Top Mass Measurement Using a Matrix Element Method with Quasi-Monte Carlo Integration

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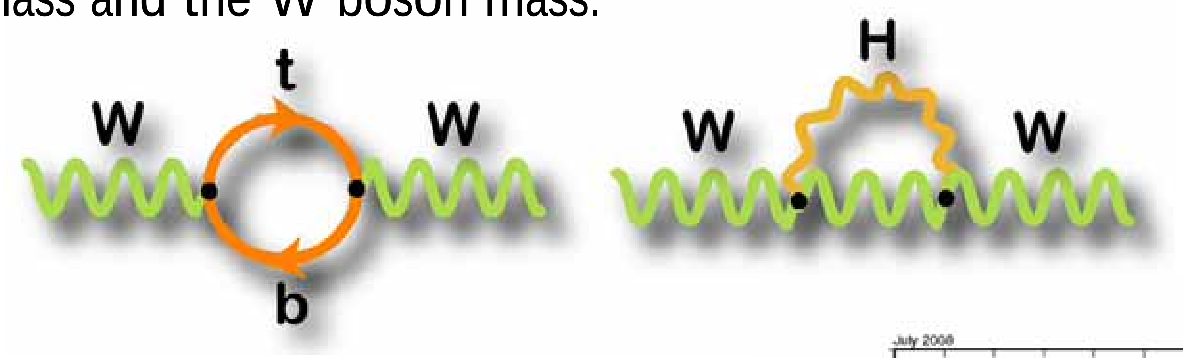
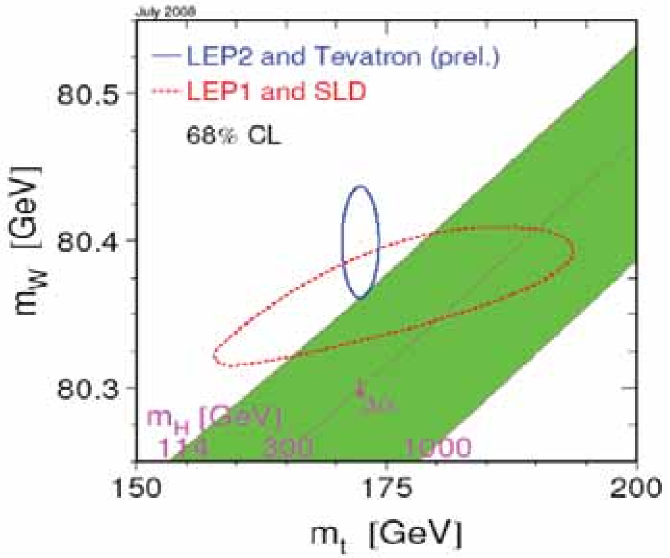
Motivation

- The top quark is the heaviest known particle in the Standard Model and hence couples strongly with the Higgs boson.
- Radiative corrections relate the Higgs boson mass to the top quark mass and the W boson mass.



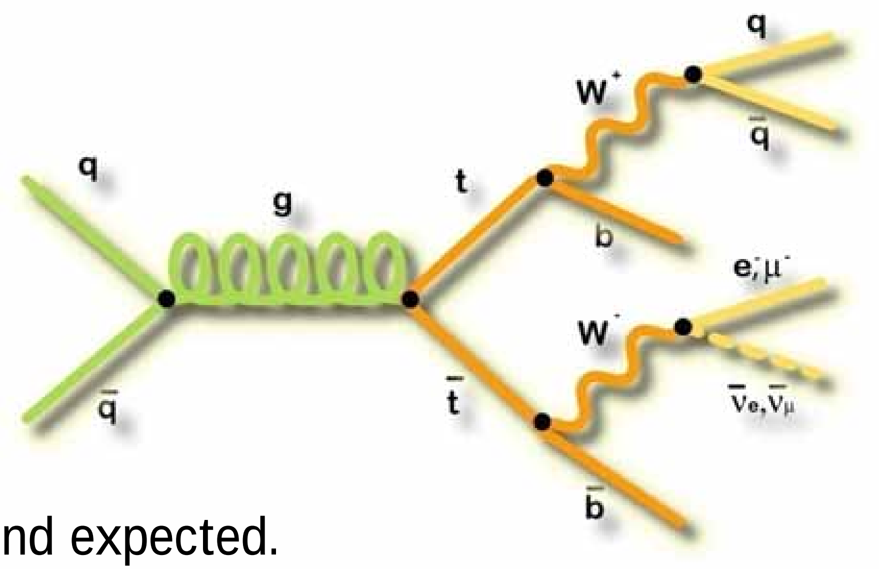
- Precision measurements of the top quark mass (in conjunction with the W boson mass) thus help to constrain the Higgs mass.

