Constraints on proton structure from CMS measurements at 8 TeV

Engin Eren (DESY)
on behalf of CMS Collaboration

PDF4LHC Meeting, 14.03.2016
CERN

Outline

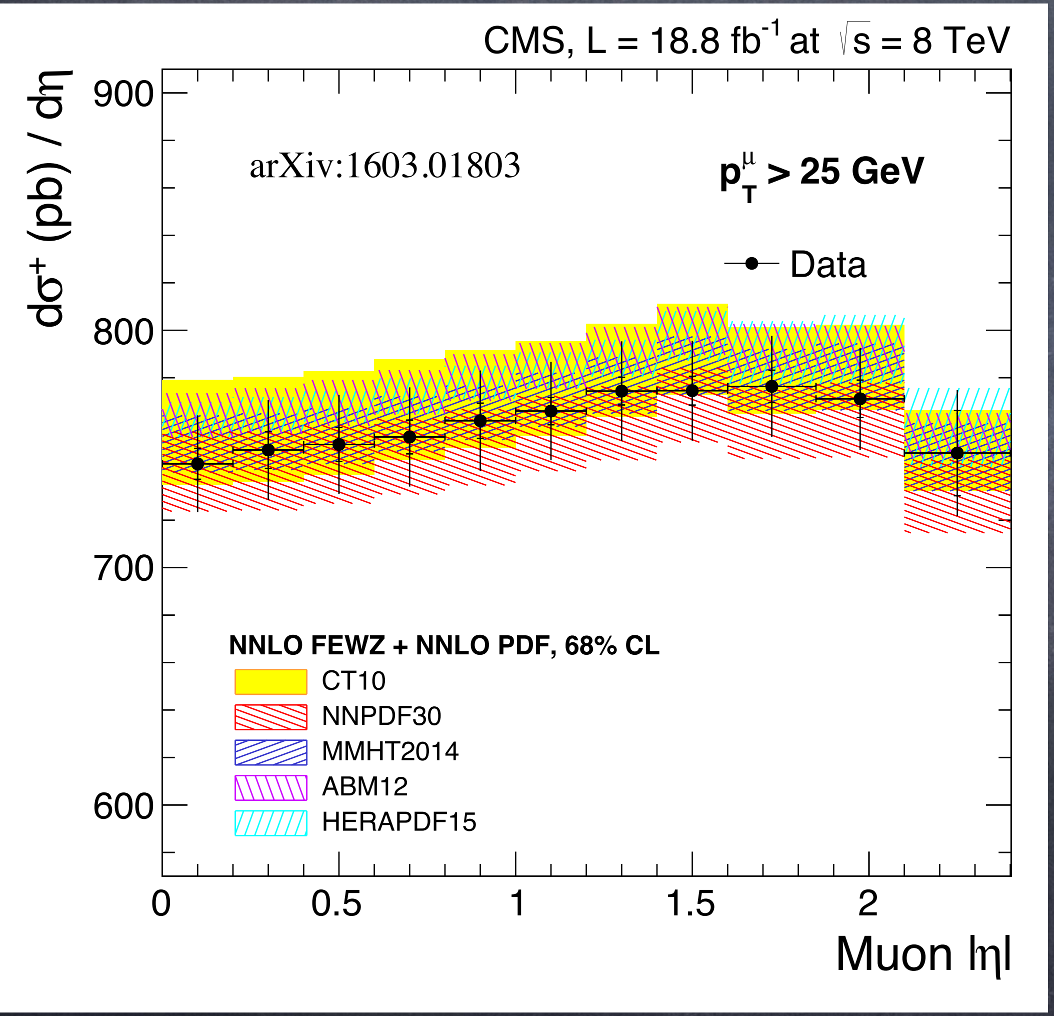
- Measurement of $W^{\pm}$ differential cross-sections and muon charge asymmetry @8TeV
- QCD analysis with muon charge asymmetry
  - ✓ PDF parametrisation and sensitivity
  - ✓ Constraints on u and d valence PDFs
- Measurement of inclusive jet cross-section @2.76TeV
- Measurement of inclusive jet cross-section @8TeV
- Ratio of 2.76 TeV and 8 TeV cross-sections
- QCD analysis with inclusive jet cross-section @8TeV
  - ✓ Determination of strong coupling α_S
  - ✓ PDF parametrisation and sensitivity
  - ✓ Constraints on gluon PDF

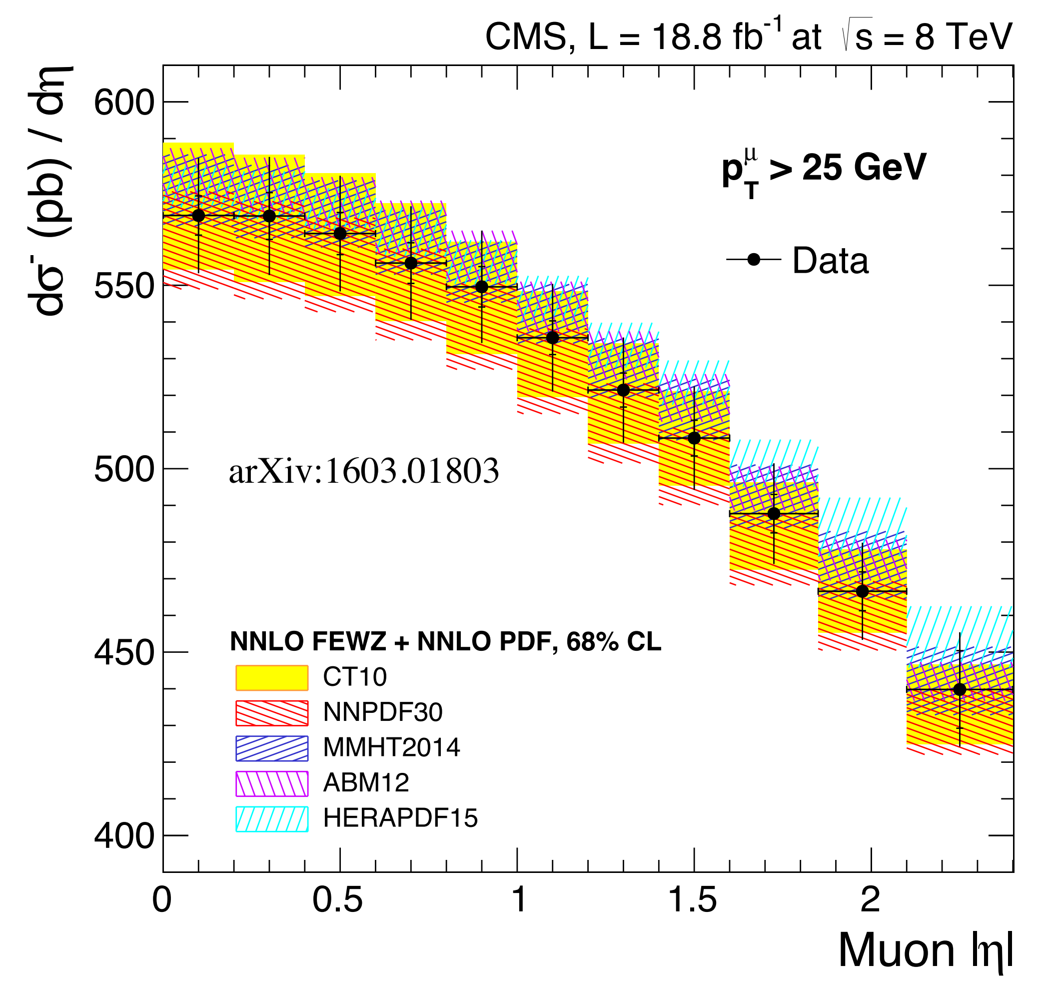
$W^{\pm}$ production at CMS

- $W^{\pm}$ production cross-section measurement @8TeV:

$$\sigma_\eta^\pm = \frac{d\sigma}{d\eta}(pp \to W^\pm + X \to \mu^\pm \nu + X)$$

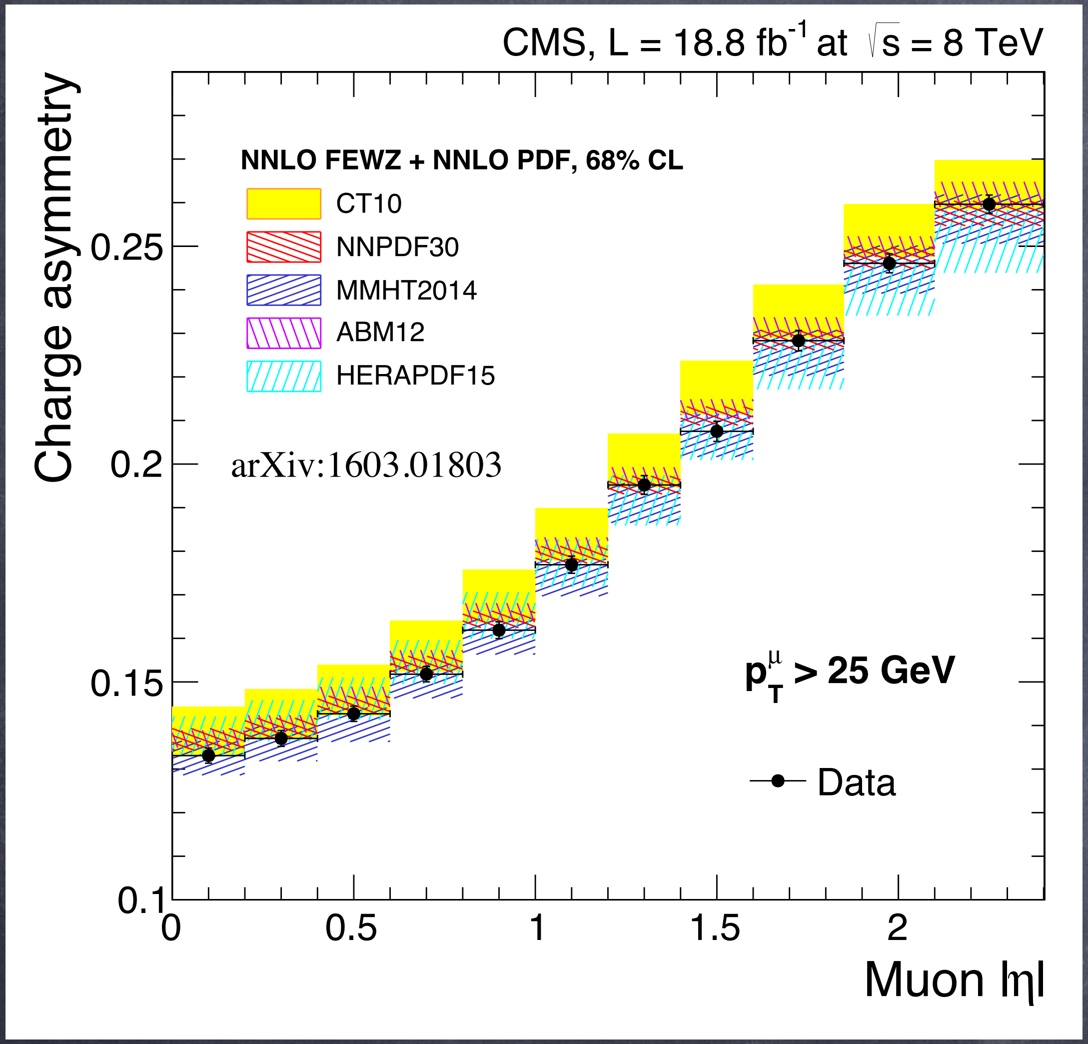
$$\text{muon}: \begin{array}{ll} 0.0 < |\eta| < 2.4 & \text{(11 bins)} \\ p_T > 25\ \text{GeV} & \text{(leading muon pT)} \end{array}$$

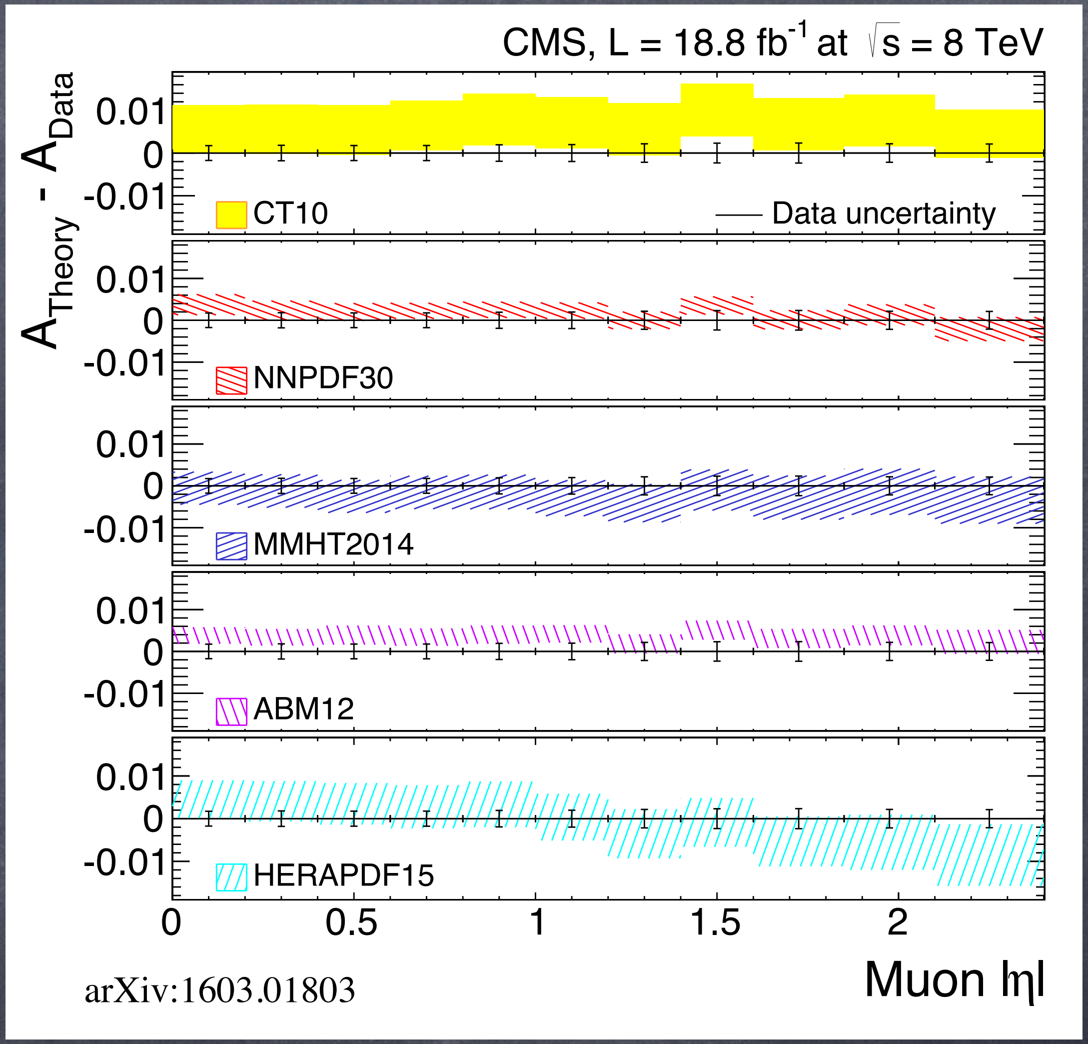




W± production asymmetry at CMS

- Muon charge asymmetry measurement :





$$A(\eta) = \frac{\sigma_\eta^+ - \sigma_\eta^-}{\sigma_\eta^+ + \sigma_\eta^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

Muon asymmetry in W production probes quark distributions at $10^{-3} < x < 10^{-1}$

QCD analyses of W charge asymmetry data

QCD analysis at NNLO, parton evolution in Q^2 via DGLAP implemented in QCDNUM.

xFitter version 1.1.1 is used.

