

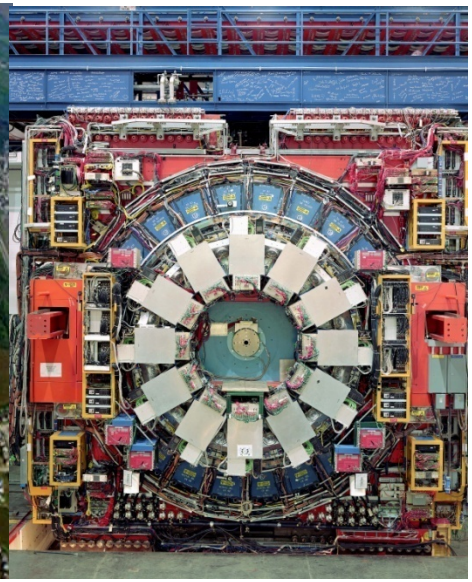

top quark properties

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Brown University
(for the D0 and CDF collaborations)

Aspen Particle Physics Conference **-** Aspen Center for Physics **-** January 17-23, 2010

the top quark

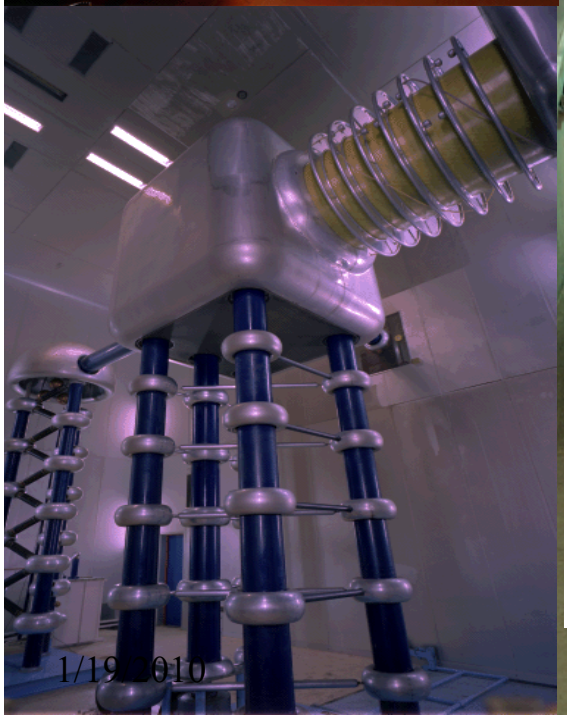
- affects SM predictions for many processes
  - dominant contributor to radiative corrections
  - measure its mass precisely

  → Lina
- top is the most massive fundamental particle
  - complicated signature
  - production and decay could involve new particles
  - direct searches for new physics

  → Andrew
- given its mass, SM predicts all other properties
  - spin, charge, couplings…
  - measure and compare to predictions
  - deviations could indicate new physics

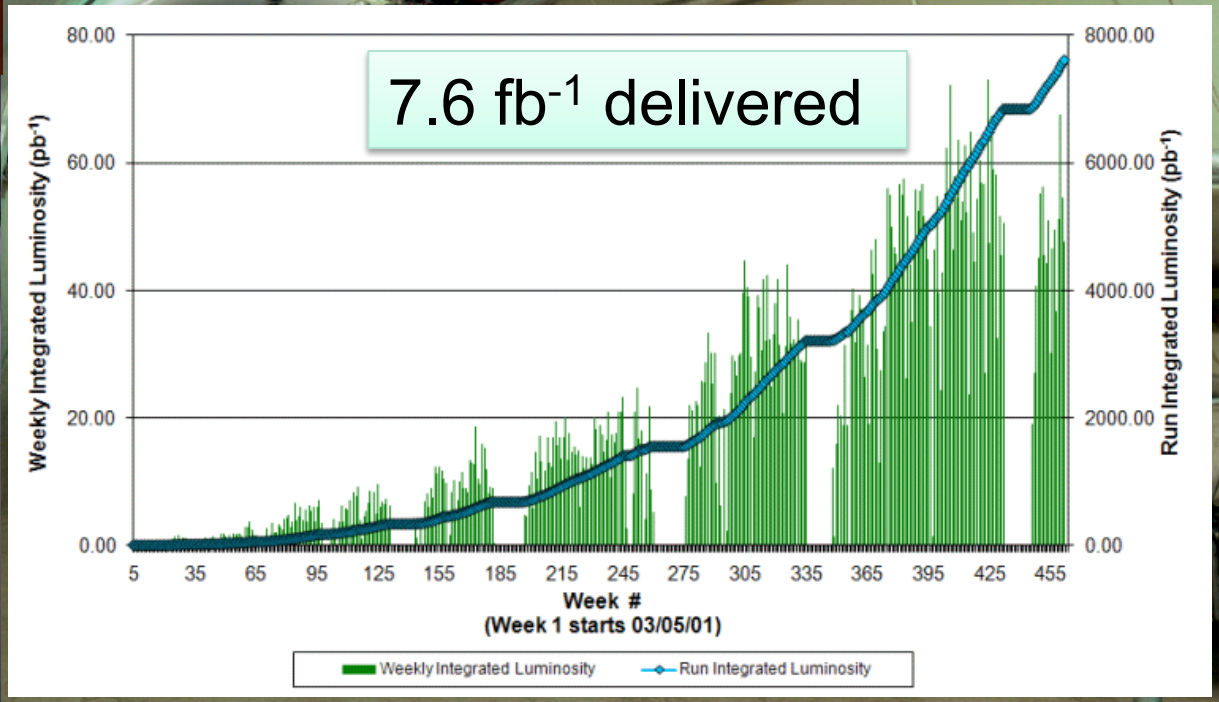
  ← this talk

Tevatron



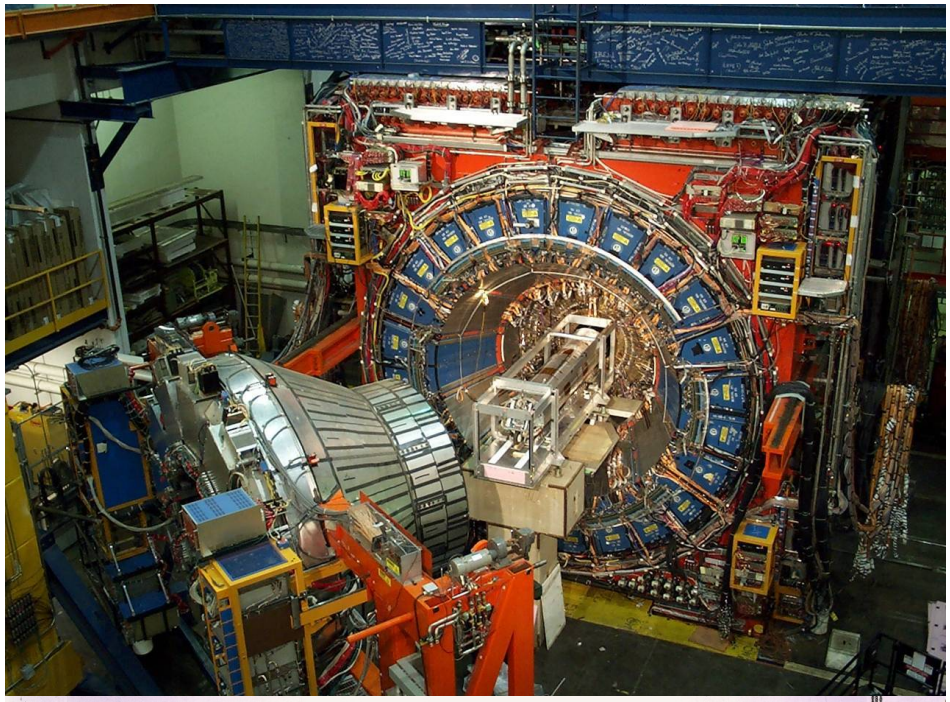
- colliding beams of protons and antiprotons
- center of mass energy = 1.96 TeV
- luminosity 3.5 x $10^{32}/cm^2/s$
- still the only source of top quarks…

