Top quark properties at CDF

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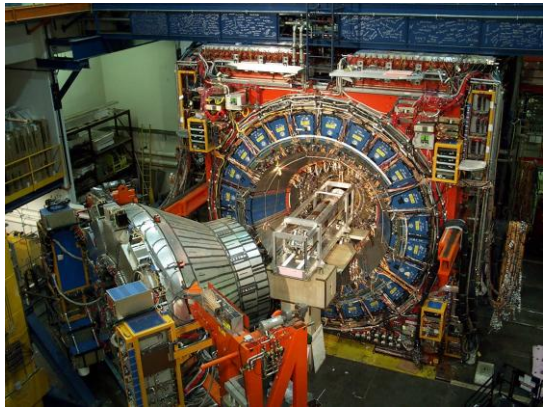
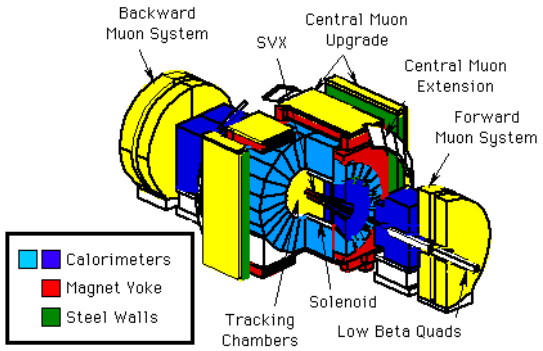
On behalf of the CDF Collaborations

