Photon production in the forward region and PDF fits

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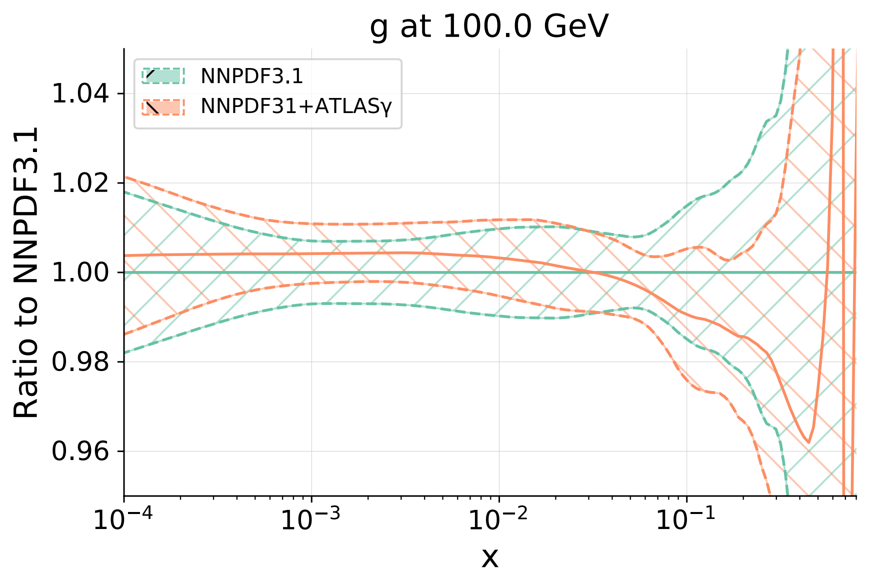
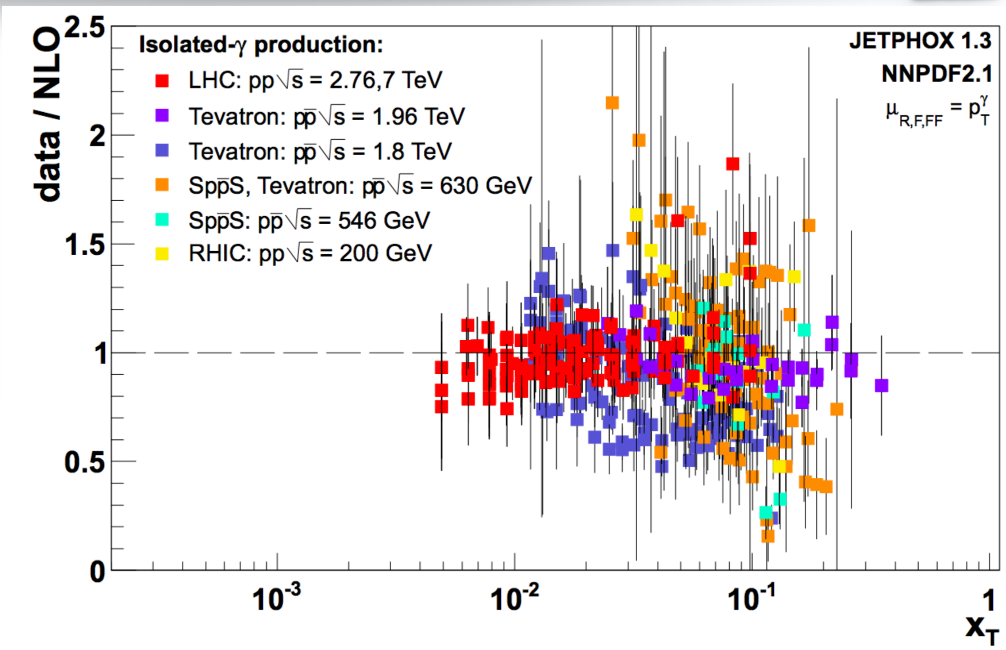


