Recent Top Physics Results and Future Prospects

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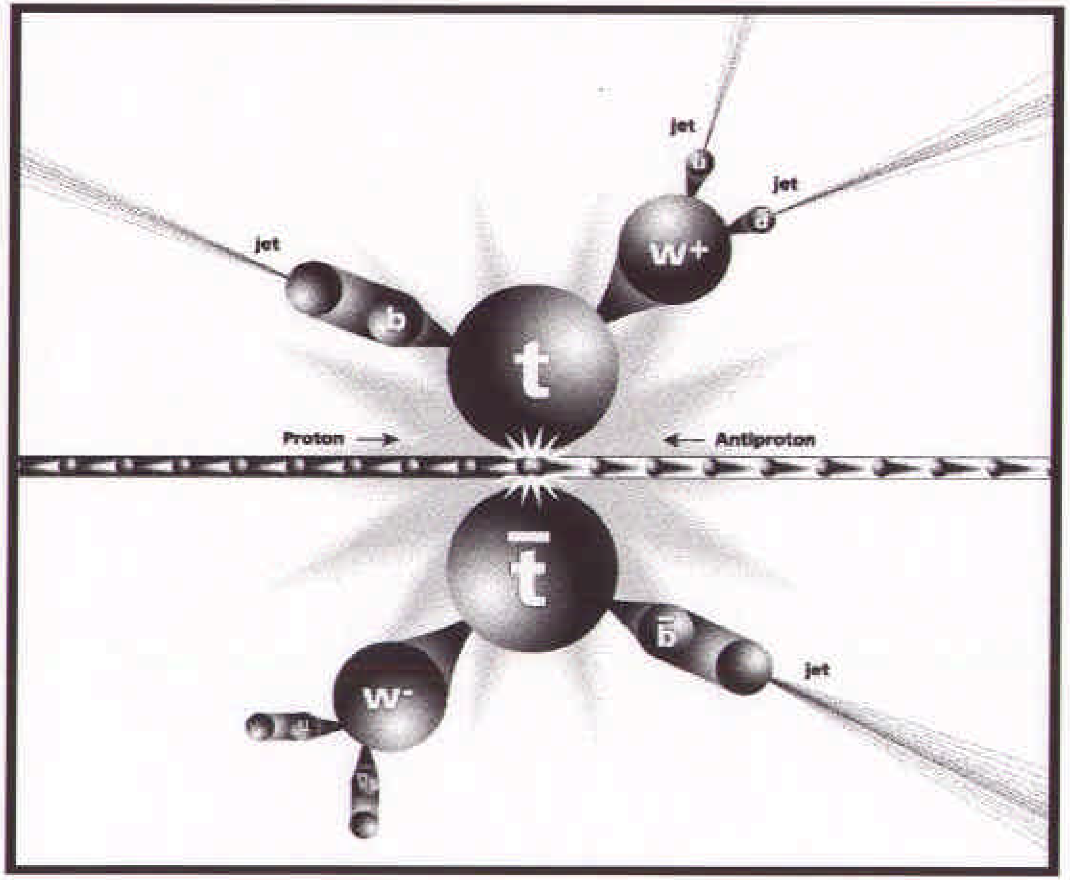
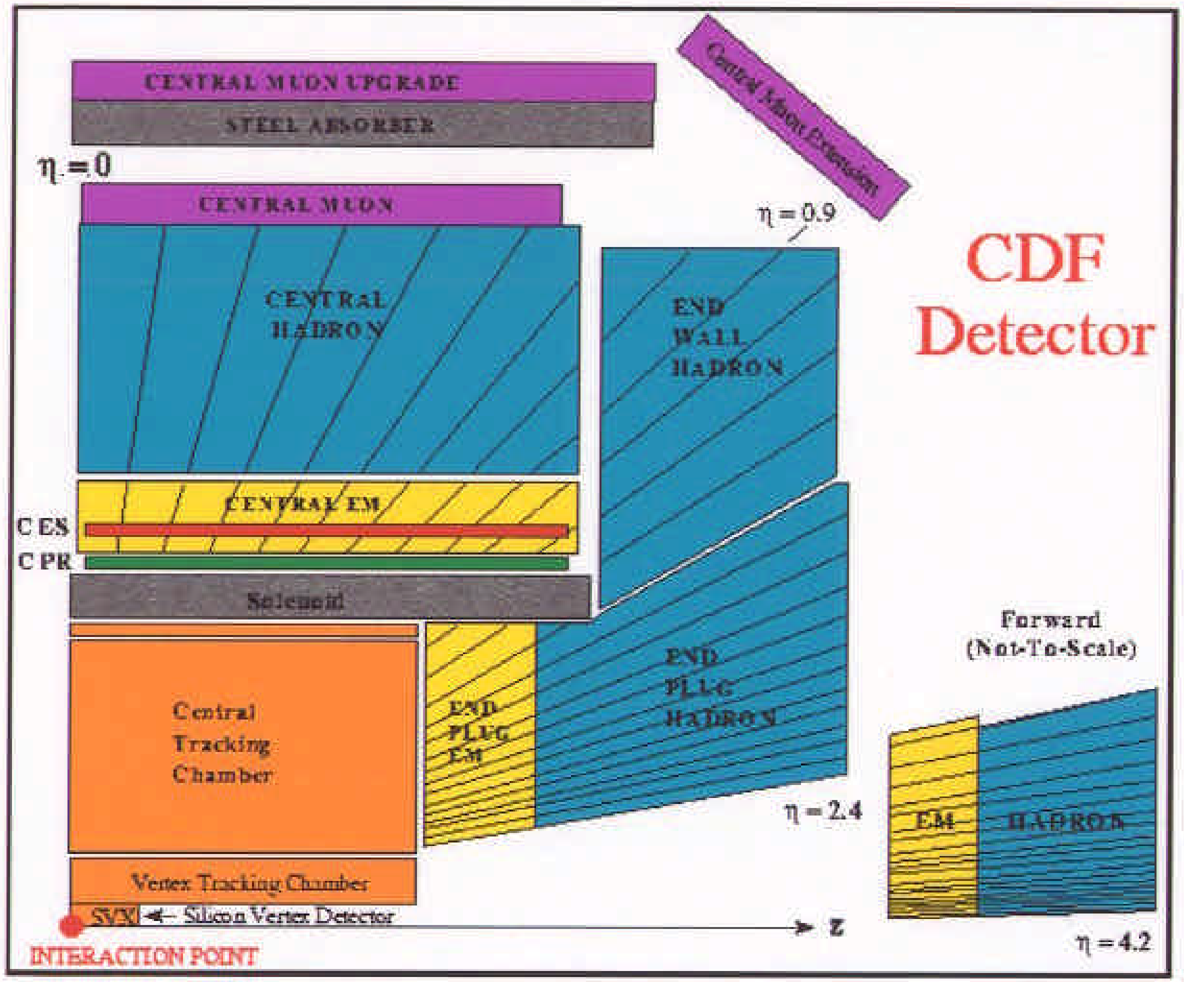


