Recent results on α_s study in ATLAS and CMS

Tanmay Sarkar on behalf of the ATLAS and CMS Collaborations

QCD@LHC2022

Introduction

- Quark and gluon production in hadron collisions and their evolution subjects of intense theoretical and experimental studies.
- The Large Hadron Collider(LHC) produces a very large number of interactions mediated by Quantum Chromodynamics (QCD).
- Can be used for precision pQCD test and for extracting the strong coupling α_s value and provide tighter constraints on new physics.

ATLAS Measurement of Strong Coupling Constant

- ATLAS measurement uses the shape variables [Ref-1]:
  - Transverse energy-energy correlations (TEEC).
  - Associated azimuthal asymmetries (ATEEC).
- Appropriate generalisation for hadron collider experiments.
- Energy-Energy Correlation (EEC) originally introduced to provide a quantitative test of QCD in e^+e^-annihilation experiments.
- Results are based on: ATLAS-CONF-2020-025.pdf.

[Ref-1] G. Altarelli, The development of Perturbative QCD, World Scientific (1994).

Shape Variables

The TEEC function:

$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} \equiv \frac{1}{\sigma}\sum_{ij}\int\frac{d\sigma}{dx_{Ti}dx_{Tj}d\cos\phi}x_{Ti}x_{Tj}dx_{Ti}dx_{Tj} = \frac{1}{N}\sum_{A=1}^{N}\sum_{ij}\frac{E^A_{Ti}E^A_{Tj}}{(\sum_k E^A_{Tk})^2}\delta(\cos\phi - \cos\phi_{ij})$$

$x_{Ti} = \frac{E_{Ti}}{E_T}$, E_T transverse energies sum of all jets.

ϕ_{ij} angle in the transverse plane between jet i and jet j.

δ Dirac delta function.

ATEEC function: $$\frac{1}{\sigma}\frac{d\Sigma^{asym}}{d\cos\phi} = \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}|_{\phi} - \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}|_{\pi-\phi}$$

Sensitive to QCD radiation and present a clear dependence on α_s.

Data, Monte Carlo samples, and event selection

ATLAS-CONF-2020-025.pdf

- ATLAS Run2 data:
  - $\sqrt{s}$ =13 TeV
  - Integrated luminosity 139 fb^{-1}.
- MC samples produced with:
  - Pythia8, Sherpa and Herwig7 event generators.
- Events are selected :
  - High- p_T jets pass single-jet trigger $p_T >$ 460 GeV.
  - At least one reconstructed vertex that contains two or more associated tracks with $p_T >$ 500 MeV
  - Jets must have:
    - $p_T >$ 60 GeV and |η| < 2.4.
    - $H_{T2} = p_{T1} + p_{T2} > 1$ TeV.

- **Particle-flow used at reconstructed level [Ref-2].**
- **Anti-k_t algorith used in both reconstructed and generator level [Ref-3].**
- **Radius parameter R = 0.4 using the FastJet program [Ref-4].**

[Ref-2] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS Detector, Eur. Phys. J. C 77 (2017) 466, arXiv: 1703.10485 [hep-ex].

[Ref-3] M. Cacciari, G.P. Salam and G. Soyez, The anti-kt jet clustering algorithm, JHEP 04 (2008) 063, arXiv: 0802.1189 [hep-ph].

[Ref-4] M. Cacciari, G.P. Salam and G. Soyez, FastJet user manual, Eur. Phys. J. C 72 (2012) 1896, arXiv: 1111.6097 [hep-ph].

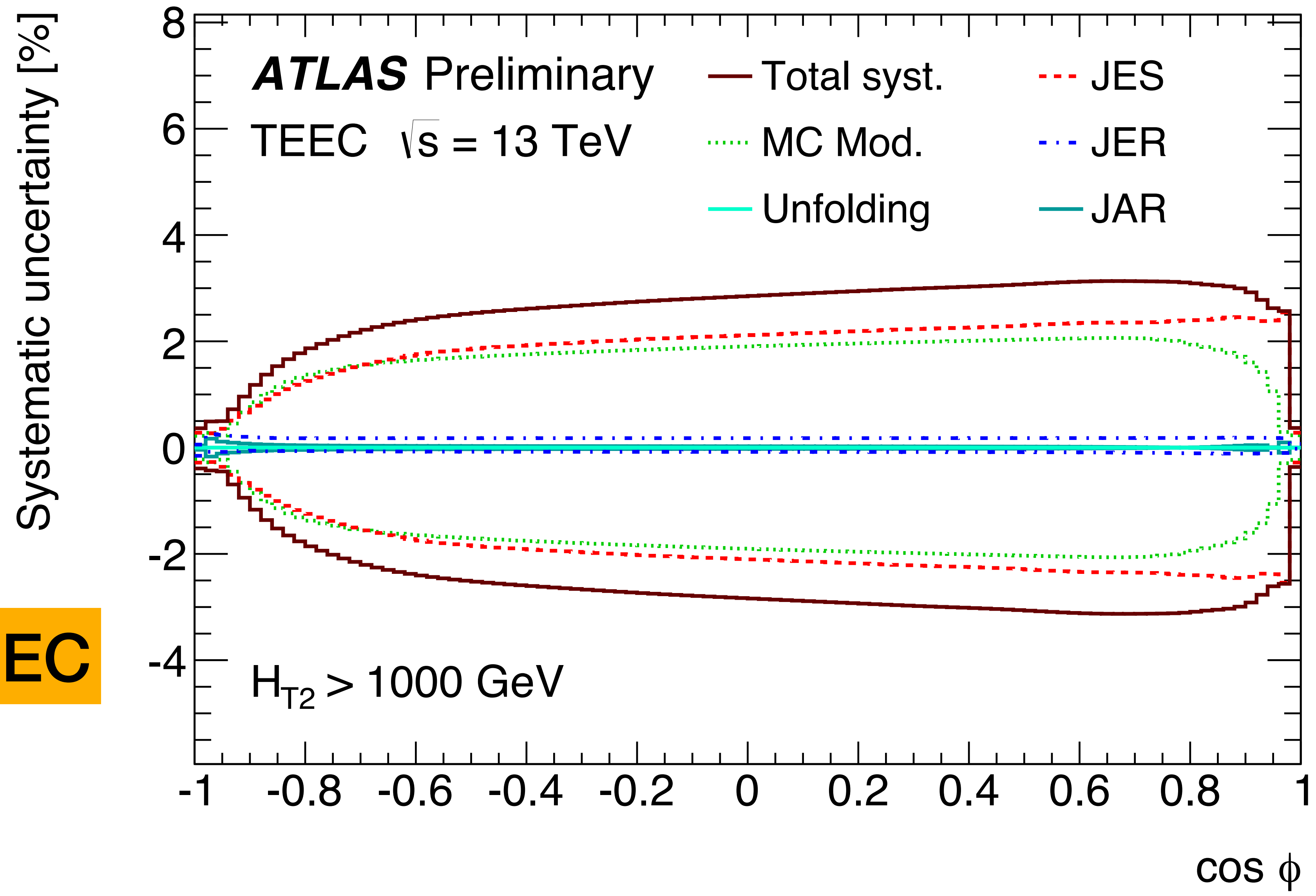
Unfolding

- To compare with particle-level theory predictions, the measured distributions need to be corrected:
  - Distortions induced by the response of the ATLAS detector.
  - Associated reconstruction algorithms.
- The unfolding is done with:
- Iterative algorithm based on Bayes theorem. [Ref-5]
- Corrects for detector inefficiencies and resolution effects into account.
- Uses the response matrix obtained from MC simulation.
- Data Unfolded with Pythia8 shown here.
- Sherpa and Herwig7 MC predictions used to estimate the model uncertainty.

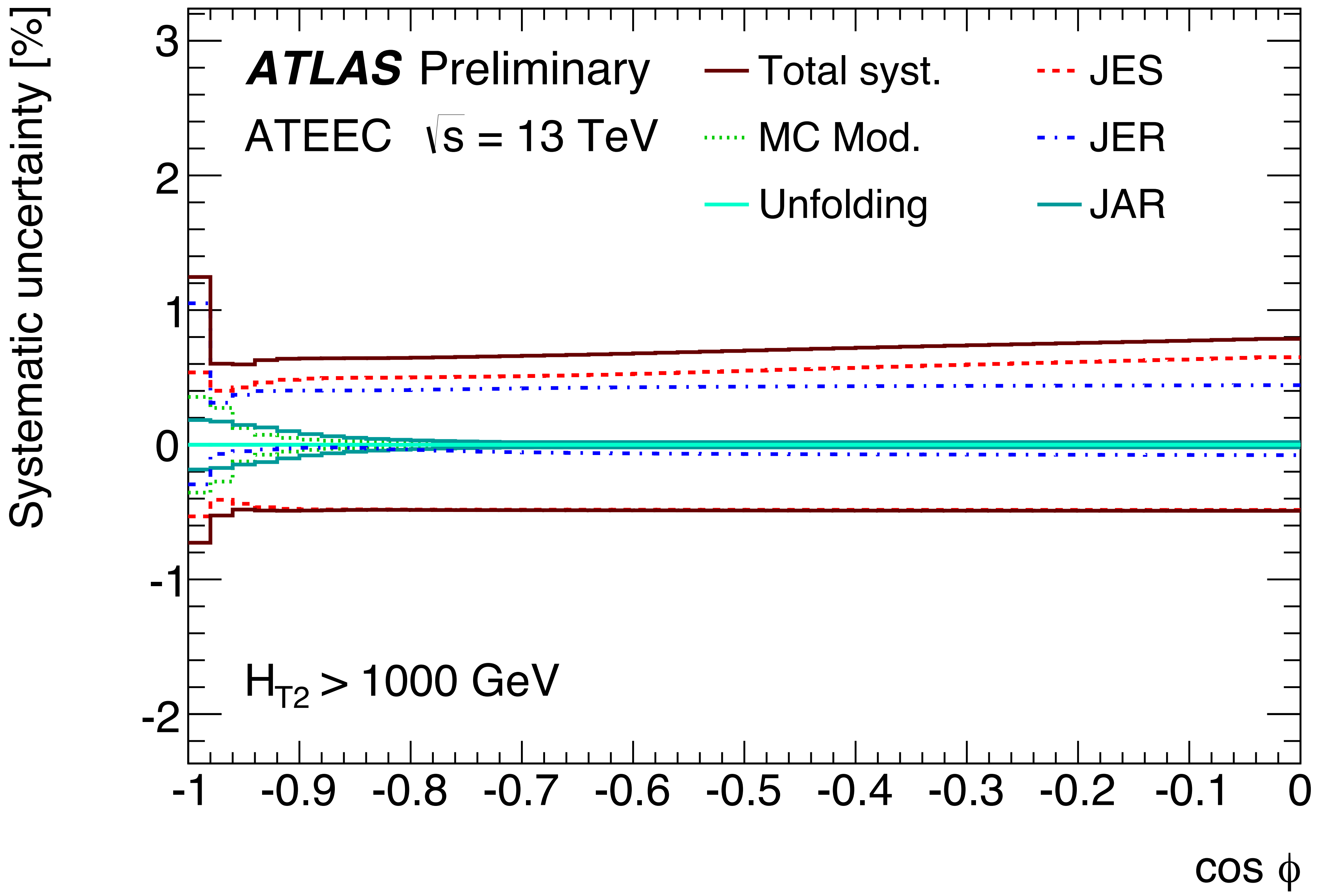
[Ref-5] G. D’Agostini, A multidimensional unfolding method based on Bayes’ theorem, Nucl. Instrum. Meth. A 362, 487 (1995).

Experimental uncertainties

TEEC



ATEEC



Jet Energy Scale (JES): ~2% $p_T \leq$ 60 GeV; <1% p_T>500 GeV.

Jet Energy Resolution (JER): ~2% at $p_T \leq$ 60 GeV to about 0.5% above.

Jet Angular Resolution (JAR): < 0.5% for both throughout the phase space.

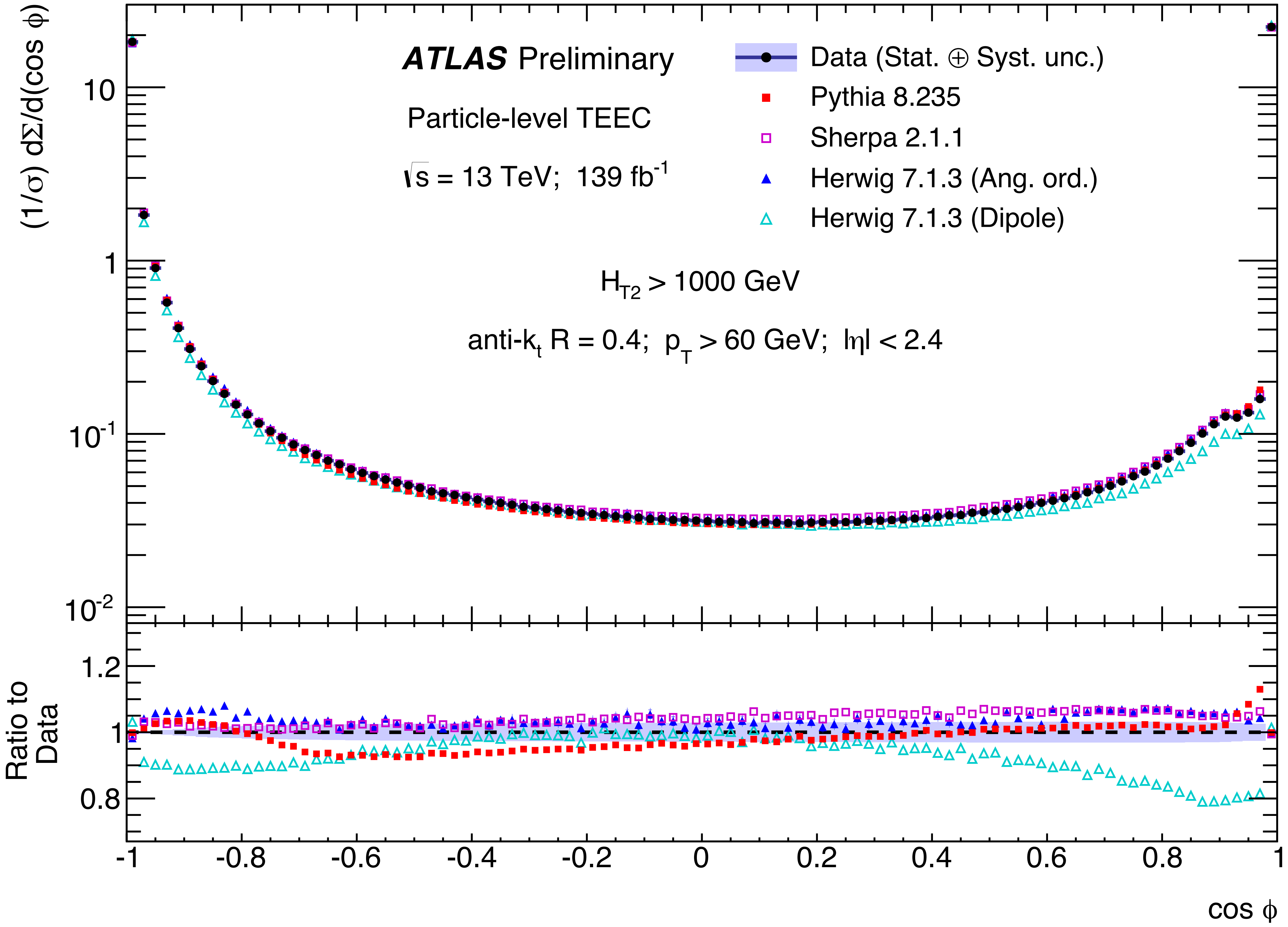
Unfolding: Negligible for both variables.

Modelling: 1.5% - 2% for TEEC, <0.5% for ATEEC.

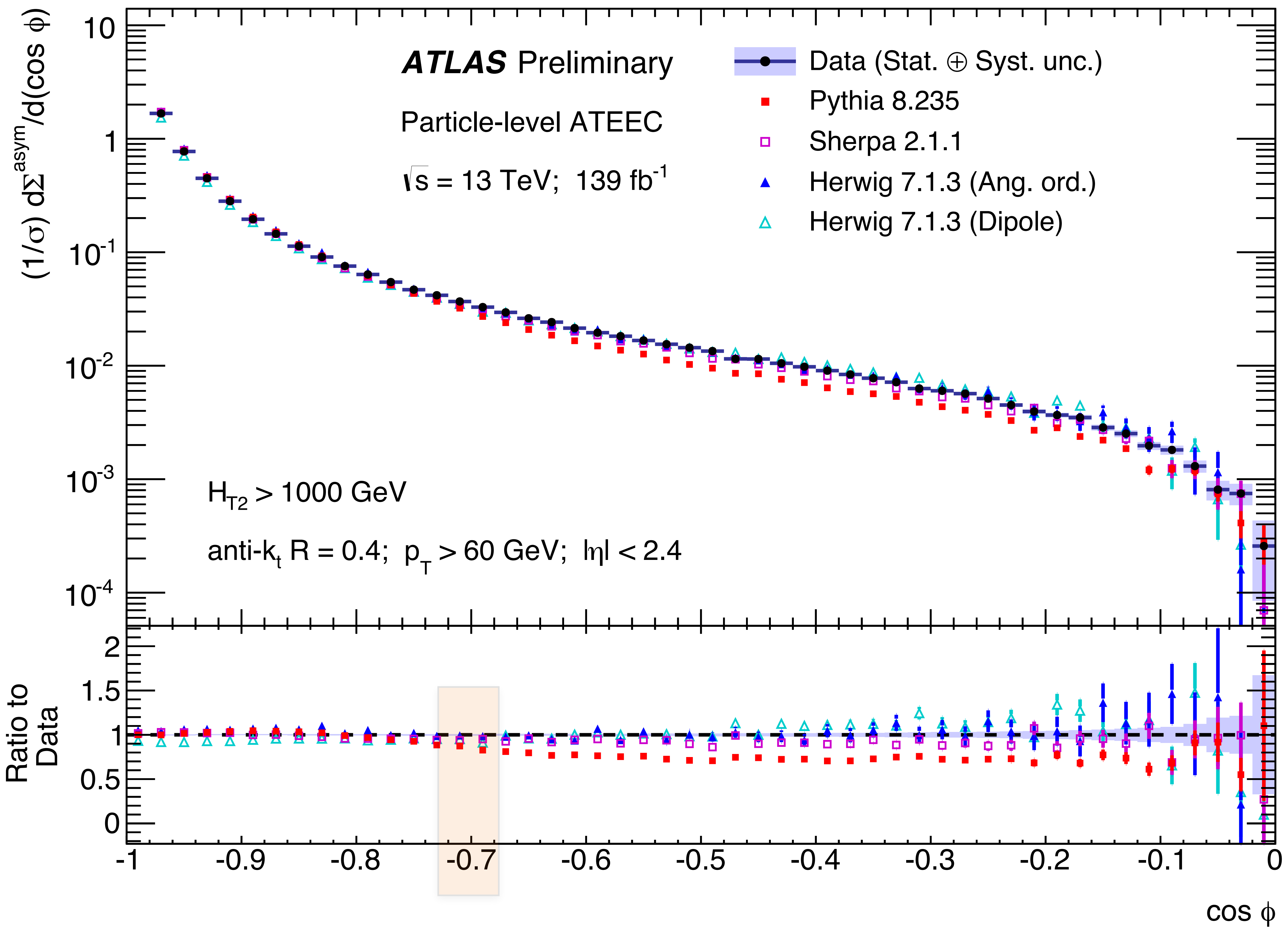
Total uncertainty : TEEC about 2% for 1 < $H_{T,2}$ < 1.2 TeV to 1.5% for $H_{T,2}$ > 3.5 TeV and ATEEC <1%.

