Top Quark Mass Measurements at DØ

- Introduction
- Results
  - Neutrino weighting
  - Matrix weighting
  - Ideogram
  - Matrix element
- Systematics
- Conclusion

Alan Magerkurth
University of Michigan

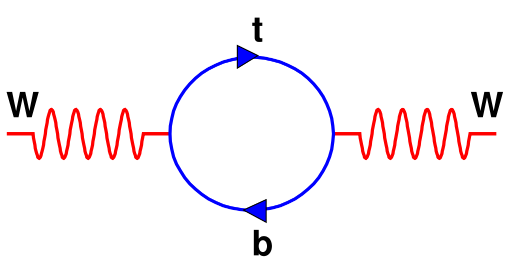
on behalf of the
DØ collaboration

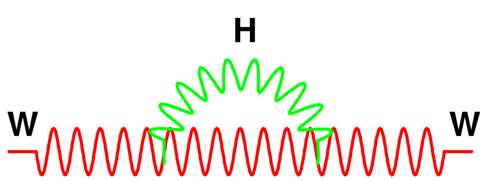
Top Quark Mass

Top quark mass:

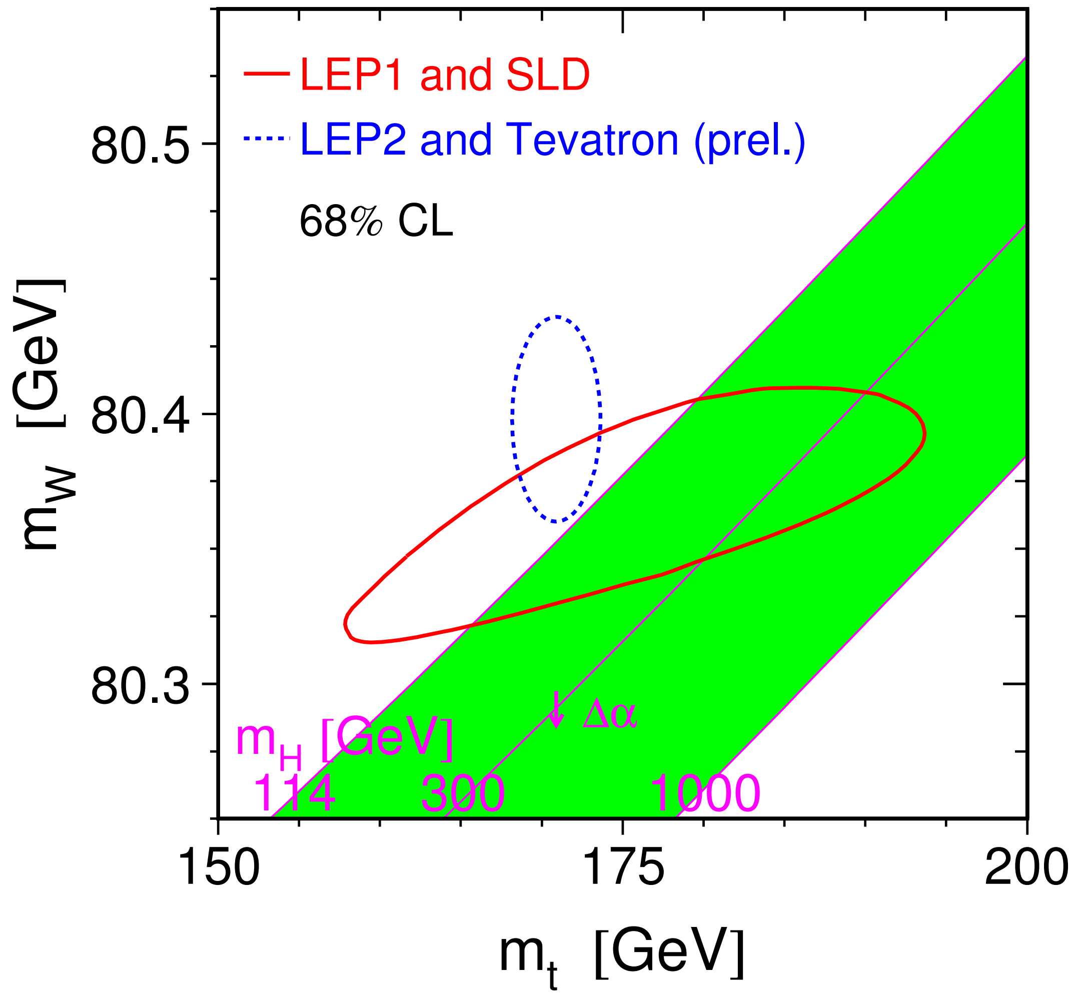
- Fundamental parameter of the standard model