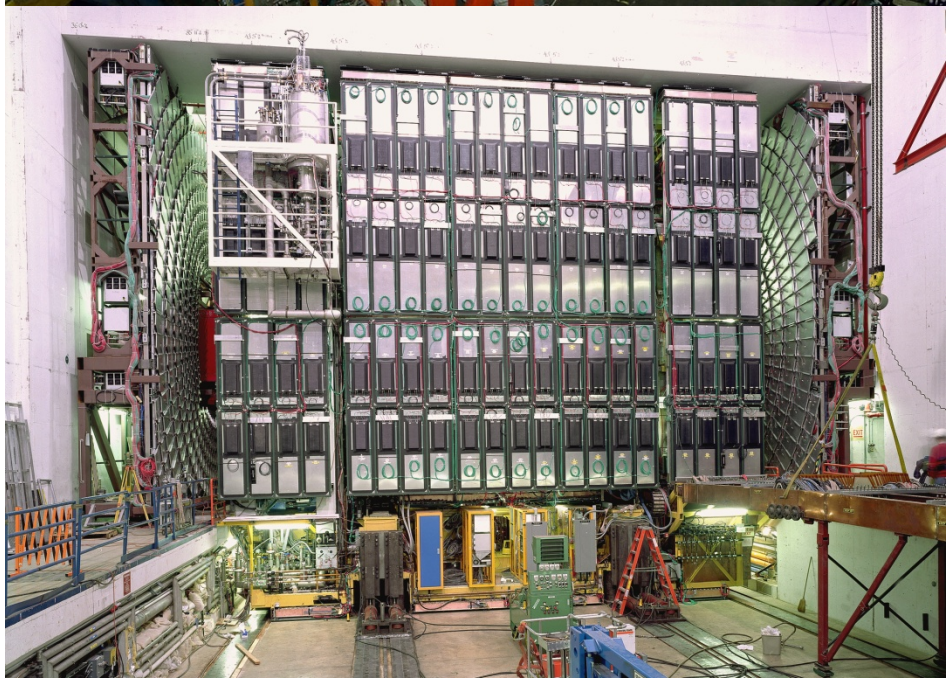
→ Claudio



CDF and DØ

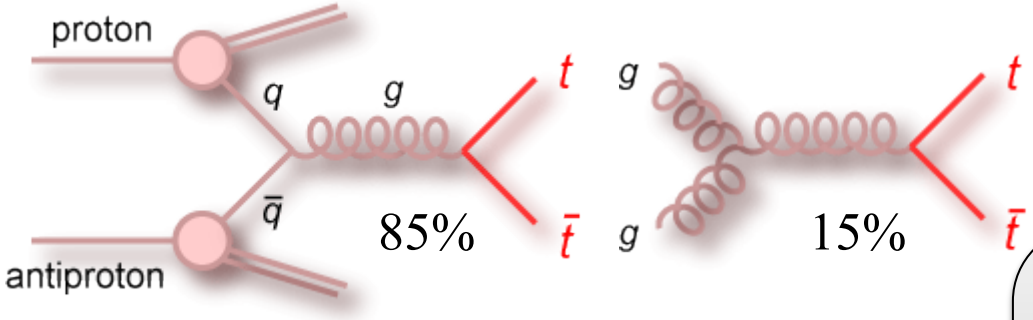
- tracking system
  - silicon
  - scintillating fibers (DØ)
  - drift chamber (CDF)
  - axial magnetic field
- calorimeter
  - U-liquid Argon (DØ)
  - scintillator-lead/steel (CDF)
- muon system
  - toroidal magnetic field (DØ)
  - drift chambers/tubes
  - scintillators for timing



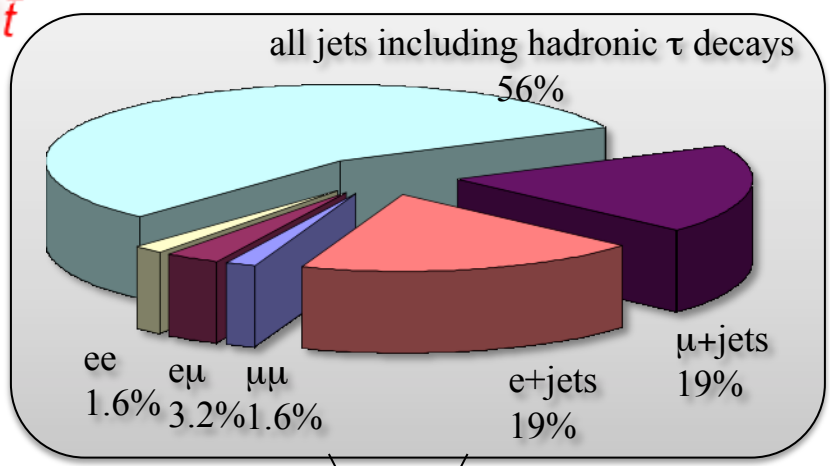


top pair production

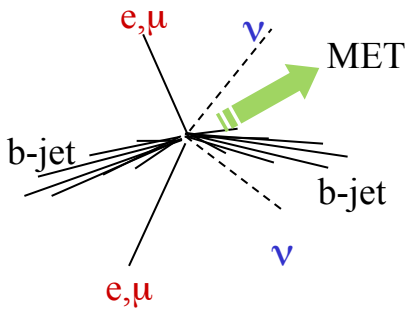
- strong interaction



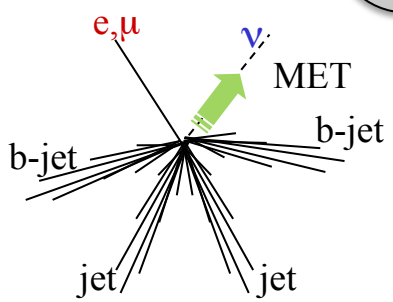
QCD (NNLO approx)
σ= 7.2-7.8 pb
@m_{top}=171 GeV



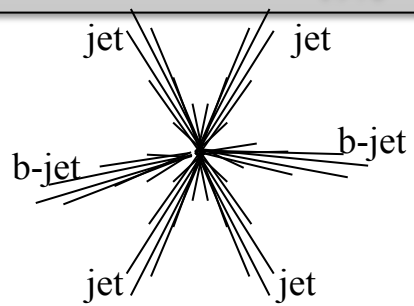
- top decay
  - t→Wb *B ≈ 100%*
- W decay
  - W→lν *B ≈ 11%*
  - W→qq *B ≈ 67 %*
- final state signatures for top-antitop pairs



Dilepton
(BR~6%, low background)



Lepton+jets
(BR~38%, moderate background)

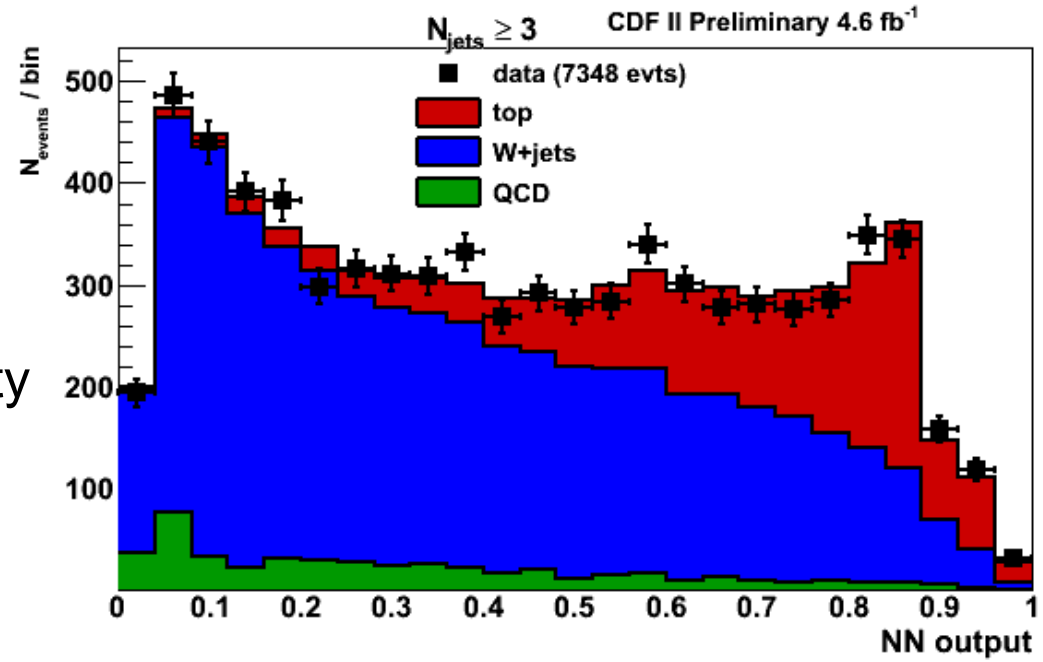


All-hadronic
(BR~56%, huge background)

top pair production in l+jets

- selection
  - e or μ p_T>20 GeV
  - ≥ 3 jets p_T>20 GeV
    - leading jets p_T>35 GeV
  - missing E_T>35 GeV
  - NN discriminant
- dominant systematics
  - integrated luminosity 5.8%
  - jet energy scale 2.9%
  - signal generator 2.5%
- eliminate luminosity uncertainty
  - scale to Z cross section
  - uncertainty 2.0%

