Precision Top Mass Measurement

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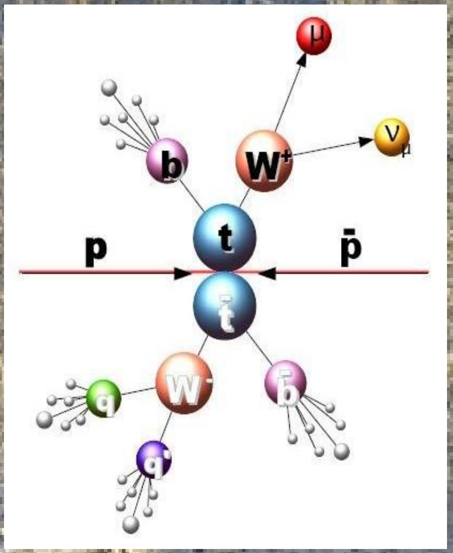
on behalf of CDF and DØ collaborations

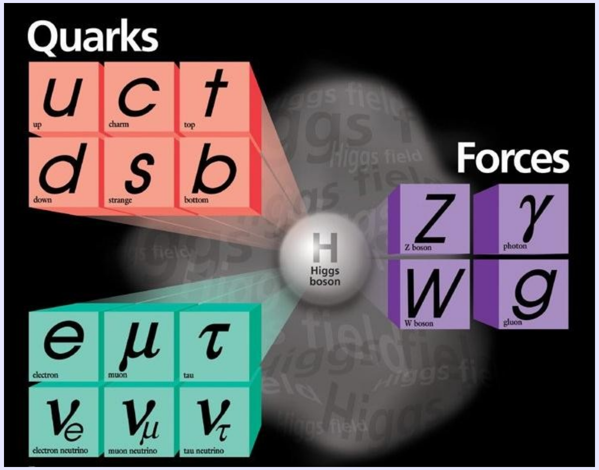
- Motivation
- How to: Direct Measurement
- Analysis Methods
- Results
- Standard Model Higgs Implication
- Conclusions

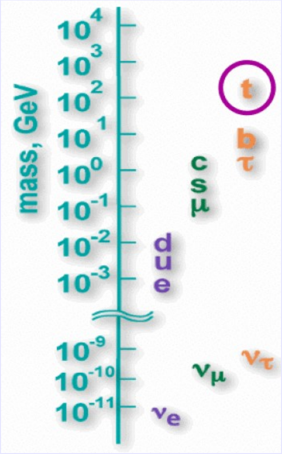


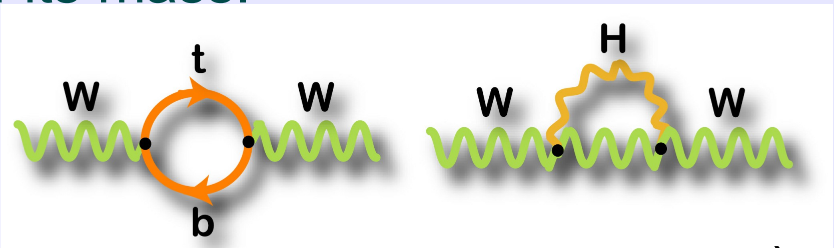
Motivation

Within the Standard Model the top quark holds a special place because it is the heaviest quark and its Yukawa coupling $g_t \sim 1$.

Many models need a precise value of its mass.

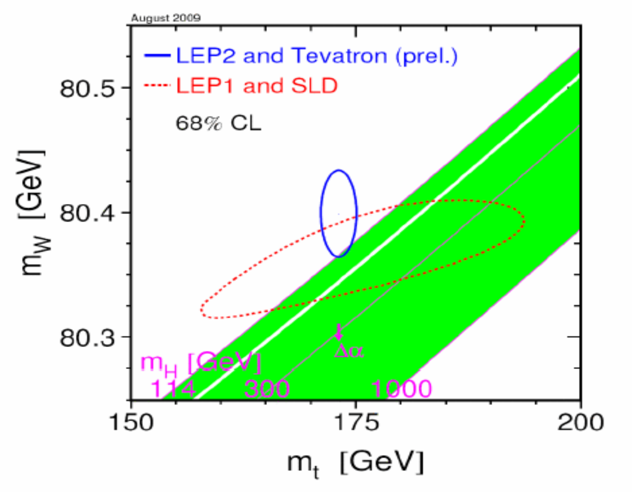






$\Delta M_W \sim M_t^2$ $\Delta M_W \sim \log(M_H)$

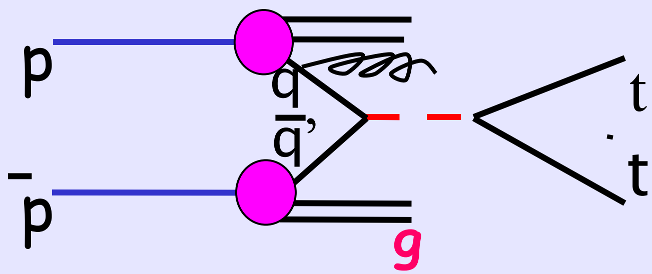
- Quantum loop corrections to many EWK observables are sensitive to the top mass
- The W mass is highly correlated to M_{top} and M_H in EWK theory

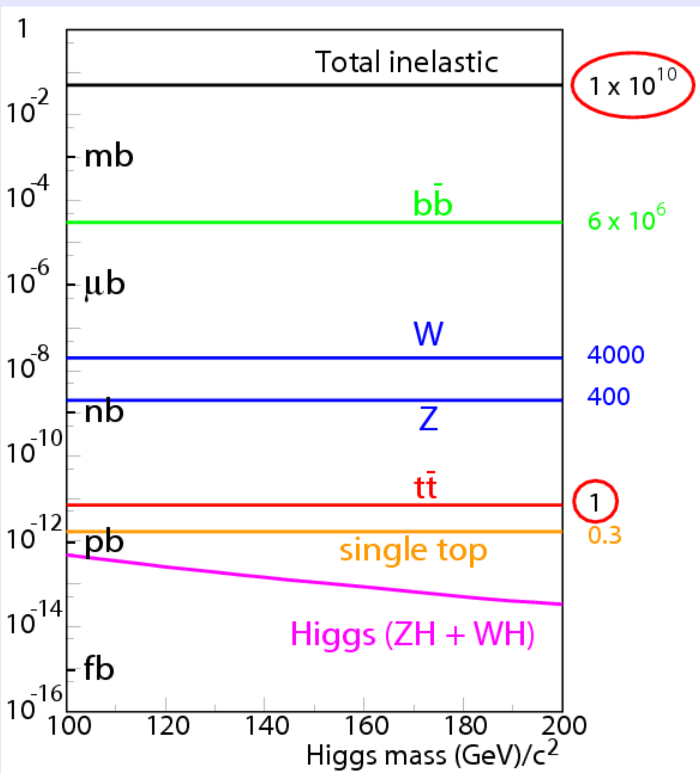


Precision measurements of the top and W mass measurements provide a better constraint to the Higgs mass than the combination of many EWK observable

Top Production and Decay

$t\bar{t}$ Production at the Tevatron:



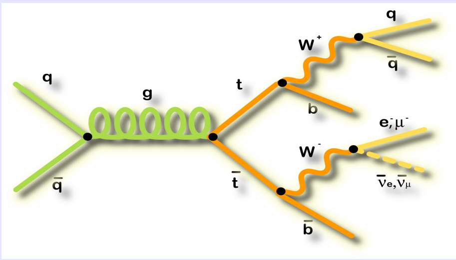


Top is heavy: decays very fast!