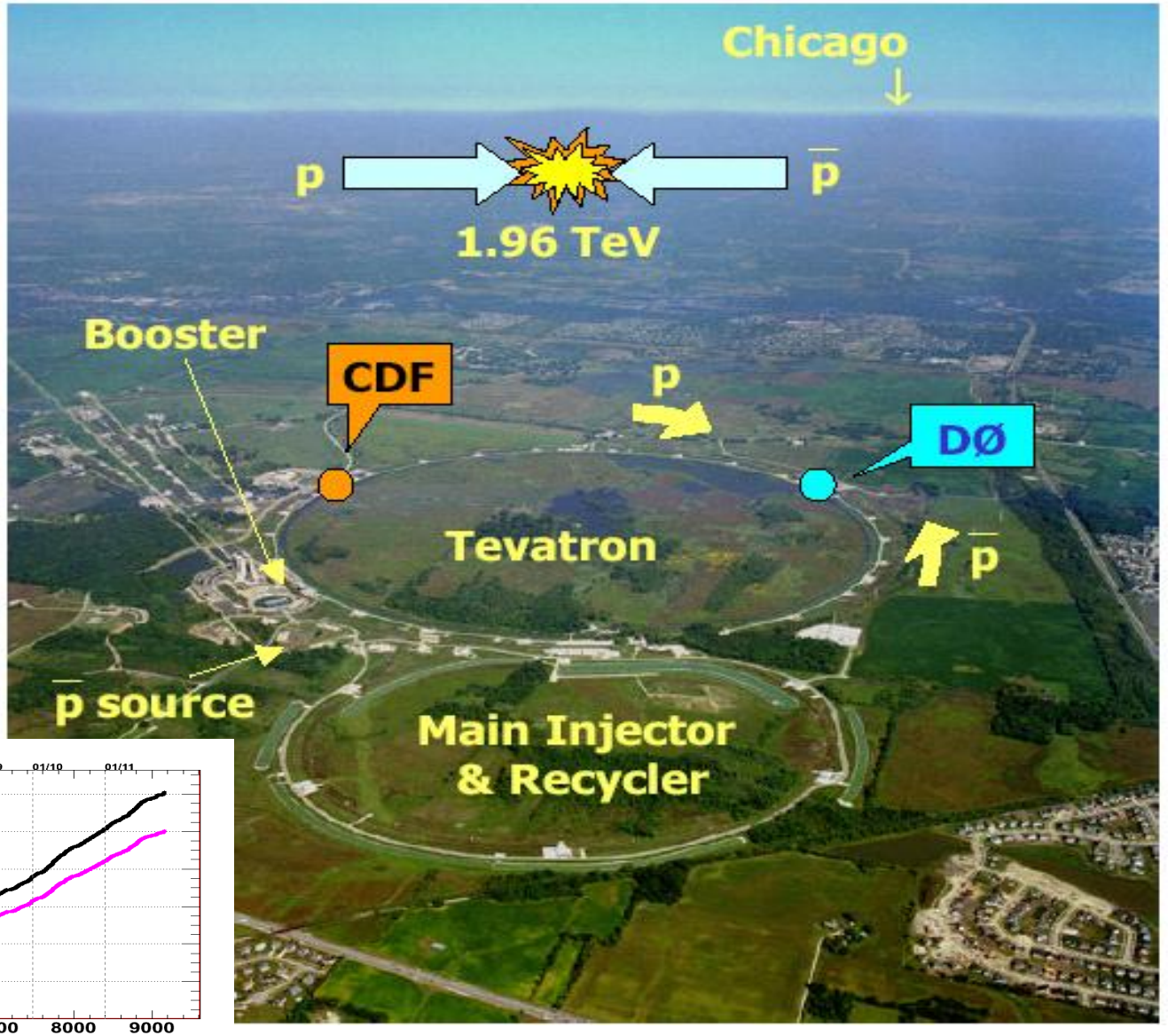
Outline

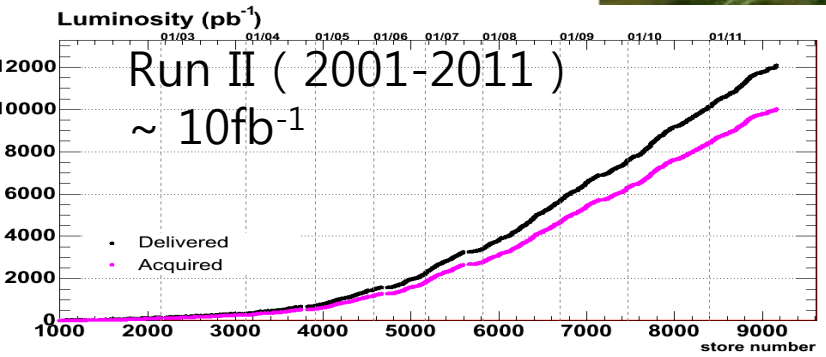
- Top quark branching ratio and width
- Spin correlations in top-antitop event
- Helicity fraction of W boson
- top quark charge
- top forward-backward asymmetry

Run II at CDF




Backward Muon System
SVX
Central Muon Upgrade
Central Muon Extension
Forward Muon System
Calorimeters
Magnet Yoke
Steel Walls
Tracking Chambers
Solenoid
Low Beta Quads

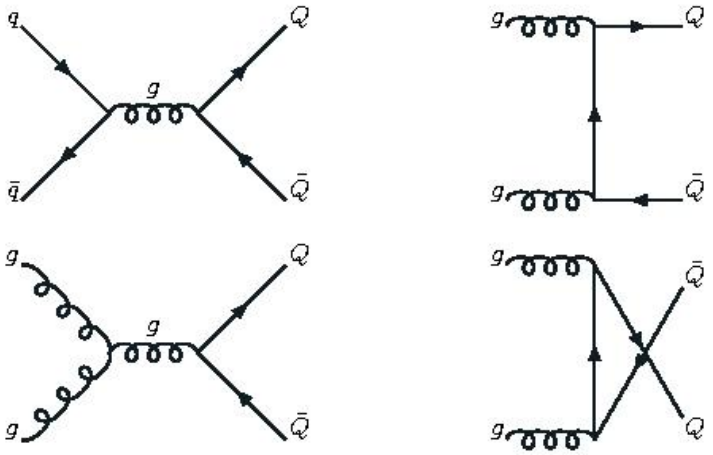

Chicago
p
p̄
1.96 TeV
Booster
CDF
p
DØ
Tevatron
p̄
p̄ source
Main Injector
& Recycler


Luminosity (pb^{-1})
01/03
01/04
01/05
01/06
01/07
01/08
01/09
01/10
01/11
Run II (2001-2011)
~ 10fb^{-1}
Delivered
Acquired
12000
10000
8000
6000
4000
2000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
store number

Top quark

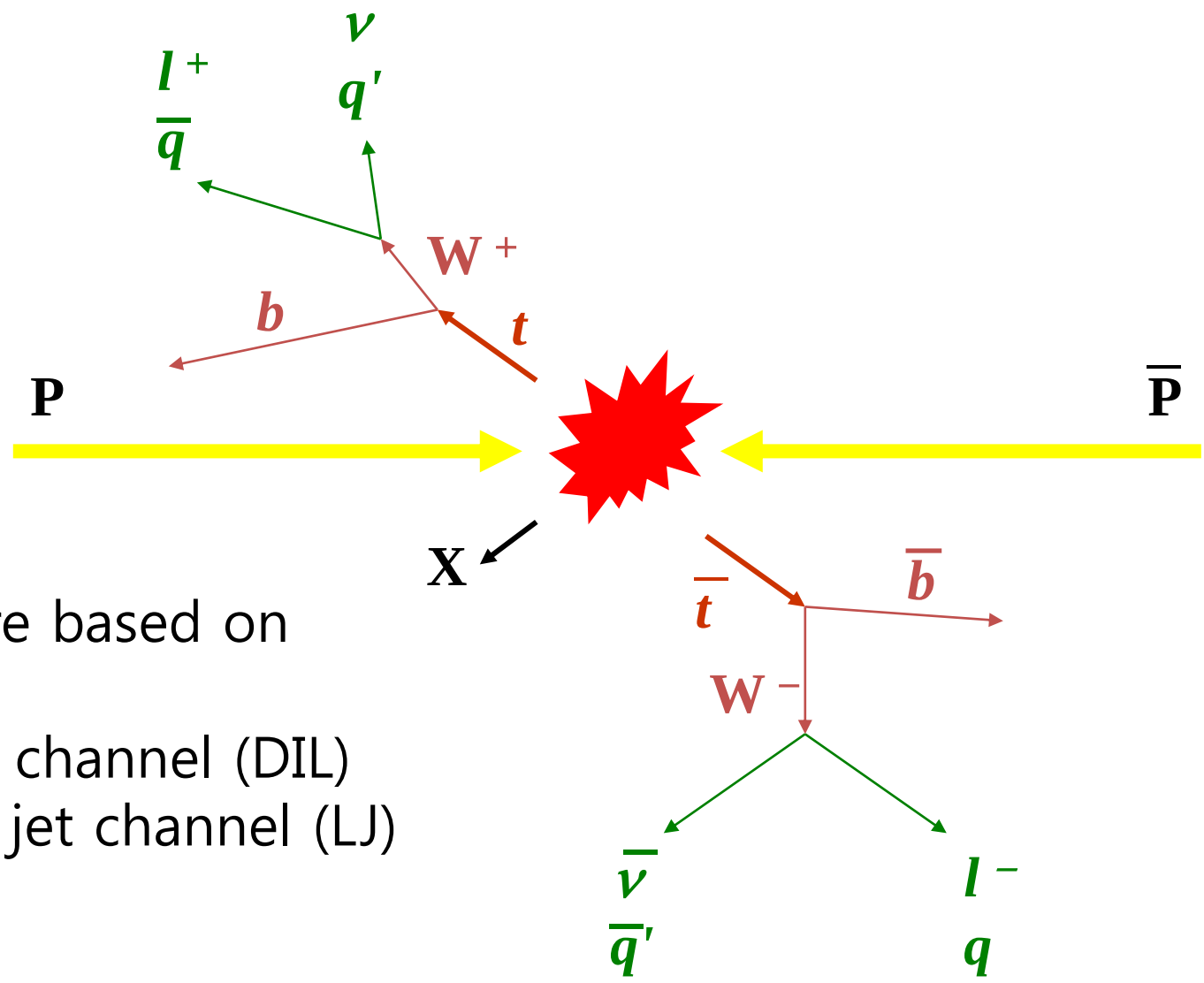
- Top quark properties
  - high mass ~ 173.5 GeV (PDG)
  - short lift time ~ 10^{-25} sec
  - charge : +2/3
  - spin : 1/2

