Measurement of the Forward-Backward Asymmetry In Top Production with 1.9 fb^{-1}

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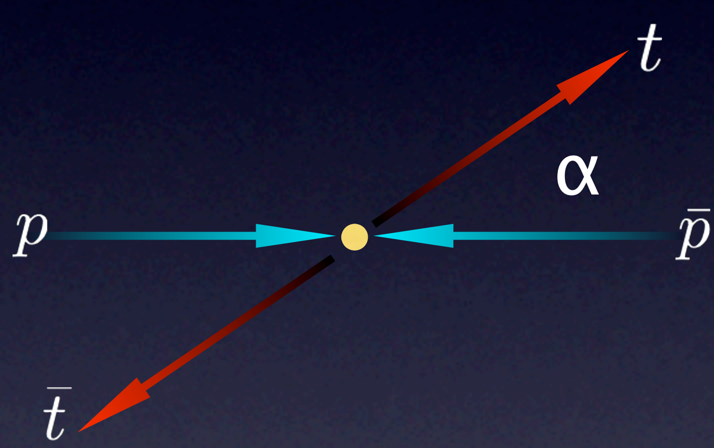
The Front-Back Asymmetry

- Measuring the forward-backward asymmetry in the production of top quarks in the **p-pbar** and **t-tbar** rest frame



$$A_{fb} = \frac{N_F - N_B}{N_F + N_B}$$

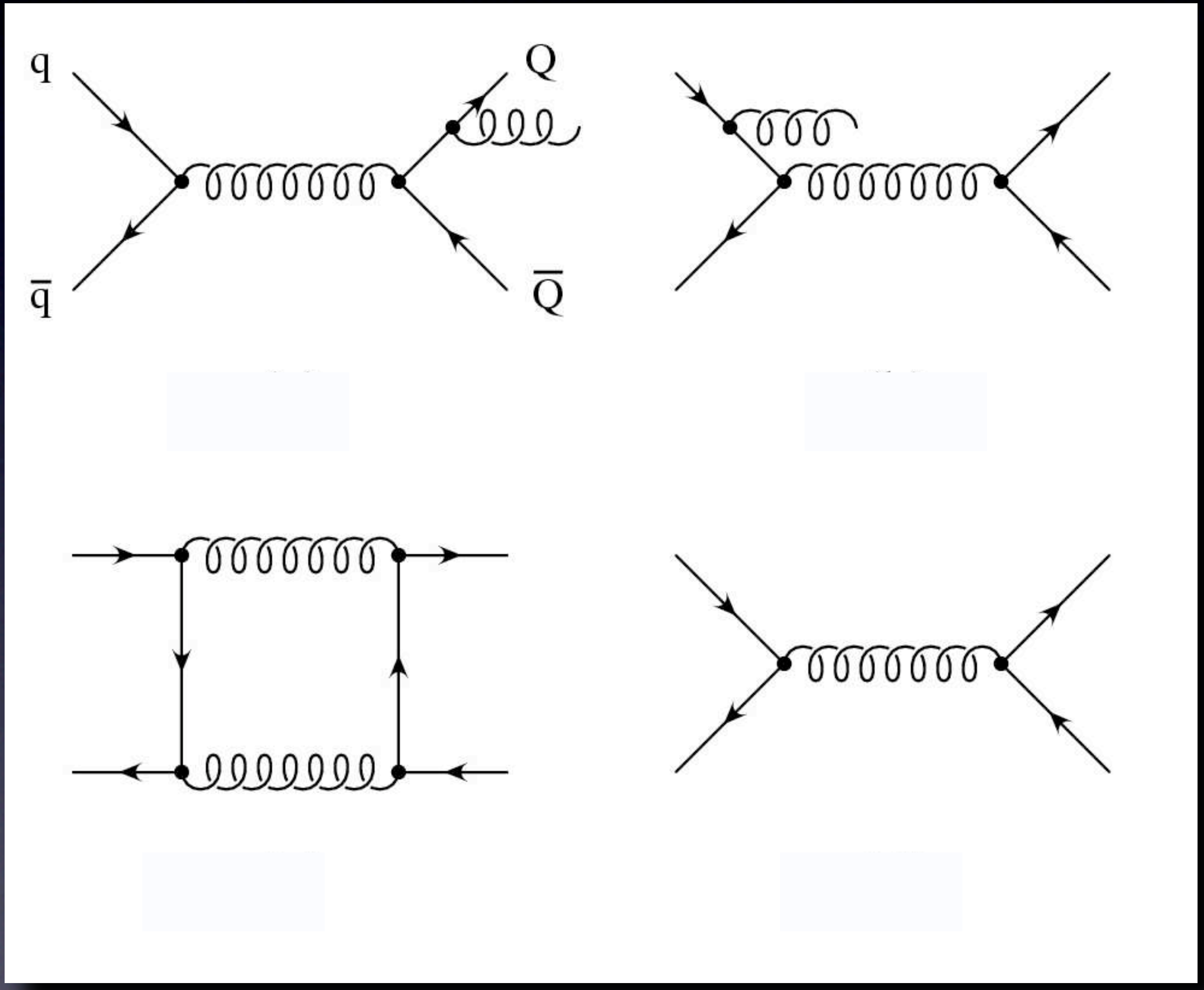
- Two measurements are complimentary:
  - p-pbar measurement less sensitive to measurement effects
  - t-tbar asymmetry less sensitive to PDF dilution

Why Measure It

- Test of discrete symmetries of the strong interaction at high energy
- NLO QCD predicts an observable asymmetry in top pair production
- For A_{fb} in top production in laboratory and t-tbar rest frame:

$$A^{p\bar{p}}_{fb\ theory} = 0.04 \pm 0.01$$

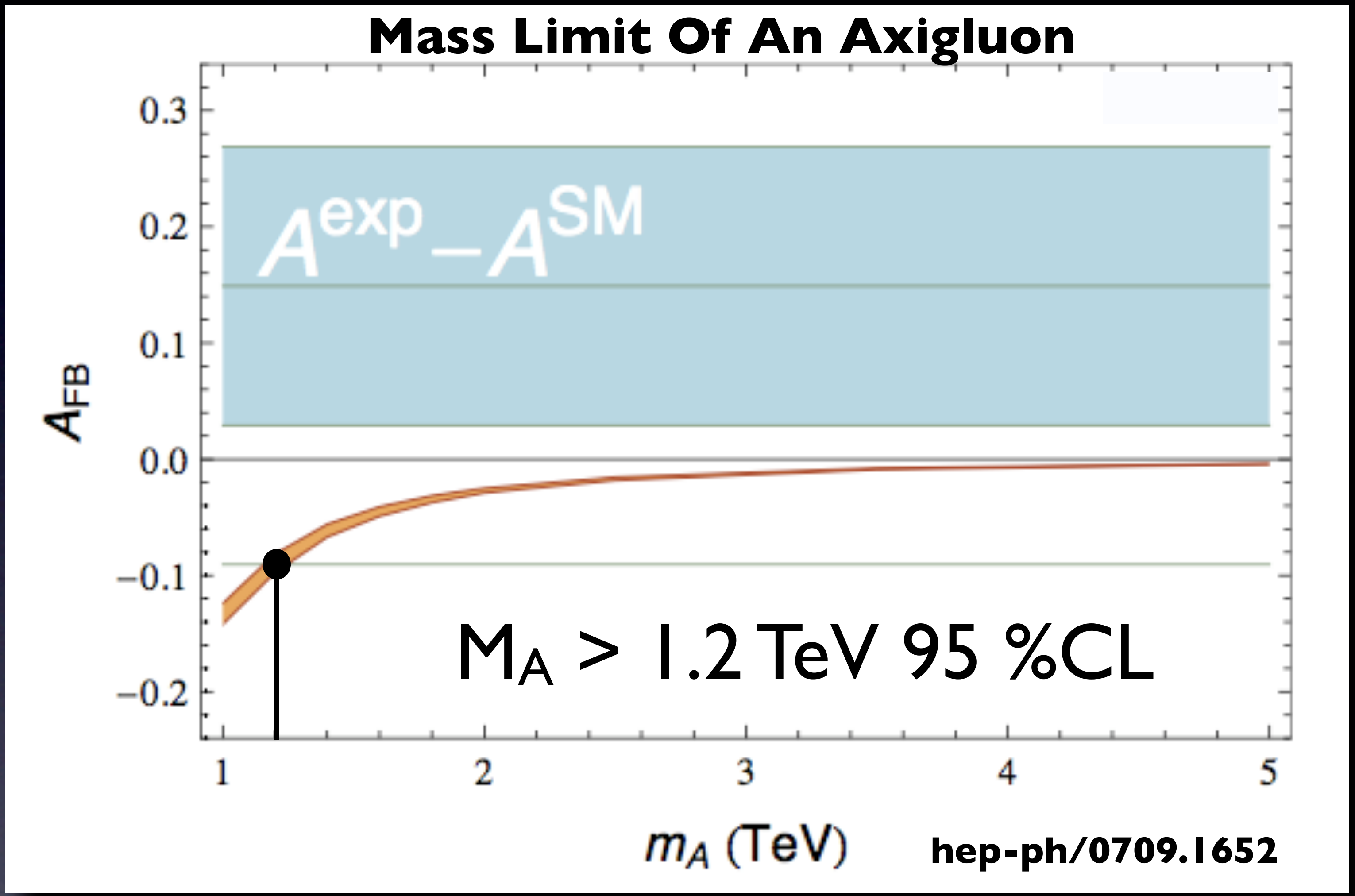
$$A^{t\bar{t}}_{fb\ theory} = 0.06 \pm 0.01$$



Kuhn, Rodrigo Phys Rev Lett. 81,89 (1998)

Why Measure It

- Several BSM production mechanisms predict an observable asymmetry (Z` , Axigluons)
- Especially interesting measurement for wide resonances
- Previous measurements at CDF used to place limits on Axigluon mass (695 pb^{-1})



- T. A. Schwarz, Ph.D. Thesis, University of Michigan, FERMILAB-THESIS-2006-51, UMI-32- 38081

- J. Weinelt, Masters thesis, Universität Karlsruhe, FERMILAB-MASTERS-2006-05; IEKP-KA-2006-21

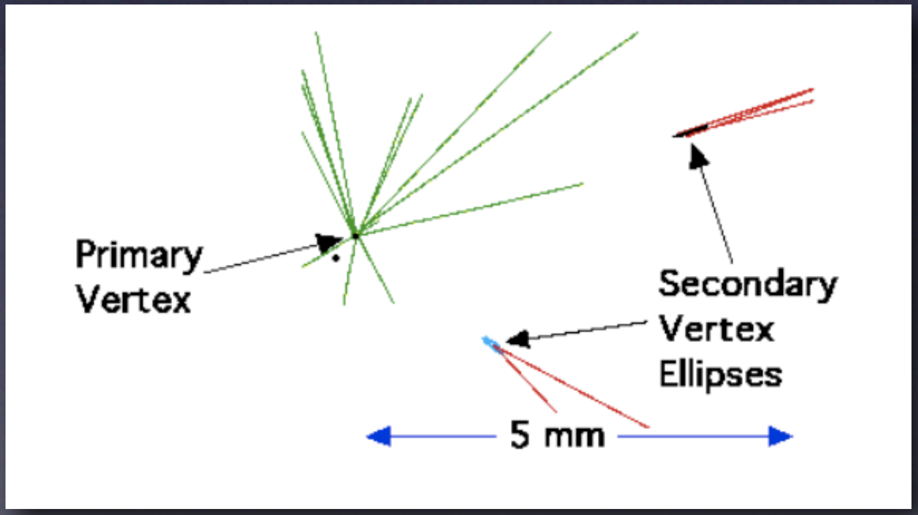
- Antunano, Kuhn, Rodrigo Arxiv hep-ph/0709.1652

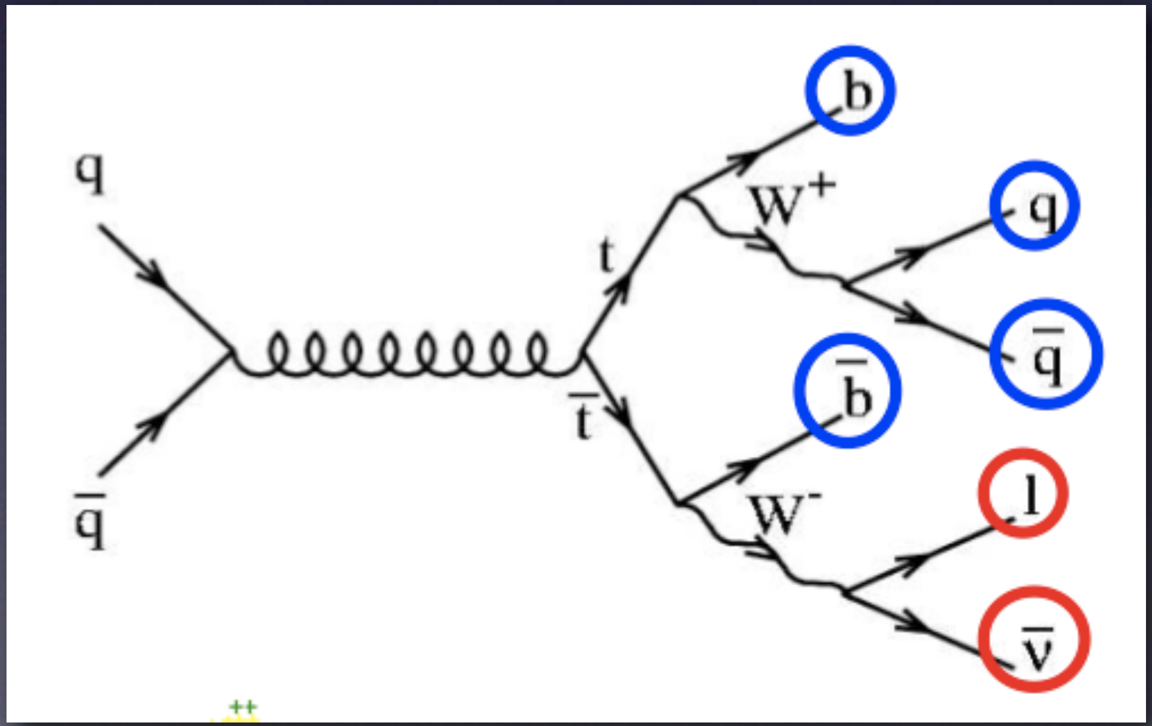
How

- Extract top-antitop events from the data collected at CDF
- Reconstruct the production angle of top in these events
- Fully correct for any distortion from the detector, background processes, and our method of reconstruction
- Measure A_{fb}

Finding ttbar Events

- Measurement is performed in the lepton plus jets channel
- $\geq$ 4 Jets (Et $\geq$ 20 GeV and $\eta < 2.0$)
- 1 Electron or Muon (Et $\geq$ 20 GeV)
- “Missing” Energy (Et $\geq$ 20 GeV)
- $\geq$ 1 Bottom “Tagged” Jet