CDF preliminary 4.6 fb^{-1}	
data	7348
ttbar (fit)	1718

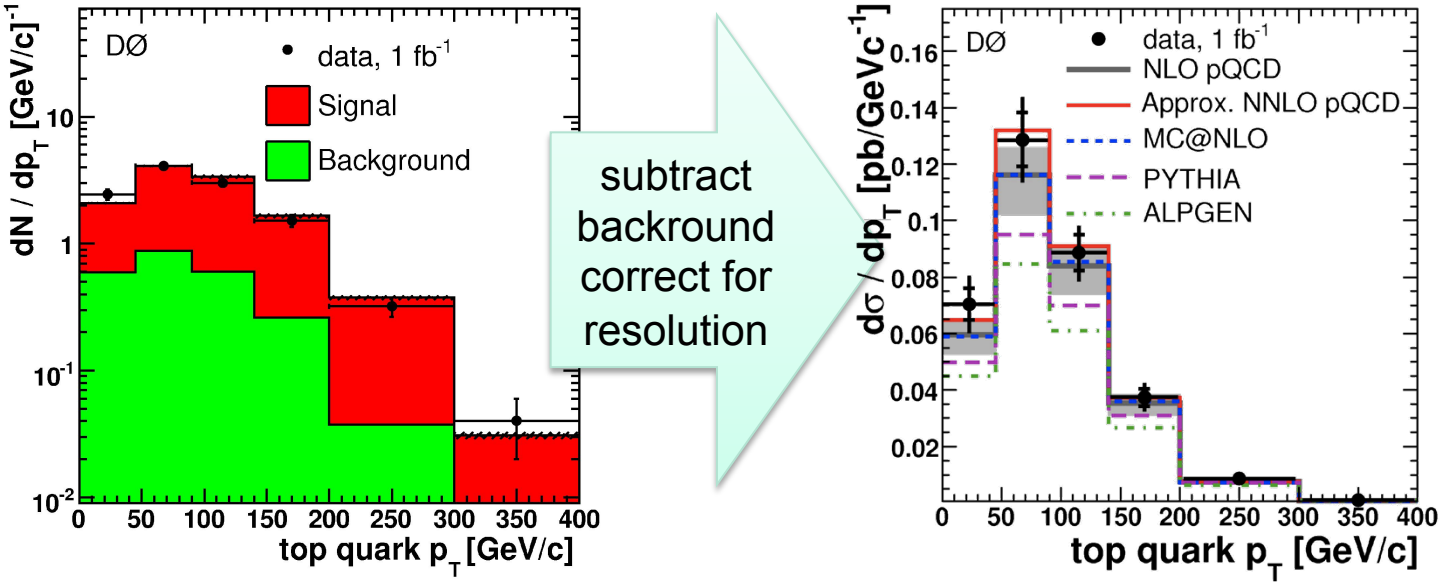


σ_{tt} = 7.63±0.37(stat)±0.35(sys)±0.15(theory) pb @m_{top}=172.5 GeV

differential cross section

- selection
  - e or μ p_T>20 GeV
  - ≥ 4 jets p_T>20 GeV
    - leading jet p_T>40 GeV, ≥1 b-tag
  - missing p_T>20-25 GeV
  - kinematic fit
    - fix m_{top}=170 GeV
    - fit signal fraction vs top p_T

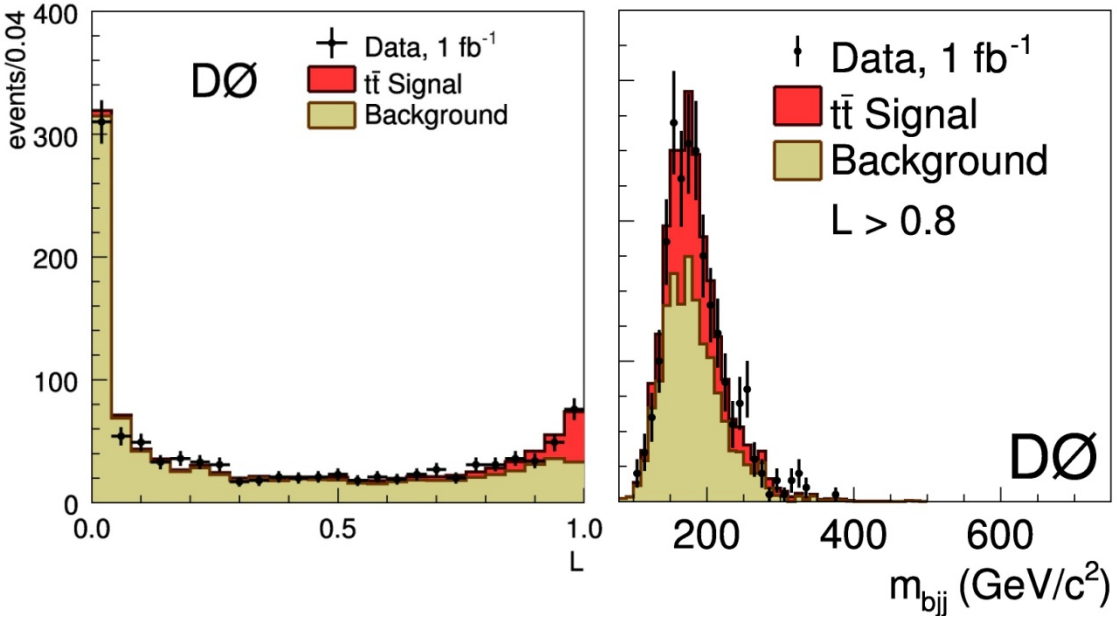
DØ 1 fb^{-1} (submitted to PLB)		
	e+jets	μ+jets
data	145	141
signal fraction	79%	



top pair production in all jets

- selection
  - ≥ 6 jets p_T>15 GeV
    - 4 leading jets pT>40 GeV
    - ≥2 b-tags
  - no leptons
  - likelihood discriminant
- background model
  - based on 4-jet and 5-jet events with added low p_T jets from 6-jet events
- fit for signal fraction
- dominant systematics
  - background model 11%
  - jet energy scale 11%

DØ 1 fb^{-1} (submitted to PRD)	
	≥2 tags
data	1051
background fit	920±24
signal fit	131±24

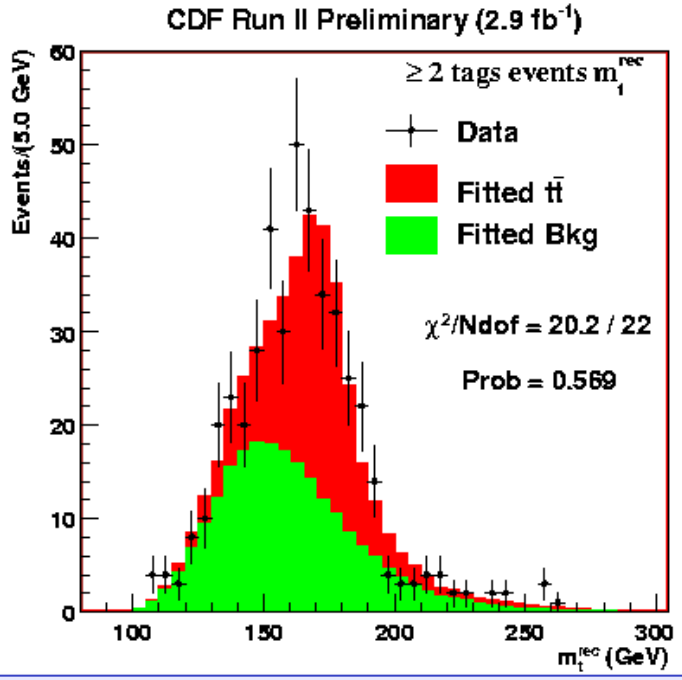


σ_{tt} = 6.9 ± 1.3(stat) ± 1.4(syst) ± 0.4 (lumi) pb @ m_{top}=175 GeV

top pair production in all jets

- selection
  - 6-8 jets p_T>15 GeV
  - 1 or ≥2 b-tags
  - no leptons
  - no significant missing p_T
  - NN discriminant
- background model
  - pretag data * tagging probability
- fit for
  - mass
  - jet energy scale
  - signal fraction
- dominant systematics
  - background normalization 8%
  - jet energy scale 9%

CDF preliminary 2.9 fb^{-1}		
	1 tag	≥2 tags
data	3452	441
background fit	2801±70	220±21
signal fit	643±80	216±25

