The Top Quark Search

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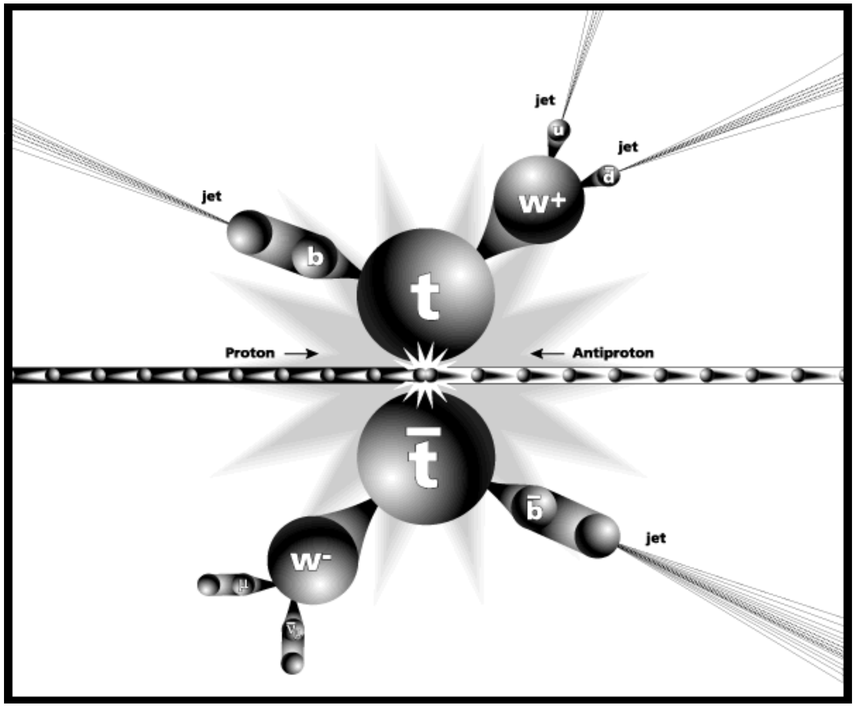
Outline



- Review of Quarks
- Predictions of Top Mass
- Tevatron Run I
- Production, Decay and Detection of Top Quark
- Future Experiments

Brief History of Quarks

- 1961: Gell-Mann and Nishijima developed notion of quarks independently.
- By 1977, five quarks had been observed.

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} ? \\ b \end{pmatrix}$$

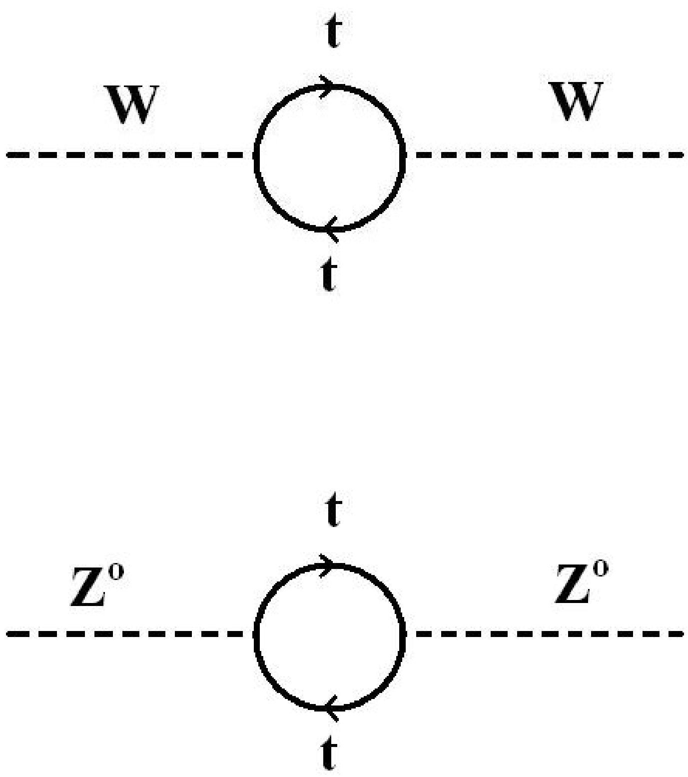
Brief History of Quarks

- 1961: Gell-Mann and Nishijima developed notion of quarks independently.
- By 1977, five quarks had been observed.
- The standard model predicted a sixth, the top quark.

$$\begin{pmatrix} \mathbf{u} \\ \mathbf{d} \end{pmatrix} \quad \begin{pmatrix} \mathbf{c} \\ \mathbf{s} \end{pmatrix} \quad \begin{pmatrix} \mathbf{t} \\ \mathbf{b} \end{pmatrix}$$

Mass of the Top Quark

- The mass of the top quark is related to the masses of the W and Z bosons through higher order Feynman diagrams.
- By analyzing these and other diagrams, one can estimate the top mass.



