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Measurement of the Top Quark Charge at D∅

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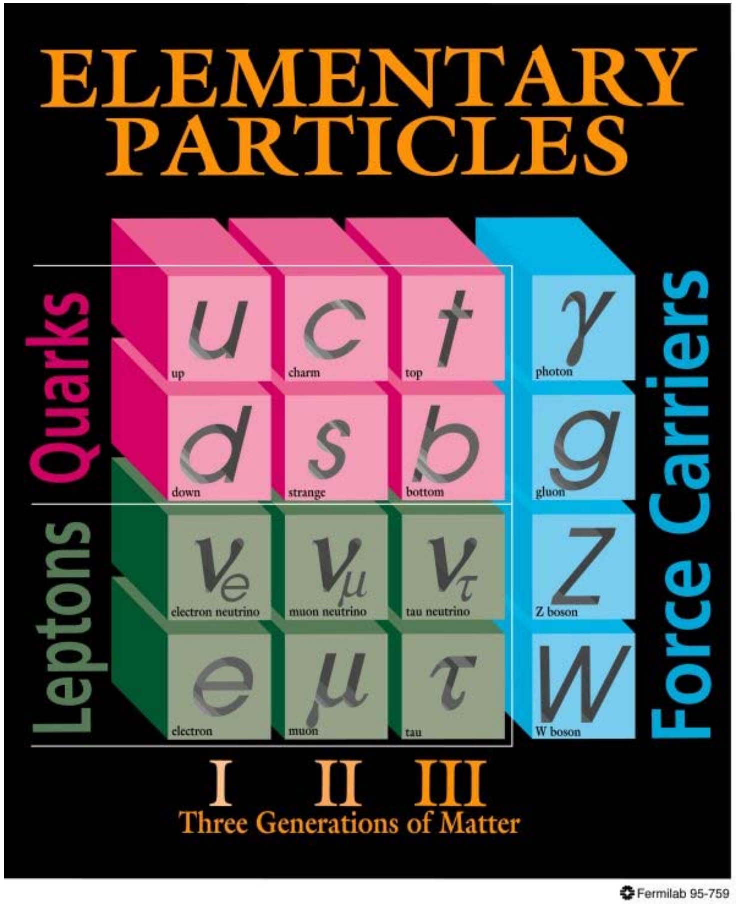
Session I13 DPF
Top Quark Properties

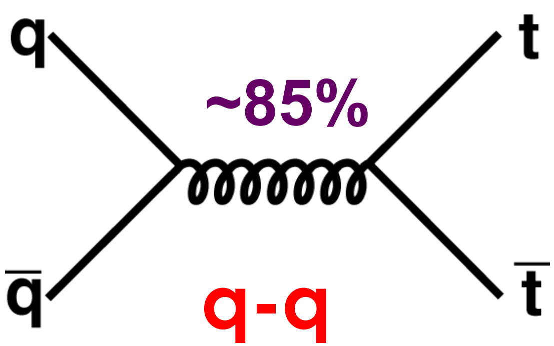
On behalf of the D∅ Collaboration

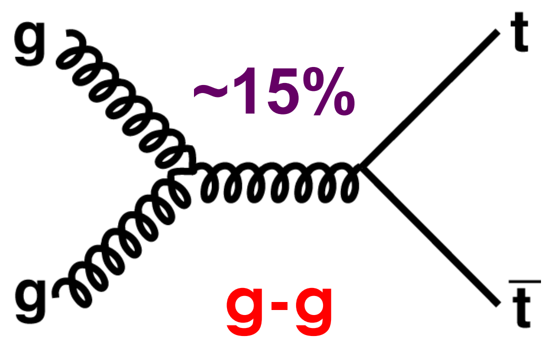
What is the top quark?

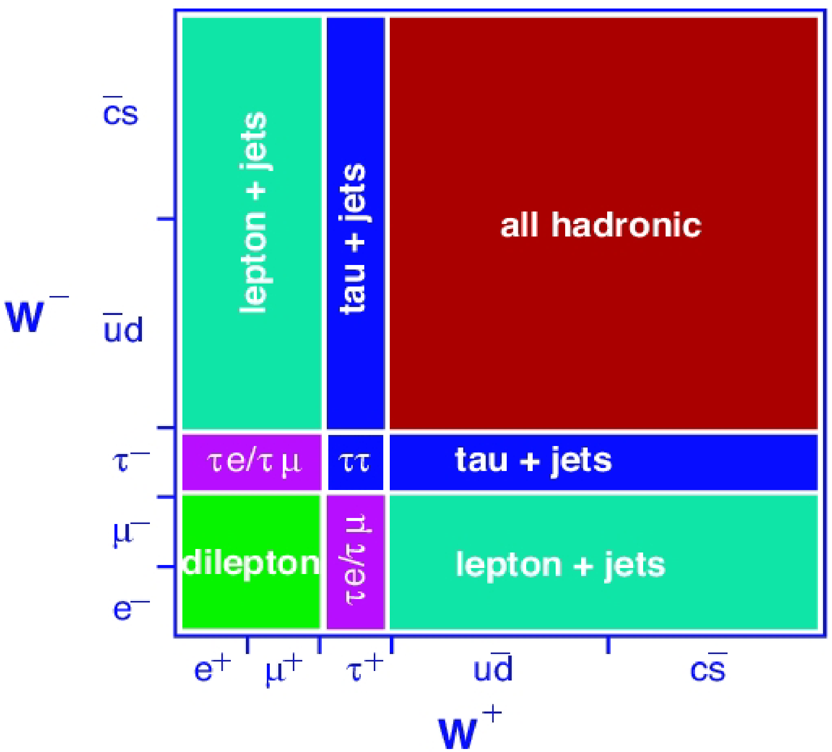
- Discovered in 1995 by both the CDF and DØ collaborations at the Fermilab Tevatron proton-antiproton collider.
- PRL74/2626 (1995) CDF, PRL74/2632 (1995) DØ.
- The top quark is one of the fundamental fermions of Nature.
- The production cross section and mass have been well measured.
- Other properties (not well known):
  - Spin
  - Electric Charge (SM top quark has charge 2/3)



