Measuring the Charge of the Top Quark at CDF

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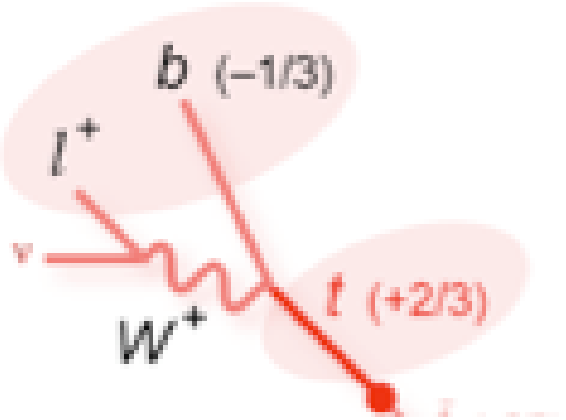
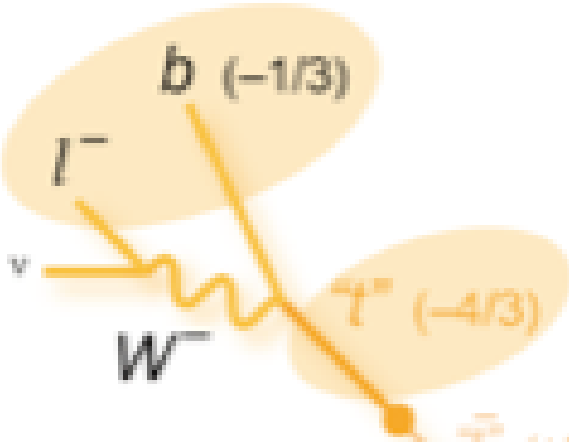
Motivation

- Precision measurements of top quark properties
- Is it SM top? Expect Q = +2/3
- Or exotic t' quark with Q = -4/3 (hep-ph 9810531)

