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

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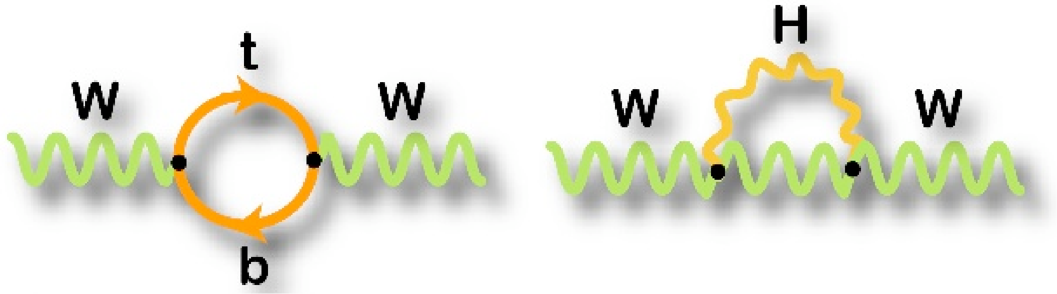
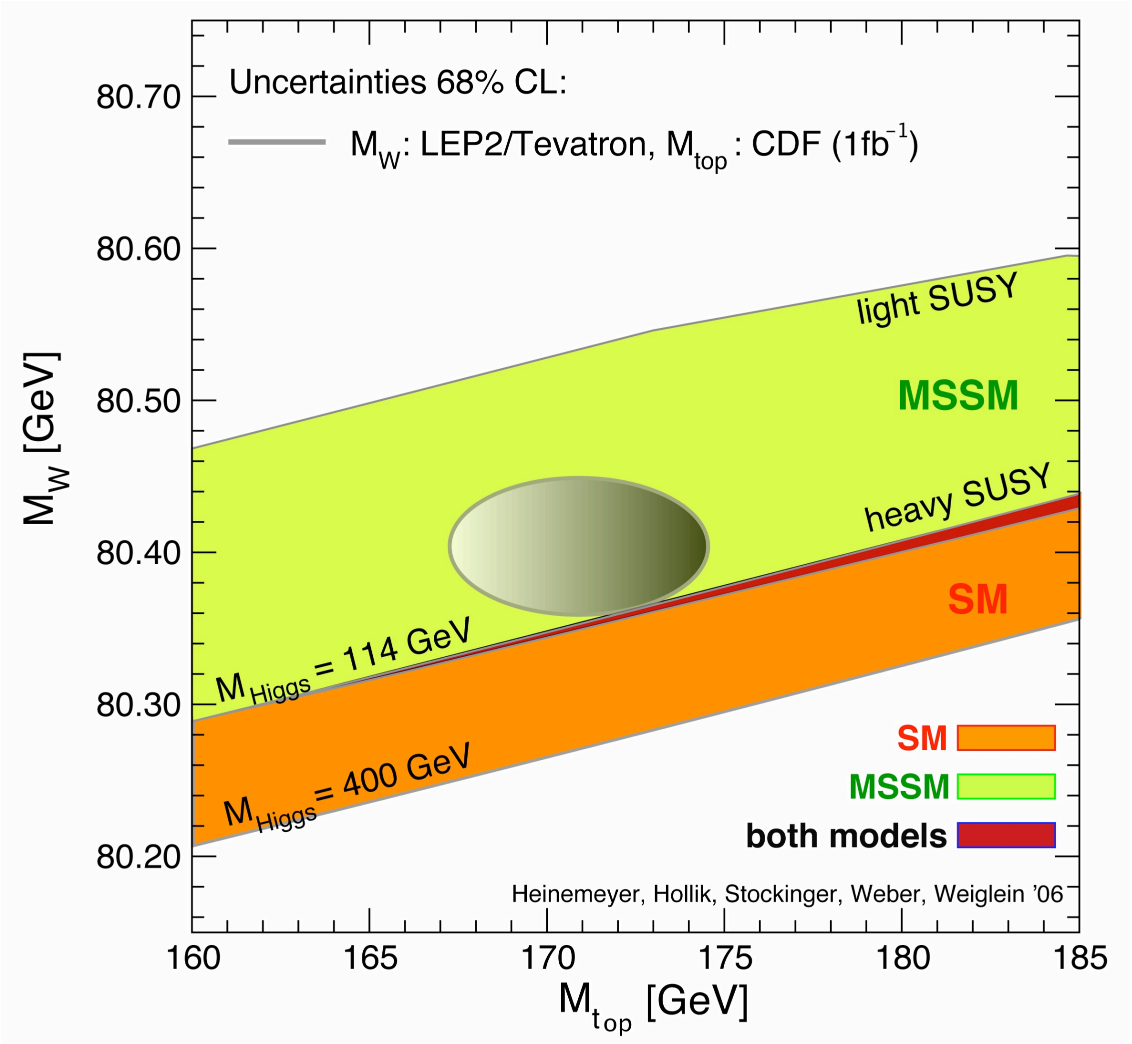
Why measure the top quark mass?

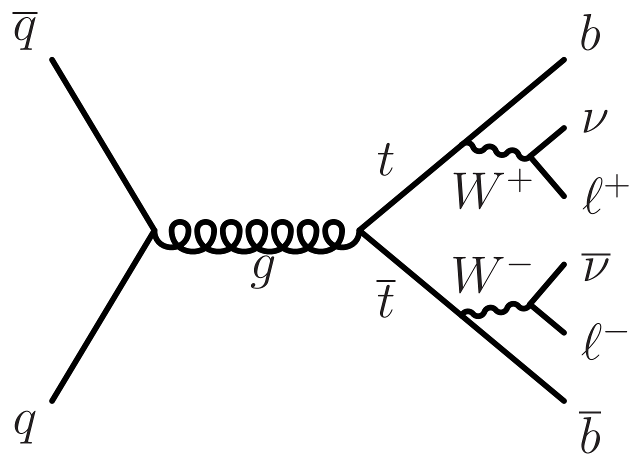
- Top mass is a fundamental parameter in the Standard Model (SM)
- Enters into radiative corrections



- Constrains (along with other precision measurements such as M_W) SM Higgs mass
- Also constraint on SUSY models
  - Some require a heavy top
  - Place limits on MSSM Higgs mass(es)



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 E_T from νs

Advantages

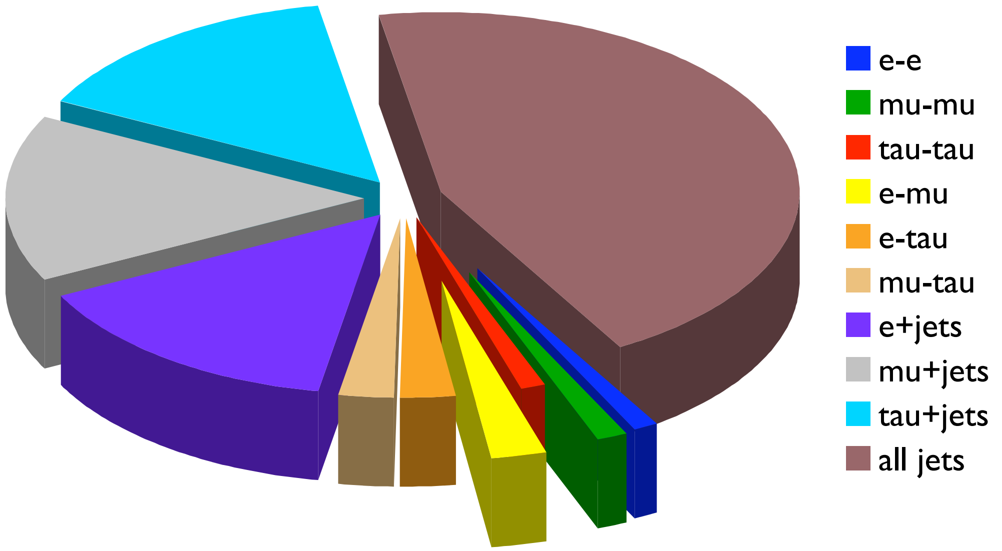
- Clean: little background without need for *b*-tagging
- Least jets of any channel (less reliant on JES, less ambiguity in jets)

Disadvantages

- Low statistics
- 2 νs escape undetected– underconstrained system

Backgrounds

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



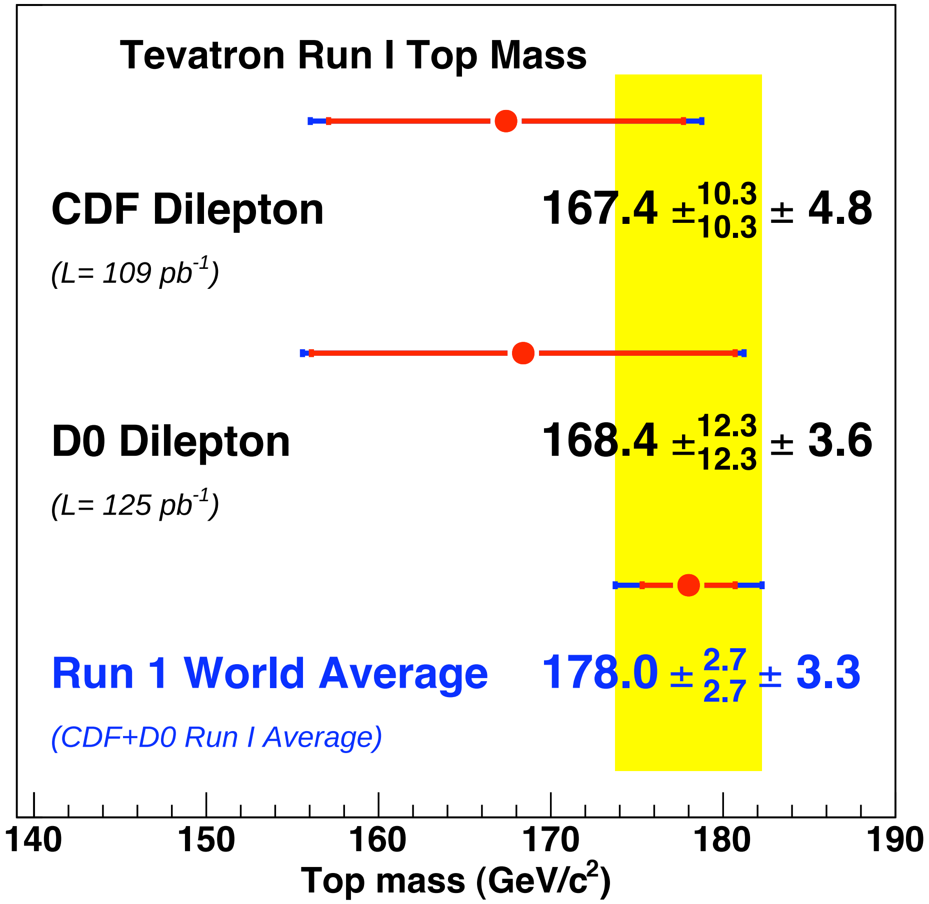
Measuring M_{top} in the dilepton channel

