Top Properties at the Tevatron

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For the CDF and DØ Collaborations

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Roadmap

- The Tevatron
- The CDF and DØ Detectors
- Review of the Top Quark
- Top Branching Fraction
- Top Charge
- W Helicity in Top Decay
- Summary

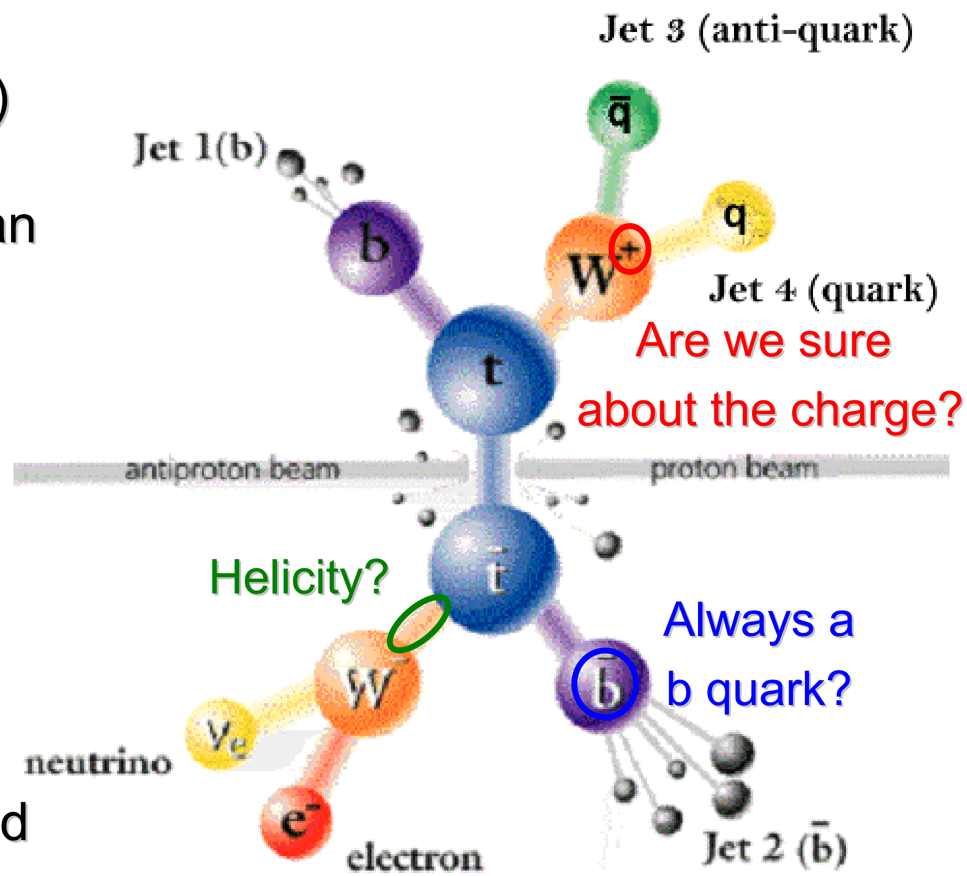
Already Covered

Tractricious

Top Review

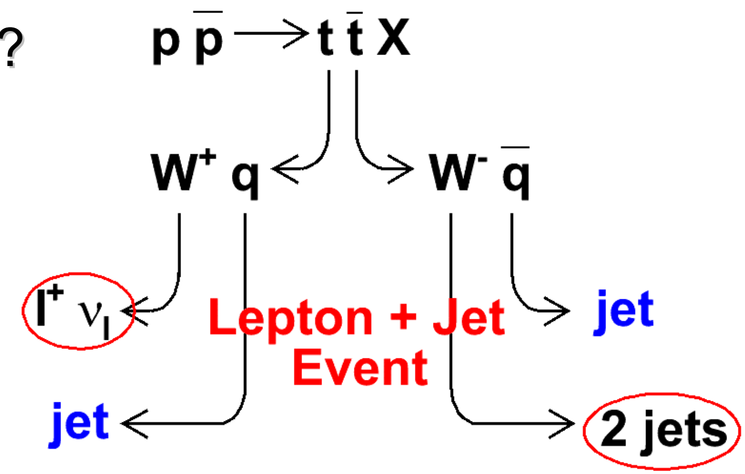
- The top quark was discovered (in pairs) by CDF and D0 in 1995.
- The ***Golden*** quark (~ 175 GeV/c^2)
  - Only fermion with mass near EW scale; 40 times heavier than the bottom quark
- Very wide (1.5 GeV/c^2)
  - The top quarks decay before they can hadronize.
    - We can study the decay of the bare quark.
- Fundamental question: Is it the *truth*, the Standard Model *truth*, and nothing but the *truth*?

$t\bar{t}$ Pair Lepton + Jet Decay



Top Branching Fraction: The Data Sample

- Does *t* always decay to *Wb*? not *Ws* or *d*?
- To date, we have only confirmed seeing top produced in pairs.
- For this analysis, we use two distinct samples (classified by W decays):
  - Dilepton events
  - Lepton + jet events



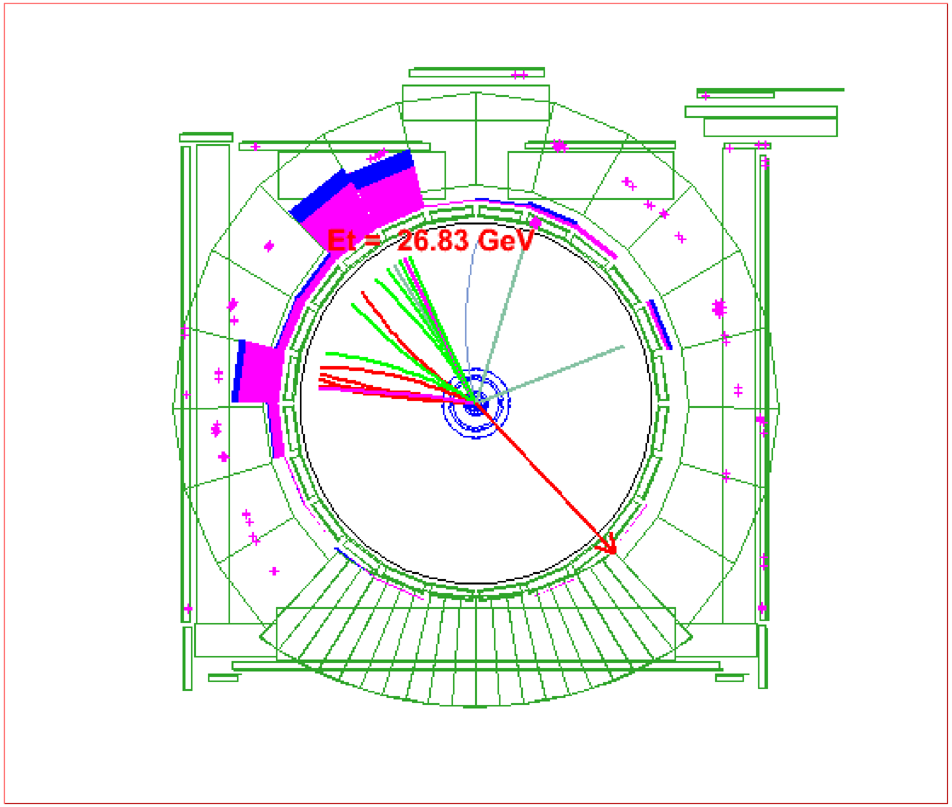
Dileptons

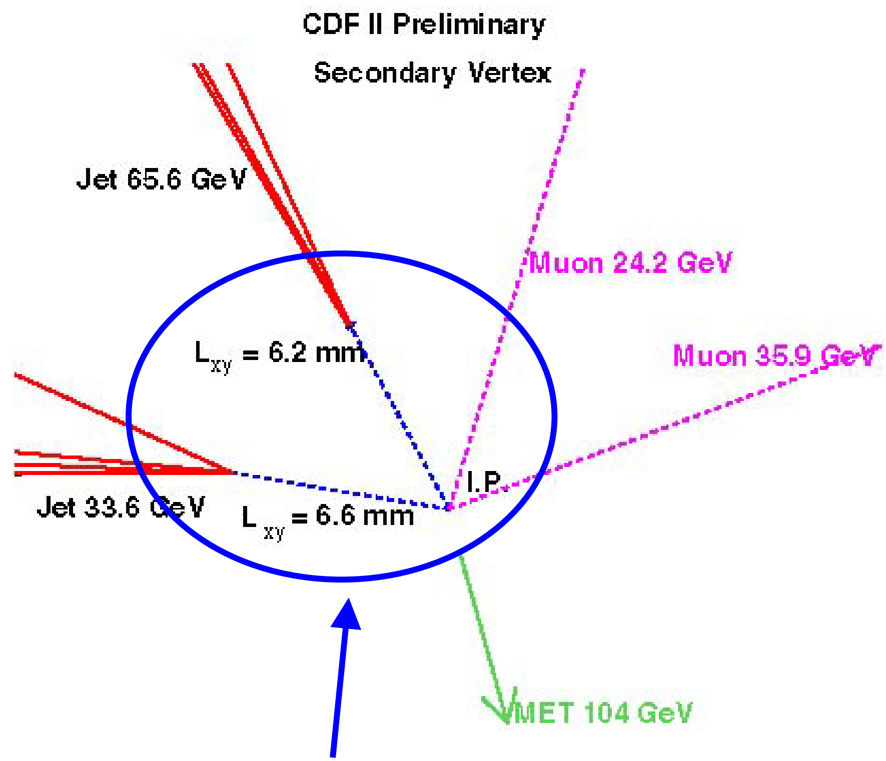
- Two high p_T leptons (e, μ)
- Two high E_T jets
- Large missing transverse energy

