Towards a ATLAS + CMS pole mass combination

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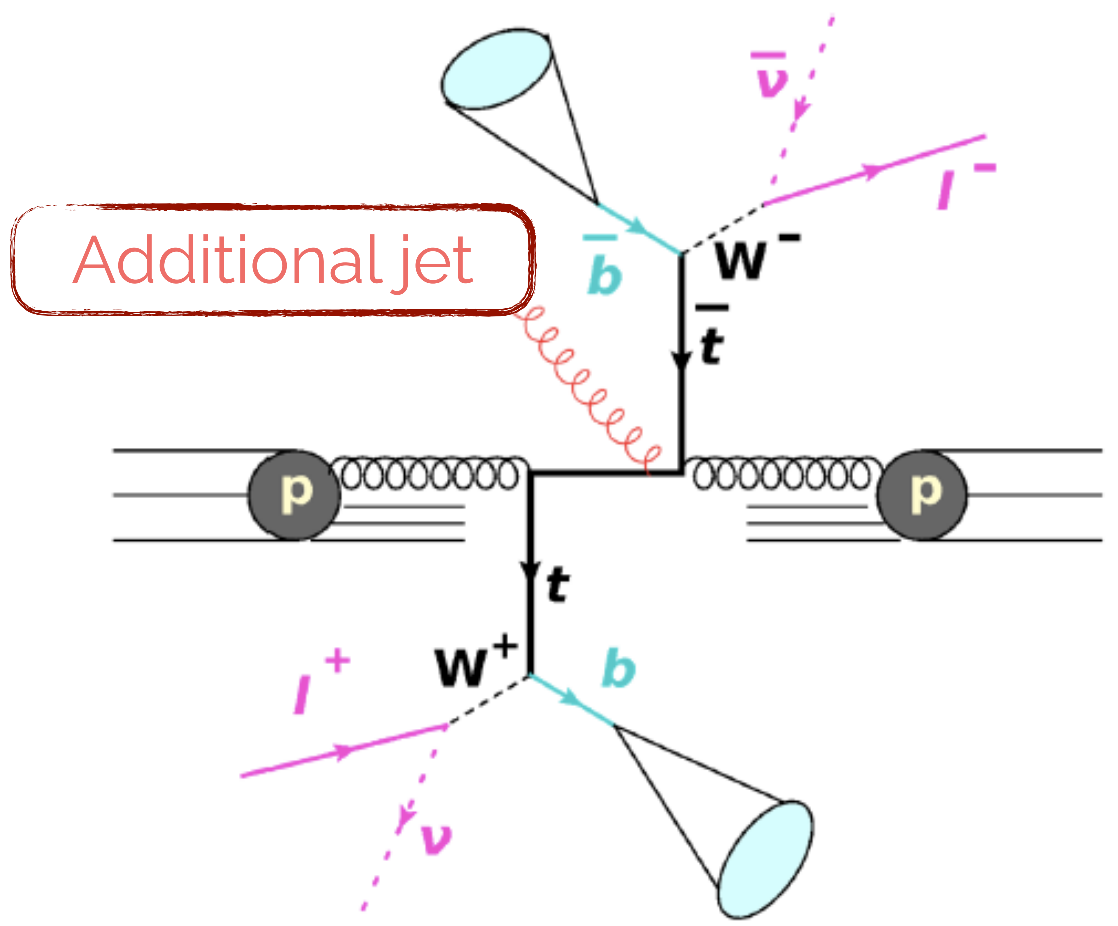
CERN[1], DESY[2], IFIC Valencia[3]

Theory-Experimental Top Quark Mass Workshop

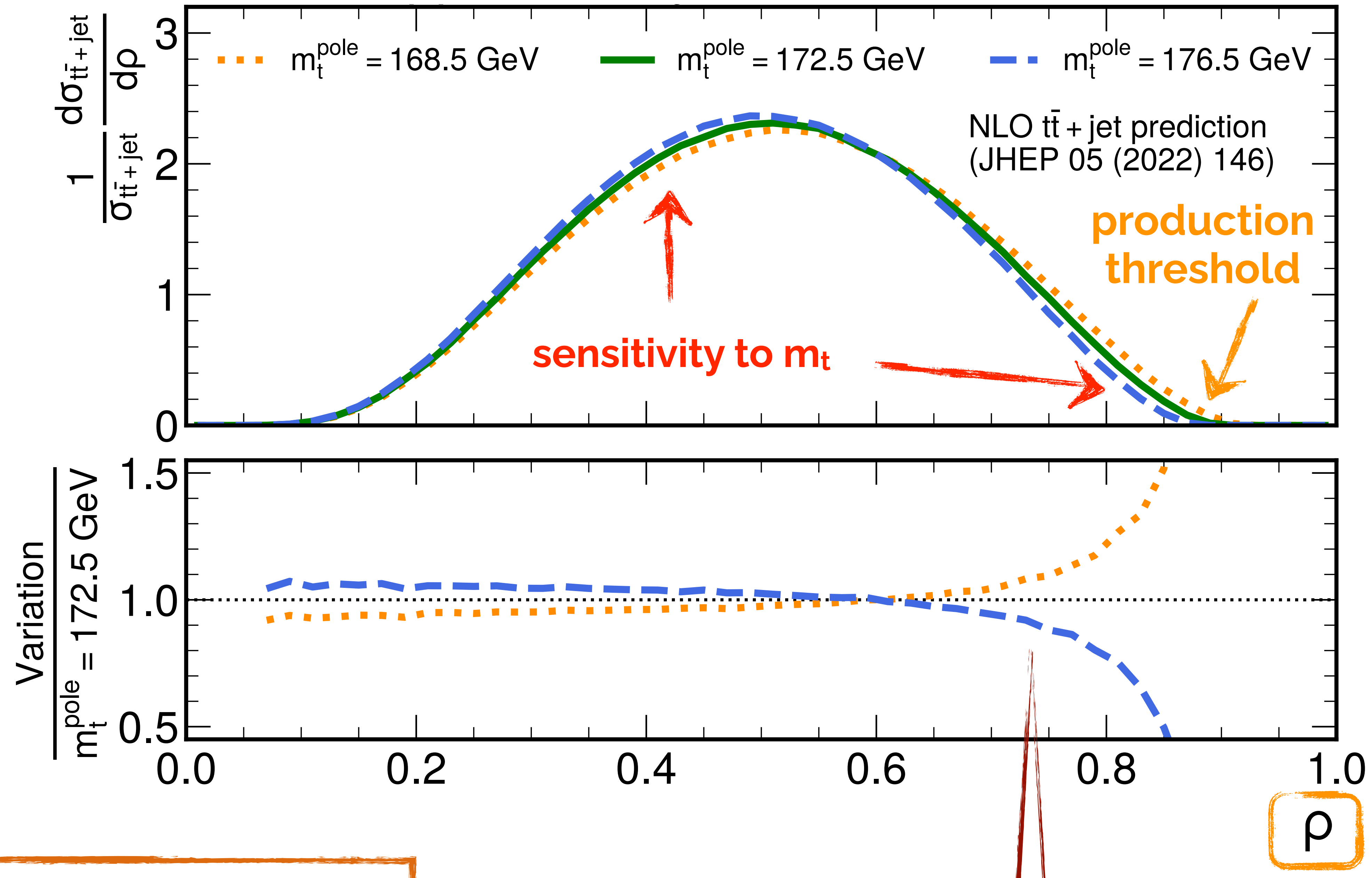
11 November 2025

Introduction - m_t^{pole} from $t\bar{t}$+jet



- First ATLAS measurement (Run 1 - 7 TeV):
  "Determination of the top-quark pole mass using $t\bar{t}$+1-jet collected with the ATLAS experiment in 7 TeV pp collisions"
  `JHEP 10 (2015) 121`

- ATLAS measurement (Run 1 - 8 TeV):
  "Measurement of the top-quark mass in $t\bar{t}$+1-jet events collected with the ATLAS detector in pp collisions at = 8 TeV"
  `JHEP 11 (2019) 150`
- CMS measurement (Run 2 - 13 TeV):
  "Measurement of the top quark pole mass using $t\bar{t}$+jet events in the dilepton final state at = 13 TeV"
  `JHEP 07 (2023) 077`
- **Recent:** ATLAS measurement (Run 2 - 13 TeV):
  "Measurement of the top quark pole mass in dileptonic $t\bar{t}$+1-jet events at = 13 TeV with the ATLAS experiment"
  `arxiv:2507.02632`



$$\rho = \frac{340\text{GeV}}{m_{t\bar{t}+\text{jet}}}$$

High sensitivity at low energies, close to production threshold

Introduction - m_t^{pole} from $t\bar{t}$+jet

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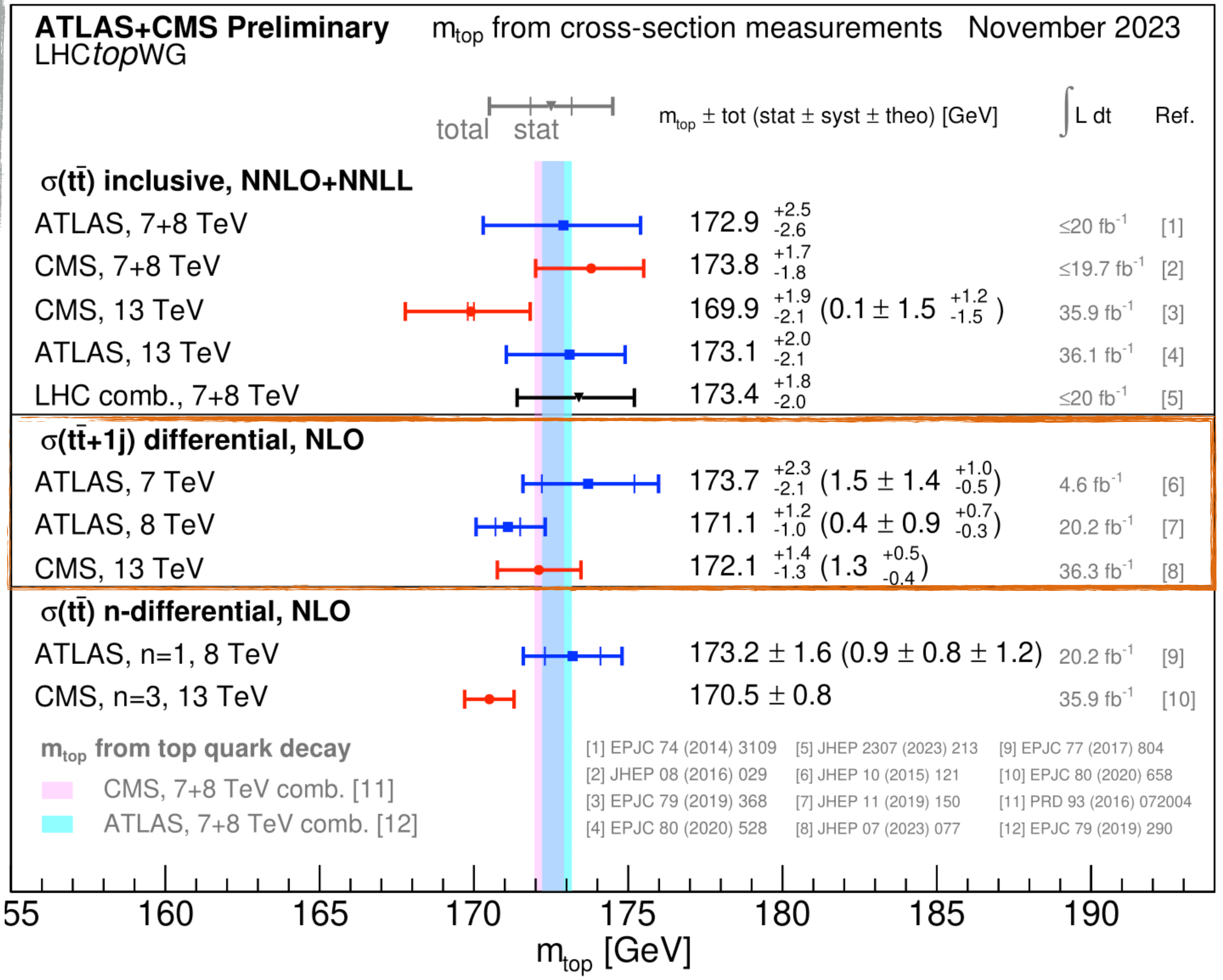
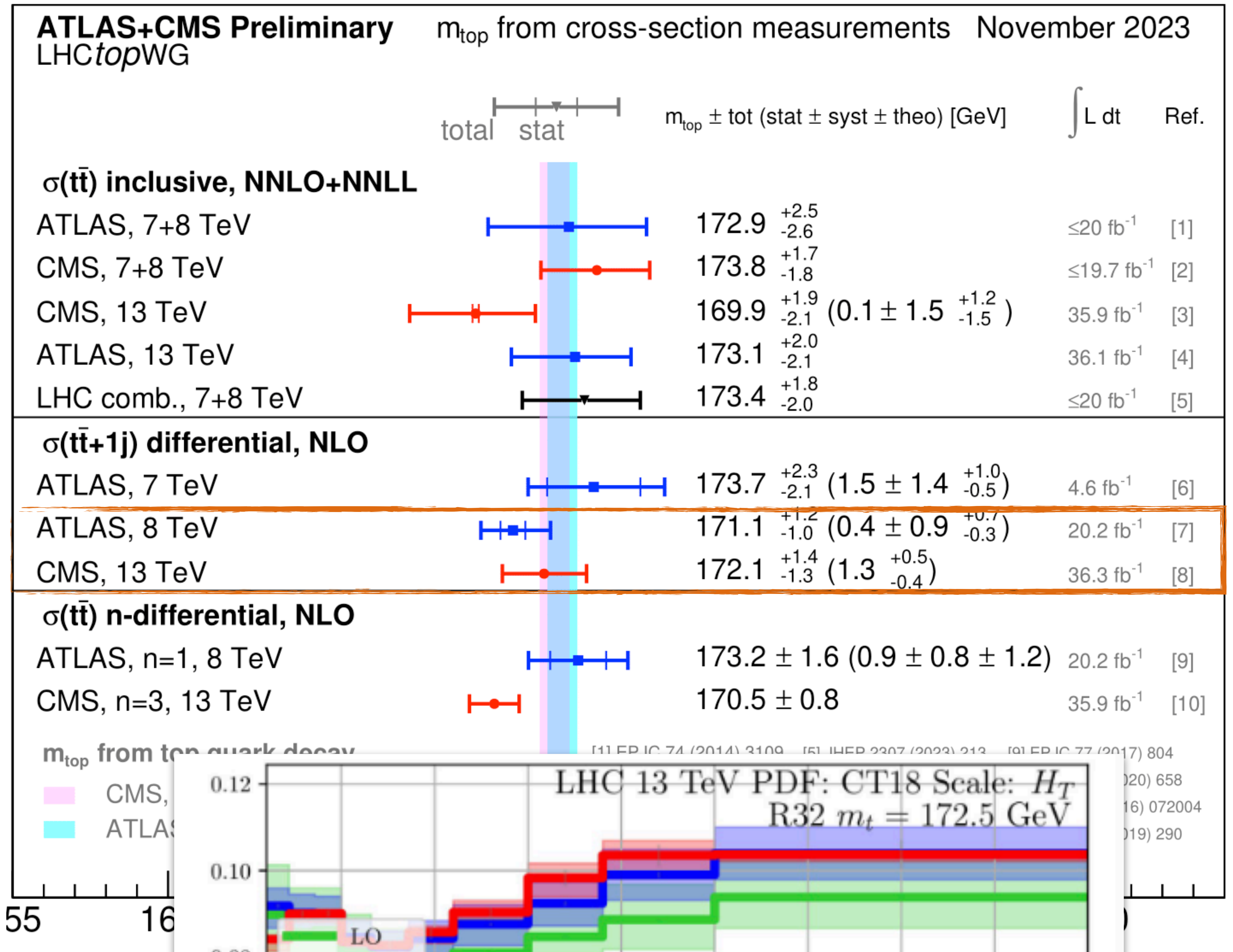
N.B. Plot needs an update

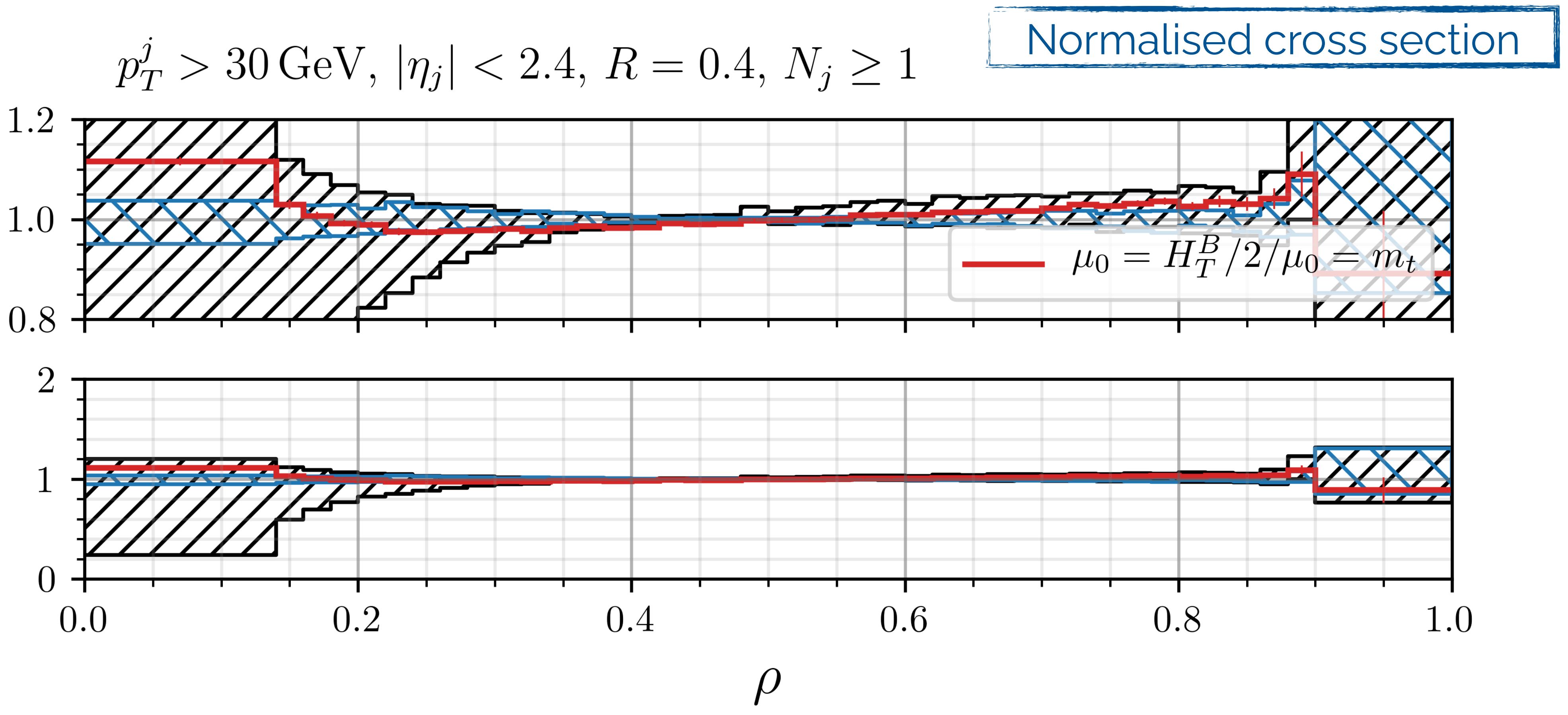


Why should we combine them?

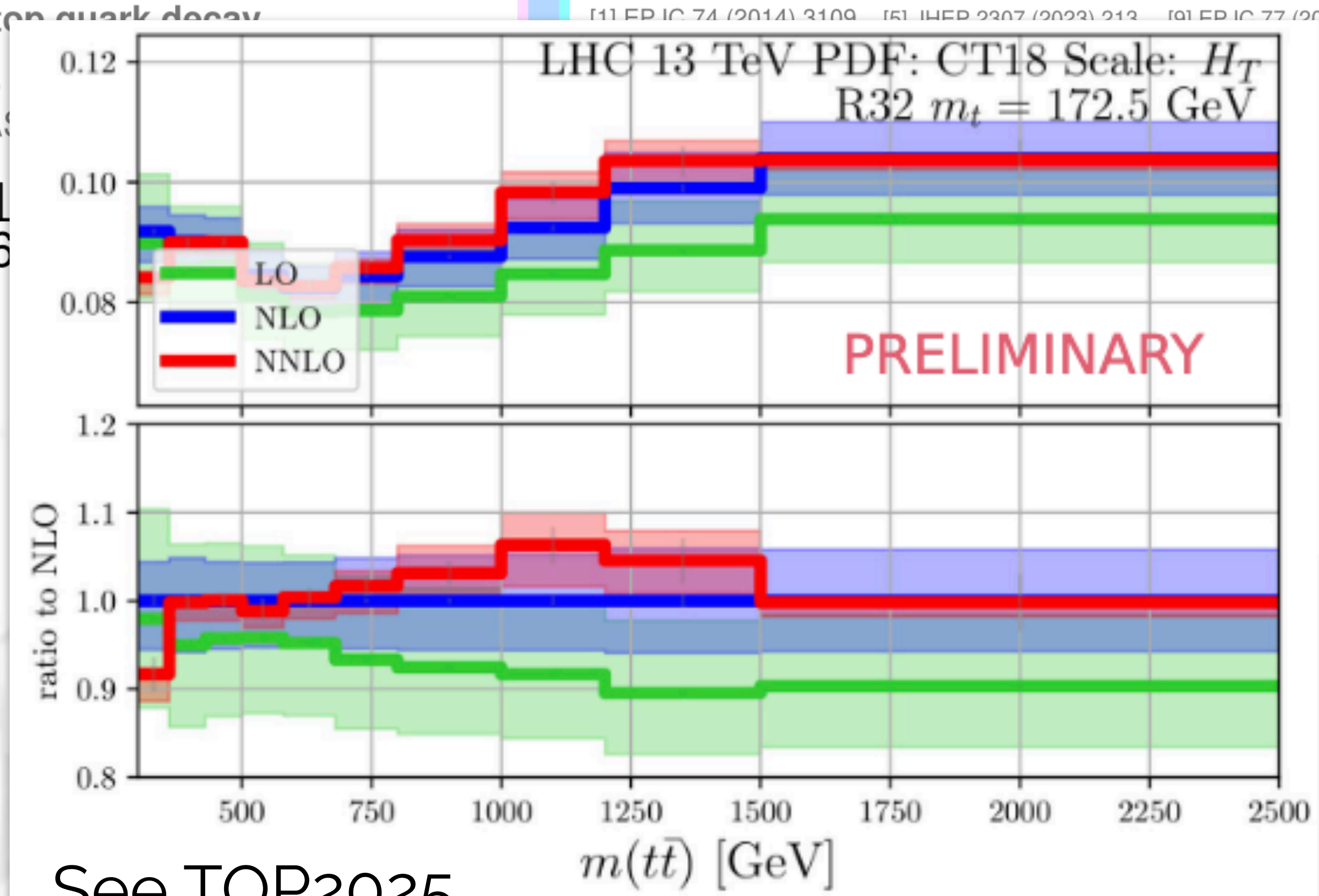
- Three of the most precise measurements of m_t^{pole}
- Largely uncorrelated uncertainties
  - 8 vs 13 TeV
  - Dilepton vs. lepton+jets channel
- "Simple" to reinterpret: 1D differential distribution
- Less affected by tt threshold
- Profit from the fact that authors are still around!
- ATLAS 7/8TeV with "old" theor. prediction:
  - New predictions using dynamical scale [JHEP 05 (2022) 146]

N.B. Plot needs an update





Even NNLO?
In exchange with the authors

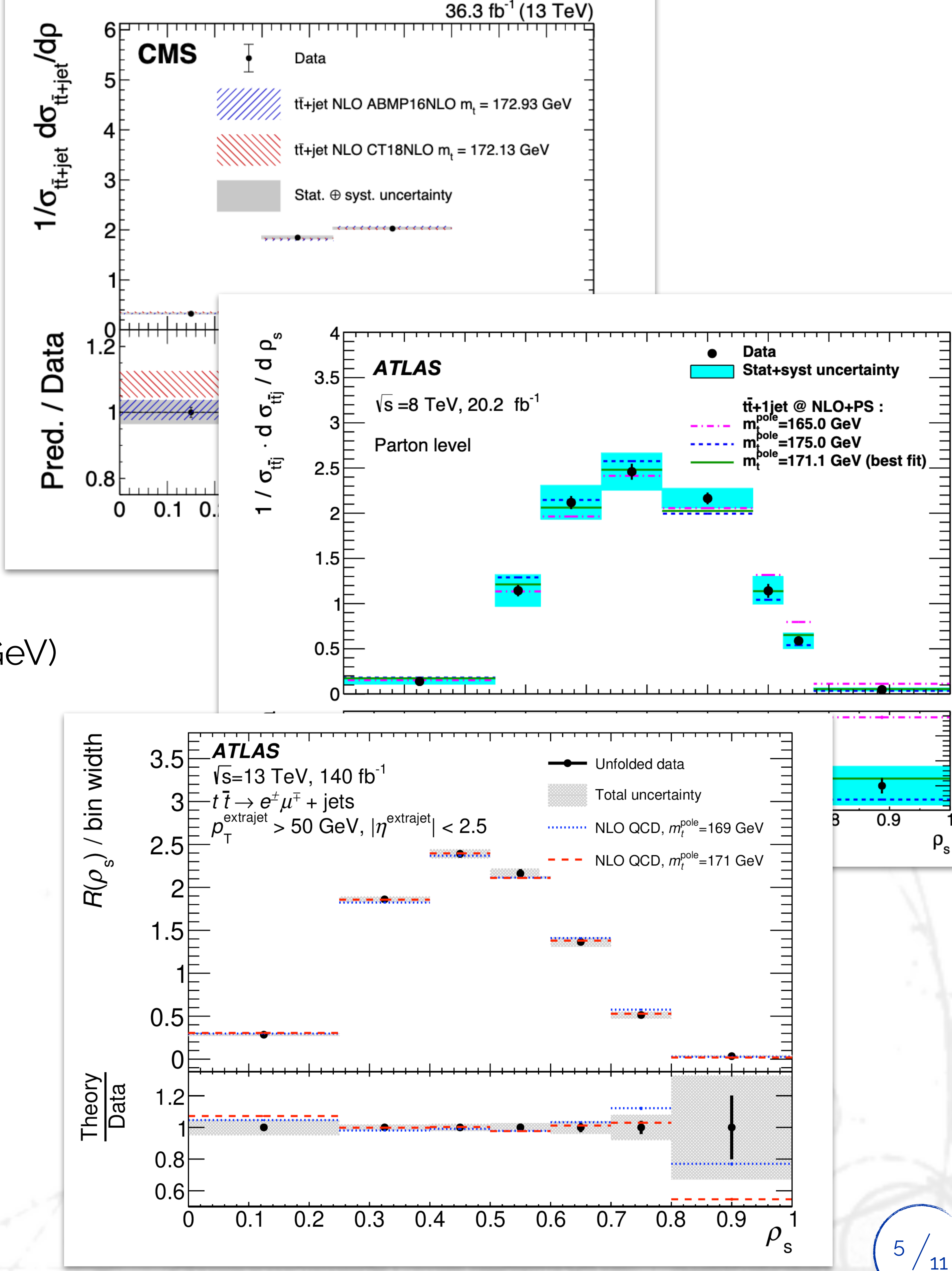


See TOP2025

How can we combine them?

