Top Mass and Properties at the Tevatron

Jean-Francois Arguin
University of Toronto

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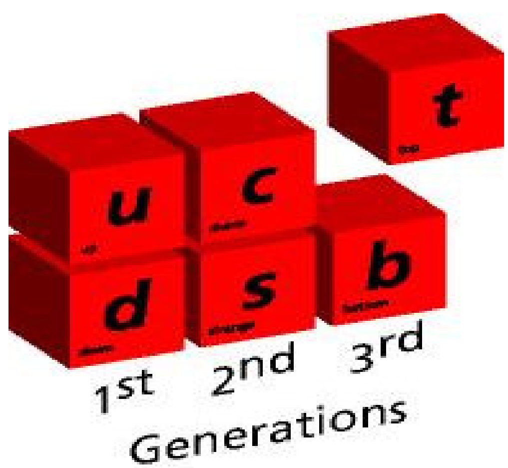
Outline

- Introduction to top quark physics
- Top mass measurements
  - Selected systematics: PDF, ISR/FSR
- Top properties: branching fractions, W helicities
- Conclusion and Outlook

The Top Quark

- Discovered only recently (1995 at CDF, DØ)
- No real surprise: existence is required for viability of the Standard Model (SM):
  - E.g. renormalizability of theory

Most striking characteristics: huge mass!



$$M_{top} \approx 180 GeV / c^2$$

How large?:

- 40 times M_{bottom}

- Comparable to gold nucleus

Top Production and Decay

- **QCD Production (~6pb)** dominates at Tevatron:

  85%: $q\bar{q} \rightarrow t\bar{t}$

  15%: $gg \rightarrow t\bar{t}$

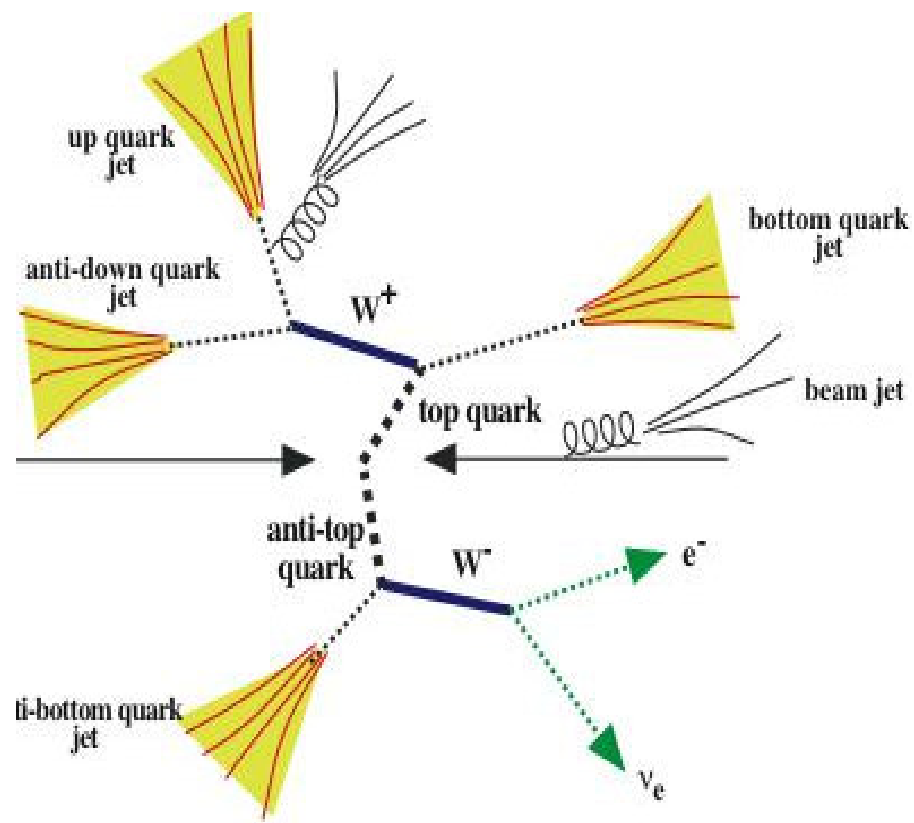
- single-top EWK production predicted but never observed
- **Decay**: in SM:

  $$V_{tb} >> V_{ts}, V_{td}$$

Thus,
$$Br(t \rightarrow Wb) \approx 100\%$$

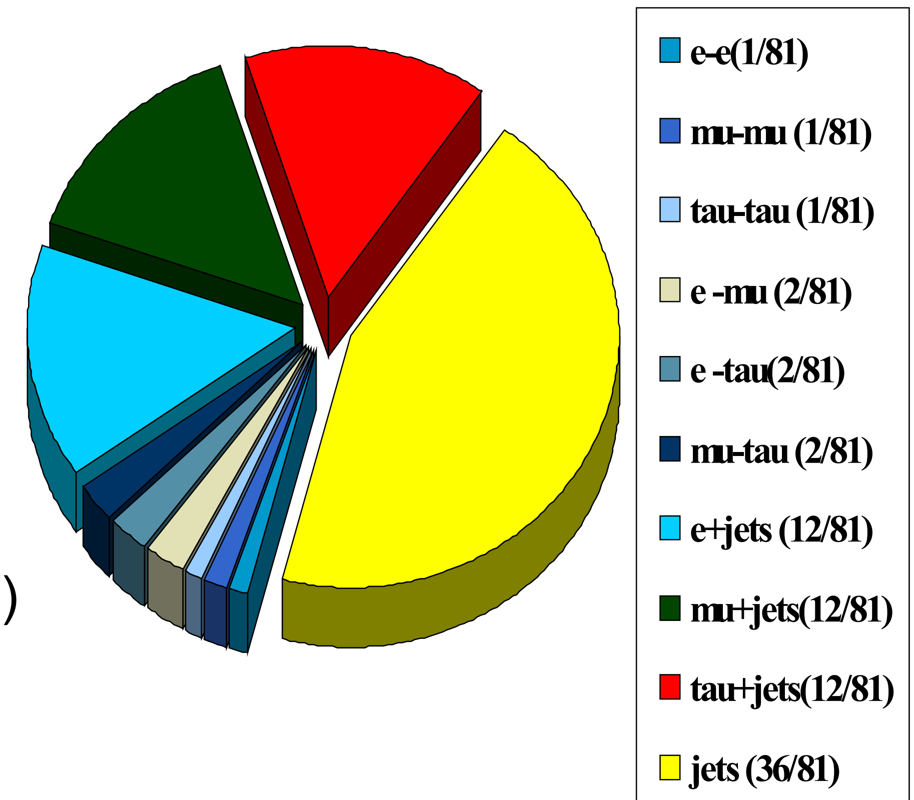
Half-life of top: ~10^{-25}s

•Top decays before hadronizing!



