# Measurement of the Mass of the Top Quark in Dilepton Channels at DØ

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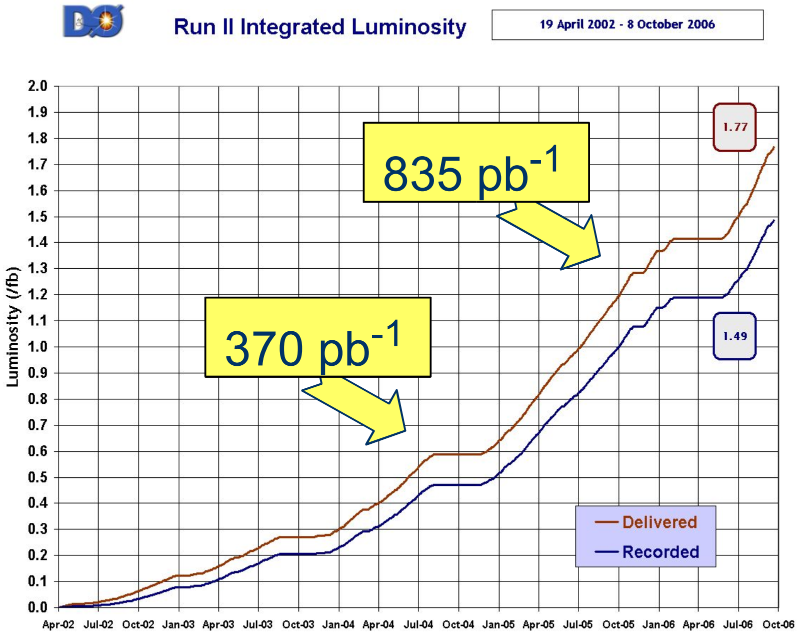
DPF 2006

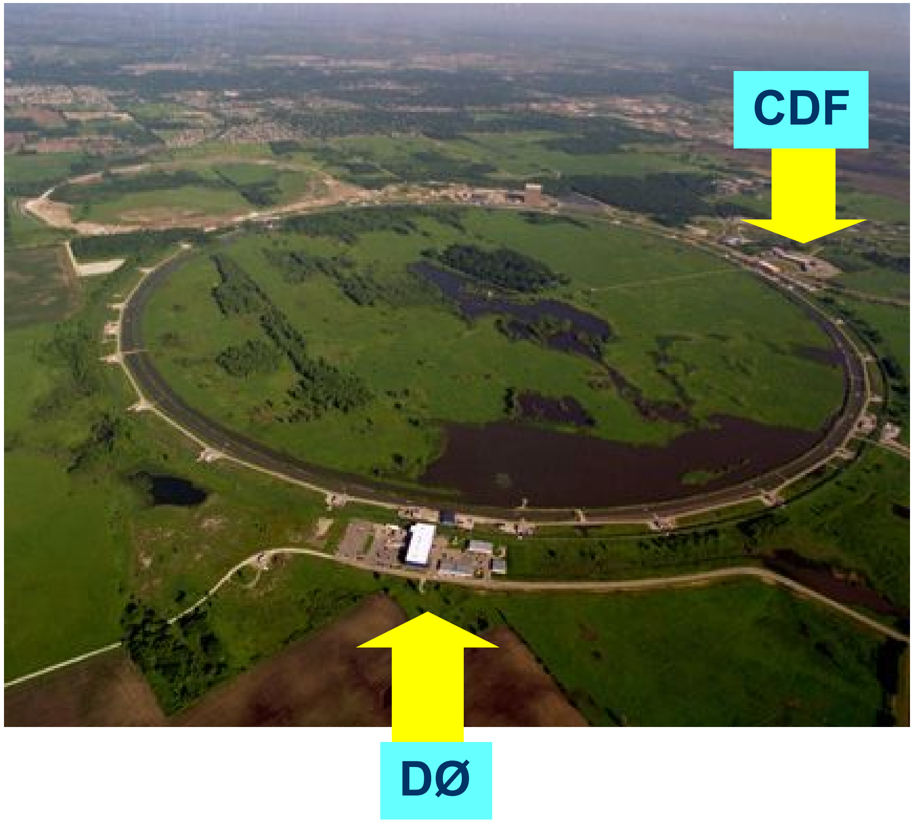
# Overview

- $t\bar{t} \longrightarrow$ dilepton decays
- Event selection
- Reconstructing top mass
  - Matrix weighting
  - Neutrino weighting




- Combined dilepton result for 370 $pb^{-1}$ sample
- Result in eμ channel for 835 $pb^{-1}$ sample

