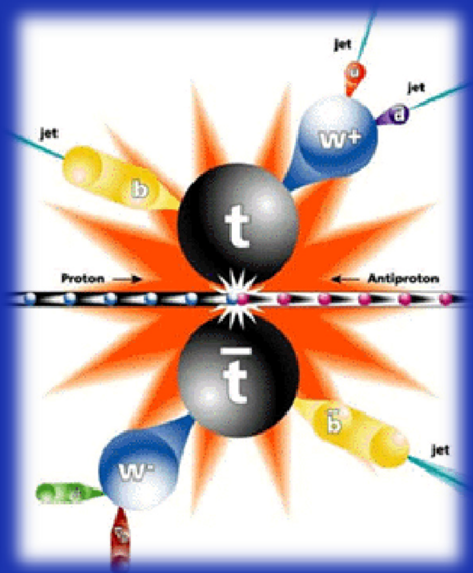
Measurement of the Top Quark Mass at DØ using lepton + jets events using the Matrix Element Method



1. Top quark physics and mass
2. Matrix Element analysis
3. Conclusion and outlook

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for the DØ Experiment

2008 Phenomenology Symposium: LHC Turn On
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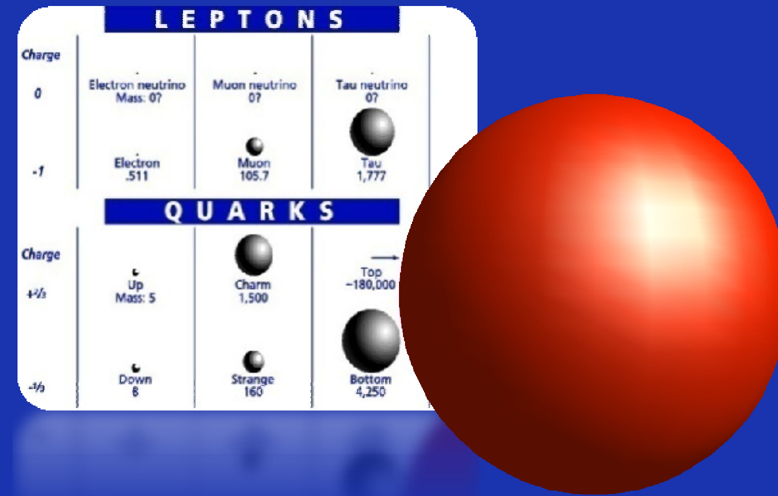
Top Quark CV



- **Discovered in 1995 by DØ and CDF after a 2 decades hunt and only produced at the Tevatron so far**

- **Heaviest fundamental particle (m_t = 172.6 ± 1.4 GeV)**

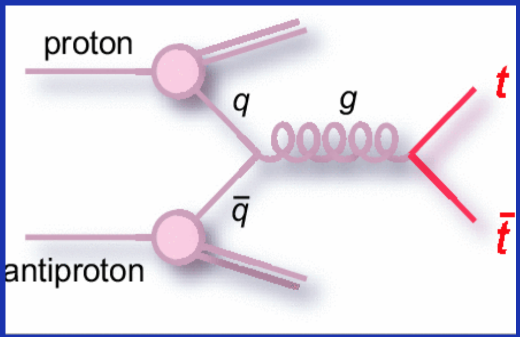
- **Strongest coupling to the Higgs (Yukawa coupling $\lambda_t \propto m_t \sim 1$)**
  - may help identify the EWSB mechanism and mass generation
  - may serve as a window to new physics related to EWSB that might couple preferentially to top

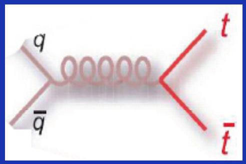
- **A unique laboratory: lifetime (5×10^{-25} s) shorter than the hadronization time makes it decay as a free quark**

- **We still have a lot to learn about this particle**
  - Indirect constraints from low energy data and statistically limited Tevatron data leave plenty of room for new physics
  - Even if the top is “just a normal quark”, precision top measurements are stringent tests of the SM

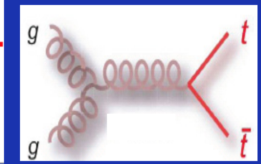
Top Quark Pair Production and Decay

- Top quarks are mainly produced in pairs (strong interactions) @ 2 TeV





85%

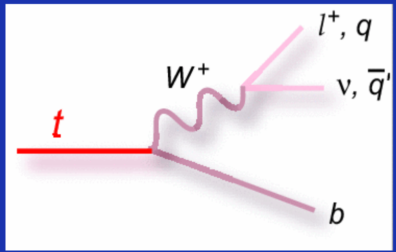


15%

$\sigma_{inel} / \sigma_{ttbar} \sim 10^{10}$

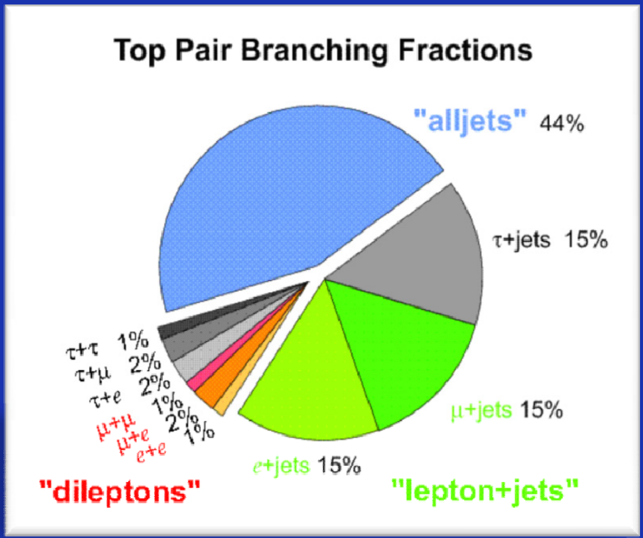
- High luminosity
- High efficiency

- No hadronic bound state due to short lifetime
- Electroweak decay



$|V_{tb}| \sim 1$

- Final state determined by the decay of the W boson



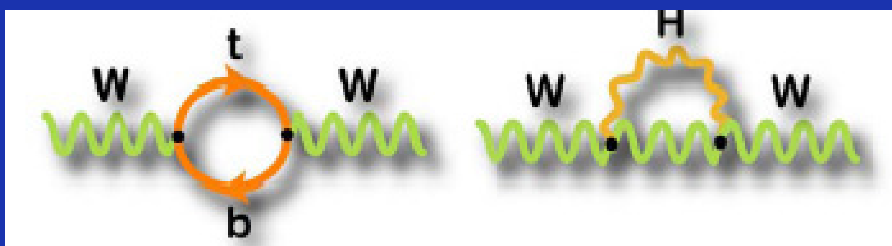
- dilepton channel: small background but low rate
- lepton + jets channel (moderate bkg and a Branching fraction of 1/3)
- all hadronic channel (largest BF but huge bkg)

