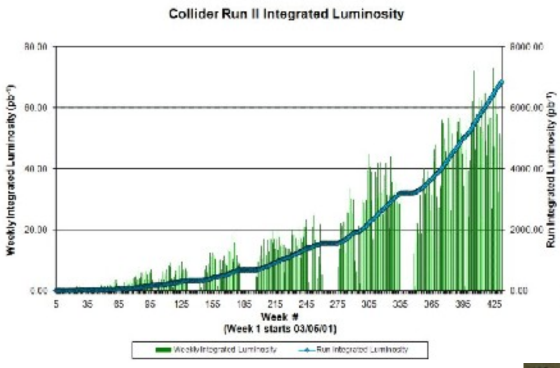
Top Mass Measurements with the D0 Detector

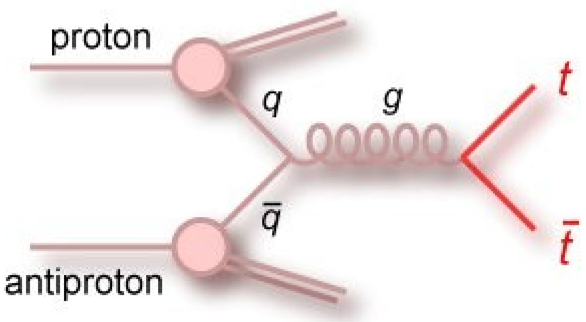
Dan Boline
On behalf of the D0 Colaboration

Wayne State University
Detroit MI
July 27-31

Introduction

- Won't discuss D0 experiment, Tevatron, Top Pair production





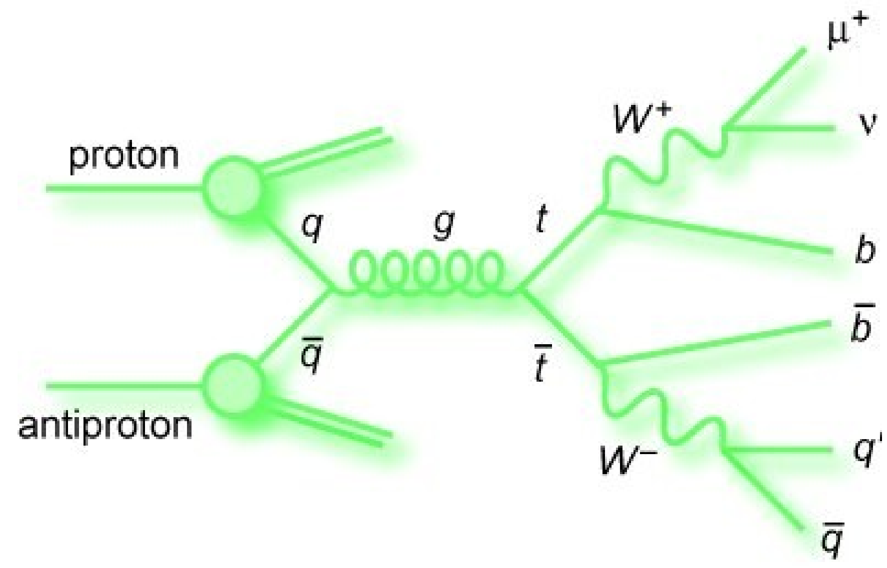
Results with up to 3.6 fb^{-1} of data.

Content of Talk

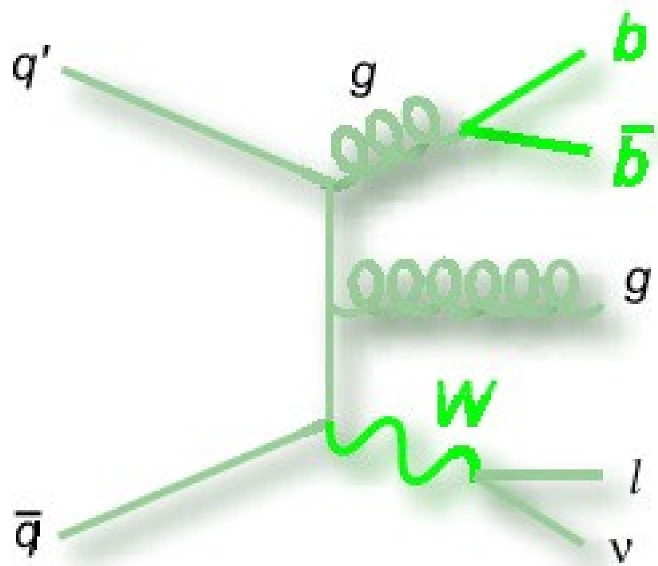
- Mass Measurement:
  - Lepton+Jets Channel:
    - First Top-antiTop Mass Difference (1.0 fb^{-1})
    - Matrix Element Mass in (3.6 fb^{-1})
  - Dilepton Channel:
    - Matrix Element Mass in $e\mu$ (3.6 fb^{-1})
    - Template-Based Mass (1.0 fb^{-1})

Event Selection : ljets channel

- Lepton+Jets Channel:
  - 1 lepton
    - e or μ (pT>15 GeV)
  - large MissingET
  - 2 b-jets, 2 light jets



- Backgrounds:
  - W+jets
  - QCD



Top Mass Difference

Top decays before it can hadronize
- -> Can directly measure top quark mass
- -> top anti-top assumed to have same mass
  - - CPT invariance requires this
- -> What happens if we drop the assumption?

Matrix Element Method

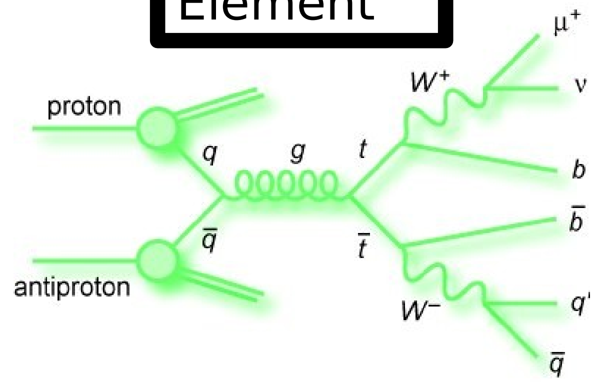
$$\mathcal{L}(m_t, m_{\bar{t}}, f_t) = \prod_{i=1}^{N_{evt}} [f_t P_{sig}(x_i; m_t, m_{\bar{t}}) + (1-f_t) P_{bkg}(x_i)]$$

$$P_{sig}(x; m_t, m_{\bar{t}}) = Acc(x) \times \frac{1}{\sigma} \int d^n\sigma(y; m_t, m_{\bar{t}}) dq_1 dq_2 f(q_1) f(q_2) W(x,y)$$

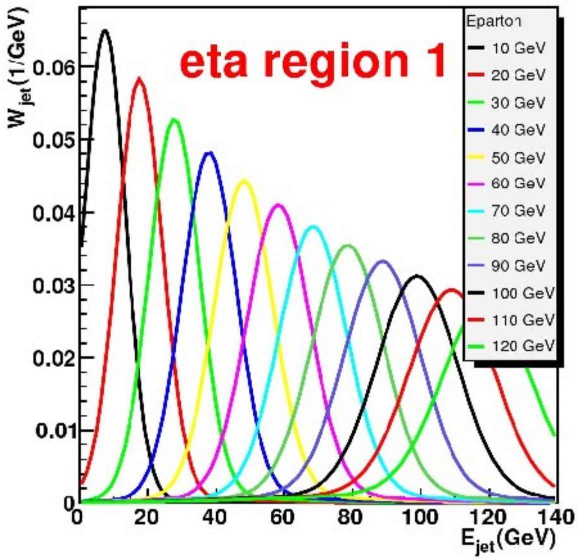
Acceptance: selection efficiency

Integrate over parton momenta

LO Matrix Element



Transfer Function



Transform to convenient variables:

$$(m_t, m_{\bar{t}}) \rightarrow (\Delta m_t = (m_t - m_{\bar{t}}), m_{sum} = (m_t + m_{\bar{t}})/2)$$