- Related to the Higgs mass

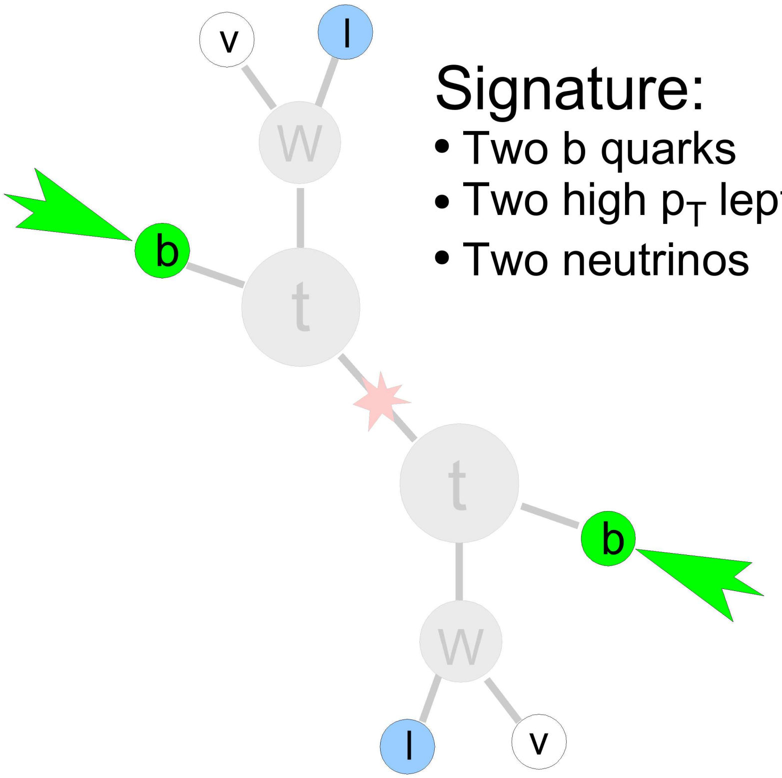




$$\delta m_W \propto m_{top}^2 , \ln (m_H)$$



Dilepton Channel



Signature:
- Two b quarks
- Two high p_T leptons
- Two neutrinos

Typical Event Selection:
- Two high p_T leptons (>15 GeV)
- Two or more high p_T jets (>20 GeV)
- Missing E_T (>35 GeV)
- Z rejection

Backgrounds:
- Diboson (WW, WZ, ZZ)
- Drell-Yan
- $Z \rightarrow \tau\tau$
- W+jets with fake lepton

Small branching ratio → low statistics

Large S/B

Two neutrinos → underconstrained kinematics
Need to assume knowledge of some quantity

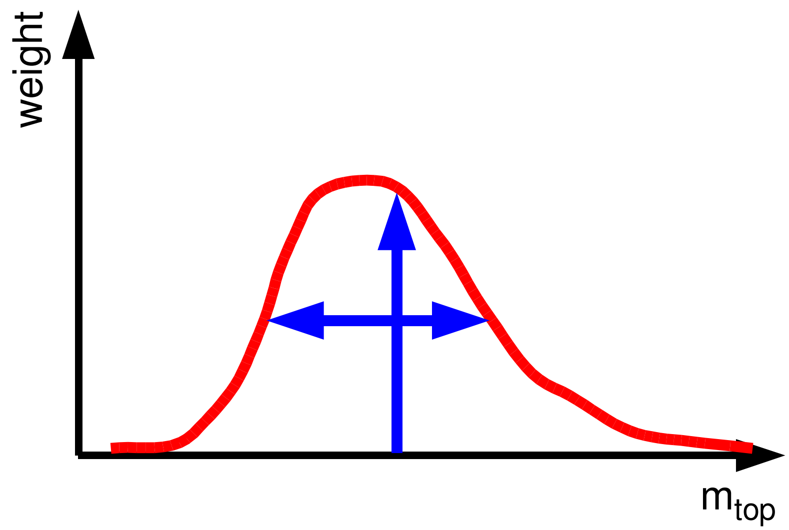
Neutrino Weighting in Dilepton Channel

For various m_{top} hypotheses, assume neutrino eta's (weakly correlated with m_{top}), then calculate an event weight

$$w = \frac{1}{N} \sum_{1}^{N} \exp\left(\frac{-(\not{E}_{x,i}^{calc} - \not{E}_{x}^{obs})^2}{2\sigma^2_{\not{E}_x}} \right) \exp\left(\frac{-(\not{E}_{y,i}^{calc} - \not{E}_{y}^{obs})^2}{2\sigma^2_{\not{E}_y}} \right)$$

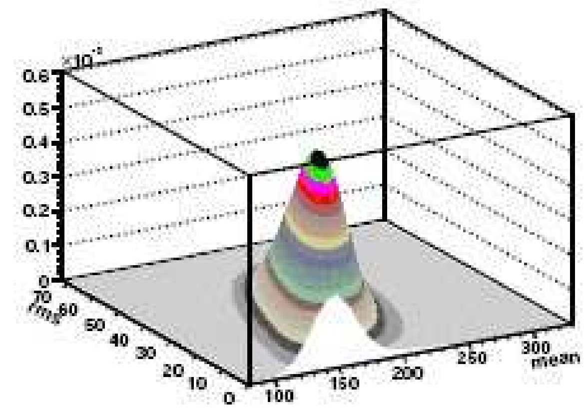
Repeat the process varying jet and lepton energies within their resolutions

For each event, calculate the mean and rms of the weight distribution



Neutrino Weighting in Dilepton Channel

Generate a signal PDF f_s(mean, rms, m_{top}) and a background PDF f_b(mean, rms) and fit PDF shapes with a functional form



Maximize the likelihood with respect to seven variables:

$m_{top}, n_s^i, n_b^i; i = ee, e\mu, \mu\mu$

Agreement of signal + background with number of events observed

$$L(mean, rms, \overline{n}_b, N; m_{top}, \vec{n}_s, \vec{n}_b) = \prod_{chan} \left[L_{gaus}(n_b, \overline{n}_b, \sigma_b) L_{poisson}(n_s + n_b, N) \prod_1^N \frac{n_s f_s + n_b f_b}{n_s + n_b} \right]$$

