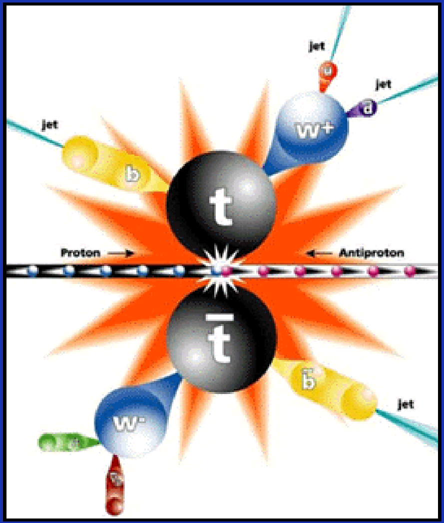
Measurement of the top quark mass at DØ using lepton + jets events



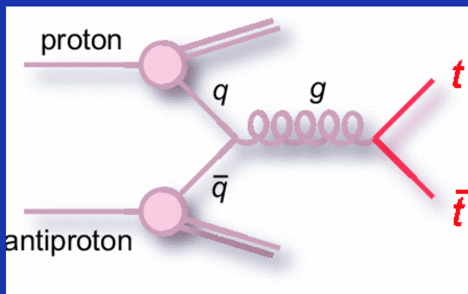
1. Introduction
2. Top quark physics and mass
3. Mass measurement techniques
4. Matrix Element analysis
5. Ideogram method
6. Conclusion and outlook

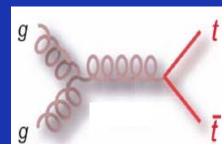
Gustavo Otero y Garzón, University of Illinois at Chicago
for the DØ experiment

2007 Phenomenology Symposium: Prelude to LHC
May 7 – 9, 2007, Madison, Wisconsin

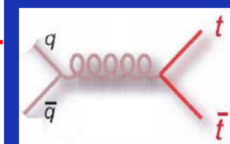
Top Quark Pair Production and Decay

- Top quarks are mainly produced in pairs (strong interactions) at Tevatron energies





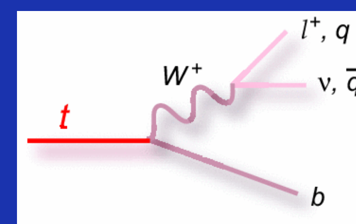
15%



85%

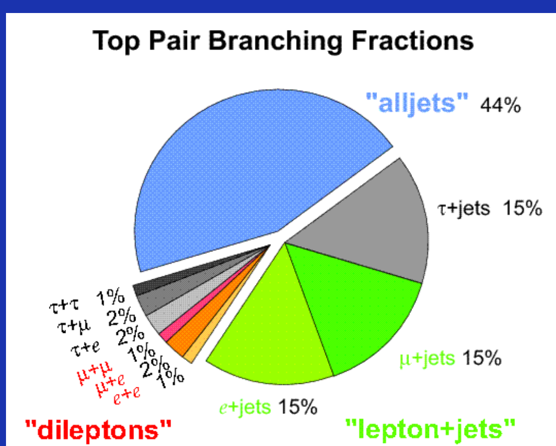
$\sigma_{inel} / \sigma_{ttbar} \sim 10^{10}$
- High luminosity
- High efficiency

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



$|V_{tb}| \sim 1$

- Final state determined by the decay of the W boson



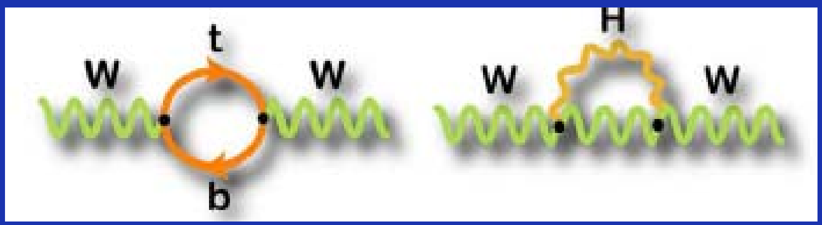
- dilepton channel (low bkg)
- lepton + jets channel (moderate bkg)
- all hadronic channel (huge bkg)

