Top Quark Mass Measurements at the Tevatron

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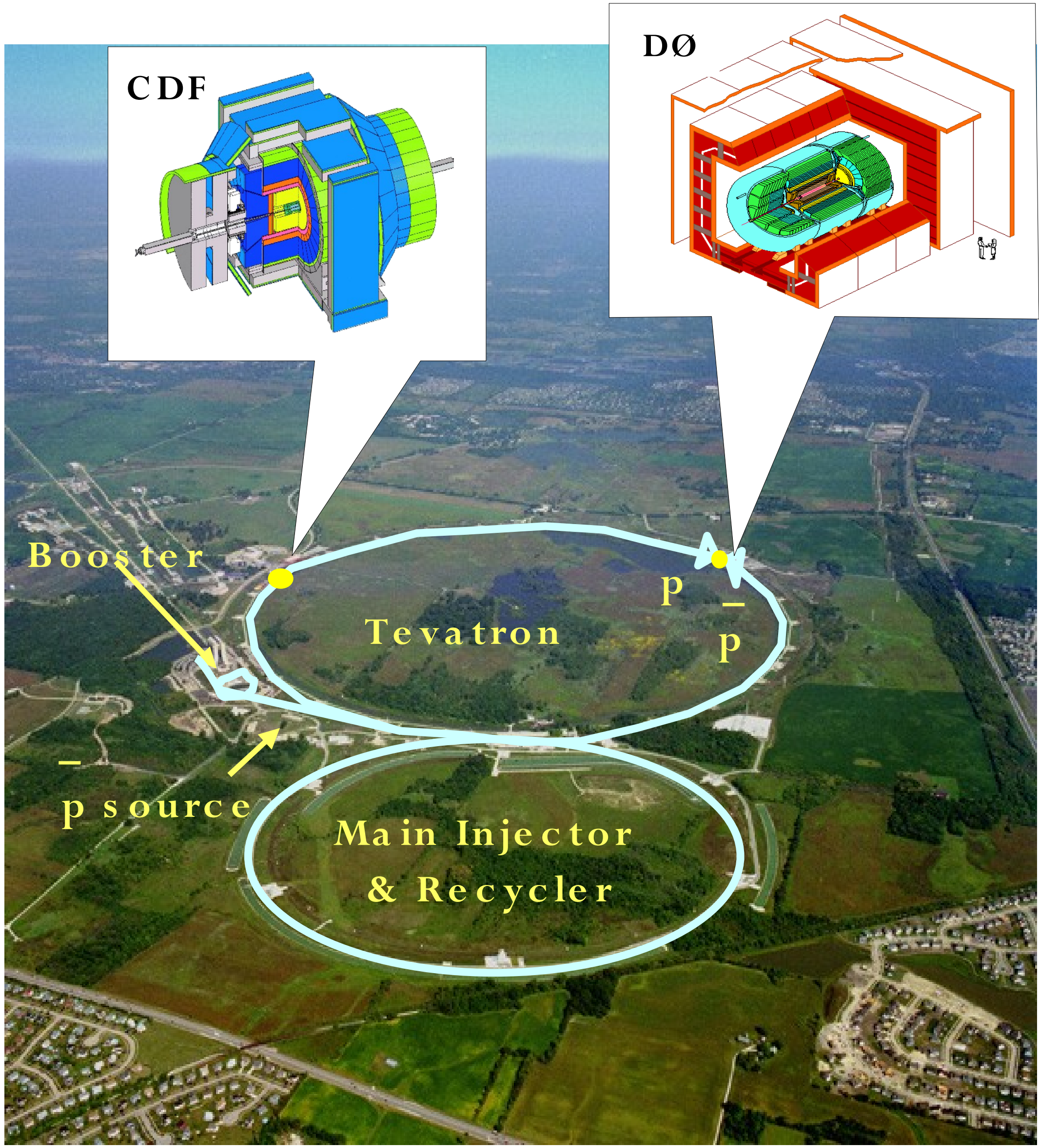
on behalf of the CDF & DØ Collaborations

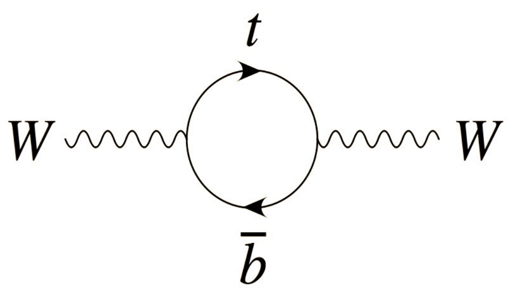
CDF and DØ

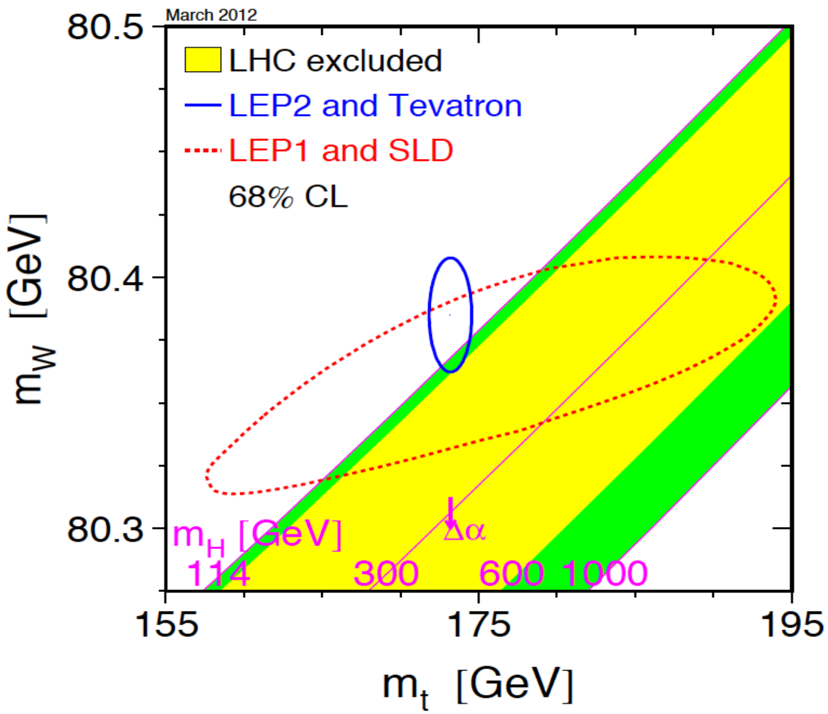
- Tevatron: proton-antiproton collisions
  - Run I: 1992-1996 with $\sqrt{s}$=1.8 TeV
  - Run II: March 2001 to 30.09.2011, 14:00 with $\sqrt{s}$=1.96 TeV
- Two general-purpose detectors:
  - CDF and DØ
- About 10fb^{-1} of data collected per experiment

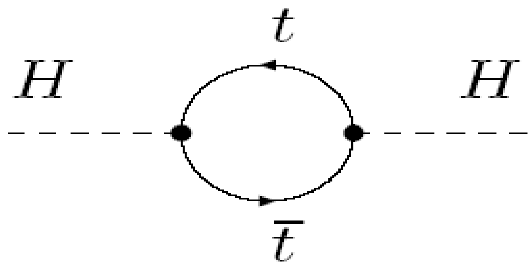


Top Quark Mass

- Free parameter of the SM
- Together with W mass: puts constraint on Higgs mass → self-consistency check







- Several methods explored for precision top mass measurement: Template method, ideogram, matrix element, etc.

