



# Top quark properties at CDF

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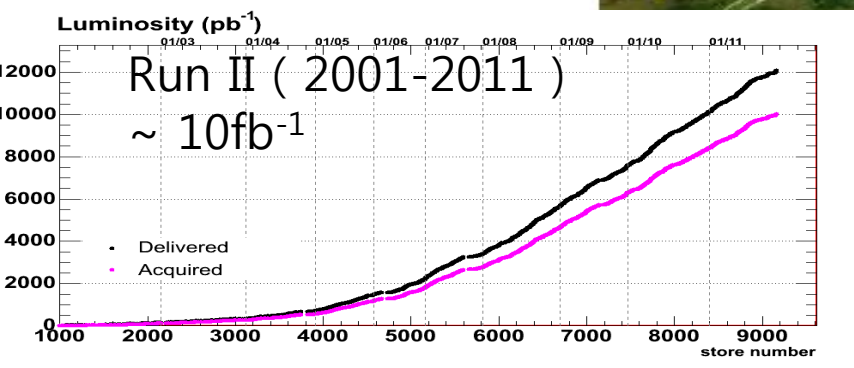
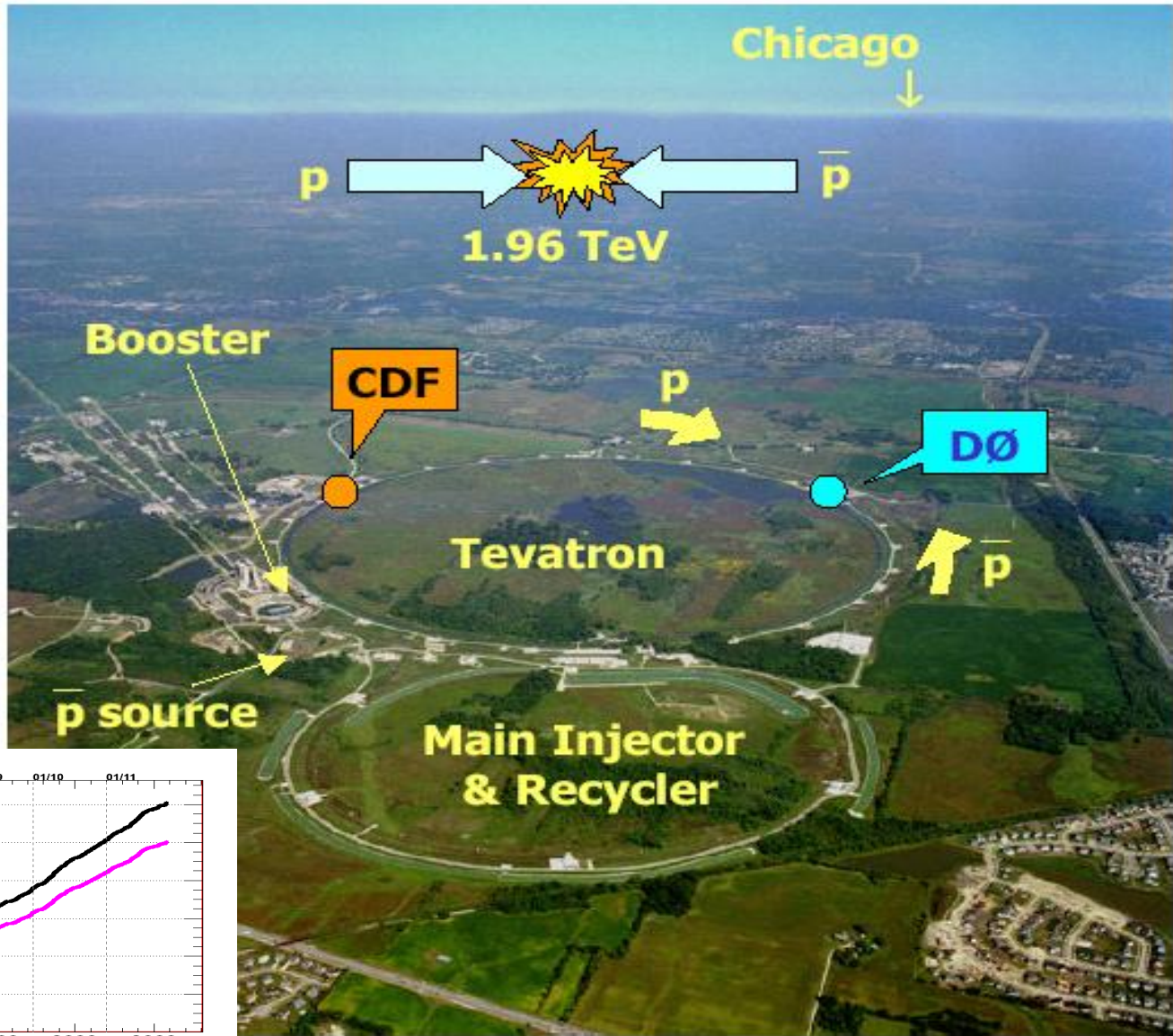
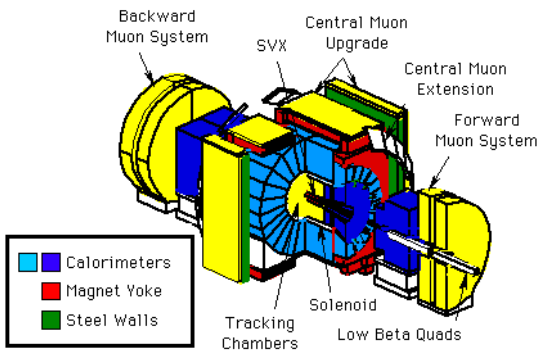
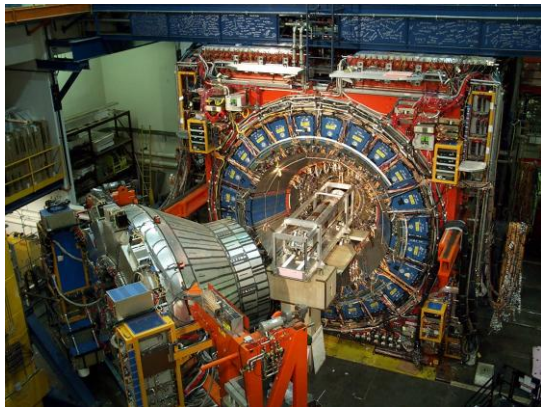
On behalf of the CDF Collaborations



