Measurement of the Top Quark Mass at DZero

Carlos Garcia
University of Rochester
for the D0 colaboration

APS Meeting
April-2006

Outline

Introduction:

Top quark at the Tevatron.

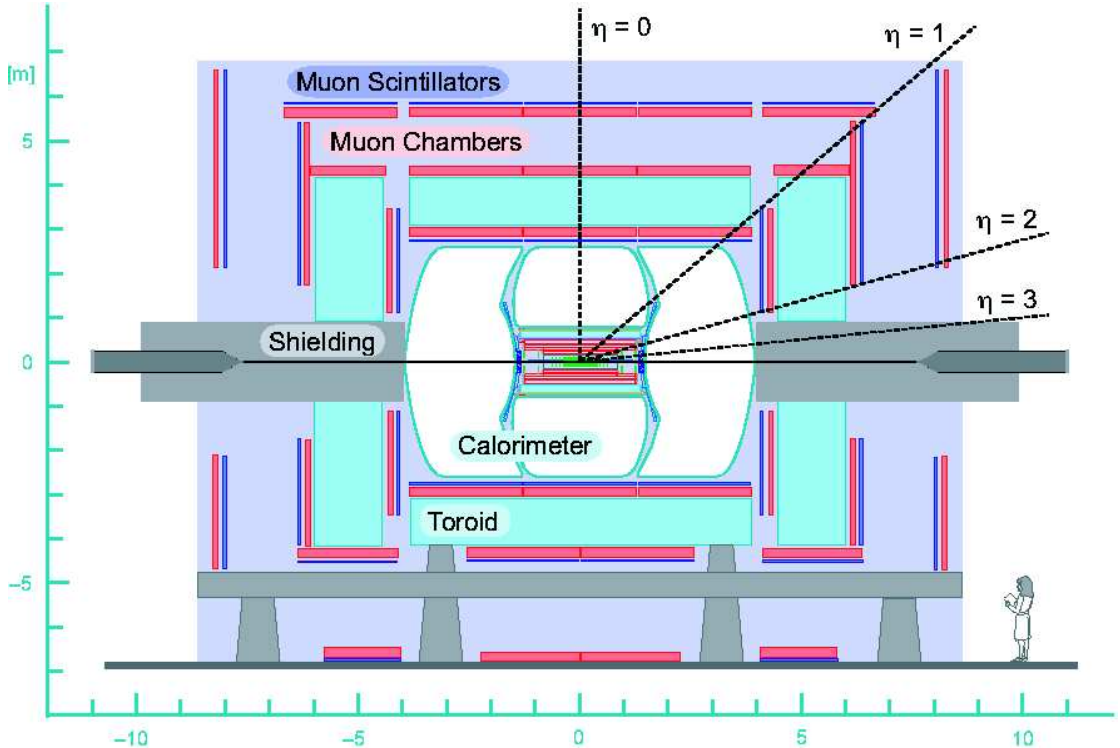
Top quark mass measurement method:

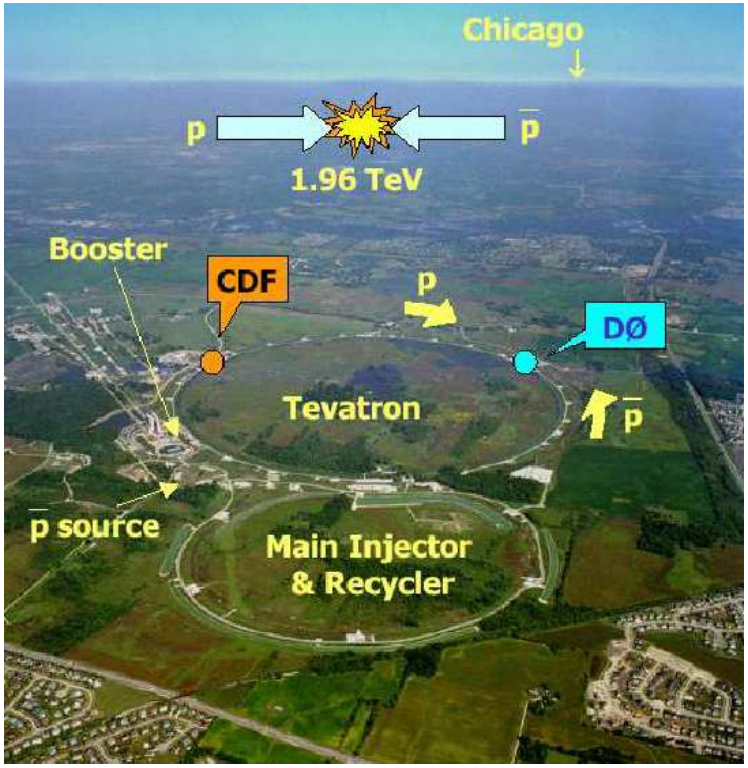
The Matrix Element Method.

Top quark mass measurement results:

Precision improvements by using b-tagging.

The DZero Detector and the Tevatron





Tracking:

Silicon vertex detector (SMT)

Central Fiber Tracker (CFT)

2 Tesla magnetic field.

|eta| < 2.5

Preshowers

EM/HAD Calorimeter:

Central, |eta|<1.1

Forward, |eta|<4.2

Muon system:

|eta|<2.0

3-Level trigger system:

Level 1 (hardware): 1.5KHz

Level 2 (hardware): 850Hz

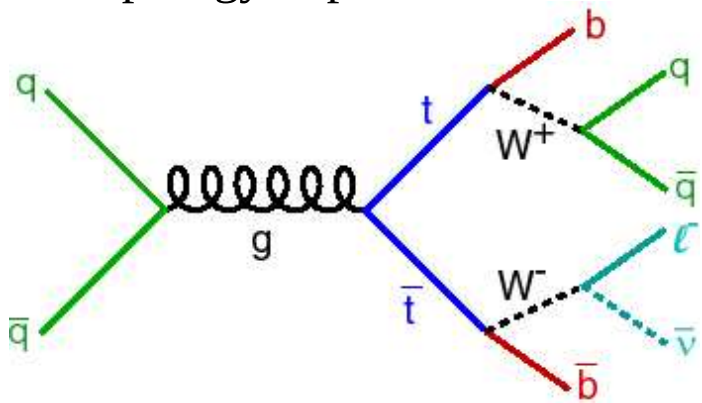
Level 3 (software): 50Hz

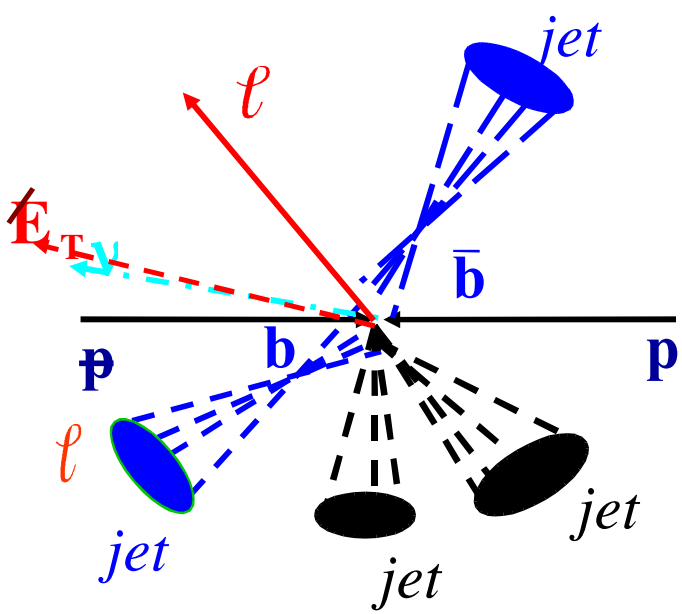
Top Quark

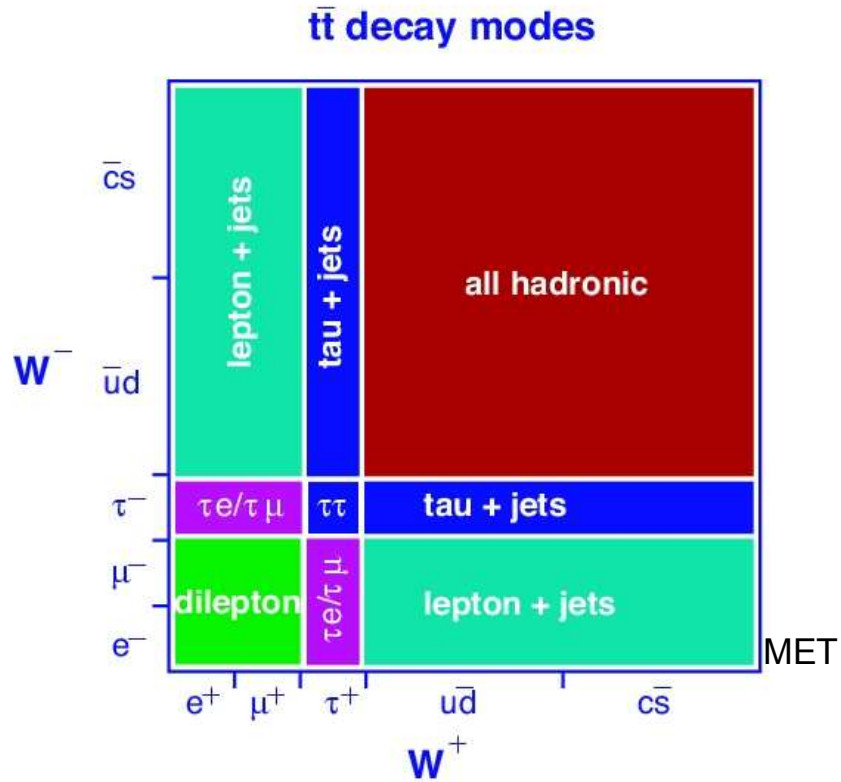
At the Tevatron, top quarks are primarily produced in pairs via the strong interaction. Since $|V_{tb}| \sim 1$, the top quark almost always decays to *Wb*

(Ws, Wd CKM suppressed)

Event topology depends on the *W* decay mode





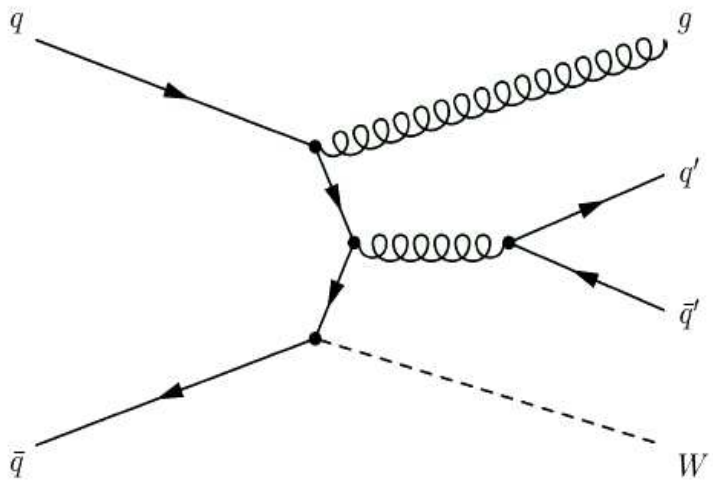


Experimental signature in the lepton+jets channel:

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

Top Quark Identification

Background Processes:

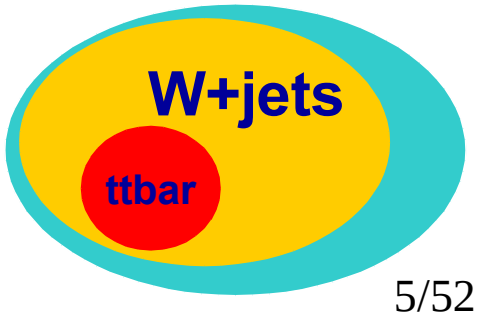


W+jets production.