Mass of the Top Quark

- Another way to estimate m_t is through the unification of electromagnetic and weak interactions.
- Examining neutral and charged currents, we can define a parameter ρ_0.

$$\rho_0 = \frac{m_W^2}{m_Z^2 \cos^2\Theta_W}$$

Mass of the Top Quark

- The standard model predicts that $\rho_0 = 1$ at the tree level, but higher order terms introduce a correction of $\Delta\rho_0$.

$$\Delta\rho_0 = \frac{3G_\mu m_t^2}{8\pi^2\sqrt{2}} = 0.006\left(\frac{m_t}{140\text{ GeV}}\right)^2$$

- Experiments do show a measurable $\Delta\rho_0$.

Mass of the Top Quark

- Through these procedures, and others, the top mass predicted by the standard model is:

$$m_t = 178.1\ ^{+10.4}_{-8.3}\ \text{GeV}$$

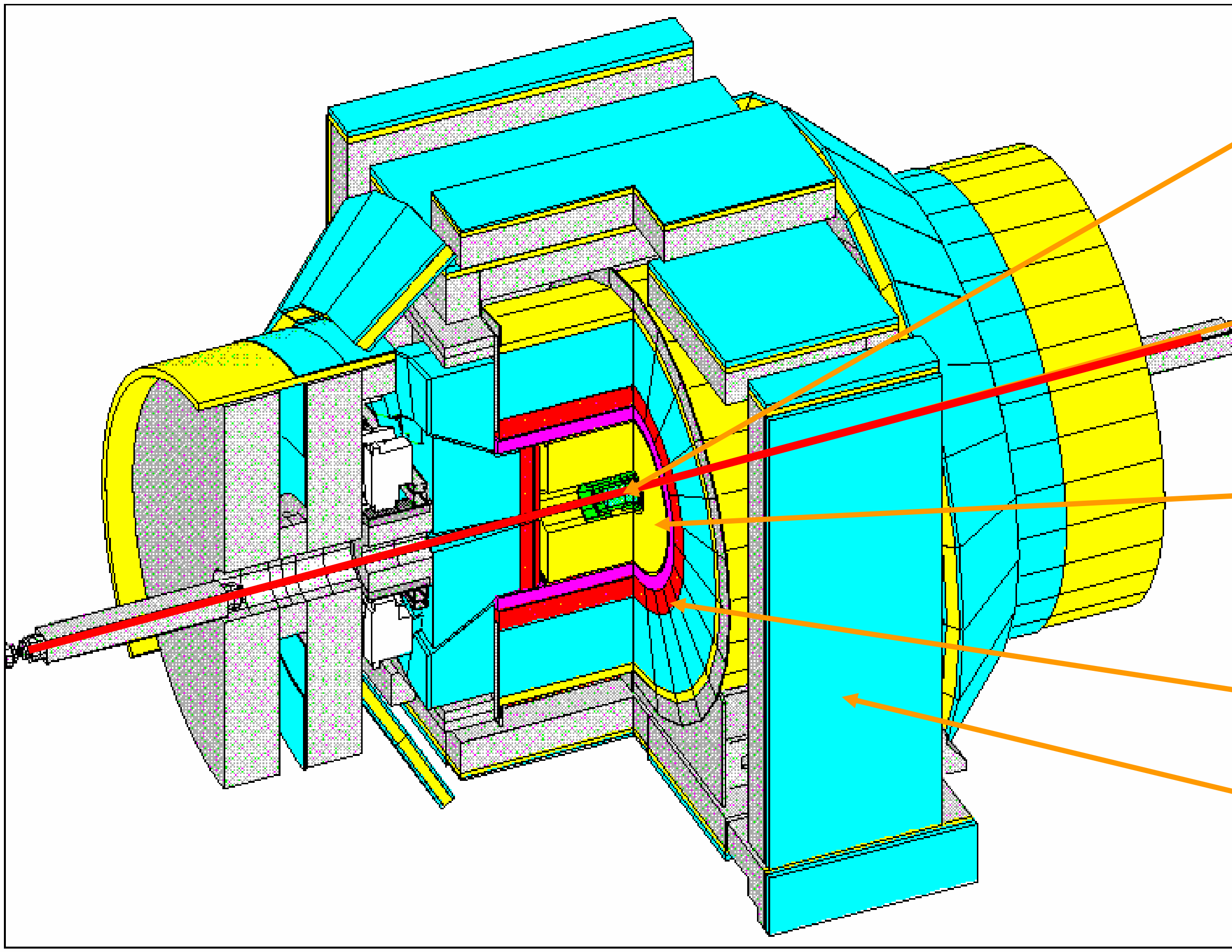
Tevatron Experiments

- Proton-antiproton collider at Fermilab
- Two detectors: CDF and DØ
- Run 1:

1992-1996

E_{cm} = 1.80 TeV

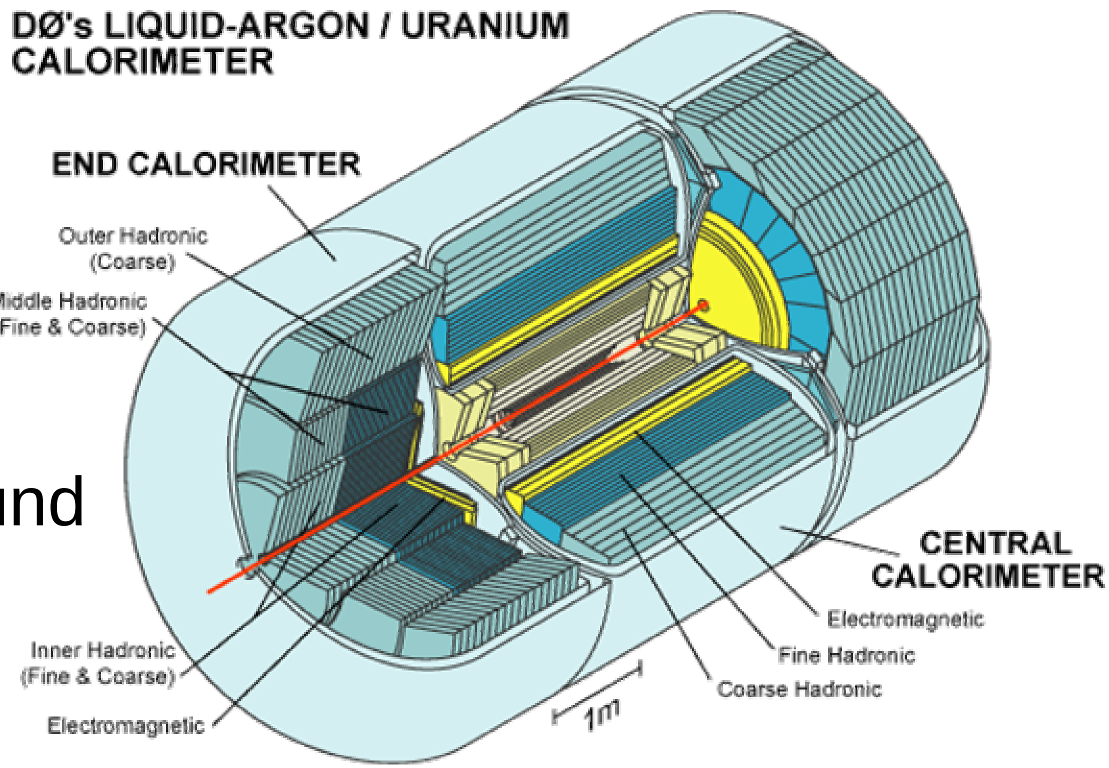
The CDF-II Detector



- $p\bar{p}$ collision point
- Vertex detector
- Tracking chamber
- Calorimeter
- Muon chambers

