Studies of the top quark at DØ

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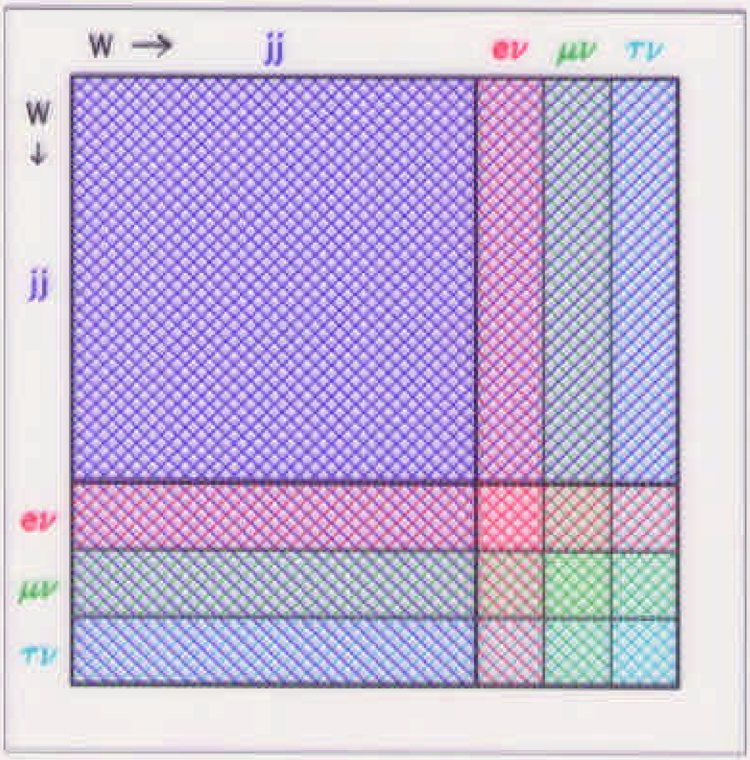
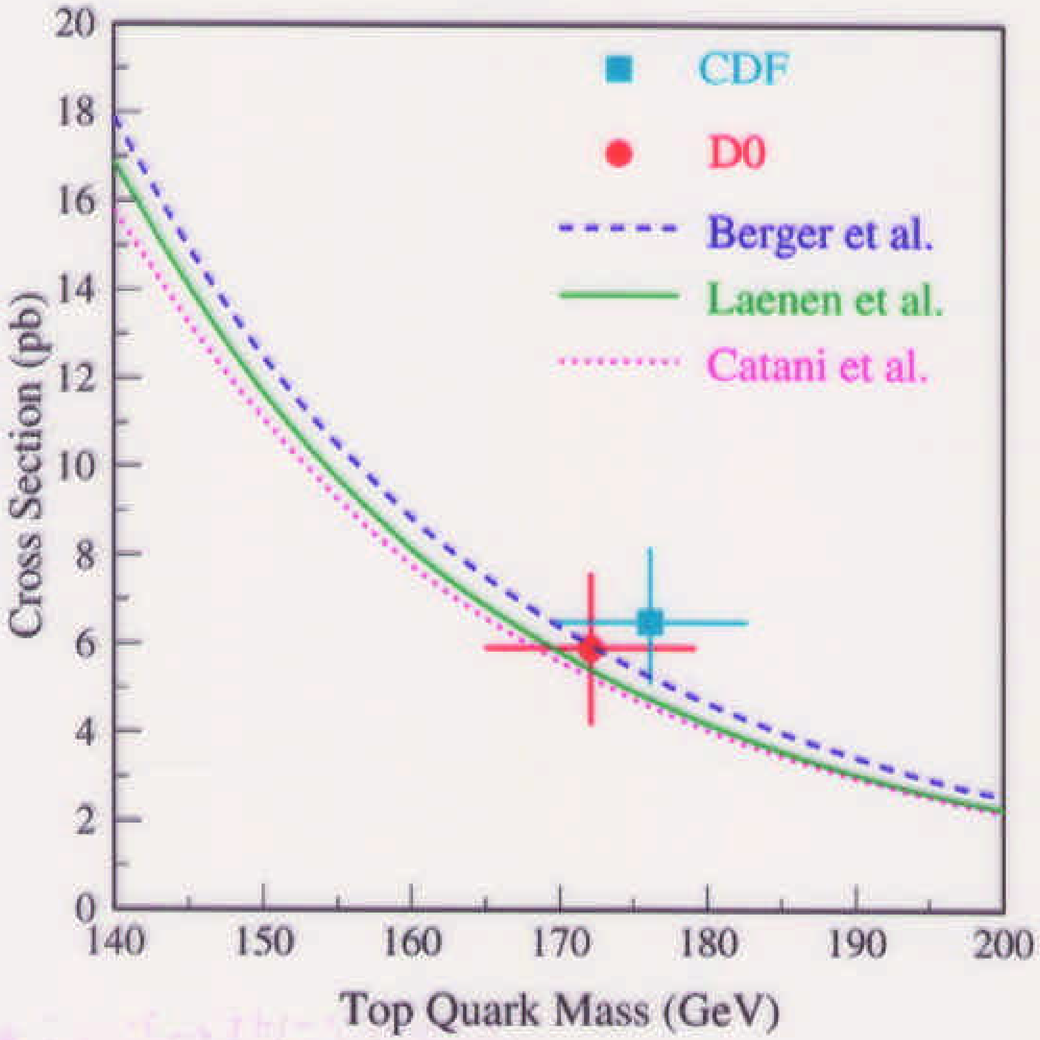
Introduction

