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

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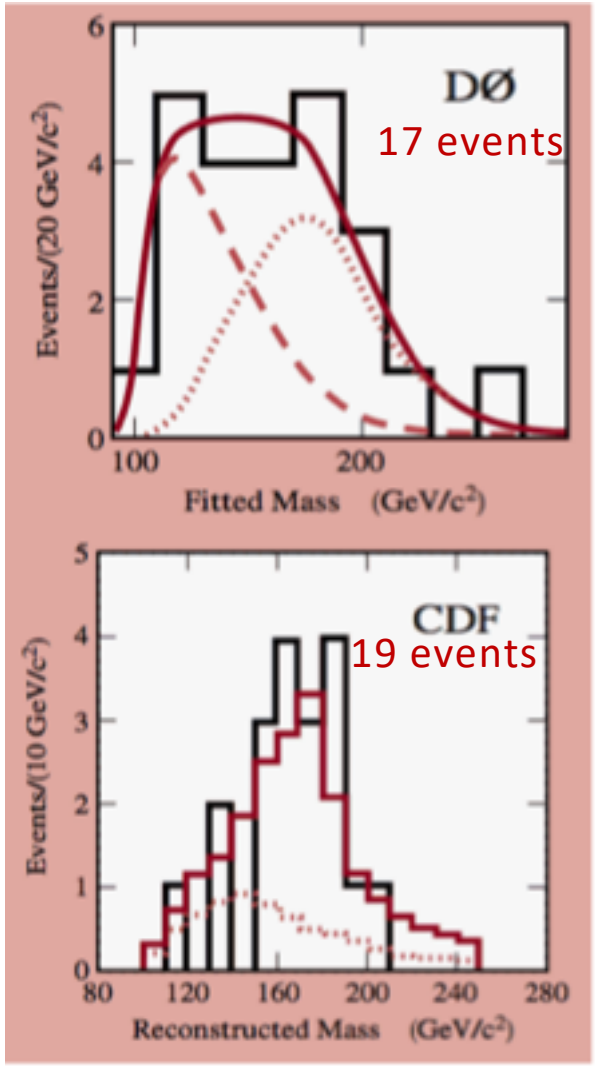
On behalf of the DØ Collaboration

The TevatrOn Particle

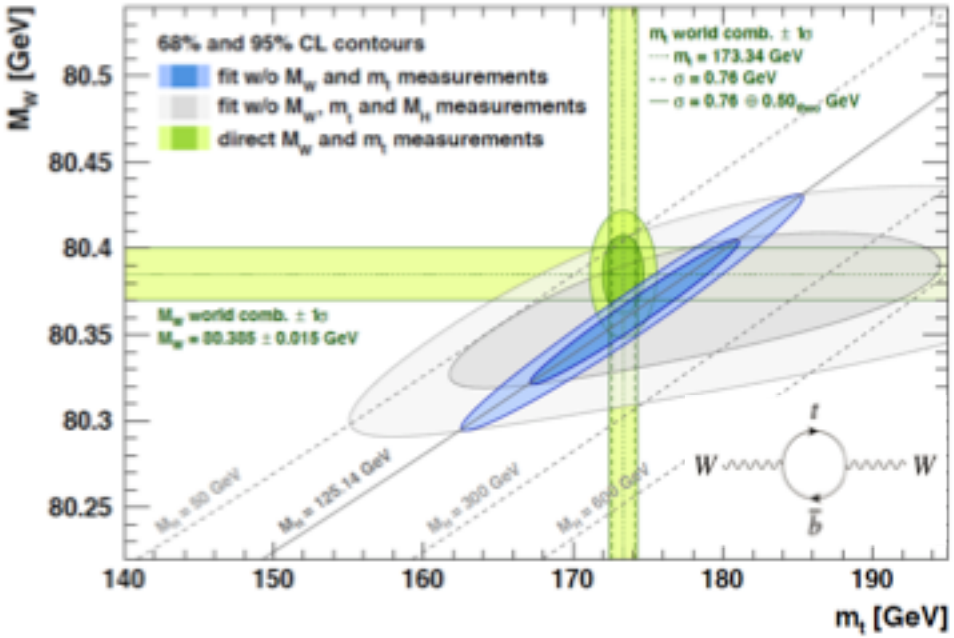
1995



All results based on full Tevatron data set

Motivation

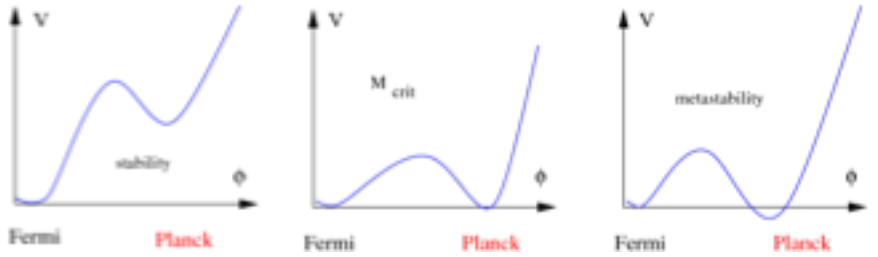
Gfitter, EPJC 74, 3046 (2014)



