Future Top Quark Pole Mass Improvements from PDF Updates

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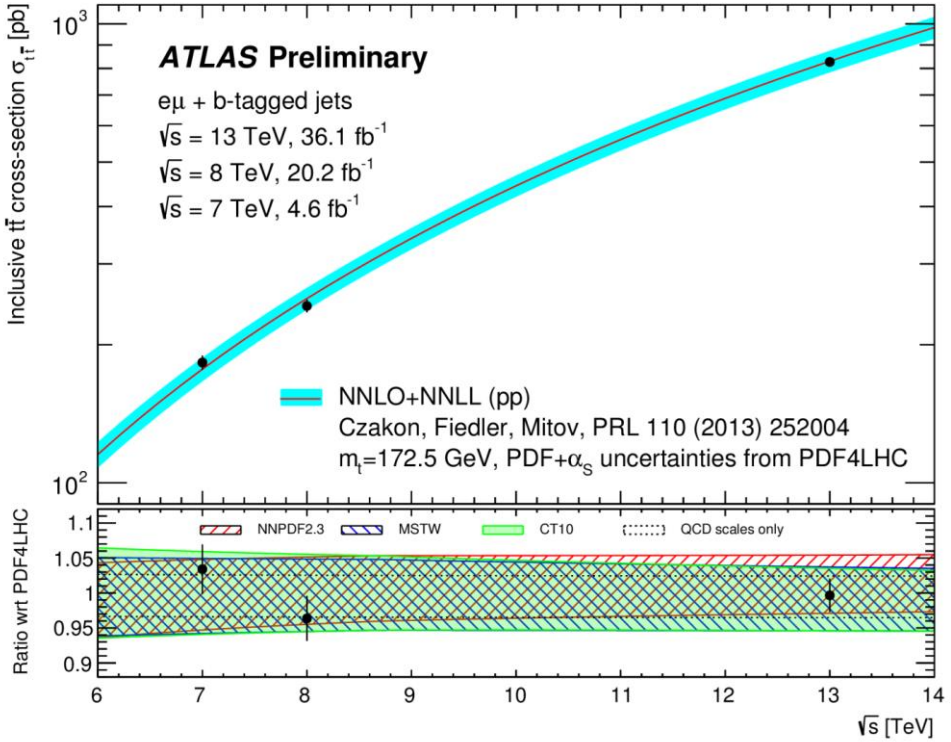
Introduction

- Two broad definitions of top quark mass:
  - Top quark pole mass (our subject of study here)
    - Measured from comparing experimental and theoretical cross-sections, both inclusive and differential
  - Monte-Carlo top quark mass
    - Measured from reconstructing the top quark from its decay products
- We perform a phenomenological study to see if we can reduce the top pole mass uncertainty with future colliders and by how much
- This study was part of the US community study on the future of particle physics (Snowmass 2021)

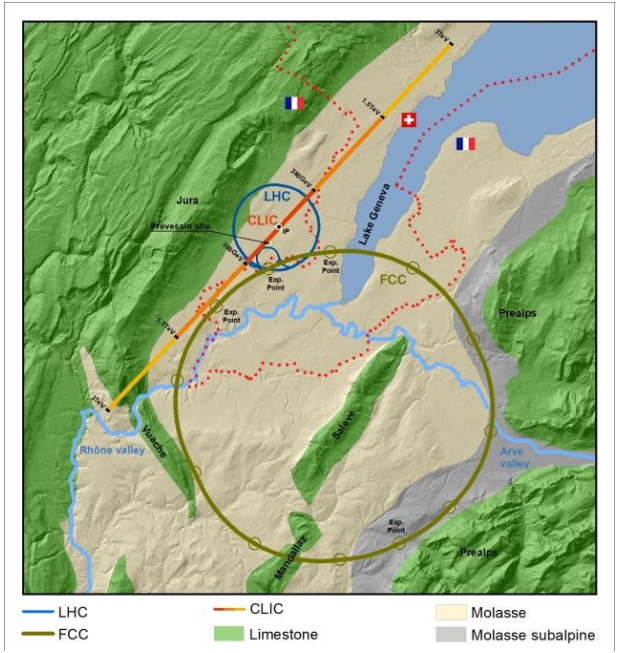
PDF Significance to Top Pole Mass Measurements

- Largest uncertainty in theory calculations is from parton distribution functions (PDFs)
  - About 5% uncertainty on the total cross-section
  - Gluon PDF at large x and large scale μ
- Goal: study the impact the PDF uncetainty on future top pole mass measurements



Future Colliders

- LHC – Run3
  - 13.6 TeV
  - Goal is to collect 300 fb^{-1}
- HL-LHC: High Luminosity Large Hadron Collider
  - 14 TeV
  - Goal is to collect 3,000 fb^{-1}
- FCC: Future Circular Collider
  (or any 100 TeV hadron collider)
  - 100 km tunnel
  - First tuned to electron collider
  - Then 100 TeV hadron collider