Top quark physics

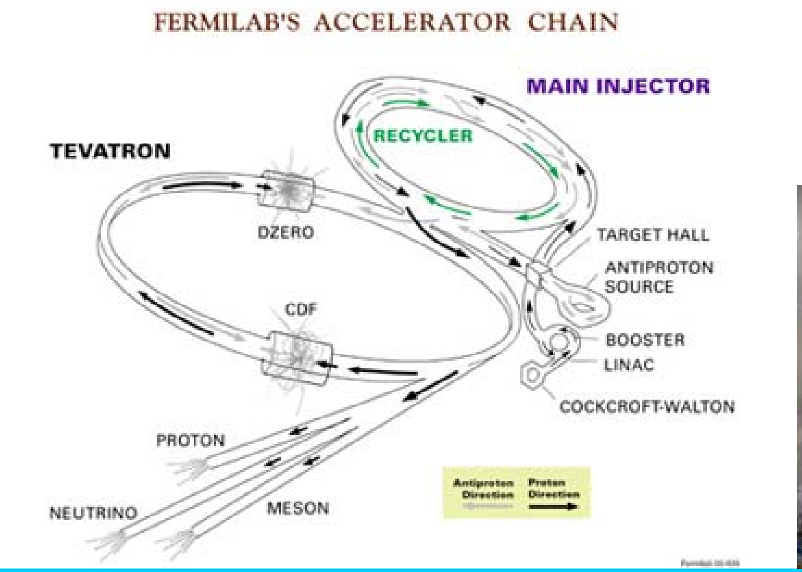






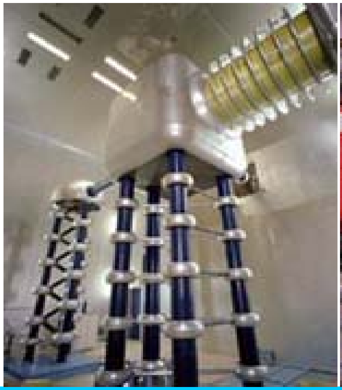
- W decay modes are used as labels for the top quark final state:
  - *Br* ($t \rightarrow Wb$) ≅ 100%
  - Lepton (e or μ) + jets
    - One W boson decays leptonically, the other decays hadronically
    - BR = 34%
    - Background: Multijet, W+jets

Fermilab and the Tevatron



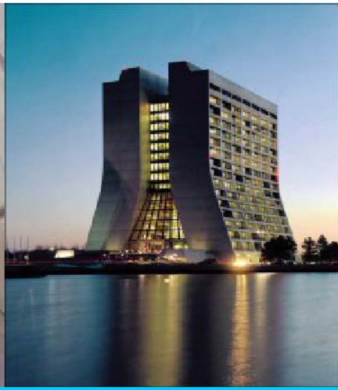
- Uses superconductive magnets to collide protons and antiprotons.
- Situated in four mile long underground tunnel.
- Center of mass energy of 1960 GeV.
- Highest energy accelerator in the world!
- World record for hadron collider peak luminosity of L=171E30 $cm^{-2}s^{-1}$!
  - Previous record held by CERN Intersecting Storage Ring (ISR) of 140E30 $cm^{-2}s^{-1}$.

