New constraints on PDFs with CMS data

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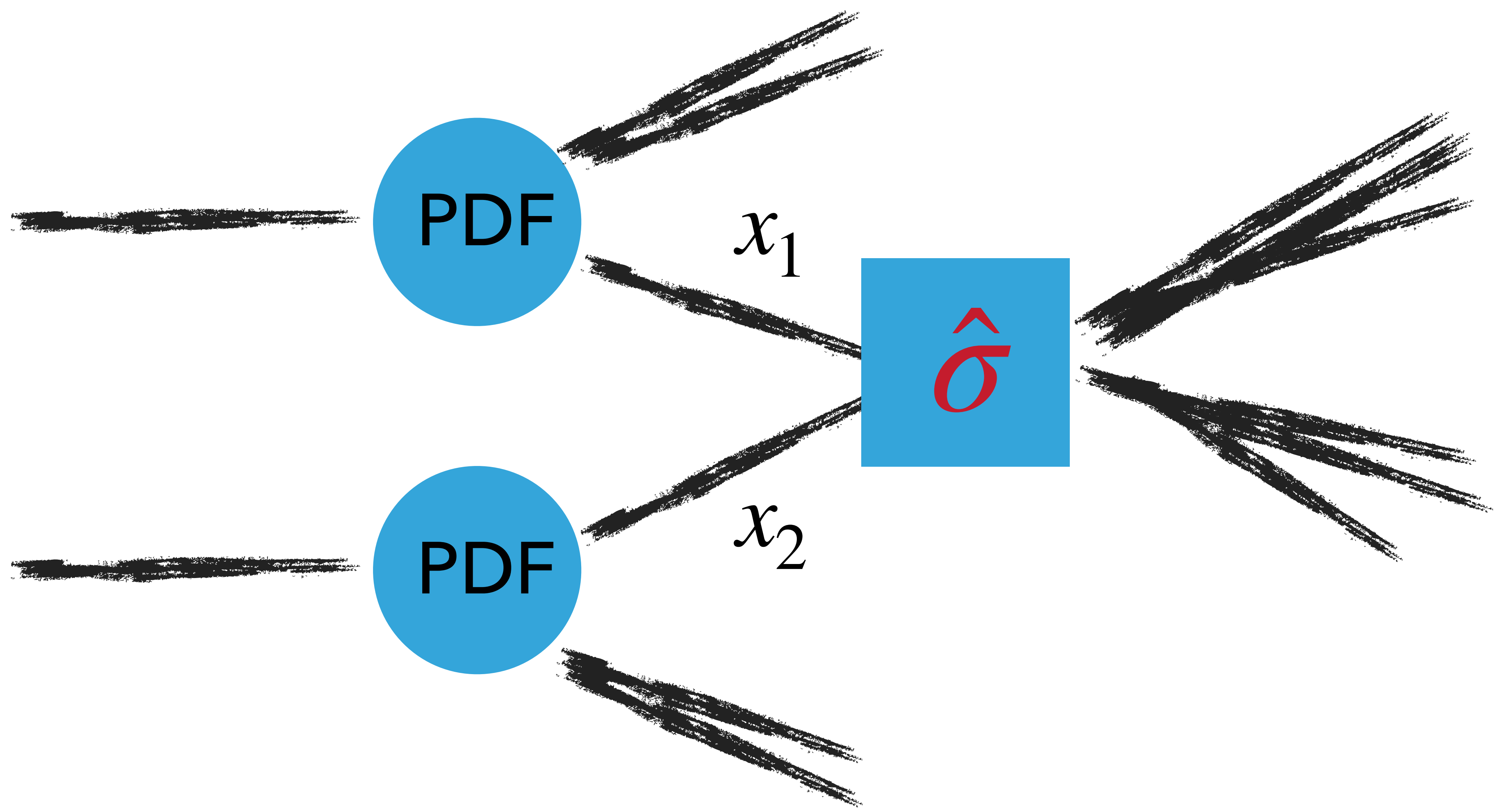
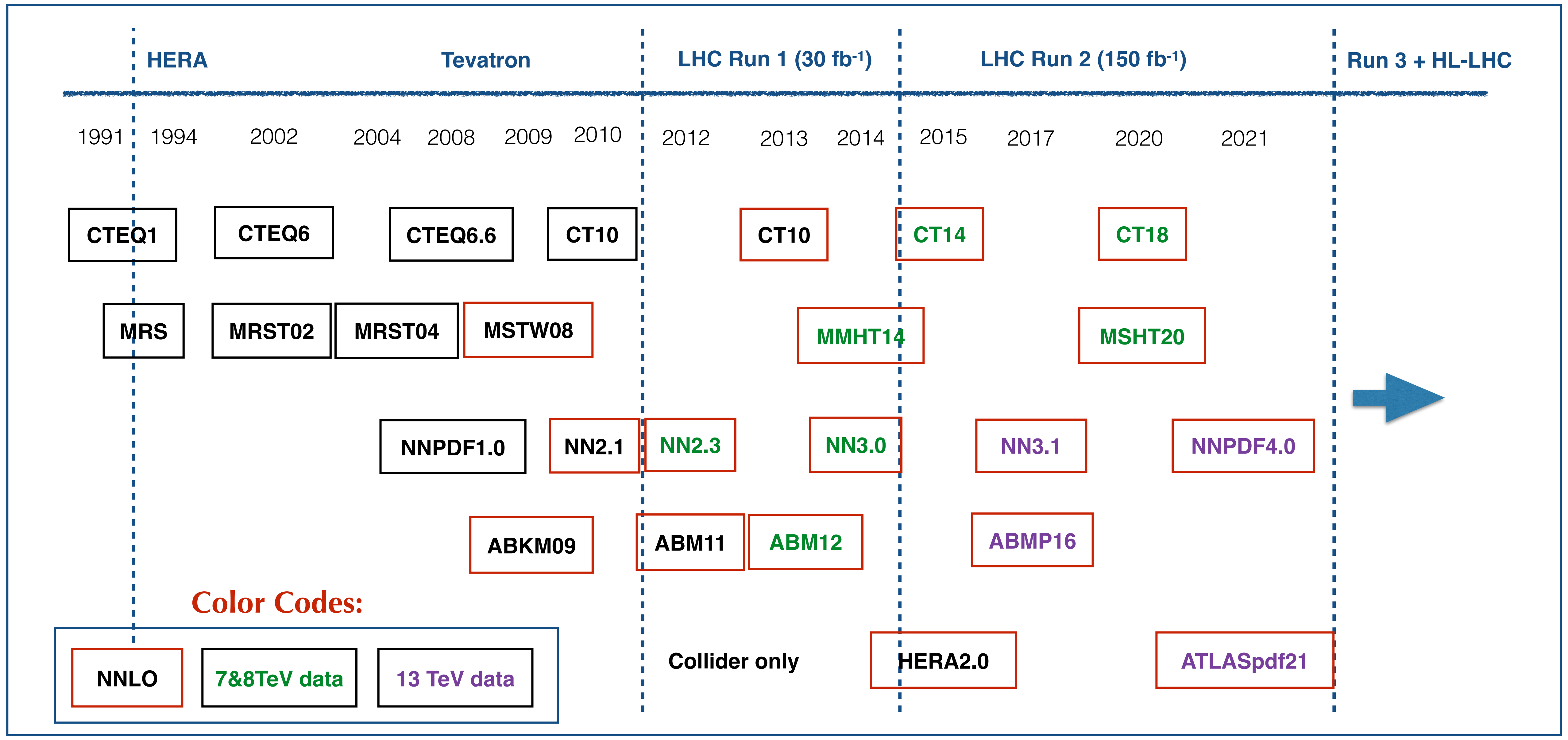
Introduction

- Collinear factorization allows us to separate long- and short-distance contributions
- PDFs:
- Intrinsic properties of nucleons → process independent
- Usually extracted from data: DIS, Drell-Yan, jets, top quark



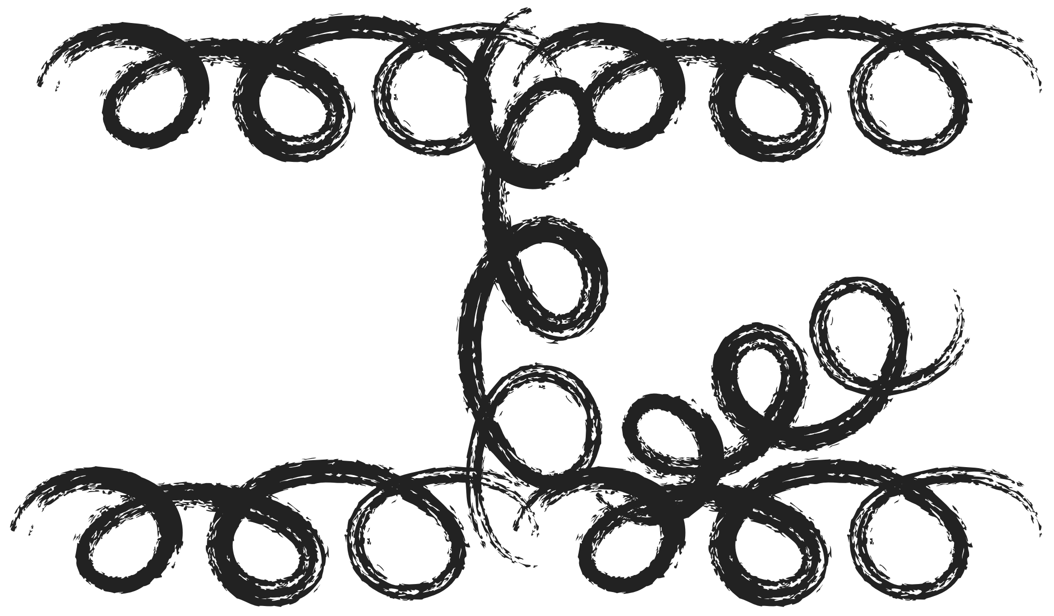
- One of the main sources of uncertainty in hadronic collisions
- Critical to precision measurements at hadron colliders.
- Several state of the art PDF sets at NNLO



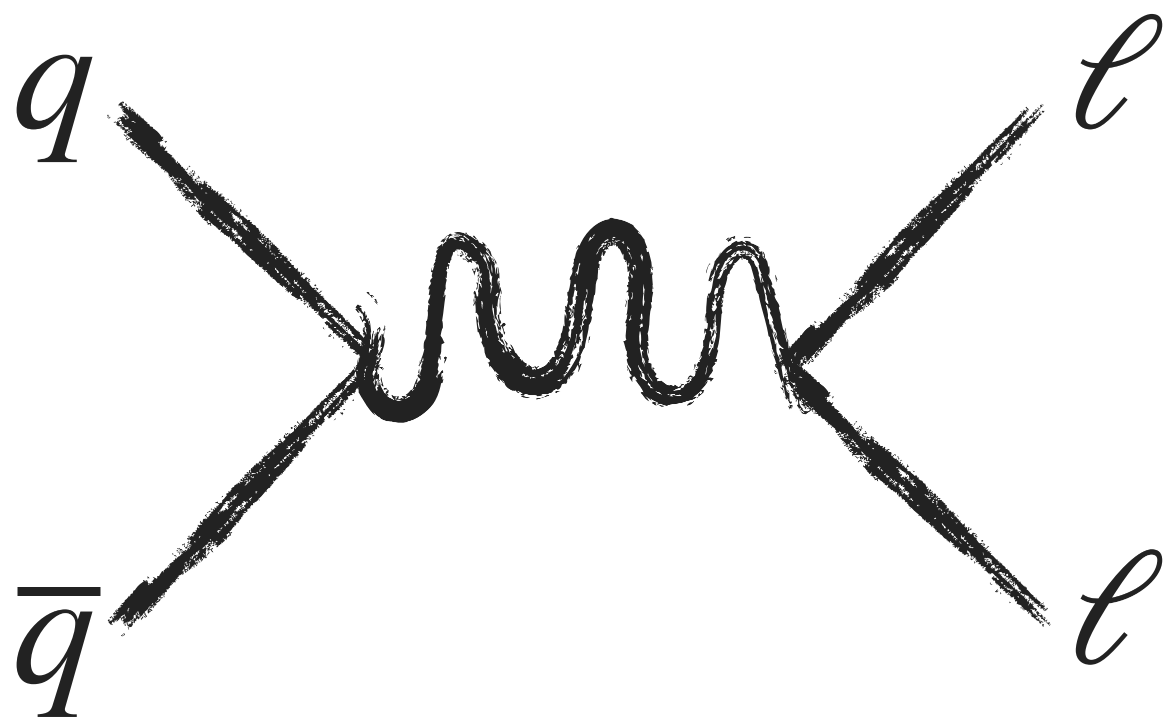
Jun Gao DIS22

Introduction

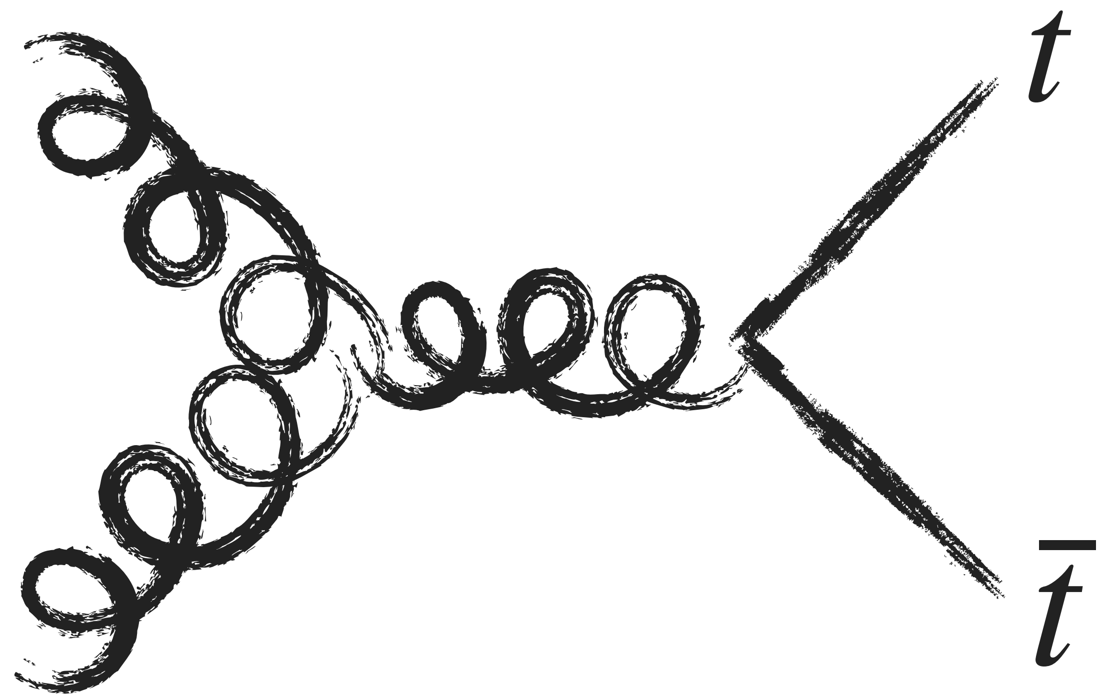
- Hard scattering processes used to constrain PDFs:
- Jets: g, q PDFs at mid-high x



