Top Properties

Results From

W Helicity
Top Charge
Top Branching Ratio

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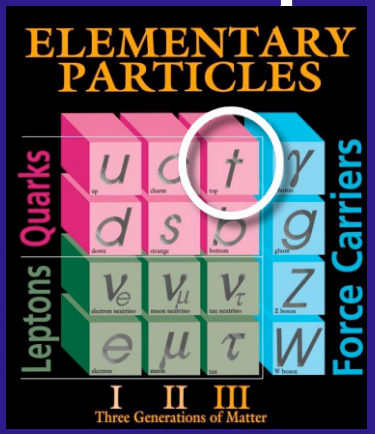
For the DØ Collaboration
University of Washington
Fermilab Wine & Cheese
January 19, 2006

Ten Years Of Top



1995: Top Quark Is Discovered

DØ Cross Section: 6.4 ± 2.2 pb
DØ Top Mass: 199 ± 20 ± 22 GeV/c^2

2006: Sitting on 1 fb^{-1} of data

DØ Cross Section: 8.1 ± 1.3 ± 0.5 pb
Combined Top Mass: 172.7 ± 2.9 GeV/c^2

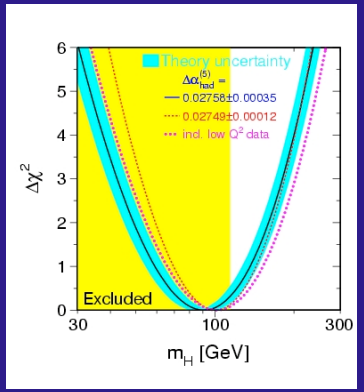
Top Factory

But These Aren't The Only Reason To Look at Top!

Top Quark Properties

Completing The Standard Model

Indirect Predictions of MH using Standard Model Fits



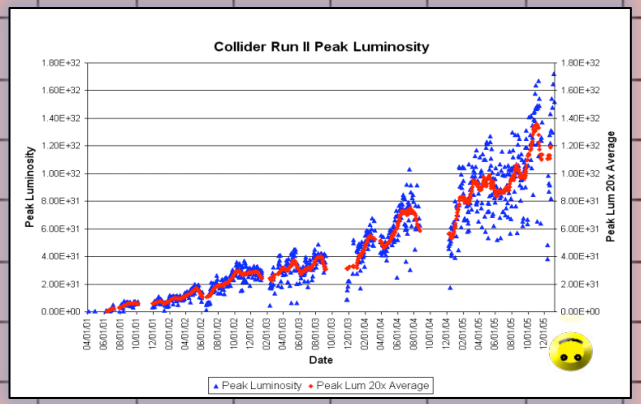
SM Precision Measurements

Mass	169.5 ± 4.4 ± 1.7 GeV/c^2 (lj ME)
Cross Section	8.1 ± 1.3 ± 0.5 pb (lj b)
Top Spin Correlations	:-(
W Helicity	This Talk
Top Charge	This Talk
Top Branching Ratios	This Talk
Rare Decays	:-(
Resonance Searches	Model Dependent Limits Set
Single Top Searches	<5.0 (s), <4.4 (t)

See DØ's Web Site for all recent results!

Run II Integrated Luminosity

19 April 2002 - 20 January 2006



Luminosity (fb^{-1})

2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

Apr-02 Jul-02 Oct-02 Jan-03 Apr-03 Jul-03 Oct-03 Jan-04 Apr-04 Jul-04 Oct-04 Jan-05 Apr-05 Jul-05 Oct-05 Jan-06 Apr-06 Jul-06

Analyses Discussed Today

1.37

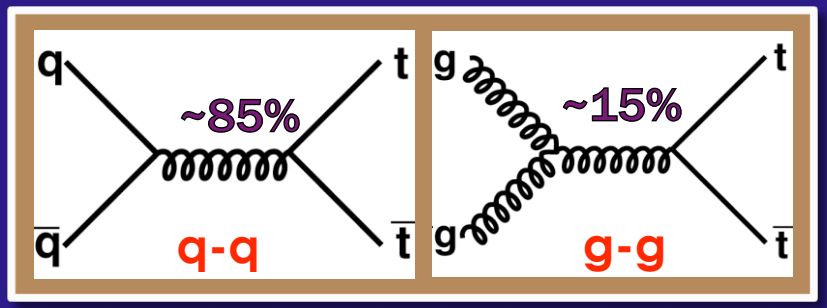
1.15

Delivered

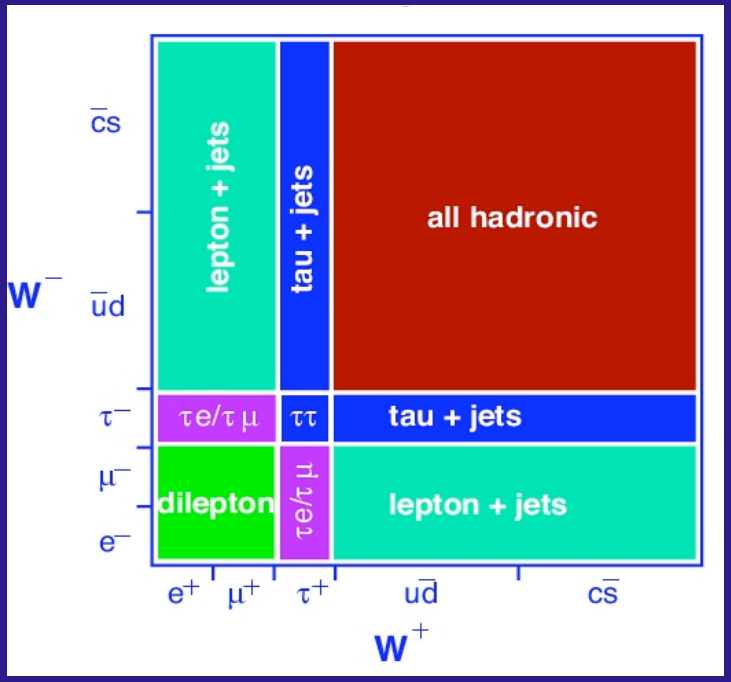
Recorded

Top Physics

1 Pair Production



2 Top Quark Decay

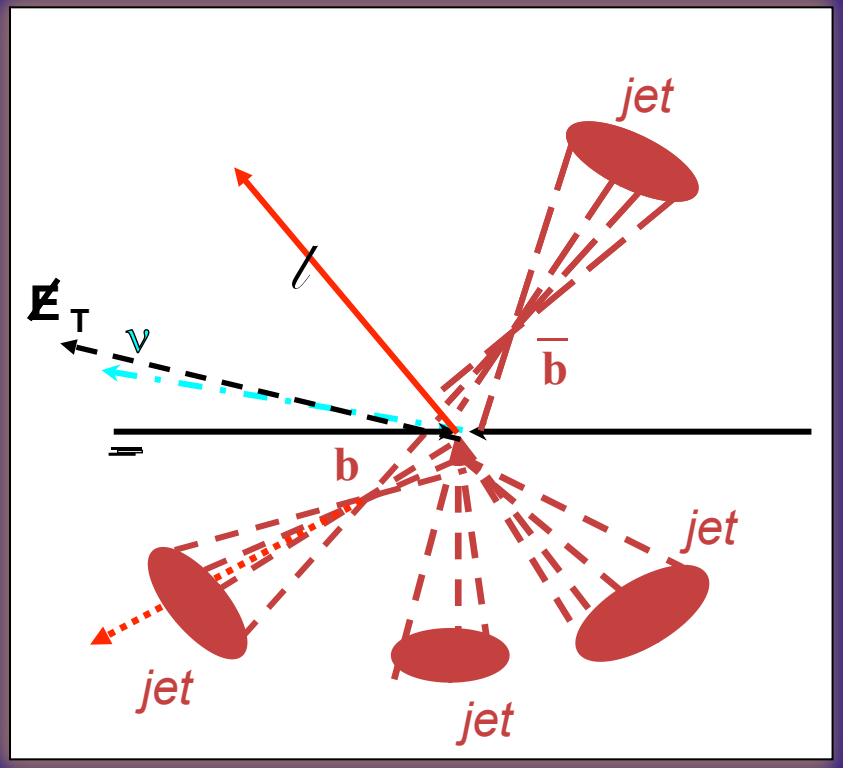


- W decay modes determine top quark final state
- Dilepton (ee, μμ, eμ)
  - Both W's decay leptonically
  - BR = 6%
  - Backgounds: WW, Z+jets, instramental
- Lepton (e or μ) + jets
  - One W decays leptonically, another one hadronically
  - BR = 34%
  - Backgrounds: Multijet, W+Jets

