Direct and Indirect Measurements of the Top Quark Mass in $p\bar{p}$ Collisions

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1995

The Tevatron Particle

All results based on full Tevatron data set
• Top mass important for self-consistency check of SM and for determining stability of EW vacuum.
• Requires a theoretically rigorous definition of top mass (pole mass).
• Difference between “MC mass” and pole mass expected to be of order 0.4 GeV.

(M. Butenschoen et al., PRL 117, 232001 (2016))
Top Pair Final States

$$\text{Br}(t \rightarrow W^+ b) = 100\%$$

W boson decays

**Top Pair Branching Fractions**

- **"alljets"** 46%
- **τ+jets** 15%
- **μ+jets** 15%
- **e+jets** 15%
- **τ+τ** 1%
- **τ+μ** 2%
- **τ+e** 2%
- **μ+μ** 1%
- **μ+e** 1%
- **μ+e+e** 1%

**Lepton + jets**
- 1 isolated lepton
- Missing $E_T$ from neutrino
- $\geq 4$ jets (2 b jets)

**Dilepton**
- 2 isolated leptons
- Large Missing $E_T$ from neutrino
- 2 b jets

Not used in combination

- All-jets channel
- Tau channels
Top Mass and Jet Energy Scale (JES)

- Joint fit of JES and top mass in lepton+jets measurement, using W mass as constraint.
- This JES is then used for the di-lepton channel.
- Uses matrix element method

Most precise Tevatron single top mass measurement

\[ m_t = 174.98 \pm 0.58 \text{(stat + JES)} \pm 0.49 \text{(syst)} \text{ GeV} \]
\[ m_t = 174.98 \pm 0.76 \text{ GeV}, \]

Production dominated by quark-antiquark annihilation (85%)
DØ Combination

- Combination of Run I and Run II direct top mass measurements in leptons+jets and dilepton channels
- Analyses use matrix element and neutrino weighting

Direct top mass reconstruction measures MC mass parameter of the parton shower.
DØ Combination

- Combination takes into account all uncertainties and their correlations.
- Uses BLUE (Best Linear Unbiased Estimate) method.
- Combined direct mass
  
  $m_t = 174.95 \pm 0.40\text{(stat)} \pm 0.64\text{(syst)}$ GeV

- Dominant systematic uncertainty from in-situ light-jet calibration (0.4 GeV).
- Good consistency:
  
  $\chi^2/\text{NDF} = 0.8$, Probability = 0.47

DØ about 2-3 standard deviations higher than world average
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\[ \chi^2/NDF = 0.8, \text{ Probability} = 0.47 \]

Top Pole Mass from Total Cross Section

• Total cross section depends on pole mass.
• Pole mass is the real part of the pole in the top-quark propagator – theoretically well defined.
• Measured cross section shows (weaker) top mass dependence due to acceptance variation.
• Use Bayesian flat prior for top mass.
• Extract pole mass (with MSTW2008):

\[
m_t = 172.8 \pm 1.1 \text{ (theo.) } ^{+3.3}_{-3.1} \text{ (exp.) GeV} \\
m_t = 172.8^{+3.4}_{-3.2} \text{ (tot.) GeV}
\]
Top Mass from Differential Cross Section

- **Variables used**
  - Mass of di-top system, m(tt)
  - Top transverse momenta, p_T(t)

- Data taken from published lepton+jets measurement (PRD 90, 092006 (2014))

- Need background subtracted and unfolded differential cross section to compare to theory calculations

- Use regularized matrix unfolding

\[
\chi^2 = \sum_i \frac{(y_i^{\text{data}} - \sum_j A_{ij} \cdot x_j^{\text{true}})^2}{(\delta y_i^{\text{data}})^2} + \sum_{ij} \tau^2 \cdot L_{ij}(L_{ij})^T
\]
Top Mass from Differential Cross Section

- Data taken from published lepton+jets measurement (PRD 90, 092006 (2014))
- Pole mass is extracted for both NLO and NNLO PDF sets from MSTW2008, CT10, NNPDF2.3 and HERAPDF
- Here compared to NNLO pQCD calculations (Czakon, Fiedler, Heymes, Mitov, JHEP, 1605, 034 (2016)) with MSTW 2008.
- Sensitivity mainly at the threshold in m(tt) and for lower p_T(t)
Top Mass from Differential Cross Section

- Mass extracted from fit to unfolded data, using correlation matrix.
- $\chi^2$(data-theory) minimized to determine mass and uncertainty using parton level calculations.

$$\chi^2 = \sum_{i,j} (x_{i}^{\text{true}} - x_{i}^{\text{theo}}) \cdot V_{xx}^{-1} \cdot i,j \cdot (x_{j}^{\text{true}} - x_{j}^{\text{theo}}),$$
Top Mass from Differential Cross Section

- Scale and PDF are varied to obtain systematic uncertainty.
- Result is average of global PDFs (MSTW2008, CT10, NNPDF2.3).
- Extracted top mass

\[ m_t = 169.1 \pm 2.5 \text{ GeV} \]

Final result is imminent with smaller uncertainties and slightly shifted central value.
Comparison of Results

- Good agreement observed within uncertainties.
- Tevatron top mass slightly higher than LHC average.
- No significant difference between direct mass and pole mass.
- Final pole mass result for total differential cross section expected soon.

![Graph showing comparison of top quark mass extractions](image-url)