Lepton≡ e, μ from W or from τ from W

The top quark mass

Fundamental parameter of the Standard Model

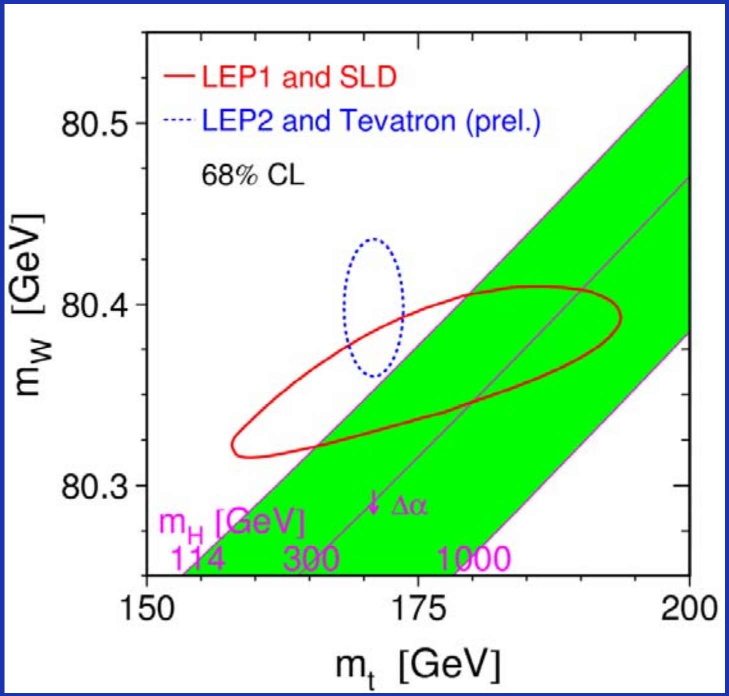
- **Affects predictions of SM via radiative corrections**



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

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

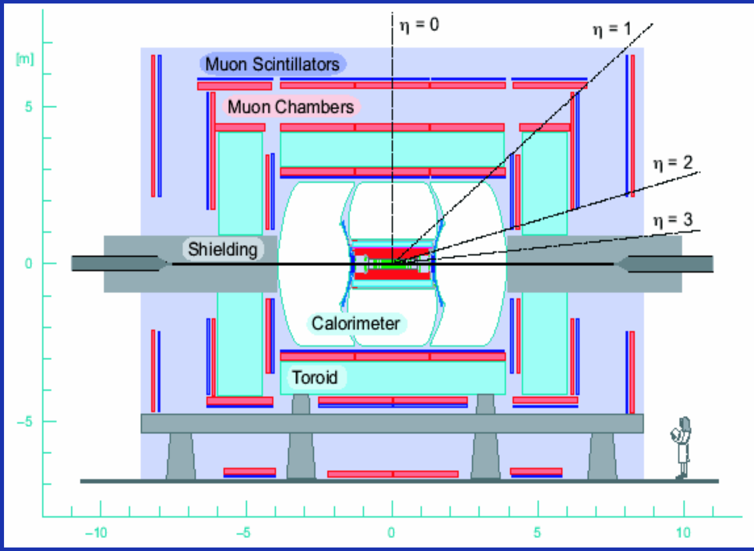
Probing the EWSB mechanism (new physics?)



- **Precision measurement → 2 (8) fb^{-1} projection: $\delta m_t \sim 1.5$ (1) GeV**

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



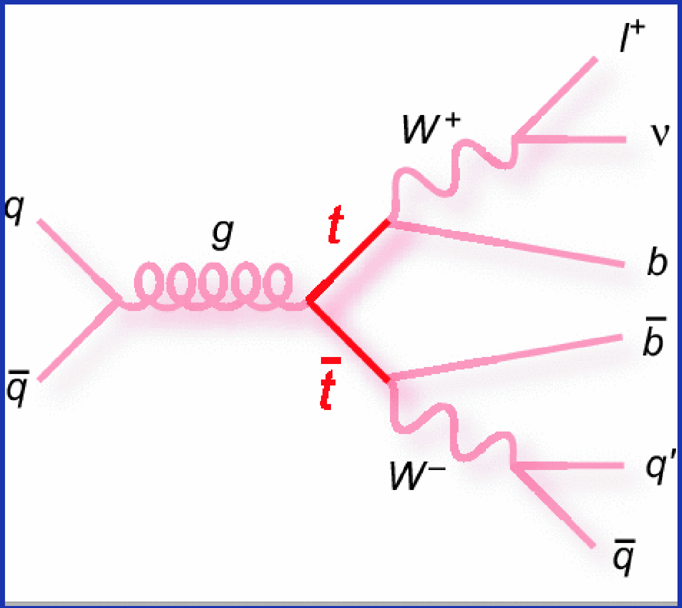
μ, e, jets (light/b), MET, PV, tracks

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 as well as combinatorial
- Many systematic uncertainties expected to decrease with larger data samples

