Top Quark Mass in the Dilepton Channel at CDF

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On behalf of the CDF Collaboration

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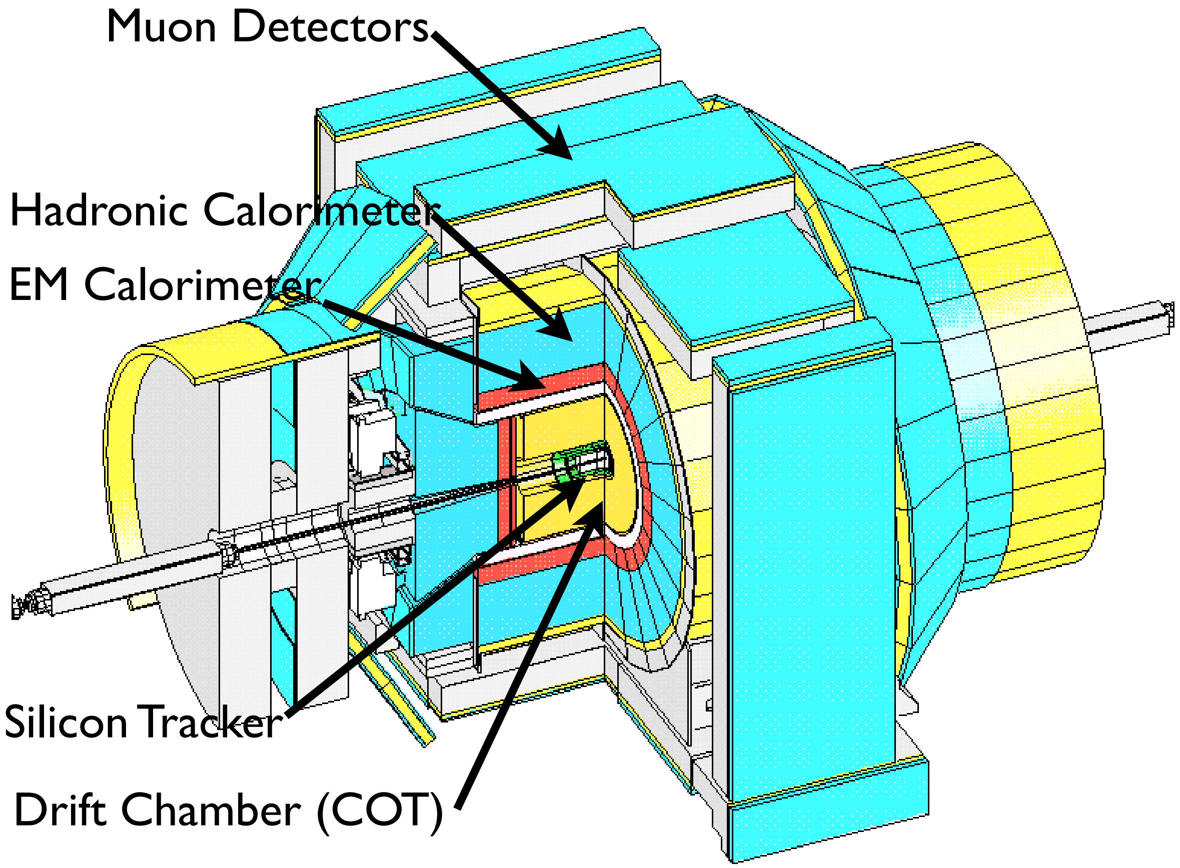
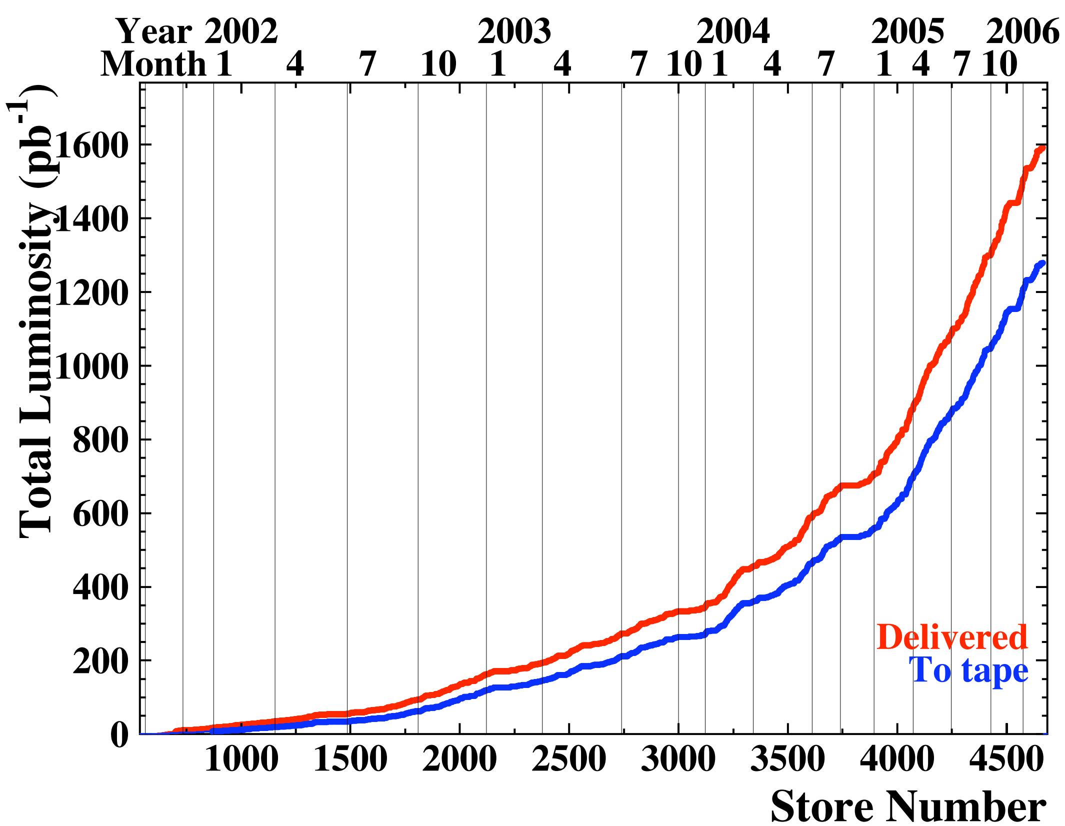
Outline

- Experimental apparatus: Tevatron and CDF Detector
- The dilepton channel
  - Difficulties of measuring M_{top} in this channel
- The Matrix Element method
  - Systematic Uncertainties
- Measurement in data
- World average and consistency with lepton+jets
- An additional measurement: b-tagged sample

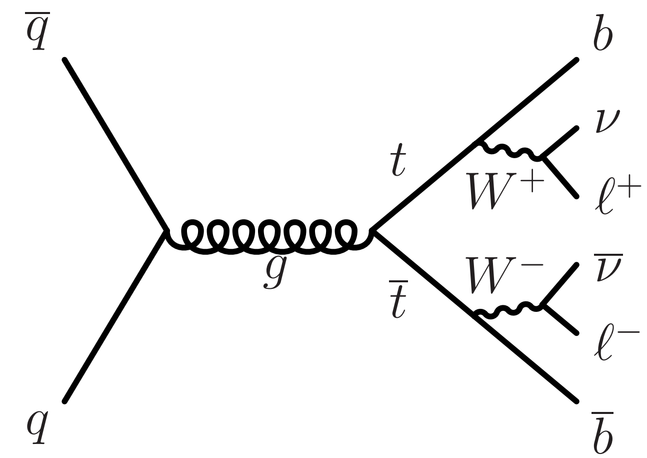
Tevatron and CDF Detector





- Tevatron
  - In past year, e cooling implemented
    - Helps with anti-proton stacking
    - Peak luminosity $>1.7\times10^{32}$ cm^{-2}s^{-1}
  - 1.6 fb^{-1} delivered to experiments
- CDF Detector - General purpose detector
  - Precision tracking (Silicon + COT)
  - EM and Hadronic calorimeters
    - Endplug new for Run II
  - Muon detectors (extended for Run II)
  - 1.3 fb^{-1} recorded at CDF
    - Measurement shown uses 750 pb^{-1} (up to December 2005)

