Top Quark Mass Measurement with a Matrix-Element Method in the Dilepton Channel

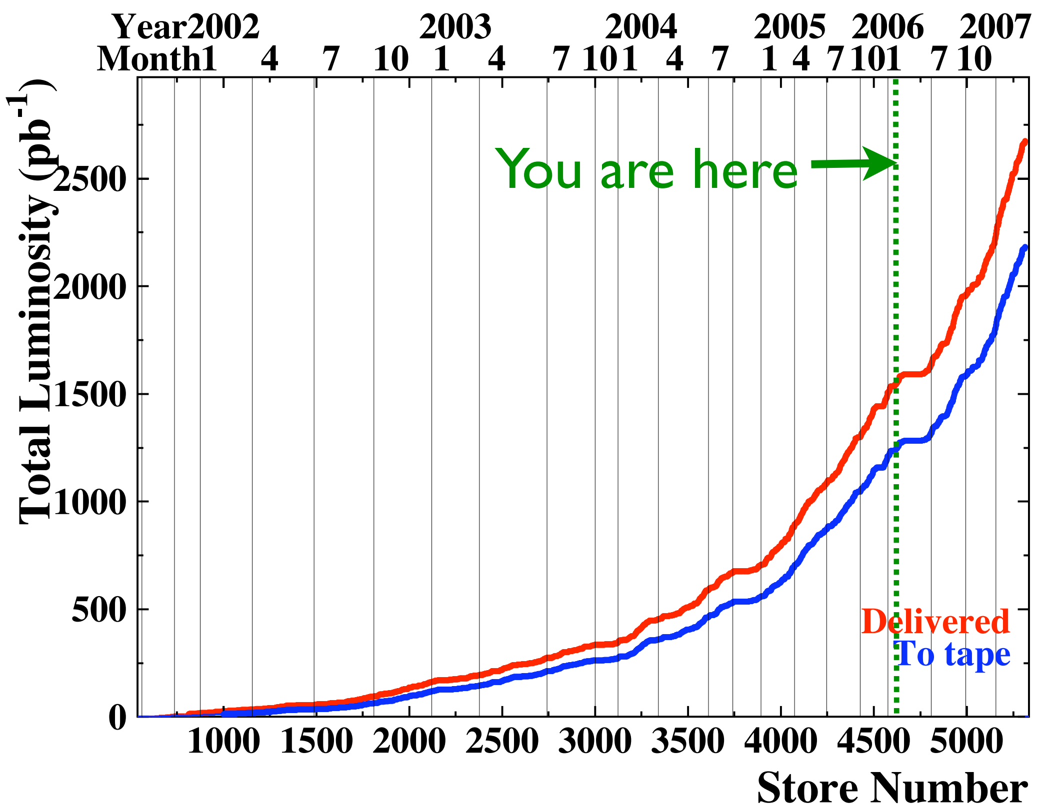
Bodhitha Jayatilaka
Duke University

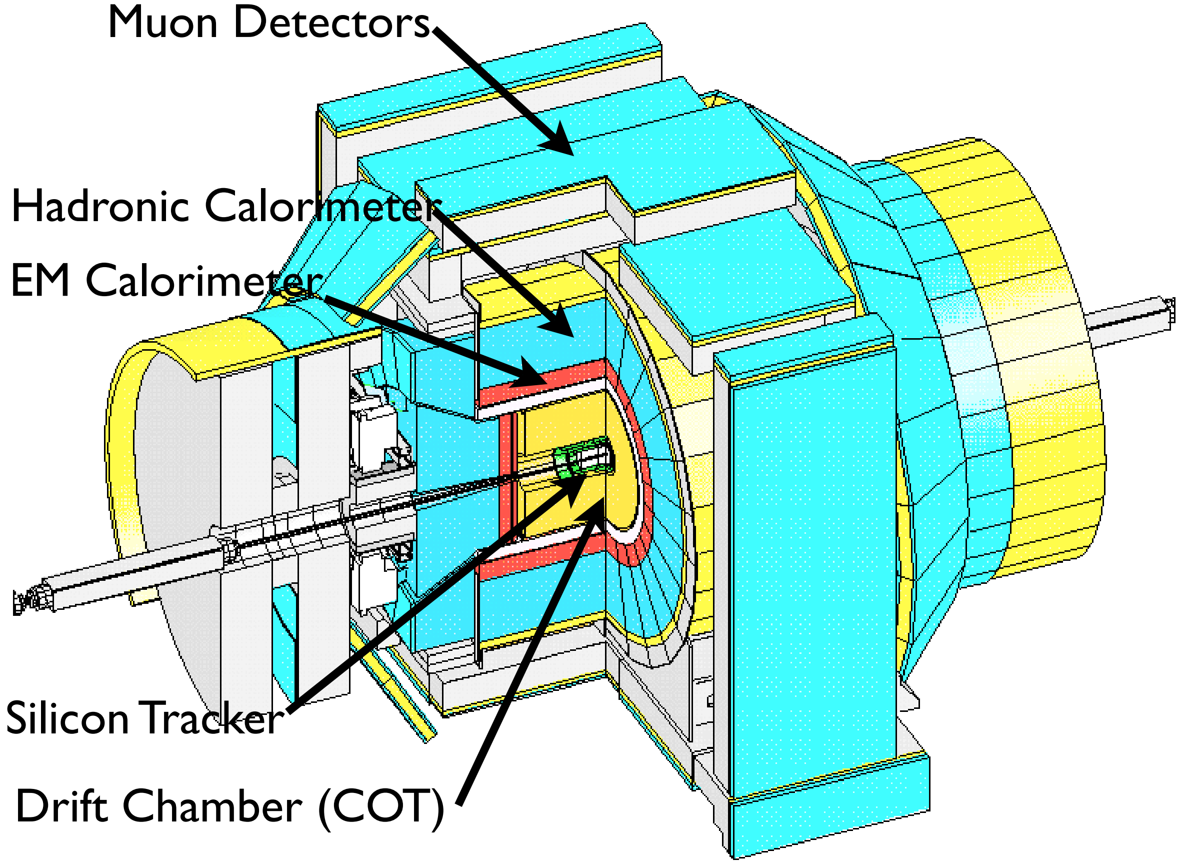
On Behalf of the CDF Collaboration

APS April Meeting
Jacksonville, Florida

April 16, 2007

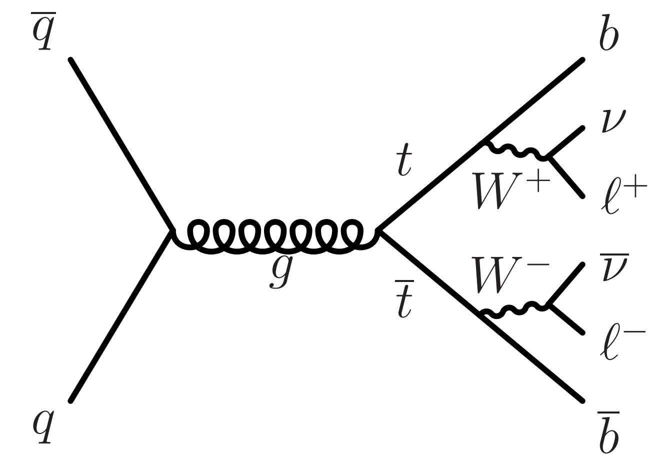
Tevatron and CDF detector





- Tevatron
  - Peak luminosity >2.8×10^{32} cm^{-2}s^{-1}
  - 2.5 fb^{-1} delivered to experiments
- CDF Detector - General purpose detector
  - Precision tracking (Silicon + COT)
  - EM and Hadronic calorimeters
