Top Quark Pole Mass Determination Using the ttbar Differential Cross Sections at 13 TeV

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on behalf of the analysis team

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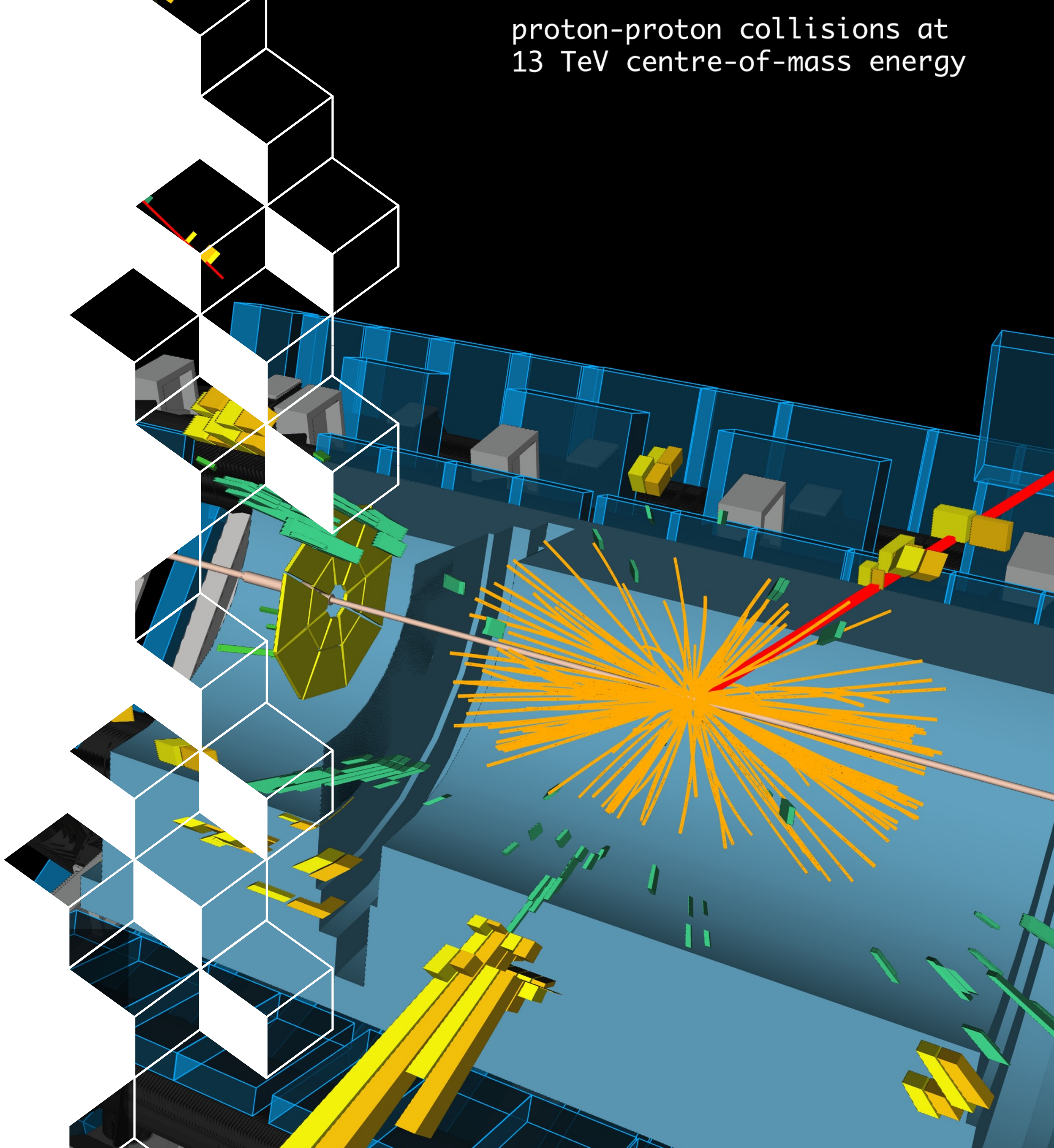
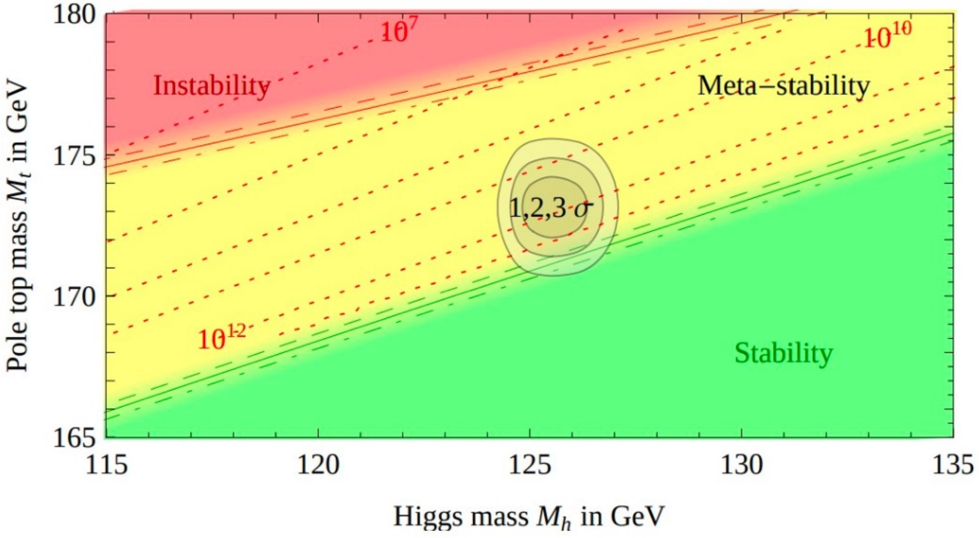
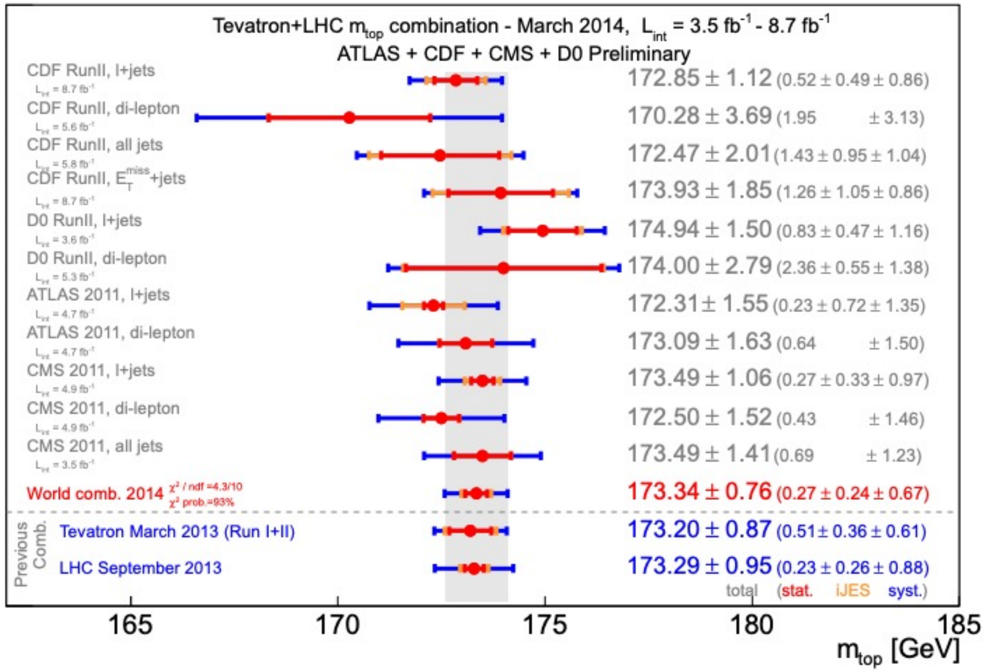


