Top Properties at Tevatron

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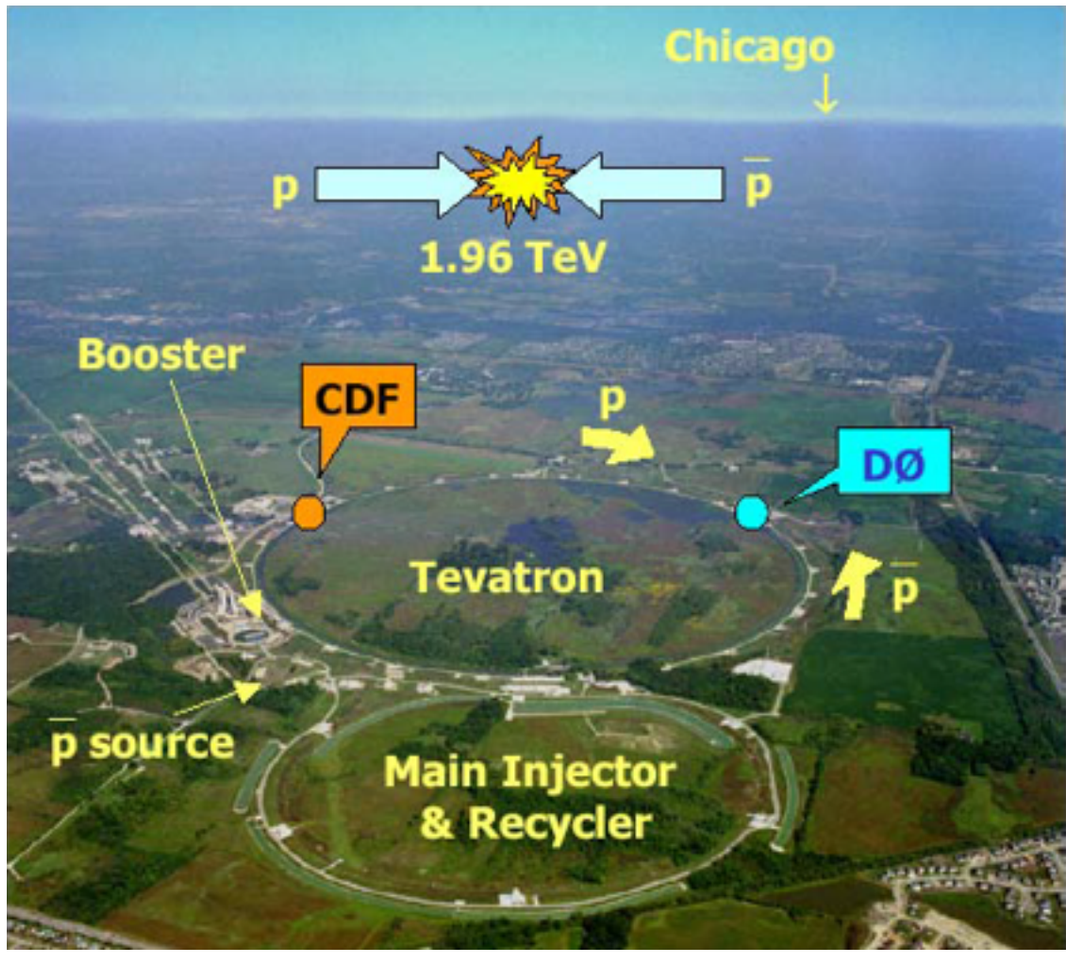
Top Physics at Tevatron

- Long history of the Top Quark since its discovery in 1995
- Tevatron has been for very long time the unique place in the world where top quark could be studied until the LHC became operational



Properties

- Beyond-the-standard-model (BSM) physics contributions can affect the top-quark phenomenology in a wide variety of ways:
  - the production mechanisms can be affected
  - the decay widths can be altered
  - its intrinsic *properties* can be changed
  - the experimental signature can be mimicked by a new particle of similar mass.

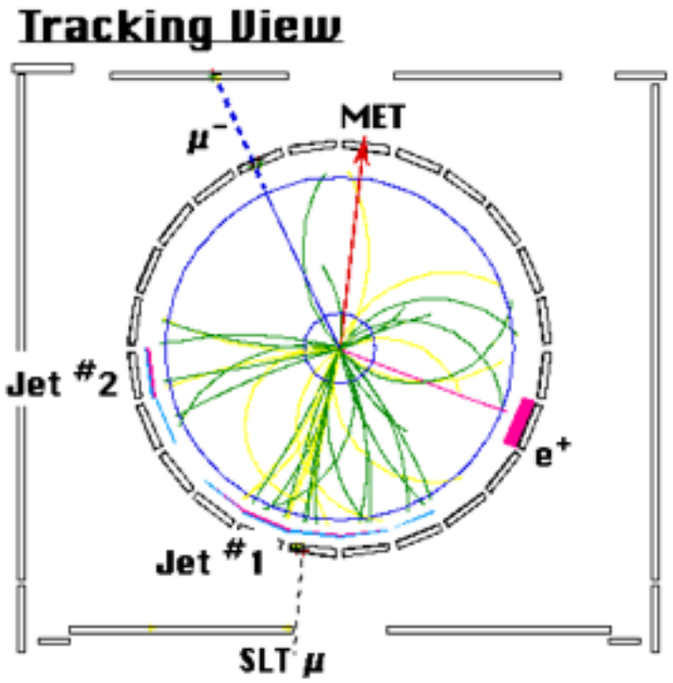
Charge

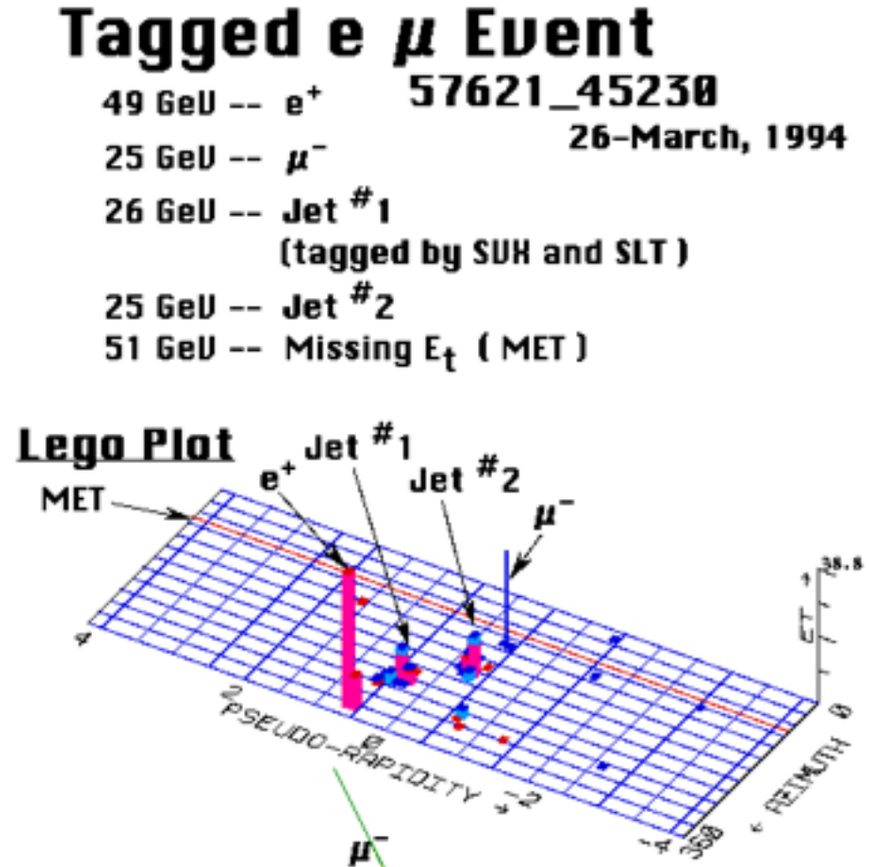
Width

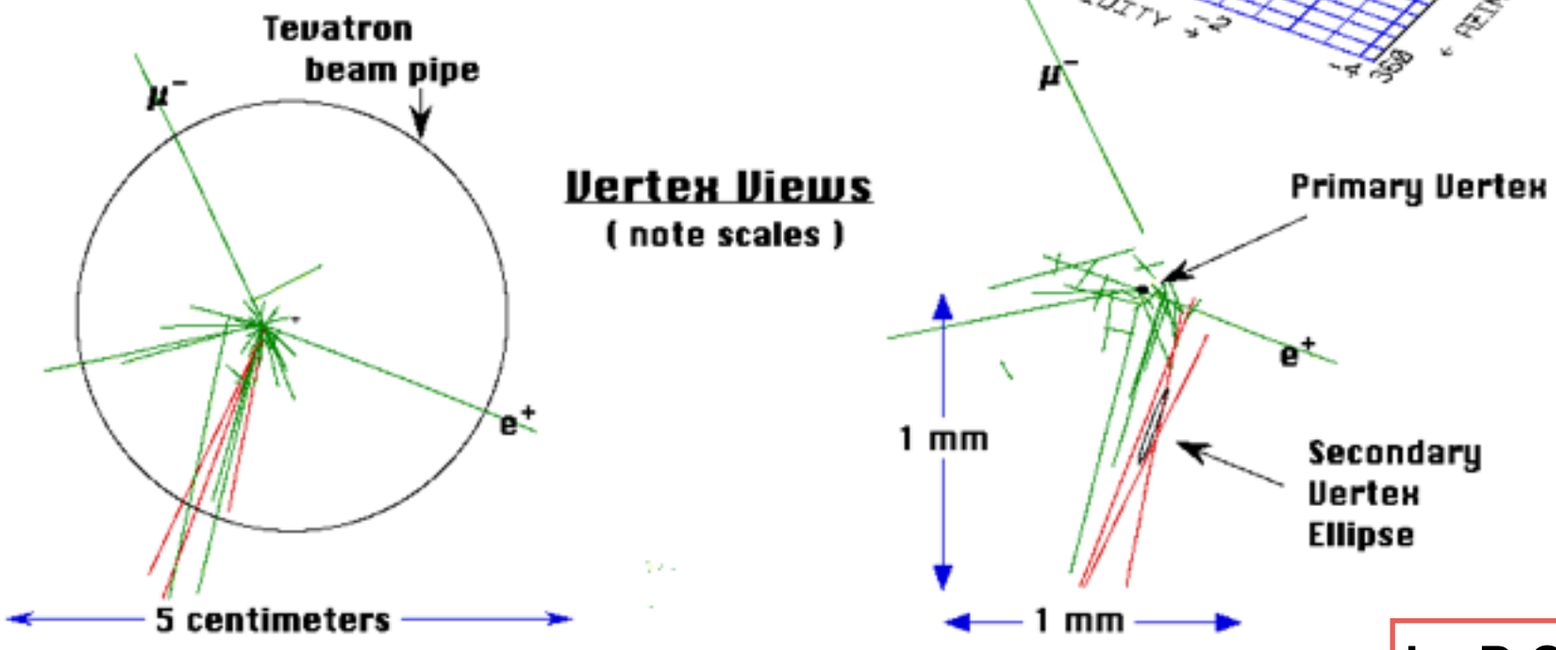
Branching Ratio (R)

W helicity

Charge







- SM top quark charge = 2/3
  - Existence of exotic top with charge -4/3 at 174 GeV and the actual top quark mass > 230 GeV

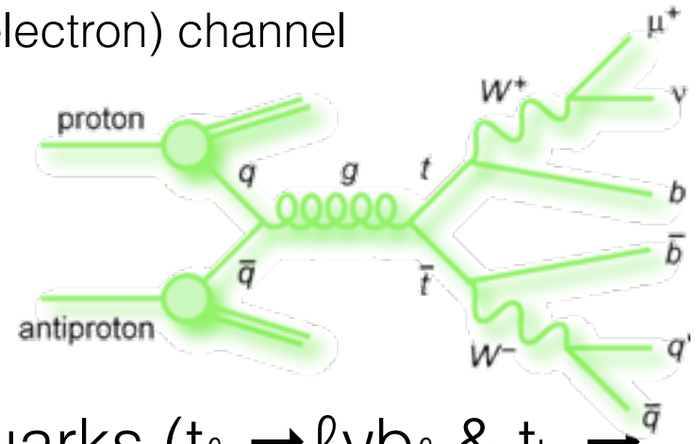
by D.Chang et al., PRD 59, 091503(R) (1999)

Charge (I) D0

- First Measurement by D0(2007)

PRL 98, 041801

  - 370 pb^{-1} collected between 2002/2004
  - lepton+jets channel 231 (277) events in the muon (electron) channel
  - 2 or more b-tagged jets : 21 events



- Pairing the decay products with the top quarks ($t_\ell \rightarrow \ell\nu b_\ell$ & $t_h \rightarrow qqb_h$):
  - χ^2 constraint on top and W masses (84 %)
- $Q1=|q_\ell + q_{b\ell}|$ and $Q2=|-q_\ell + q_{bh}|$:
  - Jet Charge algorithm for b-jet charge determination:

$$q_{\text{jet}} = (\sum_i q_i p_{T_i}^{0.6})/(\sum_i p_{T_i}^{0.6})$$

  - Data/ MC correction computed in dijet-bbar enriched sample

2007 D0

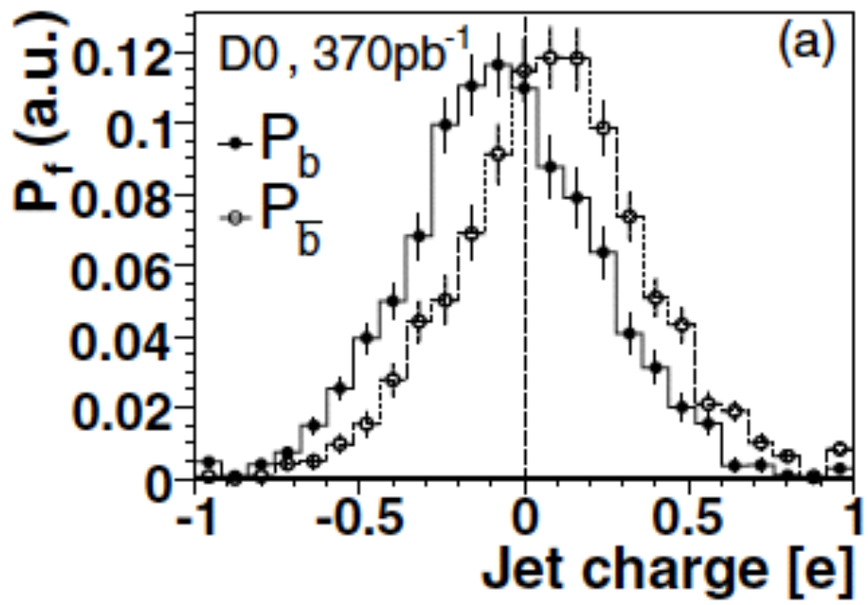
Charge (II) D0

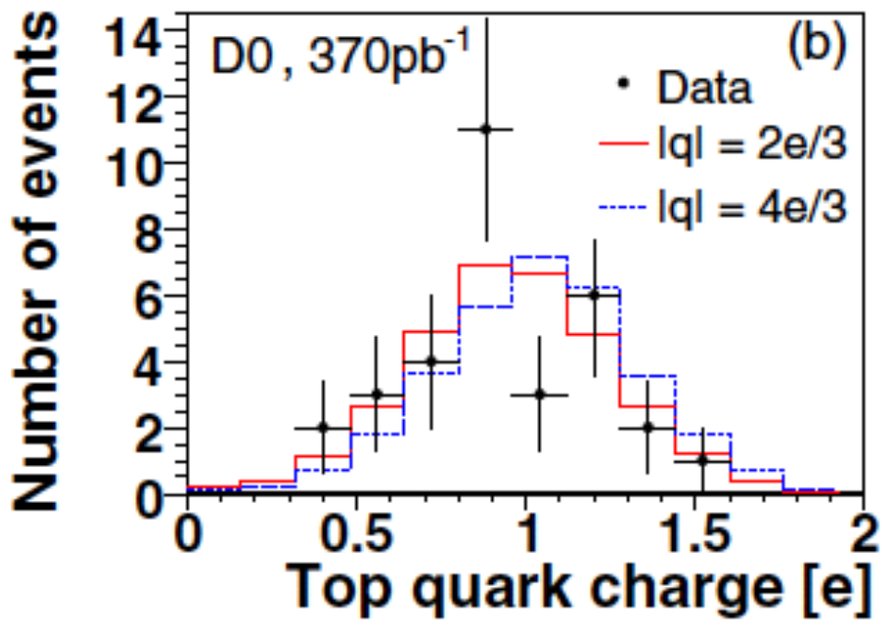
PRL 98, 041801

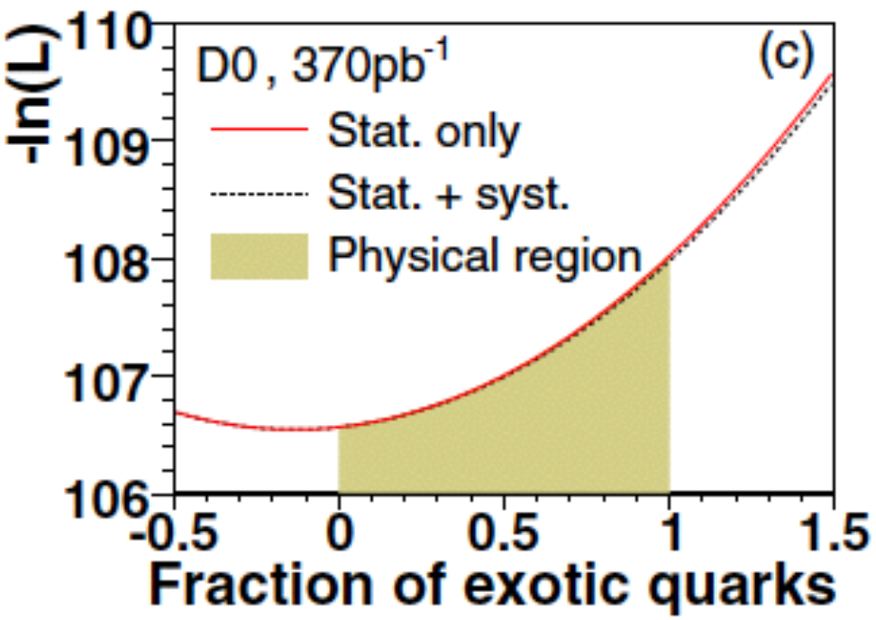
- Jet charge distribution are used as probability density function for the charge of the jet:

$$L(\rho, q) = \prod_{i=1}^{N_{\text{data}}} (1-\rho) P_{\text{SM}}(q_i) + \rho P_{\text{ex}}(q_i)$$

- Results
  - $f_{\text{XM-top}} = \rho = -0.13 \pm 0.66(\text{stat}) \pm 0.11(\text{syst})$
  - data are consistent with top charge of |2/3|
  - Exclusion at 92% C.L. that the sample is due solely to exotic top quark production
  - Upper limit of fraction of exotic top pairs < 0.8 at 90% C.L.