Unfolded data compared with MC

TEEC



ATEEC



TEEC: Best description achieved by both Sherpa and Herwig7 with the angle-ordered parton shower in low H_{T2}. Pythia 8 gives the best description in high H_{T2}.

ATEEC: Good description is achieved by Sherpa and Herwig7, Pythia underestimates higher tail in low H_{T2}. Pythia8 and Sherpa has good agreement with data.

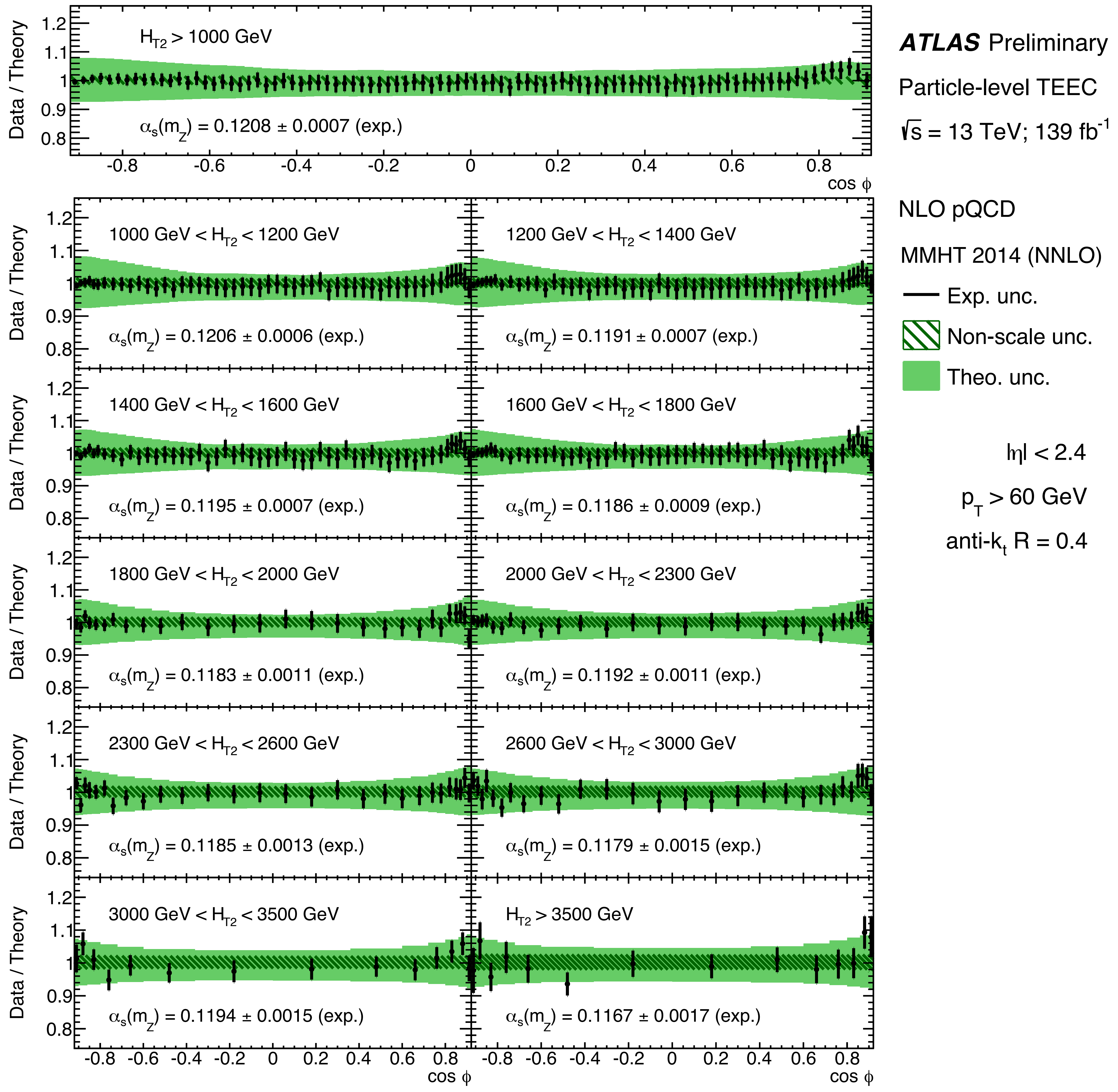
Other plots -H_{T2} in back-up

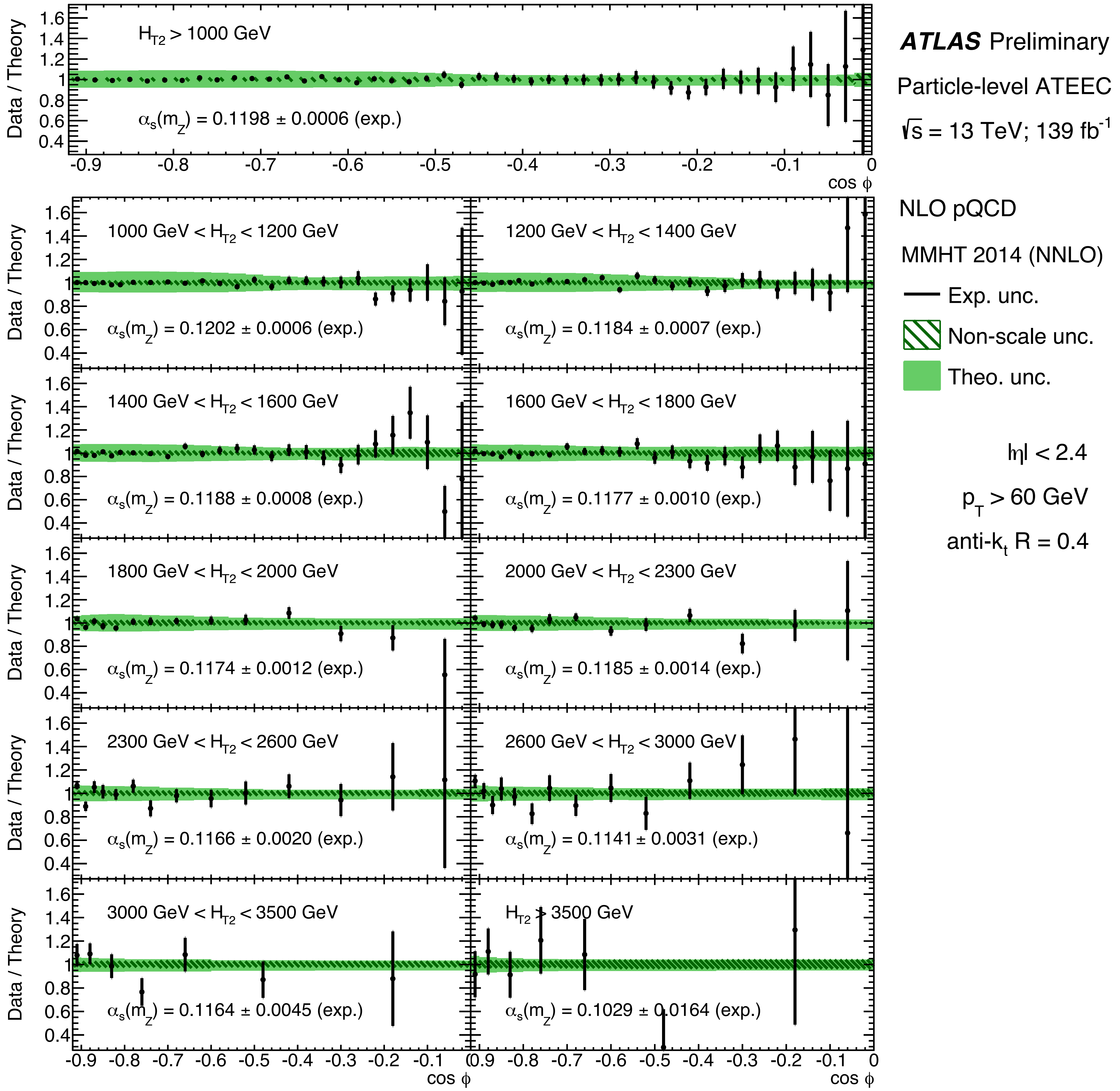
Theoretical predictions and uncertainties

- The theoretical predictions for the TEEC and ATEEC calculated:
  - Using pQCD at NLO in powers of the $\alpha_s(\mu_R)$ implemented in NLOJET++[Ref-6,7] with 5 massless quark flavours.
  - Using jets reconstructed with anti-k_t algorithm with *R* = 0.4 in FastJet.
  - Using NNLO PDF sets- MMHT 2014,NNPDF 3.0, and CT14 [Ref-8 to 10].
- Renormalisation scale $\mu_R = \hat{H}_T$, scalar sum of the transverse momenta of all final-state partons. Factorisation scale set to $\mu_F = \hat{H}_T/2$.
- Parton level distributions corrected for non-perturbative effects (multi-parton interactions and underlying event).
- The uncertainties are included- Scale, PDF, and Non-perturbative correction.

[Ref-6] Z. Nagy, Three-jet cross sections in hadron-hadron collisions at NLO, Phys. Rev. Lett. 88 (2002) 122003, arXiv: hep-ph/0110315. [Ref-7] Z. Nagy, Next-to-leading order calculation of three-jet observables in hadron-hadron collisions, Phys. Rev. D 68 (2003) 094002, arXiv: hep-ph/0307268. [Ref-8] L.A. Harland-Lang, A.D. Martin, P. Motylinski and R.S. Thorne, Parton distributions in the LHC era: MMHT 2014 PDFs, Eur. Phys. J. C 75 (2015) 204, arXiv: 1412.3989 [hep-ph]. [Ref-9] R.D. Ball et al., Parton distributions for the LHC run II, JHEP 04 (2015) 040, arXiv: 1410.8849 [hep-ph]. [Ref-10] S. Dulat et al., New parton distribution functions from a global analysis of quantum chromodynamics, Phys. Rev. D 93 (2016) 033006, arXiv: 1506.07443 [hep-ph].

Data and Theory Comparison





Good agreement observed within Uncertainty

Determination of the strong coupling constant

The strong coupling constant at $\alpha_s(m_z)$ determined from the comparison of the data with the theoretical predictions using a least-squares minimisation ap

:

$$\chi^2(\alpha_s,\vec{\lambda}) = \sum_{\text{bins}} \frac{(x_i - F_i(\alpha_s,\vec{\lambda}))^2}{\Delta x_i^2 + \Delta\xi_i^2} + \sum_k \lambda_k^2, \quad F_i(\alpha_s,\vec{\lambda}) = \psi_i(\alpha_s)\left(1 + \sum_k \lambda_k \sigma_k^{(i)}\right).$$

Theoretical predictions varied

x_i is the value of the i-th point value in data, Δx_i statistical uncertainty.

$\Delta\xi_i$ included statistical uncertainty in theoretical predictions, and uncorrelated modelling uncertainty.

σ_k^i relative value of the k-th correlated source of systematic uncertainty in bin i.

Different sources of systematic uncertainty taken into account by nuisance parameters λ_k.

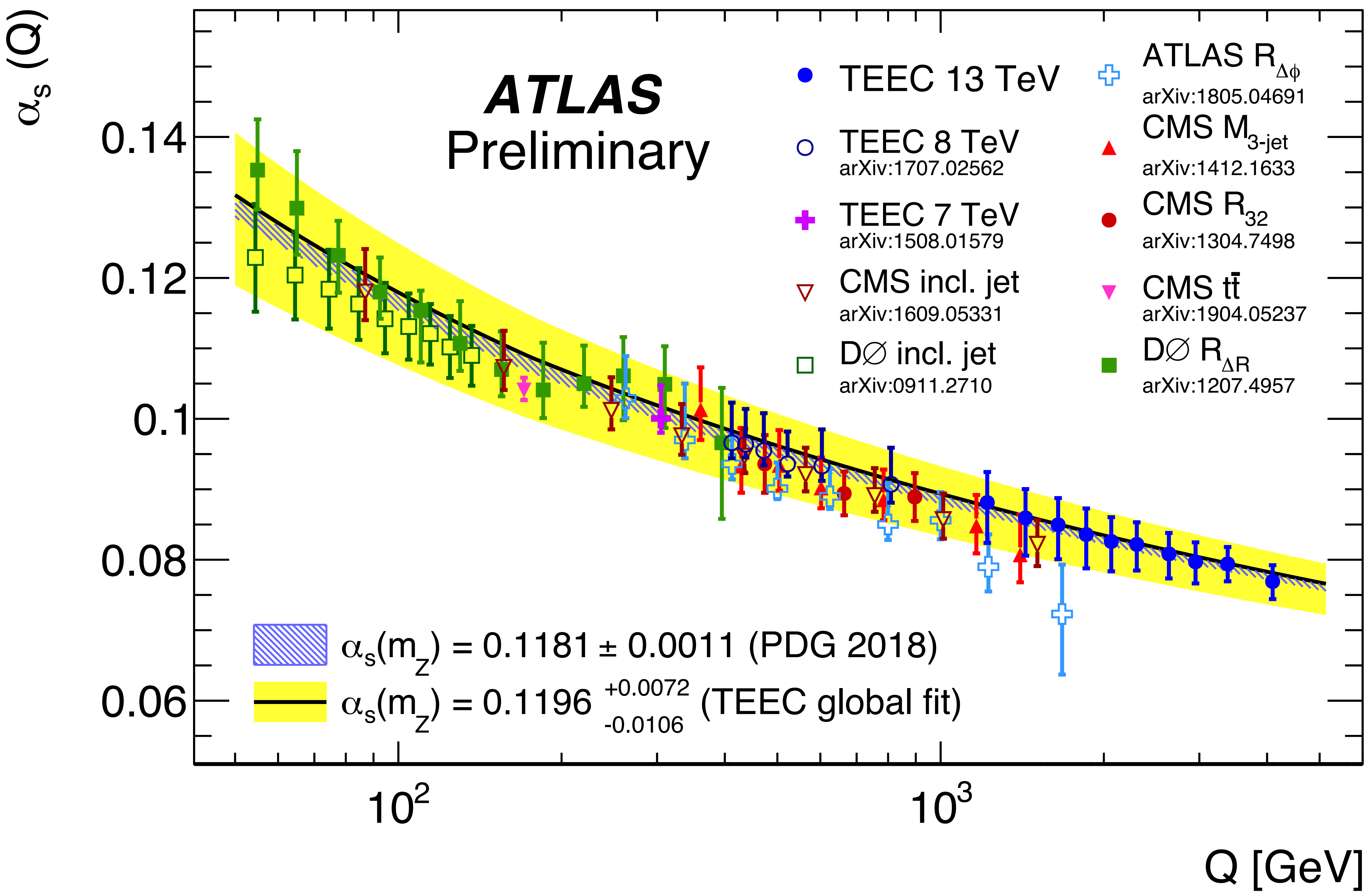
$\psi_i(\alpha_s)$ function obtained by fitting the predicted values of the TEEC or ATEEC) in each $(H_{T2}, \cos\phi)$ bin to a second-order polynomial in α_s.

Extract $\alpha_s(m_Z)$ fit are repeated separately for each H_{T2} and determine value of $\alpha_s(m_Z)$ for each energy bin.

Each fitted value of $\alpha_s(m_Z)$ is evolved to the corresponding scale using the NLO solution to the renormalisation group equation (RGE) to get $\alpha_s(Q)$

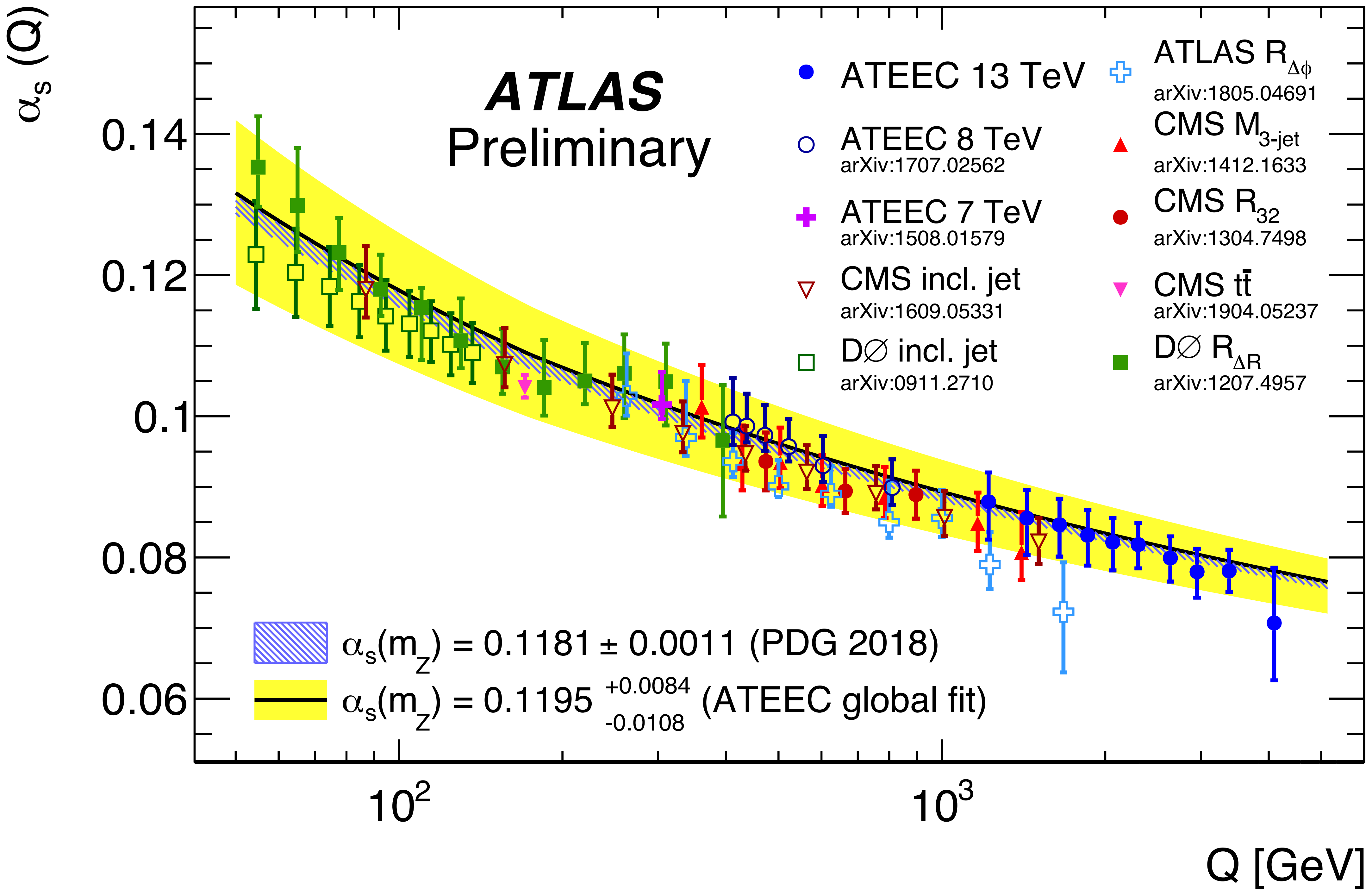
Asymptotic behaviour and comparison with other result

Comparison with world average and uncertainty provided by the Particle Data Group.



