

Testing SM in Top Quark Decays



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for the CDF and DØ collaborations

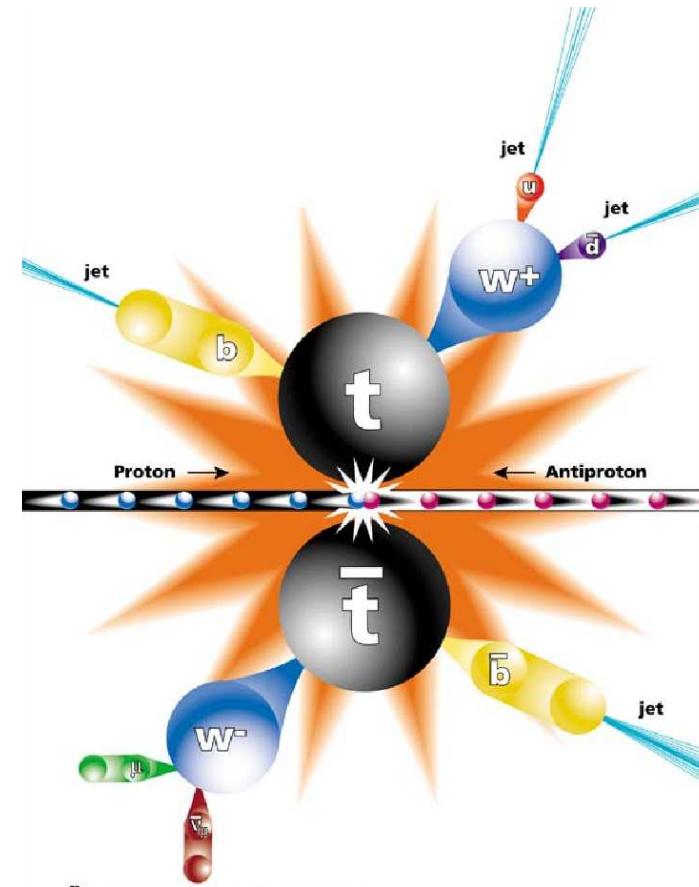
Outline

- Introduction
- W -Helicity
- Top Charge
- Branching fraction
- Summary

Introduction

The Top Quark

- Discovered by CDF and DØ in 1995.
- Completes set of quarks in SM.
- Quantum numbers as for up-type quarks.
- Production and decay properties fully determined within SM.
- Mass is the only free parameter.

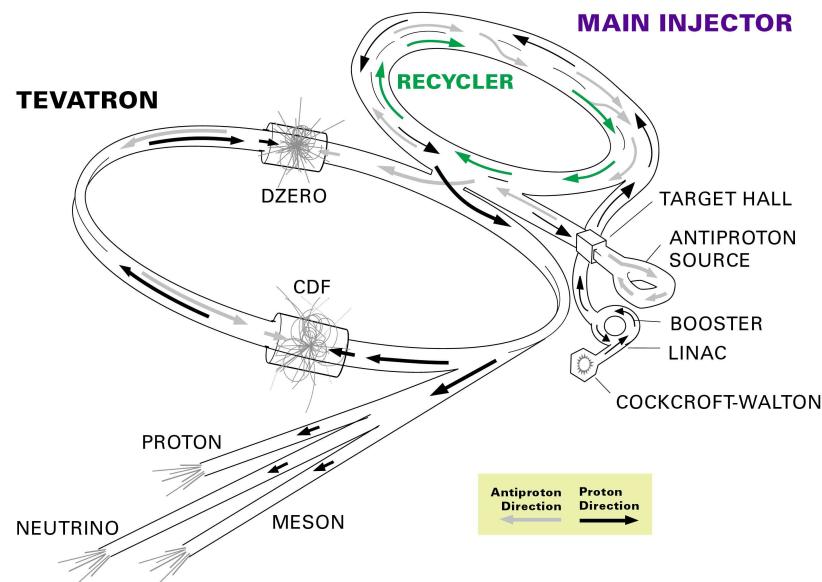


Only few of its predicted properties verified

The $p\bar{p}$ Accelerator Tevatron

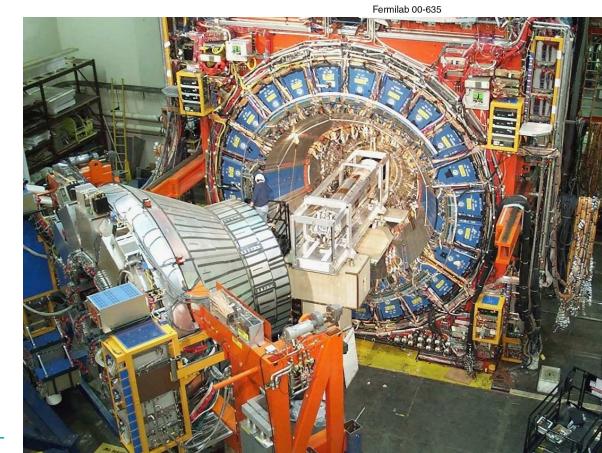
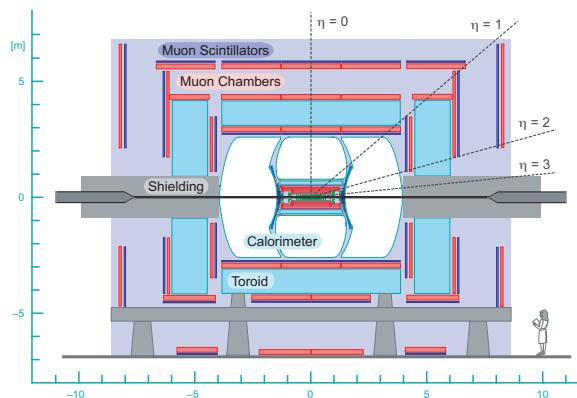
- Circumference 7 km.
- $p\bar{p}$ collisions
- Run I (1987-1995)
- Run II (since 2001)
Collision energy 2 TeV

FERMILAB'S ACCELERATOR CHAIN



- 2 experiments,
CDF and D \emptyset ,
record events.