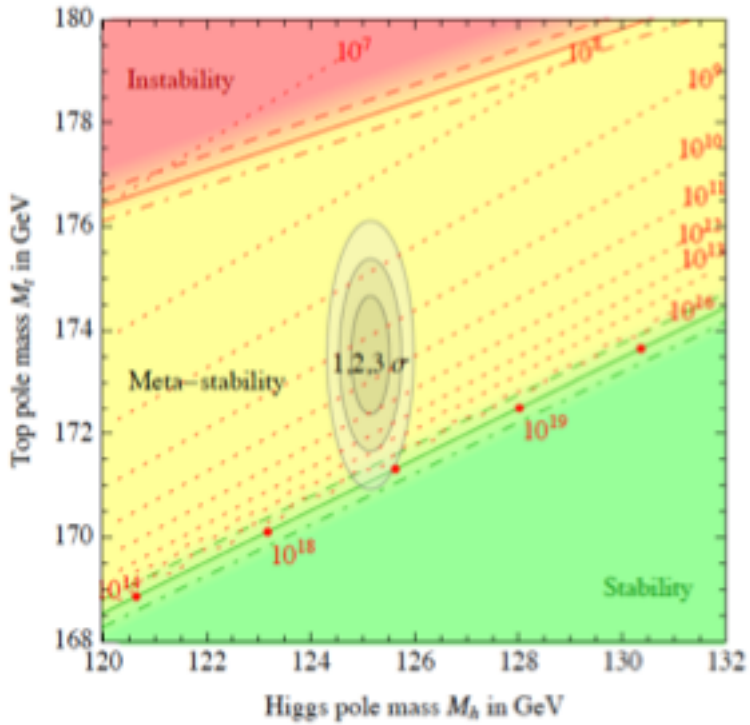
- Top mass important for self-consistency check of SM and for determining stability of EW vacuum.
- Requires a theoretically rigorous definition of top mass (pole mass).
- Difference between "MC mass" and pole mass expected to be of order 0.4 GeV.

(M. Butenschoen et al., PRL 117, 232001 (2016))

M. Shaposhnikov, EPS 2013



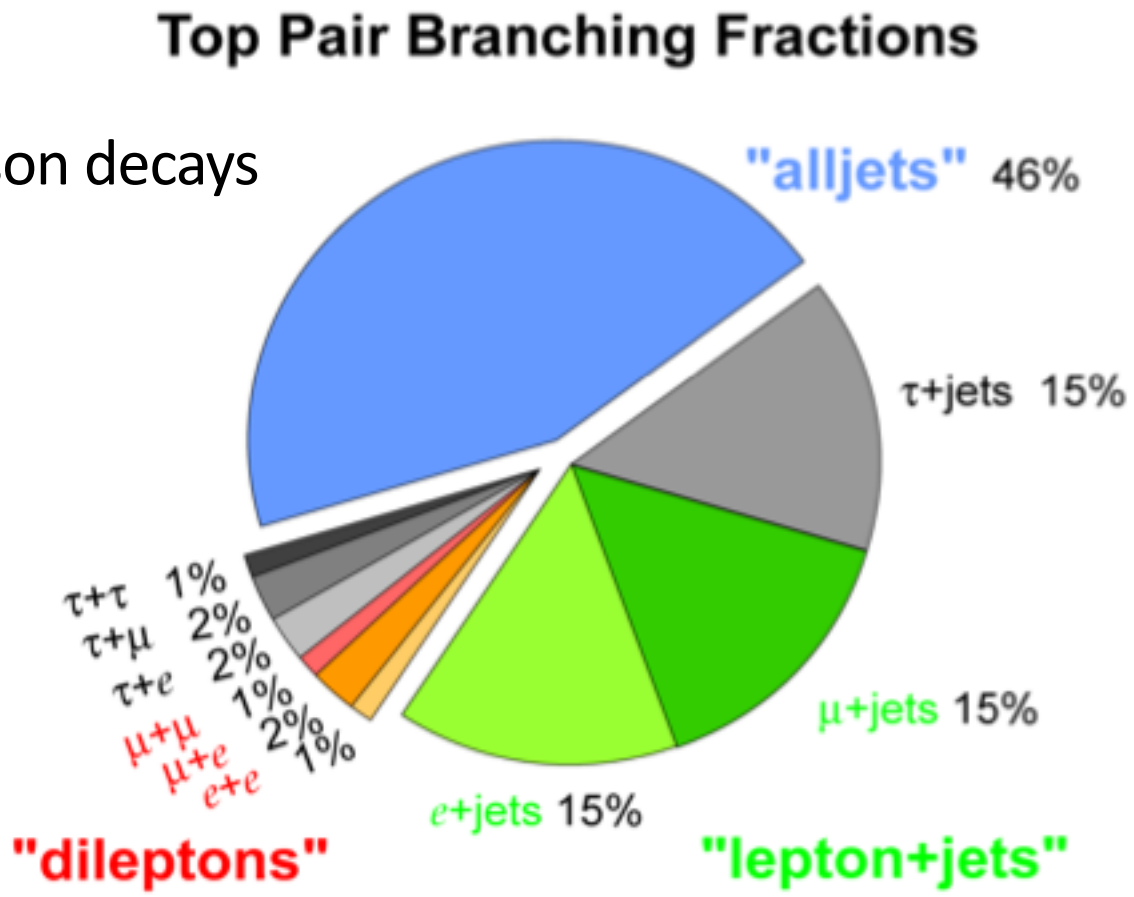
D. Buttazzo et al., JHEP 12, 89 (2013)



