Top Quark Physics at the Tevatron

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- Tevatron and CDF Detector in Run2
- Top Quark Physics, present
- Top Quark Physics, future

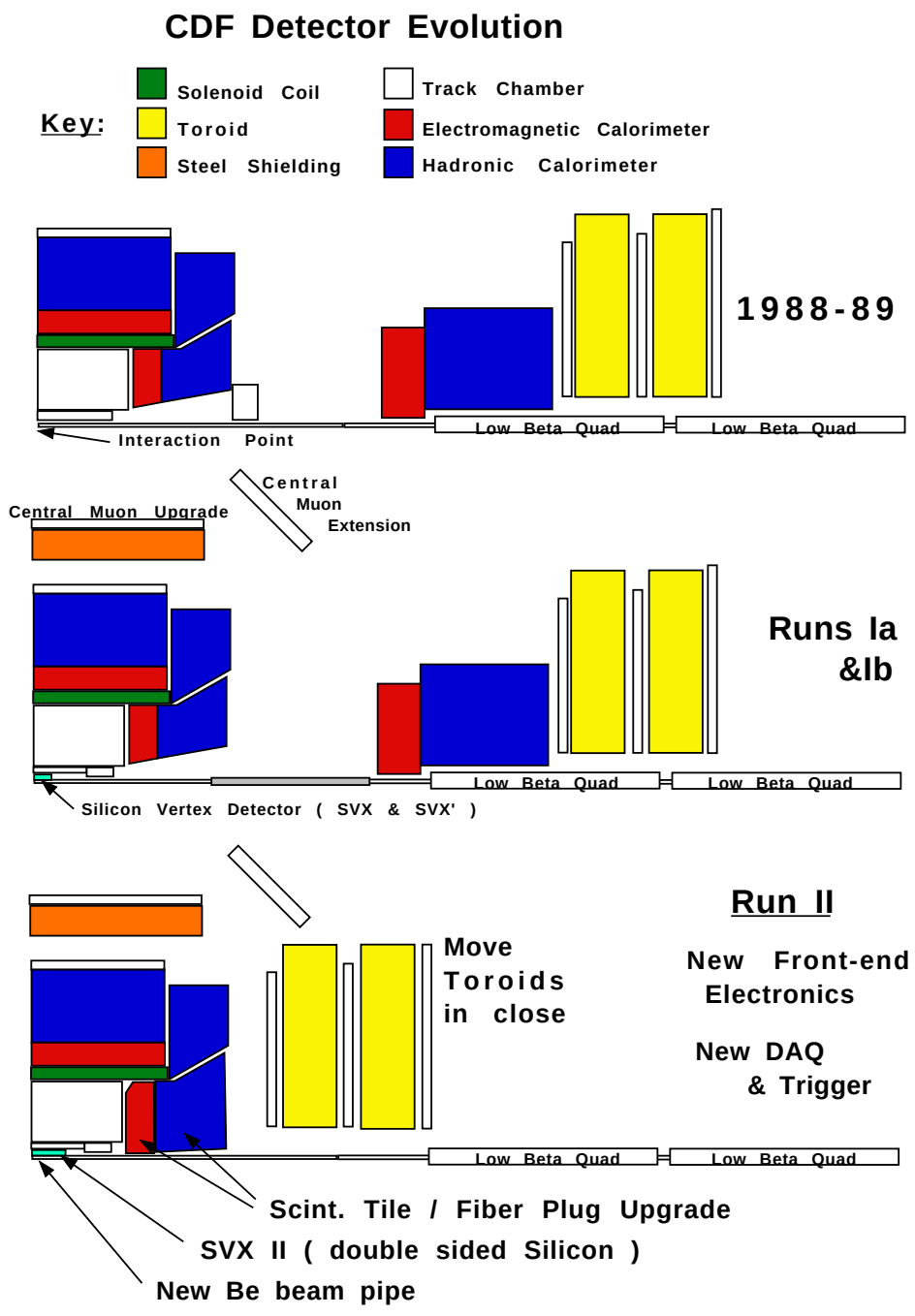
Tevatron and CDF Detector in RUN2

RUN2(will start in April 2000)

- Accelerator Upgrade
  - CM Energy: 1.8TeV $\rightarrow$ 2.0TeV
  - Integrated Luminosity: 0.1 fb^{-1} $\rightarrow$ 2 fb^{-1}
  - Instantaneous Luminosity: $2.5\times10^{31} \rightarrow 5\times10^{31} \sim 2\times10^{32}$
  - Number of Bunches: 6 $\rightarrow$ 36 $\sim$ 108
  - Bunch Period: 3.5μs $\rightarrow$ 396 $\sim$ 132 ns

- Detector Upgrade (CDF II detector, Technical Design Report Nov. 1996)
  - Quick response to the shorter bunch period
    - CTC $\rightarrow$ COT
    - Gas Calorimeter $\rightarrow$ Scintillator Calorimeter
  - Large coverage of SVX II (twice larger than SVX')

Collider Detector at Fermilab (CDF)



History of the Top Quark Search

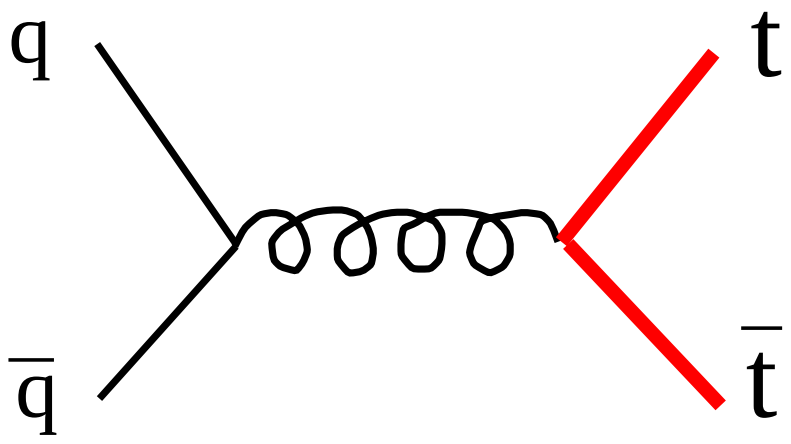
- 1977-1994: **A fine collection of null results**