$t\bar{t}$ Final States

$t\bar{t} \rightarrow W^+ b W^- \bar{b}$: Final states are classified according to W decay

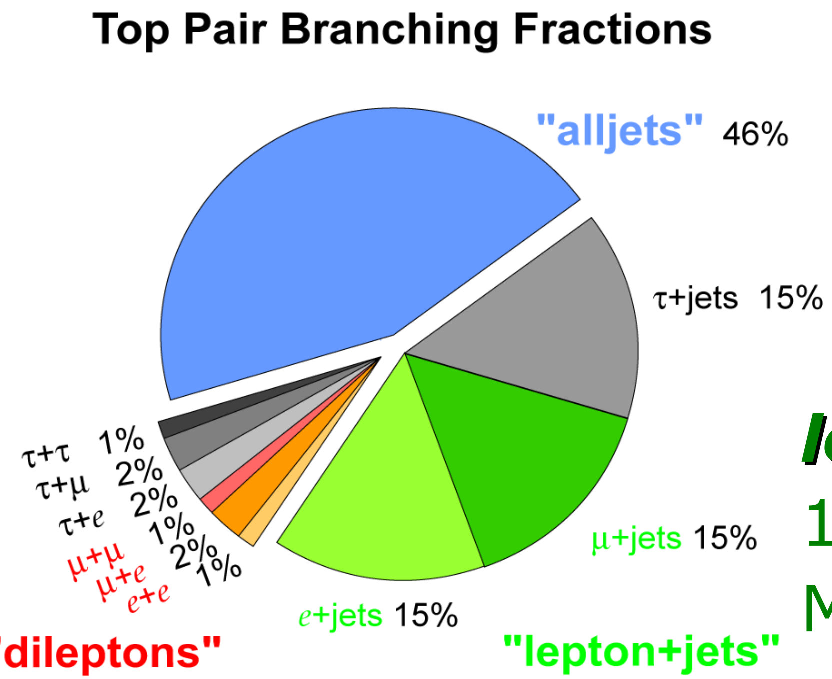
$B(t \rightarrow W^+ b) = 100\%$

met+jets:

lepton+jets events without identified electron or muon

pure hadronic:

≥6 jets (2 b-jets)



dilepton:

2 isolated leptons;
High missing E_T from neutrinos;
2 b-jets

lepton+jets:

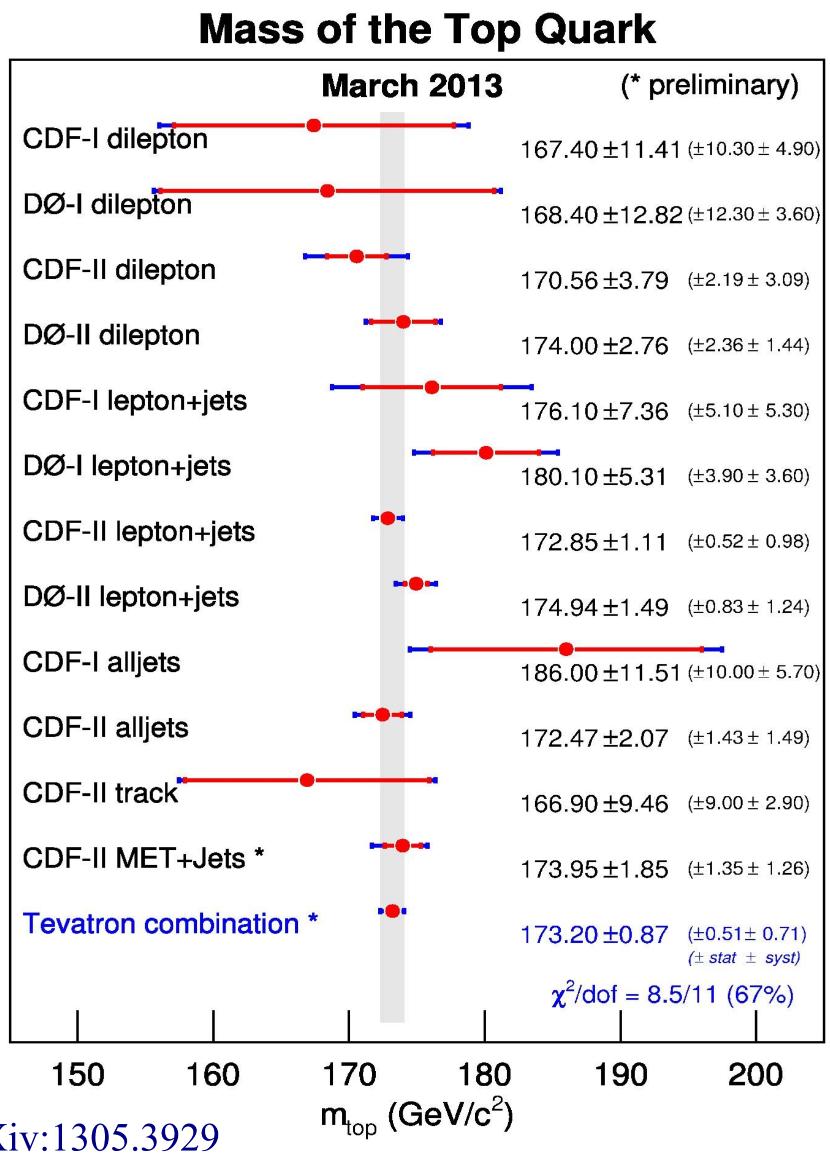
1 isolated lepton;
Missing E_T from neutrino;
≥4 jets (2 b-jets)