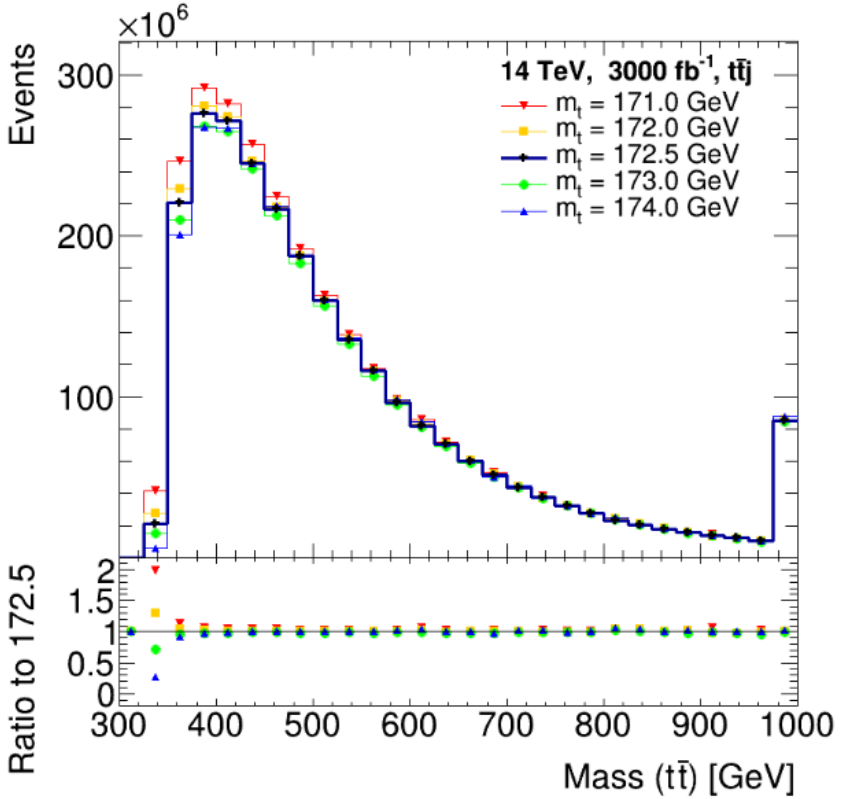
Outline of Our Study

- Generate events using Madgraph at NLO
- Calculate χ^2 with differential top quark mass distributions and “original” PDF uncertainties
- Calculate new PDF uncertainties on the mass distributions by updating with new pseudodata that is expected from future colliders
- Recalculate χ^2 with differential top quark mass distributions and “updated” PDF uncertainties
- Comparing χ^2 curves from “original” and “updated” PDF errors shows how the PDF component of the top quark pole mass can be improved with future collider data

Top Mass Measurements in $pp \rightarrow t\bar{t}$

- Two studies are done on different top quark processes
- Only truth level study
  - Don't decay tops out of Madgraph
- Calculated χ^2 using these mass distributions and their PDF uncertainties

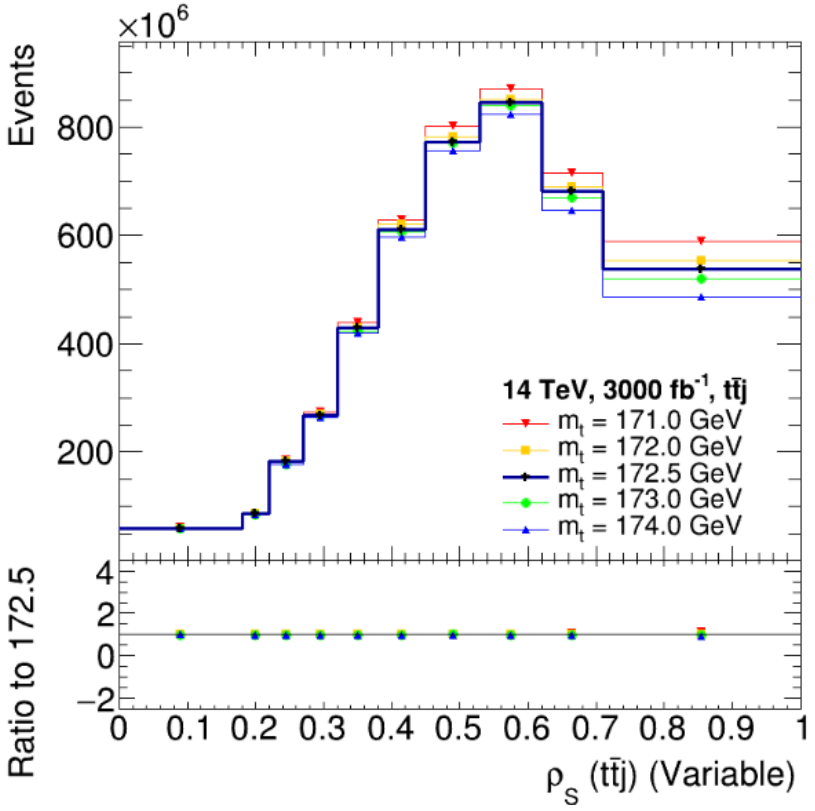
$$\chi^2 = \sum_{i=0}^{n} \frac{(O_i - E_i)^2}{\sigma_i^2}$$