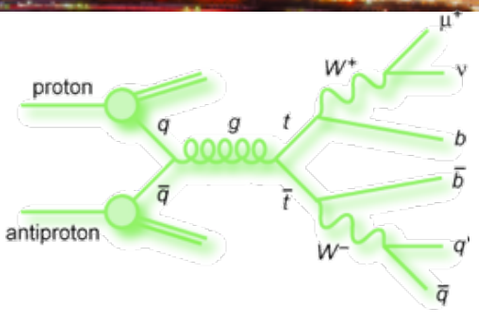


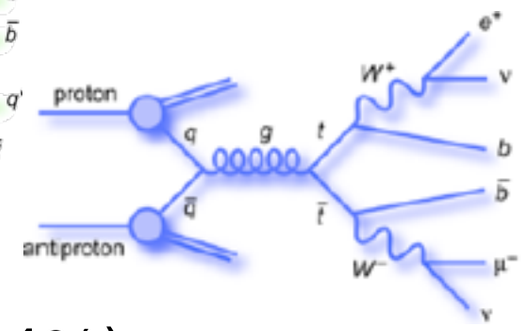




2007 D0

Charge (I) CDF





Conf.Note 8782

- 1 fb^{-1} 2002/2006 data
- Lepton + jets & dilepton events
- Pairing:
  - L+J: χ^2 constraint on top and W masses (84%)
  - Dilepton: $M_{lb}^2 = ((E_l + E_b)^2 - (\vec{p}_l + \vec{p}_b)^2)$ (96%)

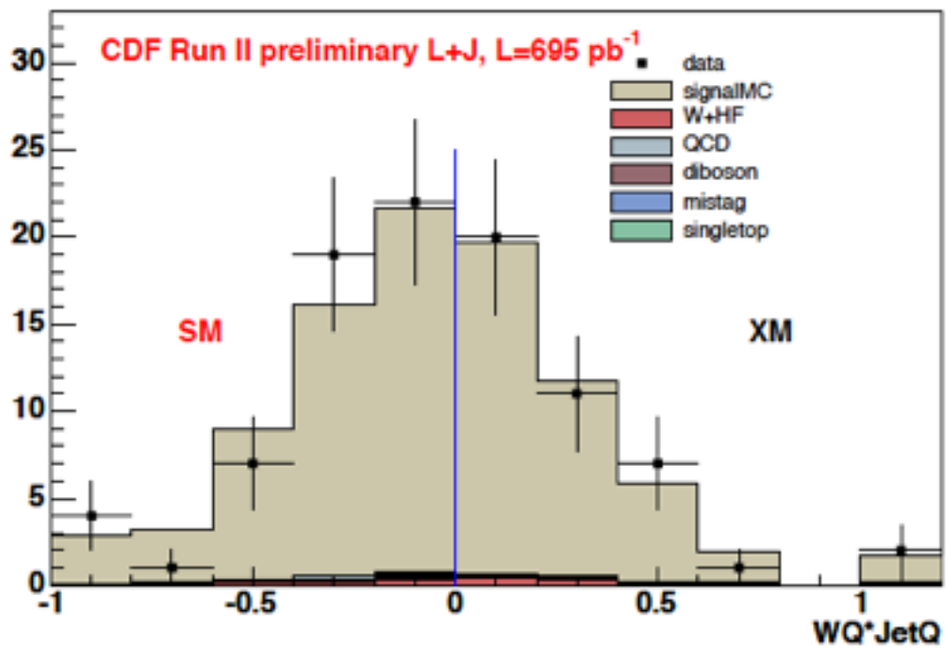
- JetQ Algorithm (purity of 61%). $JetQ = \frac{\sum(\vec{p}_{track} \cdot \vec{p}_{jet})^{0.5} Q_{track}}{\sum(\vec{p}_{track} \cdot \vec{p}_{jet})^{0.5}}$
  - Data/MC correction to the purity due to jet fragmentation discrepancy
- For each jet a combined purity is defined to keep into account all possibility of pairing and getting the right JetQ assignment

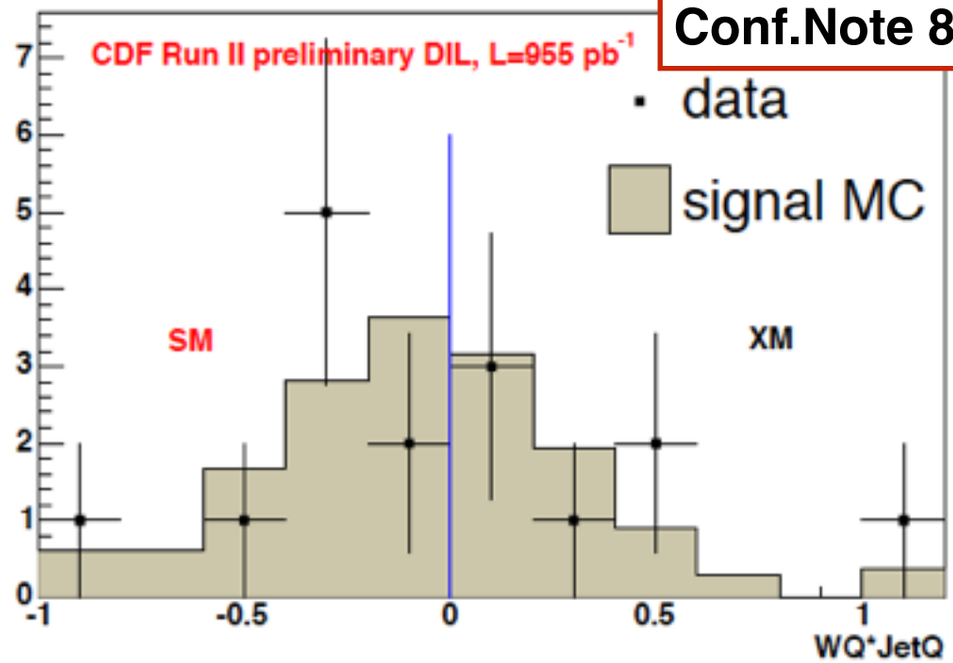
$$p = f_{nonb} SF_{nonb} p_{nonb} + (1 - f_{nonb} SF_{nonb})(p_{pairing} p_{JetQ} SF_{JetQ} + (1 - p_{pairing})(1 - p_{JetQ} SF_{JetQ}))$$

2007 CDF

2007 D0

Charge(II) CDF



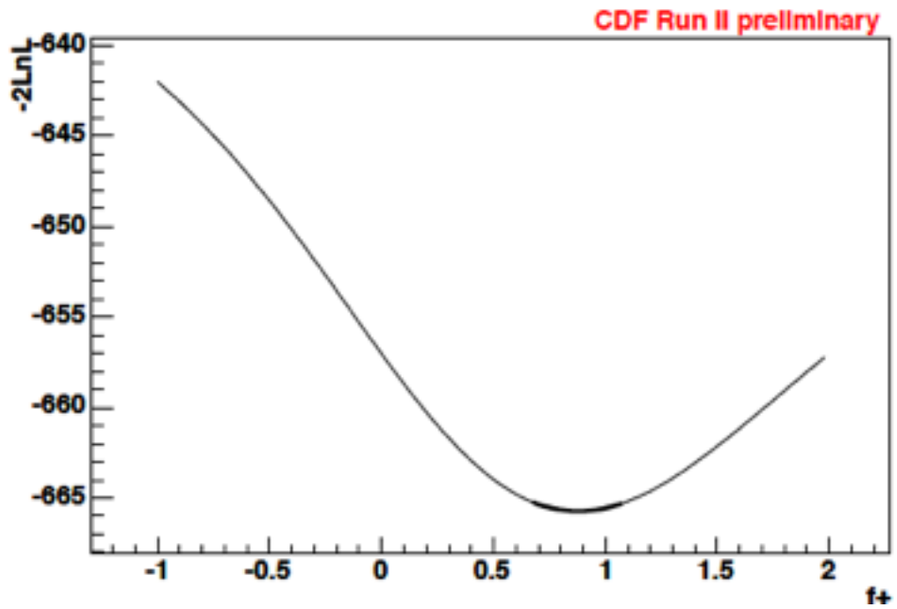


Conf.Note 8782

- Likelihood expressed as a function of the SM fraction of top quark that considers combined purities of signal and backgrounds

$$L = \frac{(N_+)^{x^+} e^{-N_+}}{x^+!} \frac{(N_-)^{x^-} e^{-N_-}}{x^-!} \frac{e^{-\frac{(y_b - N_b)^2}{2\sigma_{N_b}^2}}}{\sigma_{N_b}} \frac{e^{-\frac{(y_s - N_s)^2}{2\sigma_{N_s}^2}}}{\sigma_{N_s}} \times \frac{e^{-\frac{(z_{p_s} - p_s)^2}{2\sigma_{p_s}^2}}}{\sigma_{p_s}} \frac{e^{-\frac{(z_{p_b} - p_b)^2}{2\sigma_{p_b}^2}}}{\sigma_{p_b}},$$

- Minimum for $f_{SM\text{-}top}$ =0.88
- Exotic top excluded at 81% CL



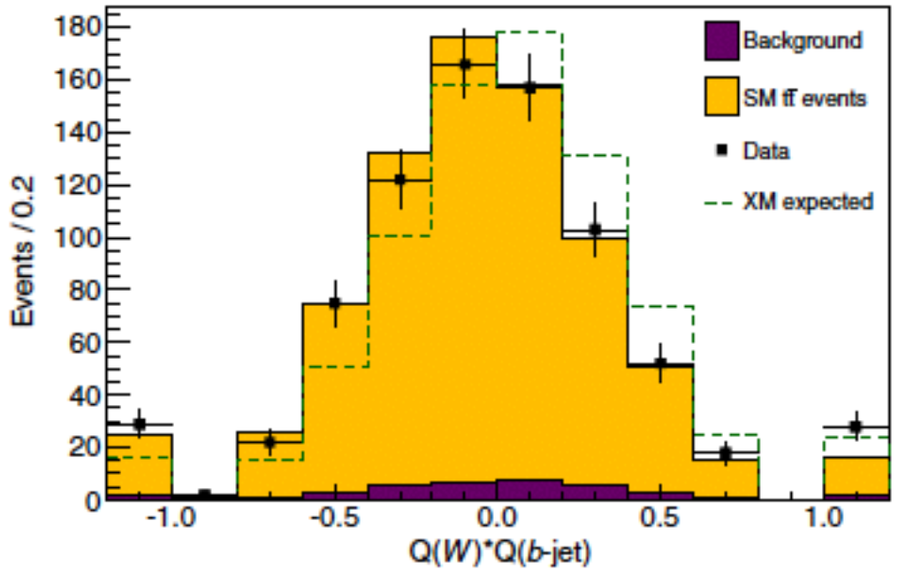
2007 CDF

2007 D0

Charge

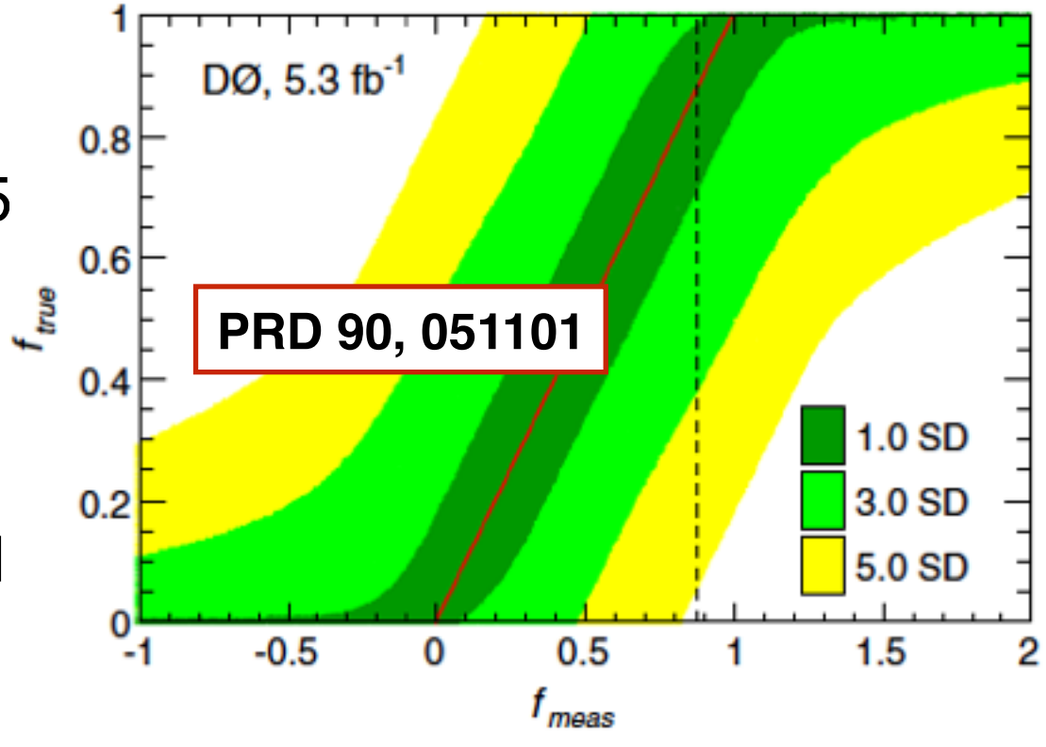
Other measurements:

- 2013 CDF: 5.6 fb^{-1} 2002/2010 data
  - Exotic top (q=4/3) is rejected at 99% CL
  - Allowing the SM and Exotic top hypotheses to coexist:
    - $0.66 < f_{SM\text{-}top} < 0.95$ with 68% CL and $0.48 < f_{SM\text{-}top} < 1.00$ with 95% CL



PRD 88, 032003

- 2014 D0: 5.3 fb^{-1} (L+jets)
  - Exotic top (q=4/3) is rejected at 5 SD
  - Allowing the SM and Exotic top hypotheses to coexist:
    - $0.70 < f_{SM\text{-}top}$ with 68% CL and $0.54 < f_{SM\text{-}top}$ with 95% CL



PRD 90, 051101

2014 D0

2013 CDF

2007 CDF

2007 CDF

2007 D0

Branching ratio

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- CKM unitary Matrix

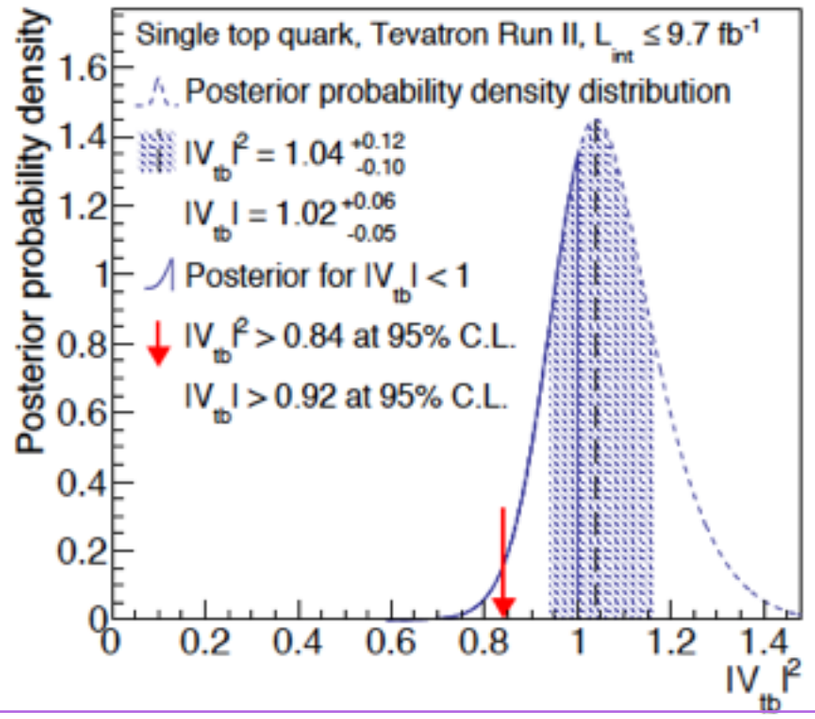
$\Rightarrow |V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1$

- $|V_{tb}| = 0.999146\ ^{+0.000021}_{-0.000046}$

(PDG),Phys. Rev. D 86, 010001 (2012)

Measurement of $|V_{tb}|$:

- **Direct:** from single top production cross section
  - $|V_{tb}| = 1.02\ ^{+0.06}_{-0.05}$ **arXiv:1503.05027**
- **Indirect:** Decay rate in top pair events



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

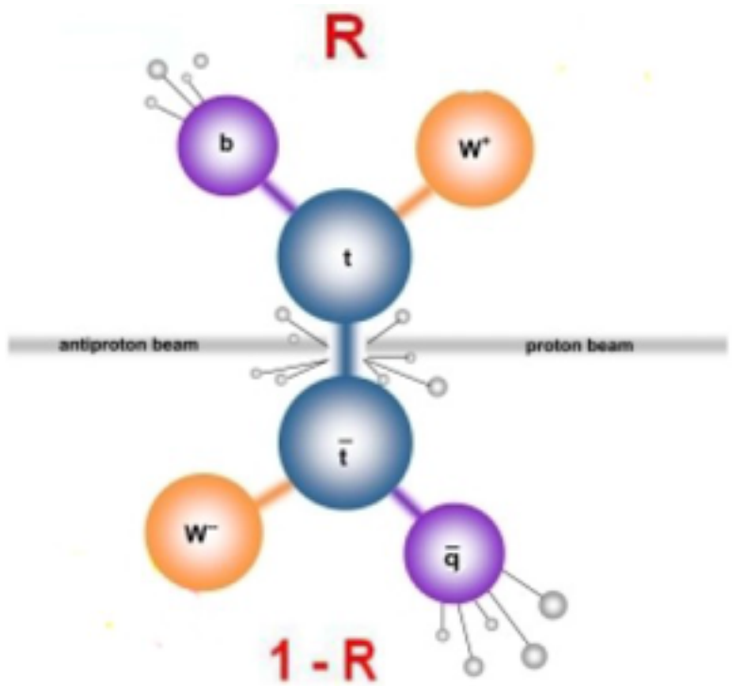
⇒ Physic observable: **number of b-tagged jets** in the event