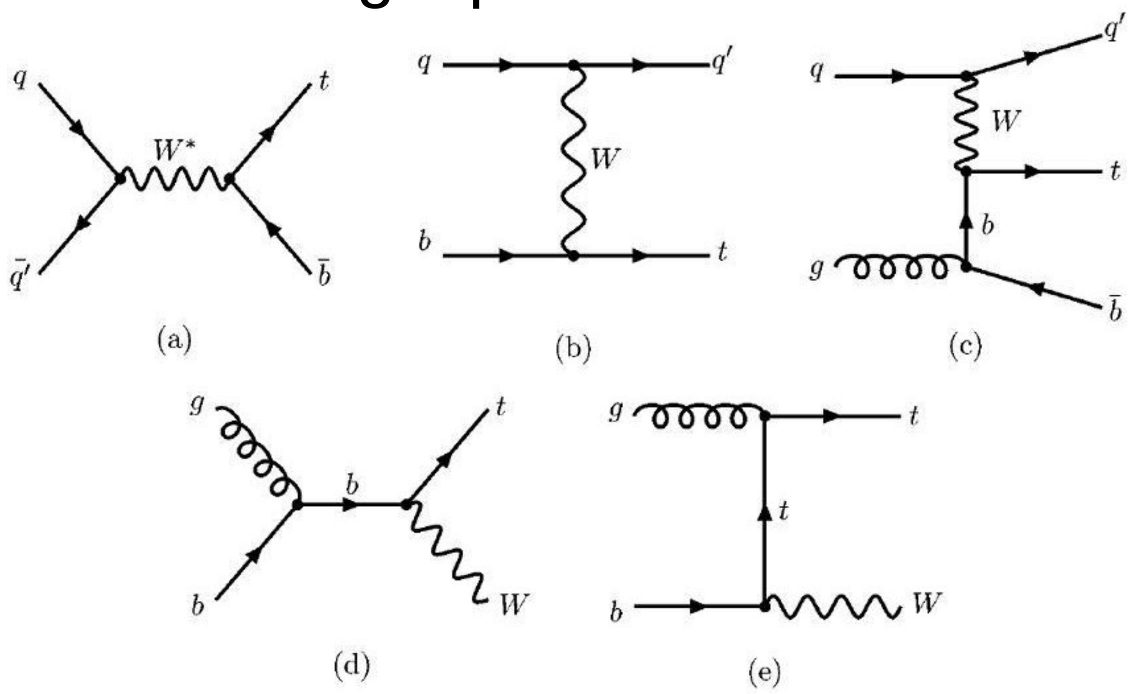
DØ Detector

- The muon chambers surround the calorimeter.



Top Quark Production

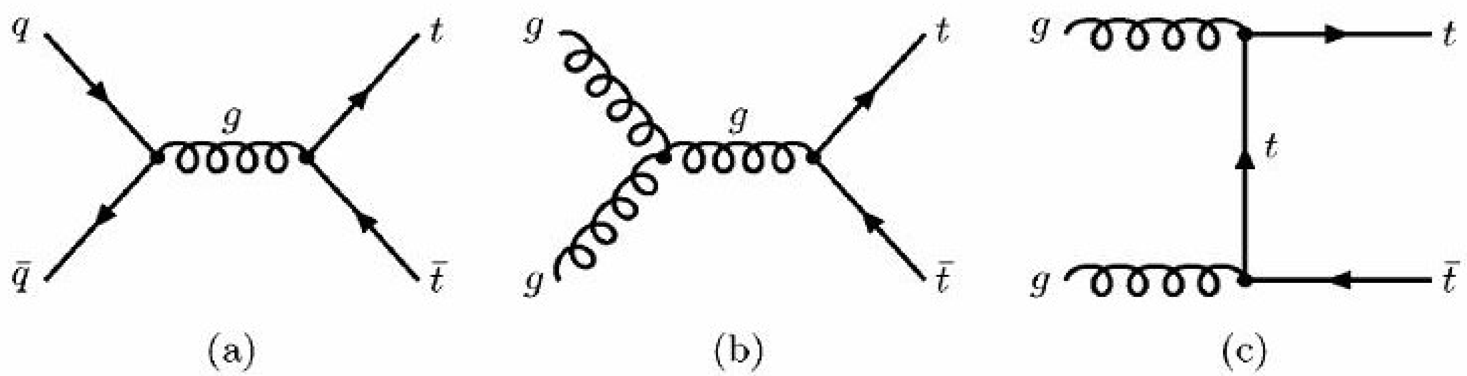
- Tops can be produce through electroweak interactions as single particles.