Top Mass Measurement

- Top mass (m_t) is an important free parameter which is not predicted in SM. It is a good method to test the internal consistency of the SM
- The top quark is not a free particle. Its mass can be determined through comparison with theoretical calculations



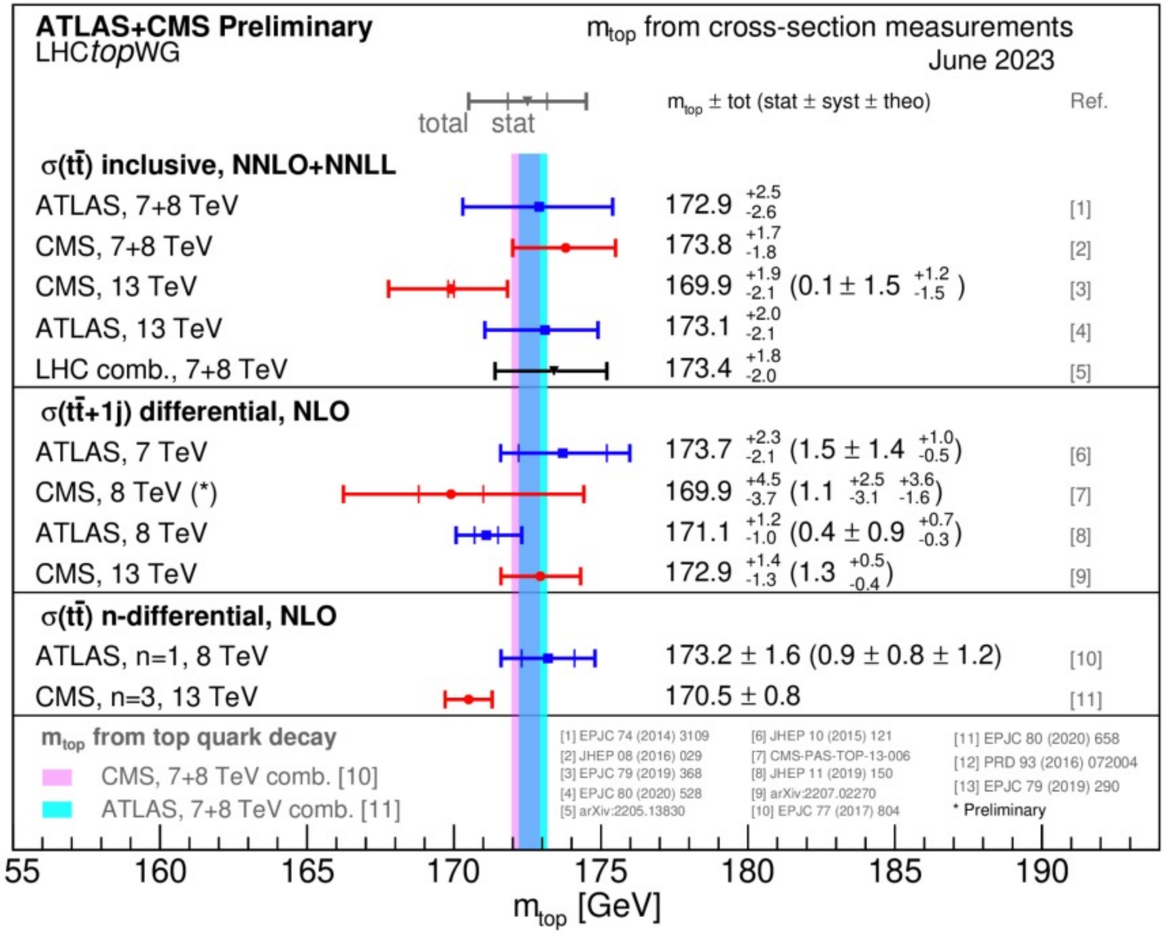
- Two methods are mainly used：
  - **Direct method** ("Monte Carlo" mass): reconstruct invariant mass of decay products and compare it with MC samples, using template fit methods
  - **Indirect method** ("Pole" mass): extract the mass from the cross section and compare it to first principle calculations



