Measurement of the Top Quark Mass at DZero In The Lepton + Jets Channel

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For The DØ Collaboration

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Outline

Introduction

Top quark at the Tevatron.

Top Quark Mass Measurement In The l+Jets Channel

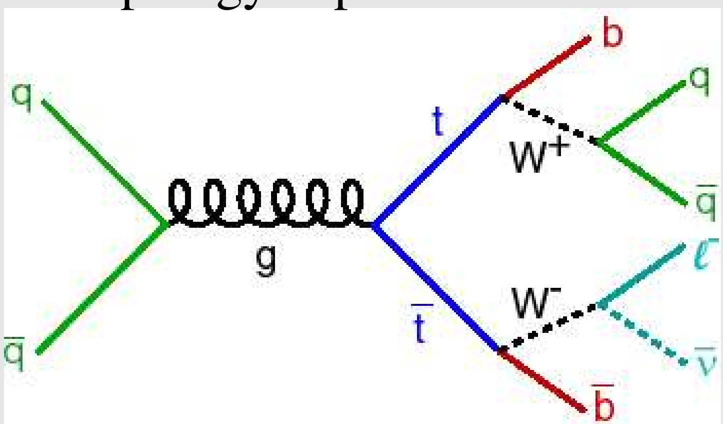
Results from the 425 pb^{-1} of data using b-tagging for:

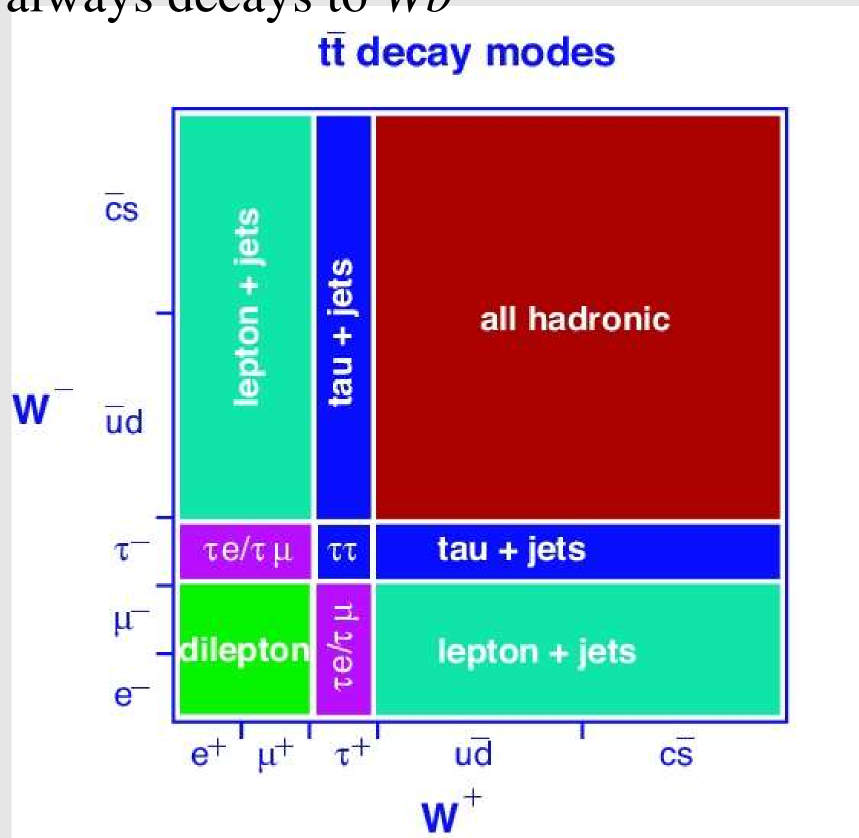
The Matrix Element Method.
The Ideogram Method Result.

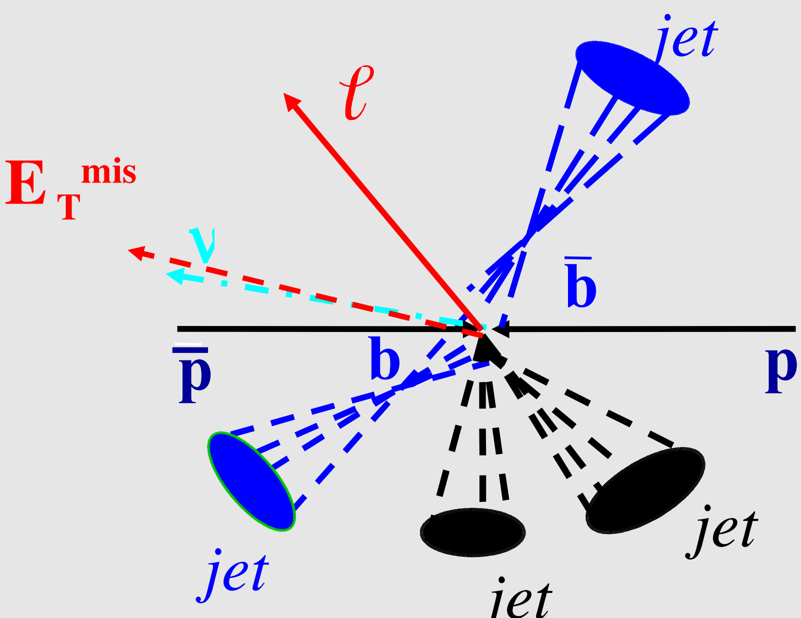
Top Quark

At the Tevatron, top quarks are primarily produced in pairs via the strong interaction. Since $|V_{tb}| \sim 1$, the top quark almost always decays to *Wb* *(Ws, Wd CKM suppressed)*

Event topology depends on the *W* decay mode





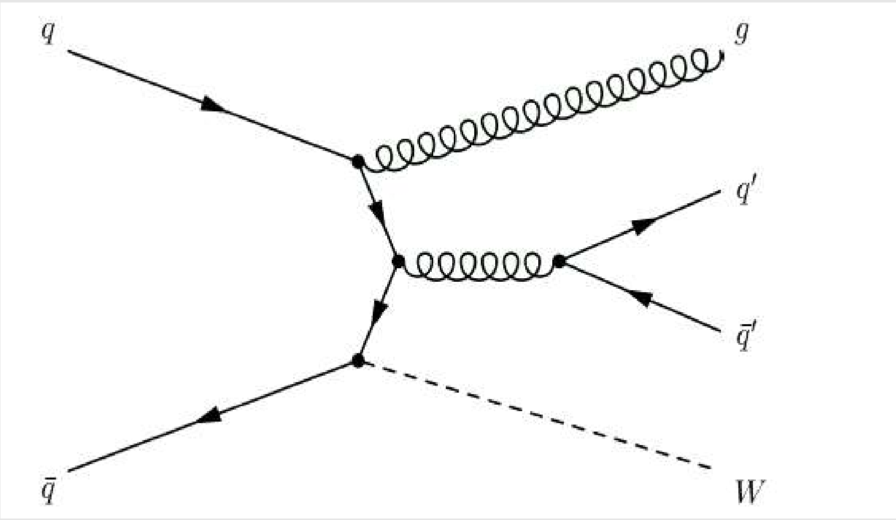


Experimental signature in the lepton+jets channel:

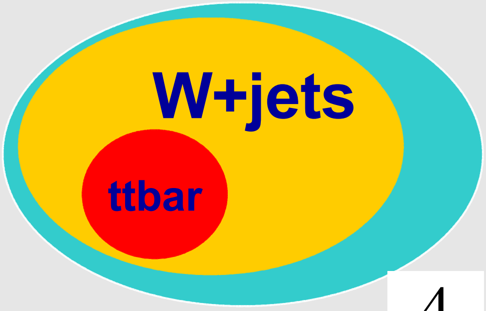
- 1 high p_T lepton
- 4 jets (2 b-jets)
- large E_T^{mis}

Top Quark Identification

Background Processes:



- Exactly 4 Calorimeter Jets
  - $p_T > 20$ GeV
  - $|\eta| < 2.5$
- Isolated Lepton
  - $p_T > 20$ GeV
  - $|\eta^e| < 1.1, \ |\eta^\mu| < 2.0$
- Missing Transverse Energy
  - $E_T^{mis} > 20$ GeV



W+jets production.

most significant

Multi-jet events:

from fake or miss-characterized lepton and fake missing transverse energy

The Matrix Element Method

Set of observables: momenta of jets and lepton: ***x***

Integrate over unknowns:

- kinematic variables of final state particles: y
  (4 quarks, a lepton, and a neutrino: 18 variables)
- longitudinal momenta of the incident partons (q1,q2)
  (2 variables) = 20 variables

Integral contains 15 (14) delta-functions for e (mu)+jets:

- total energy-momentum conservation (4 variables)
- jet and lepton angles (considered to be perfectly measured)
  (10 variables)
- Electron momentum (considered perfectly measured)
  (1 variable)

Approximations:

- LO matrix element.
- $q\bar{q} \rightarrow t\bar{t}$ production process only (no gluon fusion ~15%)

The Matrix Element Method

We calculate a probability per event to be signal or background as a function of the top mass and the Jet Energy Scale (JES)

(Dominant systematic error in Run I).

If we had all the parton level information '*y*' this probability would be just proportional to the differential cross section.

In reality is a bit more complicated:

Differential cross section, based on LO Matrix Element ($q\bar{q} \rightarrow t\bar{t}$) only

Transfer Function: probability to **measure *x***, when **parton-level *y*** was produced.

Initial state

$$P_{t\bar{t}}(x;m_{top},JES)=\frac{1}{\sigma(m_{top})}\int dq_1 dq_2 f(q) f(\bar{q}) d\sigma(y;m_{top}) Prob(x,y,JES)$$

Normalization: acceptance efficiency

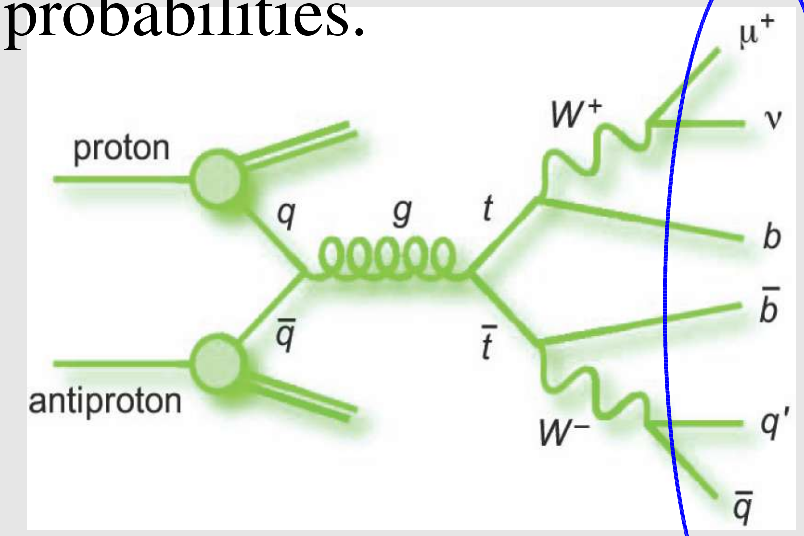
Overall JES is a free parameter in the fit, constrained in situ by the mass of the W decaying hadronically

Measurements: jets and leptons

The Matrix Element Method

b-tagging:

Weight each jet-parton assignment with b-tagging event probabilities.