Top Mass Measurements in $pp \rightarrow t\bar{t}j$

- For top pair production plus 1 jet, we found that a more sensitive variable was this ρ

$$\rho = \frac{2*170}{m_{t\bar{t}j}}$$



A few more details of our study

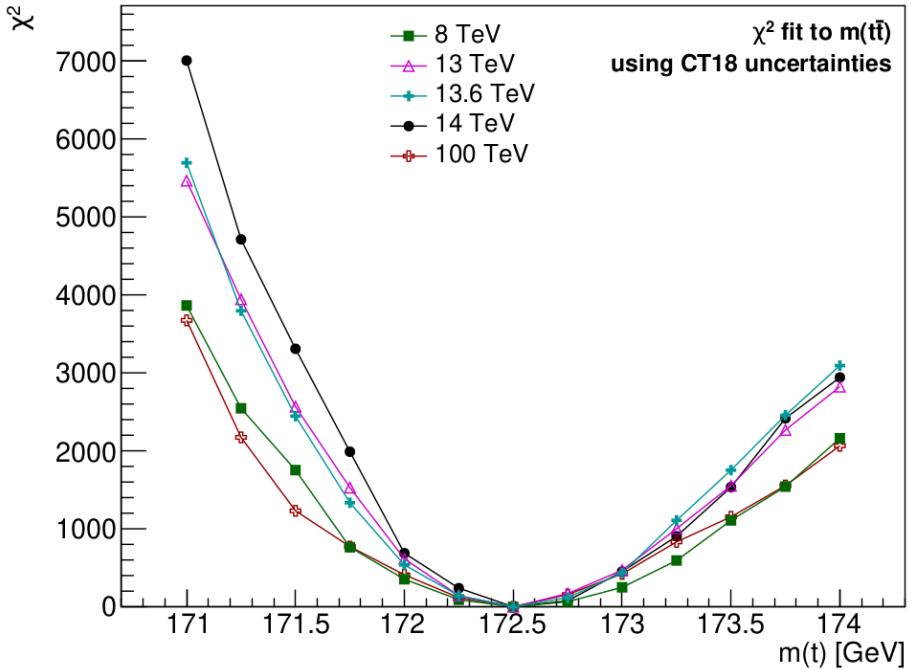
- Two parameters are varied: beam energy and top quark mass
  - COM Energies of 8 TeV, 13 TeV, 13.6 TeV, 14 TeV, and 100 TeV
- PDFs are updated with ePump, using the Hessian update method
  - This method relies on the Hessian approximation which is only valid for updates that result in small deviations from the global best fit
- Pseudodata for ePump is set to nominal theory
  - Assumed 1% uncorrelated systematic error for pseudodata (expected experimental precision)
- This is done for top masses in the nominal region (172.5 GeV), χ^2 curve shows top mass measurement improvement

Energy Frontier Report for Snowmass 2021
Full Snowmass Report
This study's whitepaper

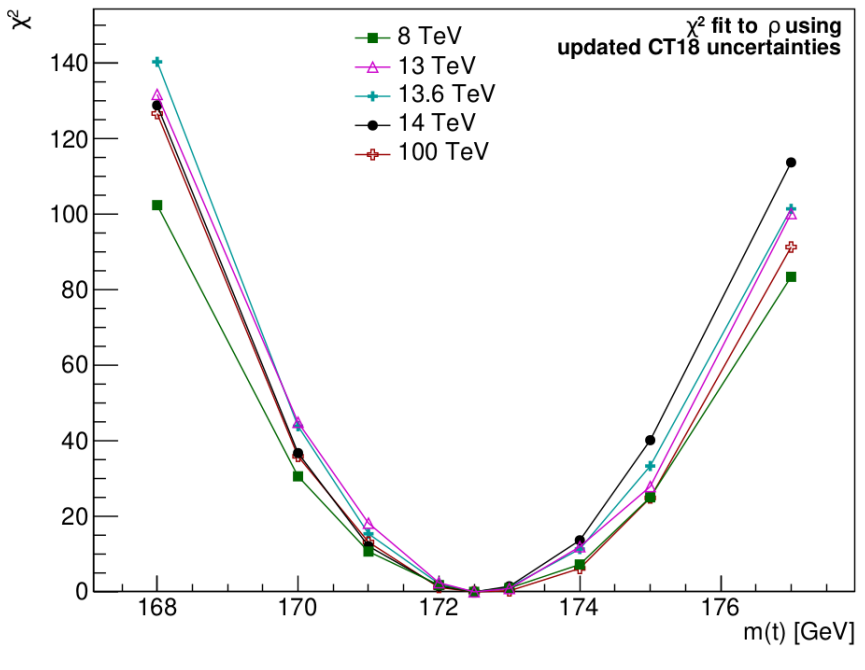
ePump: C. Schmidt, J. Pumplin, C. P. Yuan and P. Yuan, Phys. Rev. D **98**, no. 9, 094005 (2018) doi:10.1103/PhysRevD.98.094005 [arXiv:1806.07950 [hep-ph]]