Branching ratio at CDF

- Data are divided in subsamples according on the the **b-tagging content**

$$s_t = P(t;R)\, N_{PRE\text{-}TAG} = P(t;R)\, A\, L\, \sigma$$

st = number of signal events
A = MC acceptance
L = luminosity
σ = top-pair production cross section
P(t;R) = probability of having t tags



- R is measured with a Maximum Likelihood fit

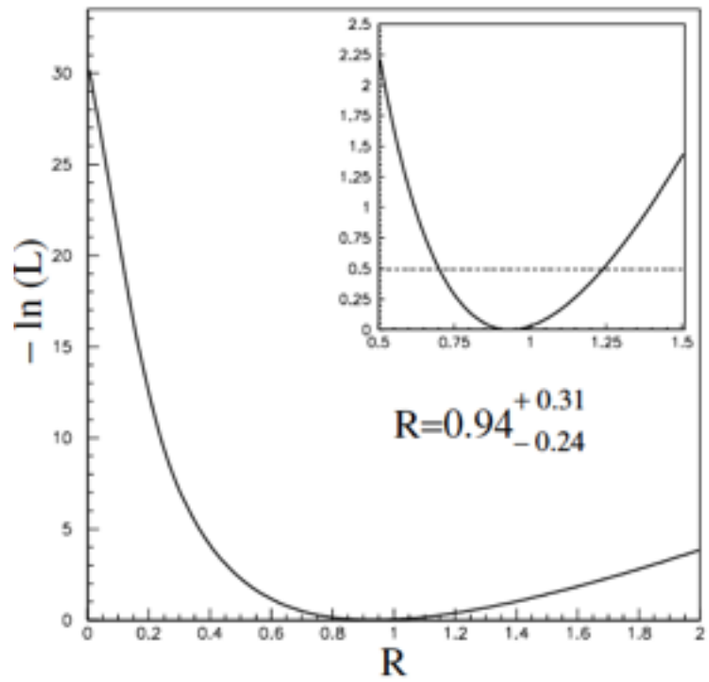
$$L = \prod_i \wp(\mu^i_{exp}\ (R, x_j)|N_{obs}) \prod_j G(x_j|\bar{x}_j, \sigma_j)$$

Branching ratio

PRL 86, 3233

Run I data

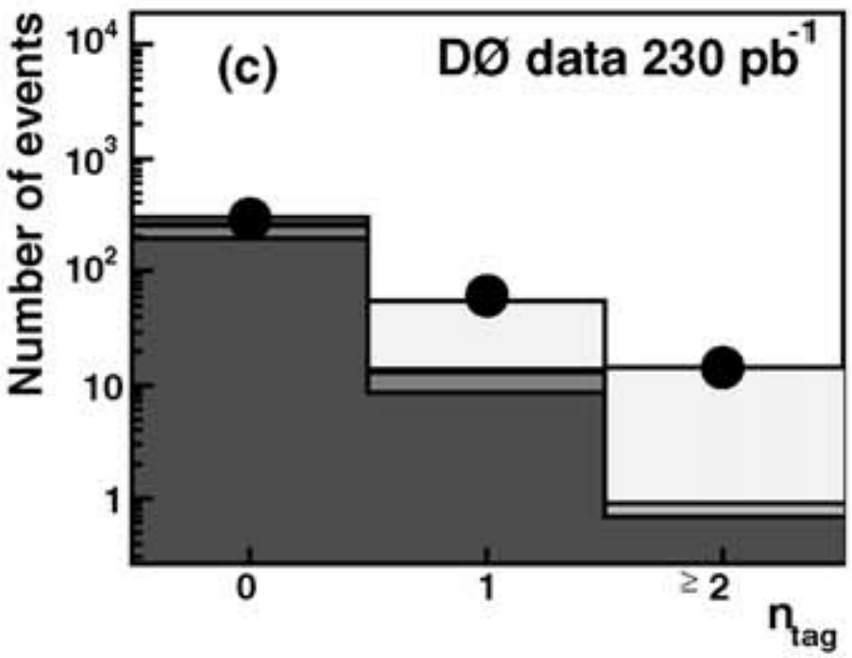
- **CDF** in 2001 with 109 pb^{-1} in lepton+jets and dilepton events
  - $|V_{tb}| = 0.97^{+0.16}_{-0.12}$ and $|V_{tb}| > 0.78(0.75)$ at 90%(95%)CL



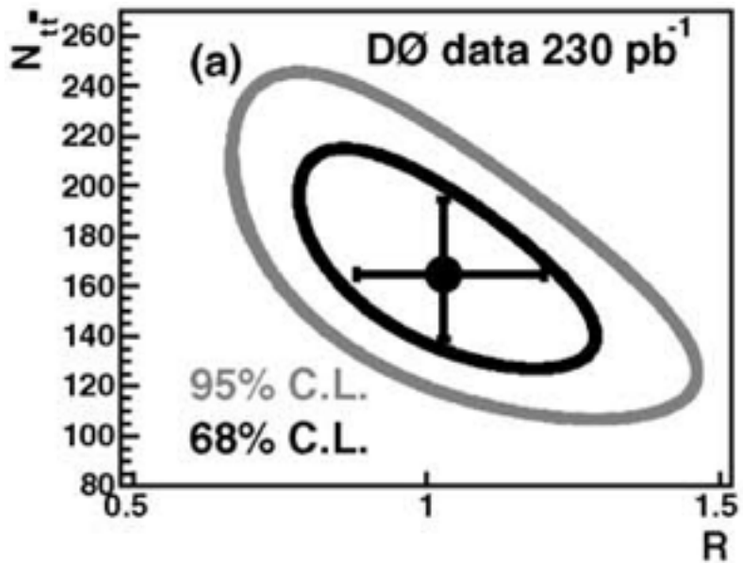
- **D0** in 2006 with 230 pb^{-1} in lepton+jets

Run II data

PLB 639, 616



- $R = 1.03^{+0.19}_{-0.17}$ (stat+syst) and $R > 0.61$ at 95% CL
- $|V_{tb}| > 0.78$ at 95% CL



2006 D0

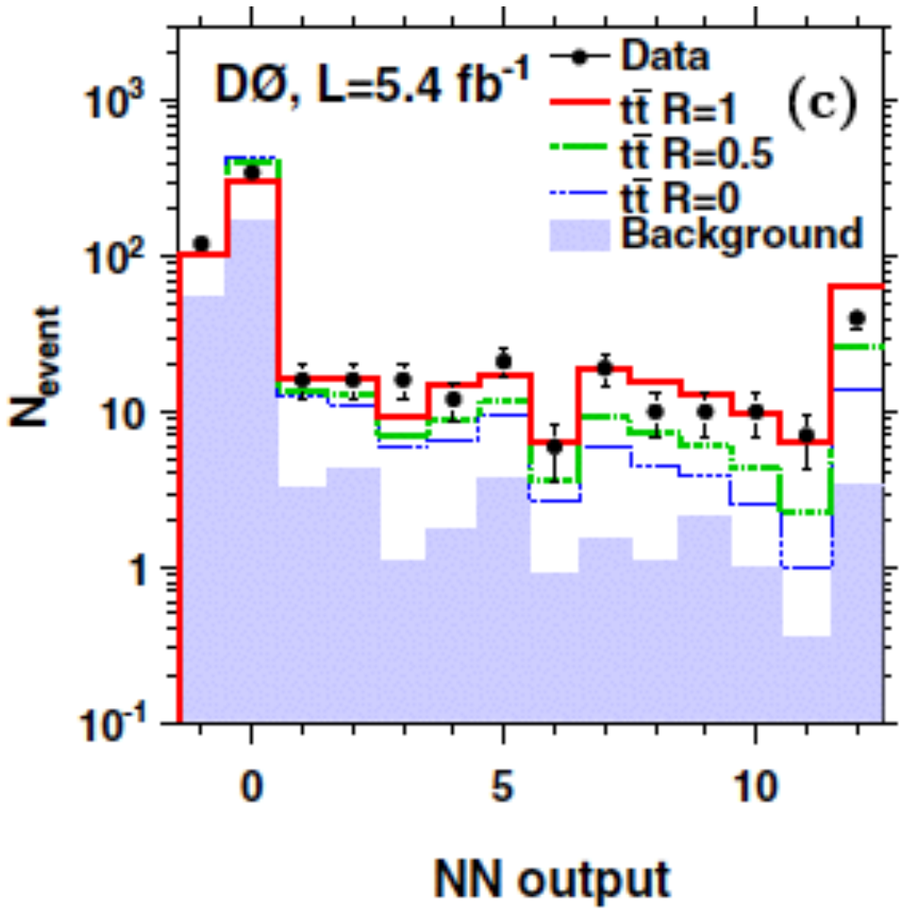
2005 CDF

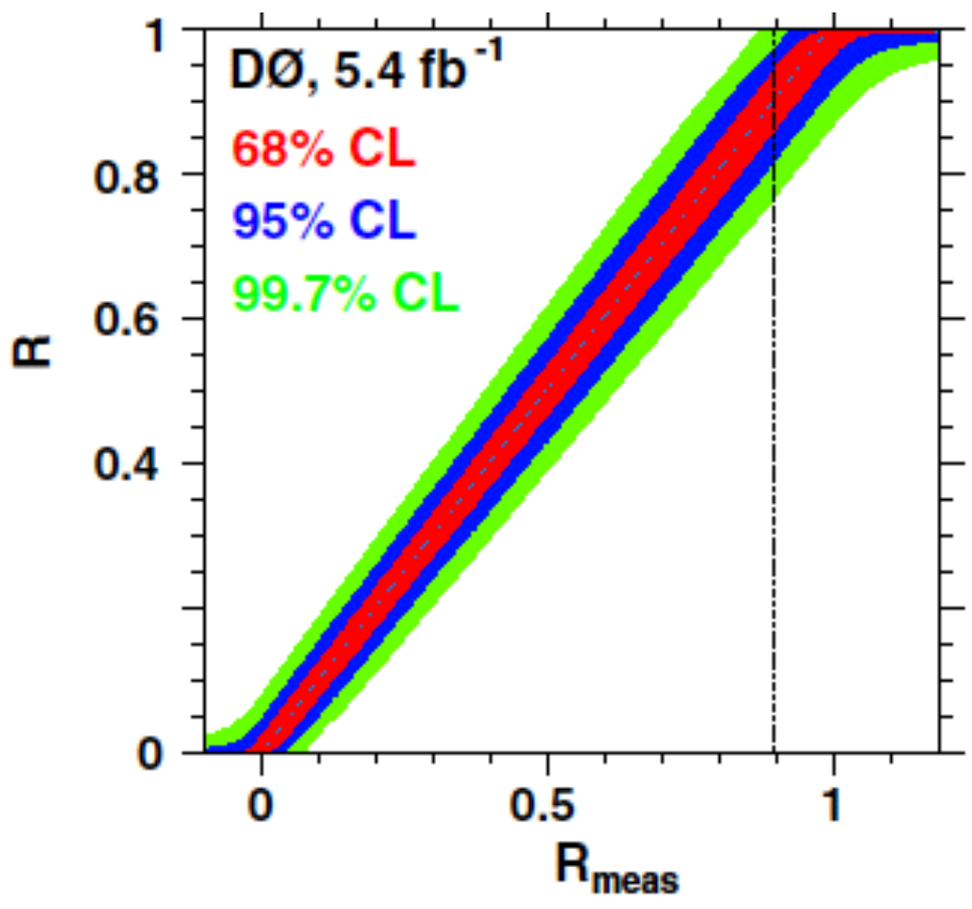
2001 CDF

Branching ratio

- **D0 in 2011** with 5.4 fb^{-1} in lepton +jets and dilepton final states
  - NN b-tagging algorithm
  - cross section and R simultaneously measured

PRL 107, 121802





$$R = 0.90 \pm 0.04(\text{stat} + \text{syst})$$

$$\sigma_{t\bar{t}} = 7.74^{+0.67}_{-0.57}(\text{stat} + \text{syst})\ \text{pb}.$$

$$|V_{tb}| = 0.95 \pm 0.02$$

$0.90 < |V_{tb}| < 0.99$ at 95% CL

2011 D0

2006 D0

2005 CDF

2001 CDF

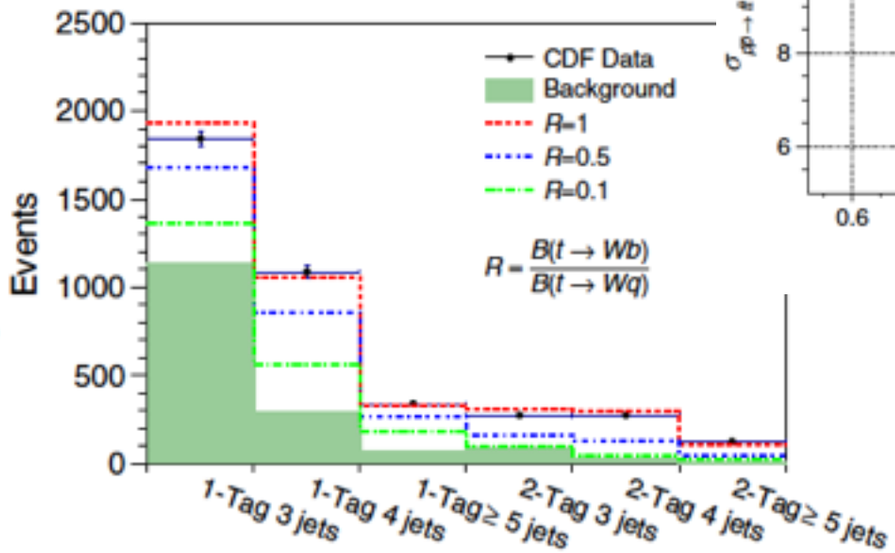
Branching ratio

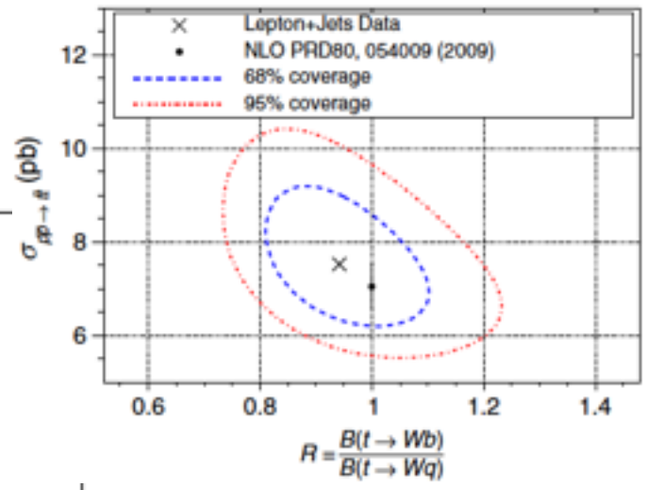
- **CDF in 2012** with 8.7 fb^{-1} in **lepton +jets** final state
  - cross section and R simultaneously measured

$$R = 0.94 \pm 0.09 \text{ and } \sigma_{t\bar{t}} = 7.5 \pm 1.0 \text{ pb}$$

$|V_{tb}|=0.97\pm0.05$ and $|V_{tb}| > 0.89$ at 95% CL

PRD 87 111101



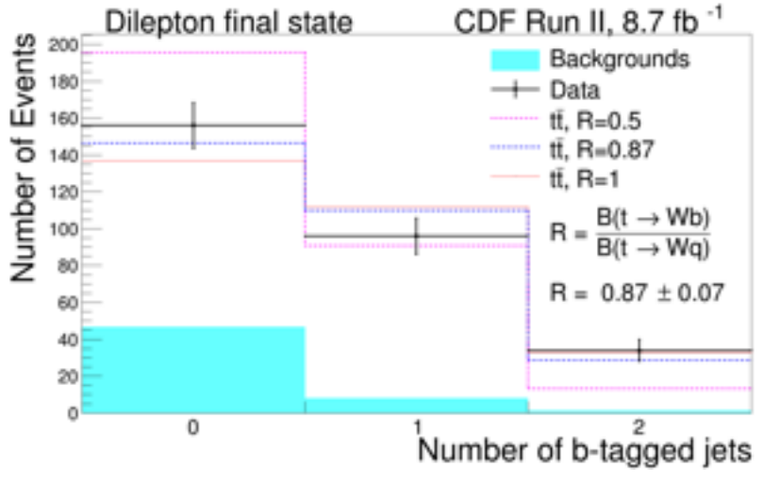


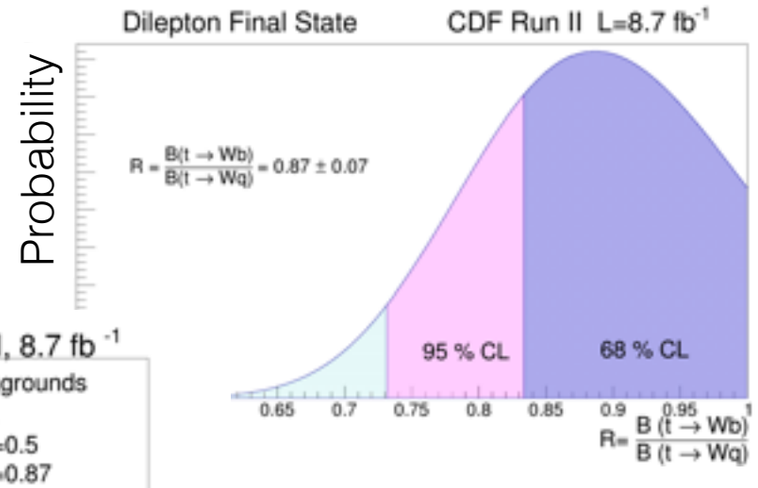
- **CDF in 2014** with 8.7 fb^{-1}in **dilepton** final state