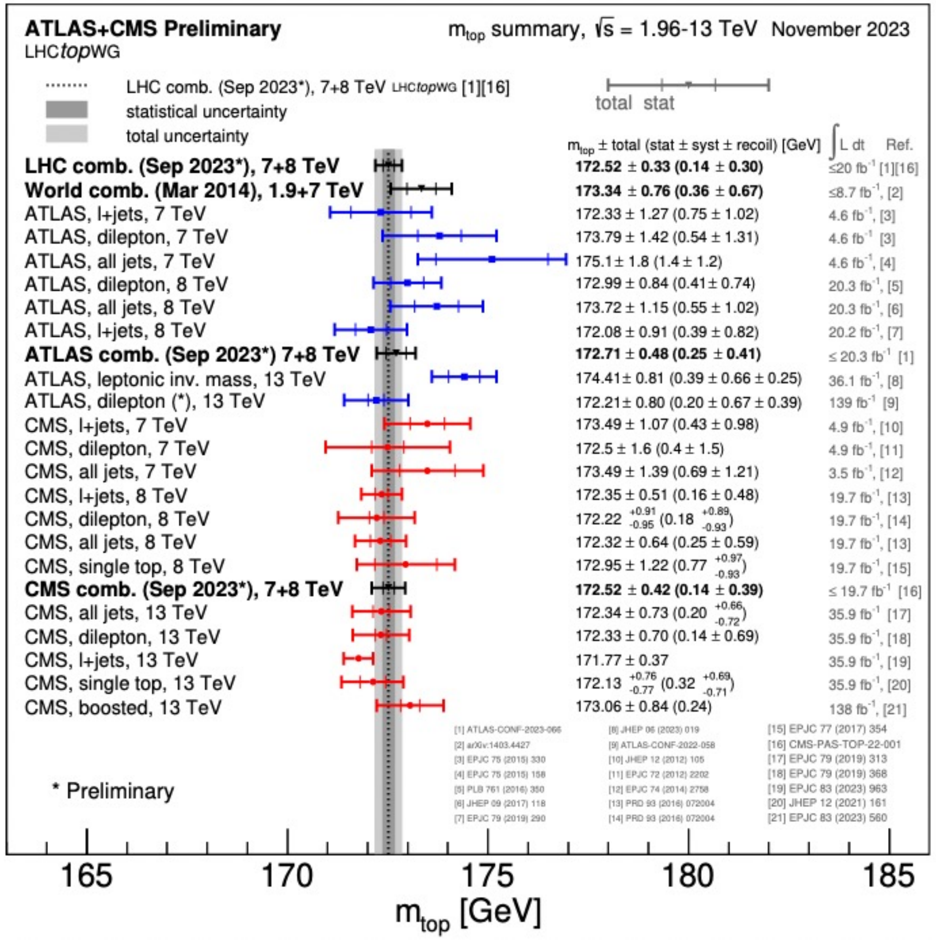
Top Mass Measurement at LHC

- Here is the summary of the ATLAS and CMS measurements of the top quark mass from $t\bar{t}$ production observables.
- The pole mass and MC mass of the top quark may have a few hundred MeV difference from those

"Indirect"



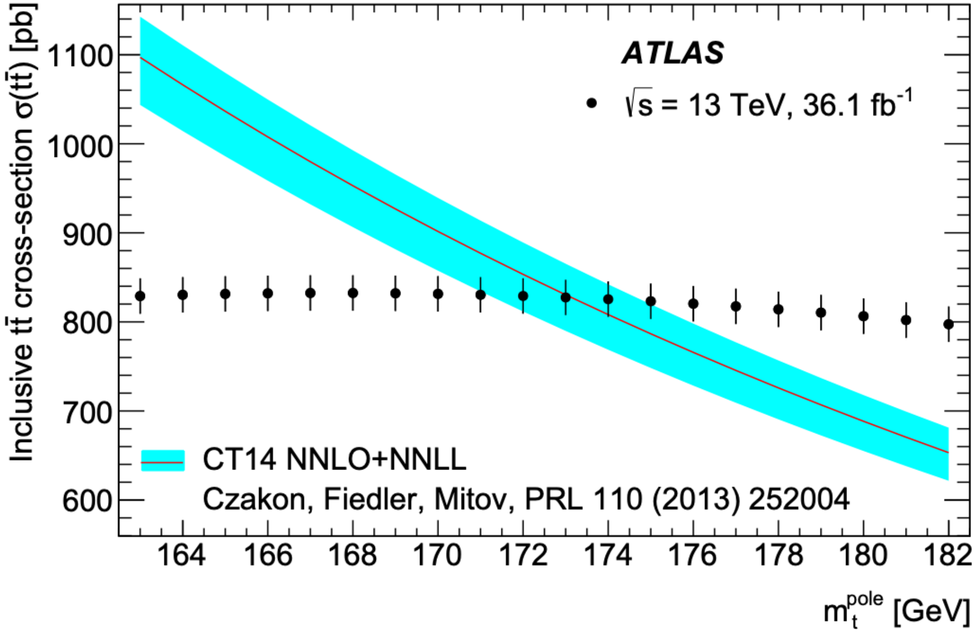
"Direct"



Pole Mass Measurement at ATLAS

Eur. Phys. J. C 80 (2020) 528

- ATLAS has released a run2 top pole mass measurement using the inclusive ttbar cross section in the di-lepton channel
  - Comparing with the NNLO+NNLL theory cross section
  - The final result is $m_t^{pole} = 173.1^{+2.0}_{-2.1}$ GeV. Mainly dominated by theory uncertainties
  - Probably get even reduce the uncertainty to 1.7 GeV by using NNPDR3.1



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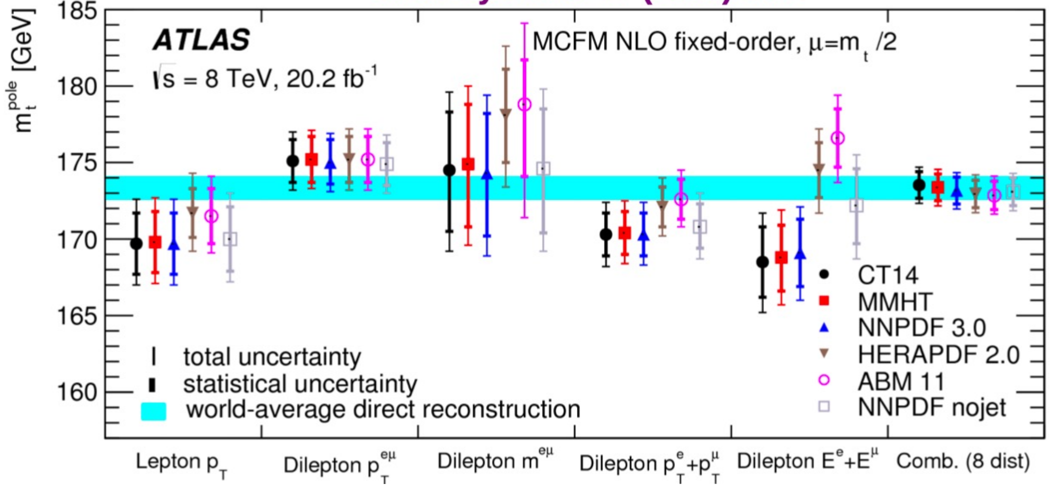


- Theory uncertainties can be reduced by using differential cross section
- Differential distributions can be computed at fixed-order, NLO or NNLO
- For NNLO, now a software is available: MATRIX

Overview of the Analysis

- This measurement is an indirect way to measure the top quark pole mass using ttbar differential cross section with Run2 data in the final state with one lepton and jets

Analysis strategy in brief:

- Extract the pole mass of the top quark using nominalized differential cross sections:
  - 1D fit: $d\sigma/dm^{\bar{t}t}$, $d\sigma/dp_T^{t,\,had}$ ($p_T^{t,\,had}$ is the sum of pT for the hadronic products of top quark decays)
  - 2D fit: $d^2\sigma/dm^{\bar{t}t}dp_T^{t,\,had}$
- Compare NNLO theoretical predictions (MATRIX) to measurements (MC or data) at the parton-level
- Determine the top pole mass by minimizing the chi-squared (χ^2)

$$\chi^2(m_{\rm top}) = \sum_{\rm i,j}(\mathrm{x}_\mathrm{i}^{\rm meas} - \mathrm{x}_\mathrm{i}^{\rm pred}(m_{\rm top}))\mathrm{Cov}_{\rm i,j}^{-1}(m_{\rm top})(\mathrm{x}_\mathrm{j}^{\rm meas} - \mathrm{x}_\mathrm{j}^{\rm pred}(m_{\rm top}))$$