Top Pair Final States

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

W boson decays



Lepton + jets

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

Dilepton

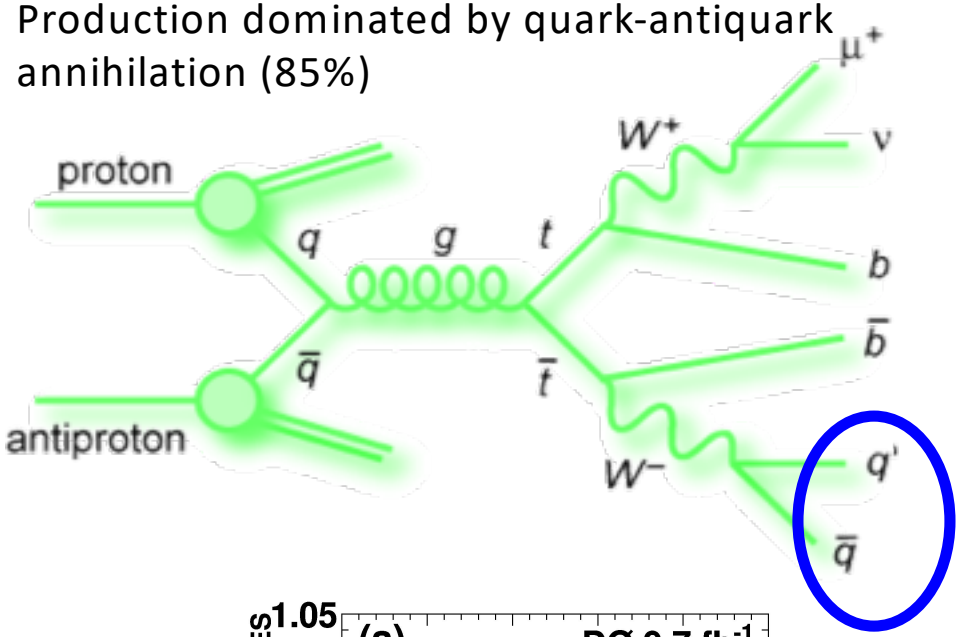
- 2 isolated leptons
- Large Missing E_T from neutrino
- 2 b jets

Not used in combination

- All-jets channel
- Tau channels

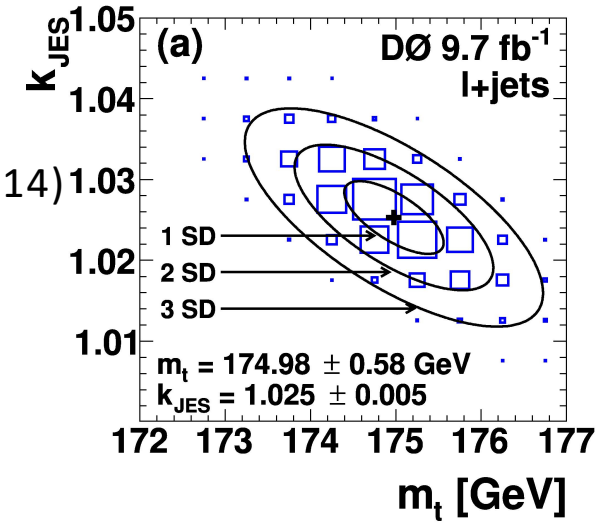
Top Mass and Jet Energy Scale (JES)

Production dominated by quark-antiquark annihilation (85%)



