Fermilab

Top Quark Mass Measurements at the Tevatron

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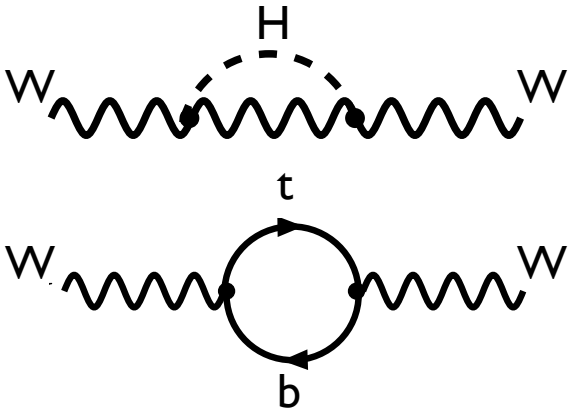
on behalf of the DØ and CDF Collaborations

Outline

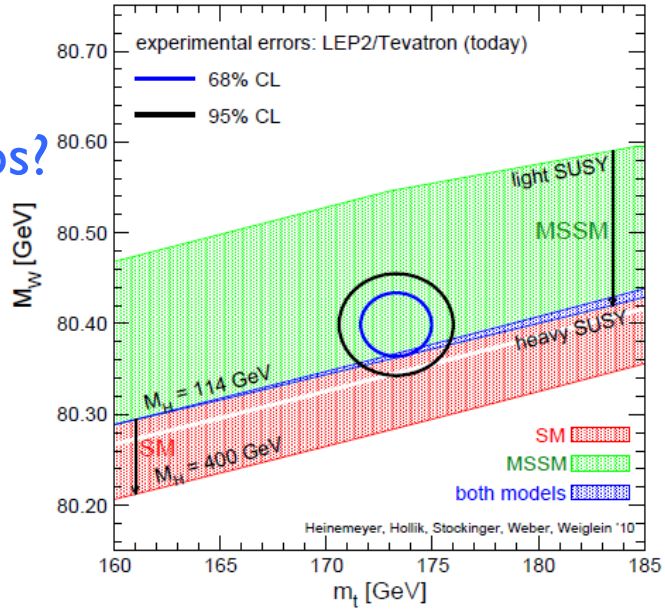
- Introduction
- Direct Measurements from Top Decay Products
  - challenges and solutions
  - methods and new results
- Top Quark Mass from Production Cross Section
- Top-Antitop Mass Difference
- Summary and Outlook

Introduction

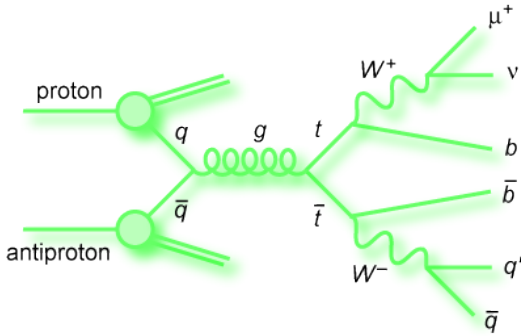
- Top Quark
  - Heaviest fundemental particle discovered.
  - Top mass a free parameter in EW theory.
  - Top and W masses constrain Higgs mass.

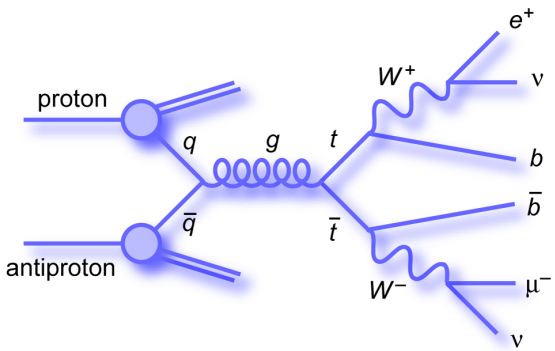


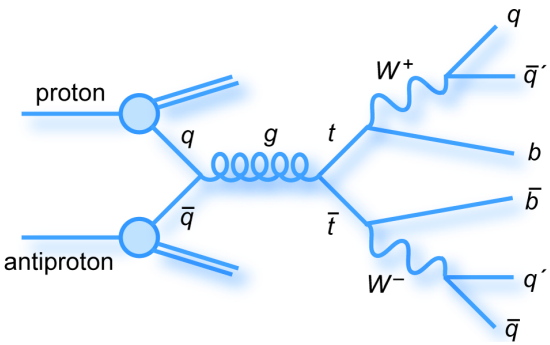
- Window to new physics?
  - Through radiative correction with top loops? Need to know precisely top mass.
  - Different influence in different final states? Check consistency across channels.



Measurements From Decay Products







lepton+jets: $t\bar{t} \rightarrow lvqq'b\bar{b}$

di-lepton: $t\bar{t} \rightarrow ll'vv'b\bar{b}$

all hadronic: $t\bar{t} \rightarrow qq'q''q'''b\bar{b}$

Event selection:

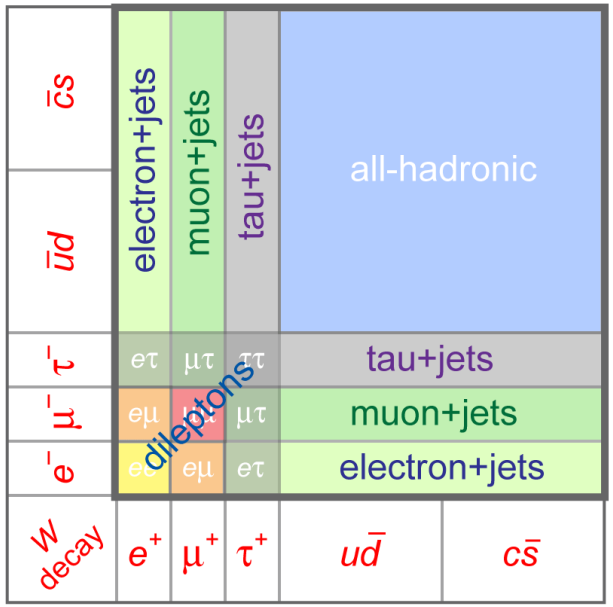
kinematics, topology, b-jet ID.

Remaing dominant background:

W/Z+jets, multi-jets, Diboson.

