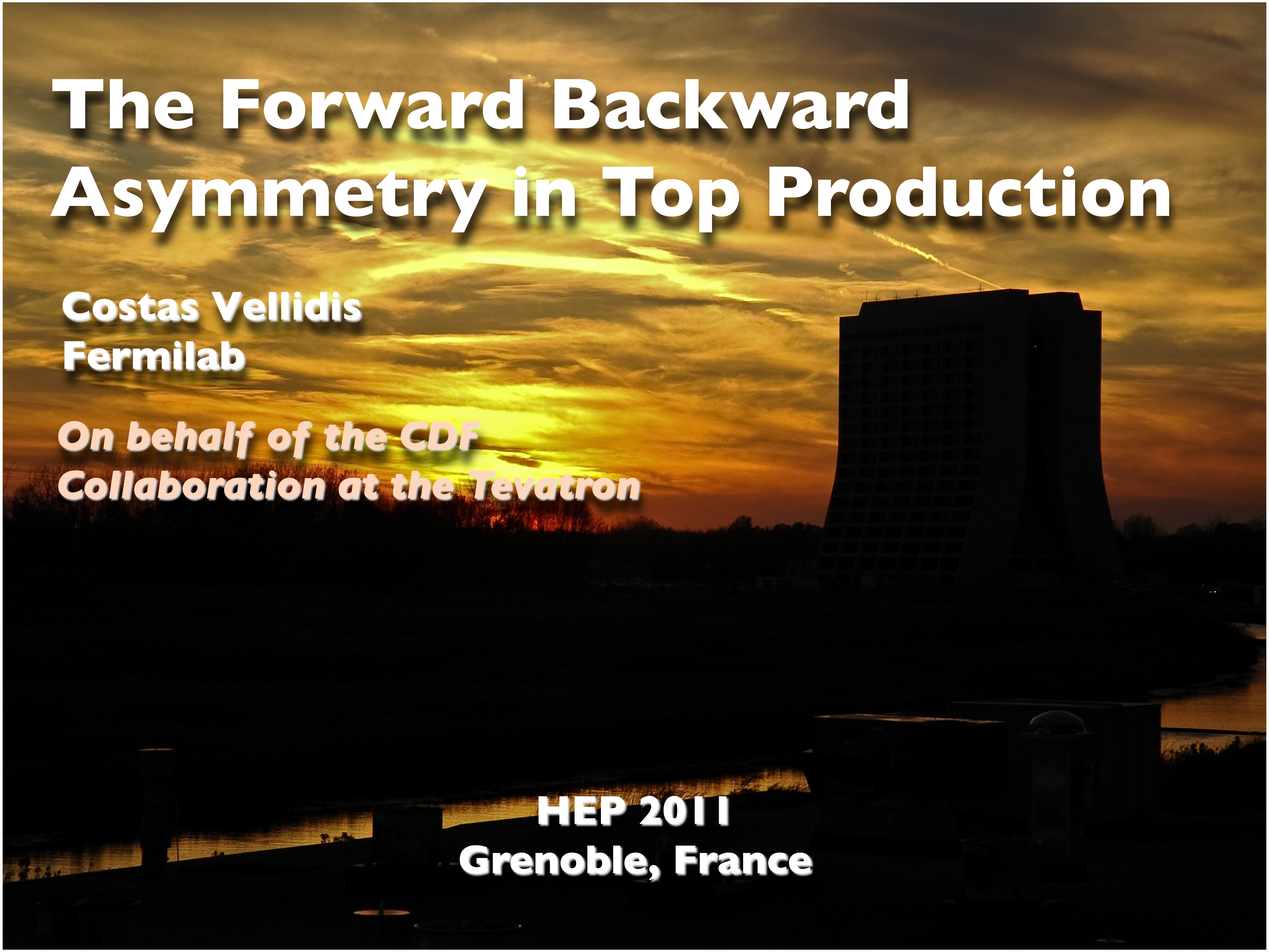
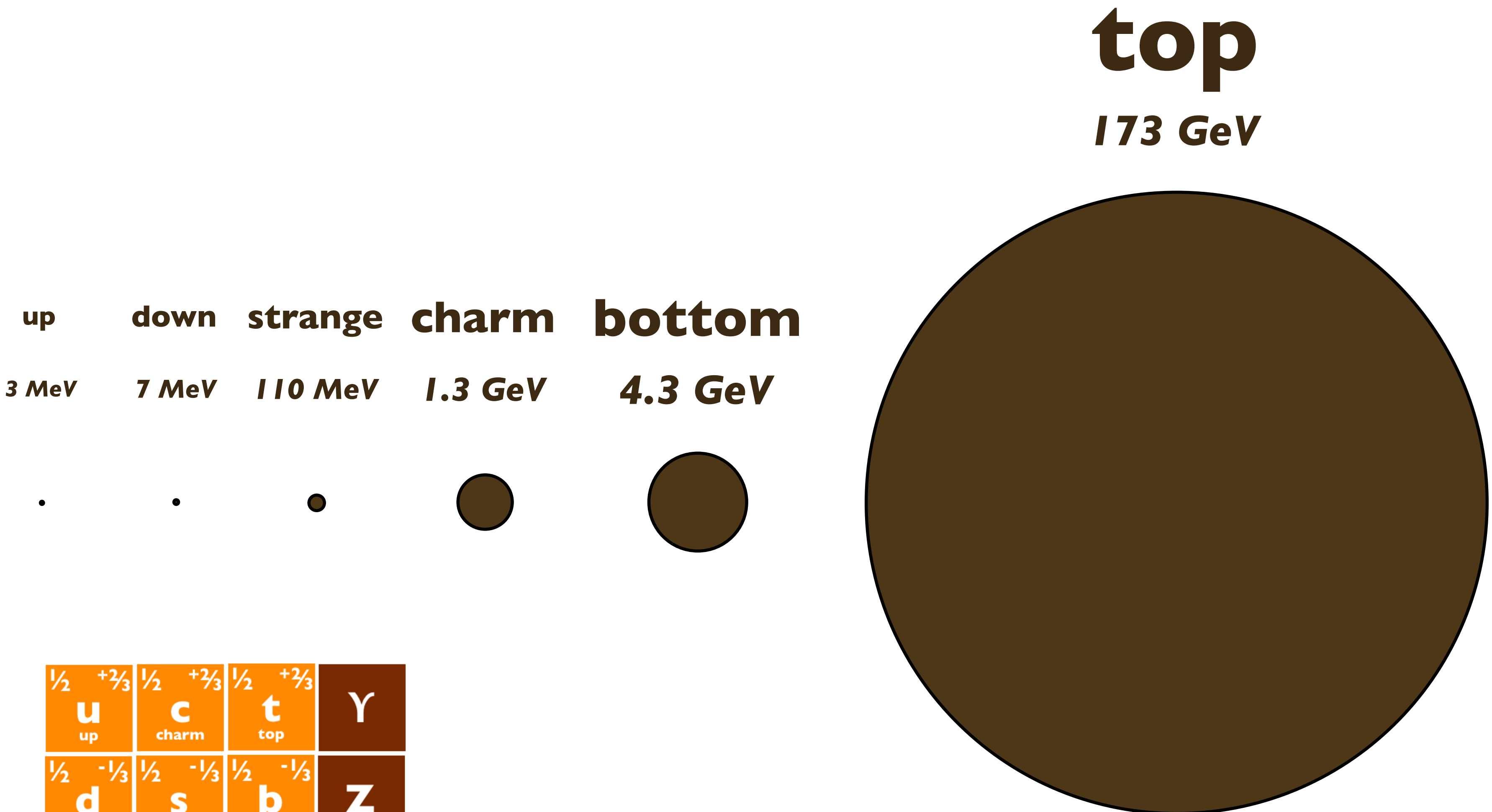


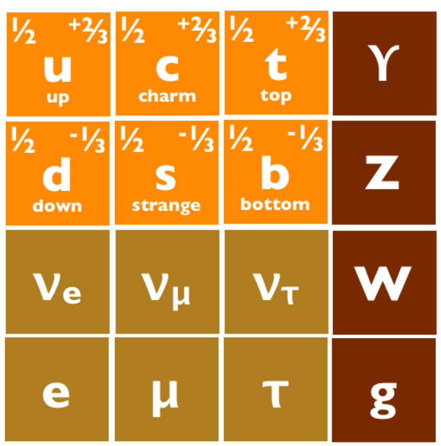
The Forward Backward Asymmetry in Top Production

Costas Vellidis
Fermilab

On behalf of the CDF Collaboration at the Tevatron

HEP 2011
Grenoble, France


top
173 GeV
up
3 MeV
down
7 MeV
strange
110 MeV
charm
1.3 GeV
bottom
4.3 GeV


½ +⅔ u up
½ +⅔ c charm
½ +⅔ t top
γ
½ -⅓ d down
½ -⅓ s strange
½ -⅓ b bottom
Z
νe
νμ
ντ
W
e
μ
τ
g

Area ∝ Mass

Top Mass

$$y_t = \sqrt{2} \cdot \frac{m_t}{v}$$

Higgs Vacuum Expectation

Average Energy in the Higgs Field

Coupling to Higgs

173 GeV

$$\mathbf{y_t = \sqrt{2} \cdot \frac{m_t}{v}}$$

243 GeV

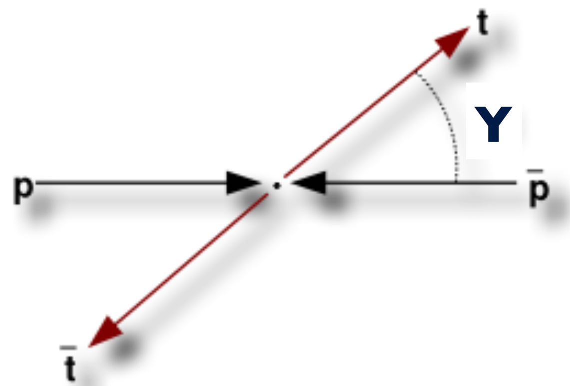
Coupling to Higgs

173 GeV

$$\mathrm{y_t} = \sqrt{2} \cdot \frac{\mathrm{m_t}}{\mathrm{v}} \approx 1.0$$

243 GeV

Top Quark Forward Backward Asymmetry

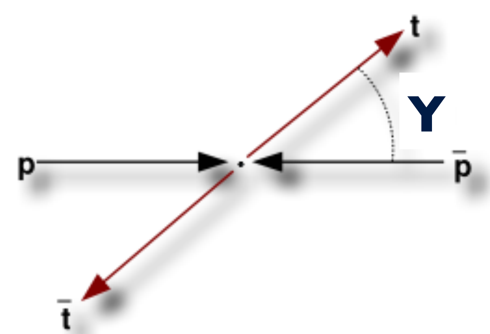


$$A_{FB} = \frac{\mathbf{F} - \mathbf{B}}{\mathbf{F} + \mathbf{B}}$$

Why Measure It?

- **Test of discrete symmetries of the strong interaction**
- **NLO QCD predicts small (~6%) asymmetry from $q\bar{q} \rightarrow t\bar{t}$**
- **New physics can show up: Big Gluons with axial vector coupling**

$$A_{FB} = \frac{\mathbf{N_{Y>0} - N_{Y<0}}}{\mathbf{N_{Y>0} + N_{Y<0}}}$$



Why Measure It?

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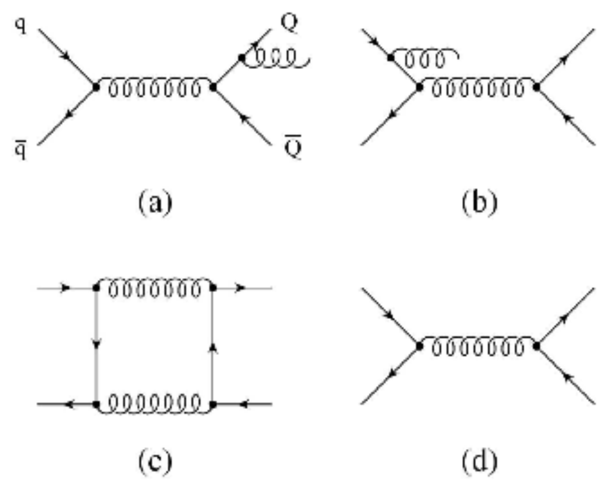


Kuhn, Rodrigo
PRL 81,89 (1998)

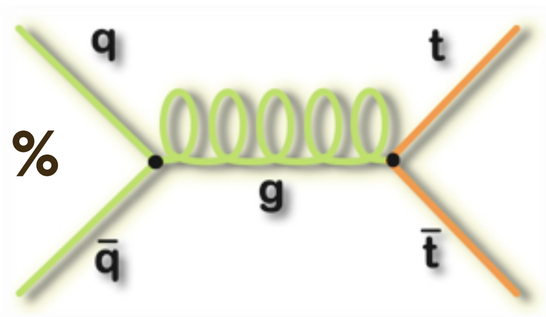
Method

- Extract $t\bar{t}$ events from data collected at CDF
- Reconstruct the production angle of top in these events
- Correct for any distortion from the detector, background processes, and the method of reconstructing the angle
- Measure A_{FB}