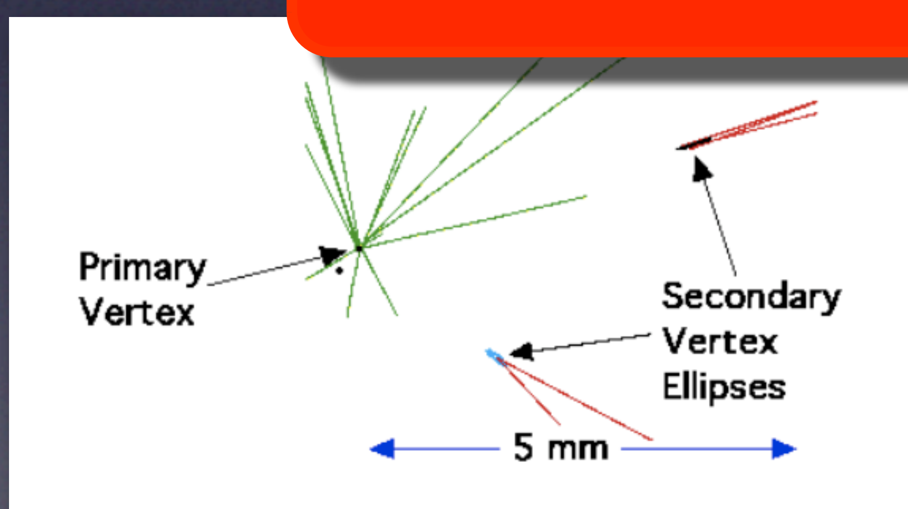


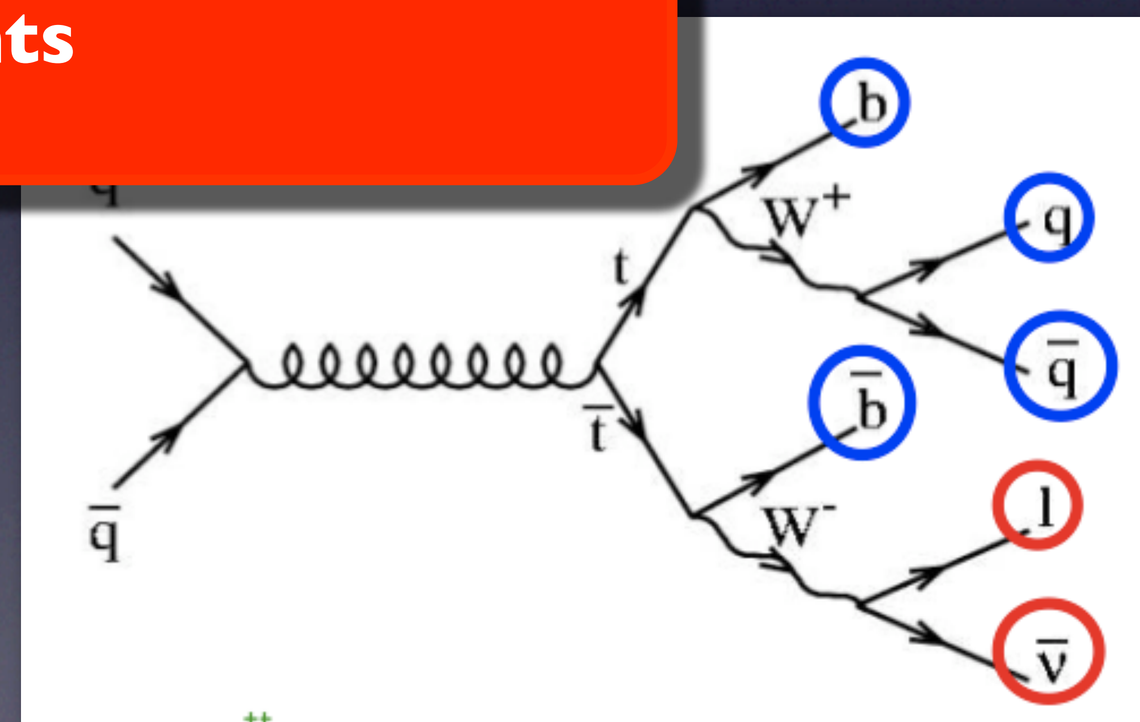


Finding ttbar Events

- Measurement is performed in the lepton plus jets channel
- ≥ 4 Jets (Et ≥ 20 GeV and η < 2.0)
- 1 Electr
- "Missing
- ≥ 1 Bott

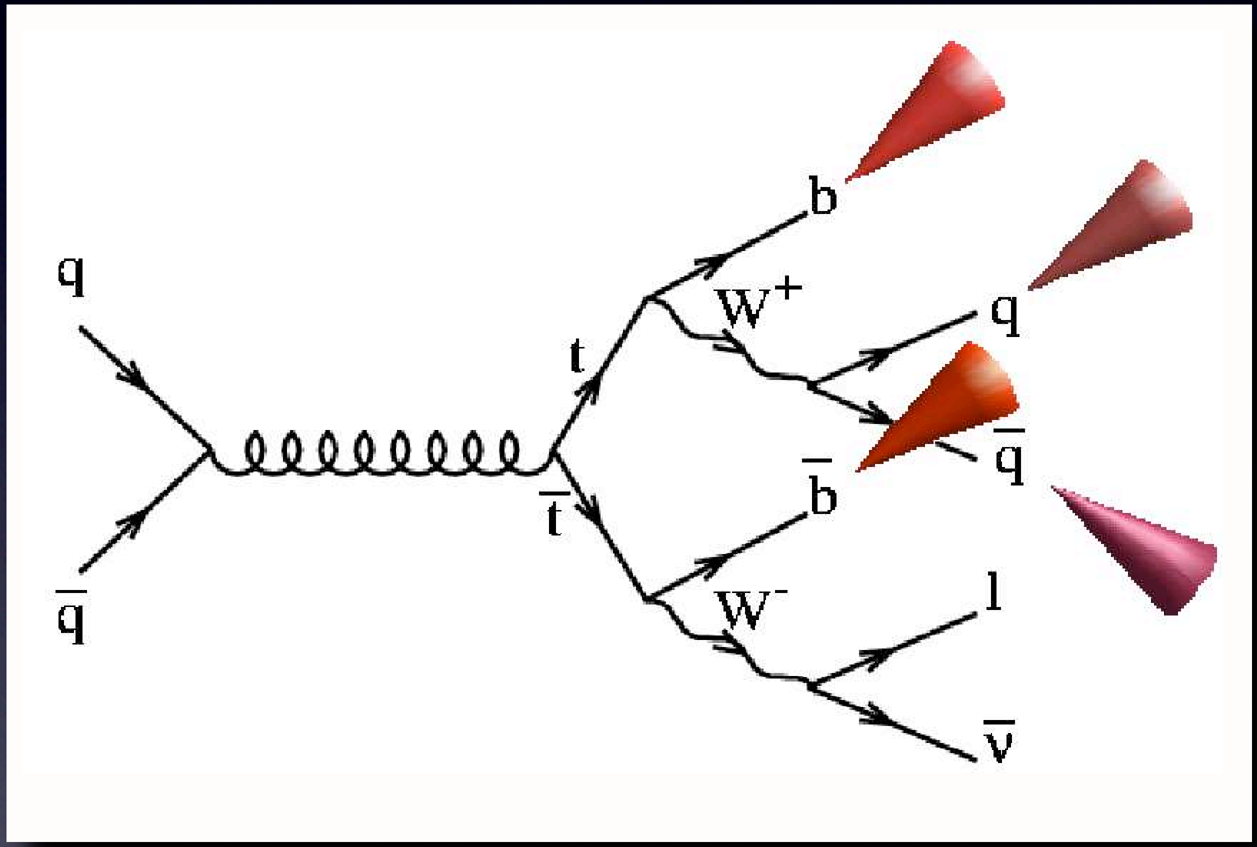
In 1.9 fb^{-1} we observe 484 events with a predicted background ~ 86 events





Reconstructing The Top Direction

- To reconstruct a top event, we must match jets to partons
- Use topology of event to decide best combination
  - *Two jets must form M_W*
  - *Three must form M_{top}*
  - *etc...*

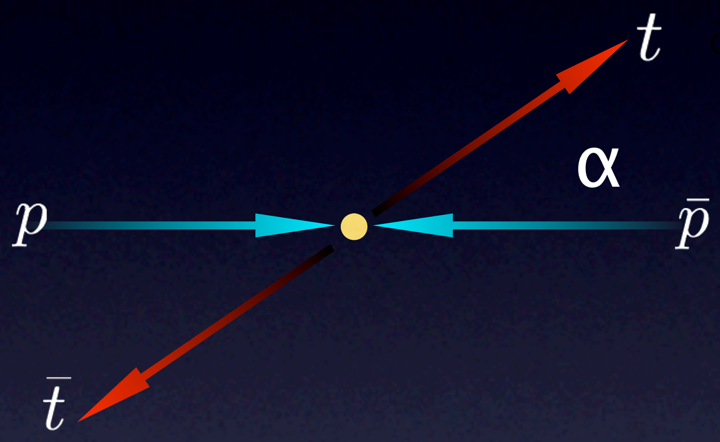


- Two similar but separate reconstruction algorithms are used to reconstruct the top direction in the p-pbar and t-tbar frame

Production Angle

- The p-pbar and t-tbar frame measurements use two different production angles to calculate the forward-backward asymmetry

$$A_{fb} = \frac{N_{\alpha>0} - N_{\alpha<0}}{N_{\alpha>0} + N_{\alpha<0}}$$



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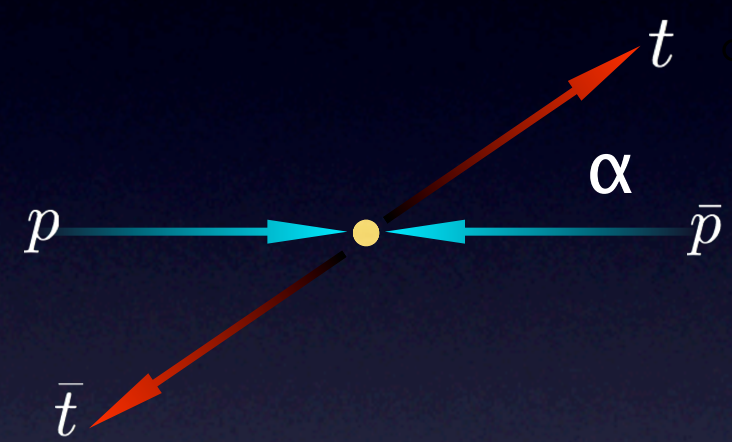


- In the p-pbar frame, the hadronic decaying top direction is more accurately reconstructed

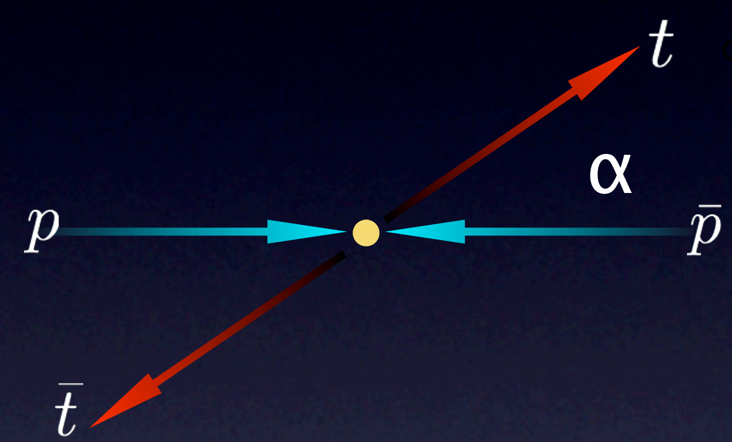
- If we assume CP is conserved in the strong interaction then we can use only the hadronic decaying side to measure Afb

$$\alpha_{p\bar{p}} = -Q_l \cdot \cos\Theta_{thad}$$

Production Angle

- The p-pbar and t-tbar frame measurements use two different production angles to calculate the forward-backward asymmetry

$$A_{fb} = \frac{N_{\alpha>0} - N_{\alpha<0}}{N_{\alpha>0} + N_{\alpha<0}}$$



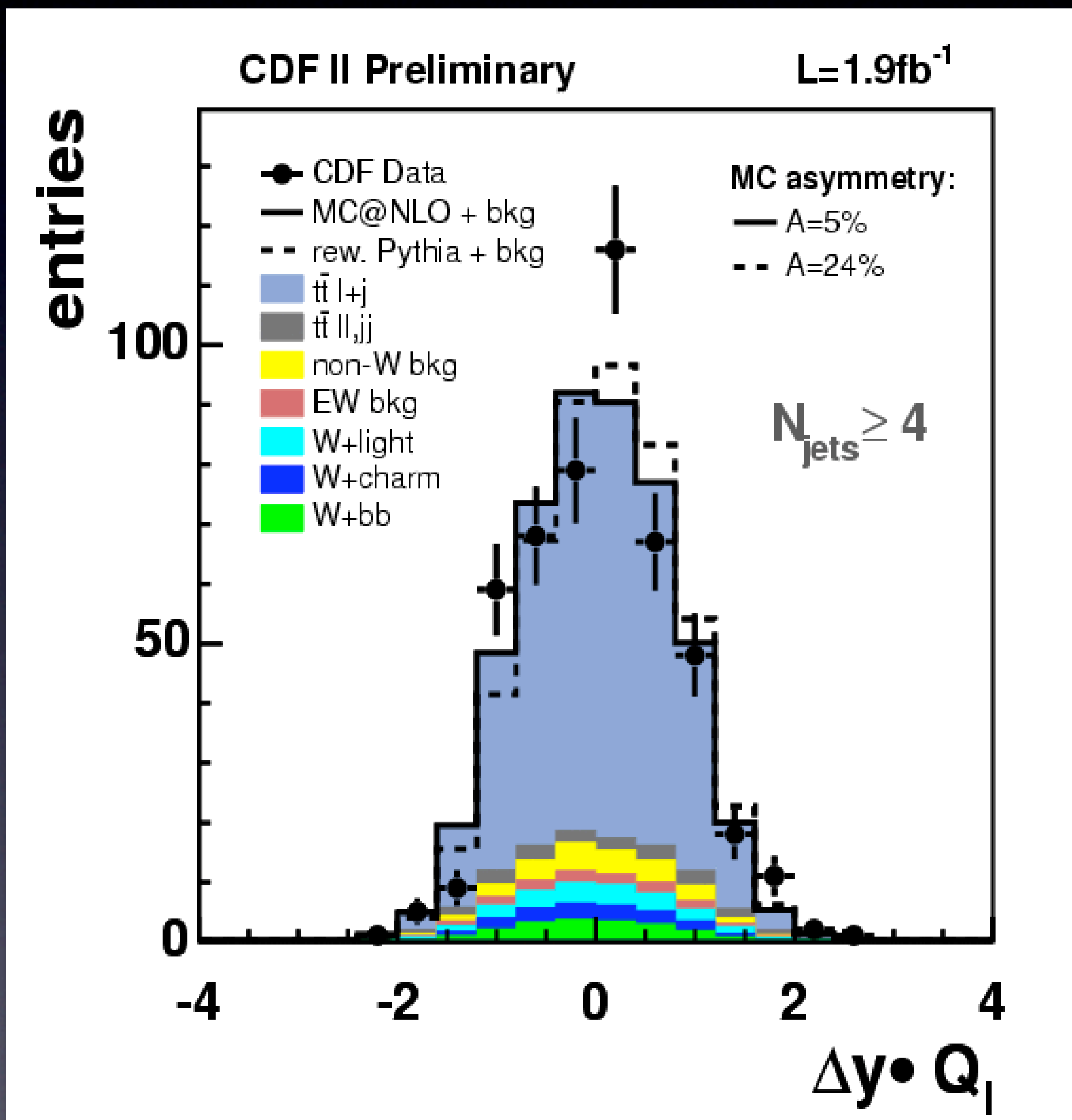
- In the t-tbar frame, both top and anti-top are required, but we can use a nice relation between Cos θ and Δy

