Top-Quark Forward-Backward Asymmetry in Randall-Sundrum Models

Susanne Westhoff
in collaboration with M. Bauer, F. Goertz, U. Haisch, and T. Pfoh

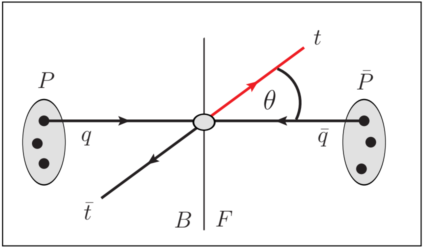
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Rencontres de Moriond, Mar 13-20 2011, La Thuile, Italy

Forward-backward asymmetry in $t\bar{t}$ production

Charge-(a)symmetric cross section

$$\sigma_{a(s)} = \int_0^1 \cos\theta \left[\frac{d\sigma(p\bar{p} \to t\bar{t}X)}{d\cos\theta} - (+) \frac{d\sigma(p\bar{p} \to \bar{t}tX)}{d\cos\theta} \right]$$



$$A_{\rm FB}^t = \frac{N_t(F) - N_t(B)}{N_t(F) + N_t(B)} = \frac{\sigma_a}{\sigma_s}$$

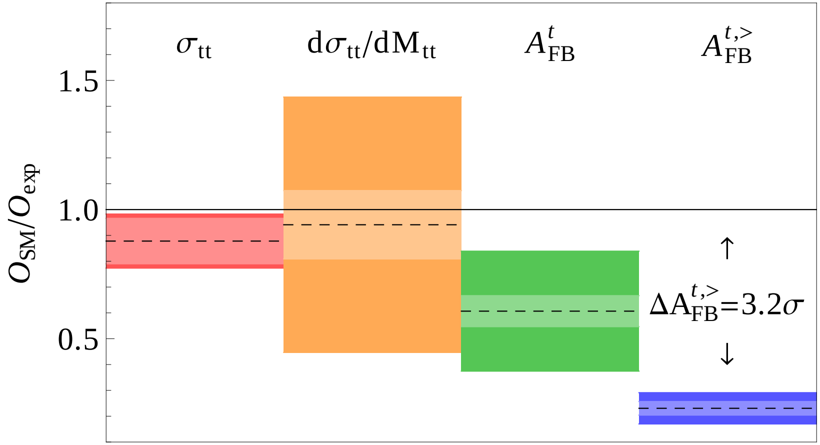
Measurement at Tevatron: inclusive and in bins of invariant mass $M_{t\bar{t}}$

$$(A_{\rm FB}^t)_{\rm exp}^{p\bar{p}} = (15.0 \pm 5.0_{\rm stat} \pm 2.4_{\rm syst})\%$$

$$(A_{\rm FB}^t)_{\rm exp}^{M_{t\bar{t}} > 450\,{\rm GeV}} \equiv (A_{\rm FB}^{t,>})_{\rm exp} = (47.5 \pm 11.4)\%$$

[CDF '11]

Standard Model predictions versus Tevatron data



Asymmetric observables lie significantly below the measurement.

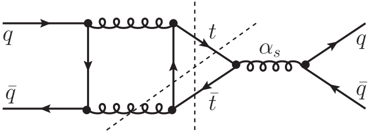
Standard deviations δO_{SM} and δO_{exp} added in quadrature.

A large charge asymmetry from New Physics

Vector V (axial-vector A) current is odd (even) under charge conjugation.

