Top Pair Forward-Backward Asymmetry at CDF

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On Behalf of the CDF Collaboration

Les Rencontres de Physique de la Vallée d'Aoste
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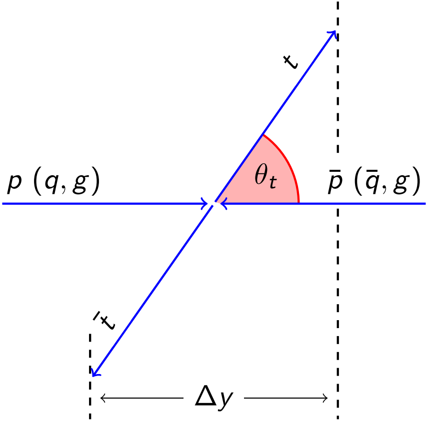


- Large top mass may signal gateway to new physics
- At Tevatron, initial state CP even eigenstate
- So charge asymmetry in $t\bar{t}$ production manifests as forward-backward asymmetry
- Measure rapidity difference between top and anti-top, Δy
- Then define asymmetry:

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

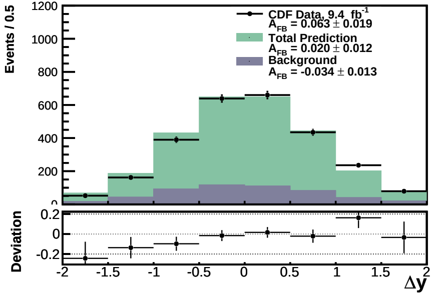
- Prediction at NLO:

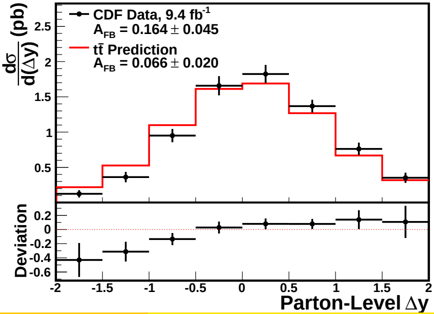
$$A_{\text{FB}} = (6.6 \pm 2.0)\,\%$$

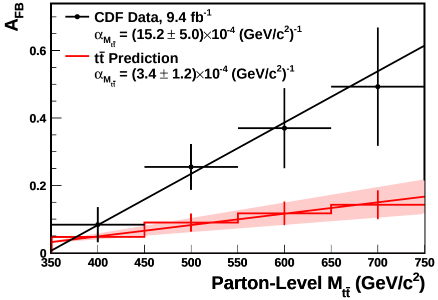
- 9.4/fb: Observe 2653 lepton plus 4 jets plus $\not{E}_T$ events
- Expect 530 background, 2186 top pair events
- Measure Δy spectrum in data
- Subtract background distributions
- Correct for acceptance and detector resolution effects
- Parton level result:

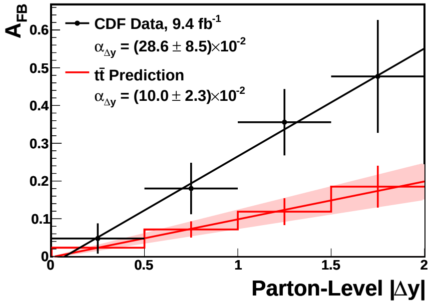
$$A_{FB} = (16.4 \pm 4.5)\,\%$$

- C.f.: $A_{FB} = (6.6 \pm 2.0)\,\%$
- Both detector and parton level $\sim 2.2\sigma$ above NLO SM