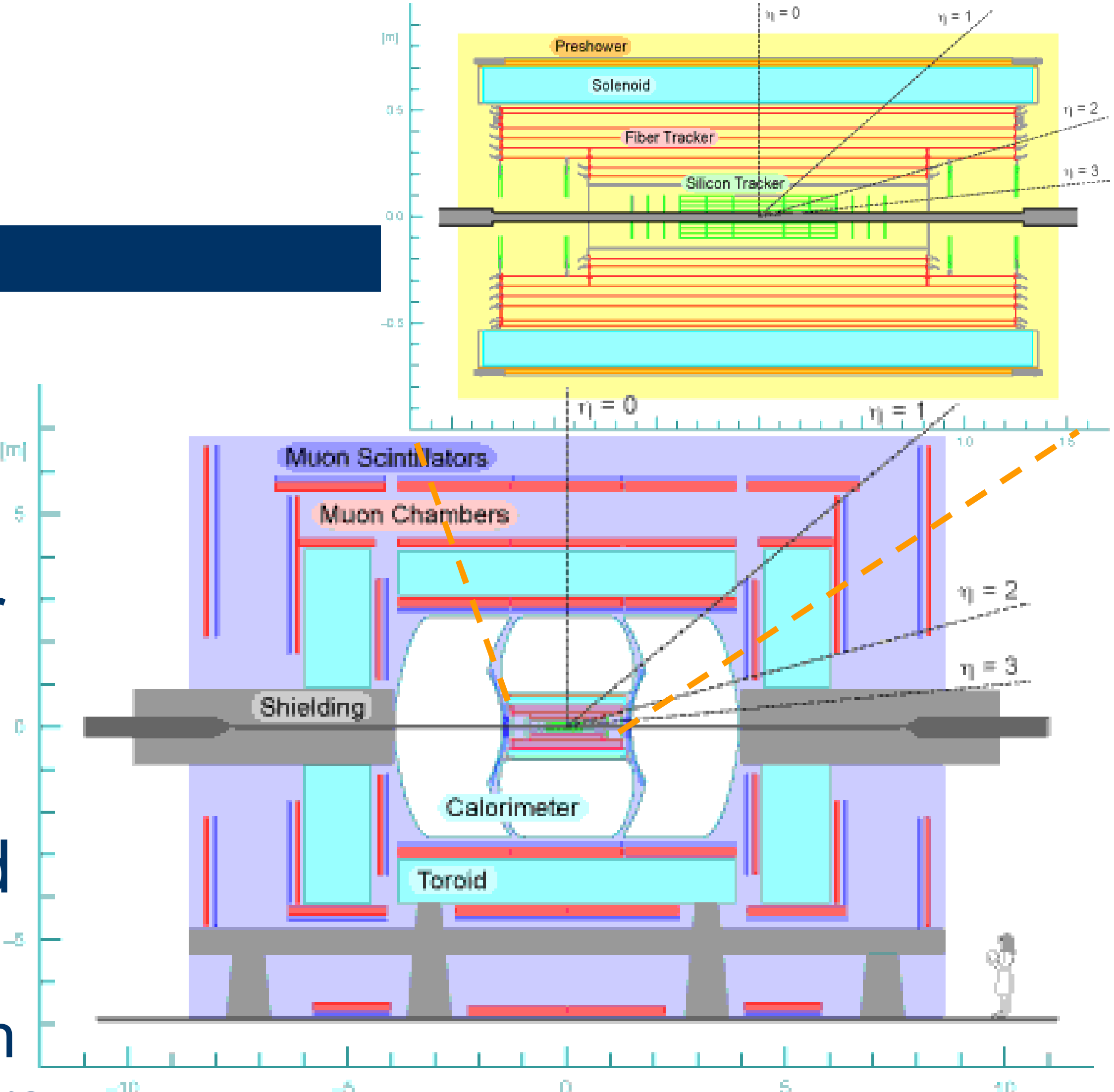
# Fermilab Accelerators



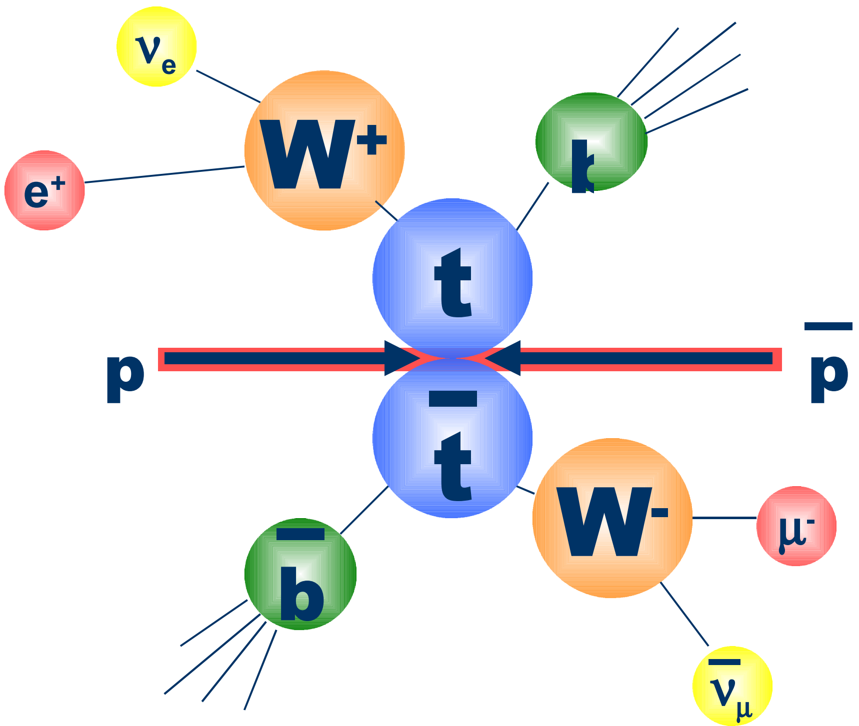

- 5 accelerators
- Collide protons and antiprotons at $\sqrt{s}$=1.96 TeV
- Collisions at CDF, DØ

# DØ Detector

- Silicon, Fiber Trackers within 2 T solenoid
- LAr calorimeter
- 3 layers of muon scintillators and wire chambers
  - Toroid between 1st and 2nd layers



# Dilepton Decay Channel




- 2 high-$p_T$ jets
- 2 high-$p_T$ leptons
- Significant missing transverse energy (MET) from neutrinos

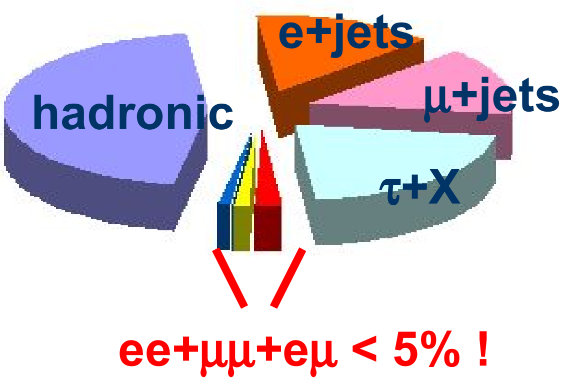
# Dilepton Channel Pros and Cons

Pros:

- Small background yields
  - $Z \rightarrow ee, \mu\mu$
  - $Z \rightarrow \tau\tau$
  - WW, WZ
  - Instrumental Fakes
- Few Jet Combinations

Cons:

- Small branching fraction




- Neutrinos not measured directly!

# Dilepton Event Selection

- 2 leptons
  - $p_T$>15 GeV
- 2 jets
  - $p_T$>20 GeV
- Channel-specific cuts
- *("b-tagging": require one jet to be identified with a secondary vertex)*

*ee channel*

- Reject 80 GeV<$M_{ee}$<100 GeV
- if $M_{ee}$<80 GeV, MET>40 GeV
- if $M_{ee}$>100 GeV, MET>35 GeV
- Sphericity > 0.15

*$\mu\mu$ channel*

- Z fitter
- MET > 35 GeV
- increase MET requirement based on MET-$\mu$ angle

*$e\mu$ channel*

- MET > 25 GeV
- Energy of jets + leading lepton >140 GeV
- Cut on electron shower shape

# Additional Selection: Lepton+Track

- Select one lepton + one isolated central track
- Increases dilepton acceptance
- Veto events satisfying ee, e$\mu$, $\mu\mu$ selection

*Lepton + Track selection*

- 1 lepton
  - $p_T$ > 15 GeV
- 1 isolated track
  - $p_T$> 15 GeV
- 2 jets
  - $p_T$>20 GeV
  - at least one b-tagged jet
- MET> 15-35 GeV

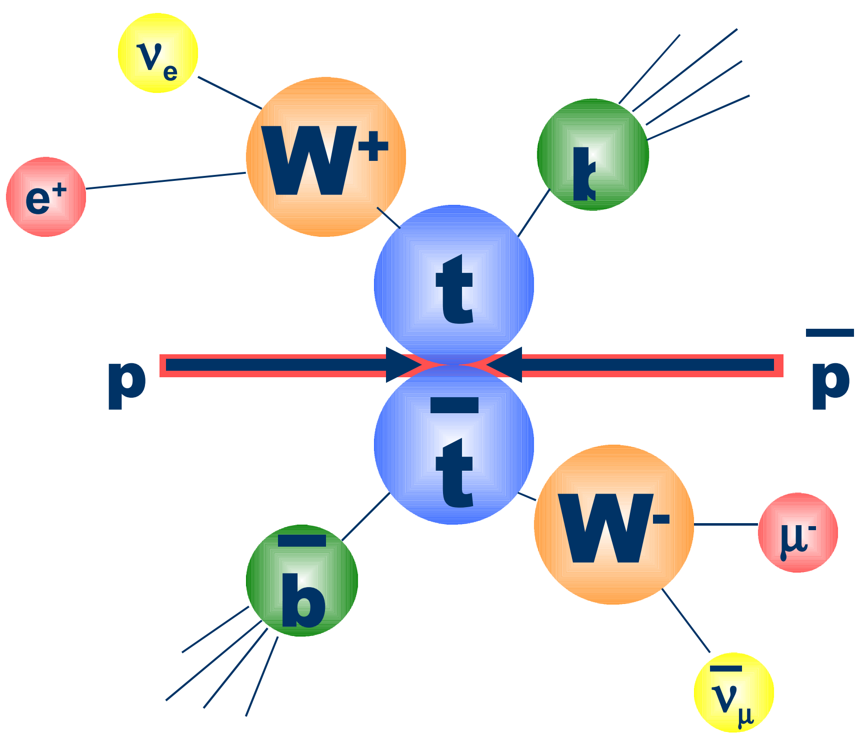
# Dilepton Events in Data

- ~370 $pb^{-1}$ of data
- Slightly different selection criteria for matrix weighting, neutrino weighting

| | tt | WW | Z | Fake | Total | Data |
|---|---|---|---|---|---|---|
| Matrix Weight | | | | | | |
| Dilepton: No b-tag | 7.2 | 1.1 | 2.6 | 2.2 | 13.1+2.8-2.1 | **12** |
| Dilepton: b-tag | 9.9 | 0.05 | 0.12 | 0.9 | 11.0+/-0.7 | **14** |
| Neutrino Weight | | | | | | |
| Dilepton | 15.8 | 1.1 | 2.4 | 0.5 | 19.6+/-0.6 | **21** |
| Lepton + Track | 6.3 | 0.01 | 1.7 | 0.4 | 8.4+/-0.3 | **9** |