- 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

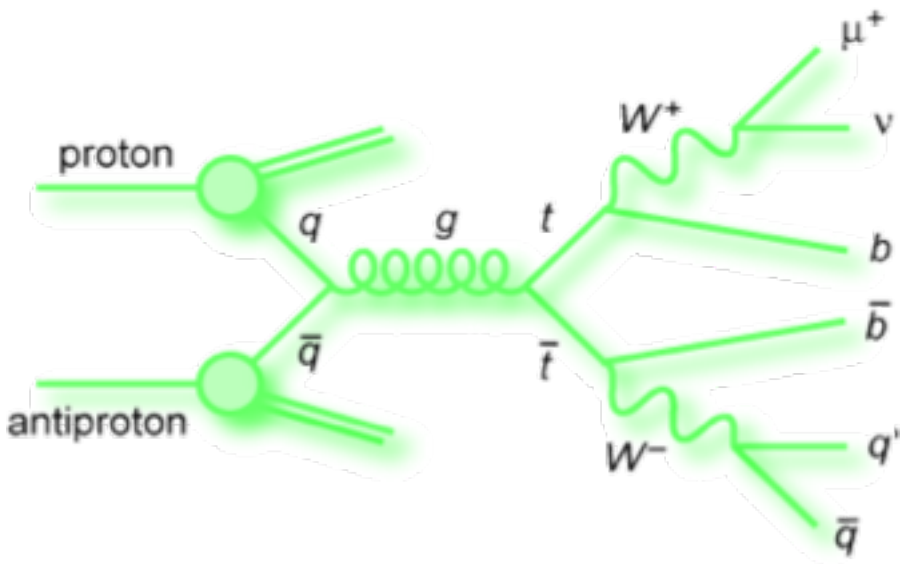
PRL 113, 032002 (2014)



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

Most precise Tevatron single top mass measurement

DØ Combination



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

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

Period	Channel	$\int \mathcal{L}dt$ (fb^{-1})	Method
Run I	$\ell\ell'$	0.1	Combination of matrix weighting and neutrino weighting
Run I	ℓ + jets	0.1	Matrix element
Run II	$\ell\ell'$	9.7	Neutrino weighting
Run II	$\ell\ell'$	9.7	Matrix element
Run II	ℓ + jets	9.7	Matrix element

DØ Combination

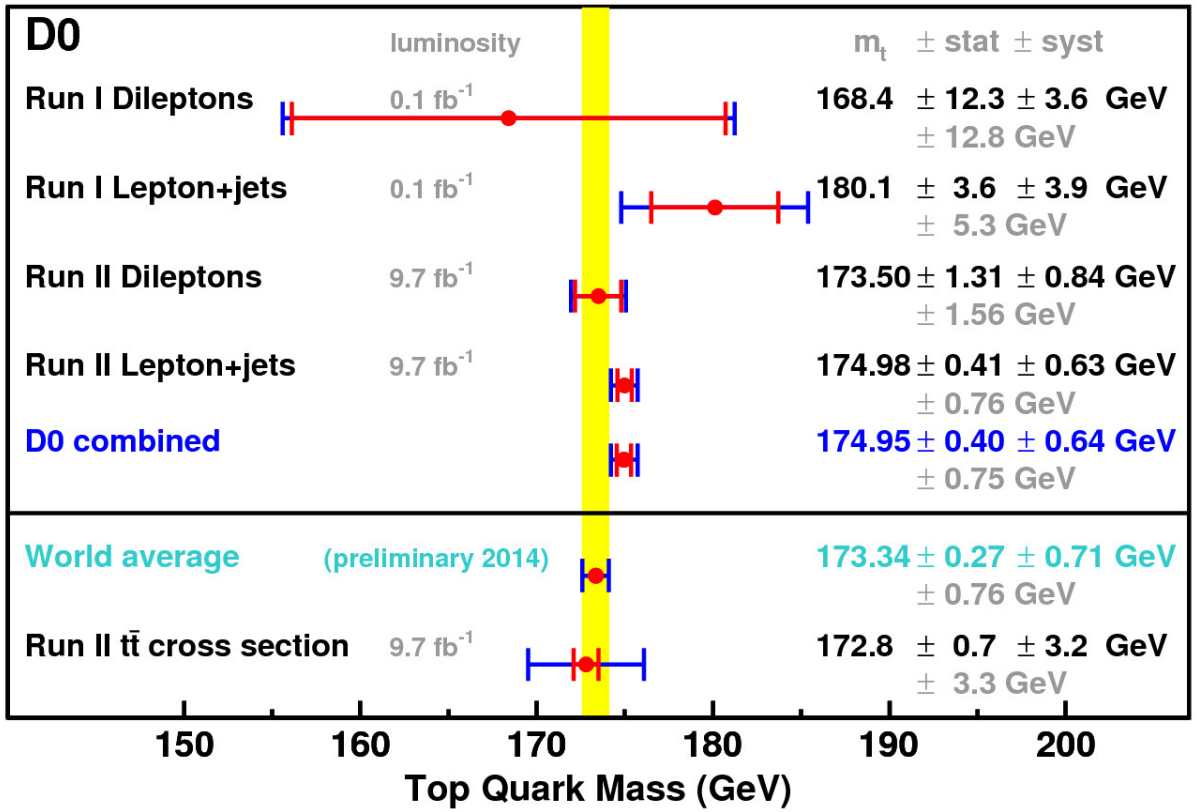
- Combination takes into account all uncertainties and their correlations.
- Uses BLUE (Best Linear Unbiased Estimate) method.
- Combined direct mass