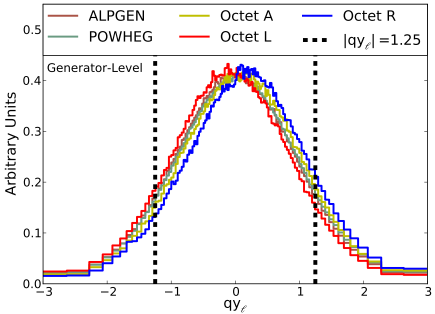


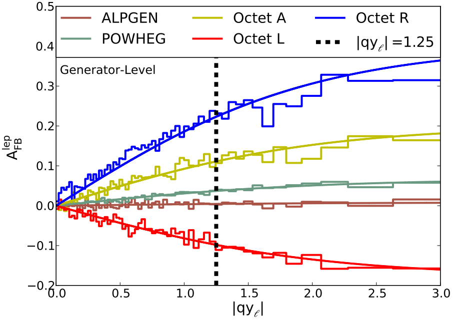
- Also important to investigate dependence of A_{FB} on top pair mass and on rapidity difference $|\Delta y|$
- Asymmetry rises steadily from near zero at threshold
- Fit a line to data and to prediction
- Slope in data exceeds prediction by $\sim 2.3\sigma$ at the parton level
- The shape of A_{FB} as a function of $M_{t\bar{t}}$ and $|\Delta y|$ is a prediction of both the NLO SM and various new physics models
- This may help to discriminate different scenarios

- Lepton direction insensitive to effects from kinematic $t\bar{t}$ reconstruction
- Lepton A_{FB} kinematically correlated with top A_{FB}
- Expect lepton A_{FB} roughly half of top A_{FB}
- Analysis strategy:
  - Measure spectrum of lepton charge times rapidity
  - Correct for acceptance
  - Fit acceptance-corrected lepton A_{FB} to model:

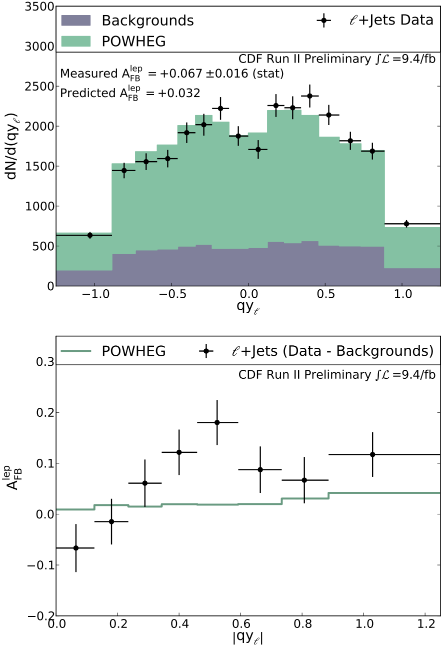
$$a \tanh\left(\tfrac{1}{2} q_\ell y_\ell\right)$$

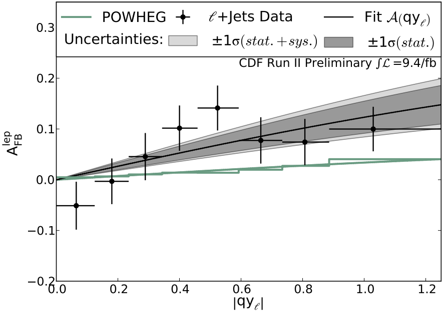
  - Use model to extrapolate into unmeasured region





- Almost same events as before, but loosen E_T cut on lowest E_T jet
- Gain 1211 data events, total 3864
- Expect to gain 564 $t\bar{t}$ (total 2750), 496 background (total 1026)
- At detector-level, can already see excess lepton A_{FB}
- Subtract backgrounds from data
- Calculate asymmetry as a function of $|qy_\ell|$





- Now correct for acceptance and then fit tanh model
- Extract inclusive lepton A_{FB} from parameters of tanh model
- Measured lepton A_{FB} exceeds Powheg prediction by 2.3σ
- Consistent with expectation from observed $t\bar{t}$ A_{FB} (7.6 %)

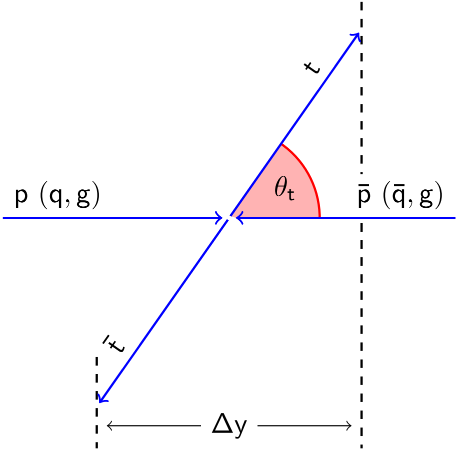
CDF Run II Preliminary $\int \mathcal{L} = 9.4/fb$

