Top Quark Mass Measurement Techniques in ℓ+Jets Events

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On behalf of CDF/DØ Top Mass Analysers

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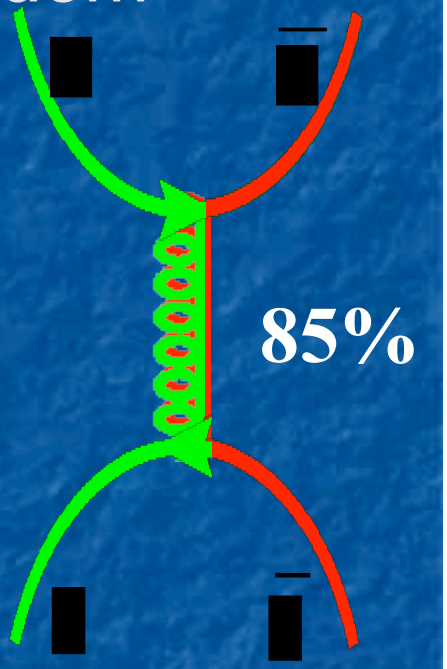
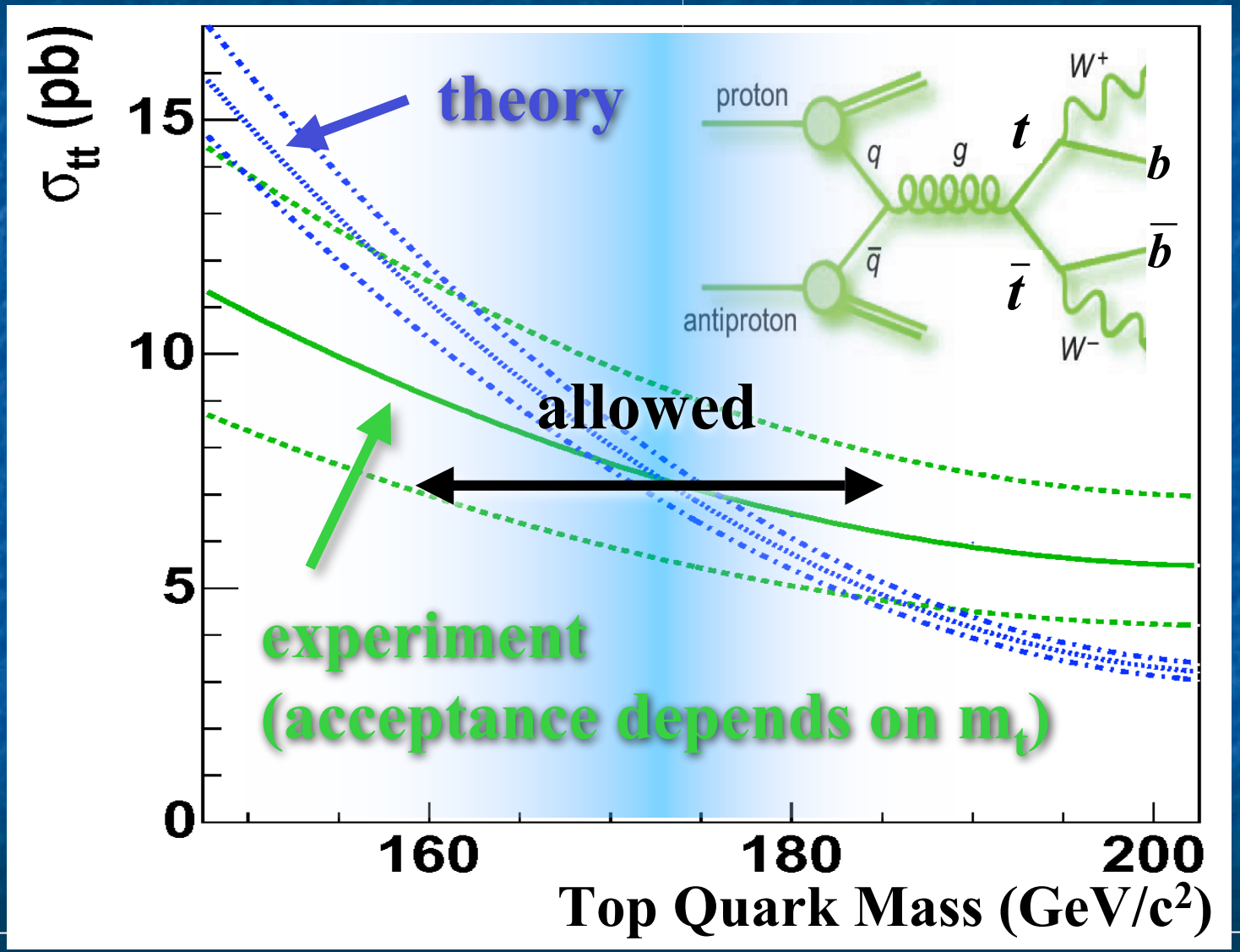
Top Quark Pair Production

- QCD as envisioned by asymptotic freedom
  - At the scale of twice the top mass, QCD describes "pair production" much in the same way as QED.
  - Cross section prediction versus mass can be precisely tested
- Top decay proceeds rapidly (10^{-24} s), but not too rapidly, $\Gamma_t \sim 1.5$ GeV/c^2

  $t \rightarrow W^+ + b$ No longer "weak"
  - QCD doesn't have a chance to act on this timescale

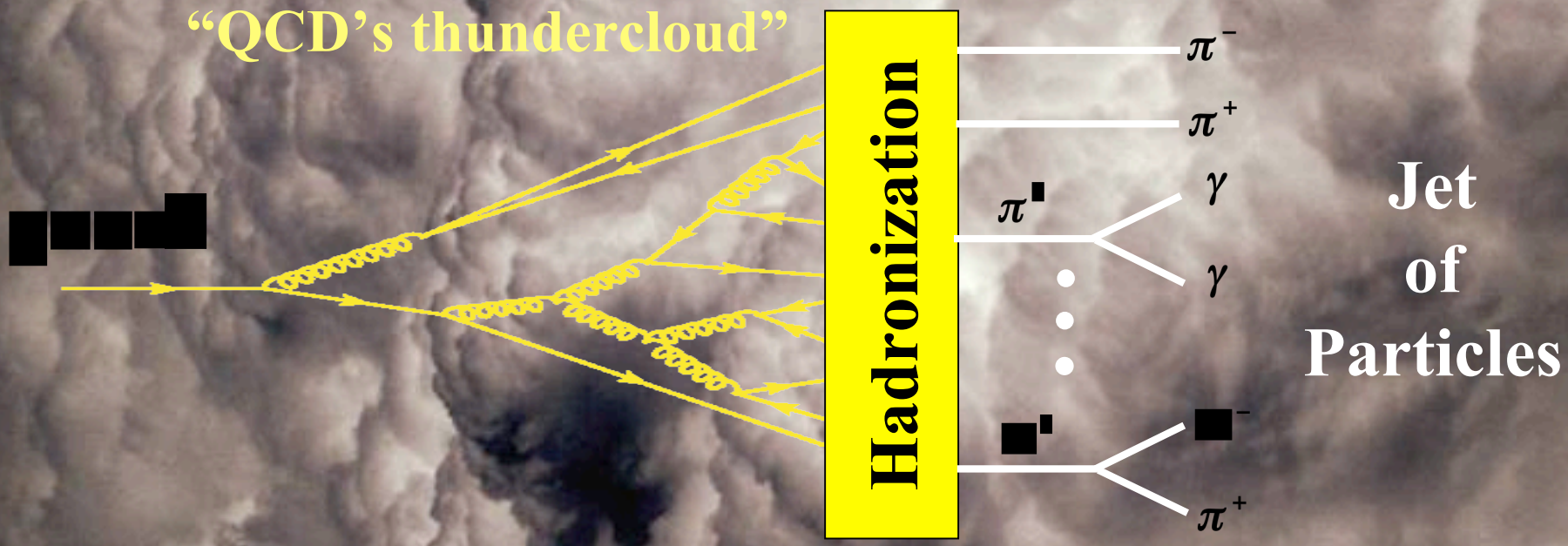


Top Quarks Pairs from QCD



Experimental Challenge No. 1

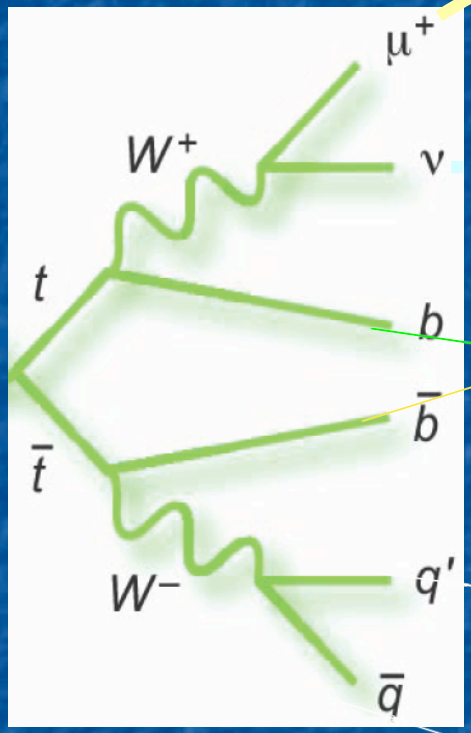
- High-Energy Quarks are born free, but QCD anti-screening results in a dramatic consequence: Jets



Complication: Hadronization is a non-Calculable process.

How could we ever measure the top quark mass to 1%?

Deciphering ℓepton + 4-Jet tt Events



muon penetrates to outer spectrometer

undetected

Hadronization

jet

Hadronization

jet

Hadronization

Hadronization

Hadronization

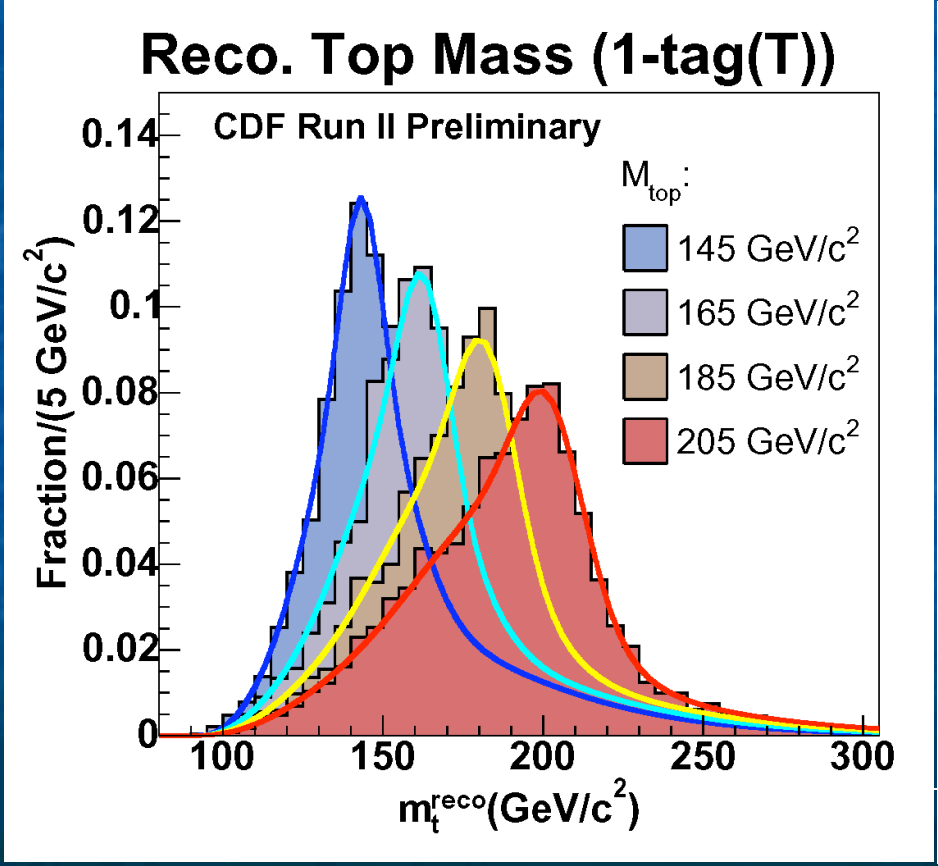
Hadronization is a non-Calculable Process