Observed Final State and Selections

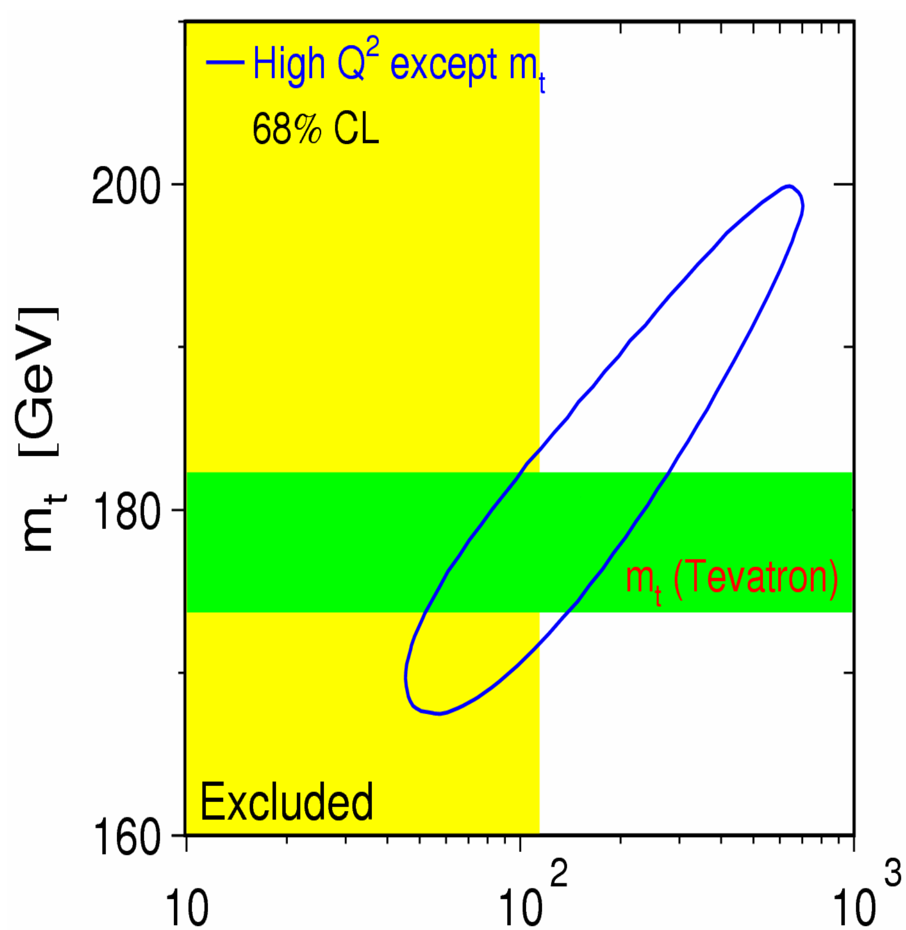
- W bosons decay either hadronically or leptonically.
- **W decays define channel:**
  - Dilepton: 5%
  - Lepton+jets: 30%
  - All-hadronic: 44%
  - Taus+anything: 21%
- **Typical event selections:**
  - Well-identified electron(s) or muon(s)
  - Large missing E_T
  - Several reconstructed jets identified in calorimeters



Motivation for M_{top} Measurement

- **Radiative corrections to SM predictions of EWK measurements dominated by M_{top}**
- **Therefore, high accuracy M_{top} measurement is crucial for:**

1. Constrain unknown model parameters → M_{Higgs}
2. Consistency check of SM
3. Sensitivity to new physics



Summary of Run I Measurements

- M_{top} meas. in Run I ($\sim$100pb^{-1}) world ave.:

$$M_{top} = 178.0 \pm 4.3 Gev / c^2$$

- Higgs mass fit:

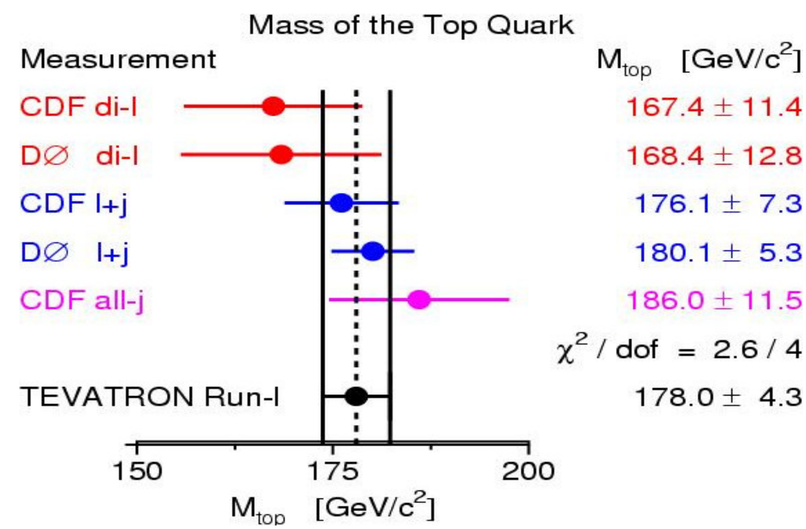
$$M_H = 126^{+73}_{-48} GeV / c^2$$

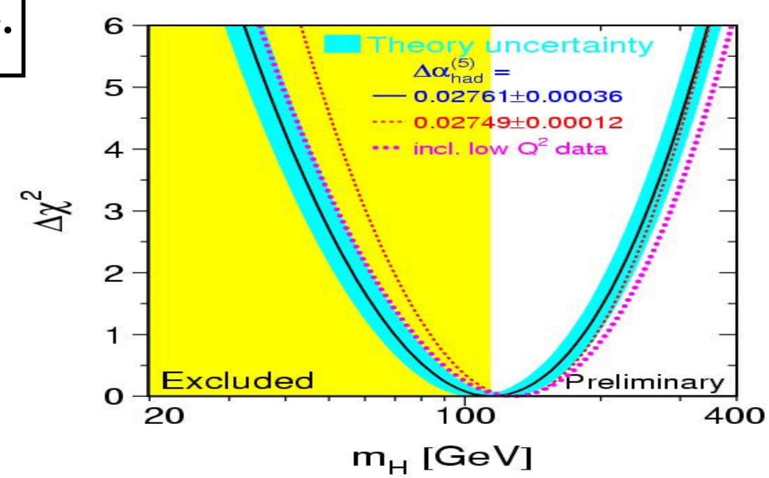
$$M_H < 280 GeV / c^2 @ 95\% C.L.$$

- Run II Goals per experiment:

$$\int L dt \approx 4-8 fb^{-1}$$

$$\delta M_{top} \approx 2 GeV / c^2$$





Challenge I for Measuring M_{top}

Statistical limitations (for lepton+jets channel):