Integrate out M_{sum}:

$$\mathcal{L}(\Delta m_t) = \int dm_{sum} \mathcal{L}(\Delta m_t, m_{sum})$$

Simulating $m_t \neq m_{\bar{t}}$

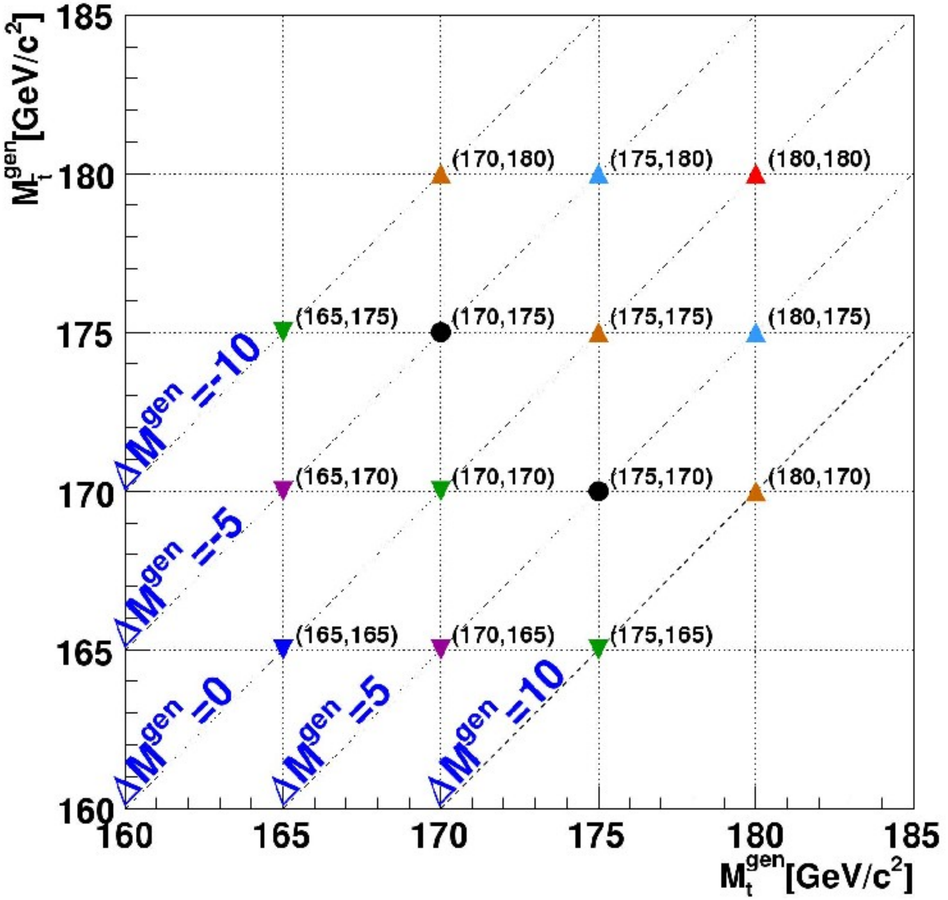
Samples generated with PYTHIA event generator

m_t, $m_{\bar{t}}$ set to different values.

Monte Carlo run through standard D0 Reconstruction (GEANT, etc)

W+jets background simulated with ALPGEN+PYTHIA

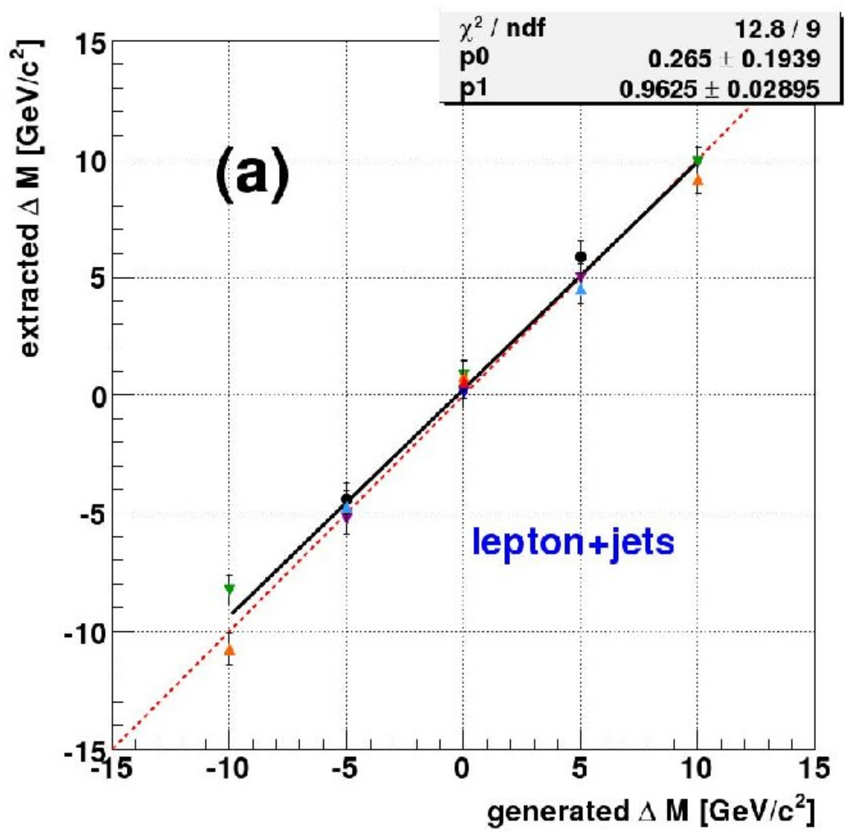
QCD Background taken from Data



Performance on Simulated Data

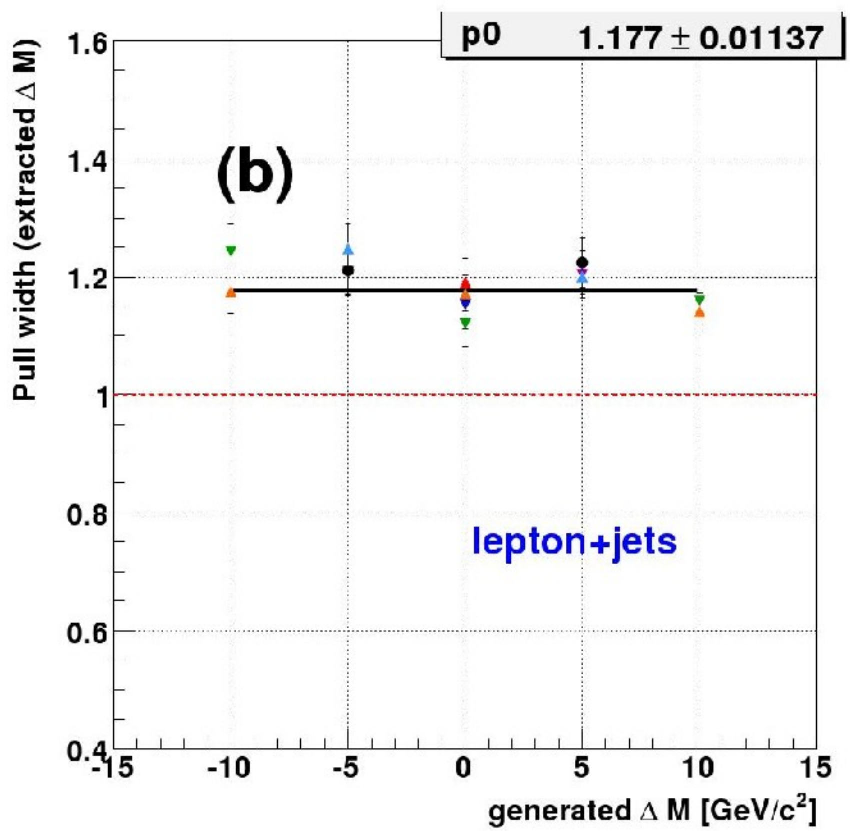
Remove bias on measured mass

$$< \Delta m_t^{\text{measured}} > \text{ vs } \Delta m_t^{\text{true}}$$



Remove bias on measured error

$$PULL = \frac{\Delta m_t^{measured} - \Delta m_t^{true}}{\delta(\Delta m_t)^{measured}}$$