Data in the QCD analysis:

- HERA I+II combined inclusive DIS data, Charged and Neutral Current [Eur. Phys. J. C 75 (2015) 2604]
- Investigated CMS data :
  - W charge asymmetry measurement with muons @ 8 TeV [arXiv:1603.01803]

PDF Uncertainties : Quadratic sum of experimental, model and parametrisation errors.

Experimental uncertainties: originate from uncertainties of the data

- Hessian error estimate: criterion $\Delta\chi^2$=1 is applied

Model uncertainties: originate from variations of model input parameters:

- Fraction of strange quarks in the sea f_s=0.31±0.08
- Values of charm and beauty quark masses.
- Q^2 cut on inclusive DIS data.

Parametrisation uncertainties:

- Originate from variations on assumed parametrization

PDF parametrization and χ^2

Basic parametrization at the starting scale Q^2_0=1.9 GeV^2 :

W Charge Asymmetry (13p)

$$xg(x) = A_g x^{B_g} \cdot (1-x)^{C_g}(1+D_g x)$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1+E_{u_v}x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}}$$
$$x\overline{U}(x) = A_{\overline{U}} x^{B_{\overline{U}}} \cdot (1-x)^{C_{\overline{U}}}(1+E_{\overline{U}}x^2)$$
$$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}} \cdot (1-x)^{C_{\overline{D}}}$$

Data sets	Partial χ^2/n_{dp}
HERA1+2 neutral current, e^+p, $E_p = 920$ GeV	440/377
HERA1+2 neutral current, e^+p, $E_p = 820$ GeV	69/70
HERA1+2 neutral current, e^+p, $E_p = 575$ GeV	214/254
HERA1+2 neutral current, e^+p, $E_p = 460$ GeV	210/204
HERA1+2 neutral current, e^-p, $E_p = 920$ GeV	218/159
HERA1+2 charged current, e^+p, $E_p = 920$ GeV	46/39
HERA1+2 charged current, e^-p, $E_p = 920$ GeV	50/42
CMS $W^\pm$ muon charge asymmetry $\mathcal{A}(\eta_\mu)$, $\sqrt{s} = 8$ TeV	3/11
Correlated χ^2	141
Global χ^2/n_{dof}	1391/1143

arXiv:1603.01803

Normalization parameters A are determined by QCD sum rules

B: define low-x behaviour, C: high-x shape

Parametrization uncertainties:

originate from variations on assumed parametrization, in which additional parameters are added one by-one in the functional form of the parametrization;
additional variation of 1. 5<Q^2_0<2.5 GeV^2

Largest difference of resulting PDFs to the central result (envelope) is assigned as uncertainty

Asymmetry in W± production at CMS in PDF studies

QCD analysis at NNLO

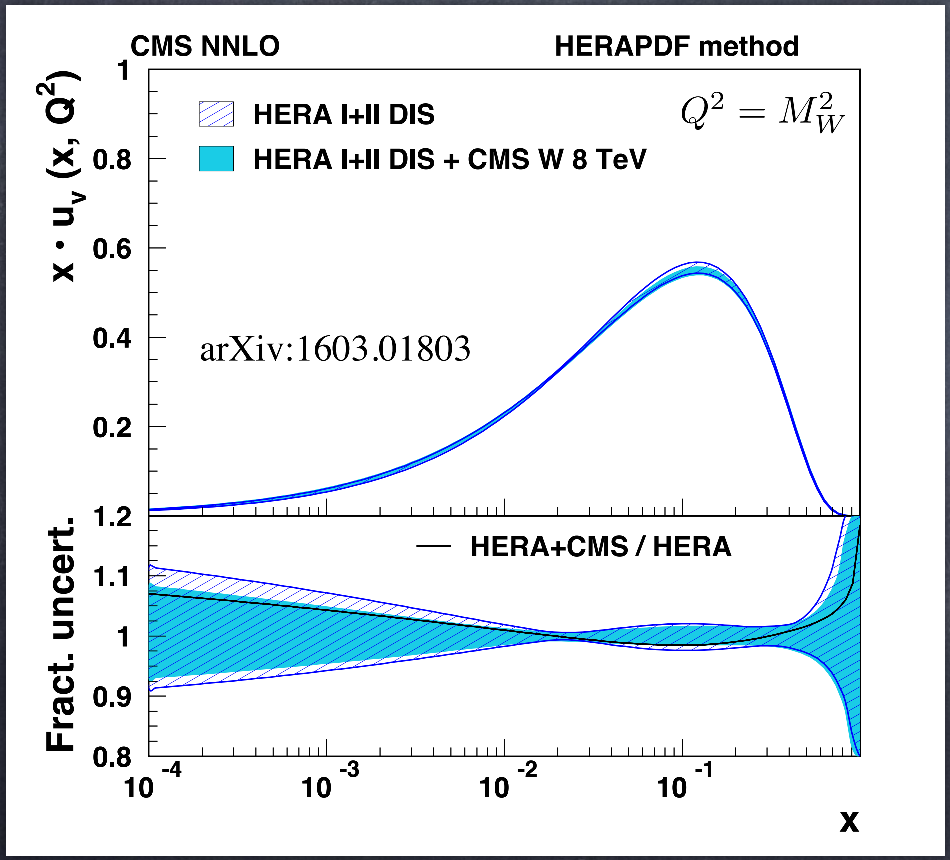
Data: Combined HERA I+II DIS data [Eur. Phys. J. C 75 (2015) 2604]

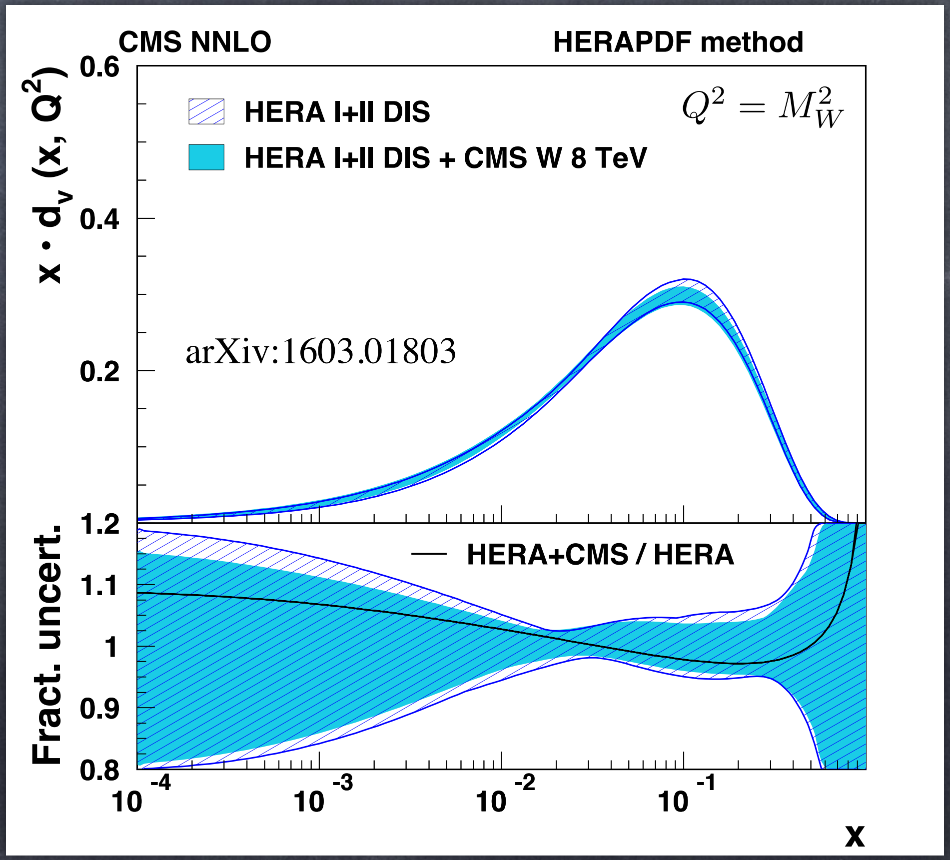
+ CMS muon charge asymmetry measurement at 8-TeV [arXiv:1603.01803]

Theory for A_W: NLO prediction with MCFM, interfaced via APPLGRID

K-factors, which are calculated by FEWZ, are applied

QCD scales $\mu_r = \mu_f = m_W$, strong coupling $\alpha_S(m_Z)$=0.118;