Leading-order Feynman diagrams for electroweak production of single top quarks: (a) s channel, (b; c) t channel, and (d; e) associated production with a W.
(From Chakraborty et al)

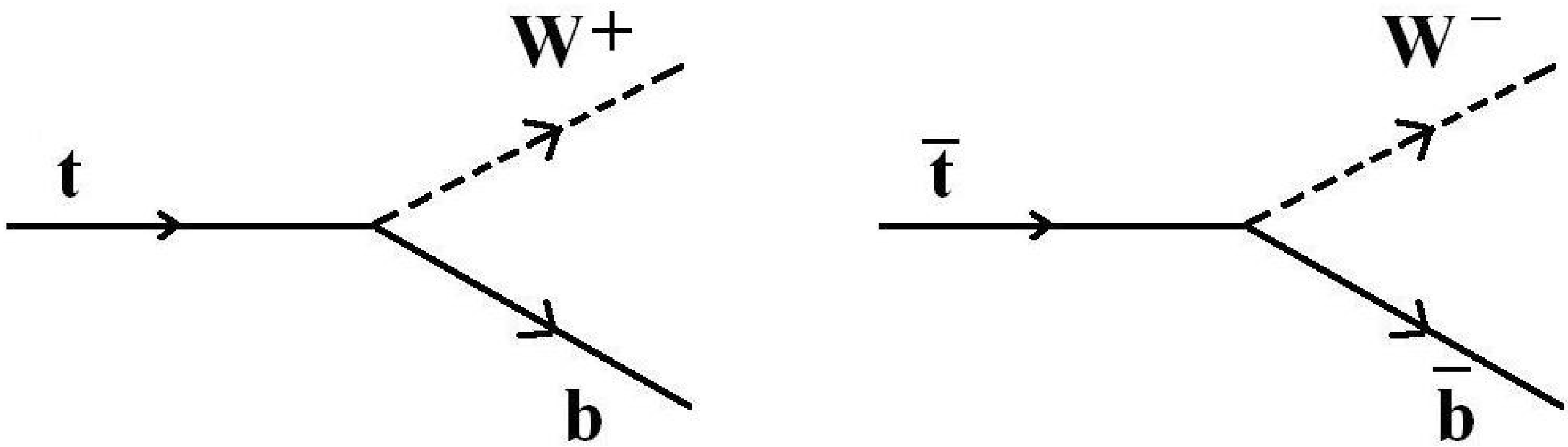
Top Quark Production

- At the tevatron tops are produced as quark-antiquark pairs.



Leading-order Feynman diagrams for strong-interaction production of $t\bar{t}$ pairs.
(From Chakraborty et al)

Top Quark Decay



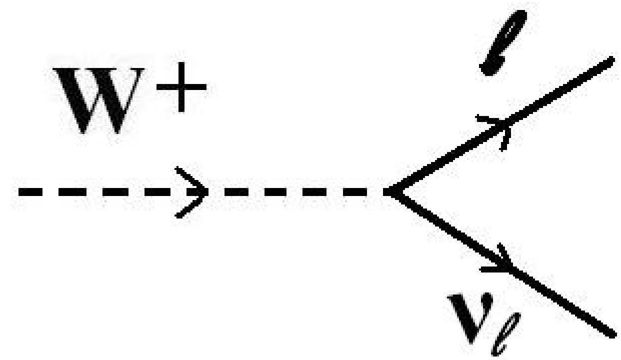
- The top quark decays into a W boson and a bottom quark.

Top Quark Decay

- The b creates a “jet” of particles.
- This jet begins a small but measurable distance from the collision.

Top Quark Decay

- The W decays leptonically about 1/3 of the time.
- The branching ratios for each of the three lepton-neutrino pairs (electron, muon, and tau) are about equal.



Top Quark Detection

- The other two-thirds of the time, the W decays hadronically.
- $W^+ \longrightarrow u\bar{d}$ or $W^+ \longrightarrow c\bar{s}$, each with the same branching ratio (due to the large mass of W).
- Each of these quarks initiate jets.

Top Quark Detection

- Top quark pair events can result in different numbers of jets.