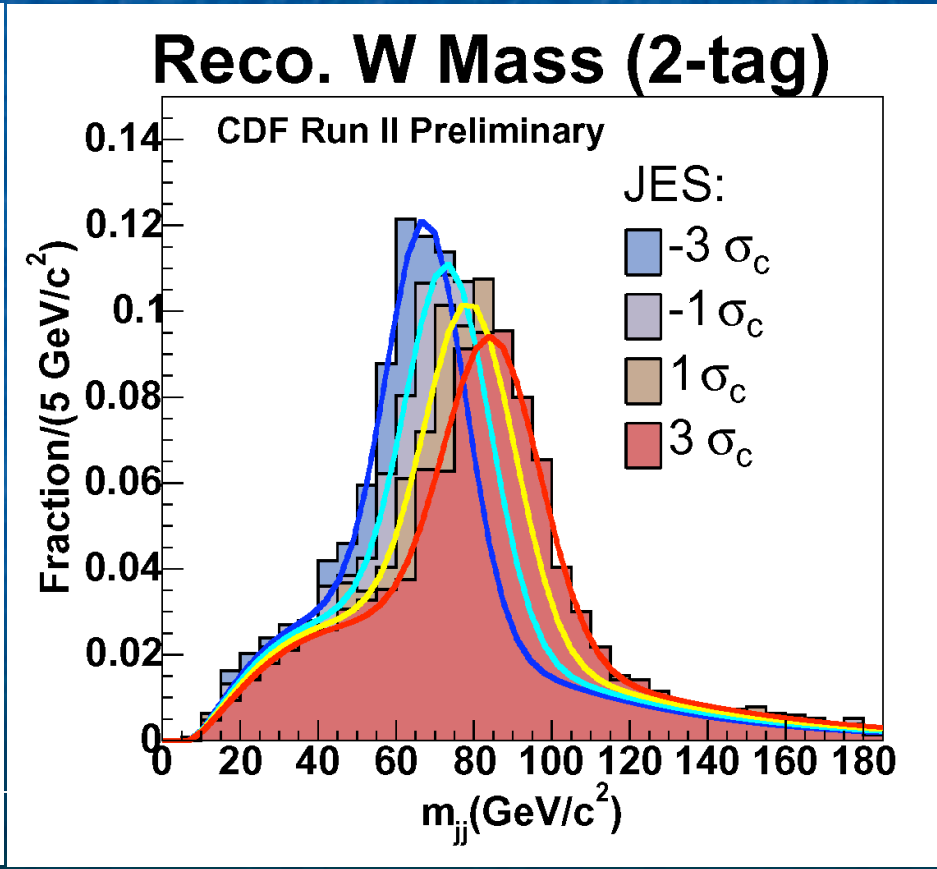
Di-Jet Mass = W Mass provides calibration for jet energy scale

Two Approaches to Measuring Mass

1) 2D Template

- Determine from MC the expected shapes of the reconstructed top quark and W masses versus the top pole mass and jet energy scale, respectively:





Template Method (1D View)

Data

Wbb MC

tt MC

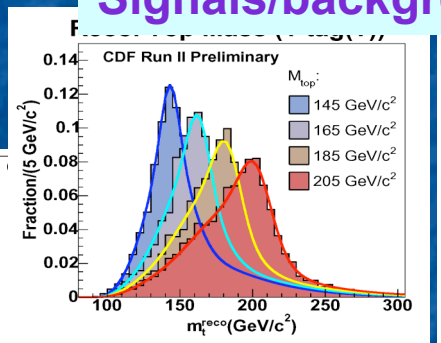
Datasets

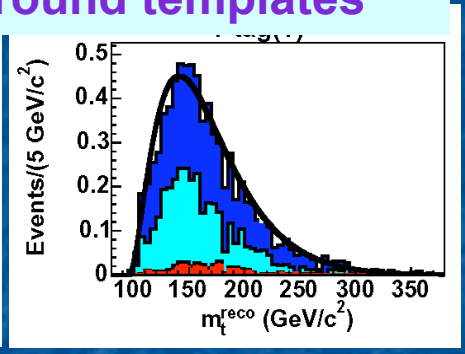
Mass fitter

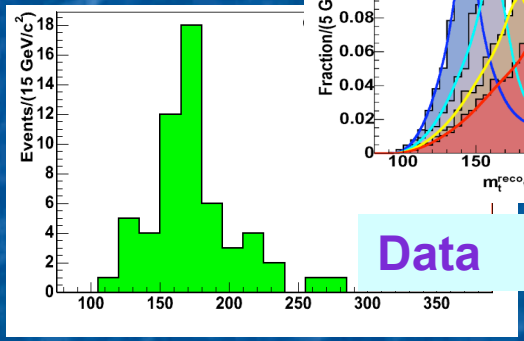
c^2 mass fitter:

- Finds top mass that fits event best
- One number per event
- Additional selection cut on resulting c^2

Signals/background templates







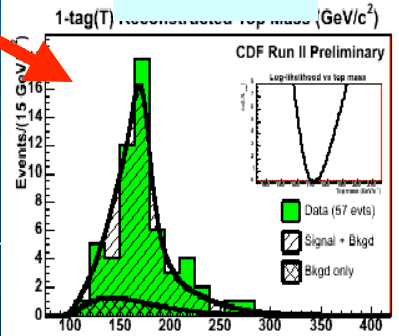
Data

Likelihood fit

Likelihood fit:

Best signal + bkgd templates to fit data with constraint on background normalization

Result



Template Resolution Assignment

$$\chi^2 = \sum_{i=1,2,3,4} \frac{(m_i - \mu_i)^2}{\sigma_i^2} + \sum_{j=1,2} \frac{(m_j - \mu_j)^2}{\sigma_j^2}$$

$$+ \frac{(m_{l\nu} - \mu_{l\nu})^2}{\Gamma_{l\nu}^2} + \frac{(m_{jj} - \mu_{jj})^2}{\Gamma_{jj}^2} + \frac{(m_{l\nu} - \mu_{l\nu})^2}{\Gamma_{l\nu}^2} + \frac{(m_{jjb} - \mu_{jjb})^2}{\Gamma_{jjb}^2}$$

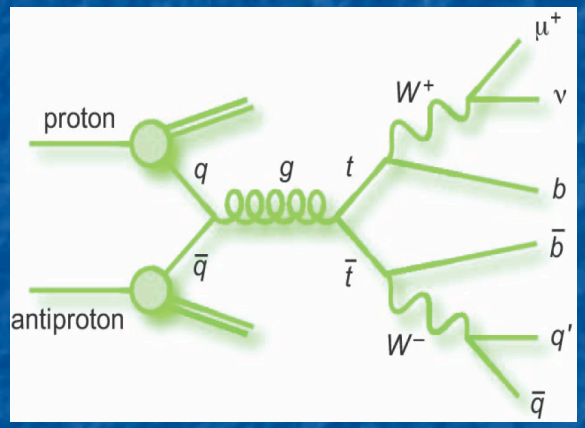
Evaluated for every parton-jet assignment and neutrino solution

Reconstruct top mass with Gaussian constraints ($m(W^+)=m(W^-)=80.4$ GeV/c^2, $m(t)=m(\bar{t})$) in each event using the best combination for data/MC

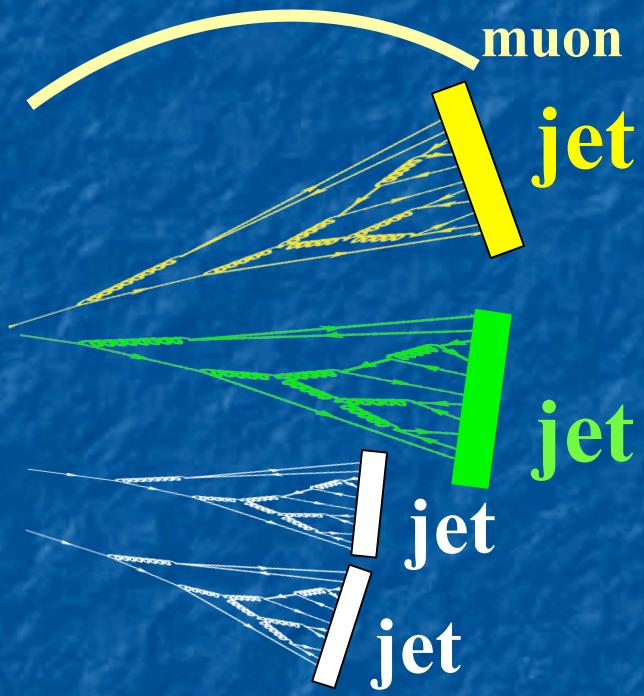
Two Approaches to Measuring Mass

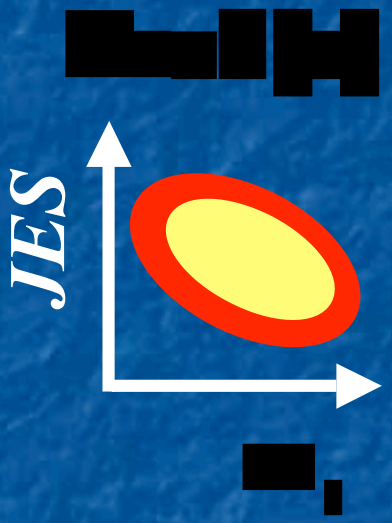
2) Matrix Element

Theory



Experiment





[redacted] × [redacted]

Signal Probability

= [redacted]