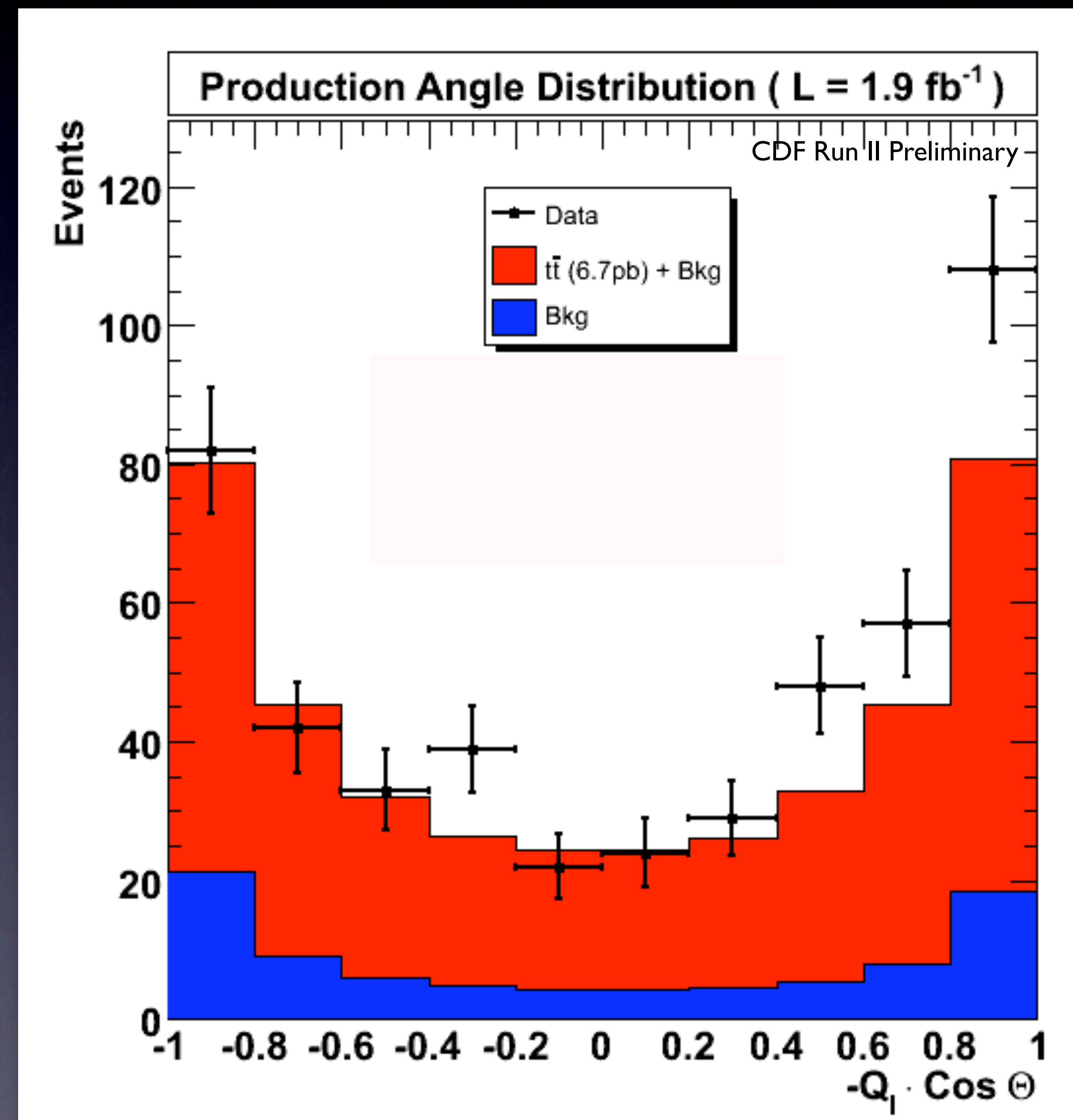
$$\cos\theta_{t\bar{t}} \propto y_t - y_{\bar{t}} = Q_l \cdot \Delta y$$

- Measuring the asymmetry using a Lorentz invariant quantity

$$\alpha_{t\bar{t}} = Q_l \cdot (y_{tlep} - y_{thad})$$

Production Angle





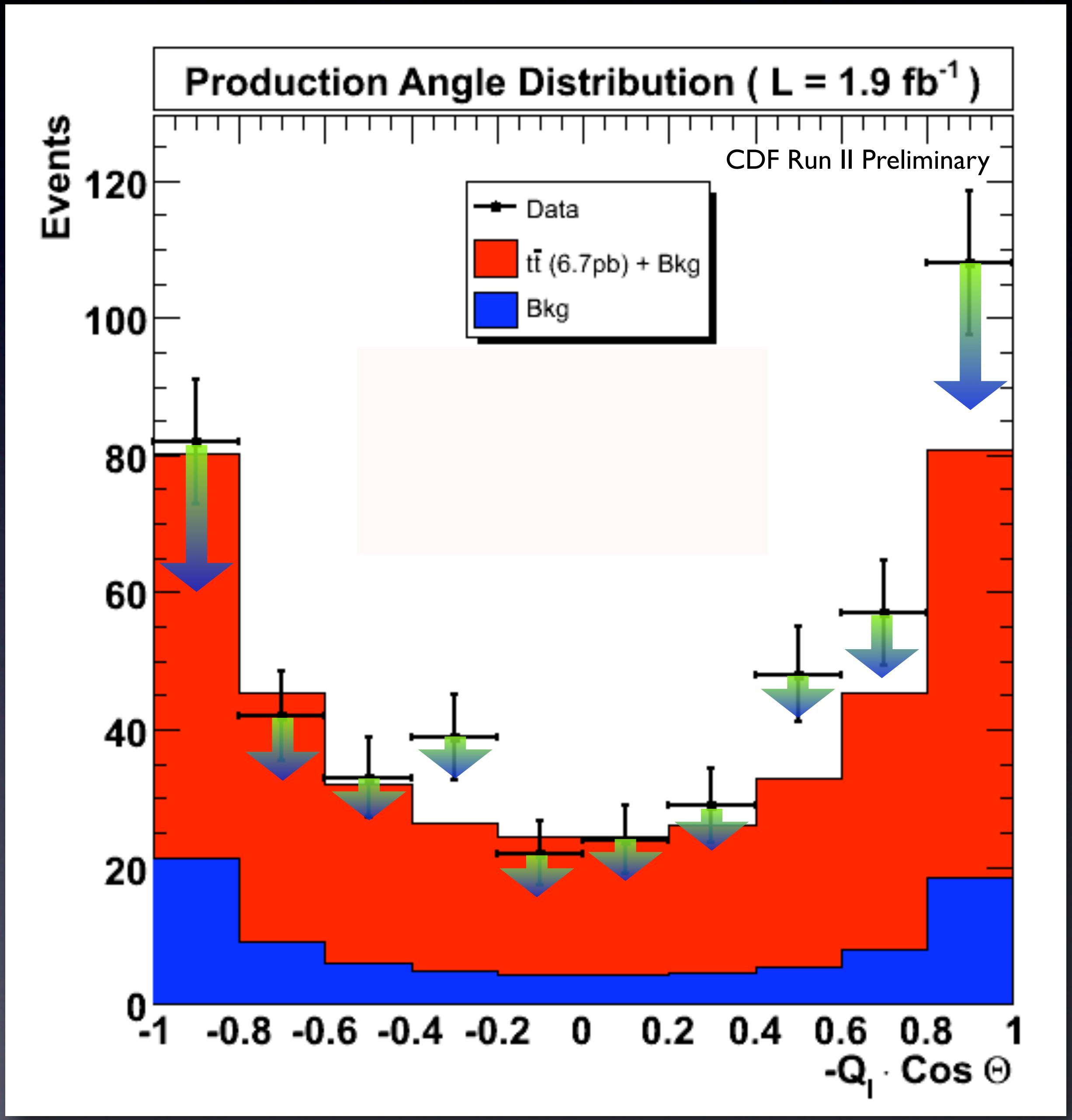
Background Correction

- We correct for backgrounds by subtracting the predicted background from the data
- The resulting distribution is the predicted reconstructed shape for ttbar

$$A_{fb}^{p\bar{p}}\ (bkg) = -0.053 \pm 0.4$$

$$A_{fb}^{t\bar{t}}\ (bkg) = -0.021 \pm 0.7$$

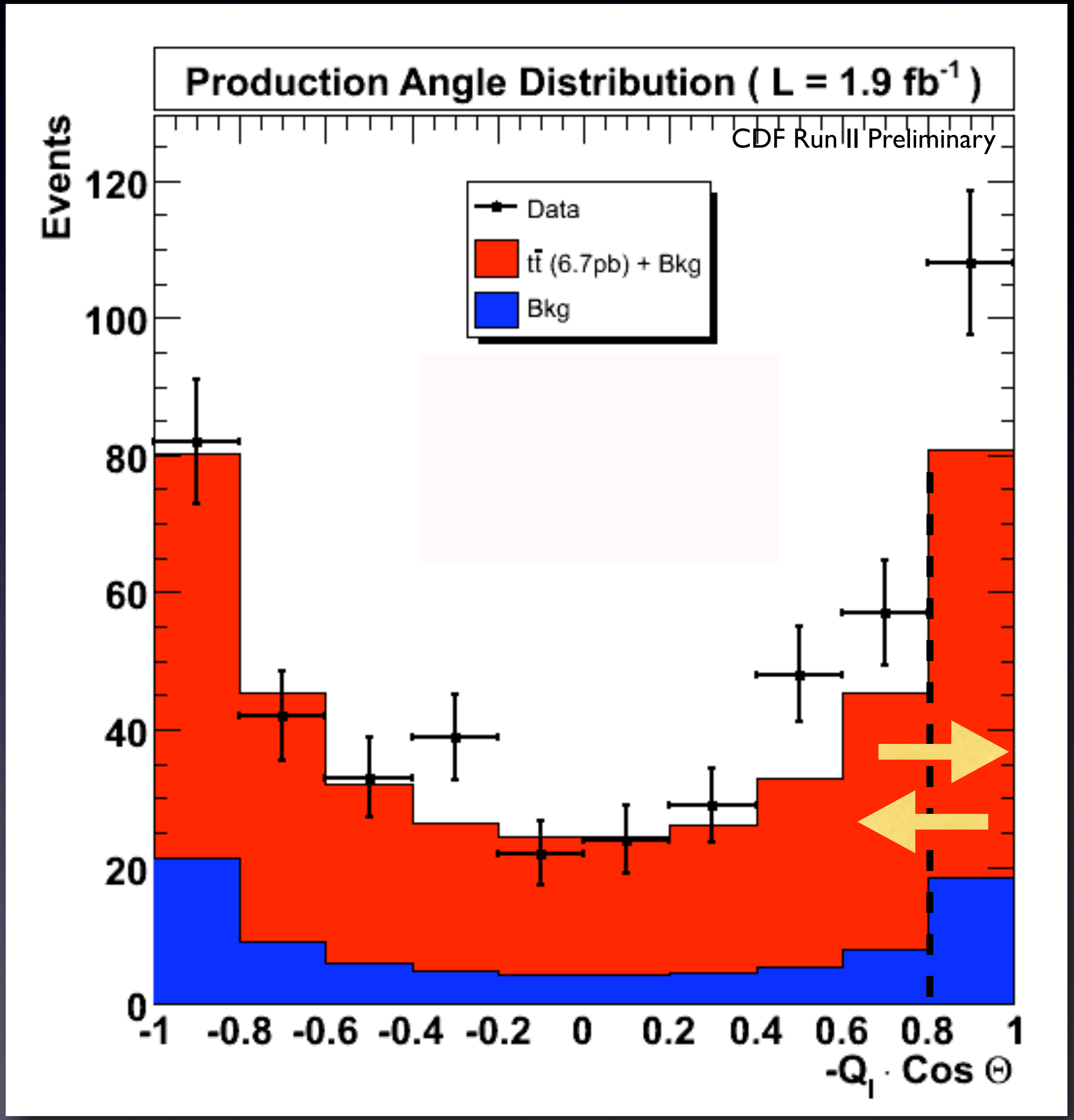
- NOTE: Method of corrections are applied to both A_{fb} analyses



Reconstruction Corrections

- The effect of imperfect reconstruction is a smearing of events between bins and therefore a dilution of the front-back asymmetry

- We model this effect in ttbar Monte Carlo in order to correct the data



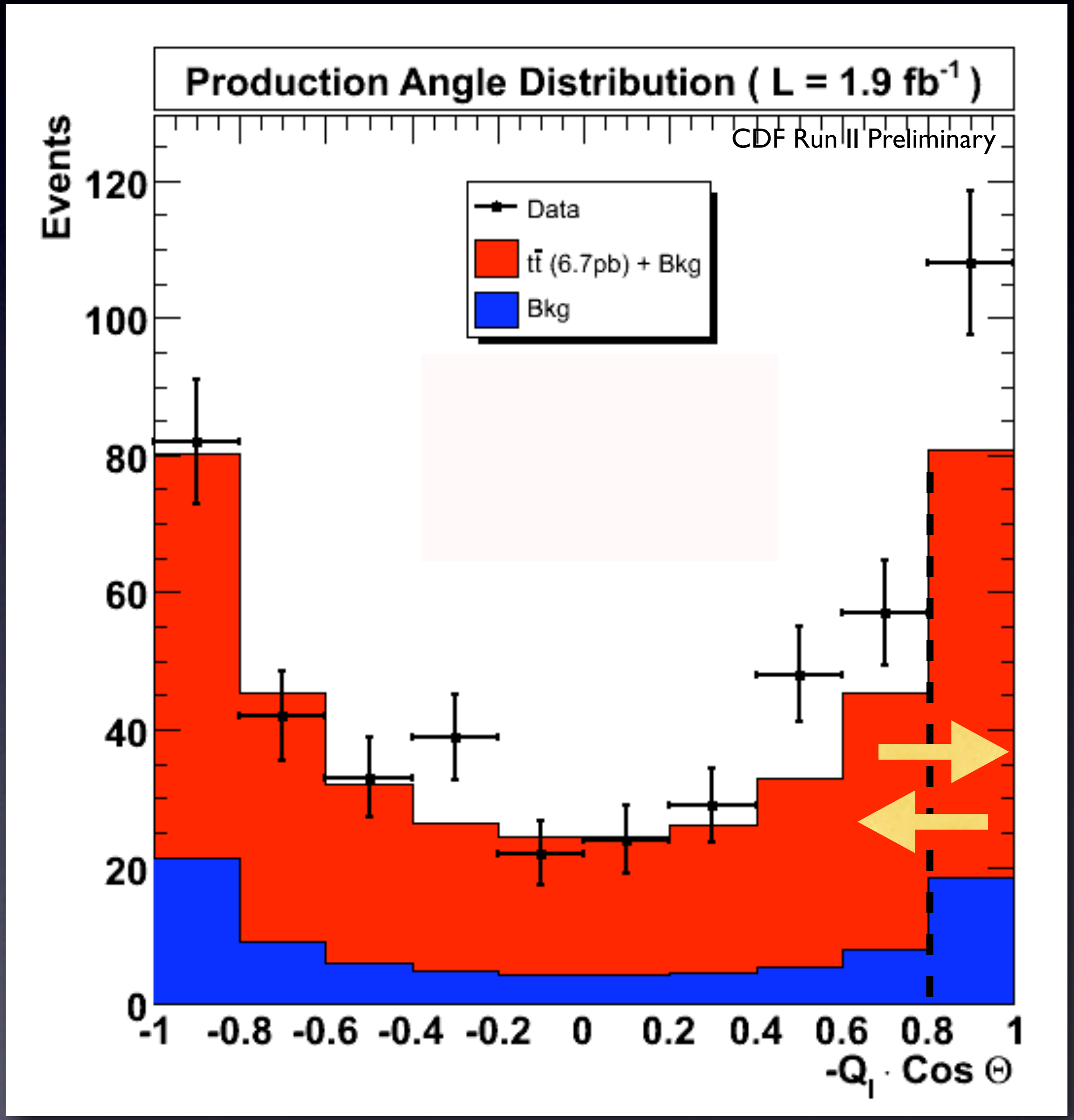
Reconstruction Corrections

- The smearing of the "true" distribution is related to the "reconstructed" distribution by a matrix

$$[Recon] = \begin{bmatrix} s_{0,0} & s_{0,1} & \cdots & s_{0,nbins} \\ s_{1,0} & s_{1,1} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ s_{nbins0} & \cdots & \cdots & s_{nbins,nbins} \end{bmatrix} [True]$$