Important measurement

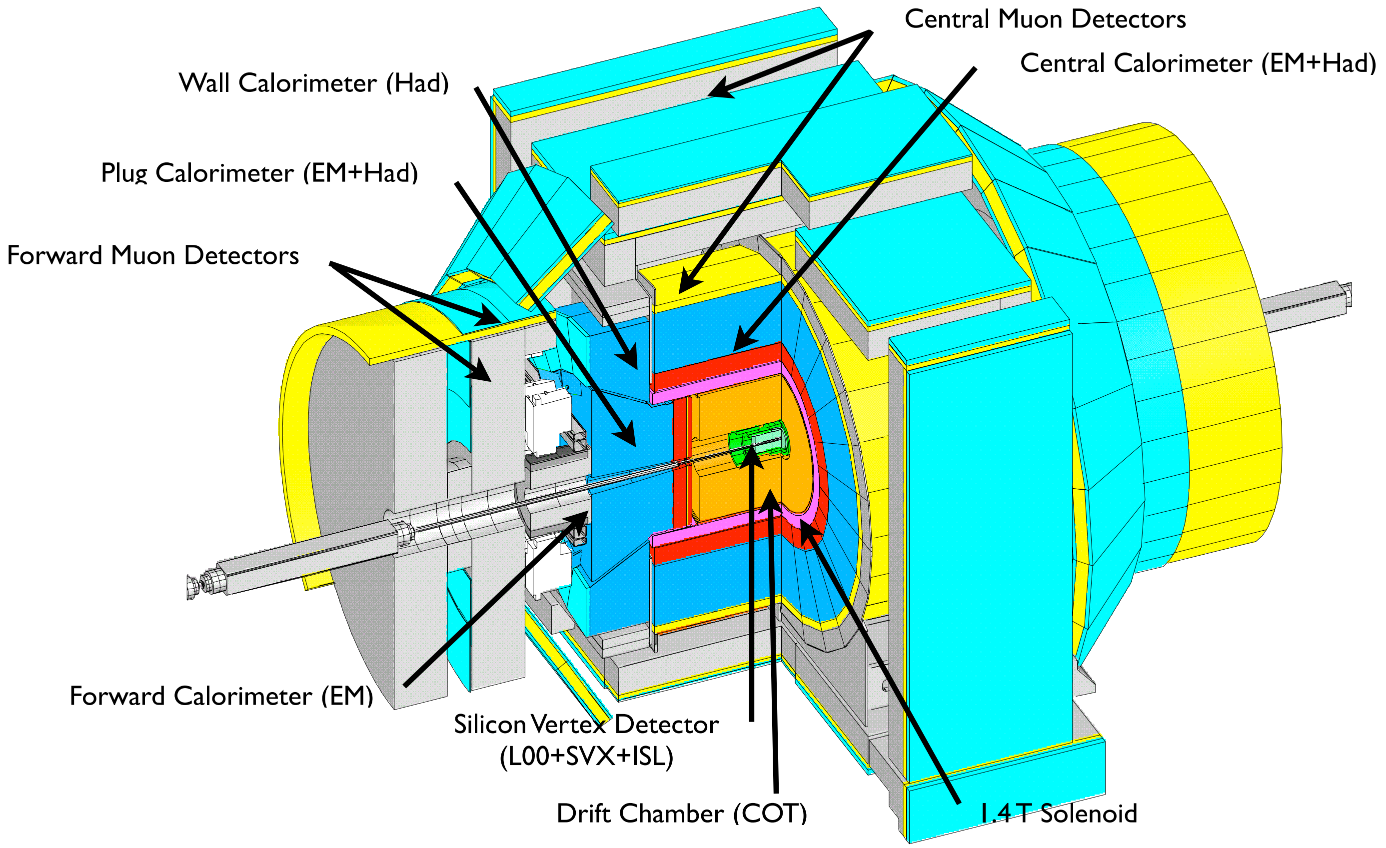
- Contributes to overall knowledge of top mass
- Verify that we are measuring SM top
- If results across channels inconsistent, new physics might be in sample

Difficult channel to work in

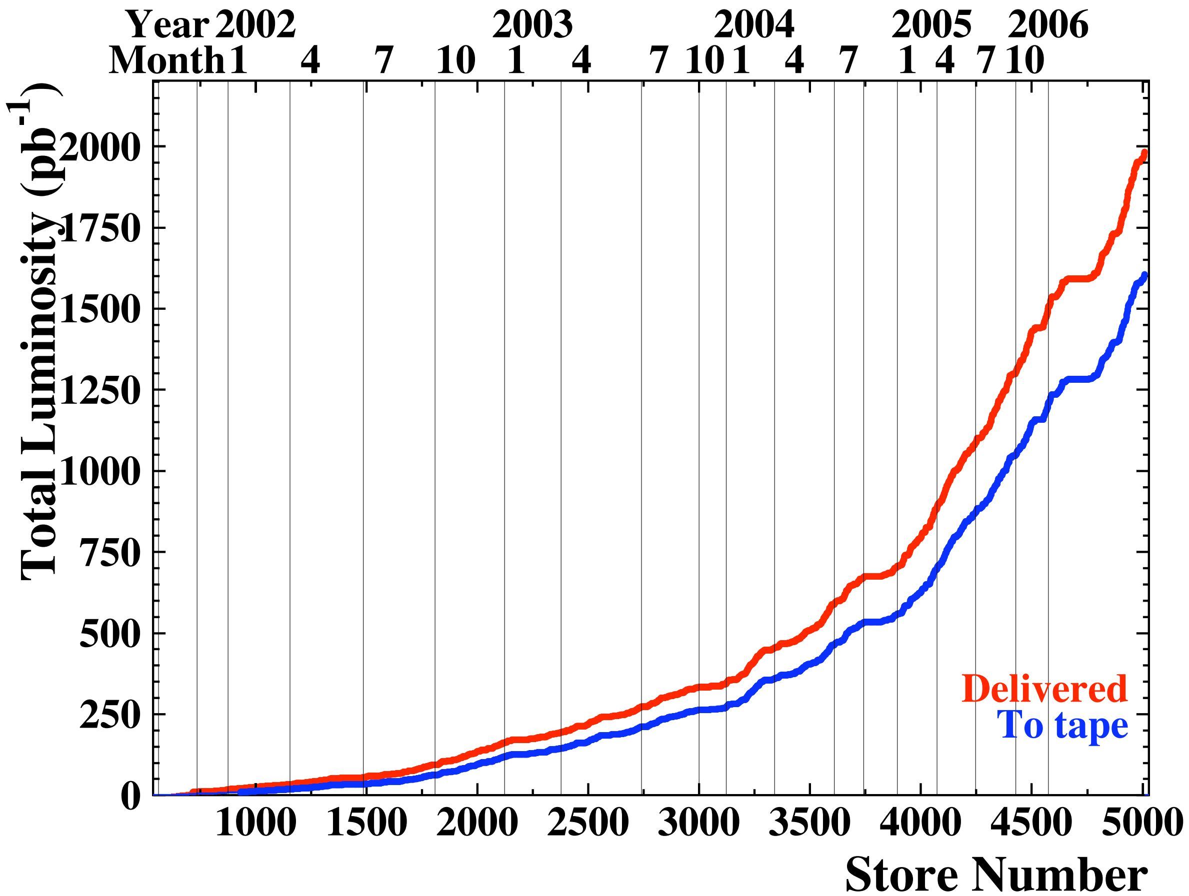
- Low statistics
- Two neutrinos escape undetected
- Only one missing transverse energy measurement
    - Kinematically under-constrained
- Forced to make assumptions and integrate



The Tevatron and CDF detector



- Record inst. lumi. of $2.3 \times 10^{32} cm^{-2} s^{-1}$
- Nearly 2 fb^{-1} delivered to-date
  - CDF has 1.6 fb^{-1} recorded
- Expect 4-8 fb^{-1} for Run II