Top Property Analyses use cross section samples

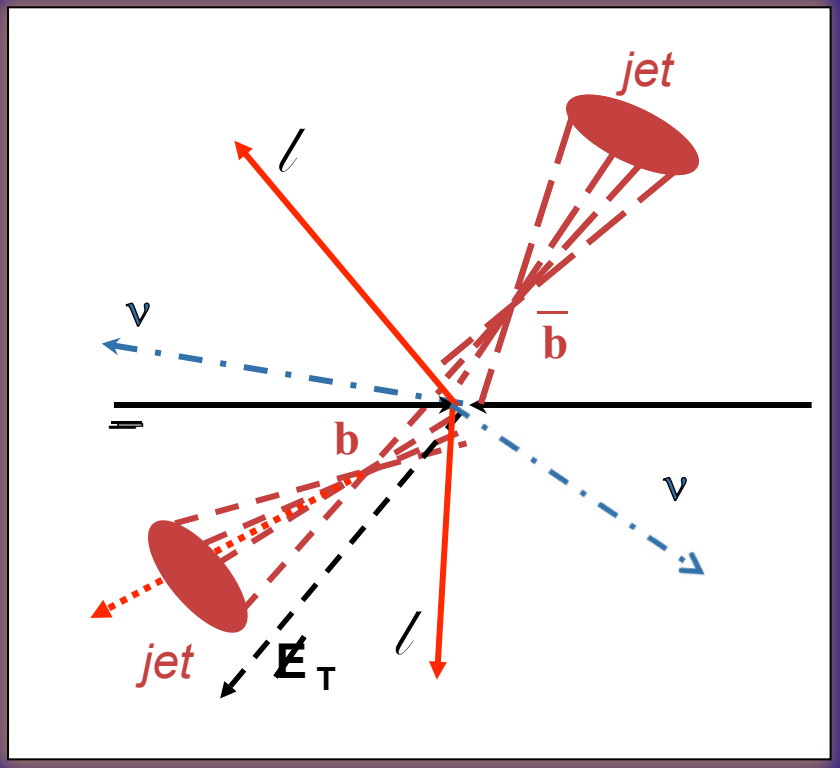
Signatures

Lepton + Jets Channel



- One isolated lepton (p_T>20 GeV; e: |η|<1.1, μ: |η|<2)
- At least four jets (p_T>20 GeV, |ψ|<2.5)
- ME_T >20 GeV and not collinear with lepton direction in transverse plane

Dilepton Channel



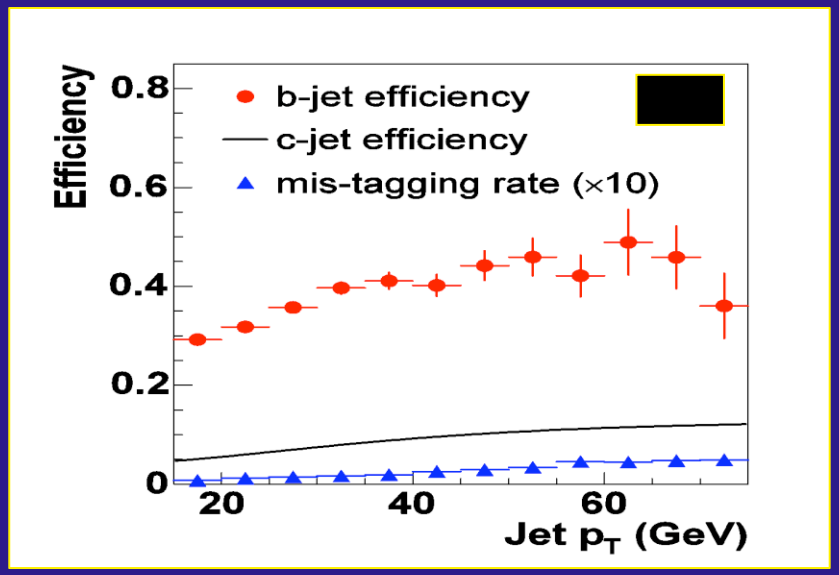
- Two isolated leptons (p_T>15 GeV; e: |η|<1.1, μ: |η|<2)
- At least two jets (p_T>20 GeV, |ψ|<2.5)
- ME_T >35 GeV (ee,μμ) only, Z removal

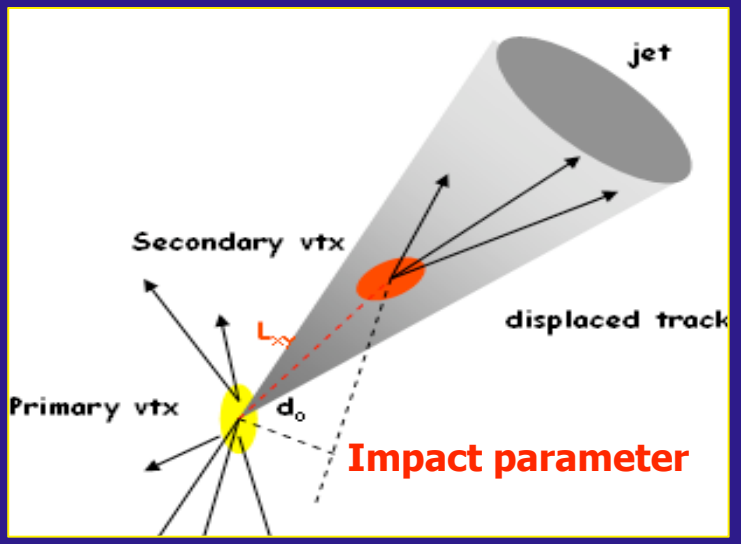
B-Tagging

Secondary Vertex Tagger

Reconstruct Vertex From Displaced Tracks

Operating Point:
"TIGHT"





Efficiencies and fake rates measured on data

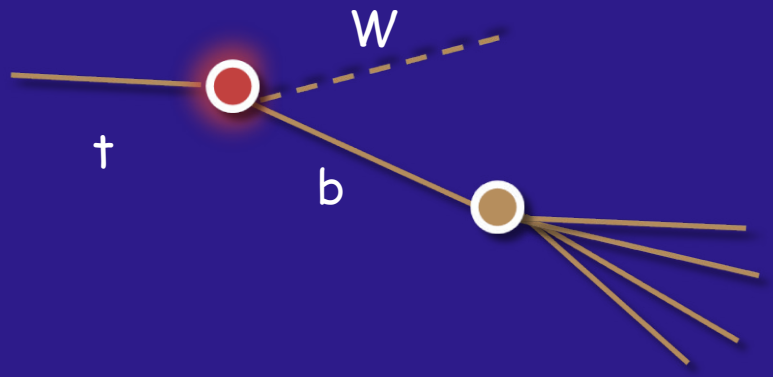
Outline

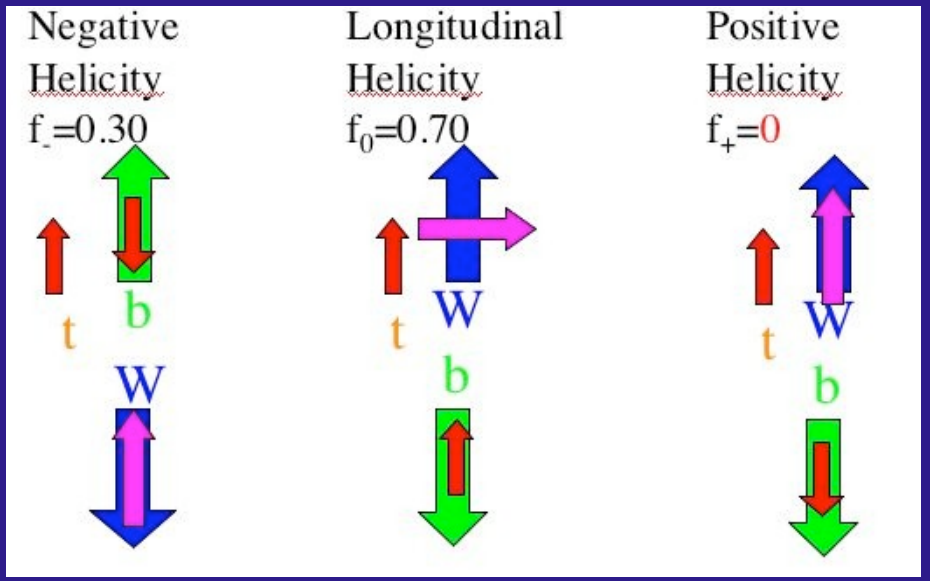
W Helicity Measurement

Top Charge

Top Branching Fractions

W Helicity





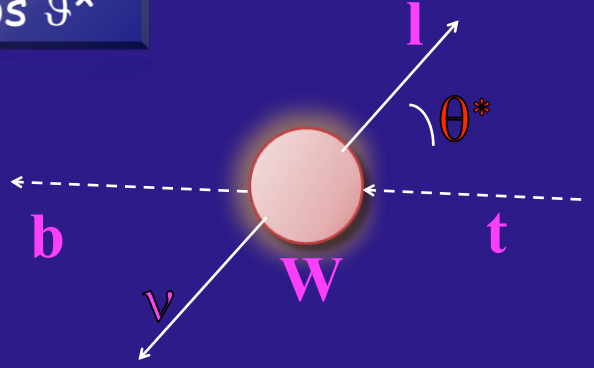
SM Top decay occurs via the charged current interaction (V-A like)

Observation of Positive Helicity would be an indication of a V+A interaction and new physics