- ~ 15% (25%) forward events reconstruct backward and vice-versa in the $p\bar{p}$ ($t\bar{t}$) frame

- The matrix can be inverted to correct for smearing



Reconstruction Corrections

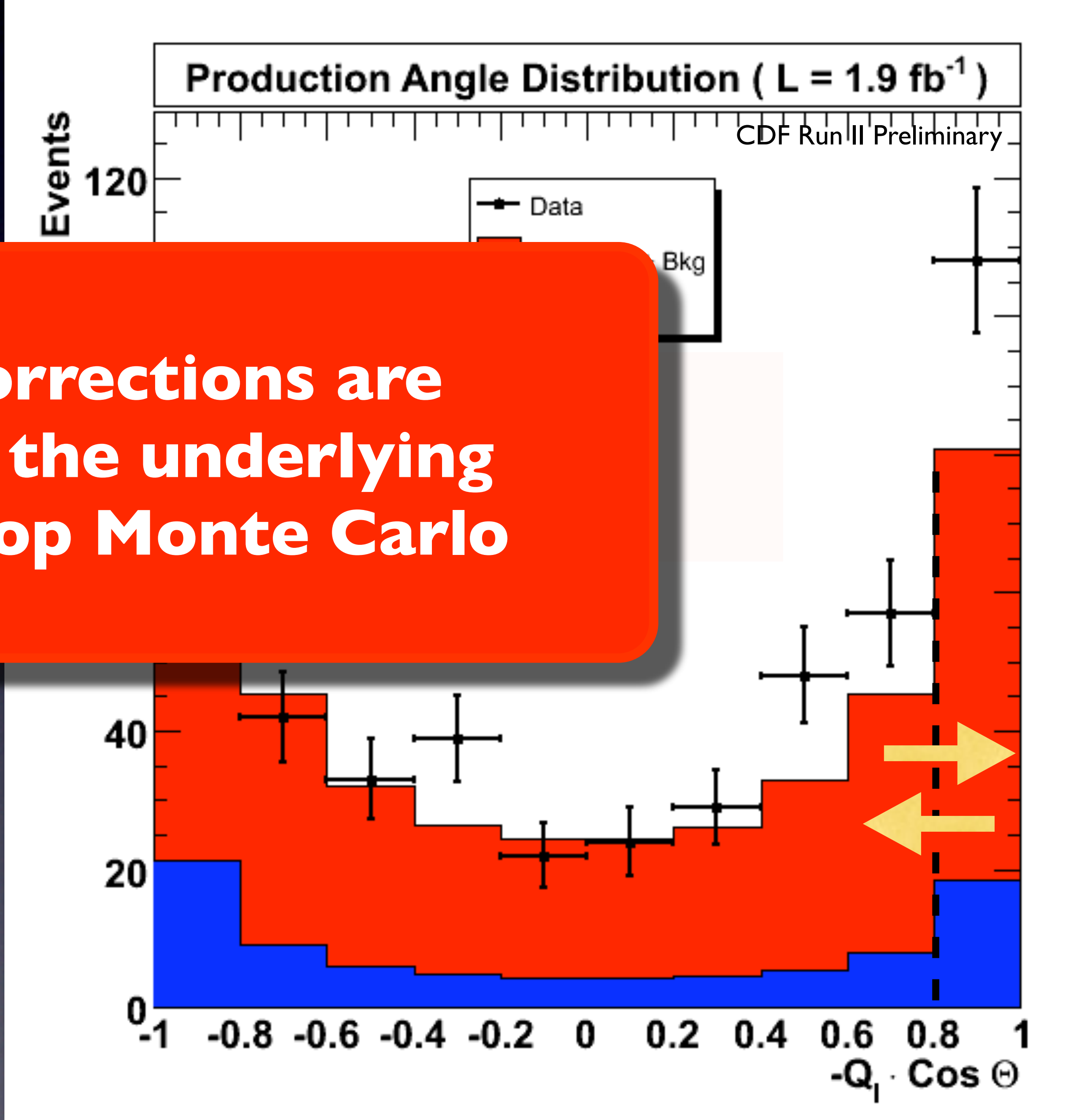
- The smearing of the “true” distribution is related to the “reconstructed” distribution by a matrix

$$[Recon] = \begin{bmatrix} s_{0,0} \\ s_{1,0} \\ \dots \\ s_{nbins0} \end{bmatrix}$$

Unfolding corrections are insensitive to the underlying shape of the top Monte Carlo

- ~ 15% (25%) forward events reconstruct backward and vice-versa in the $p\bar{p}$ ($t\bar{t}$) frame

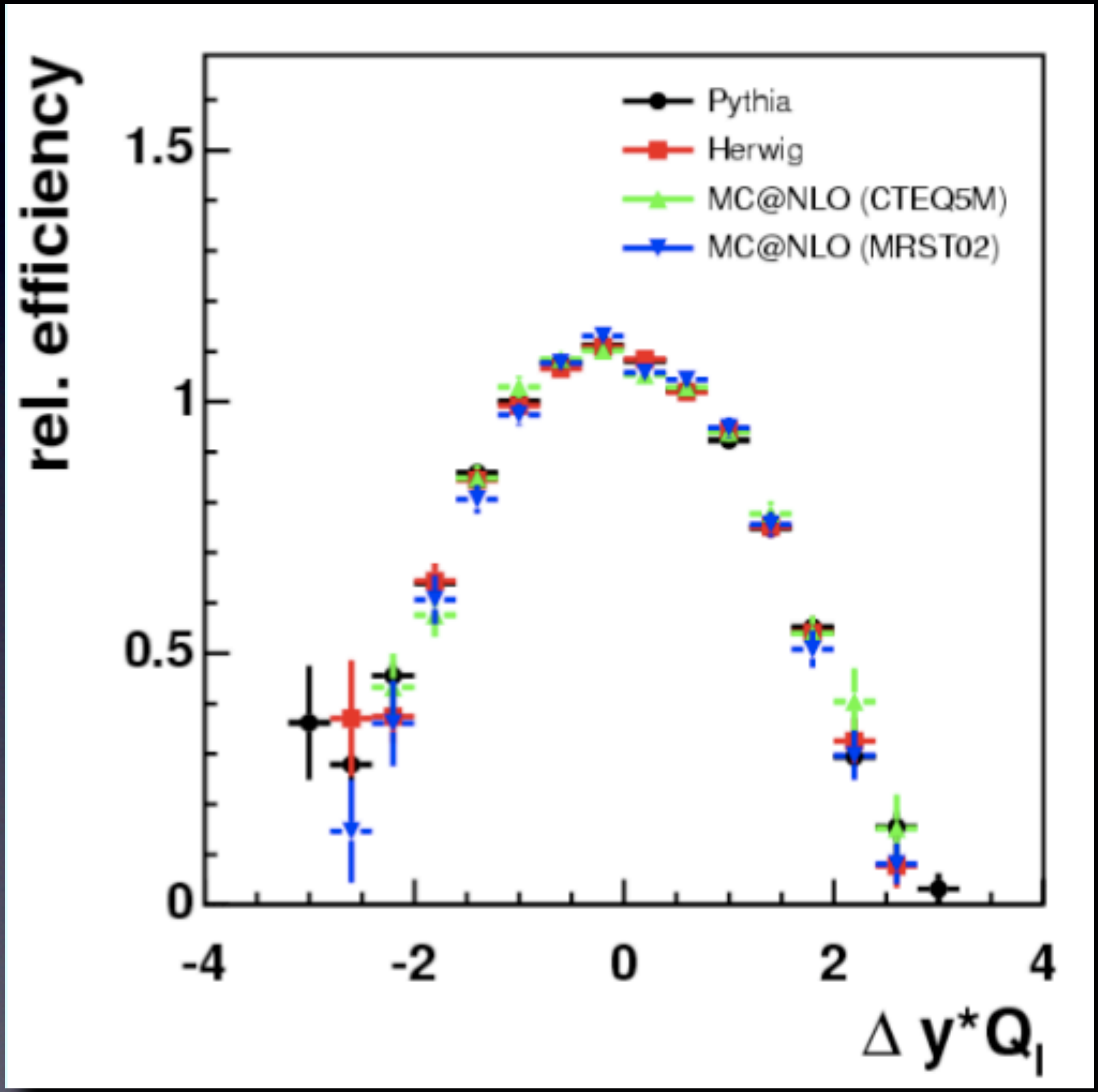
- The matrix can be inverted to correct for smearing



Acceptance Correction

- Detector and Selection can introduce bias
- Selection Efficiency for bin 'i' :

$$\epsilon_i = \frac{N_i^{Selected}}{N_i^{generated}}$$

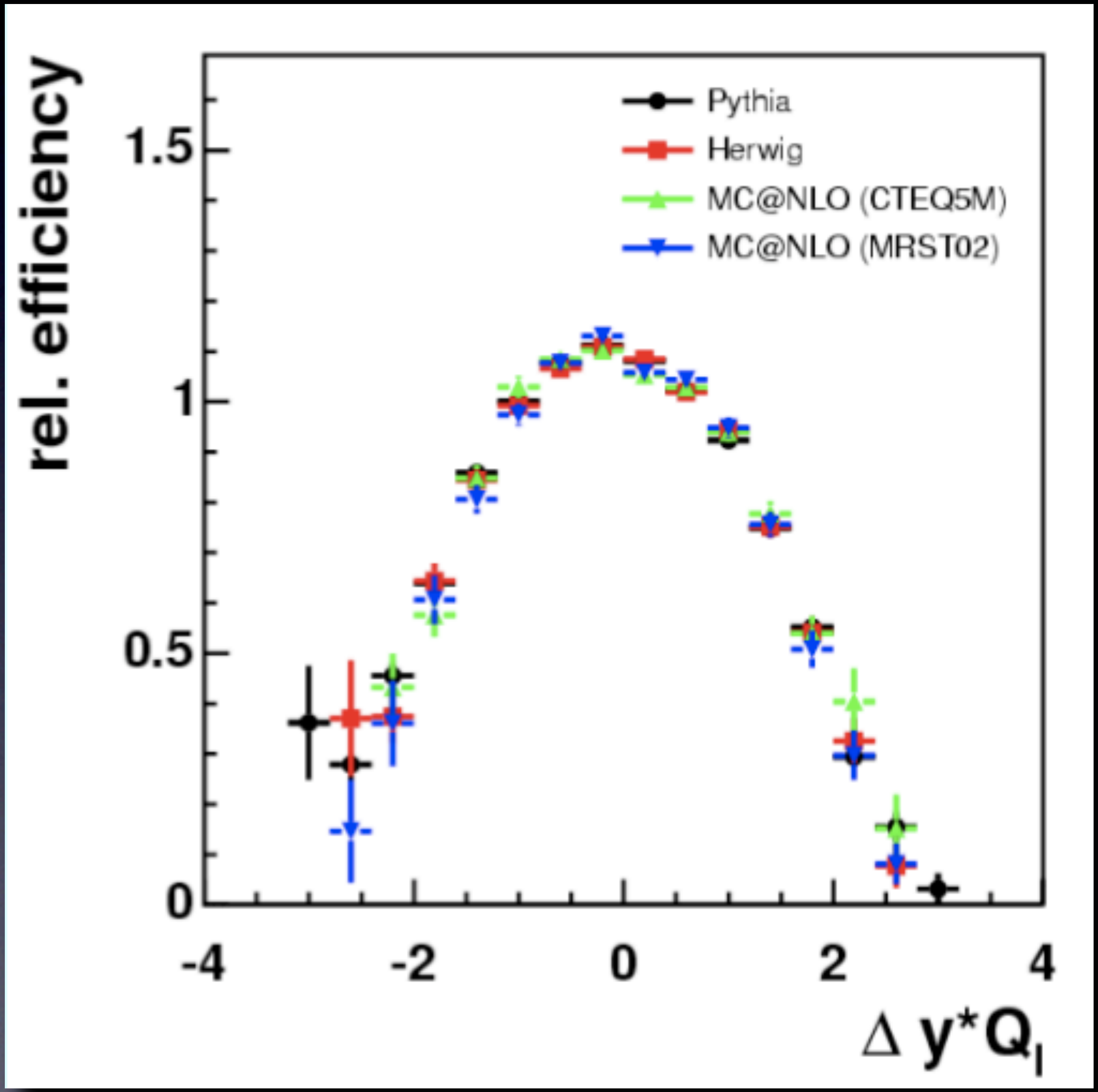


Acceptance Correction

- The distribution "after selection" can be related to the "true" distribution again by a matrix

$$[Selected] = \begin{bmatrix} \epsilon_0 & 0 & 0 & 0 \\ 0 & \epsilon_1 & 0 & 0 \\ 0 & 0 & ... & 0 \\ 0 & 0 & 0 & \epsilon_{nbins} \end{bmatrix} [True]$$

- The matrix can be inverted to correct for acceptance



Putting It All Together

- The correction matrices are cascaded and applied to the background corrected data to produce a result independent of the effects of acceptance and reconstruction

$$Corrected = A^{-1} \cdot S^{-1} \cdot (Data - Bkg)$$

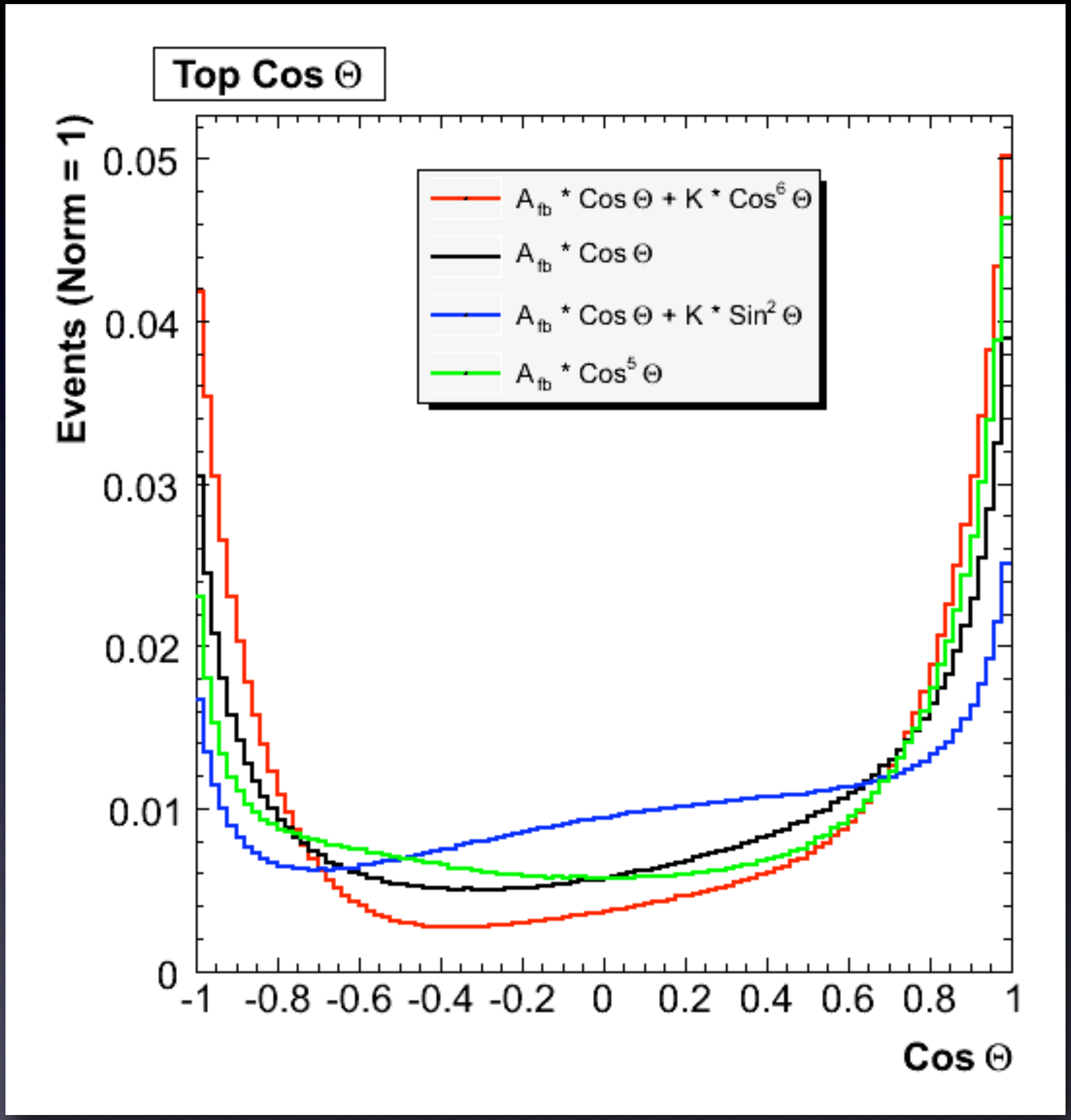
Result is fully corrected for backgrounds, acceptance, and reconstruction:

Directly Comparable to Theory

The Underlying Shape

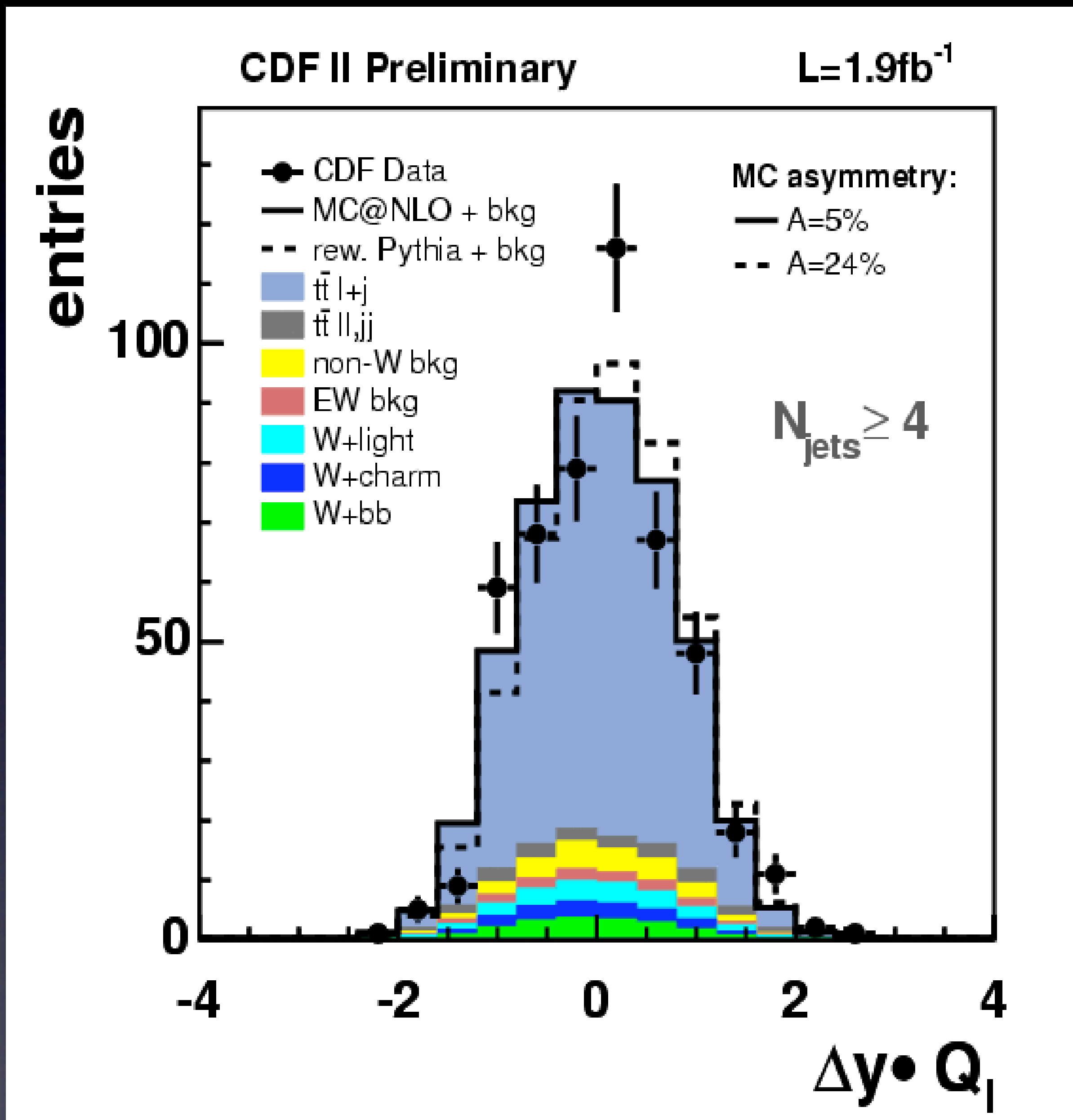
- Is the method invariant to reasonable differences in the true production angle distribution from the SM prediction?
- Test entire machinery for various exotic scenarios

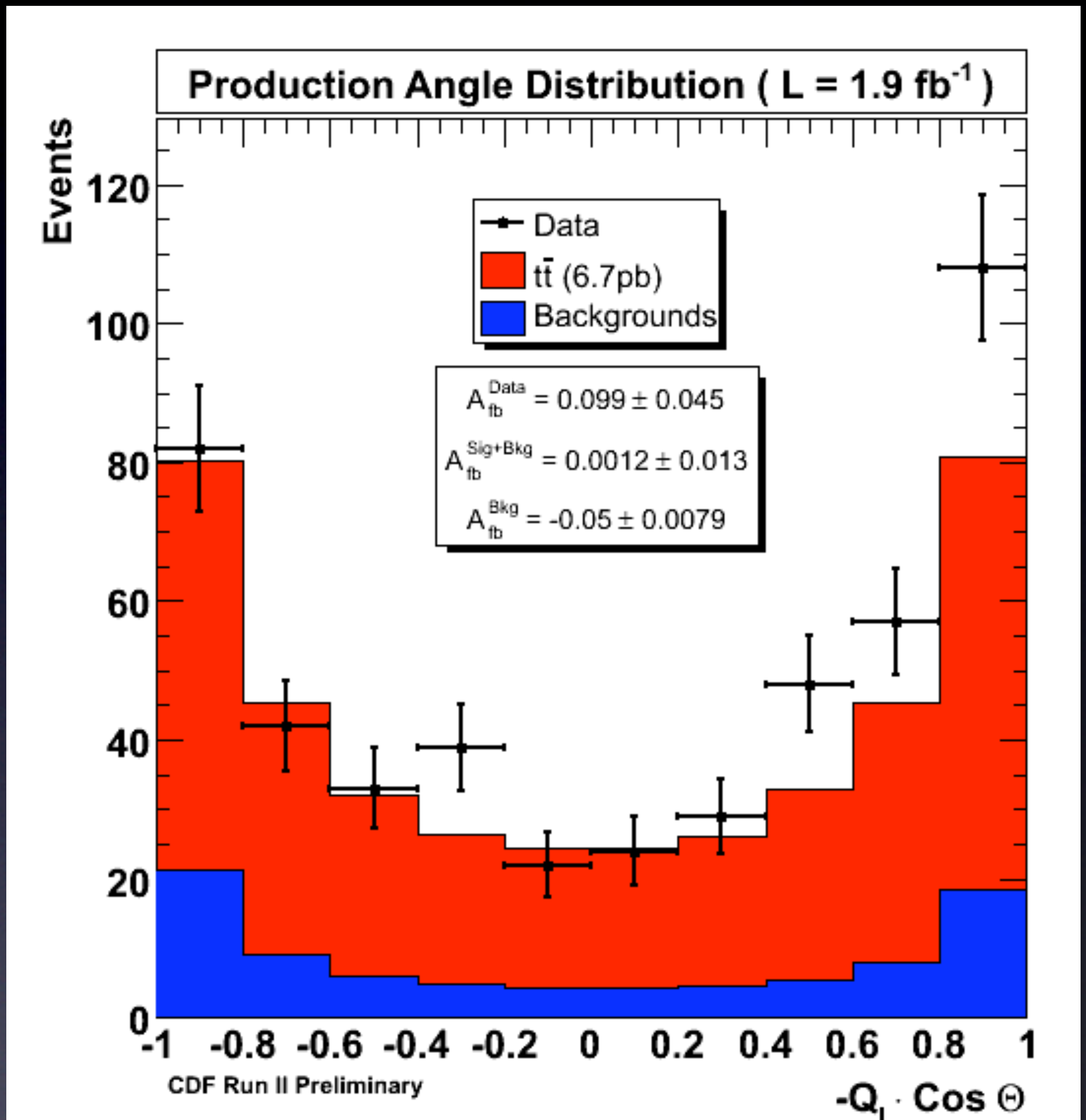
Distribution	Truth A_{fb}	Corrected A_{fb}
$A_{fb} \cdot \cos\Theta + K \cdot \cos^6\Theta$	0.2	0.22
$A_{fb} \cdot \cos\Theta$	0.2	0.21
$A_{fb} \cdot \cos\Theta + K \cdot \sin^2\Theta$	0.2	0.22
$A_{fb} \cdot \cos^5\Theta$	0.2	0.20



The method is invariant to reasonable differences in the underlying distribution

Measurement





$A_{fb}^{t\bar{t}\ uncorrected} = 0.087 \pm 0.045$ $A_{fb}^{p\bar{p}\ uncorrected} = 0.099 \pm 0.045$

Measurement of A_{fb} In Top Production with 1.9 fb^{-1}

For M_{top} = 175.0 GeV

$$A_{fb}^{p\bar{p}} = 0.17 \pm (0.07)^{stat} \pm (0.04)^{syst}$$

$$\mathbf{A_{fb}^{p\bar{p}}}_{\mathbf{theory}} = \mathbf{0.04 \pm 0.01}$$

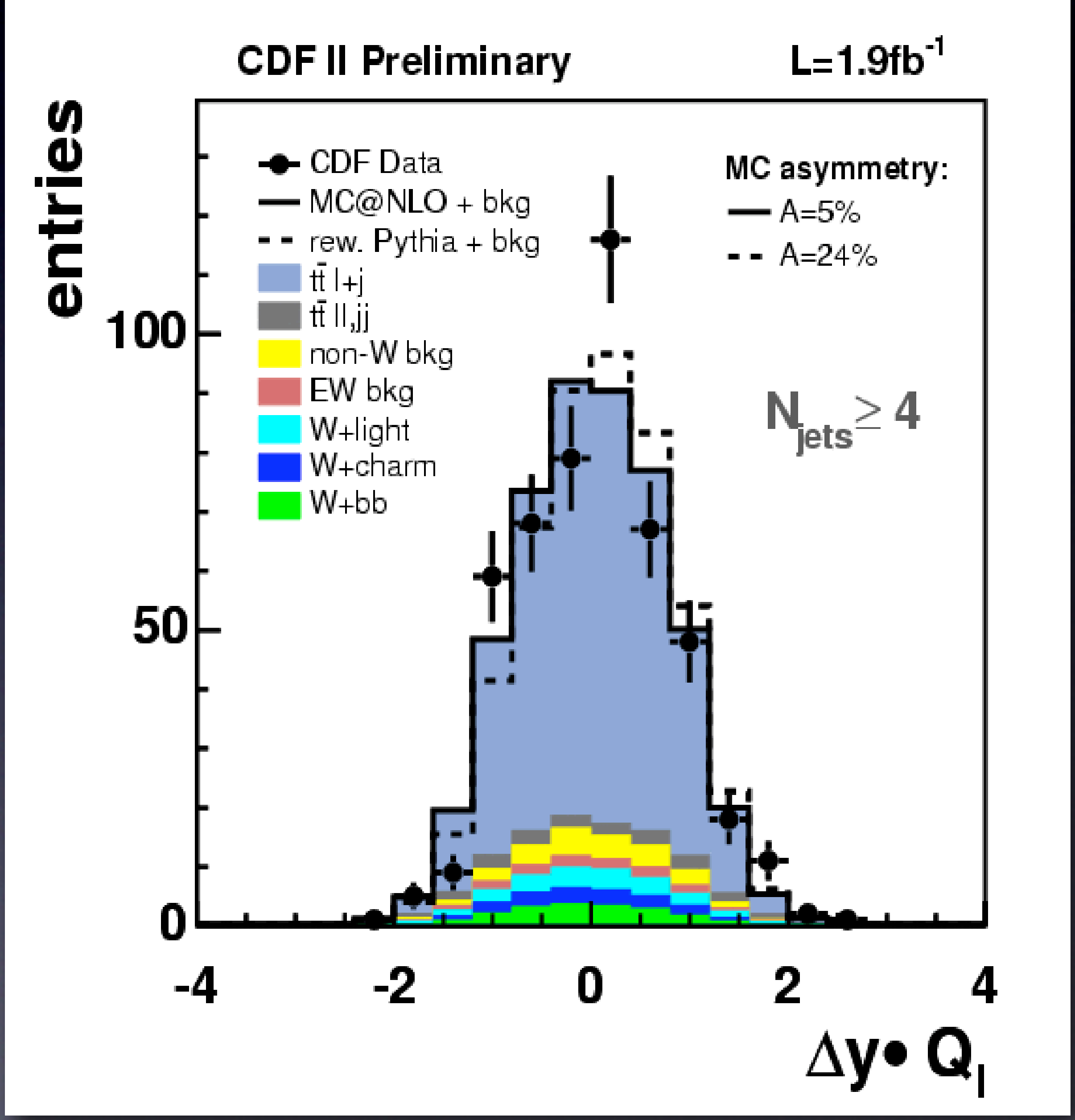
$$A_{fb}^{t\bar{t}} = 0.24 \pm (0.13)^{stat} \pm (0.04)^{syst}$$