$\mathcal{L} > 1 \text{ fb}^{-1}$ on tape.

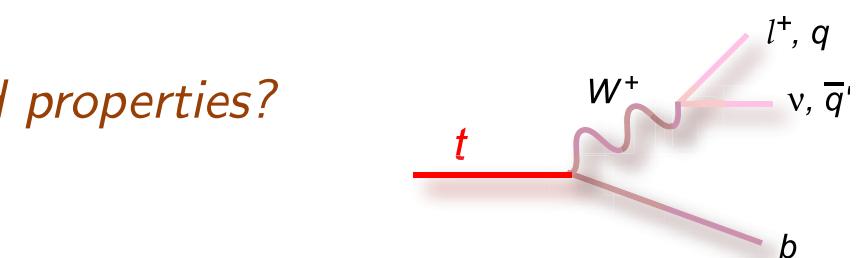
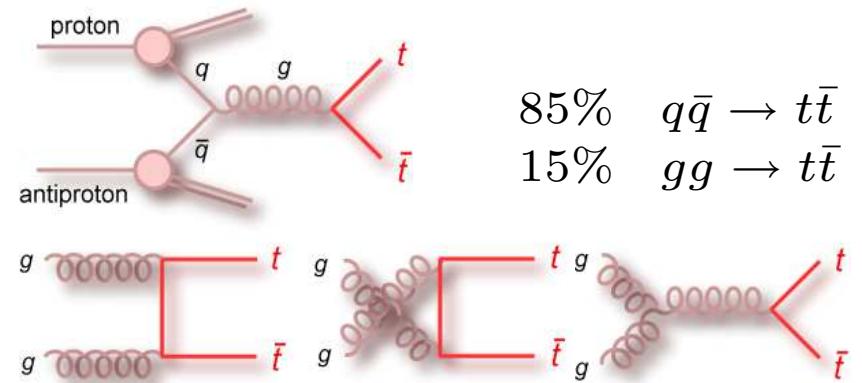


Top Production & Decay Channels

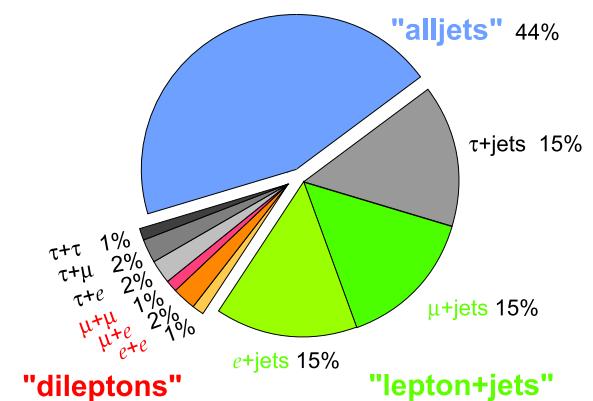
Strong production mechanism.
Electroweak production (single top) covered
by W. Wagner

- Top quarks produced in pairs
- In SM top quark decays to bW ($\sim 100\%$).
Can this be verified? Does it show expected properties?
- Decay modes are defined by W -decays:
 - Dilepton $(2b + 2l + 2\nu)$
 - Lepton+jets $(2b + 2q + l\nu)$
 - Alljets $(2b + 4q)$

Cleanest channel: Dilepton.
Golden channel: Lepton+jets.



Top Pair Branching Fractions

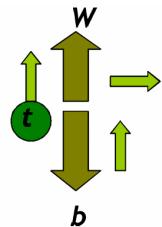


W -Helicity in Top Decays

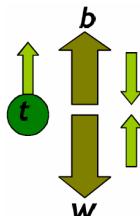
Does the top decay show the expected spin structure?

SM: only lefthanded particle couple to W s ($V-A$ coupling),

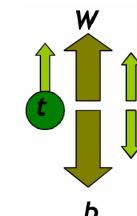
W is lefthanded or longitudinal.



Longitudinal W
SM: $f_0 = 70\%$



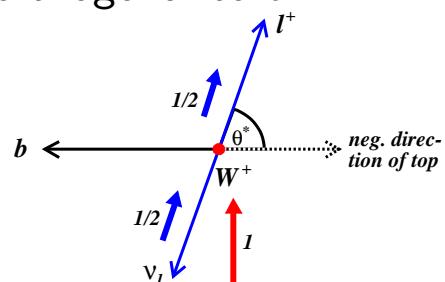
Left-handed W
SM: $f_- = 30\%$



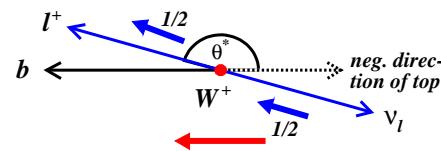
Right-handed W
SM: suppressed ($f_+ \simeq 0$)

