Jet Measurements from CMS

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Low-x meeting, 10.06.2016

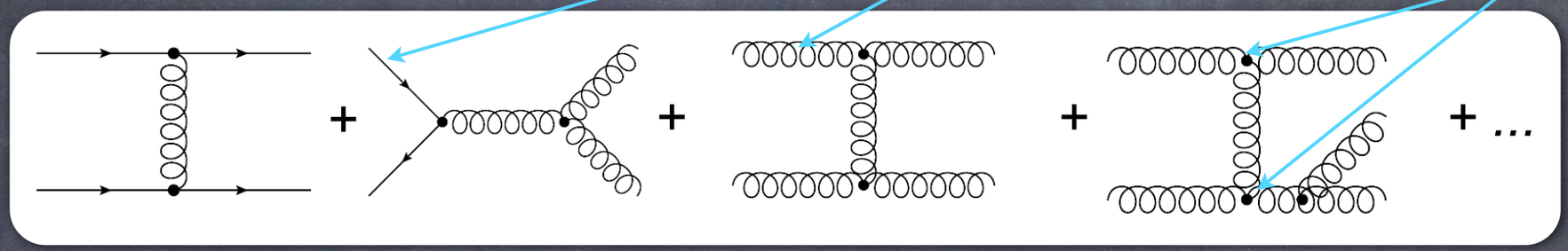
Gyöngyös, Hungary

Outline

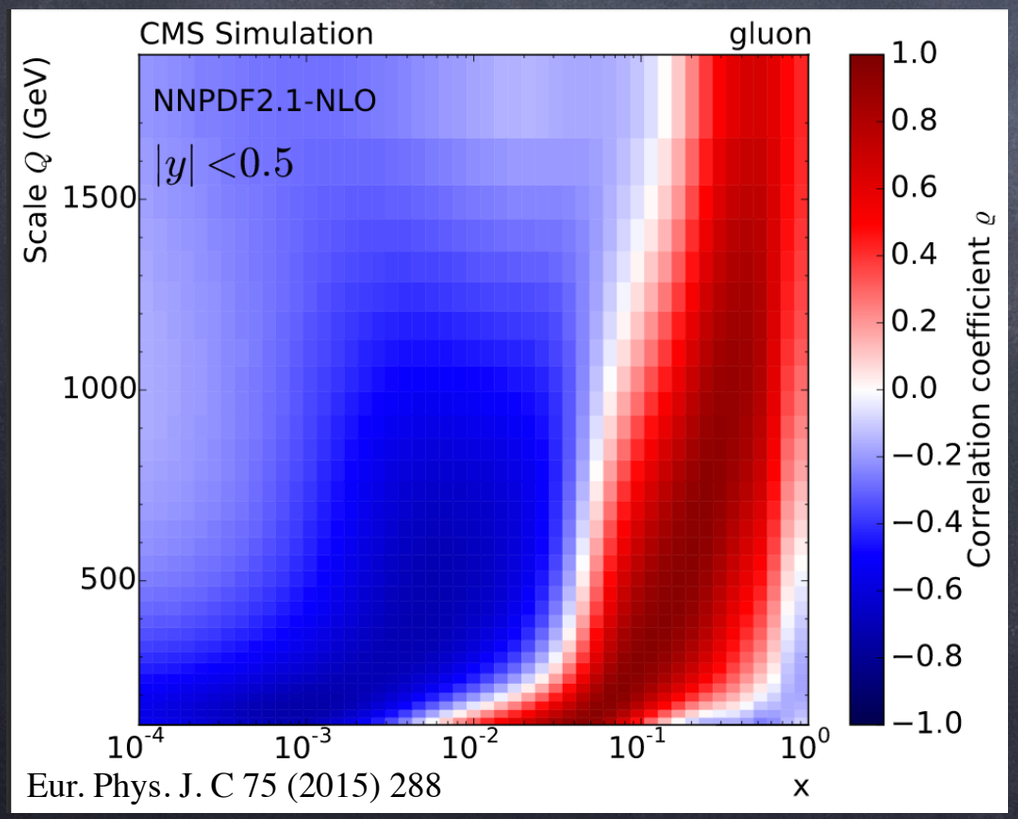
- Measurement of inclusive jet cross-section @2.76TeV
- Measurement of inclusive jet cross-section @8TeV
- Ratio of 2.76 TeV and 8 TeV cross-sections
- QCD analysis with inclusive jet cross-section @8TeV
  - ✓ Determination of strong coupling α_s
  - ✓ PDF parametrisation and sensitivity
  - ✓ Constraints on gluon PDF
- Measurement of inclusive jet cross-section @13TeV

Probing QCD with Jet Cross Sections

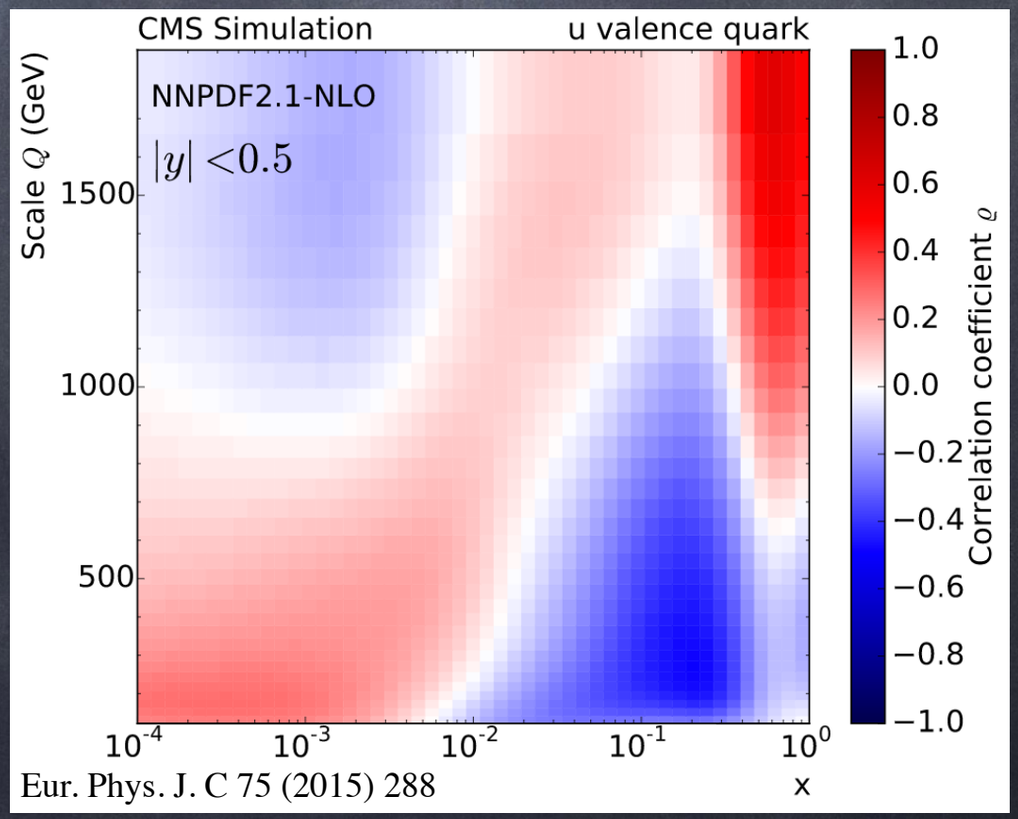
- Jet production sensitive to quark and gluon distributions, and to α_S



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

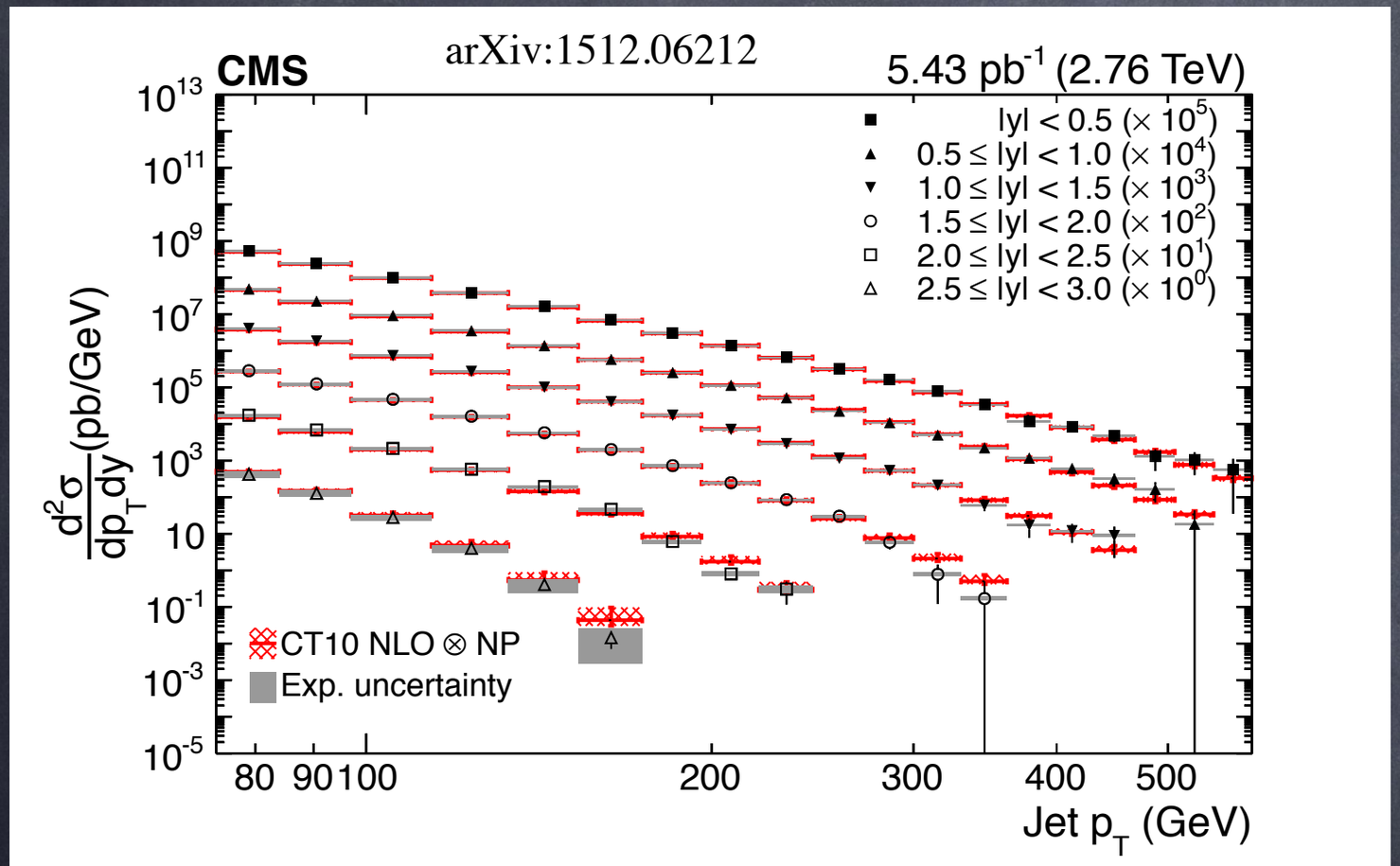


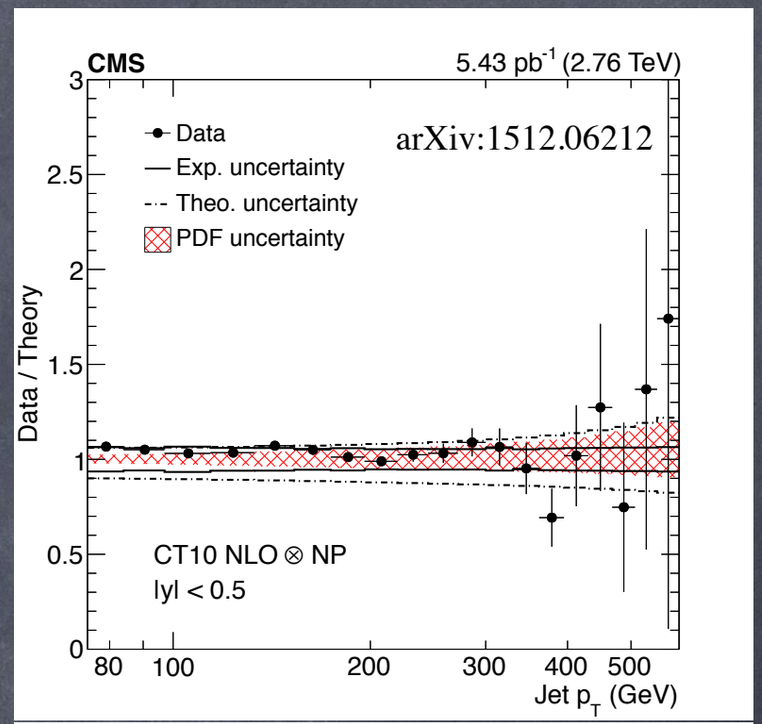
Strong correlation between inclusive jet cross section and quark at high x

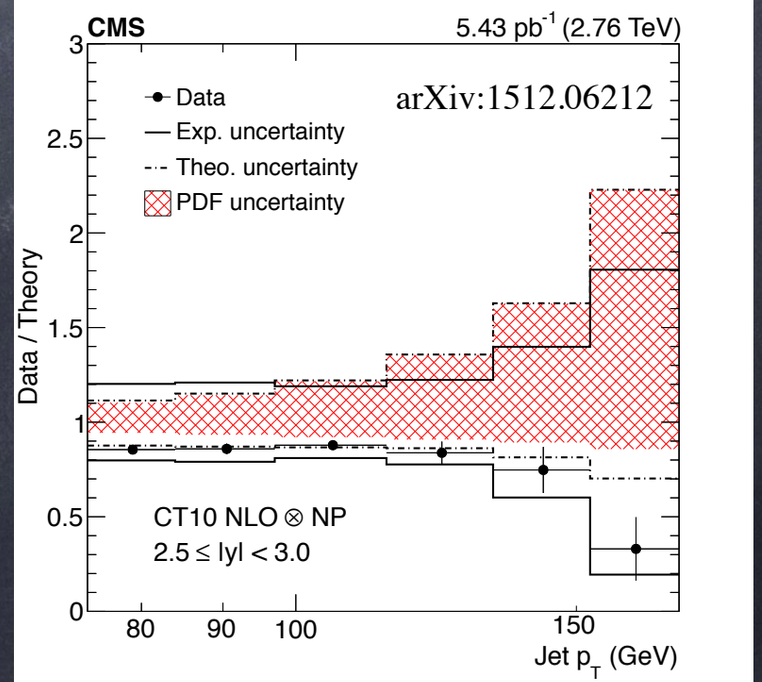


Inclusive Jet Cross Section at 2.76TeV

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.