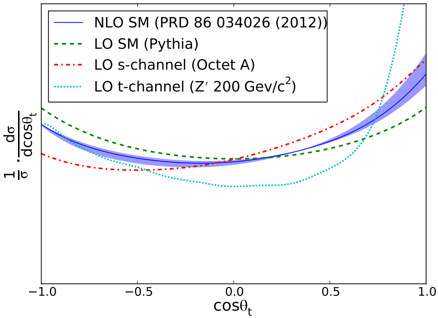
Correction Level	CDF Data	POWHEG
Data Only	0.067 ± 0.016	0.031
Backgrounds Subtracted	$0.070 \pm 0.019 \pm 0.011$	0.022
Fully Extrapolated	$0.094 \pm 0.024^{+0.022}_{-0.017}$	0.027

- Top A_{FB} is a very simple statement about the distribution of the production angle, $\cos\theta_t$

$\cos\theta_t$ Angle between top momentum and proton momentum measured in top-antitop center-of-mass frame

- Just two bins: forward and backward
- May be more information in full differential cross section
- What components of shape explain A_{FB}?
- Legacy differential cross section measurement





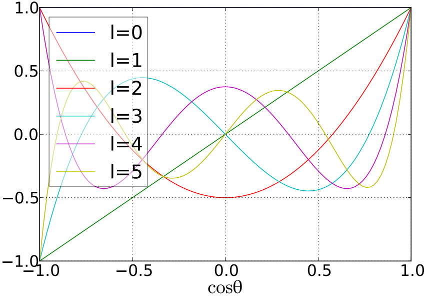
- LO SM predicts $1 + \cos^2\theta_t$
- NLO SM adds additional terms
  - Calculation by Bernreuther and Si
  - Includes QCD+EWK
- Two broad classes of new physics have been proposed to explain top A_{FB}:

s-channel (e.g. axigluon): predict additional term $\cos\theta_t$

t-channel (e.g. flavor-changing Z'): predict leading behavior $\frac{1}{\hat{t}} \sim \frac{1}{1-\cos\theta_t}$

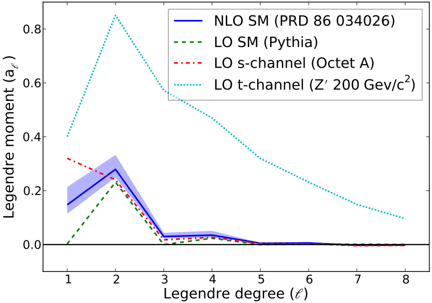
- These all lead to very different shapes
- We may be able to discriminate among them

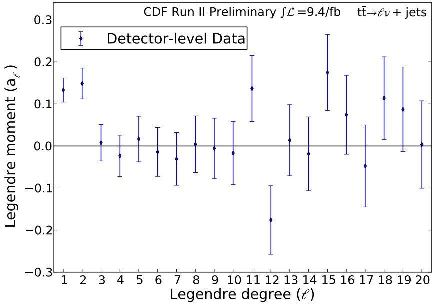
- How to study $\cos\theta_t$ diff. cross section shape?
- Legendre polynomials are orthonormal over $\cos\theta_t$ domain
- Well motivated from quantum mechanics via angular momentum
- Measure "Legendre moments" – coefficient multiplying each Legendre polynomial in diff. cross section
- Zeroth moment carries total cross section – scale to unity
- Even moments carry symmetric shape information
- Odd moments carry asymmetry

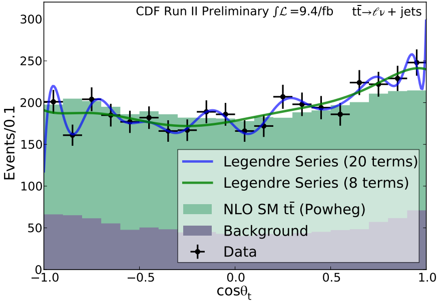


ℓ	$P_\ell(x)$
0	1
1	x
2	$\frac{1}{2}(3x^2-1)$
3	$\frac{1}{2}(5x^3-3x)$
4	$\frac{1}{8}(35x^4-30x^2+3)$
5	$\frac{1}{8}(63x^5-70x^3+15x)$