# Reconstructing Top Mass

- 18 independent kinematic variables
- 12 measured directly (jets, charged leptons)
- Also measure $MET_x$, $MET_y$
- 2 constraints from $m_{W+}$, $m_{W-}$
- 1 constraint from $m_t = m_{\bar{t}}$

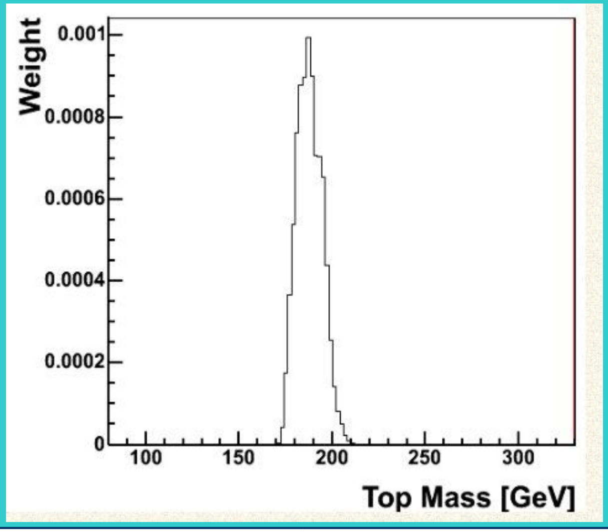



Insufficient constraints to determine $m_t$!

# Assigning Event Weight

- *Assume* $m_t$
- Assign weight $W(m_t)$ to mass assumption based on agreement with observables
  - matrix weighting
  - neutrino weighting
- Repeat for many values of $m_t$
- Use weights to determine mass

Sample event weight distribution for Monte Carlo 175 GeV top



# Matrix Element Weighting (MWT)

$$W(m_t) = f(x)\,f(\bar{x})\,P(E_\ell^{CM}|m_t)\,P(E_{\bar{\ell}}^{CM}|m_t)$$

- f(x) = parton distribution function
- $P(E|m_t)$=probability that lepton has energy E in rest frame of top quark:

$$P(E|m_t) = 4\,m_t\,E\,\frac{m_t^2 - m_b^2 - 2\,m_t\,E}{(m_t^2 - m_b^2)^2 + m_W^2(m_t^2 + m_b^2) - 2\,m_W^4}$$

*R. H. Dalitz and G.R. Goldstein, Phys. Rev. D **45**, 1531 (1992)*

**Weight based on consistency of observed lepton energy with $m_t$ hypothesis**

# Neutrino Weighting (νWT)

- Ignore $MET_x$, $MET_y$
- Assume $m_t$, $\eta_\nu$, $\eta_{\bar{\nu}}$
- Repeat for many rapidity assumptions

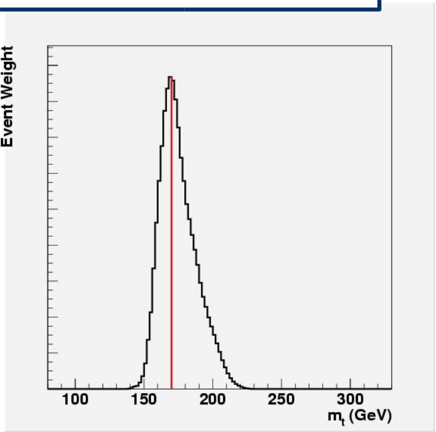
$$W(m_t) = \sum_{\eta_\nu, \eta_{\bar{\nu}}} \sum_{i=x,y} \exp\left(-\left(MET_i - p_{\nu_i} - p_{\bar{\nu}_i}\right)^2 ¿ 2\sigma_i^2\right)$$

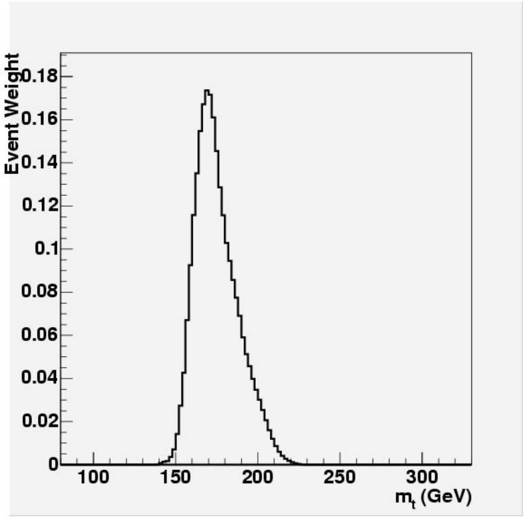
**Weight based on agreement between assumed total neutrino momentum and observed MET**

# Generating Event Templates

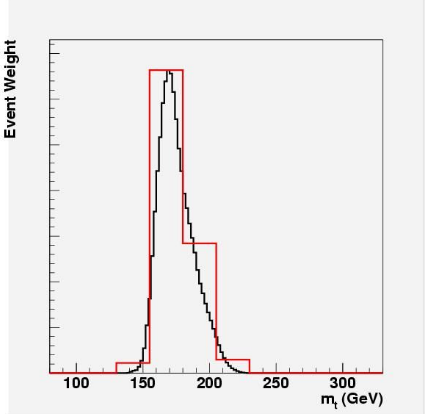
- Extract mass information from event weights

MWT uses peak weight




νWT uses entire (rebinned) distribution




- Collection of event weight info is a *template*
- Form templates for signal, backgrounds
  - Monte Carlo for different values of $m_t$
  - Monte Carlo/Data for backgrounds

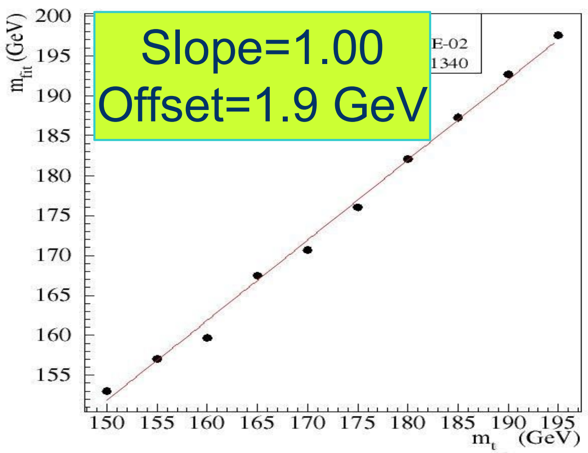
# Likelihood Fit

- Determine $m_t$ with maximum likelihood fit

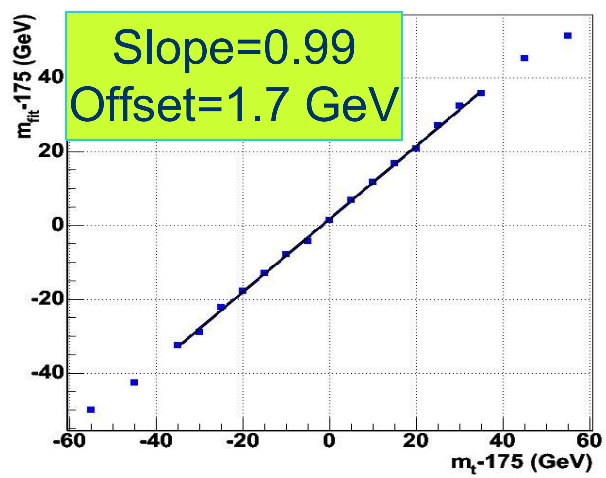
$$\text{MWT}: \quad L(m_t) = L_{template}(m_t)$$

$$\nu\text{WT}: \quad L(m_t) = L_{template}(m_t) \times L_{n_b} \times L_{n_s+n_b}$$