Lepton≡ e, μ from W or from τ from W

The top quark mass

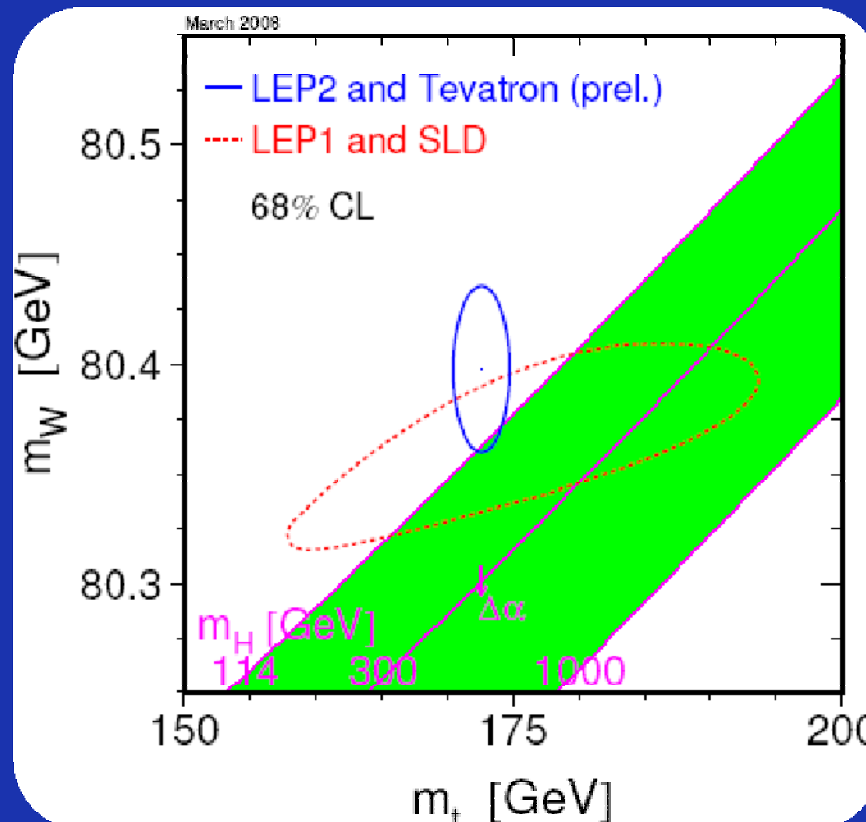
Fundamental parameter of the Standard Model

- **Affects predictions of SM via radiative corrections**



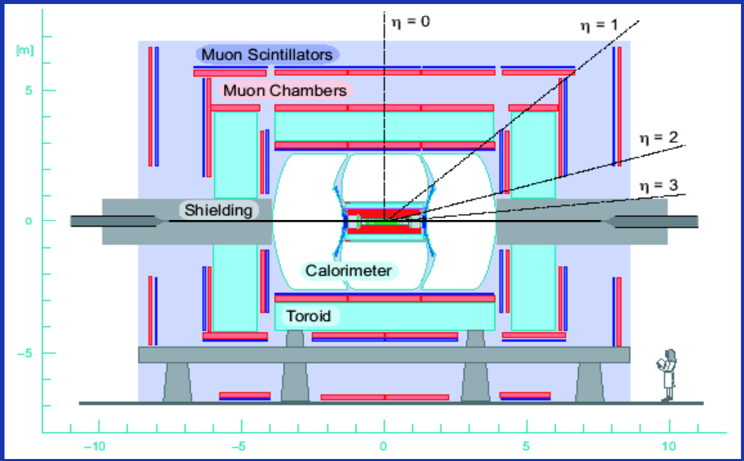
m_t can be related, with M_W, to the Higgs mass

$\delta m_W \propto m_t^2, ln(m_H)$



Probing the EWSB mechanism

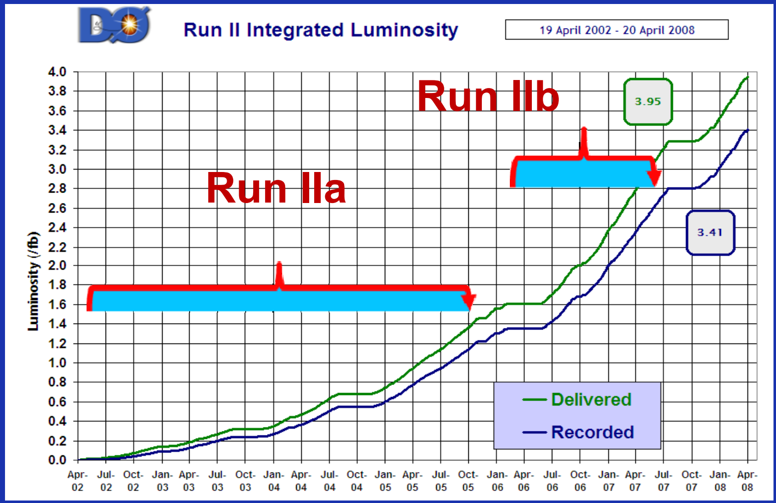
Challenges of this measurement



- Top quark physics exercises the understanding of all detector components
- It is a rare process with significant backgrounds
- Jets and MET are observed in the detector, not quarks or neutrinos