- 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

Multi-jet events:

- jet mis-identified as a lepton and fake missing transverse energy



The Matrix Element Method - I

We calculate a probability per event to be signal or background as a function of the top mass.

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:

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

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

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

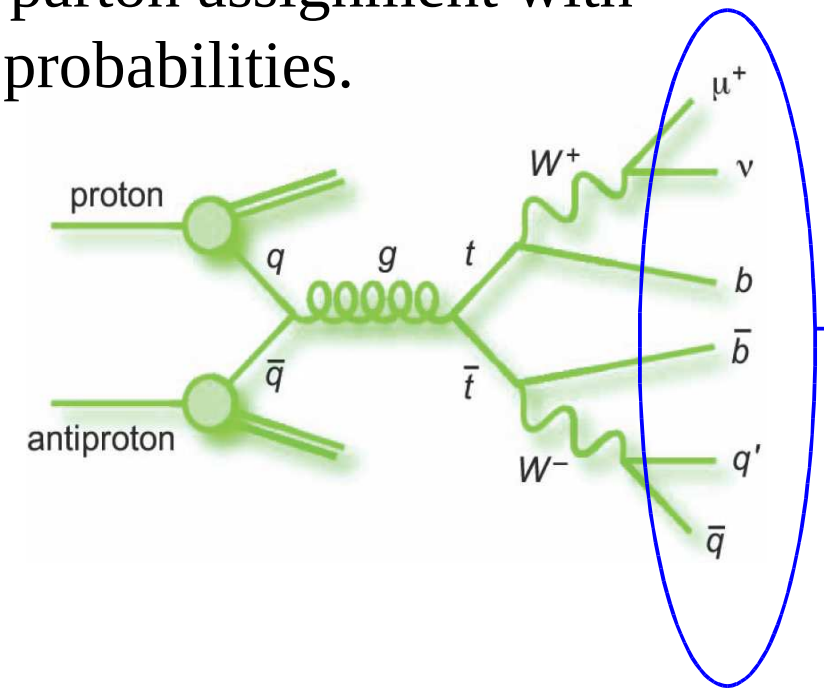
Overall JES is a free parameter in the fit, constrained in situ by the mass of the W decaying hadronically

Measurements: jets and leptons

The Matrix Element Method - II

b-tagging:

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



Six particle final state

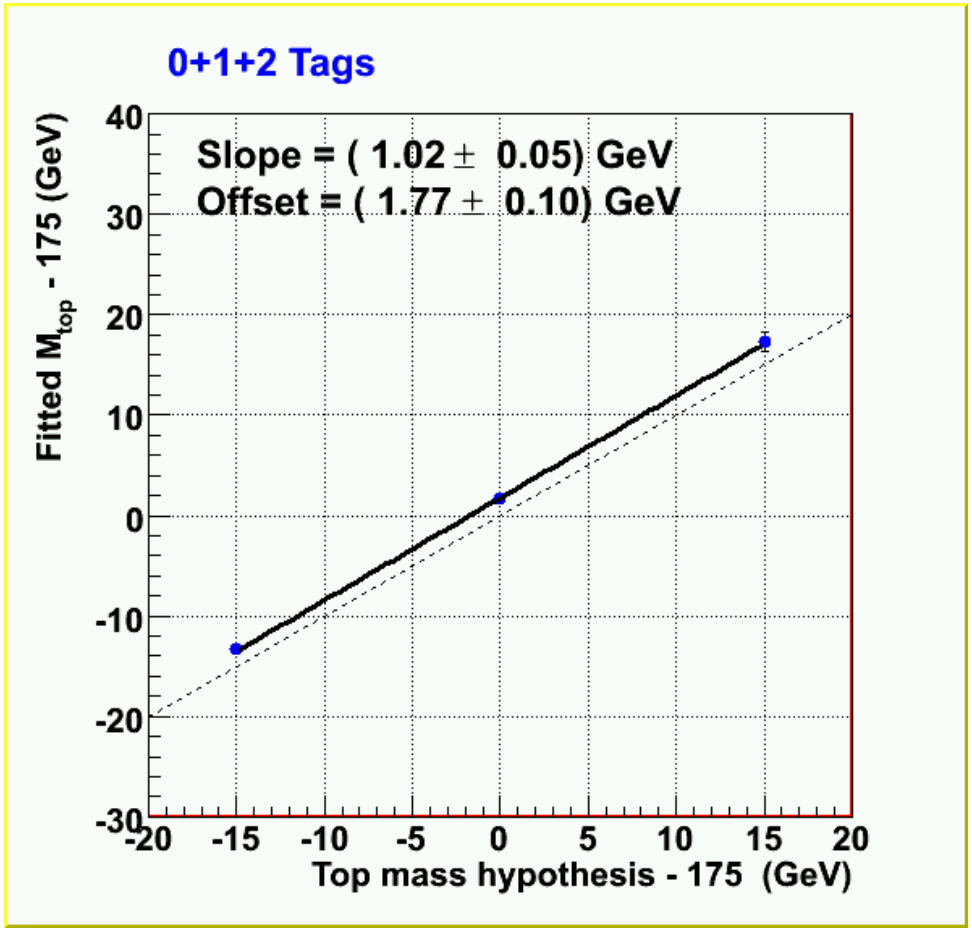
24 possible weighted assignments between jets and partons

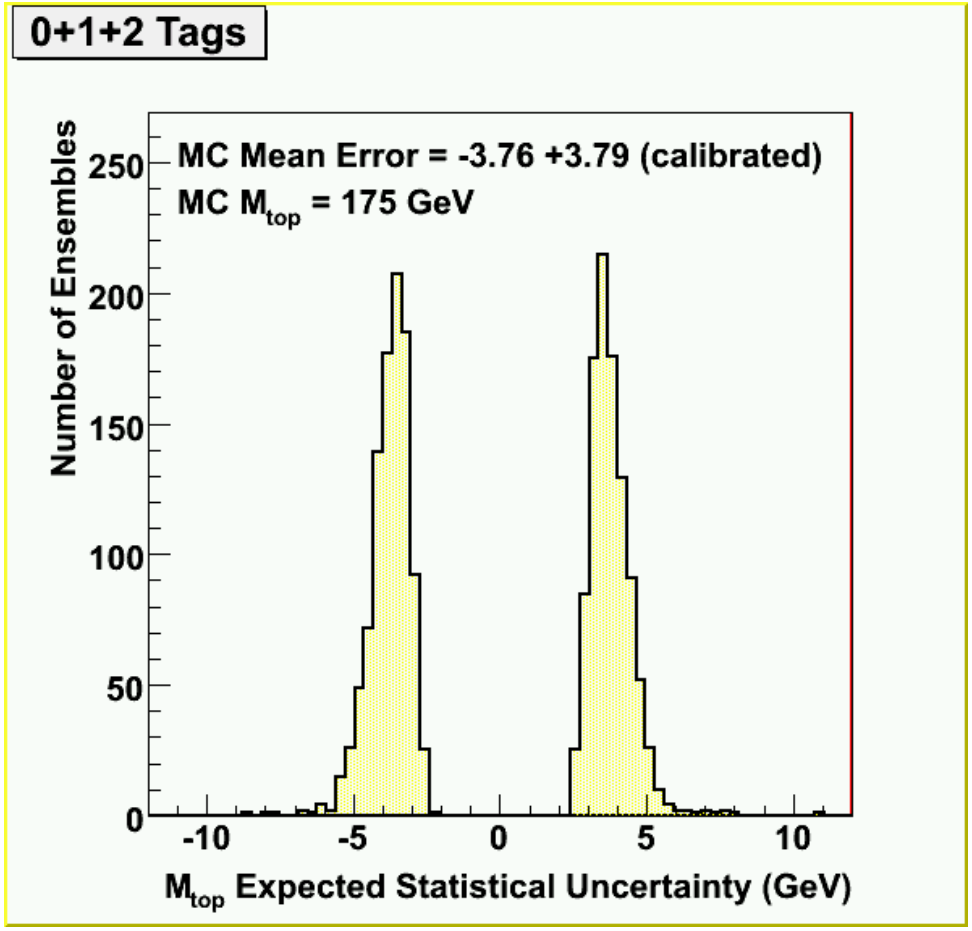
$$P_{t\bar{t}}^{N-tag}(x;m_{top},JES)=\sum_J W_J^{t\bar{t}} P_{t\bar{t}}^{J}(x;m_{top},JES)$$