- Top pair production in $p\bar{p}$ collision
  - σ ~ 7.22 pb at $\sqrt{S}$ = 1.96 TeV:
    (NNLL, C. Schwinn, arXiv:1205.0988)
  - $q\bar{q} \rightarrow t\,\bar{t}$: ~90% , $gg \rightarrow t\,\bar{t}$: ~10%



- SM top quark → Wb (~ 100%)
  final states of top pair are given by W decay states
  - lepton + jets
  - dilepton
  - all hadronic

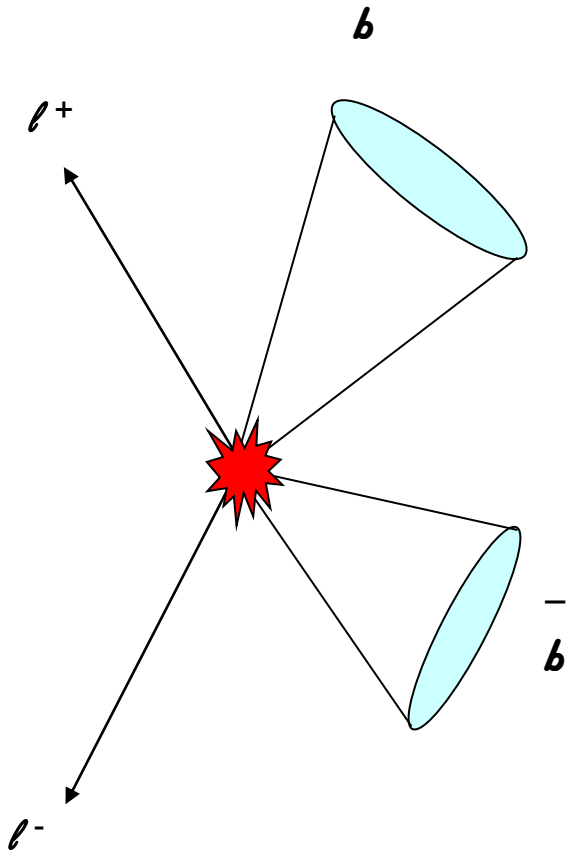
Decay of top quark pair



- The topics are based on
  - Di-lepton channel (DIL)
  - Lepton + jet channel (LJ)

Di-lepton events(DIL)