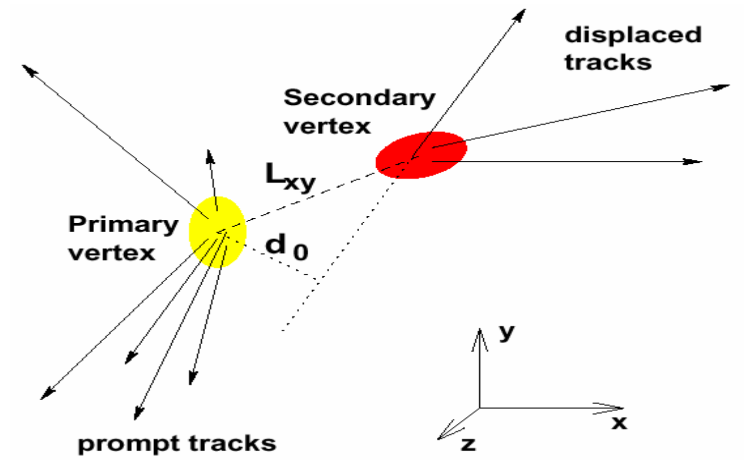
- **Small statistics**: ~25 b-tag lepton+jets ev. / 100 pb^{-1} for CDF
- **Complicated final state to reconstruct**:

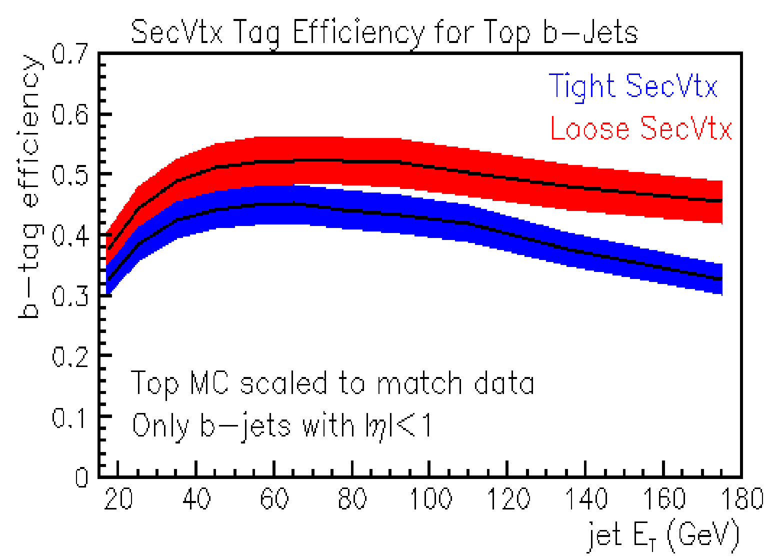
Observed l+jets final state:

$$t\bar{t} \rightarrow l \not{E}_T jjjj$$

Complications:

- 12 possible jet-parton assignments (if ==4-jets)
  - B-tagging helps a lot

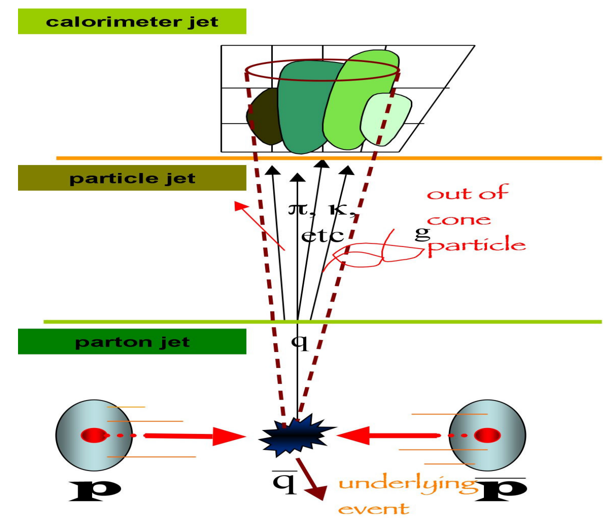


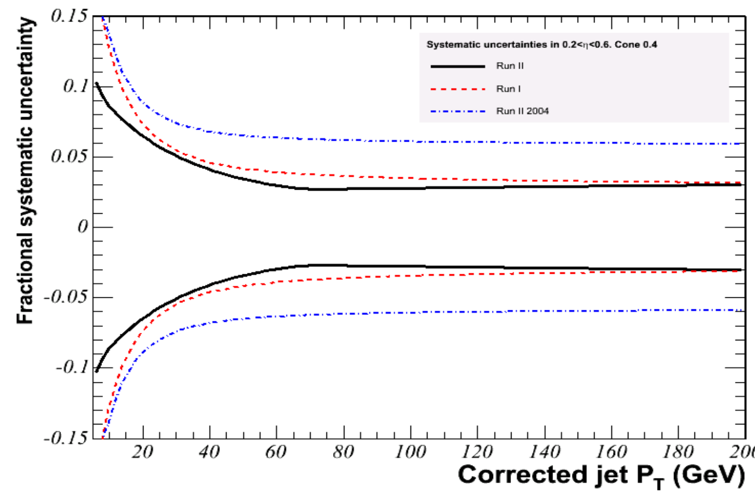


Challenge II for Measuring M_{top}

Jet energy scale uncertainty

- Dominant systematics
- Comes from uncertainty in modeling the behavior of jets (particles response, fragmentation)
- Current world average uncertainty (±4.3GeV/c^2):
  - 2.6 GeV/c^2 from JES
  - 2.7 GeV/c^2 from stat.
- As more data is accumulated: JES will become dominant