- At Tevatron, top quarks are mainly produced in pairs: $q\bar{q} \rightarrow t\bar{t}$ or $gg \rightarrow t\bar{t}$
- SM $\Rightarrow B(t \rightarrow W^{+}b) = 1$
- $B(W \rightarrow e\nu_e) = B(W \rightarrow \mu\nu_\mu) = B(W \rightarrow \tau\nu_\tau) = \frac{1}{9}$
  $B(W \rightarrow u\bar{d}) = B(W \rightarrow c\bar{s}) = \frac{1}{3}$
- $t\bar{t}$ decay modes are characterized as "dilepton", "single lepton", or "all jets"



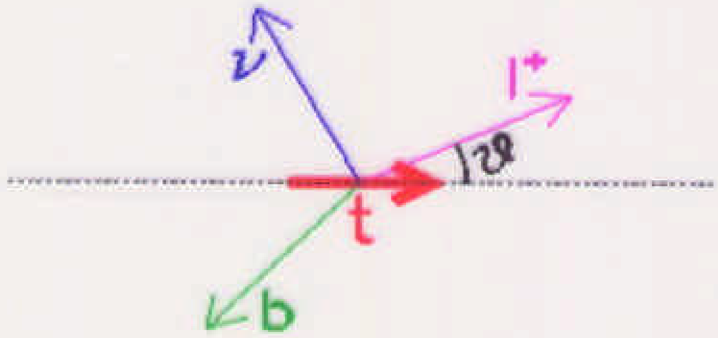
Measurements of top mass and pair production cross section



	DØ	CDF	DØ +CDF
m_t (GeV)	172.1 ± 7.1	176.1 ± 6.6	174.3 ± 5.1
$\sigma(t\bar{t})$ (pb)	5.9 ± 1.7	$6.5^{+1.7}_{-1.4}$	?

Top-antitop spin correlation

- In $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, 90% of top-antitop pairs are produced by $q\bar{q}'$ annihilation via spin-1 gluon.
- SM $\Rightarrow$ $\tau_t \ll$ top hadronization timescale $\ll t\bar{t}$ spin decorrelation timescale $\Rightarrow$angular correlations among decay products should reflect that between t and $\bar{t}$ spin states.
- Direct probe to properties of a bare quark, free of QCD long-distance effects.