Agreement of background estimate with background prediction

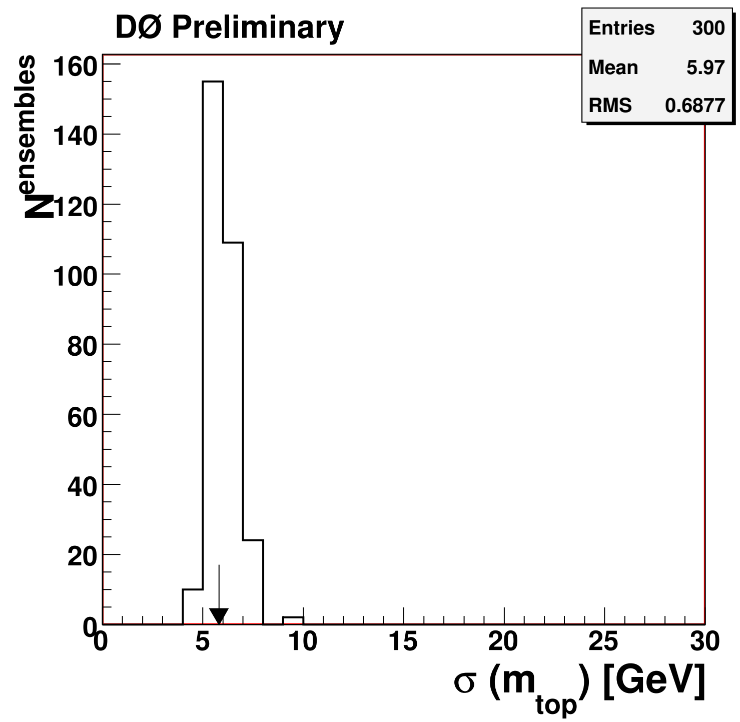
Agreement of data with PDF shapes

Neutrino Weighting in Dilepton Channel

Result from ~1 fb^{-1} of data (stat errors):

eμ: m_{top} = 170.6±8.6 GeV
ee: m_{top} = 173.9±9.3 GeV
μμ: m_{top} = 179.7±15.5 GeV

Systematics (GeV)	
JES	±5.0
b-jet scale	±2.0
Jet resolution	±0.3
Muon resolution	±0.4
Signal modeling	±0.14
PDF variation	±0.7
Bkgd template	±0.3
Template stats	±0.9
Underlying event	±0.13
Total	±5.5



combined:
m_{top} = 172.5±5.8 (stat)±5.5(syst) GeV

Matrix Weighting in Dilepton Channel

For various m_{top} hypotheses, solve event kinematics

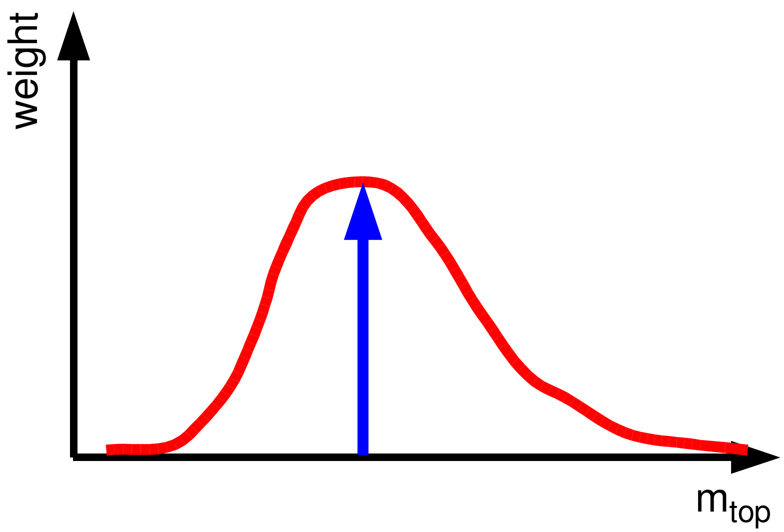
Assign an event weight

$$w = f(x) f(\bar{x}) p(E_l^0; m_{top}) p(E_{\bar{l}}^0; m_{top})$$

$f(x)$: PDF

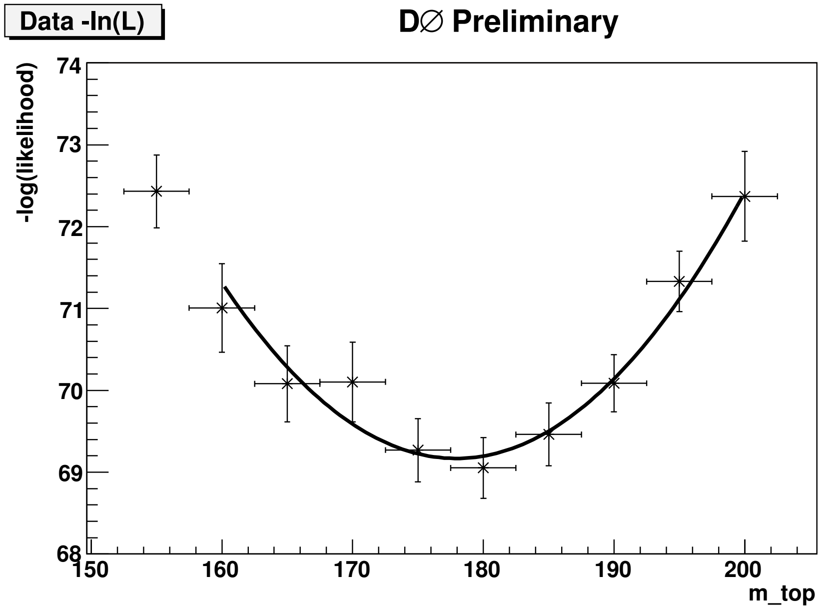
$p(E_l^0; m_{top})$: probability of lepton energy E_l^0 in top quark rest frame