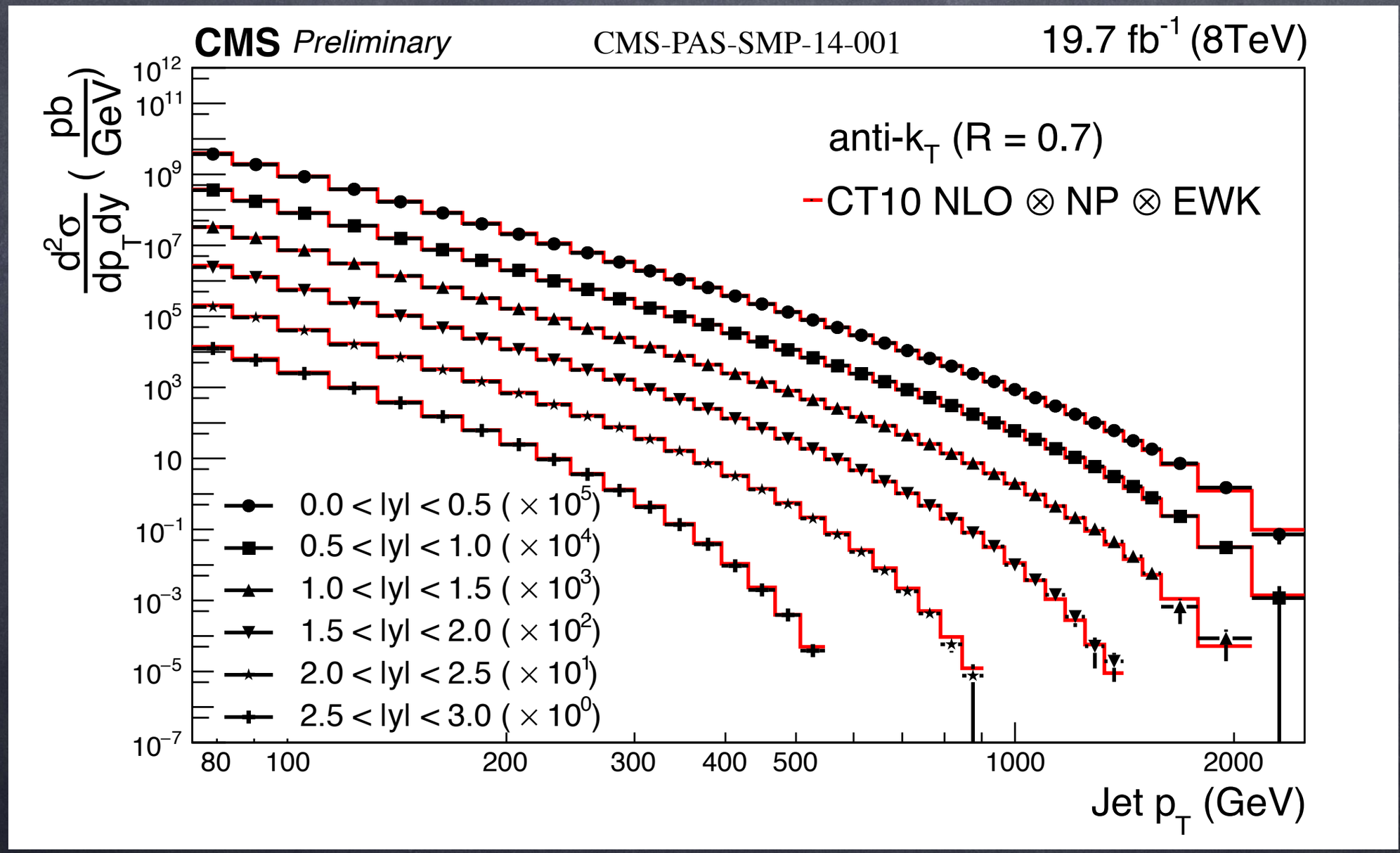




Transverse momenta range from 74 GeV to 592 GeV. Good description by **NLO QCD**

Inclusive Jet Cross Section at 8TeV

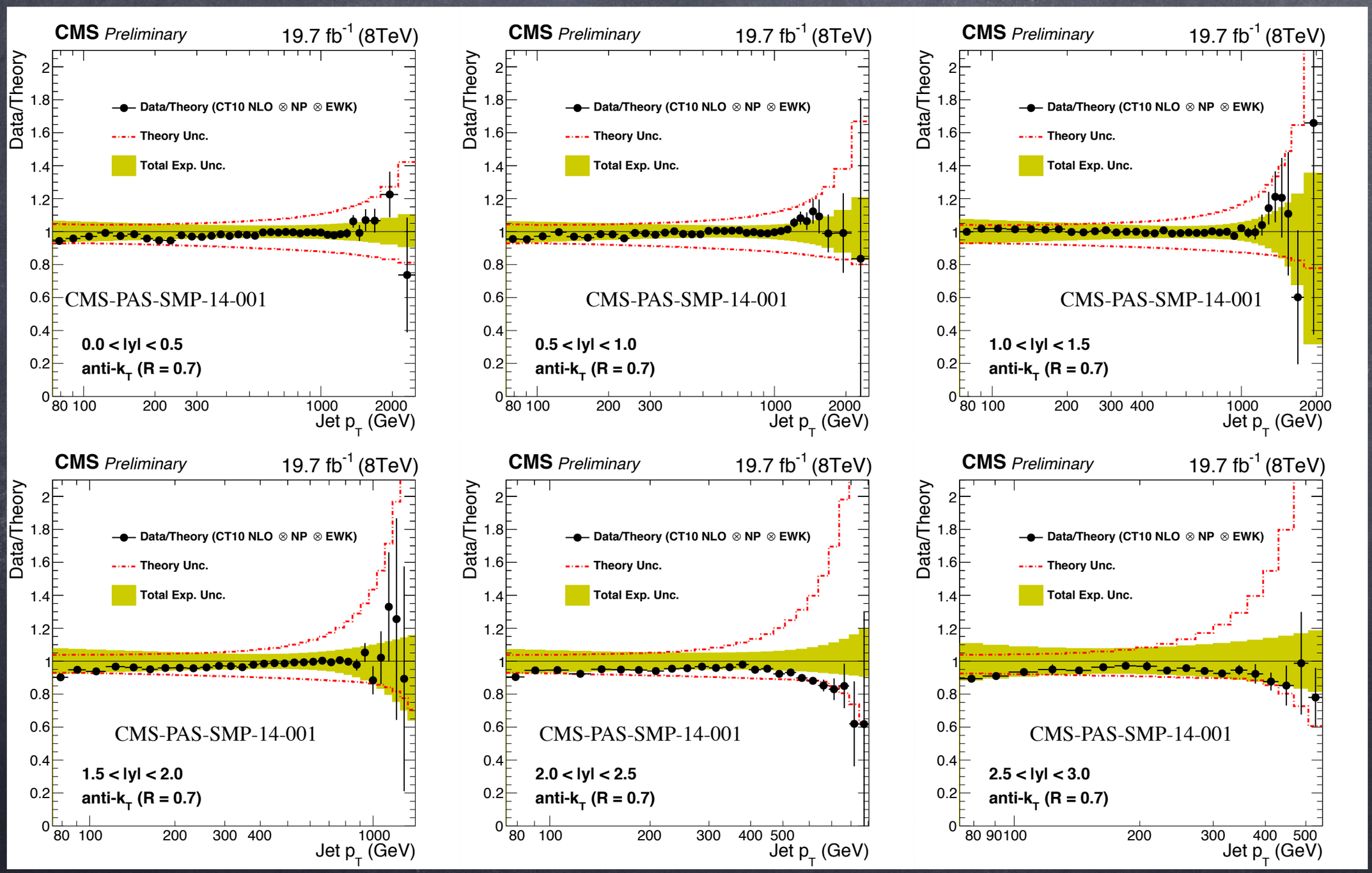
Measurement at $\sqrt{s}$=8 TeV (L = 19.7 fb^{-1})
Anti-k_T, R=0.7; double-differential cross sections as functions of p_T and y.



Transverse momenta range from 74 GeV to 2.5 TeV.

Inclusive Jet Cross Section at 8TeV

Data/Theory comparisons for 6 rapidity bins :



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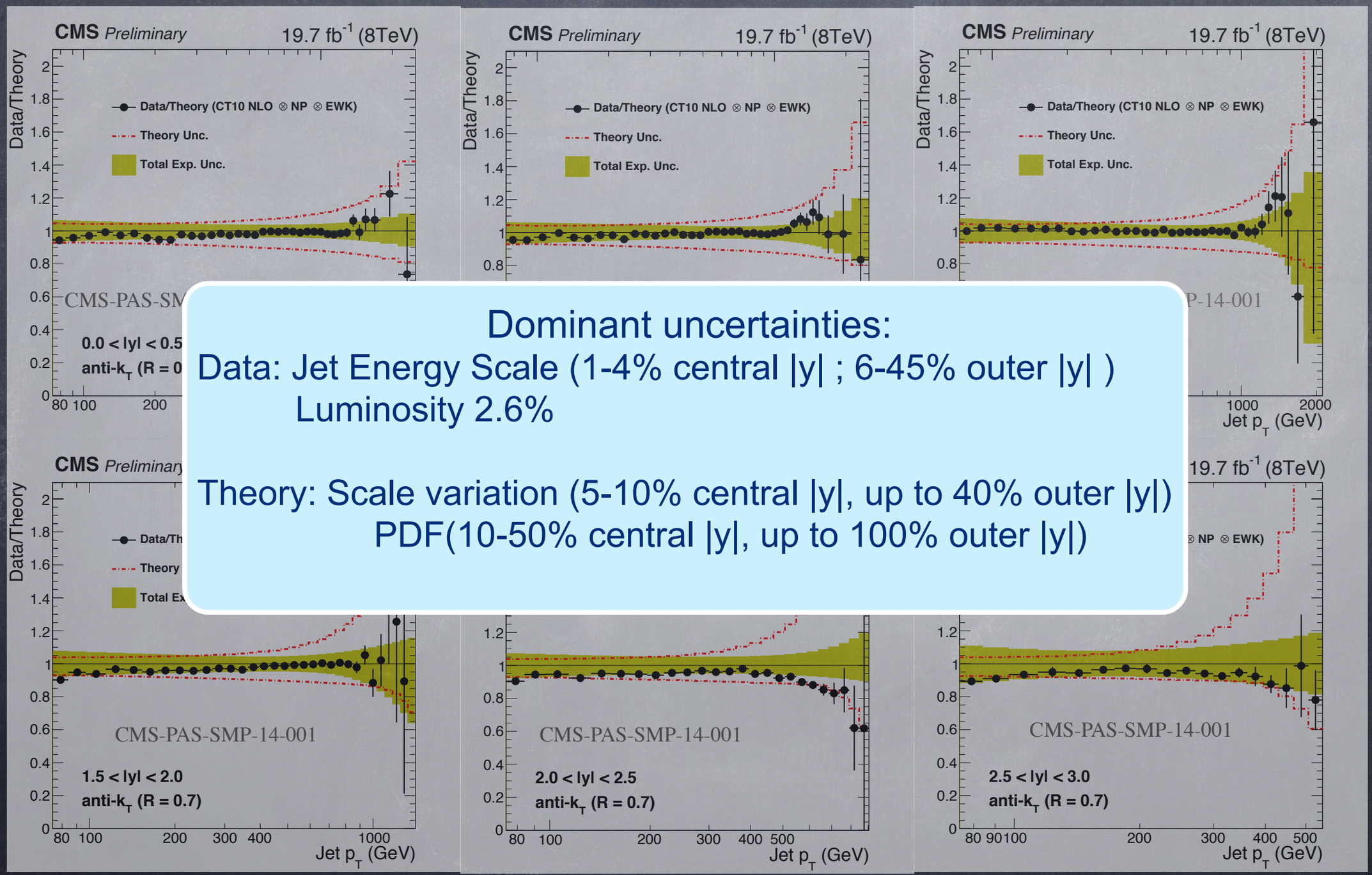
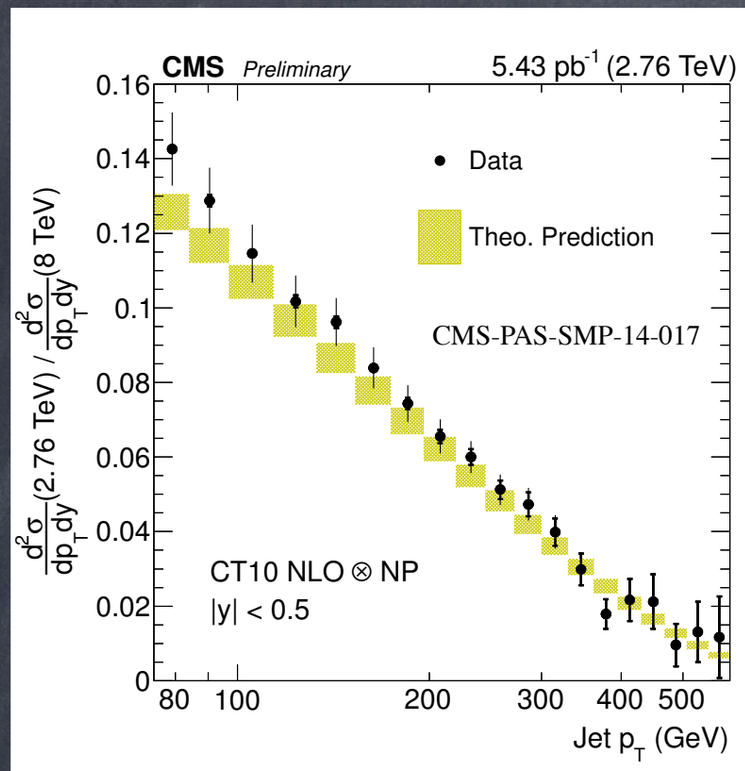


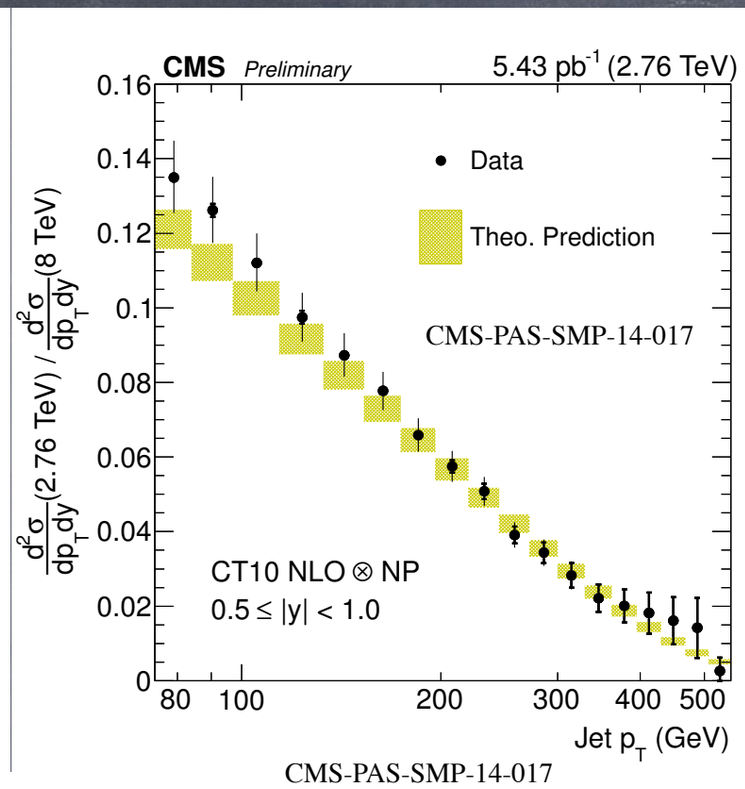
Dominant uncertainties:

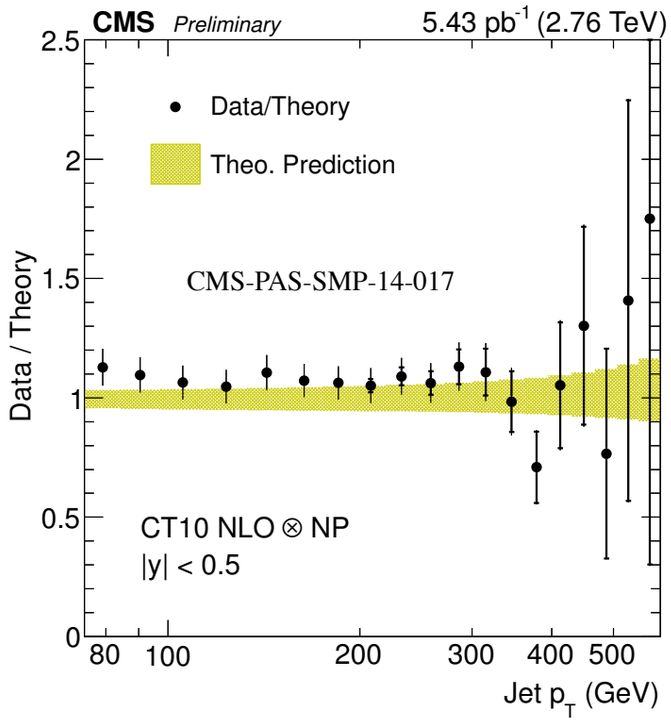
Data: Jet Energy Scale (1-4% central |y| ; 6-45% outer |y|)
Luminosity 2.6%

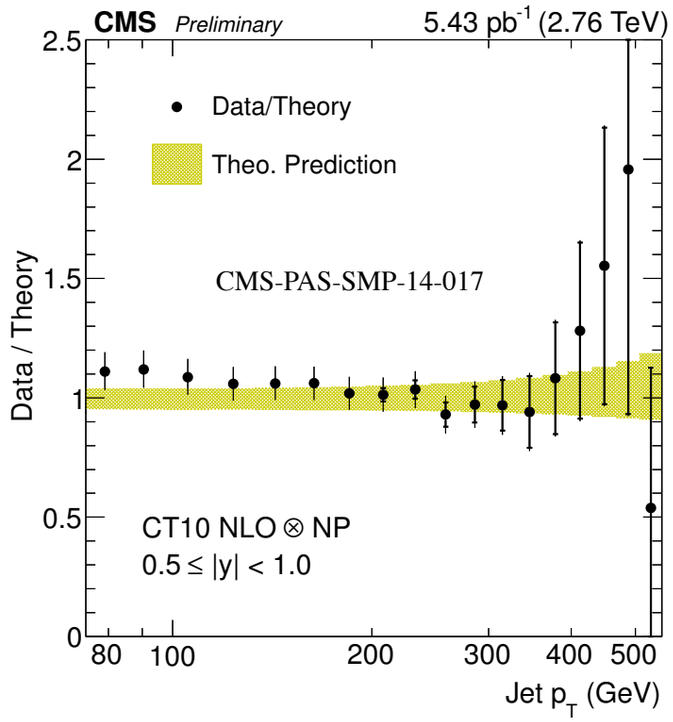
Theory: Scale variation (5-10% central |y|, up to 40% outer |y|)
PDF(10-50% central |y|, up to 100% outer |y|)

Inclusive Jet Cross Section Ratio 2.76 / 8TeV









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

$$\rho = \frac{\sigma^{2.76\,\mathrm{TeV}}_{\mathrm{Data}} / \sigma^{2.76\,\mathrm{TeV}}_{\mathrm{Theory}}}{\sigma^{8\,\mathrm{TeV}}_{\mathrm{Data}} / \sigma^{8\,\mathrm{TeV}}_{\mathrm{Theory}}}$$

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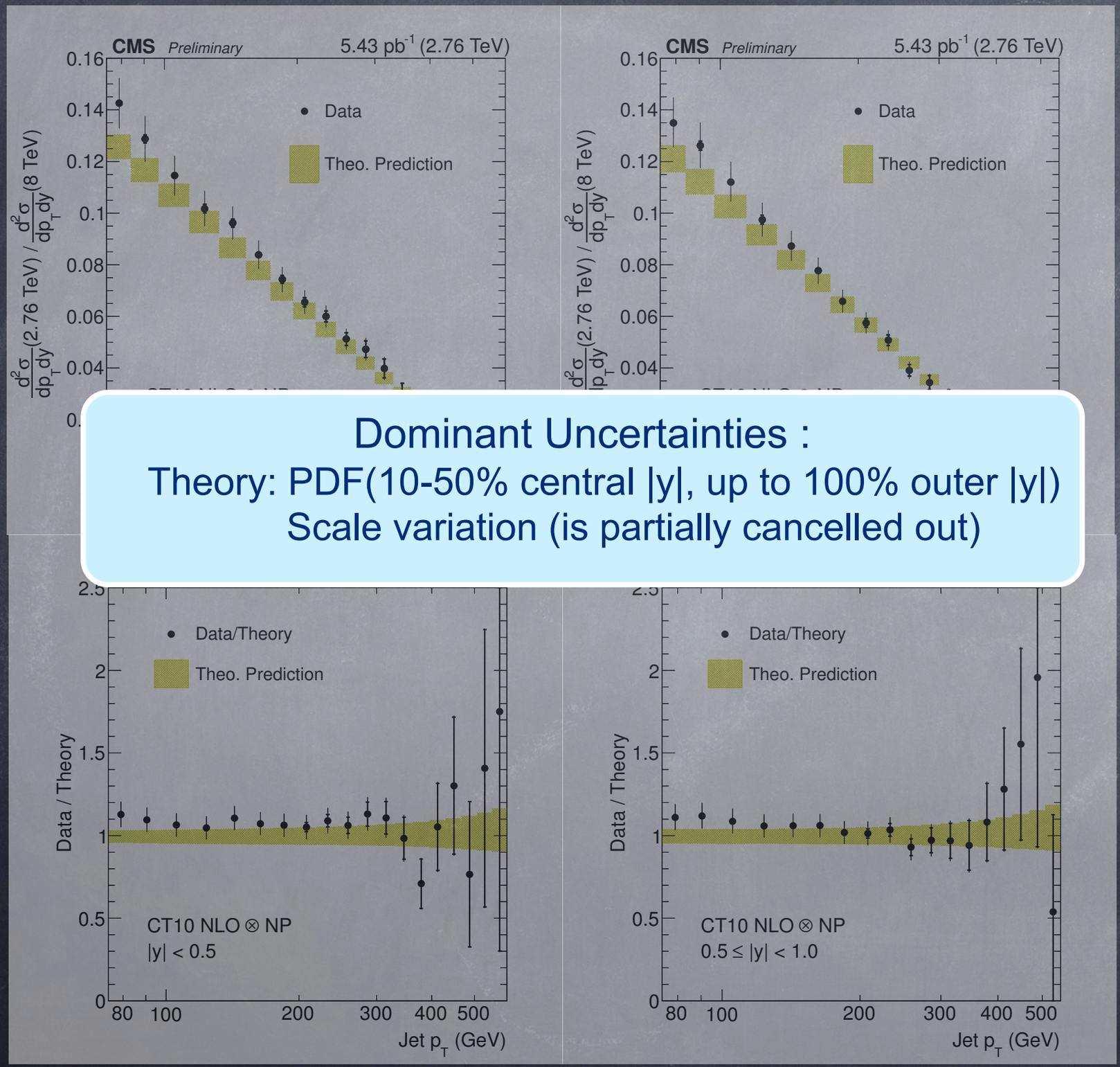

