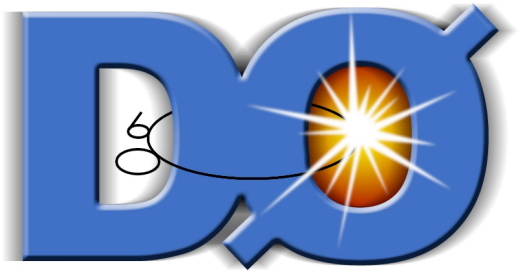
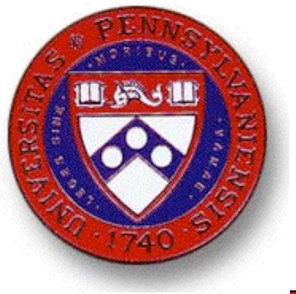


Precision Measurements of the Top Quark Mass at the Tevatron

DANIEL WHITESON

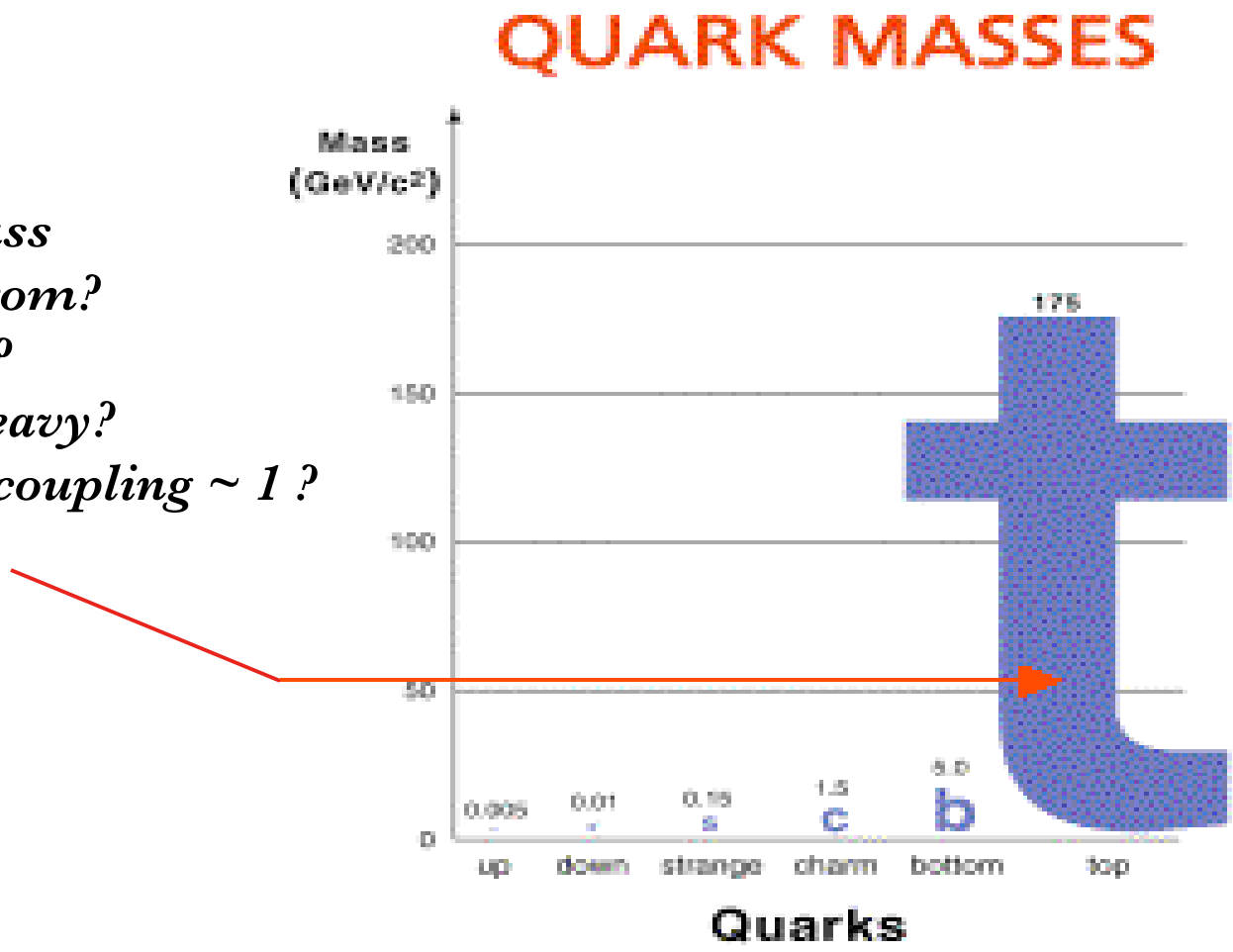
UNIVERSITY OF PENNSYLVANIA

ON BEHALF OF THE CDF AND DZERO COLLABORATIONS



Top Quark

Where does this mass structure come from?
What does it reveal?
Why is the top so heavy?
Why is its Yukawa coupling ~ 1 ?