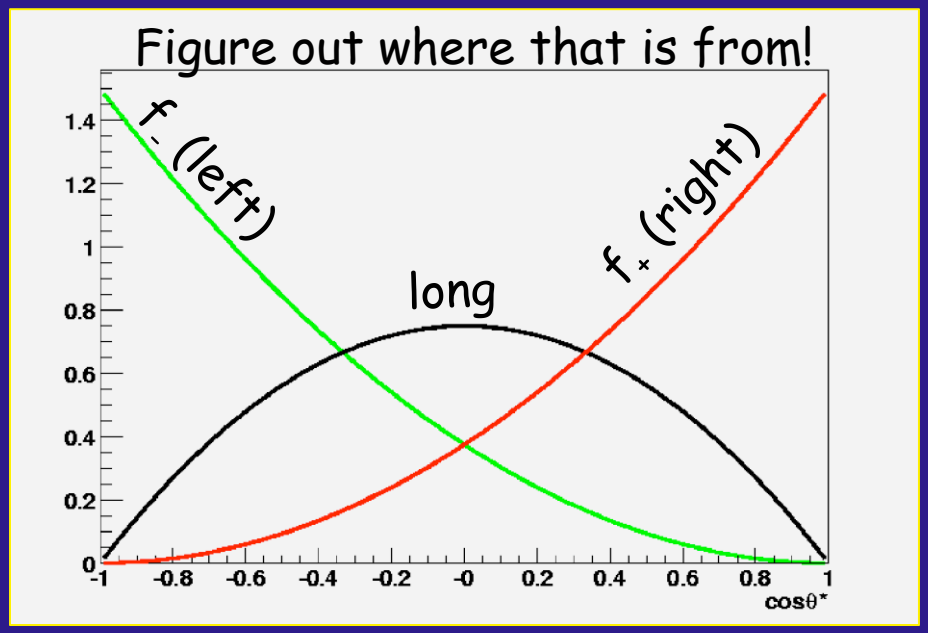
Restricts phase space available to the decay

Measurement Strategy

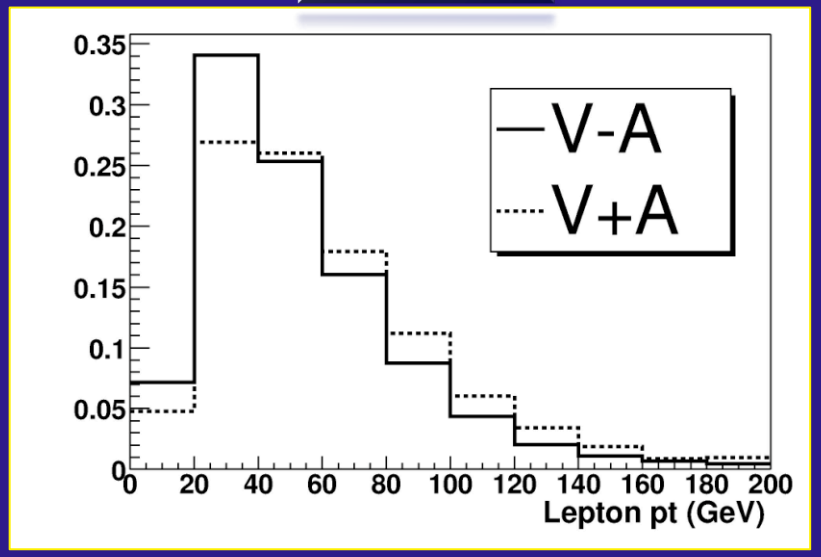
cos ϑ^*



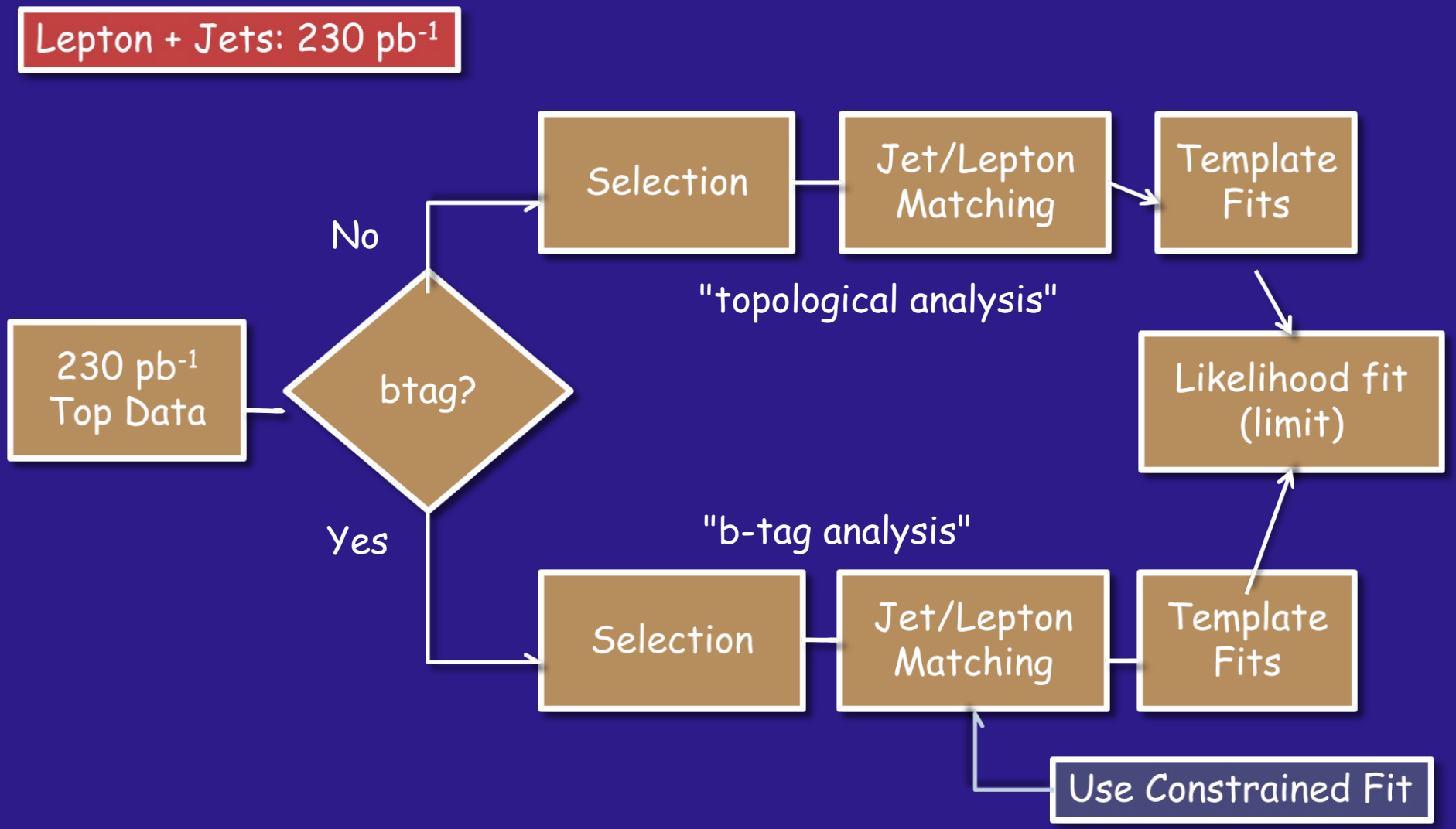
State	SM Frac Decay
f_- (left)	~0.3
f_+ (right)	< 3.6×10^{-4}
longitudinal	0.703



lepton p_T

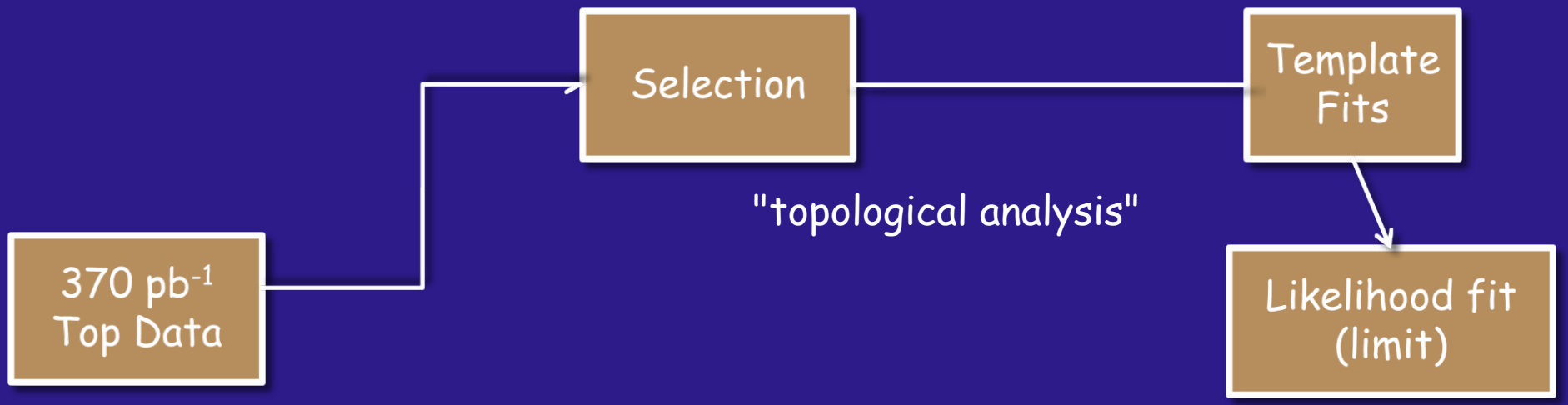


Analysis Strategy



Analysis Strategy

Dilepton: 370 pb^{-1}



Lepton Jet matching done in dilepton channel

- The event is under constrained
- Lepton p_T used directly

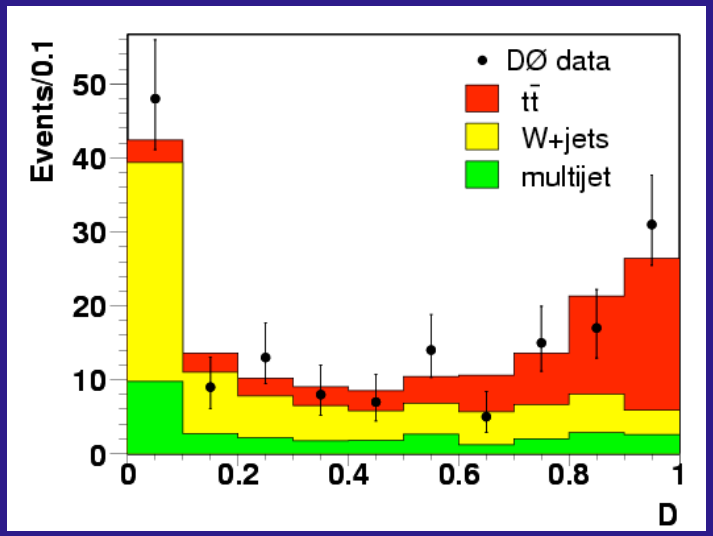
Selection

Lepton + Jets Discriminant

Input Variables Depend on Analysis

Non-btag Analysis (D > 0.6)