μ, e, jets (light/b), MET, PV, tracks

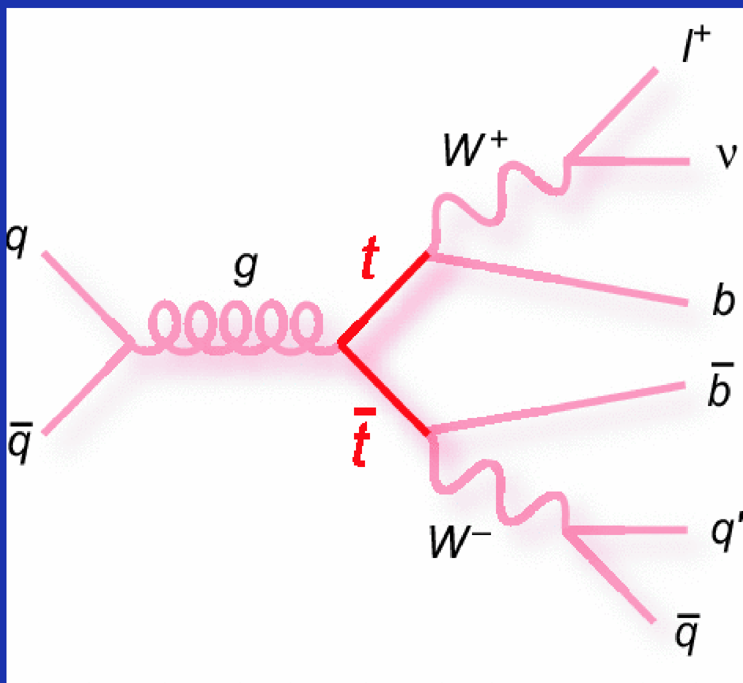
With increased statistics the focus is now on systematics



- In situ calibration of the Jet Energy Scale using W mass in top decays
- b-jets identification (b-tagging) can be used to reduce physics backgrounds
- Many systematic uncertainties expected to decrease with larger data samples

The Lepton + Jets Channel

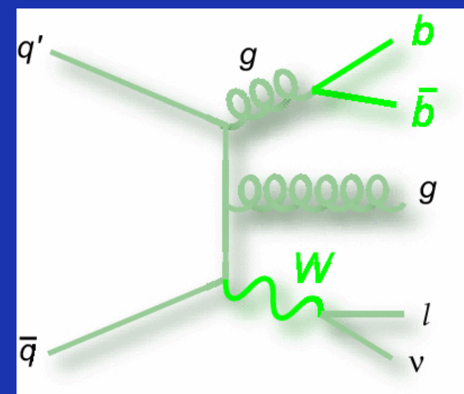
signal



- 1 isolated high p_T lepton (μ, e)
- 1 ν (reconstructed as missing transverse energy (MET))
- = 4 high p_T central jets

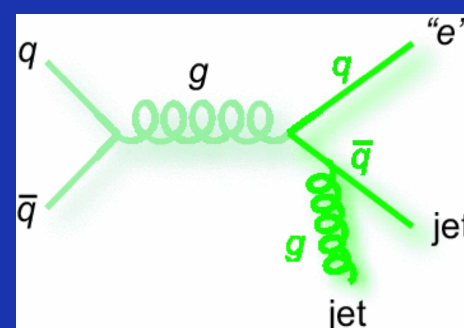
Background

W (→ *l* ν) + 4 jets



QCD Multijet

- fake isolated lepton
- misreconstructed MET

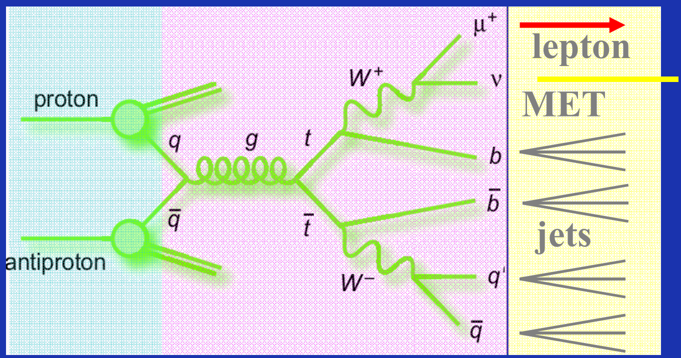


The Matrix Element method - I

Dynamical method pioneered by DØ yielding the most precise results

Maximal use of information in each event by calculating event-by-event probabilities to be signal or background based on the respective matrix elements.

Based on all the parton level information *"y"* the probability to be signal or background would be just proportional to the differential cross section, but…



Differential Cross Section based on LO Matrix Element

Transfer function: probability to measure *x* when parton-level *y* is produced

$$P(x; m_{top}, JES) = \frac{1}{\sigma(m_{top})} \int dq_1 \, dq_2 \, f(q_1) \, f(q_2) \, d^n\sigma(y; m_{top}) \, Prob(x, y, JES)$$

normalization

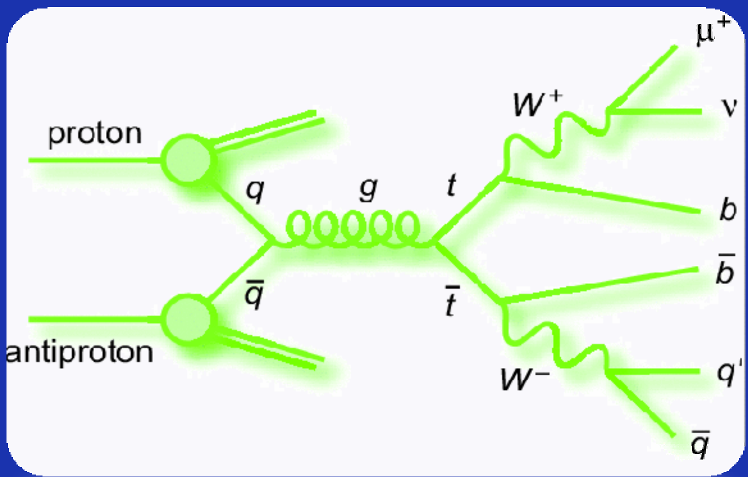
Initial state

Overall JES constrained in situ by $M_W^{hadronic}$

Measurements *x*: jets, MET and leptons

The Matrix Element method - II

Each jet-to-parton assignment is weighted with b-tagging event probabilities



Six particle final state

(24 possible weighted assignments between jets and partons)

$$P^{N_{tag}}(x; m_{top}, JES) = \sum_{j=1}^{24} W_j P_j(x; m_{top}, JES)$$

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

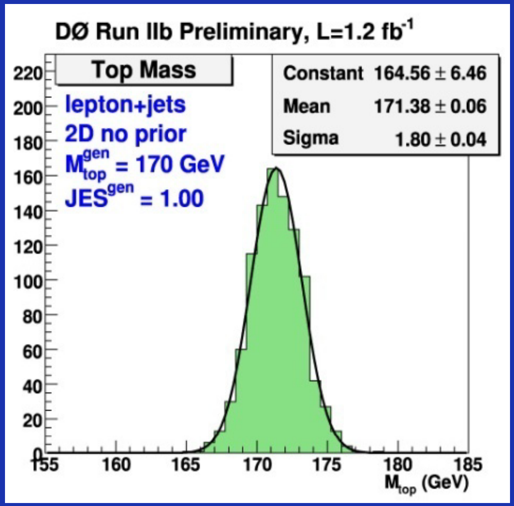
All events are combined in a likelihood…