Outline

- **Introduction**
- **Run I Physics Results**
  - σ(tt)
  - M_{top}
  - M_{tt}
  - Top P_t Distribution
  - W Helicity in top decays
  - Limits on V_{tb}
  - Rare decays
  - Single top
- **Run II Physics and Expectations**
- **Summary**

Collider Detector at Fermilab



CDF Detector

Jets
Energy clusters in calorimeters

Leptons (e, μ)
Tracking chambers + calorimeters

Neutrinos
Indirectly observed as an imbalance in the total transverse energy

b-quark jets
Jet in calorimeter, plus, either

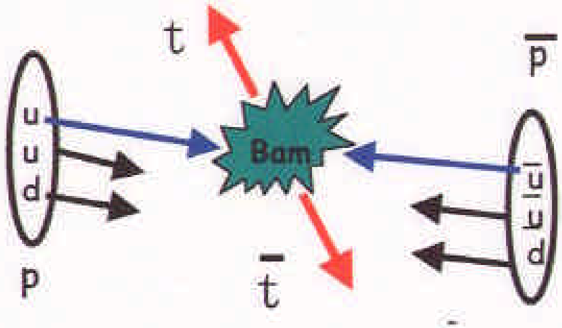
(a) SVX tag -reconstructed decay vertex using silicon vertex detector,

or

(b) SLT tag - a low energy e or μ in the jet

Standard Model Top

Production



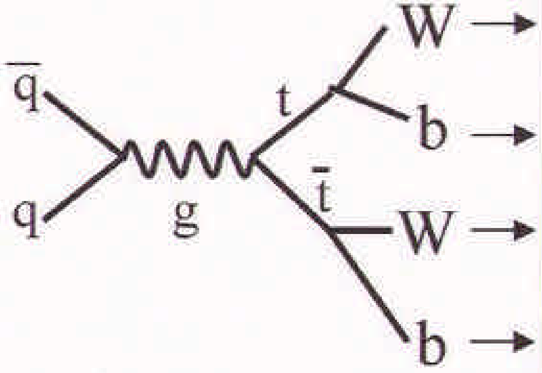
- Top is primarily produced in pairs
- ~90% of production is from $q\bar{q}$ annihilation (at Tevatron)

  $\sigma(t\bar{t})_{theory} \sim 5.1$ pb
- Single top is expected with

  $\sigma(\textit{single top}) \sim 2.5$ pb

…but, it has a different signature (see later slides)

Decay



ℓν	jj	ℓν	jj
b	b	b	b
ℓν	ℓν	jj	jj
b	b	b	b
5%	15%	15%	44%

Dilepton - 2 high P_T leptons, MET, 2 high p_T jets

ℓ + jets - 1 high P_T lepton, MET, 4 high p_T jets

All jets - 6 high p_T jets

Backgrounds

Dilepton

Observed	9
Total Backgrd	2.4
Drell-Yan	26%
$Z \rightarrow \tau\tau$	25%
Fake leptons	16%
WW	15%
Mismeasured μ	13%
bb	2%
Other	4%
S/B	~2.7

$l + \geq 3$ jets

	SVX tag	SLT tag
Observed	29	25
Total Backgrd	8.1	13.2
mistags	17%	78%
non-W (bb)	13%	4%
Wbbar, Zbbar	34%	3%
Wccbar, Zccbar	12%	5%
Wc, Zc	7%	5%
Single top	10%	2%
$Z \rightarrow \tau\tau$	2%	1%
WW, WZ, ZZ	5%	1%
S/B	2.6	0.9