Systematics

Source	Uncertainty
Statistical	± 3.44
Physics modeling:	
Signal modeling	± 0.85
Background modeling	± 0.034
b-fragmentation	± 0.12
PDF uncertainty	± 0.26
Heavy flavor scale factor	± 0.067
Detector modeling:	
Jet energy scale	± 0.076
Residual jet energy scale	± 0.071
b/light response ratio	± 0.037
Jet ID efficiency	± 0.16
Jet resolution	± 0.39
Trigger	± 0.09
Wrong sign leptons	± 0.075
Method:	
Signal fraction	± 0.10
QCD contamination	± 0.40
MC calibration	± 0.25
b-tagging efficiency	± 0.25
μ resolution	± 0.09
luminosity reweighting	± 0.016
Total systematic uncertainty	± 1.15
Total uncertainty	± 3.63

Statistics Limited

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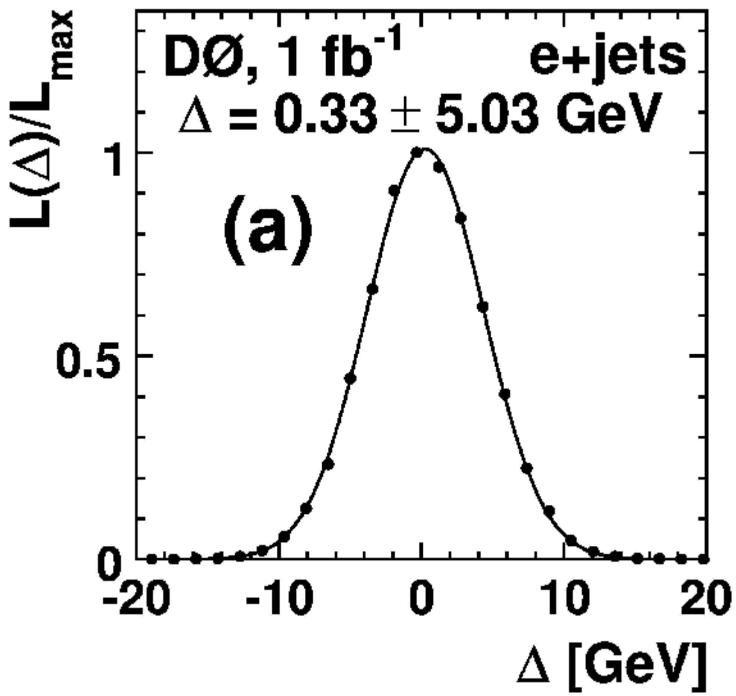
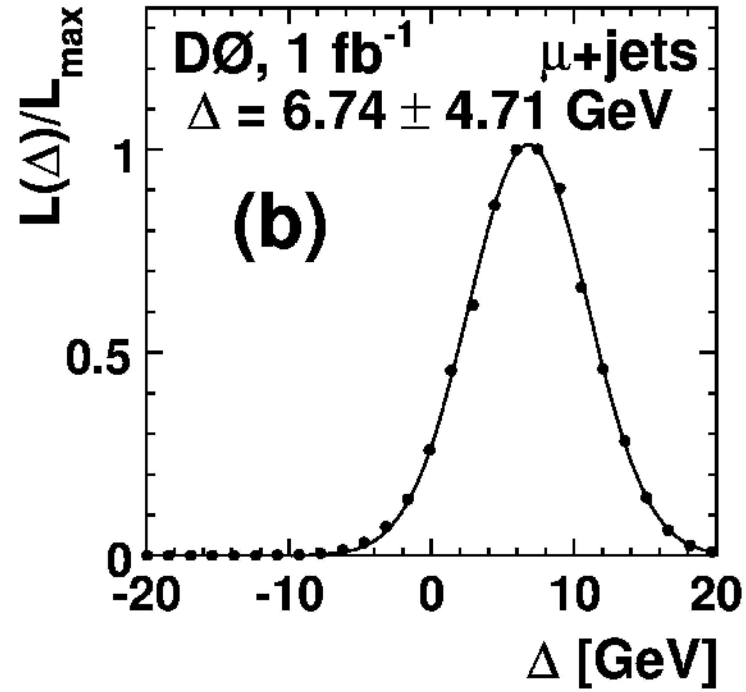
Measurement in Data





$e + jets$	$\Delta m_t = 0.33 \pm 5.03(stat)$ GeV
$\mu + jets$	$\Delta m_t = 6.74 \pm 4.71(stat)$ GeV
$combined$	$\Delta m_t = 3.75 \pm 3.44(stat) \pm 1.15(syst)$ GeV

First measurement of mass difference between quark and its antiquark partner

arXiv:0906.1172 Submittted to PRL

Matrix Element Method l+jets

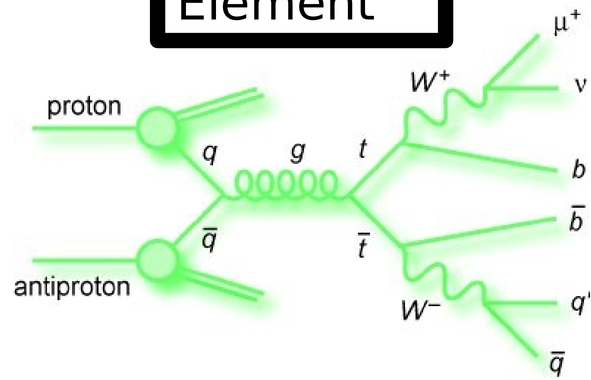
$$\mathcal{L}(m_{top}, JES, f_{top}) = \prod_{i=1}^{N_{evt}} [f_{top} P_{sig}(x_i; m_{top}, JES) + (1 - f_{top}) P_{bkg}(x_i)]$$

$$P_{sig}(x; m_t, JES) = Acc(x) \times \frac{1}{\sigma} \int d^n\sigma(y; m_t) dq_1 dq_2 f(q_1) f(q_2) W(x, y; JES)$$