- April, 1994: **First Evidence**
  - **Phys. Rev. D50, 2966 (1994) CDF**
  - 15 events on a background of 6.0
  - 2.8 σ excess
  - $M_{top} = 174 \pm 17$ GeV/c^2
  - $\sigma_{t\bar{t}} = 13.9^{+6.1}_{-4.8}$ pb

- February, 1995: **Confirmation**
  - **PRL 74, 2626 (1995) CDF**
  - 4.8 σ excess
  - $M_{top} = 176 \pm 8(\text{stat}) \pm 10(\text{syst})$ GeV/c^2
  - $\sigma_{t\bar{t}} = 6.8^{+3.6}_{-2.4}$ pb
  - **PRL 74, 2632 (1995) D0**
  - 4.6 σ excess
  - $M_{top} = 199^{+19}_{-21}$ (stat) $+14_{-21}$(syst) GeV/c^2
  - $\sigma_{t\bar{t}} = 6.4 \pm 2.2$ pb

Top Production at the Tevatron

Top quarks are predominantly produced in pairs by the process $p\bar{p} \to t\bar{t}$.

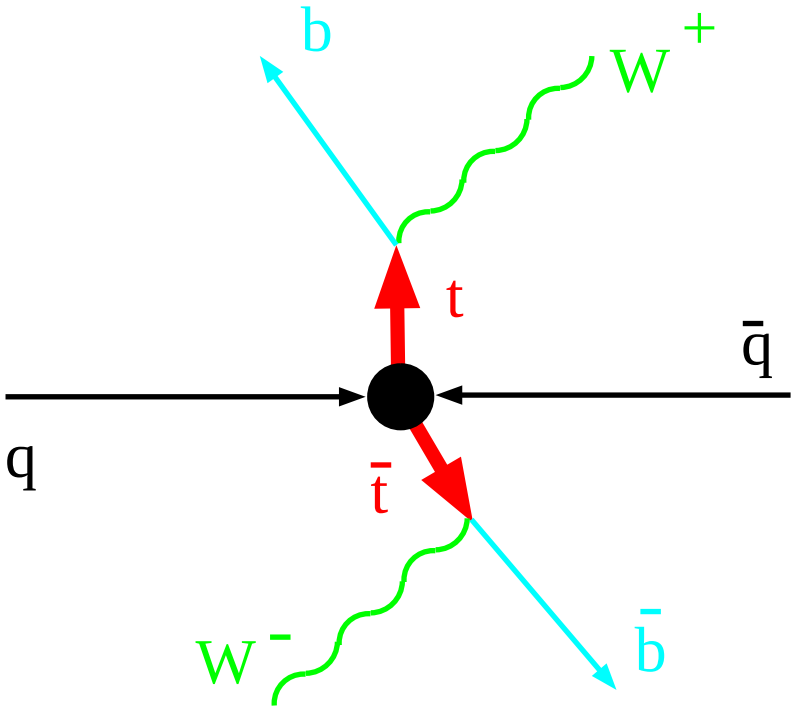


In Tevatron Run I,

- Integrated Luminosity exceeded 100 pb^{-1}
- over 5×10^{12} $p\bar{p}$ collisions
- **$\approx$ 500 $t\bar{t}$ pairs produced.**

$$\frac{\sigma_{\mathbf{t\bar{t}}}}{\sigma_{\mathbf{inel}}} \sim \mathbf{10^{-9}}, \qquad \frac{\sigma_{\mathbf{t\bar{t}}}}{\sigma_{\mathbf{W}}} \sim \mathbf{10^{-3}}$$

Top Quark Decay Signatures



We categorize top decays by how the two W bosons decay.

- Both W's Decay $W \rightarrow l\nu$ (Dilepton Channel)

  Final State: $l^+\nu l^-\nu b\bar{b}$ (l:e or μ; 5%)

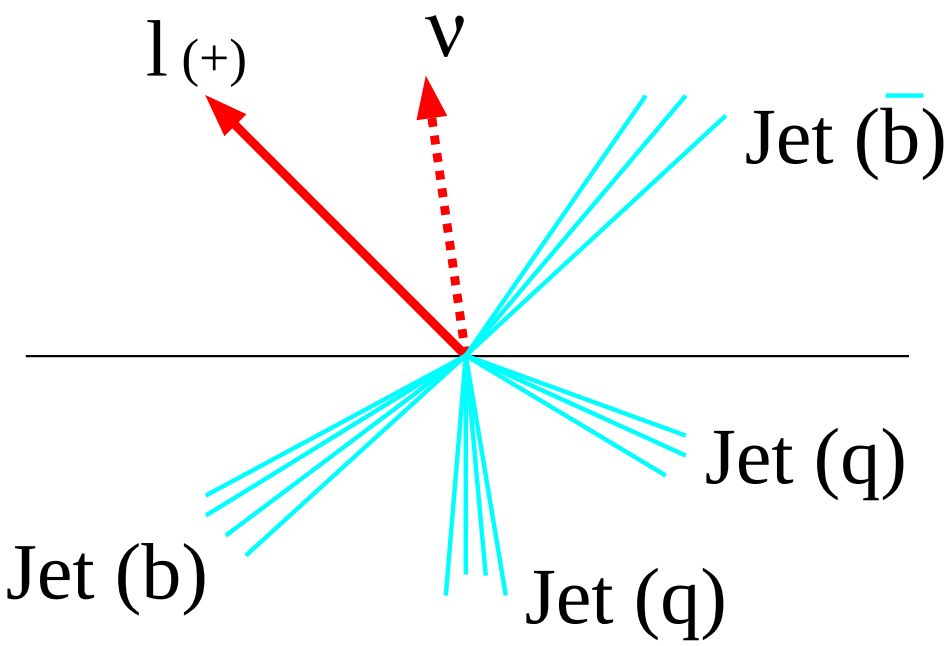
- One W Decay $W \rightarrow l\nu$ (Lepton+Jets Channel)