July 2008 averages



Event Selection

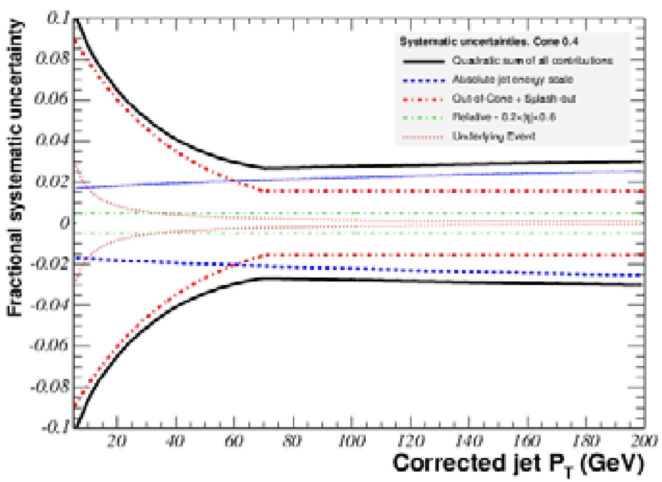
- Our latest measurement is performed with 3.2 fb^{-1} of integrated luminosity collected at the CDF II detector, using events in the "lepton+jets" channel.
- We require 4 tight jets (corrected E_T > 20 GeV) with at least one b-tag, a tight lepton (electron or muon), and missing E_T from the neutrino.
- Total of 578 observed events with ~23% background expected.



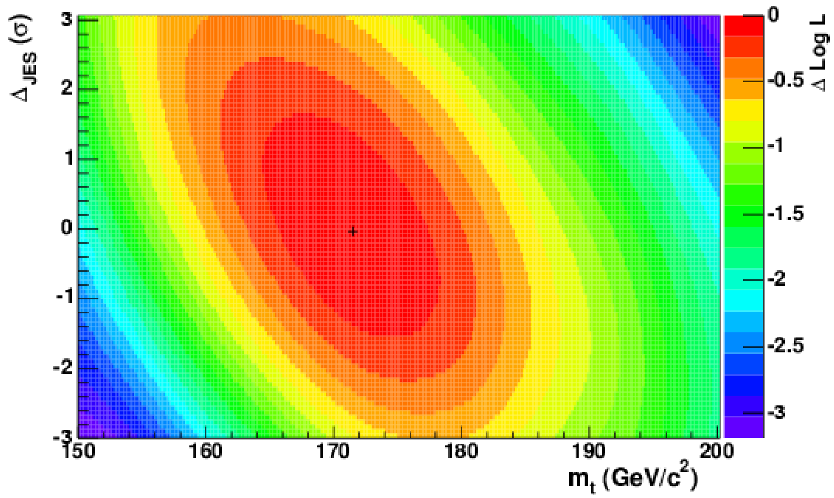
Background type	Expected contribution
W + heavy flavor (bb, cc, c)	70.1 ± 22.0
W + light mistag	23.5 ± 5.7
Non-W QCD	25.0 ± 20.5
Single top, diboson, Z+jets	16.5 ± 0.9

Matrix Element Method

- The matrix element method is based on integrating the matrix element for top pair production and decay over the unknown variables to generate a likelihood.
- We introduce an additional parameter representing the jet energy scale, Δ_{JES}, into our likelihood. This allows us to use the information in the W decay to determine the JES and reduce the systematic uncertainties associated with JES.