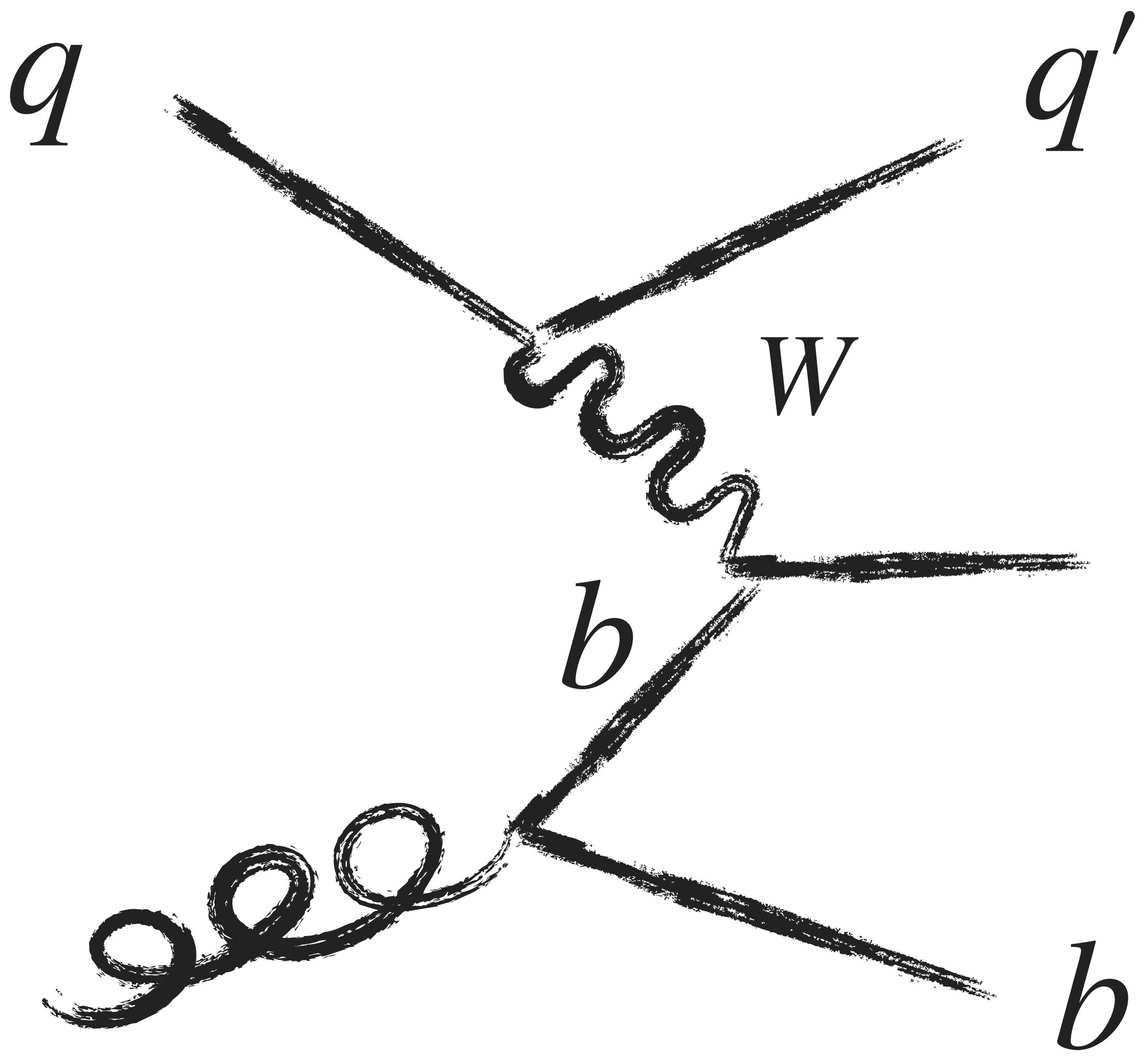
- DY+Jets: q, g



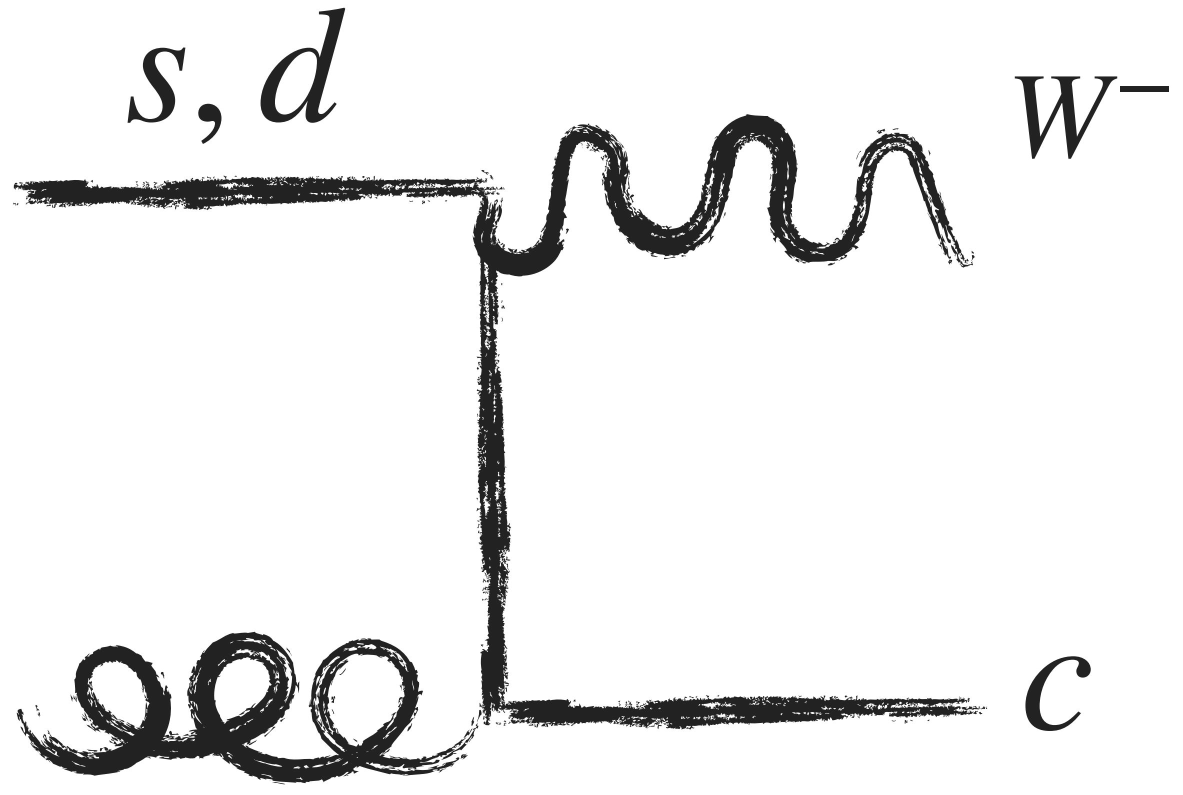
- Top quark pair: g at high x



- Single top: b and light quarks PDFs



- V + heavy quark: s-quark content



Introduction

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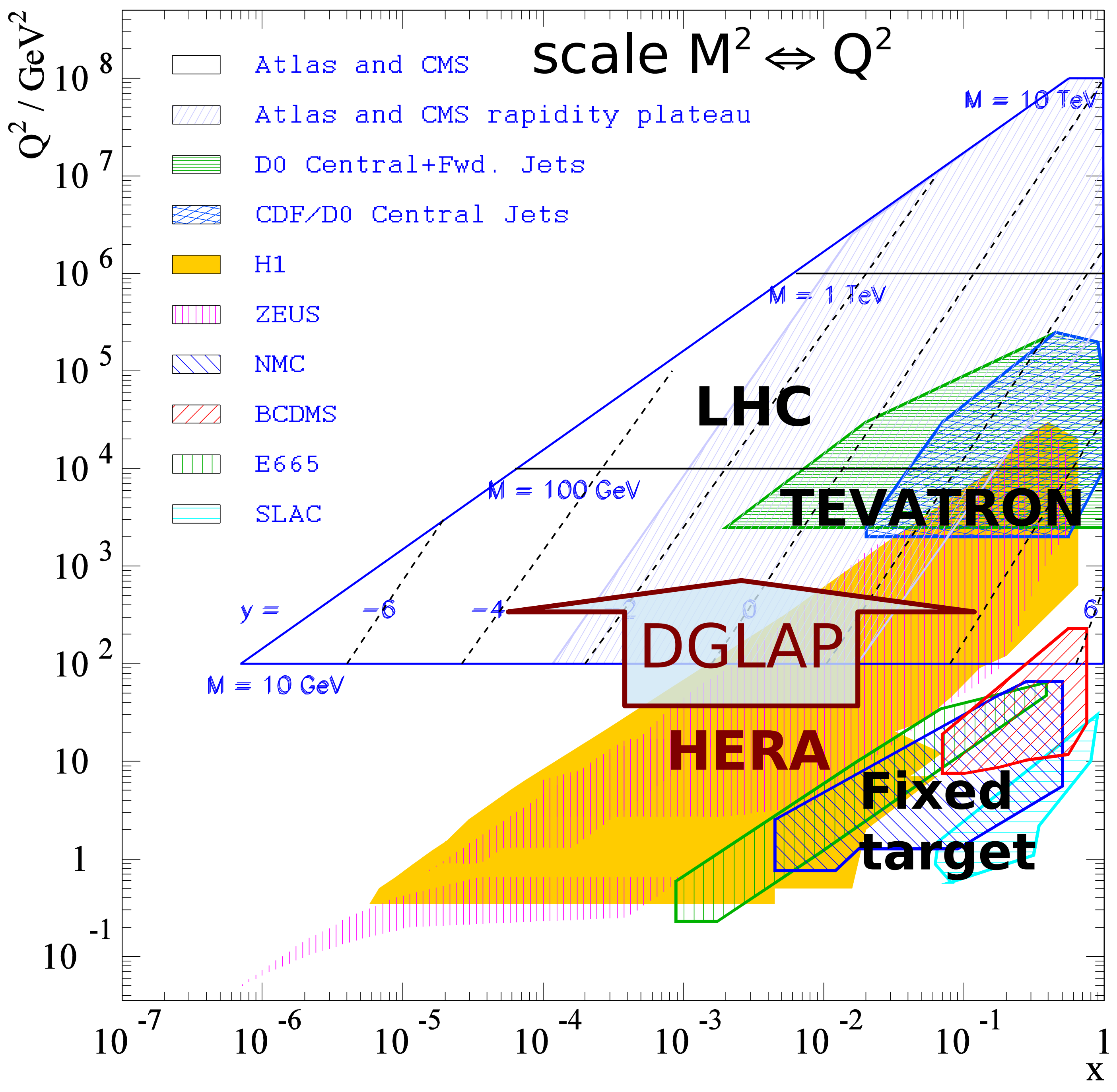
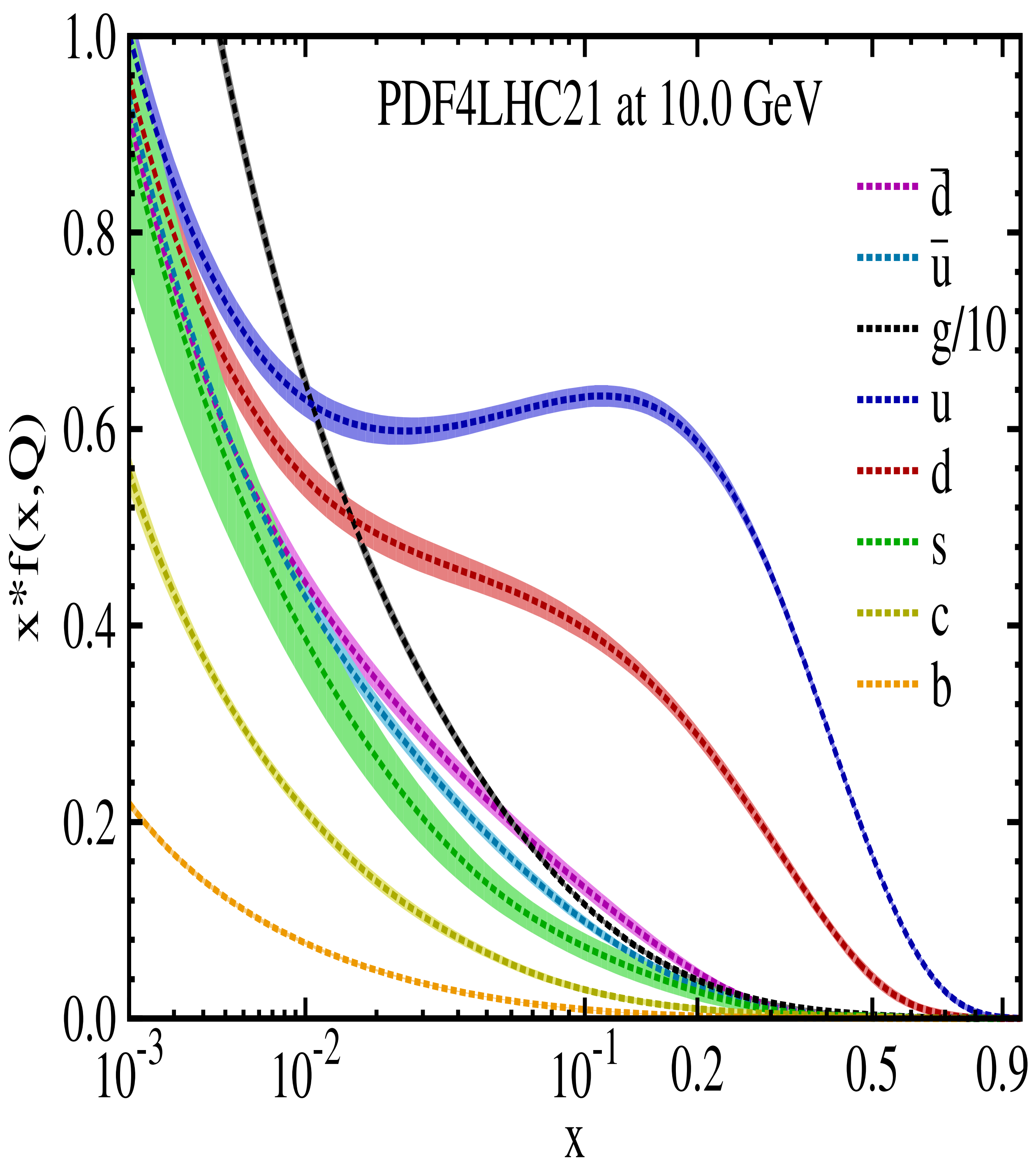
- Top quark pair: g at high x