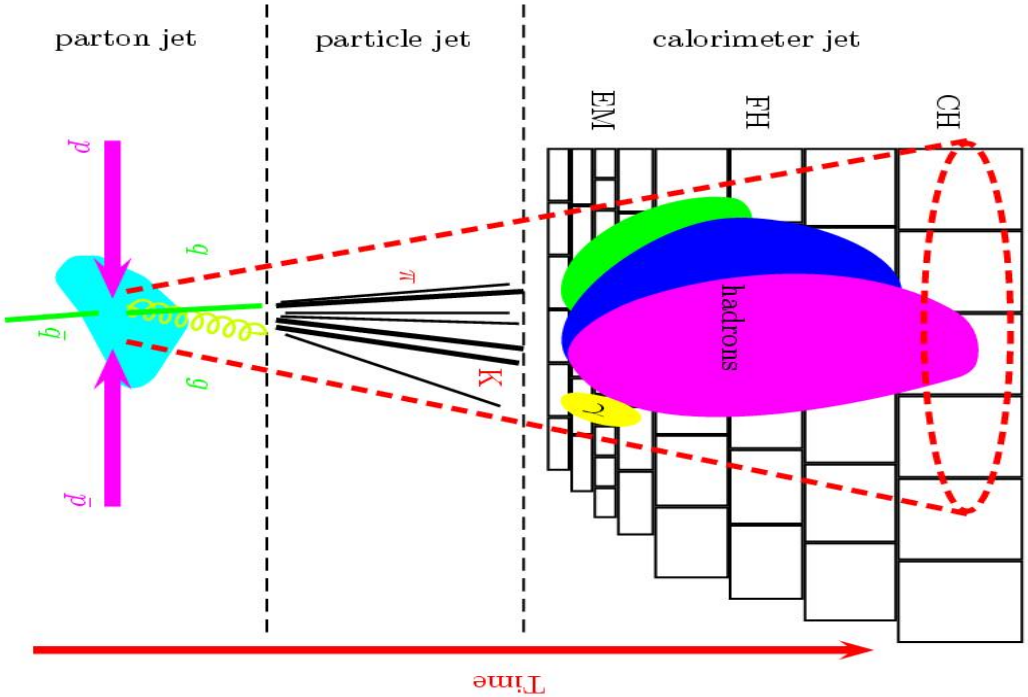
More details in Silvia Amerio's presentation

Top Pair Decay Channels



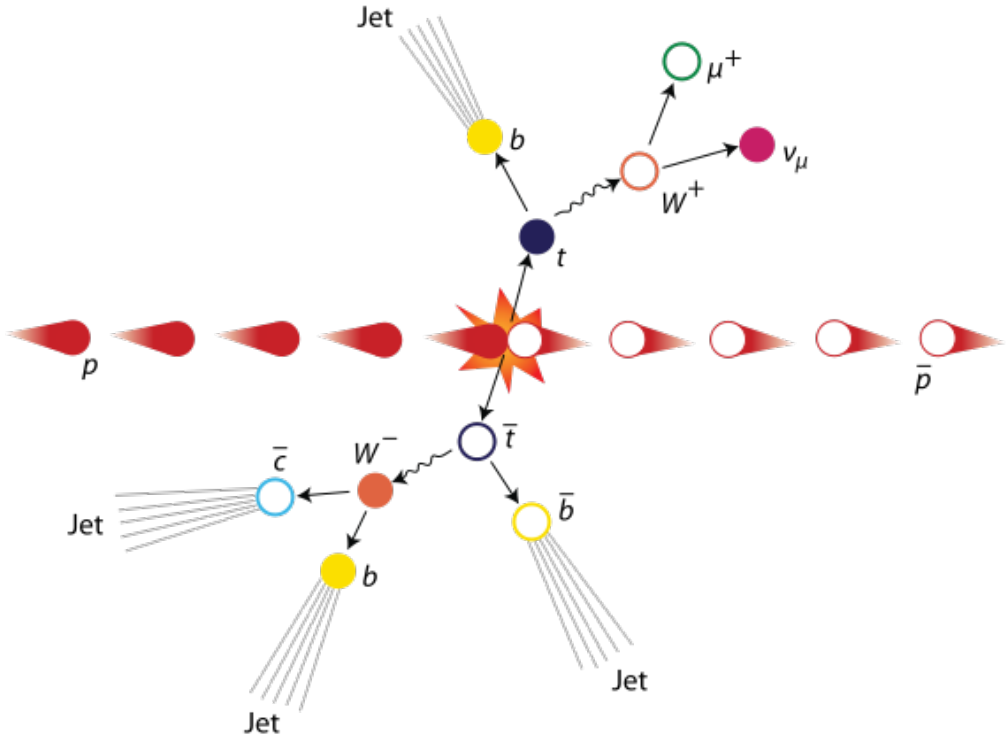
Challenges and Solutions

- Jet energy scale: ±2% Δ JES ~ ±2GeV Δ m_t
  - in-situ JES by using the constraint from hadronic W mass, can be done in l+jets and all hadronic channels, not in di-lepton channel alone.
  - look at quantities insensitive to JES, e.g. lepton p_T.



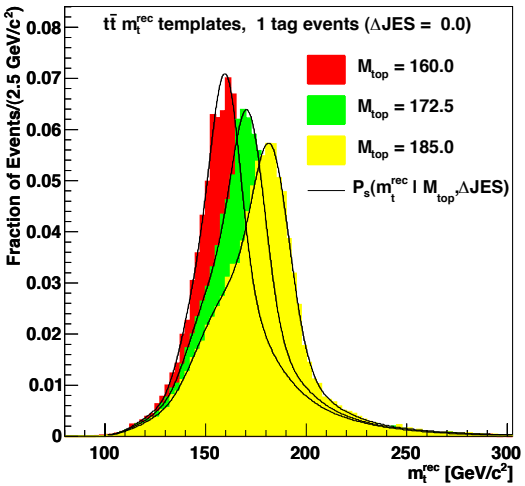
Challenges and Solutions

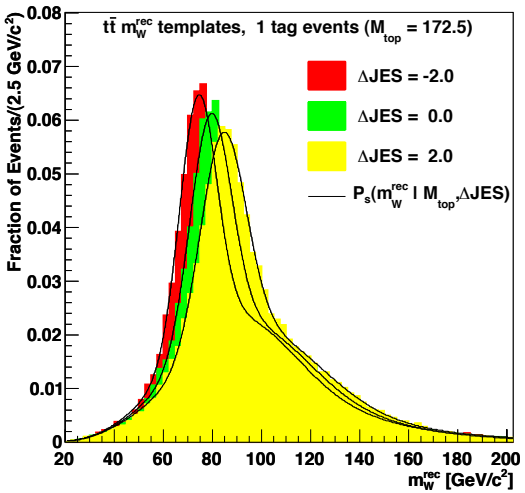
- Jet-parton match: n^{jet}! Permutations
  - b-jet ID helps reducing the number of permutations.
  - kinemiatc fitter to pick up the permutation(s) with best χ^2.

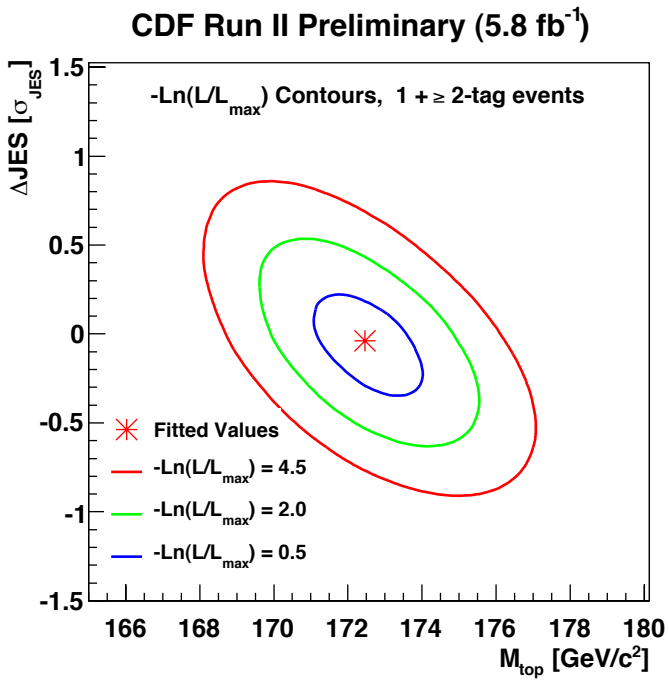


Template Fitting in All Hadronic Channel

- Build MC templates for quantities sensitive to top quark mass and JES.
- Fit data to MC templates with different generated top masses or JES.