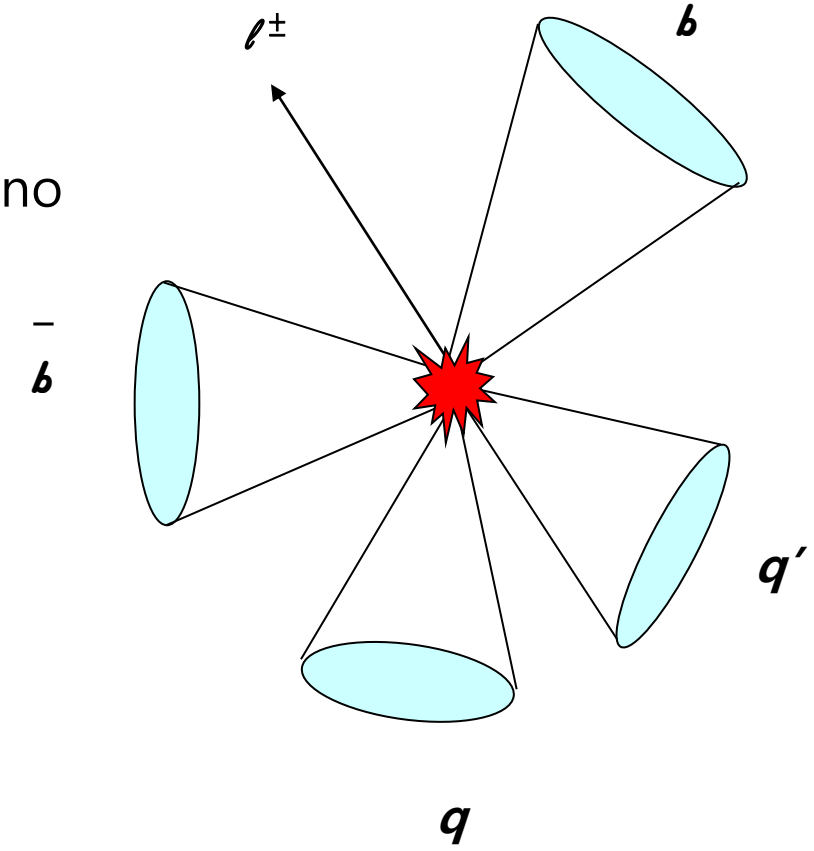
- Event Selection
  - Two high p_T leptons
    - > 20 GeV
    - $|\eta| < 2$
  - High missing E_T due to the two neutrinos
  - Suppressing of Z boson events
  - High total transverse energy
  - Two or more jets



Lepton+jet events(LJ)

- Event Selection
  - high p_T lepton(e/μ)
    - > 20 GeV (CDF)
    - $|\eta| < 1.0$
  - Missing E_T due to the one neutrino
  - Four or more jets
    - $|\eta| < 2.0$
  - at least one b-tagged jet
    - $|\eta| < 1.0$

- full CDF RUN II data, with one good b-tag : **8.7 fb^{-1}**



Top quark branching ratio(t→b)

- Direct measurement in lepton+jet, **8.7 fb^{-1}**

$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

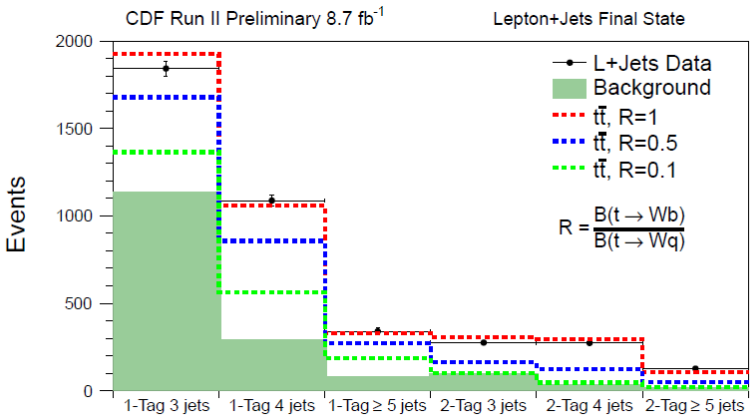
- LJ samples are divided to 18 subsamples
  - 1,2 btag X 3jet, 4jet, ≥5jets X lepton type
  - R is determined from the maximum likelihood for each subsample

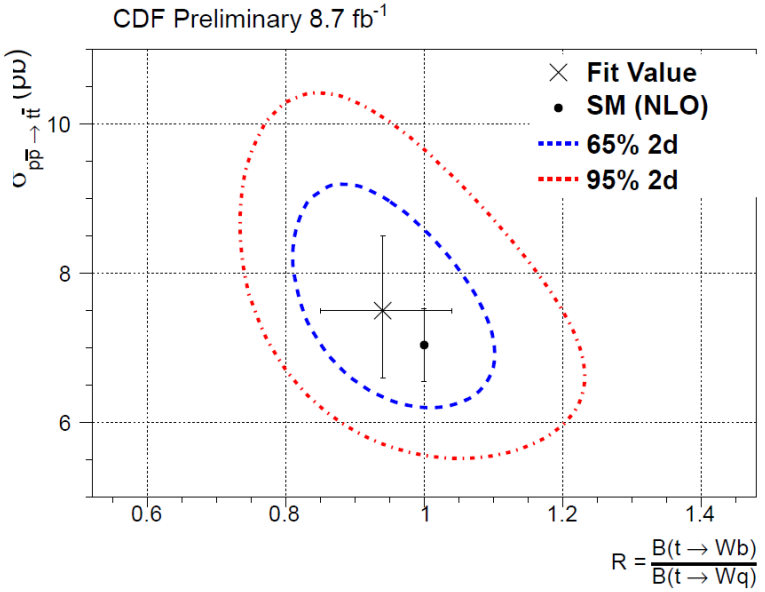
$$\mathcal{L} = \prod_i \mathscr{P}\left(\mu^i_{exp}(R, \sigma_{p\bar{p}\to t\bar{t}}, x_j) | N^i_{obs}\right) \prod_j G\left(x_j | 0, 1\right)$$