- LO SM has non-zero 2nd moment as expected
- Non-zero 4th, 6th, etc come from $gg \to t\bar{t}$, which includes a t-channel diagram
- NLO SM has non-zero 1st moment, all moments slightly larger than LO
- LO s-channel gains 1st moment (linear term), other moments nearly unchanged from LO SM
- LO t-channel has large moments everywhere

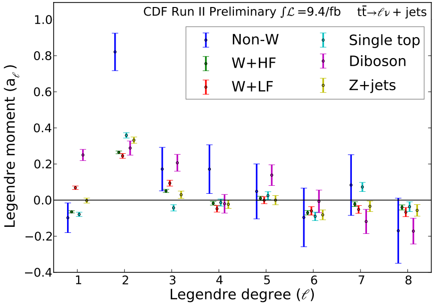


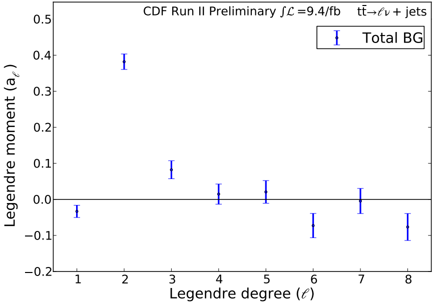


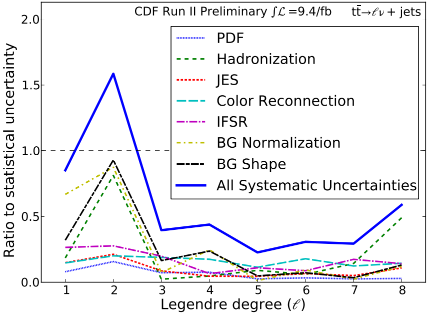


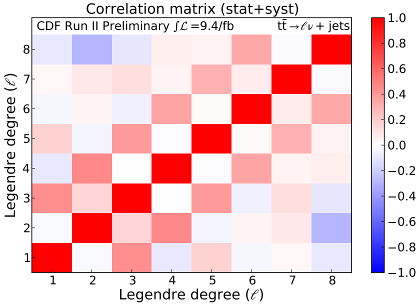
- Moments of detector-level distribution
- Computed without binning
- Includes backgrounds, imperfect acceptance, finite detector resolution
- Compare resulting Legendre series to histogram
- 20 term Legendre series is a faithful representation of data
- 8 term series very smooth – has less information

- Moments of backgrounds also estimated without binning
- Total background subtracted from data moments
- Estimate a moments response matrix from fully simulated Monte Carlo
- Normalize by generator-level $\cos\theta_t$ distribution to account for acceptance
- Invert response matrix and multiply by BG-subtracted moments
- No regularization needed

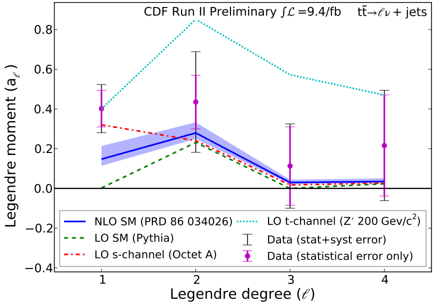




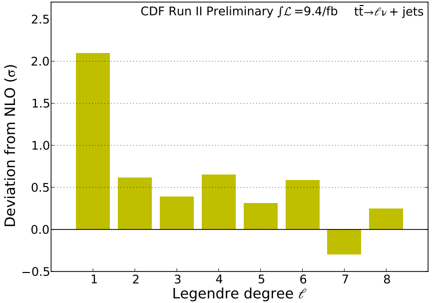




- RMS statistical uncertainties propagated through correction
- Several sources of systematic uncertainty
  - Vary nuisance parameter
  - Redo BG-sub and correction
  - Treat change in moments as systematic uncertainty
- Sum statistical and systematic covariances
- Total covariance matrix (backup slides) can be inverted to form a χ^2 for fits to our results
- Uncertainties Gaussian (tested w/ pseudodata), χ^2 with 8 d.o.f.



