Top cross section and SM properties at CDF

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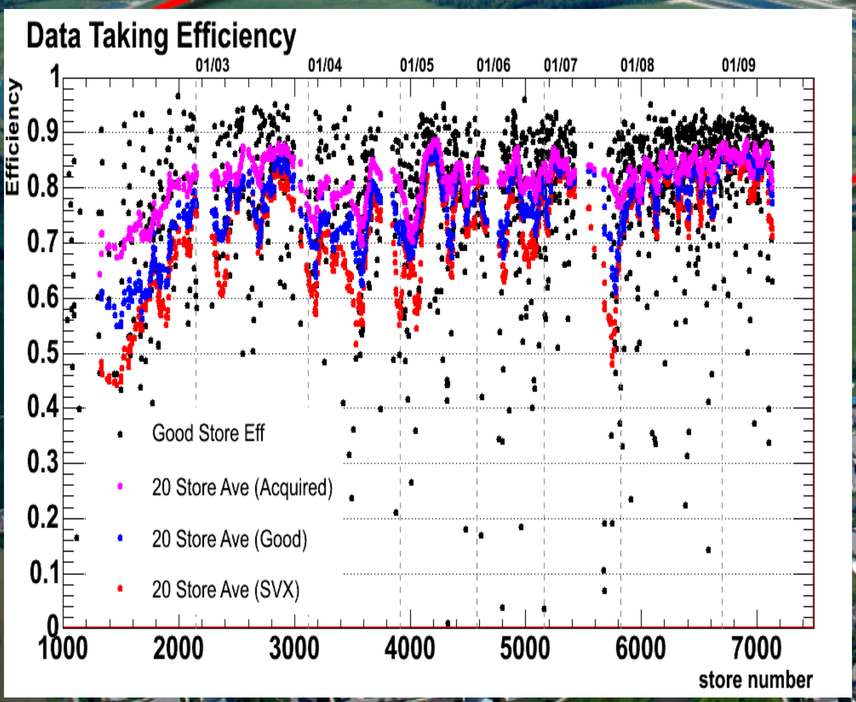
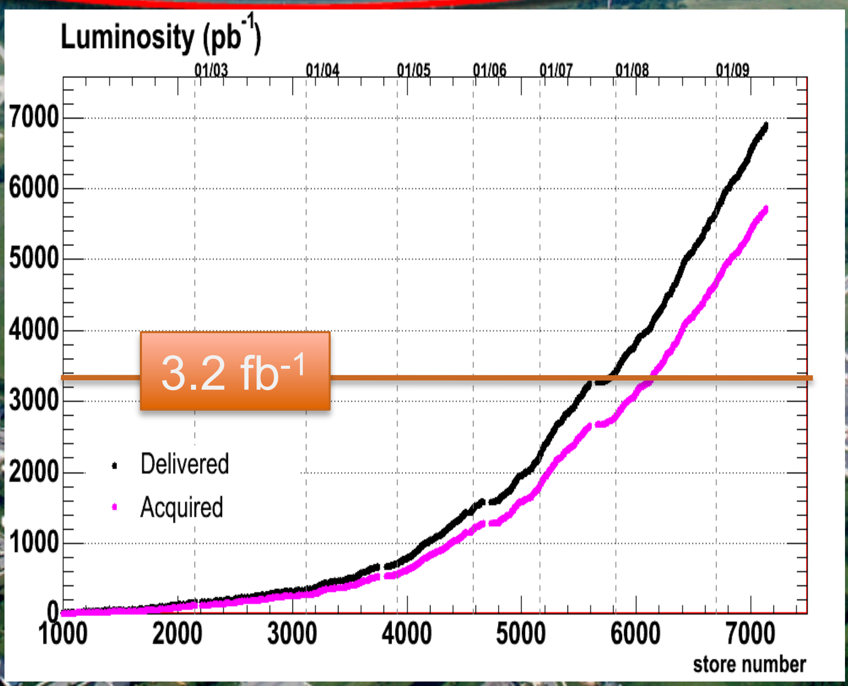
For the CDF collaboration

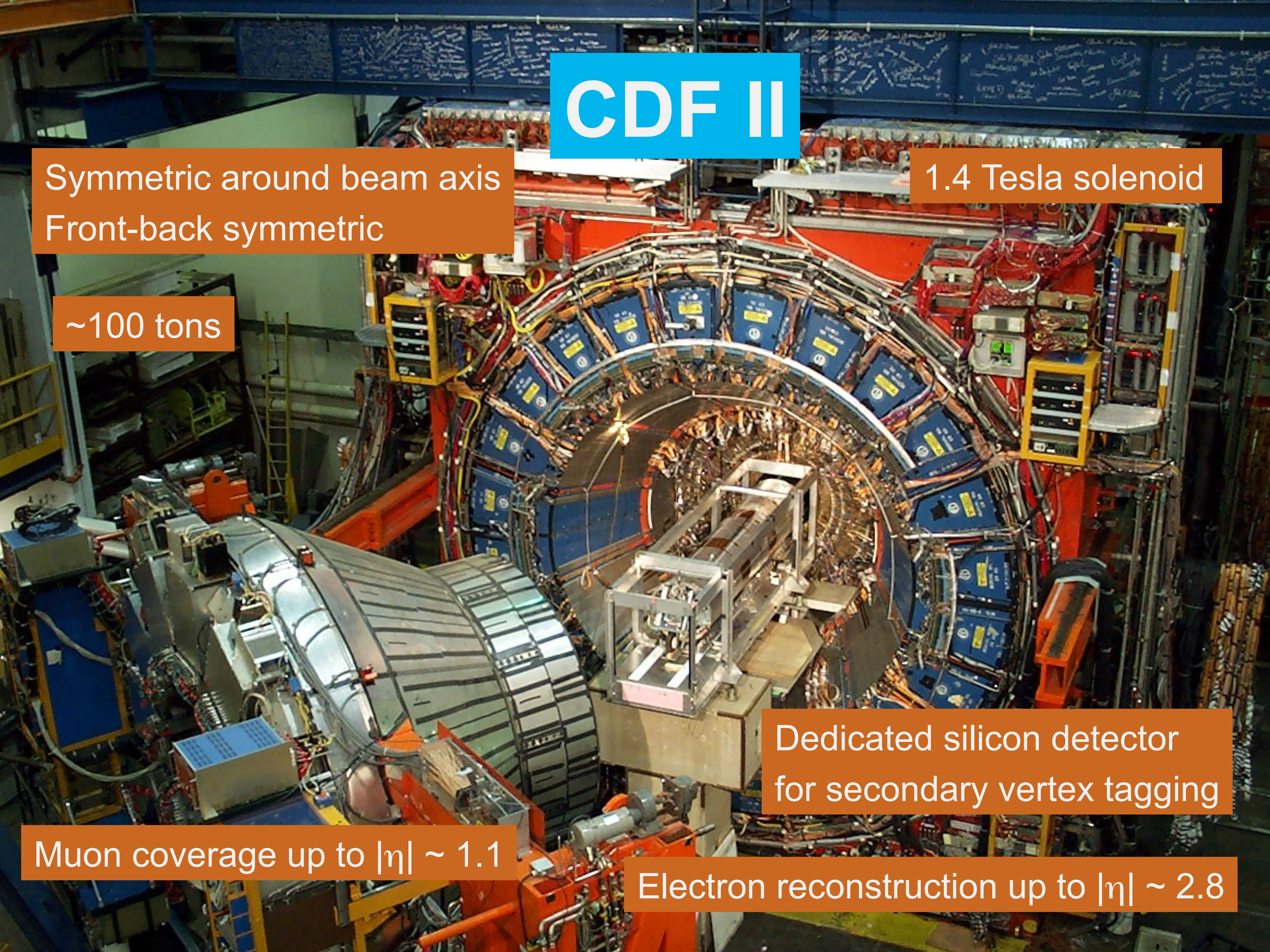
Tevatron Performance

- Accelerator complex breaking records all the time
- Peak Luminosity record $3.18 \cdot 10^{32}$ $cm^{-2}sec$
- Weekly integrated luminosity record 57 pb^{-1}
- Total integrated luminosity delivered ~6.9 fb^{-1}
  - ~5.7 fb^{-1} recorded by each experiment

Thanks to the Accelerator Division!