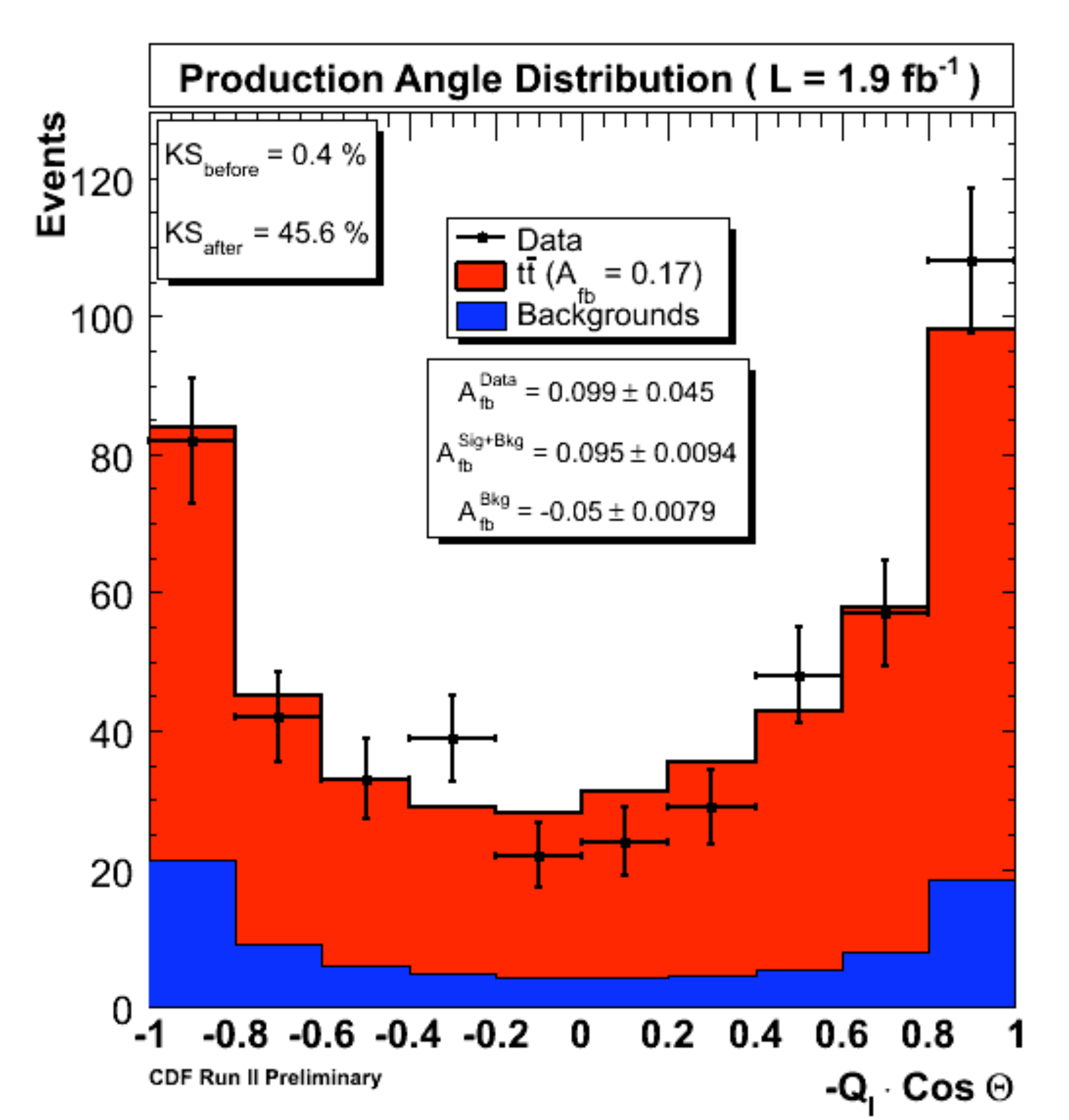
$$\mathbf{A_{fb}^{t\bar{t}}}_{\mathbf{theory}} = \mathbf{0.06 \pm 0.01}$$

Cross-Check (Template Method)

- Reweight the ttbar signal Monte Carlo at the truth level to measured A_{fb} and observe agreement between reconstructed asymmetries
- Using pythia ttbar Monte Carlo with a linear asymmetric component: $Afb \cdot \cos \Theta$ (1st order term)
- Reweighted events through the entire machinery of the analysis and compare the resulting reconstructed asymmetry to data

Cross-Check (Template Method)





For More Detail

http://www-cdf.fnal.gov/physics/new/top/2007/topProp/Afb/

$$A_{fb}^{p\bar{p}} = 0.17 \pm (0.07)^{stat} \pm (0.04)^{syst}$$

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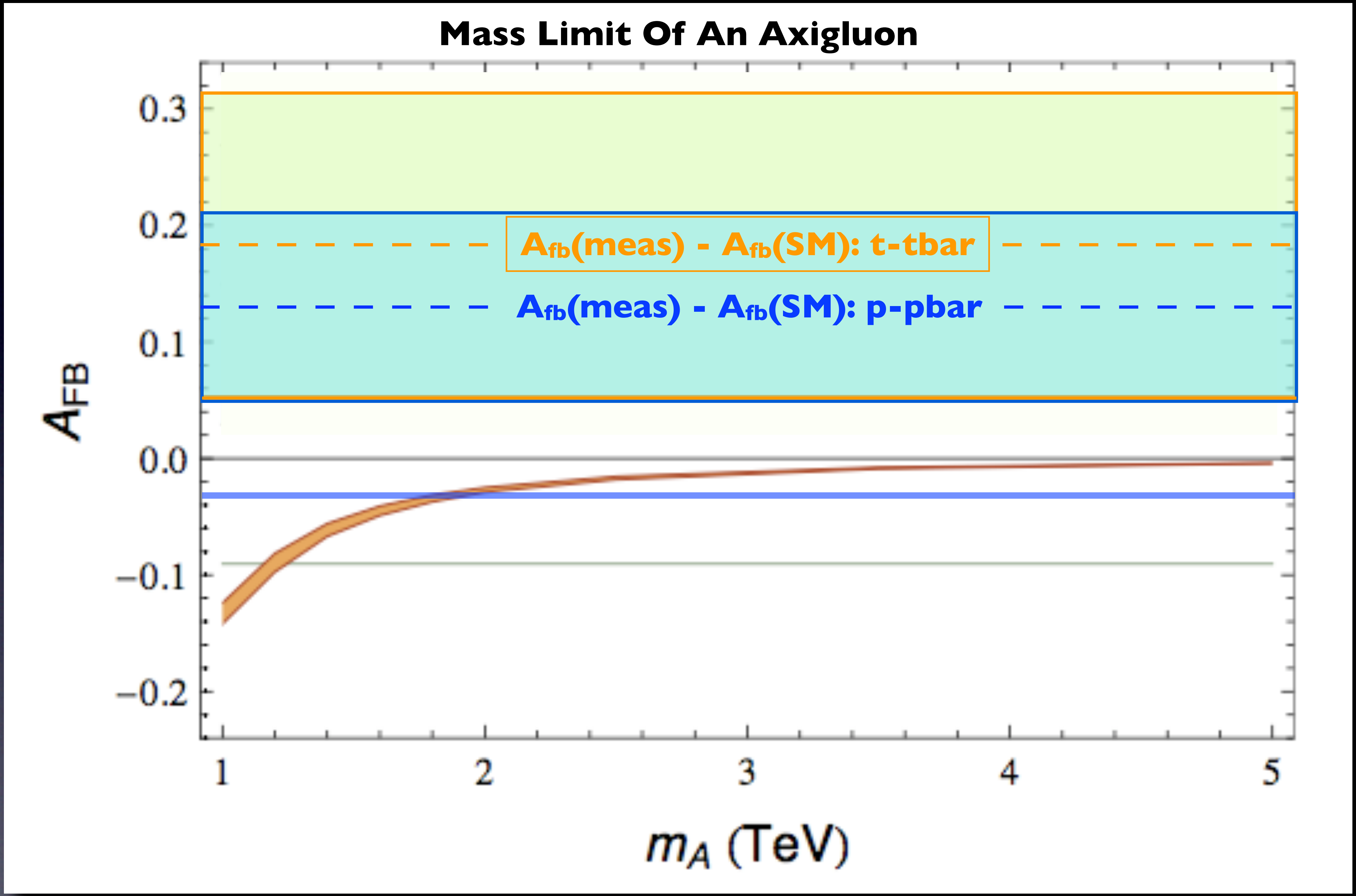
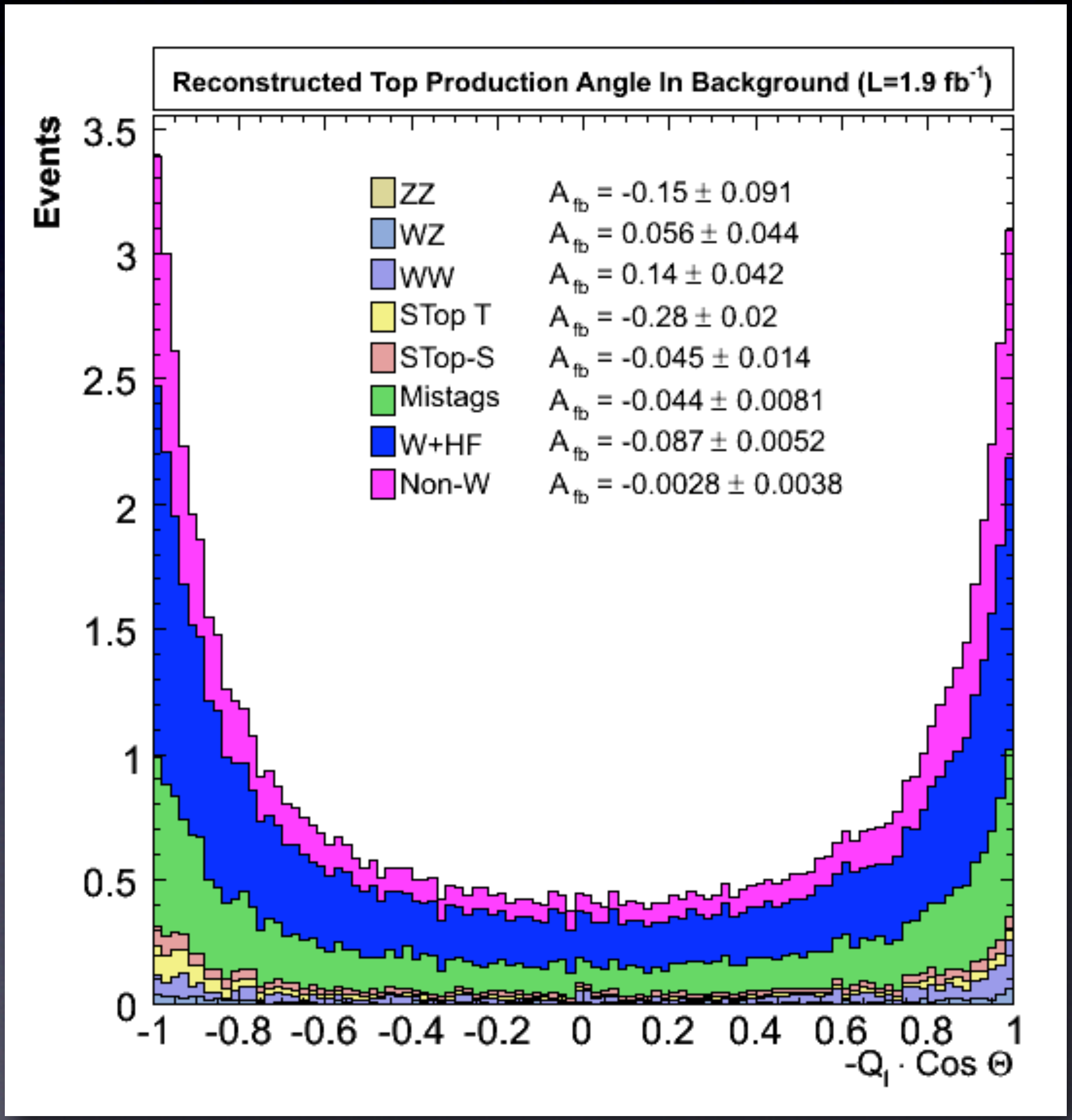
Appendix



Mass Limit Of An Axigluon
0.3
0.2
0.1
0.0
−0.1
−0.2
A_FB
Afb(meas) - Afb(SM): t-tbar
Afb(meas) - Afb(SM): p-pbar
1
2
3
4
5
m_A (TeV)

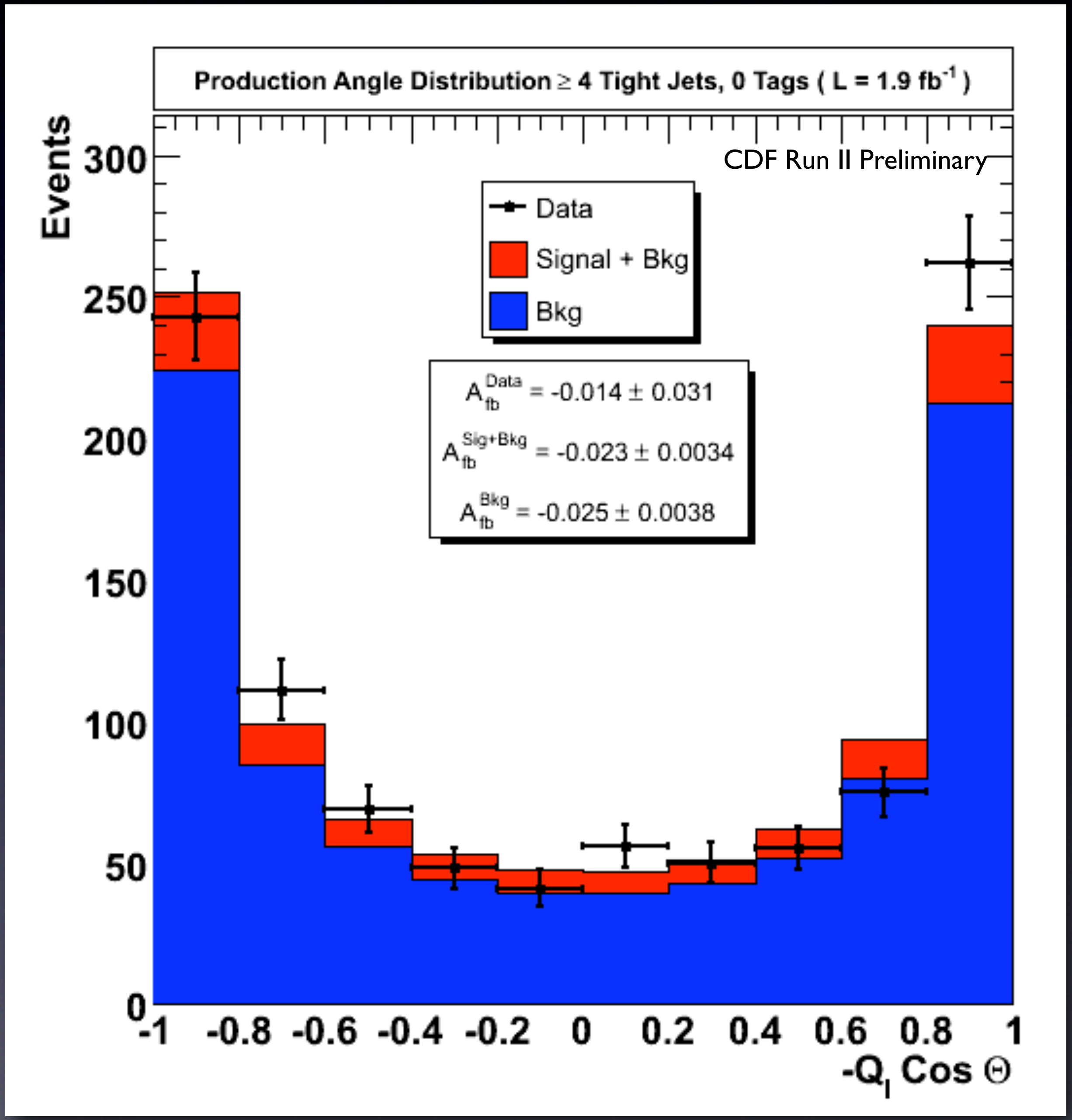
Background Correction

- Backgrounds dilute the signal and, if they have any asymmetric components, bias it
- To properly correct for this effect we need to know the prod angle shape in background
- The background Cos Θ distribution is formed by putting the background models through the entire selection and reconstruction machinery



Background Correction

- How do we know the background shape is correct?
- Test in a background dominated side-band region (Anti-Tag Sample)
- Background prediction is consistent in this distribution