- Combination of ATLAS 8/13 TeV + CMS 13 TeV measurements
  - 7 TeV result basically superseded (*and 2 GeV unc.*)
  - Establish a setup in which new results could be added
- Possible issues:
  - Different binning in ρ (4 vs. 8 vs. 7 bins)
  - Different CME (8 vs 13 TeV)
  - Different object definition at parton level (add. Jet p_T: 50 vs. 30 GeV)
  - Different theoretical prediction (fixed vs. dyn. scale)
  - Combination at top mass level is unfeasible

- Perform a combined extraction using the same theor. predictions for 8 and 13 TeV measurements
  - Needs a combined cross section
  - But also allows for reinterpretations



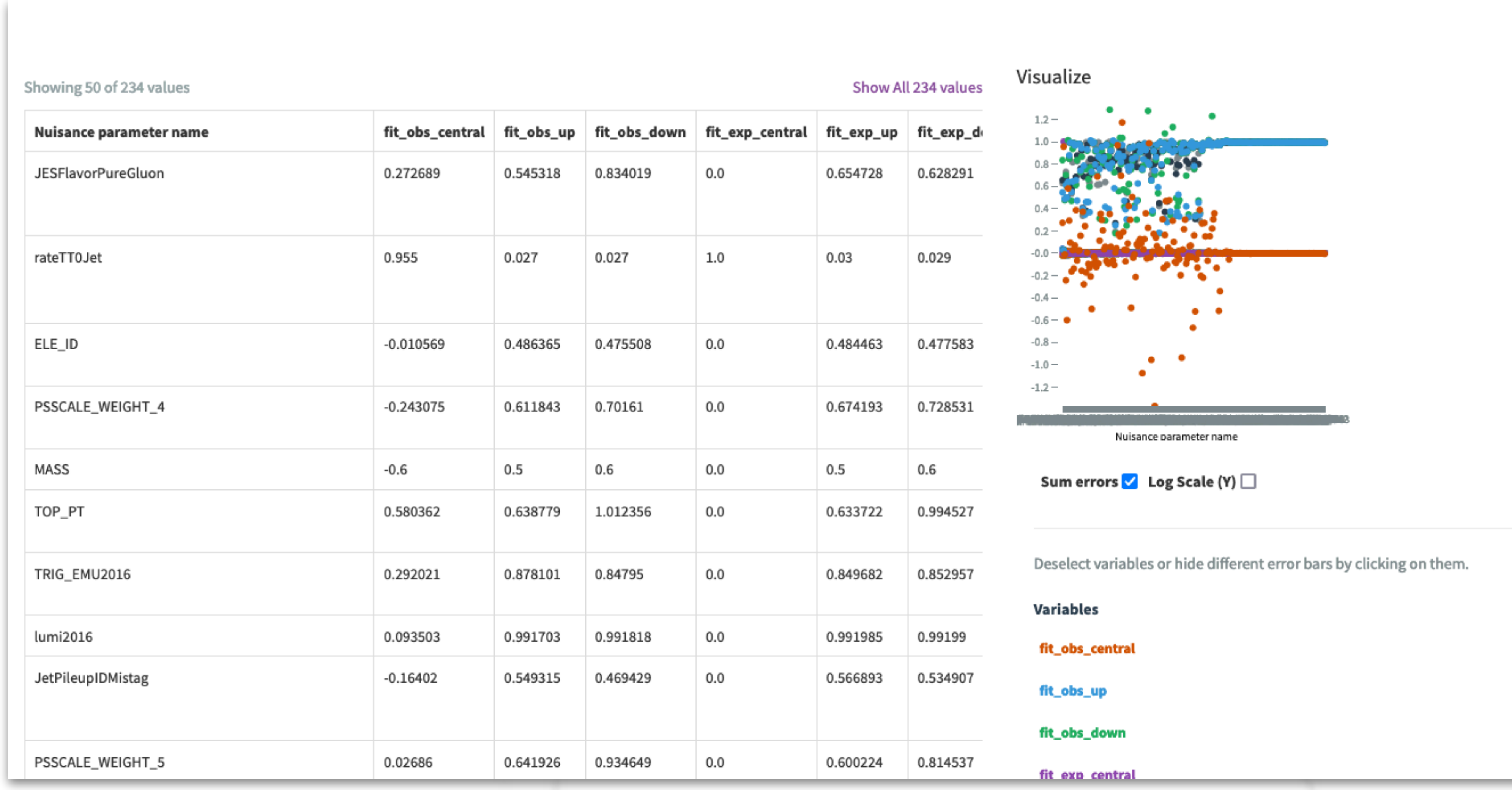
Combining the differential cross sections

- Same problems here: binning, ρ definition, CME, …
- But, we can correlate the uncertainties and get three "combined" distributions
  - Means introducing 4+8+7 POIs in the combination
  - Needs ideally a full uncertainty breakdown

- CMS cross section based on likelihood unfolding:
  - Has nuisance parameters with correlations (constraints/pulls)
  - Provides the full covariance matrix, pulls, constraints, impacts, correlations, prefit and post fit on HEPData (link)

- ATLAS result based on classical unfolding:
  - Auxiliary material only provides total normalised cov. matrix
  - Recently: ATLAS provided updated breakdown

CMS results on HEPData


Showing 50 of 234 values | Show All 234 values

Nuisance parameter name	fit_obs_central	fit_obs_up	fit_obs_down	fit_exp_central	fit_exp_up	fit_exp_d
JESFlavorPureGluon	0.272689	0.545318	0.834019	0.0	0.654728	0.628291
rateTT0Jet	0.955	0.027	0.027	1.0	0.03	0.029
ELE_ID	-0.010569	0.486365	0.475508	0.0	0.484463	0.477583
PSSCALE_WEIGHT_4	-0.243075	0.611843	0.70161	0.0	0.674193	0.728531
MASS	-0.6	0.5	0.6	0.0	0.5	0.6
TOP_PT	0.580362	0.638779	1.012356	0.0	0.633722	0.994527
TRIG_EMU2016	0.292021	0.878101	0.84795	0.0	0.849682	0.852957
lumi2016	0.093503	0.991703	0.991818	0.0	0.991985	0.99199
JetPileupIDMistag	-0.16402	0.549315	0.469429	0.0	0.566893	0.534907
PSSCALE_WEIGHT_5	0.02686	0.641926	0.934649	0.0	0.600224	0.814537

ATLAS covariance

ρ_s range	0.000 - 0.250	0.250 - 0.325	0.325 - 0.425	0.425 - 0.525	0.525 - 0.675	0.675 - 0.725	0.725 - 0.775	0.775 - 1.000
0.000 – 0.250	331.4	−187.6	95.9	30.8	−62.5	−3.7	−10.6	−5.4
0.250 – 0.325	−187.6	1278.6	−569.8	242.9	−66.9	−62.5	39.5	34.8
0.325 – 0.425	95.9	−569.8	2966.9	−1080.7	101.0	177.7	−3.4	−26.2
0.425 – 0.525	30.8	242.9	−1080.7	4737.8	−1082.2	−210.4	63.5	81.9
0.525 – 0.675	−62.5	−66.9	101.0	−1082.2	4286.1	−301.3	−248.7	−98.0
0.675 – 0.725	−3.7	−62.5	177.7	−210.4	−301.3	940.1	95.9	−75.8
0.725 – 0.775	−10.6	39.5	−3.4	63.5	−248.7	95.9	192.9	45.3
0.775 – 1.000	−5.4	34.8	−26.2	81.9	−98.0	−75.8	45.3	123.0

Combining the differential cross sections

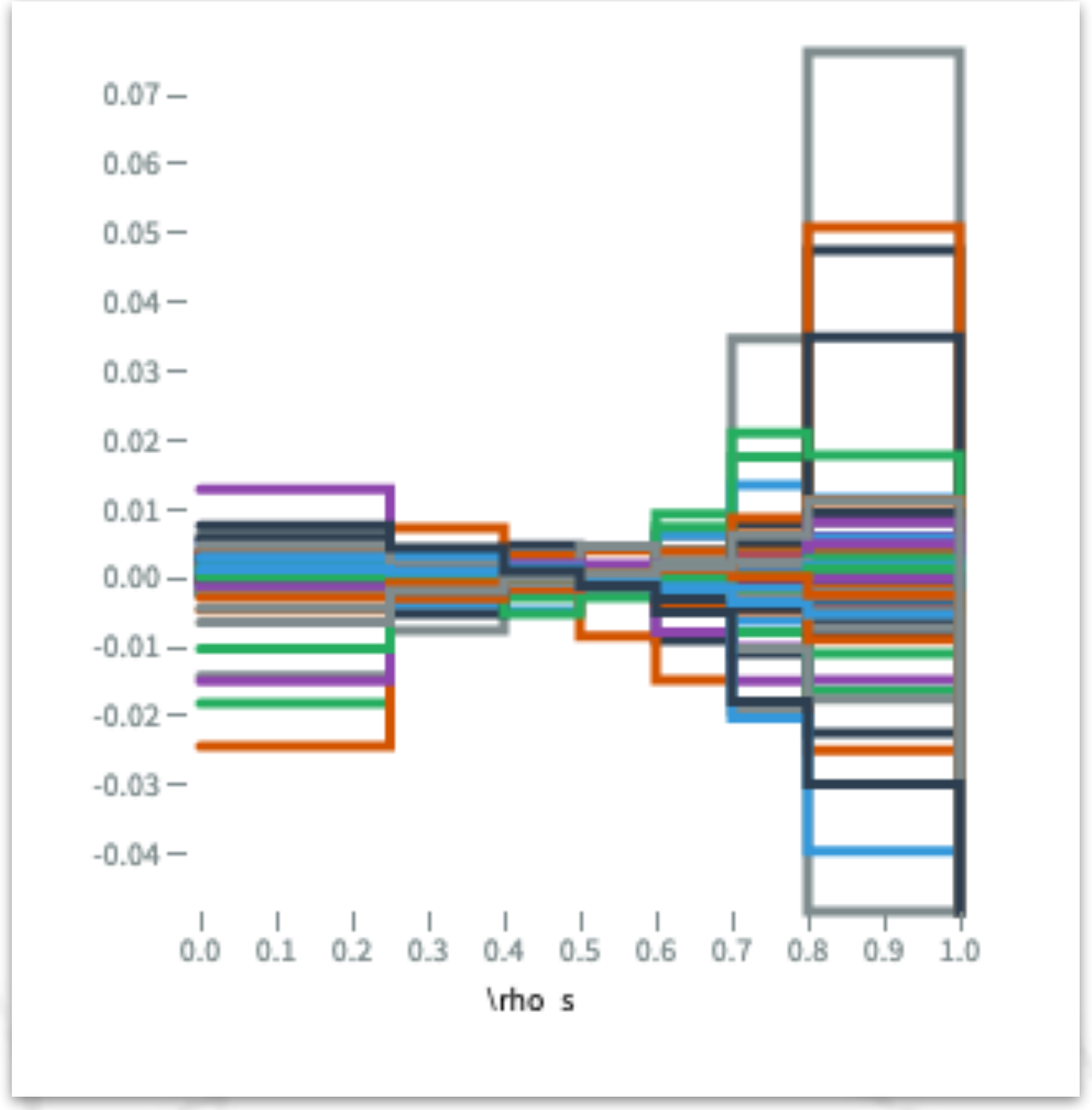
- ATLAS provided the 8 and 13 TeV results consistent format:
  - All uncertainties and their impacts on the absolute cross section
  - With the full covariance matrix for the stat. uncertainty

    → We can now combine the CMS +ATLAS absolute cross section directly!

- Consistent 8 + 13 TeV predictions
  - PDF4LHC, CT18 ***done***
  - MHSTW, ABMP, NNPDF31 ***planned*** PDFs
  - + uncertainties/mass variations

- We use Convino (Eur. Phys. J. C (2017) 77: 792)
  - Approximates the full likelihood
  - Can deal with externalised uncertainties (ATLAS) or nuisance parameters (CMS)
  - Was also used as a cross-check for the Run 1 mass combination (wrt. BLUE)

ATLAS also on HEPData



A method and tool for combining differential or inclusive measurements obtained with simultaneously constrained uncertainties

Jan Kieseler CERN, 1211 Geneva 23, jan.kieseler@cern.ch

August 2, 2018

Looking at some impacts: no correlation setup

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- As expected, no cross-impacts

Looking at some impacts: JES correlation setup

CMS bins

ATLAS bins

x-axis: relative impact in % (max. is 20%)

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt modeling impact the other measurement, although only JES correlated by hand

Looking at some impacts: JES+modeling correlation setup

x-axis: relative impact in % (max. is 20%)

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt modeling impact the other measurement, although only JES correlated by hand
- b jet efficiency and MC stat play a minor role, too

Looking at some impacts: JES+modeling+tt0jet correlation setup

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt modeling impact the other measurement, although only JES correlated by hand
- b jet efficiency and MC stat play a minor role, too
- Explicitly correlated tt0jet makes no difference, entered already before

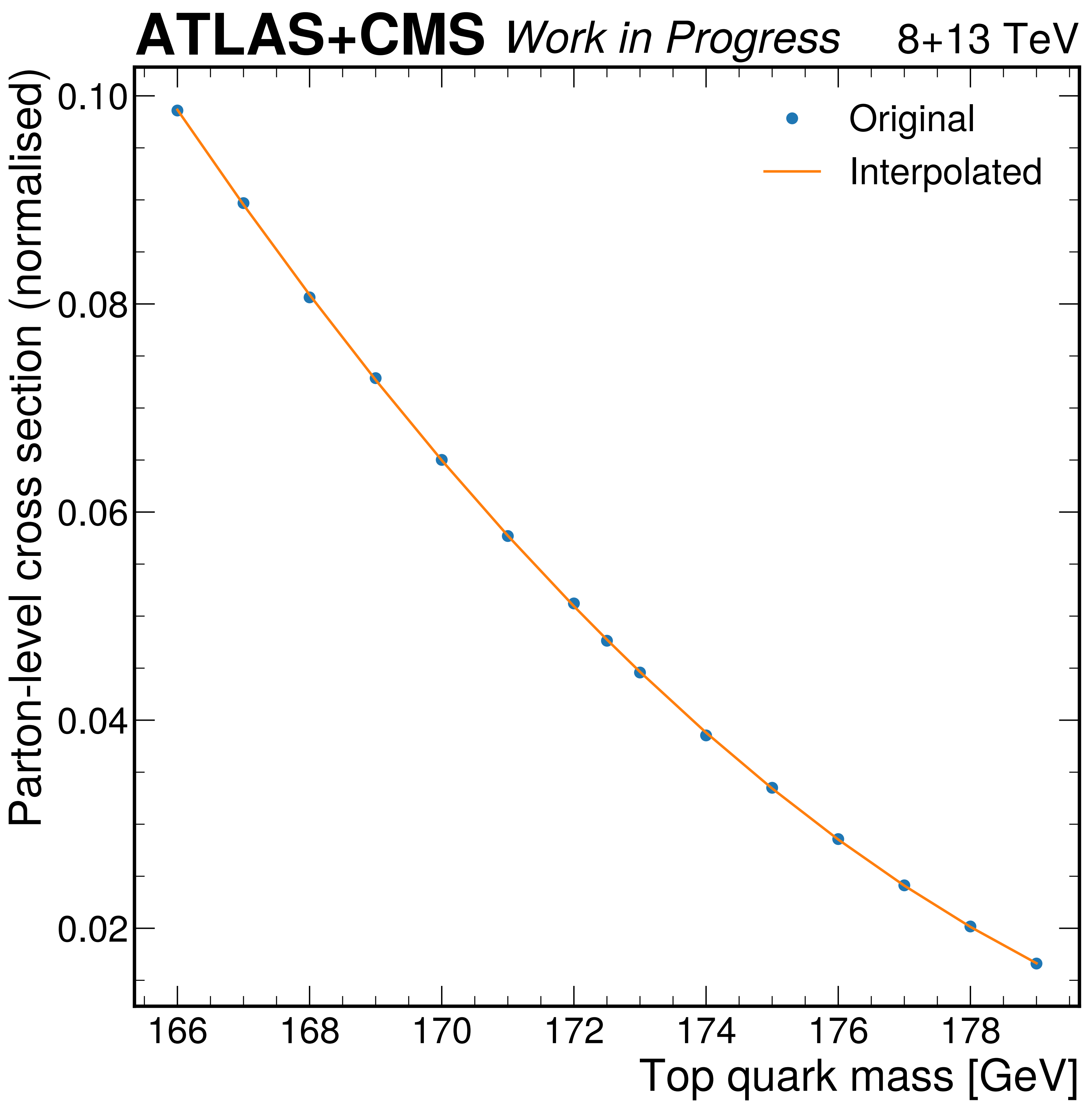
Technical implementation - fitting setup

Thanks mostly to Matteo!

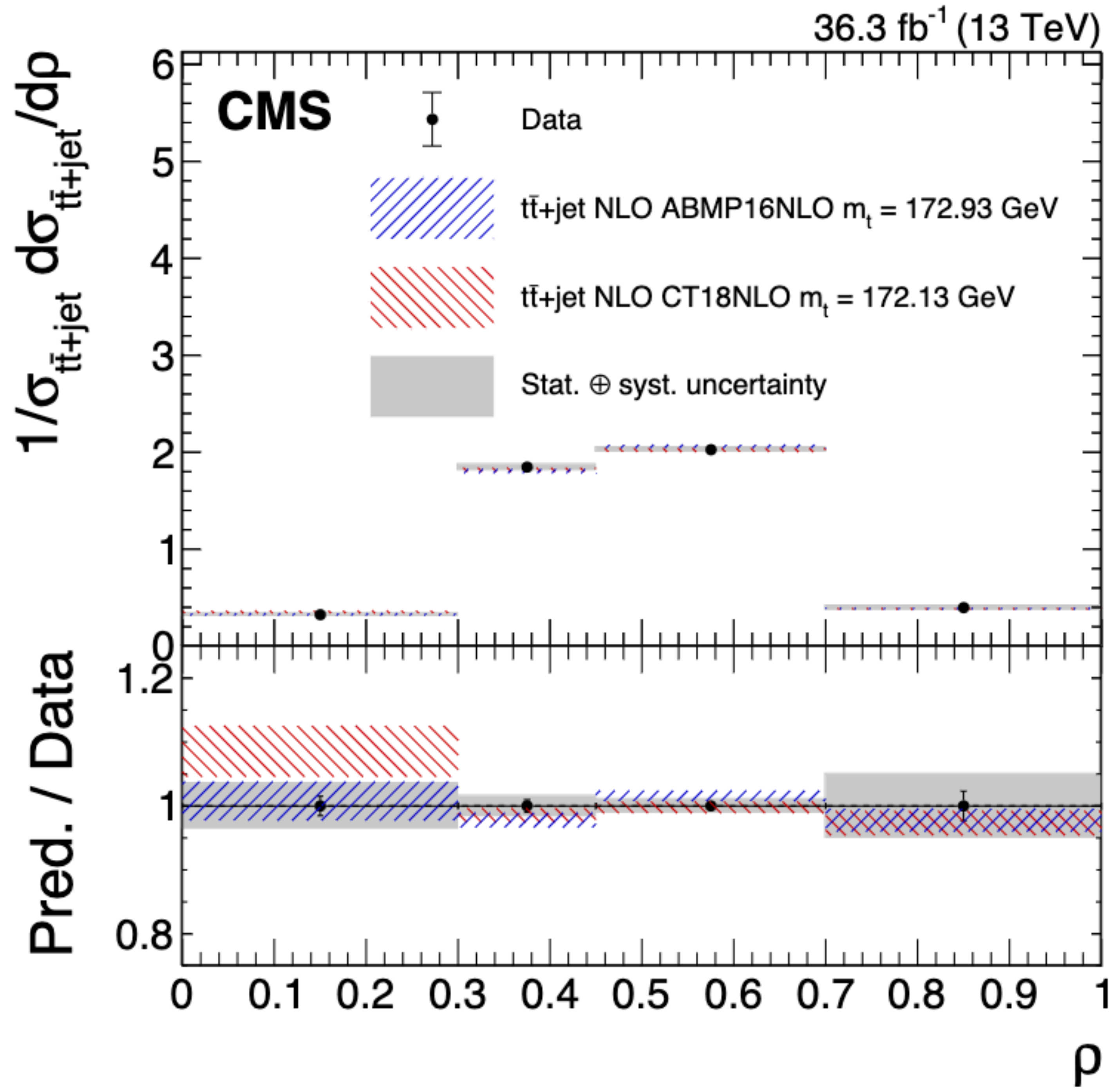
- Flexible setup in place: repository here
  - Fit "individual" measurements or combined 8+13 TeV cross sections
  - Consistent correlation of PDF uncertainties between centre-of-mass energies
  - Correlated/uncorrelated variation of ME scales
  - Freezing PDFs, different minimisers, …

- Using consistent NLO tt+j calculations (Thanks to Andrej!)
  - Powheg FO, alphaS = 0.118, scale = ET/2
  - Effectively smoothing theory prediction via polynomial interpolation of x-sec vs mass in each rho bin

- NB: For all results shown, I use the CT18NLO PDF set
- More to come soon (predictions for 8 TeV are running..)



Cross-check: CMS 13 TeV



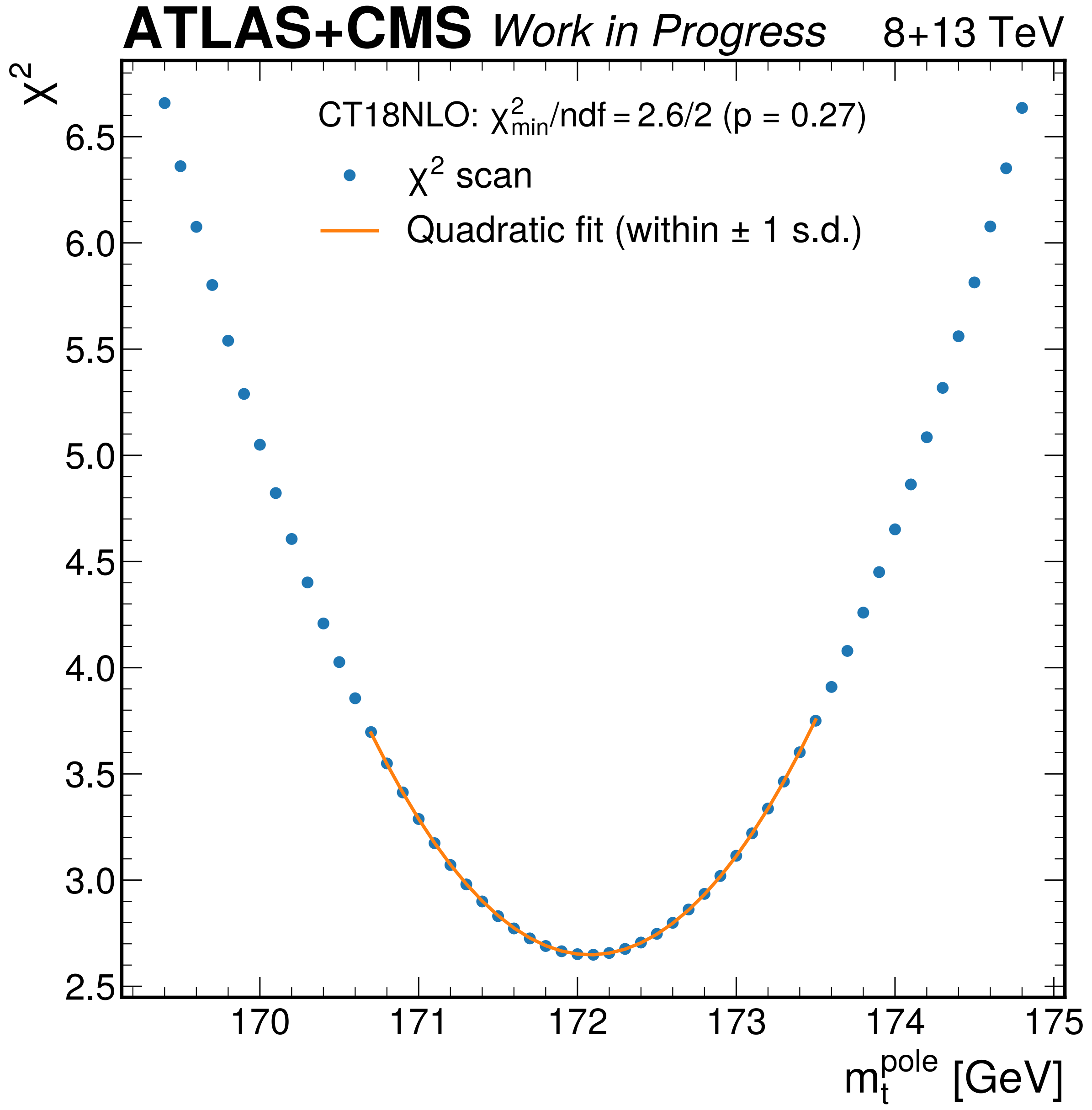
Published result

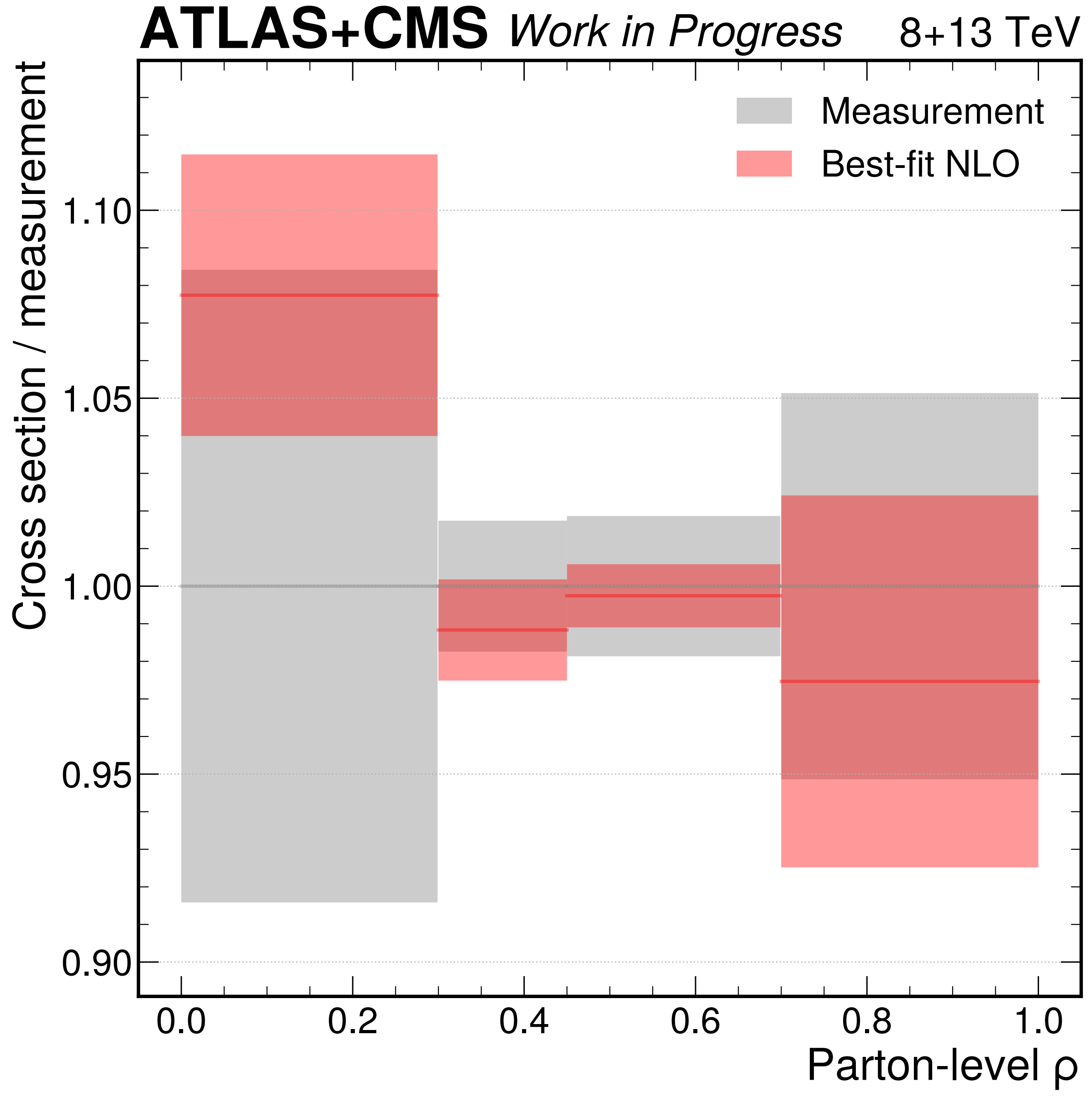
CT18 NLO (scale = HT/2)

$$m_t^{pole} = 172.13 \pm 1.34\,(\text{fit})\,^{+0.50}_{-0.40}\,(\text{scale})\,\text{GeV}$$

- Using the HEPData public info in the same setup as used for the combination
  - But, profiling the PDFs as in m_t running paper
  - **m_t = 172.08 ± 1.29 (exp) ± 0.41 (PDF) GeV**
  - Scale uncertainty = +0.32 -0.43 GeV
  - Good closure and consistent results (within 50 MeV!

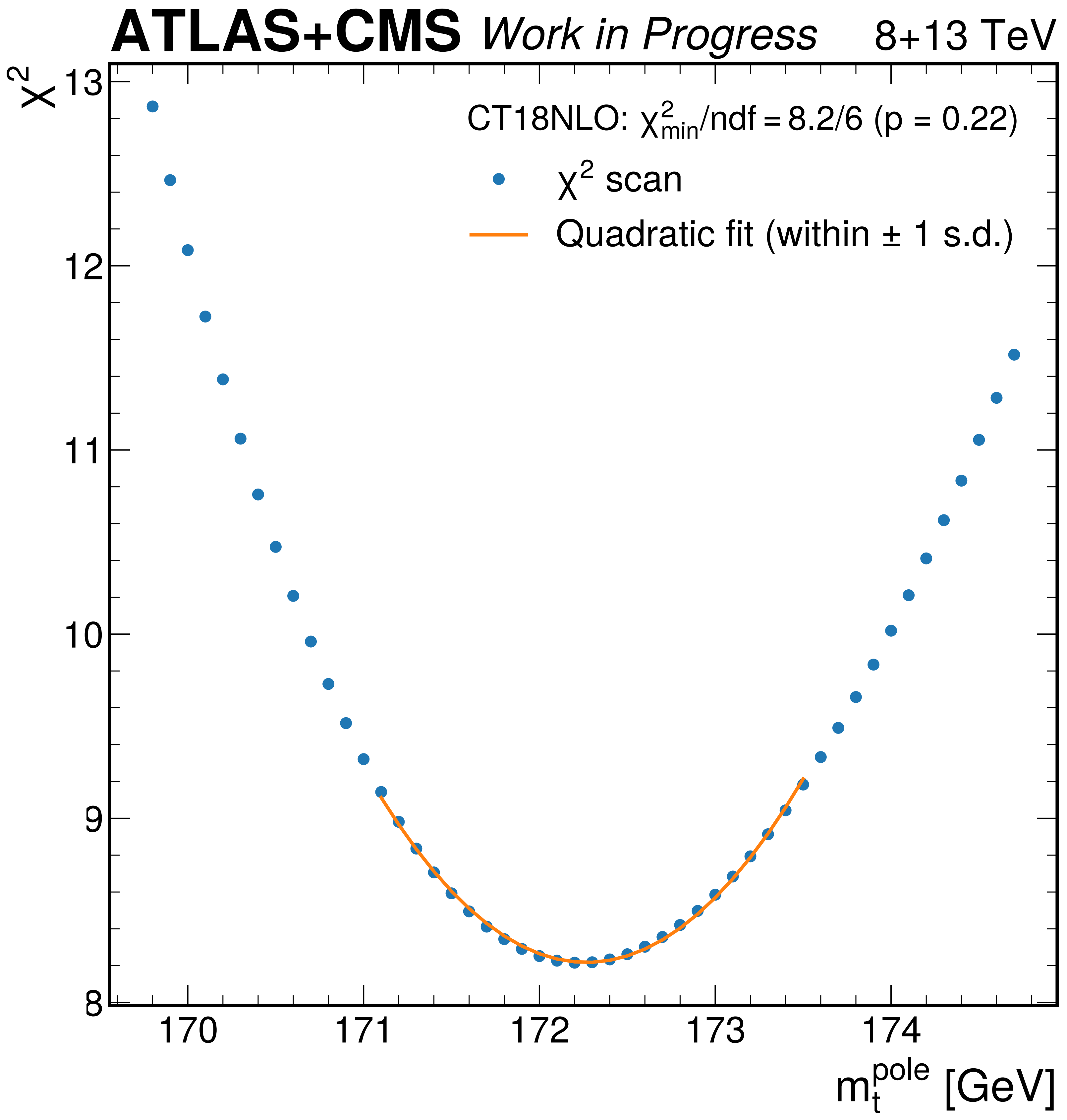
Theory band includes PDFs + m_t^{pole} post-fit uncertainty