Cockcroft-Walton



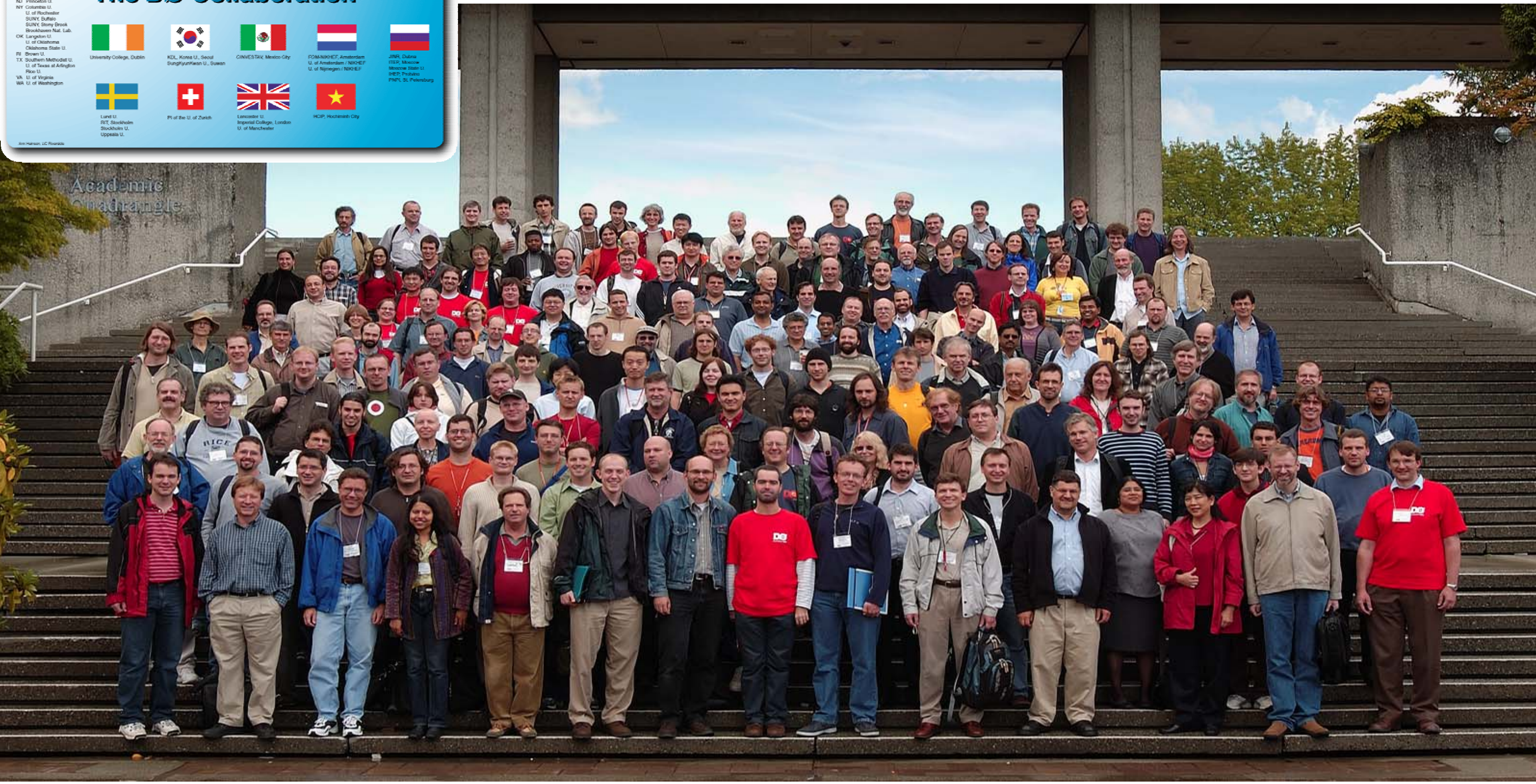
Tevatron

Wilson Hall

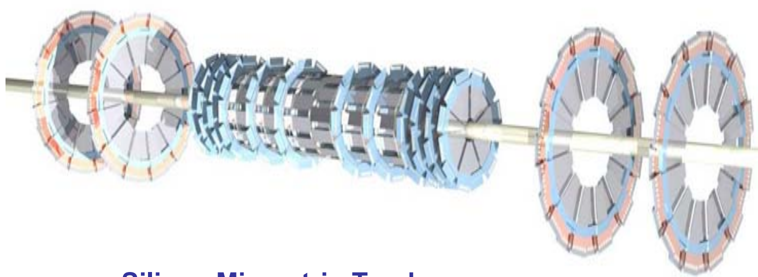


The DØ Collaboration

- 19 countries, 80 institutions, 670 physicists



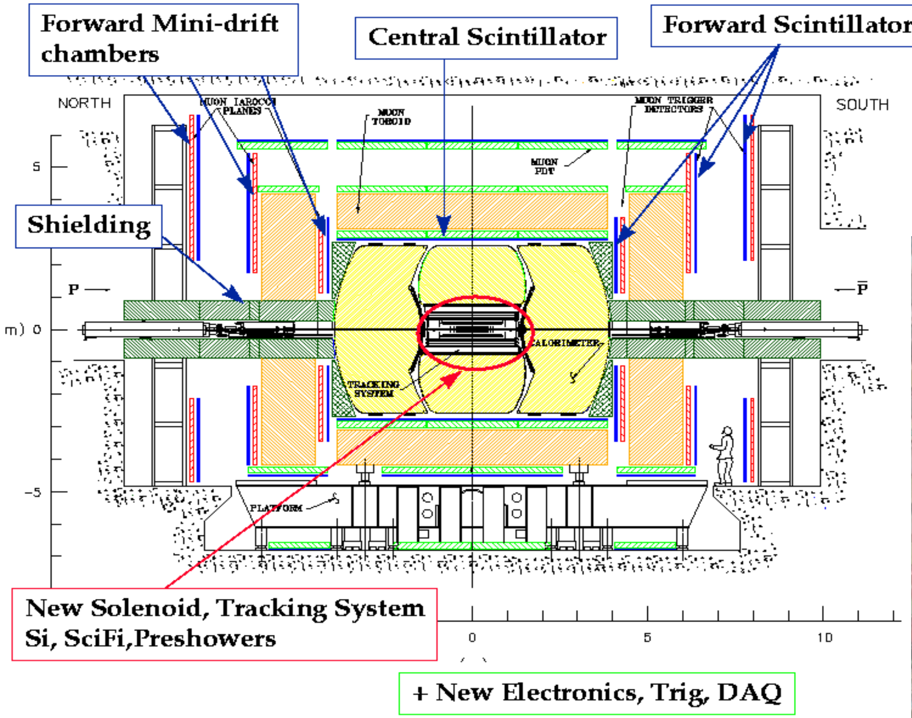
The DØ Detector



Silicon Microstrip Tracker

- **High precision tracking detector:**
  - **Silicon vertex detector.**
  - **Central fiber tracker.**
- **Solenoid magnetic field of 2 T.**
- **Liquid argon calorimeter:**
  - **Electron/jet identification.**
- **Drift chambers for muon identification.**