- Use ensemble tests to calibrate fit minimum




MWT ensemble tests

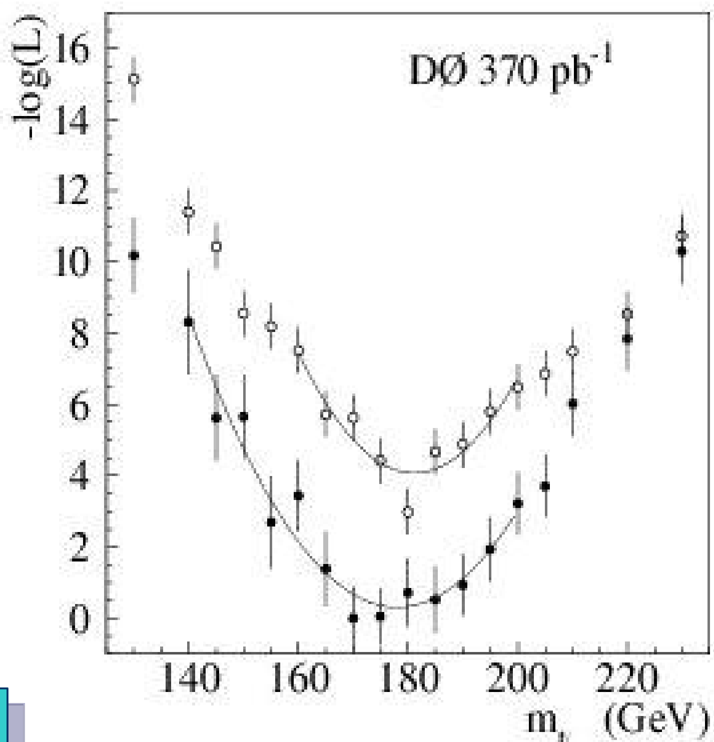



νWT ensemble tests

# Results from 370 $pb^{-1}$ Data Set

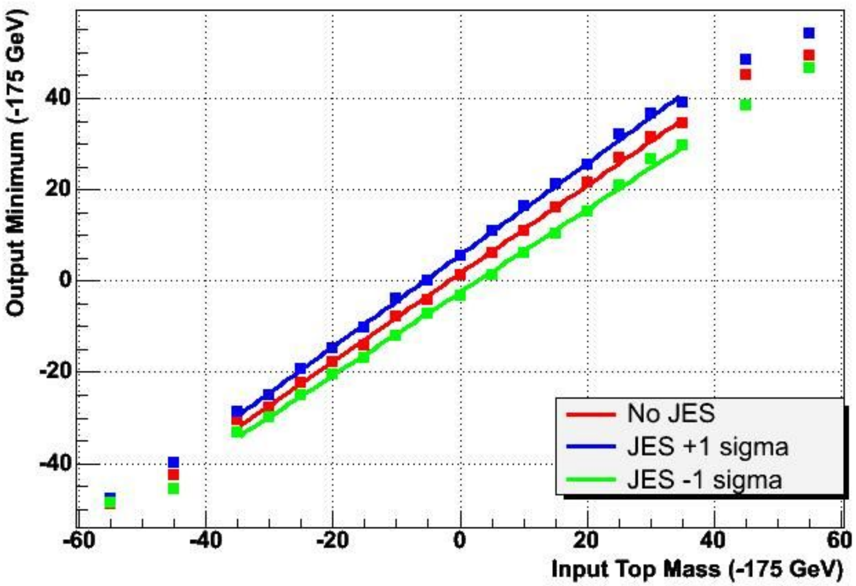
- open circles: νWT
  - dilepton
  - lepton + track
- closed circles: MWT
  - dilepton
    - b-tagged
    - no b-tagged
- Combined measurement:

$$m_t = 178.1 \pm 6.7 (stat.)\ \text{GeV}$$



# Estimating Systematics

- Largest uncertainty: Jet Energy Scale (JES)
- Create ensembles with jet energies varied by their uncertainties, and compare to original templates
- Similar approach for other uncertainties



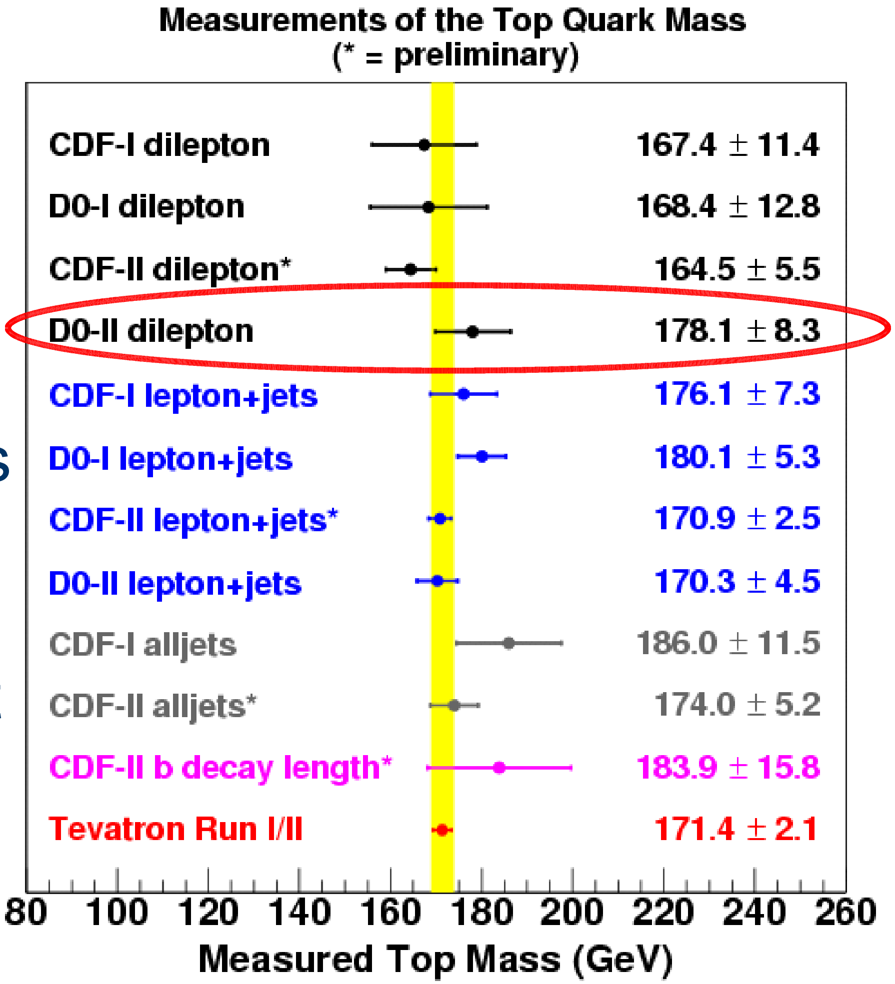

Combined JES uncertainty: 4.3 GeV

# Systematic Uncertainties

| Source | Uncertainty (GeV) |
|---|---|
| Jet Energy Scale | 4.3 |
| Gluon Radiation | 1.5 |
| Background Statistics | 0.9 |
| Signal MC Statistics | 0.9 |
| PDFs | 0.8 |
| Jet Resolution | 0.3 |
| Heavy Flavor | 0.3 |
| Muon Resolution | 0.2 |
| **Total** | **4.8** |

# Combined Result for 370 $pb^{-1}$

- $m_t$=178.1±8.3 GeV
  - Submitted to PRL
  - hep-ex/0609056
- Consistent with previous measurements
- Significant improvement on Run I dilepton uncertainty



# Event Selection for 835 $pb^{-1}$

- MWT, $\nu$WT analyses for e$\mu$ channel only

*e$\mu$ event selection*

1 muon, $p_T$ >15 GeV
1 electron, $p_T$ > 15 GeV
2 jets, $p_T$> 15 GeV
Energy of jets + leading lepton > 120 GeV