$\alpha_s(m_Z)$ =

$0.1196 \pm 0.0001(\text{stat.}) \pm 0.0004(\text{syst})^{+0.0071}_{-0.0104}(\text{scale}) \pm 0.0011(\text{PDF}) \pm 0.0002(\text{NP})$



$\alpha_s(m_Z)$ =

$0.1195 \pm 0.0002(\text{stat.}) \pm 0.0006(\text{syst})^{+0.0084}_{-0.0106}(\text{scale}) \pm 0.0009(\text{PDF}) \pm 0.0003(\text{NP})$

Introduction

Dijet production cross section performed at $\sqrt{s}$ = 13 TeV with CMS : [**SMP-21-008**]

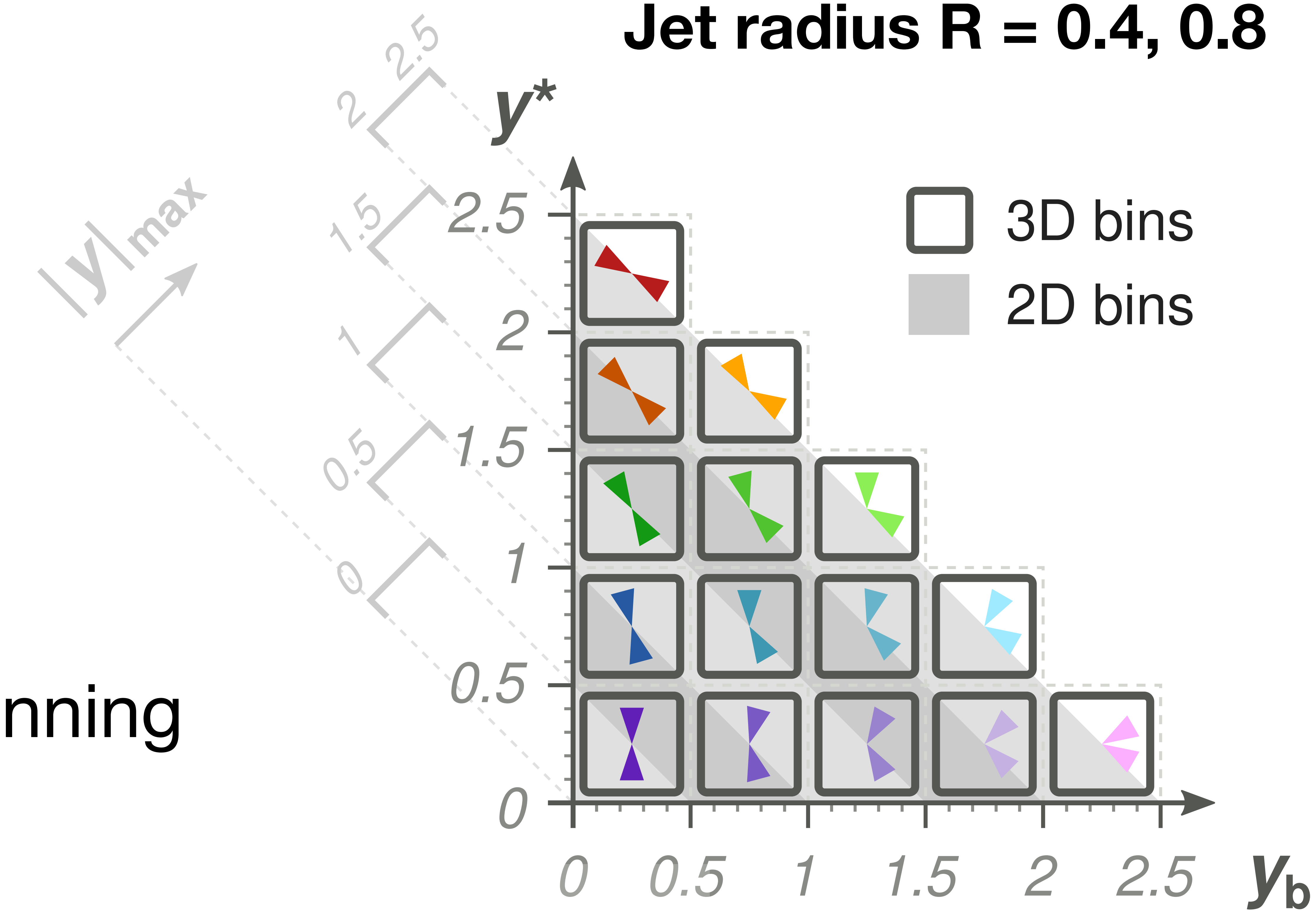
Double differential(2D):

$$y_{\max} = \max(|y_1|, |y_2|)$$

Measured in invariant mass $m_{1,2}$

Five rapidity regions: Binning steps of 0.5

Jet radius R = 0.4, 0.8



Triple-diferential(3D) :

Dijet rapidity separation

$$y^* = \frac{1}{2}|y_1 - y_2|$$

Total boost $y_b = \frac{1}{2}|y_1 + y_2|$

Measured in $m_{1,2}$ or

Transverse momentum $< p_T >_{1,2}$

For 2D

$m_{1,2} =$ 249, 306, …, 6094, …, 10050 GeV

For 3D

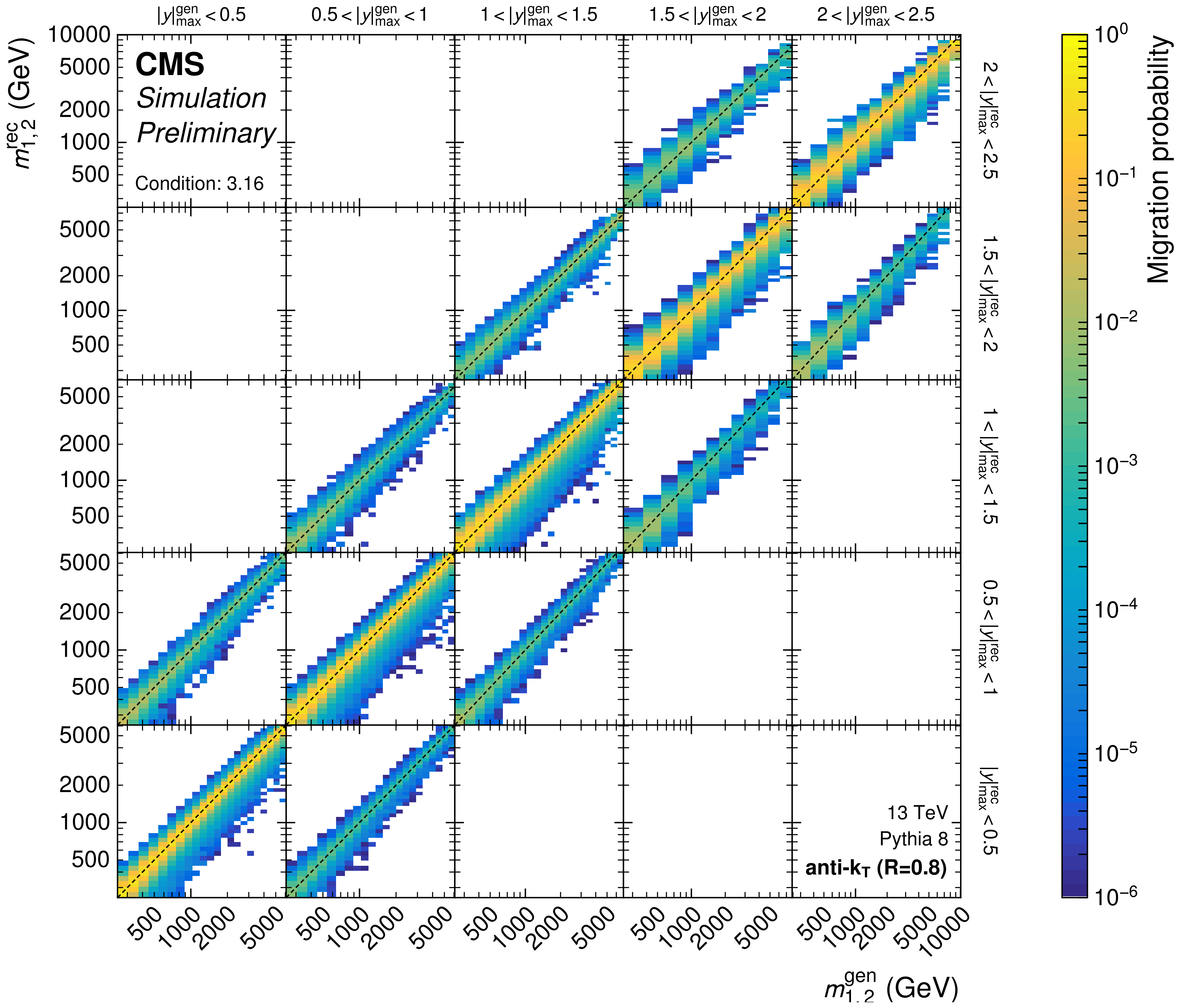
$< p_T >_{1,2} = 147, \ldots, 2702$ GeV

Event selection, Data and Monte Carlo samples

- Data: CMS pp collision $\sqrt{s}$=13 TeV, integrated luminosity 36.3 fb^{-1}.
- MC Samples: Pythia8 and MadGraph+Pythia8.
- Events are rejected:
  - Jet do not pass identification criteria, MET filters.
  - Events selected at least with two jets satisfy:
    1. $p_{T,1} > 100$ GeV, $p_{T,2} > 50$ GeV.
    2. $|y_1|$ and $|y_2| < 2.5$.
- Jets are clustered with: Anti-k_T algorithm R = 0.4 and 0.8.

Unfolding

- Detector level effects corrected by unfolding:
  - Simulation derived response matrices
  - Using the TUNFOLD [Ref-11] package.
- Taken account of :
  - Migrations through response matrix.
  - Background subtracted from fakes.
  - Correct for inefficiencies due to misses.



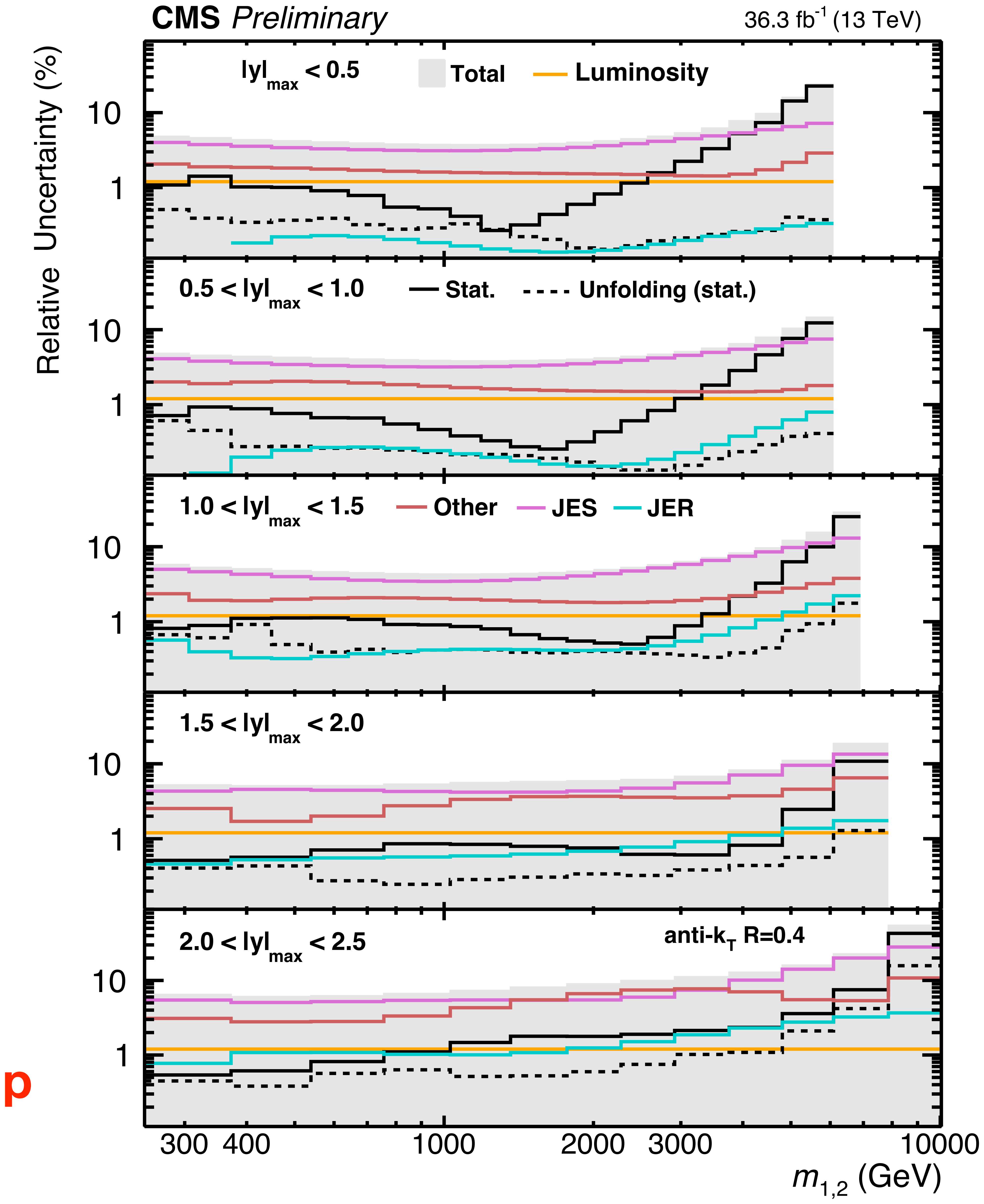
[Ref-11] S. Schmitt, "TUnfold: an algorithm for correcting migration effects in high energy physics", JINST 7 (2012) T10003, doi:10.1088/1748-0221/7/10/T10003, arXiv:1205.6201.

Uncertainties

- Jet energy scale(JES) : 4–20%
- Jet energy resolution(JER): ~1%, larger in outer |y|)
- Unfolding statistical uncertainty: <1%
- Luminosity uncertainty: =1.2%
- Statistical uncertainty: ~1%
- Other Uncertainty:

L1 prefiring, pileup, propagation of miss,fake fractions through unfolding, model dependence

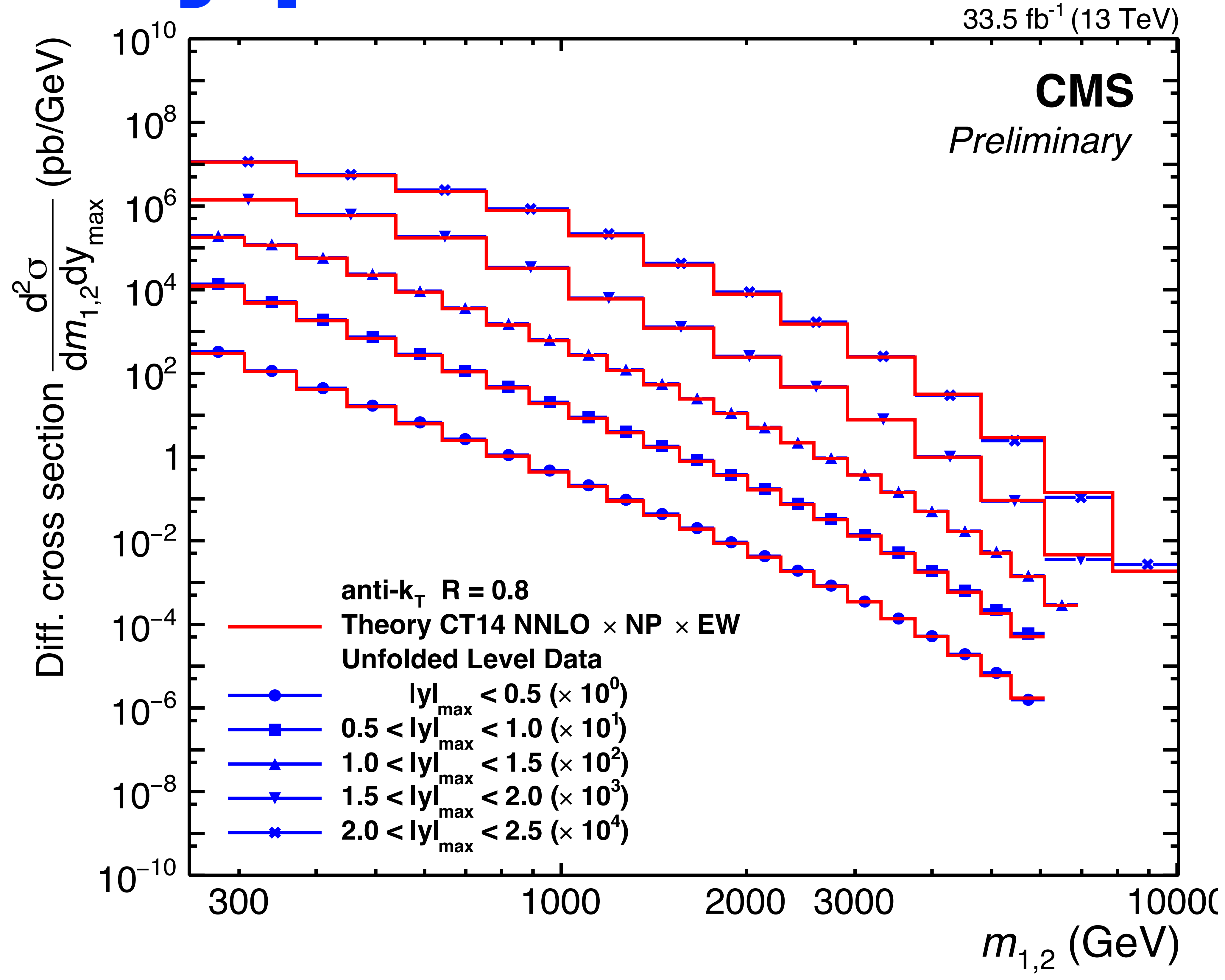
JER is the dominant systematic



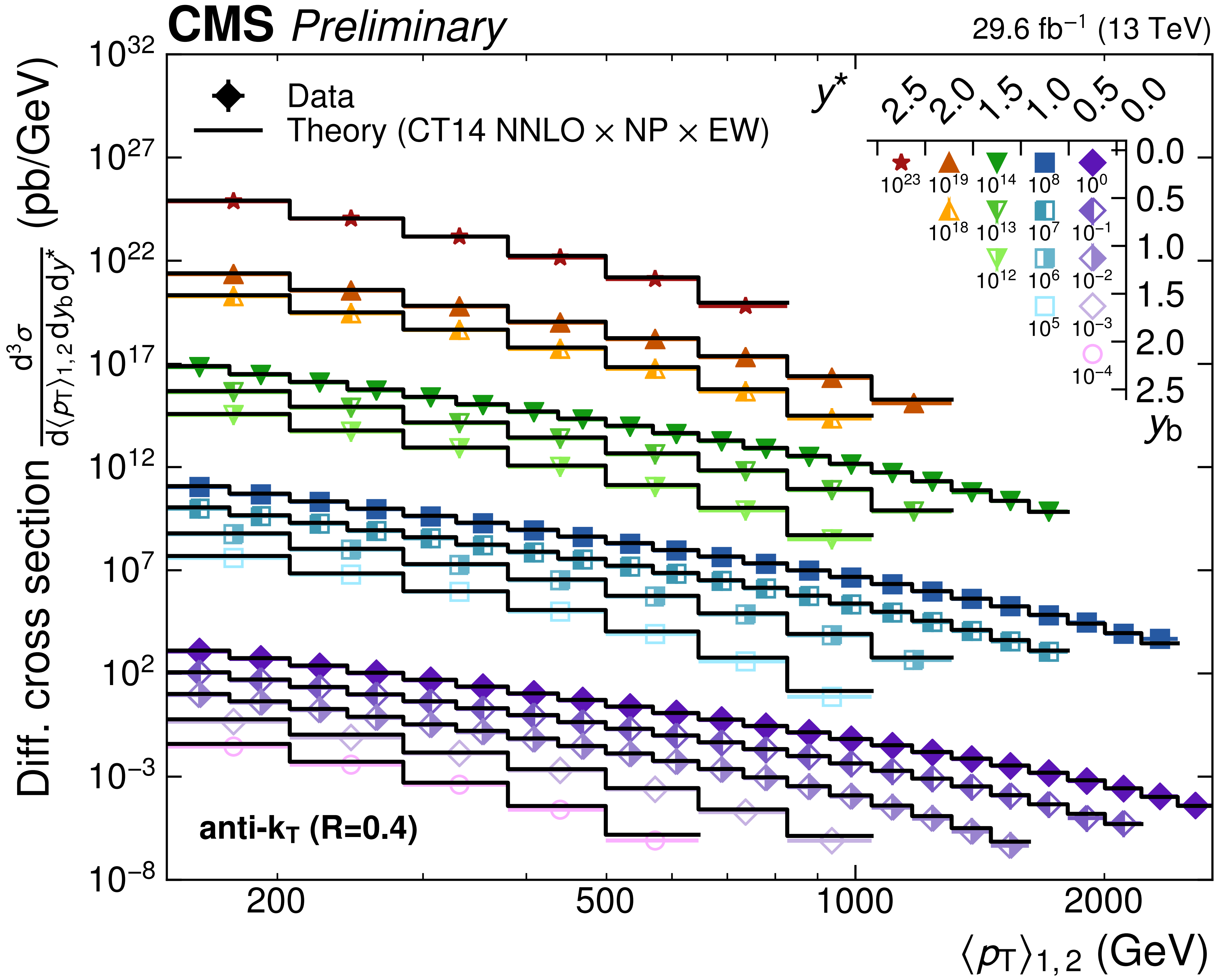
2D : R=0.4
Other plots are in back up

Theory predictions

2D
R=0.8



3D
R=0.8



- Fixed order predictions obtained at NNLO pQCD:
  - NNLOJET as fastNLO interpolation package.
  - Provide prediction for alternative PDFs and for varying parameters α_s, μ_R, μ_F.
- Corrections added: Hadronization (HAD), multi-parton interactions (MPI) Electroweak(EW).