R=0.87±0.07

$|V_{tb}|=0.93\pm0.04$ and $|V_{tb}| > 0.86$ at 95% CL

PRL 112, 221801





2014 CDF

2012 CDF

2011 D0

2006 D0

2005 CDF

2001 CDF

Top Width

- Due to its large mass, the top quark has a large width and a very short lifetime (~10^{-25} s)
- The leading order width:

$$\Gamma_t^0 = |V_{tb}|^2 G_F m_t^3/(8\pi\sqrt{2})$$

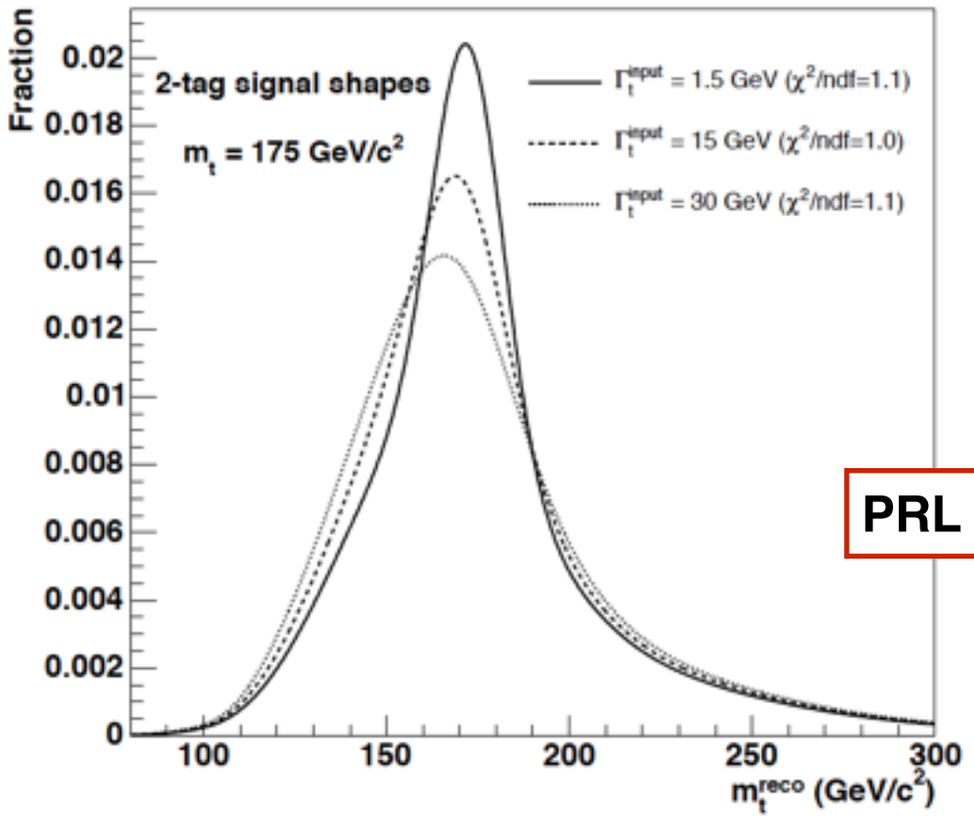
- The next-to-leading order (neglecting terms of order)

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

- Theoretical calculation precision ~1% (width = 1.5 GeV for top mass 175 GeV)
- Possible deviation from the SM predicted value could indicate contribution from top quark non-SM decays ($t \to bH^+$ SUSY), flavor changing neutral currents or vary rare SM decay ($t \to dW^+$ or $t \to sW^+$)

Width (I) CDF

- First direct measurement by CDF in 2009 (1 fb^{-1})
  - in lepton + jets final state
  - for each event the top mass is reconstructed (m_t^{reco})
  - likelihood estimator using simulated signal and background distribution parametrized as a function of Γ_t

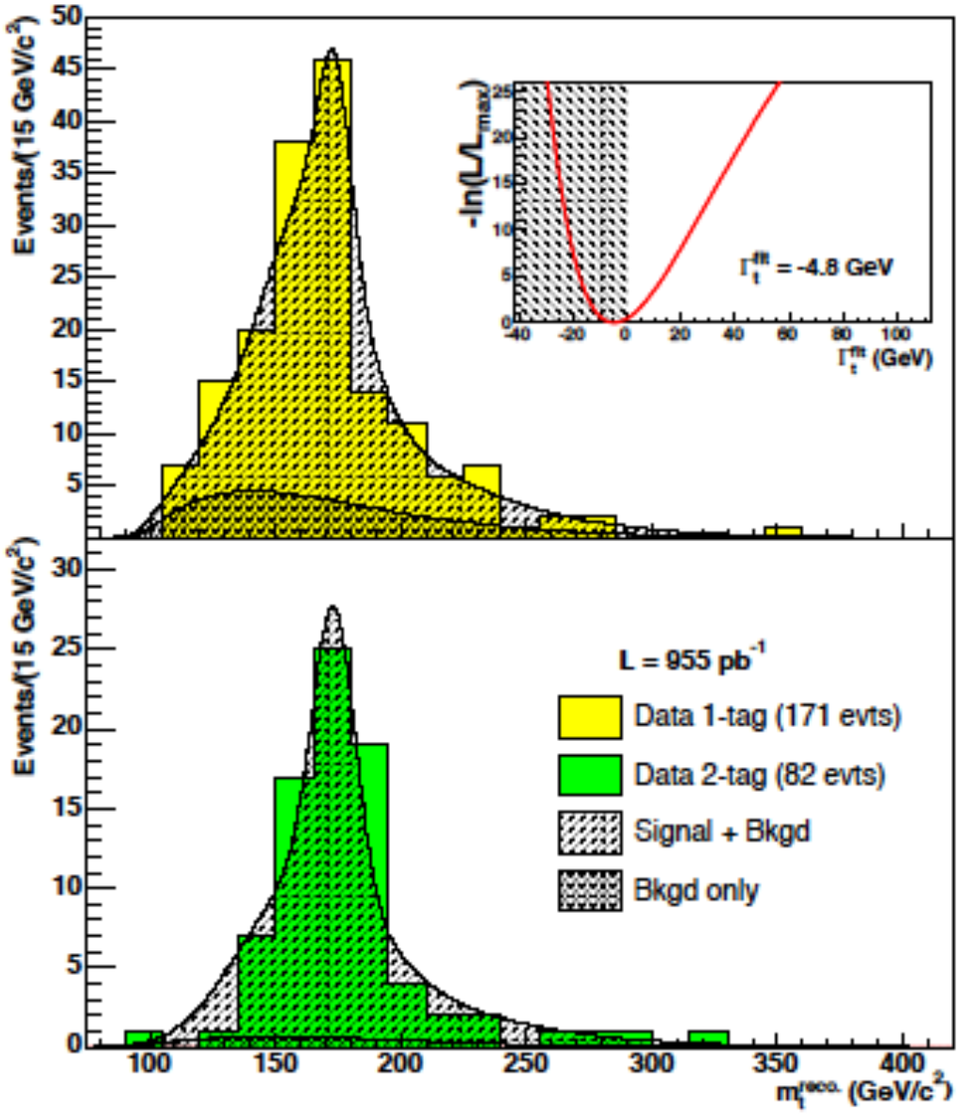


PRL 103, 042001

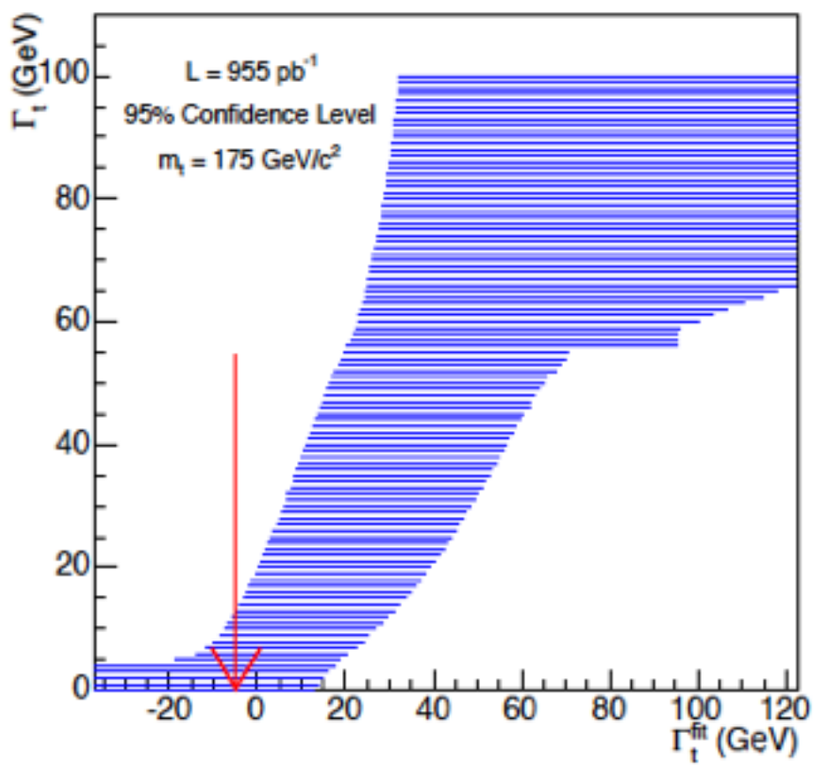
2009 CDF

Width (II) CDF

PRL 103, 042001



- Assuming $m_t = 175$ GeV :
  - $\Gamma_t^{Fit} < 13.1$ GeV at 95% CL
  - $\Rightarrow \tau_t > 5\ 10^{-26}$ s



2009 CDF

Width (I) D0

- First indirect measurement by D0 2.3 fb^{-1} in 2010

PRL 106, 022001

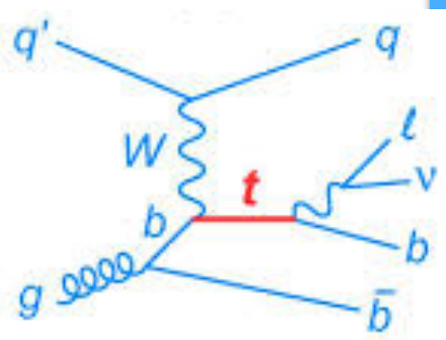
- Single top t-channel cross section measurement

$$\sigma(t-\text{channel})\mathcal{B}(t\to Wb) = 3.14^{+0.94}_{-0.80}\ \text{pb}$$

PLB 682, 363(2010)

- can be used to measure indirectly the partial width of top decay, given the linear dependence of the cross section on the partial width

$$\Gamma(t\to Wb) = \sigma(t-\text{channel})\frac{\Gamma(t\to Wb)_{\text{SM}}}{\sigma(t-\text{channel})_{\text{SM}}}$$



- The total and partial width are related

$$\Gamma_t = \frac{\Gamma(t\to Wb)}{\mathcal{B}(t\to Wb)} \qquad \Gamma_t = \frac{\sigma(t-\text{channel})\Gamma(t\to Wb)_{\text{SM}}}{\mathcal{B}(t\to Wb)\sigma(t-\text{channel})_{\text{SM}}}$$

NLO QCD calculation

$$\sigma(t-\text{channel})_{\text{SM}} = 2.14 \pm 0.18\ \text{pb}$$
$$\Gamma(t\to Wb)_{\text{SM}} = 1.26\ \text{GeV}$$

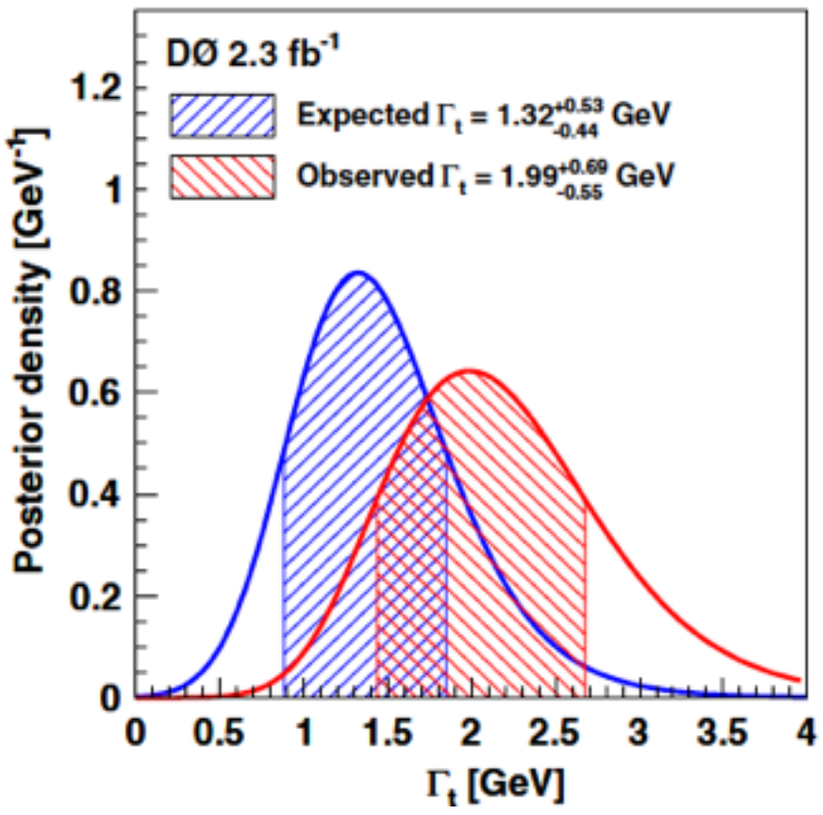
2010 D0

- For the top BR:

$$\mathcal{B}(t\to Wb) = 0.962^{+0.068}_{-0.066}(\text{stat})^{+0.064}_{-0.052}(\text{syst})$$

2009 CDF

Width (II) D0



- Partial width is determined

$$\Gamma(t \to Wb) = 1.92^{+0.58}_{-0.51}\ \text{GeV}$$

- For the total width:

$$\Gamma_t = 1.99^{+0.69}_{-0.55}\ \text{GeV} \qquad \Gamma_t > 1.21\ \text{GeV} \quad \text{at } 95\%\text{C.L.}$$

$$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}\ \text{s} \qquad \tau_t < 5.4 \times 10^{-25}\ \text{s}$$

2010 D0

2009 CDF

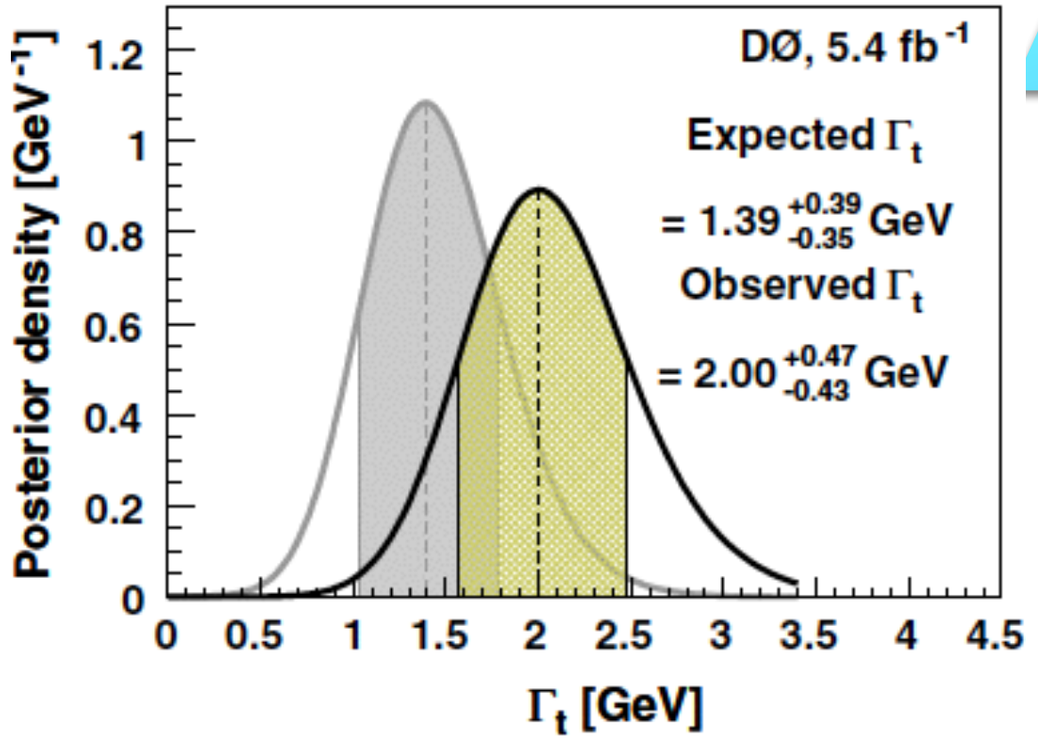
Width

- 2012 D0 with 5.4 fb^{-1} :

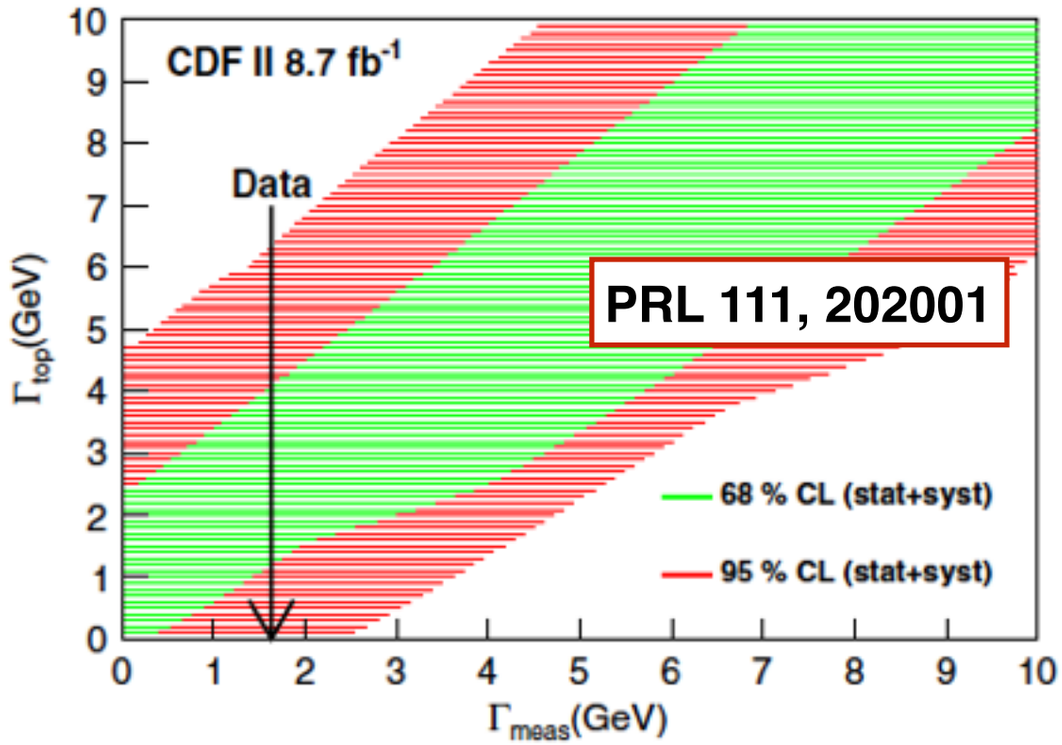
$$\Gamma_p = 1.87^{+0.44}_{-0.40}\ \text{GeV} \qquad \Gamma_t = 2.00^{+0.47}_{-0.43}\ \text{GeV}$$

$$\tau_t = (3.29^{+0.90}_{-0.63}) \times 10^{-25}\ \text{s}$$

PRD 85, 091104



- 2013 CDF with 8.7 fb^{-1} :
  - JES *in situ* calibration
  - Two template fit (m_{top} and hardonic W mass m_{jj})with various Γ and JES
  - $\Gamma_t < 6.38$GeV at 95% CL and $1.10 < \Gamma_t < 4.05$ GeV at 68% CL
    - $\Rightarrow 1.6\ 10^{-25}\ \text{s} < \tau_t < 6\ 10^{-25}\ \text{s}$ at 68% CL