The Lepton + Jets Channel

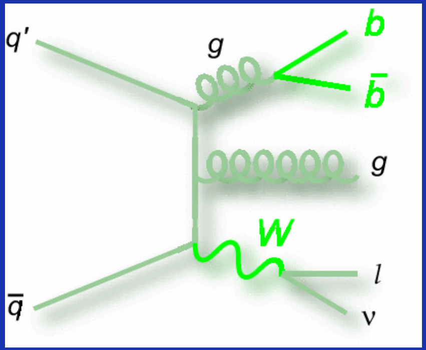
signal



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

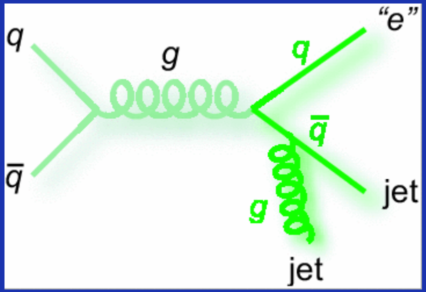
Background

W (→ l ν) + 4 jets



QCD Multijet

- fake isolated lepton
- misreconstructed MET

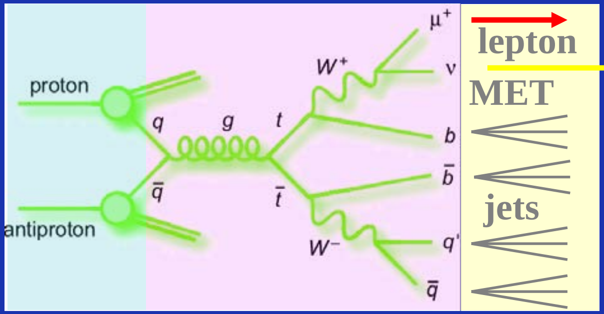


The Matrix Element method - I

Dynamical method pioneered by DØ yielding the most precise results at the Tevatron

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

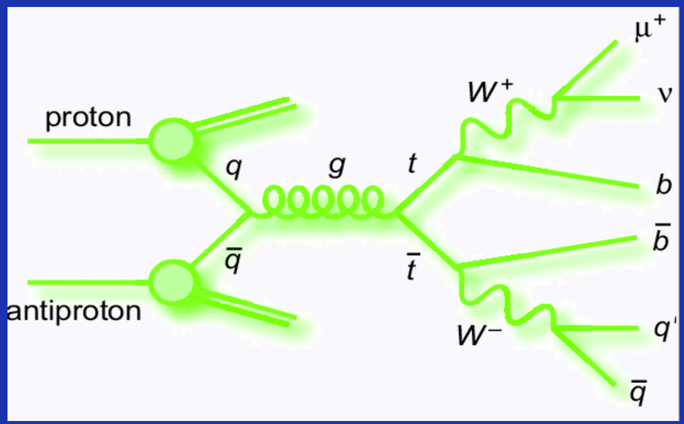
Initial state

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

Measurements *x*: **jets 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)

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

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

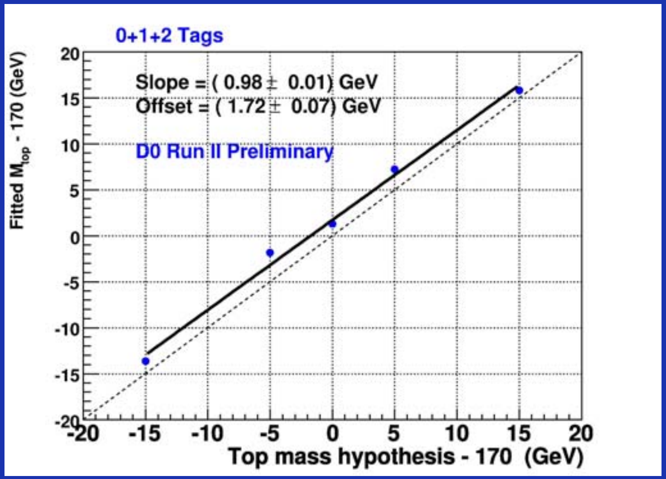
All events are combined in a likelihood…

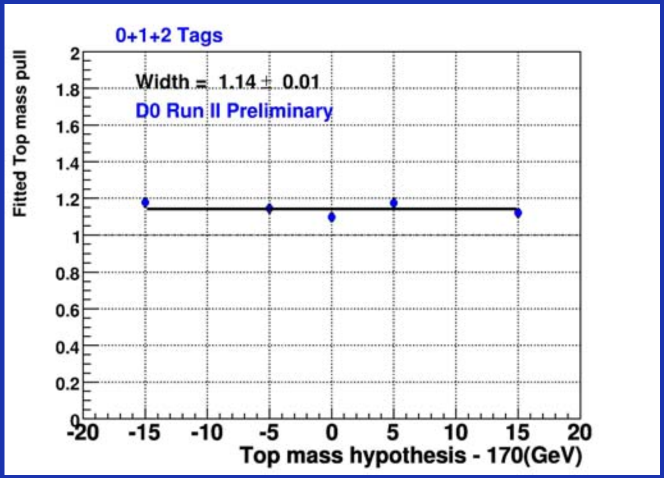
$$-\ln L(x_1,\ldots,x_n;m_{top},JES)=-\sum_{i=1}^{n}\ln P_{evt}(x;m_{top},JES)$$

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

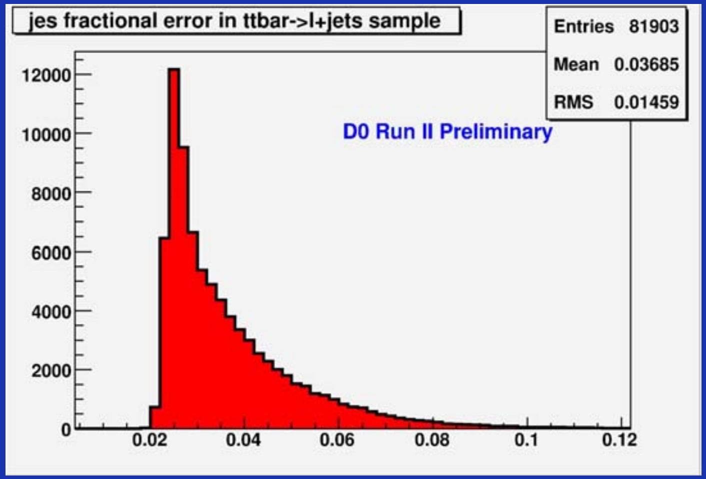
The Matrix Element method - III

The method is calibrated for shifts in mean and uncertainties using ensemble testing in simulated MC events