QCD analysis and PDFs Fit

- Performed QCD analysis to evaluate :
  - Impact of proton PDFs determinations.
  - Strong coupling constant α_s.

- Based on:
  - HERAPDF2.0 analysis. [Ref-12to14]

- Data from HERA(deep inelastic scattering-DIS) in addition this dijet measurements.

- Fitted together with 2D or 3D dijet(R = 0.8) cross sections as a function of $m_{1,2}$.

- PDFs, x dependence is parametrized by:

$$x\,f(x) = A_f\,x^{B_f}\,(1-x)^{C_f}\,(1 + D_f\,x + E_f\,x^2)$$

○ **PDFs normalization is given by A.**

○ **B and C control the distribution shape: when x approaches edges of its domain at 0 and 1.**

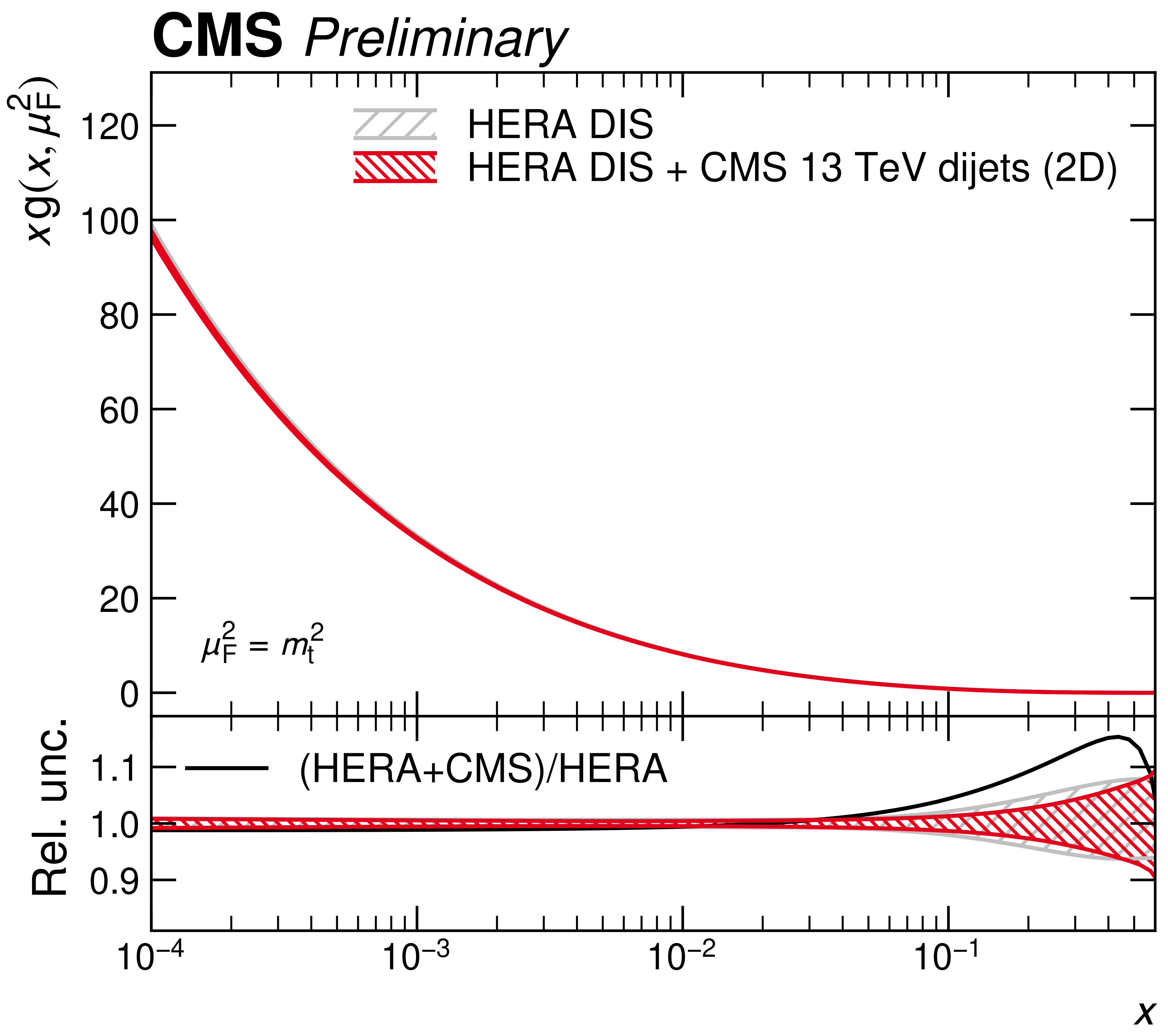
○ **D and E added to improve fit quality.**

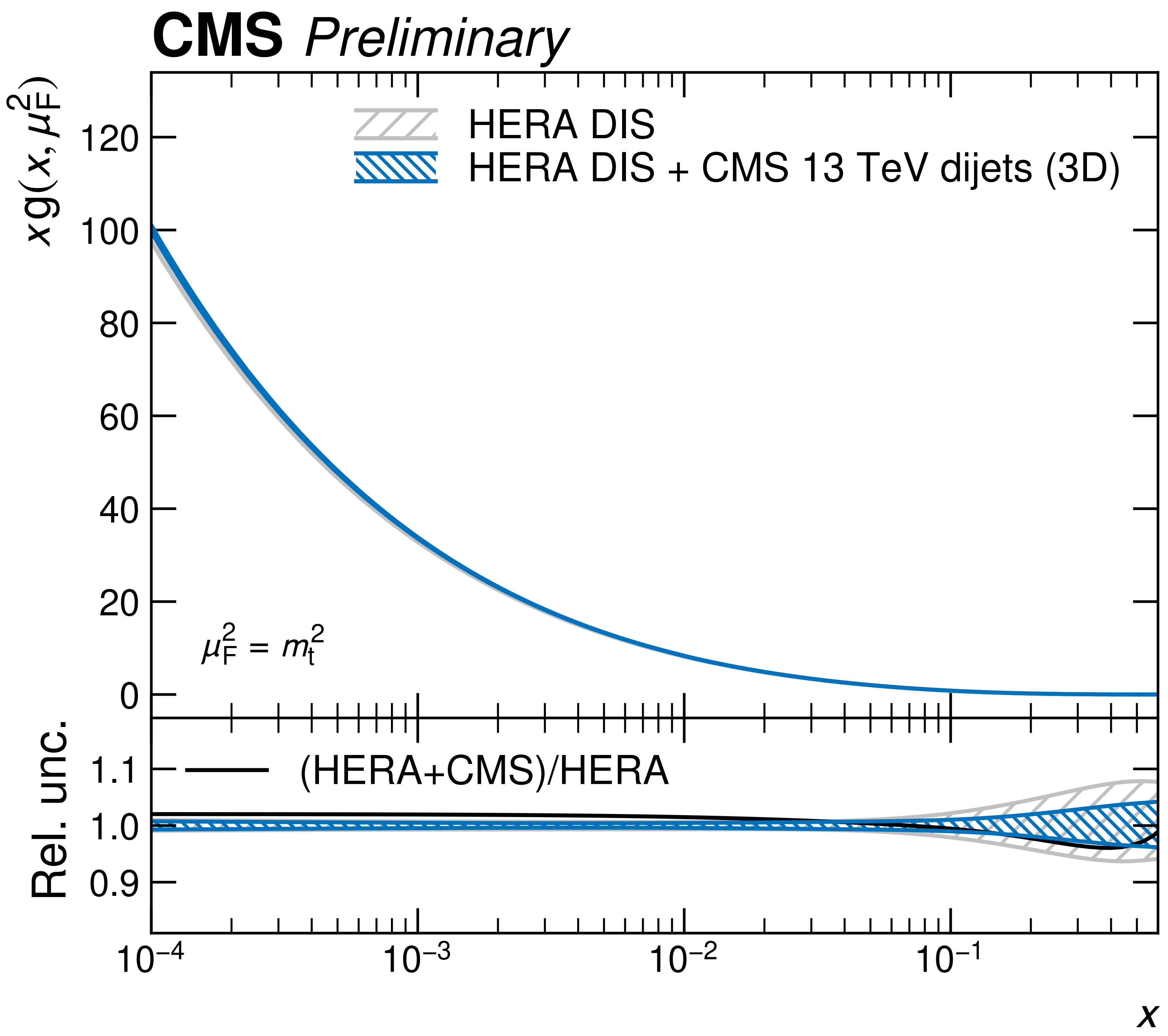
- For PDFs determinations performed at fixed $\alpha_s(m_z)$ = 0.118 and

  simultaneous fits PDF+$\alpha_s(m_z)$

[Ref-12] H1, ZEUS Collaboration, “Impact of jet-production data on the next-to-next-to-leading-order determination of HERAPDF2.0 parton distributions”, Eur. Phys. J. C 82 (2022), no. 3, 243, doi:10.1140/epjc/s10052-022-10083-9, 664 arXiv:2112.01120. [Ref-13]] H1, ZEUS C
measurements of inclusive deep inelastic e ± scattering cross sections and QCD analysis of HERA data”, Eur. Phys. J. C 75 (2015), no. 12, 580, doi:10.1140/epjc/s10052-015-3710-4, arXiv:1506.06042. [Ref-14] H1, ZEUS Collaboration, “Combined Measurement and QCD Analys
Scattering Cross Sections at HERA”, JHEP 01 (2010) 109, doi:10.1007/JHEP01(2010)109, arXiv:0911.0884

Result: PDF+$\alpha_s(m_z)$ Simultaneous Fits





- **2D:** $\alpha_s(m_z) = 0.1201 \pm 0.0012$ **(fit)** $\pm\, 0.0008$ **(scale)** $\pm\, 0.0008$ **(model)** $\pm\, 0.0005$ **(param.)**
- **3D:** $\alpha_s(m_z) = 0.1201 \pm 0.0010$ **(fit)** $\pm\, 0.0005$ **(scale)** $\pm\, 0.0008$ **(model)** $\pm\, 0.0006$ **(param.)**

Smaller uncertainty in 3D case and good agreement between 2D and 3D $\alpha_s(m_z)$ result

Inclusive jet cross sections

- CMS inclusive jet double-differential cross section measured (Ref-15):

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\mathscr{L}} \frac{N_{jets}^{eff}}{\Delta p_T \Delta y'}$$

Δp_T , Δy bin width of the jet p_T and N_{jets}^{eff} is the number of detector effect corrected jets per bin.

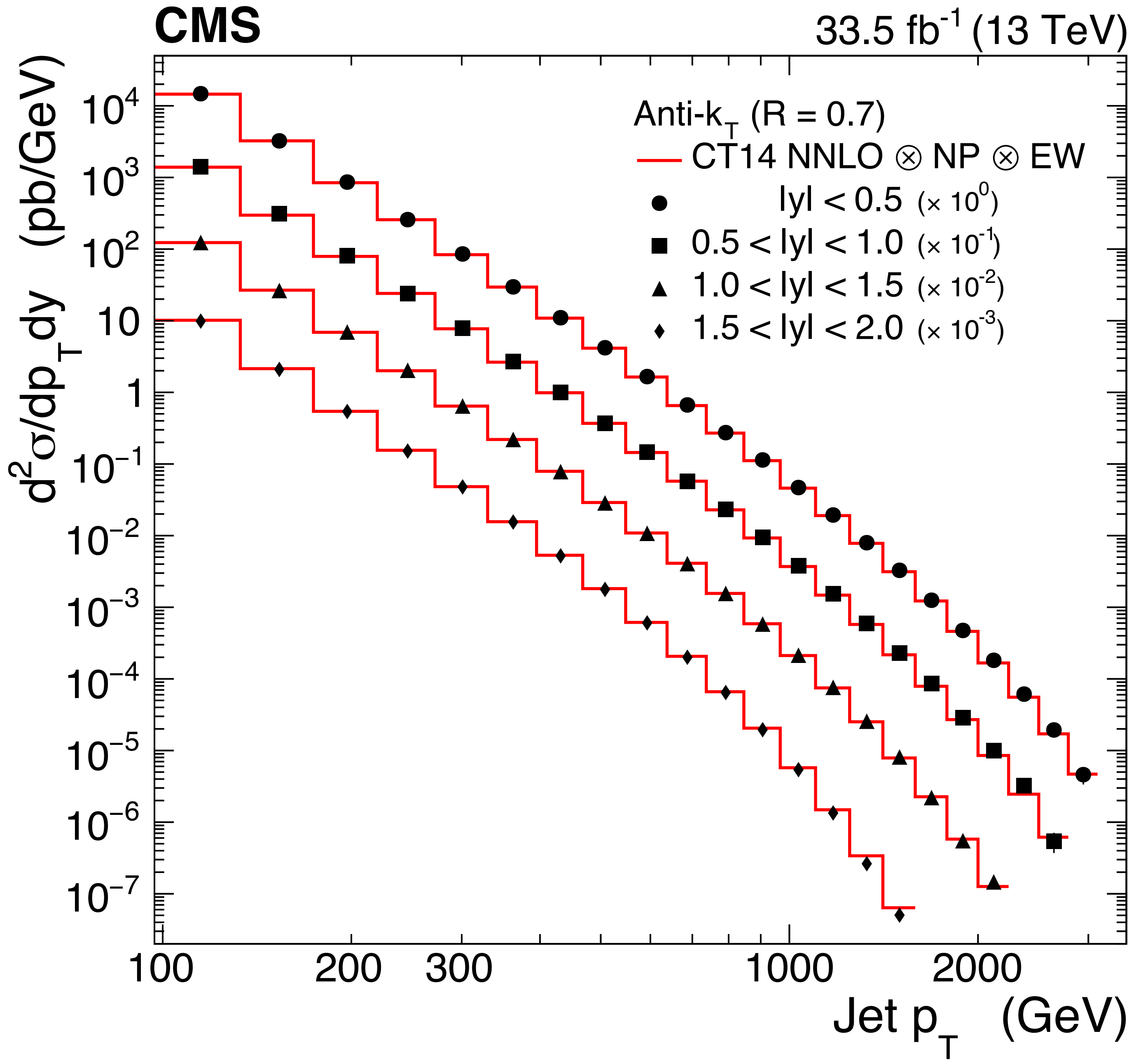
- In jet p_T and |y| with R = 0.4 and R = 0.7

- @ $\sqrt{s}$=13 TeV, integrated luminosity 36.3 fb^{-1}.