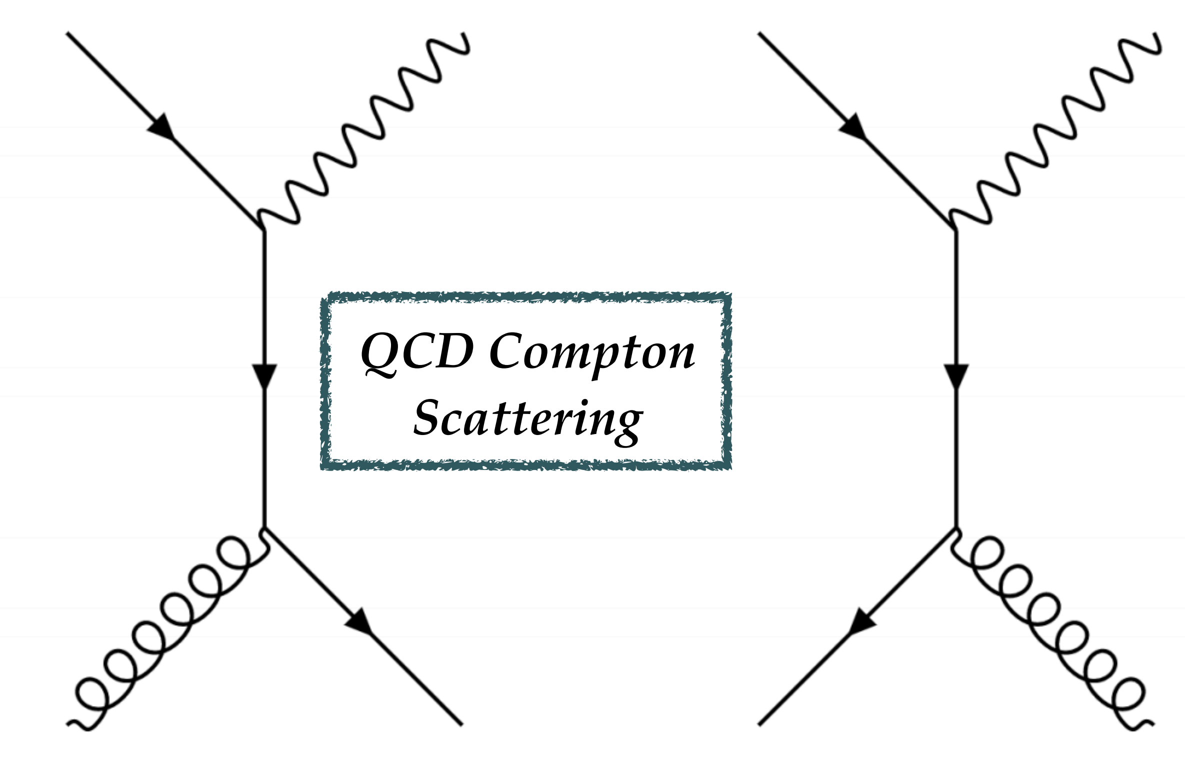
Direct photon production and PDF fits reloaded