Introduction: Analysis Strategy

- Here is the Analysis work flow in brief

MC (data) :
- Use the 36 fb-1 MC ttbar sample (Powheg + Pythia, NLO+PS) as the **Pseudo-data**

Unfolding

Covariance matrix:
- Contain statistical, detector, and modelling systematics
- PDF+αS theoretical uncertainties

Uncertainty breaking-down: Estimate the effect of a given systematics by removing it from the covariance matrix

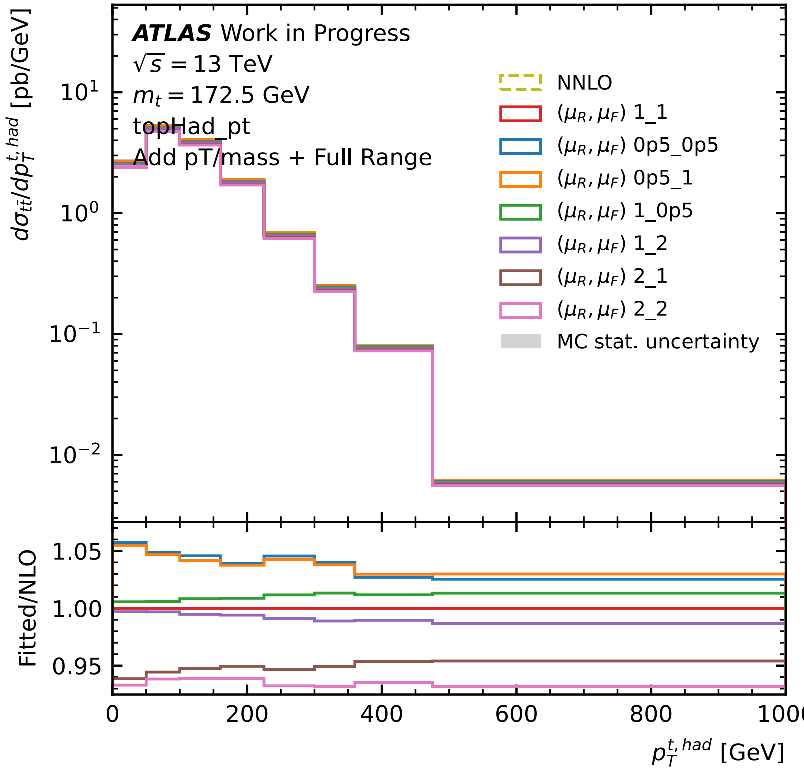
$$\chi^2(m_{top}) = \sum_{i,j}(x_i^{meas} - x_i^{pred}(m_{top}))Cov_{i,j}^{-1}(m_{top})(x_j^{meas} - x_j^{pred}(m_{top}))$$

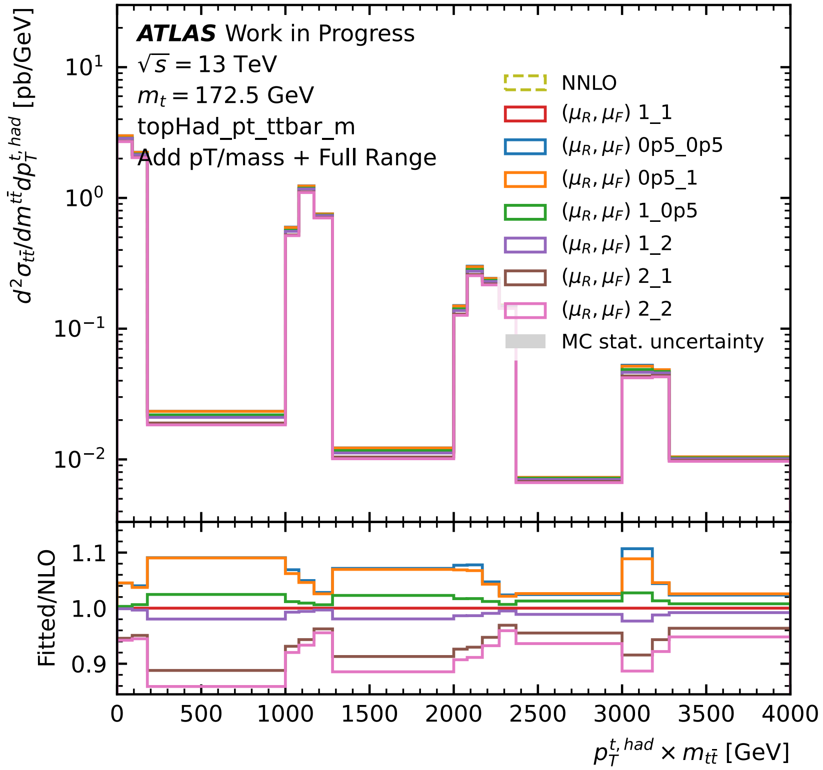
Theory prediction:
- Derive the **theory prediction** of ttbar differential XS at NNLO from MATRIX
- Need to interpolate between the computed mass points

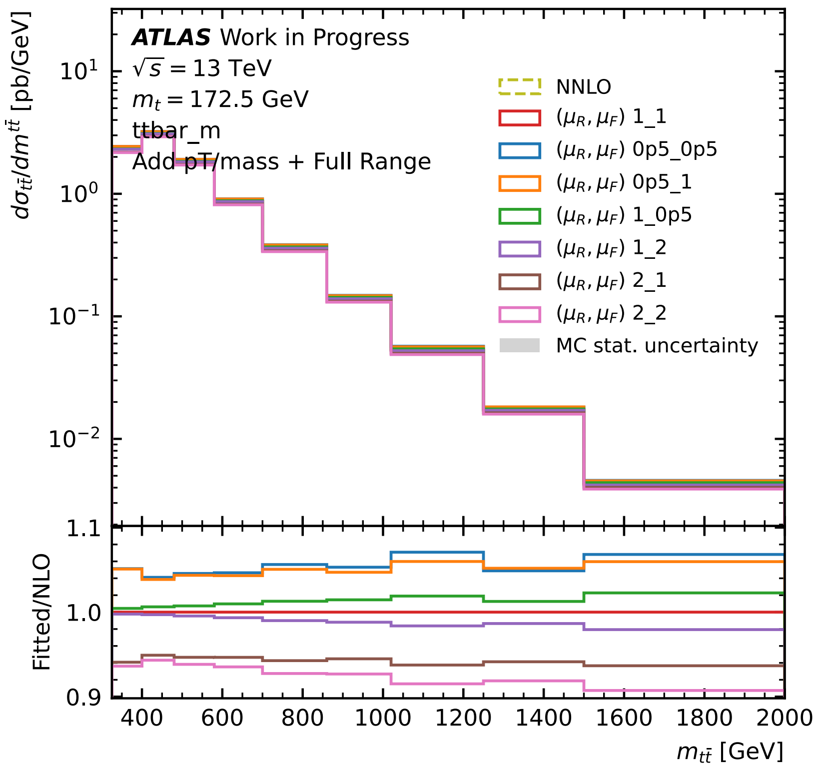
Mass extraction:
- Calculate a chi2 for different mass points, finding its lower value (and the mass uncertainties) numerically
- Done binning study and closure tests