Tevatron Combination

- Recent Tevatron top mass combination
  - Results using up to 8.7fb^{-1}
  - Run I and Run II results
- Combination performed using BLUE

$$m_t = 173.20 \pm 0.51\,(stat) \pm 0.71\,(syst)\,GeV$$

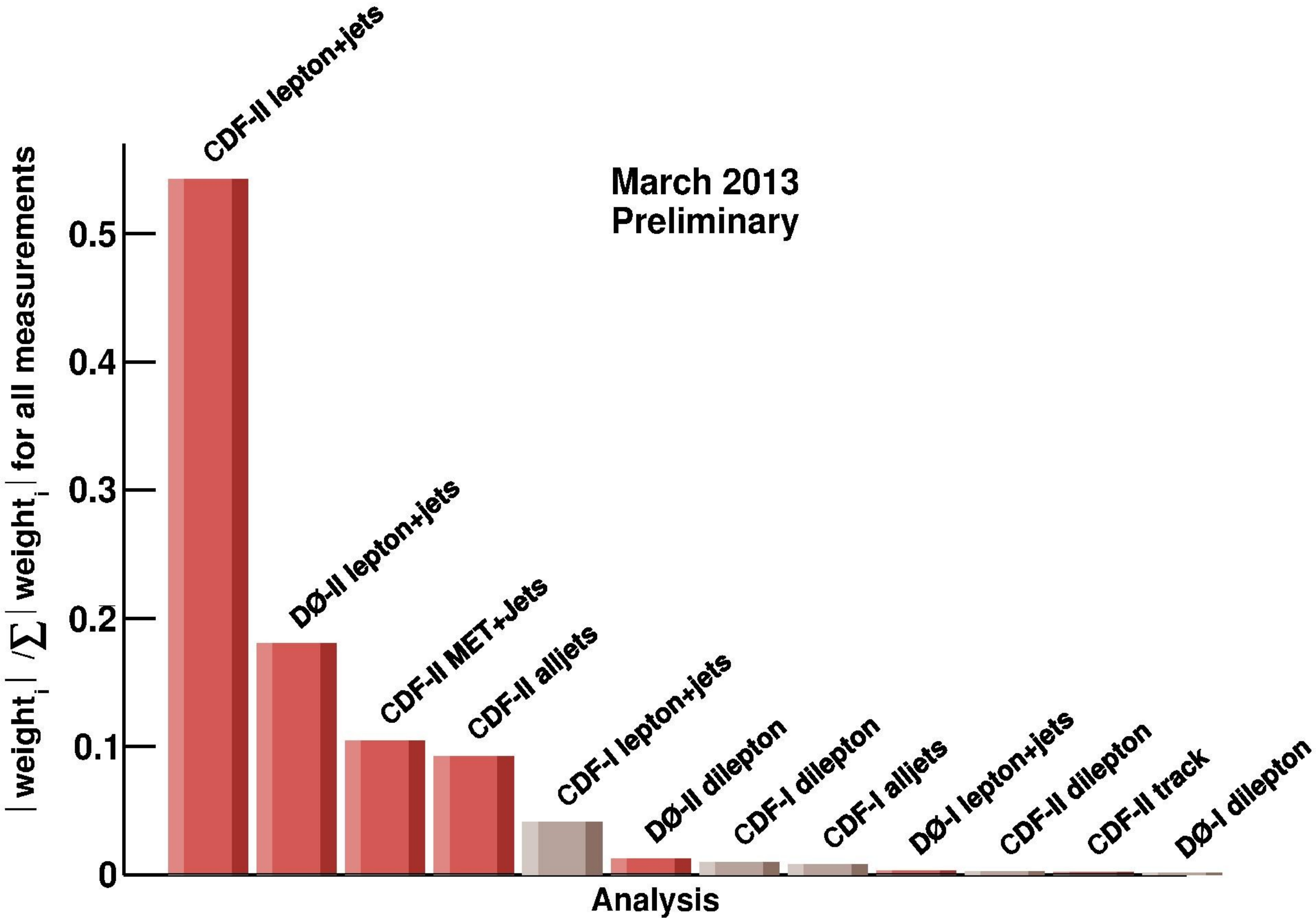
  - Limited by systematic uncertainties
    - Dominant: signal modeling and light-jet calibration
- Combination has χ^2 of 8.5 for NDF of 11 → probability of 67%



arXiv:1305.3929

Tevatron Combination

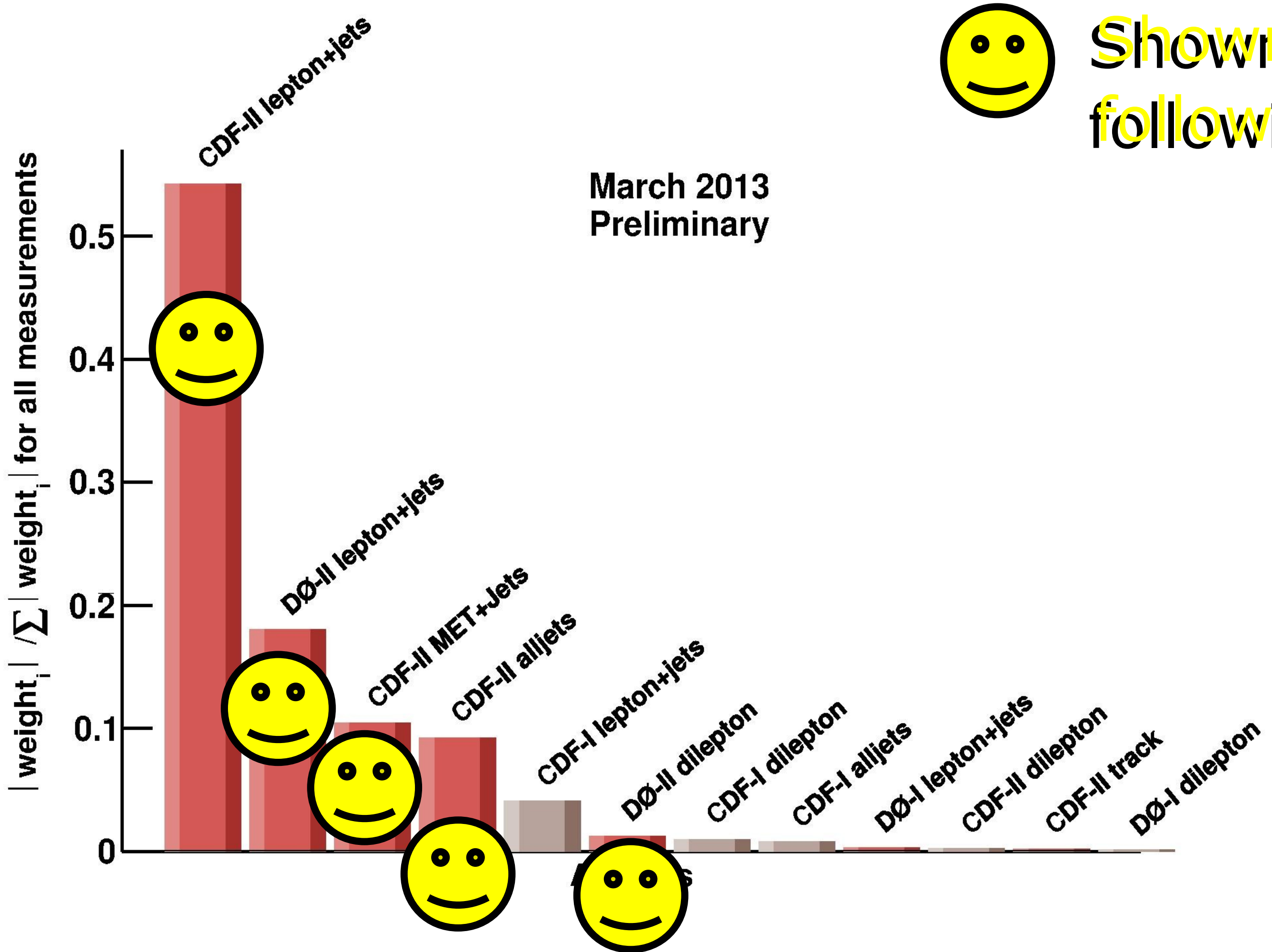
- Weights per measurement:
  - Negative weights (grey) if large correlations