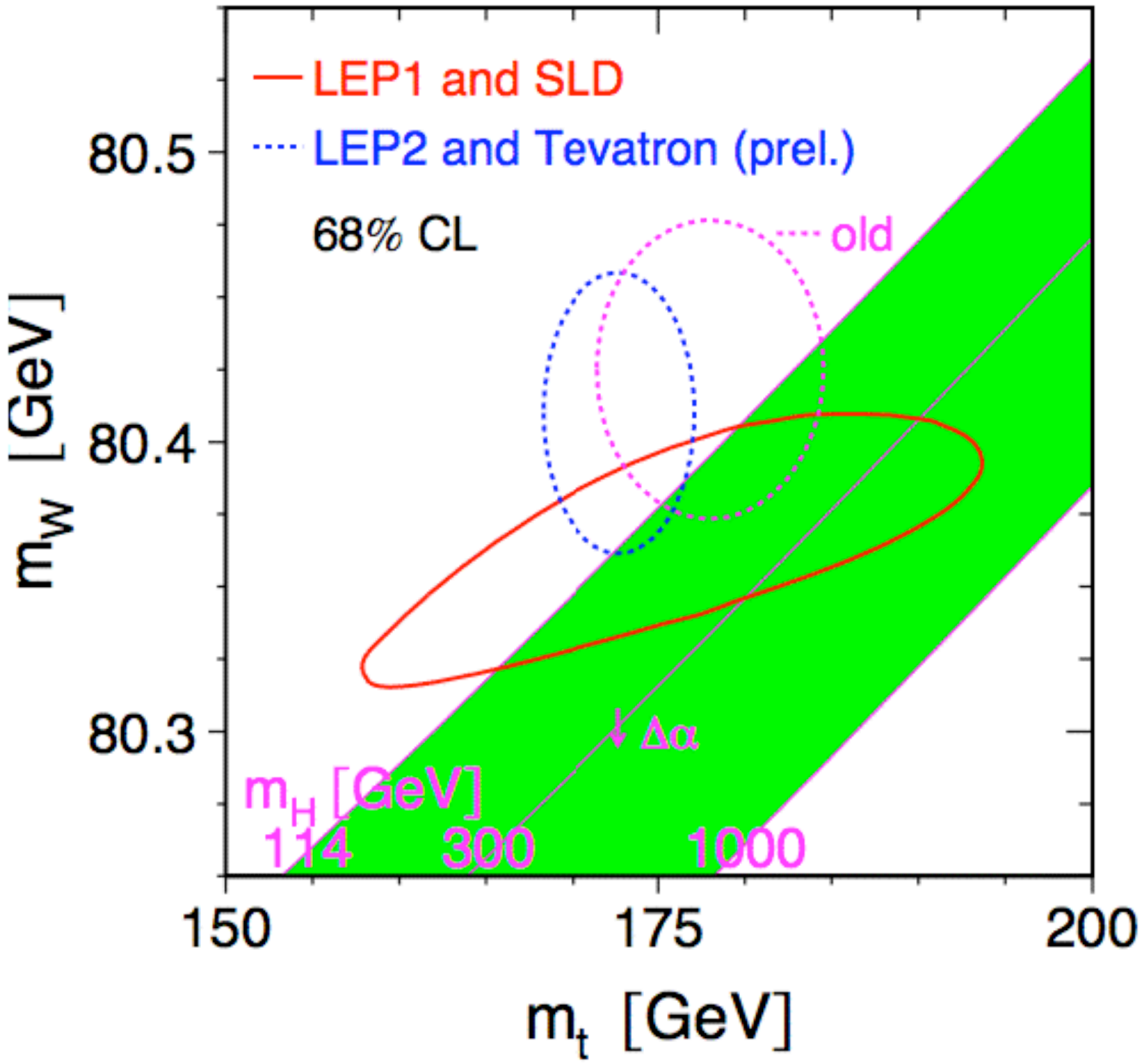


Higgs

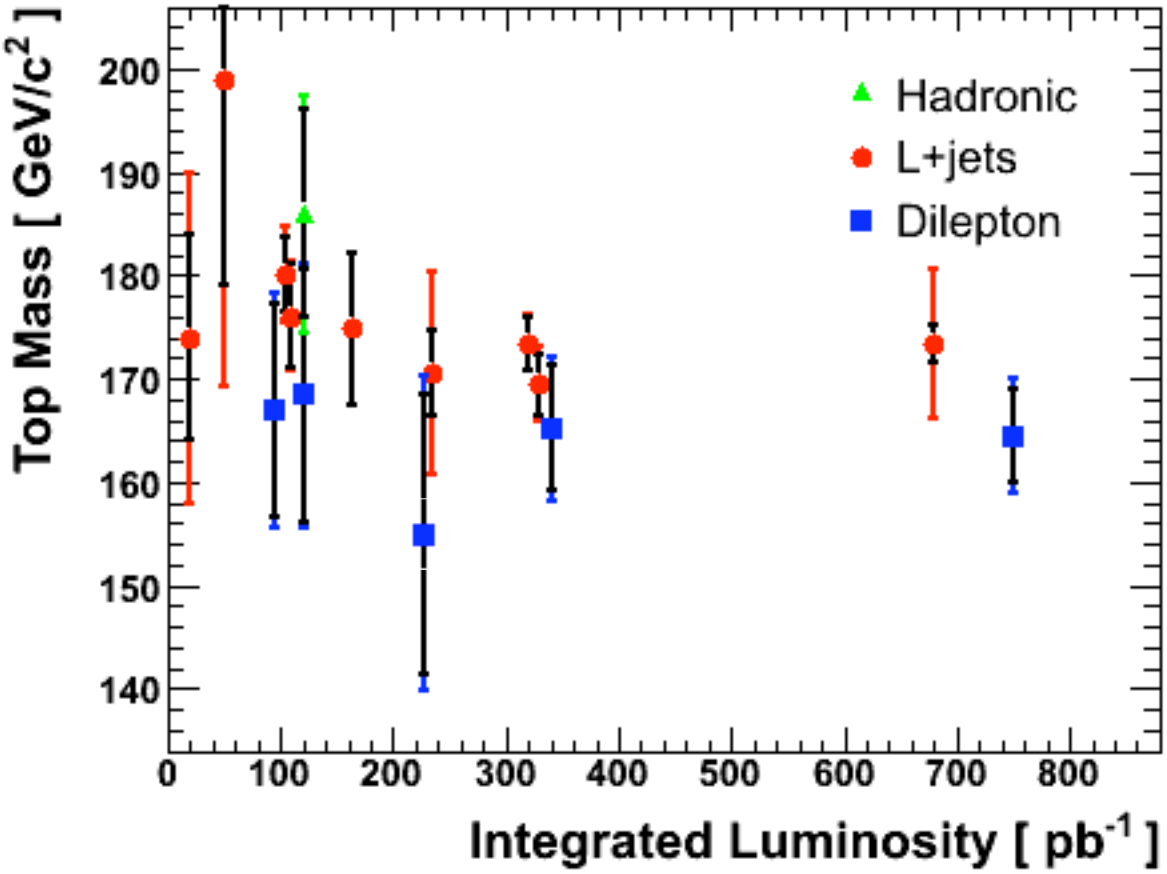
Update plot!

Higgs connection

Radiative corrections
Heavy top means heavy Higgs
M_t provides constraints on M_h



Top measurements



L+jets error dominated by systematics!

Dilepton error will soon be systematics limited.

The future era will be devoted to systematic errors, and comparison among channels

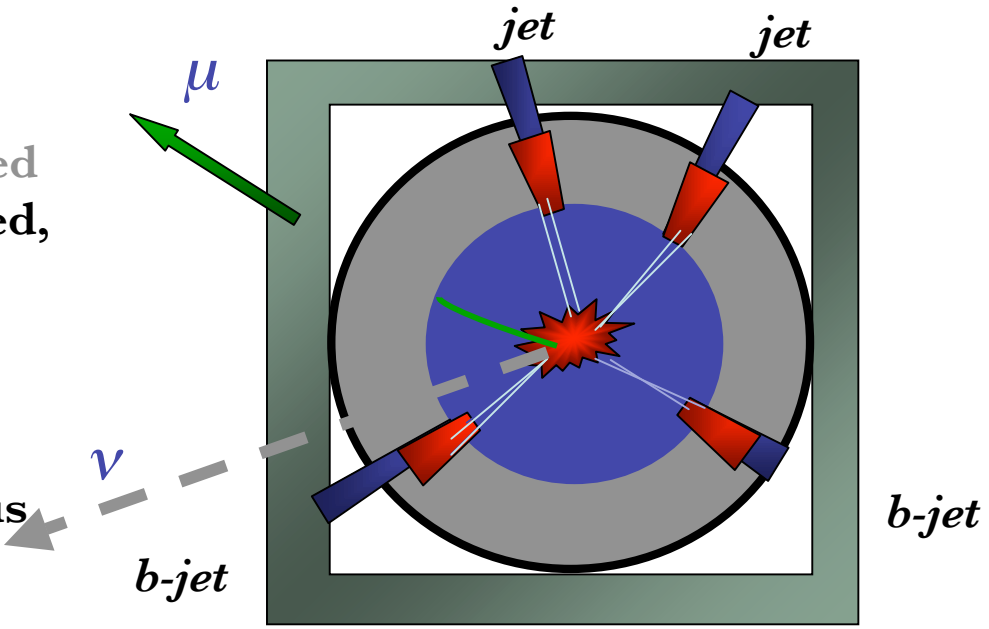
How to measure mass

How do we measure the mass?

Can't just put the pieces back together again

Lost information

- **Neutrinos have escaped undetected**
- **Quarks have hadronized, showered, been clustered into *jets***
- **Lepton resolution is good, but not perfect**
- **Assignment of reconstructed objects to partons is not obvious**



Misinformation

-Background processes mimic top-ology

Solution

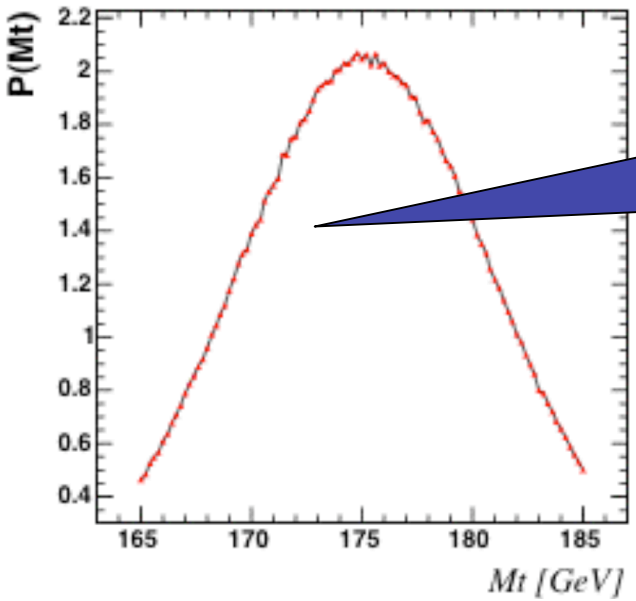
Lepton+jets

4 jet resolutions
Jet-parton assignments
24 (no *b*-tags)
12 (1 *b*-tag)
4 (2 *b*-tags)
1 missing neutrino

Dileptons

2 jet resolutions
Jet-parton assignments (2)
2 missing neutrinos

Monte Carlo integration over unmeasured quantities.

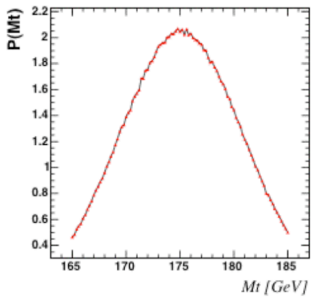


Each event has a curve, rather than a single mass value

Construct probability curve $P(M_t)$ for each event.

Form joint probability for sample, choose most probable value.

Probability calculation



Template strategy

Example: parameterize $P(M_t)$ in terms of event-level variable: Reconstucted M_{top}

Derive parameters from templates of simulated events.

Best measurement in *lepton+jets*

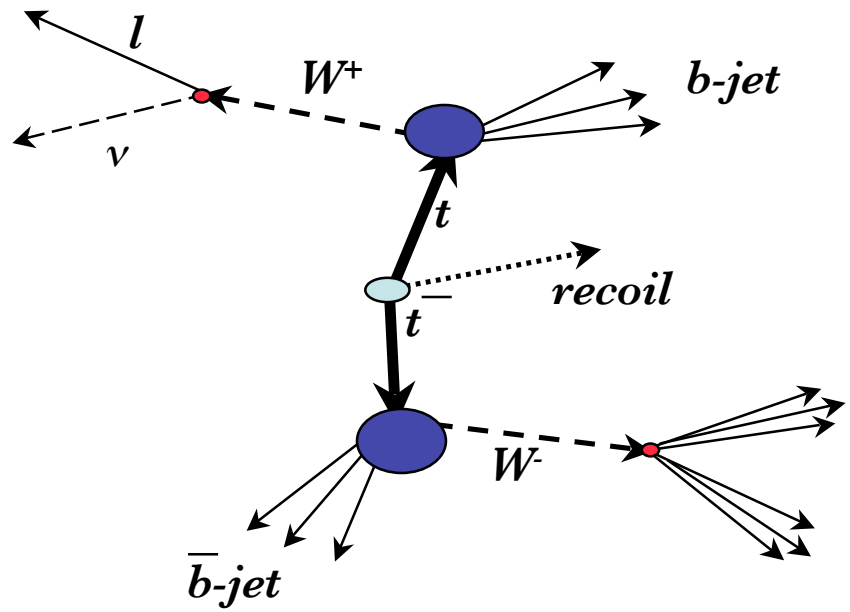
Matrix-element strategy

Calculate $P(M_t)$ directly for each event by convoluting matrix element with resolution functions.

Make simplifying approximations and measure corrections in simulated events.

Best measurement in *dileptons*.