χ^2 before PDF updates

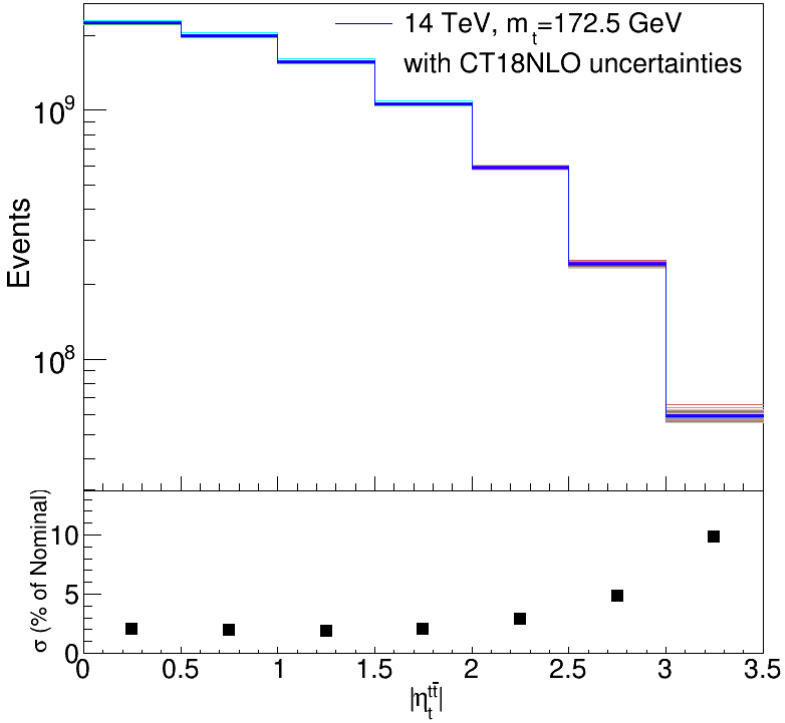
χ^2 for $t\bar{t}$ study

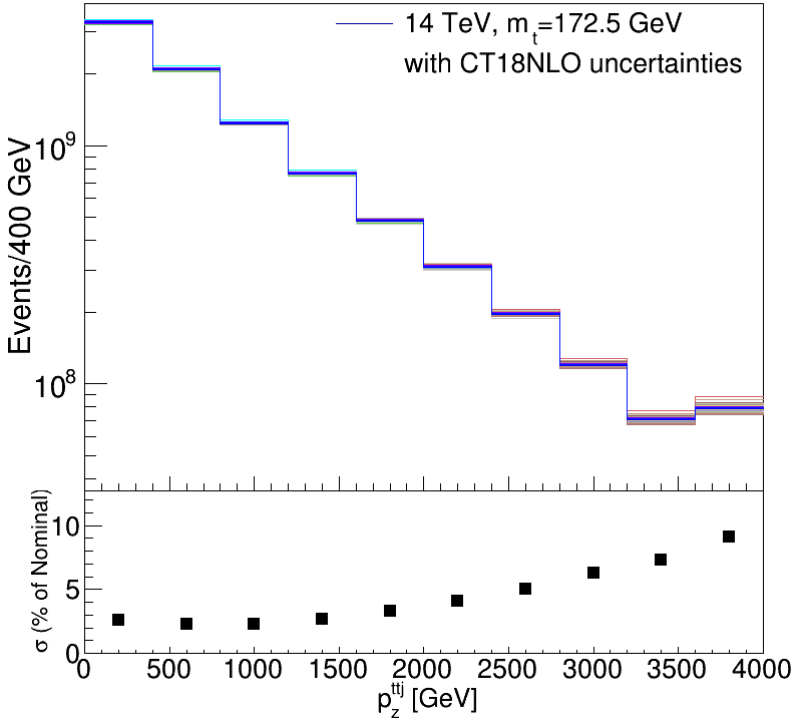


χ^2 for $t\bar{t}j$ study



Pseudo-data Histograms used in PDF Update



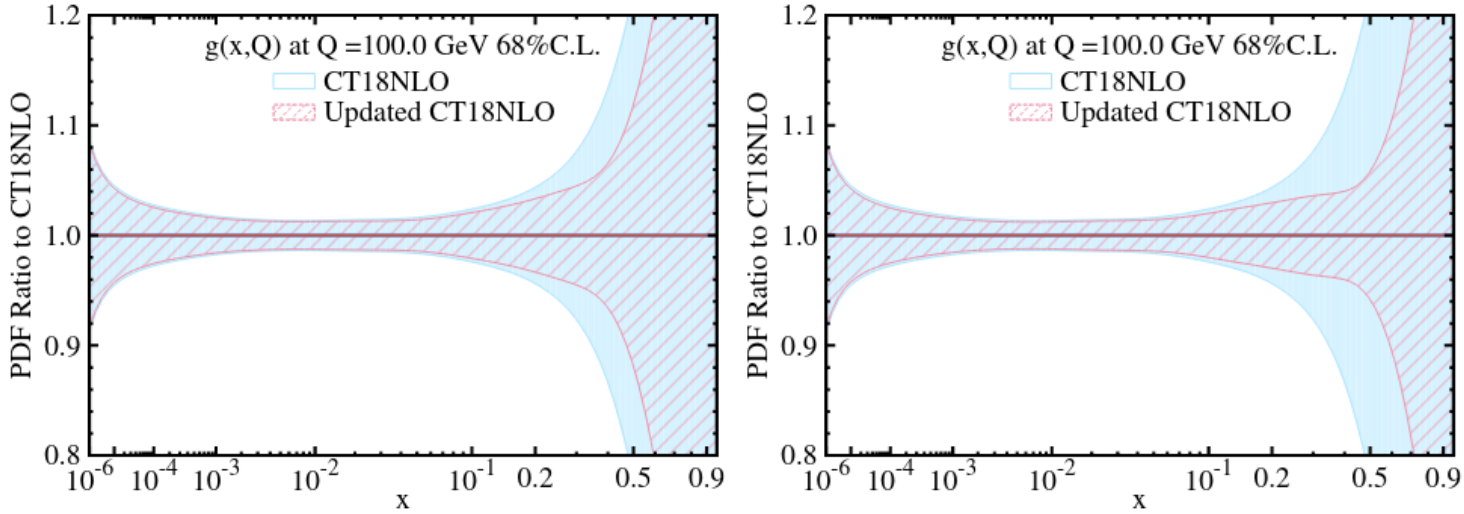


Different distributions from the same MC set were used to update the PDF