Top 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 E_T from νs

Advantages

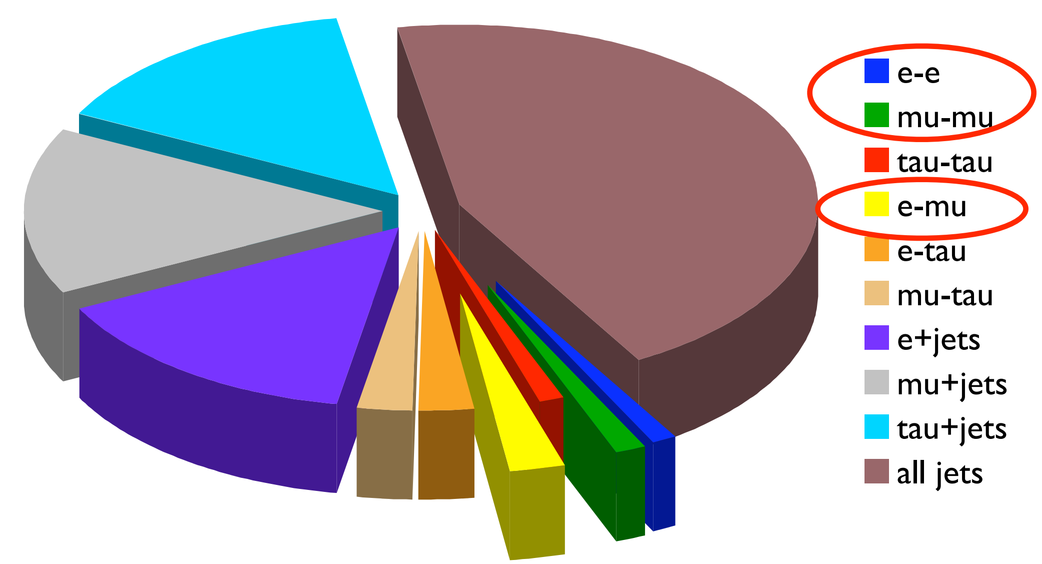
- Clean: little background without need for *b*-tagging
- Least jets of any channel (less reliant on JES, less ambiguity in jets)

Disadvantages

- Low statistics
- 2 νs escape undetected– underconstrained system

Backgrounds

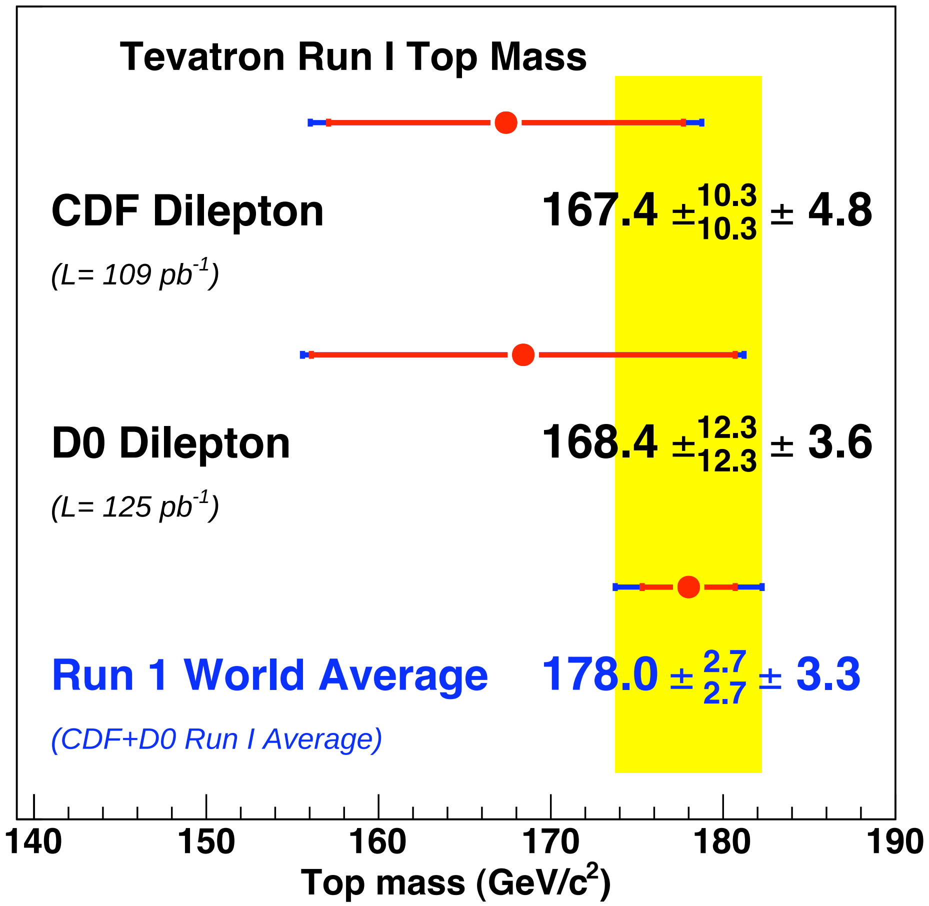
- Drell-Yan + jets
- Diboson + jets
- Mis-ID leptons ("fakes")



Measuring M_{top} in the Dilepton Channel

Important measurement

- Verify that we are measuring SM top
- If results across channels inconsistent, new physics might be in sample



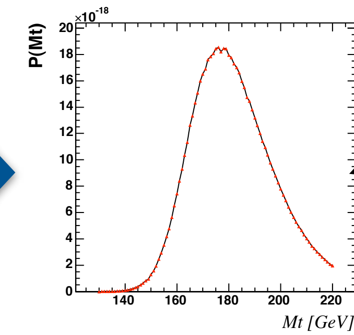
Difficult channel to work in

- Low statistics
- Two neutrinos escape undetected
- Only one missing transverse energy measurement
    - Kinematically under-constrained
- Forced to make assumptions and integrate

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

$$\frac{d\sigma(M_t)}{d\mathbf{x}} = \frac{1}{N}\int d\Phi_6 |\mathcal{M}_{t\bar{t}}(p_i; M_t)|^2 \prod W(p_i, \mathbf{x}) f_{PDF}(q_1) f_{PDF}(q_2)$$

  - Transfer functions link measured quantities **x** to parton-level ones, p_i
  - Perform integrals over unknown quantities (6)

Integrals still take 2-3 hours per event!

- Simplifying assumptions made for tractability
- Use similar differential cross-sections for background processes
  - Final probability becomes weighted sum of signal and background probabilities

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

- First application of method to dilepton channel (340 pb^{-1}), published in PRL **96**, 152002

Uncertainties

Statistical Uncertainty

- Expected for M_{top}=175 GeV/c^2, σ = 5.9 GeV/c^2
- Expected for M_{top}=165 GeV/c^2, σ = 5.1 GeV/c^2

Systematic Uncertainty

Source	ΔM_{top} (GeV/c^2)
Jet Energy Scale	2.6
Generator	0.5
Method	0.3
Sample Composition	0.7
Background Statistics	0.8
Background Modeling	0.8
FSR	0.5
ISR	0.5
PDFs	0.6
Total	*3.1*

Improves with better methods and/or more data (red: Jet Energy Scale, Method, Sample Composition, Background Statistics, Background Modeling, FSR, ISR)

Improves with more CPU (blue: Generator, PDFs)

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Working on using $Z \to bb$ to improve

