

## Measurements of forward-backward asymmetries in top-quark pair production at the D0 experiment

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## **Overview**



- Setting the stage
- $A_{FB}$  in 5.4 fb<sup>-1</sup> of l+jets events
- First D0 measurement of A<sup>-1</sup><sub>FB</sub> in
   5.4 fb<sup>-1</sup> of dilepton events
- $A_{_{FB}}$  and top quark polarization
- Conclusion and outlook







Does the top or anti-top quark more often follow the proton direction?



- different ways to answer this question and quantify asymmetry
  - rapidity difference of top and anti-top

$$\Delta y = y_t - y_t = q_l (y_{t, lep} - y_{t, had}) \qquad \qquad y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z}\right)$$

• rapidity gap used for a **frame-independent** definition

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





- no asymmetry at LO QCD in SM
- at NLO asymmetries arises from interferences of process not symmetric under t and t exchange



♦ A<sub>FB</sub> at parton level including NNLL (arXiv:1106.6051) and
 **QED** corrections (arXiv:1107.2606):

MC@NLO	NLO+NNLL	NLO+QED corr.
( <b>5.0 ± 0.1)</b> %	(7.2 ± 1.0) %	(8.9 ± 0.8) %





- event selection:
  - isolated and high energetic jets and lepton (either electron or muon)
  - one identified b-quark jet
- tt modeled by MC@NLO+Herwig
- main background from W+jets

   (Alpgen+Pythia) and multijet events
   (estimated from data)
  - both nearly symmetric in  $\Delta y$
- event reconstruction by kinematic fitter
  - using top and W mass constraints
  - including detector resolution
    - $\rightarrow$  only most probable solution kept









• measured  $A_{_{FR}}$  at detector level after background subtraction:

 $A_{_{FR}}^{det} = (9.2 \pm 3.7 (stat+syst))\%$ 

- result agrees within 1.9 SD with the prediction from MC@NLO of  $A_{_{\rm FR}}^{}^{det} = (2.4 \pm 0.7)\%$
- result dominated by statistical uncertainty: 3.6%
- largest systematic uncertainty from jets: 0.5%



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- asymmetry depends on several variables like  $|\Delta y|$
- new physics could e.g. cause different  $\mathbf{m}_{t}$  dependency
  - no significant dependency found at D0
  - largest deviation from SM prediction observed by CDF in high m<sub>it</sub> bin Forward-Backward To









 regularized unfolding in ∆y to correct for acceptance and reconstruction

 $A_{FR}^{pat} = (19.6 \pm 6.5 (stat+syst))\%$ 

- result agrees within 2.4 SD with the prediction from MC@NLO
- performed cross check using maximum likelihood unfolding
  - consistent results
  - better description of migrations across ∆y = 0 using reg. unfolding
    - → better statistical strength





unfolding illustration from "Statistical Data Analysis" by Glen Cowan





• lepton based definition offers an alternative way to study  $A_{fi}$ 

$$A_{FB}^{l} = \frac{N(q_{l} y_{l} > 0) - N(q_{l} y_{l} < 0)}{N(q_{l} y_{l} > 0) + N(q_{l} y_{l} < 0)}$$

- based on well measured angles → sufficient to correct for acceptance
- restrict to  $|y_1| < 1.5$  to avoid large acceptance corrections
- using ~1500 of  $t\bar{t}$  candidate events:

 $A_{_{FB,l}}^{}^{det} = (14.2 \pm 3.8 (stat+syst))\%$ 

 $A_{_{FR1}}^{}^{pat} = (15.2 \pm 4.0 (stat+syst))\%$ 

- result deviates by 3.4 SD from MC@NLO prediction of (2.1 ± 0.1)%
- dominated by statistical uncertainty
- largest systematic of 0.5% (1.6%) from
  - $\mathbf{p}_{T}^{\mathbf{t}}$  modeling on detector (parton) level





## **Cross Checks**



- extracted A<sub>FB</sub> and A<sub>FB</sub><sup>-1</sup> for W+jets in background enriched sample
  - both agree well with Alpgen prediction of 2% and 14% resp.
- no dependencies observed on
  - solenoid/toroid polarities
  - lepton charge
  - lepton final state







• the lepton based asymmetry:

