xFitter related activities in CMS and in the LHEWWG1

xFitter workshop - CERN

May 2nd, 2023

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Introduction

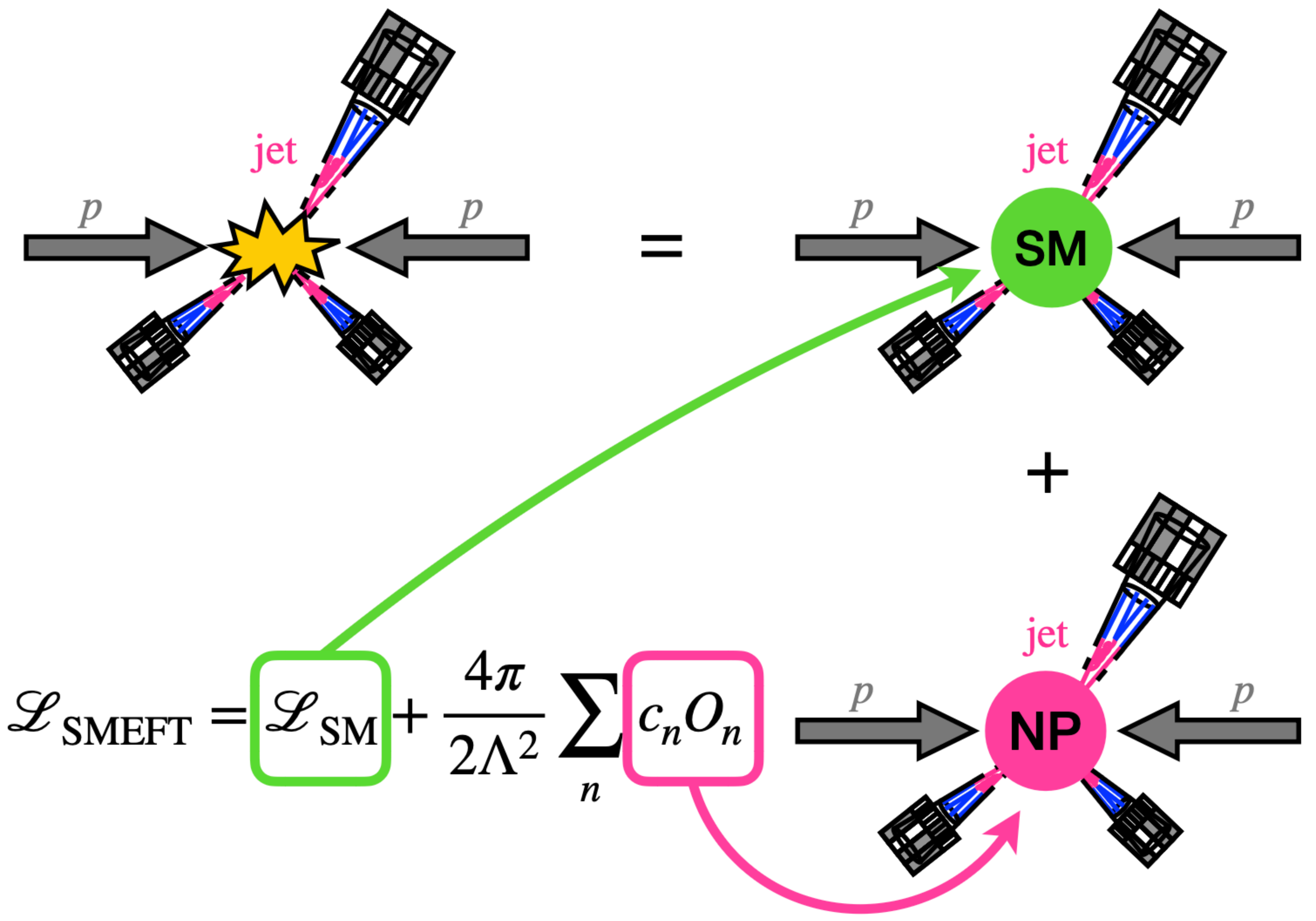
- Recent CMS results sensitive to PDFs and xFitter analyses
  - Jets, strong coupling and **SMEFT**, slowly adding top to the game
  - Studies with **Drell-Yan** (motivated by upcoming precision EW measurements)
  - Attempts at a global fit a la ATLASpdf, mainly to insure data consistency and that sufficient information is provided for reinterpretation

- Usage of xFitter in PDF related studies within the LHCEWWG1
  - Combination and PDF benchmarking for the W-mass averaging project
  - Pseudo-data and future combination of the weak mixing angle
  - PDF correlations through common pseudo-data fits

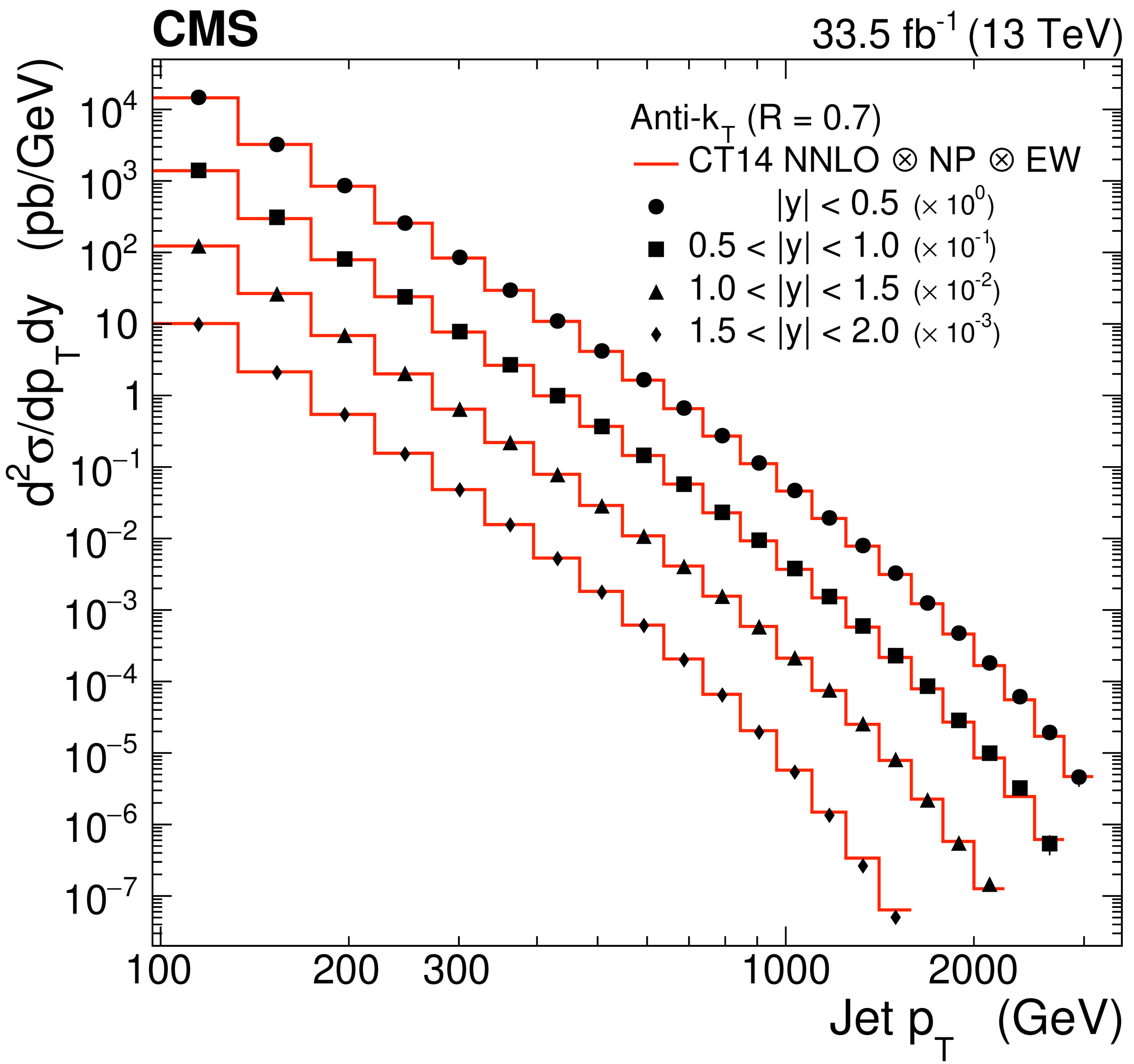
Inclusive jets at 13 TeV

http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP-20-011/

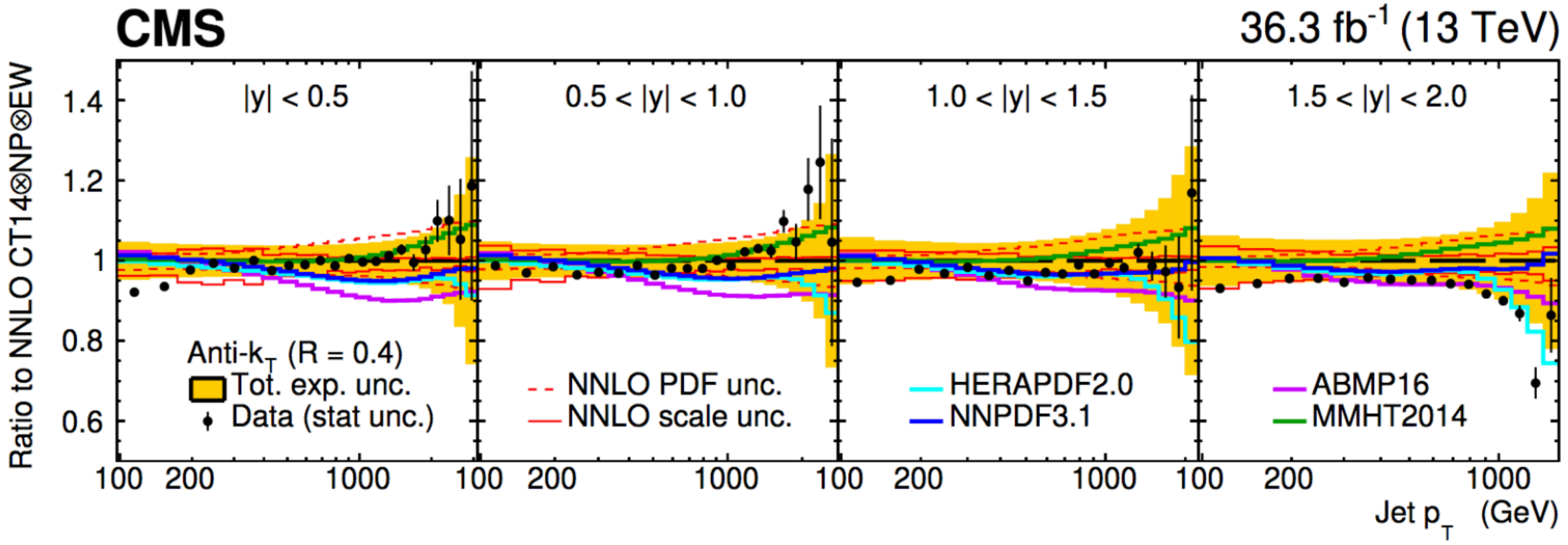
- 13 TeV inclusive jet cross-sections using 36 fb^{-1} of data
  - Performs PDF, PDF+SMEFT analyses and strong coupling measurement
  - NNLO theory using k-factors
    -> **New: updated to NNLO grids**