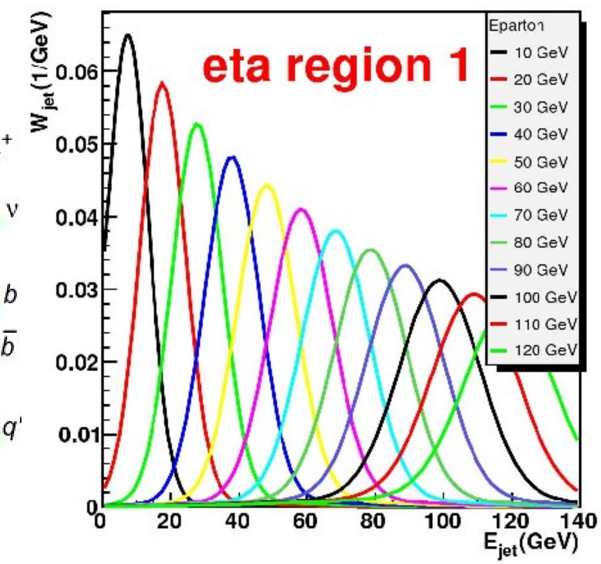
Acceptance: selection efficiency

Integrate over parton momenta

LO Matrix Element

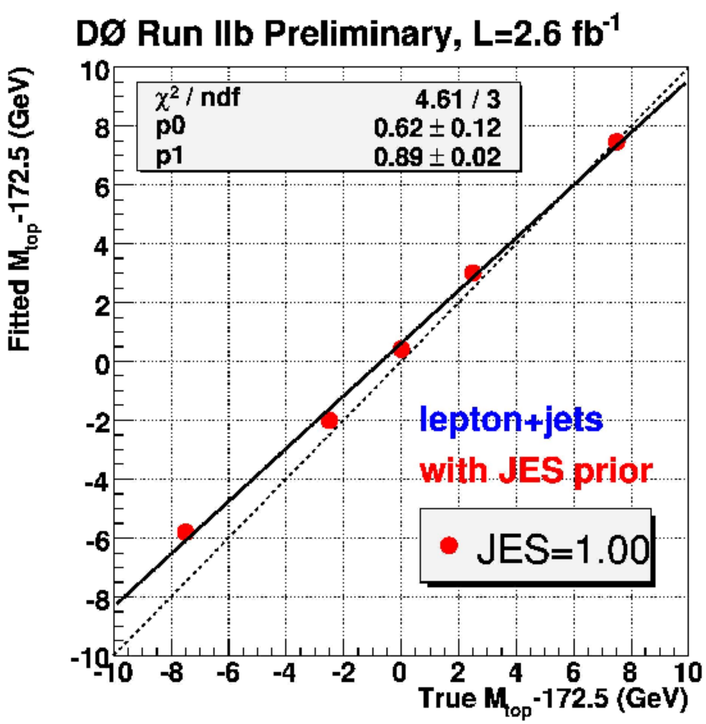


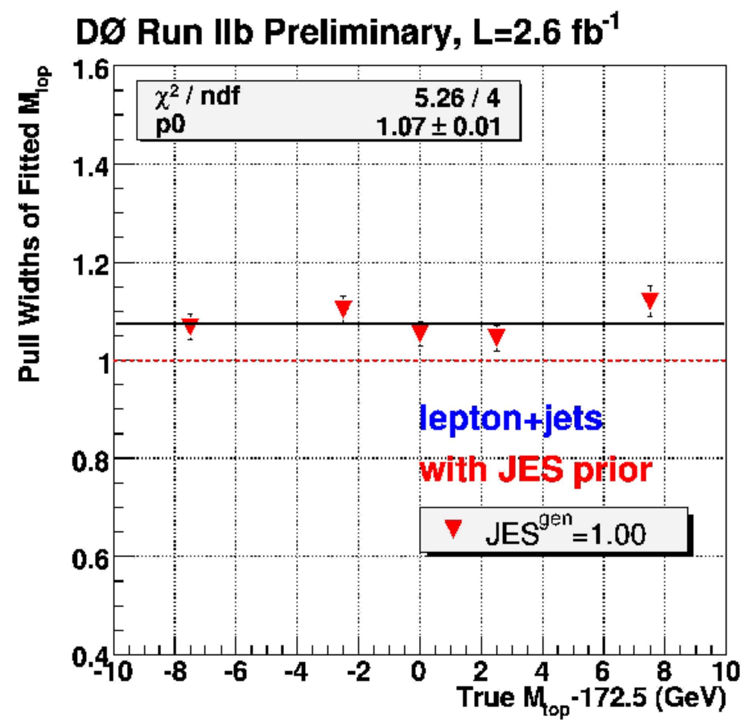
Transfer Function



Performance on Simulated Data
Top Mass

Need to remove bias on measured mass and statistical error





Systematics

Source	Uncertainty on top mass in Run IIb (GeV)	Uncertainty on top mass in Run IIa (GeV)
Higher Order Effects	± 0.25	± 0.25
ISR/FSR	± 0.26	± 0.40
Hadronization and UE	± 0.58	± 0.58
Color Reconnection	± 0.40	± 0.40
Multiple Hadron Interactions	± 0.07	± 0.01
Background Modeling	± 0.03	± 0.04
W HF factor	± 0.07	± 0.09
b-Modeling	± 0.09	± 0.03
PDF Uncertainty	± 0.24	± 0.14
Residual JES Uncertainty	± 0.21	± 0.10
Relative b/Light Response	± 0.81	± 0.83
Sample-Dependent JES	± 0.56	± 0.56
b-Tagging Efficiency	± 0.08	± 0.15
Trigger Efficiency	± 0.01	± 0.19
Lepton Momentum Scale	± 0.17	± 0.17
Jet Identification Efficiency	± 0.26	± 0.26
Jet Energy Resolution	± 0.32	± 0.03
QCD Background	± 0.14	± 0.14
Signal Fraction	± 0.10	± 0.09
Muon Resolution	-	± 0.10
Signal Contamination	-	± 0.13
MC Calibration	± 0.20	± 0.26
Total	± 1.41	± 1.43

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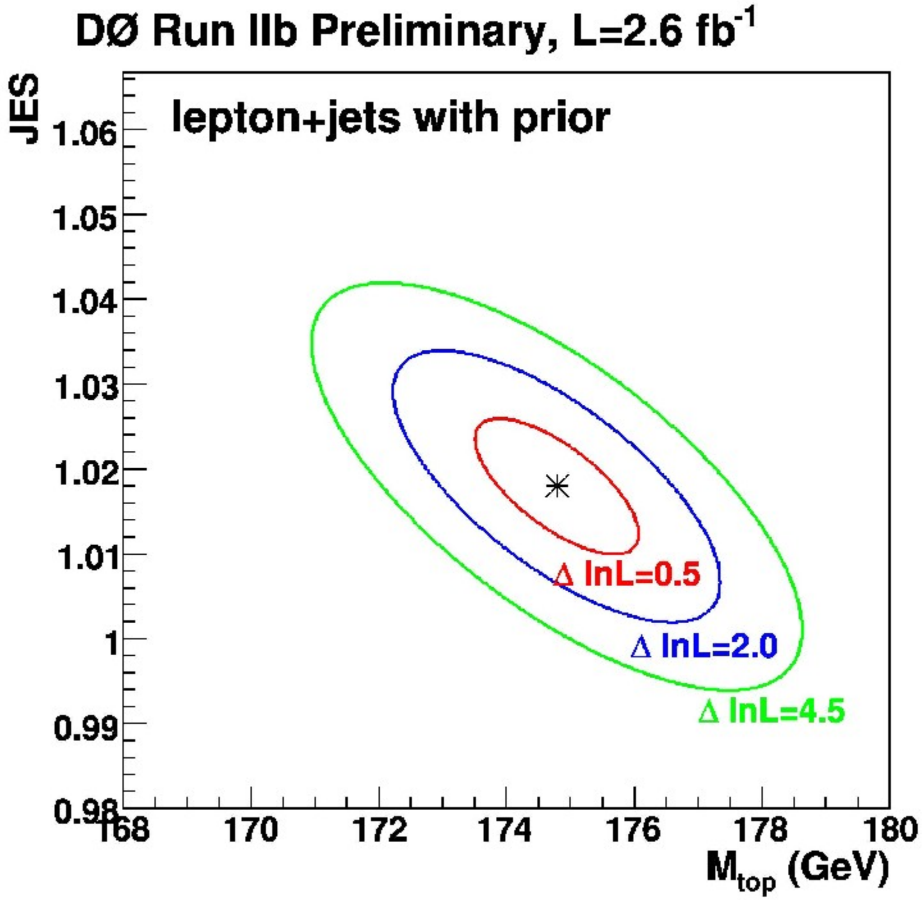
Measurement in Data



PRL 101, 182001 (2008)

RunIIa 1.0 fb^{-1}	$m_t = 171.5 \pm 1.4(stat) \pm 1.8(syst)$ GeV
RunIIb 2.6 fb^{-1}	$m_t = 174.8 \pm 1.0(stat) \pm 1.6(syst)$ GeV
Combined	$m_t = 173.8 \pm 0.8(stat) \pm 1.6(syst)$ GeV