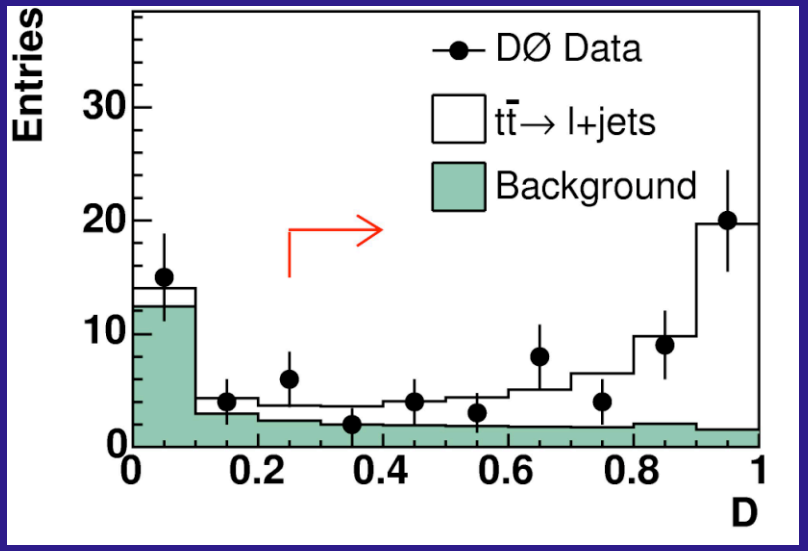
H_T, min dijet-mass, χ^2 of constrained fit, aplanarity, sphericity, centrality, K_t'



Cut on D optimized to minimize statistical error on f_+.

btag Analysis (D > 0.25)

H_T, min dijet-mass, centrality, χ^2 of constrained fit



Jet/Lepton Matching

Cos ϑ^* requires correct association of b-quark jet!

There are 2 b's per event!

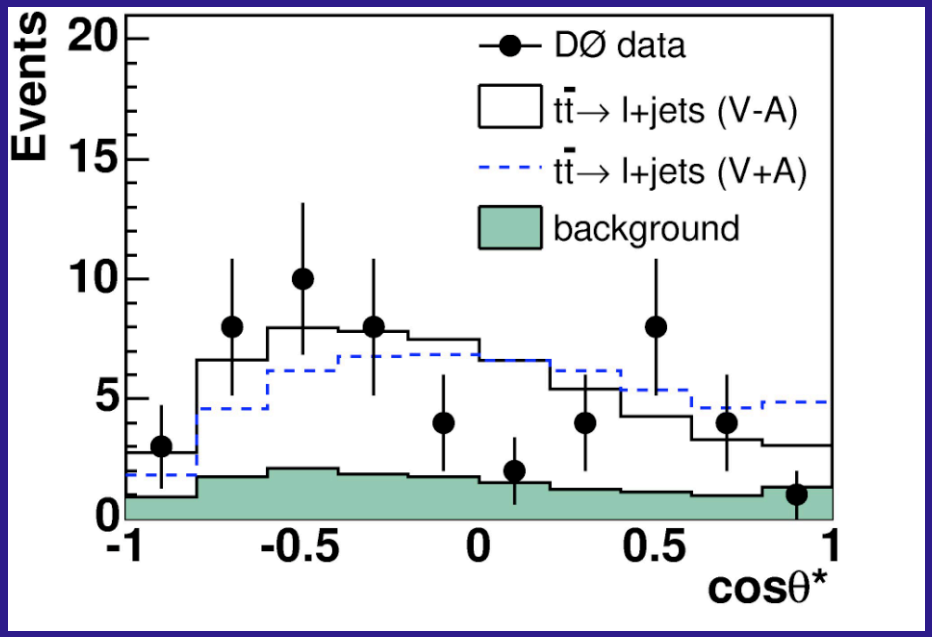
Use a constrained kinematic fit to the tt hypothesis.

- Two Jets must form W Mass
- p_z of neutrino is calculated (best solution kept)
- Two top masses must be 175 GeV/c^2
- Tag Information is not used

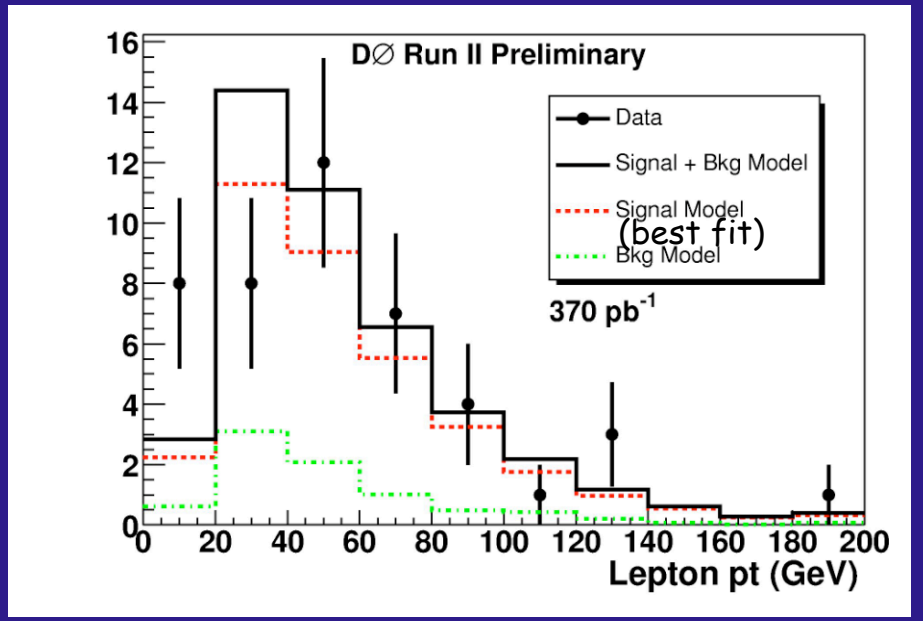
Get the correct b-quark about 60% of the time

Templates

- Apply selection Cuts, perform Matching
- Generate template for background events
- Generate MC for top decay with f_+ = (0.0 – 0.3 in 7 steps. ($f_- = 0.3 - f_+$).



Lepton + Jets



Dilepton

ALPGEN used for both top and W samples

Systematic Errors

Lepton + Jets

TABLE II: Systematic uncertainties on f_+ for the two independent analyses and for the combination.

Source	Kinematic	b-tagged	Combined
Jet energy calibration	0.03	0.04	0.04
Top quark mass	0.04	0.04	0.04
Template statistics	0.05	0.02	0.03
b-tag	0.03	0.02	0.02
$t\bar{t}$ model	0.01	0.02	0.02
W+jets model	0.01	0.01	0.01
Sample composition	—	0.02	0.01
Calibration	0.01	0.01	0.01
Total	0.08	0.07	0.07

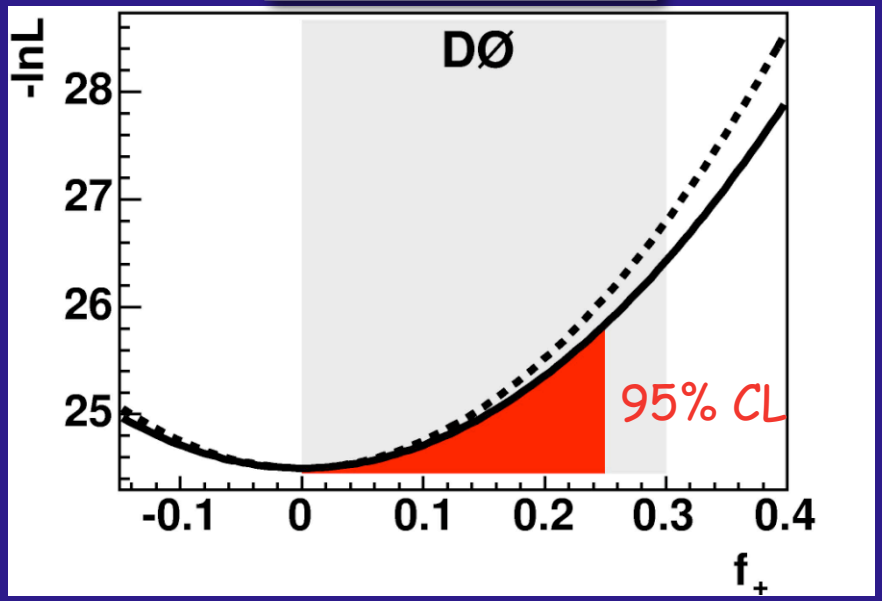
Dilepton

TABLE IV: Summary of the systematic uncertainties on f^+.