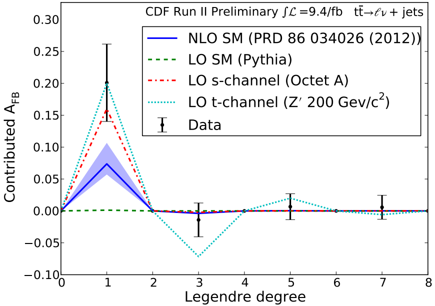
- Good agreement with NLO SM except for $\ell = 1$
- Benchmark Z' model disfavored
- Excess linear term in differential cross section

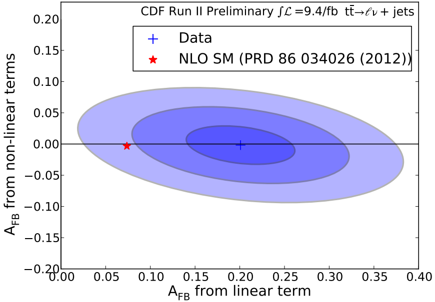


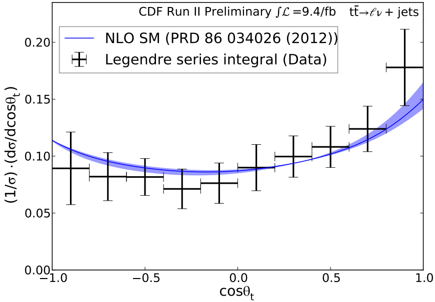
CDF Run II Preliminary, 9.4/fb

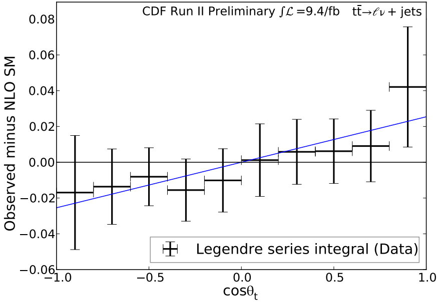
ℓ	a_ℓ	ℓ	a_ℓ
1	0.40±0.12	2	0.44±0.25
3	0.11±0.22	4	0.22±0.27
5	0.11±0.33	6	0.24±0.41
7	−0.15±0.48	8	0.16±0.65

- Which moment(s) explain A_{FB}?
- Even moments do not contribute to A_{FB}
- Odd moments may
- Moments 3, 5, 7 consistent with zero contributed A_{FB}
- Asymmetry dominated by 1st moment
- Excess linear term, $\cos\theta_t$, in differential cross section completely explains excess A_{FB}



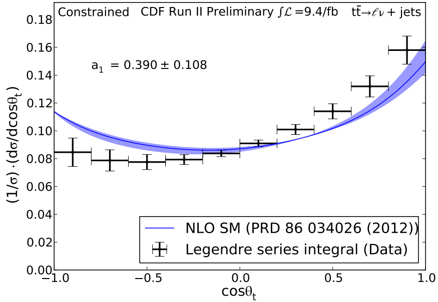


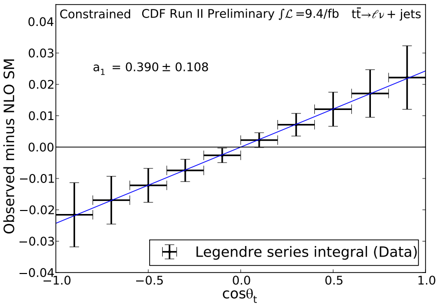




- Hard to visualize differential cross section from Legendre moments
- Easy to integrate Legendre series
- Make 10 bins of $\cos\theta_t$, integrate over width of each bin
- Gives more traditional differential cross section, easy to visualize
- Big error bars, dominated by large uncertainties on high-order moments
- Uncertainties very correlated

- Since a_2–a_8 are in agreement with NLO SM
- Introduce assumption that NLO SM (with scale uncertainties) is correct for all but a_1
- Combine assumption with measurement using likelihood (from covariance)
- Obtain more precise, but more model-dependent estimate of moments
- About 10 % improvement in a_1 precision under assumption