Standard Model: A_{FB}^t at NLO

$$\sigma_a \sim \alpha_s^3$$



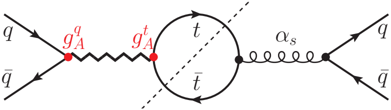
+ 10% electroweak corrections

NLO+NNLL: [Ahrens et al. '11]

$$(A_{\mathrm{FB}}^t)_{\mathrm{SM}}^{p\bar{p}} = 4\% - 5.6\%$$

New physics: A_{FB}^t at tree level

$$\sigma_a \sim -\alpha_s\, g_A^q g_A^t$$



+ t- and u-channel new physics

Tree-level effects in cross section:

$$\sigma_s \sim \alpha_s\, g_V^q g_V^t.$$

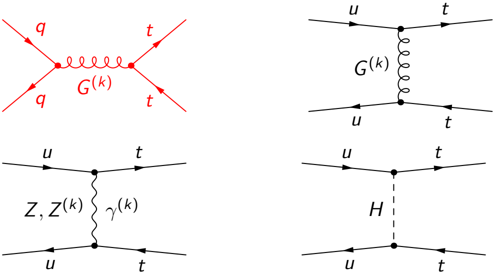
Good fit to $t\bar{t}$ observables expected for $g_A^q g_A^t < 0$ and $|g_V/g_A| < 1$.

Top-quark pair production in Randall-Sundrum models

Massive Kaluza-Klein (KK) gluons $G^{(k)}$
with effective vector and axial-vector couplings to quarks,

$$C_V^{q\bar{q}} = \sum_{X,Y=L,R} C_{XY}^{q\bar{q}}, \qquad C_A^{q\bar{q}} = \sum_{X\neq Y} C_{XX}^{q\bar{q}} - C_{XY}^{q\bar{q}}.$$

Interference with Standard-Model gluon:

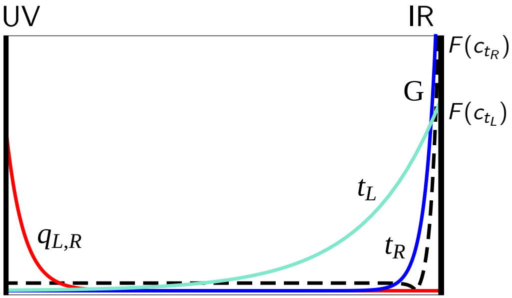


Effective theory for $M_G \gtrsim 1\,\text{TeV}$:

$$\mathcal{L}_{\text{eff}} = \sum_{X,Y=L,R} C_{XY}^{q\bar{q}}\, Q_{XY}^{q\bar{q}}\,, \qquad Q_{XY}^{q\bar{q}} = (\bar{q}_X \gamma_\mu T^a q_X)(\bar{t}_Y \gamma^\mu T^a t_Y)$$

Quark mass hierarchy from a warped extra dimension

The masses and mixings of quarks follow from their localization along the extra dimension: [Grossman, Neubert '99, Gherghetta, Pomarol '00]



These quark field "profiles" depend on the bulk mass parameters $c_{q_{L,R}}$. For anarchic 5D Yukawa couplings one has

$$c_{t_{L,R}} > -\tfrac{1}{2}: \quad F^2(c_t) \approx (1 + 2c_t)\,,$$

$$c_{q_{L,R}} < -\tfrac{1}{2}: \quad F^2(c_q) \approx (-1 - 2c_q)\, e^{L(2c_q+1)}\,, \quad L = \log\frac{M_{Pl}}{M_W} \approx 37$$

Couplings of quarks to Kaluza-Klein gluons

The vector coupling $C_V^{q\bar{q}}$ is governed by the top-quark profiles:

$$C_V^{q\bar{q}} \sim \frac{4\pi\alpha_s}{M_G^2}\left[F^2(c_{t_L}) + F^2(c_{t_R}) + F^2(c_{q_L}) + F^2(c_{q_R})\right] = \frac{4\pi\alpha_s}{M_G^2}\,\mathcal{O}(1)$$

The axial-vector coupling $C_A^{q\bar{q}}$ is doubly suppressed:

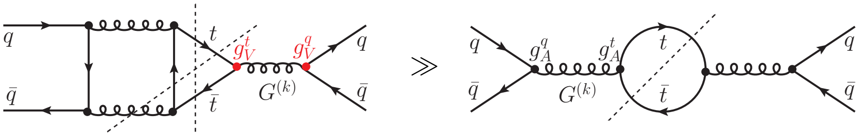
- Light quarks reside in the UV $\rightarrow$ exponential.
- Left- and right-handed light quarks exhibit similar profiles $\rightarrow$ linear.

$$C_A^{q\bar{q}} \sim \frac{4\pi\alpha_s}{M_G^2}\underbrace{\left[F^2(c_{t_L}) - F^2(c_{t_R})\right]}_{\updownarrow\ (c_{t_L} - c_{t_R})}\underbrace{\left[F^2(c_{q_L}) - F^2(c_{q_R})\right]}_{\updownarrow\ (c_{q_L} - c_{q_R})\, e^{L(1+c_{q_L}+c_{q_R})}} = \frac{4\pi\alpha_s}{M_G^2}\,\mathcal{O}(10^{-3})$$

No increase of A_{FB}^t by tree-level KK gluon exchange $\sim C_A^{q\bar{q}}$.

Vector contributions to $A_{\rm FB}^t$ at next-to-leading order

The suppression of the asymmetry in $q\bar{q} \to t\bar{t}$ at tree level is lifted at next-to-leading order (NLO) by vector contributions. [Bauer et al. '10]



$$(A_{\rm FB}^t)_{\rm RS}^{p\bar{p}} = \left[\frac{1 + 0.22\,\tilde{C}_A^{u\bar{u}} + 0.034\,\tilde{C}_V^{u\bar{u}}}{1 + 0.053\,\tilde{C}_V^{u\bar{u}}}\right] \left(5.6^{+0.8}_{-1.0}\right)\%$$

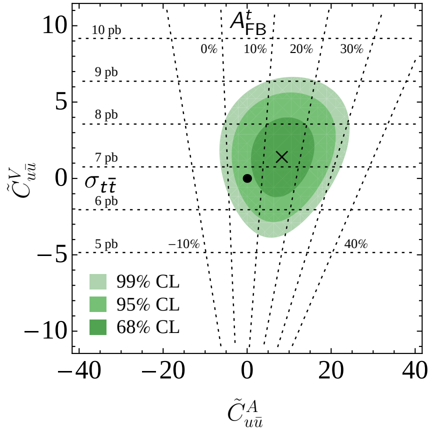
Tree-level contributions in σ_s (over-)compensate NLO contributions in σ_a.

No enhanced asymmetry at NLO: $(A_{\rm FB}^t)_{\rm RS} \lesssim (A_{\rm FB}^t)_{\rm SM}$.

$$\tilde{C}_V^{u\bar{u}} = 1\,\text{TeV}^2\, C_V^{u\bar{u}} = \mathcal{O}(1)\,, \quad \tilde{C}_A^{u\bar{u}} = 1\,\text{TeV}^2\, C_A^{u\bar{u}} = \mathcal{O}(10^{-3})$$

Generalization: Heavy colour-octet bosons in $t\bar{t}$ production

Combined fit to $A_{\rm FB}^t$, $\sigma_{t\bar{t}}$, and $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ in the bin $M_{t\bar{t}} \in [0.8, 1.4]$TeV.



Best fit point ($\times$):

$(\tilde{C}^A_{u\bar{u}}, \tilde{C}^V_{u\bar{u}}) = (8.3, 1.4)$

Improvement w.r.t. SM ($\bullet$) for

- large axial-vector couplings at tree level ($A_{\rm FB}^t$, $A_{\rm FB}^{t,>}$)
- moderate vector couplings ($\sigma_{t\bar{t}}, d\sigma_{t\bar{t}}/dM_{t\bar{t}}$)

For $M_G \lesssim 1$TeV, width effects and contributions $\sim M_G^{-4}$ are important.