  Final State: $l^+\nu q\bar{q}^{'} b\bar{b}$ (l:e or μ; 30%)

- Both W's Decay $W \rightarrow q\bar{q}^{'}$ (All Hadronic Channel)

  Final State: $q\bar{q}^{'} q\bar{q}^{'} b\bar{b}$ (44%)

Lepton + Jets Channels



Signature:

- One isolated high P_T lepton (e or μ)
- Missing Energy ($\not\!\!E_{\rm T}$)
- 4 or more jets, 2 of which are from b-quarks

Dominant Backgrounds:

- $p\bar{p} \rightarrow W + jets$
- QCD background (Fake leptons)

Two Distinct Differences between $t\bar{t}$ and W+jets

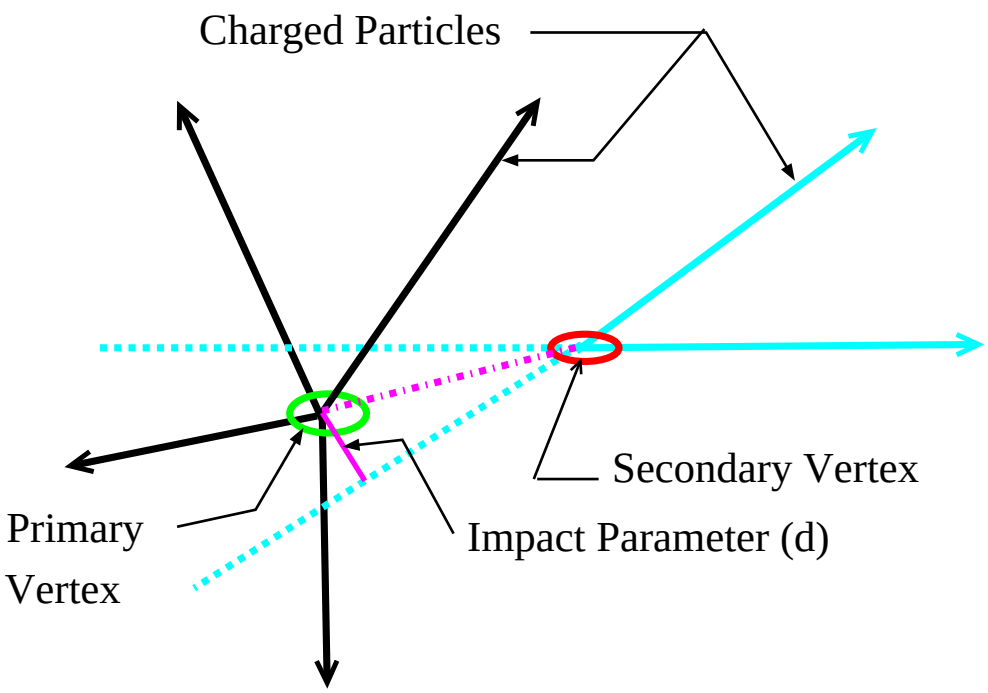
- $t\bar{t}$ events always contain b quarks, W+jet events usually do not.
- The jets in W+jet events tend to be softer than in $t\bar{t}$ (low E_t)

Need to further suppress backgrounds either with:

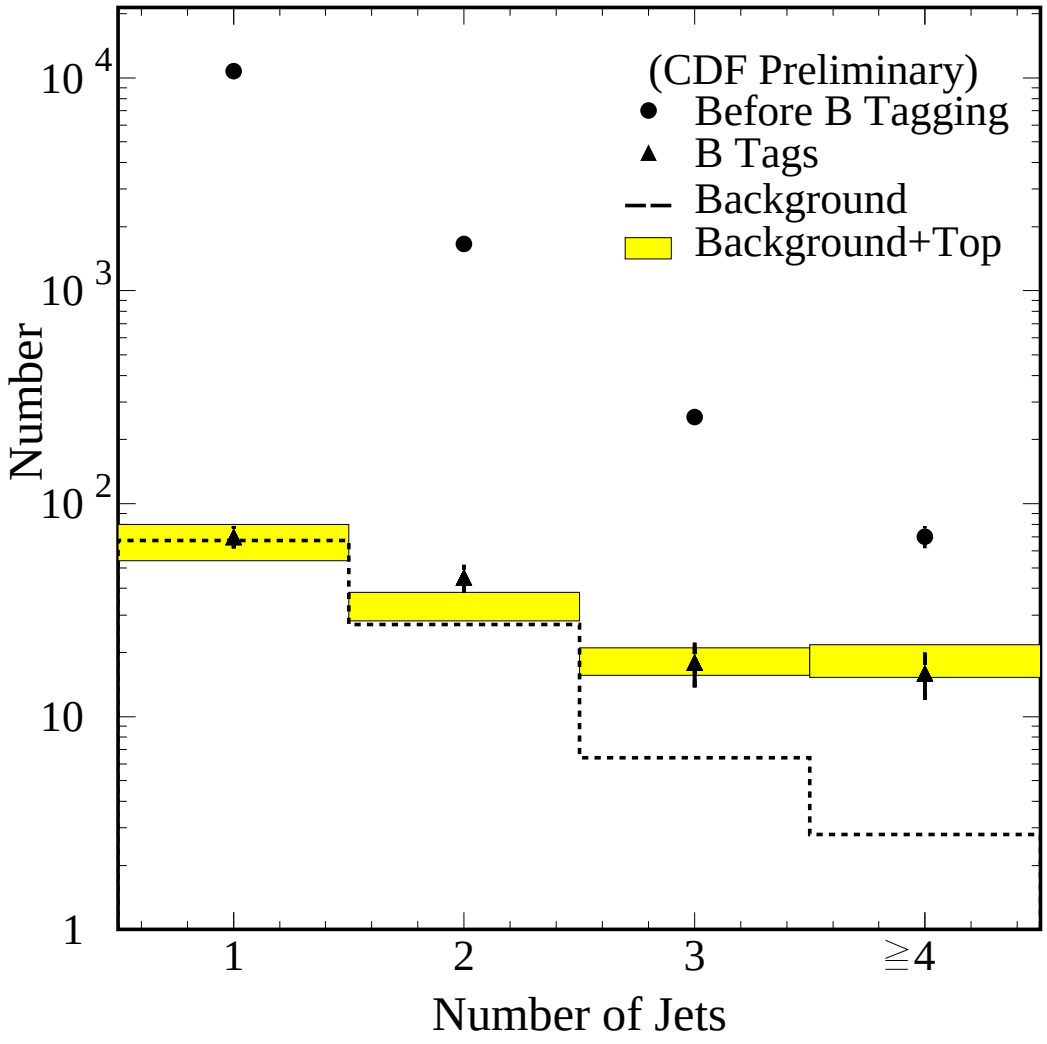
- Topological/kinematic requirements:
  - Aplanarity
  - $H_T = E_T(\text{leptons}) + \not\!\!E_T + \Sigma E_t(\text{jets})$
  - Form likelihood ($t\bar{t}$ vs. Bkgd) based on Jet E_t's
- Tag b-quarks using semileptonic decays (SLT b-tag)

$$b \to eX \ , \ b \to \mu X \ (20\%)$$

- Tag b-quarks using Displaced vertex (SVX b-tag)



CDF W+Jet Events



The final numbers are in ....

We have (CDF and D0 Combined):

$\approx$ 13 Dileptons
$\approx$ 60 Lepton+Jets
$\approx$ 60 All Hadronic

What do we do next ?

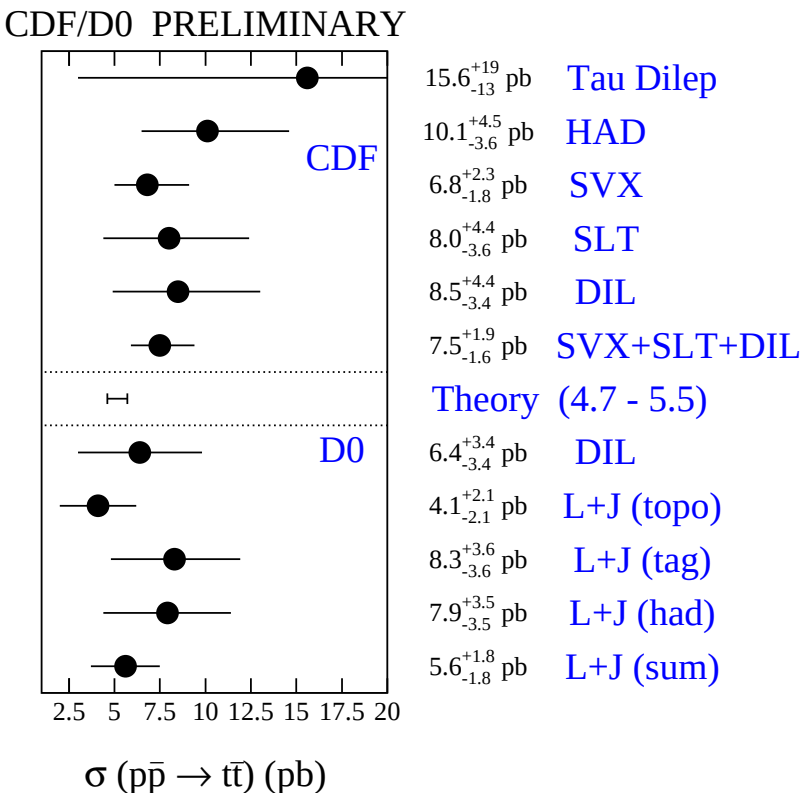
- Production Properties ($\sigma_{t\bar{t}}$)
- Decay Properties (V_{tb})
- Top Quark Mass
- Search for new physics (Rare decays, $M_{t\bar{t}}$)