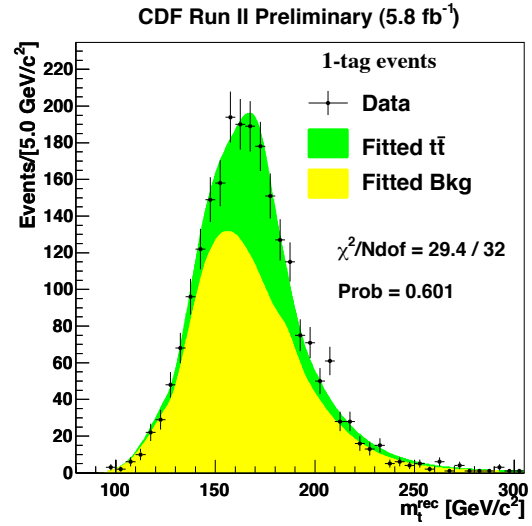


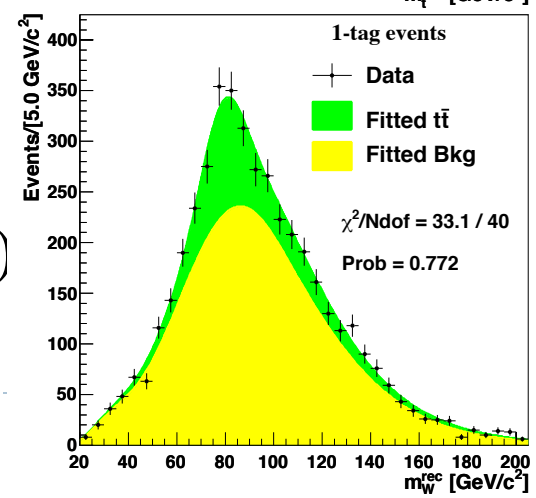




$$m_t = 172.5 \pm 1.4(\text{stat}) \pm 1.5(\text{syst})$$

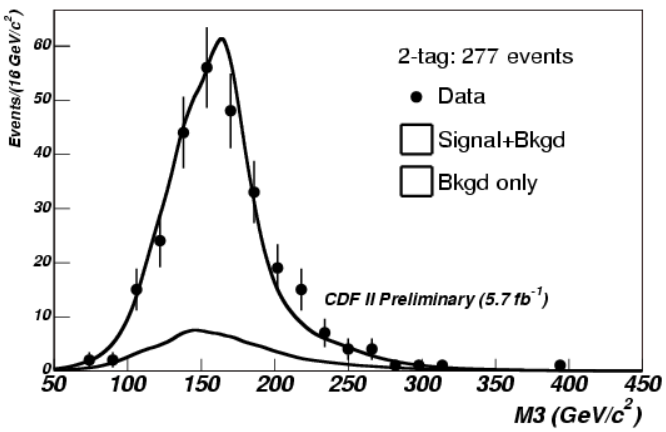
CDF Public Note 10426

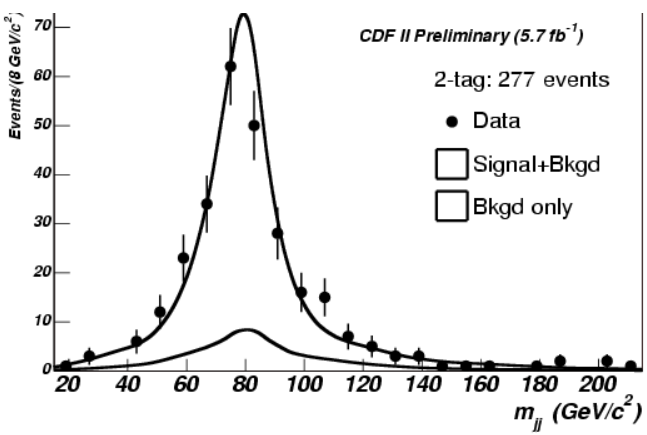


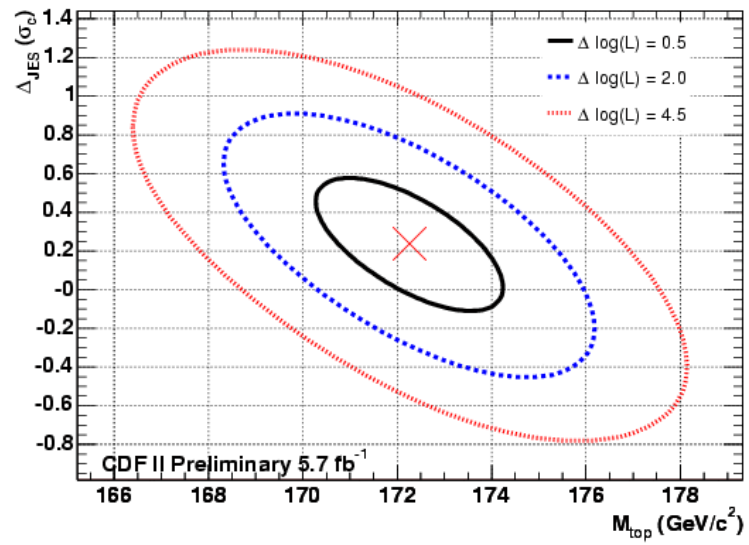


Template Fitting in MET+Jets Channel

- Signal is W-> τ ν (hadrnoic τ decay) or missing lepton+jets
- Template fit to 3 jet invariant mass from the hadronic top decay.







$$m_t = 172.3 \pm 2.4(\text{stat+JES}) \pm 1.0(\text{syst})$$

CDF Public Note 10433

Recent Results from Template Fitting Method

new since summer 2010

channel		Top quark mass		luminosity
l+jets/dilepton	m_t^{reco} with in-situ JES	172.1±1.1(stat)	±1.0(syst)	4.8 fb^{-1}
l+jets/dilepton	lepton pt	172.8±7.2(stat)	±2.3(syst)	2.8 fb^{-1}
l+jets	L_{xy} of b-jets and lepton pt	170.7±6.3(stat)	±2.6(syst)	1.9 fb^{-1}
all hadronic	m_t^{reco} with in-situ JES	172.5±1.4(stat)	±1.5(syst)	5.8 fb^{-1}
MET+jets	m_t^{reco} with in-situ JES	172.3±1.8(stat)	±1.8(syst)	5.7 fb^{-1}

channel		Top quark mass		luminosity
electron+muon	$w(m_t)$ with v weighting	173.3±2.4(stat)	±2.1(syst)	5.3 fb^{-1}
dilepton/l+track	v and matrix weighting	174.7±4.4(stat)	±2.0(syst)	1.0 fb^{-1}

Matrix Element Method

- Matrix element method is based on the calculation of event probability densities estimated from differential cross section and detector resolutions.