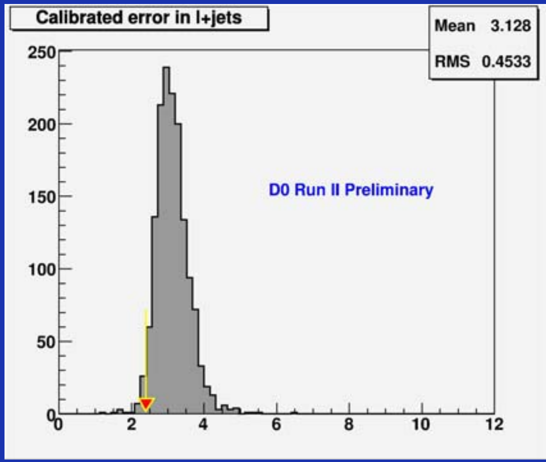


The likelihood is convoluted with a prior knowledge of the JES determined in an orthogonal sample (Gaussian likelihood centered at JES = 1 with a width of 3.7% as extracted form ttbar MC)

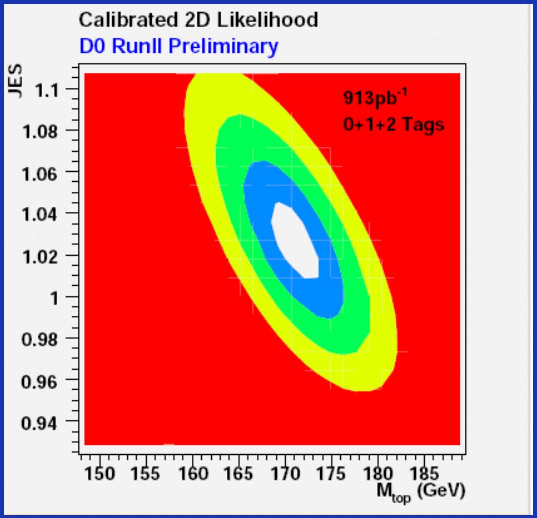


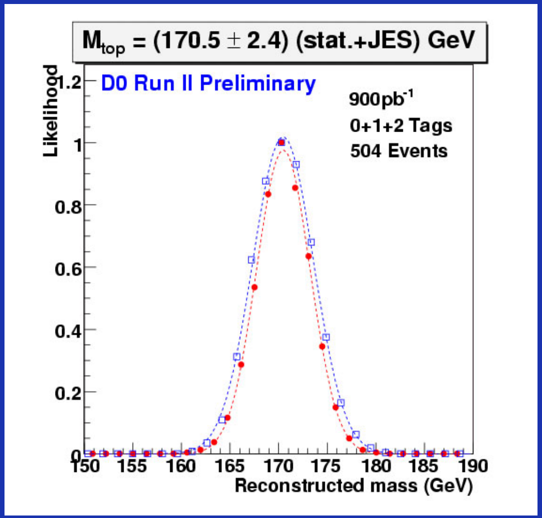
ME Result

Using 0.9 fb^{-1} of data (504 events) the combined 0+1+2 tags, calibrated + prior results yields:



$$M_{top} = 170.5 \pm 2.4\ (\text{stat + JES})\ ^{+1.2}_{-1.1}\ (\text{syst})\ \text{GeV}$$





Main syst. nncertainties	(+)	(-)
signal modeling	0.45	0.45
b-fragmentation model	0.54	0.54
b/l ratio	0.59	0.59
JES p_T dependence	0.23	0.23
tagging MC	0.29	0.29
signal fraction	0.53	0.24
QCD contamination	0.21	0.21

The Ideogram Method - I

This method was used by DELPHI to measure the W mass and this is the first time DØ uses this method to measure the top mass with l+jets events

Use of a constrained kinematic fit and build up an event-by-event likelihood, each event gives a distribution of masses

- Measured variables: 4 jet energies, 4 jet directions, lepton energy and direction, MET and MET direction
- Fit ttbar hypothesis to these kinematic variables
- Constraints: both W masses are constrained to the known W mass, both top masses are equal
- Per jet-parton assignment: m_t, σ_t and χ^2