Six particle final state

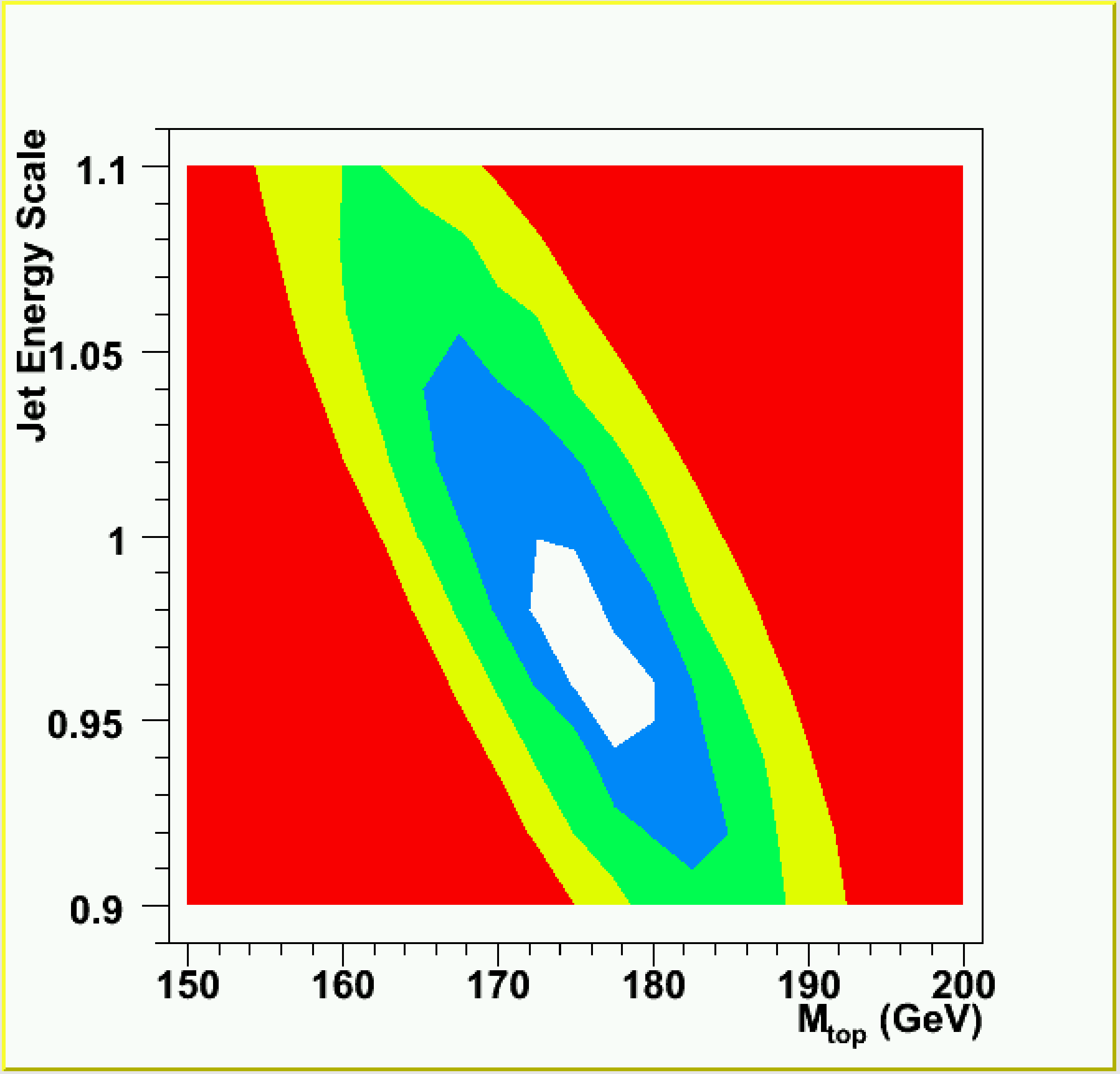
24 possible weighted assignments between jets and partons

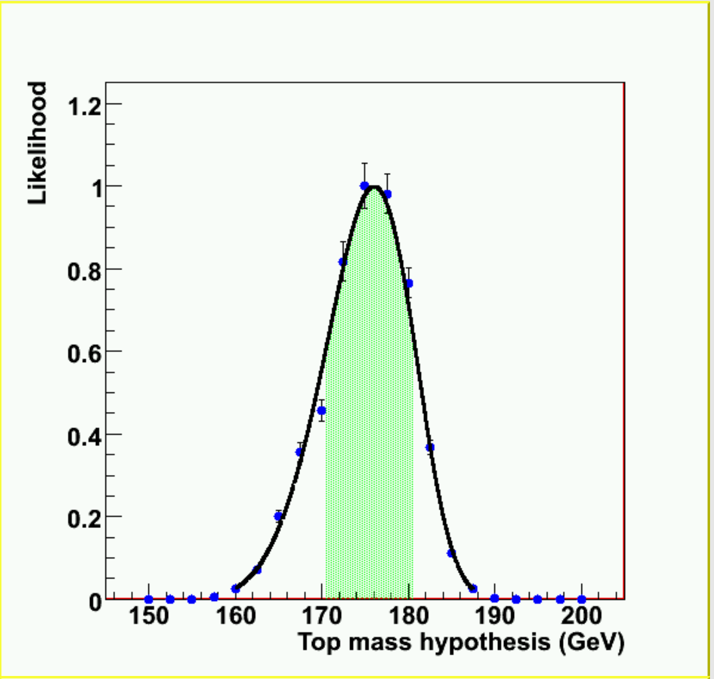
$$P_{t\bar{t}}^{N-tag}(x;m_{top},JES)=\sum_J W_J^{t\bar{t}} P_{t\bar{t}}^J(x;m_{top},JES)$$

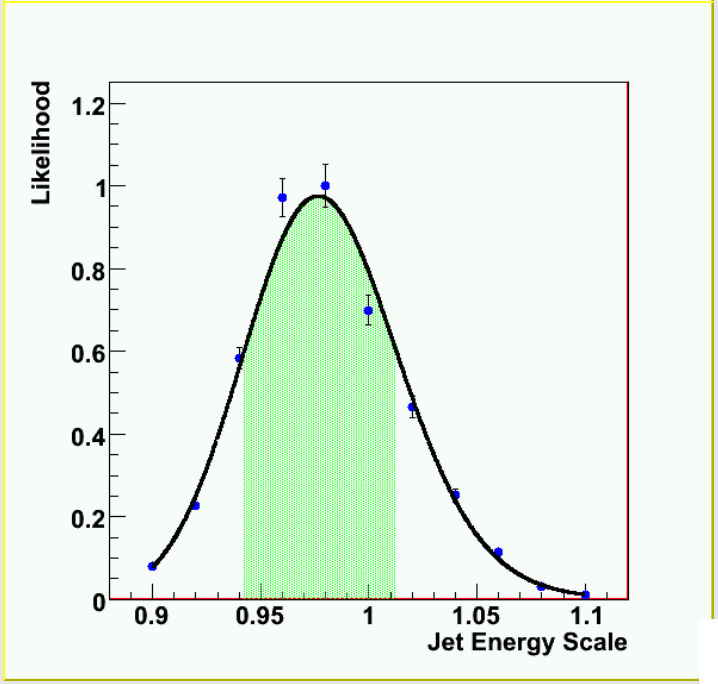
f_{top}: signal fraction is fitted simultaneously

$$P_{evt}^{N-tag}(x;m_{top},JES)=f_{top}P_{t\bar{t}}^{N-tag}(x;m_{top},JES)+(1-f_{top})P_{bkg}(x,JES)$$

Example of 2D Top Mass – JES Fit





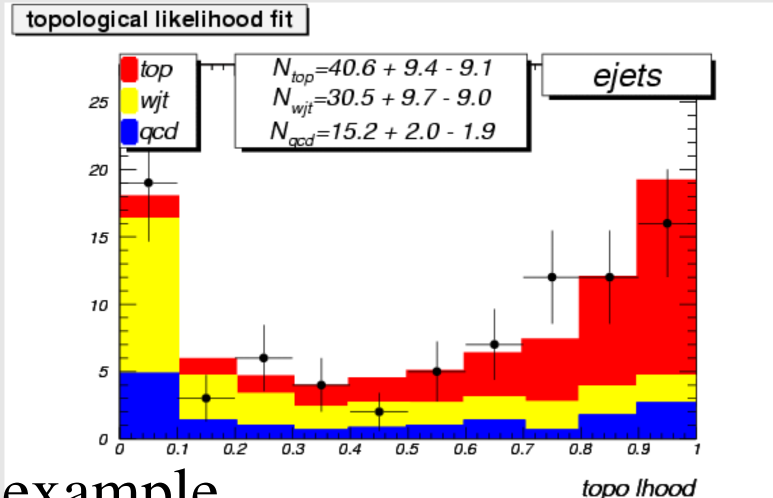


200 simulated events (m_t = 175 GeV)

Calibration of the Method

Transform Leading-Order Matrix Element mass estimator to full simulation, including ISR/FSR and reconstruction effects.

Build 1000 pseudo-experiments using full DZero simulated events and calibrate out biases from the hypothesis made.



example

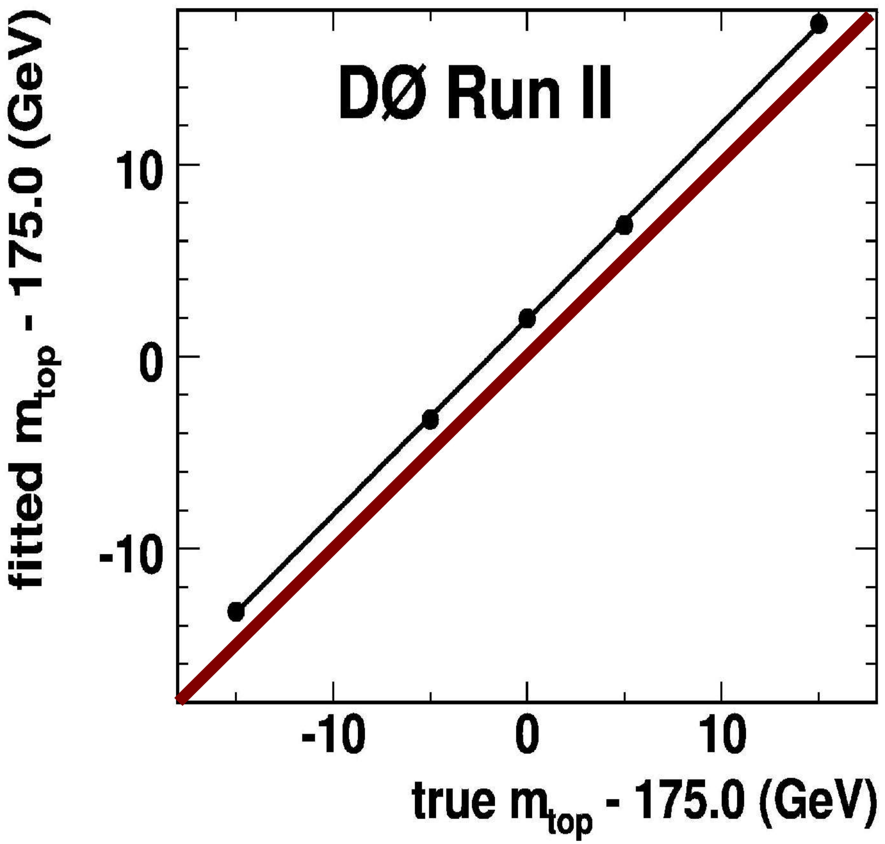
	e+jets	mu+jets
Number of events	86	89
Signal fraction	47+/-12%	29+/-10%

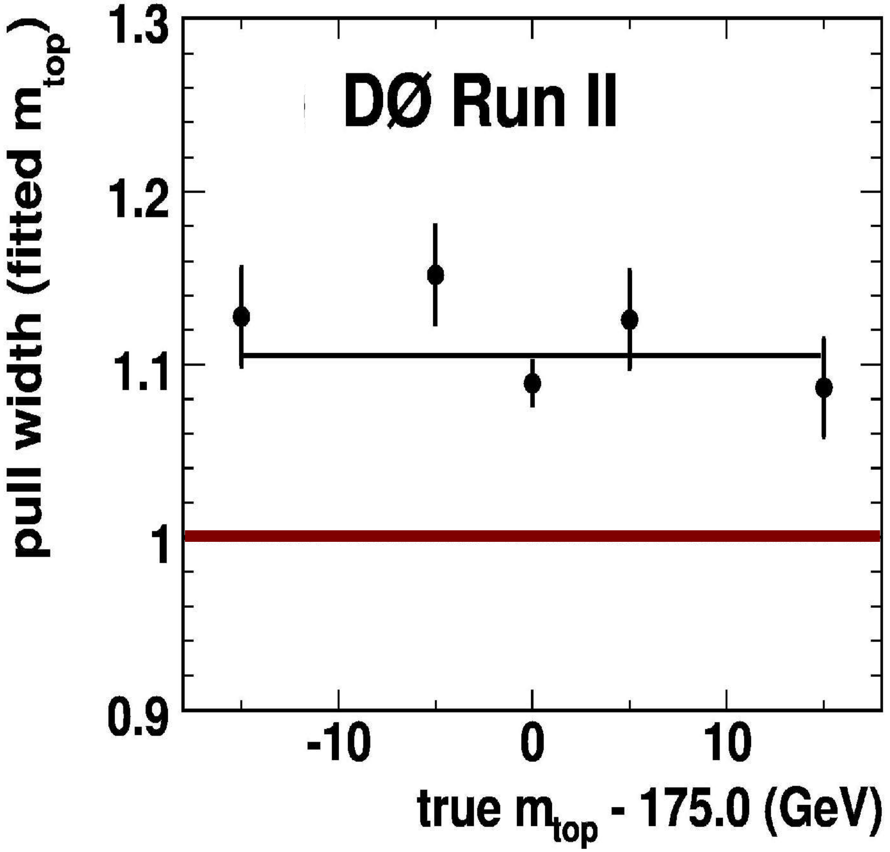
We measure the sample composition in data using a likelihood discriminant (based on topological variables) and we use these values to generate the ensembles composition.