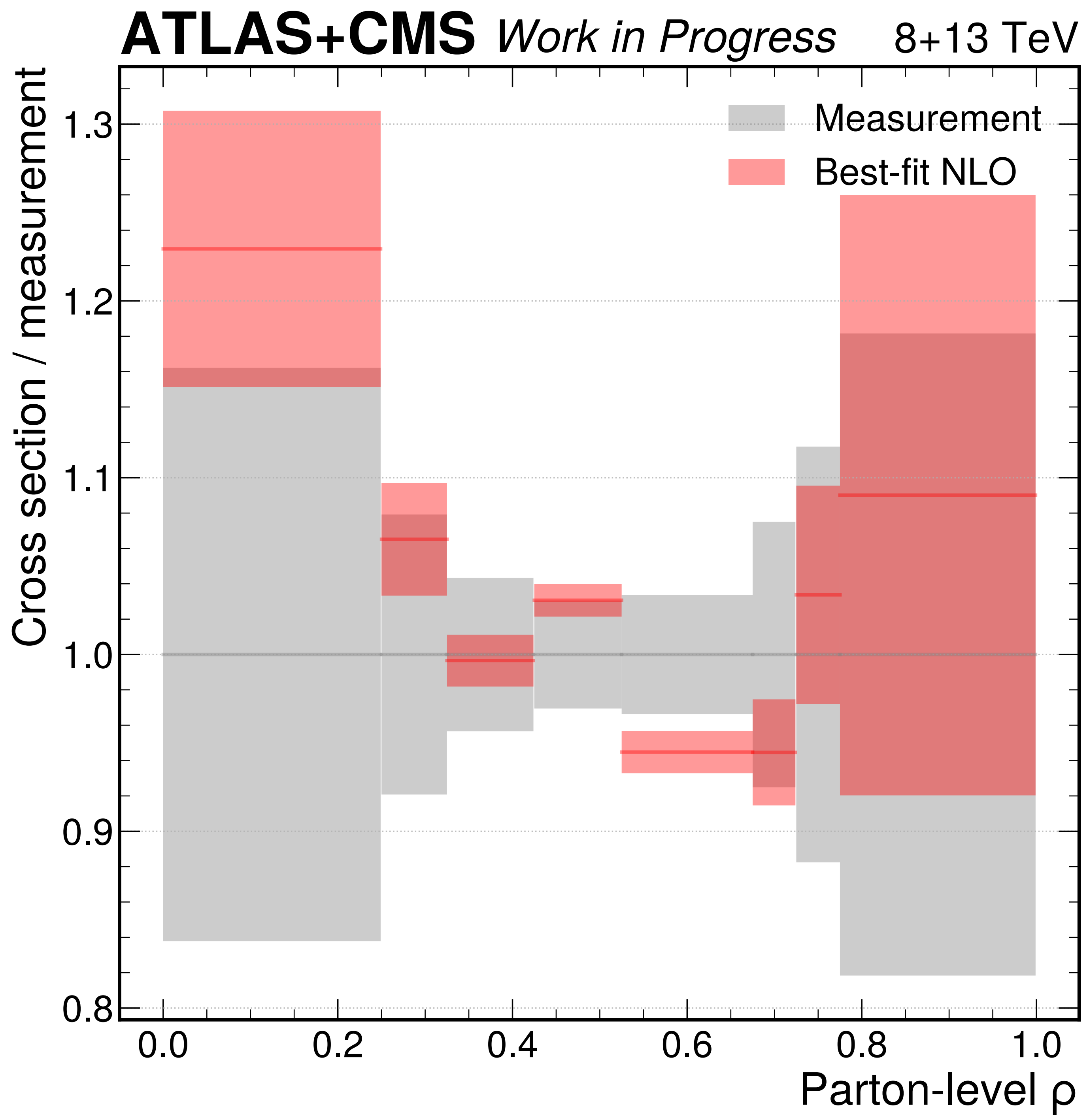
ATLAS reinterpretation

- Results not directly comparable:
  - Different theory prediction (dyn. scale)
  - Different fit setup (PDF and systematics in the chi2 fit)
  - **m_t = 172.23 ± 1.19 (exp) ± 0.27 (PDF) GeV**
  - Scale uncertainty = +0.11 -0.02 GeV
  - Changes reproducible with original analysis setup and new fit strategy



Published result

$$m_t^{pole} = 171.1 \pm 0.4\,(\text{stat}) \pm 0.9\,(\text{syst})\, ^{+0.7}_{-0.3}\,(\text{theo})\ \text{GeV}$$



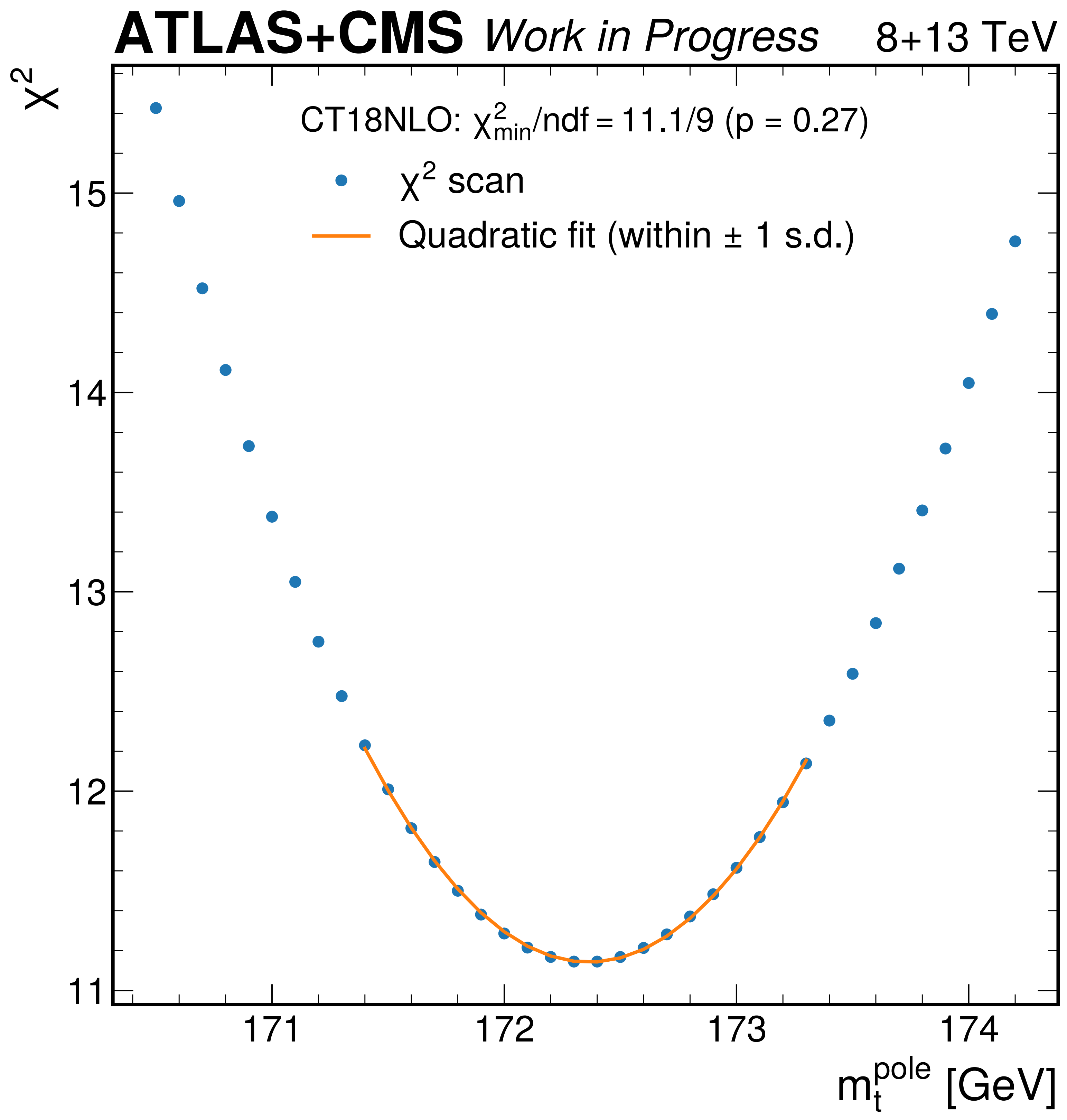
Combination results v1: CMS - ATLAS 8 TeV

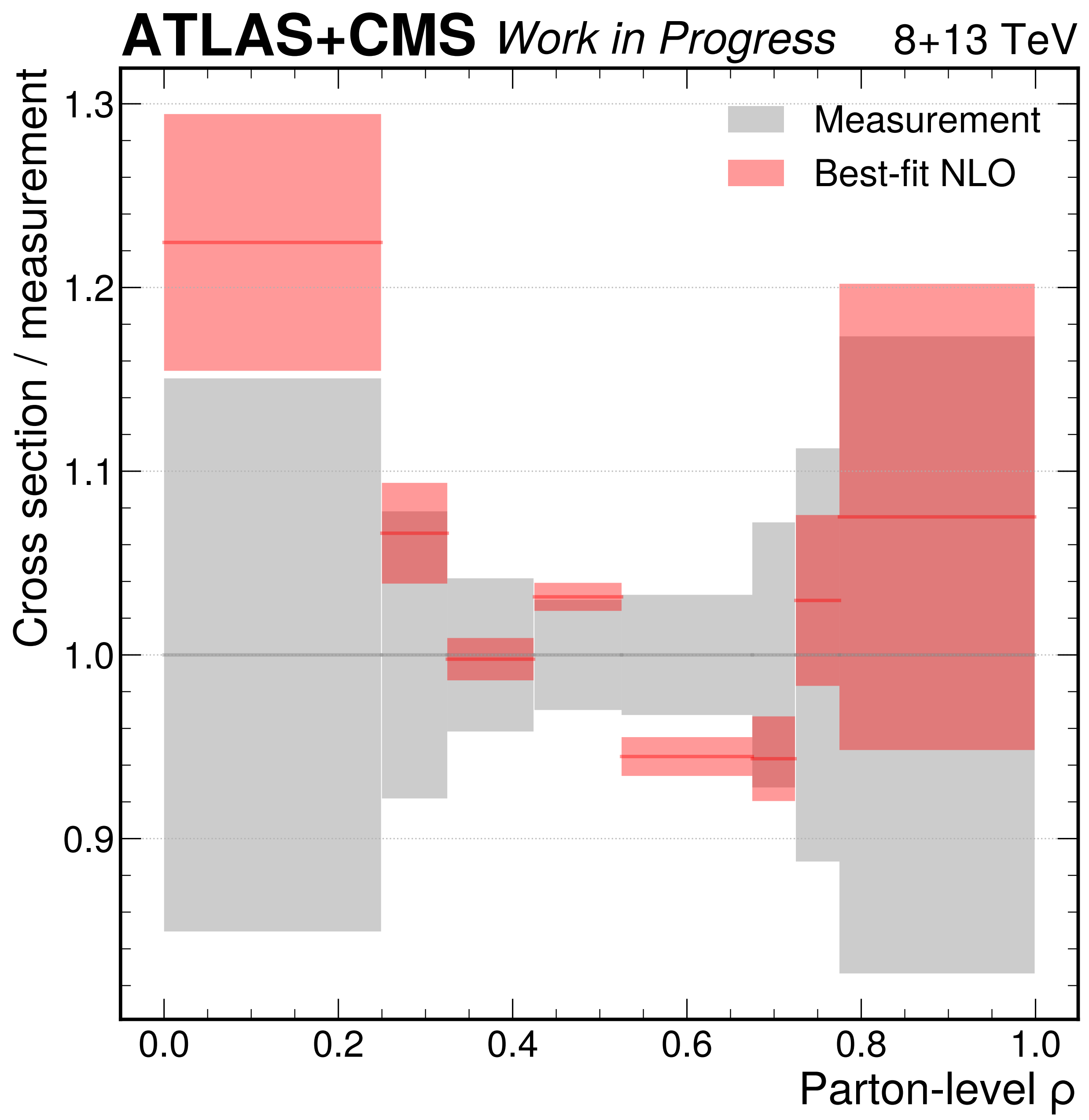
- mt = 172.25 ± 0.87 (exp) ± 0.28 (PDF) GeV
  - → 0.91 (exp+PDF) GeV

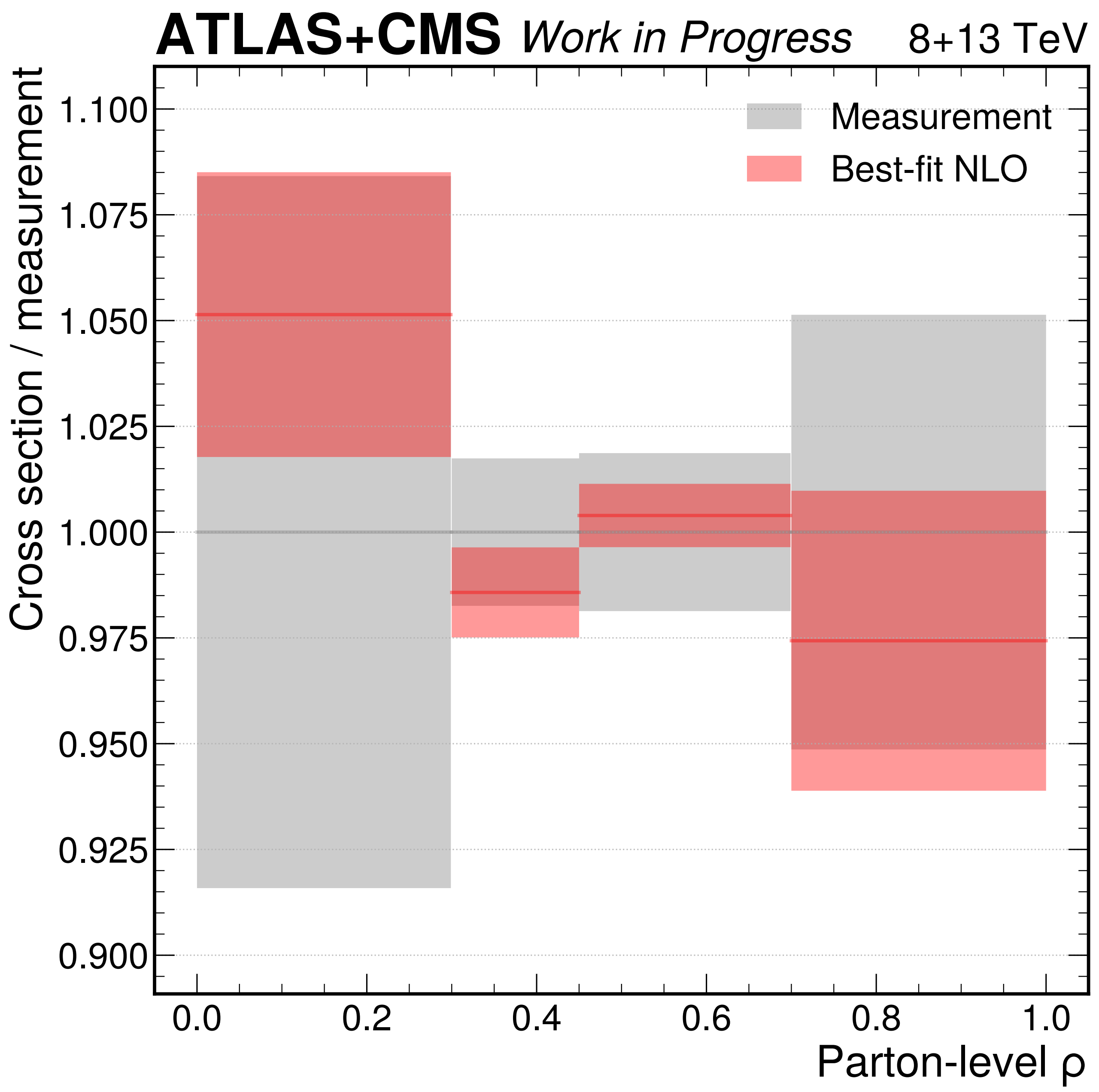
- Correlated scale uncertainty = +0.18 -0.19 GeV
- Uncorrelated scale uncertainty = +0.14 -0.18 GeV

0.92 GeV total

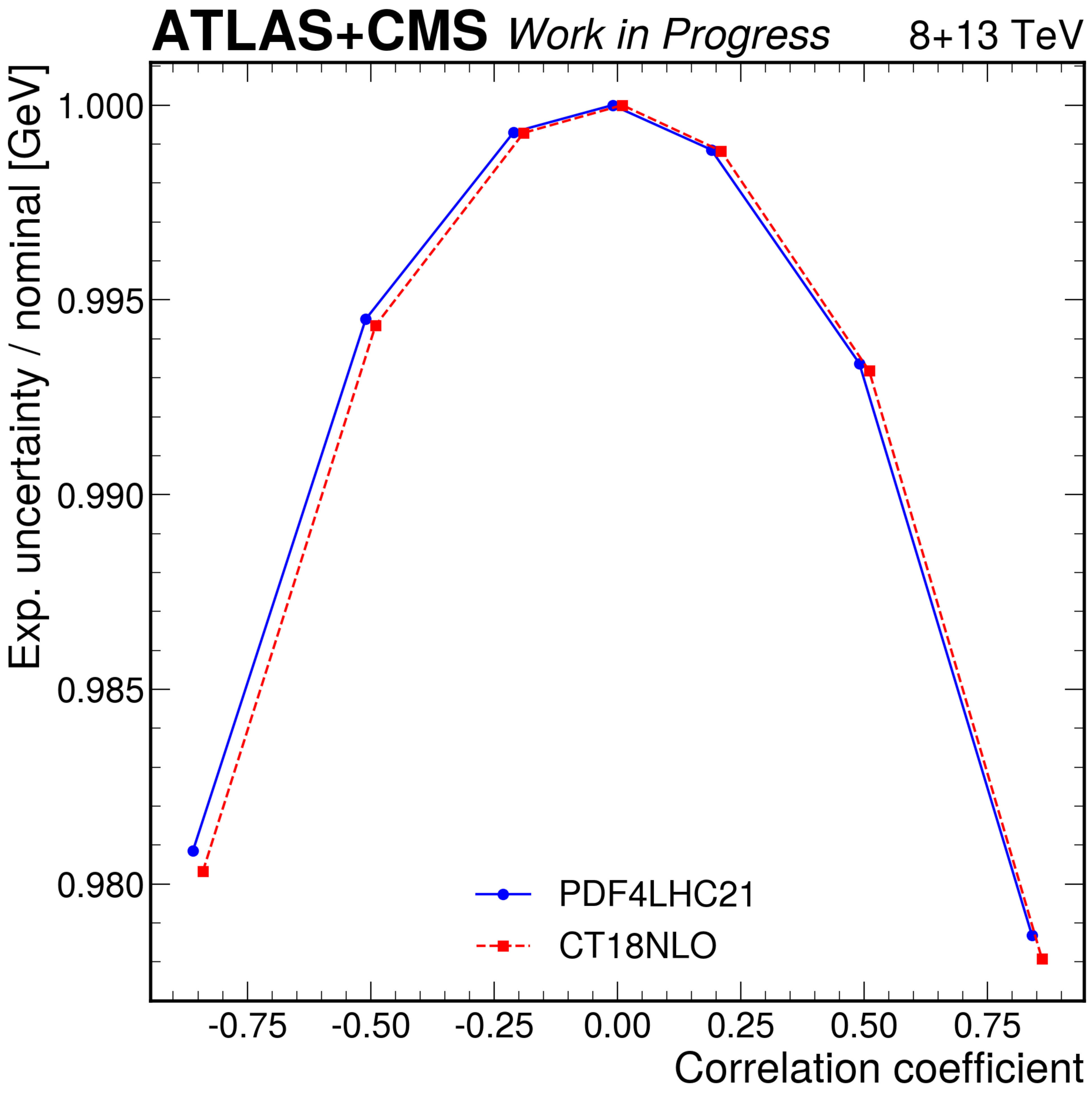
- → more than 20% improvement wrt. most precise input (ATLAS)

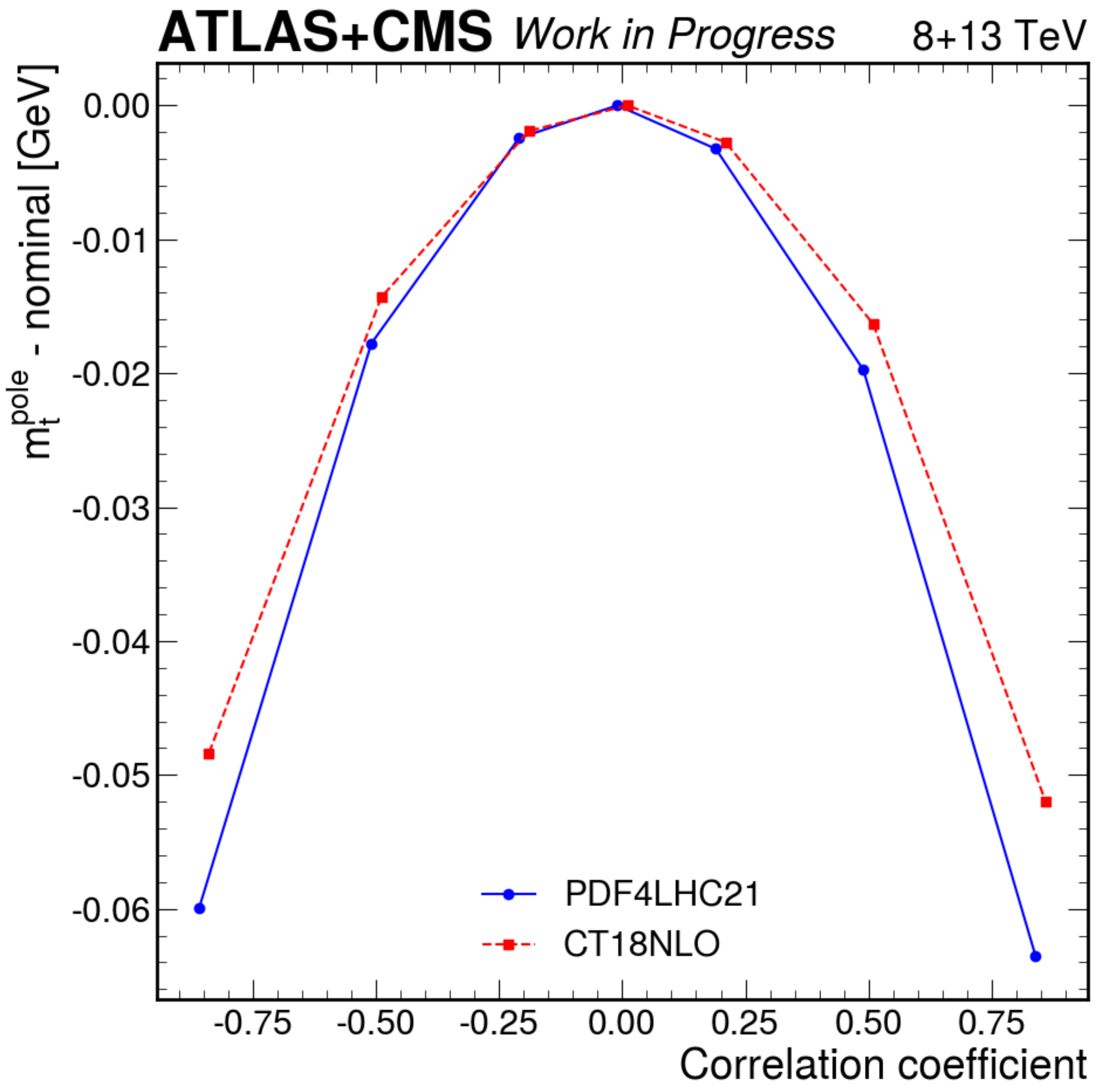






Combination results v1: dependence on tt+0jet corr. assumptions

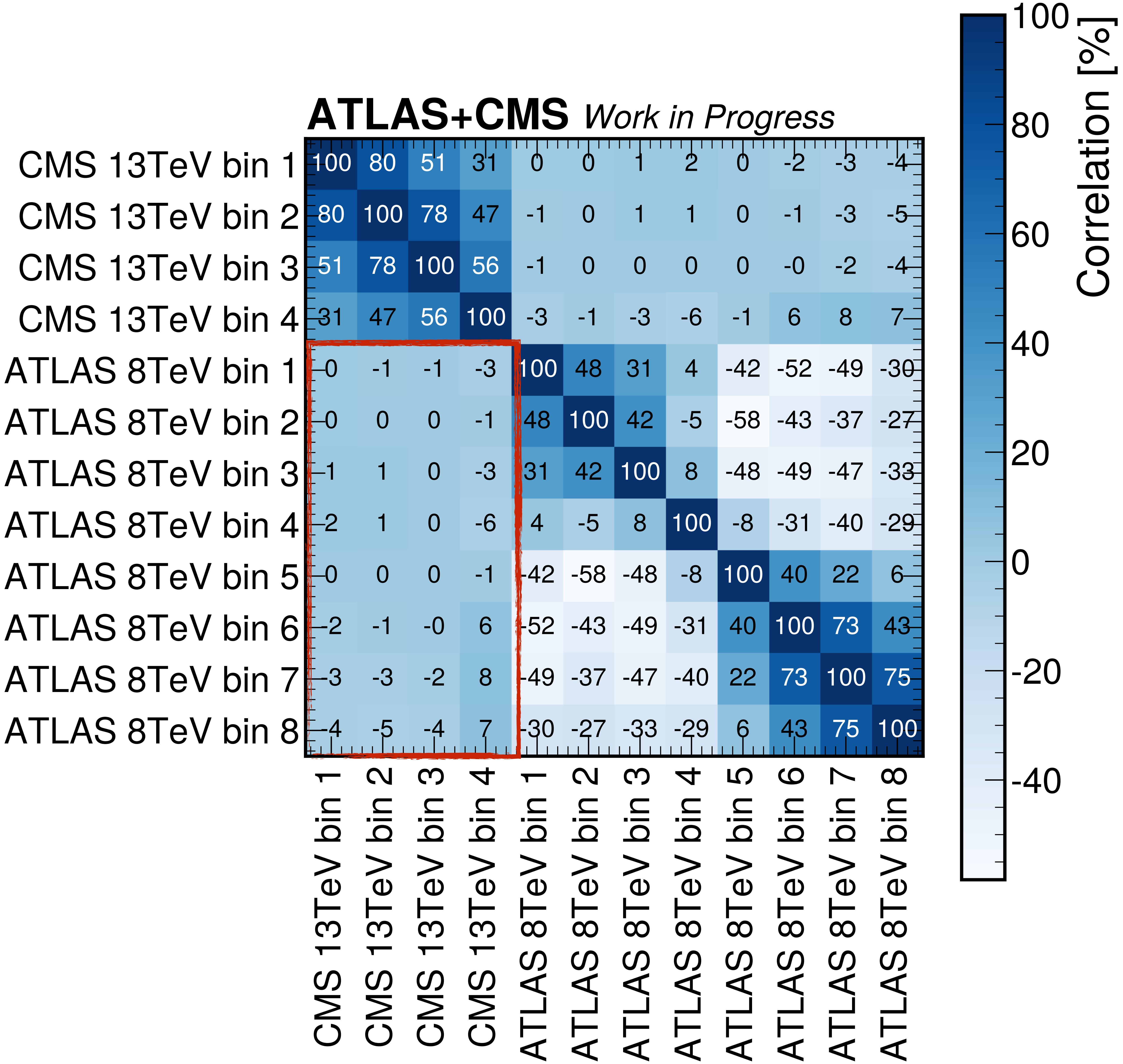




- Negligible effect for 8 TeV combination (focusing on dominant ME uncertainty)
- 60 MeV effect on central value, uncertainty changes less than 2%

Combination results v1: post-fit correlations

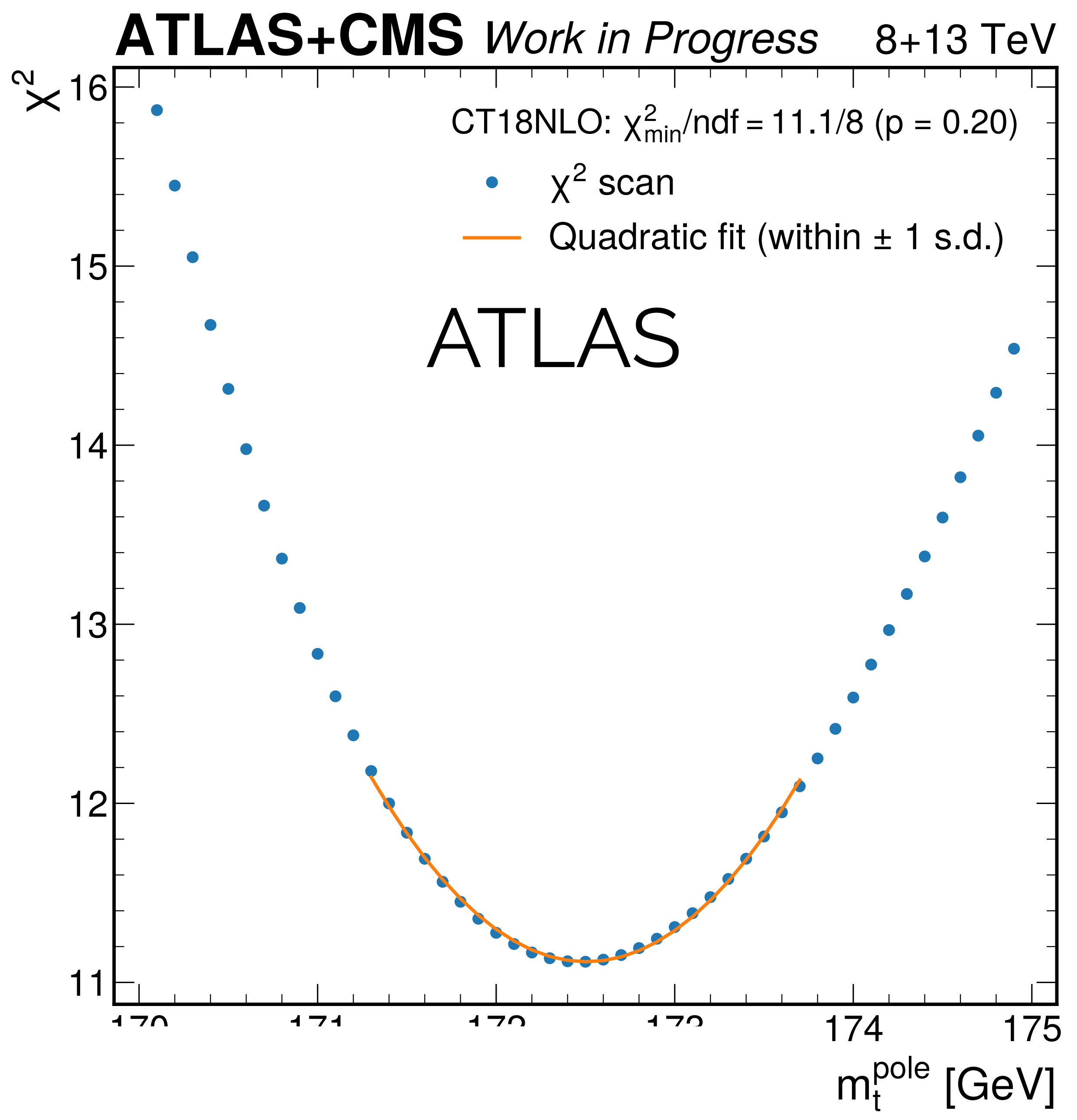
- Mild correlations:
  - Maximum effect is 8%
- → Results should be stable wrt. changes in the correlation scheme