$$m_t = 174.95 \pm 0.40(\text{stat}) \pm 0.64(\text{syst})\ \text{GeV}$$

- Dominant systematic uncertainty from in-situ light-jet calibration (0.4 GeV).
- Good consistency:

χ^2/NDF = 0.8, Probability = 0.47

Phys. Rev. D 95, 112004 (2017)



DØ about 2-3 standard deviations higher than world average

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	D0 combined values (GeV)
Top quark mass	174.95
In situ light-jet calibration	0.41
Response to b, q, and g jets	0.16
Model for b jets	0.09
Light-jet response	0.21
Out-of-cone correction	< 0.01
Offset	< 0.01
Jet modeling	0.07
Multiple interaction model	0.06
b tag modeling	0.10
Lepton modeling	0.01
Signal modeling	0.35
Background from theory	0.06
Background based on data	0.09
Calibration method	0.07
Systematic uncertainty	0.64
Statistical uncertainty	0.40
Total uncertainty	0.75

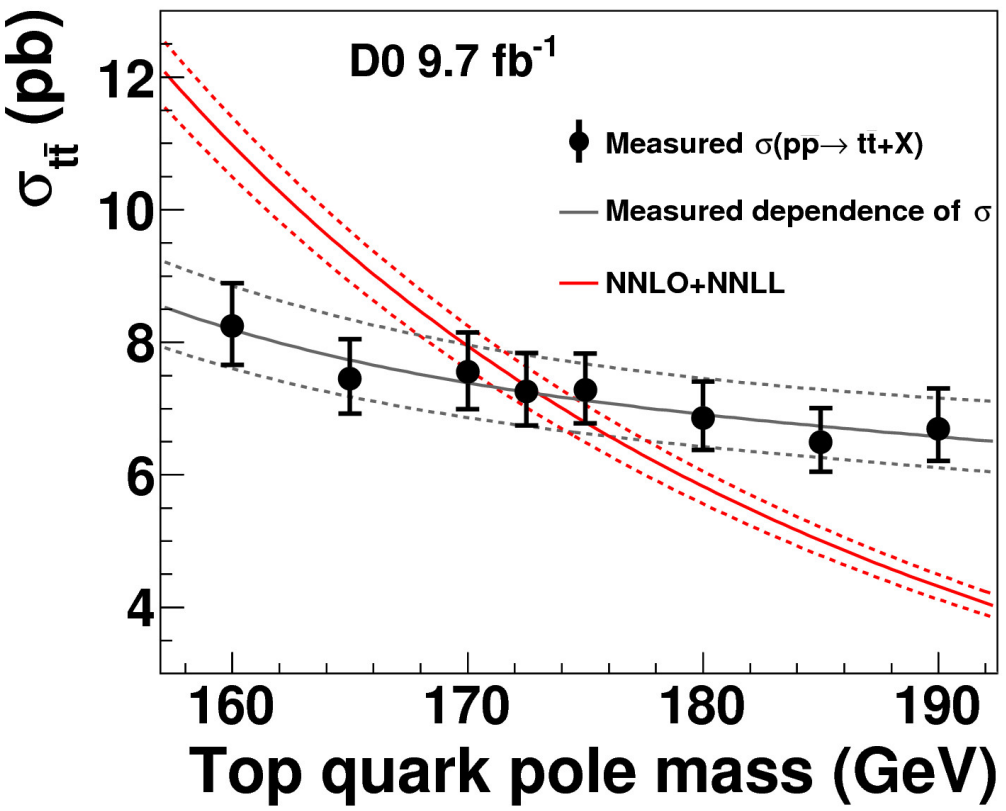
Phys. Rev. D 95, 112004 (2017)

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):