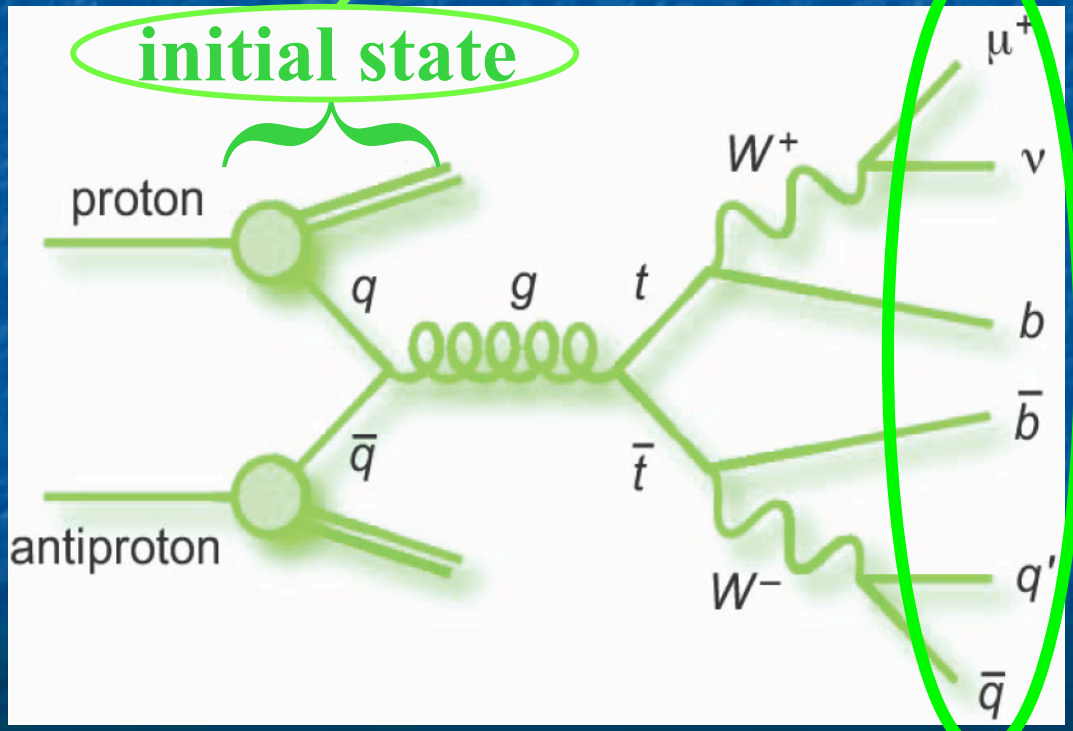
Probability of Event to come from W+4Jets also evaluated.

idealized particles:
"partons"

$$\frac{1}{N}\sum_{\text{perms},\nu}\int \text{[redacted]}\,|M|^2\,\text{[redacted]}\,d\Phi$$

Transfer Function

measurements:
"jets" and leptons



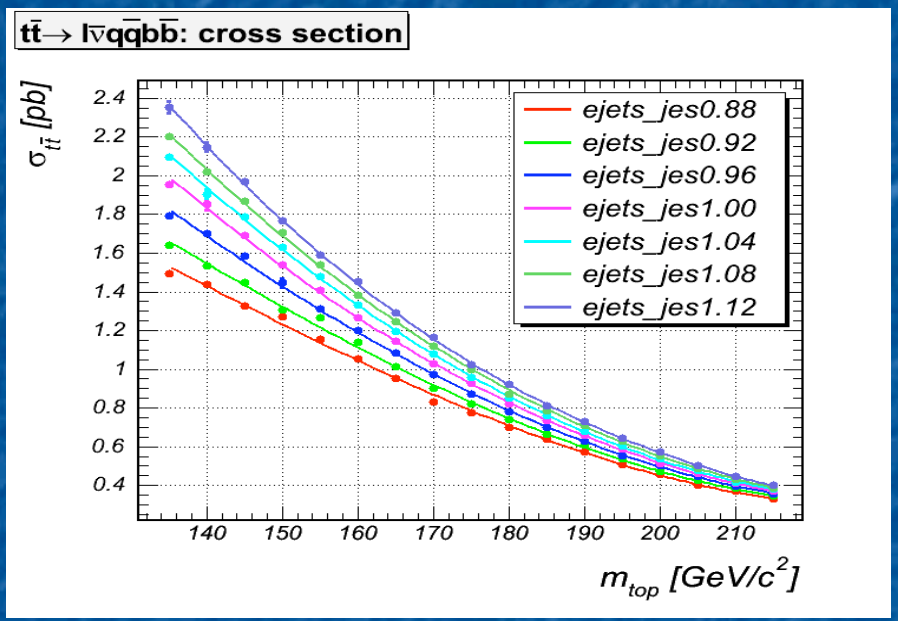
six particle final state

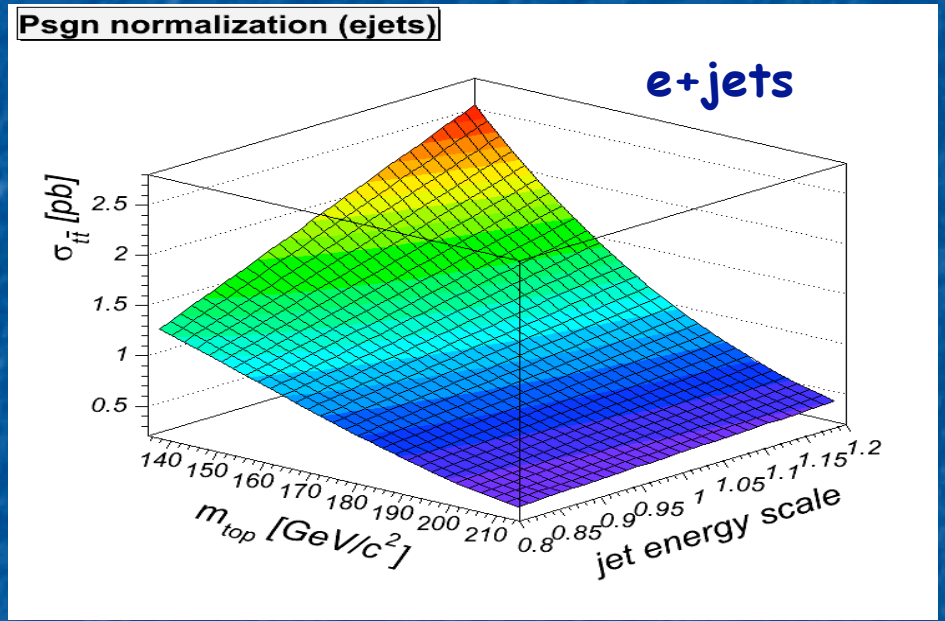
Integrate over possible neutrino directions

Normalization, N, includes acceptance efficiencies.

Matrix Element Probability Normalization

- Normalization, N, includes the effect of events moving across the jet p_T cut from a shift in JES



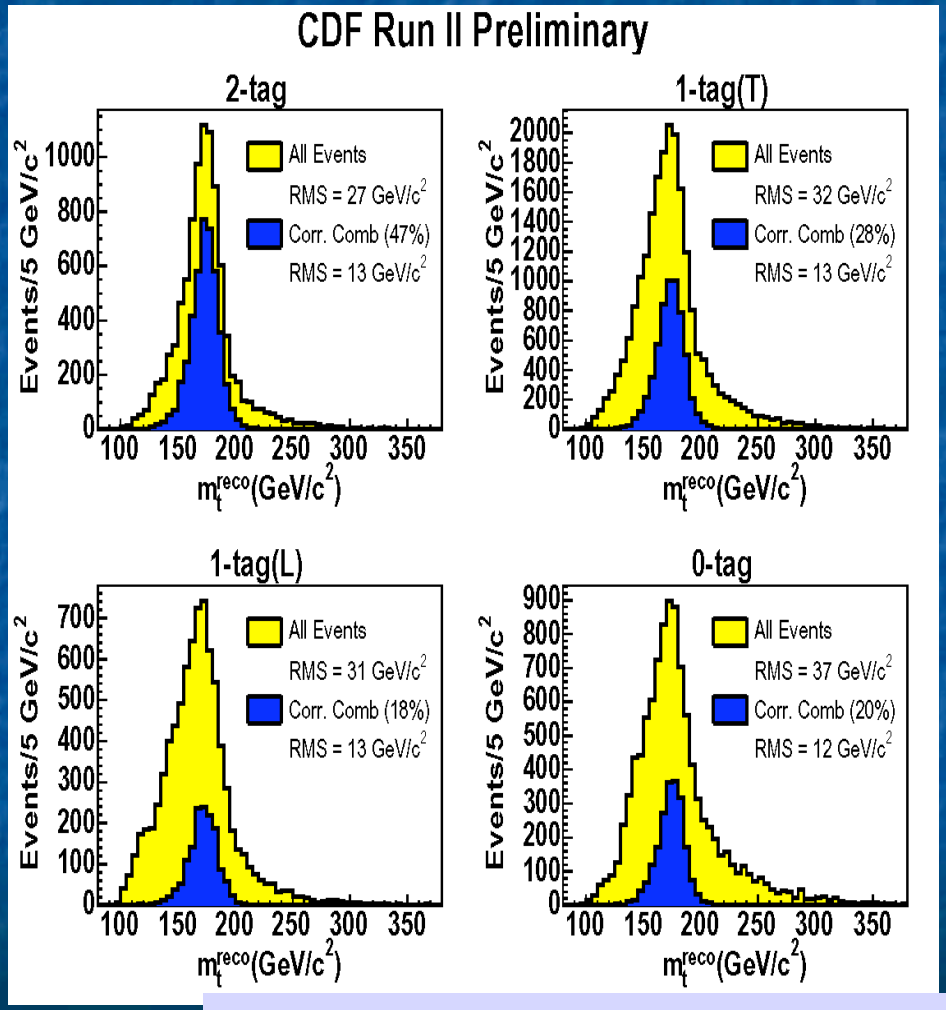


"background subtraction"

$$P_{tt}(\vec{x}|m_{top}) = f_{top} P_{tt}(\vec{x}|m_{top}) + (1 - f_{top}) P_{bkg}(\vec{x}|m_{top})$$

f_{top} : signal fraction fitted simultaneously

Event Categories in Template Method



M_t Signal Templates (no background)

3 Categories with differing # of b-tags and jet cuts

Sample	S/B	Jet E_T cut [GeV]
2-tag	10.6	3 jets w/ Et>15 4th jet w/ Et > 8
1-tag(T)	3.7	4 jets E_T > 15
1-tag(L)	1.1	3 jets E_T > 15 4th jet 8 < E_T <15
0-tag	<1	4 jets E_T > 21

