Top quark mass and property measurements at Tevatron

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On behalf of the CDF and D0 collaborations

Hadron Collider Physics 2011

Top production and decay

Production

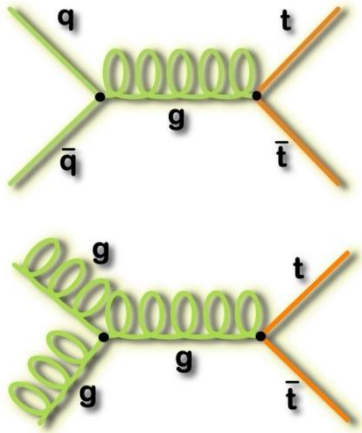
Pair production

Tevatron

~85%

~7.5 pb

~15%



LHC

~20%

~160 pb

~80%

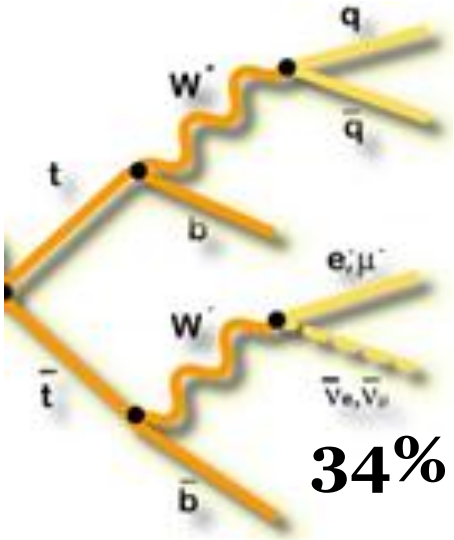
And Electroweak single top

See E. Shabalina's talk

Decay

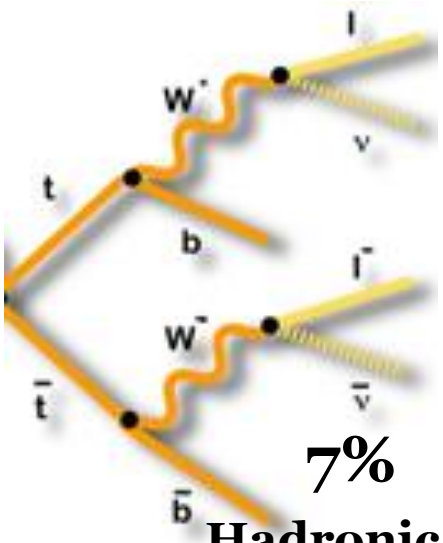
t→bW ~100%

Lepton+Jets



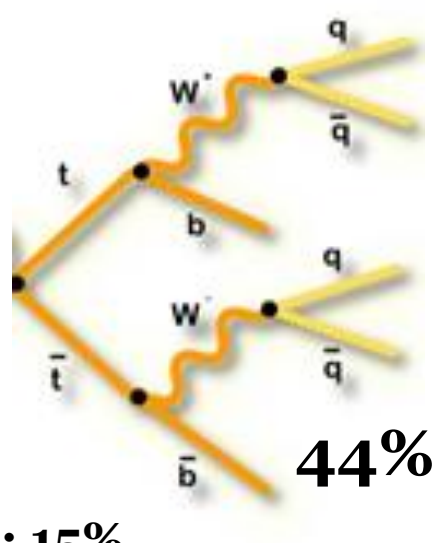
34%

Dilepton



7%

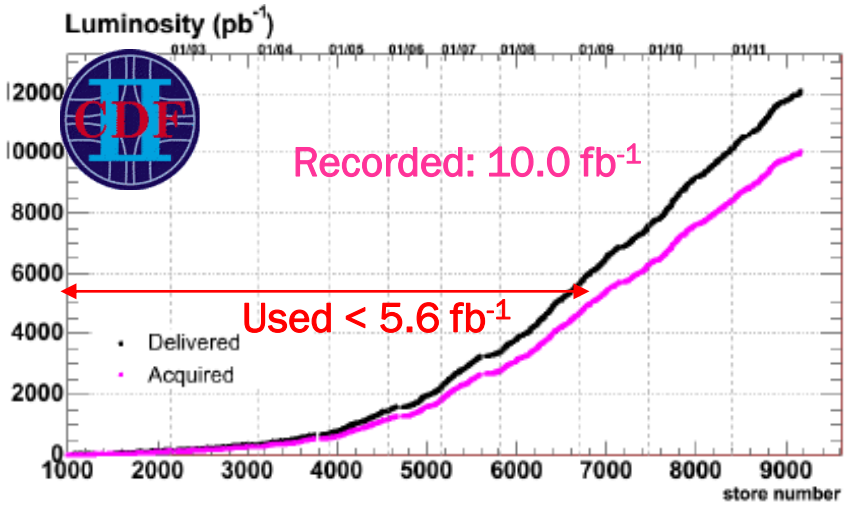
All Jets

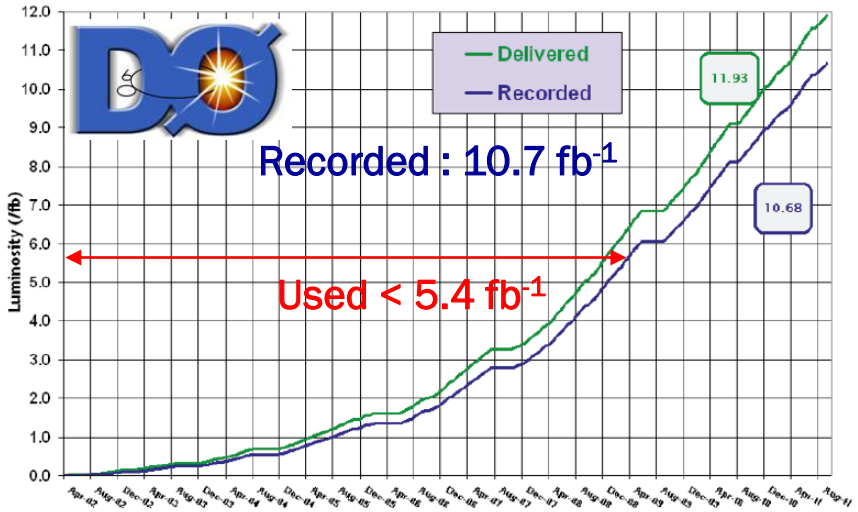


44%

Hadronic tau : 15%

Tevatron and Top Physics



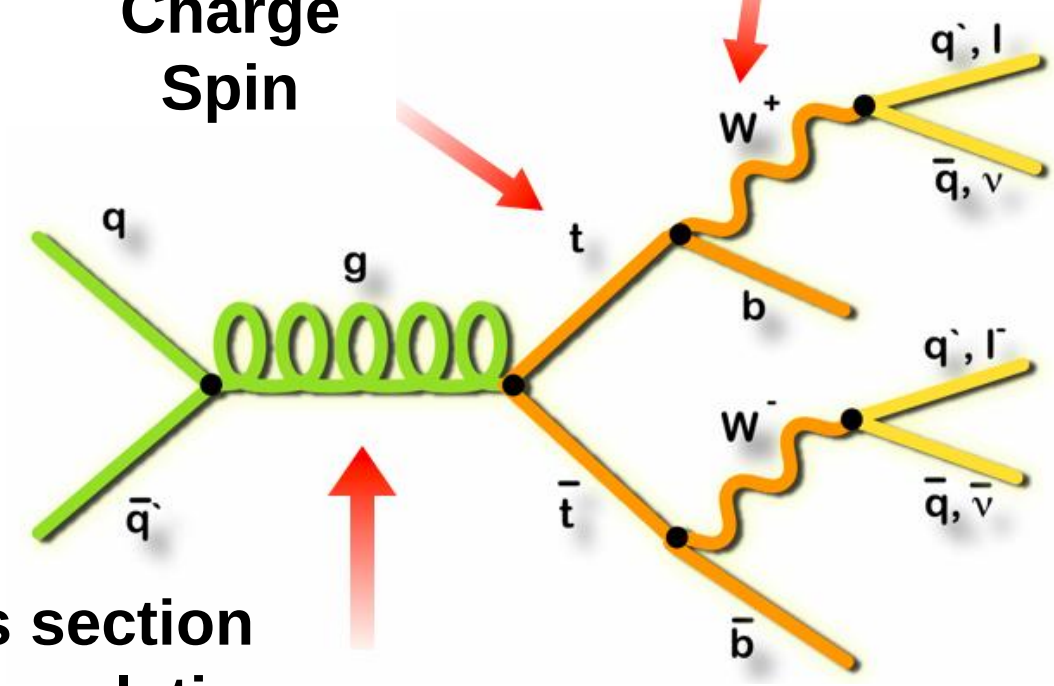


- Tevatron was shutdowned
  - ❖ Have > 10 fb^{-1} in each experiment
- LHC accumulated more than 5fb^{-1} of data
  - ❖ Order of magnitude larger top events
- Tevatron top physics
  - ❖ Best result
    - ❑Well known detector, small systematics (mass)
  - ❖ Uniqueness
    - ❑ppbar collider, different energy (Forward backward asymmetry, color reconnection)
  - ❖ Complementary
    - ❑Many properties and searches

What we are interested in?