In W -restframe lepton from W stays (preferably)

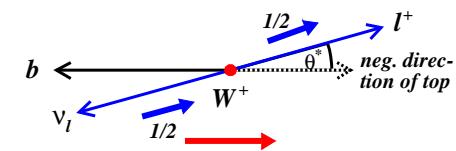
orthogonal to b



along b -direction



opposite to b -direction

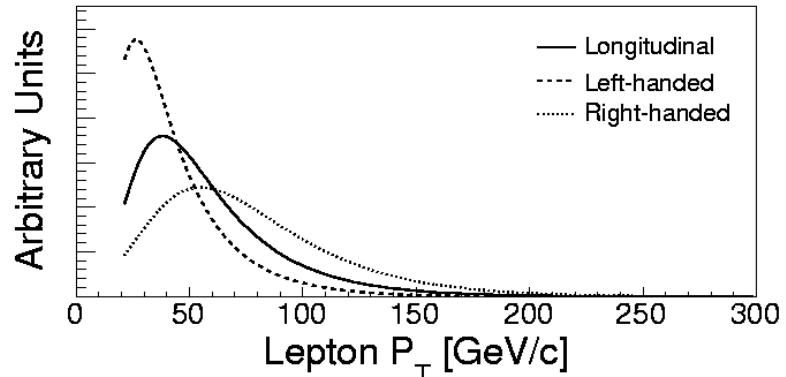


An admixture of $V+A$ wouldn't change longitudinal contribution.

Sensitive Observables

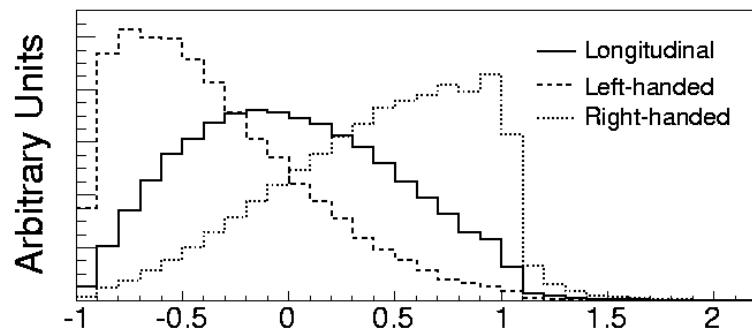
Lepton transvers momentum, p_T^{lept}

SM suppresses leptons against W direction
no ambiguities



Lepton- b -quark inv. mass, M_{lb}^2

Uses b and l 4-vectors only.

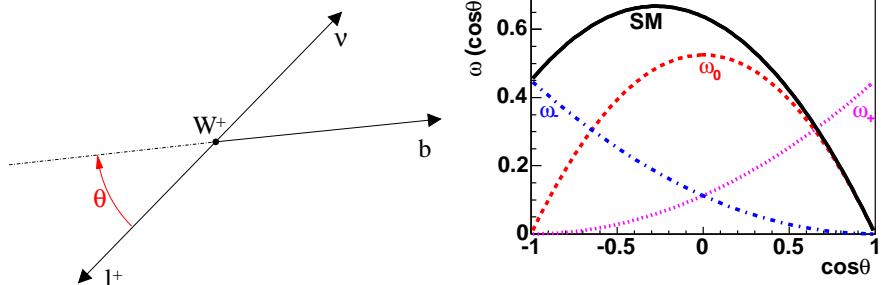


Angular distributions, $\cos \theta^*$:

Angle θ between lepton and direction
from where the top came in W restframe.

Full reconstruction of $t\bar{t}$ kinematics

Uses t , W and l 4-vectors.



CDF Results using M_{lb}^2

Dilepton and $l+jets$ on 695 to 750 pb $^{-1}$

$l+jets$

- Single and double b -tag separately
- One measurement per event
- Compares rec. M_{lb}^2 to $V \pm A$ templates

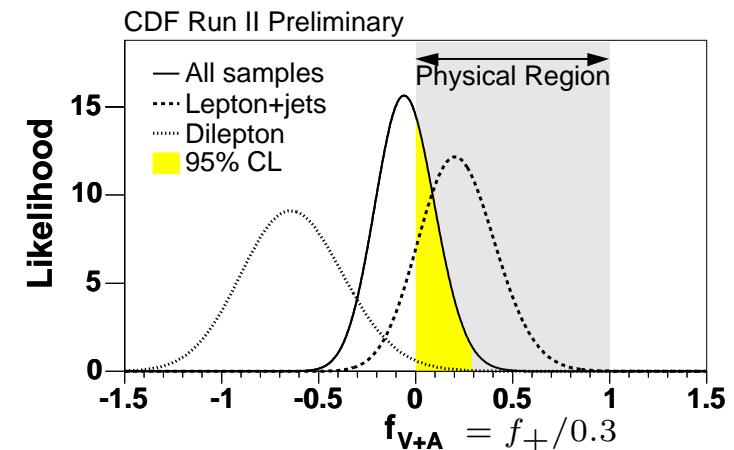
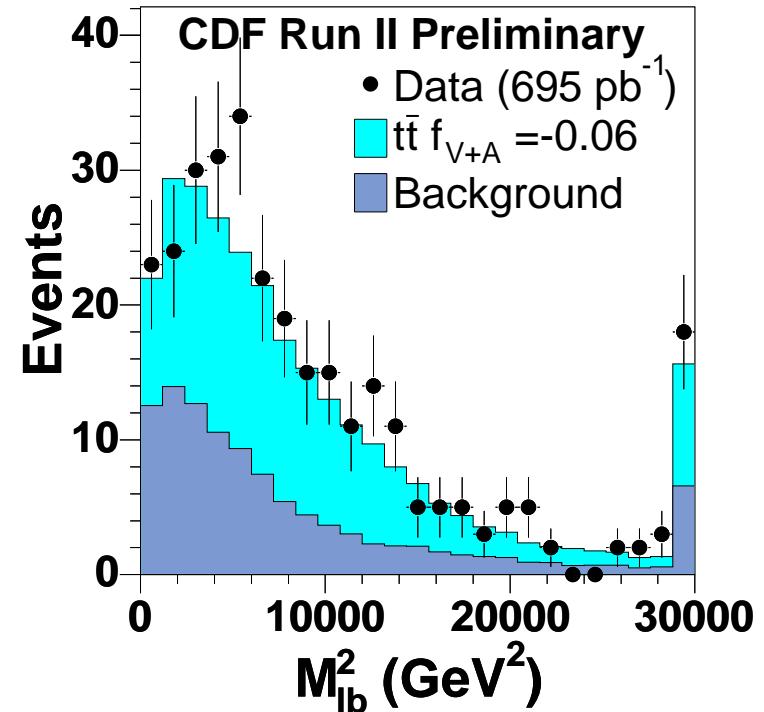
Dilepton

