Determination of the pole top-quark mass from LHC experimental data for single- and double-differential cross sections of top-quark pair production

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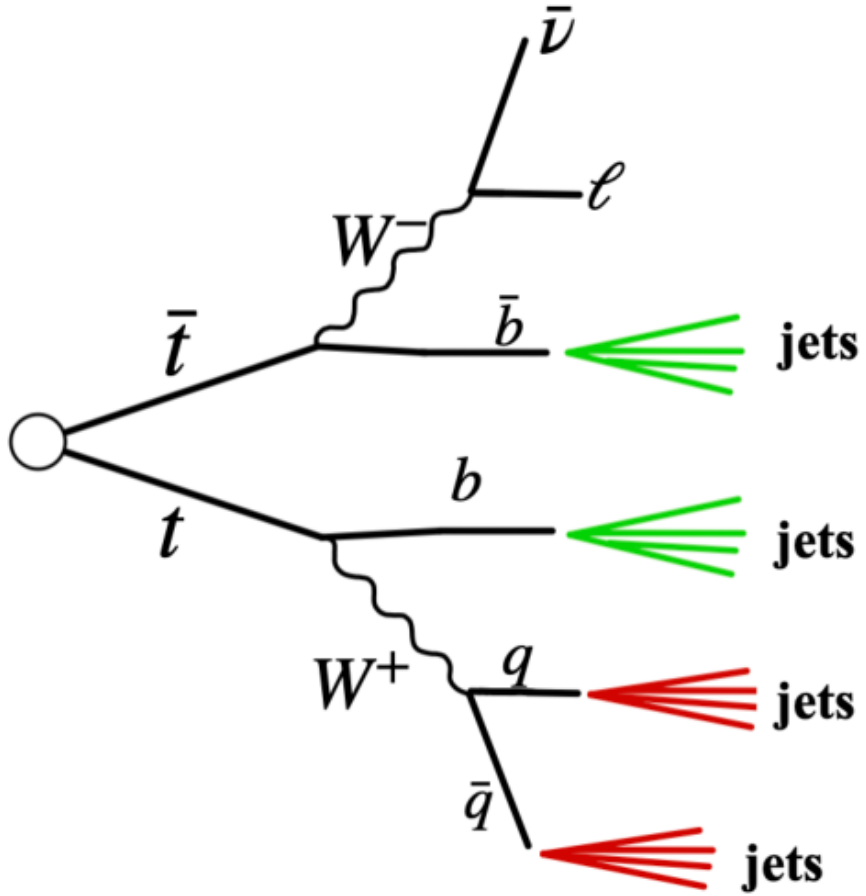
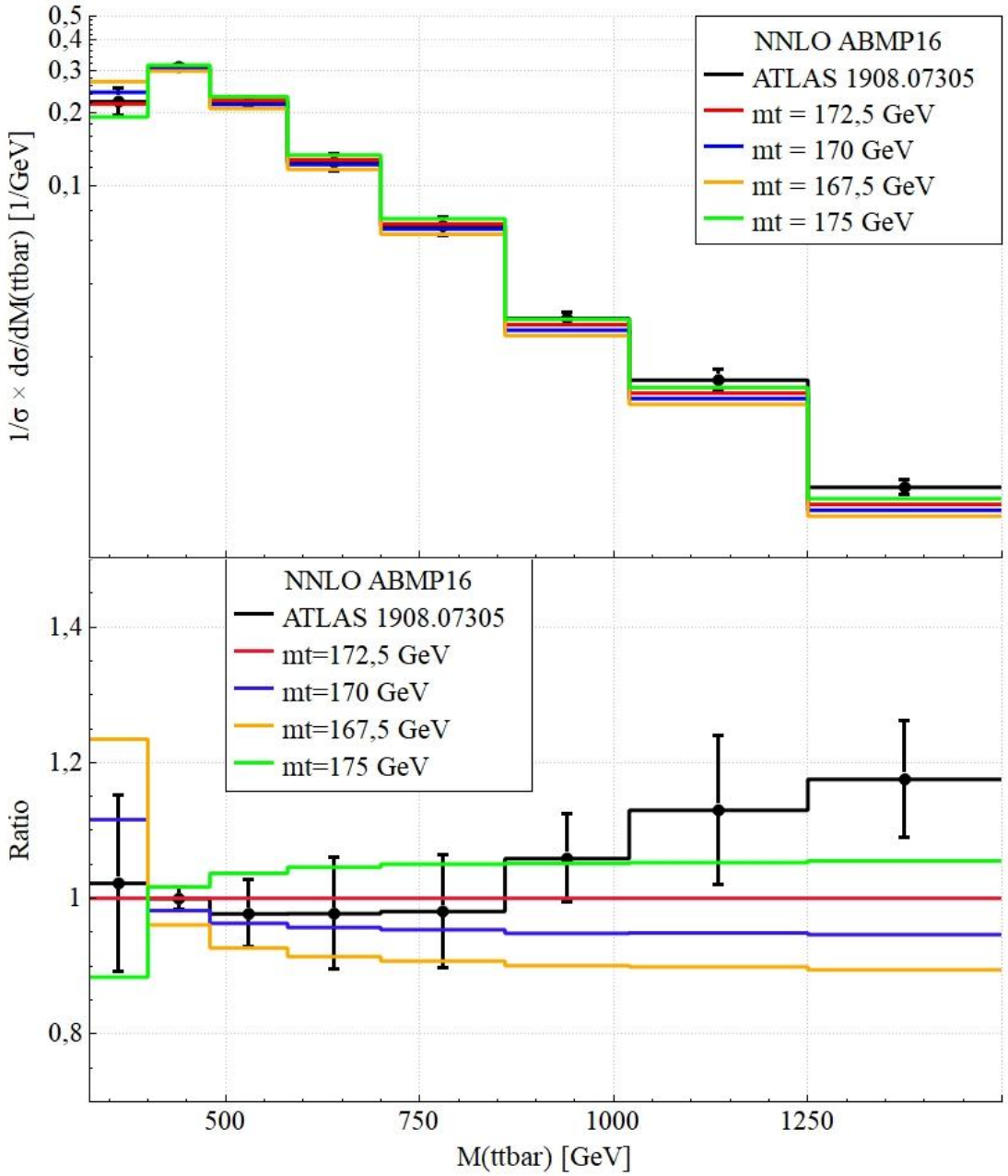
Introduction

The aim of this work is to investigate and compare two methods for determining the pole top-quark mass based on the analysis of differential cross sections, as well as to evaluate the accuracy that they allow to achieve.