  - $|V_{tb}|$ is derived from the result

$$R = 0.94 \pm 0.09$$
$$|V_{tb}| = 0.97 \pm 0.05$$

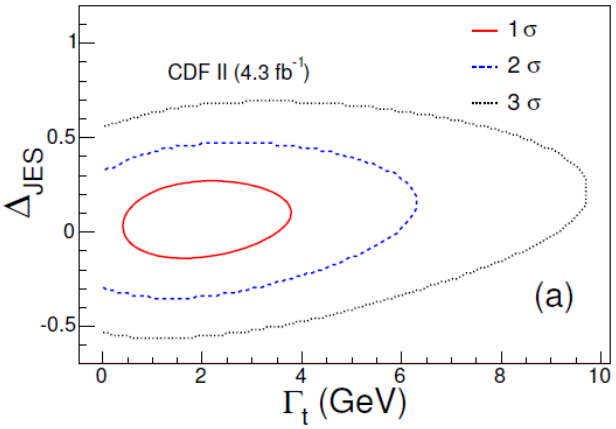
(LJ, 8.7fb^{-1} , CDF note 10723)





Top width

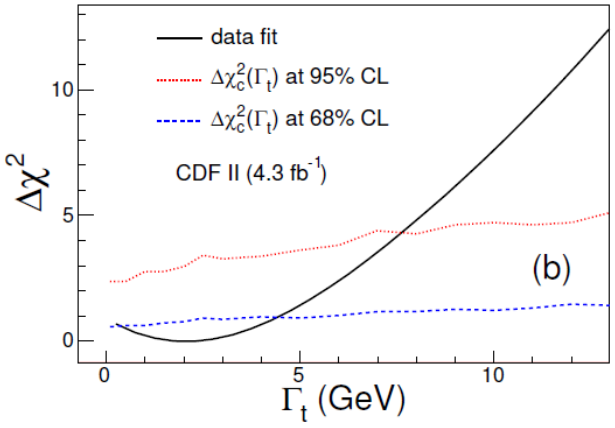
- SM prediction : Γ_t ~ 1.5 GeV
- Direct measurement in lepton+jet, 4.3fb^{-1}
  - template method with different top quark Γ_t and in situ JES
  - subsamples with 1,2 b-tags (diff. s+b)
  - comparing s + b probability density
    - unbinned maximum likelihood



0.3 GeV < Γ_t < 4.4 GeV at 68% C.L.

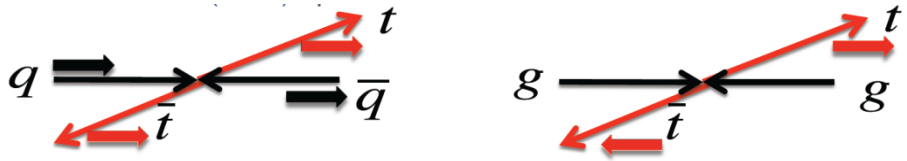
Γ_t < 7.6 GeV at 95% C.L.

(LJ, 4.3fb^{-1} , PRL 105, 232003(2010))



Spin correlations

- Top pairs are produced with a definite spin depending on production mechanism



- Top decays before hadronization :
  - spin information passed to decay products
  - spin correlation can be studied from the angular distribution of decay products reflects
- Correlation strength (κ) is defined as

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

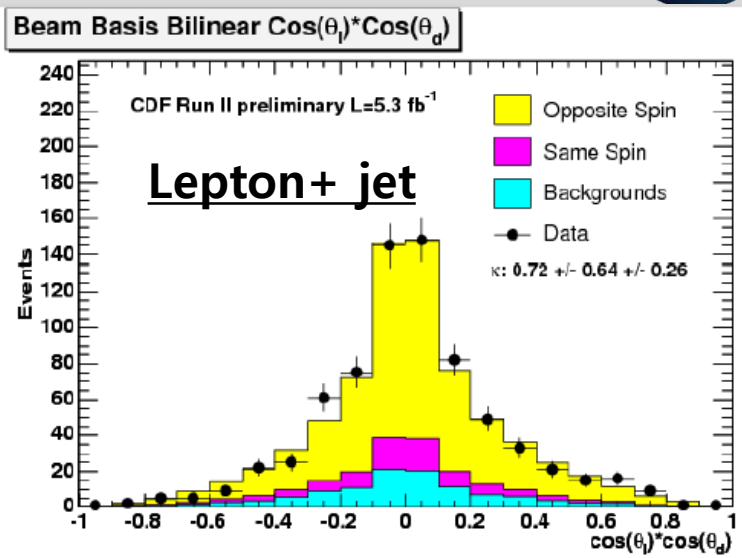
$\theta_+(\theta_-)$: angle of lepton in top rest frame

$$\kappa = \frac{N_{\uparrow\uparrow}+N_{\downarrow\downarrow}-N_{\uparrow\downarrow}-N_{\downarrow\uparrow}}{N_{\uparrow\uparrow}+N_{\downarrow\downarrow}+N_{\uparrow\downarrow}+N_{\downarrow\uparrow}}$$

– SM predicts κ = 0.78 +0.03 -0.04 (Nucl. Phys. B 690,81 (2004))

The measurement Spin correlation

- Using templates for $\cos\theta_{-}\cos\theta_{+}$
- Binned maximum likelihood for C_{meas}
- Statistically limited
- Consistent with SM