- Veto against $Z \rightarrow ll$
- Use 2 assignments
 × 2 measurements per event
- Compares rec. M_{lb}^2 to templates

Combined result

$$f_+ = -0.02 \pm 0.07$$

$$f_+ < 0.09 \quad 95\% CL$$



DØ Results using $\cos \theta^*$

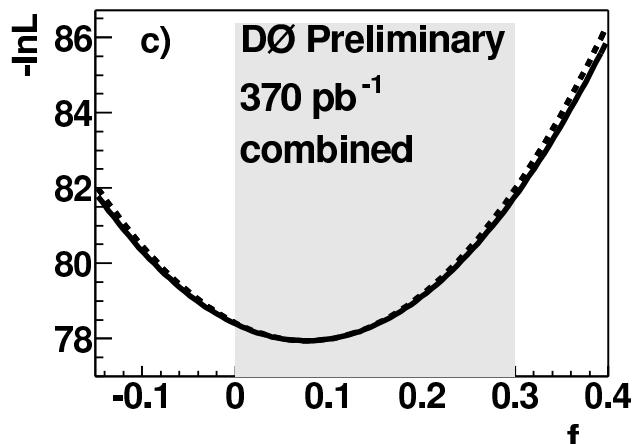
Dilepton and $l+jets$ channel with $\sim 370 \text{ pb}^{-1}$.

$l+jets$ channel

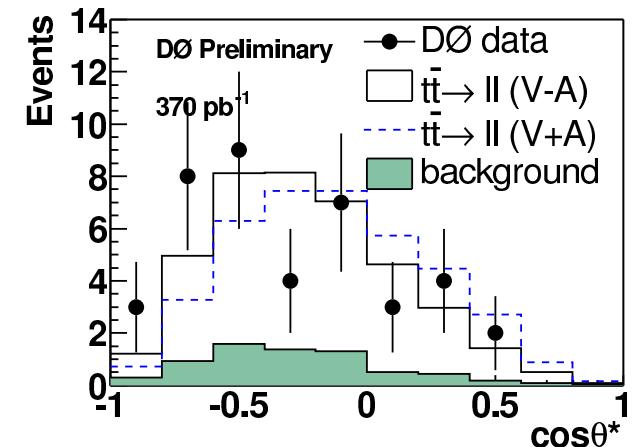
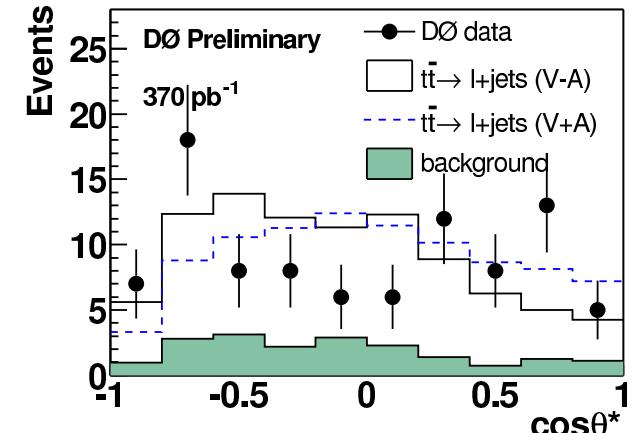
- Compares rec. $\cos \theta^*$ to $V \pm A$ templates

Dilepton channel

- Special difficulty: find W restframe.
- Assumes m_t ; use all 4 solutions.
- Repeat reconstruction with smeared momenta 100 times to account detector resolution.