Background Prediction

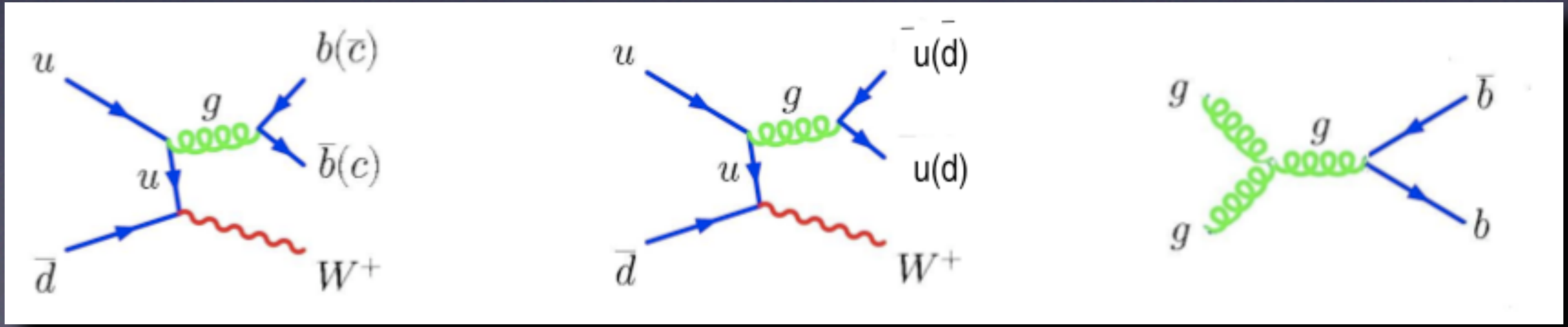
- For our selection we predict 373 top pairs with a S:B = 4:1 for a Top Mass of 175.0 GeV in 1.9 fb^{-1} of collected data

- We observe 484 events with a predicted background of 85.7 events

Signal and Background Prediction

Process	4jets	5jets
Wbb	16.5 ± 6.7	3.5 ± 1.5
Wcc/Wc	12.9 ± 5.2	2.6 ± 1.1
WW	2.5 ± 0.3	0.7 ± 0.1
WZ	0.9 ± 0.1	0.2 ± 0.0
ZZ	0.1 ± 0.0	0.0 ± 0.0
Stop S	2.0 ± 0.2	0.4 ± 0.0
Stop T	1.9 ± 0.2	0.3 ± 0.0
Z+Jets	2.4 ± 0.3	0.5 ± 0.1
Mistags	16.7 ± 3.6	3.3 ± 1.1
Non-W	13.6 ± 11.7	4.6 ± 4.6
$t\bar{t}$ (6.7pb)	252.0 ± 34.9	85.3 ± 11.8
Total Prediction	321.6 ± 39.1	101.4 ± 13.0
Observed	371.0	113.0

CDF Run II Preliminary $L = 1.9 fb^{-1}$



Systematics

t-tbar

Source	Uncertainties $\Delta A^{\Delta y Q_l}$
Monte Carlo generator (Herwig)	0.018
Parton distribution function	0.012
ISR / FSR	0.010
Mass	0.005
Jet energy scale	0.010
$\Delta y Q_l$ top shape	0.020
BG, shape	0.015
Number of z-vertices	0.010
Total	**0.038**

p-pbar

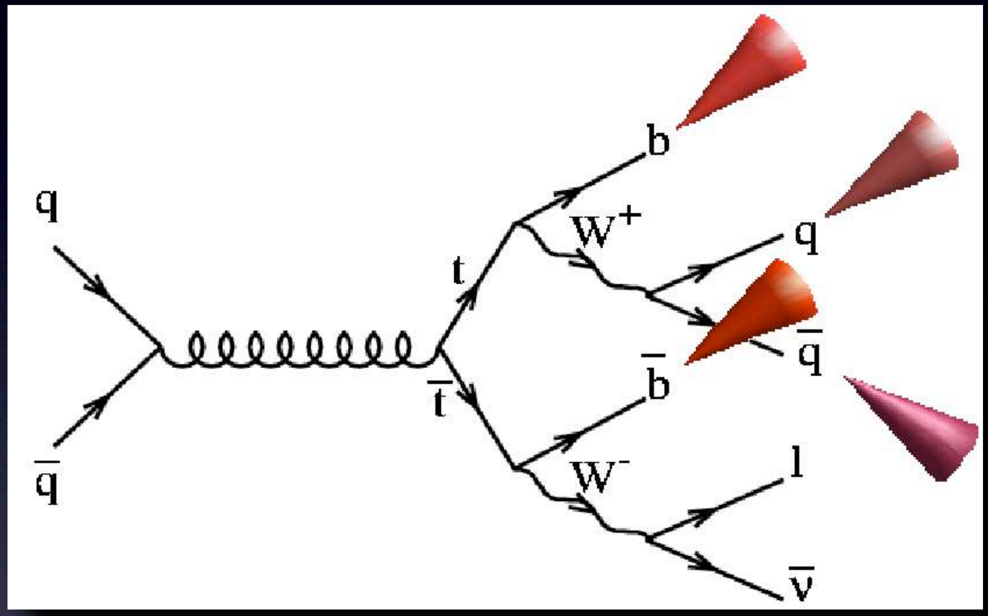
Systematic Uncertainties on A_{fb}

SYSTEMATIC	-Δ	+Δ	σ
MC GEN	0.000	0.012	0.012
JES	-0.005	0.004	0.005
ISR	0.000	0.004	0.004
FSR	-0.013	-0.007	0.012
TOP SHAPE	-0.012	0.008	0.012
BKG SHAPE	-0.008	0.018	0.018
BKG NORM	-0.014	0.021	0.021
PDF	-0.011	0.011	0.011
TOTAL	-		0.038

CDF Run II Preliminary

Reconstructing The Event

- 4 jets must be matched to 4 partons
- 24 different combinations to choose from
- Jet and unclustered energies can vary within error
- Known Top Mass can be used as a constraint
- Choose combination with lowest χ^2



$$\chi^2 = \sum_{i=l,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,meas} - p_j^{UE,fit})^2}{\sigma_j^2}$$

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{bl\nu} - M_{fit})^2}{\Gamma_t^2}$$

Full Reconstruction

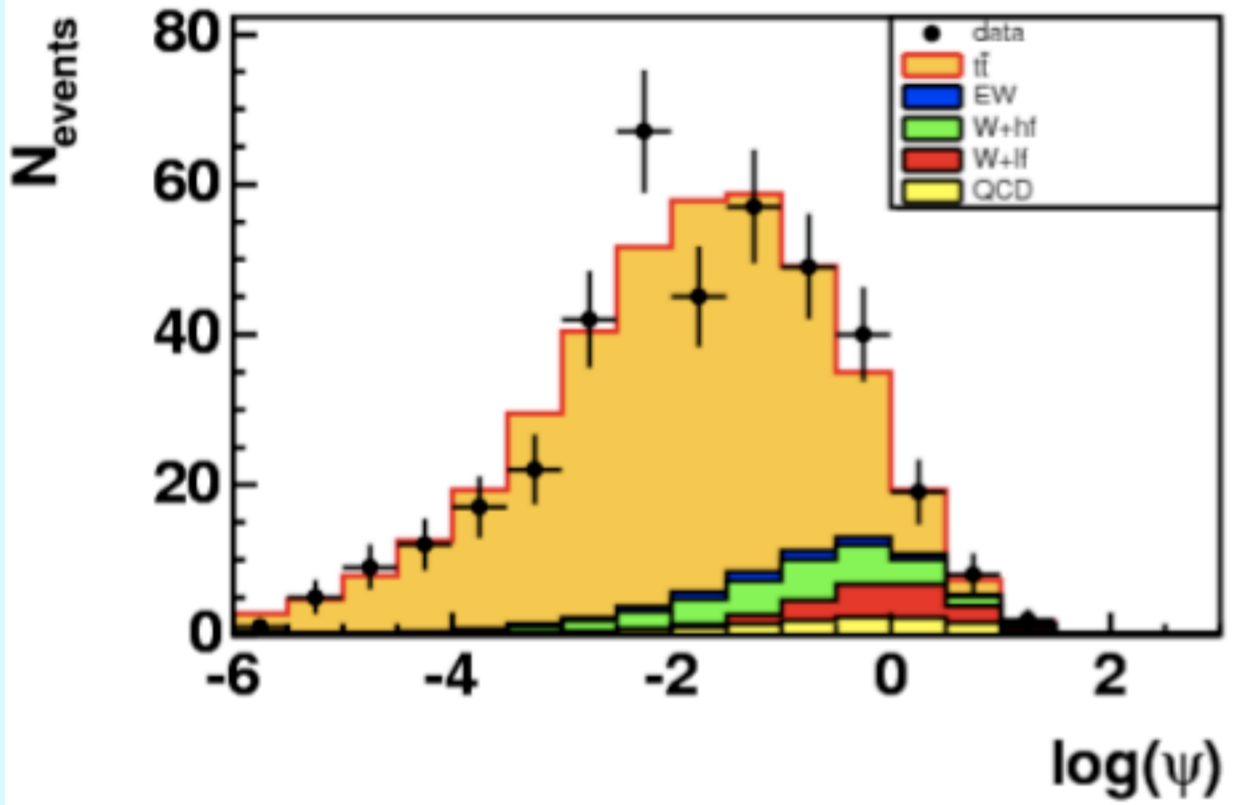
CDF note 7809 and 8338

Several hypotheses for top anti-top reconstruction due to jet combination and neutrino p_z

→ Select hypothesis with smallest value of ψ

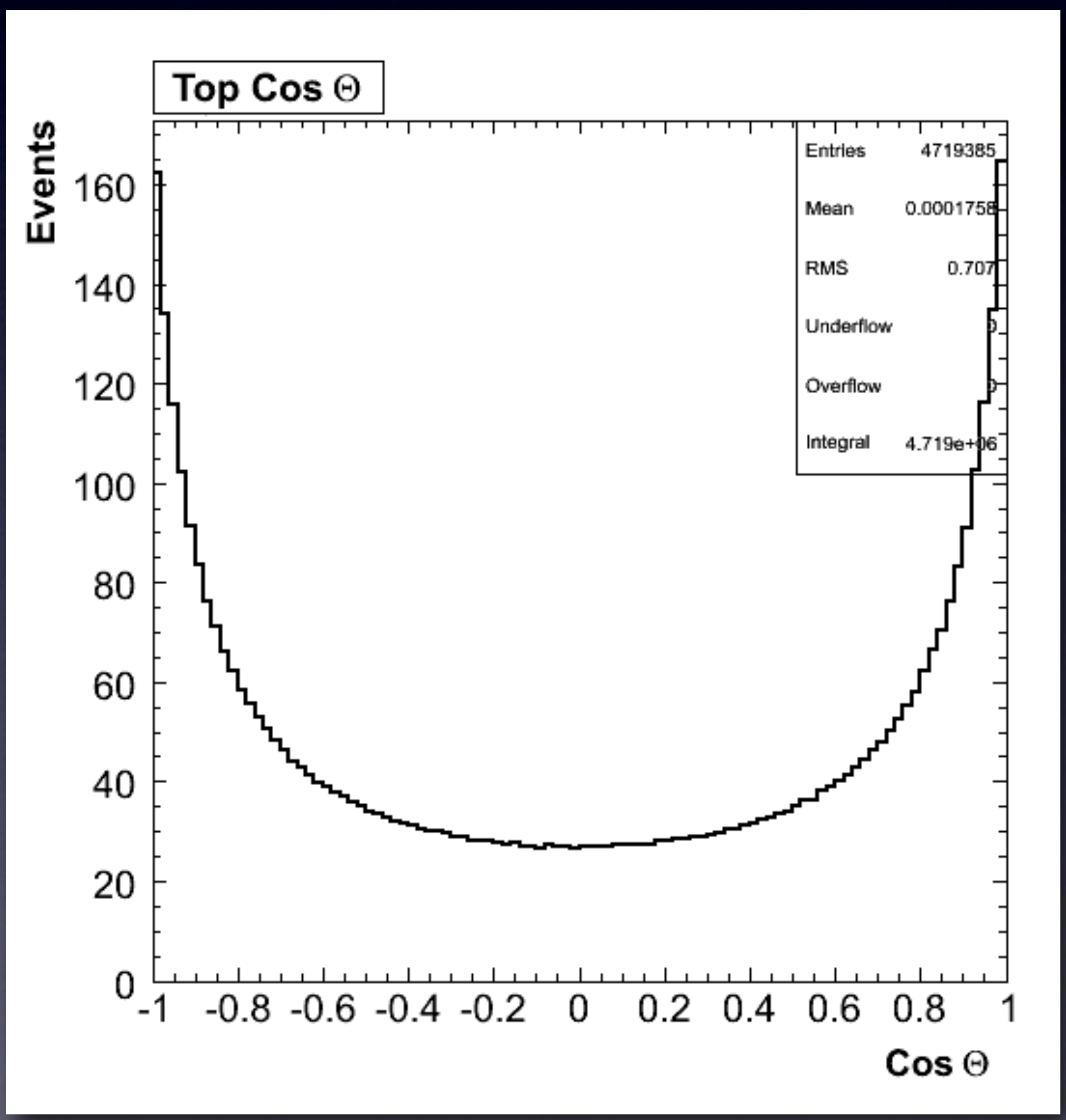
$$\psi = P_\nu \cdot \chi^2 \cdot P_{b-light}$$

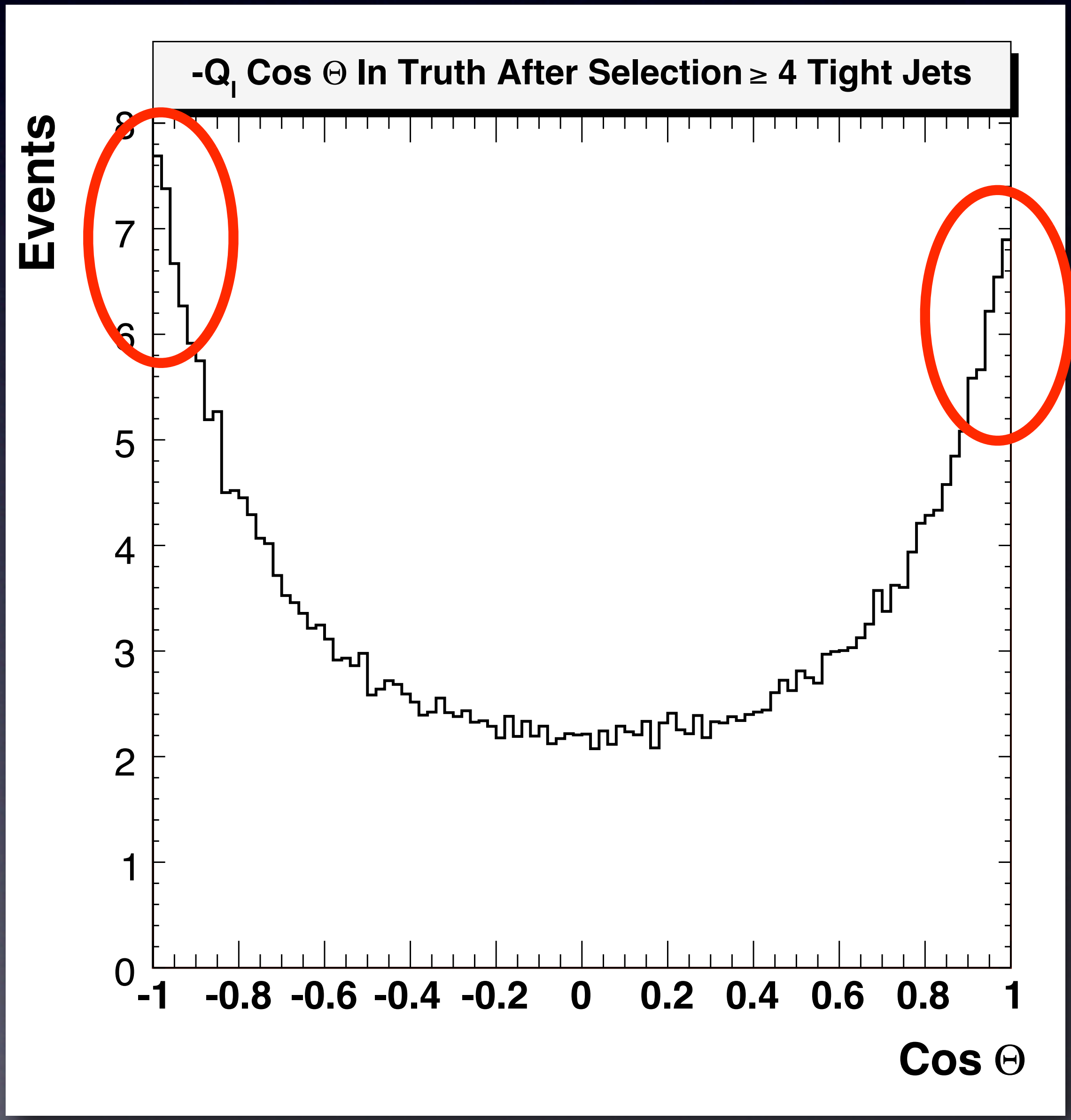
- **Neutrino factor: in 70% the p_z solution with smaller value $|p_z|$ is correct**
- **Constraints on reconstructed W_{had} mass, on the mass difference of the two rec. tops and on E_T of the two tops with respect to total event E_T**
- **Probability for jets assigned to b-quarks to be light jets (jetprob, KA NN b-tagger)**