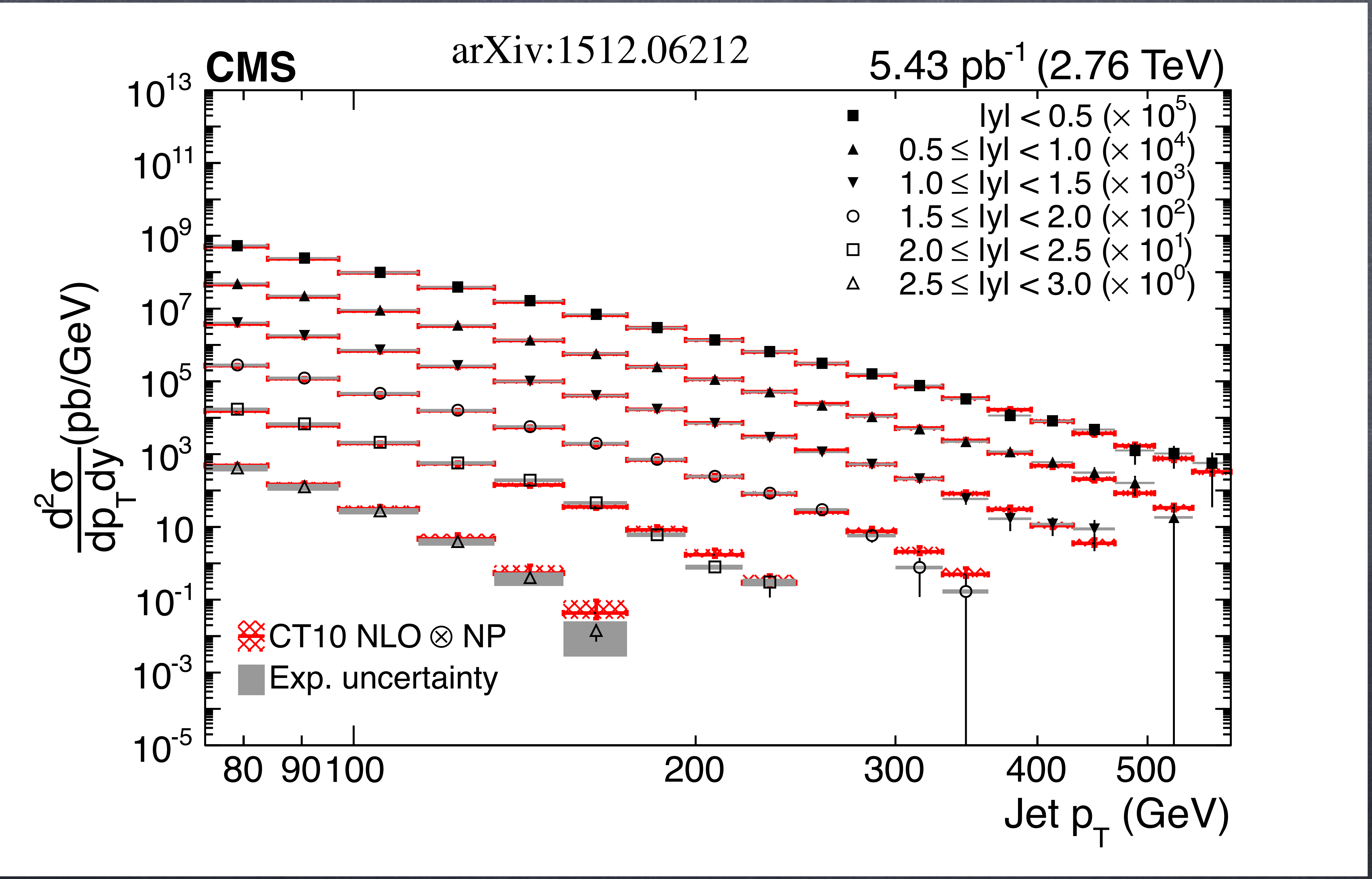




Improvement in the uncertainty of the valence-quark distributions

Inclusive Jet Cross Section at 2.76TeV

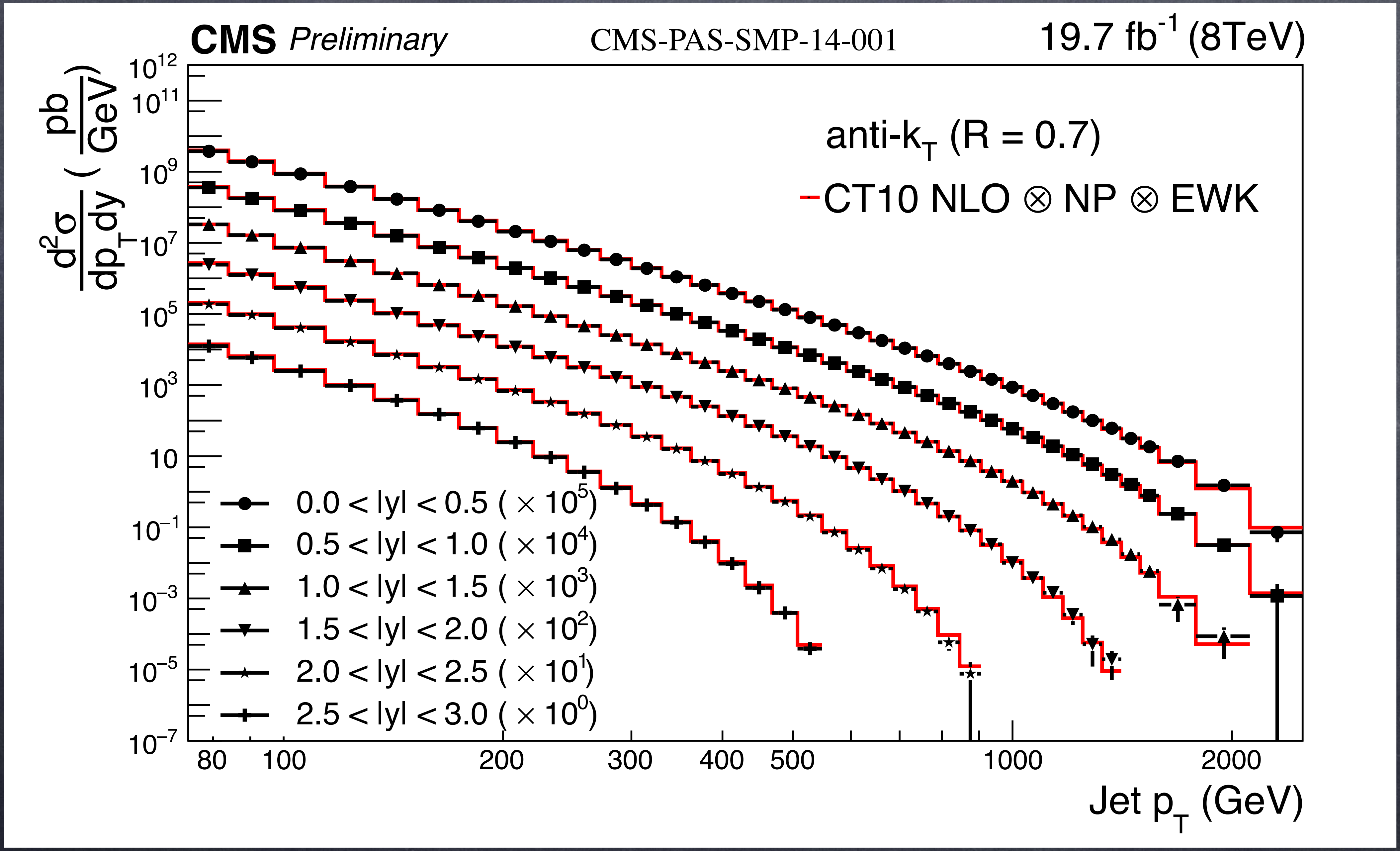
Measurement at $\sqrt{s}$=2.76 TeV (L = 5.43 pb^{-1})
Anti-k_T, R=0.7; double-differential cross sections as functions of p_T and y.



Transverse momenta range from 74 GeV to 592 GeV. Good description by **NLO QCD**

Inclusive Jet Cross Section at 8TeV

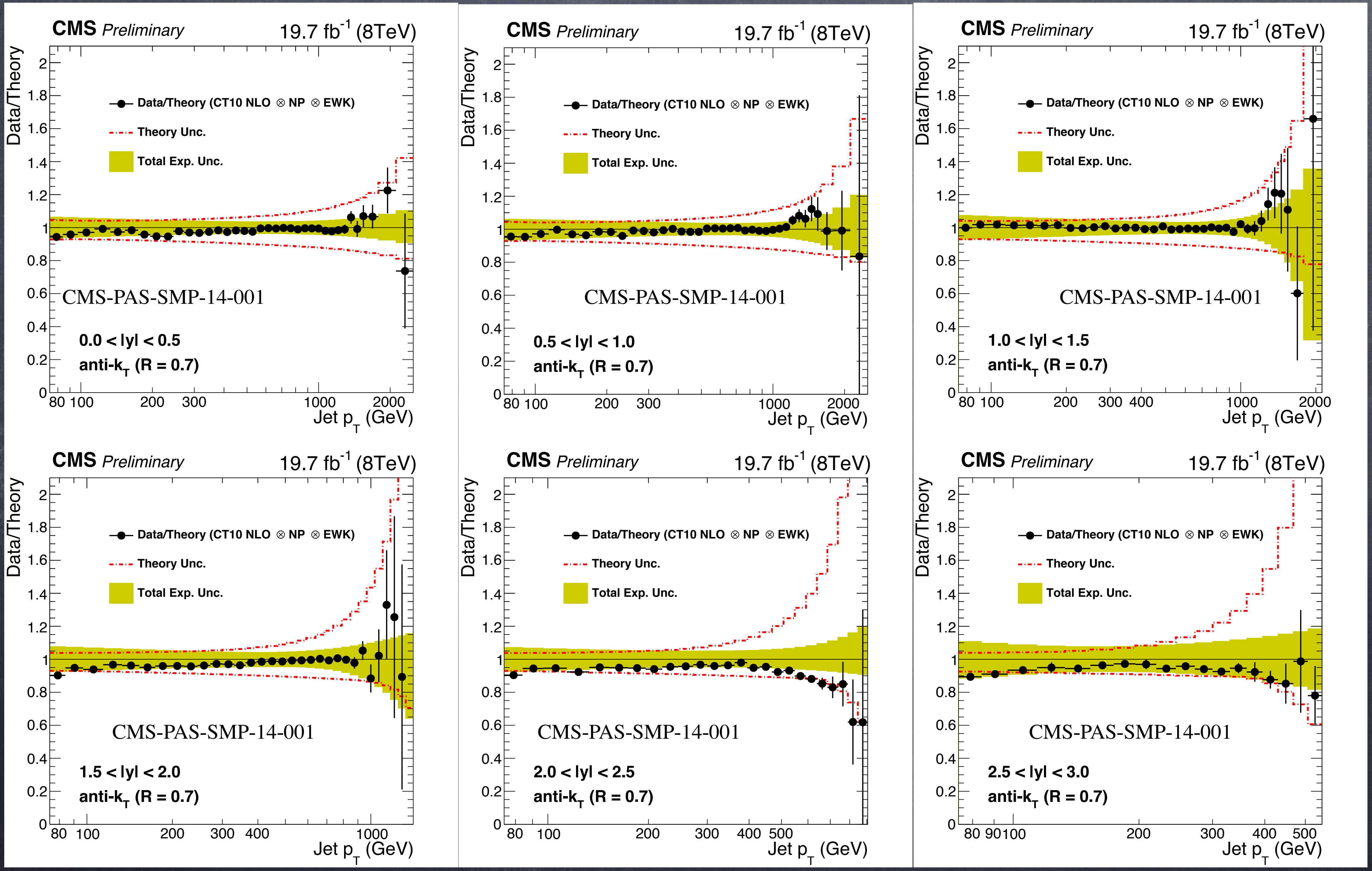
Measurement at $\sqrt{s}$=8 TeV (L = 19.7 fb^{-1})
Anti-k_T, R=0.7; double-differential cross sections as functions of p_T and y.



Transverse momenta range from 74 GeV to 2.5 TeV. Good description by **NLO QCD**

Inclusive Jet Cross Section at 8TeV

Data/Theory comparisons for 6 rapidity bins :



Inclusive Jet Cross Section at 8TeV

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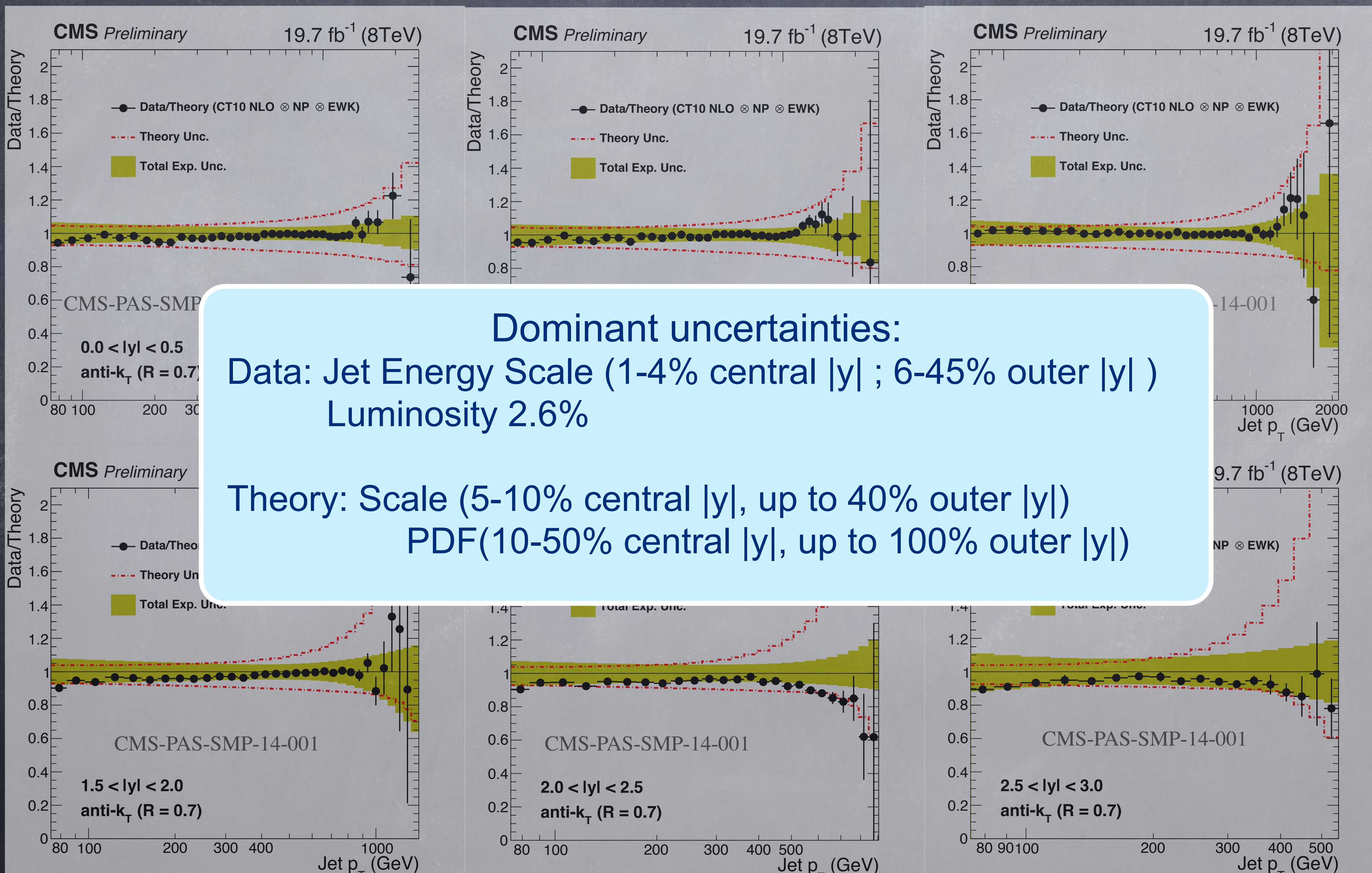
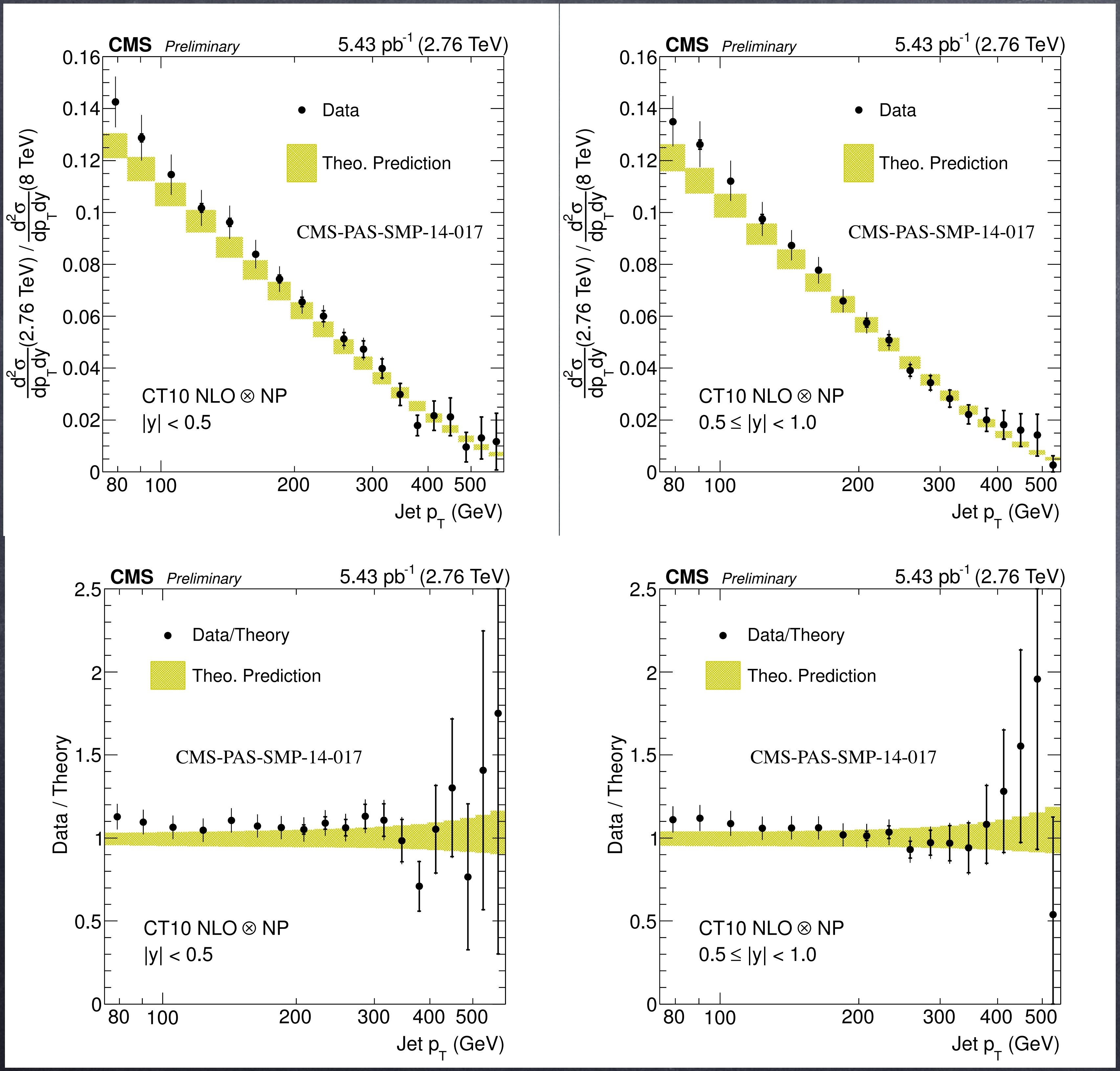