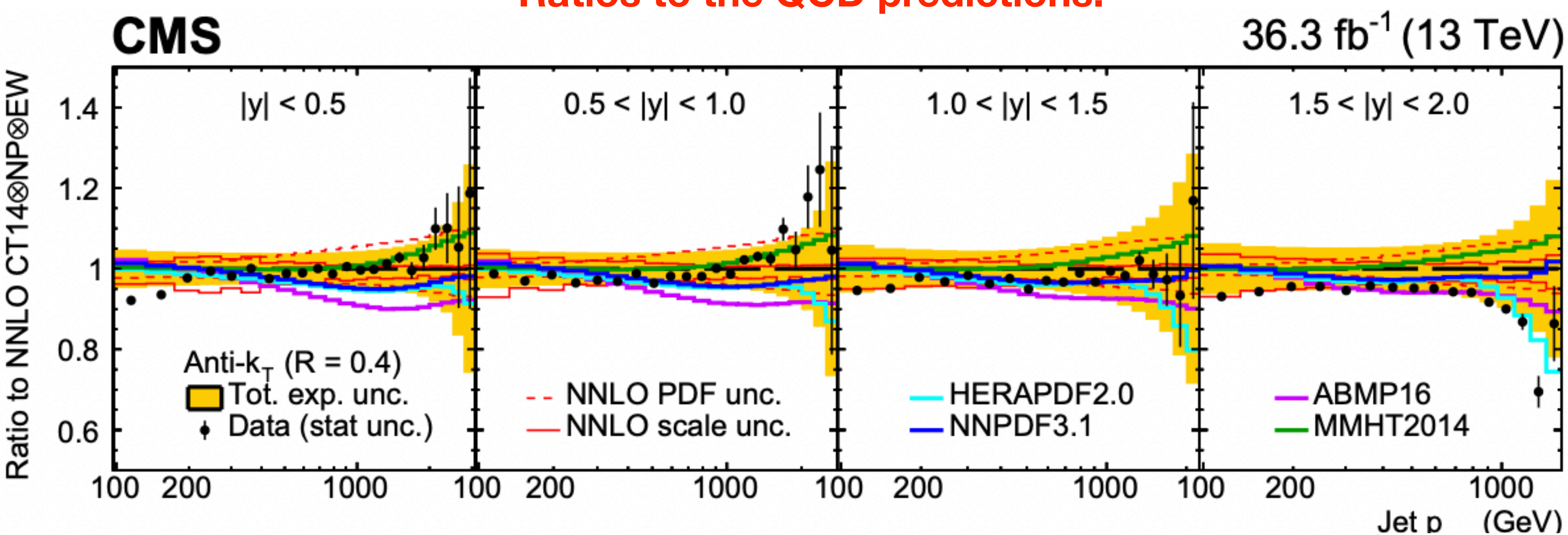
[Ref-15] CMS Collaboration, "Measurement and QCD analysis of double-differential inclusive jet cross sections in proton-proton collisions at √s = 13 TeV", JHEP 02 (2022) 142, arxiv.2111.10431v3.pdf

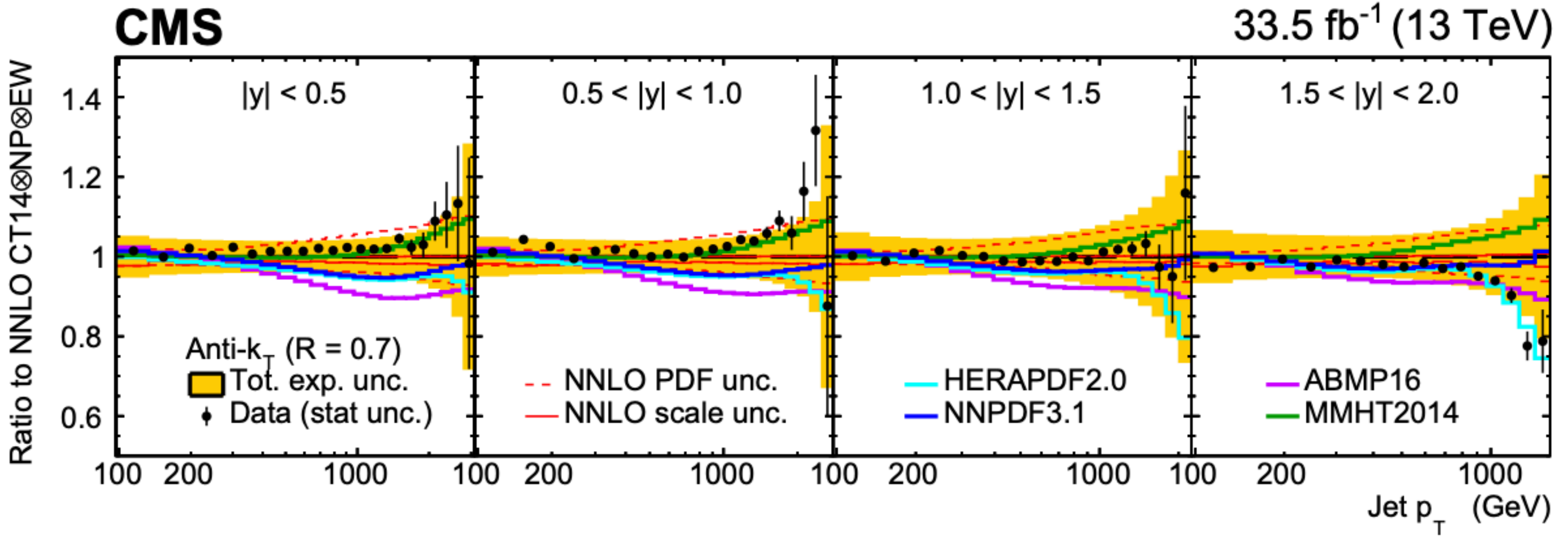
Inclusive jet cross sections

- Fixed order NNLO QCD predictions using CT14 PDF and NP, EW corrected.



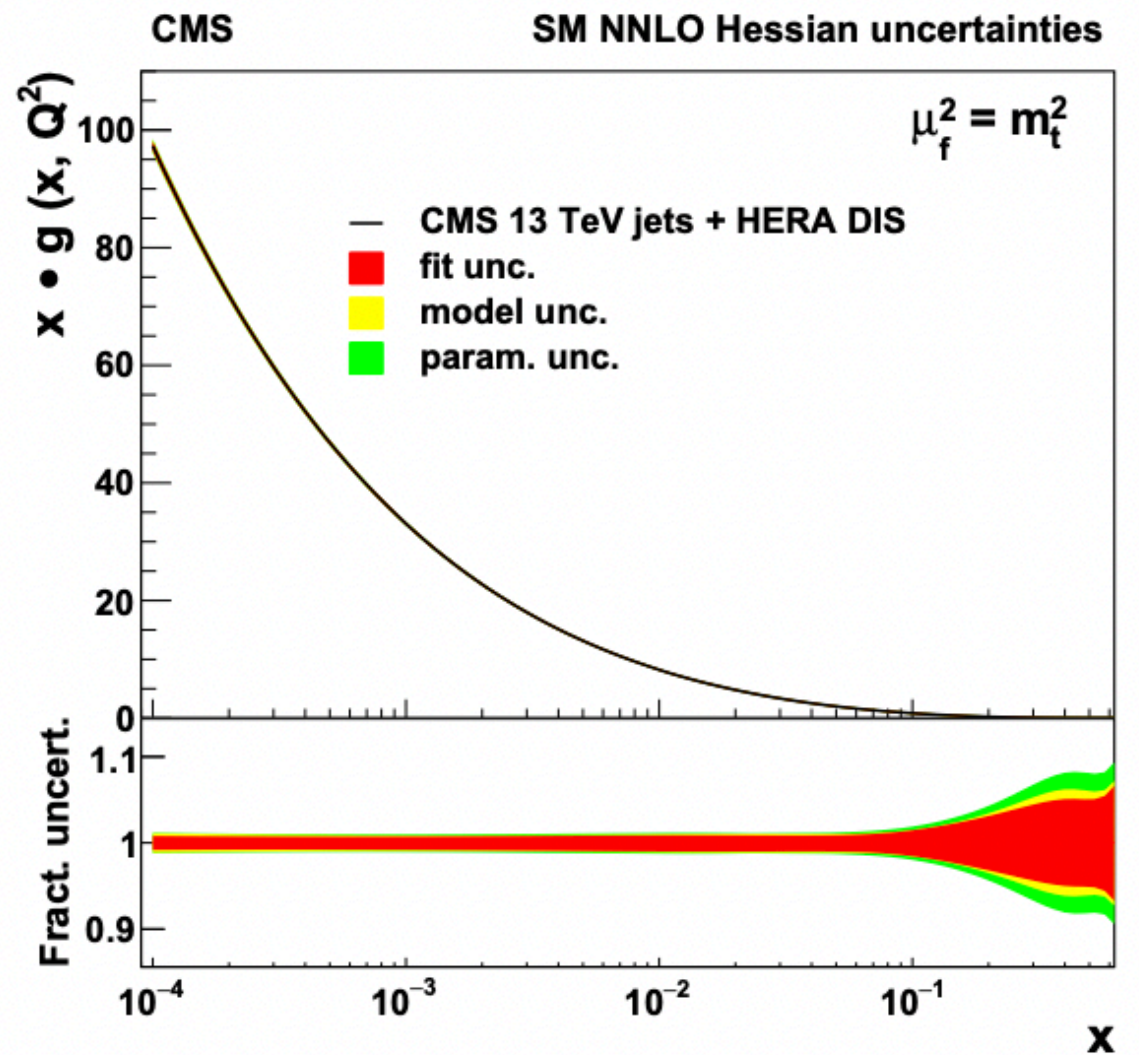
Ratios to the QCD predictions.

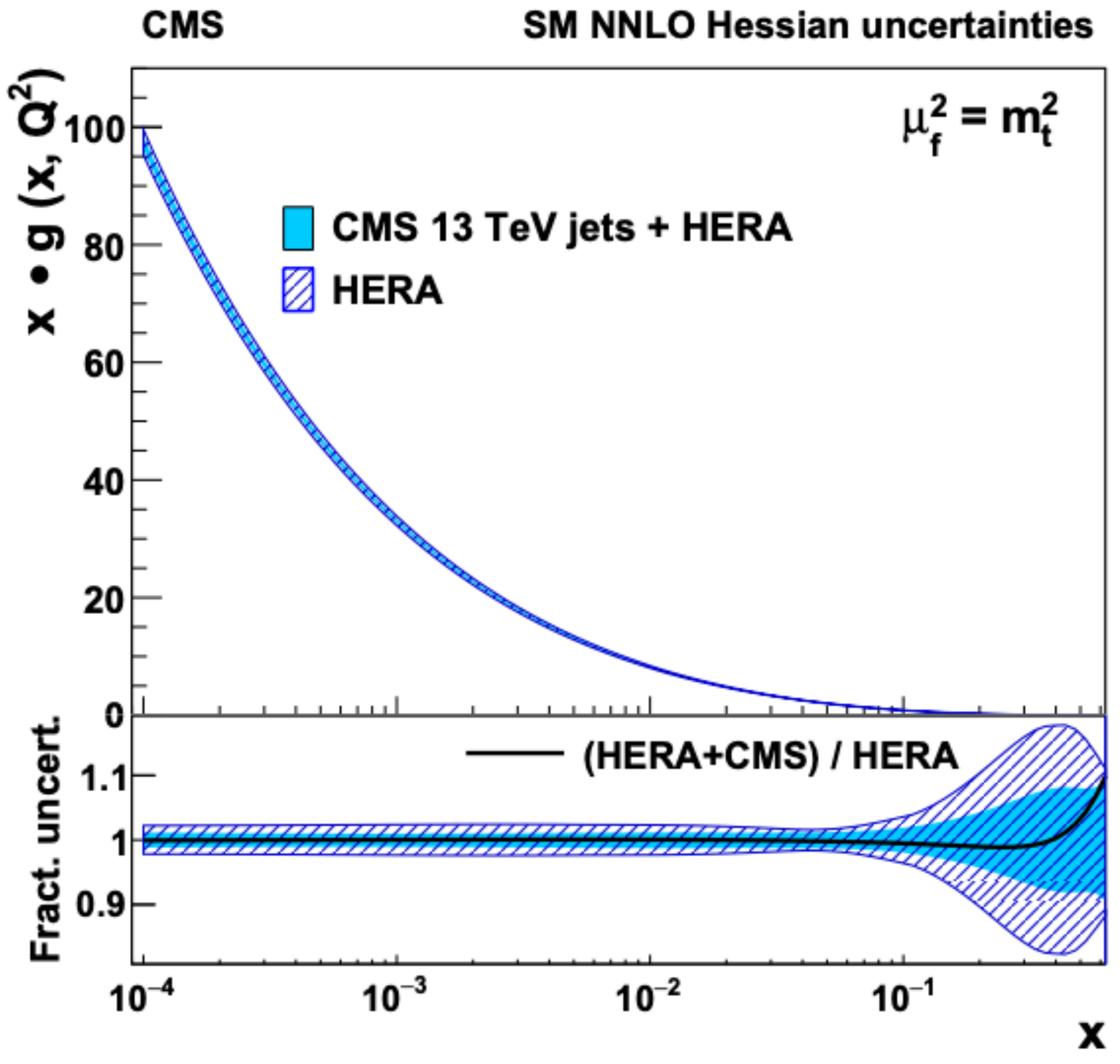




Inclusive jet cross sections

- Theory predictions at NNLO pQCD NNLOJET + fastNLO interpolation grids.
- R= 0.7 data used for PDF + $\alpha_s(m_z)$fits @ NNLO
- Addendum accepted by JHEP (on arXiv as an Appendix to v3) [Ref-16]





$\alpha_s(m_z)$

$$0.1170 \pm 0.0014(\textbf{fit}) \pm 0.0007(\textbf{model})$$

$$\pm 0.0008(\textbf{scale}) \pm 0.0001(\textbf{param})$$

NNLOJET + fastNLO interpolation grids:

K Factors → NNLO grids

Updated

$$0.1166 \pm 0.0014(\textbf{fit}) \pm 0.0007(\textbf{model})$$

$$\pm 0.0004(\textbf{scale}) \pm 0.0001(\textbf{param})$$

[Ref-16] D. Britzger et al. "NNLO interpolation grids for jet production at the LHC", Eur. Phys. J. C 82 (2022) 10, doi:10.1140/epjc/s10052-022-10880-2, arXiv:2207.13

Summary

ATLAS preliminary prediction ($\alpha_s(m_z)$) :

TEEC: $0.1196 \pm 0.0001(\textbf{stat}) \pm 0.0004(\textbf{syst})^{+0.0071}_{-0.0104}(\textbf{scale}) \pm 0.0011(\textbf{PDF}) \pm 0.0002(\textbf{NP})$

ATEEC: $0.1195 \pm 0.0002(\textbf{stat}) \pm 0.0006(\textbf{syst})^{+0.0084}_{-0.0106}(\textbf{scale}) \pm 0.0009(\textbf{PDF}) \pm 0.0003(\textbf{NP})$

NLO to NNLO prediction reduce this uncertainty if any!!

CMS prediction ($\alpha_s(m_z)$):

Strong coupling constant determined simultaneously with PDFs:

Inclusive jet cross section with NNLO grids:

$$0.1166 \pm 0.0014(\textbf{fit}) \pm 0.0007(\textbf{model}) \pm 0.0004(\textbf{scale}) \pm 0.0001(\textbf{param})$$

CMS preliminary prediction ($\alpha_s(m_z)$):

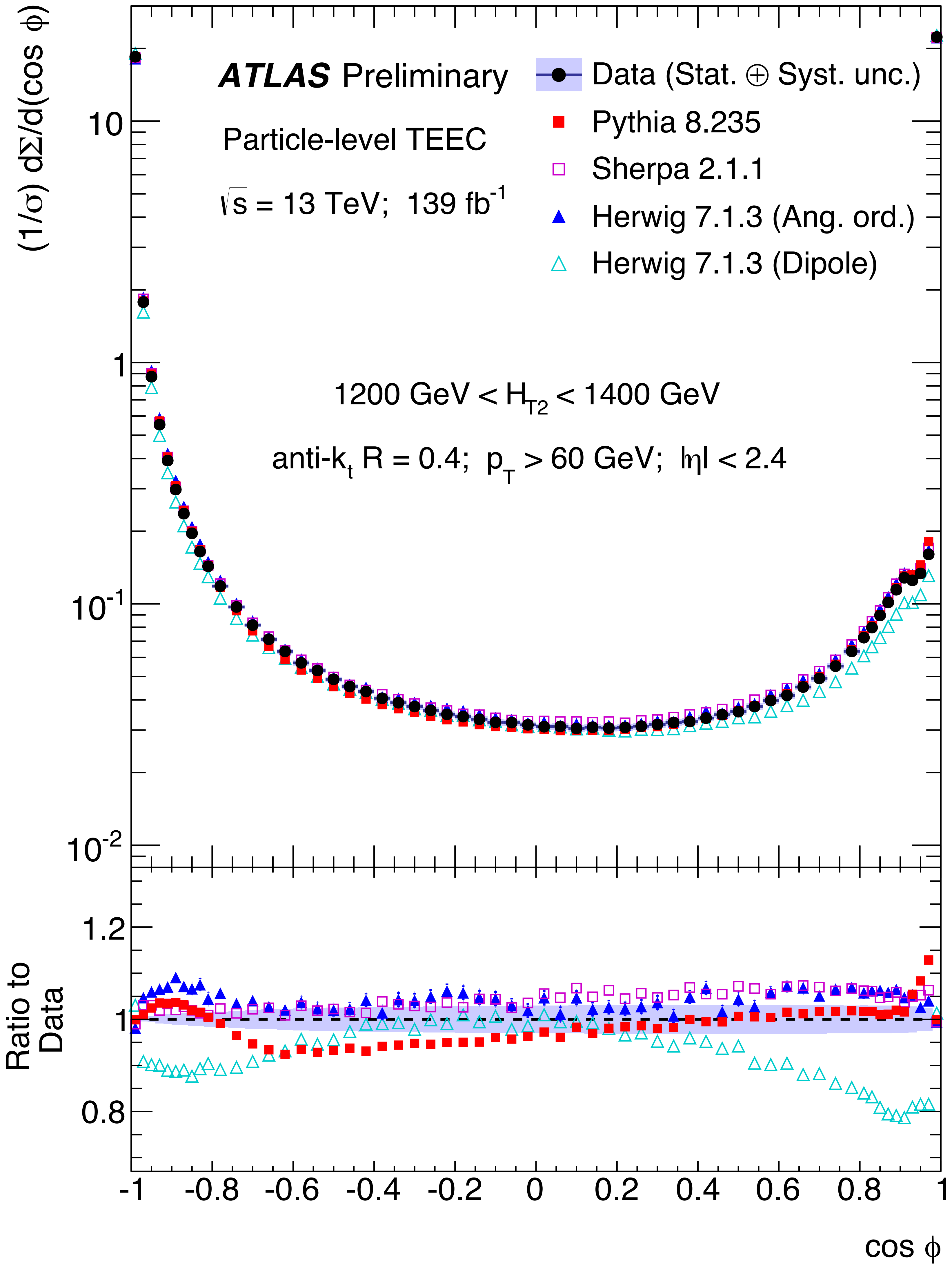
2D: $0.1201 \pm 0.0012\,(\textbf{fit}) \pm 0.0008\,(\textbf{scale}) \pm 0.0008\,(\textbf{model}) \pm 0.0005\,(\textbf{param})$

3D: $0.1201 \pm 0.0010\,(\textbf{fit}) \pm 0.0005\,(\textbf{scale}) \pm 0.0008\,(\textbf{model}) \pm 0.0006\,(\textbf{param})$