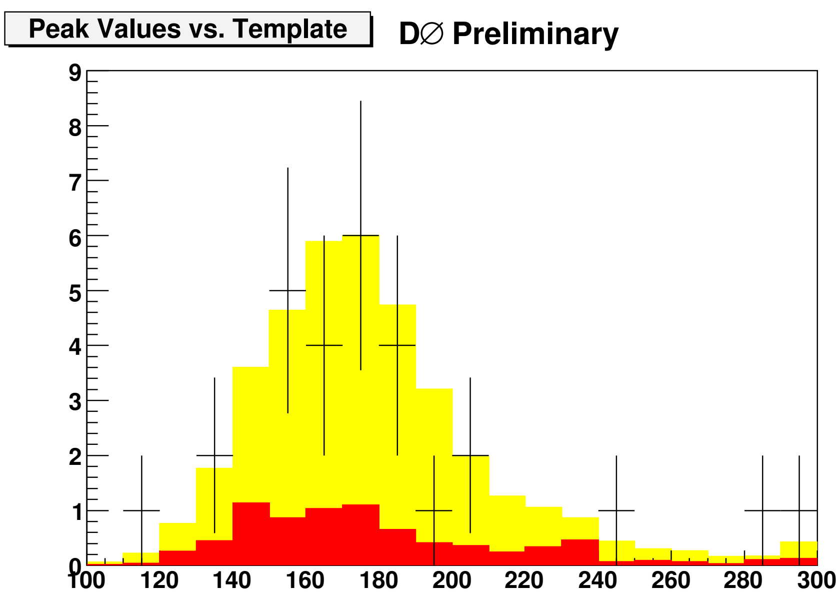
Repeat the process varying jet and lepton energies within their resolutions



Use the most probable top quark mass as estimator, then fit data with signal and background templates

Matrix Weighting in Dilepton Channel



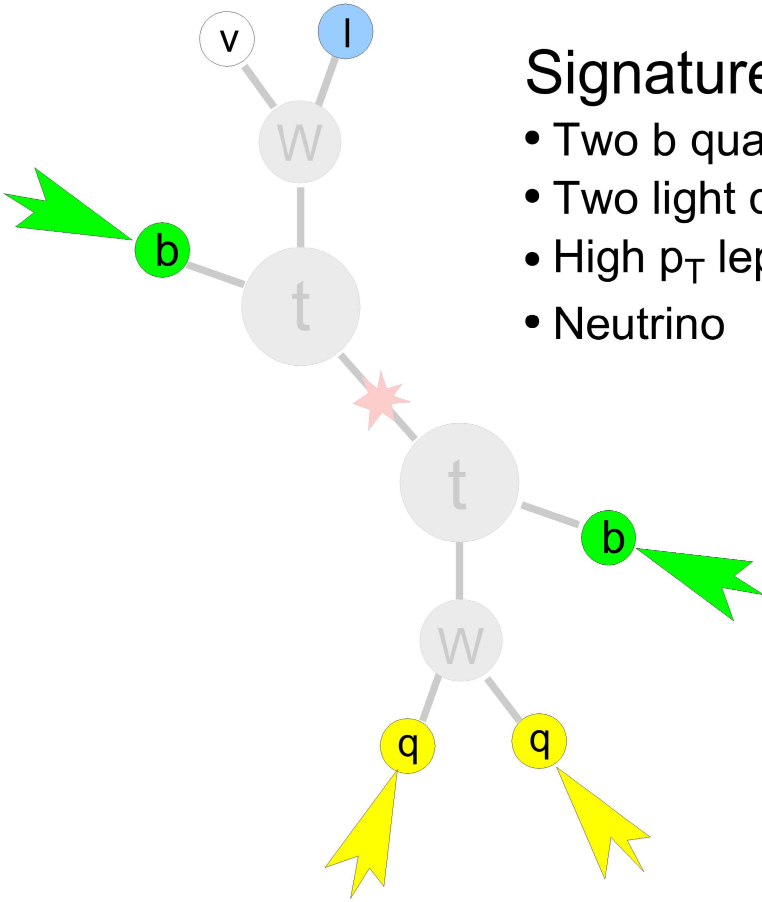


Using the eμ channel (830 pb^{-1})

Uncertainties (GeV)	
Statistical	±8.8
JES	+3.5 -3.9
Background	+0.3 -1.9
PDF variation	±0.8
Gluon radiation	±0.7
Calibration	±0.5
Template stats	±0.3
Total	+9.6 -9.9

$$m_{top} = 177.7 \pm 8.8\,(stat)^{+3.7}_{-4.5}\,(syst)\,GeV$$

Lepton+jets channel



Signature:

- Two b quarks
- Two light quarks
- High p_T lepton
- Neutrino

Typical Event Selection:

- One high p_T lepton (>20 GeV)
- Four or more high p_T jets (>20 GeV)
- Missing E_T (>20 GeV)
- b-tagging

Larger branching ratio → better statistics

More background

One neutrino → overconstrained kinematics

Backgrounds:

- W+jets
- Multi-jet with fake lepton

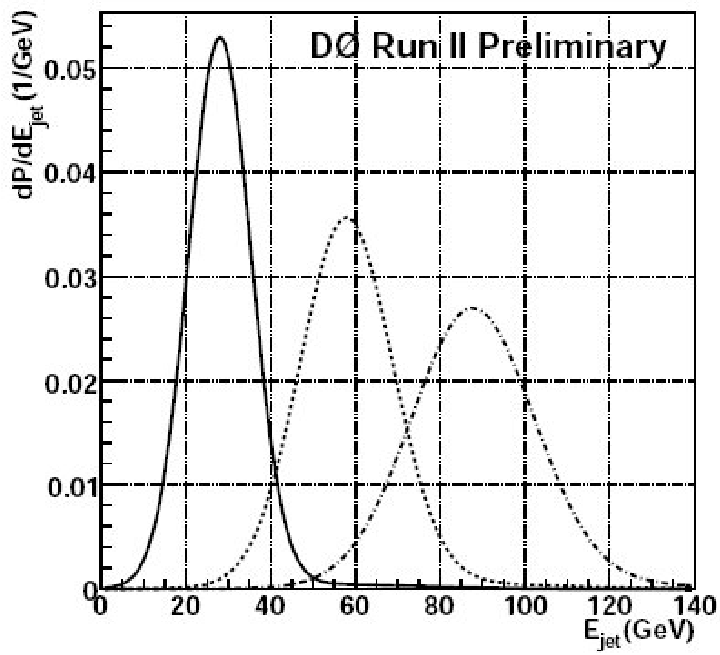
Matrix Element in Lepton+Jets Channel

Goal is to maximize use of kinematic information (x) by comparing to matrix elements of signal and background processes (y)

$$P_{evt} = f_{sgn} P_{sgn}(x; m_{top}, JES) + (1 - f_{sgn}) P_{bkg}(x)$$

$$P_{sgn}(x; m_{top}, JES) = \frac{1}{\sigma} \sum w_i \int T(x, y, JES)\, d\sigma^n(y, m_{top})\, f(q_1) f(q_2)\, dq_1\, dq_2$$

- 10-D numerical integration
- Transform variables to speed up computation
- Integrate on m_{top}, JES grid
- Very CPU intensive!