*Expected Yields*

$t\bar{t}$ signal: $17.5 \pm 2.6$

$WW$ : $1.0^{+1.5}_{-0.3}$

$Z \to \tau\tau$ : $2.2^{+1.5}_{-1.3}$

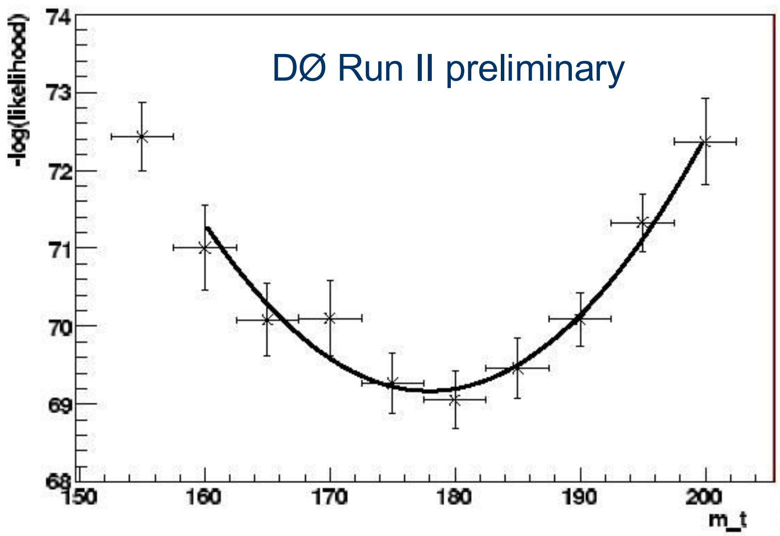
fakes : $0.4 \pm 0.2$

total : $21.1^{+3.4}_{-2.9}$

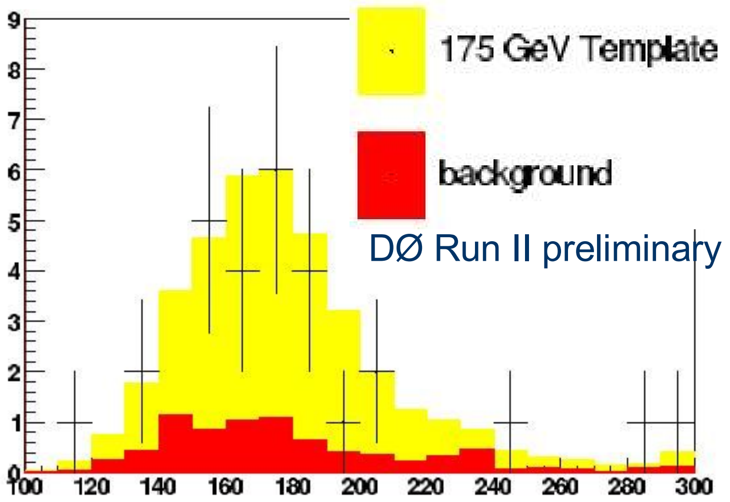
**OBSERVED: 28**

# MWT Measurement

-log (likelihood)




Event Weight Peaks vs. Top Mass

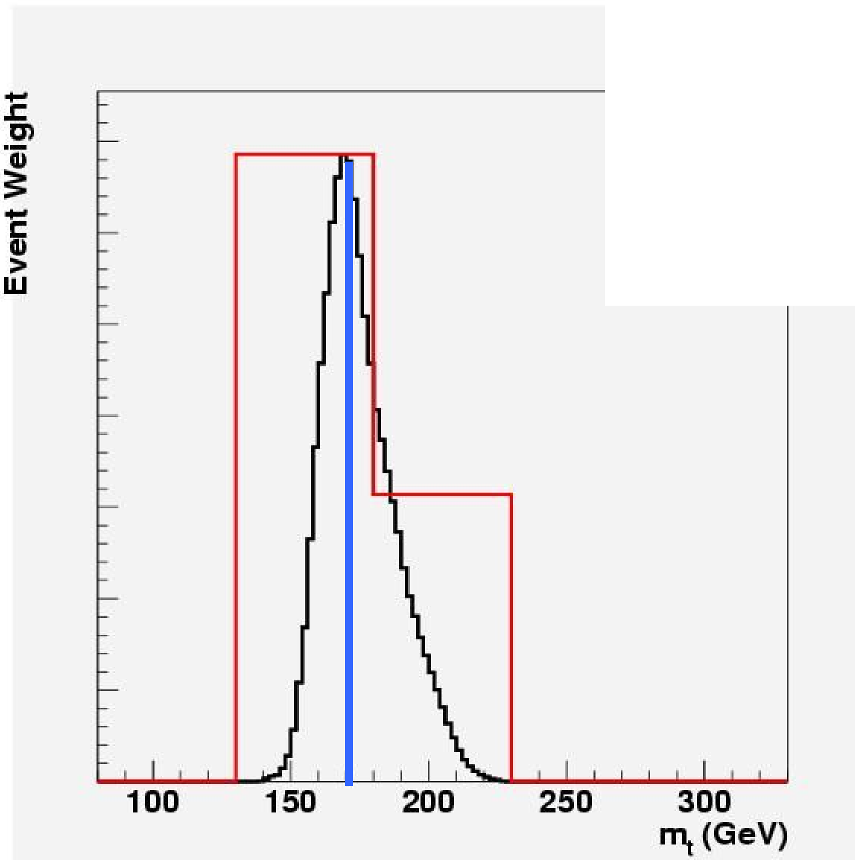



$m_t$ (GeV)

$$m_t = 177.7 \pm 8.8 (stat.)^{+3.7}_{-4.5} (syst.)\ \text{GeV}$$

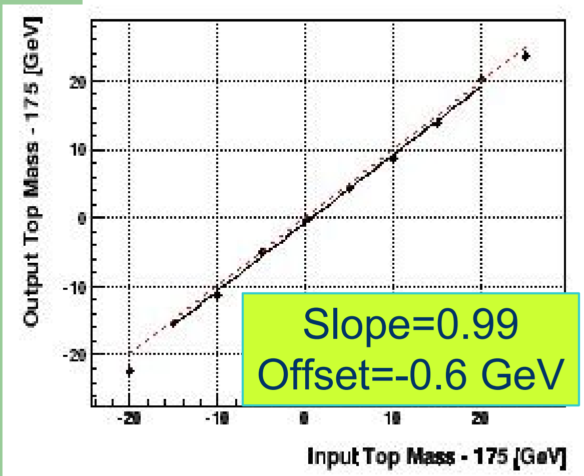
# Revised νWT Event Weights

- 3 approaches
  - Coarse binning
    - same as previous νWT analysis
    - 6 bins, not 10
  - peak value
    - à la MWT
    - Modified fitting procedure
  - Mean + RMS