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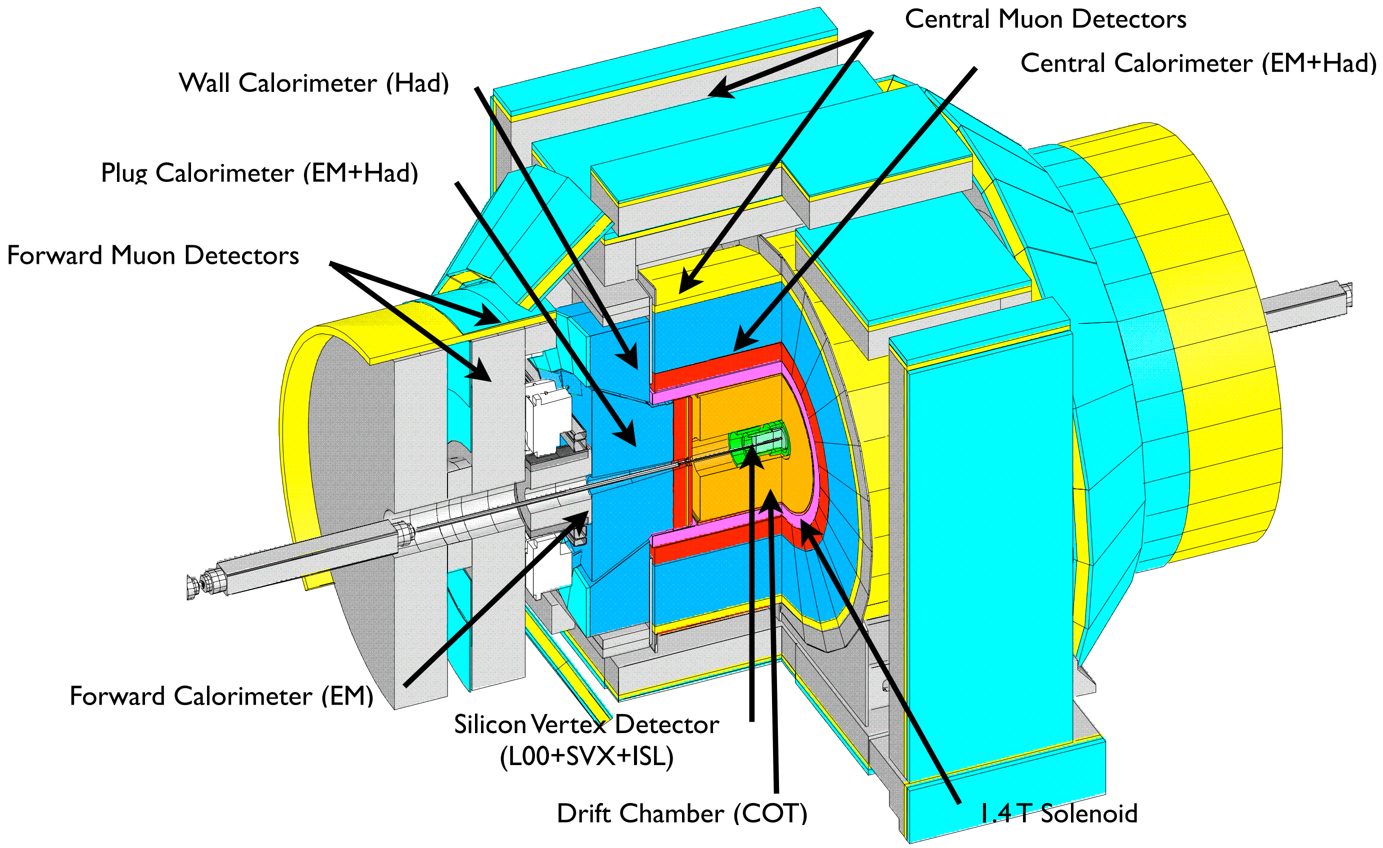

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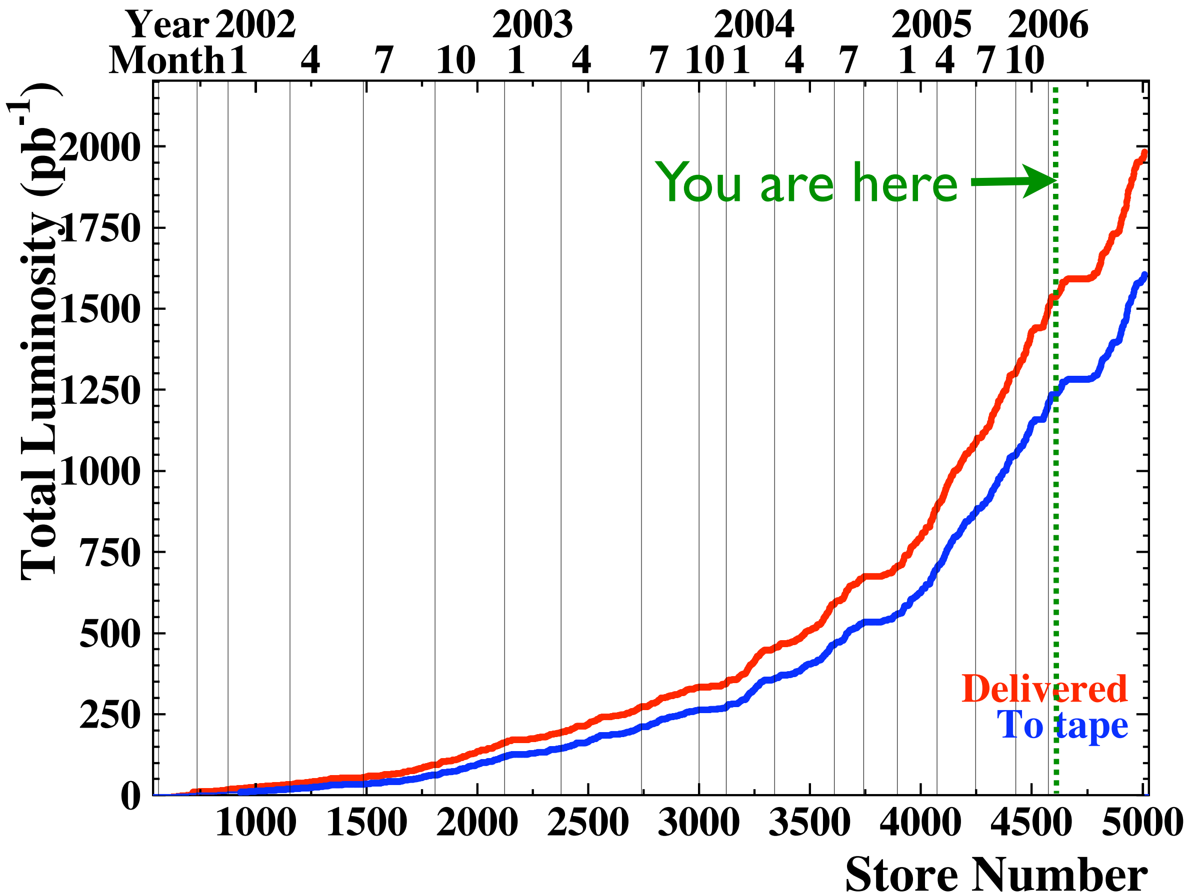
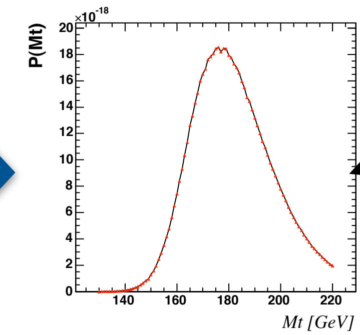


The matrix element method

- 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 **x** to parton-level ones, p_i
    - Jet energy-parton energy
    - tt p_T - measured recoil
  - Perform integrals over unknown quantities (8)
    - Variable change from neutrino momenta to inv. masses
- Simplifying assumptions made for tractability
  - e.g. lepton momenta and jet angles perfectly measured

Integrals still take 2-3 hours per event!

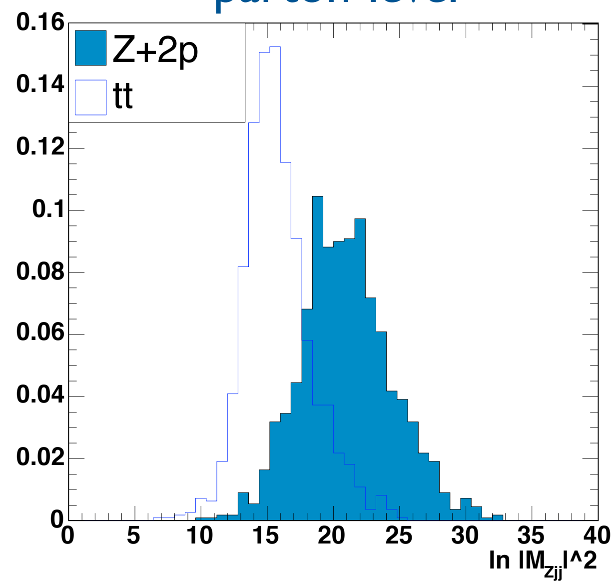
Incorporating backgrounds

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

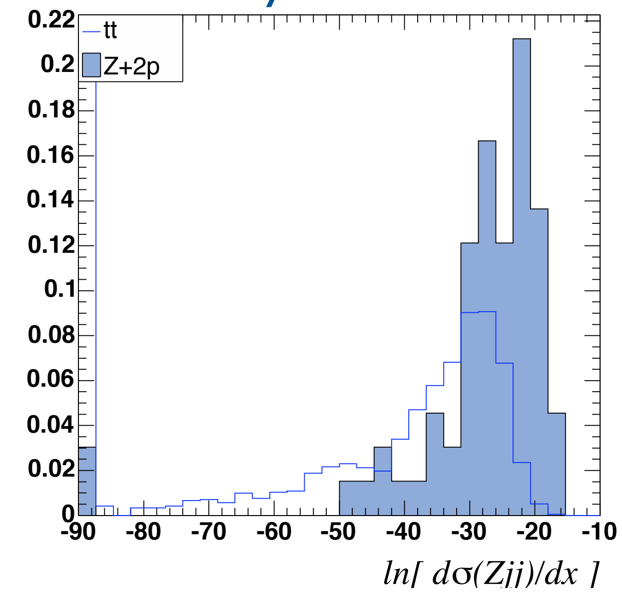
$$P(\mathbf{x}|M_t) = P_s(\mathbf{x}|M_t)p_s + P_{bg_1}(\mathbf{x})p_{bg_1} + P_{bg_2}(\mathbf{x})p_{bg_2} + \cdots$$