Matrix Element in Lepton+Jets Channel

Constraining the jet energy scale (JES) uncertainty:

Jet resolution function is parameterized in terms of overall energy scale J, which is constrained by the W mass

$$T(E_x, E_y; J) = \frac{T\left(\frac{E_x}{J}, E_y; 1\right)}{J}$$

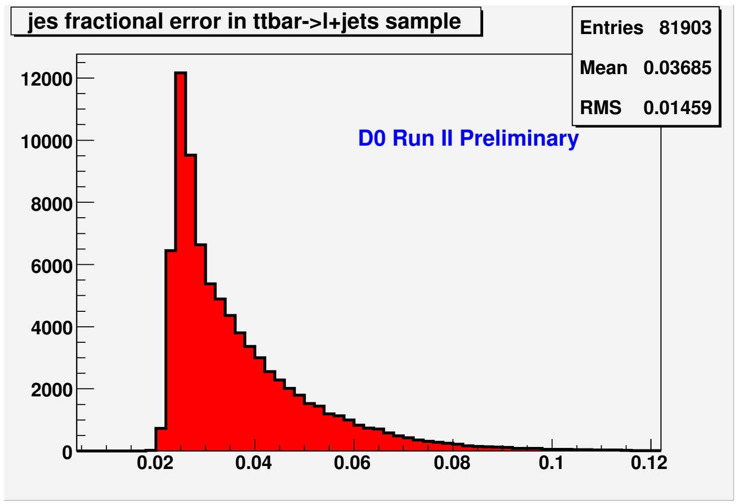
x = detector level
y = parton level

With no prior input on the uncertainty on J:

$$L(x_1, \ldots, x_n; m_{top}) = \int L(x_1, \ldots, x_n; m_{top}, J)\, dJ$$

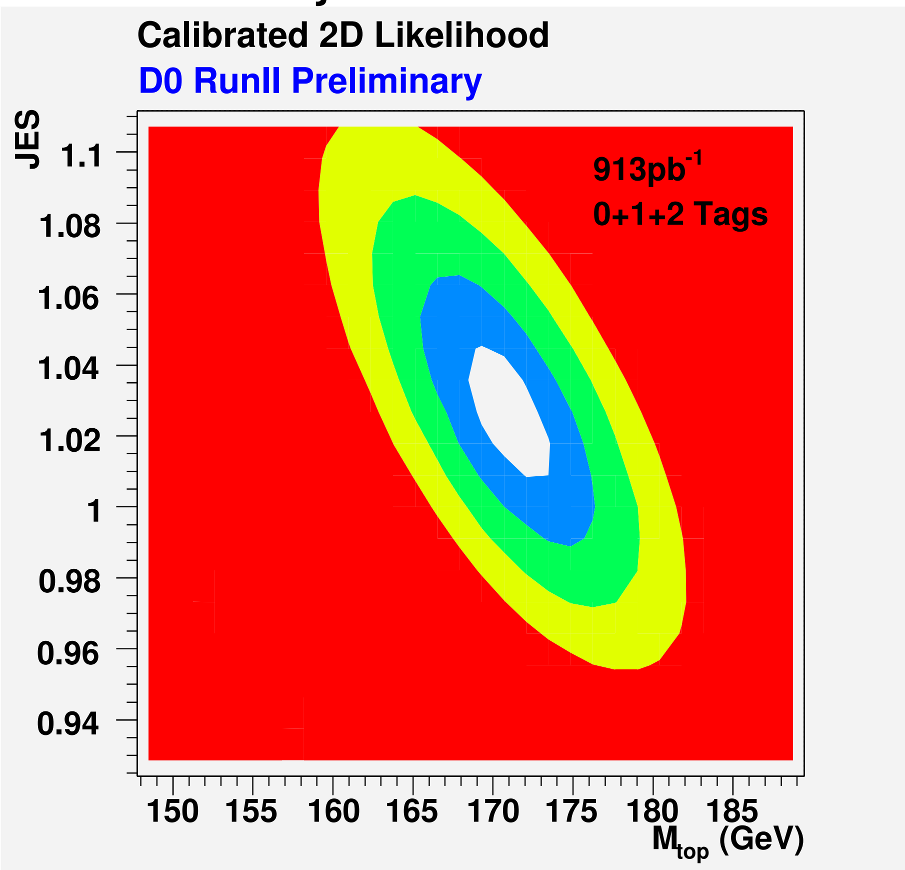
With prior input on the uncertainty on J:

$$L(x_1, \ldots, x_n; m_{top}) = \int L(x_1, \ldots, x_n; m_{top}, J)\, G(J)\, dJ$$



Matrix Element in Lepton+Jets Channel

likelihood for the
e+jets channel



Uncertainties (GeV)

Signal modeling	±0.45
Bkgd modeling	±0.15
PDF	$^{+0.26}_{-0.40}$
b fragmentation	±0.54
b/c semileptonic	±0.05
JES p_T dependence	±0.23
b response (h/e)	±0.57
Trigger	±0.08
Signal fraction	$^{+0.53}_{-0.24}$
QCD fraction	±0.21
MC calibration	±0.07
b-tagging	±0.29
Total	±1.2