Consistency check: one parameter per experiment

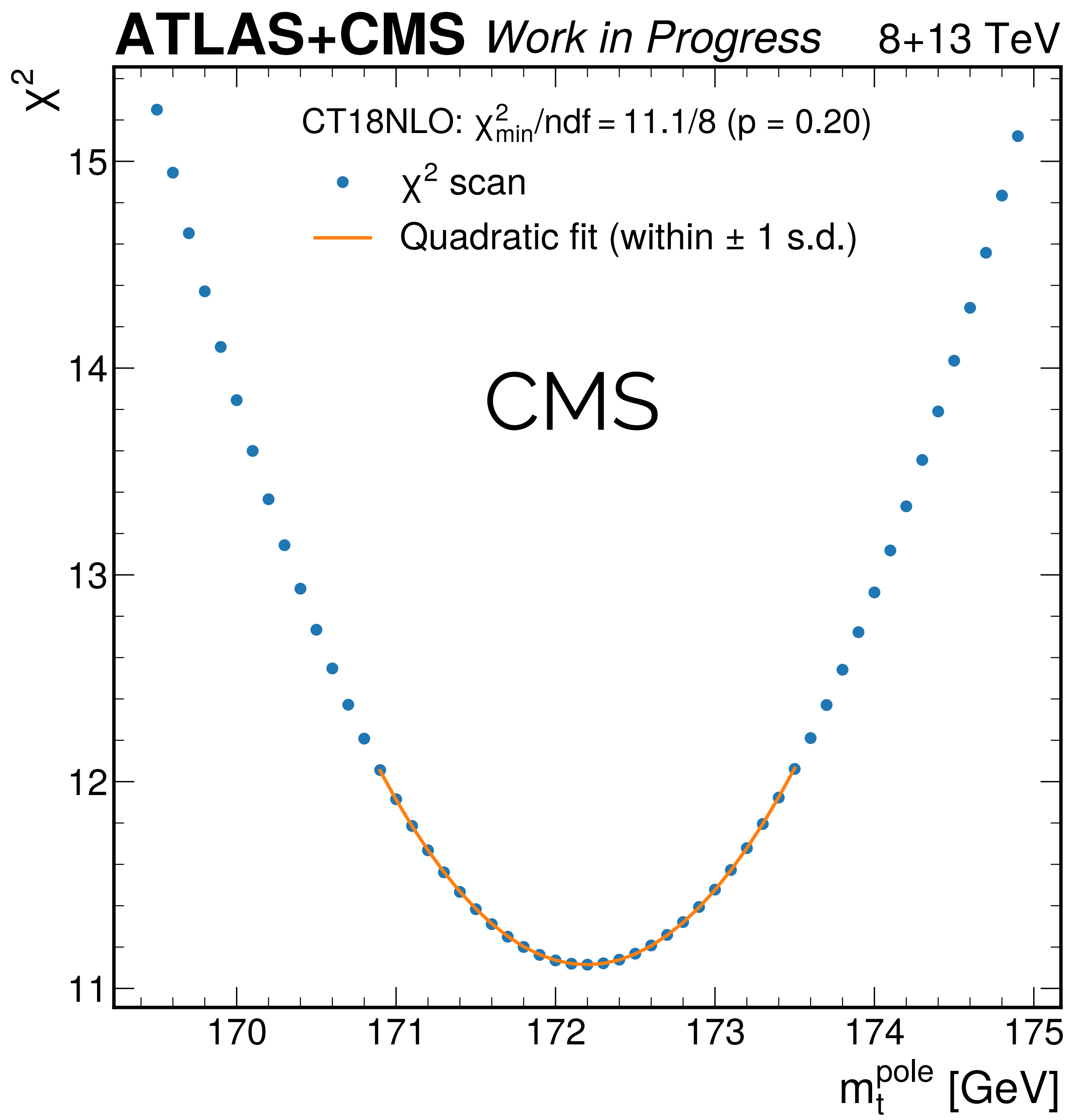
- Two separate mass parameters fit *simultaneously* to ATLAS and CMS, taking correlations into account

- Correlation includes experimental (tt+0j, JES, modelling) and PDFs
- Mass values compatible within uncertainties



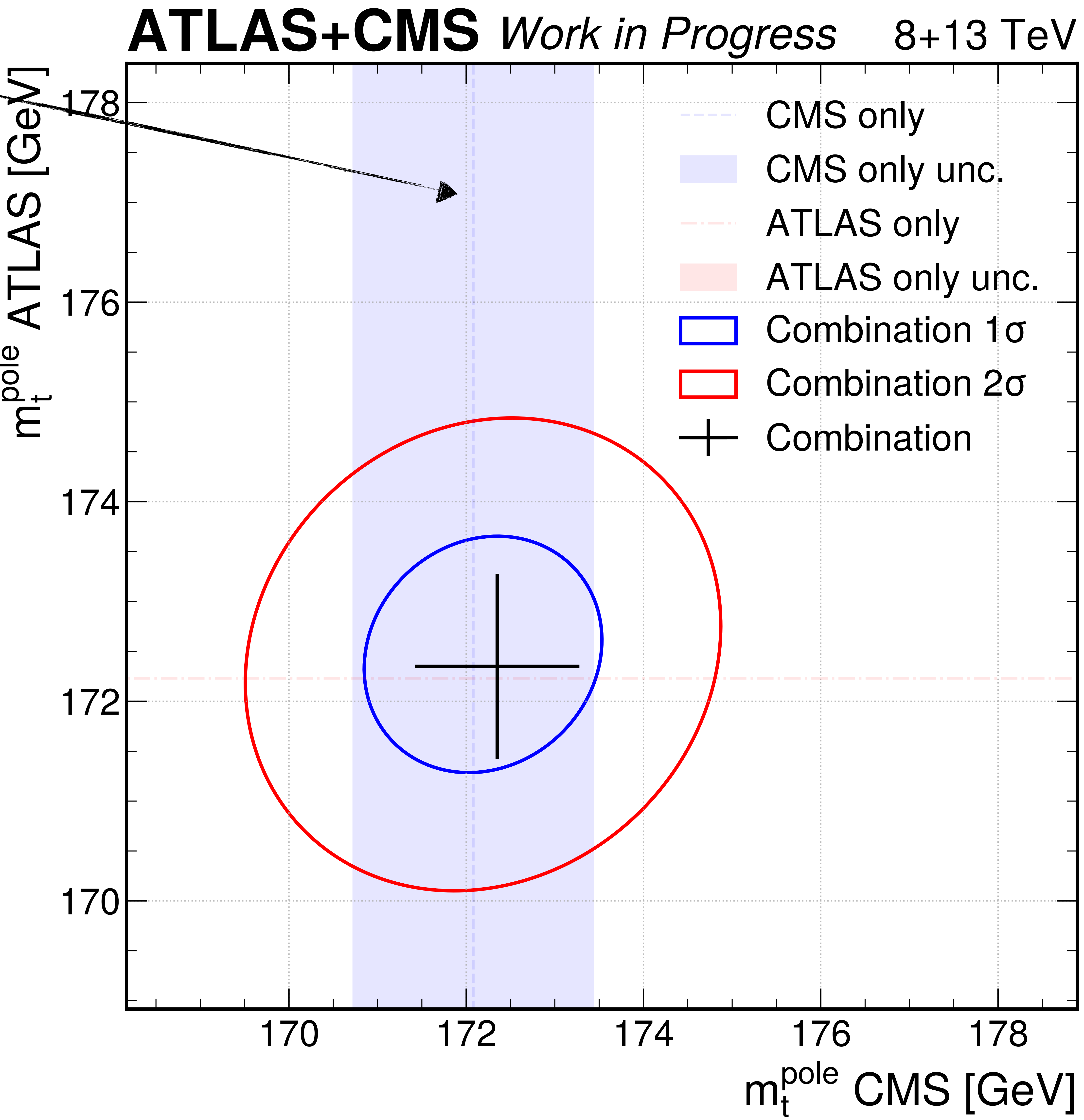
m_t CMS= 172.19 ± 1.28 (exp) ± 0.40 (PDF) GeV
m_t ATLAS = 172.47 ± 1.16 (exp) ± 0.24 (PDF) GeV
Correlation = 12.1 %
Difference = -0.3 ± 1.7 GeV
Ratio = 0.998 ± 0.010

p=0.27 (2 POI) vs. 0.60 (1 POI)



Everything in one plot

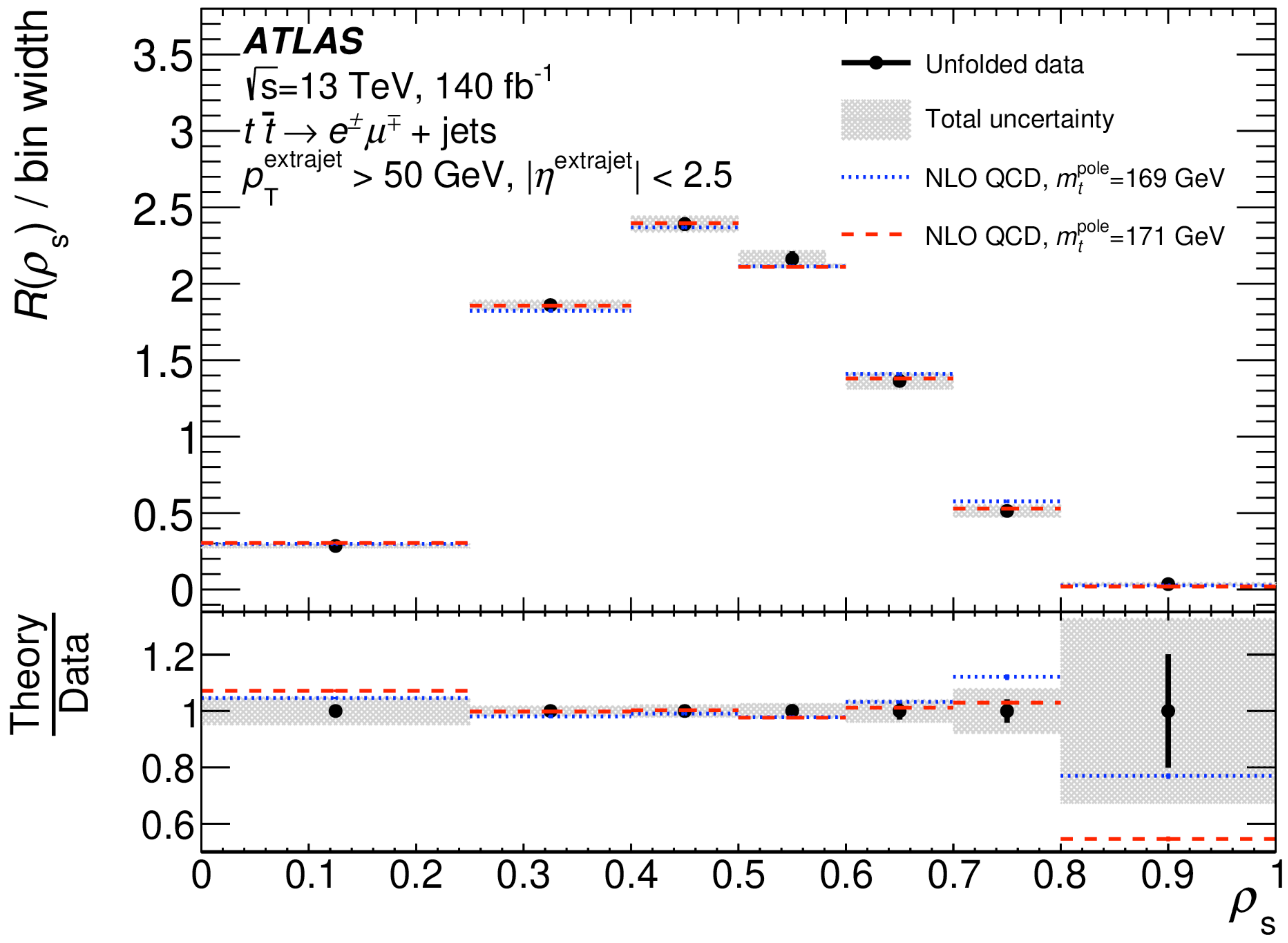
Standalone CMS



Standalone ATLAS

Contour from the 2D fit

The new player in the game…



- New uncertainties bring a challenge
  - Large impact
  - No experience in previous combinations
  - Precedent for LHCTopWG?

Uncertainty source	Δm_t^{pole} [GeV]	MC stat. unc. [GeV]
Data statistics	0.33	-
Detector unc.		
b-tagging and mistag	0.44	0.06
Jets	0.65	0.06
Leptons	0.25	0.06
Others	0.18	0.06
Modeling unc.		
MC statistical uncertainty	0.08	-
Backgrounds normalization	0.02	-
Single-top modeling	0.03	0.06
m_t^{MC} dependence	0.10	0.09
PS Recoil model	0.68	0.06
Parton shower	0.43	0.14
Underlying event	0.39	0.12
Color reconnection	0.13	0.08
ME+PS matching: p_T^{hard}	0.09	0.06
ME+PS matching: h_{damp}	0.26	0.06
ME+PS matching: line shape	0.38	0.12
3D NNLO reweight	0.21	0.06
PDF	0.26	0.06
Initial-state radiation	0.24	0.06
Final-state radiation	0.04	0.16
Factorization scales	0.09	0.06
Renormalization scales	0.03	0.06
Theory unc.		
Scale variations	+0.34 -0.28	+0.05 -0.06
PDF ⊕ α_S	0.24	+0.06 -0.06
Total	+1.47 -1.44	-

The new player in the game…

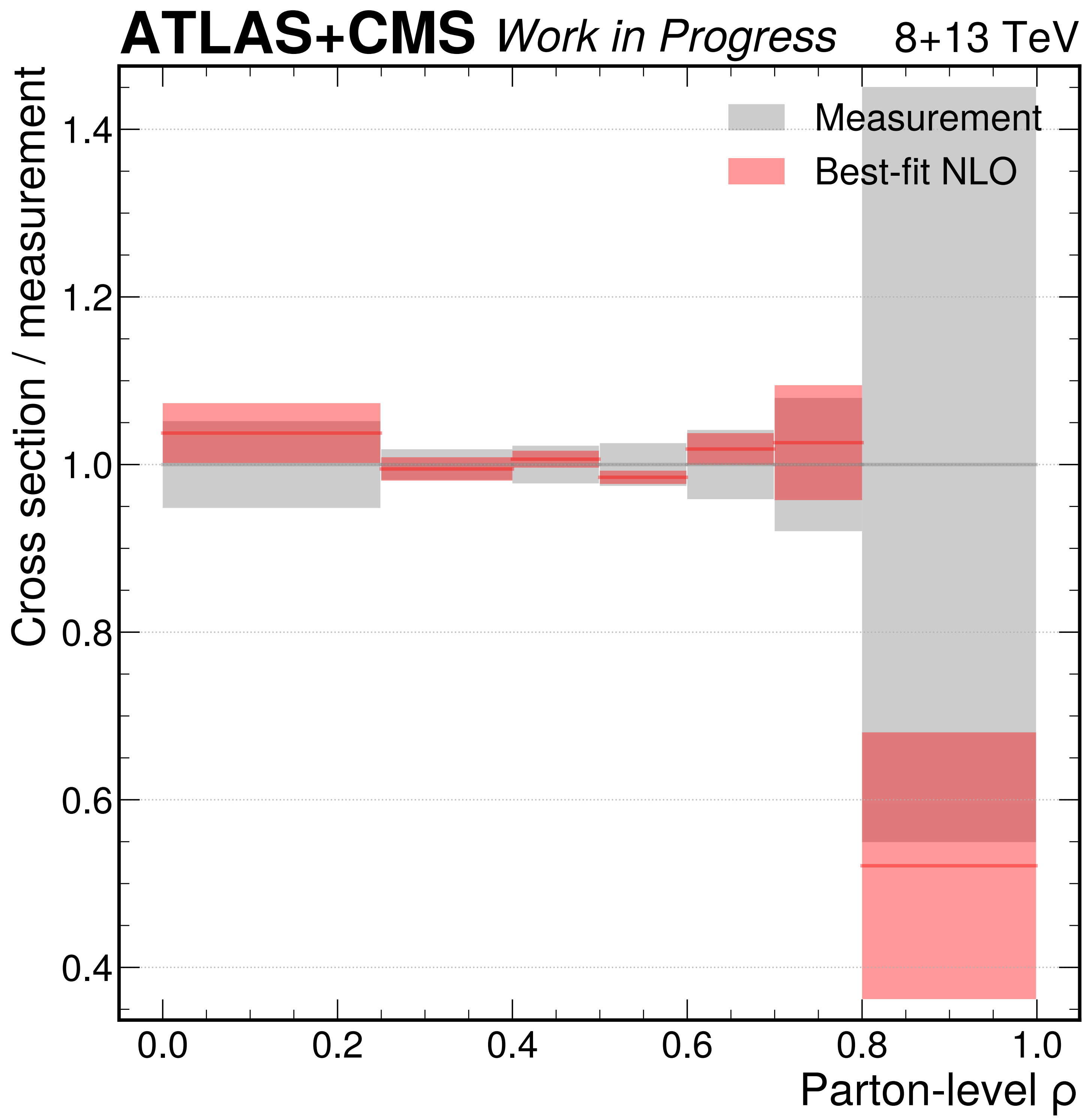
- Needs discussion
- Do we have any additional guidance for ATLAS/CMS 13 TeV correlations? → best estimate and scan?

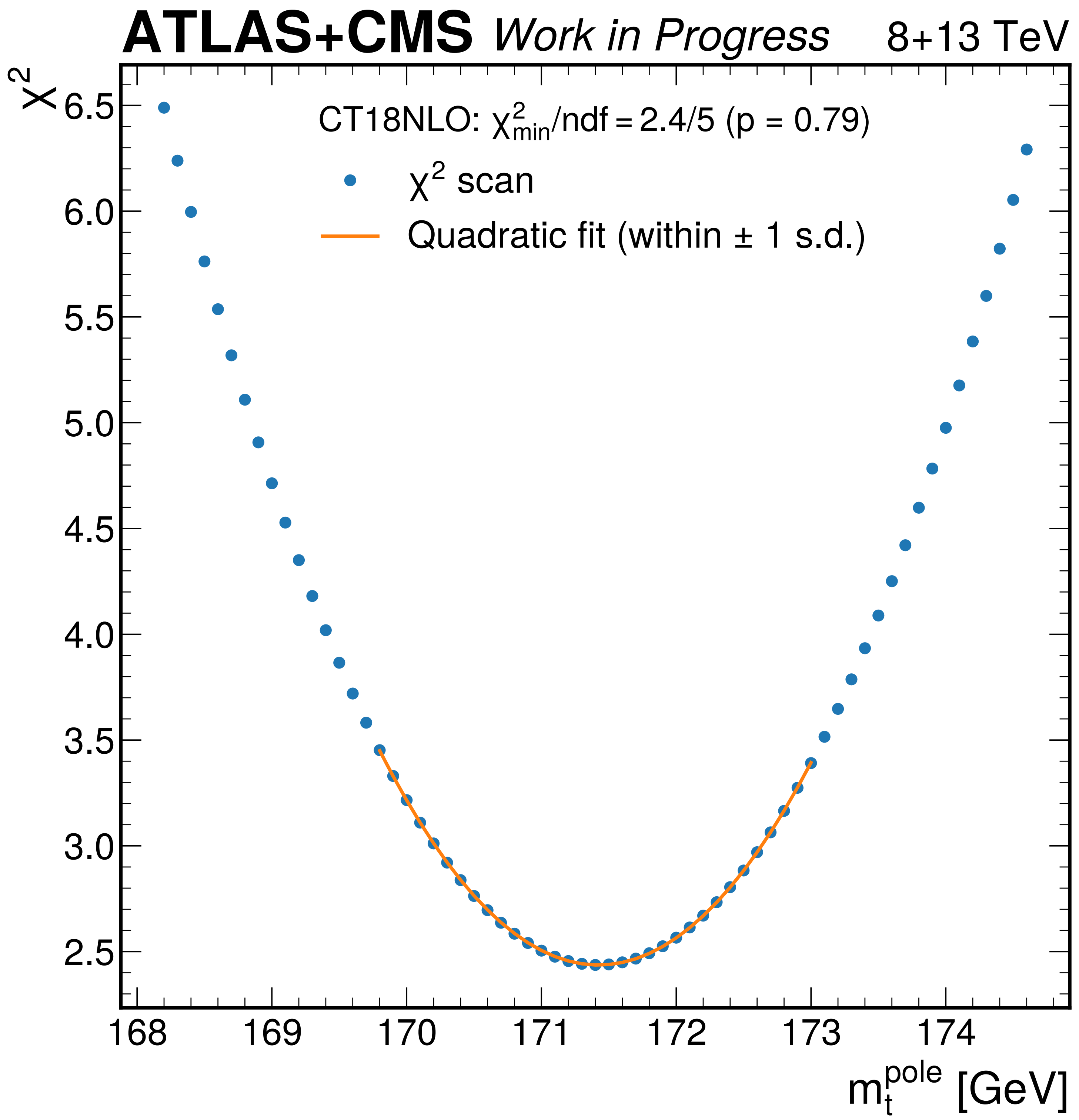
Systematic effect	Run 1 naming	Run 2 naming	Correlation (Strong scenario)	Correlation (Weak scenario)
b-tagging efficiency	ATLAS_eff_b*	ATLAS_eff_b*	0%	0%
Electron energy scale	ATLAS_scale_e*	ATLAS_scale_e*	0%	0%
Electron energy resolution	ATLAS_res_e*	ATLAS_res_e*	0%	0%
Electron identif. efficiency	ATLAS_eff_e*	ATLAS_eff_e*	0%	0%
Muon energy scale	ATLAS_scale_m*	ATLAS_scale_m*	0%	0%
Muon energy resolution	ATLAS_res_m*	ATLAS_res_m*	0%	0%
Muon identif. efficiency	ATLAS_eff_m*	ATLAS_eff_m*	0%	0%
E_T^{miss} scale	ATLAS_scale_met*	ATLAS_scale_met*	0%	0%
E_T^{miss} resolution	ATLAS_res_met*	ATLAS_res_met*	0%	0%
MC normalization	ATLAS_norm_*	ATLAS_norm_*	100% for *tW*, *Z*+jets 0% for others	100% for *tW*, *Z*+jets 0% for others
Non-prompt leptons	ATLAS_fake_j*	ATLAS_fake_j_norm	0%	0%
Pileup-jet tagger	ATLAS_eff_j_jvf	ATLAS_eff_j_jvt	100%	0%
Jet energy scale	ATLAS_scale_j_Stat*	ATLAS_scale_j_NPStatistical*	0%	0%
	ATLAS_scale_j_Model*	ATLAS_scale_j_NPModelling*	100%	0%
	ATLAS_scale_j_Det*	ATLAS_scale_j_NPDetector*	100% for Det1 and [Det3,NPDetector2] 0% for Det2 (to be checked)	0%
	ATLAS_scale_j_Mix*	ATLAS_scale_j_NPMixed*	100%	0%
	ATLAS_scale_j_Det*	ATLAS_scale_j_NPDetector*	100% for [Mix1,NPMixed] 0% otherwise	0%
	ATLAS_scale_j_EtaIntercalibration*	ATLAS_scale_j_EtaIntercalibration*	100% for modelling 0% otherwise	0%
	ATLAS_scale_j_PunchThrough	ATLAS_scale_j_PunchThroughMC16	100%	0%
	ATLAS_scale_j_SinglePart	ATLAS_scale_j_SingleParticleHighPt	100%	0%
	ATLAS_scale_j_Pileup*	ATLAS_scale_j_Pileup*	100%	0%
	ATLAS_scale_b*	ATLAS_scale_FlavorResponse	0%	0%
	ATLAS_scale_j_flavor*	ATLAS_scale_j_Flavor* ATLAS_scale_j_PerJet*	0%	0%
Jet energy resolution	ATLAS_res_j_*	ATLAS_res_j_*	100% for [np0, EffectiveNP1] 0% otherwise	0%
Parton shower	ATLAS_modelling_ttbar_PartonShower	ATLAS_modelling_ttbar_Herwig	100%	100%
Underlying event	ATLAS_modelling_ttbar_UnderlyingEvent	ATLAS_modelling_ttbar_A14Var1Up	100%	0%
Color reconnection	ATLAS_modelling_ttbar_ColorReconnection	ATLAS_modelling_ttbar_ATLCR2	100%	0%
Initial- and final-state radiation	ATLAS_modelling_ttbar_Radiation	ATLAS_modelling_ttbar_isrmuRfac1.0fsrmuRfac0.5 ATLAS_modelling_ttbar_hdamp3mt ATLAS_modelling_ttbar_Var3cUp	0% (50% maybe possible, as for CMS)	0%
Powheg ME&matching	ATLAS_modelling_ttbar_MatrixElement	ATLAS_modelling_ttbar_TtbarNNLOReweight ATLAS_modelling_ttbar_muR1.0muF2.0 ATLAS_modelling_ttbar_muR2.0muF1.0 ATLAS_modelling_ttbar_PtHard1	0%	0%
Top-quark decay modelling	-	ATLAS_modelling_ttbar_lineshape ATLAS_modelling_ttbar_Trec	0%	0%
Others	-	ATLAS_modelling_ttbar_mTopMC ATLAS_modelling_singletop_DSvsDR	0%	0%
Proton PDF	ATLAS_pdf[0-52]	ATLAS_pdf_909[01-30]	0%	0%

ATLAS reinterpretation - v2

- Now here the situation is different wrt. 8 TeV:
  - Same theory prediction
- Different fit setup (PDF and systematics in the chi2 fit)
- mt = 171.42 ± 1.48 (exp) ± 0.64 (PDF) GeV
- Scale uncertainty = +0.31 -0.38 GeV

- Total exp. uncertainty 5% larger
  1.48 vs. 1.40
- Twice PDF and scale unc.?
  How estimated?
  The paper is not really clear here
  Let's discuss!





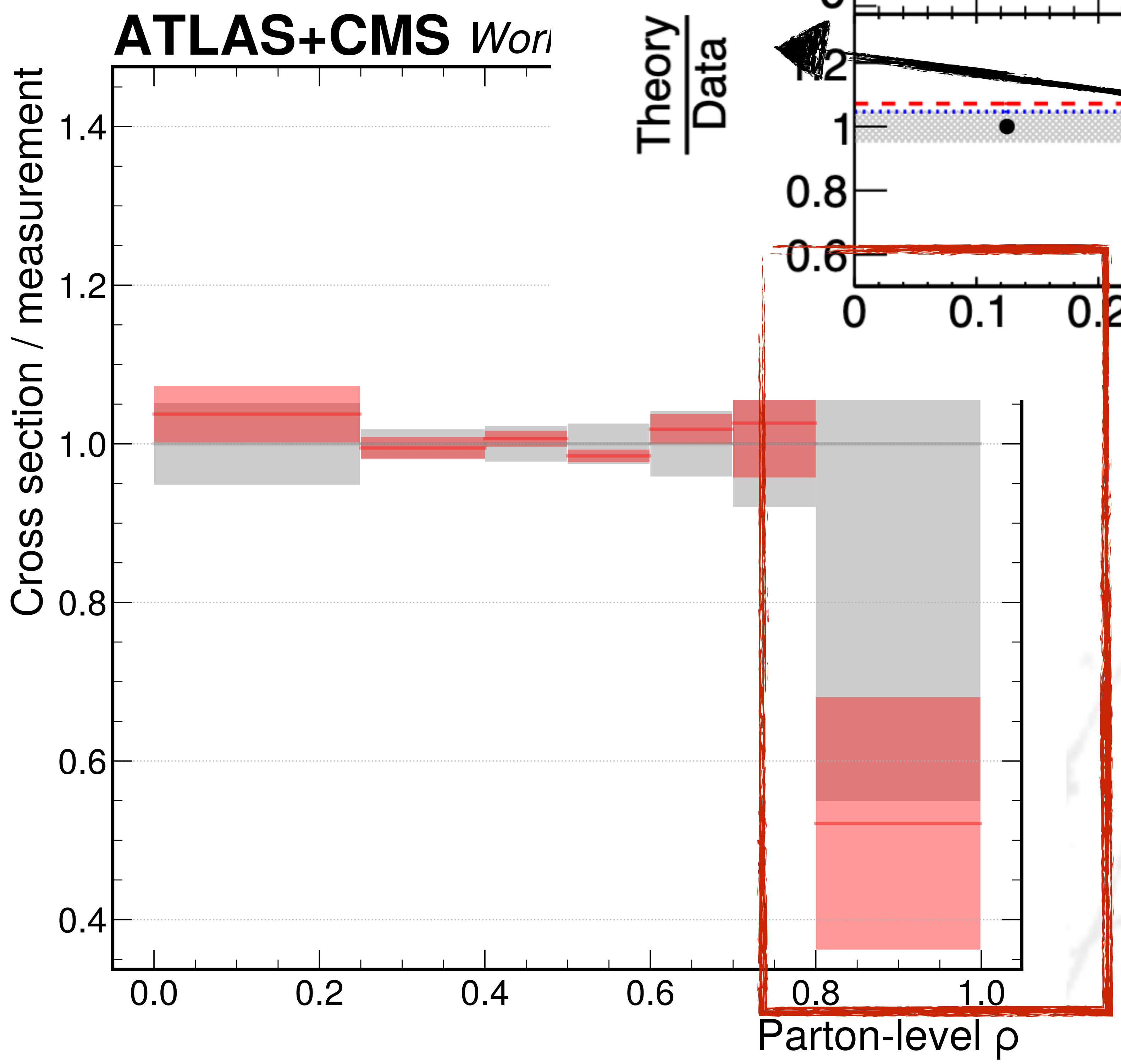
Published result

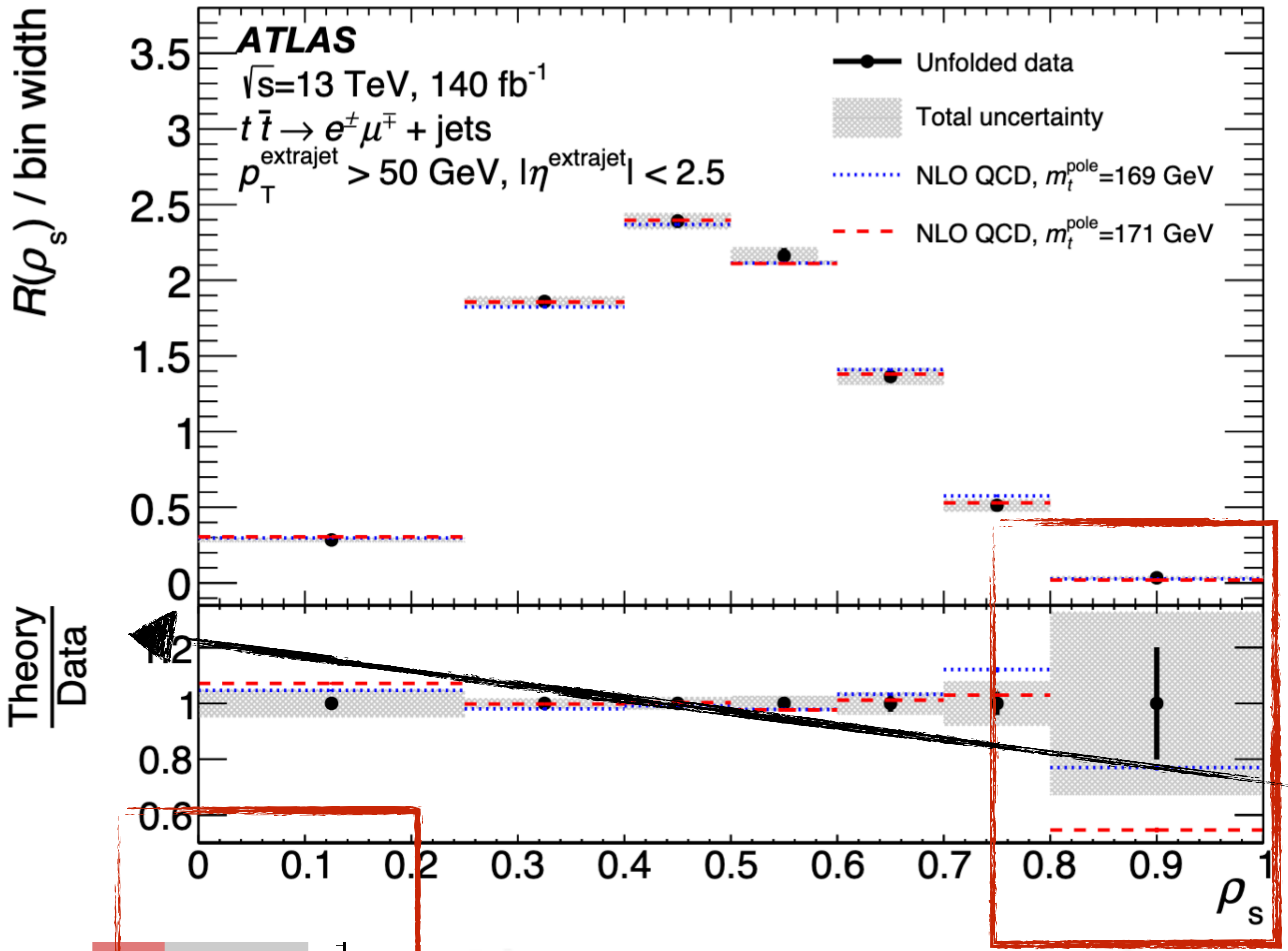
$$m_t^{pole}(\text{CT18 [95]}) = 170.94 \pm 0.33\ (\text{stat.}) \pm 1.36\ (\text{syst.})\ ^{+0.37}_{-0.28}\ (\text{scale})\ \pm 0.28\ (\text{PDF} \oplus \alpha_s)\ \text{GeV},$$

ATLAS reinterpretation - v2

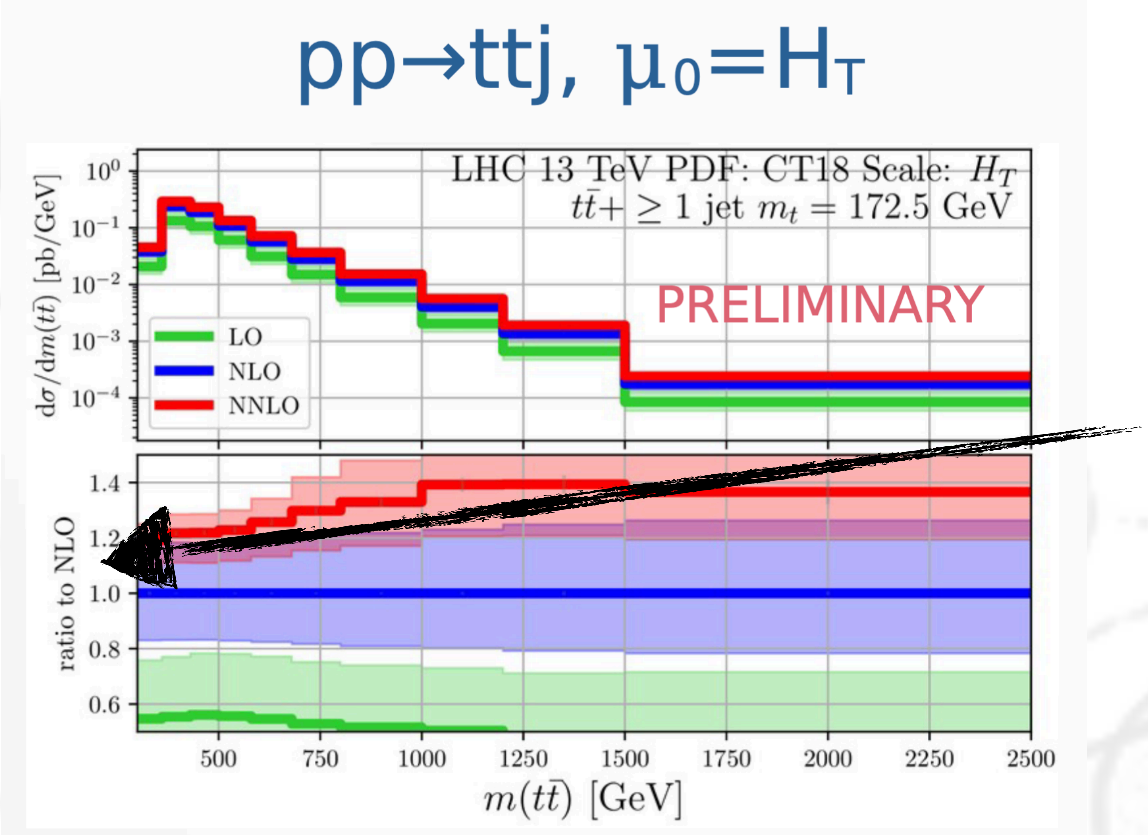
- Now here the situation is different wrt. 8 TeV:
  - Same theory prediction
- Different fit setup (PDF and systematics in the chi2 fit)
- mt = 171.42 ± 1.48 (exp) ± 0.64 (PDF) GeV
- Scale uncertainty = +0.31 -0.38 GeV

- Total exp. uncertainty 5% larger
  1.48 vs. 1.40
- Twice PDF and scale unc.?
  How estimated?
  The paper is not really clear here
  Let's discuss!





