SINGLE TOP and TOP PROPERTIES

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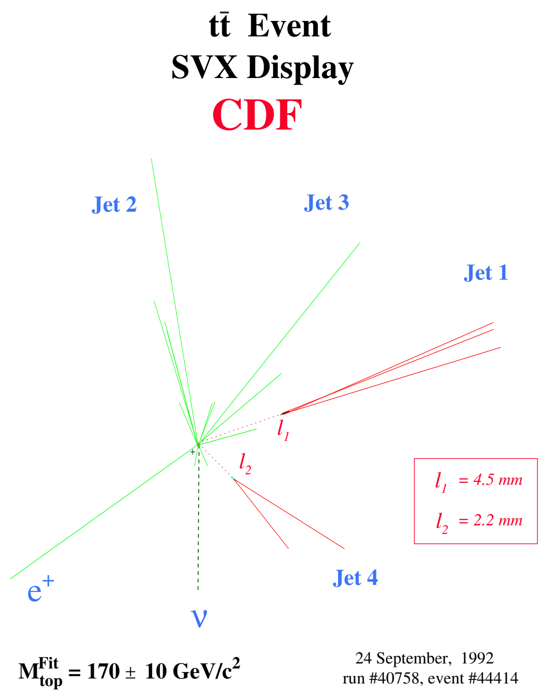
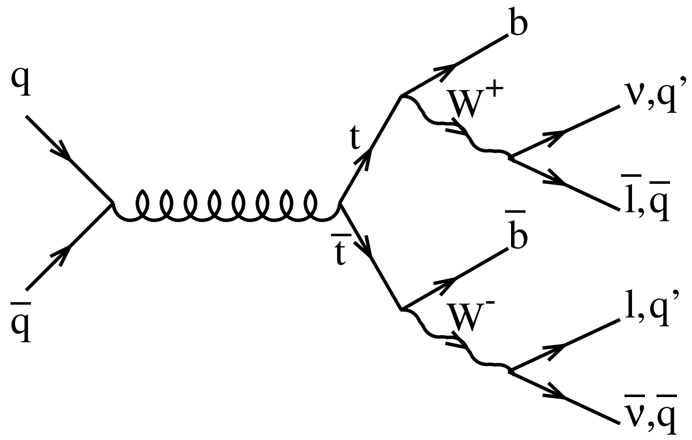


Introduction

Top Quark Production and Decay

Top pairs are produced 90% of the time via a $q\overline{q}$ diagram

$$p\overline{p} \to t\overline{t}$$



Within the SM top decays into W+b $\sim$ 100% of the time.

$W^+ \to$	$e^+\nu$	$\mu^+\nu$	$\tau^+\nu$	$u\overline{d}$	$c\overline{s}$
Br	1/9	1/9	1/9	3/9	3/9

Event topologies are:

- Dilepton Channel ($\ell\nu\ell\nu b\overline{b}$), 5%
  - both W's decay into e *or* μ (τ is separate)
- Lepton+jet Channel ($\ell\nu q\overline{q}b\overline{b}$), 30%
  - one W decays into e *or* μ
- All-hadronic Channel ($q\overline{q}q\overline{q}b\overline{b}$), 44%
  - both W's decay into quarks pairs

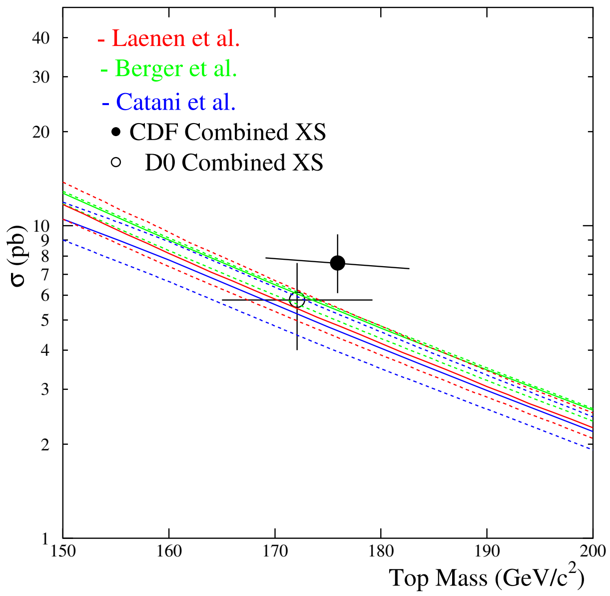
A few hundred top events have been detected in the D0 and CDF experiments in Run I (106 pb^{-1}).
CDF has observed:

Sample	$a \times \epsilon$	Events	Background
Dileptons	0.0074	9	2.4
ℓ+jets (SVX tag)	0.037	34	9.2
ℓ+jets (SLT tag)	0.017	40	22.6
W + 4jets(no-tag)	n.a.	42	23.5
W + 4jets(loose jet4)	n.a.	163	115
All-Hadr (1 SVX)	0.044	187	142

$a \times \epsilon$ = acceptance $\times$ efficiency.
E_T(lepton) > 20 GeV $\not{E}_T$ > 20 GeV
Jets: calor. clusters with E_T > 15 GeV, R(cone)=0.4.

In Run II expect a factor 40 more data in most channels.

Run I Cross section measurement by both CDF and D0:



Direct Top mass measurements were also made
Combined CDF and D0 $M_{top} = 174.3 \pm 5.1$ GeV/c^2