Lepton + Jets

- One high p_T lepton (e, μ)
- (Three or) Four high E_T jets
- Large missing transverse energy

Top Dilepton Event at CDF





We use these displacements to “tag” b jets (SecVtx b tagging algorithm).

$$\mathcal{R} = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)}$$

- According to what we know about the CKM matrix, BR(t →Wb) ~ 100%.
- $\mathcal{R} = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} \stackrel{?}{=} |V_{tb}|^2$
- We can measure *R* by looking at the ***relative*** rates of top candidate events with zero, one, or two b-tagged jets.
- Assuming no background and that b-jets are identified with efficiency ε_b,
  - $N_0 = N_{tt} (1 - R\, \varepsilon_b)^2 \equiv N_{tt}\, \varepsilon_0$,
  - $N_1 = 2 N_{tt} R\, \varepsilon_b (1 - R\, \varepsilon_b) \equiv N_{tt}\, \varepsilon_1$,
  - $N_2 = N_{tt} (R\, \varepsilon_b)^2 \equiv N_{tt}\, \varepsilon_2$.
- The R measurement is therefore:
  - Sensitive to R ε_b,
  - Over determined, and
  - Largely independent of N_{tt} and $\sigma(t\bar{t})$.
- ε_b is measured separately (~40% for CDF).

Assuming no background:

$$\mathcal{R} \cdot \epsilon_b = \frac{2}{N_1/N_2 + 2} = \frac{1}{2N_0/N_1 + 1} = \frac{1}{\sqrt{N_0/N_2} + 1}$$

CDF's $\mathcal{R}$ Likelihood

- We first need to estimate the total number of tt candidates:

$$N_{\mathrm{tt}} = \frac{\sum_{\mathrm{b\ tags}} \left(\overset{\text{Measured}}{N_{\mathrm{obs}_i}} - \overset{\text{Estimated}}{N_{\mathrm{back}_i}} \right)}{\underbrace{\sum_{\mathrm{b\ tags}} \epsilon_i}_{= 1 \text{ when we loop over } 0,\, 1, \text{ and } 2 \text{ b- tags}}}$$

Efficiency to have *i* jets b-tagged.

- Our likelihood is:

$$\mathcal{L}(\mathcal{R}) = \prod P(N_{\mathrm{obs}_i} | N_{\mathrm{exp}_i}) \quad \text{where} \quad N_{\mathrm{exp}_i} = N_{\mathrm{tt}} \cdot \epsilon_i + N_{\mathrm{back}_i}$$

- Remember:

  ε_i and therefore N_{tt} depend on R ε_b.

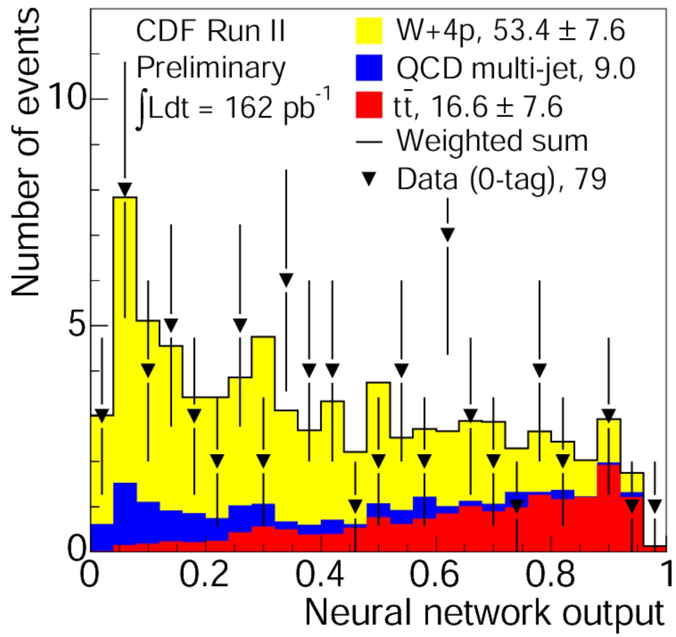
CDF Dilepton and L+J Numbers

Lepton + Jets (L+J)	0-tag	1-tag	2-tag
ϵ_i $(R=1)$	0.45 ± 0.03	0.43 ± 0.02	0.12 ± 0.02
a priori background	N/A	4.2 ± 0.7	0.2 ± 0.1
ANN background	62.4 ± 9.2	5.8 ± 5.1	$0.1^{+1.0}_{-0.1}$
Total expected	80.4 ± 5.2	21.5 ± 4.1	5.0 ± 1.4
Observed	79	23	5

Dileptons (DIL)	0-tag	1-tag	2-tag
ϵ_i $(R=1)$	0.47 ± 0.03	0.43 ± 0.02	0.10 ± 0.02
a priori background	2.0 ± 0.6	0.2 ± 0.1	negl.
Total expected	6.1 ± 0.4	4.0 ± 0.2	0.9 ± 0.2
Observed	5	4	2

$$\int \mathcal{L}dt = 162\text{pb}^{-}1$$

- In addition to using *a priori* background estimates, we also use an artificial neural net in the L+J sample.
  - Our best 0-tag estimate
- We see very good agreement bin by bin.



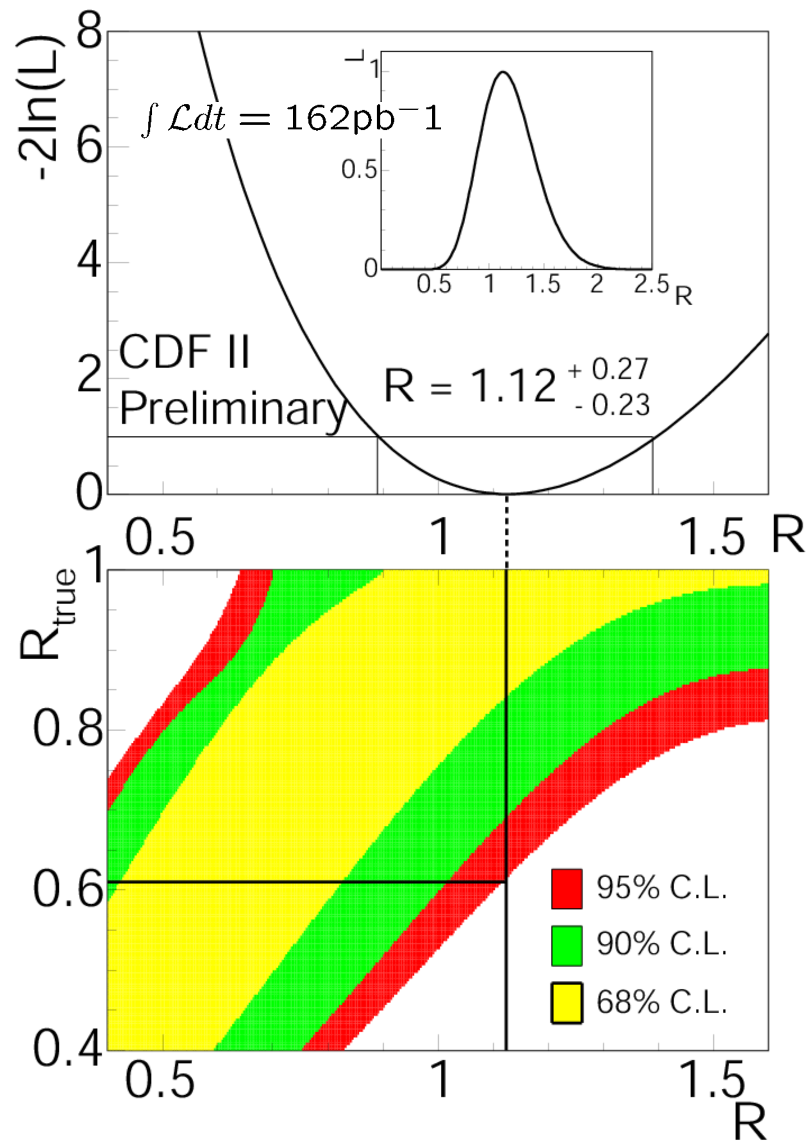
The CDF $\mathcal{R}$ Measurement

- We use both the Dilepton and the Lepton + Jets data samples.
- Uses $\int \mathcal{L}dt = 162\text{pb}^-1$
- $\mathcal{R} = 1.12^{+0.27}_{-0.23}$ (stat. + syst.)
- We use a Feldman-Cousins construction to find our final answer:

  $\mathcal{R} > 0.61$ at the 95% C.L.