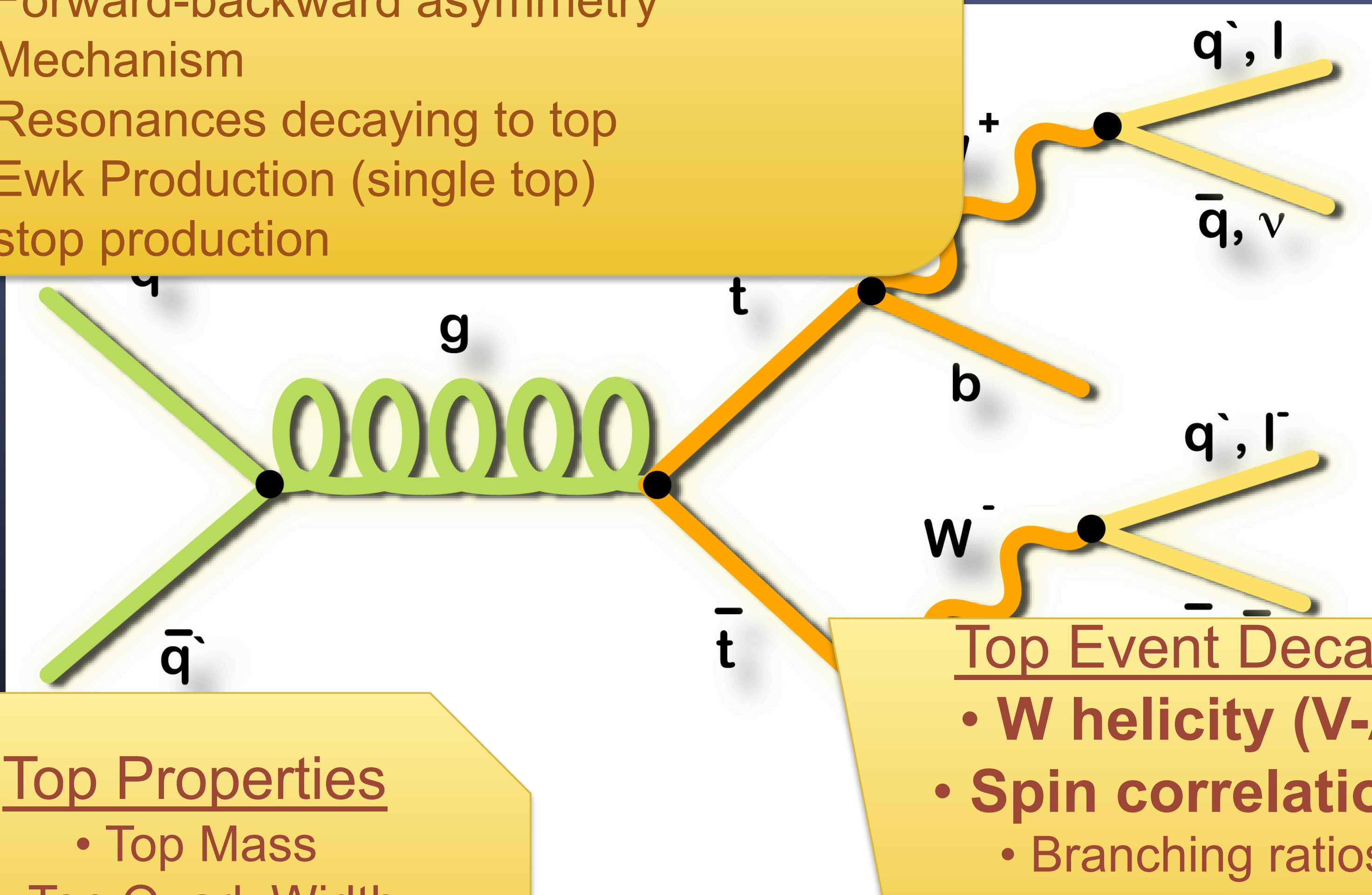





CDF II
Symmetric around beam axis
Front-back symmetric
1.4 Tesla solenoid
~100 tons
Dedicated silicon detector
for secondary vertex tagging
Muon coverage up to |η| ~ 1.1
Electron reconstruction up to |η| ~ 2.8

Top Quark Production

- **Top Pair Cross Section**
- Forward-backward asymmetry
- Mechanism
- Resonances decaying to top
- Ewk Production (single top)
- stop production



Top Properties

- Top Mass
- Top Quark Width
- Charge of Top Quark

Top Event Decays

- **W helicity (V-A)**
- **Spin correlations**
- Branching ratios
- Top to charged higgs
- Top sample (W+c)
- FCNC

Older values assume m_{tt} = 175 GeV/c^2
New values assume m_{tt} = 172.5 GeV/c^2

Top Quark Pair Production Cross Section

New measurements since summer 2008

- All hadronic top cross section
- Ratio of top to Z cross section in lepton + jets channel

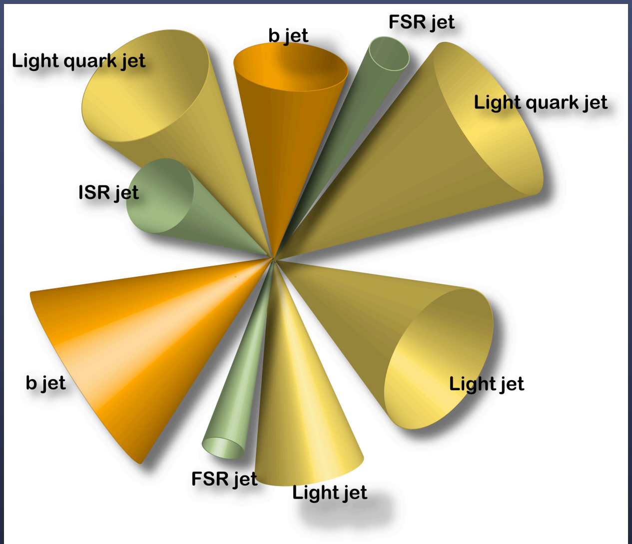
$$\sigma_{t\bar{t}} = \frac{N_{data} - N_{bck}}{\epsilon \cdot A \cdot L}$$

All Hadronic

2.9 fb^{-1}

Event selection (same as used for the mass measurement)

- No lepton
- ≥ 6-8 jets
  - $\Delta R_{jj} > 0.5$
  - 1 or ≥ 2 b-tags
- Low Missing E_T
- Neural Network output > fixed value
  - 13 input variables



- Obtain cross section from likelihood fit to reconstructed top mass

$$\chi^2 = \frac{\left(m_{jj}^{(1)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jj}^{(2)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jjb}^{(1)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \frac{\left(m_{jjb}^{(2)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \sum_{i=1}^{6} \frac{\left(p_{T,i}^{fit} - p_{T,i}^{meas}\right)^2}{\sigma_i^2}$$

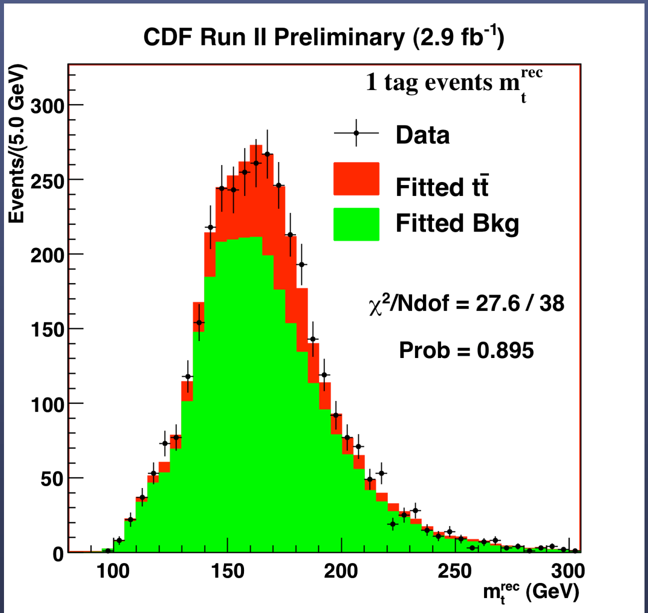
All Hadronic

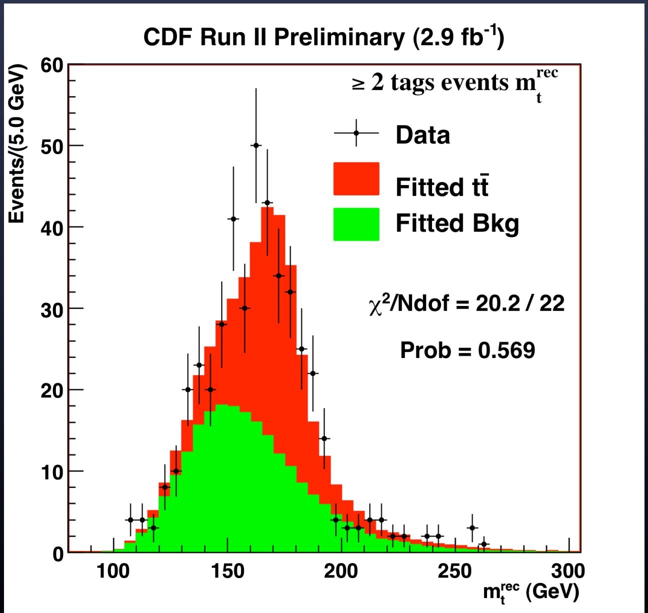
- Systematic uncertainties evaluated from pseudo-experiments
  - Dominated by
    - Jet Energy Scale
    - Generator
- Fit performed at
  - New standard top mass point
    - M_{top} = 172.5 GeV/c2

σ_{tt}= 7.2±0.5(stat)±1.4(syst)±0.4(lumi) pb

  - Top Mass and JES value from mass measurement
    - $M_{top}=174.8^{+2.7}_{-2.8}$ GeV/c^2
    - ΔJES = -0.3