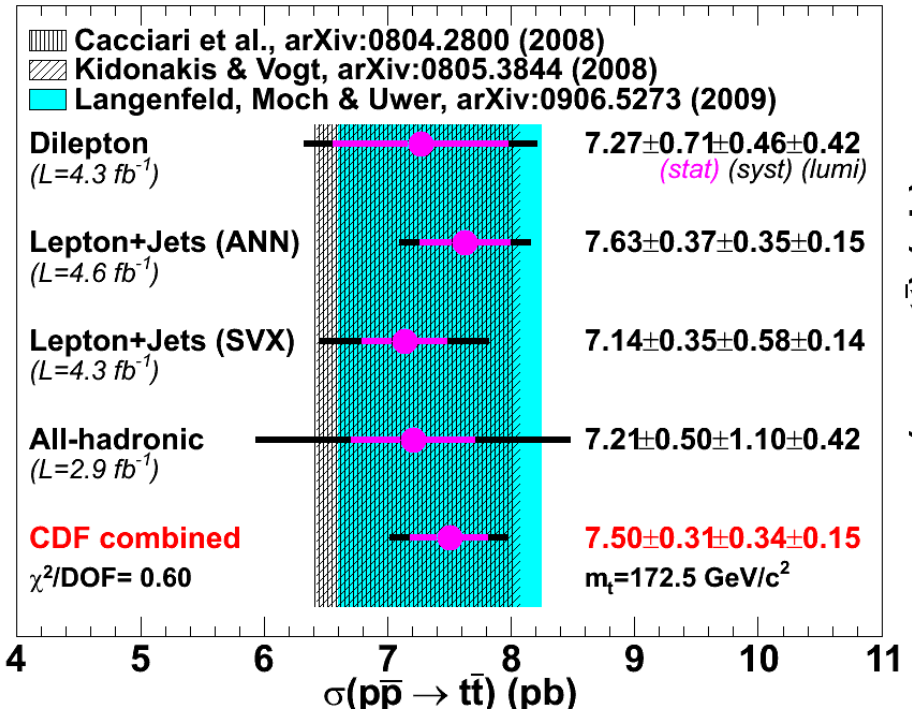


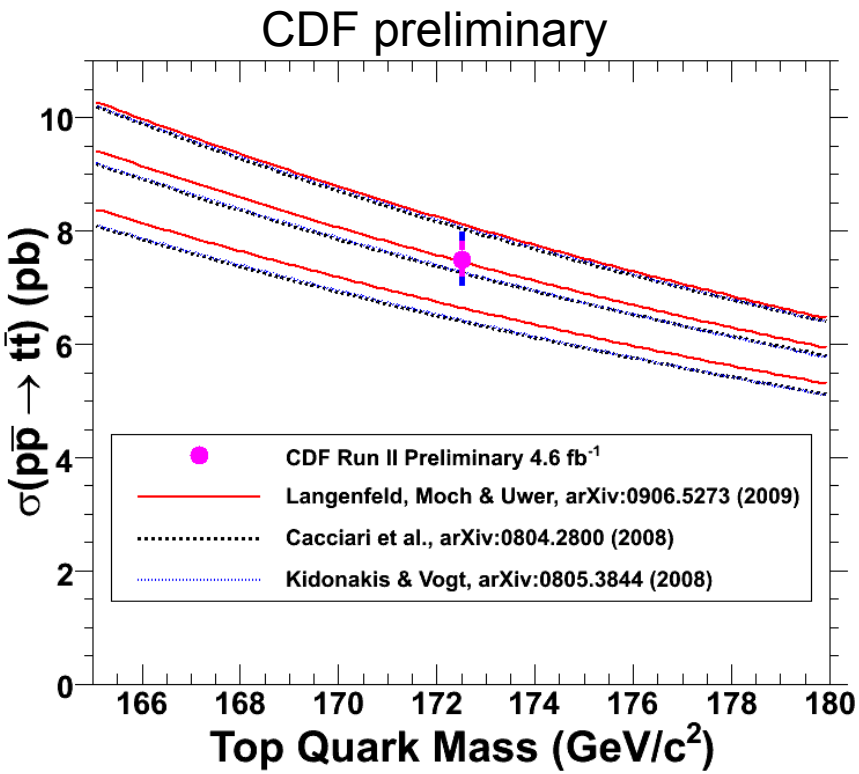
σ_{tt} = 7.2 ± 0.5(stat) ± 1.1(syst) ± 0.4 (lumi) pb @ 172.5 GeV

top quark pair production

- combined cross section measurement
  - BLUE method

CDF preliminary

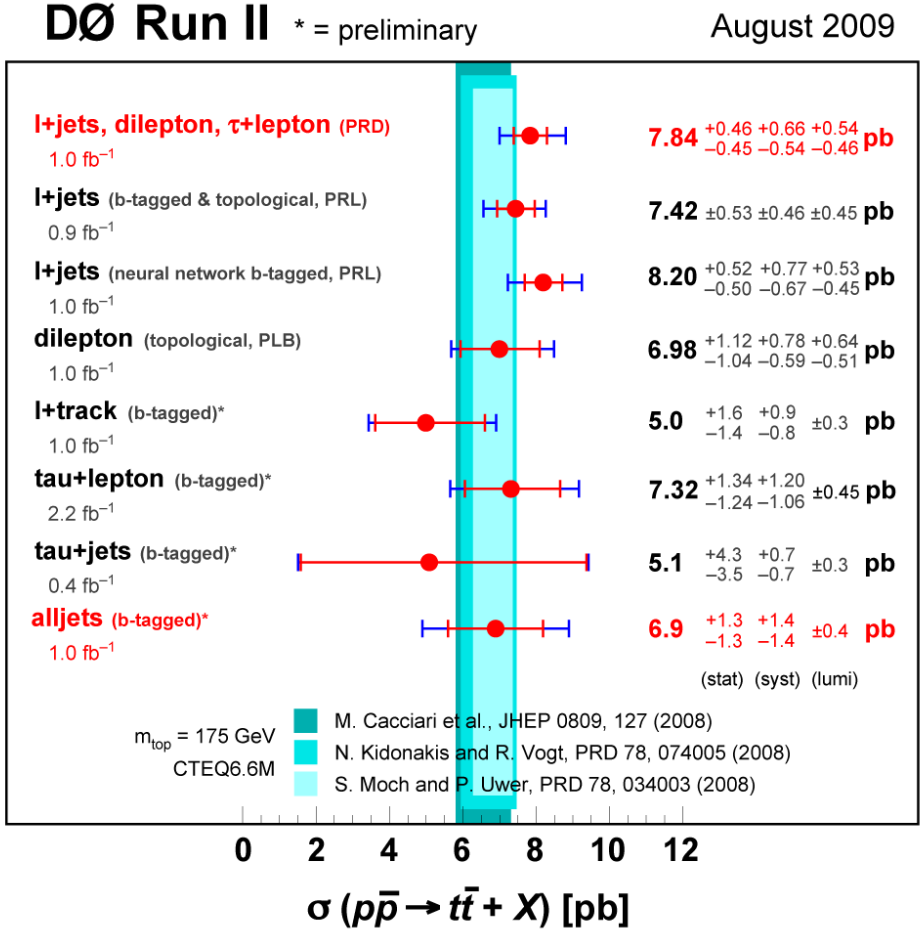


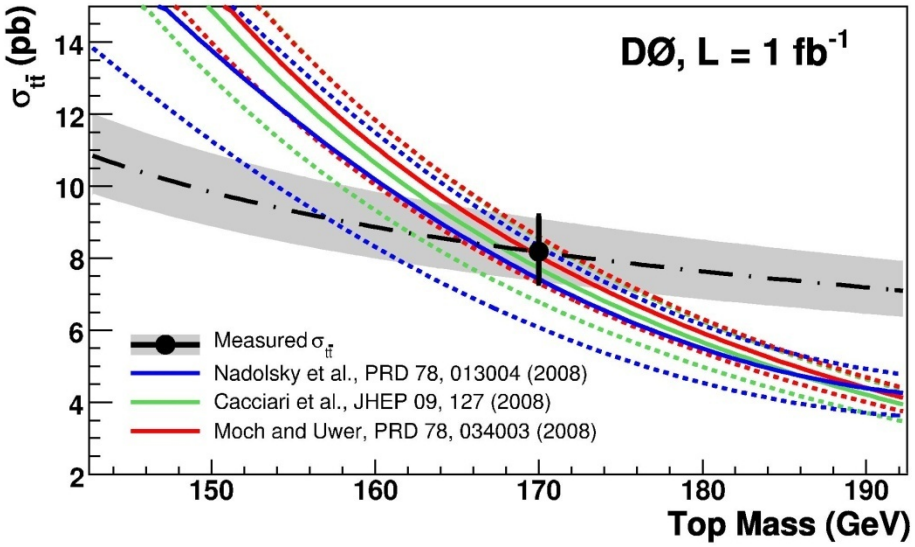


σ_{tt} = 7.50 ± 0.31 ± 0.34 ± 0.15 pb @ 172.5 GeV

top quark pair production

- combined cross section measurement **DØ PRD 80, 071102 (2009)**





$\Rightarrow m_{top} = 168 \pm 6$ GeV

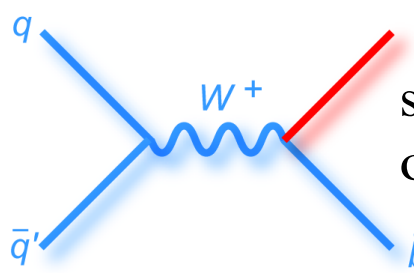
$\Rightarrow B(t \rightarrow H^+ b) > 13\text{-}55\%$