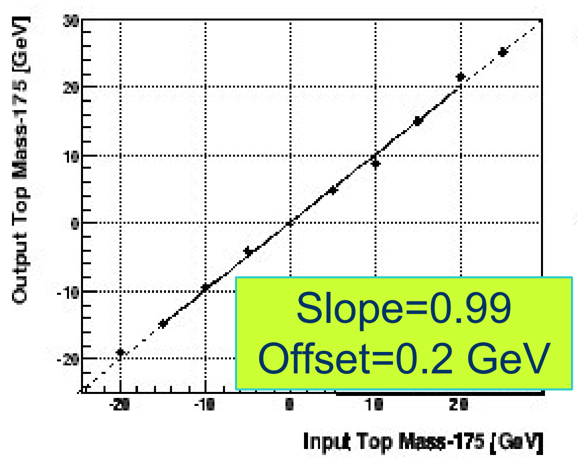
# νWT Ensemble Tests

DØ Run II preliminary



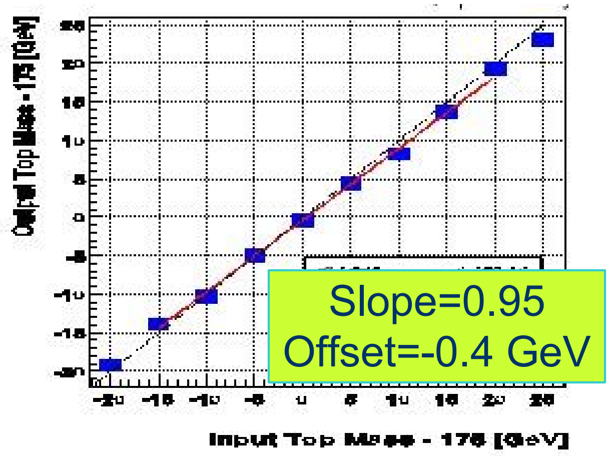

5 bins

DØ Run II preliminary




peak value

DØ Run II preliminary

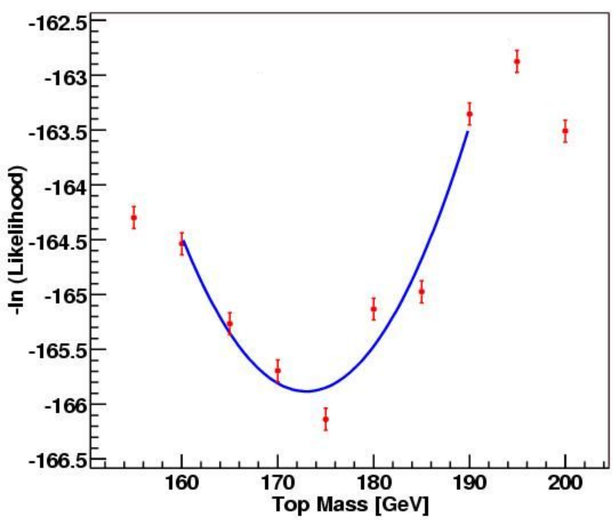



mean+RMS

- Each method shows good agreement between input, output top mass

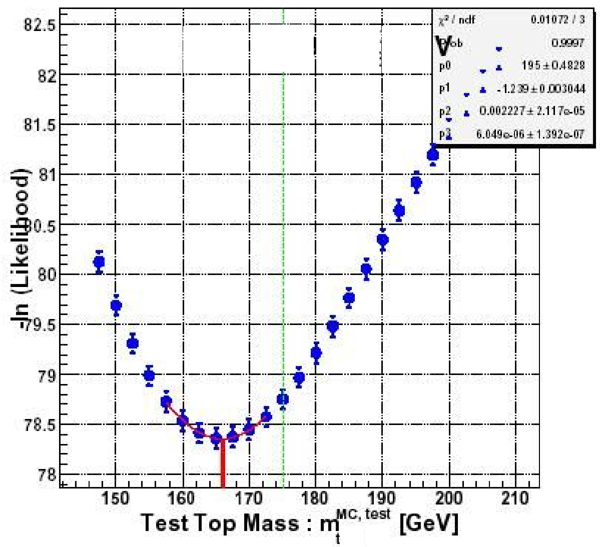
# νWT Measurements

DØ Run II preliminary



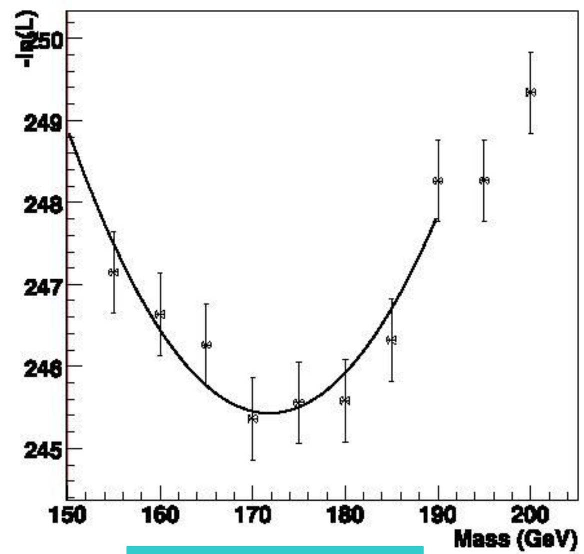

5 bins

DØ Run II preliminary




peak value

DØ Run II preliminary

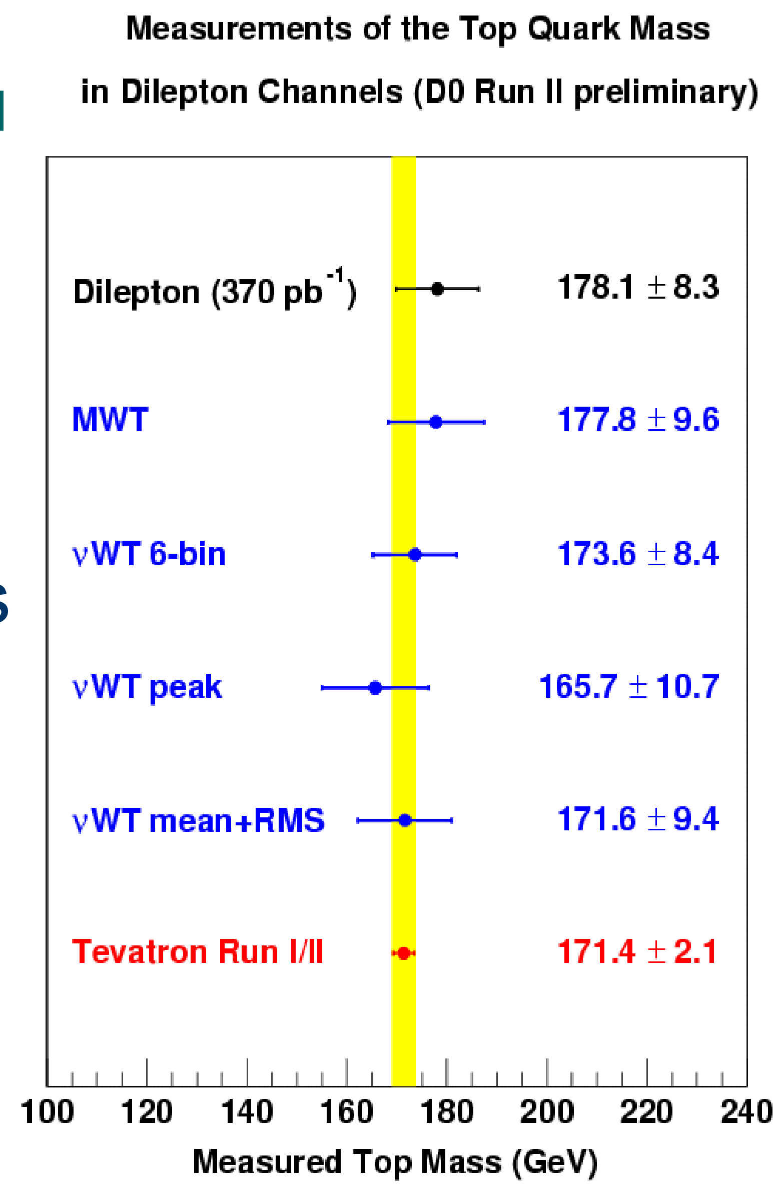



mean+RMS

- **5 bins:** $m_t = 173.6 \pm 6.7$ (stat.) $^{+5.1}_{-4.0}$ (syst.) GeV
- **peak:** $m_t = 165.7 \pm 9.7$ (stat.) $^{+4.4}_{-4.7}$ (syst.) GeV
- **Mean+RMS:** $m_t = 171.6 \pm 7.9$ (stat.) $^{+5.1}_{-4.0}$ (syst.) GeV

# Results for 835 $pb^{-1}$

- New results consistent with one another and world average top mass
- Uncertainties in eμ channel comparable to combined uncertainty for 370 $pb^{-1}$