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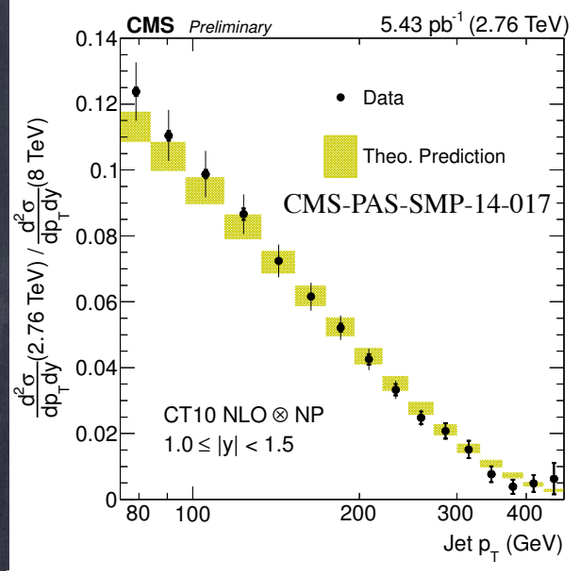

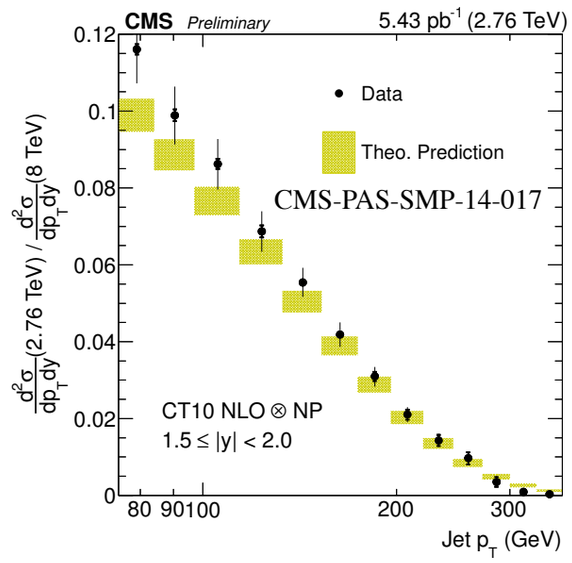

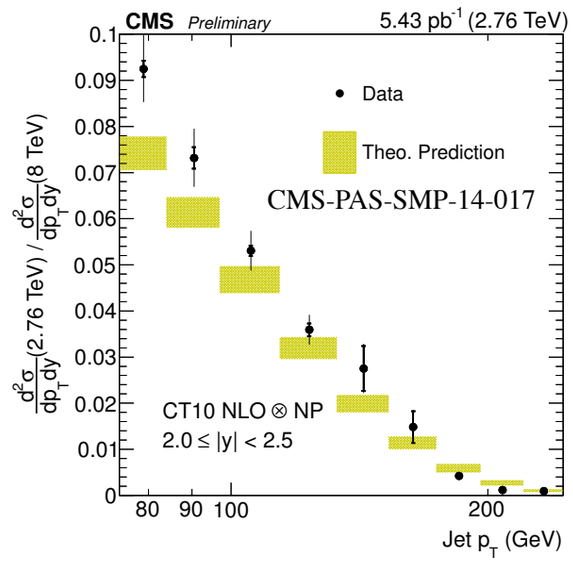

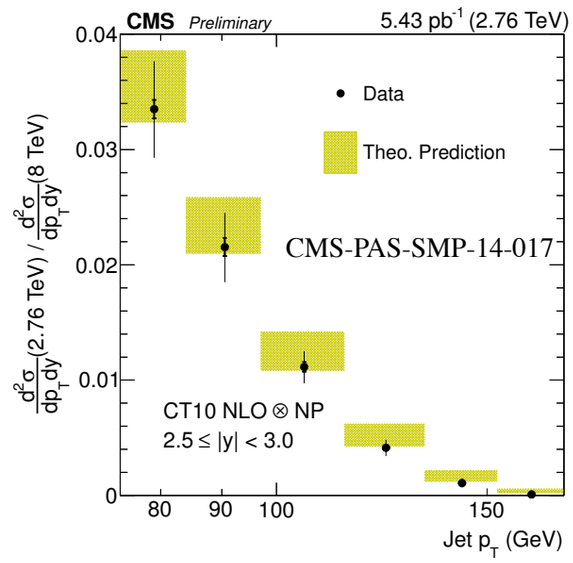

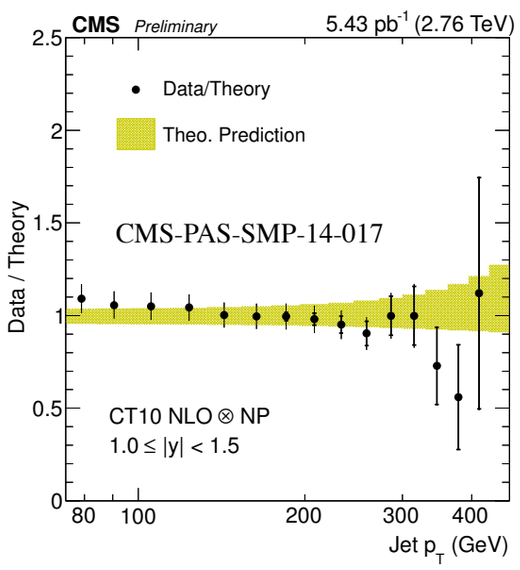

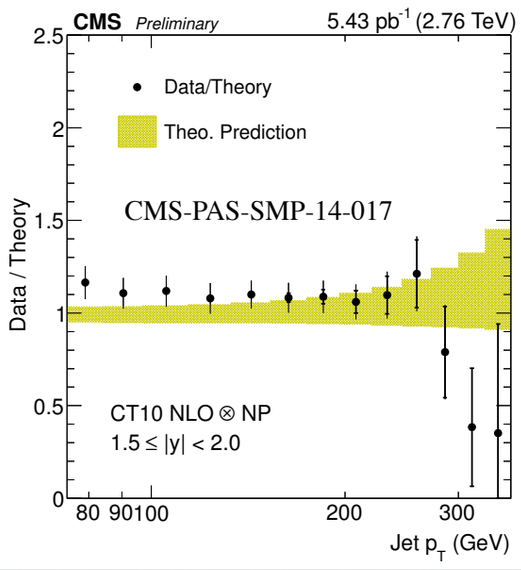

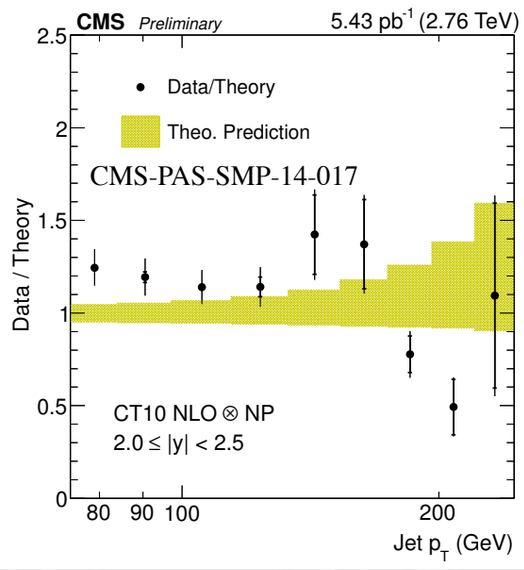

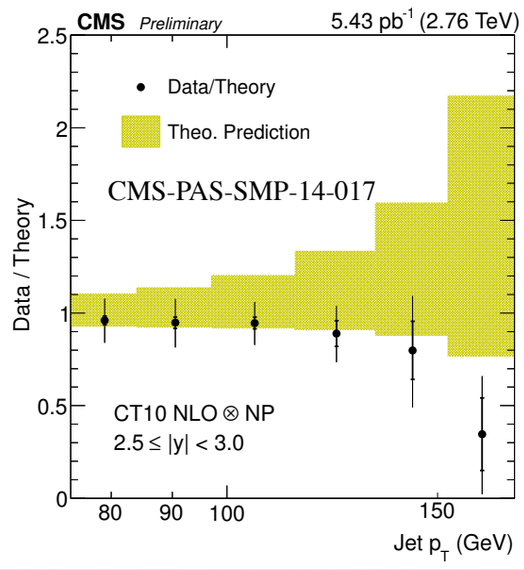

Inclusive Jet Cross Section Ratio 2.76 / 8TeV

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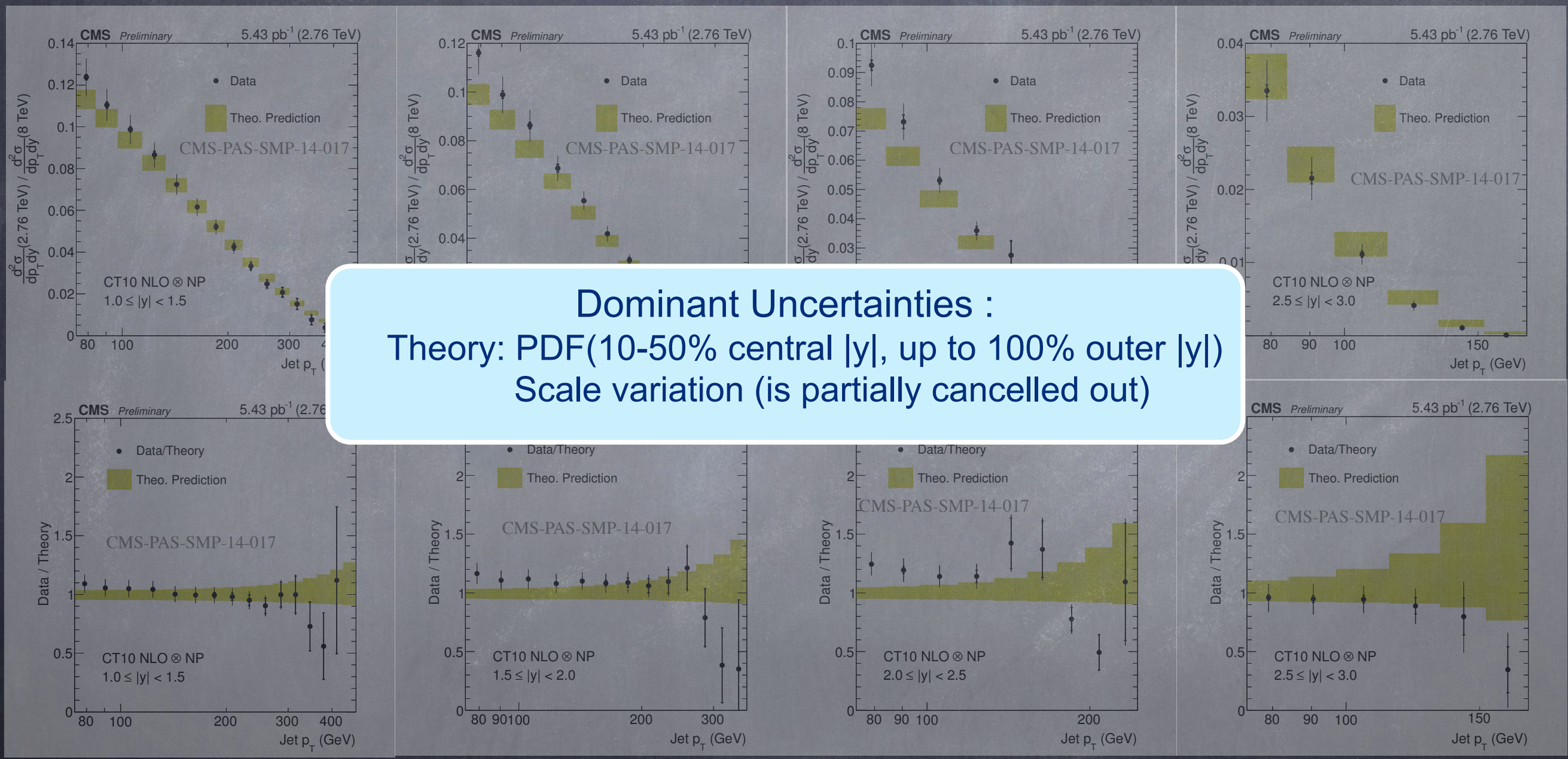

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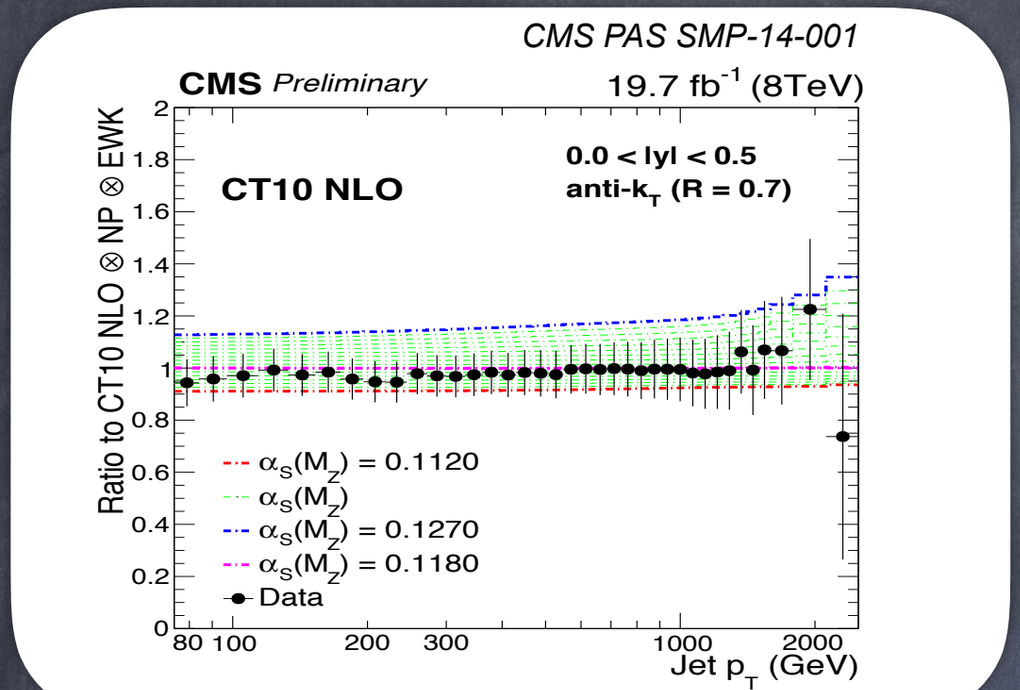
Determination of strong coupling α_s : inclusive jets @ 8TeV



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

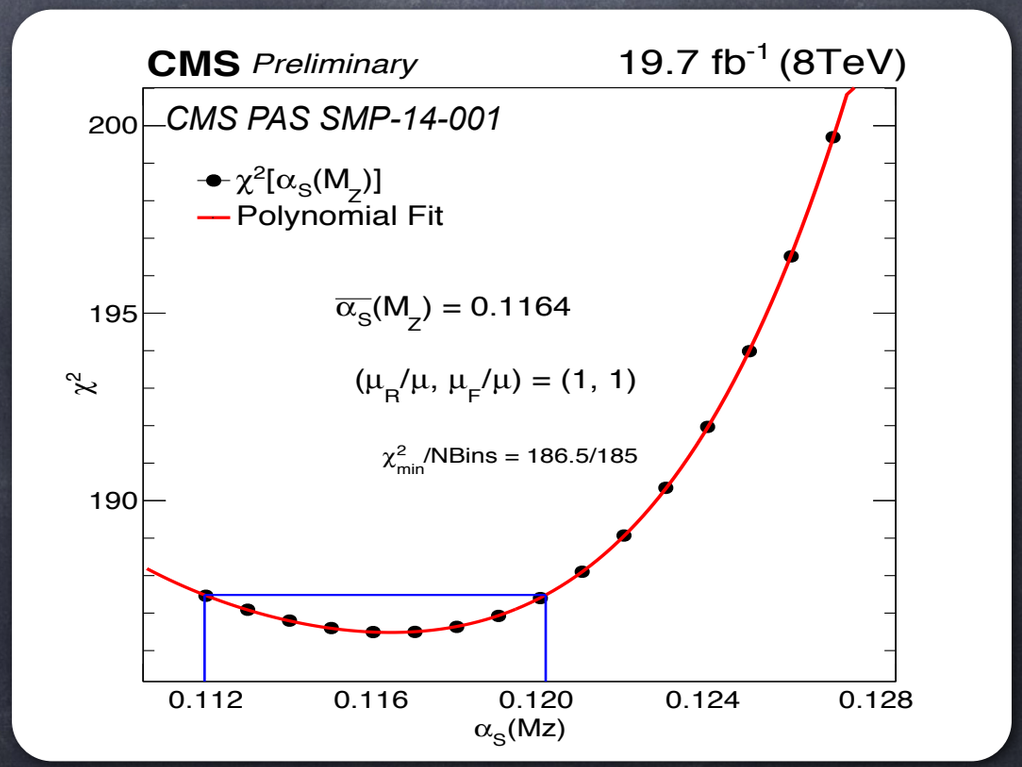
In each y bin, for each PDF, α_s is determined by minimizing χ^2 between data and NLO