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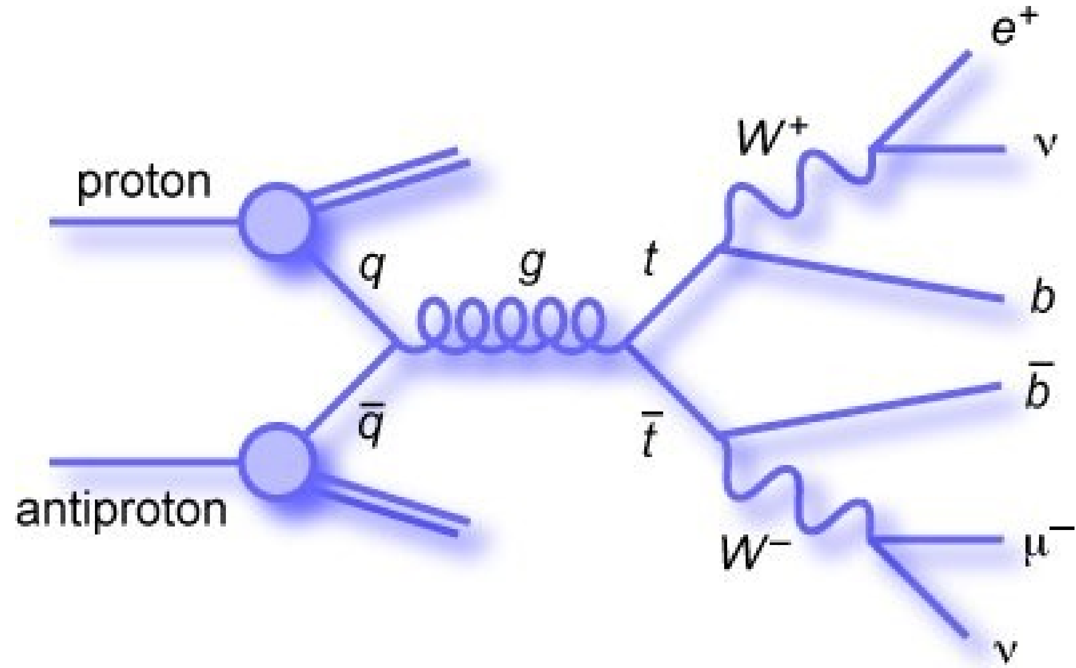
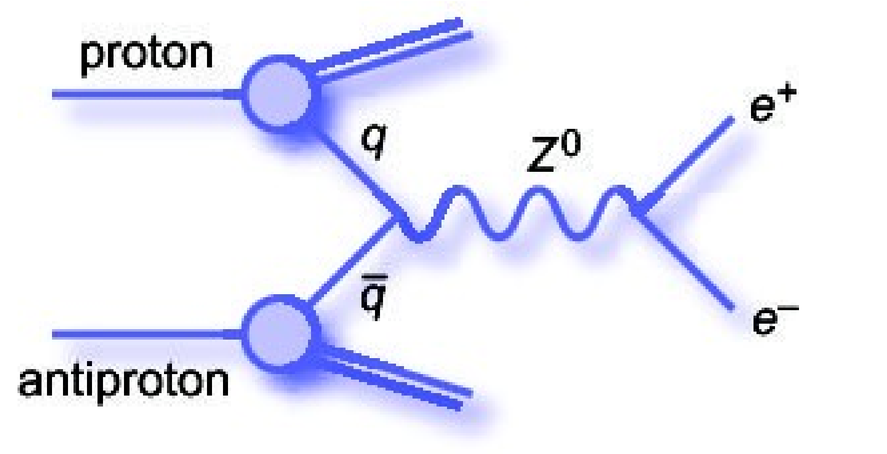
Systematically Limited

Event Selection : ll channel

- Dilepton Channel:
  - 2 leptons
    - ee,eμ,$\mu\mu$,etrk,μtrk
  - large MissingET
  - 2 b-jets
- Backgrounds:
  - Z -> ee/$\mu\mu$/$\tau\tau$+jets
  - WW -> ee/eμ/$\mu\mu$+jets
  - Fake leptons (W+jets, QCD)





Matrix Element Method (eμ)

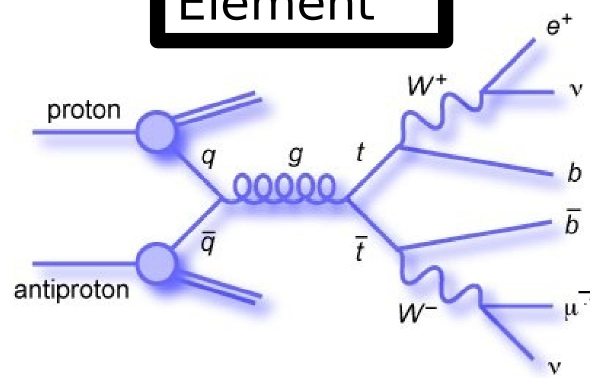
$$\mathcal{L}(m_t, f_t) = \prod_{i=1}^{N_{evt}} [f_t P_{sig}(x_i; m_t) + (1 - f_t) P_{bkg}(x_i)]$$

$$P_{sig}(x; m_t) = Acc(x) \times \frac{1}{\sigma} \int d^n\sigma(y; m_t) dq_1 dq_2 f(q_1) f(q_2) W(x, y)$$