- See more at http://www-cdf.fnal.gov/physics/new/top/public_tprop.html
- We see an anomalously large forward-backward asymmetry in top-antitop production at CDF in our full data set
- This asymmetry grows with $t\bar{t}$ mass and rapidity difference
- When examining only the lepton in $t\bar{t} \to \ell\nu qqbb$ events, we see a compatible asymmetry
- We measure the moments of the angular differential cross section, and we see an anomalously large linear term
- The A_{FB} is dominated by this linear term

Thank you for your attention and thanks to the organizers for their kind hospitality

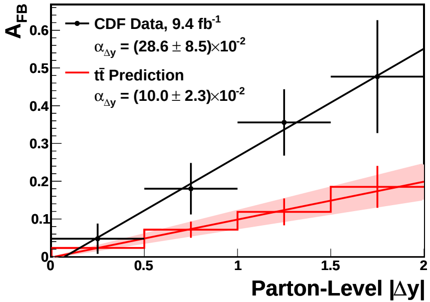
BACKUP

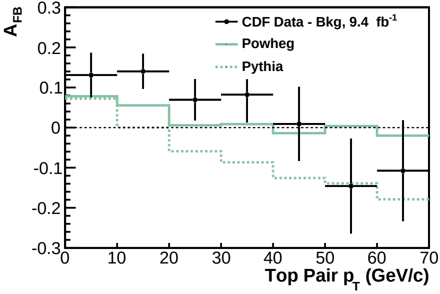
The covariance matrix describing the uncertainty of our measurement. Likelihood is very Gaussian. Inverting this matrix induces a χ^2 goodness-of-fit statistic with 8 degrees of freedom. Can be used for likelihood fits to our result.

CDF Run II Preliminary $\int \mathcal{L} = 9.4$ fb^{-1}

	1	2	3	4
1	1.47×10^{-2}	-7.60×10^{-4}	1.14×10^{-2}	-2.95×10^{-3}
2	-7.60×10^{-4}	6.41×10^{-2}	8.96×10^{-3}	3.29×10^{-2}
3	1.14×10^{-2}	8.96×10^{-3}	4.50×10^{-2}	-8.18×10^{-5}
4	-2.95×10^{-3}	3.29×10^{-2}	-8.18×10^{-5}	7.72×10^{-2}
5	6.86×10^{-3}	-3.70×10^{-3}	2.72×10^{-2}	-7.32×10^{-4}
6	-1.73×10^{-3}	4.12×10^{-3}	-4.88×10^{-3}	4.00×10^{-2}
7	2.01×10^{-3}	1.05×10^{-2}	1.36×10^{-2}	5.49×10^{-3}
8	-7.34×10^{-3}	-4.69×10^{-2}	-1.33×10^{-2}	1.13×10^{-2}

	5	6	7	8
1	6.86×10^{-3}	-1.73×10^{-3}	2.01×10^{-3}	-7.34×10^{-3}
2	-3.70×10^{-3}	4.12×10^{-3}	1.05×10^{-2}	-4.69×10^{-2}
3	2.72×10^{-2}	-4.88×10^{-3}	1.36×10^{-2}	-1.33×10^{-2}
4	-7.32×10^{-4}	4.00×10^{-2}	5.49×10^{-3}	1.13×10^{-2}
5	1.06×10^{-1}	2.31×10^{-3}	4.85×10^{-2}	1.13×10^{-2}
6	2.31×10^{-3}	1.63×10^{-1}	1.42×10^{-2}	8.81×10^{-2}
7	4.85×10^{-2}	1.42×10^{-2}	2.32×10^{-1}	-5.45×10^{-3}
8	1.13×10^{-2}	8.81×10^{-2}	-5.45×10^{-3}	4.17×10^{-1}





- Also study dependence on $|\Delta y|$
- Again, fit a line, slope exceeds prediction
- Dependence on top pair p_T is very interesting
- Sensitive to soft QCD effects, details of parton shower model, underlying event, etc
- Data qualitatively resembles Pythia prediction with some excess A_{FB}