Dominant uncertainties:

Data: Jet Energy Scale (1-4% central |y| ; 6-45% outer |y|)
Luminosity 2.6%

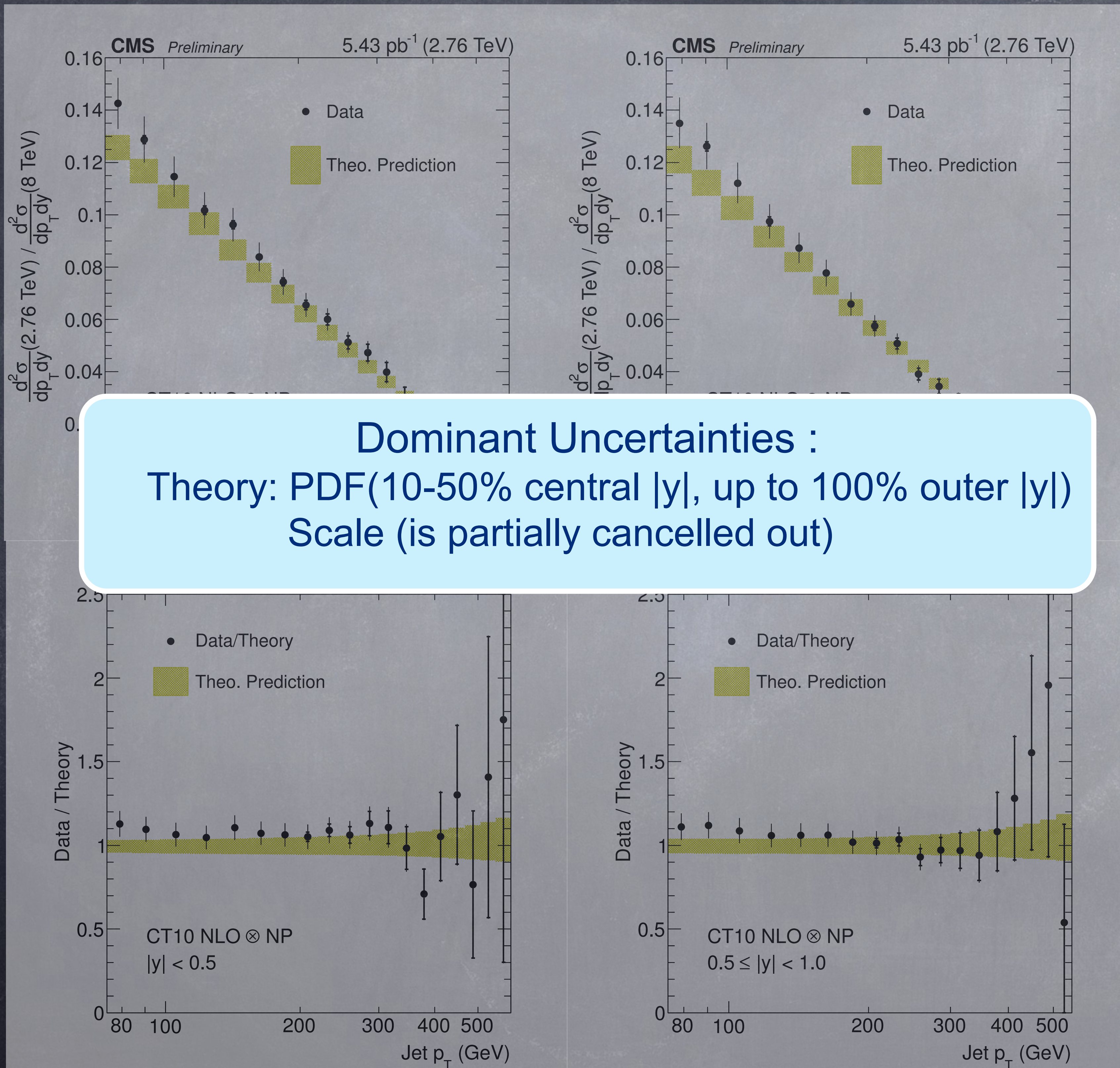
Theory: Scale (5-10% central |y|, up to 40% outer |y|)
PDF(10-50% central |y|, up to 100% outer |y|)

Inclusive Jet Cross Section Ratio 2.76 / 8TeV



- Careful study of the uncertainty between 8 and 2.76 TeV is performed.
- Partial cancelation of systematic uncertainties!
- This measurement can be used to constrain Pdfs.

Inclusive Jet Cross Section Ratio 2.76 / 8TeV



Dominant Uncertainties :

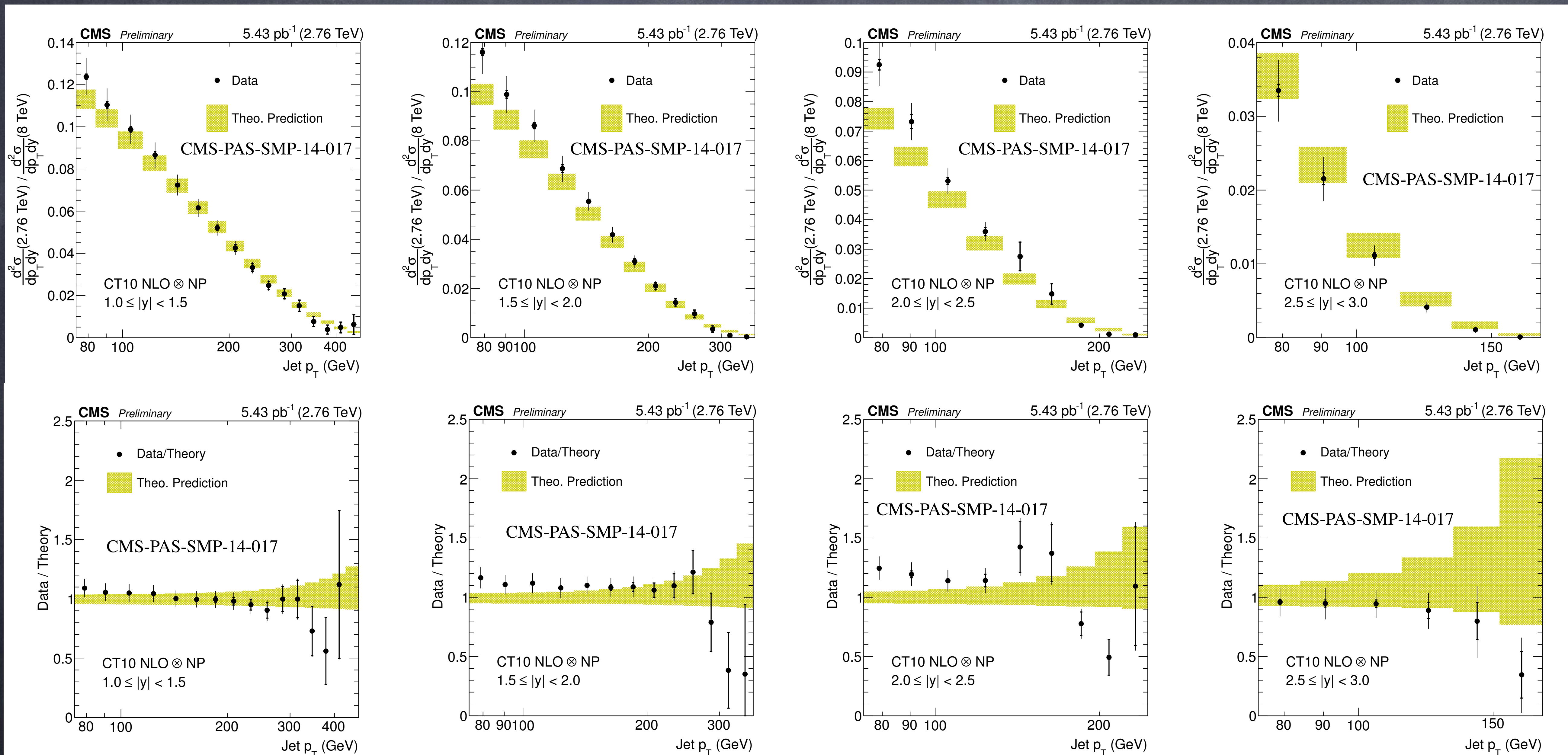
Theory: PDF(10-50% central |y|, up to 100% outer |y|)

Scale (is partially cancelled out)

- Careful study of the uncertainty between 8 and 2.76 TeV is performed.
- Partial cancelation of systematic uncertainties!
- This measurement can constrain Pdfs.

Inclusive Jet Cross Section Ratio 2.76 / 8TeV

Other rapidity bins :



Inclusive Jet Cross Section Ratio 2.76 / 8TeV

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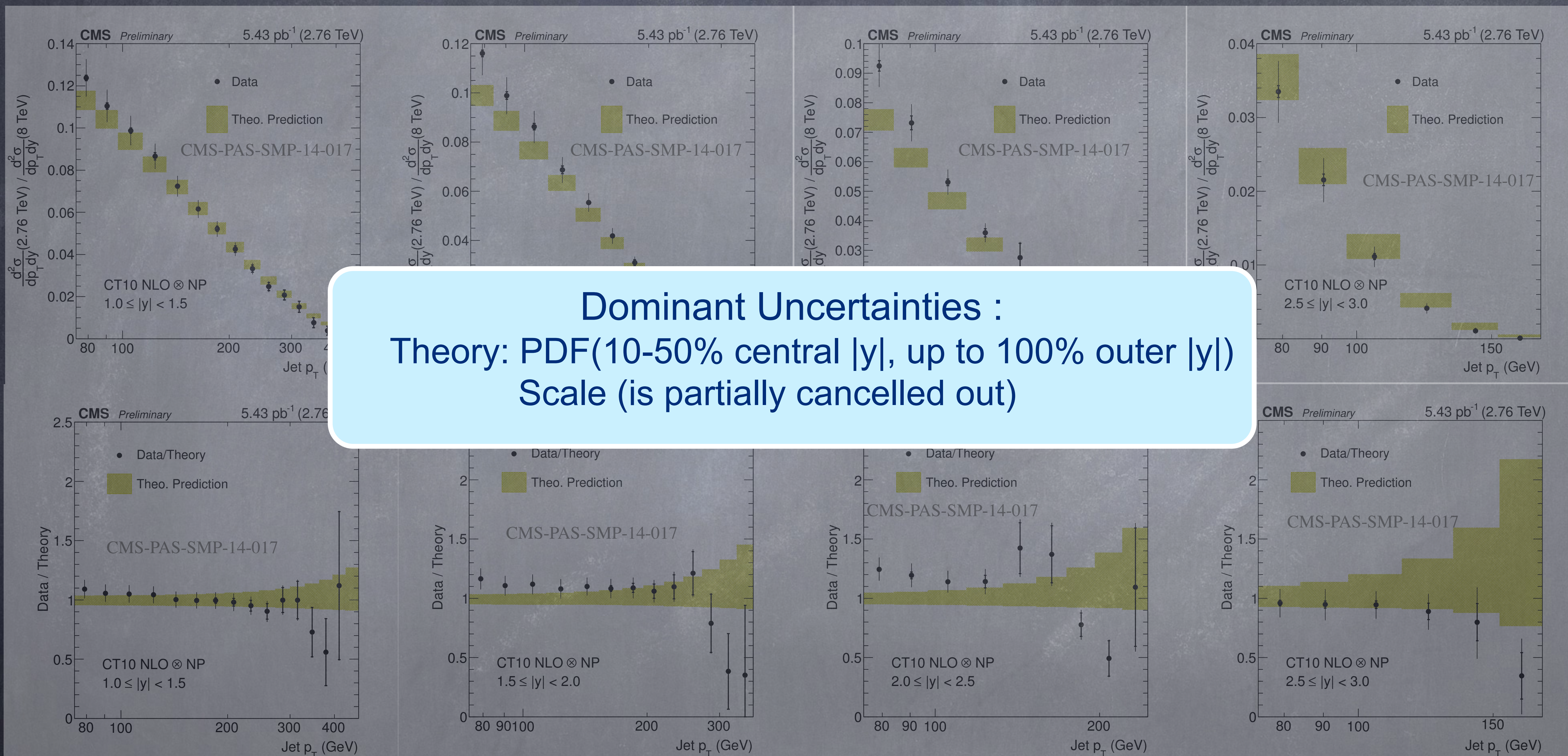