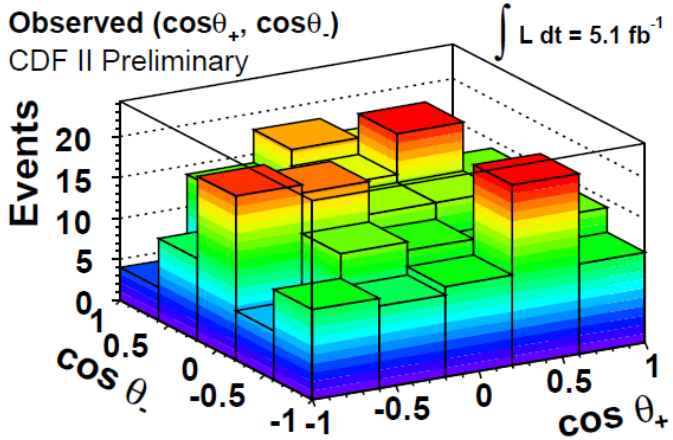
$\kappa_{\text{lepton+jet}} = 0.72 \pm 0.69$

(LJ, 5.3fb^{-1} , CDF note 10211)

$\kappa_{\text{Dilepton}} = 0.04 \pm 0.56$

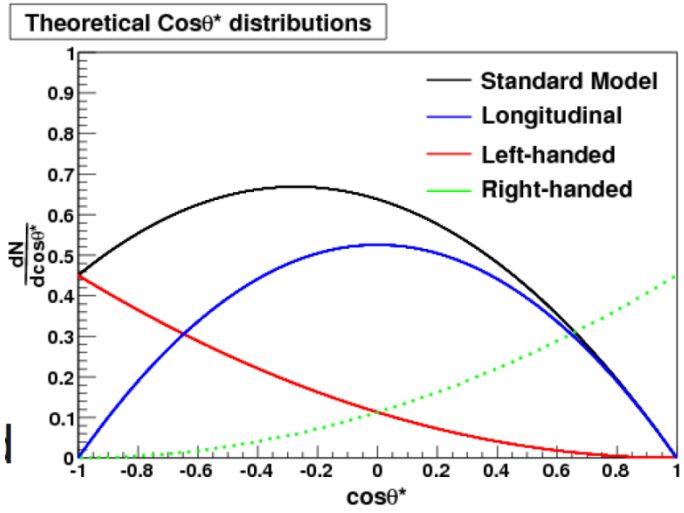
(DIL, 5.1fb^{-1} , CDF note 10719)

Dilepton



W helicity

- W helicity can be Measured in t→Wb(~100%)
- Three possible helicity states
  - Longitudinal (f_0), left-handed (f_-) and right-handed (f_+)
  - angular distribution of decay products in W rest frame dependent on helicity state
- In SM, right-handed is strongly suppressed
  - V-A interaction
  - fraction of f_0, f_+ and f_- depends on m_t and m_W
  - deviation would provide evidence of BSM



SM predection :

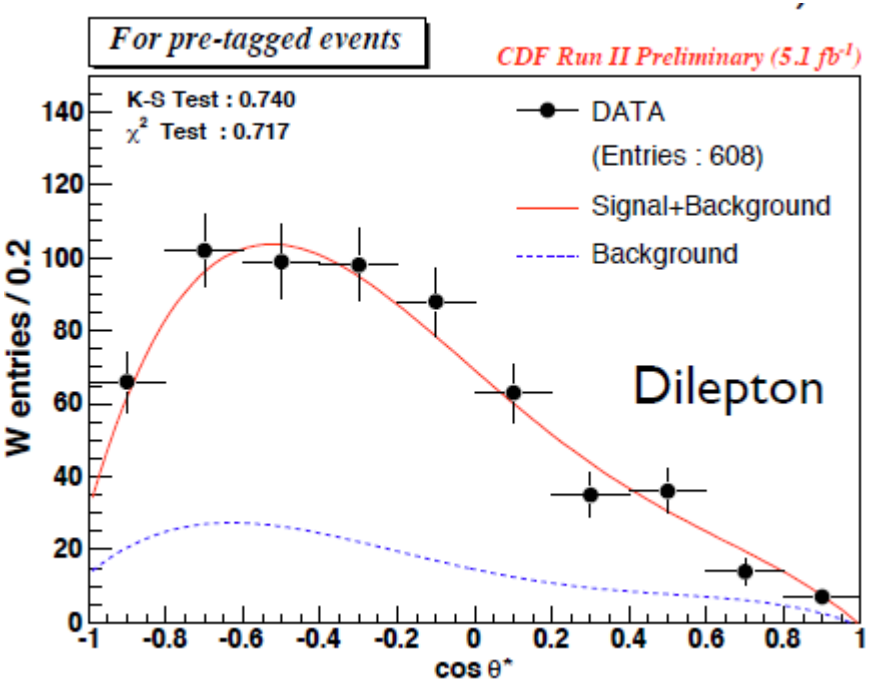
f_0 = 69.6 %
f_- = 30.3 %
f_+ = 0.1 %

The measurement of W helicity

- Extract f_0, f_+ from distribution of θ* (angle between lepton and top direction in W rest frame)

$$\omega(\cos\theta^*) \propto 2(1-\cos^2\theta^*) f_0 + (1-\cos\theta^*)^2 f_- + (1+\cos\theta^*)^2 f_+$$

