BSM top quark physics

Production and decay

Jure Drobnak

Institut
"Jožef Stefan"
Ljubljana, Slovenija

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Introduction

- Top quark physics being explored with ever increasing precision!
- SM predictions in **production** and **decay** put under scrutiny.

NP in the main decay channel of the top quark $t \to Wb$

- Anomalous charged quark currents affect the helicity fractions of W boson.
- Indirect constraints from meson physics to be considered! Nice interplay of top and bottom physics.

NP in top production

- Single top production (weak process).
- The persisting Tevatron $t\bar{t}$ production anomaly in A_{FB}.
- LHC measuring A_C.
- **How correlated are A_{FB} and A_C?** JD, Kamenik, Zupan 1205.4721

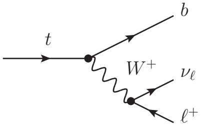
W helicity fractions is $t \to bW$

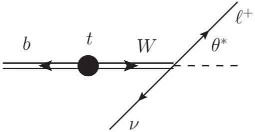
- More than 99% of tops decays through the main decay channel

$$\Gamma(t \to Wb) = |V_{tb}|^2 \frac{m_t}{16\pi} \frac{g^2}{2} \frac{(1-x^2)^2(1+2x^2)}{2x^2} \sim 1.5 \text{ GeV}$$

- We can split the decay width $\Gamma(t \to Wb)$ with respect to the polarization of W boson.

$$\Gamma_{t\to bW} \quad = \quad \Gamma_L + \Gamma_- + \Gamma_+ \,, \qquad \mathcal{F}_i = \Gamma_i/\Gamma \,.$$





W helicity fractions is $t \to bW$

- Non-zero $\mathcal{F}_+$ in SM comes from QCD and EW corrections, $m_b \neq 0$.

  A. Czarnecki et al. 1005.2625 **H. S. Do et al.** hep-ph/0209185 **M. Fischer et al.** hep-ph/0101322

- Helicity fractions are accessible through angular distribution of final state leptons. Latest measurements from Tevatron and ATLAS **CDF&D0** 1202.5272 **ATLAS** 1205.2484

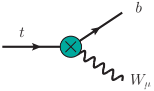
SM vs Experiment

	SM prediction	Tevatron	ATLAS
$\mathcal{F}_+$	$0.0017(1)$	-0.039 ± 0.045	0.01 ± 0.05
$\mathcal{F}_L$	$0.687(5)$	0.732 ± 0.081	0.67 ± 0.07

- Measured $\mathcal{F}_+ > 0.2\%$ NP effect!
- Projected sensitivity for LHC ($L = 10\text{fb}^{-1}$) **J. A. Aguilar-Saavedra et al.** 0705.3041

$$\sigma(\mathcal{F}_+) = \pm 0.002 \qquad \sigma(\mathcal{F}_L) = \pm 0.02$$

- How much room for NP?



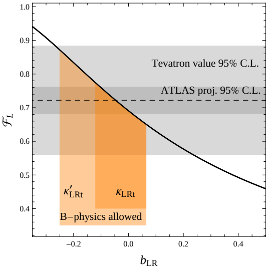
$$\underbrace{\mathrm{i}\frac{g}{\sqrt{2}} V_{tb}^* \gamma^\mu P_L}_{\text{SM}} + \frac{\mathrm{i}g}{\sqrt{2}}\left[\boldsymbol{a}_L \gamma^\mu P_L - \boldsymbol{b}_{LR} \frac{2\mathrm{i}\sigma^{\mu\nu}}{m_t} q_\nu P_R + (L \leftrightarrow R)\right]$$

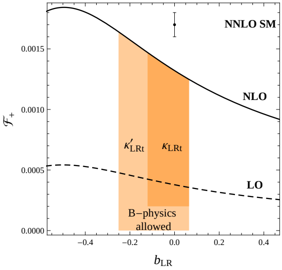
- Indirect constraints for a_R and b_{RL}: mostly from $b \to s\gamma$