Event Categories in Matrix Element Method

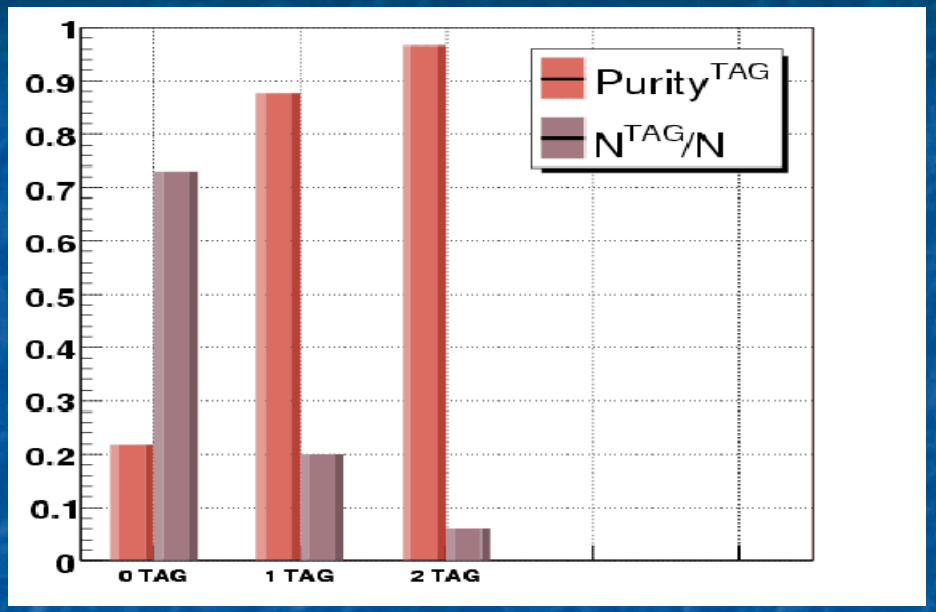
3 Categories: 0-,1-,2-tag

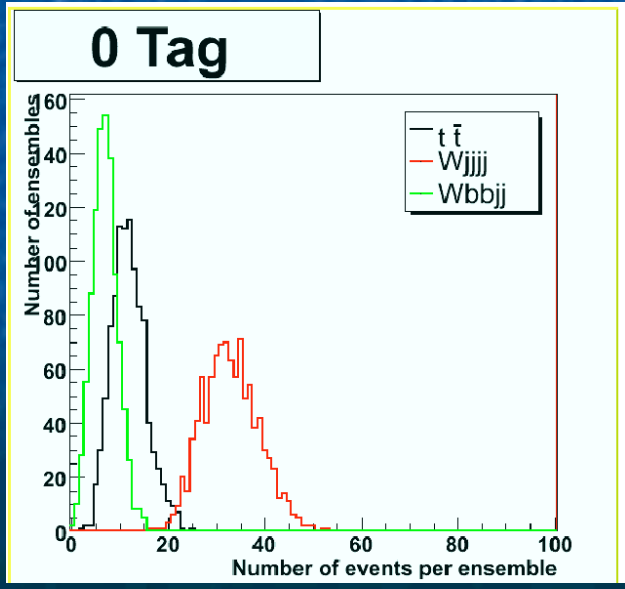
Common Jet Threshold

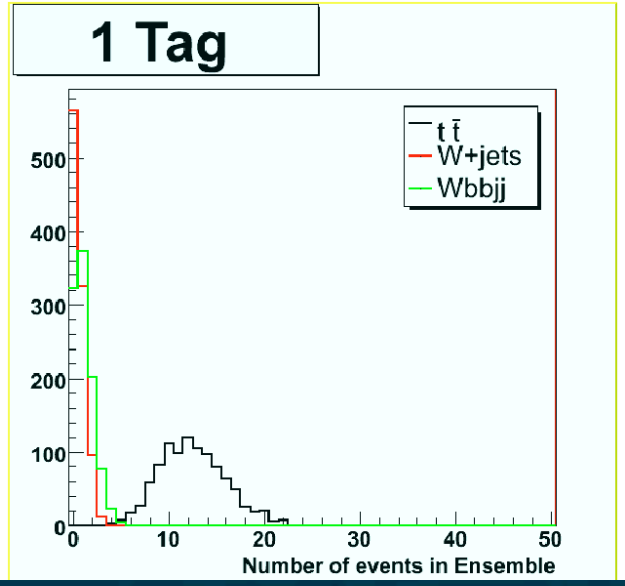
- p_T>20 GeV (calibrated, R=0.5)
- 5th Jet Veto
  - 8 GeV uncalibrated

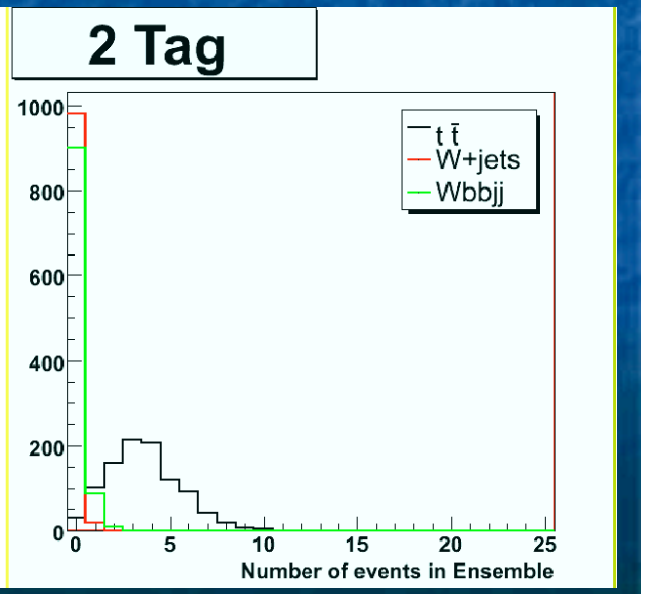
Also: Topological Analysis

- b-tag information is not used



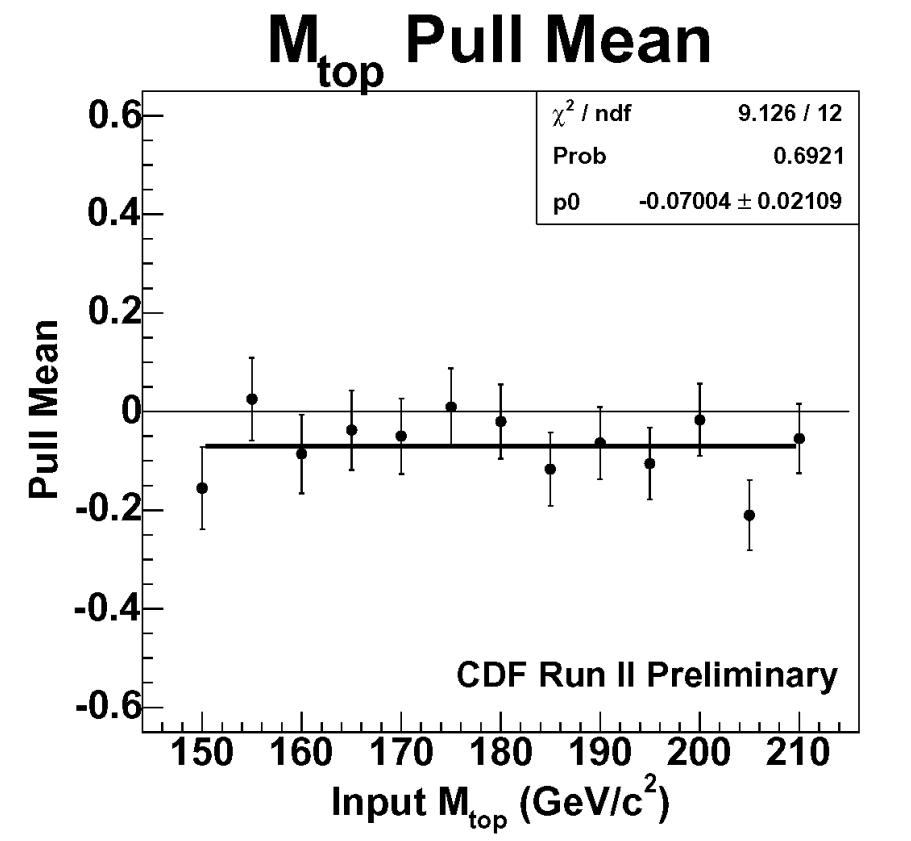


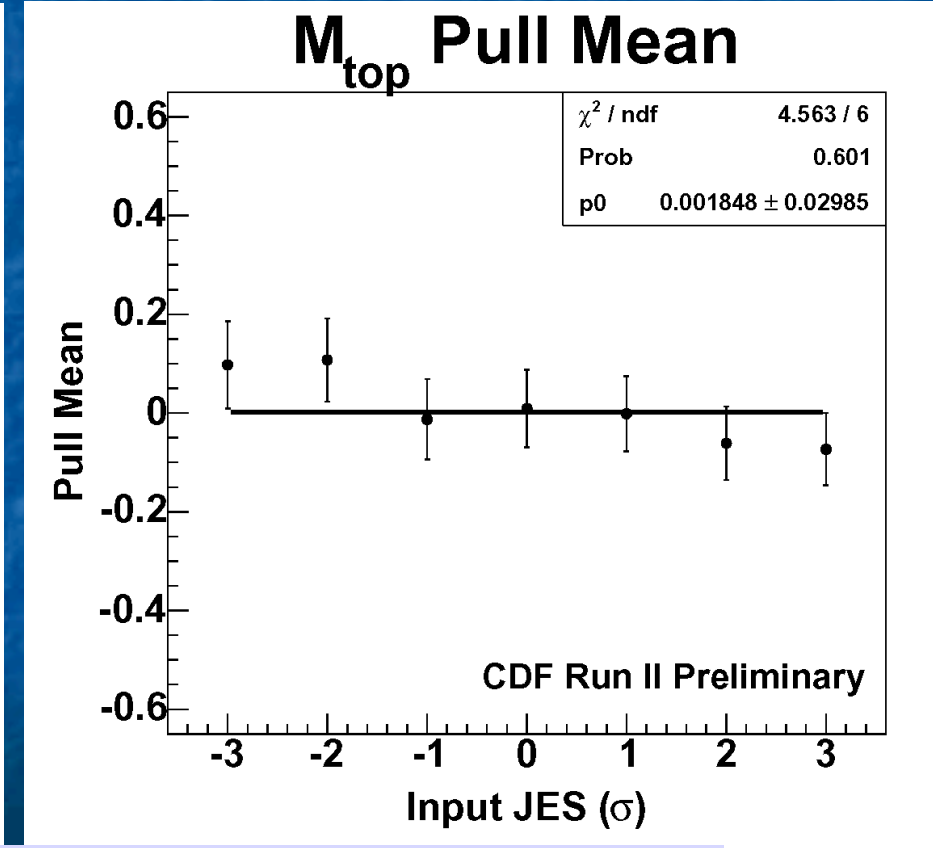




Template Calibrations and Pulls

- Template is self-calibrating, and testing is done by pulling reconstructed mass values directly from the templates and feeding them through the likelihood