- 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

parton-level

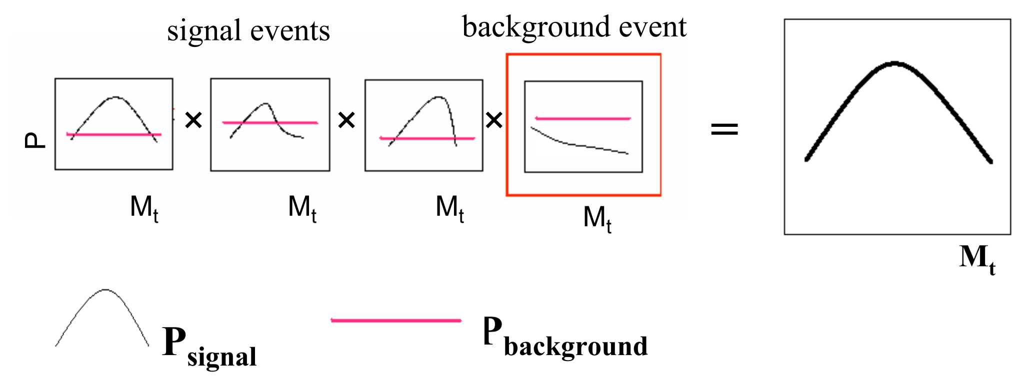


fully simulated



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

  give likelihood for sample

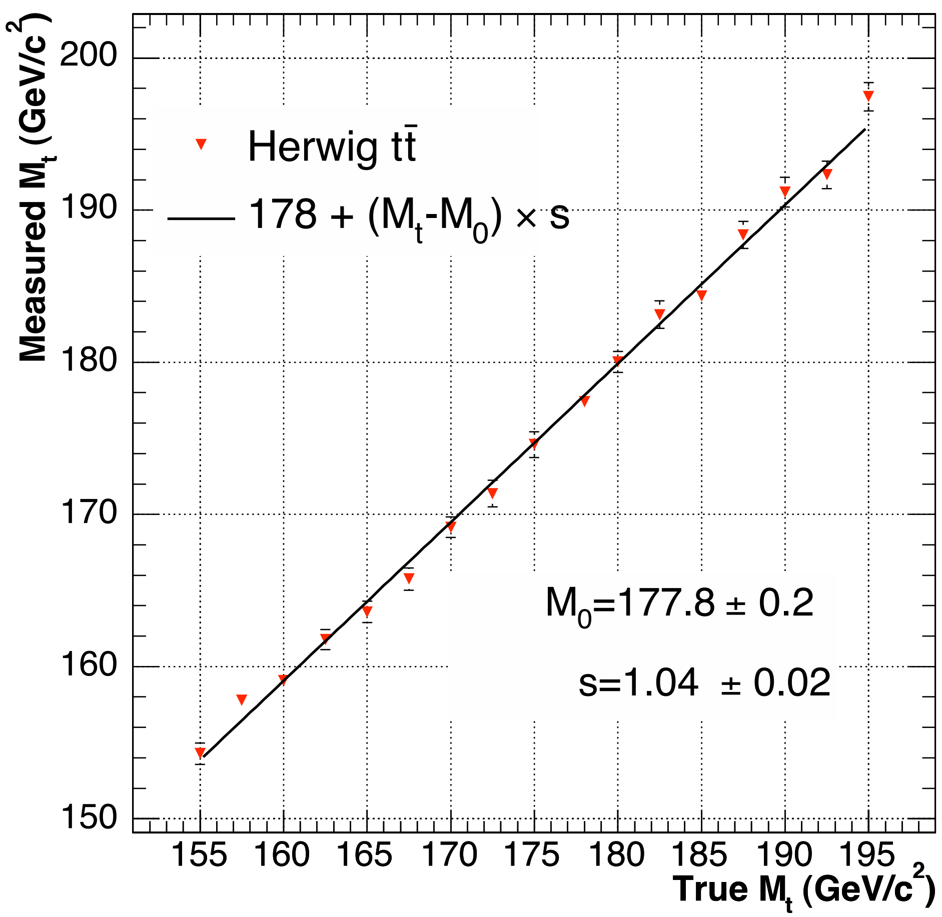


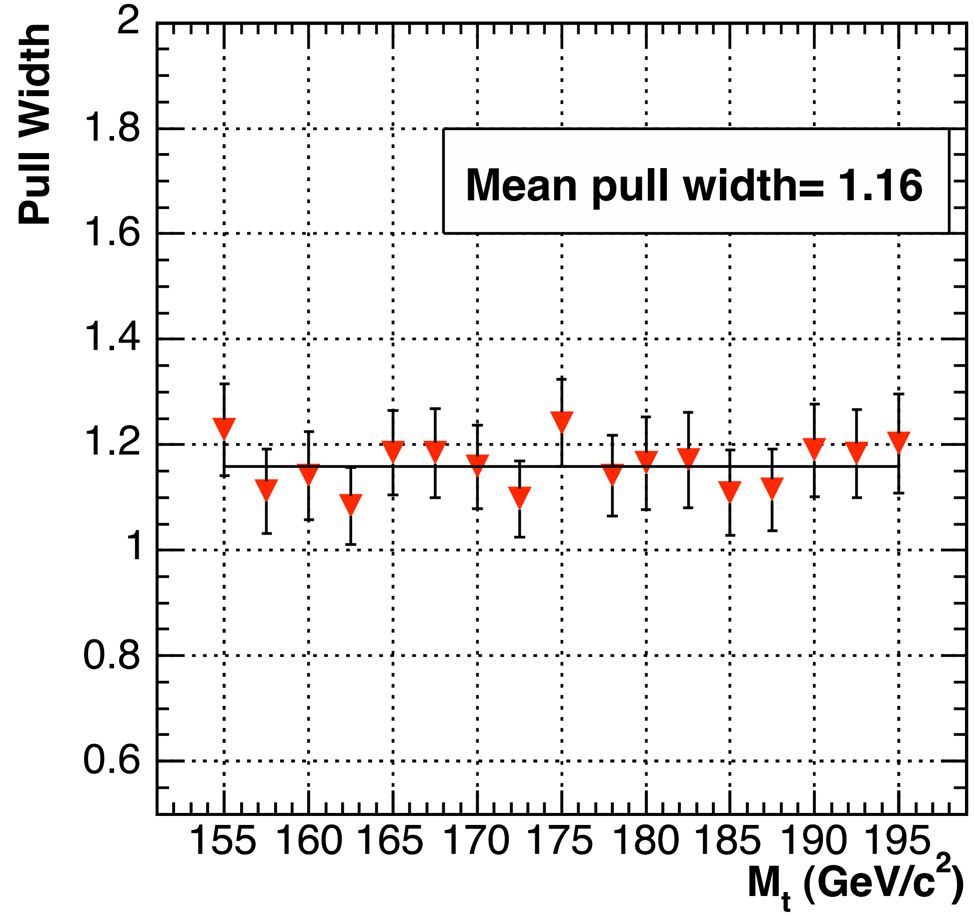
Dataset used

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

Tests: signal only





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

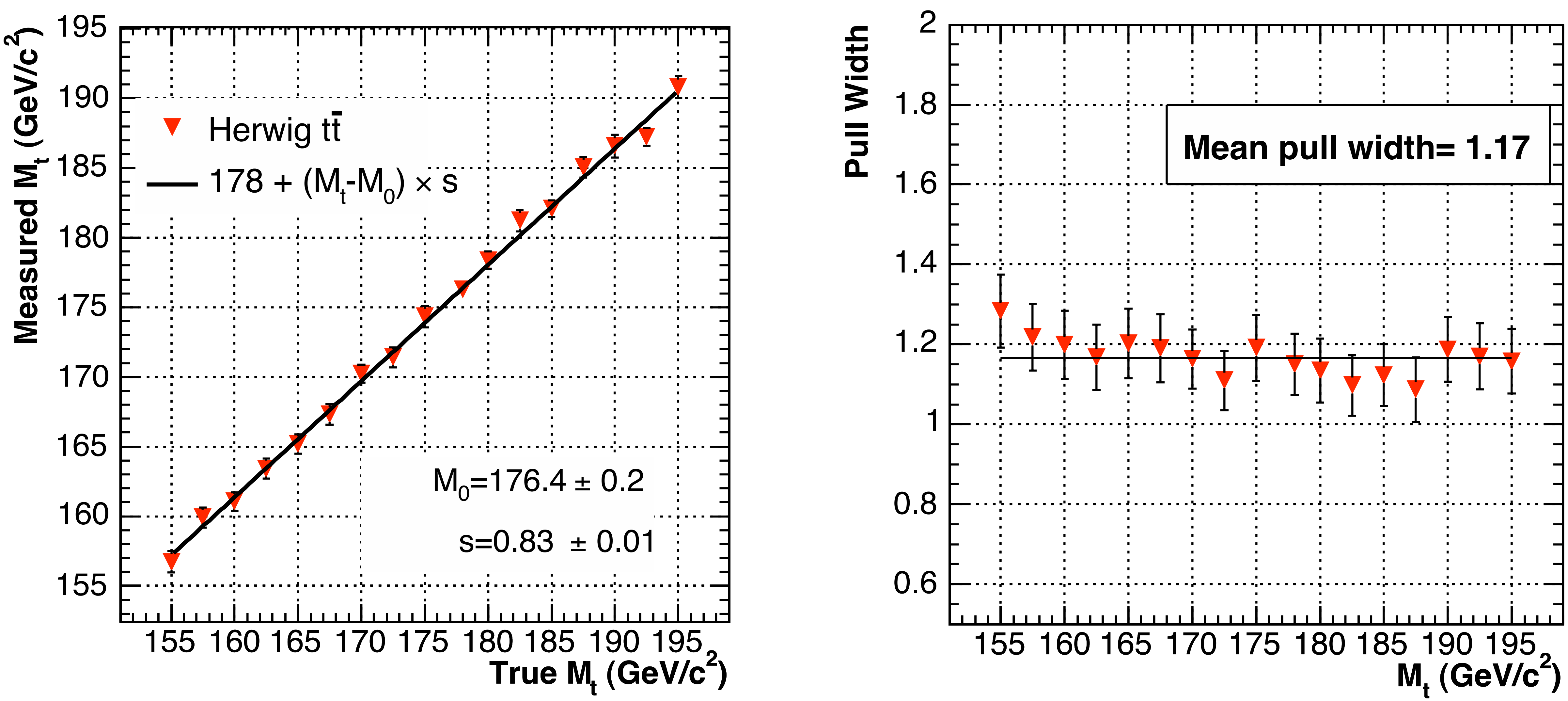
Response

- Linear
- Unbiased

Pull Widths

- Flat
- ~1.0 for parton-level events (assumptions held)
- ~1.16 for fully simulated events