  - Muon detectors (extended for Run II)
- >2.0 fb^{-1} recorded at CDF
  - Measurement shown uses 1fb^{-1} (up to March 2006)

Top quark decay: the dilepton channel



- Top quarks are primarily pair produced at Tevatron
  - Decay channel is defined by *W* decay modes
- Both *W*s decay leptonically in ~5% of all decays
  - 2 leptons (e or μ), 2 jets (from *b*-quarks), large missing $\not{E}_T$ from νs

Advantages

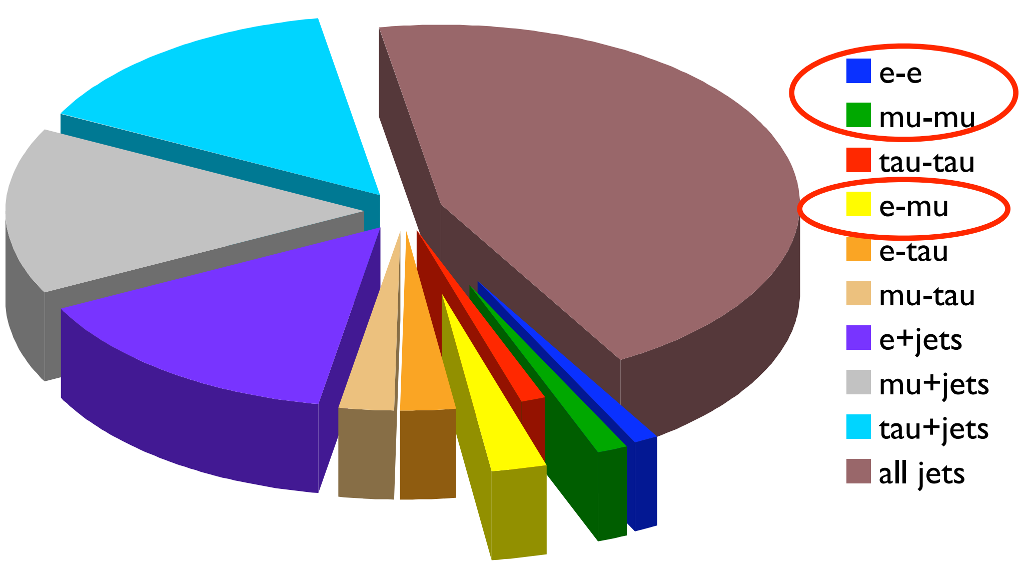
- Clean: little background without need for *b*-tagging
- Least jets of any channel (less reliant on JES, less ambiguity in jets)