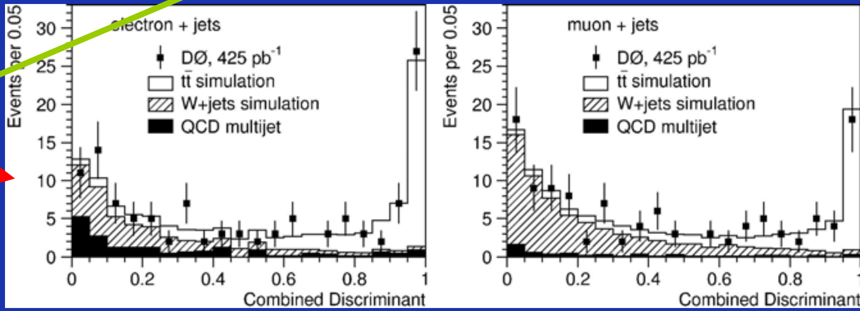
JES taken from M_W constraint, all jet energies are normalized to a JES parameter that has the lowest χ^2 for M_W closest to 80.4 GeV

The Ideogram Method – II

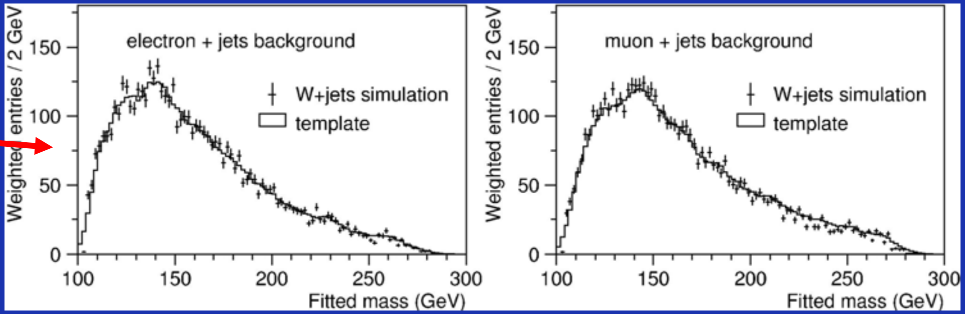
Compute an event likelihood based on 3 variables: m_t, σ_t and χ^2

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

$$P_{sig}(m_{top}, JES) = P_{sig}(D) P_{sig}(fit; m_{top}, JES)$$



$$P_{bkg}(fit; JES) = \sum_{i=1}^{24} e^{-\frac{1}{2}\chi_i^2} w_{btag,i} BG(m_i)$$



The Ideogram Method – III

Compute an event likelihood based on 3 variables: m_t, σ_t and χ^2

$$P_{sig}(fit; m_{top}, JES) = \sum_{i=1}^{24} e^{-\frac{1}{2}\chi_i^2} w_{btag,i} \{ \int_{m_{min}}^{m_{max}} G(m_i, m', \sigma i) BW(m', m_{top}) dm' + S_{wrong}(m_i, m_{top}) \}$$

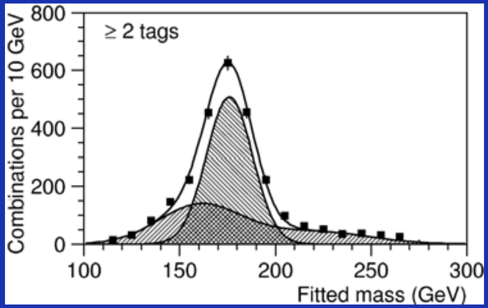
Combinatorics weight

b-tagging weight

Gaussian resolutions

Relativistic Breit-Wigner (ttbar invariant mass distribution)

"wrong" permutation signal shape



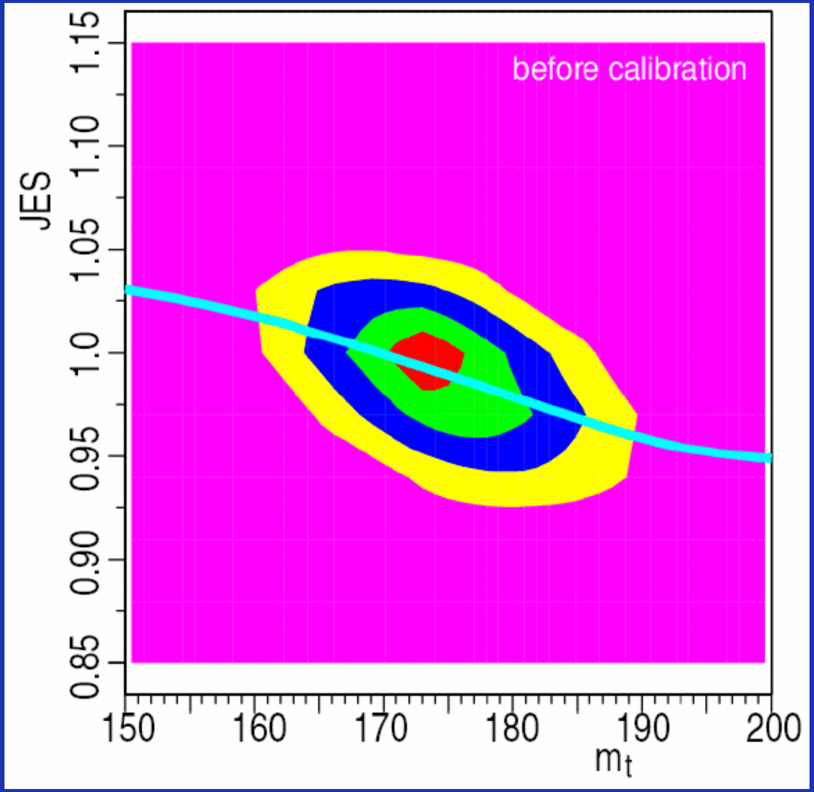
A sample likelihood is maximized to determine m_{top}