Disagreement, worrying?



Published result

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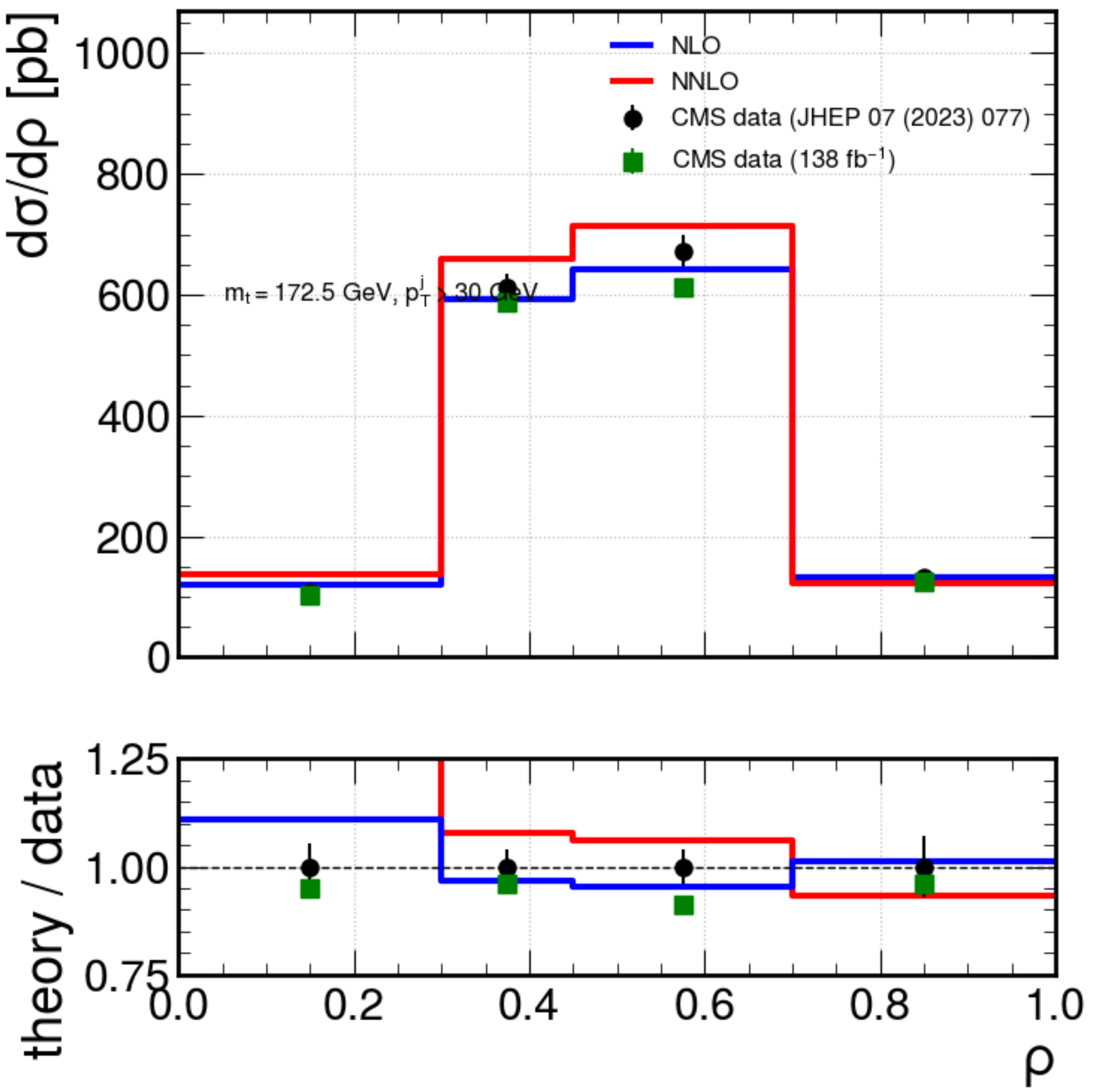
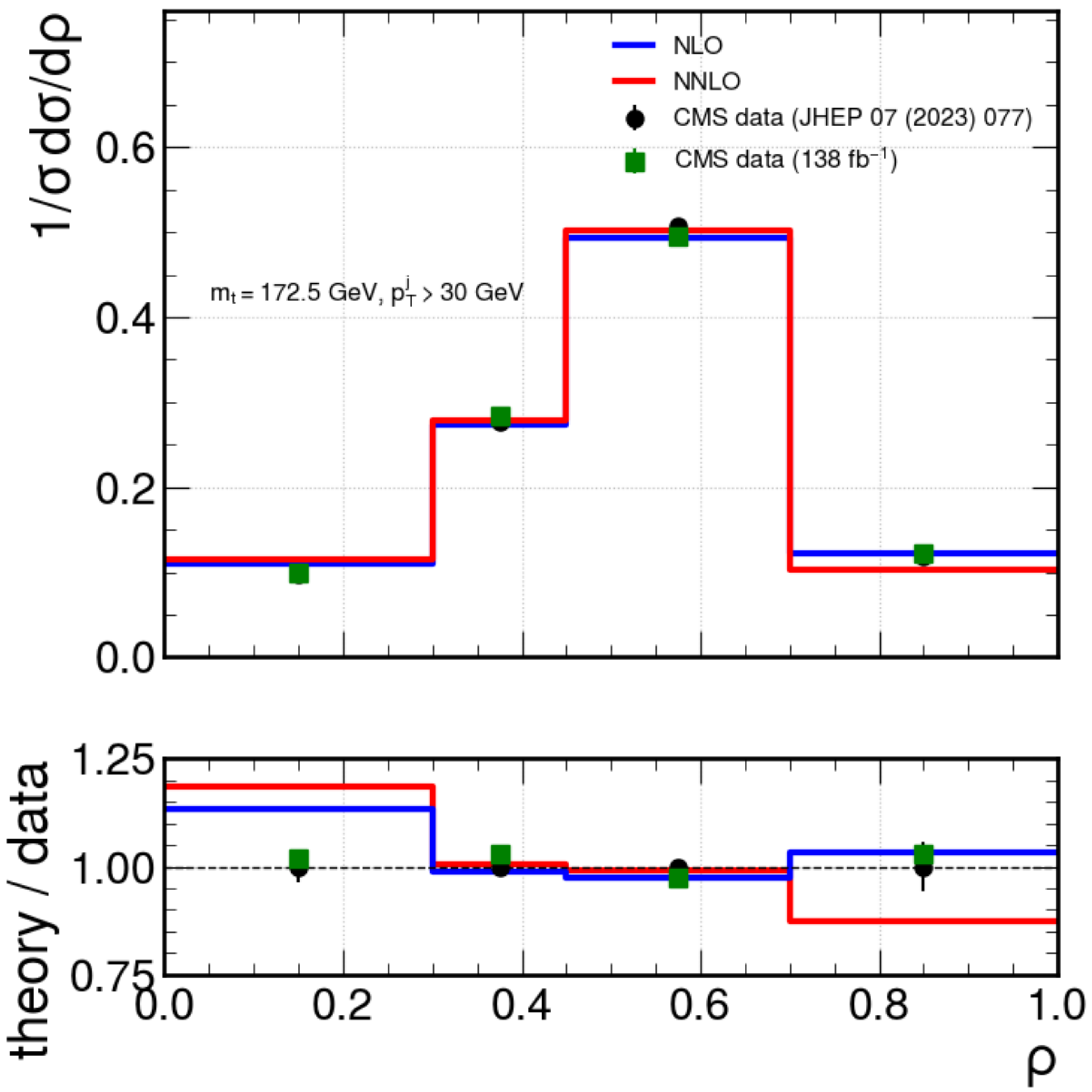
Insert: NNLO ρ from yesterday

Thanks Colomba!

Absolute

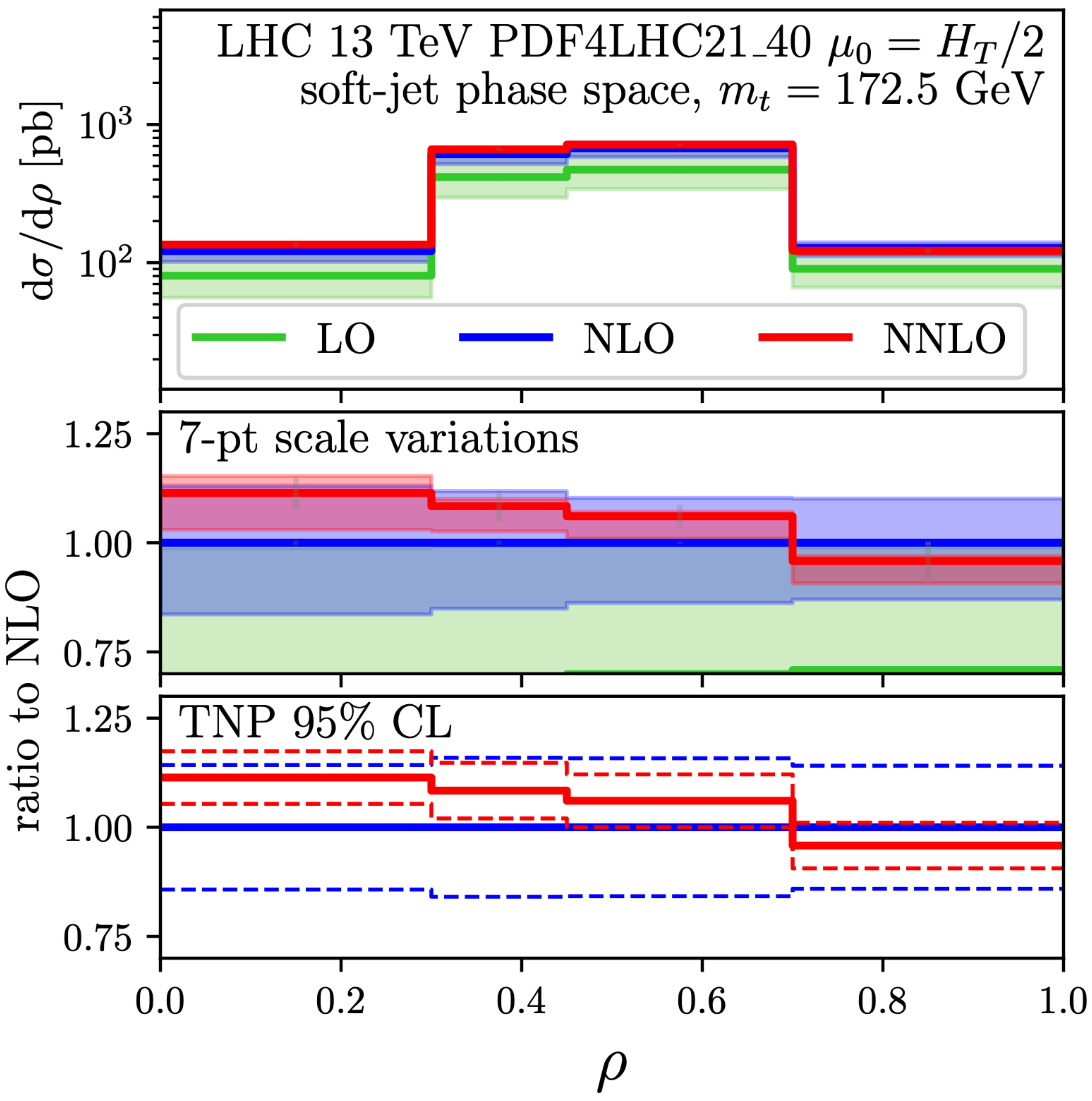


Normalised



N.B. This is read from the digitised .png image, so the real picture is slightly different

Insert: NNLO ρ from yesterday

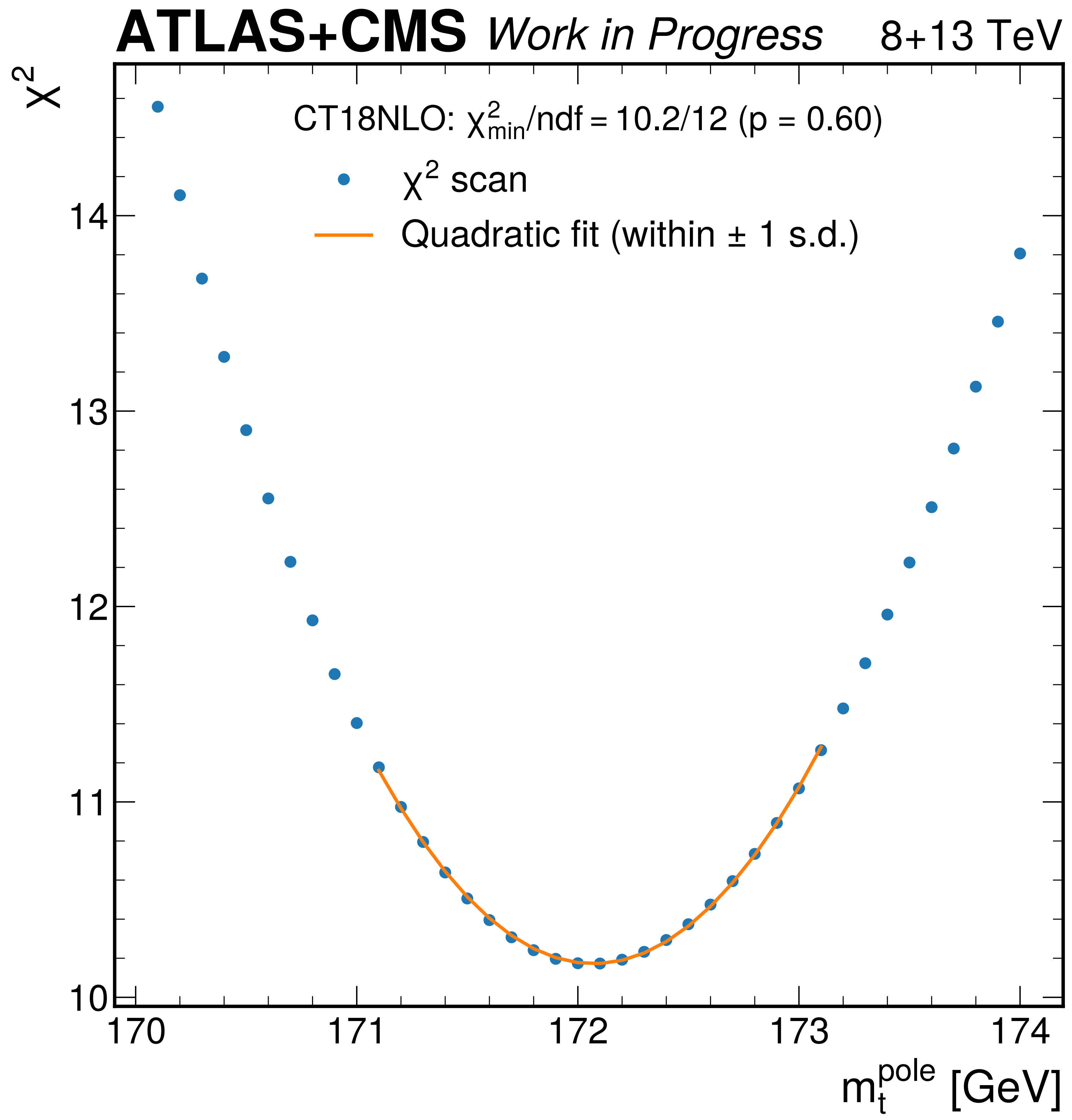


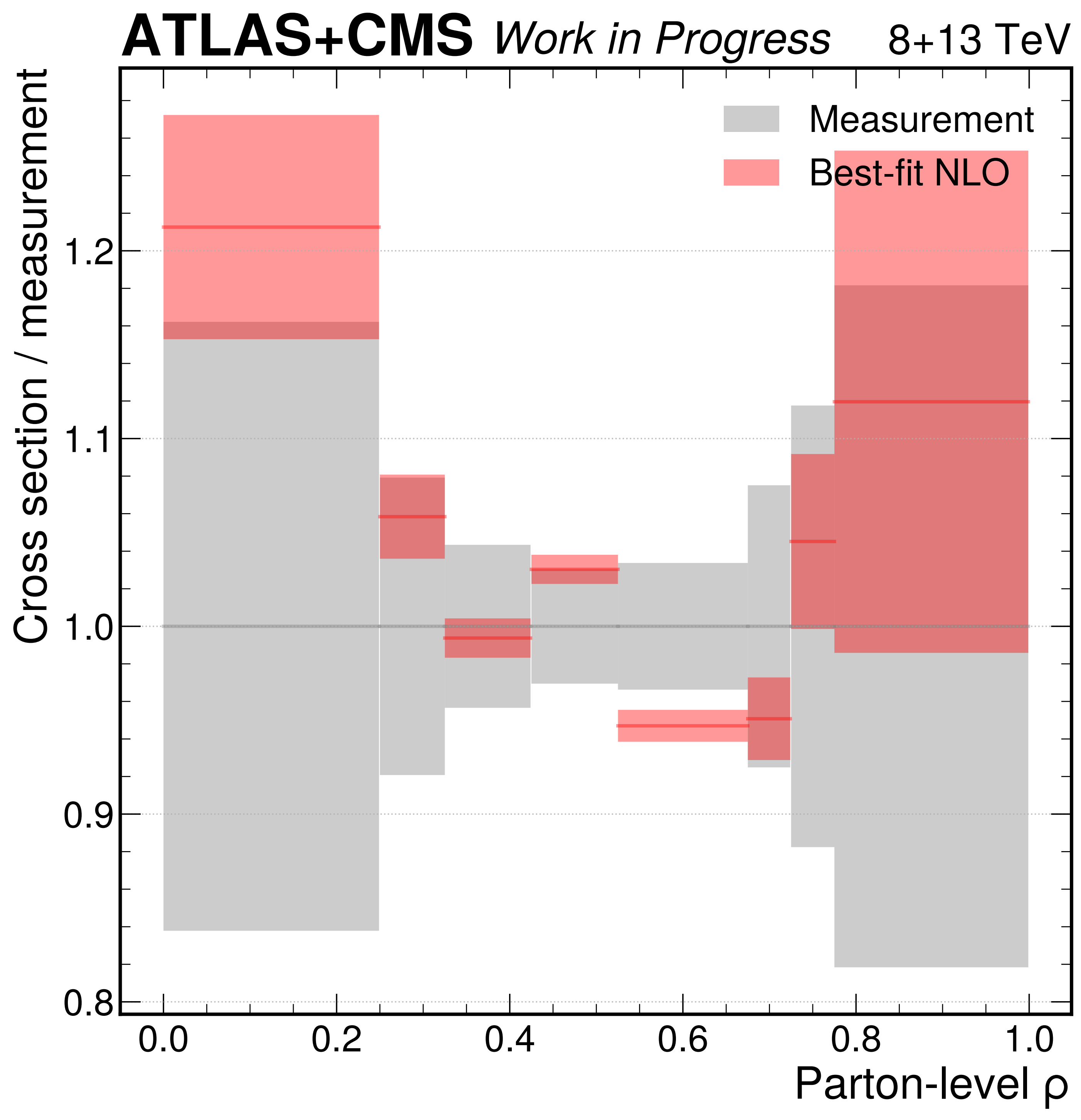
We can get theory nuisance parameters..? See arXiv:2412.14910

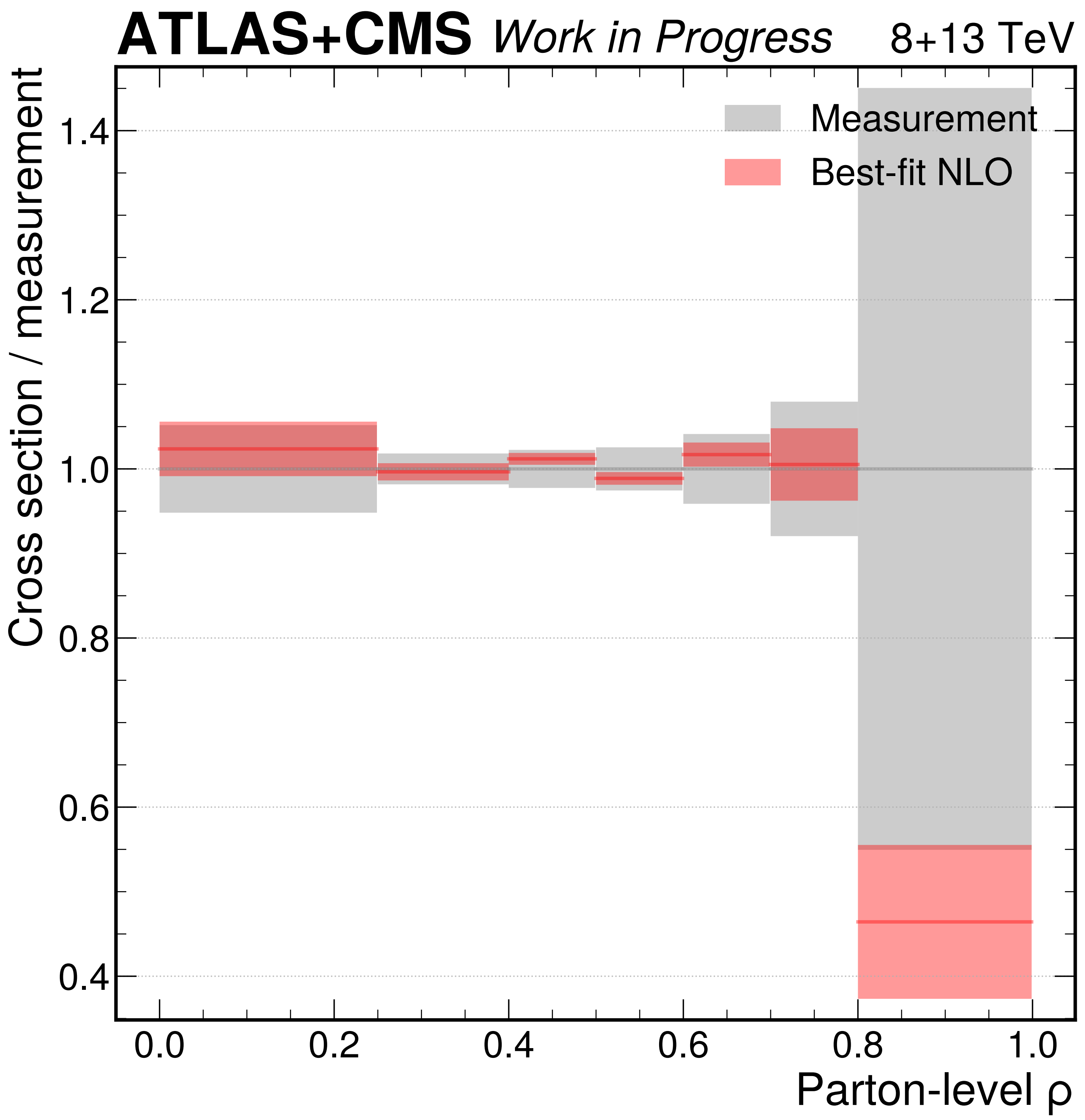
ATLAS 8 - ATLAS 13 combination - uncorrelated

- mt = 172.06 ± 0.91 (exp) ± 0.34 (PDF) GeV
- Scale uncertainty = +0.14 -0.12 GeV

- Seems largely driven by the 8 TeV result







ATLAS 8 - ATLAS 13 combination - with correlations

Correlated tt modeling

mt = 172.05 ± 0.86 (exp) ± 0.24 (PDF) GeV

Scale ± 0.08

ρ=+0.5

Correlated JES

ρ=+0.9

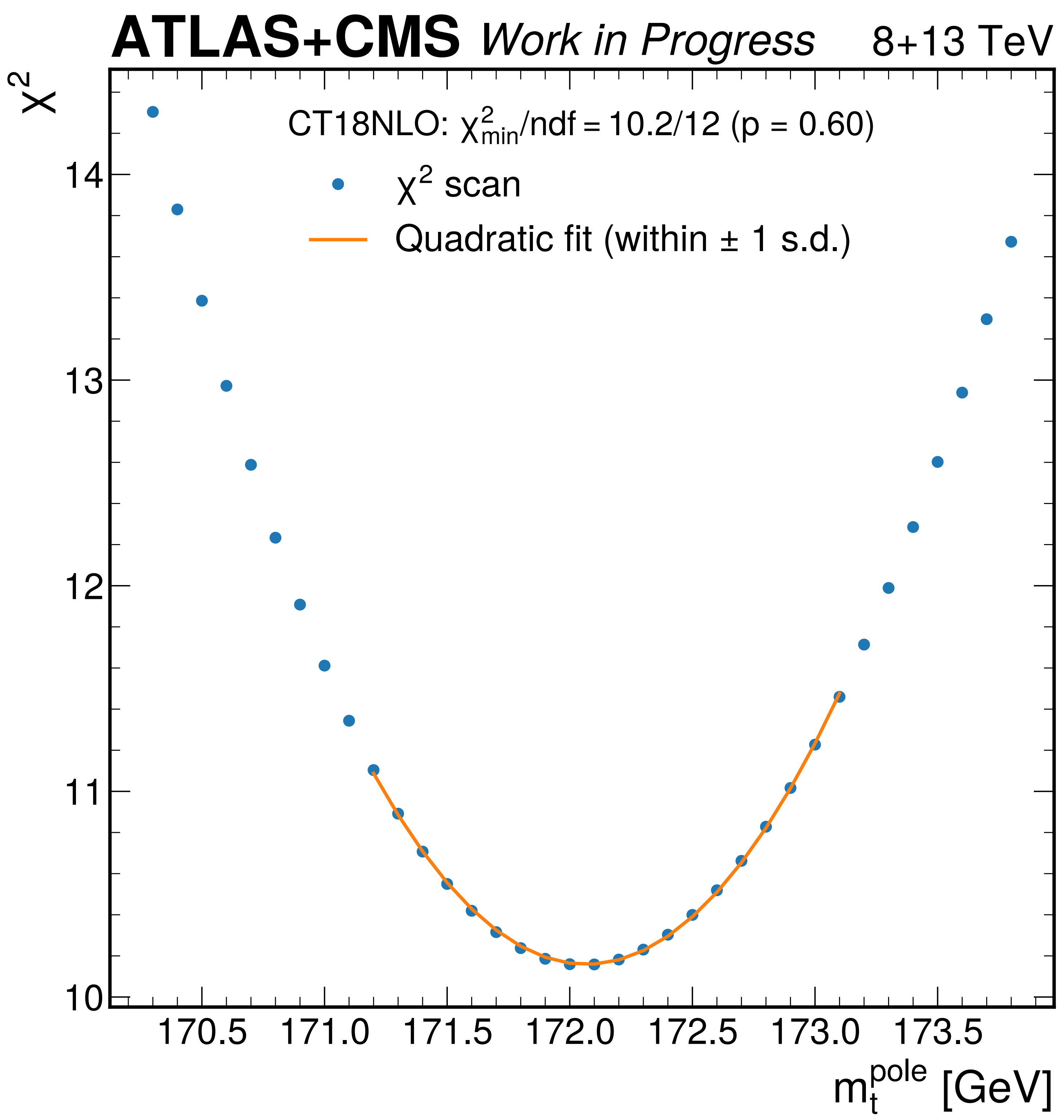
mt = 172.12 ± 0.88 (exp) ± 0.33 (PDF) GeV