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 9 p_T bins
⇛ running of α_s=α_s (Q^2)



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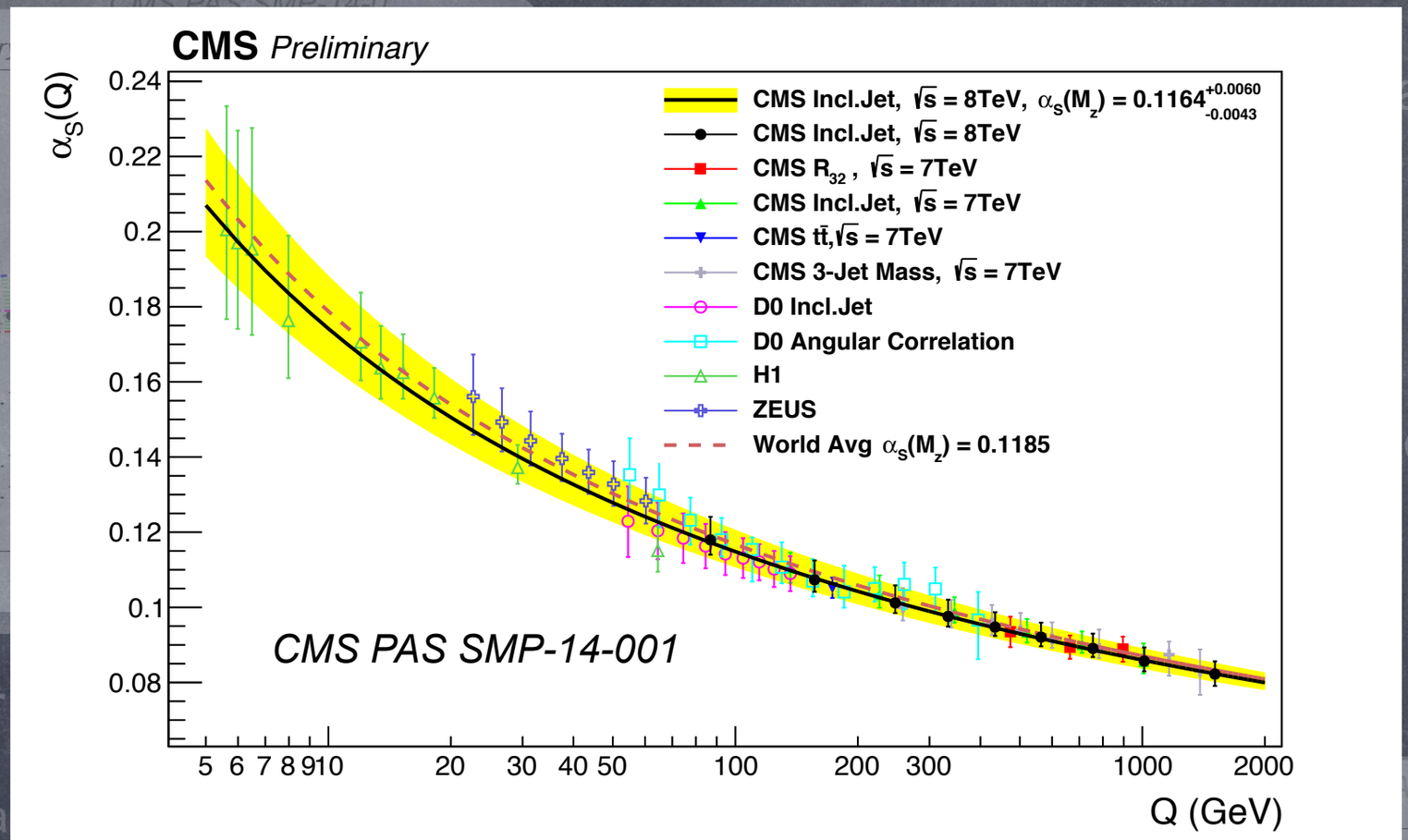

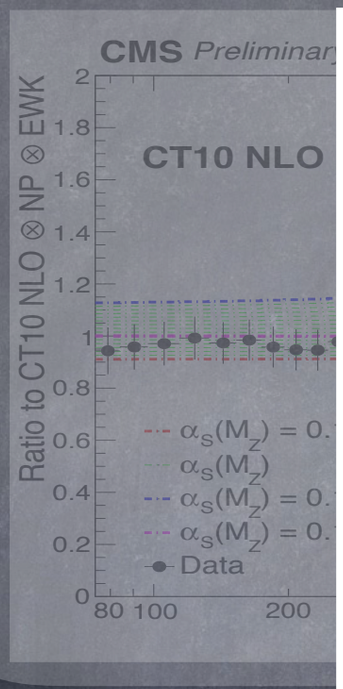

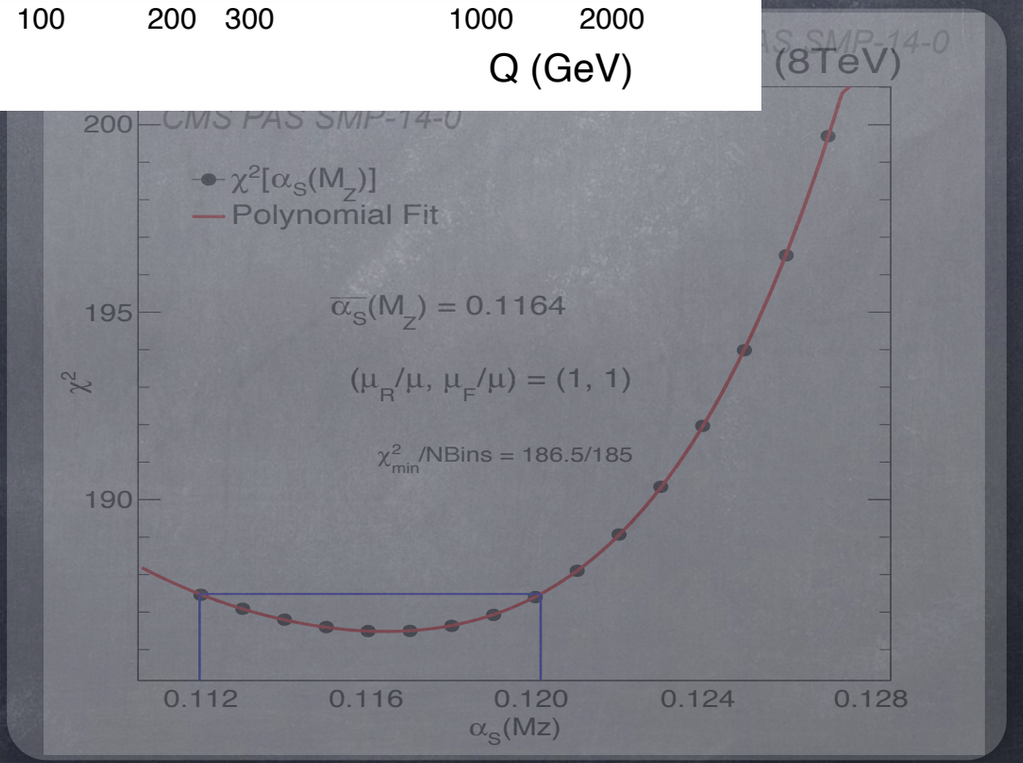

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Impact of the CMS jet measurements on PDFs

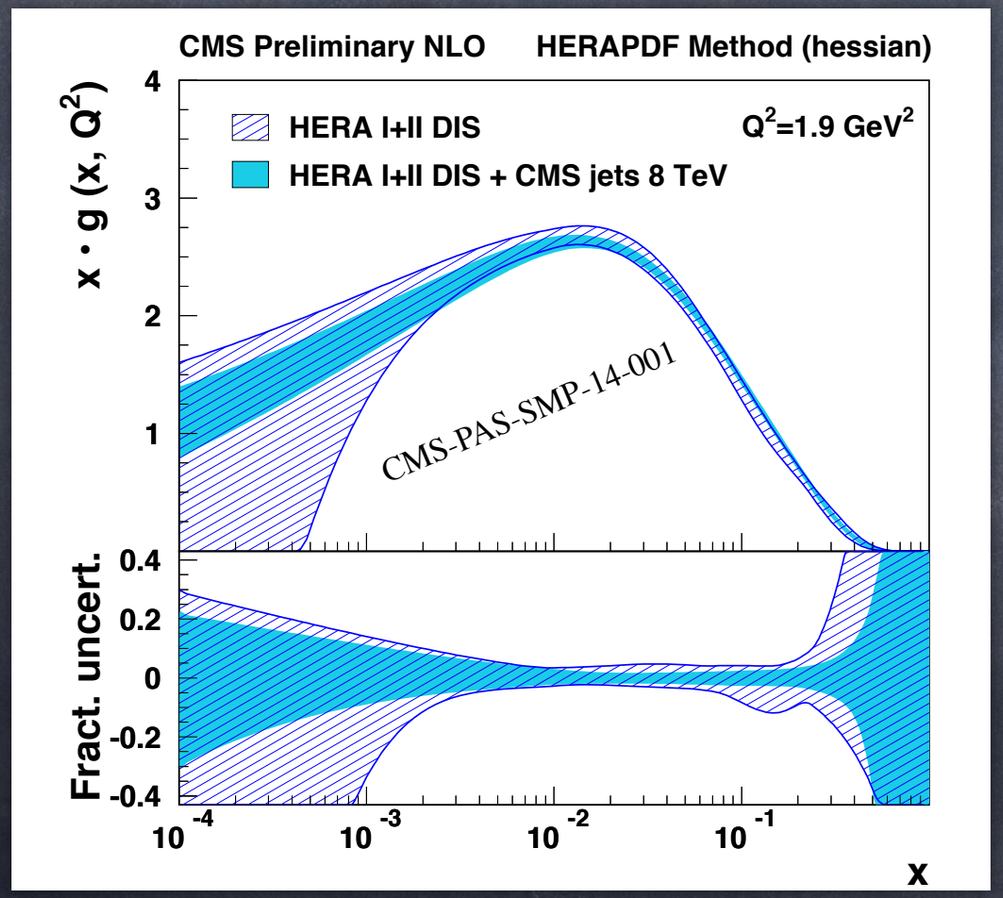
QCD analysis at NLO

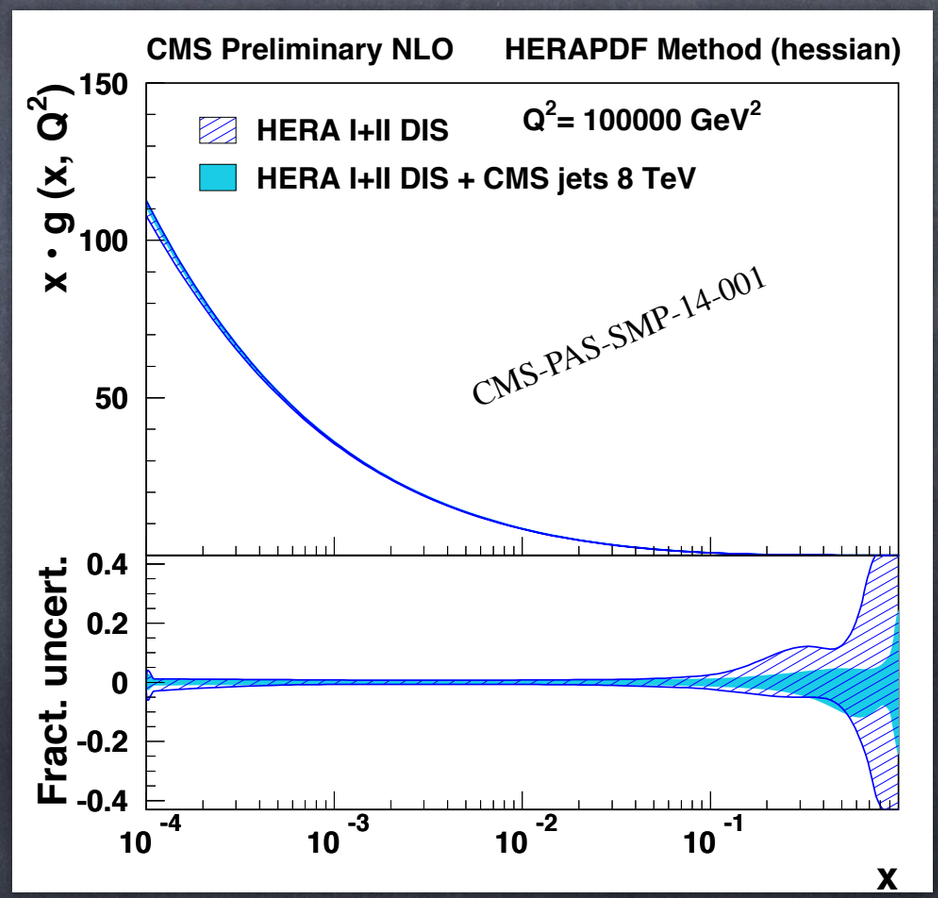
Data: combined HERA I+II DIS [Eur. Phys. J. C 75 (2015) 2604]

+ 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

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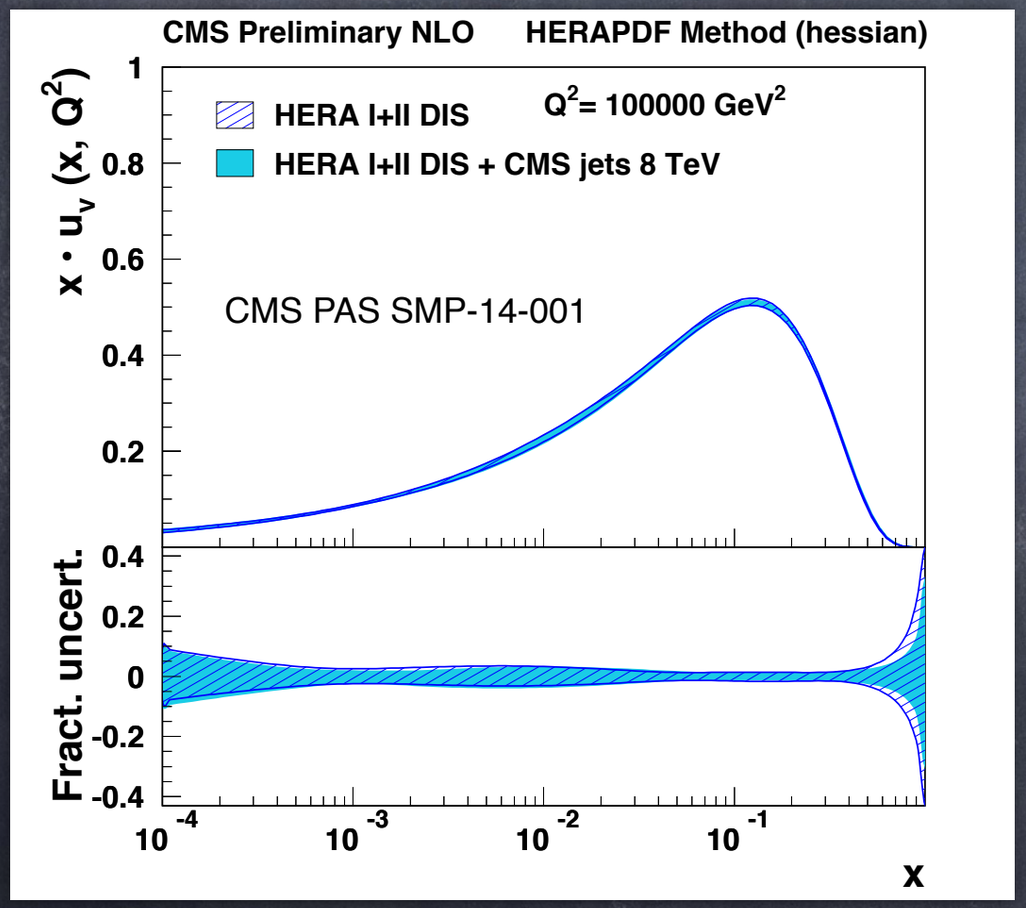
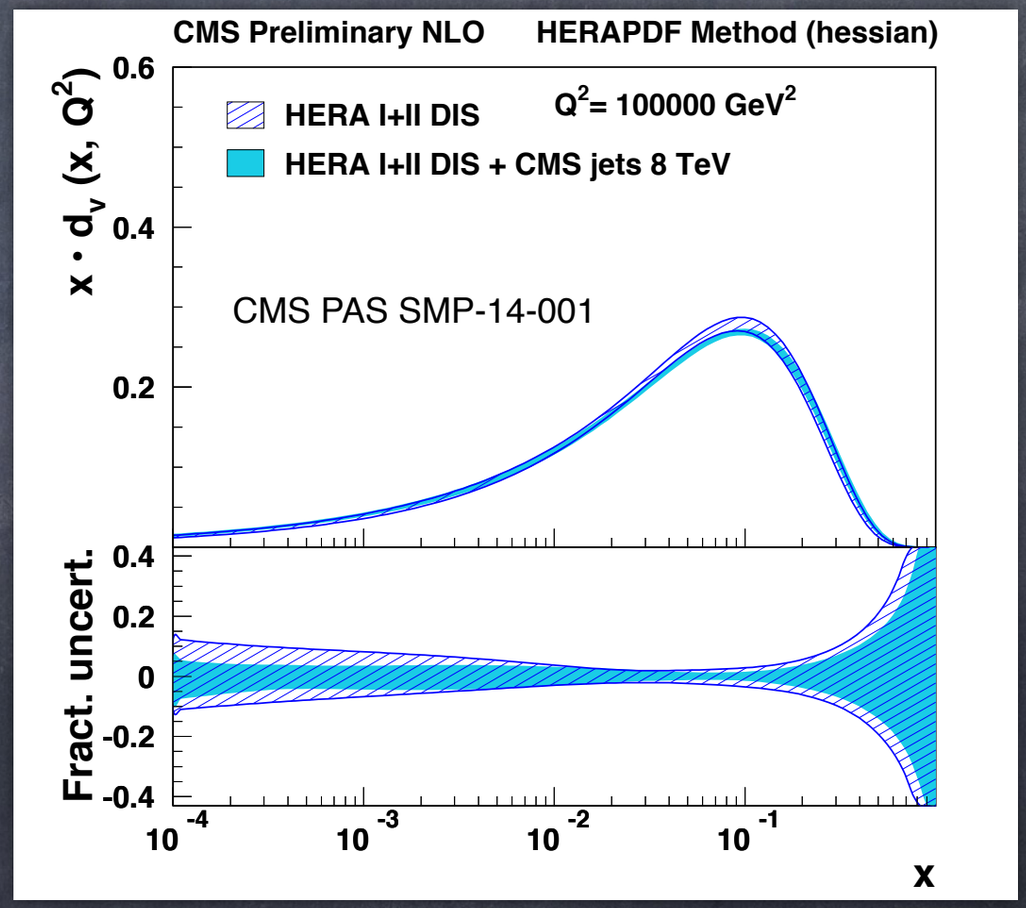
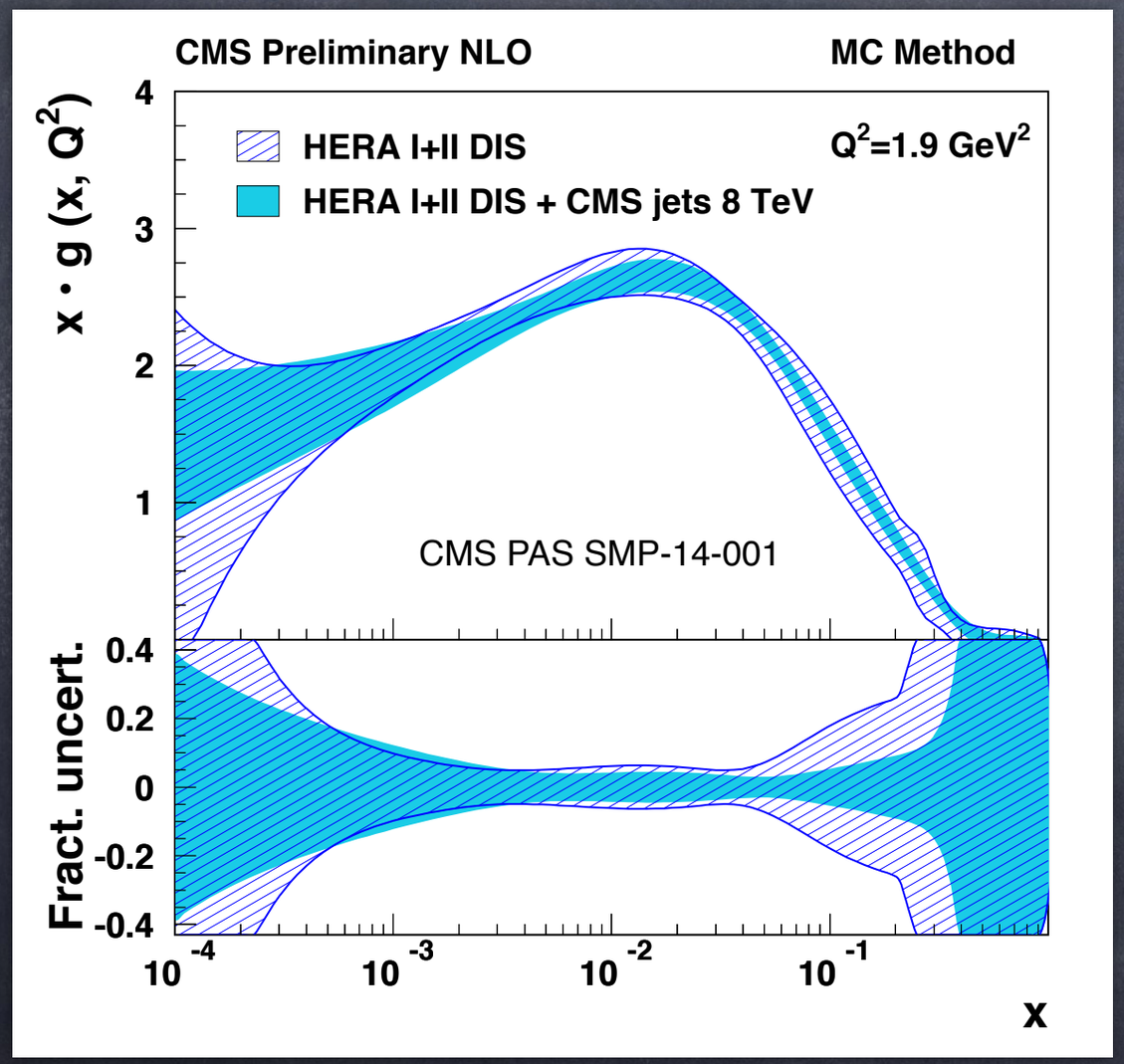