Daniel Wicke, Testing SM in Top Quark Decays, W -Helicity in Top Decays



Combined results (assuming SM $f_0 = 0.7$)

$$f_+ = 0.08 \pm 0.08 \pm 0.05$$

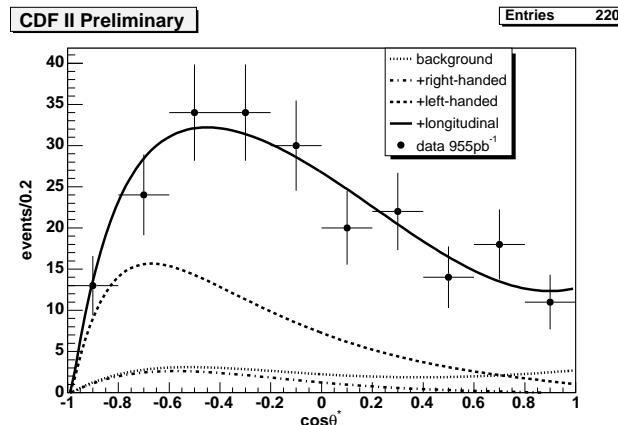
$$f_+ < 0.24 \quad 95\% \text{CL}$$

CDF Results using $\cos \theta^*$

Two method in $l + \text{jets}$ channel with $\sim 1 \text{ fb}^{-1}$:

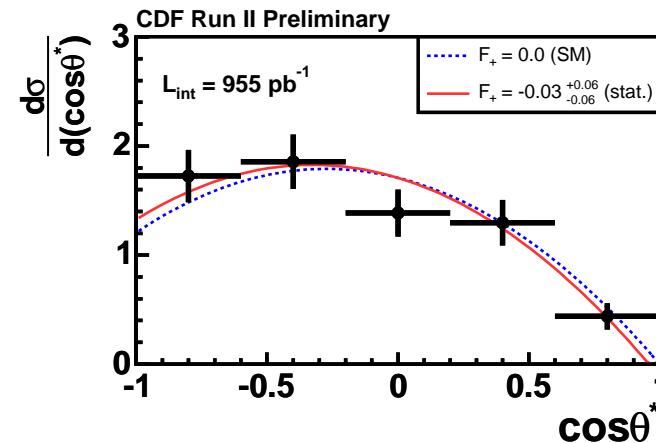
Template based

Compares rec. $\cos \theta^*$ to templates
 $l + 4\text{jets}$ using “best” χ^2 assignment.



Unfolded $\cos \theta^*$

Unfold w/ migration matrix, compare to theory
 $l+4$ or more jets using all assignments; weighed.



Results obtained assuming SM f_0

$$f_+ = -0.05 \pm 0.06 \pm 0.03$$

$$f_+ < 0.11 \quad 95\% \text{CL}$$

($f_0 = 0.7$):

$$f_+ = -0.03 \pm 0.03 \pm 0.04$$

$$f_+ < 0.10 \quad 95\% \text{CL}$$

Results obtained assuming SM f_+

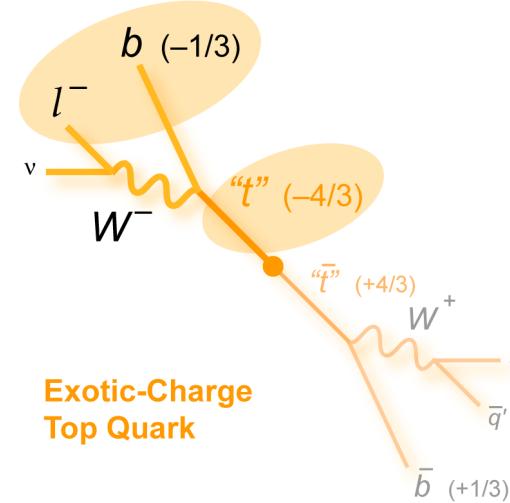
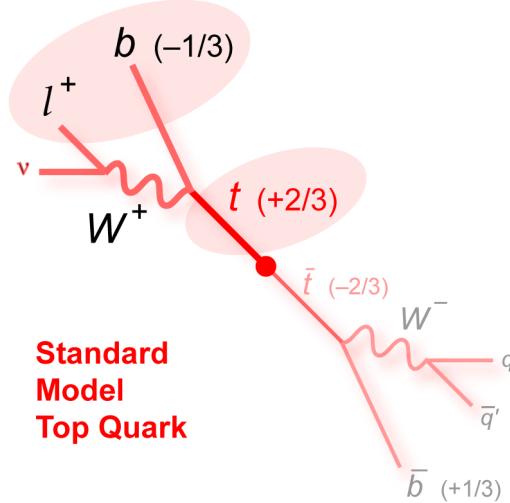
$$f_0 = 0.606 \pm 0.12 \pm 0.06$$

($f_+ = 0$):

$$f_0 = 0.59 \pm 0.12 \pm 0.07$$

Top Quarks Electrical Charge

Do objects used to reconstruct tops add up to the expected charge?



Requires reconstruction of:

- W charge \implies lepton charge
- b -quark charge \implies jet charge (more involved)