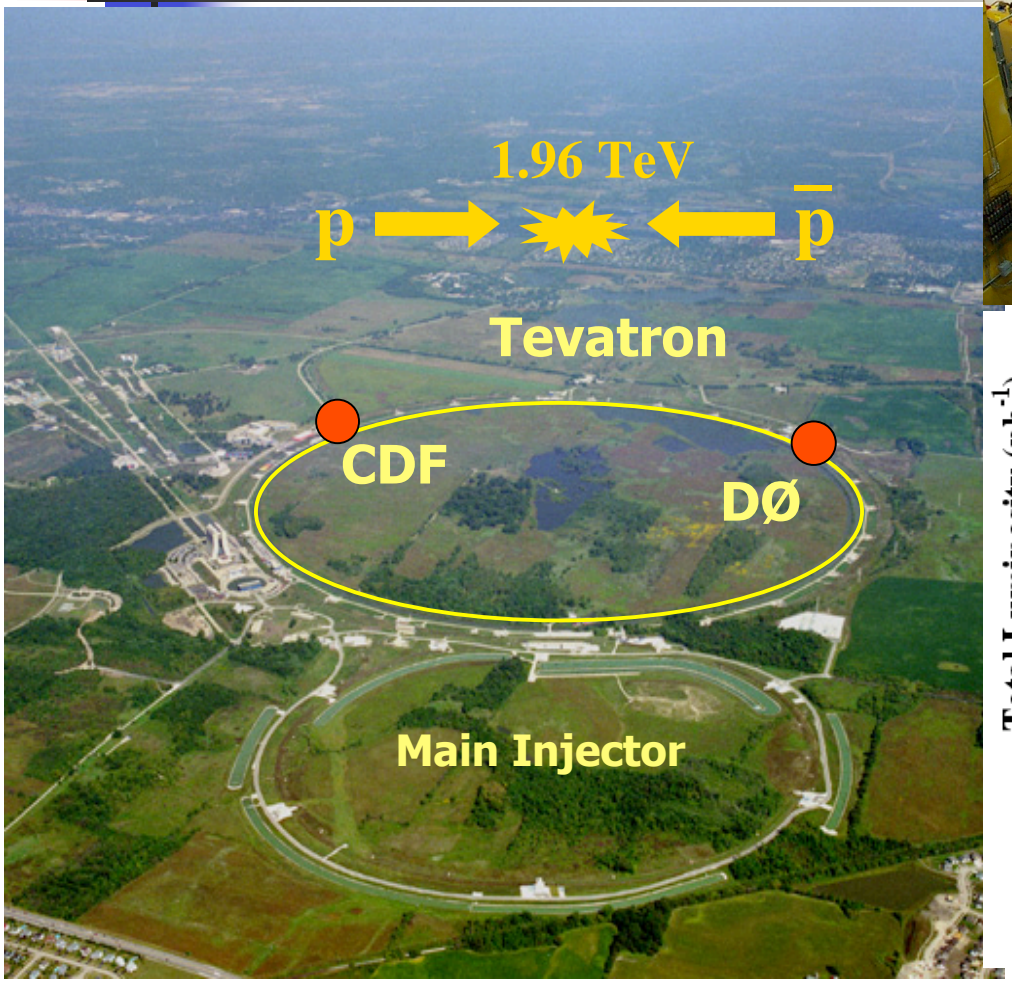


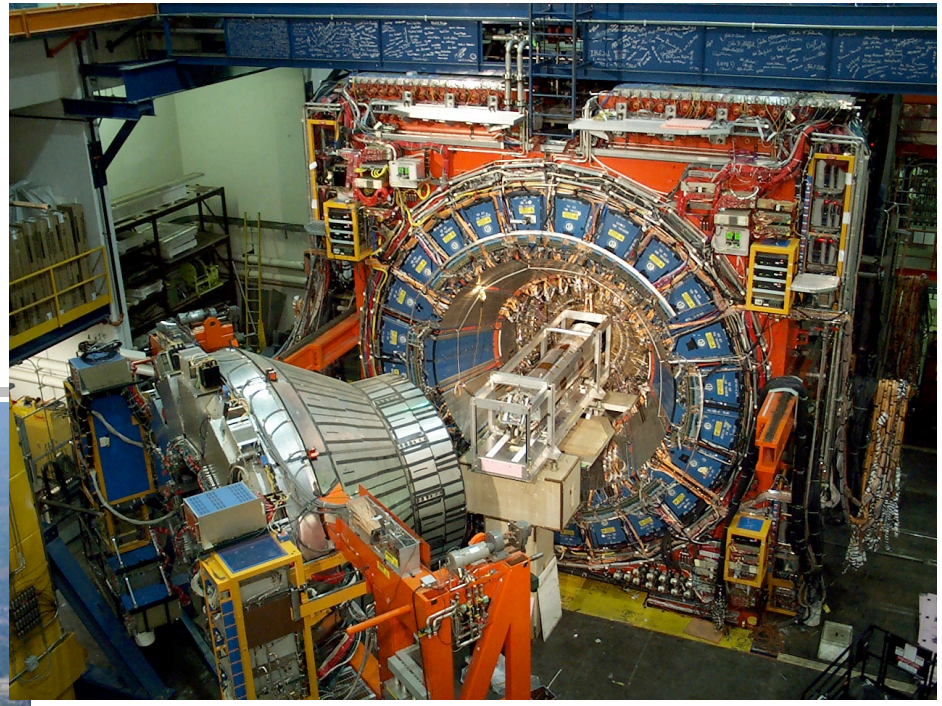
SM Top

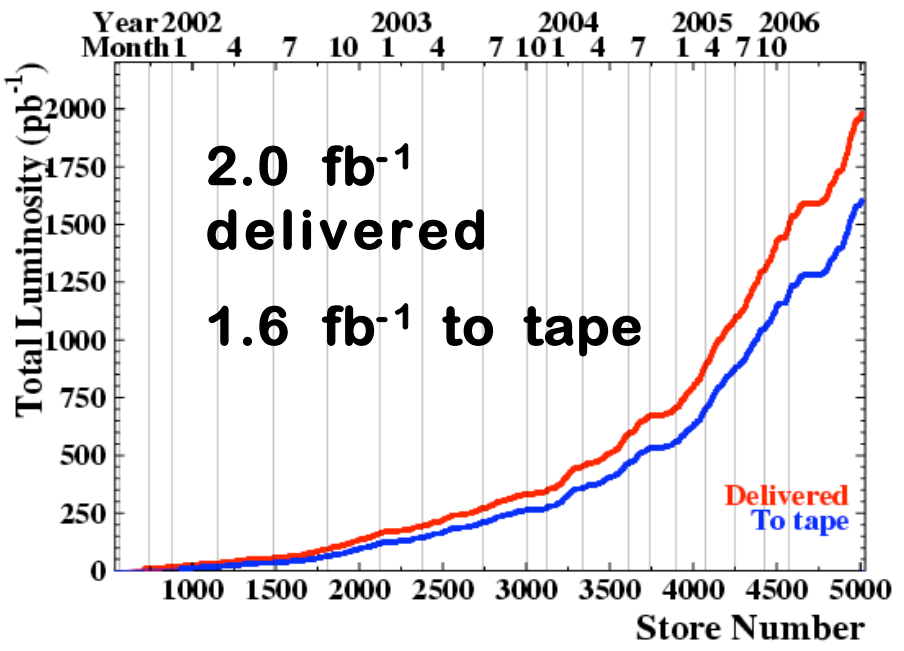


Exotic t'