Overlaying all 58 error PDF calculations with nominal CT18NLO PDF

Actual number of events expected at HL-LHC

Gluon PDF Error Band Constraints



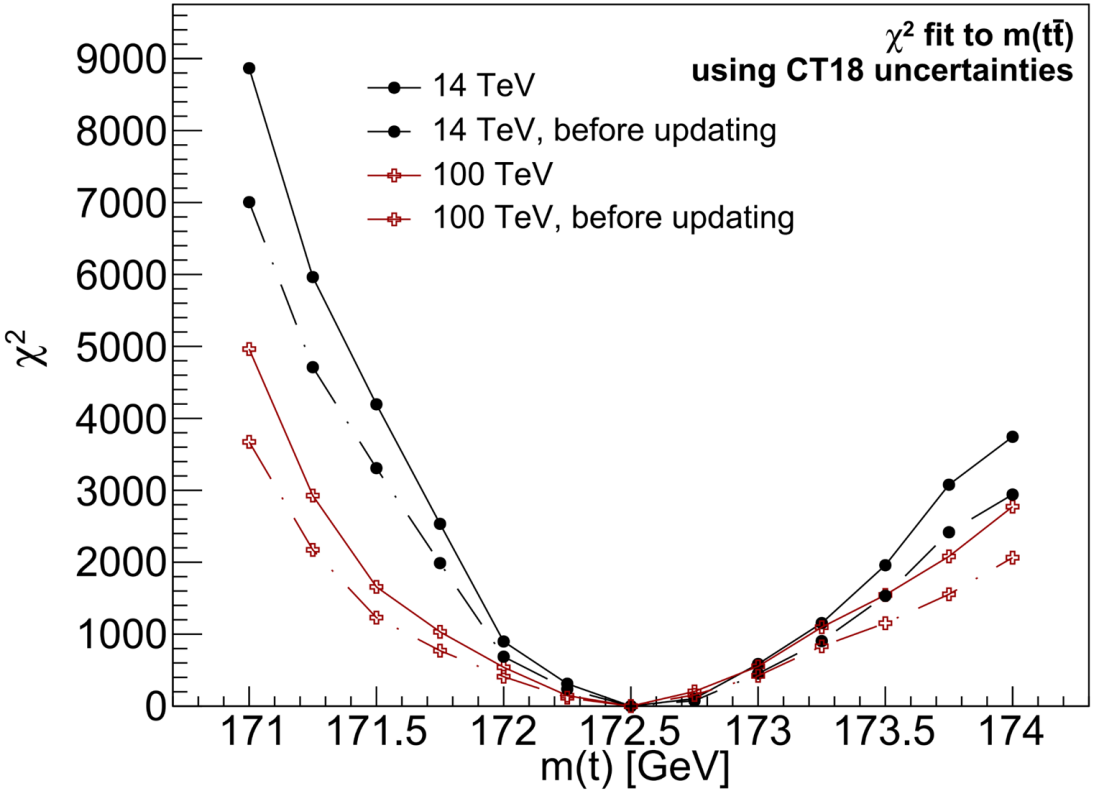
(Left) Reduction of PDF error bands from the η_t **in** $t\bar{t}$ **events**