Improvement in the uncertainty of the valence distributions at high-x

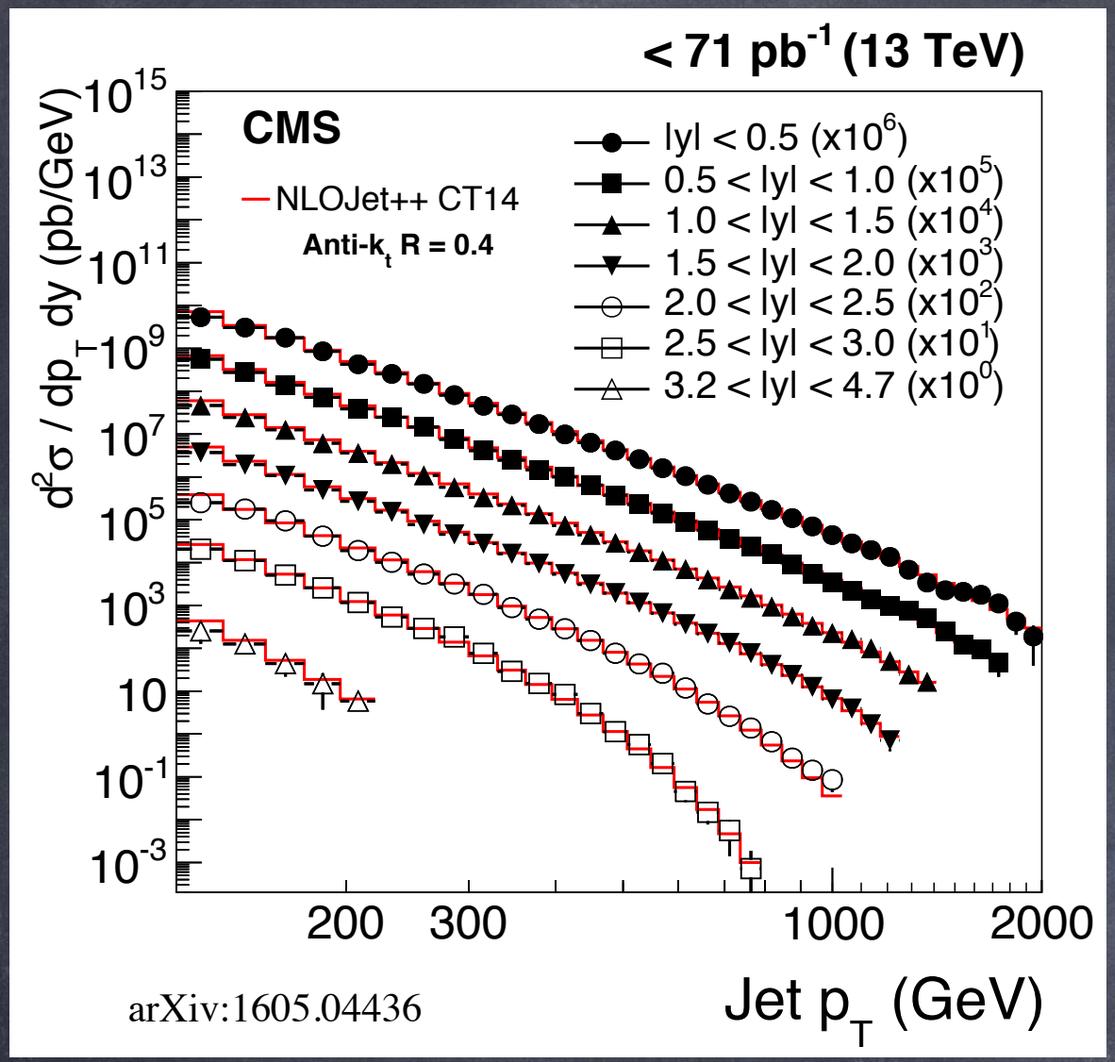
Estimation of PDF Uncertainty with MC Method

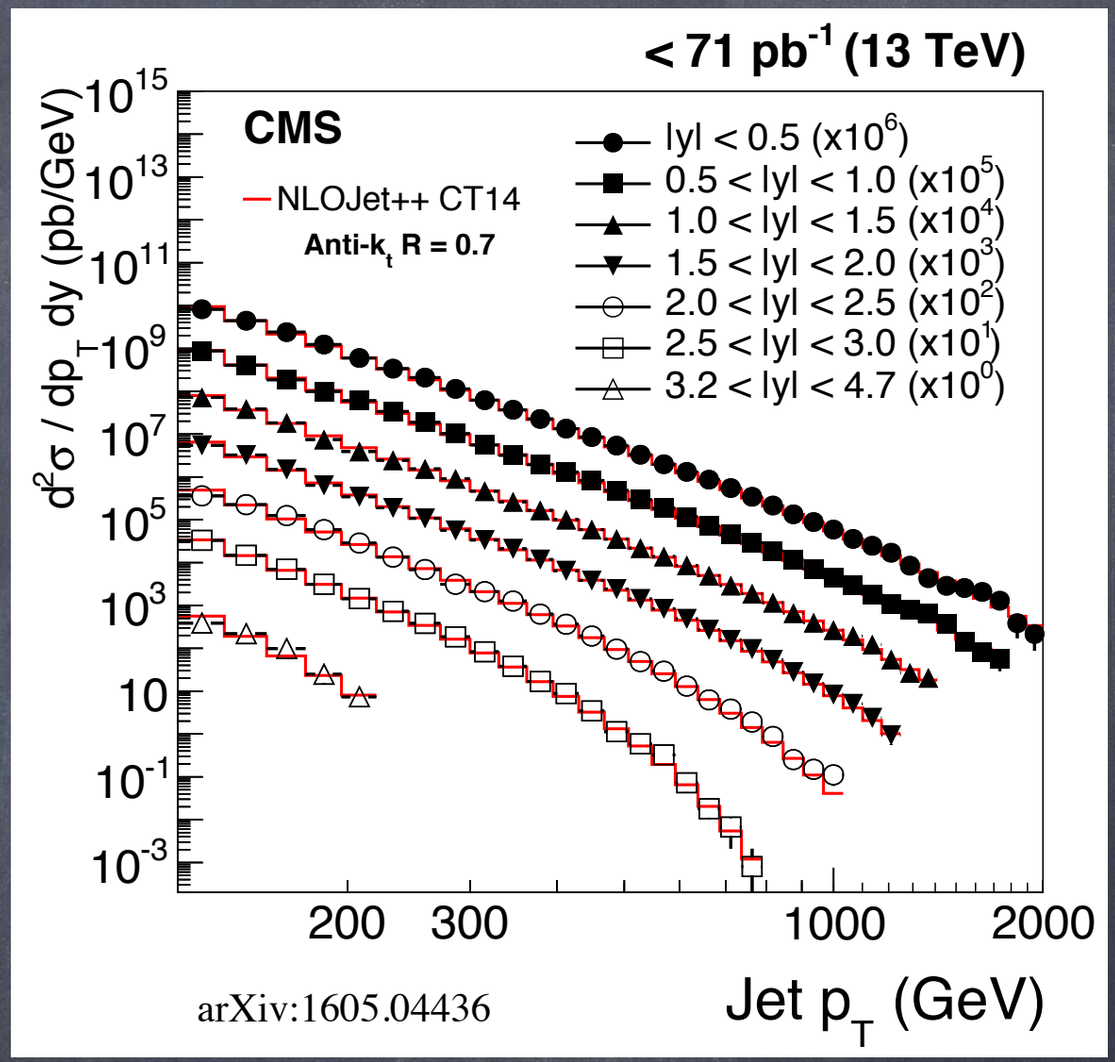
- 200 of replicas allowing the central values of cross-sections to fluctuate within their systematic and statistical uncertainties.
- For each replica, **NLO QCD** fit is performed. Errors on the PDFs are estimated from the RMS of the spread of the curves.



Similar reduction of uncertainties observed as in hessian estimate

Inclusive Jet Cross Section @ 13 TeV

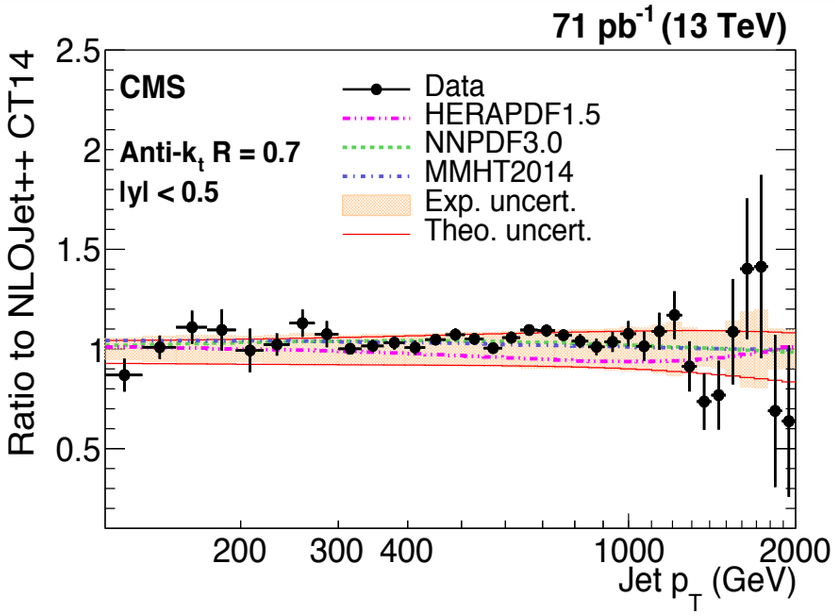


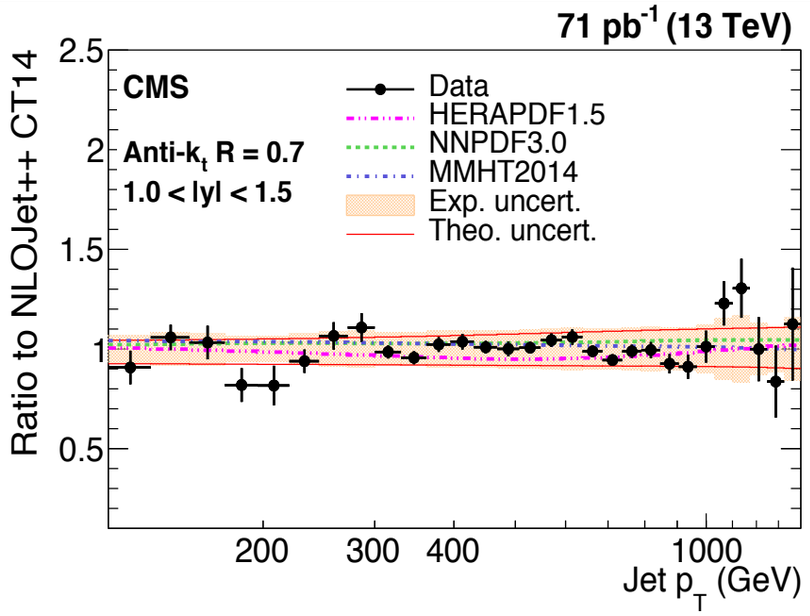


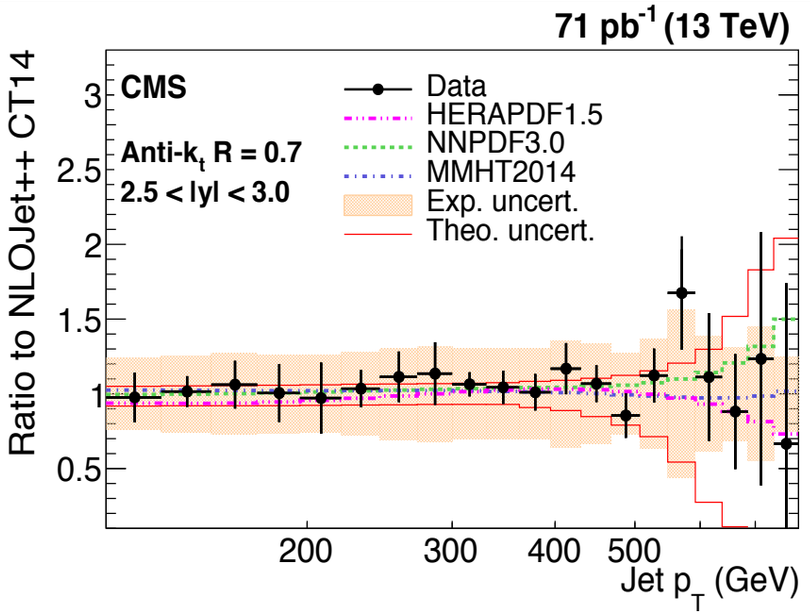
Unfolded results compared to predictions from :

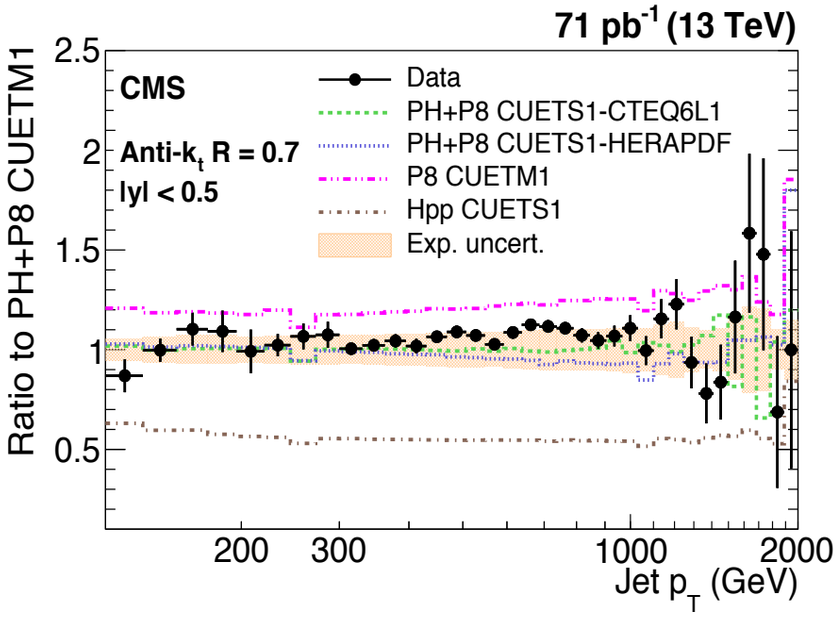
- NLOJet++ corrected for NP and electroweak effects
- POWHEG NLO dijet matrix element + Pythia UE simulation
- Pythia 8 and HERWIG++ LO