Production & Decay

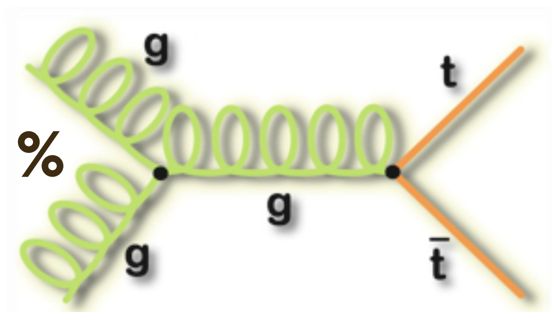
Production

~ 85 %

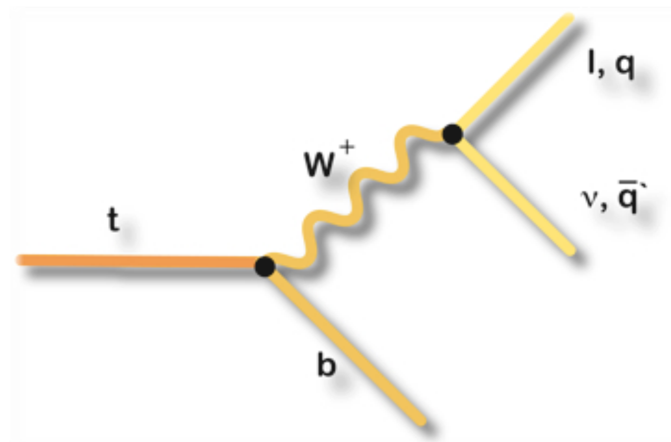


$\boxed{\sigma_{tt}^{SM} = 7.5\ \text{pb}}$

~ 15 %

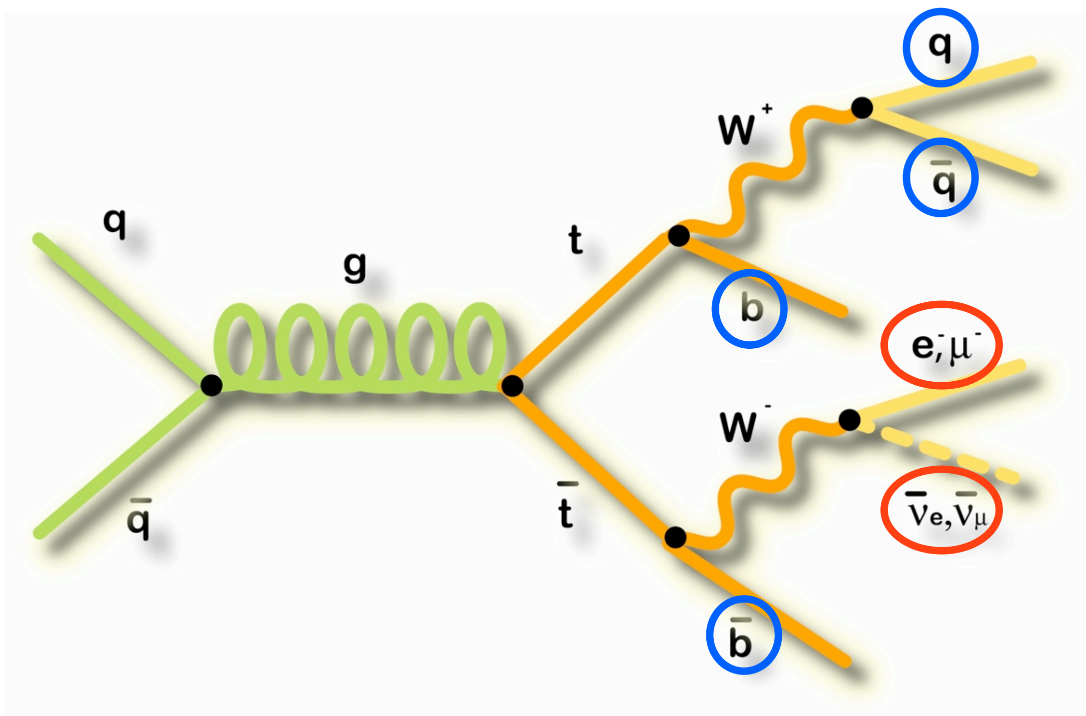


Decay



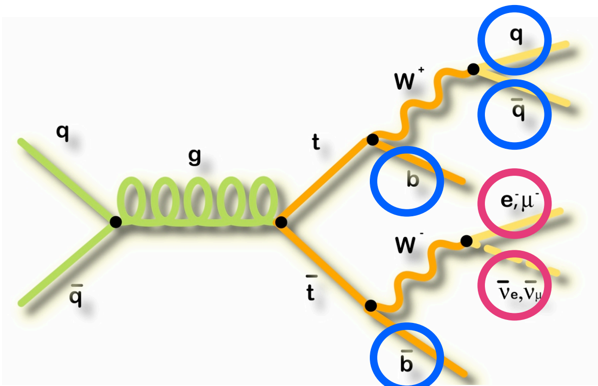
~100 %

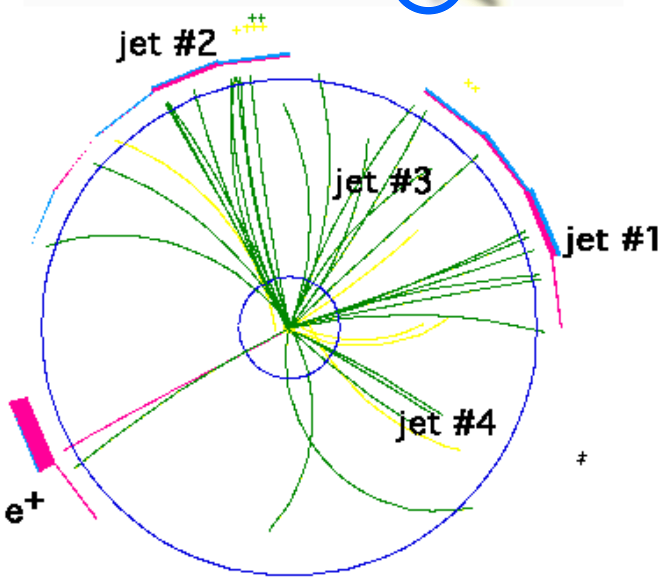
Production & Decay



One Lepton, One Neutrino, and 4 Quarks

Finding Top





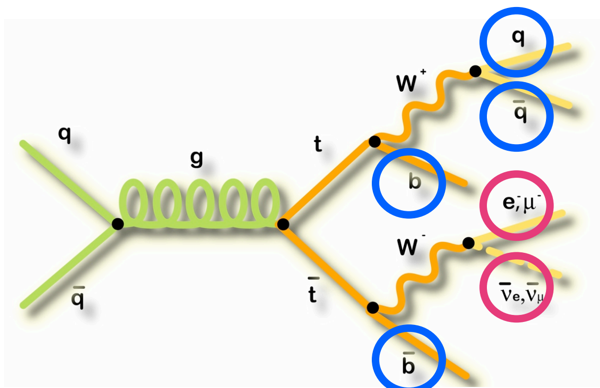
1 Electron or Muon ($E_T \geq$ 20 GeV, $|\eta| < 1.1$)

Large "Missing" Energy ($Et \geq$ 20 GeV)

$\geq$ 4 Jets ($Et \geq$ 20 GeV, $|\eta| < 2.0$)

At least 1 Jet with displaced secondary vertex (Evidence of a 'b'-jet)

Finding Top



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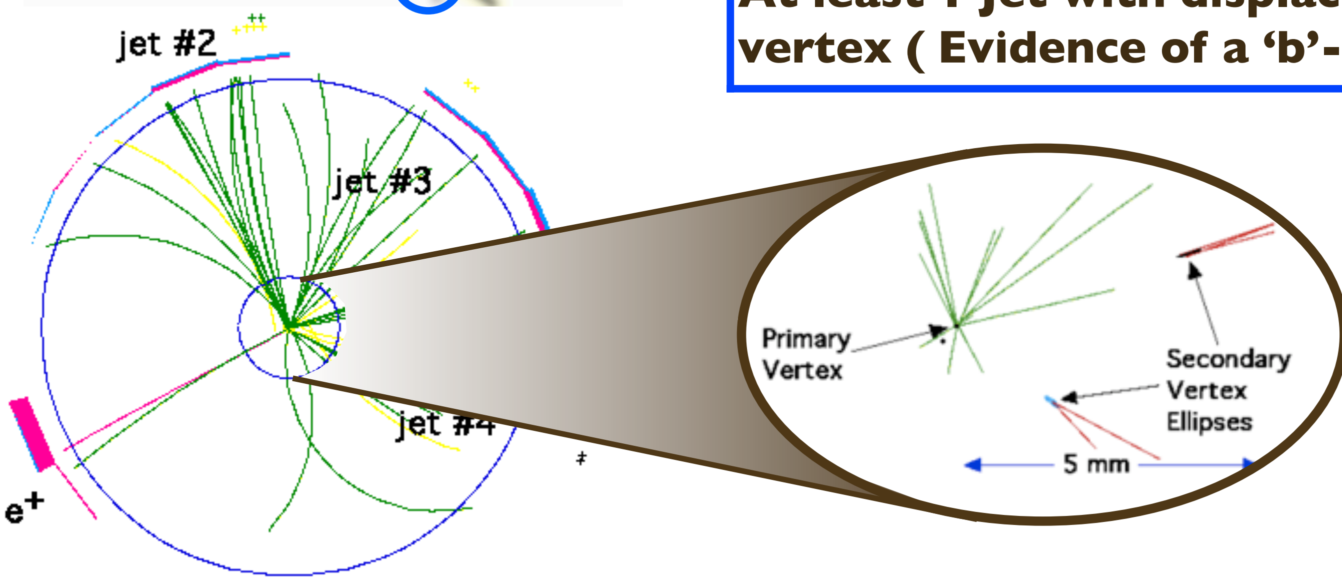
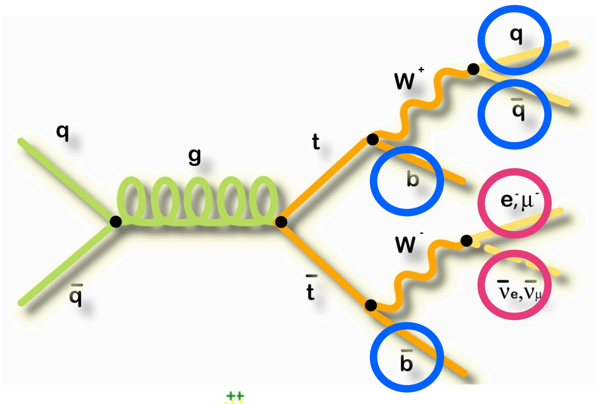
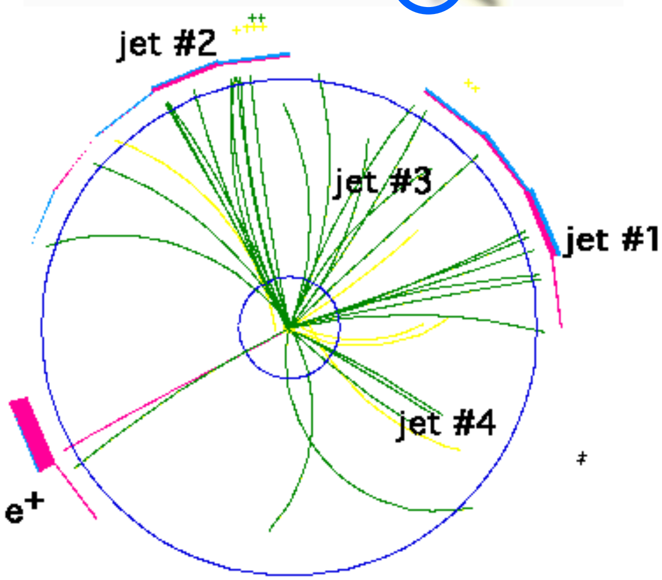


Finding Top





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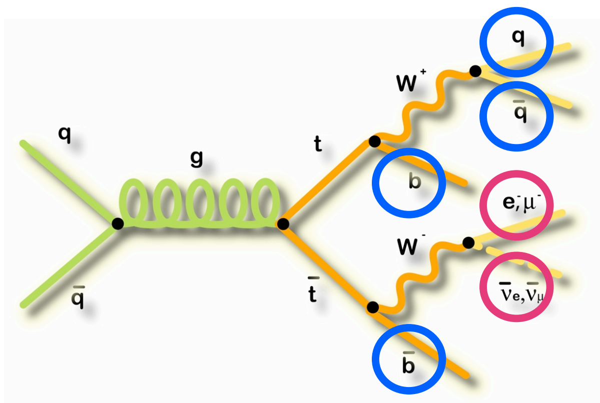
Large "Missing" Energy ($Et \geq 20$ GeV)

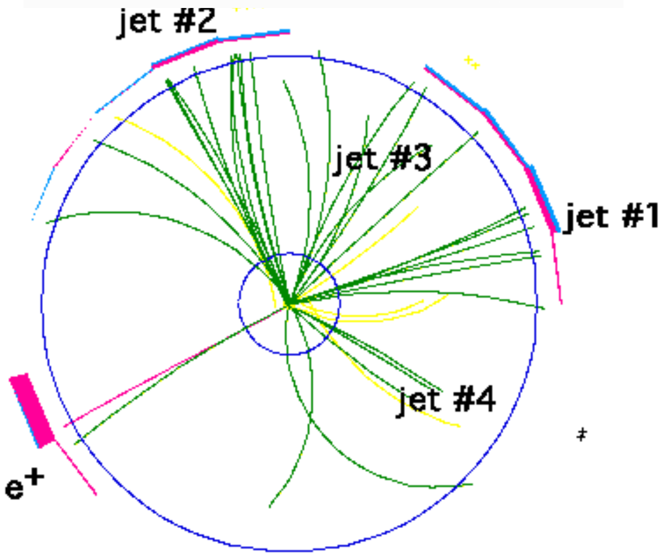
≥ 4 Jets ($Et \geq 20$ GeV, $|\eta| < 2.0$)