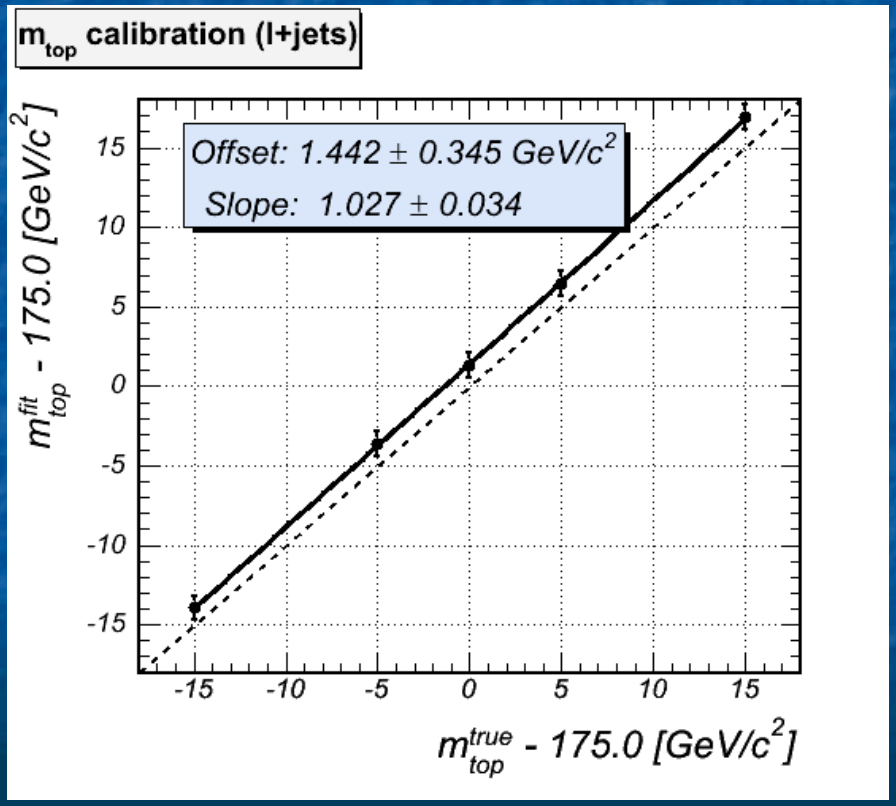


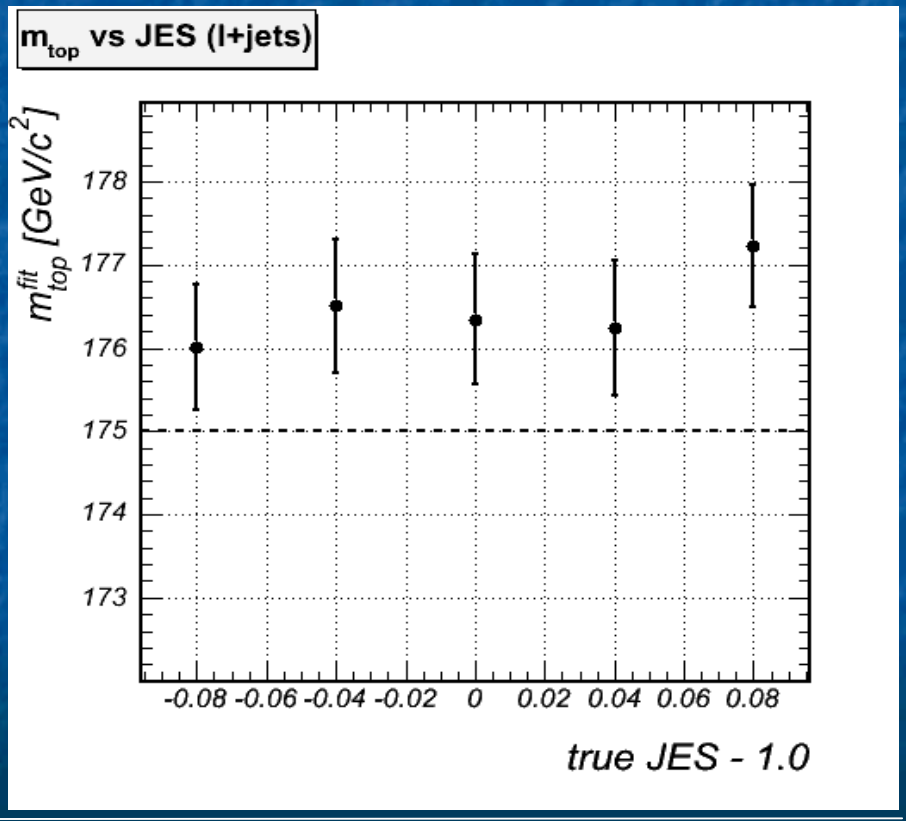


Top Mass measurement uncertainties are corrected for pull widths

Matrix Element Calibrations and Pulls

- Ensemble testing is essential for Matrix Element method, transforms LO mass estimator to a full simulation (including ISR/FSR and Reco) calibrated procedure





Matrix Element Calibrations and Pulls

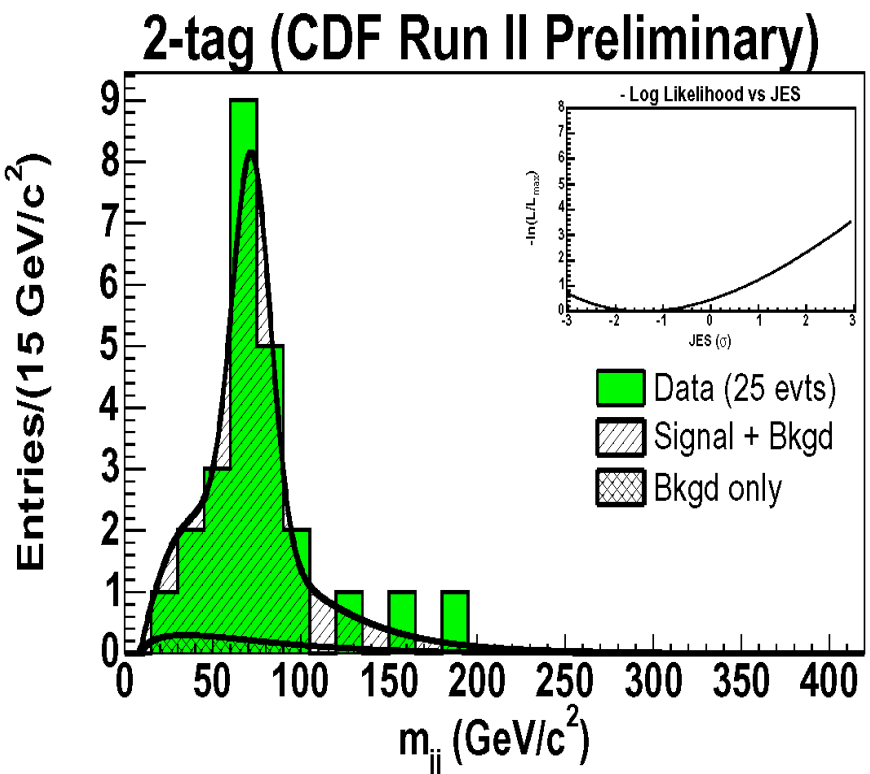
- Ensemble testing is essential for Matrix Element method, transforms LO mass estimator to a full simulation (including ISR/FSR and Reco) calibrated procedure
  - Perfect agreement required at parton-level, near perfect for parton-matched fully simulated events, and finally calibrations come from the entire fully simulated samples, including non-parton matched jets and background events

Note that the calibration procedure also removes the biases from particular choices of fitting functions for the likelihood or number of points included in the 2D fits

Thus, the top mass ME fit is not comparing data with a LO calculation, it compares the LO calculation to full simulation and uses full simulation to determine the mass biases or pull calibrations.

Cross-Check of Internal Calibration

Template (2-tag sample)

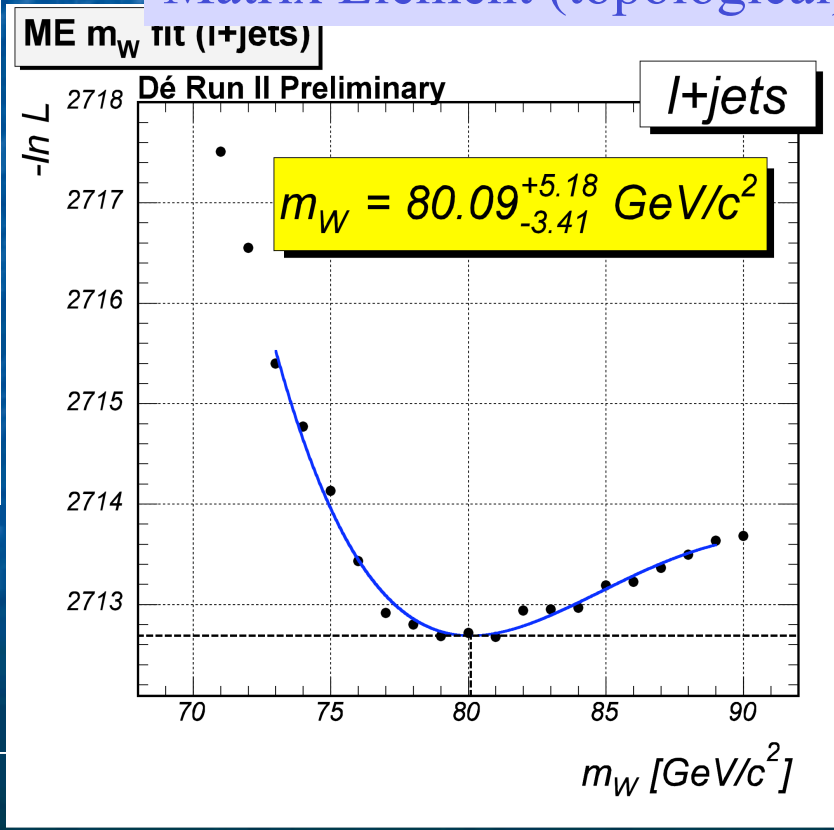


CDF Run II Preliminary ($318\ pb^{-1}$)

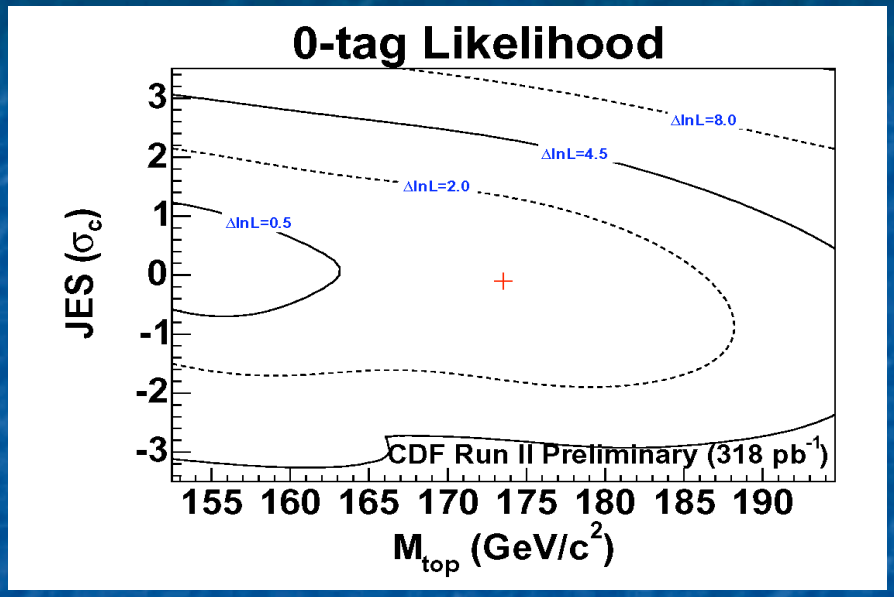
Subsample	JES (σ)
2-tag	$-1.43^{+1.30}_{-1.31}$
1-tag(T)	$0.53^{+1.41}_{-1.28}$
1-tag(L)	$2.16^{+3.79}_{-3.25}$
0-tag	$-5.64^{+0.86}_{-1.31}$