Fermilab and CDF

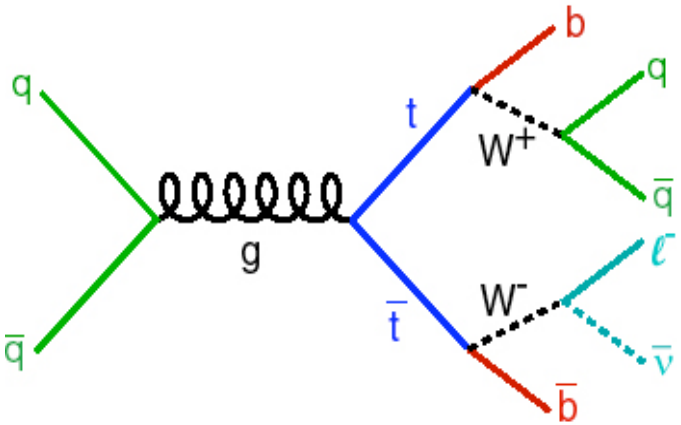






Top Decay

- B(t→Wb) ~ 100%
- Classify by W decay



- Dilepton:
  - 2 leptons P_T > 20 GeV
  - $\not\!\!E_T$ > 25 GeV
  - ≥ 2 jets, E_T > 15 GeV
- Lepton+Jets:
  - Lepton P_T > 20 GeV
  - $\not\!\!E_T$ > 20 GeV
  - ≥ 3 jets, E_T > 15 GeV

(no inc. τ)	**BR**	**background**
dilepton	~5%	low
lepton + jets	~30%	moderate
all hadronic	~44%	high

Determining Top Charge using Top Decay Products

In SM $t \rightarrow W^+ b$, can it be $t \rightarrow W^- b$?

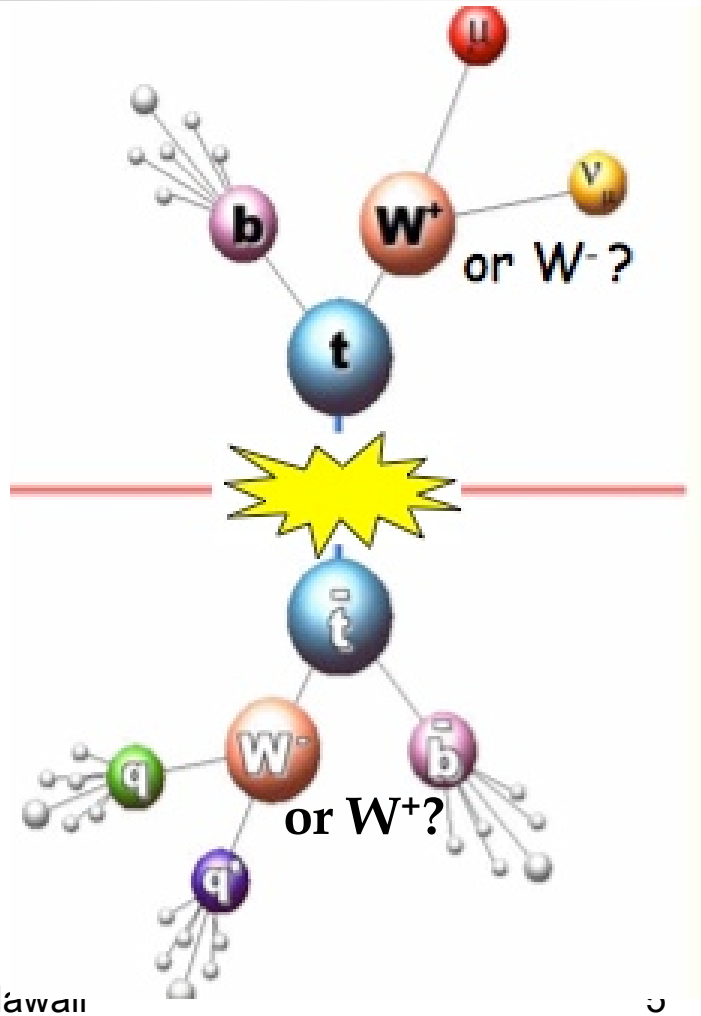
Need to know:

1) Charge of W (charge of lepton)
2) Pairing between W and b
3) Flavor of b jet

Event samples:

Dilepton

Lepton + Jets



Defining Performance

- Define $N_+ = N_{+2/3} = W^+b$ $N_- = N_{-4/3} = W^-b$
- N_{right} = # events correctly assigned to N_+ or N_-

$$\textbf{Asymmetry} = A_{meas} = \frac{N_+ - N_-}{N_+ + N_-}$$

$$A_{true} = \frac{A_{meas}}{D}$$

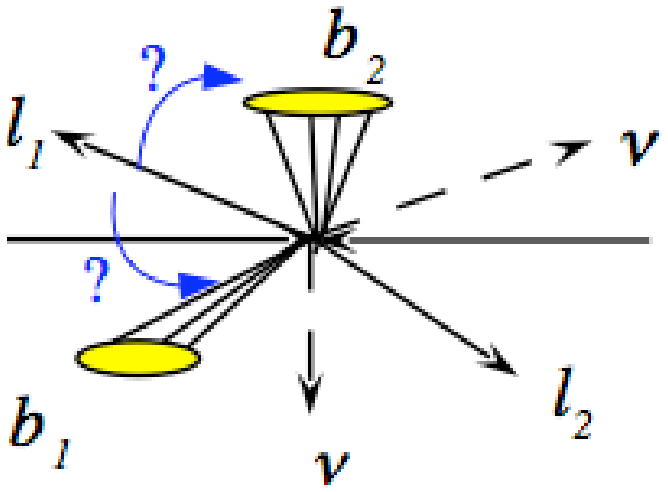
$$\textbf{Purity} = P = \frac{N_{right}}{N_{right} + N_{wrong}}$$

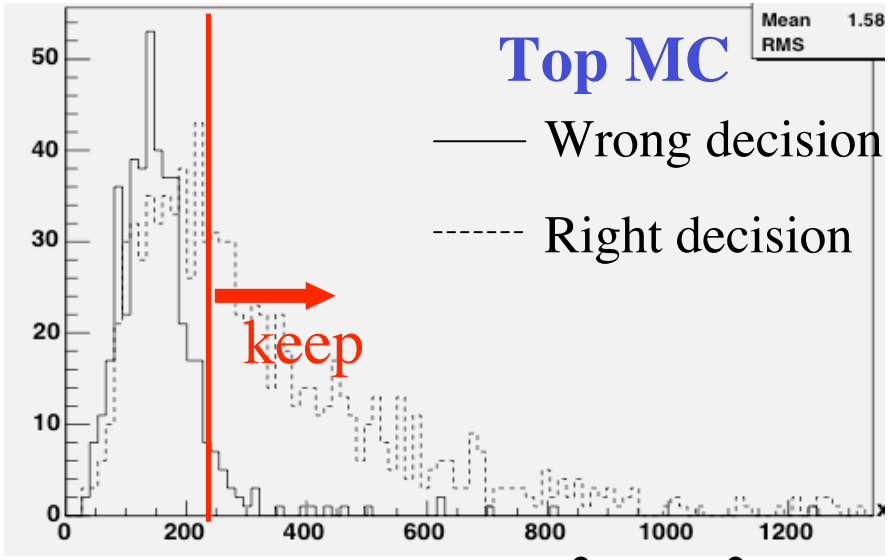
$$\textbf{Dilution} = D = 2P - 1$$

- Optimize method using $\sigma(A_{true}) \propto (\varepsilon D^2 N)^{-1/2}$

Wb Pairing - Dilepton Channel

- 2 leptons + 2 highest E_t jets





M_{lb}^2 x 10^2

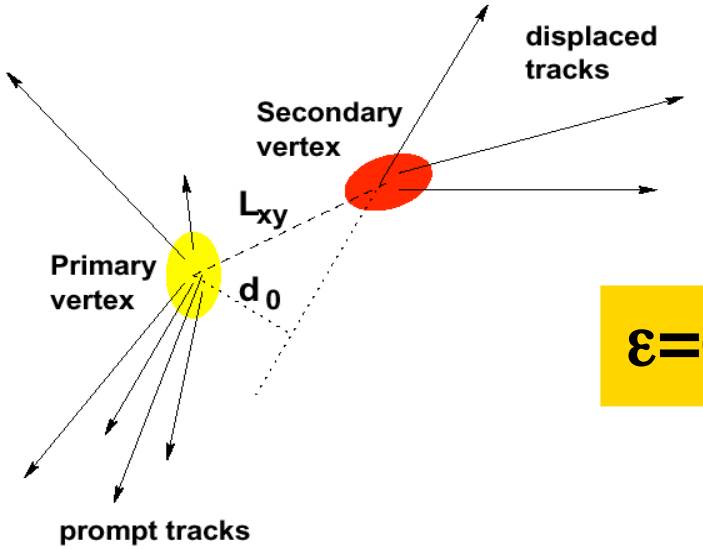
$$M_{lb}^2 = (E_l + E_b)^2 - (\vec{p}_l + \vec{p}_b)^2$$