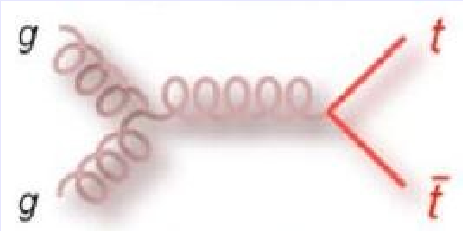
$$t\bar{t} \rightarrow W^{+} b W^{-} \bar{b}$$

$\Gamma(t \rightarrow Wb) \sim 1.5$ GeV, $\tau \sim 4\times10^{-25}$ sec

No hadronization: measure quark properties (mass etc.) directly



~85%



~15%

Major backgrounds:

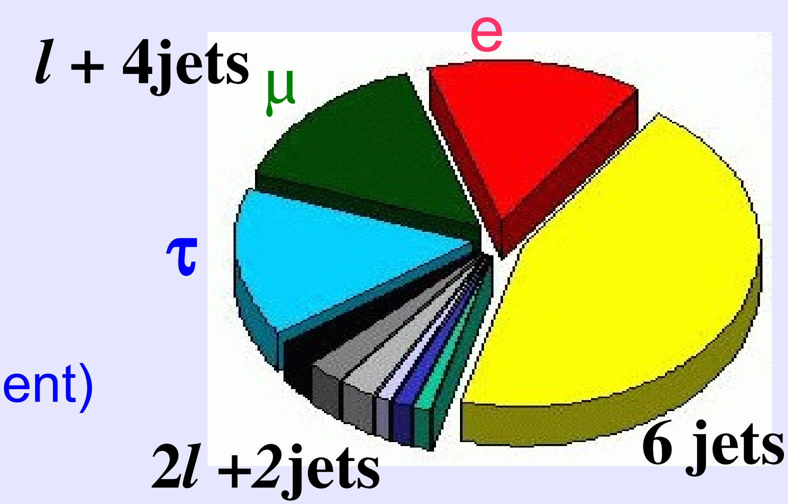
Total inelastic $\sigma = 10^{10}$ times larger!

- QCD multijet
- W and Z +jets production,

Top Quark Topologies

Reconstruct top events t t --> W^- b W^+ b

- Many channels, depending on W's decays
- Experimental Challenges
  - reduce QCD, other backgrounds (b-tagging)
  - jet energy measurements systematics
  - measure jets and not partons (method dependent)

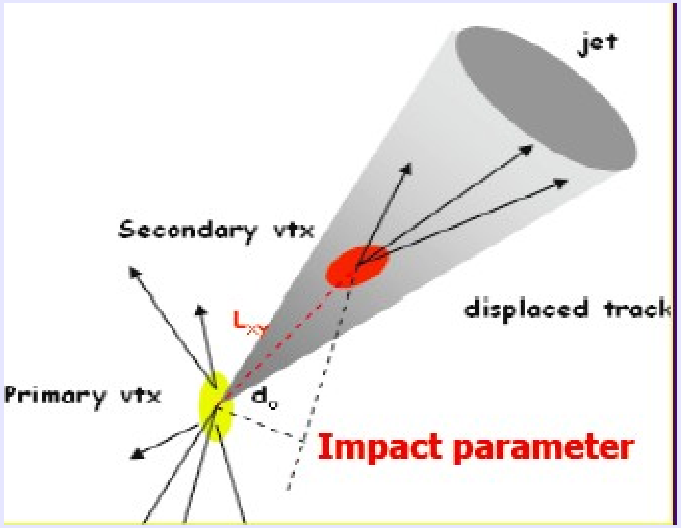


Sample	Di-lepton (e,μ)	Lepton+jets (e,μ)	All Hadronic NN selection
BR Signature	6.4% 2 lept+2ν+2jets	30% 1 Lept+1ν+4jets	44% 6 jets
Major Back.	DY, W/Z+jets	QCD, W/Z+jets	QCD multi-jets
0-b-tags S/B 1-b-tags S/B 2-b-tags S/B	1:1 4:1 20:1	1:4 4:1 20:1	1:20 1:5 1:1
Events in 1 fb^{-1} ($\geq$ 1 b-tag)	25	180	150 (2 b-tags)

τ decays not included

the MET has info about ν kinematics

Challenge(1): tagging of b-jets

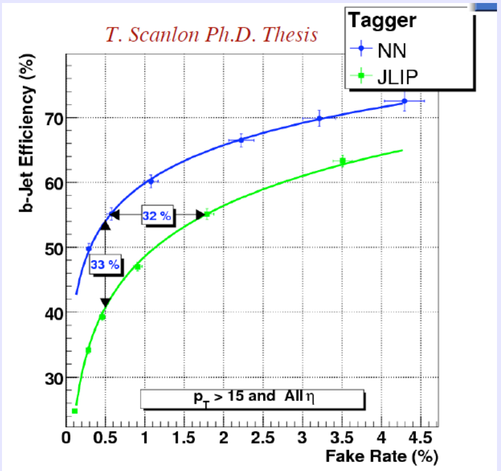


Reduction of background is obtained by identifying jets from b-quarks.

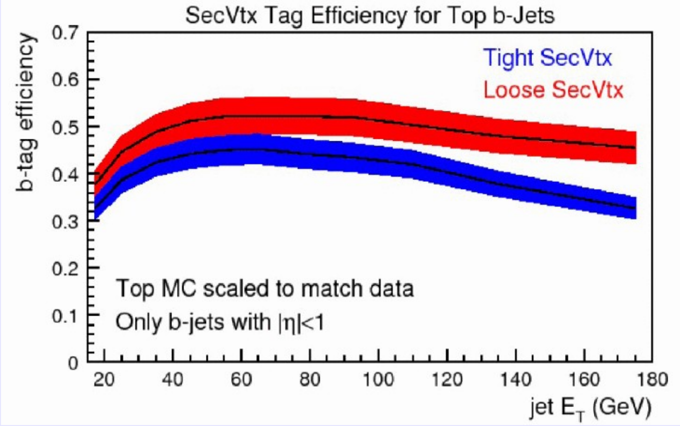
Two methods:

- secondary vertex tagging most efficient
- semileptonic decays of B hadrons in jets

Secondary vertex b-tagging



B-tag algo. Optimized by a NN discriminant



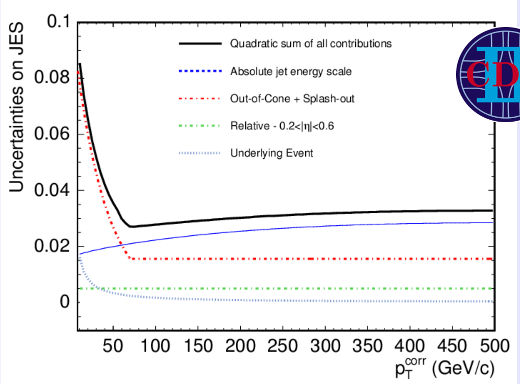
Effic. per top event = $(60 \pm 3)\%$

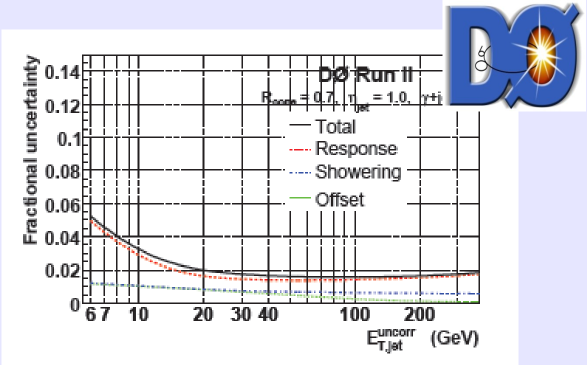
Mistag rate = $(0.48 \pm 0.04)\%$

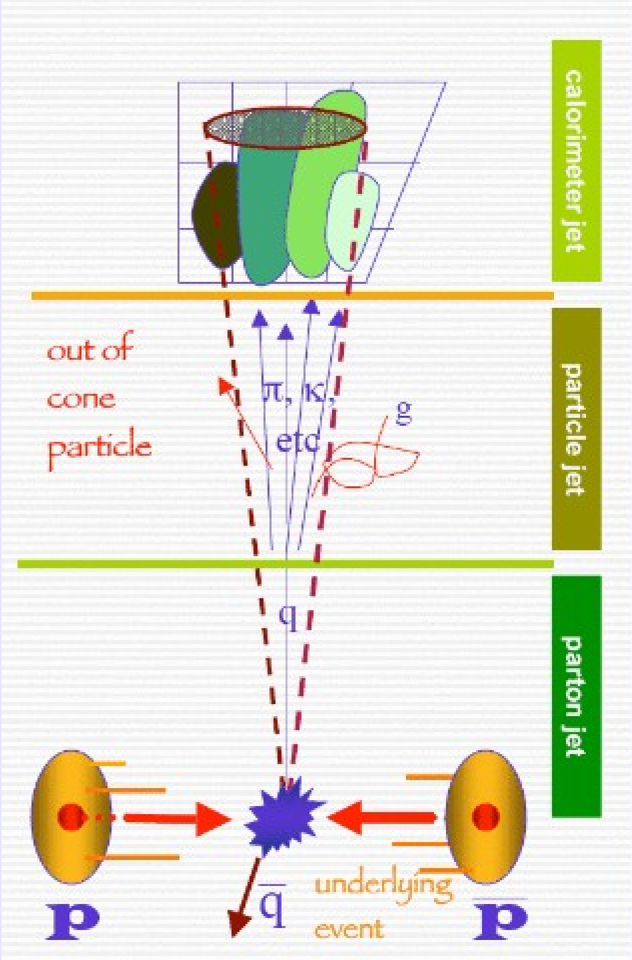
Challenge(2): Jet Reconstruction

Top mass measurement needs parton information, we measure jets

- Use calorimeter information to correct the jets to the particle level .
- JES (jet energy scale) is the major source of the top mass uncertainty