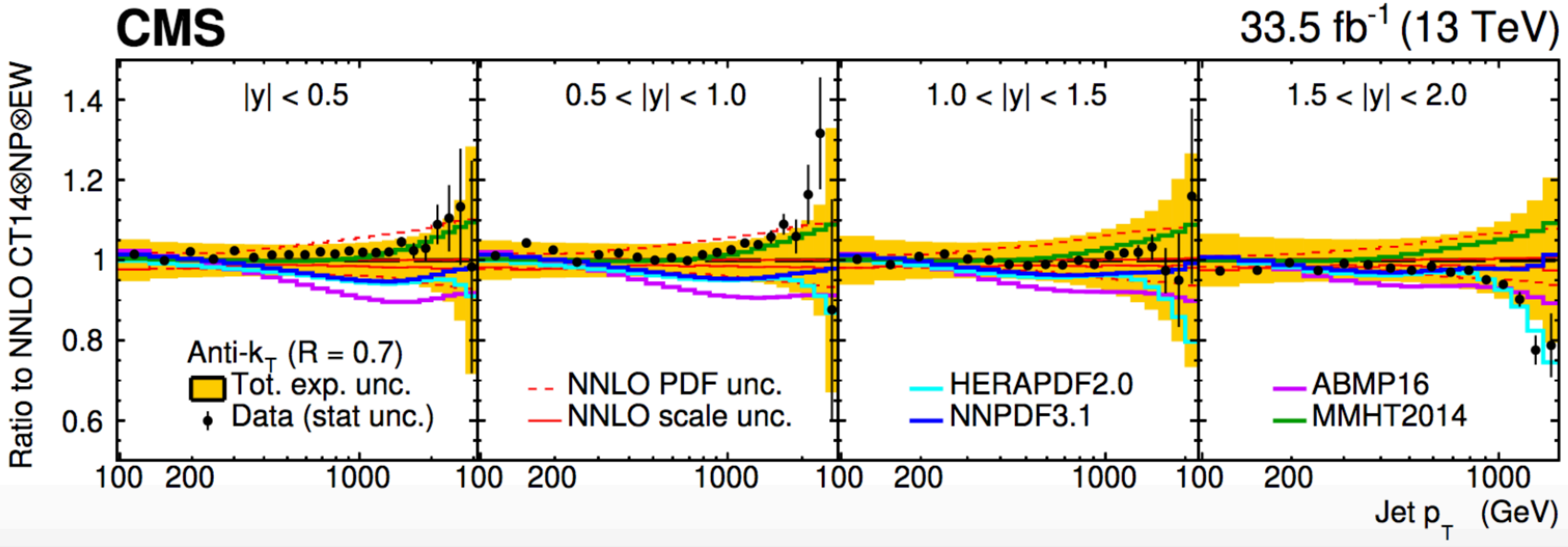


CI: contact interaction operators

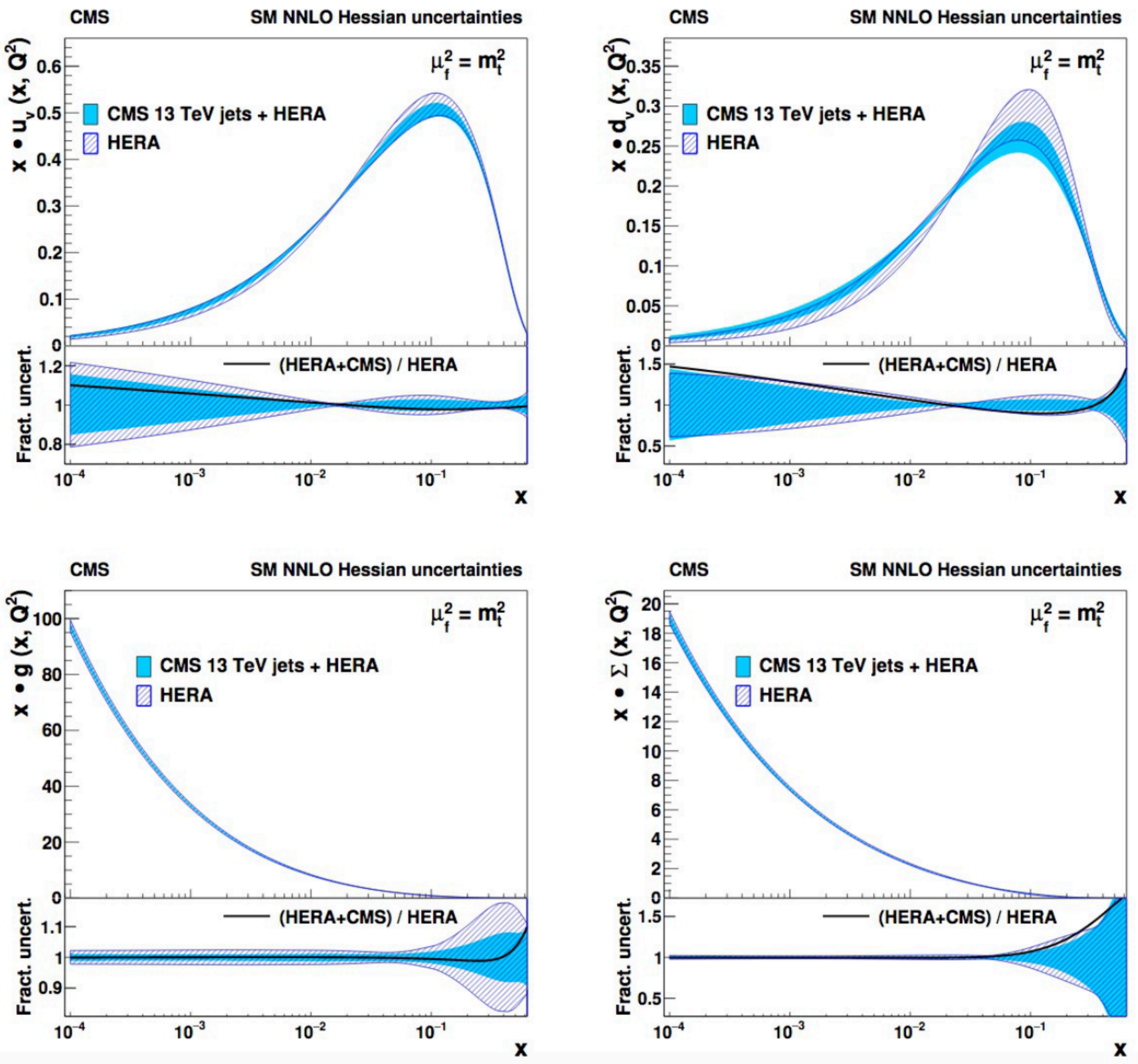


Data / predictions comparison





Determination of PDFs and strong coupling



- Improved gluon constraints in the "usual" HERA+X fit
- Reduction in the MHOU impact on the strong coupling using the NNLO grids

With NNLO k-factors

$$\alpha_S(m_Z) = 0.1170 \pm 0.0014\,(\text{fit}) \pm 0.0007\,(\text{model})$$
$$\pm 0.0008\,(\text{scale}) \pm 0.0001\,(\text{param.})$$

With NNLO grids

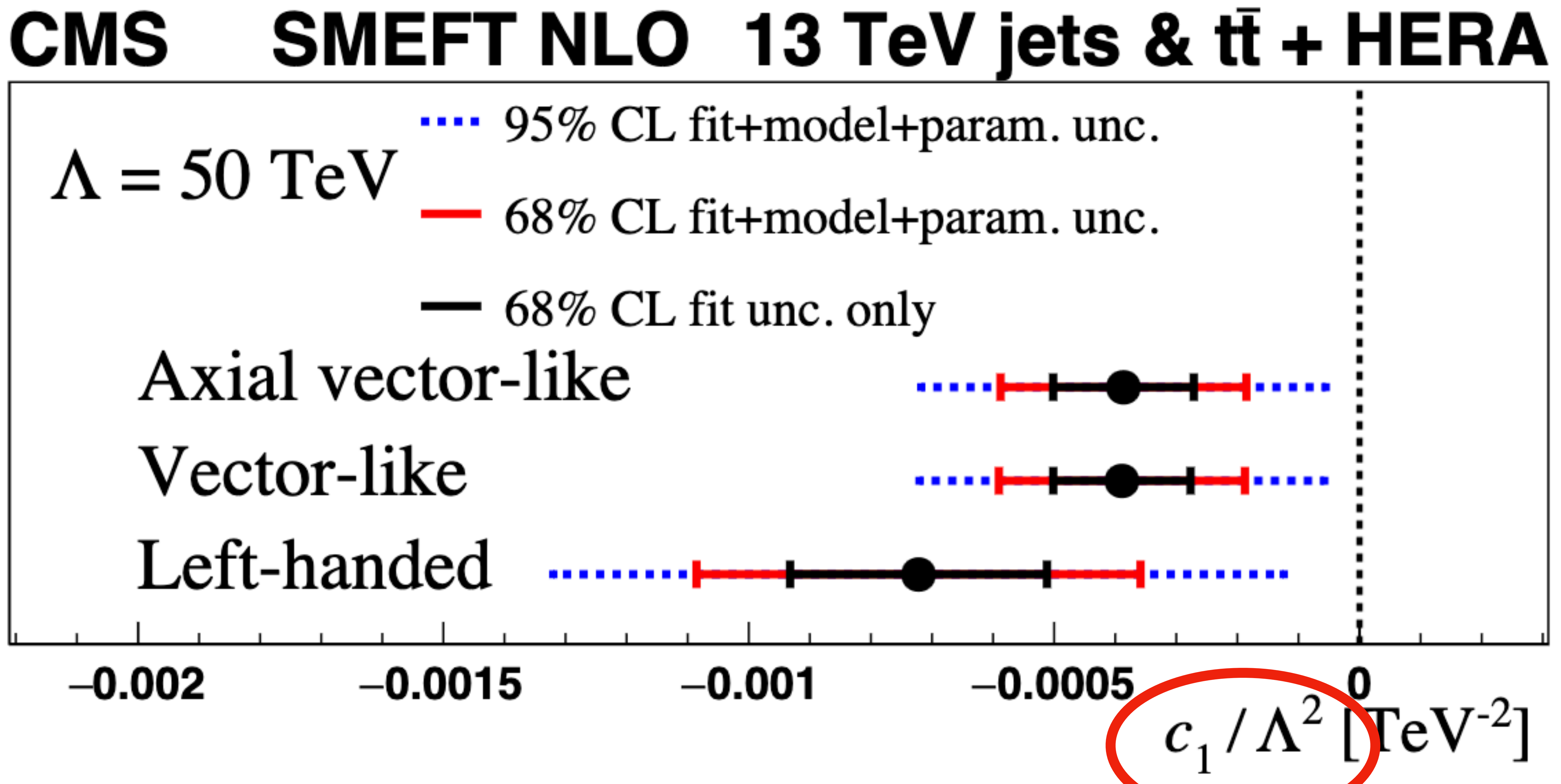
$$\alpha_S(m_Z) = 0.1166 \pm 0.0014\,(\text{fit}) \pm 0.0007\,(\text{model})$$
$$\pm 0.0004\,(\text{scale}) \pm 0.0001\,(\text{param.})$$

SMEFT interpretation

- Effect of **Contact Interactions** (CI) is then added to the fit using CIJET interface (Toni)
- Simultaneous determination of PDFs, SM parameters and Wilson coefficients
- Fit performed at NLO QCD using the inclusive jets and top-quark pair data

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{2\pi}{\Lambda^2} \sum_{n\in\{1,3,5\}} c_n O_n.$$

95% CL on Λ with $c_1 = -1$:
Axial vector-like: 24 TeV
Vector-like: 31 TeV
Left-handed: 31 TeV

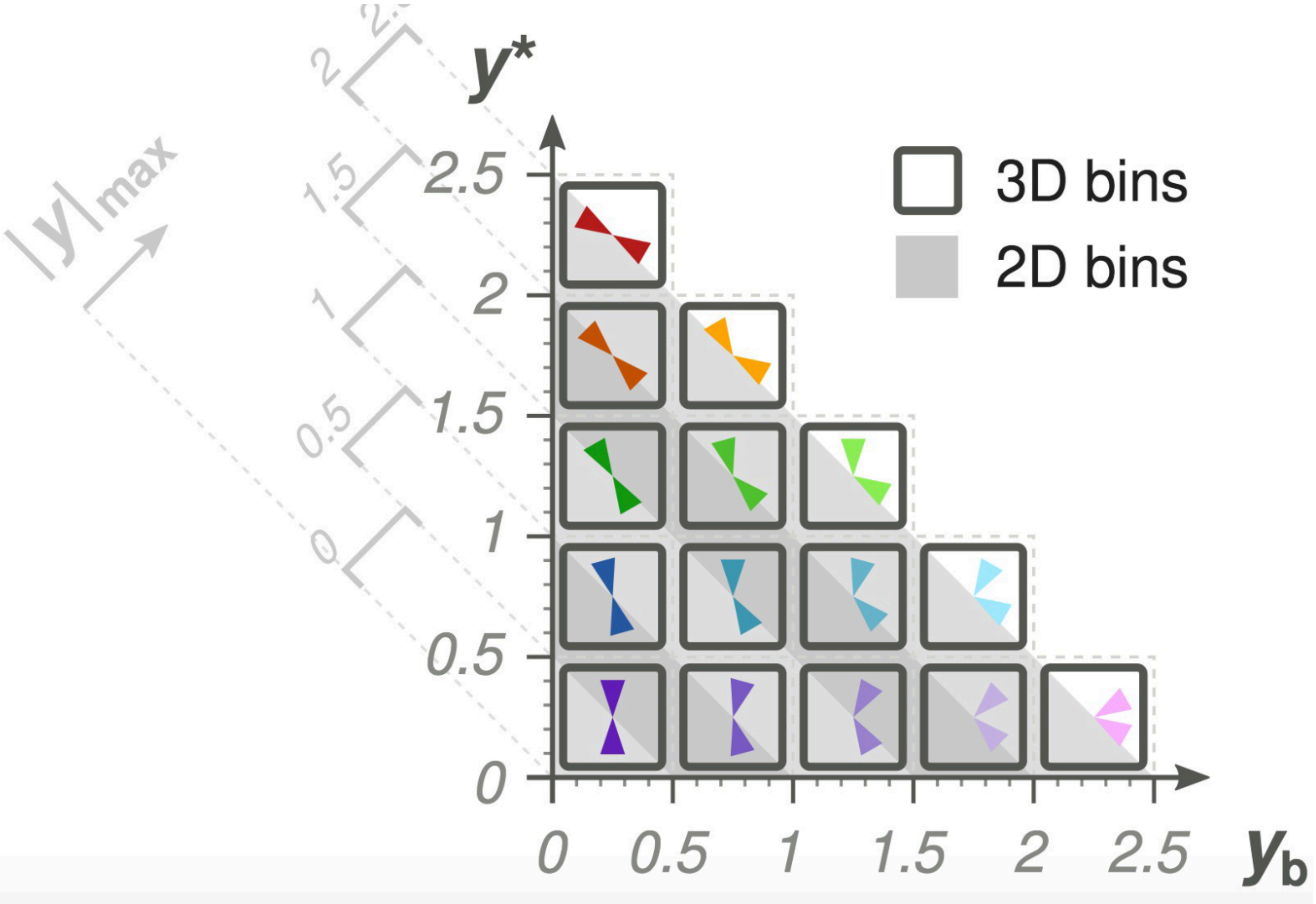


- Ongoing work to go beyond CI and towards full PDF+SMEFT analyses

Triple-differential dijet cross-sections at 13 TeV

- Measured double- and triple-differentially as a function of leading dijet variables
- **2D** : dijet mass in five rapidity regions $y_{max} = \mathrm{sign}(|\max(y_1, y_2)| - |\min(y_1, y_2)|) \max(|y_1|, |y_2|)$
- **3D**: mass and average pT in bins of rapidity separation and boost of the diet system

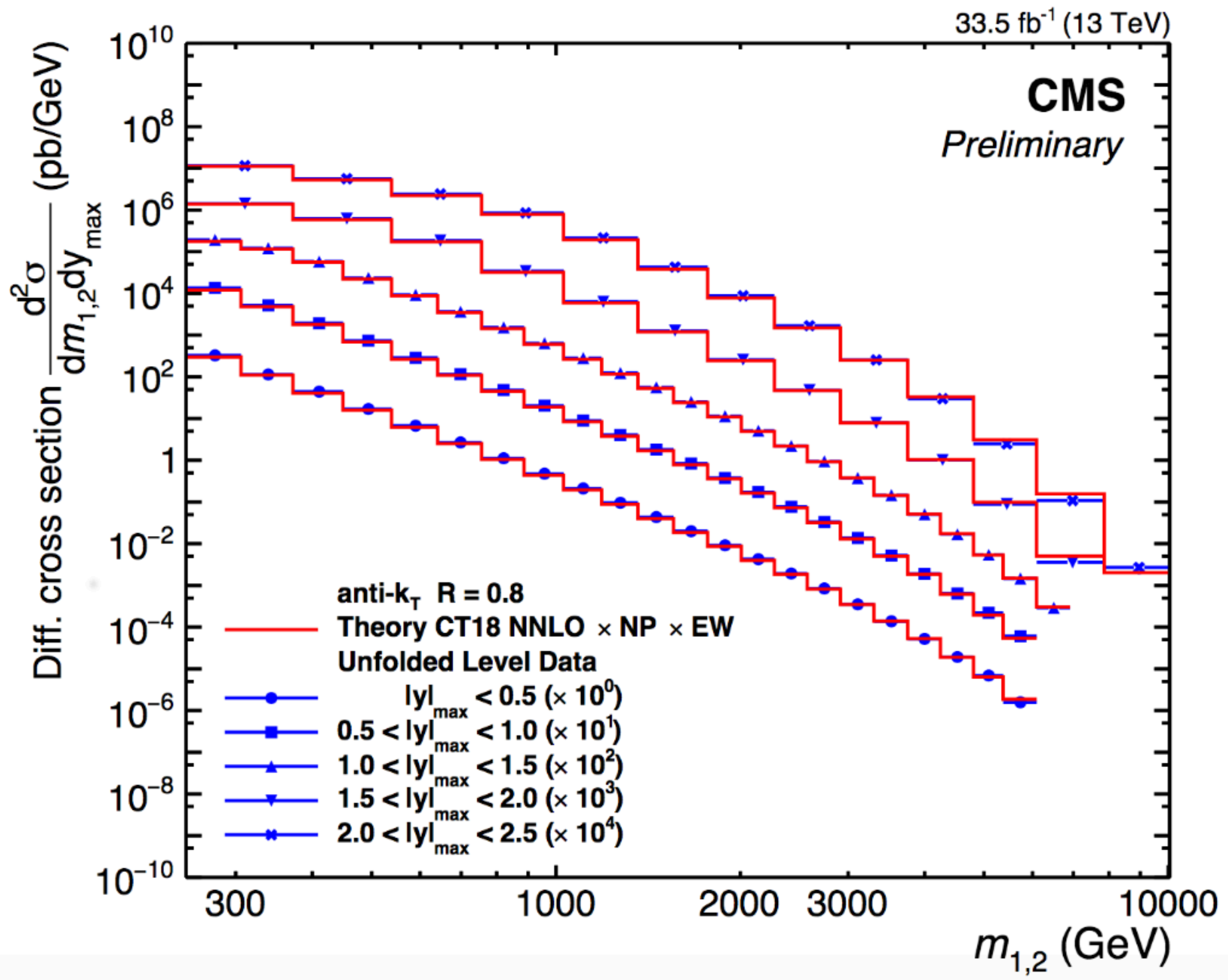
$$y^* = \frac{1}{2}|y_1 - y_2|, \quad y_b = \frac{1}{2}|y_1 + y_2| \quad m_{1,2} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}, \quad \langle p_T \rangle_{1,2} = \frac{1}{2}(p_{T,1} + p_{T,2})$$