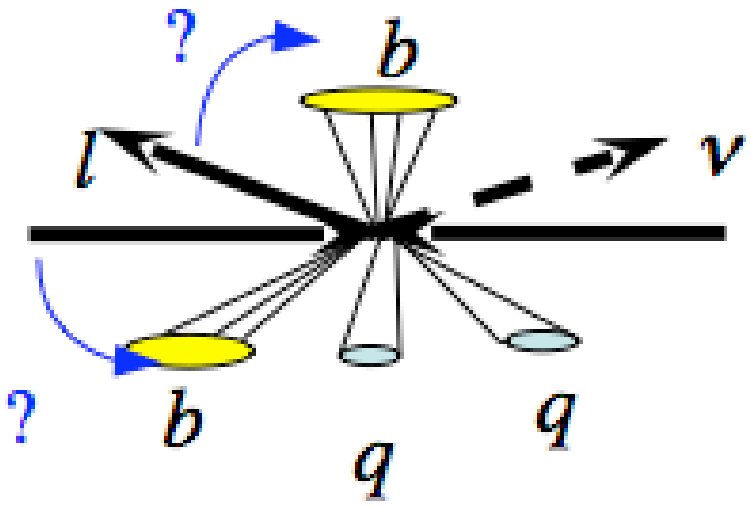
ε=39%, P=97%, εD²=0.34

- Max. M_{lb}^2 > 22,000 GeV²/c⁴

Wb Pairing - L+Jets Channel

- Kinematic mass fitter
  - Constrained fit, χ^2<9
- 2 jets b-tagged
  - Secondary vertex tagger



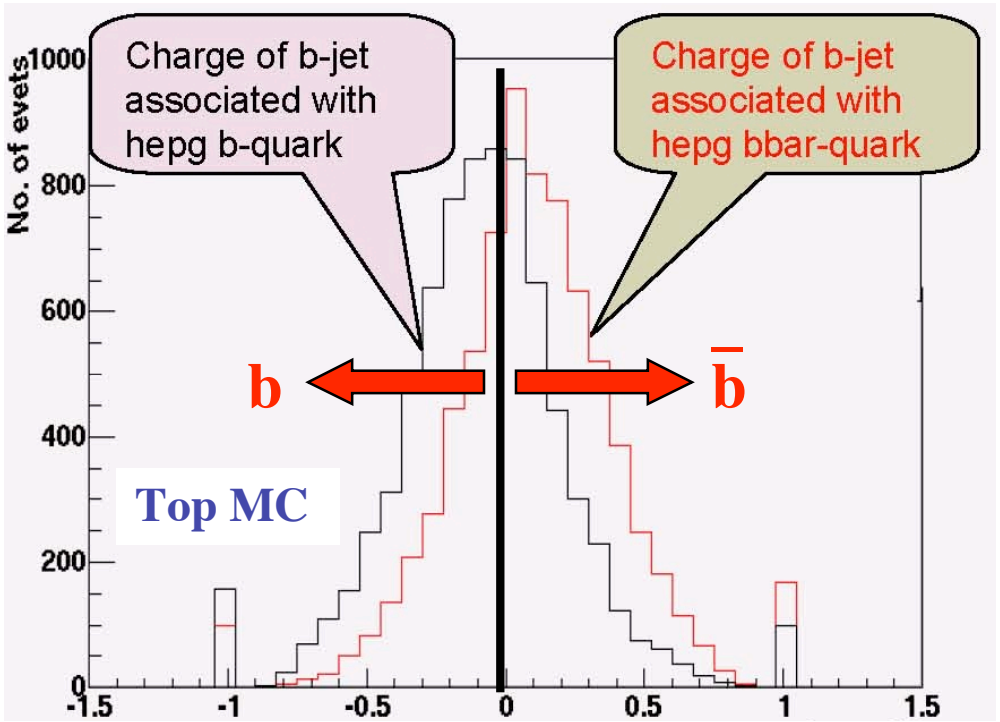


ε=63%, P=86%, εD²=0.33

b Flavor Tagging
Momentum Weighted Jet Charge

$$Q_{b-jet} = \frac{\sum_i q_i \cdot (\vec{p}_i \cdot \hat{a})^X}{\sum_i (\vec{p}_i \cdot \hat{a})^X}$$

$\hat{a}$ = jet axis, $\vec{p}_i$ = track momentum



- Use good silicon tracks with P_T>1.5 GeV
- Weight factor X = 0.5
- Require 2 b-jets have opposite sign (OS)