Jet systematic uncertainties



Sample 2-D likelihood curve

Integration Ingredients

normalization and acceptance ***sum over all 24 possible permutations***

$$L(\vec{y}\mid m_t,\Delta_{\rm JES}) = \frac{1}{N(m_t)}\frac{1}{A(m_t,\Delta_{\rm JES})}\sum_{i=1}^{24} w_i L_i(\vec{y}\mid m_t,\Delta_{\rm JES})$$

with

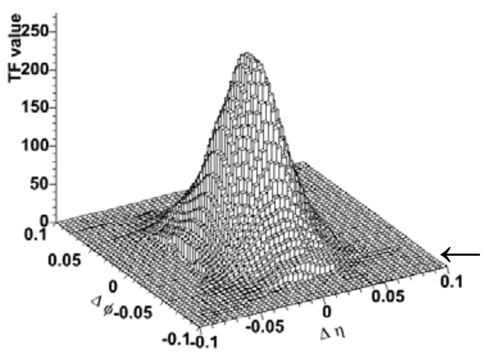
$$L_i(\vec{y}\mid m_t,\Delta_{\rm JES}) = \int \frac{f(z_1)f(z_2)}{FF}\,{\rm TF}(\vec{y}\mid\vec{x},\Delta_{\rm JES})\,|M(m_t,\vec{x})|^2\,d\Phi(\vec{x})$$

parton distribution functions (PDFs) for incoming partons

transfer functions (TF) connect the measured jet momenta with the partons

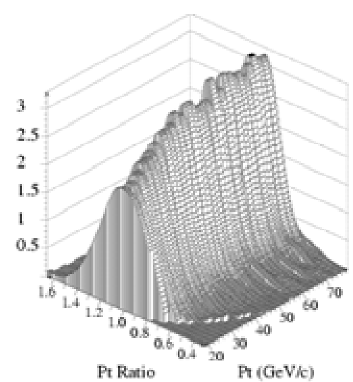
matrix element

19-dimensional integral – very computationally intensive. Quasi-Monte Carlo integration reduces the time to ~80 min/event.