depending on mass and H^+ decay model

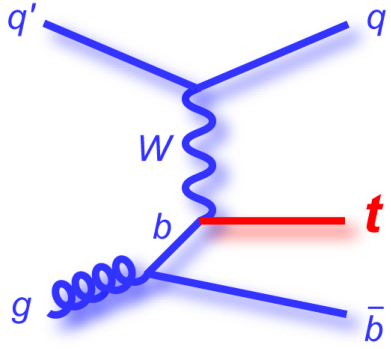
$$\sigma_{tt} = 7.84 \pm 0.46^{+0.66+0.54}_{-0.54-0.46}\ \text{pb} \ @\ m_{top} = 175\ \text{GeV}$$

single top production

- electroweak production of top quarks



s-channel
$\sigma = 1.12 \pm 0.05$ pb



t-channel
$\sigma = 2.34 \pm 0.13$ pb

Kidonakis and Vogt, PRD 68, 114014 (2003) , NLO @ m_t =170 GeV

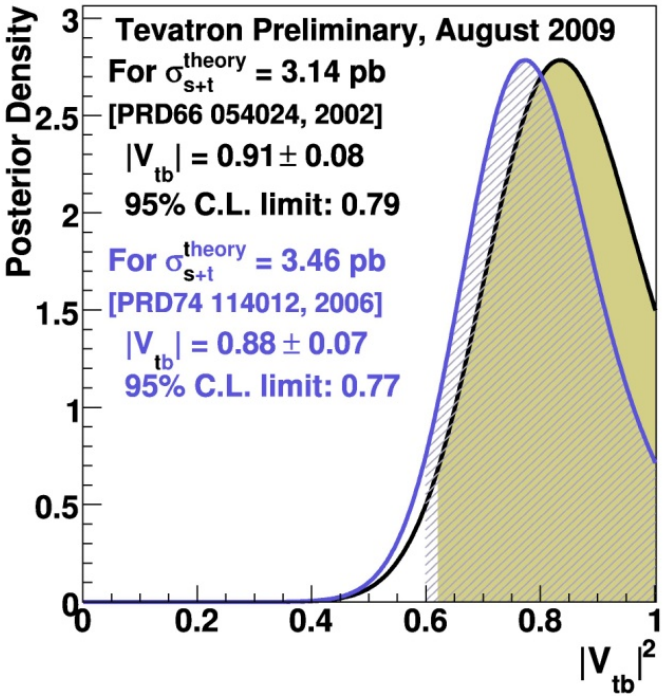
- measure $|V_{tb}|$ without assuming 3 generations
- sensitive to
  - 4^{th} quark generation
  - anomalous couplings at Wtb vertex
  - new particles (H^+, W')
  - FCNC
- observation of single production of top quarks

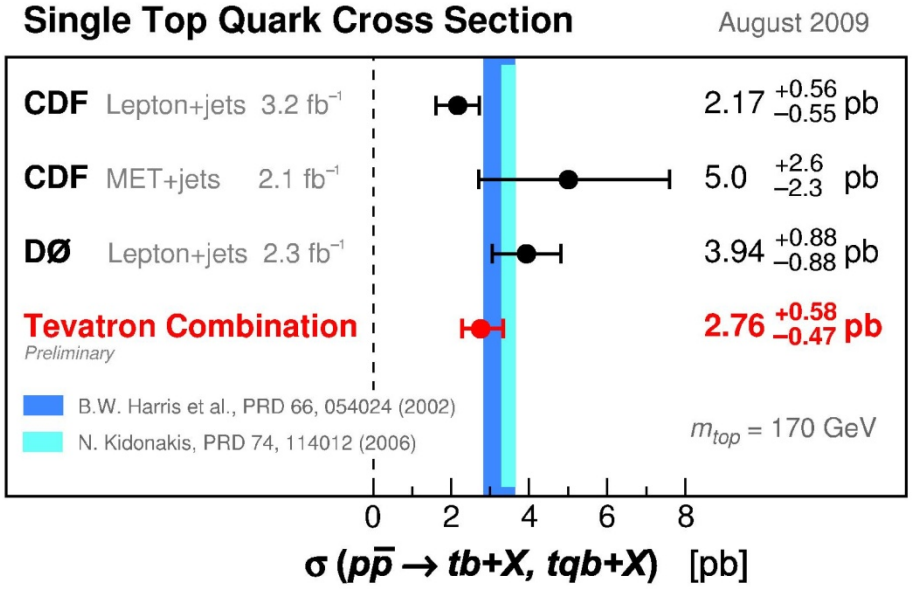
CDF:	$\sigma = 2.3\ ^{+0.6}_{-0.5}$ pb (5.0 σ)	PRL 103, 092002 (2009)
DØ:	$\sigma = 3.9 \pm 0.9$ pb (5.0 σ)	PRL 103, 092001 (2009)

single top production

- combine all xsection measurements
  - assume m_{top}=170 GeV
  - theory cross section for $|V_{tb}|$
    - CDF: Harris & Sullivan
      σ_s = 0.99±0.07 pb, σ_t = 2.15±0.24 pb
    - DØ: Kidonakis
      σ_s = 1.12±0.05 pb, σ_t = 2.34±0.13 pb

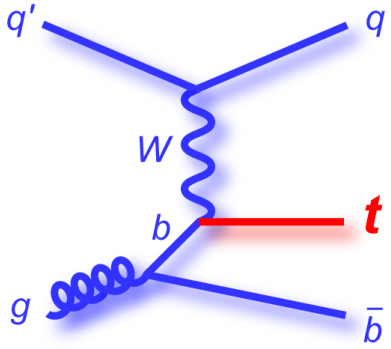
uncertainty	DØ	CDF	corr
luminosity (detector)	4.5%	4.6%	no
luminosity (xsection)	4.0%	4.0%	yes
signal model	2-20%	4-14%	yes
background (MC)	12%	15%	yes
background (data)	17-40%	14-54%	no
detector model	0-9%	7%	no
b-tagging	0-29%	2-30%	no
jet energy scale	0-16%	0-13%	no

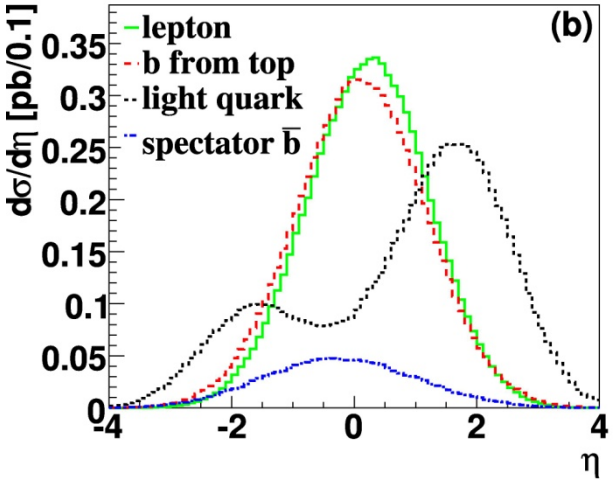




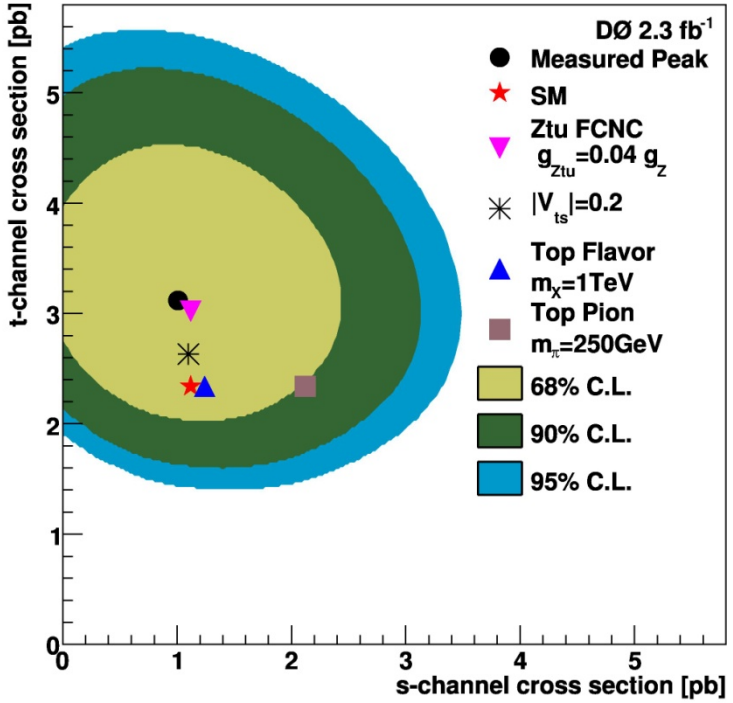
single top production

- selection
  - isolated high-p_T e or μ
  - high missing p_T
  - 2-4 jets p_T>15 GeV
    - leading jet p_T>25 GeV
    - ≥1 b-tag
  - multivariate discriminants
  - same analysis as for observation result but multivariate discriminators trained on t-channel only → fit for σ_t and σ_s