Standard Model Implications

Measurement tests SM beyond tree level

Ultimately $\rightarrow$ constrain Higgs Mass

$\rightarrow$ indicate physics beyond SM

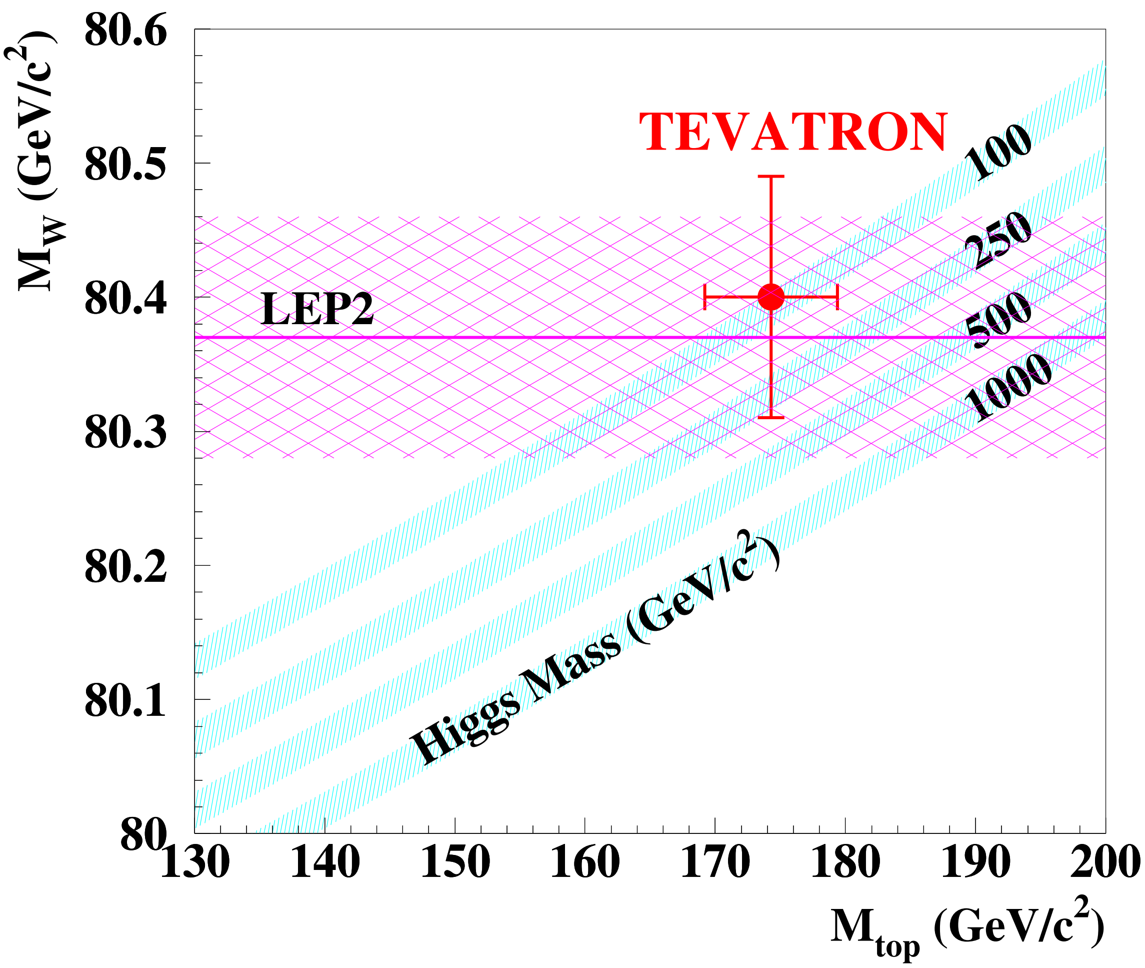
CDF + D0 average $M_t = 174.3 \pm 5.1$ GeV

CDF + D0 average $M_W = 80.400 \pm 0.090$ GeV

LEP2 average $M_W = 80.370 \pm 0.090$ GeV

World average $M_W = 80.345 \pm 0.055$ GeV.

$\rightarrow \Delta M_{top} \sim 5$ GeV $\equiv \Delta M_W \sim 40$ MeV

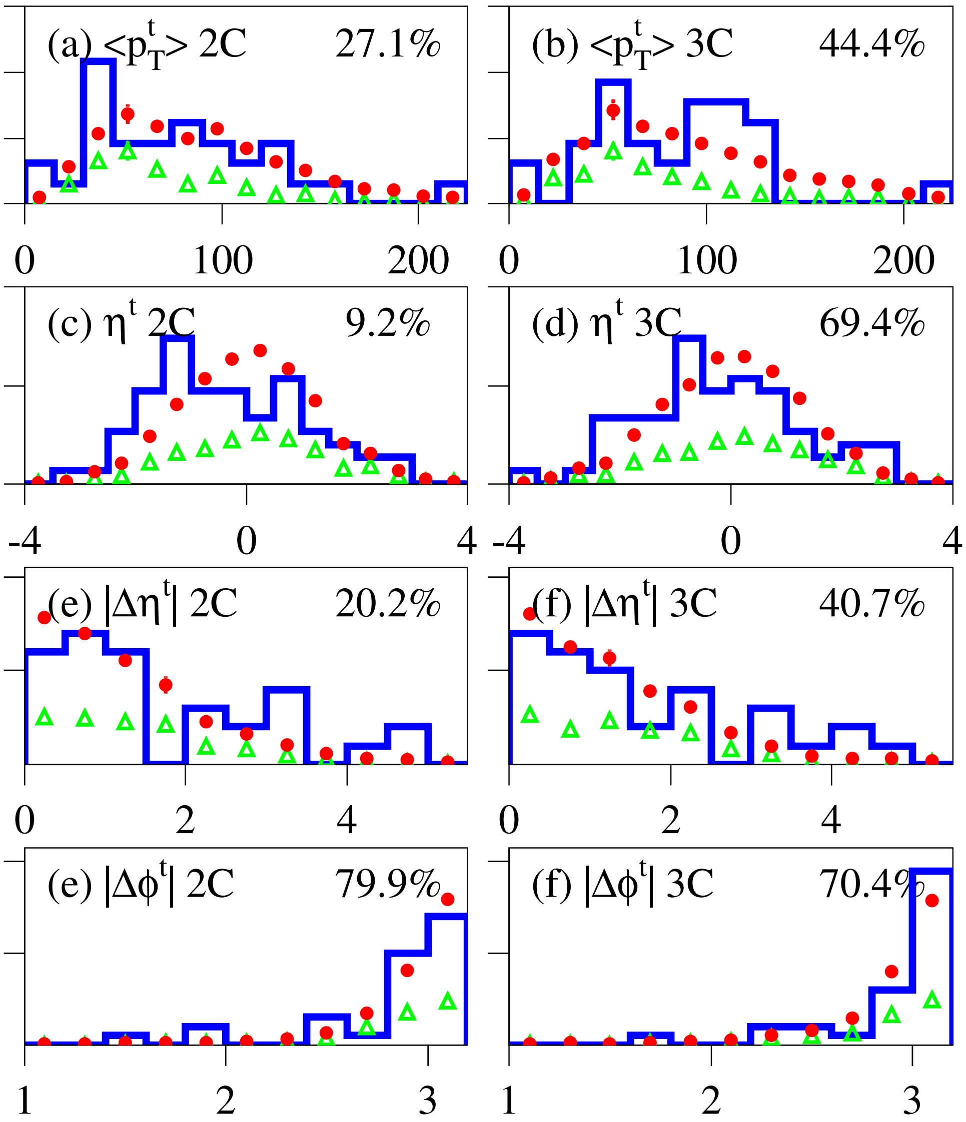


Top Pair Production

$t\bar{t}$ Kinematics (D0)

Constrained fit to events like $p\bar{p} \rightarrow t\bar{t} + X = W + \geq 4$ Jets yield information on top production variables.