Top Mass Calibration

offset = 1.932 +- 0.085 GeV
slope = 1.018+- 0.011

pull width = 1.11+- 0.01

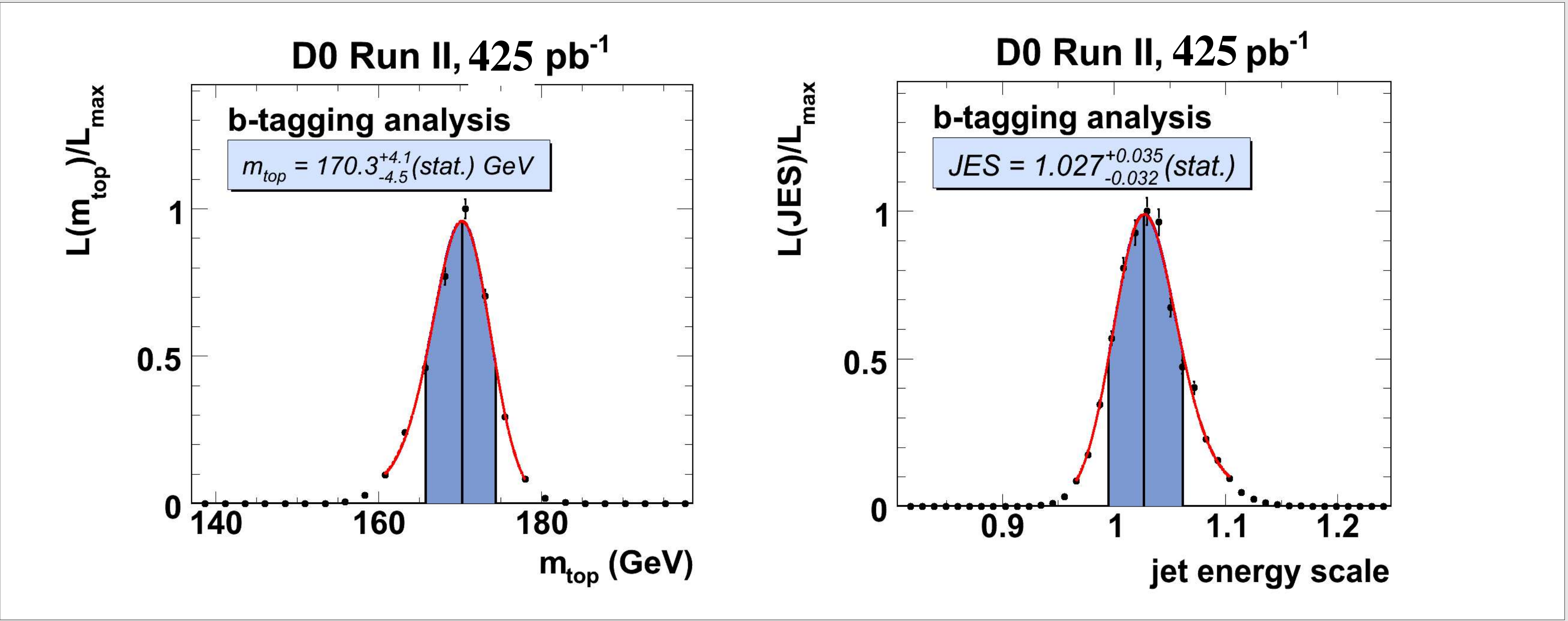




1000 full-simulated pseudo-experiments

Top Mass Fit in 425pb^{-1} lepton+jets Data

$$m_{top} = 170.3 \pm^{4.1}_{4.5} (stat. + JES) \pm^{1.2}_{1.8} (syst.)\, GeV$$



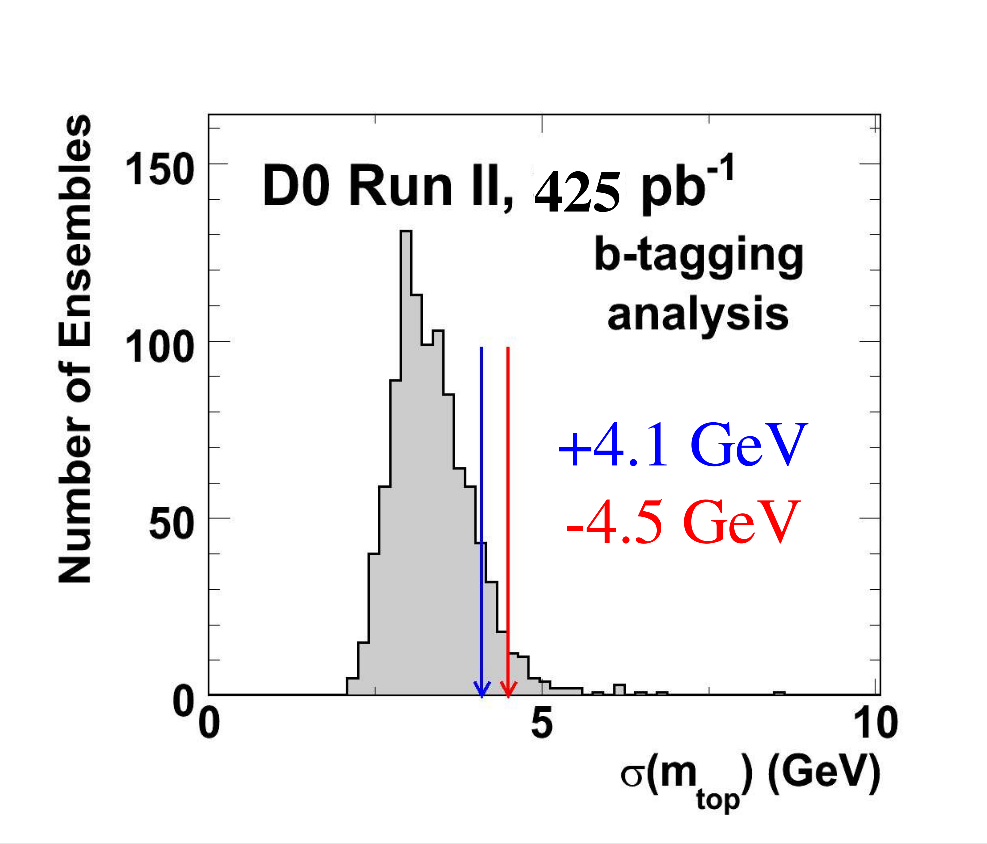
Measured JES is consistent with the reference scale (JES=1)

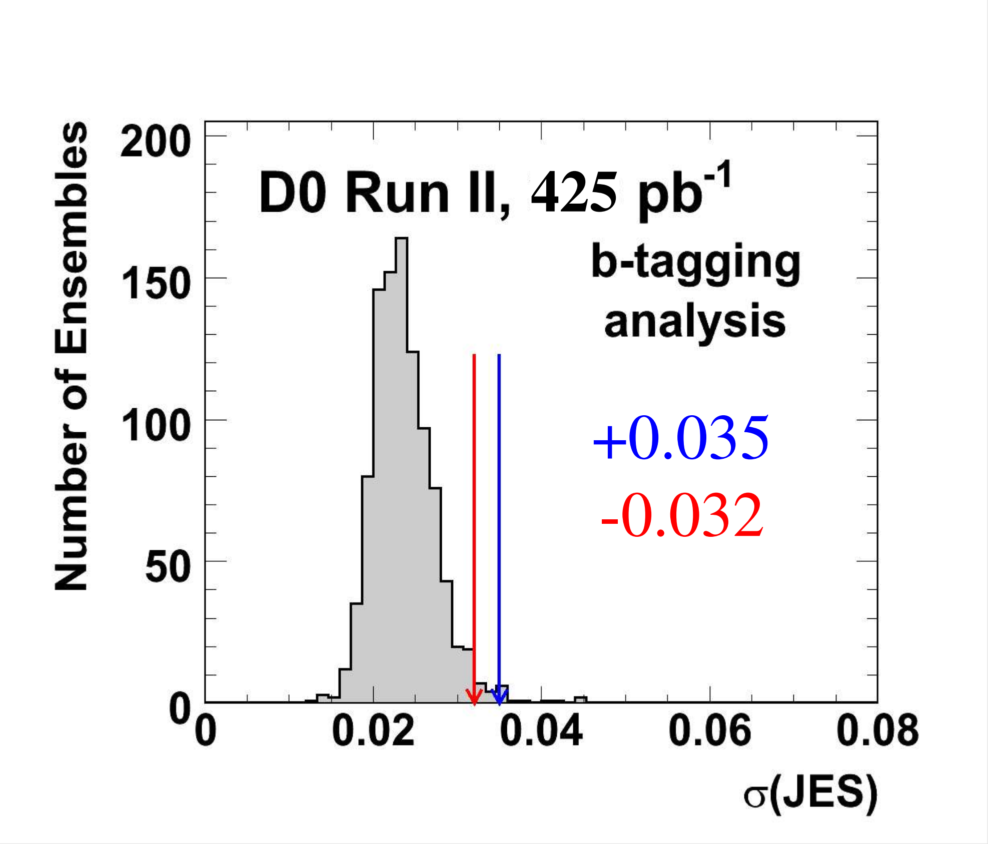
The statistical errors include the JES error.

Major systematic error from b fragmentation and b/light jets response

Top Mass Fit Error in Data and MC

$$m_{top} = 170.3 \pm^{4.1}_{4.5} (stat. + JES) \pm^{1.2}_{1.8} (syst.)\, GeV$$



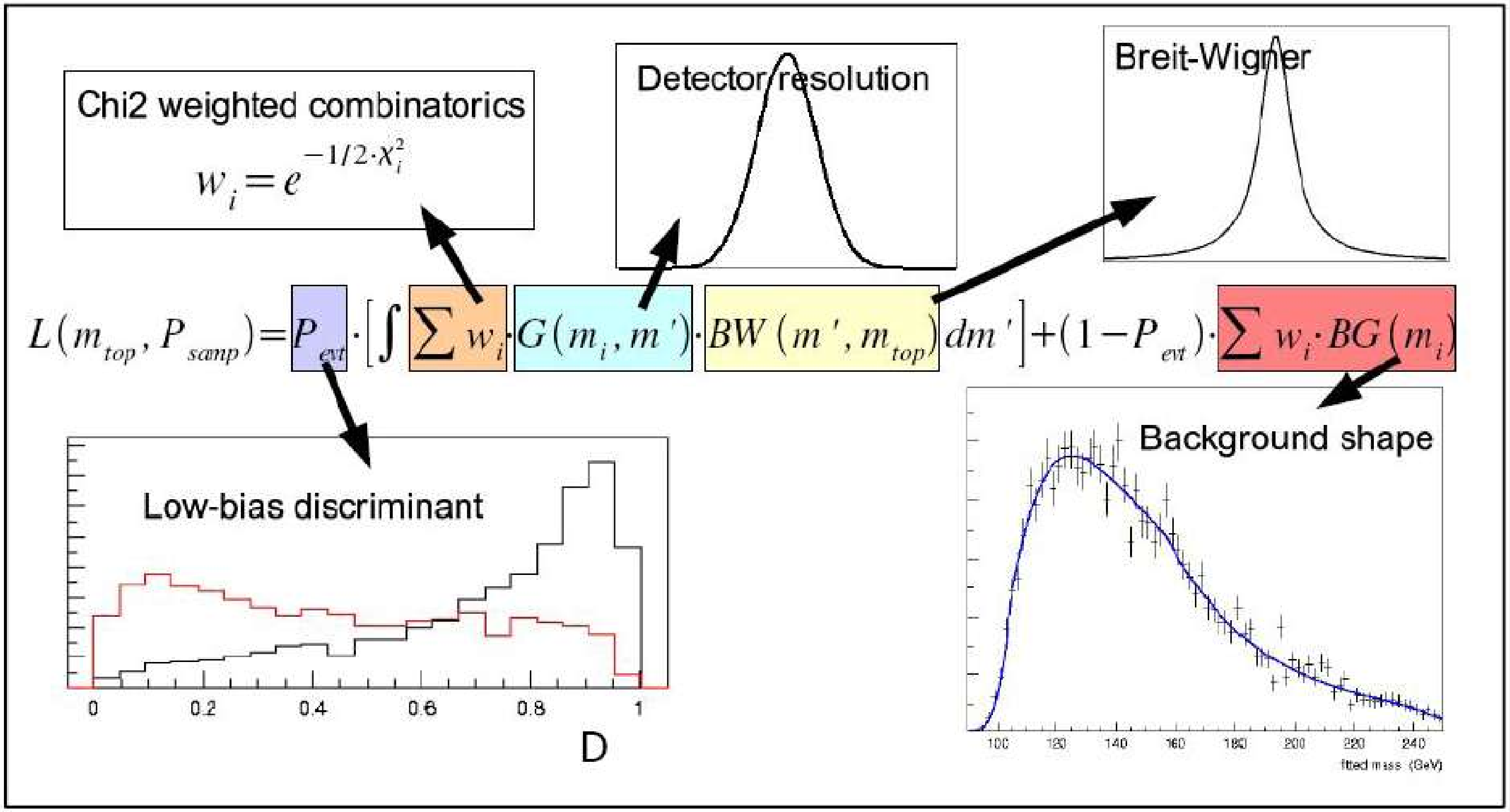


The arrows show the upper and lower uncertainties in data respect to MC for the mass and for the JES .

