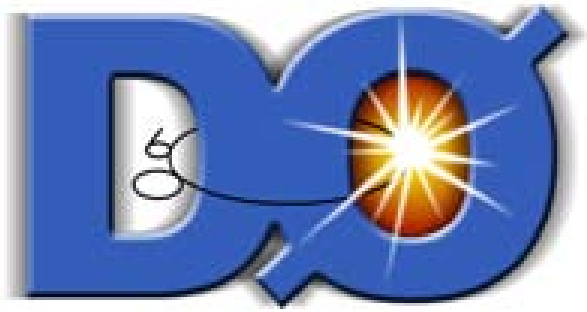
Top Physics at Tevatron



Hyun Su Lee

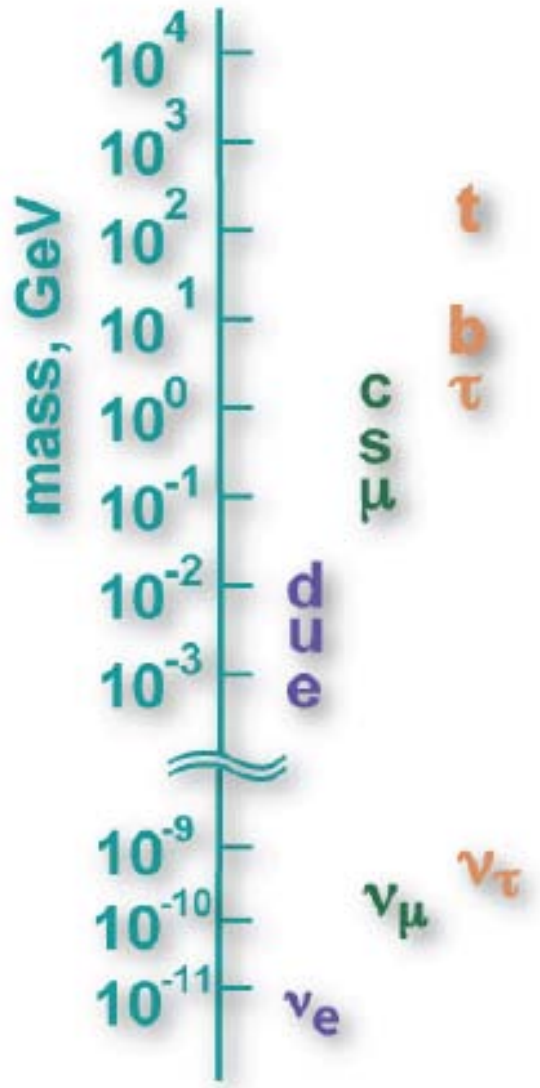
The University of Chicago

On behalf of the CDF and D0 collaborations

Les Rencontres de Physique de la Vallee d'Aoste

The top quark

- It was discovered in Fermilab at 1995
  - Single top observation at 2009
- The heaviest known elementary particle
  - It's about Electro Weak Symmetry Breaking scale
  - Largest coupling with Higgs boson
- Lifetime is very short
  - Decay before hadronization
  - Study "bare quark"
- Special role in many new physics model
  - Ideal place to study new physics

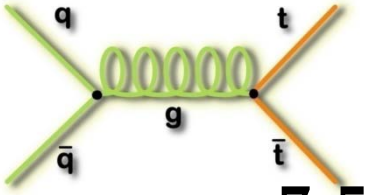


Top quark production and decay at Tevatron

Production

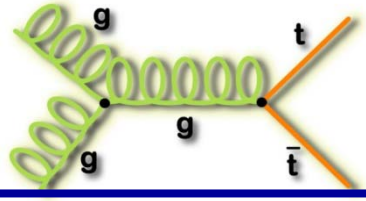
Pair production

~85%

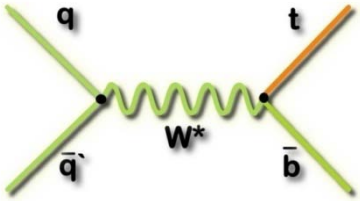


~7.5 pb

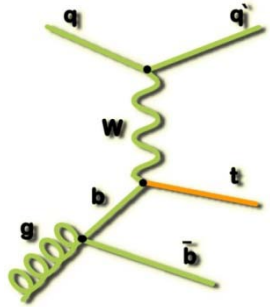
~15%



Single top production



s channel~1 pb

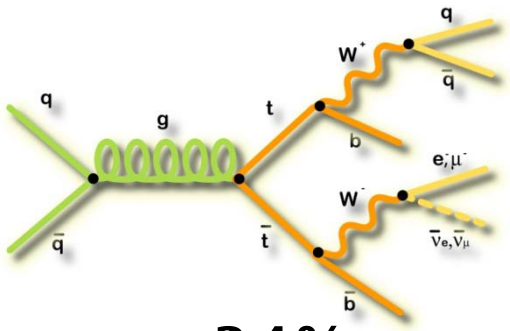


t channel~2 pb

Decay

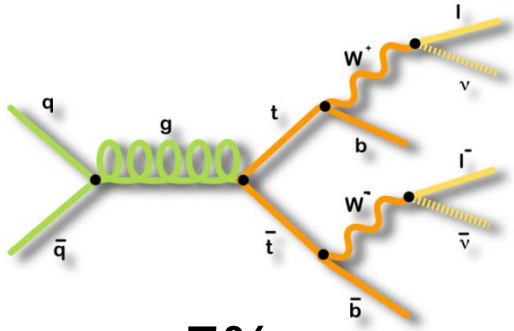
t→bW ~100%

Lepton+Jets



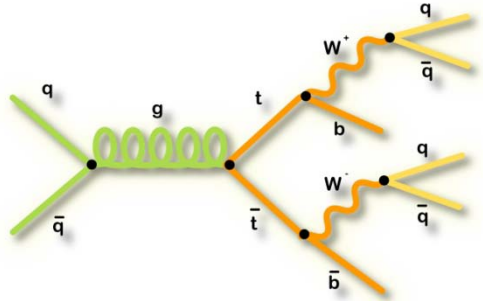
34%

Dilepton



7%

All Jets



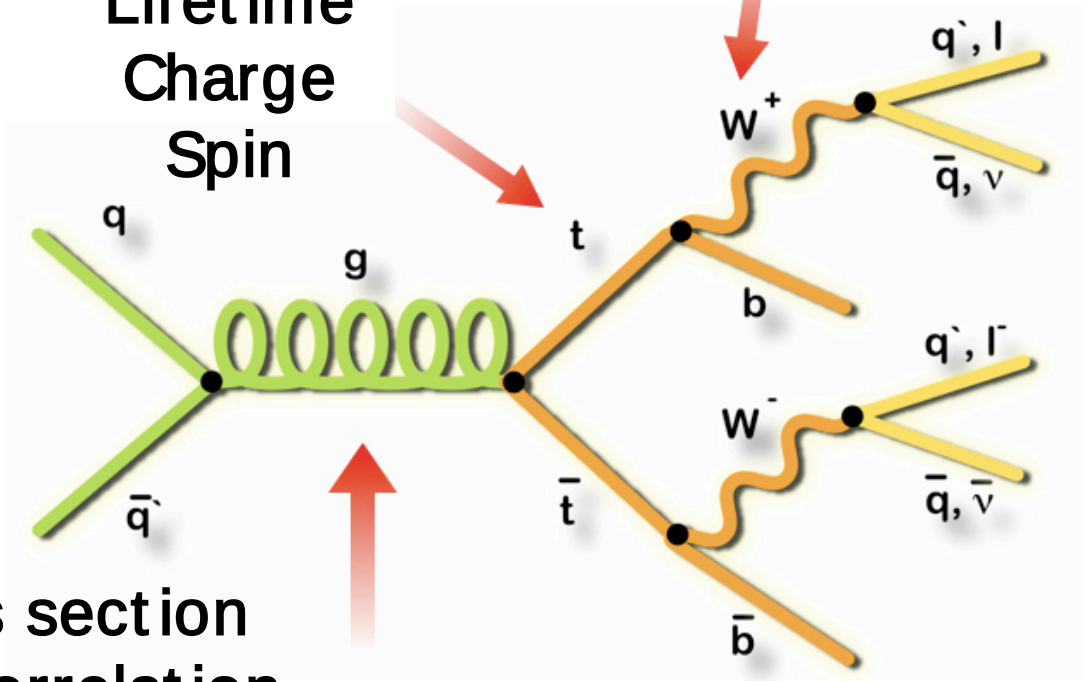
44%

Hadronic tau : 15%

What we are interesting?

W helicity
Anomalous coupling
FCNC
Charged Higgs

Mass
Width
Lifetime
Charge
Spin



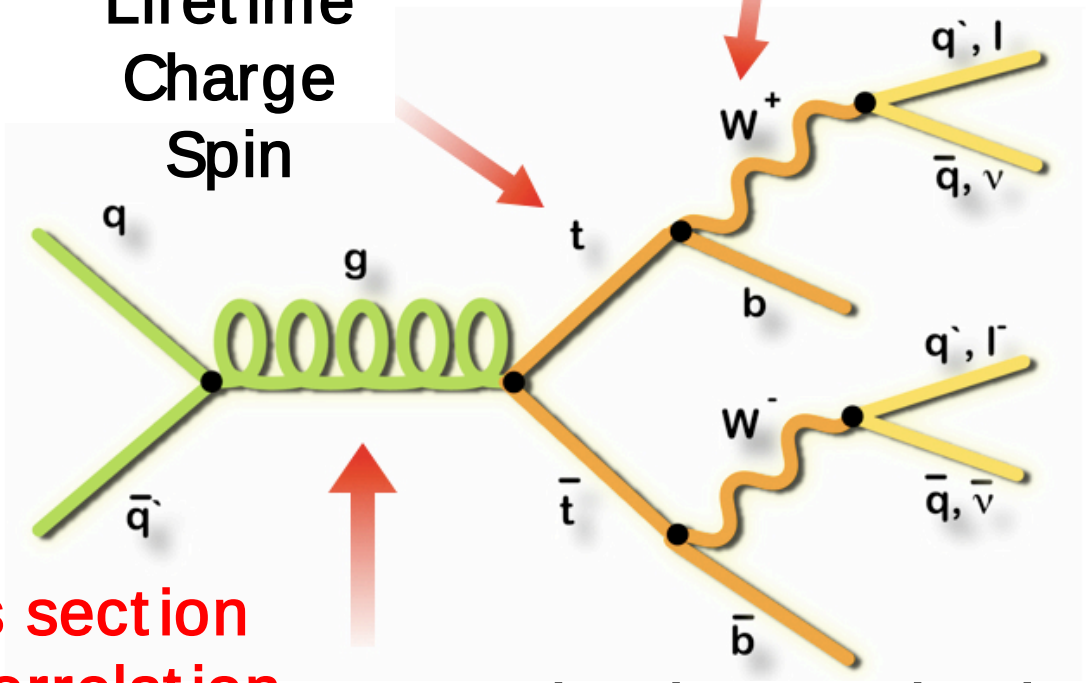
Cross section
Spin correlation
FB asymmetry
New particle production