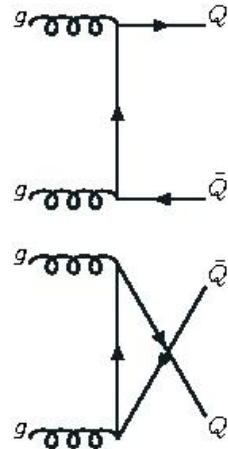
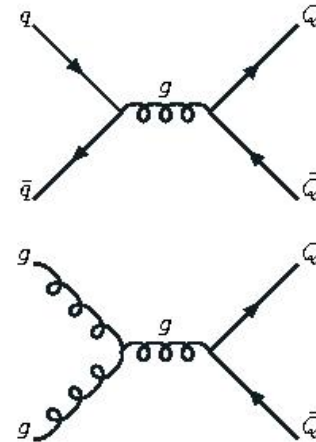
# Outline



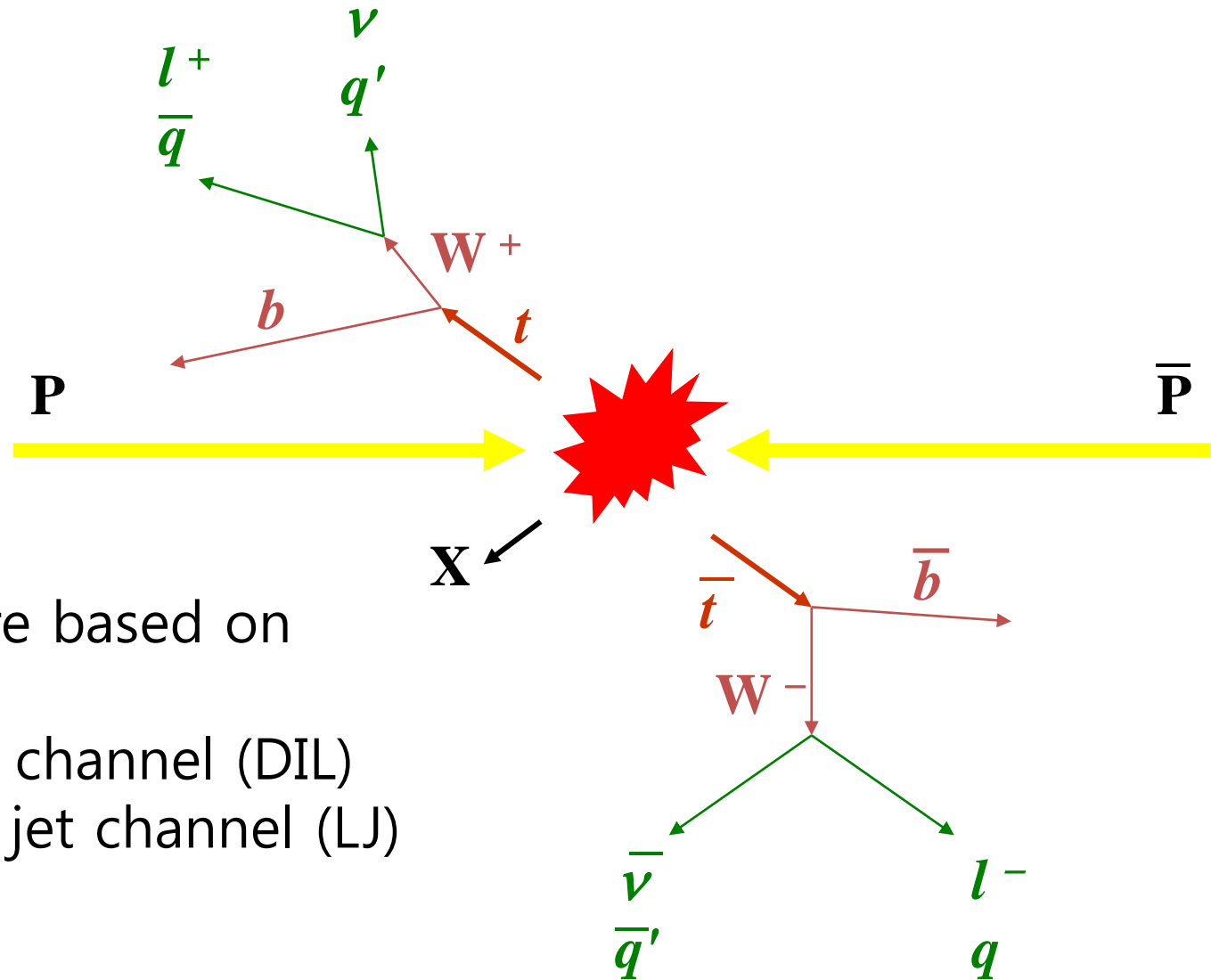
- Top quark branching ratio and width
- Spin correlations in top-antitop event
- Helicity fraction of W boson
- top quark charge
- top forward-backward asymmetry