σ_{tt}=7.2±0.5(stat)±1.3(syst)±0.4(lumi) pb

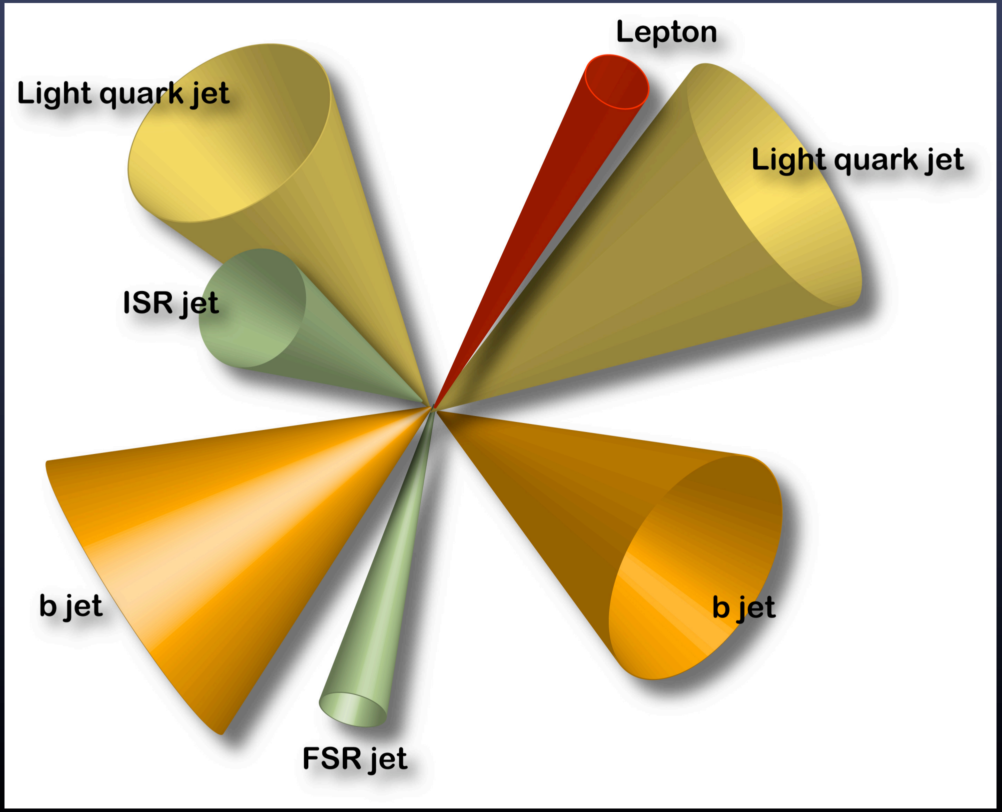




Lepton + Jets

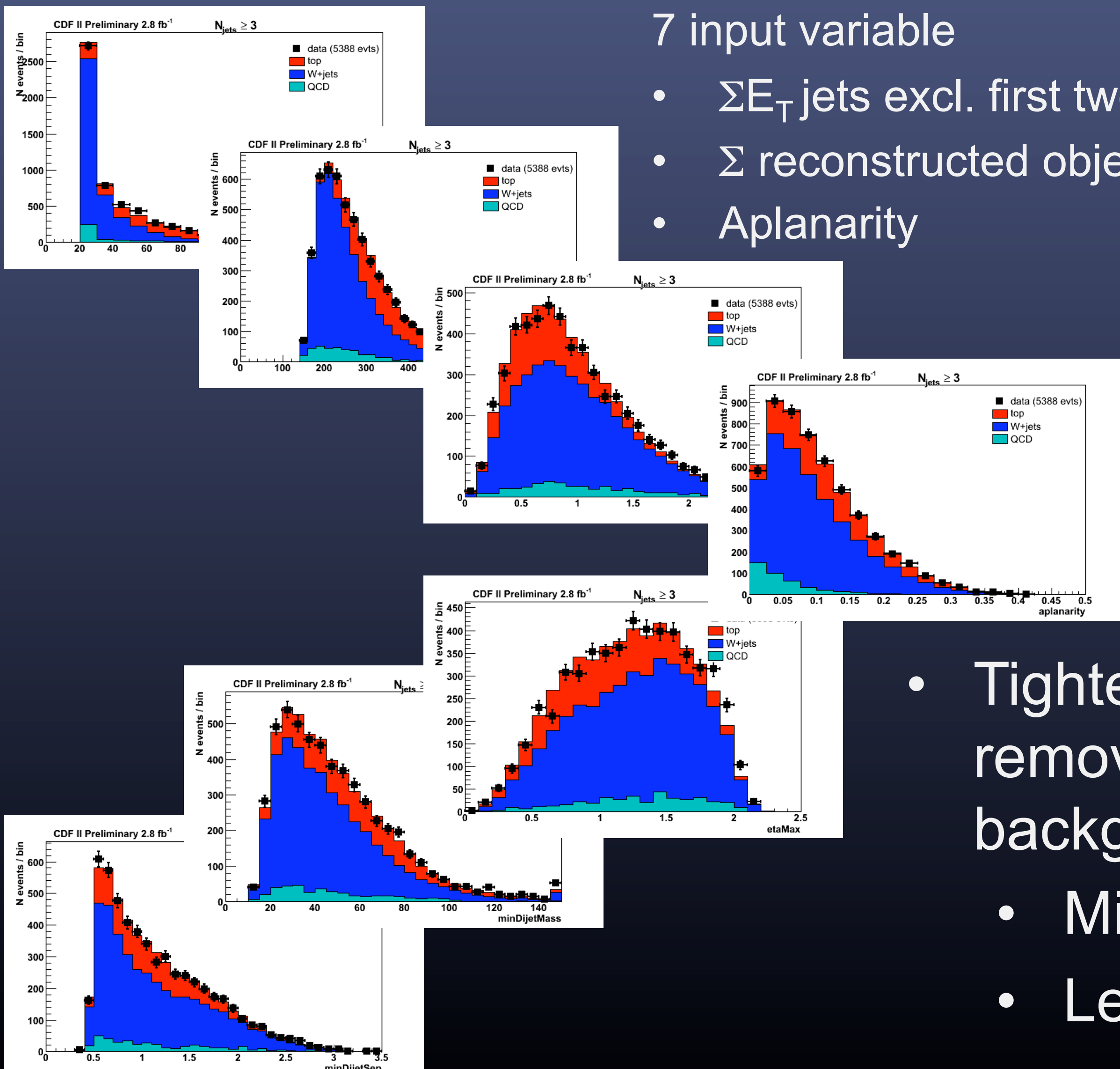
Event selection

- $\geq$ 3 jets
  - $E_T \geq 20$
- 1 isolated electron or muon
  - $p_T \geq 20$ GeV/c
- High Missing E_T
  - $ME_T \geq 20$ GeV



Neural Network Fit

2.8 fb^{-1}



7 input variable

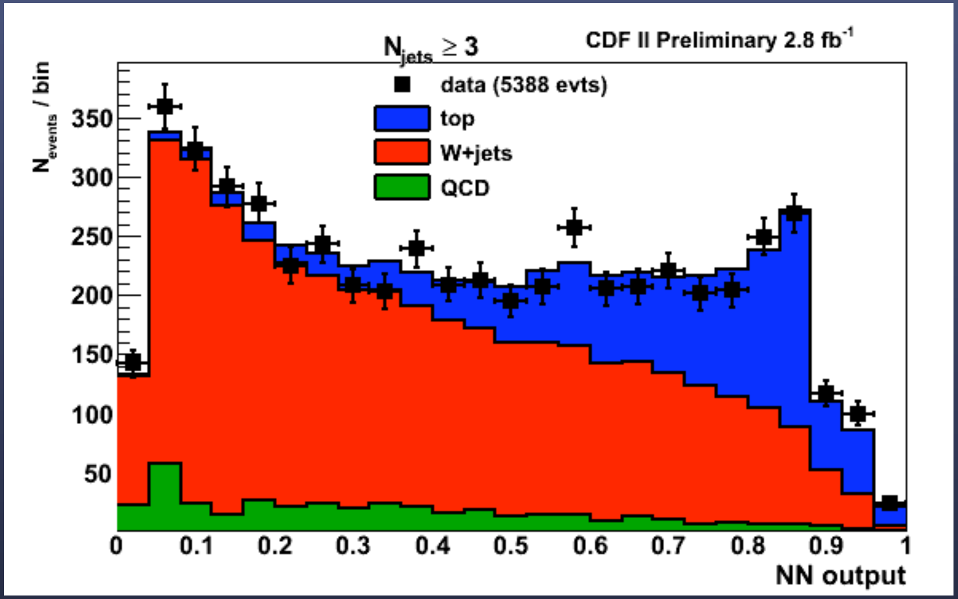
- ΣE_T jets excl. first two
- Σ reconstructed objects (H_T)
- Aplanarity

3 highest E_T jets

- $\Sigma E_T / \Sigma p_z$
- Min dijet mass
- Min dijet separation
- Max η

- Tighten analysis cuts to remove most non-W (QCD) background
  - Missing E_T > 35 GeV
  - Leading jet E_T > 35 GeV

Neural Network Fit



Background model

- Non-W (QCD) from data
  - Normalisation constrained by fit to Missing transverse energy
- W+jets (ALPGEN) used to model all other backgrounds
  - Normalisation floated freely

σ_{ttbar} = 7.1 ± 0.4 (stat) ± 0.4 (syst) ± 0.4 (lumi) pb

Dominant systematics (estimated from pseudo-experiments)