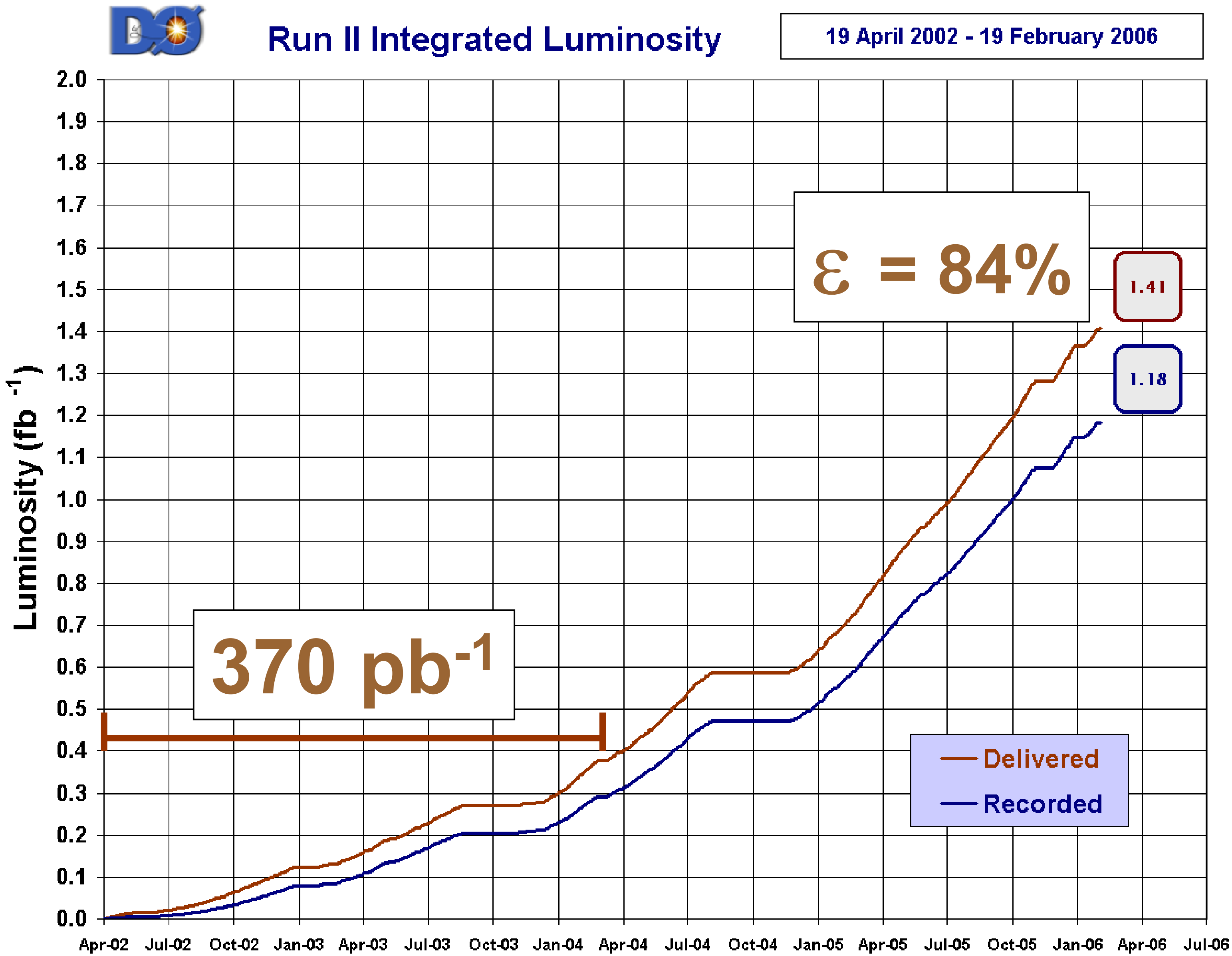
DØ Control Room



End view of calorimeter

A True Masterpiece

Tevatron and DØ Performance

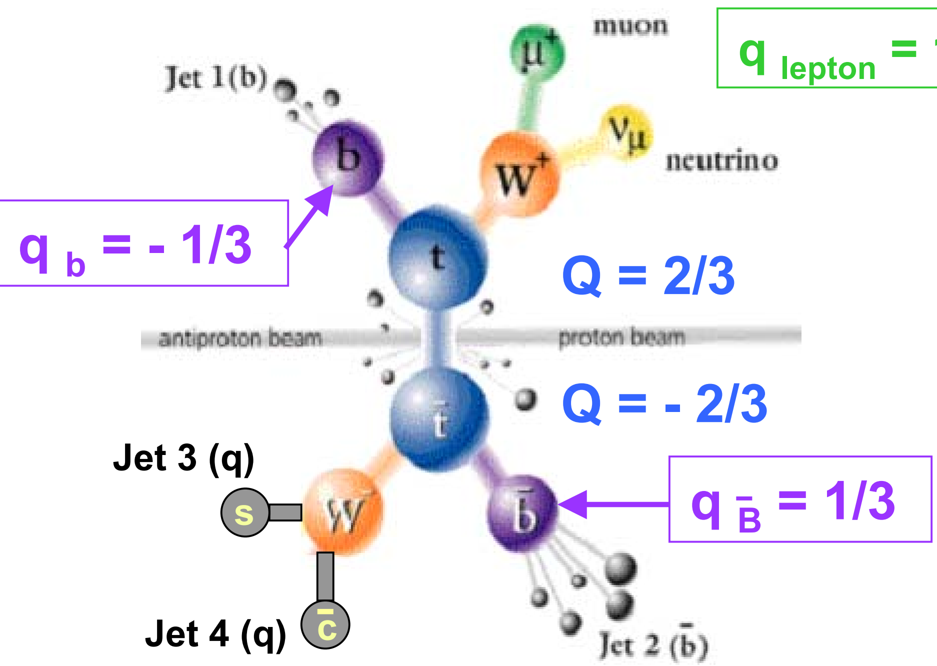


Analysis strategy

- The measurement of the charge occurs in 4 steps:
  - Selection of a pure sample of top quark events
    - Use lepton plus jets final states
      - Large statistical sample
      - Large signal to background ratio
      - Use b-quark tagging to enhance purity
        - » Require 2 b-tagged jets in each event
  - Assignment of the correct jet and leptons
    - Two-fold ambiguity in assignment of lepton with b-quark jet
    - Use a constrained kinematical fit:
      - Masses of the W boson and top quarks are used as physical constraints