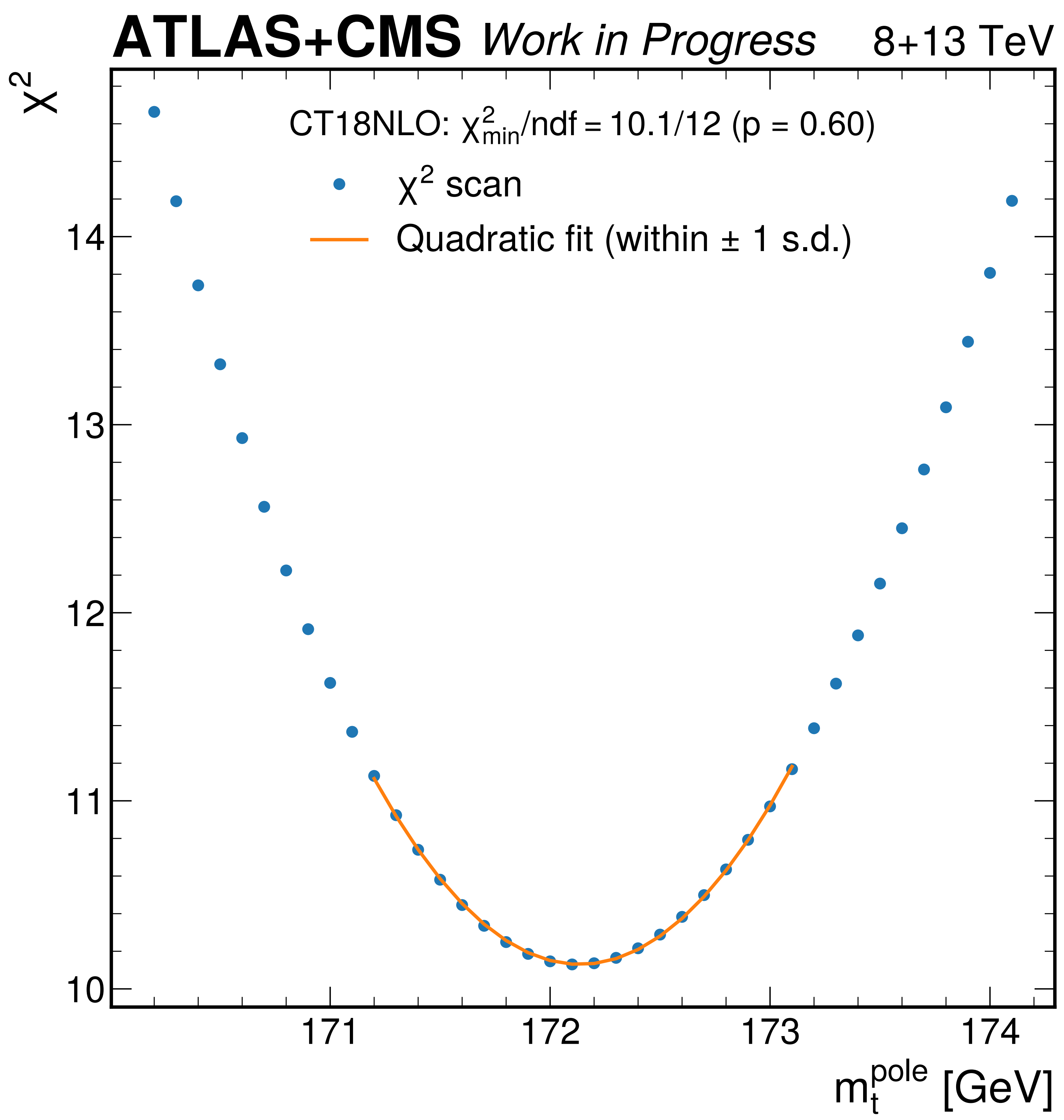
Scale ± 0.12

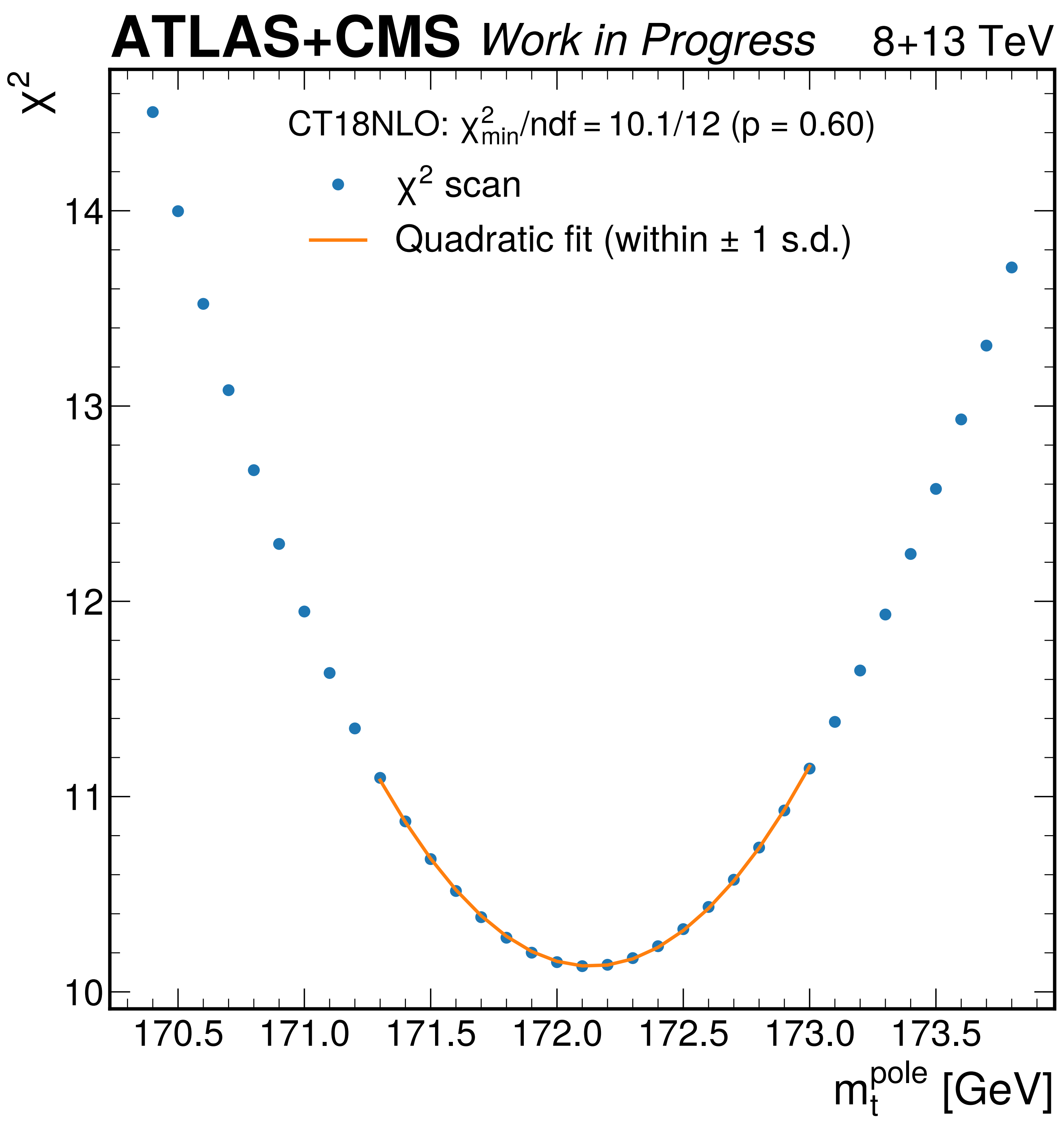
Correlated tt modeling+JES

mt = 172.12 ± 0.82 (exp) ± 0.22 (PDF) GeV

Scale ± 0.08







ATLAS 8 - ATLAS 13 combination - with correlations

Correlated tt modeling

mt = 172.05 ± 0.86 (exp) ± 0.24 (PDF) GeV

Scale ± 0.08

ρ=+0.5

Correlated JES

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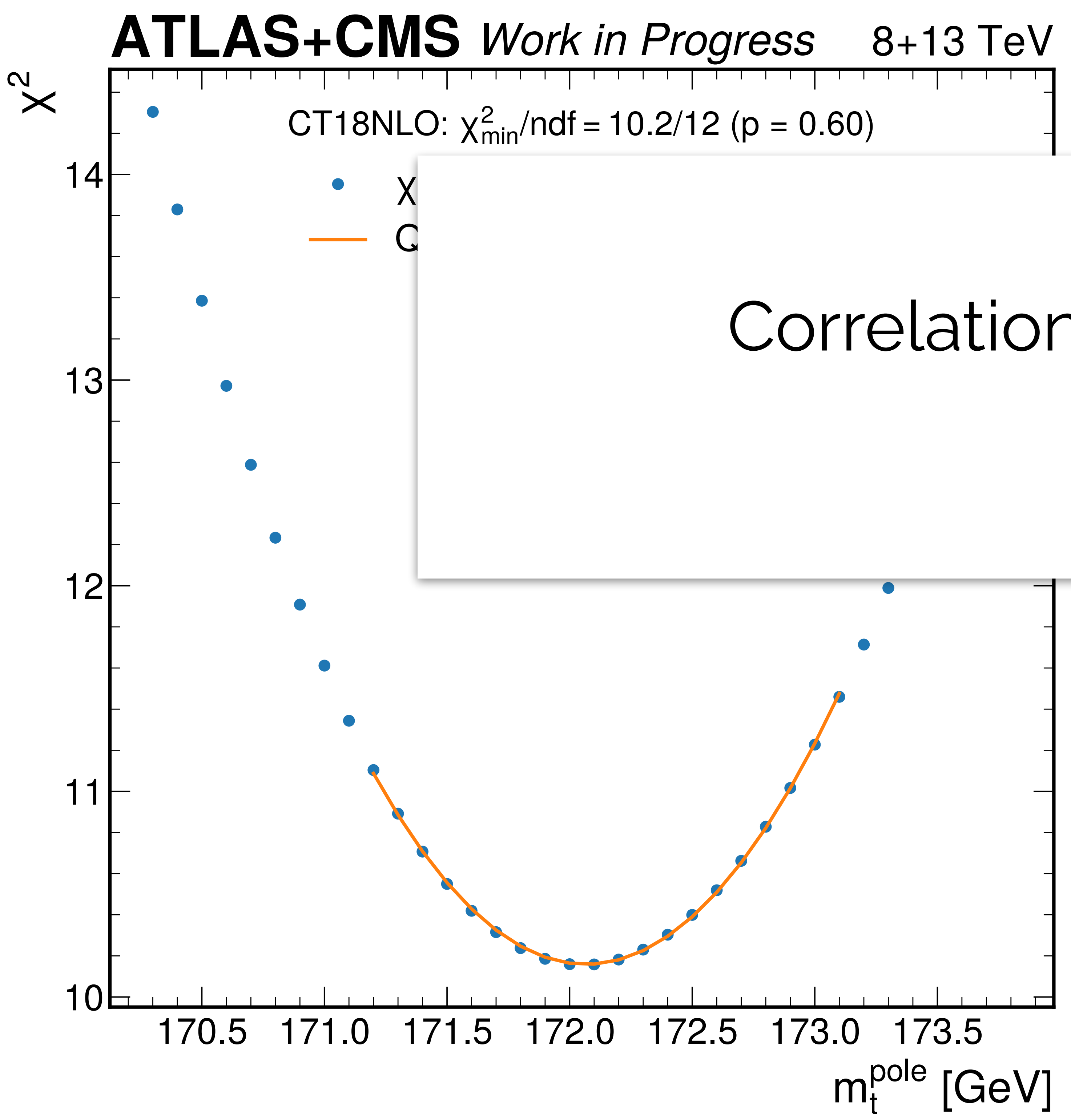
mt = 172.12 ± 0.88 (exp) ± 0.33 (PDF) GeV

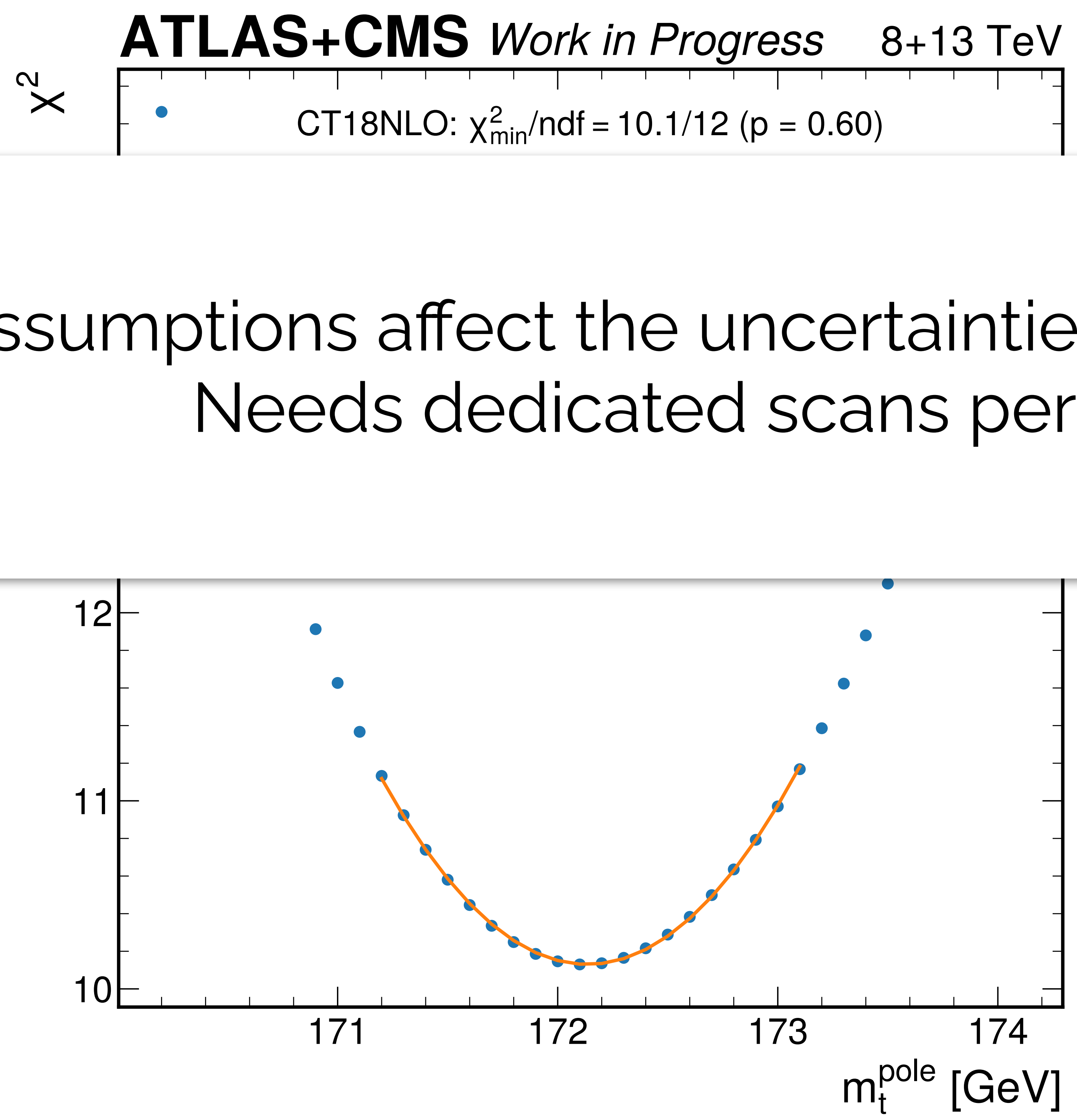
Scale ± 0.12

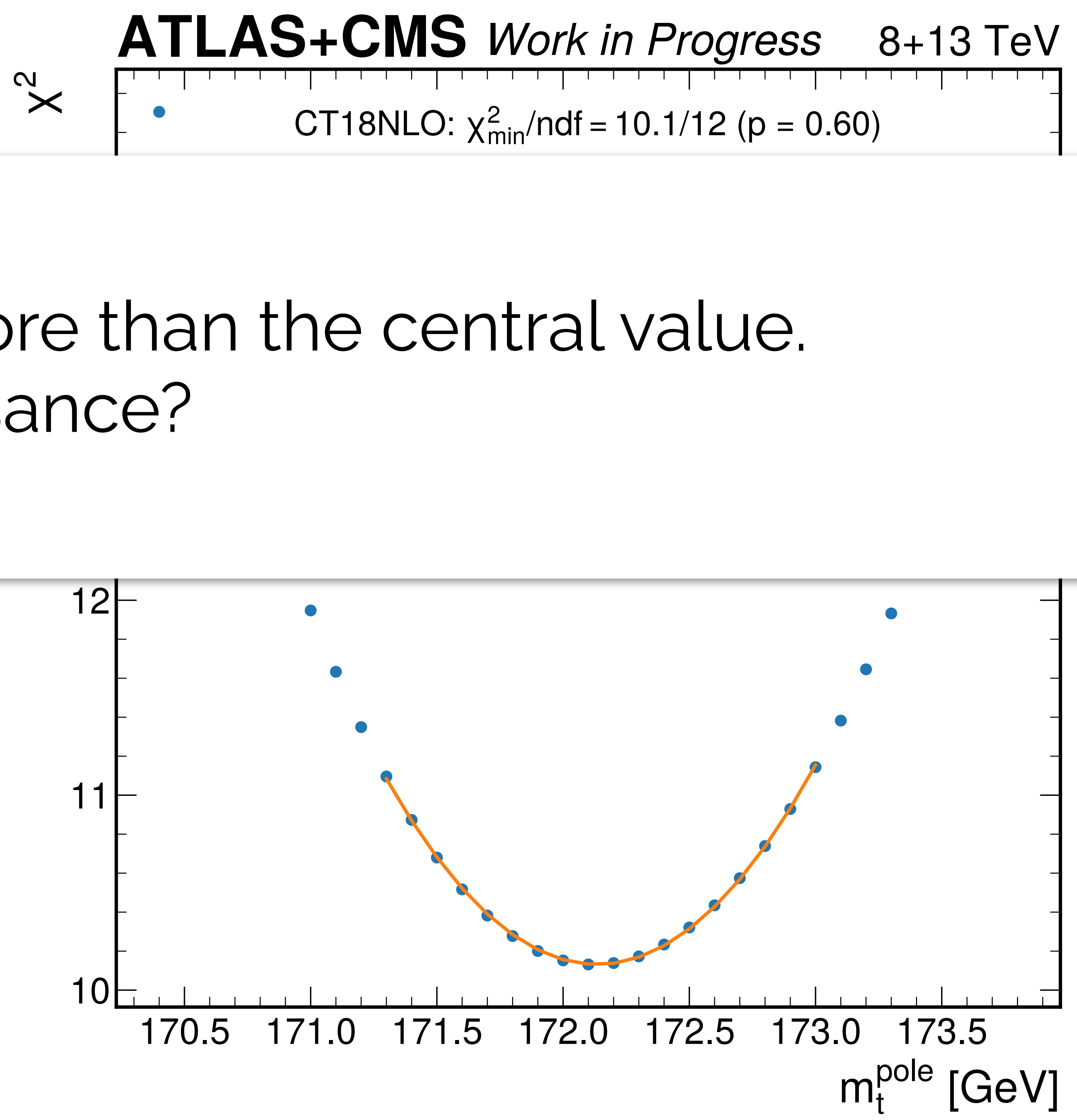
Correlated tt modeling+JES

mt = 172.12 ± 0.82 (exp) ± 0.22 (PDF) GeV

Scale ± 0.08







Correlation assumptions affect the uncertainties more than the central value.
Needs dedicated scans per nuisance?

ATLAS 8 - ATLAS 13 combination - with correlations

13 TeV JES and tt large effect on 8 TeV results - ~10%

ATLAS 8 TeV uncertainties, grouped

ATLAS 13 TeV uncertainties, grouped

8 TeV JES and tt each 7% effect on 13 TeV, last bins

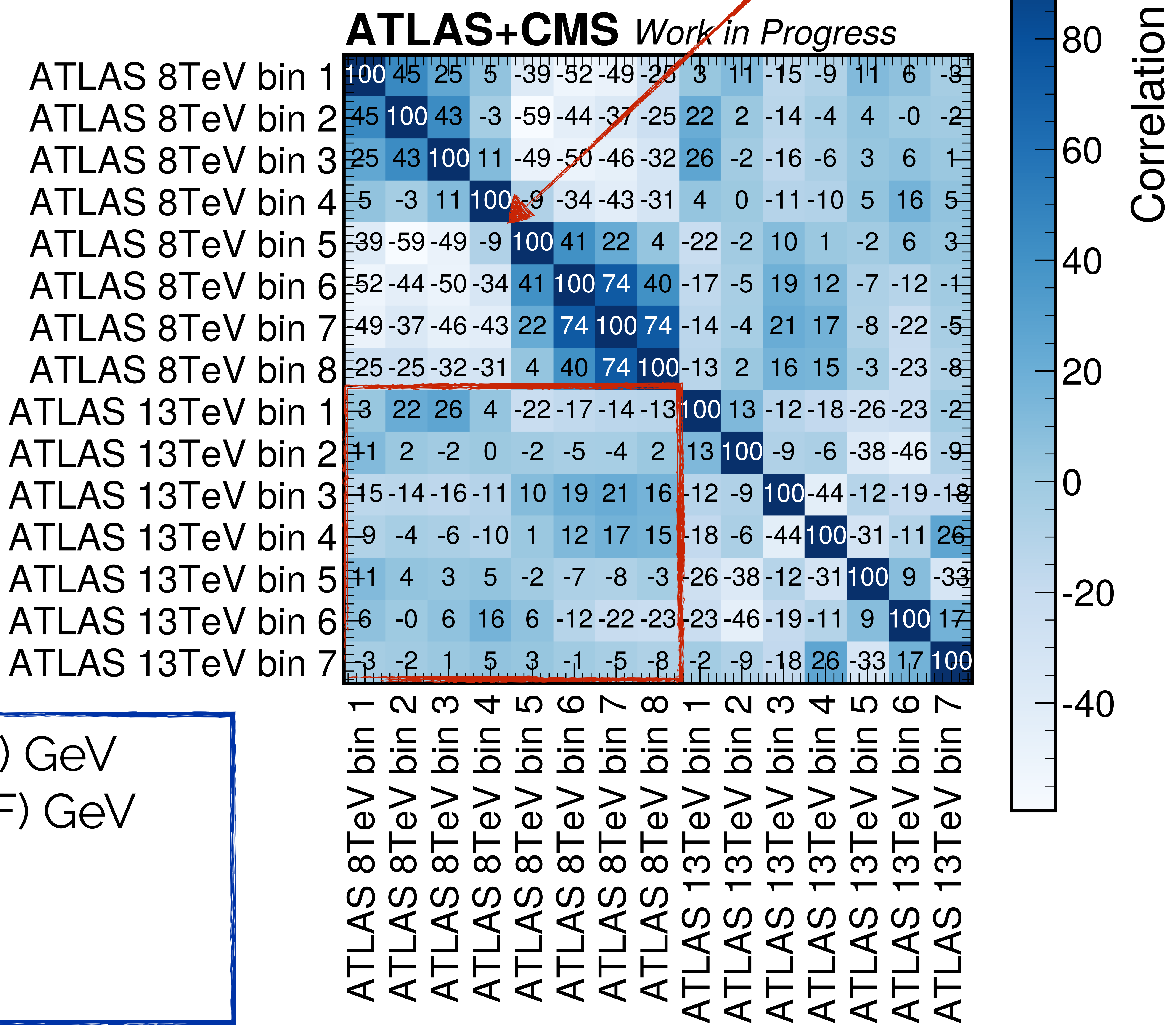
ATLAS 8 - ATLAS 13 combination - with correlations

- Explainable by post-fit correlation matrix
  - Up to -23 / + 26 percent correlations
  - Mostly between first bins:

    → Driving normalization?

    → Same crossing structure as in 8 TeV data alone

Due to norm. crossing?



If we fit 2 POIs:

m_t 8 TeV= 172.29 ± 1.15 (exp) ± 0.22 (PDF) GeV
m_t 13 TeV = 171.84 ± 1.46 (exp) ± 0.62 (PDF) GeV
Correlation = -16.8 %
Difference = 0.4 ± 2.1 GeV
Ratio = 1.003 ± 0.012

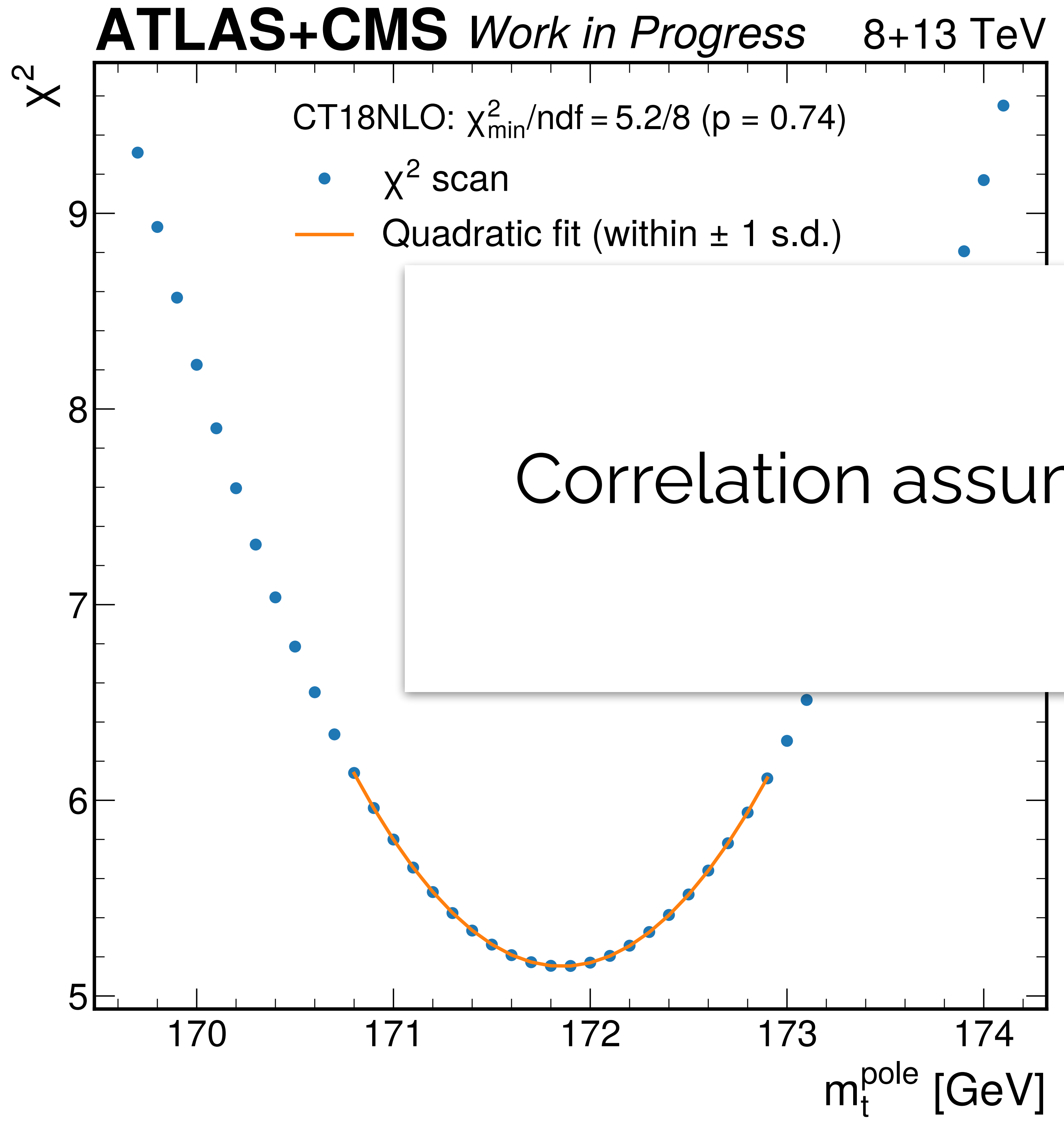
p=0.52 (2 POI) vs. 0.60 (1 POI)