Improves with better methods and/or more data

Improves with more CPU

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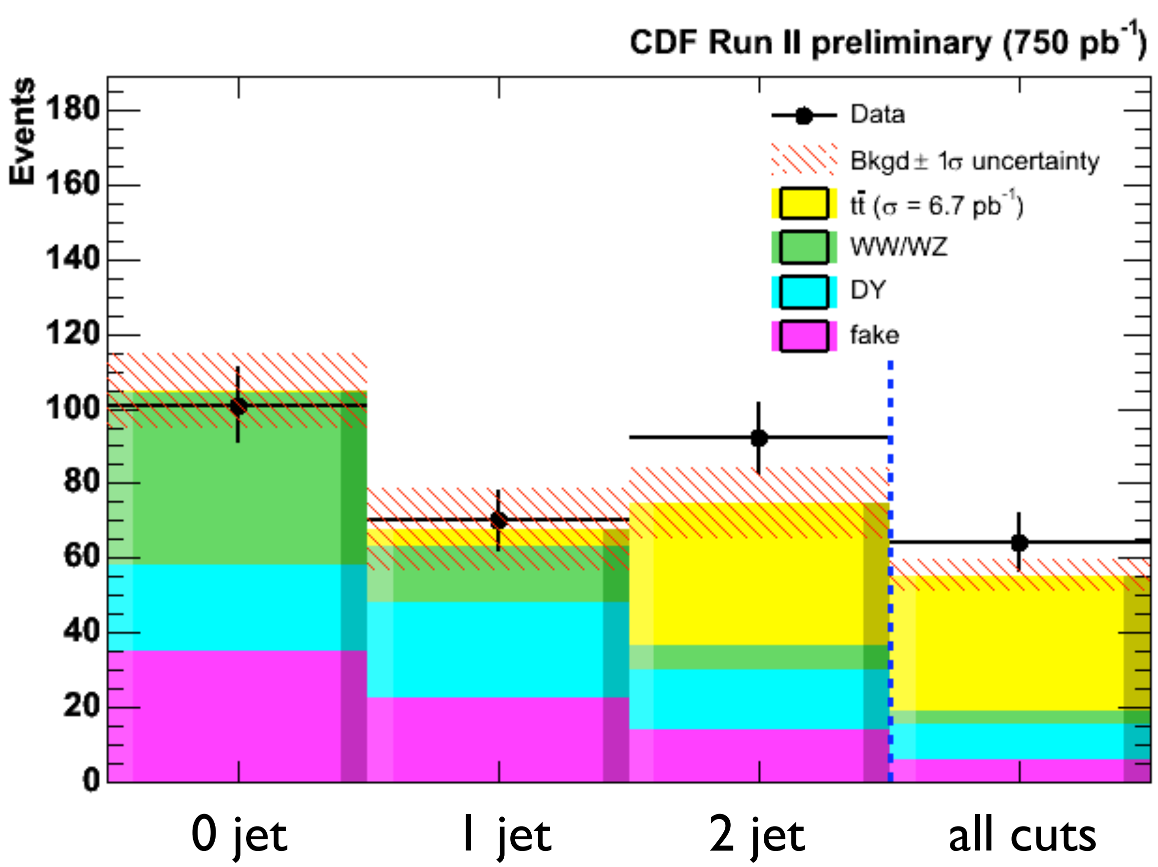
Driven by small sample of (data-based) “fake” lepton events (Background Statistics)

Legend:
- Pink: Improves with better methods and/or more data (Jet Energy Scale, Method, Sample Composition, Background Statistics, Background Modeling, FSR, ISR)
- Blue: Improves with more CPU (Generator, PDFs)