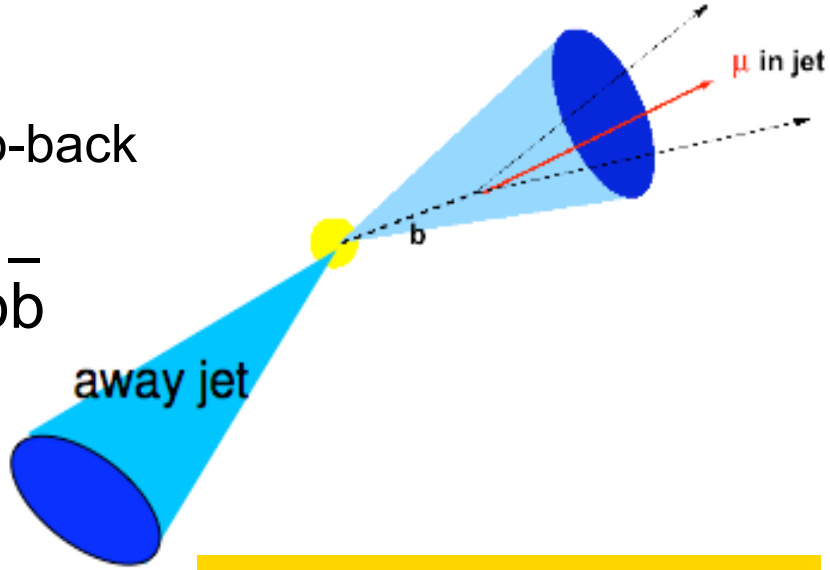
DIL → ε =42%, P=73%, εD^2=0.09

L+Js → ε =51%, P=73%, εD^2=0.11

Jet Charge Performance

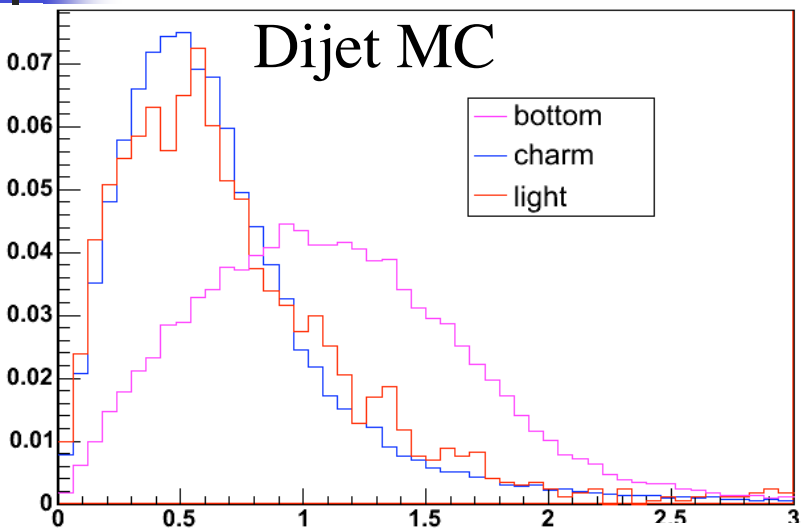
- Dijet data with:
  - Muon jet and away jet back-to-back
  - Both jets b-tagged
- Expect sign correlation for $b\bar{b}$
  - Opp. sign between jets
- Need to correct for:
  - $b \rightarrow c \rightarrow \mu$
  - Mixing

  } From MC
- Extrapolate in P_T and η from dijet to ttbar sample

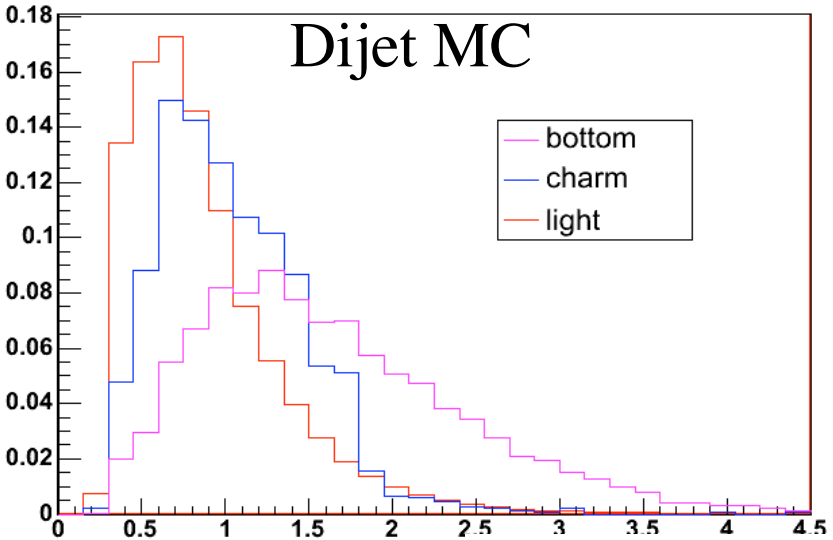


$$\textbf{\textit{Purity}} = \frac{N_{OS}}{N_{OS} + N_{SS}}$$

Getting $b\bar{b}$ Fraction

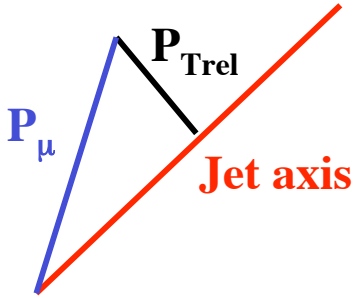


P_{Trel}



Vertex Mass

- Use P_{Trel} for b fraction of muon jet



- Use mass of secondary vertex tracks for b fraction of away jet

Backgrounds

- Is background more likely to mimic +2/3 or -4/3 events?
- If no bias, purity in background $p_b = 0.5$