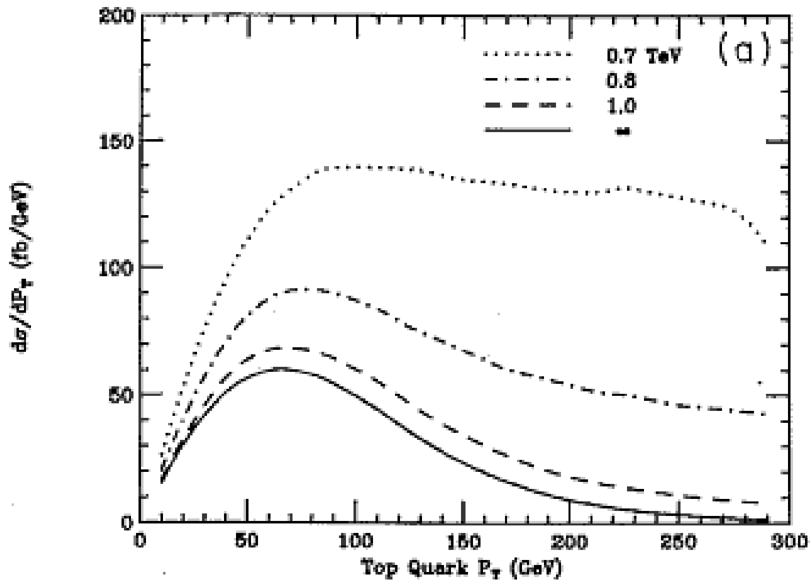
Agreement of data with $t\bar{t}$ HERWIG MC and VECBOS background is good



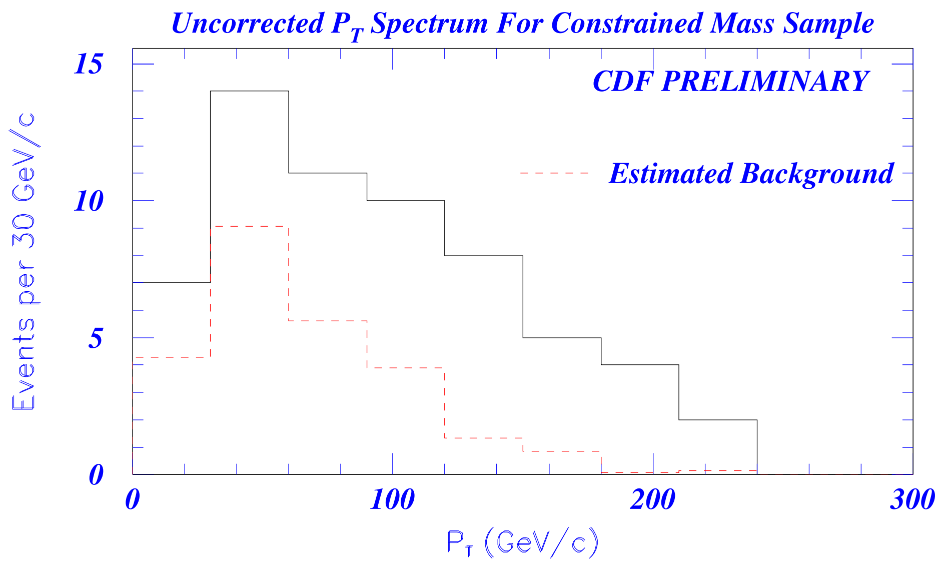
Top P_T in $t\bar{t}$ Production (CDF)

Can we rule out models with large top P_T?

Example: Hill and Park topcolor model with a Z' with strong coupling to top quark. Z' $\rightarrow t\bar{t}$.



Use top mass kinematic fitting with M_{top} fixed at 175 GeV/c^2. After the requirement $\chi^2 > 10$, 61 events remain with a background of 24.6 ± 5.8 events.

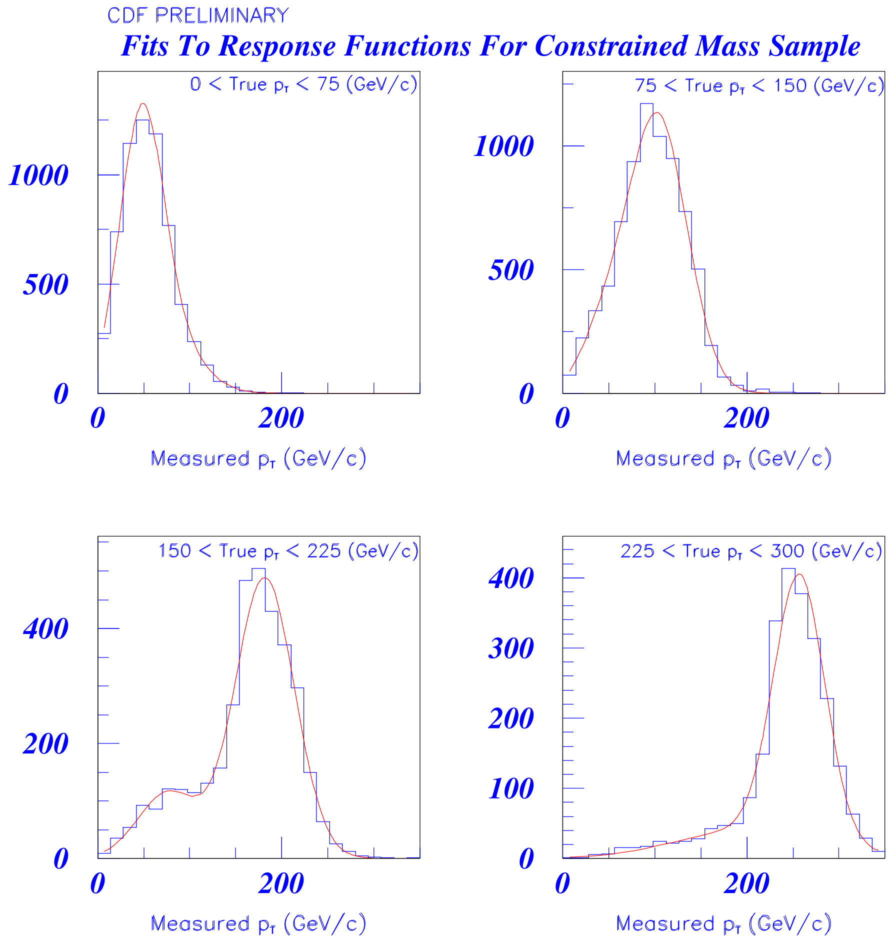


To extract P_T spectrum of produced top quark, unfold for resolution smearing and correct for acceptance as a function of P_T.

Use four bins of "true" top P_T. Obtain response functions from HERWIG Monte Carlo plus detector simulation. Use VECBOS for background.

Unbinned likelihood fit to response functions for $t\bar{t}$ and background.

Use iterative technique to minimize assumptions about shape of P_T spectrum within each bin.