Tevatron Combination

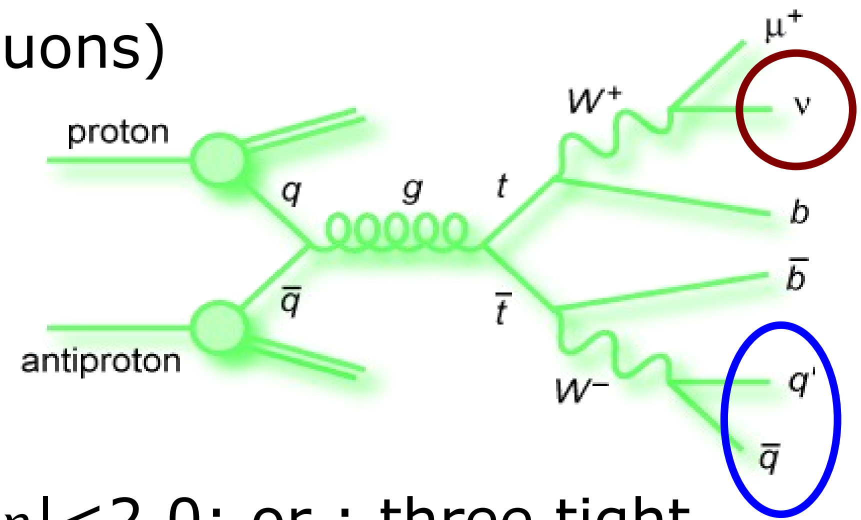
- Weights per measurement:
  - Negative weights (grey) if large correlations

Shown in the following



L+jets Analyses

- l+jets selection:
  - 1 high-p_T (>20GeV) isolated electron or muon
  - $|\eta|<1.1$ of the lepton (DØ: $|\eta|<2$ for muons)
  - $\geq$ 4 jets with $|\eta|<2.5$
    (CDF: $|\eta|<2.0$ or $|\eta|<2.4$)
    and $p_T>20$GeV
    (CDF: for loose jets: $p_T>12$GeV)
    - CDF: ==4 jets with $E_T>20$GeV and $|\eta|<2.0$; or : three tight
  - Missing $E_T>20$GeV
  - Identification of b-jets

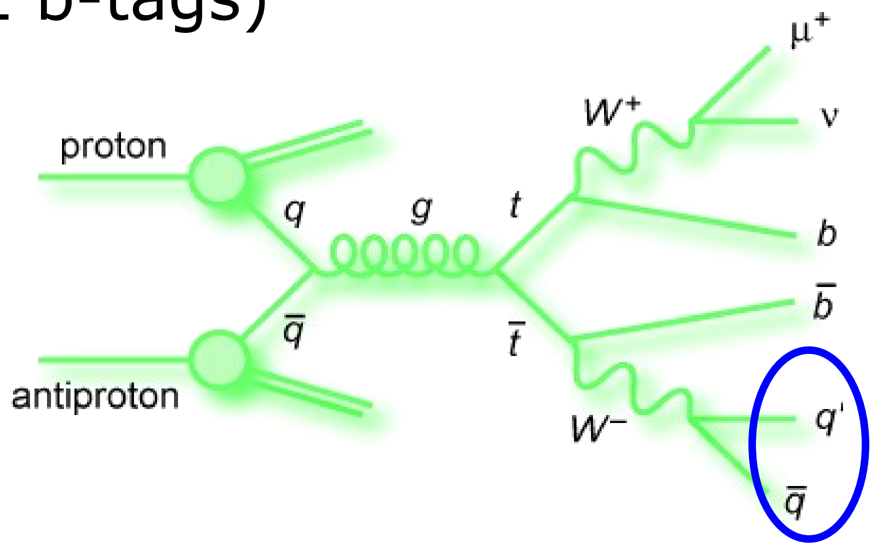


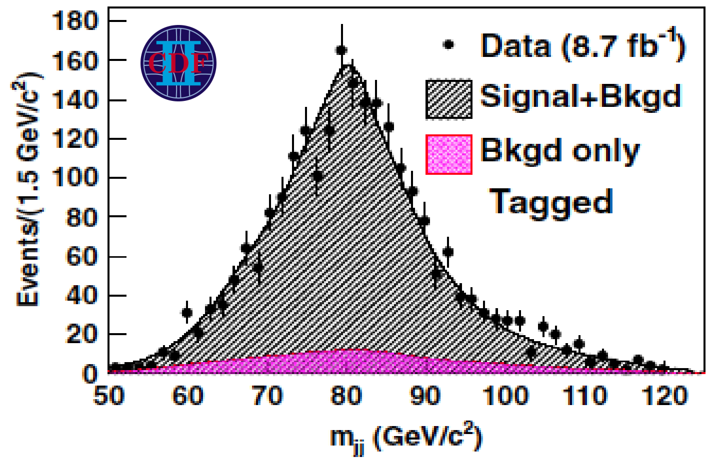
- Alljets and l+jets: Take info from hadronically decaying W mass to constrain jet energy scale

L+jets Analyses (CDF)

- Events divided into subsamples (0,1,2 b-tags)
- Reconstruct $t\bar{t}$ kinematics
  - Constraints from known W mass
  - Require t and $\bar{t}$ mass to be the same

  → χ^2 minimization
  - Use m_t^{reco} yielding lowest χ^2
    - And $m_t^{reco(2)}$ yielding second lowest χ^2
- From m_{jj}: constrain JES
- Perform unbinned maximum likelihood fit