$\sigma_{t\bar{t}}$ Measurements

$$\sigma = \frac{N_{obs} - N_{bkg}}{A\mathcal{L}}$$

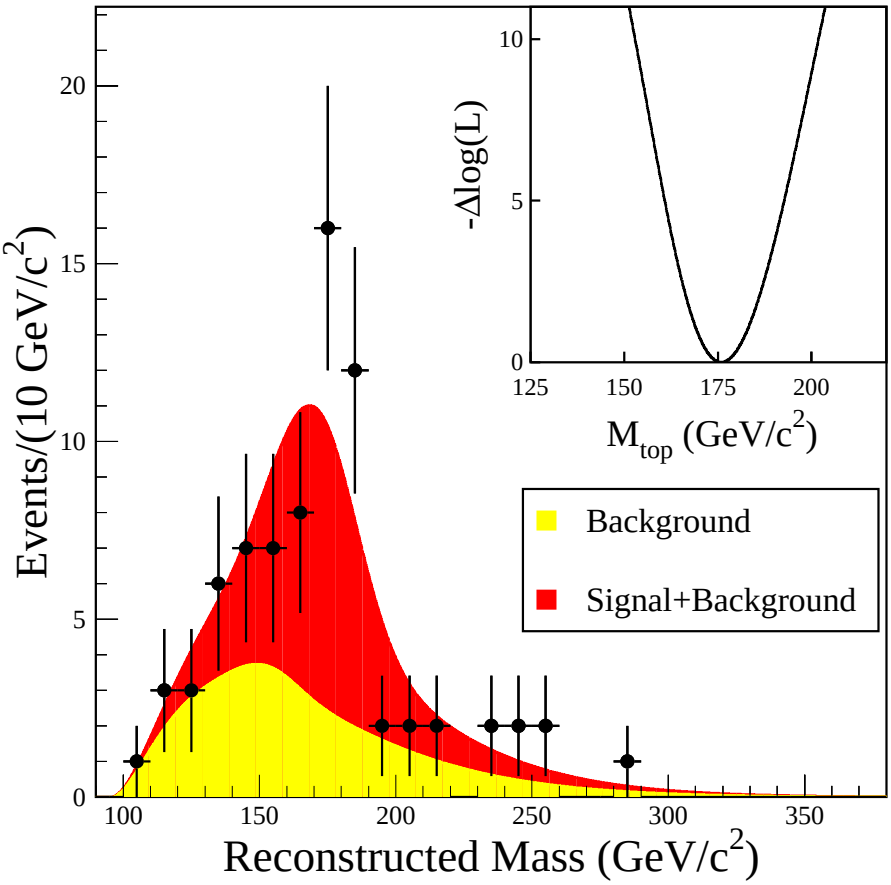
Goal: Determine the top cross section

- **as accurately as possible**
- **in as many different decay channels as possible as a check of top decay and compare it to theoretical prediction.**



Top Quark Mass in Lepton + Jet Channel at CDF

76 Events

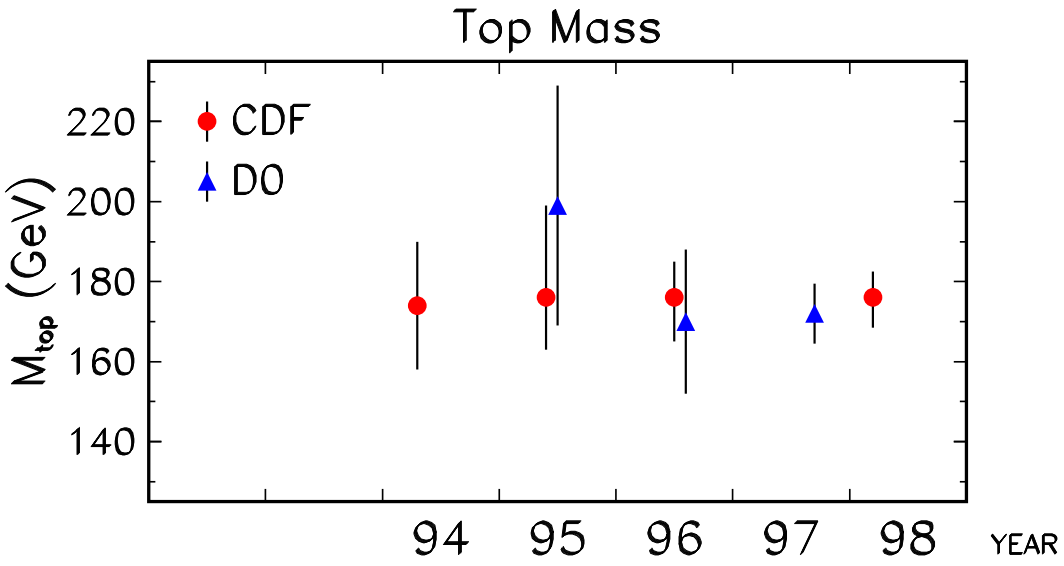


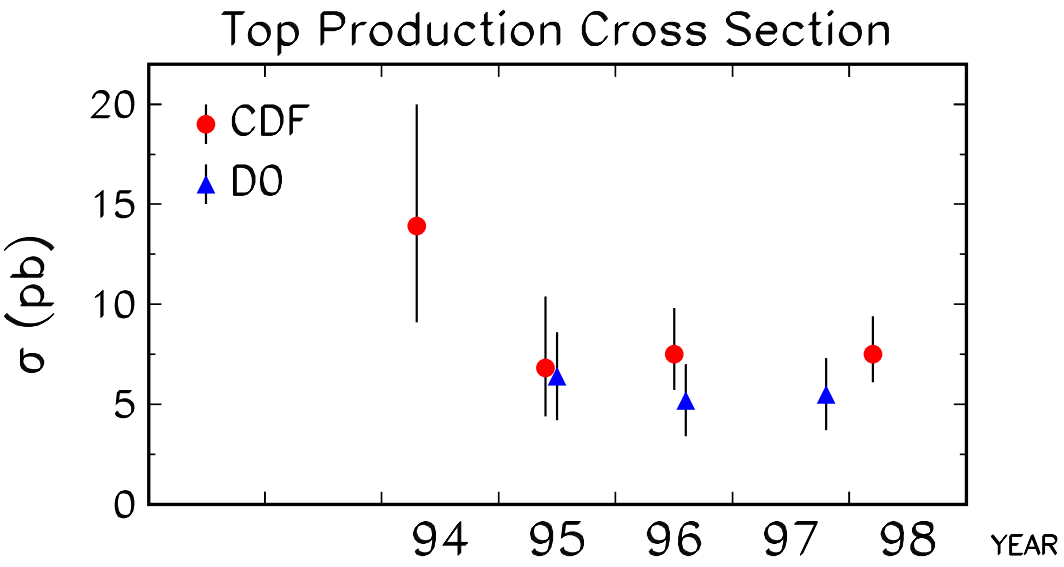
$$M_{top} = 175.9 \pm 4.8(\text{stat}) \pm 5.3(\text{syst}) \text{ GeV}/c^2$$