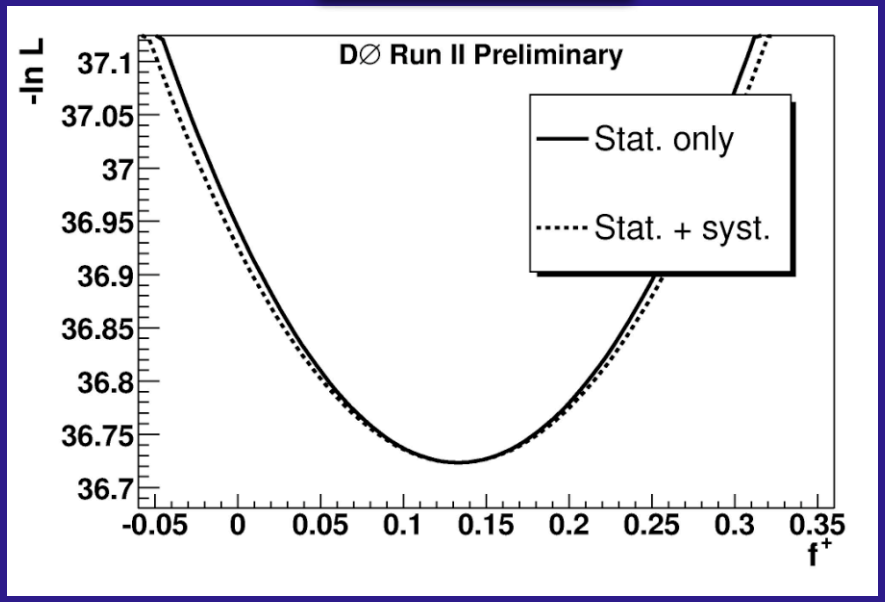
Source	Uncertainty
Monte Carlo statistics	0.046
Analysis self-consistency	0.010
Top quark mass	0.008
Jet energy calibration	0.013
$t\bar{t}$ model	0.03
Fake lepton model	0.013
Lepton p_T resolution	0.010
Trigger	0.008
Total	0.061

The Data

Lepton + Jets



Dilepton



Binned Likelihood Fit

Combined Result

$$f^{+}_{\mathrm{comb}} = 0.04 \pm 0.11(\mathrm{stat.}) \pm 0.06(\mathrm{syst.})$$

Limit: $0.0 < f_+ < 0.25$ @ 95% CL

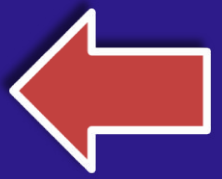
CDF Limit: $0.0 < f_+ < 0.17$ @ 95% CL R1

CDF Limit: $0.0 < f+ < 0.27$ @ 95% CL R2

Outline

W Helicity Measurement

Top Charge

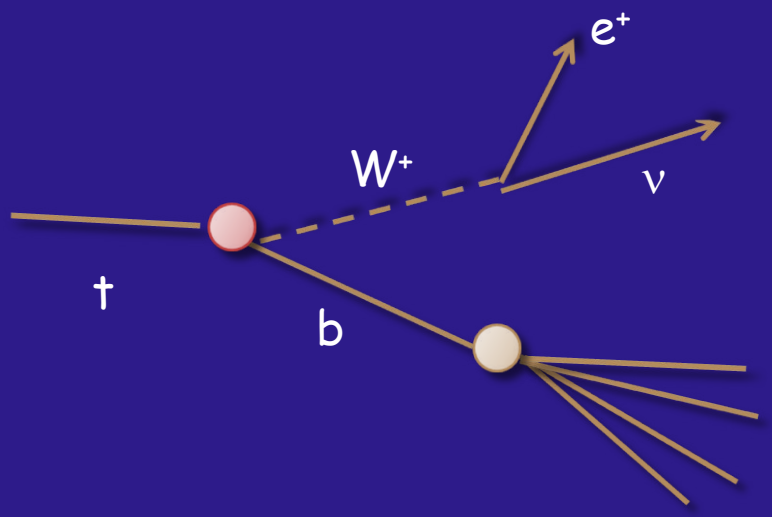


Top Branching Fractions

Charge Of The Top Quark

SM: top charge +2/3 e

Current results for pair production would not differentiate between the two possible top quark charges.

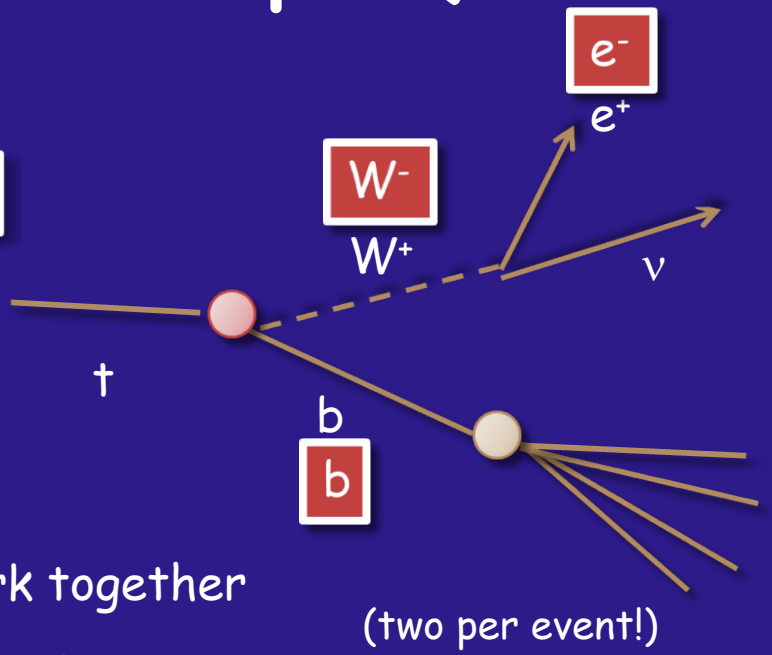


Charge Of The Top Quark

SM: top charge +2/3 e

Models Predict top quark charge of -4/3

Current results for pair production would not differentiate between the two possible top quark charges.



(two per event!)

→ Associate the proper lepton and b quark together

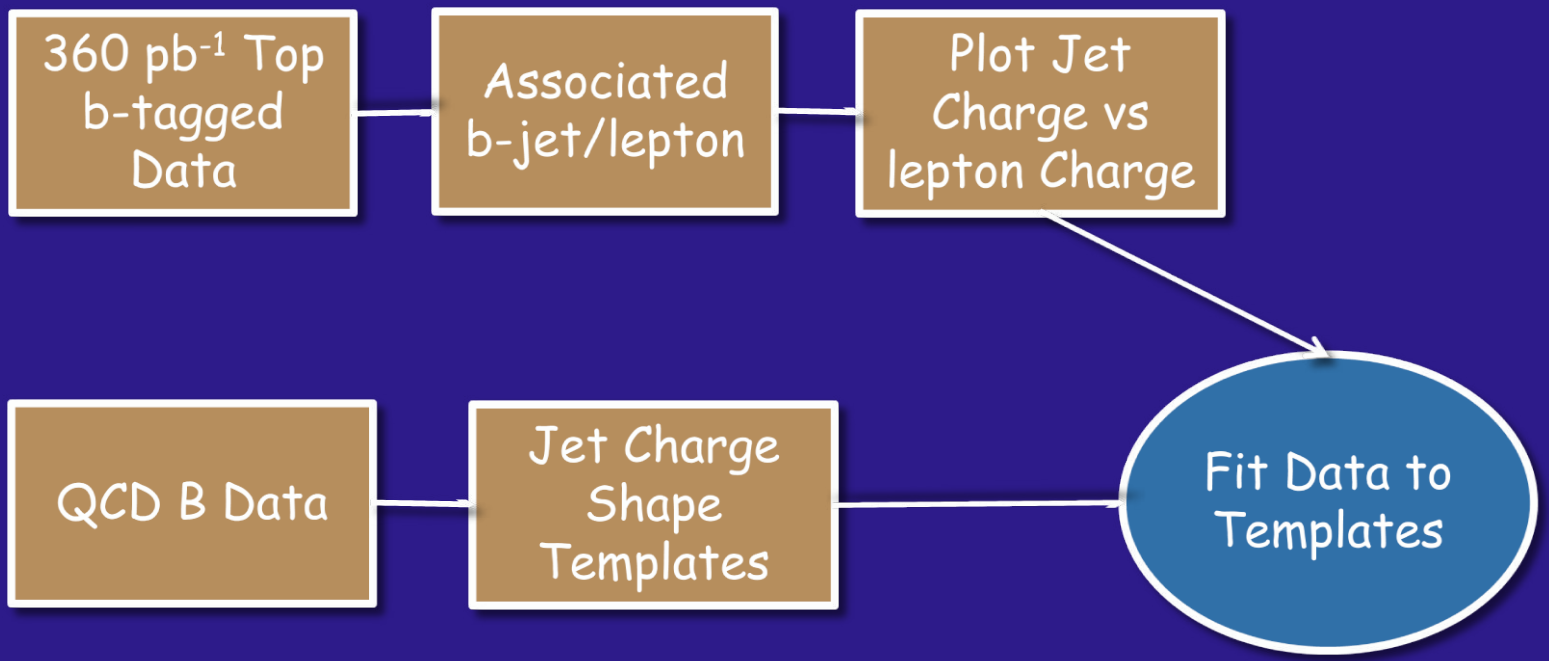
Use a kinematic fit (to tt hypothesis)

→ Determine Charge of the b-jet

Use convolution of charges of the tracks from the b hadron decay

Analysis Strategy

Lepton + Jets Only



Jet/Lepton Matching

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Use a constrained kinematic fit to the tt hypothesis.