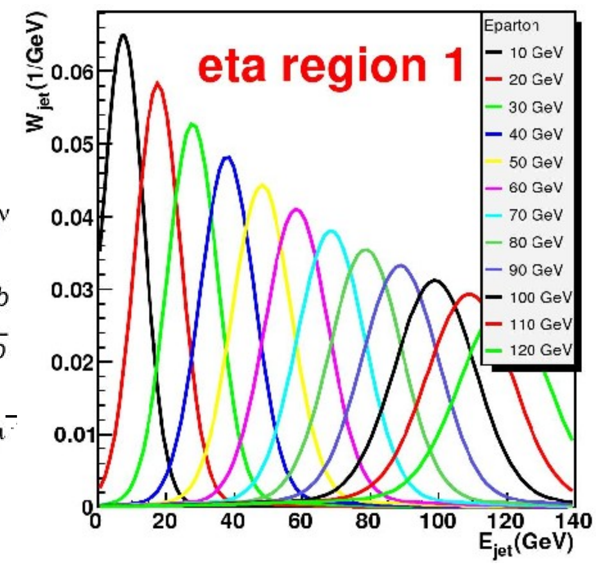
Acceptance: selection efficiency

Integrate over parton momenta

LO Matrix Element

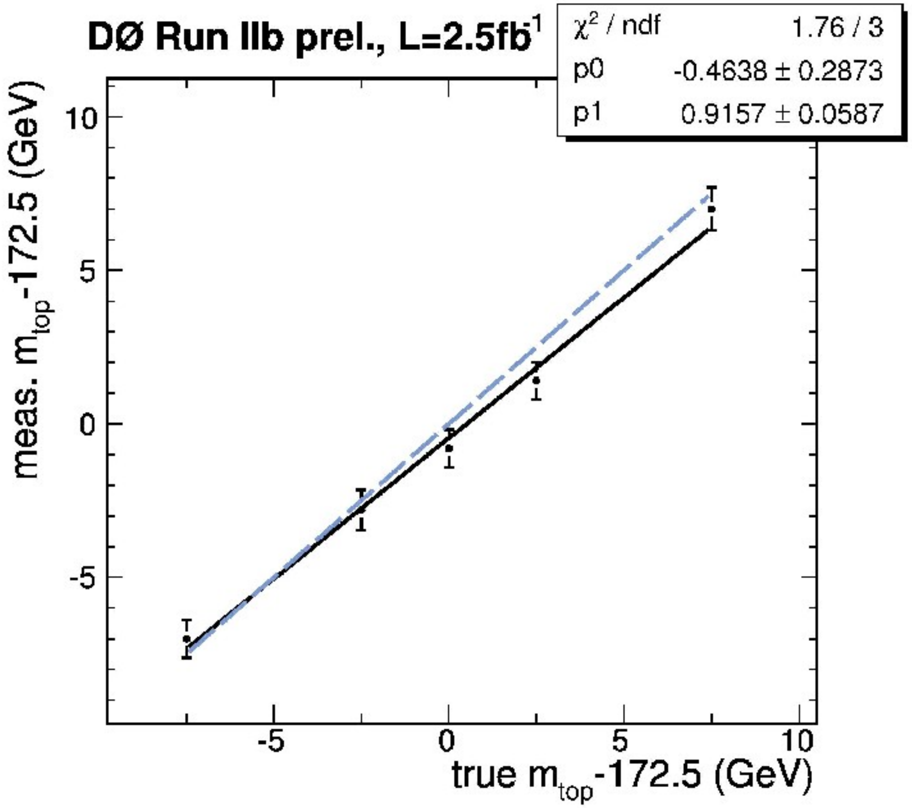


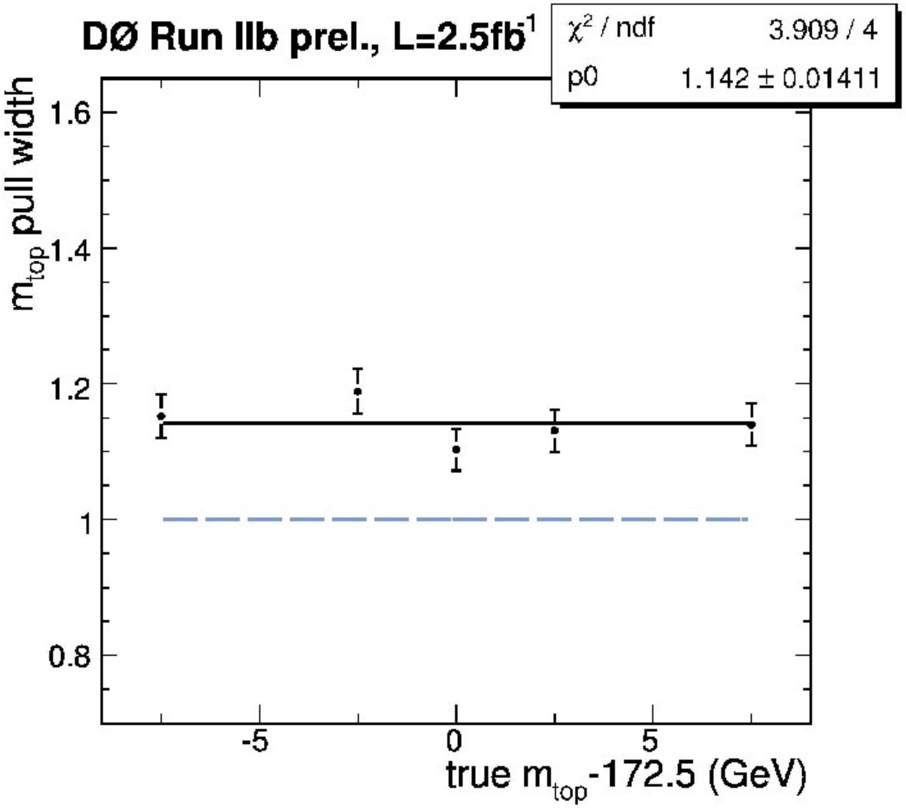
Transfer Function



Performance on Simulated Data

- Need to remove bias on measured mass and statistical error
- Includes events with 2 or more jets

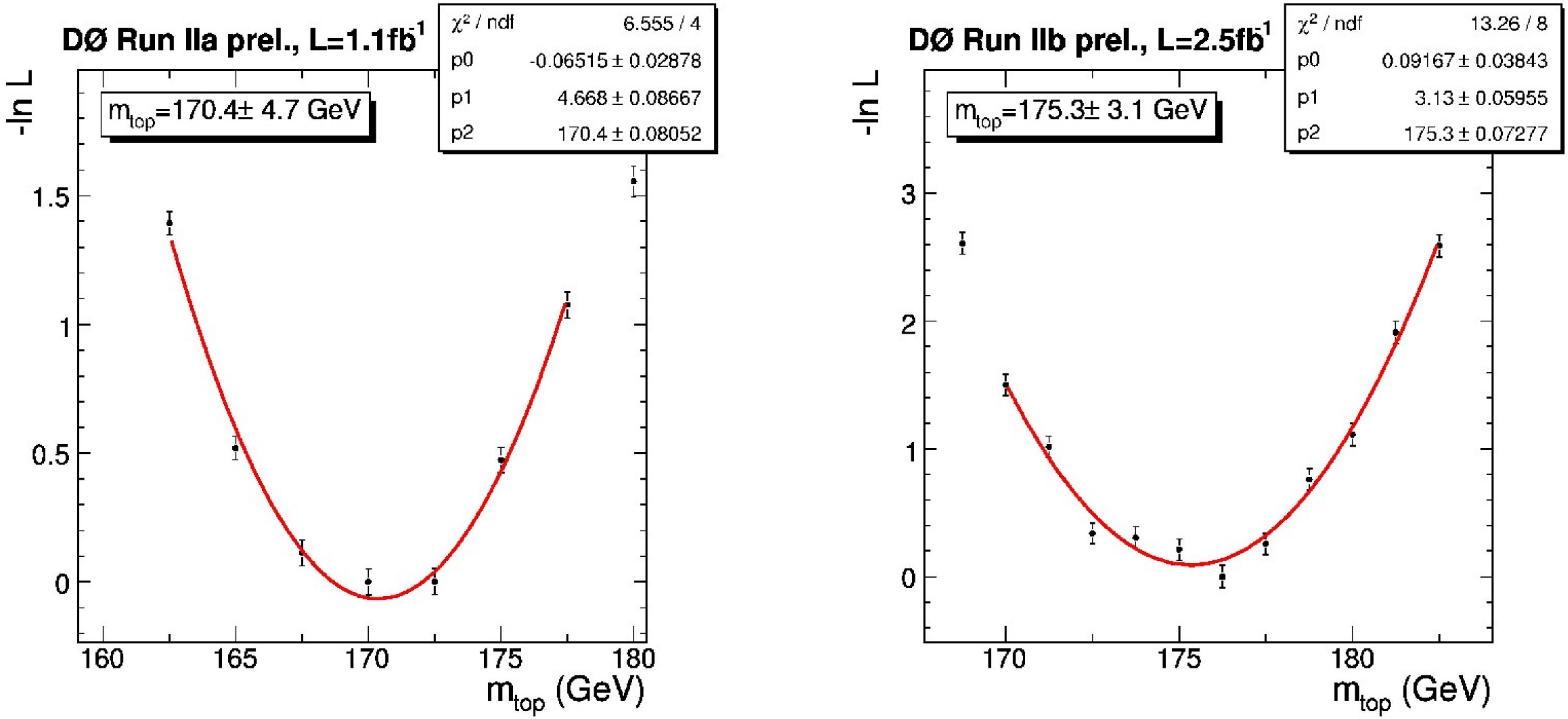




Systematics (eμ)

Uncertainty	$e\mu$ Run IIa [GeV]	$e\mu$ Run IIb [GeV]
JES	$^{+1.2}_{-1.3}$	$^{+1.5}_{-1.6}$
b/light quark response	± 1.4	± 1.6
jet resolution	$^{+0.6}_{-0.6}$	$^{+0.2}_{-0.3}$
sample-dependent JES	± 0.2	± 0.1
muon smearing	$^{+0.3}_{-0.0}$	± 0.3
b quark modeling	± 0.1	± 0.3
PDF uncertainty	$^{+0.3}_{-0.0}$	$^{+0.1}_{-0.2}$
MC calibration	± 0.4	± 0.4
signal fraction	$^{+0.2}_{-0.0}$	± 0.3
QCD background modeling	± 0.6	± 0.6
electron energy scale	± 0.1	± 0.1
muon momentum scale	± 0.2	± 0.2
hadronization and UE	± 1.0	± 1.0
ISR/FSR	± 0.6	± 0.6
Color reconnection	± 0.4	± 0.4
TOTAL	± 2.4	± 2.6

Result on Data ($e\mu$)



RunIIa	$m_t = 171.7 \pm 6.4(stat)$ GeV
RunIIb	$m_t = 176.1 \pm 3.9(stat)$ GeV
Combined	$m_t = 174.8 \pm 3.3(stat) \pm 2.6(syst)$ GeV

Dilepton Mass with Templates

- Kinematic Reconstruction (2 neutrinos)
- Two Methods:
  - Neutrino Weighting
    - Sample neutrino eta's from expected distributions
    - Compare reconstructed MET to real MET:

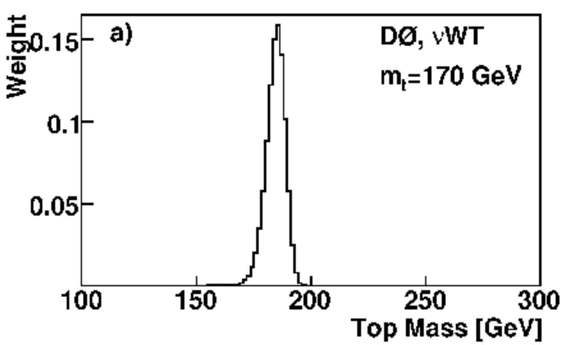
$$w = \exp\left[\frac{-(\not{E}_x^{\mathrm{calc}} - \not{E}_x^{\mathrm{obs}})^2}{2(\sigma_x^{\mathrm{u}})^2}\right] \exp\left[\frac{-(\not{E}_y^{\mathrm{calc}} - \not{E}_y^{\mathrm{obs}})^2}{2(\sigma_y^{\mathrm{u}})^2}\right]$$