  - Determine the charge of the b-jet
    - Use convolution of charges of the tracks from the b hadron decay
    - Construct the observables Q_1 and Q_2
  - Use charge templates for the standard model (2/3) and exotic case (4/3) to determine which the data prefers

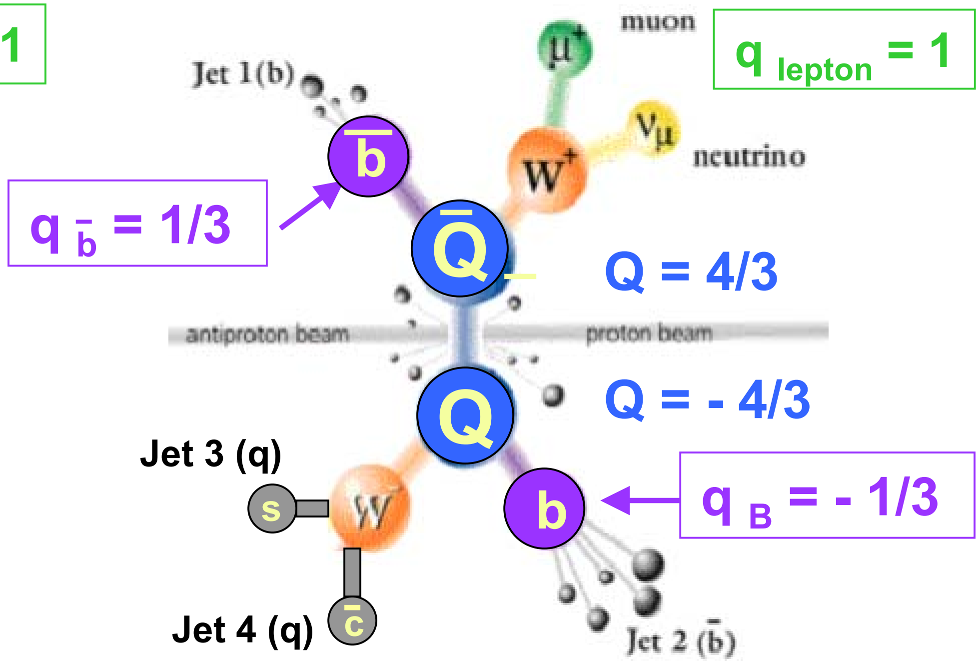
What does one look for?

Standard Model Top Quark



$Q_1 = 2/3,\ Q_2 = 2/3$

Exotic Top Quark



$Q_1 = 4/3,\ Q_2 = 4/3$

PRD 59, 091503 & PRD 61, 037301

- One high P_T lepton: $P_T > 15$ GeV
- Missing transverse energy: $E_T > 15$ GeV
- Four or more jets: $P_T > 15$ GeV

Each scenario has two bottom quarks!

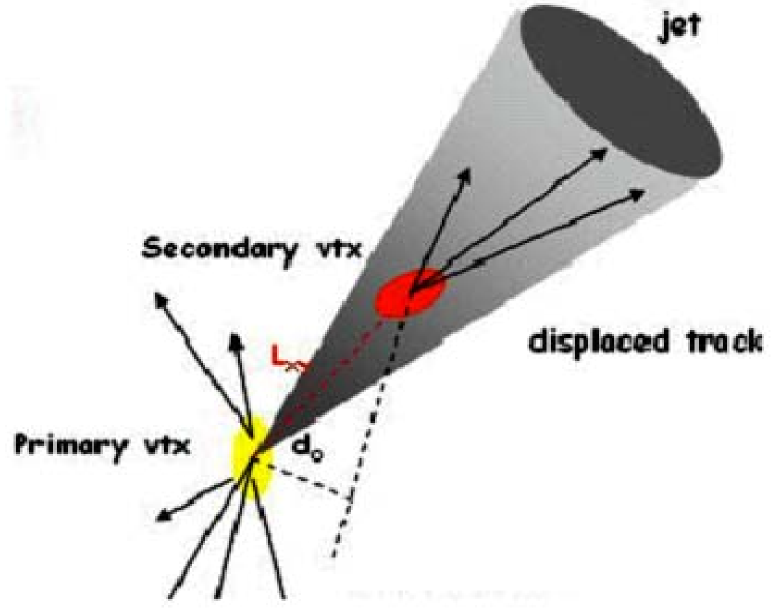
Form two observables:

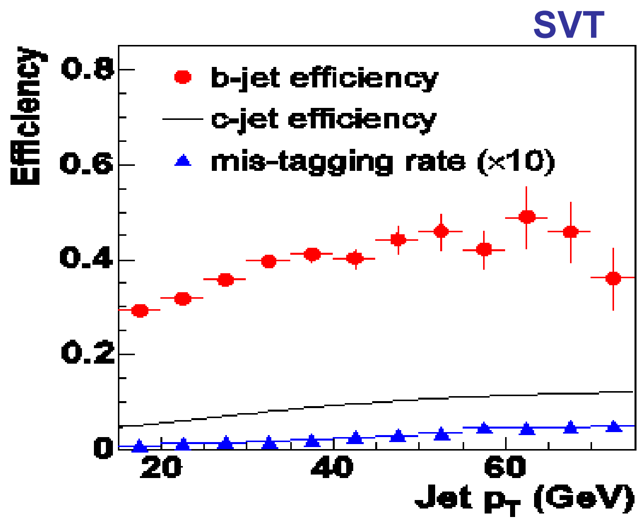
$$Q_1 = |\ q_{lepton} + q_b\ (q_{\bar{b}})\ |$$
$$Q_2 = |\ -q_{lepton} + q_{\bar{B}}\ (q_B)\ |$$

Finding bottom quarks

- A bottom quark is present in all top quark decays.
- The bottom quark forms a B hadron that propagates away from the primary vertex and then decays.
  - Look for tracks that form another vertex separate from the primary vertex.
  - Measure the track's impact parameter.
- Mistag rate, i.e. the probability to tag a jet that did not originate from a bottom quark is 0.025%.
- Efficiencies and mistag rates are determined from data