- Top quark properties
  - high mass  $\sim 173.5$  GeV ( PDG )
  - short lift time  $\sim 10^{-25}$  sec
  - charge :  $+2/3$
  - spin :  $1/2$
  
- Top pair production in  $p\bar{p}$  collision
  - $\sigma \sim 7.22$  pb at  $\sqrt{S} = 1.96$  TeV:  
(NNLL, C. Schwinn, arXiv:1205.0988)
  - $q\bar{q} \rightarrow t\bar{t} : \sim 90\%$  ,  $gg \rightarrow t\bar{t} : \sim 10\%$



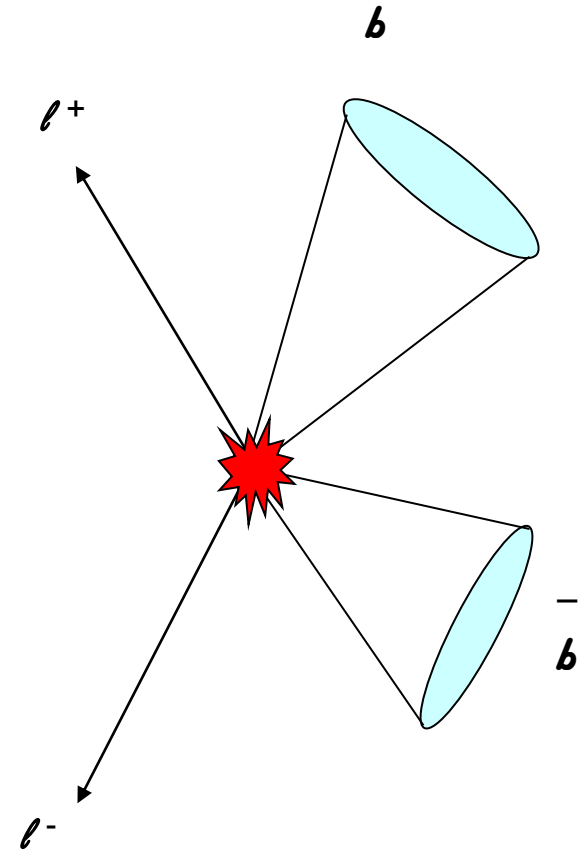
- SM top quark  $\rightarrow Wb$  (  $\sim 100\%$  )  
final states of top pair are given by W decay states
  - lepton + jets
  - dilepton
  - all hadronic