# Conclusions

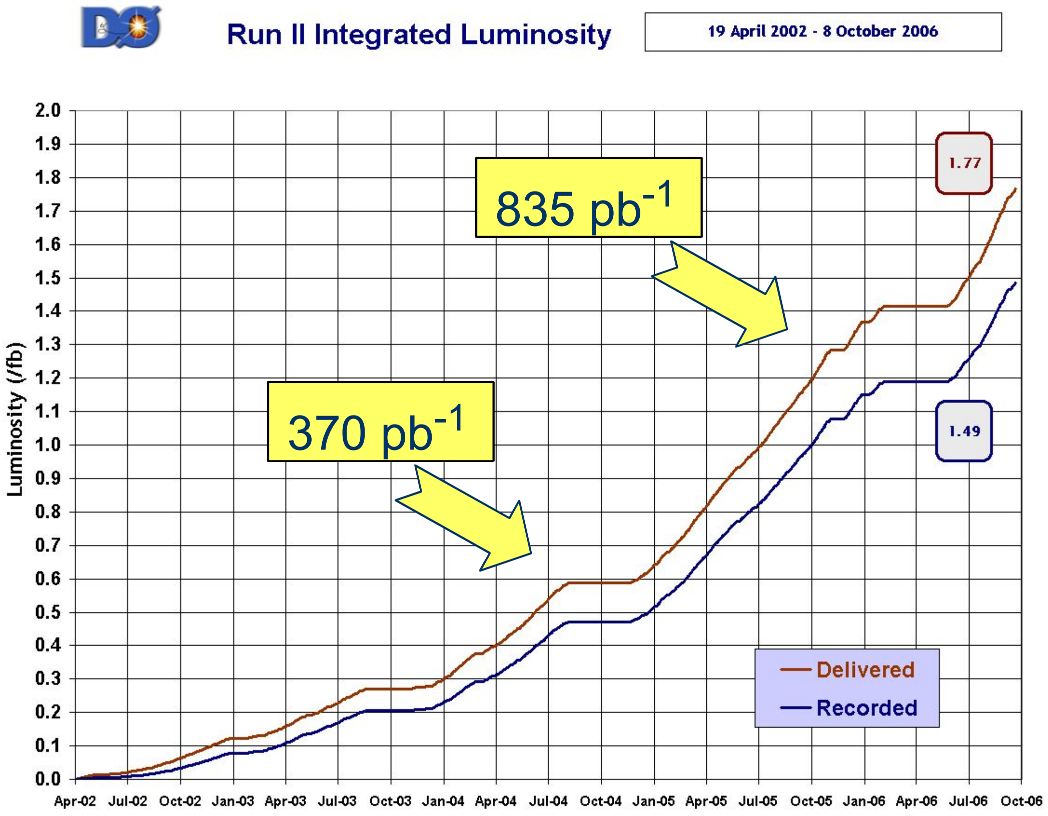
- Combined 370 $pb^{-1}$ Run II dilepton measurement improves upon Run I result
- 835 $pb^{-1}$ result in $e\mu$ channel provides further reduction in uncertainty
  - ee, $\mu\mu$ analyses proceeding
  - $\nu$WT converging on preferred mass extraction method
- Approaching point where measurement is limited by systematics!

# Backup Slides

- Run II luminosity
- Sample event weights
- Individual mass measurements
- Pull Distributions

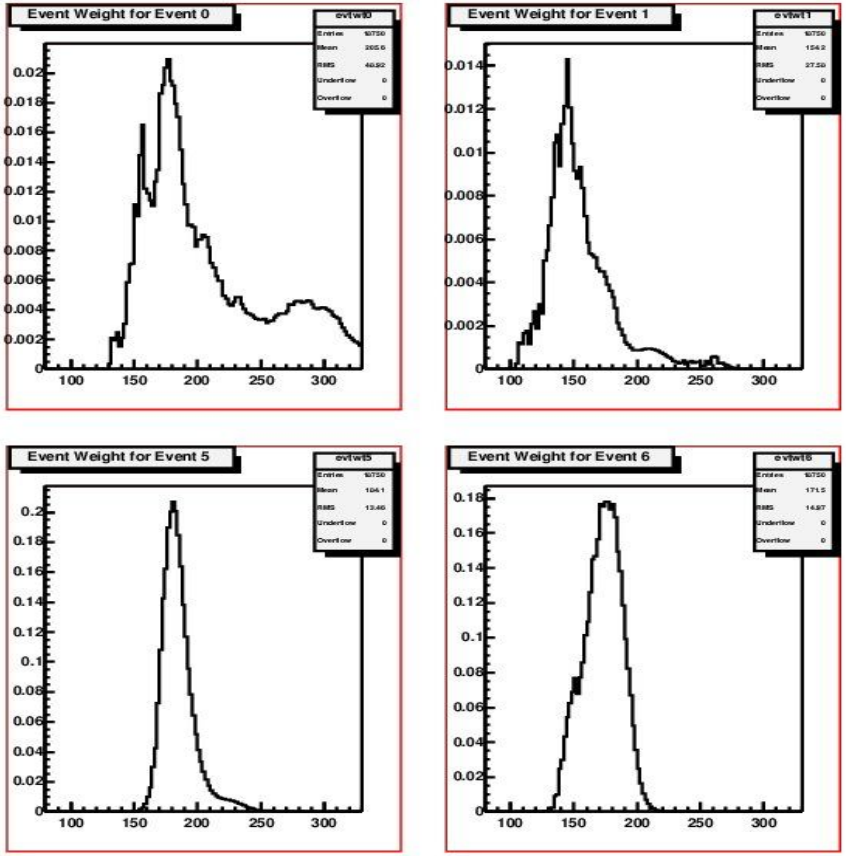
# DØ Run II Integrated Luminosity

- Run II started in April, 2002
- Data collection efficiency > 85%
- 370 $pb^{-1}$ collected by fall 2004
- 835 $pb^{-1}$ collected by fall 2005
- (compare to 110 $pb^{-1}$ for Run I)



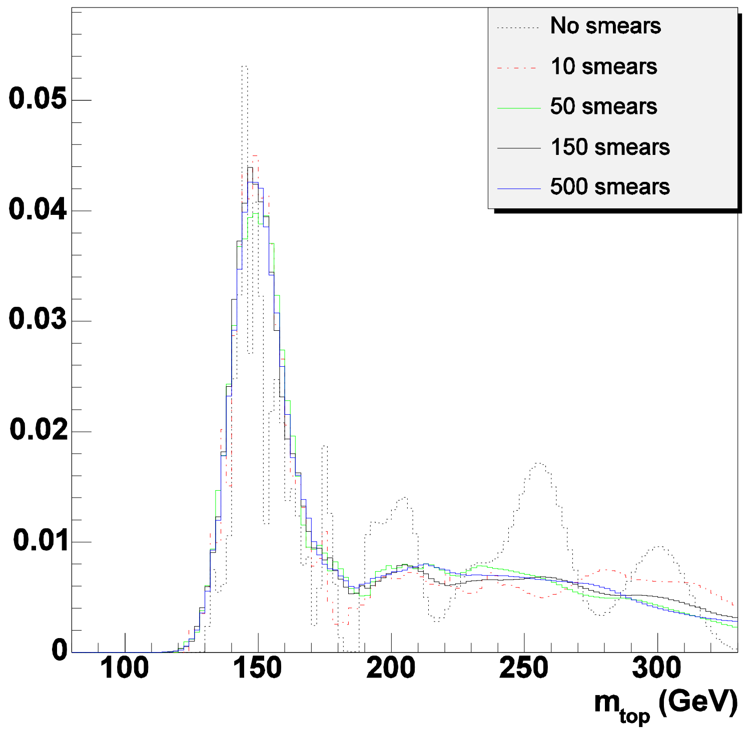
# Sample Event Weights – $\nu$WT 370 $pb^{-1}$

- Correct assumption of $m_{t,}$ $\eta_{\nu,}$ $\eta_{\bar{\nu}}$ leads to non-zero weight
- Incorrect assumptions can also produce valid solutions!