- Luminosity (5.8%)
- Jet Energy Scale (3.2%)
- ttbar generator (2.7%)

Lepton + Jets B-Tagged

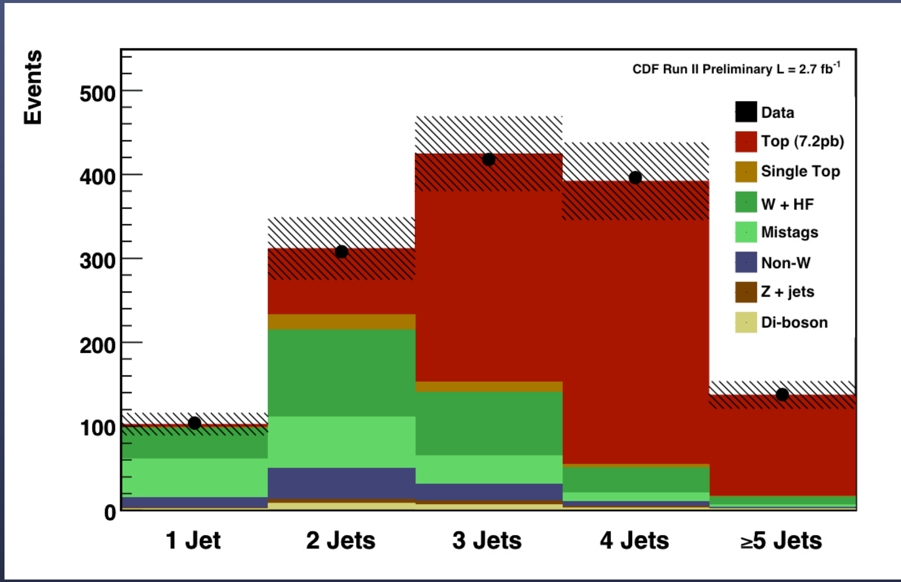
2.7 fb^{-1}

Tighten event selection

- Missing $E_T \geq 25$ GeV
- ≥1 heavy flavour tagged jet
- $H_T \geq 250$ GeV

Background estimation

- Estimate backgrounds for a given σ_{tt}
- Vary σ_{tt} by small amount
- Iterate until find minimum of log likelihood distribution as a function of σ_{tt}

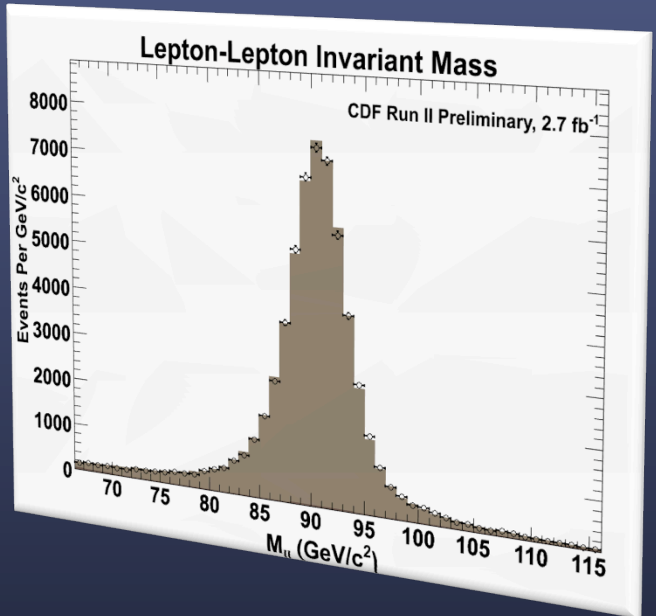


- Dominant systematics
  - Heavy flavour tagging
  - Heavy flavour corrections
  - Luminosity

σ_{tt} = 7.2 ± 0.4 (stat) ± 0.5 (syst) ± 0.4 (lumi) pb

Ratio: σ_{tt} / σ_Z

- σ_Z well known theoretically
  - $\sigma_{Z\text{->}ll}$ (theory) = 251.3 ± 5.0 pb
- Z well modeled in data
  - Small background
  - $\sigma_{Z\text{->}ll}$ = 256.8 ±1.1(stat) ±7.0(sys)±15.1(lumi)
- Luminosity uncertainty cancels out in ratio of ttbar to Z cross section if use same triggers and data periods
  - σ_{ttbar} = 7.0 ± 0.4 (stat) ± 0.4 (sys) ± 0.4 (lumi) pb
  - $\sigma_{Z\text{->}ll}$ / σ_{ttbar} = 37.1±2.2(stat) ±2.1(sys)



σ_{tt} = 6.8 ± 0.4(stat) ± 0.4 (syst) ± 0.1 (theory) pb — **$\Delta\sigma_{tt}$ /σ_{tt} = 8%**

$\sigma_{tt\ (b\text{-tagged})}$ = 7.0 ± 0.4(stat) ± 0.6 (syst) ± 0.1 (theory) pb — $\Delta\sigma_{tt}$ /σ_{tt} = 10%

Single measurement better than summer 2008 combination (same luminosity)

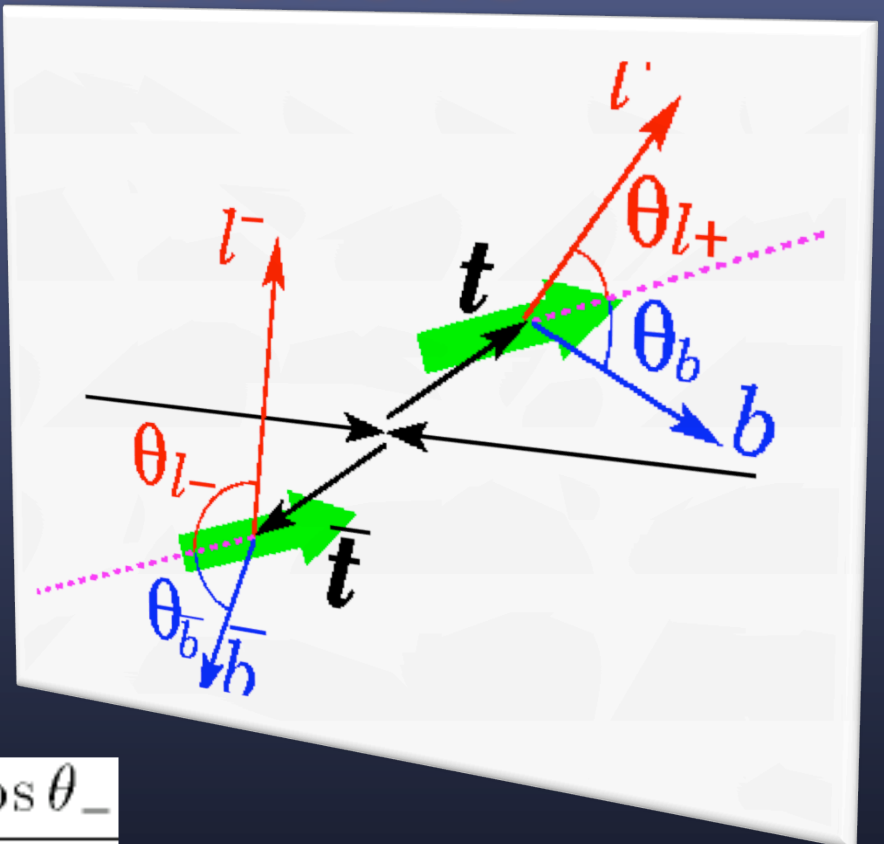
Similar total uncertainty to theoretical predictions

$2.8\ fb^{-1}$

Spin Correlations Dilepton Channel

Spin-Spin Correlations

- Top quarks do not hadronise before they decay
  - Can observe original polarization from when they are produced
- Spin-spin correlations at ttbar production can be observed through correlations between flight direction of of decay products
- Can measure κ from angular distribution of θ^{+} vs θ^{-} and θ_b vs θ_{bbar}



$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + \kappa\cos\theta_+\cos\theta_-}{4}$$