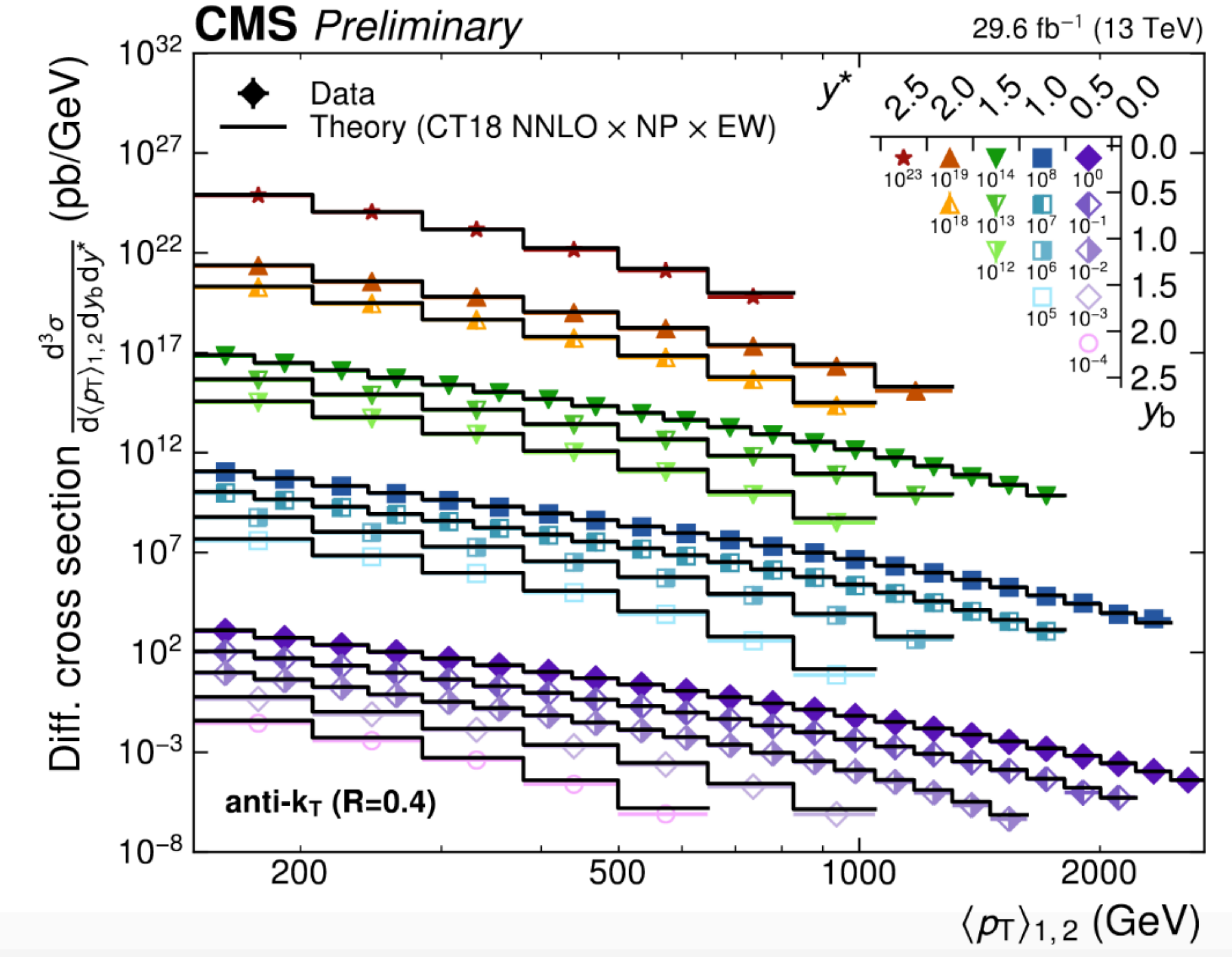


- The dijet rapidity phase-space, highlighting the relationship between variables used for 2D and 3D measurements
- Colored triangles suggest the orientation of two jets in different phase-space regions in the lab frame

2D/3D Data / Theory comparisons

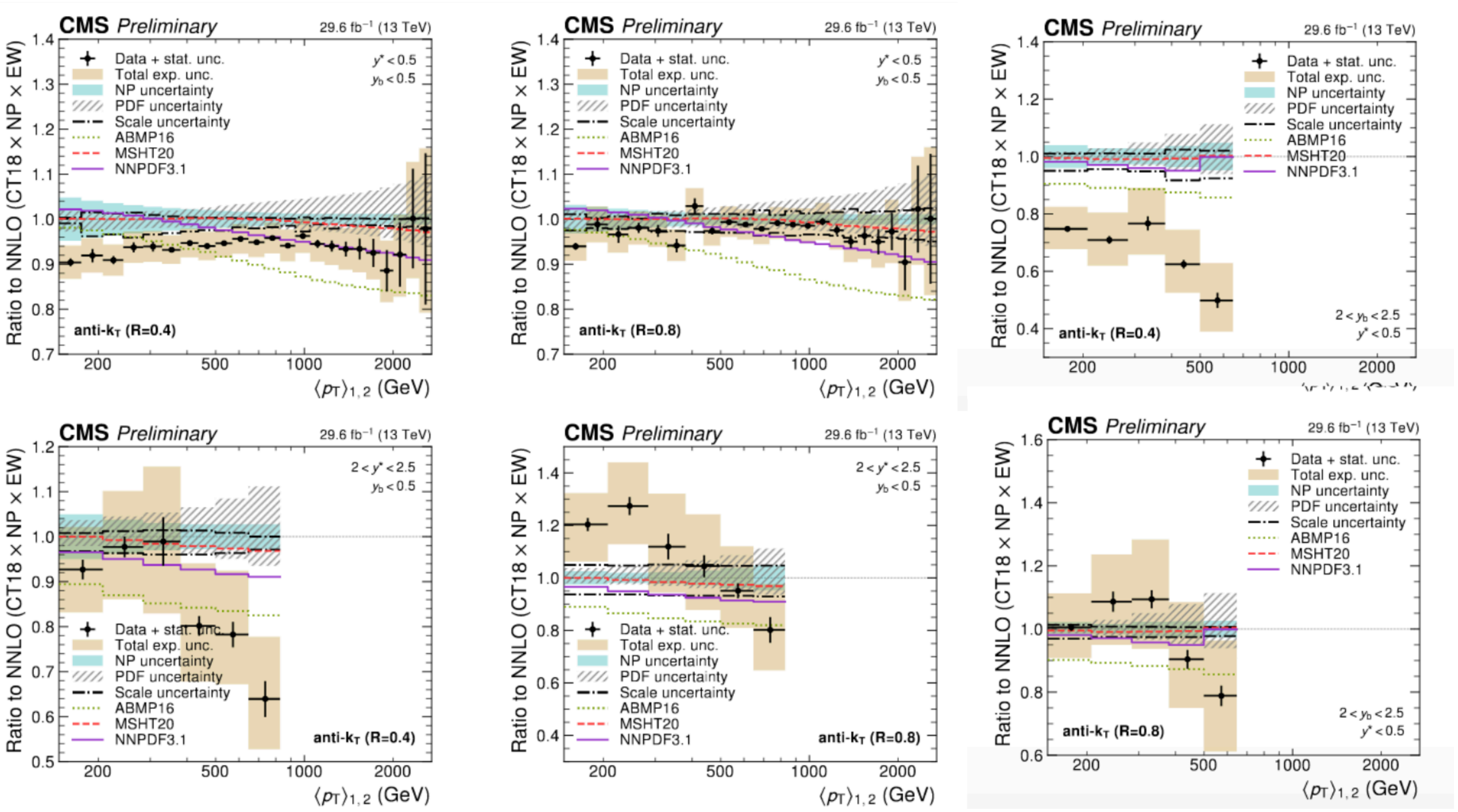
- Data compared to predictions at NNLO QCD x NLO EW x NP
- In good agreement but for ABMP16
- Generally smaller predicted cross-sections





http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP-21-008/index.html

Data/predictions - 3D dijets



* Some differences in the shape visible in the most forward y_b bins

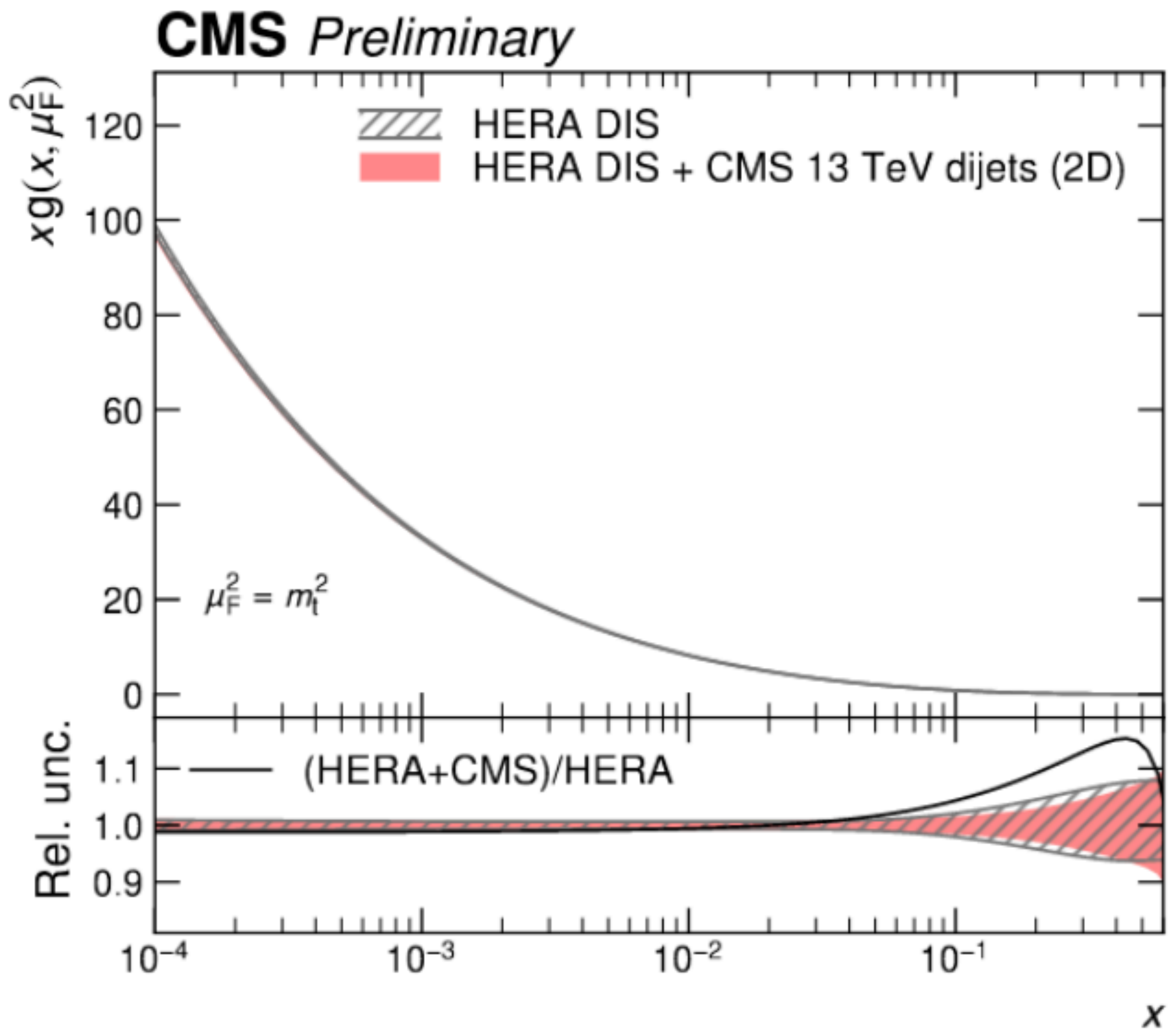
PDFs and strong coupling

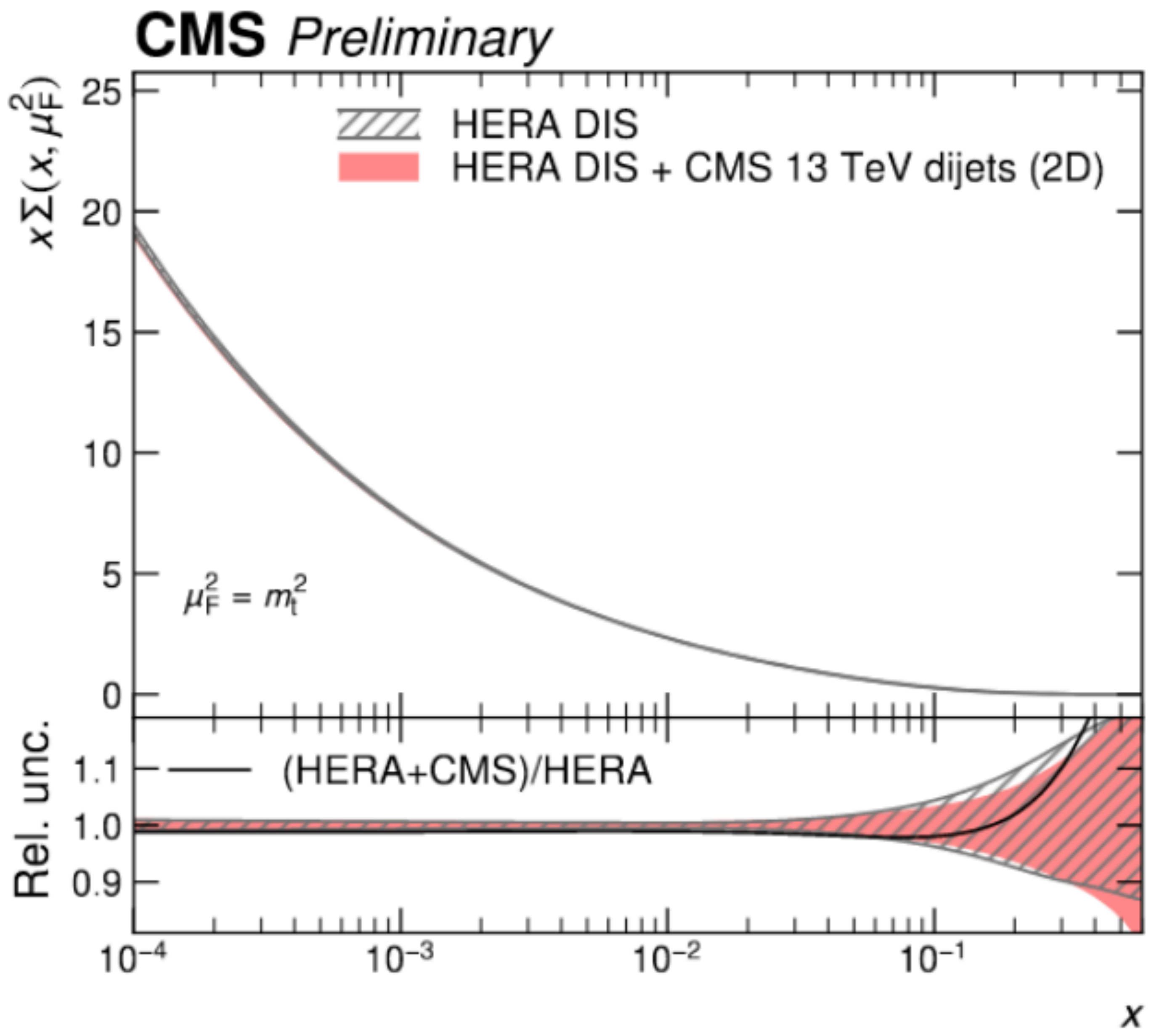
- Results used in simultaneous PDF + strong coupling extractions
- Stronger PDF constraints and smaller strong coupling uncertainties with 3D data