DØ 2.3 fb^{-1} PLB 682, 363 (2010)	
data	4519
expected t-channel	130±17
expected s-channel	93±14

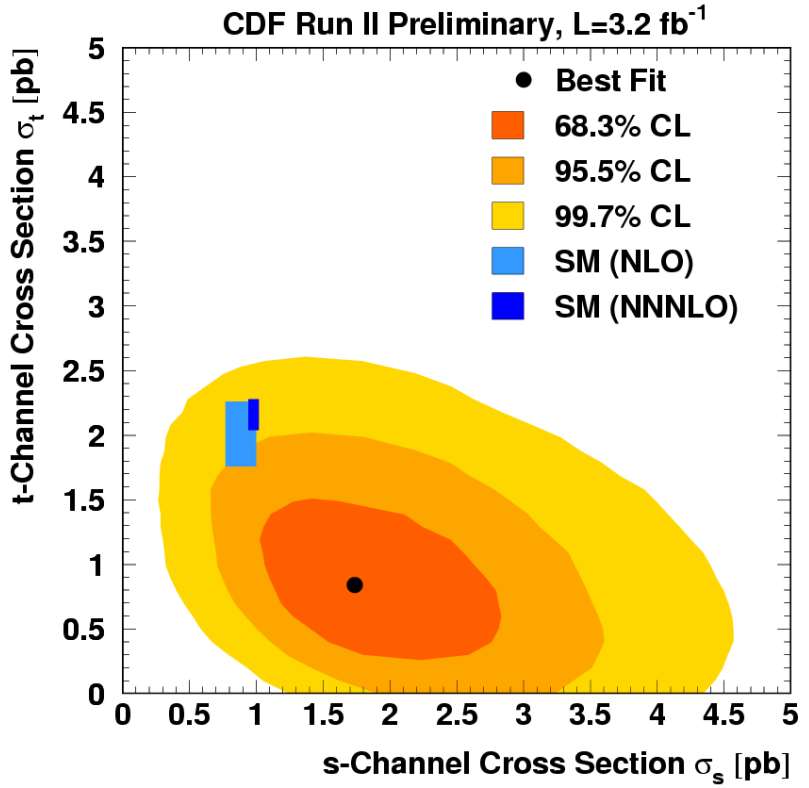


$\sigma_{\text{t-channel}} = 3.14\ ^{+0.94}_{-0.80}$ pb $\sigma_{\text{s-channel}} = 1.05 \pm 0.81$ pb

single top production

- l+jets selection
  - isolated e or μ p_T>20 GeV
  - missing p_T>25 GeV
  - 2-3 jets p_T>20 GeV
    - ≥1 b-tag
  - multivariate discriminants
- missing pT + jets selection
  - missing p_T>50 GeV
  - 2-3 jets
    - leading jet p_T>35 GeV
    - 2nd leading jet p_T>25 GeV
  - NN discriminant

CDF preliminary 3.2 fb^{-1}	l+jets	p_T+jets
data	3315	1411
expected t-channel	114±17	35±6
expected s-channel	77±11	30±4



$\sigma_{t\text{-channel}} = 0.8 \pm 0.4$ pb $\sigma_{s\text{-channel}} = 1.8\ ^{+0.7}_{-0.5}$ pb

Wtb couplings

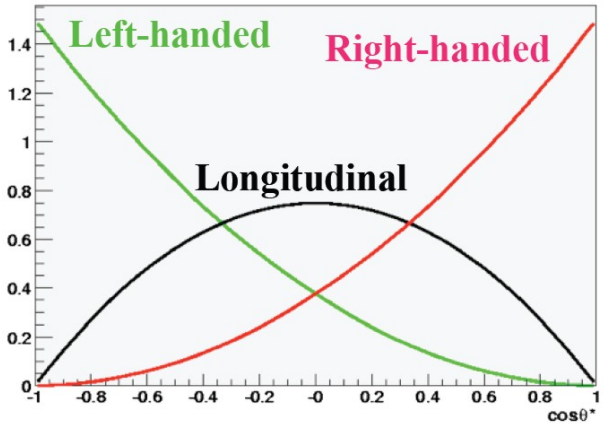
- general CP-conserving Lagrangian

$$L = \frac{g}{\sqrt{2}} V_{tb} \bar{b} \left[W_\mu \gamma^\mu \left(f_1^L P_L + f_1^R P_R \right) - \partial_\nu W_\mu \frac{\sigma^{\mu\nu}}{M_W} \left(f_2^L P_L + f_2^R P_R \right) \right] t$$

- in SM the coupling is purely V-A and $f_1^L = 1 \quad f_1^R = f_2^L = f_2^R = 0$
- in single top production/decay
  - coupling affects rate and angular distributions
- in top pair decays
  - coupling affects angular distributions
  - W boson can have helicity states -1,0,+1
  - analyze using angular distribution of decay lepton

$$\frac{d\Gamma}{d\cos\theta^*} \propto f_{-1}\left(1-\cos\theta^*\right)^2 + 2 f_0 \left(1-\cos^2\theta^*\right) + f_{+1}\left(1+\cos\theta^*\right)^2$$

  - in SM $f_{-1} \approx 0.7 \quad f_0 \approx 0.3 \quad f_{+1} \approx 3\times10^{-4}$



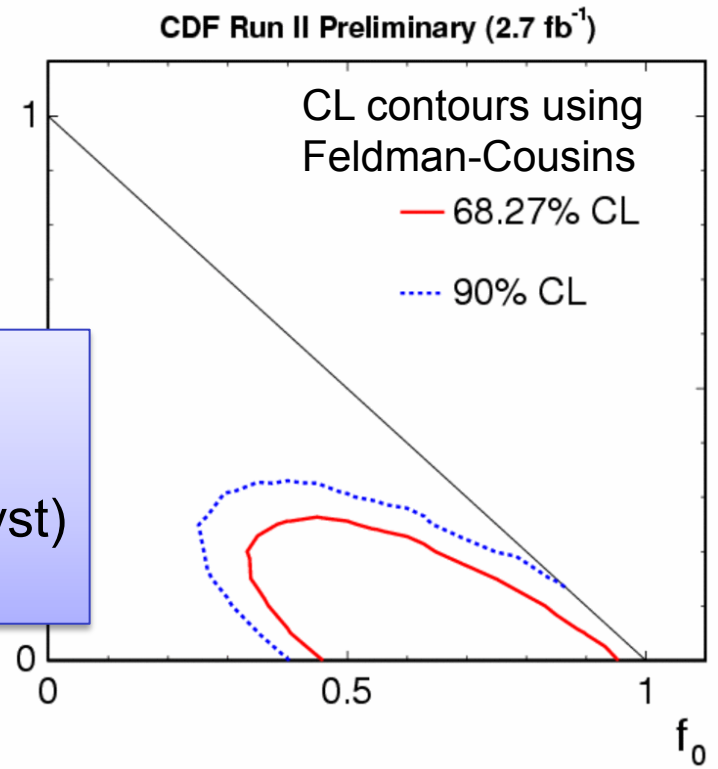
W helicity

- selection
  - lepton + ≥4 jets
  - 1 b-tag
- matrix element analysis
  - maximize joint likelihood for all events

$$P(X_i; f_s, f_0, f_+) = f_s P_s(X_i; f_0, f_+) + (1 - f_s) P_b(X_i)$$

$$L(f_s, f_0, f_+) = \prod_{i=1}^{N} P(X_i; f_s, f_0, f_+)$$

CDF preliminary 2.7 fb^{-1}	
ttbar expected	670±69
background expected	237±52
data	906



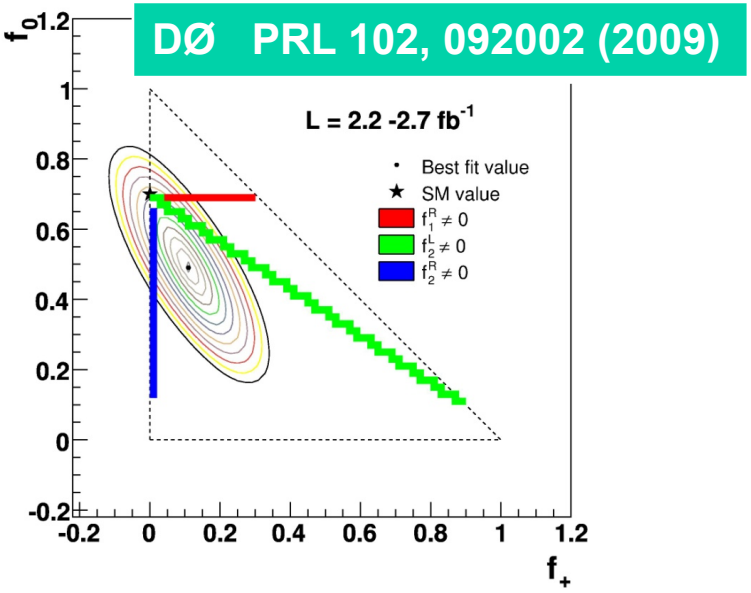
f_0 = 0.88 ± 0.11 (stat) ± 0.06 (syst)
f_+ = -0.15 ± 0.07 (stat) ± 0.06 (syst)

for $f_+ = 0$: f_0 = 0.70 ± 0.07 (stat) ± 0.04 (syst)
for $f_0 = 0.7$: f_+ = < 0.12 at 95% CL