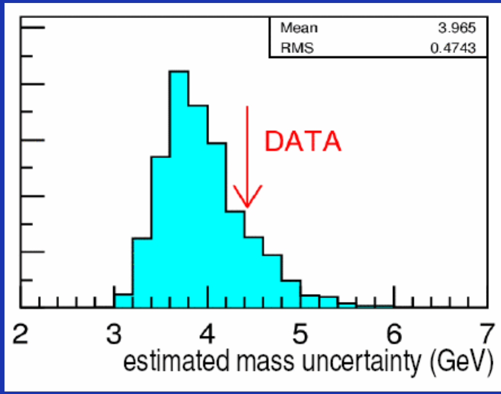
$$L_{samp}(m_{top}, JES, f_{top}) = \prod_j L_{evt}^j(m_{top}, JES, f_{top})$$

Ideogram Method Result

Using 0.42 fb^{-1} of data (230 events) the method yields:

M_{top} = 173.7 ± 4.4 (stat + JES) $^{+2.1}_{-2.0}$ (syst) GeV





Main syst. nncertainties	(+)	(-)
signal modeling	0.73	0.73
b-fragmentation model	1.30	1.30
b-response	1.15	1.15
JES p_T dependence	0.45	0.45
b-tagging	0.29	0.29
Trigger uncertainty	0.61	0.28
QCD contamination	0.28	0.28

Summary: it is heavy!

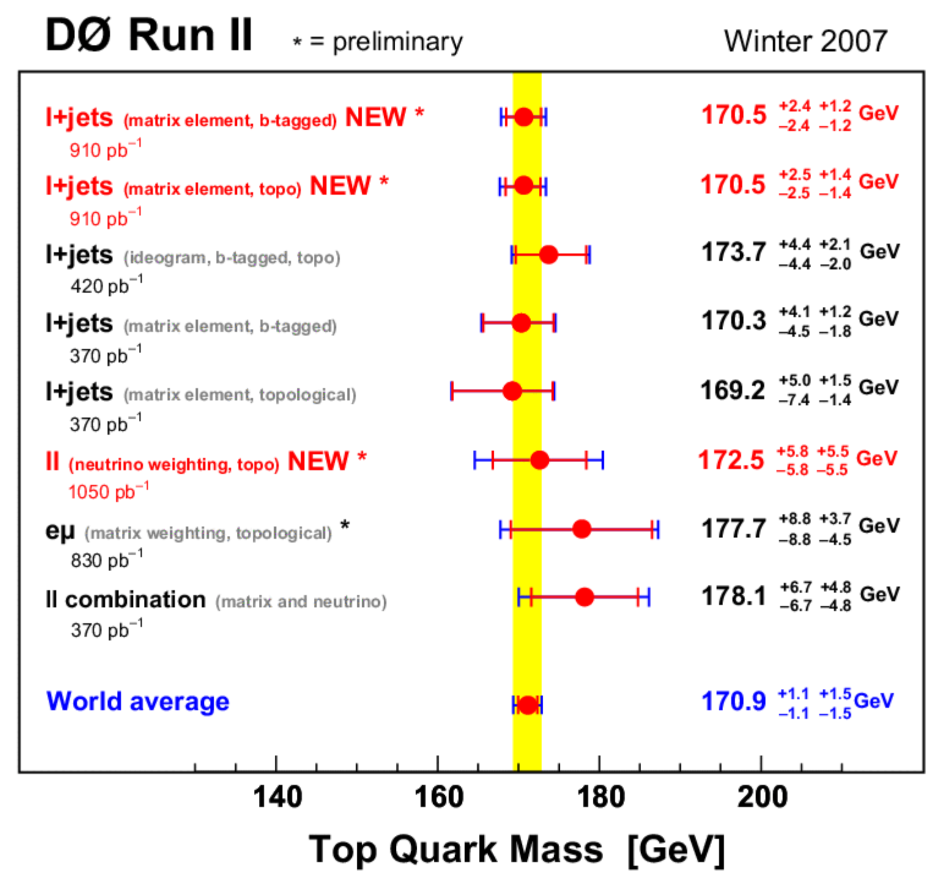
Two new measurements of the Top Quark mass presented

M_t=170.5 ± 2.4(stat+JES)$^{+1.2}_{-1.1}$(syst) GeV

MATRIX ELEMENT METHOD (0.9 fb^{-1})
DØ's most precise measurement

M_t=173.7 ± 4.4(stat+JES)$^{+2.1}_{-2.0}$(syst) GeV

IDEOGRAM METHOD (0.42 fb^{-1})
hep-ex/0702018 (accepted for publication in PRD)