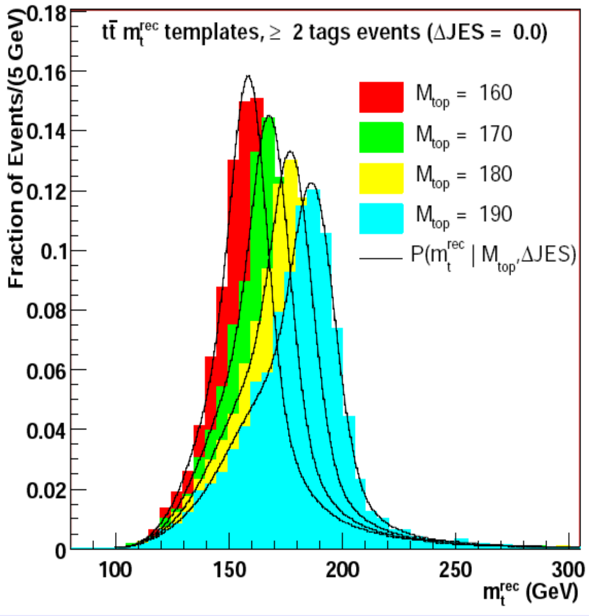
Use cone algorithm

- JES "in situ" calibration in ttbar events
  - Use W->jj constraint to measured W mass
  - A systematic is now a statistical uncertainty
  - Can be used for l+jets and all had. topology

Mass Measurement Methods

Many approaches have been used.

- Template method
  - Choose an observable , x, that is sensitive to m_t
  - Predict the distribution of x as a function of m_t using Monte Carlo (templates)
  - For each event evaluate a likelihood for each m_t value
  - Maximize the likelihood for the entire sample.



Examples of variables used:

- m_t after complete kinematic reconstruction
- Lepton P_T
- L_{xy}, decay length of the b-quarks in the event

Systematics are somewhat different for different methods.

"In situ" calibration of JES is used for topologies with $W \to j\ j$

- Matrix Element Method (ME)
  Uses all information from the event, integrating over the least known variables.

Top Mass Measurement: ME

- For each event evaluate a likelihood as a function of the top mass and Δ_{JES} related to the jet momenta uncertainty.
- All possible jet permutations are included with weights = w_i (24 for l+jets)

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

measured quantities | normalization | acceptance | 24 Permutations

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

Incoming partons | Transfer functions | parton level quantities

- Integrate over phase space (d Φ) and Matrix Element (M) for t t production and decay. Integration is over parton level quantities (32). Make some assumptions, integrate over the least known variables. Subtract background.

CDF Lepton+jets: Templates

NEW

- 4.8 fb-1 of data are used.
- 986 events selected

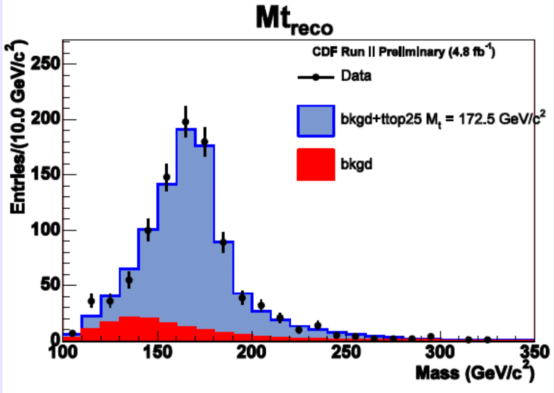
  P_T lepton (e,μ) > 20 GeV, MET>20 GeV,

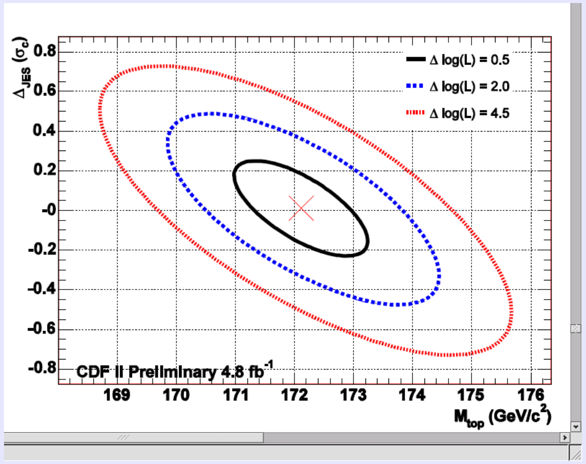
  4 jets with P_T>20 GeV, 1 b-tags

  Jet 4 P_T> 12 GeV for ≥ 2 b-tags
- Background estimated at 169 ± 57 events
- Uses 3D Template: M_t^{reco}, $M_t^{reco(2)}$, M_w

  M^{reco}: top mass reconstructed by constrained fit

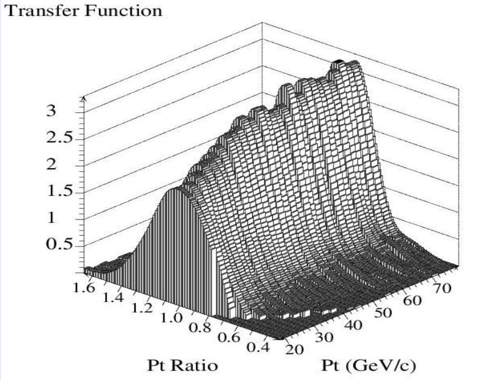
  $M^{reco(2)}$: second best solution
- JES calibration "in situ" : constrain M_{jj} to M_W





M_{top} = 172.2 ± 0.9 (stat.) ± 0.8 (JES) ± 1.0 (syst) = 172.2 ± 1.5 GeV

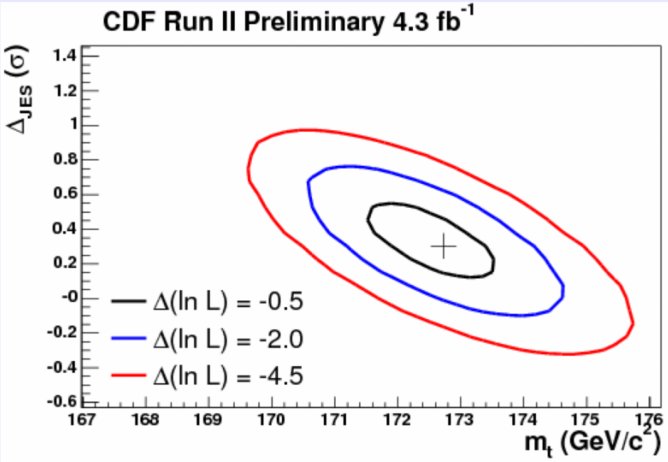
CDF: Lepton+jets, ME



- 4.3 fb^{-1} of data are used. 738 events selected
  - P_T lepton (e,m) > 20 GeV, MET>20 GeV
  - 4 jets with P_T>20 GeV, ≥ 1 b-tag
  - Background estimated at 173 ± 50 events
- P_T transfer functions built as a function of η and jet mass for light and b-jets
- "In situ" JES calibration is performed

A Quasi-Montecarlo integration is used, that allows integration over 19 variables