Disadvantages

- Low statistics
- 2 νs escape undetected– underconstrained system

Backgrounds

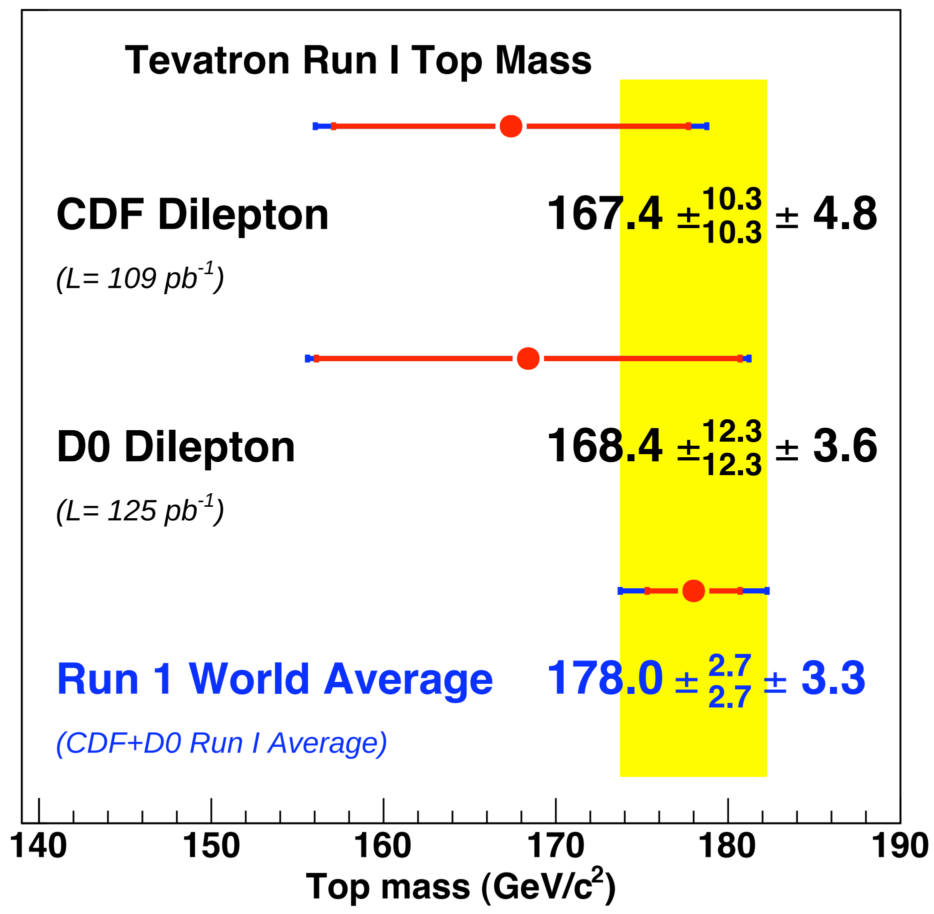
- Drell-Yan + jets (DY)
- Diboson + jets
- Mis-ID leptons ("fakes")



Measuring M_{top} in the dilepton channel

Important measurement

- Contributes to overall knowledge of top mass
- Verify that we are measuring SM top
- If results across channels inconsistent, new physics might be in sample



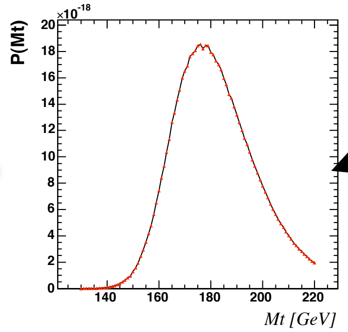
Difficult channel to work in

- Low statistics
- Two neutrinos escape undetected
- Only one missing transverse energy measurement
  - Kinematically under-constrained
- Forced to make assumptions and integrate
- No hadronic *W* to make *in situ* JES measurement

The matrix element method

- Use differential cross-section to calculate probability of event coming from M_{top}

$$\frac{1}{\sigma(M_t)}\frac{d\sigma(M_t)}{d\mathbf{x}}$$



Probability curve rather than single mass per event

- Formulate differential cross-section using LO matrix element and transfer functions

$$\frac{d\sigma(M_t)}{d\mathbf{x}} = \int d\Phi |\mathcal{M}_{t\bar{t}}(p_i;M_t)|^2 \prod W(p_i,\mathbf{x}) f_{PDF}(q_1) f_{PDF}(q_2)$$

  - Transfer functions link measured quantities $\mathbf{x}$ to parton-level ones, p_i
    - Jet energy-parton energy
    - $t\bar{t}$ p_T - measured recoil
  - Perform integrals over unknown quantities (8)
- Simplifying assumptions made for tractability
  - e.g. lepton momenta and jet angles perfectly measured
- Use similar differential cross-sections for background processes
  - Final probability becomes weighted sum of signal and background probabilities

Integrals still take 2-3 hours per event!

$$P(\mathbf{x}|M_t) = P_s(\mathbf{x}|M_t)p_s + P_{bg_1}(\mathbf{x})p_{bg_1} + P_{bg_2}(\mathbf{x})p_{bg_2} + \cdots$$

Dataset used

- 1 fb^{-1} of data collected up to March 2006 at CDF
- Basic selection: 2 high-p_T (>20 GeV/c) leptons, 2 high-E_T (>15 GeV) jets, large $\not{E}_T$ (>25 GeV)
- Additional cuts to help reduce background
  - Elevate $\not{E}_T$ requirement when m_{ll} is close to Z mass
  - Require scalar sum of energies in event, H_T>200 GeV

Source	N_{evs}
$t\bar{t}$ (M_t=175 GeV/c^2, σ=6.7pb)	50.2
$Z\rightarrow ee/\mu\mu$	10.9
Fakes	8.7
WW/WZ	5.1
$Z\rightarrow\tau\tau$	2.2
Total	77.1
Observed (1.0 fb^{-1})	***78***

Uncertainties

Statistical Uncertainty

- Expected for M_{top}=175 GeV/c^2, σ = 5.0 GeV/c^2
- Expected for M_{top}=165 GeV/c^2, σ = 4.2 GeV/c^2