 $A_{FB}^{l} = \frac{N(q_{l} y_{l} > 0) - N(q_{l} y_{l} < 0)}{N(q_{l} y_{l} > 0) + N(q_{l} y_{l} < 0)}$ 

- a definition based on the lepton difference in  $\boldsymbol{\eta}$  :

$$A_{FB}^{ll} = \frac{N\left(\Delta\eta > 0\right) - N\left(\Delta\eta < 0\right)}{N\left(\Delta\eta > 0\right) + N\left(\Delta\eta < 0\right)}$$

$$\Delta \eta = \eta_{\bar{l}} - \eta_{l}$$

• CP testing asymmetry:

$$A_{FB}^{CP} = \frac{N_{l}(\eta > 0) - N_{l}(\eta < 0)}{N_{\bar{l}}(\eta > 0) + N_{l}(\eta < 0)}$$

reweighted lepton η distributions in MC@NLO considering
 QED corrections (arXiv:1205.6580) to get parton level predictions:

	A <sub>FB</sub> <sup>1</sup>	A <sub>FB</sub> <sup>II</sup>	A <sub>FB</sub> <sup>CP</sup>
<b>Prediction</b> (%)	4.7 ± 0.1	$6.2 \pm 0.2$	$-0.3 \pm 0.1$





- selection strategy follows event topology
- main background from Z+jets (Alpgen+Pythia)
  - background symmetric in  $\eta$ , asymmetric in  $\Delta \eta$
  - good agreement with prediction
- Iepton angles well measured
  - $\rightarrow$  sufficient to correct for acceptance<sub>3000</sub>
    - checked correction from MC@NLO with acceptance from Z → ll data
- fraction of events with mis-measured lepton charges only 0.2%









## • acceptance corrected asymmetries:

	A <sub>FB</sub> <sup>1</sup>	A <sub>FB</sub> <sup>II</sup>	A <sub>FB</sub> <sup>CP</sup>
Unfolded (%)	5.8 ± 5.3 (stat+syst)	5.3 ± 8.4 (stat+syst)	-1.8 ± 5.3 (stat+syst)
Prediction (%)	4.7 ± 0.1	$6.2 \pm 0.2$	$-0.3 \pm 0.1$

- good agreement with MC@NLO including QED corrections
- statistical uncertainty still large: 5-8%
- main systematic uncertainty from jet uncertainties
- 1+jets and dilepton result for  $A_{FR}^{-1}$  consistent within 68%
  - combined using the **BLUE** method (see talk by **F. Déliot**):

 $A_{_{\rm FR}}^{-1}$  = (11.8 ± 3.2) %

agreeing within 2.2 SD with MC@NLO prediction

• l+jets channel contributes ~2/3





- ♦ many BSM models trying to explain A<sub>FB</sub>, couple to right-handed tops only
   → measurement of top polarization
- longitudinal polarization would show up in  $B_1$  and  $B_2 \neq 0$

$$\frac{1}{\sigma} \frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4} (1 + B_1 \cos\theta_1 + B_2 \cos\theta_2 + C\cos\theta_1 \cos\theta_2)$$



- leptophobic Z' with P-violating top couplings shows effect from polarized tops
  - good agreement between data and SM









- measured asymmetries in l+jets (arXiv:1107.4995) and dilepton (arXiv:1207.0364) channel
   Forward-Backward Top Asymmetry, %
  - unfolded A<sub>FB</sub> = 19.6% in l+jets agrees within 2.4 SD with MC@NLO prediction of 5.0%
  - combined lepton based asymmetry from 1+jets and dilepton:  $A_{rp}^{1} = (11.8 \pm 3.2) \%$

 

 Porward-Backward Top Asymmetry, %

 Production Level

 CDF, 5.3 fb<sup>-1</sup>
 Production Level

 ØØ, 5.4 fb<sup>-1</sup>
 15.8±7.2±1.7

 DØ, 5.4 fb<sup>-1</sup>
 19.6±6.0<sup>+1.8</sup><sub>-2.6</sub>

 S. Frixione and B.R. Webber, JHEP 06, 029 (2002)
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agrees within 2.2 SD with prediction of 4.7%

- however:
  - all results dominated by statistical uncertainty
  - ongoing work for improved predictions
- many models predict very different values for  $A_{FR}^{1}$  and  $A_{FR}^{1}$ 
  - → new results with full data set (~9 fb<sup>-1</sup>) in l+jets and dilepton in preparation