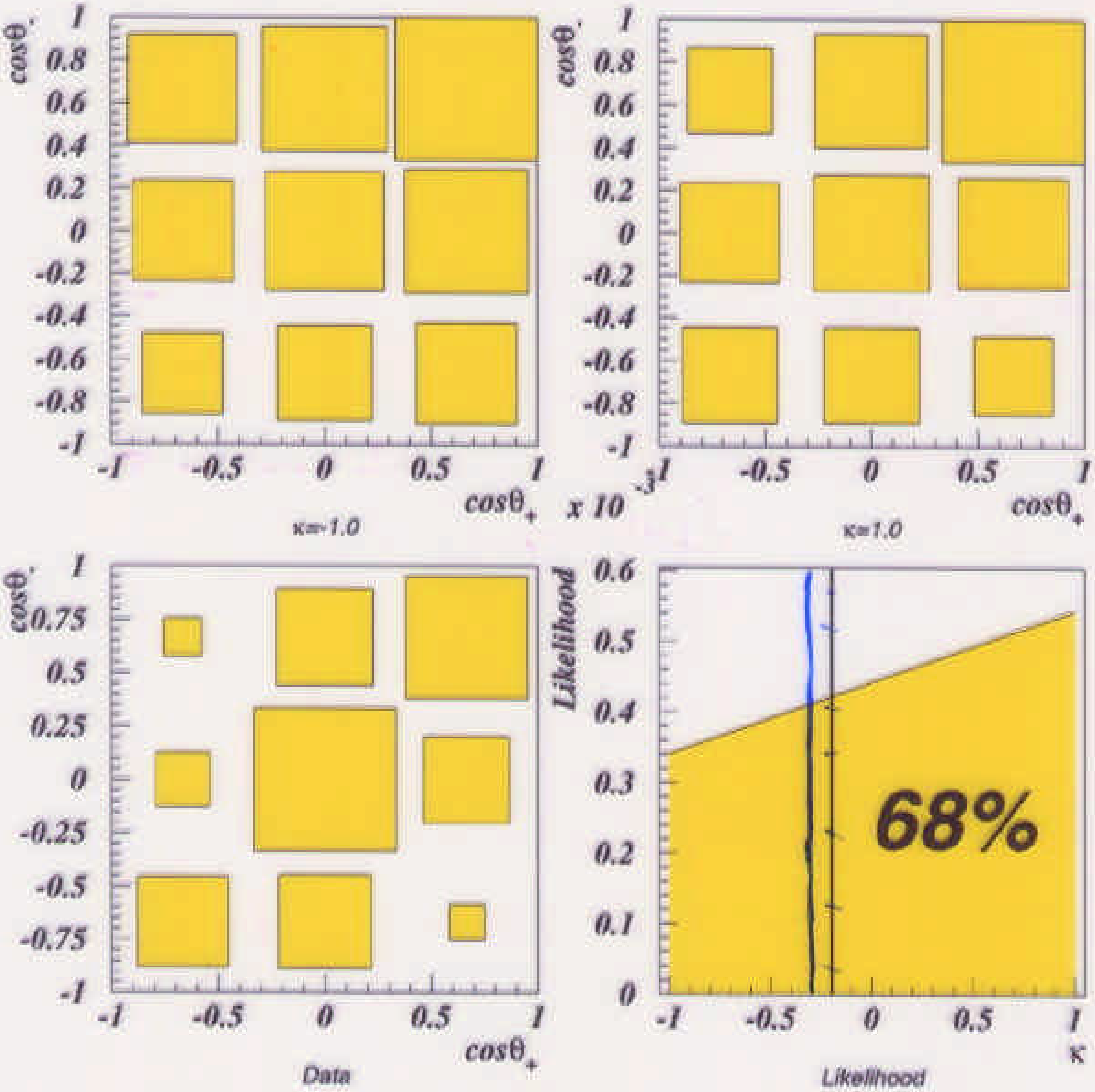


- For $t\bar{t} \to l^+l^-X$ events,

$$\frac{1}{\sigma}\frac{d^2\sigma}{d(\cos\theta_+)d(\cos\theta_-)} = \frac{1+\kappa\cos\theta_+\cos\theta_-}{4} \quad (1)$$

- At Tevatron with $\sqrt{s} = 1.8$ TeV, $\kappa \approx 0.9$.

- Event selection and reconstruction are same as dilepton mass analysis.
- Binned 2D likelihood fit to data using templates for $\kappa = -1.0$, $\kappa = 1.0$ and background $\Rightarrow \kappa > -0.25$ at 68% C.L.