Jet charge

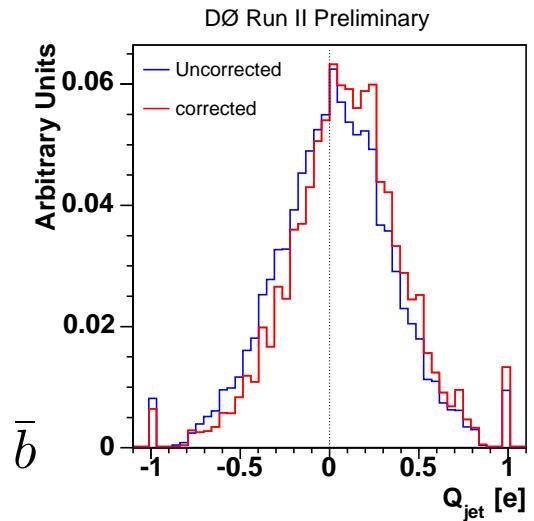
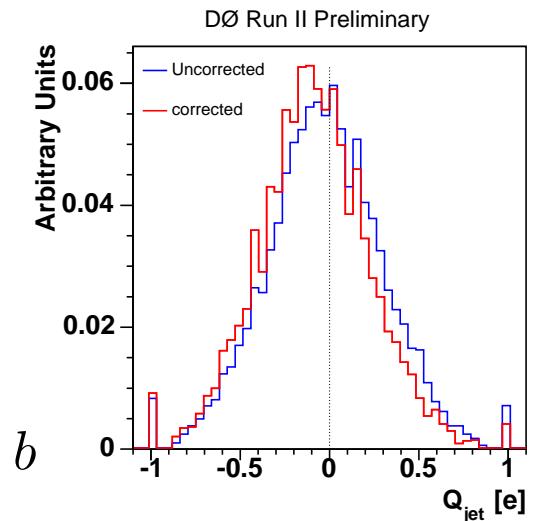
Sum charge of tracks in b -jet

- Errors from in- and out-of-cone tracks
- Statistical method
- Weighting with p_T helps

$$Q_{\text{jet}} := \frac{\sum q_i \cdot p_{Ti}^{0.6}}{\sum p_{Ti}^{0.6}}$$

Calibration

- Using double (vertex) tagged $b\bar{b}$ dijets w/ soft μ ($\Delta\phi \leq 3.0$)
- Soft μ determines b charge, Q_{Jet} calibrated on opposite jet.
- Disentangle b, \bar{b}, c, \bar{c} contributions to obtain pure b -jet Q_{Jet} distribution



Top Quark Charge Analysis

- Need to assign b -jet to right top
Choose best fit to top hypothesis
- Combine lepton and b -jet charge to top charge
(leptonic and hadronic side):

$$Q_{\text{lep}} = |q_l + q_{b_l}|$$

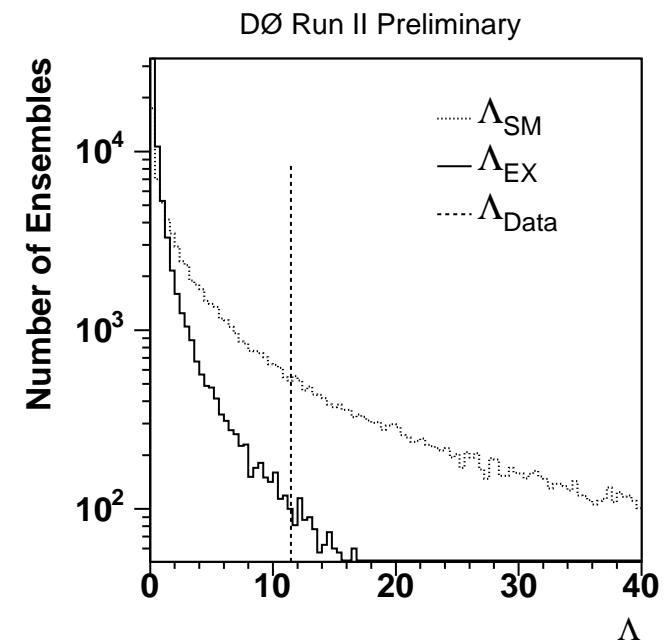
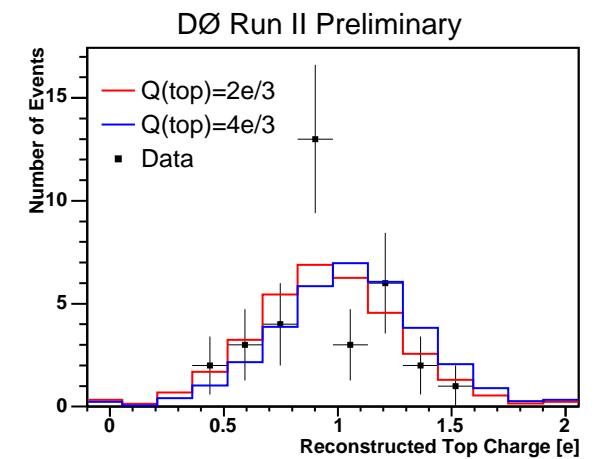
$$Q_{\text{had}} = |-q_l + q_{b_h}|$$

- Templates generated from standard model MC.
Exotic case by permuting jet charge.

DØ Result (370 pb^{-1})

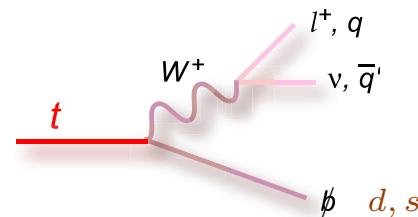
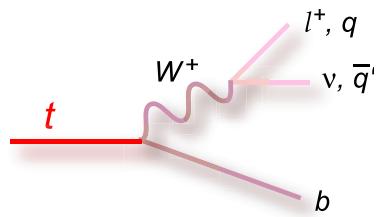
Unbinned likelihood ratio also accounting for remaining background yields

$|q_{\text{top}}| = 4e/3$ excluded at 94% CL.