- Standard Model
  - qqbar -> g ->ttbar: κ =1
  - At Tevatron expect κ ~0.8

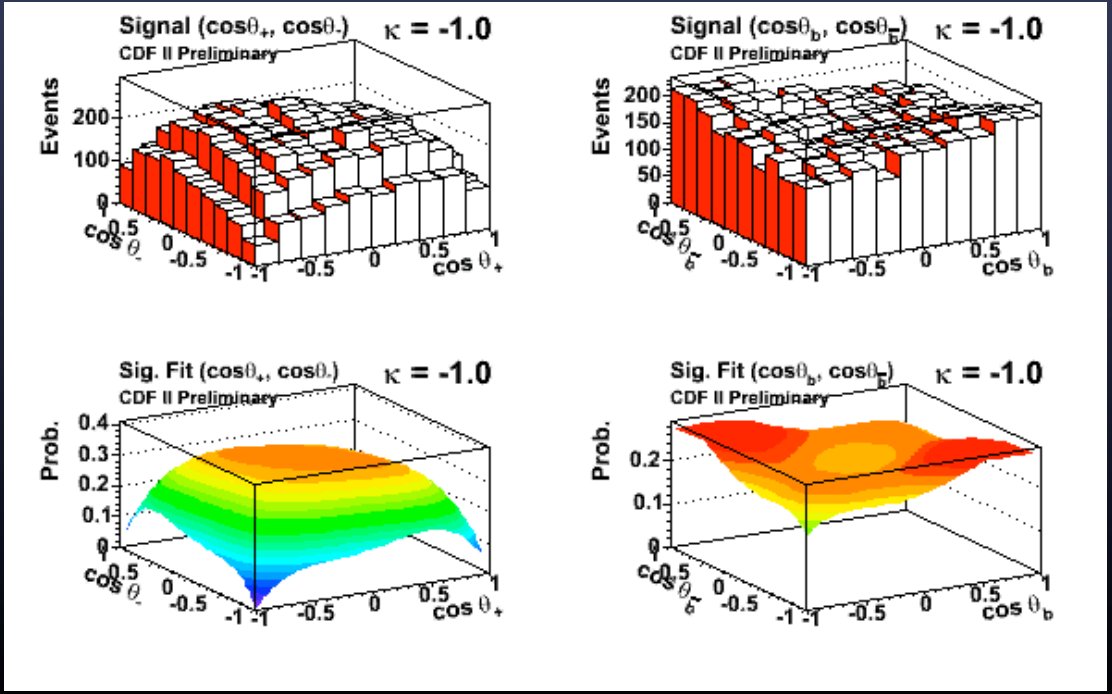
Spin-Spin Correlations

Event selection

- 2 electrons or muons
  - p_T / E_T>20 GeV
  - ≥1 isolated
  - ≥1 central
  - Opposite charge
- Missing E_T > 25
  - MET >50 if angle MET-lepton/jet < 20°
- ≥2 jets (E_T > 15 GeV)
- H_T > 200 GeV

Dominant backgrounds

- WW/ZZ/WZ
- Drell-Yan
- W+jets
  - 1 jet fakes a lepton
- Can ignore Wγ



Results

- Minimum unbinned likelihood fit to obtain κ
- Feldman-Cousins confidence intervals
- Statistics limited

Dominant systematics

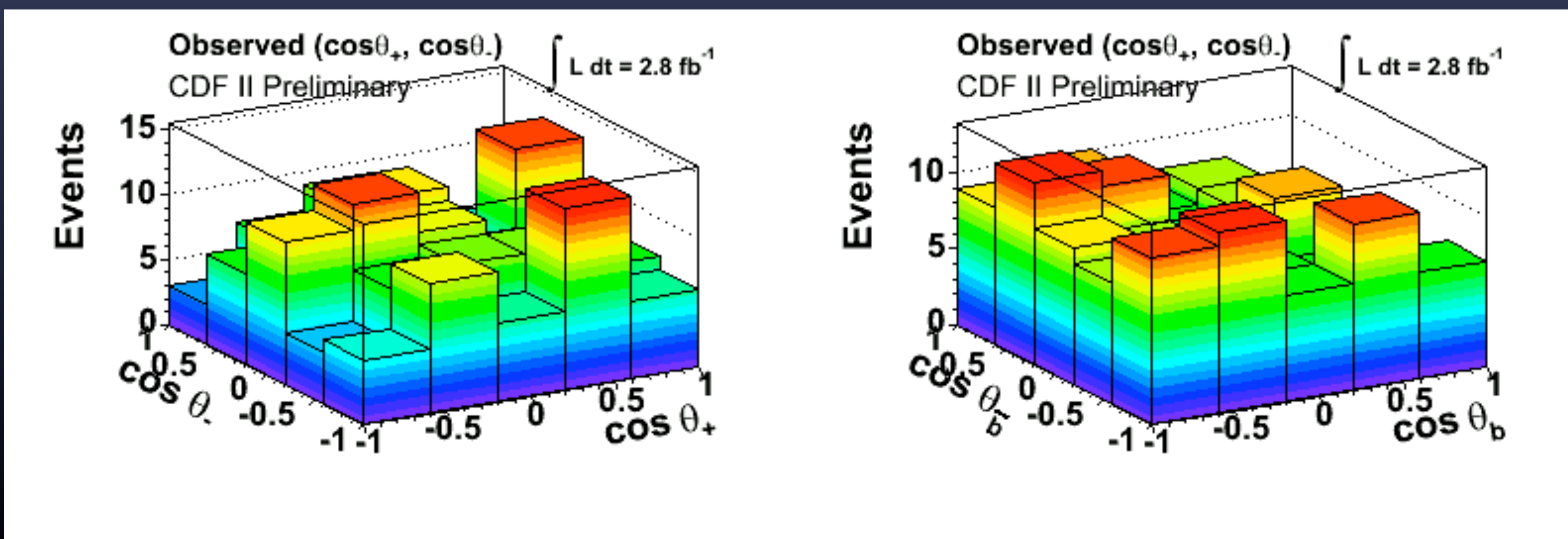
- Background uncertainty
- PDFs

M_{top} = 175 GeV/c^2

- κ value flat wrt top mass

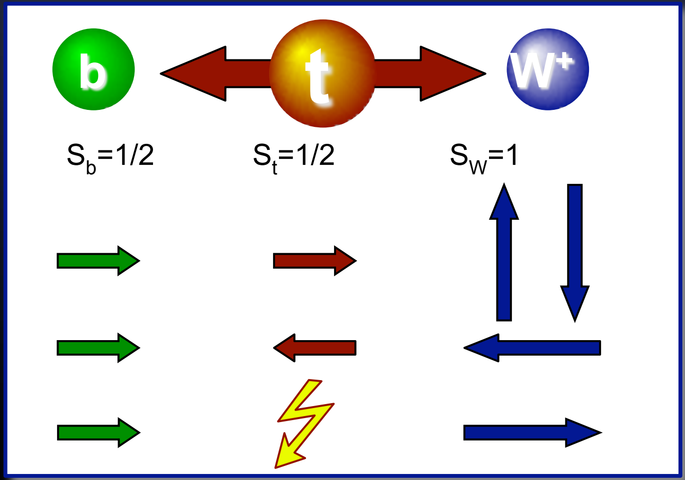
$\kappa = 0.32^{+0.55}_{-0.78}$

$-0.455 < \kappa < 0.865$ (68% CL)



1.9 fb^{-1}

W-Helicity Measurements + Combination



Phys.Lett.B674:160-167,2009

W-boson Helicity in Top Quark Decays

- Decay products preserve helicity content of underlying weak interaction
- Probe the V-A structure of the weak interaction in the top-quark decay
- Helicity fractions ≠ SM ➔ new physics
- e.g. V+A component in weak interaction, anomalous couplings in top-decay.

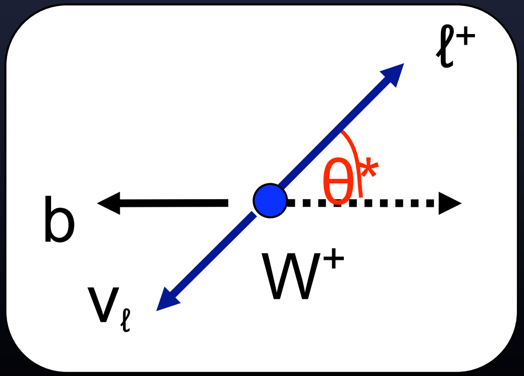
- Angle between direction of charged lepton in the W-boson rest frame and direction of W-boson in the top-quark rest frame
- To calculate θ* we have to reconstruct the four-vectors of top-quark, W-boson, and charged lepton