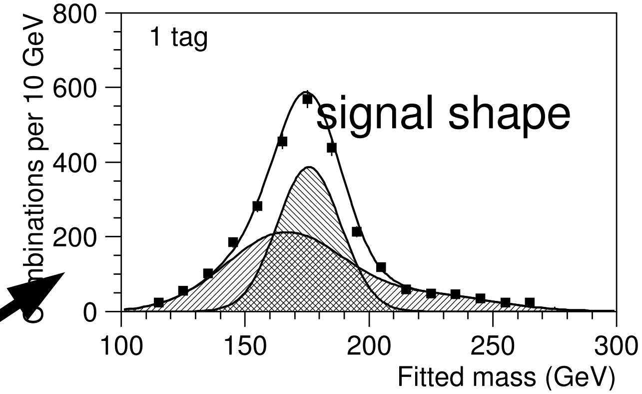
m_{top} = 170.5±1.8(stat)±1.6(JES)±1.2(syst) GeV

Ideogram Method in Lepton+Jets Channel

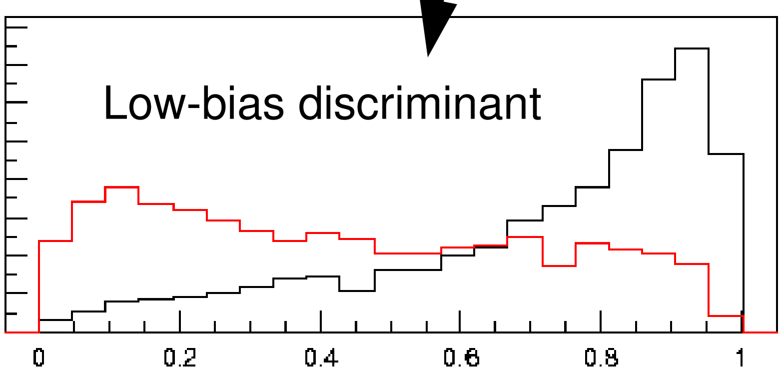
- Uses kinematic fit to determine consistency with top hypothesis
- Calculate likelihood for each event in sample

χ^2, btag weighted combinatorics

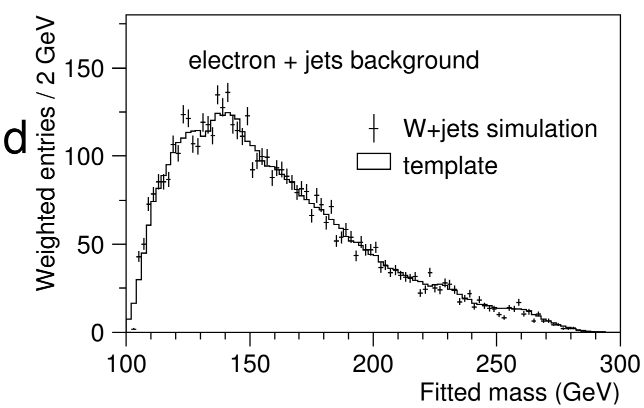
$$w_i = e^{-1/2\cdot\chi_i^2} w_{btag,i}$$



$$L(m_{top}, JES, P_{samp}) = P_{evt} \cdot \left[\int \sum w_i \cdot G(m_i, m') \cdot BW(m', m_{top})\, dm' \right] + (1 - P_{evt}) \cdot \sum w_i \cdot BG(m_i)$$



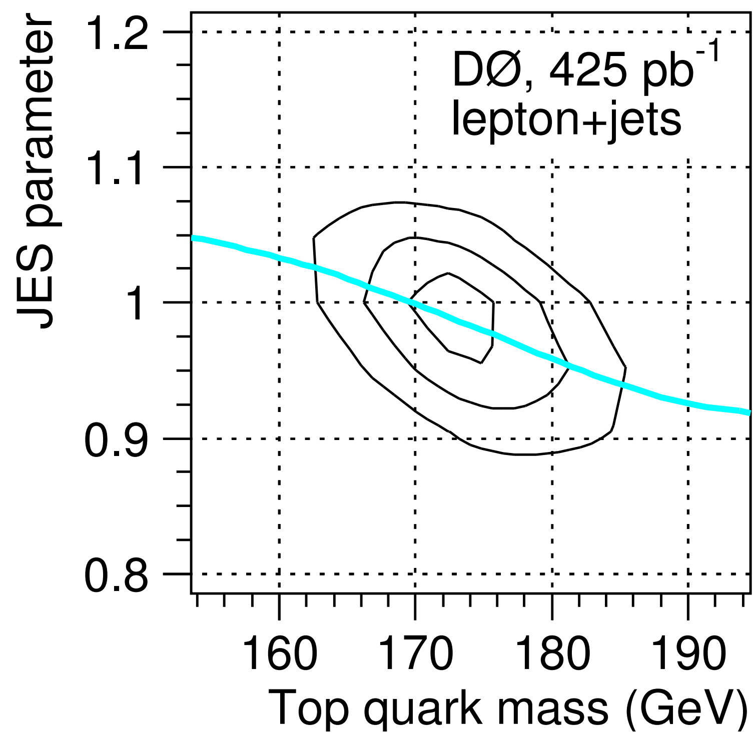
Background shape



Ideogram Method in Lepton+Jets Channel

Systematic uncertainties (GeV)

JES pT dependence	±0.45
Jet ID and resolution	±0.22
b fragmentation	±1.30
b response (h/e)	±1.15
b tagging	±0.29
Trigger	$^{+0.61}_{-0.28}$
Signal modeling	±0.73
Signal fraction	±0.12
Background modeling	±0.20
Multijet background	±0.28
MC calibration	±0.25
PDF	±0.02
Total	$^{+2.10}_{-2.04}$