Flavour of Top Decay: V_{tb}

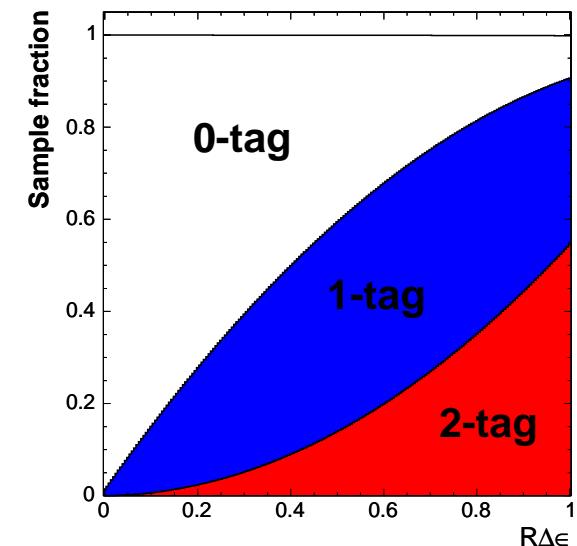
Deviation from SM prediction $|V_{tb}| \simeq 0.999$, $BR(t \rightarrow bW) \simeq 100\%?$



Various SM extensions allow for $|V_{tb}| \ll 1$

Investigate ratio of 0, 1 and 2 b -tagged top events to infer

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

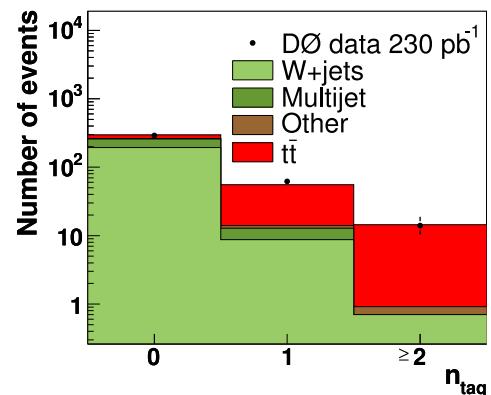
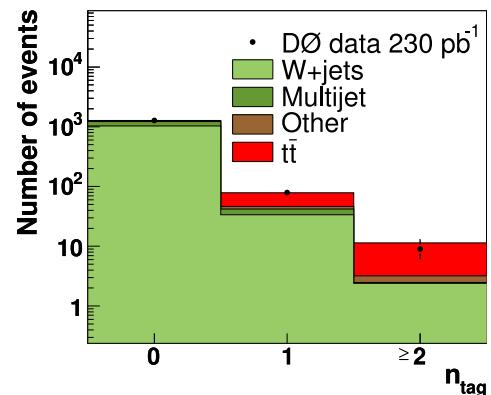
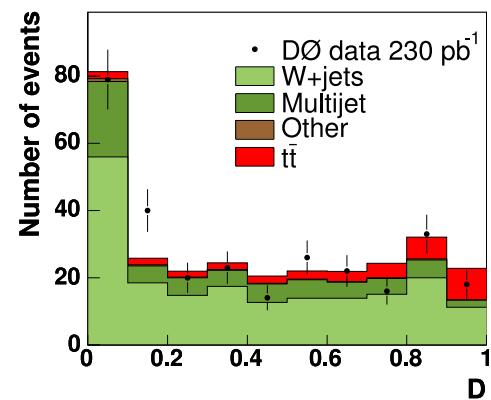


CDF expected fractions as function of $R \cdot \epsilon_{b\text{-tag}}$

DØ Analysis

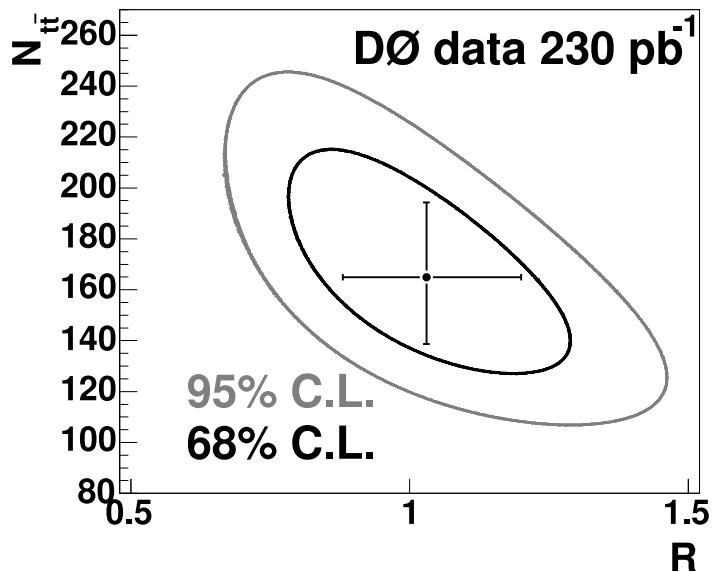
$l+jets$ channel using 230 pb^{-1} .

- Measure R and $N_{t\bar{t}}$ simultaneously.
- Tagging probabilities for different jet types required (obtained separately)
- Use kinematic discriminant in 0 b -tag sample to improve separation of signal and background.
- Binned max. likelihood to fit R and $N_{t\bar{t}}$.