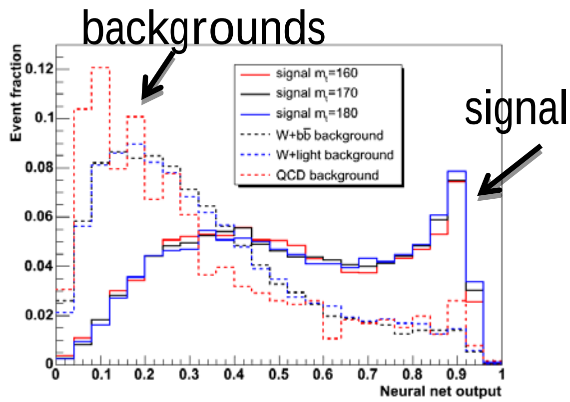
← **angle TF**

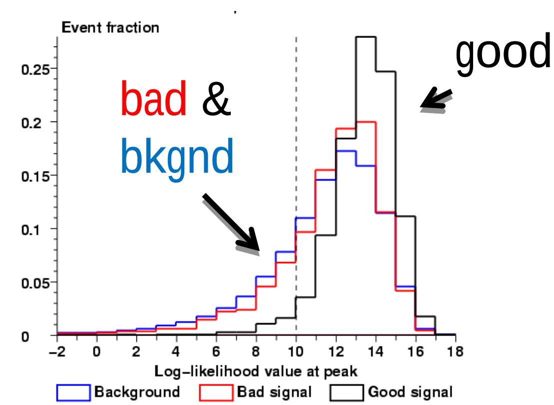
momentum TF →

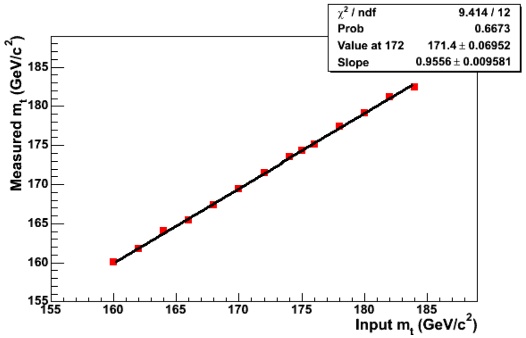


After the Integration

- Events likely to be background are identified using a neural network and their likelihood is subtracted from the total.
- A cut on the peak value of the log-likelihood is applied to reduce background and "bad signal" events (where we see a jet or lepton not from the top pair decay).
- Monte Carlo simulated samples are used to test and calibrate the method.

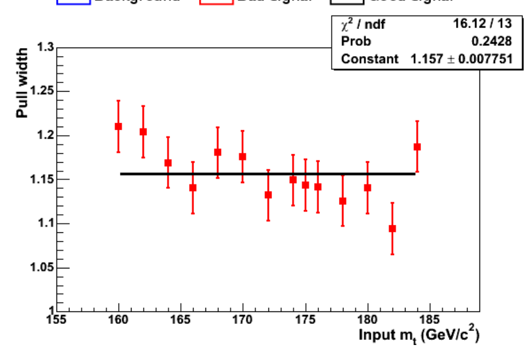






← output vs. input mass

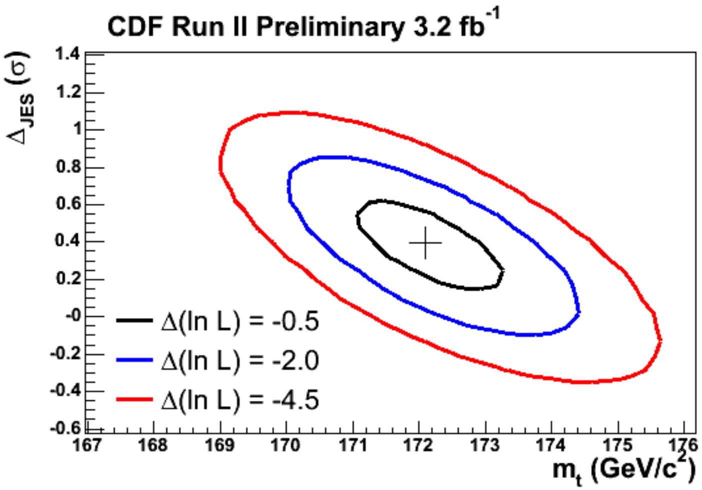
pull (uncertainty correction) →



Results

$m_t = 172.1 \pm 0.9$ (stat.) ± 0.7 (JES) ± 1.1 (syst.) GeV/c^2

Total uncertainty of 1.6 GeV/c^2: Best individual top mass measurement to date!

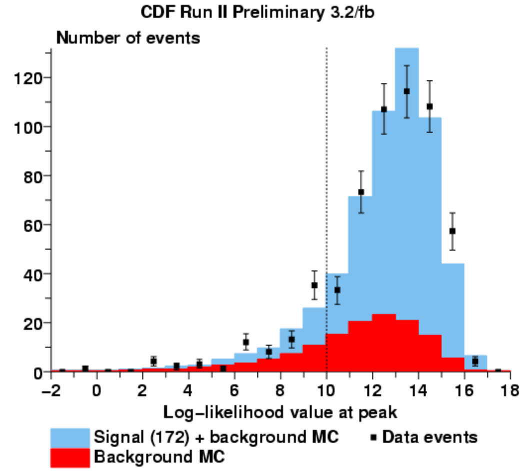


Total of 497 events passing all cuts

← Overall contours of 1-σ, 2-σ, and 3-σ uncertainty about our measured value

Log-likelihood peaks agree well in data and MC!

Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.2
MC generator	0.5
ISR and FSR	0.3
Residual JES	0.5
b-JES	0.4
Lepton P_T	0.2
Multiple hadron interactions	0.1
PDFs	0.2
Background	0.5
Color reconnection	0.4
Total	1.1

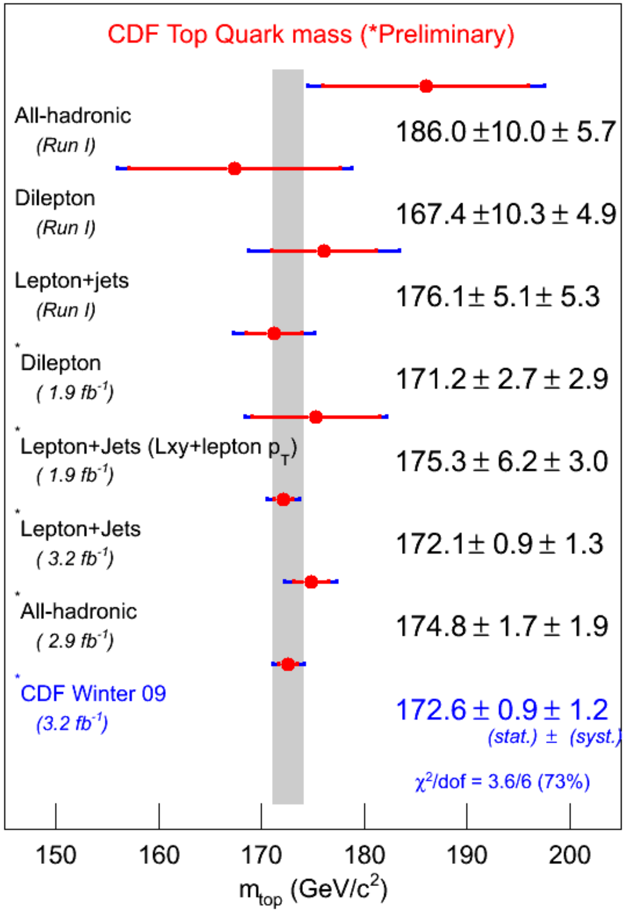


http://www-cdf.fnal.gov/physics/new/top/2009/mass/mtm3_p19_public/

Backup Slides

Latest m_t Combination

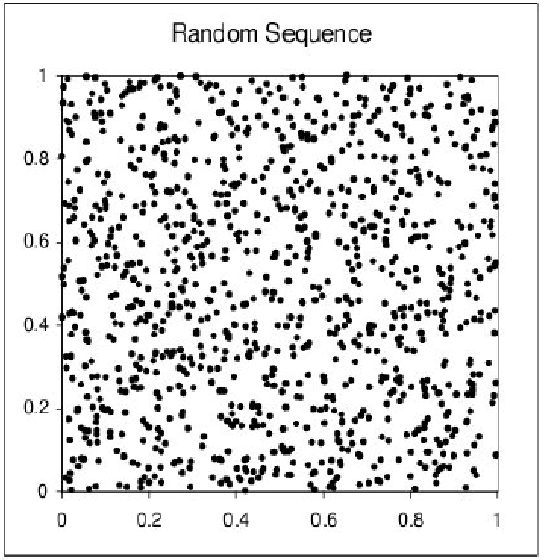
- Winter 2009 CDF combination

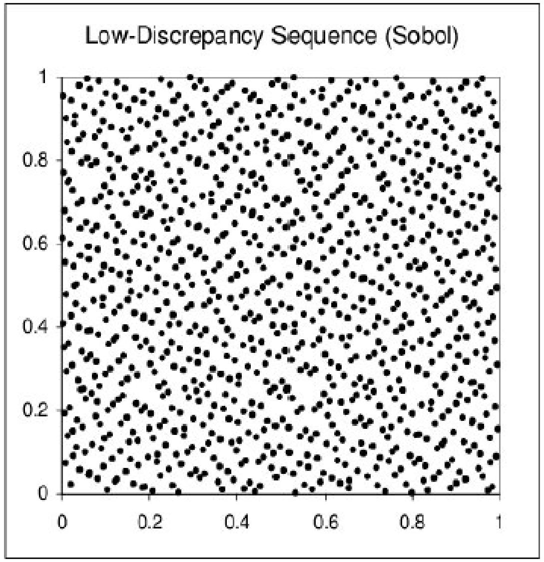


This measurement = 76.5% weight

Quasi-MC Integration

- Quasi-Monte Carlo integration uses, instead of a random point sequence (top), a quasi-random sequence (bottom).