At least 1 Jet with displaced secondary vertex (Evidence of a 'b'-jet)

1300 Events (5.3 fb^{-1})
20 % Background

Reconstructing the Top Direction





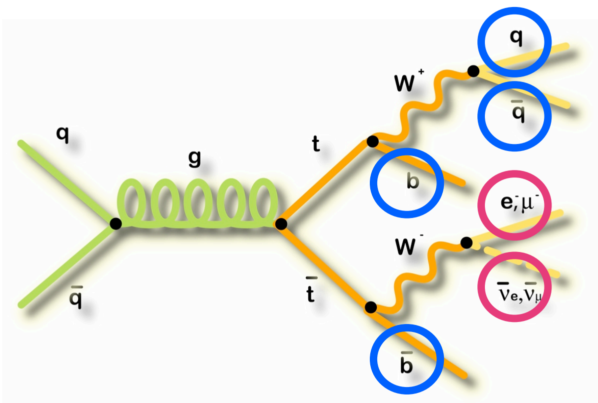
- **Reconstruct the top direction from the observables in the detector**

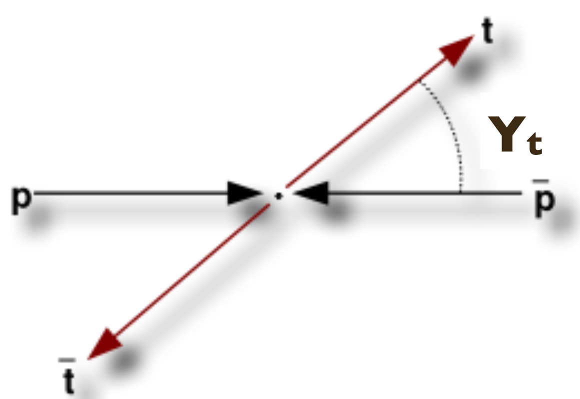
- **Algorithm used to match jets to partons ➔ just add 4-vectors to get top direction**

- **We use the rapidity difference (ΔY) of $t \to l\nu b$ and $t \to jj\bar{b}$, which is proportional to Y_t in $t\bar{t}$ frame**

$$Y_t \propto q_{lepton} \cdot \Delta Y$$

Reconstructing the Top Direction





- Reconstruct the top direction from the observables in the detector

- Algorithm used to match jets to partons ➔ just add 4-vectors to get top direction

- We use the rapidity difference (ΔY) of t➔lvb and t➔jjb, which is proportional to Y_t in $t\bar{t}$ frame

$$Y_t \propto q_{lepton} \cdot \Delta Y$$

Measurement

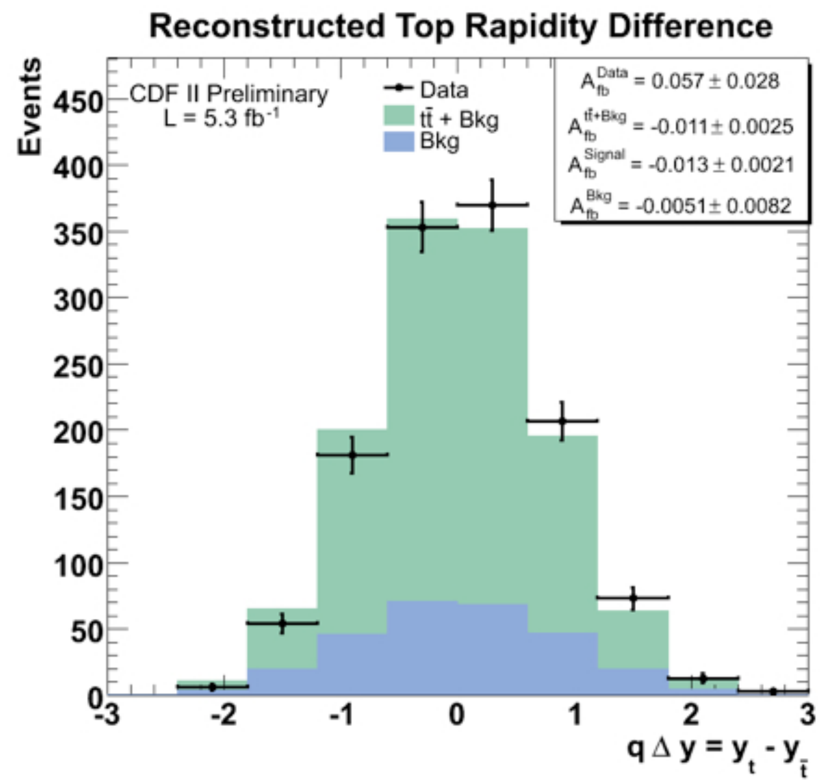
$A_{FB} = 16 \pm 7_{stat} \pm 2_{syst}$ %

5.3 fb^{-1}

Directly comparable to SM

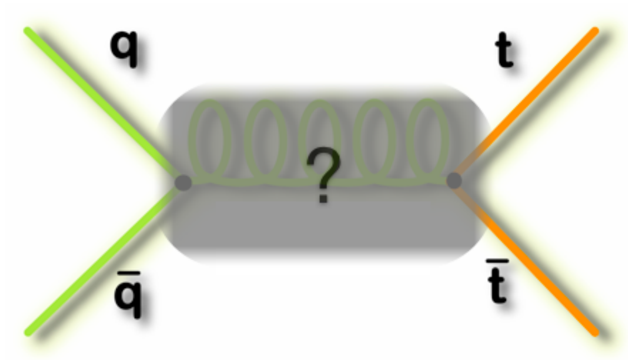
$A_{FB}^{Theory} = 6 \pm 1$ %

Kuhn, Rodrigo PRL 81,89 (1998)



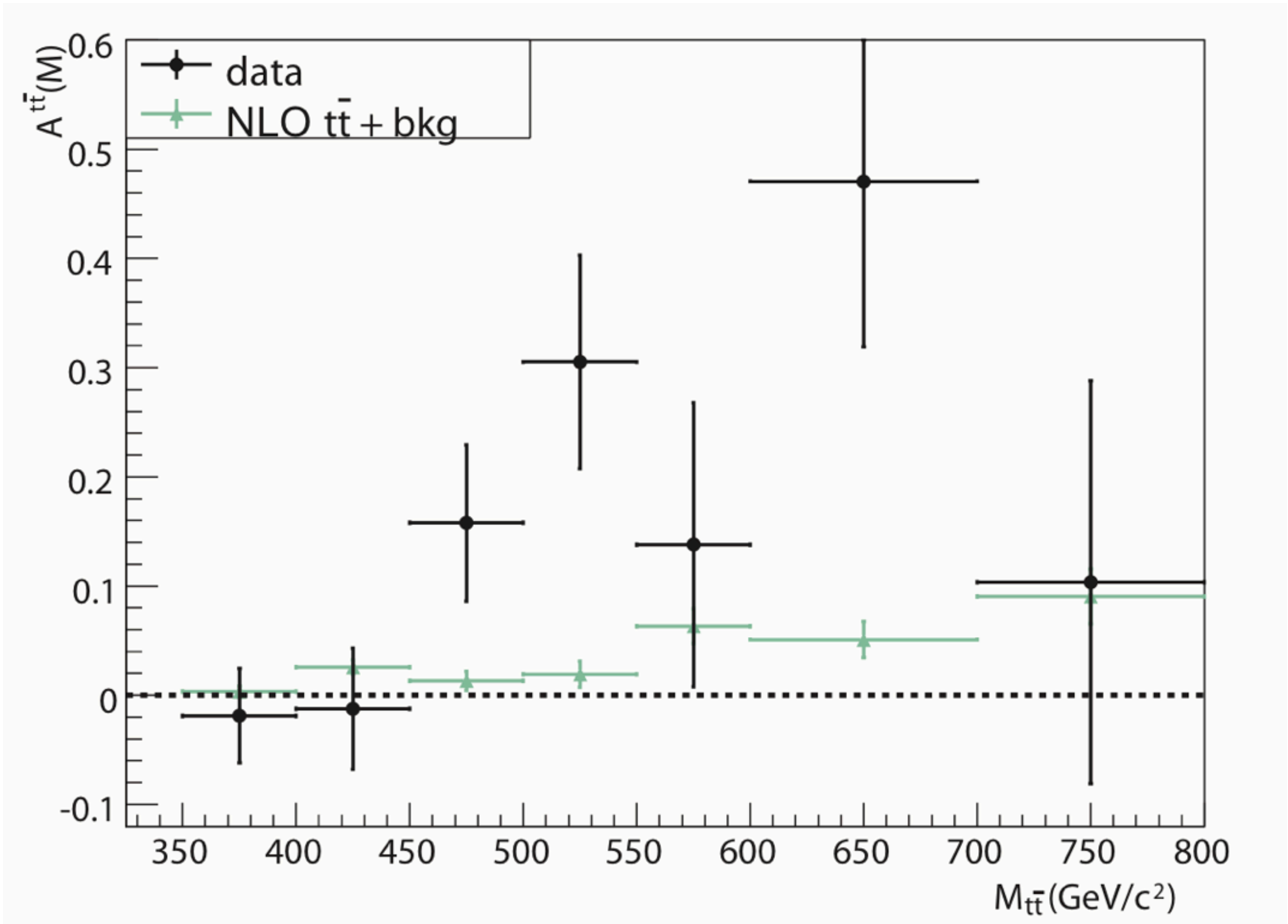
$M_{t\bar{t}}$ Dependence

- **A_{FB} could increase at higher energy due to new production mechanisms**
- **Study the asymmetry vs. the mass of the $t\bar{t}$ system ($M_{t\bar{t}}$)**
- **Simply divide sample into high/low $M_{t\bar{t}}$**
- **Use 450 GeV → based on MC studies**

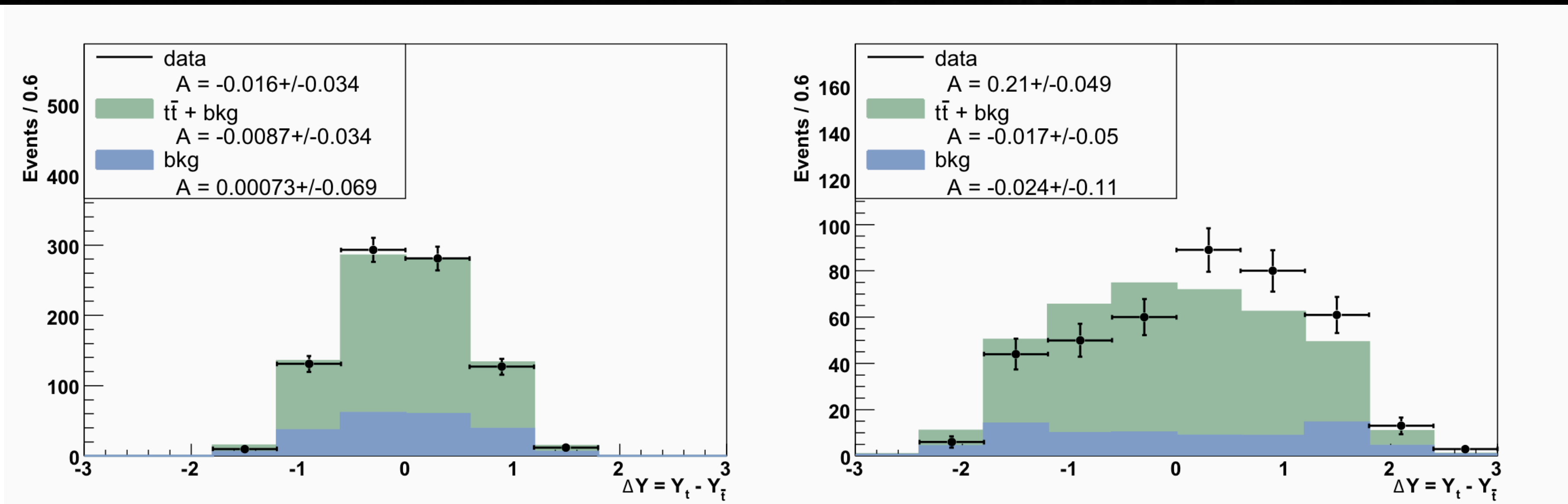


All PETRA experiments ($\sqrt{s}$ = 34 GeV)

$M_{t\bar{t}}$ Dependence



$M_{t\bar{t}}$ Dependence



	Inclusive	M < 450 GeV	M > 450 GeV
Data	5.7 ± 2.8 %	-1 ± 3 %	21 ± 5 %
SM MC	2 ± 0.4 %	1 ± 0.6 %	3 ± 0.7 %