Systematic Uncertainty

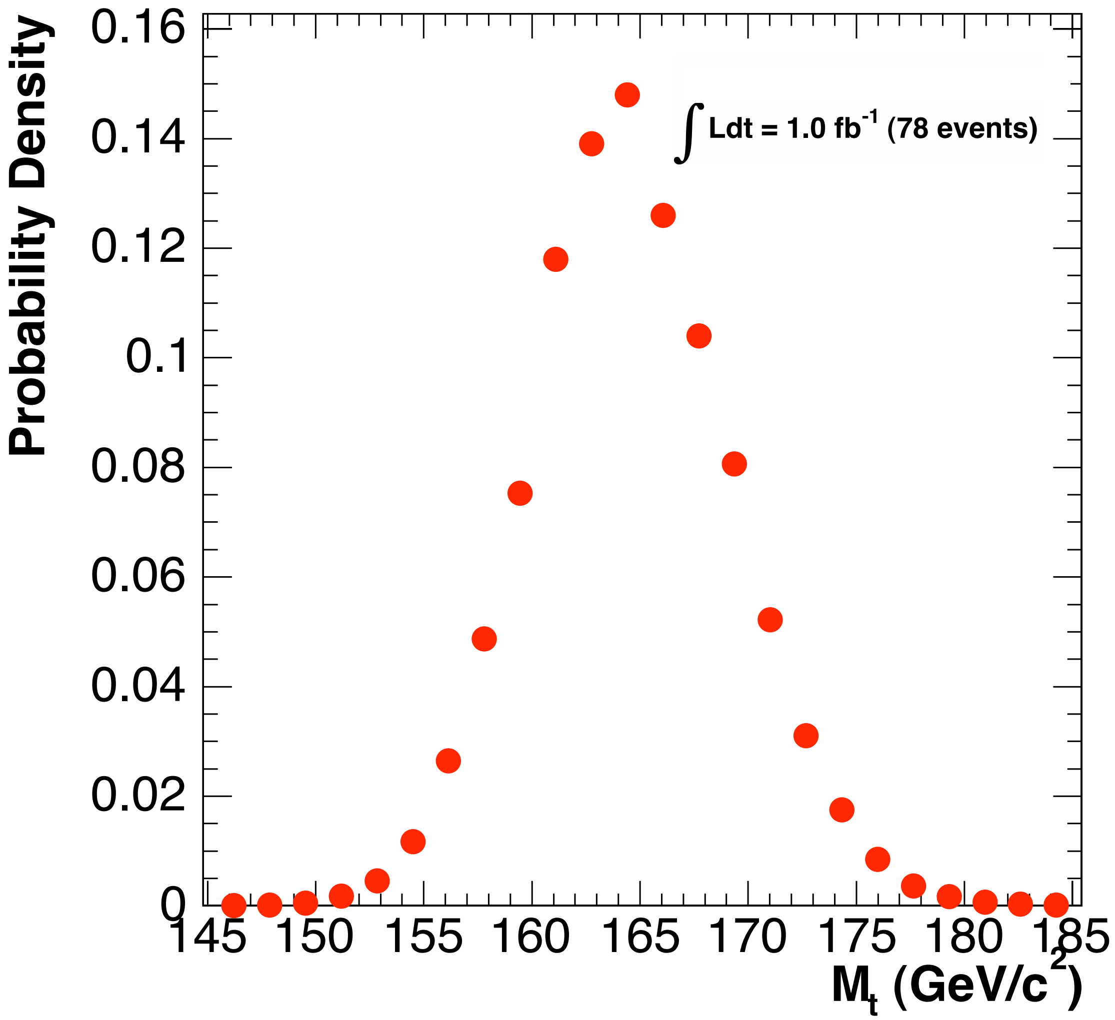
Source	ΔM_{top} (GeV/c^2)
Jet Energy Scale	3.5
Generator	0.9
Method	0.6
Sample Composition	0.7
Background Statistics	0.7
Background Modeling	0.2
FSR	0.3
ISR	0.3
PDFs	0.8
Total	*3.9*

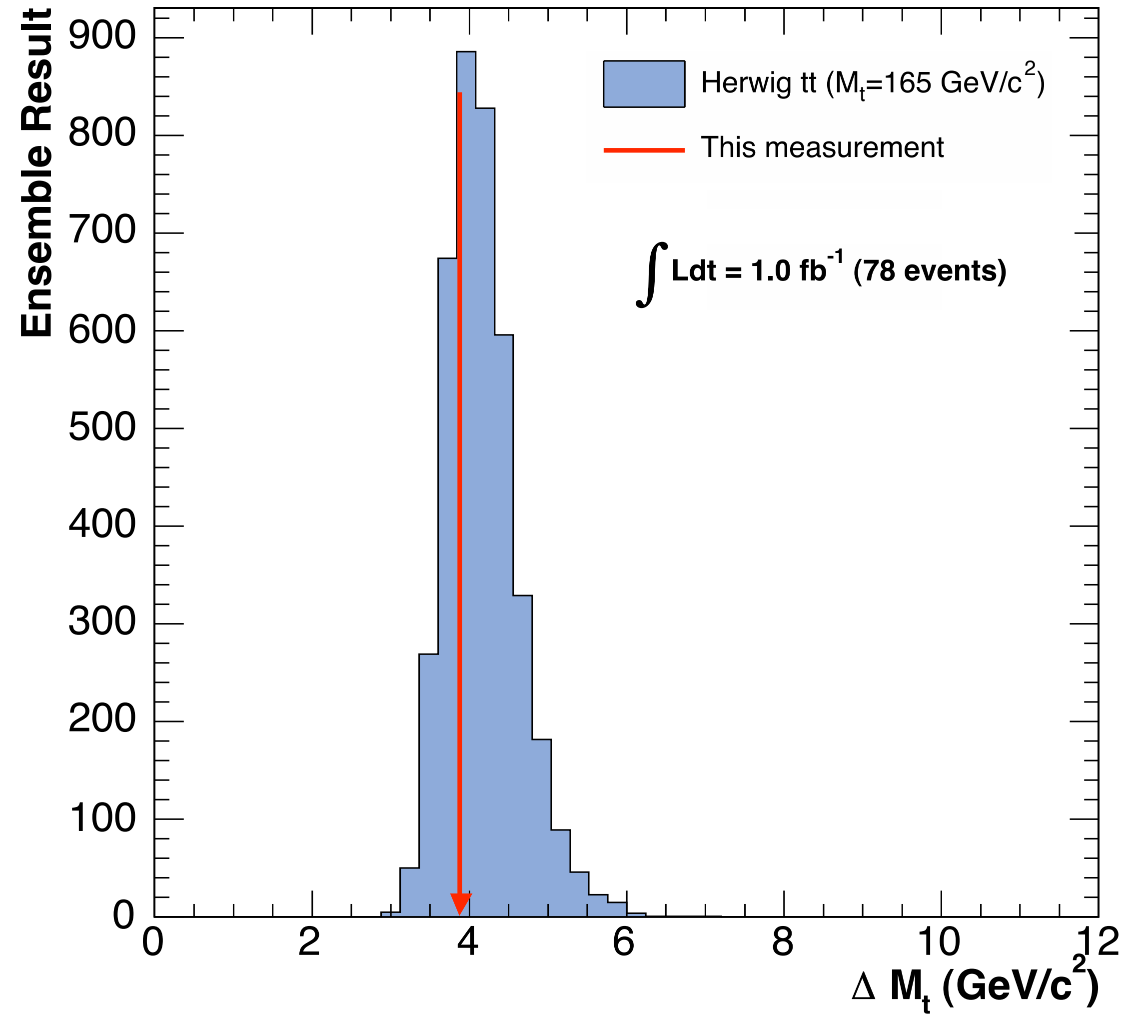
Jet Energy Scale: Working on using $Z \rightarrow bb$ to improve