Combining CMS + ATLAS 13

Uncorrelated

mt = 171.86 ± 0.97 (exp) ± 0.44 (PDF) GeV

Scale ± ~0.30

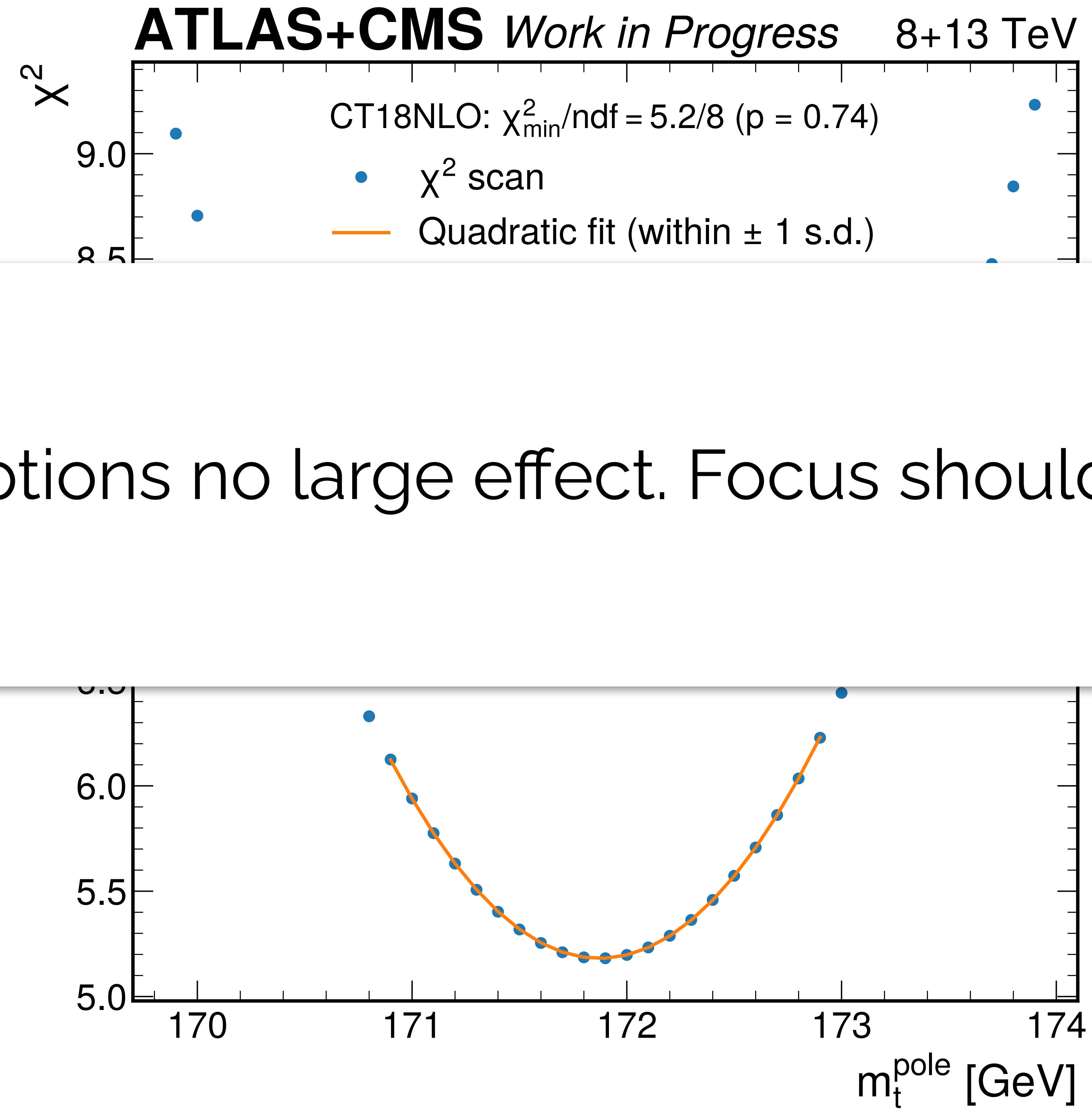


Correlated JES+modeling

ρ=+0.5

mt = 171.87 ± 0.91 (exp) ± 0.42 (PDF) GeV

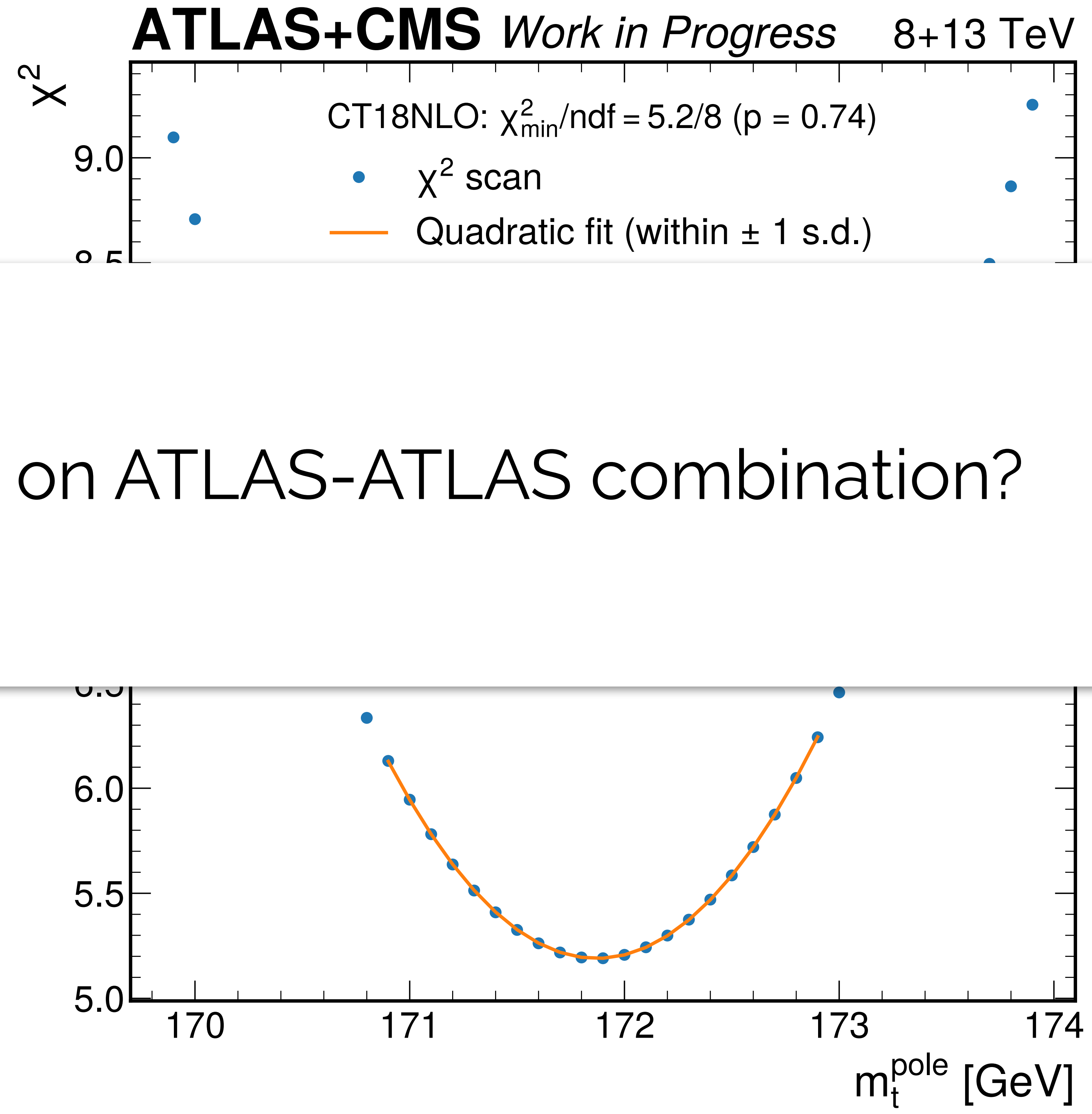
Scale ± ~0.30



Correlated JES+modeling+tt0jet

mt = 171.87 ± 0.91 (exp) ± 0.42 (PDF) GeV

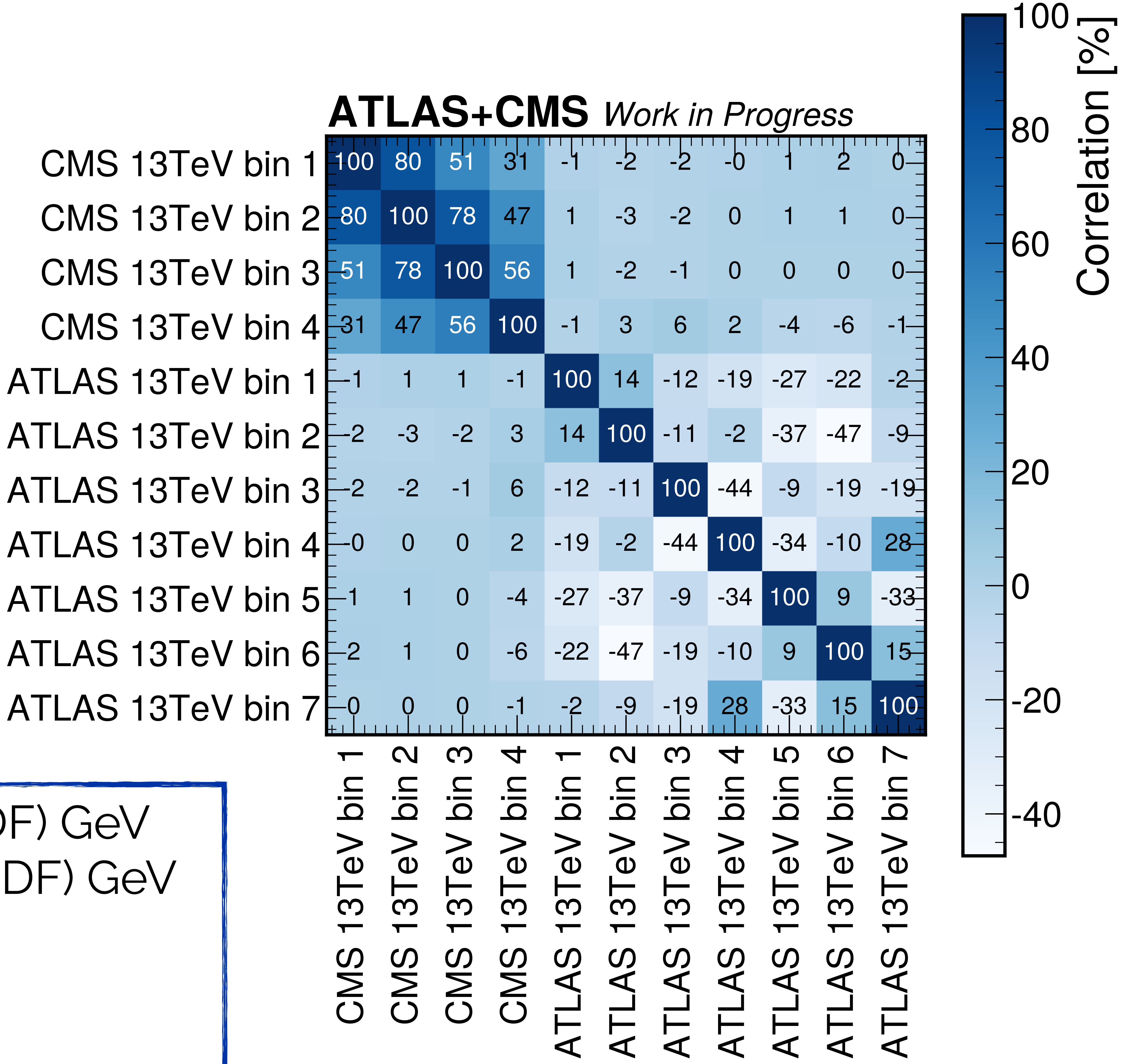
Scale ± ~0.30



Correlation assumptions no large effect. Focus should be on ATLAS-ATLAS combination?

Combining CMS + ATLAS 13

- Mild correlations, as in 8 TeV case



If we fit 2 POIs:

m_t CMS TeV= 172.27 ± 1.28 (exp) ± 0.31 (PDF) GeV
m_t ATLAS TeV = 171.31 ± 1.44 (exp) ± 0.60 (PDF) GeV
Correlation = -0.8 %
Difference = 1.0 ± 2.1 GeV
Ratio = 1.006 ± 0.012

p=0.66 (2 POI) vs. 0.74 (1 POI)

Combining CMS + ATLAS 13

CMS uncertainties affect flat 2% on last ATLAS bins

Mild impact from tt modelling - 2 % in the last bin

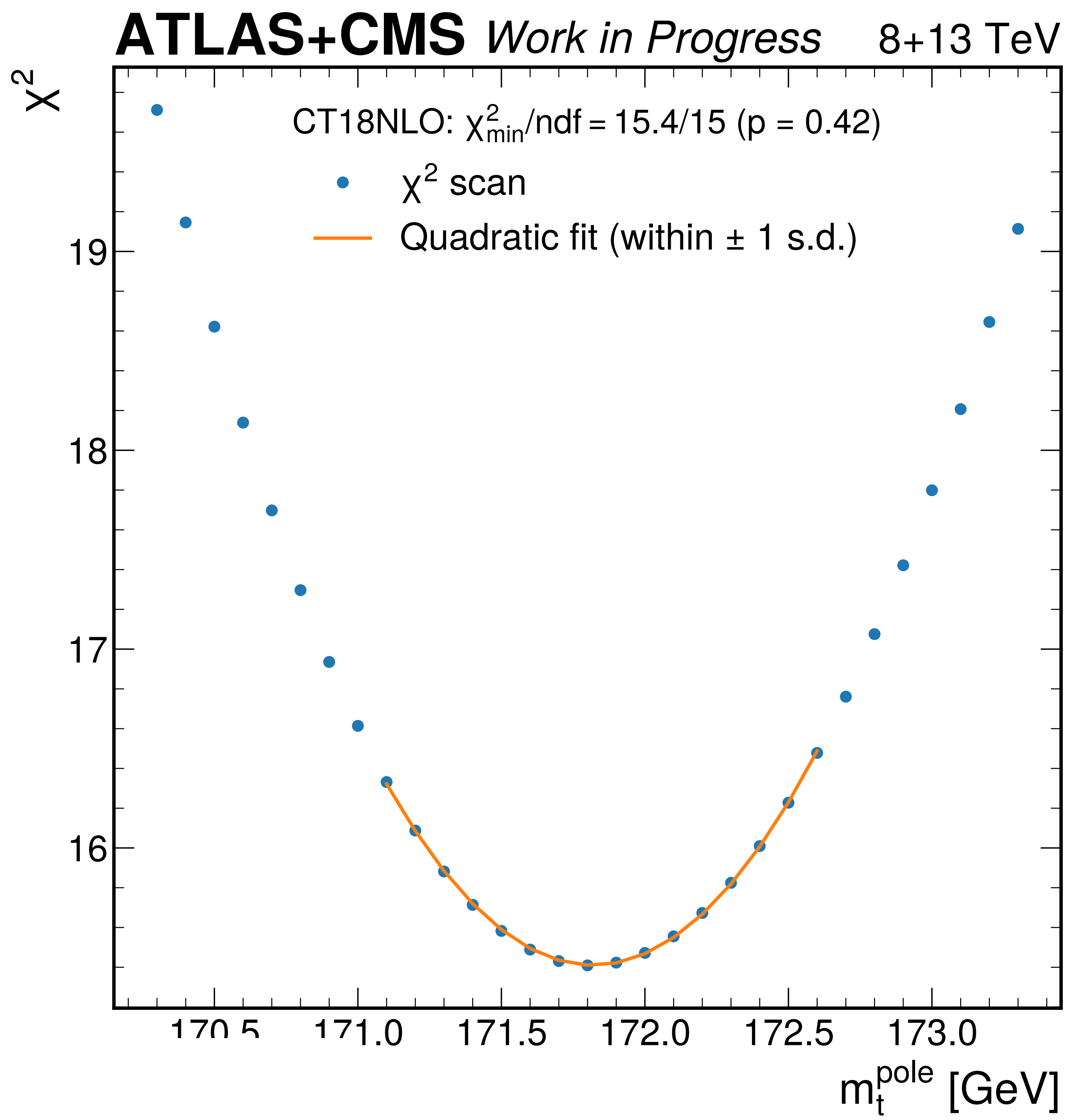
CMS uncertainties, grouped

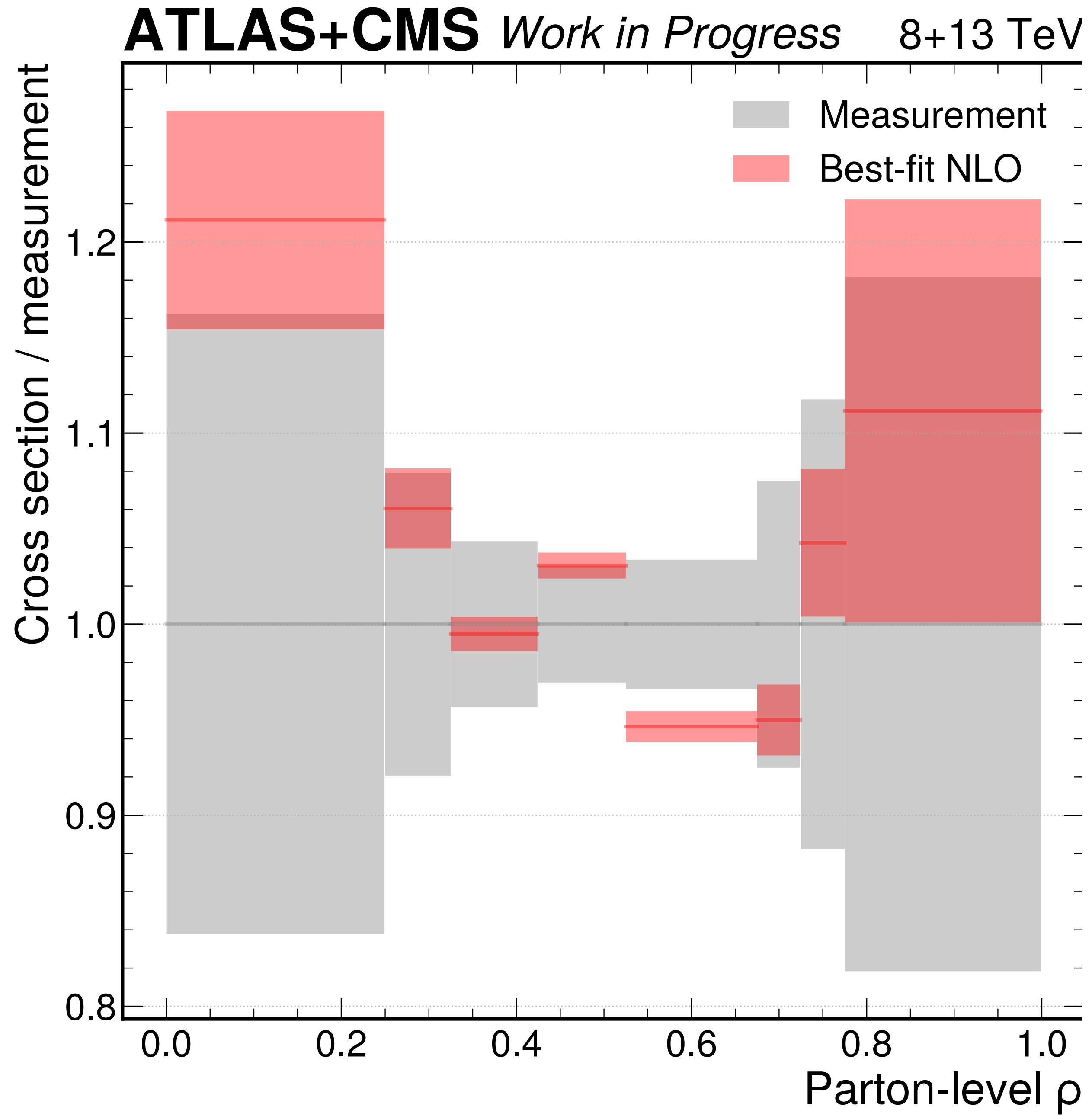
ATLAS 13 TeV uncertainties, grouped

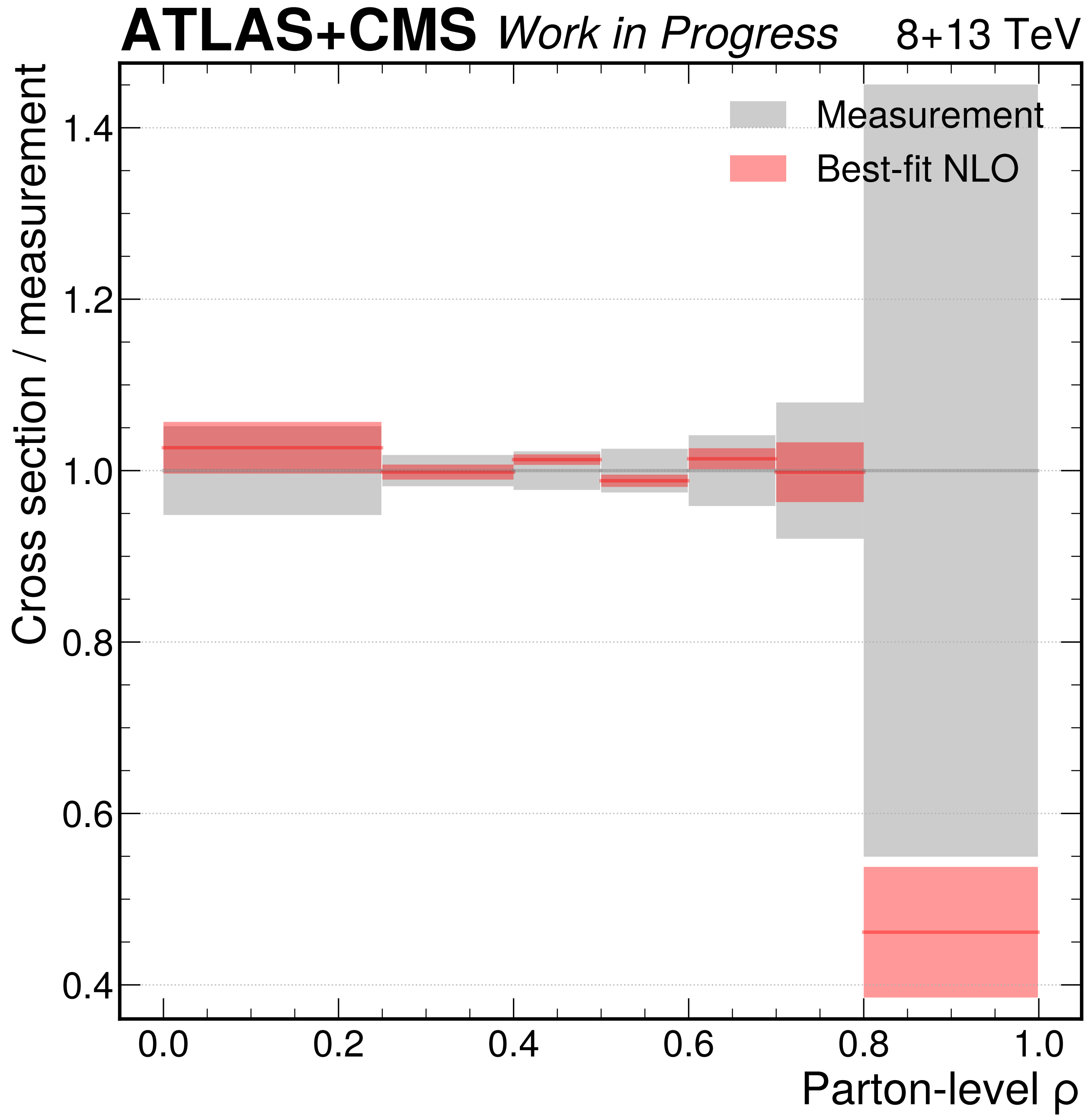
Grand combination - no correlations (yet)

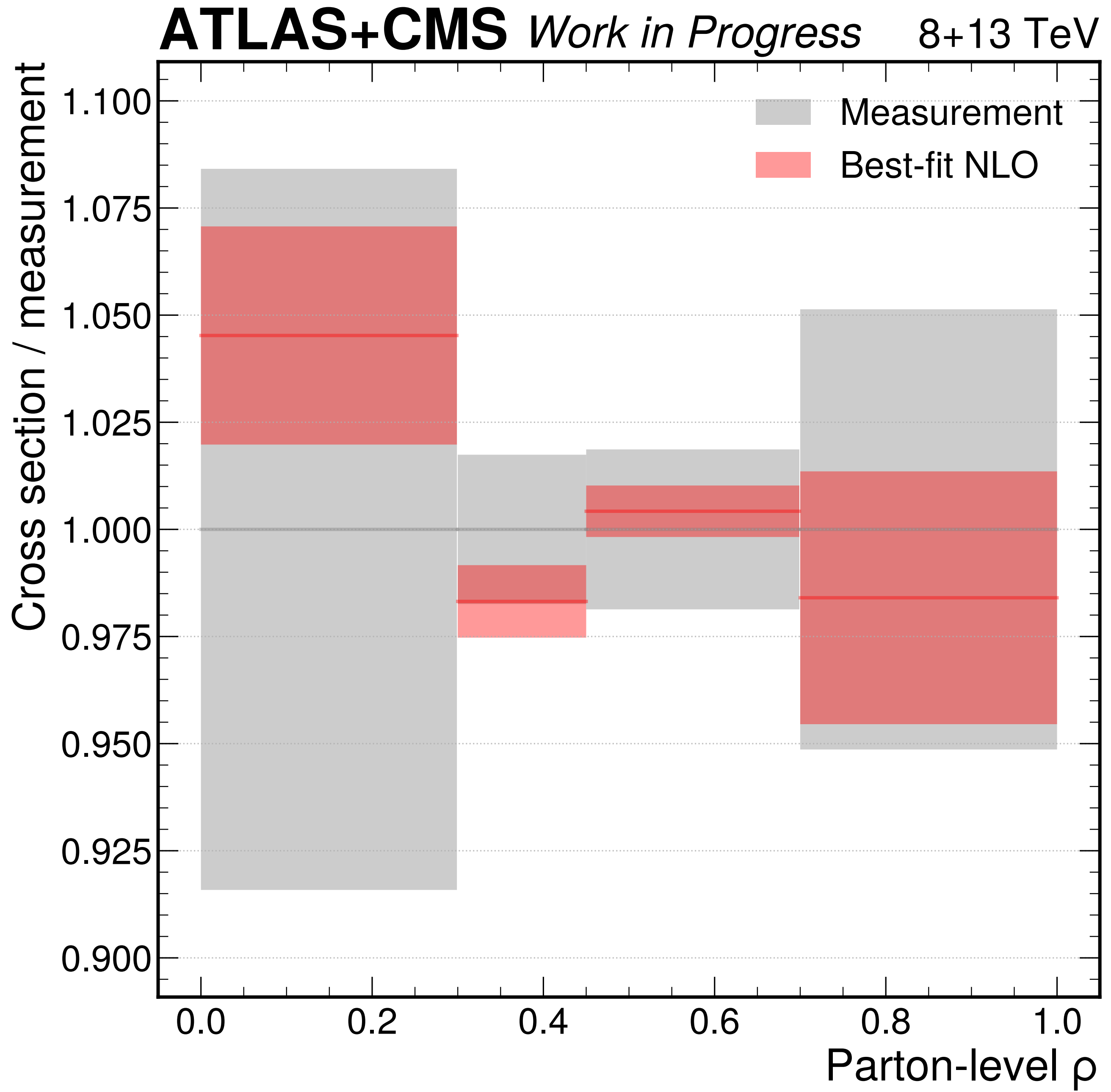
- Good overall agreement
- mt = 172.12 ± 0.75 (exp) ± 0.31 (PDF) GeV
- Scale uncertainty = +0.16 -0.17 GeV

- Version with correlations unstable, coming from TBD
  - Trials with Convino take 1-2 days per setup…
  - Need separate configs…









p=0.48 (3 POI) vs. 0.42 (1 POI)

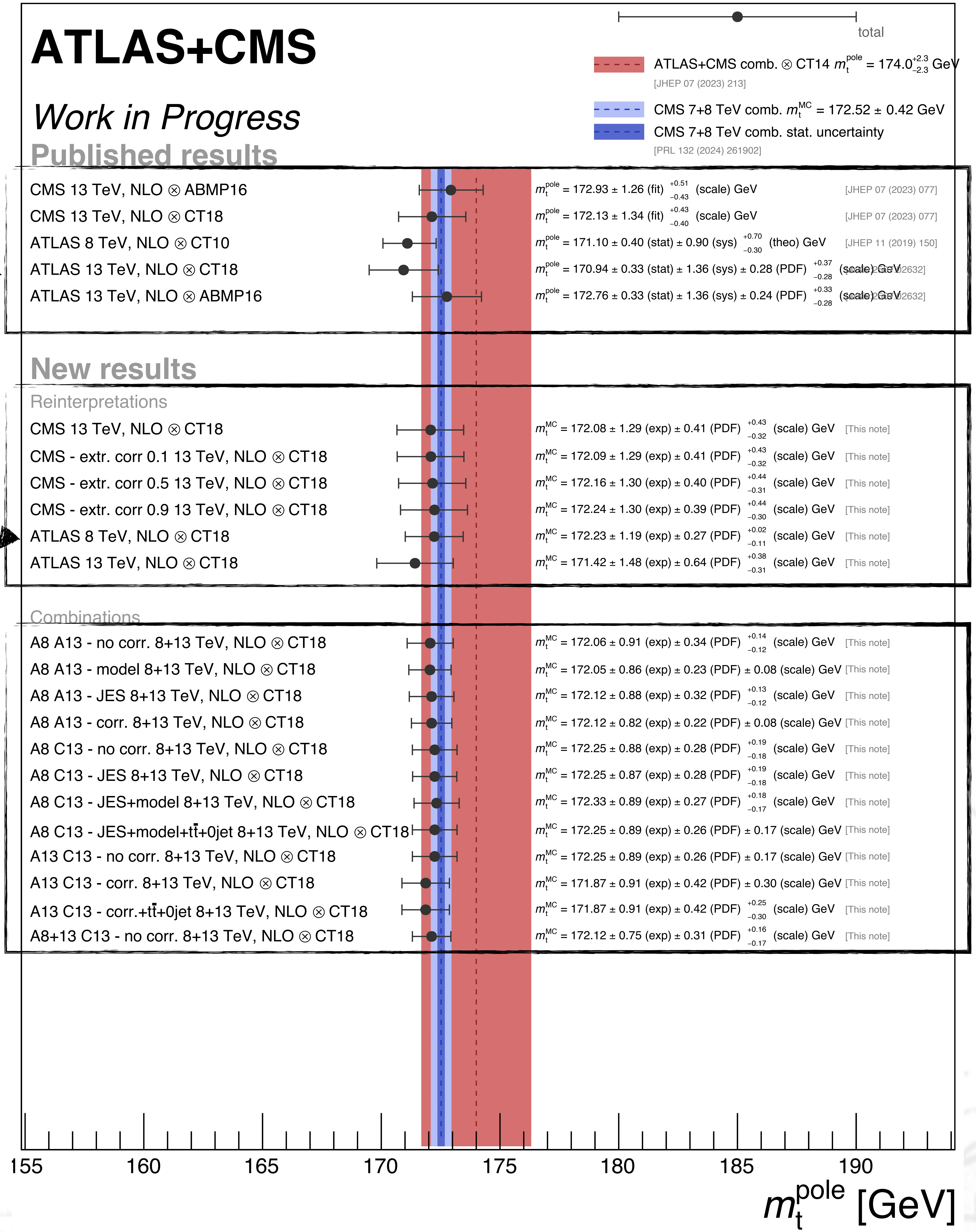
Correlations
A8/A13: 3.2 %
A8/C13: 1.8%
A13/C13: 8.7 %

Let's put it in comparison

- Input measurements as published
  - ATLA 13 lower wrt. mean

- Reinterpretations standalone
  - CMS results closes within 50 MeV
- ATLAS 8 TeV result moves by 1.1 GeV towards CMS result
  - ~10% more precise
- ATLAS 13 different, see above

- Combinations:
  - Very compatible although different inputs
  - Driven by CMS / ATLAS 8 TeV?
  - Converging on ~172.1 w/ 0.7 GeV unc?



Conclusions and outlook

- We have a good baseline setup ready:
  - Any CMS + single ATLAS combination is solid
  - Well documented in AN

- Correlations to be studied in detail:
  - ATLAS — ATLAS
  - CMS — ATLAS 13 TeV
    - Especially “new” uncertainties

- We need a solution for Convino/flexibility?