W helicity
Anomalous coupling
FCNC
Charged Higgs

Mass
Width
Charge
Spin



Cross section
Spin correlation
FB asymmetry
New particle production

Production mechanism
Resonance Production

This talk

W helicity

Anomalous coupling

FCNC

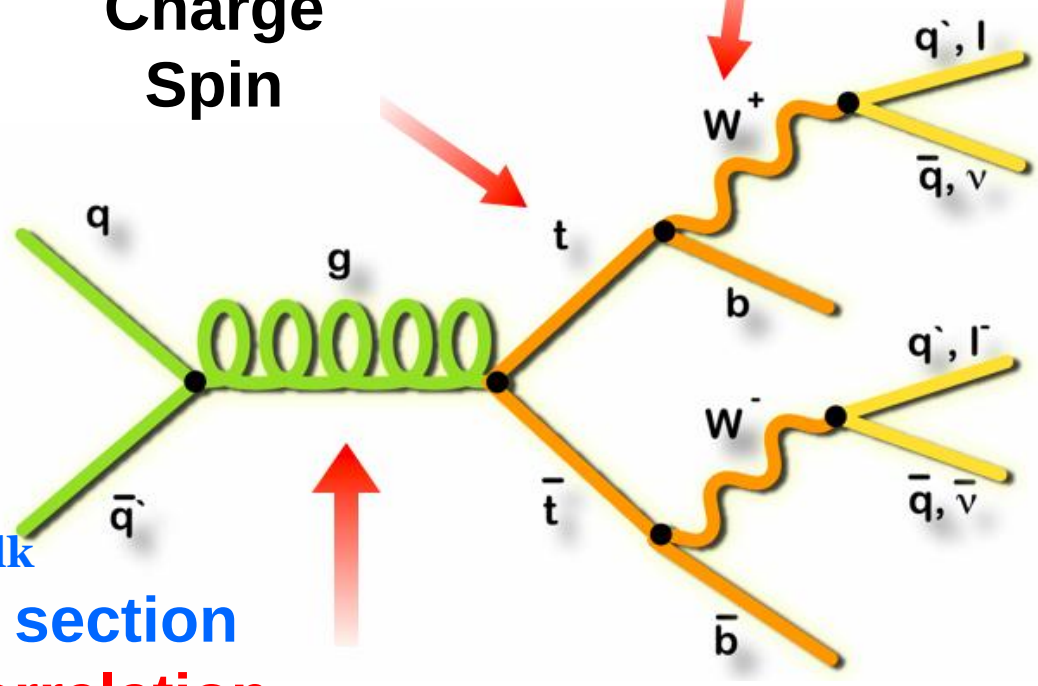
Charged Higgs

Mass

Width

Charge

Spin



See E. Shabalina's talk

Cross section

Spin correlation

FB asymmetry

New particle production

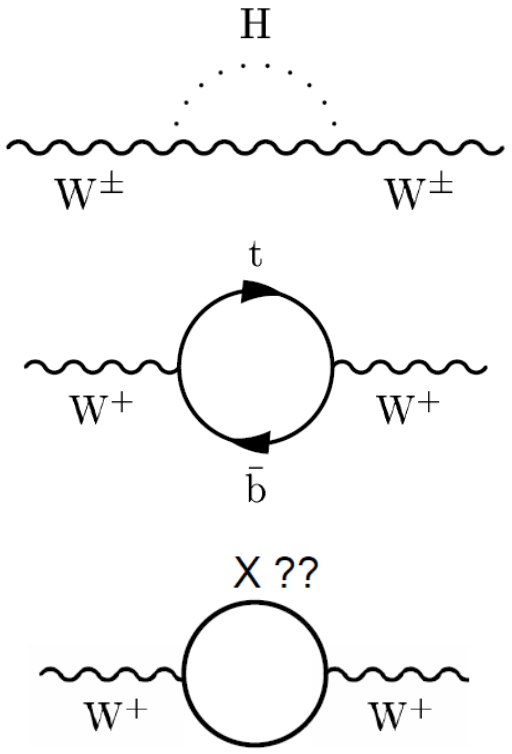
Production mechanism

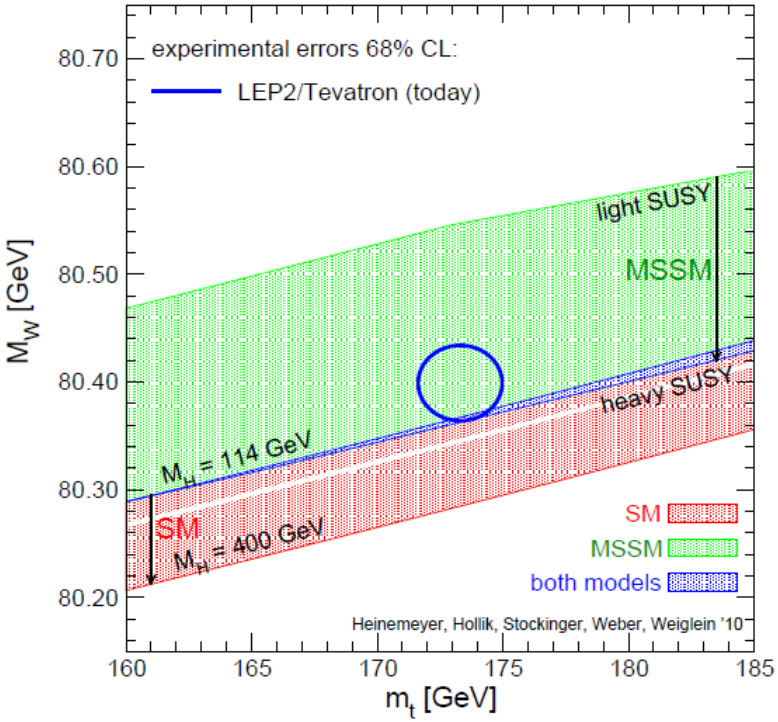
Resonance Production

See U. Heintz's talk

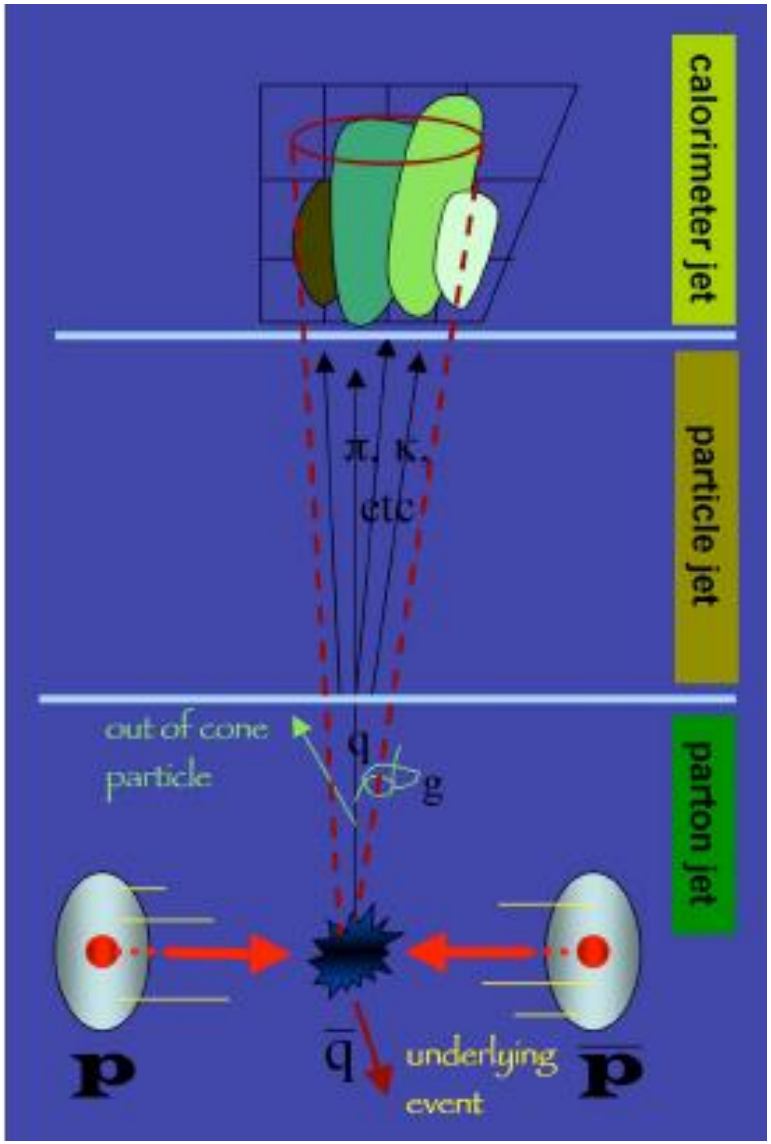
Top quark mass

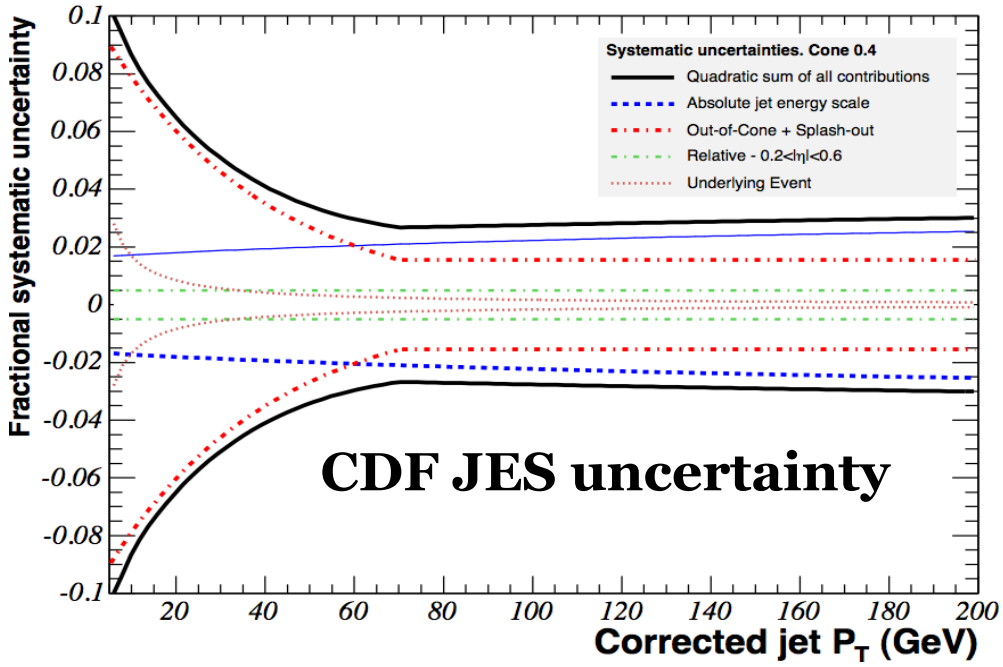
- Top quark mass is not predicted by SM
- Can constrain SM Higgs boson mass
  - ❖ Important contribution in radiative correction of W
  - ❖ Important test of SM

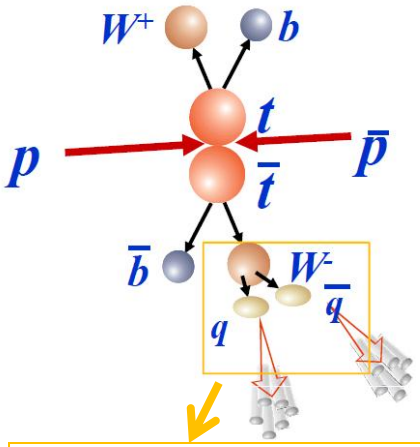




Jet energy scale (JES)