(Right) Reduction of PDF error bands from the p_Z **in** $t\bar{t}j$ **events**

Updated χ^2 with Top Rapidity in $t\bar{t}$ Events

Top mass uncertainty due to PDF reduced by:

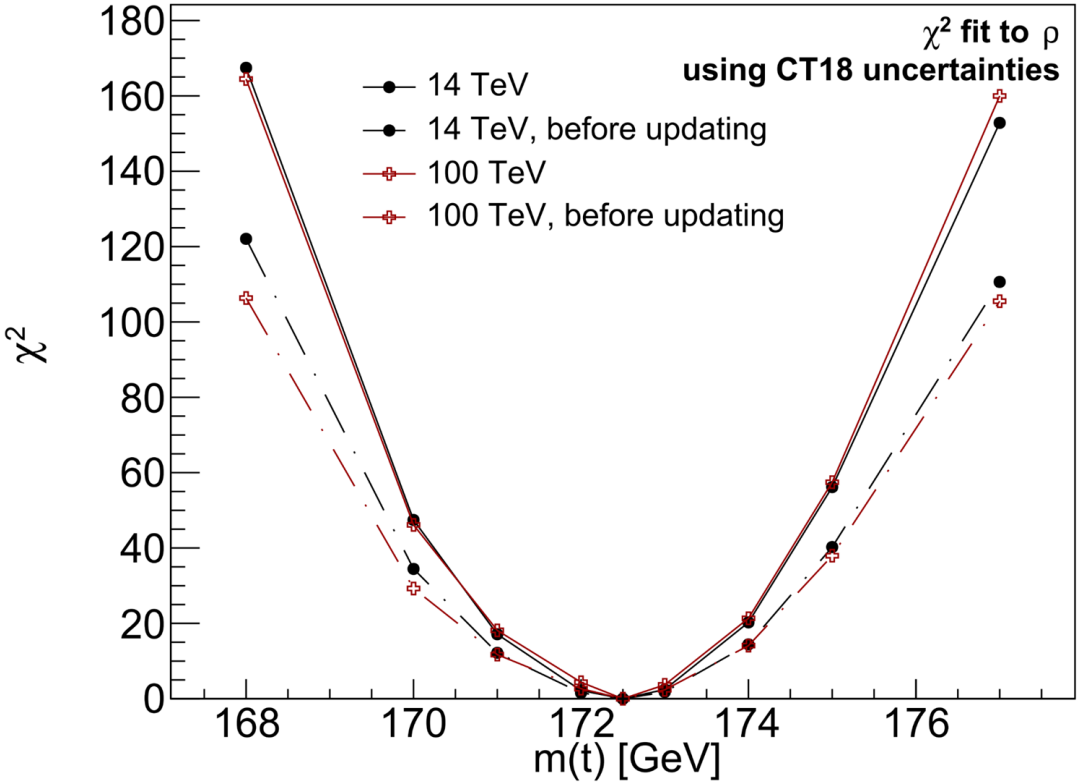
- 13% for 14 TeV, 3,000 fb^{-1}
- 14% for 100 TeV, 20,000 fb^{-1}



Updated χ^2 with p_z in $t\bar{t}j$ Events

Top mass uncertainty due to PDF reduced by:

- 17% for 14 TeV, 3,000 fb^{-1}
- 20% for 100 TeV, 20,000 fb^{-1}



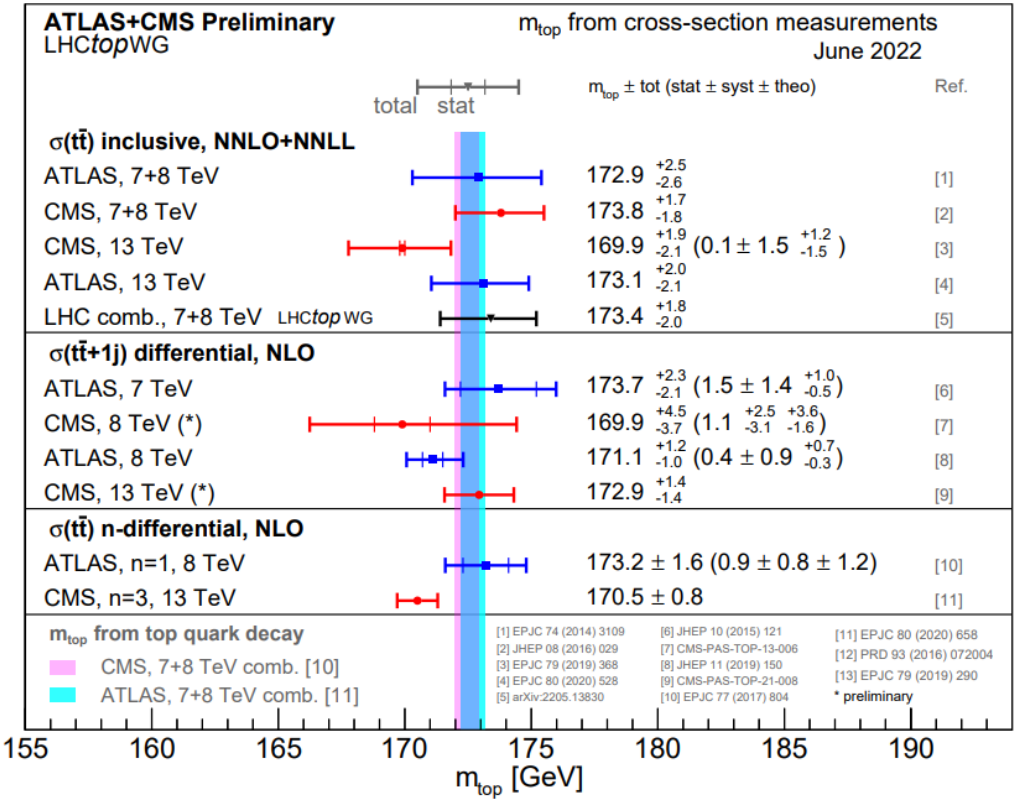
Summary

- With the HL-LHC, there is an opportunity to improve the PDF component of the top quark pole mass uncertainty with measurements such as η_t in $t\bar{t}$ and p_Z in $t\bar{t}j$
- Improvements on the PDF component of the top quark pole mass uncertainty can be expected to be reduced by about ~13% up to ~17% with the upcoming HL-LHC with auxiliary measurements
- We also looked at other variables such as η and p_Z of t and $t\bar{t}$ with and without detector cuts. We saw similar improvements with these variables

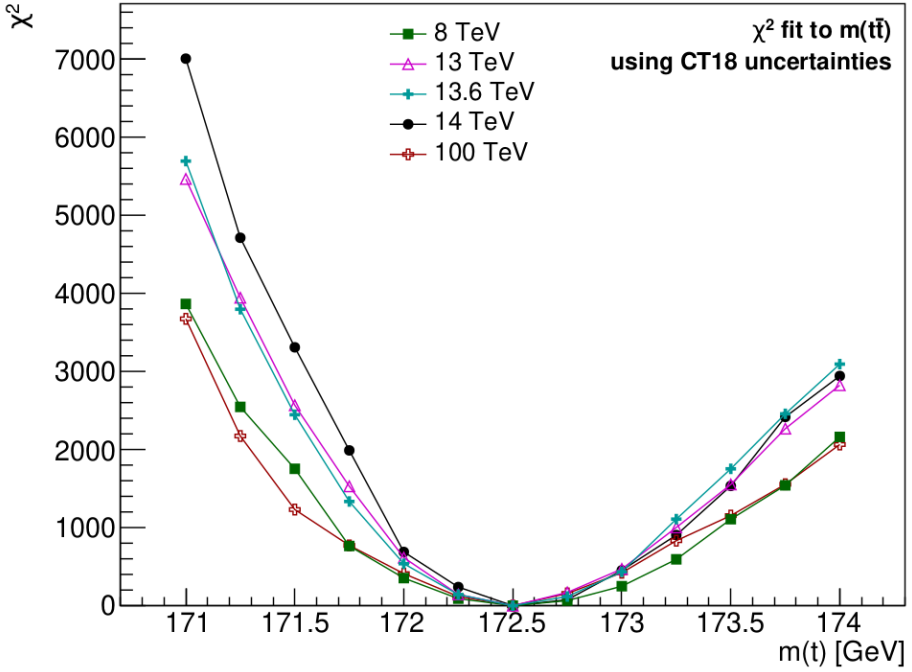
Thank you!