Production mechanism
Resonance Production

Today's talk

W helicity
Anomalous coupling
FCNC
Charged Higgs

Mass
Width
Lifetime
Charge
Spin

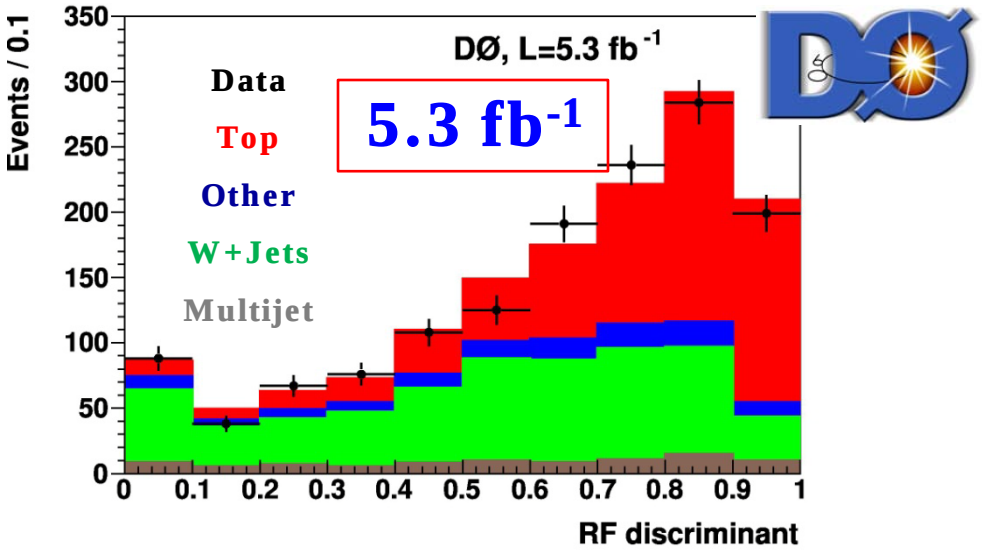


Cross section
Spin correlation
FB asymmetry
New particle production

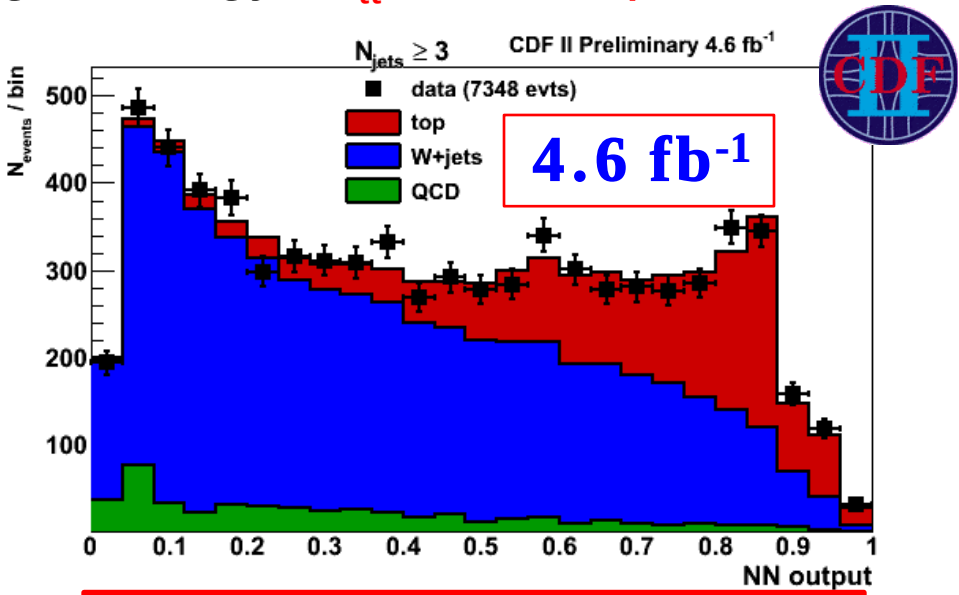
Production mechanism
Resonance Production

$t\bar{t}$ cross section

- Testing perturbative QCD at high energy, σ_{tt}^{SM}=7.45 pb



btag lepton + Jets channel



Pretag lepton + Jets channel

Assume M_{top} = 172.5GeV/c^2

Topological discrimination

$\sigma_{t\bar{t}} = 7.78\ ^{+0.77}_{-0.64}$ pb

(with ±0.45 lumi. uncertainty)

arXiv:1101.0124

Measure $\sigma_{t\bar{t}}/\sigma_Z$ to reduce lumi (~0.4) uncertainty and then multiply theory σ_Z

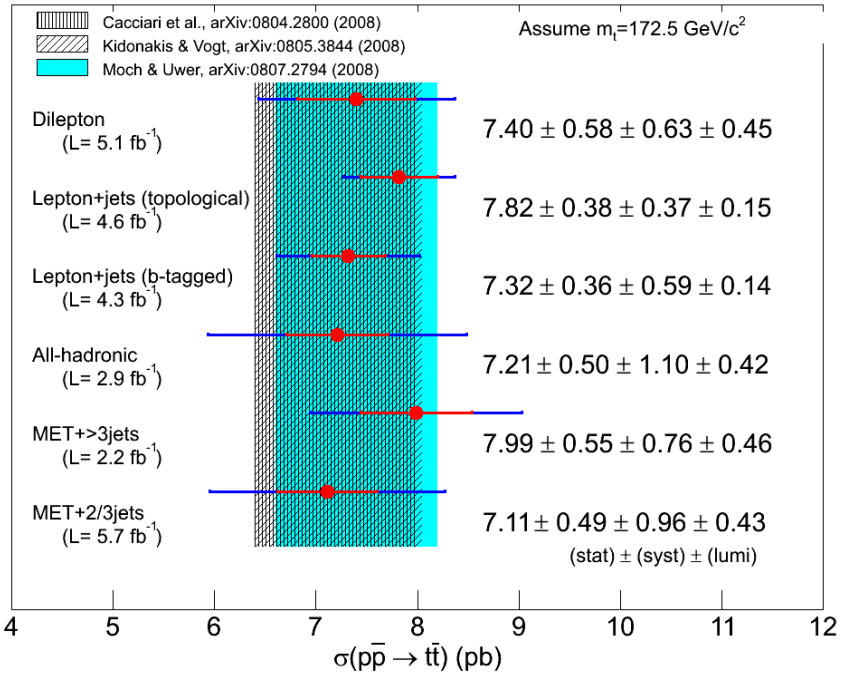
$\sigma_{t\bar{t}} = 7.82 \pm 0.38_{Stat.} \pm 0.35_{Syst.} \pm 0.15(theory)$ pb