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

## ● Event Selection

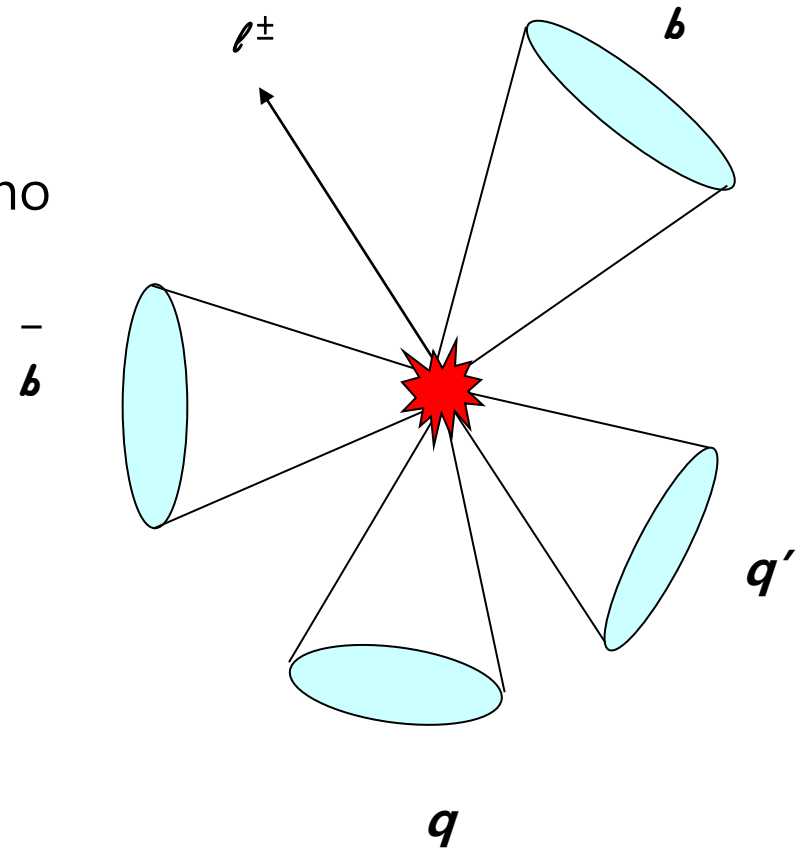
- Two high  $p_T$  leptons
  - $> 20$  GeV
  - $|\eta| < 2$
- High missing  $E_T$  due to the two neutrinos
- being missing in detection
- Suppressing of Z boson events
- High total transverse energy
- Two or more jets



## ● Event Selection

- high  $p_T$  lepton( $e/\mu$ )
  - $> 20$  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 :  **$8.7 \text{ fb}^{-1}$**







# Top quark branching ratio( $t \rightarrow b$ )

- Direct measurement in lepton+jet, **8.7 fb<sup>-1</sup>**

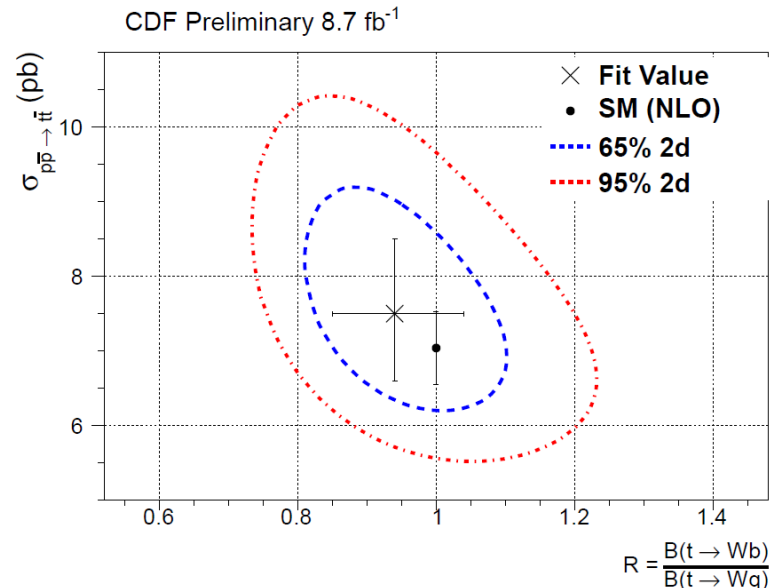
$$R = \frac{\mathcal{B}(t \rightarrow Wb)}{\mathcal{B}(t \rightarrow Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

- two b's are expected in top anti-top event
  - b tagging efficiency determines expected size of samples with 0, 1 or 2 tagged jets
  - R is determined from the size of each subsample
  - $|V_{tb}|$  is derived from the result

$$R = 0.94 \pm 0.09$$

$$|V_{tb}| = 0.97 \pm 0.05$$

(LJ, 8.7fb<sup>-1</sup>, CDF note 10723)