f_{top}: signal fraction is fitted simultaneously

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

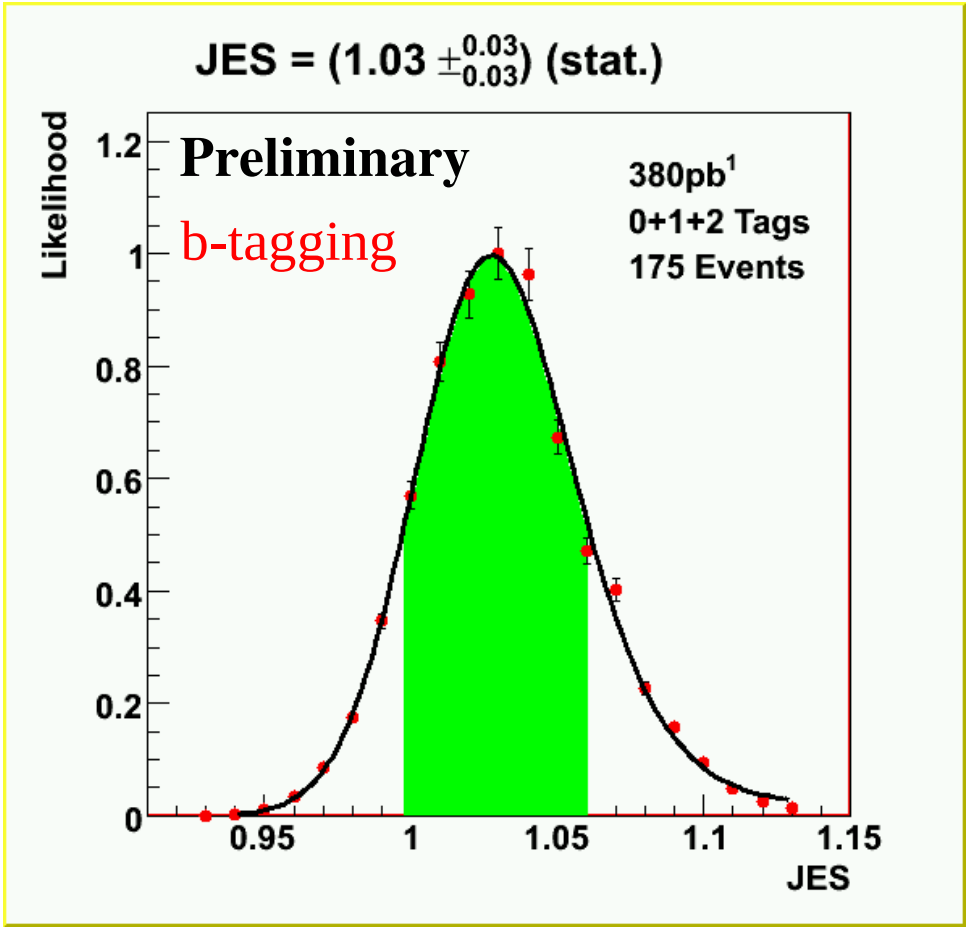
Top Mass Calibration

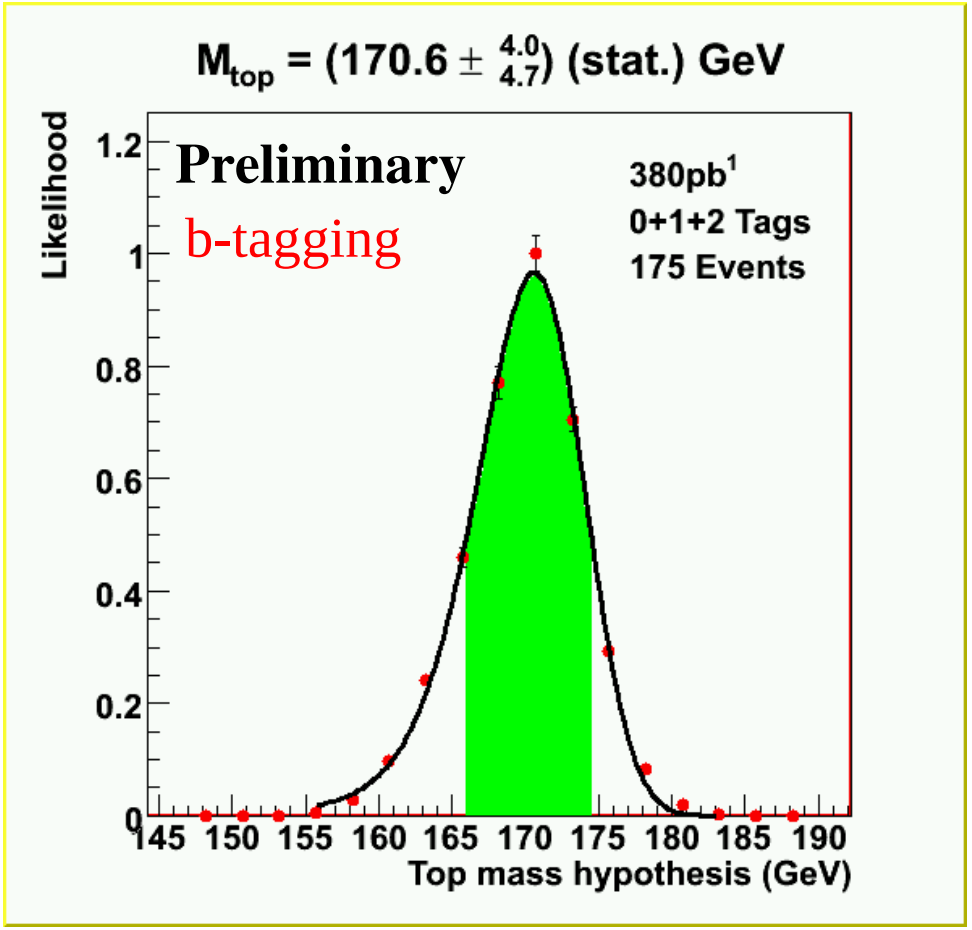




1000 full-simulated pseudo-experiments

Top Mass Fit in 380pb^{-1} lepton+jets Data

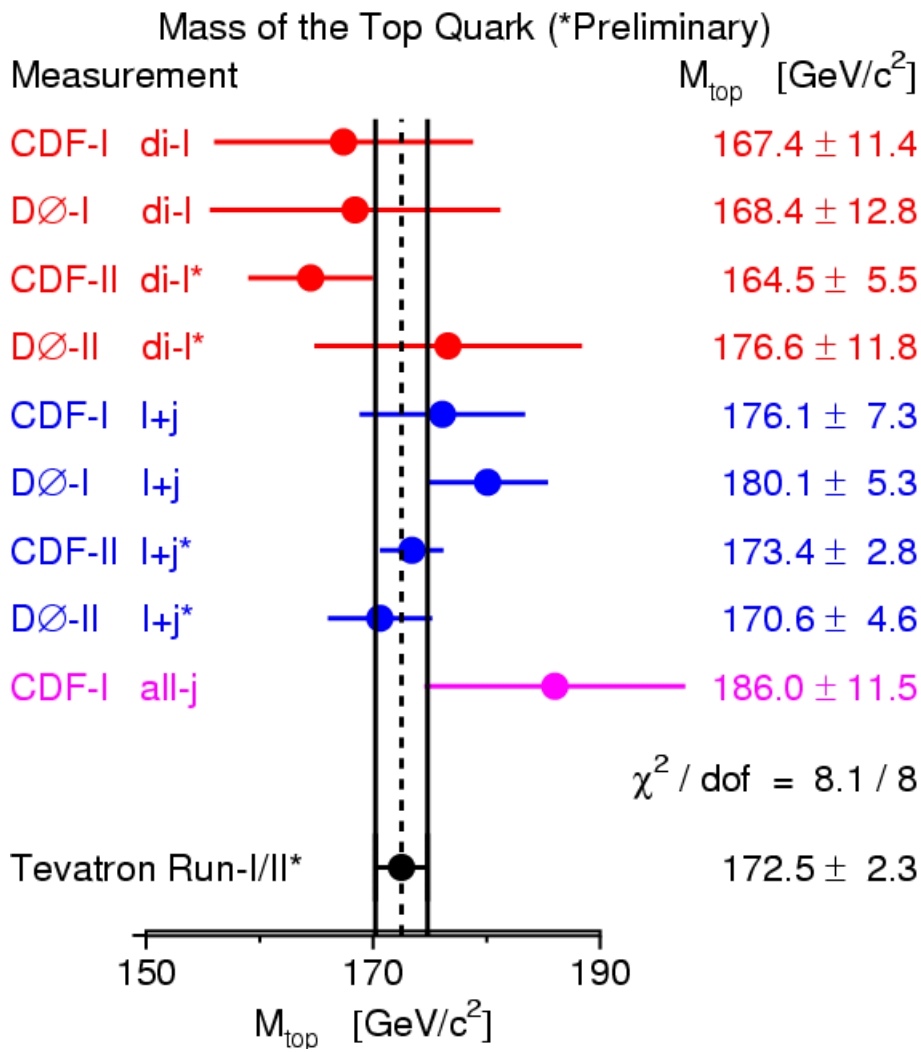




Measured JES is consistent with the reference scale (JES=1)

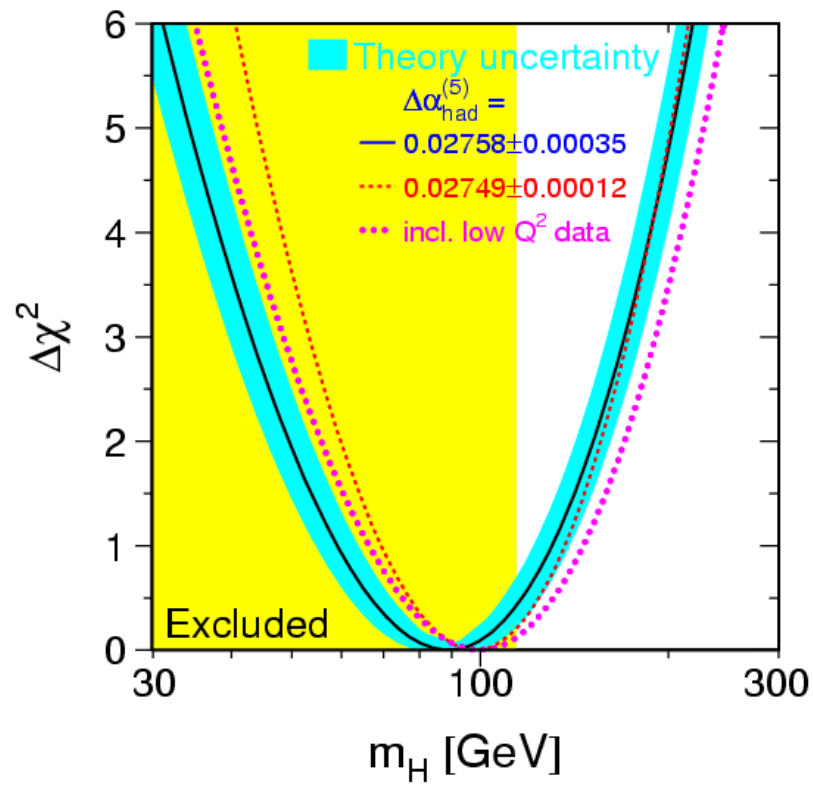
The use of b-tagging information improves the top quark mass statistical error by 35% (17% expected from simulation)