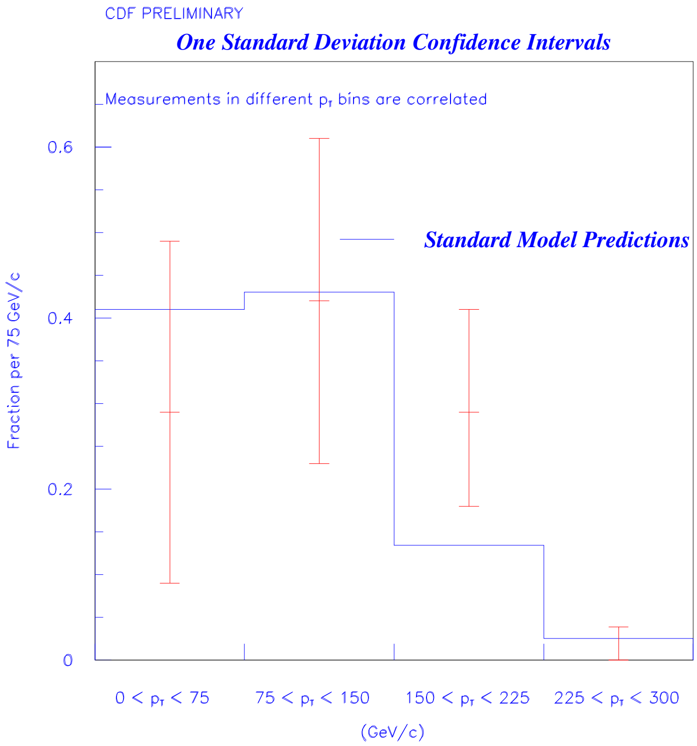


Include systematic uncertainties for each bin from different sources: M_{top} value, jet E_T scale, gluon radiation, background shape, acceptance.

Obtain limit for R_4, i.e., fraction of events in top P_T in 225-300 GeV/c bin.

Top Quark Differential Cross Section

$$\begin{aligned} R_1 + R_2 &= 0.72^{+0.13}_{-0.13}(\text{stat})^{+0.06}_{-0.06}(\text{syst}) \\ R_4 &< 0.114 \text{ at } 95\% \text{ C.L.} \end{aligned}$$

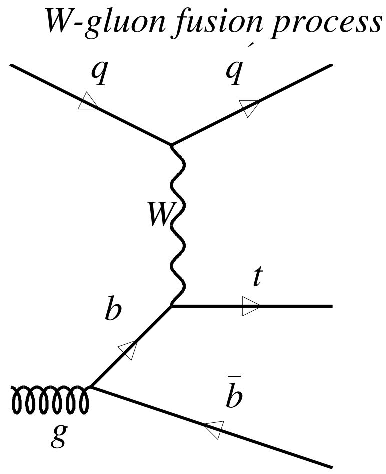


p_T Bin	Measured Fraction of Top Quarks
$0 < p_T < 75$ GeV/c	$R_1 = 0.29^{+0.18}_{-0.18}(\text{stat})^{+0.08}_{-0.08}(\text{syst})$
$75 < p_T < 150$ GeV/c	$R_2 = 0.42^{+0.18}_{-0.18}(\text{stat})^{+0.05}_{-0.07}(\text{syst})$
$150 < p_T < 225$ GeV/c	$R_3 = 0.29^{+0.12}_{-0.10}(\text{stat})^{+0.06}_{-0.05}(\text{syst})$
$225 < p_T < 300$ GeV/c	$R_4 = 0.000^{+0.035}_{-0.000}(\text{stat})^{+0.019}_{-0.000}(\text{syst})$

Single top production

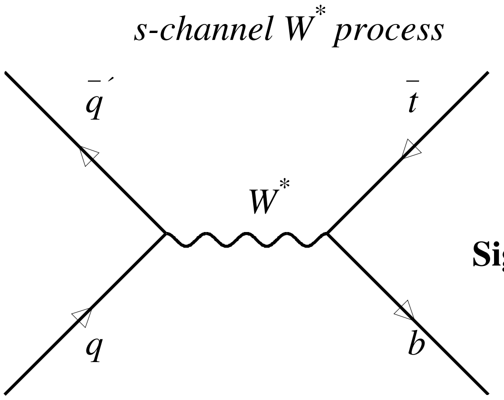
Electro-weak Top quark production. Can be used to measure the CKM matrix element V_{tb}.

Sensitive to new physics at the t-W-b vertex, like W' or FCNC.



Signal is W+b+q

$\sigma = 1.7 \pm 0.3$ pb
(Stelter et al. '98)
soft b jet from gluon
only one b jet



Signal is W+b+$\bar{b}$

$\sigma = 0.73 \pm 0.10$ pb
(Smith et al. '96)
two b jets in event

W-g fusion: require no b jet at lower vertex (i.e., $E_T < 15$ GeV) to reduce $t\bar{t}$ background ($\sigma_{top} = 5.1$ pb).

W-g sample: lepton + 2jets (1 SVX b-tag).
W* sample: lepton + 2jets (≥ 1 b-tag).

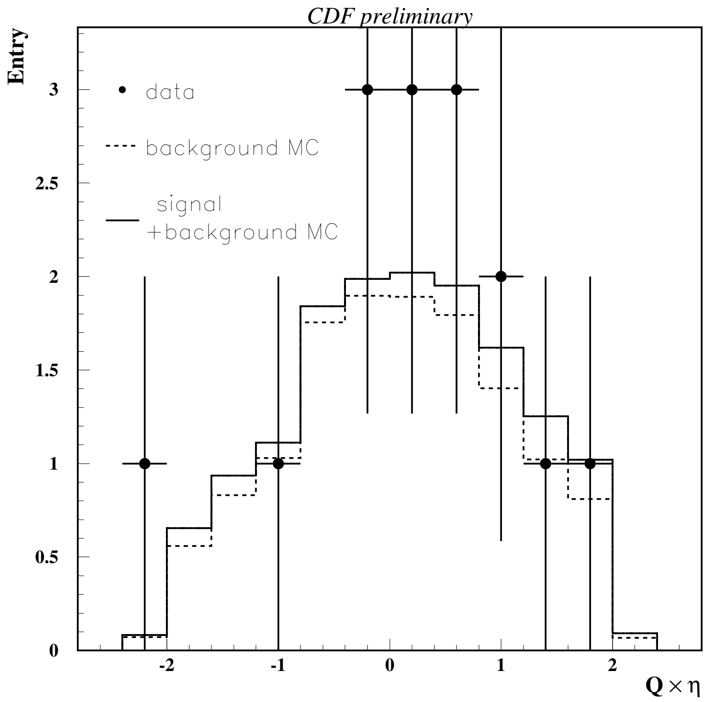
Background from QCD (Wbb, Wcc, Wc,W+2 jets (mistag) and $t\bar{t}$ production.