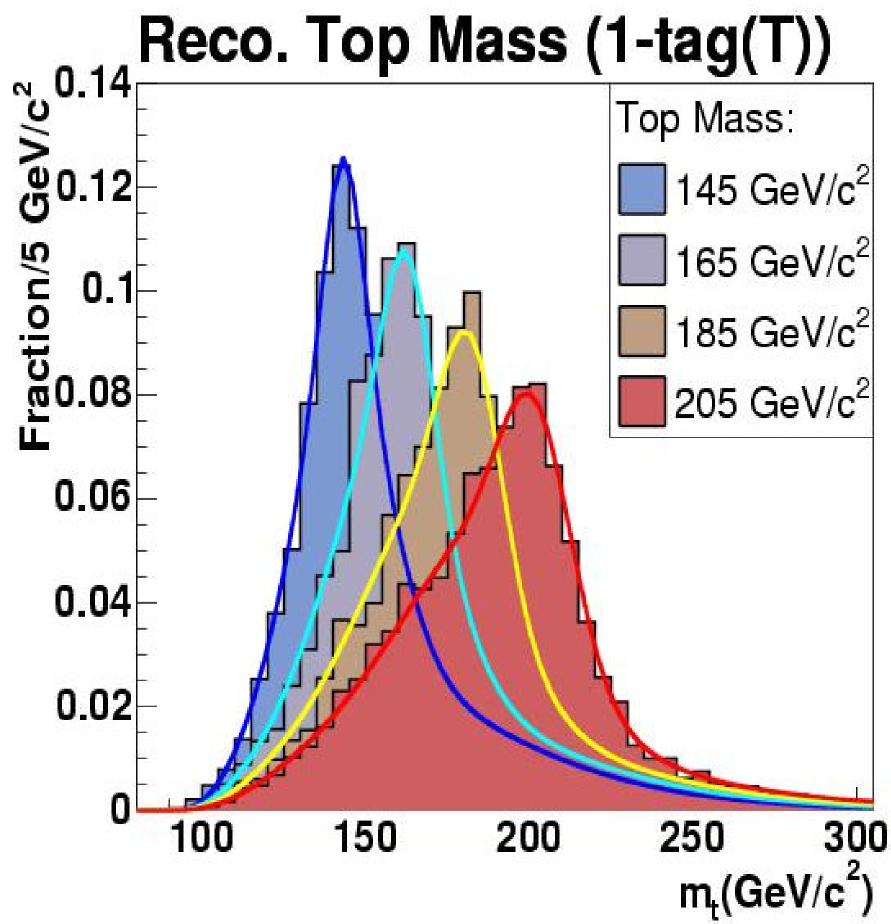




Lepton+Jets Measurements

Template technique:

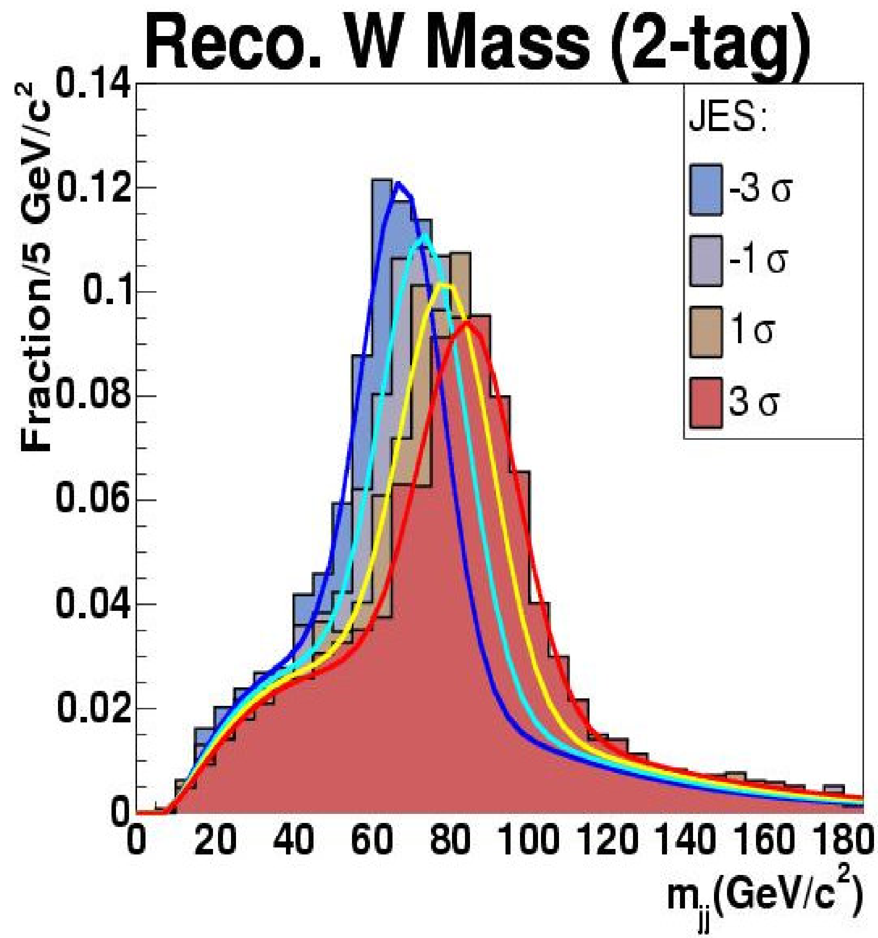
- Reconstruct top mass for each event using kinematic fit
- Reco. top mass templates for various true top mass
- Compare reco. top mass in data with MC expectations



W Mass Reconstruction

New CDF results:

- Novelty: take advantage of hadronic W decays *in situ* top-antitop events to reduce JES uncertainty
- Use templates of reco. Top and W mass
- Fit simultaneously for M_{top} and JES