Top Mass Measurement Current Status



$$M_{top} = 172.5 \pm 2.3\, GeV/c^2$$

Impact on Standard Model Higgs boson:



$$M_H = 89^{+42}_{-30}\, GeV\,; \quad M_H < 175\, GeV \text{ @ } 95\ CL$$

Begging to rule out $H \rightarrow ZZ$

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 significantly improved after adding b-tagging information to the Matrix Element technique:

A new improved measurement of the top quark mass allow us to reach the 1.3% precision (Combined DZero+CDF measurement)

Backup Slides

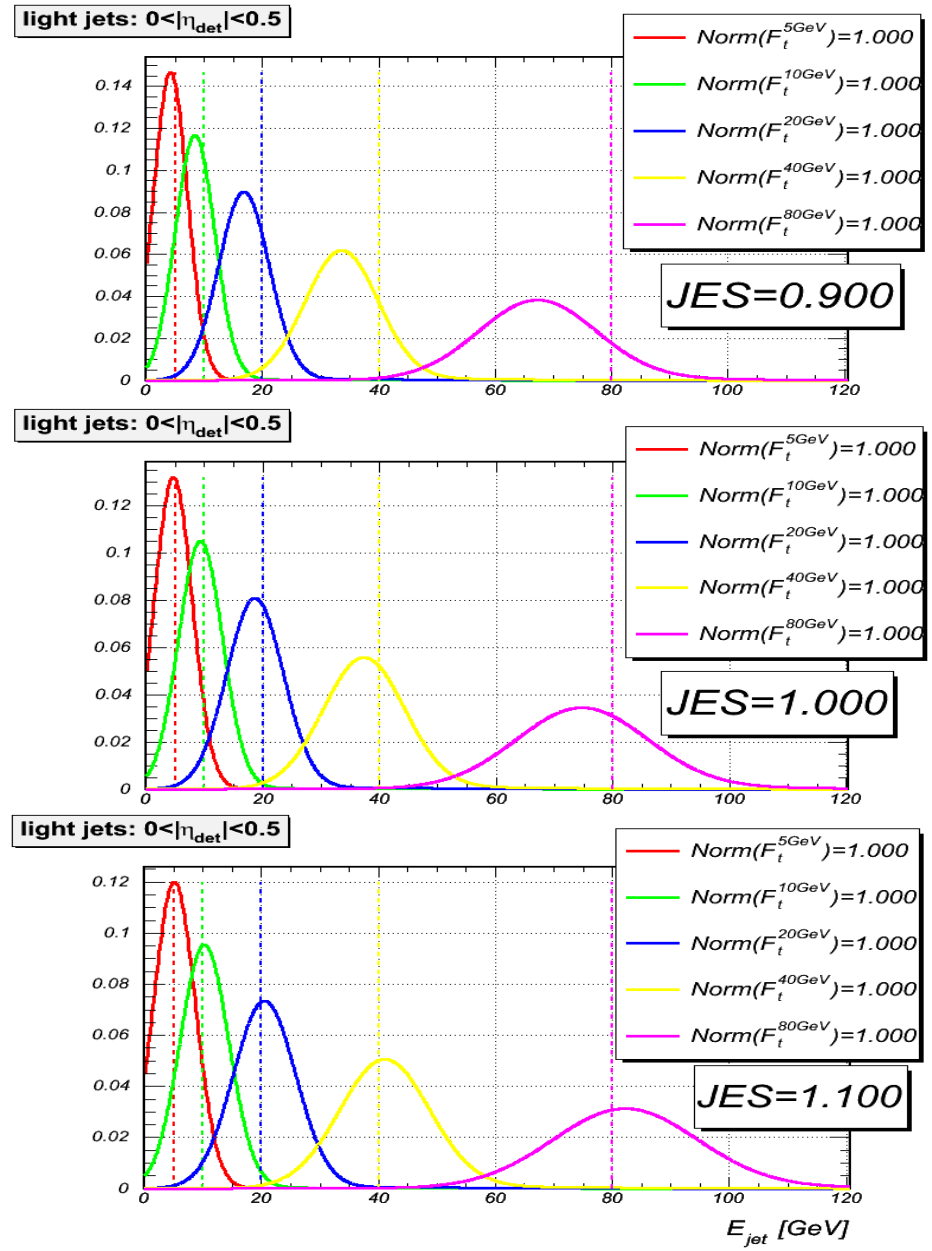
Transfer Function

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.

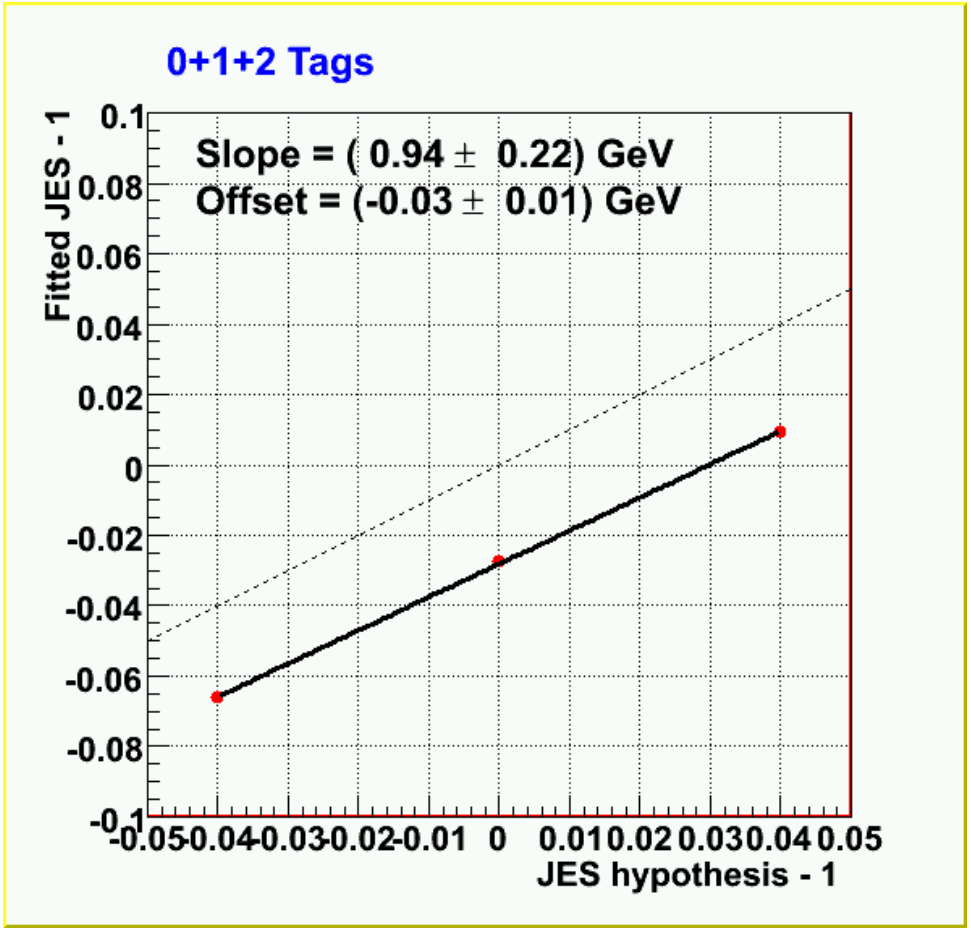
Assume perfect measurements for:

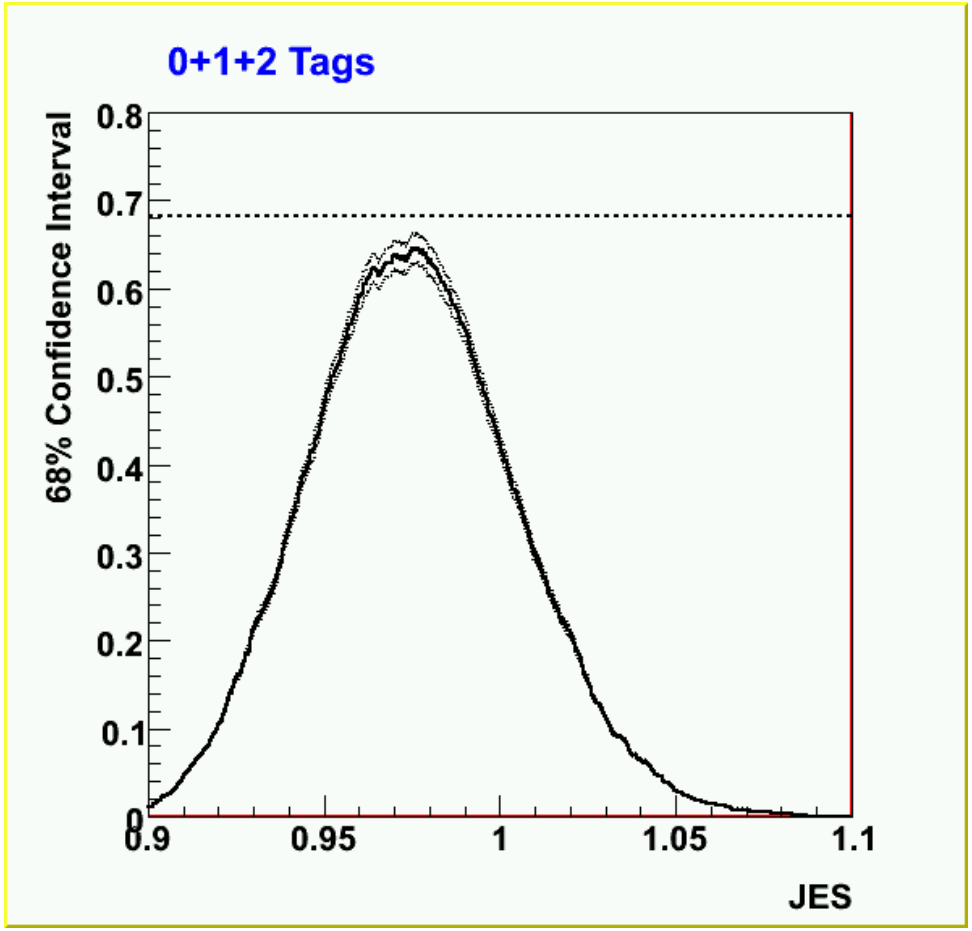
- Angles of all jets and lepton.
- Energy of the electron.