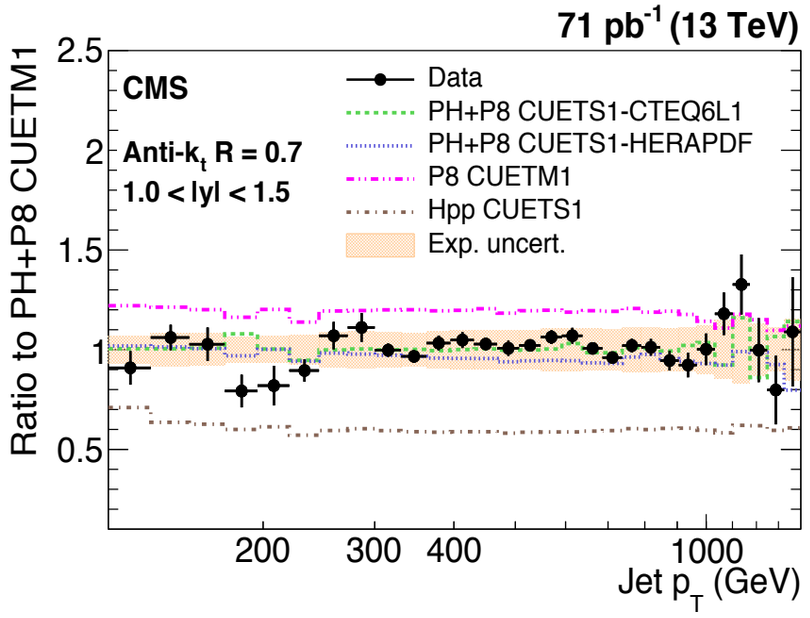
Inclusive Jet Cross Section @ 13 TeV : Ratios

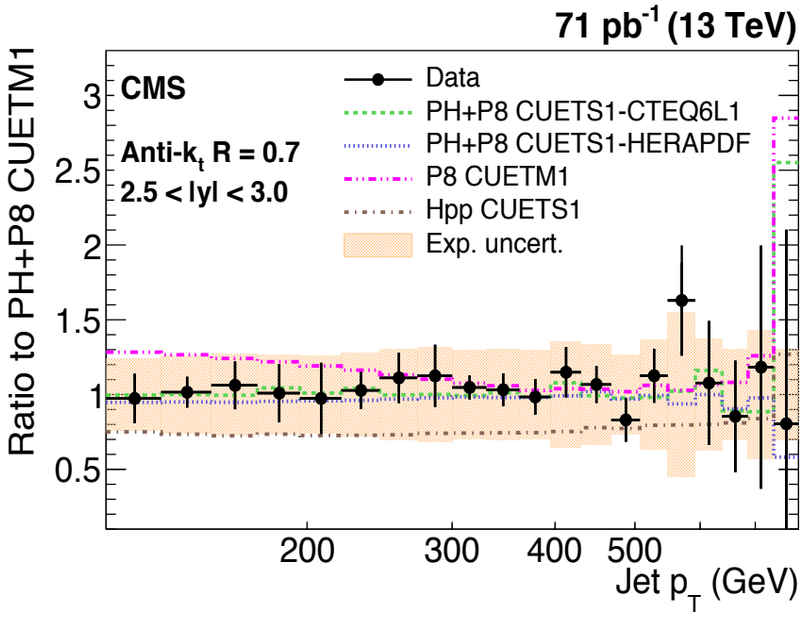












arXiv:1605.04436

- Predicted cross sections follow the data in each rapidity bin
- Similar performance of predictions from pure ME calc. and MC generators

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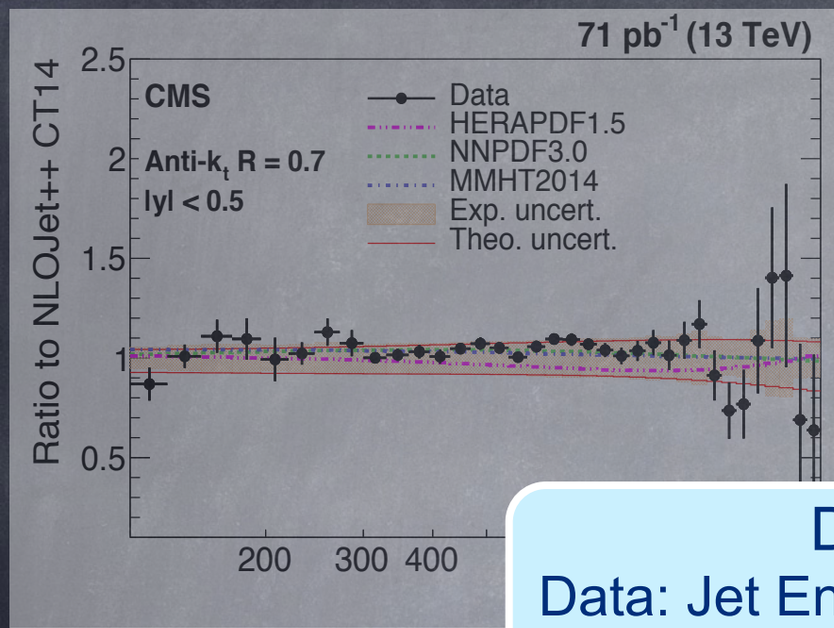

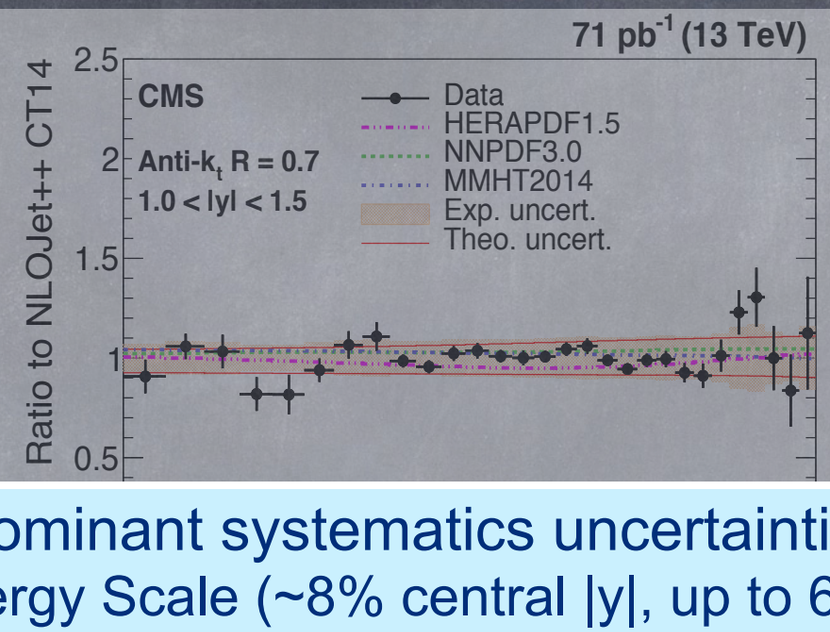

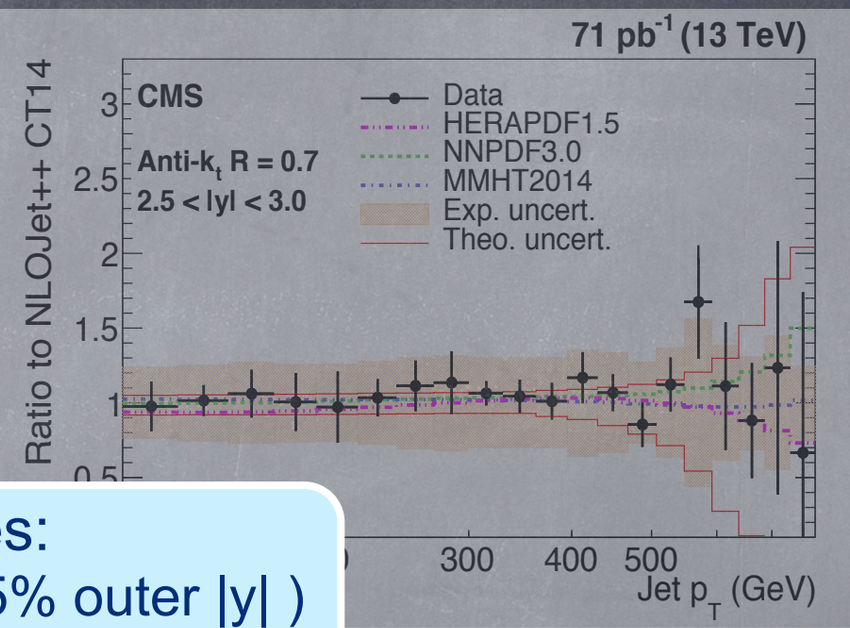

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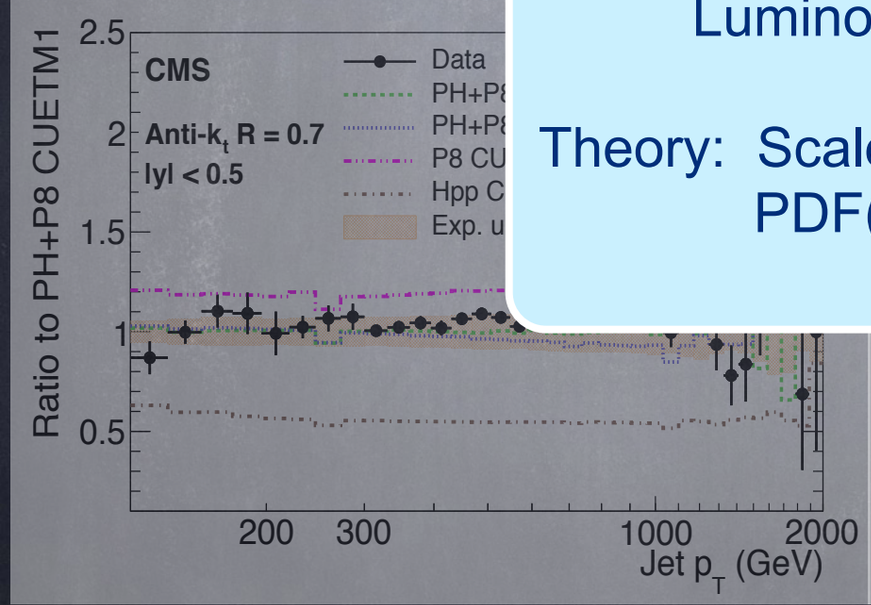