W-gluon fusion process

To reduce QCD background require 145 $< M(\ell\nu b) <$ 205 GeV/c^2. Expected and observed events are shown below.

Source	QCD	W*	$t\bar{t}$	W-g	Found
Events	10.3±1.9	0.5±0.3	2.2±0.6	1.2±0.3	15

Charge of top correlated with pseudorapidity (ℓ^+ has positive η, ℓ^- has negative η). Variable used is Q $\times\eta$.



Likelihood method used to estimate single top fraction, using templates for W$b\bar{b}$, W + jets, $t\bar{t}$, etc.

Including systematics uncertainties, it resulted in a limit:

$$\sigma_{singletop} < 15.4\ pb\ at\ 95\%\ CL$$

W^* process

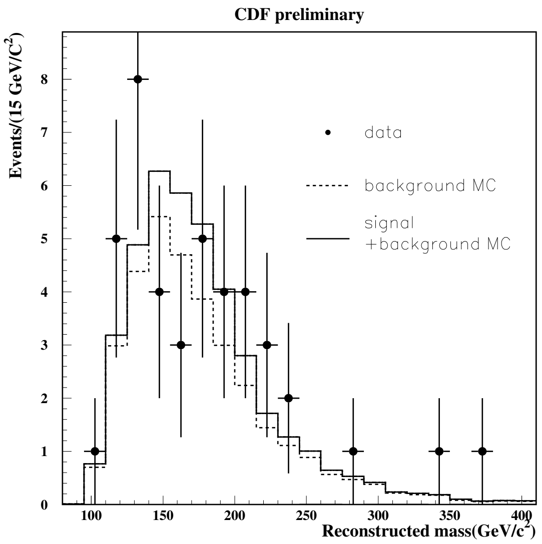
Events with two jets with b-tag are included in this study. Expected and observed events are shown below.

Source	QCD	$t\bar{t}$	W-glu	W*	Found
Events	24.0±4.5	5.7±1.3	1.5±0.3	1.0±0.3	42

Variable of choice is $M(\ell\nu b)$, assuming b with larger η to be associated with ℓ^+ in W^+ production (the opposite for W^-). Monte Carlo studies show this choice to be correct 64% of the time.

Maximum likelihood method used to estimate individual contribution to sample. With fixed $t\bar{t}$ and W-g fusion cross sections, the analysis gives $N(W^*) = 6.6^{+7.3}_{-6.5}$. Including systematic uncertainties this gives

$$\sigma_{W^*} < 15.8 \; pb \;\; at \;\; 95\% \;\; CL$$



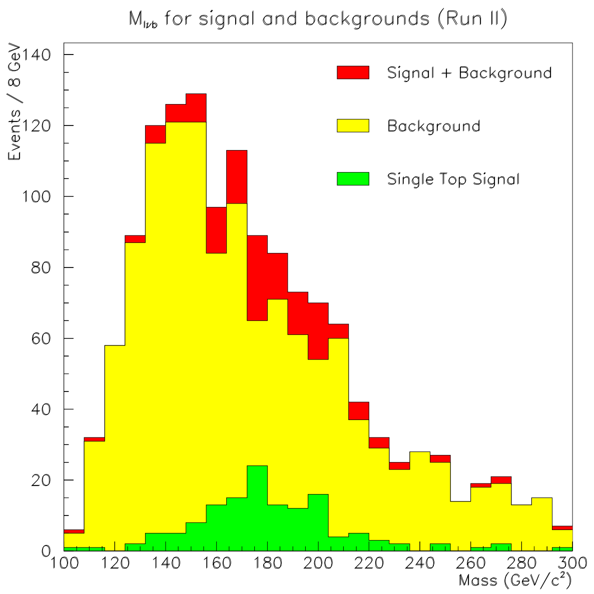
Run II expectation

Limits obtained in Run I are an order of magnitude larger the expected cross section. Is there a chance to obtain a measurement in Run II (2 fb^{-1} of data)? Improvements are expected in Run II.

- Factor 20 in luminosity Tevatron Energy up to 2.0 TeV, top cross sections larger by 40%, whereas QCD background increases by 12%.
- Detector improvements expected:
  - ℓ acceptance increases, e by 33%, μ by 12%.
  - SVX $b$tagging efficiencies increases by about 50%

Expected number of events:

Source	QCD	$t\bar{t}$	W-glu	W*
Events	170	80	50	15



BF$(t \to Wb)$ and $|V_{tb}|$

- BF$(t \to Wb)$ is $\sim$ 100% in the Standard Model. A value significantly different from this could signal new physics.
- Expectation for decays into quarks other then b is very low, $|V_{tb}|$ is constrained by the SM to be $0.9991 < |V_{tb}| < 0.9994$ (PDG).

  We measure the ratio

$$R_b = \frac{BF(t \to Wb)}{BF(t \to Wq)}$$

In SM (3 generations) R_b is given by:

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

- Use a few independent data samples. Events with:
  - 0, 1 or 2 b-tagged jets in the Lepton+jets sample
  - 0, 1 or 2 b-tagged jets in the Dilepton sample
- Using a maximum likelihood estimator, we measure R$_b$, hence V$_{tb}$:

$$R_b = 0.99 \pm 0.29 \quad \mathit{CDF\ Preliminary}$$

Assuming unitarity CDF obtains:

$$|V_{tb}| = 0.99 \pm 0.15 \quad or \quad |V_{tb}| > 0.76 \ (95\% CL)$$

W Boson Helicity in Top Decays

The Standard Model has an exact prediction (in leading order) of the W helicity states in the top rest frame. Since the top quark decays before it hadronizes the spin information at production is preserved.