Tests: signal+background



- Including BG prob. improves uncertainty by ~10% over only signal prob.
- Corrections applied for slope, offset and pull width
    - Unbiased with correctly estimated error after corrections

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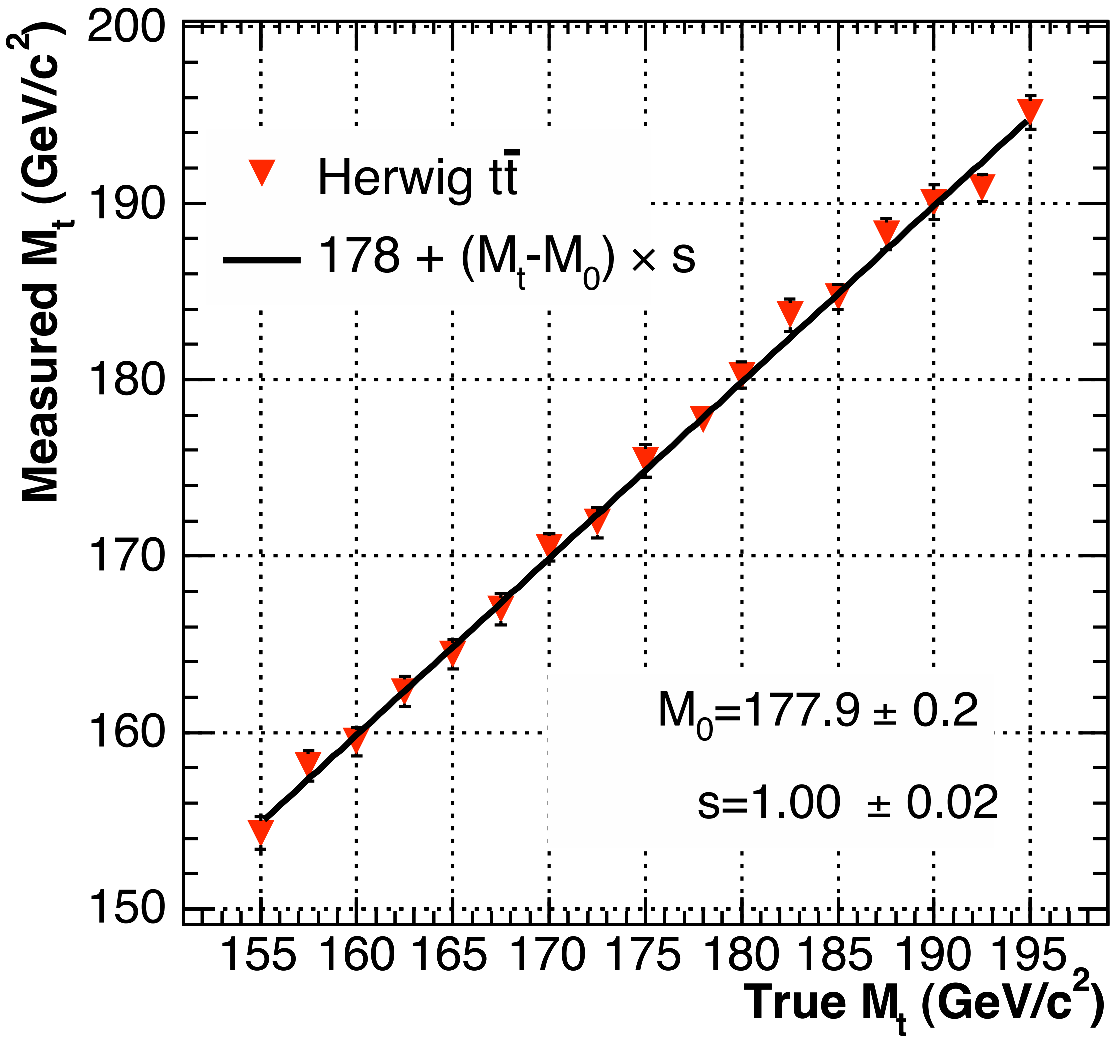
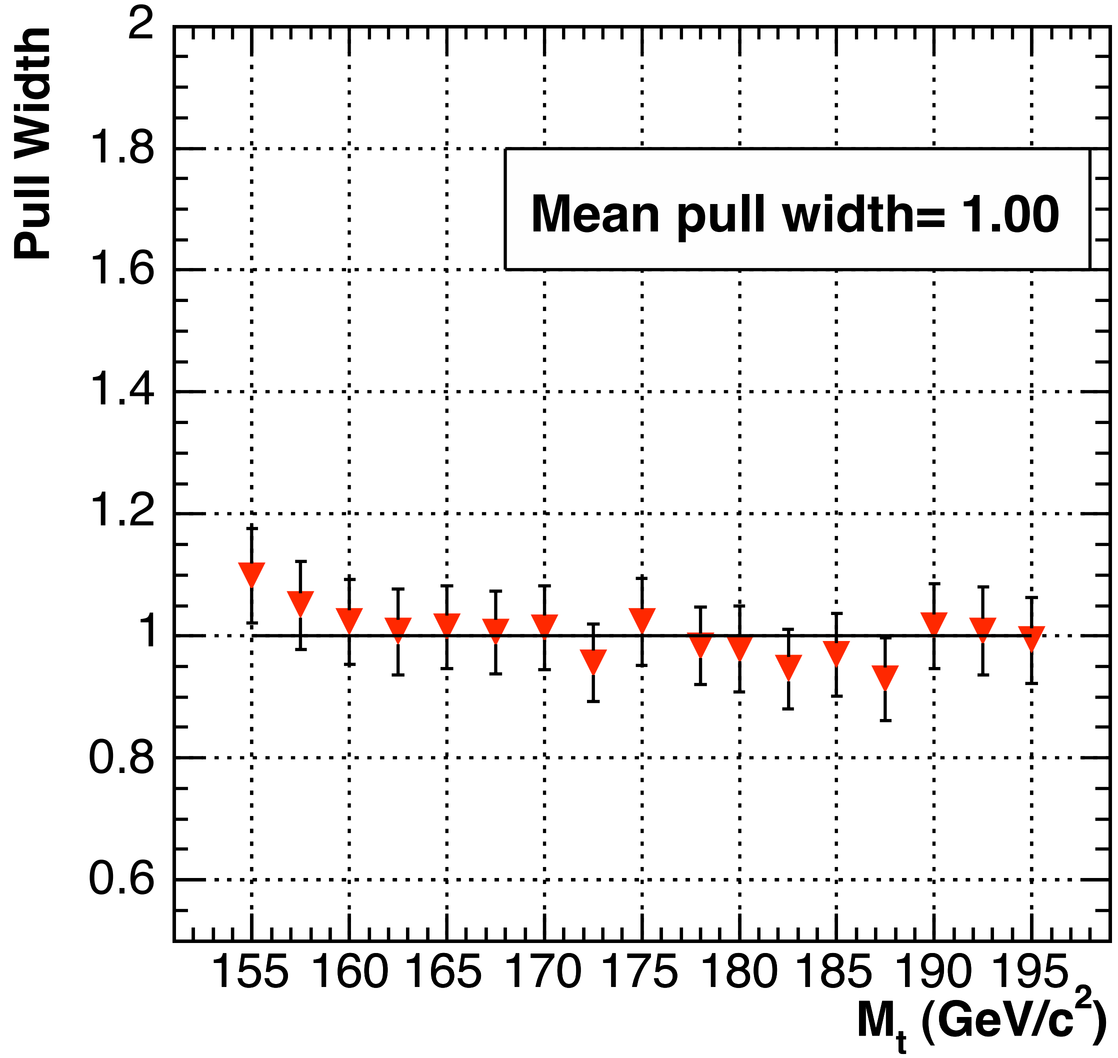


After corrections



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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*

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

Improves with more CPU (Generator, PDFs)

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Working on using $Z\rightarrow bb$ 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