- Let’s follow-up and get NNLO quickly :)

Available on the CMS information server **CMS AN-25-003**

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2025/01/29
Archive Hash: untracked
Archive Date: 2025/01/29

LHC combination of the ATLAS and CMS top quark pole mass measurements using $t\bar{t}$+jet events

Matteo Defranchis[1], Davide Melini[2], Andrej Saibel[2], Marcel Vos[2], Juan Fuster[2], Sebastian Wuchterl[1], and Katerina Lipka[3]

[1] CERN
[2] IFIC (UV/CSIC) Valencia, Spain
[3] DESY

Backup

Revisiting the ATLAS 8 TeV result

- Revisited the 8 TeV published result implementing systematic uncs in a global covariance matrix
- Results:
  - Stat-only fit: 171.1 +- 0.45 (stat) GeV
  - Stat+syst fit: 172.1 +- 1.16 (stat+exp syst) GeV

Change in central value is possible as the bins weighting in the chi2 minimization changes when systematics are included

- Published result used a stat-only covariance matrix (i.e. expected same central value as stat-only fit) and evaluated systematic uncertainties with a different approach (fitted mass values), obtaining:
  - Published value: 171.1 +- 1.0 (stat+exp syst) GeV

- *Total exp unc re-produced with a 150/200MeV precision.*
- *Same central value for same fit type*

N.B. In addition a smoothing procedure was implemented to reduce stat. Fluctuations in the systematic shapes

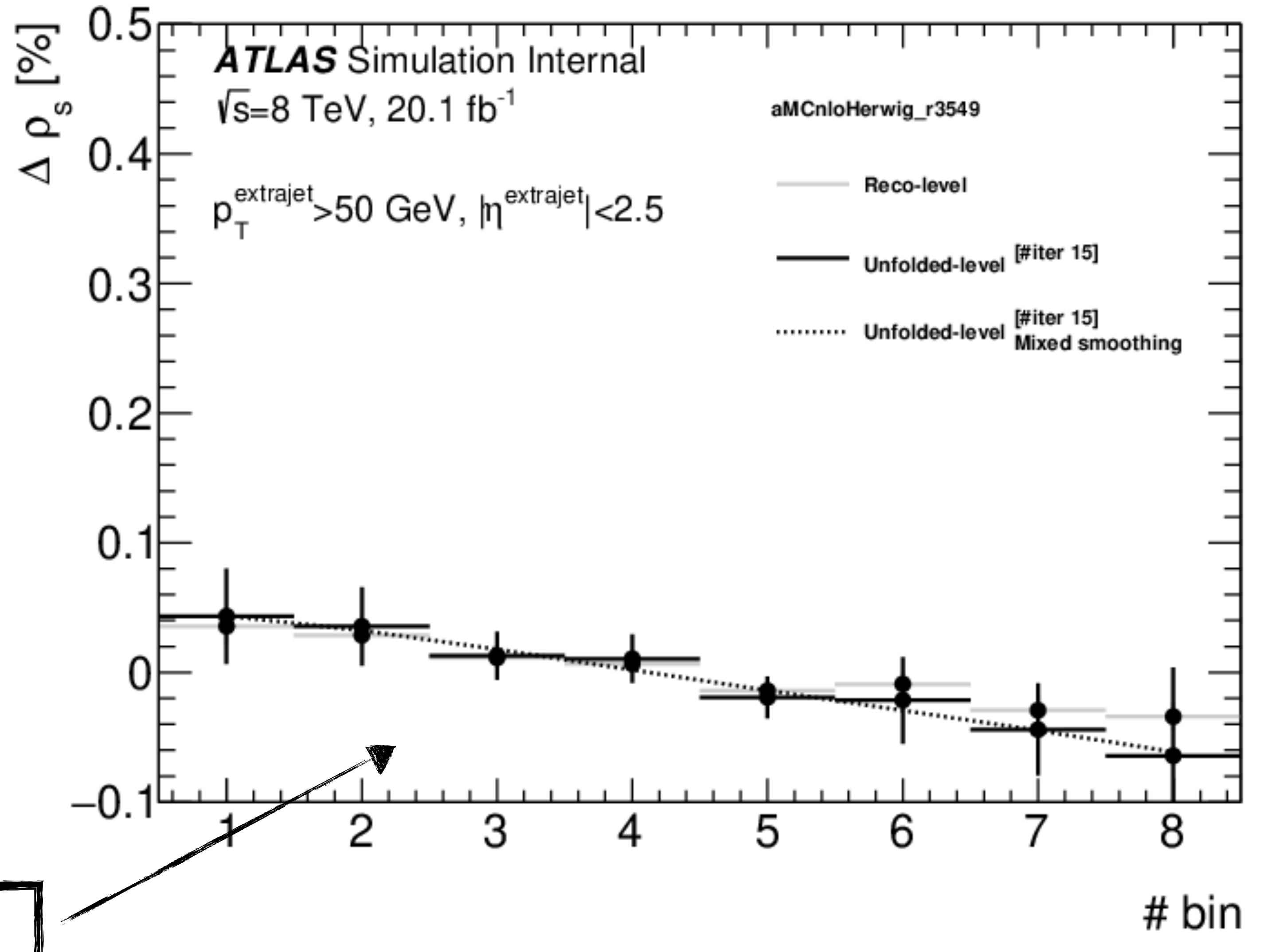
ATLAS tt+jet: re-visiting the 8TeV result

- Comparison of breakdown of uncertainties:
  - Breakdowns obtained with different methods:
    - Original 8TeV analysis: unfold and fit alternative distribution, compare mTsyst with ref.
    - Updated approach: do not add syst effect in the covariance matrix and get difference in uncertainty on mTop
  - Systematic uncs from alternative MC samples had associated statistical uncs up to 200MeV (per mTop extracted).

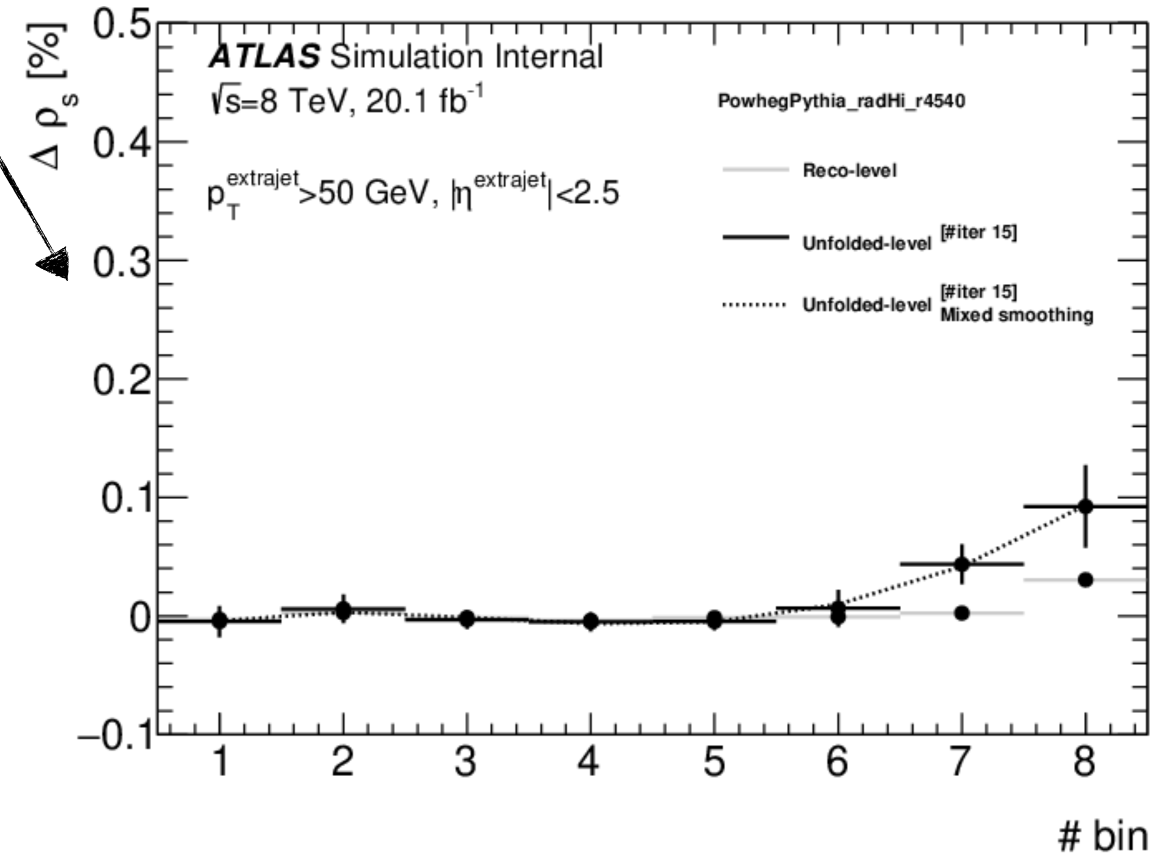
Description	Re-obtained value [GeV]	Ref. [7] value [GeV]
m_t^{pole}	172.11 (171.09 stat-only fit)	171.1
Total experimental uncertainty	1.20	0.9
Statistical uncertainty	0.45	0.4
Shower and hadronization uncertainty	0.32	0.4
Color reconnection uncertainty	0.2	0.4
Underlying event uncertainty	0.2	0.3
Signal Monte Carlo generator uncertainty	0.32	0.2
Proton PDF uncertainty	0.25	0.2
Initial- and final-state radiation uncertainty	0.47	0.2
Background uncertainty	0.07	<0.1
Jet energy and efficiency uncertainty	0.6	0.4
b-tagging efficiency and mistag uncertainty	0.13	0.1
Leptons and E_T^{miss} uncertainty	0.04	0.1

ATLAS tt+jet: re-visiting the 8TeV result

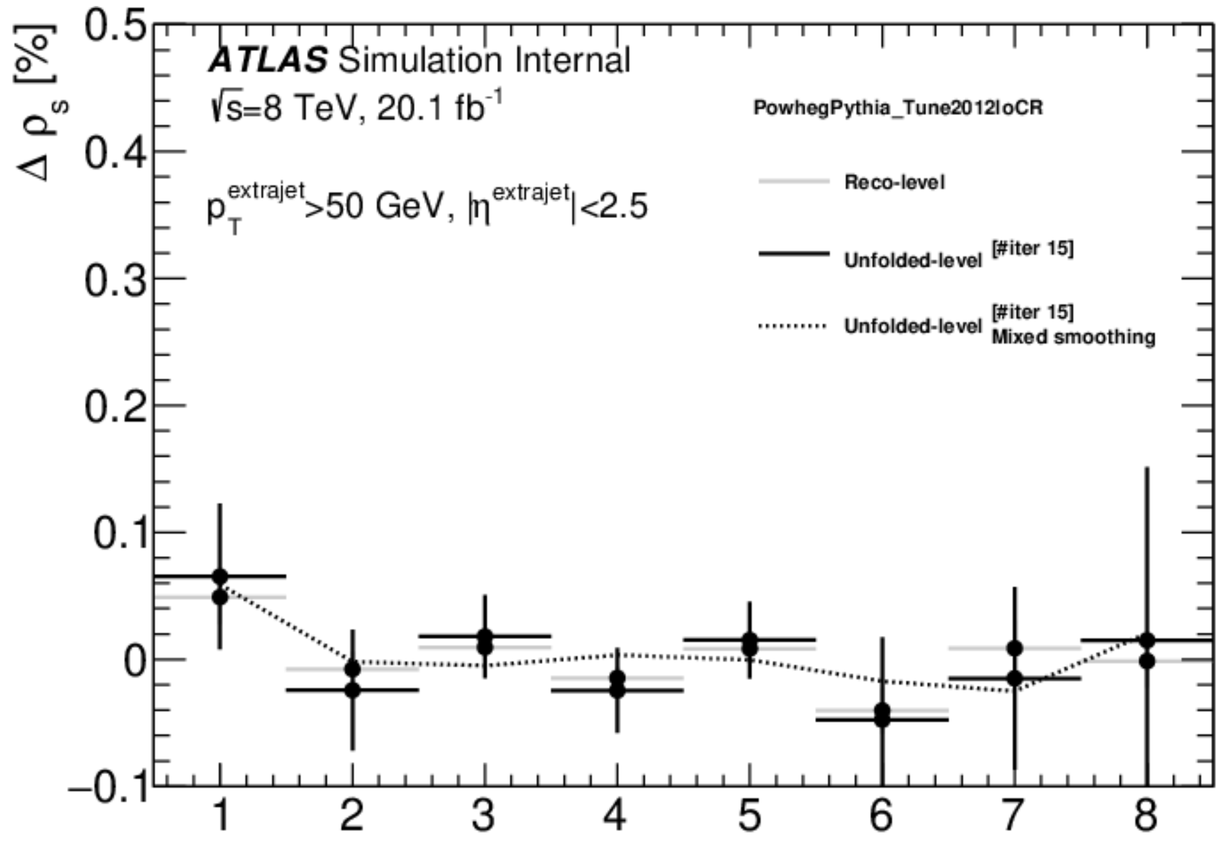
- New smoothing procedure:
  - Smoothing (dashed lines) applied to the shifts on the unfolded observable due to systematic effects
  - Mitigates the effect of statistical fluctuations

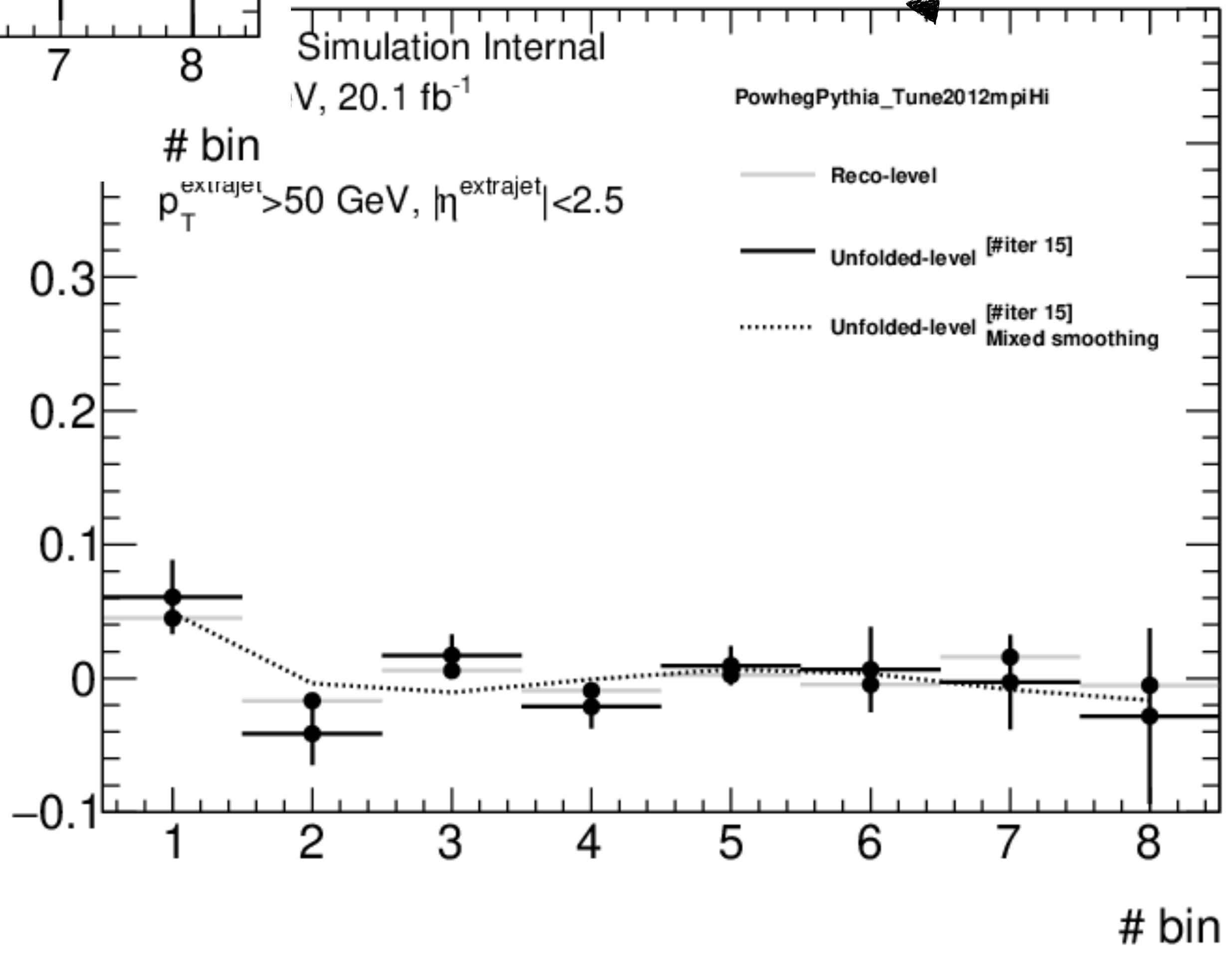


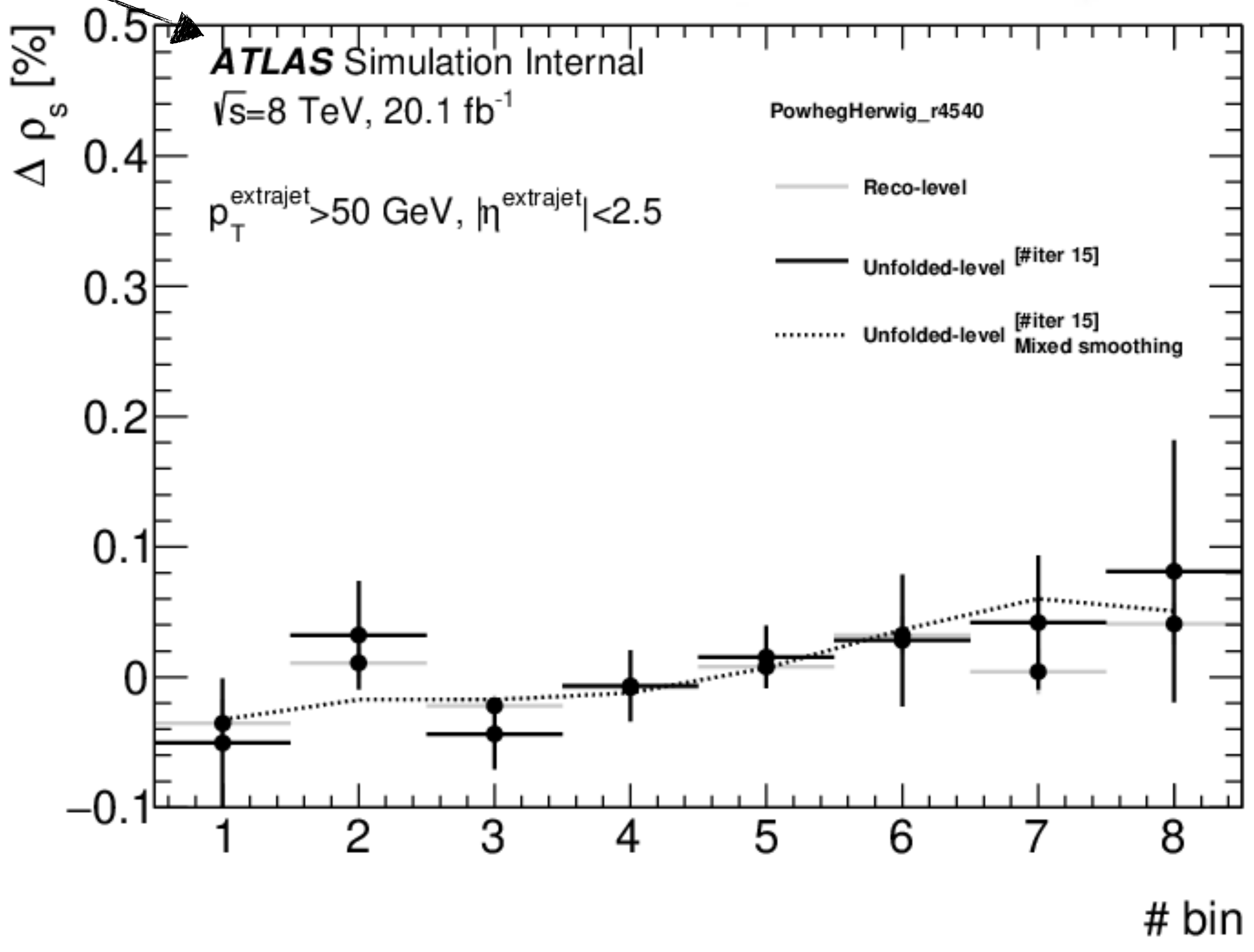
Smoothing does nothing for some systematic shifts



Smoothing cleans statistical fluctuations in other cases







Correlation assumptions: JES

- How do we decide on the correlations?
  - Work was ~already done: Run 1 direct top quark mass combination
  - → Fully applicable for JES and modeling
- Looking at TOPLHC NOTE: link

Description	Components, CMS	Components, ATLAS	Corr. range
1a. Statistical *in situ* terms	AbsoluteStat, SinglePionHCAL, RelativeStat[FSR][EC2][HF]	[11] **Z**-jet balance `stat./meth.` terms (p_T), [13] γ-jet balance `stat./meth.` terms (p_T), [10] multi-jet balance `stat./meth.` terms (p_T), η-intercalibration statistical term (p_T,η)	0%
1b. Detector *in situ* terms	AbsoluteScale, SinglePionECAL, RelativeJER[EC1][EC2][HF], RelativePt[BB][EC1][EC2][HF]	**Z**-jet balance `det.` term, γ-jet balance `det.` term, [2] correlated **Z**/γ-jet balance `det.` terms (p_T)	0%
2. Absolute balance modeling	AbsoluteMPFBias	[7] **Z**-jet balance `model` + `mixed` terms (p_T), [4] γ-jet balance `model` + `mixed` terms (p_T), [2] correlated **Z**/γ-jet balance terms (p_T), [5] multi-jet balance `model` + `mixed` terms (p_T)	0-50%
3. Relative balance modeling	RelativeFSR	η-intercalibration modeling (p_T,η)	50-100%
4. *g*-jet fragmentation	FlavorPureGluon	Flavor response (p_T,η)	100%
5. *b*-jet fragmentation	FlavorPureBottom	*b*-jet response (p_T)	50-100%
6. Other fragmentation types	FlavorPureQuark, FlavorPureCharm	Flavor composition (p_T,η)	0%
7. Pileup	PileupDataMC, PileupPt[Ref][BB][EC1][EC2][HF]	N_{PV} offset (p_T,η,N_{PV}), $\langle\mu\rangle$ offset (p_T,η,$\langle\mu\rangle$), p_T term (p_T,η,N_{PV},$\langle\mu\rangle$), ρ topology (p_T,η)	0%
8. High-p_T	Fragmentation	High-p_T (p_T)	0%
9. Single-experiment terms	TimeEta, TimePt	Fast simulation closure (p_T,η), punch-through (p_T,η,$N_{segments}$)	0%

Table 4: The range of correlation coefficients to be used for each individual ATLAS and CMS JES uncertainty source and component grouping when combining measurements between the experiments. The variables used to parametrize each ATLAS uncertainty component are listed in parentheses. If more than one ATLAS uncertainty component matches a given classification, the corresponding number is listed at the start in square brackets. The variable named $N_{segments}$ is the number of segments in the muon system behind the jet, as described in Ref. [10].

Implement it one to one:

```
# Obvious ones from the JES mapping
ATLAS_scale_b = (0.75)  CMS_scale_j_flavorBottom
ATLAS_scale_j_flavorresponse = (0.9)  CMS_scale_j_flavorGluon
ATLAS_scale_j_EtaIntercalibrationModel = (0.75)  CMS_scale_j_relativeFSR
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix1
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix2
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix3
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix4
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model1
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model2
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model3
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model4
```

Correlation assumptions: tt modeling

- Checking the analysis note of the Run 1 combination: link

- LHC Had: CMS b fragmentation and ATLAS Herwig vs Pythia

LHC HAD This term includes uncertainties associated with hadronisation. As discussed in Section 3, there are significant differences between ATLAS and CMS in the way the uncertainty is evaluated. The category is therefore treated as partially correlated (0.5).

- LHC Rad: ATLAS envelope of scales, hdamp, ISR/FSR
  CMS split of the same uncertainties

LHC RAD This term includes uncertainties in the amount of extra QCD radiation in $t\bar{t}$ events. As the nominal MC setups are different between ATLAS and CMS, the category is treated as partially correlated (0.5).

- Color reconnection and UE: ATLAS sum, CMS breakdown

Color reconnection and underlying event For both these categories, ATLAS and CMS rely on simulated event samples. The nominal tunes differ between the experiments and the variations, while similar as discussed in Section 3 are not identical, and hence these categories are assumed to be partially correlated between ATLAS and CMS.

Implement it similarly:

```
# Other ones taken from the Run 1 mass combination
CMS_modelling_ttbar_bfrag = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_bfragPythiaDefault = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_bfragPeterson = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_erdOn = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_tuneQCD  = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_tuneGluon  = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_hdamp = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_isr = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_fsr = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_tune = (0.50) ATLAS_modelling_ttbar_UnderlyingEvent
```

Correlation assumptions

- Numbers taken from final table
  - Correlation scans need to be done

Uncertainty category	ρ	Scan range	$\Delta m_t/2$ [MeV]	$\Delta\sigma_{m_t}/2$ [MeV]
LHC JES 1	0	—	—	—
LHC JES 2	0	[−0.25, +0.25]	8	7
LHC JES 3	0.5	[+0.25, +0.75]	1	<1
LHC b-JES	0.85	[+0.5, +1]	26	5
LHC g-JES	0.85	[+0.5, +1]	2	<1
LHC l-JES	0	[−0.25, +0.25]	1	<1
CMS JES 1	—	—	—	—
JER	0	[−0.25, +0.25]	5	1
Leptons	0	[−0.25, +0.25]	2	2
b tagging	0.5	[+0.25, +0.75]	1	1
p_T^{miss}	0	[−0.25, +0.25]	<1	<1
Pileup	0.85	[+0.5, +1]	2	<1
Trigger	0	[−0.25, +0.25]	<1	<1
ME generator	0.5	[+0.25, +0.75]	<1	4
LHC radiation	0.5	[+0.25, +0.75]	7	1
LHC hadronization	0.5	[+0.25, +0.75]	1	<1
CMS B hadron BR	—	—	—	—
Color reconnection	0.5	[+0.25, +0.75]	3	1
Underlying event	0.5	[+0.25, +0.75]	1	<1
PDF	0.85	[+0.5, +1]	1	<1
Top quark p_T	—	—	—	—
Background (data)	0	[−0.25, +0.25]	8	2
Background (MC)	0.85	[+0.5, +1]	2	<1
Method	0	—	—	—
Other	0	—	—	—

Correlation assumptions

What matters?

ATLAS

Mass scheme	m_t^{pole} [GeV]	$m_t(m_t)$ [GeV]
Value	**171.1**	**162.9**
Statistical uncertainty	**0.4**	**0.5**
Simulation uncertainties		
Shower and hadronisation	0.4	0.3
Colour reconnection	0.4	0.4
Underlying event	0.3	0.2
Signal Monte Carlo generator	0.2	0.2
Proton PDF	0.2	0.2
Initial- and final-state radiation	0.2	0.2
Monte Carlo statistics	0.2	0.2
Background	<0.1	<0.1
Detector response uncertainties		
Jet energy scale (including *b*-jets)	0.4	0.4
Jet energy resolution	0.2	0.2
Missing transverse momentum	0.1	0.1
b-tagging efficiency and mistag	0.1	0.1
Jet reconstruction efficiency	<0.1	<0.1
Lepton	<0.1	<0.1
Method uncertainties		
Unfolding modelling	0.2	0.2
Fit parameterisation	0.2	0.2
Total experimental systematic	**0.9**	**1.0**
Scale variations	(+0.6, −0.2)	(+2.1, −1.2)
Theory PDF⊕α_s	0.2	0.4
Total theory uncertainty	**(+0.7, −0.3)**	**(+2.1, −1.2)**
Total uncertainty	**(+1.2, −1.1)**	**(+2.3, −1.6)**

CMS

Uncertainty Source	$\Delta\sigma^1_{t\bar{t}+jet}$ [%]	$\Delta\sigma^2_{t\bar{t}+jet}$ [%]	$\Delta\sigma^3_{t\bar{t}+jet}$ [%]	$\Delta\sigma^4_{t\bar{t}+jet}$ [%]
Experimental				
Muon identification	1.8	1.5	1.5	1.4
Muon energy scale and resolution	0.7	0.2	0.3	0.5
Electron identification	2.0	1.7	1.7	2.1
Electron energy scale and resolution	0.9	1.0	0.9	1.5
Jet energy scale	2.6	2.0	2.2	3.6
Jet energy resolution	0.6	0.5	0.5	0.4
Jet identification	1.1	0.8	0.8	1.3
p_T^{miss}	0.2	0.3	0.4	0.8
b jet identification	1.0	0.7	0.6	1.2
Trigger efficiency	1.8	1.2	1.1	1.8
Total	4.0	3.1	3.1	4.7
Background normalization				
$t\bar{t}$+0 jet	2.2	2.0	1.7	0.7
Z+jets	2.4	1.9	1.7	2.6
Single top quark	0.9	0.8	0.7	0.1
Total	3.1	2.5	2.4	2.7
Modeling				
Z+jets ME scale	0.7	0.4	0.2	0.3
Single top quark ME/FSR/ISR scales	1.2	0.6	0.4	0.1
$t\bar{t}$ PDF	0.1	0.1	0.1	0.6
$t\bar{t}$ ME scale	1.0	0.5	0.6	0.4
$t\bar{t}$ ISR scale	1.2	0.8	0.6	1.6
$t\bar{t}$ FSR scale	1.3	0.8	0.6	1.7
$t\bar{t}$ top quark p_T	2.0	1.3	0.1	1.2
b fragmentation	0.9	0.7	0.8	0.8
Color reconnection	0.5	0.6	0.2	0.7
$t\bar{t}$ matching scale	0.6	0.5	0.6	≤0.1
Underlying-event tune	0.2	0.5	0.2	0.5
Total	3.2	1.9	1.8	3.1
Integrated luminosity	1.2	1.4	1.3	1.2
m_t^{MC}	1.7	1.0	0.4	2.3
Finite size of simulated samples	2.0	1.4	1.3	2.2
Total systematic	5.0	3.4	3.2	5.6
Statistical	1.6	1.0	0.8	2.4
Total	5.2	3.6	3.3	6.1

Correlation assumptions

What matters?

- Numbers taken from final table
  - Correlation scans need to be done

- Our expectations are:
  - They shouldn't really matter, besides maybe
    - b-JES (also Run 1 combination)
    - tt0Jet normalization as it has a large impact for the CMS absolute measurement

Uncertainty Source	$\Delta\sigma^1_{t\bar{t}+jet}$ [%]	$\Delta\sigma^2_{t\bar{t}+jet}$ [%]	$\Delta\sigma^3_{t\bar{t}+jet}$ [%]	$\Delta\sigma^4_{t\bar{t}+jet}$ [%]
Experimental				
Muon identification	1.8	1.5	1.5	1.4
Muon energy scale and resolution	0.7	0.2	0.3	0.5
Electron identification	2.0	1.7	1.7	2.1
Electron energy scale and resolution	0.9	1.0	0.9	1.5
Jet energy scale	2.6	2.0	2.2	3.6
Jet energy resolution	0.6	0.5	0.5	0.4
Jet identification	1.1	0.8	0.8	1.3
p_T^{miss}	0.2	0.3	0.4	0.8
b jet identification	1.0	0.7	0.6	1.2
Trigger efficiency	1.8	1.2	1.1	1.8
Total	4.0	3.1	3.1	4.7
Background normalization				
$t\bar{t}$+0 jet	2.2	2.0	1.7	0.7
Z+jets	2.4	1.9	1.7	2.6
Single top quark	0.9	0.8	0.7	0.1
Total	3.1	2.5	2.4	2.7
Modeling				
Z+jets ME scale	0.7	0.4	0.2	0.3
Single top quark ME/FSR/ISR scales	1.2	0.6	0.4	0.1
$t\bar{t}$ PDF	0.1	0.1	0.1	0.6
$t\bar{t}$ ME scale	1.0	0.5	0.6	0.4
$t\bar{t}$ ISR scale	1.2	0.8	0.6	1.6
$t\bar{t}$ FSR scale	1.3	0.8	0.6	1.7
$t\bar{t}$ top quark p_T	2.0	1.3	0.1	1.2
b fragmentation	0.9	0.7	0.8	0.8
Color reconnection	0.5	0.6	0.2	0.7
$t\bar{t}$ matching scale	0.6	0.5	0.6	$\leq$0.1
Underlying-event tune	0.2	0.5	0.2	0.5
Total	3.2	1.9	1.8	3.1
Integrated luminosity	1.2	1.4	1.3	1.2
m_t^{MC}	1.7	1.0	0.4	2.3
Finite size of simulated samples	2.0	1.4	1.3	2.2
Total systematic	5.0	3.4	3.2	5.6
Statistical	1.6	1.0	0.8	2.4
Total	5.2	3.6	3.3	6.1