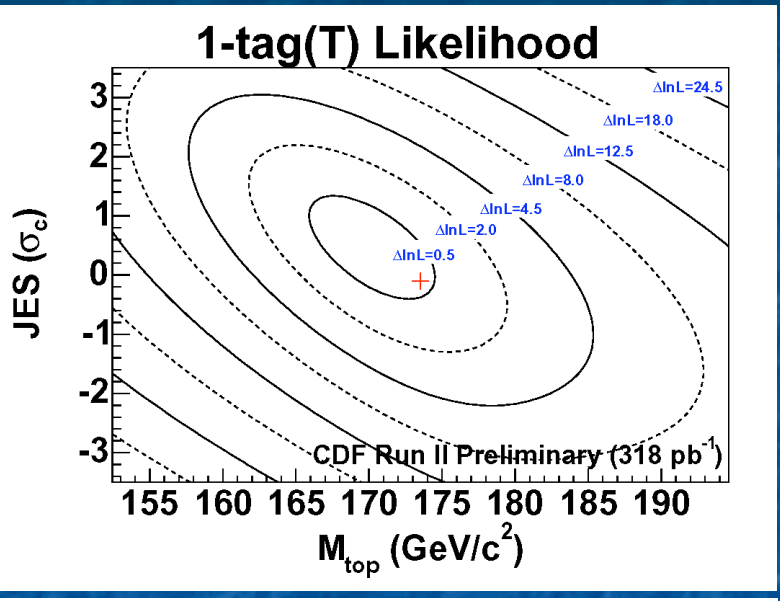
- Reconstructed W mass distributions/likelihoods

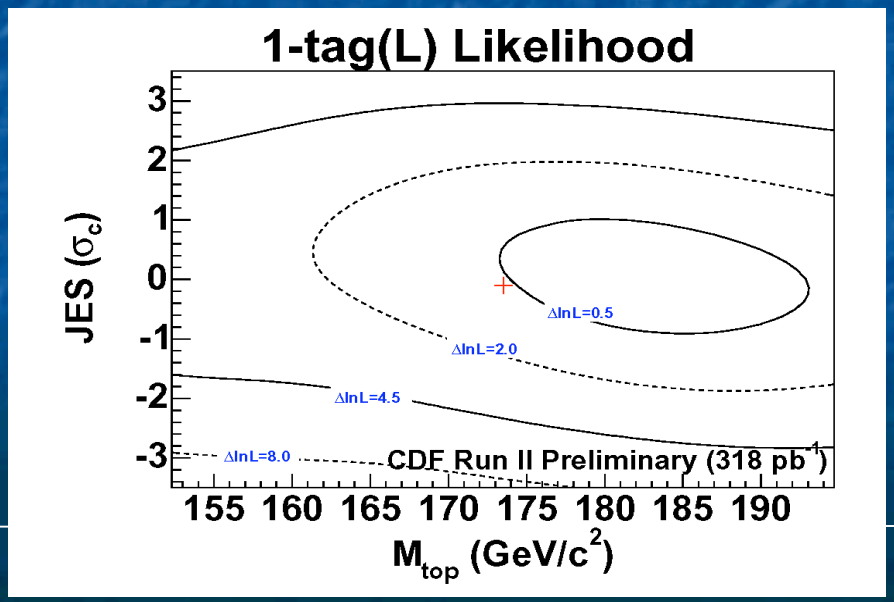
Matrix Element (topological)