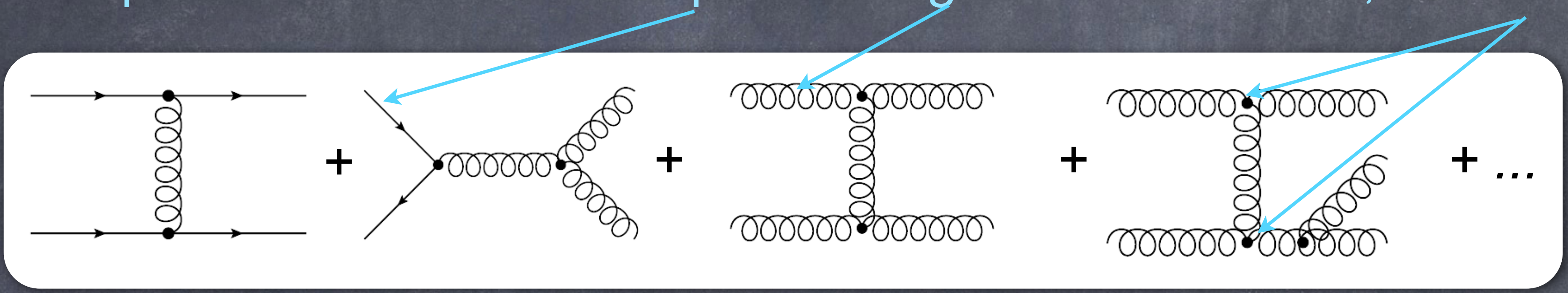
Dominant Uncertainties :

Theory: PDF(10-50% central |y|, up to 100% outer |y|)

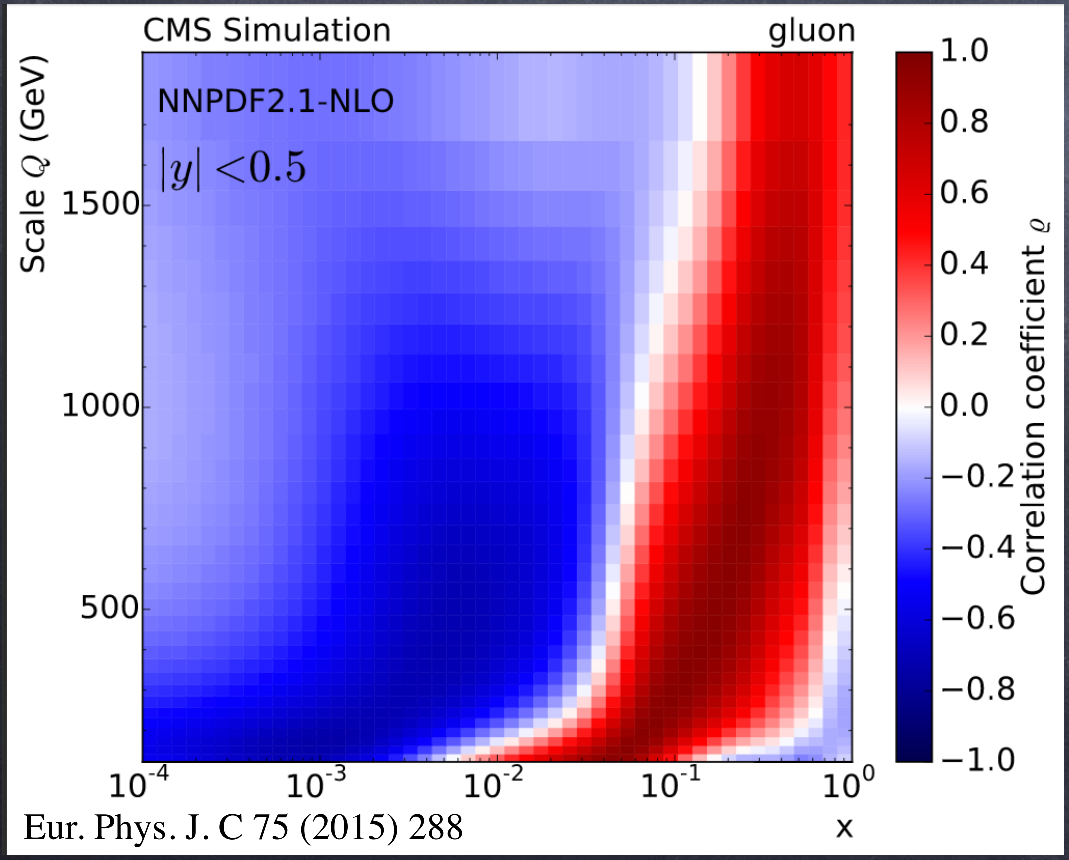
Scale (is partially cancelled out)

Probing QCD with Jet Cross Sections

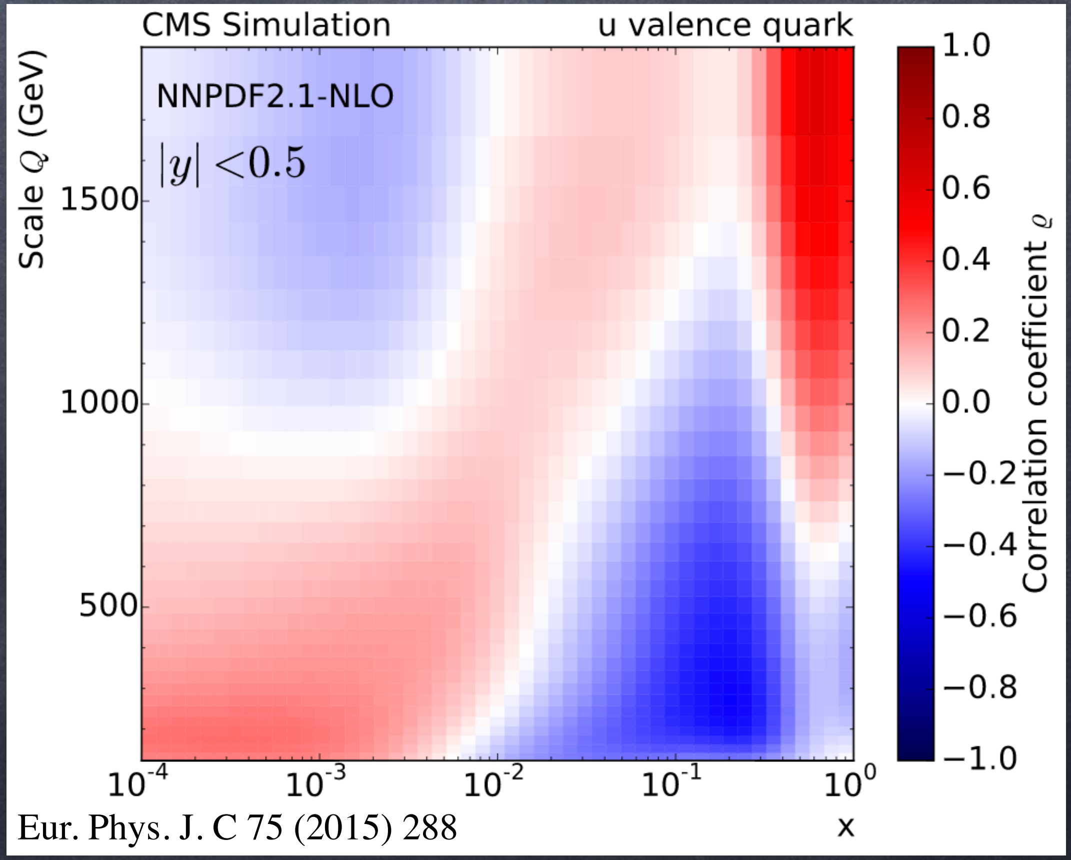
- Jet production sensitive to quark and gluon distributions, and to α_S



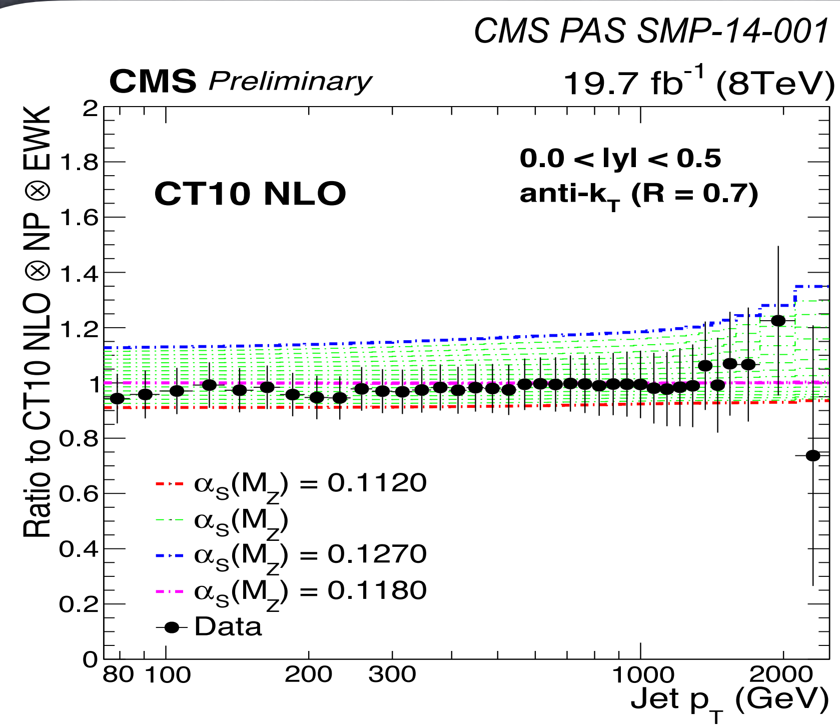
Strong correlation between inclusive jet cross section and gluon at high-middle x



Strong correlation between inclusive jet cross section and quark at high x



Determination of strong coupling α_s : inclusive jets @ 8TeV



CMS jet cross section measurement
$\sqrt{s}$=8TeV (19.7 fb^{-1}) CMS-PAS-SMP-14-001

compared to NLO QCD ⊗ PDFs

in each bin of p_T and y
different sets of PDFs used
each set has its α_s - dependence

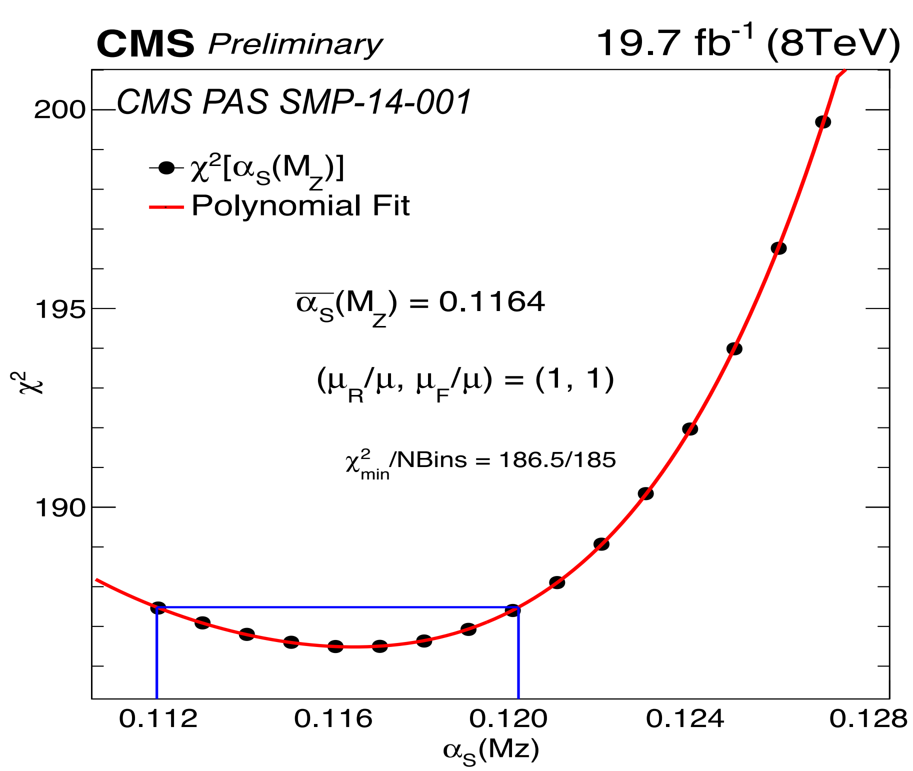
In each y bin, for each PDF, α_s is determined by minimizing χ^2 between data and NLO

Similar results obtained with different PDFs

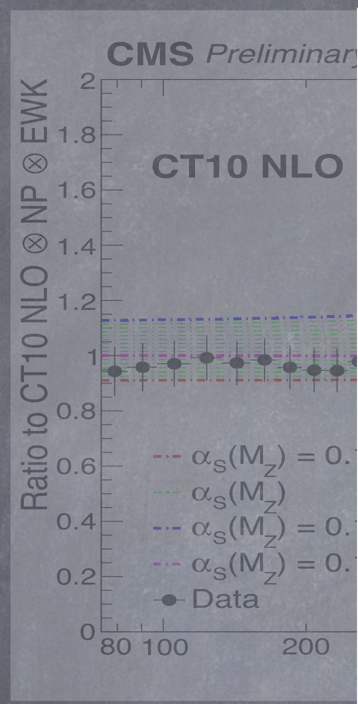
Using CT10NLO :