Measured JES uncertainty

Lepton+jets : 0.9 GeV/c²

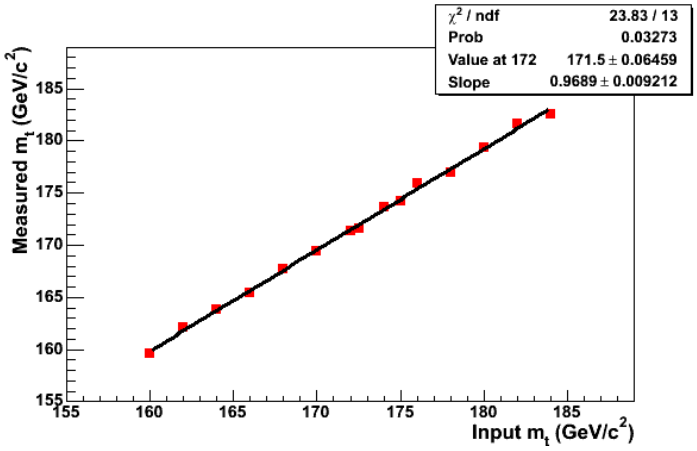
Dilepton : 2.9 GeV/c²

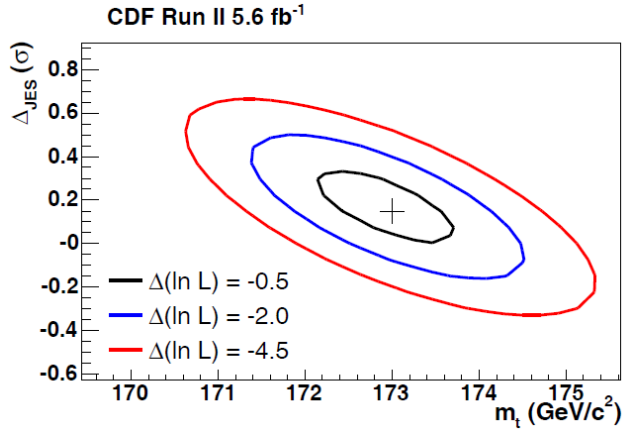
(CDF 5.6 fb^{-1}, template method)

In situ JES calibration

CDF lepton+jets

- 5.6 fb^{-1} data – 1263 events
  - We select events having 1 lepton (p_T>20GeV/c), four jets (E_T>20GeV), and large missing energy (MET>20GeV)
  - At least one b-tagged jet
  - Additional NN based selection
- Matrix element (ME) technique
  - Transfer function was parameterized by eta and jet mass for b-jet and light jet
- *In situ* JES calibration
- This is the most precise top quark measurement to date





PRL 105 (2010) 252001

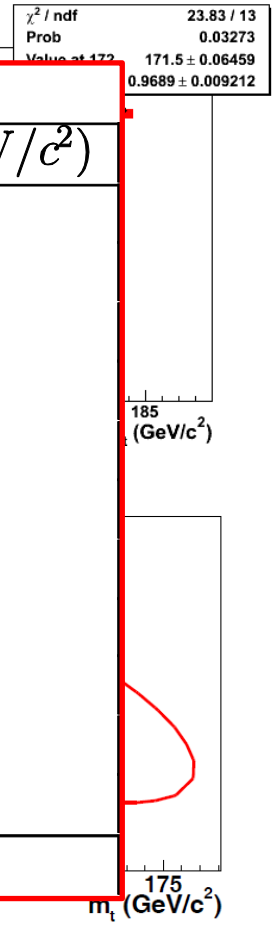
$$173.0 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.9(\text{syst})\ \text{GeV}/c^2$$
$$= 173.0 \pm 1.2\ \text{GeV}/c^2$$

CDF lepton+jets

- 5.6 fb^{-1} data – 1263 events
  - ❖ We sel
    (p_T>20
    large m
  - ❖ At leas
  - ❖ Additio
- Matrix el
  - ❖ Transfe
    and jet
- *In situ* JE
- This is th
  measurement to date

CDF Run II Preliminary, 5.6 fb^{-1}

Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.10
MC generator	0.37
ISR and FSR	0.15
Residual JES	0.49
b-JES	0.26
Lepton P_T	0.14
Multiple hadron interactions	0.10
PDFs	0.14
Background modeling	0.34
Gluon fraction	0.03
Color reconnection	0.37
Total	0.88

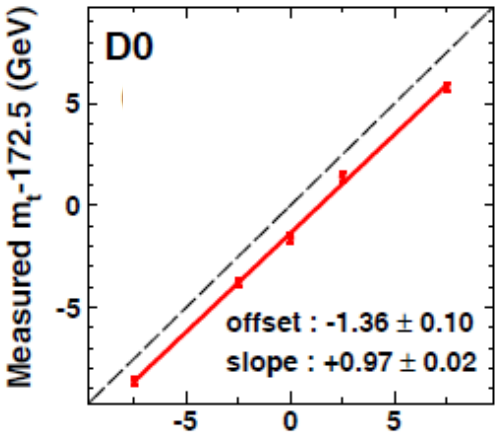


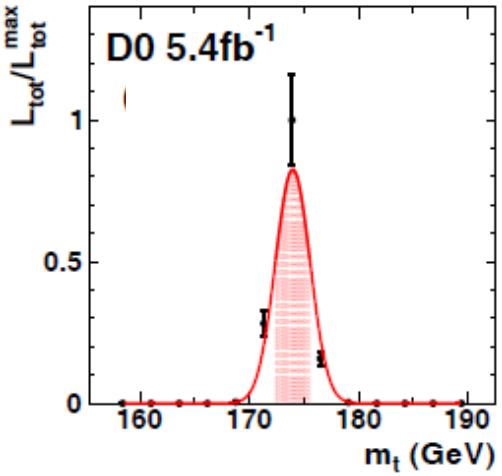
PRL 105 (2010) 252001

173.0 ± 0.7(stat) ± 0.6(JES) ± 0.9(syst) GeV/c^2
=173.0 ± 1.2 GeV/c^2

D0 dilepton channel

- 5.4 fb^{-1} data – 479 events
  - We select events having 2 lepton (p_T>15GeV/c), at least two jets (E_T>20GeV), and large missing energy (MET>40GeV)
  - No b-tagging requirement
- ME technique
- Dominant uncertainties
  - Overall Jet energy scale and b-JES
- This is the most precise top quark mass measurement in dilepton channel to date



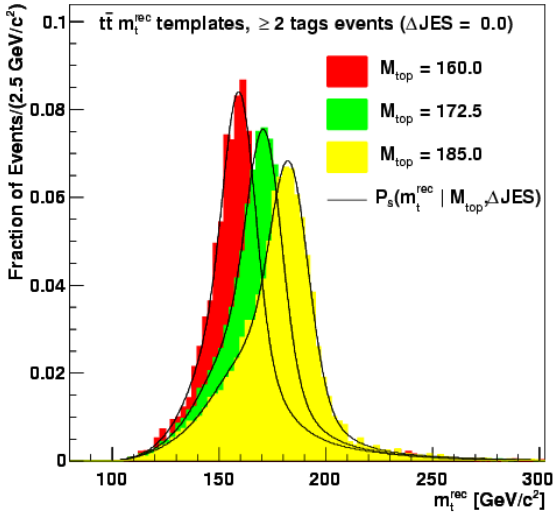


PRL 107 (2011) 082004

$$174.0 \pm 1.8\,(\text{stat}) \pm 2.4(\text{syst})\ \text{GeV}/c^2$$
$$= 174.0 \pm 3.1\ \text{GeV}/c^2$$

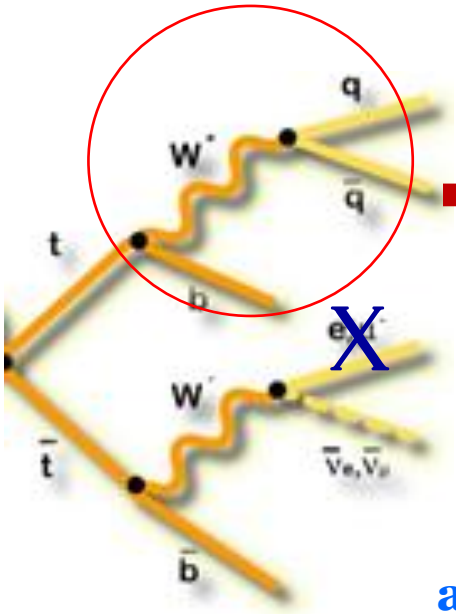
Jets (no lepton) channels

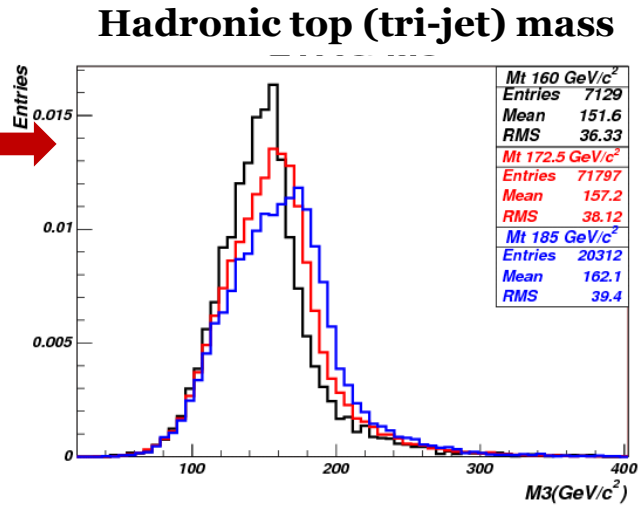
- All Jets channel (5.8 fb^{-1})
  - Six jet final state
  - Neural network training to reject dominant multijet background
  - ~1 S/B ratio for 2tag (~300 signal)



cdfnote 10456

- MET+Jets channel (5.7 fb^{-1})
  - Large MET+four jets final state
  - NN selection for dominant multijet background rejection
  - Large acceptance of tau final state