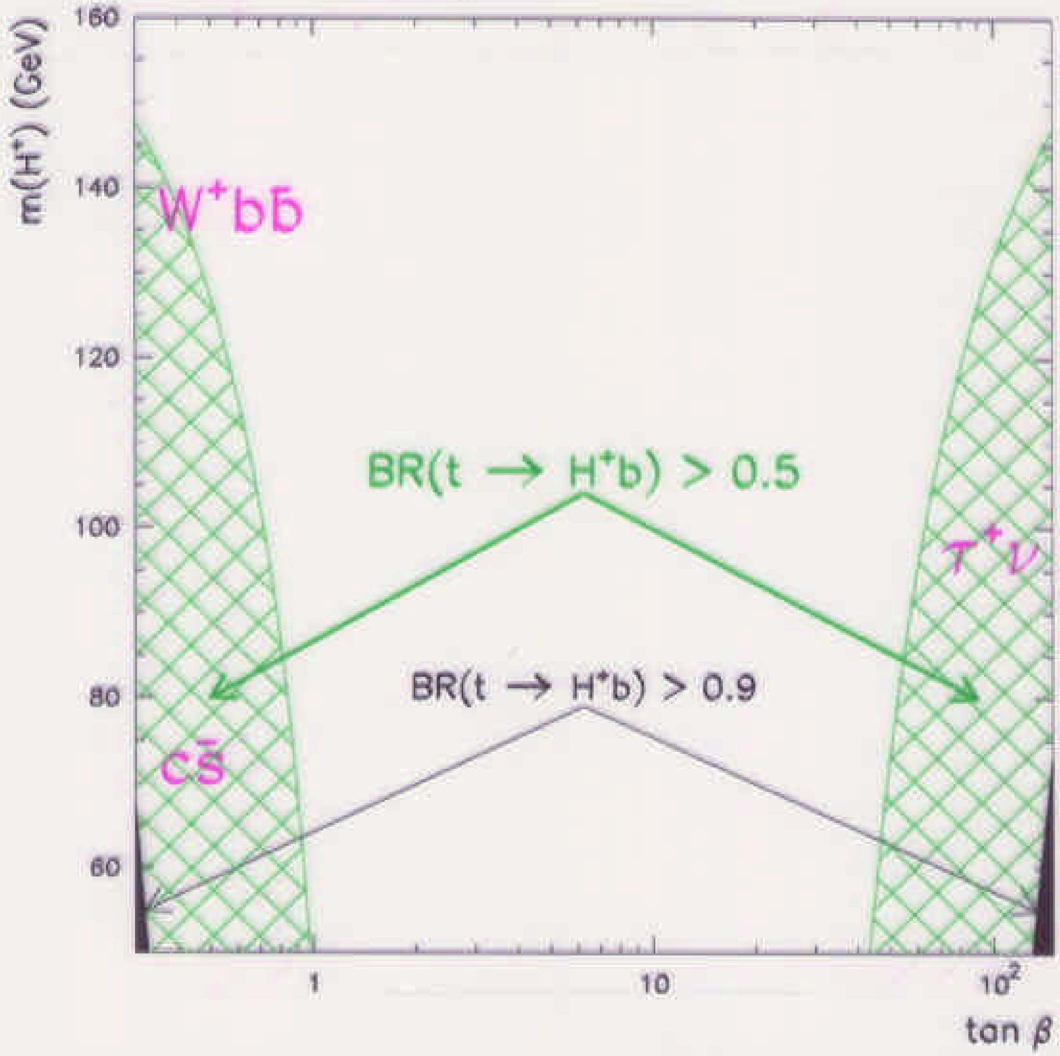
Search for $t \to H^+b$

- The Standard Model has one complex Higgs doublet.
  - Results in one physical Higgs boson: H^0.
- Simplest extension to the SM $\Rightarrow$ two-Higgs-doublet models (2HDM).
  - Results in five physical Higgs bosons: H^0, h^0, A^0, H^+, H^-.
  - and two additional parameters: $\tan\beta$, m_{H^+} (or m_A).

    $\tan\beta \equiv$ ratio of V.E.V.'s of the two doublets
- A 2HDM is an integral feature of SUSY.
- If $m_{H^+} < m_t - m_b$, then $t \to H^+b$ can compete with $t \to W^+b$.

Charged Higgs production and decay

- BR($t \to H^+b$) is significant for small m_{H^+} and either large or small $\tan\beta$.
- 3 decay modes for H^+:
  - $H^+ \to c\bar{s}$
  - $H^+ \to t^*\bar{b} \to W^+b\bar{b}$
  - $H^+ \to \bar{\tau}\nu_\tau$