MATRIX Production

- NNLO differential calculations are performed for 17 mass points, each mass point has 7 scale variations. PDF and α_S are derived from NLO.
- The binning of variables are optimized based on the significance. 2D variable folded into 1D with pt distribution for different $m^{\bar{t}t}$ bins

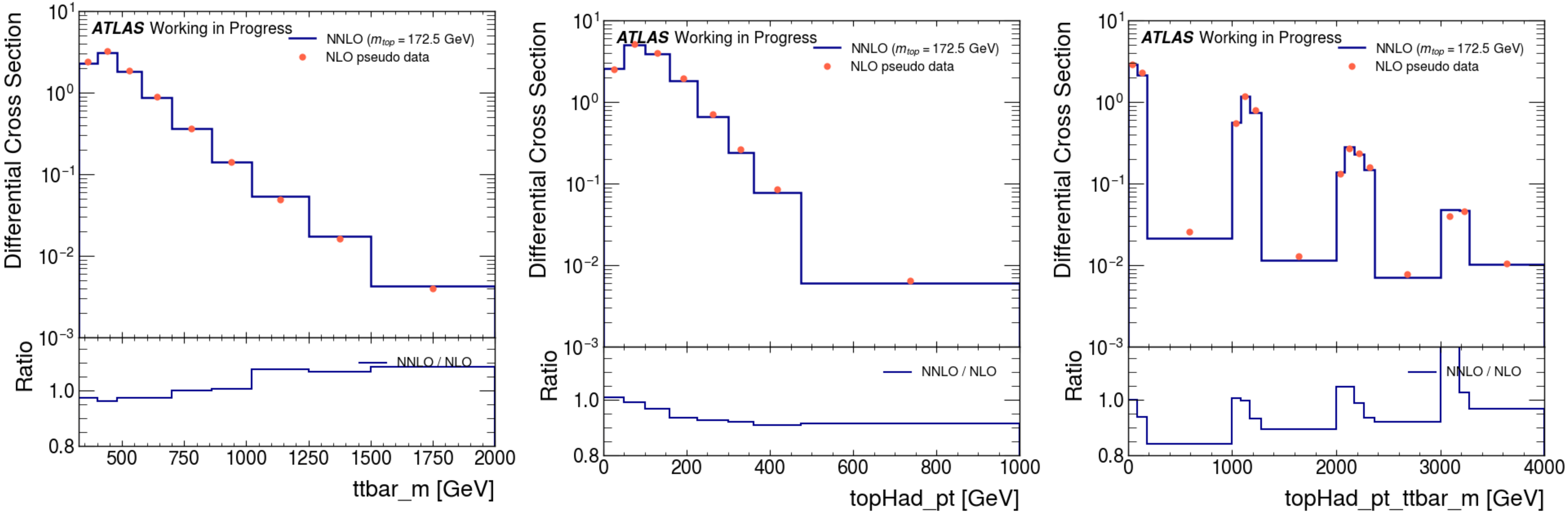






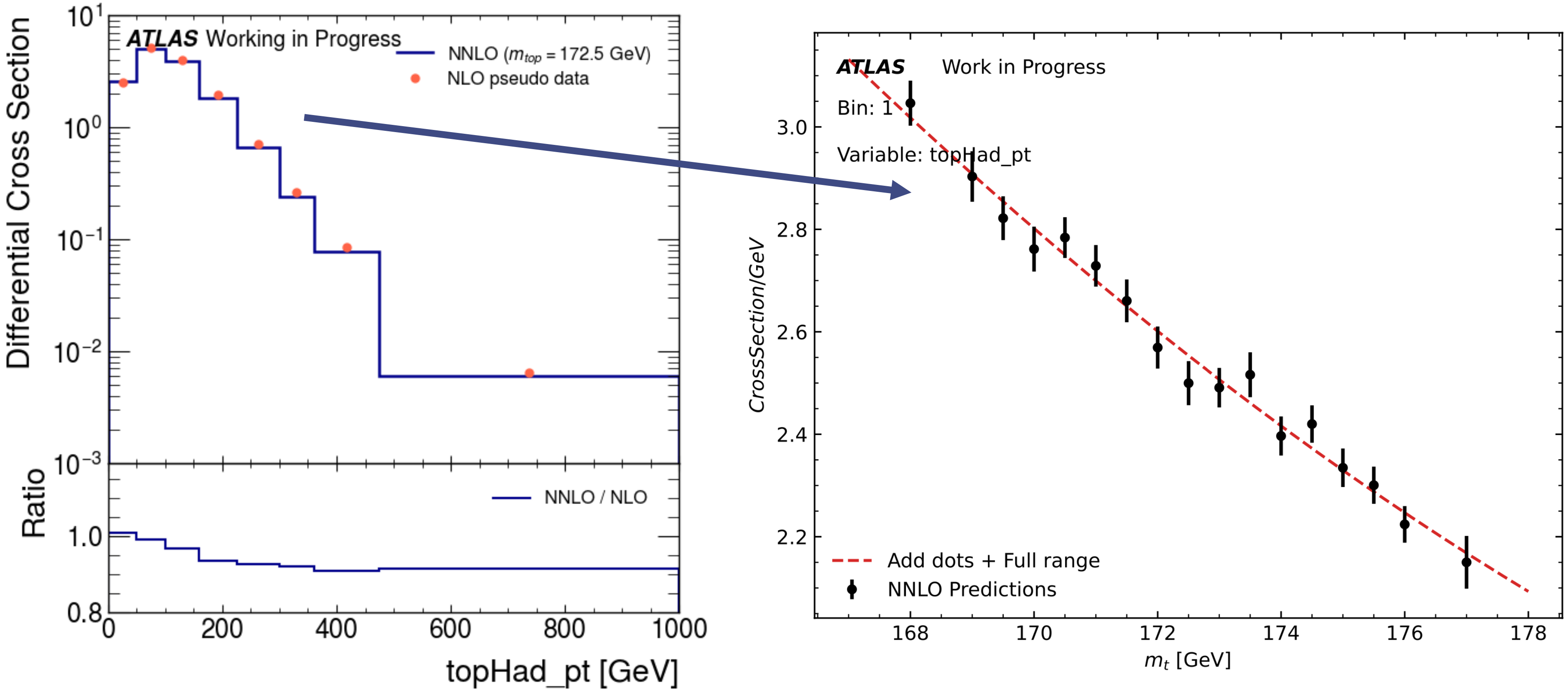
MC/Prediction Comparison

- Comparison between the NNLO theory prediction with the NLO from MC



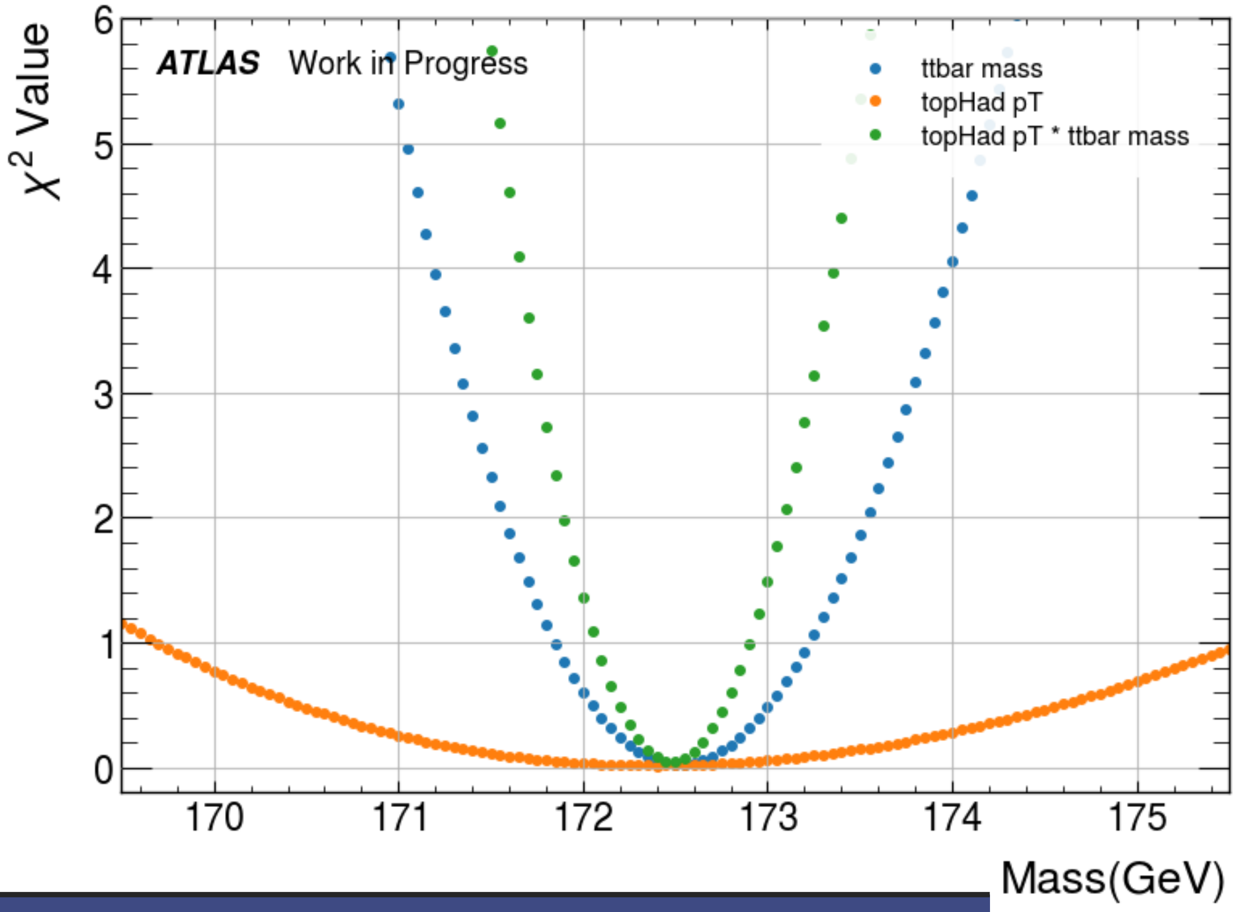
Mass Extraction – NNLO Interpolation

- The mass extraction is done by calculating the difference between theory predictions with pseudo data