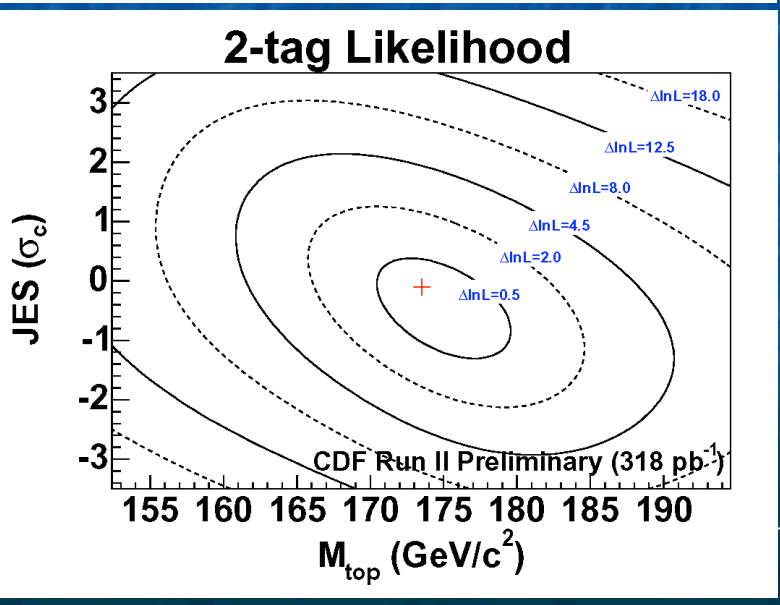


2D Template Results by Category

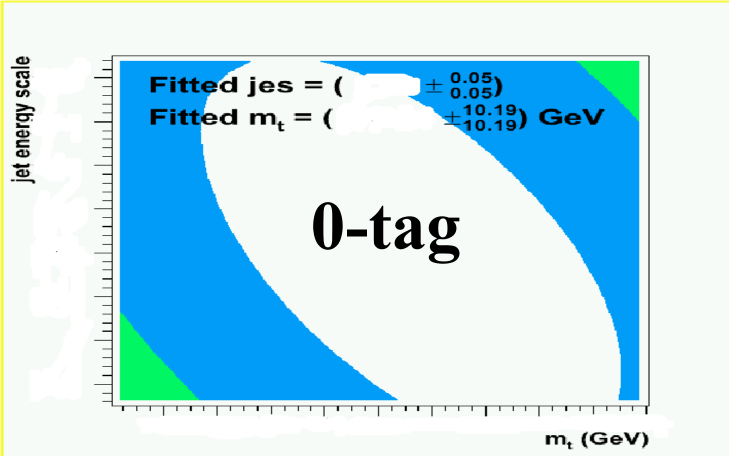


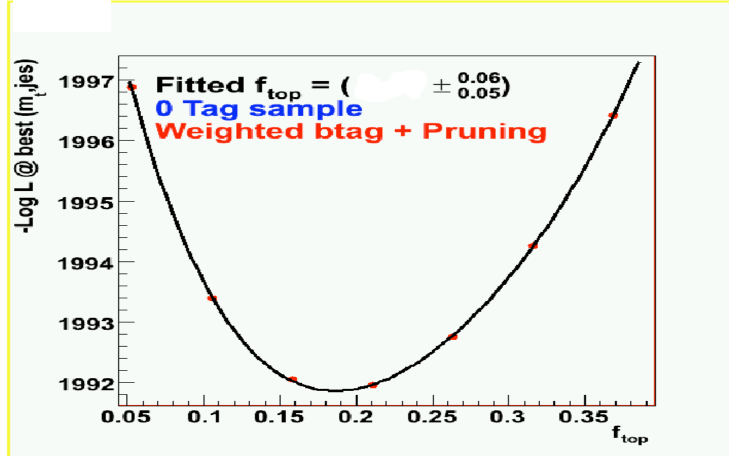


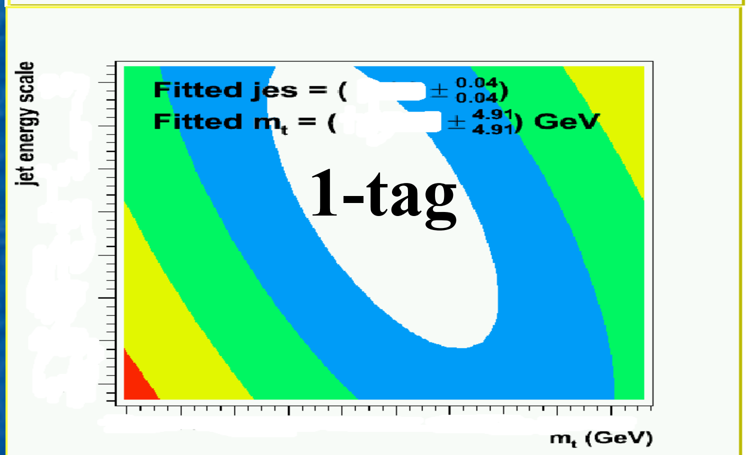


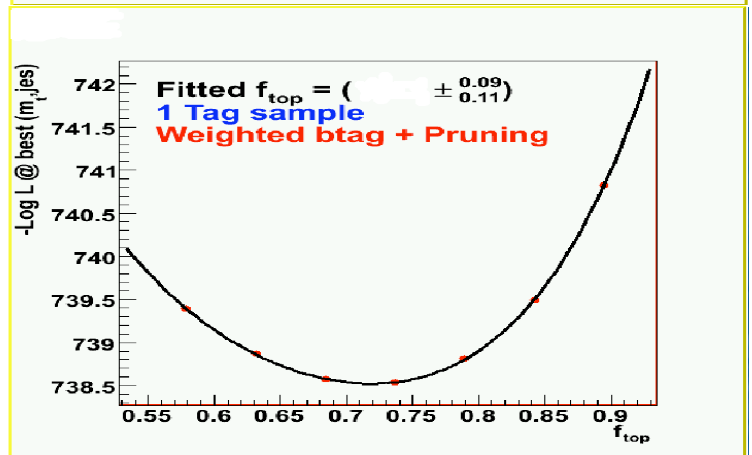


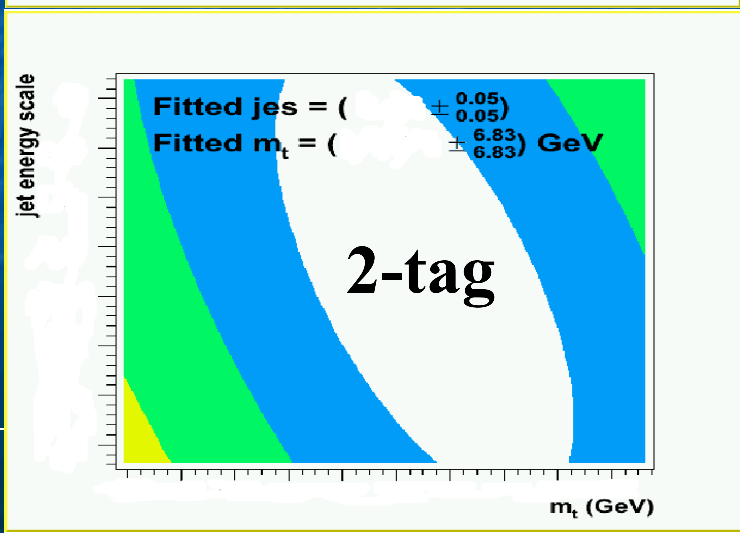
Matrix Element Results by Category

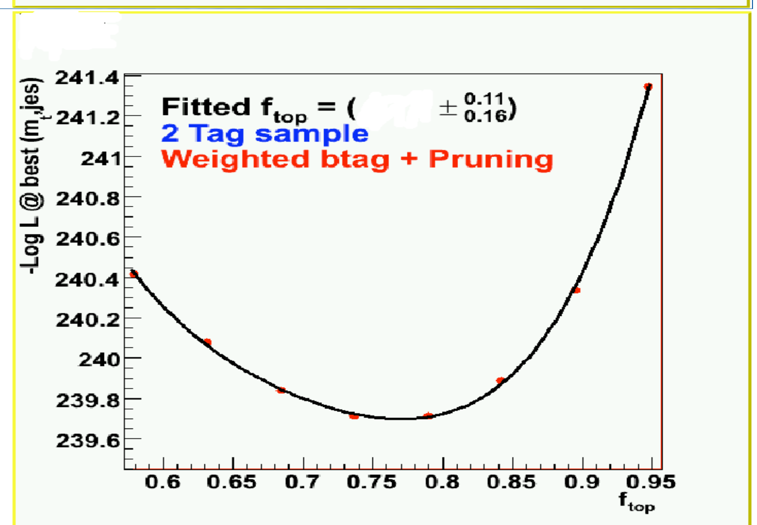












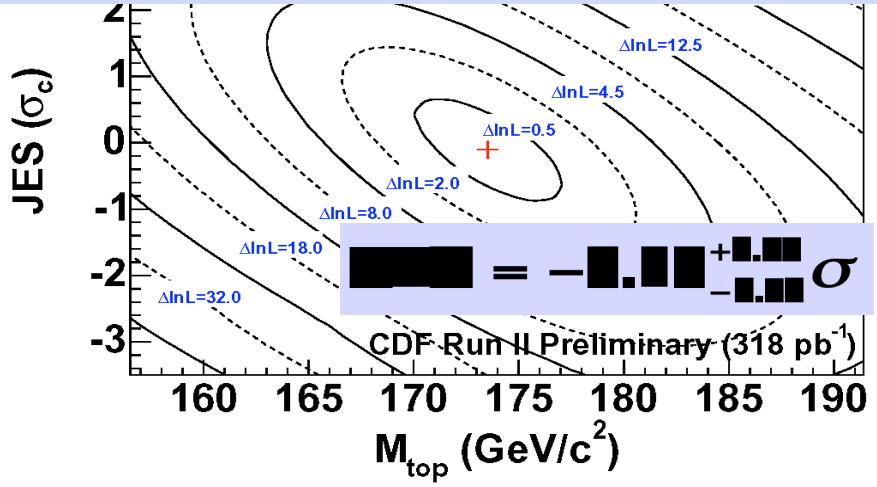
Top Mass Results

Statistical error is becoming small in combination

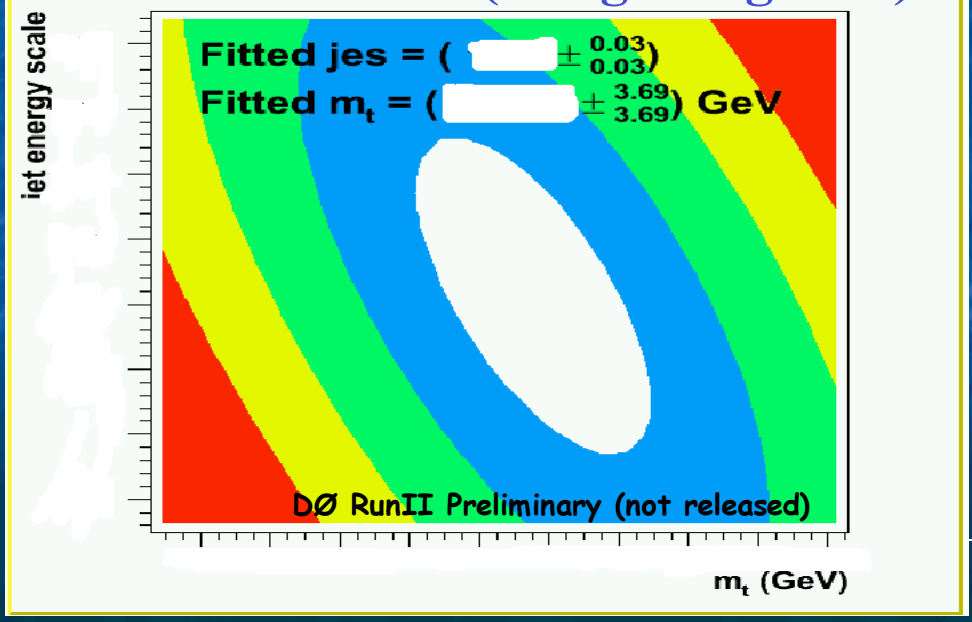
- With 1 fb^{-1} analyses, focus is on how well the data and simulation are understood

2D Template

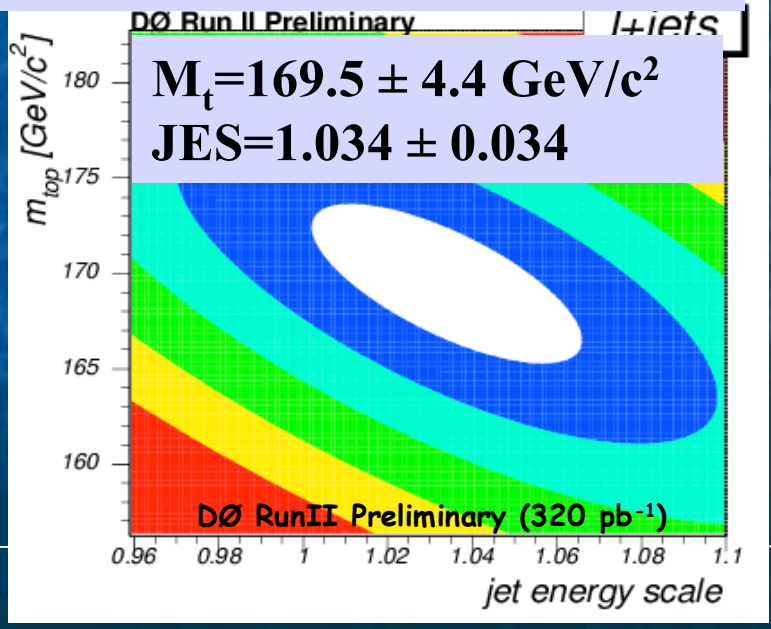
$M_t = 173.5^{+3.7}_{-3.6}$ (stat +JES) GeV/c^2



Matrix Element (b-tag categories)

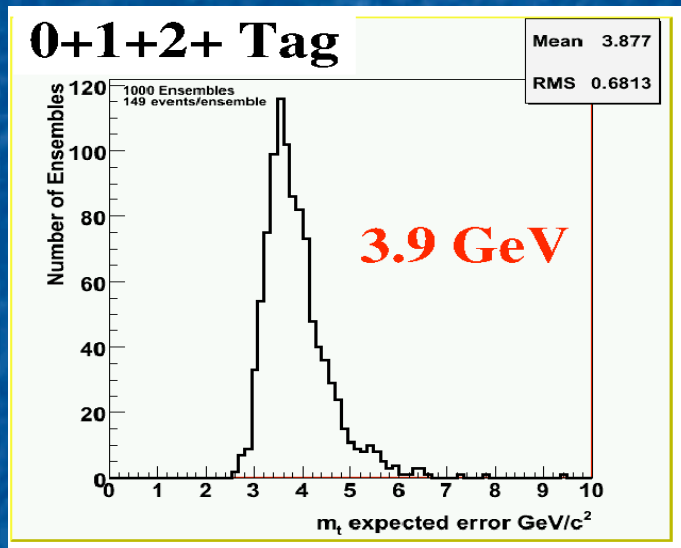


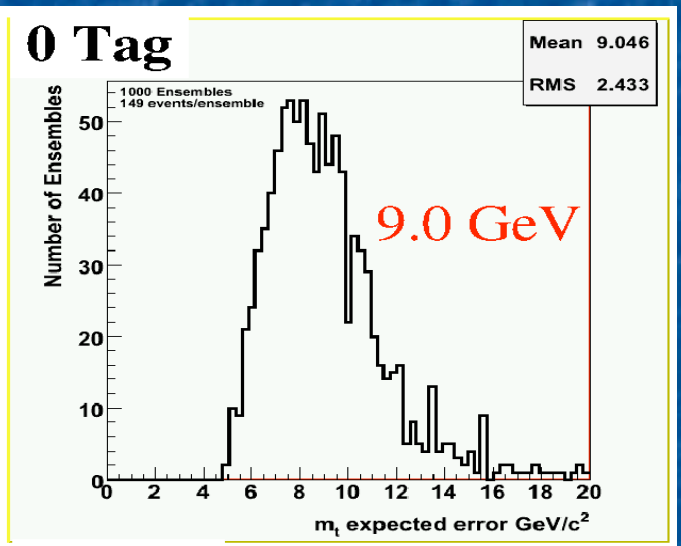
Matrix Element (topological)