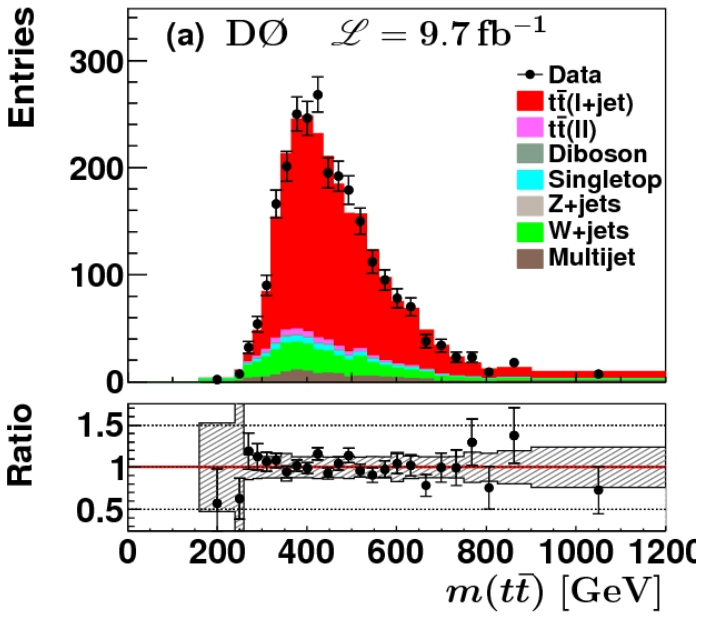
$$m_t = 172.8 \pm 1.1\,(\text{theo.})\,^{+3.3}_{-3.1}\,(\text{exp.})\,\text{GeV}$$
$$m_t = 172.8^{+3.4}_{-3.2}\,(\text{tot.})\,\text{GeV}$$

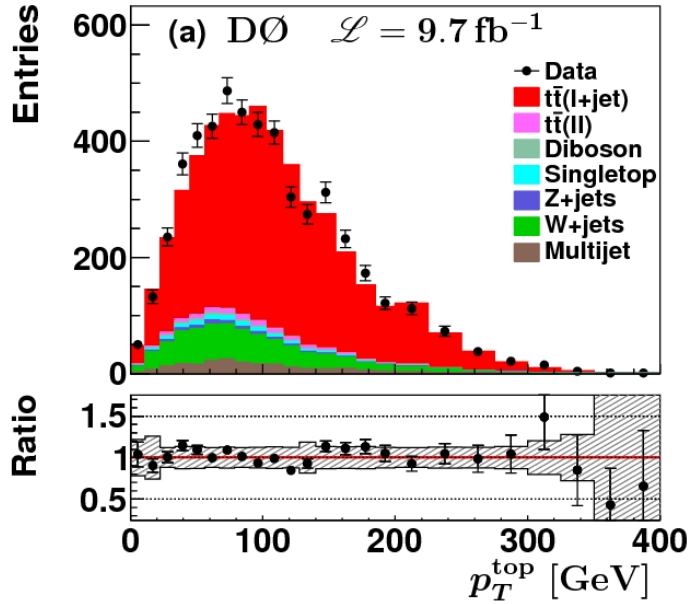
Phys. Rev. D 94, 092004 (2016)



Top Mass from Differential Cross Section

Combined lepton+jets sample



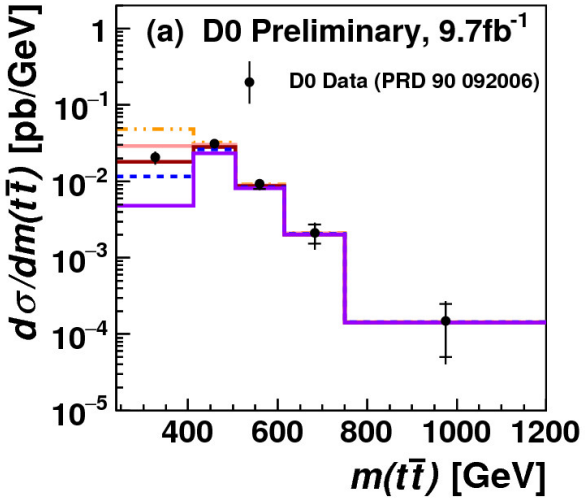


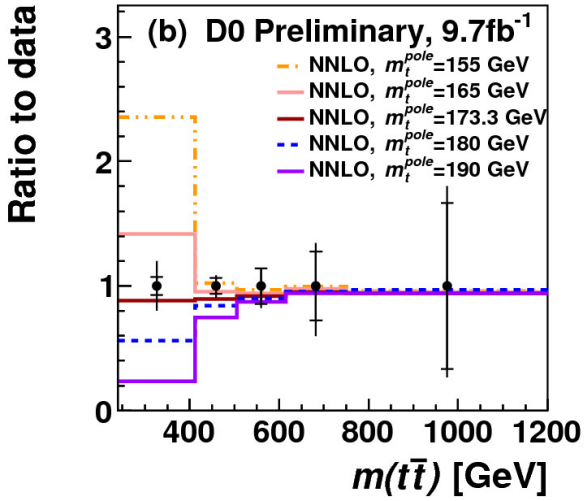
PRD 90, 092006 (2014)