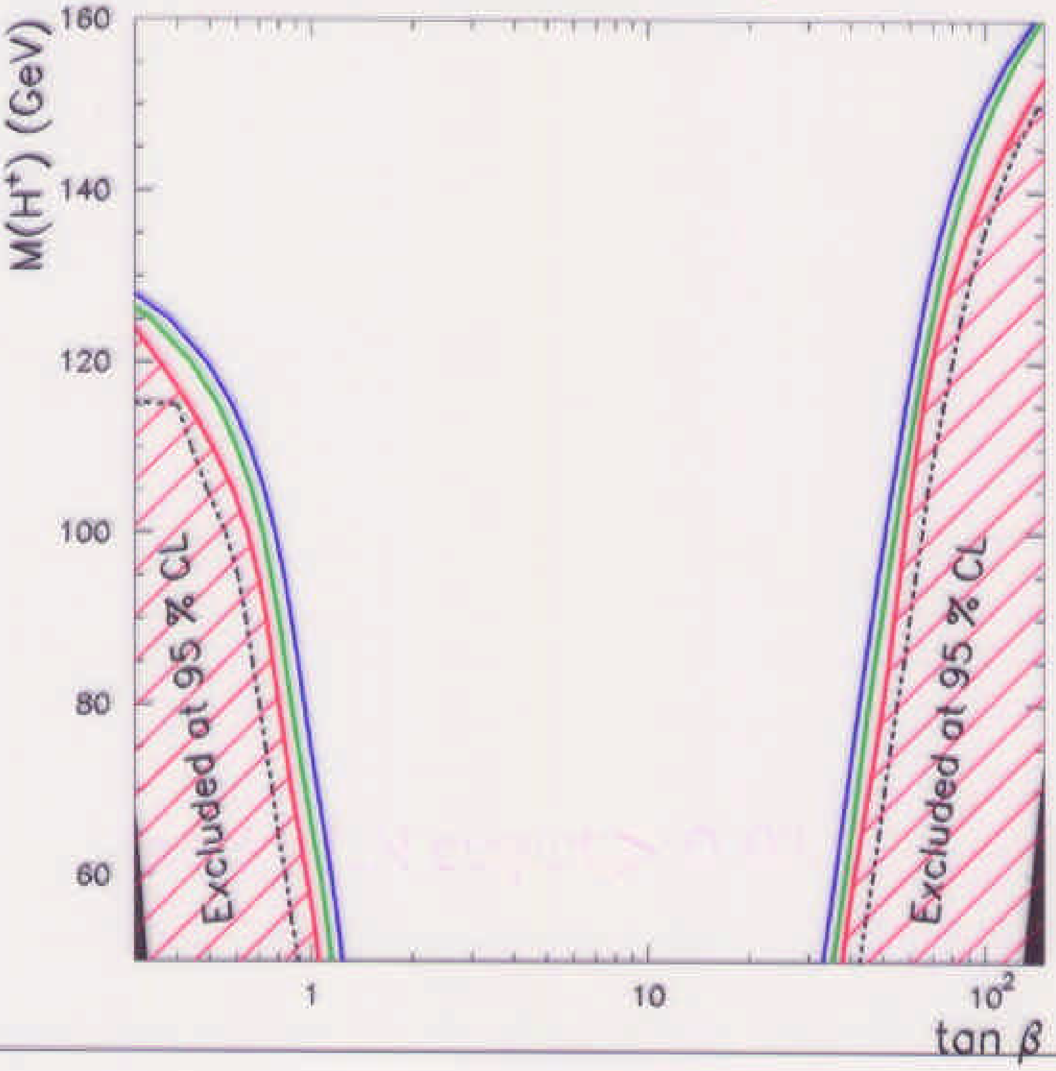


$t \to H^+b$

Indirect (disappearance) search

Selection criteria optimized for $t\bar{t} \to W^+bW^-\bar{b}$ have a lower efficiency for $t\bar{t} \to H^+X$. Hence, the number of events expected to pass those criteria decreases as $B(t \to H^+b)$ increases. Based on n_{obs}, we can thus put an upper limit on $B(t \to H^+b)$.