- Formally speaking, a quasi-random sequence has a low discrepancy, where the discrepancy is a measure of the nonuniformity of the distribution. We use the scrambled Sobol sequence.
- Quasi-MC integration can offer better convergence than the $1/\sqrt{N}$ convergence of normal MC integration.
- See, for instance, hep-ph/0504085 or hep-ph/9601270.





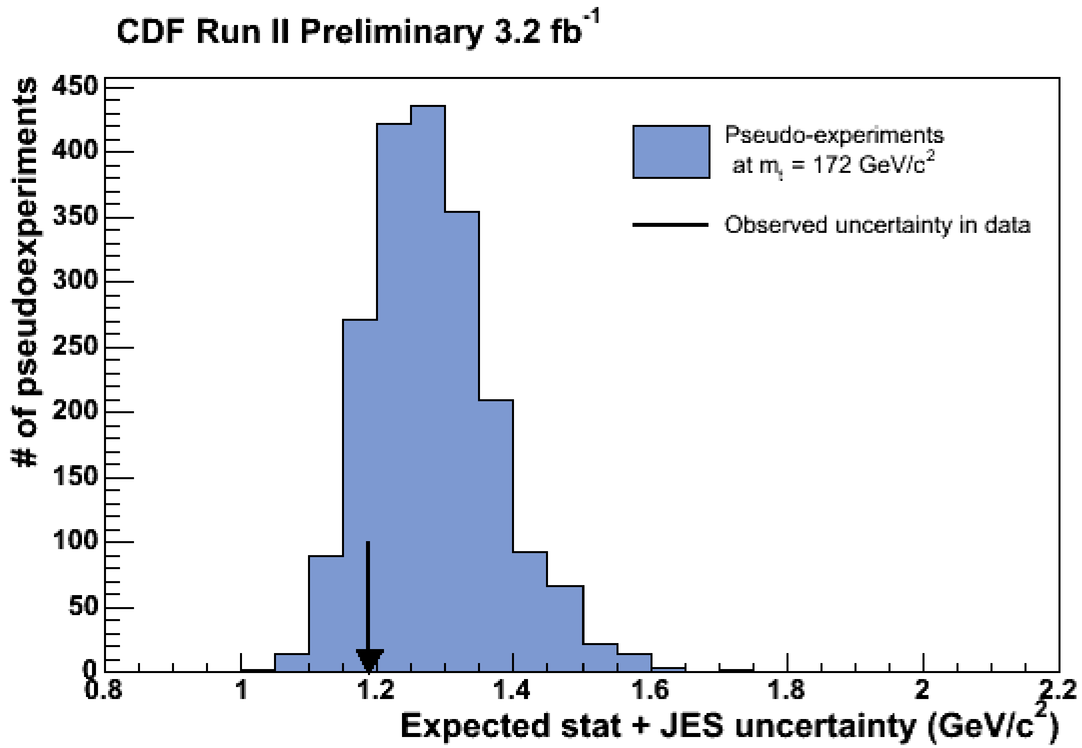
Likelihood Cut

Type of event	Fraction before cut	Efficiency of cut	Fraction after cut
Good signal	49.9%	96.6%	55.6%
Bad signal	26.9%	79.6%	24.7%
Background	23.2%	73.4%	19.7%

Adding in the likelihood cut improves our expected resolution at $m_t = 172$ GeV/c^2 by 0.23 GeV/c^2 – a substantial gain!