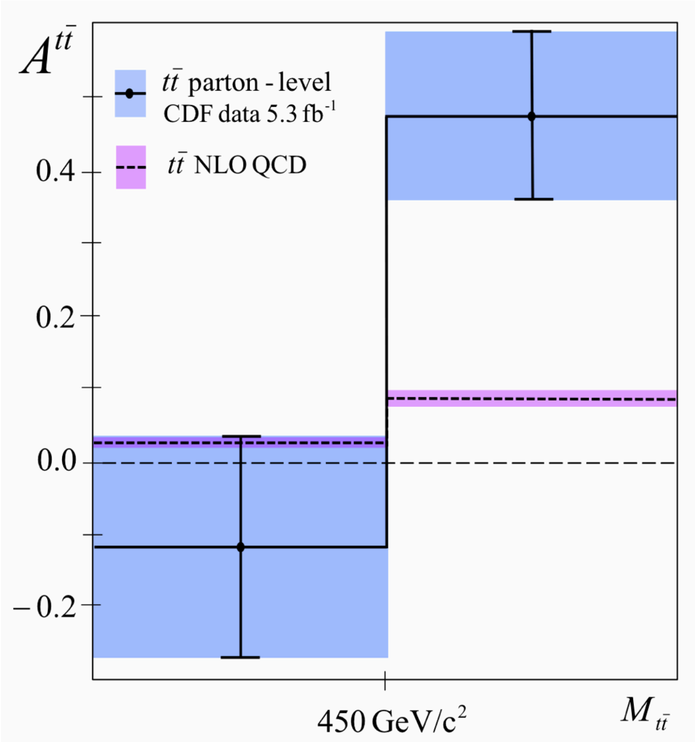
$M_{t\bar{t}}$ Dependence

- **Unfold M_{tt} dependence back to parton level**

$A_{FB} = 48 \pm 11_{stat+syst}$ %

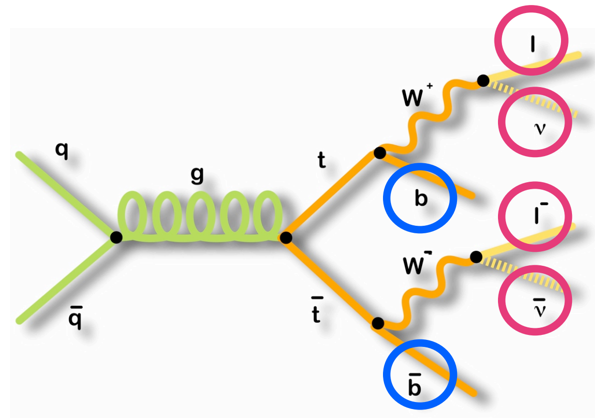
5.3 fb^{-1}

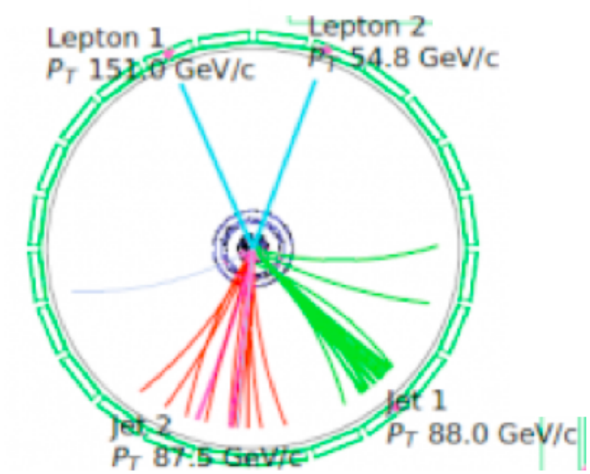
$A_{FB}^{Theory} = 9 \pm 1$ %



A_{FB} in Dileptons

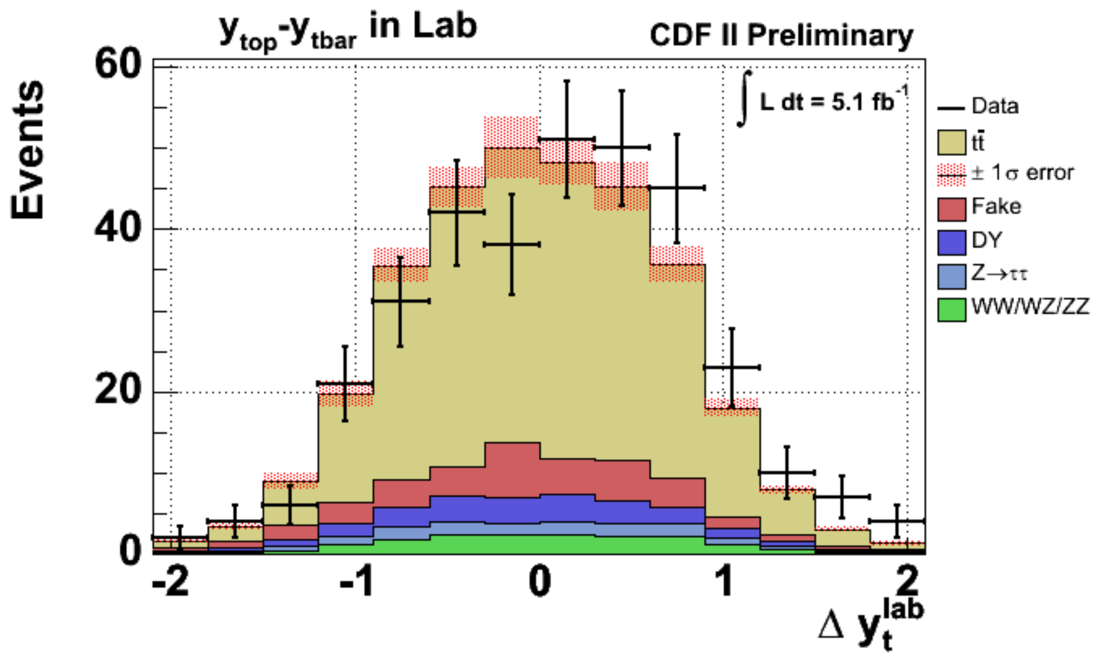
- **Alternative channel to previous measurement in single lepton+jets events**
- **Independent events using different reconstruction algorithm**





2 Leptons ($E_T \geq 20$ GeV, $\lvert\eta\rvert < 1.1$)
Large "Missing" Energy ($E_T \geq 50$ GeV)
≥ 2 Jets ($E_T \geq 15$ GeV, $\lvert\eta\rvert < 2.5$)
$\sum E_T$ (jets, leptons) > 200 GeV

A_{FB} in Dileptons



A_{FB} = 42 ± 15$_{stat}$ ± 5$_{syst}$ %

5.1 fb^{-1}

A_{FB}^{Theory} = 6 ± 1 %

A_{FB}^{l+Jets} = 16 ± 7 %

A_{FB} LL+LJ combination

	L+J	DIL
Afb	0.158 ± 0.072(stat) ± 0.017 (sys)	0.420 ± 0.150(stat) ± 0.053 (sys)
Bkg L+J	0.013	0
Bkg DIL	0	0.043
JES	0.007	0.008
PDF	0.005	0.004
Signal Model	0.0065	0.029

$A_{FB} = 20 \pm 7_{stat} \pm 2_{syst}$ %

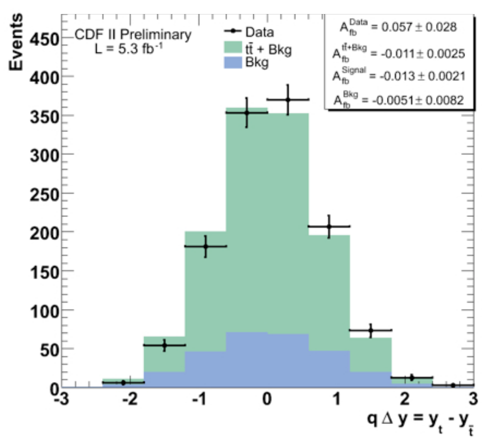
2.9 σ away from no symmetry

Summary of Results

Inclusive Asymmetry

A_{FB} = 16 ± 7 %

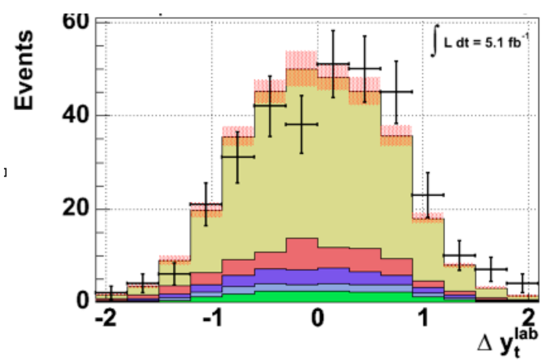
~ 2 σ (5 fb^{-1})



A_{FB}^{sm} ~ 6 %

A_{FB} = 42 ± 16 %

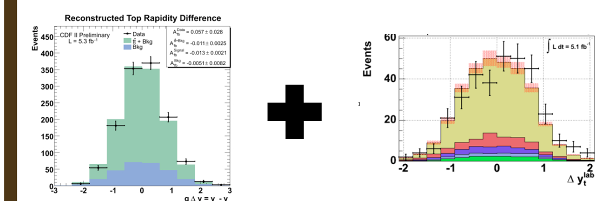
~ 2.7 σ (5 fb^{-1})



A_{FB}^{sm} ~ 6 %

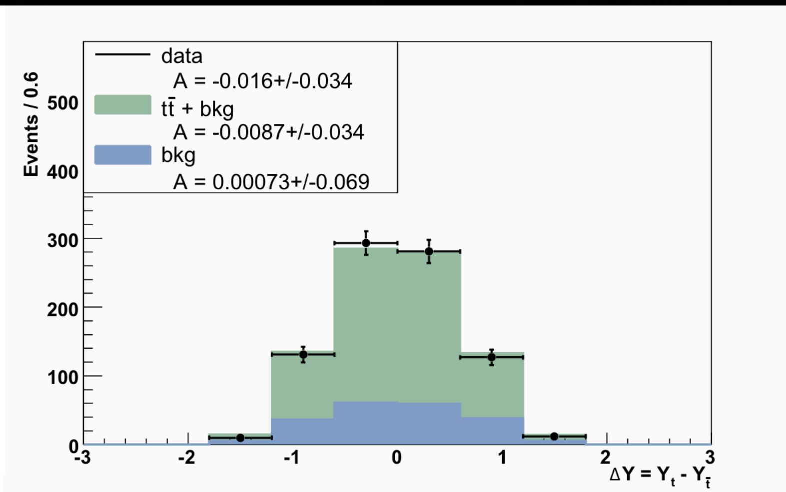
A_{FB} = 20 ± 7 %

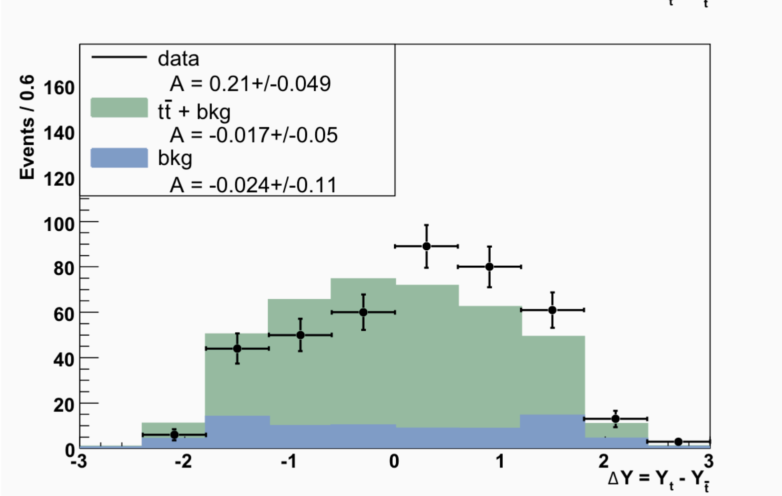
~ 2.9 σ (5 fb^{-1})



A_{FB}^{sm} ~ 6 %

Summary of Results





For M_{tt} > 450 GeV

$A_{FB} = 48 \pm 11_{stat+syst}$ %

5.3 fb^{-1}

$A_{FB}^{Theory} = 9 \pm 1$ %

Not Clear Yet...

- **Could be statistics**
- **Some very devious problem with reconstruction or acceptance**
- **NLO QCD effect is mis-calculated or requires further corrections**
- **Something new?**

What's Next for A_{FB}

- Time and data - really need 4-5σ before we're sure it's not statistics
- D0 will tell us more - comparable results, study mass dependence, combination
- Correlated to other observables ➔ LHC needs to see something

STAY TUNED!


Thanks!!!

What you shouldn't worry about

- **Backgrounds**
  - **Too small, and the predicted asymmetry in backgrounds goes in the opposite direction**
- **Reconstruction**
  - **If it's broken, it's broken for MANY precision measurements that agree with the SM and other well-vetted techniques**
- **Unfolding**
  - **The significance of the result is present before the acceptance/reconstruction corrections - they only scale the result**

Questions...