Templates: extracting fitted masses



Constrain

P_T balance

$M_{l\nu} = M_W$

$M_{jj} = M_W$

$M_{t1} = M_{t2}$

Vary

24 jet-parton assignments

Measurements within resolutions

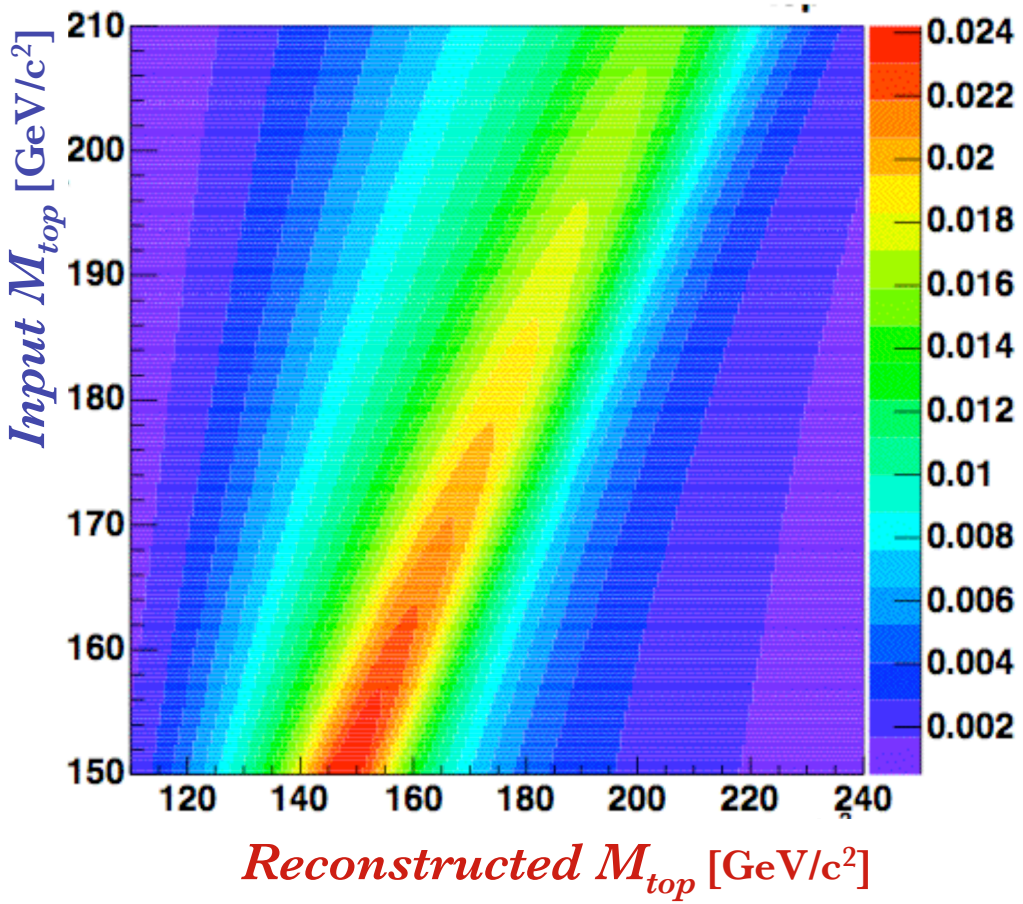
Reconstruct

Top mass (with best χ2)

$$\chi^2 = \sum_{i=l,4\,\text{jets}} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,fit} - p_j^{UE,meas})^2}{\sigma_j^2}$$

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_t)^2}{\Gamma_t^2} + \frac{(M_{bl\nu} - M_t)^2}{\Gamma_t^2}$$

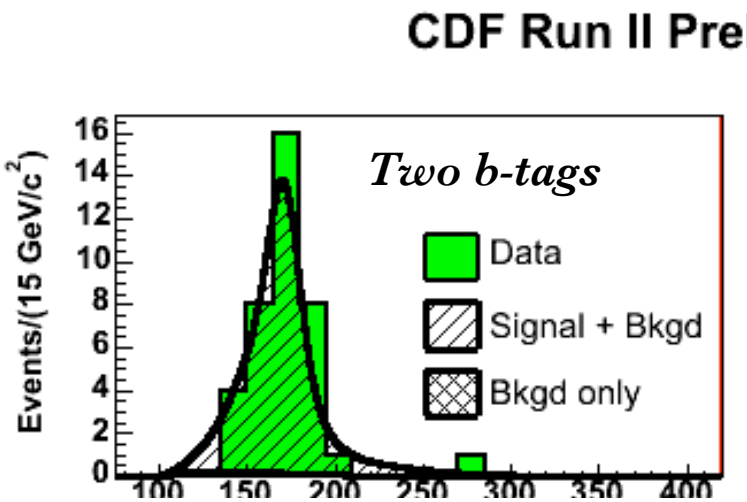
Lepton+Jets template

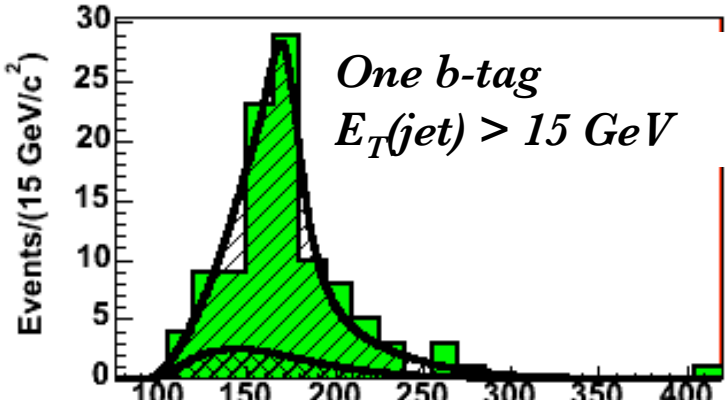


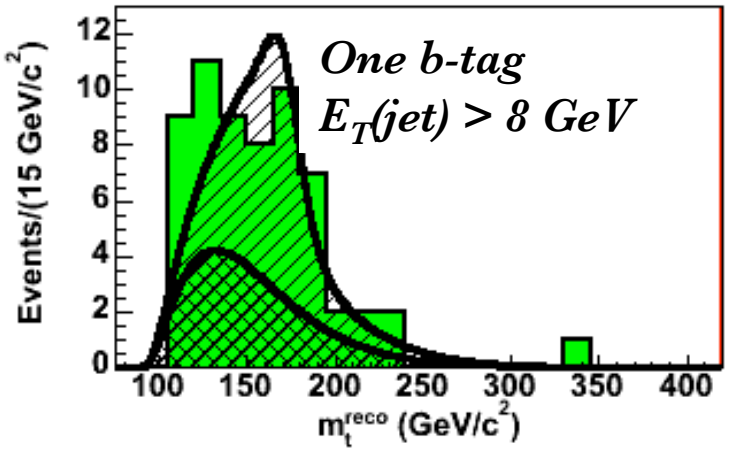
Reconstructed top mass is well correlated to input top mass.