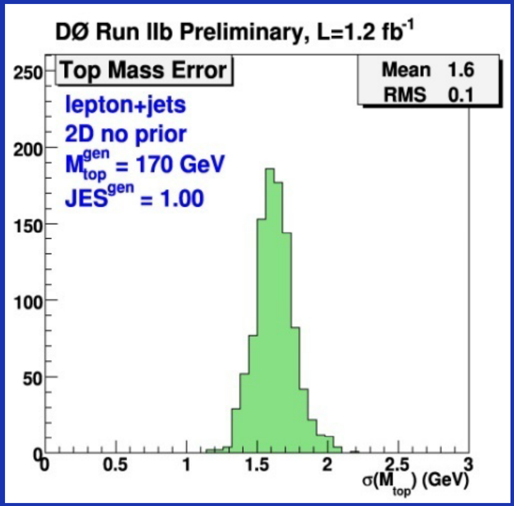
$$-\ln L(x_1, \ldots, x_n; m_{top}, JES) = -\sum_{i=1}^{n} \ln P_{evt}(x; m_{top}, JES)$$

…which is maximized as a function of m_{top} and JES

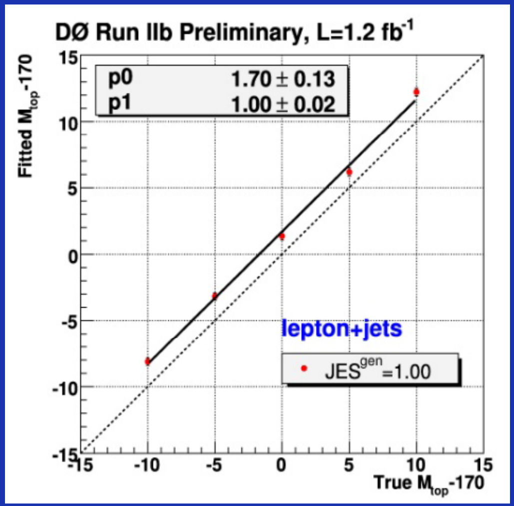
The Matrix Element method - III

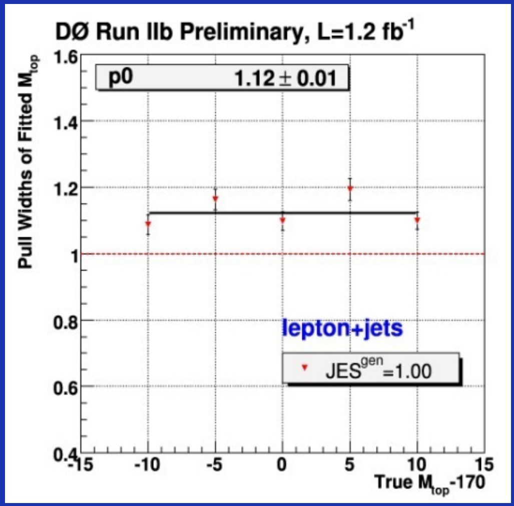
The method is calibrated for shifts in mean and uncertainties using ensemble testing in simulated MC events at different top masses and JES



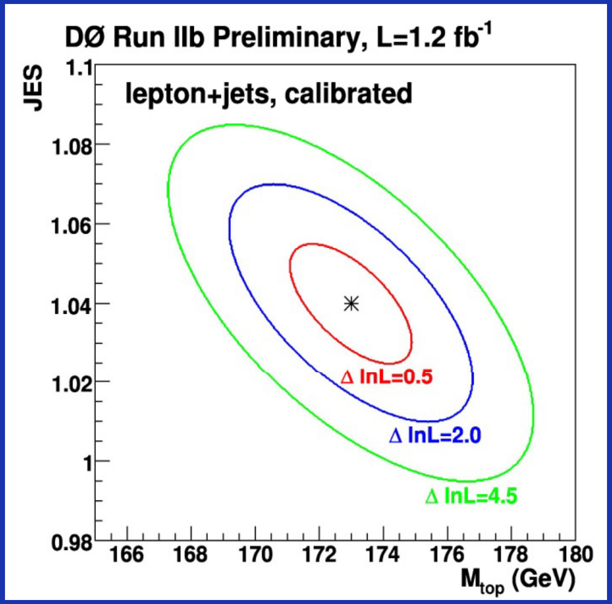


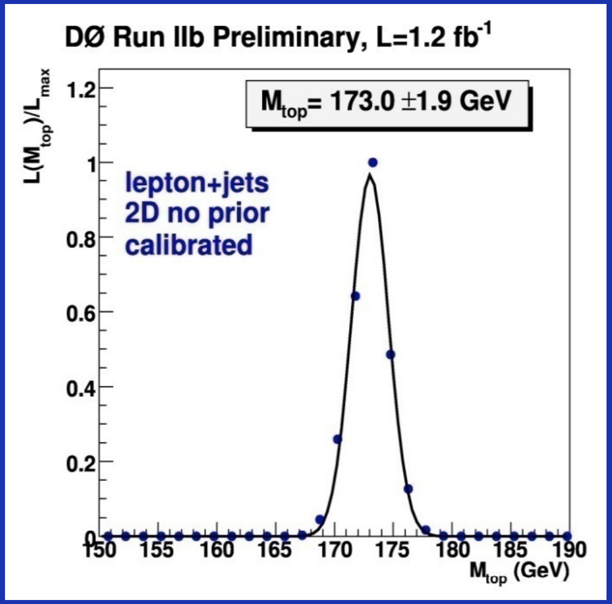
From these, functions are determined to calibrate the data