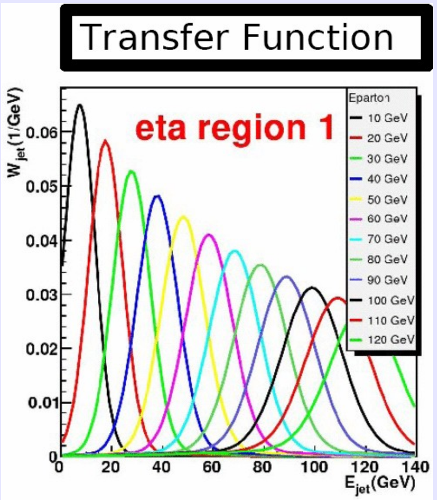
- Use NN discriminant to weigh background contribution
- Major systematics are: MC generator(0.5), b-jets JES(0.4), residual JES(0.5), CR (0.4)

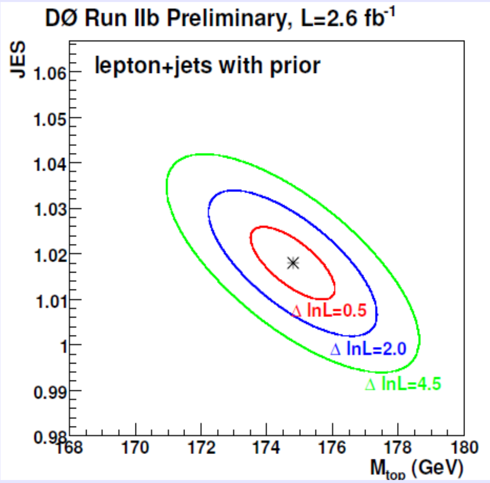


M_{top} = 172.6 ± 0.9 (stat.) ± 0.7 (JES) ± 1.1 (syst) = 172.6 ± 1.6 GeV

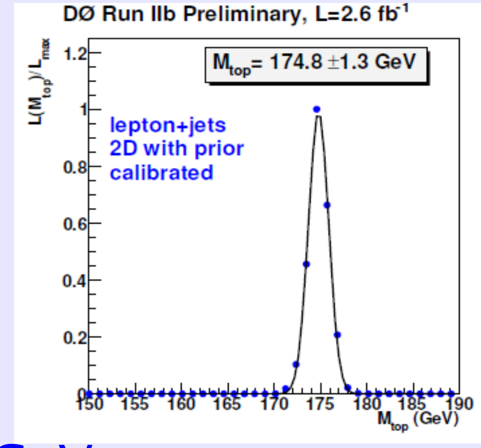
DØ lepton+jets: ME

- Uses the ME method on two separate samples
- Event selection similar to CDF. NN optimized b-tagging used to improve efficiency, reduce mistag
- Transfer functions are generated from Monte Carlo for light, heavy jets in 4 different η regions, leptons.





- Matrix Element for signal uses qq->t t only.
- Background ME from VECBOS
- "In situ" calibration of JES using a prior



RunIIa 1.0 fb−1 M_{top} = 171.5±1.4 (stat.)±1.8 (syst) GeV

RunIIb 2.6 fb−1 M_{top} = 174.8±1.0 (stat.)±1.6 (syst) GeV

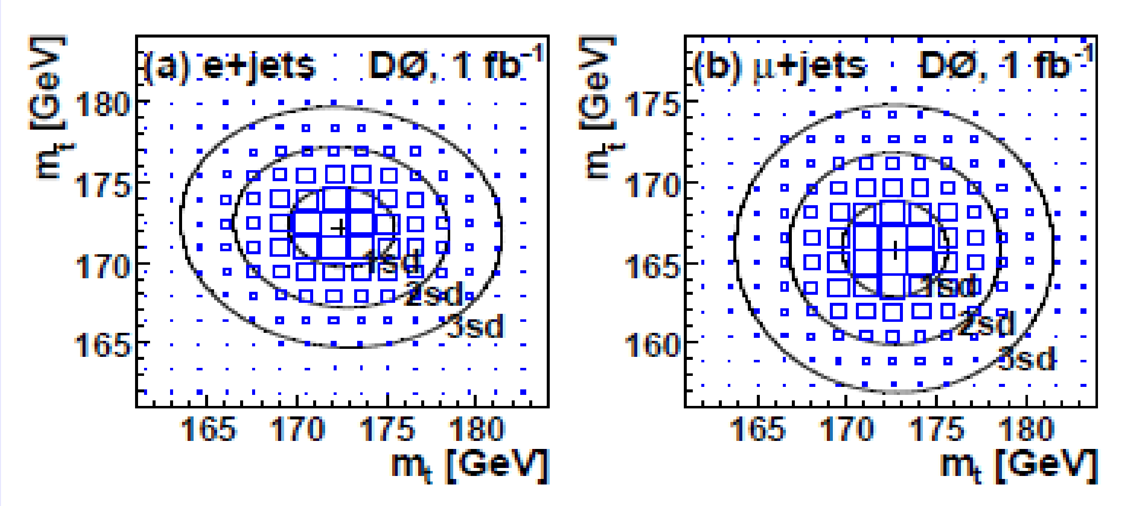
Combined M_{top} = 173.8±0.8 (stat.)±1.6 (syst) =173.8±1.8 GeV

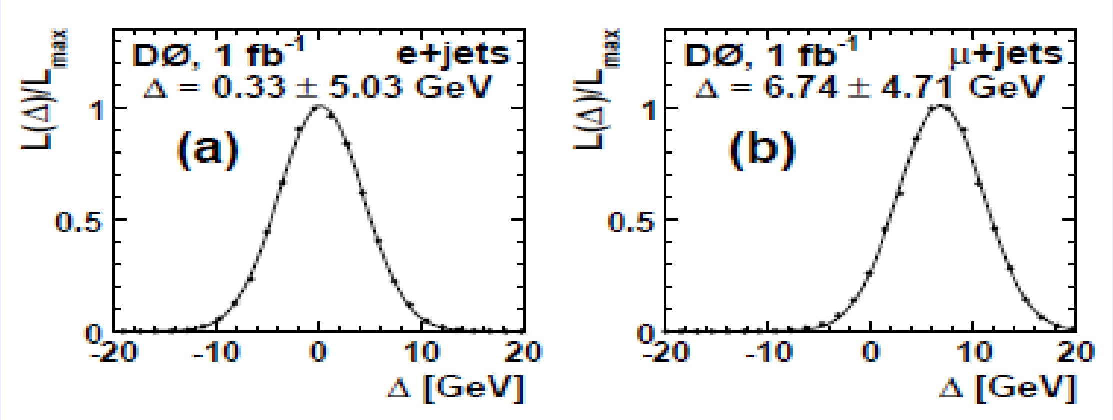
DØ top-antitop Mass Difference

Test of CPT invariance: particle and antiparticles have the same mass

Test never done on a quark.
Top quark is unique because
it decays before hadronizing

- Use ME analysis
- Samples with m_t and m_{tbar} set to different values
- Likelihood as a function of Δm_t
- Analyse e and μ samples separately





Combined Result:

Δm_t = 3.8 ± 3.4(stat) ± 1.2 (syst) = 3.8 ± 3.7 GeV

DØ di-leptons +jets

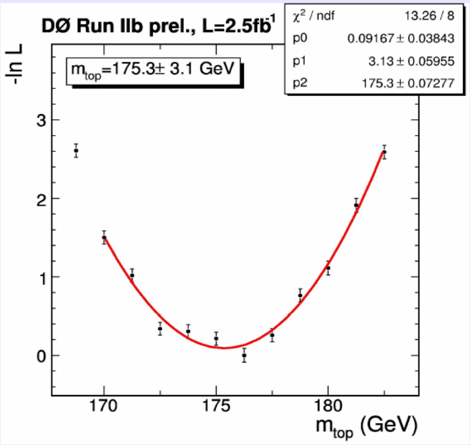
Event selection

2 leptons: ee, eμ, μμ, etrk, μtrk
large MET, 2 jets

Background: Z+jets, WW, W+jets

ME: eμ only

run2a 1.1fb-1,
run2b 2.5 fb-1



- transfer functions
- integration
- final likelihood

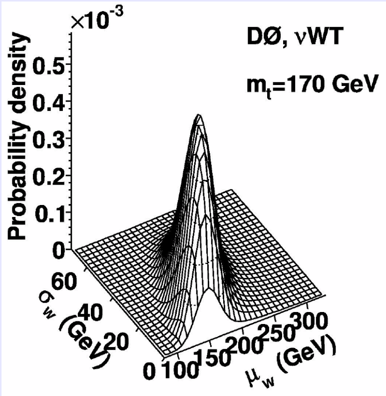
M_{top}=174.8 ±3.3(stat)± 2.6(syst) GeV

Template method: run2a (1 fb-1)

data: ee, μμ, e-track, μ-track

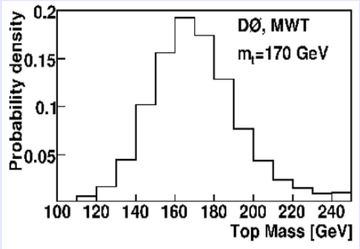
Neutrino weighting:

- sample η of ν's
- compare MET_{reco} to MET_{obs}: get weight w
- 2D templates: weight-vs-Δσ(w)



Matrix weighting

use measured MET
construct 1D weight



Combine results

M_{top}=174.7± 4.4(stat)±2.0(syst) GeV

Combined average

M_{top}=174.7 ± 2.9 (stat.) ± 2.4(syst.) = 174.7 ± 3.8 GeV

CDF di-leptons

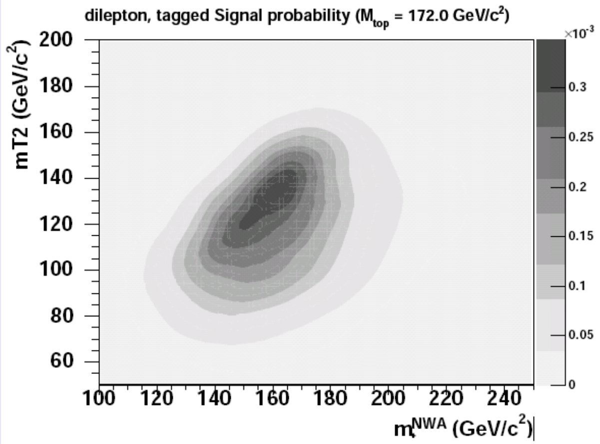
NEW 4.8 fb-1 Template Method

2D templates: NWA-vs-mT2

NWA: m_t from neutrino weighting algorithm

m_{T2}: m_t transverse mass from assumptions on

m_t and the 2ν P_T values

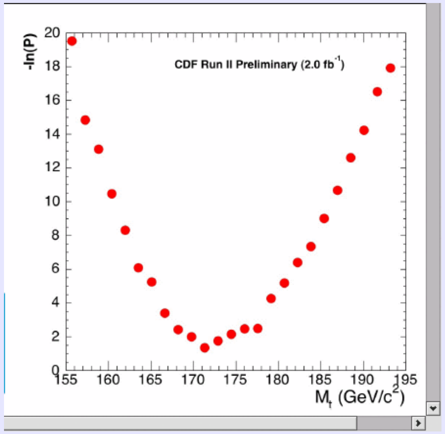


Lester,Summers,PLB,463,99(99);Barr,Stephens G29,2343(03)

M_{top} = 170.6 ± 2.2 (stat.) ± 3.1(syst) = 170.6 ± 3.8 GeV

1.9 fb-1 Matrix Element Integration

- integrate over the 2 unknown ν
- improve event selection with a NN optimized on mass resolution
- obtain 20% improvements despite lower S/B
- overall result with 1.9 fb-1 similar to TMT above



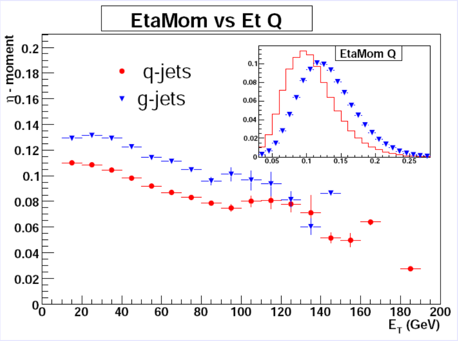
M_{top} = 171.2 ± 2.7(stat.) ± 2. 9(syst) = 171.2 ± 4.0 GeV

CDF: ALL HADRONIC Channel

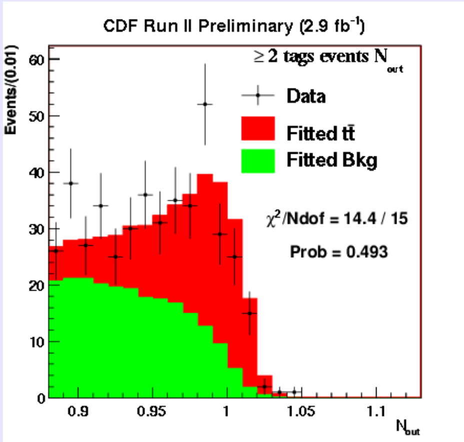
Template method (2.9 fb^{-1})

- Event selection:
  - 6-8 jets P_T> 15 GeV
  - ≥ 1 b-tagged jet
  - no leptons, small MET
- Background suppression
  - S/B ~ 10^{-3} after trigger
  - use NN (13 variables)
  - S/B = 1:4 (1 b-tag), 1:1 (2 b-tags)
- Analysis Strategy
  - use jet shapes:distinguish quark from gluon
  - "in situ" JES calibration
- Major Systematics
  - jet uncertainties = 1.7 GeV

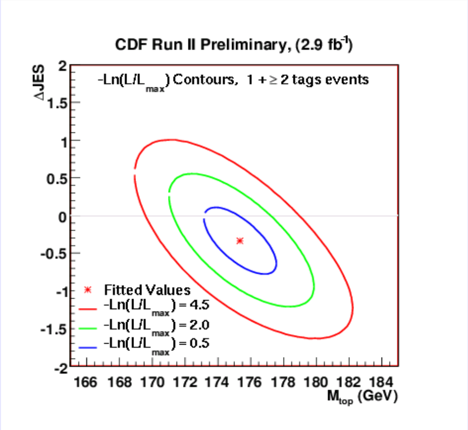
jet shapes

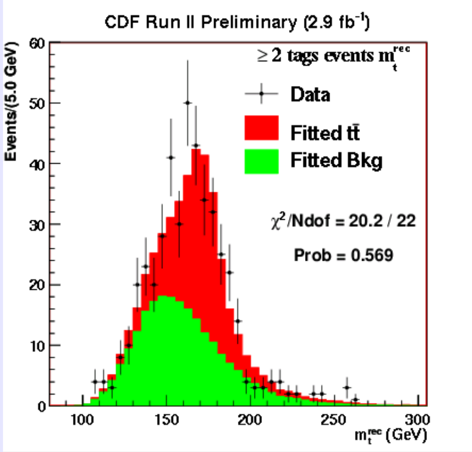


≥ 2 b-tags required
441 events



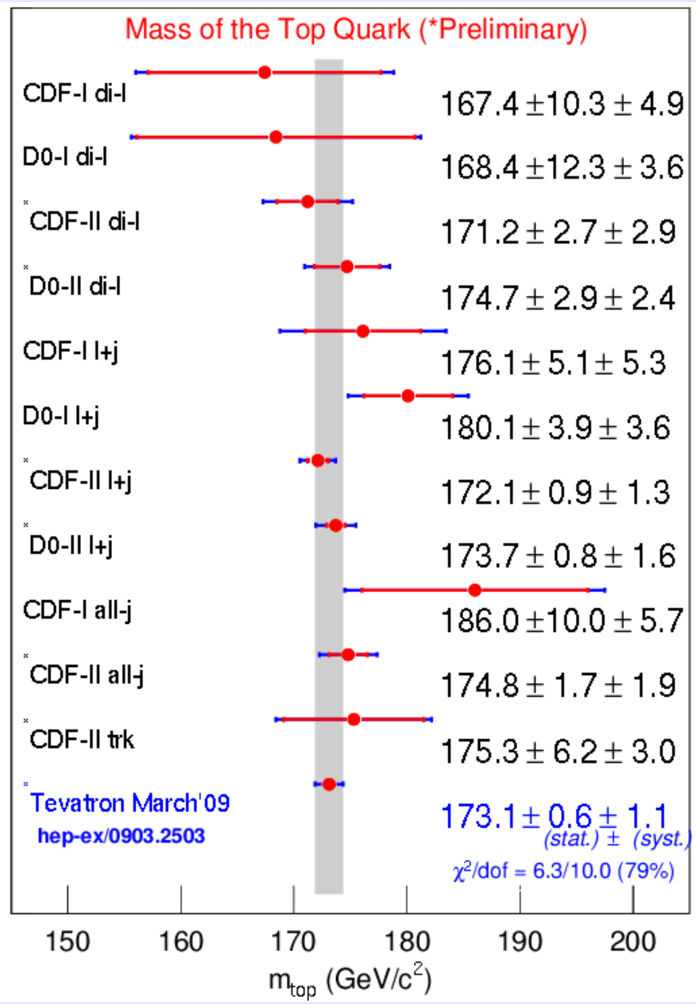
2-D likelihood, ≥ 1 b-tags





$$M_{top} = 174.8 \pm 1.7(stat.) \pm 1.6(JES) \pm^{1.2}_{1.0} (syst)\ GeV = 174.8 \pm 2.7\ GeV$$