2D:
$$\alpha_s(m_Z) = 0.1201 \pm 0.0012\,(\text{fit}) \pm 0.0008\,(\text{scale}) \pm 0.0008\,(\text{model}) \pm 0.0005\,(\text{param.})$$
$$= 0.1201 \pm 0.0021\,(\text{total}),$$

3D:
$$\alpha_s(m_Z) = 0.1201 \pm 0.0010\,(\text{fit}) \pm 0.0005\,(\text{scale}) \pm 0.0008\,(\text{model}) \pm 0.0006\,(\text{param.})$$
$$= 0.1201 \pm 0.0020\,(\text{total}),$$

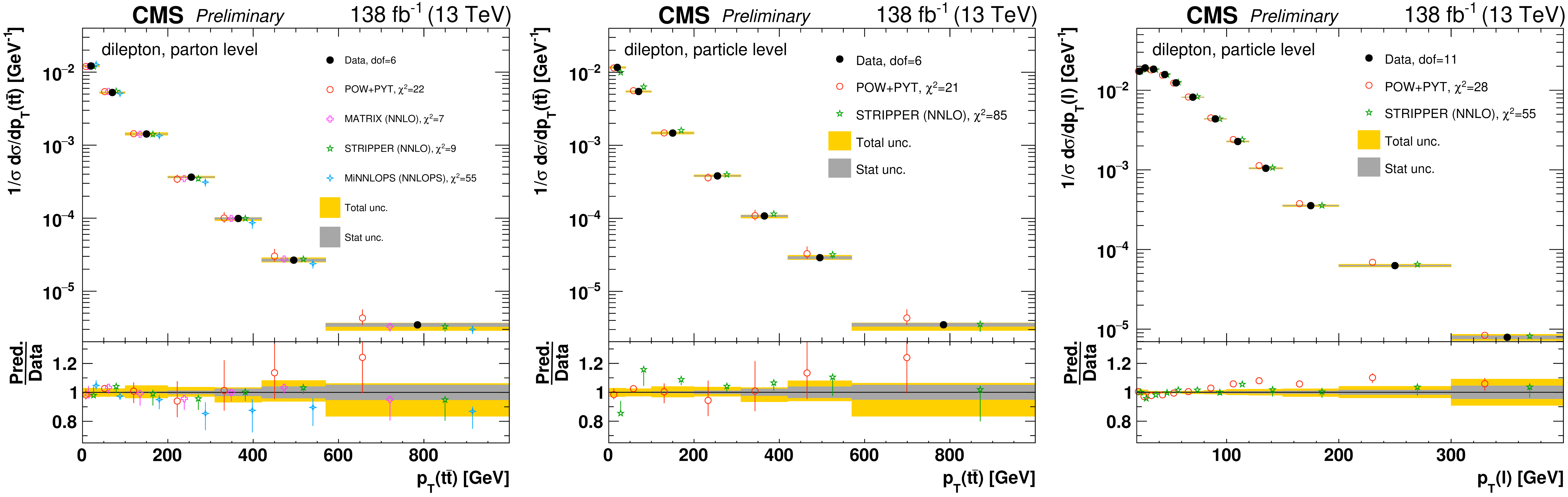
- Some tensions with 3D data in the high rapidities bins (NNLO insufficient?)





PDF constraints from top data

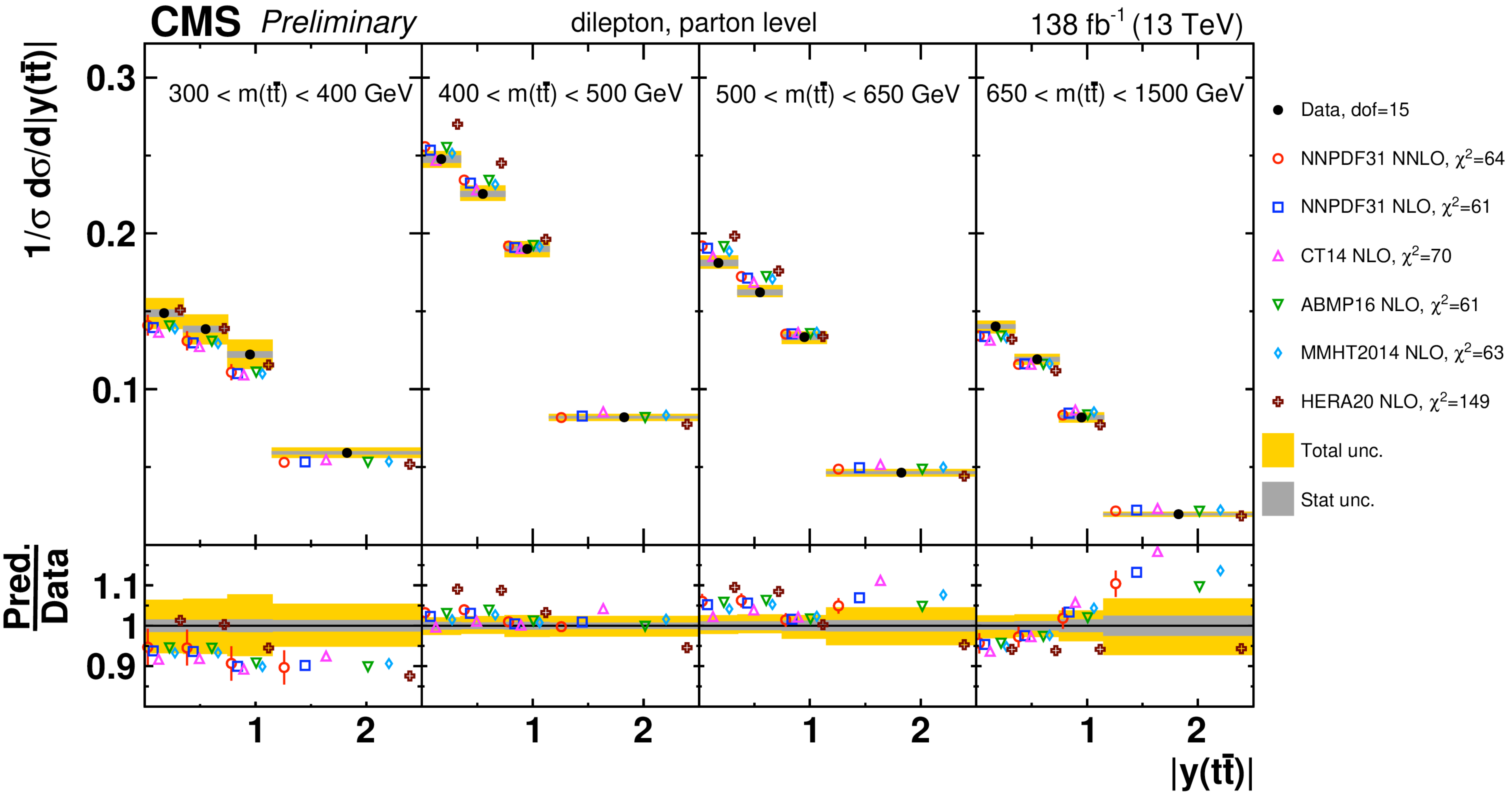
- New measurement of parton- and particle-level top-quark pair cross-sections
- Interesting for PDFs, top mass and strong coupling



http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TOP-20-006/index.html

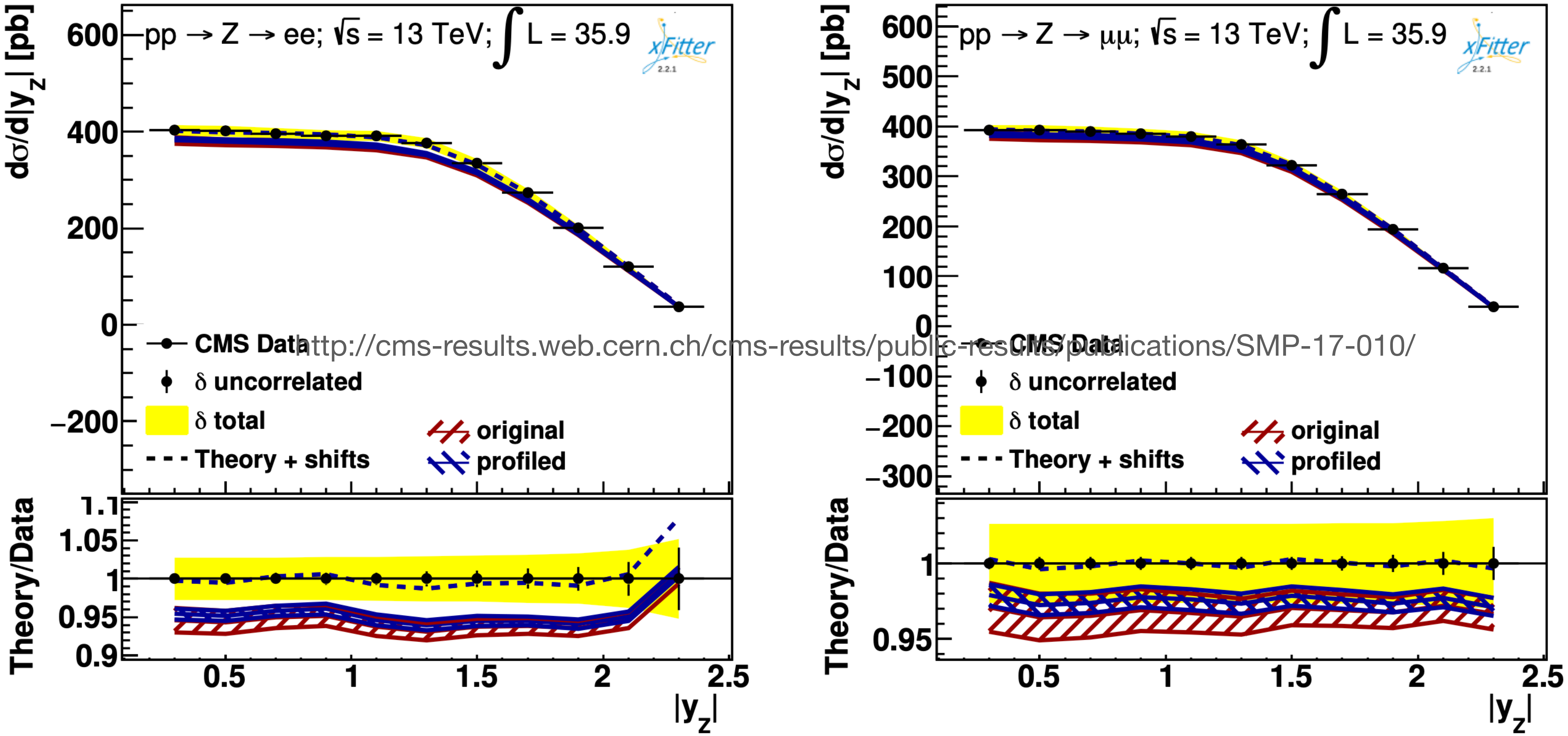
- Predictions at NNLO prod. X NNLO decay (Stripper) available
- Further work needed to understand how to incorporate corrections for NLO EW and finite width effects beyond the NWA

Parton-level ttbar cross-sections and PDFs



13 TeV Z-rapidity and PDFs

- Rapidity distribution of file-ton pairs with 36 fb-1 at 13 TeV
- Theory: NLO grids (aMCfast) + NNLO QCD k-factors (DYTURBO)

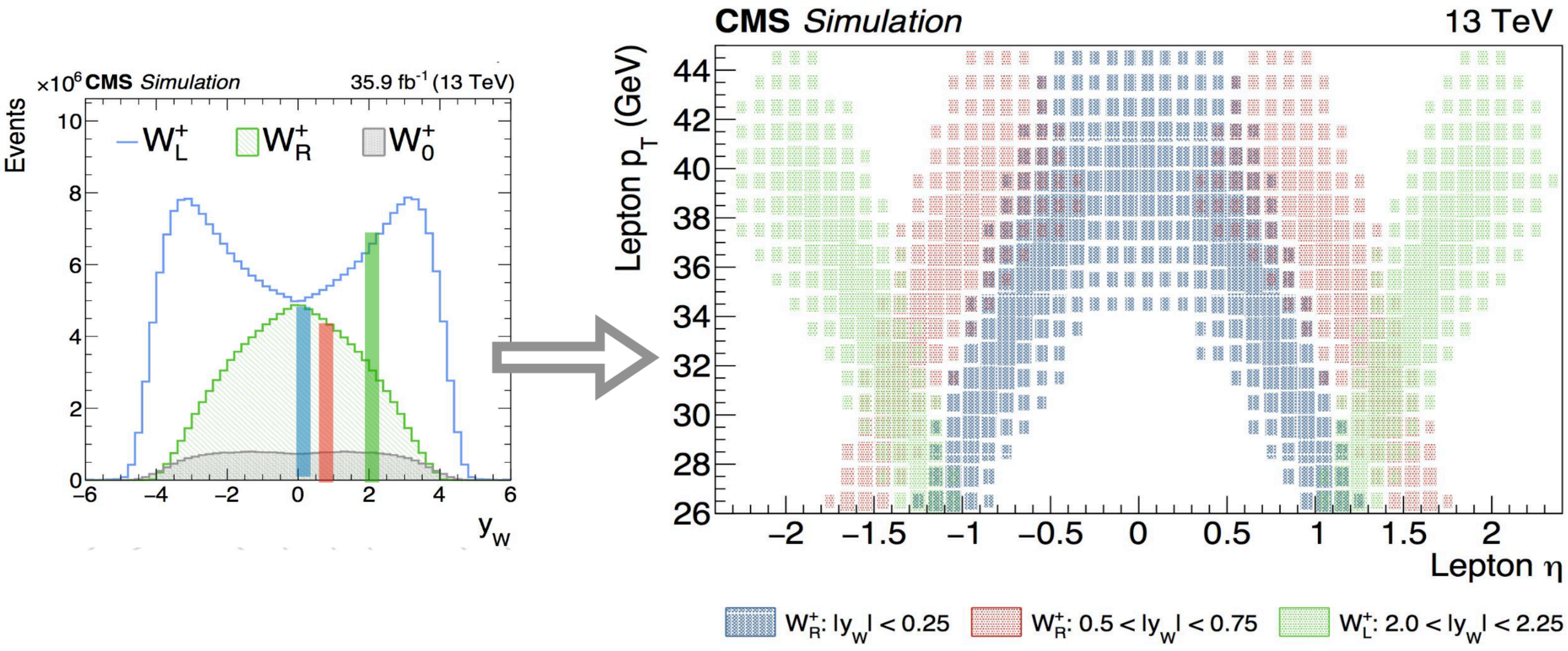


http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP-17-010/index.html

- Good description of the data, after working out proper systematics decomposition
- Some issues with the most forward electron bins, likely due to “prefiring”