$= 7.82 \pm 0.54$ pb

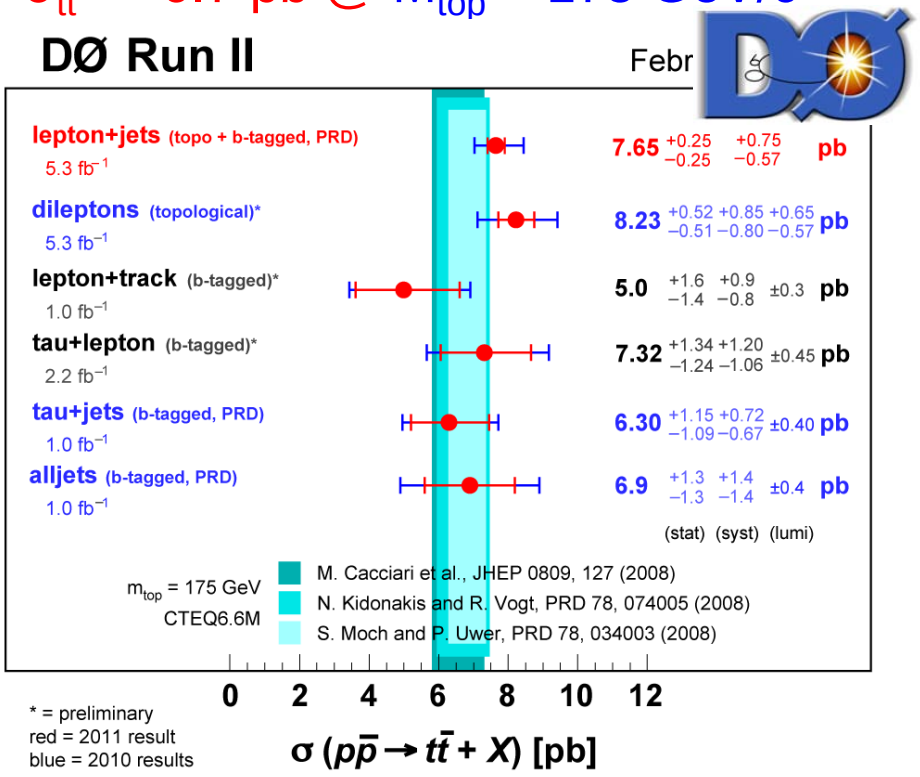
PRL 105 (2010) 012001

$t\bar{t}$ cross section

σ_{tt}^{SM}=7.5 pb @ M_{top} = 172.5GeV/c^2



σ_{tt}^{SM}=6.7 pb @ M_{top} = 175 GeV/c^2

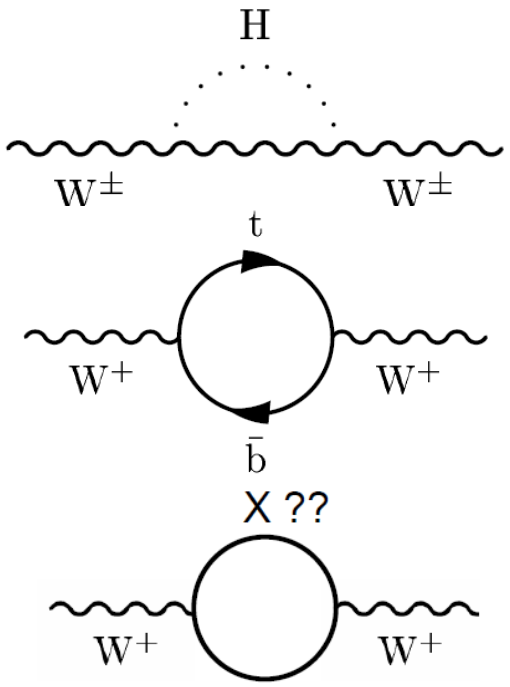


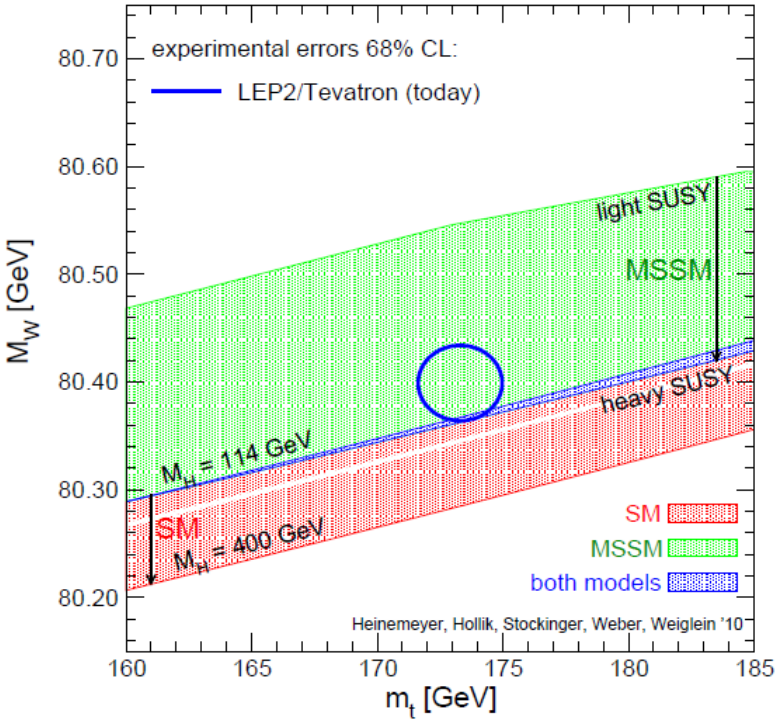
All results are consistent with Standard Model

Systematic limited measurements

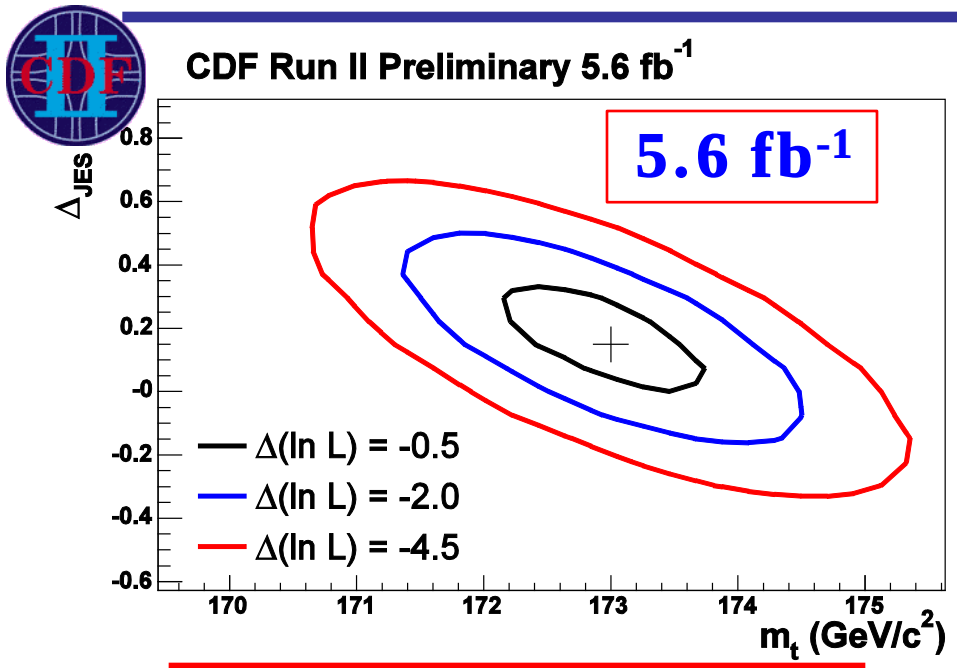
Top quark mass

- Top quark is the heaviest known elementary particle
- Top quark mass is not predicted by SM
- Can constrain SM Higgs boson mass
  - ❖ Important contribution in radiative correction of W
  - ❖ Important test of SM