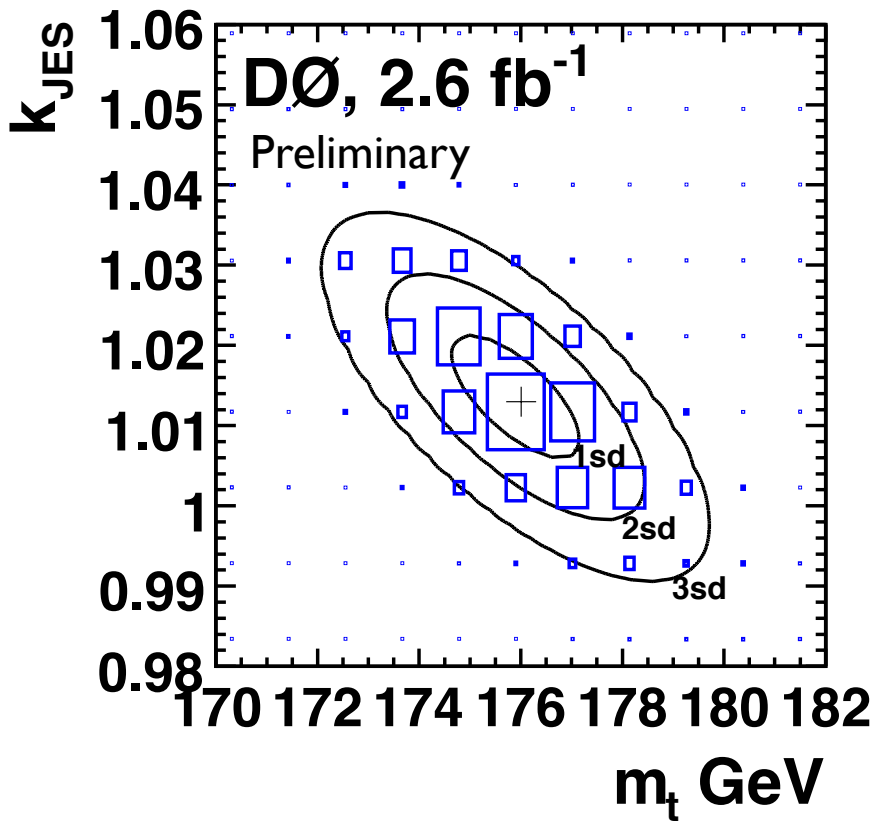
$$P_{sig}(x;m_{top},JES) = \frac{1}{\Phi_{obs}(m_{top})} \times \int \boxed{dq_1\, dq_2 f(q_1) f(q_2)} \boxed{\frac{(2\pi)^4 \left|M(y,m_{top})\right|^2}{4\sqrt{(q_1 \cdot q_2 - m_1 m_2}}} \boxed{d\Phi_6\, W(y,x,JES)}$$

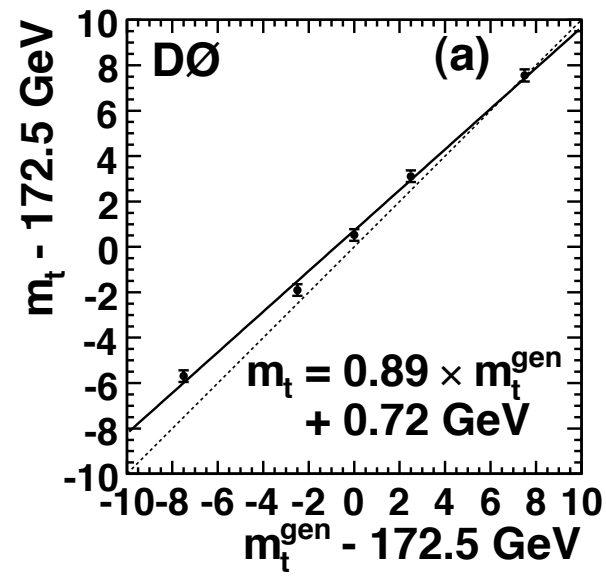
Parton densities | LO matrix element | Transfer functions

- JES is a global multiplicative factor for the jet energy scale.

- Transfer functions encode the detector resolution and provides the mapping from a parton y to the measured x.

Matrix Element in Lepton+Jets Channel



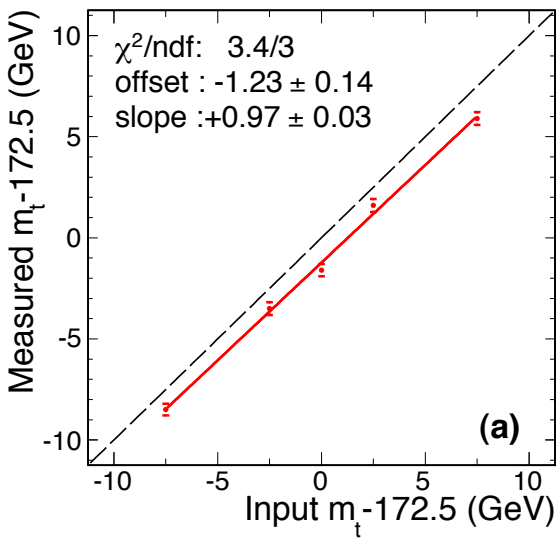


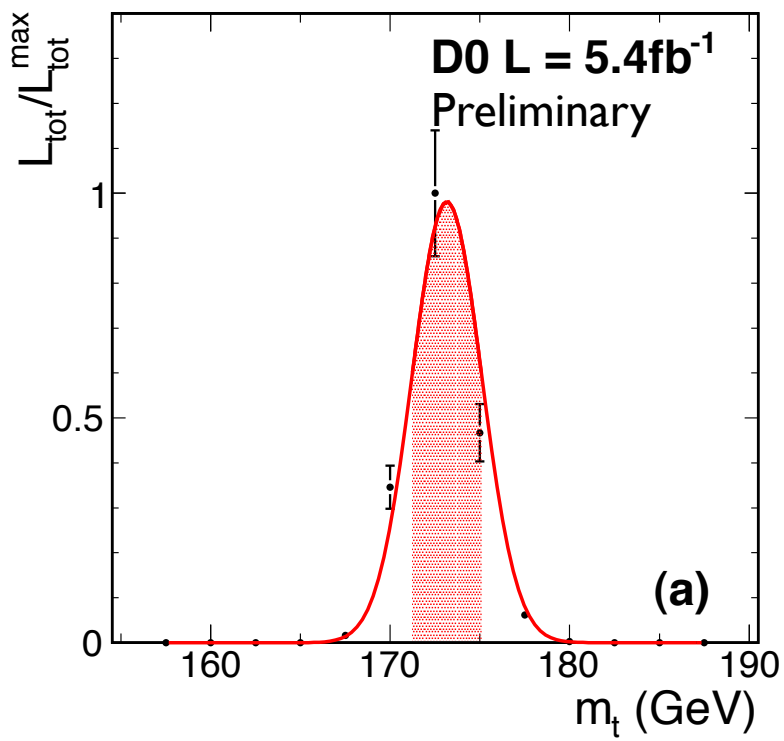
most precise DØ measurement!