- **Why do muons have a larger asymmetry than electrons?**
- **Why is the lab frame asymmetry stronger, yet less dependent on M_{tt} ?**
- **Why is the result in dileptons so much larger?**

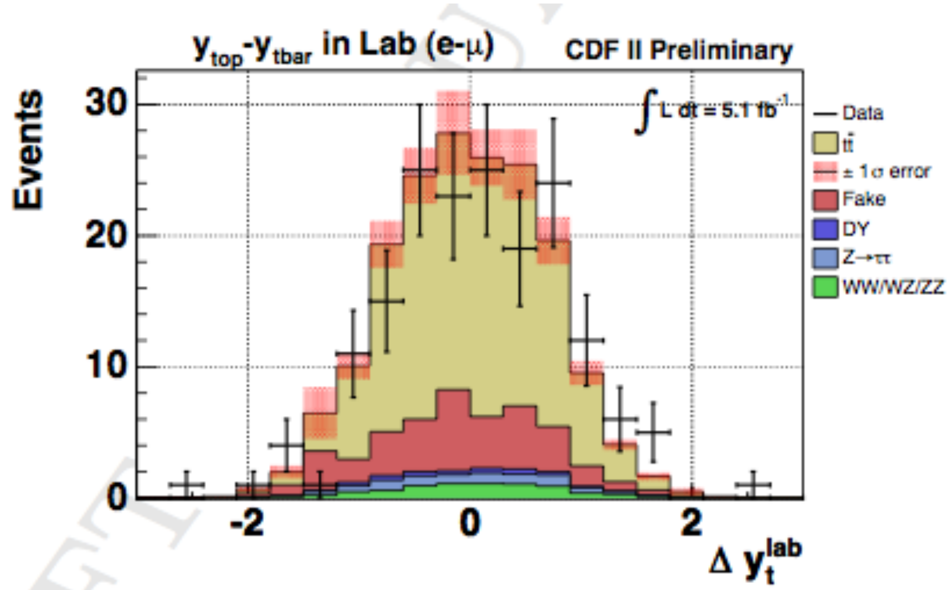
Muons vs Electrons

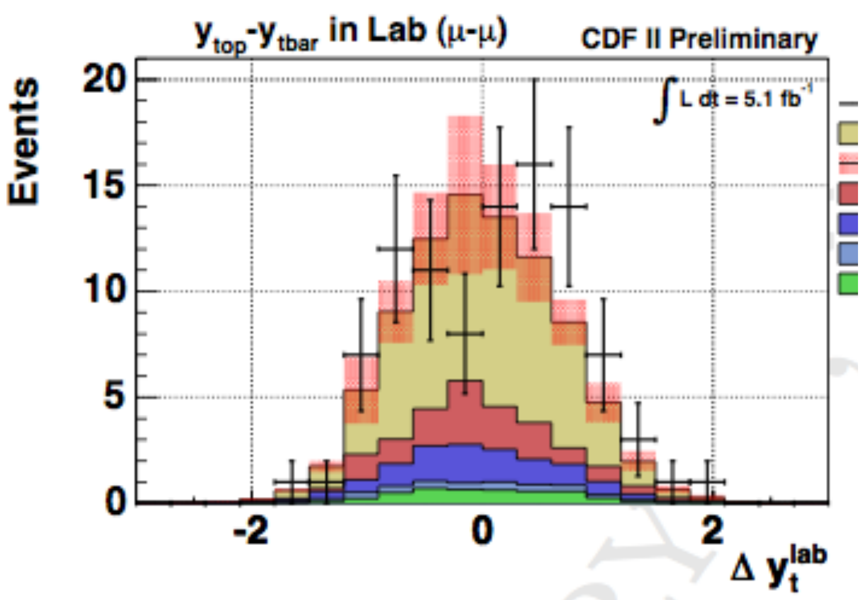
*** before corrections**

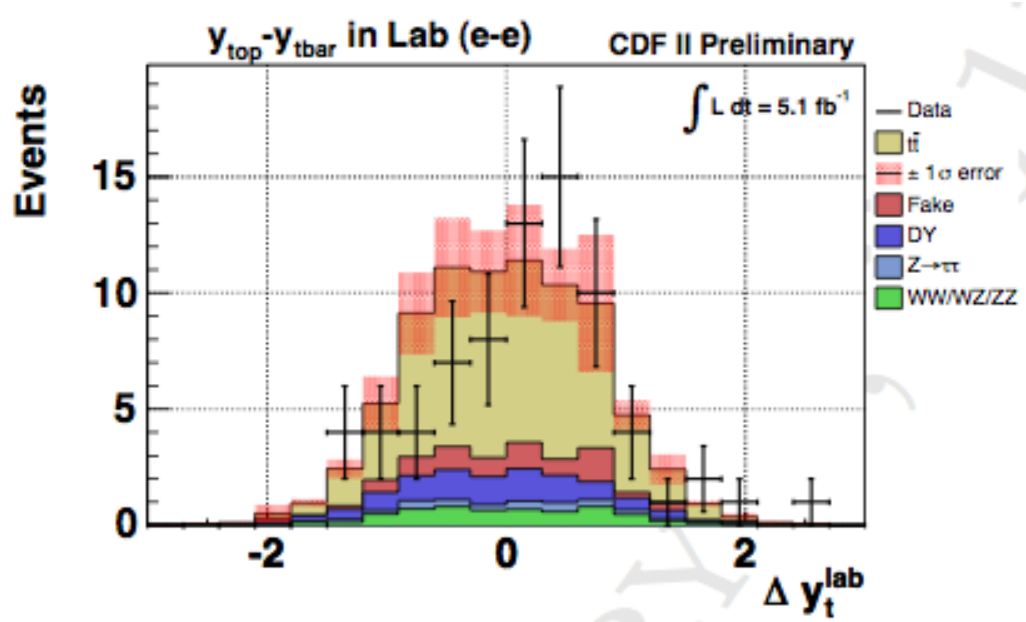
selection	N events	all M	$M < 450$ GeV$/c^2$	$M \geq 450$ GeV$/c^2$
standard	1260	0.057±0.028	-0.016±0.034	0.212±0.049
electrons	735	0.026±0.037	-0.020±0.045	0.120±0.063
muons	525	0.105±0.043	-0.012±0.054	0.348±0.080
data $\chi^2 < 3.0$	338	0.030±0.054	-0.033 ± 0.065	0.180 ± 0.099
data no-b-fit	1260	0.062±0.028	0.006 ± 0.034	0.190 ± 0.050
data single b-tag	979	0.058±0.031	-0.015±0.038	0.224±0.056
data double b-tag	281	0.053±0.059	-0.023±0.076	0.178±0.095
data anti-tag	3019	0.033±0.018	0.029±0.021	0.044±0.035
pred anti-tag	-	0.010±0.007	0.013±0.008	0.001±0.014
pre-tag	4279	0.040±0.015	0.017±0.018	0.100±0.029
pre-tag no-b-fit	4279	0.042±0.015	0.023±0.018	0.092±0.029

What about the di-lepton result?

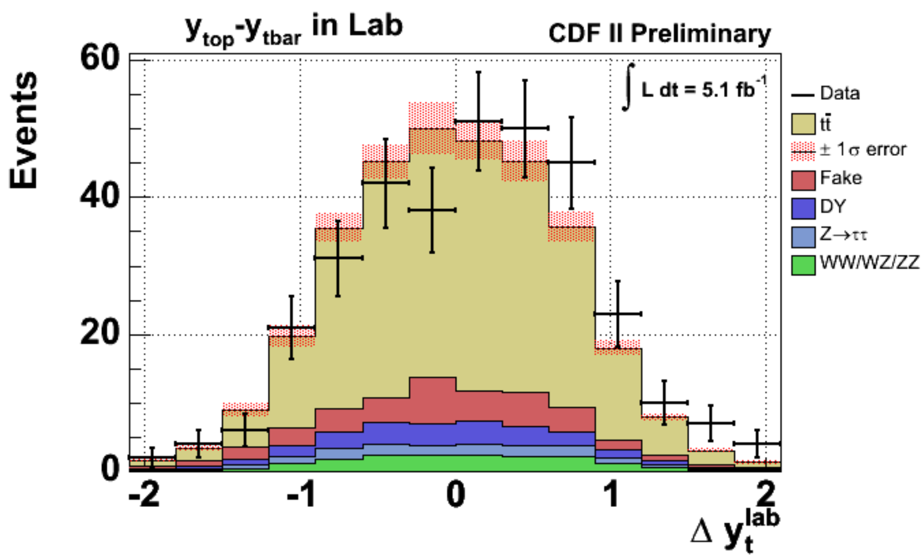
Flavor	Asymmetry
Inclusive	14 ± 5 %
e-e	27 ± 11 %
e-u	6.4 ± 7.6 %
u-u	17 ± 10 %

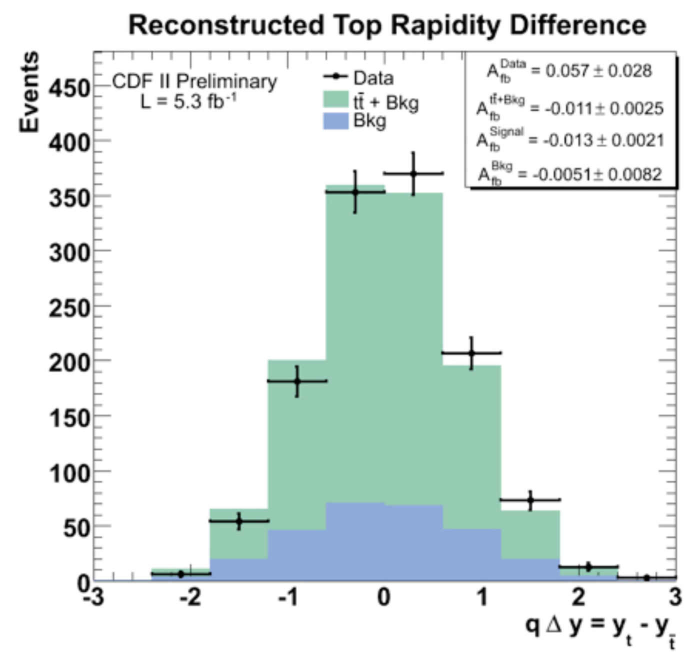






Dileptons vs L+Jets





A_{FB} = 42 ± 15$_{stat}$ ± 5$_{syst}$ %

5.1 fb^{-1}

A_{FB} = 16 ± 7$_{stat}$ ± 2$_{syst}$ %

5.3 fb^{-1}

$M_{t\bar{t}}$ Dependence

- **What is the optimal high/low bin-edge (based on MC) ?**

	OctetA		OctetB	
bin-edge (GeV/c^2)	A^{tt}	significance	A^{tt}	significance
345	0.082 ± 0.028	2.90	0.168 ± 0.028	5.99
400	0.128 ± 0.036	3.55	0.235 ± 0.035	6.74
450	0.183 ± 0.047	3.91	0.310 ± 0.044	7.08
500	0.215 ± 0.060	3.60	0.369 ± 0.054	6.81
550	0.246 ± 0.076	3.25	0.425 ± 0.066	6.43
600	0.290 ± 0.097	2.97	0.460 ± 0.081	5.70

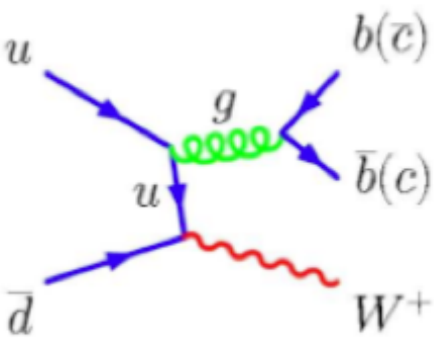
Models provided by Tim Tait

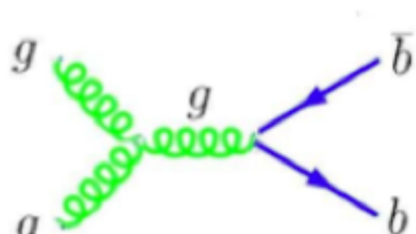
Reconstruction and Corrections

Backgrounds

- Select 1260 Events
- Predict ~ 1287
- ~ 20% background

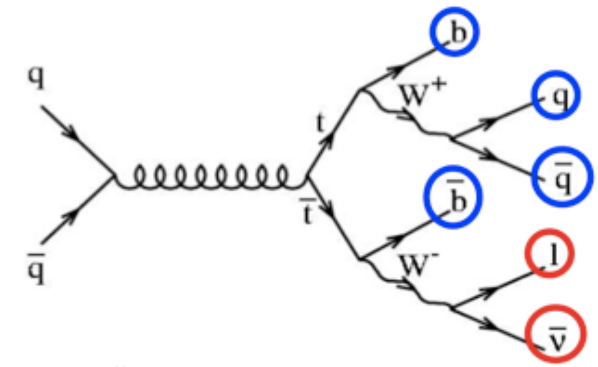
Process	Prediction
W+Jets	181
QCD	67
Other	35
$t\bar{t}$	1004
Data	1260

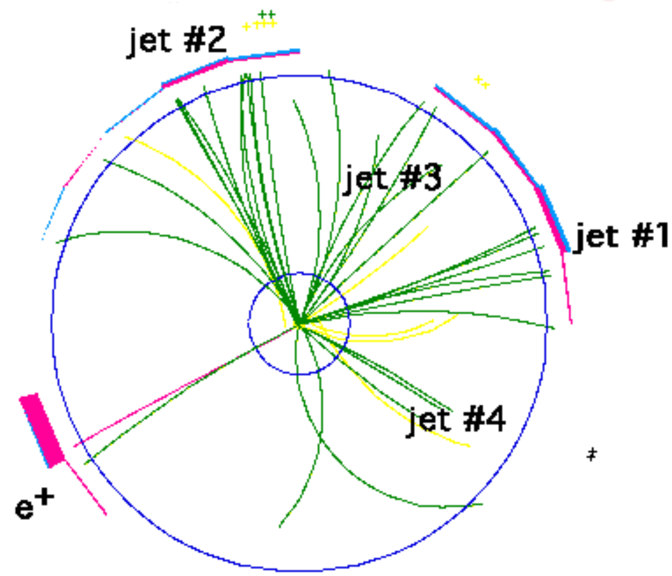




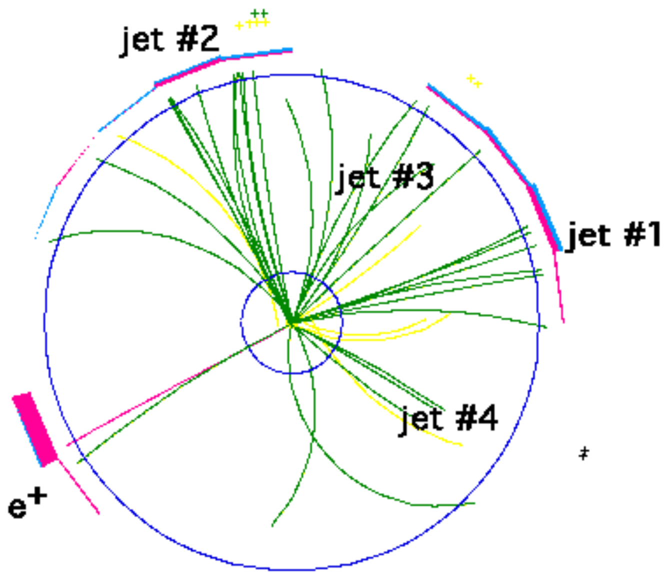
Event Reconstruction

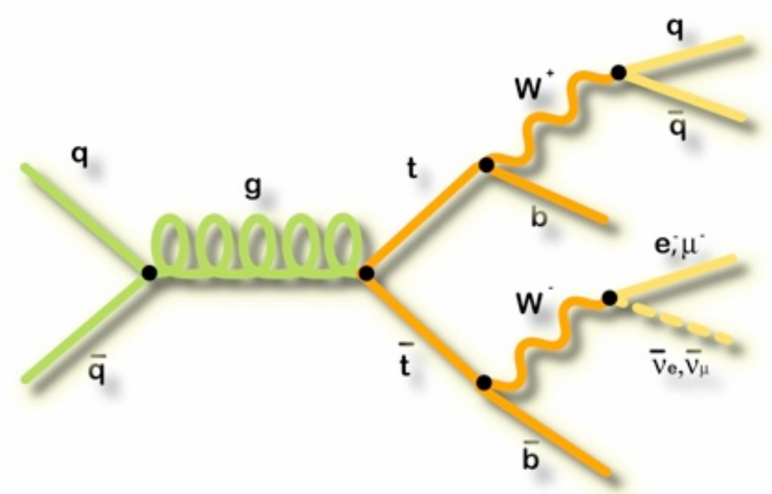
- **Reconstruct the top direction from the observables in the detector**
- **Biggest problem is to match the jets in the detector to the “true” decay products of t and $\bar{t}$?**
- **4 Jets to match to 4 quarks leads to 24 combinations**
- **Use the event topology to build an algorithm!**