Direct photon production and PDF fits

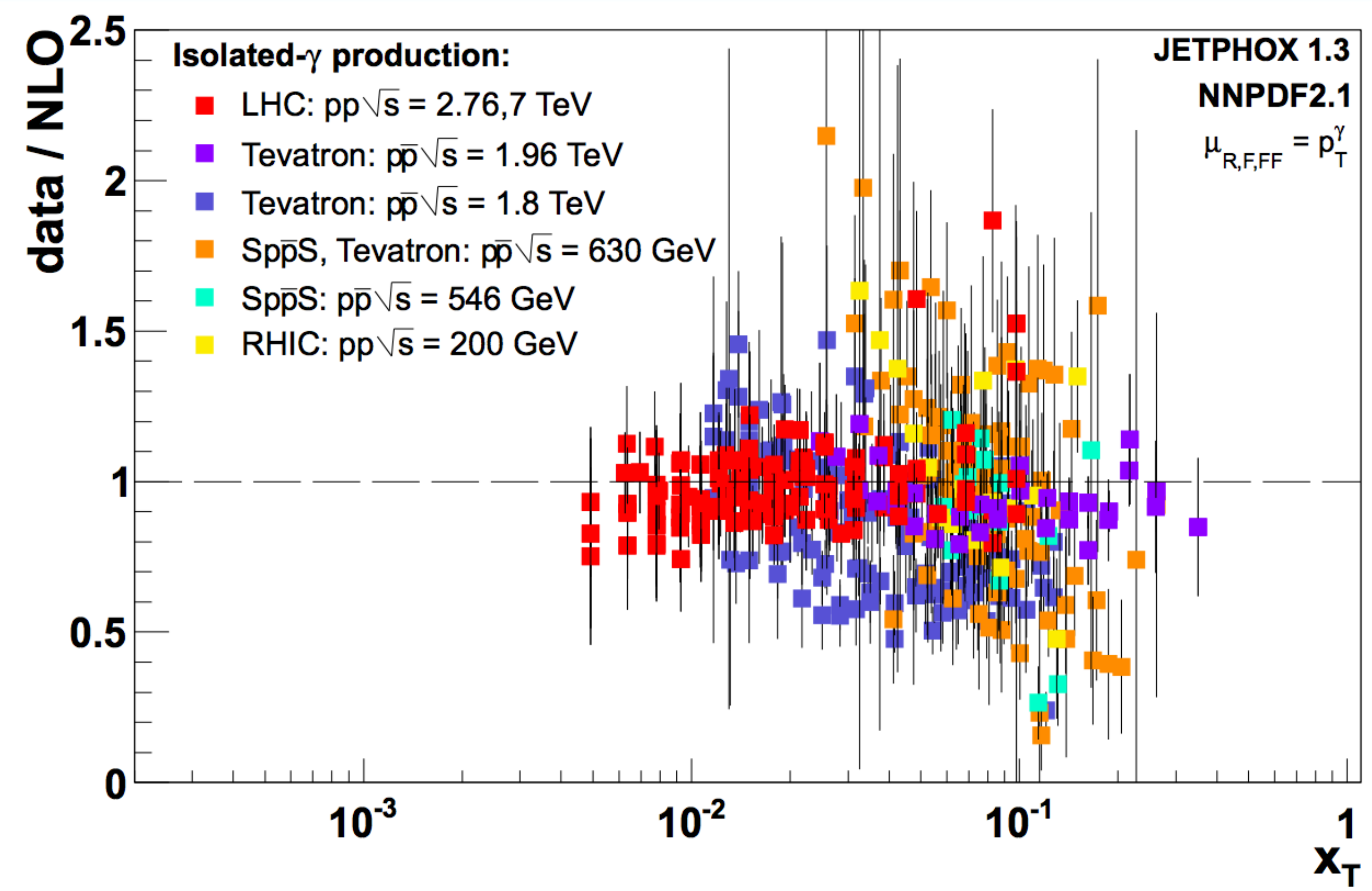
- Photon production in hadronic collisions is directly sensitive to the **gluon PDF**

- Photon production data from **fixed-target experiments** was used in the very early global PDF fits to constrain the gluon PDF, but the apparent tension with some data lead to its **replacement by jets**



- In 2012 we showed that all **available isolated photon production data** was consistent with NLO QCD calculations