- Dilepton samples in 5.1fb^{-1}



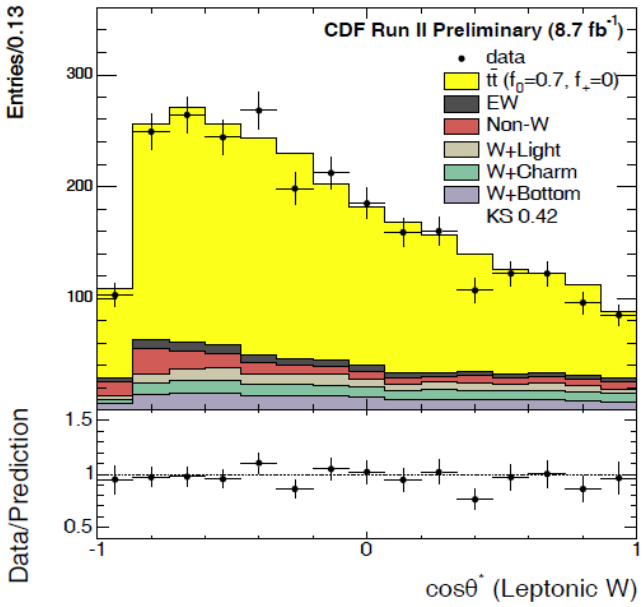
f_0 = 0.71 ± 0.18(stat) ± 0.06(syst)

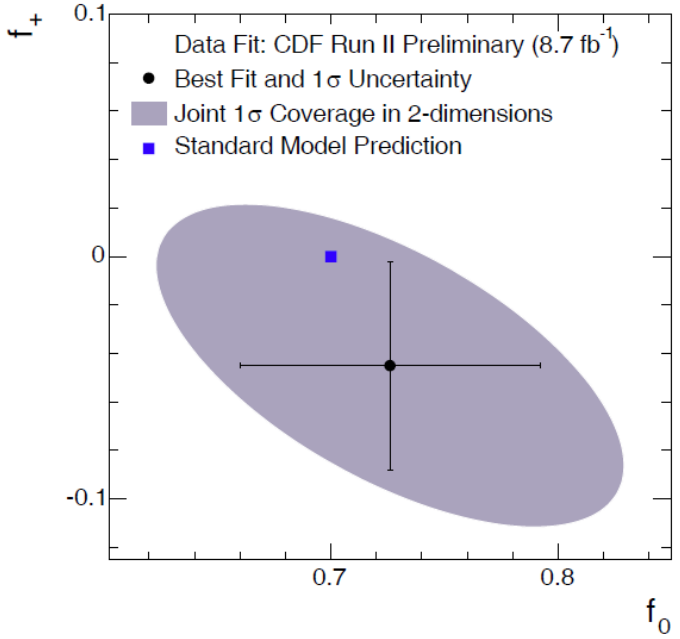
f_+ = -0.07 ± 0.09(stat.) ± 0.03(syst.)

(DIL, 5.1fb^{-1} , CDF note 10543)

The measurement of W helicity

- lepton+jet samples in **8.7 fb^{-1}**
- matrix element method adopted





$f_0 = 0.726 \pm 0.066(\text{stat}) \pm 0.067(\text{syst})$

$f_+ = -0.045 \pm 0.043(\text{stat.}) \pm 0.058(\text{syst.})$

(LJ, 8.7 fb^{-1}, CDF note 10855)

Top quark charge

- top quark charge from standard model : +2/3 (SM)
  exotic quark : -4/3 (XM)
  (D. Chang, W. Chang Phys. Rev. D(59) 1999)

	t	→	W	b
(SM)	+2/3		+1	-1/3
(XM)	- 4/3		-1	-1/3

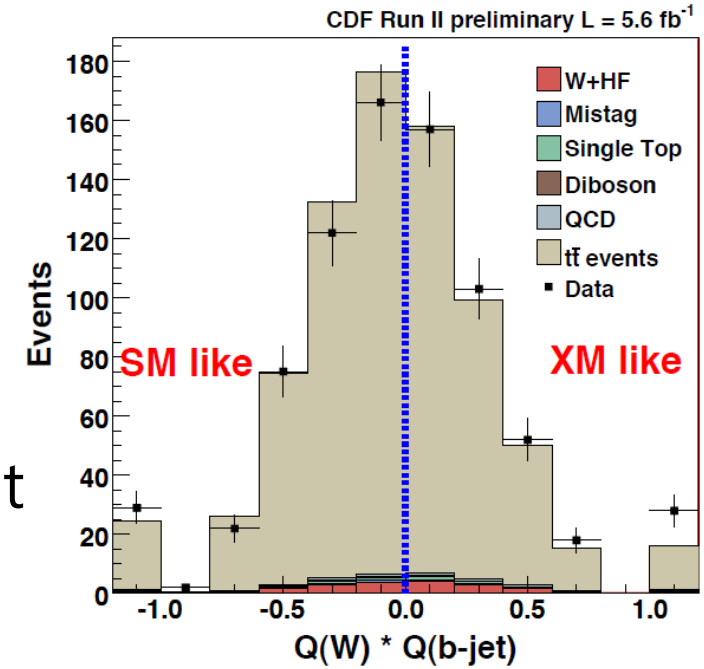
- Using Lepton+jet smaples,
  three main components to assign **the sign of top charge**

  - determining W charge from the charge of lepton
  - pairing the W with b jet to ensure that they are coming from the same top decay branch
  - finally, getting the flavor of the b jet using jet charge algorithm to find the sign of top charge

Top quark charge

- From 5.6fb^{-1} lepton+jet samples,
  416 SM like pairs and
  358 XM like pairs
  has been observed in data.