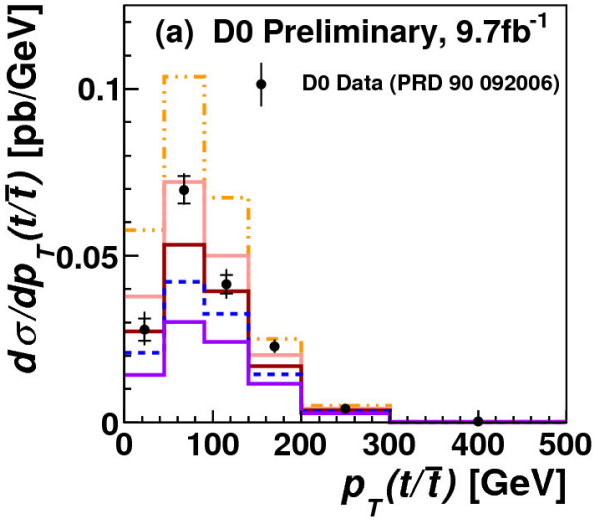
- Variables used
  - Mass of di-top system, m(tt)
  - Top transverse momenta, $p_T(t)$
- Data taken from published lepton+jets measurement (PRD 90, 092006 (2014))
- Need background subtracted and unfolded differential cross section to compare to theory calculations
- Use regularized matrix unfolding

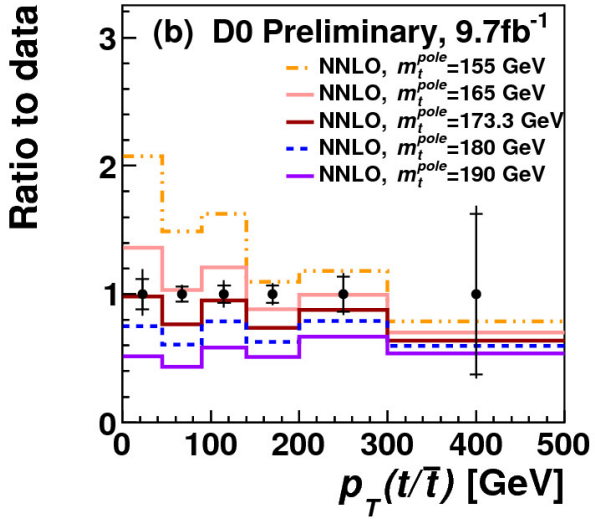
$$\chi^2 = \sum_i \frac{\left(y_i^{\mathrm{data}} - \sum_j A_{ij} \cdot x_j^{\mathrm{true}}\right)^2}{\left(\delta y_i^{\mathrm{data}}\right)^2} + \sum_{ij} \tau^2 \times L_{ij}(L_{ij})^T$$