$l + \geq 4$ jets

S/B	7.1	1.4

All Jets: ≥ 5 jets

≥ 1 SVX b-tag

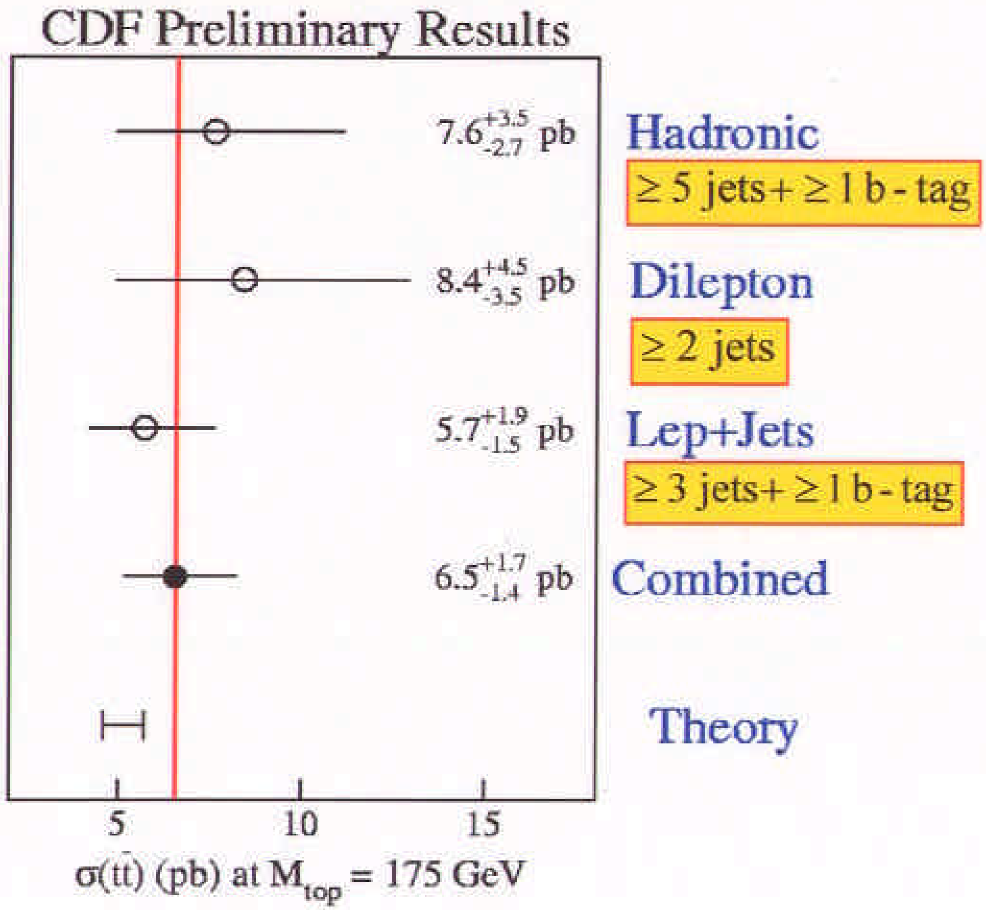
Observed	187
h.f + fakes	151.4
S/B	0.24

≥ 2 SVX b-tags

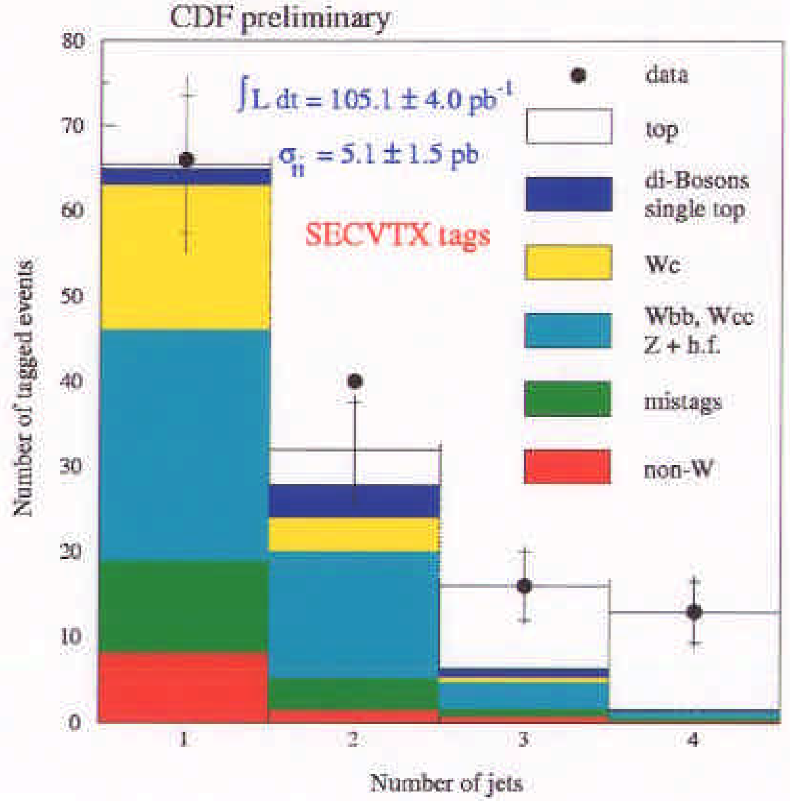
Observed	157
h.f + fakes	122.7
S/B	0.28

$t\bar{t}$ Cross Section Results

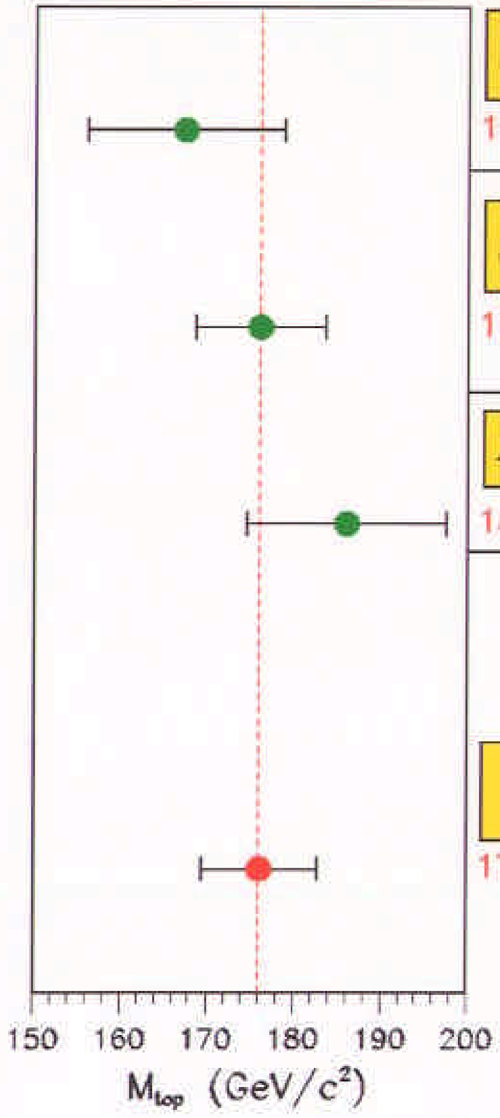
$$\sigma(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A \cdot \int L}$$



ℓ + jets with SVX b-tags



Top Quark Mass



$ll + \geq 2$ jets — 167.4 ± 11.4 GeV/c^2

Underconstrained because of the two ν's
A weighting technique is used to find the most probable top mass for each event.

$l + \geq 4$ jets — 176.1 ± 7.4 GeV/c^2

χ^2 technique. Constrains:

$M(\ell\nu)=M_W$ $M(jj)=M_W$

$M(\ell\nu j) = M_{top}$ $M(jjj)=M_{top}$

Choose lowest χ^2 solution

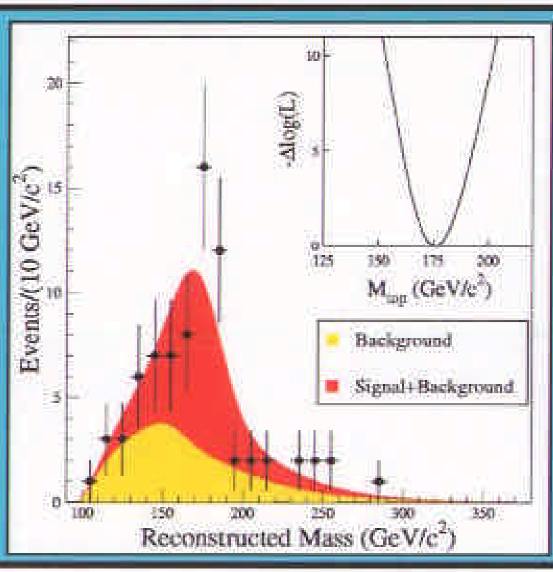
All Jets (≥ 6 jets) — 186.0 ± 11.5 GeV/c^2