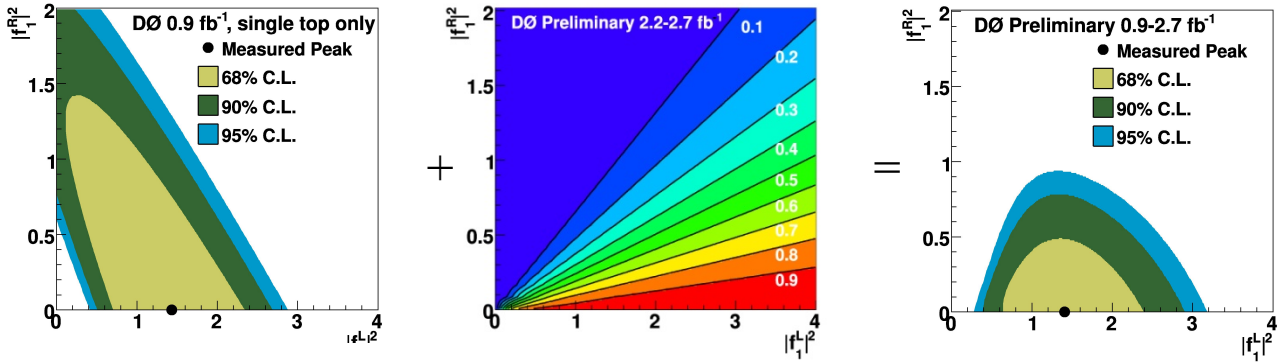
Wtb couplings

- combine constraints on coupling constants from single top analysis and from W helicity measurement

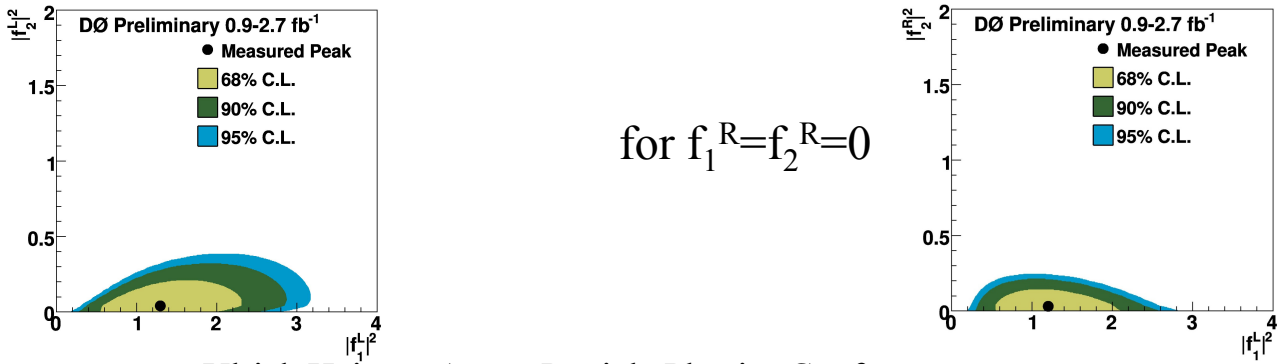
f_0 = 0.49 ±0.11 (stat) ±0.09 (syst)
f_+ = 0.11 ±0.06 (stat) ±0.05 (syst)



for $f_2^L=f_2^R=0$



for $f_1^R=f_2^L=0$



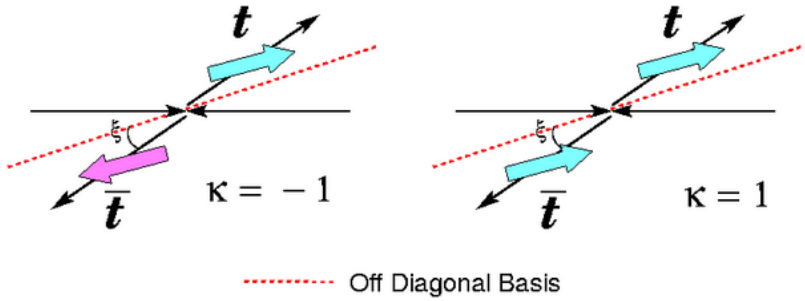
for $f_1^R=f_2^R=0$

top spin correlations

- top quarks produced in pp collisions are not polarized
- the spin of the top and anti-top quarks are correlated
- top decays before the spins decorrelate
- analyze spin using angular distribution of decay products

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}\left(1+\kappa\cos\theta_1\cos\theta_2\right)$$

- θ_1 and θ_2 are the angles of decay products wrt a quantization axis
- value of κ depends on spin basis
- at tree level $\kappa = \dfrac{n_{\pm\pm} - n_{\pm\mp}}{n_{\pm\pm} + n_{\pm\mp}}$
  - $n_{\pm\pm}$ = number of events with spins aligned
  - $n_{\pm\mp}$ = number of events with spins anti-aligned



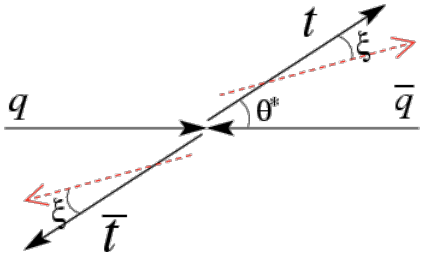
- observation of non-zero κ would place an upper limit on the top lifetime

top spin correlations

CDF preliminary 2.8 fb^{-1}	
data	195

- dilepton selection
- offdiagonal basis

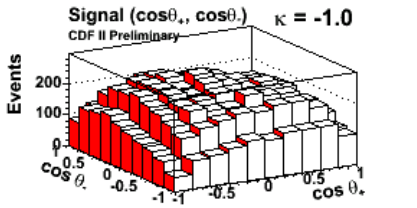
  (optimal choice to maximize κ)

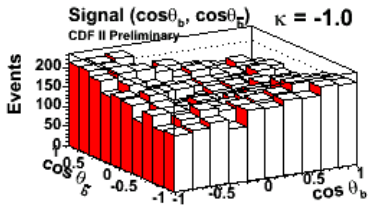


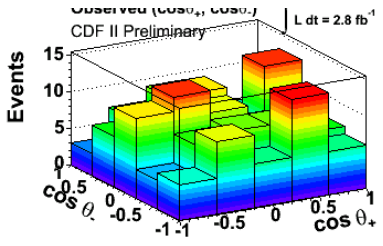
$$\tan\xi = \sqrt{1-\beta^2}\,\tan\theta^*$$

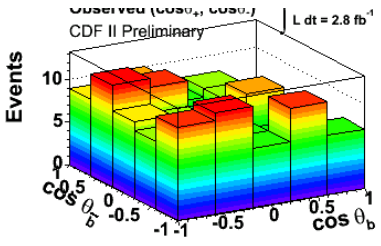
β is top velocity

θ^* is angle of top with proton in ttbar C.M. frame

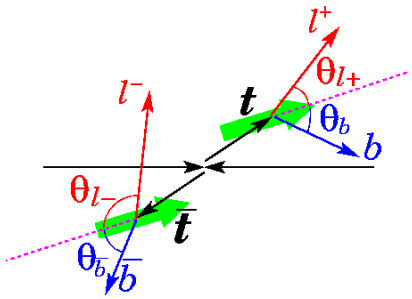




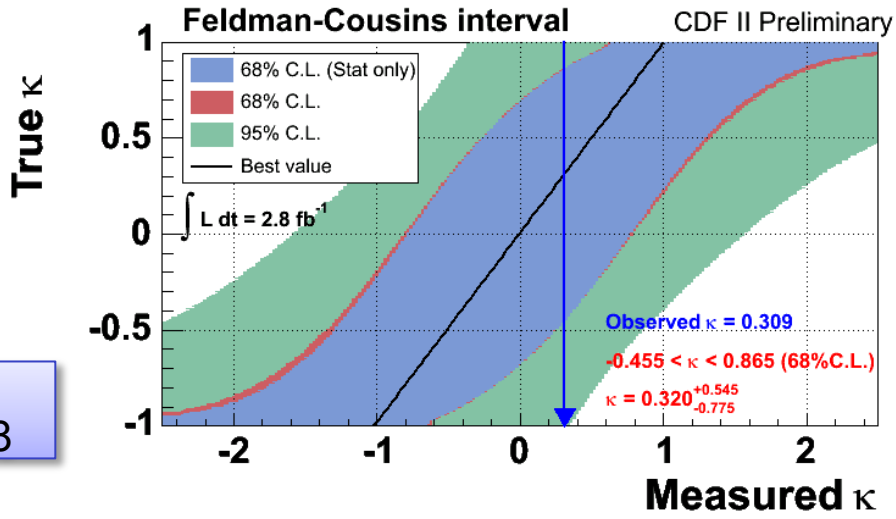




- SM expectation: κ = 0.78
- likelihood to pick best top quark
- use angles of leptons and b-jets