Top Mass from Differential Cross Section







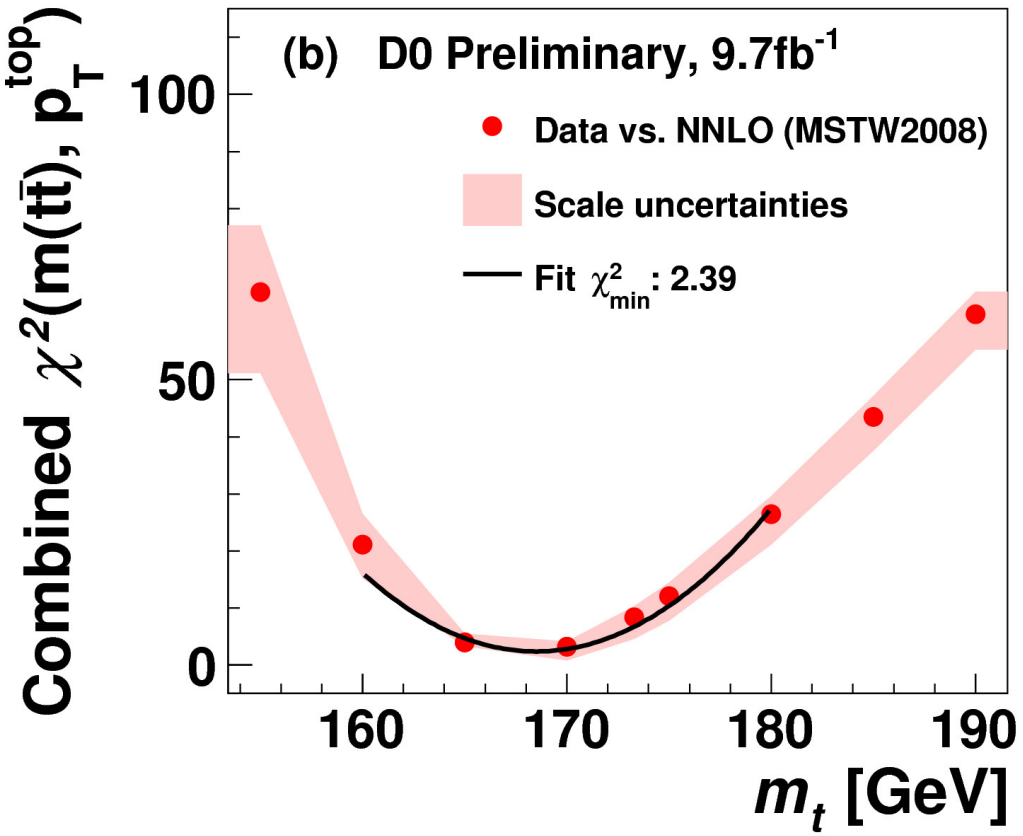


- Data taken from published lepton+jets measurement (PRD 90, 092006 (2014))
- Pole mass is extracted for both NLO and NNLO PDF sets from MSTW2008, CT10, NNPDF2.3 and HERAPDF
- Here compared to NNLO pQCD calculations (Czakon, Fiedler, Heymes, Mitov, JHEP, 1605, 034 (2016)) with MSTW 2008.
- Sensitivity 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.
- χ^2(data-theory) minimized to determine mass and uncertainty using parton level calculations.

$$\chi^2 = \sum_{i,j} (x_i^{\text{true}} - x_i^{\text{theo}}) \cdot \mathbf{V}^{-1}_{\mathbf{xx;\ i,j}} \cdot (x_j^{\text{true}} - x_j^{\text{theo}}),$$

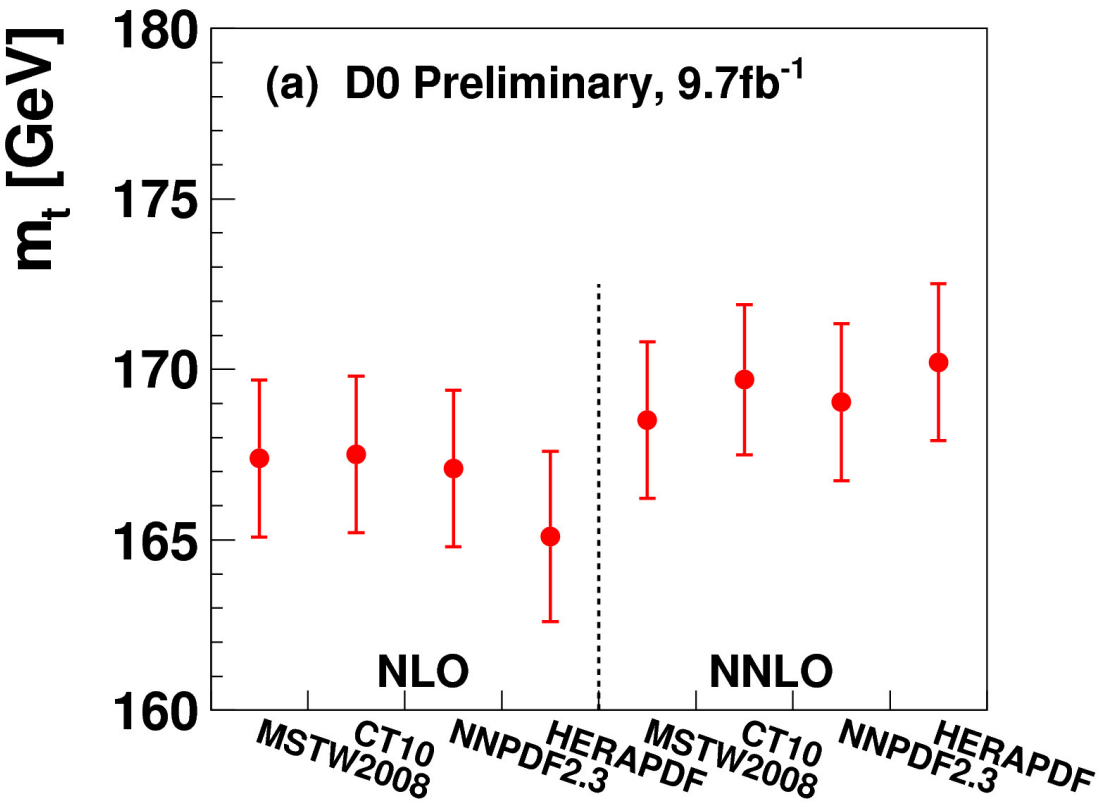


Top Mass from Differential Cross Section

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

$m_t = 169.1 \pm 2.5$ GeV

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



Higher NNLO cross section leads to higher m_t

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.