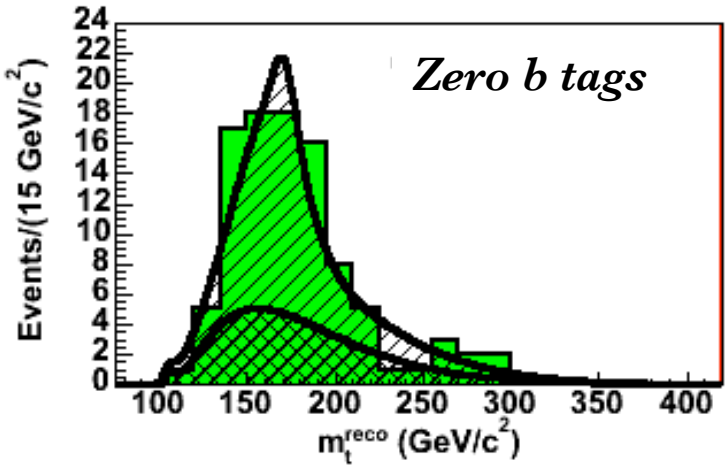
Lepton+jets

Reconstructed top mass in lepton + jets events

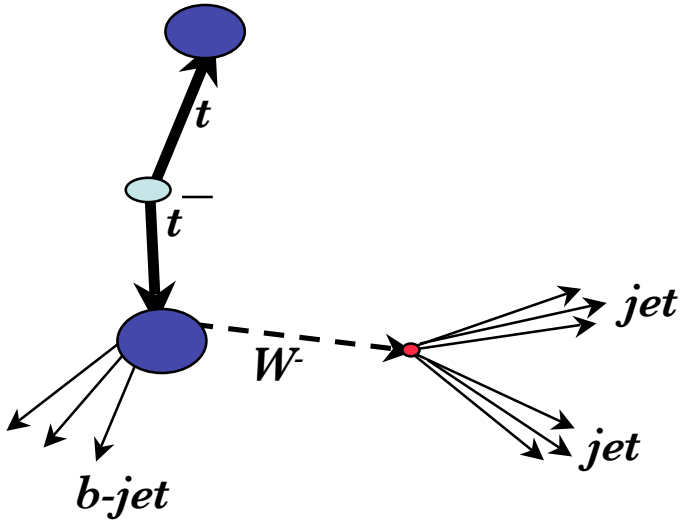


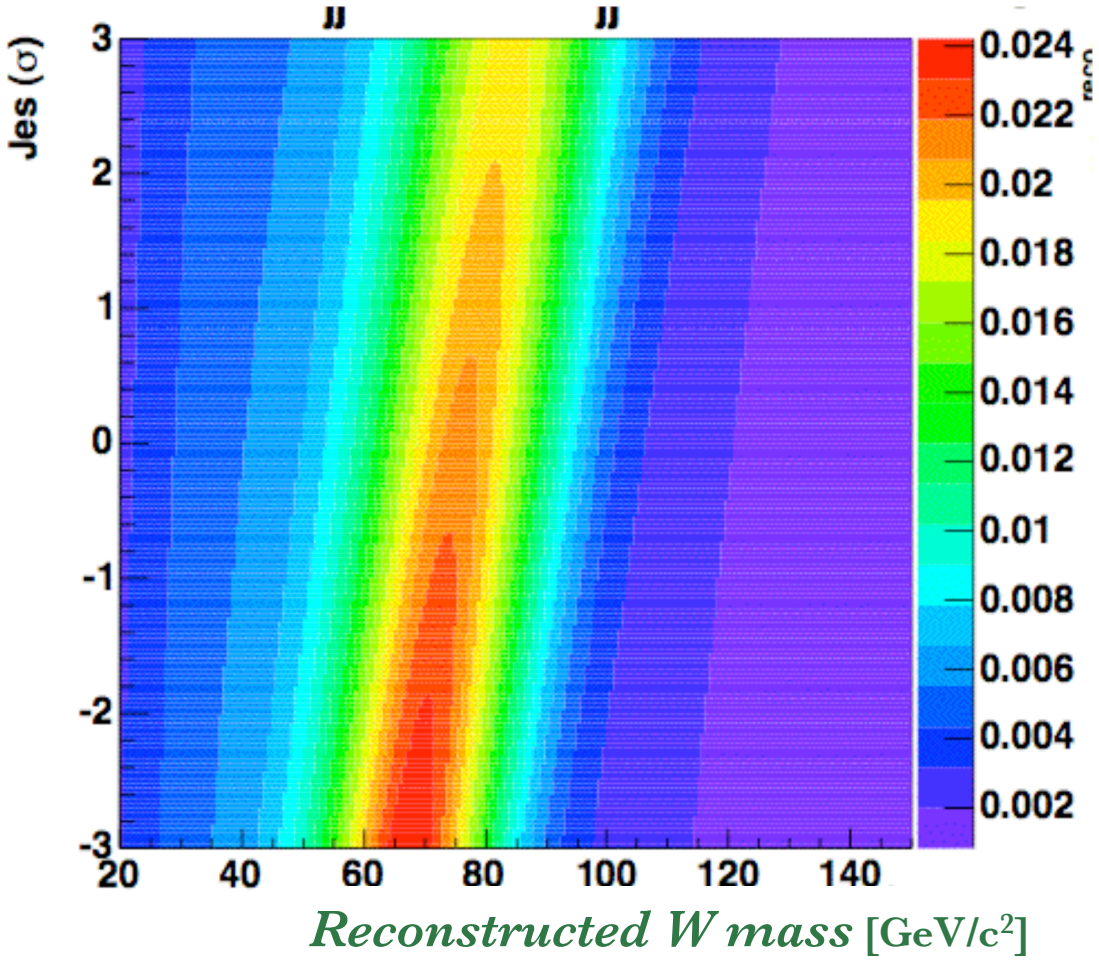






Reconstructed W mass



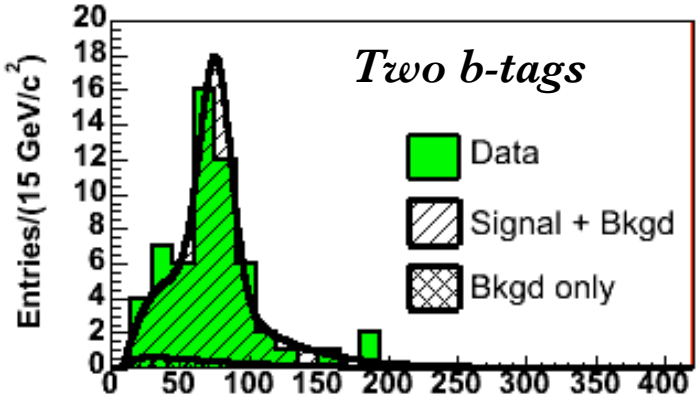


Reconstructed *W* mass is correlated to jet energy scale, expressed in units of $\sigma(P_T,\eta)$ from the external calibration.

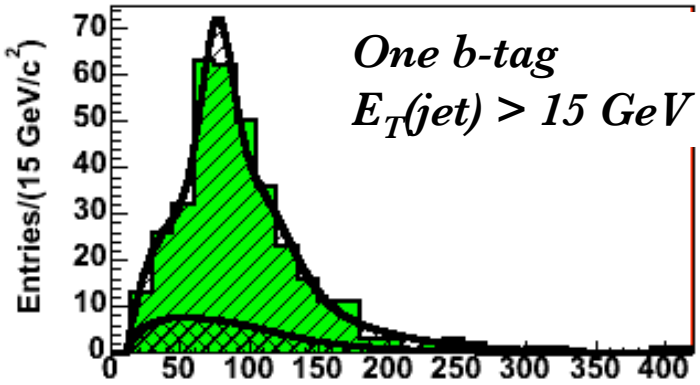
Lepton+Jets events

Reconstructed hadronic W mass in lepton + jets events

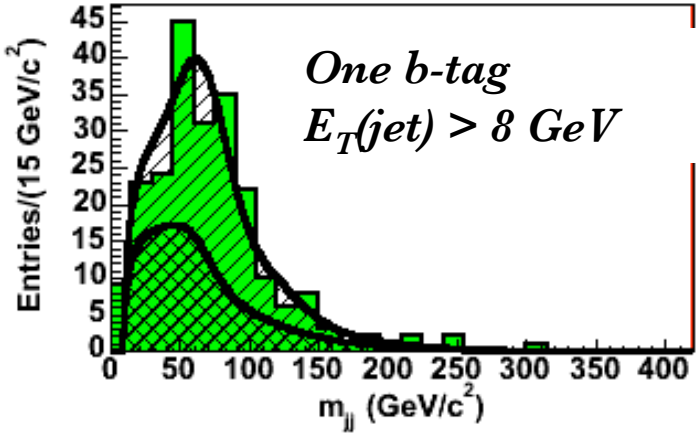
CDF Run II Preliminary (680 pb^{-1})



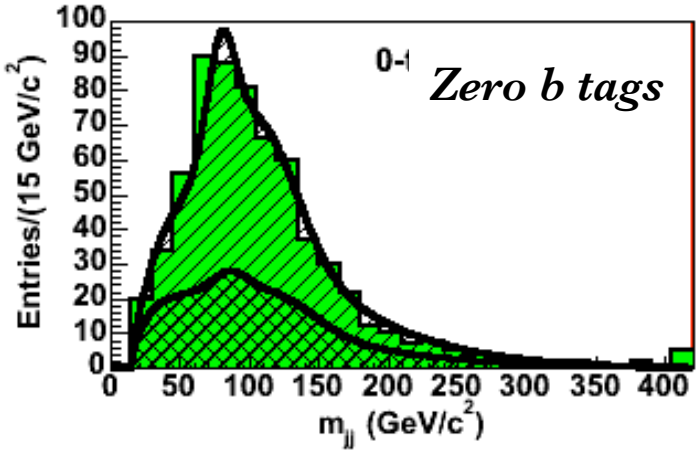
Reconstructed W Mass [GeV/c^2]



Reconstructed W Mass [GeV/c^2]

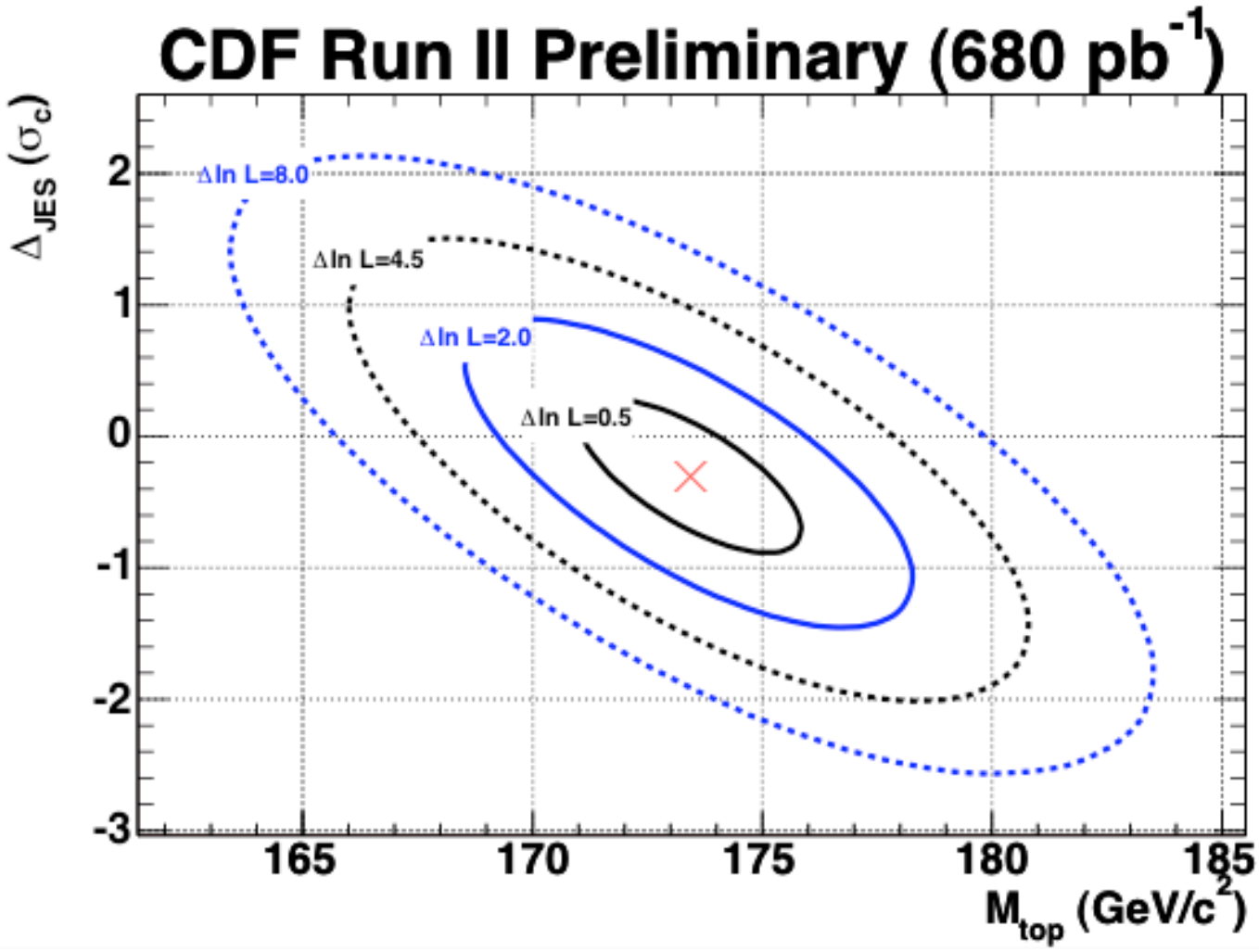


Reconstructed W Mass [GeV/c^2]



Reconstructed W Mass [GeV/c^2]

2D Likelihood



2D Result: $M_t = 173.4 \pm 1.7_{(Stat)} \pm 1.8_{(JES)} \pm 1.3_{(syst)}$ GeV/c^2

$\Delta JES = -0.3 \pm 0.6\ \sigma$

Single best measurement of M_t. More precise than Run1!

Systematics

Systematics are largely due to uncertainties in modeling.

Source	$\Delta M_{top}(GeV/c^2)$
Remaining Jet Energy Scale	0.7
ISR/FSR	0.6
B-jet modeling	0.6
Background Shape	0.5
Background JES	0.4
Parton Distributions	0.3
Generator	0.2
Simulation Statistics	0.3
B-tagging	0.1
Total	1.3

Systematics

Systematics are largely due to uncertainties in modeling.

Source	$\Delta M_{top}(GeV/c^2)$
Remaining Jet Energy Scale	0.7
ISR/FSR	0.6
B-jet modeling	0.6
Background Shape	0.5
Background JES	0.4
Parton Distributions	0.3
Generator	0.2
Simulation Statistics	0.3
B-tagging	0.1
Total	1.3

From p_T and η dependence of modeling uncertainties

Systematics

Systematics are largely due to uncertainties in modeling.