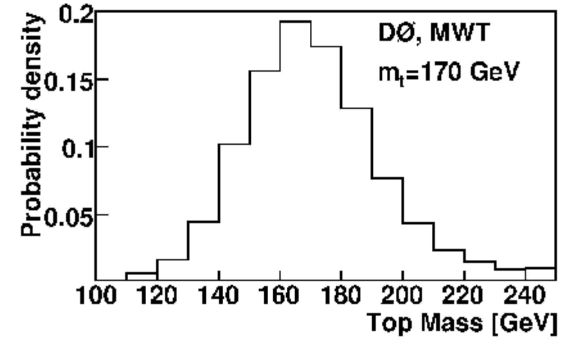
  - Matrix Weighting
    - Use Measured Missing E_T
    - Construct weight: $w = f(x)f(\bar{x})p(E_\ell^*|m_t)p(E_\ell^*|m_t)$

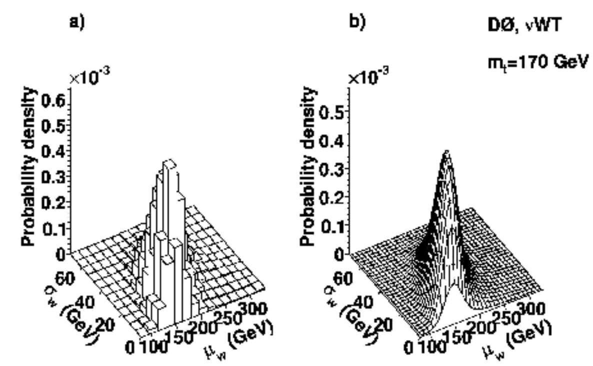
$$p(E_\ell^*|m_t) = \frac{4m_t E_\ell^*(m_t^2 - m_b^2 - 2m_t E_\ell^*)}{(m_t^2 - m_b^2)^2 + M_W^2(m_t^2 - m_b^2) - 2M_W^4}$$

Dilepton Mass with Templates

- Use weight distribution, Form Templates
  - MWT uses mt with maximum weight
  - NuWT uses 2D templates
    - mean and RMS of weight distribution

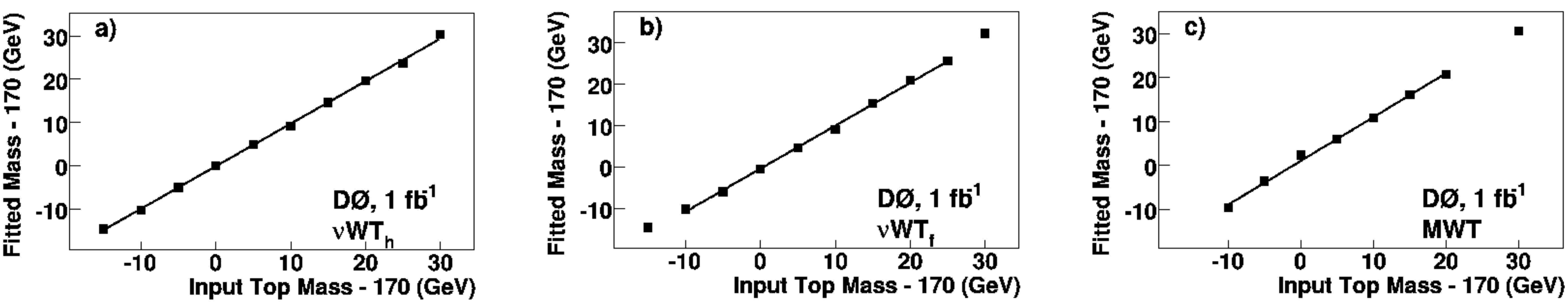






Performance on Simulated Data

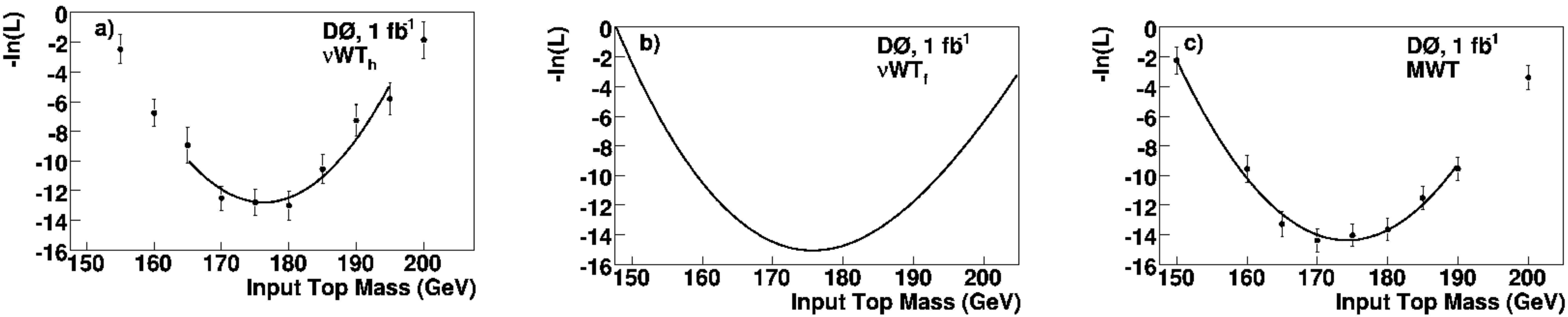
Method	Channel	Slope: α	Offset: β [GeV]	Pull width	Expected statistical uncertainty [GeV]
νWT_h	2ℓ	0.98 ± 0.01	-0.04 ± 0.11	1.02 ± 0.02	5.8
νWT_h	ℓ+track	0.92 ± 0.02	2.28 ± 0.27	1.04 ± 0.02	13.0
νWT_h	combined	0.99 ± 0.01	-0.04 ± 0.11	1.03 ± 0.02	5.1
νWT_f	2ℓ	1.03 ± 0.01	-0.32 ± 0.15	1.06 ± 0.02	5.8
νWT_f	ℓ+track	1.07 ± 0.03	-0.04 ± 0.37	1.07 ± 0.02	12.9
νWT_f	combined	1.04 ± 0.01	-0.45 ± 0.13	1.06 ± 0.02	5.3
MWT	2ℓ	1.00 ± 0.01	0.95 ± 0.05	0.98 ± 0.01	6.3
MWT	ℓ+track	0.99 ± 0.01	0.64 ± 0.12	1.06 ± 0.01	13.8
MWT	combined	0.99 ± 0.01	0.97 ± 0.05	0.99 ± 0.01	5.8



Systematics

Source of uncertainty	νWT_h [GeV]	νWT_f [GeV]	MWT [GeV]
b fragmentation	0.4	0.5	0.4
Underlying event modeling	0.3	0.1	0.5
Extra jets modeling	0.1	0.1	0.3
Event generator	0.6	0.8	0.5
PDF variation	0.2	0.3	0.5
Background template shape	0.4	0.3	0.3
Jet energy scale (JES)	1.5	1.6	1.2
b/light response ratio	0.3	0.4	0.6
Sample dependent JES	0.4	0.4	0.1
Jet energy resolution	0.1	0.1	0.2
Muon/track p_T resolution	0.1	0.1	0.2
Electron energy resolution	0.1	0.2	0.2
Jet identification	0.4	0.5	0.5
MC corrections	0.2	0.3	0.2
Background yield	0.0	0.1	0.1
Template statistics	0.8	1.0	0.8
MC calibration	0.1	0.1	0.1
Total systematic uncertainty	2.1	2.3	2.0