D'Enterria, Rojo 12

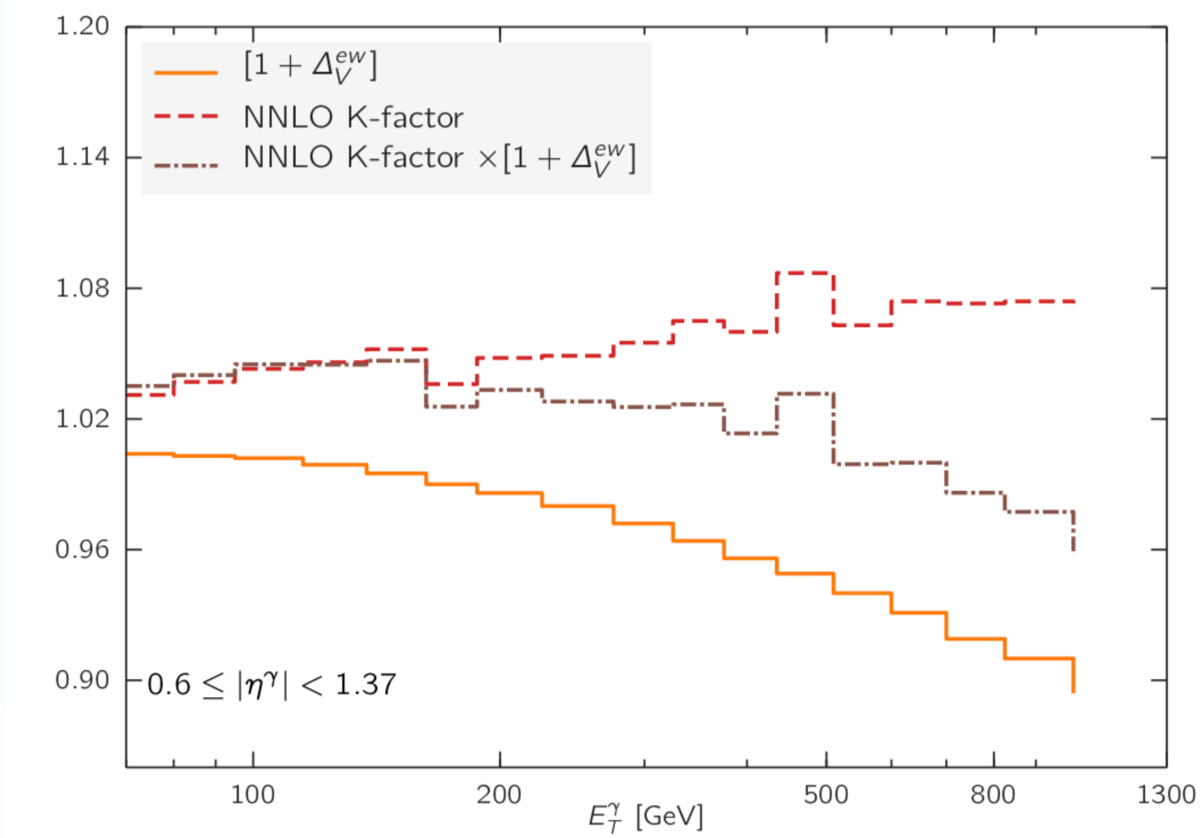


- However the precision of most recent LHC data required using NNLO QCD theory, which only recently became available

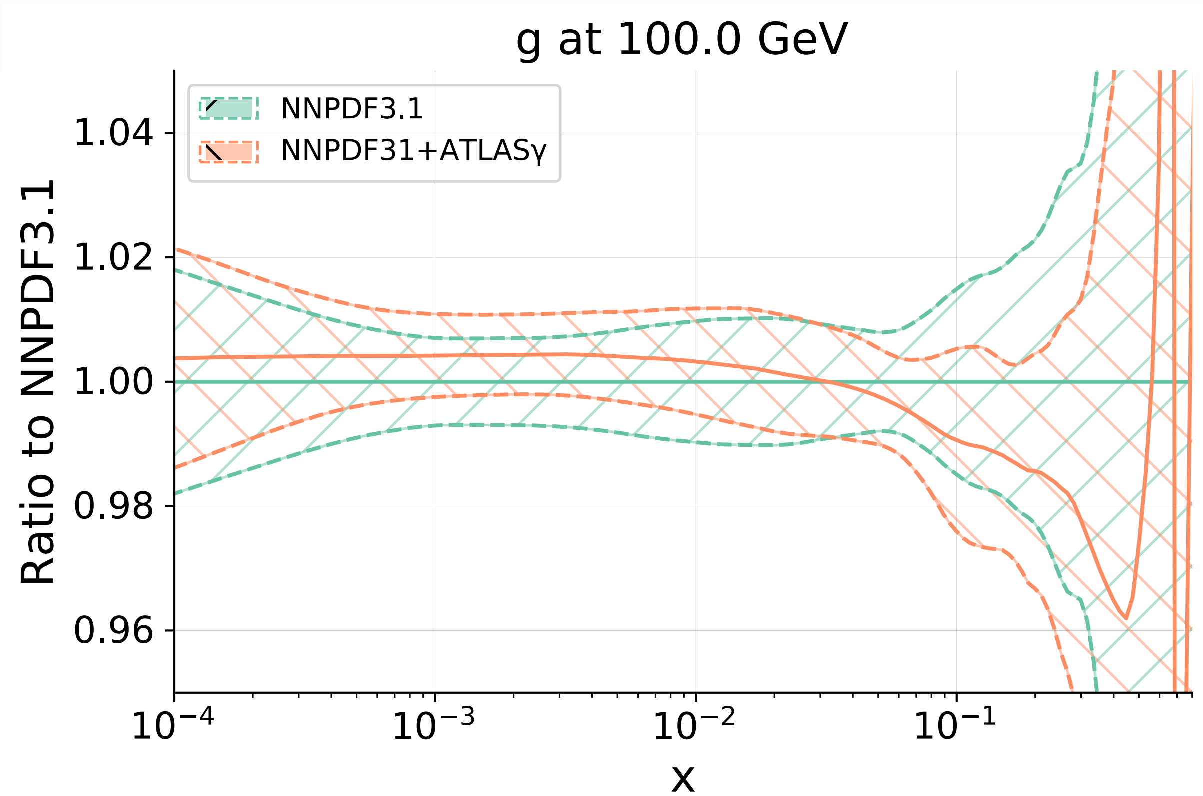
Campbell, Ellis, Williams 16

Direct photon production and PDF fits

- Recently we have revisited the impact of LHC photon data into the global PDF fit, specifically the ATLAS 8 TeV data
  Campbell, Rojo, Slade, Williams 18
- Theory based on **NNLO QCD** and **LL electroweak** calculations
- Moderate impact on the medium-x gluon, consistent with previous studies at NLO
- Good consistency with the rest of gluon-sensitive experiments in NNPDF3.1