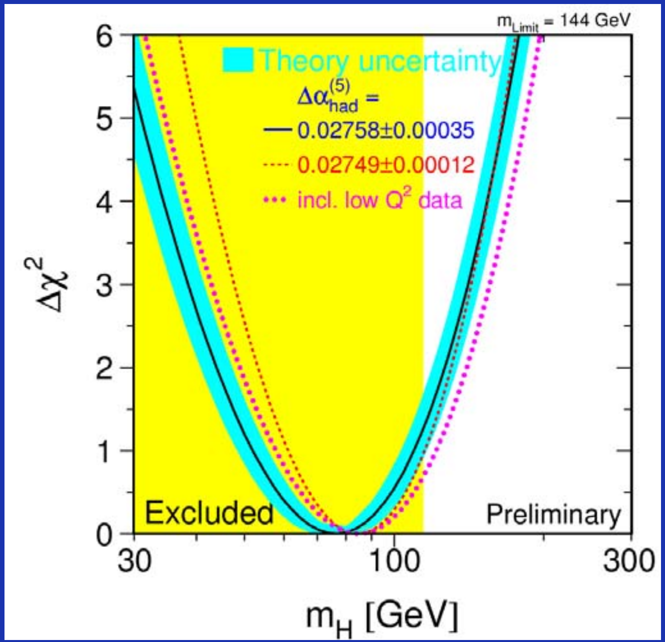


Conclusions and outlook

- Preliminary top quark mass measurement with ~ 1 fb^{-1} presented (2 fb^{-1} data sets' results coming!)

- Improved measurements allows us to reach a 1.1% precision (DØ and CDF combined)
  - 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

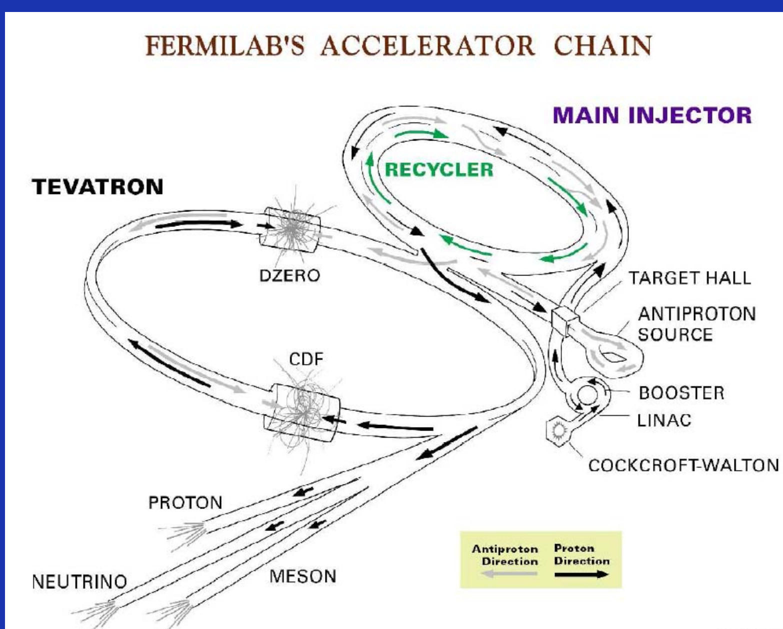


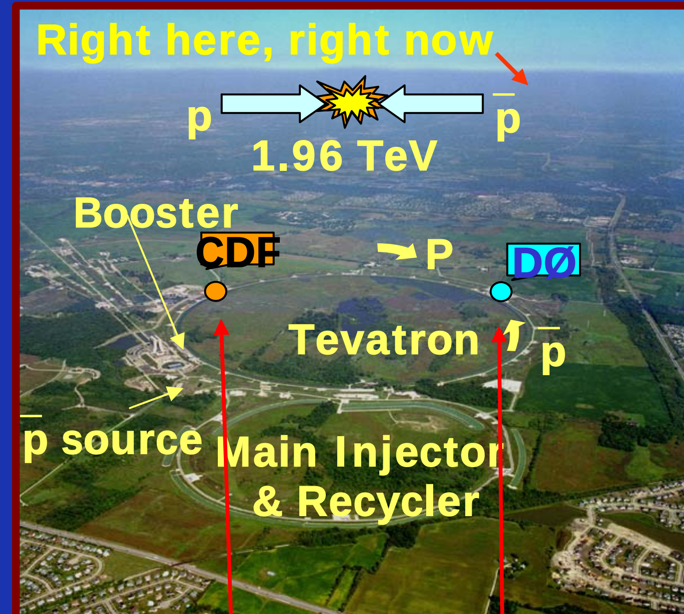
$M_H = 76^{+33}_{-24}$ GeV, M_H < 144 @95%CL