Jun Gao DIS22





parameter variations

$\alpha_S(M_Z)$

Mc, Mb, Mt

QCD/EW corrections

nuclear corrections

EW parameters

New Physics

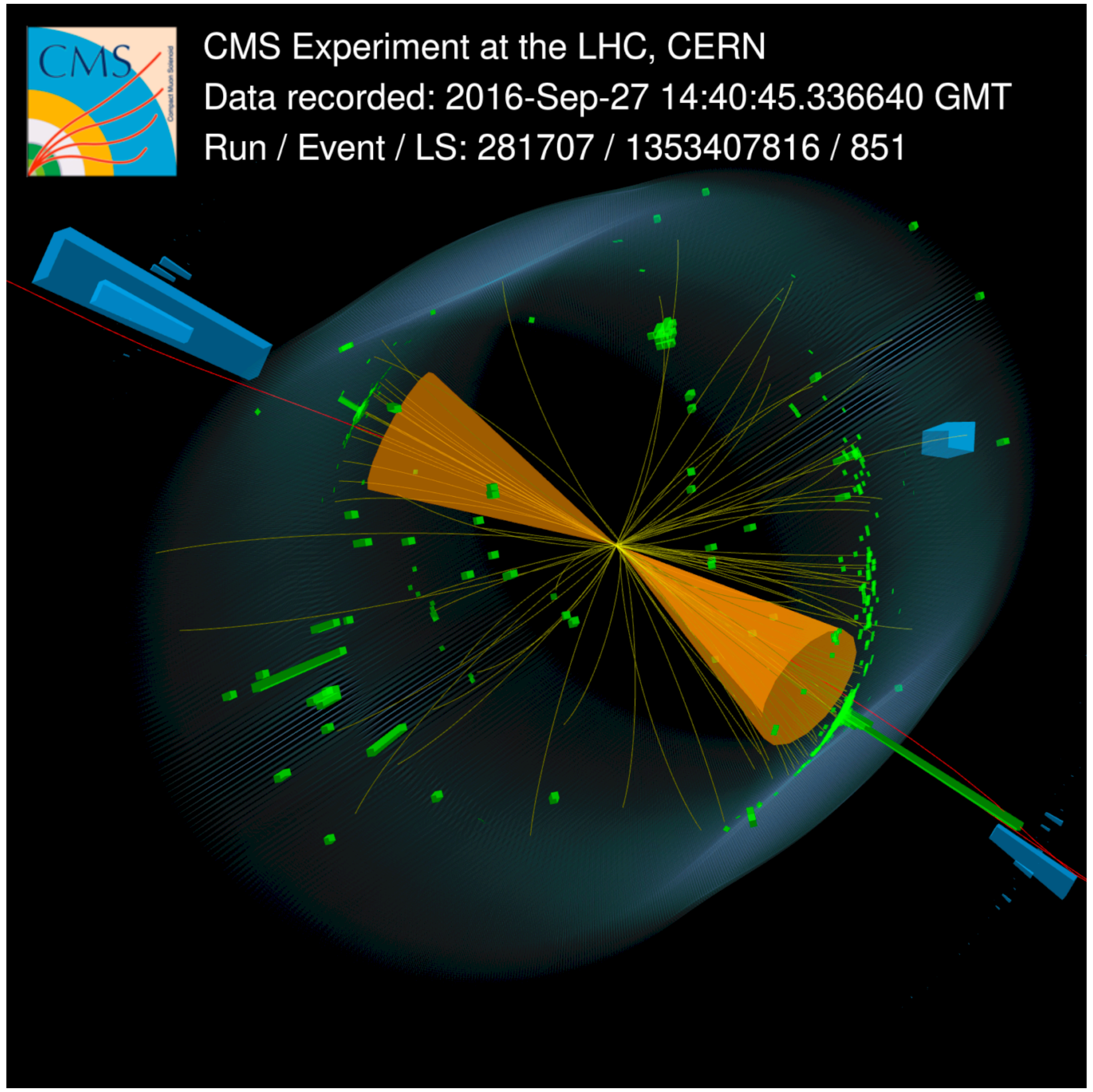
Inclusive jet production [JHEP 02, (2022) 142]

- Inclusive jet production extensively studied @ ATLAS and CMS at different $\sqrt{s}$
- Directly sensitive to gluon distribution
- Xsec measurements put constraints to PDFs and α_S

Methods

- Data sample corresponds to 36.3 fb^{-1} (33.5 fb^{-1}) recorded in 2016 for events with jets clustered with anti-kt algorithm (AK) with R = 0.4 (0.7)
- Inclusive jet double-differential xsec is calculated

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

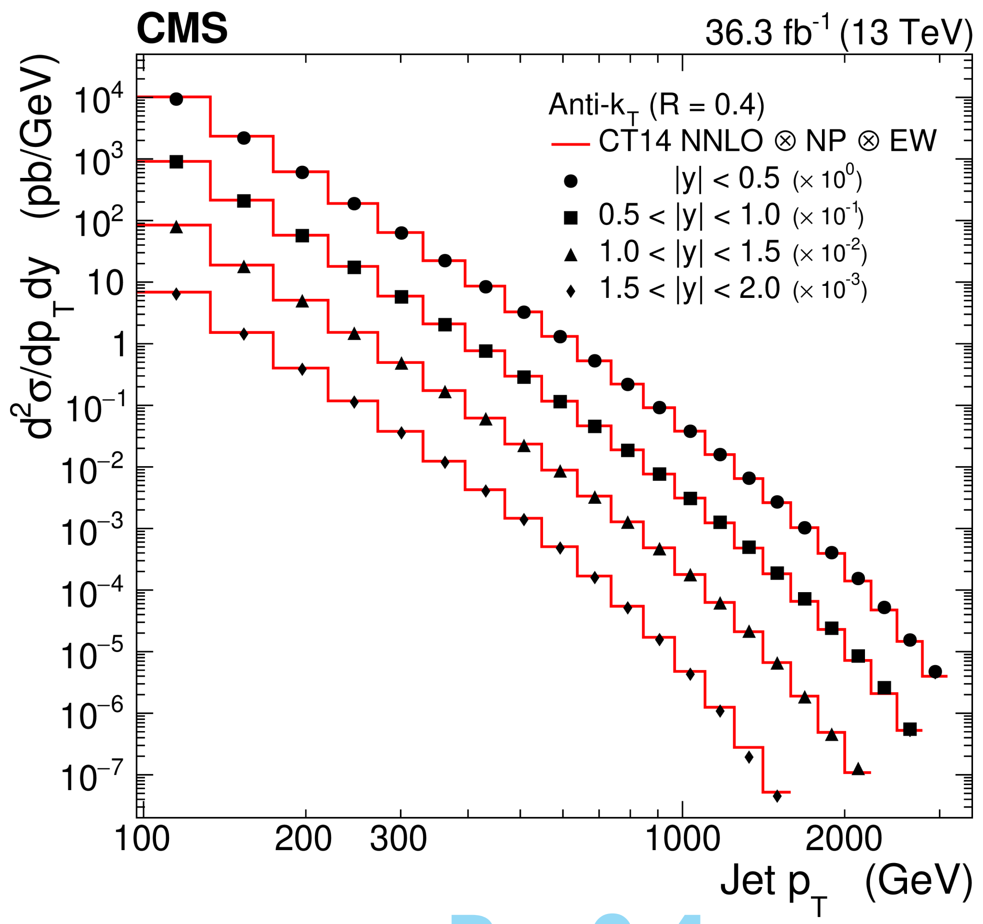


CMS-PHO-EVENTS-2021-020

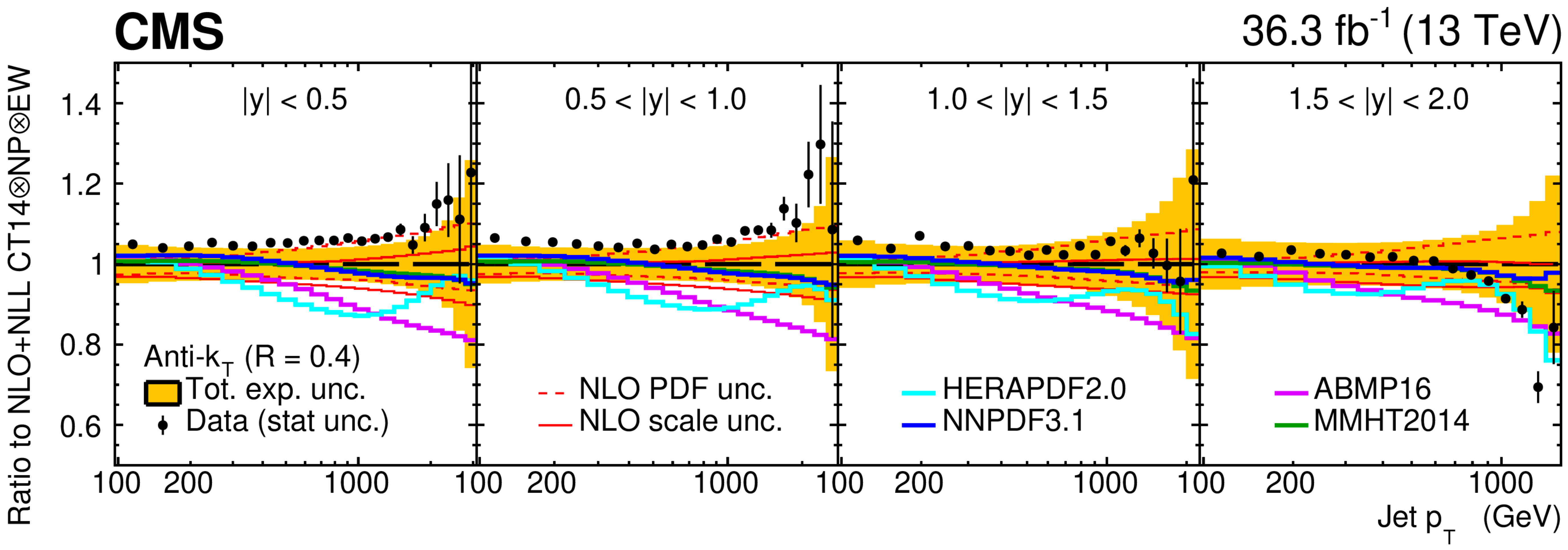
Inclusive jet production [JHEP 02, (2022) 142]

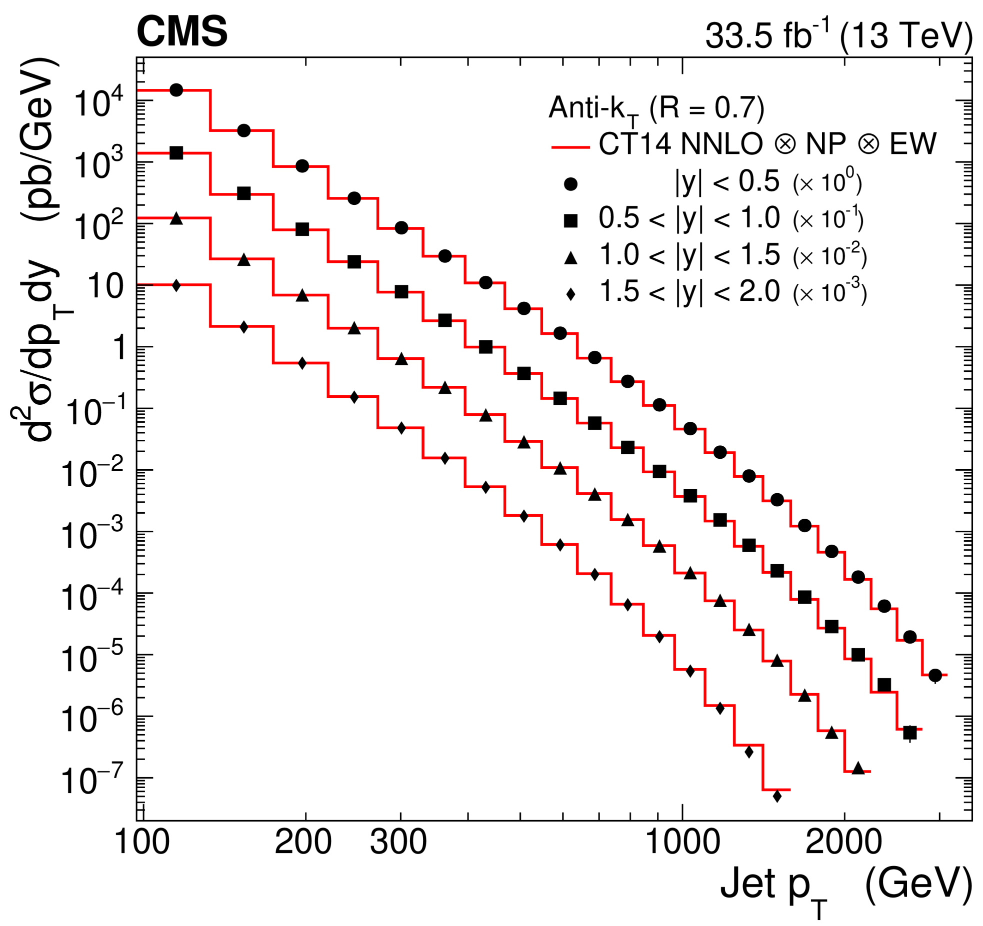
Results

- Xsec compared to QCD predictions.
- Significant differences at high pT → need for higher PDFs sensitivities at large x