- Before that, we have to derive an interpolation between the NNLO produced theory predictions
- Considering stat uncertainties in interpolation, also tried polynomial function with different orders



Closure Test

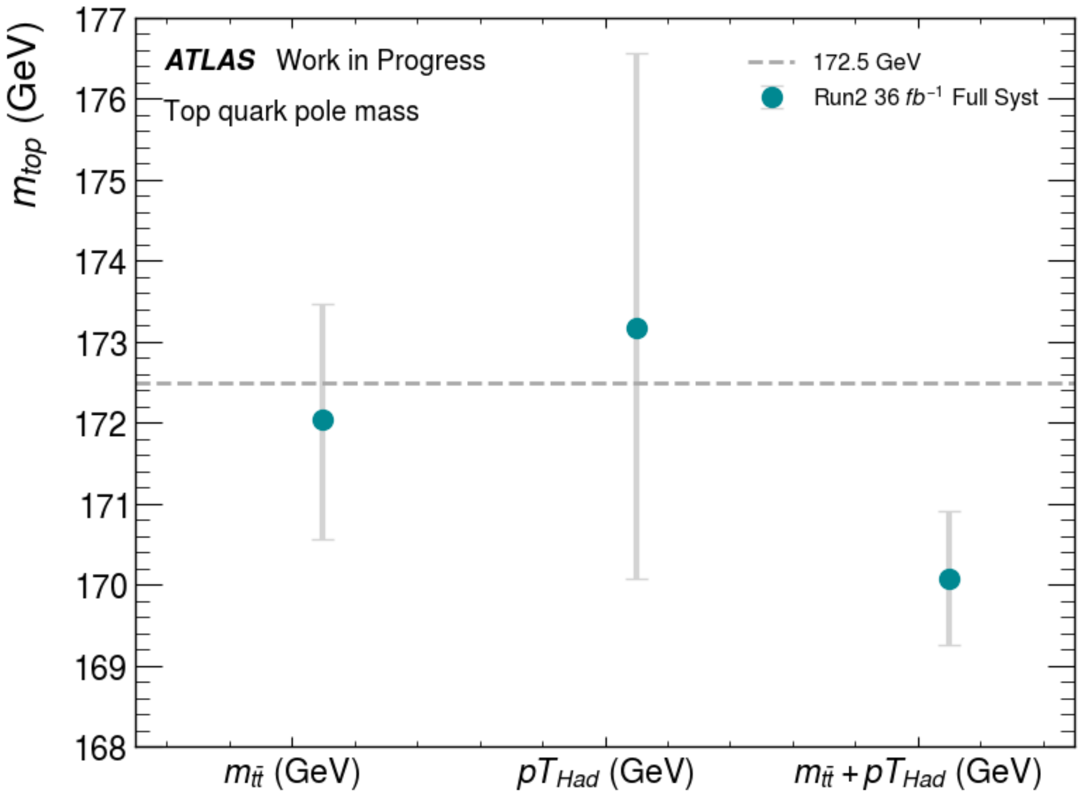
- The closure test uses the NLO+PS sample as prediction to check the method consistency and fitting
- The uncertainties are determined by the chi value at 1 for both three variables
- The result of all three variables are close to 172.5 GeV and the 2D variable gives the result with the smallest uncertainties among three variables