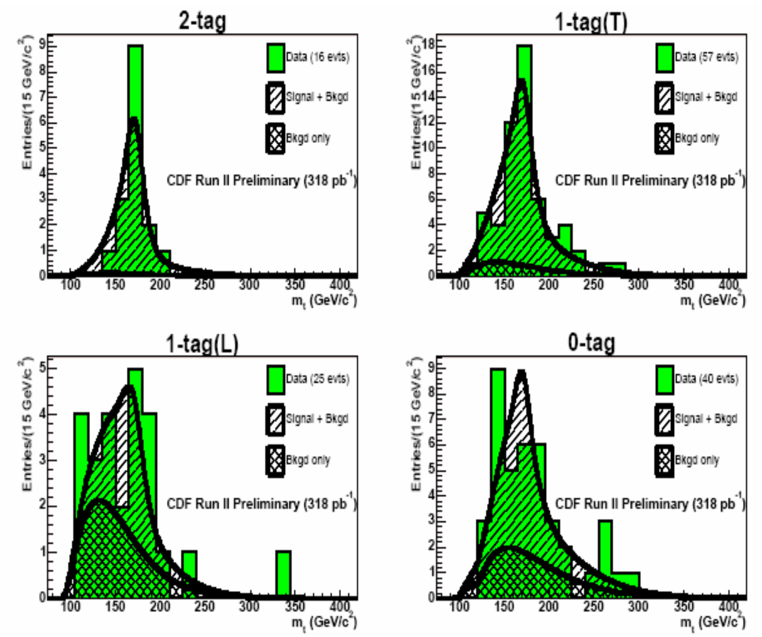
CDF Result on Data

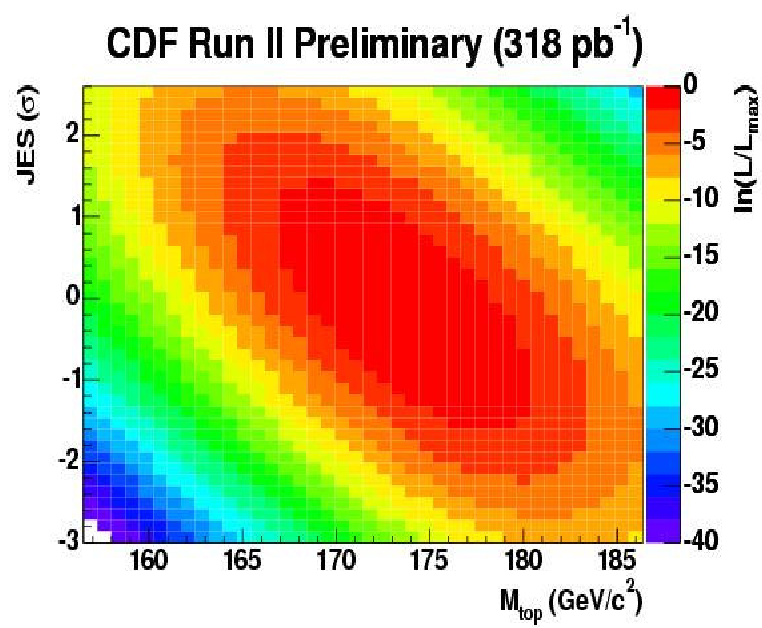
- Use 318 pb^{-1} of data
- 2-D fit: best single top mass measurement in the world:

$$M_{top} = 173.5^{+2.7}_{-2.6}(stat.) \pm 2.5(JES) \pm 1.7(syst.) GeV / c^2$$

- Cross-check using traditional 1-D fit:

$$M_{top} = 173.2^{+2.9}_{-2.8}(stat.) \pm 3.1(JES) \pm 1.5(syst.) GeV / c^2$$



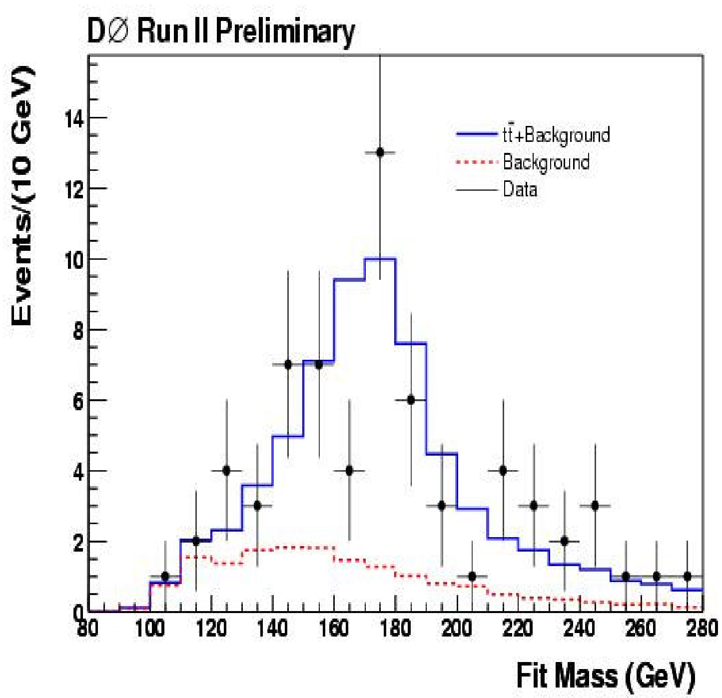


Latest DØ l+jets Results

- use 230pb^{-1} of data
- JES uncertainty: ~5-6 GeV/c^2, expected to go down soon

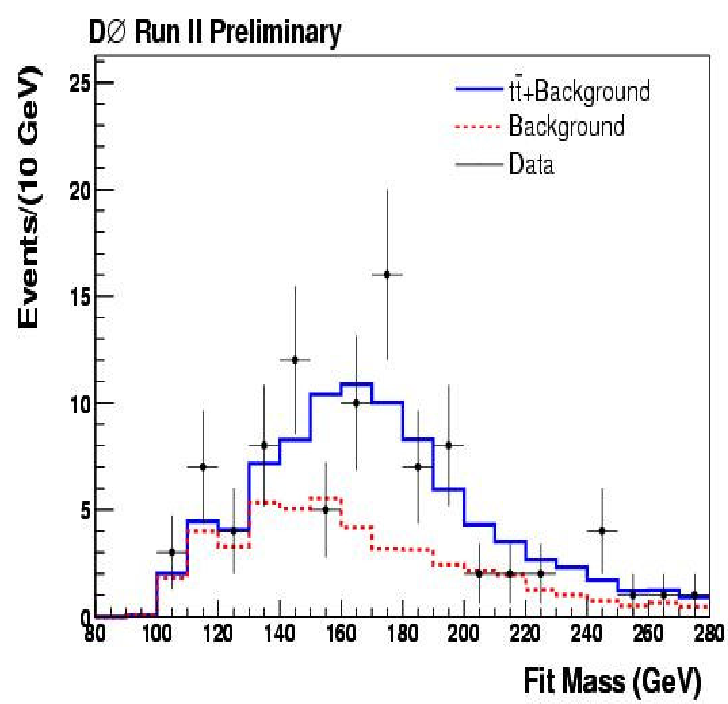
Template b-tag analysis:

$$M_{top} = 170.6 \pm 4.2(stat.) \pm 6.0(syst.) GeV/c^2$$



Topological analysis:

$$M_{top} = 169.9 \pm 5.8(stat.)^{+7.8}_{-7.1}(syst.) GeV/c^2$$



Dilepton results

Pros:

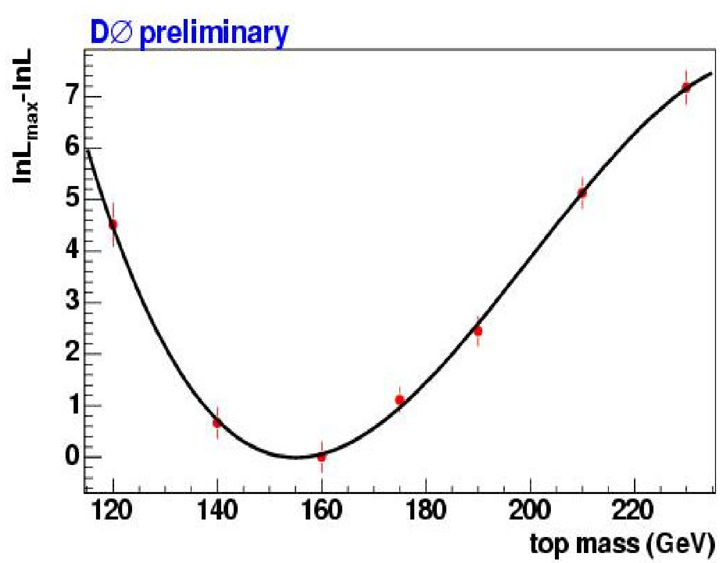
- Less combinatorics

Cons:

- Unconstrained kinematics: 2 neutrinos in final state
- Small branching fraction (5%)

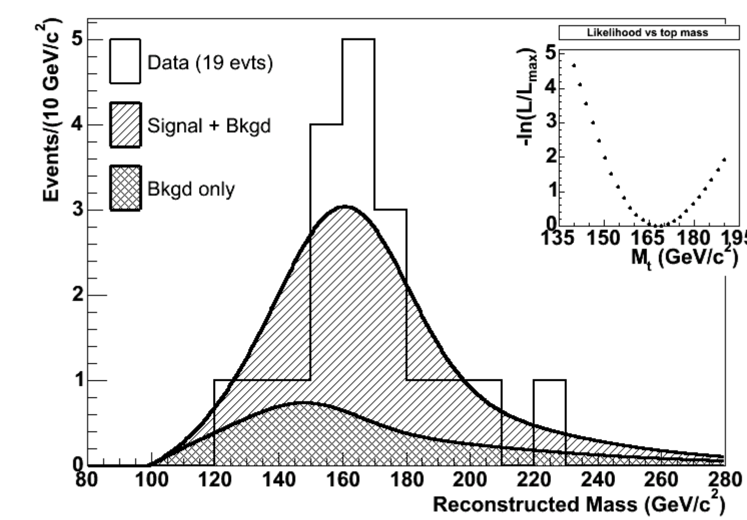
DØ: 230pb^{-1}

$M_{top} = 155^{+14}_{-13}(stat.) \pm 7(syst.) GeV/c^2$



CDF: 200 pb^{-1}

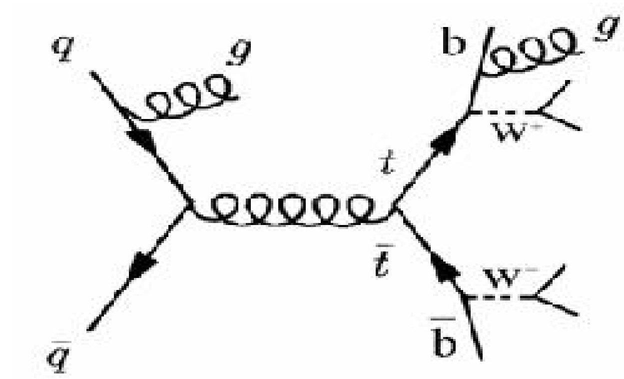
$M_{top} = 168.1^{+11.0}_{-9.8}(stat.) \pm 8.6(syst.) GeV/c^2$

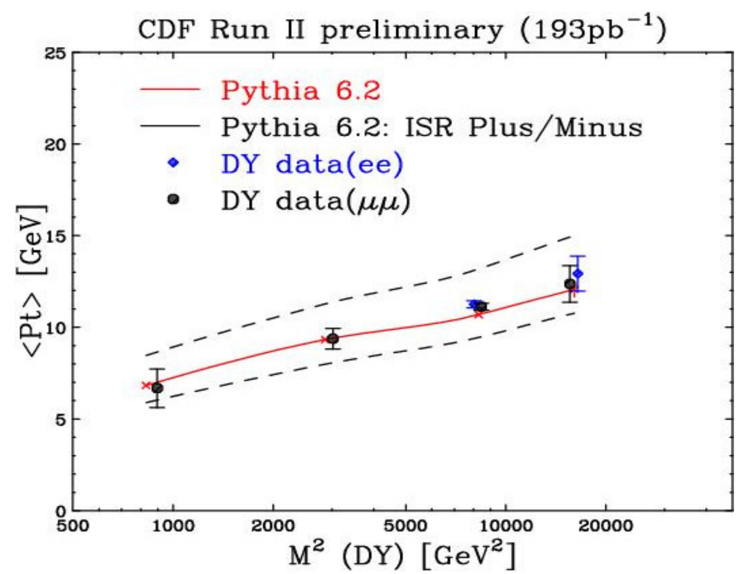


Gluon radiation uncertainty

Gluon ISR/FSR jets: often misidentified for quark jets in M_{top} reco.

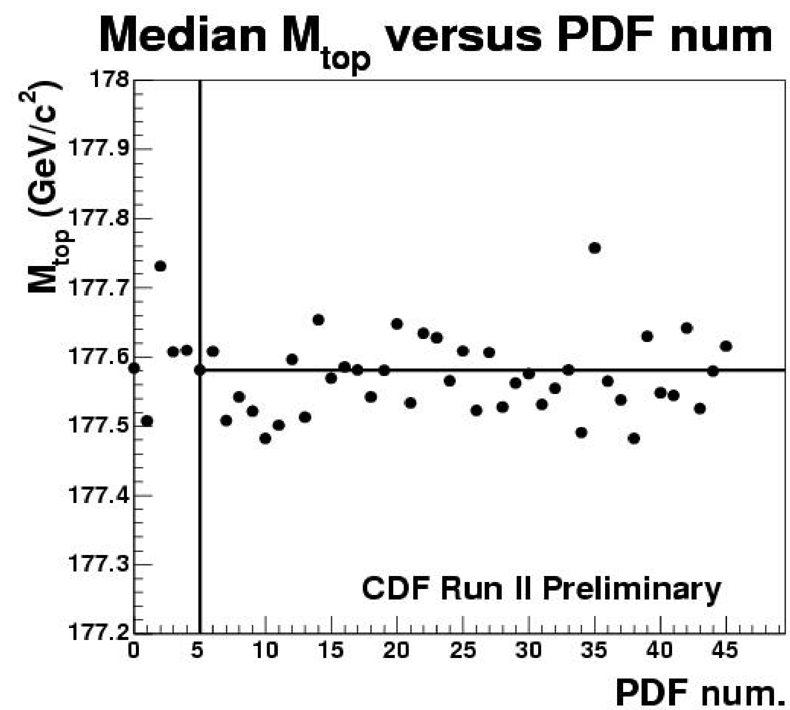
- **DØ:**
  - Estimate ΔM_{top} for events with and without gluon jets
  - ΔM_{top} ~2.5GeV/c^2 in l+jets ev.
  - Take full difference as uncertainty
- **CDF:**
  - Study ISR in Drell-Yan events
  - Extrapolate uncertainties to top mass energies
  - FSR: same DGLAP eq. as ISR
  - ISR/FSR $\Delta M_{top=}$=0.7GeV/c^2