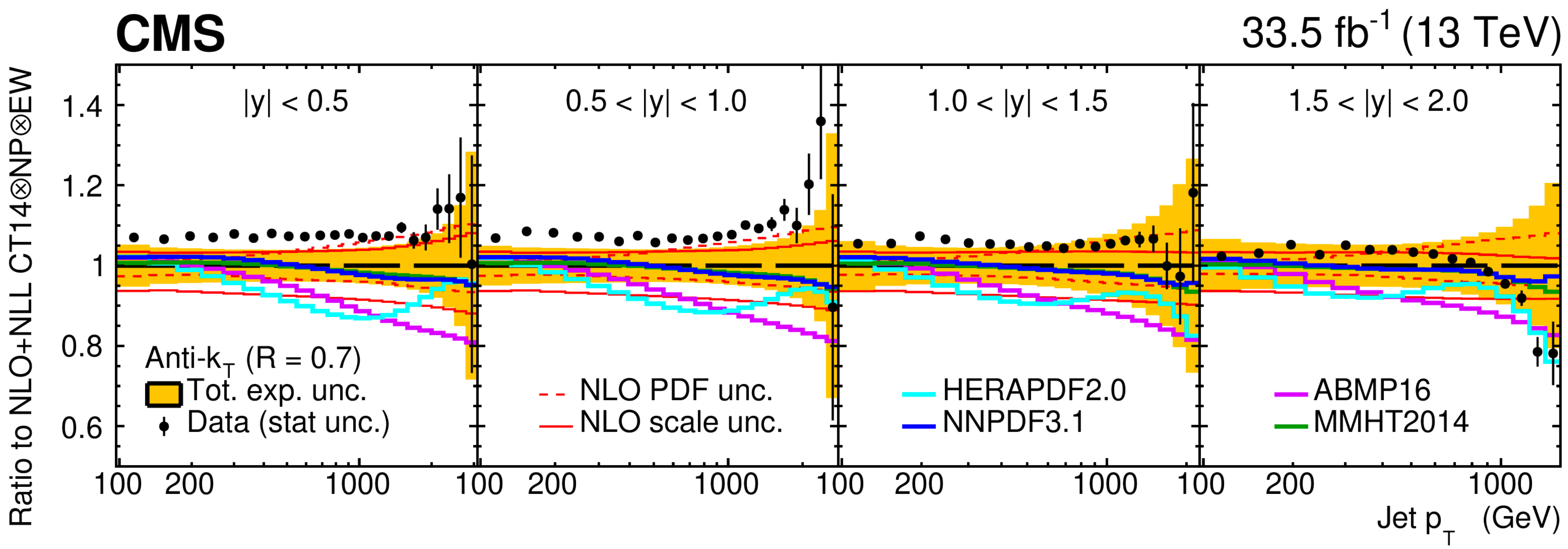


R = 0.4





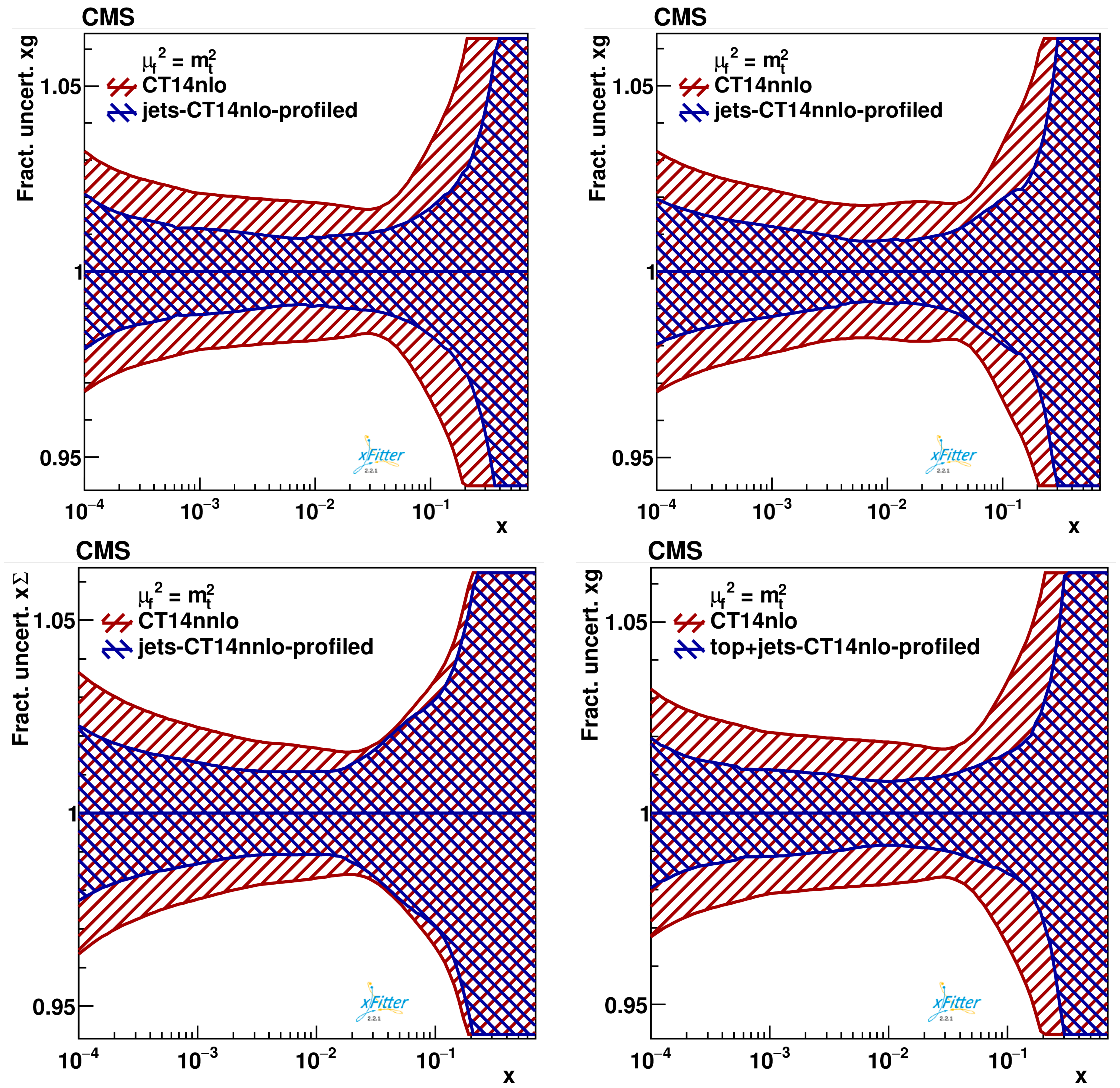
R = 0.7



Inclusive jet production [JHEP 02, (2022) 142]

QCD profiling analysis

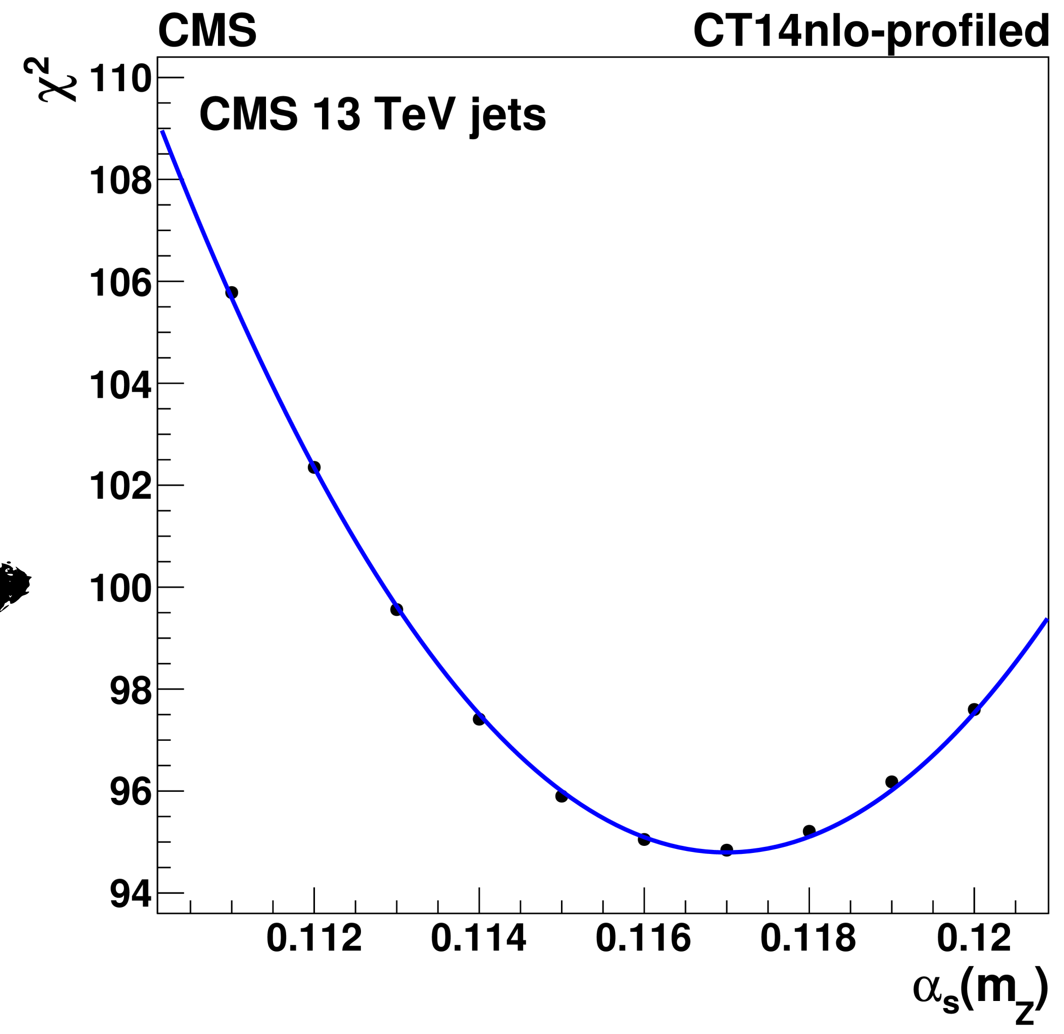
- AK7 jet result is used for this analysis. In addition $t\bar{t}$ xSecs from CMS [EPJ C 80, 658 (2020)].
- PDF profiling with CT14 at NLO and NNLO
- Significant improvement in gluon PDF in full x range and medium x range for sea distribution.
- $t\bar{t}$ reduces uncertainties at high x values.



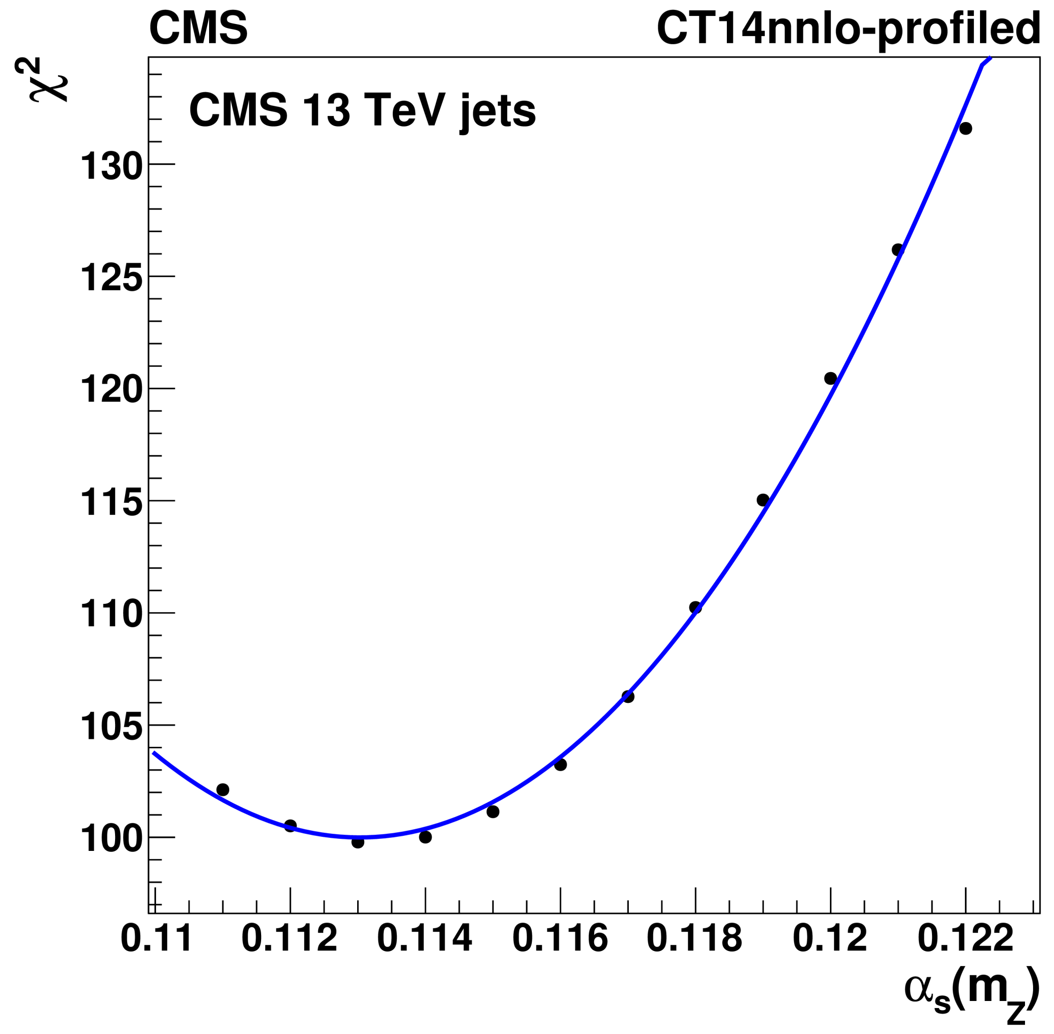
Inclusive jet production JHEP 02, (2022) 142

Impact on α_s

- In addition to the PDF profiling, impact of the measurement on α_s is investigated at NLO and NNLO.