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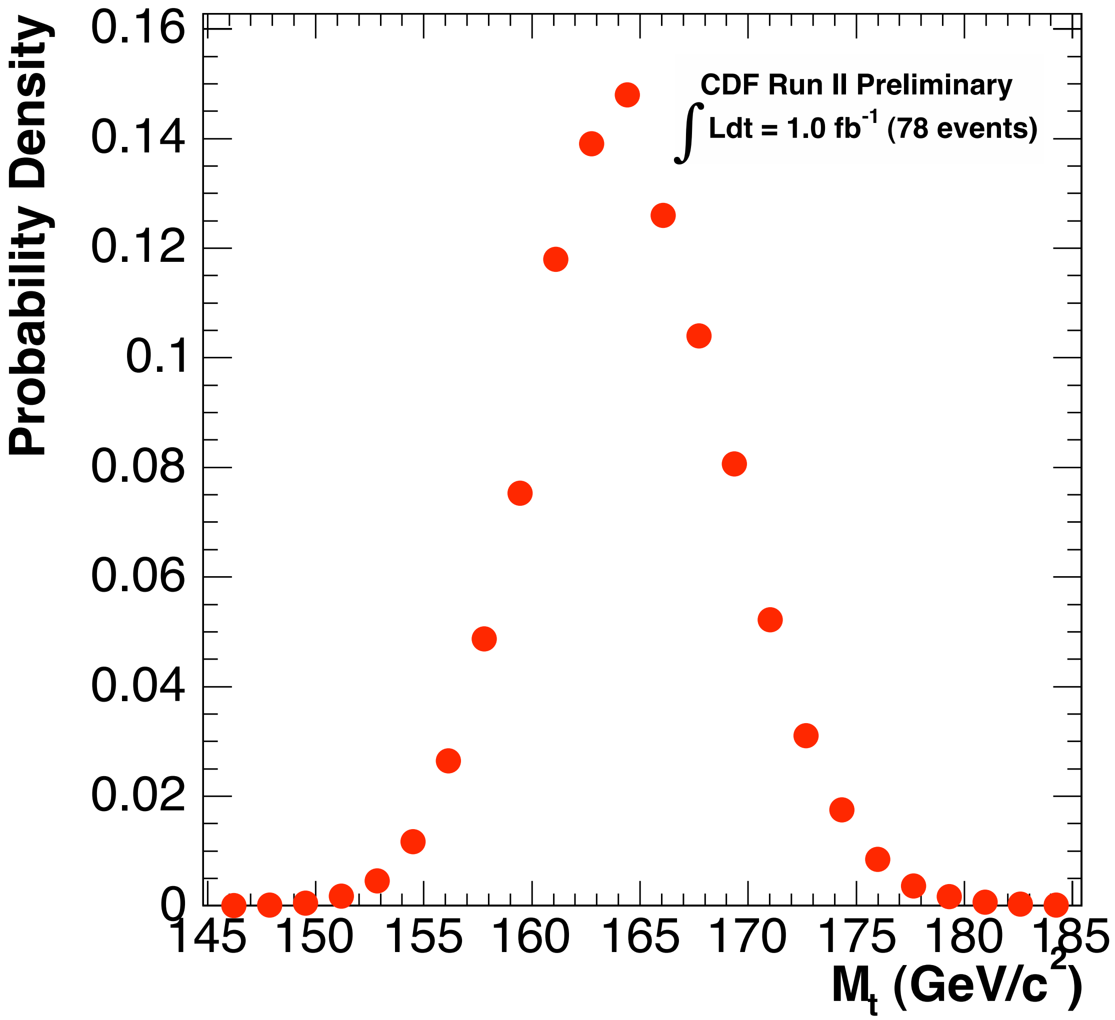
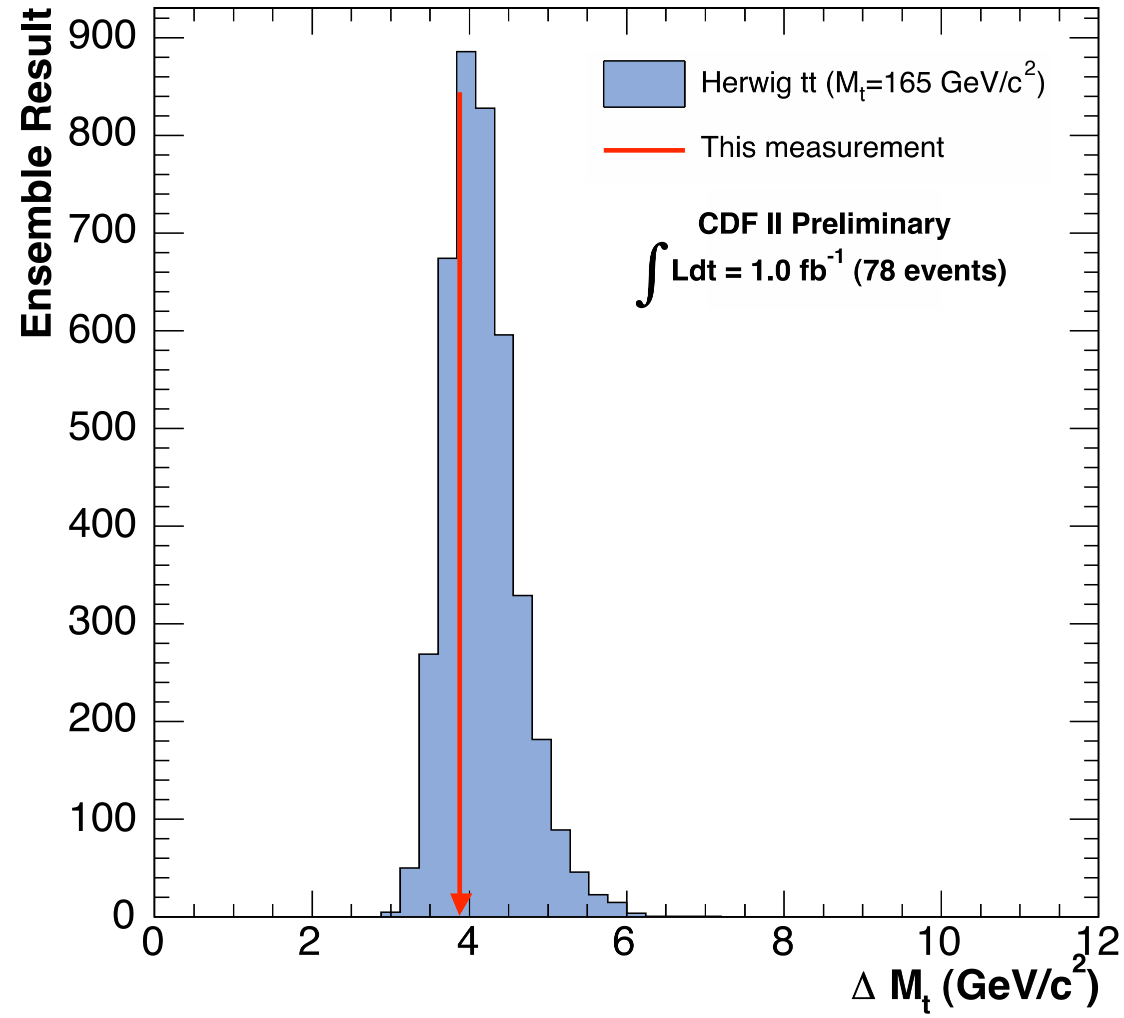
Result