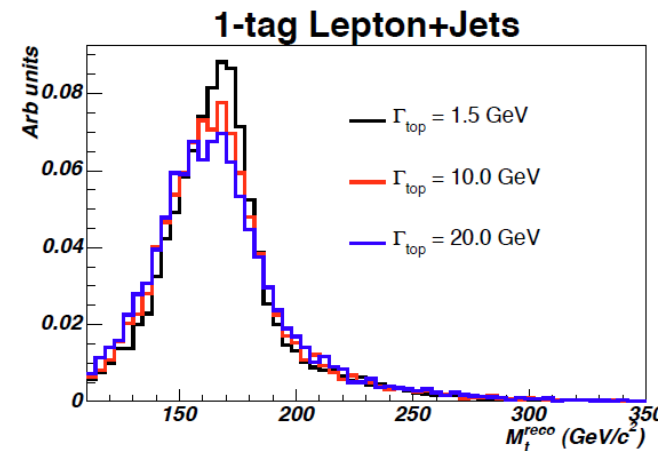
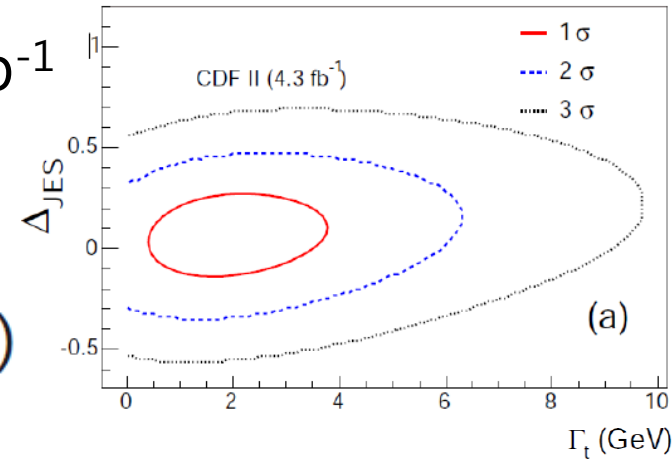


- SM prediction :  $\Gamma_t \sim 1.5 \text{ GeV}$
- Direct measurement in lepton+jet,  $4.3\text{fb}^{-1}$ 
  - template method with different top quark  $\Gamma_t$  and in situ JES
  - subsamples with 1,2 b-tags (diff. s+b)
  - comparing s + b probability density
    - unbinned maximum likelihood

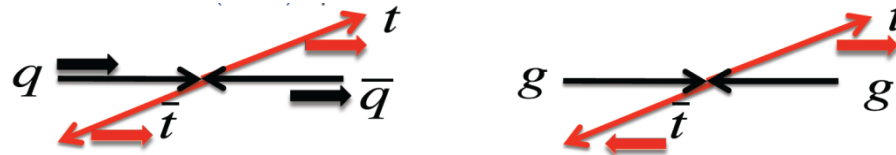
$0.3 \text{ GeV} < \Gamma_t < 4.4 \text{ GeV}$  at 68% C.L.

$\Gamma_t < 7.6 \text{ GeV}$  at 95% C.L.

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



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



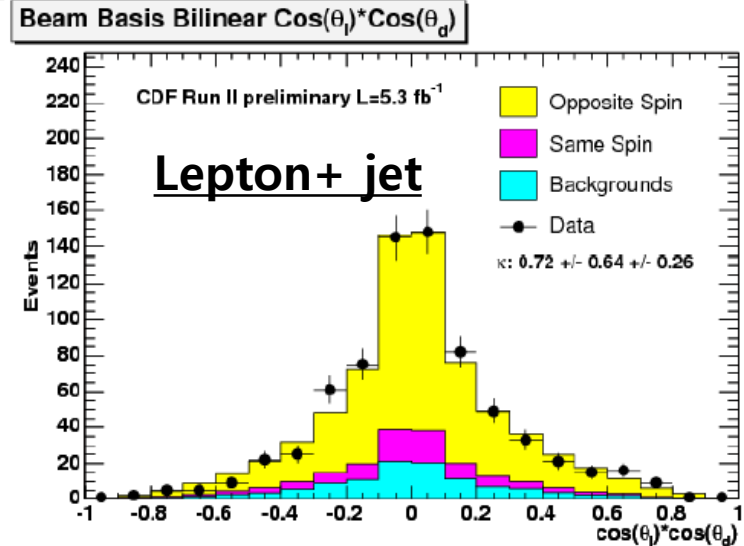
- Top decays before hadronization :
  - spin information passed to decay products
  - spin correlation can be studied from the angular distribution of decay products reflects
- Correlation strength (  $\kappa$  ) is defined as

$$\frac{1}{\sigma} \frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + \kappa \cos\theta_+ \cos\theta_-}{4} \quad \theta_+ (\theta_-) : \text{angle of lepton in top rest frame}$$