Top Mass Using the Ideogram Method

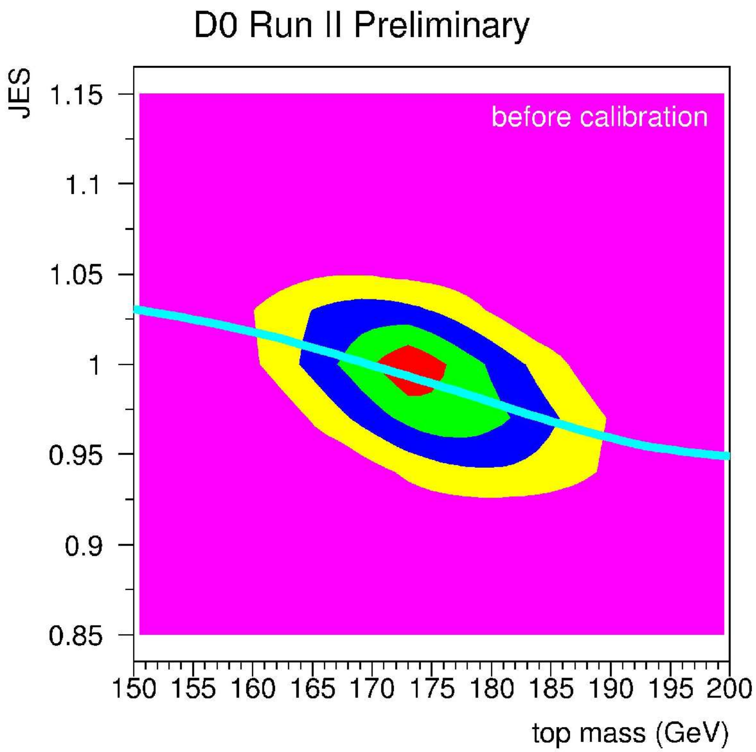
Basic Idea: use event-by-event likelihood technique taking into account all possible jet combinations and the possibility that the event was signal or background (like Matrix Element method)

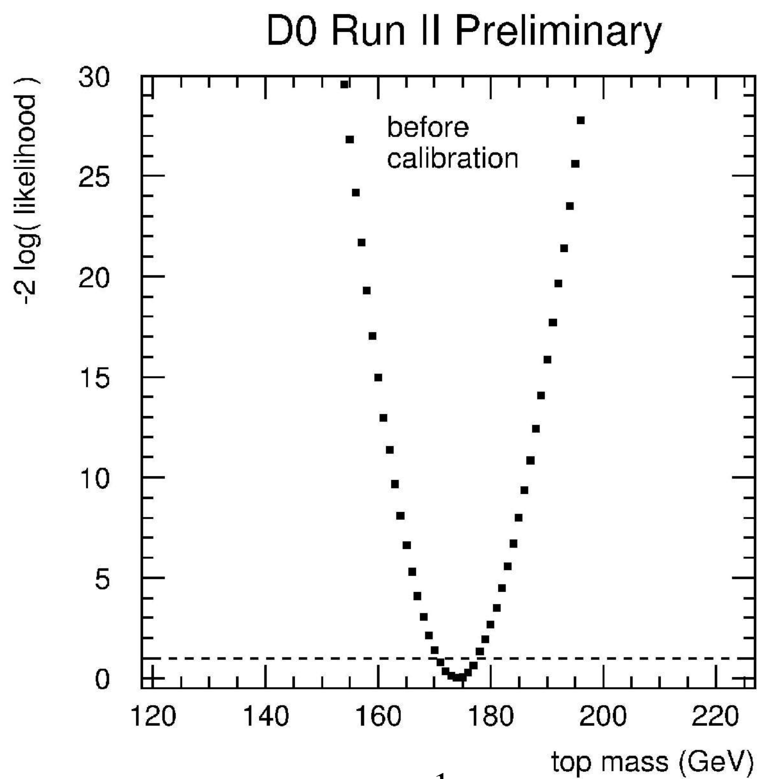
- Instead of ME method use constrained fit + topological discriminant. Also, in contrast to ME analysis, 4 or more jets are used.



Ideogram Method Result

$$m_{top} = 173.3 \pm 4.4 (stat. + JES) \pm^{2.1}_{2.0} (syst.) GeV$$



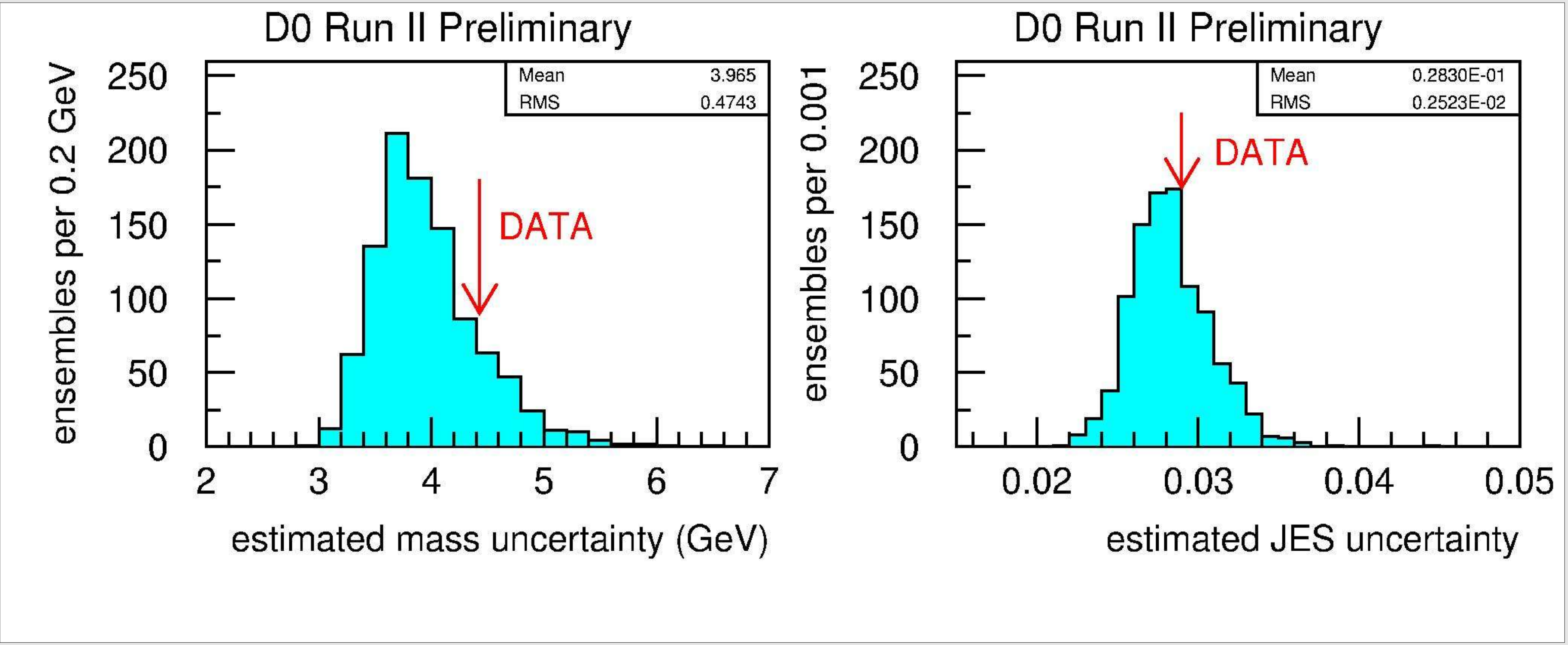


b-tagging analysis, 425 pb^{-1}

The top mass likelihood is evaluated at the JES value with maximum likelihood (light blue line)

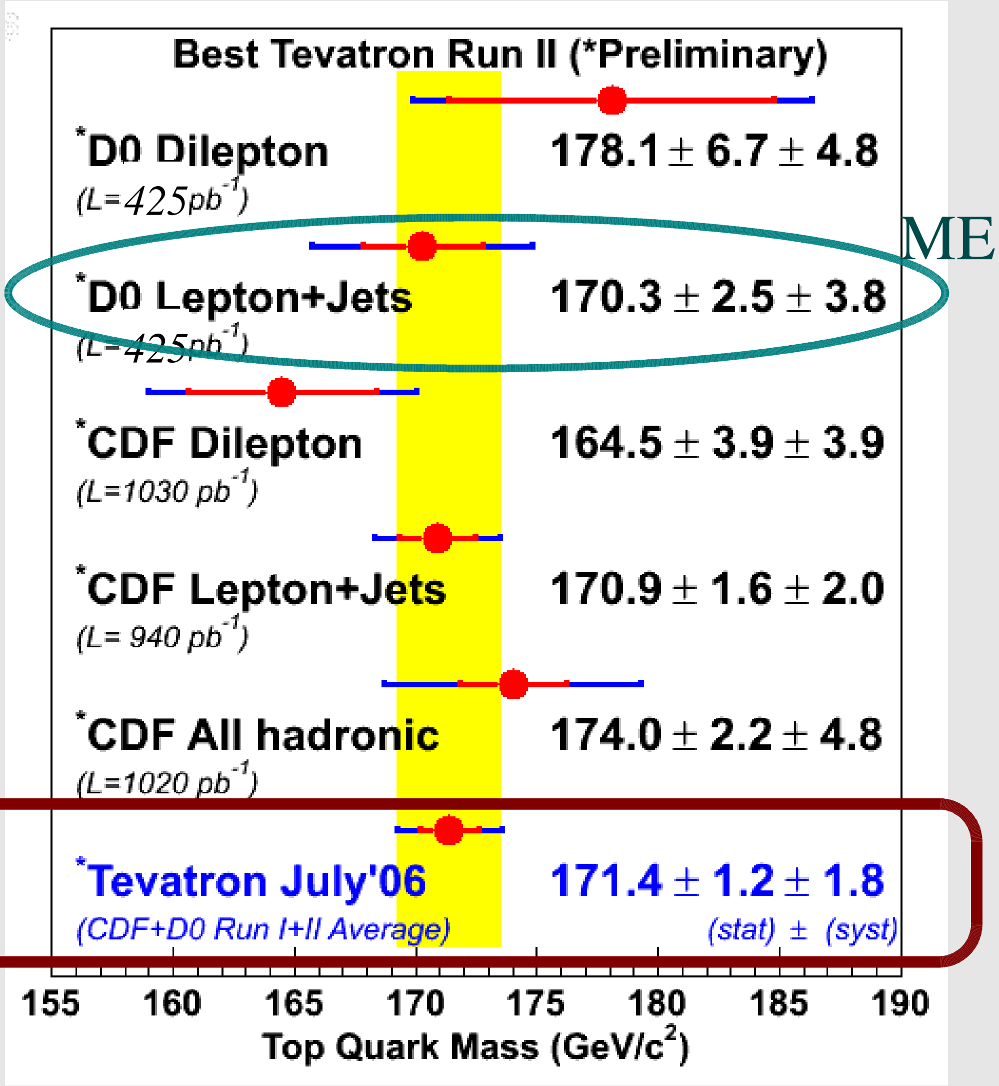
Ideogram Fit Error in MC and Data

$$m_{top} = 173.3 \pm 4.4 (stat. + JES) \pm^{2.1}_{2.0} (syst.) GeV$$

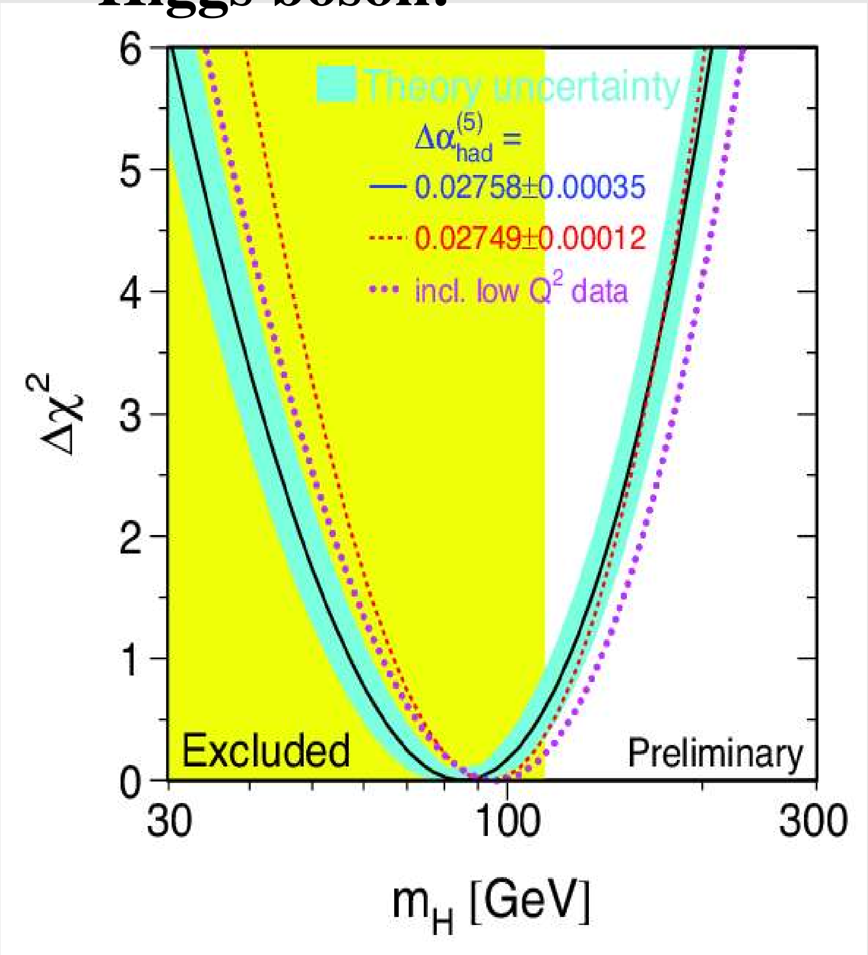


The arrows show the uncertainties in data respect to MC for the mass and for the JES .