SM prediction for m_t=175 GeV/c^2, m_b=0

$$F_0 = \frac{m_t^2}{2m_W^2 + m_t^2} = 0.7$$ longitudinal

$$F_- = 0.3$$ left-handed

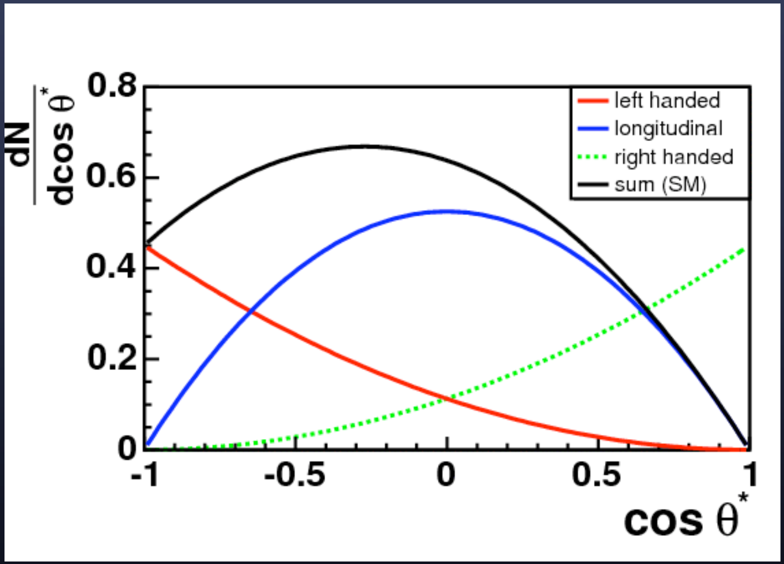
$$F_+ = 0.0$$ right-handed

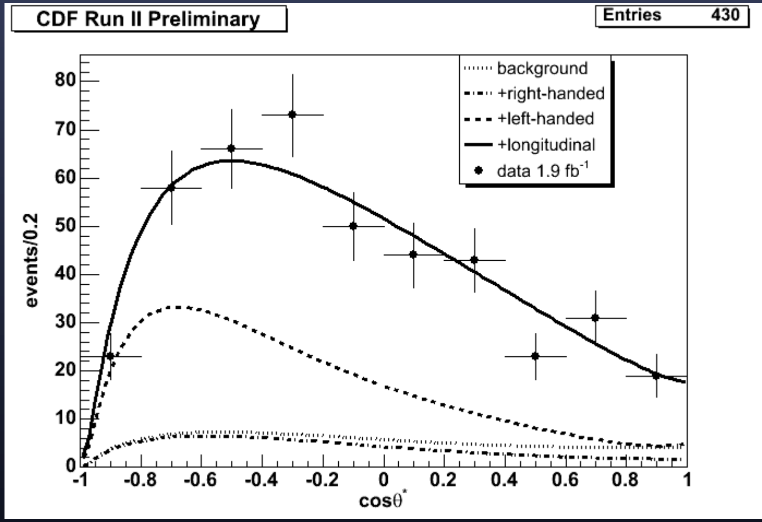


cosθ* Reconstruction

- Unbinned likelihood fit to expected distributions
- Then correct for acceptance effects

- Use theoretically predicted # events in each bin at particle level
- Convolute acceptance and resolution effects
- Get expected number events at detector level



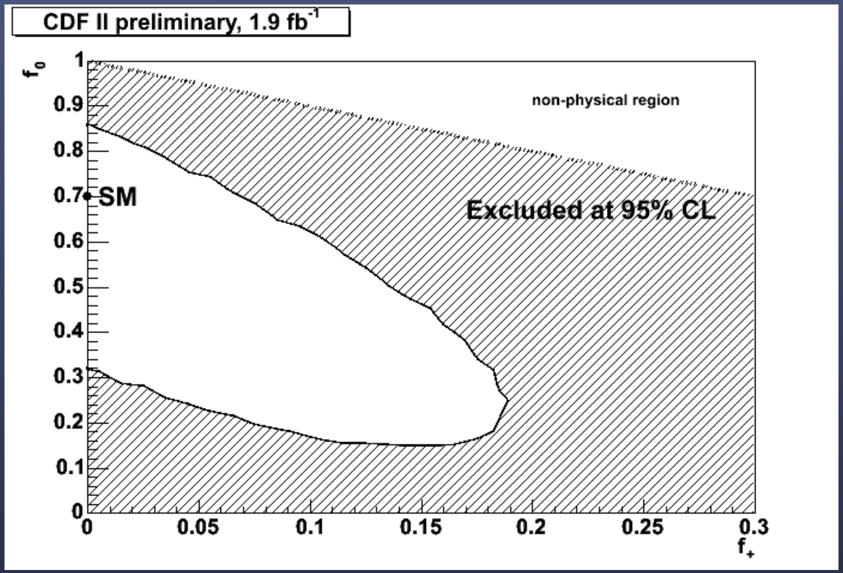


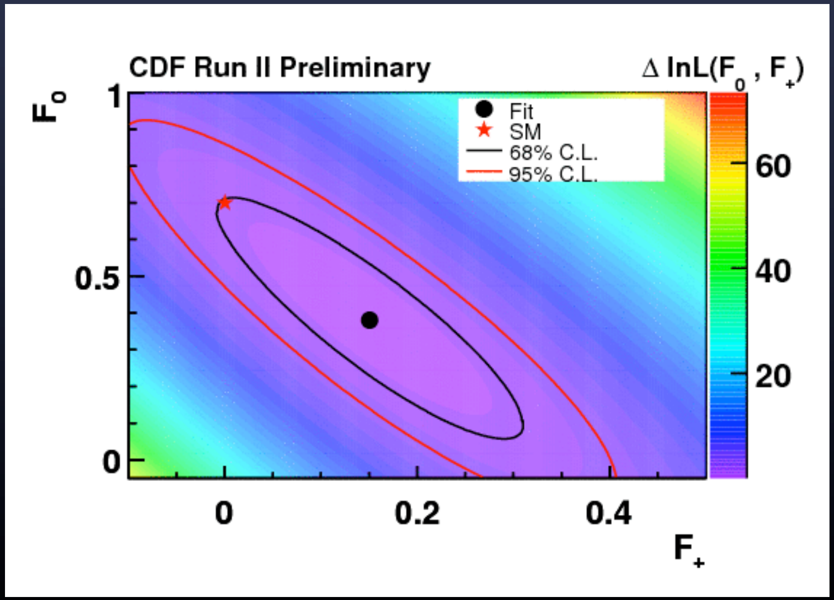
$$\frac{dN}{d\cos\theta^*} = F_- \cdot \frac{3}{8}\left(1-\cos\theta^*\right)^2 + F_0 \cdot \frac{3}{4}\left(1-\cos^2\theta^*\right) + F_+ \cdot \frac{3}{8}\left(1+\cos\theta^*\right)^2$$

Fit Results

All values consistent with SM predictions

- F^0 with $F^+ = 0.0$
  - Template: $F^0 = 0.59 \pm 0.11 \pm 0.04$
  - Convolution: $F^0 = 0.66 \pm 0.10 \pm 0.06$
  - Combination: $F^0 = 0.62 \pm 0.10 \pm 0.05$
- F^+ with $F^0 = 0.7$
  - Template: $F^+ = -0.04 \pm 0.04 \pm 0.03$
  - Convolution: $F^+ = 0.01 \pm 0.05 \pm 0.03$
  - Combination: $F^+ = -0.04 \pm 0.04 \pm 0.03$
- Simultaneous fit of F^0 and F^+
  - Template
    - $F^0 = 0.65 \pm 0.19 \pm 0.04$
    - $F^+ = -0.03 \pm 0.07 \pm 0.03$
  - Convolution
    - $F^0 = 0.38 \pm 0.21 \pm 0.07$
    - $F^+ = 0.15 \pm 0.10 \pm 0.05$
  - Combination
    - $F^0 = 0.66 \pm 0.16 \pm 0.05$
    - $F^+ = -0.03 \pm 0.06 \pm 0.03$





http://www-cdf.fnal.gov/physics/new/top/public_tprop.html

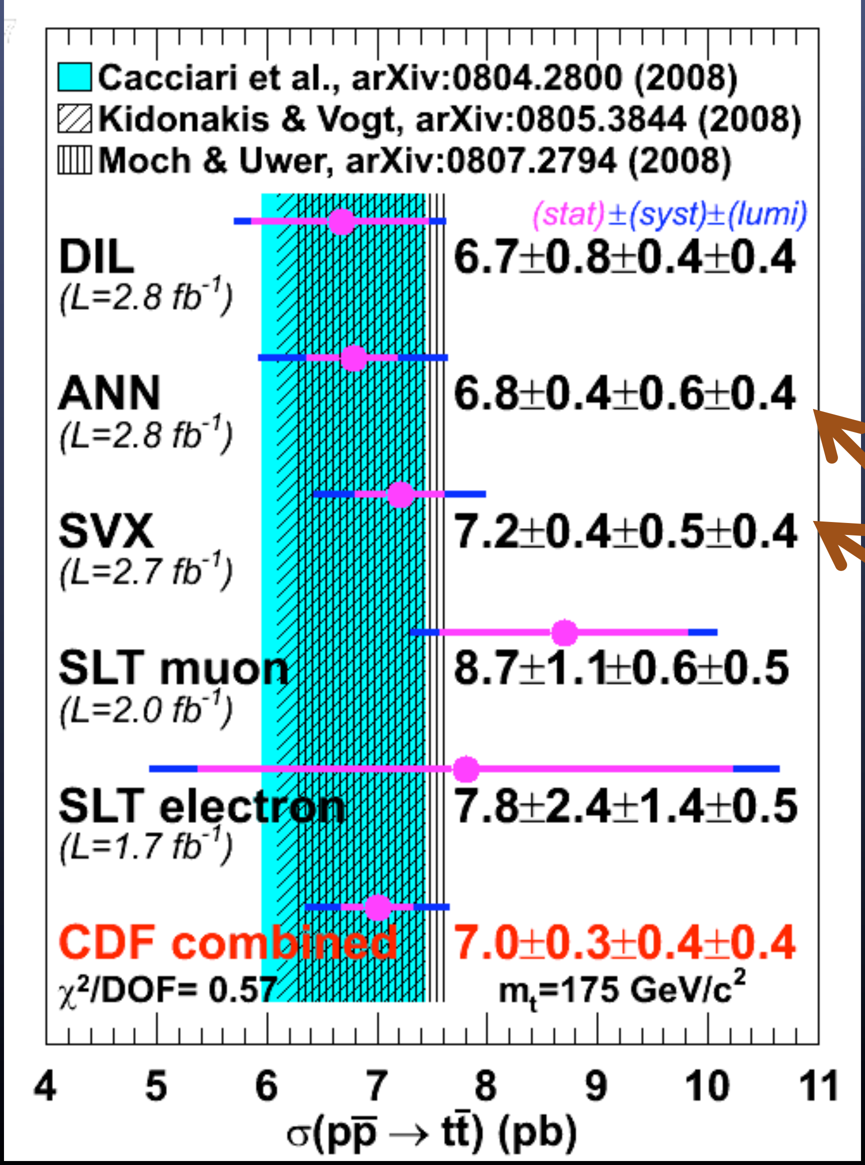
	Value	Lum fb^{-1}	SM value	SM-like
M_{top}	…have to wait until tomorrow ☺		N/A	Yes
σ_{ttbar}	7.0 ± 0.3 ± 0.4 ± 0.3 ± 0.4 pb @M_{top} = 175 GeV/c^2	2.8	6.7	Yes
W-helicity	F^0 = 0.66 ± 0.16 ± 0.05 F^+ = -0.03 ± 0.06 ± 0.03	1.9	F^0 = 0.7 F^+ = 0.0	Yes
Spin Correlations	-0.455 < κ < 0.865 (68% CL)	2.8	κ = 0.8	Yes
A_{FB}	A_{FB} = 0.19 ± 0.07(stat) ± 0.02(syst)	3.2	A_{FB} = 0.05 (NLO)	Yes
Width	Γ_{top} < 13.1 GeV @ 95% confidence level	1.0	1.5 GeV	Yes
Lifetime	$c\tau_t$ < 52.5 μm @ 95% C.L.	0.3	~10^{-16} m	Yes
Branching Ratio	BR(t->Wb)/BR(t->Wq)> 0.61 @ 95% C.L.	0.2	~100%	Yes
Gluon fusion fraction	F_{gg} = 0.53 ± 0.36 ± 0.08	2.0	~15% (NLO)	Yes
Top charge	Exclude top charge of -4/3 with 87% C.L.	1.5	2/3	Yes