$$W(E_j, E_p, JES) \cdot \frac{W(\frac{E_j}{JES}, E_p)}{JES}$$

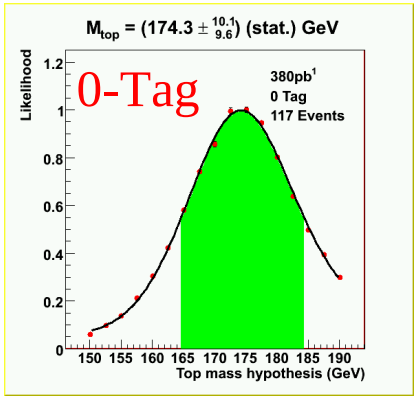


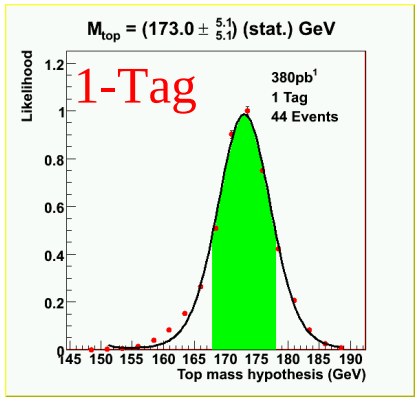
Jet Energy Scale Calibration

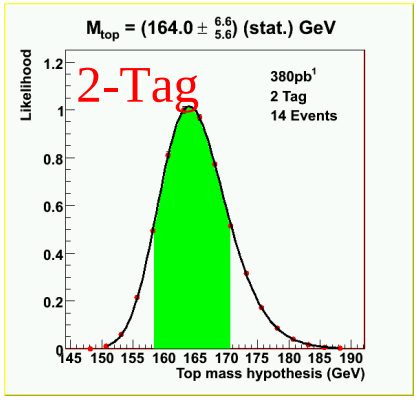


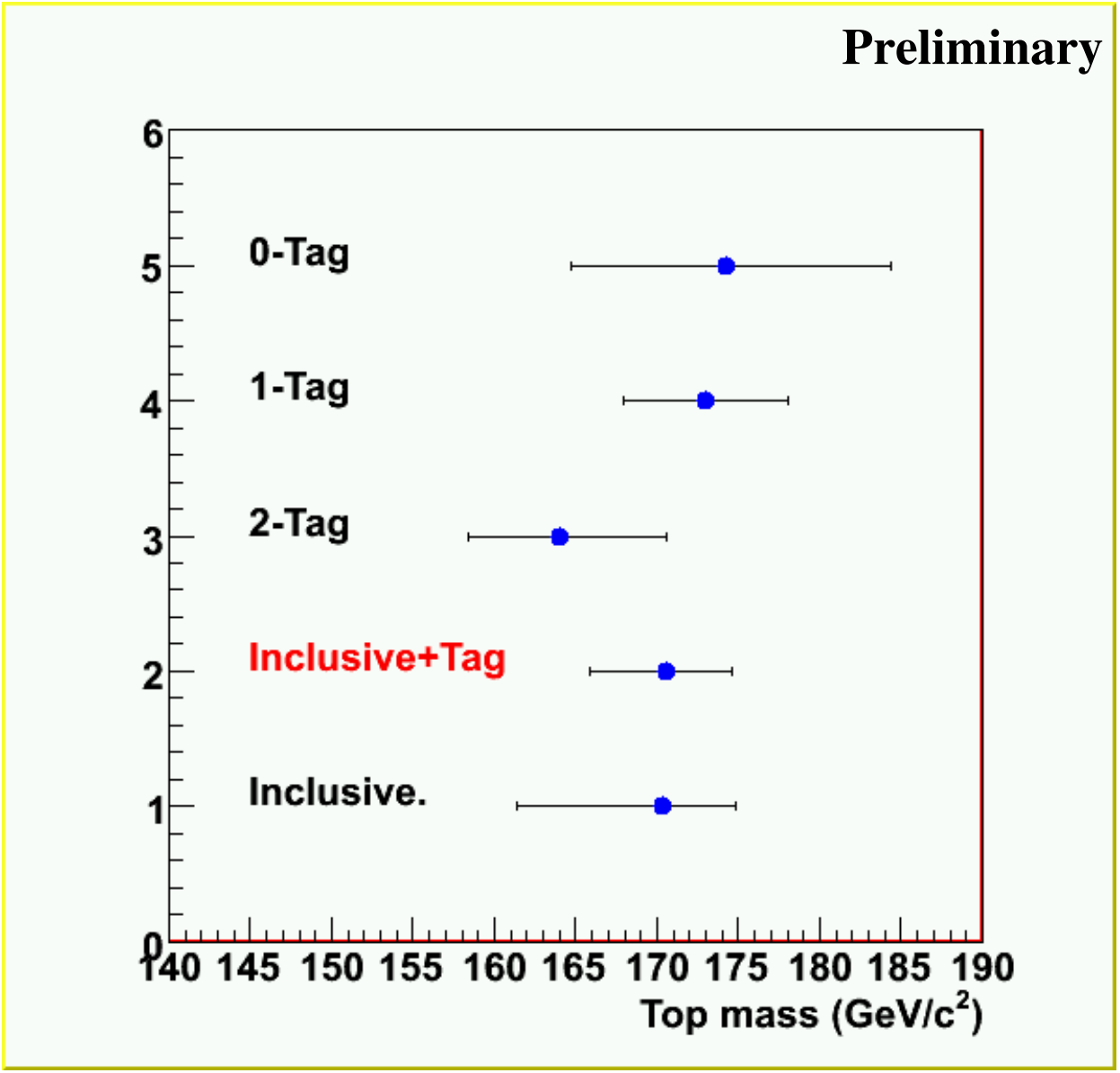


Top Mass Fit in 0, 1, and 2-Tag Samples

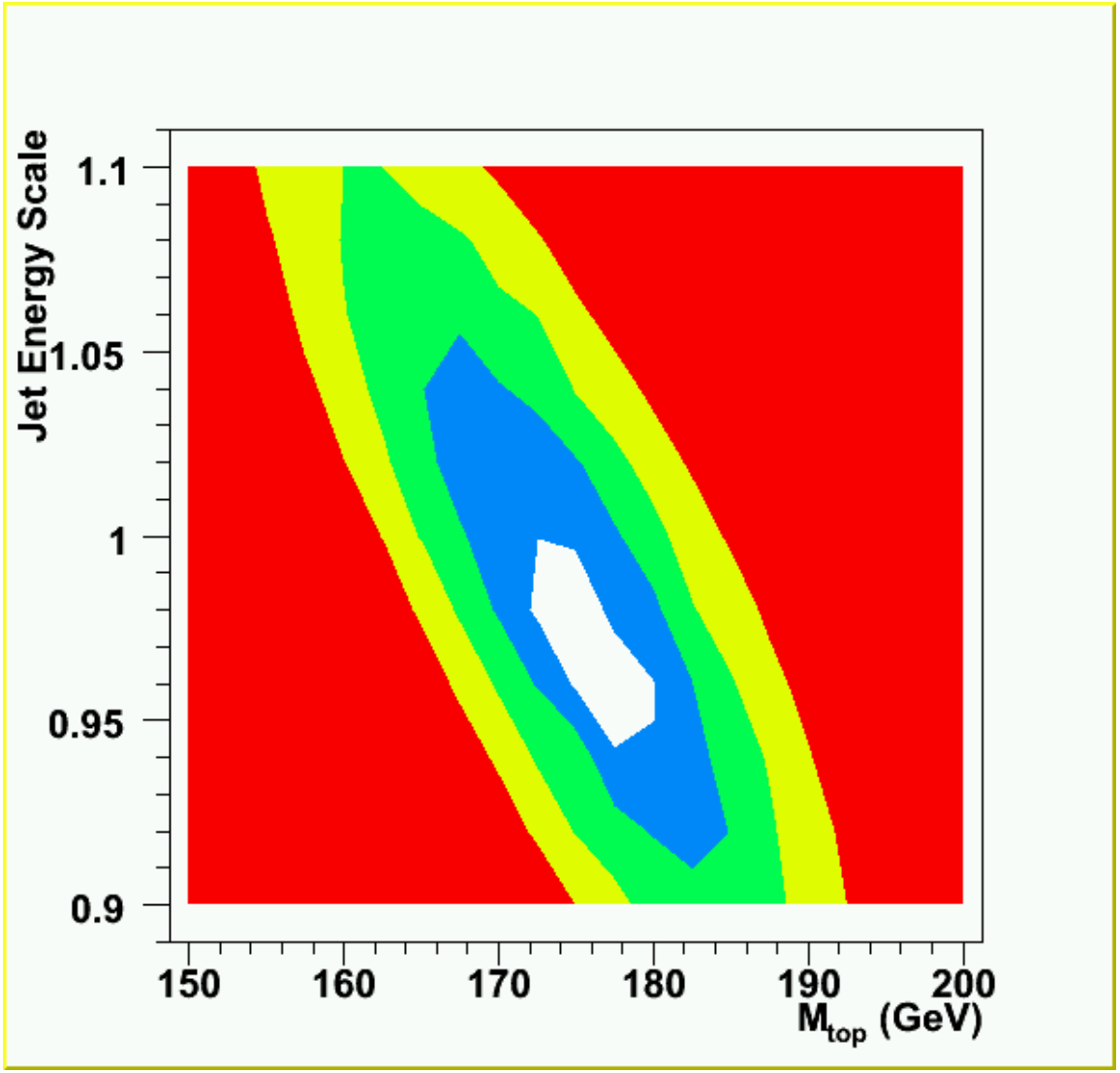


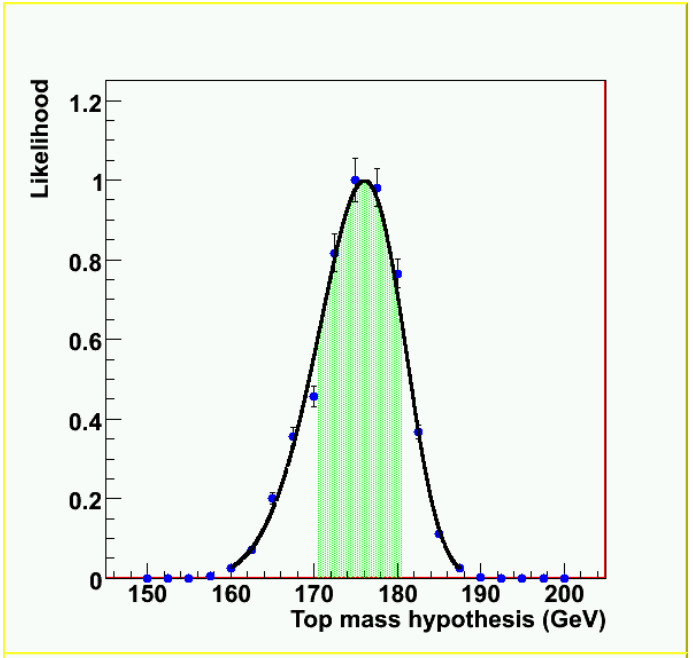


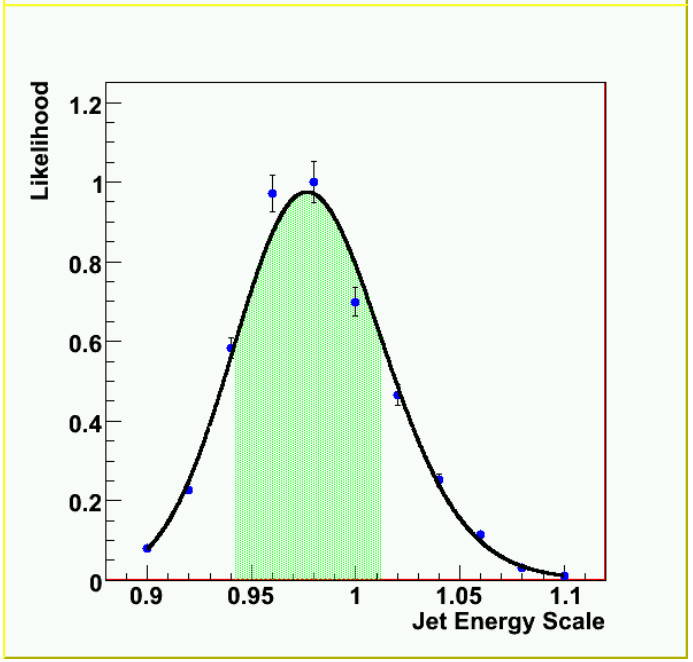




Example of 2D Top Mass – JES Fit





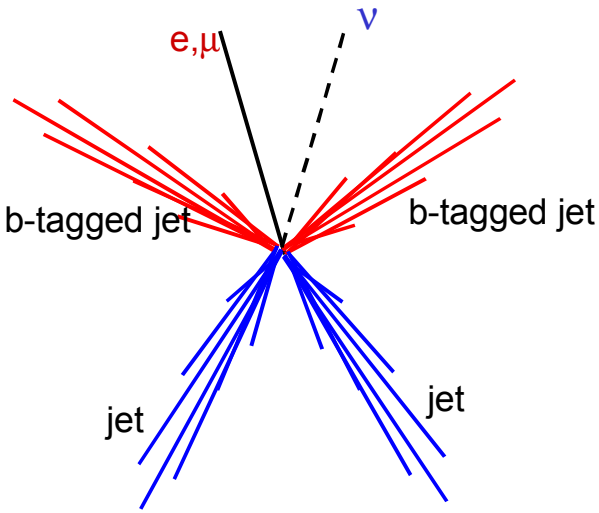


200 simulated events (m_t = 175 GeV)