$$m_t(3.6\ \mathrm{fb}^{-1}) = 174.9 \pm 0.8(\mathrm{stat}) \pm 1.3(\mathrm{syst+JES})$$

DØ Publication in Preparation

Matrix Element in Dilepton Channel





most precise measurement in the dilepton channel!

$$m_t = 173.6 \pm 1.8(\text{stat}) \pm 2.6(\text{syst})$$

DØ Publication in Preparation

Recent Results from Matrix Element Method

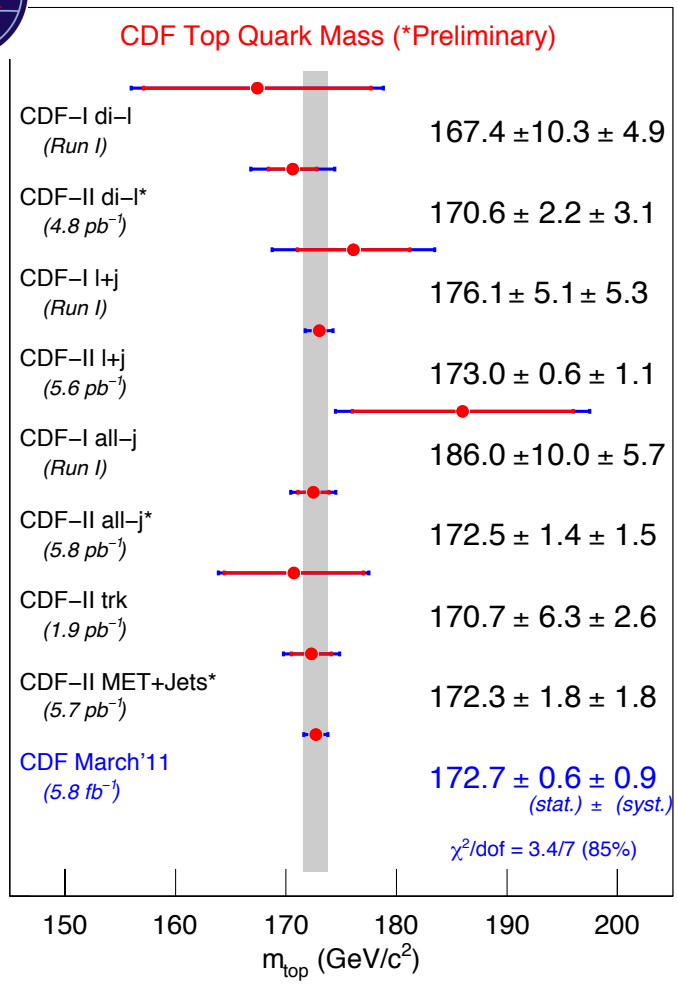
new since summer 2010

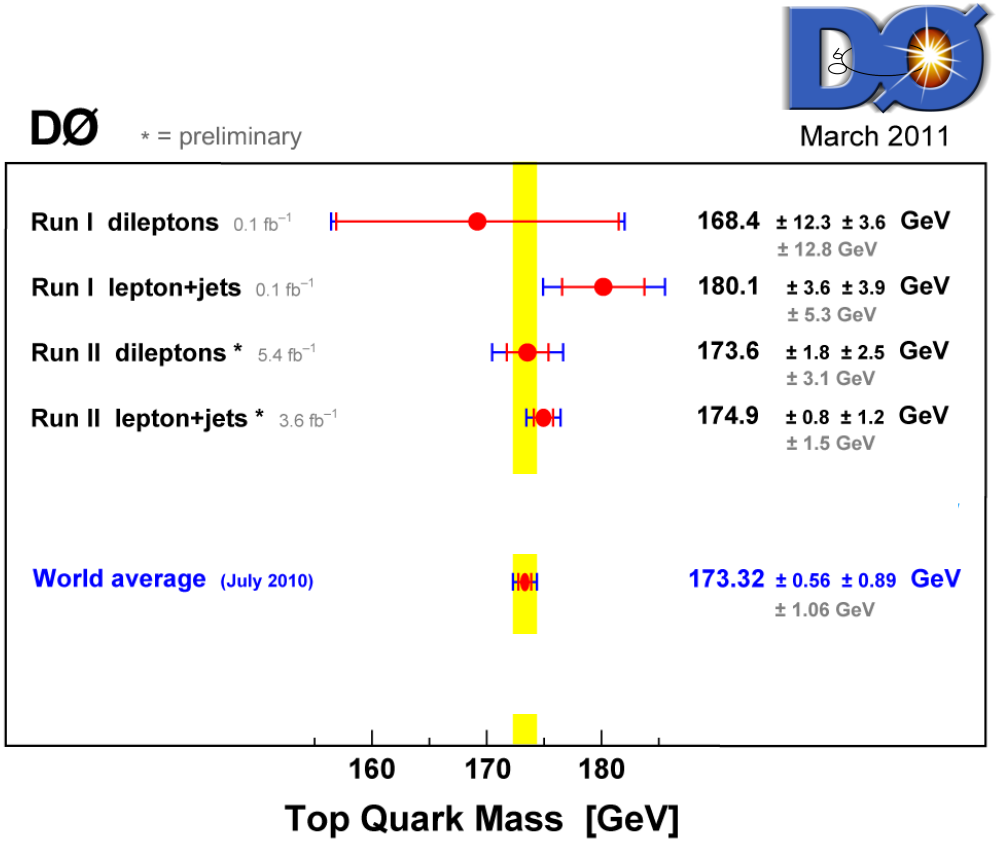
most precise measurement!

channel		Top quark mass	luminosity
l+jets	In-situ JES with NN selection	173.0±0.9(stat+JES)±0.9(syst)	5.6 fb^{-1}
l+jets	In-situ JES	172.4±1.4(stat+JES)±1.3(syst)	3.2 fb^{-1}
dilepton	NN selection	171.2±2.7(stat) ±2.9(syst)	1.9 fb^{-1}

channel		Top quark mass	luminosity
l+jets	In-situ JES	174.9±0.8(stat)±1.3(syst+JES)	3.6 fb^{-1}
dilepton		173.6±1.8(stat)±2.6(syst)	5.4 fb^{-1}

Latest D0 and CDF Top Mass Results





Tevatron Combination July 2010:

$$m_t = 173.3 \pm 0.6(\text{stat}) \pm 0.9(\text{syst})$$

Challenges and Solutions

- Difference between MC and data
  - improve MC simulation
  - account for possible remaining difference as systematic
- Common systematic uncertainties
  - Physics modeling

    higher order effects, ISR/FSR, color reconnection, showering, hadronization, underlying event, multiple proton interaction, PDF, b quark fragmentation, …
  - Detector modeling

    trigger, lepton identification, lepton energy scale and resolution, jet identification, jet energy scale and resolution, b-jet identification, b-jet response, …

Top Quark Mass From Cross Section

- Top quark mass depends on the renormalization scheme.