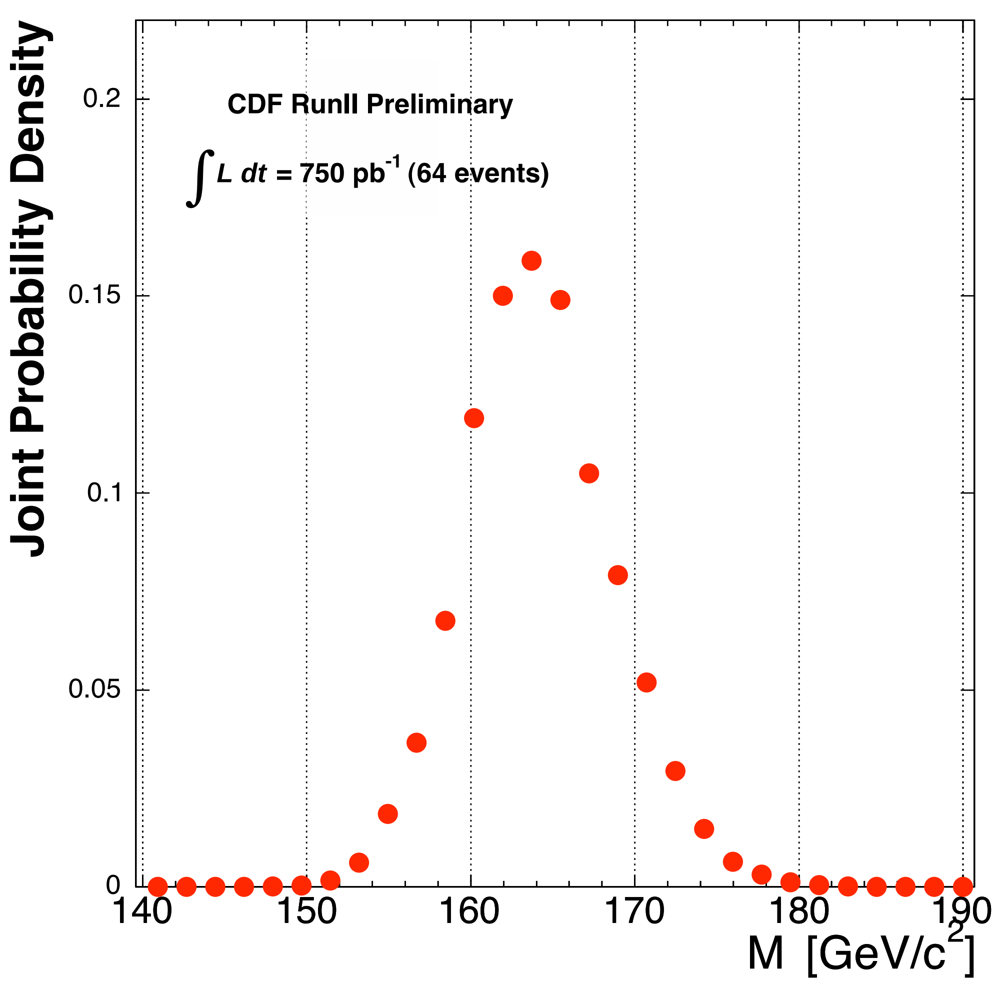
Dataset Used

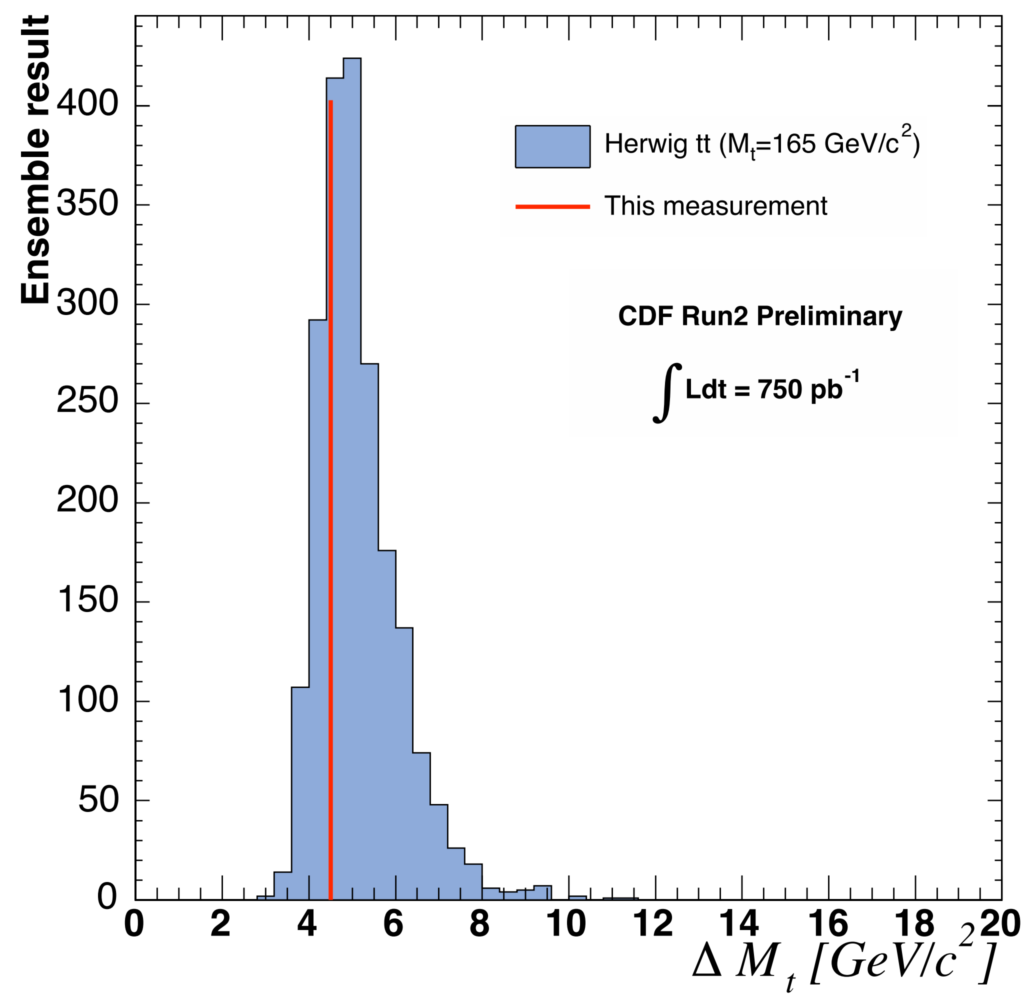
- 750 pb^{-1} of data collected up to December 2005 at CDF
- Basic selection: 2 high-p_T (>20 GeV/c) leptons, 2 high-E_T (>15 GeV) jets, large $\not{E}_T$ (>25 GeV)
- Additional cuts to help reduce background
  - Elevate $\not{E}_T$ requirement when m_{ll} is close to Z mass
  - Require scalar sum of energies in event, H_T>200 GeV



Source	N_{evs}
tt (M_t=175 GeV/c^2, σ=6.7 pb)	36.1
Z→ee/μμ	7.8
Fakes	6.3
WW/WZ	3.6
Z→ττ	1.6
Total Expected	55.4
Observed (750 pb^{-1})	*64*

Result





M_{top} = 164.5±4.5(stat.)±3.1(syst.)GeV/c^2

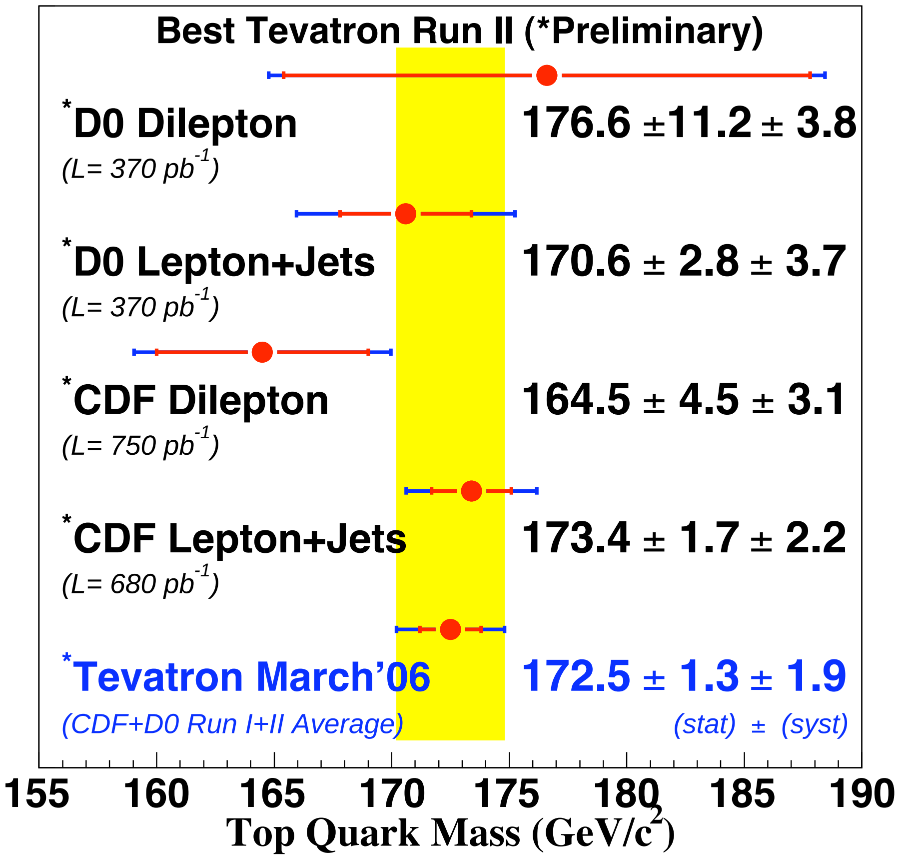
- Uses 64 events in 750 pb^{-1} of data
- Most precise single measurement of M_{top} in dilepton channel to-date
  - Expected stat error of 5.1 GeV/c^2 for M_t = 165 GeV/c^2

World Average and Consistency

- Dilepton measurement included in world average

  M_{top} = 172.5±1.3(stat.)±1.9(syst.)GeV/c^2

  - hep-ex/0603039
  - 11% weight
    - Will contribute more as systematics come to dominate