Combining this with the measurments in the dilepton and all-hadronic channels,

$$M_{top} = 176.0 \pm 6.5 \text{ GeV}/c^2 \text{ (CDF)}$$

Comparison between CDF and D0

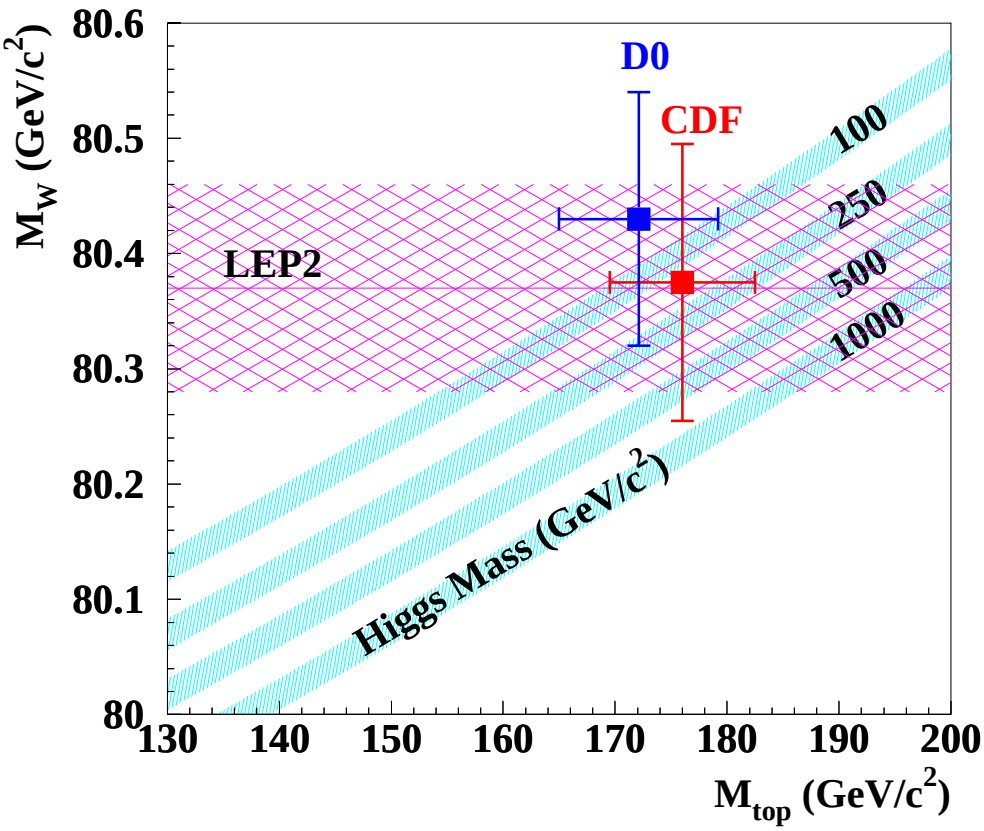




CDF + D0 Combined Top Mass

$$M_{top} = 174.3 \pm 3.2(\text{stat}) \pm 4.0(\text{syst}) \text{ GeV/c}^2$$
$$= 174.3 \pm 5.1 \text{ GeV/c}^2$$

M_W vs M_T



Higgs Mass Constraint

From M_{top}(CDF,D0), M_W(CDF,D0,LEPII) and other electroweak results at LEP and SLC

- $M_H = 76^{+85}_{-47}$ GeV/c^2
- $M_H < 262$ GeV/c^2 at 95% C. L.

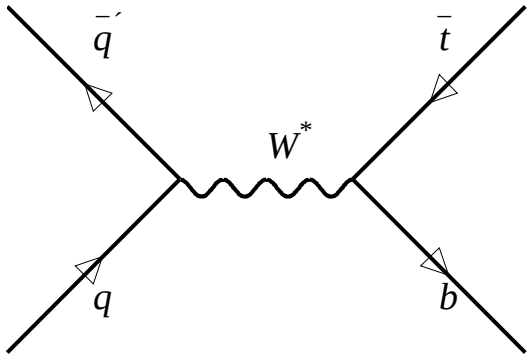
[ref] LEP Electroweak Working Group, CERN EP/99-15.