	Backgrounds	N_b in 1 fb^{-1}	Is $p_b = 0.5$?	Measured Purity p_b
Lepton + Jets	W+HF	0.6±0.1	Yes Wbb, Wcc No for Wc	**0.52±0.01**
	QCD fakes	0.85±0.17	No	
	Diboson	0.05±0.14	Yes	
	Mistags	1.1±0.4	Yes	
Dilepton	Drell-Yan	4.5±1.2	Yes	**0.50±0.04**
	Fakes	1.4±0.5	Yes	
	Diboson	0.56±0.06	Yes	

Expectations with 1 fb^{-1}

Channel	Cross Section # S/B Events	After applying Wb pairing and b flavor tagging			
		# Signal N_s	# Bckg N_b	Signal Purity p_s	Bckg Purity p_b
Lepton + Jets	87.6 / 26.4	26.5±3.3	2.7±0.2	0.689	0.52±0.01
Dilepton	48.1 / 23.7	9.4±1.2	6.4±1.3	0.702	0.50±0.04
TOTAL	135.7 / 50.1	**35.4±3.5**	**9.1±1.3**	**0.693**	**0.51±0.05**

Top MC Ideal case

- Top MC signal purity p_s ~ 70%
- Dijet MC signal purity p_s ~ 65%
- Dijet data signal purity p_s ~ 60%

Statistical Treatment

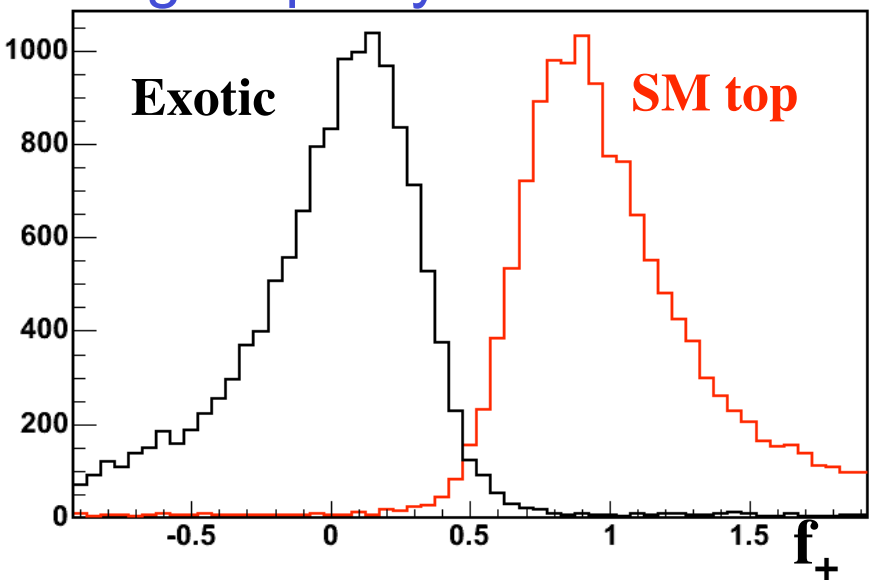
- Exclude the exotic -4/3 (or SM +2/3) model to X% C.L.
  - Investigating Binomial and Profile Likelihood methods
- What is the probability of observing N_+ and N_- events in data given the fraction, f_+, of true +2/3 events

  SM Top $f_+=1$ Exotic case $f_+=0$
- Sensitivity studies using the Profile Likelihood method
  - Frequentist approach with multiple nuisance parameters
    - $N_s \pm \sigma_{Ns}$, $p_s \pm \sigma_{ps}$, $N_b \pm \sigma_{Nb}$, $p_b \pm \sigma_{pb}$
  - Scan over fraction of true +2/3 events (f_+) fitting for nuisance parameters to get minimum likelihood