Background Statistics: Driven by small sample of (data-based) "fake" lepton events

Legend:
- Red: Improves with better methods and/or more data
- Blue: Improves with more CPU

Result



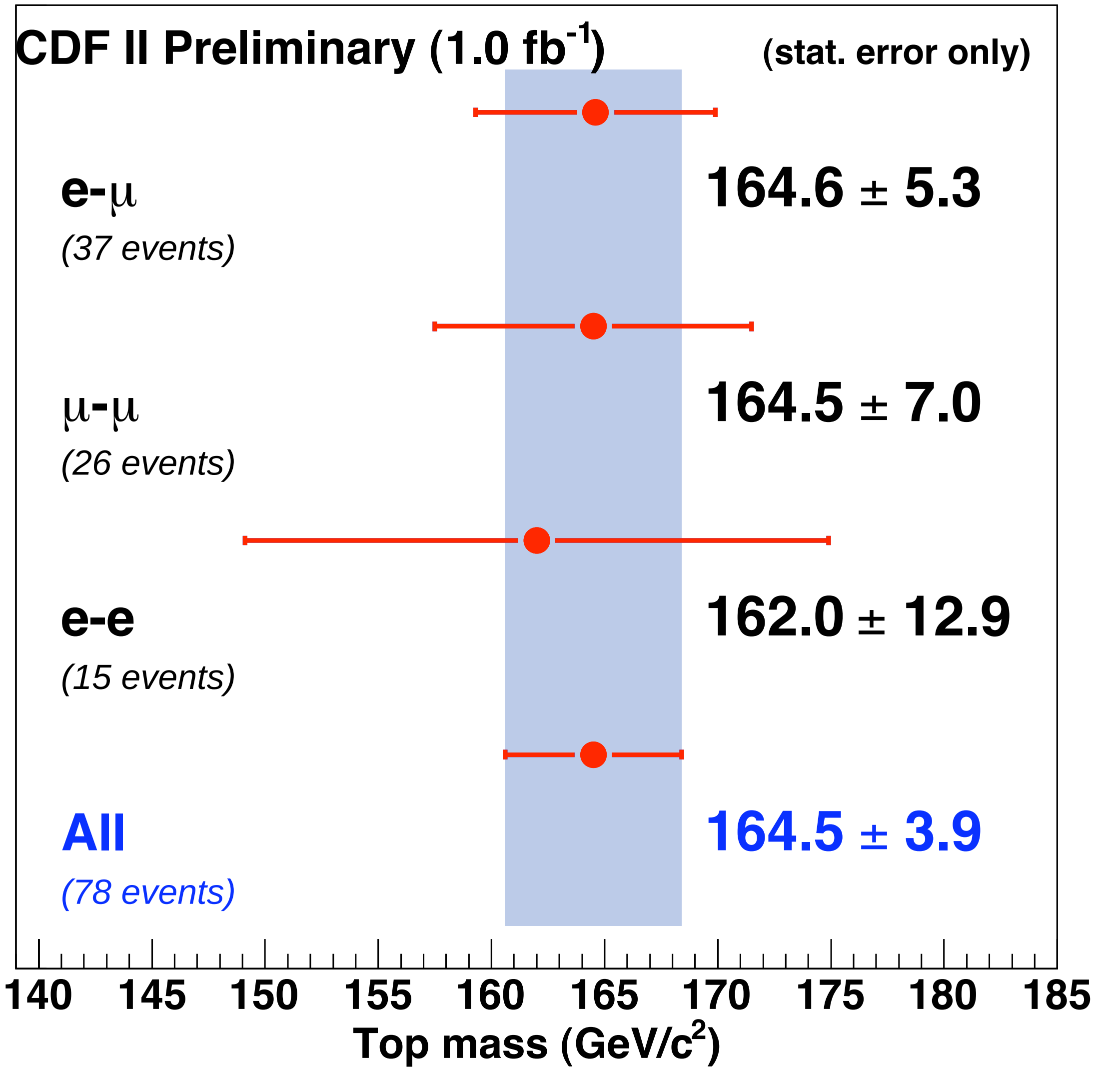


$$M_{top} = 164.5 \pm 3.9(\text{stat.}) \pm 3.9(\text{syst.})\,\text{GeV}/c^2$$

- Single most precise dilepton top mass measurement to-date
  - With no improvements to method, projected stat. error with 4 fb^{-1} is 2.5 GeV/c^2
- Published in PRD **75**, 031105(R)
  - Previously (340 pb^{-1}) PRL **96**, 152002, PRD **74** 032009 (with more detail)