Top mass measurement



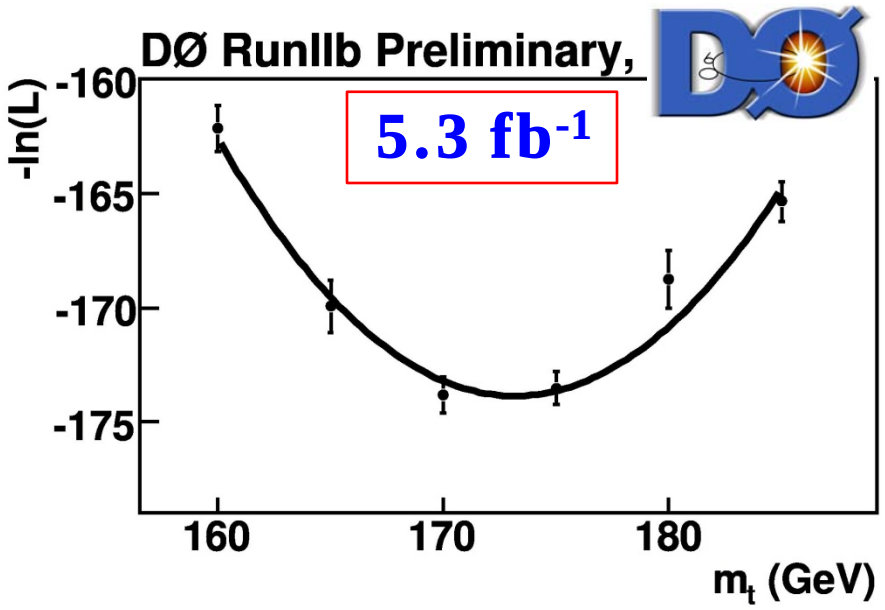
Lepton+Jets channel

Matrix element technique

In situ JES calibration

173.0 ± 1.2 GeV/c^2

PRL 105 (2010) 252001



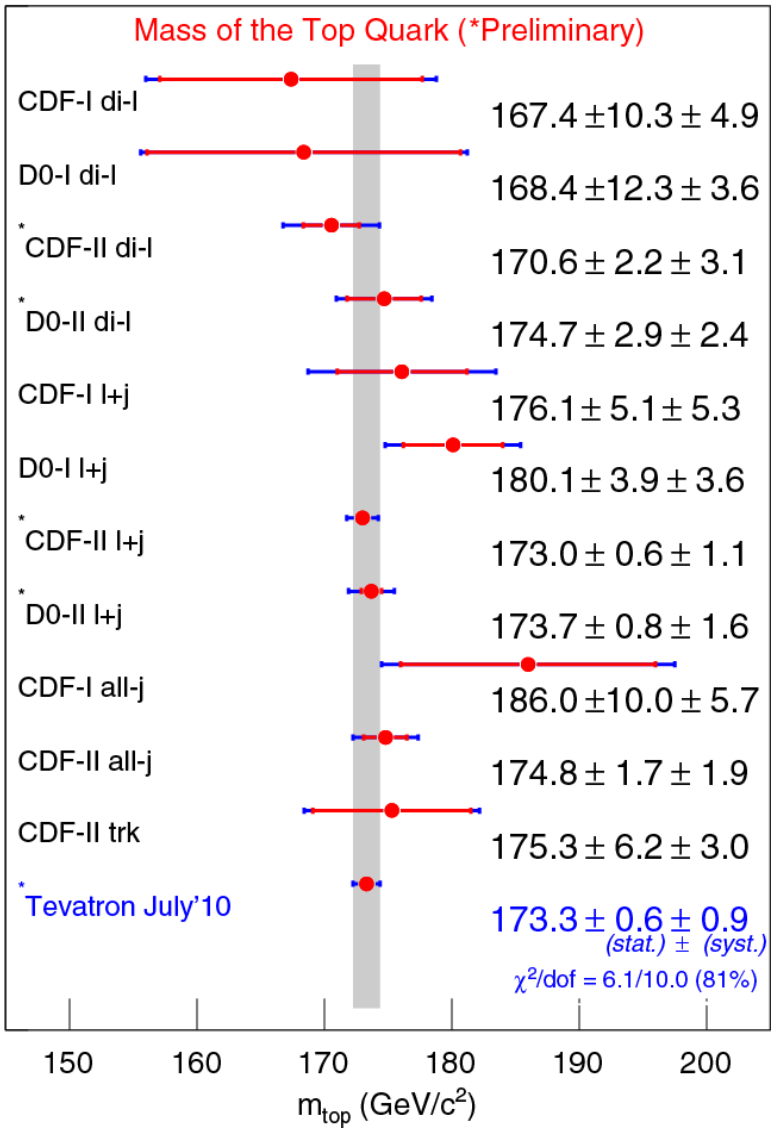
Dilepton channel

Kinematic reconstruction

Template method

173.3 ± 3.2 GeV/c^2

Tevatron Combination



World average = 173.3 ± 1.1 GeV/c^2

~0.61 % Precision

Very Precise measuremet

Understanding of systematic is the key

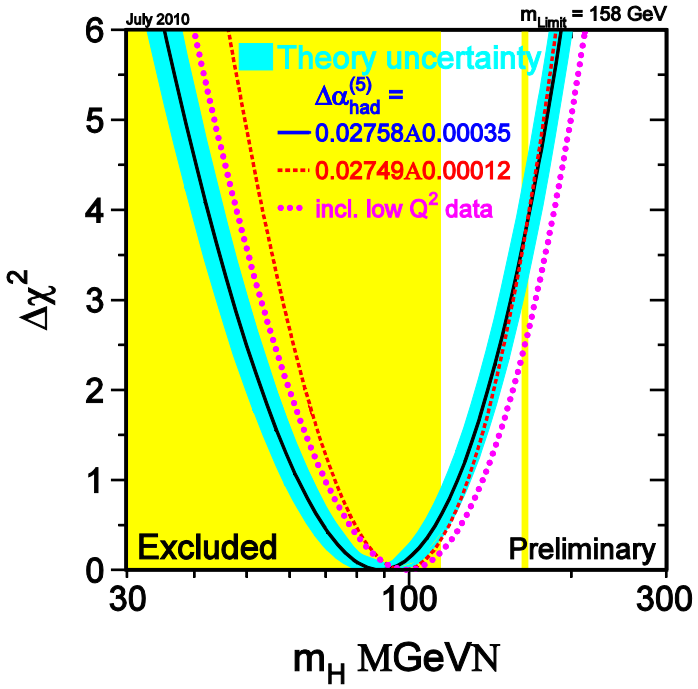
Legacy measurement for a while

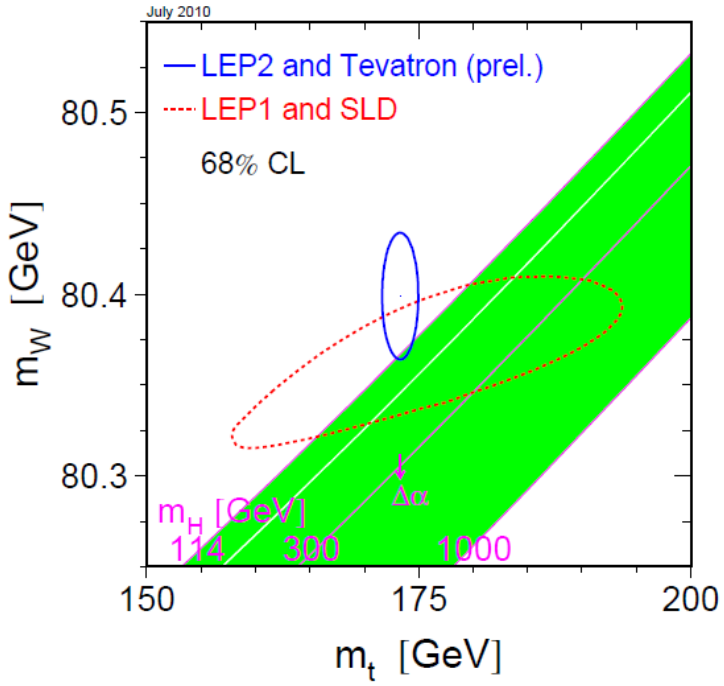
All results are consistent each others

Global EWK fit and Higgs constraints

LEP Electro Weak Working Group July 2010 Update

http://lepewwg.web.cern.ch/LEPEWWG/





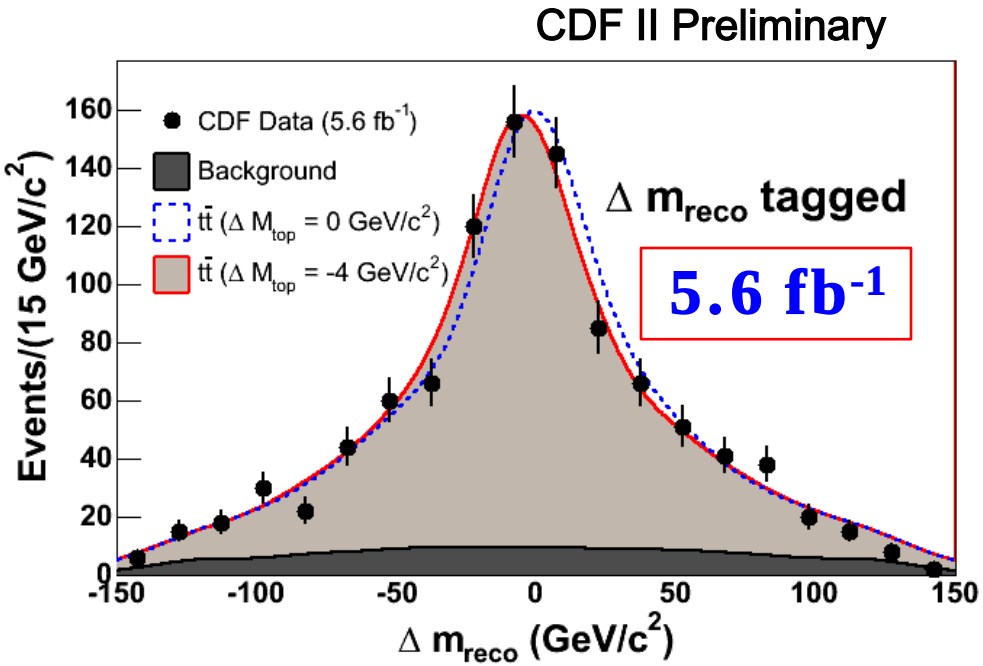
$$m_H = 89^{+35}_{-26}\ \mathrm{GeV/c^2} \qquad m_H < 158\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

$$m_H < 185\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

With direct limit from LEPII

t and $\bar{t}$ mass difference

- If CPT is conserved, ΔM_{top} should be zero (SM)
- We break this assumption and measure the ΔM_{top}
- We use similar technique to mass measurements



1.0 fb^{-1} **Lepton+Jets**

Matrix Element technique

$\Delta M_{top} = +3.8 \pm 3.7\ GeV/c^2$

PRL 103 (2009) 132001

Lepton+Jets

kinematic reconstruction

$\Delta M_{top} = -3.3 \pm 1.4_{Stat.} \pm 1.0_{Syst.}$

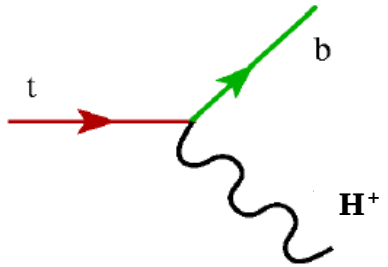
$= -3.3 \pm 1.7\ GeV/c^2$

Why top quark width ?

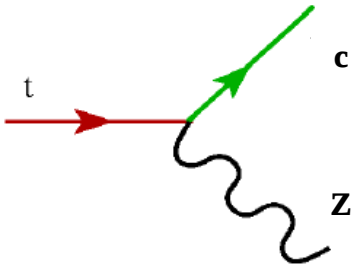
- It is intrinsic parameter of SM
  - Very precise estimation using NLO calculation (~1% precision)

$$\Gamma_t = \Gamma_t^0\left(1-\frac{M_W^2}{m_t^2}\right)^2\left(1+2\frac{M_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right]$$

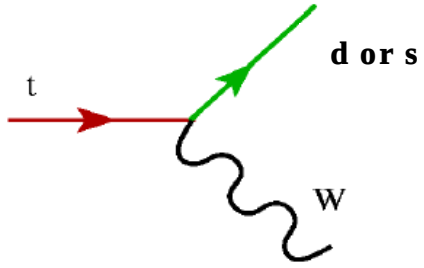
  - 1.3 GeV at M_{top} = 172.5 GeV/c^2
- Deviation from SM indicate new physics
  - Charged Higgs decay, FCNC, and other exotic models



top quark decay



top quark decay



top quark decay

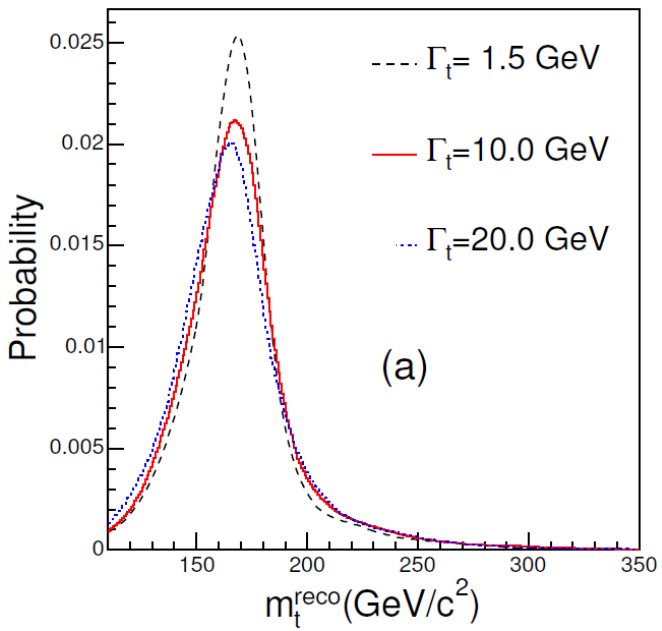
- Resolving Top quark life time

$$\tau = \frac{\hbar}{\Gamma}$$

Short life time (decay before hadronization)

Top quark width

Direct measurement



Use reconstructed top quark mass shape

PRL 105 (2010) 232003

4.3 fb^{-1}

$\Gamma_{top} < 7.4$ GeV @ 95% CL

$0.3 < \Gamma_{top} < 4.4$ GeV @ 68% CL

Indirect measurement

- the single top t-channel cross section

2.3 fb^{-1}

- Ratio of t→Wb/t →Wq

$$\Gamma_t = \frac{\sigma(t-ch)}{Br(t \to bW)} \cdot \frac{\Gamma(t \to bW)_{SM}}{\sigma(t-ch)_{SM}}$$