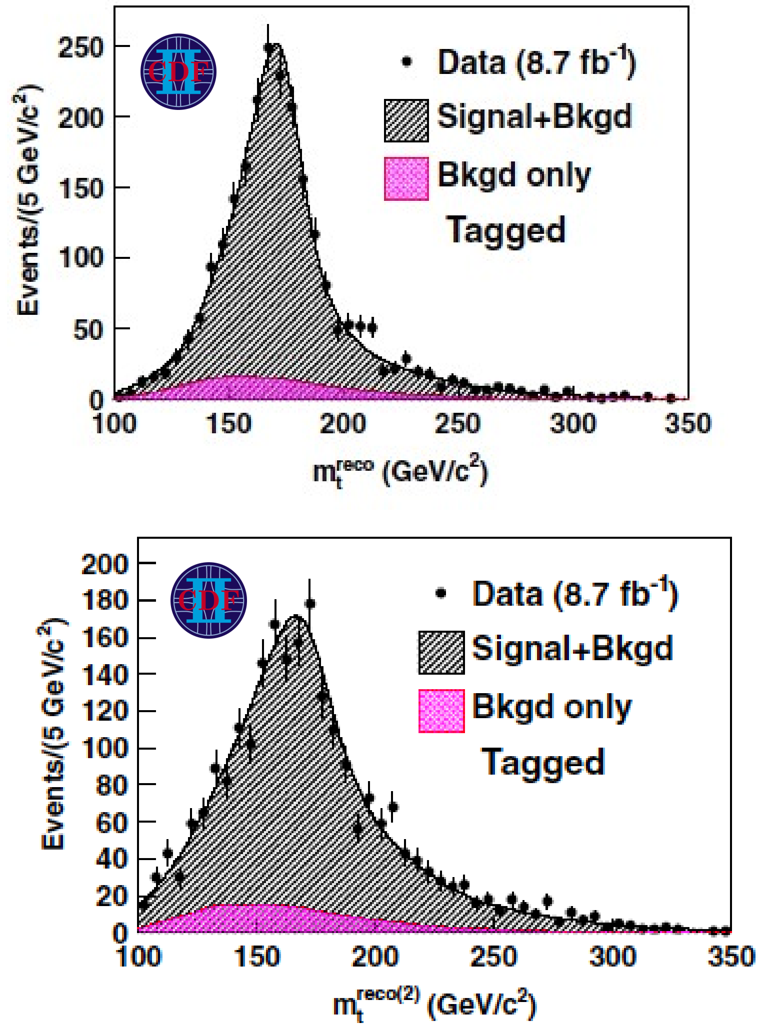


L+jets Analyses (CDF)

- Best single measurement:

$$m_t = 172.85 \pm 0.71\,(stat) \pm 0.85\,(syst)\,GeV$$

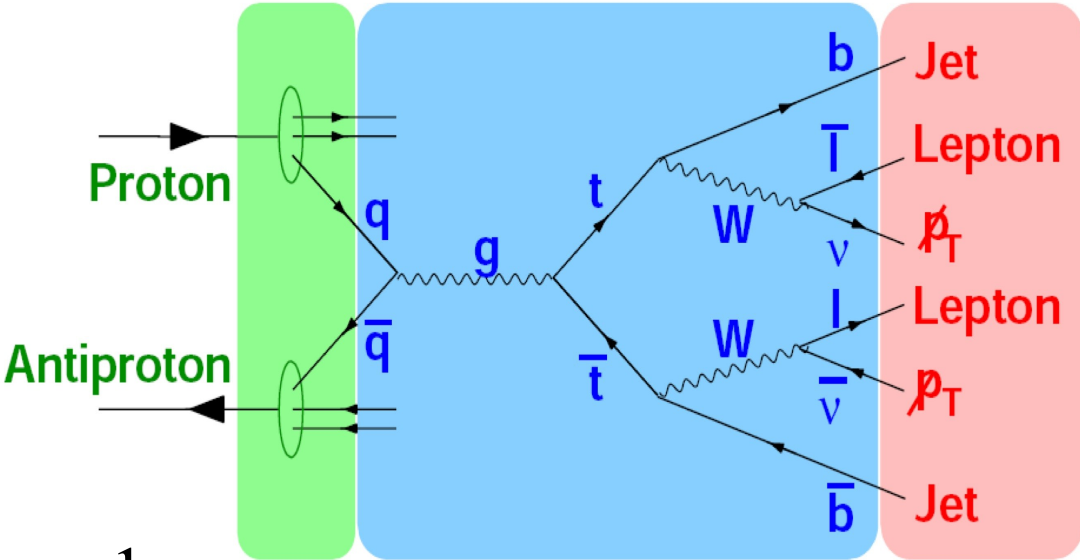
- Main systematic uncertainties:
  - Signal modeling: MC generator
  - Color reconnection
  - Residual JES
  - b-jet energy scale
- Highest weight in Tevatron combination



PRL 109, 152003 (2012)

L+jets Analyses (DØ)

- Matrix element method: Use full event kinematics
  → most precise method
- For each event calculate probability to belong to certain top mass



$$P_{sig}(x;m_{top}) = \frac{1}{\sigma_{obs}} \int \sum_{flavors} dq_1 dq_2 dy\, f(q_1) f(q_2) \sigma(y;m_{top}) W(x,y)$$

PDFs

Matrix element & phase space

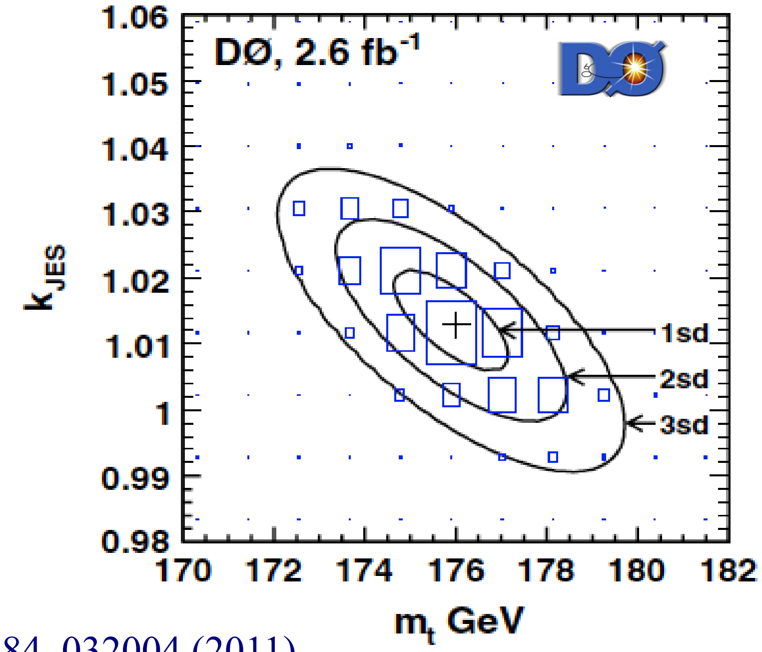
Transfer function: mapping of true momenta y to measured momenta x

L+jets Analyses (DØ)

- In l+jets events (3.6fb^{-1})
  - JES also constrained from hadronically decaying W boson
- Measured value:

$$m_t = 174.94 \pm 0.83(stat) \pm 0.78(JES) \pm 0.96(syst)\, GeV$$

- Main systematics:
  - Signal modeling:
    hadronization and UE; color reconnection
  - Modeling of detector:
    jet energy resolution; jet response