	W+jets	t-tbar
≥4j, 1 tag	4%	44%
≥4j, 2 tag	0.4%	15%

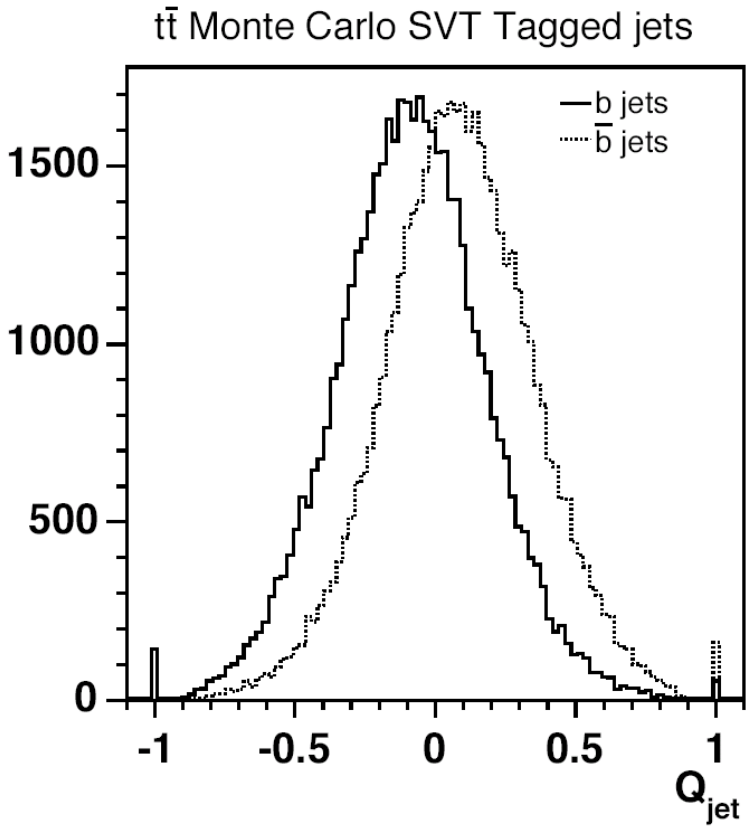




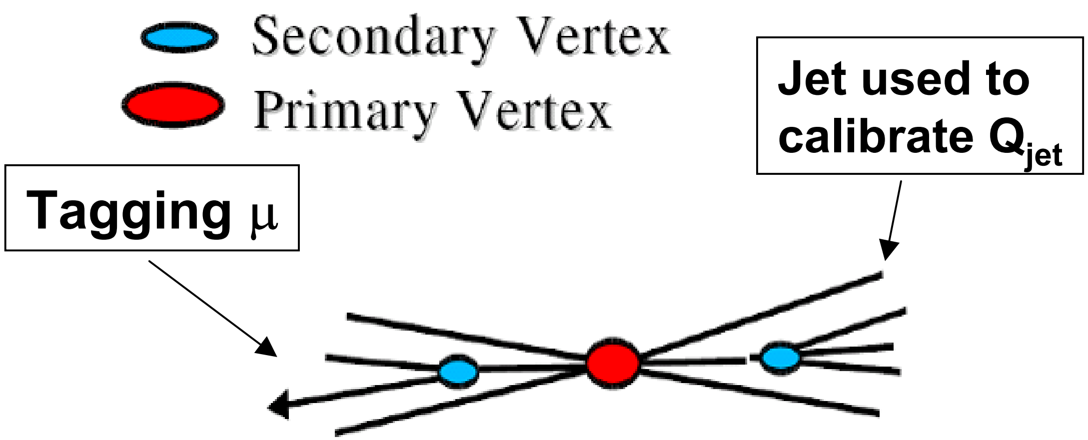
Jet Charge Algorithms

$$Q_{jet} = \frac{\sum_i q_i \cdot p_{T_i}^a}{\sum_i p_{T_i}^a}$$

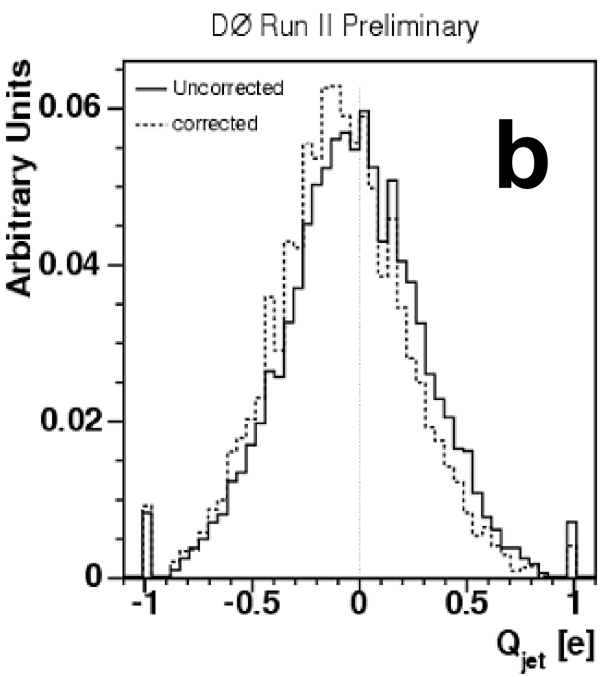
- p_T weighted sum of charged tracks
- Applied only to b-tagged jets
- Optimization of parameters from $t\bar{t}$ simulated events (Monte Carlo)
  - a = 0.6
- Use only tracks with:
  - $p_T > 0.5$ GeV
  - $\Delta R < 0.5$ (jet, track)

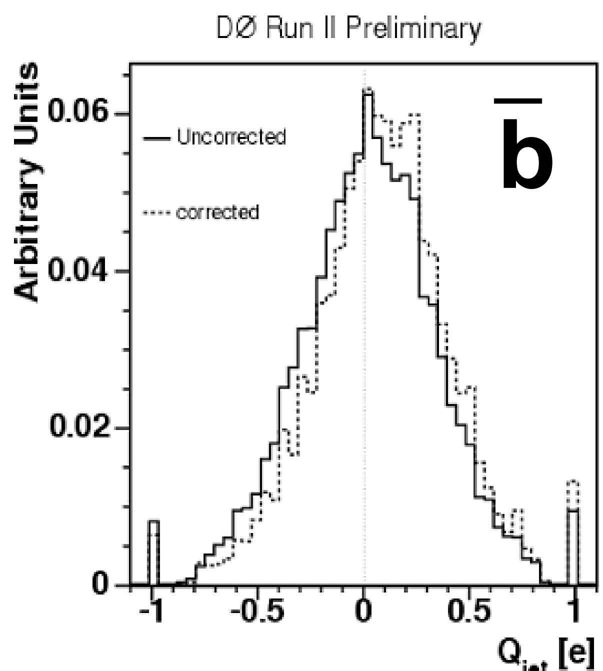


Calibrating Q_{jet} on data



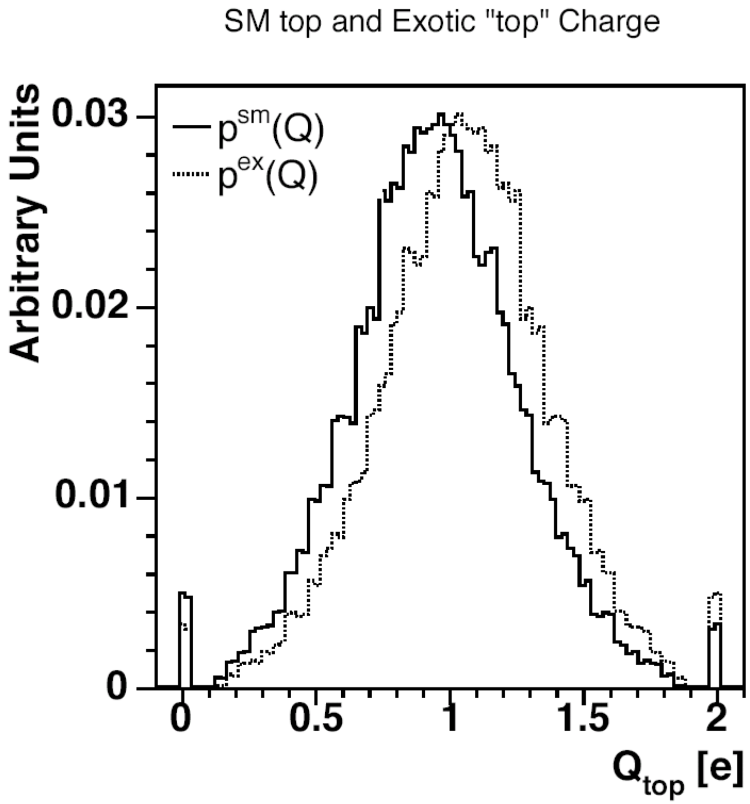
- Use a sample of multijets that are back-to-back:
  - Both are b-tagged
  - One has a muon to determine charge of jet
  - Calibration derived from second jet