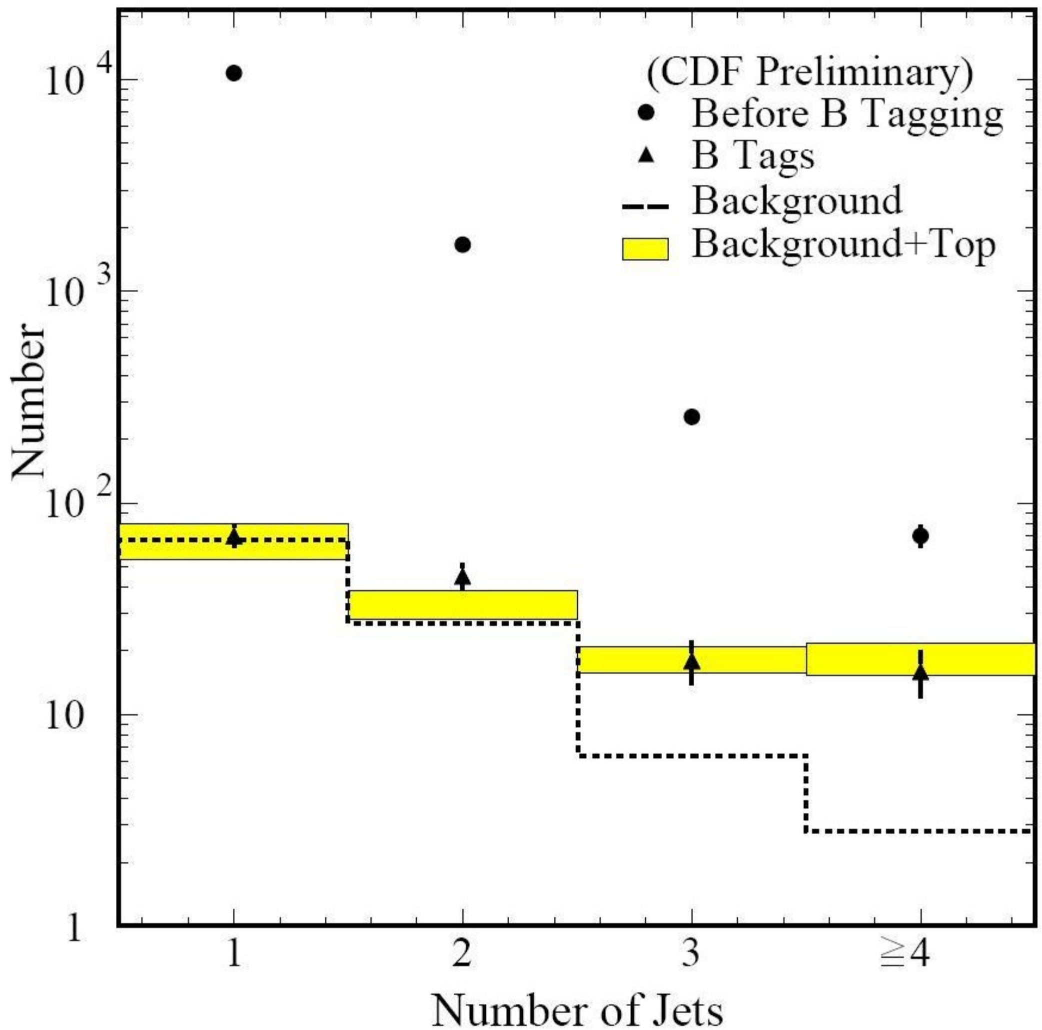
- There are three main types of top pair events:

1. Dilepton – Both W decay to leptons. Only two jets, from the b quarks.
2. Single-Lepton – One W decays to leptons, other to quark pair. Four jets.
3. All-Hadronic – Both W decay to quarks. Six jets.

Top Quark Detection

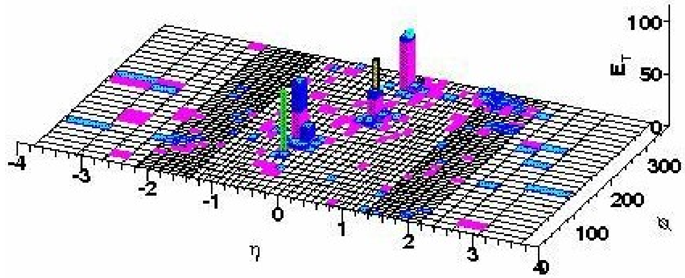
- There is a relatively high background, as other particles can be created in the collision.
- Events that resemble top production are recorded for analysis.
- These events are selected through an automatic triggering system.