13 TeV W-helicity measurement

- Lepton direction in W-decays retains information on the W polarization state
- W rapidity and helicity are inferred statistically from lepton pT-eta distribution



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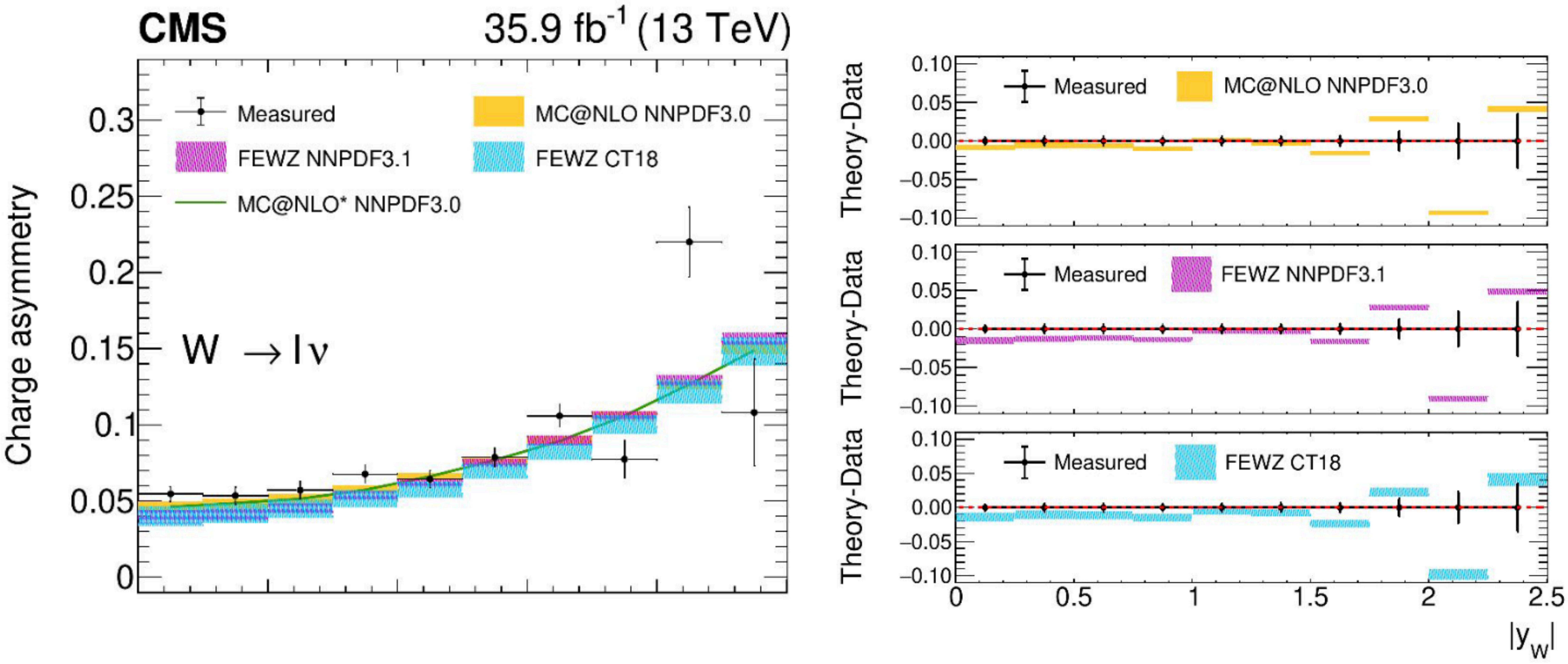
Lepton pT/eta cross-sections

- W rapidity and helicity can be inferred statistically from lepton p_T-eta distribution

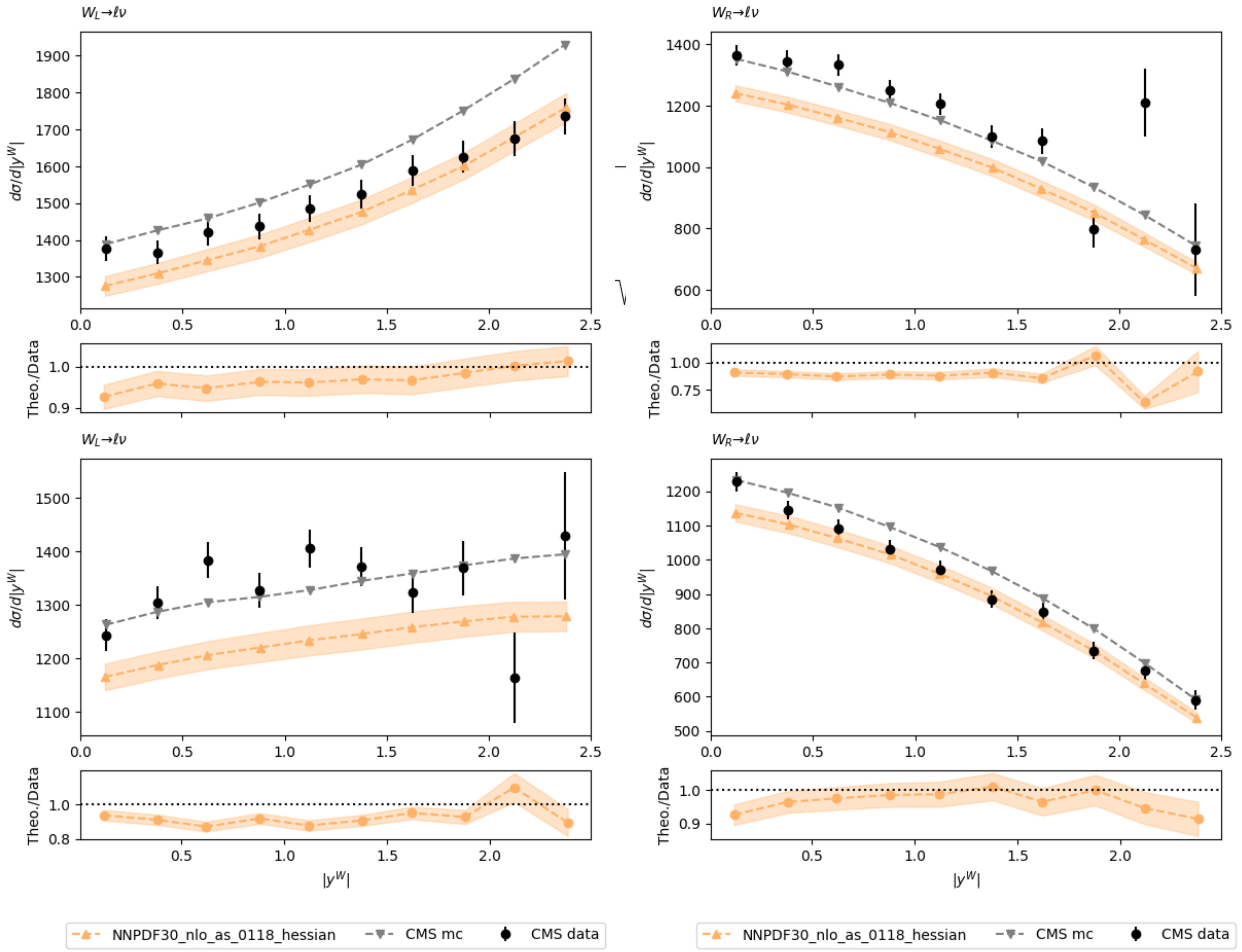
- This distribution is what is actually measured, but cannot be fitted at fixed-order

W charge asymmetry measurement

- Helicity integrated results measured without assumptions on underlying polarization
- Avoids the issue of circular pdf uncertainties in e.g. Tevatron W-asymmetry measurements



W helicity cross-sections

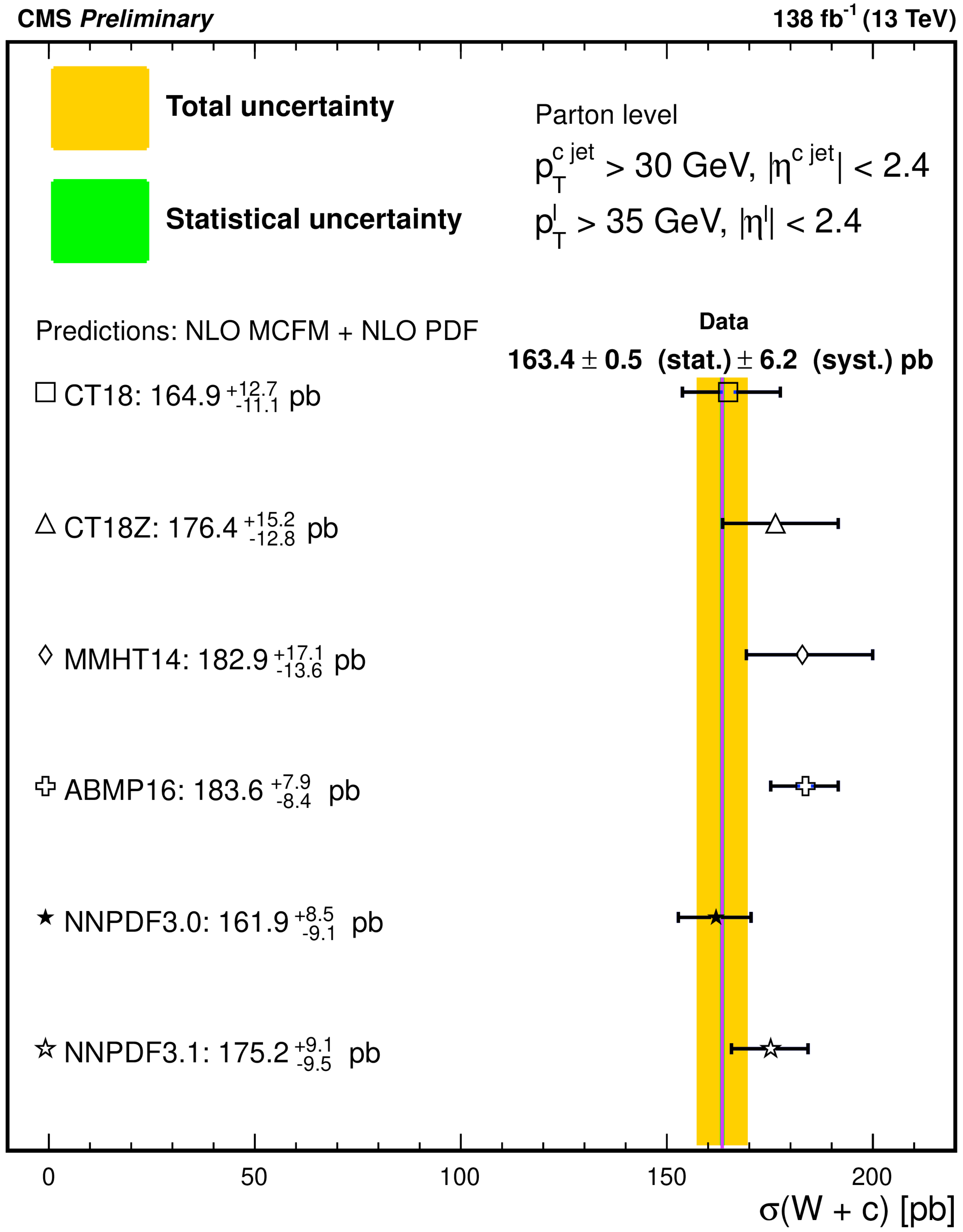


- Aim to directly fit the helicity cross-sections
  - Predictions at NLO QCD obtained with aMCfast
  - NNLO corrections (pending) computed with DYTURBO
  - Good chi2 when using provided covariance matrices
  - Struggling a bit in reconstructing a nuisance parameter representation for the likelihood fit output (needed to combine with Z)

W+charm and strangeness

* CMS measurements of W+charm production at 8 TeV and 13 TeV
  - Charm identified through a combination of soft-muon and secondary vertex
  - Usual opposite-sign - same-sign subtraction
  - Unfolded to particle- and particle-level anti-kT charm jets with R=0.4

* Compared to NLO QCD theory from MCFM
  - Jet definition soft unsafe starting at NNLO QCD, needs to correct the data to a calculable algorithm
  - Involves large extrapolation down to charm $p_T \sim 0$