- Assuming three generations of quarks:

  $|V_{tb}| > 0.79$ at the 95% C.L.



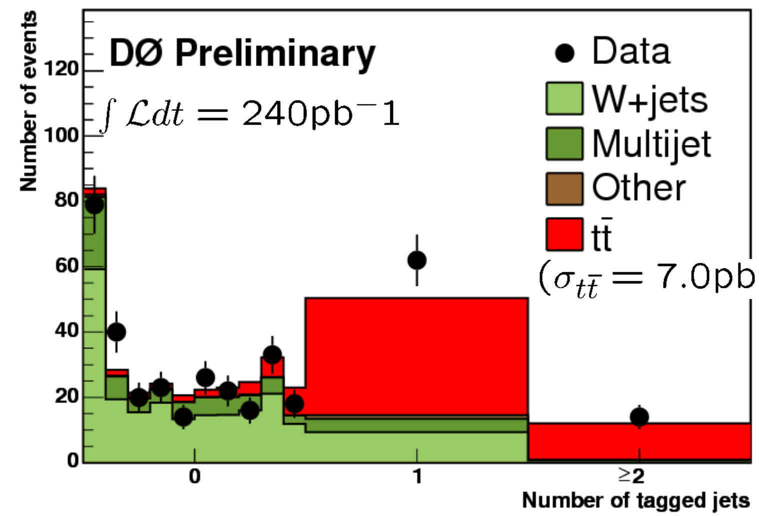
The DØ $\mathcal{R}$ Measurement

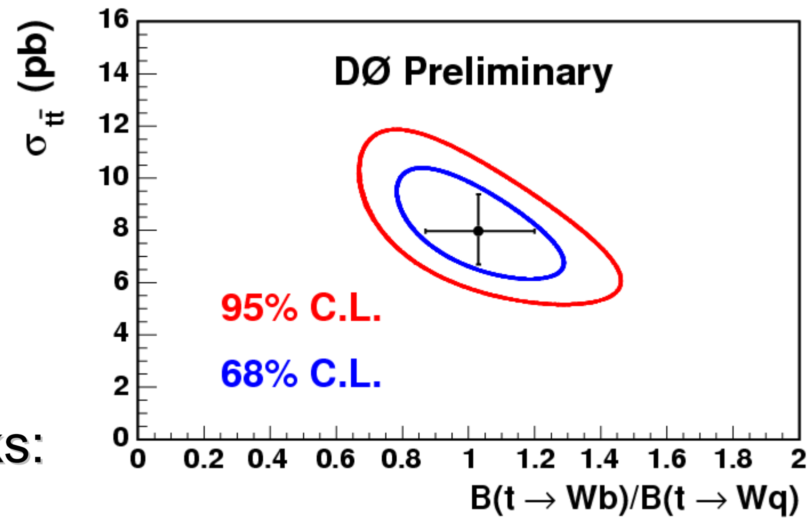
- Uses 240 pb^{-1} lepton + jets sample
- DØ Likelihood depends on both $\mathcal{R}$ and $\sigma_{t\bar{t}}$.
- DØ uses "SVT" – Displaced secondary vertices (similar to CDF)
- Uses lepton + jets events
  - Likelihood discriminant in 0-tag sample

$$\mathcal{R} = 1.03^{+0.19}_{-0.17}\ (\mathrm{stat} + \mathrm{syst})$$

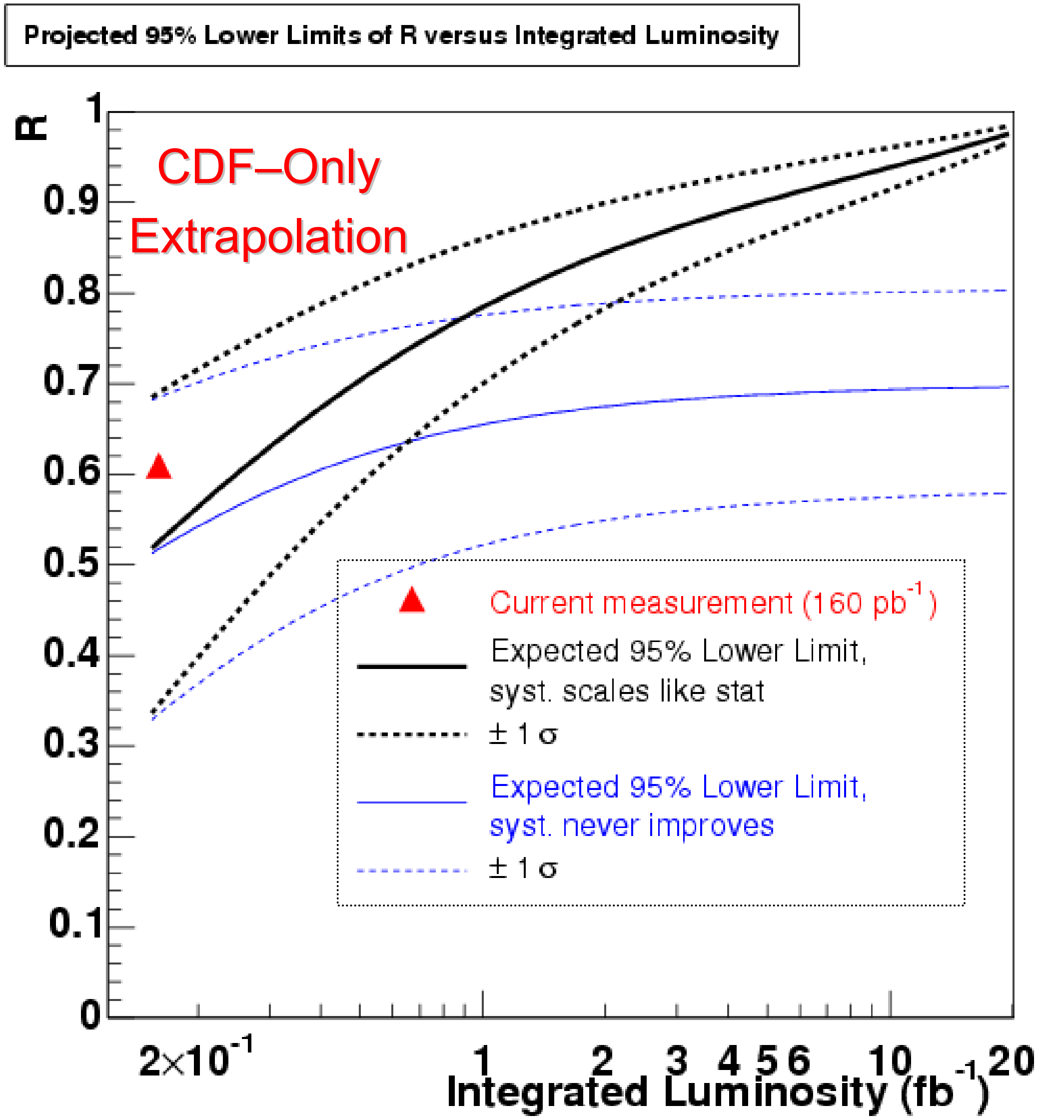
$$\sigma_{t\bar{t}} = 7.9\ ^{+1.7}_{-1.5}\ (\mathrm{stat} + \mathrm{syst}) \pm 0.5\ (\mathrm{lumi})\ \mathrm{pb}$$

- Using a flat prior in $\mathcal{R}$, DØ finds $\mathcal{R} > 0.64$ at the 95% C.L.
- Assuming three generations of quarks: $|V_{tb}| > 0.80$ at the 95% C.L.





Our $\mathcal{R}$ Reach



- Quick-and-dirty back of the envelop calculation.
- Assume R = 1 (3 gen).
- Ignores innovation.
- If we keep systematic uncertainties down, can be a very promising measurement.

So What?

Could we test 3 generations?

If $|V_{ts}| = 0.1$ and three generations, ➔R = 0.99

If four generations and, for example, $|V_{tb}| = 0.5$, ➔R = 0.96

Could CDF and DØ ***together*** see evidence of this at the Tevatron?

DØ Top Charge

BRAND NEW RESULTS Just Days Old!

Why check top charge?

- Is it really top?
- t → W b could mean that top has charge –4/3.

How do we check top charge?