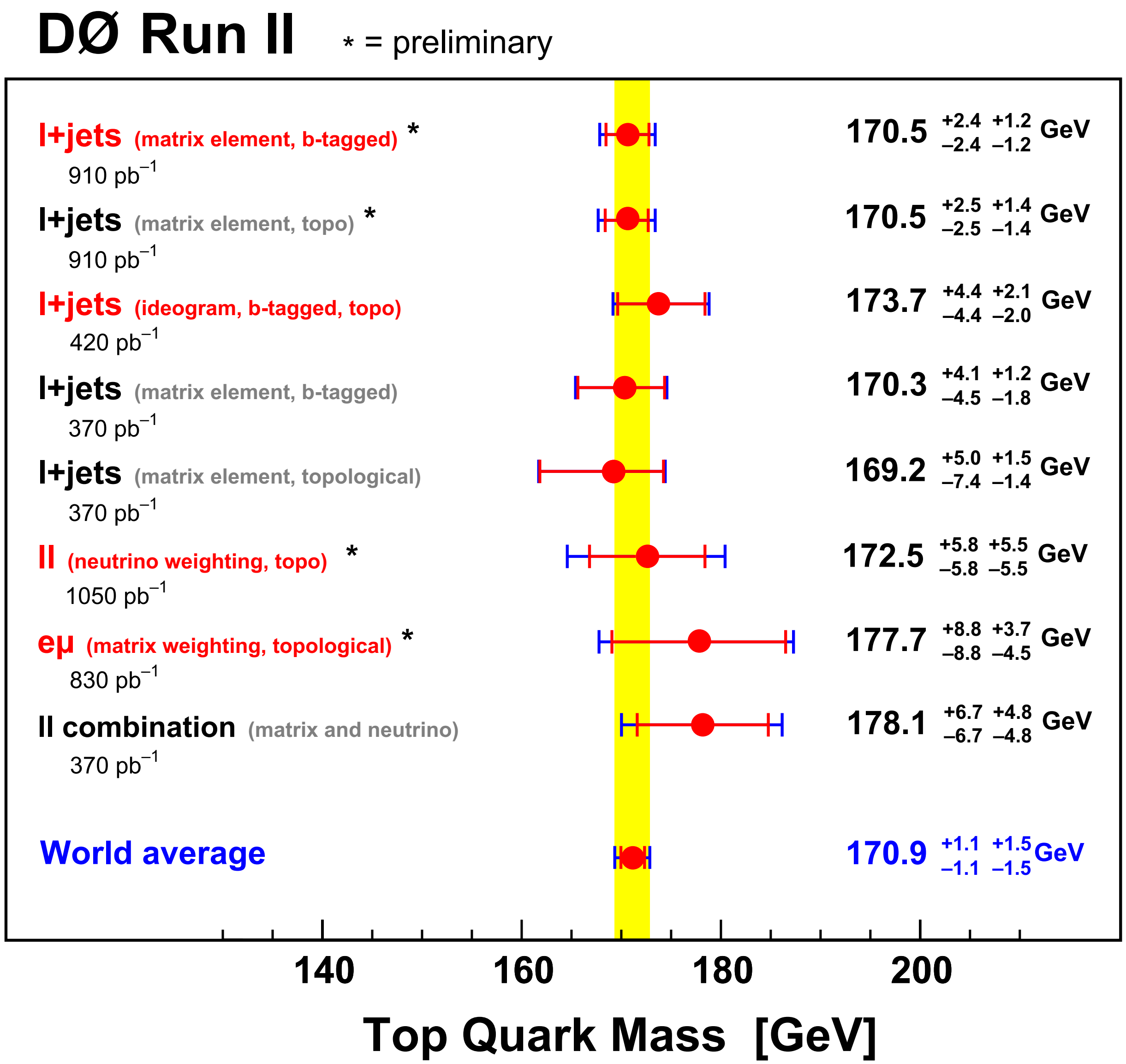


JES = 0.989±0.029

m_{top} = 173.7±4.4(stat+JES)±2.1(syst) GeV

PRD **75**, 092001 (2007)

Summary of DØ Results



Results in red shown in this presentation

Systematic Uncertainties

- JES uncertainty is the leading source of systematic uncertainty on m_{top}
  - W mass constraint can help
  - Residual shape differences are important
  - b/light jet response differences
  - b fragmentation, semileptonic braching ratios
  - No longer sufficient to have one overall JES uncertainty estimate – must understand individual components
- Many sources of uncertainty at O(0.1 GeV)
  - Signal modeling (ISR, FSR, PDF)
  - Background modeling (sample composition, fragmentation scale)
  - Fitting methods, calibration, MC generators
- CDF and DØ continue to discuss uncertainties to ensure that they are treated consistently and that measurements can be combined