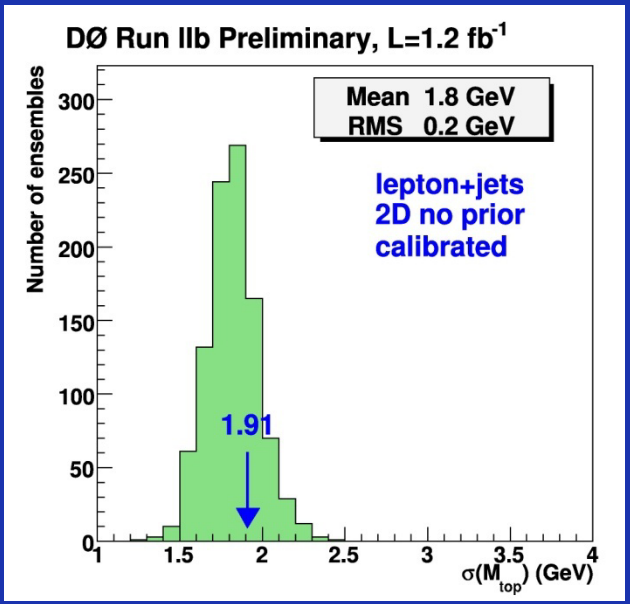




Result





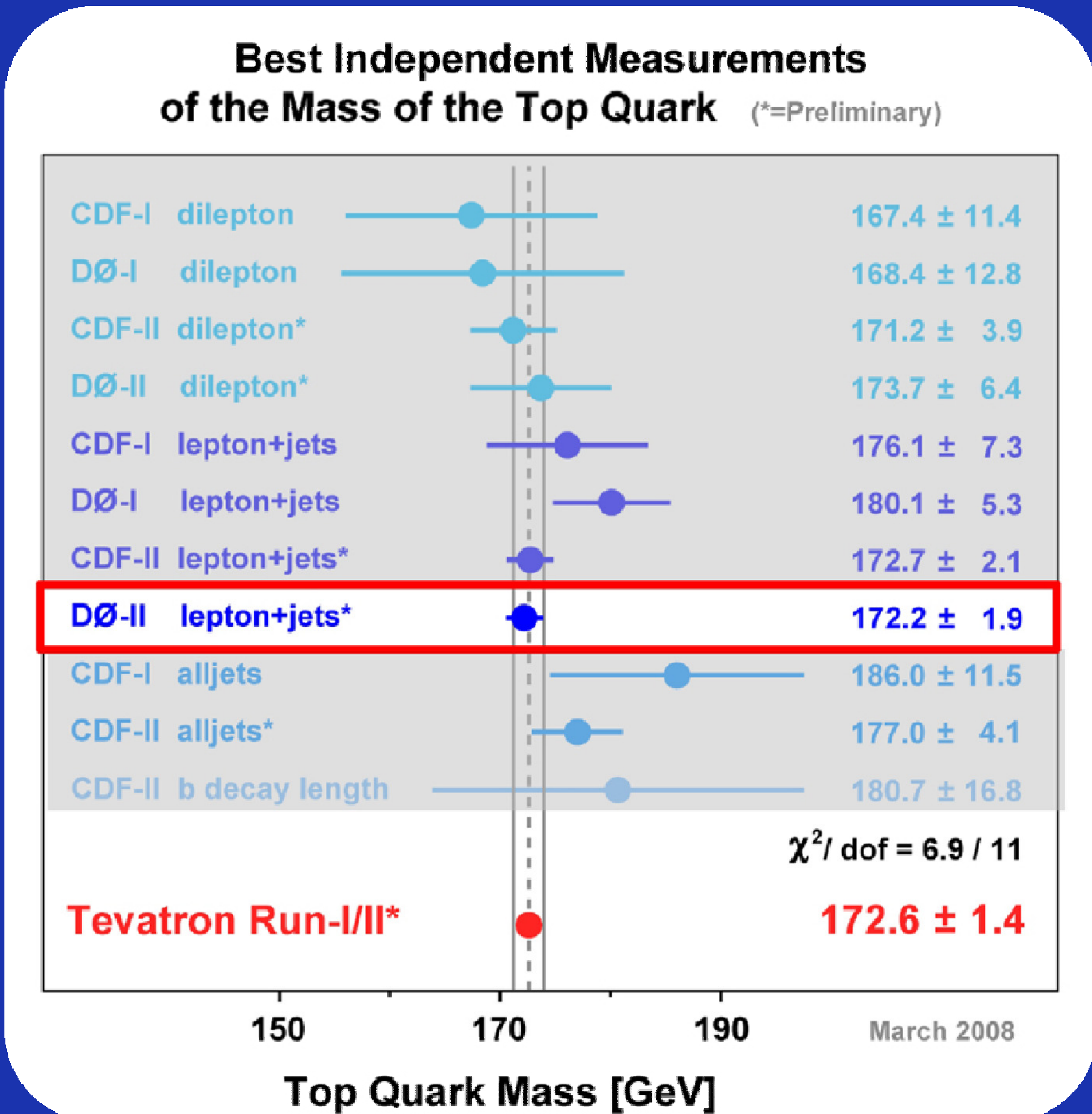


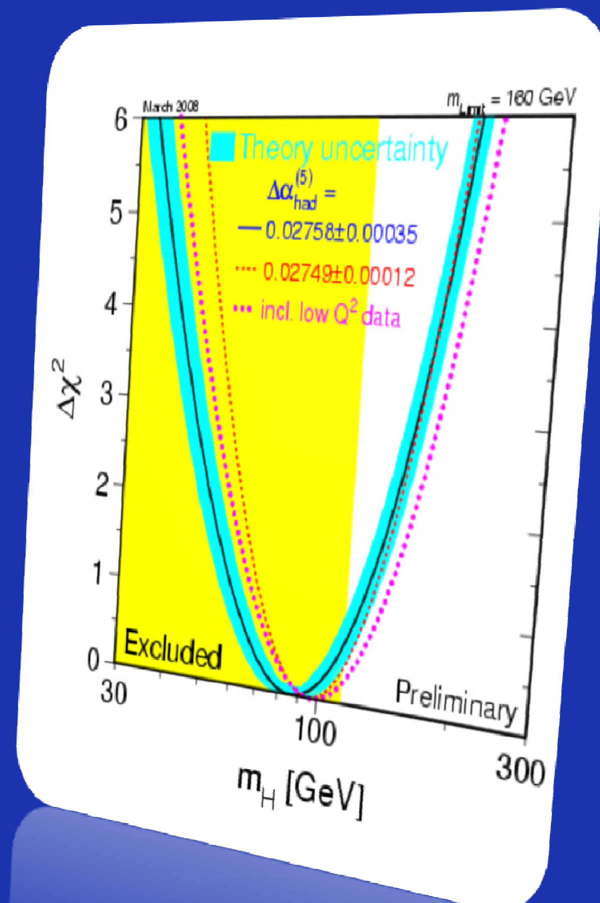
Using 0.9 fb^{-1} of RunIIa data: M_{top} = 170.5 ± 2.5 (stat+JES) ± 1.4 (syst) GeV

Using 1.2 fb^{-1} of RunIIb data: M_{top} = 173.0 ± 1.9 (stat+JES) ± 1.0 (syst) GeV

Combined RunII: M_{top} = 172.2 ± 1.1 (stat) ± 1.6 (syst) GeV

Summary: it is heavy!