- Q(W)*Q(b-jet) of data is consistent with the one of SM prediction.



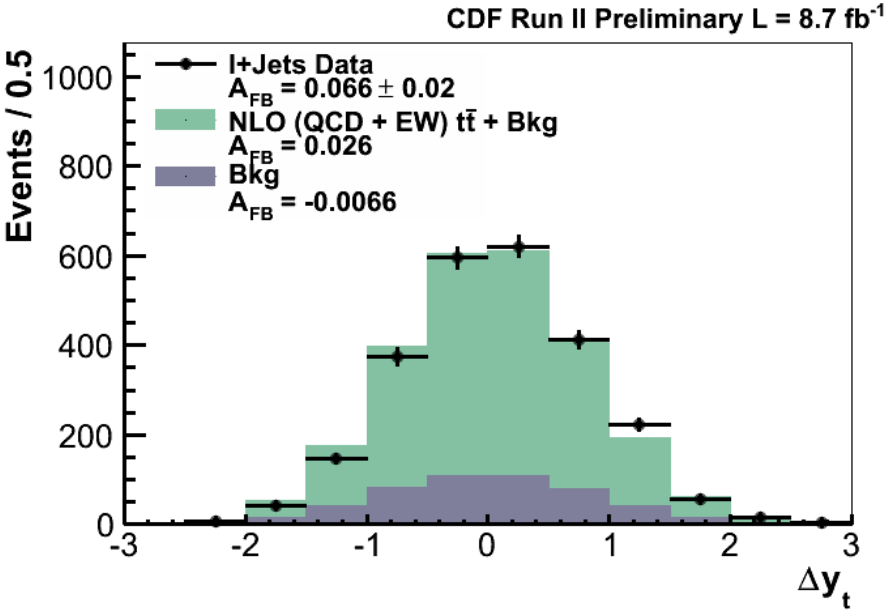
- An exotic quark hypothesis is excluded with 99% C.L.
  (LJ, 5.6fb^{-1} , CDF note 10460)

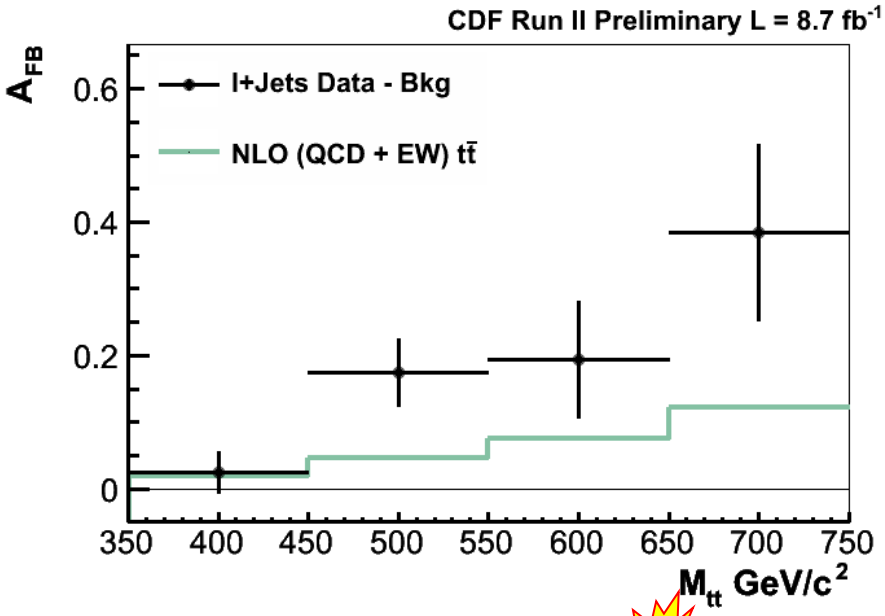
Top forward-backward asymmetry

- Measurement asymmetry in Δy

$$A_{FB} = \frac{N_{\Delta y>0} - N_{\Delta y<0}}{N_{\Delta y>0} + N_{\Delta y<0}}$$

- SM prediction
  Leading order : No asymmetry
  Next-to-leading order : 0.066





A_{fb} = 0.162 ± 0.047(stat) (lepton+jet, **8.7 fb^{-1}**)

(LJ, 8.7fb^{-1} , CDF note 10807)

➔ Tomorrow, please listen to the talk by Chris Hays for details.

Conclusion

- The full CDF dataset is being studied in top properties measurement.
- Spin correlations, A_{FB} are complementary to LHC measurements
- Data taking is done. But there is a lot left to be learned from the CDF top quark sample.
- Please look at the websites of CDF's Top group for more informations and results

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