$$F_0 = \frac{\frac{1}{2}m_t^2/M_W^2}{1+\frac{1}{2}m_t^2/M_W^2}$$

For $M_{top} = 175$ GeV/c^2 $\quad F_0 = 0.70$

$$F_+ = 0.0$$

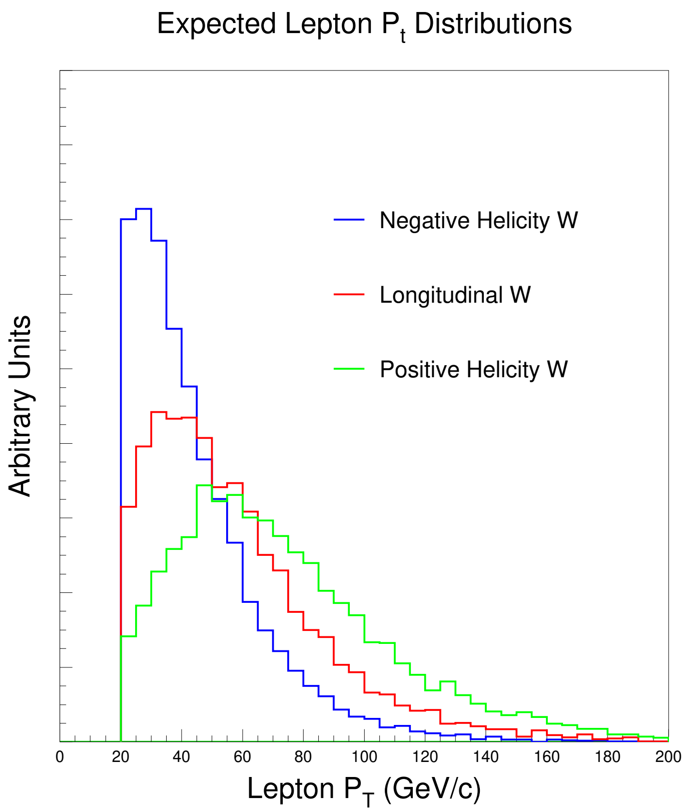
where F_0 = fraction of longitudinal W bosons (H_W =0) and F_+ = fraction of right handed W bosons ($H_W = +1$).

Large deviations from these predictions can be due to :

- Top has non-SM couplings
- What we have observed is not top

Relevant information available from decay angular distributions of leptons in the top rest frame. This requires full reconstruction of the event, with its uncertainties due to combinatorics.

CDF uses the lepton P_T distribution, which also carries this information. More statistics as full reconstruction is not required. Method more sensitive to Monte Carlo model used.



Data used include events from the dilepton and lepton+jets samples.

Sample	SVX tags	SLT tags	No-tag	Dilepton
Events	34	14	46	7
Background	9.2±1.2	6.6±1.2	24.8±6.5	0.76 ±0.21

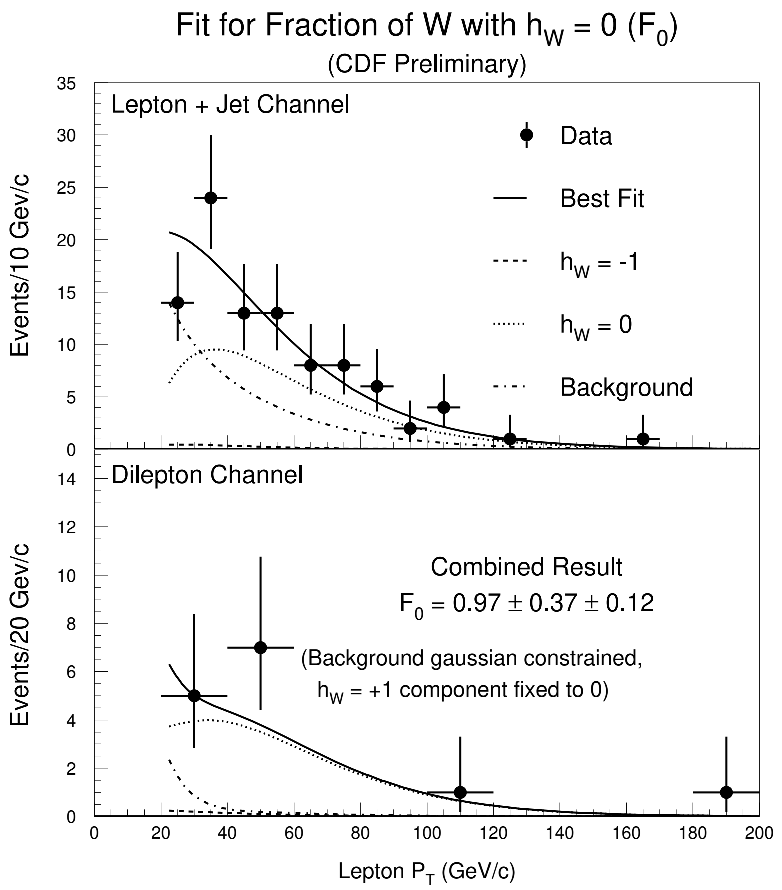
Background in each bin has different composition: b-mistag(QCD) non-W background, W$b\bar{b}$, etc. Background rates and background shapes obtained from data and Monte Carlo.

A maximum likelihood method is used to estimate F_0. The likelihood uses the response functions for the helicity states, the background shapes, and constrains the background rate to the expected value.

CDF obtains:

$$F_0 = 0.97 \pm 0.37(\text{stat}) \pm 0.12(\text{syst})$$

where $F_0 = 0.70$ was expected.



The systematic error includes uncertainties from: m_t, acceptance at low P_T, non-W background shape, gluon radiation in Monte Carlo and other small contributions.

To evaluate a possible F_+ contribution, the F_0 value was fixed in the likelihood to the Standard Modelprediction and a new maximization was performed. The result is

$$F_+ = 0.11 \pm 0.15(\text{stat}) \pm 0.06(\text{syst})$$

Conclusions: with the present statics no deviation from the SM is observed.

D0 spin correlations

The polarization state is transmitted to the angular distributions of the decay products.

$$d\sigma/dcos\theta \sim 1 + \alpha cos\theta$$

where we expect:

particle	α
e^+ or d quark	1
ν or u quark	-0.31
W^+	0.41
b	-0.41

- Charged leptons carry most of the information about the top spin
- For dilepton events, i.e., $t\bar{t} \to \ell^+\ell^- + X$ there is correlations between the two leptons:

$$\frac{d\sigma}{d(cos\theta_+)d(cos\theta_-)} \sim (1 + \kappa cos\theta_+ cos\theta_-)$$

- all the spin correlation information is now in κ.

The analysis is actually carried out using a particular frame defined by Mahon and Parke, where θ is the angle with respect to the so called "off diagonal axis". Here the expectation is $\kappa \sim 0.84$.