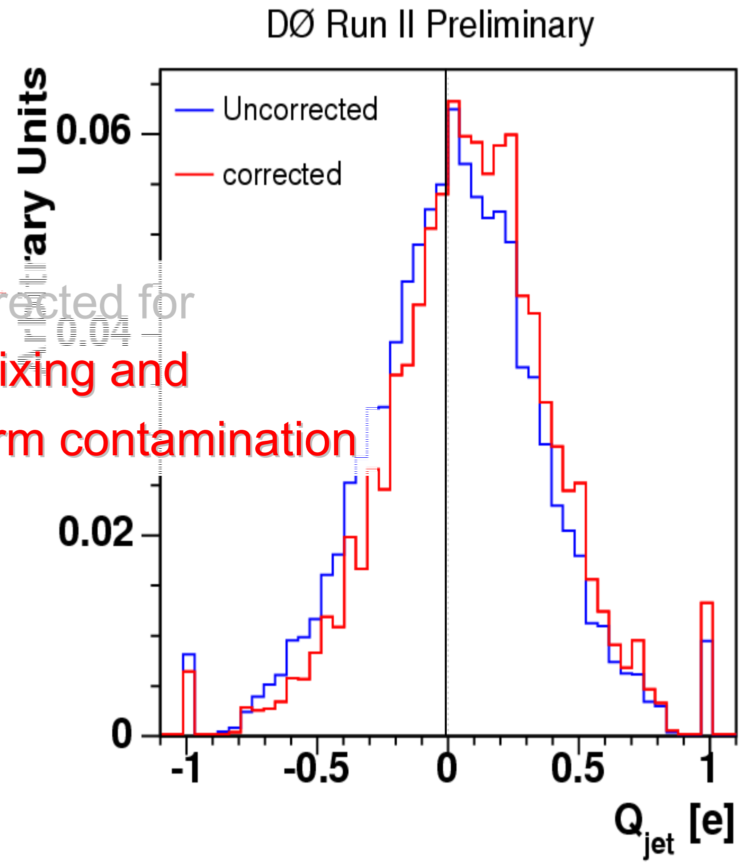
- Double b-tagged lepton + jets sample.
  - Use kinematic fit to pair lepton with correct b jet. → 17 events.
- Use an algorithm for determining the "charge" of b jets.

$$q_{\text{jet}} = \frac{\sum q_{\text{track}} * p_T^{0.6}}{\sum p_T^{0.6}}$$

- Two entries per event:

$$Q_1 = |+q_{\text{lepton}} + q_{\text{lepton b jet}}|$$
$$Q_2 = |-q_{\text{lepton}} + q_{\text{other b jet}}|$$

Jet Charge Tagging on $b\bar{b}$ sample with other jet tagged with μ flavor.



Corrected for B mixing and charm contamination

Top Charge, cont.

- Create two templates:
  - top with 2/3 charge and background
  - top with -4/3 charge and background
- Use likelihood ratio:

$$\lambda = \prod_{i=1}^{2*17} \frac{\text{Prob(top has 2/3 charge)}}{\text{Prob(top has } -4/3 \text{ charge)}}$$

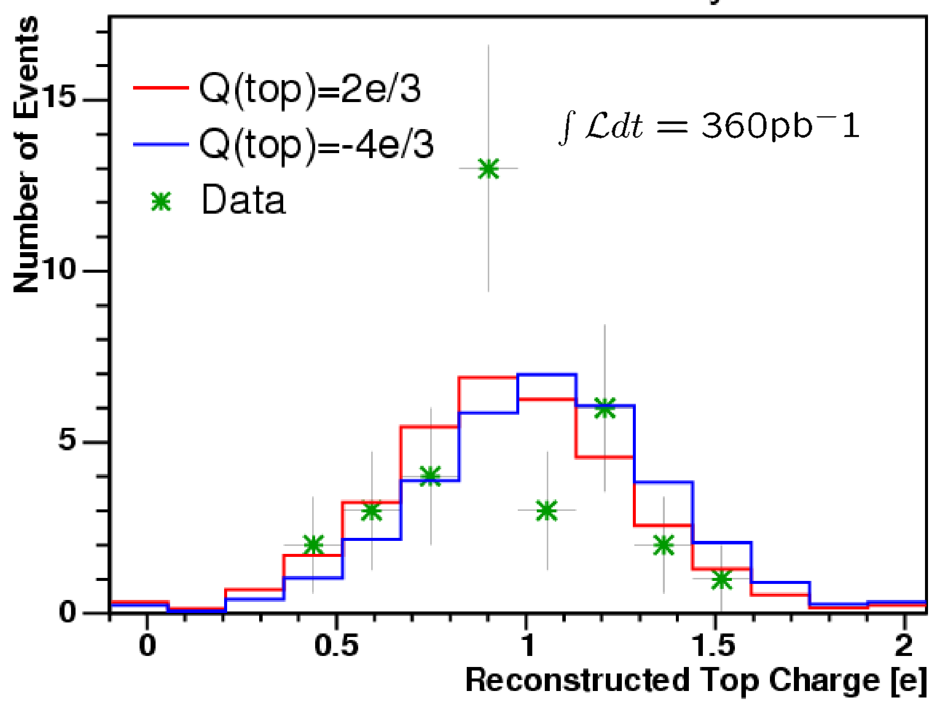
$$= 11.5$$

- Using pseudo-experiments, the probability of seeing λ = 11.5 or greater when the top charge = -4/3

  ➔ Less than 6.3% probability.

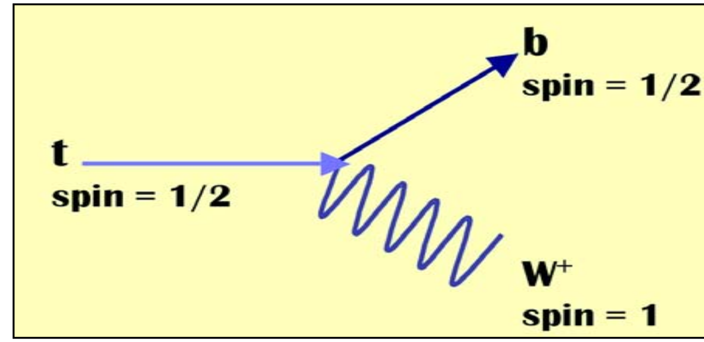
- CDF result with 1 fb^{-1} coming…

DØ Run II Preliminary



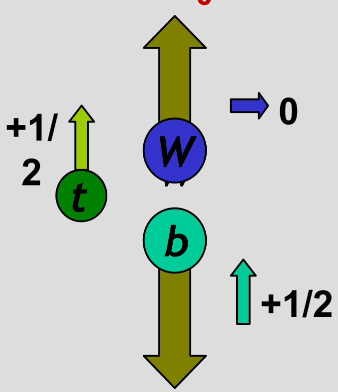
W Helicity from $t \rightarrow W\, b$ Decays

- Examines the nature of the tWb vertex, probing the structure of weak interactions at energy scales near EWSB

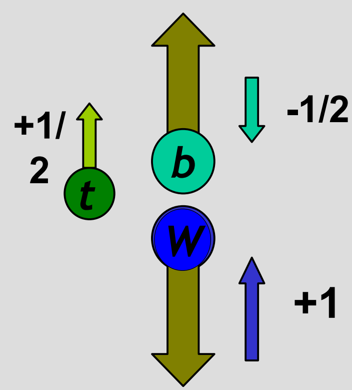


- Stringent test of V-A interaction in SM: Standard Model expectations: $F_0 = 0.7$, $F_- = 0.3$ and $F_+ = 0.0$