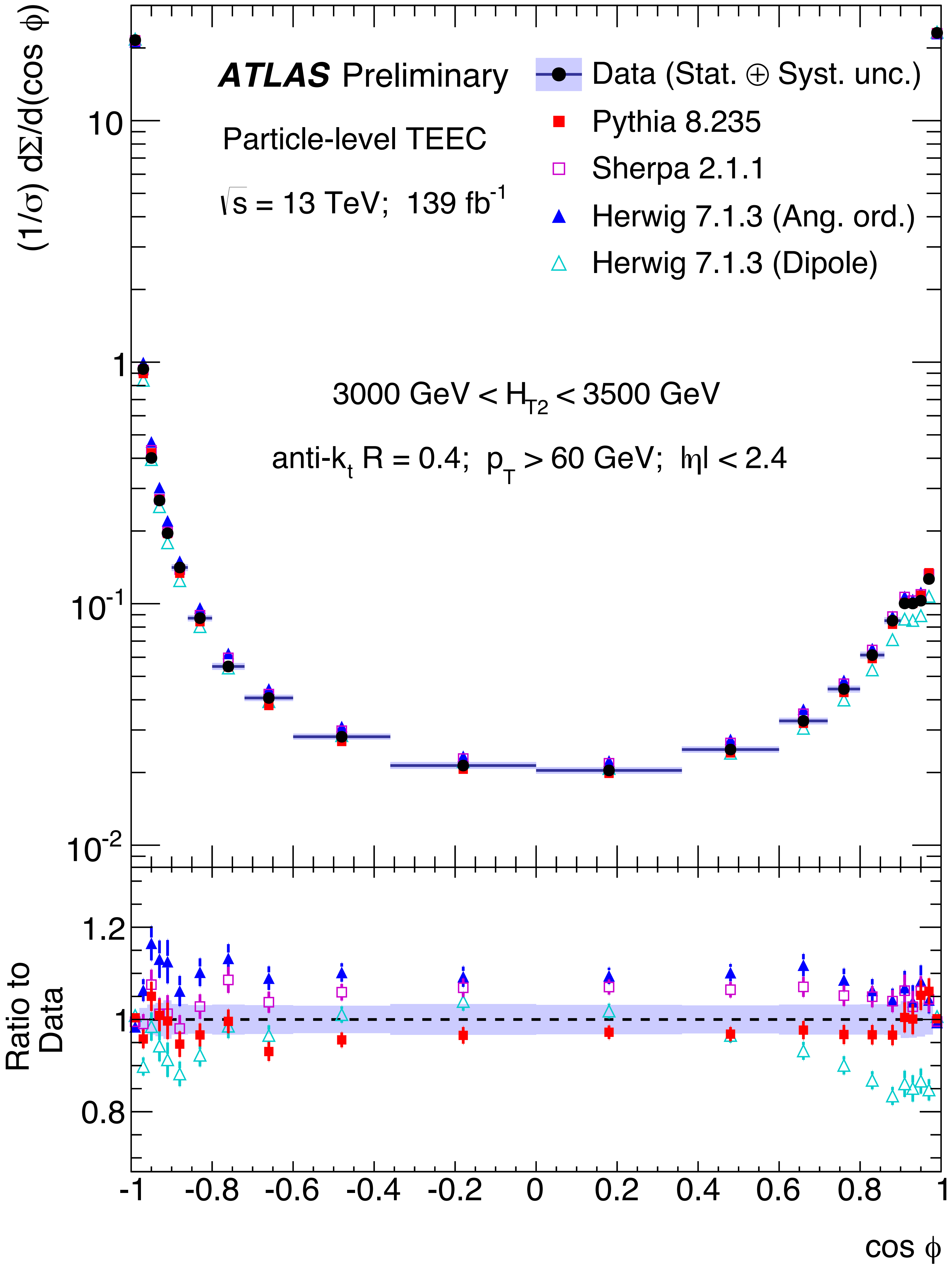
BACK-UP

Unfolded data compared with MC

TEEC

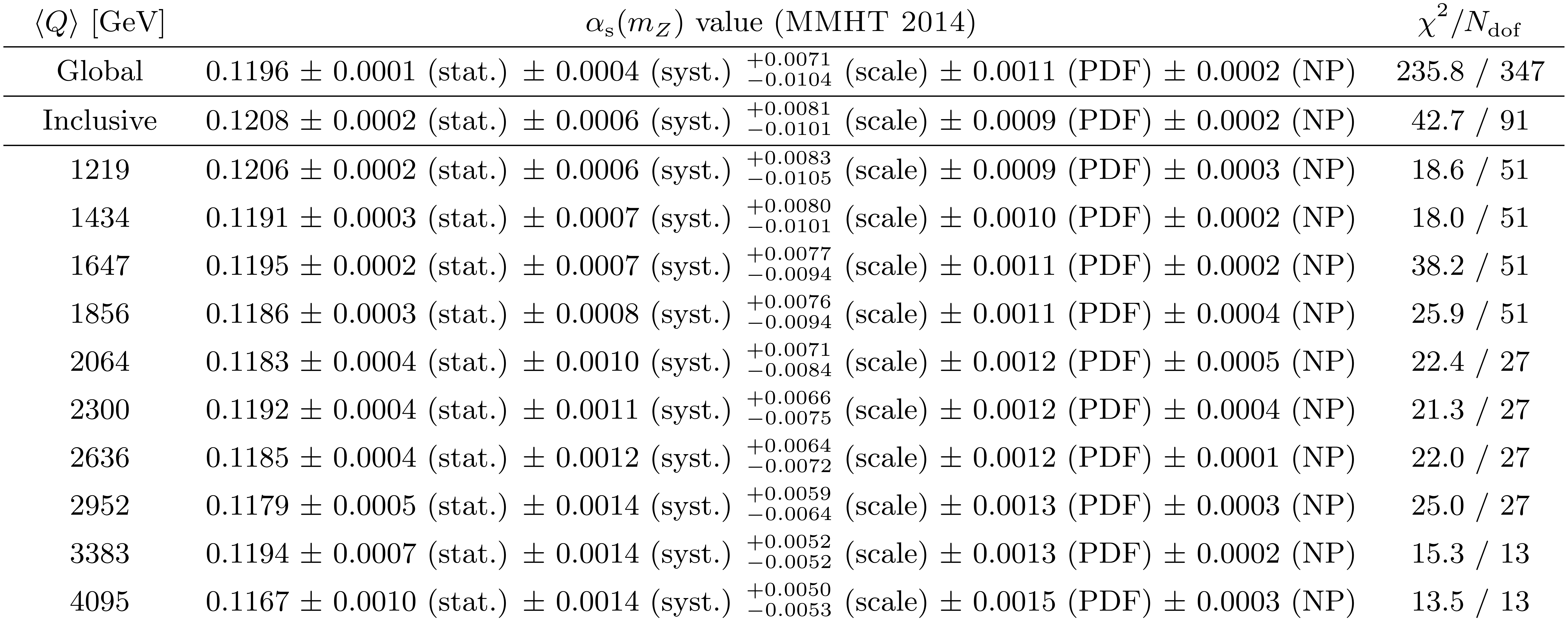


TEEC : Best description achieved by both Sherpa and Herwig 7 with the angle-ordered parton shower in low H_{T2}. Pythia 8 gives the best description in high H_{T2}



Fitted α_s result

- $\alpha_s(m_Z)$ TEEC function fits using MMHT 2014 PDF



$\langle Q \rangle$ [GeV]	$\alpha_s(m_Z)$ value (MMHT 2014)	χ^2/N_{dof}
Global	0.1196 ± 0.0001 (stat.) ± 0.0004 (syst.) $^{+0.0071}_{-0.0104}$ (scale) ± 0.0011 (PDF) ± 0.0002 (NP)	235.8 / 347
Inclusive	0.1208 ± 0.0002 (stat.) ± 0.0006 (syst.) $^{+0.0081}_{-0.0101}$ (scale) ± 0.0009 (PDF) ± 0.0002 (NP)	42.7 / 91
1219	0.1206 ± 0.0002 (stat.) ± 0.0006 (syst.) $^{+0.0083}_{-0.0105}$ (scale) ± 0.0009 (PDF) ± 0.0003 (NP)	18.6 / 51
1434	0.1191 ± 0.0003 (stat.) ± 0.0007 (syst.) $^{+0.0080}_{-0.0101}$ (scale) ± 0.0010 (PDF) ± 0.0002 (NP)	18.0 / 51
1647	0.1195 ± 0.0002 (stat.) ± 0.0007 (syst.) $^{+0.0077}_{-0.0094}$ (scale) ± 0.0011 (PDF) ± 0.0002 (NP)	38.2 / 51
1856	0.1186 ± 0.0003 (stat.) ± 0.0008 (syst.) $^{+0.0076}_{-0.0094}$ (scale) ± 0.0011 (PDF) ± 0.0004 (NP)	25.9 / 51
2064	0.1183 ± 0.0004 (stat.) ± 0.0010 (syst.) $^{+0.0071}_{-0.0084}$ (scale) ± 0.0012 (PDF) ± 0.0005 (NP)	22.4 / 27
2300	0.1192 ± 0.0004 (stat.) ± 0.0011 (syst.) $^{+0.0066}_{-0.0075}$ (scale) ± 0.0012 (PDF) ± 0.0004 (NP)	21.3 / 27
2636	0.1185 ± 0.0004 (stat.) ± 0.0012 (syst.) $^{+0.0064}_{-0.0072}$ (scale) ± 0.0012 (PDF) ± 0.0001 (NP)	22.0 / 27
2952	0.1179 ± 0.0005 (stat.) ± 0.0014 (syst.) $^{+0.0059}_{-0.0064}$ (scale) ± 0.0013 (PDF) ± 0.0003 (NP)	25.0 / 27
3383	0.1194 ± 0.0007 (stat.) ± 0.0014 (syst.) $^{+0.0052}_{-0.0052}$ (scale) ± 0.0013 (PDF) ± 0.0002 (NP)	15.3 / 13
4095	0.1167 ± 0.0010 (stat.) ± 0.0014 (syst.) $^{+0.0050}_{-0.0053}$ (scale) ± 0.0015 (PDF) ± 0.0003 (NP)	13.5 / 13

Fitted α_s result

- $\alpha_s(m_Z)$ ATEEC function fits using MMHT 2014 PDF

$\langle Q \rangle$ [GeV]	$\alpha_s(m_Z)$ value (MMHT 2014)	χ^2/N_{dof}
Global	0.1195 ± 0.0002 (stat.) ± 0.0006 (syst.) ${}^{+0.0084}_{-0.0106}$ (scale) ± 0.0009 (PDF) ± 0.0003 (NP)	254.1 / 173
Inclusive	0.1198 ± 0.0002 (stat.) ± 0.0006 (syst.) ${}^{+0.0078}_{-0.0095}$ (scale) ± 0.0010 (PDF) ± 0.0002 (NP)	46.3 / 45
1219	0.1202 ± 0.0003 (stat.) ± 0.0006 (syst.) ${}^{+0.0079}_{-0.0098}$ (scale) ± 0.0010 (PDF) ± 0.0002 (NP)	25.7 / 25
1434	0.1184 ± 0.0003 (stat.) ± 0.0007 (syst.) ${}^{+0.0078}_{-0.0098}$ (scale) ± 0.0011 (PDF) ± 0.0002 (NP)	35.6 / 25
1647	0.1188 ± 0.0004 (stat.) ± 0.0007 (syst.) ${}^{+0.0073}_{-0.0087}$ (scale) ± 0.0012 (PDF) ± 0.0001 (NP)	41.9 / 25
1856	0.1177 ± 0.0006 (stat.) ± 0.0008 (syst.) ${}^{+0.0072}_{-0.0083}$ (scale) ± 0.0013 (PDF) ± 0.0006 (NP)	24.6 / 25
2064	0.1174 ± 0.0008 (stat.) ± 0.0009 (syst.) ${}^{+0.0069}_{-0.0078}$ (scale) ± 0.0013 (PDF) ± 0.0007 (NP)	18.7 / 13
2300	0.1185 ± 0.0009 (stat.) ± 0.0010 (syst.) ${}^{+0.0063}_{-0.0067}$ (scale) ± 0.0014 (PDF) ± 0.0005 (NP)	22.5 / 13
2636	0.1166 ± 0.0016 (stat.) ± 0.0012 (syst.) ${}^{+0.0062}_{-0.0066}$ (scale) ± 0.0015 (PDF) ± 0.0000 (NP)	21.7 / 13
2952	0.1141 ± 0.0029 (stat.) ± 0.0013 (syst.) ${}^{+0.0062}_{-0.0069}$ (scale) ± 0.0018 (PDF) ± 0.0003 (NP)	15.2 / 13
3383	0.1164 ± 0.0043 (stat.) ± 0.0015 (syst.) ${}^{+0.0050}_{-0.0044}$ (scale) ± 0.0017 (PDF) ± 0.0001 (NP)	6.3 / 6
4095	0.1029 ± 0.0163 (stat.) ± 0.0014 (syst.) ${}^{+0.0066}_{-0.0012}$ (scale) ± 0.0010 (PDF) ± 0.0003 (NP)	5.9 / 6

Summary

- Measurements of transverse energy-energy correlations and their corresponding asymmetries in multijet events using pp collisions at $\sqrt{s} = 13$ TeV are presented.
- Measurement done with binned data in high phase space region >1TeV.
- The results are compared with Monte Carlo predictions by different generators, including Pythia8, Sherpa and Herwig7
- The data are compared to theoretical predictions at next-to-leading order in perturbative QCD, corrected for non-perturbative effects.
- The agreement between the data and the theoretical predictions is very good.

Introduction

- Dijet production cross section performed at $\sqrt{s}$ = 13 TeV with CMS : [**SMP-21-008**]
- Double-differential(2D) & triple-diferential(3D) with jet radius R = 0.4, 0.8.
- The 2D cross section is defined: $\dfrac{d^2\sigma}{dy_{max}dm_{1,2}} = \dfrac{1}{\varepsilon\mathscr{L}_{\text{int}}} . \dfrac{N}{(2.\Delta|y|_{max})\Delta_{1,2}}$

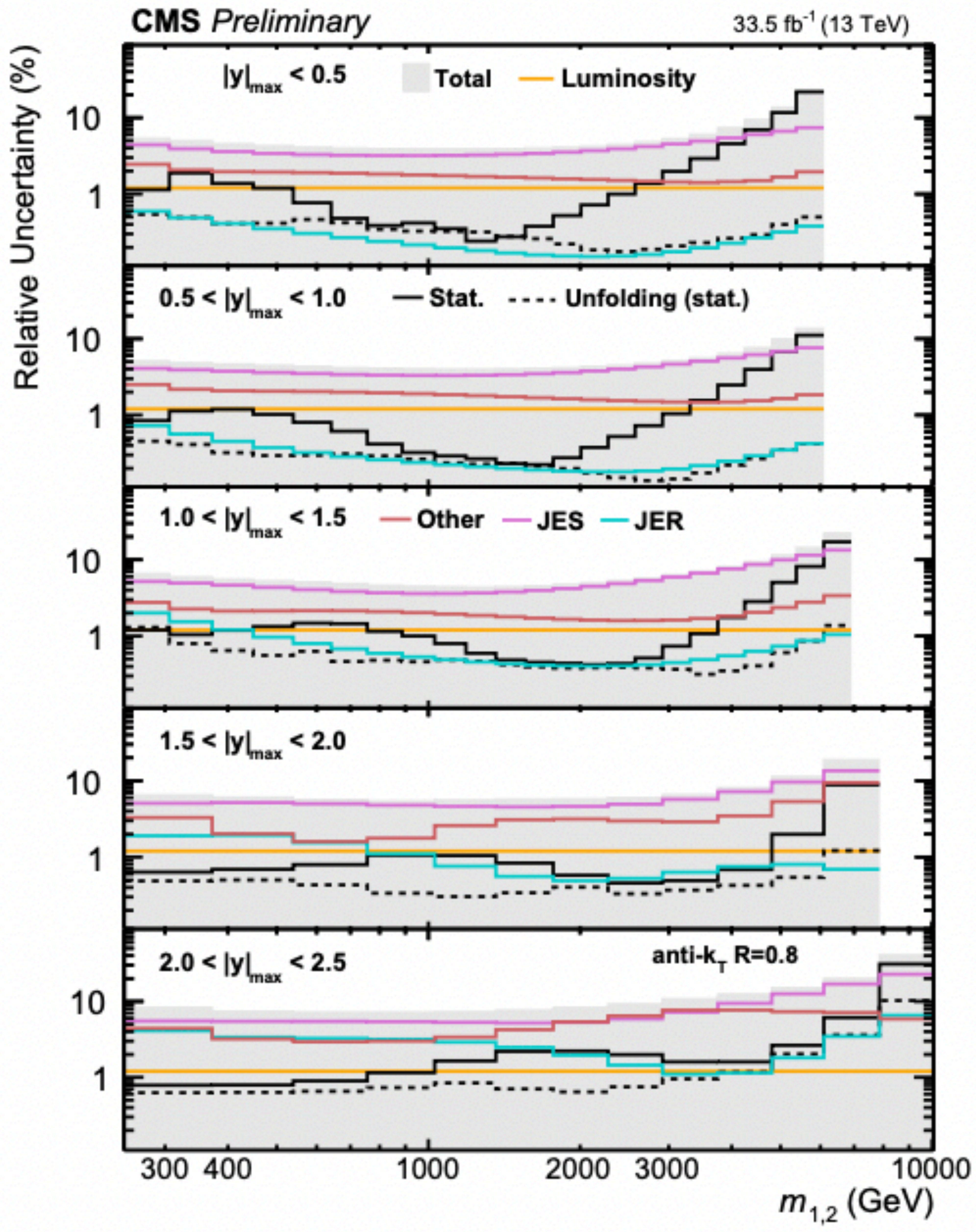
Measured, function of the dijet invariant mass $m_{1,2}$ in five rapidity regions

- The 3D cross section is defined: $\dfrac{d^3\sigma}{dy^* dy_b dx} = \dfrac{1}{\varepsilon\mathscr{L}_{\text{int}}} . \dfrac{N}{\Delta y^* \Delta y_b \Delta x}$

Measured as a function of both $m_{1,2}$ and the average dijet transverse momentum $< p_T >$

- $y_{\text{max}} = \text{sing}(|\max(y_1, y_2)| - |\min(y_1, y_2)|)\max(|y_1|, |y_2|)$
- Dijet rapidity separation $y^* = \dfrac{1}{2}|y_1 - y_2|$; Longitudinal boost $y_b = \dfrac{1}{2}|y_1 + y_2|$
- $m_{1,2} = \sqrt{(E_1 + E_2)^2 - (\overrightarrow{p_1} + \overrightarrow{p_2})^2}$; $< p_T >_{1,2} = \dfrac{1}{2}(p_{T,1} + p_{T,2})$