2013 CDF

2012 D0

2010 CDF

2010 D0

2009 CDF

W helicity

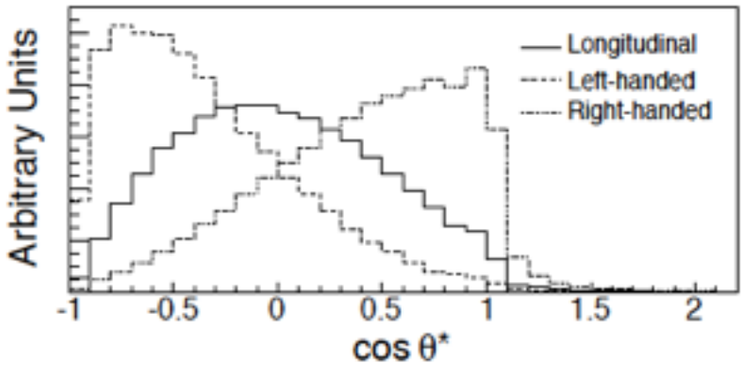
- In the SM the coupling at the Wtb vertex is purely left-handed and can be used to test the V-A structure of weak interaction. The angular distribution of the top decay products is affected by the W polarization

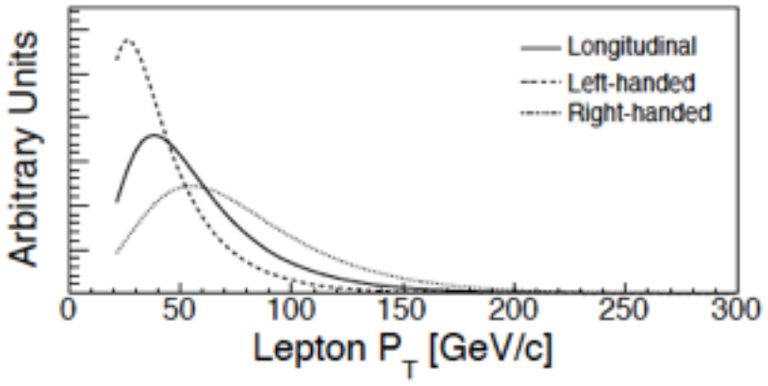
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = f_- \cdot \frac{3}{8}(1-\cos\theta^*)^2 + f_0 \cdot \frac{3}{4}(1-\cos^2\theta^*) + f_+ \cdot \frac{3}{8}(1+\cos\theta^*)^2$$

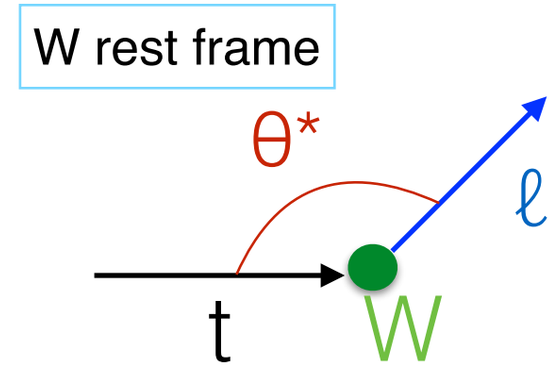
- The W^+ boson is expected to have :
  - longitudinal polarization f_0 = 0. 696,
  - left-handed polarization f_- = 0. 303,
  - right-handed polarization f_+ = 3.8 10^{-4}

- The presence of anomalous couplings at the tWb vertex can modify the observed W polarization

- Variables that are used to determine the W polarization are :
  - angular distribution
  - lepton p_T spectrum







Longitudinal $\propto (1-\cos^2\theta^*)$

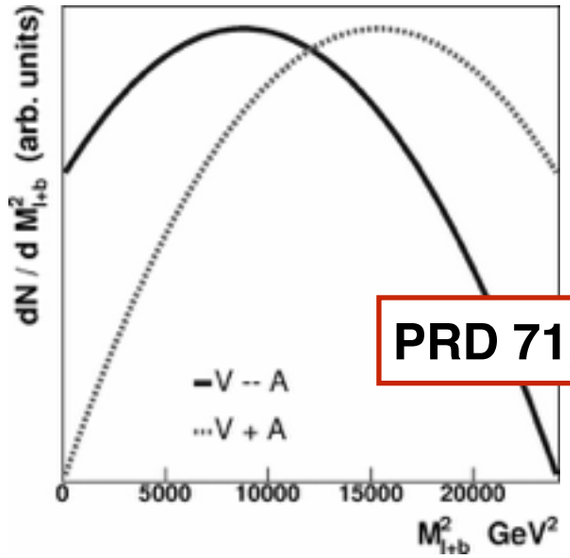
Left-handed $\propto (1-\cos\theta^*)^2$

W helicity early measurements

- CDF Run I dataset with 100 pb^{-1}:
  - Fitting the lepton p_T spectrum and the $\cos(\theta^*)$ distribution :
    - $F_0 = 0.91 \pm 0.37(stat) \pm 0.13(syst)$ and $F_+ < 0.18$ at 95 % CL

PRL 84, 216

$$\cos\theta^* = \frac{p_\ell \cdot p_b - E_\ell E_b}{|\mathbf{p}_\ell||\mathbf{p}_b|} \simeq \frac{2{M_{lb}}^2}{m_t^2 - M_W^2} - 1$$



PRD 71, 031101

- D0 Run I dataset with 125 pb^{-1}:
  - Matrix element method
    - $F_0 = 0.56 \pm 0.31$

PLB 617, 1

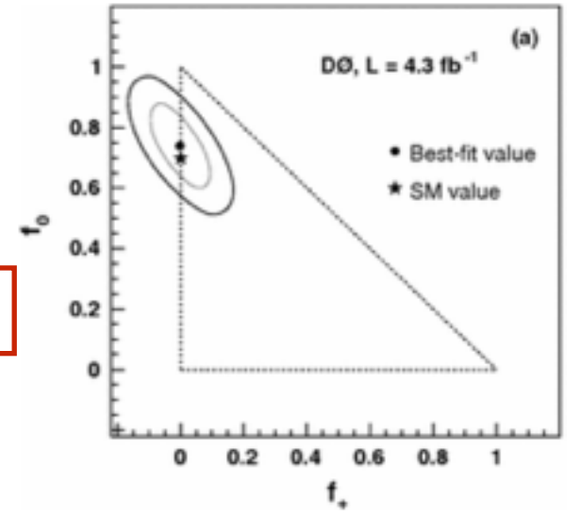
2005 D0

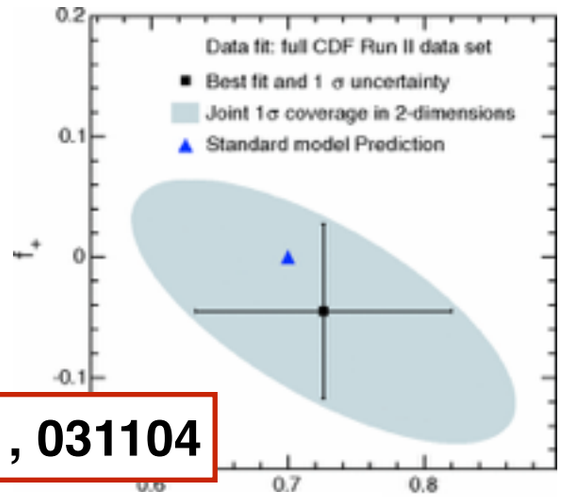
2000 CDF

Latest W helicity

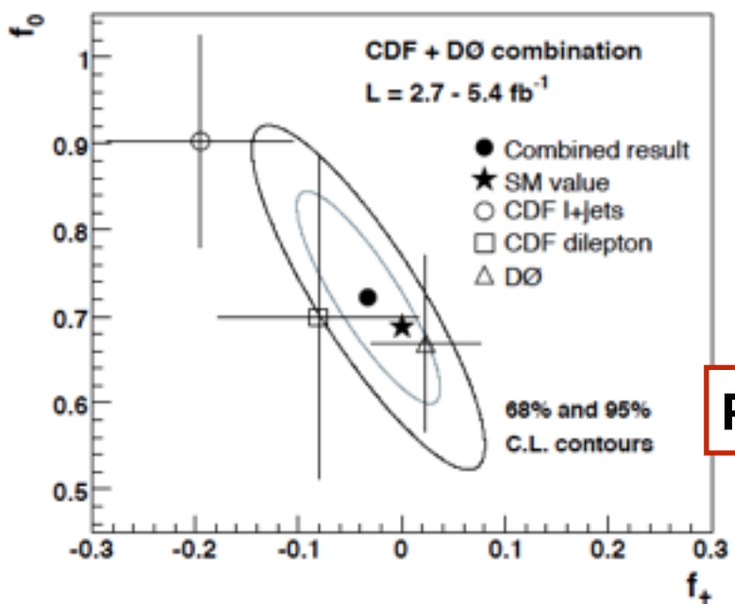
- D0 Run II with 5.4 fb^{-1} in L+jets and dilepton
  - Simultaneous measurement
    - f0=0.669±0.102[±0.078(stat.)±0.065(syst.)]
    - f+=0.023±0.053[±0.041(stat.)±0.034(syst.)]
- CDF Run II with 8.7 fb^{-1} in L+J channel with ME method:
  - Constrained measurement:
    - f0=0.686±0.042(stat)±0.040(syst)
    - f+=–0.025±0.024(stat)±0.040(syst)
  - Simultaneous measurement:
    - f0=0.726±0.066(stat)±0.067(syst)
    - f+=–0.045±0.043(stat)±0.058(syst)
- Combination CDF and D0 : 2.7 - 5.4 fb^{-1} :
  - Simultaneous measurement
    - f0 = 0.722 ± 0.062 (stat) ± 0.052 (syst)
    - f+ = –0.033 ± 0.034 (stat) ± 0.031 (syst)

PRD 83 , 032009





PRD 87 , 031104



PRD 85 , 091104

2012 CDF

2012 CDF D0

2011 D0

2008 D0

2007 CDF

2005 CDF

2005 D0

2005 CDF

2000 CDF

Conclusions

One of the principal goals of the Tevatron Run II (2001-2011) program, which produced data samples O(100) times larger than Run I, was to thoroughly explore the properties of the top quark.

The main studies of top properties at the Tevatron have been presented

This 20 years have been very rich and exciting!

Thanks for your attention

Back up

Back up

Systematics charge analysis

Charge at D0

PRL 98, 041801

- Jet charge distribution for b, bbar, c , cbar are used as probability density function for the charge of the jet originating from a given quark

$$L(\rho, q) = \prod_{i=1}^{N_{\text{data}}} (1-\rho) P_{\text{SM}}(q_i) + \rho P_{\text{ex}}(q_i)$$

- Results
  - $f_{\text{XM-top}} = \rho$ = -0.13 ± 0.66(stat) ± 0.11(syst)
  - data are consistent with top charge of |2/3|
  - Exclusion at 92% C.L. that the sample is due solely to exotic top quark production
  - Upper limit of fraction of exotic top pairs < 0.8 at 90% C.L.

TABLE I. Expected and observed confidence levels as function of the cumulated systematic uncertainties.

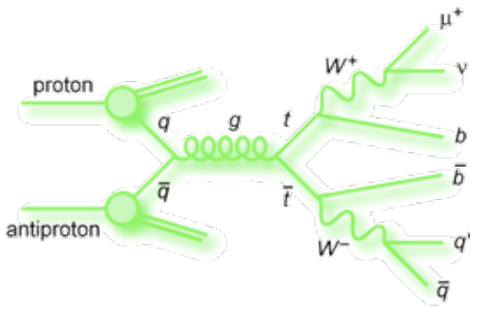
Systematic	Observed	Expected
Statistical uncertainty only	95.8	95.3
+ Fraction of $c\bar{c}$ events	95.8	95.2
+ Charge-flipping processes	95.7	95.2
+ Weighting with respect to p_T and y spectra	94.4	94.1
+ Fraction of flavor creation	93.7	93.4
+ Statistical error on P_f	93.3	93.1
+ Jet energy calibration[a]	92.4	91.8
+ Top quark mass	92.2	91.2

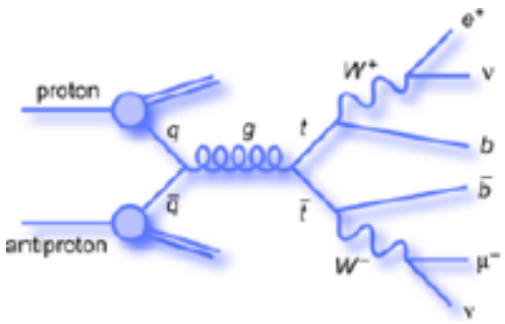
2007 D0

Charge (I) CDF

Conf.Note 8782

- Results from CDF :
  - 1 fb^{-1} 2002/2006 data
  - Lepton + jets & dilepton events
    - Pairing:
      - L+J: χ^2 constraint on top and W masses (efficiency 56% with purity of 84%)
      - Dilepton: $M_{lb}^2 = ((E_l + E_b)^2 - (\vec{p}_l + \vec{p}_b)^2)$ (efficiency 37% with purity of 96%)





    - JetQ Algorithm with selection efficiency of 97% (87%) and a purity of 61%.
      - Data/MC correction to the purity due to jet fragmentation discrepancy

$$JetQ = \frac{\sum(\vec{p}_{track} \cdot \vec{p}_{jet})^{0.5} Q_{track}}{\sum(\vec{p}_{track} \cdot \vec{p}_{jet})^{0.5}}$$

  - Signal and background estimation
    - Combined purity keeps into account all possibility of pairing and getting the right JetQ assignment

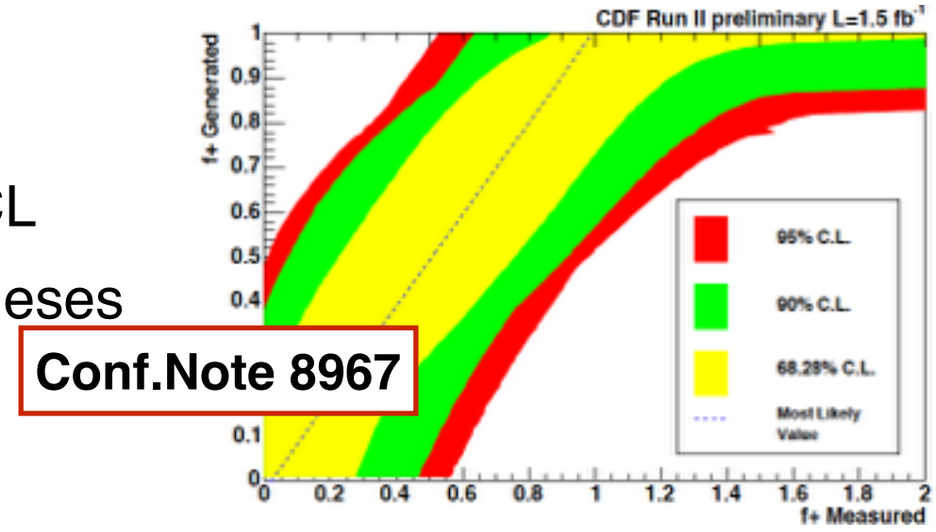
$$p = f_{nonb} SF_{nonb} p_{nonb} + (1 - f_{nonb} SF_{nonb})(p_{pairing} p_{JetQ} SF_{JetQ} + (1 - p_{pairing})(1 - p_{JetQ} SF_{JetQ}))$$

2007 CDF

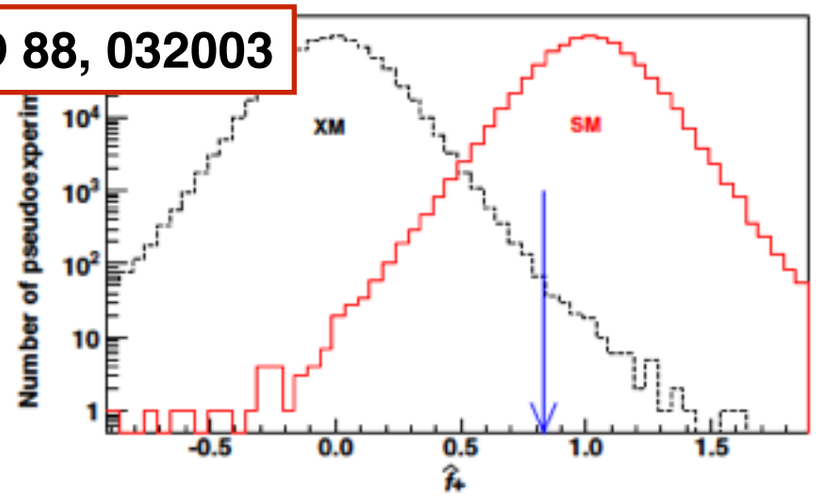
2007 D0

Charge

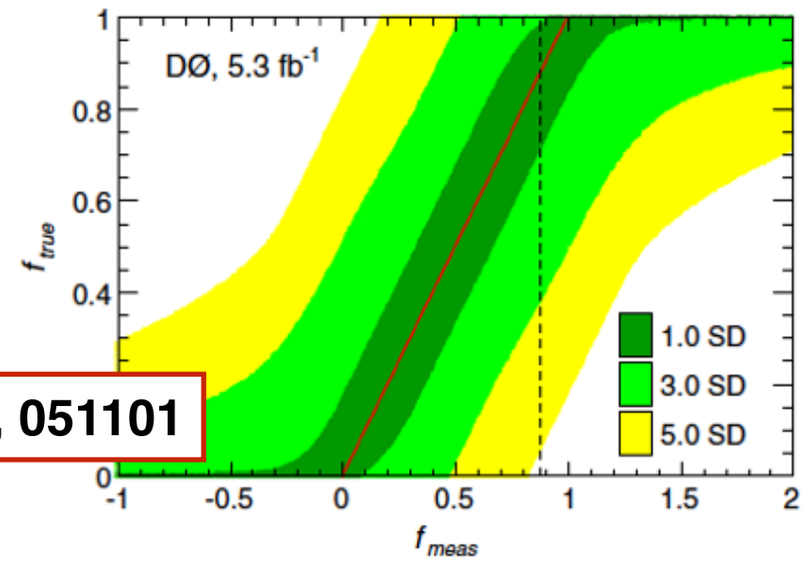
- Other measurements:
  - 2007 CDF: 1.5 fb^{-1} 2002/2007 data
    - Exotic top (q=4/3) is rejected at 87% CL
    - Allowing the SM and Exotic top hypotheses to coexist:
      - $0.6 < f_{SM\text{-}top}$ with 68% CL and $0.4 < f_{SM\text{-}top}$ with 95% CL
  - 2013 CDF: 5.6 fb^{-1} 2002/2010 data
    - Exotic top (q=4/3) is rejected at 99% CL
    - Allowing the SM and Exotic top hypotheses to coexist:
      - $0.66 < f_{SM\text{-}top} < 0.95$ with 68% CL and $0.48 < f_{SM\text{-}top} < 1.00$ with 95% CL
- 2014 D0: 5.3 fb^{-1} (L+jets)
  - Exotic top (q=4/3) is rejected at 5 SD
  - Allowing the SM and Exotic top hypotheses to coexist:
    - $0.70 < f_{SM\text{-}top}$ with 68% CL and $0.54 < f_{SM\text{-}top}$ with 95% CL