Cross-Checks

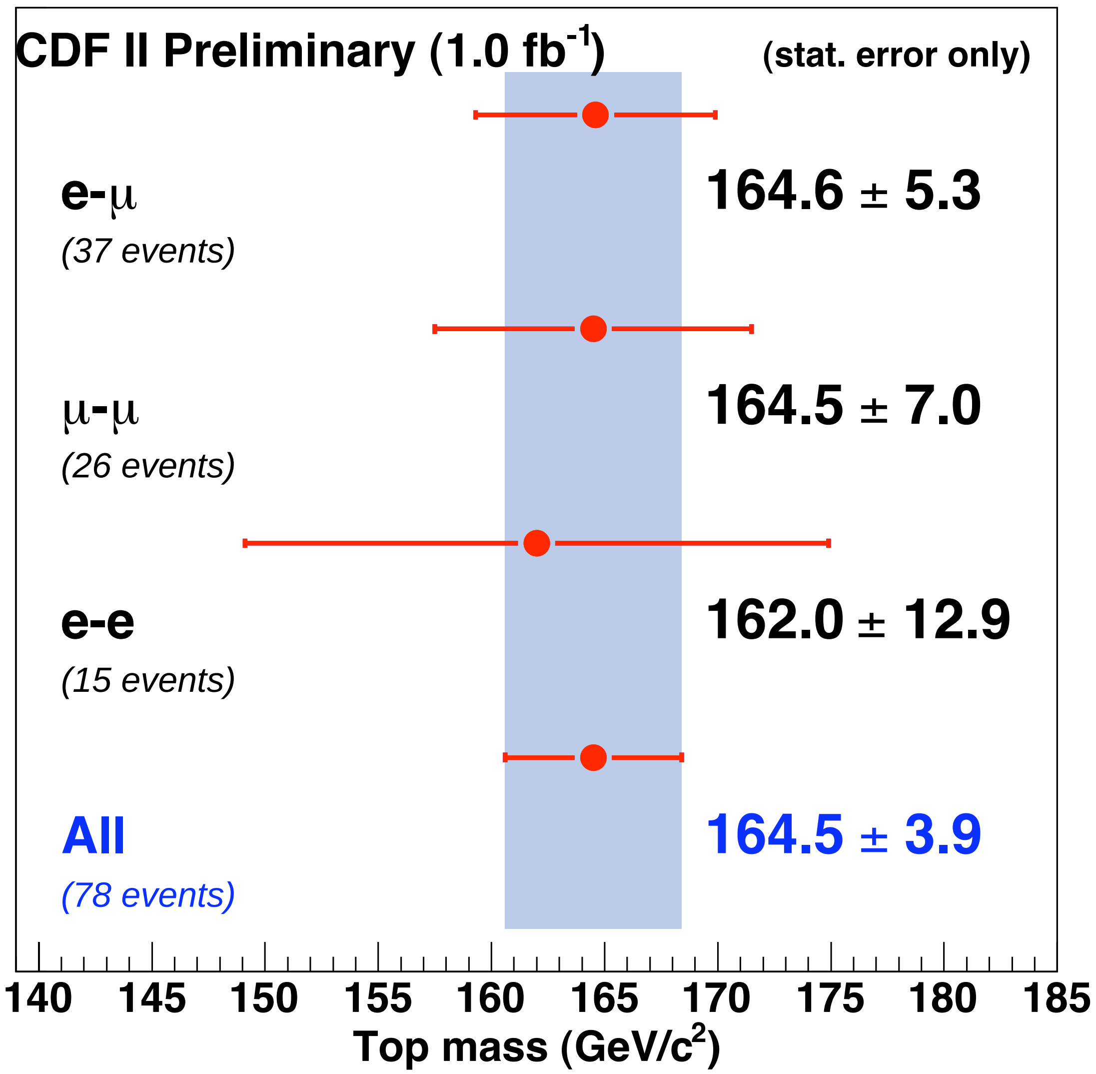
Lepton Flavor



- Measure mass separately for ee, *eμ* and *μμ* events
- Results consistent

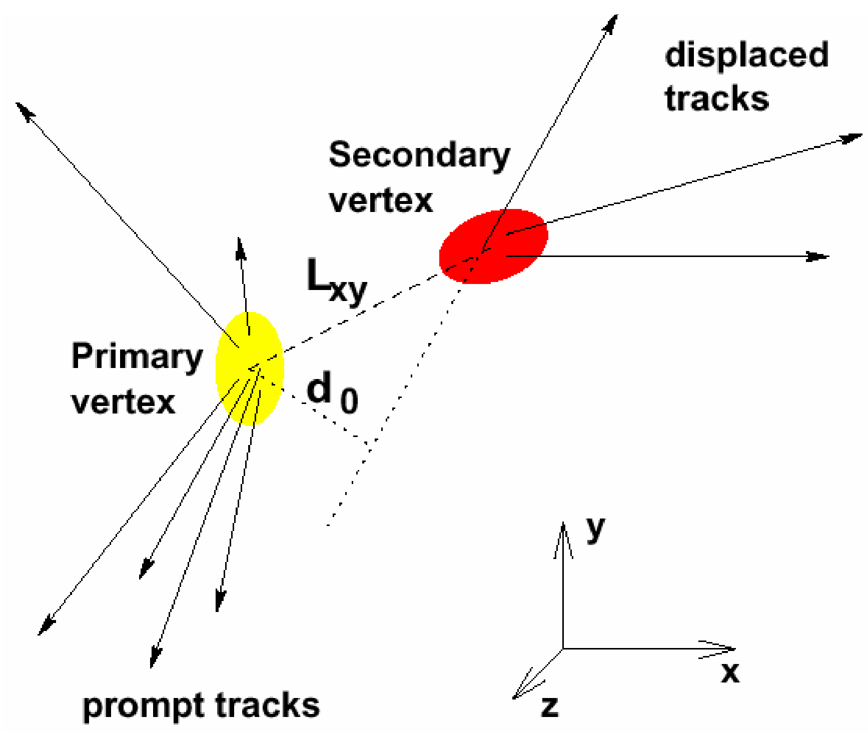
Cross-Checks

Lepton Flavor