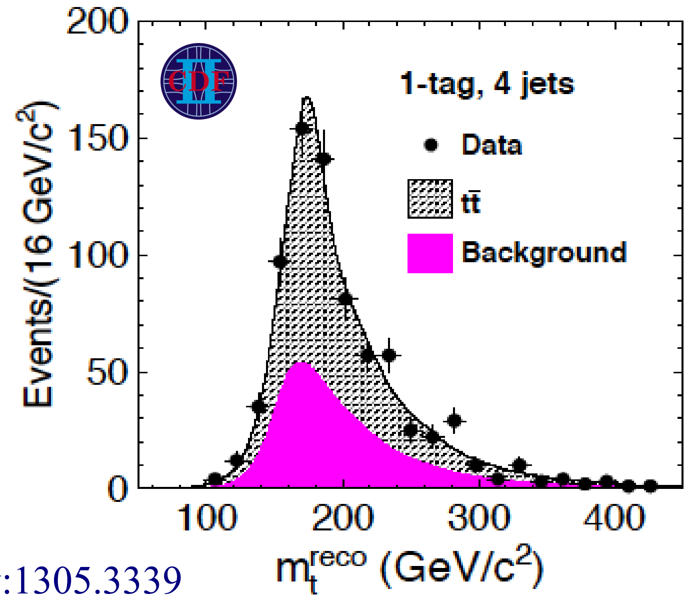
PRD 84, 032004 (2011)

- Analysis of full dataset ongoing

$\not{E}_T$+jets Analysis (CDF)

- Events from l+jets, where no muon or electron is reconstructed → $\not{E}_T$+jets
- Reconstruct m_t^{reco} and $m_t^{reco(2)}$
  - Use jets and $\not{E}_T$ → modified kinematic fitter (both decay particles of leptonically decaying W missing)
  - Events with 4,5,6 jets and 1 or >1 b-tag
    - Events with 5 jets: τ+jets with τ misidentified as jets
- Mass (8.7fb^{-1}):

$$m_t = 173.93 \pm 1.64 (stat) \pm 0.87 (syst) GeV$$



arxiv:1305.3339

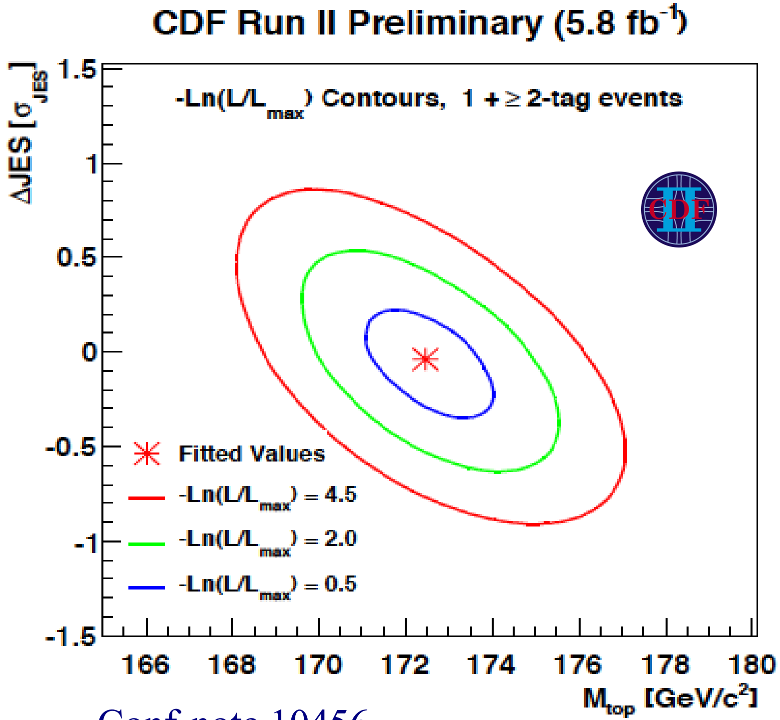
  - Main systematics: residual JES; signal modeling (MC generator)

Alljets Analysis (CDF)

- Events with ≥6 jets, no leptons, no $\not{E}_T$
  - Main challenge: large QCD multijet background
    → data-driven background determination
  - Construct neural network based on variables depending on energy, direction and shape of jets
- Top reconstruction: using χ^2-like quantity
  - W mass constraint for in-situ JES fit
- Mass (5.8fb^{-1}):

$$m_t = 172.5 \pm 1.4(stat) \pm 1.4(syst)\,GeV$$

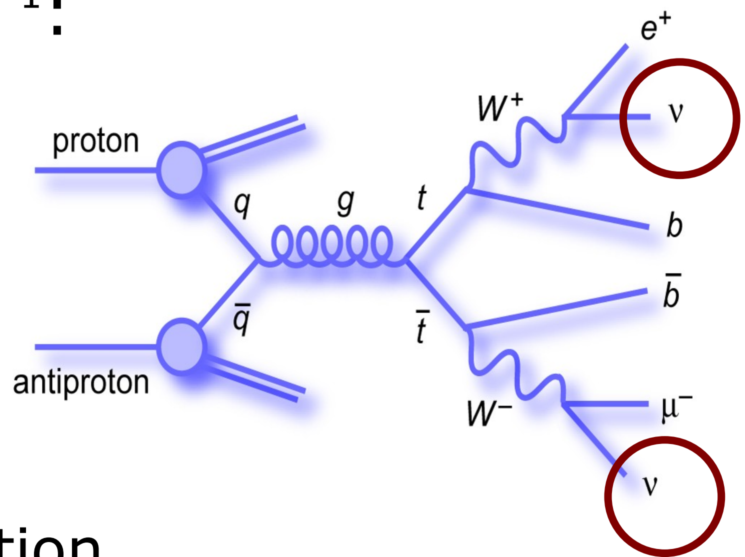
  - Main systematics:
    signal modeling (MC generator), background model, residual JES



Conf-note 10456

Dilepton Analysis (DØ)

- Dilepton events: very clean signature; but: two neutrinos
  - More challenging event reconstruction
    → under-constrained kinematics
- Two methods explored at DØ with 5.3fb^{-1}:
  - Matrix element method
  - Neutrino weighting technique
- Neutrino weighting:
  - Assume neutrino ηs
  - solve event kinematics for each assumption
  - Calculate $\not{E}_T$ from neutrino momentum solutions
  - Calculate weight based on the comparison of calculated and measured $\not{E}_T$