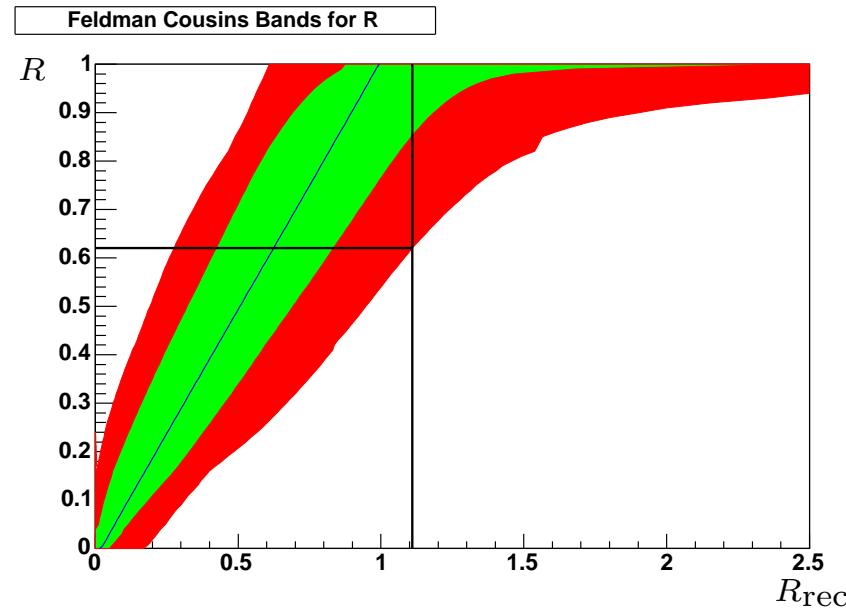
Results

DØ (230 pb⁻¹)
l+jets



$R > 0.64 \quad 95\% \text{ CL}$
 $|V_{tb}| > 0.80 \quad 95\% \text{ CL}$

CDF (162 pb⁻¹)
l+jets and dilepton



$R > 0.62 \quad 95\% \text{ CL}$
 $|V_{tb}| > 0.78 \quad 95\% \text{ CL}$

Conversion assumes
 $\downarrow |V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1$

A long way to SM $|V_{tb}| \simeq 0.999$

Further Results

Many other tests of the SM in top decay have been performed:

H^+ in top decays

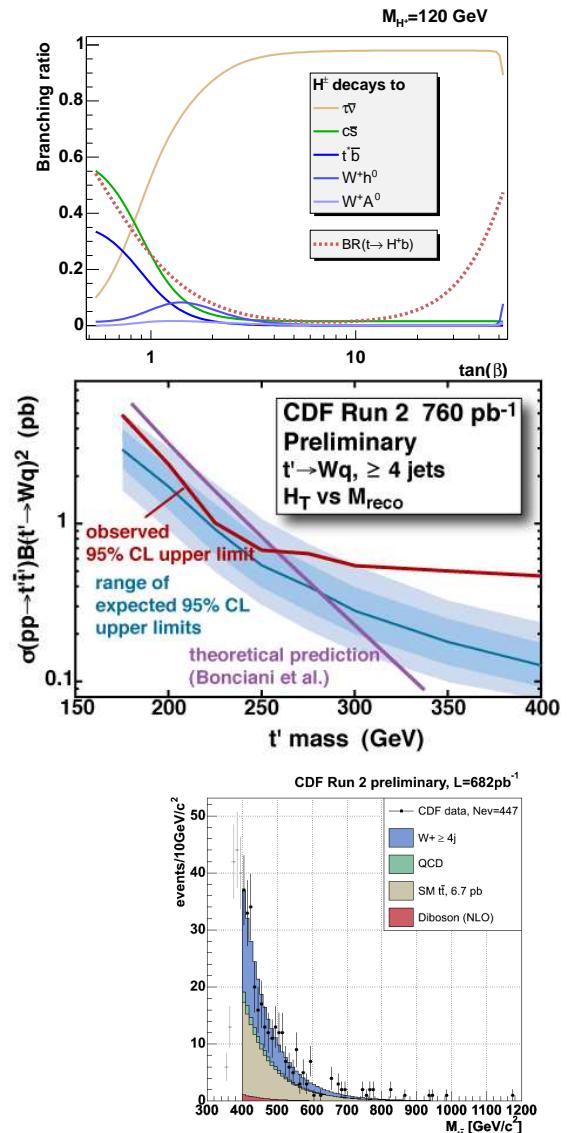
Investigate decays of top events
Limits on $\text{BR}(t \rightarrow bH^+)$ set for various
 H^+ decay modes and masses.

t' search

Check reconstructed top mass distribution
CDF: 760 pb^{-1} : $M_{t'} > 258 \text{ GeV}$ at 95% CL

$t\bar{t}$ Resonance

Investigate $m_{t\bar{t}}$ -distribution.
CDF and DØ: Compatible with SM.
CDF: 680 pb^{-1} : $M_{Z'} > 725 \text{ GeV}$ at 95% CL
 $\text{for } \Gamma(Z') = 1.2\% M_{Z'}$.



Summary

- Testing SM in top decay is gaining more and more interest.
- **W -Helicity:** No hint for an admixture of $V + A$
CDF (1 fb^{-1}): $f_+ < 0.09$ (95% CL)



- **Electrical Charge:** Exotic charge value disfavoured

DØ (370 pb^{-1}): $4e/3$ excluded at 94% CL

- **Decay Flavour:**

DØ (230 pb^{-1}): $R > 0.64$ (95% CL)



- Several additional searches for deviations available.

No significant deviations from Standard Model observed (yet).