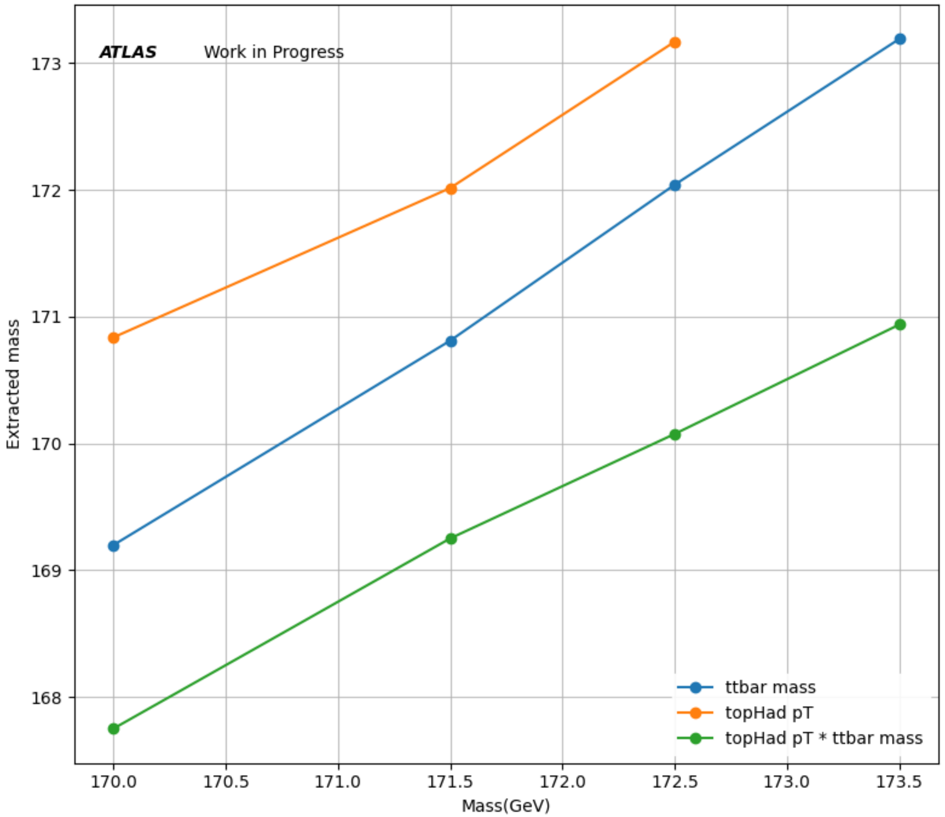


Variable (Full experimental syst)	ttbar_m (GeV)	ttbar Had pT (GeV)	ttbar_m + ttbar Had pT (GeV)
Mass	172.520	172.402	172.479
Uncertainty	+ 0.715 - 0.681	+ 3.214 - 2.729	+ 0.432 - 0.419

Preliminary Result

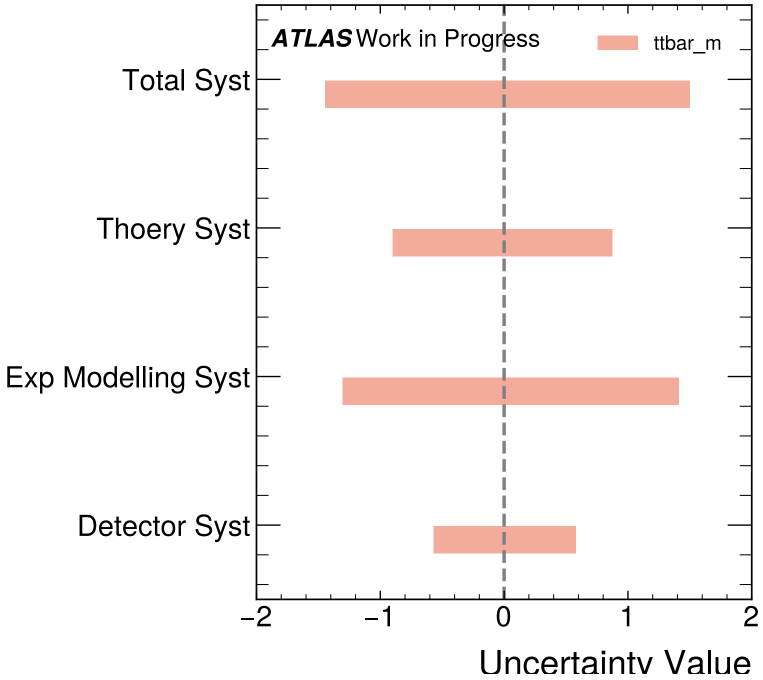
- Using NNLO prediction to extract the mass using NLO MC pseudo-data, and test it with different MC samples with different top mass
- Shifts coming from the difference from the different orders between the MC and the theory