Top anti-top quark decay in the semi-leptonic channel.



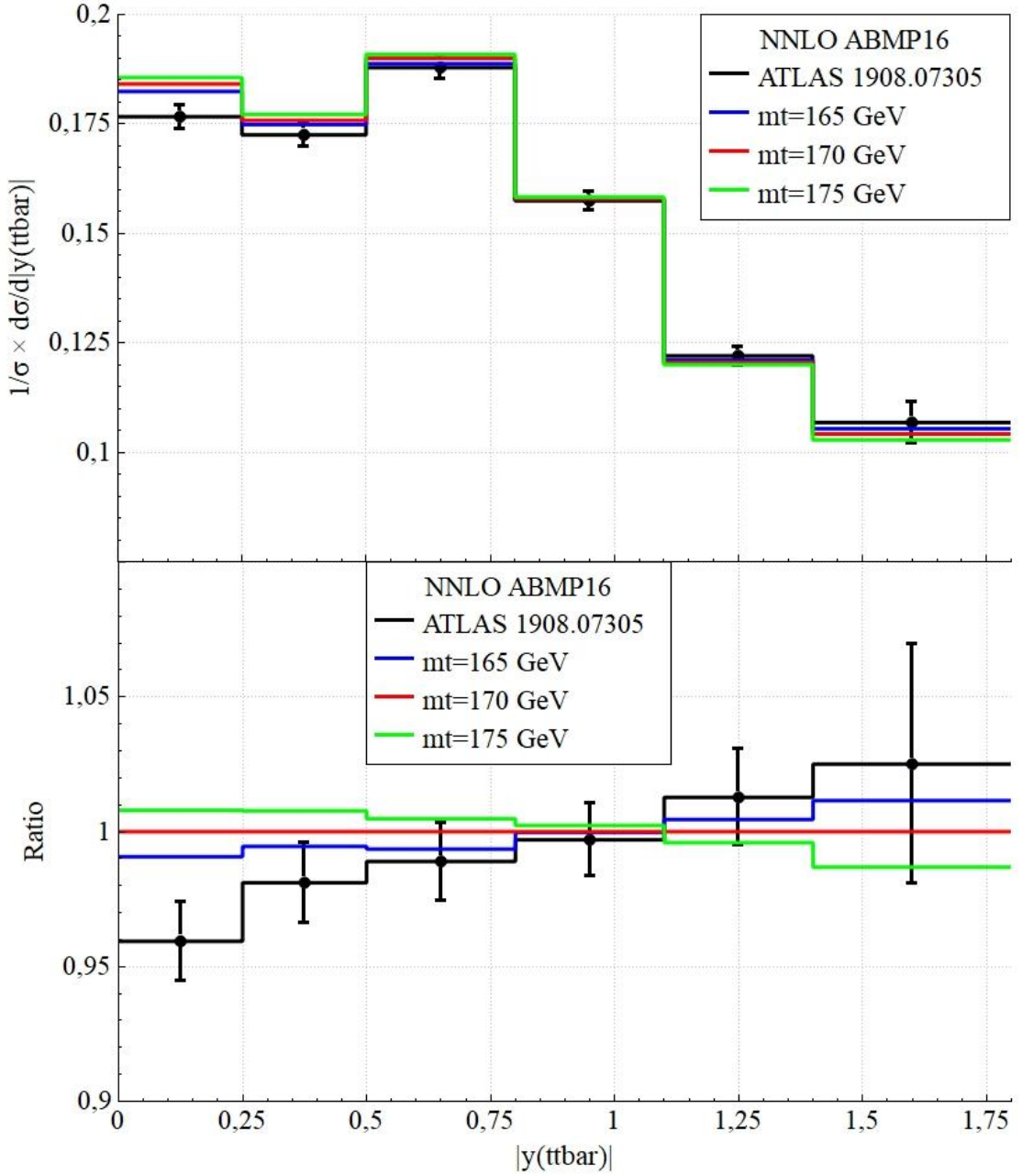
Used data

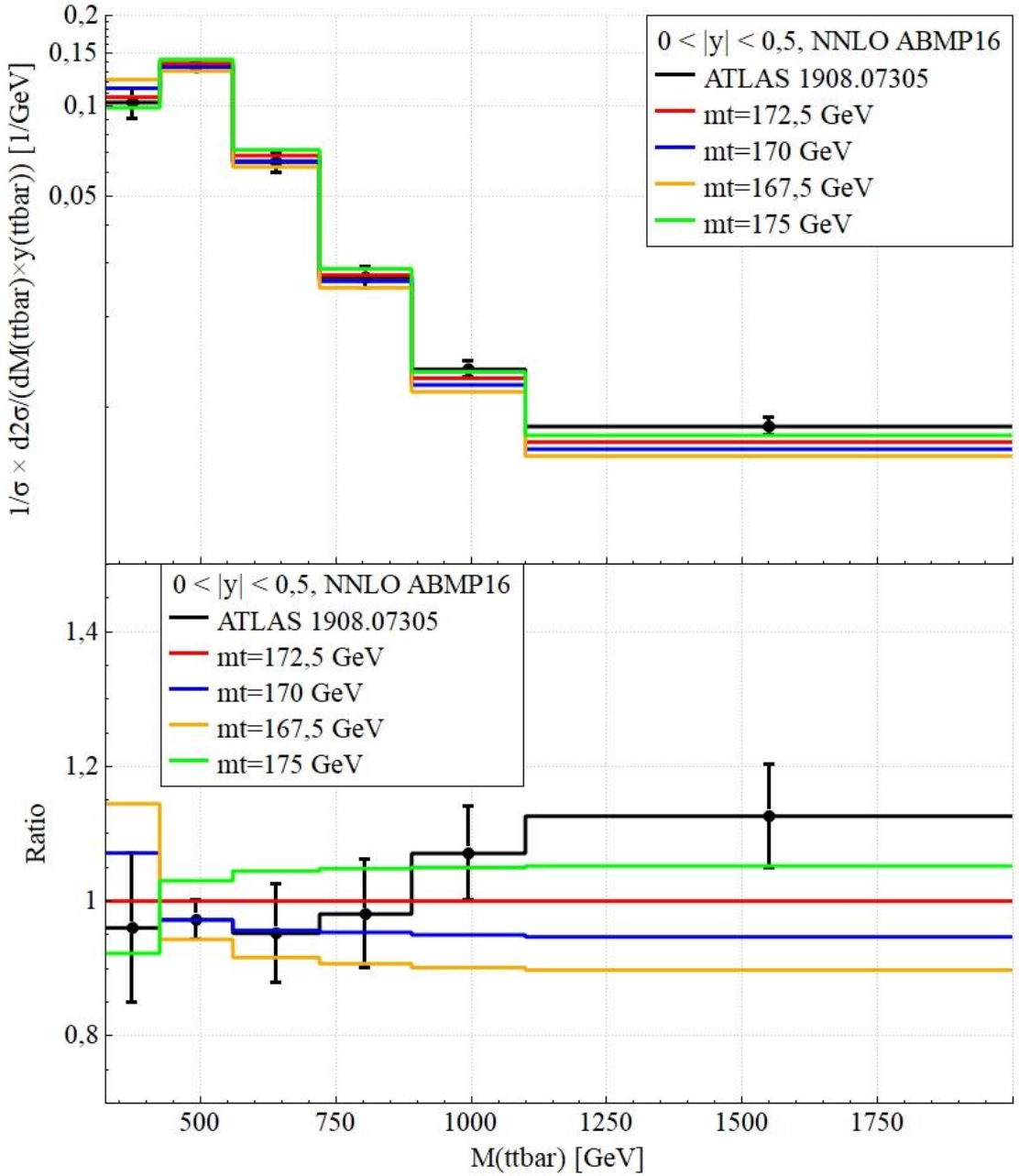
- The theoretical predictions are calculated at NNLO using the MATRIX framework interfaced with PineAPPL (stored on the *ploughshare* resource and used for JHEP 05 (2024) 321) and the ABMP16 proton PDFs.