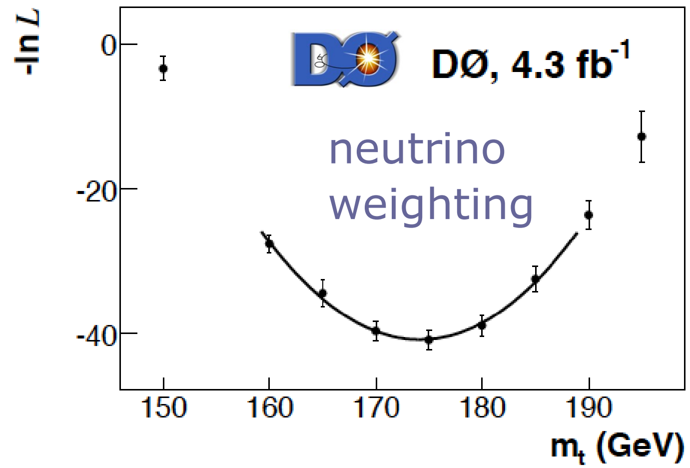


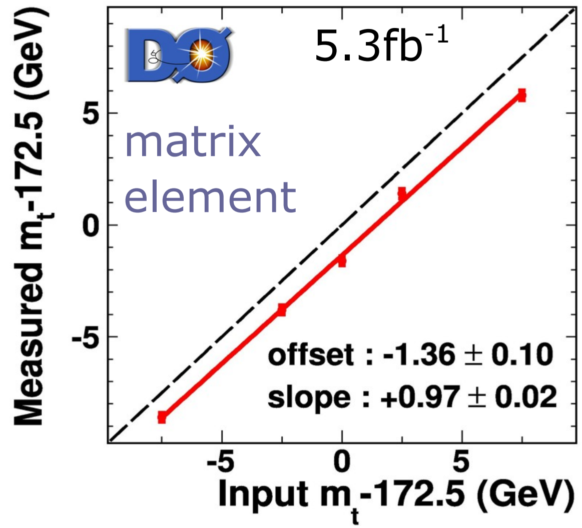
Dilepton Analysis (DØ)

- First two moments of weight distribution used (mean and rms)
- Use in-situ JES measurement from l+jets to constrain JES in dilepton channel → improved jet energy calibration
- Combined mass from matrix element and neutrino weighting:

$$m_t = 173.9 \pm 1.9(stat) \pm 1.6(syst)\,GeV$$

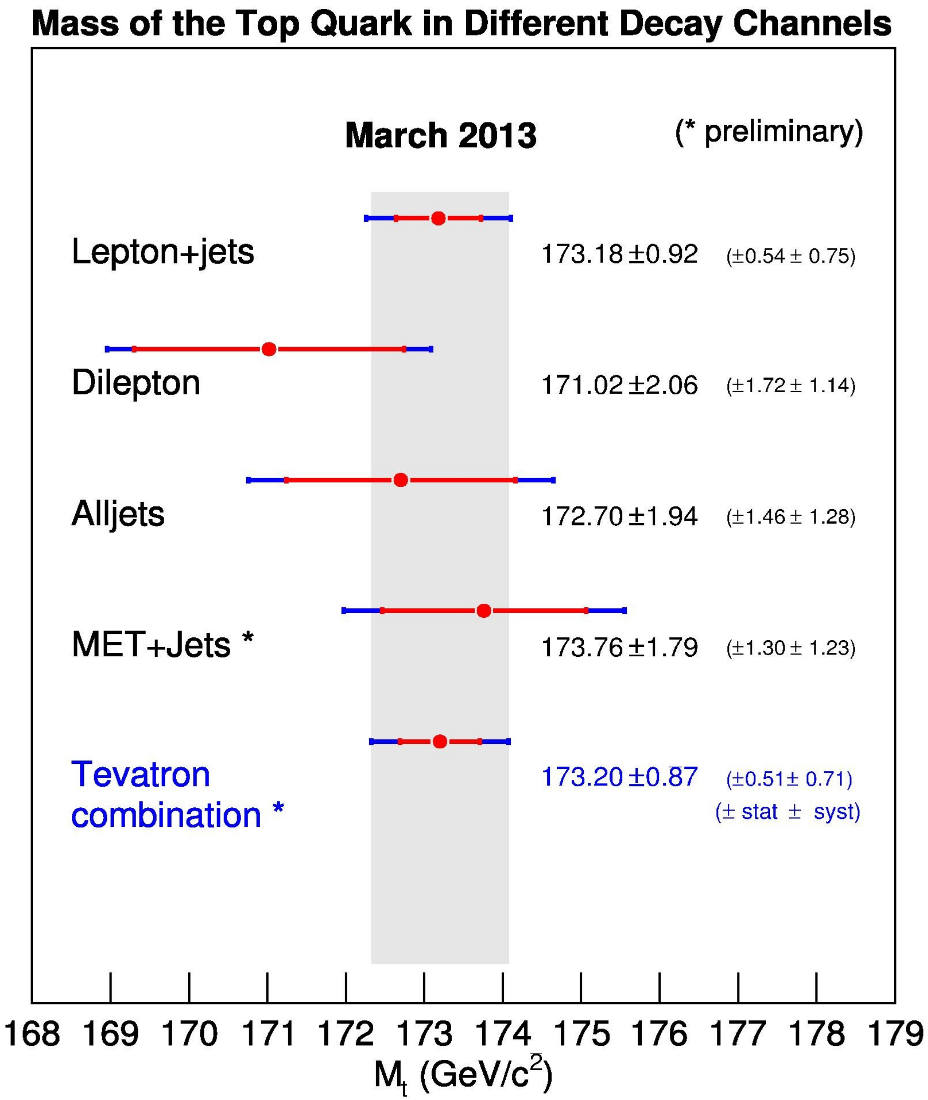
  - Main systematics: JES; signal modeling (MC generator)





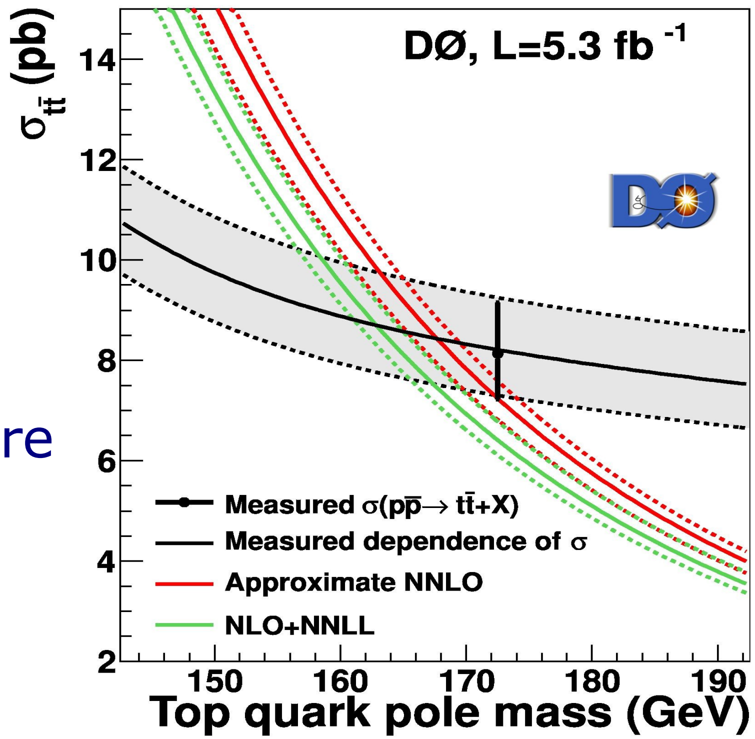
PRD RC 86, 051103 (2012)