- Measure mass separately for ee, *eμ* and *μμ* events
- Results consistent

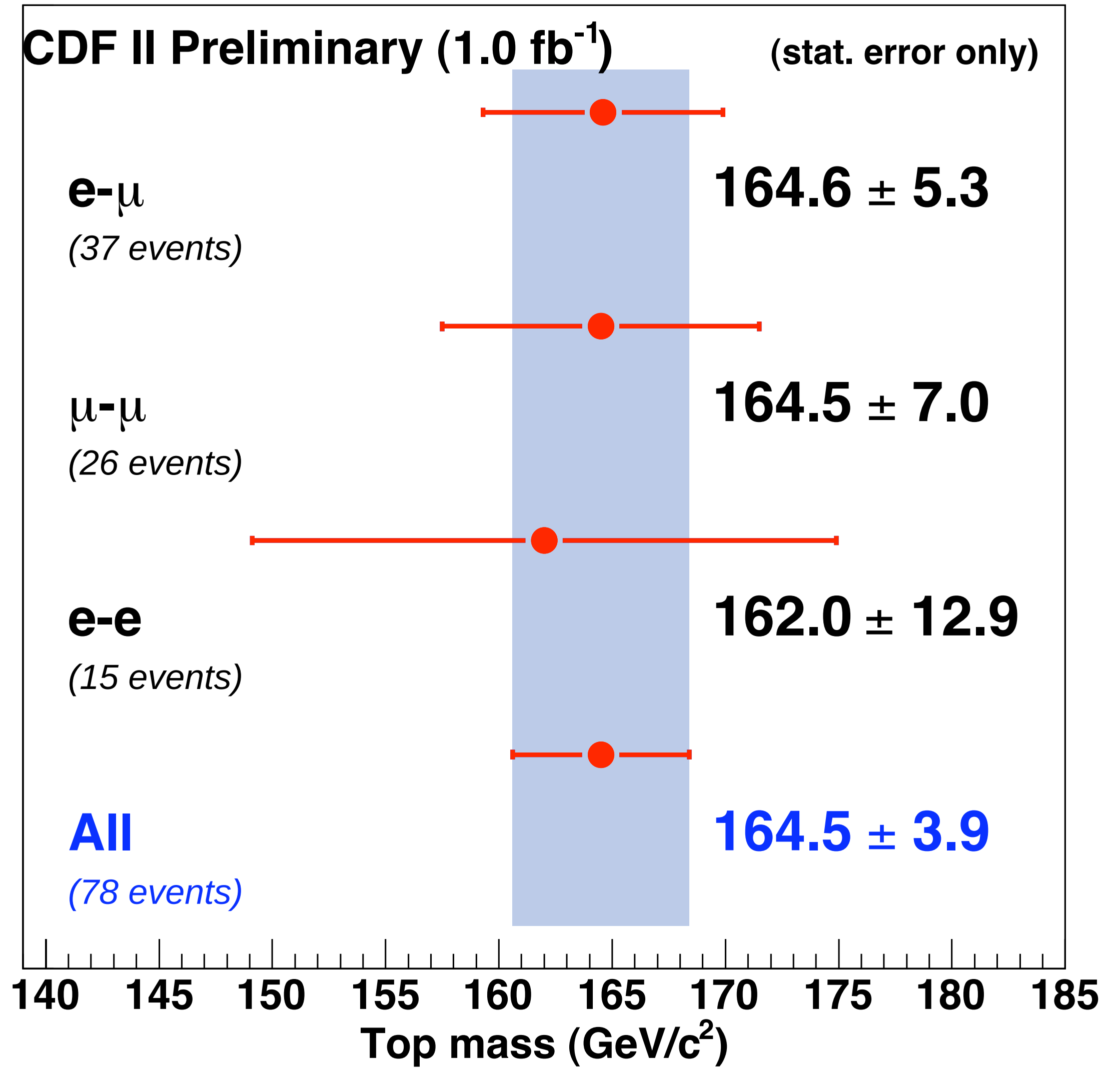
B-tagging



- Use secondary vertex tagging
  - Increases *S:B* to ~15:1
  - Retains ~60% of signal events
- See if measurement consistent with full sample