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

- SM predicts  $\kappa = 0.78 \pm 0.03 \pm 0.04$  (Nucl. Phys. B 690,81 (2004))

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



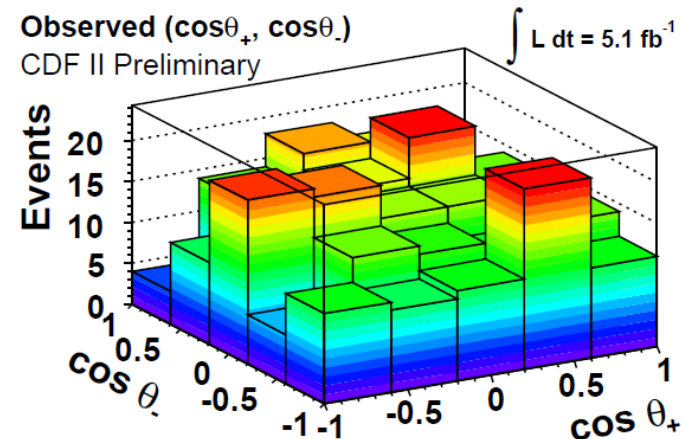
$$K_{\text{lepton+jet}} = 0.72 \pm 0.69$$

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

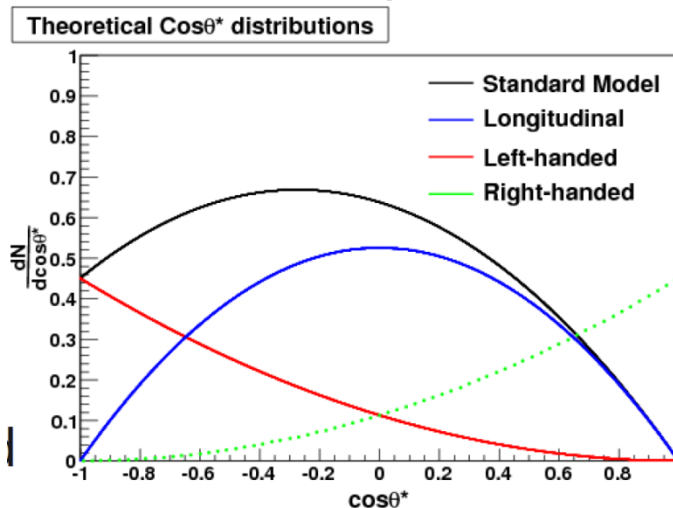
$$K_{\text{Dilepton}} = 0.04 \pm 0.56$$

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

## Dilepton



- W helicity can be Measured in  $t \rightarrow Wb$  ( $\sim 100\%$ )
- 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 prediction :

$$f_0 = 69.6 \%$$

$$f_- = 30.3 \%$$

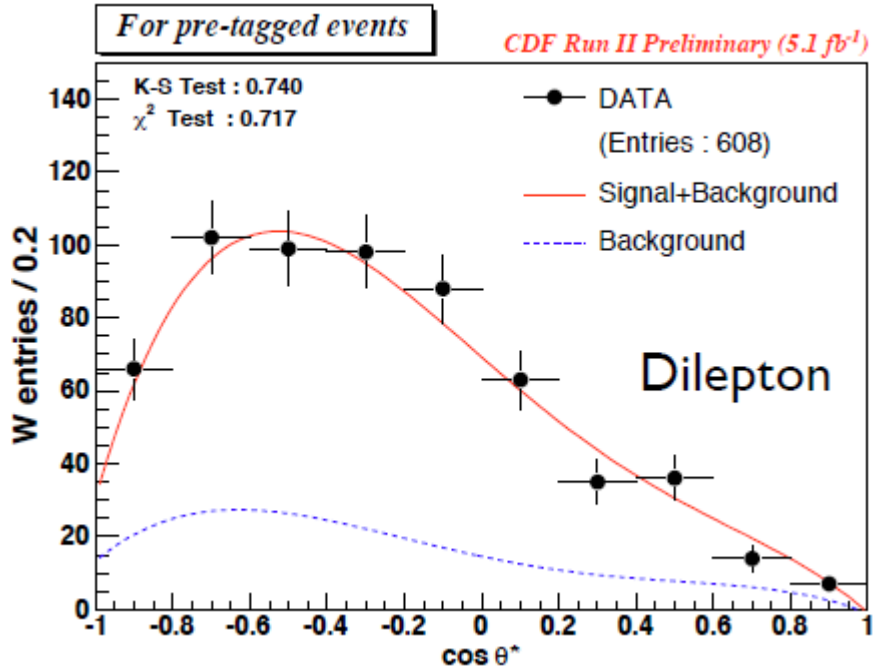
$$f_+ = 0.1 \%$$

# The measurement of W helicity

- Extract  $f_0, f_+$  from distribution of  $\theta^*$  (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  $5.1\text{fb}^{-1}$