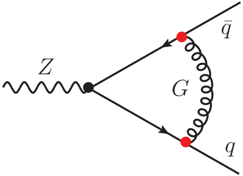
Constraints on massive colour octets in $q\bar{q} \to t\bar{t}$

- Dijet production at the LHC [ATLAS, CMS '10,'11]

Resonances in $pp \to G \to jj$ spectrum and angular distribution

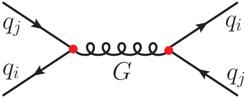
- Electroweak precision observables

$Zb\bar{b}$ coupling, decay width Γ_Z



- Flavour-changing neutral currents at tree level (model-dependent)

Neutral meson mixing (ϵ_K)

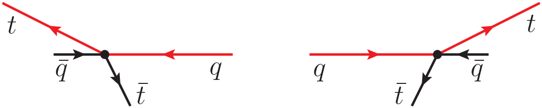


[Bai, Hewett, Kaplan, Rizzo '11, Haisch, Westhoff '11, et al.]

Charge asymmetry at the LHC

The process $pp \to t\bar{t}$ is symmetric $\Rightarrow$ no forward-backward asymmetry.

Top quarks are preferentially emitted along the beam axis at large rapidity:



Charge-asymmetric contributions to $q\bar{q} \to t\bar{t}$ can be probed by an asymmetry in pseudo-rapidities η, [Antunano, Kühn, Rodrigo '98,'08]

$$A_\eta = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}, \quad \Delta\eta = |\eta_t| - |\eta_{\bar{t}}|,$$

$$(A_\eta)_{\text{exp}} = (6.0 \pm 13.4_{\text{stat}} \pm 2.6_{\text{syst}})\% \qquad (36\text{pb}^{-1})$$ [CMS '11]

$$(A_\eta)_{\text{SM}} = (1.3 \pm 0.1)\%$$

To be taken home

No large forward-backward asymmetry in Randall-Sundrum models with anarchic flavour structure:

- Axial-vector couplings of KK gluons to light quarks are strongly suppressed.
- Vector contributions at NLO are constrained by the $t\bar{t}$ cross section.

Dijet production at the LHC sets strong constraints on new physics in $t\bar{t}$ production.

The $t\bar{t}$ charge asymmetry can be probed at the LHC with rapidity-dependent observables.

References

- T. Aaltonen *et al.* [CDF Collaboration], arXiv:1101.0034 [hep-ex].
- V. Ahrens, A. Ferroglia, M. Neubert, B. D. Pecjak and L. L. Yang, arXiv:1103.0550 [hep-ph].
- Y. Grossman and M. Neubert, Phys. Lett. B **474**, 361 (2000), arXiv:hep-ph/9912408.
  T. Gherghetta and A. Pomarol, Nucl. Phys. B **586**, 141 (2000), arXiv:hep-ph/0003129.
- M. Bauer, F. Goertz, U. Haisch, T. Pfoh and S. Westhoff, JHEP **1011**, 039 (2010), arXiv:1008.0742 [hep-ph].
- G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **694**, 327 (2011), arXiv:1009.5069 [hep-ex].
  V. Khachatryan *et al.* [CMS Collaboration], Phys. Rev. Lett. **105**, 211801 (2010), arXiv:1010.0203 [hep-ex].
- Y. Bai, J. L. Hewett, J. Kaplan and T. G. Rizzo, JHEP **1103**, 003 (2011), arXiv:1101.5203 [hep-ph].
  U. Haisch and S. Westhoff, in preparation.
- J. H. Kühn and G. Rodrigo, Phys. Rev. D **59**, 054017 (1999), arXiv:hep-ph/9807420.
  O. Antunano, J. H. Kühn and G. Rodrigo, Phys. Rev. D **77**, 014003 (2008), arXiv:0709.1652 [hep-ph].
- V. Khachatryan *et al.* [CMS Collaboration], CMS-PAS-TOP-10-010.