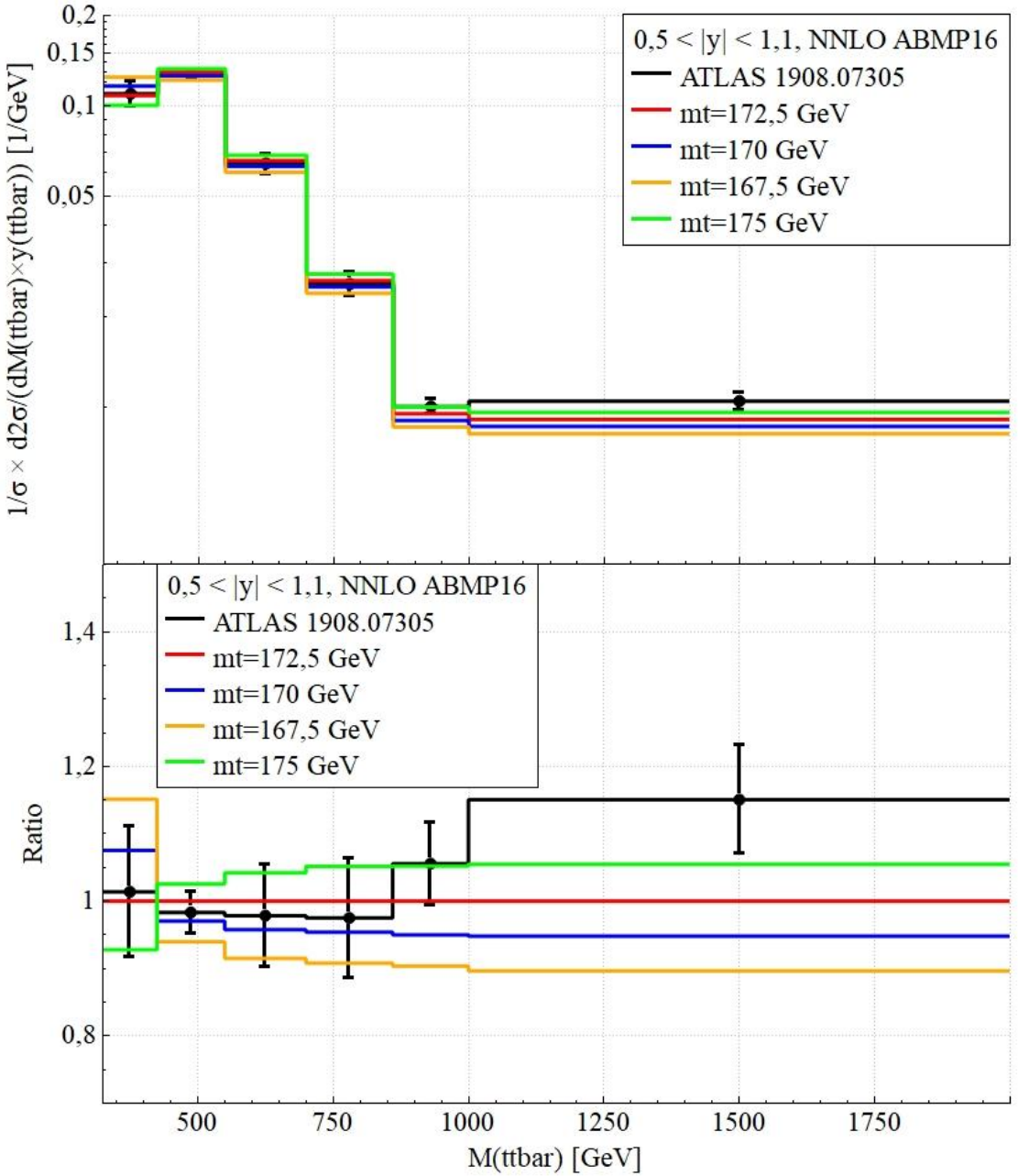
- Experimental data obtained from the hepdata resource – normalized differential cross sections for the $t\bar{t}$ pairs production in the semilepton channel in proton-proton collisions at $\sqrt{s}$= 13 TeV, published by the ATLAS collaboration. *Eur. Phys. J. C* 79 (2019) 1028 [1908.07305]).

Comparison of the normalized single-differential cross section of $t\bar{t}$ по production as a function of rapidity with theoretical predictions for different m_t.

Ratio – all data divided by the theoretical prediction for m_t = 170 GeV.