World Average and Consistency

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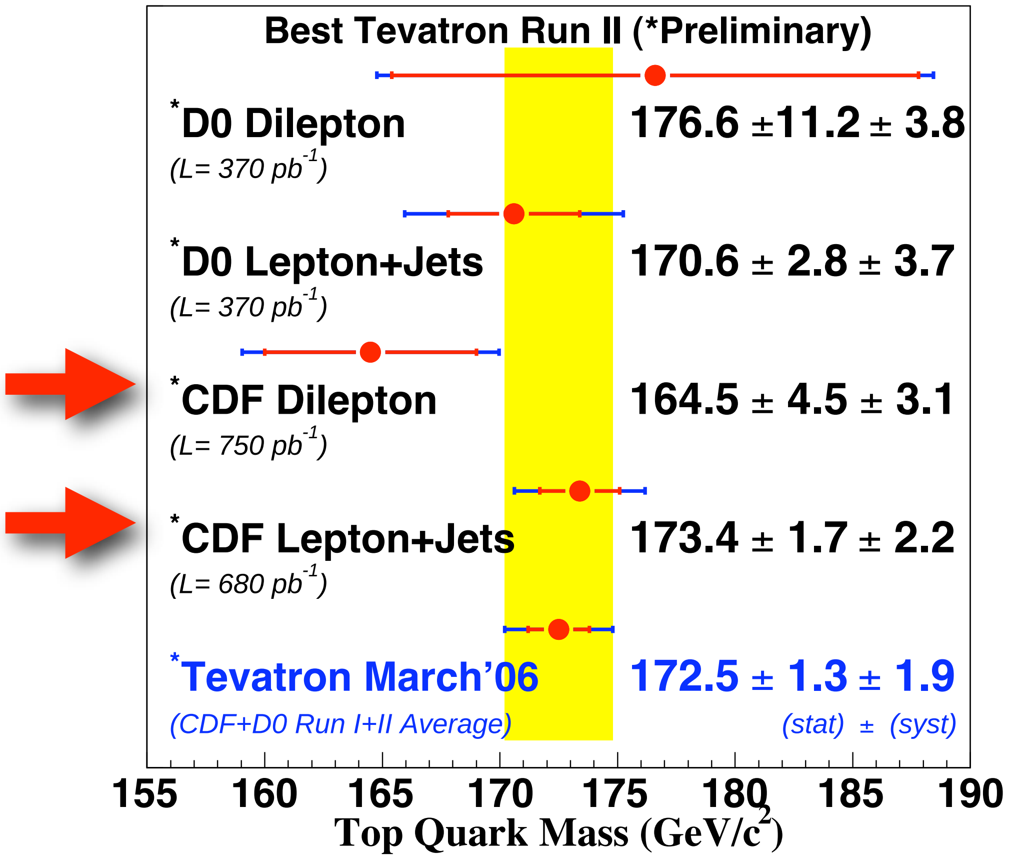
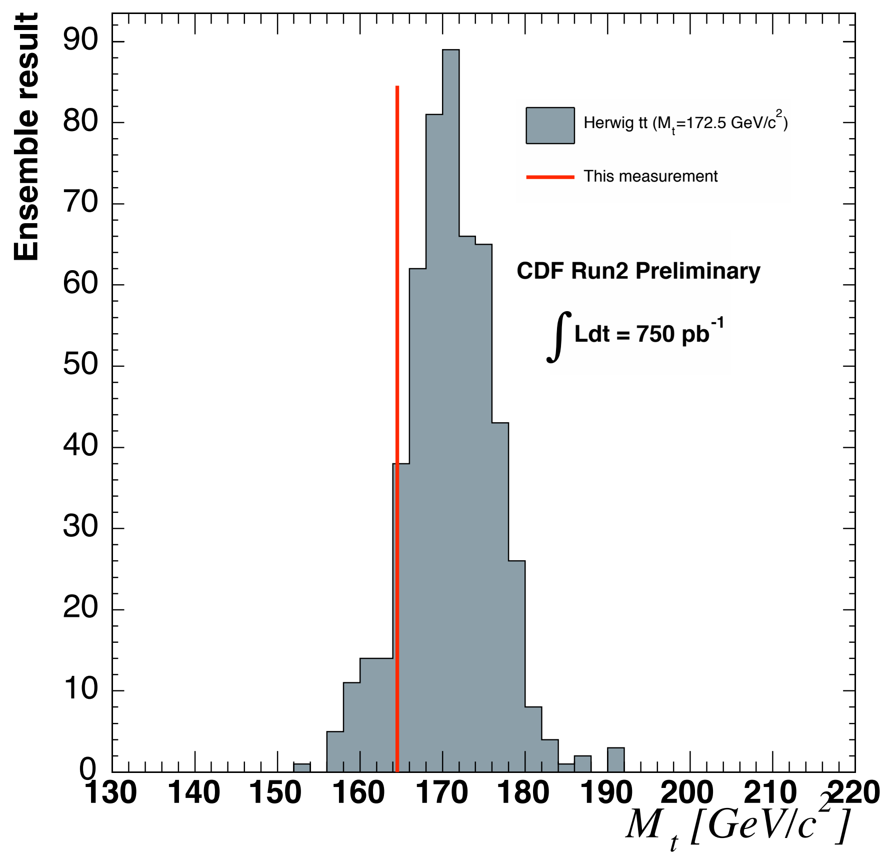
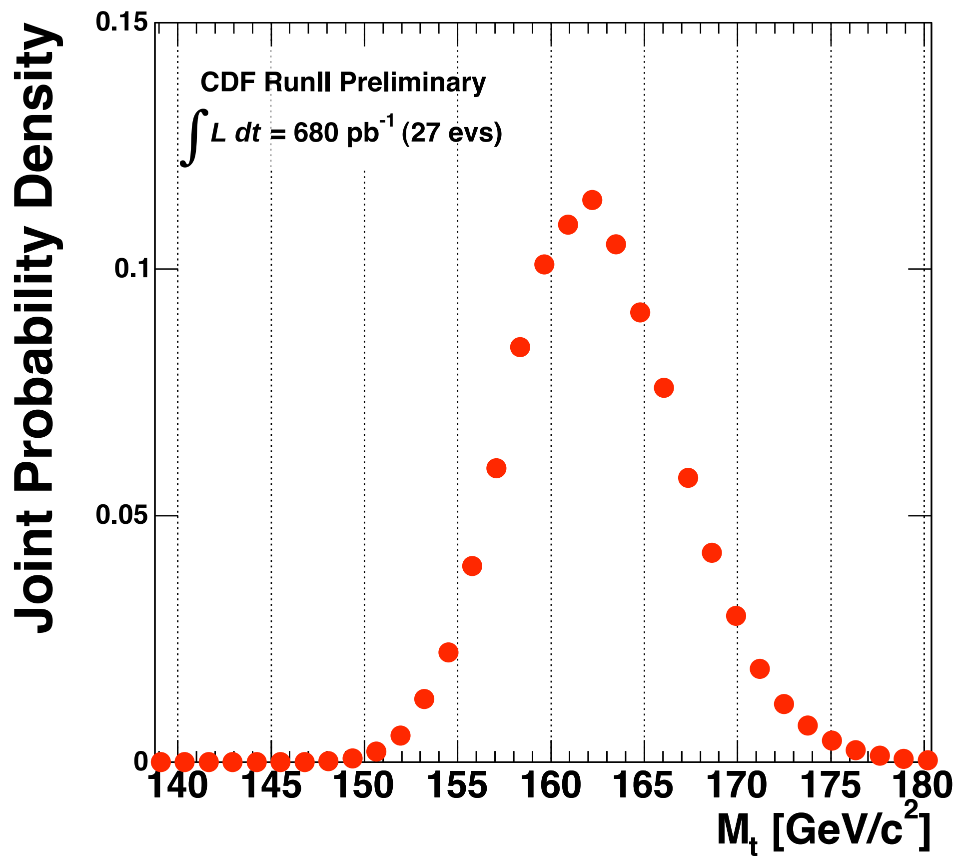
  M_{top} = 172.5±1.3(stat.)±1.9(syst.)GeV/c^2

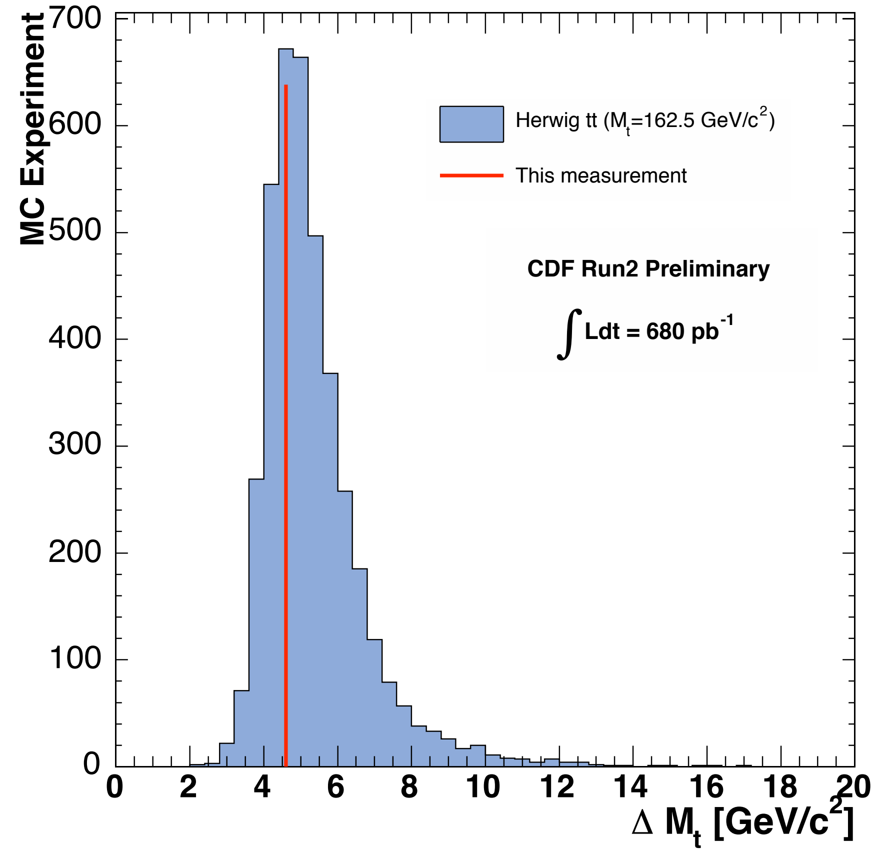
  - hep-ex/0603039
  - 11% weight
    - Will contribute more as systematics come to dominate
- How consistent is 164.5 with 173.4?
  - Need more data to tell if discrepant
  - Trend is intriguing
- Other ways to probe whether sample has unexpected content?
  - Measure mass in subsample with different purity