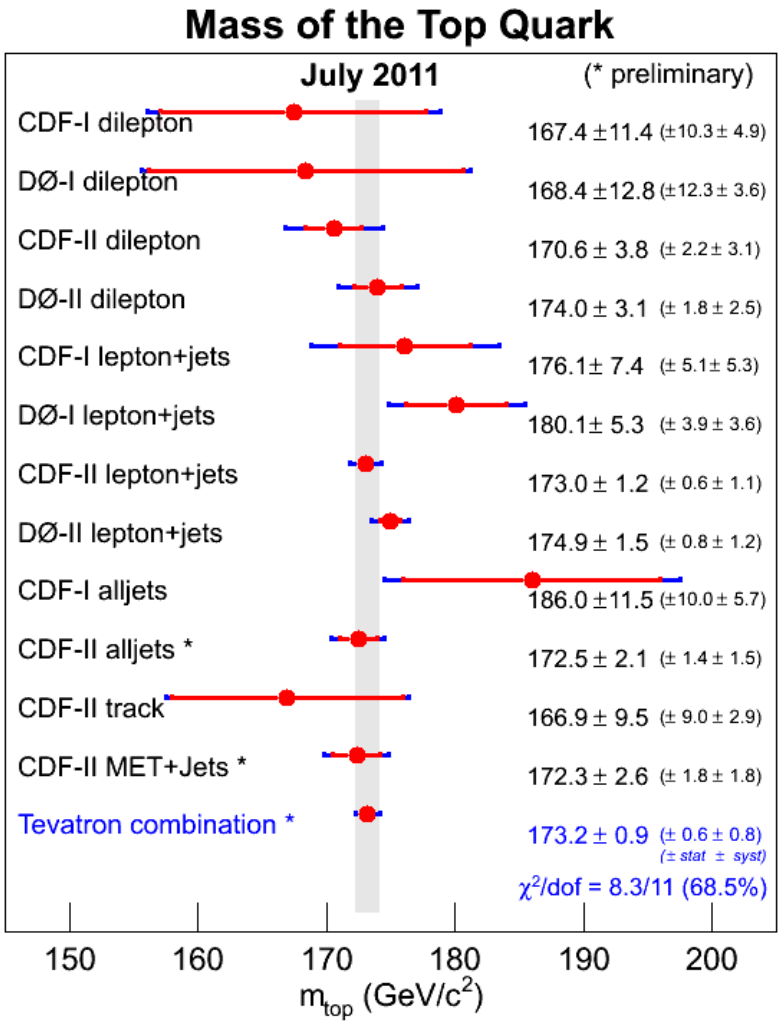


arXiv:1109.1490

172.5±1.4(stat.) ±1.0(JES) ±1.1(syst) =172.5±2.0 GeV/c^2

172.3±1.8(stat.) ±1.5(JES) ±1.0(syst) =172.3±2.6 GeV/c^2

Tevatron Combination and future

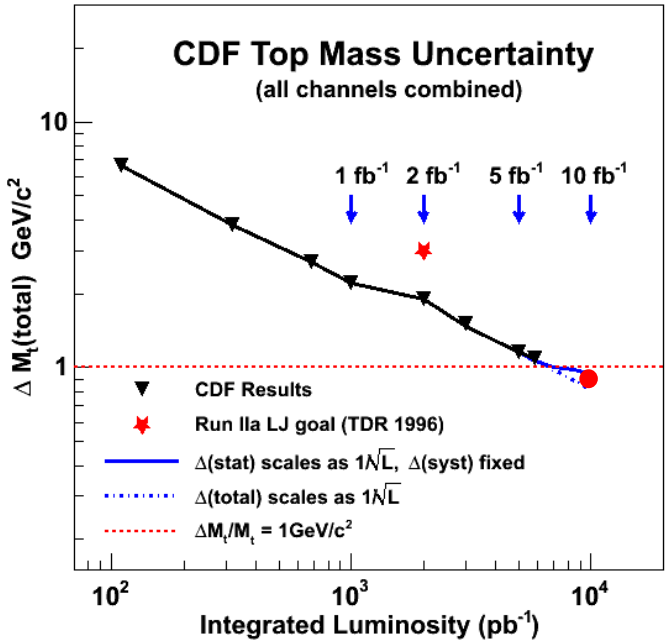


173.2 ± 0.6(stat) ± 0.8(syst) GeV/c^2

Tevatron average = 173.2 ± 0.9 GeV/c^2

~0.54 % Precision

All results are consistent each others

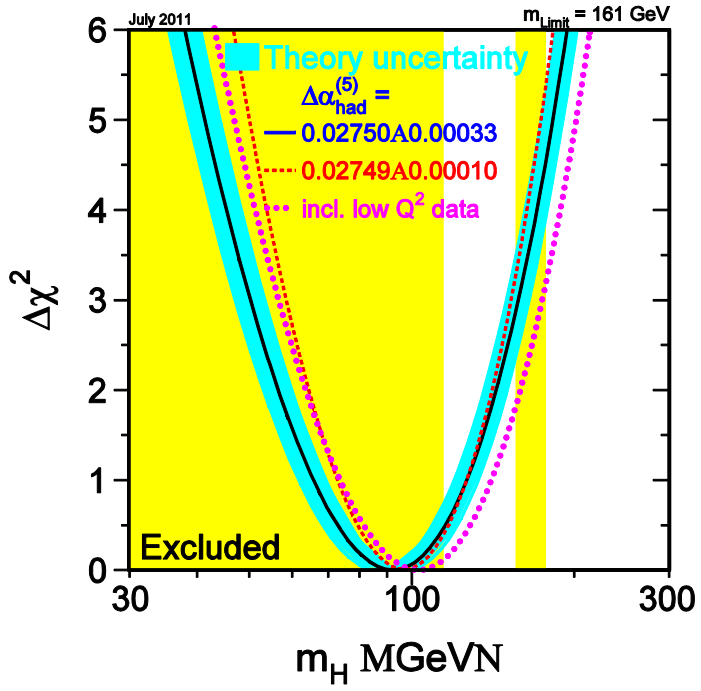


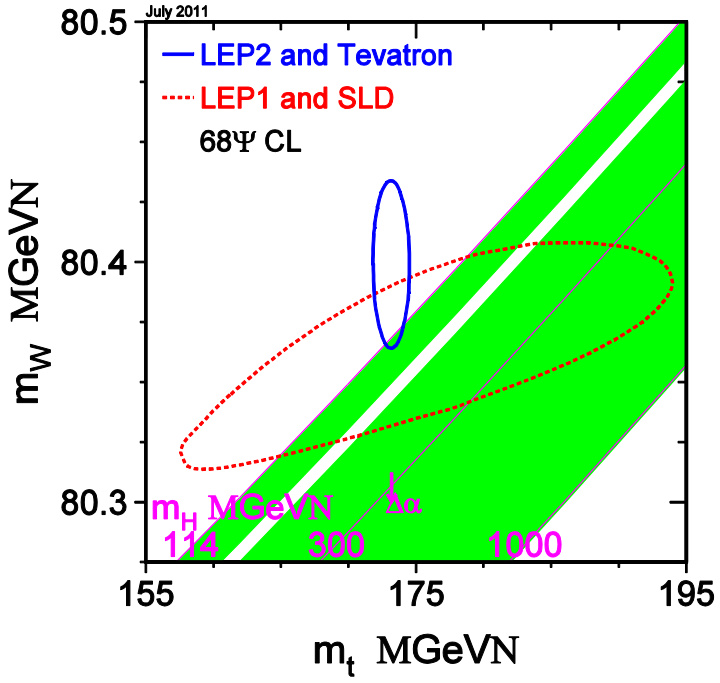
< 1GeV precision in each experiment

Still having extensive effort to improve machinery and systematic understanding

Global EWK fit and Higgs constraints

LEPEWWG, http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2011/





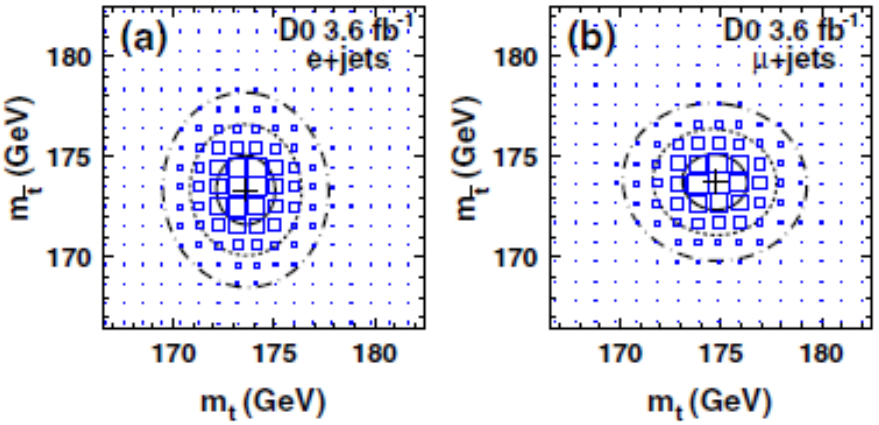
$$m_{\mathrm{H}} = 92^{+35}_{-26}\ \mathrm{GeV/c^2} \qquad m_{\mathrm{H}} < 161\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

$$m_{\mathrm{H}} < 187\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

With direct limit from LEPII

t and $\bar{t}$ mass difference

- If CPT is conserved, ΔM_{top} should be zero (SM)
- We test this assumption by measuring ΔM_{top}
- We use similar technique with mass measurements



Matrix element technique but allow different mass of top and anti-top

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

Kinematic reconstruction

$\Delta M_{top} = -3.3 \pm 1.7$ GeV/c^2

PRL 106 (2011) 152001

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

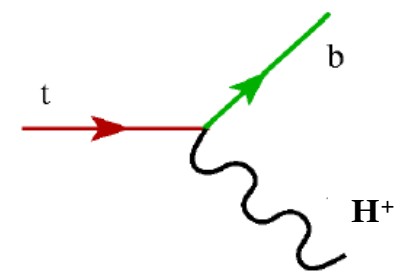
$\Delta M_{top} = +0.8 \pm 1.9$ GeV/c^2

PRD 84 (2011) 052005

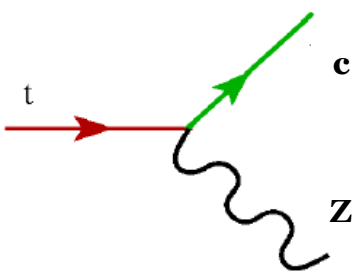
Top quark width

- It is intrinsic parameter of SM
  - ❖ Very precise estimation using NLO calculation (~1% precision)
  - ❖ 1.3 GeV at M_{top} = 172.5 GeV/c^2

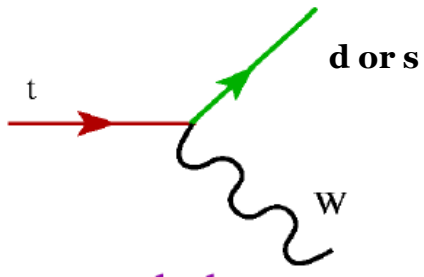
- Deviation from SM indicate new physics
  - ❖ Charged Higgs decay, FCNC, and other exotic models



top quark decay



top quark decay



top quark decay

- Resolving Top quark life time

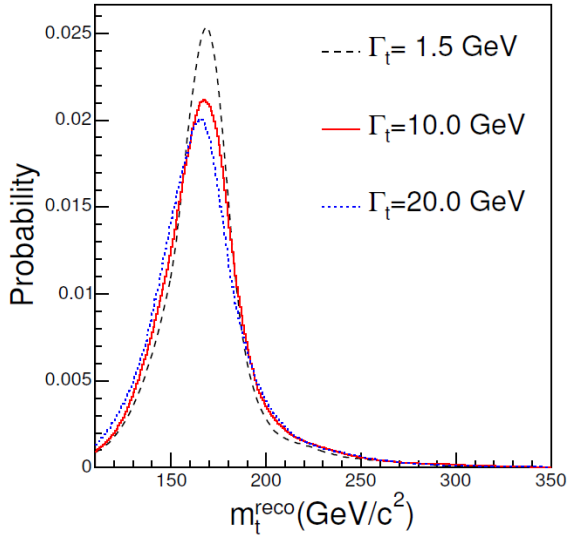
$$\tau = \frac{\hbar}{\Gamma}$$

Short life time (decay before hadronization)?