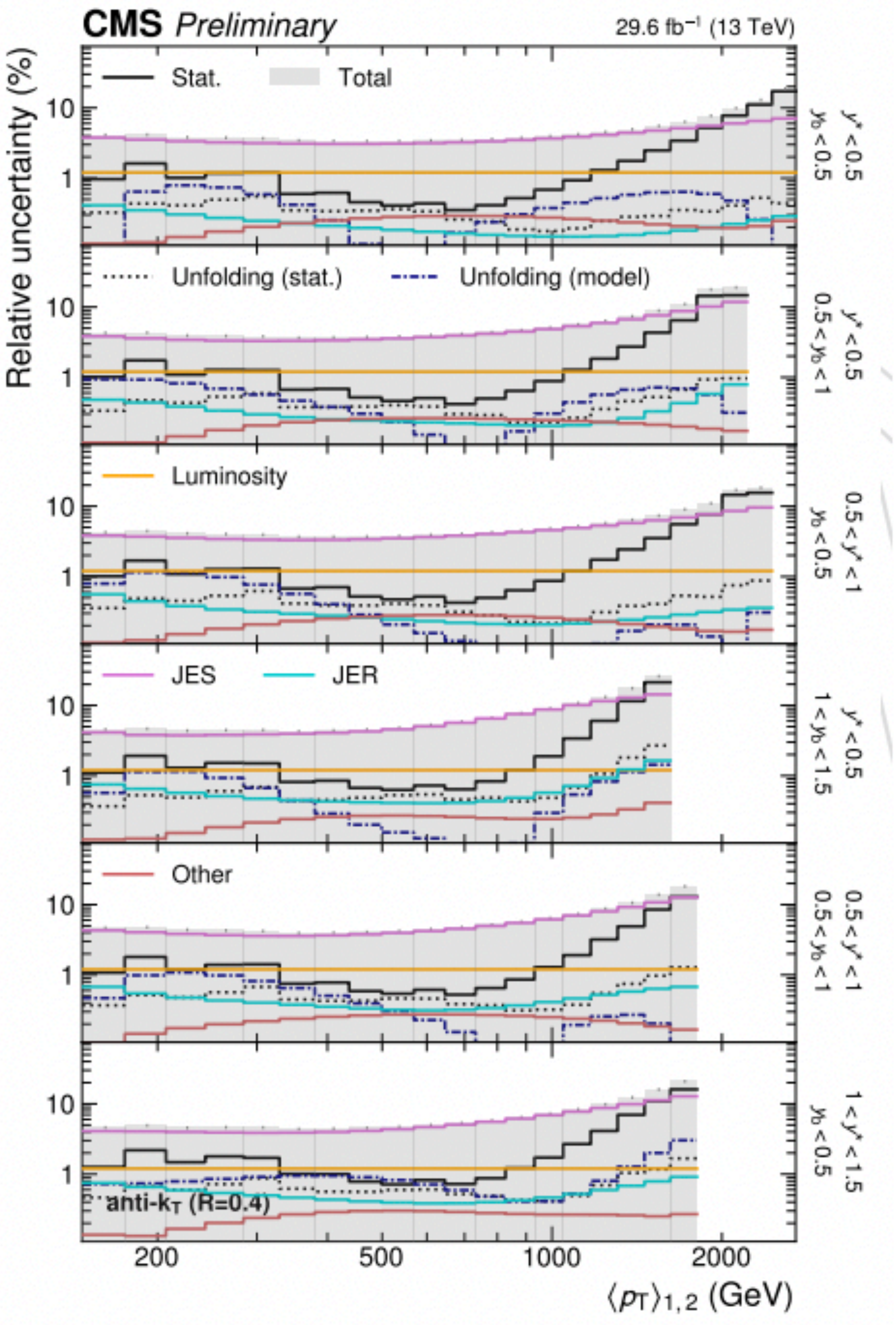
Uncertainties



2D : R=0.8

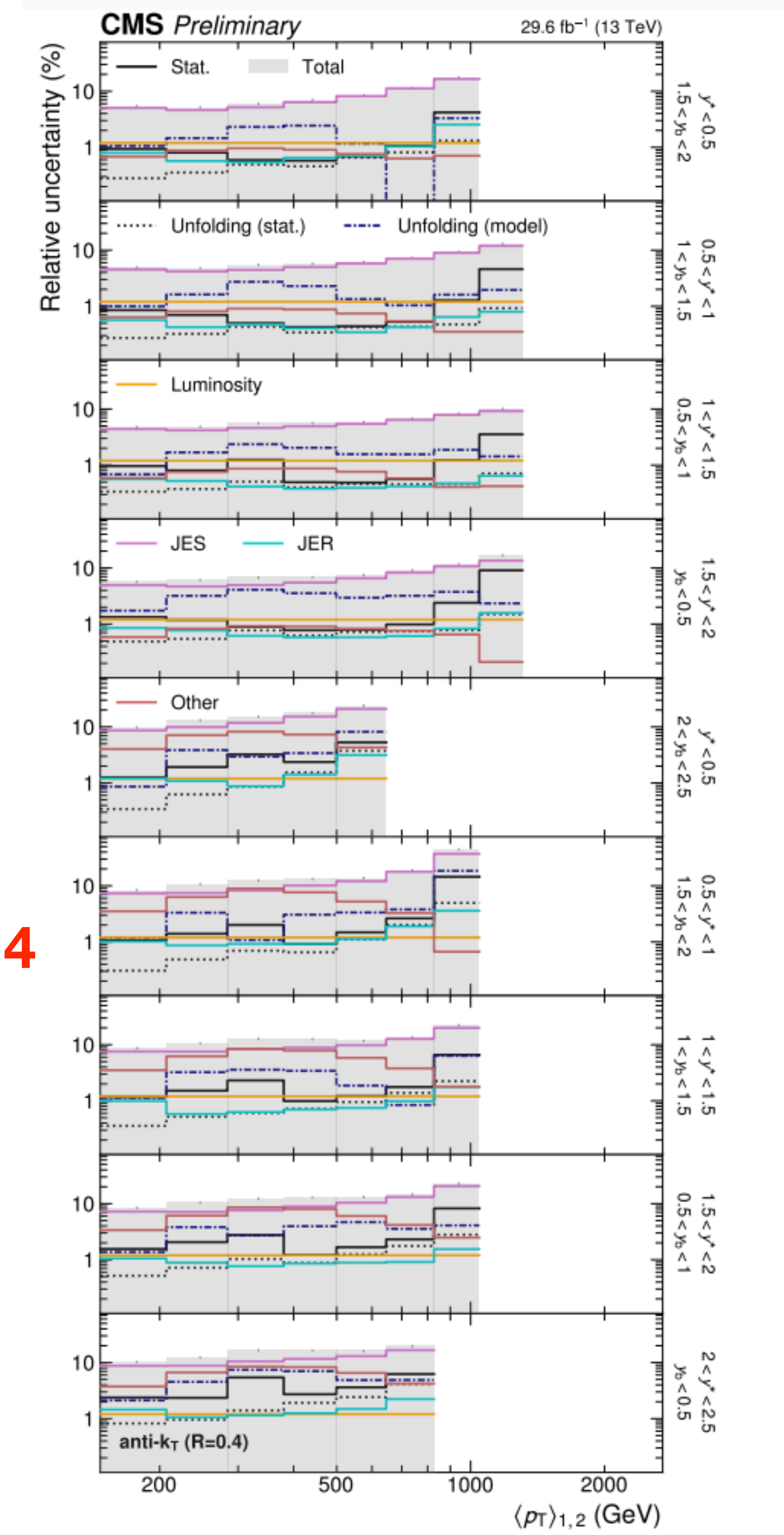
Other plots are in back up

Uncertainties



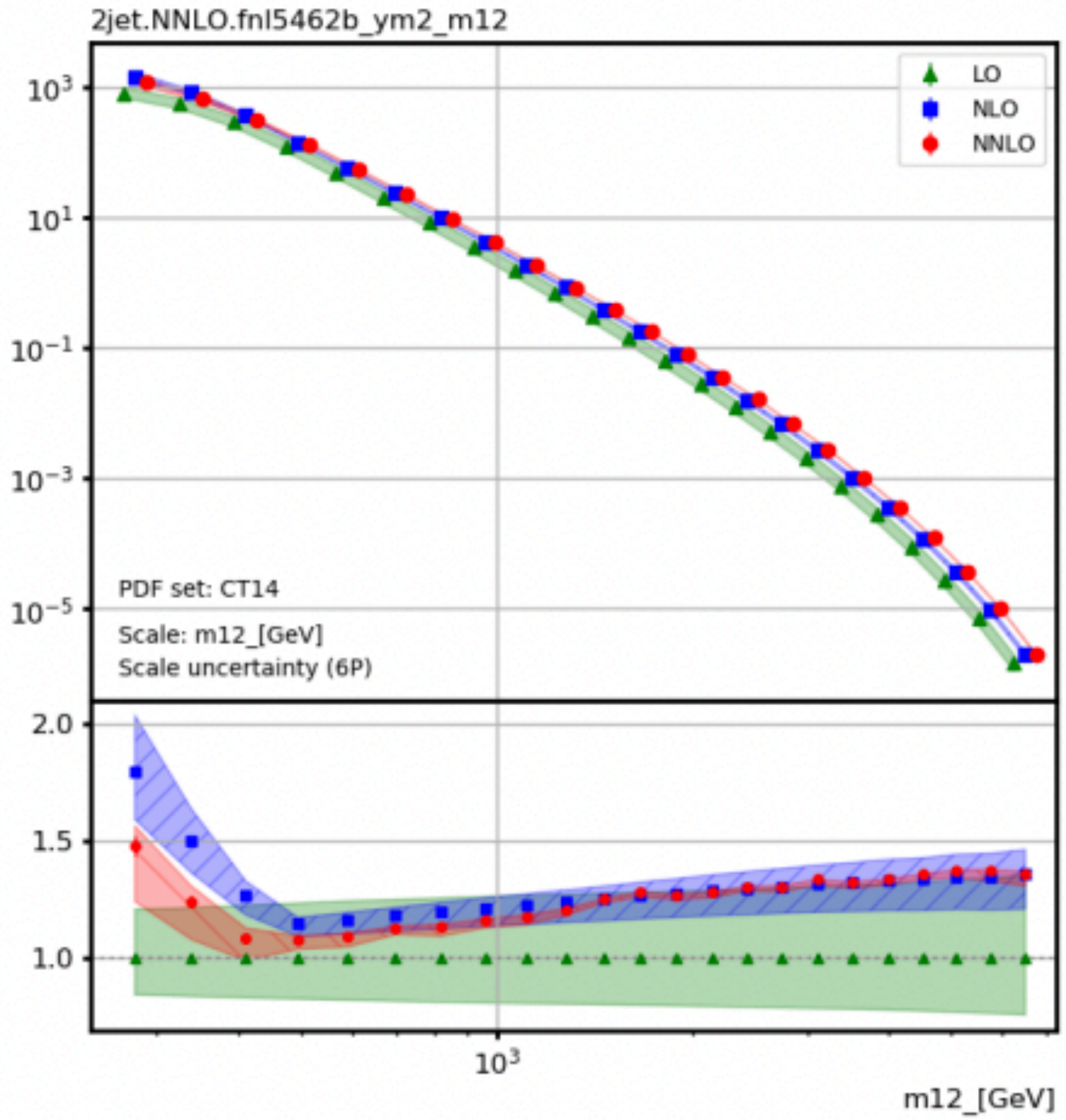
3D : R=0.8

3D : R=0.4

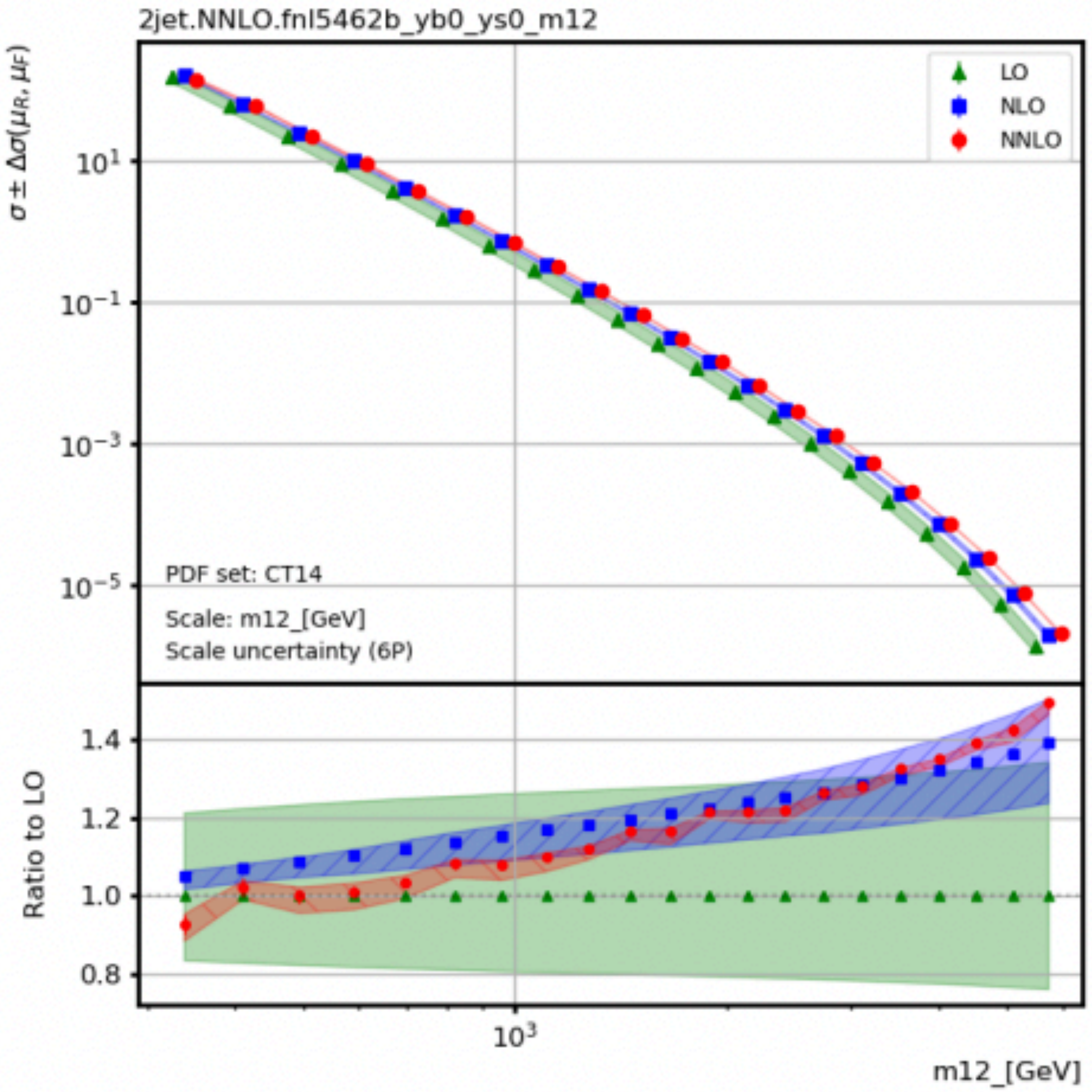


Theory predictions

2D : R=0.8

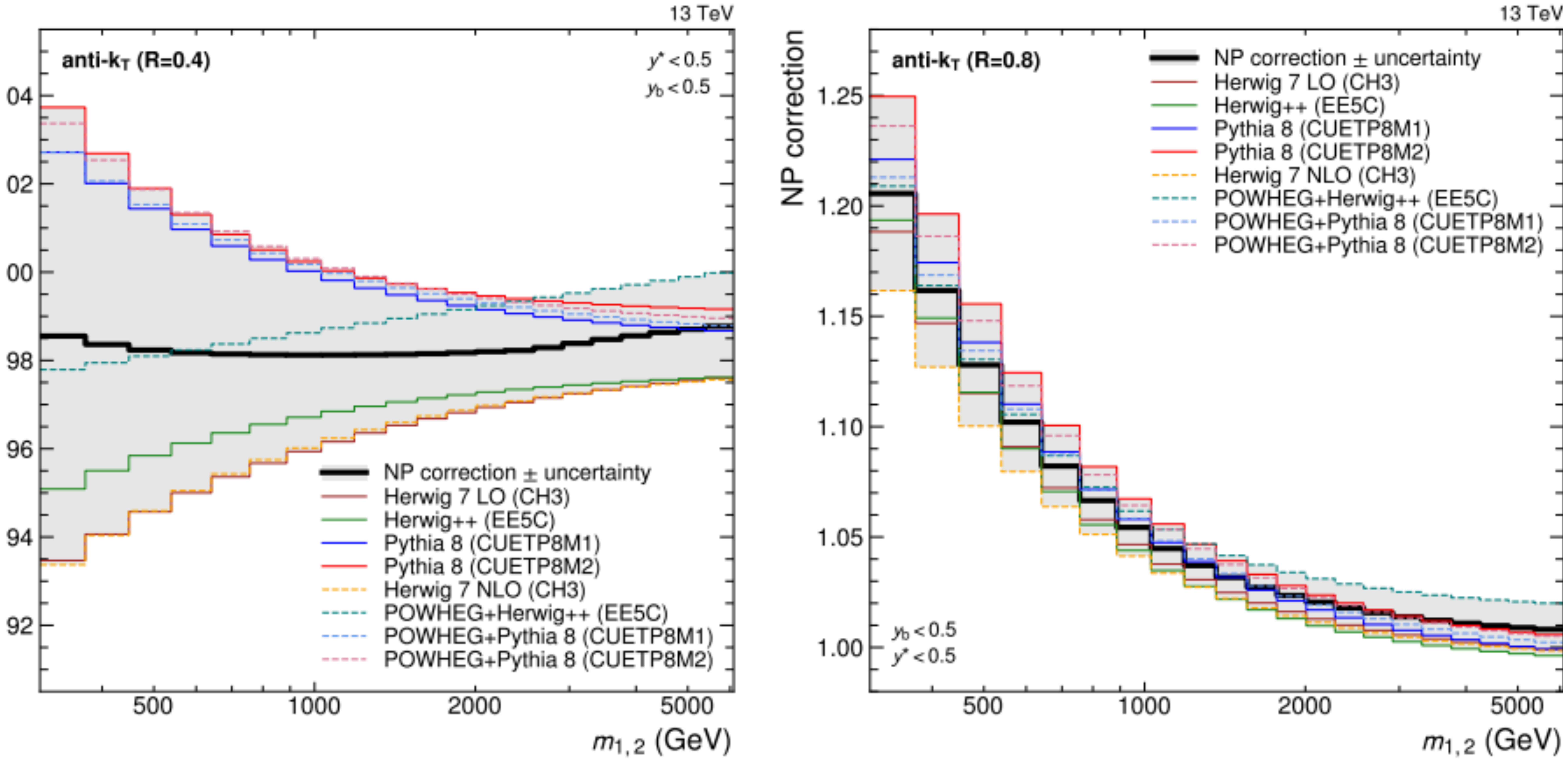


3D : R=0.8



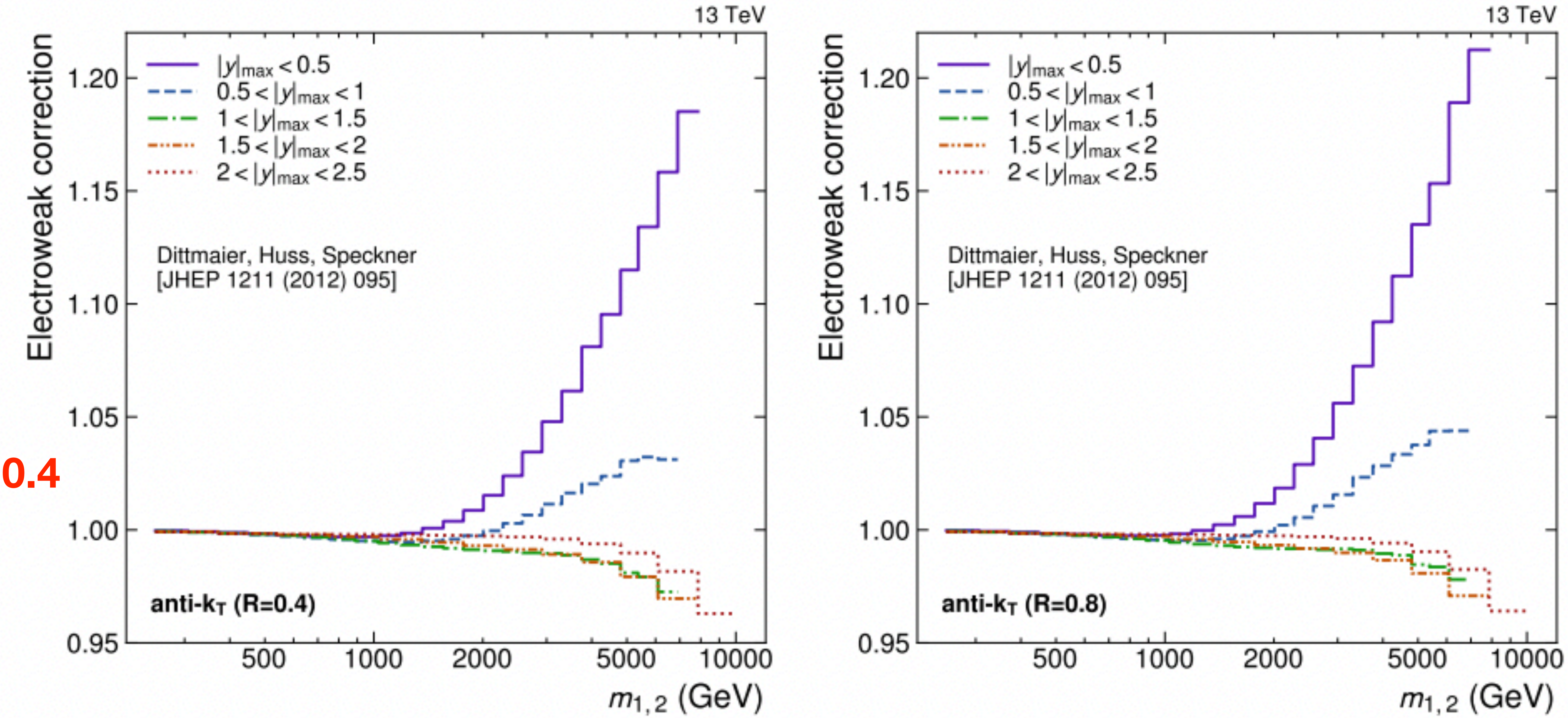
Scale uncertainty reduced @NNLO

Nonperturbative (NP) corrections



Jets with R = 0.8 larger >20% at low values of $m_{1,2}$

Electroweak corrections



R=0.4