$\sigma(t\bar{t})$ = 5.5, 5.0, 4.5 pb

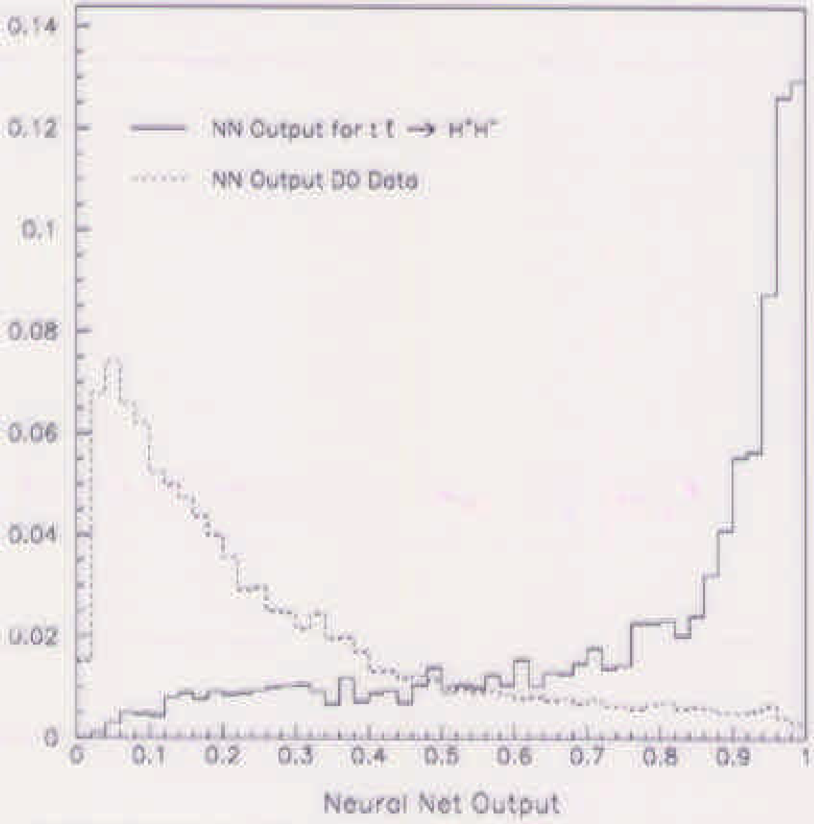


Direct (appearance) search

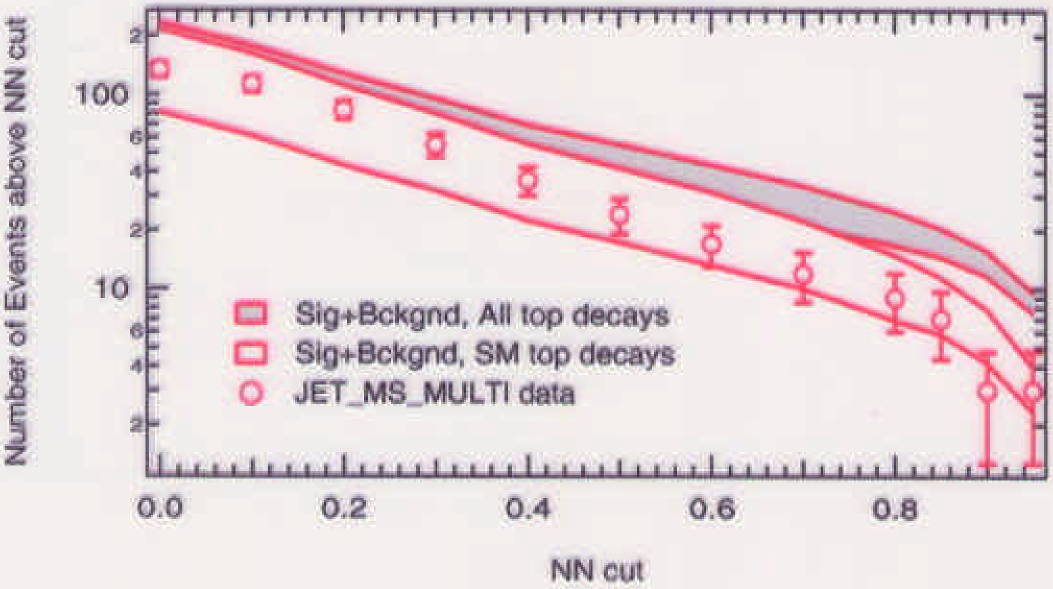
Search strategy:

- Search for $t\bar{t} \rightarrow H^+X$; $H^+ \rightarrow \bar{\tau}\nu_\tau$ through hadronic decays of τ.
- Most often, a signal event will have 4 or more jets (2 b's, 1 or 2 τ's, 2 or 0 light quarks, gluon(s) from ISR/FSR) and multiple neutrinos ⇒trigger: 4 jets + $\not\!\!E_T$ ($\int \mathcal{L}dt = 62 \pm 3$ pb^{-1})
- Background:
  - $W+$ jets (modeled by VECBOS)
  - QCD (fake τ, $\not\!\!E_T$; modeled by data)
- Loose selection:
  - $\not\!\!E_T > 25$ GeV
  - ≥ 4 jets, $E_T > 20$ GeV, $|\eta| < 2.5$
- Tight selection: a Neural Network analyzes $\not\!\!E_T$, and eigenvalues of the normalized momentum tensor.
  Require NN output > 0.91
- ≥ 1 jet, $E_T < 60$ GeV, $|\eta| < 0.9$, must pass τ id (mostly based on jet shape)