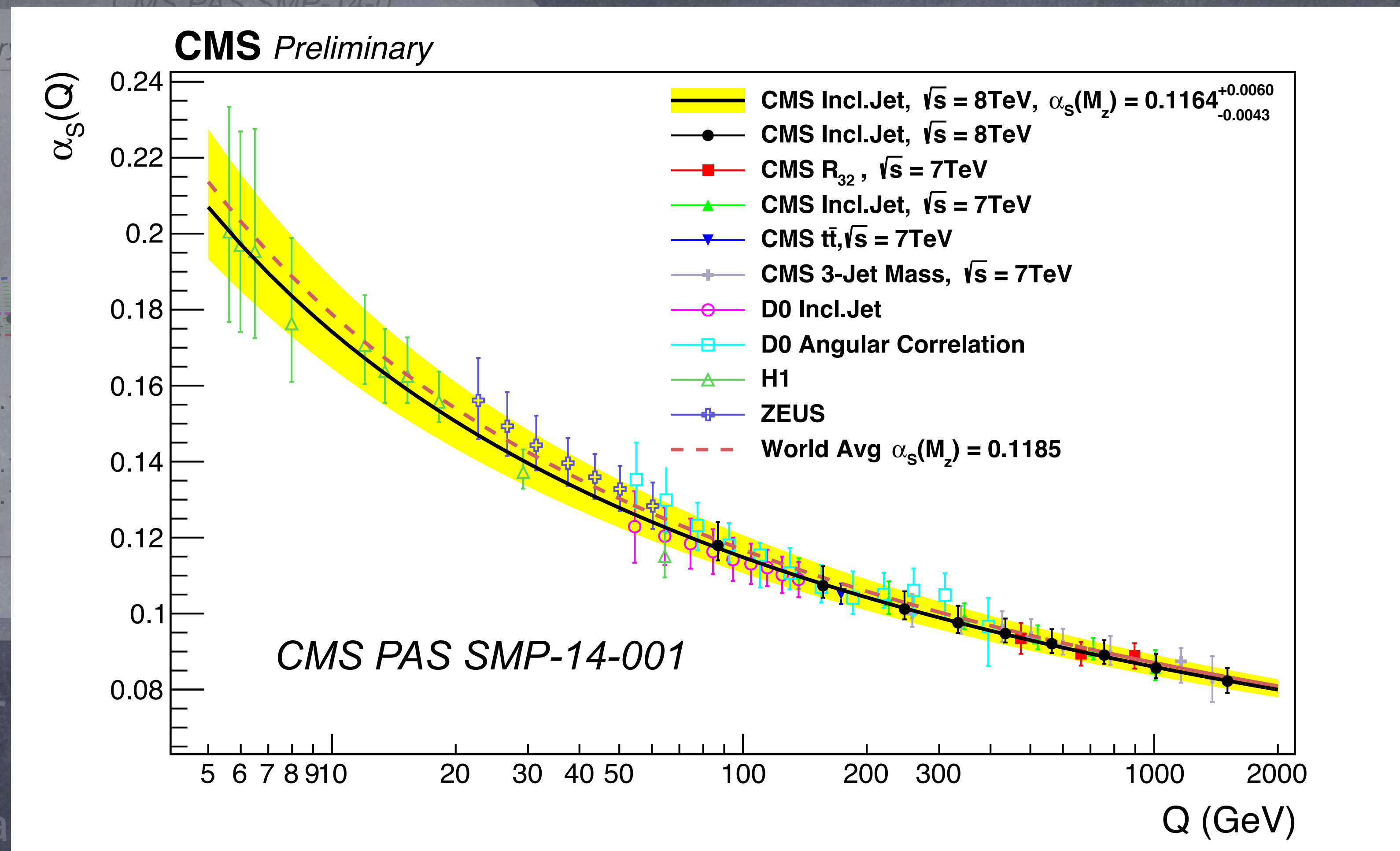
$$\alpha_s(M_Z) = 0.1164\,^{+0.0025}_{-0.0029}(\mathrm{PDF})\,^{+0.0053}_{-0.0028}(\mathrm{Scale}) \pm 0.0001\,(\mathrm{NP})\,^{+0.0014}_{-0.0015}(\mathrm{Exp})$$

Analysis performed in 6 p_T bins
⇛ running of $\alpha_s = \alpha_s(Q^2)$



Determination of strong coupling α_s : inclusive jets





...asurement

In each y bin, for...

Similar results obta...

Using CT10NLO :

$$\alpha_s(M_Z) = 0.1164\,^{+0.0025}_{-0.0029}(\mathrm{PDF})^{+0.0053}_{-0.0028}(\mathrm{Scale})$$
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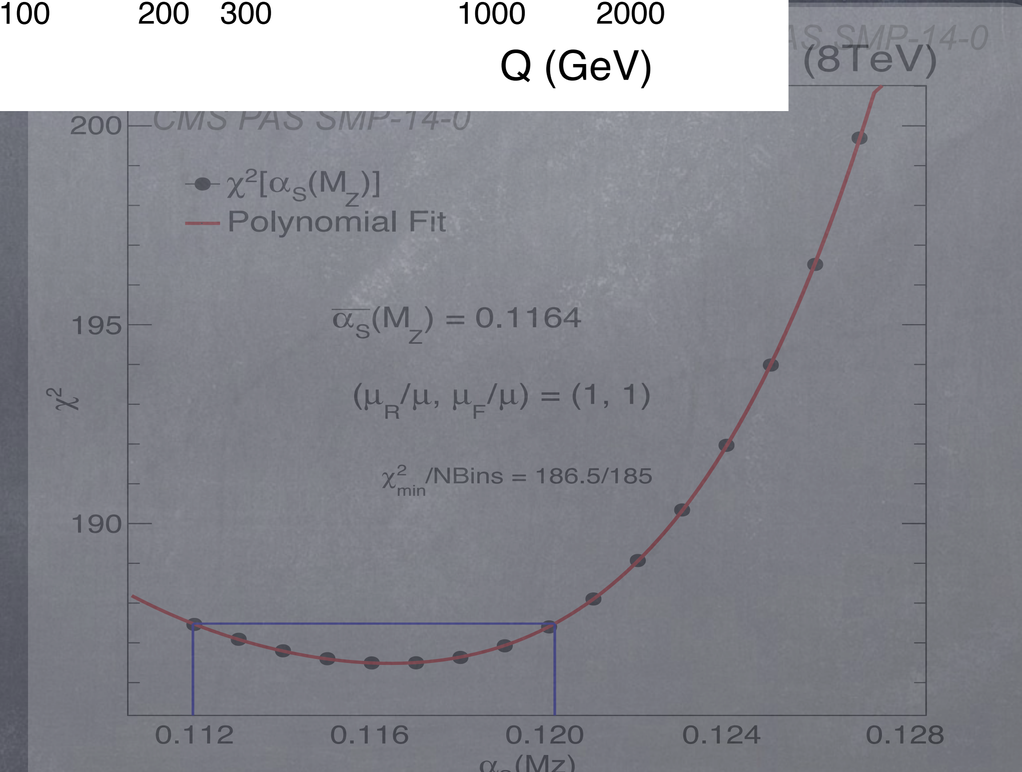

QCD analyses of Inclusive Jets at 8 TeV.

QCD analysis at NLO, parton evolution in Q^2 via DGLAP implemented in QCDNUM.

xFitter version 1.1.1 is used.

Data in the QCD analysis:

- HERA I+II combined inclusive DIS data, Charged and Neutral Current [Eur. Phys. J. C 75 (2015) 2604]
- Investigated CMS data :
  - Inclusive Jets @ 8 TeV [CMS-PAS-SMP-14-001]

PDF Uncertainties : Quadratic sum of experimental, model and parametrisation errors.

Experimental uncertainties: originate from uncertainties of the data

- Hessian error estimate: criterion $\Delta\chi^2=1$ is applied
- MC Method (as a cross check)

Model uncertainties: originate from variations of model input parameters:

- Fraction of strange quarks in the sea $f_s=0.31\pm0.08$
- Values of charm and beauty quark masses.
- Q^2 cut on inclusive DIS data.

Parametrisation uncertainties:

- Originate from variations on assumed parametrization

QCD Analysis of Inclusive Jet Measurements at 8 TeV

Basic parametrization at the starting scale Q^2_0=1.9 GeV^2 :

Inclusive Jets @8TeV (18p)

$$xg(x) = A_g x^{B_g} \cdot (1-x)^{C_g}(1+E_g x^2) - A'_g x^{B'_g}(1-x)^{C'_g}$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1+D_{u_v} x)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}} \cdot (1+D_{d_v} x)$$
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Table 7: Partial χ^2/n_{dp} per number of data points n_{dp} for the data sets used in the QCD analysis. The global χ^2/n_{dof} per degrees of freedom of 1471/1216 is obtained, with correlated χ^2 of 94.

Data sets		Partial χ^2/n_{dp}
HERA1+2 Neutral Current	e^+p $E_p = 920$ GeV	440/377
HERA1+2 Neutral Current	e^+p $E_p = 820$ GeV	416/379
HERA1+2 Neutral Current	e^+p $E_p = 575$ GeV	214/254
HERA1+2 Neutral Current	e^+p $E_p = 460$ GeV	210/204
HERA1+2 Neutral Current	e^-p	218/159
HERA1+2 Charged Current	e^+p	46/39
HERA1+2 Charged Current	e^-p	50/42
CMS inclusive jets 8 TeV	$0 < y < 0.5$	53/36
	$0.5 < y < 1.0$	34/36
	$1.0 < y < 1.5$	35/35
	$1.5 < y < 2.0$	52/29
	$2.0 < y < 2.5$	49/24
	$2.5 < y < 3.0$	4.9/18

CMS-PAS-SMP-14-001

Normalization parameters A are determined by QCD sum rules

B: define low-x behaviour, C: high-x shape

Impact of the CMS jet measurements on PDFs

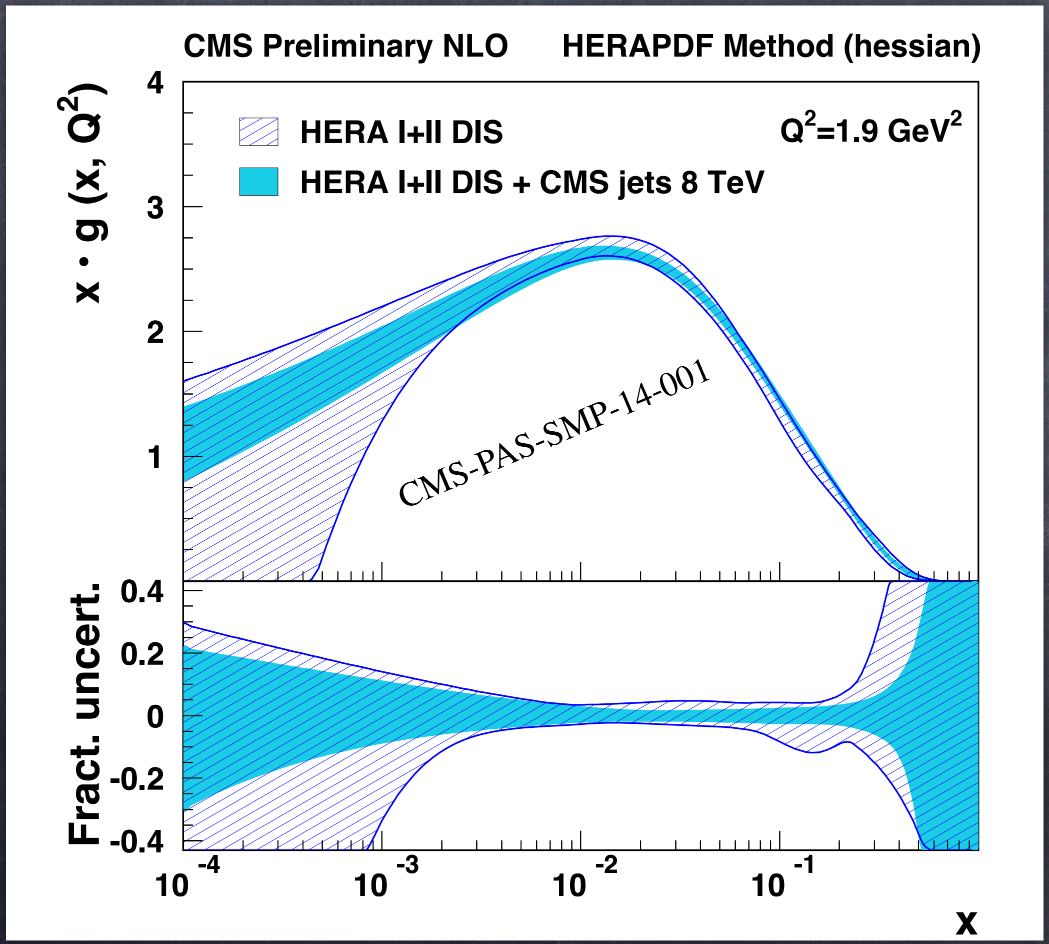
QCD analysis at NLO

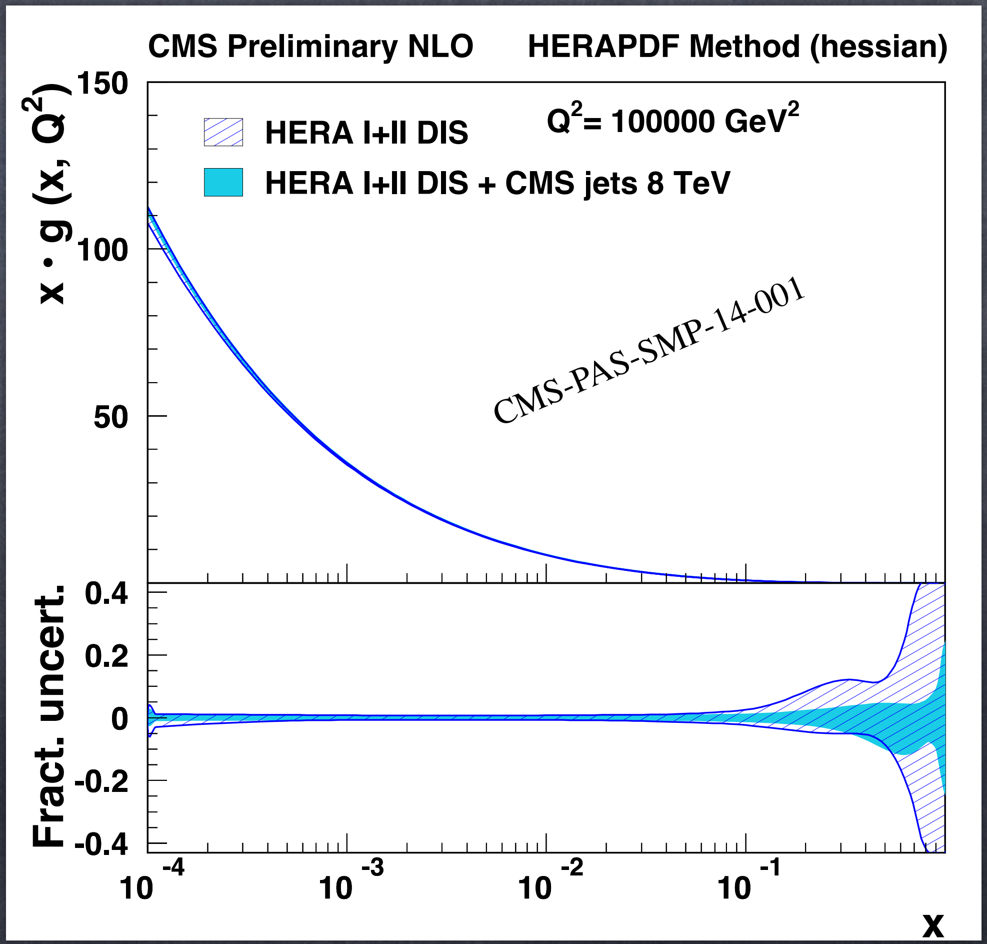
Data: combined HERA I+II DIS [Eur. Phys. J. C 75 (2015) 2604]