Event Reconstruction

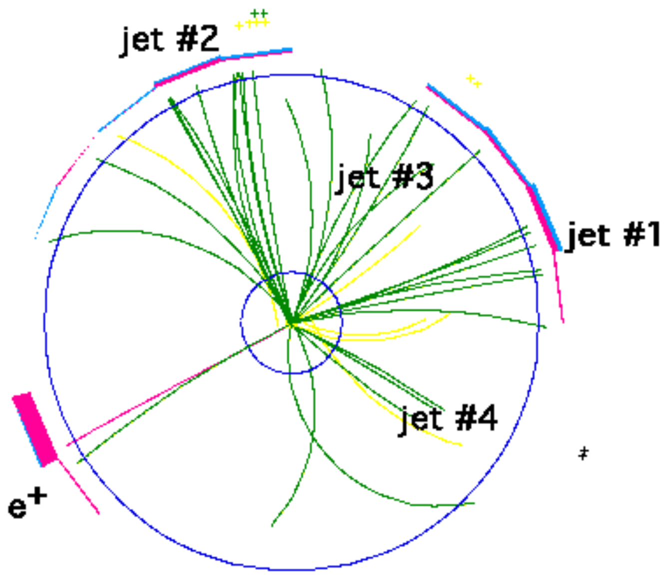


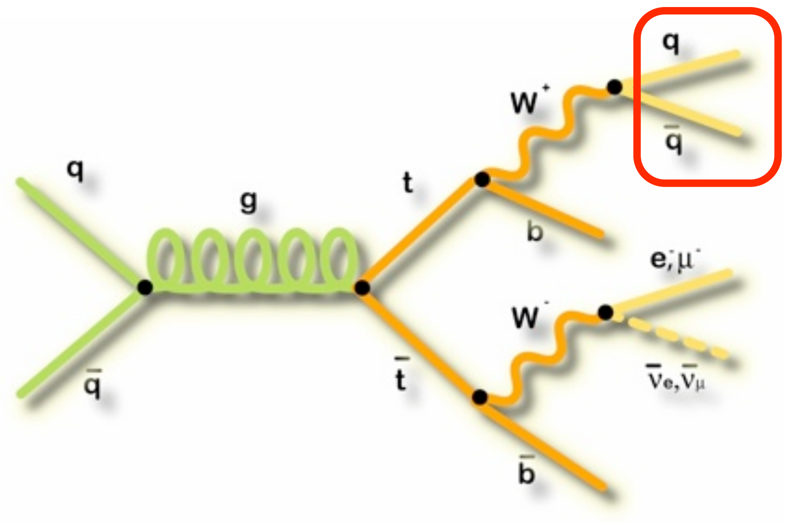


$$\chi^2 = \sum_{i=l,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,meas} - p_j^{UE,fit})^2}{\sigma_j^2}$$

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{lv} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{blv} - M_{fit})^2}{\Gamma_t^2}$$

Event Reconstruction

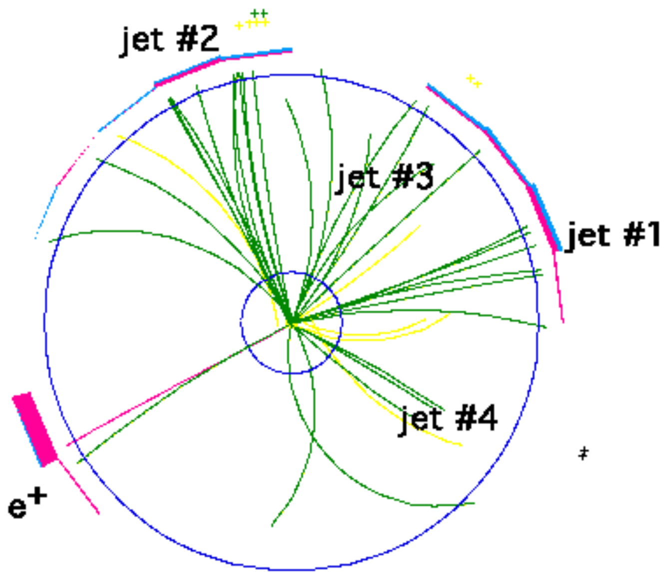


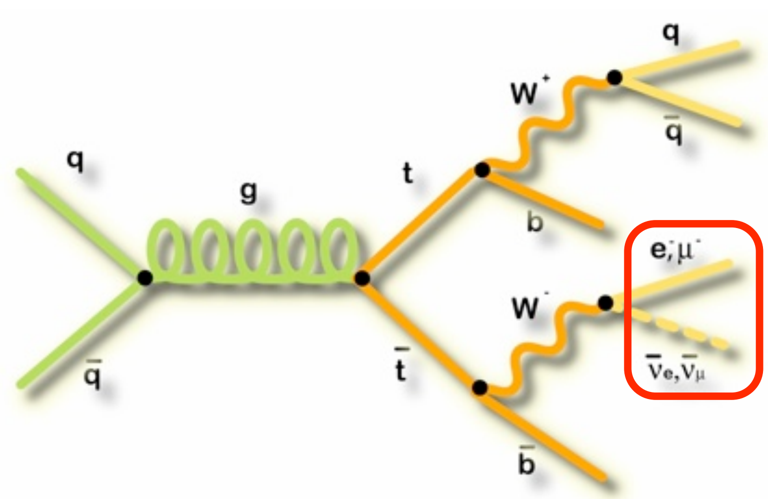


$$\chi^2 = \sum_{i=l,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,meas} - p_j^{UE,fit})^2}{\sigma_j^2}$$

$$+ \boxed{\frac{(M_{jj} - M_W)^2}{\Gamma_W^2}} + \frac{(M_{lv} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{blv} - M_{fit})^2}{\Gamma_t^2}$$

Event Reconstruction





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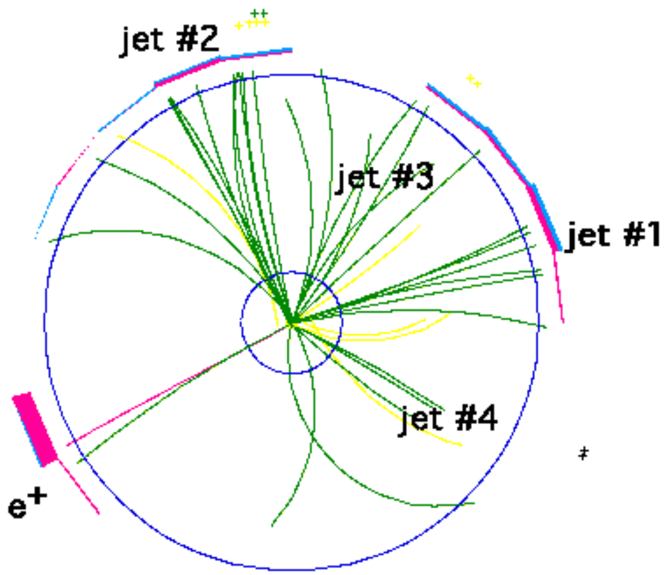

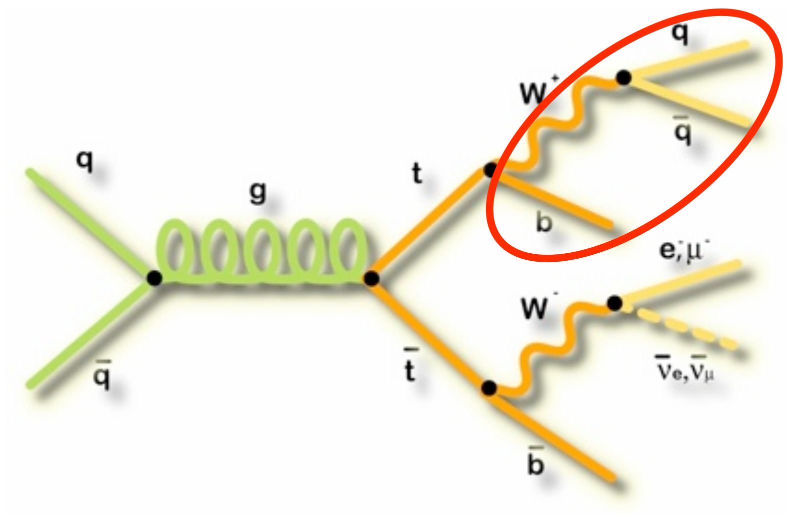

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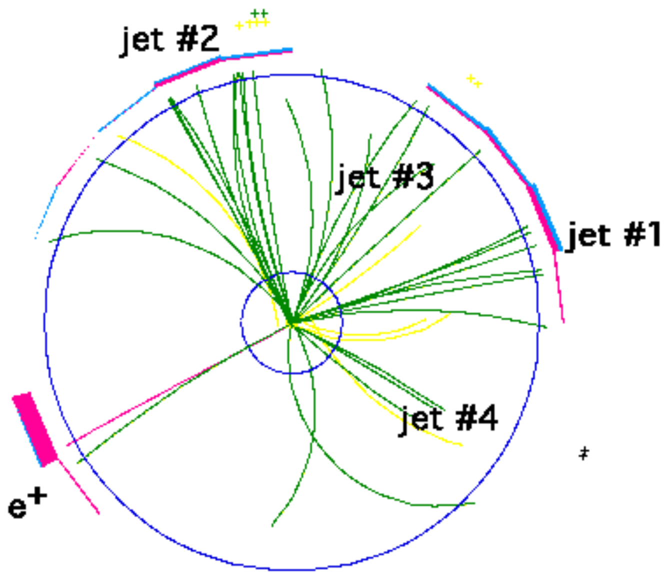

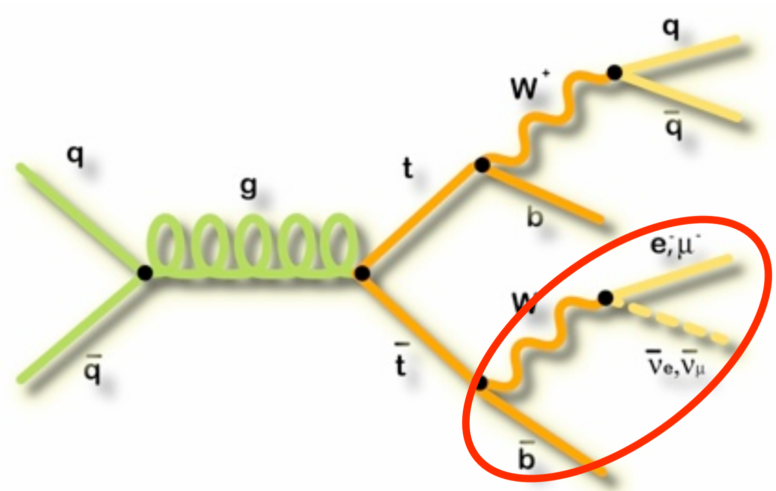

$$\chi^2 = \sum_{i=l,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,meas} - p_j^{UE,fit})^2}{\sigma_j^2}$$

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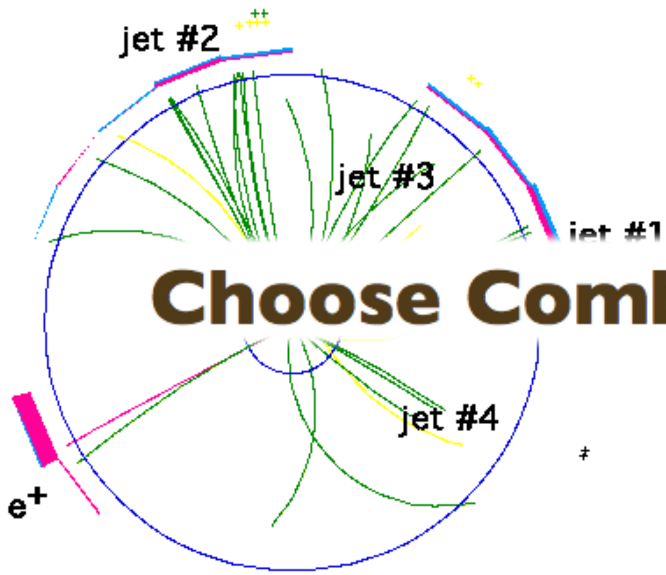
Event Reconstruction