W_0 Longitudinal fraction **$F_0 = 0.7$**

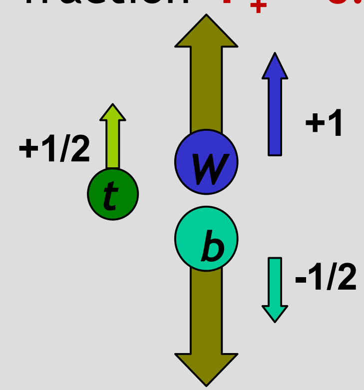


W_- Left-Handed fraction **$F_- = 0.3$**



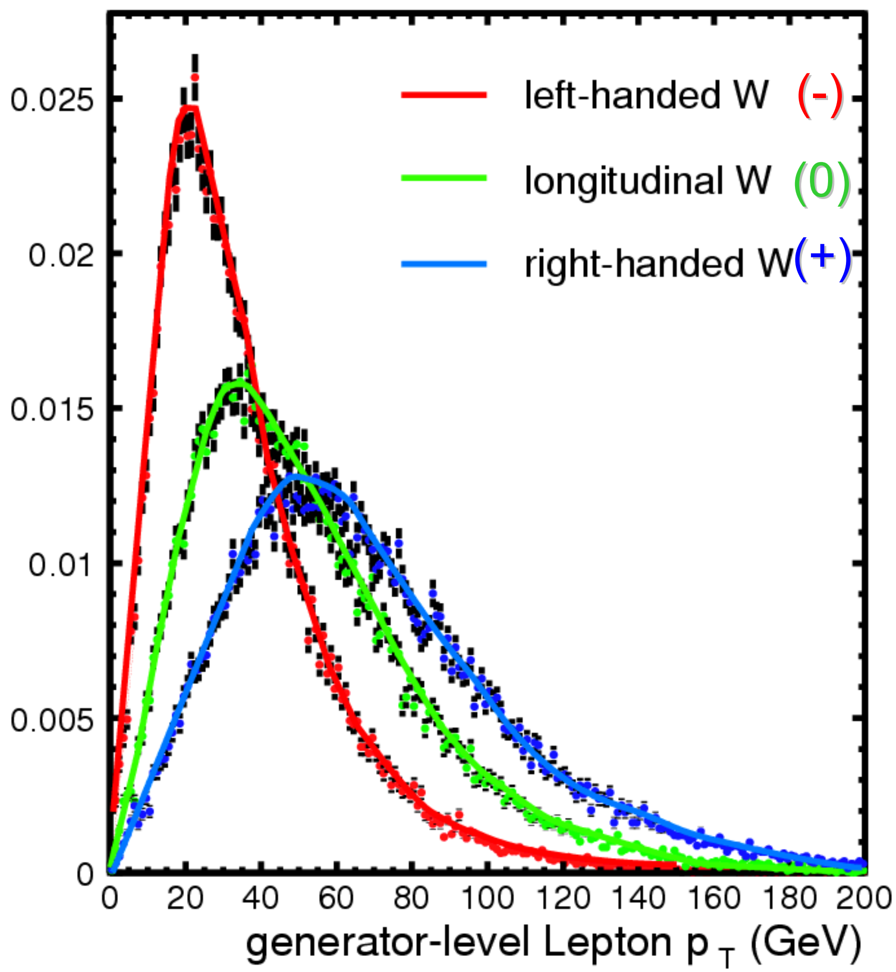
V+A Suppressed

W_+ Right-Handed fraction **$F_+ = 0.0$**

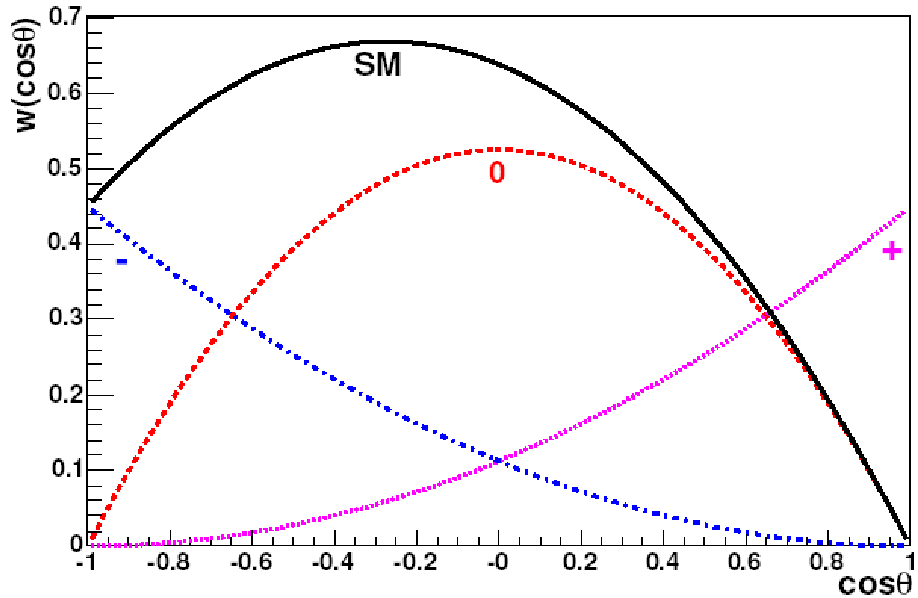


How We Measure W Helicity

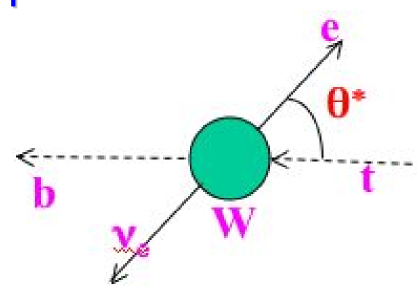
Lepton p_T



cos(θ*)

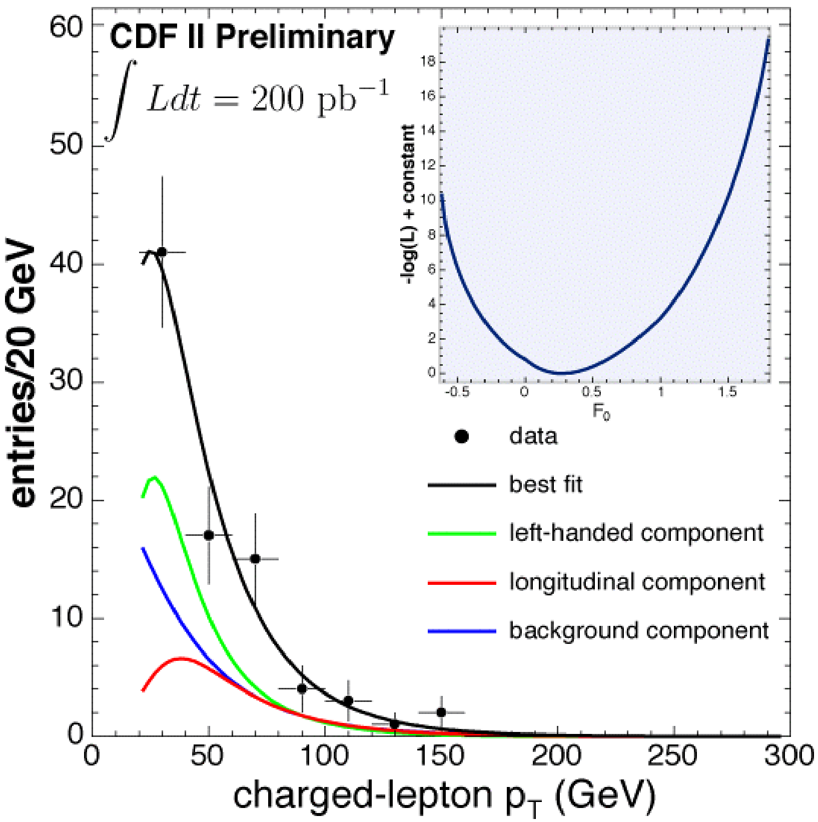


Angle between charged lepton and top direction in W rest frame.



Lepton p_T

- SM: $f_0 = 0.7$, $f_+ = 0.0$
- CDF's f_0 result is low due to "softer" than expected dilepton p_T spectrum.



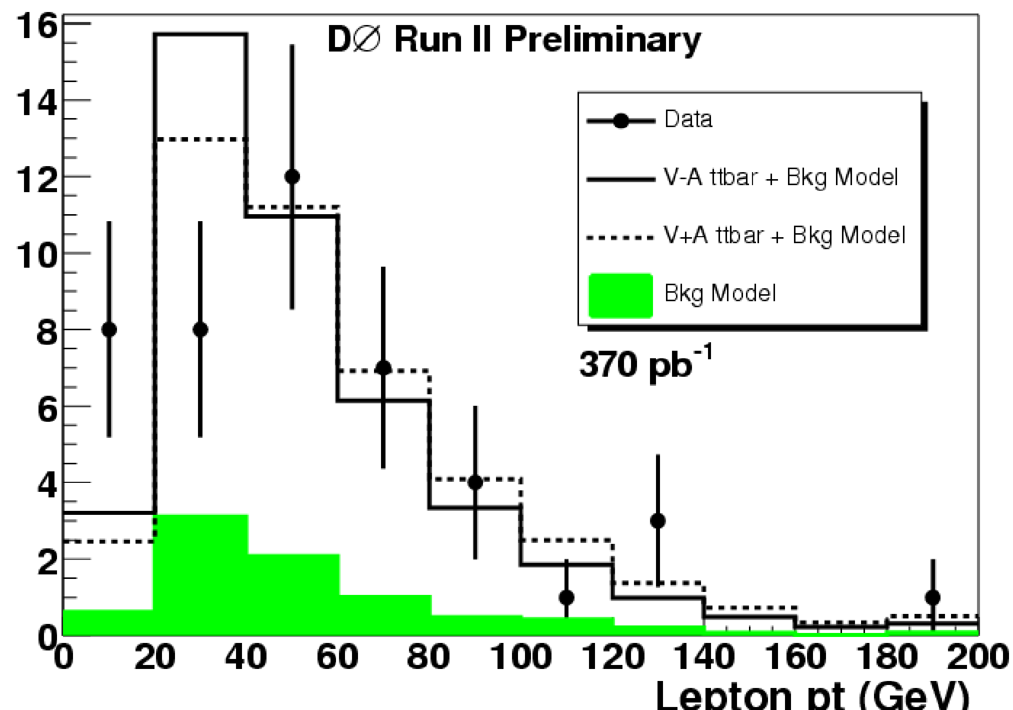
f_+: (fixing $f_0 = 0.70$)

D0: 0.13 ± 0.20(stat + syst)

CDF: $-0.18^{+0.14}_{-0.12}$(stat) ± 0.12 (syst)

f_0: (fixing $f_+ = 0.0$)

CDF: $0.31^{+0.37}_{-0.23}$(stat) ± 0.17 (syst)