Top Physics is "obviously" THE sexiest topic at the Tevatron

Extras..

Combination: Summer 08

2.8 fb^{-1}



- Assuming top mass of 175 GeV/c^2
- Total CDF uncertainty 9%
- Latest theory uncertainty 8%

New measurements since then

- All hadronic top cross section
- Ratio of top to Z cross section in lepton + jets channel
  - Neural Network fit
  - B-tagged

Will be updated soon…

$3.2\ fb^{-1}$

Forward-Backward Asymmetry in ttbar Production

Update of measurement in ppbar rest frame using top/anti-top rapidity rather than θ

Charge Asymmetry

SM

Asymmetry caused by interference of ME amplitudes for same final state

- Predictions in parton rest frame
- tt (general)
  - A_{NLO} = 4-7%
  - A_{LO} = 0%

(J. Kühn et al.: arXiv:0709.1652)

- tt + g
  - A_{NLO} = -(0-2)%
  - A_{LO} = - (9-10)%

(P. Uwer et al.: hep-ph/0703120)

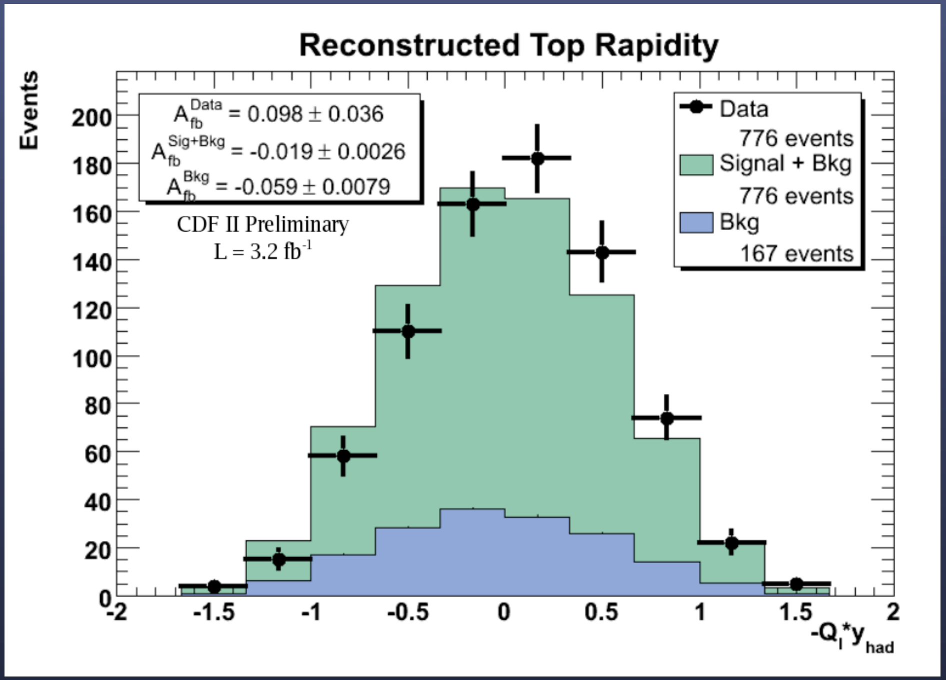
$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

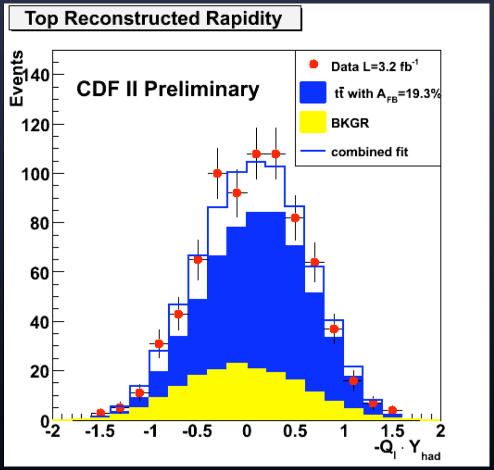
- Test of discrete symmetries of strong interaction at high energy
- Significant deviations would be an indication of new physics
  - E.g. Z' or axigluons
- Assume CP invariance

  A_{FB} asymmetry ➔ charge asymmetry

A_{FB}

- Fully reconstruct L+J events
  - ≥1 b-tag
  - Minimum chi² fit
- Look at angle between hadronically decaying top and proton direction
- Multiply by charge of lepton on other side
- $A_{FB} > 0$ means net top current in the proton direction





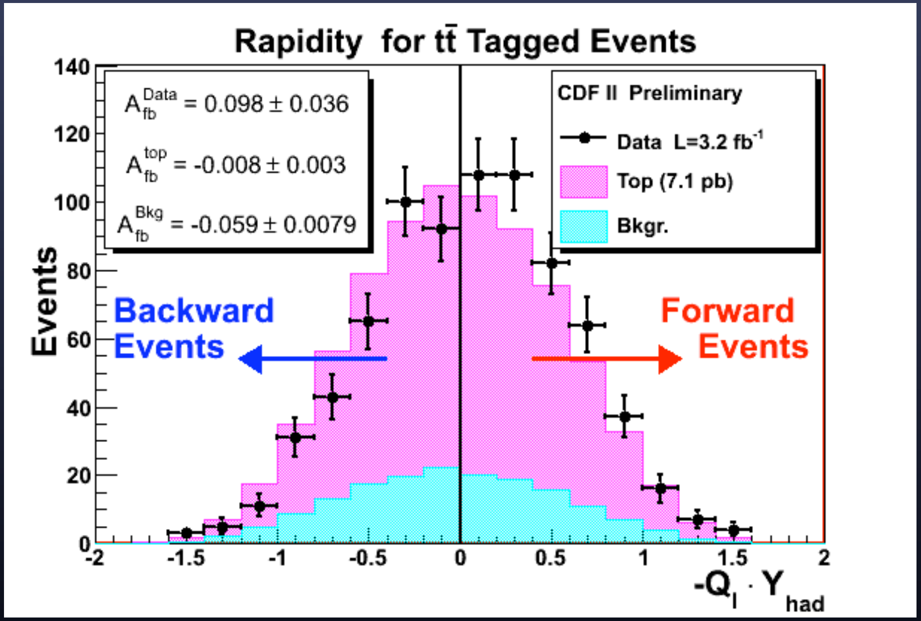
Unfold observed distribution

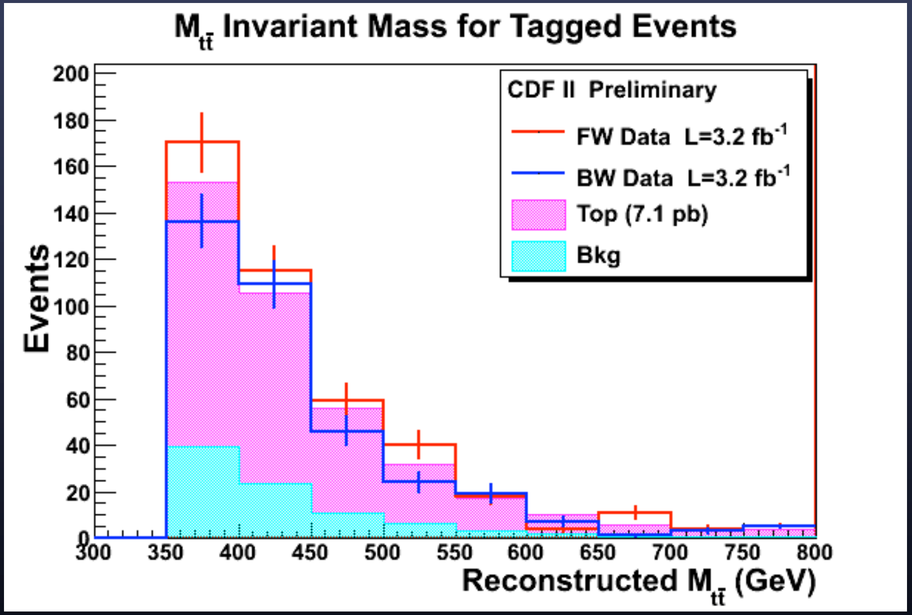
- Subtract backgrounds
  - Some have asymmetry
- Unfold for trigger and acceptance effects
- Unfold for detector bias
  - Bin migration roughly symmetric