Top Mass Measurement Current Status



Impact on Standard Model Higgs boson:



$$M_H = 85^{+39}_{-28}\, GeV\ ; \quad M_H < 166\, GeV\ @\ 95\ CL$$

Summary and Conclusions

The precise measurement of top quark mass allows to constrain the mass of the SM Higgs boson, and is one of the most important measurements at the Tevatron.

Top quark mass precision is improved after adding b-tagging information to both the Matrix Element and Ideogram techniques.

$m_{top} = 173.3 \pm 4.4\,(stat. + JES) \pm^{2.1}_{2.0}\,(syst.)\,GeV$	**ID**
$m_{top} = 170.3 \pm^{4.1}_{4.5}\,(stat. + JES) \pm^{1.2}_{1.8}\,(syst.)\,GeV$	**ME**

A new improved measurement of the top quark mass allow us to reach the 1.2% precision (Combined Dzero+CDF measurement).

Backup Slides

$$m_{top} = 170.3 \pm^{4.1}_{4.5} (stat. + JES) \pm^{1.2}_{1.8} (syst.) GeV$$

ME Systematic Errors

Source of uncertainty	Effect on top mass (GeV)
Physics Modeling	
Signal modeling	+-0.46
Background modeling	+-0.40
PDF uncertainty	+0.16-0.39
b-fragmentation	+-0.56
b/c semileptonic decays	+-0.05
Detector modeling	
JES pT dependence	+-0.19
Relative b/light jet energy scale	+0.63 -1.43
Trigger	+0.08-0.13
B-tagging	+-0.24
Method	
Signal fraction	+-0.15
QCD background	+-0.29
MC calibration	+-0.48

ID Systematic Errors

$$m_{top} = 173.3 \pm 4.43\,(stat. + JES) \pm^{2.10}_{2.04}\,(syst.)\,GeV$$

Physics Modeling

Signal modeling	+-0.73
Background modeling	+-0.20
PDF uncertainty	+-0.023
b-fragmentation	+-1.30

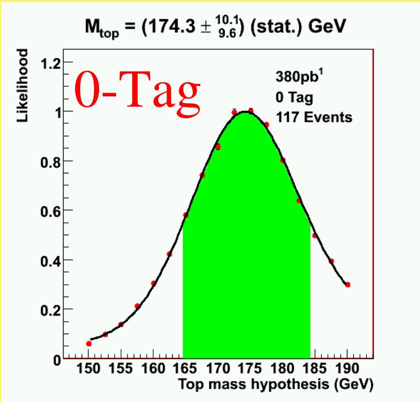
Detector modeling

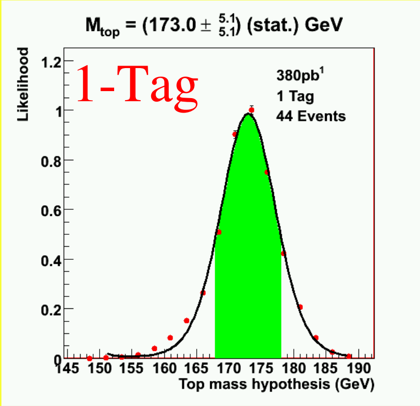
Jet ID efficiency and resolution	+-0.22
JES pT dependence	+-0.45
Relative b/light jet energy scale	+-1.15
Trigger	+0.61-0.28
B-tagging	+-0.29

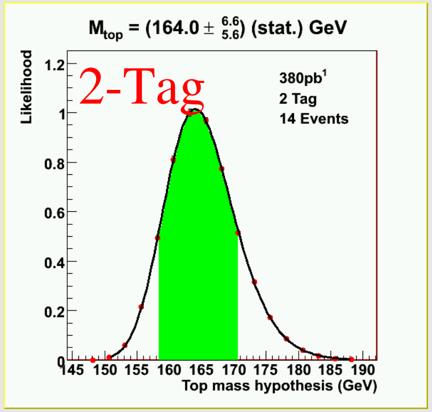
Method

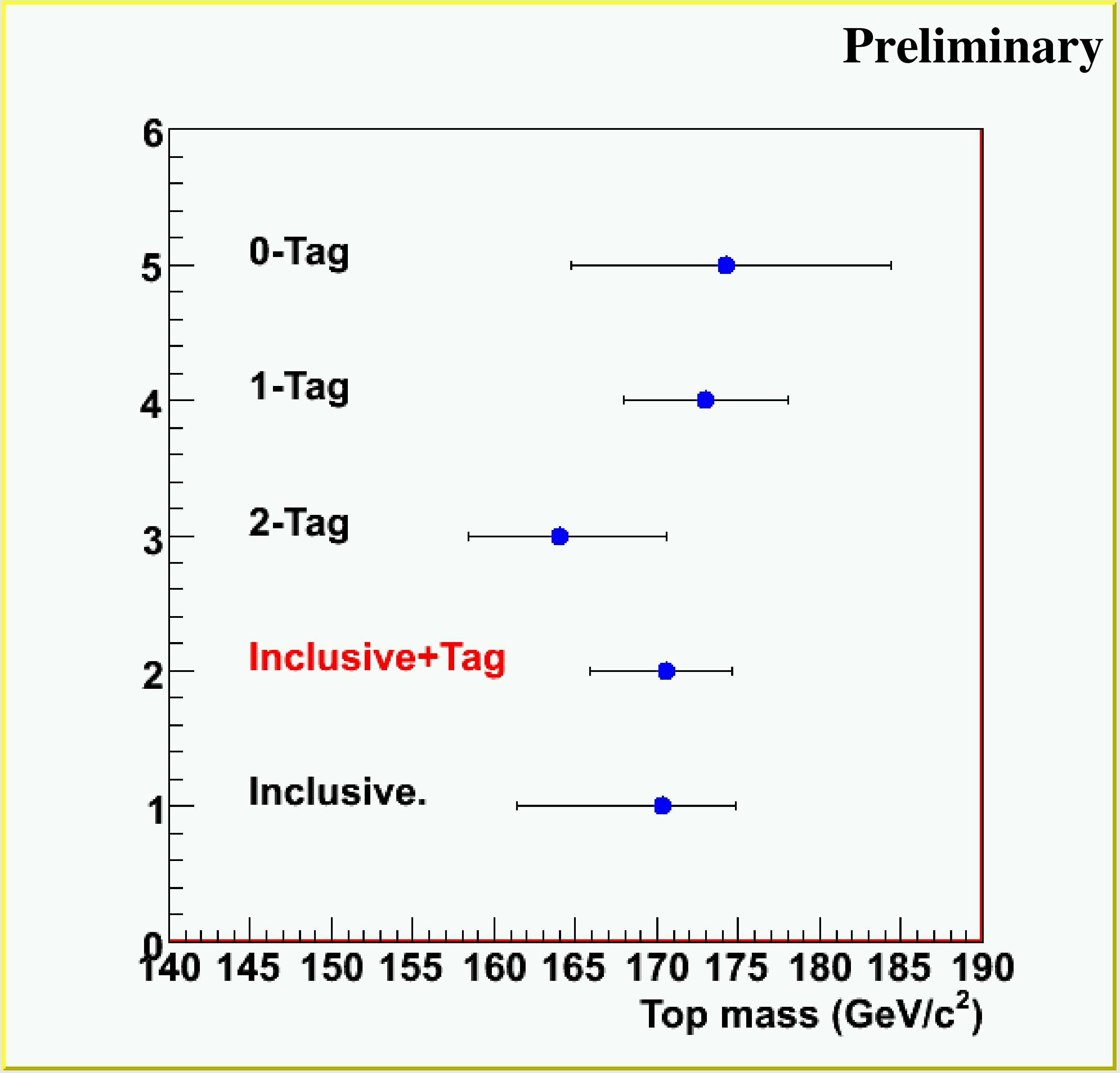
Signal fraction	+-0.12
QCD background	+-0.28
MC calibration	+-0.25

Top Mass Fit in 0, 1, and 2-Tag Samples





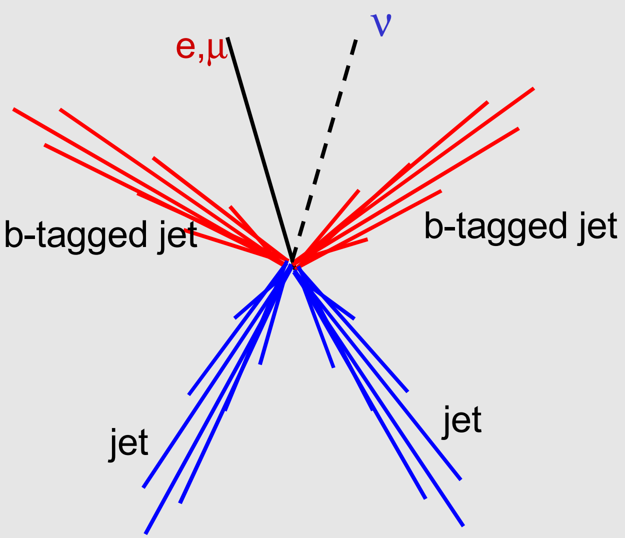




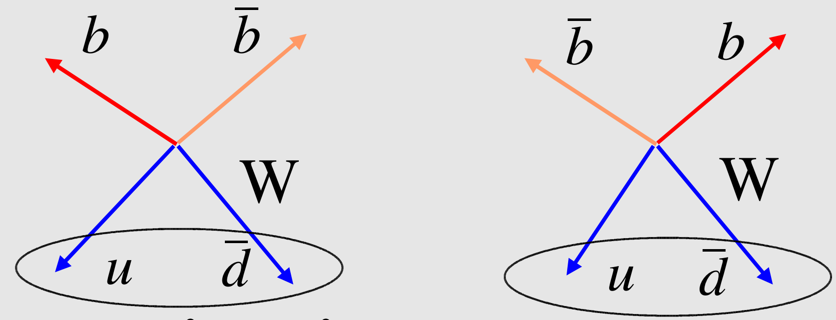
Improving the Precision of the Method

Example: **Double-Tag events:**

4 dominant terms:

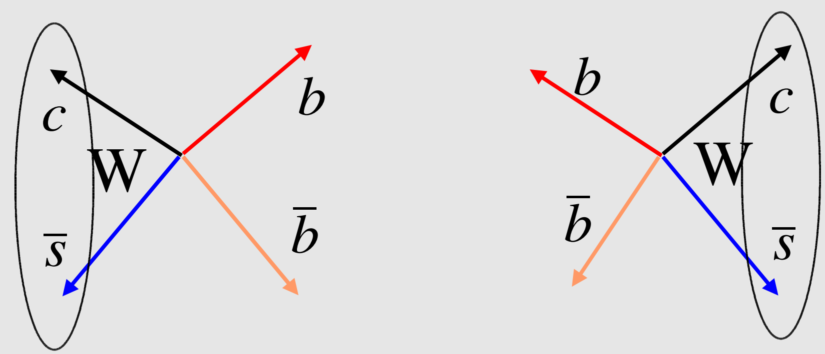


$\epsilon_b \sim 0.35, \quad \epsilon_c \sim 0.1, \quad \epsilon_l \sim 0.005$



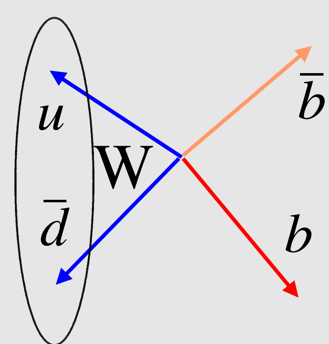
(84%)

$W_J = \epsilon_b^2 (1-\epsilon_l)^2$



(13%)

$W_J = \epsilon_b \epsilon_c (1-\epsilon_b)(1-\epsilon_l)$



. . .

(3%)

$W_J = \epsilon_l \epsilon_b (1-\epsilon_l)(1-\epsilon_b) \rightarrow 0$

Improving the Precision of the Method

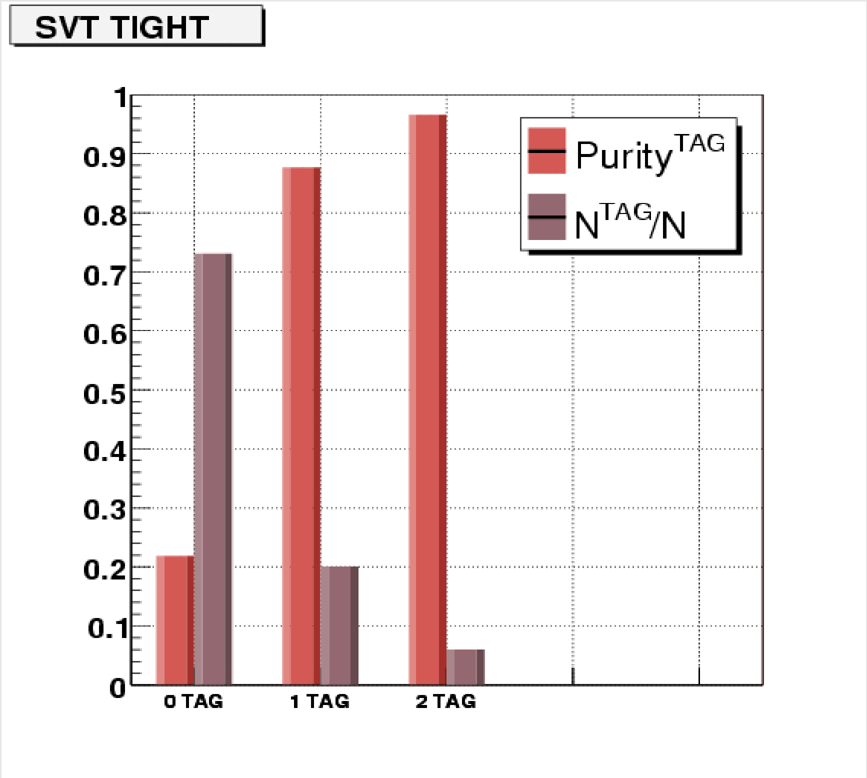
Use b-tagging to improve the statistical precision of the Matrix Element Method

b-tagging classifies events in 3 tag categories, with different S/B.