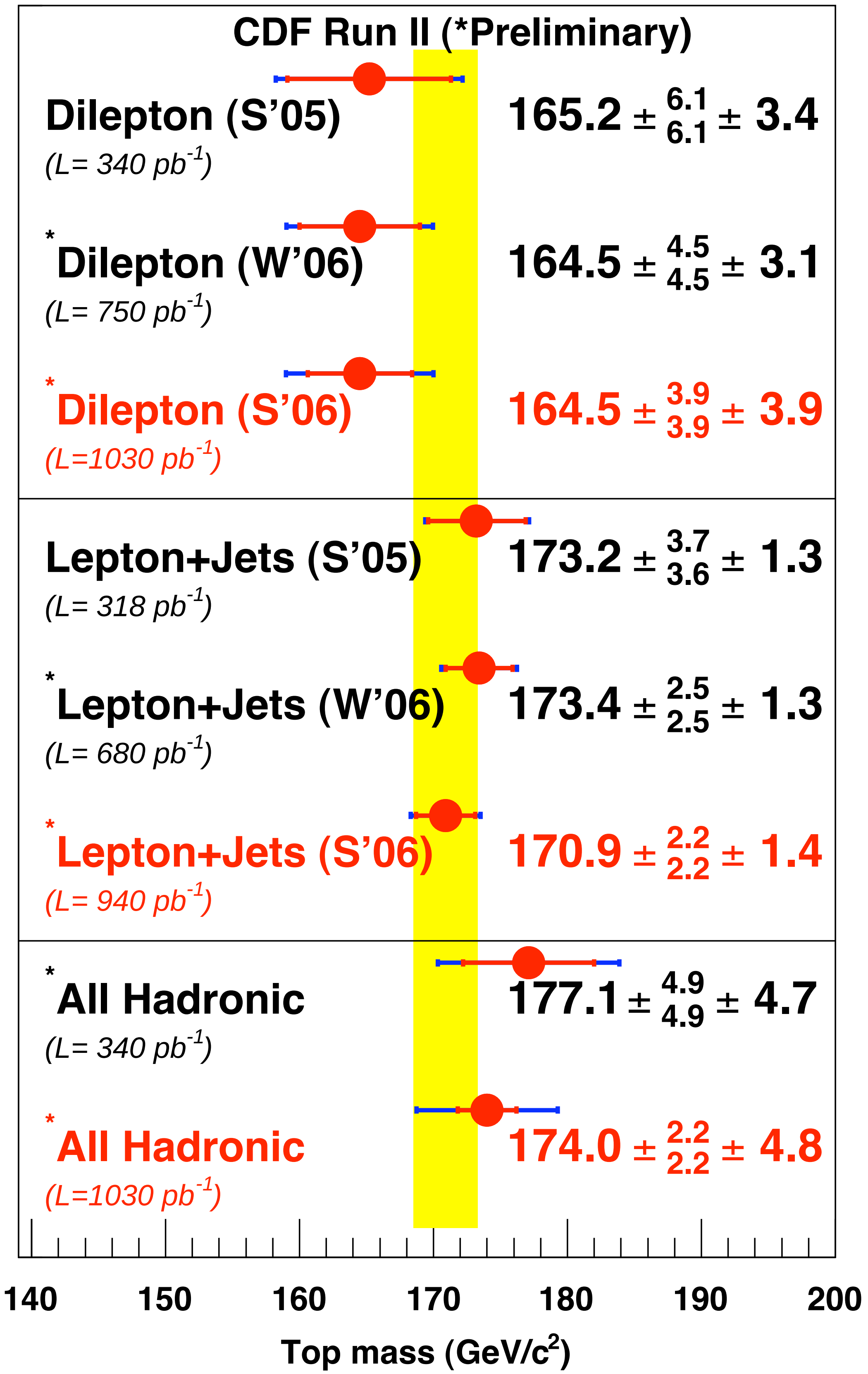


$$M_{top} = 164.5 \pm 3.9(\text{stat.}) \pm 3.9(\text{syst.})\,\text{GeV}/c^2$$

- 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

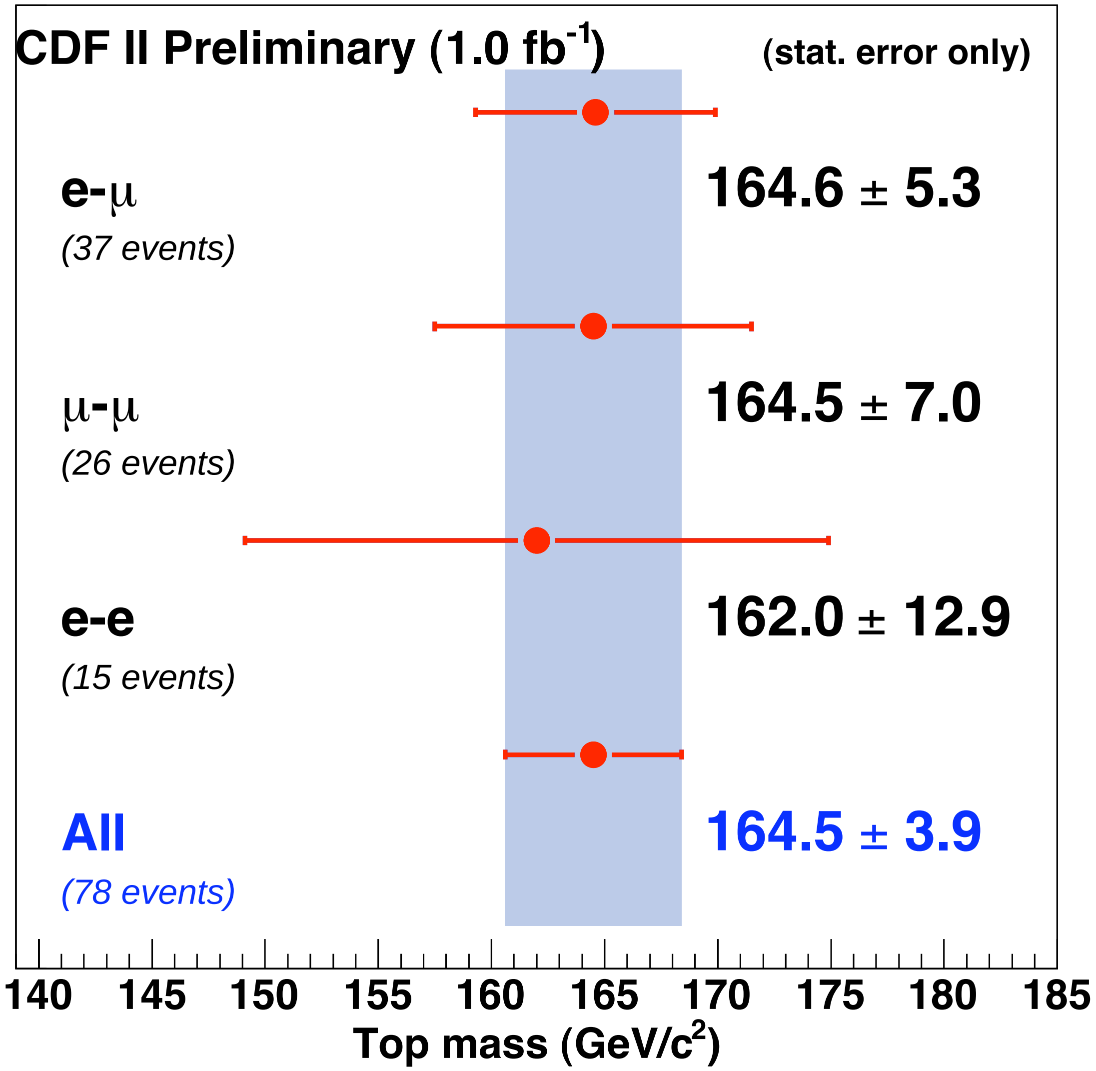
In perspective

- The "evolving" top mass in three different channels
  - Best measurement in each channel at CDF for 3 data-taking periods shown
- Is the dilepton channel lower than the others?
  - Deviation not inconsistent with fluctuation
  - Trend is intriguing
- Other ways to probe with data at hand



Cross-checks

Lepton Flavor



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

Cross-checks

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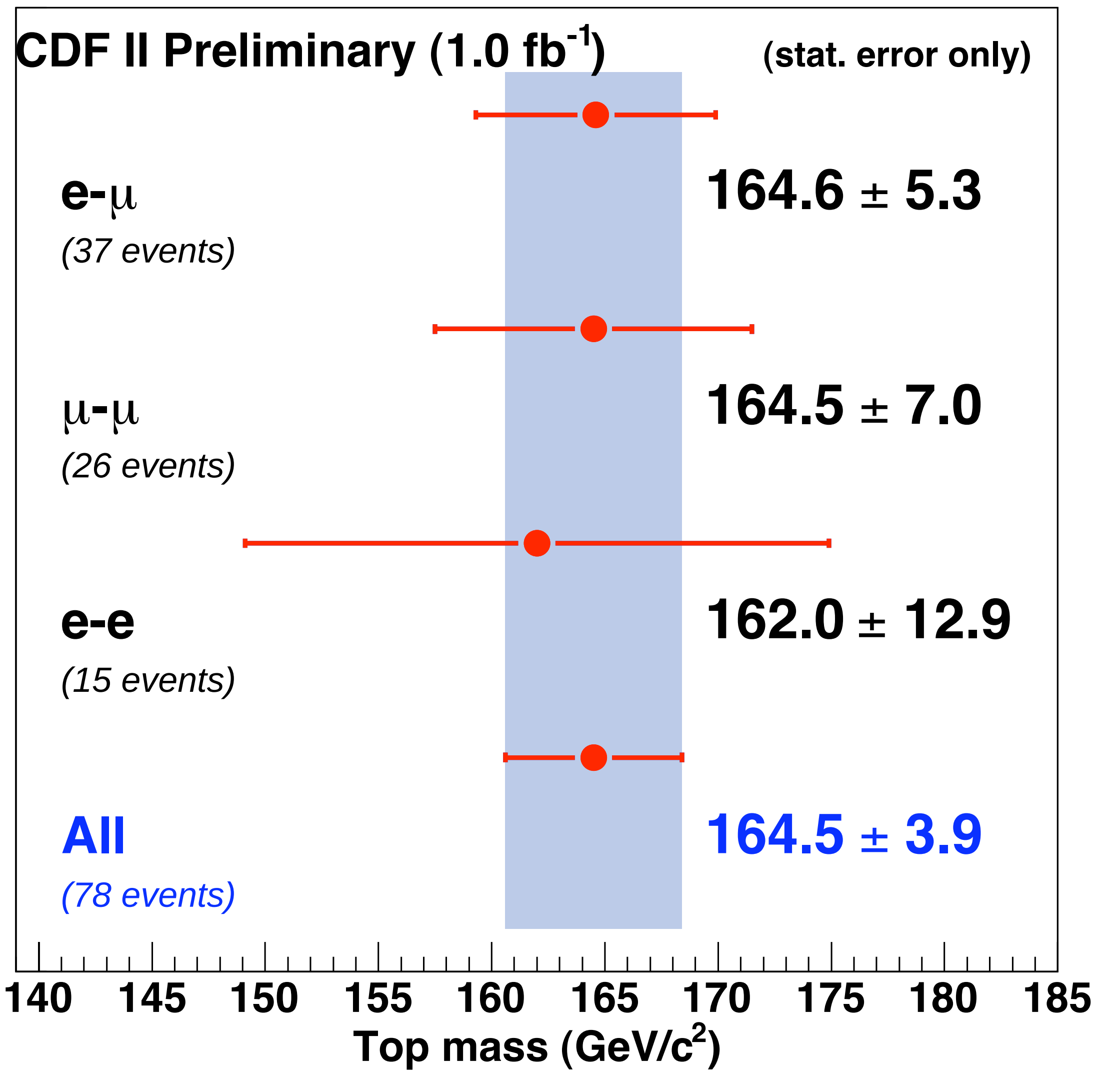

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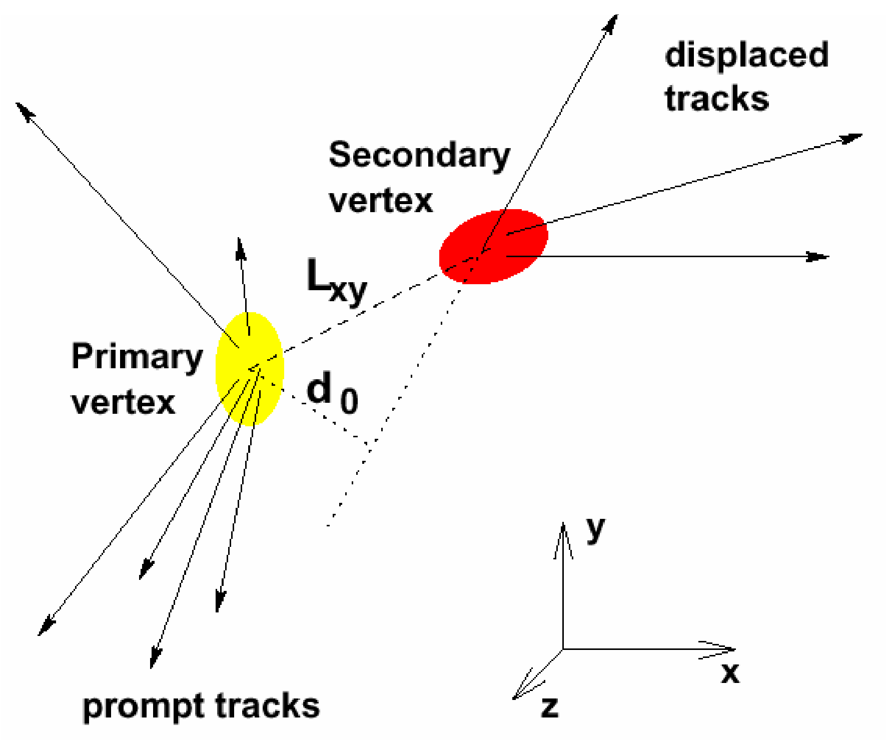
B-tagging



- Use secondary vertex tagging
  - Increases *S:B* to ~20:1
  - Retains ~60% of signal events
- See if measurement consistent with full sample