- Two Jets must form W Mass
- p_z of neutrino is calculated (best solution kept)
- Two top masses must be 175 GeV/c^2
- Tag Information is not used

Get the correct b-quark about 60% of the time

Additionally Require Double Tags
Require that the Tags match the B-Quarks

Get the correct b-quark about 80% of the time

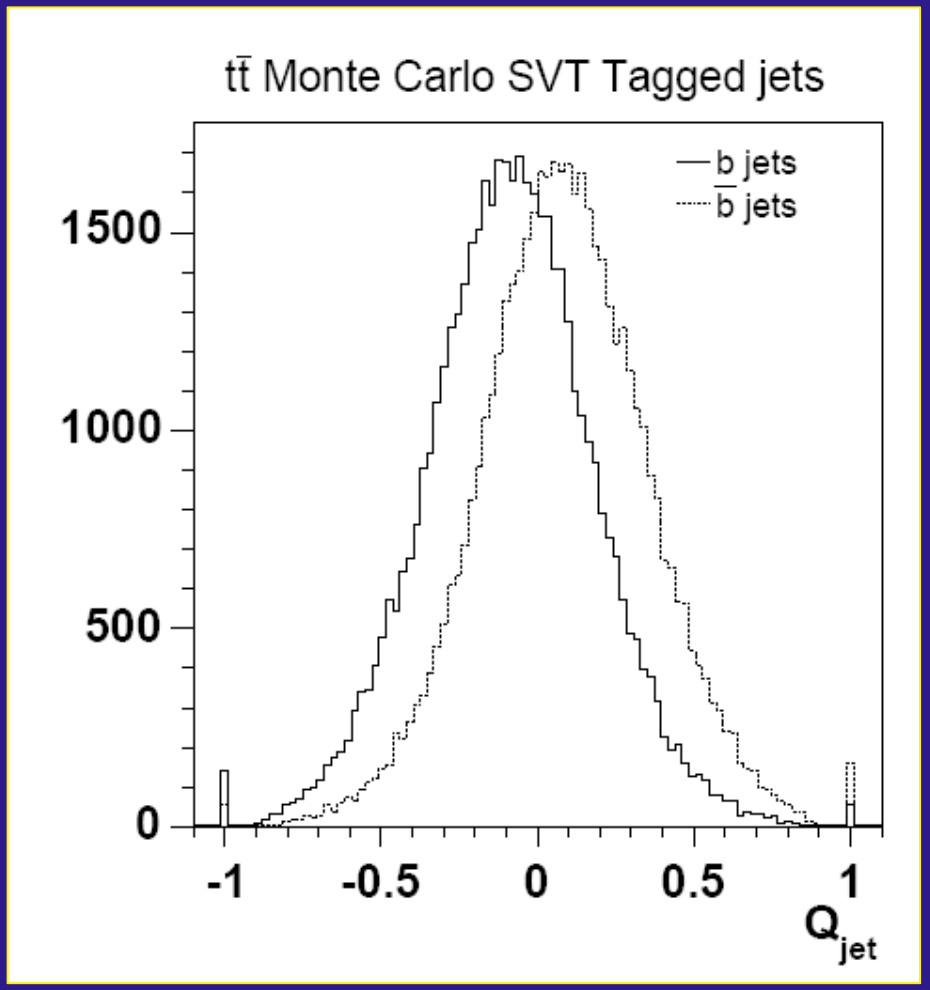
Jet Charge

p_T weighted sum of charged tracks

Tracks
$p_T > 0.5$ GeV
$\Delta R < 0.5$ (Jet, Track)

$$q_{jet} = \frac{\sum_i q_i p_{T_i}^{0.6}}{\sum_i p_{T_i}^{0.6}}$$

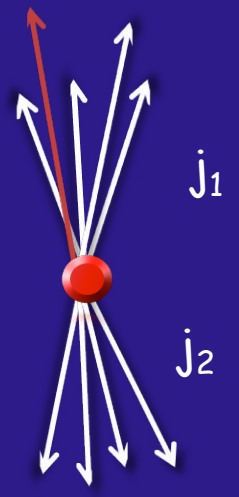
Optimization
ttbar MC
Separation of b vs $\bar{b}$



Calibrating q_{jet}

Use sample of (QCD) back-to-back jets

- Both are b-tagged ($\Delta\phi(j_1,j_2)>3.0$)
- One has a muon (p_T > 4 GeV)
  - Used to determine charge of j_1
- Calibration derived from second jet



But…

The μ charge is not 100% correlated with b-quark type!

- Direct b to μ decay
- B hadron oscillation
- Cascade decay to μ thru c quark
- Charm pair production background

Calibrating q_{jet}

(and systematic errors)

Production
- Back To Back Jets: *flavor Creation*
- Vary $\Delta\phi(j_1,j_2)$ cut 2.65-3.0
  - 80%-95% flavor creation
- Propagate result as systematic error

Oscillations and Cascade Decays
- Derive Correction Factor from Z MC.

η Dependence
- Tracking Efficiency falls off
- Ratio derived from tt MC.

Charm Production
- Use m p_T^{rel} templates on j_1.
- Charm Fraction is 6 ± 2%

Jet Multiplicity
- tt 2 and 4 jet sample studied
- No clear trend

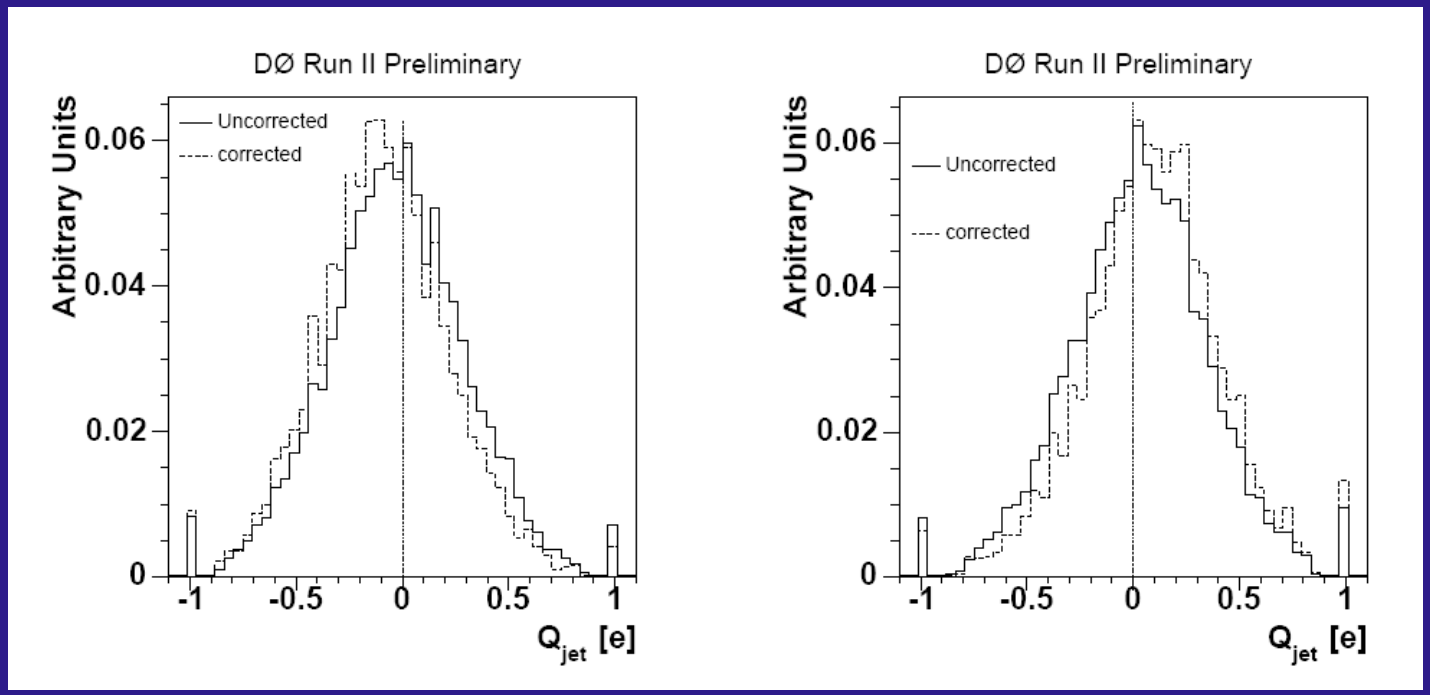
Kinematics
- No E_T dependence found above 20 GeV

Muon vs Hadronic Jets
- Better separation in tt than Z
- Using current method is conservative.