Conf.Note 8967



PRD 88, 032003



PRD 90, 051101

2014 D0

2013 CDF

2007 CDF

2007 CDF

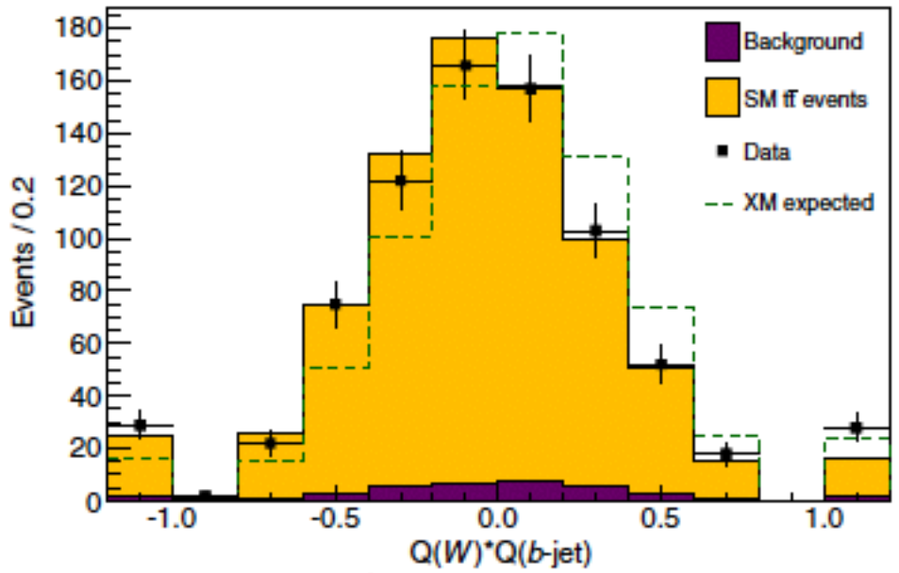
2007 D0

Charge

Other measurements:

- 2013 CDF: 5.6 fb^{-1} 2002/2010 data
  - Exotic top (q=4/3) is rejected at 99% CL
  - Allowing the SM and Exotic top hypotheses to coexist:
    - $0.66 < f_{SM\text{-}top} < 0.95$ with 68% CL and $0.48 < f_{SM\text{-}top} < 1.00$ with 95% CL

$$L = \frac{(N_+)^{x^+} e^{-N_+}}{x^+!} \frac{(N_-)^{x^-} e^{-N_-}}{x^-!} \frac{e^{-\frac{(y_b - N_b)^2}{2\sigma_{N_b}^2}}}{\sigma_{N_b}} \frac{e^{-\frac{(y_s - N_s)^2}{2\sigma_{N_s}^2}}}{\sigma_{N_s}} \times \frac{e^{-\frac{(z_{p_s} - p_s)^2}{2\sigma_{p_s}^2}}}{} \frac{e^{-\frac{(z_{p_b} - p_b)^2}{2\sigma_{p_b}^2}}}{}$$



PRD 88, 032003

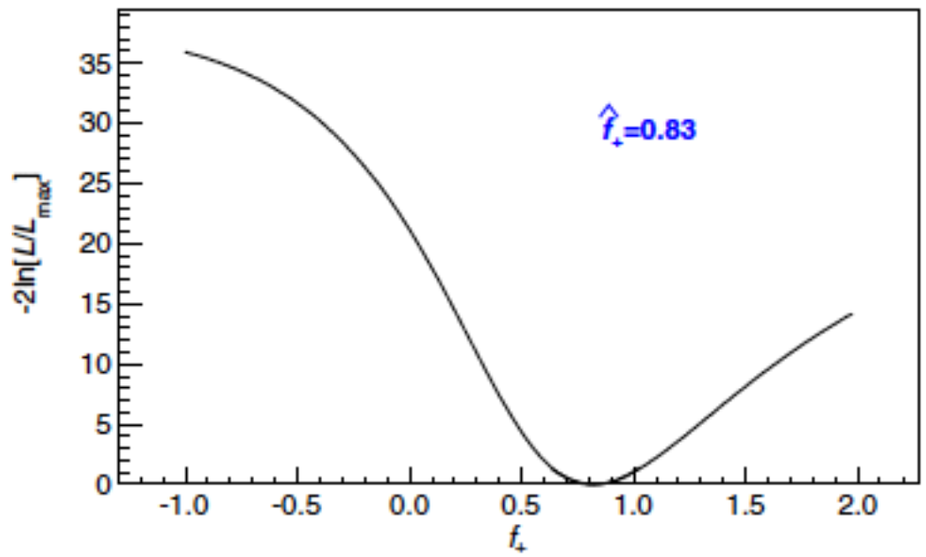


TABLE VII. Number of observed candidates and results for the electron and muon candidates separately.

Number of candidates:	Electrons 206 SM and 155 XM	Muons 210 SM and 203 XM
f_+	1.11	0.57
p_{SM}	65.9%	5.2%
p_{XM}	0.04%	0.7%
N_s	308 ± 51	392 ± 67
N_b	17 ± 5	17 ± 4
p_s	0.56 ± 0.01	0.56 ± 0.01
p_b	0.50 ± 0.02	0.50 ± 0.01

Systematic (in %)	χ^2 selection efficiency	JetQ efficiency	Pairing purity	JetQ purity
Jet energy scale	0.2	0.04	0.1	0.1
Initial- and final-state radiation	0.5	0.1	0.2	0.2
MC generator	0.2	0.1	0.1	(0.7)
Top-quark mass	0.4	0.2	0.9	0.5
PDF	0.7	0.02	0.1	0.02
Total	1.0	0.3	1.0	0.6

2013 CDF

2007 CDF

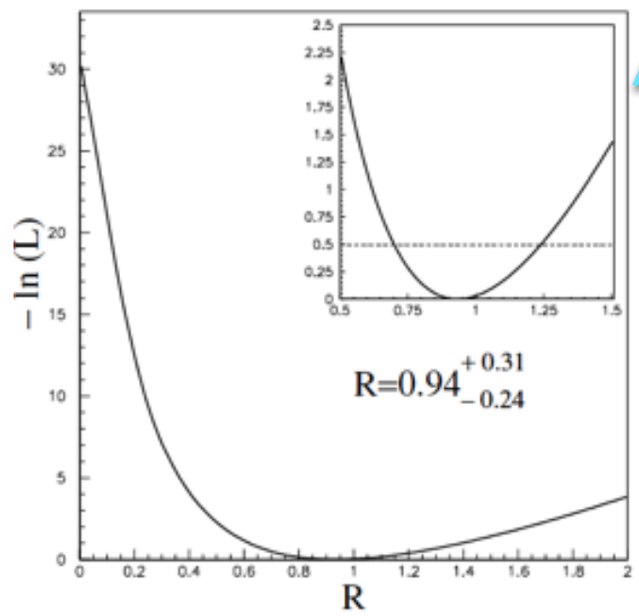
2007 CDF

2007 D0

Branching ratio at CDF

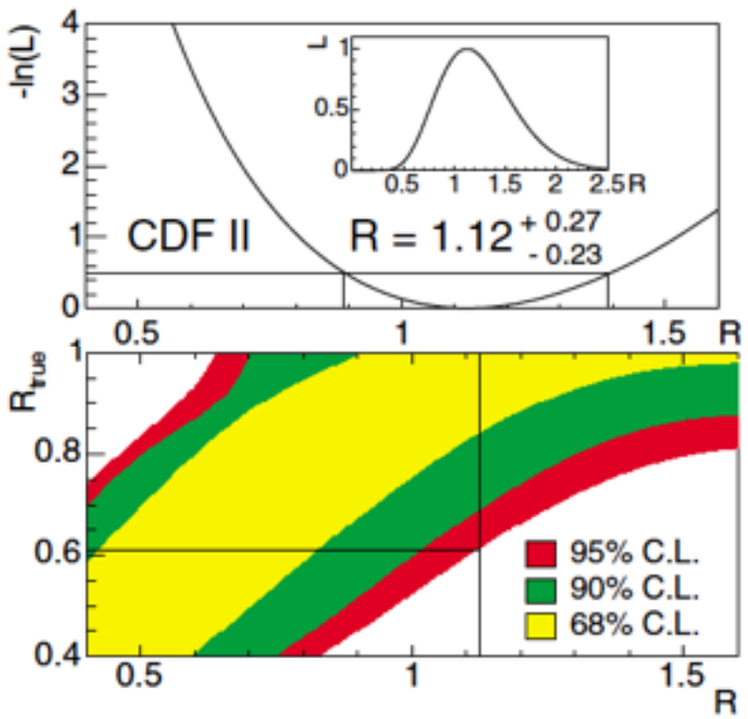
Run I data **PRL 86, 3233**

- in 2001 with 109 pb^{-1} in lepton+jets and dilepton events
  - $|V_{tb}| = 0.97^{+0.16}_{-0.12}$ and $|V_{tb}| > 0.78(0.75)$ at 90%(95%)CL



- in 2005 with 160 pb^{-1} in lepton+jets and dilepton events

Run II data **PRL95,102002**



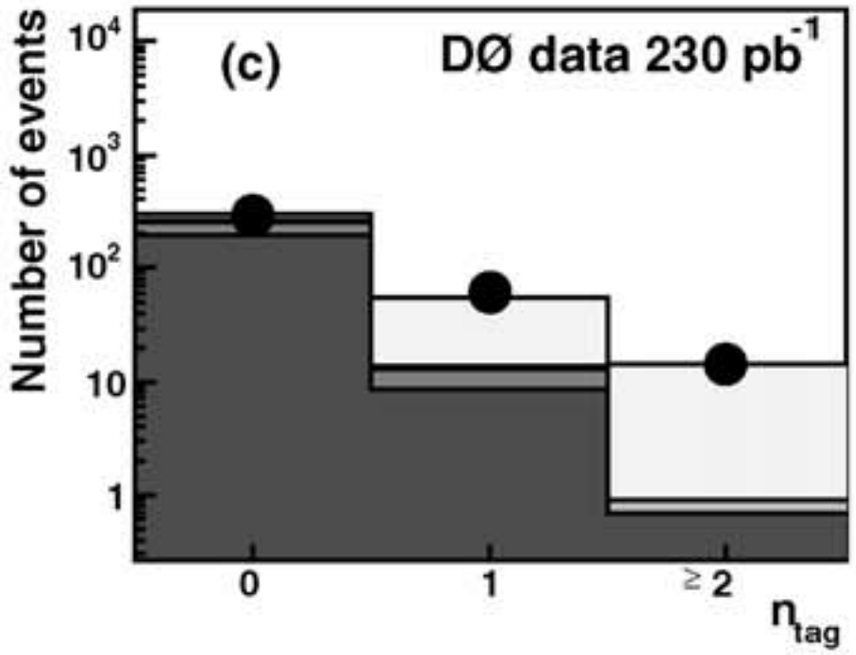
- $R = 1.12^{+0.21}_{-0.19}$ (stat) $^{+0.17}_{-0.13}$ (syst) and $R>0.61$ at 95% CL
- $|V_{tb}| > 0.78$ at 95% CL

2005 CDF

2001 CDF

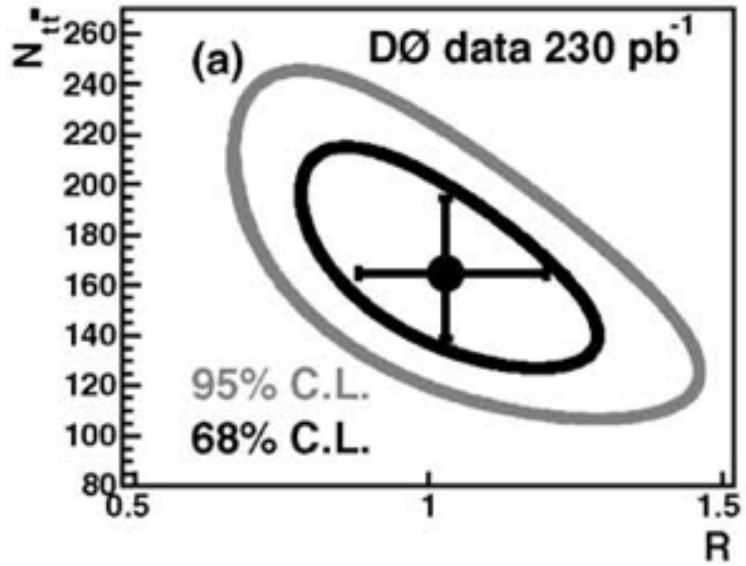
Branching ratio at D0

- in 2006 with 230 pb^{-1} in lepton+jets



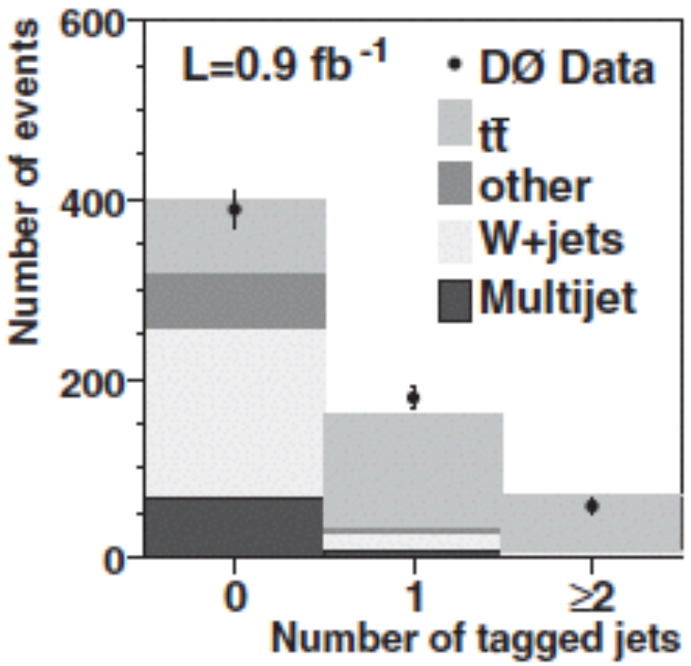
- $R = 1.03^{+0.19}_{-0.17}$ (stat+syst) and $R > 0.61$ at 95% CL
- $|V_{tb}| > 0.78$ at 95% CL

PLB 639, 616



PRL 100, 192003

- in 2008 with 0.9 fb^{-1} in lepton+jets

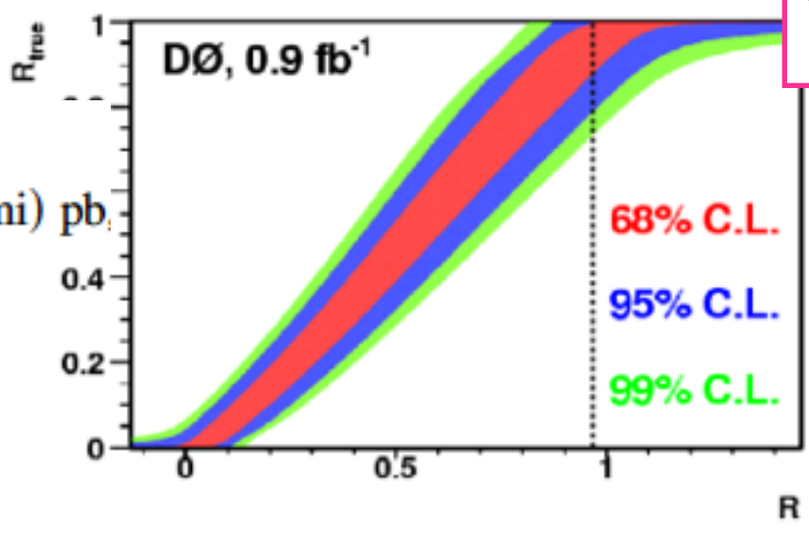


- <u>cross section and R simultaneously measured</u>

$$R = 0.97^{+0.09}_{-0.08}(\text{stat} + \text{syst}) \quad \text{and}$$

$$\sigma_{t\bar{t}} = 8.18^{+0.90}_{-0.84}(\text{stat} + \text{syst}) \pm 0.50(\text{lumi}) \text{ pb}$$