- Direct measurements use LO MC with parton shower to extract the mass from data. The renormalization scheme is not well-defined.

- It is believed that the mass from direct measurements is close to pole mass but there is no precise understanding.

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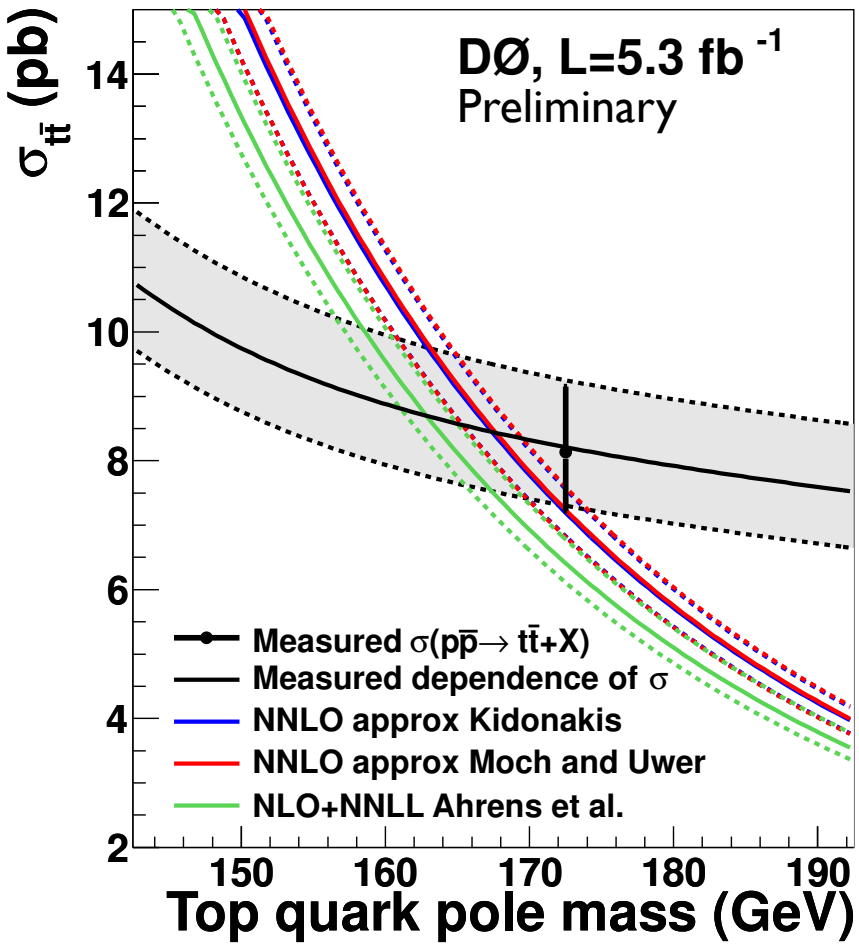
Top Quark Mass From Cross Section