Γ_{top} = 1.3 GeV @SM

$\Gamma_{top} = 1.99\ ^{+0.65}_{-0.55}$ GeV

$\tau_{top} = 3.3\ ^{+1.3}_{-0.9}\ 10^{-25}$sec $< \tau^{had.}$

PRL 106 (2010) 022001

Spin Correlation

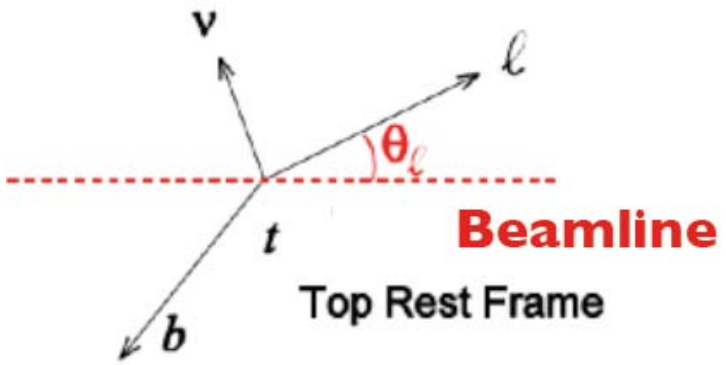
- Top quark decay before hadronization – Spin information of top quark passed to decay products

SM prediction $$\kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}} \approx 0.78$$

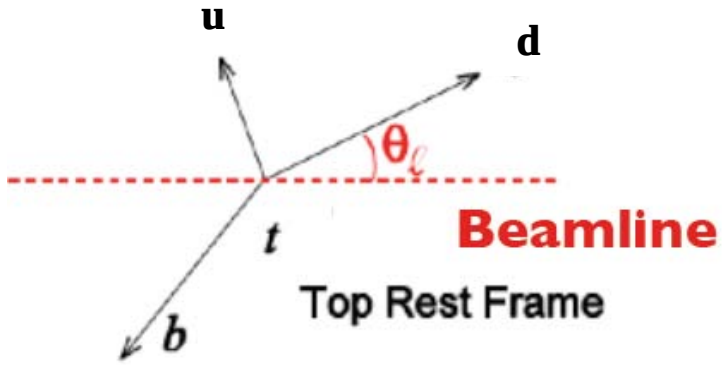
- κ is related with angles of decay products

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1-\kappa\cos\theta_1\cos\theta_2}{4}$$

- where



or



Spin Correlation

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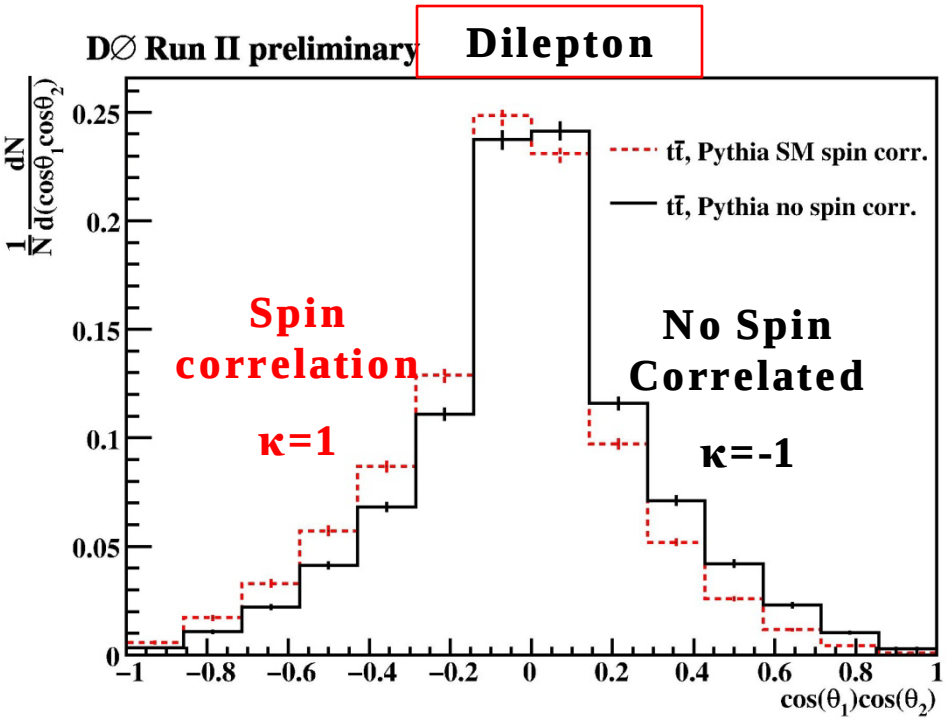
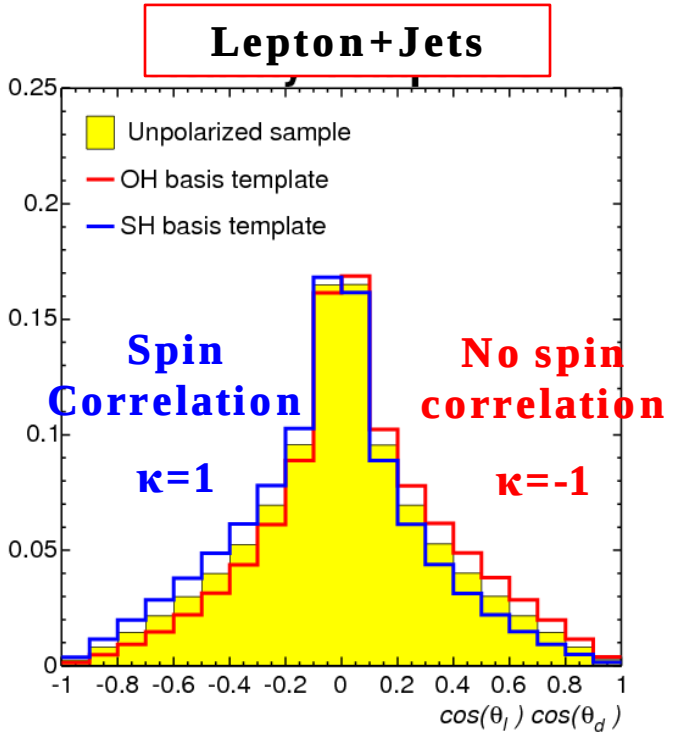
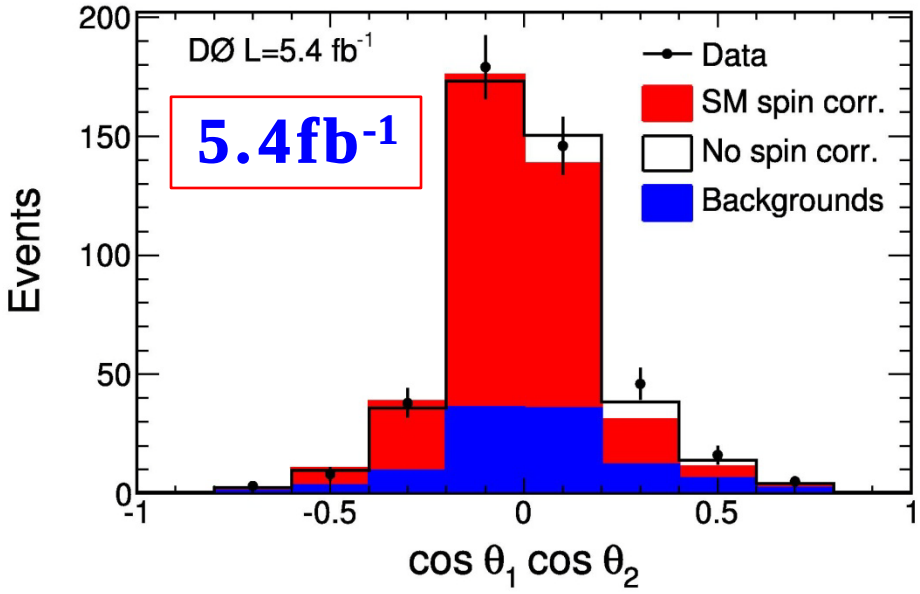
$$\textbf{SM prediction}\quad \kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}} \approx 0.78$$