Source	$\Delta M_{top}(GeV/c^2)$
Remaining Jet Energy Scale	0.7
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B-jet modeling	0.6
Background Shape	0.5
Background JES	0.4
Parton Distributions	0.3
Generator	0.2
Simulation Statistics	0.3
B-tagging	0.1
Total	1.3

Model constrained by Z+jets data

Systematics

Systematics are largely due to uncertainties in modeling.

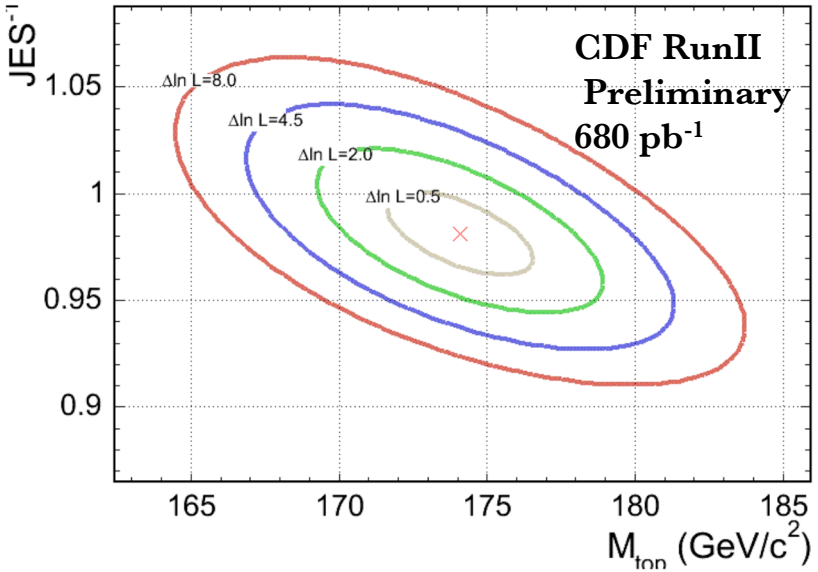
Source	$\Delta M_{top}(GeV/c^2)$
Remaining Jet Energy Scale	0.7
ISR/FSR	0.6
B-jet modeling	0.6
Background Shape	0.5
Background JES	0.4
Parton Distributions	0.3
Generator	0.2
Simulation Statistics	0.3
B-tagging	0.1
Total	1.3

Uncertanties from semi-leptonic decay, fragmentation and color flow.

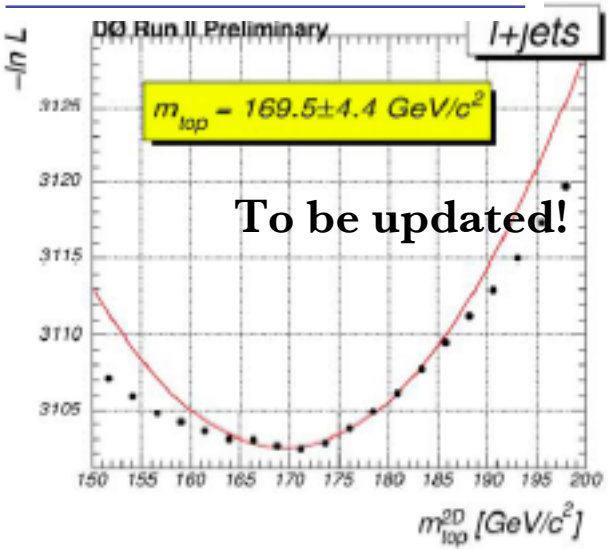
Other L+jets results

Add numbers to all.

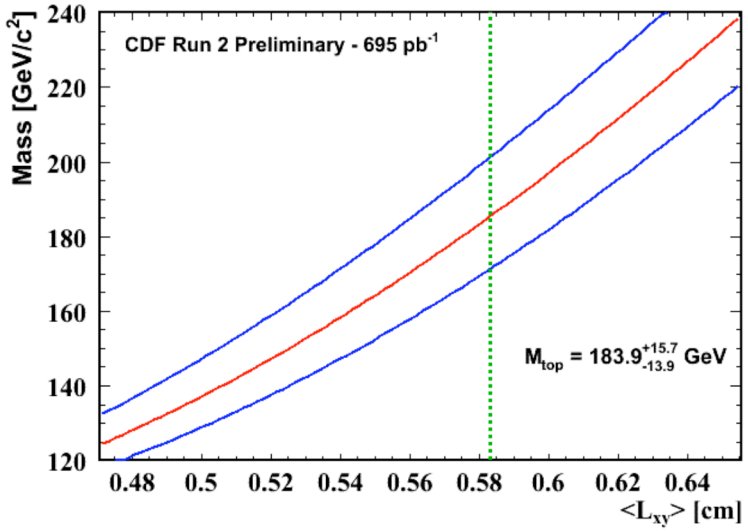
Matrix Element method



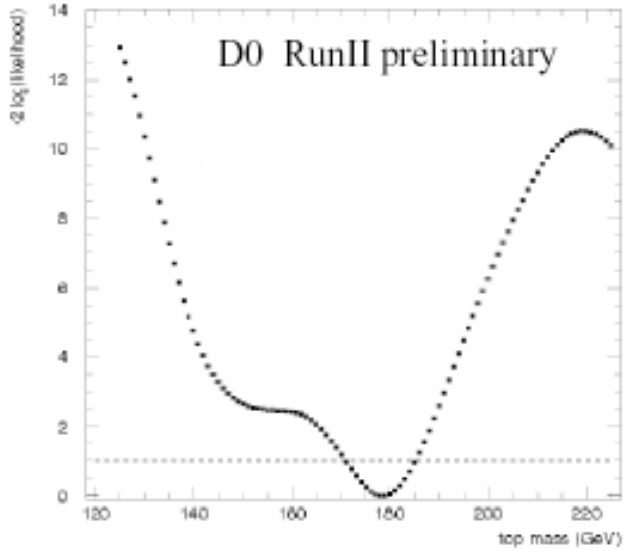
Matrix Element method



Transverse Decay Length of b



Ideogram method

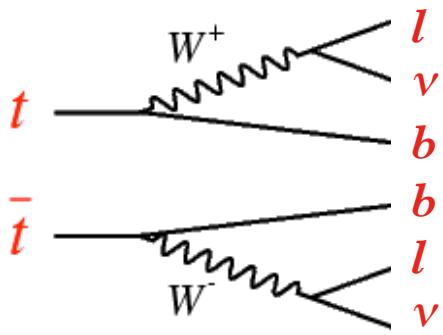


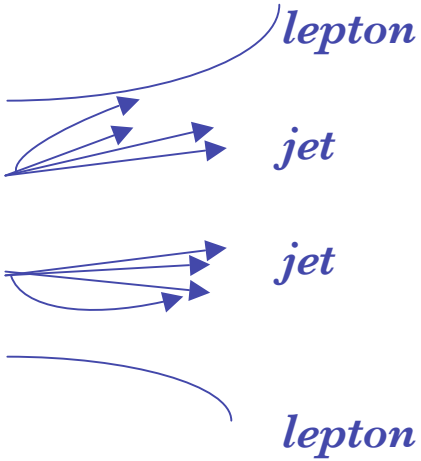
Matrix Element Method

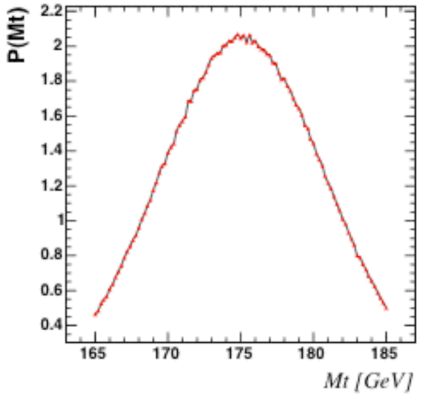
(as applied to dileptons)

Break into two pieces: parton-level process and showering/resolution effects

$$P(\textit{partons} \mid M_t) \quad x \quad P(\textit{event x} \mid \textit{partons}) \quad = \quad P(\textit{event x} \mid M_t)$$







Integrate over 6 variables

2 Top masses

2 W masses

2 b-quark energies

Matrix Element method

$$\mathbf{P}\,(\,\mathbf{event\ x}\ |\ \mathbf{M_t}\,)\ :$$

Differential cross-section calculation:

$$\frac{d\sigma(M_t)}{d\,\mathbf{x}} = \int d\Phi_6 |\mathcal{M}_{t\bar{t}}(p; M_t)|^2 \prod_{jets} f(p_i, j_i) f_{PDF}(q_1) f_{PDF}(q_2)$$

Phase-space Integral

Matrix Element
P(partons | M_t)

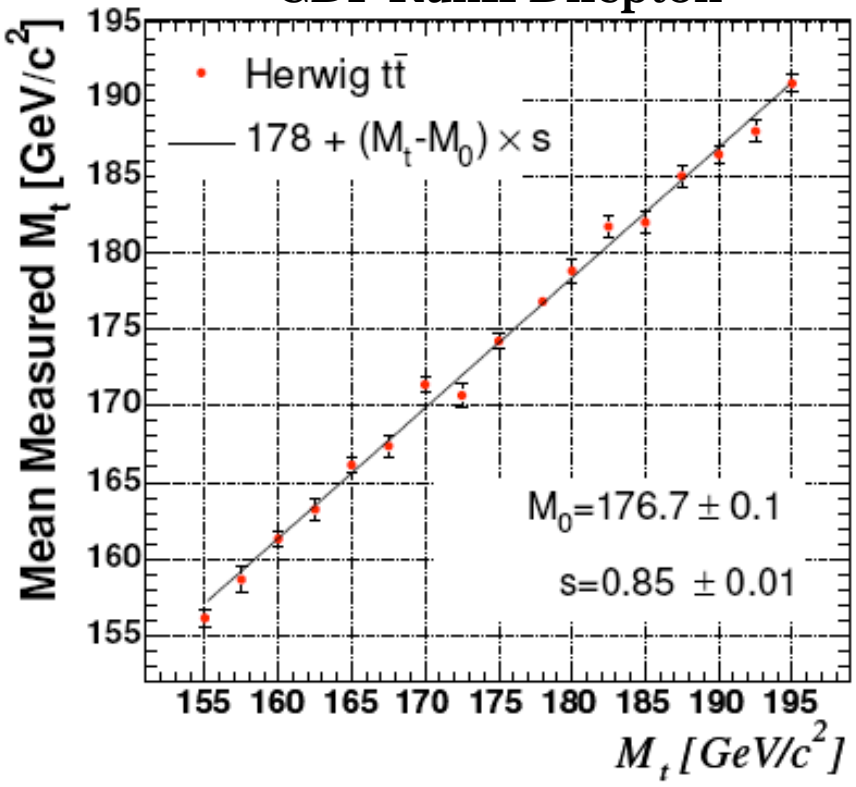
Transfer Functions
P (event x | partons)

p **4-momentum of final partons**
q **4-momentum of initial partons**
x **measured event variables**