+ CMS inclusive jet production at 8 TeV, L = 19.71 fb^{-1}

Theory for jet production in *pp*: NLOJET++ version 4.1.3, interfaced via fastNLO

QCD scales $\mu_r = \mu_f = p_{T\,jet}$, strong coupling $\alpha_S(m_Z)$=0.1180;

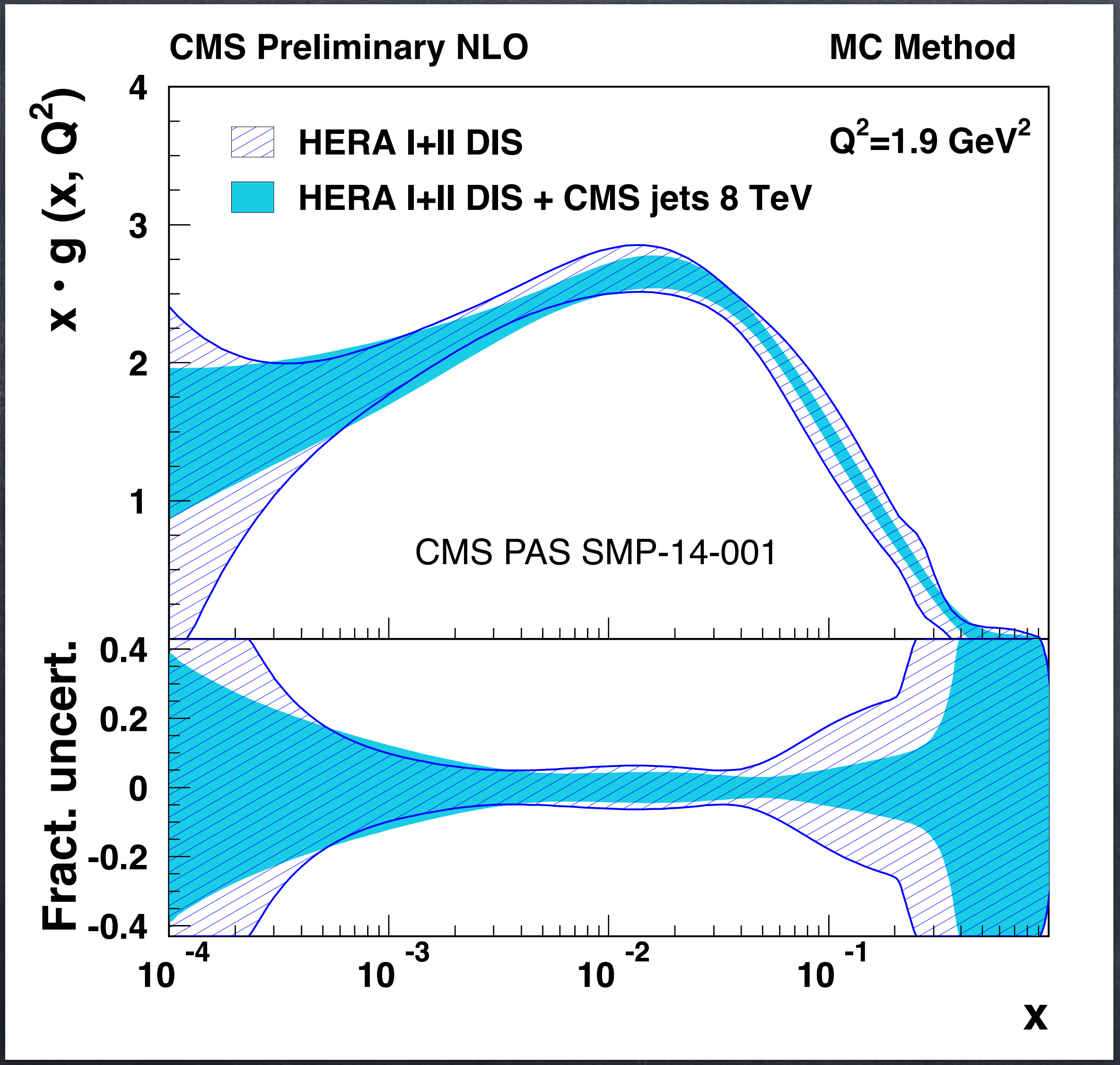




Improvement in the uncertainty of the gluon distributions at high-x

Estimation of PDF Uncertainty with MC Method

- 200 of replicas allowing the central values of cross-sections to fluctuate within their systematic and statistical uncertainties.
- For each replica, **NLO QCD** fit is performed. Errors on the PDFs are estimated from the RMS of the spread of the curves.



Similar reduction of uncertainties observed as in hessian estimate

Summary

- W Charge Asymmetry (Muon) Data :
  - ★ Precision of the valence quark distributions improves.
- CMS Inclusive Jet Data :
  - ★ Precision of the gluon distributions improves.
- Prospects :
  - ★ Both data can be used in global QCD analysis by PDF collaborations.

Backup Slides

Framework for CMS QCD analyses in this talk

QCD analysis at NLO and NNLO, parton evolution in Q^2 via DGLAP implemented in QCDNUM

Data in the QCD analysis:

- HERA I+II combined inclusive DIS data, Charged and Neutral Current [arXiv:1506.06042]
- Different CMS data sets (W charge asymmetry and Inclusive Jets @ 8TeV)

Experimental uncertainties: originate from uncertainties of the data, criterion $\Delta\chi^2$=1 is applied

Model input:

- Theory calculations at NLO and NNLO appropriate for each data set
- Starting scale of PDF evolution Q^2_0 = 1.9 GeV^2
- Heavy quark treatment: general mass variable flavor number scheme by Thorne-Roberts (TR)
- Heavy quark masses:
  - NLO : m_c = 1.47 GeV, m_b = 4.50 GeV.
  - NNLO : m_c = 1.43 GeV, m_b = 4.50 GeV.

Model uncertainties: originate from variations of model input parameters:

- NLO (Incl. Jets) : 1.41 GeV < m_c < 1.53 GeV and 5 GeV^2 < Q^2_{min} < 10 GeV^2
- NNLO (W asymmetry) : 1.37 GeV < m_c < 1.49 GeV and 2.5 GeV^2 < Q^2_{min} < 5 GeV^2
- 4.25 GeV < m_b< 4.75 GeV same for both.

fraction of strange quarks in the sea f_s=0.31±0.08

K-Factors and χ^2 definitions

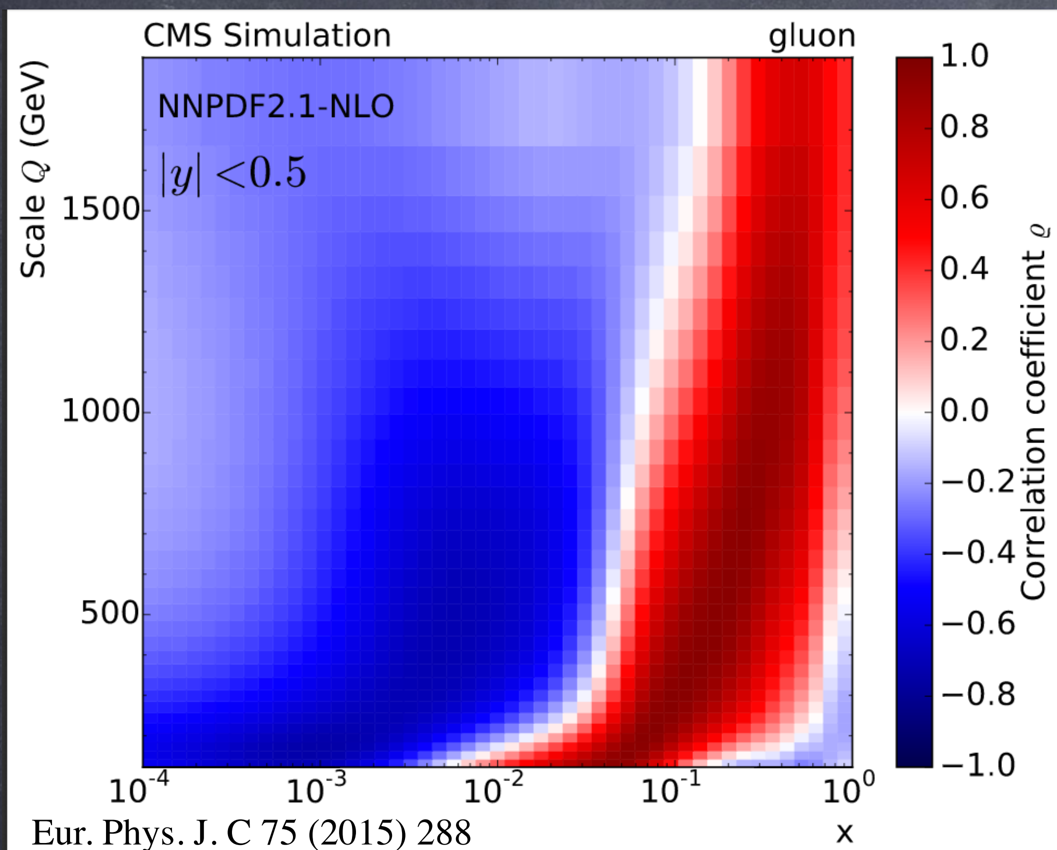
$$K = \frac{\hat{\sigma}_{NNLO} \otimes PDF(NNLO)}{\hat{\sigma}_{NLO} \otimes PDF(NNLO)}$$

$$\chi^2(m,b) = \sum_i \frac{[\mu_i - m_i(1 - \sum_j \gamma^i_j b_j)]^2}{\delta^2_{i,unc} m_i^2 + \delta_{i,stat}\mu_i m_i (1 - \sum_j \gamma^i_j b_j)} + \sum_j b_j^2$$

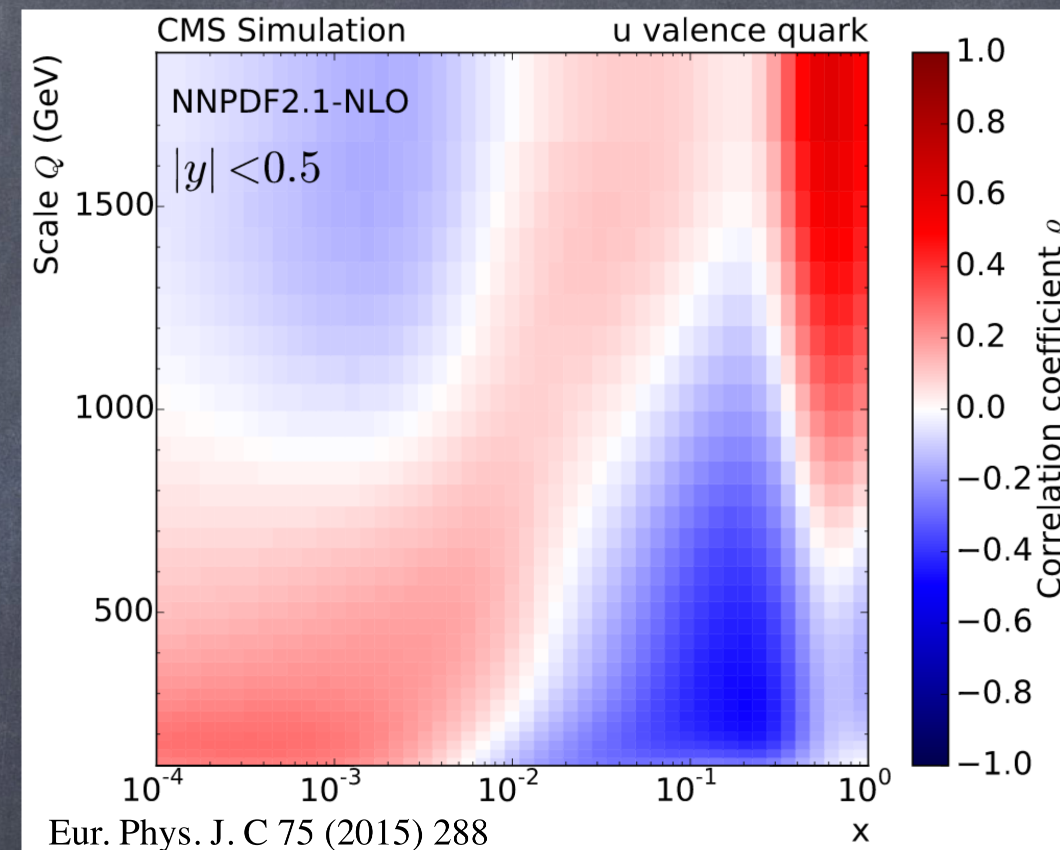
$$\chi^2(m) = \sum_{i,k} (m_i - \mu_i) C^{-1}_{ik} (m_k - \mu_k)$$

Probing QCD with Jet Cross Sections

Strong correlation between inclusive jet cross section and gluon at high-middle x