χ^2 technique. Fully constrained
Choose lowest χ^2 solution

Combined — 176.1 ± 6.6 GeV/c^2

ℓ + jets Channel

b-tags	#ev
SVX Single	15
SVX Double	5
SLT	14
No Tags	42



Narrow $t\bar{t}$ Resonances

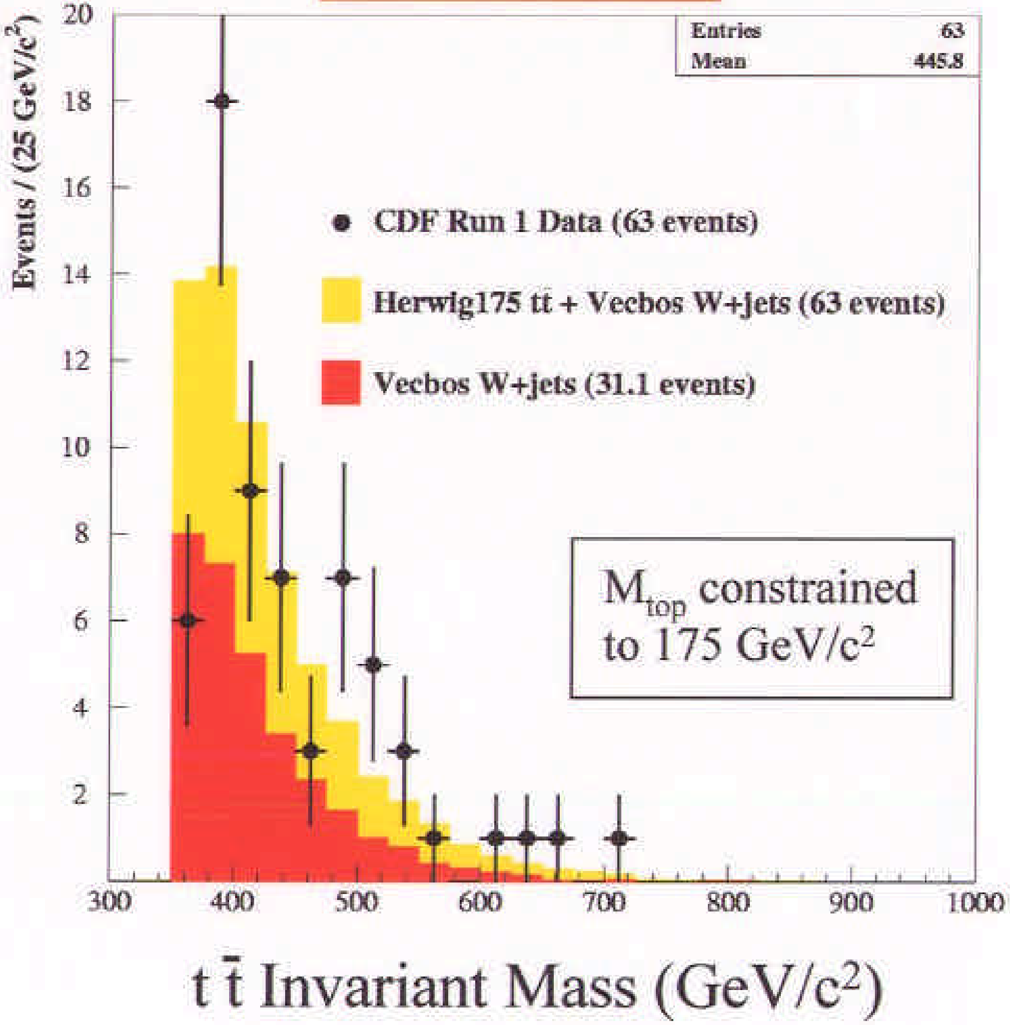
The large value of M_{top} could be an indication that the 3rd generation plays a special role in EWSB.

Various models such as "topcolor assisted technicolor" or those invoking a "top quark seesaw" introduce new dynamics to explain EWSB and the large top quark mass.

These models generally predict the existence of $t\bar{t}$ condensates, such as topgluons and a Z', each which may decay to $t\bar{t}$.

Motivated by such models, we search for narrow resonances in the **400-1000 GeV/c² range.**

$l + \geq 4$ jets



Limits on Narrow Resonances

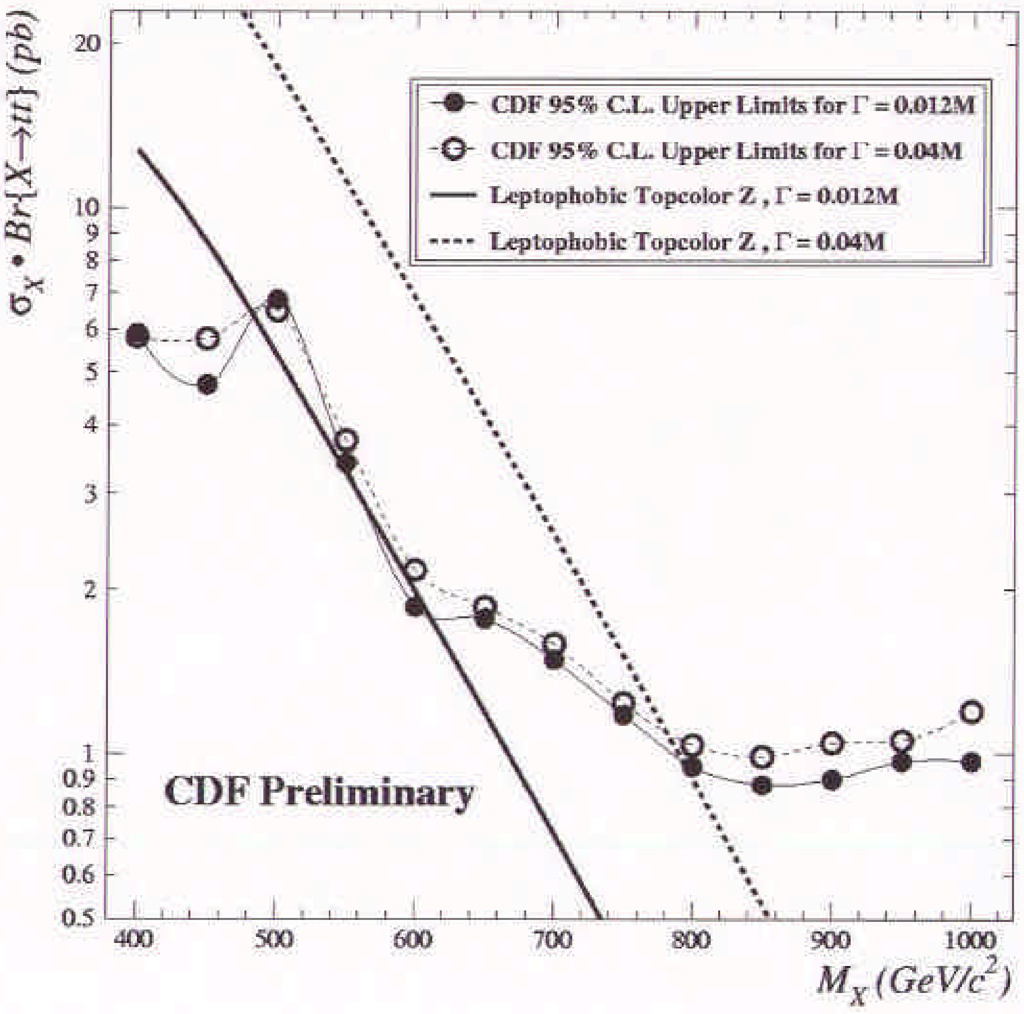
- Fit the $t\bar{t}$ invariant mass distribution in data to a combination of S.M. $t\bar{t}$, W+jets, and Z' using a binned likelihood.
- Perform the fit for a variety of Z' masses (400-1000 GeV/c^2)

$$L = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$$

$$\mu_i = N_{sig}(i) + \alpha N_{t\bar{t}}(i) + \beta N_{W+jets}(i)$$

- Smear each likelihood by both shape and acceptance uncertainties:
  - Included are: Jet Et scale, M_{top}, ISR & FSR, S.F., background shape, b-tag eff. and luminosity

The data rule out a leptophobic Topcolor Z' with Γ=0.012 (0.04) and mass lower than 480 (780) GeV/c^2.