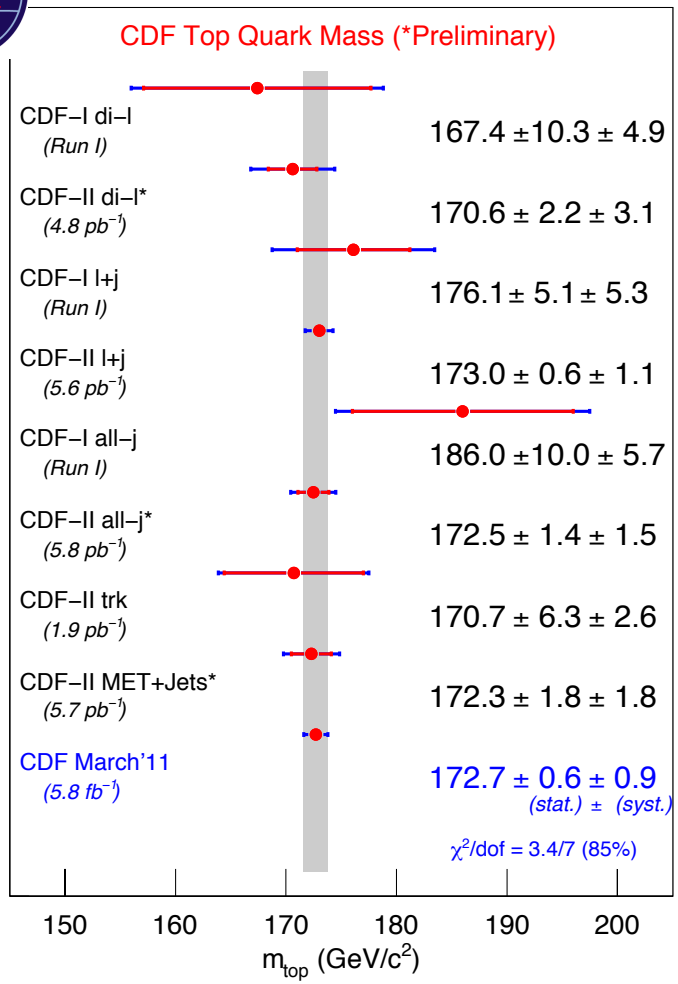


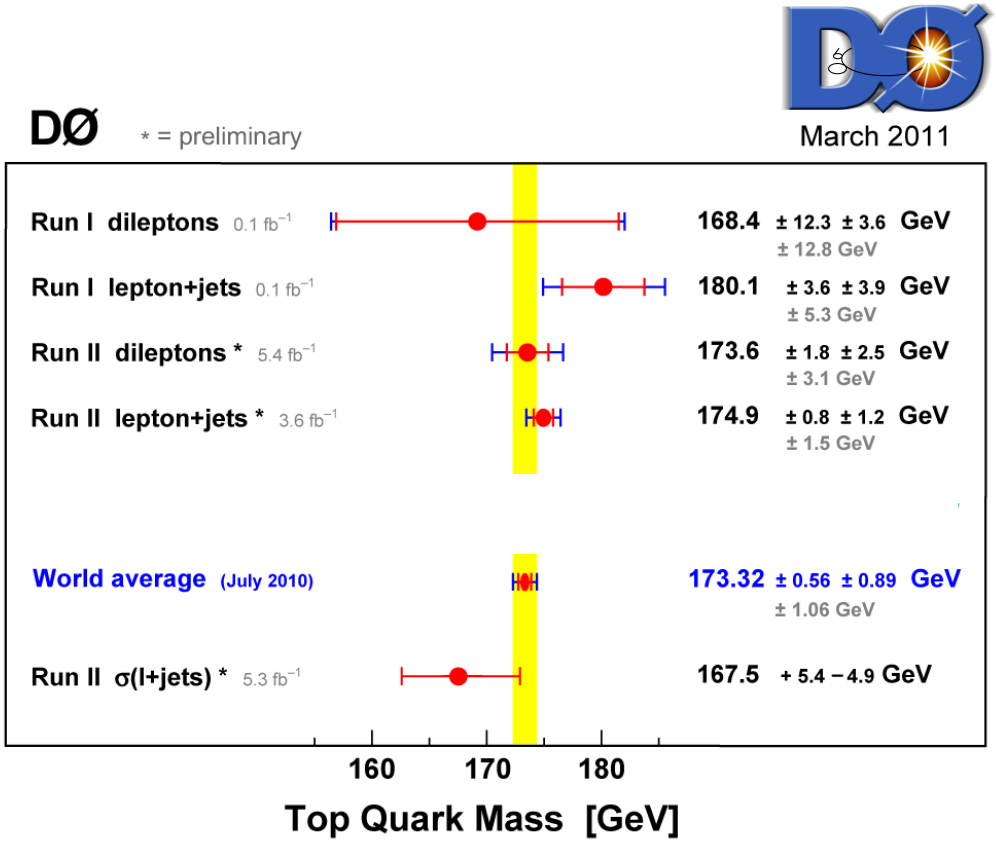
Theoretical prediction	$m_t^{\rm pole}$ (GeV)	
MC mass assumption	$m_t^{\rm MC} = m_t^{\rm pole}$	$\Delta(m_t^{\rm MC} = m_t^{\overline{\rm MS}})$
NLO [9]	$164.8^{+5.7}_{-5.4}$	-2.8
NLO+NLL [10]	$166.5^{+5.5}_{-4.8}$	-2.6
NLO+NNLL [11]	$163.0^{+5.1}_{-4.6}$	-3.3
Approximate NNLO [12]	$167.5^{+5.2}_{-4.7}$	-2.6
Approximate NNLO [13]	$166.7^{+5.2}_{-4.5}$	-2.6

- Measured cross section where MC is used to estimate the acceptance is less dependent on the top quark mass in MC.
- A constraint on the top quark pole mass can be obtained by combining the experimental and theoretical inputs.
- The result is insensitive to the interpretation of the top quark mass in MC.

DØ Publication in Preparation

Latest D0 and CDF Top Mass Results





Tevatron Combination July 2010:

$$m_t = 173.3 \pm 0.6(\text{stat}) \pm 0.9(\text{syst})$$

Top-Antitop Quark Mass Difference

- Because of the very short life time, the top (and antitop) quark decays before hadronizing.
- This allows direct measurements of top and antitop masses and to examine the CPT invariance theorem.

- The first result from DØ (1 fb^{-1}) in 2009:

$$\Delta m_t = 3.8 \pm 3.4(\text{stat}) \pm 1.2(\text{syst})\ \text{GeV}$$

PRL 103, 132001 (2009)

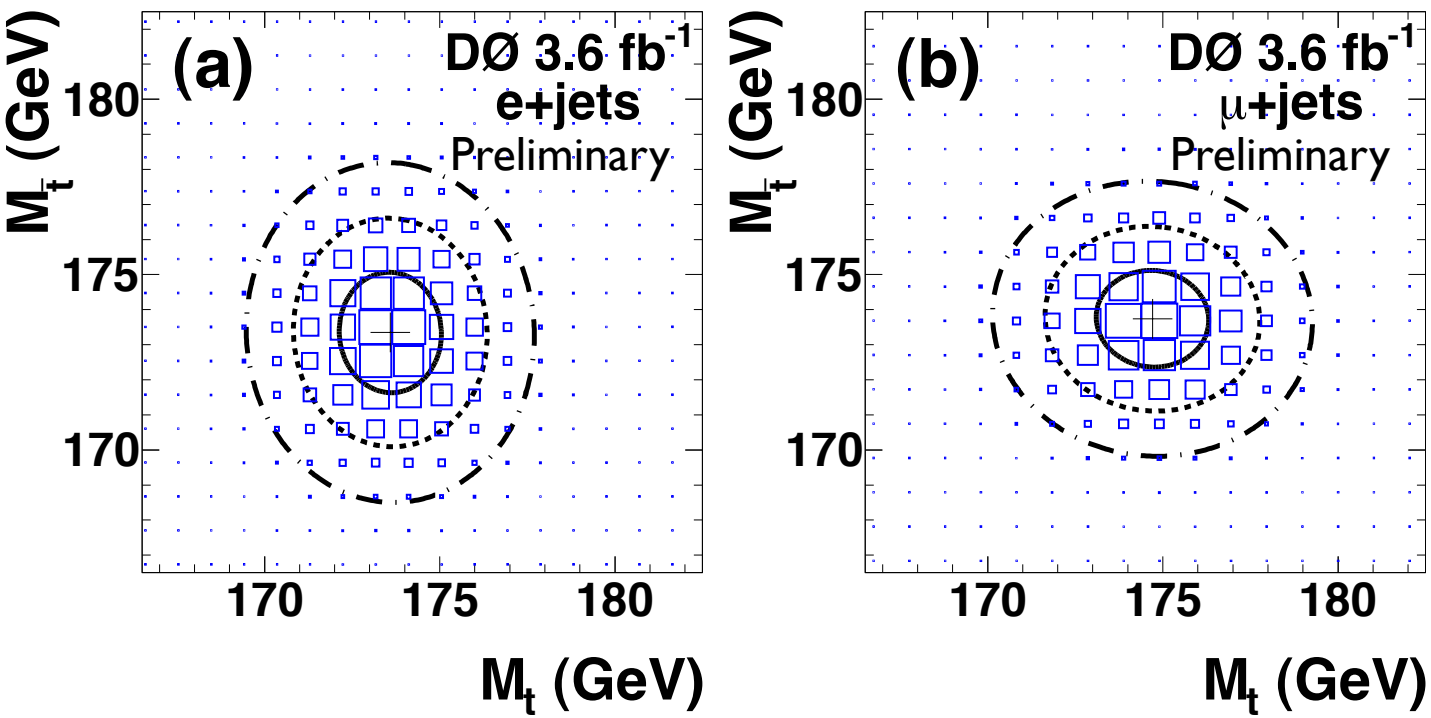
- The first result from CDF (5.6 fb^{-1}) in 2010:

$$\Delta m_t = -3.3 \pm 1.4(\text{stat}) \pm 1.0(\text{syst})\ \text{GeV}$$

arxiv: 1103.2782
Submitted to PRL

2 σ effect ?!