Search for single top quark production

s-channel W^* process

σ_{theory} = 0.73 pb

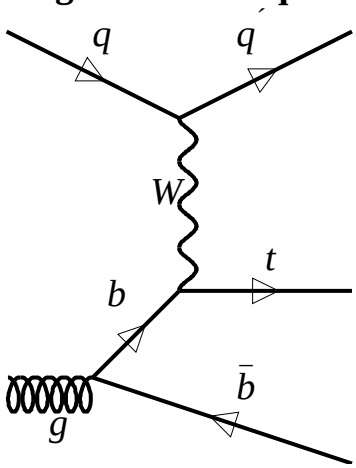
Signal is W+b+$\bar{b}$



W-gluon fusion process

σ_{theory} = 1.70 pb

Signal is W+b+q



- Event selection
  - Isolated lepton $E_T \geq 20$ GeV
  - Missing $E_T \geq 20$ GeV
  - Exactly two jets with uncorrected $E_T \geq 15$ GeV and $|\eta| \leq 2$.
  - Standard Z and top dilepton removal

W^* signal search:

at least one b-tagged jet

W-gluon fusion signal search:

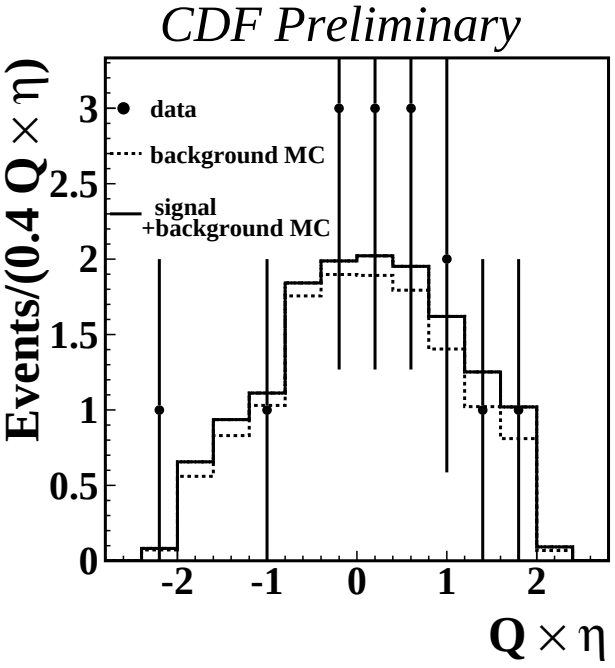
only one b-tagged jet + top mass window cut

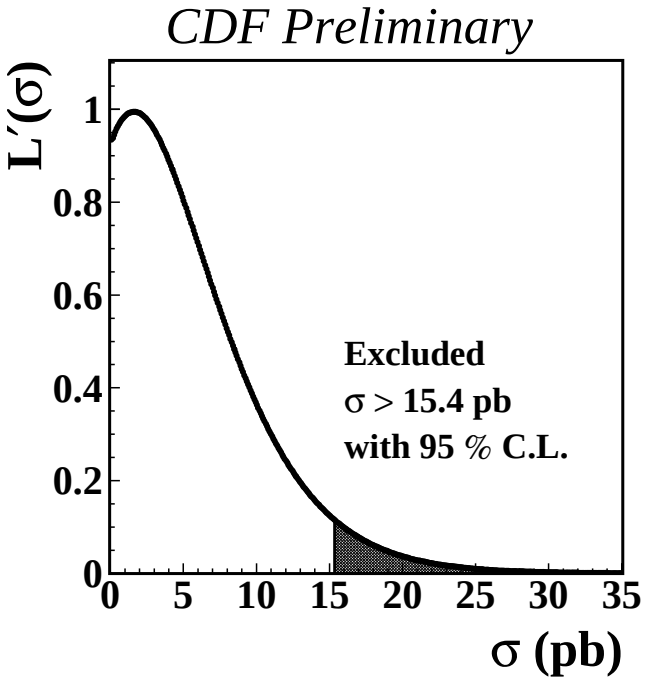
W-gluon fusion single top search

Candidate : 15 events
Expected background ($Wb\bar{b}$, $t\bar{t}$ ...)
: 12.9 ± 2.1 events
Expected signal : 1.2 ± 0.3 events

Perform a likelihood fit of $Q \times \eta$ distribution:

Fitted background : 13.1 ± 1.9 events
Fitted signal : 1.4 $^{+4.2}_{-3.4}$ events





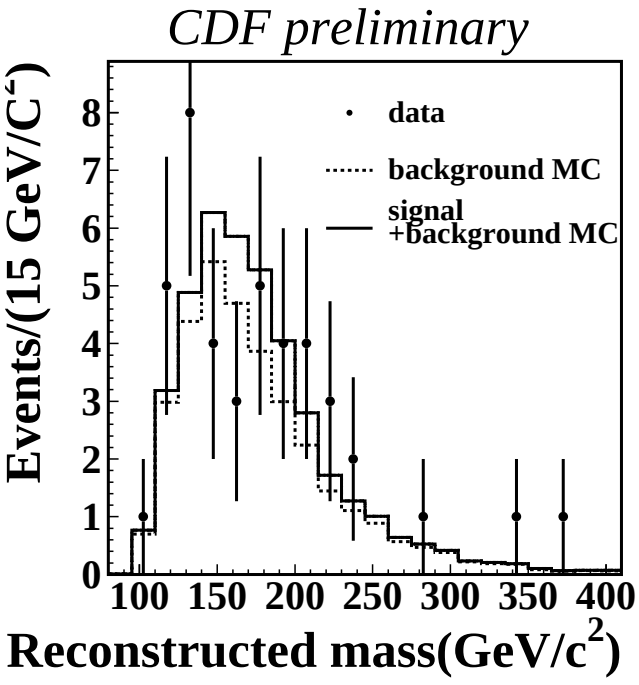
Q: lepton charge (± 1)
η: untagged jet pseudo-rapidity