Backup

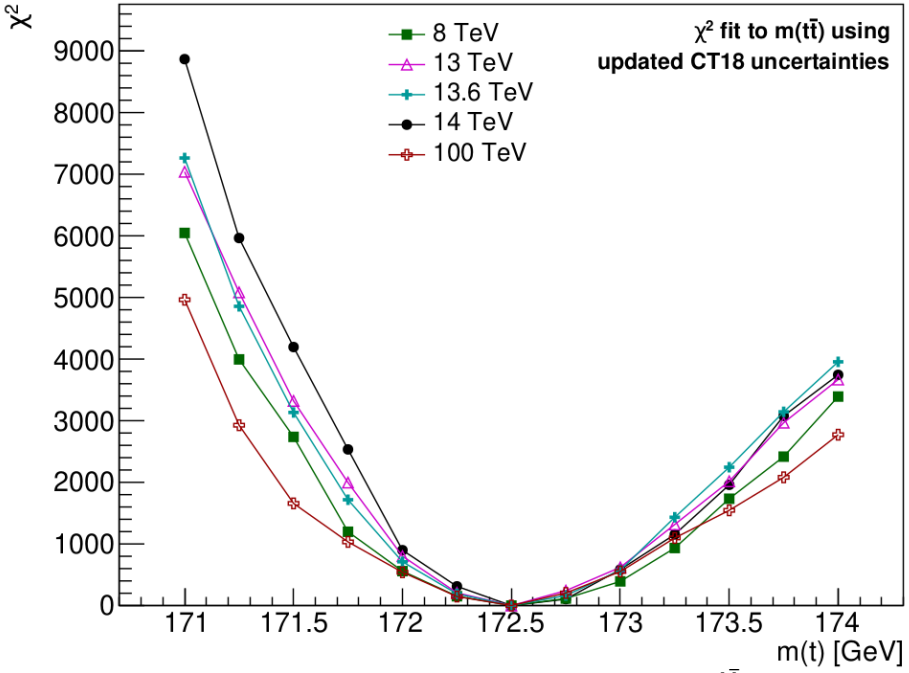
Current Top Quark Pole Masses



χ^2 Curves from $t\bar{t}$ mass

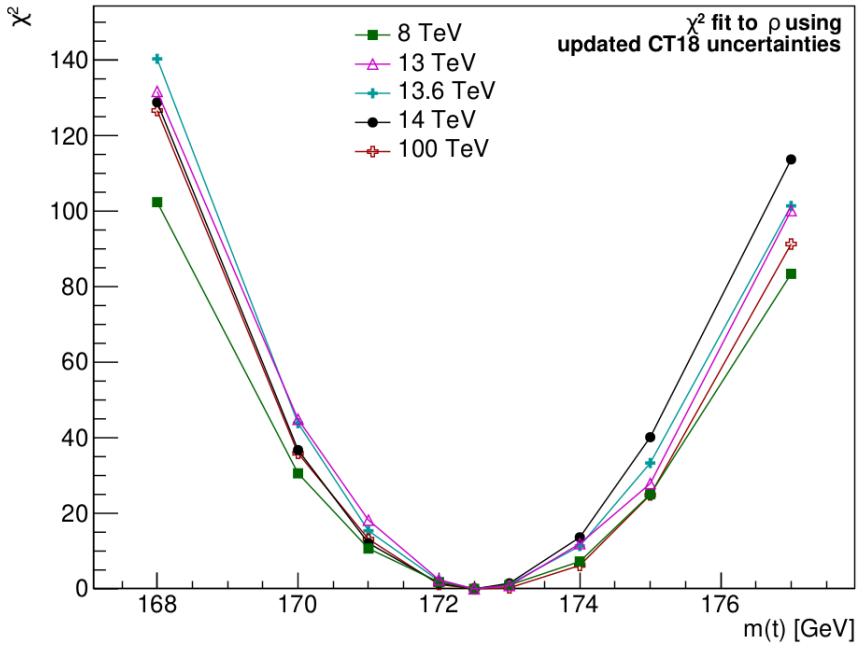


Before

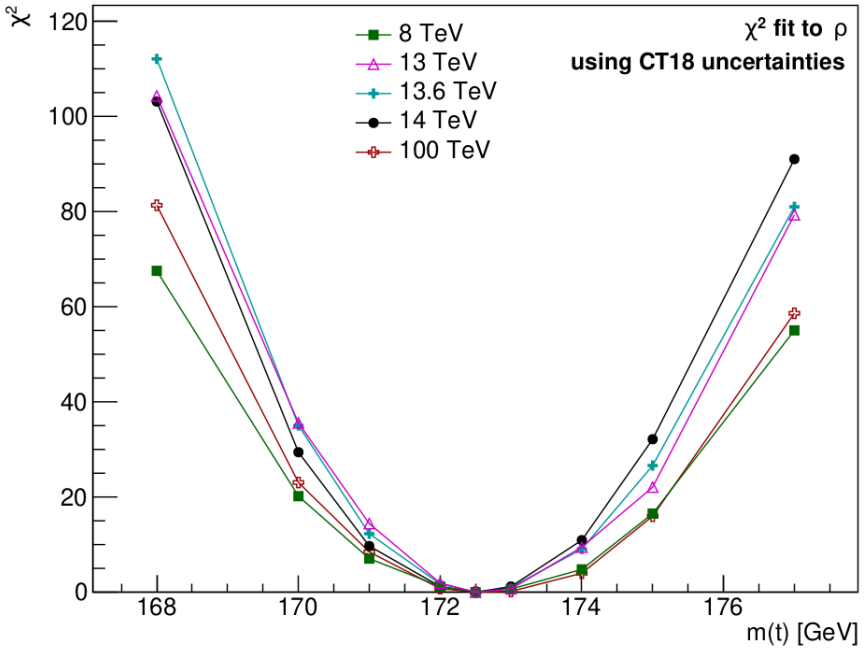


Updated with $\eta_t^{t\bar{t}}$

χ^2 Curves from $\rho^{t\bar{t}j}$



Before



Updated with $p_Z^{t\bar{t}j}$