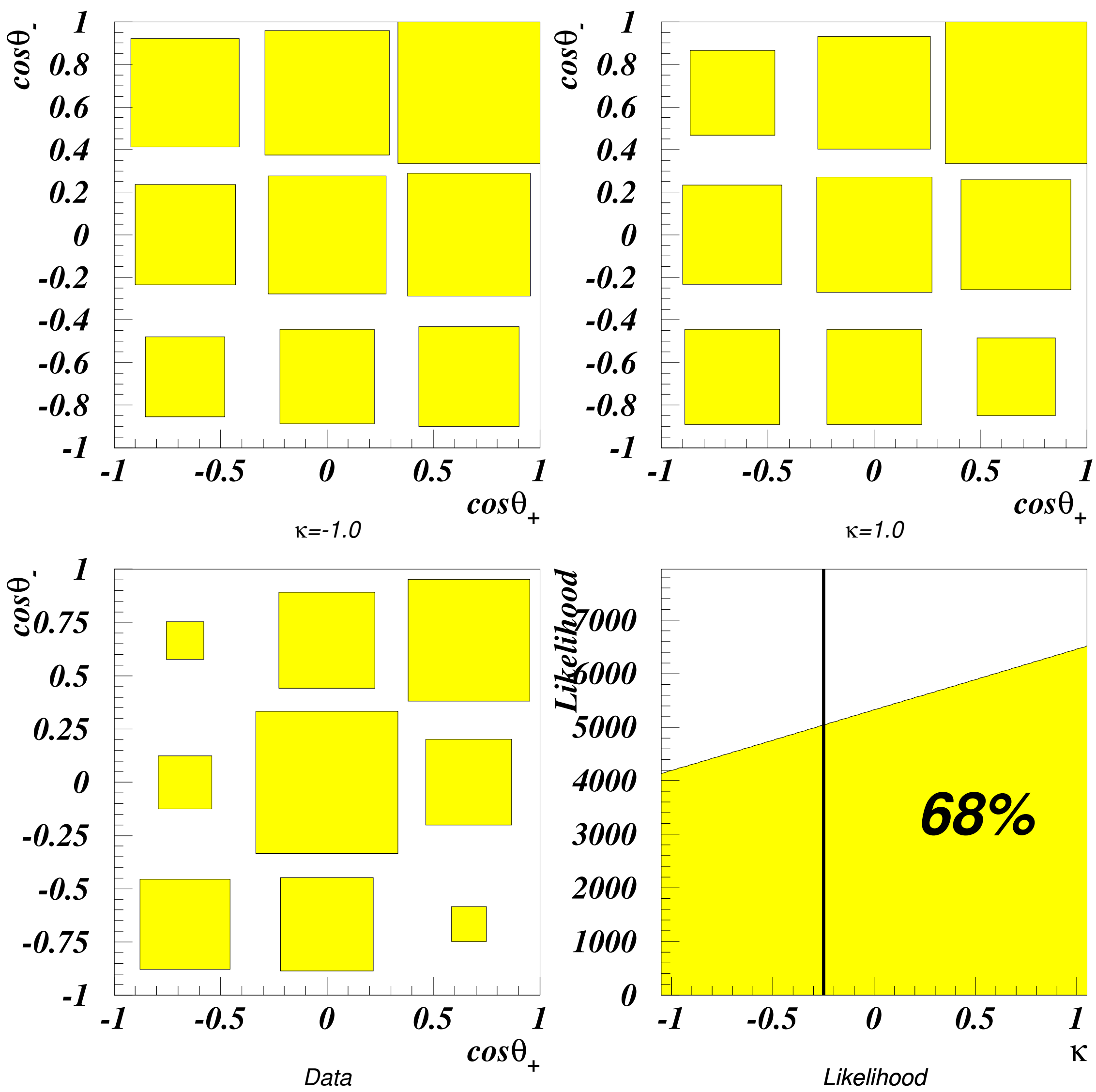
Event reconstruction is needed so allow moving from one reference frame to another. Because of missing constraints in the fitting of dilepton events (two ν are missing) the sensitivity is somewhat diminished. Also combinatorics and backgrounds will dilute the expected effect.

D0 uses the top dilepton sample of Run I, consisting of six events, to test out this analysis.

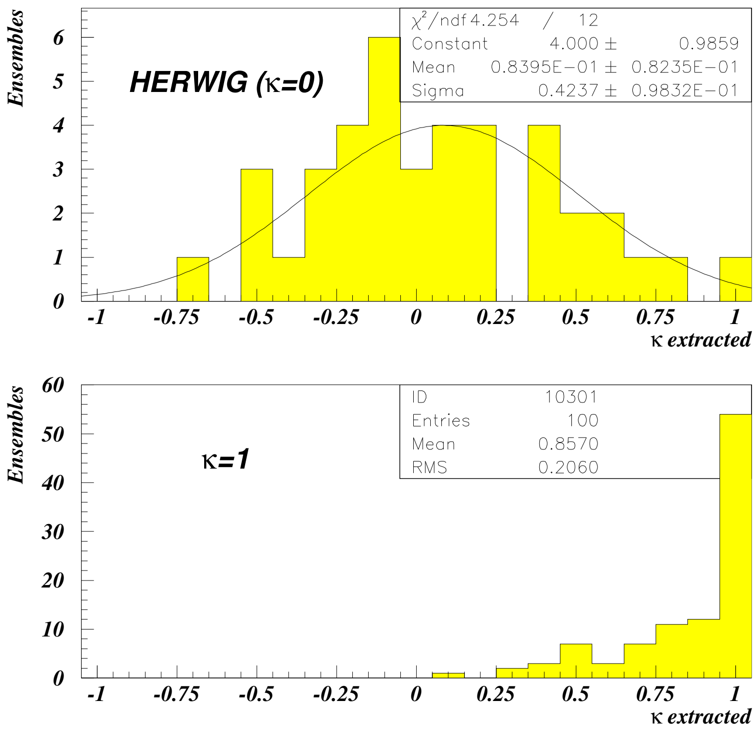
A binned 2 Dimensional likelihood is used to estimate the value of κ. Templates from Monte Carlo are used for the values of κ = -1.0 and 1.0. Also for the background.

D0's preliminary result is:

$$\kappa > -0.2 \text{ at the } 68\% \text{ C.L.}$$



Run II expectation for D0



Beyond the Standard Model

Search for rare Top Decays Two FCNC top decays have been investigated: $t \to Z + q$ and $t \to \gamma + q$

Search for t $\to$ Z q

SM with FCNC predicts BR(t $\to$ Z q) $\leq$ 0.001 We search in the channels ($\ell = e$ or μ)

$$p\bar{p} \to t\bar{t} \to \mathrm{Zq(W/Z)b} \to \ell^+\ell^- + 4 \text{ jets}$$

with jet $\mathrm{E}_T > 20$ GeV. We find one Z $\to \mu\mu$ event. Background (from WZ, ZZ, ZZ pair production) is expected to be B = 0.6 $\pm$ 0.2 events.

Assuming that it is signal, we set a limit:

$$\mathrm{BR(t \to Z\ q)} < 0.33 \qquad (95\%\ \mathrm{CL})$$

Search for t $\to \gamma$ q

We search for t $\to \gamma$ q (q=u or c).