Tevatron Combination



Top Quark Mass: Be aware

- Ongoing discussion:
  What is theoretical interpretation of the measured parameter?
  - We extract the top mass based on Monte Carlo → Is it the pole mass?
- Alternative method: Extract m_t from measurement of $t\bar{t}$ cross section
  - Assuming MC mass =pole or $\overline{\text{MS}}$ mass
    - Take difference as systematics
  - Calculate $\sigma_{t\bar{t}}$ as function of pole mass; compare to measured $\sigma_{t\bar{t}}$ as function of pole mass
    → Extract pole mass: $m_t = 167.5^{+5.2}_{-4.7}\,GeV$



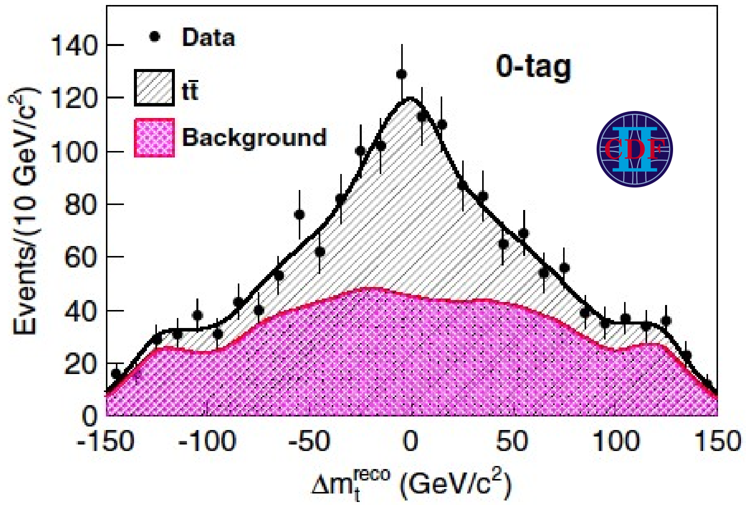
PLB 703, 422-427 (2011)

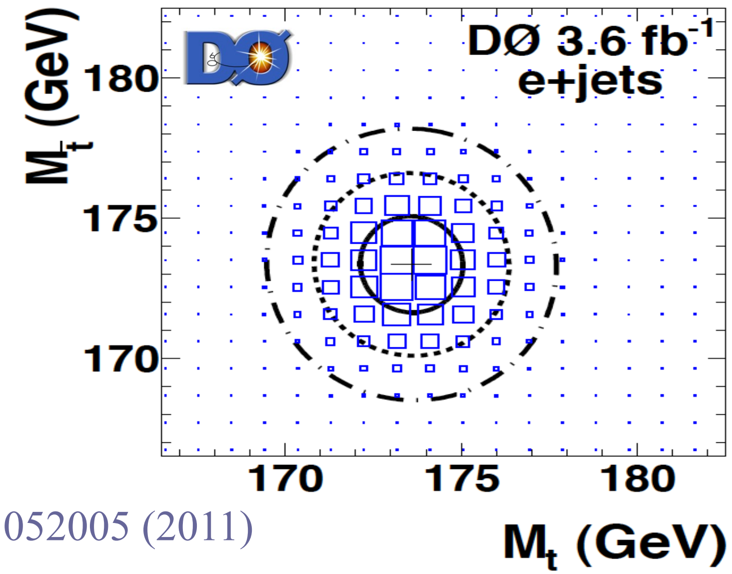
- Assuming $\overline{\text{MS}}$ mass leads to ~7GeV smaller value
- World average a bit more compatible with pole mass

Top-Antitop Mass Difference

- Do top and anti-top have equal mass?
  - If not: CPT violation!
- Using template technique (l+jets)
  - CDF (Assume average top mass of 172.5GeV) $m_t - m_{\bar{t}}=-1.95\pm1.26$GeV ($8.7fb^{-1}$)
    - Final mass difference measurement from CDF
- Using Matrix Element technique (l+jets)
  - $P_{sig}(x;m_t, m_{\bar{t}})$ instead of $P_{sig}(x;m_t)$
  - DØ: $m_t - m_{\bar{t}}=0.8\pm1.9$GeV ($3.6fb^{-1}$)
- Both measurements still statistically limited
- Good agreement with the SM!

PRD 87, 052013 (2013)





PRD 84 , 052005 (2011)

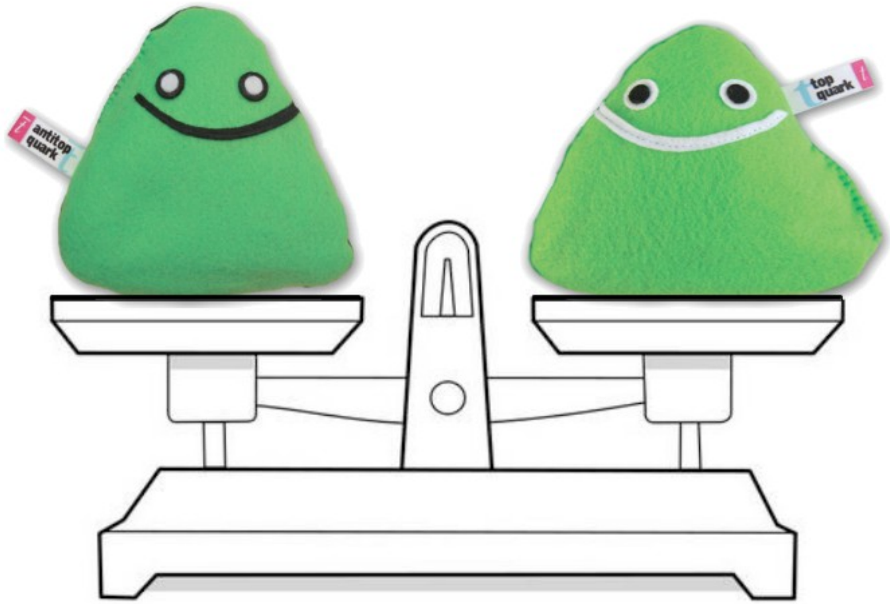
Summary

- New Tevatron top mass combination: uncertainties of 0.5%!

$$m_t = 173.20 \pm 0.51 (stat) \pm 0.71 (syst) GeV$$

- Various techniques and channels explored for precision top mass measurements

- Final data samples from CDF and DØ: explored right now
  → more results to come



- More details:

DØ: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

CDF: http://www-cdf.fnal.gov/physics/new/top/top.html

BACKUP

Jet Energy Scale