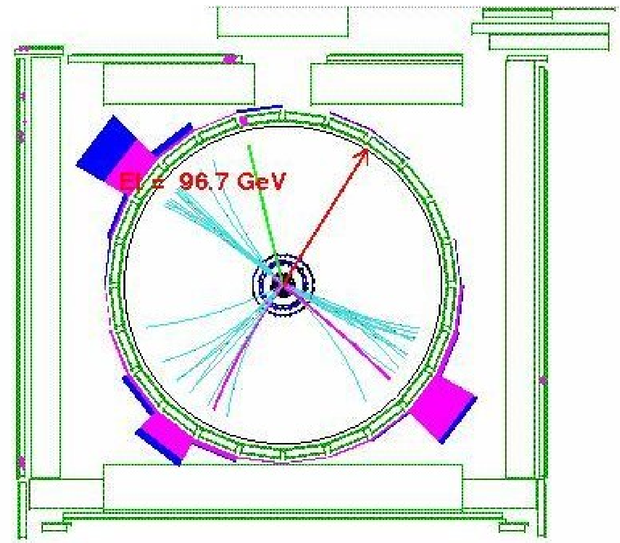
Background



The CDF jet multiplicity distribution of SVX-tagged lepton+jets events.
(From 'Top Quark Physics At The Tevatron," Bhat et al)