Top Mass Summary



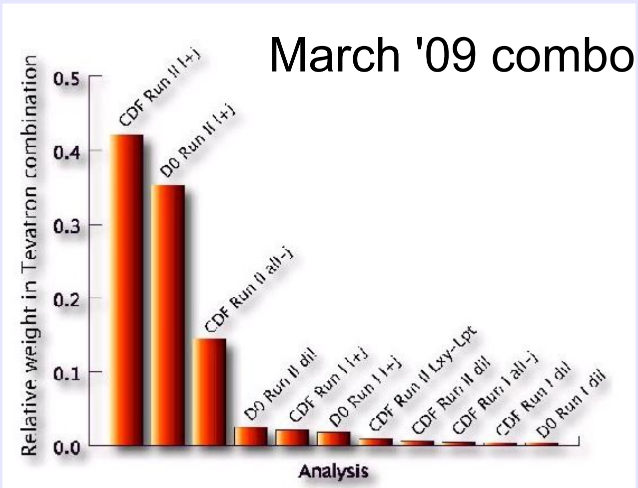
New measurements at this Conference

CDF l+jets Templates

M_{top}=172.2±0.9(stat.)±1.3(syst)=172.2±1.5 GeV

CDF dilepton Templates

M_{top}=171.2±2.2(stat.)±3.1(syst)=171.2±3.8 GeV

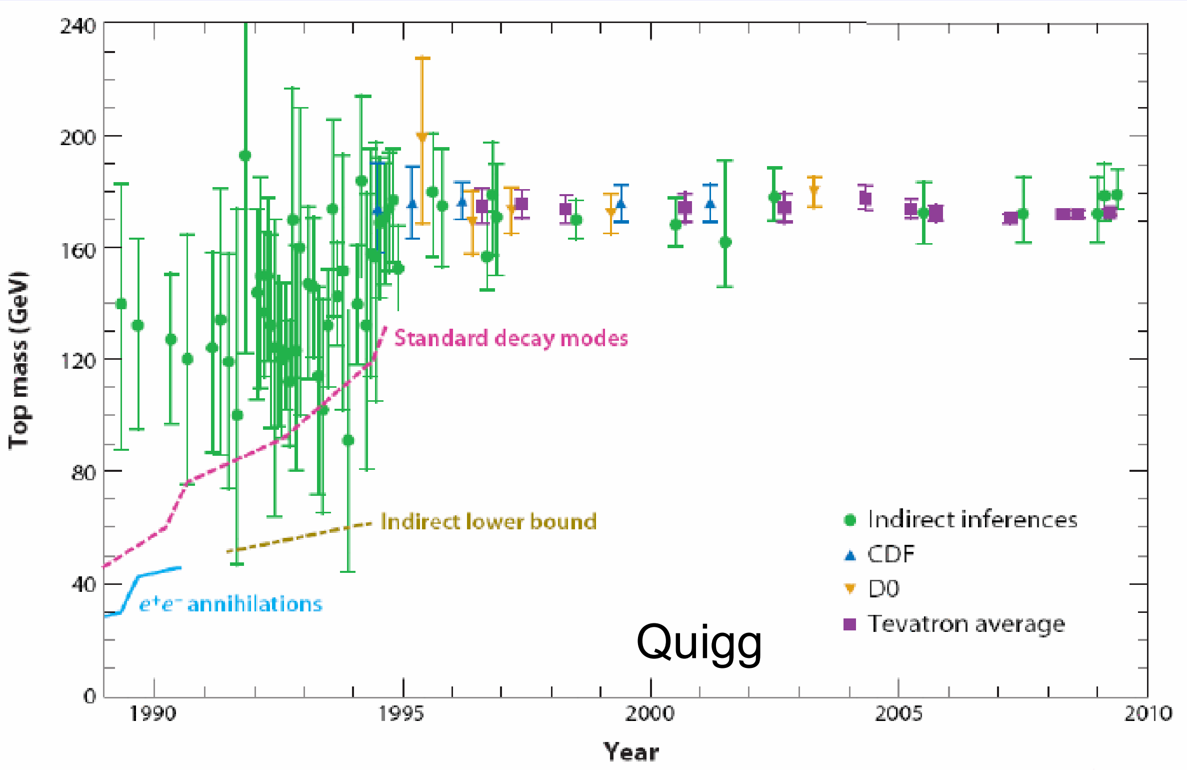


Mt=173.1 ± 1.3 GeV

History of the top mass

Measurement uncertainty on M_T has improved since 1994, but mass value has not changed much

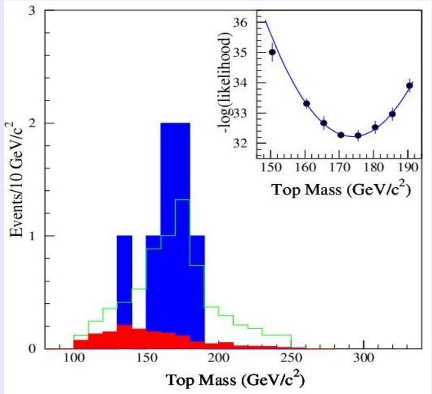
$M_{top} = 173.1 \pm 1.3$ GeV



First measurement

7 events (1.4 background)

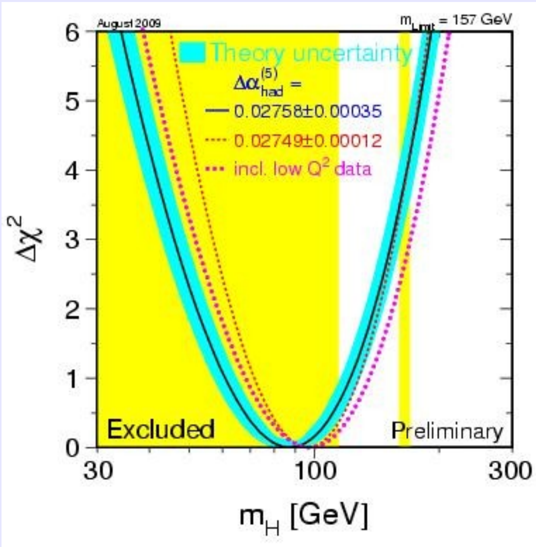
CDF, PRD **50**, 2966 (1994)

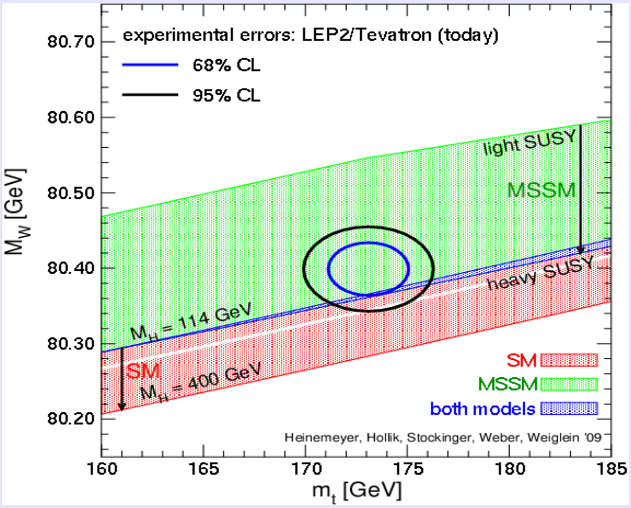


$$M_{top} = 174 \pm 10 \, ^{+13}_{-12} \text{ GeV}$$

Higgs Mass Constraint

Winter Conferences 2009 EWK Fit, gives M_H < 186 GeV/c^2





Winter 2009 best Fit

$M_H = 87^{+35}_{-26}$ GeV/c^2

and

M_H< 157 GeV/c^2 at 95% CL

Direct limit:

M_H > 114 GeV at 95% CL

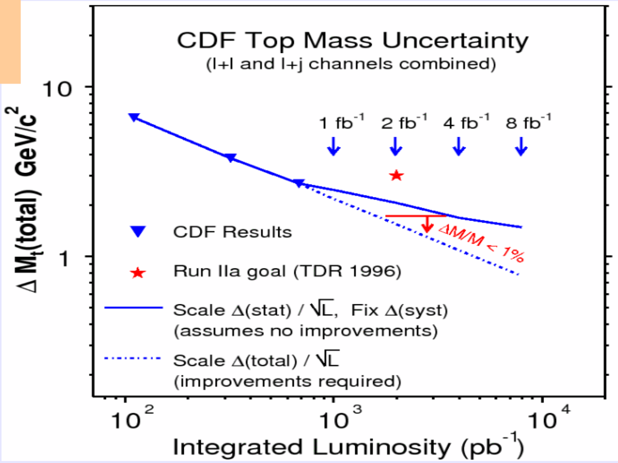
Adding the direct limit

M_H< 186 GeV/c^2 at 95% CL

Conclusions

M_{top}=173.1± 0.6(stat) ± 1.1(syst) = 173.1± 1.3 GeV

- CDF and DØ have performed many measurements of the top mass, bringing its precision down to 0.75%



- DØ has measured the top-antitop mass difference, consistent with CPT invariance

$$\Delta m_t = 3.8 \pm 3.7 \text{ GeV}$$

- At this point systematic uncertainties dominate over the statistical ones

- Additional data can help reduce some of the systematic uncertainties (JES) . Major terms:
    - generator (0.5 GeV)
    - Jet Energy uncertainty(1.0 GeV)
    - b-jets Energy scale (0.4 GeV)

Example systematic uncertainties

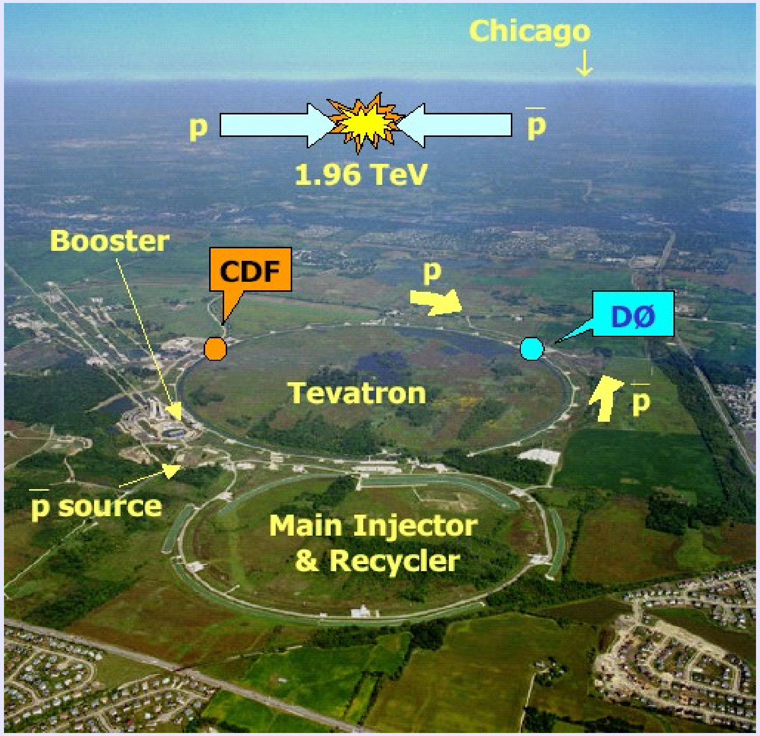
Systematic source (Lepton+jets, ME)	Systematic uncertainty (GeV/c^2)
MC generator	0.5
Background	0.5
Residual JES	0.5
b-jet JES	0.4
Colour reconnection	0.4
ISR and FSR	0.3
Lepton P_T uncertainty	0.2
PDFs	0.2
Method calibration	0.2
Multiple hadron interactions	0.1
Total	1.1

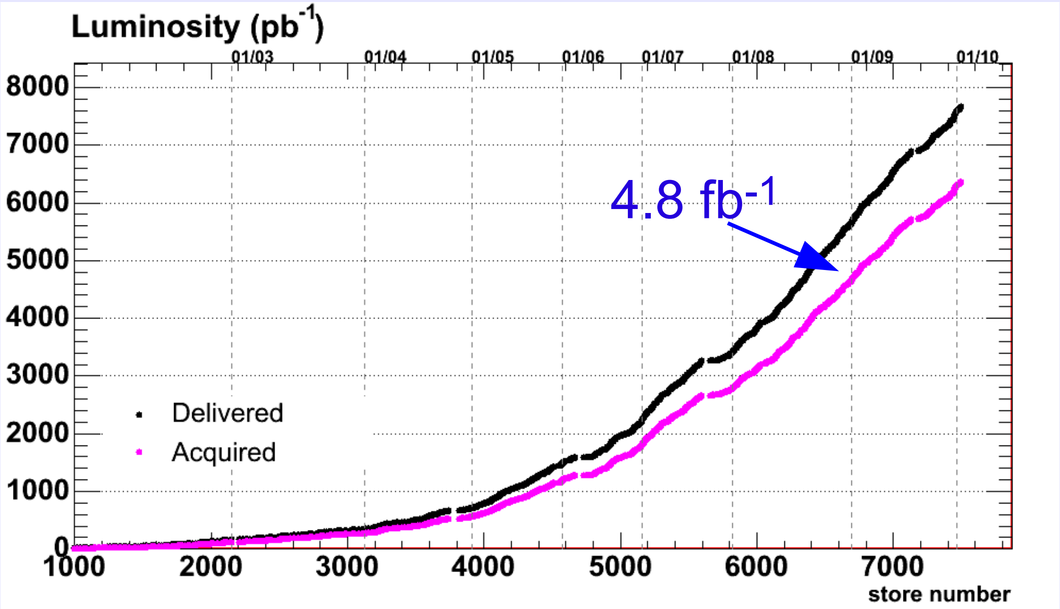
BACKUP SLIDES

MORE INFO

The Tevatron

Direct measurements are the most precise and can only be done at hadron colliders, at present. The Tevatron now, LHC in the future





Pbar-p at 1.96 TeV since 2001
Record luminosity: 3.6×10^{32} cm^{-2} s^{-1}
January 20, 2009

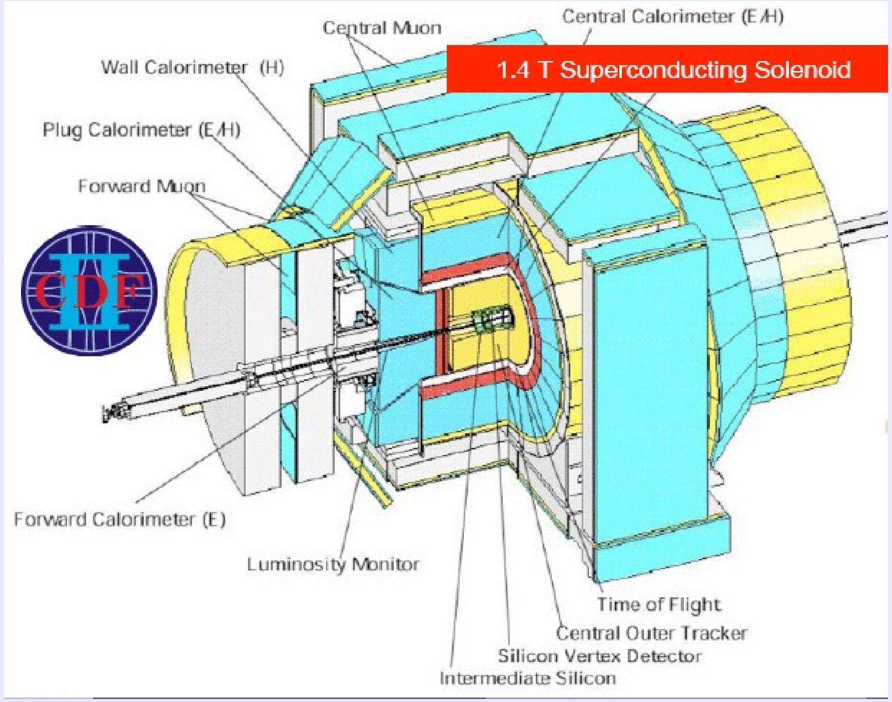
Expected to run through 2011: integrated luminosity up to 12 fb^{-1}