Before τ id requirement

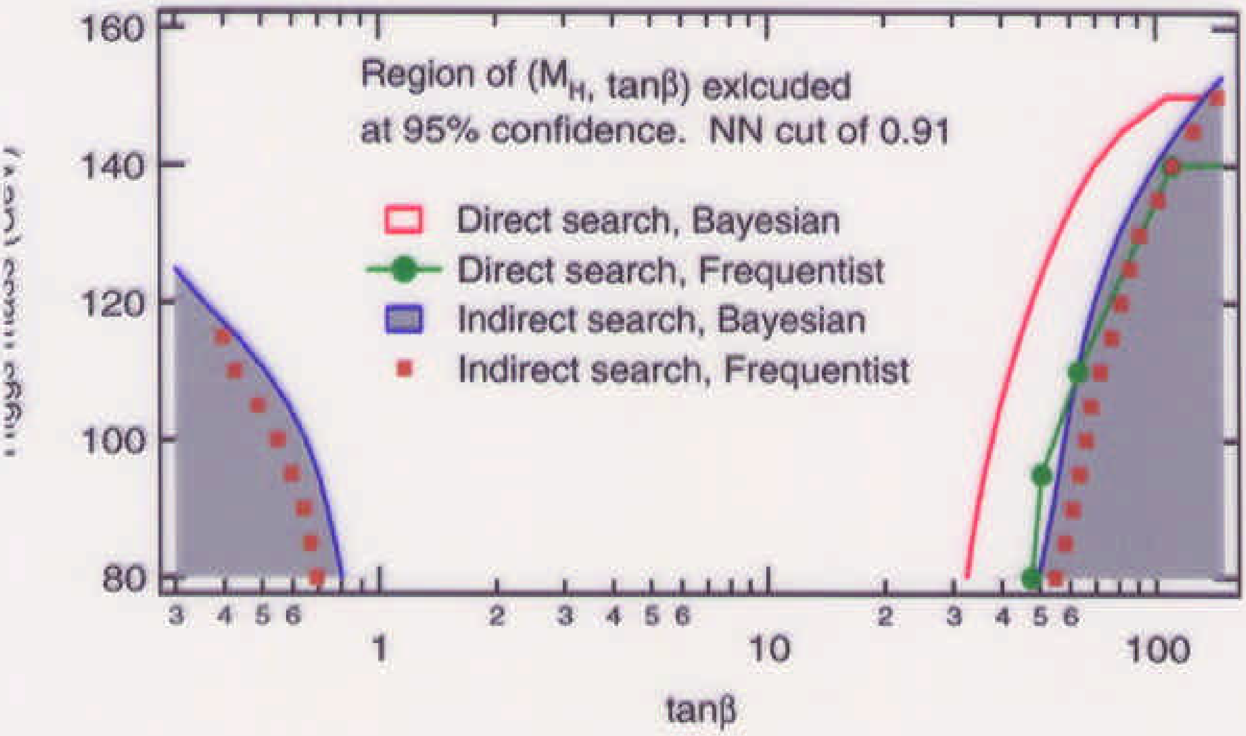


After τ id requirement

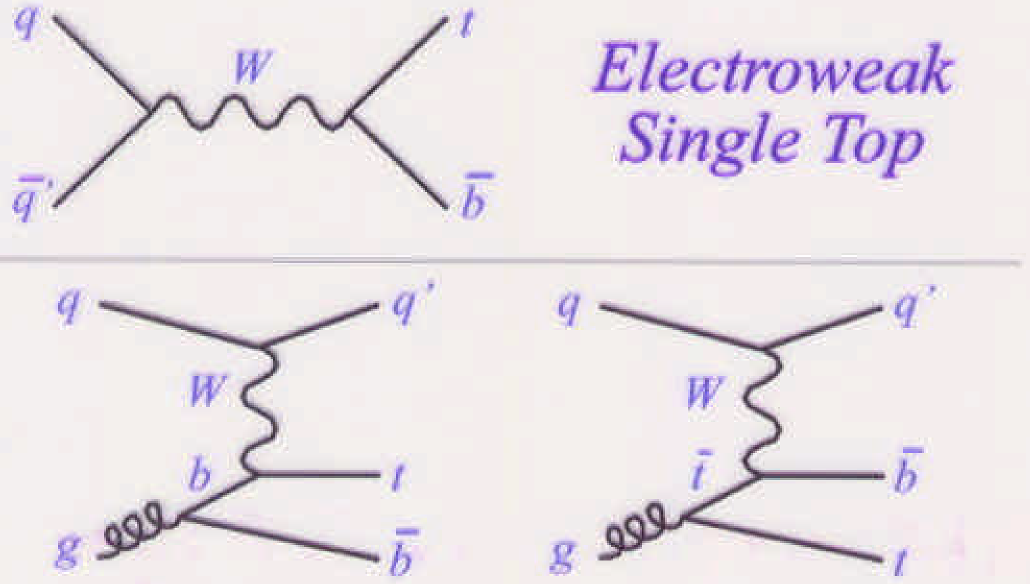


Result

Source	(Expected) $n_{\rm evt}$
W+jets	0.9 ± 0.3
QCD	3.2 ± 1.5
SM $t\bar{t}$	1.1 ± 0.3
Max signal	$\sim 16 \pm 2$
SM total	5.2 ± 1.6
Data	3



Search for electroweak production of (single) top quark



Electroweak Single Top

- Measurement of single top production processes could provide the magnitude of the CKM matrix element V_{tb}, since the cross sections are proportional to $|V_{tb}|^2$.
- SM (NLO, $m_t = 175$ GeV, $\sqrt{s} = 1.8$ TeV):

$$\sigma(q'\bar{q}) \rightarrow t\bar{b}) = 0.73 \pm 0.04 \text{ pb}$$

$$\sigma(q'g) \rightarrow tqb) = 1.70 \pm 0.19 \text{ pb}$$

Search strategy:

- SM $\Rightarrow B(t \rightarrow W^+b) \approx 1$
- Search for $W \rightarrow \ell\nu$ ($\ell = e/\mu$, $B = 0.11$ for each)
- Large background $\Rightarrow$attempt to identify at least one b jet (through semileptonic decays containing a non-isolated muon, $\epsilon \times B \approx 0.09$)
- Final states:
  - tb: ℓ, $\not\!\!E_T$, two high-p_T central jets (b), at least one with a μ tag.
  - tqb: ℓ, $\not\!\!E_T$, one high-p_T central jet (b), one low-p_T central jet (b), one high-p_T forward jet (light quark). At least one jet is required to have a μ tag.
- Background:
  - W+jets
  - $t\bar{t}$
  - QCD (fake/misclassified leptons + $\not\!\!E_T$)

Event selection:

- Triggers:
  - Electromagnetic cluster + jet + $\not\!\!E_T$
  - OR Muon + jet/MEt

  (10^6 events in each channel).