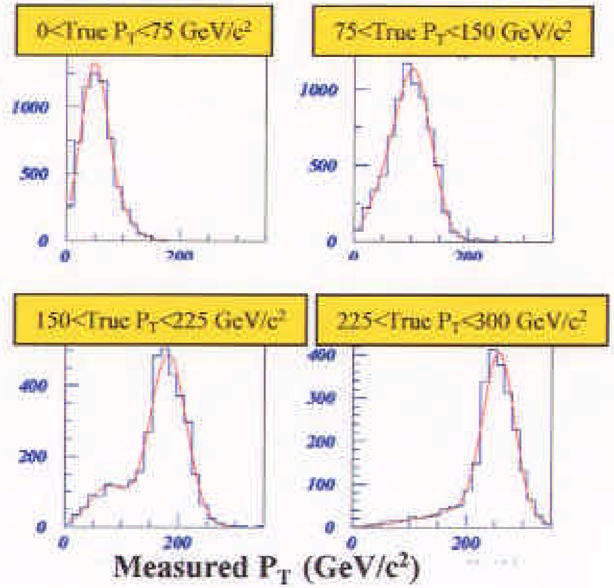


Top P_T Distribution

Technicolor and SUSY predict an excess an excess of top quarks at high p_T

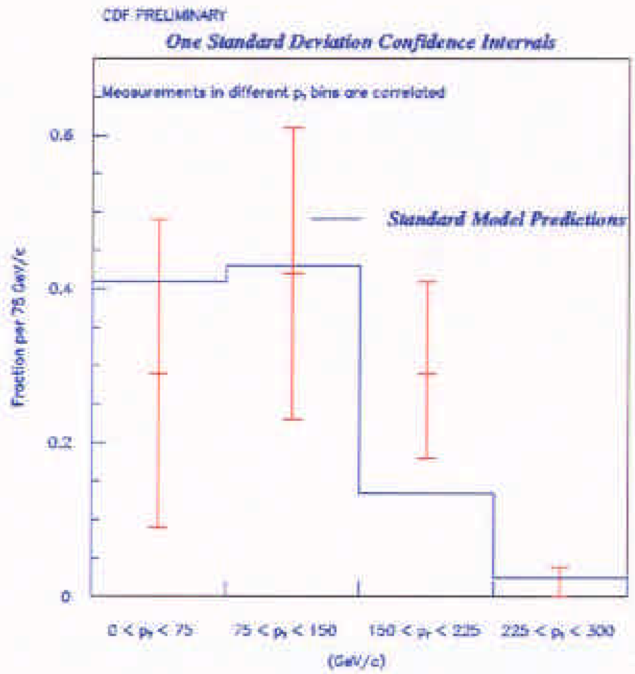
Measure p_T spectrum using $l + \geq 4$ jets

- constrain M_{top}=175 GeV/c^2.
- Due to correlations, only use the p_T of the hadronic top
- Determine initial "Response functions"



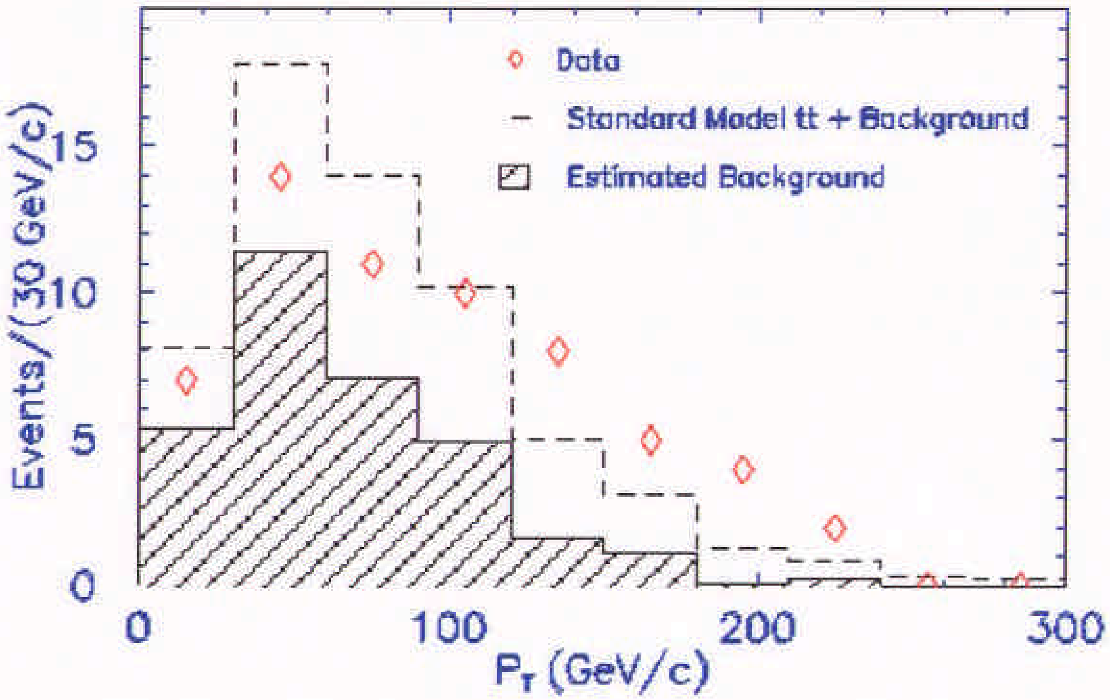
An iterative technique is used which results in only a minimal dependence on the initial p_T distribution

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



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	$R_4 = 0.000^{+0.035}_{-0.000}(\text{stat})^{+0.019}_{-0.000}(\text{syst})$

Top P_T Distribution (Cont)