PDF uncertainty on M_{top}

- **CDF:** (effect on l+jets meas.)
  - CTEQ5L vs MRST72:
    $\delta M_{top} = 0.1 GeV/c^2$
  - Λ_{QCD} variations: MRST72 vs MRST75:
    $\delta M_{top} = 0.2 GeV/c^2$
  - CTEQ6M variations of 20 eigenvectors:
    $\delta M_{top} = 0.2 GeV/c^2$
- **DØ:**
  - Neglected so far (dominated by JES systematics)
  - Will include in next round



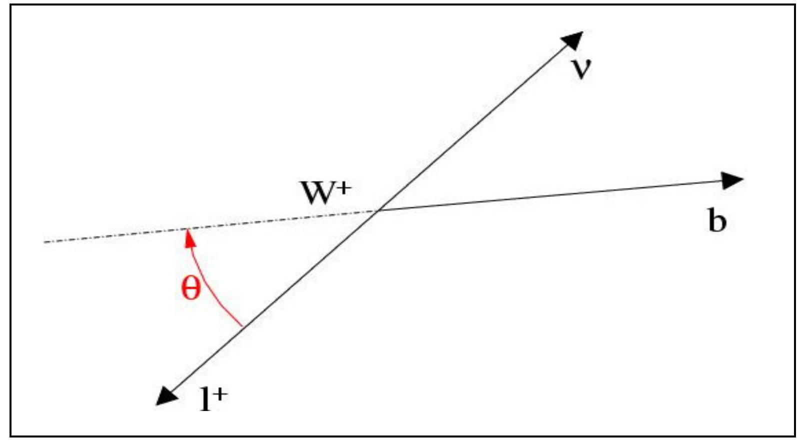
More Top Properties

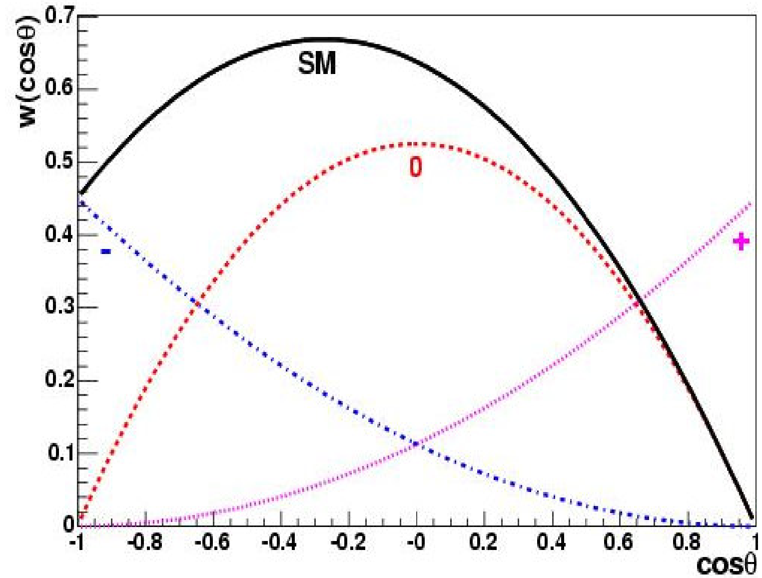
- Top mass measurements assume Standard Model top properties
- We need to check our assumptions, e.g.:
  - Branching fractions: top decays 100% of the time $t \rightarrow Wb$
  - W polarization SM predictions:
    - 70% longitudinal
    - 30% left-handed
    - 0% right-handed
  - Other measurements (not covered today): charge, spin correlations, charged Higgs in top decay, non-SM production

W Helicity

- Three techniques have been used to measure W helicity:
  - $\cos\theta^*$ (or M_{lb})
  - p_T of lepton from W boson decay
  - Matrix-element
- Best result still from Run I:
  - DØ: $f^0 = 0.56 \pm 0.31$
  - CDF:

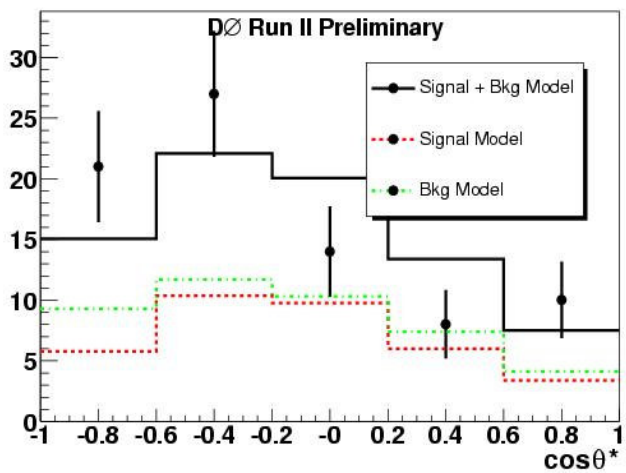
    $f^+ < 0.18 @ 95\% C.L.$





Results On W helicity

- DØ: measure right-handed fraction f^+:

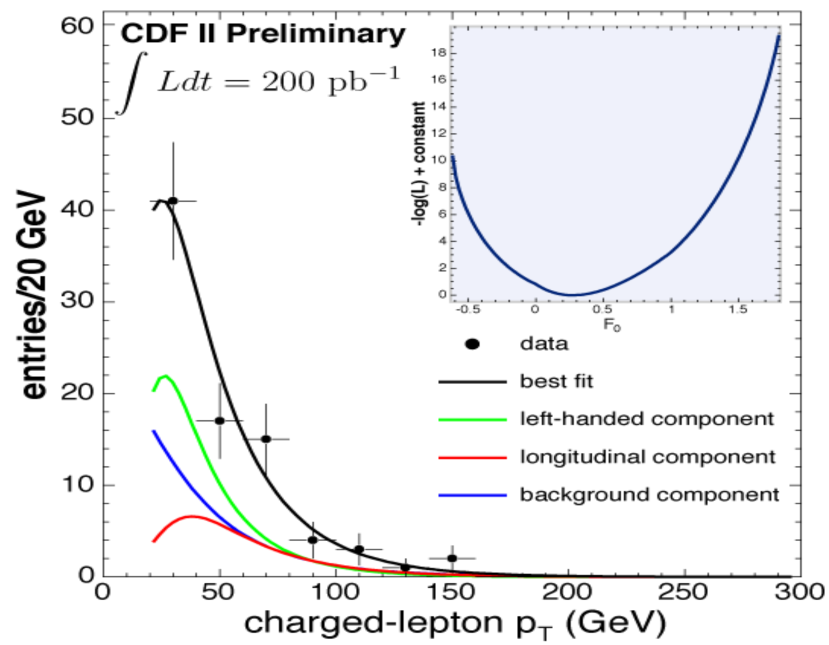


$f^+ < 0.244 @ 90\% C.L.$

- CDF: use $\cos\theta^*$ to measure longitudinal fraction:

$f^0 > 0.25 @ 95\% C.L.$

- CDF: measure longitudinal fraction from lepton p_T:

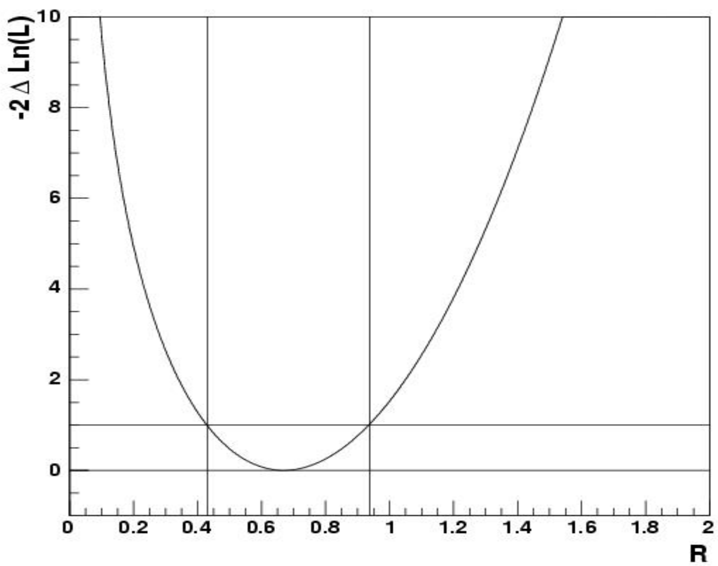


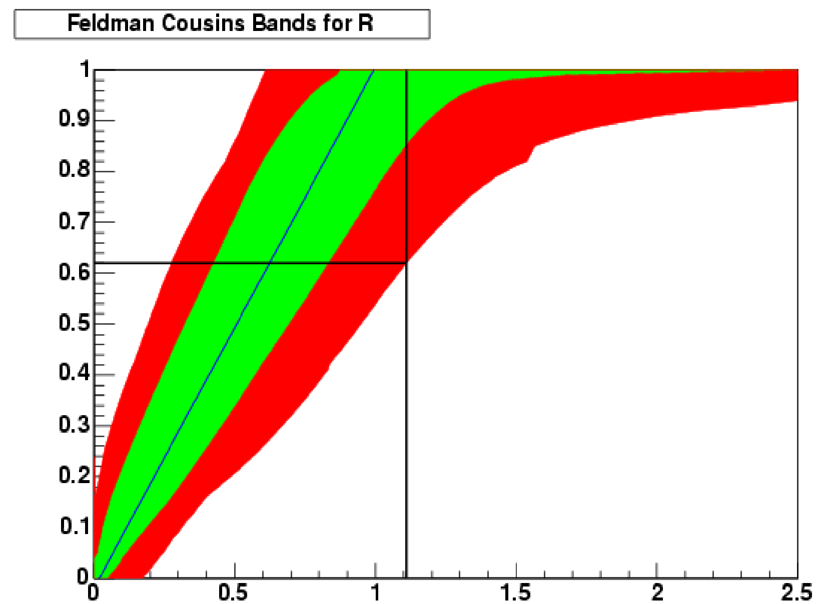
$f^0 = 0.27^{+0.35}_{-0.21}$

- Consistent with S.M. at ~2σ level

Branching Ratio

- In SM: $R = Br(t \to Wb) / Br(t \to Wq) \approx 1$
- Can measure this branching ratio by counting the rate of b-tags in ttbar events





DØ (~160pb^{-1}) (SVT result):

$$R = 0.70^{+0.27}_{-0.24}(stat.)^{+0.11}_{-0.10}(syst)$$

CDF(~160pb^{-1}):

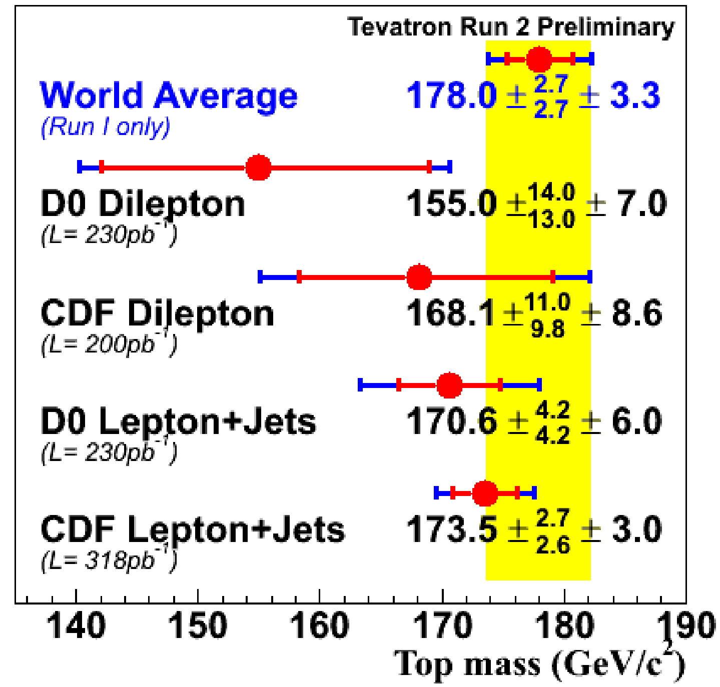
$$R > 0.62 @ 95\% C.L.$$

Conclusion

- New CDF top mass result better than world average:

$$M_{top} = 173.5^{+4.1}_{-4.0}\, GeV/c^2$$

- New competitive DØ measurements coming soon (more data, better JES uncertainty)
- CDF matrix-element results coming soon



- Plenty of other precision measurement of top properties to come: W helicity, branching ratios, rare decays, top spin correlations…

Top Quark Physics

<u>Different behavior than other quark due to large mass:</u>

- Only known particles decaying to a real boson:

$$t \rightarrow Wb$$

- So short-lived ($\tau_t \sim 5 \times 10^{-25}$sec)

$\rightarrow$ *It decays before hadronizing!*

Last feature has interesting experimental consequences

- can observe bare quark!

<u>Top quark measurements:</u>