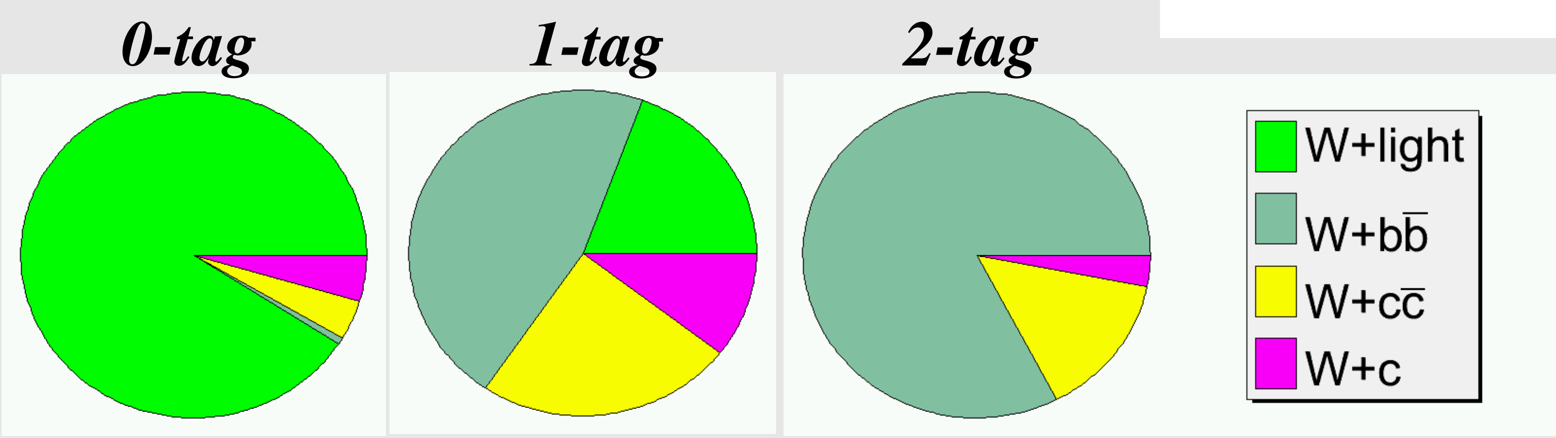
0-tag: 73%, $f_{top} = 22\%$

1-tag: 20%, $f_{top} = 88\%$

2-tag: 7%, $f_{top} = 97\%$,



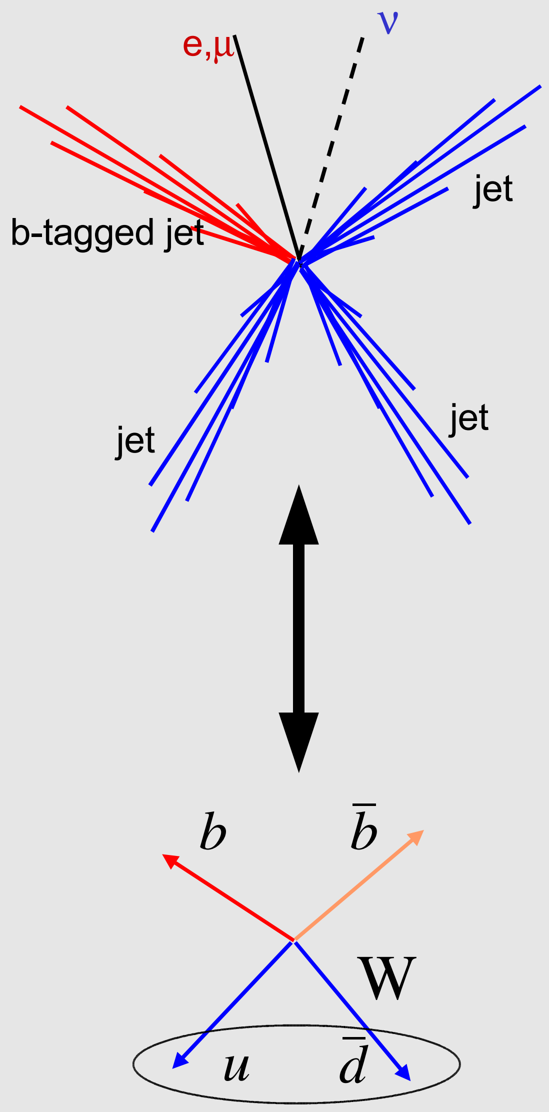
<u>W+jets flavor composition:</u>



Improving the Precision of the Method

b-tagging:

Weight each jet-parton assignment with b-tagging event probabilities.



$$P_{t\bar{t}}^{N-tag}(x;m_{top},JES)=\sum_J W_J^{t\bar{t}} P_{t\bar{t}}^J(x;m_{top},JES)$$

$$W_J^{t\bar{t}}=\frac{w_J^1 w_J^2 w_J^3 w_J^4}{\sum_K w_K^1 w_K^2 w_K^3 w_K^4}$$

$$w_J^i=\epsilon_{jet}(\alpha)(E_T,\eta) \quad tagged\ jets$$

$$w_J^i=(1-\epsilon_{jet}(\alpha)(E_T,\eta)) \quad untagged\ jets$$

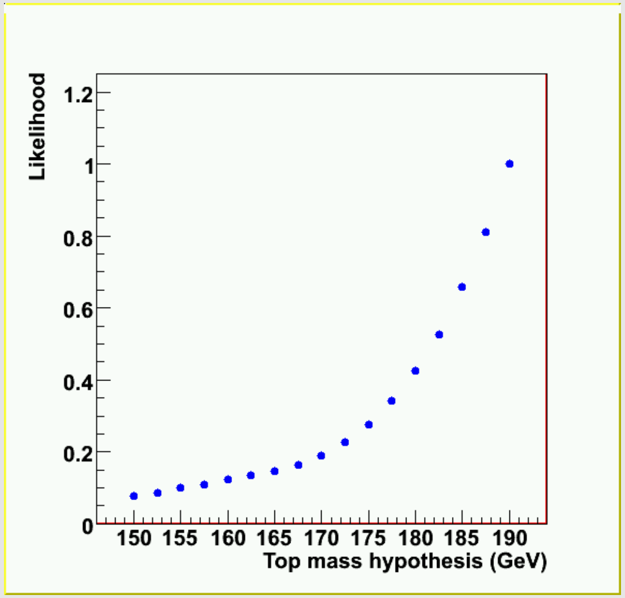
24 terms:

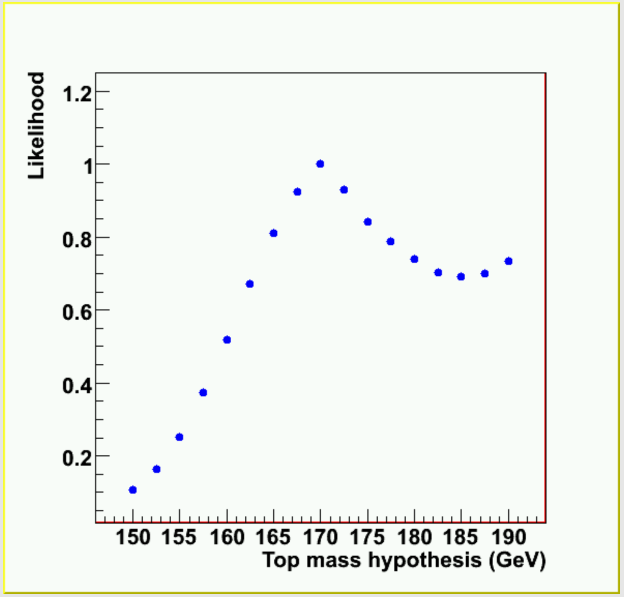
$\alpha=b,c,light$

12 from

W^+ 12 from $\bar{d}$

Data Events


Likelihood
0
0.2
0.4
0.6
0.8
1
1.2
150 155 160 165 170 175 180 185 190
Top mass hypothesis (GeV)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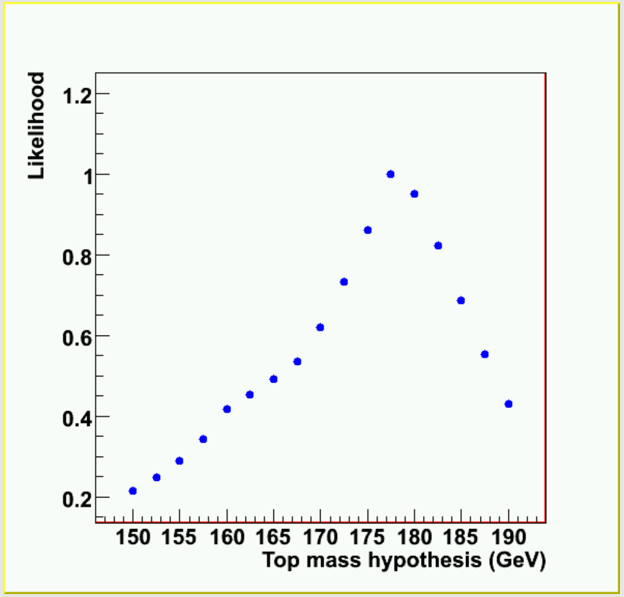
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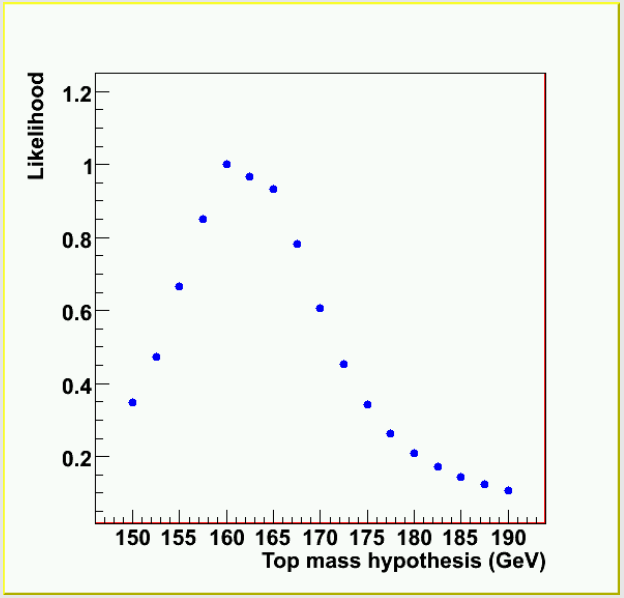
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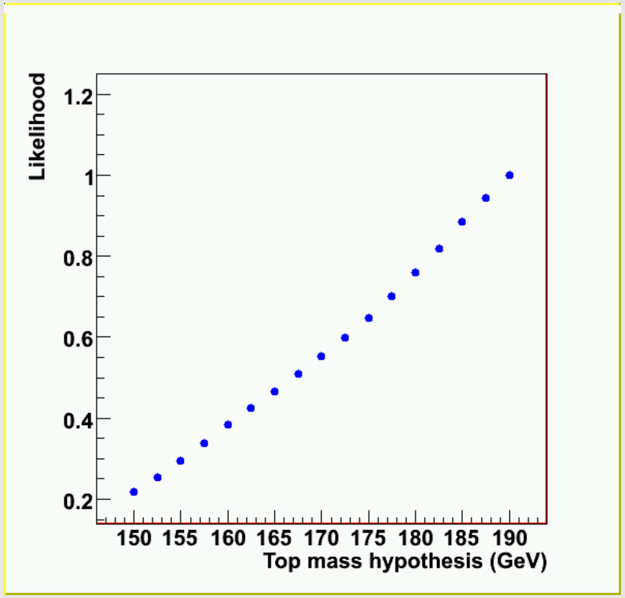
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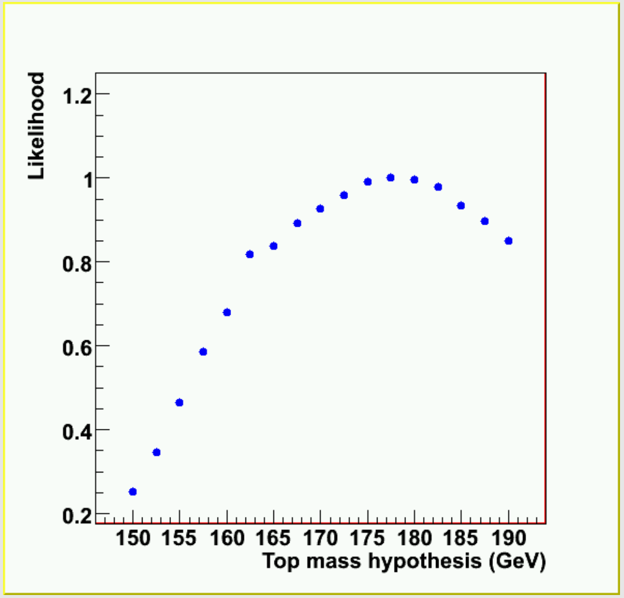
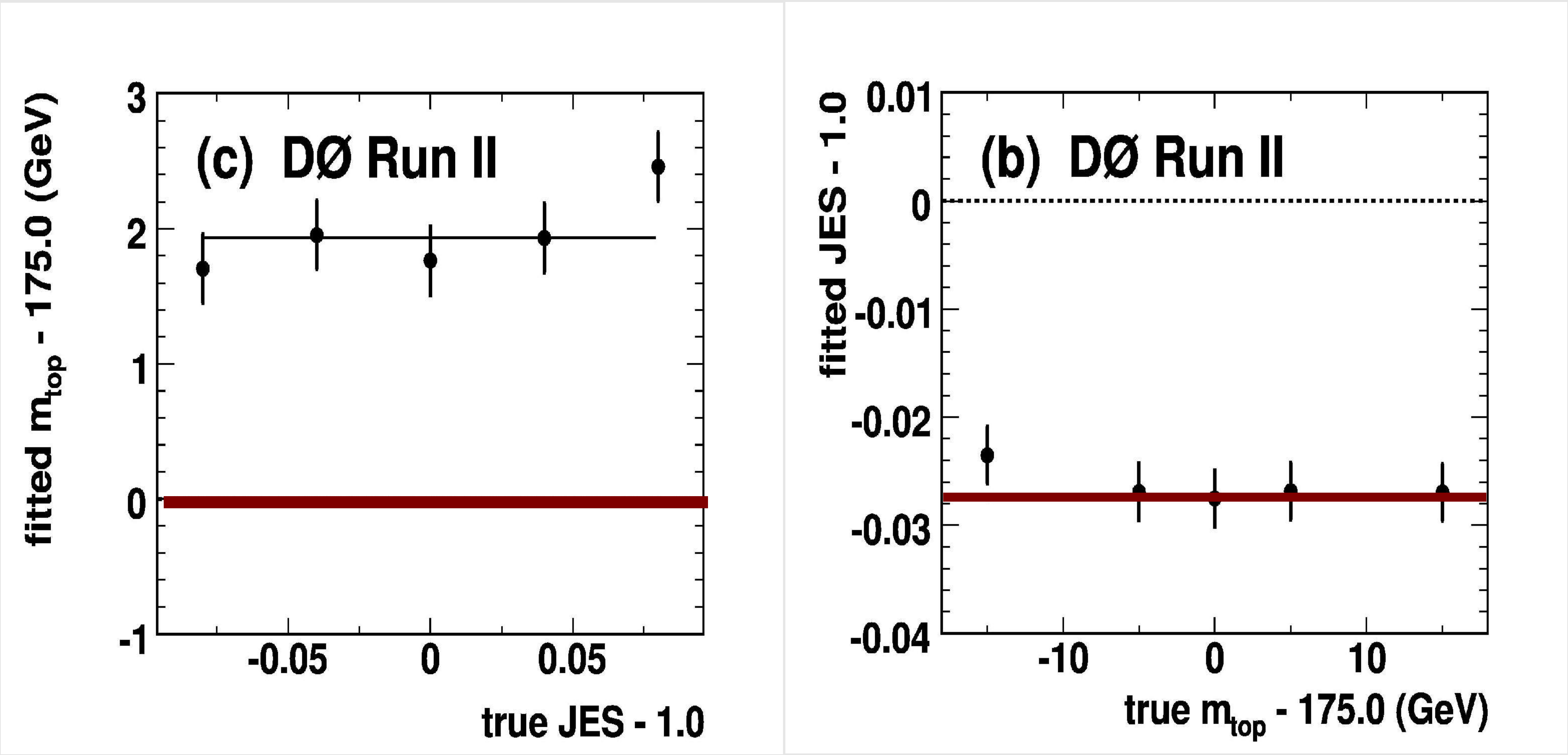

Likelihood
0.2
0.4
0.6
0.8
1
1.2
150 155 160 165 170 175 180 185 190
Top mass hypothesis (GeV)

JES Top Mass Correlation



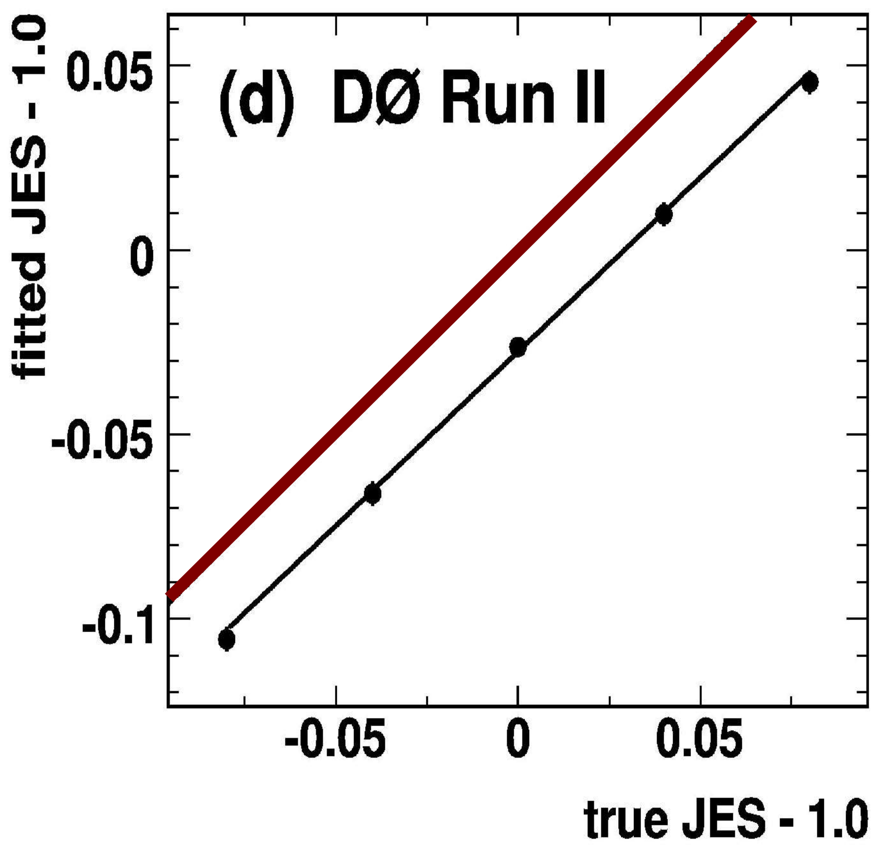
The slope is null for both top mass dependence on JES and JES dependence on mass.