Top quark width

Direct measurement

Reconstructed top mass



- Use reconstructed top quark mass (RMS distribution)
- No assumption of SM

4.3 fb^{-1}

PRL 105 (2010) 232003

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

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

Indirect measurement

- Assume SM
- the single top t-channel cross section
- Ratio of t→Wb/t →Wq

2.3 fb^{-1}

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

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

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

PRL 106 (2010) 022001

Spin Correlation

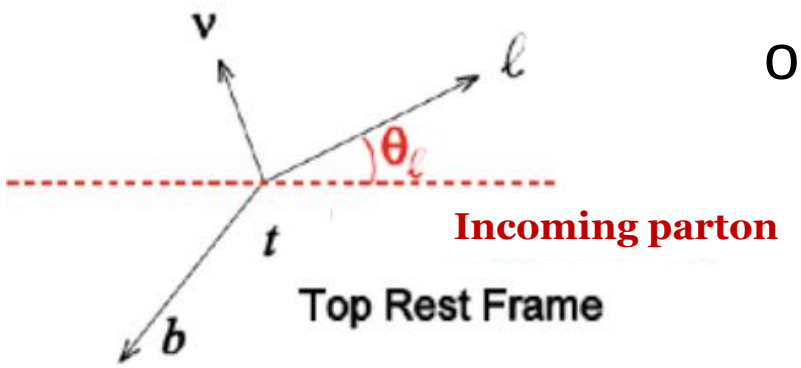
- Top quark decay before hadronization – Spin information of top quark passed to decay products

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

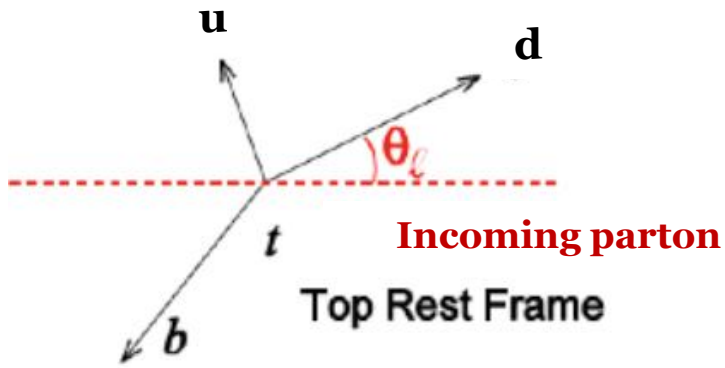
- κ is related with angles of decay products

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

- where



or



Spin Correlation

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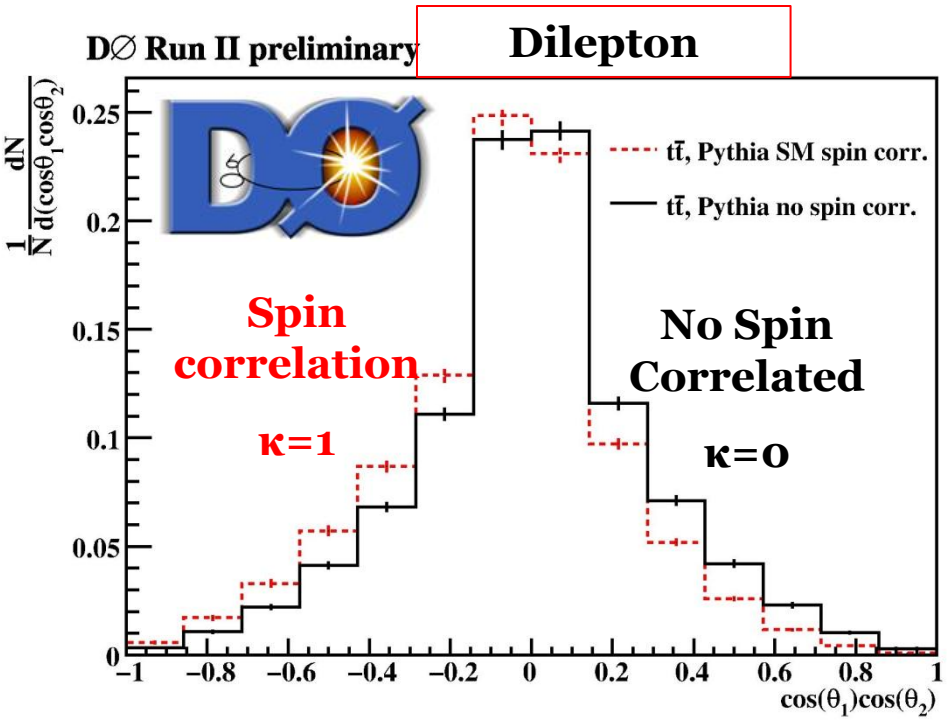
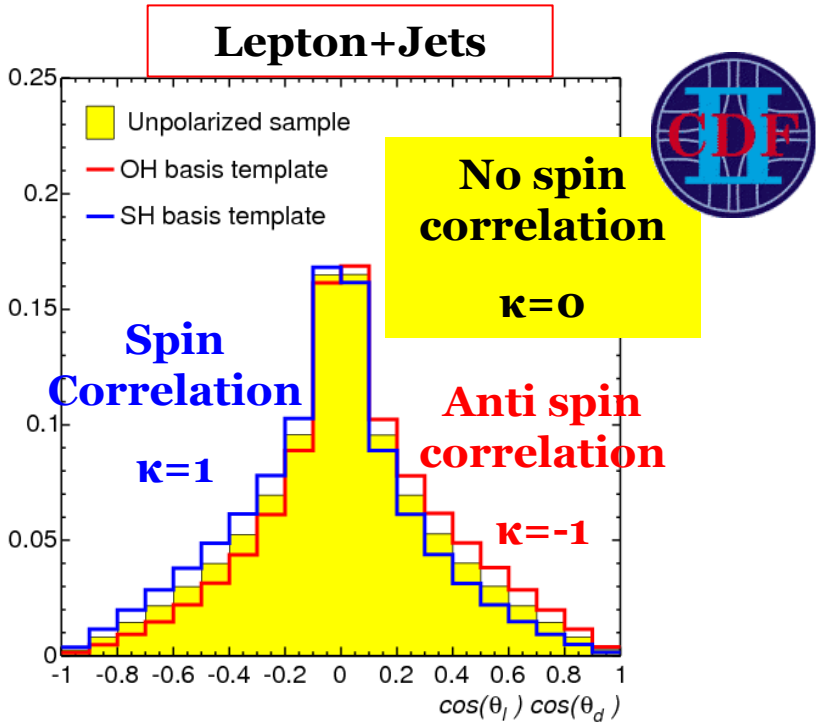
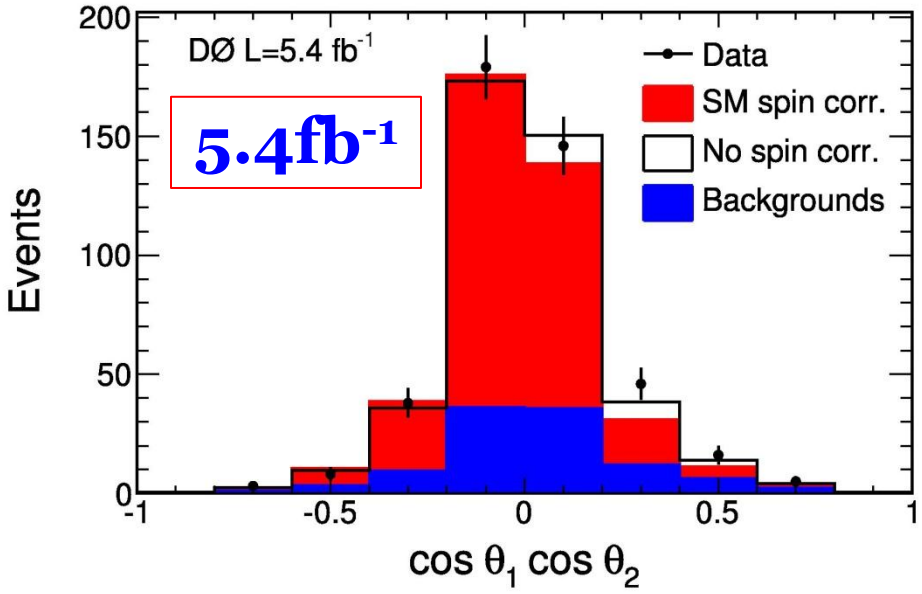
$$\textbf{SM prediction}\quad \kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}} \approx 0.78$$