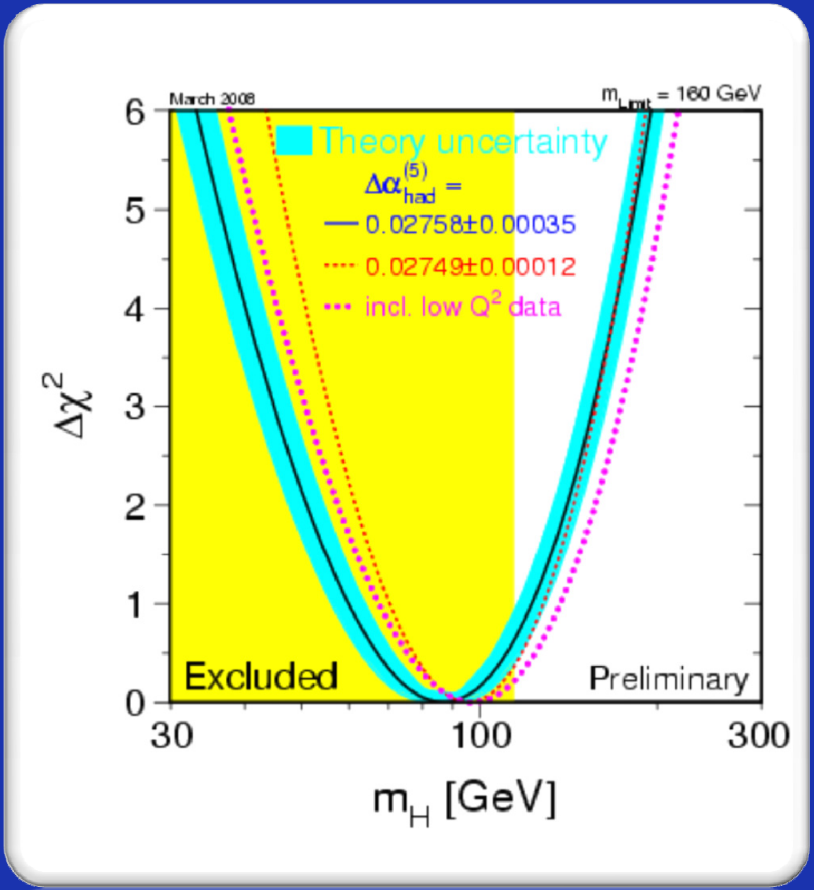


Back up slides

Outlook

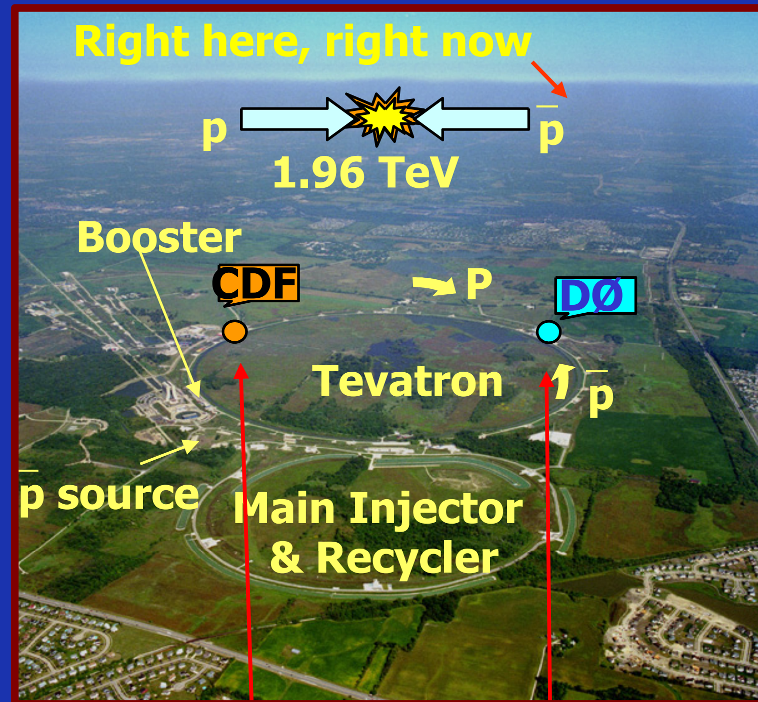
- Improved measurements allows us to reach a 1.1% precision at DØ
  - aim at < 1% with 8 fb^{-1}

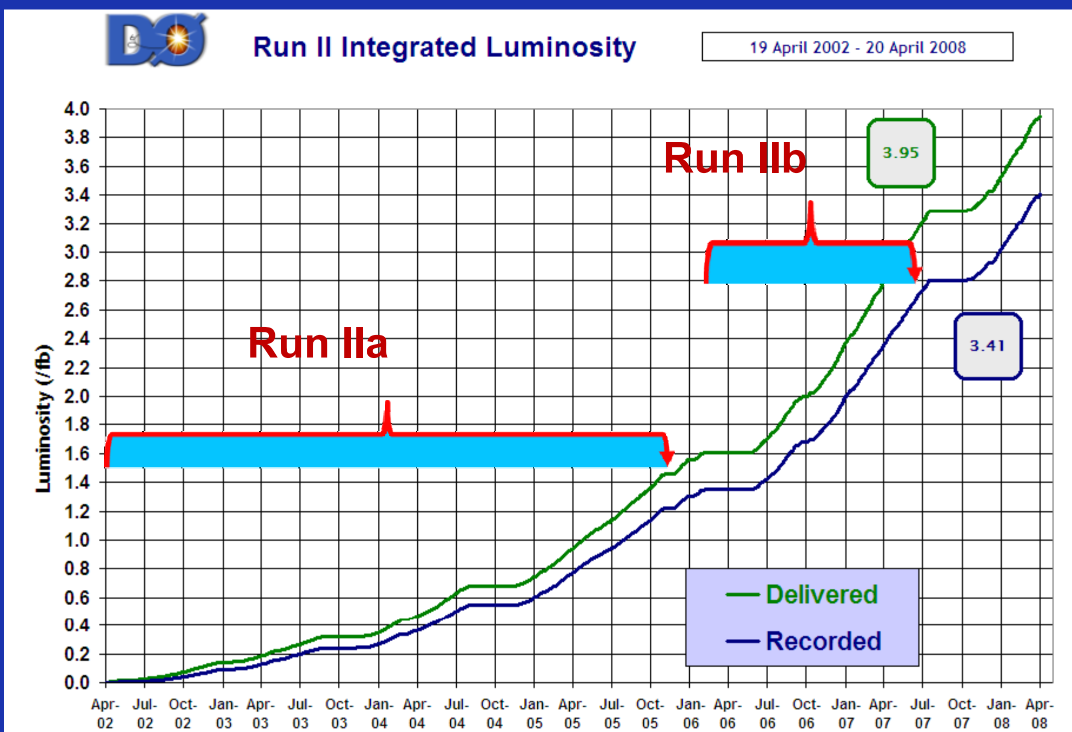
- The precise measurement of the top mass helps constrain the mass of the SM Higgs and it is one of the most important measurements at the Tevatron