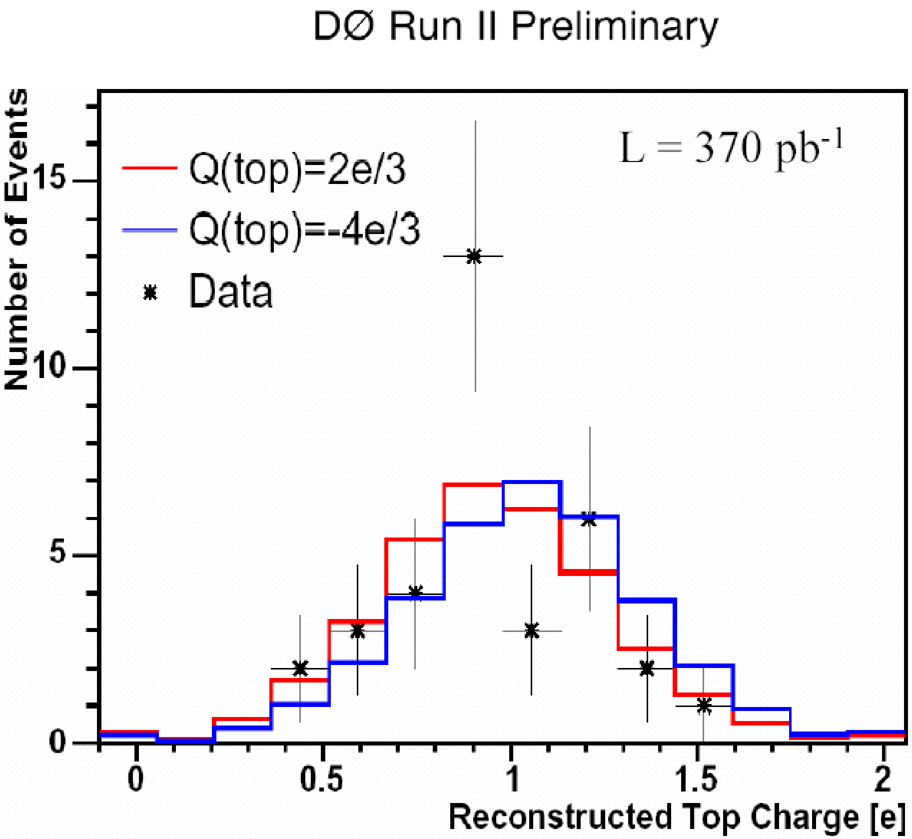


- Correct charge assignment for:
  - B hadron oscillation
  - Cascade decay $b \to c \to \mu$
  - Charm pair production background

Templates and Data



17 fitted double b-tagged events

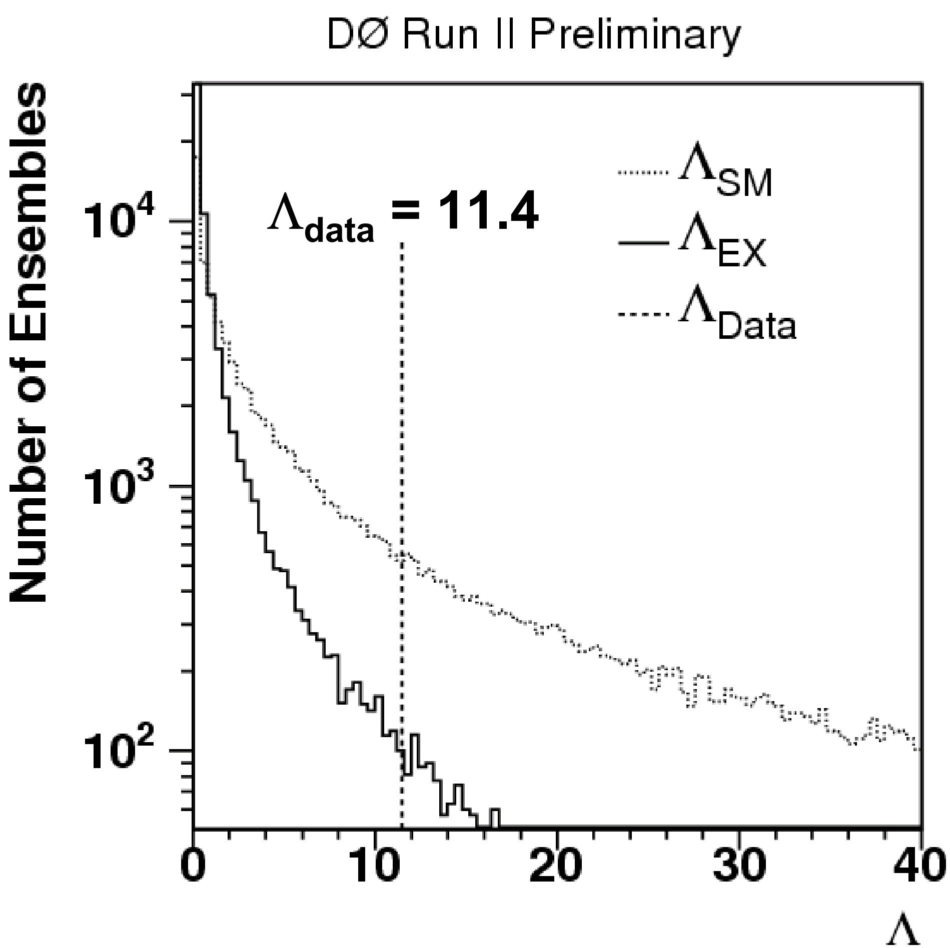


Charge templates for the standard model and exotic top quarks

Limits

$$\Lambda = \frac{\prod_i p^{\mathrm{sm}}(q_i)}{\prod_i p^{\mathrm{ex}}(q_i)}$$

- Form a likelihood ratio
- p^{sm} (q) is the probability to observe top quark charge in standard model
- p^{ex} (q) is the probability to observe top quark charge in exotic scenario
- Rule out 4/3 or exotic model at 93.7%



Summary

- DØ has made a measurement of the top quark charge at the Fermilab Tevatron.
- Using a sample of top quark events in the lepton plus jets channel, with an integrate luminosity of 370 pb^{-1}, we find 17 events with two b-tagged jets.
- Using a likelihood ratio, we find the data are in good agreement with a standard model top quark charge of 2/3.
- The exotic quark hypothesis with charge 4/3 is exclude at a 94% confidence level.