$A_{FB} = 0.193 \pm 0.065$ (stat) ± 0.024 (sys)

Dependence of A_{FB} on M_{ttbar} cut

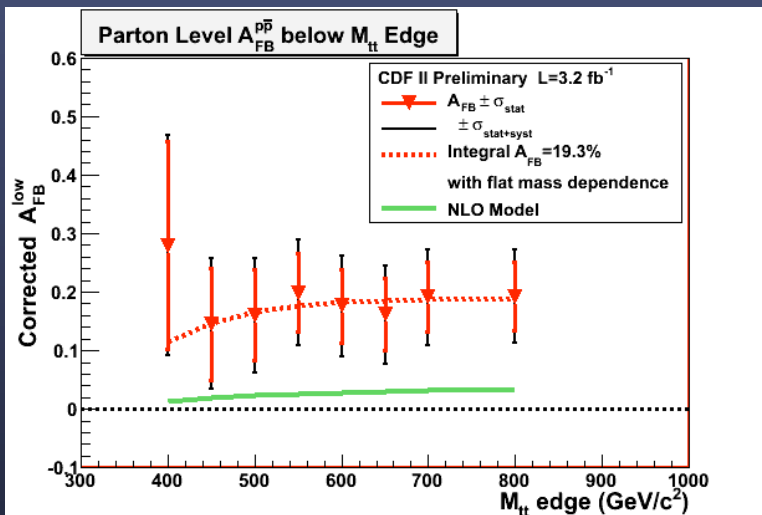
- Do forward and backward events have different M_{ttbar} distributions?
  - NLL calculations predict some small dependence on M_{ttbar}
  - Presence of structure ("bump"/enhancement) in spectrum could be sign of new physics

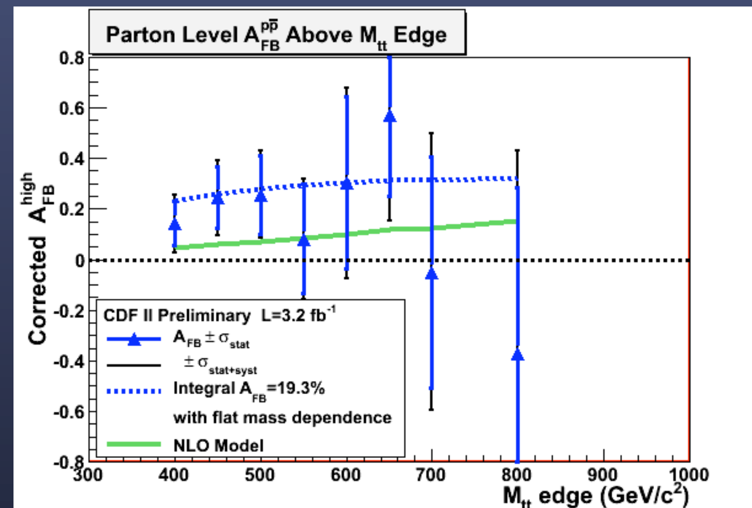




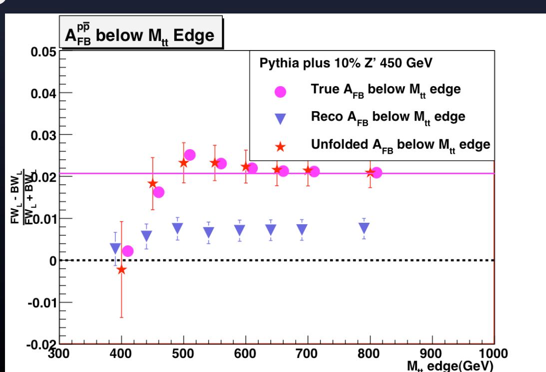
Dependence of A_{FB} on M_{ttbar} cut

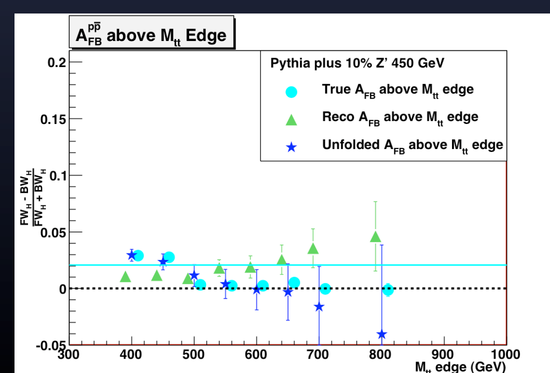
- Look at A_{FB} as a function of the minimum/maximum cut on M_{ttbar}





- No significant sign of M_{ttbar} dependence…. Yet ☺
- e.g. Z’ would have an invariant mass dependence

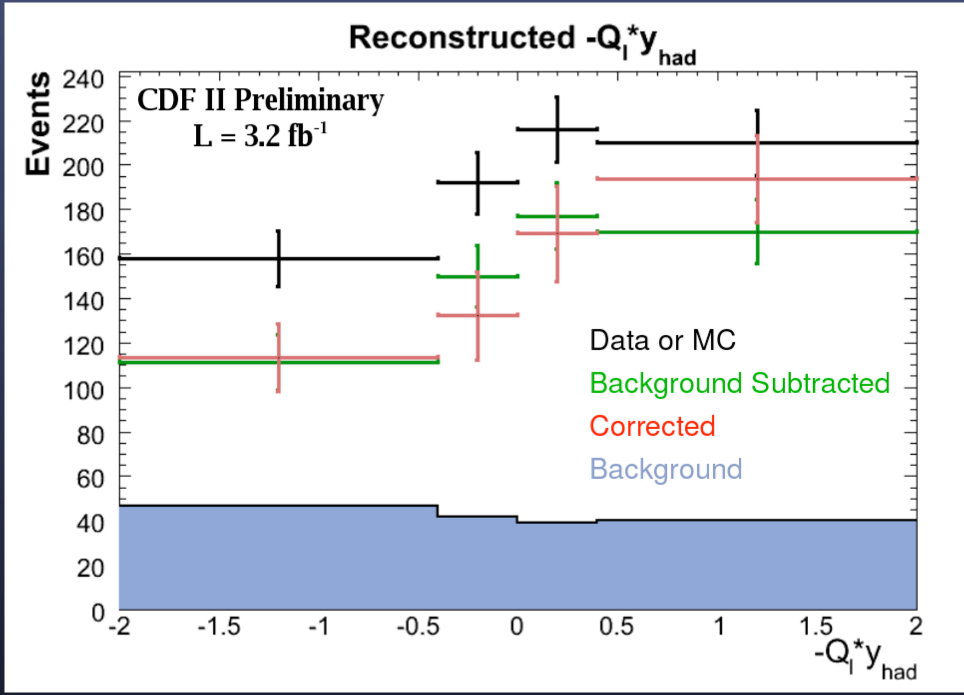


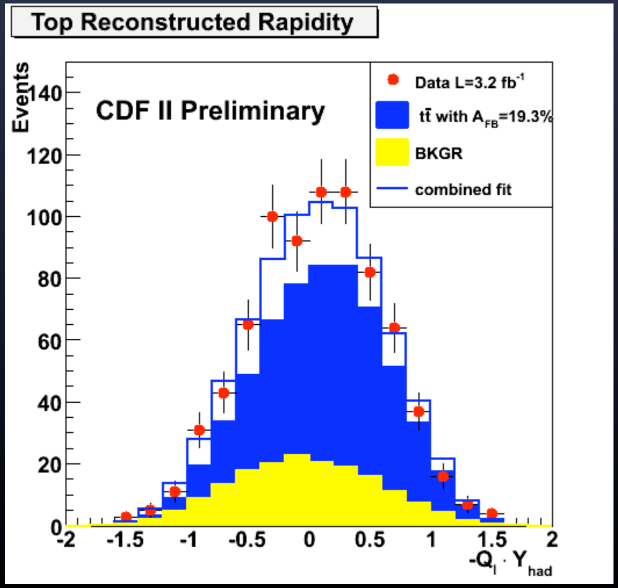


Results

A_{FB} = 0.193 ± 0.065 (stat) ±0.024 (sys)

- Cross check observed distribution with parametrisation of asymmetry
  - 1+A cos(θ)
  - Min log likelihood as a function of asymmetry
    - A_{FB} = 0.173 ± 0.052
    - Consistent with measurement





Previous result (1.9 fb^{-1})
A_{FB} = 0.17 ± 0.08