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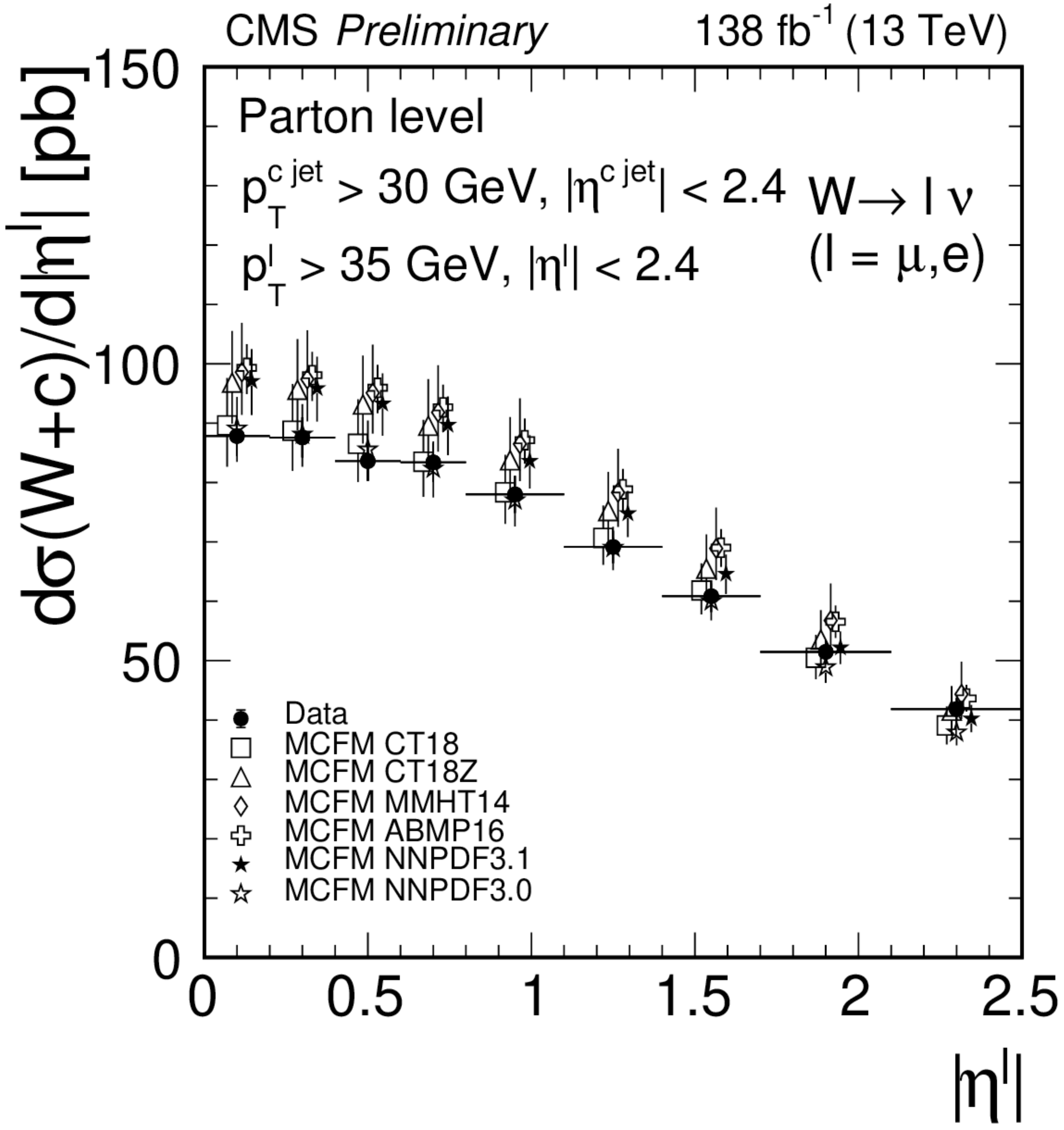
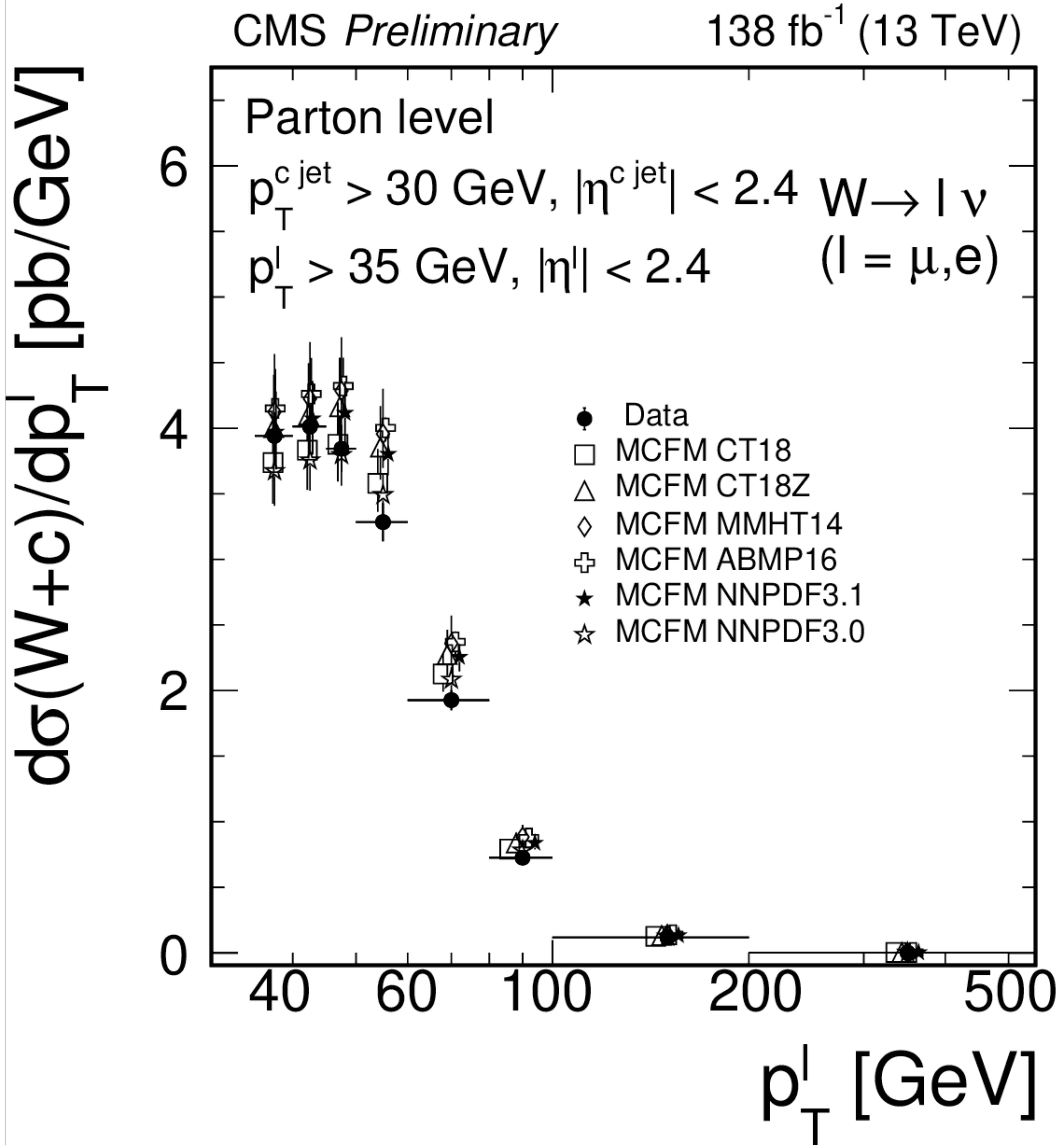
W+charm and strangeness





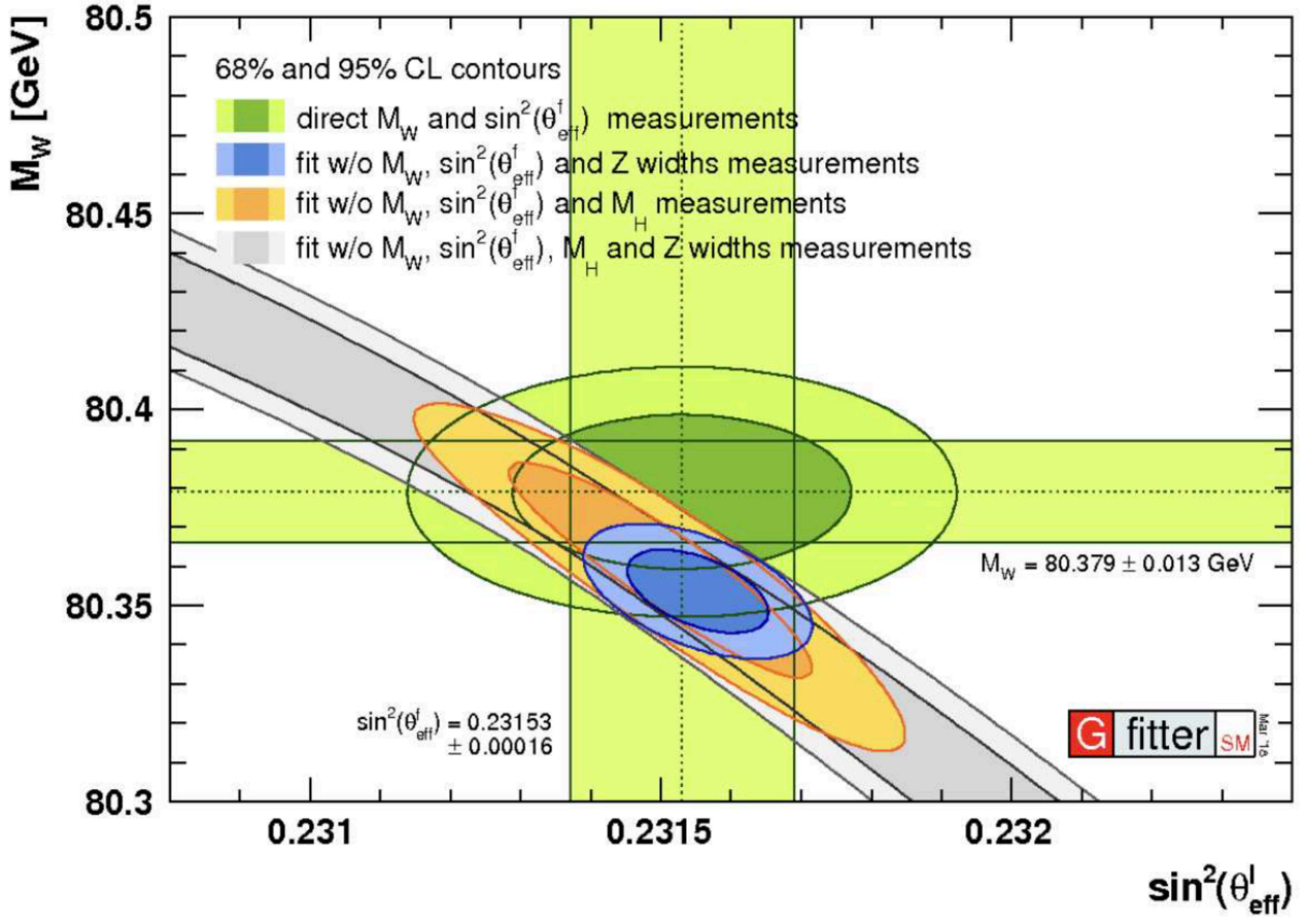
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP-21-005/index.html

W-boson mass averaging project

* Provide endorsed **world average combination** of hadron collider m_W results

  - Establish a **methodology** to combine present and future measurements
  - Enable **physics modelling updates** of past measurements (i.e. PDFs, p_T^W)
  - Properly **correlate m_W and $\sin^2\theta^l_{eff}$** measurements in EW fits

[*Eur. Phys. J.* **C74** (2014) 3046]



Combination procedure

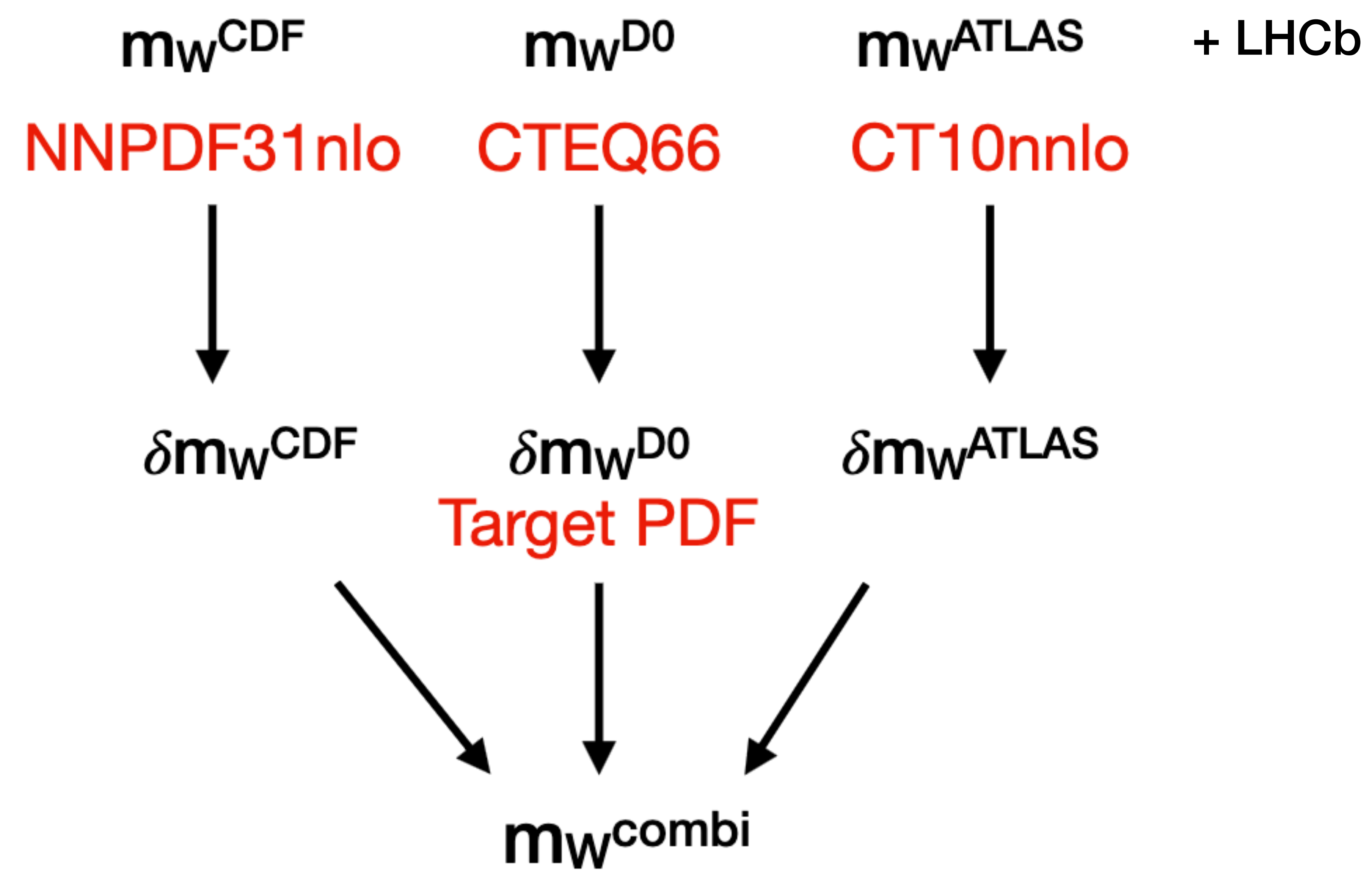
- PDFs main source of correction and uncertainty correlations
  - Other sources very small (EW corrections) or mostly decorrelated (p_T W/Z)