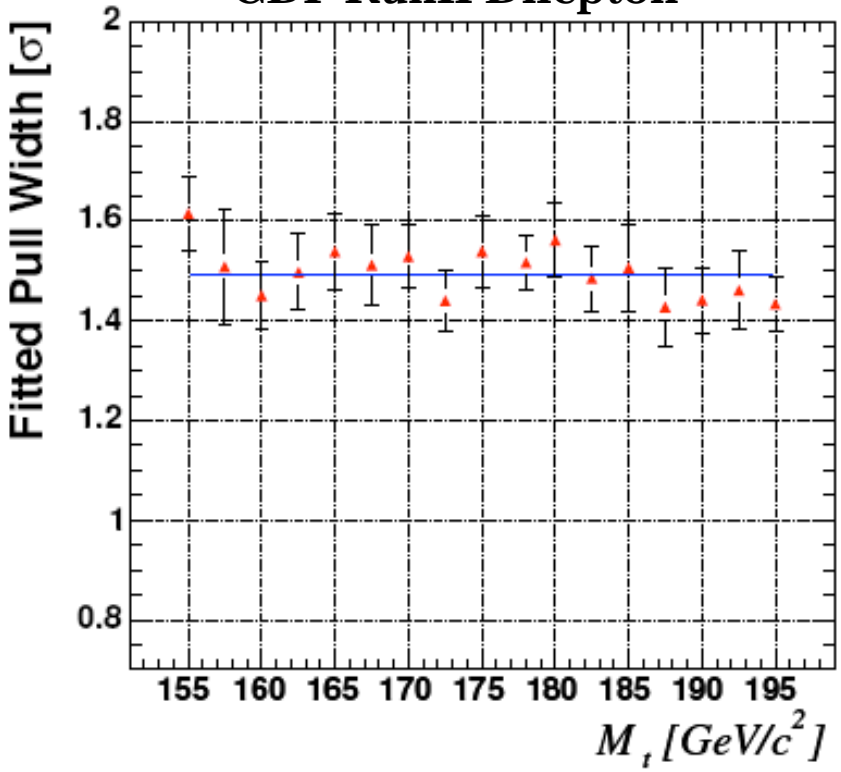
Simulation Calibration: CDF RunII Dilepton

Approximations in calculation require calibration in simulation.

CDF RunII Dilepton



CDF RunII Dilepton



Response

Linear.

Slope < 1 due to backgrounds.

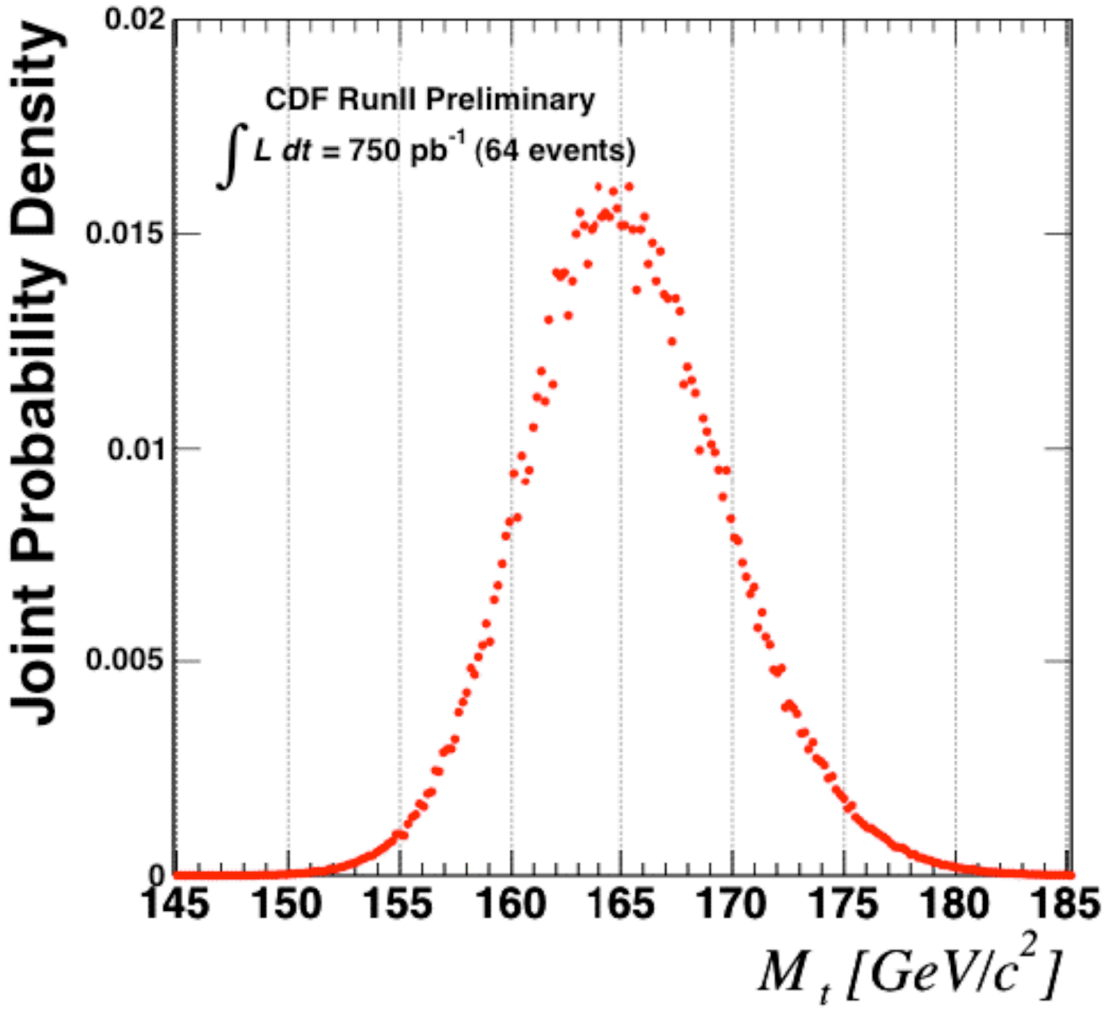
Pull width

Flat.

Pulls > 1 due to approximations made in P(Mt) calculation.

Measurement!

Most precise single dilepton measurement to date.



$$M_t = 164.6 \pm 4.5_{stat} \pm 3.1_{syst}\ \mathrm{GeV}/c^2$$

b-tagged: $M_t = 162.7 \pm 4.6_{stat} \pm 3.0_{syst}\ \mathrm{GeV}/c^2$

Systematic Errors

Source	$\Delta M_{top}(GeV/c^2)$
Jet Energy Scale	2.6
Background Statistics	0.8
Background Shape	0.8
ISR/FSR	0.7
Sample Composition	0.7
Parton Distributions	0.6
Generator	0.5
Method	0.3
Total	3.1

Systematic Errors

Source	$\Delta M_{top}(GeV/c^2)$
Jet Energy Scale	2.6
Background Statistics	0.8
Background Shape	0.8
ISR/FSR	0.7
Sample Composition	0.7
Parton Distributions	0.6
Generator	0.5
Method	0.3
Total	3.1

Could include $W \rightarrow jj$ calibration, but adds nothing to knowledge of M_t.

Will include calibration from $Z \rightarrow bb$ and $\gamma+b$

Systematic Errors

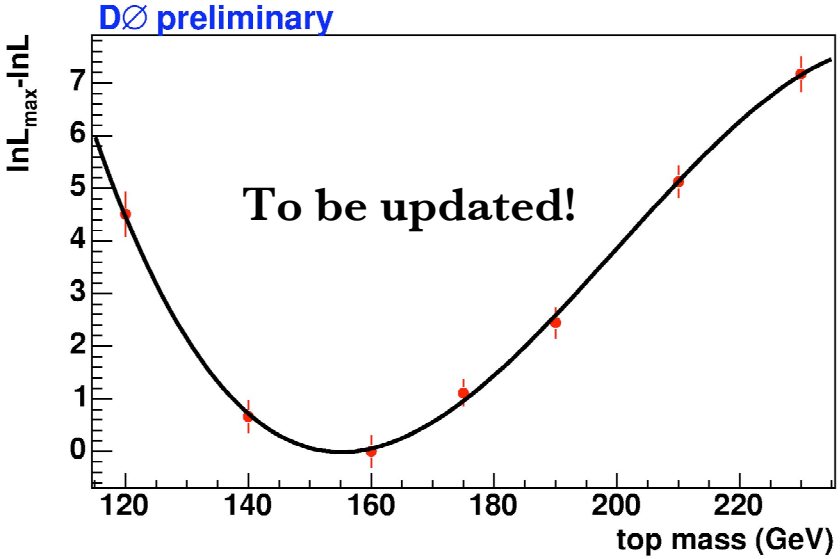
Source	$\Delta M_{top}(GeV/c^2)$
Jet Energy Scale	2.6
Background Statistics	0.8
Background Shape	0.8
ISR/FSR	0.7
Sample Composition	0.7
Parton Distributions	0.6
Generator	0.5
Method	0.3
Total	3.1

Driven by small sample of mis-ID lepton candidates drawn from data.

