{t}}$ spectrum at Tevatron and LHC CDF 0903.2850 ATLAS 1207.5644 .
  - ◇ Atlas search for top-jet resonances ATLAS CONF-2012-096 .
  - ◇ CMS jet multiplicity distribution in semileptonic $t\bar{t}$ events CMS PAS-TOP-11-003 .
  - ◇ Indirect constraint - Atomic Parity Violation.

Validity

Compliance with other observables

- $m_{t\bar{t}}$ spectrum **CDF** 0903.2850 **ATLAS** 1207.5644
- Jet multiplicities **CMS** PAS-TOP-11-003

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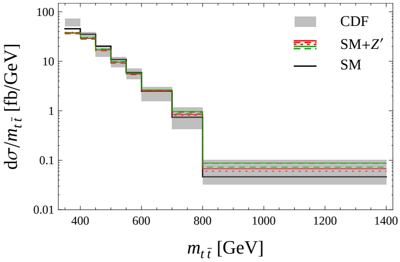

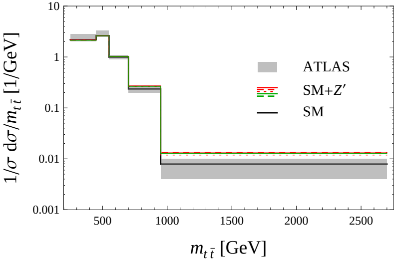

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- $m_{t\bar{t}}$ spectrum — CDF 0903.2850 — ATLAS 1207.5644 — $\surd$
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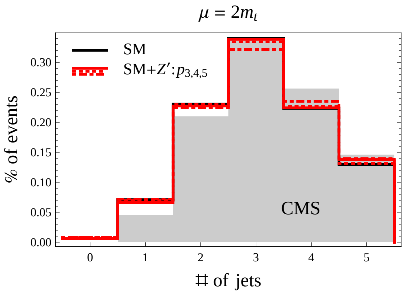

Conclusions

- NP can still accommodate both A_{FB} and A_C measurements.
- The strong correlation between A_{FB} and A_C can be removed due to the different valence quark structure of the pp and $p\bar{p}$
- NP has to couples to u and d quarks substantially and with opposite sign.
- We have implemented this in an light axigluon model, which seems to survive all present experimental constraints and in addition predicts a large $b\bar{b}$ asymmetry.

- t-channel NP can resolve the A_{FB} and lead to significant increases in A_C predictions.
- Substantial associated NP production contributing to $t\bar{t}j$ final gives negative A_C contributions.
- This can reconcile the A_{FB} vs. A_C issue, leaving A_FB above SM and bringing A_C back down to SM value.
- We have implemented the mechanism in form of a simple Z' model, checking the compatibility with other collider constraints.