Result in Data



$$\nu\text{WT} \qquad m_t = 176.2 \pm 4.8(stat) \pm 2.1(syst)\ \text{GeV}$$

$$\text{MWT} \qquad m_t = 173.2 \pm 4.9(stat) \pm 2.0(syst)\ \text{GeV}$$

$$\text{Combined} \qquad m_t = 174.7 \pm 4.4(stat) \pm 2.0(syst)\ \text{GeV}$$

arXiv:0904.3195 Submitted to PRD

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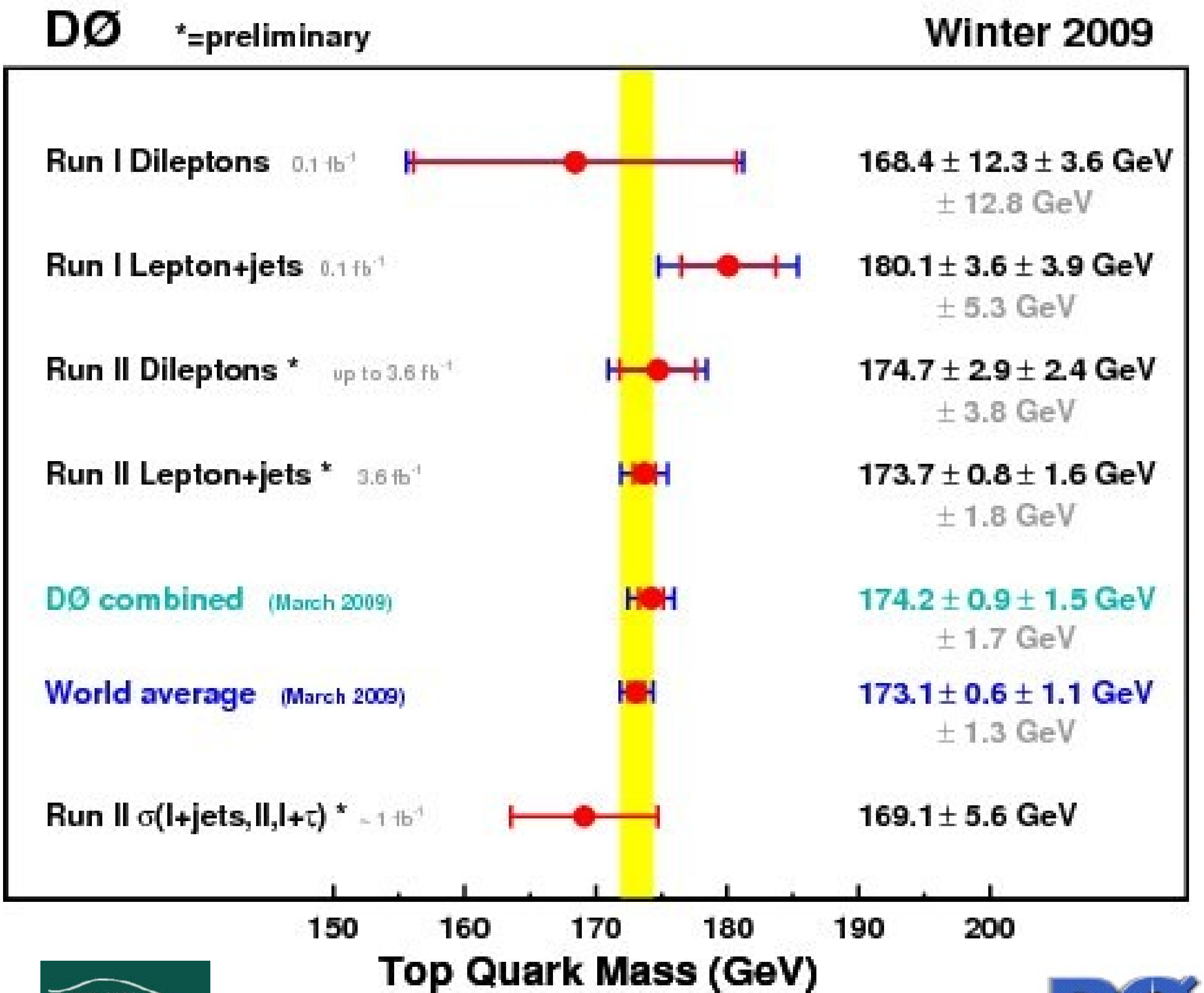
Combination D0 Mass Results



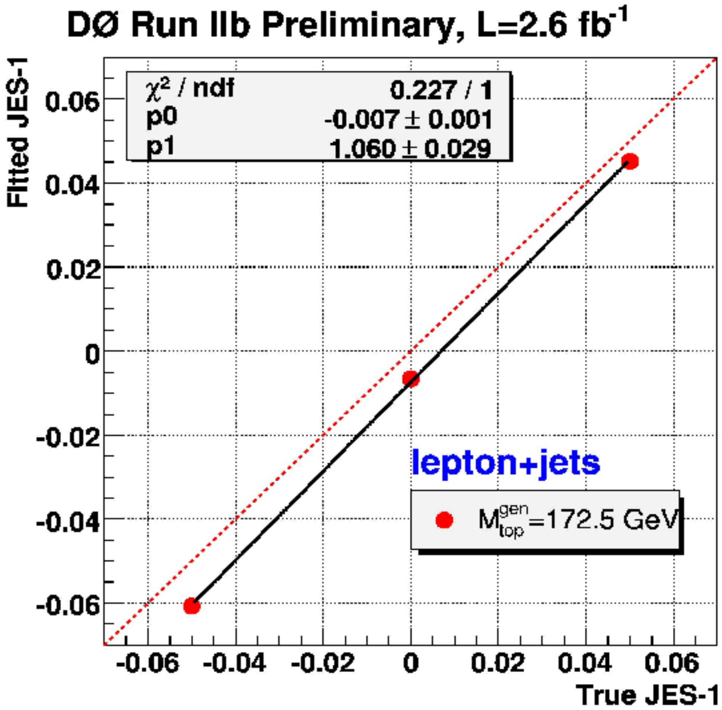
Conclusion

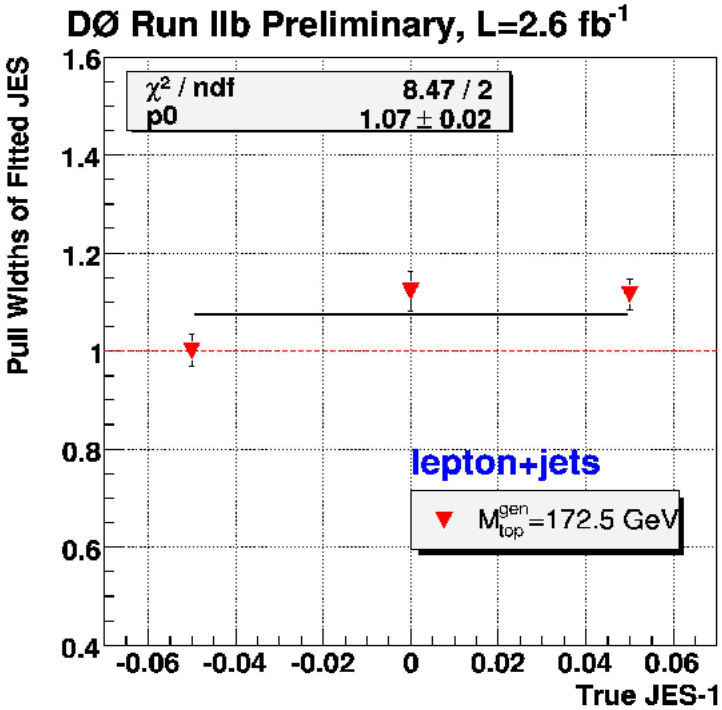
- Lepton+jets:
  - First Measurement of Top Anti-top Mass Difference
    - First time quark and anti-quark mass compared
  - High precision measurement of l+jets
    - measurement systematically limited
- Dilepton Channels
  - Matrix Element, Template based
    - measurement statistically limited
    - important consistency check

Backup

Performance on Simulated Data
Jet Energy Scale

M_W Constraint -> In-situ Jet Energy Calibration





Top Mass Difference

Transform to convenient variables:

$$(m_t, m_{\bar{t}}) \rightarrow (\Delta m_t = (m_t - m_{\bar{t}}), m_{sum} = (m_t + m_{\bar{t}})/2)$$

Integrate out M_{sum}:

$$\mathcal{L}(\Delta m_t) = \int dm_{sum} \mathcal{L}(\Delta m_t, m_{sum})$$