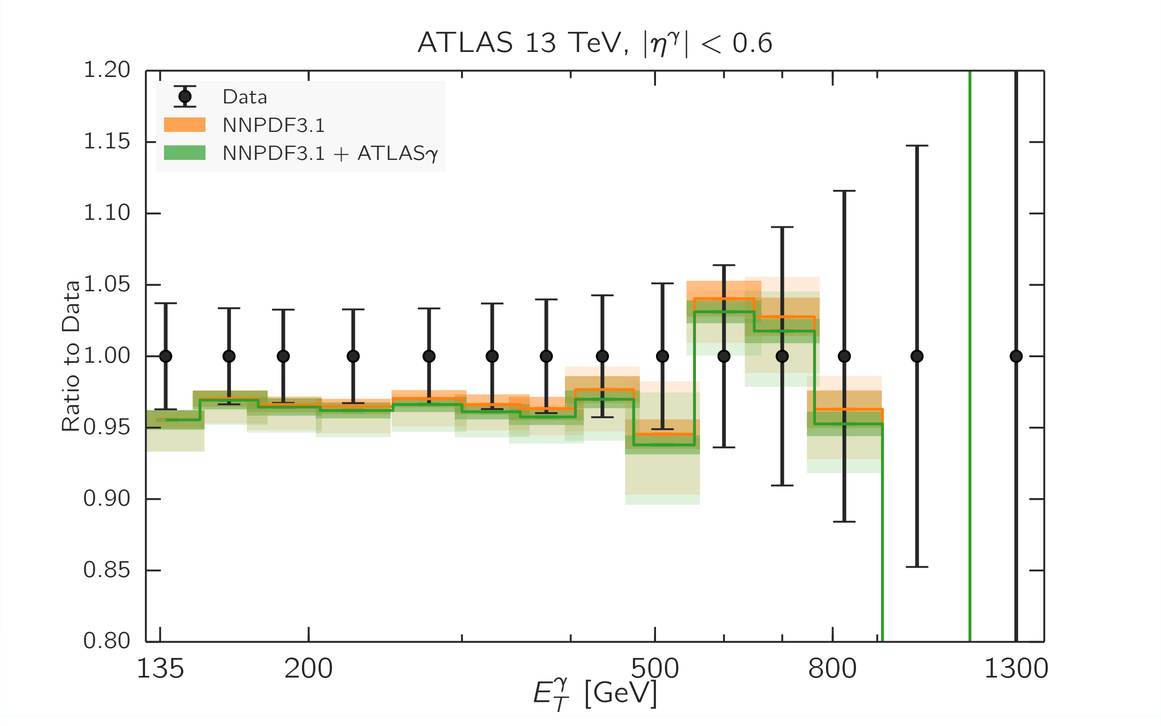


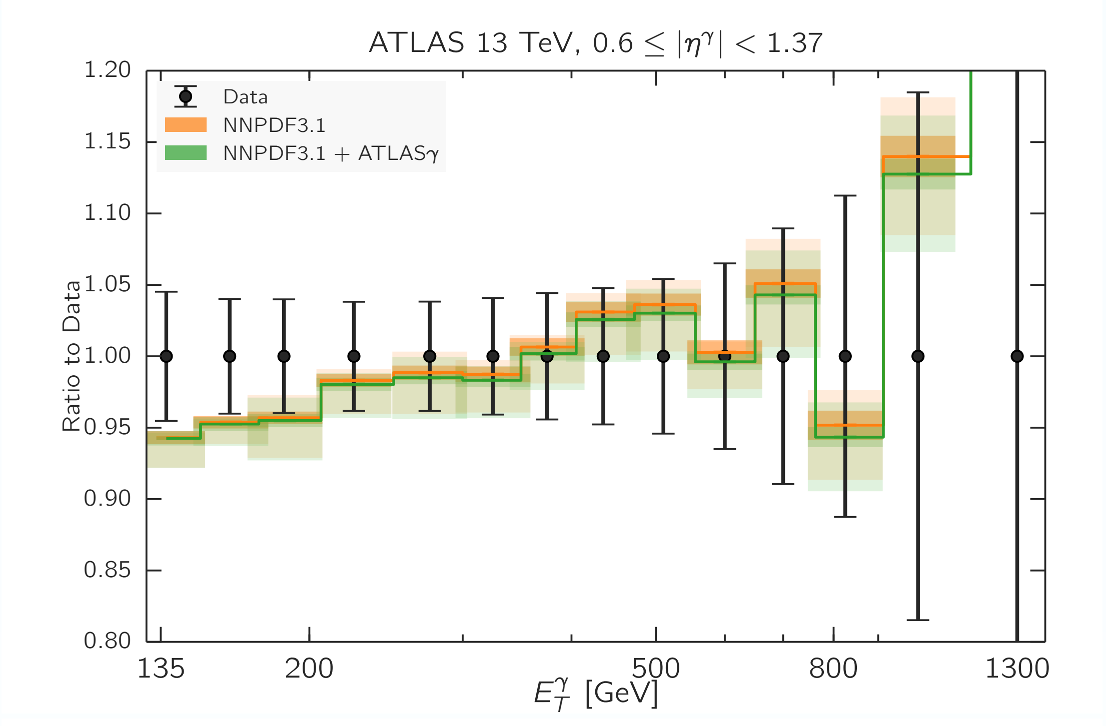
	NNPDF3.1	NNPDF3.1+ATLASγ
Fixed-target lepton DIS	1.207	1.203
Fixed-target neutrino DIS	1.081	1.087
HERA	1.166	1.169
Fixed-target Drell-Yan	1.241	1.242