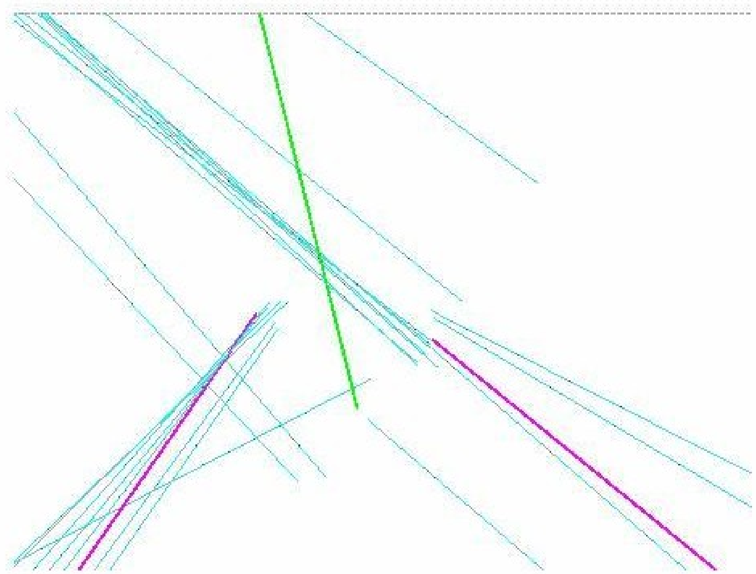
Top Pair Event



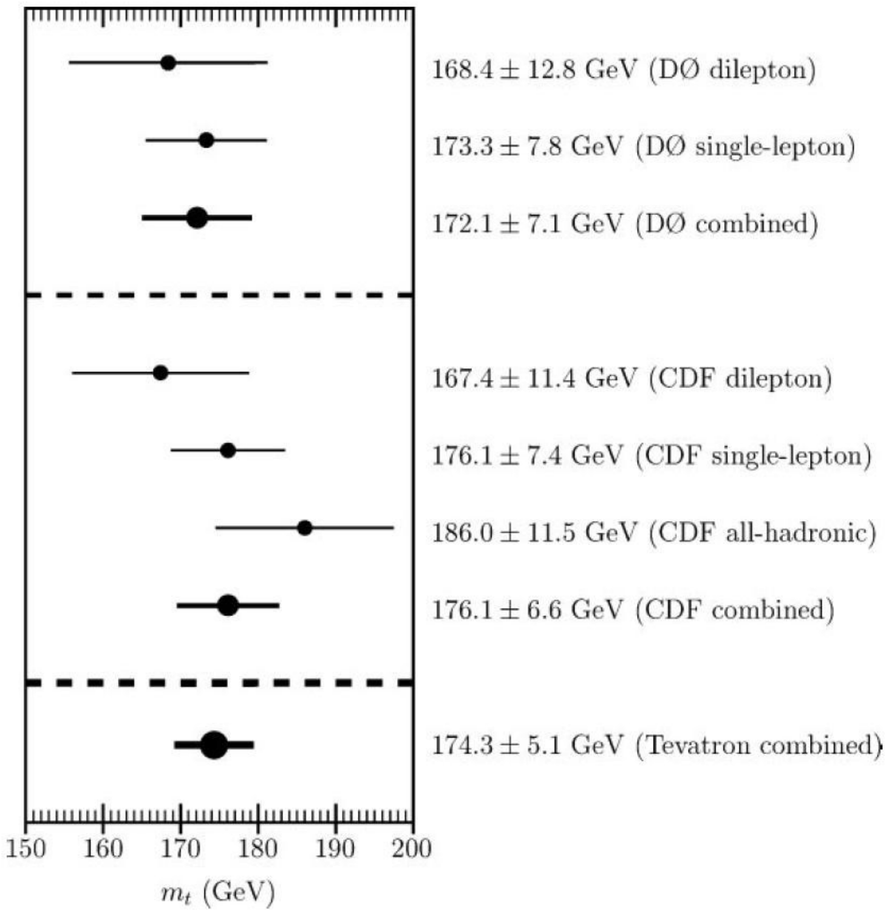


Run 153693, Event=799494 [top μ-jet candidate]

- $P_t(\mu) = 54.4$ GeV | CMUP
- $E_t(jet) = 96.7, 65.8, 54.8, 33.8$ GeV (4jets)
- $MET = 40.8$ GeV
- $H_t = 346.3$ GeV
- Two bjets : $L_{xy}/\sigma = 10.8$ (1st jet), 21.9(3rd jet)



Top Mass Findings



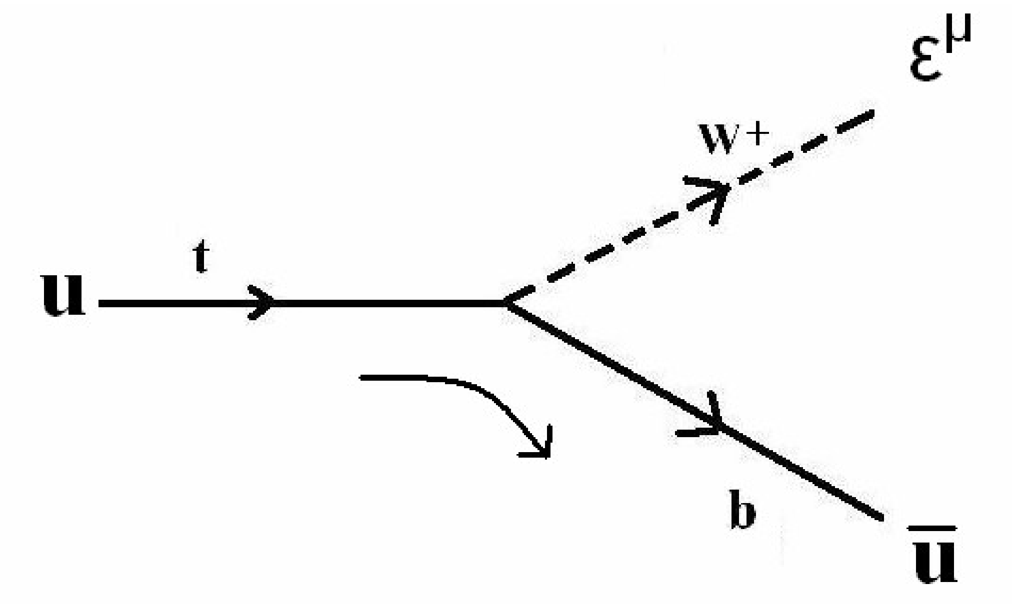
Tevatron measurements of top mass in different final states, and the combined result.
(From Chakraborty et al)

Lifetime of the Top Quark

- The lifetime can be related to the width by

$$\tau = \hbar/\Gamma$$

- By analyzing the following diagram, we can find the width.



Lifetime of the Top Quark

- We find that:

$$\Gamma(t \to Wb) = \frac{G_F}{8\pi\sqrt{2}} m_t^3 |V_{tb}|^2 \left(1 - 3\frac{m_W^4}{m_t^4} + 2\frac{m_W^6}{m_t^6}\right)$$

$$\Gamma(t \to Wb) = 1.56 \text{ GeV}$$

- This leads to a lifetime of ~ 4 x 10^{-25} s

Future Experiments

- Tevatron Run 2 (in progress) 2001-2009

  $p\,\bar{p}$ $E_{cm} = 1.96$ TeV
- Large Hadron Collider (LHC) 2007?

  $p\,p$ $E_{cm} = 14.0$ TeV

  Production on order of ten million per year.
- Linear e^- / e^+ collider ?

  $E_{cm} \sim 1.0$ TeV

  No QCD background, polarizable beam.

Questions?