JD, Kamenik, Fajfer 1109.2357,1102.4347 , **B. Grzadkowski, M. Misiak** 0802.1413

$$-0.0006 < a_R < 0.003 \qquad -0.0004 < b_{RL} < 0.002$$

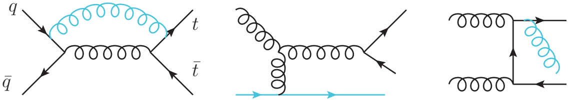
- Effects of b_{LR} on helicity fractions at NLO in QCD **JD, Kamenik, Fajfer** 1010.2402





$t\bar{t}$ production

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



- Only higher order quantum corrections give rise to charge asymmetries

Definition of asymmetries

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

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

$t\bar{t}$ production

- 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, Kamenik, Zupan 1205.4721

SM vs Experiment

	SM prediction	Experiment	Discrep.
A_{FB}	$0.07(2)$	0.187 ± 0.037	3.2σ
A_{FB}^{high}	$0.11(2)$	0.296 ± 0.067	2.8σ
A_C	$0.007(1)$	0.001 ± 0.014	/
A_C^{high}	$0.009(2)$	-0.008 ± 0.047	/

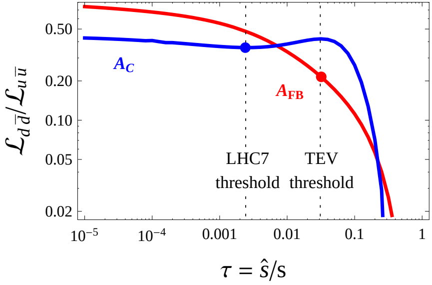
- Models addressing the A_{FB} puzzle typically predict non-negligible A_C in tension with LHC data. Kamenik et al. 1107.5257 — Aguilar-Saavedra, Perez-Victoria 1105.4606
- Should we conclude that observed A_{FB} is not due to NP but a statistical fluctuation?
- Through general considerations we investigate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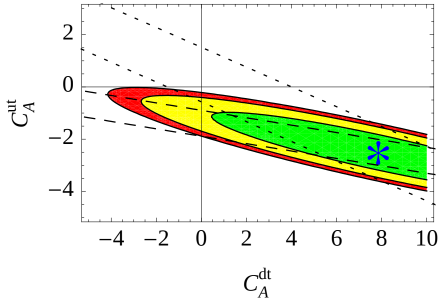


Asymmetric Axigluon

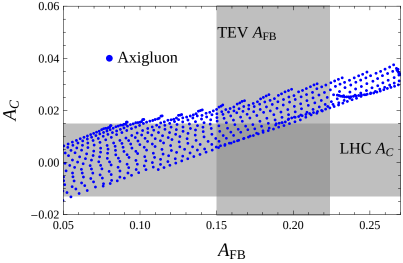
- We present a study of a model that indeed resembles the presented EFT conditions.
- Simple modification of light axigluon model introduced by Tavares and Schmaltz **Tavares, Schmaltz** 1107.0978
- $SU(3)_L \times SU(3)_R$ gauge symmetry broken spontaneously via $\phi_{3,\bar{3}}$ scalar to diagonal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

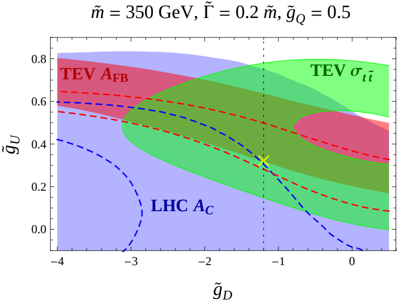
$$\begin{aligned}\mathcal{L} &= -\frac{1}{4}(G^a_{\mu\nu})^2 - \frac{1}{4}(\tilde{G}^a_{\mu\nu})^2 + \frac{\tilde{m}^2}{2}\tilde{A}^2_\mu + \bar{Q}(i\not{D} - \tilde{g}_Q \tilde{\not{A}})Q \\ &\quad + \bar{U}(i\not{D} + \tilde{g}_U \tilde{\not{A}})U + \bar{D}(i\not{D} + \tilde{g}_D \tilde{\not{A}})D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

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
- Dijet production
- Dijet pair production