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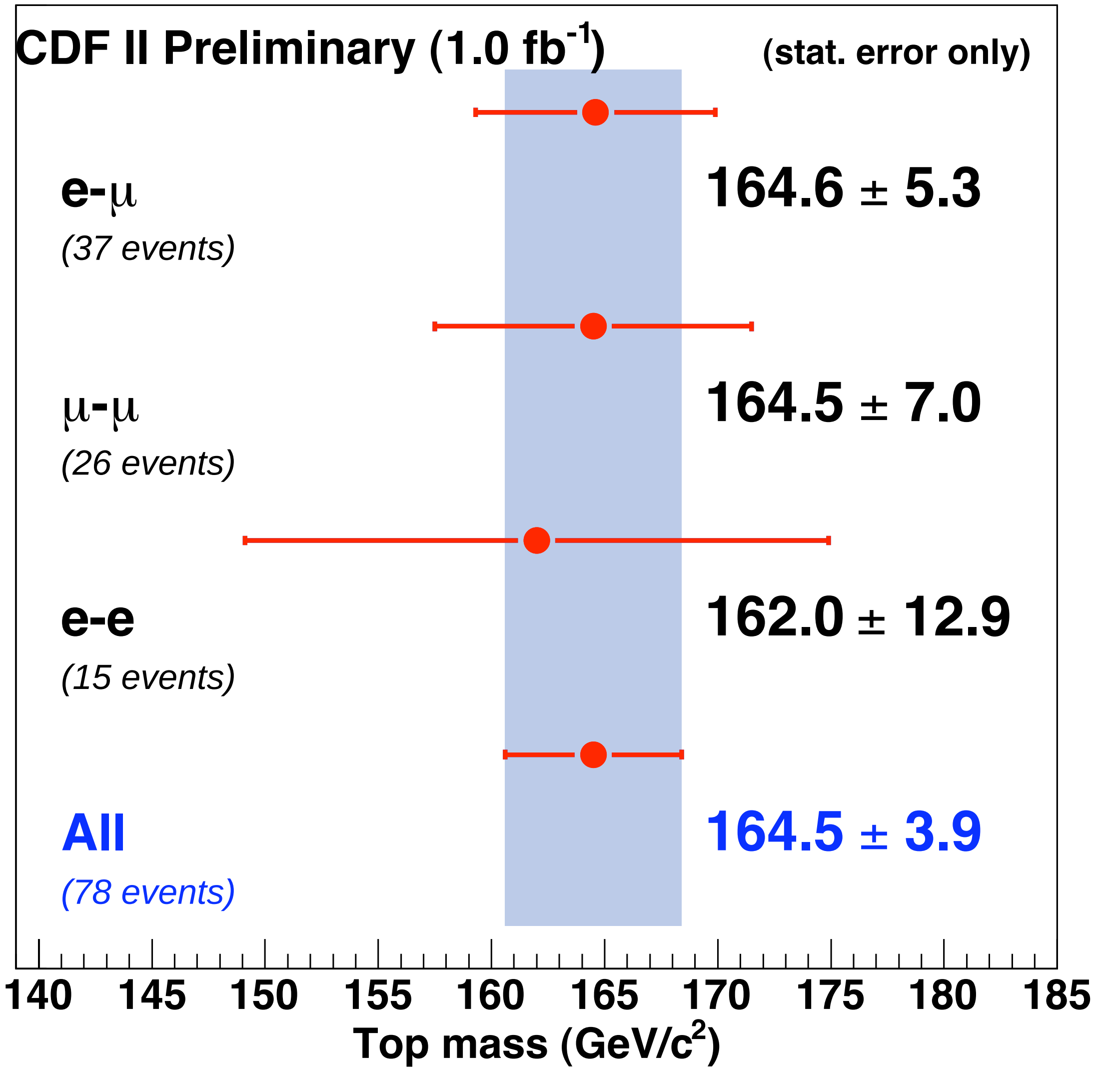

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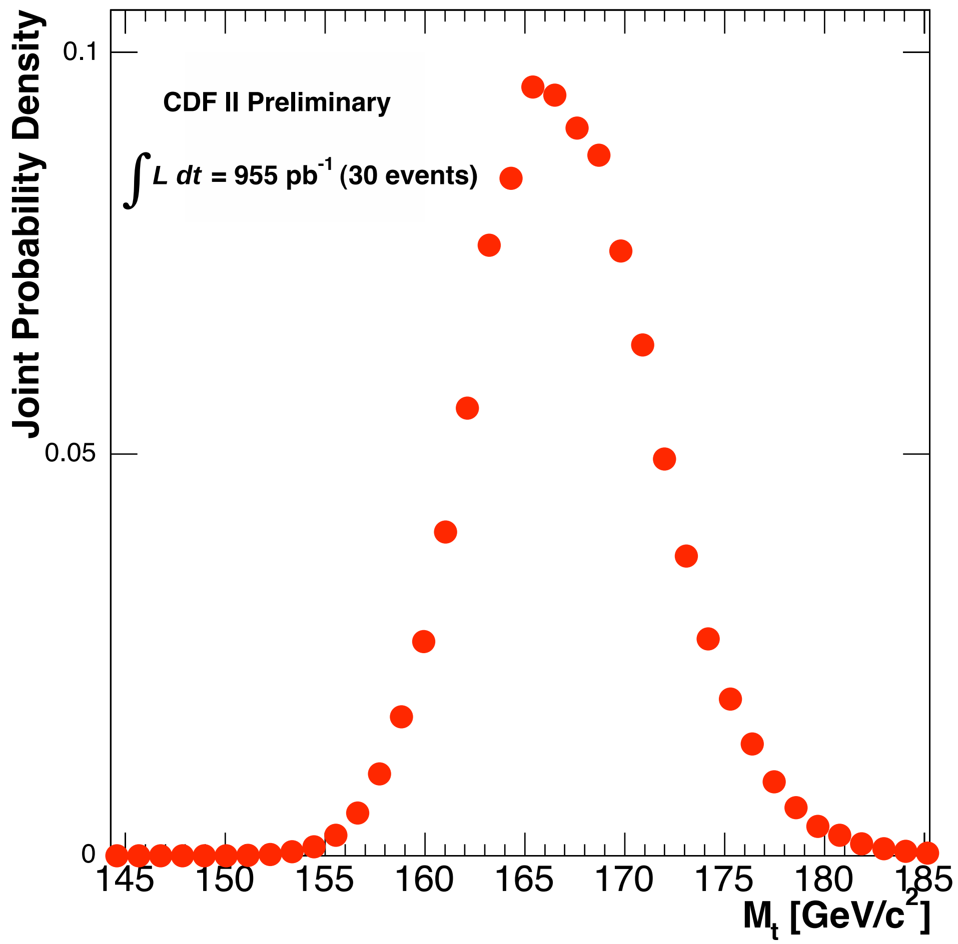

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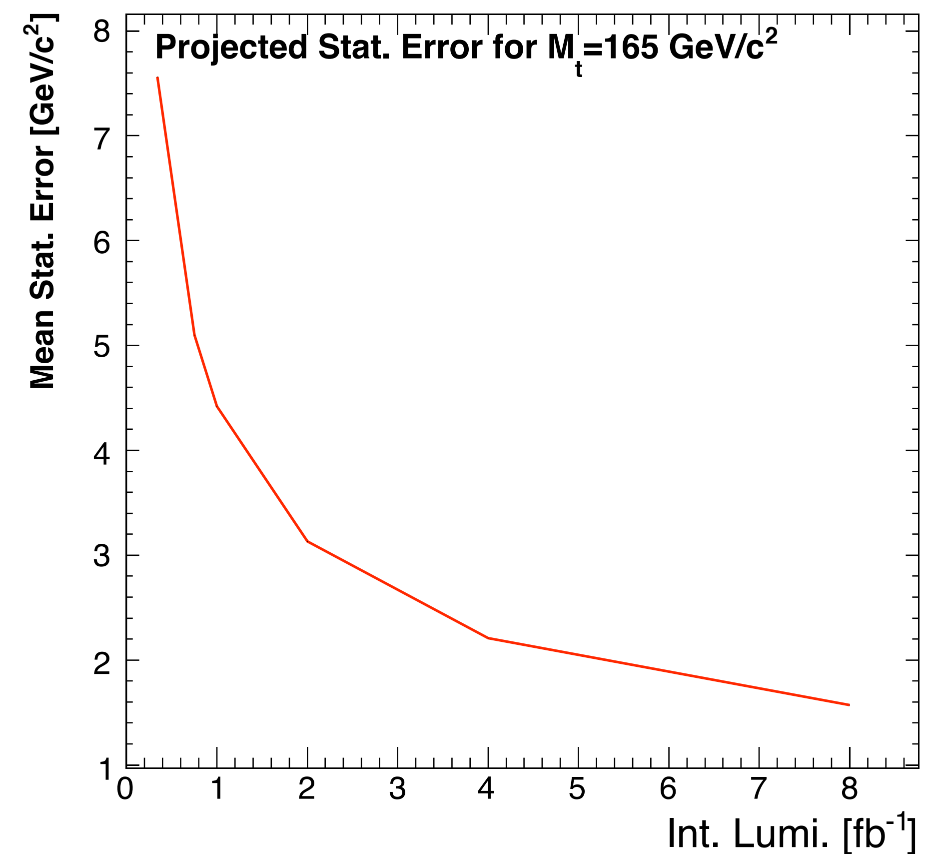
$M_{top} = 167.3 \pm 4.6(\text{stat.}) \pm 3.8(\text{syst.}) \text{GeV}/c^2$

Conclusion

- Matrix element based measurement of top quark mass in dilepton channel
  - Single best measurement in this channel
    M_{top} = 164.5±3.9(stat.)±3.9(syst.)GeV/c^2
  - Result with smaller (340 pb^{-1}) dataset published as PRL and PRD
  - Plan to publish 1fb^{-1} in near future
- Dilepton top mass will be systematics dominated by end of Run II
  - New set of challenges



Backup Slides

Data event curves