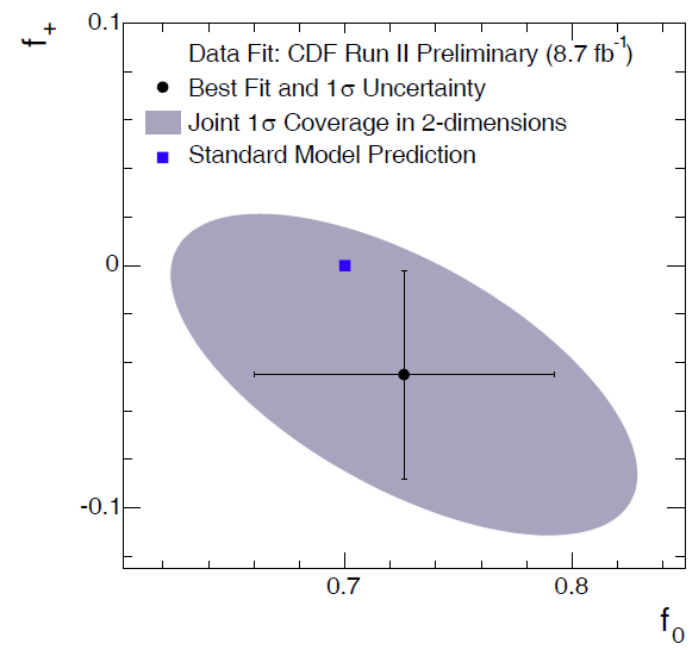
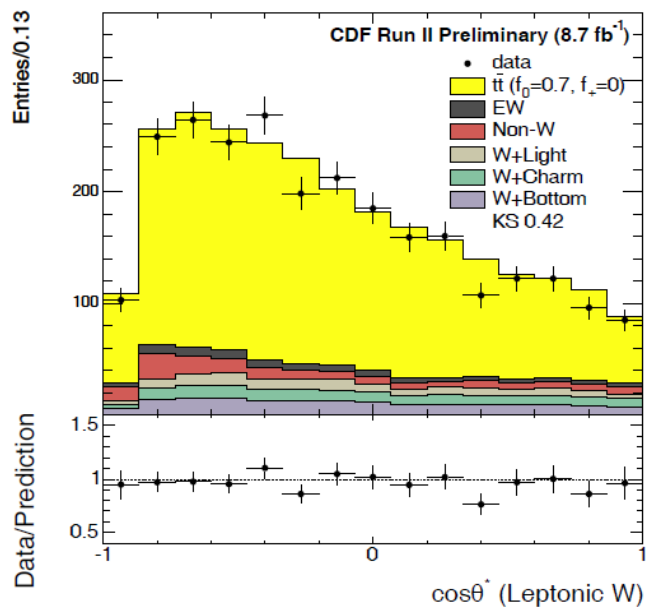
$$f_0 = 0.71 \pm 0.18(\text{stat}) \pm 0.06(\text{syst})$$

$$f_+ = -0.07 \pm 0.09(\text{stat.}) \pm 0.03(\text{syst.})$$

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

# The measurement of W helicity

- lepton+jet samples in **8.7 fb<sup>-1</sup>**
- 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<sup>-1</sup>, CDF note 10855)



# Top quark charge



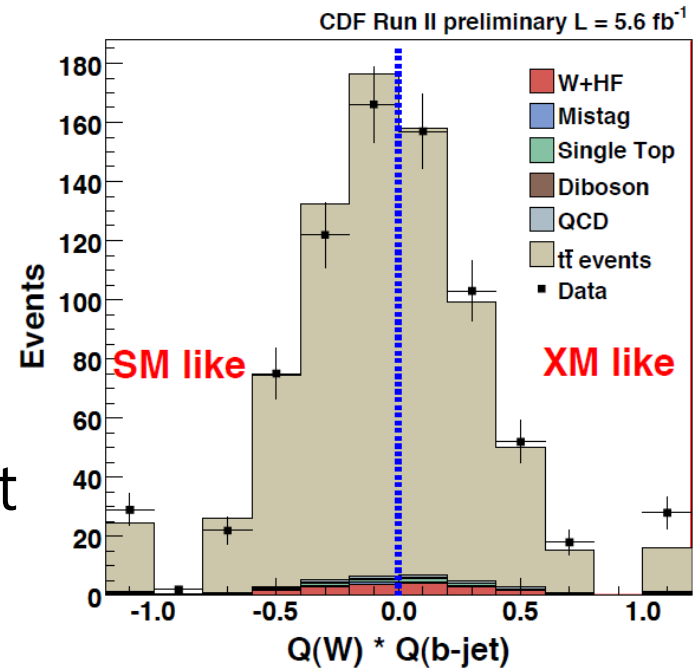
- top quark charge from standard model :  $+2/3$  (SM)  
 exotic quark :  $-4/3$  (XM)  
 (D. Chang, W. Chang Phys. Rev. D(59) 1999)