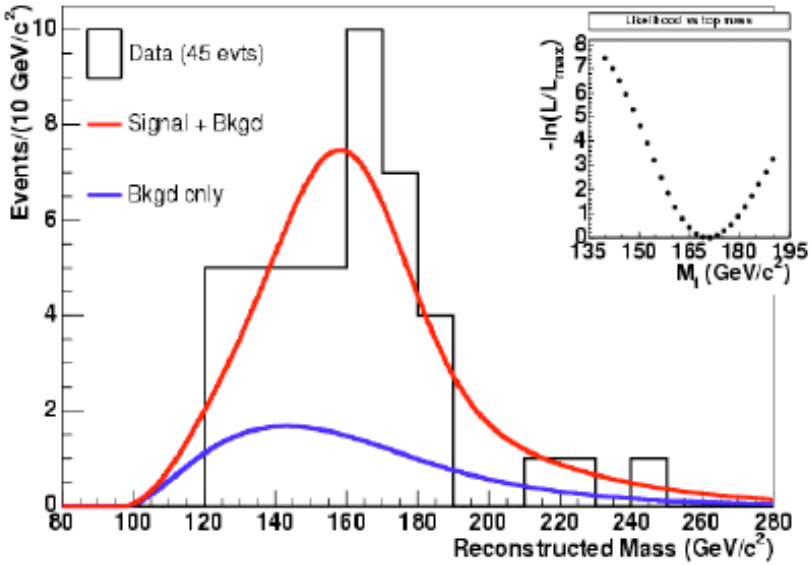
Dilepton results

D0 Neutrino Weighting
Result 320pb-1 here

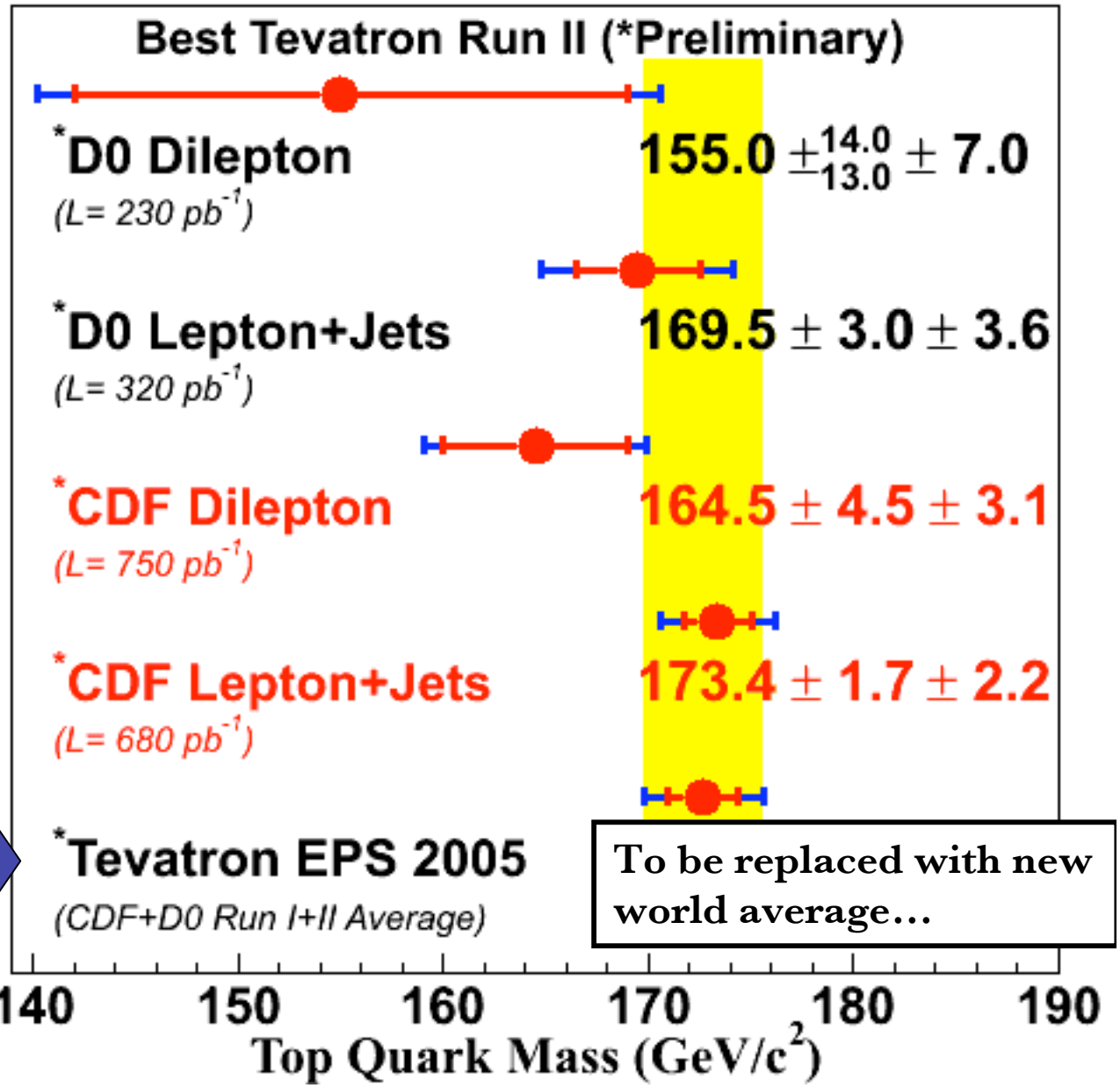
Matrix-Element Weighting



Neutrino Weighting Templates



Impact



World Average

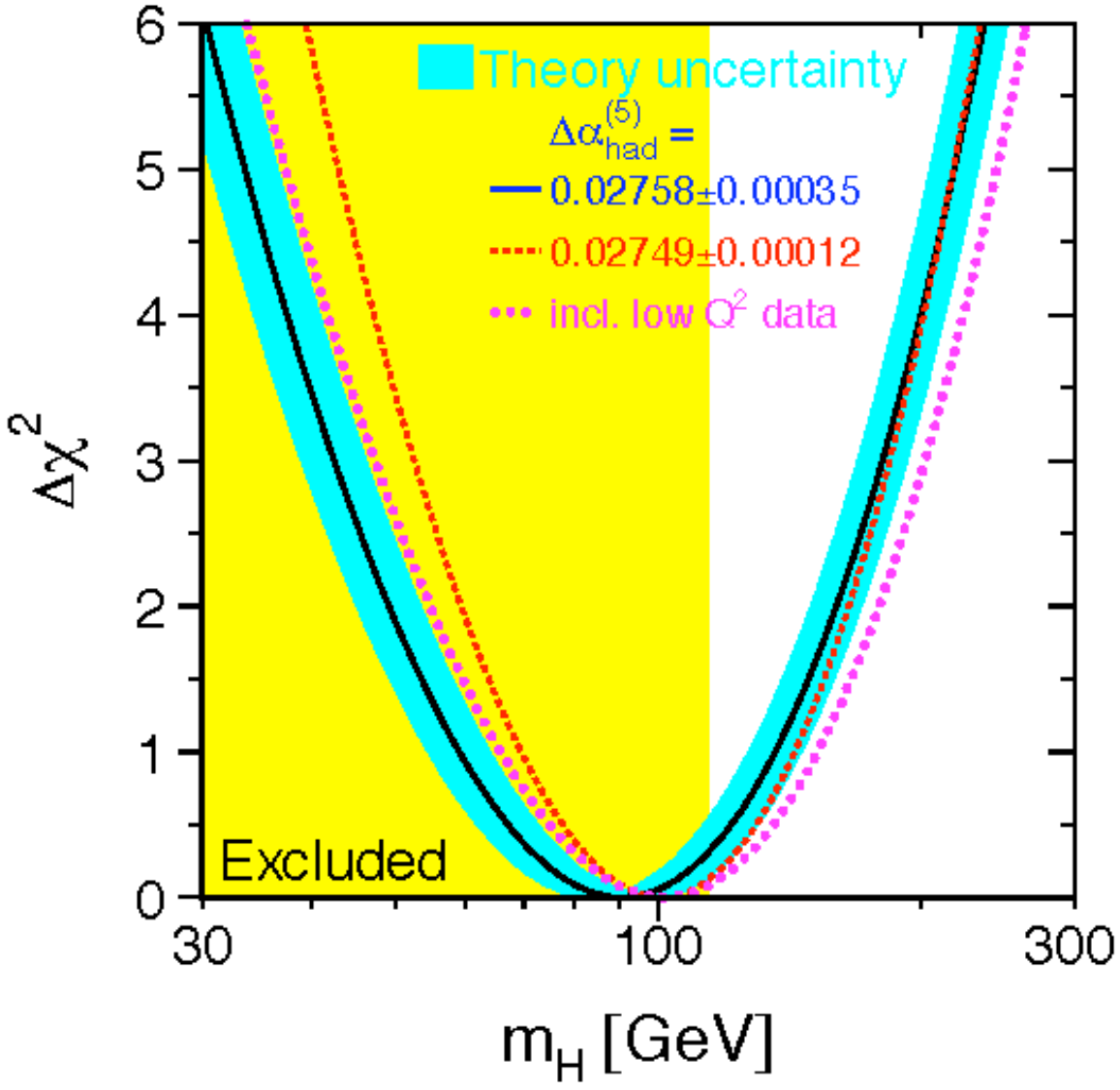
Total result has error of 2.4 GeV, systematics limited.

Higgs Impact

$M_{higgs} = 91^{+45}_{-32}$ GeV/c^2

$M_{higgs} < 186$ GeV/c^2 (95% conf)

To be updated!