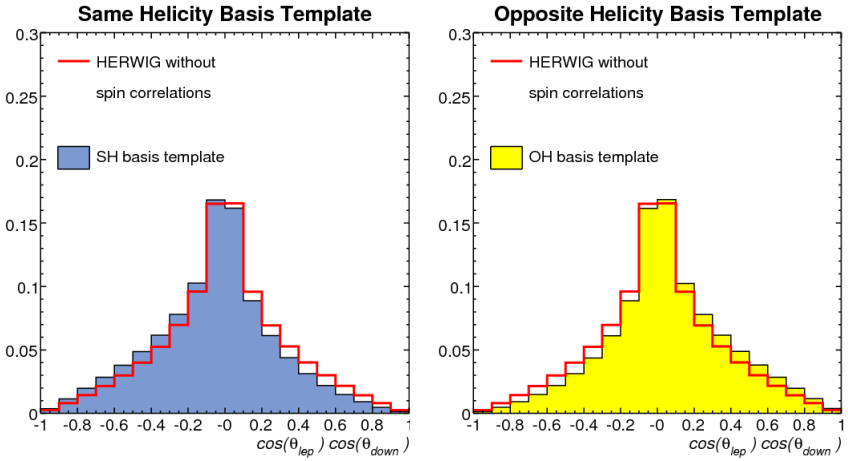
$\kappa = 0.32^{+0.55}_{-0.78}$

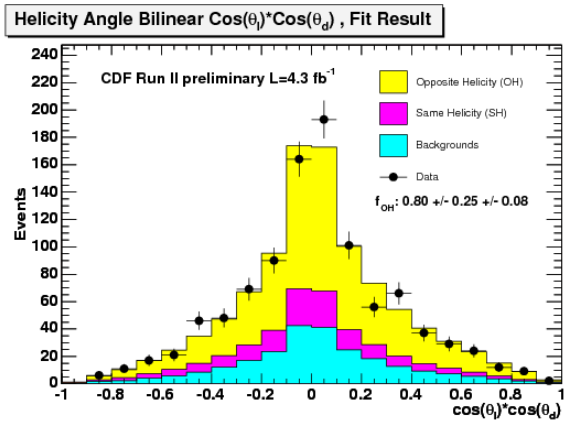


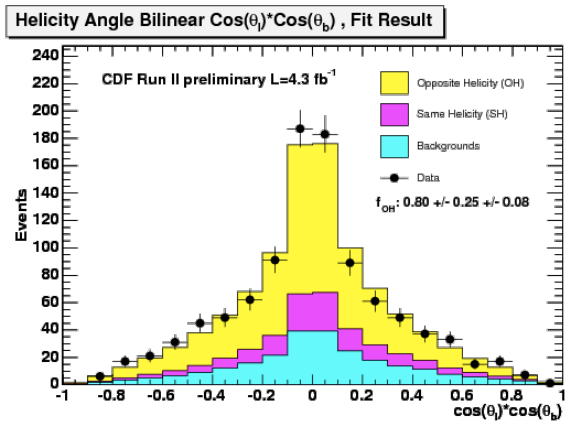
top spin correlations

CDF preliminary 4.3 fb^{-1}	
data	1001
expected background	215±48

- lepton+jets selection
  - lepton + ≥4 jets
  - 1 b-tag
- use angles of leptons, d-jets, and b-jet
  - with top quark direction in top rest frame
  - 2-dimensional fit of $\cos(\theta_{lep})\cos(\theta_{down})$ and $\cos(\theta_{lep})\cos(\theta_{bot})$ with same and opposite helicity templates
  - f_0 = 0.80 ± 0.25 (stat) ± 0.08 (syst)







$\kappa = 0.60 \pm 0.50(\text{stat}) \pm 0.16(\text{syst})$

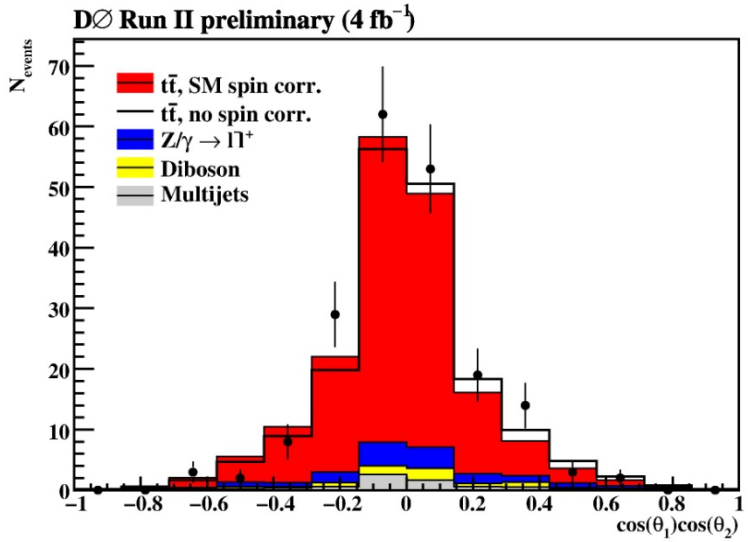
top spin correlations

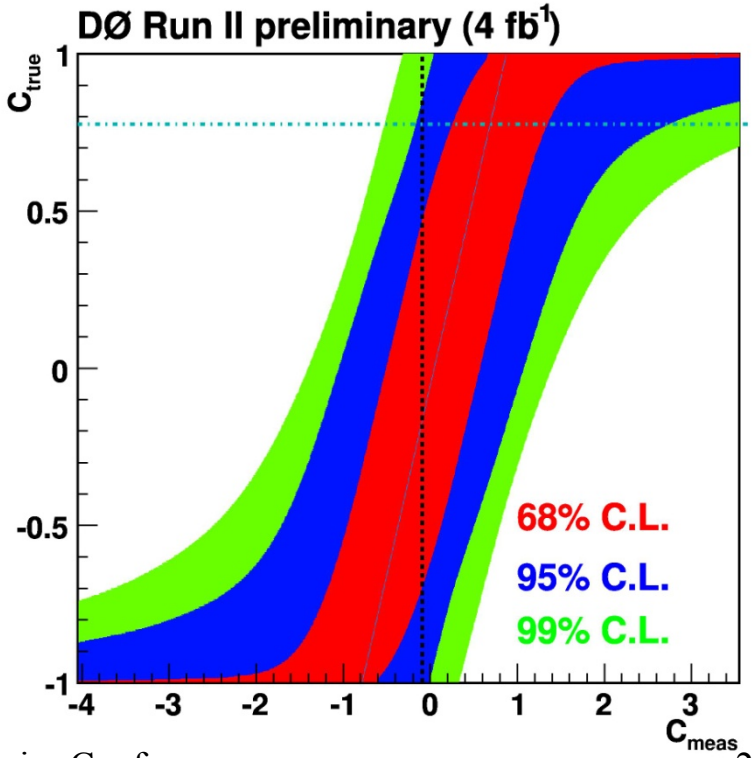
- dilepton selection

DØ preliminary 1.1-4.2 fb^{-1}			
	ee	eμ	μμ
ttbar	11.5	140	8.3
background	3.4	24.3	5.4
data	17	168	13

- beam basis
  - quantization axis along beam axis
  - simple and close to optimal choice
  - SM predicts κ=0.78
- event reconstruction
  - neutrino weighting
  - try range of neutrino directions and weight by agreement with missing pT
  - use weighted mean of $\cos\theta_1\cos\theta_2$
- use angles of leptons

$$\kappa = -0.17^{+0.64}_{-0.53}$$





conclusions

- CDF and DØ are sizing up the top quark
  - Tevatron delivered 7.6 fb^{-1} - more to come…
  - up to 4.6 fb^{-1} analyzed
  - measure
    - xsection for single top and top pair production
    - ewk coupling of top quark
    - spin correlations
  - no deviations from SM predictions
  - for more details

http://www-d0.fnal.gov/Run2Physics/top/
http://www-cdf.fnal.gov/physics/new/top/top.html