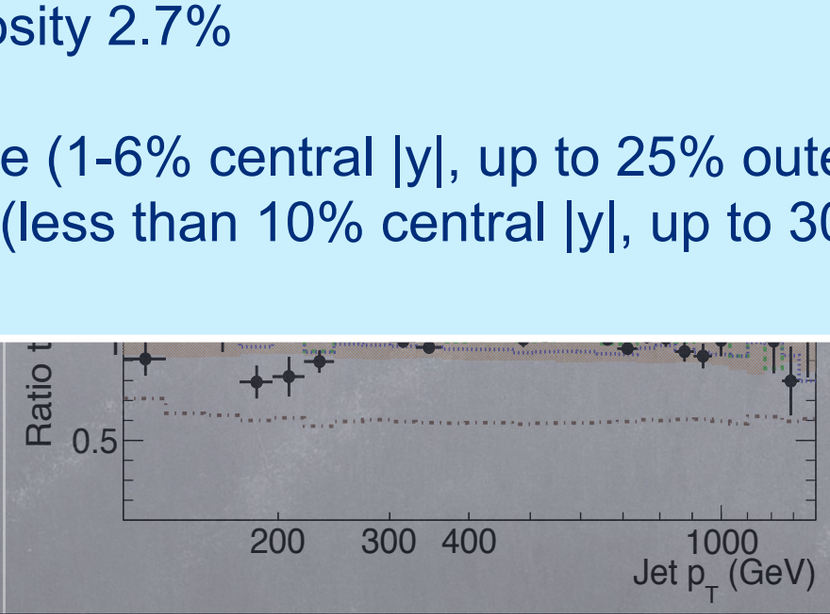

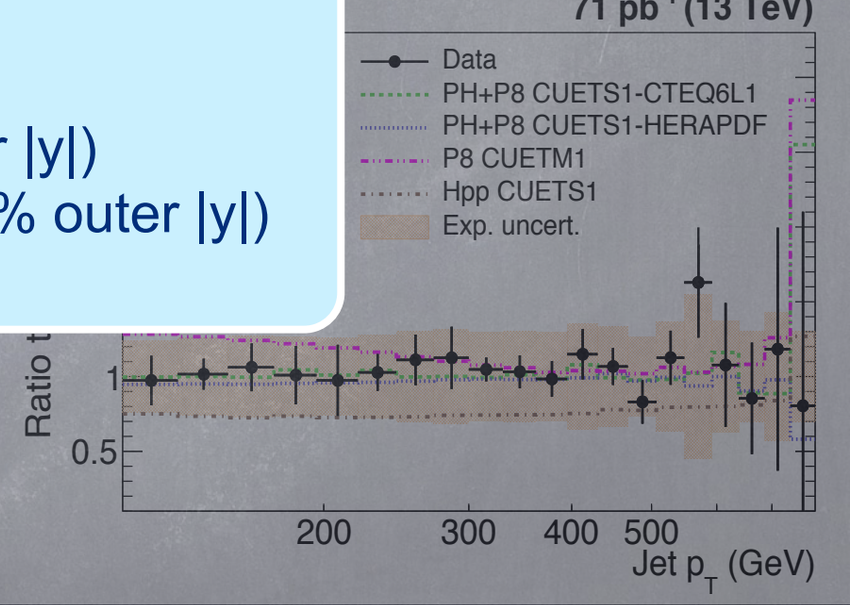

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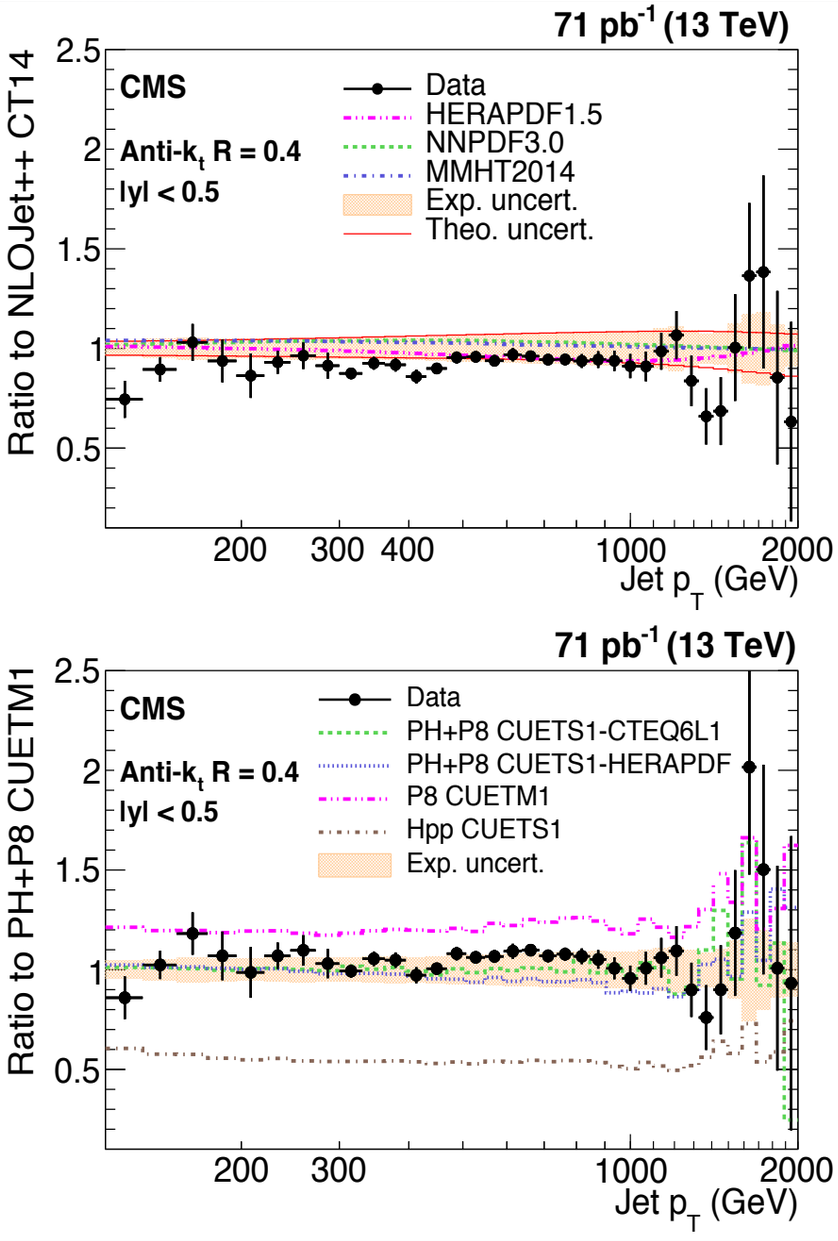
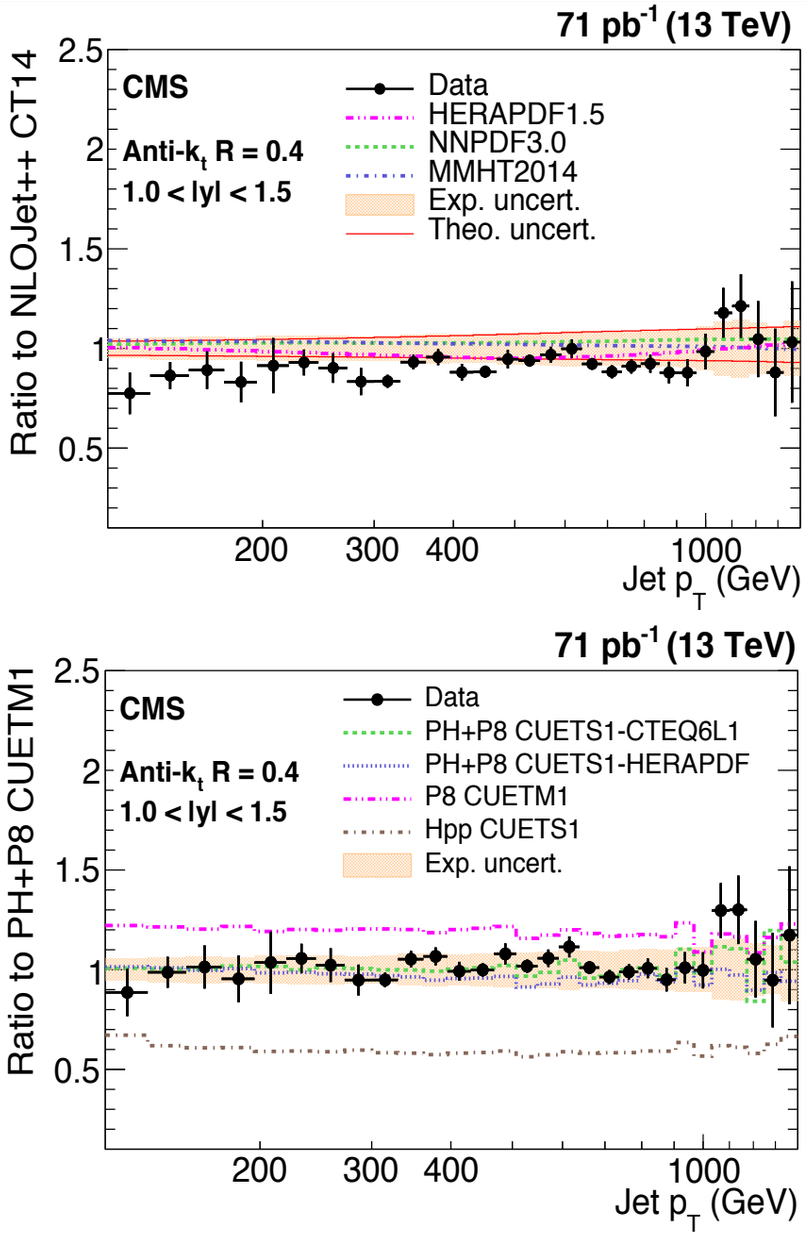
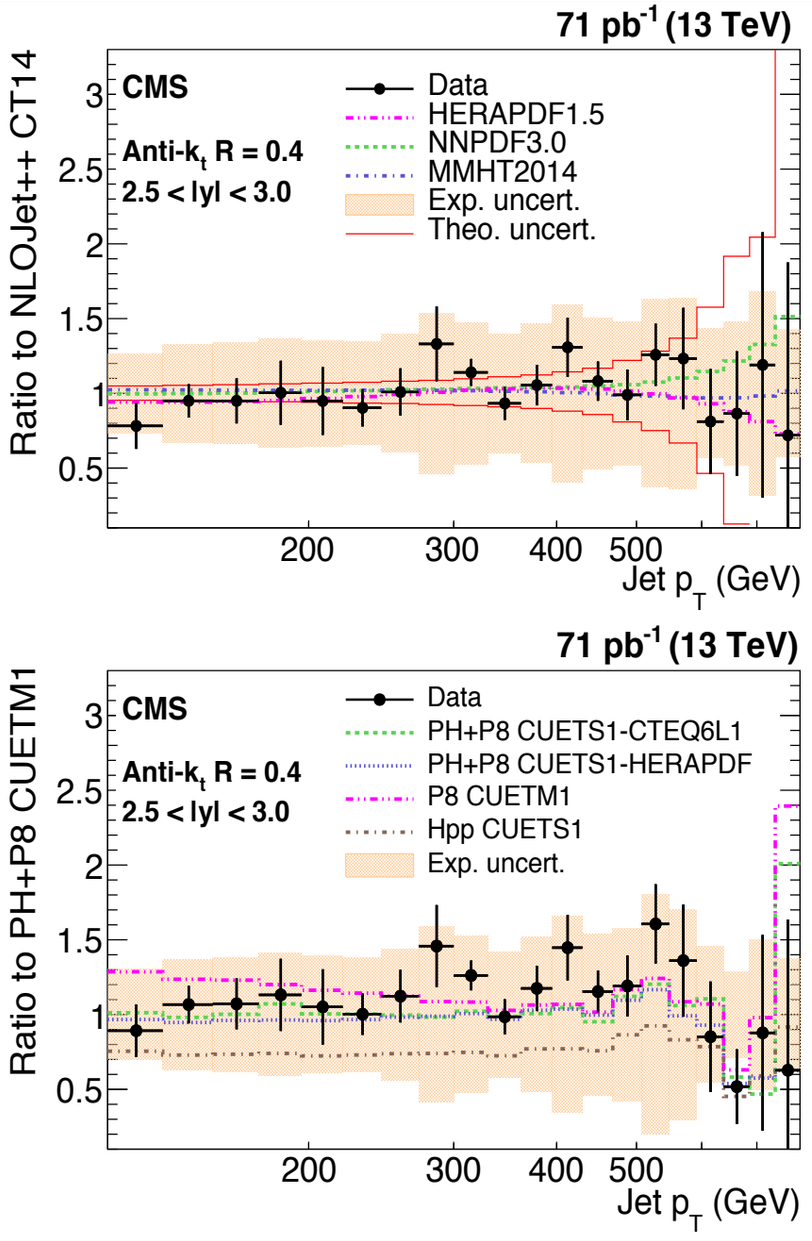
Inclusive Jet Cross Section @ 13 TeV : Ratios



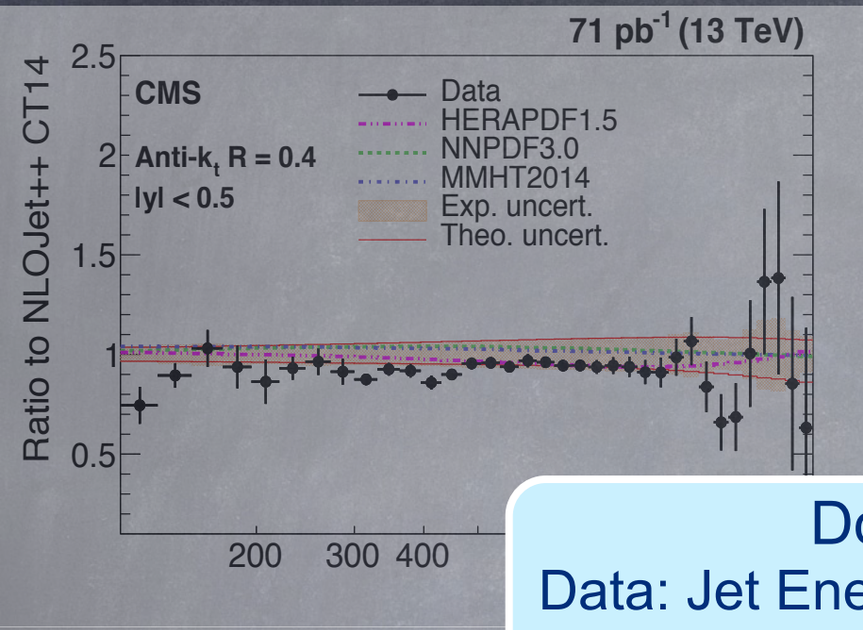


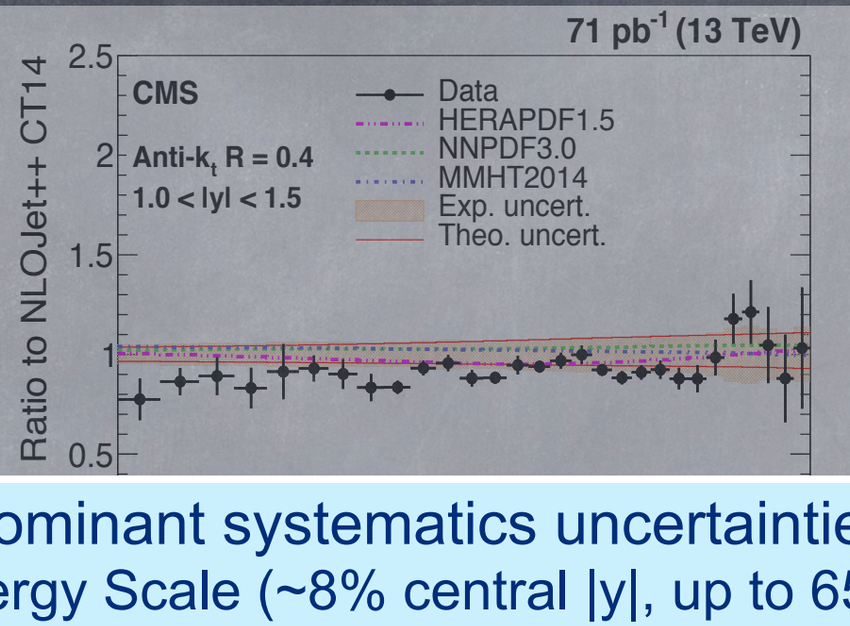


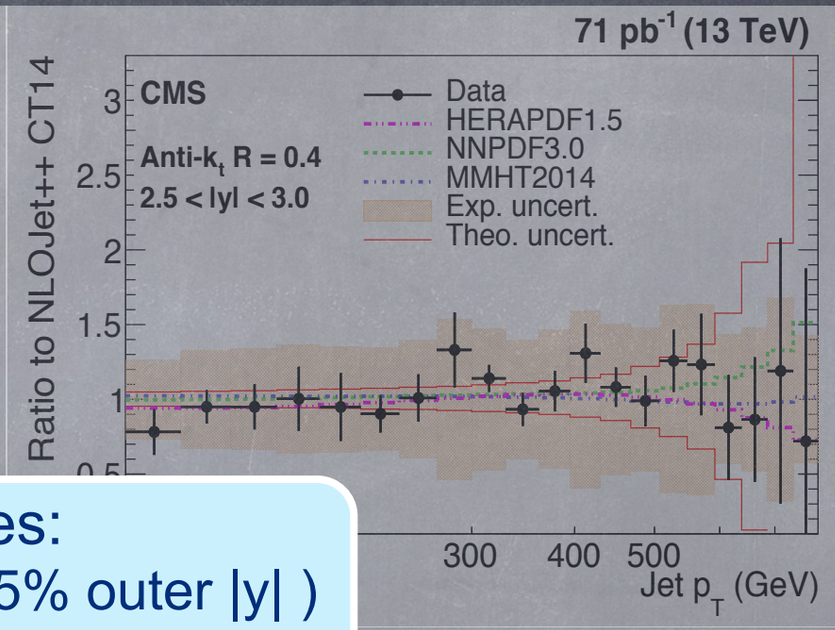
arXiv:1605.04436

- Predicted cross sections follow the data in each rapidity bin
- Better performance of predictions from MC generators than pure ME calc.

Inclusive Jet Cross Section @ 13 TeV : Ratios



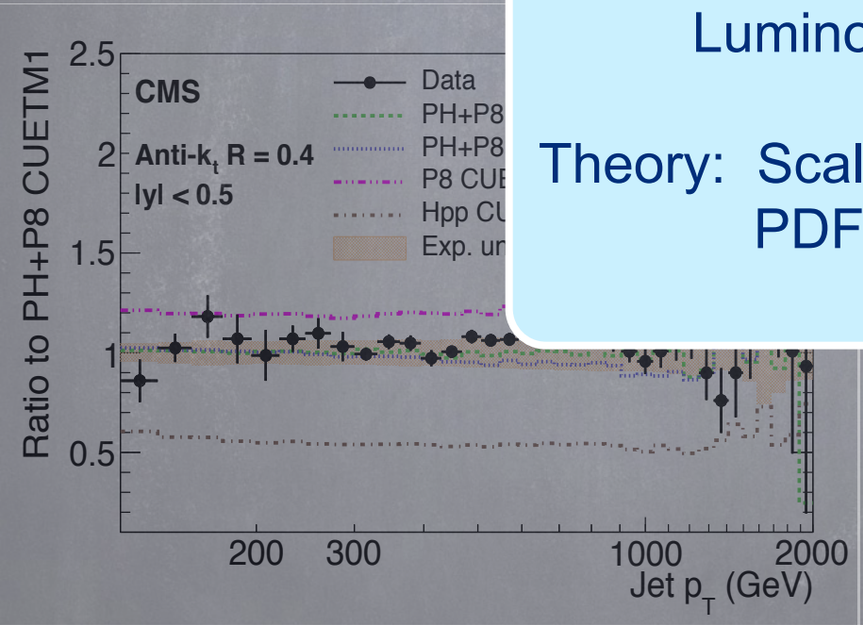


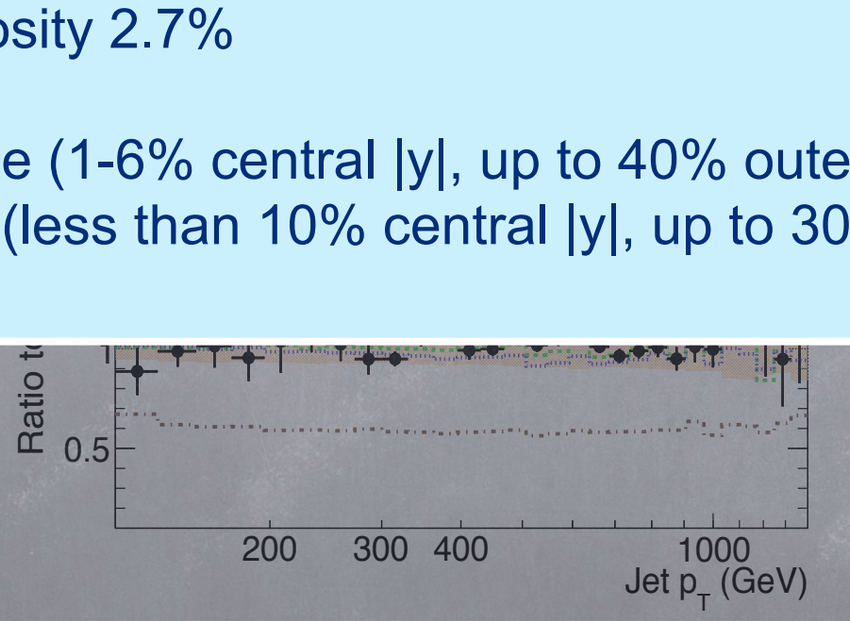


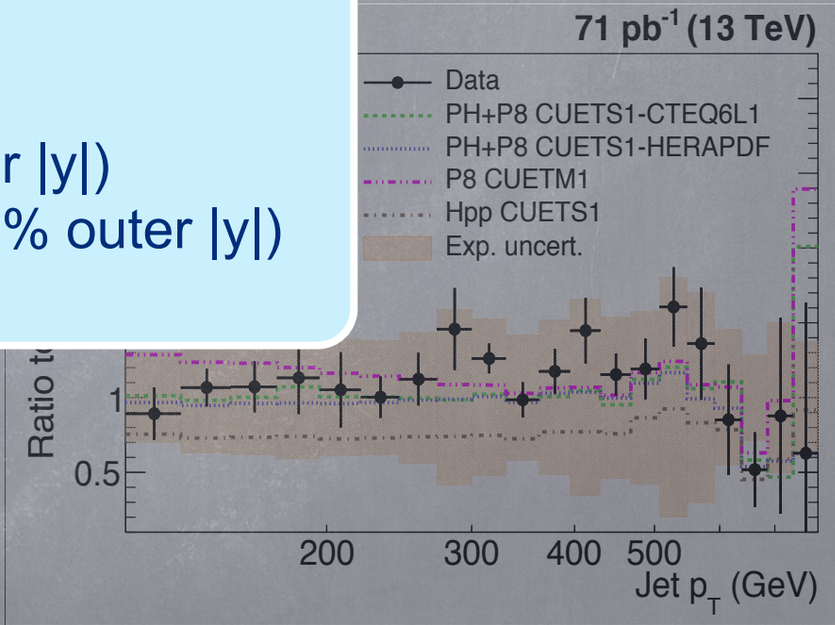
Dominant systematics uncertainties:

Data: Jet Energy Scale (~8% central |y|, up to 65% outer |y|)
Luminosity 2.7%

Theory: Scale (1-6% central |y|, up to 40% outer |y|)
PDF(less than 10% central |y|, up to 30% outer |y|)