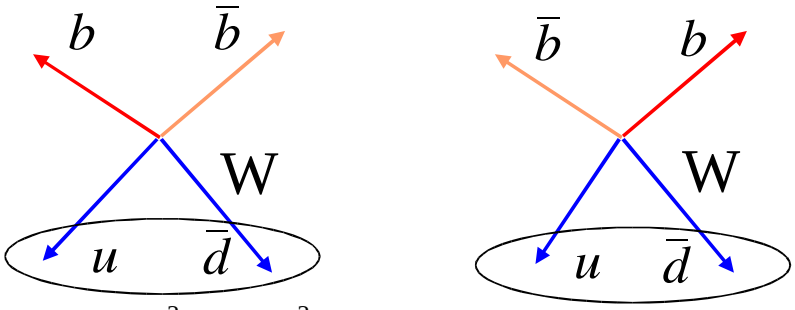
Improving the Precision of the Method (IV)

Example: **Double-Tag events:**

4 dominant terms:

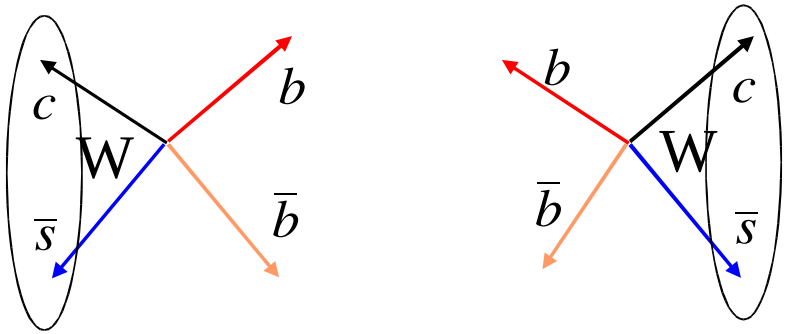


$\epsilon_b \sim 0.35, \quad \epsilon_c \sim 0.1, \quad \epsilon_l \sim 0.005$



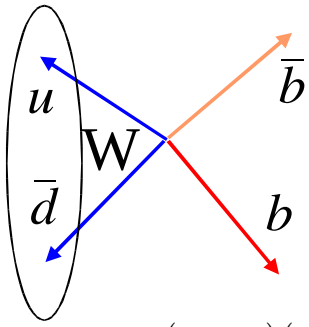
(84%)

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



(13%)

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

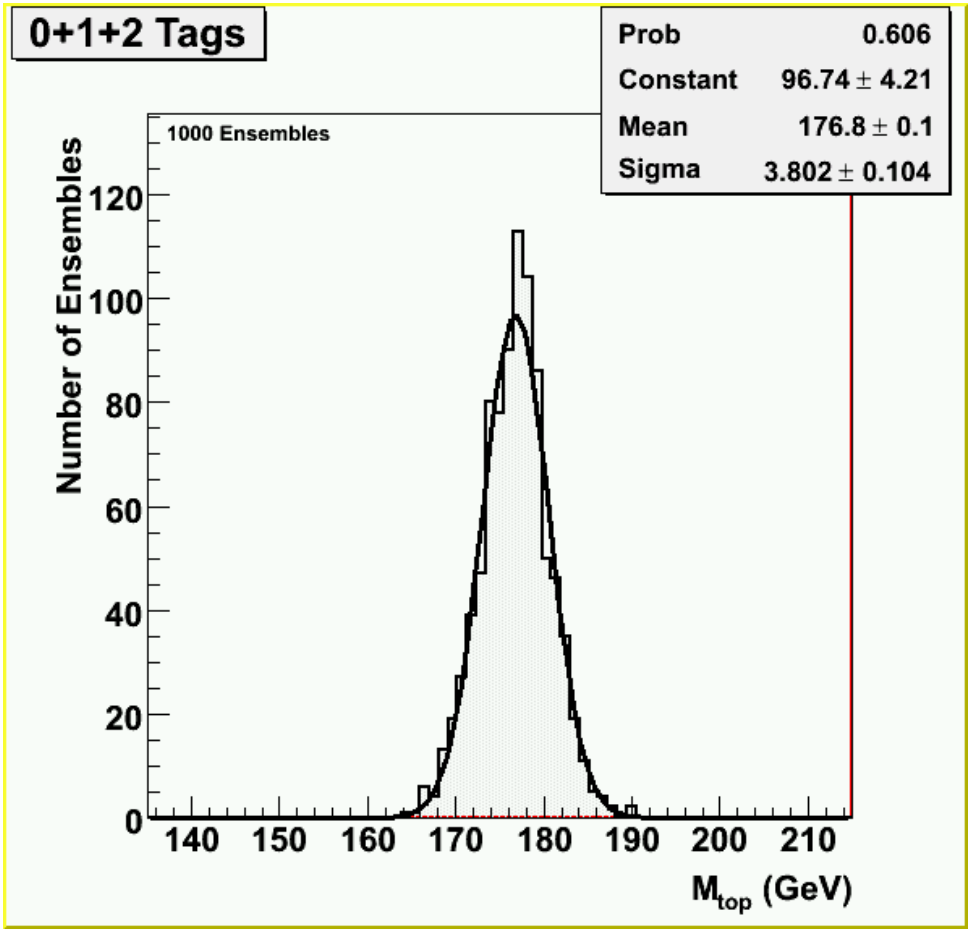


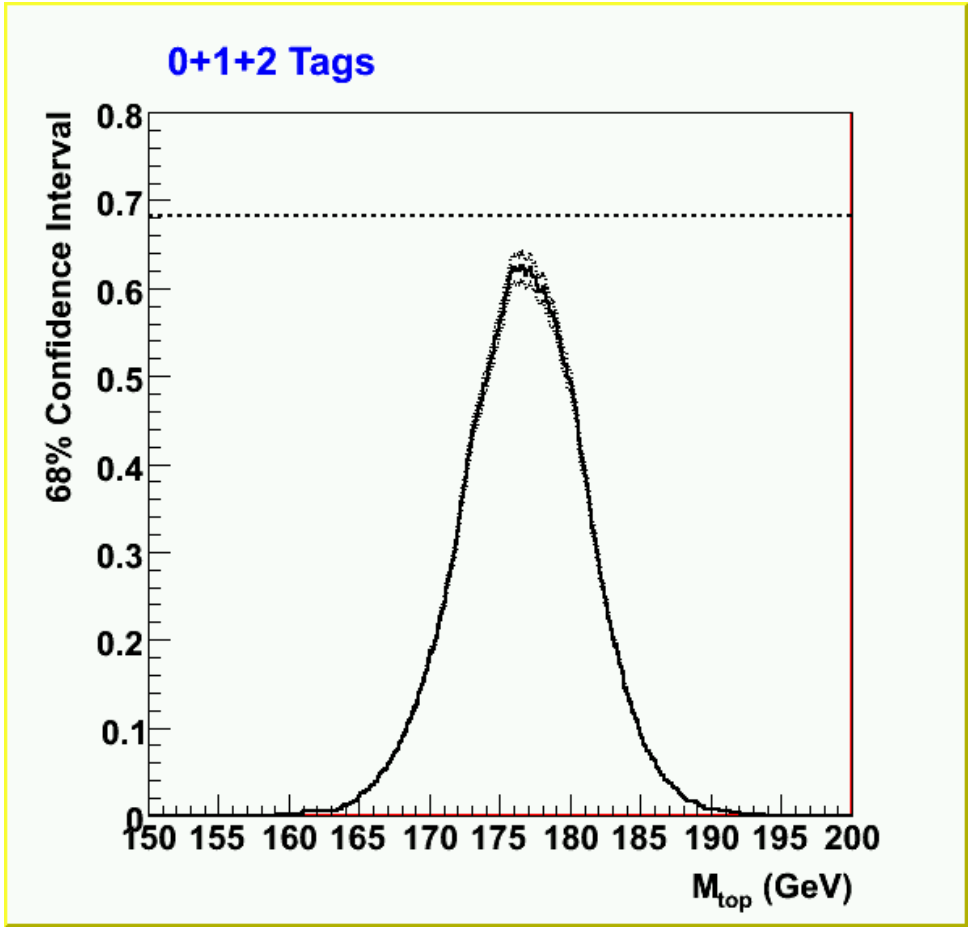
• • •

(3%)