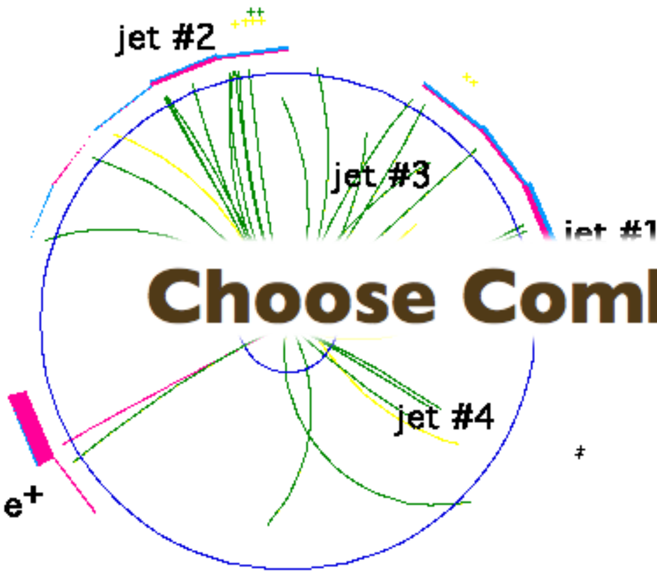


Choose Combination with Best χ^2

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

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{lv} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{blv} - M_{fit})^2}{\Gamma_t^2}$$

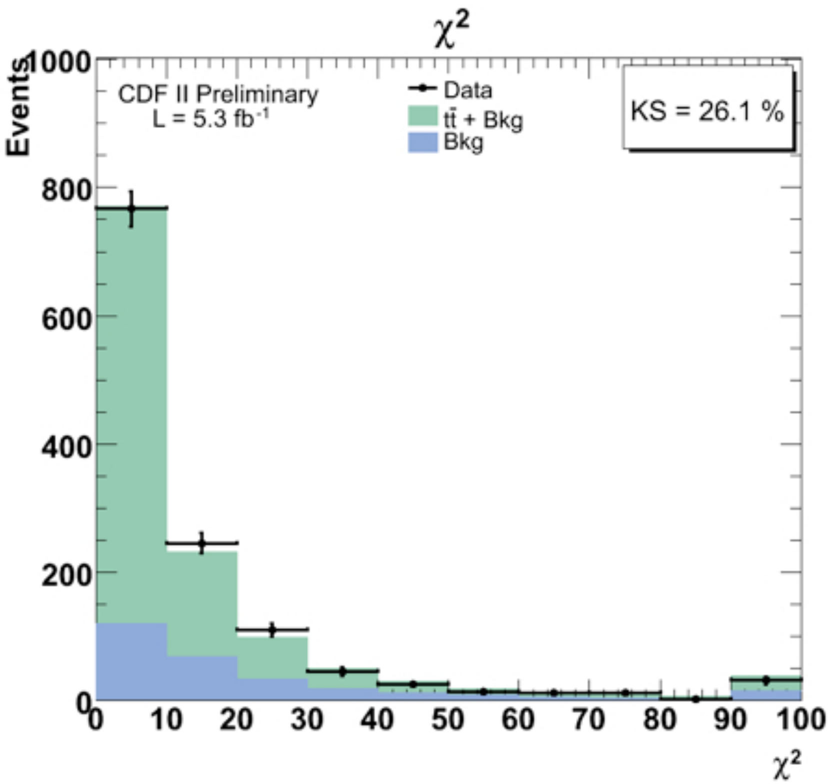
Event Reconstruction

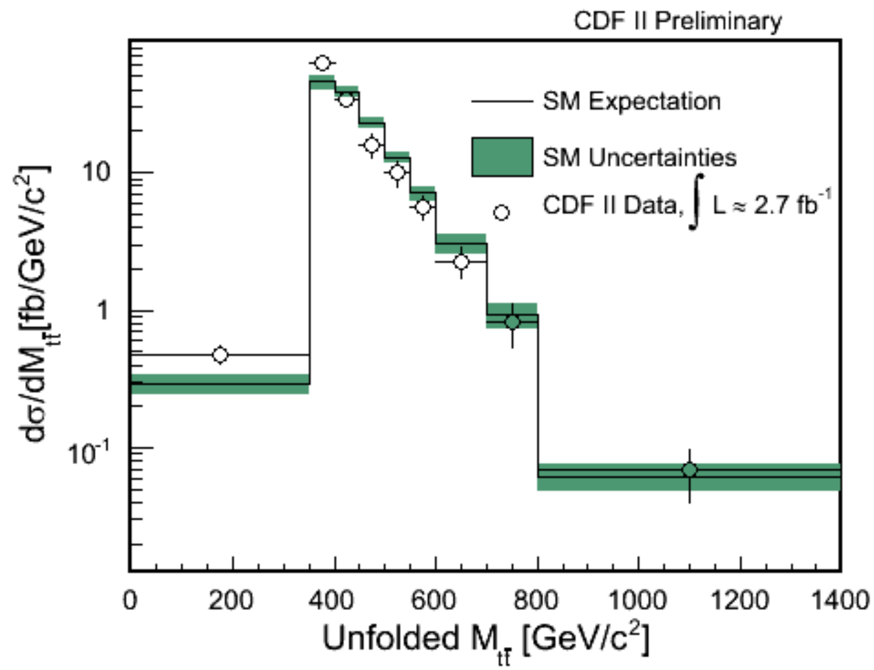


Choose Combination with Best χ^2

All particle energies and angles are available after reconstruction

Event Reconstruction





http://www-cdf.fnal.gov/physics/new/top/2010/tprop/Afb/validation.html

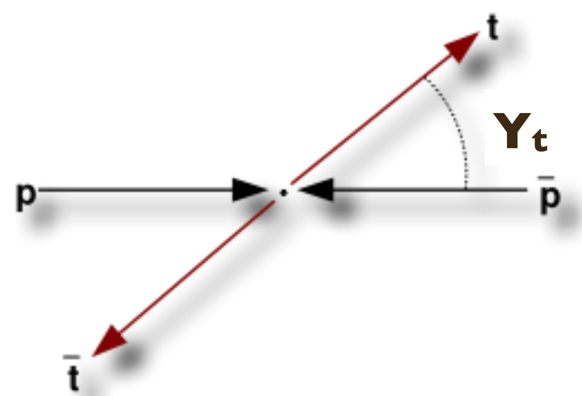
Top Angle

- **Use the top rapidity (Y_t) to measure the asymmetry**

- **Unfortunately, we do not reconstruct top or antitop, rather t➔lvb and t➔jjb**

- **Rapidity difference (ΔY) of t and t is proportional to Y_t in tt rest frame**

- **Measure A_{FB} using ΔY**



$$\Delta Y = q_{\mathrm{lep}} \cdot (Y_{\mathrm{lep}} - Y_{\mathrm{had}})$$

Top Angle

- **Use the top rapidity (Y_t) to measure the asymmetry**

- **Unfortunately, we do not reconstruct top or antitop, rather t→lνb and t→jjb**

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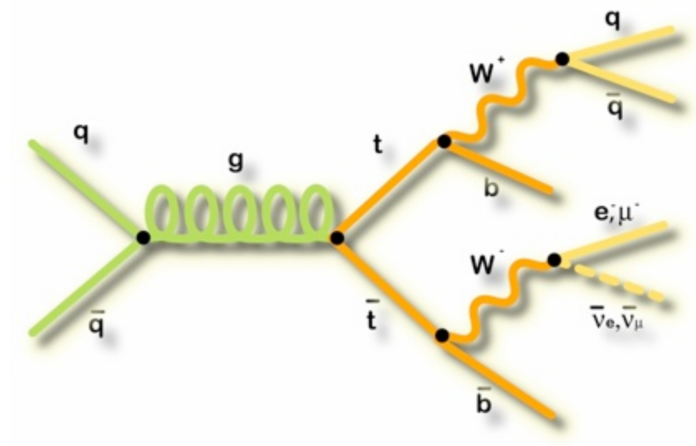
- **Measure A_{FB} using ΔY**



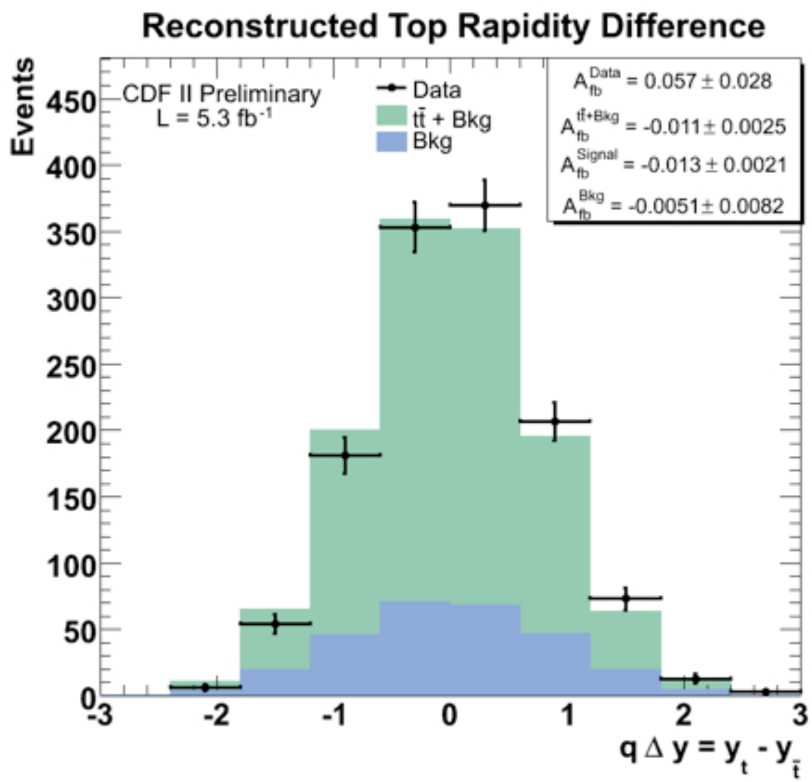
$$\Delta Y = q_{lep} \cdot (Y_{lep} - Y_{had})$$

Top Angle

Uncorrected

A_{FB} = 5.7 ± 2.8 %

- **The shape in data can be biased and diluted by backgrounds, acceptance, and poor reconstruction**
- **Each effect has to be corrected to compare our measurement to theory**

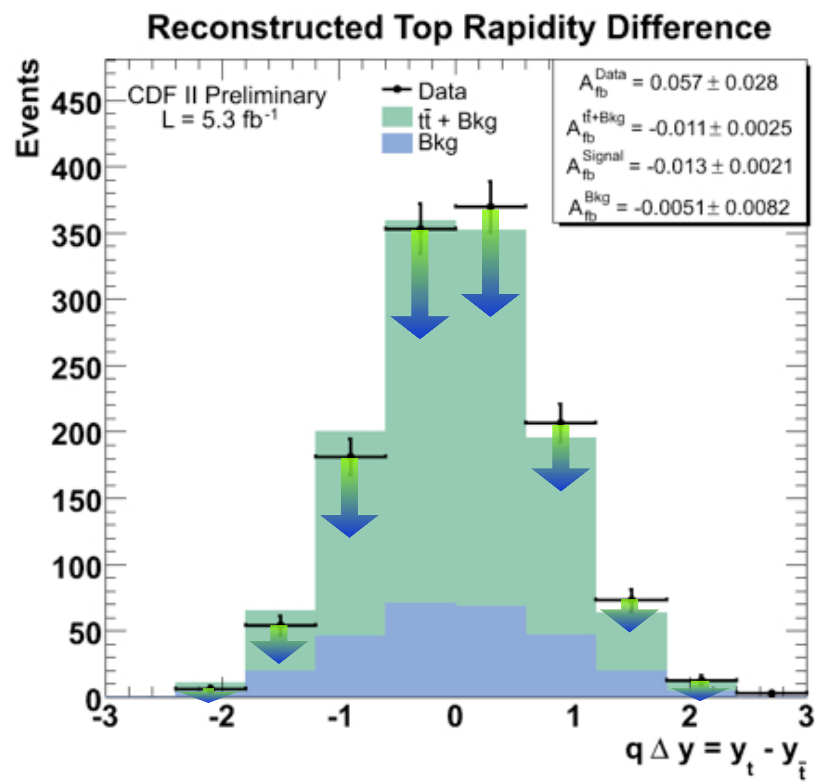


Backgrounds

- **Subtract predicted background shape from data**
- **Resulting distribution is the $t\bar{t}$ production angle after selection and reconstruction**