Spin Correlation

Dilepton

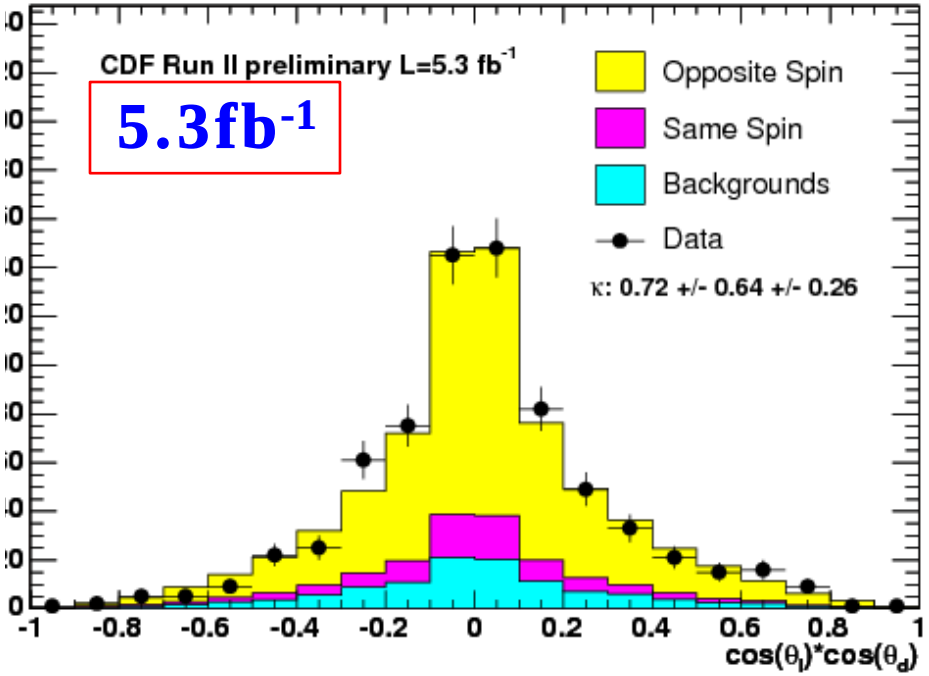


$\kappa = 0.21^{+0.39}_{-0.41}$

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

2.8fb^{-1}

Lepton+Jets



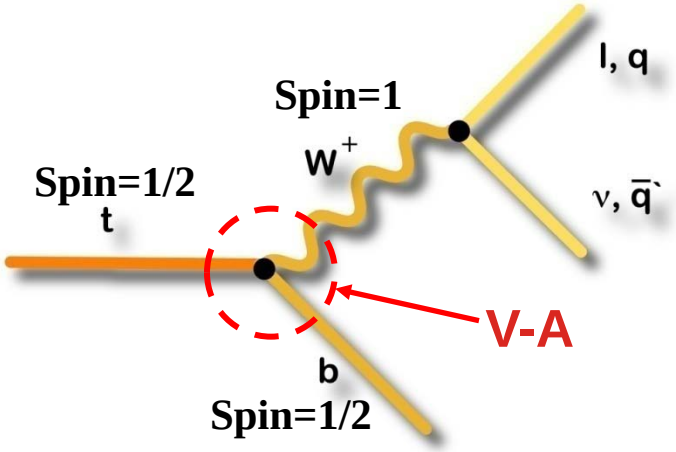
$\kappa = 0.72 \pm 0.62 \pm 0.26$

$\kappa_{SM} = 0.78$

PRD83 (2011) 031104

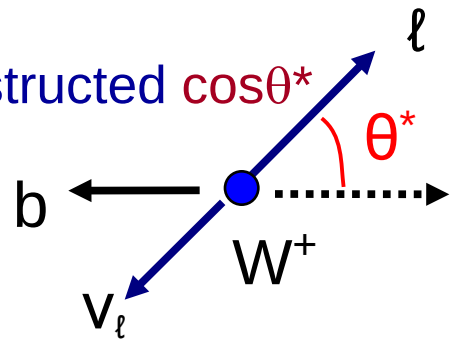
W Helicity

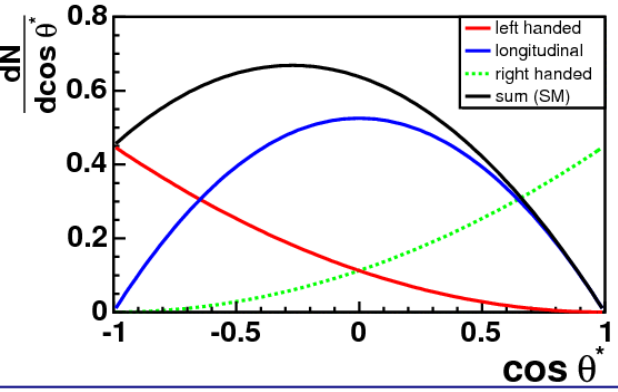
- The SM top decays via EW interaction
  - Top decays as a bare quark ⇒ spin information transferred to final state particles



- V-A coupling predict
  - f_0 = 0.7 (longitudinal polarization)
  - f_+ = 0 (right handed polarization)
  - f_- = 0.3 (left handed polarization)

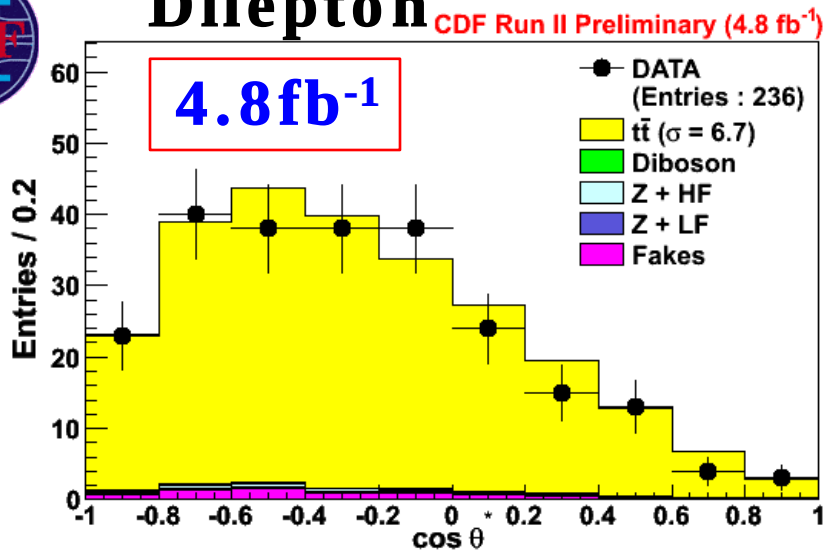
- Measuring the fraction of longitudinally polarized W bosons
  - Reconstructed cosθ*





W Helicity

Dilepton



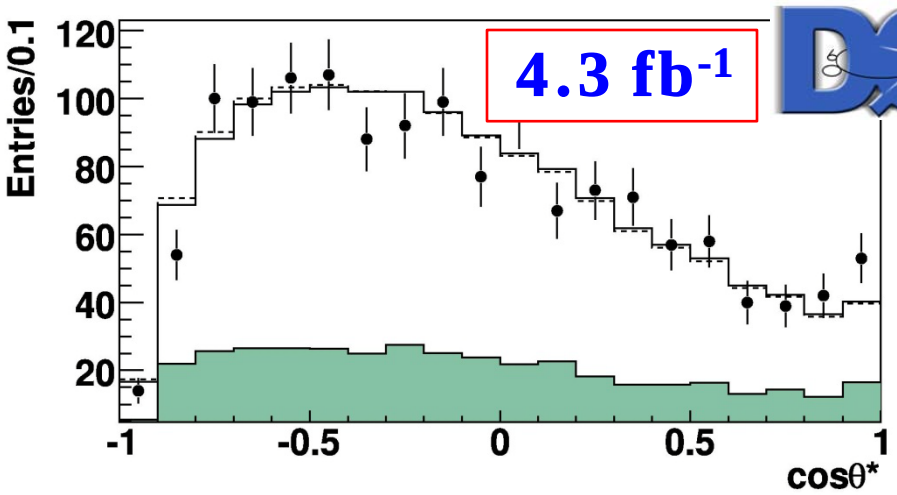
$f_+ = -0.12^{+0.12}_{-0.11}$

$f_0 = 0.78^{+0.20}_{-0.21}$

$f_+(SM) = 0$

$f_0(SM) = 0.7$

Lepton+Jets & Dilepton



$f_+ = 0.02 \pm 0.05$

$f_0 = 0.67 \pm 0.10$

Lepton+Jets

$f_+ = -0.15 \pm 0.13$

$f_0 = 0.88 \pm 0.09$

2.7 fb^{-1}

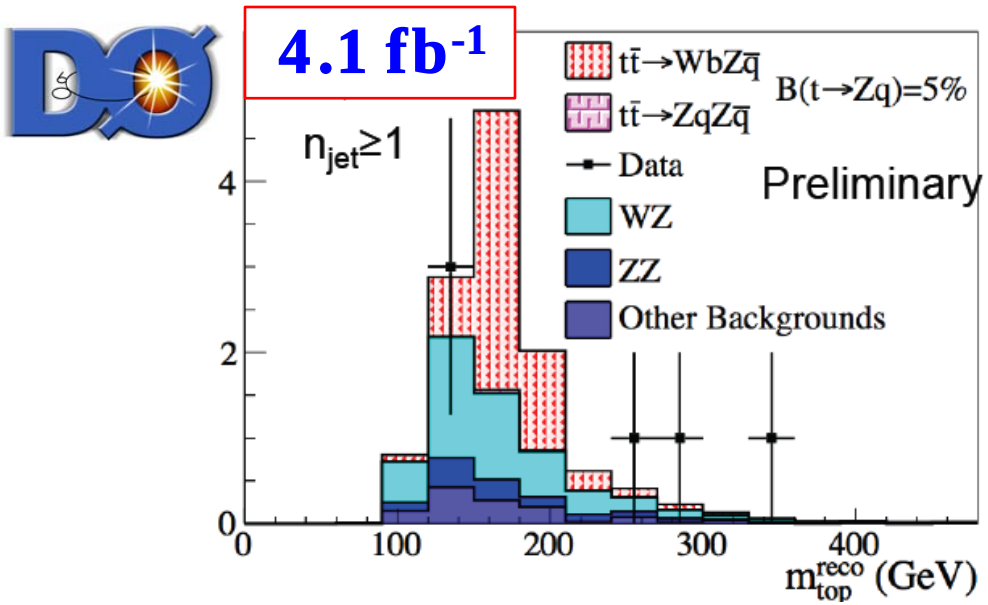
PRL 105 (2010) 042002

Consistent with SM @ 98% level

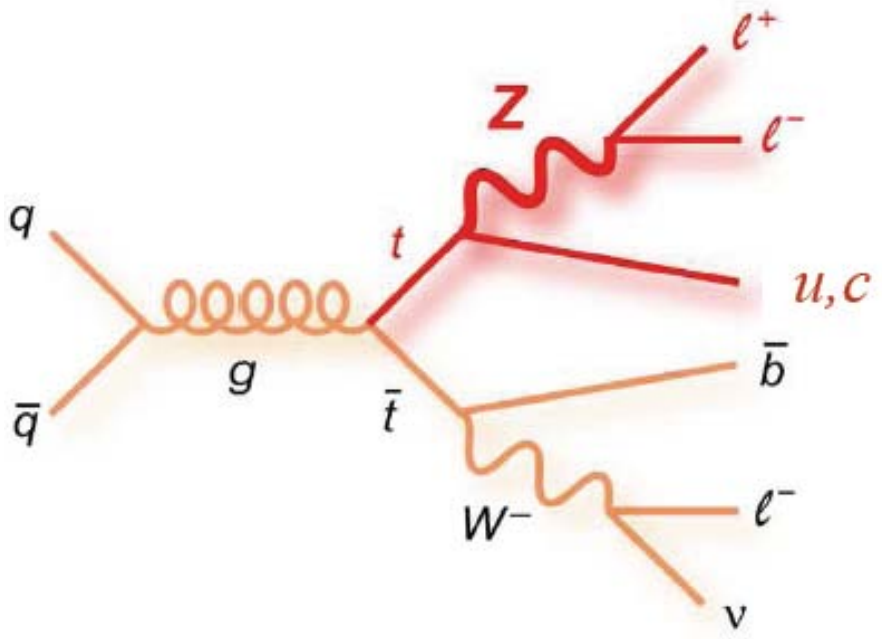
arXiv:1011.6549

Flavor Changing Neutral Current (FCNC)

- Top FCNC is extremely small in SM ~ O(10^{-14})
- Beyond SM : up to O(10^{-4})
- Any signal = new physics