Fragmentation model
- Base templates derived from data

Vertex Position

Jet Charge Templates



b

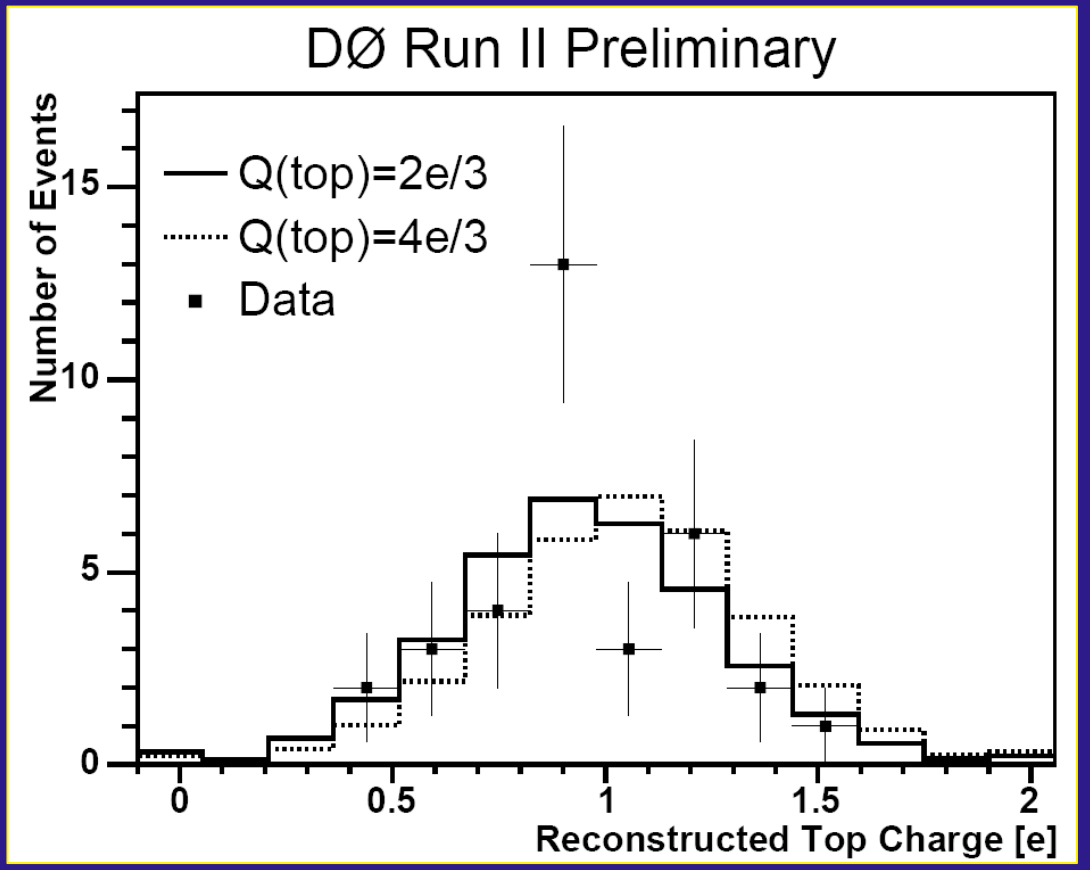
$\bar{b}$

Making The Measurement

Looking at Lepton + Jets Events

$Q_1 = |q_l + q_{bl}|$
$Q_2 = |-q_l + q_{bh}|$

17 Fittable Double Tagged Events



Limits

Likelihood Ratio

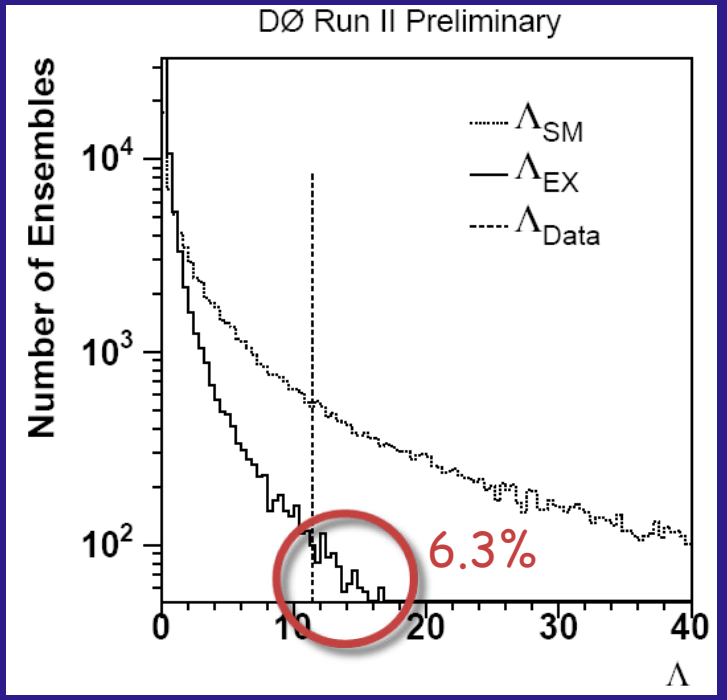
$$\Lambda = \frac{\prod_i p^{\mathrm{sm}}(q_i)}{\prod_i p^{\mathrm{ex}}(q_i)}$$

Probability charge observed in SM

Probability charge observed in 4/3 model

$p^x(q_i)$ are the templates

Rule out 4/3 model at 93.7% (very close to expected sensitivity of 89%).



Effects of Systematic Error

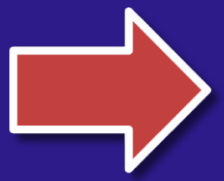
Systematic Errors

Source	Predicted C.L.	Observed C.L.
Stat. only.	96.9	98.7
+ Jet energy resolution	96.9	98.5
+ Jet energy calibration	97.0	98.6
+ Jet reconstruction	96.6	98.3
+ Jet charge corrections	94.9	97.4
+ b-jet production meachanism	94.5	97.0
+ η spectrum of b-jets	93.8	96.6
+ Top mass	92.4	96.1
+ p_T spectrum of b-jets	89.0	93.7

Outline

W Helicity Measurement

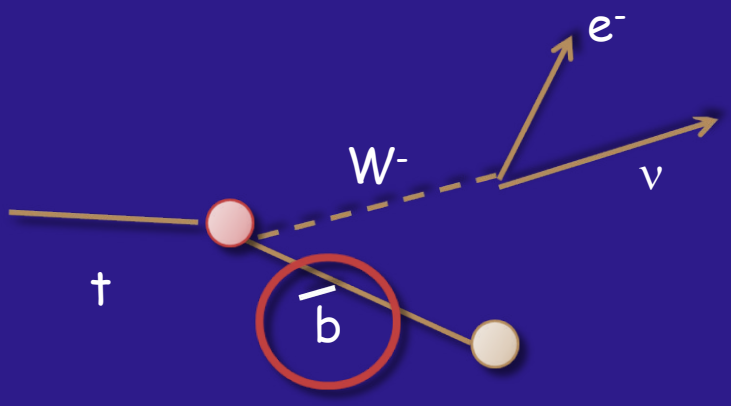
Top Charge



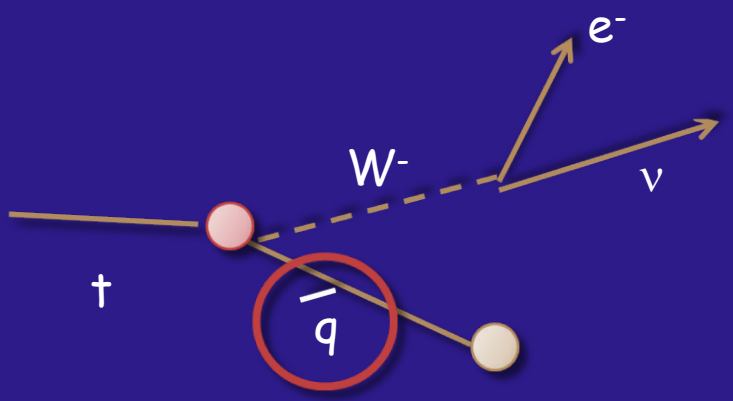
Top Branching Fractions

Top Branching Ratio

Standard Model



Model



This assumption is central to most pair-production analyses!

$\sigma(t\bar{t} \to WbWb)$ with b-tagging, for example.

➡ Measure this in Single Top

➡ Deconvolute cross section, detector, and tagging

A direct consequence of our current understanding of the CKM.

Analysis Strategy

Can't Claim To Know Overall Cross Section!

➡ Count # of Tagged Jets (R)

- SM Cross section analysis is an event count.
- This is a "shape" analysis in # of tagged jets

Pair Decay	# of tagged Jets
$t \rightarrow Wb, tWb$	2
$t \rightarrow Wb, t \rightarrow Wq$	1
$t \rightarrow Wq, t \rightarrow Wq$	0

➡ Fit to background fraction (cross section)

Use Discriminant, as before.

- Sphericity, Centrality, K_{Tmin}, H'_{T2}

Tagging Probabilities

This can be turned into a tagging probability

$$R = \frac{BR(t \to Wb)}{BR(t \to all)}$$

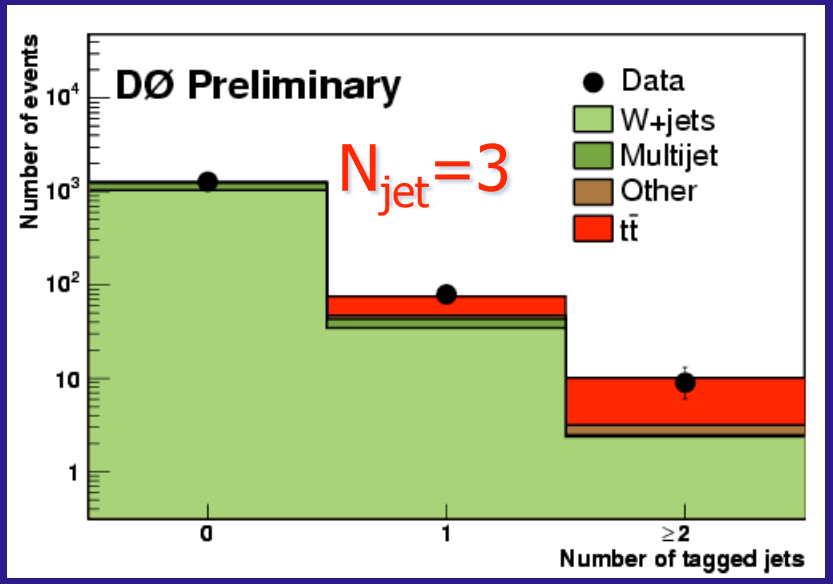
And for *n* taggs, the probability to tag an event:

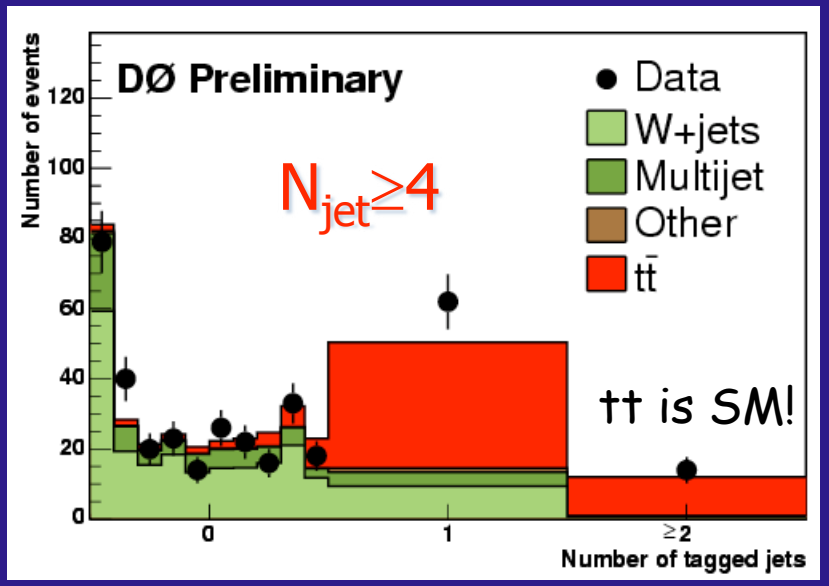
$$P_n(t\bar{t}) = R^2 P_n(t\bar{t} \to WWbb) + R(1-R)P_n(t\bar{t} \to WWbq) + (1-R)^2 P_n(t\bar{t} \to WWqq)$$

SM Contribution

Background

Binned Likelihood Fit to determine R and σ





- 10 bins in the Discriminate for 0 tag events, 4 Jet Events
- 2 bins for 1 tag events (3, 4 jet samples)
- 2 bins for >2 tag events (3, 4 jet samples)
- Double above for e and μ channels.

Systematic Errors

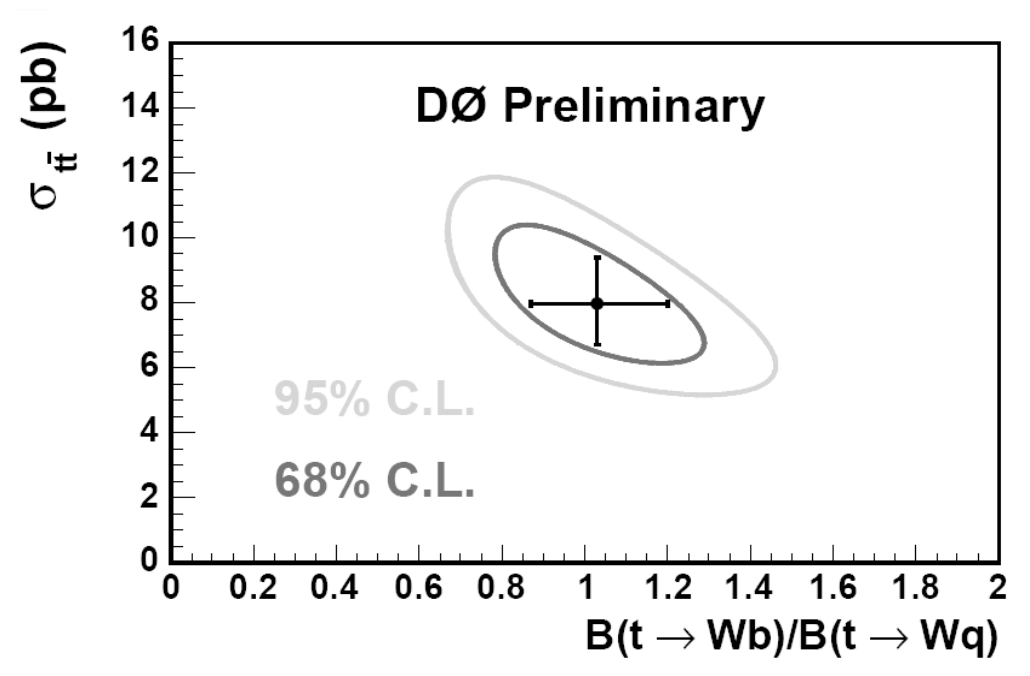
Source	Uncertainty on $\mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$
Statistical	$+0.17\ -0.15$
Jet energy resolution	$+0.02\ -0.01$
Jet reconstruction and identification	± 0.03
b-tagging efficiency in Monte Carlo	± 0.02
b-tagging efficiency in data	$+0.06\ -0.05$
Flavor composition of W+jets background	$+0.03\ -0.02$
Kinematical properties of W+jets background	± 0.04
Others	$+0.04\ -0.02$
Total error	$+0.19\ -0.17$

TABLE 1: *Statistical and systematic uncertainties on* $\mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$ *in units of* $\mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$.

Source	Uncertainty on $\sigma_{t\bar{t}}$ (pb)
Statistical	$+1.4\ -1.3$
Lepton identification and trigger	$+0.4\ -0.3$
Jet energy scale	± 0.3
Jet energy resolution	± 0.1
Jet reconstruction and identification	± 0.2
b-tagging efficiency in data	± 0.1
Flavor composition of W+jets background	± 0.5
Kinematical properties of W+jets background	$+0.4\ -0.3$
Statistics in control samples	± 0.2
Others	$+0.2\ -0.1$
Total error	$+1.7\ -1.5$

TABLE 2: *Statistical and systematic uncertainties on* $\sigma_{t\bar{t}}$ *in pb.*

Results



Limit using zero prior outside $0 < R < 1$

$$\mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq) = 1.03^{+0.19}_{-0.17}\,(\text{stat} + \text{syst})$$

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

$\sigma(tt \to WbWb) = 8.1 \pm 1.3 \pm 0.5$ pb
SM Cross Section Measurement (l+jets, btag)

Limits on V_{tb}

Unitarity of the SM

$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2$$

$\Rightarrow |V_{tb}| > 0.80$ @ 95% CL

CDF: $V_{tb} > 0.78$

In good agreement with measurements on other CKM elements
0.999 < Vtb < 0.9992

Run II Integrated Luminosity

19 April 2002 - 20 January 2006

- Improved Reconstruction
- Improved MC
- Improved BTagging (NN)
- Luminosity!

Spring/Summer Update

1.37

1.15

Delivered

Recorded

Luminosity (fb^{-1})

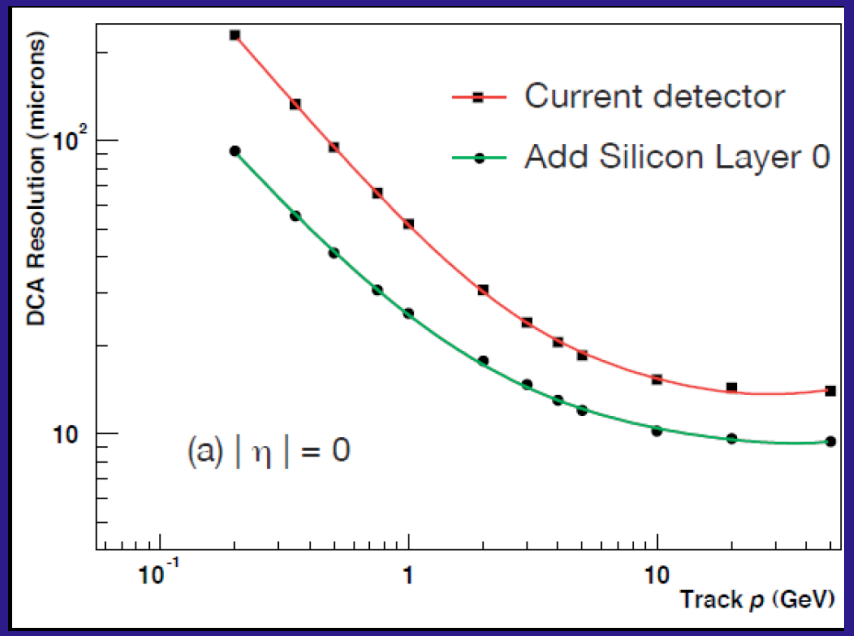
2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

Apr-02 Jul-02 Oct-02 Jan-03 Apr-03 Jul-03 Oct-03 Jan-04 Apr-04 Jul-04 Oct-04 Jan-05 Apr-05 Jul-05 Oct-05 Jan-06 Apr-06 Jul-06

The Future

Improvements in b-tagging will directly translate into physics

Layer 0 to be installed in March Shutdown



Conclusions

W Helicity

L+J: PRD 72 011104 (2005)

$$f^{+}_{\mathrm{comb}} = 0.04 \pm 0.11(\mathrm{stat.}) \pm 0.06(\mathrm{syst.})$$

Top Charge

Preliminary

Rule out +4/3 model at 93.7%

Top BR

Preliminary

$|V_{tb}| > 0.80$ @ 95% CL

Updates to come Spring/Summer with ~ 1 fb^{-1} of data.