0 < |y| < 0,5, NNLO ABMP16
ATLAS 1908.07305
mt=172,5 GeV
mt=170 GeV
mt=167,5 GeV
mt=175 GeV
1/σ × d2σ/(dM(ttbar)×y(ttbar)) [1/GeV]
Ratio
M(ttbar) [GeV]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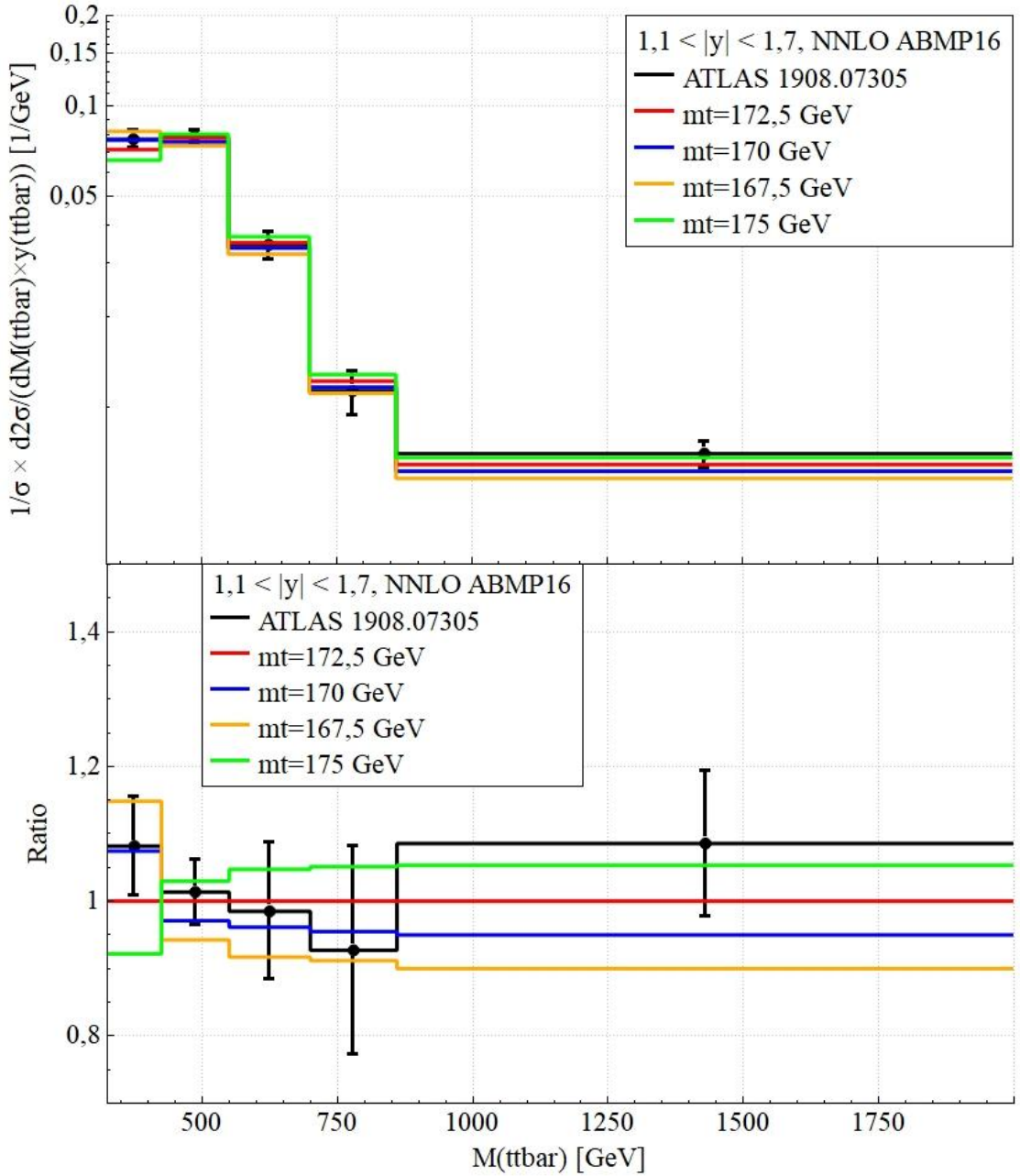
ATLAS 1908.07305
mt=172,5 GeV
mt=170 GeV
mt=167,5 GeV
mt=175 GeV
1/σ × d2σ/(dM(ttbar)×y(ttbar)) [1/GeV]
Ratio
M(ttbar) [GeV]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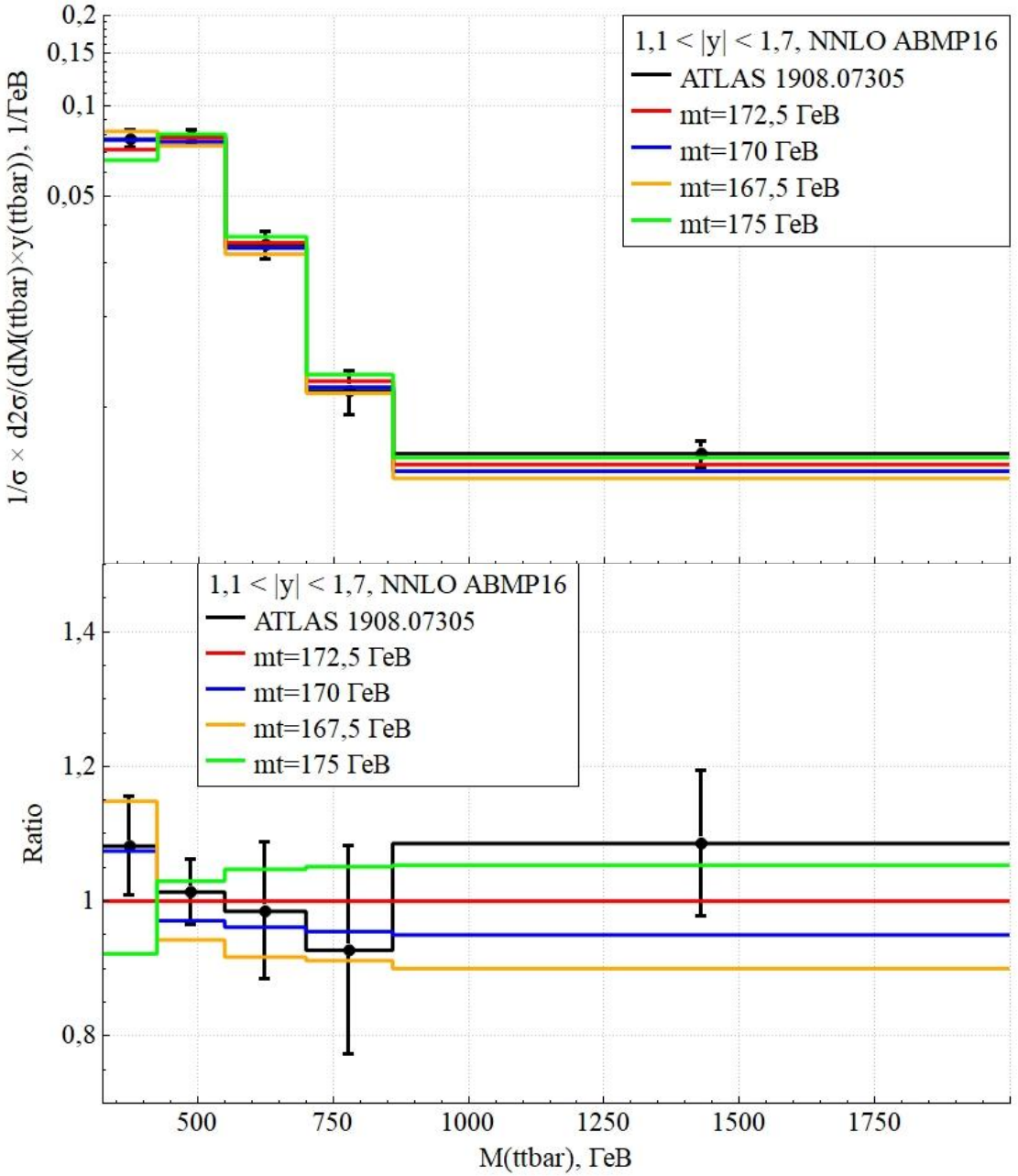
mt=175 GeV
1/σ × d2σ/(dM(ttbar)×y(ttbar)) [1/GeV]
Ratio
M(ttbar) [GeV]