$$|V_{tb}| > 0.89 \text{ at } 95\% \text{ C.L}$$



2006 D0

2005 CDF

2001 CDF

Branching ratio

- **D0 in 2011** with 5.4 fb^{-1} in lepton+jets and dilepton final states

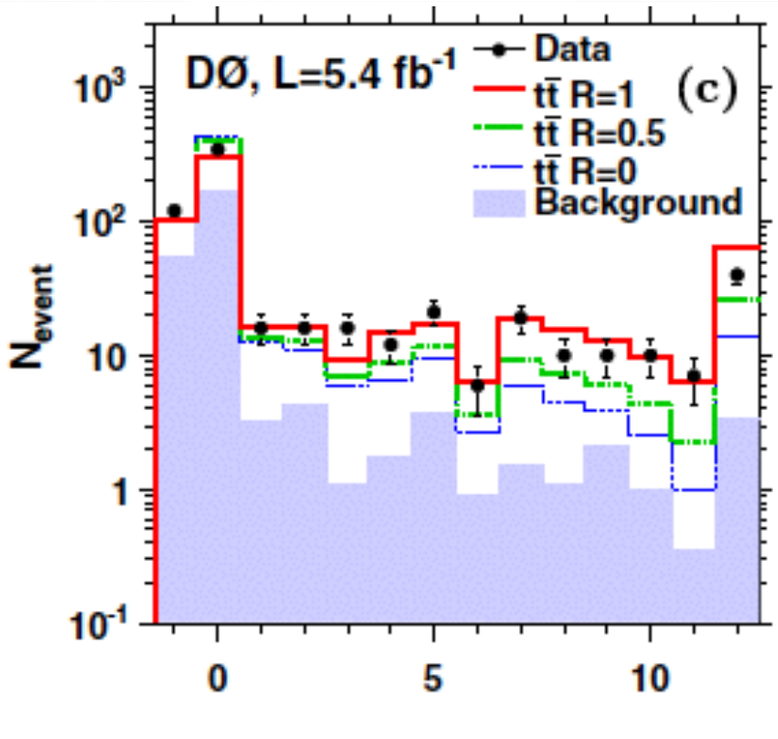
PRL 107, 121802

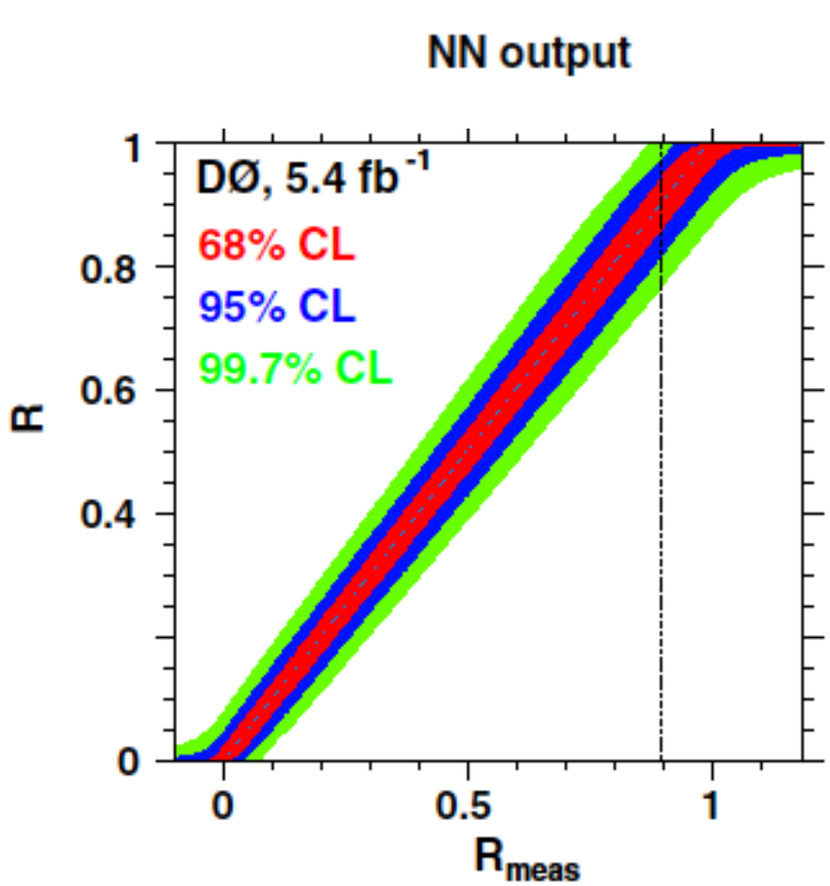
  - NN b-tagging algorithm
  - cross section and R simultaneously measured

$$R = 0.90 \pm 0.04(\text{stat} + \text{syst})$$
$$\sigma_{t\bar{t}} = 7.74^{+0.67}_{-0.57}(\text{stat} + \text{syst})\ \text{pb}. \quad |V_{tb}| = 0.95 \pm 0.02$$

0.90<| V_{tb} |<0.99 at 95% CL

	$\ell\ell$		ℓ + jets		Combination	
Source	+SD	−SD	+SD	−SD	+SD	−SD
Statistical	0.041	−0.042	0.030	−0.029	0.023	−0.023
Muon identification	0.002	−0.002	0.000	−0.001	0.001	−0.001
Electron identification and smearing	0.004	−0.004	0.000	−0.000	0.001	−0.002
Signal modeling	0.007	−0.006	0.009	−0.011	0.004	−0.006
Triggers	0.003	−0.003	0.001	−0.001	0.002	−0.002
Jet energy scale	0.008	−0.008	0.017	−0.016	0.003	−0.008
Jet reconstruction and identification	0.010	−0.009	0.018	−0.022	0.009	−0.013
b-tagging	0.018	−0.019	0.065	−0.056	0.034	−0.033
Background normalization	0.020	−0.020	0.004	−0.005	0.008	−0.010
W fractions matching + higher order effects	...	...	0.001	−0.001	0.001	−0.002
Instrumental background	0.013	−0.013	0.003	−0.004	0.005	−0.007
Luminosity	0.010	−0.010	0.001	−0.001	0.004	−0.004
Other	0.002	−0.002	0.000	−0.000	0.001	−0.001
Template statistics for template fits	0.002	−0.002	0.011	−0.011	0.010	−0.010
Quadratic sum of systematics	0.035	−0.035	0.071	−0.064	0.038	−0.040





2011 D0

2006 D0

2005 CDF

2001 CDF

Branching ratio

- **CDF in 2012** with 8.7 fb^{-1} in **lepton+jets** final state

PRD 87 111101

Source	$+\delta R$	$-\delta R$	$+\delta\sigma_{t\bar{t}}$ (pb)	$-\delta\sigma_{t\bar{t}}$ (pb)
b-tagging	0.078	−0.073	0.06	−0.03
Background normalization	0.056	−0.052	0.78	−0.66
Jet-energy scale	0.016	−0.019	0.46	−0.41
ISR/FSR	0.006	−0.006	0.22	−0.21
Luminosity	0.001	−0.002	0.44	−0.39
Top-quark mass	0.001	−0.000	0.33	−0.32
Others	0.005	−0.006	0.17	−0.15
Total syst. uncert.	0.088	−0.081	1.04	−0.92
Statistical	0.043	−0.043	0.29	−0.29

  - cross section and R simultaneously measured

$$R = 0.94 \pm 0.09 \text{ and } \sigma_{t\bar{t}} = 7.5 \pm 1.0 \text{ pb}$$

$|V_{tb}|=0.97\pm0.05$ and $|V_{tb}| > 0.89$ at 95% CL

- **CDF in 2014** with 8.7 fb^{-1}in **dilepton** final state

$R=0.87\pm0.07$

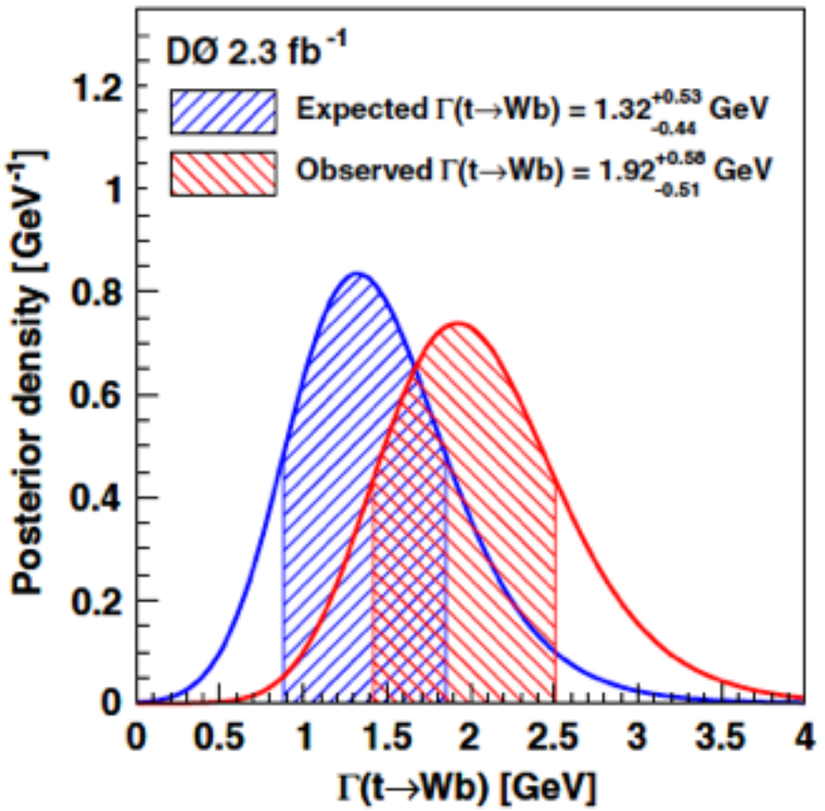
$|V_{tb}|=0.93\pm0.04$ and $|V_{tb}| > 0.86$ at 95% CL

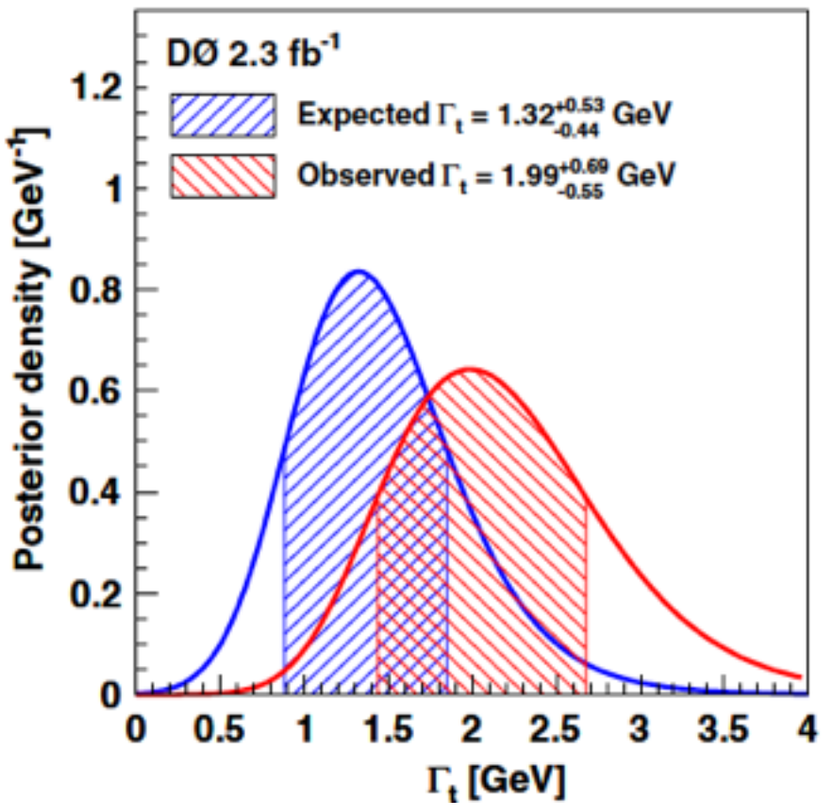
Source	Systematic uncertainty
Correction to b-tagging efficiency in data and MC simulations	+0.045, −0.040
$\sigma_{t\bar{t}}$	±0.01
Luminosity	+0.009, −0.012
Jet energy scale	+0.033, −0.025
ISR and FSR	+0.013, −0.025
Total systematic uncertainty	+0.059, −0.057
Statistical uncertainty	±0.045
Total uncertainty	+0.074, −0.073

PRL 112, 221801

2014 CDF
2012 CDF
2011 D0
2006 D0
2005 CDF
2001 CDF

Width (II) D0





PRL 106, 022001

- Cross section is determined as in Single top cross section analysis

PLB 682, 363(2010)

- And partial width is determined

$$\Gamma(t \to Wb) = 1.92^{+0.58}_{-0.51}\ \text{GeV}$$

- For the total width:

$$\Gamma_t = 1.99^{+0.69}_{-0.55}\ \text{GeV} \qquad \Gamma_t > 1.21\ \text{GeV} \quad \text{at 95\%C.L.}$$

$$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}\ \text{s} \qquad \tau_t < 5.4 \times 10^{-25}\ \text{s}$$

Sources	$\sigma(t-\text{channel})$, %	$\mathcal{B}(t \to Wb)$, %	Correlations
Components for Normalization			
Luminosity	6.1	0.0	
Single Top Quark Signal Modeling	3.5–13.6	0.0	
Top Pair Production Signal Modeling	-	1.0	*X*
Other Background from MC	15.1	0.6	*X*
Detector Modeling	7.1	0.1	*X*
Components for Normalization and Shape			
Background from Data	13.7–54	1.7	*X*
b-Jet Identification	2–30	6.3	*X*
Jet Energy Scale	0.1–13.1	0.0	

2010 D0

2009 CDF

Width

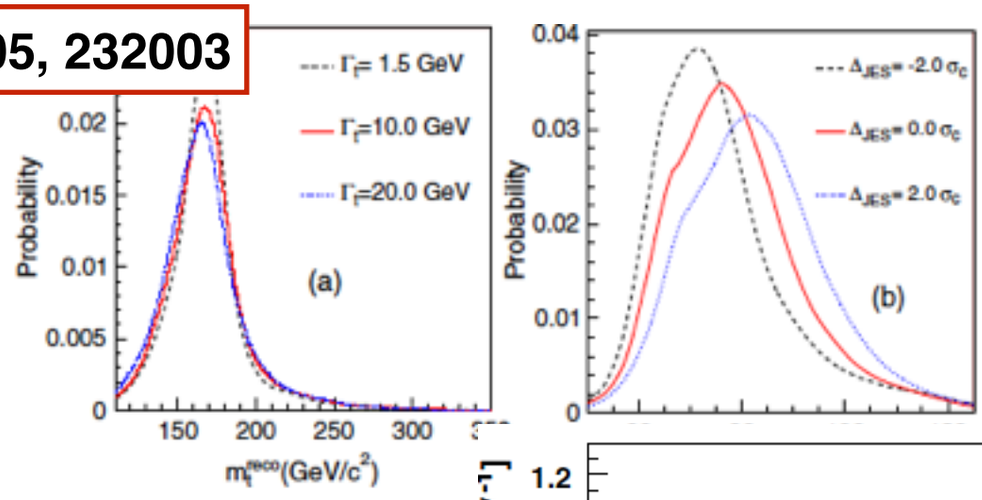
- 2010 CDF with 4.3 fb^{-1} :
  - JES *in situ* calibration
  - Two template fit (m_{top} and hardonic W mass m_{jj})with various Γ and JES
  - $\Gamma_t < 7.6$ GeV at 95% CL and $0.3<\Gamma_t< 4.4$ GeV at 68% CL
    - $\Rightarrow 1.5\ 10^{-25} < \tau_t < 3.3\ \ 10^{-24}$ s
- 2012 D0 with 5.4 fb^{-1} :

$$\Gamma_p = 1.87^{+0.44}_{-0.40}\ \text{GeV} \qquad \Gamma_t = 2.00^{+0.47}_{-0.43}\ \text{GeV}$$

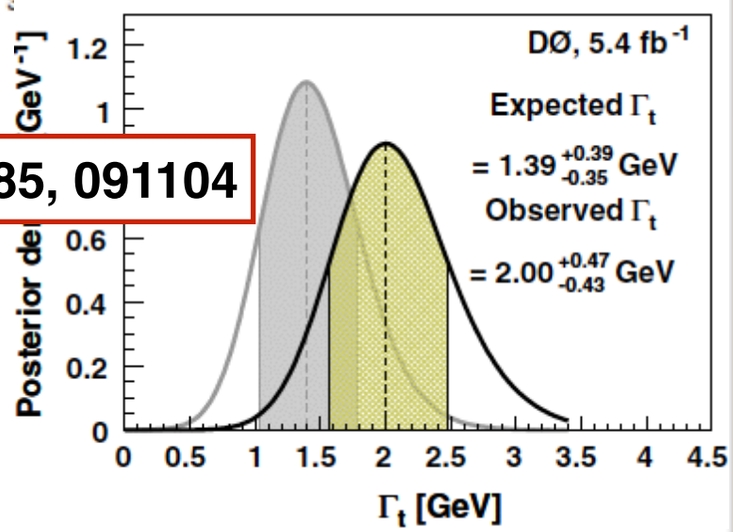
$$\tau_t = (3.29^{+0.90}_{-0.63}) \times 10^{-25}\ \text{s}$$

- 2013 CDF with 8.7 fb^{-1} :
  - $\Gamma_t < 6.38$GeV at 95% CL and $1.10<\Gamma_t< 4.05$ GeV at 68% CL
    - $\Rightarrow 1.6\ 10^{-25}$ s$<\tau_t < 6\ 10^{-25}$ s at 68% CL

PRL 105, 232003



PRD 85, 091104



PRL 111, 202001

Source	Uncertainty (GeV)
Jet resolution	0.56
Color reconnection	0.69
Event generator	0.50
Higher-order effects	0.21
Residual jet-energy scale	0.19
Parton distribution functions	0.24
b-jet energy scale	0.28
Background shape	0.18
Gluon fusion fraction	0.26
Initial- and final-state radiation	0.17
Lepton energy scale	0.03
Multiple hadron interaction	0.23
Total systematic uncertainty	1.22

2013 CDF

2012 D0

2010 CDF

2010 D0

2009 CDF

W helicity at CDF (ME)

- CDF Run II with 1.9 fb^{-1}:
  - The likelihood for each event is created based on the LO matrix elements for tt-bar and the dominant background W+jets.