Spin Correlation

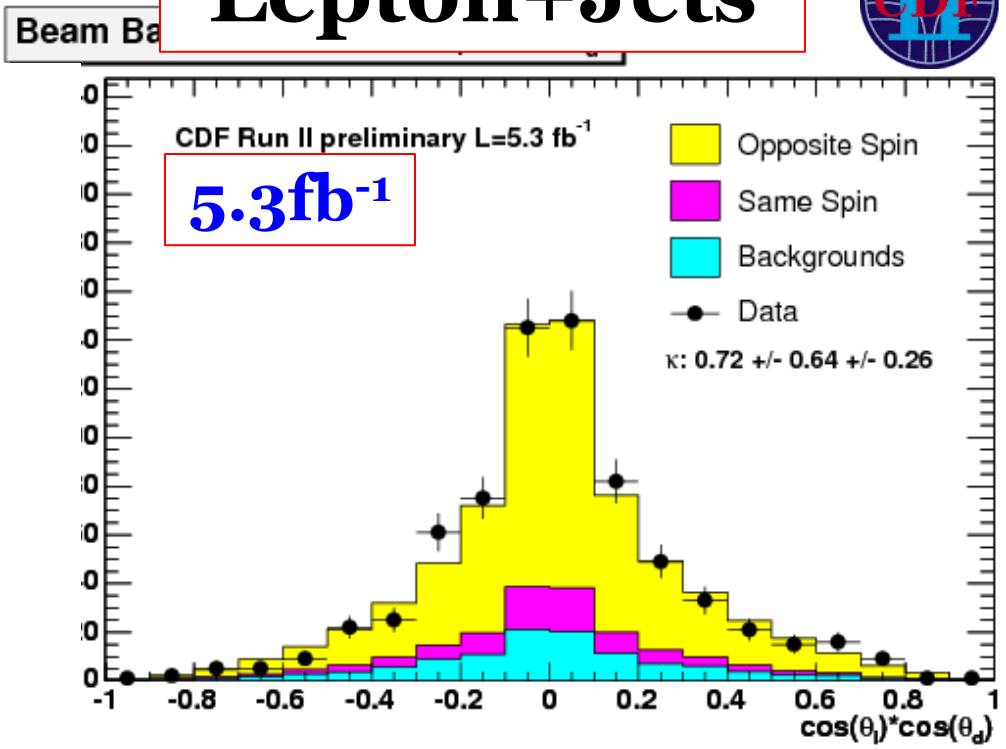
Dilepton



PLB 702 (2011) 16

$\kappa = 0.10^{+0.45}_{-0.45}$

Lepton+Jets



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

$\kappa_{SM} = 0.78$

PRD83 (2011) 031104

Dilepton

2.8fb-1

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

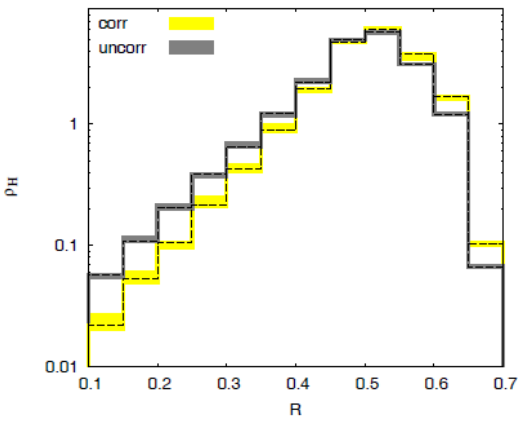
CDF note 9824

Spin correlation with ME method

- Define R

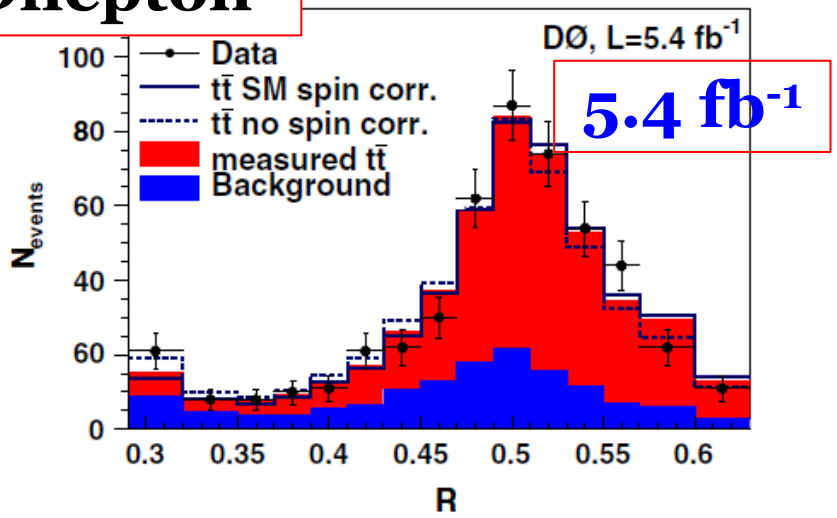
K.Melnikow and M. Schulze , PLB 700 (2011) 17

$$R = \frac{P_{sgn}(H = c)}{P_{sgn}(H = u) + P_{sgn}(H = c)}$$



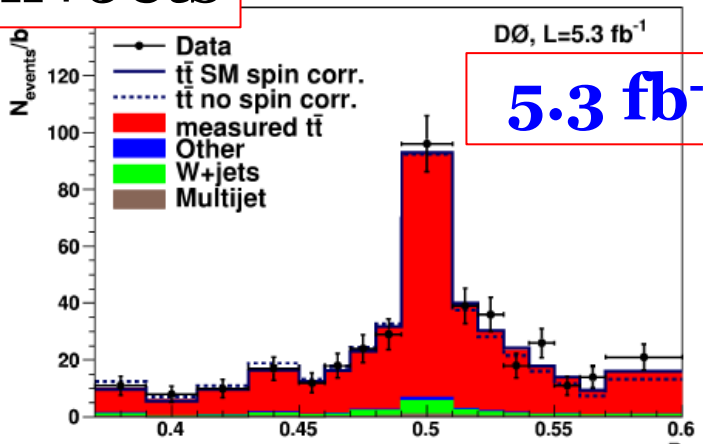
- Calculate probability using LO ME for spin correlation (H=c) and spin uncorrelated (H=u)

Dilepton



5.4 fb^{-1}

Lepton+Jets



5.3 fb^{-1}

κ=0.57 $\pm$0.31 | **κ_{SM} =0.78**

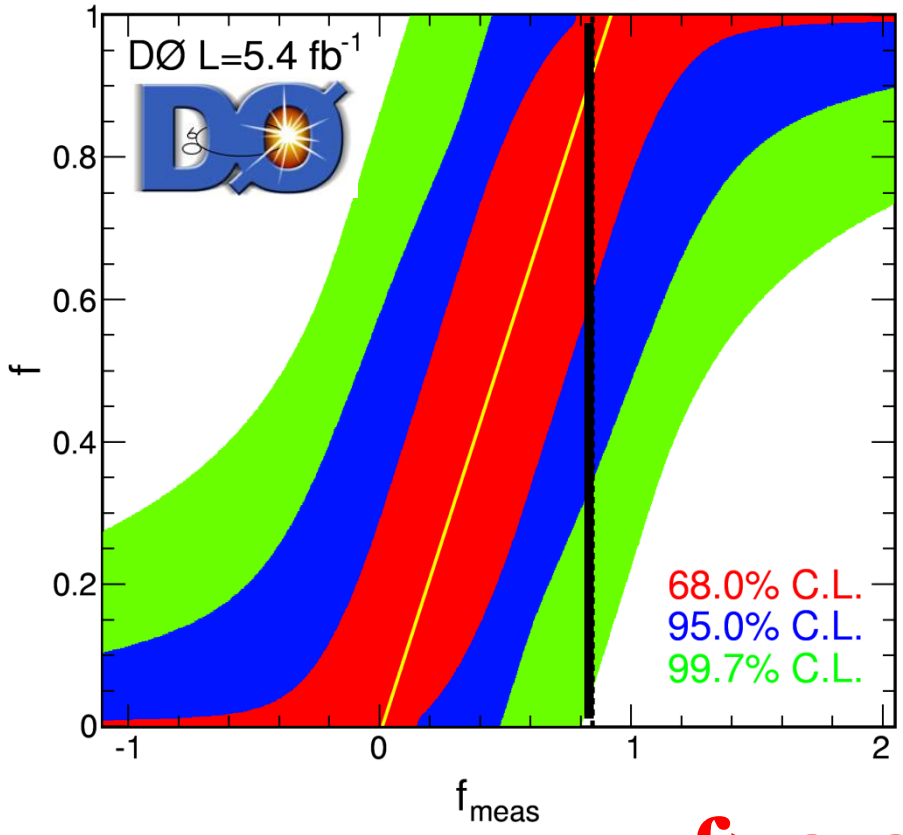
PRL 207 (2011) 032001

f_{SM} =1

f_{meas}=1.15 $\pm$ 0.42

(f is correlation fraction)

Combination of lepton+jets and dilepton



arXiv:1110.4194

f_{meas}=0.85 ±0.29

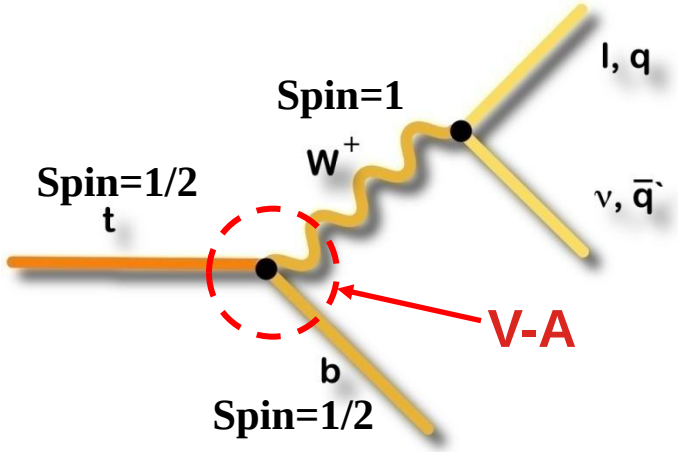
f>0.34 (95% CL)

f>0.05 (99.7% CL)

First evidence (3 standard deviation) of spin correlation

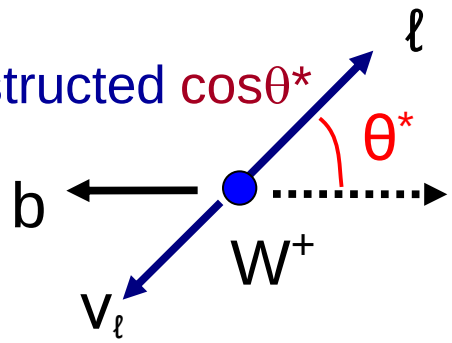
W Helicity

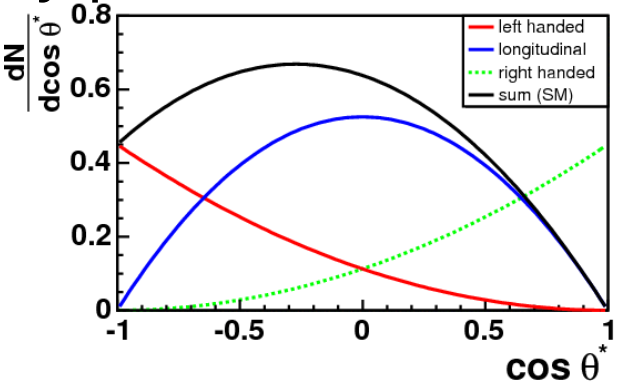
- The SM top decays via EW interaction
  - Top decays as a bare quark ⇒ spin information transferred to final state particles



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

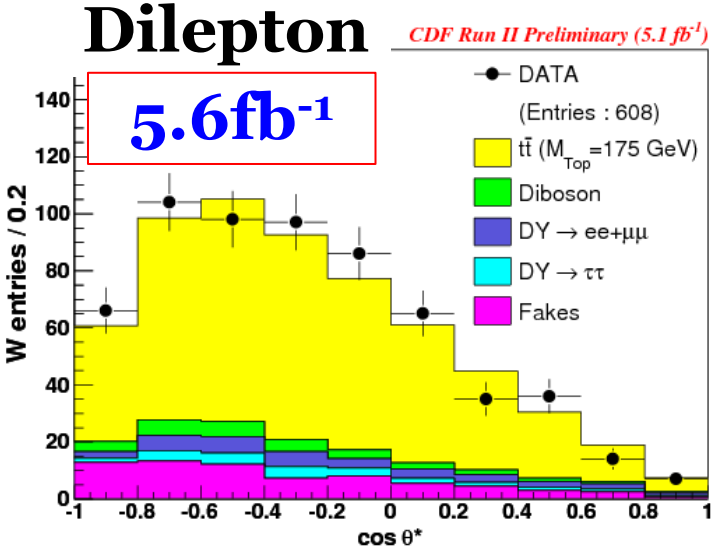
- Measuring the fraction of longitudinally polarized W bosons
  - Reconstructed cosθ*