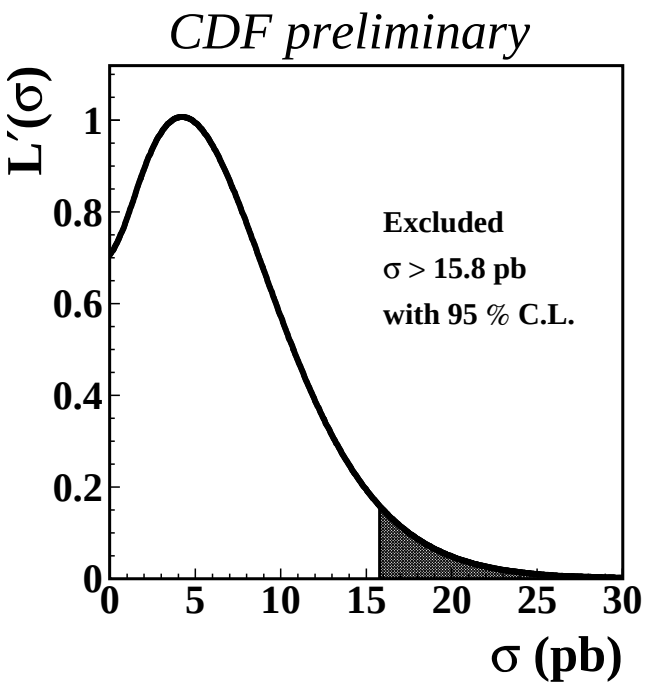
W^* single top search

Candidate : 42 events
Expected background : 31.3 ± 4.7
Expected signal : 1.0 ± 0.3

Perform a likelihood fit of reconstructed top mass distribution:

Fitted background : $33.0\ ^{+4.4}_{-4.3}$
Fitted signal : $6.6\ ^{+7.3}_{-6.5}$





Top Quark Physics in RUN2

- Accelerator Upgrade
  - CM Energy:
    - 1.8TeV $\rightarrow$ 2.0TeV ($\sigma_{t\bar{t}}$: $\times$ 1.4)
  - Integrated Luminosity:
    - 0.1 fb^{-1} $\rightarrow$ 2 fb^{-1} ($\times$ 20)
- Detector Upgrade (CDF)
  - Acceptance for $t\bar{t} \rightarrow W(\rightarrow \ell\nu)+ \geq 3$ jets:
    - 8.7% $\rightarrow$ 10% ($\times$ 1.15)
  - b-tagging efficiency for $t\bar{t} \rightarrow W(\rightarrow \ell\nu)+ \geq 3$ jets:
    - 52% $\rightarrow$ 86% ($\times$ 1.65)

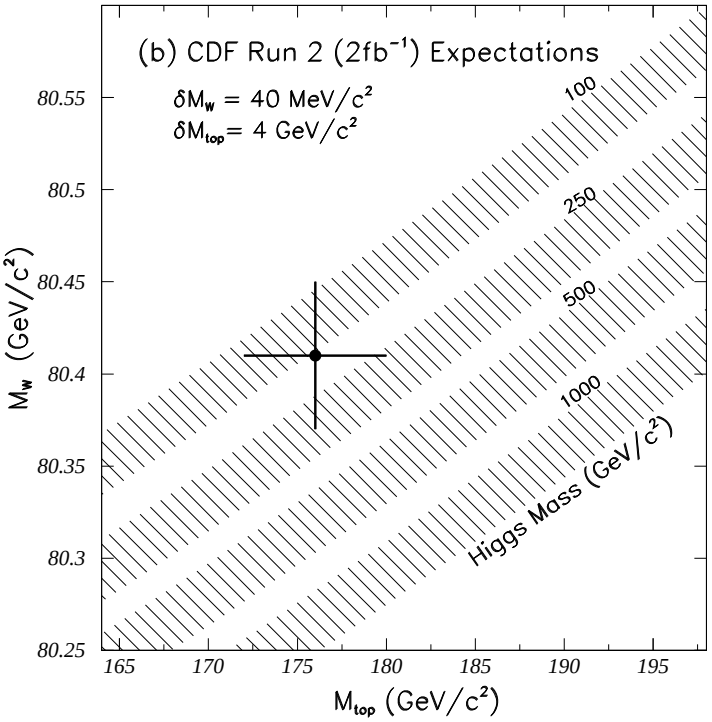
From the above, we have 50 times higher rate of $t\bar{t} \rightarrow W(\rightarrow \ell\nu)+ \geq 3$ jet events with one b-tagged jet in RUN2 (2fb^{-1}).

Number of $t\bar{t}$ events in RUN2(CDF)

- $W(\rightarrow \ell\nu)+ \geq 4$ jets (1 b-tag): $\sim$ 1,000
- $W(\rightarrow \ell\nu)+ \geq 4$ jets (2 b-tags): $\sim$ 500

CDF RUN2 (2fb^{-1})

- Top Quark Mass: $\Delta M_{top} \sim 3\text{GeV}/c^2$
- $\sigma_{t\bar{t}}$: $\Delta\sigma/\sigma \sim 9\%$
- Γ_{top} from $q\bar{q} \to W^* \to t\bar{b}$ and $gW^* \to t\bar{b}$: $\Delta\Gamma/\Gamma \sim 25\%$
- V_{tb} : $\Delta|V_{tb}|/|V_{tb}| \sim 13\%$
- New Particle Search such as $t \to H^+ b$ or $X \to t\bar{t}$.



From M_{top}(Tevatron RUN2), M_W(Tevatron RUN2,LEPII) and other electroweak results at LEP and SLC,

$$\Delta M_H/M_H \sim 30\%$$

[Ref] TEV2000 Rroup Report FERMILAB-PUB-96/082 and Light Higgs Working Group Report at SNOWMASS 96.