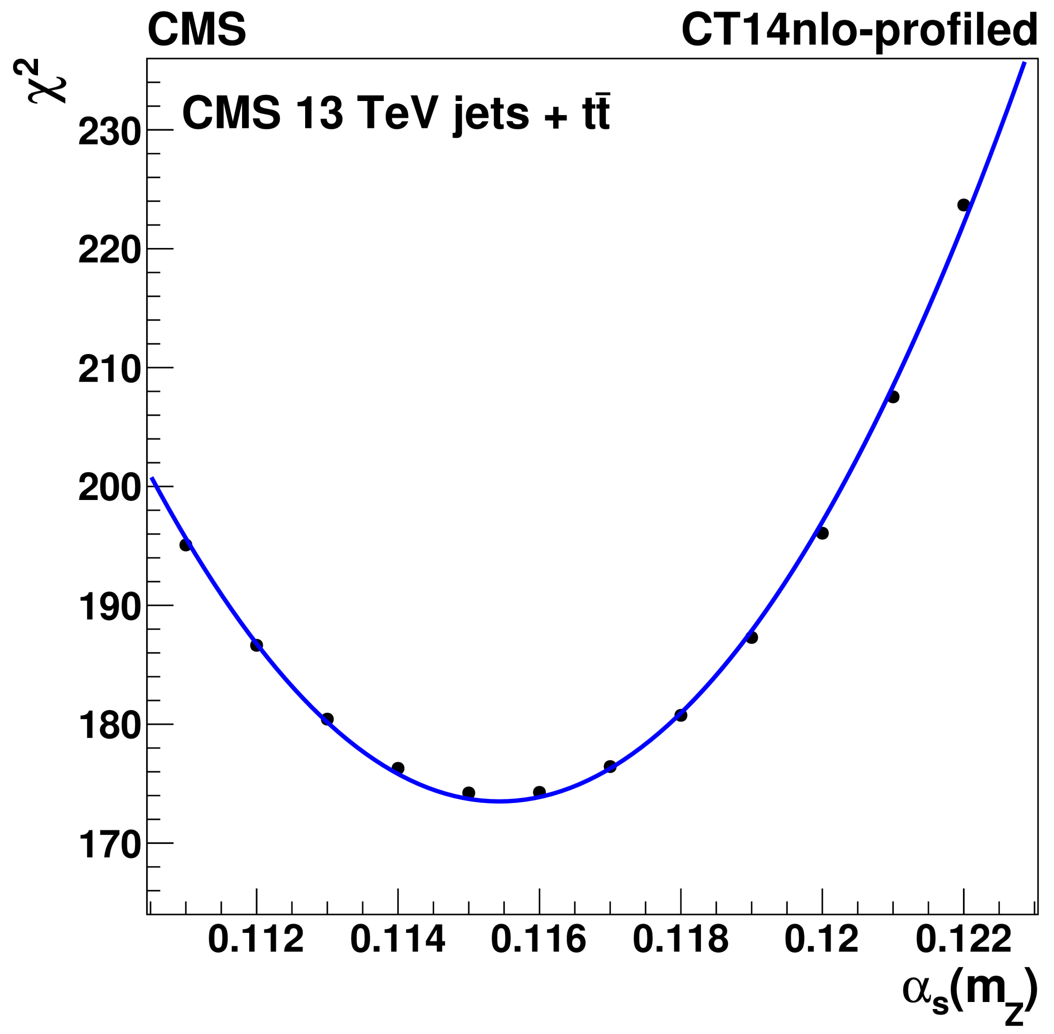


$\alpha_s(m_Z) = 0.1170 \pm 0.0018(\text{PDF}) \pm 0.0035(\text{scale})$



$\alpha_s(m_Z) = 0.1130 \pm 0.0016(\text{PDF}) \pm 0.0014(\text{scale})$

- Profiling analysis repeated including $t\bar{t}$.



$\alpha_s(m_Z) = 0.1154 \pm 0.0009(\text{PDF}) \pm 0.0015(\text{scale})$

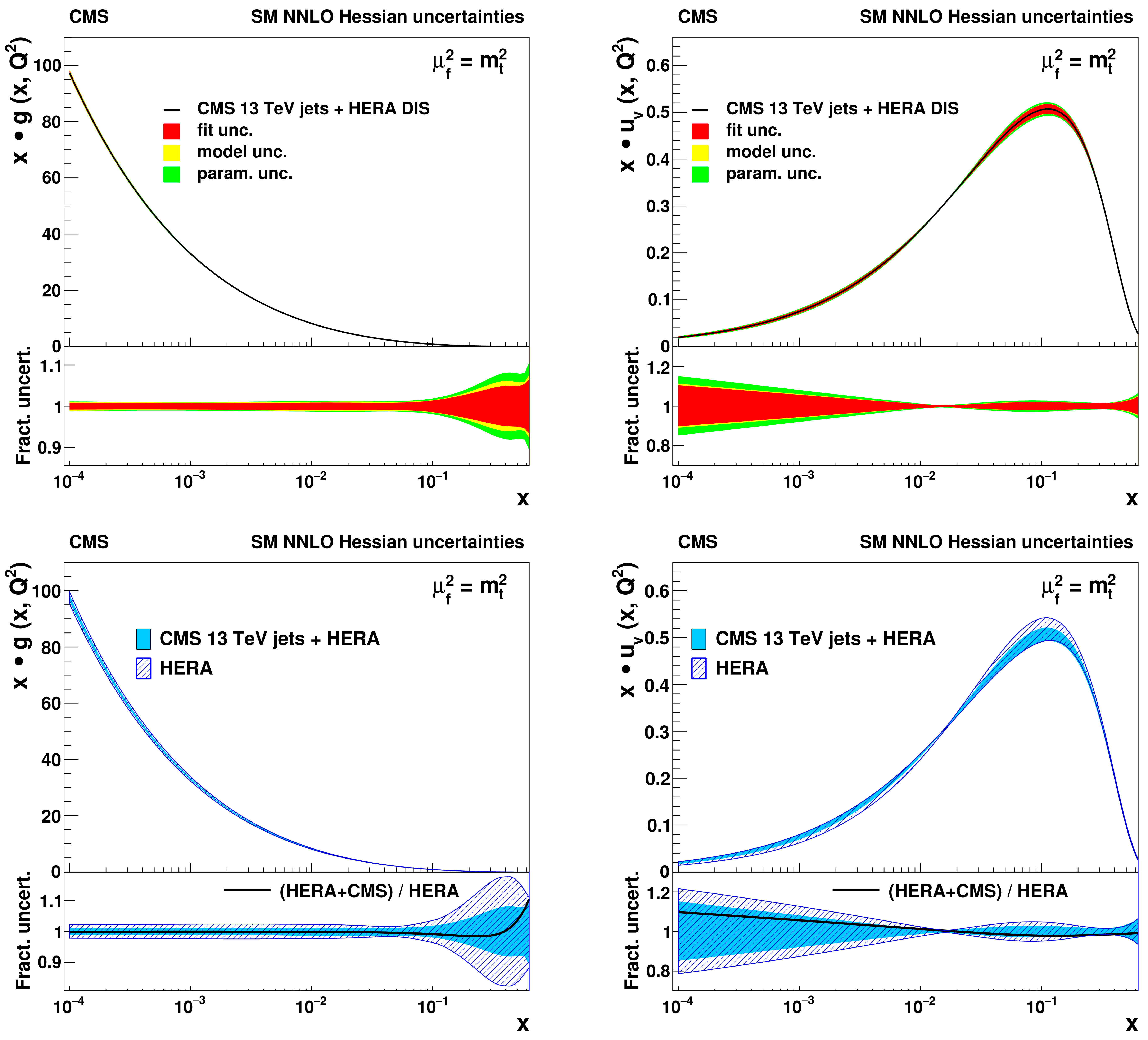
- Simultaneous PDF and α_s determination at NNLO:

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

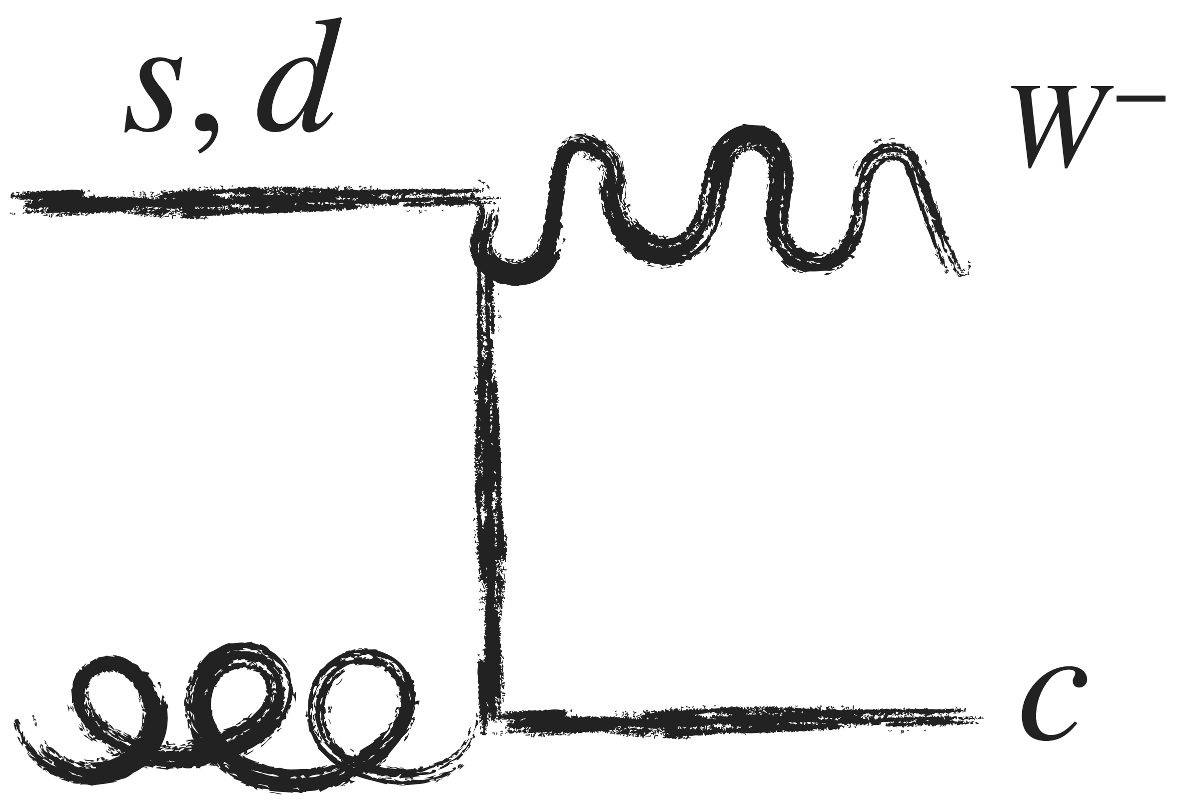
Inclusive jet production [JHEP 02, (2022) 142]

QCD fit

- AK7 jet result together with the inclusive HERA DIS, at NNLO.
- Impact of this CMS jet result is compared with a fit with only HERA data.
- Uncertainties are significantly reduced.

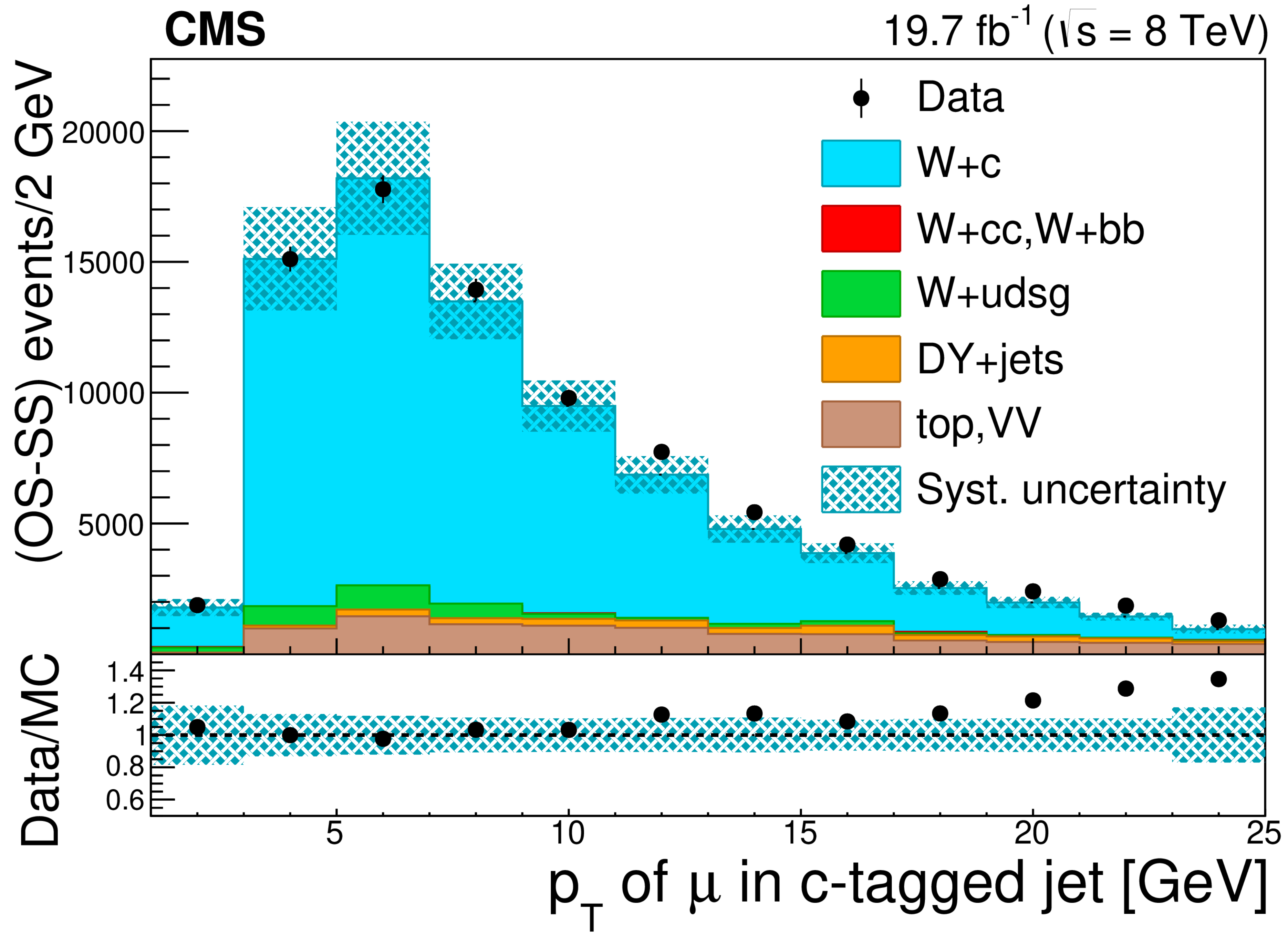


- Direct probe of strange PDF.
- Previously studied by ATLAS and CMS at $\sqrt{s} = 7$ and 13 TeV.
- First results using data at $\sqrt{s} = 8$ TeV from 2012.