Bkg Corrected

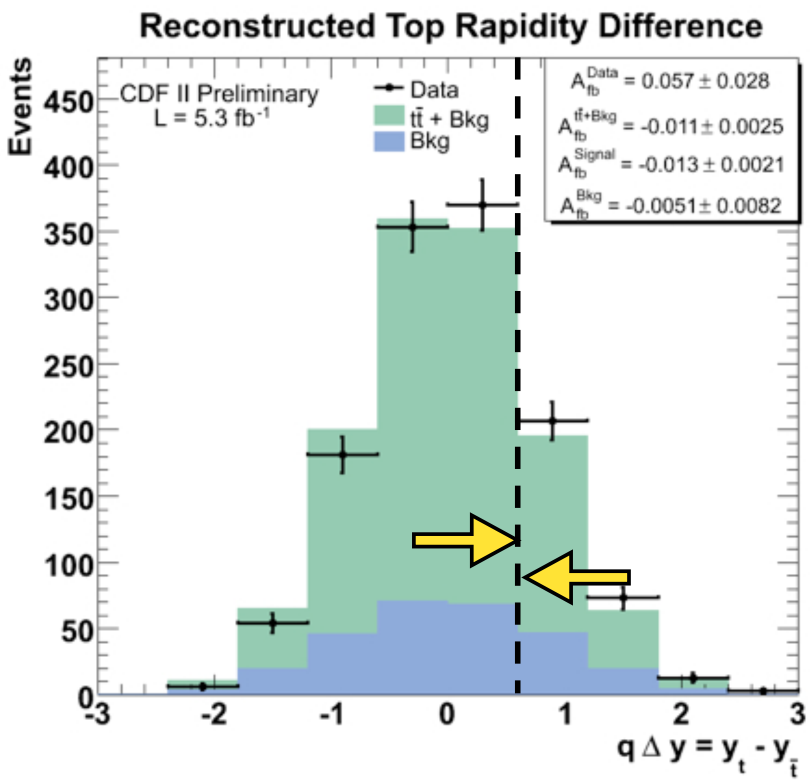
A_{FB} = 7.5 ± 3.7 %



Correcting Reconstruction

- **Mis-reconstruction of the top production angle will dilute or skew the true asymmetry**

- **Can correct for this by simulating smearing in Monte Carlo and applying to data**

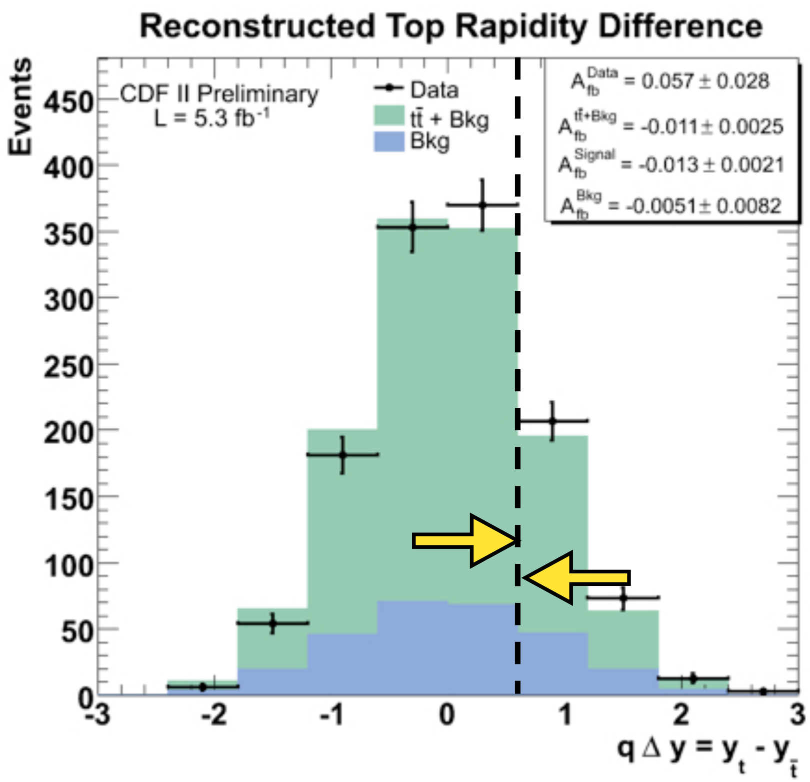


Correcting Reconstruction

- **Derive smearing matrix (S) from MC**

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

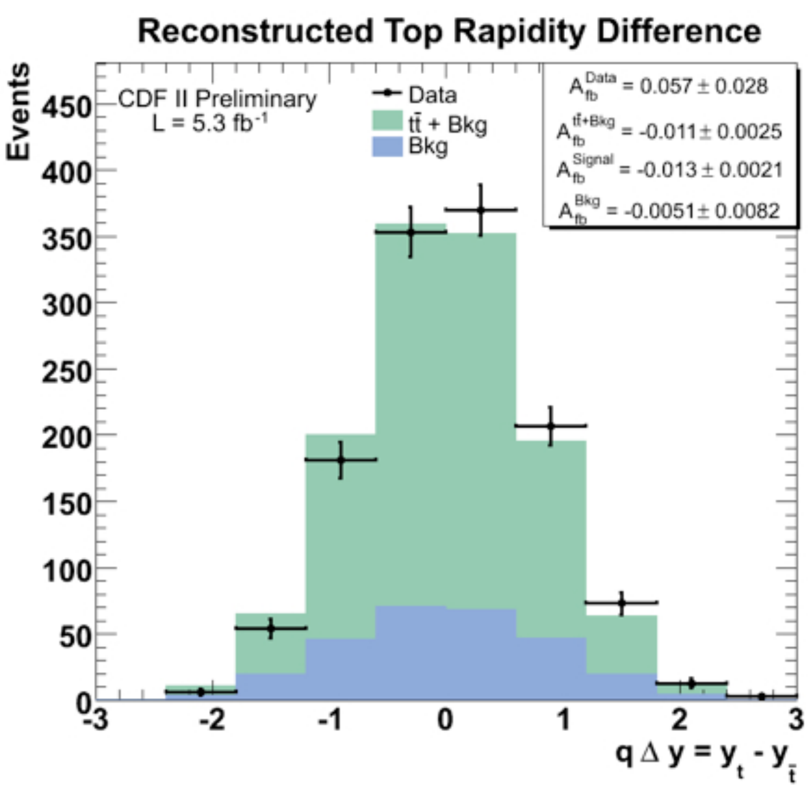
- **The matrix is inverted to correct for smearing**



Correcting Acceptance

- **Similarly, detector acceptance is represented as a matrix (A)**

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

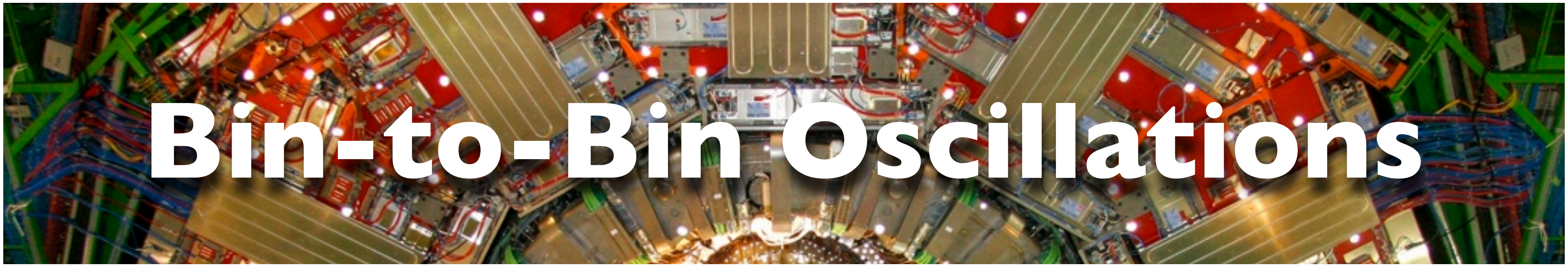


Putting it All Together

- **Cascade correction matrices and apply to the background corrected data**

- **Result can then be directly compared to the Standard Model**

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



Bin-to-Bin Oscillations

- **Simple Example of a smearing matrix**

$$\begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \frac{1}{2} \cdot \begin{bmatrix} 1+\epsilon & 1-\epsilon \\ 1-\epsilon & 1+\epsilon \end{bmatrix} \cdot \begin{bmatrix} t_1 \\ t_2 \end{bmatrix}$$

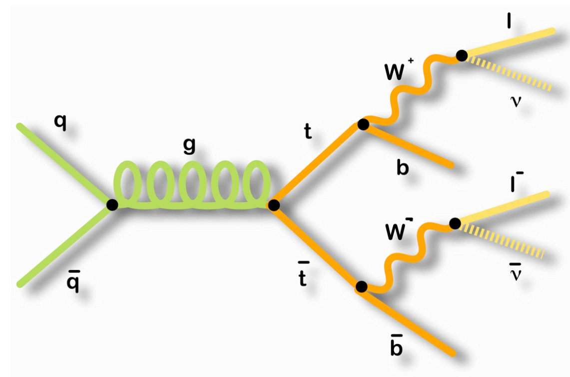
- **Inverted to solved for truth, you get**

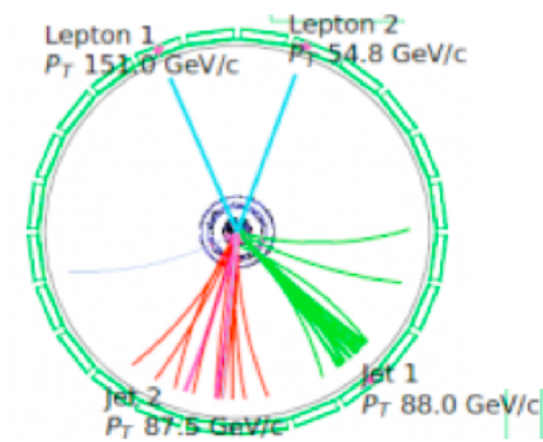
$$\begin{bmatrix} t_1 \\ t_2 \end{bmatrix} = \frac{d_1 + d_2}{2} \cdot \begin{bmatrix} 1 \\ 1 \end{bmatrix} + \frac{d_1 - d_2}{2\epsilon} \cdot \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

- **If d1 - d2 are not statistically distinct, then bad smearing can dominate the solution! Need a way to dampen these terms...**

A_{FB} in Dileptons

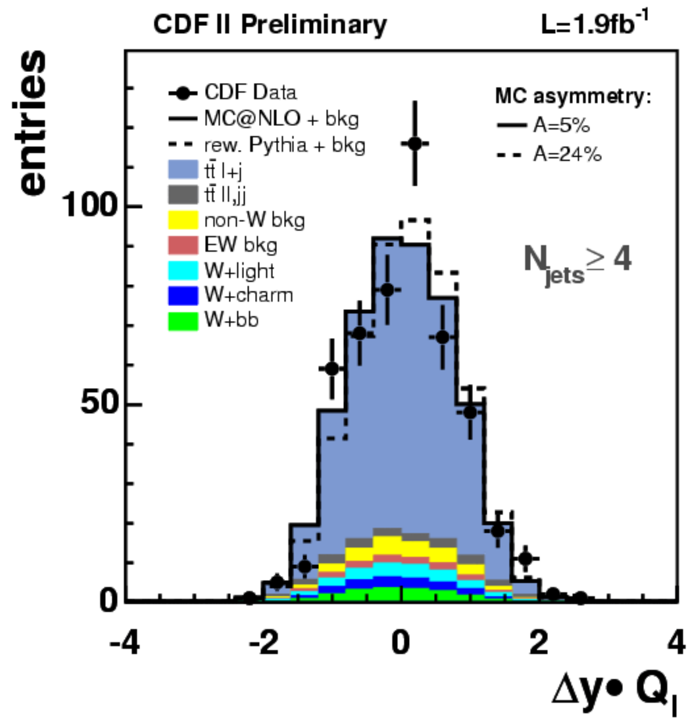
- **Leptons well measured, but missing two neutrino momenta and match jets to b quarks**
- **Energy, momentum constraints lead to 4 possible solutions**
- **Best solution chosen from likelihood based on PDF's for P_Z^{tt}, P_T^{tt}, and M_{tt}**
- **Top and anti-top direction both fully reconstructed**





Other Signs?

- **Alternative measurement at CDF (Karlsruhe)**
- **Measured in $t\bar{t}$ rest frame**
- **Performed with 1.9 fb^{-1}**

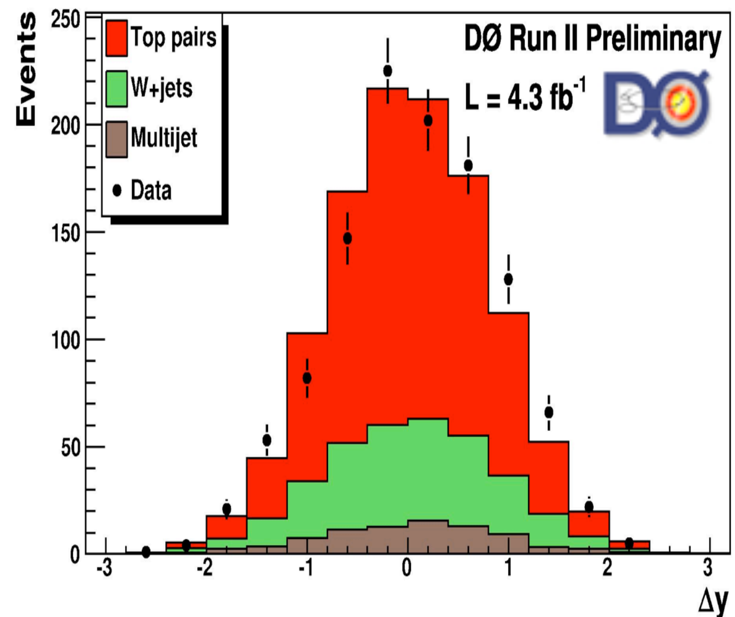


$A_{FB} = 24 \pm 14_{stat+sys}$ %

$A_{FB}^{SM} = 7 \pm 2$ %

Other Signs?

- DØ collaboration has also performed this measurement
- DØ compares the result to the SM as seen by the detector (only corrects for backgrounds)



$A_{FB}^{data\text{-}bkg} = 8 \pm 4_{stat+sys}$ %

$A_{FB}^{mc@nlo} = 1^{+2.0}_{-1.0}$ %

$A_{FB}^{CDF} = 7.5 \pm 3.7$ %