- Offline step 1:
  - e: $E_T > 20$ GeV,
    $|\eta_D| < 1.1$ or $1.1|\eta_D| < 1.5$.
  - OR μ: $p_T > 20$ GeV, $|\eta_D| < 1.7$.
  - ≥ 2 jets: $E_T > 5$ GeV, $|\eta_D| < 4.0$.
  - Tagging μ: $p_T > 5$ GeV, $|\eta_D| < 1.7$.

  (116 $e+$ jets/μ, 110 $\mu+$ jets/μ events).

- Offline step 2:
  - Electron channel:
    - $E_T(j1) + E_T(j2) + E_T(e) + \not\!\!E_T > 125$ GeV
    - $E_T(j3) + 5 \times E_T(j4) < 47$ GeV
    - $E_T(j1) + 4 \times \not\!\!E_T > 155$ GeV
  - Muon channel:
    - $\sum E_T(j) > 70$ GeV
    - $E_T(j3) + 5 \times E_T(j4) < 47$ GeV

Single top

Number of events from signal, background and data ($\int \mathcal{L}dt \approx 90 \pm 4$ pb^{-1}):

source	Electron channel	Muon channel
tb	0.18 ± 0.03	0.08 ± 0.01
tqb	0.28 ± 0.05	0.13 ± 0.03
W+jets	5.59 ± 0.64	1.12 ± 0.17
QCD	5.92 ± 0.58	0.40 ± 0.09
$t\bar{t}$	1.14 ± 0.35	0.45 ± 0.14
Total bkg	12.65 ± 0.93	1.97 ± 0.24
Data	12	5

Result

95% CL upper limits:

- $\sigma(p\bar{p} \rightarrow tb + X) < 39$ pb
- $\sigma(p\bar{p} \rightarrow tqb + X) < 58$ pb
- $\sigma(p\bar{p} \rightarrow tb, tqb + X) < 52$ pb

Future Prospects

- Run 2 of the Tevatron to begin on March 1, 2001.
- $\sqrt{s} = 1.8$ TeV $\rightarrow$ 2.0 TeV
  $\Rightarrow\sim$ 40% increase in $\sigma(p\bar{p} \rightarrow t\bar{t})$
  (similarly for $\sigma(p\bar{p} \rightarrow tb/tqb)$)
- $\int \mathcal{L}dt = 0.1$ fb$^{-1} \rightarrow 2$ fb^{-1}
- Detctor upgrade $\Rightarrow$improved resolution, particle id:
  - Electron (magnet, fiber tracker, preshower)
  - Muon (magnet, fiber tracker)
  - b (silicon tracker, e-tag)
  - τ (magnet, fiber tracker, preshower)
  - jet
- Expected yield improvement factor over Run 1:
  $t\bar{t}$: 50-100, single top: $\sim$ 200

Run 2

Measurements

Quantity	fractional uncertainty	
	Run 1	Run 2
m_t	0.03	< 0.02
$\sigma(p\bar{p} \to t\bar{t})$	0.3	< 0.1
$\sigma(p\bar{p} \to tb/tqb)$	?	$\sim 0.3\%$
$B(t \to W_0 b)$	?	0.06
$\Gamma(t \to W^+ b)$	?	0.25
$\lvert V_{tb} \rvert$	?	0.15
κ (spin correlation)	?	0.4

Searches

Quantity	upper limit	
$B(t \to H^+ b)$	~ 0.4	< 0.12
$B(t \to cZ)$	?	< 0.015
$B(t \to c\gamma)$	?	< 0.0025
$\sigma(Z')B(Z' \to t\bar{t})$	?	90 fb

Anomalies may lead to new physics!

Summary

- Using $\sim 110\,\mathrm{pb}^{-1}$ of data collected from Run 1 of the Fermilab Tevatron, DØ has studied several aspects of top physics beyond measurements of its pair-production cross section and mass.
- Two independent searches for charged Higgs bosons in decays of pair-produced top quarks result in exclusion of a large part of the $[m_{H^+}, \tan\beta]$ parameter space.
- Within large statistical uncertainties, top-antitop spin correlation agrees well with the SM predictions.
- Search for electroweak production of single top quarks puts upper limits on cross section consistent with the SM.
- Vast improvements in current results, and many interesting new results, are expected from Run 2, to begin in Spring, 2001.