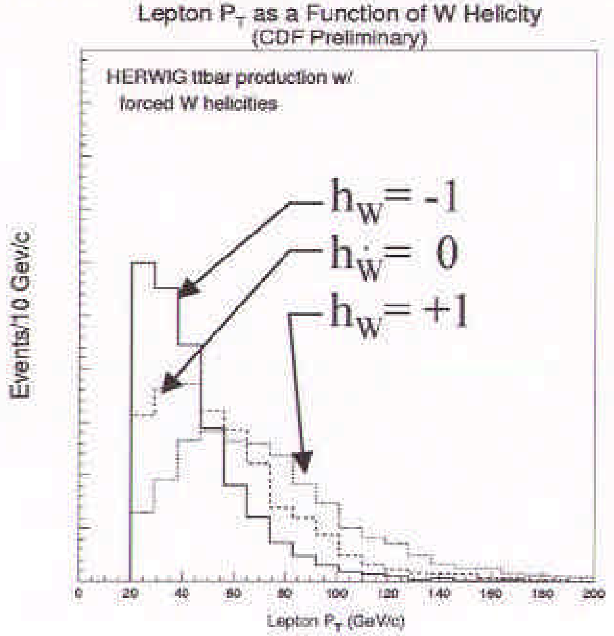
W Helicity in Top Decays

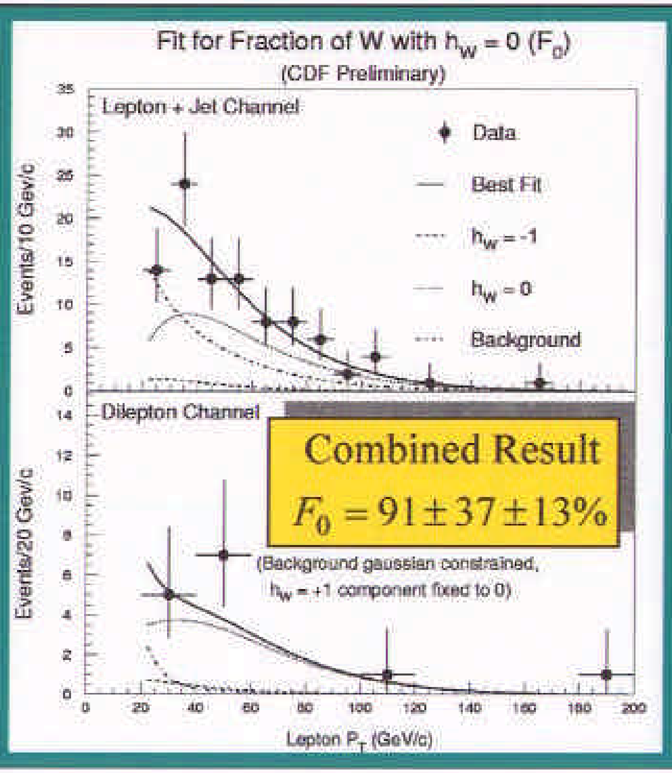
The V-A theory of charged current interactions makes a specific prediction for the W polarization in top decays.

$$F_0 \cong \frac{M_{top}^2/2M_W^2}{1+M_{top}^2/2M_W^2} = 70.1 \pm 1.6\%$$ for M_{top}=175 GeV/c^2 $$F\_ \approx 1 - F_0$$

- Since top decays before hadronization, the helicity information is directly imparted to the decay products which then carry the information on the t→Wb coupling.

- The lepton p_T spectrum carries information on the polarization of the W.





Limits on V_{tb}

❑ With the assumption of 3 generations and Unitarity, we can expect that $V_{tb} > 0.9985$

❑ If V_{tb} is measured and found to be less than this value, this would imply that there are likely more than 3 generations.

We measure :

$$B \equiv \frac{BF(t \to W + b)}{BF(t \to W + q)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

❑ We compare the number of events with 0, 1, and 2 b-tagged jets in the $l + \geq 4$ jets and *dilepton* samples, and compare to predictions as a function of B.

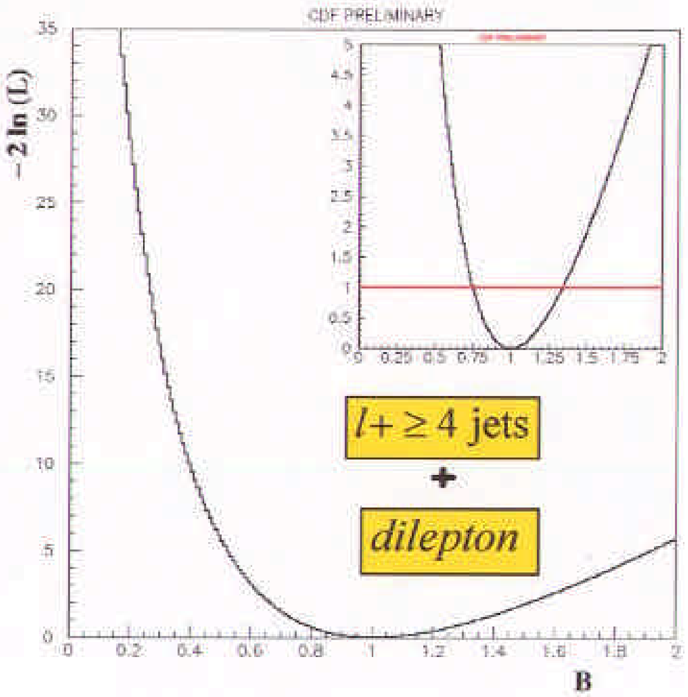
Assuming 3 generations, $B = |V_{tb}|^2$

$B = 0.99 \pm 0.29$ and $|V_{tb}| = 0.99 \pm 0.15$

$|V_{tb}| > 0.74$ @ 95% CL

Assuming >3 generations $|V_{tb}| = \sqrt{\frac{B}{1-B}(|V_{ts}|^2 + |V_{td}|^2)}$

$|V_{tb}| > 0.048$ @ 95% CL



Search for Rare Decays

- Good region to search for non-Standard Model physics
- Two FCNC t-decays, $t \rightarrow Zq$ and $t \rightarrow \gamma q$ (q=u or c), were investigated
- Within SM, these decays are suppressed ~ 10^{-8}–10^{-12}
- $t \rightarrow Zq$: search for events where at least one top decays via this mode
  - observe: 1 event ($Z \rightarrow \mu\mu$+4jets)
  - background: 0.6±0.2 from WW/ZZ+jets

$Br(t \rightarrow Zq) < 33\%$ at 95% c.l.

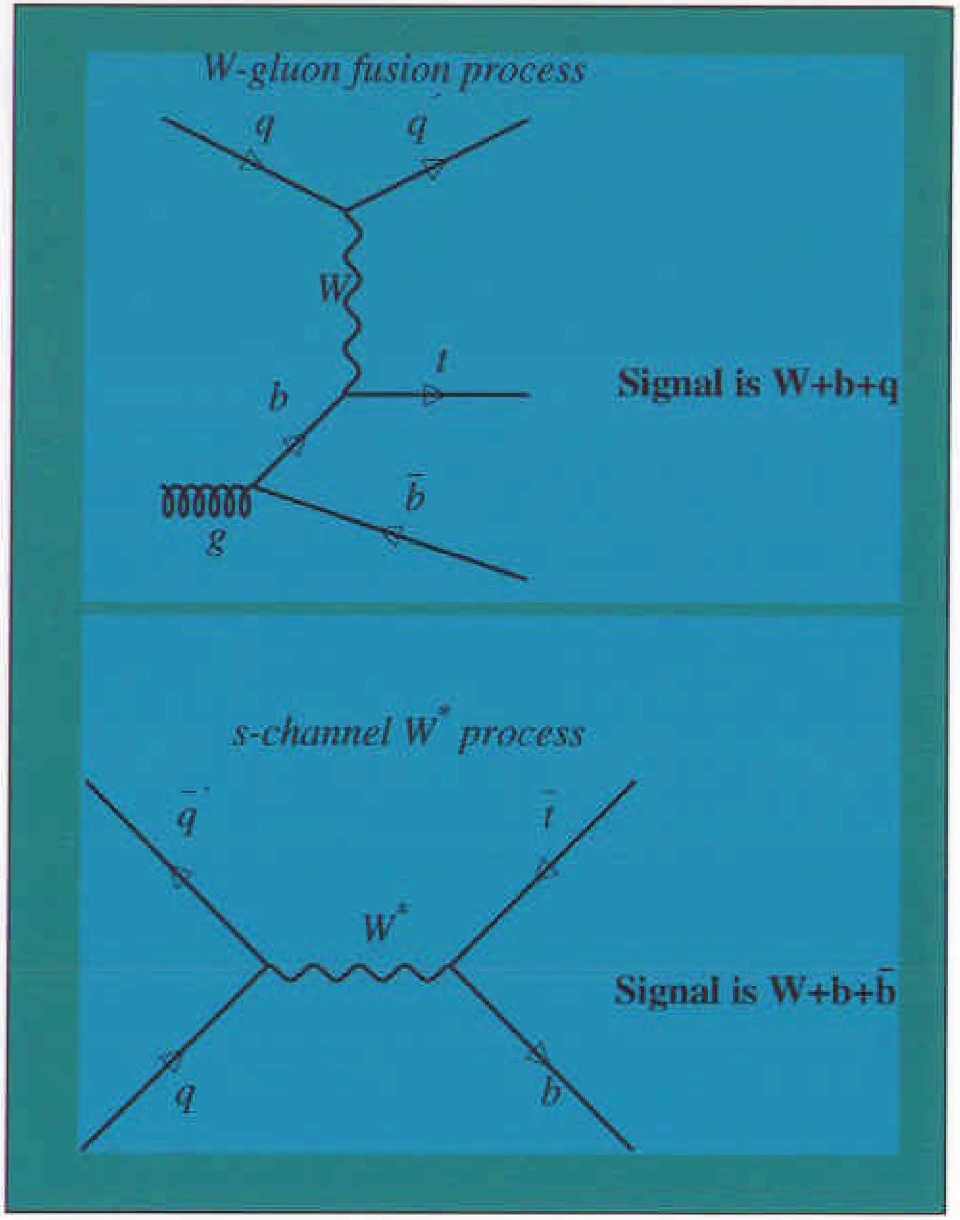
In the S.M. these decays are suppressed by ~10^{-8} to 10^{-12}