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

Calibration of the Method

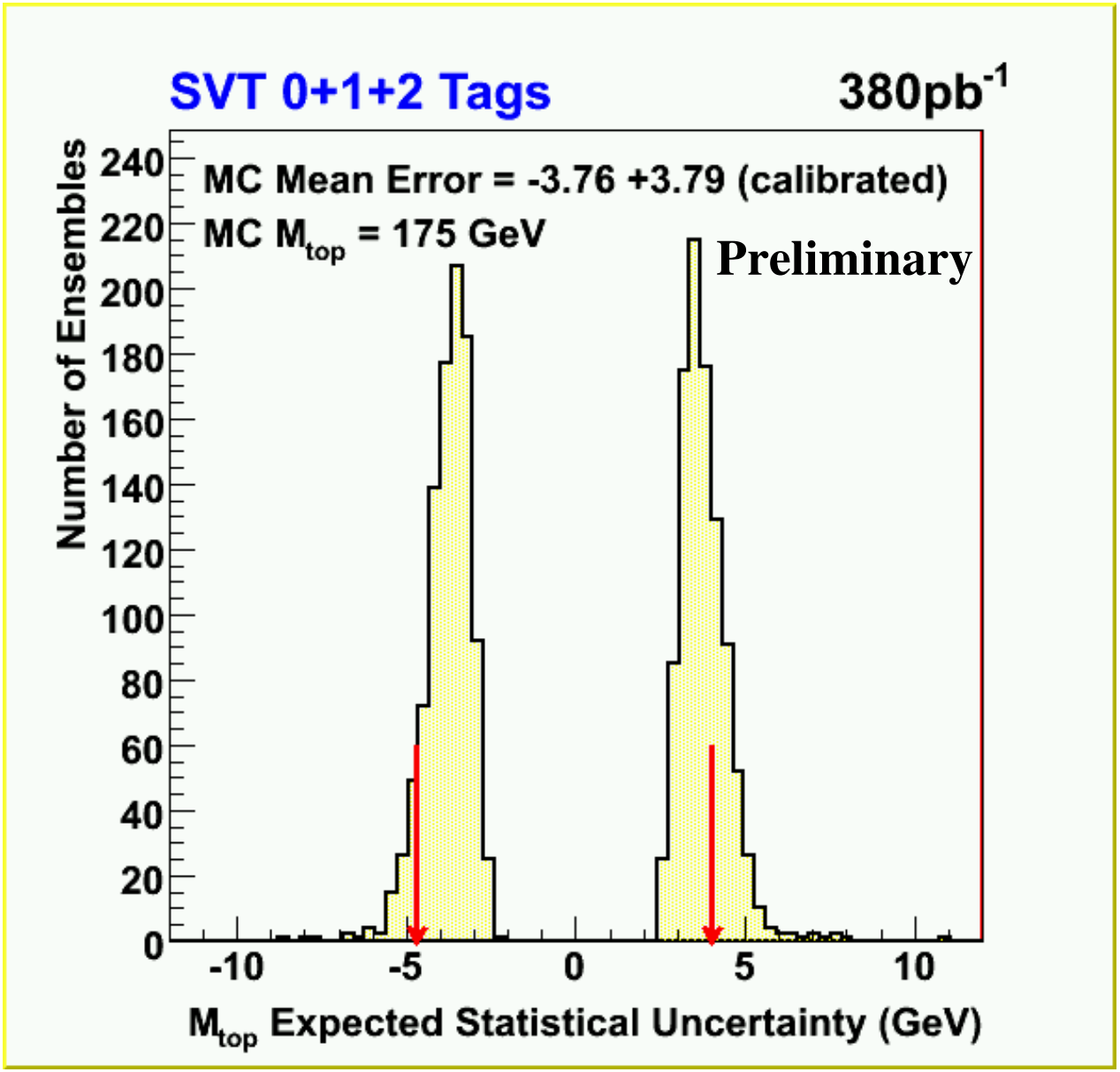




1000 full-simulated pseudo-experiments:

In order to properly compute the top mass error, the 68% confidence interval is obtained by integrating 73.8% of the likelihood.

Top Mass Fit Error in Data and MC



Systematic Errors

$$m_{top} = 170.6 \pm^{4.0}_{4.7} (stat. + JES) \pm^{1.4}_{1.4} (syst.) GeV$$

Source of uncertainty	Effect on top mass (GeV)
Physics Modeling	
Signal modeling	+-0.46
Background modeling	+-0.32
PDF uncertainty	+-0.07
b-fragmentation	+-0.71
b/c semileptonic decays	+0.06 -0.07
Detector modeling	
JES pT dependence	+-0.25
Relative b/light jet energy scale	+0.87 -0.75
Trigger	+-0.08
B-tagging	+-0.24
Method	
Signal fraction	+-0.15
QCD background	+-0.29
MC calibration	+-0.48

Improving the Precision of the Method (I)

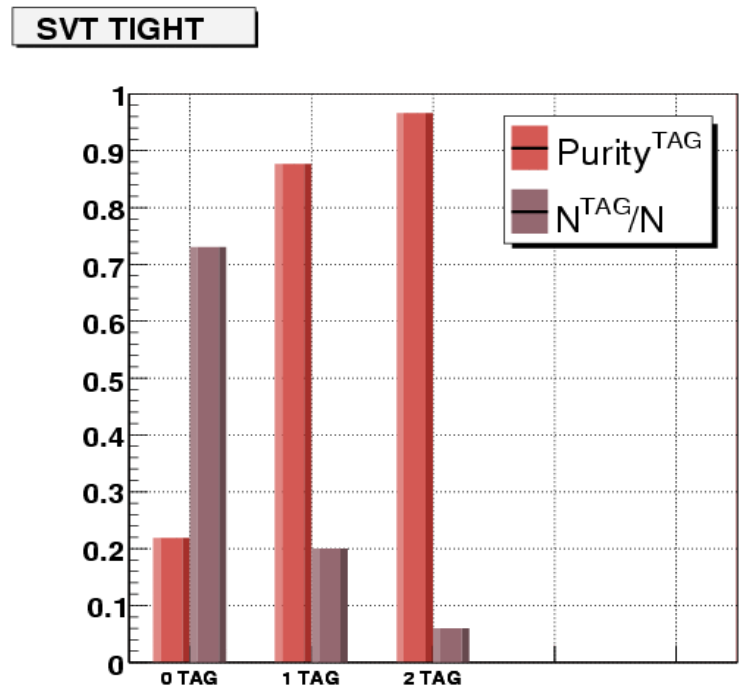
Use b-tagging to improve the statistical precision of the Matrix Element Method

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

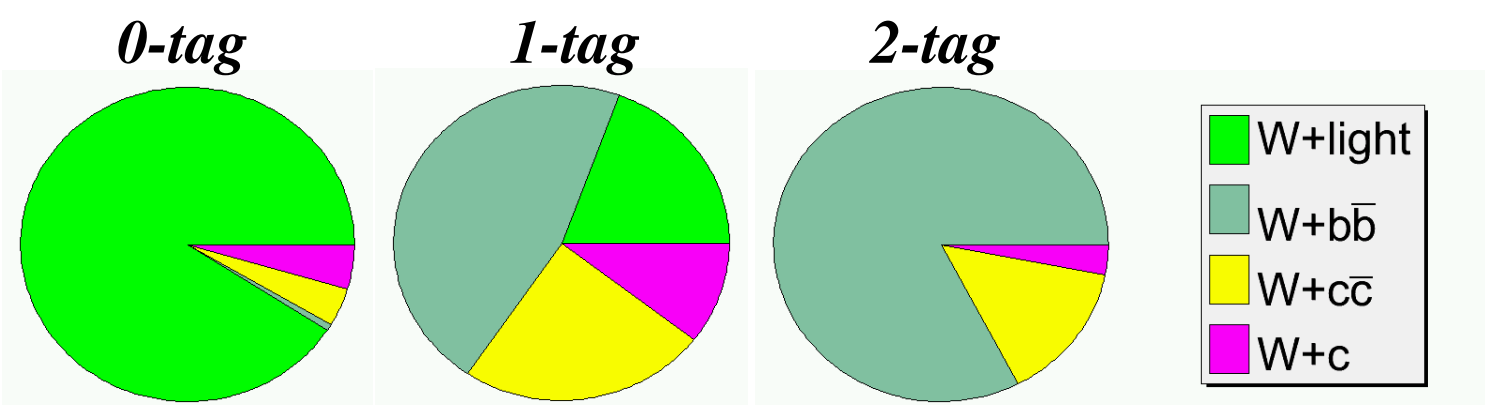
0-tag: 73%, f_{top} = 22%

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

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



W+jets flavor composition:



Improving the Precision of the Method

b-tagging:

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

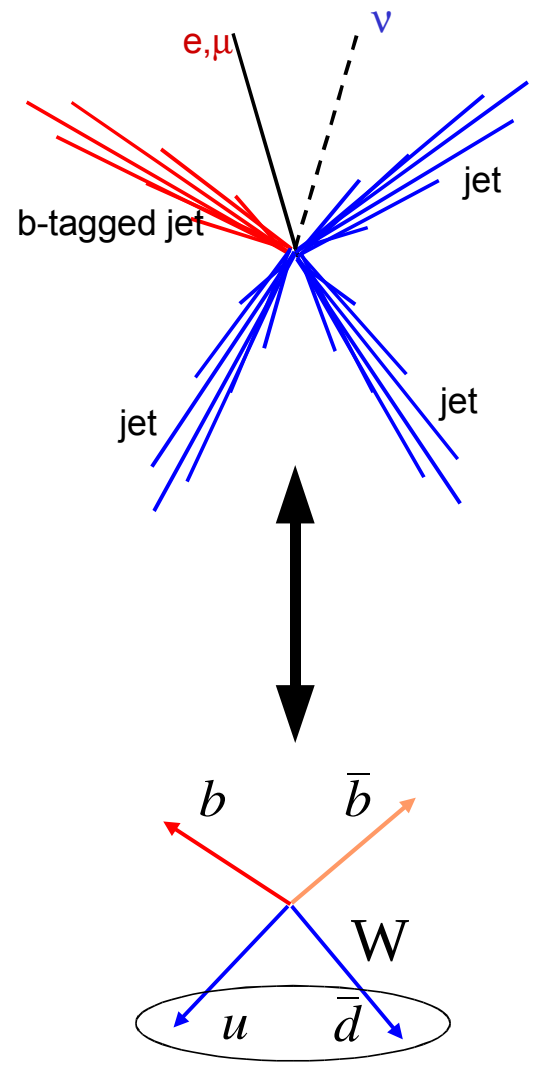
$$P_{t\bar{t}}^{N-tag}(x;m_{top},JES)=\sum_J W_J^{t\bar{t}} P_{t\bar{t}}^{J}(x;m_{top},JES)$$