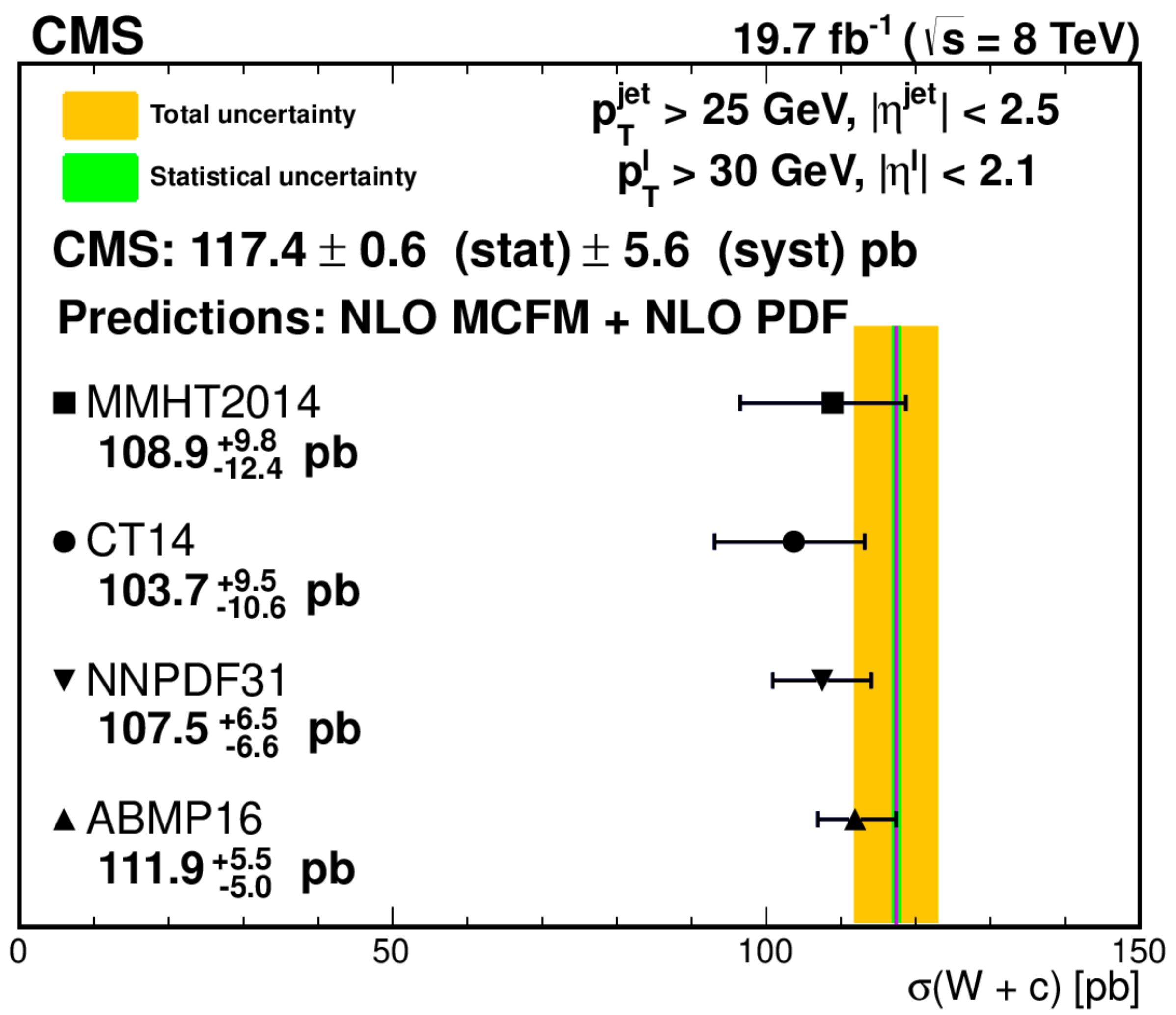
Methods

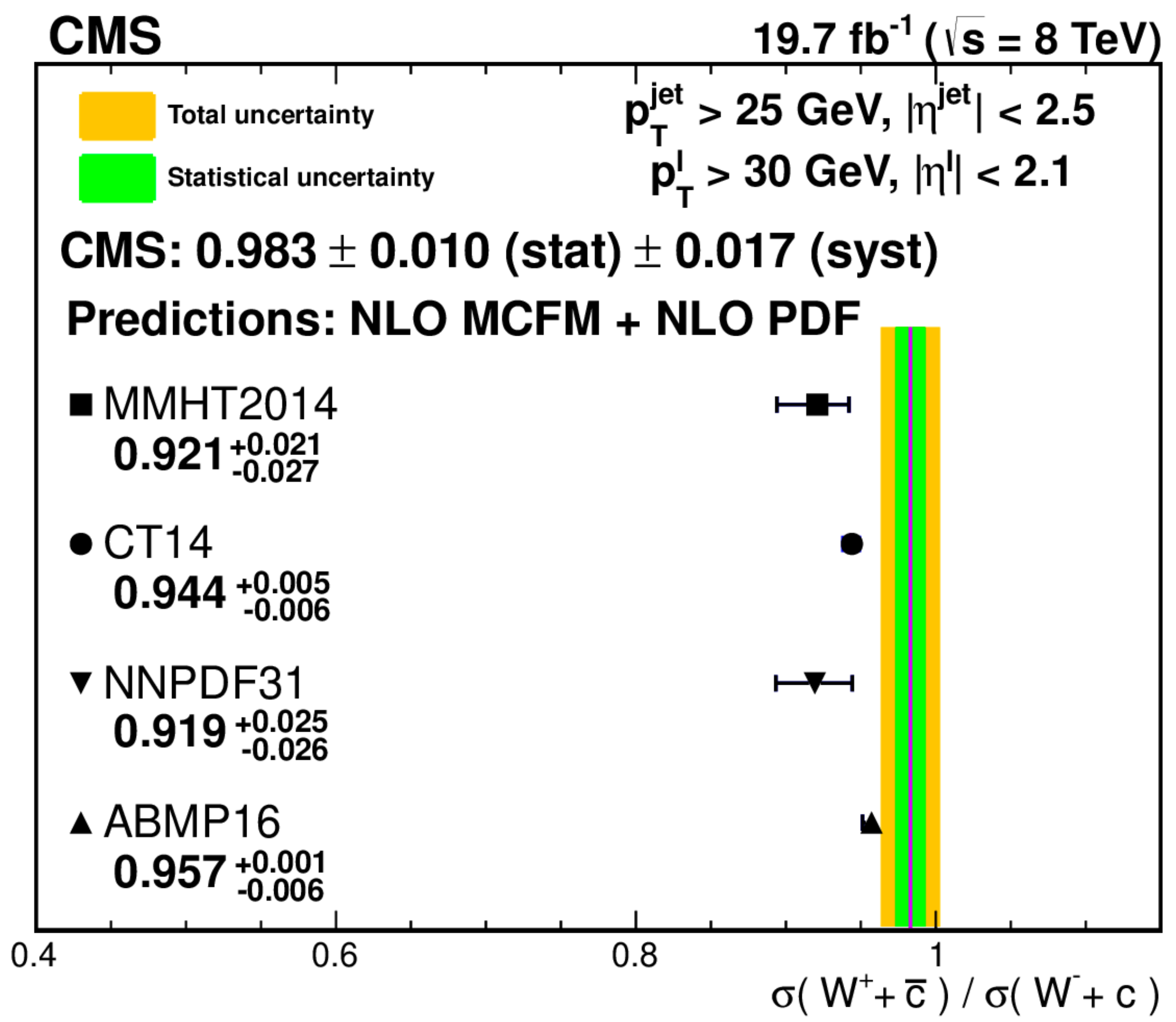
- Data sample of 19.7 pb^{-1} of pp.
- Signal always OS while background is 50% OS - 50% SS. → Strategy: OS-SS subtraction
- W bosons measured via leptonic decay.
- Charm jets:
  - Semileptonic (SL): muon inside jet
  - Secondary Vertex (SV): secondary vertex inside jet.

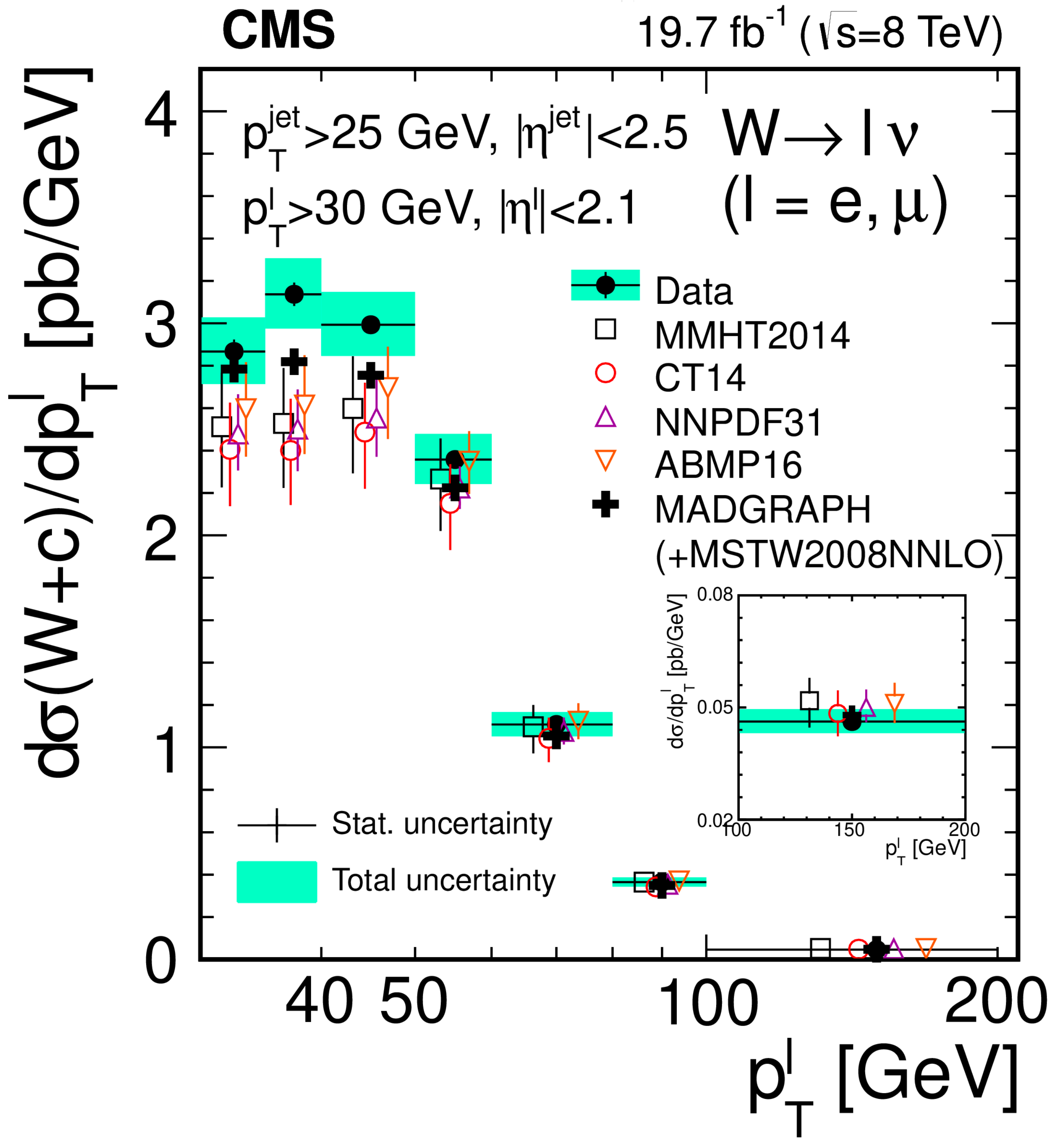


Cross sections

- Inclusive $\sigma(W+c)$ cross section and cross section ratio $R_s^{\pm} = \frac{W^{+}+\bar{c}}{W^{-}+c}$ are obtained.
- $\sigma(W+c)$ in agreement within theory uncert.
- $R_s^{\pm}$ higher than theory, but within 2-3 σ.
- Differential xSec: theory below measurement (possible NNLO corrections).