$\cos(\theta^*)$

- SM: $f_0 = 0.7$, $f_+ = 0.0$

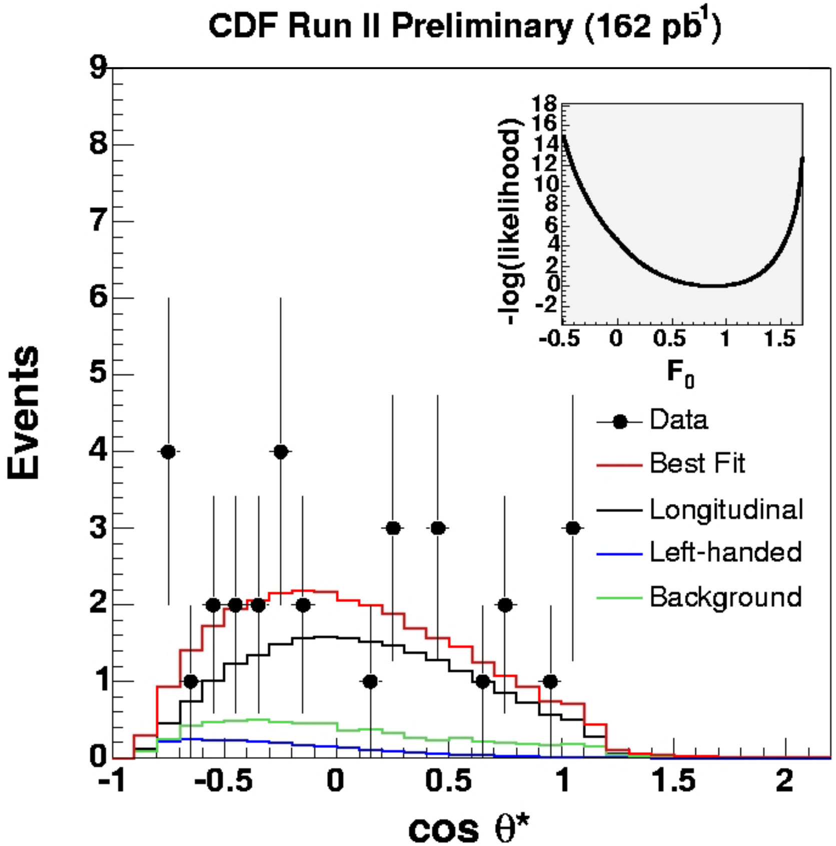
f_+: (fixing $f_0 = 0.70$)

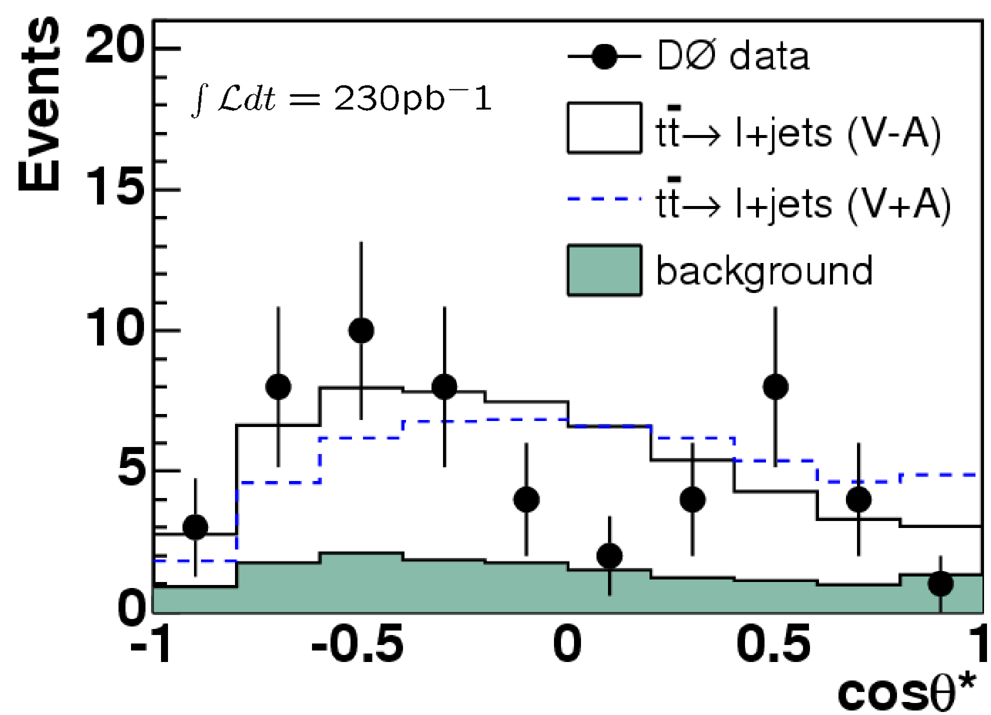
D0: 0.00 ± 0.13(stat) ± 0.07(syst)

CDF: 0.23 ± 0.16(stat) ± 0.08 (syst)

f_0: (fixing $f_+ = 0.0$)

CDF: $0.99^{+0.29}_{-0.35}$(stat) ± 0.19 (syst)





W Helicity Summary

- CDF and DØ combinations of p_T and $\cos(\theta^*)$:

f_+: (fixing $f_0 = 0.70$)

D0:	$0.04 \pm 0.13(\text{stat}) \pm 0.07\ (\text{syst})$	or < 0.25 at the 95% C.L.
CDF:	$0.00 \pm 0.20(\text{stat} + \text{syst})$	or < 0.27 at the 95% C.L.

f_0: (fixing $f_+ = 0.0$)

CDF: $0.74^{+0.22}_{-0.34}(\text{stat} + \text{syst})$ or $f_0 \in [0.18, 0.95]$ at the 95% C.L.

Looking Forward

- Lots of exciting top physics happening at the Tevatron.
- Top branching fraction
  - CDF and DØ agree:
    $|V_{\mathrm{tb}}| > 0.8$
    at the 95% C.L.
  - Assumption about number of generations → Can explicitly test in future.
- Top charge
  - Very exciting new DØ result!
  - CDF 1 fb^{-1} soon.
- W Helicity
  - (Most) everything looks like Standard Model.

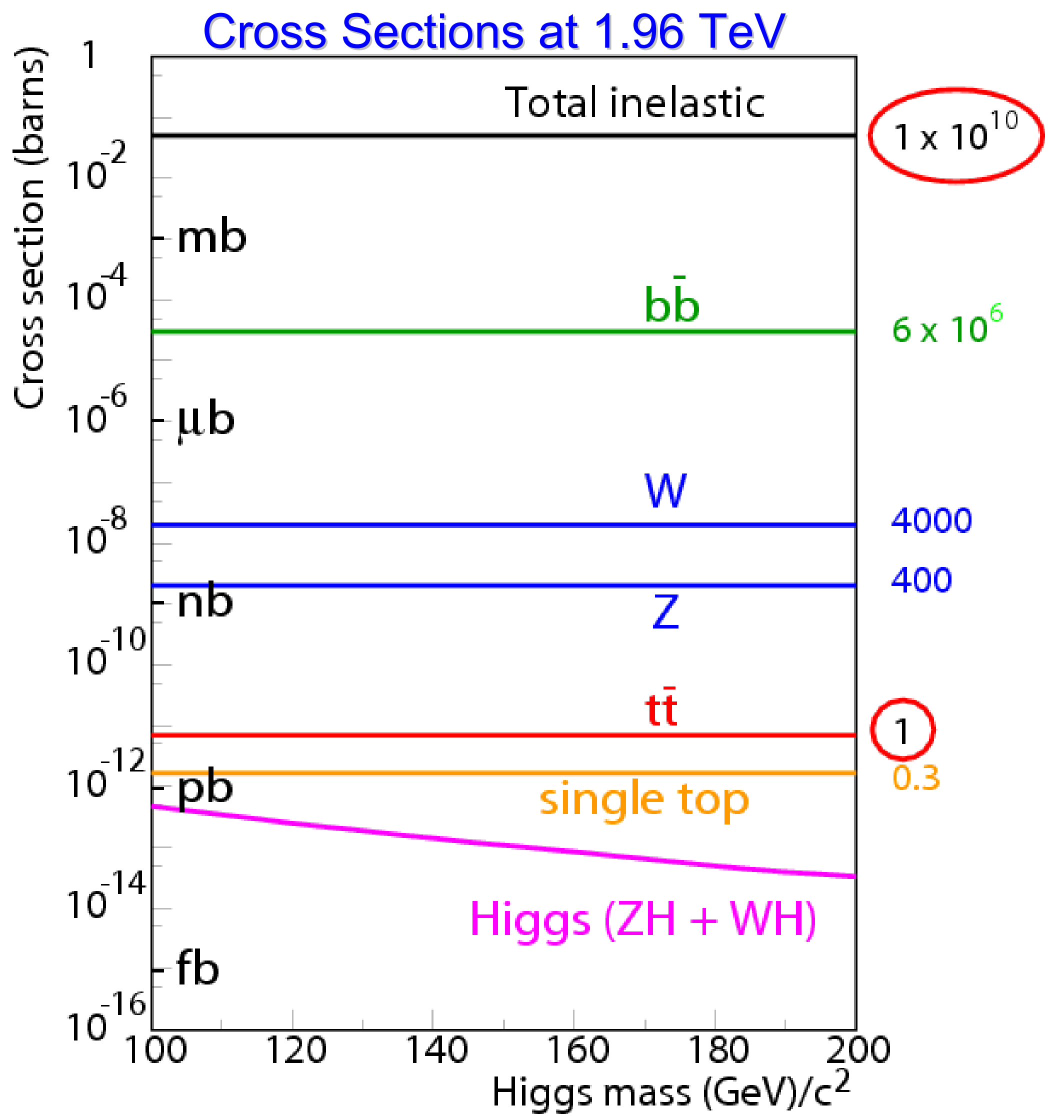
Backup Slides

A Quick Note About Scale

Since we're not all intimately familiar with hadron colliders.