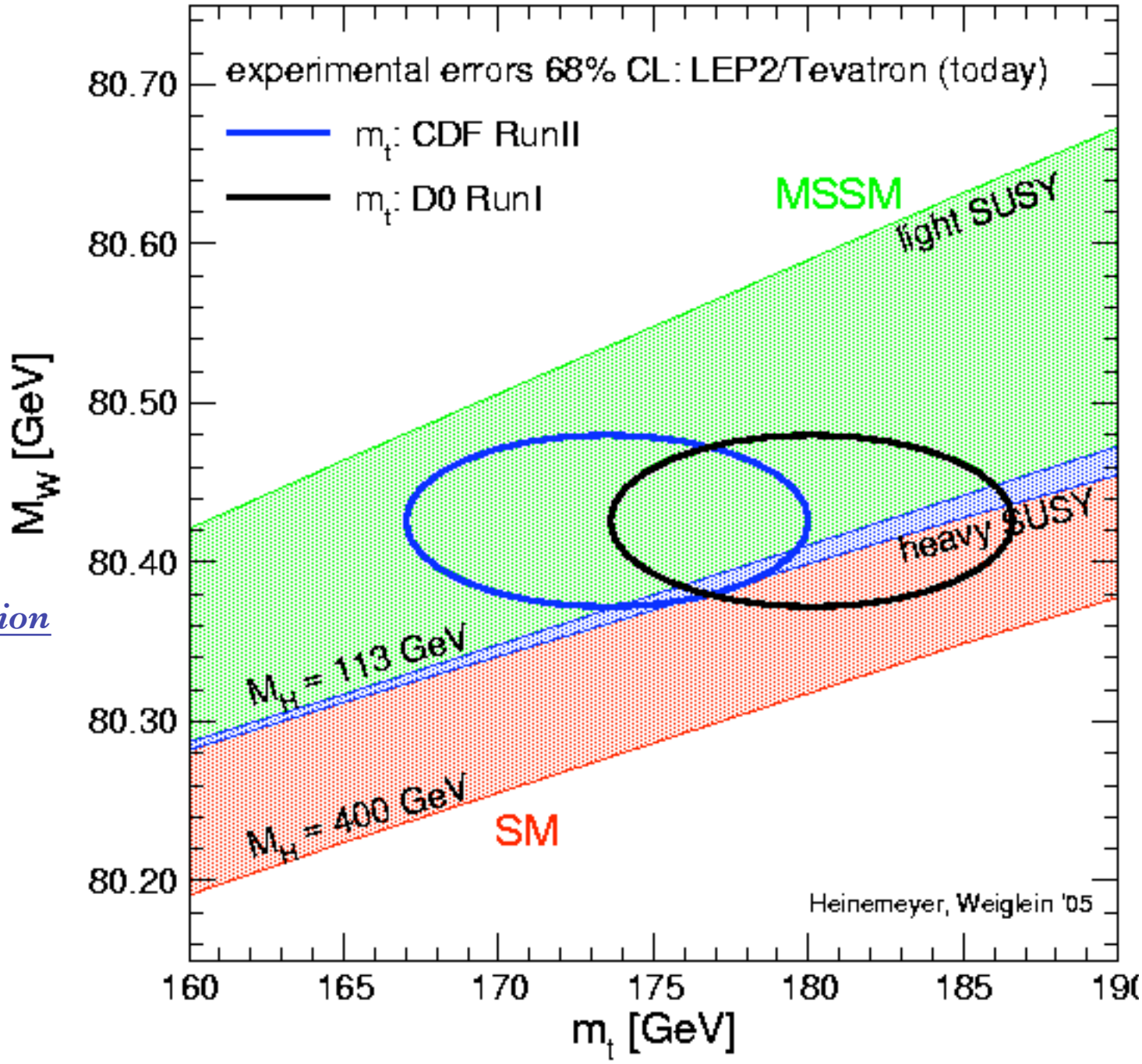


Impact of Mtop

To be updated!

Improving precision

Precision M_{top} affects SUSY calculations.

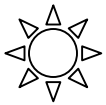


Prospects for Systematics

Source	*dilepton* $\Delta M_{top}(GeV/c^2)$	*l+jets* $\Delta M_{top}(GeV/c^2)$
Jet Energy Scale	2.6	2.1
Background Statistics	0.8	0.3
Parton Distributions	0.6	0.3
Generator	0.5	0.2
Background Shape	0.8	0.5
ISR/FSR	0.7	0.6
Sample Composition	0.7	---
Method	0.3	---
B-tagging	---	0.1
Total	3.1	2.2

Improves with luminosity

More sophisticated treatments ahead



Improves with CPU time

Summary

Precision Measurement

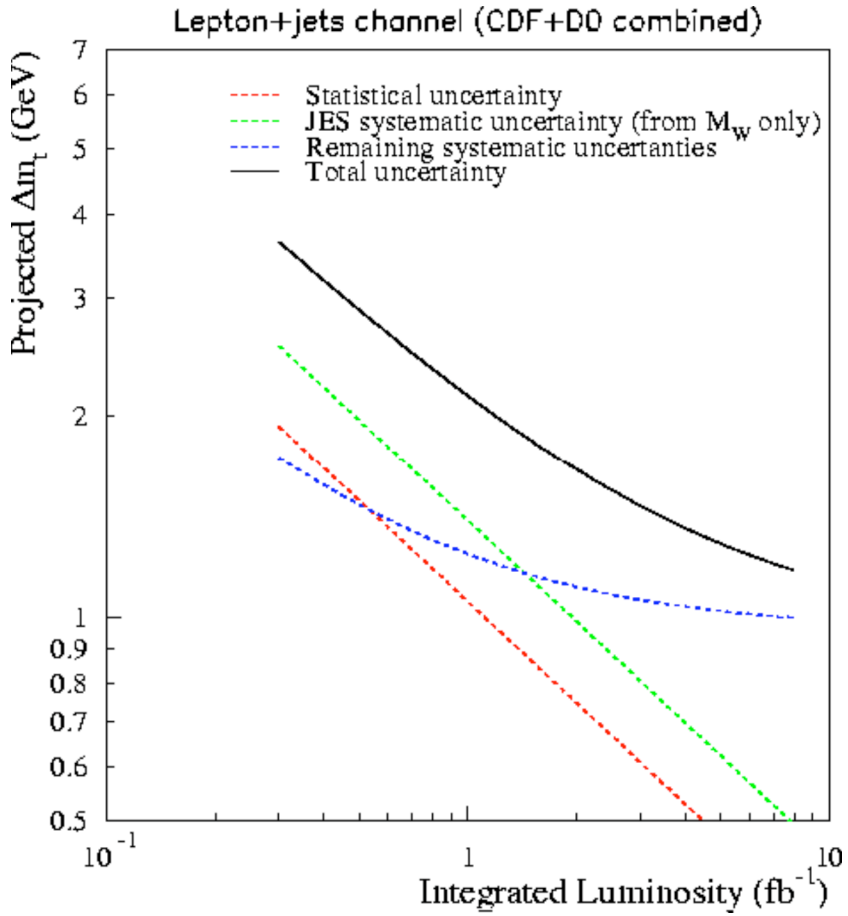
Detector understanding leads to precision results

We have measured the top mass with an error of < 3 GeV

Dileptons & l+jets consistent

Room for Improvement

Systematic errors will decrease
All hadronic measurement in progress



Higher Precision Future

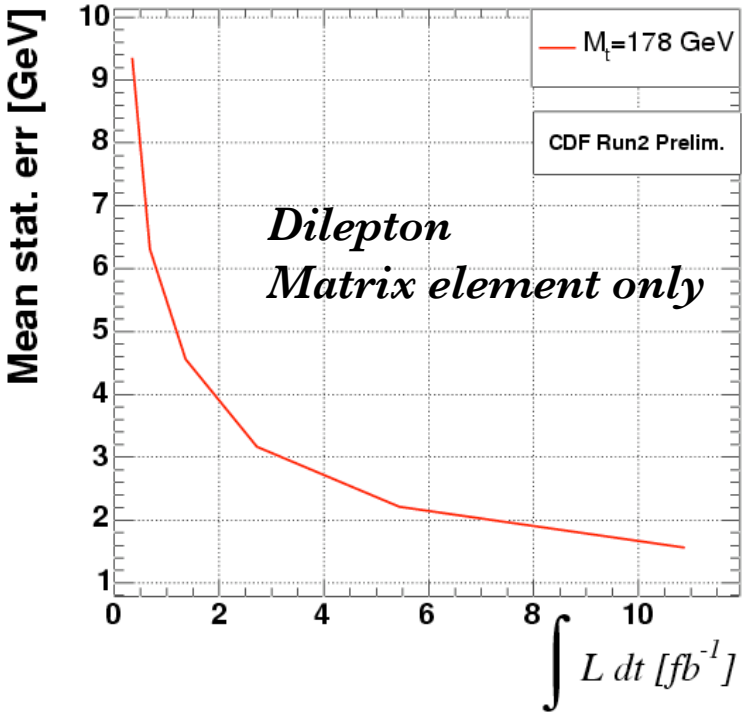
In 4fb^{-1},
- expect 2 GeV *total* error
- Dileptons become systematics limited.
- l+jets and dileptons approach equal weight
- Comparison of channels to test top hypothesis, look for new physics

- These results will be relevant for some years, even after LHC turn on

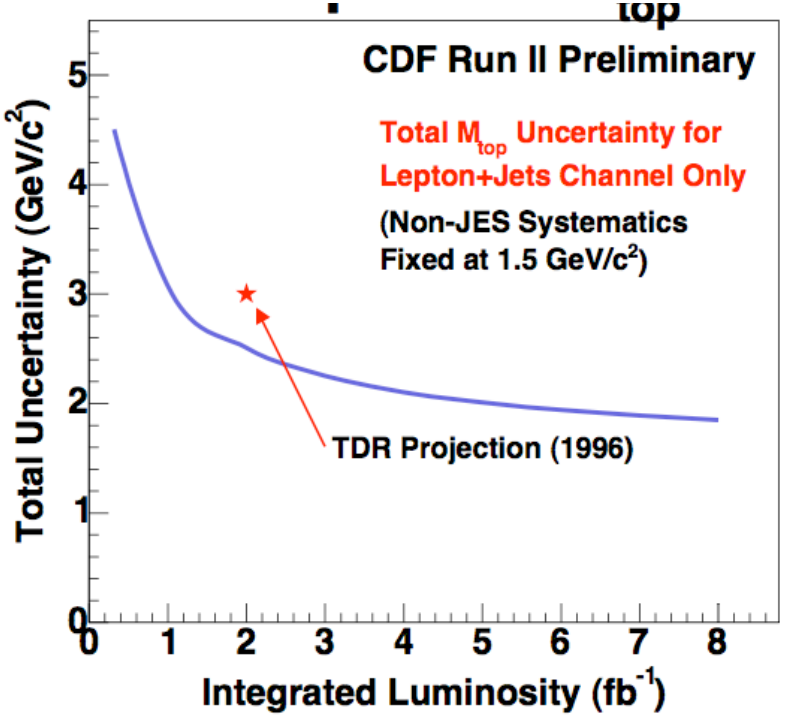
Backup material

Prospects

Dilepton Statistical Error



L+jets Total Error



Dileptons

Not yet systematics limited
(mean stat error of 2.5 GeV at 4fb-1)
Improved modelling of ISR
Extract b-jet energy scale from *Z->bb*

L+jets

Already systematics limited
Data improves systematics (*W->jj*)