B-Tagged Measurement





- Require one or more b-tag in sample
  - Removes nearly all background, leaves 60% of signal
  - Comparable sensitivity to full sample

$$M_{top} = 162.7 \pm 4.6(\text{stat.}) \pm 3.0(\text{syst.}) \text{GeV}/c^2$$

- Result consistent with full sample

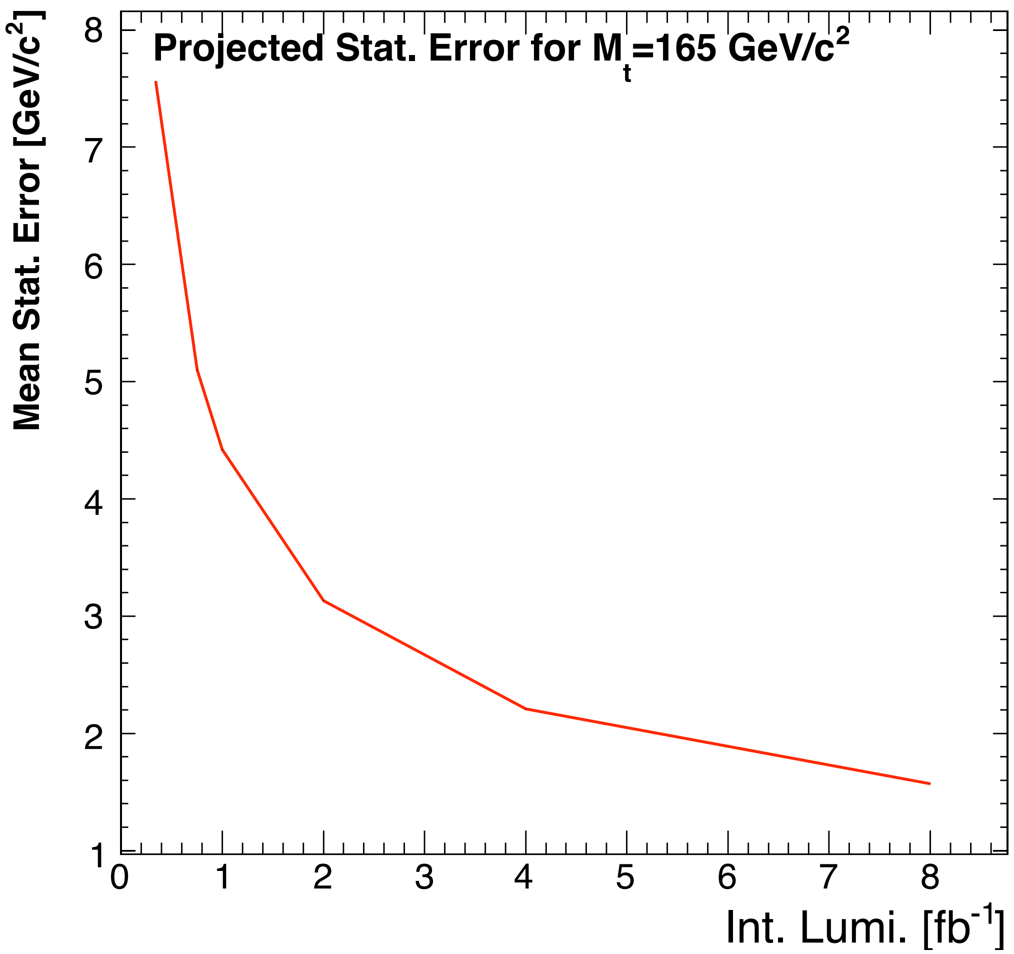
Conclusion and Outlook

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

  M_{top} = 164.5±4.5(stat.)±3.1(syst.)GeV/c^2

  - Included in current world average (11% weight)
- With no improvements to method, projected stat. error with 4 fb^{-1} is ~2 GeV/c^2
  - Improvements to method in progress

Dilepton only



Backup Slides

Measuring the Top Mass

1. Template-based

Reconstruct mass for each event → Form "templates" for signal (varying M_{top}) and background using simulated events → Perform maximum likelihood fit to extract measured M_{top}

Advantages: Takes all (simulated) detector effects into account, (relatively) computationally simple

Disadvantages: Only single number (recon. mass) per event in final Likelihood, all events have equal weight