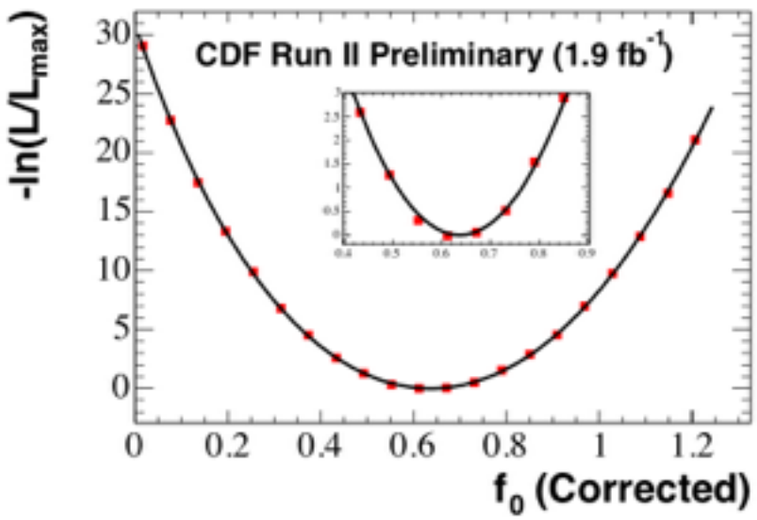
$$L(f_0, C_s) = \prod_{i=1}^{N} C_s P_{t\bar{t}}(\vec{x}_i; f_0) + (1 - C_s) P_{W+jets}(\vec{x}_i)$$

  - where x are the measured quantities, P the event production probabilities and C is the fraction of event consistent with signal hypothesis.

$$P(\vec{x}) = \frac{1}{\sigma_{obs}} \int \frac{d\sigma(\vec{y})}{d\vec{y}} f(\tilde{q}_1) f(\tilde{q}_2)\, W(\vec{x}, \vec{y})\, d\tilde{q}_1 d\tilde{q}_2\, d\tilde{p}^x_{t\bar{t}} d\tilde{p}^y_{t\bar{t}}\, d\vec{y}$$

  - The signal probability for a set of x measurement is obtained integrating over the parton level cross section with a transport function, which translate the measured parameter to parton level with their resolution

  - F_0=0.637 ± 0.084(stat) ± 0.069 (syst)



PRD 73 111103

2007 CDF

2005 CDF

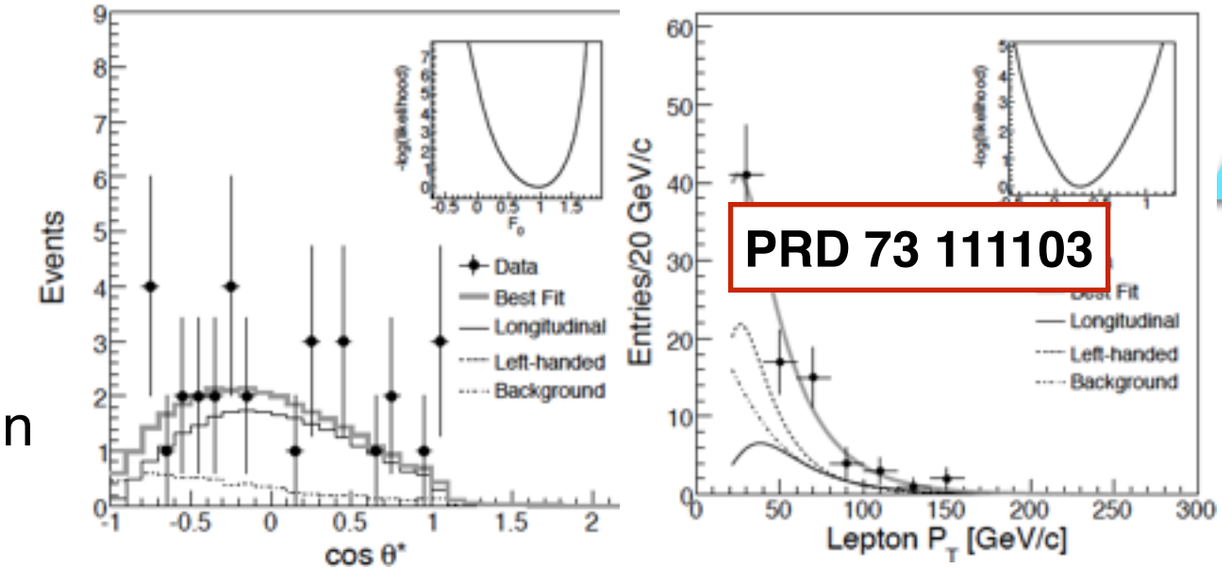
2005 D0

2005 CDF

2000 CDF

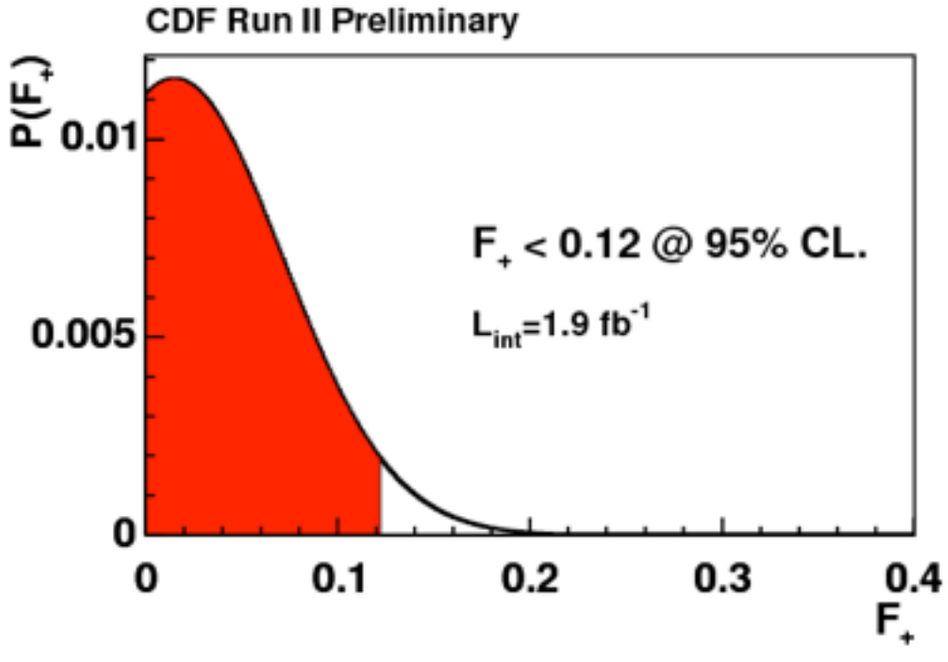
W helicity at CDF

- CDF Run II dataset 200 pb $^{-1}$:
  - L+jets and dilepton samples
  - Pt spectrum and cos(θ*) fit independently for each polarization assuming for the other the SM value.



$F_0 = 0.74^{+0.22}_{-0.34}$ (stat.+syst.) $F_+ = 0.00^{+0.20}_{-0.19}$ (stat.+syst.) $F_+ < 0.27$ at the 95% C.L.

- Updated in 2007 with 1.9 fb^{-1}:
  - F_0=0.62 ± 0.10 (stat) ± 0.06 (syst)
  - F_+=0.01 ± 0.05 (stat) ± 0.03 (syst)
  - Simultaneous fit:
    - F_0=0.66 ± 0.16 (stat) ± 0.05 (syst) and F_+=-0.03±0.06(stat) ±0.03(syst).



2007 CDF

2005 CDF

2005 D0

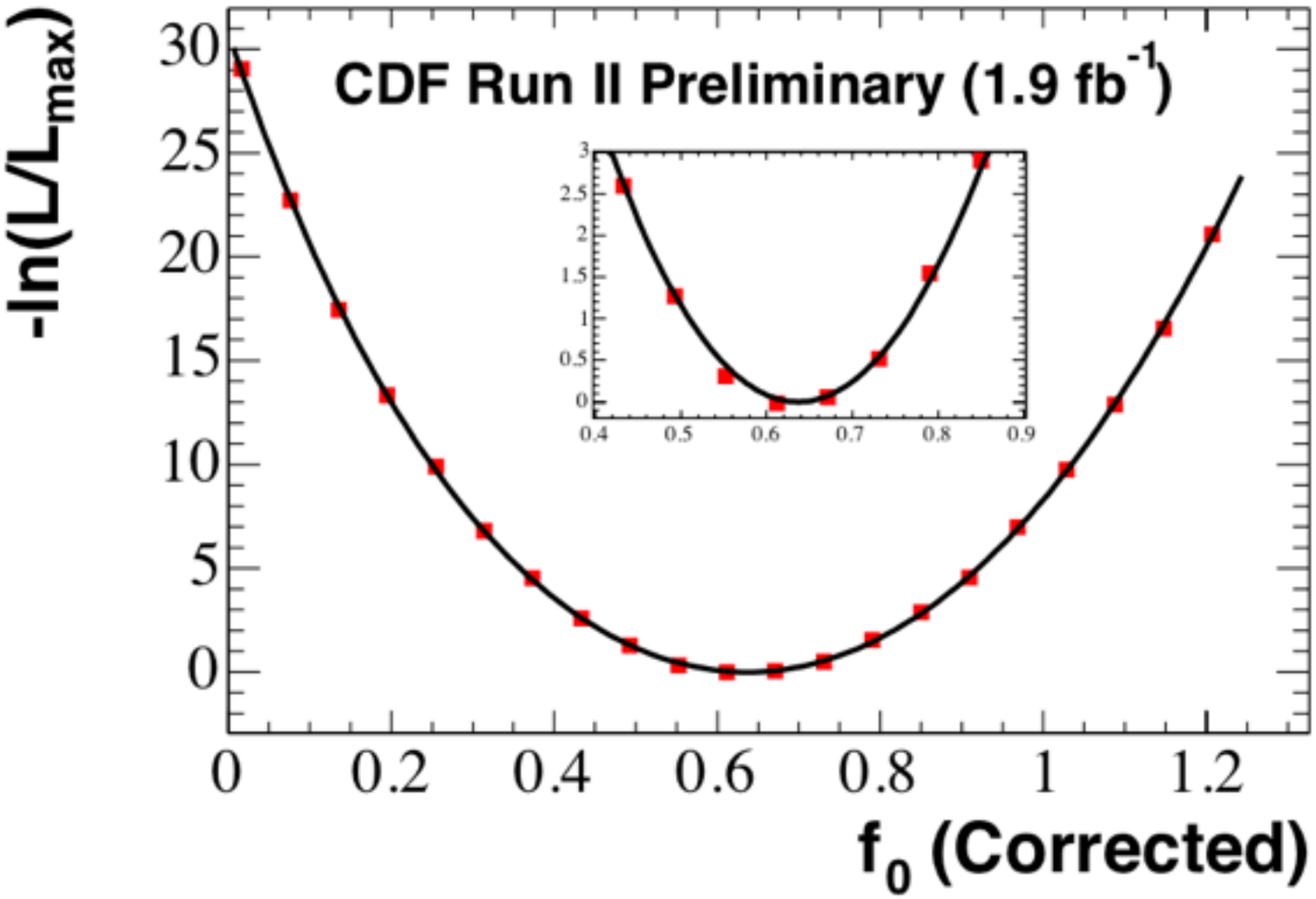
2005 CDF

2000 CDF

W helicity at CDF (ME)

- CDF Run II with 1.9 fb^{-1} with Matrix Element method:

PRD 73 111103



- $F_0 = 0.637 \pm 0.084\ (stat) \pm 0.069\ (syst)$

2007 CDF

2005 CDF

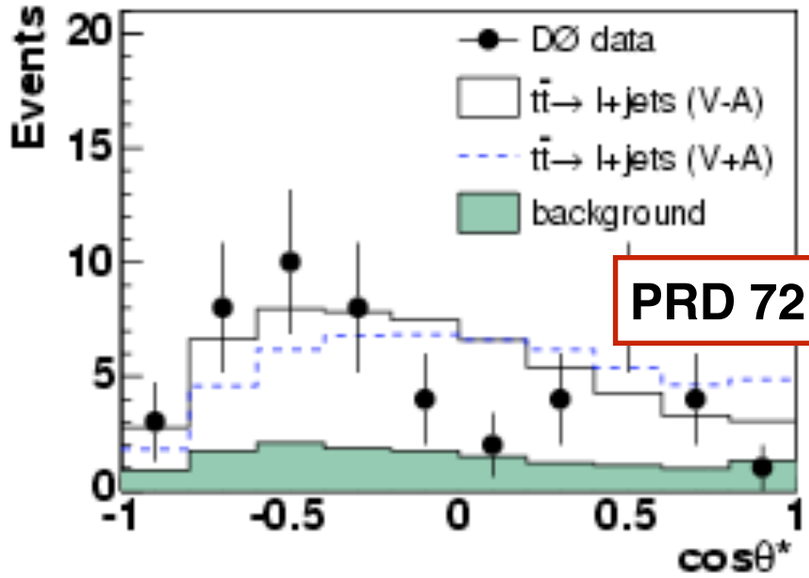
2005 D0

2005 CDF

2000 CDF

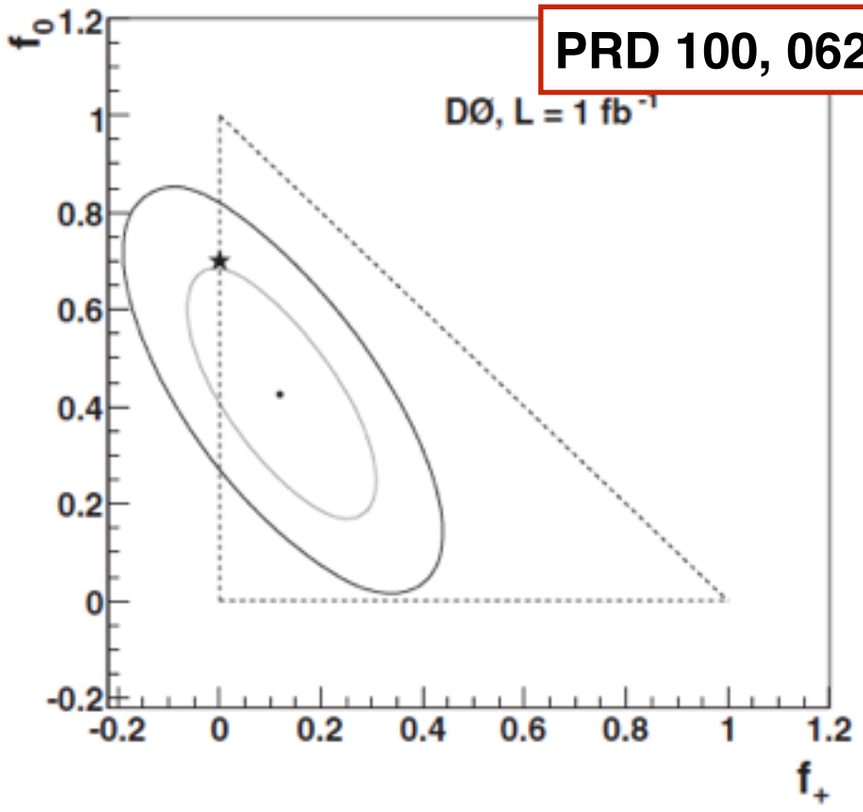
W helicity at D0

- D0 Run II dataset 230 pb $^{-1}$ in L +jets final state:
  - f+= 0.00 ± 0.13 (stat) ± 0.07 (syst)
  - f+ < 0.25 (95% CL)



PRD 72 011104

- Updated in 2008 with 1 fb^{-1}:
  - f0 = 0.425 ± 0.166 (stat) ±0.102 (syst)
  - f+ = 0.119 ±0.090 (stat) ±0.053 (syst)
  - f+ < 0.13 at 95 % CL



PRD 100, 062004

2008 D0

2007 CDF

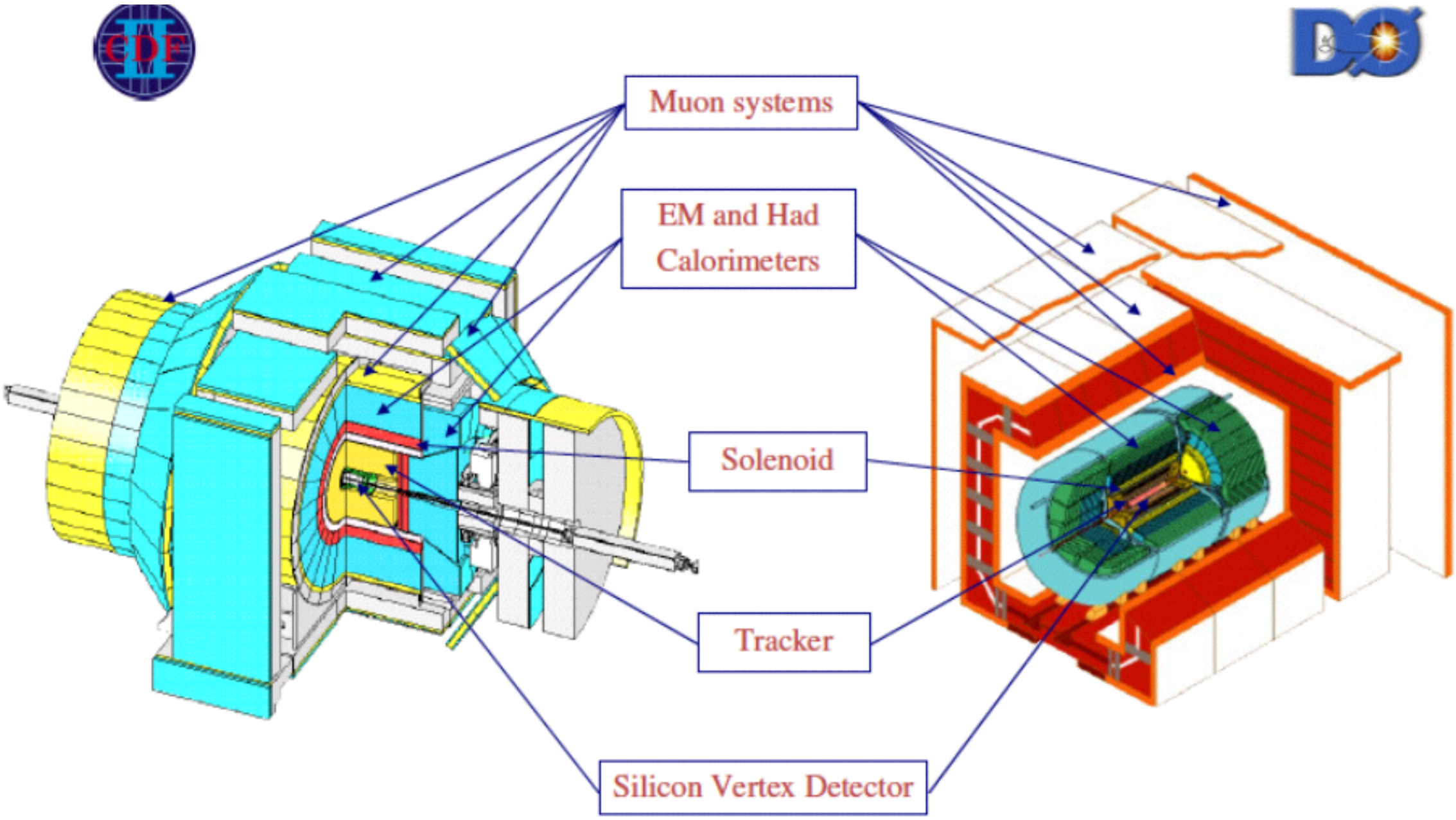
2005 CDF

2005 D0

2005 CDF

2000 CDF

Detectors


Muon systems
EM and Had Calorimeters
Solenoid
Tracker
Silicon Vertex Detector