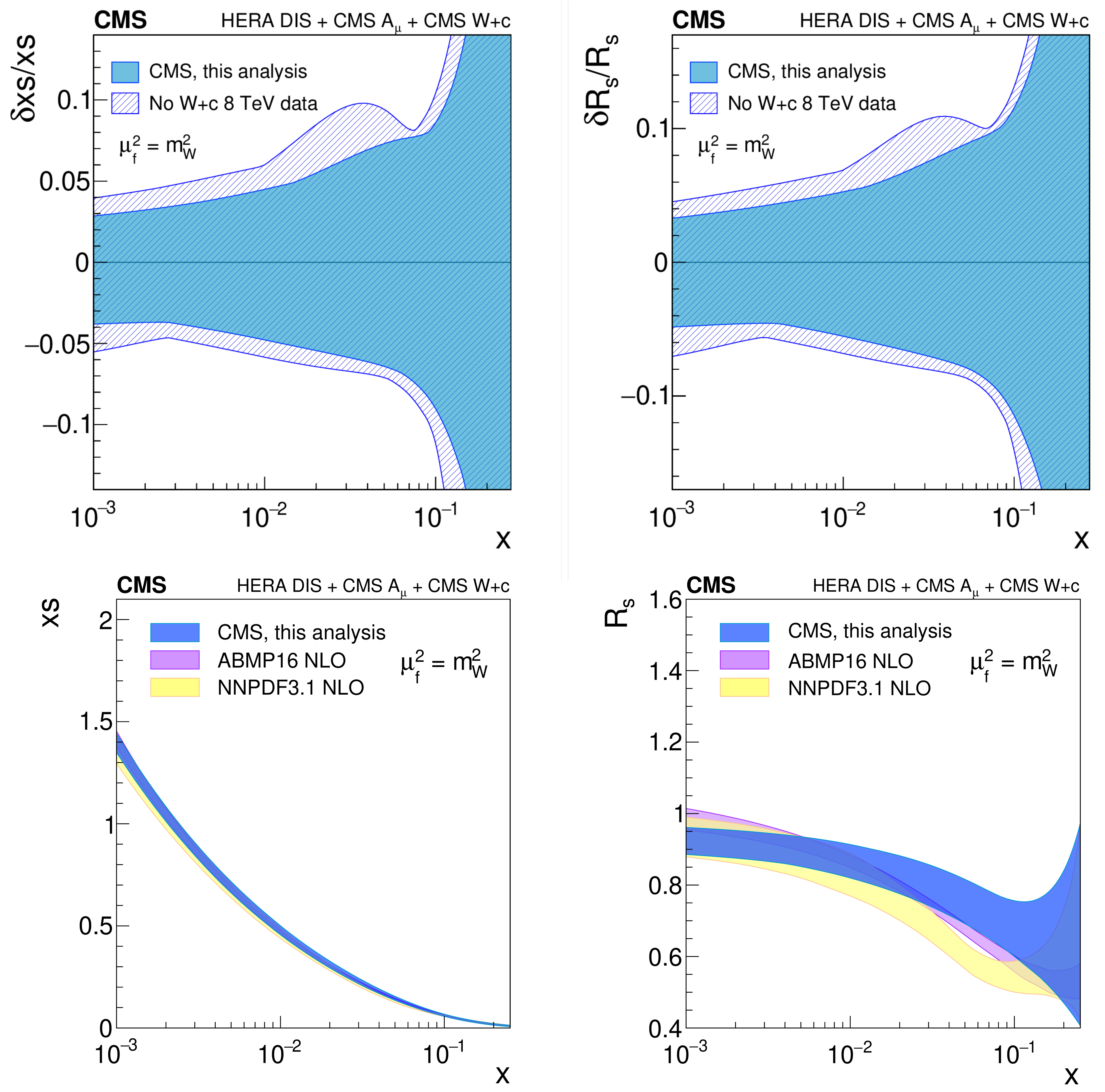




W+c quark production CMS-SMP-18-013 (Submitted to EPJ C)

QCD analysis

- HERA DIS xSecs, CMS W lepton charge asymmetry (7, 8 TeV) and CMS W+c (7,13 TeV) are used with this result.
- Strange distribution and suppression ratio $R_s = \dfrac{s+\bar{s}}{\bar{d}+\bar{u}}$ are obtained.
- New data clearly improves uncertainties.
- New results in agreement also with other global PDFs analyses.



$t\bar{t}$ production

Results

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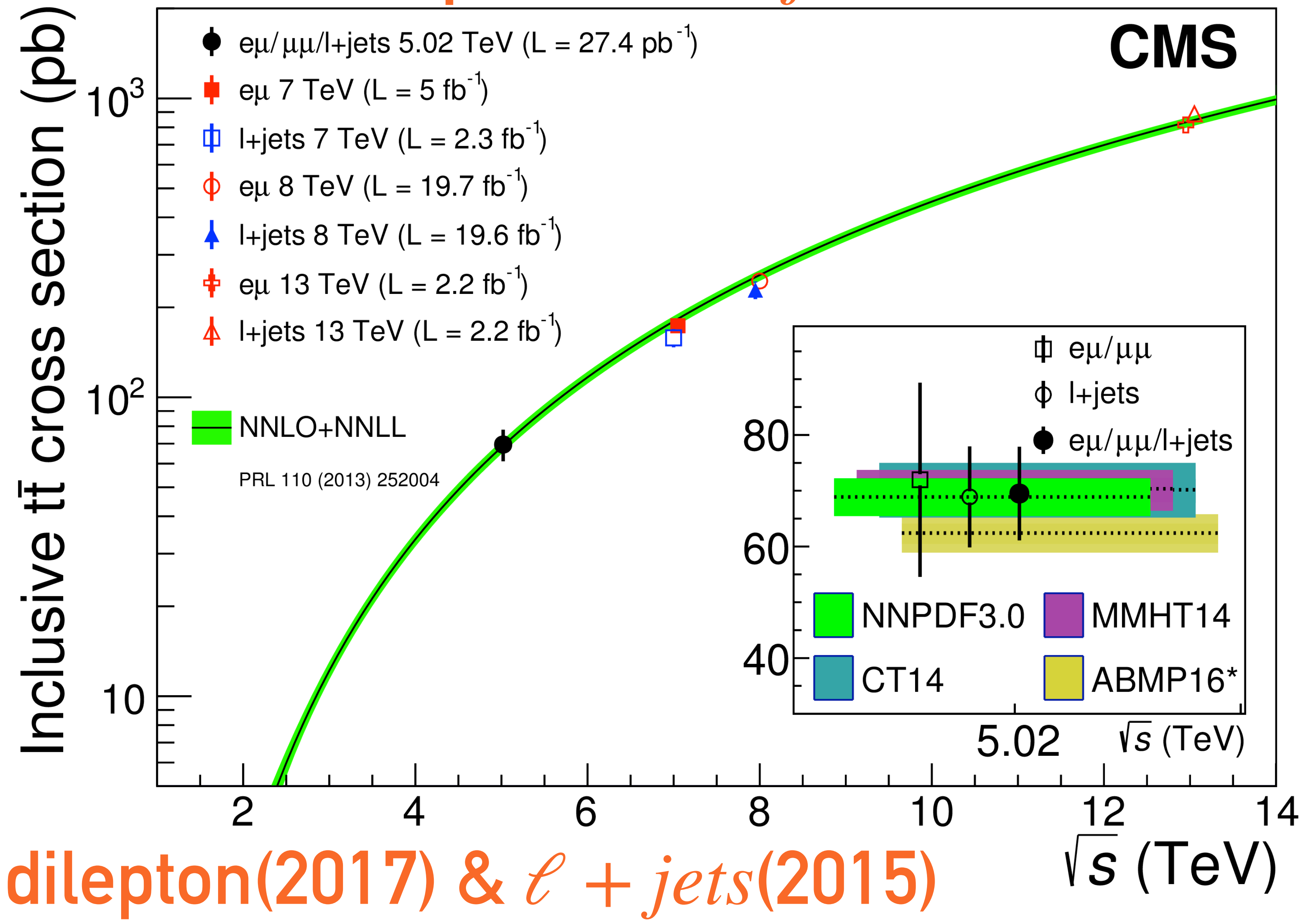
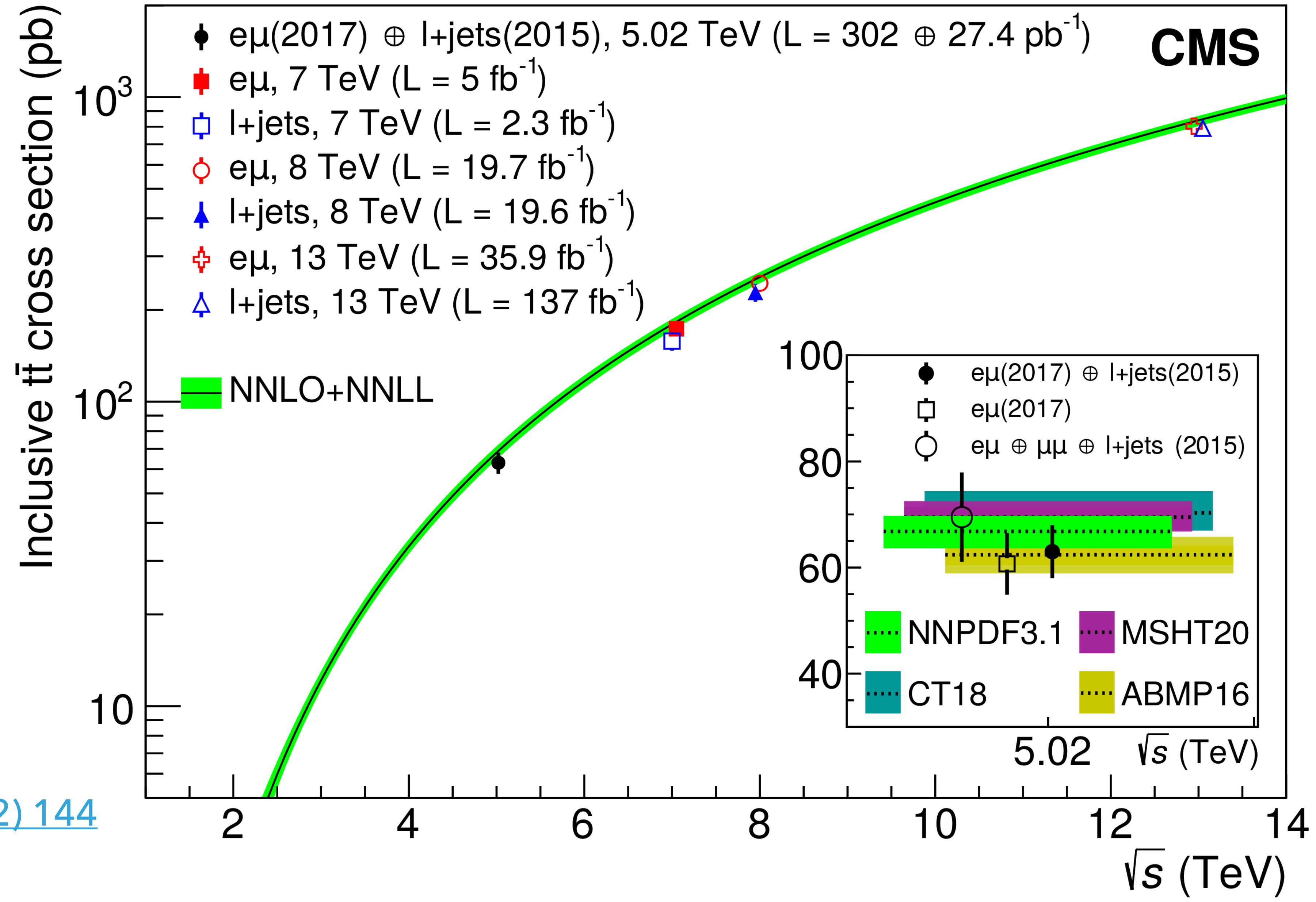
2015: dilepton & $\ell + jets$



dilepton(2017) & $\ell + jets$(2015)