1,1 < |y| < 1,7, NNLO ABMP16
ATLAS 1908.07305
mt=172,5 ГеВ
mt=170 ГеВ
mt=167,5 ГеВ
mt=175 ГеВ
1/σ × d2σ/(dM(ttbar)×y(ttbar)), 1/ГеВ
Ratio
M(ttbar), ГеВ

Determination of the top-quark mass using the χ^2 minimization method

$$\chi^2 = V_{N-1}^T \times COV_{N-1}^{-1} \times V_{N-1}$$

V_{N-1} – vector column of differences between measured and theoretically predicted normalized cross section

COV_{N-1} – submatrix of the covariance matrix of size $(N-1) \times (N-1)$ obtained by discarding the corresponding row and column, where N is the number of bins.

Errors in determining the top-quark mass are obtained by determining the values of the top quark masses corresponding to the values $\chi^2 = \chi^2_{min} + 1$.

The covariance matrices for the cross sections used in this work were non-degenerate. This may result from excessive rounding or another error present in the ATLAS data published on HEPData.

xFitter software package

The xFitter software package was used to calculate the values of χ^2.

Key features of xFitter:

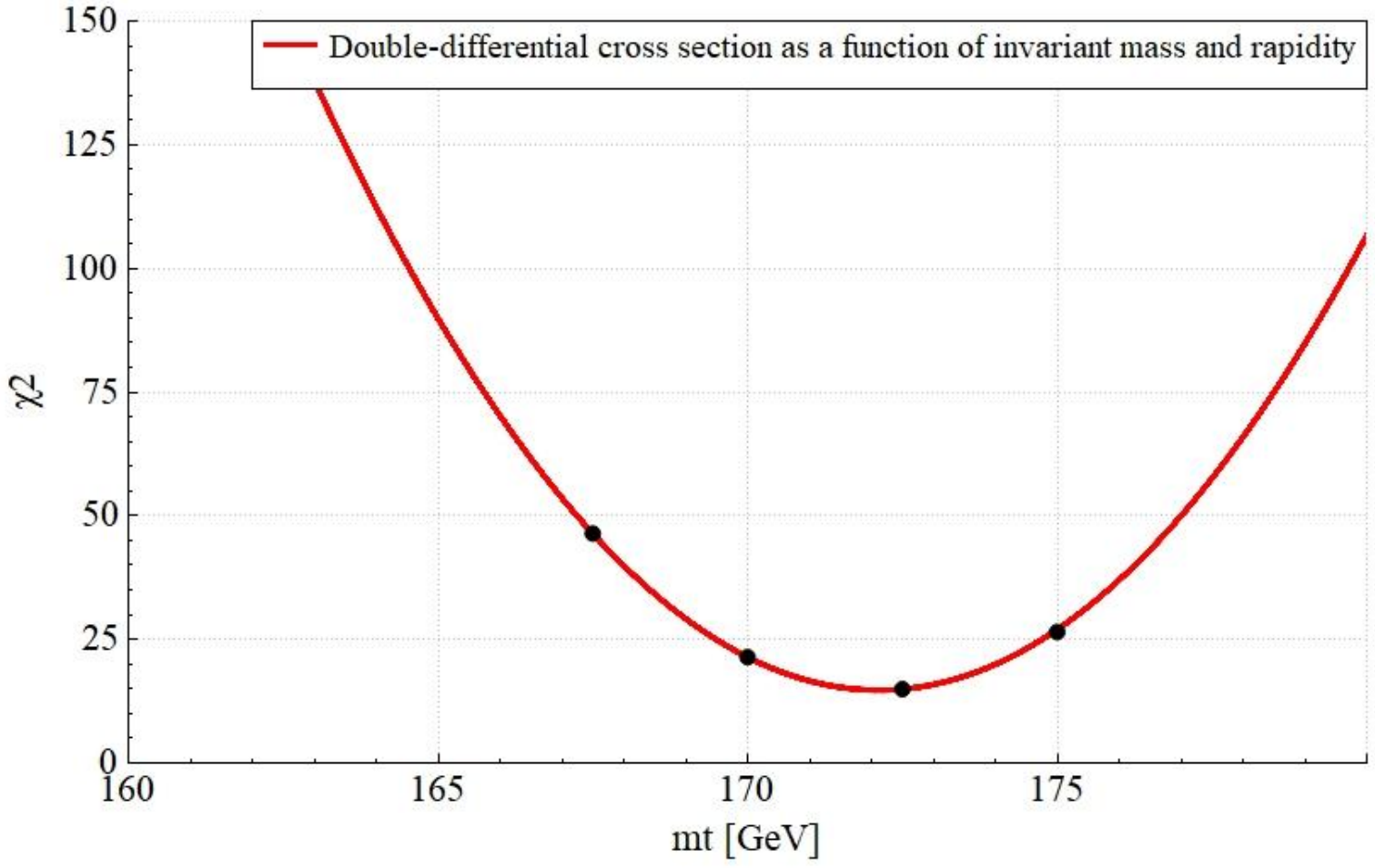
- Flexibility. This package supports a large number of existing methods and schemes used to define PDF.
- Support for various theoretical models.
- Analysis of new data. Can be used to study the impact of precise measurements from hadron colliders.