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

- Using Lepton+jet samples,  
 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



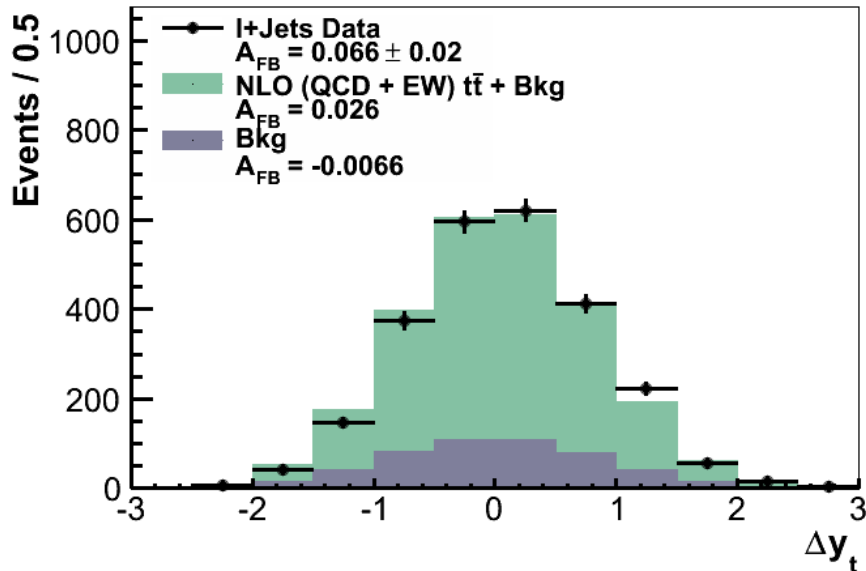
- From  $5.6\text{fb}^{-1}$  lepton+jet samples, 416 SM like pairs and 358 XM like pairs has been observed in data.
- $Q(W) \cdot Q(\text{b-jet})$  of data is consistent with the one of SM prediction.
- An exotic quark hypothesis is excluded with 99% C.L. (LJ,  $5.6\text{fb}^{-1}$ , CDF note 10460)



- Measurement asymmetry in  $\Delta y$

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

CDF Run II Preliminary L = 8.7 fb<sup>-1</sup>

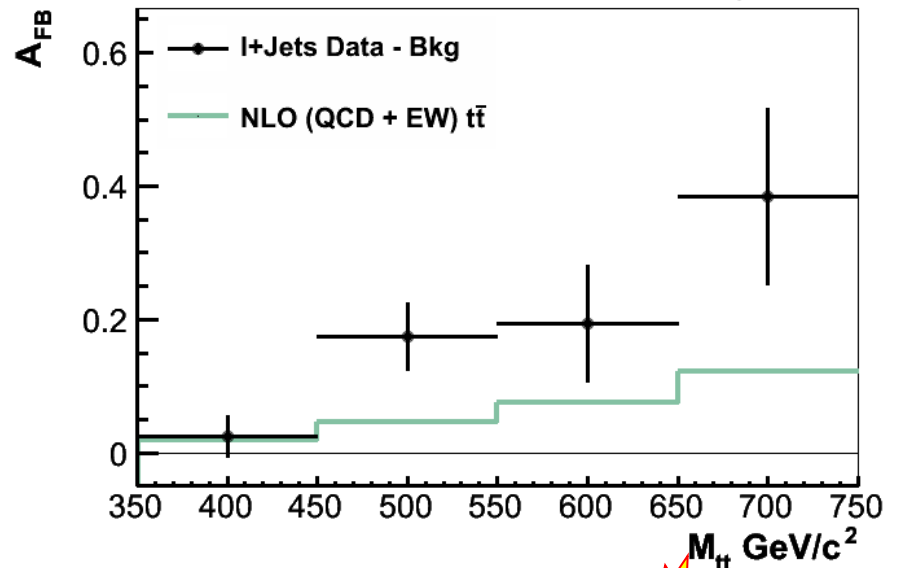


- SM prediction

Leading order : No asymmetry

Next-to-leading order : 0.066

CDF Run II Preliminary L = 8.7 fb<sup>-1</sup>



$$A_{fb} = 0.162 \pm 0.047(\text{stat}) \quad (\text{lepton+jet, } 8.7 \text{ fb}^{-1})$$

(LJ, 8.7fb<sup>-1</sup>, 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>