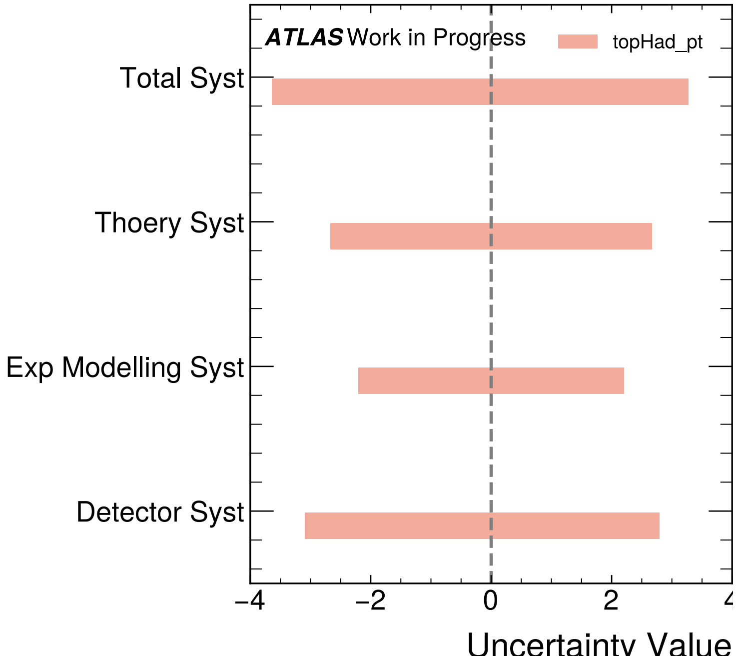


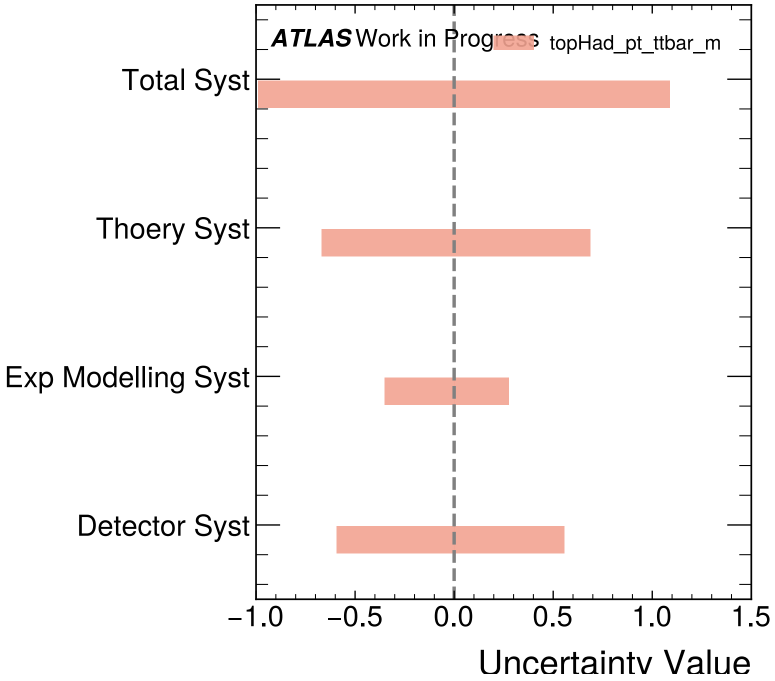


Expected Uncertainties

- The uncertainty breaking down for each variable is ongoing
- The mass extracted using ttbar mass is modeling syst dominated, pT is detector systs dominated and 2D is similar to pT



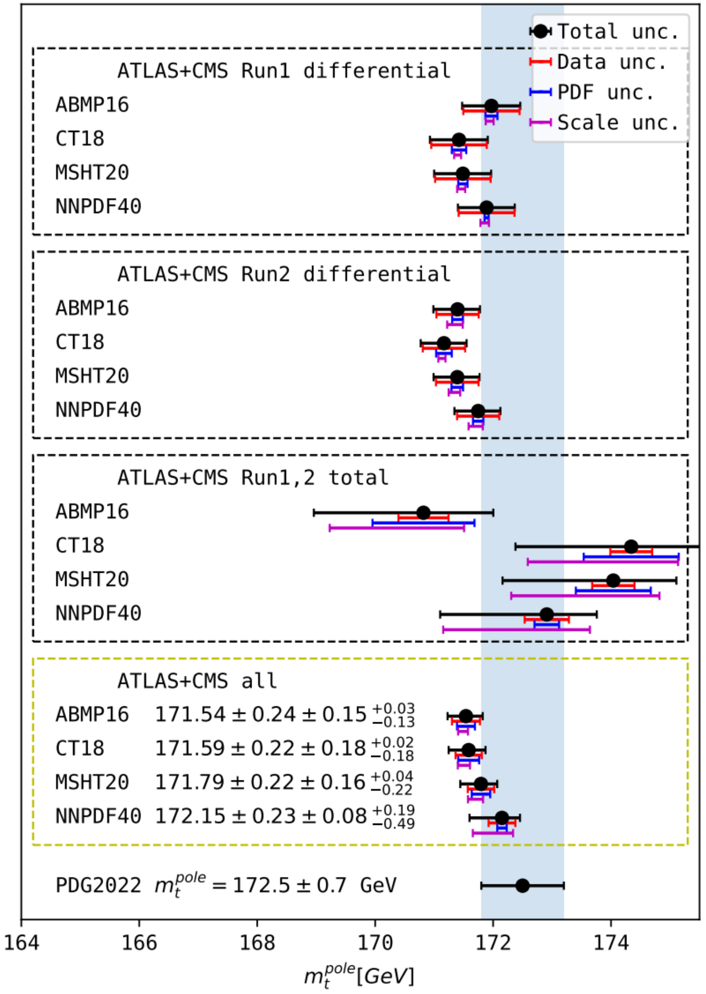


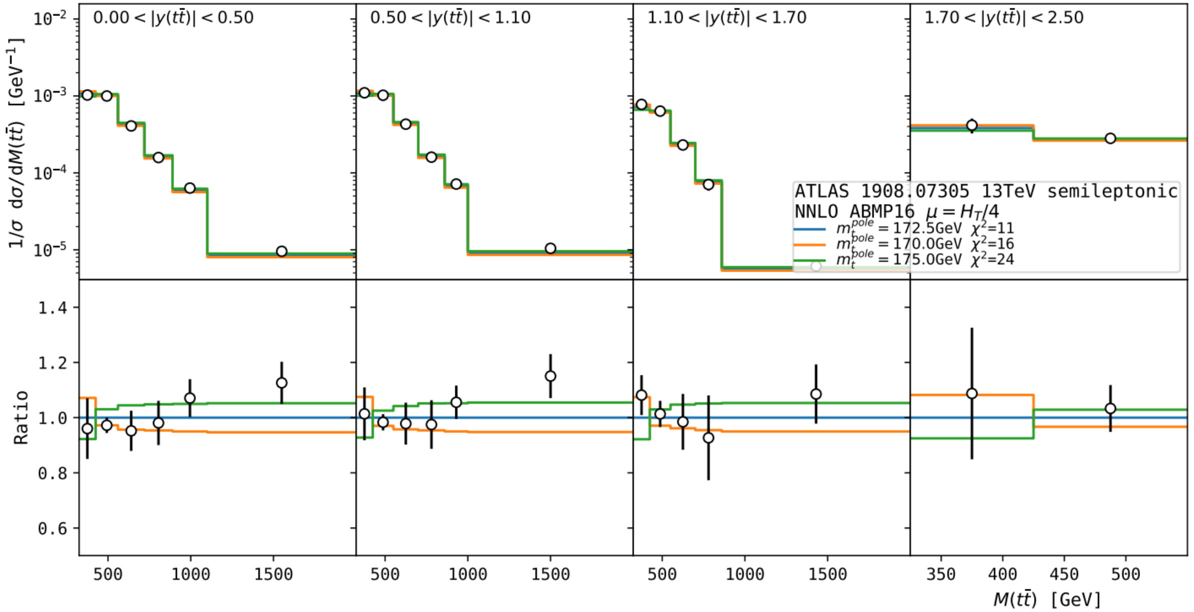


Studies from Theorists: Extraction Using Several Experiments

Arxiv:2311.05509

- Thinking about combining the results from different experiments
- Generating the NNLO prediction for different variables and running the mass extraction





- Then can get a result with restively small uncertainties
- But they don't consider the correlation between uncertainties

$$m_t^{\rm pole} = 171.54 \pm 0.24\,(\exp) \pm 0.15\,({\rm PDF})^{+0.03}_{-0.13}\,(\mu)\ {\rm GeV} = 171.54^{+0.28}_{-0.31}\ {\rm GeV},$$

Summary and Future Plan

Top quark pole mass measurement using differential cross-section with 13 TeV 36fb-1 data

- Using NNLO predictions generated from MATRIX
- Optimizing the interpretation for theory uncertainties
- Good performance for closure test
- Currently, we are doing the preliminary test to use the full Run2 results and move to run on (blinded) data afterward

Backups