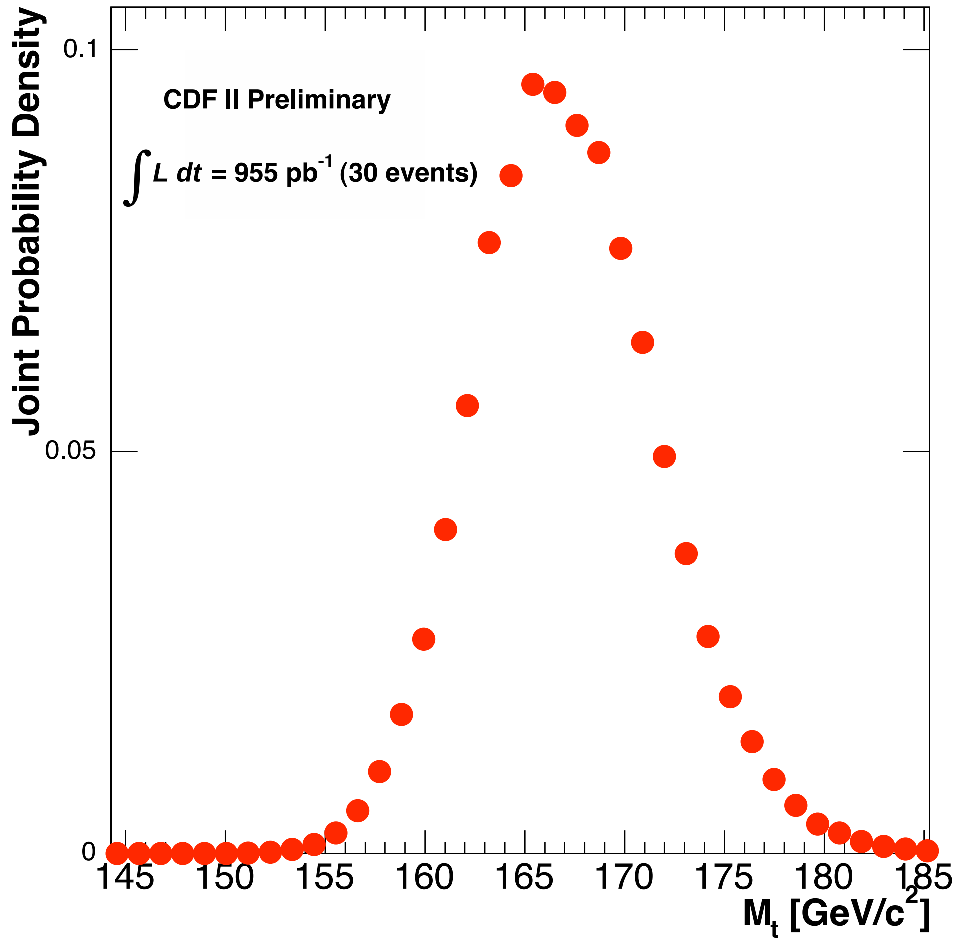
Cross-Checks

Lepton Flavor



- Measure mass separately for ee, *eμ* and *μμ* events
- Results consistent

B-tagging

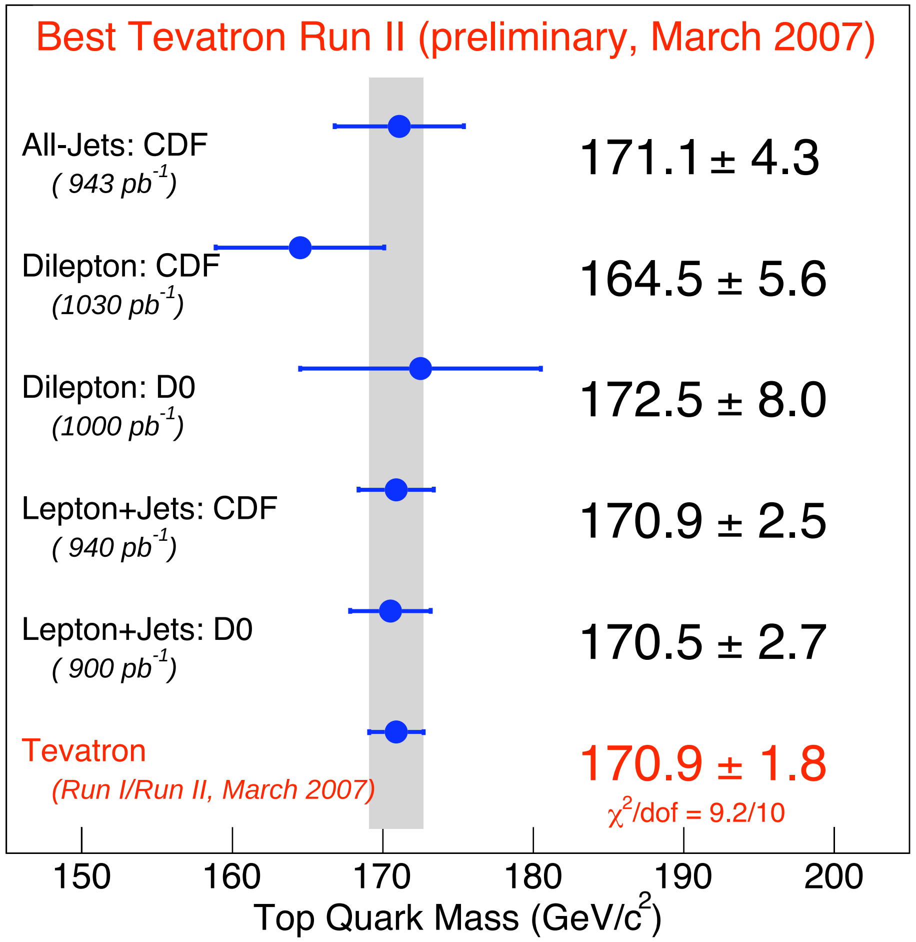


- Use secondary vertex tagging
  - Increases *S:B* to ~15:1
  - Retains ~60% of signal events
- See if measurement consistent with full sample

$M_{top} = 167.3 \pm 4.6(\text{stat.}) \pm 3.8(\text{syst.})\,\text{GeV}/c^2$

Impact and outlook

- Measurement is included in world average
  - Carries ~5% weight
- Starts to get limited by systematic uncertainty
  - Cannot use *in situ* measurement of JES
    - Can use $Z \rightarrow b\bar{b}$ to measure *b*-jet specific JES
  - Studying genetically evolving neural net selection
  - Studying further optimization of integration



Conclusion

- Application of Matrix Element technique to the dilepton channel
- Most precise single measurement of M_{top} in the dilepton channel

  M_{top} = 164.5±3.9(stat.)±3.9(syst.)GeV/c^2

  - Included in current world average
- With no improvements to method, projected stat. error with 4 fb^{-1} is ~2 GeV/c^2
  - Improvements to method in progress