Double-differential cross section

m_t [GeV]	χ^2
167,5	46,37
170	21,38
172,5	14,91
175	26,46

m_t = 172,12 ± 0,82 GeV

$\chi^2_{min}/dof = 14{,}7/19$
(p = 0,74).

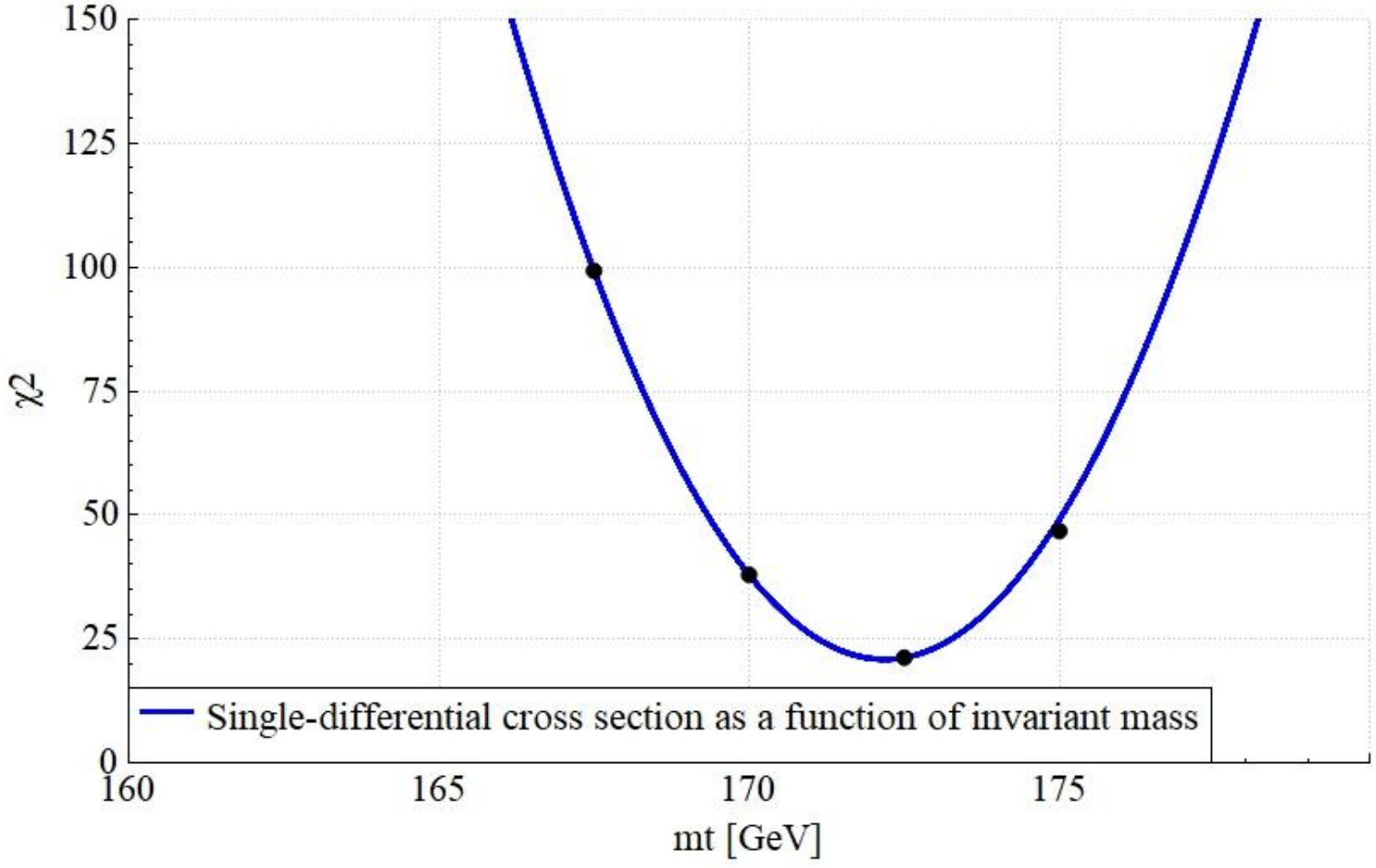


Single-differential cross section as a function of invariant mass

m_t [GeV]	χ^2
167,5	99,23
170	37,91
172,5	21,19
175	46,73

m_t = 172,19 ± 0,53 GeV

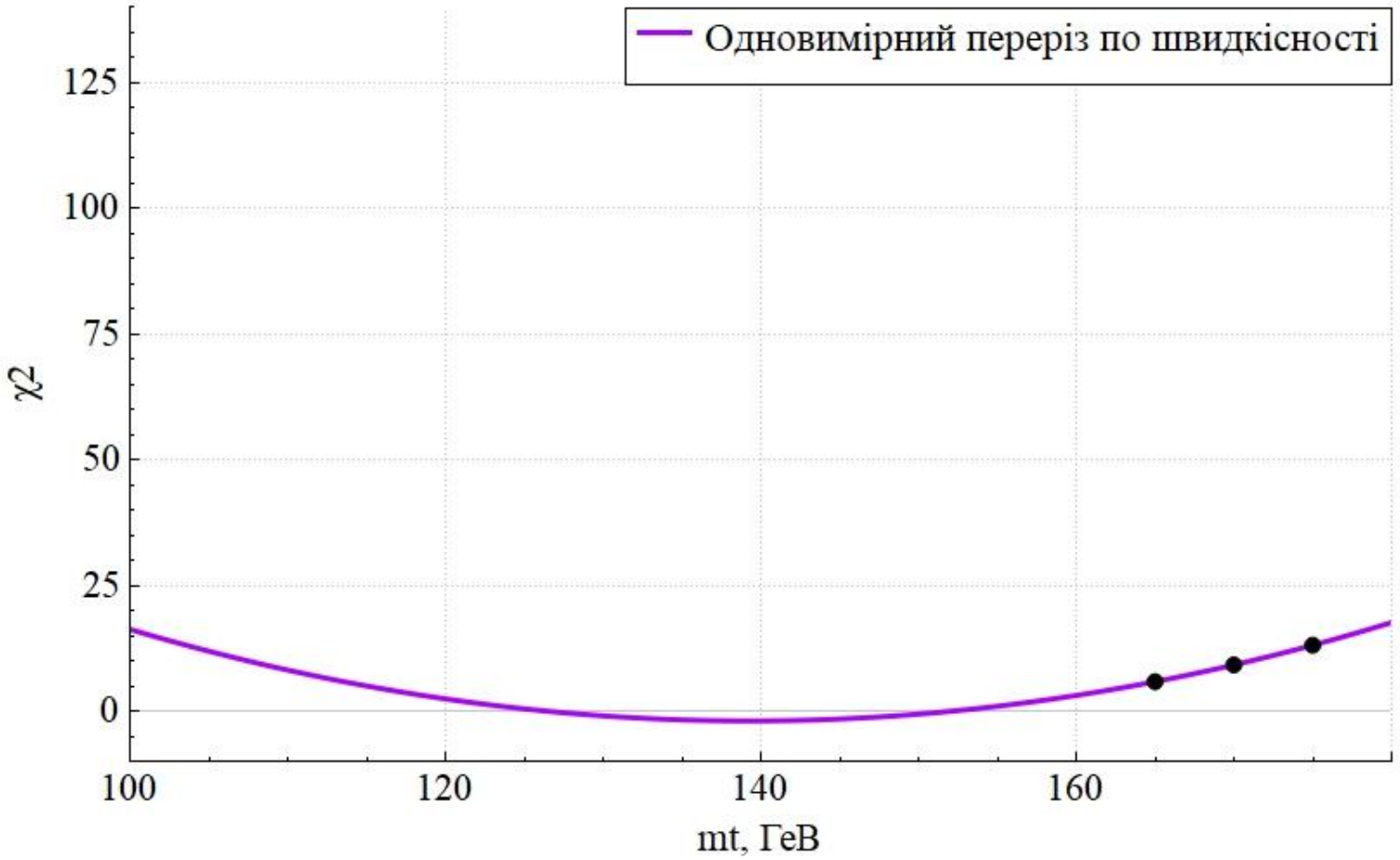
$\chi^2_{min}/dof = 20{,}8/8$
(p = 0,008).



Single-differential cross section as a function of rapidity

m_t [GeV]	χ^2
165	5,81
170	9,14
175	13,06

m_t = 143 ± 13 GeV.