W Helicity

Dilepton



$f_+ = -0.09 \pm 0.09$

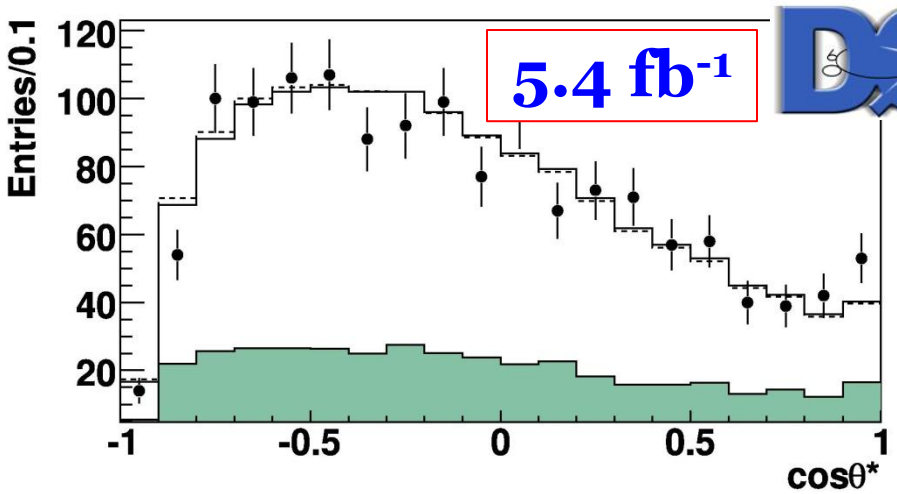
$f_0 = 0.72 \pm 0.19$

cdf note 10541

$f_+(SM) = 0$

$f_0(SM) = 0.7$

Lepton+Jets & Dilepton



$f_+ = 0.02 \pm 0.05$

$f_0 = 0.67 \pm 0.10$

PRD 83 (2011) 032009

Lepton+Jets

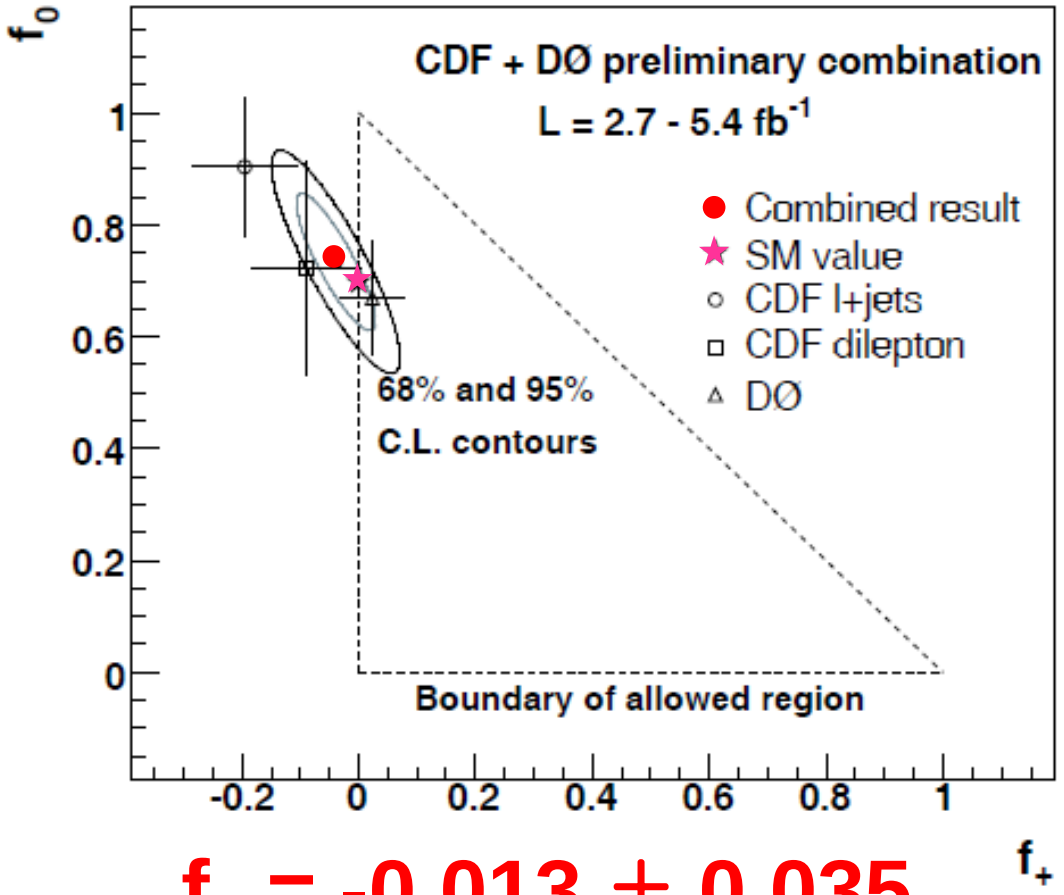
$f_+ = -0.20 \pm 0.09$

$f_0 = 0.90 \pm 0.12$

2.7 fb^{-1}

PRL 105 (2010) 042002

Tevatron combination



$f_{+\,SM} \sim 0$

$f_{0\,SM} = 0.7$

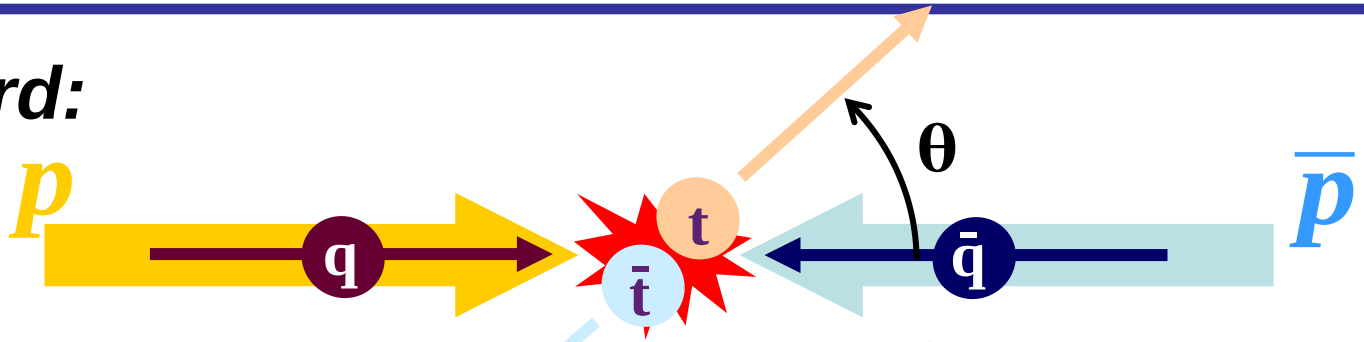
$f_+ = -0.013 \pm 0.035$

$f_0 = 0.685 \pm 0.057$

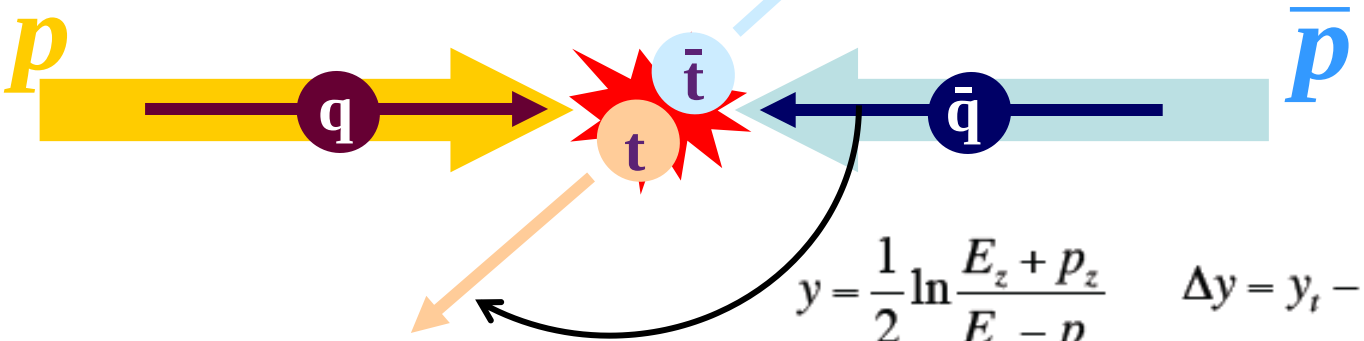
Consistent with SM

Forward backward asymmetry (A_{FB})

Forward:



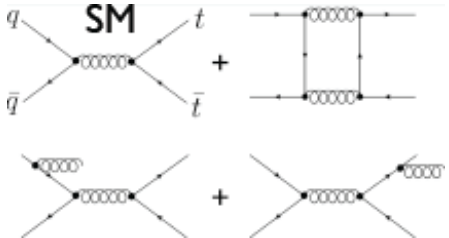
Backward:



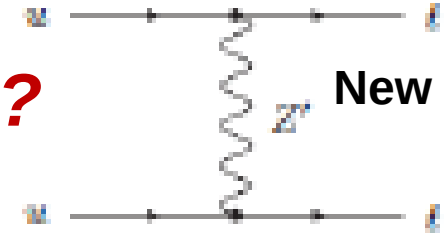
$$y = \frac{1}{2}\ln\frac{E_z + p_z}{E_z - p_z} \qquad \Delta y = y_t - y_{\bar{t}}$$

$$A = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$

$$A = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$



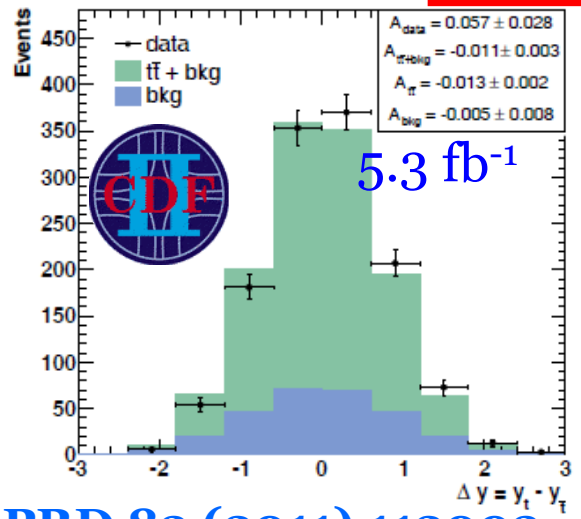
~5% + ??