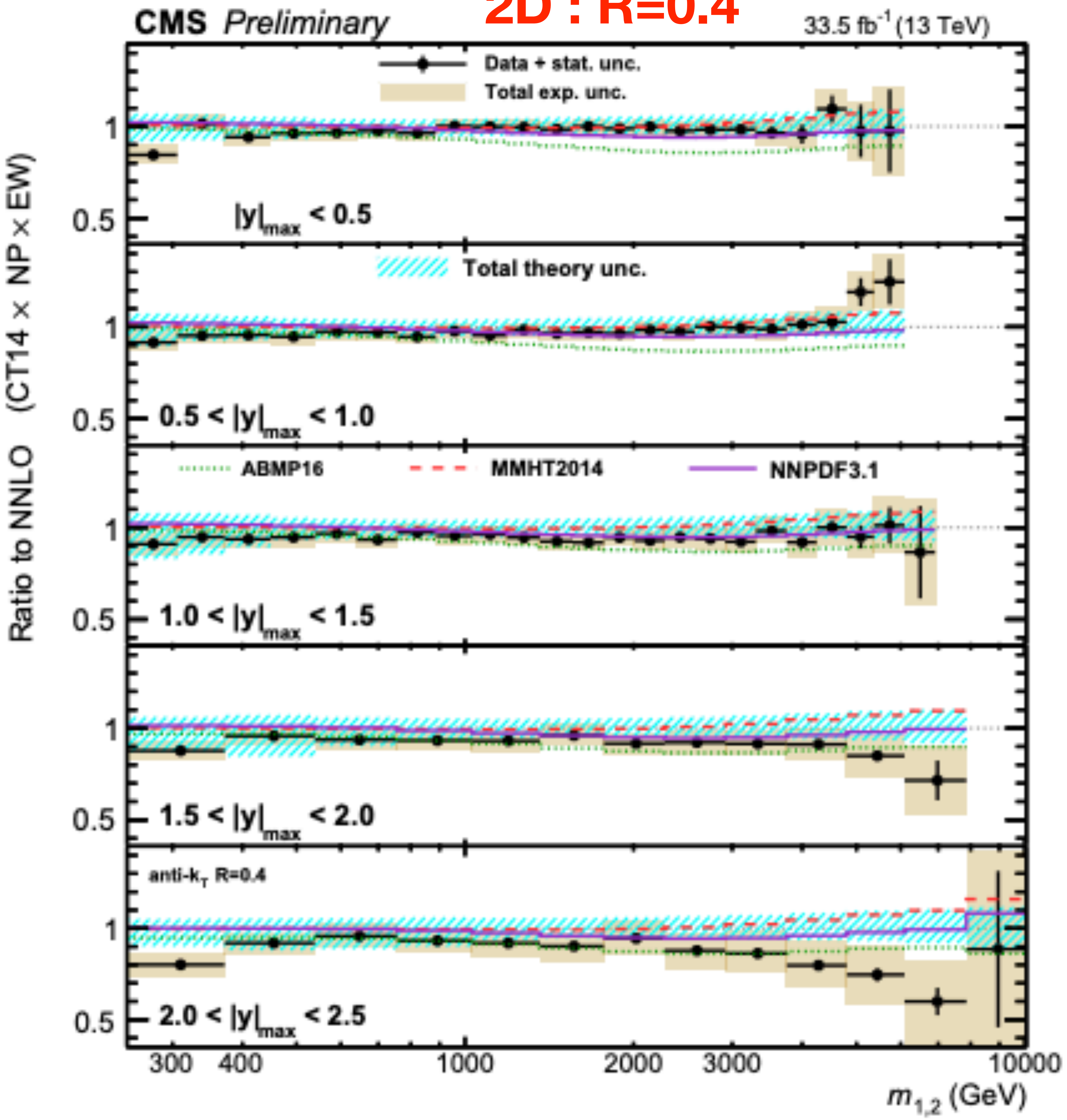
R=0.8

Largest effect :

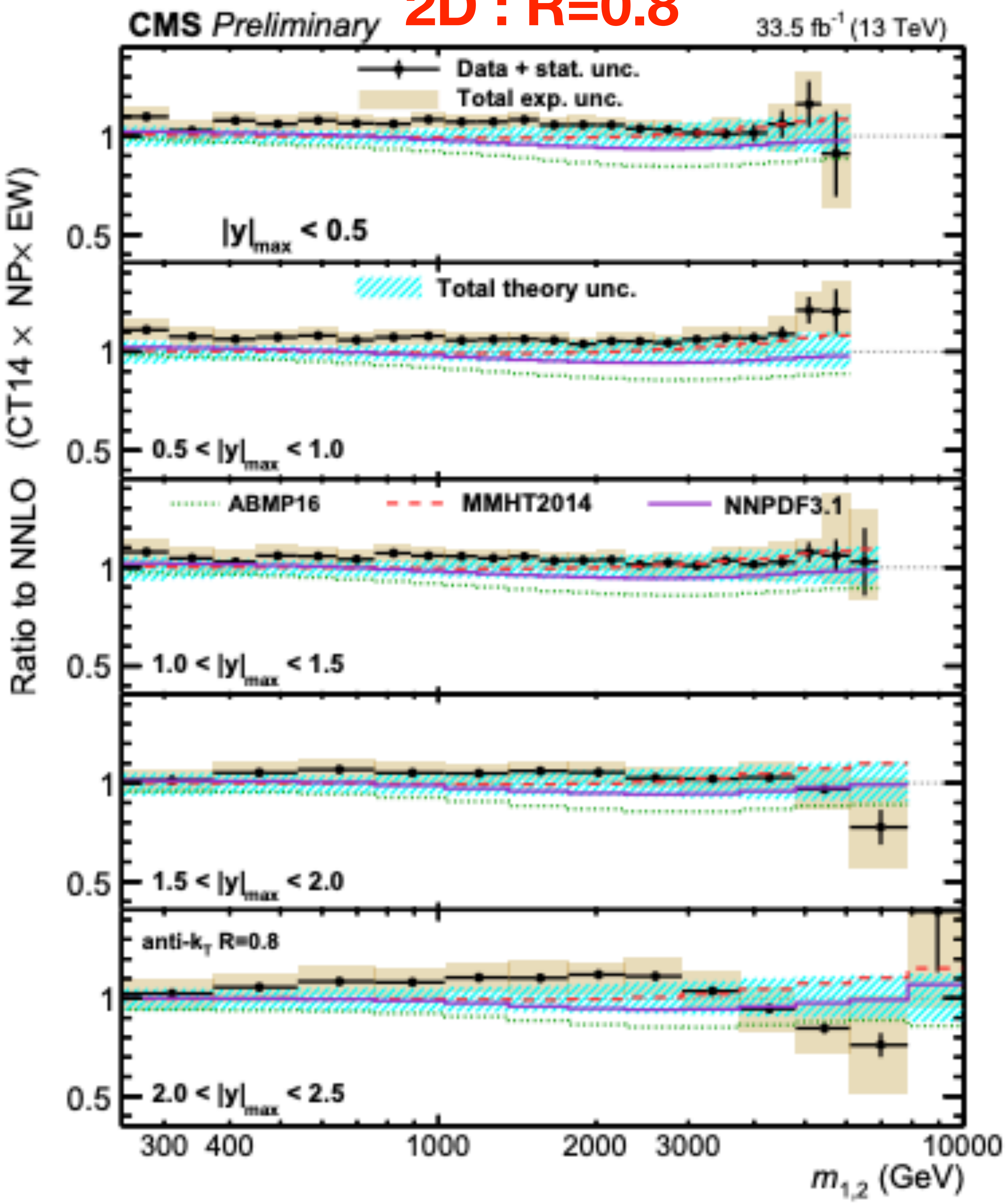
- $m_{1,2}$ > **1TeV**
- $|y|_{max} < 0.5$

Theory predictions: Ratio

2D : R=0.4



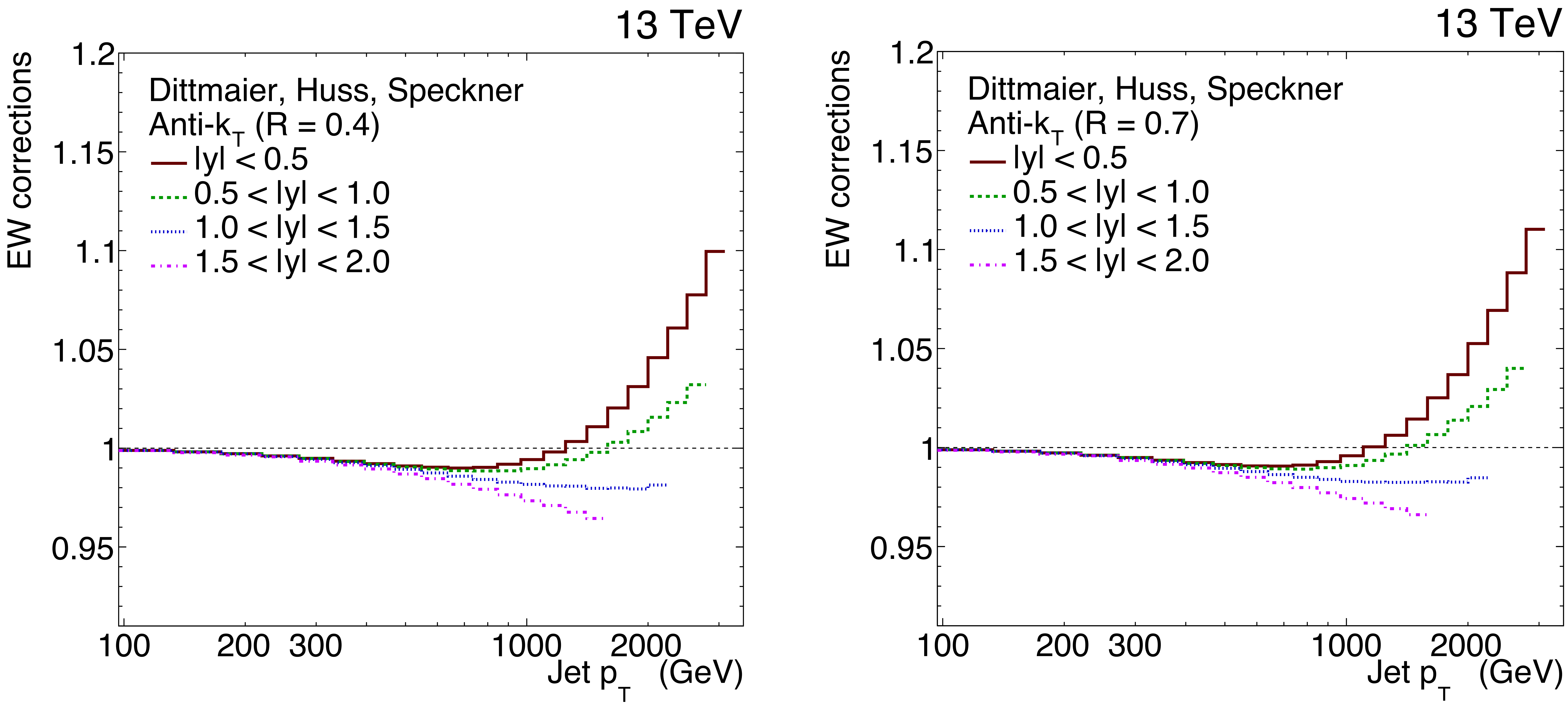
2D : R=0.8



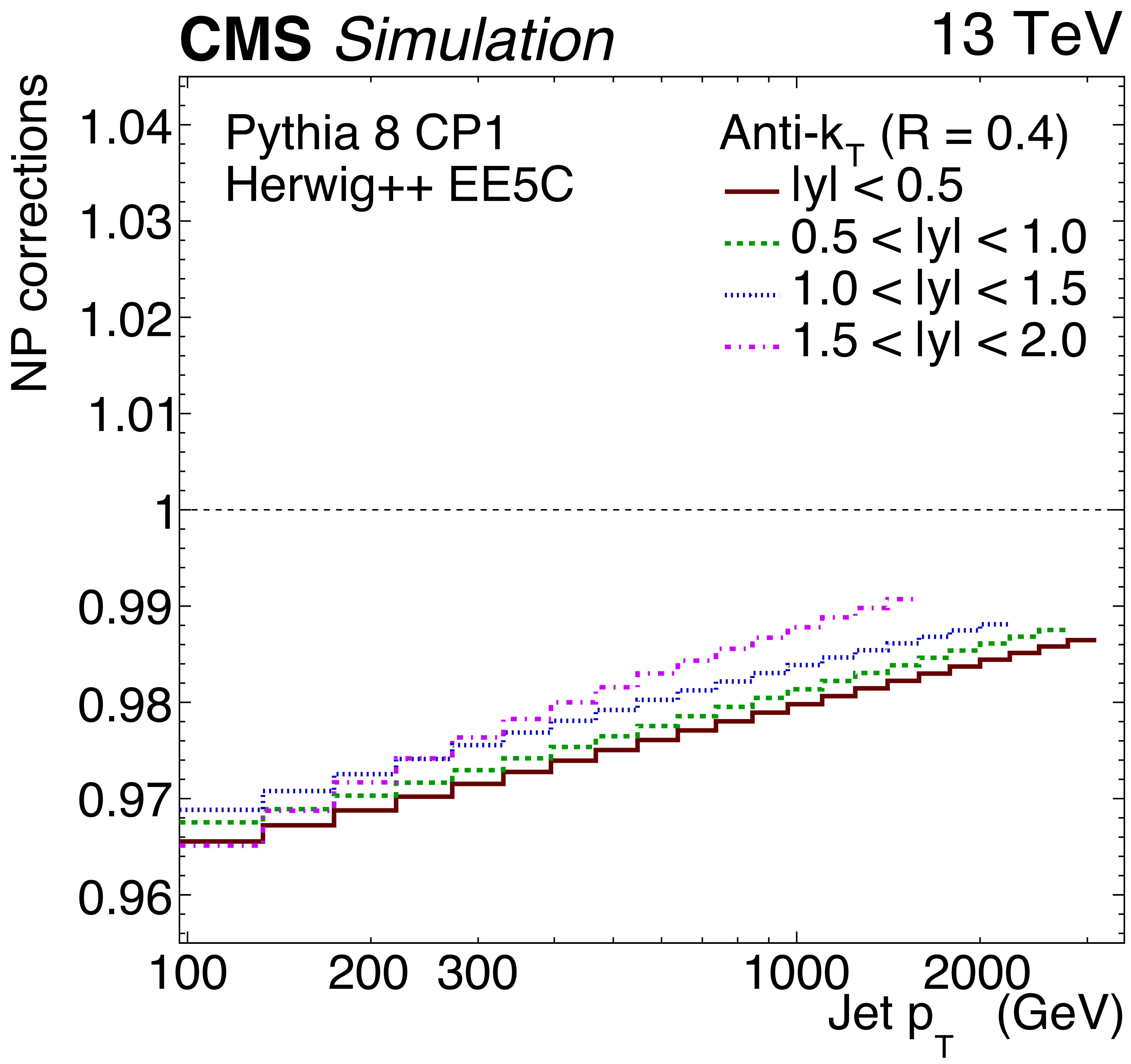
Data agreements are good, described by the theory

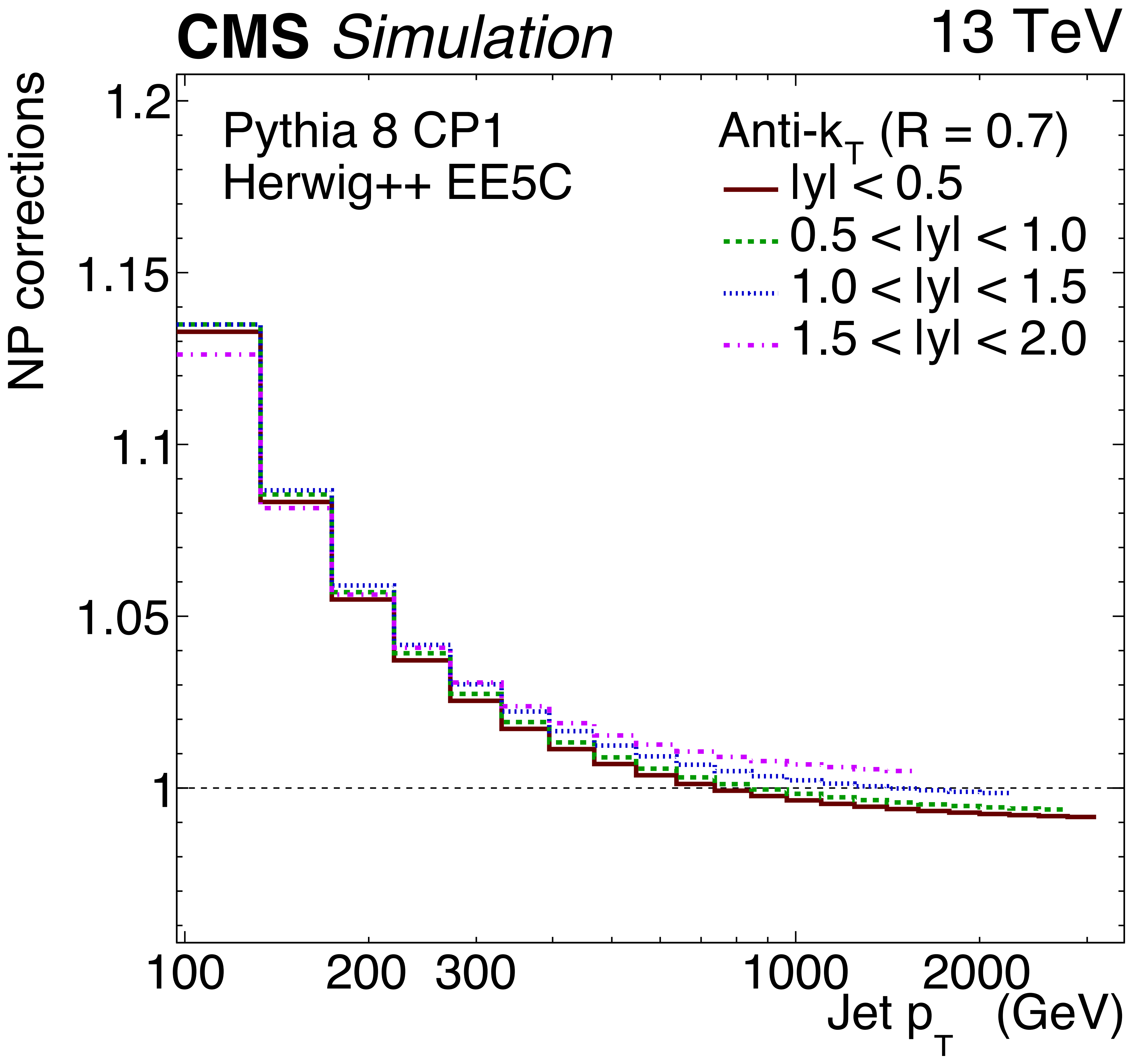
R = 0.8 measurement is described better than R = 0.4

Inclusive jet cross sections: EW Correction:



Inclusive jet cross sections: NP Correction





Inclusive jet cross sections