χ^2 calculation using two single-differential cross sections

COV_{mY} – covariance matrix between the bins of the cross section in invariant mass and the bins of the cross section in rapidity

COV_{mm} – covariance matrix between the bins of the cross section in invariant mass

COV_{YY} – covariance matrix between the bins of the cross section in rapidity

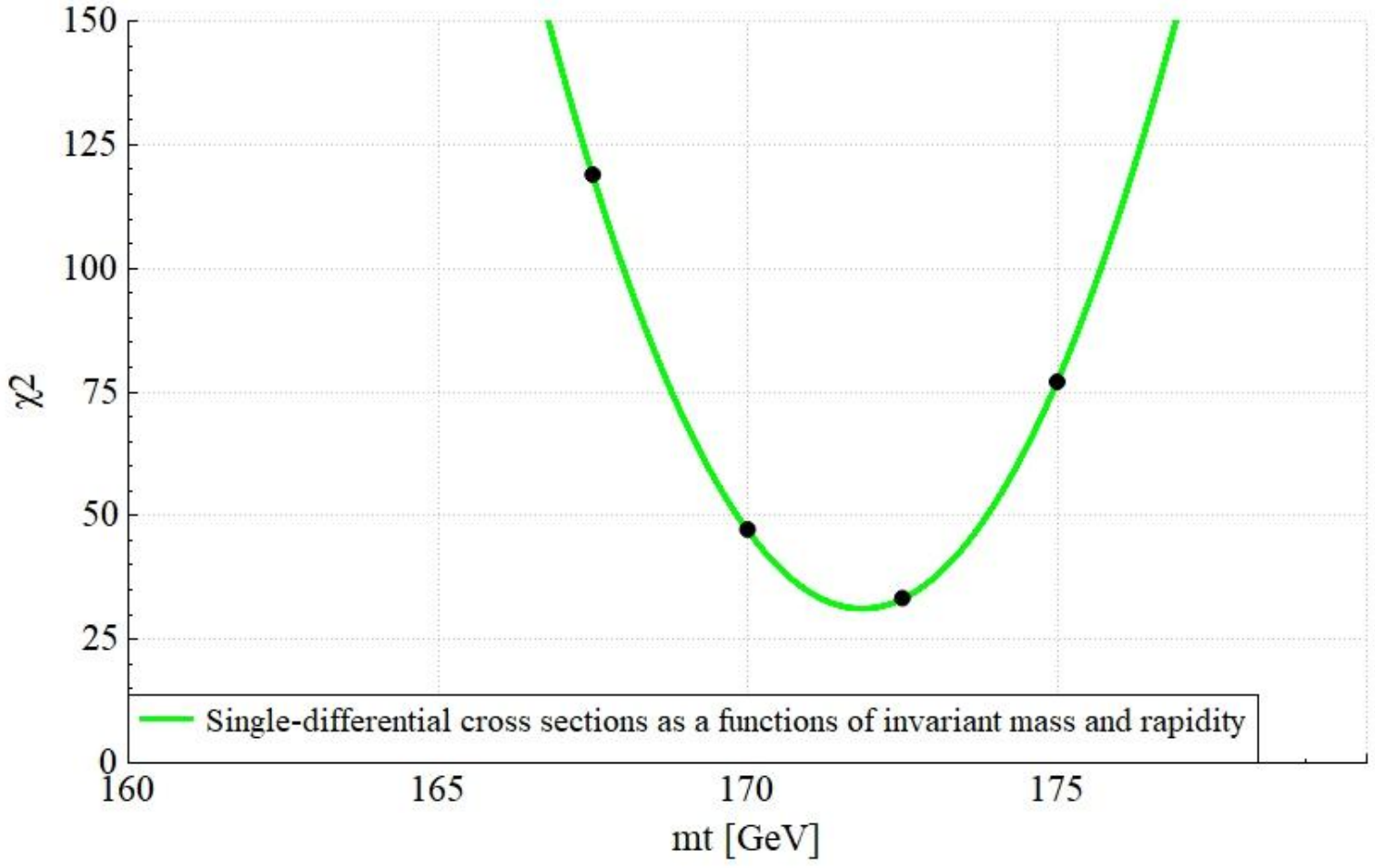
$$\left(\begin{array}{c|c} \left(COV_{mm}\right) & \left(COV_{mY}\right) \\ \hline \left(COV_{mY}^{T}\right) & \left(COV_{YY}\right) \end{array}\right)$$