Asymmetric Axigluon

Compliance with other observables

- $m_{t\bar{t}}$ spectrum $\surd$
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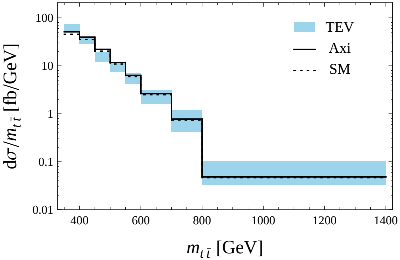
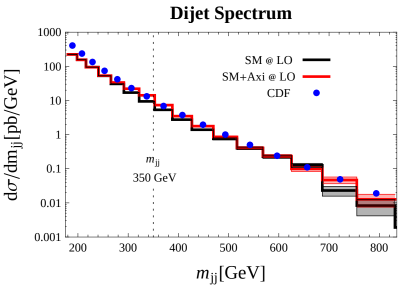


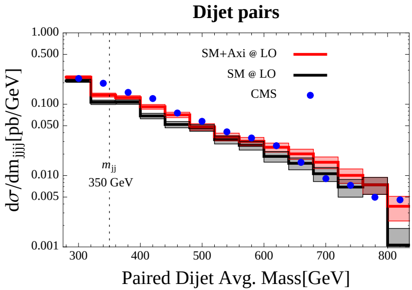
- Axigluon is light, $\tilde{m} = 350$ GeV - below the $t\bar{t}$ threshold!

Asymmetric Axigluon

Compliance with other observables

- $m_{t\bar{t}}$ spectrum $\surd$
- Dijet production $\surd$
- Dijet pair production $\surd$





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

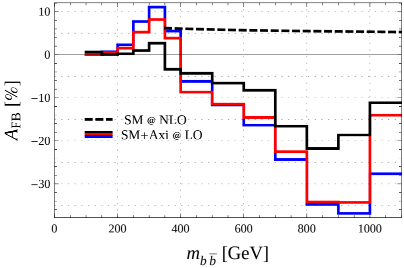
$$\tilde{g}_D^{(s)} = \tilde{g}_D^{(b)} = -3.7 \quad \text{or} \quad \tilde{g}_D^{(b)} = -5.1$$

Asymmetric Axigluon

Compliance with other observables

- $m_{t\bar{t}}$ spectrum $\surd$
- Dijet production $\surd$
- Dijet pair production $\surd$

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

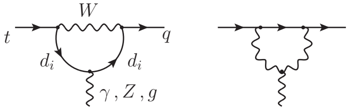


Conclusions

- Helicity fractions of the W boson in the main decay channel can probe the structure of tWb vertex.
- Present measurements of $\mathcal{F}_L$ constrain the anomalous couplings. a_R and b_{RL}, which are associated with right-handed b quarks are highly constrained by B phyiscis, while for b_{LR} direct bounds are competitive with the indirect.
- A potential measurement of $\mathcal{F}_+ > 0.002$ could not be explained by our simple anomalous coupling consideration, even when NLO QCD corrections are included.

- The strong correlation between A_{FB} and A_C can be removed due to the different valence quark structure of the pp and $p\bar{p}$ granted that NP 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.

Top quark FCNC decays



- $t \to q\gamma, Z, g$ decays highly suppressed in SM. The suppression of the branching ratios is two fold.

$$\mathrm{Br}[t \to qV] \propto |V_{qb}|^2 |f^{(V)}(x_b)|^2 \sim [10^{-14}, 10^{-12}]$$

  - ◇ $x_b \ll 1$, so the loop functions give small contributions
  - ◇ and secondly $|V_{qb}| \ll 1$.

Top quark FCNC decays

- Within many BSM models, THDM, MSSM, models with up-type quark singlets, etc., the suppression of FCNC top quark decays can be lifted Aguilar 2004, Yang 2008 .
- An observation of FCNC top quark decays would signal presence of NP.
- Model independent indirect constraints: observation still possible! Fox et al. 0704.1482

- So far upper limits on branching fractions are creeping lower and lower.
  - CMS with 4.6 fb^{-1} CMS-PAS-TOP-11-028

$$\text{Br}[t \to qZ] \quad < \quad 3.4 \times 10^{-3}$$

  - ATLAS with 2.05 fb^{-1} ATLAS 1203.0529

$$\text{Br}[t \to \{u, c\}g] \quad < \quad \{5.7, 27\} \times 10^{-5}$$