Final Uncertainty

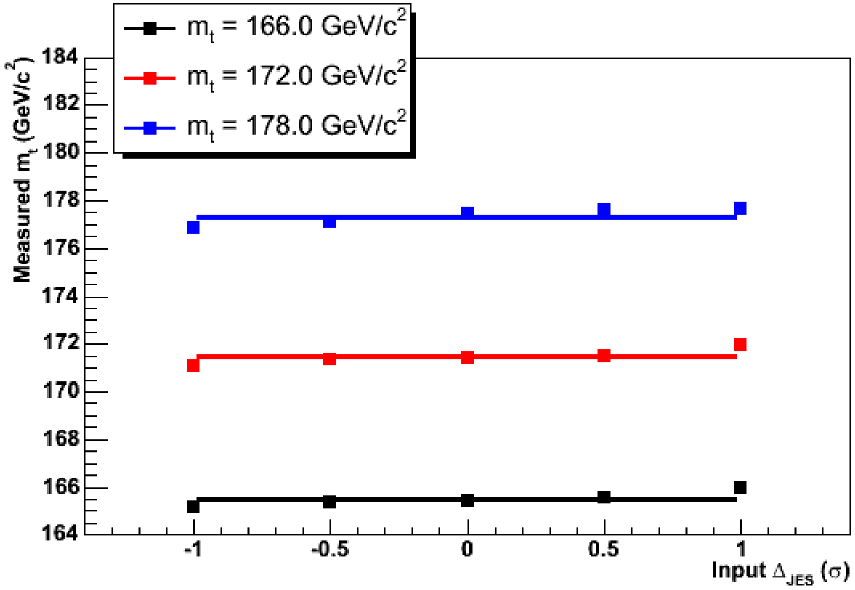
How lucky are we in our observed uncertainty?

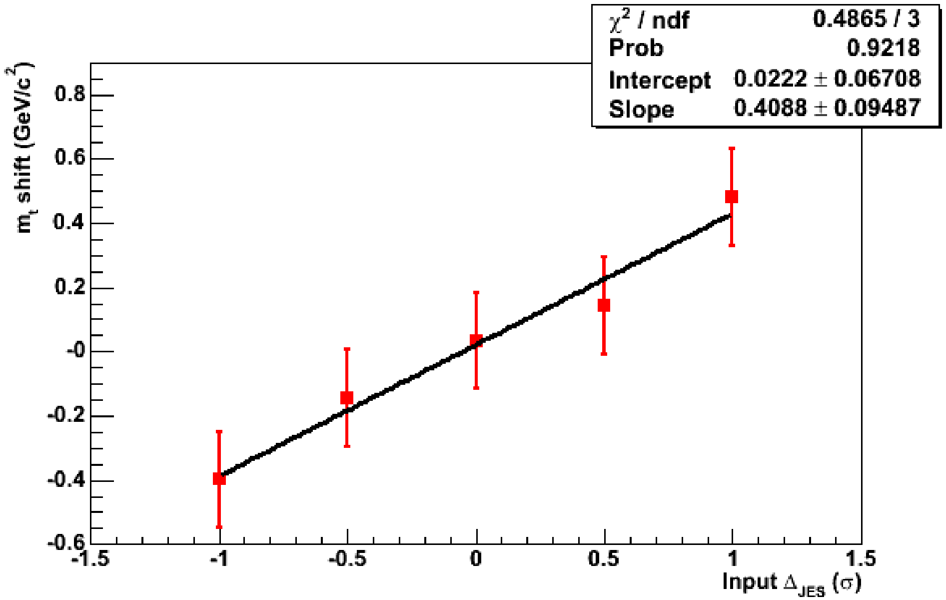


14% of pseudo-experiments show a lower uncertainty than measured in data.