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

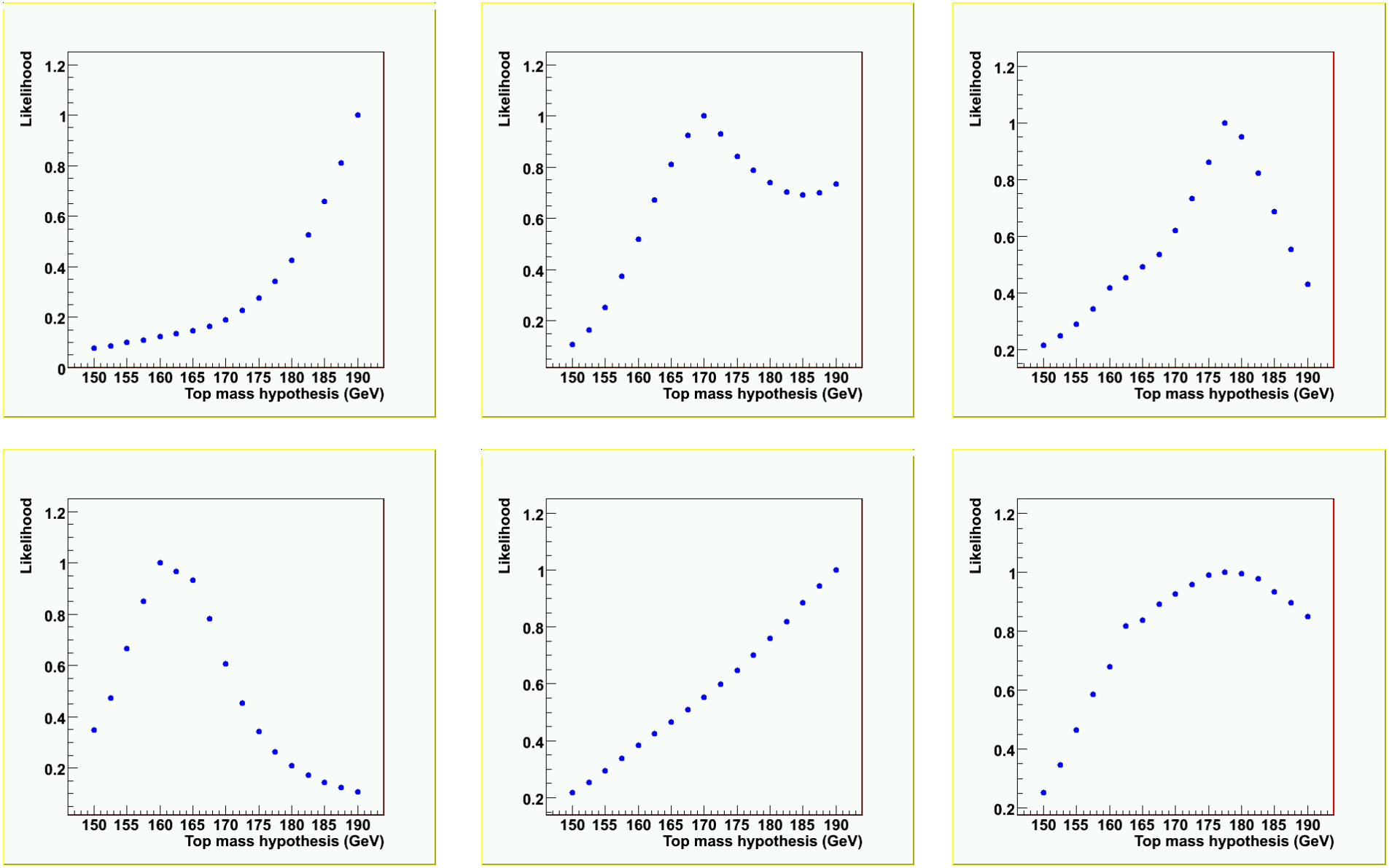
$$w_J^i=\epsilon_{jet}(\alpha)(E_T,\eta) \quad tagged\ jets$$

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

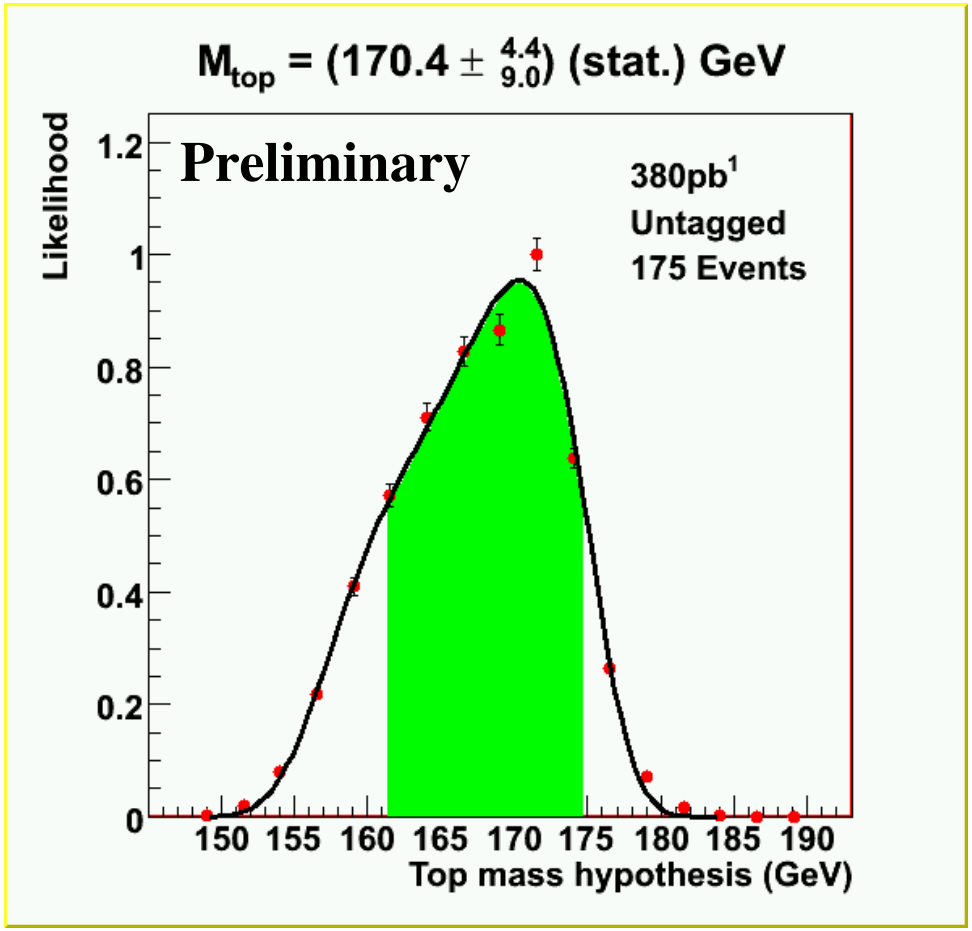
$$\alpha=b,c,light$$

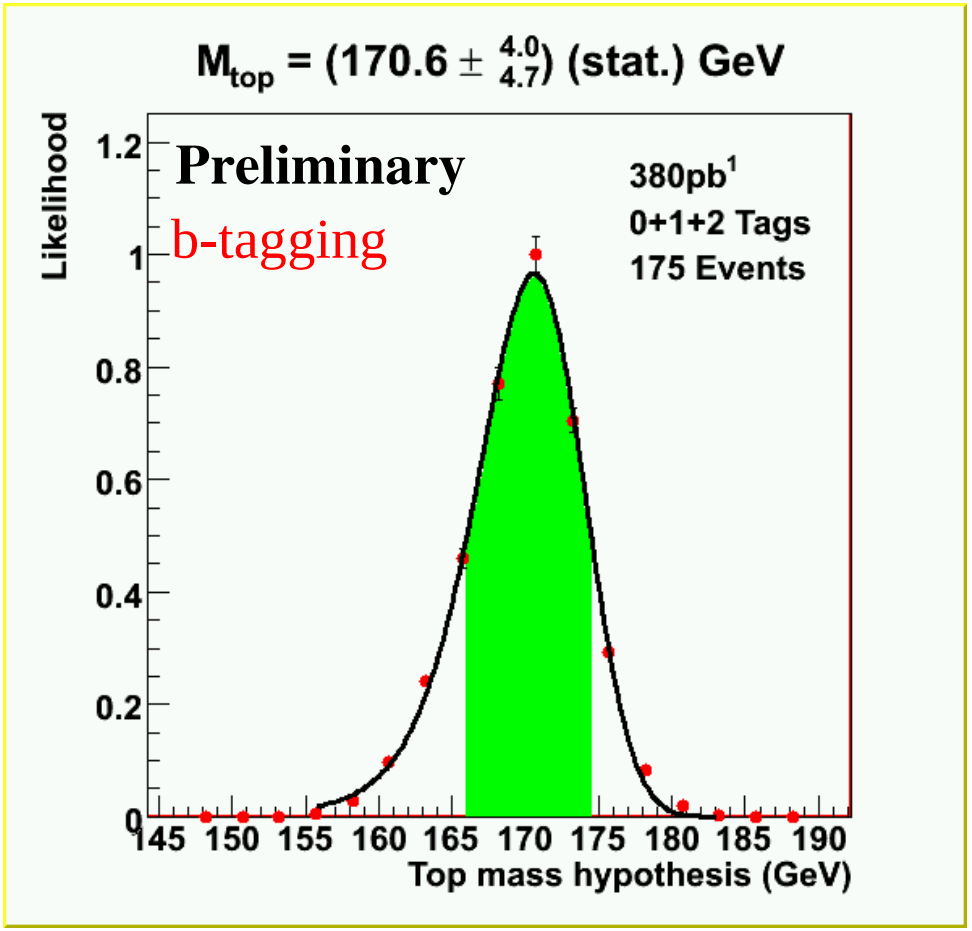


Data Events



Top Mass Fit in 380pb^{-1} lepton+jets Data





The use of b-tagging information improves the top quark mass statistical error by 35% (17% expected from simulation)