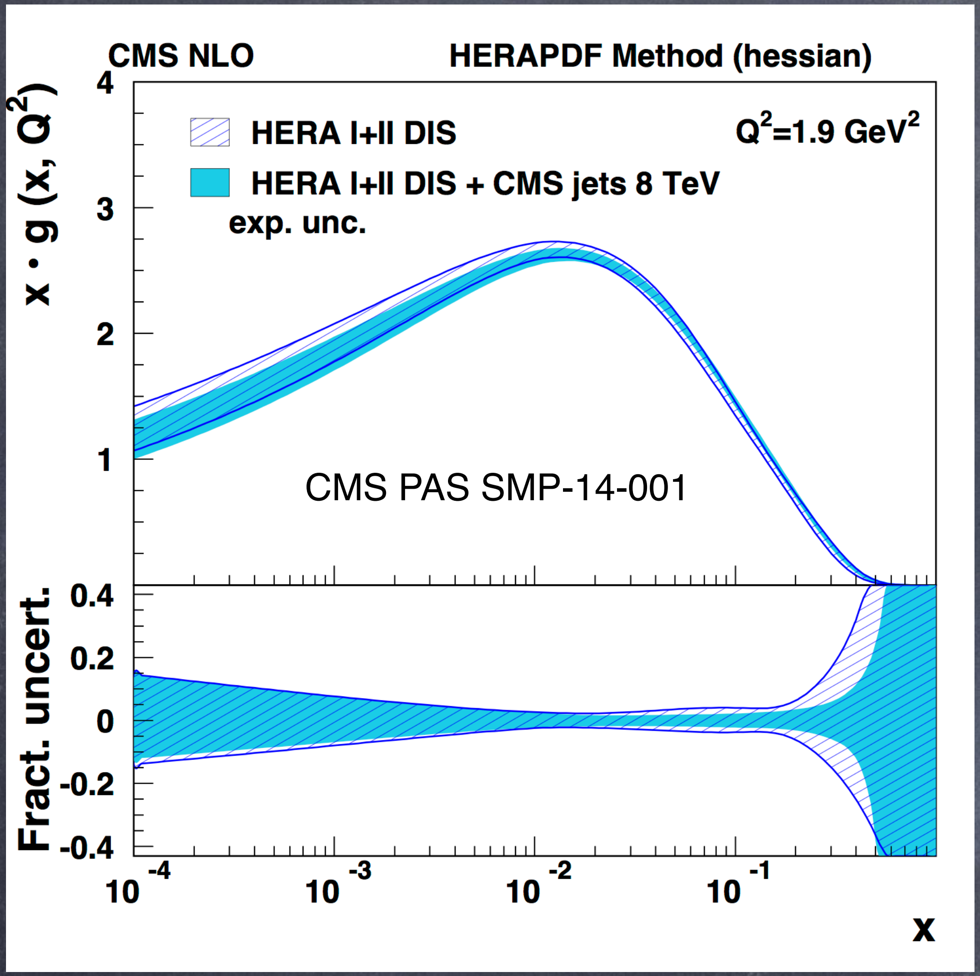
Strong correlation between inclusive jet cross section and quark at high x

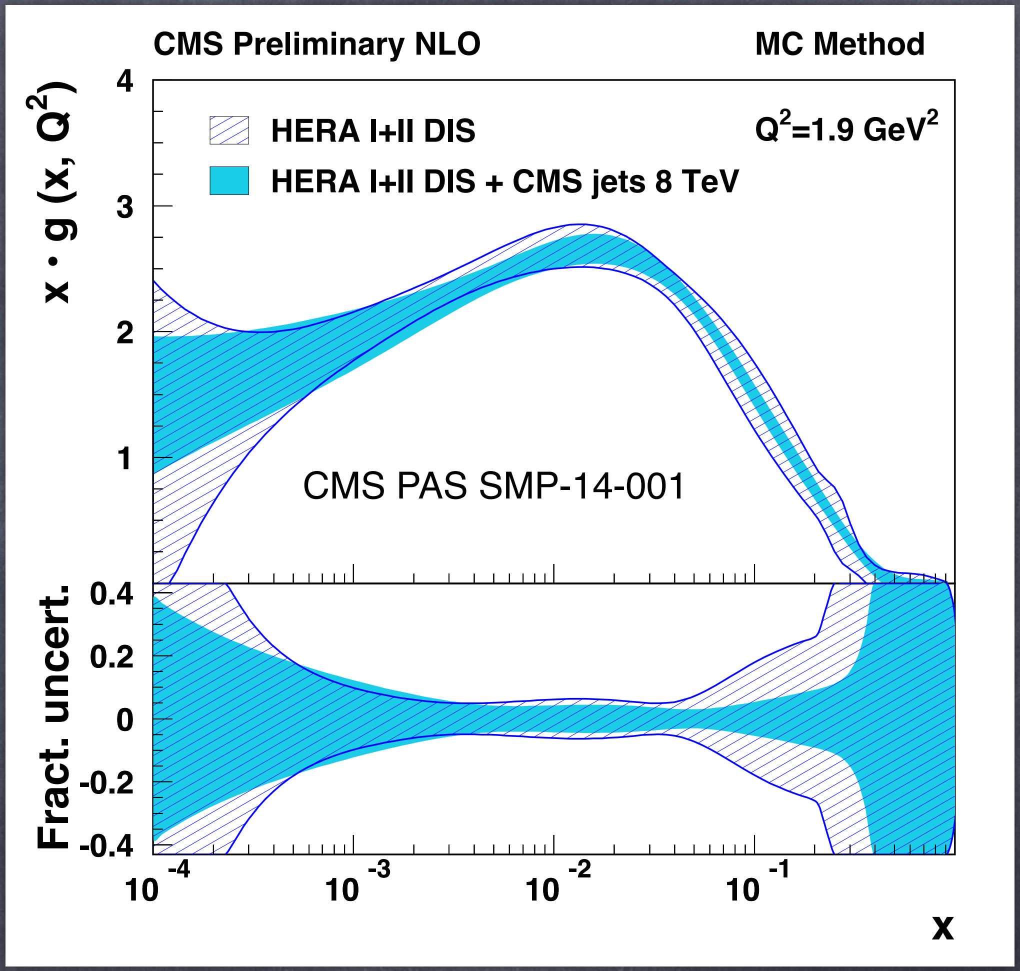


The potential impact of the CMS inclusive jet data can be illustrated by the correlation between the inclusive jet cross section $\sigma_{\text{jet}}(Q)$ and the PDF $xf(x,Q^2)$ for any parton flavour f. The NNPDF Collaboration [63] provides PDF sets in the form of an ensemble of replicas i, which sample variations in the PDF parameter space within allowed uncertainties. The correlation coefficient $\varrho_f(x,Q)$ between a cross section and the PDF for flavour f at a point (x,Q) can be computed by evaluating means and standard deviations from an ensemble of N replicas as

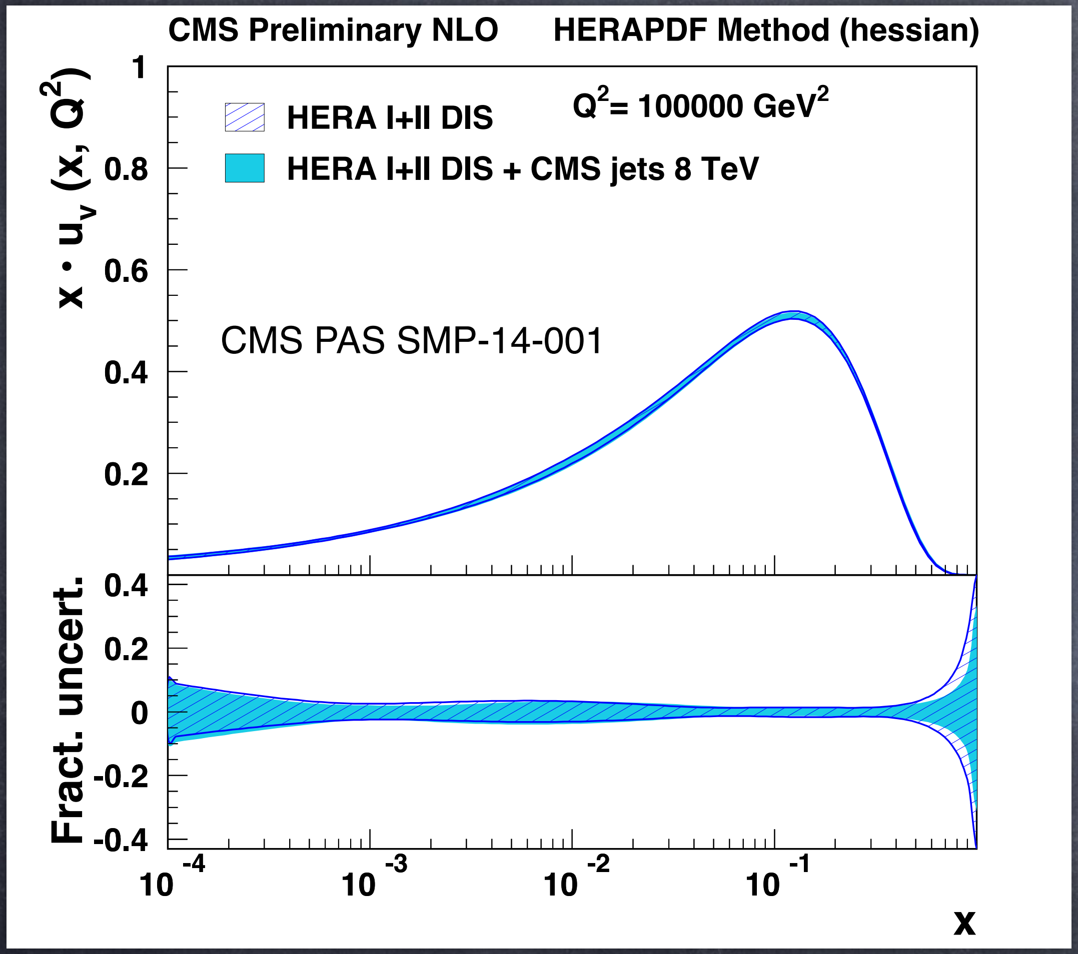
$$\varrho_f(x,Q) = \frac{N}{(N-1)} \frac{\langle \sigma_{\text{jet}}(Q)_i \cdot xf(x,Q^2)_i \rangle - \langle \sigma_{\text{jet}}(Q)_i \rangle \cdot \langle xf(x,Q^2)_i \rangle}{\Delta_{\sigma_{\text{jet}}(Q)} \Delta_{xf(x,Q^2)}}. \qquad (12)$$

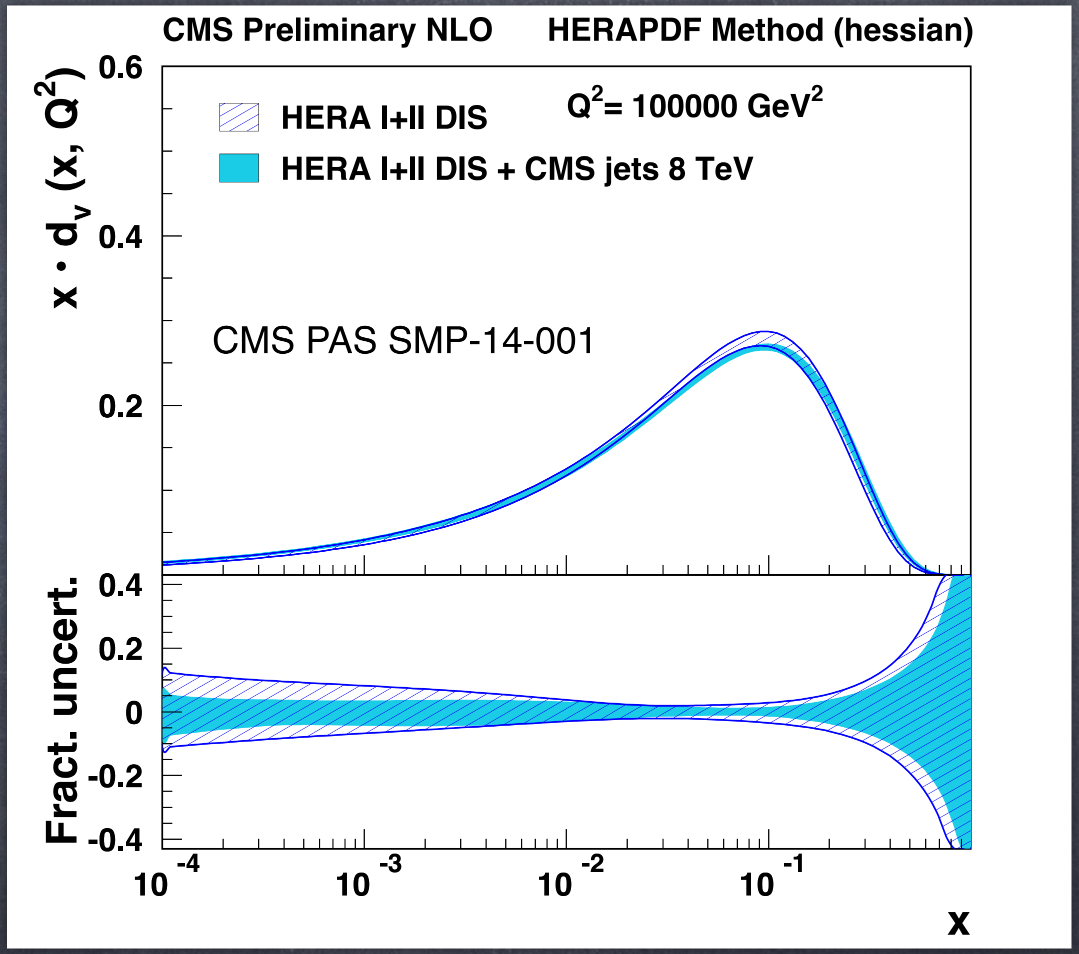
Hessian vs MC





u and d valence PDFs from inclusive jet @8TeV





Parametrisation Uncertainty

Center

18p

18p + Euv

18p + DDbar

18p + Edv

……

Converged fits

- Get the largest difference
- Construct envelope