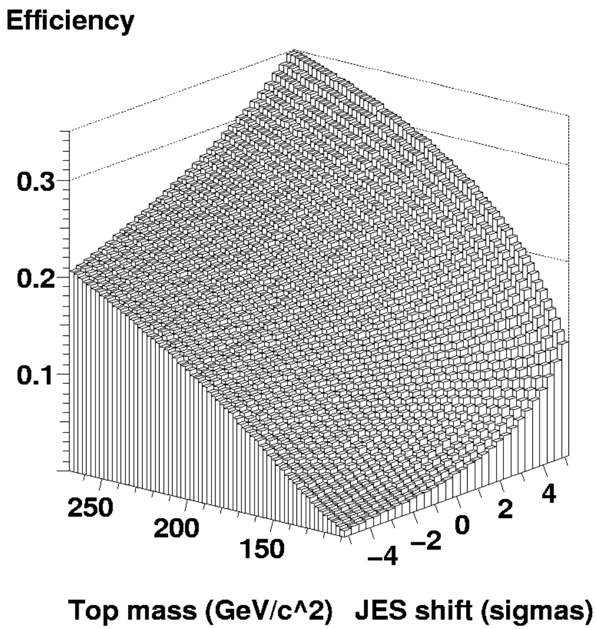
2-D Calibration

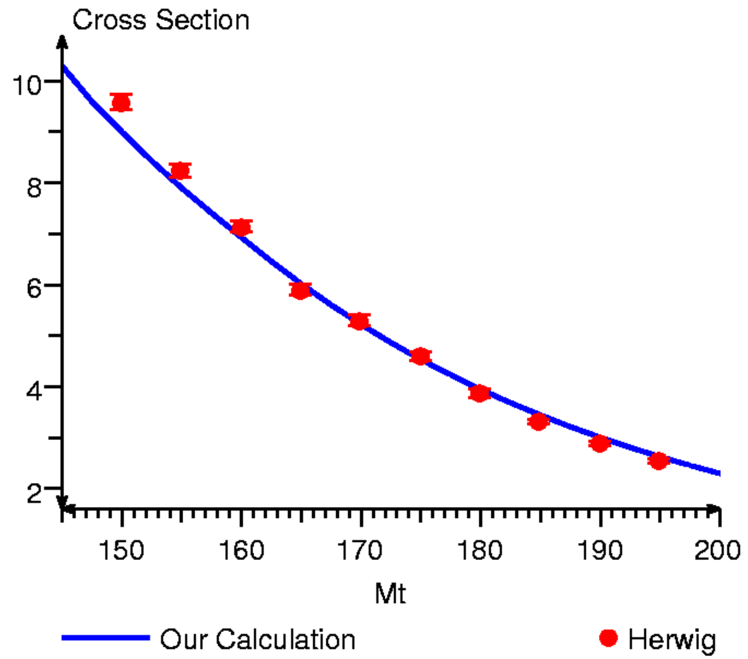
By observing the measured top mass as a function of the input Δ_{JES} (top), we can see that there is some slight dependence. We thus fit a line to the observed m_t shift as a function of Δ_{JES} (bottom) and add this term to our calibration.





Acceptance & Normalization





Acceptance (left) accounts for the changes in detector acceptance with m_t and Δ_{JES}.
Normalization (right) is obtained by integrating the matrix element and PDFs over the parton phase space.

Integration Variables

- m_t^2 and m_W^2 on the two sides of the event (4)
- p_T of the ttbar system (2)
- $\beta = \log(p_{q1}/p_{q2})$, where q_1 and q_2 are the decay products of the hadronic W (1)

New with the quasi-MC integration:

- Masses for each of the four partons (4)
- $\Delta\eta$ and $\Delta\phi$ for each of the four partons (8)