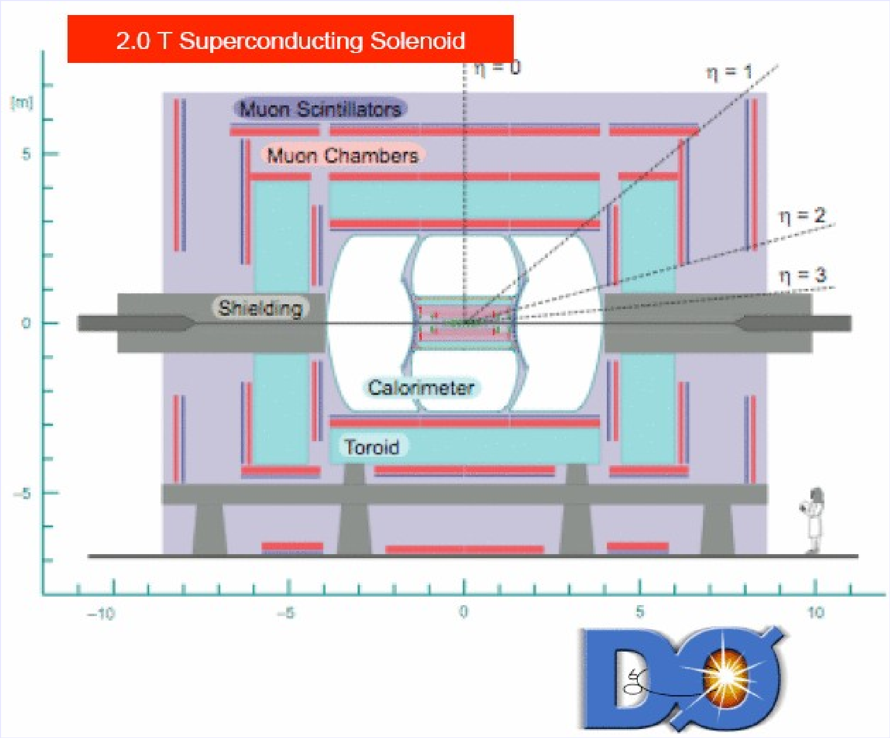
Results on top studies use up to 4.8 fb-1

Detectors for t–>W+b studies

Precision top mass measurement requires:

- Accurate tracking system with Silicon Detectors
- Good calorimetry to measure jet momenta.
- Efficient b-tagging capabilities

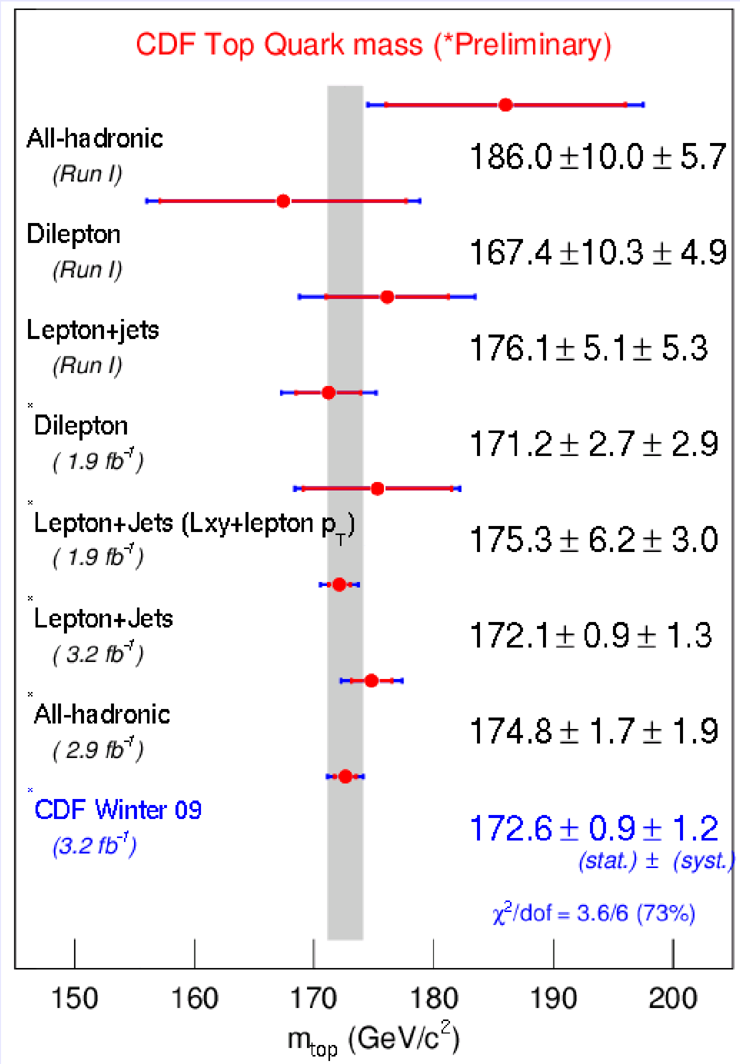


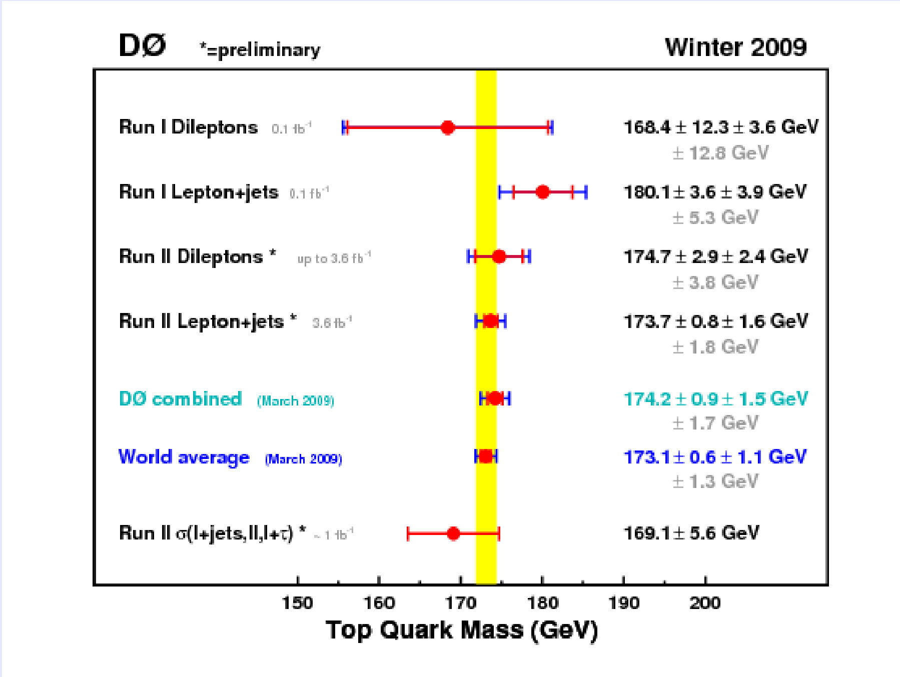


Excellent tracking system

Excellent muon coverage

CDF and D0 averages





Mt=174.2 ±1.7 GeV

Mt=172.6 ± 1.5 GeV