Summary

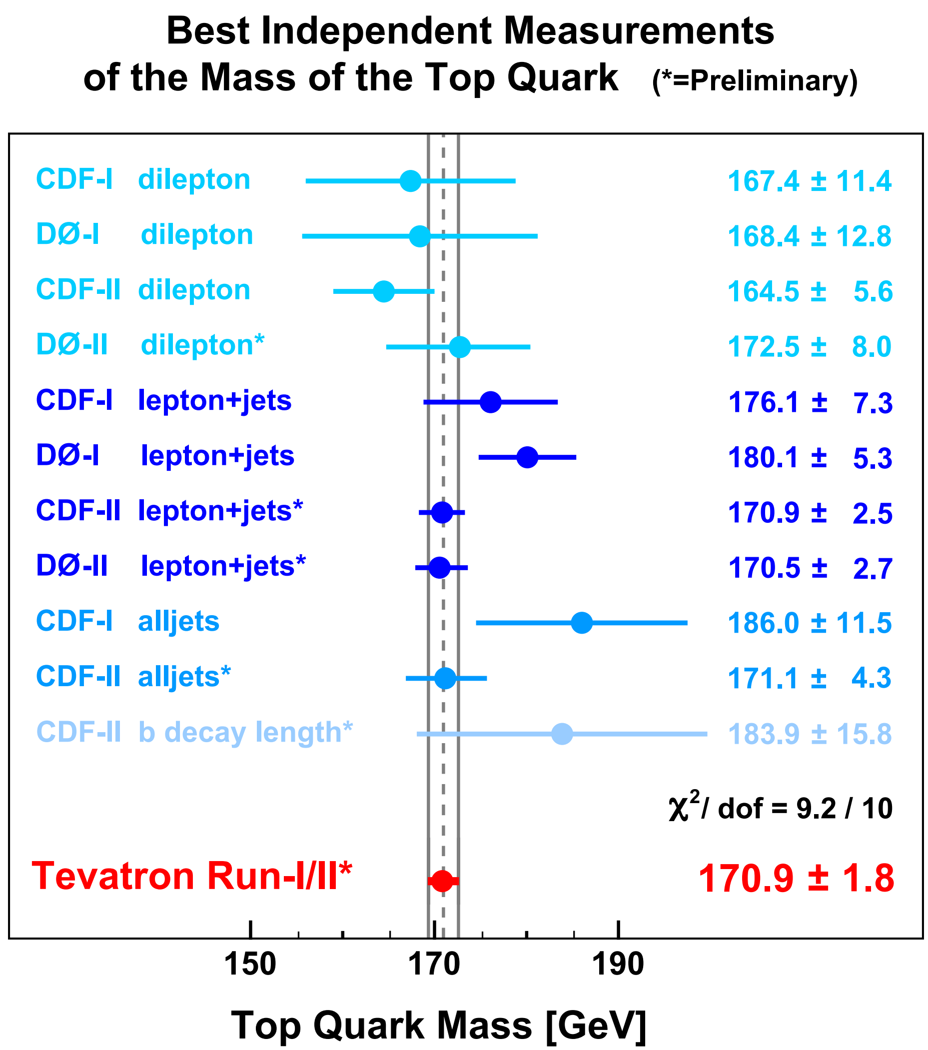
- Sophisticated analysis techniques are well understood and have demonstrated performance
- Progress on reducing leading systematic uncertainties
- Future measurements will be systematics-dominated

m_{top}=170.9±1.1±1.5 GeV

=170.9±1.8 GeV

→ 1.1% uncertainty

Latest combination of CDF and DØ top quark mass measurements



hep-ex/0703034

Backup

Details on dilepton selection

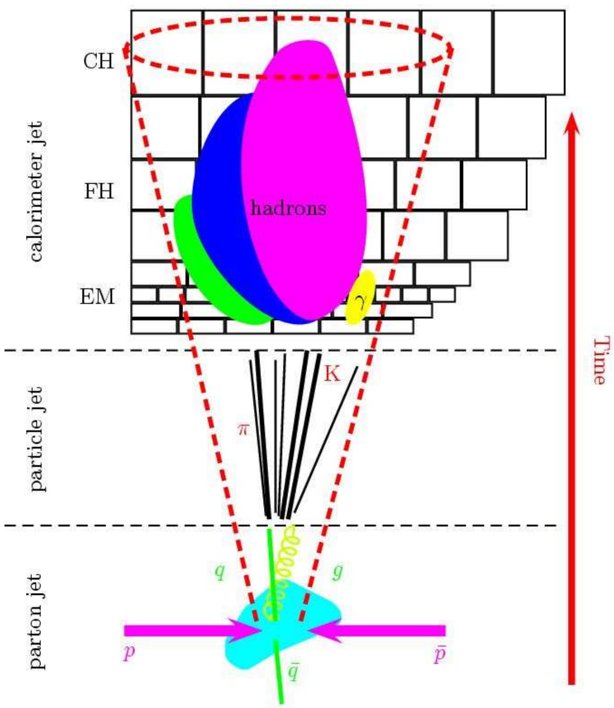
- e^+e^-
  - Veto M_{ee}<15 GeV or 80 GeV<M_{ee}<100 GeV
  - $\not{E}_T$ >35 (40) GeV for M_{ee}>100 GeV (15 GeV<M_{ee}<80 GeV)
  - sphericity > 0.15
- $\mu^+\mu^-$
  - $\not{E}_T$ >35 GeV
  - χ^2 of Z→ $\mu^+\mu^-$ fit > 8
- $e^\pm\mu^\mp$
  - $p_T^{l_1}+\sum(p_T^j)>115$ GeV

Contribution to World Average

Weight of each measurement in world average (%)

Run I					Run II					
CDF			DØ		CDF				DØ	
l+j	di-l	all-j	l+j	di-l	l+j	di-l	all-j	lxy	l+j	di-l
-1.3	-0.4	-0.3	+6.1	+0.4	+39.3	+6.4	+11.0	+0.5	+39.7	-1.9

Jet Energy Scale



$$E_{corr} = \frac{E_{meas} - O}{F_n \times R \times S}$$

Offset Correction: (O)
Multiple interactions
Underlying event

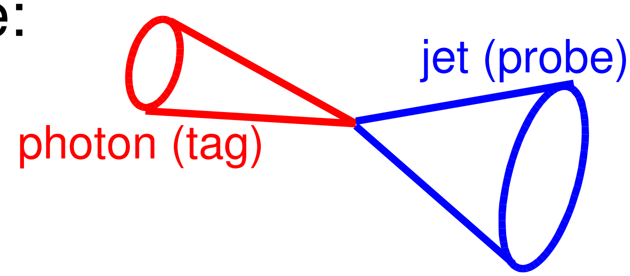
Showering Correction: (S)
Particles outside of cone

Eta intercalibration: (F_n)
Detector coverage

Response Correction: (R)
Hadronic response
Uninstrumented regions

Largely measured in data

For example:



$$R_{had} = 1 + \frac{\vec{\not{E}}_T \cdot \vec{p}_{T,\gamma}}{\vec{p}_{T,\gamma}^{\,2}}$$