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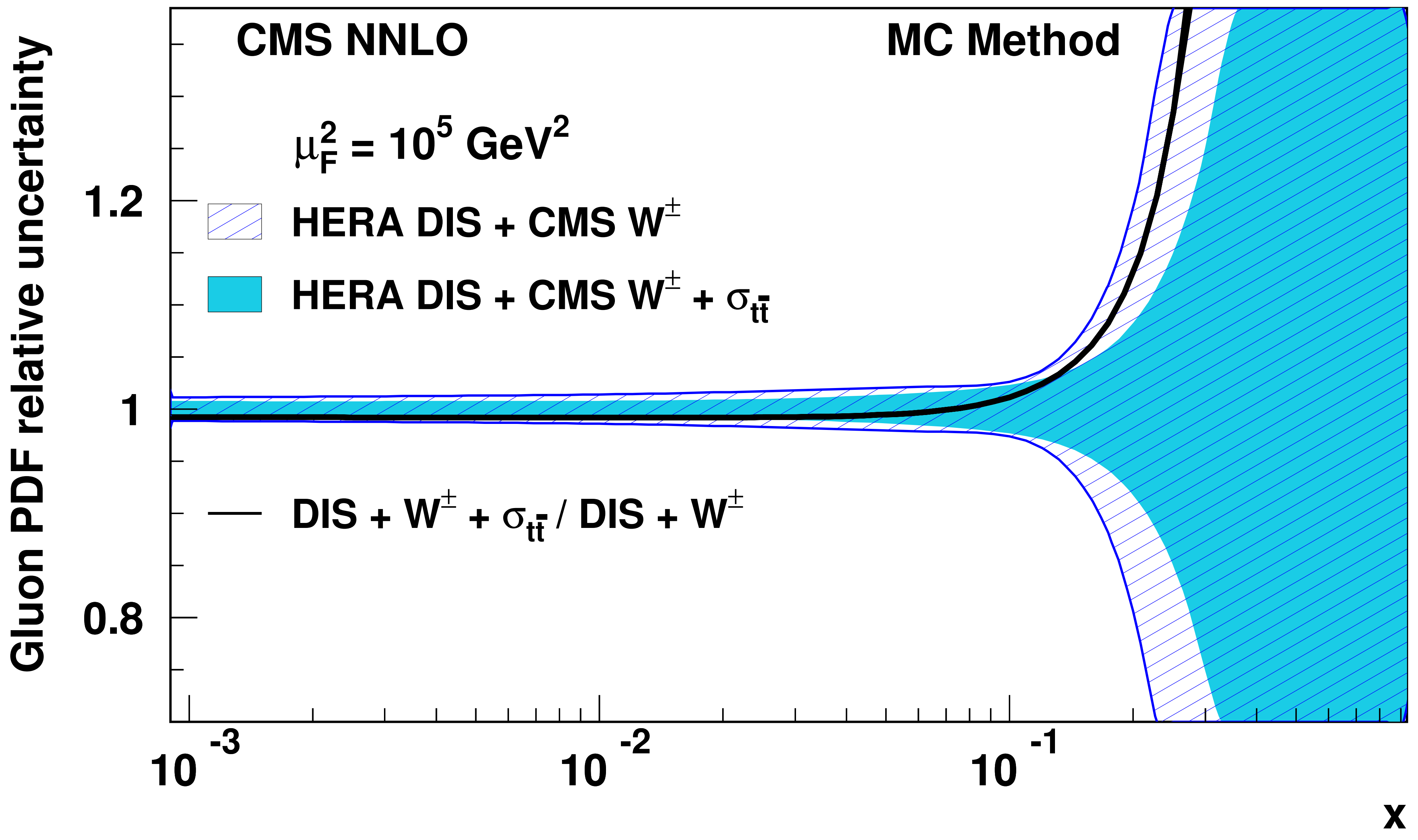
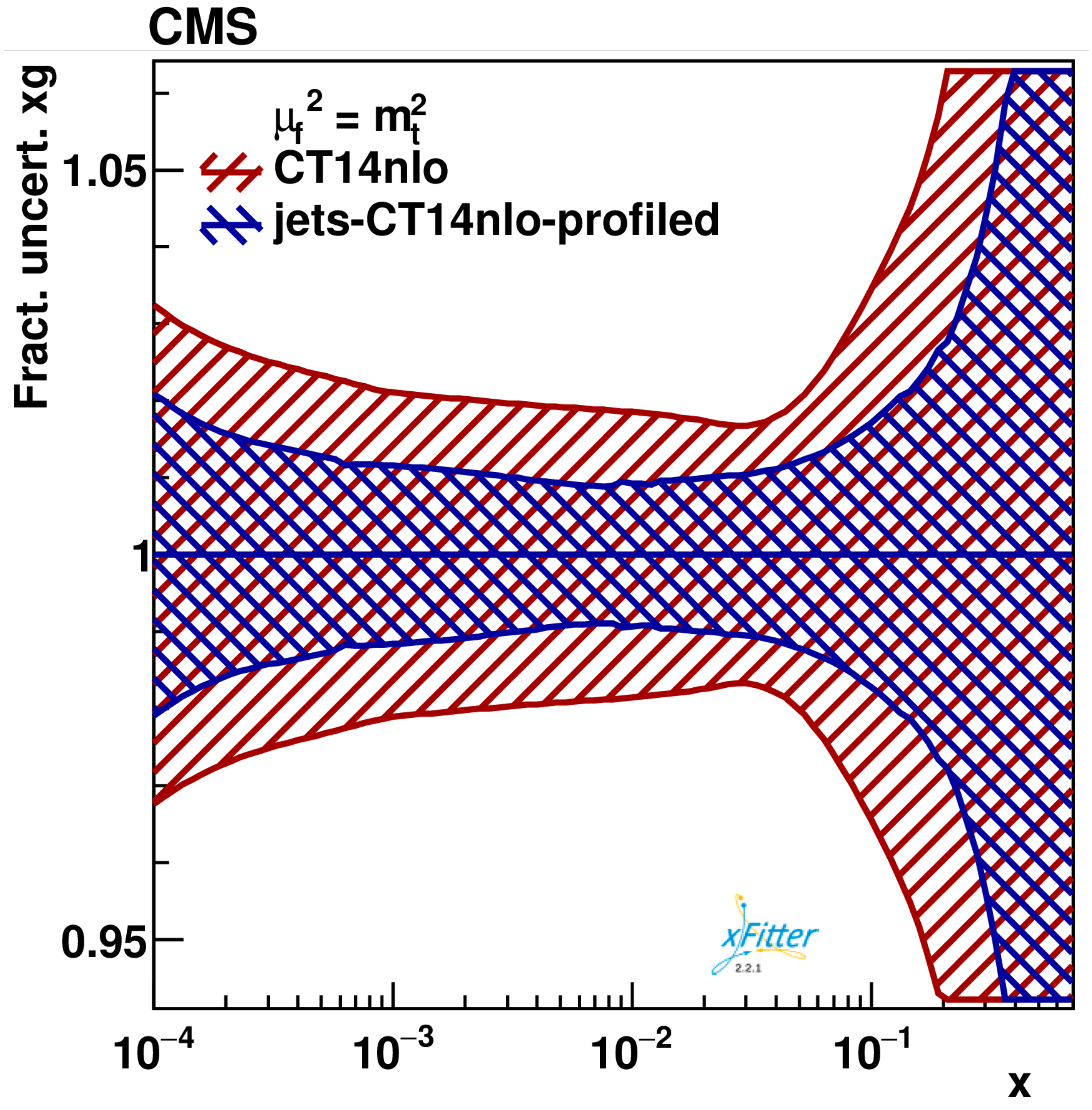
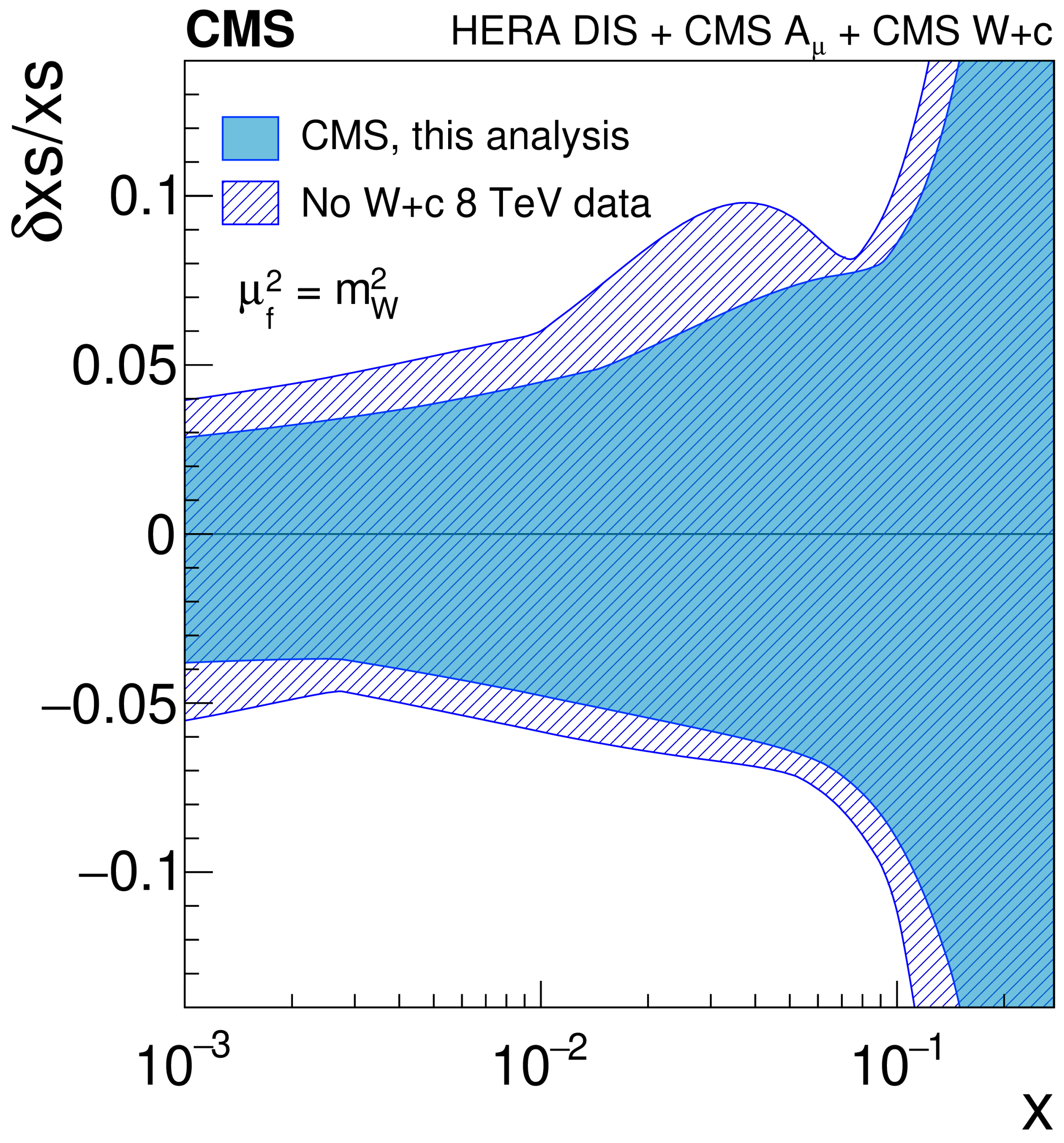


Update in $\ell + jets$ with 2017 data expected

Summary

- QCD analysis using inclusive jet data @ 13 TeV shows a significant reduction of the gluon PDF uncertainties in the full x range.
- New QCD analysis at NLO using W+c production xSec @ 8 TeV in addition to previous results of DIS, W+c at different energies and W lepton asymmetry further constrains strange distribution and R_s.
- $t\bar{t}$ important probe for high x.

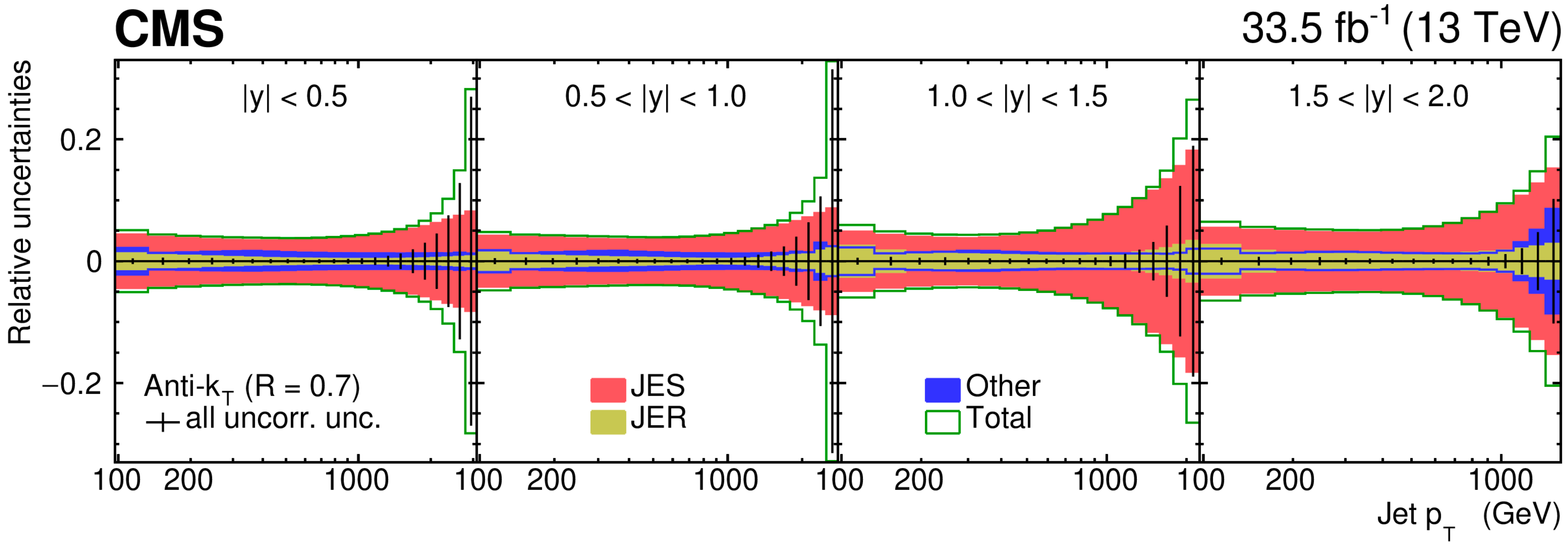




Backup slides

Inclusive jet production JHEP 02, (2022) 142

Relative uncertainties in the double-differential cross section



PDF parametrization

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + D_g x + E_g x^2),$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}},$$

$$x\overline{U}(x) = A_{\overline{U}} x^{B_{\overline{U}}} (1-x)^{C_{\overline{U}}} (1 + D_{\overline{U}} x),$$

$$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}} (1-x)^{C_{\overline{D}}} (1 + E_{\overline{D}} x^2).$$

Systematics

Impact of the sources of systematic uncertainty in the combined $\sigma(\mathrm{W+c})$ measurement.

Source	Uncertainty [%]
Lepton efficiency	0.7
Jet energy scale and resolution	0.8
$p_{\mathrm{T}}^{\mathrm{miss}}$ resolution	0.3
Pileup modelling	0.4
μ in jet reconstruction efficiency	0.9
Secondary vertex reconstruction efficiency	1.8
Secondary vertex charge determination	1.0
Charm fragmentation and decay fractions	2.6
Charm fragmentation functions	0.3
Background subtraction	0.8
PDF	1.0
Limited size of MC samples	0.6
Integrated luminosity	2.6

PDF parametrization

$$
\begin{aligned}
x\mathrm{g}(x) &= A_{\mathrm{g}} x^{B_{\mathrm{g}}} (1-x)^{C_{\mathrm{g}}}, \\
x\mathrm{u_v}(x) &= A_{\mathrm{u_v}} x^{B_{\mathrm{u_v}}} (1-x)^{C_{\mathrm{u_v}}} \left(1 + E_{\mathrm{u_v}} x^2\right), \\
x\mathrm{d_v}(x) &= A_{\mathrm{d_v}} x^{B_{\mathrm{d_v}}} (1-x)^{C_{\mathrm{d_v}}}, \\
x\overline{\mathrm{u}}(x) &= A_{\overline{\mathrm{u}}} x^{B_{\overline{\mathrm{u}}}} (1-x)^{C_{\overline{\mathrm{u}}}} \left(1 + D_{\overline{\mathrm{u}}} x\right), \\
x\overline{\mathrm{d}}(x) &= A_{\overline{\mathrm{d}}} x^{B_{\overline{\mathrm{d}}}} (1-x)^{C_{\overline{\mathrm{d}}}}, \\
x\overline{\mathrm{s}}(x) &= A_{\overline{\mathrm{s}}} x^{B_{\overline{\mathrm{s}}}} (1-x)^{C_{\overline{\mathrm{s}}}}.
\end{aligned}
$$