New physics

A_{FB}

Lepton+Jets



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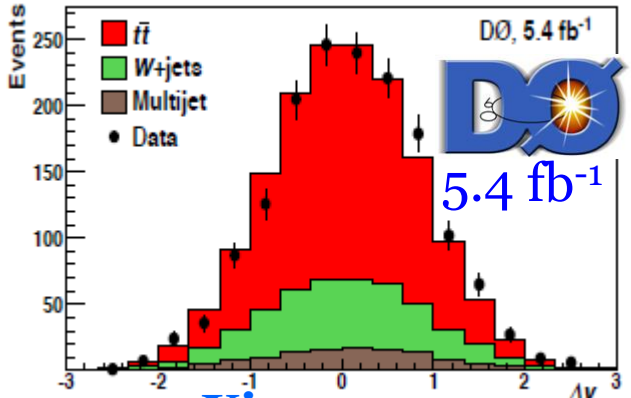
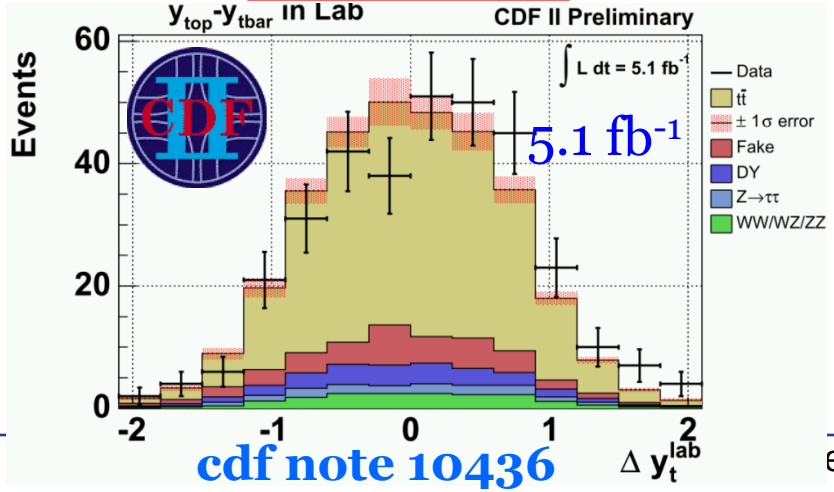
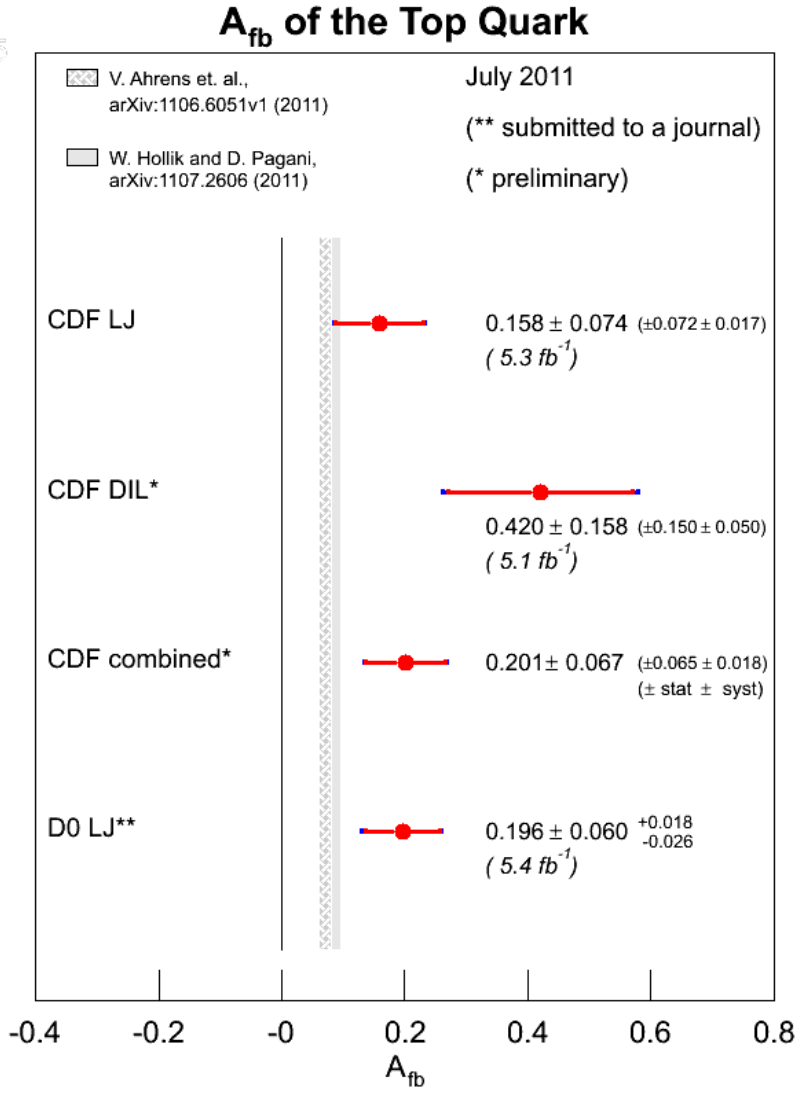


arXiv:1107.4995

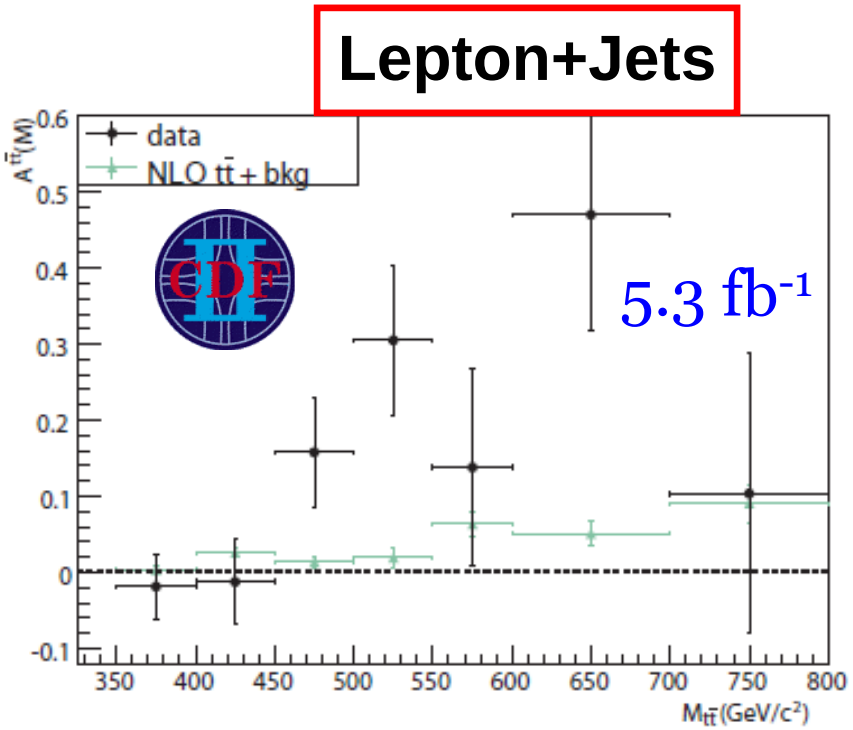
Dilepton

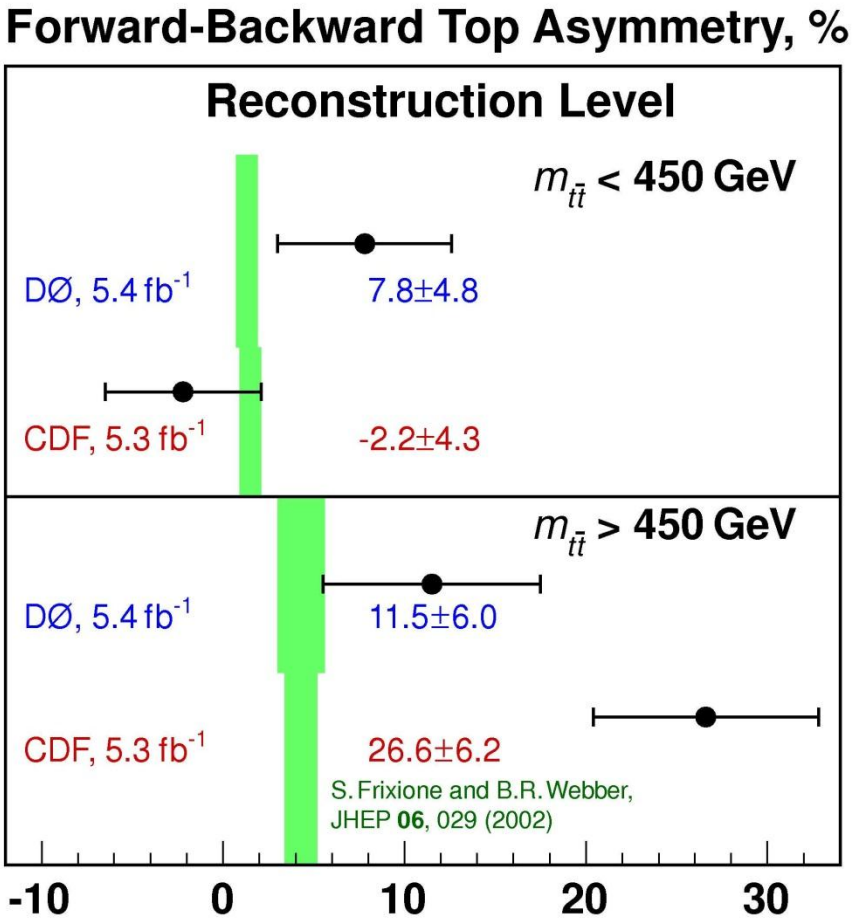


cdf note 10436



A_{FB}





- CDF has clear dependence of A_{FB} for m_{ttbar} but, D0 has not
- Update with full data set will be interesting – stay tuned

Conclusion

- Top quarks properties are well being studied at Tevatron
  - ❖ We are performing rigorous study for top quark
  - ❖ Unique/Complementary measurements to test SM and new physics

- Tevatron's legacy on top physics is still ongoing
  - ❖ We have twice of data and will update interesting top property measurements soon
  - ❖ It is not only adding ~x2 data but also improvement of machinery

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

http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html