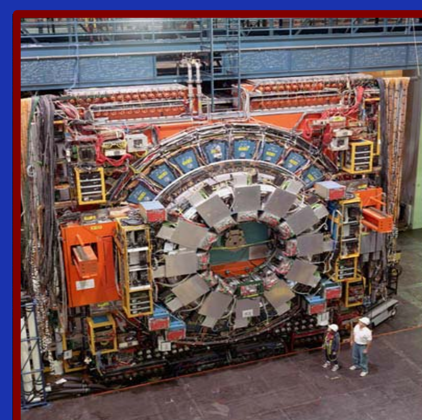
Back up slides

The Tevatron Collider

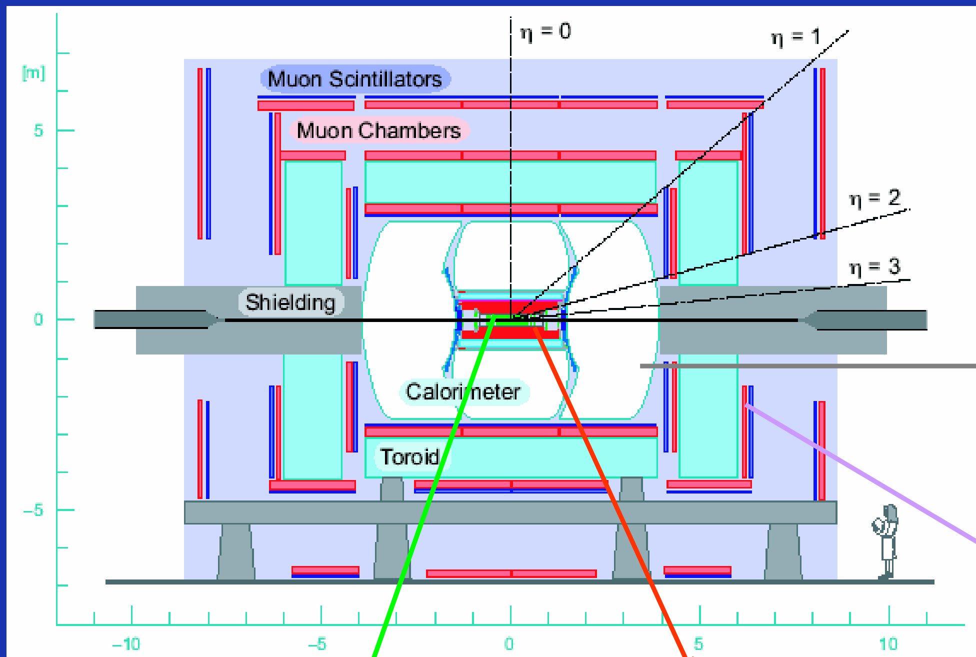
- Proton-antiproton collider with $\sqrt{s}$=1.96 TeV
- 36x36 bunches with 396ns between crossings
- 3 ~ collisions per bunch crossing
- $L_{inst} > 1 \times 10^{32} cm^{-2} s^{-1}$
- Expected 4-8 fb^{-1} integrated luminosity for RunII (0.11fb^{-1} in RunI)

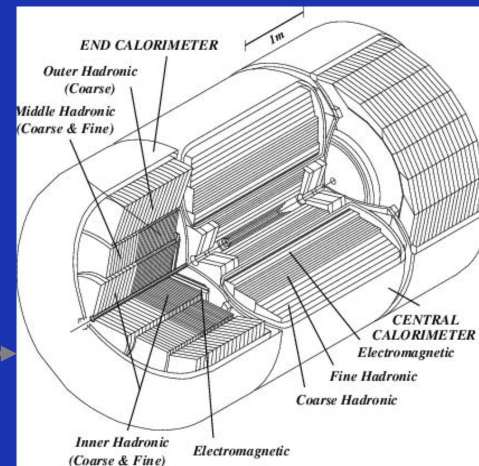


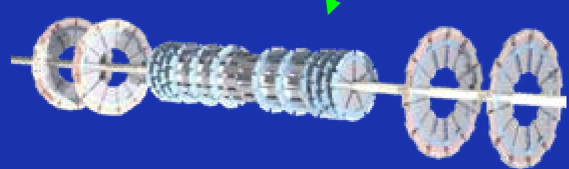


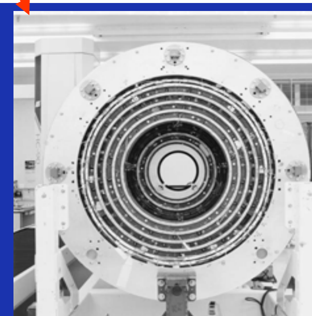


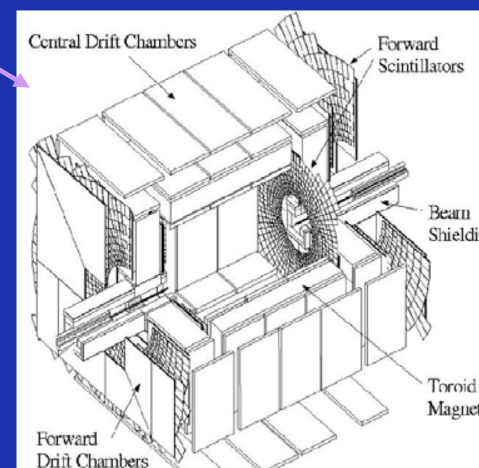
DØ Detector











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