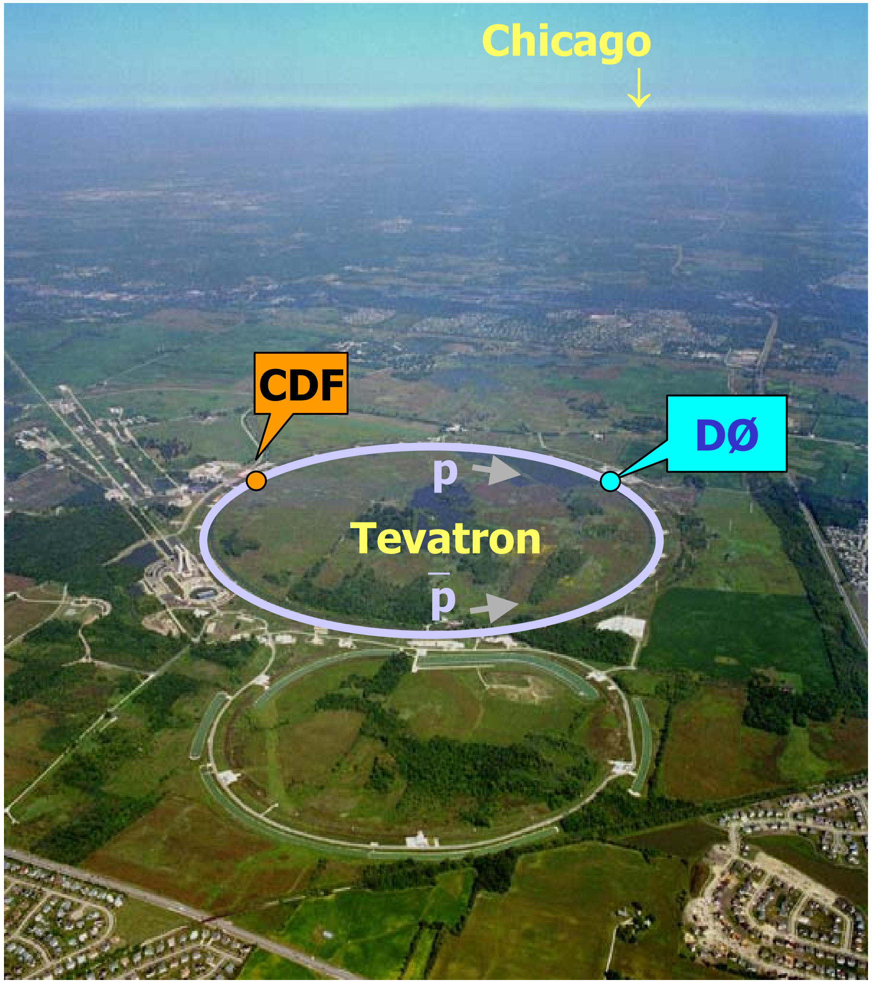
Top:

1 in 10 billion



The TeVatron

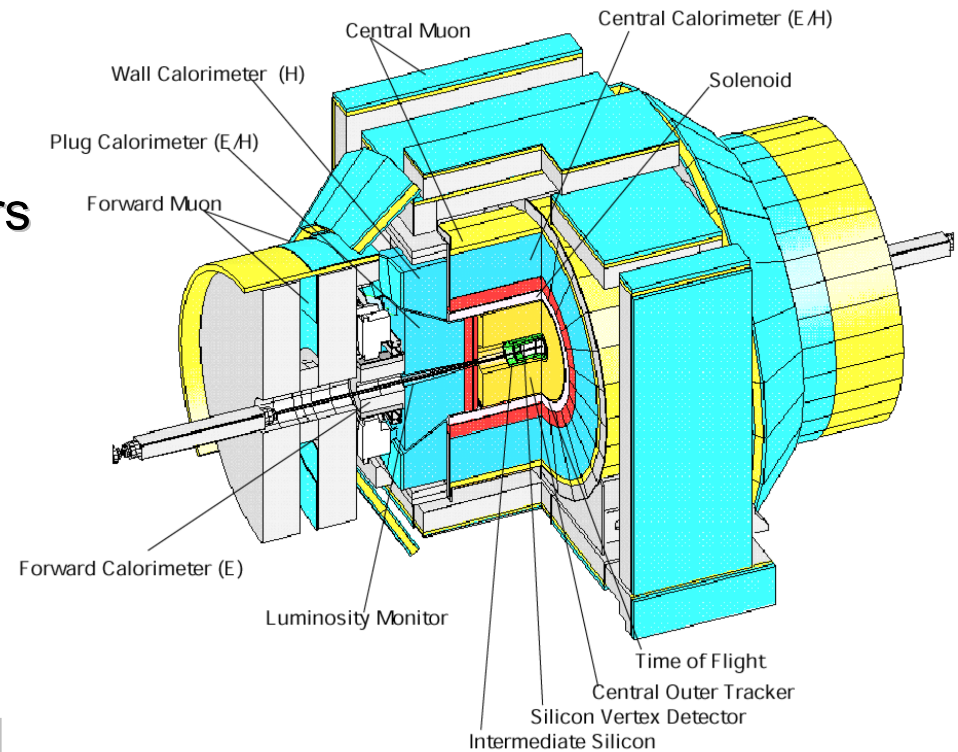
- Proton-antiproton collisions at 1.96 TeV (Run I: 1.8 TeV)
- Peak Luminosity: > $1.4 \cdot 10^{32}$ cm^{-2} s^{-1}.
- What's new for Run II?
  - Main Injector: 150 GeV proton storage ring.
  - Recycler: Antiproton storage ring
    - Working well.
    - Electron Cooling established.
- Total Integrated luminosity:
  - Currently, over 1 fb^{-1}.
  - Should have between 4 fb^{-1} and 9 fb^{-1} by 2009.



The Run II CDF Detector

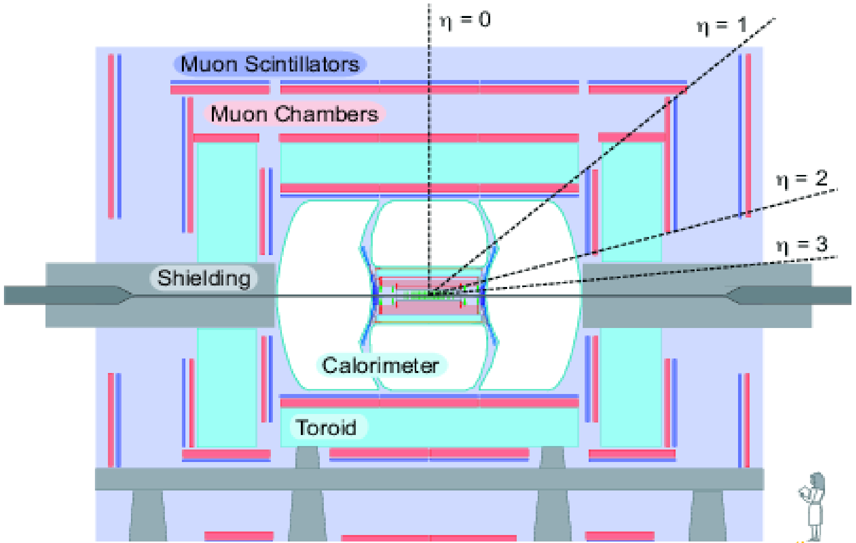
- Similar to most colliding detectors:
  - Inner silicon tracking
  - Drift Chamber
  - Solenoid
  - EM and Hadronic Calorimeters
  - Muon Detectors

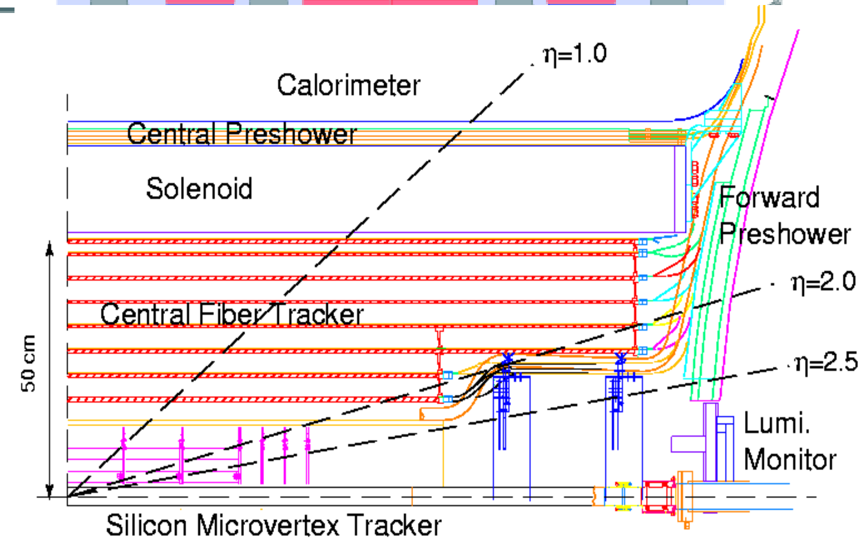
- New for Run II:
  - Tracking: 8 layer silicon and drift chamber
  - Trigger/DAQ
  - Better silicon, calorimeter and muon coverage