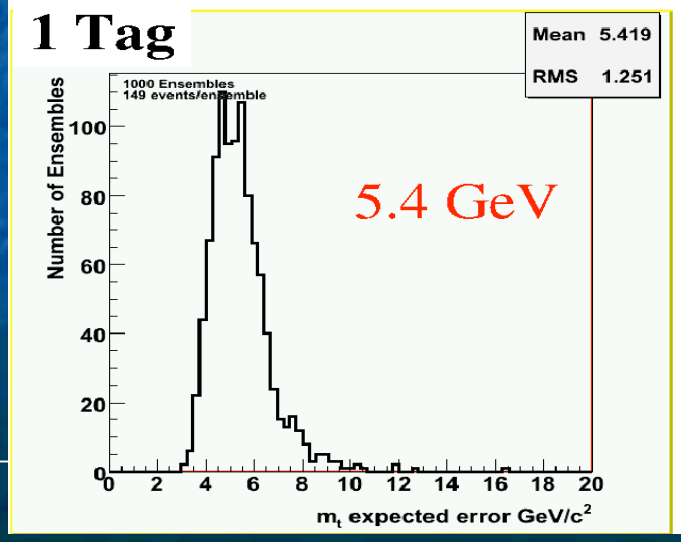


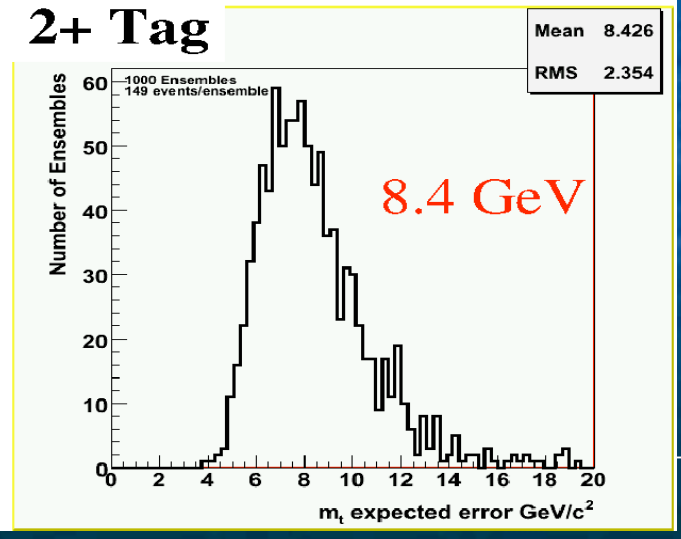
Further Optimization

- Example, Matrix Element b-tag optimization

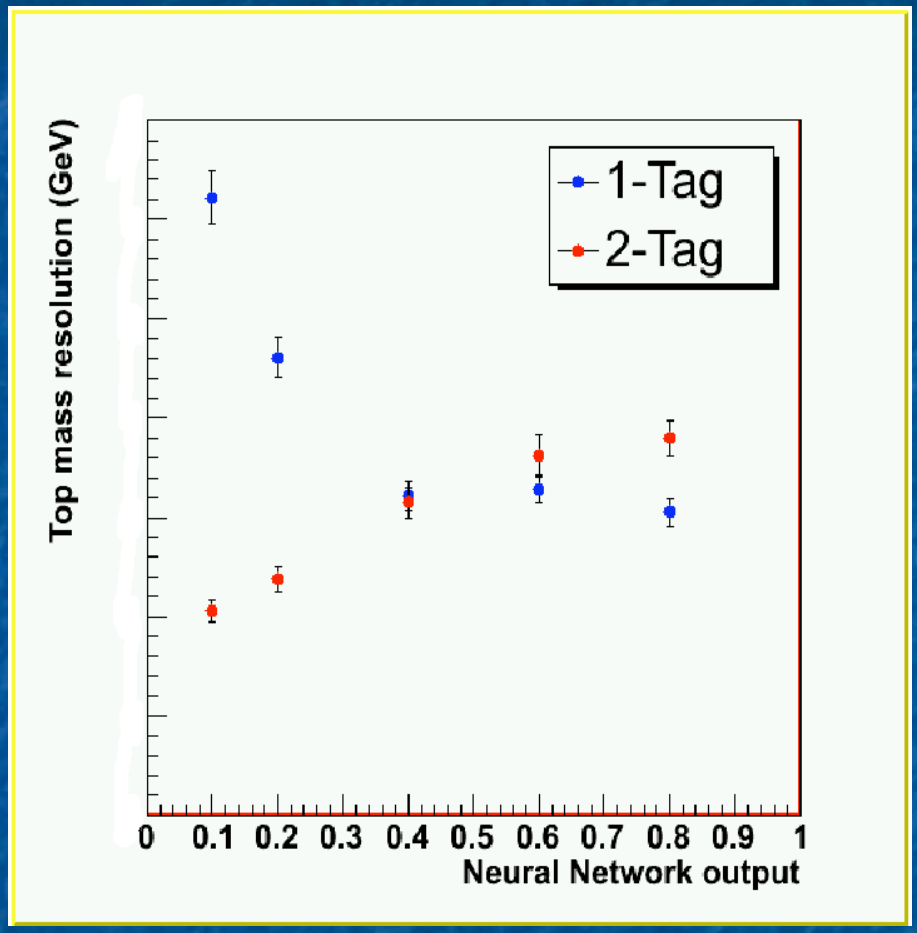


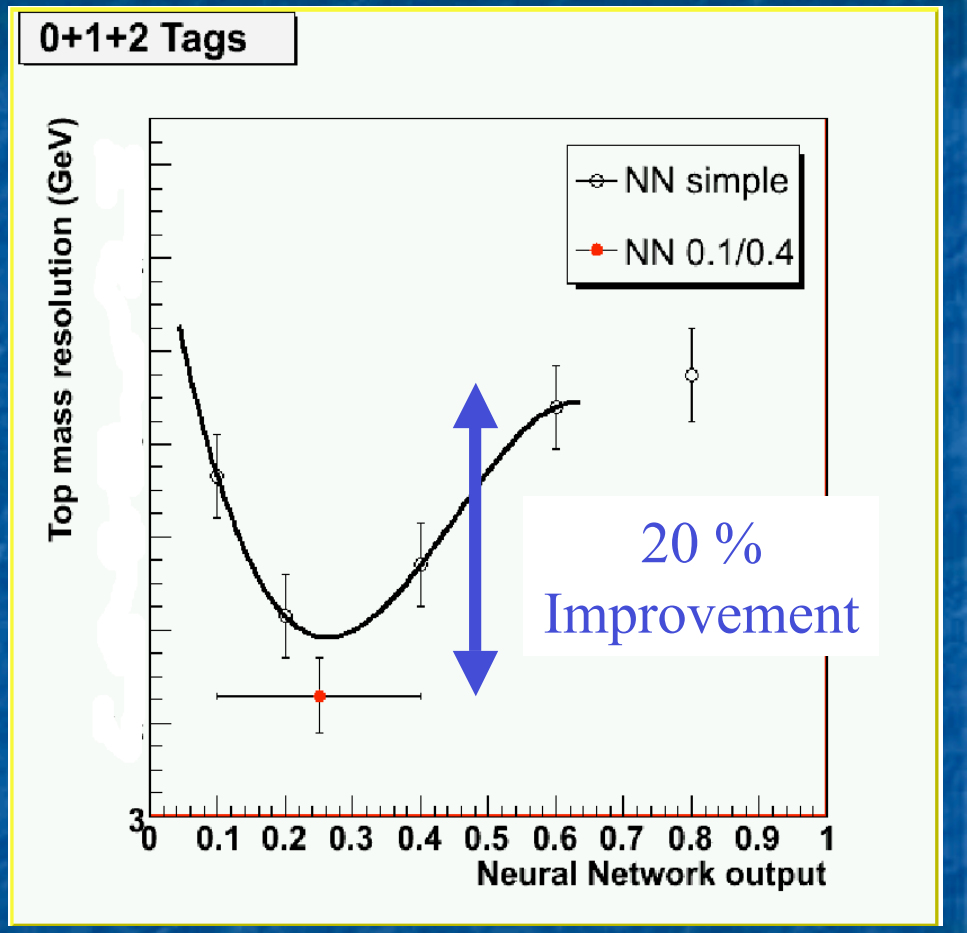






Optimization of b-tag Operating Point

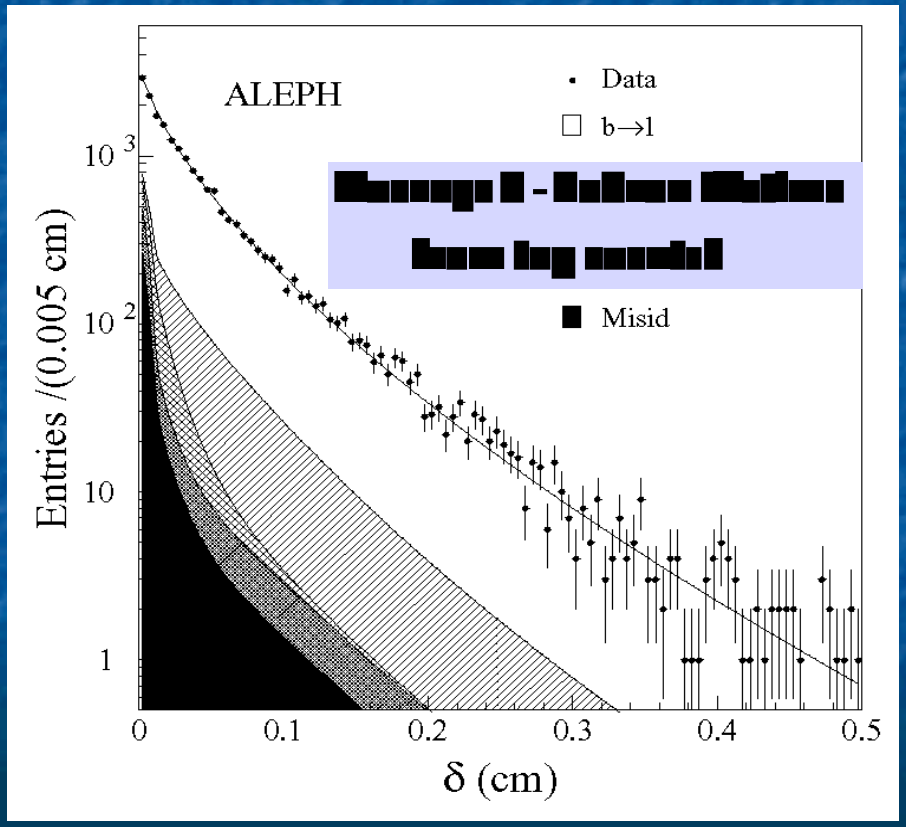


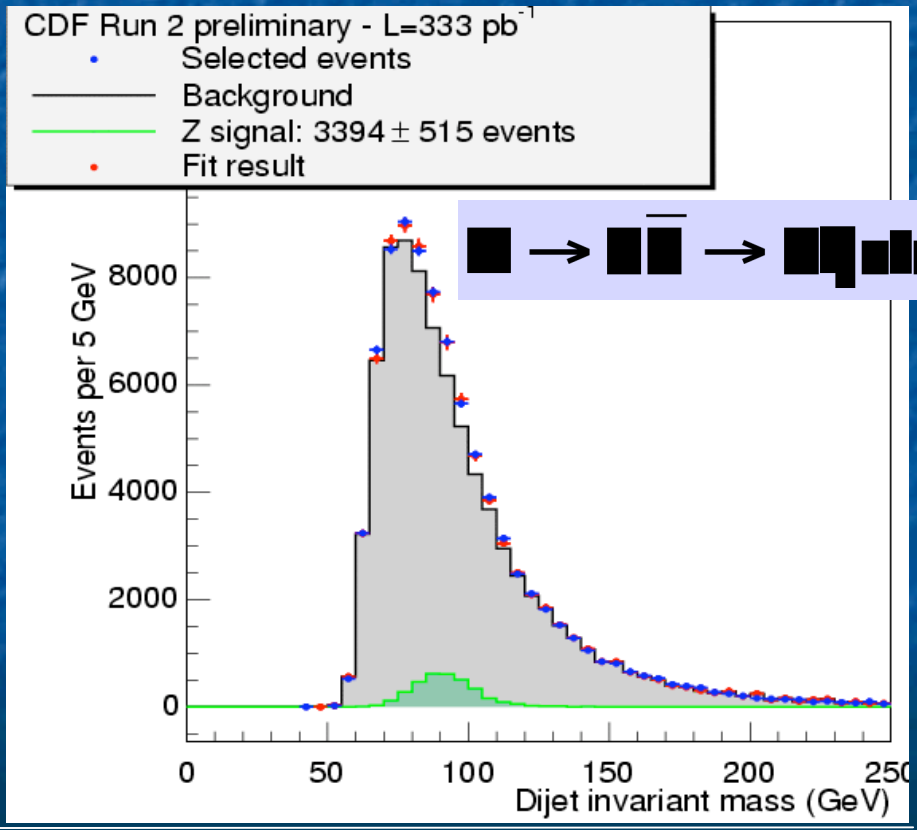


- Possibility exists for continuous b-tag weighting or relative weighting within event categories

Other Internal Calibrations or Cross-Checks?

- Will we ever get a handle on b-jet energy scale at the 1% level from Tevatron data?





General Remarks

- CDF/DØ have each tested both types of mass measurement techniques, 2D template and ME
- At this level in the analysis, template and matrix element methods give similar sensitivities
- Going below 2 GeV/c^2 in total mass uncertainty will be a courageous step, whereby the systematic uncertainties will be the dominant e

Somewhat similar to the LEP collaborations waiting for the beam energy scale group to come out with their 2 MeV uncertainty from g-2 depolarization, setting the ultimate precision on the Z mass

Backup Slides

Reconstructed W Mass Templates