Two single-differential cross sections

m_t [GeV]	χ^2
167,5	118,93
170	47,2
172,5	33,31
175	77,05

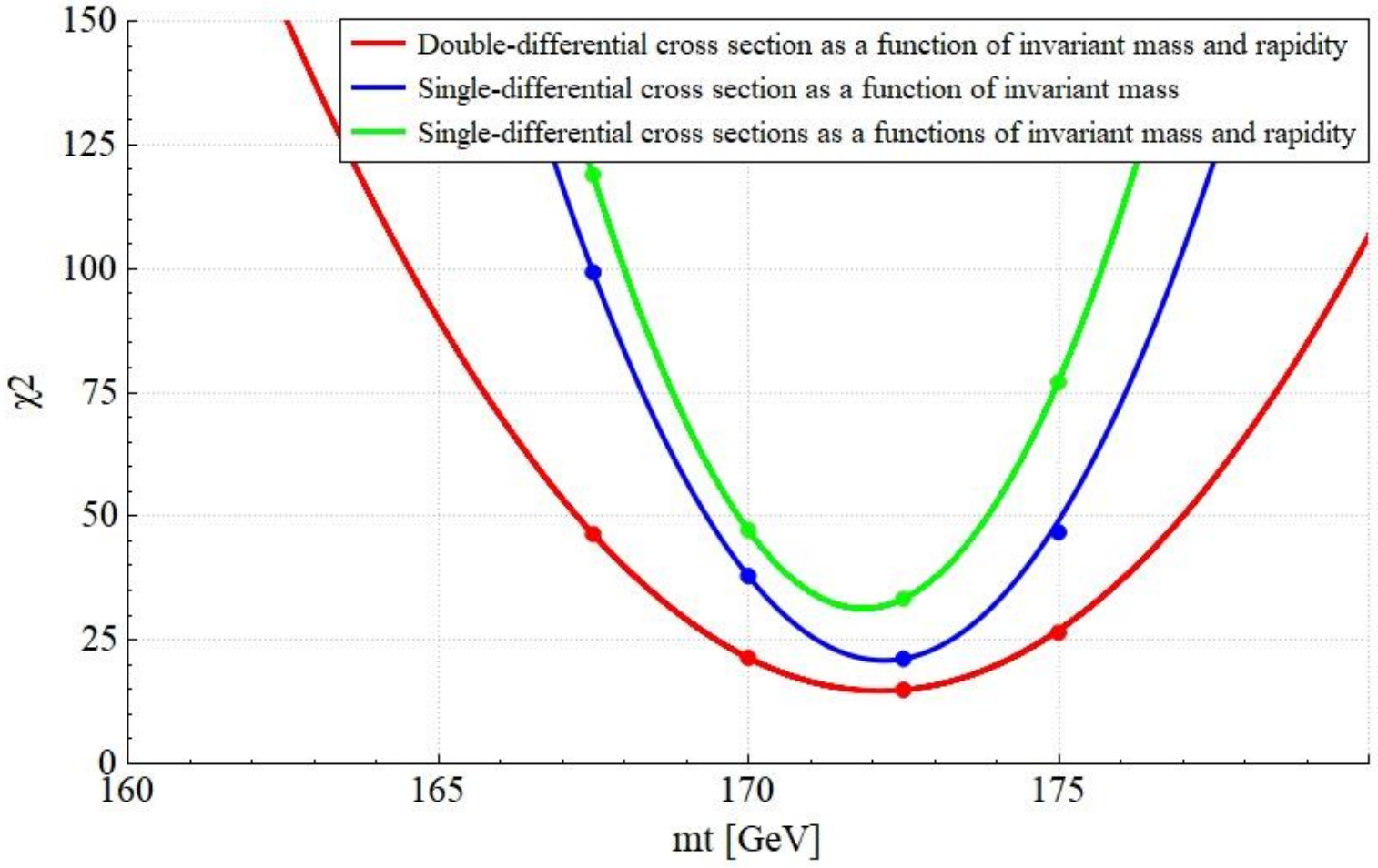
m_t = 171,85 ± 0,46 ГеВ

$\chi^2_{min}/dof = 31{,}4/14$
(p = 0,005).



Comparison of the obtained results

Cross sections used	Obtained m_t [GeV]
Double-differential	172,12 ± 0,82
Single-differential cross section in invariant mass	172,19 ± 0,53
Single-differential cross section in rapidity	143 ± 13
Two single-differential cross sections	171,85 ± 0,46
PDG mass	172,4 ± 0,7



Conclusions

- For the first time, the top-quark mass was determined taking into account the correlation between two single-differential cross sections.

- The obtained results are consistent, within uncertainties, with the PDG value of 172,4 ± 0.7 GeV. All cross sections are reasonably well described by the NNLO predictions.

- The value of χ^2 calculated using the two single-differential cross sections was found to be the most sensitive to variations in the top-quark mass. This is explained by the larger number of bins at low $t\bar{t}$ invariant mass, which are most sensitive to variations in the top-quark mass.

- Future steps of this study could include accounting for the theoretical uncertainties of the proton PDFs and increasing the number of single-differential cross sections used in the determination of the top-quark mass.

Thank you for your attention