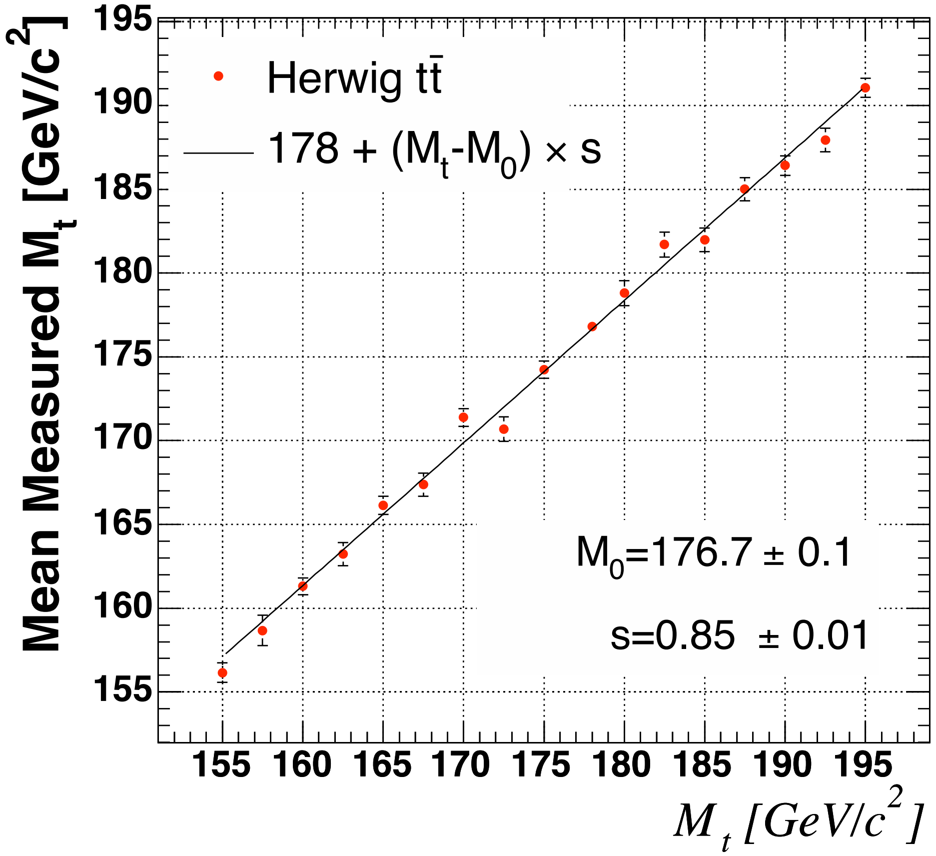
2. Matrix Element-based

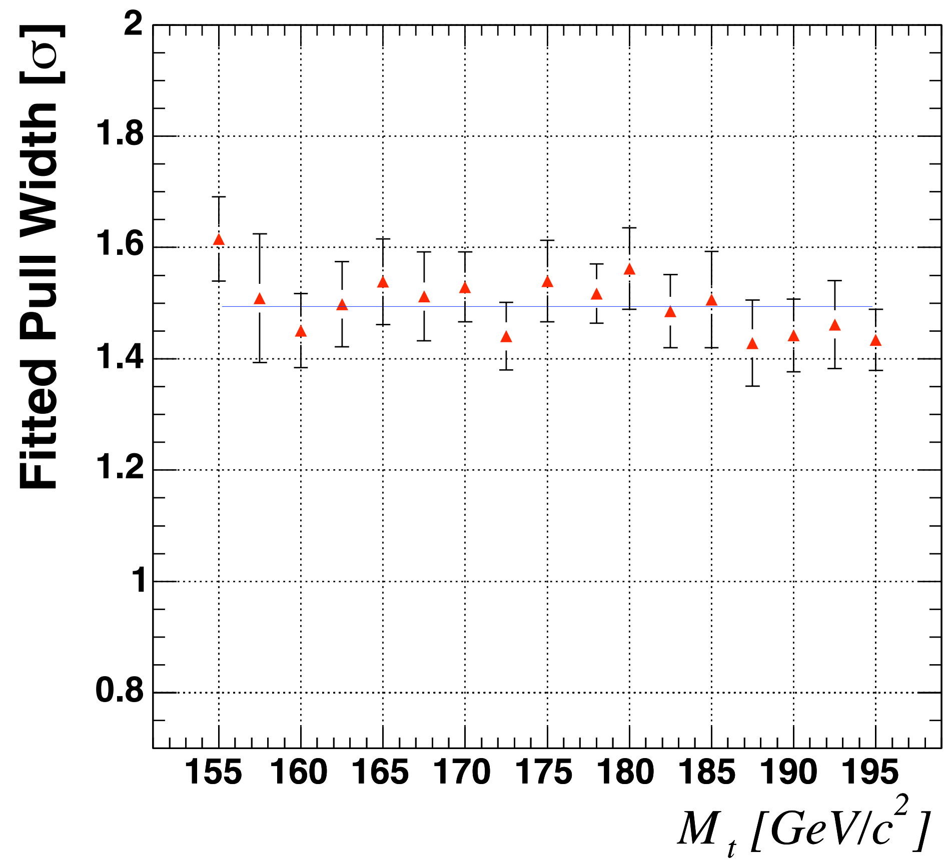
Form per-event probability using matrix element → Integrate over unmeasured quantities → Form ensemble probability and calibrate using simulated events

Advantages: More statistical power, probability curve rather than single mass per event, events weighted naturally

Disadvantages: Complex numerical integration (much CPU)→machinery does not account for all detector effects

Test of Method

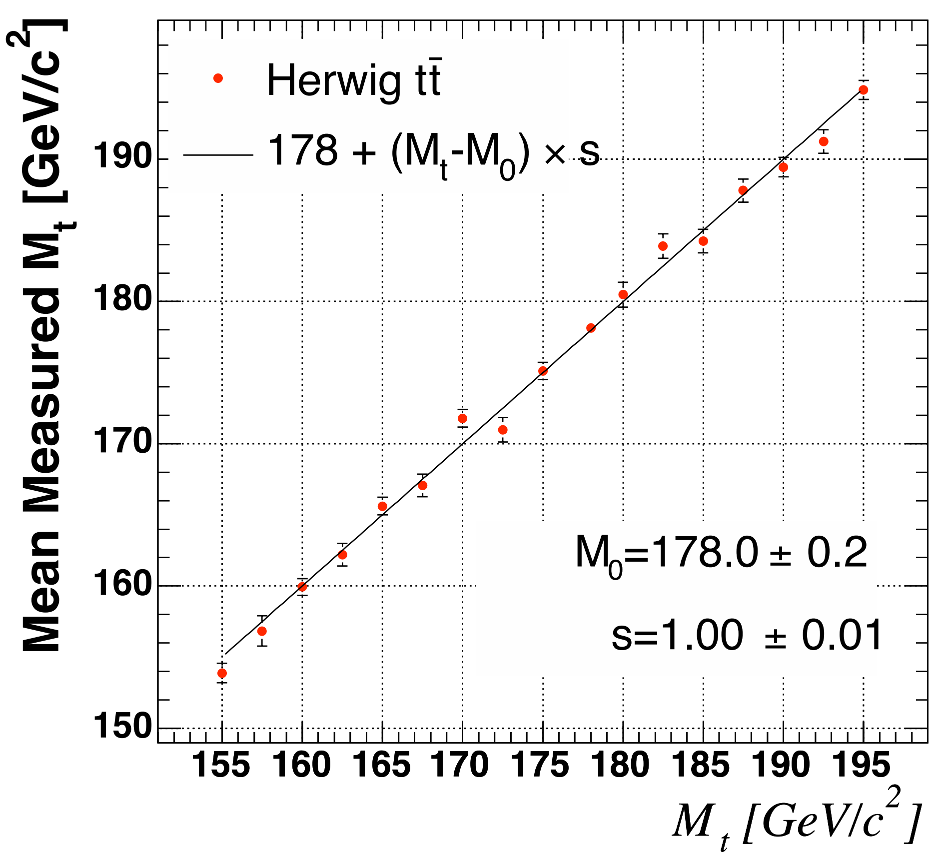


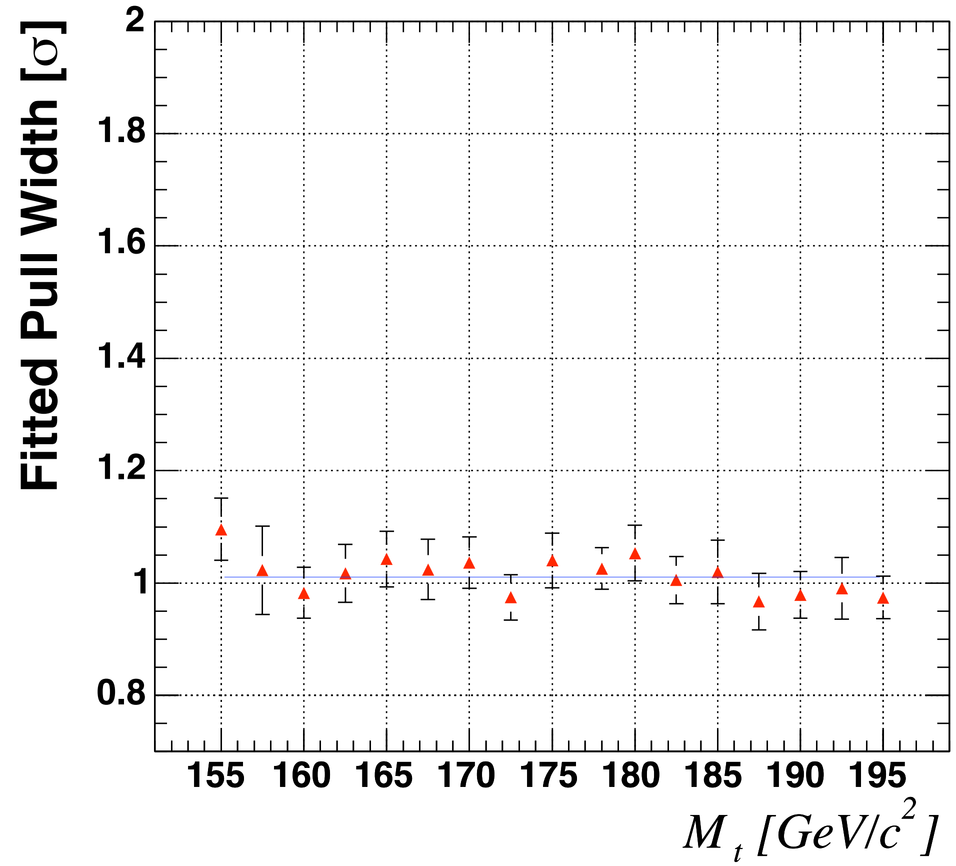


$$= \frac{M_{top}^{meas} - M_{top}^{true}}{\sigma_{M_{top}}^{meas}}$$

- Response (left) is linear, sensitivity is degraded due to presence of unmodeled backgrounds
- Pulls (right), flat as function of top mass, ~1.5 (~1.4 for signal only)
  - Using parton-level information (all assumptions held), pull width ~1.0
  - As assumptions violated (realistic events) pull widths increase
  - Apply scale factor flat in top mass