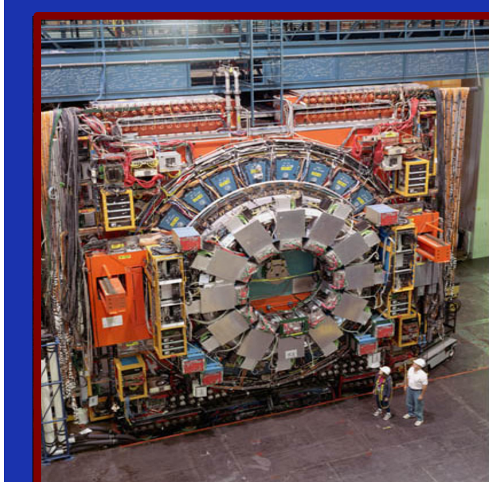


The Tevatron Collider

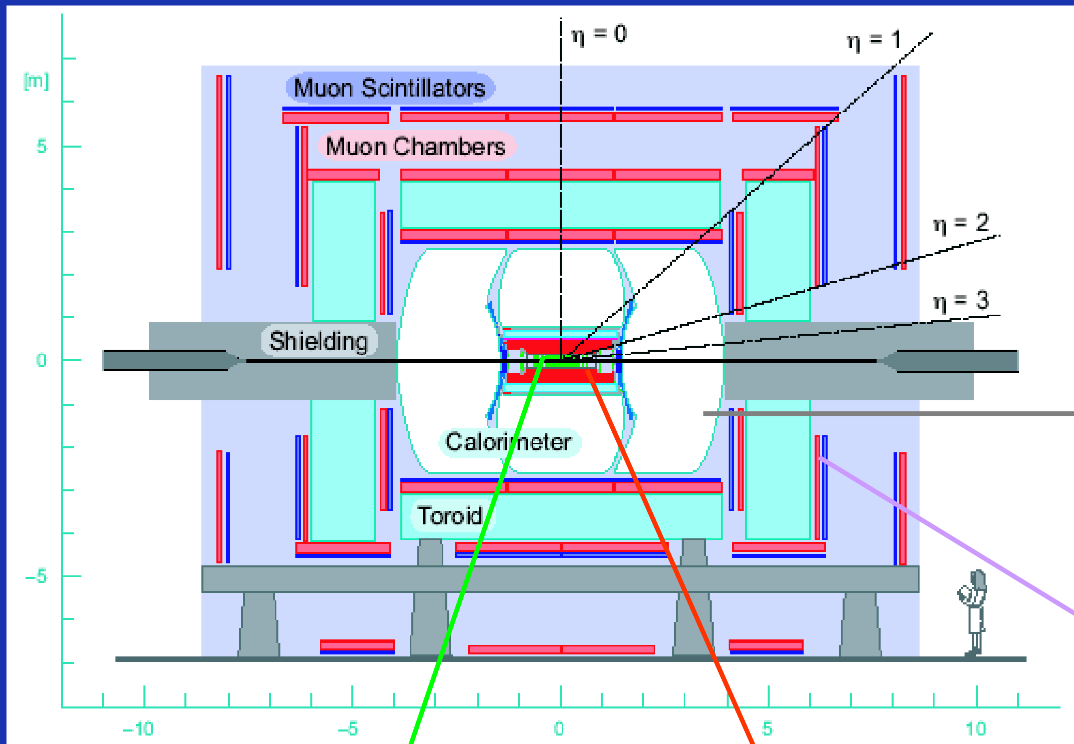
- Proton-antiproton collider with √s=1.96 TeV
- 36x36 bunches with 396ns between crossings
- 3 ~ collisions per bunch crossing
- $L_{inst} > 1\times10^{32} cm^{-2}s^{-1}$
- Expected 4-8 fb^{-1} integrated luminosity for RunII (0.11fb^{-1} in RunI)