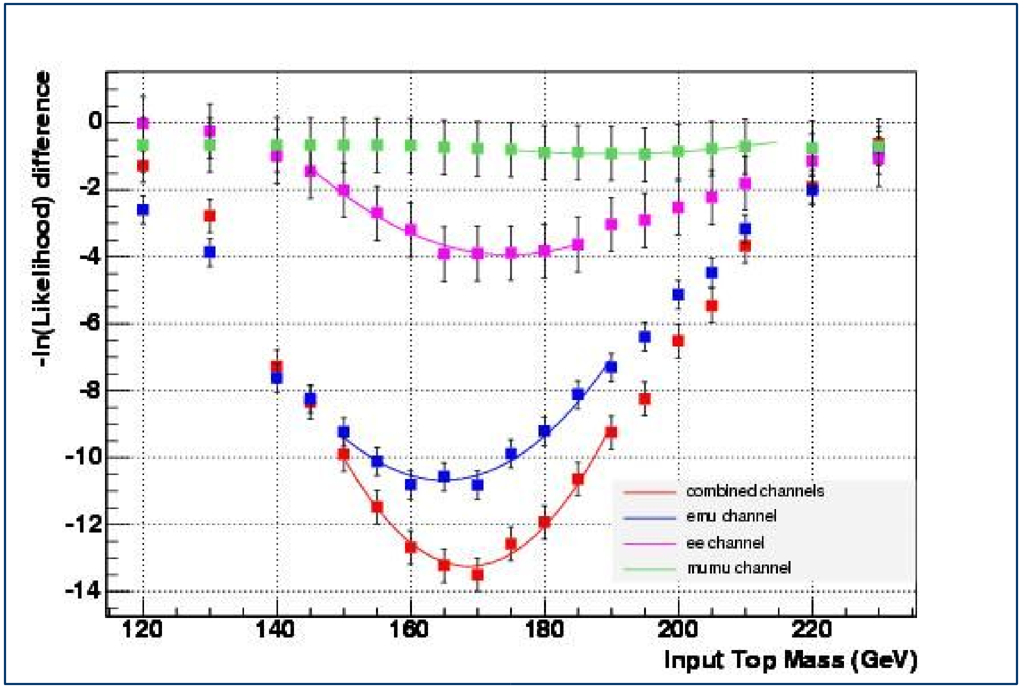


# Detector Smearing – νWT 370 $pb^{-1}$

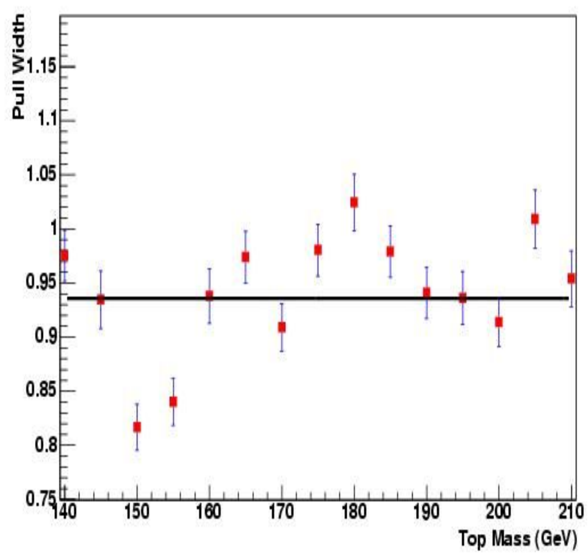
- Object momenta not measured perfectly
- Repeat weight calculations, smearing over detector resolutions
- ~150 smears "stabilizes" weight distribution



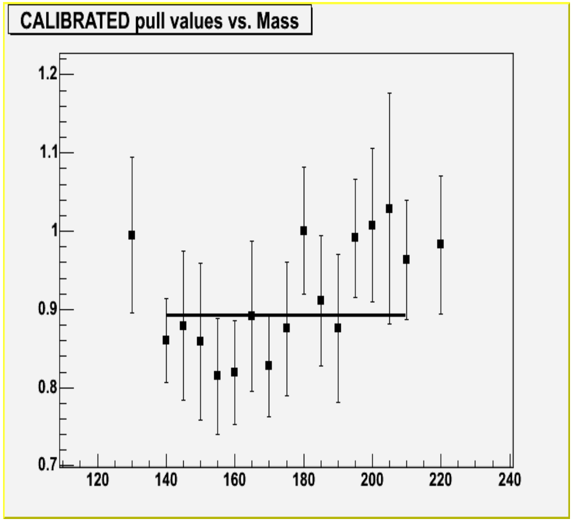
# Individual Channel Results – νWT 370 pb$^{-1}$



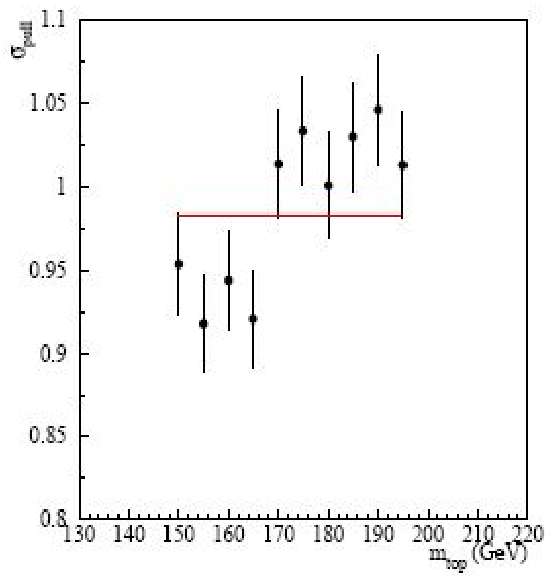
# Pull Distributions – 370 $pb^{-1}$




νWT dilepton



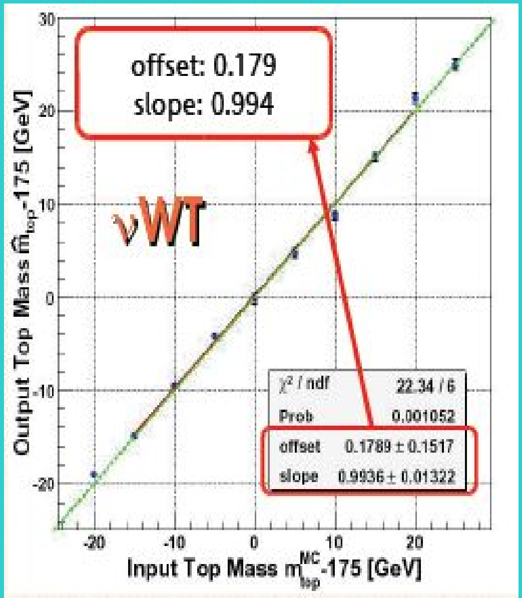

νWT dilepton & lepton+track



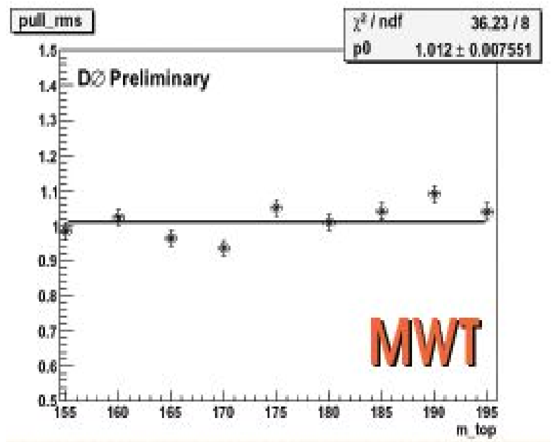

MWT dilepton

$$Pull \equiv \frac{(m_t^{measured} - m_t^{input})}{\sigma_{m_t}}$$

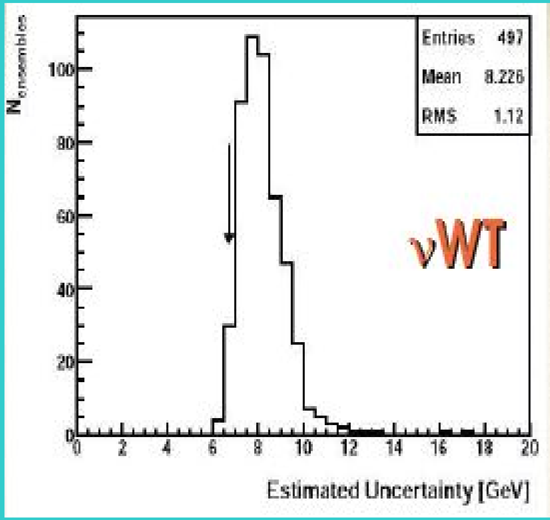
# Ensemble Checks – 835 pb$^{-1}$




νWT Peak Calibration




MWT Pull Widths




νWT 6-bin
Expected Error