- $t \rightarrow \gamma q$: search for events where at least one top decays via this mode, $tt \rightarrow Wb\,\gamma q$
  - observe: 1 event (γ, ℓ, $\not{E}_T$ and 2 jets)
  - background: 0.5 ($W \rightarrow \ell\nu$) and 0.5 ($W \rightarrow qq$)

$Br(t \rightarrow \gamma q) < 3.2\%$ at 95% c.l.

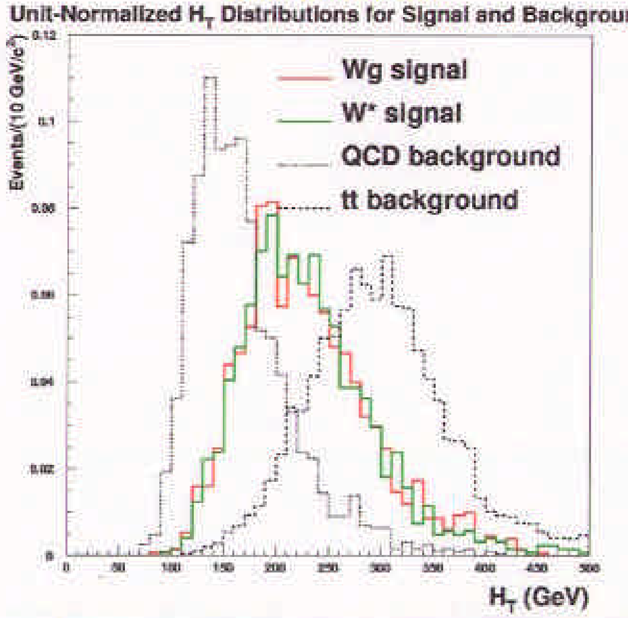
Single top

- Predicted by standard model. Direct probe of the strength (V_{tb}) of the electroweak vertex t-W-b. Sensitive to new physics (FCNC).
- W-gluon fusion:
  - Hard b-jet, W decay products, soft b-jet(usually lost), light q jet
  - $\sigma = 1.70 \pm 0.09$ pb (Stelzer 1998)
- s-channel W*:
  - 2 hard b-jets, W decay products
  - $\sigma = 0.73 \pm 0.04$ pb (Smith 1996)
- Backgrounds include: $Wb\bar{b}$, $Wc\bar{c}$, Wc, mistags, and $t\,\bar{t}$ production.



H_T Analysis

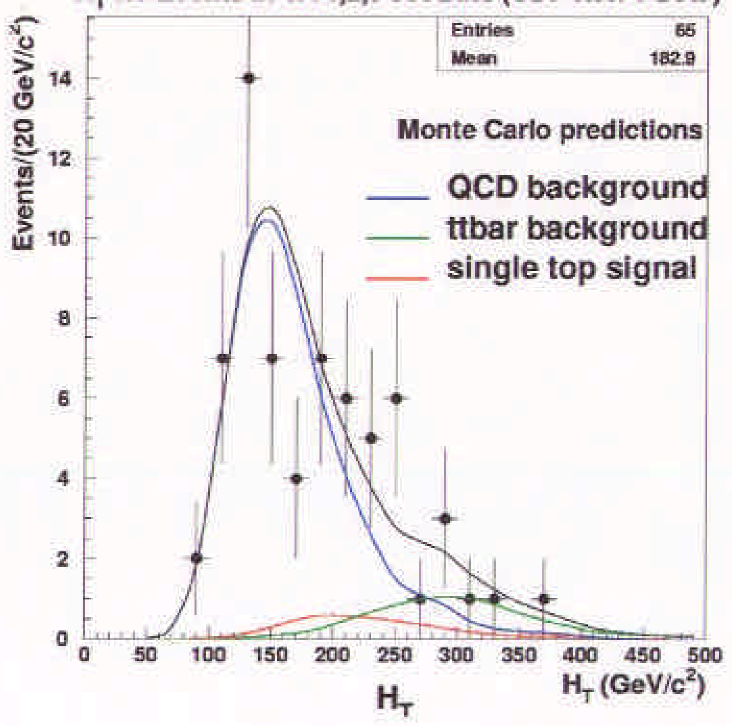
- First method searches for both processes.
- Event Selection:
  - W+1,2,3 jet events+ **at least 1 jet SVX b-tagged**
  - $140 < M_{l\nu b} < 210$ GeV/c^2
  - **65 Events Observed**
- **Background** from t-tbar production and QCD background.
  - Est. **62.4 +/- 11.5 Events**
- **Signal** (W* and Wg)
  - Est. **4.3 Events**



$H_T = \sum E_T$ (summed over lepton, $\not{E}_T$, and all jets)