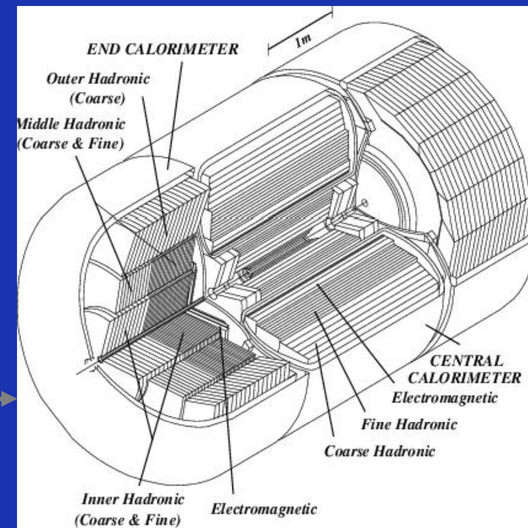


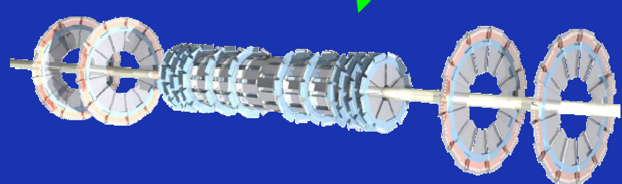


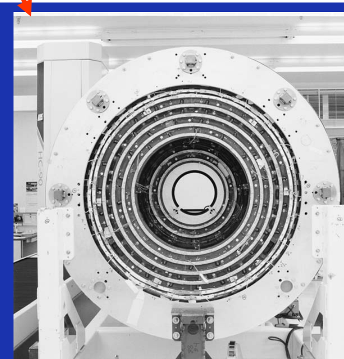


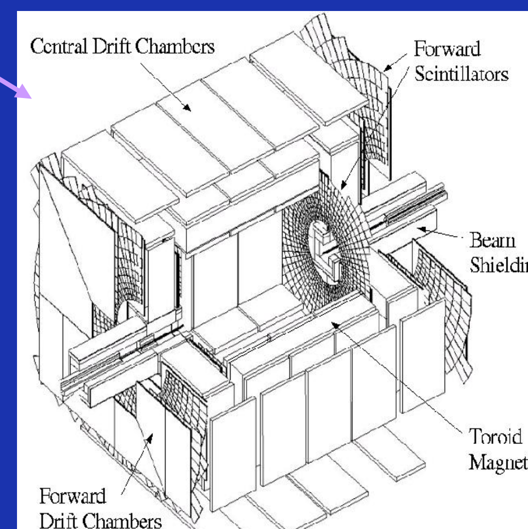
DØ Detector











+ three tiered trigger system (Event rate reduction from 1.7 MHz to 50 Hz, ≈200 kB/event**)**

Signal Fractions

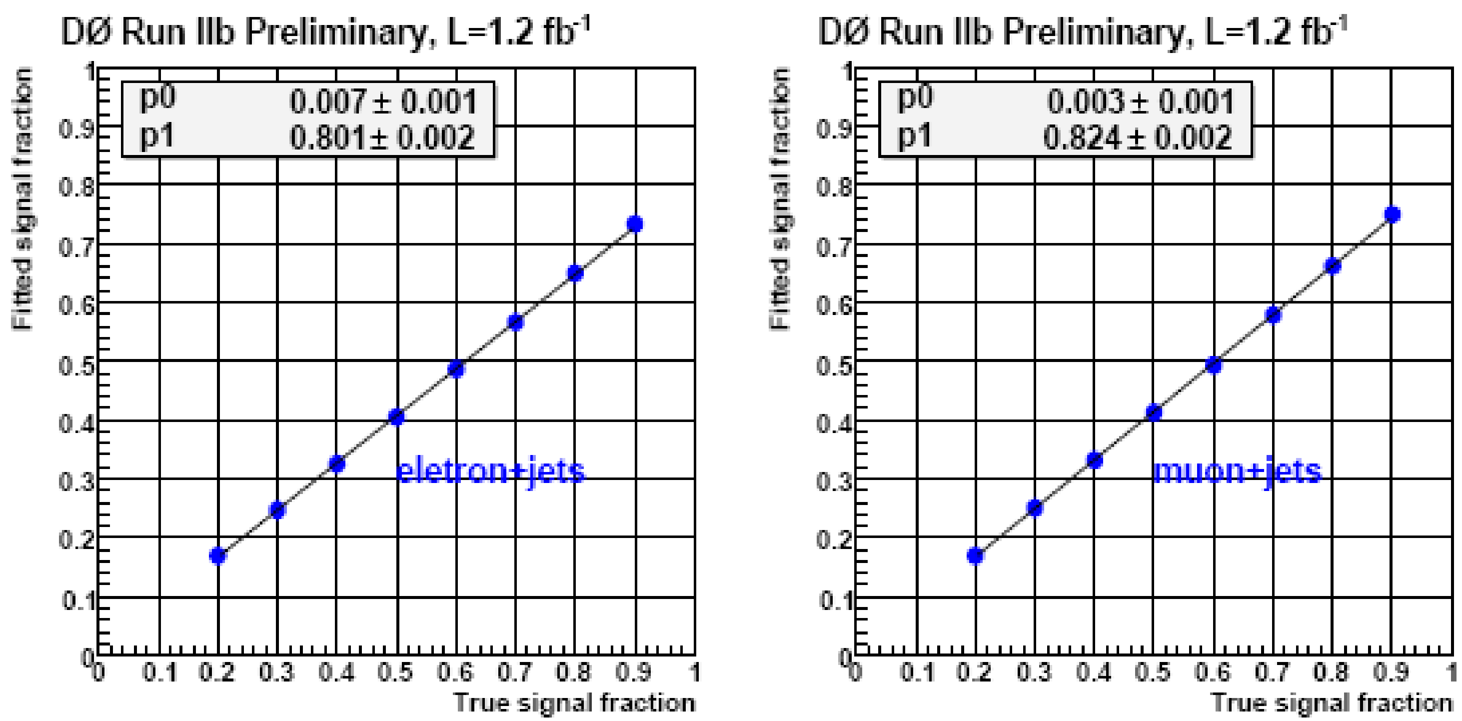


Figure 1: Fitted signal fraction as a function of true signal fraction for e+jets (left) and μ+jets (right) channels.

Systematic Uncertainties

RunIIa

Source	$\sigma(m_T)$ [GeV/c^2]
Signal modeling	± 0.98
Relative b / light JES	± 0.71
Background modeling	± 0.47
PDF uncertainty	+ 0.26 – 0.40
Multijet background	± 0.16
Signal fraction	± 0.15
b fragmentation	± 0.14
Residual JES uncertainty	± 0.14
Trigger efficiency	± 0.08
b / c semileptonic decays	+ 0.06 – 0.07
MC calibration	± 0.06
TOTAL	± 1.40

RunIIb

Source	$\sigma(m_T)$ [GeV/c^2]
Relative b / light JES	± 0.82
Signal modeling	± 0.40
Jet energy resolution	± 0.30
PDF uncertainty	± 0.24
Multijet background	± 0.20
b-tagging efficiency	± 0.16
MC calibration	± 0.14
b-fragmentation	± 0.10
Trigger efficiency	± 0.09
Background modeling	± 0.08
W heavy flavor factor	± 0.07
Residual JES uncertainty	± 0.03
TOTAL	± 1.00

RunIIa Result

Using 0.9 fb^{-1} of RunIIa data:

M_{top} = 170.5 ± 2.5 (stat+JES) ± 1.4 (syst) GeV