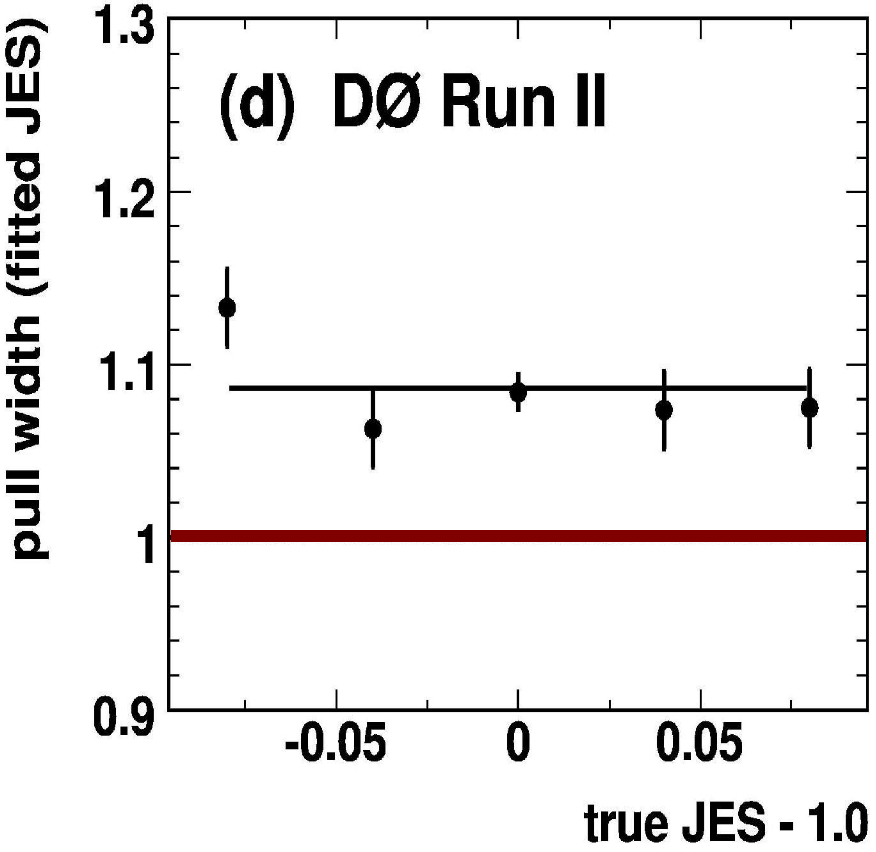
JES Calibration

offset = -0.028 +- 0.001 GeV

slope = 0.945 +- 0.021

pull width = 1.09+- 0.01





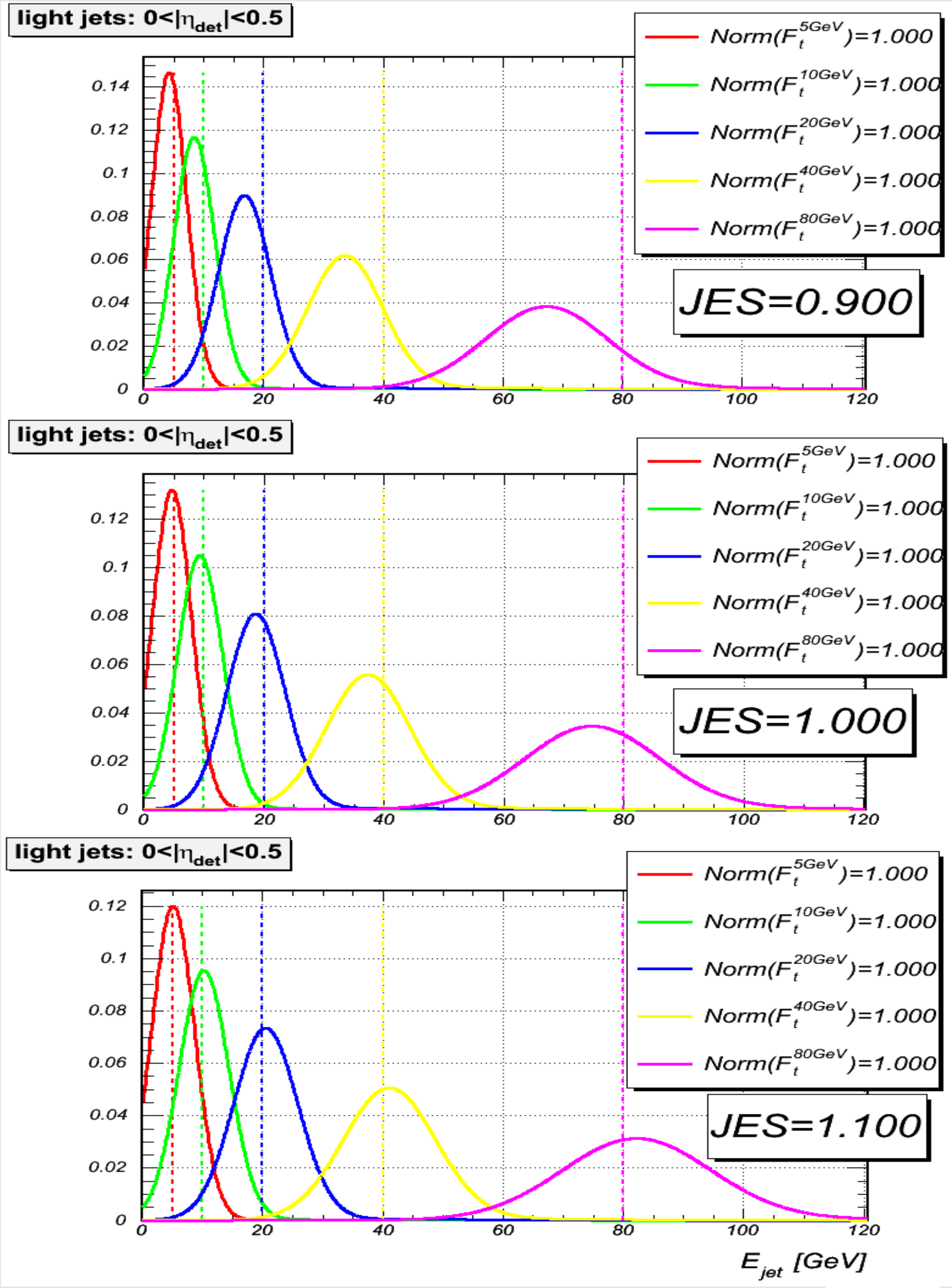
1000 full-simulated pseudo-experiments

Transfer Function

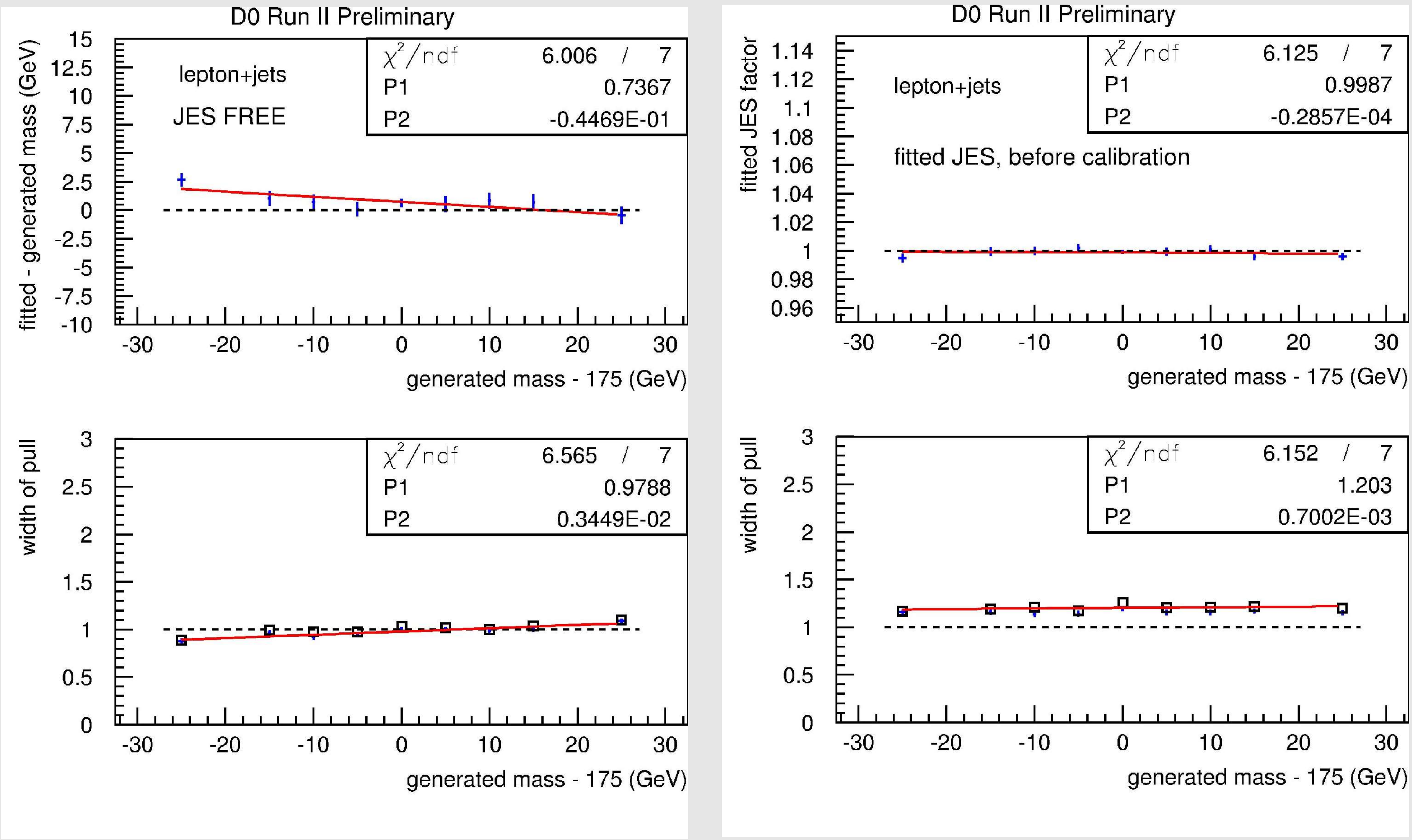
The transfer function ***W(x,y; JES)*** relate the individual top pair decay products at parton level ***y*** to the measurements ***x*** in the detector.

Assume perfect measurements for:
- Angles of all jets and lepton.
- Energy of the electron.

$$W(E_j, E_p, JES) \,.\qquad \frac{W\left(\frac{E_j}{JES}, E_p\right)}{JES}$$

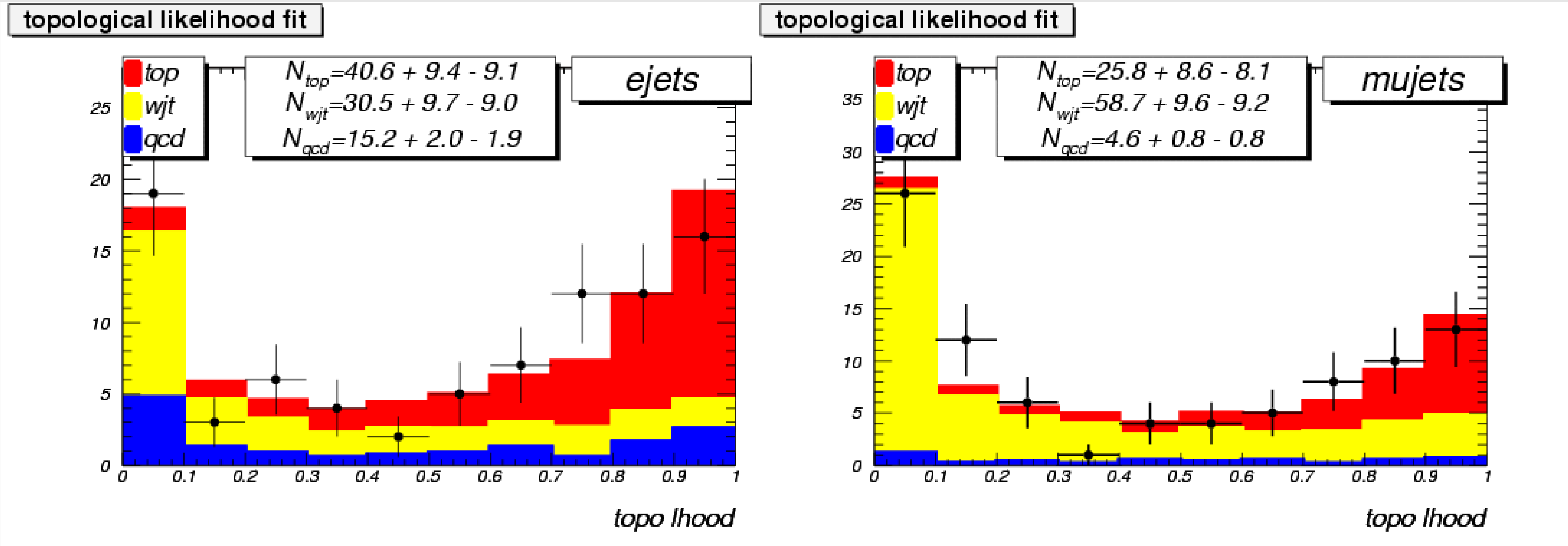


Top Mass Using the Ideogram Method



Sample Composition

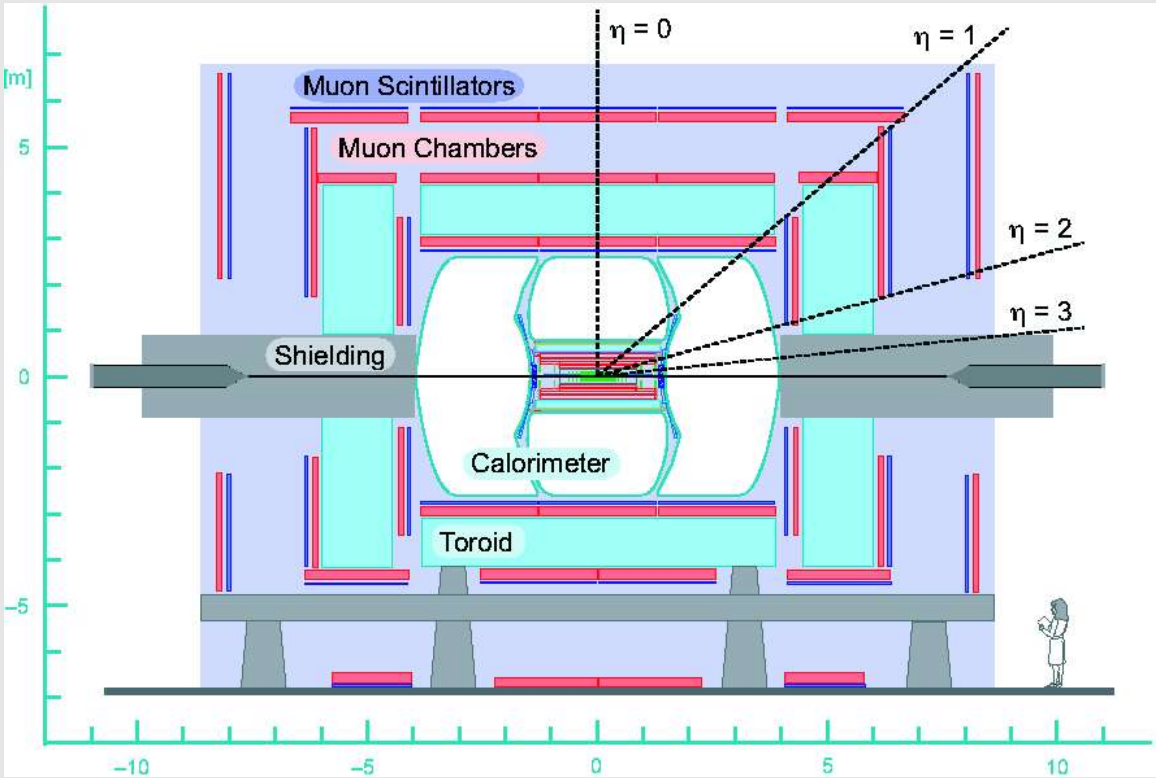
The sample composition is measured using a likelihood discriminant based on topological event variables (HT, Centrality, Aplanarity, Sphericity)

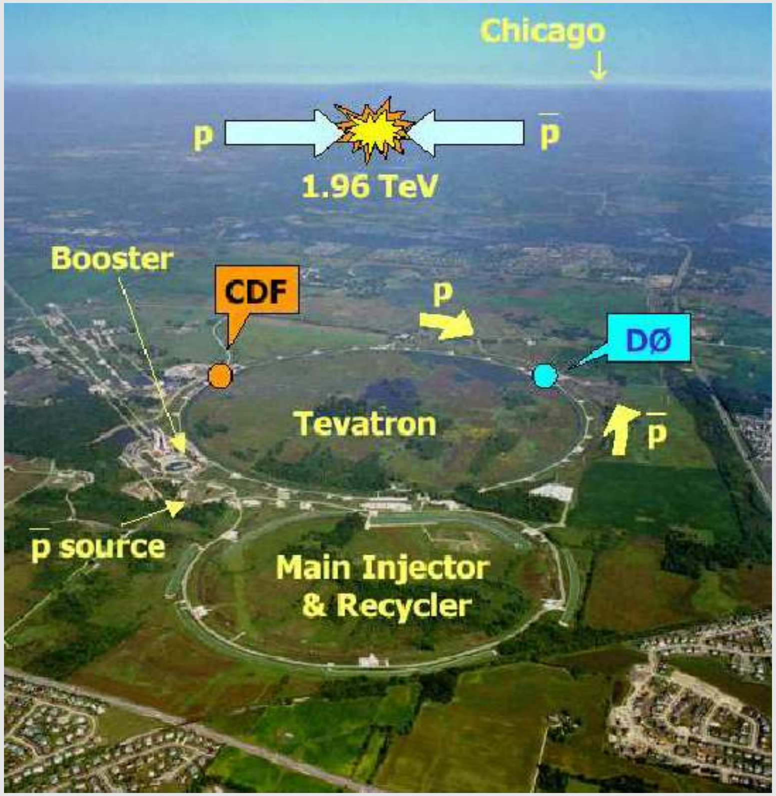


	e+jets	mu+jets
Number of events	86	89
Signal fraction	47+/-12%	29+/-10%

Fitted top quark fraction is not used for the top mass measurement.

The DZero Detector and the Tevatron





Tracking:

Silicon vertex detector (SMT)
Central Fiber Tracker (CFT)
2 T Superconducting Solenoid.
$|\eta| < 2.5$

Preshowers

EM/HAD Calorimeter:

Central, $|\eta|<1.1$
Forward, $|\eta|<4.2$

Muon system:

1.8 T iron toroids.
$|\eta|<2.0$

3-Level trigger system:

Level 1 (hardware): 2 kHz
Level 2 (hardware): 1 kHz
Level 3 (software): 50 Hz