Test of Method





$$= \frac{M_{top}^{meas} - M_{top}^{true}}{\sigma_{M_{top}}^{meas}}$$

Response unbiased after correction

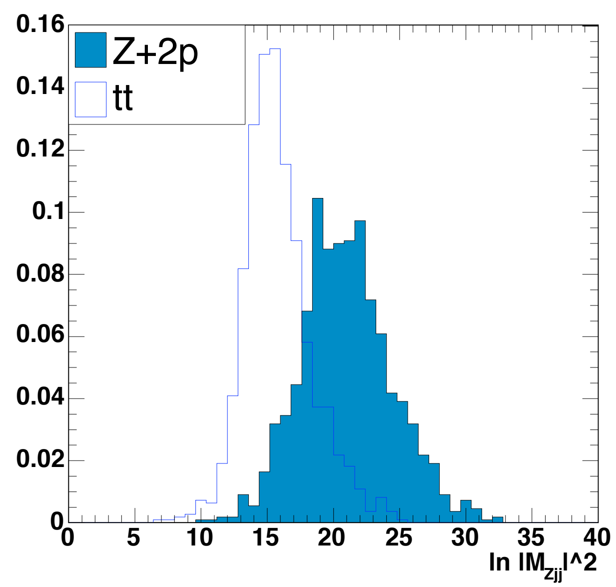
Error estimation correct

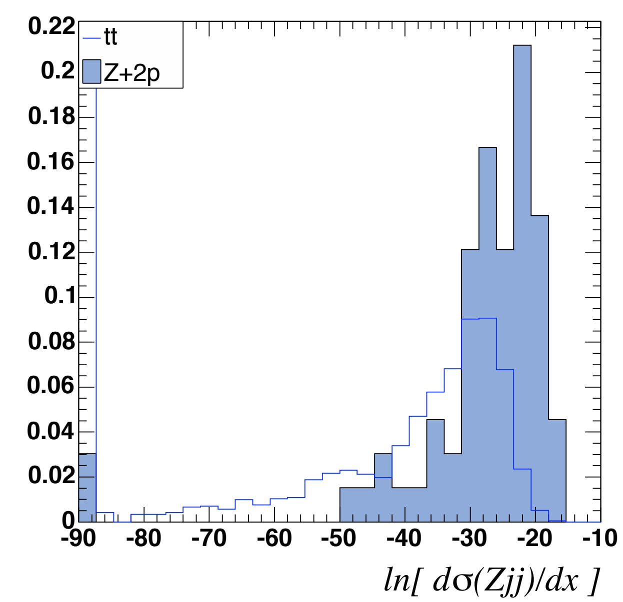
Treating Backgrounds

- Final event probability is weighted sum of signal and background probabilities

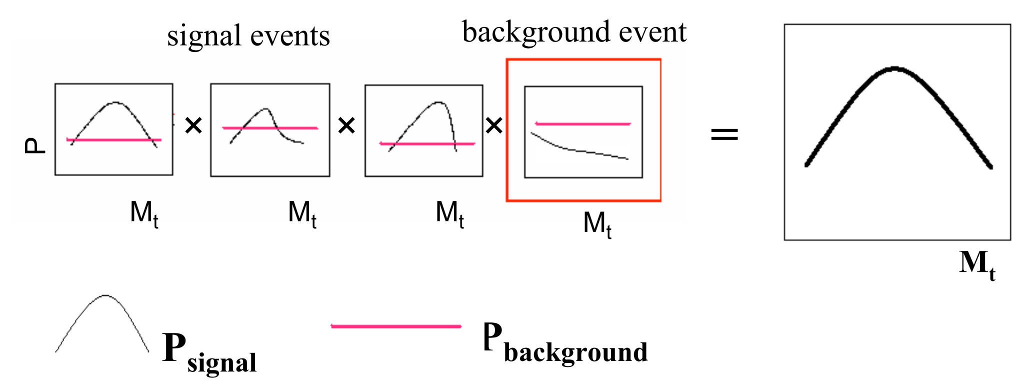
$$P(\mathbf{x}|M_t) = P_s(\mathbf{x}|M_t)p_s + P_{bg_1}(\mathbf{x})p_{bg_1} + P_{bg_2}(\mathbf{x})p_{bg_2} + \cdots$$

- Weights are determined from expected fractional contribution of each source
- Form differential cross-sections as in signal for each modeled background process
  - Difficult to determined closed-form expression for backgrounds: use ME-based generators instead (e.g. ALPGEN)
- Example: DY+2 jets



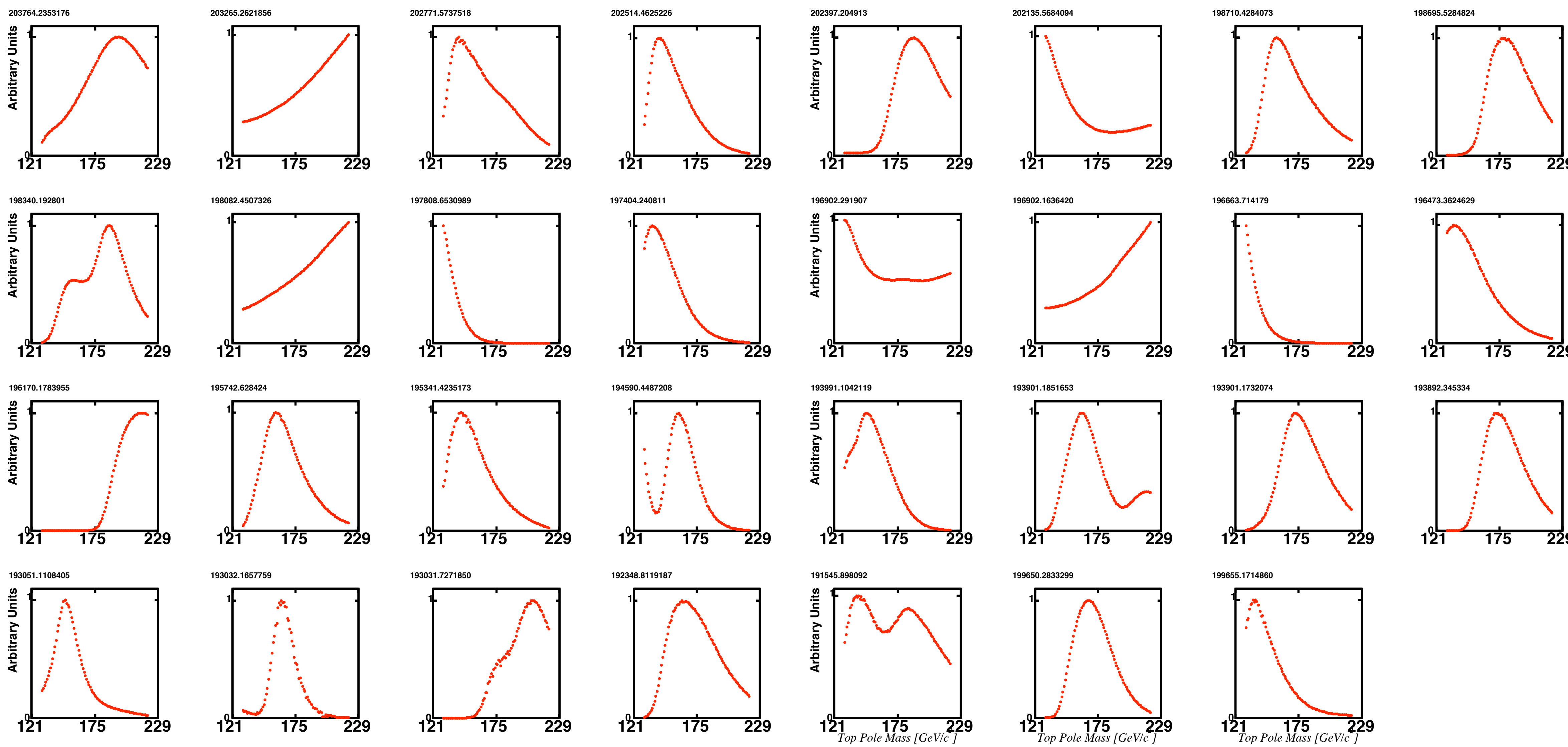


- Modeled backgrounds
  - DY+jets
  - WW+jets
  - W+3 jets (for fakes)
- Product of per-event prob. densities give likelihood for sample



Data Events

CDF II Preliminary 400 pb^{-1} (31 events)



- Only 31 candidate events from data collected in 2005
  - Full data set has 64 events
- Curves are weighted signal+background probabilities
  - Signal probability evaluated for M_t = 130-220 GeV/c^2