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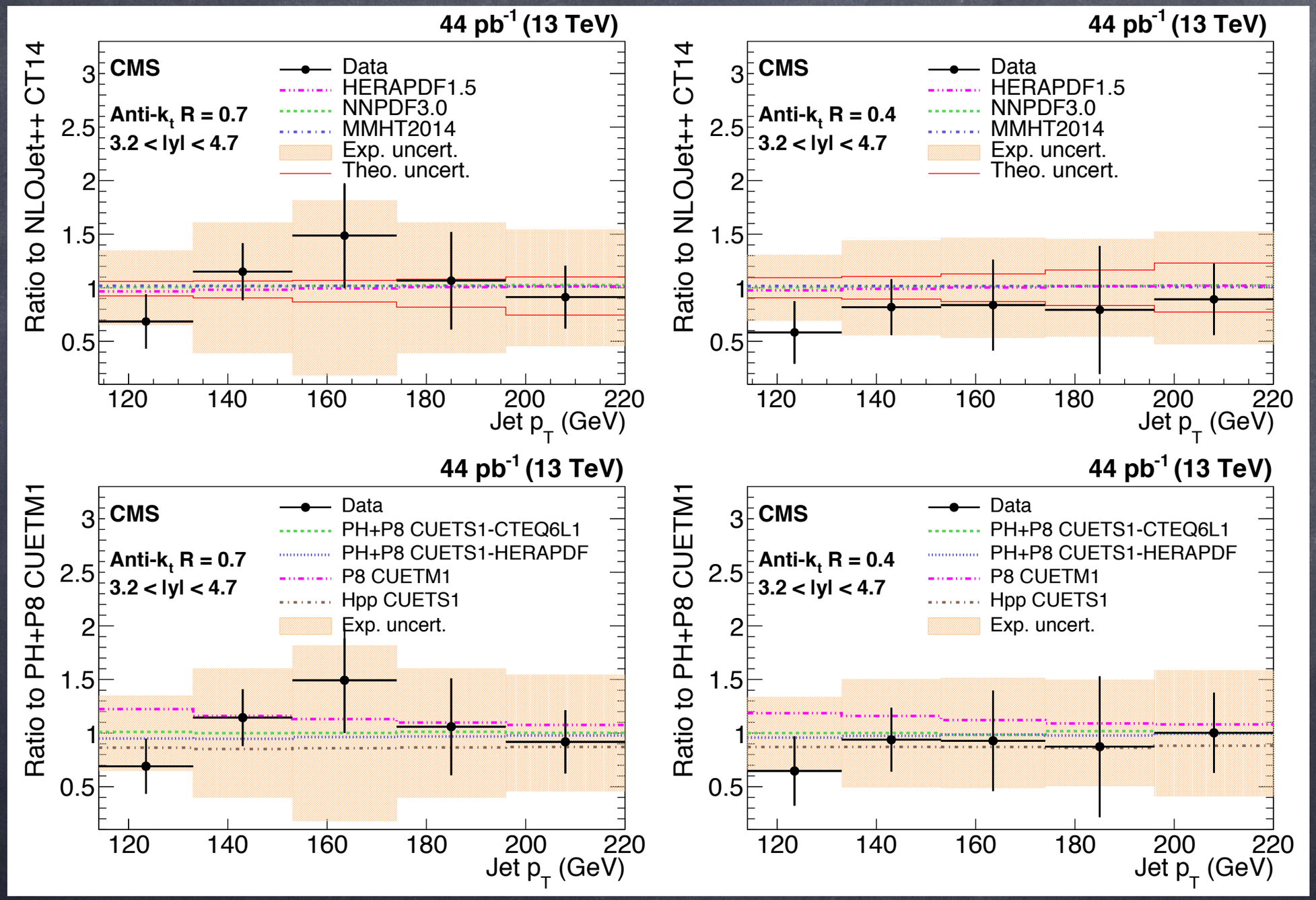
Inclusive Jet Cross Section @ 13 TeV : Forward region



arXiv:1605.04436

Predicted cross sections follow the data well in the outermost rapidity region

Summary

- CMS experiment performed a wide range of jet measurements at various collision energies
- Double differential cross-sections are measured for inclusive jets :
  - ★ $p_T \in [74,2500]$ GeV
  - ★ $|y| < 4.7$
- CMS Inclusive Jet @ 8 TeV Data :
  - ★ Precision of the gluon distributions improves.
  - ★ Extraction of strong coupling compatible with world average
- Fixed order NLO calculations describes well jet cross section in various rapidity bins but better for large R for clustering algorithm.
- MC event generators with NLO matrix element follow slightly better the data for jets clustered with small R.

Backup Slides

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)

$$xg(x) = A_g x^{B_g} \cdot (1-x)^{C_g}(1+E_g x^2) - A'_g x^{B'_g}(1-x)^{C'_g}$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1+D_{u_v} x + E_{u_v} x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}} \cdot (1+D_{d_v} x)$$
$$x\overline{U}(x) = A_{\overline{U}} x^{B_{\overline{U}}} \cdot (1-x)^{C_{\overline{U}}}(1+D_{\overline{U}} x)$$
$$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}} \cdot (1-x)^{C_{\overline{D}}}(1+D_{\overline{D}} x + E_{\overline{U}} x^2)$$

Table 7: Partial $\chi^2/n_{\rm dp}$ per number of data points $n_{\rm dp}$ for the data sets used in the QCD analysis. The global $\chi^2/n_{\rm dof}$ per degrees of freedom of 1471/1216 is obtained, with correlated χ^2 of 94.

Data sets		Partial $\chi^2/n_{\rm dp}$
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

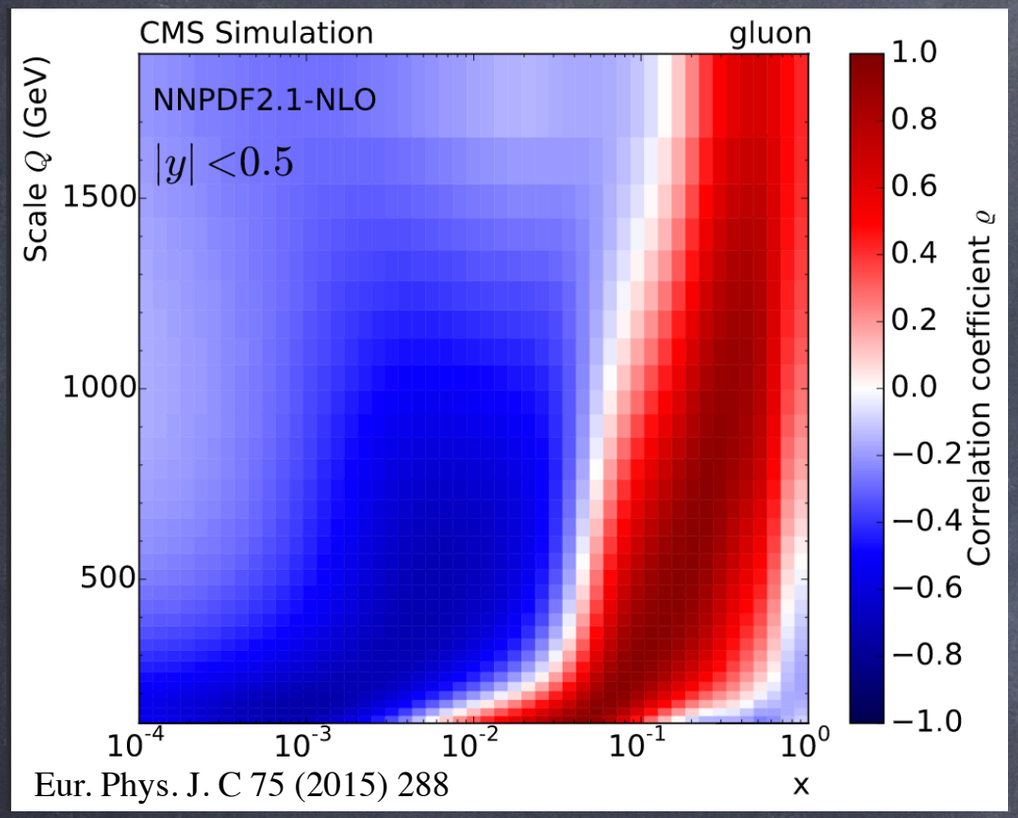
χ^2 definitions

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

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

Probing QCD with Jet Cross Sections

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



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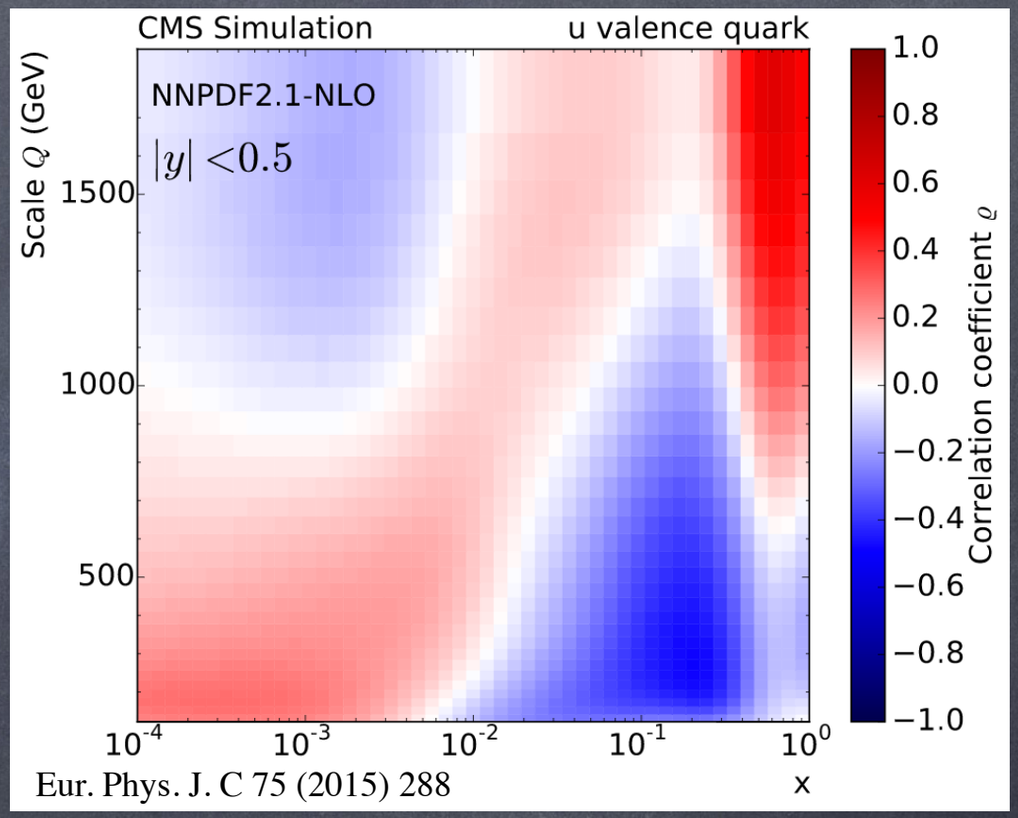
Strong correlation between inclusive jet cross section and quark at high x



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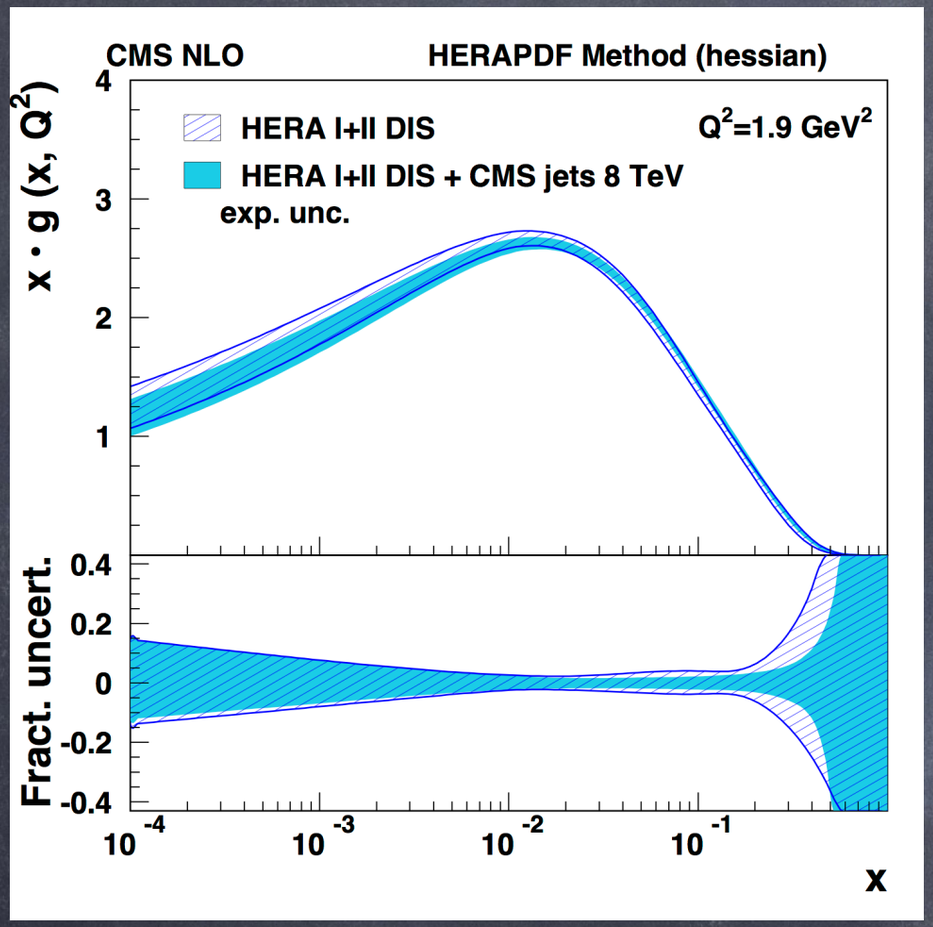
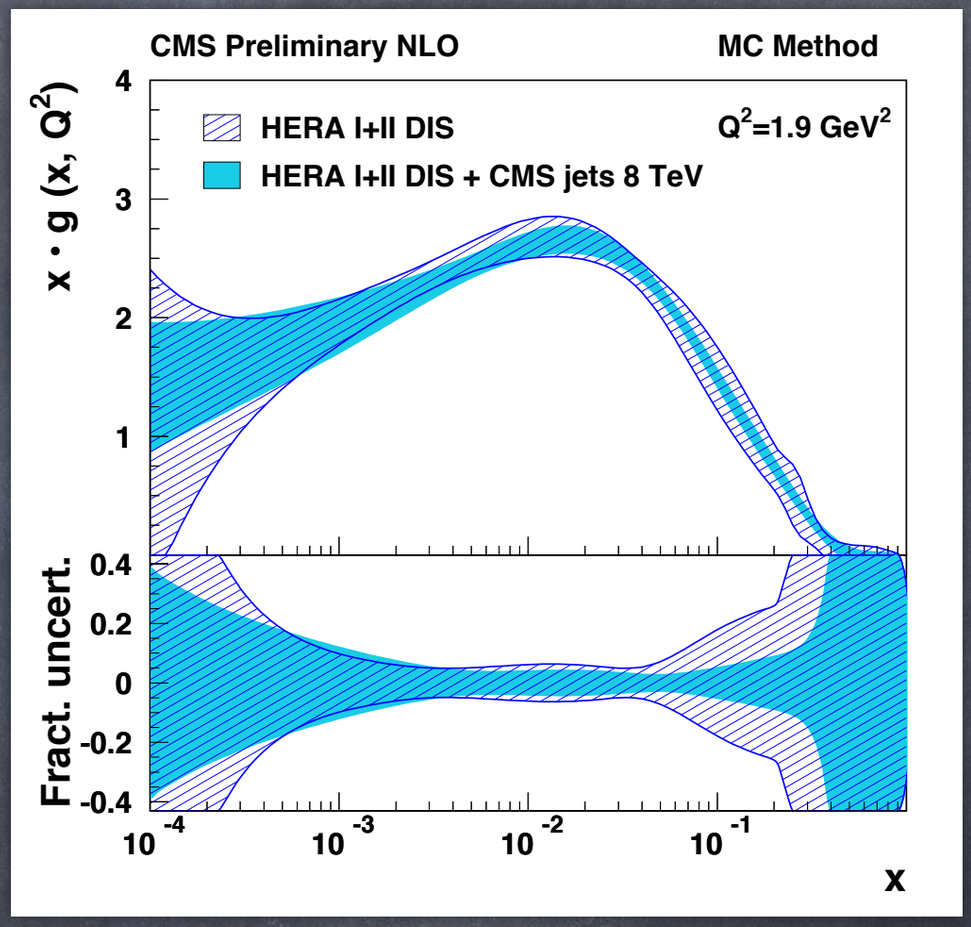
The potential impact of the CMS inclusive jet data can be illustrated by the correlation between the inclusive jet cross section $\sigma_{\text{jet}}(Q)$ and the PDF $xf(x, Q^2)$ for any parton flavour f. The NNPDF Collaboration [63] provides PDF sets in the form of an ensemble of replicas i, which sample 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

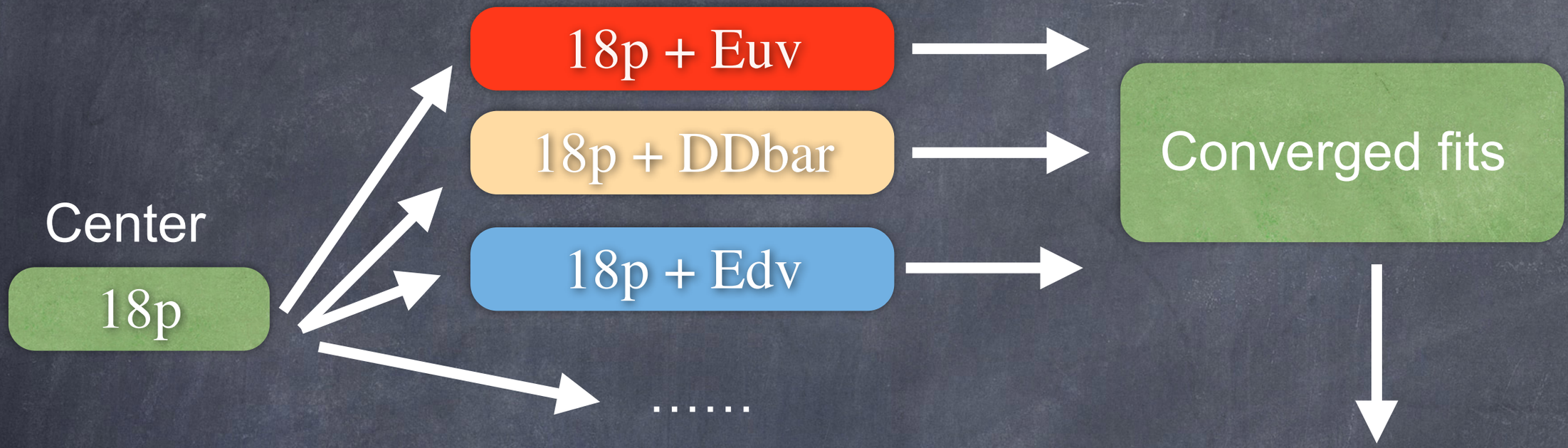
$$\varrho_f(x,Q) = \frac{N}{(N-1)} \frac{\langle \sigma_{\text{jet}}(Q)_i \cdot xf(x,Q^2)_i \rangle - \langle \sigma_{\text{jet}}(Q)_i \rangle \cdot \langle xf(x,Q^2)_i \rangle}{\Delta_{\sigma_{\text{jet}}(Q)} \Delta_{xf(x,Q^2)}}. \quad (12)$$

Hessian vs MC





Parametrisation Uncertainty



- Get the largest difference
- Construct envelope