Acceptance Skew

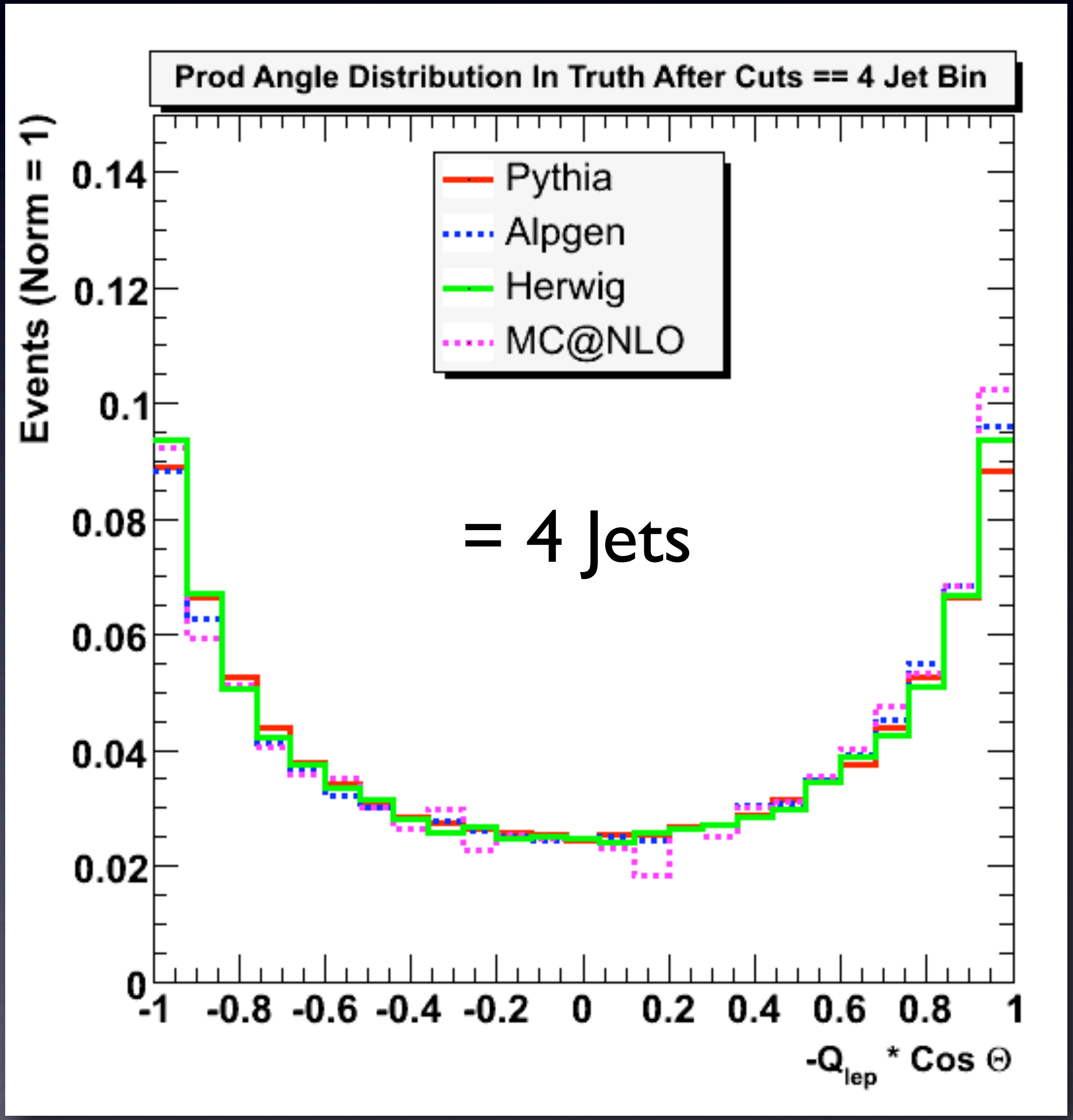
- Acceptance plot is really just the HEPG top production angle distribution AFTER SELECTION divided by that BEFORE SELECTION

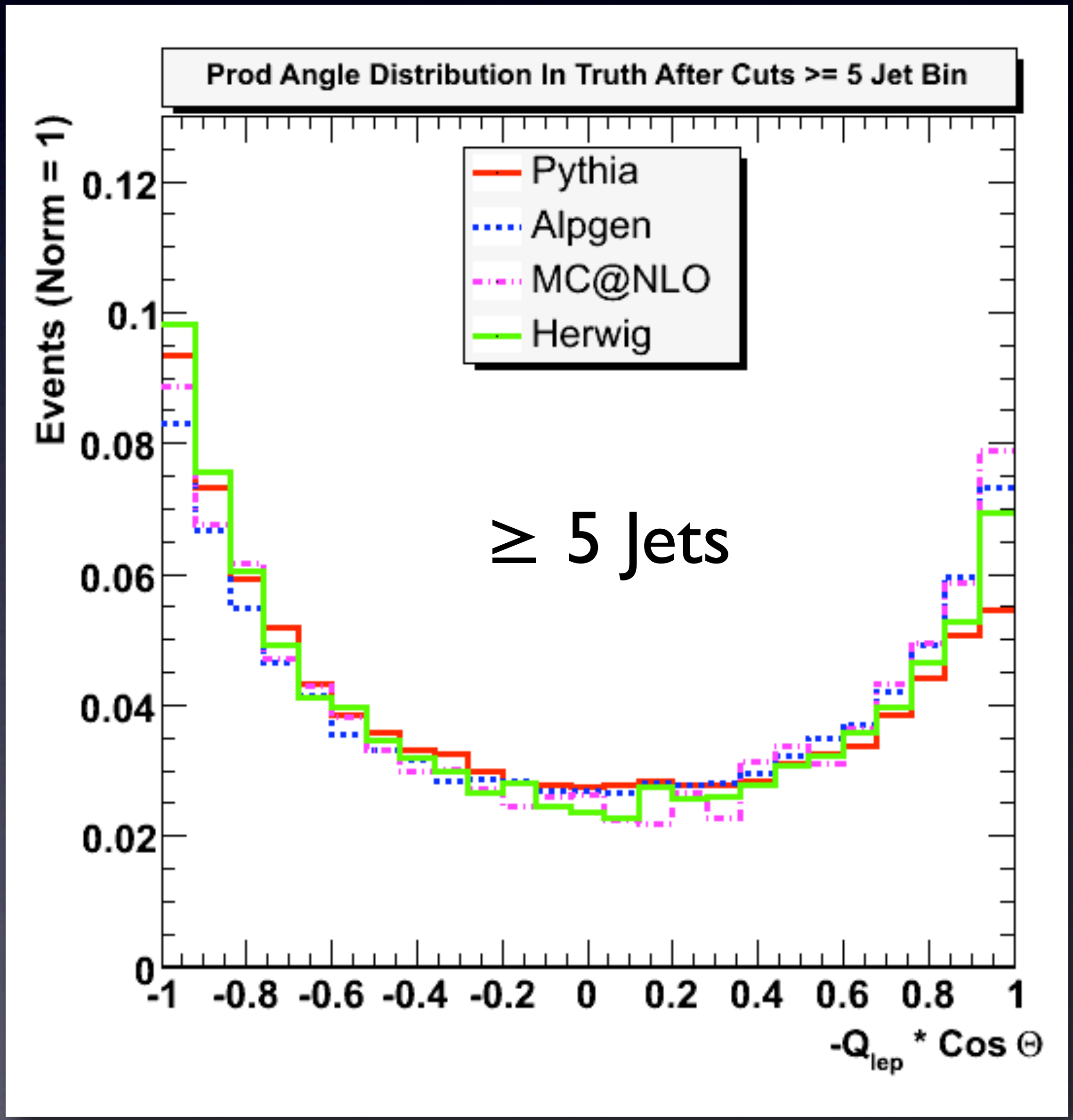




Acceptance Skew

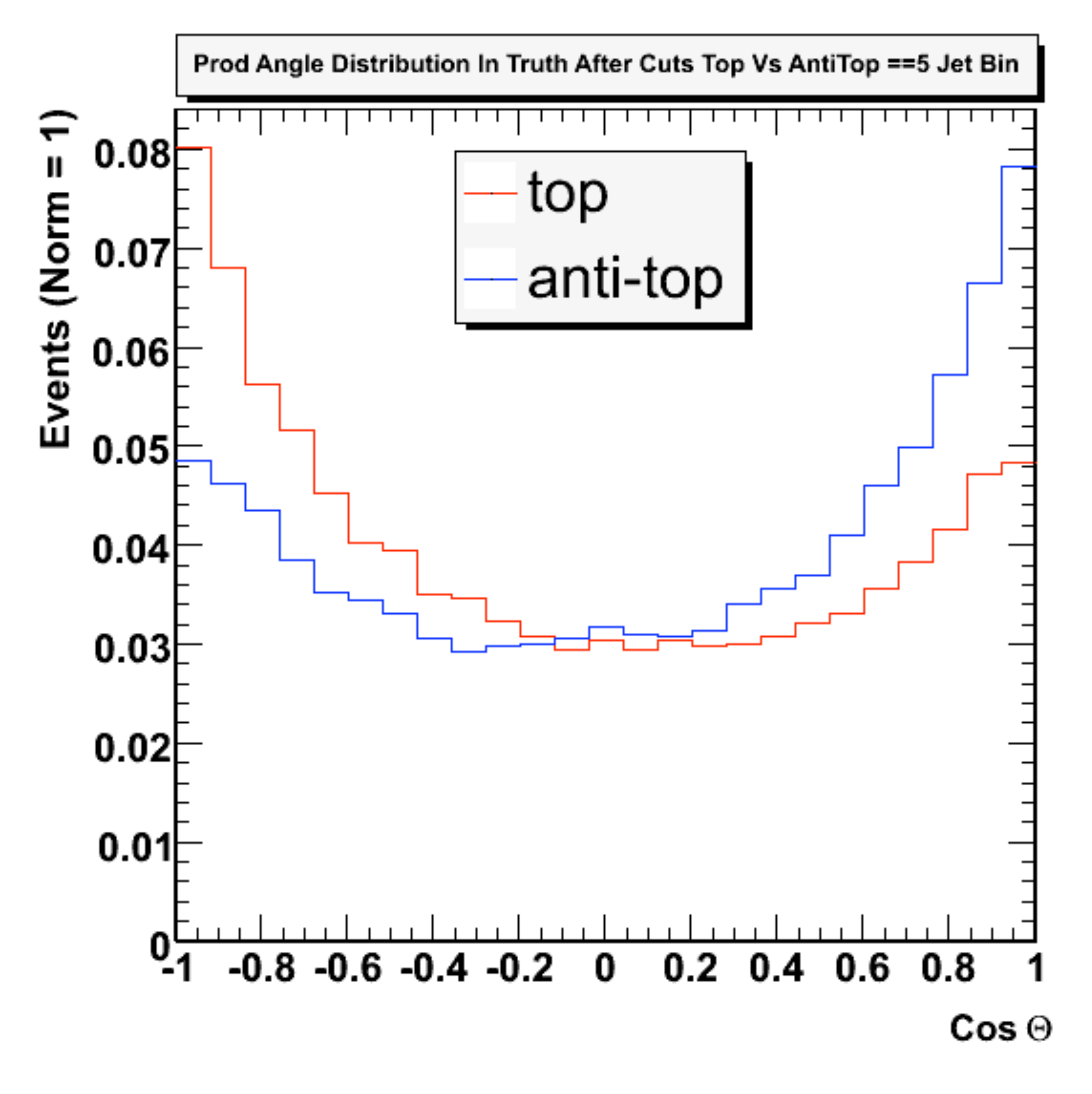
- Can identify the culprit by breaking this down by jet multiplicity





Acceptance Skew

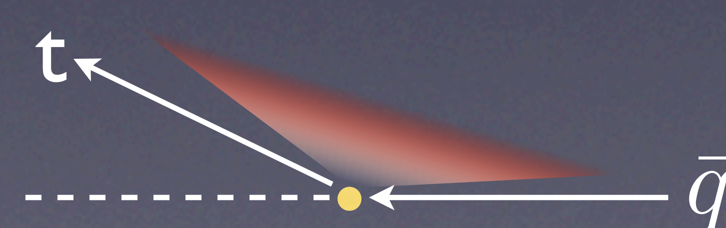
- Break down 5 jet bin into Top and Anti-Top Production Angle Vs Truth(Note i'm not X by charge now)
- Very clear top is being polarized in one direction in the 5 jet bin
- So Why?
- Answer: Color flow and angular ordering of radiation



Color Flow Effects

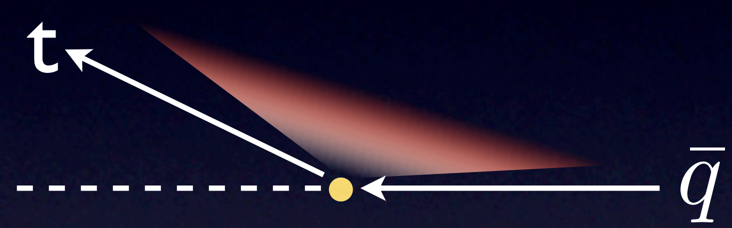
- Angular ordering in QCD says that radiation is mostly contained within the cone formed by color lines.
- ttbar's are mostly produced at threshhold so top is color connected to the incoming quark and tbar to the incoming qbar
- When top is produced in the same direction as the incoming quark, then the angle between them is small and angular ordering says most of the radiation flies down the beam pipe

- When top is produced in the opposite direction, the angle is large (180 degrees) so there is a larger angle for the radation to go



Color Flow Effects

- Because we are selecting more central jets we are biased towards



over

- which translates into prefering

over

- This results in a polarization in the selected ttbar events in the 5 jet bin
- **<u>Thanks To S. Mrenna</u>**

MC Comparison