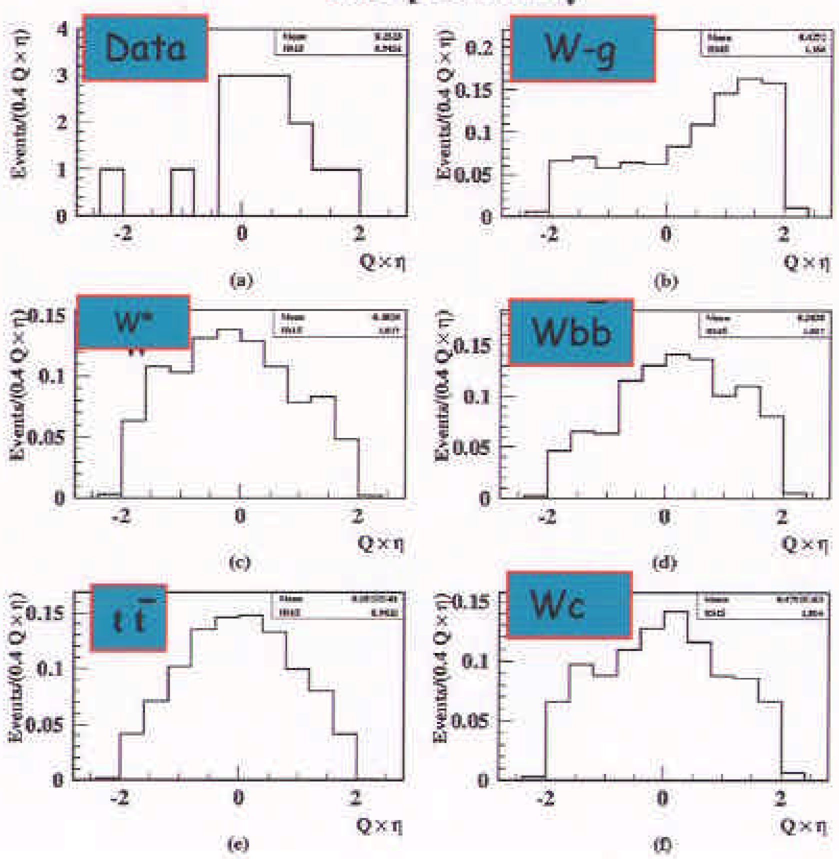
Perform an unbinned Likelihood fit to the H_T distribution to extract the 95% CL limit on single top production.

95% CL limit on single top production (Wg + W*):
$\sigma < 13.5$ pb

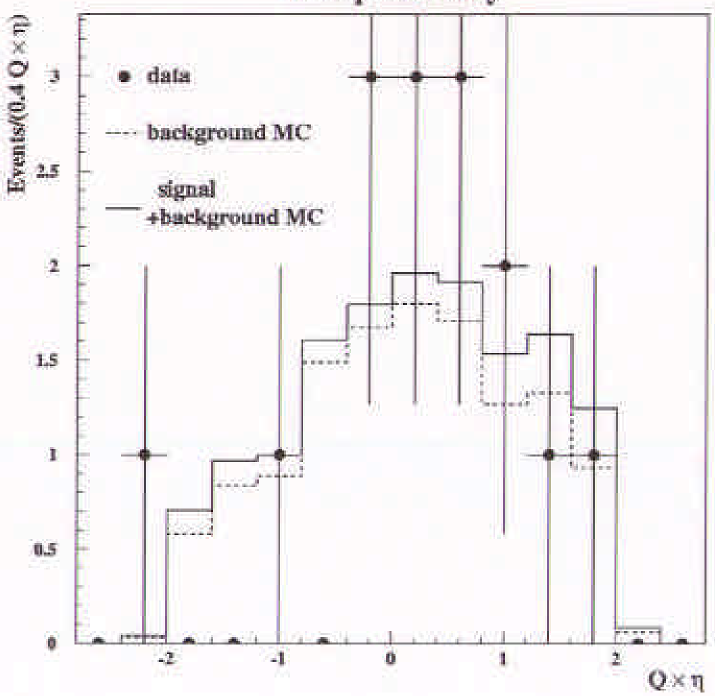


W-gluon fusion - Q x η Analysis

- **W+2 jet data,** require 140 < $M_{l\nu b}$ < 210 GeV/c^2
- Pseudo-rapidity (η) of the non-tagged (light quark) jet tends to be positive for top and negative for antitop.
- Assume + (-) charged lepton is from top (tbar).
- **Q * η distribution is asymmetric for signal events.**



- Observe **15 events**
  - ➢Expected Total **Bkg 12.9 ± 2.1**
  - ➢Expected **signal 1.2 ± 0.3**
- Fitted Signal:
  - ➢$1.4^{+4.2}_{-3.4}$ w/ bkg constraint
  - ➢$0.0^{+6.7}_{-0.0}$ w/out
- Extract upper limit: **$\sigma_{W\text{-}gluon}$ < 15.4 pb at 95% c.l.**



Run II at the Tevatron

Item	Run I	Run IIa
Instantaneous luminosity (cm^{-2} s^{-1})	$2x10^{31}$	$2x10^{32}$
Integrated luminosity (fb)	0.1	2.0
Bunch spacing	3.5 μs	132/396 ns
Proton/anti-proton energy	900 GeV	1 TeV
σ(ttbar) (pb)	~5	~7
b-tagging efficiency (at least one b tag)	~50%	~ 65-70%
Yield of **SVX single tagged signal events** (4 jets)	**~17**	**~800**
Yield of **SVX double tagged signal events** (4 jets)	**~5**	**~250**
Dilepton signal events	**~6**	**~150**

- ❑ Run I measurements, such as M_{top} and σ_{ttbar} will be systematics dominated
- ❑ Analyses which gave 95% CL will yield O(10%)-ish measurements

Reducing Systematics

- Dominant systematics are generally jet energy scale and MC modelling
- Many uncertainties will decrease as $1/\sqrt{N}$
- We will have a large sample of $Z \rightarrow b\bar{b}$ events from which to calibrate/check the energy scale for b-jets
- With the ~250 SVX double tagged events (S/B~25), we can unambiguously reconstruct the W mass
- Detailed studies of extra jets from gluon radiation should reduce the systematics from gluon radiation.

Run IIa Expectations

Measurement	Precision
Top Mass	~1.5%
$t\bar{t}$ cross section	~9 %
Single top cross section	~24%
V_{tb} (from Single top)	~13%
$B(W_{longitudinal})$	~5.5%
$\sigma * B(X \rightarrow t\bar{t})$	~.1 pb at 1 TeV/c^2
$B(t \rightarrow c\gamma)$	$<2.8 \times 10^{-3}$
$B(t \rightarrow Zc)$	$<1.3 \times 10^{-2}$

Other measurements we expect to make:

- o Kinematics of top
- o Spin Correlations
- o B(V+A) to ~3%
- o $\Gamma(t \rightarrow Wb)$ to ~25%
- o $B(t \rightarrow Hb)$ to <12%

+

Search for Higgs.

Possible signatures in

$p\bar{p} \rightarrow t\bar{t}H$?

Summary

- ❑ We have made a wide range of measurements of the top quark using a relatively small sample of events (~60 ev, total).
  - ➢ δm_{top} is known to 2.9% (Better than any other quark!)
- ❑ The top quark is unique in several ways
  - ➢ Very massive compared to other quarks
  - ➢ Decays prior to hadronization. We can examine the properties of a "bare" quark.
- ❑ Run IIa at the Tevatron ~ 8 months away.
  - ➢ Sample sizes will be much bigger (~40X)
  - ➢ Much improved silicon detector
  - ➢ Our understanding of the top quark should improve dramatically.
  - ➢ **We are eager to get going!**