The Run II DØ Detector

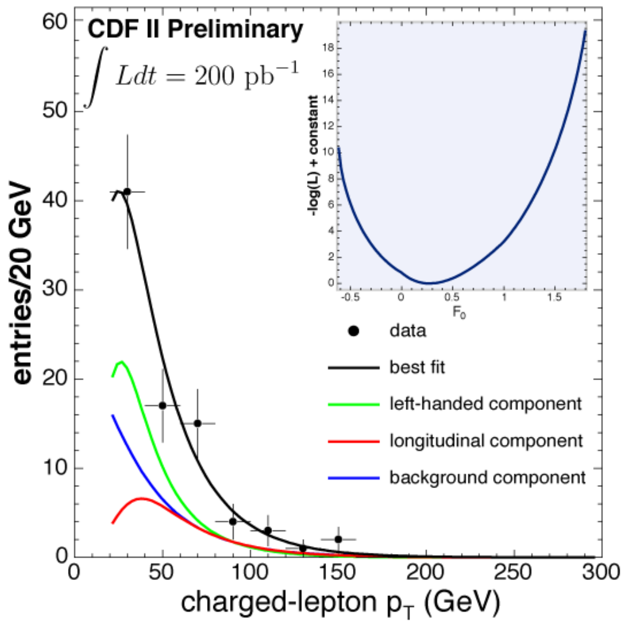
- New central tracking inside 2 T solenoid
  - Silicon vertex detector
    - b-tagging
  - Scintillating fiber tracker
- New forward muon system
- New readout / trigger electronics



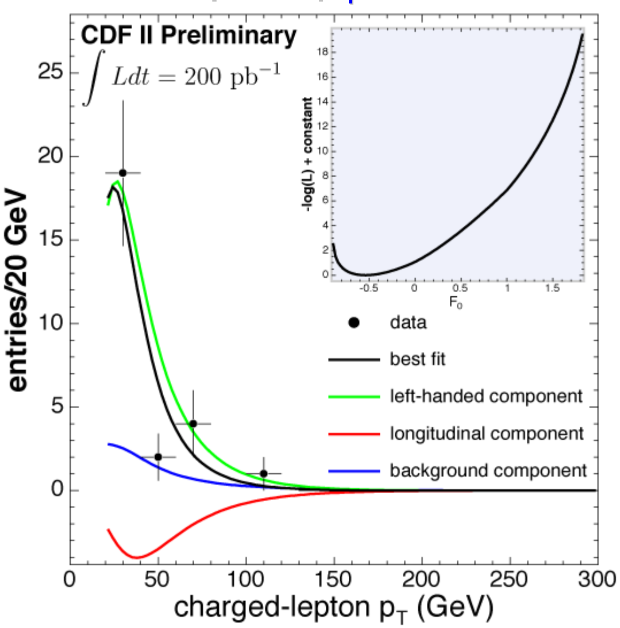


CDF W Helicity from p_T

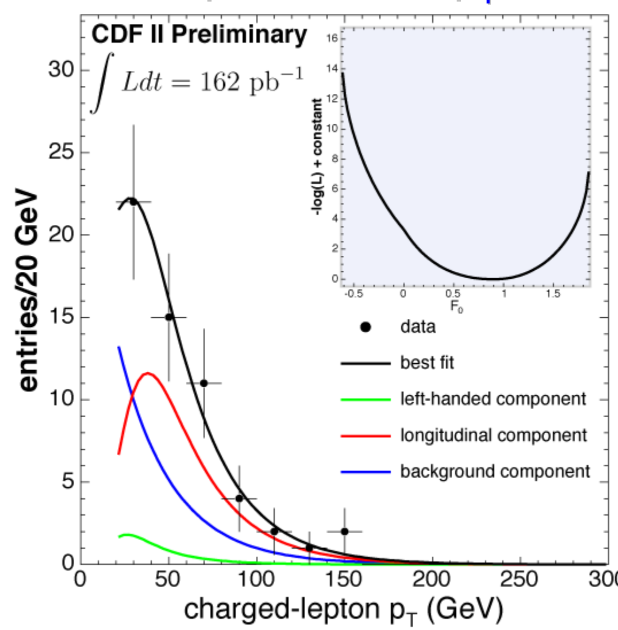
Combined p_T Fit



Dilepton p_T Fit

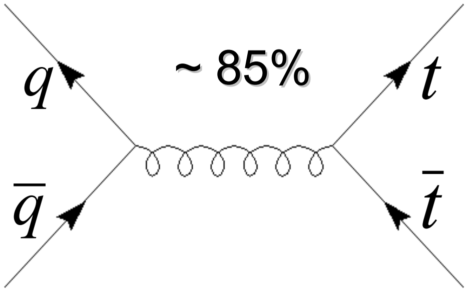


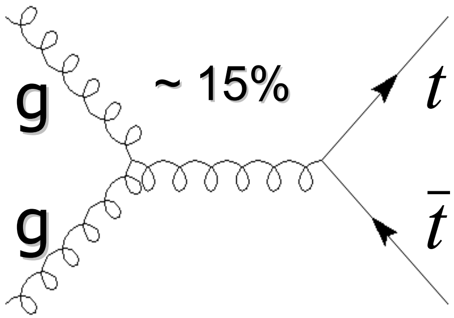
Lepton + Jets p_T Fit



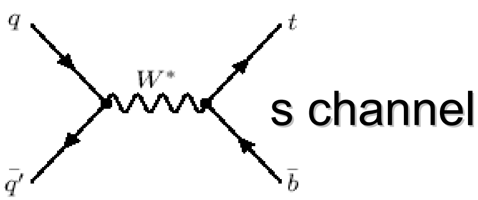
Top Production at the Tevatron

- Pair production
  - $\sigma_{\text{pair- theory}}$ = 6.7 pb.



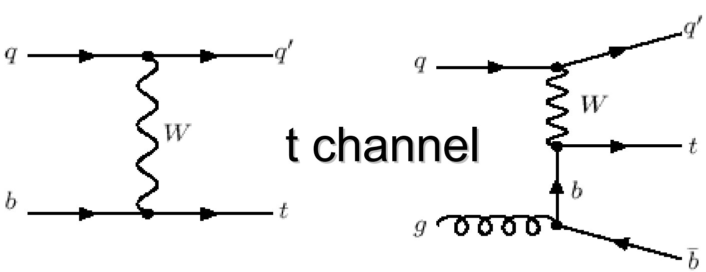


All of these theoretical values assume
a top quark mass of 175 GeV/c^2
at a center of mass energy of 1.96 TeV.



(a)

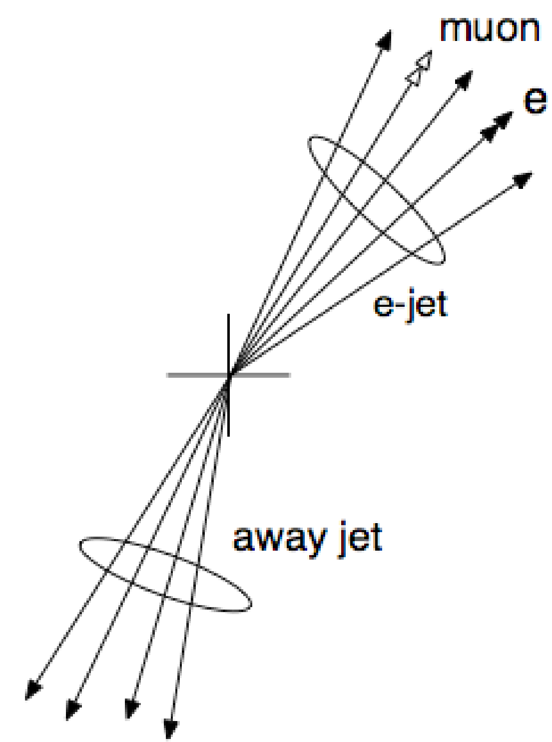
- Single top
  - Not yet observed
  - $\sigma_{\text{s-channel - theory}}$ = 0.88 pb.
  - $\sigma_{\text{t-channel - theory}}$ = 1.98 pb.



Calibrating the b-tagging Efficiency

Measure ratio of single- and double-tagged events in b-enriched sample with soft (p_T>8 GeV) electrons

$\epsilon_{\rm data}$	$24.0 \pm 1.6\%$
$\epsilon_{\rm MC}$	$29.2 \pm 1.1\%$
ratio	$82 \pm 6\%$



“Scale factor” measured on this sample is applied to other samples, even if the efficiencies differ

Other V_{tb} Results

- J. Swain and L. Taylor (hep-ph/9712420) looked at V_{tb} by looking at EW corrections to Z → bb (no assumption of unitarity):

$$|V_{\mathrm{tb}}| = 0.77^{+0.24}_{-0.17}$$