Mass Difference from ME Method



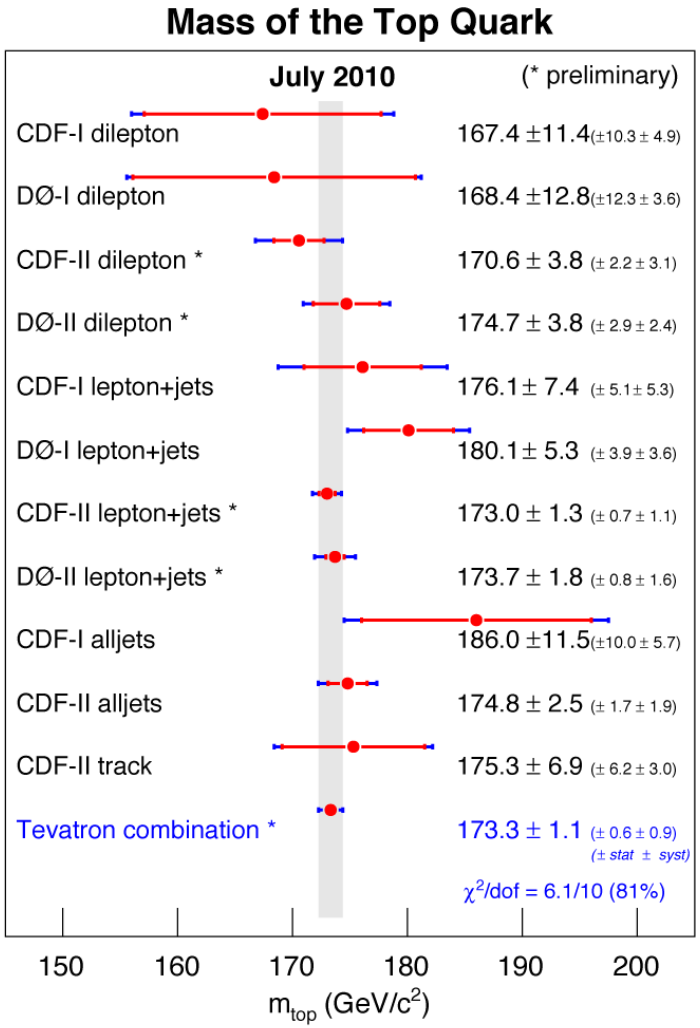
D0 3.6 fb^{-1}: $\Delta m_t = 0.8 \pm 1.8(\text{stat}) \pm 0.8(\text{syst})$ GeV

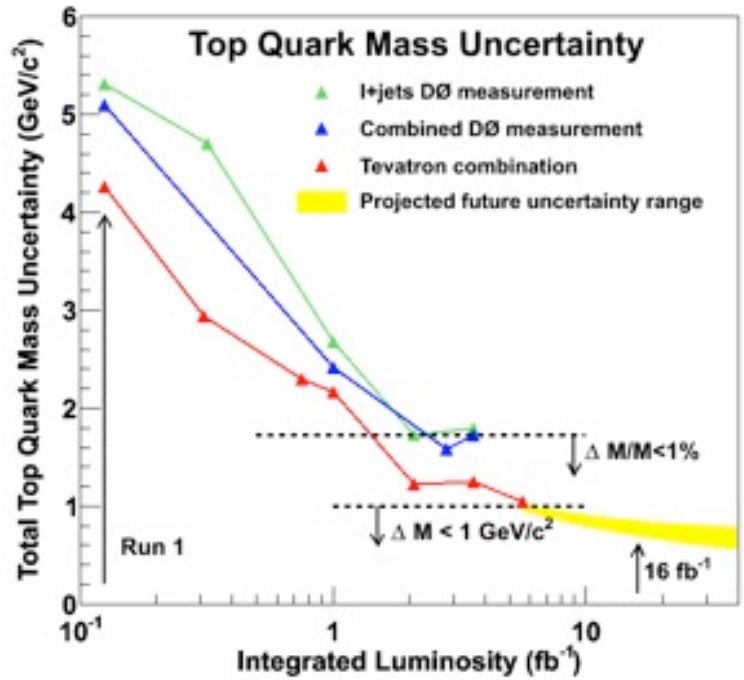
DØ Publication in Preparation

Summary and Outlook

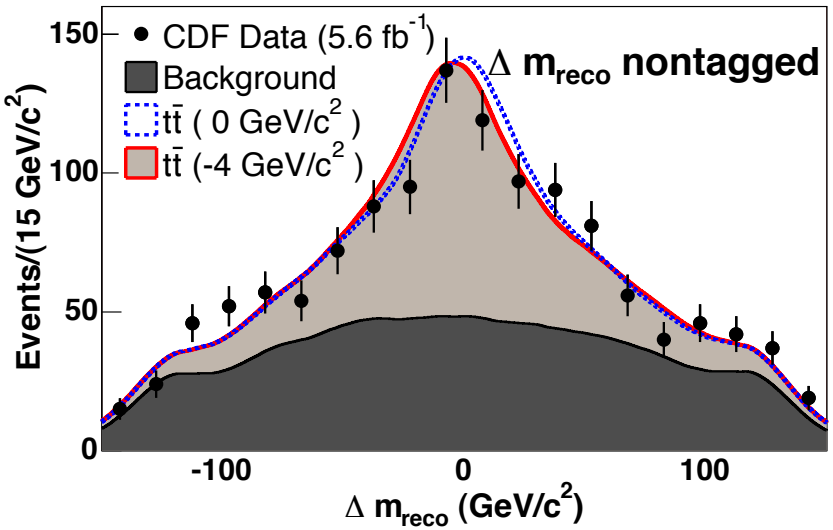
- Thanks to well-developed analysis methods, well-understood detectors, and largest top quark samples, top quark mass from Tevatron is currently better than 0.6% and is dominated by sysematics.
- Results are consistent among different final states and between CDF and D0.
- With the final data set of ≥2-3 times the statistics shown here, the expected uncertainty from the Tevatron could be below 1GeV!

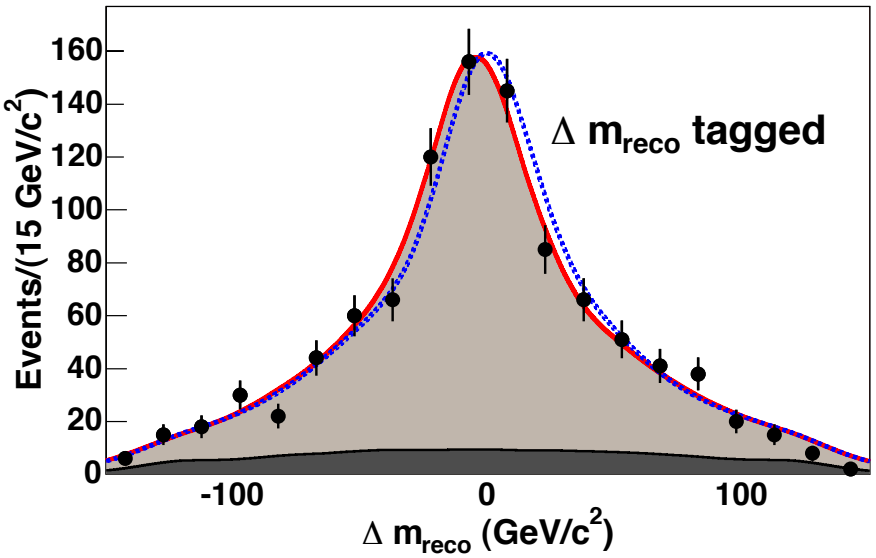
Summary and Outlook





Mass Difference from Template Fitting





CDF 5.6 fb^{-1} $\Delta m_t = -3.3 \pm 1.4(\text{stat}) \pm 1.0(\text{syst})$ GeV

arxiv: 1103.2782
Submitted to PRL