$$m_W^{new} = m_W^{ref} - \delta m_W^{QCD} - \delta m_W^{PDF}$$

published value — Improved predictions — PDF extrapolation

δm_W^{PDF} correction to reference PDF

δm_W^{QCD} correction to QCD modelling beyond quoted uncertainties



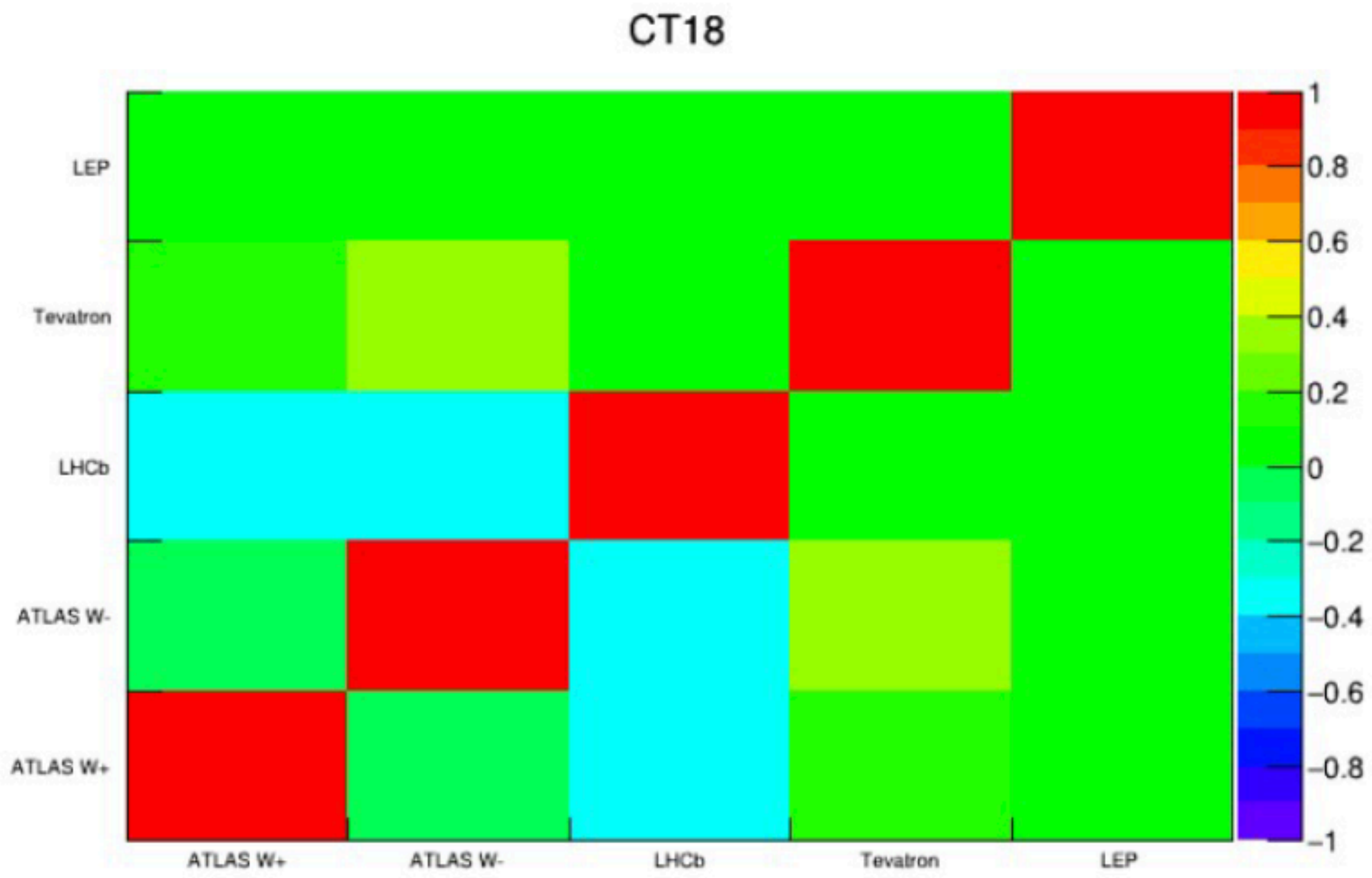
- Correction applied in a two-step procedure:
  1. Correct all measurements to a common PDF/QCD
  2. Combine them properly including correlations

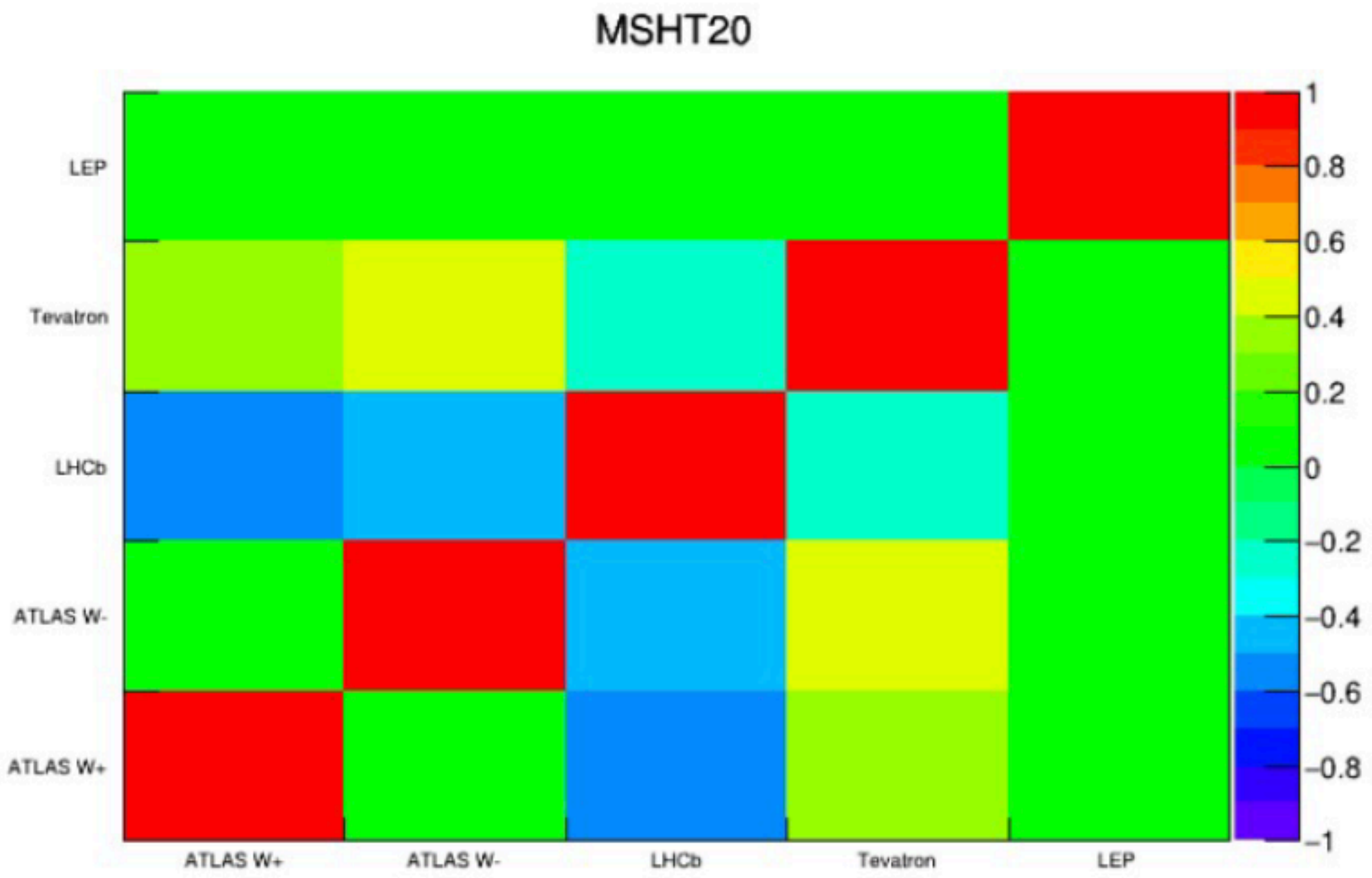
PDF extrapolations

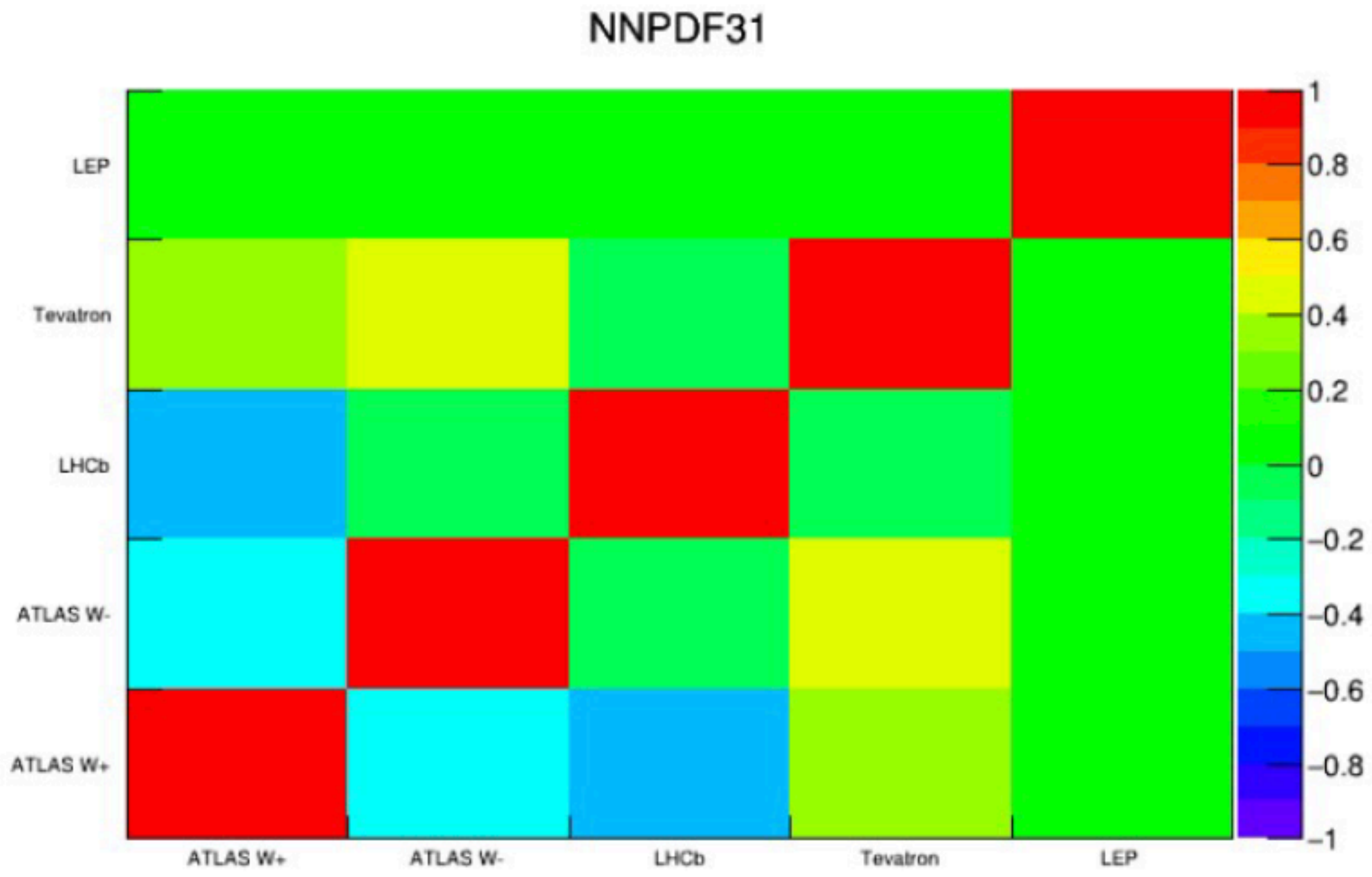
- PDF extrapolations (preliminary) shown for Tevatron p_T^{lep} measurements
- Comparing different codes to evaluate generator dependence

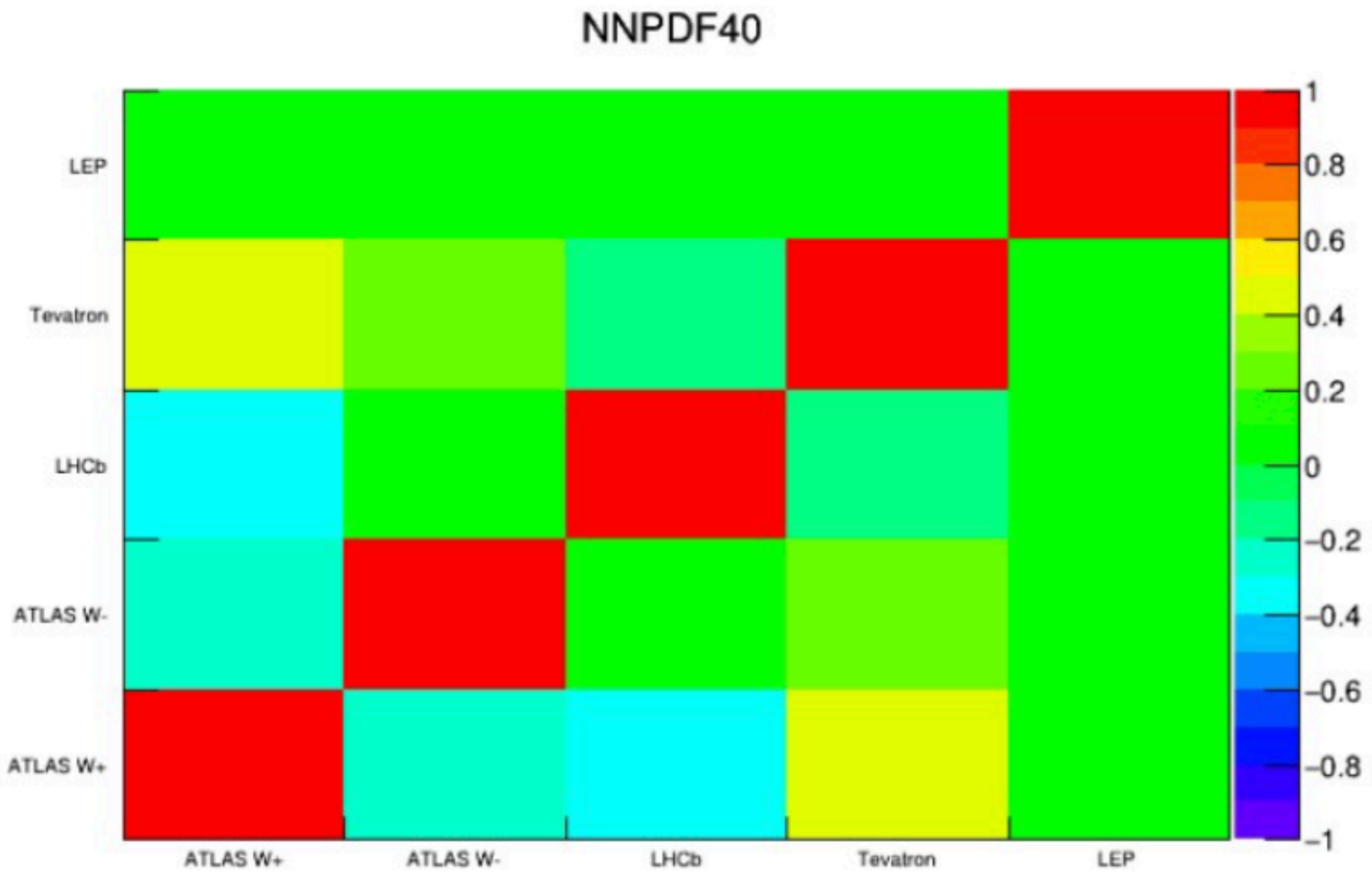
Generator	Powheg	Powheg	MiNNLO	Resbos
Sample type	Reweighted	Direct	Reweighted	Direct
QCD accuracy	NLO+NLL	NLO+NLL	NNLO+NLL	NLO+NLL
PDF set			Shift	
CTEQ6M	0	0	0	0
CTEQ66	-15.4 ± 0.8	-15.8 ± 0.8	-14.0 ± 1.3	-17.8 ± 1.0
CT10	-6.3 ± 0.8	-6.2 ± 0.8	-4.2 ± 1.3	–
CT10nnlo	-16.2 ± 0.8	-16.6 ± 0.8	-16.8 ± 1.3	–
CT14	-4,1 ± 0.8	-3.9 ± 0.8	-6.8 ± 1.3	-7.1 ± 1.0
CT18	-6.2 ± 0.8	-6.6 ± 0.8	-8.5 ± 1.3	-9.4 ± 1.0
CJ15	7.7 ± 0.8	7.9 ± 0.8	10.1 ± 1.3	–
MMHT14	-6.2 ± 0.8	-6.4 ± 0.8	-6.9 ± 1.3	-8.1 ± 1.0
MSHT20	-5.0 ± 0.8	-4.9 ± 0.8	-4.9 ± 1.3	–
ABMP16	5.2 ± 0.8	5.0 ± 0.8	-0.2 ± 1.3	–
NNPDF3.1	-13.8 ± 0.8	-14.3 ± 1.4	-14.1 ± 1.3	-15.8 ± 1.0