Br(t→Zq)<3.3% @ 95% CL



- Two lepton channel
- Hadronic decay W

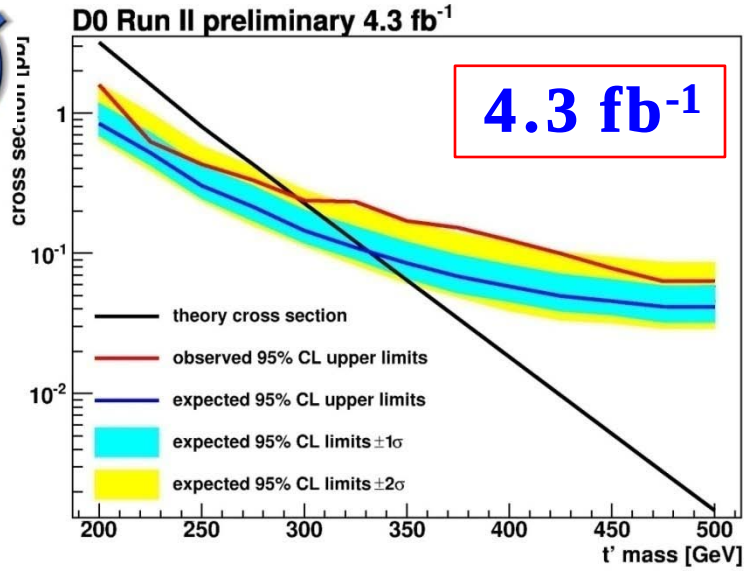
1.9 fb-1

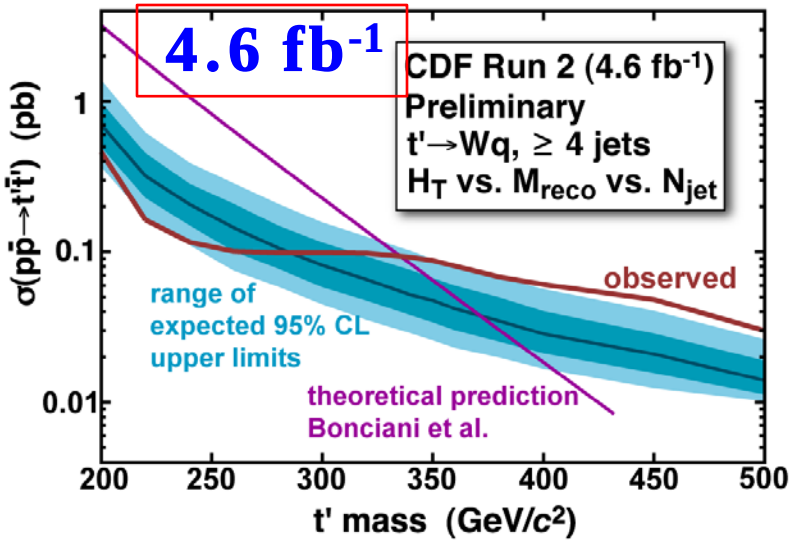
Br(t→Zq)<3.7% @ 95% CL

PRL 101 (2008) 192002

Fourth generation top-like quark search

- Why it was only three generation?
  - ❖ Fourth generation top-like quark
- 100% t'→Wb but, more massive
- Two variables (reconstructed t' mass, scalar sum of the transverse energy in the event (H_T))



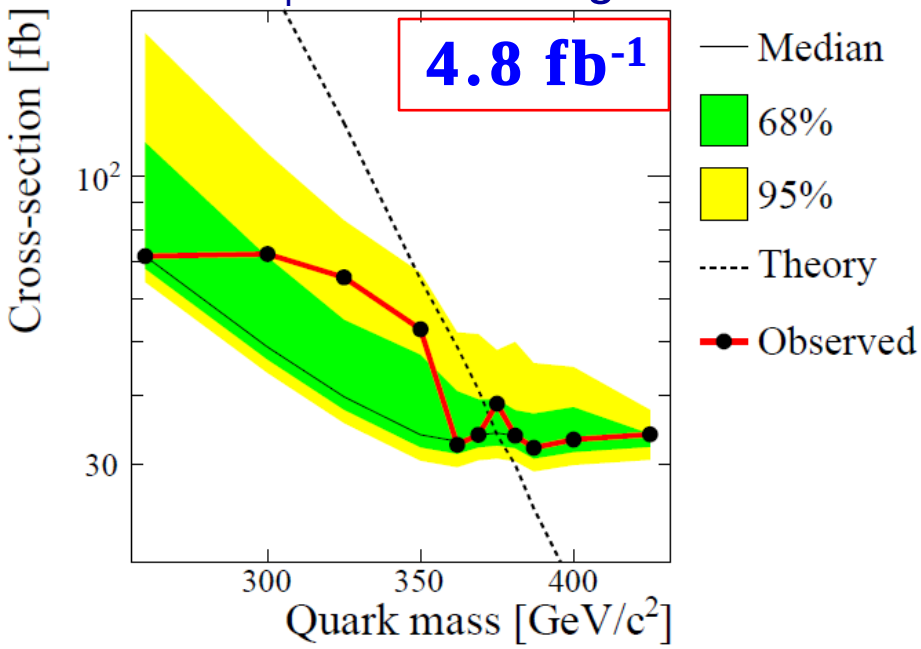


$m_{t'} > 296$ GeV @ 95% CL $m_{t'} > 335$ GeV @ 95% CL

b' and exotic t'

100% b'→Wt, so four W and two b final state

- Very energetic and large jet multiplicities
- We use H_T to extract signal

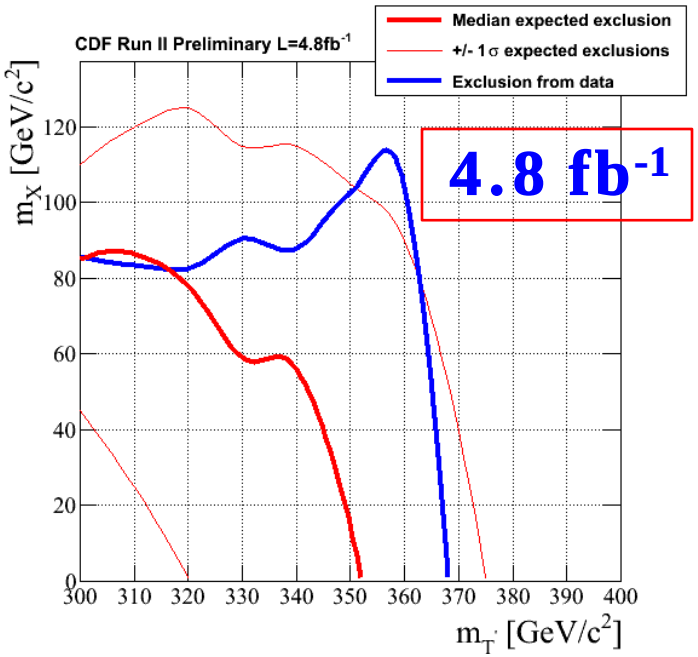


$m_{b'} > 372$ GeV @ 95% CL

arXiv:1101.5728

100% t'→tX where X is invisible (dark matter candidate)

- Use transverse W mass

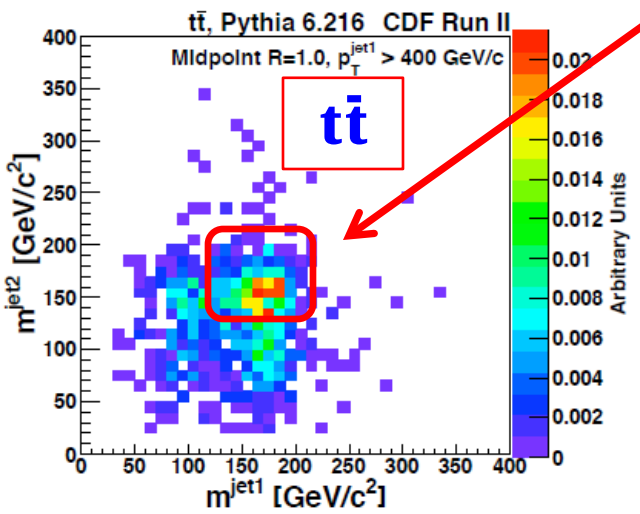


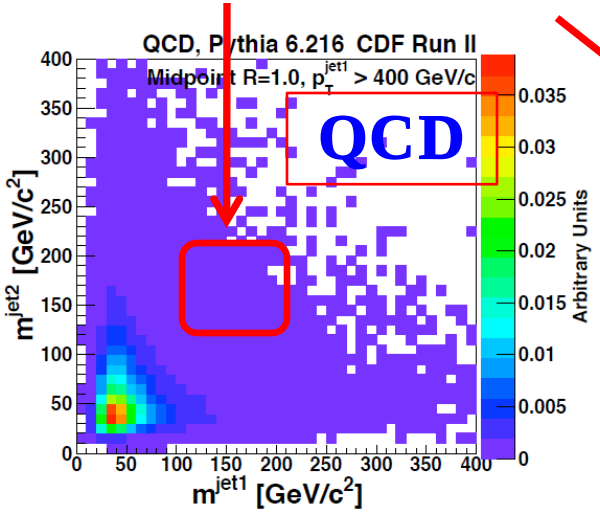
$m_{t'} < 360$ GeV@ 95% CL for $m_X < 80$ GeV (exclusion)

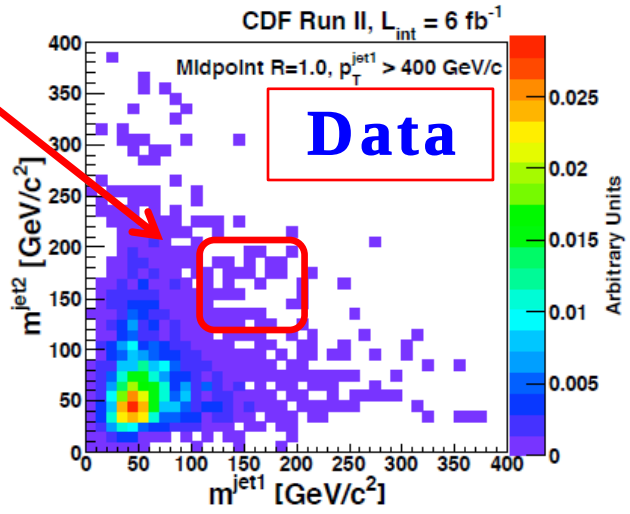
Boosted Top search

- Search for massive top-jets in high p_T inclusive jet sample (p_T > 400 GeV, 130GeV<m_{jet}<210GeV)
  - Interesting to test pertubative QCD at high P_T region
  - Have MC tune and transfer to LHC
  - Resonance productions enhance the boosted tops