We use the production channel:

$$q\bar{q} \to t\bar{t} \to \mathrm{W\ b}\ \gamma\ \mathrm{q}$$

There are two topologies:

1. for W $\to \ell\nu$ we search for $\gamma + \ell + \not{E}_{\mathrm{T}} + \geq 2$ jets
2. for W $\to q\bar{q}\prime$ we search for $\gamma + \geq 4$ jets and a b-tag

One event of type 1.) is observed. Background 0.5 ev. (W $\to \ell\nu$) and 0.5 ev. from W qq'. We can set a limit:

$$\mathrm{Br(t \to \gamma\ q)} < 0.032 \qquad (95\%\ \mathrm{CL})$$

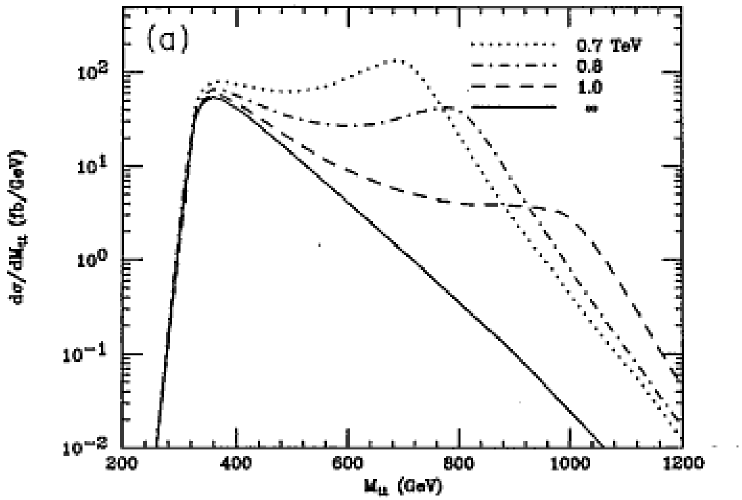
Study of the $t\bar{t}$ Mass

- New strong dynamics can be at the origin of a $t\bar{t}$ state. A number of models can be found in the letterature on this.

- Topcolor model of Hill and Park predicts a process like:

$$q\bar{q} \rightarrow \; V \; \rightarrow t\bar{t}$$

where V are color octet (and or singlet) Vector bosons



- Technicolor or Topcolor assisted technicolor models of Eichten and Lane, predict the process:

$$g\; g \rightarrow \; \eta_T \; \rightarrow t\bar{t}$$

where the techni-eta is a scalar.

- In some models the $t\bar{t}$ state provides an explanation for the large value of M_{top}, or top itself helps explain the origin of mass.

M($t\bar{t}$),cont.

This is physics to be pursued in Run II and the LHC later on.

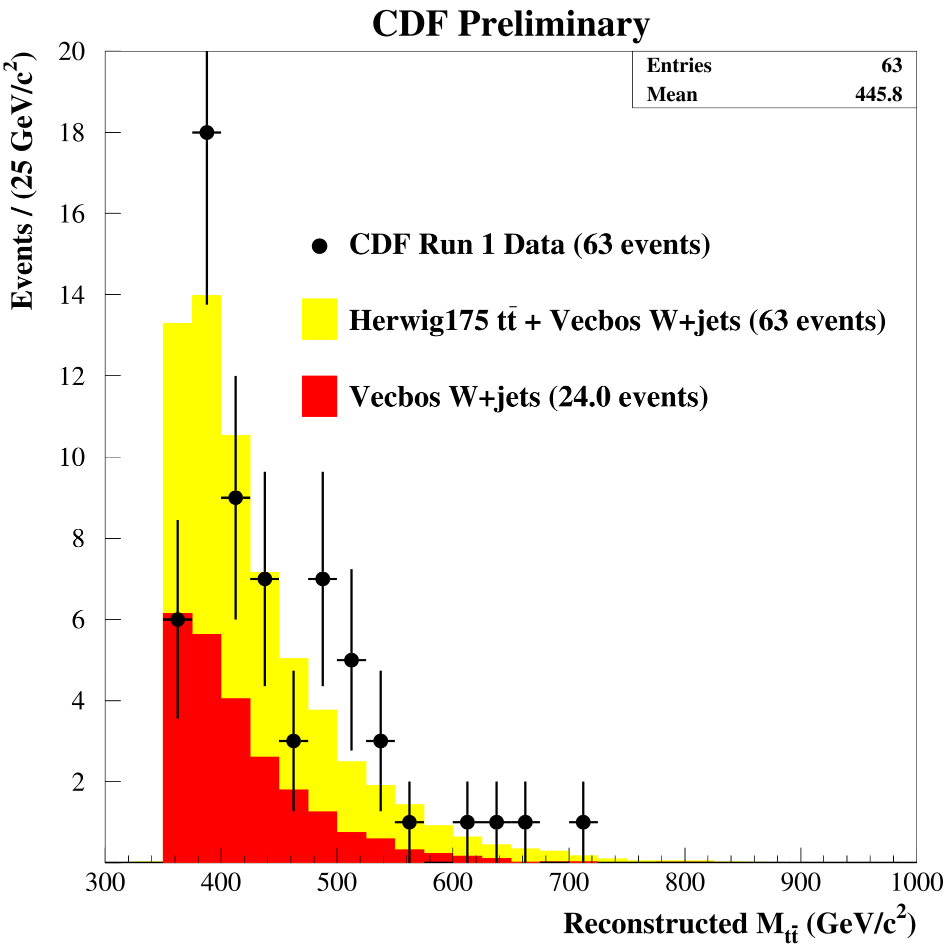
CDF is looking at Run I data for possible hints of a $t\bar{t}$ state and to establish cross sections limits for these models.

Event selection is the same as for the top mass analysis:

E_T(lepton) > 20 GeV $\quad$ $\not{E}_T > 20$ GeV
raw E_T(jet 1-3) > 15 GeV
jet4: tagged as b or $E_T > 15 GeV$

- Apply mass fitting technique with M_{top} fixed at 175 GeV/c^2 (3C fit).
- Loosen χ^2 cut to 50.
- To reduce effect of wrong jet combinations require that the 3-body masses in each event (for the same combination as above, in a fit with no mass constrain) be in the interval 150-200 GeV/c^2.
- A total of 63 events remain with a background of 23.8 events.

$\mathbf{M(t\bar{t})}$,cont.



- Work is in progress to estimate limits on cross sections for production of a colored vector boson, a Z'.

Summary and Conclusions

- CDF and D0 have observed a few hundred top events each.
- Analyses of the data have been made to check that both production and decays agree with the standard model.
- Production: no surprises
  - Kinematic variables agree with SM.
  - Production of high P_T top agrees with SM.
  - Single top production is out of reach in Run I.
- Decays: no surprises
  - V_{tb} agrees with the SM assumption.
  - W helicity and spin correlations agree with SM.
- New phenomena: no surprises
  - Rare decays limits well within SM expectations.
  - No evidence for a state that decays into a $t\bar{t}$.

All these analyses are "engineering runs".

Run II data (2 fb^{-1}) is expected to be factors 20-40 larger in statistics.