And PDF correlations





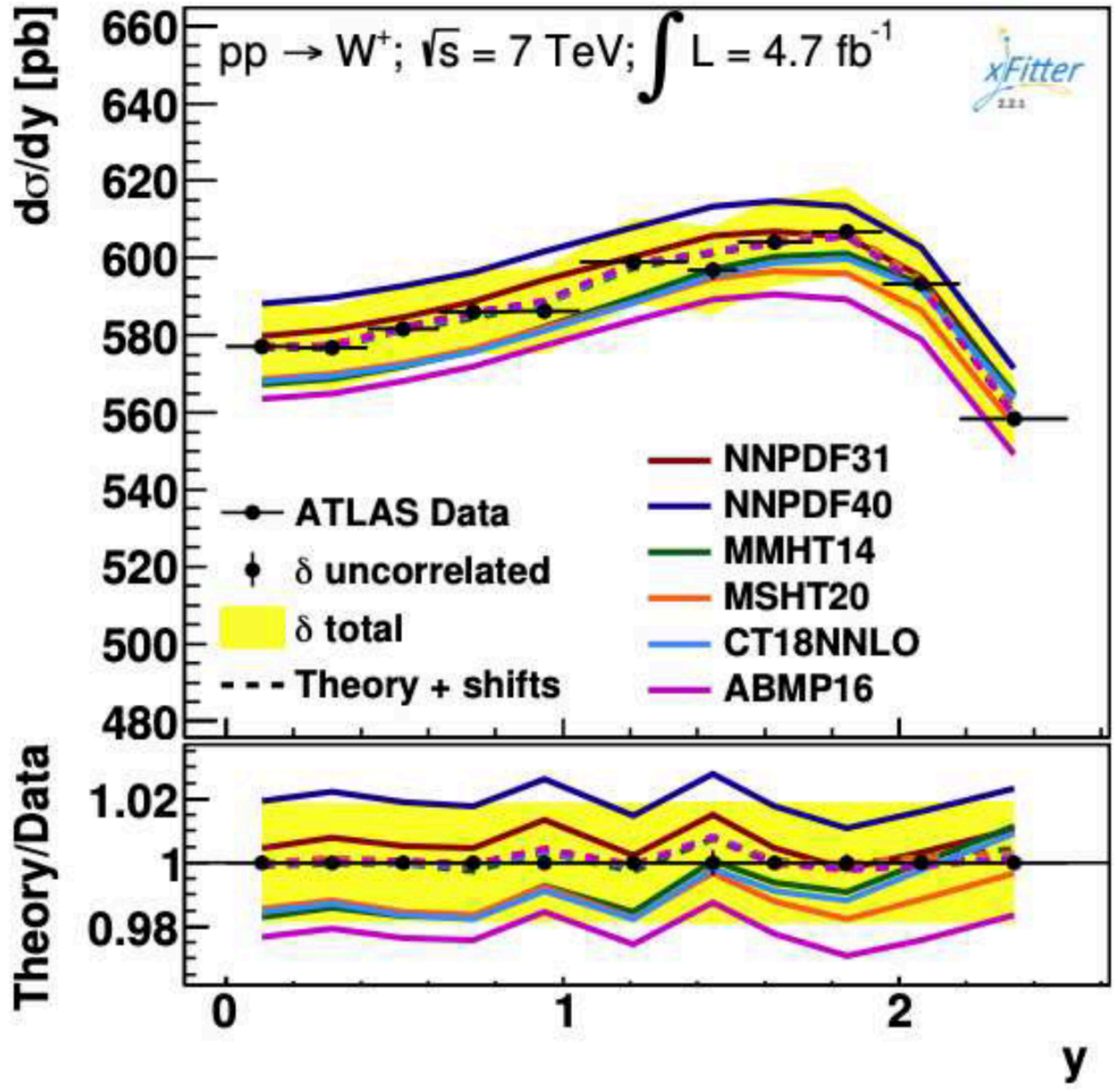




Choice of PDFs

- Performed a benchmarking of PDF sets against Tevatron and LHC cross-section measurements
  - Considering measurements of W and Z cross-sections from Tevatron and LHC
  - Theory predictions at NNLO QCD x NLO EW

PDF set	Chi2/ndf	PDF set	Chi2/ndf
Cteq66	231/126	CT18NNLO	163/126
CT10	179/126	CT18ANNLO	170/126
NNPDF31	200/126	MSHT20	270/126
NNPDF40	195/126	ABMP16	236/126



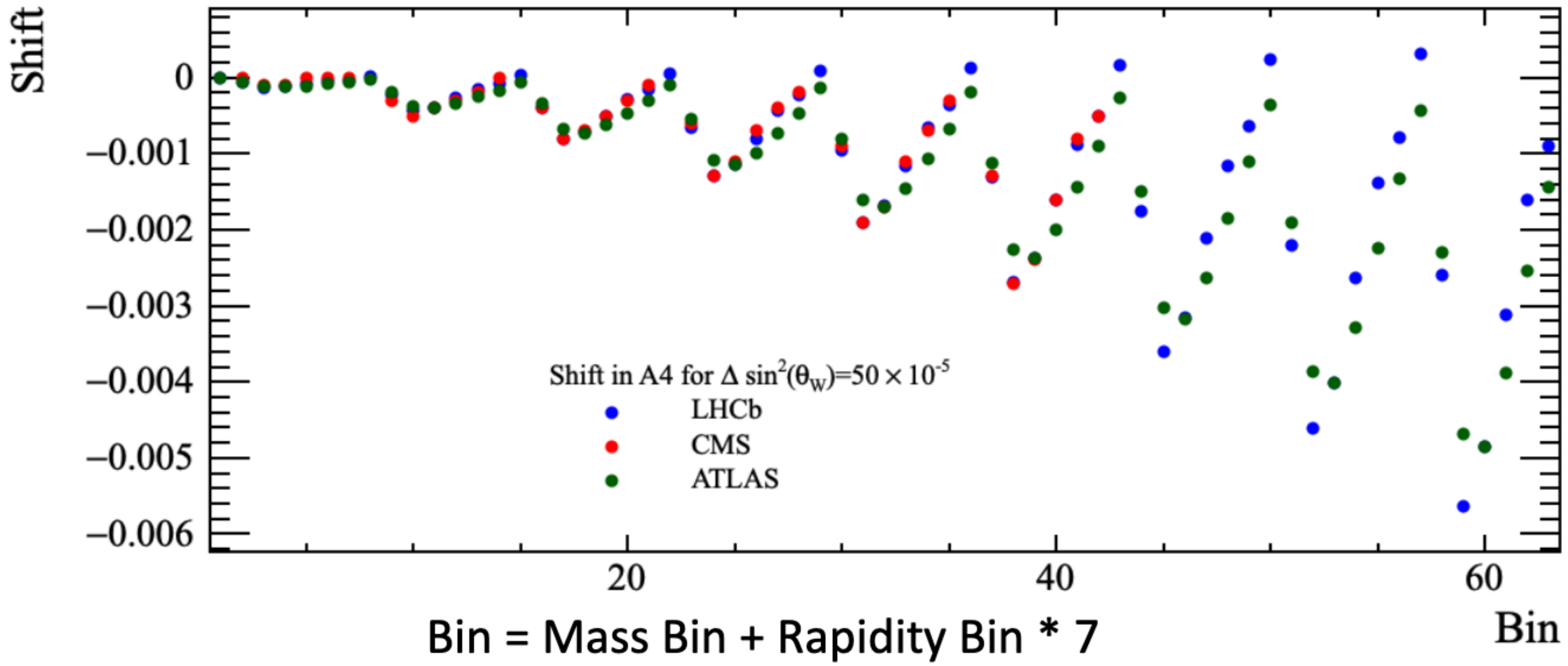
CERN-LPCC-2022-06

- Modern NNLO PDFs provide the best description, no set gives a χ^2/ndf~1
- Decision on the final PDF will consider χ^2 and uncertainty of the combination itself

Relevance of resummation corrections (Alessandro's talk on Thursday) ?

Weak-mixing angle (pseudo-)combination and PDF correlations

- Sensitivity study towards a future ***combination of LHC 13 TeV weak mixing angle measurements***



- Consider A_4 pseudo-data from Powheg at NLO QCD + EW accuracy

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- Estimate of the ***correlations between PDFs fitted by different groups***
- Needed to quantify differences between SM parameters extracted with different PDFs
- Fits to common pseudo-data for the reduced PDF4LHC21 dataset generated within xFitter

Summary

* xFitter the “go-to” choice for QCD/PDF analyses in CMS
* Interest moving to PDF+X fits (X=SMEFT, EW parameters, …)
* Unique xFitter role in the LHC EW precision studies
* But, high threshold for using the code (no way without external input/help) and knowledge shared by a very restricted group of people

Backup

PDFs benchmarking

Dataset	NNPDF31	NNPDF40	MMHT14	MSHT20	CT18NNLO	ABMP16
CDF Z rapidity	24|28 / 28	28|30 / 28	30|31 / 28	32|32 / 28	27|27 / 28	31|31 / 28
CDF W asymmetry	11|57 / 13	14|17 / 13	12|13 / 13	28|27 / 13	11|35 / 13	21|43 / 13
D0 Z rapidity	22|22 / 28	23|23 / 28	23|23 / 28	24|23 / 28	22|22 / 28	22|22 / 28
D0 $We\nu$ lepton asymmetry	22|32 / 13	23|29 / 13	52|51 / 13	42|40 / 13	19|32 / 13	26|24 / 13
D0 $W\mu\nu$ lepton asymmetry	12|14 / 10	12|16 / 10	11|14 / 10	11|13 / 10	12|13 / 10	11|12 / 10
ATLAS peak CC Z rapidity	13|18 / 12	13|17 / 12	58|89 / 12	17|19 / 12	11|77 / 12	18|32 / 12
ATLAS W^- lepton rapidity	12|18 / 11	12|15 / 11	33|33 / 11	16|17 / 11	9.9|28 / 11	14|17 / 11
ATLAS W^+ lepton rapidity	8.9|13 / 11	8.6|11 / 11	15|21 / 11	12|13 / 11	9.4|16 / 11	10|12 / 11
Correlated χ^2	76|110	63|83	212|236	91|102	43|251	86|108
Log penalty χ^2	-0.62|-0.62	-0.58|-0.58	-1.62|-1.62	-2.89|-2.89	-1.68|-1.68	-2.72|-2.72
Total χ^2 / dof	200|312 / 126	195|242 / 126	445|509 / 126	270|283 / 126	163|499 / 126	236|300 / 126
χ^2 p-value	0.00	0.00	0.00	0.00	0.02	0.00

Table 8: Goodness-of-fit for the Tevatron 1.96 TeV and ATLAS 7 TeV Z and W cros-section measurements compared to NNLO QCD + NLO EW theory predictions using different modern global PDF sets. The numbers before (after) the vertical bar "|" denote the χ^2 computed including (excluding) the PDF uncertainties. The CTEQ PDFs uncertainty corresponds to a 68% coverage, and is obtained by rescaling the eigenvectors by a factor 1/1.645.

PDFs benchmarking

Dataset	CT18ANNLO	CT18ZNNLO	CT18XNNLO	CT14nnlo	CT10nnlo	CJ15nlo
CDF Z rapidity	28|29 / 28	28|29 / 28	28|27 / 28	29|29 / 28	29|28 / 28	32|30 / 28
CDF W asymmetry	12|30 / 13	12|28 / 13	11|33 / 13	12|28 / 13	16|34 / 13	21|27 / 13
D0 Z rapidity	22|22 / 28	22|23 / 28	22|22 / 28	22|22 / 28	22|22 / 28	23|22 / 28
D0 $We\nu$ lepton asymmetry	21|33 / 13	21|29 / 13	21|31 / 13	20|32 / 13	24|69 / 13	39|49 / 13
D0 $W\mu\nu$ lepton asymmetry	11|12 / 10	11|12 / 10	11|13 / 10	11|13 / 10	11|18 / 10	17|26 / 10
ATLAS peak CC Z rapidity	10|19 / 12	9.7|21 / 12	12|71 / 12	13|42 / 12	12|27 / 12	60|104 / 12
ATLAS W^- lepton rapidity	10|17 / 11	10|17 / 11	13|27 / 11	11|27 / 11	10|41 / 11	23|27 / 11
ATLAS W^+ lepton rapidity	8.7|10 / 11	8.1|9.5 / 11	8.9|15 / 11	9.3|12 / 11	9.6|43 / 11	14|15 / 11
Correlated χ^2	49|113	43|113	82|230	63|175	58|198	269|314
Log penalty χ^2	-1.69|-1.69	-0.33|-0.33	-1.05|-1.05	-2.04|-2.04	-1.51|-1.51	-5.38|-5.38
Total χ^2 / dof	170|284 / 126	165|280 / 126	209|468 / 126	187|376 / 126	190|478 / 126	492|610 / 126
χ^2 p-value	0.01	0.01	0.00	0.00	0.00	0.00

Table 9: Goodness-of-fit for the Tevatron 1.96 TeV and ATLAS 7 TeV Z and W cros-section measurements compared to NNLO QCD + NLO EW theory predictions using different global PDF sets by the CTEQ Collaboration. The numbers before (after) the vertical bar "|" denote the χ^2 computed including (excluding) the PDF uncertainties. The CTEQ PDFs uncertainty corresponds to a 68% coverage, and is obtained by rescaling the eigenvectors by a factor 1/1.645.