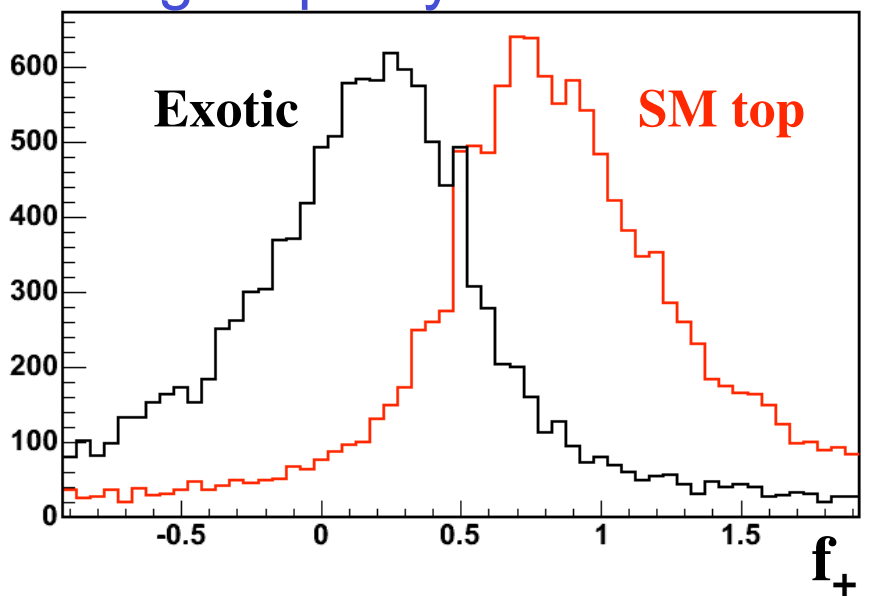
Sensitivity Studies

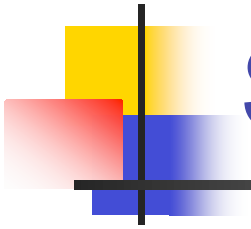
- Not sensitive to # N_b or purity p_b of background
- Strong dependence on signal purity p_s

Signal purity = 69.3±15%



Signal purity = 60±15%





Summary and Plans

- CDF measuring charge of top quark in Dilepton and Lepton+Jets channels
- Finalizing work on understanding purity in signal and statistical treatment
- Plan to have result for winter conferences using >1 fb-1 of data
- Already looking into possible improvements for larger data samples
  - Add b-tags to dileptons reduces background<5%
  - Add alternative b-tagging algorithms

Backup Slides

Expectations for 1 fb^{-1}

background	*prediction*	*efficiency*	N_b	*measured asymmetry*	*used asymmetry*	N_+	N_-
Lepton + Jets							
W+HF	7.2 ± 0.4	0.08 ± 0.01	0.6 ± 0.1	0.43 ± 0.07	0.5 ± 0.0	0.3 ± 0.05	0.3 ± 0.05
QCD fakes	6.5 ± 1.2	0.13 ± 0.01	0.85 ± 0.17	$0.538^{+0.006}_{-0.04}$	-	$0.455^{+0.091}_{-0.097}$	$0.390^{+0.083}_{-0.085}$
Diboson	0.5 ± 0.02	0.091 ± 0.025	0.046 ± 0.14	0.58 ± 0.14	0.5 ± 0.0	0.02 ± 0.07	0.02 ± 0.07
Mistag	10.8 ± 1.0	0.099 ± 0.035	1.07 ± 0.37	0.43 ± 0.19	0.5 ± 0.0	0.54 ± 0.19	0.54 ± 0.19
Singletop	1.39 ± 0.29	0.129 ± 0.014	0.18 ± 0.06	0.59 ± 0.06	-	0.106 ± 0.044	0.07 ± 0.03
Total	26.39 ± 1.64	-	2.74 ± 0.20	0.52 ± 0.12	-	1.42 ± 0.23	1.33 ± 0.23
Signal (tt)	87.56		25.99	0.69 ± 0.09		17.91	8.08
Dilepton							
Drell-Yan	12.57 ± 3.17	0.36 ± 0.03	4.46 ± 1.19	0.47 ± 0.04	0.5 ± 0.0	2.23 ± 0.595	2.23 ± 0.595
Fakes	6.29 ± 1.53	0.23 ± 0.05	1.41 ± 0.47	0.52 ± 0.07	0.5 ± 0.0	0.705 ± 0.245	0.705 ± 0.245
Diboson	4.84 ± 0.45	0.115 ± 0.006	0.56 ± 0.06	0.51 ± 0.02	0.5 ± 0.0	0.28 ± 0.03	0.28 ± 0.03
Total	23.7 ± 3.55	-	6.43 ± 1.28	0.5 ± 0.16	-	3.215 ± 0.644	3.215 ± 0.644
Signal (tt)	48.12		9.42	0.70 ± 0.15		6.62	2.8

Profile Likelihood

Profile Likelihood

$$\lambda(f_{+0},\theta|X)=\frac{max((L(f_{+0},\theta)|X);\theta)}{max((L(f_{+},\theta)|X);f_{+},\theta)}$$

f_+ = parameter of interest

fraction of true +2/3 events(=

θ = nuisance parameters

purities, backgrounds

Data: X =(N_+,N_-)

- Not a func. of nuisance parameters
- -2logλ is an approx. χ^2 dist. with 1 dof

- L has 5 parts - L_s: Poisson(sig+bg), L_θ: Gaussian(θ,σ)
- Nuisance parameters are $N_s \pm \sigma_{Ns}$, $p_s \pm \sigma_{ps}$, $N_b \pm \sigma_{Nb}$, $p_b \pm \sigma_{pb}$
- Scan in f_+ and fit for nuisance parameters at each point