Search Window







Expected : $N_{t\bar{t}}$=5±1 N_{QCD}=44±15 Observed : N_{data} = 58

$\sigma_{t\bar{t}}$ (p_T>400 GeV) < 40 fb @ 95% CL

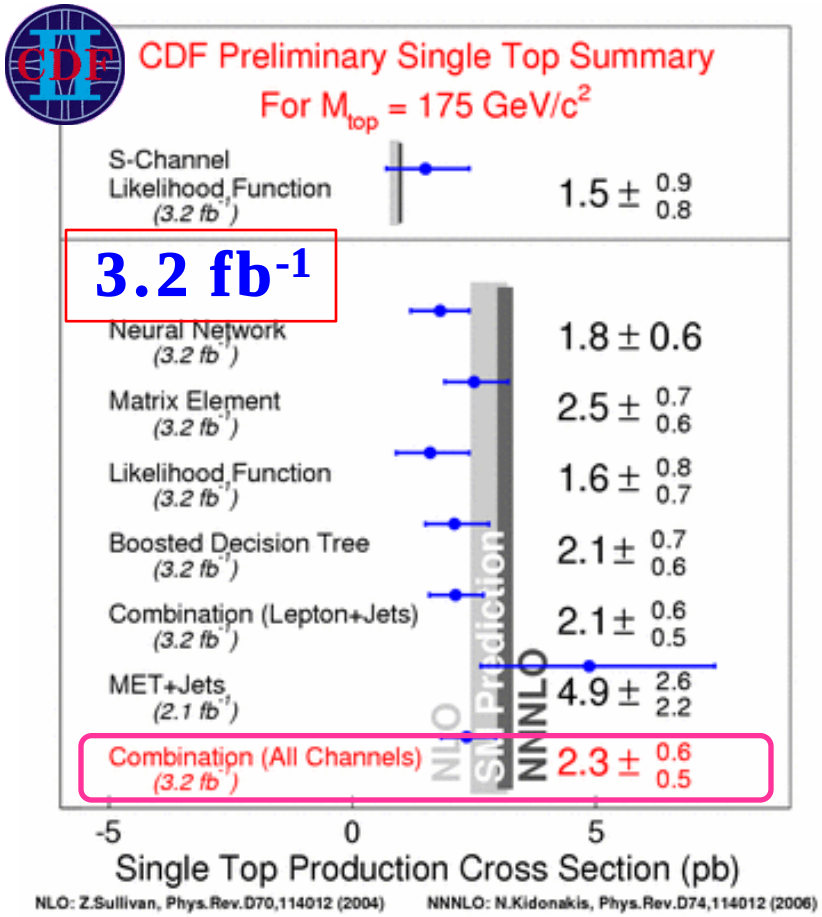
Conclusion

- Top quarks are well being studied at CDF and D0
  - ❖ We are performing rigorous study for top quark
- Top physics is an era of the precision measurements
  - ❖ Order of 1,000 top events are obtained
- Many measurements will be complement for LHC results
- Tevatron's legacy is still ongoing
  - ❖ We will have twice of data soon and may have the most interesting results

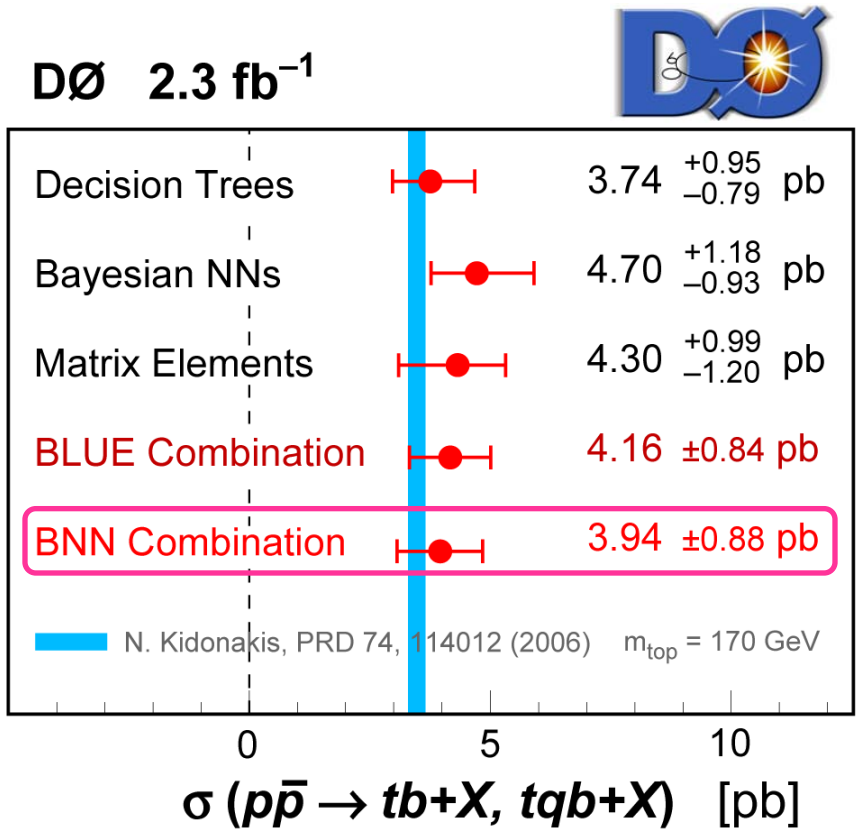
http://www-cdf.fnal.gov/physics/new/top/top.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/top.htm

Single top observation



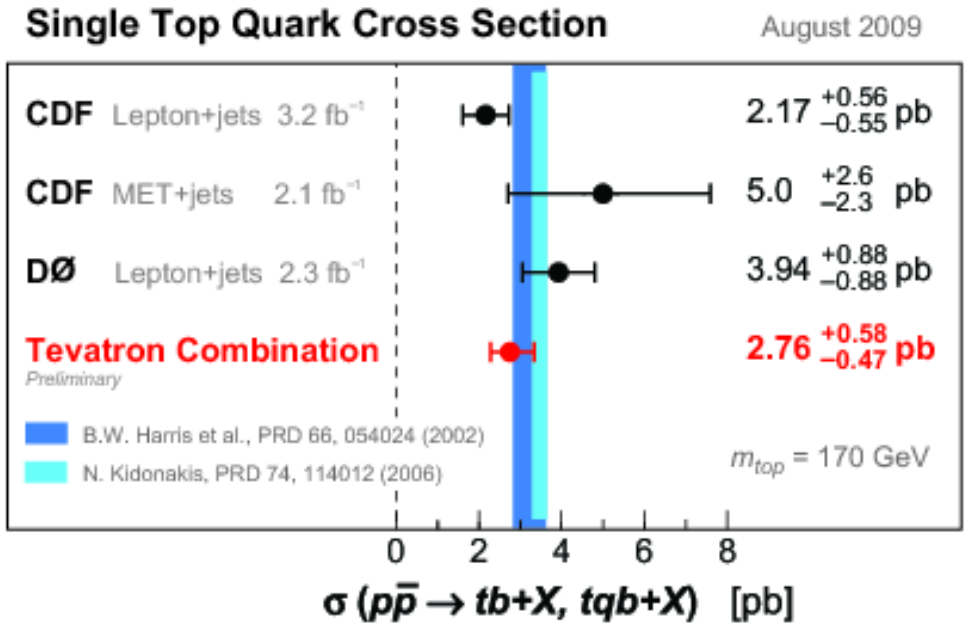
PRL 103 (2009) 092002

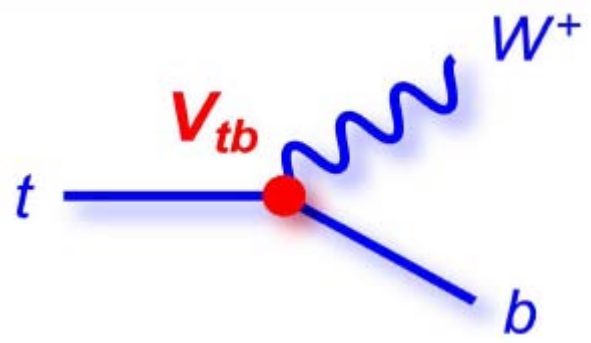


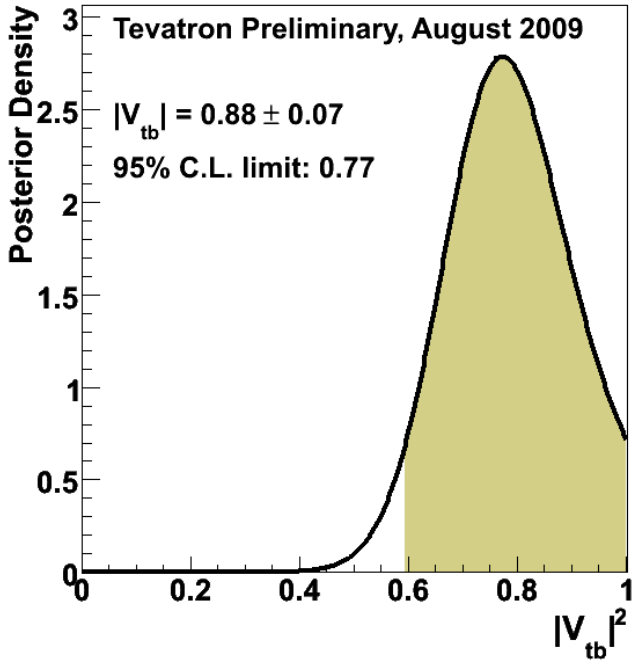
PRL 103 (2009) 092001

First Observation of Single Top

Tevatron combination







$$|V_{tb}| = 0.88 \pm 0.07$$

95% C.L. limit : 0.77