Collider Drell-Yan	1.356	1.346
Top-quark pair production	1.065	1.049
Inclusive jets	0.939	0.915
Z p_T	0.997	0.980
Total dataset	**1.148**	**1.146**



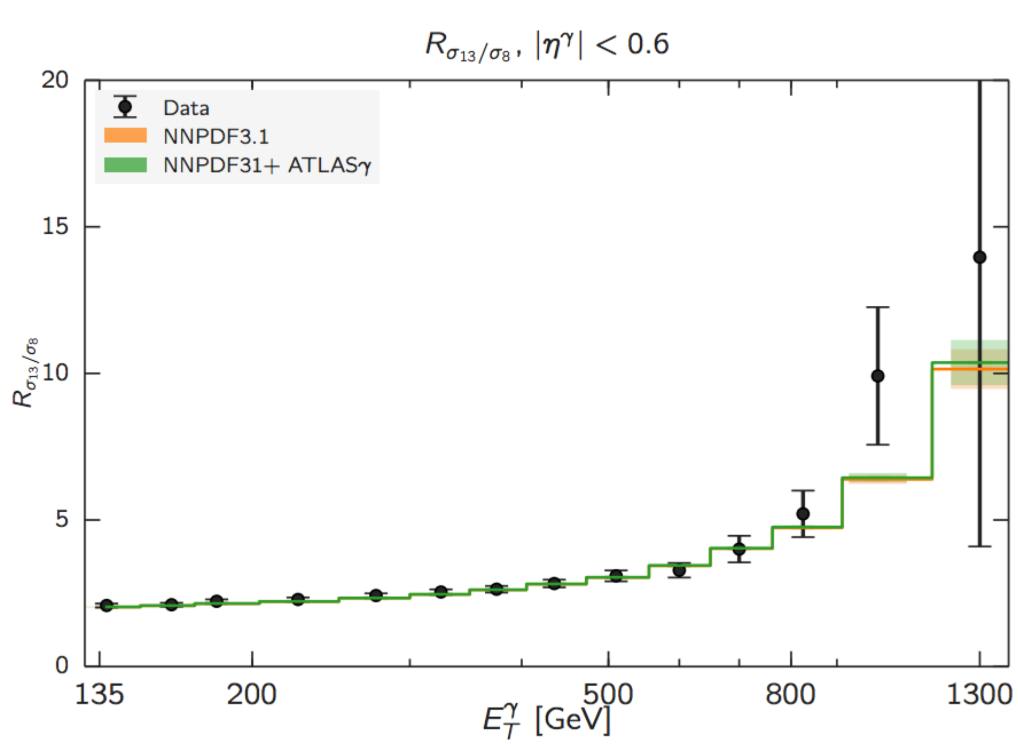
Direct photon production and PDF fits

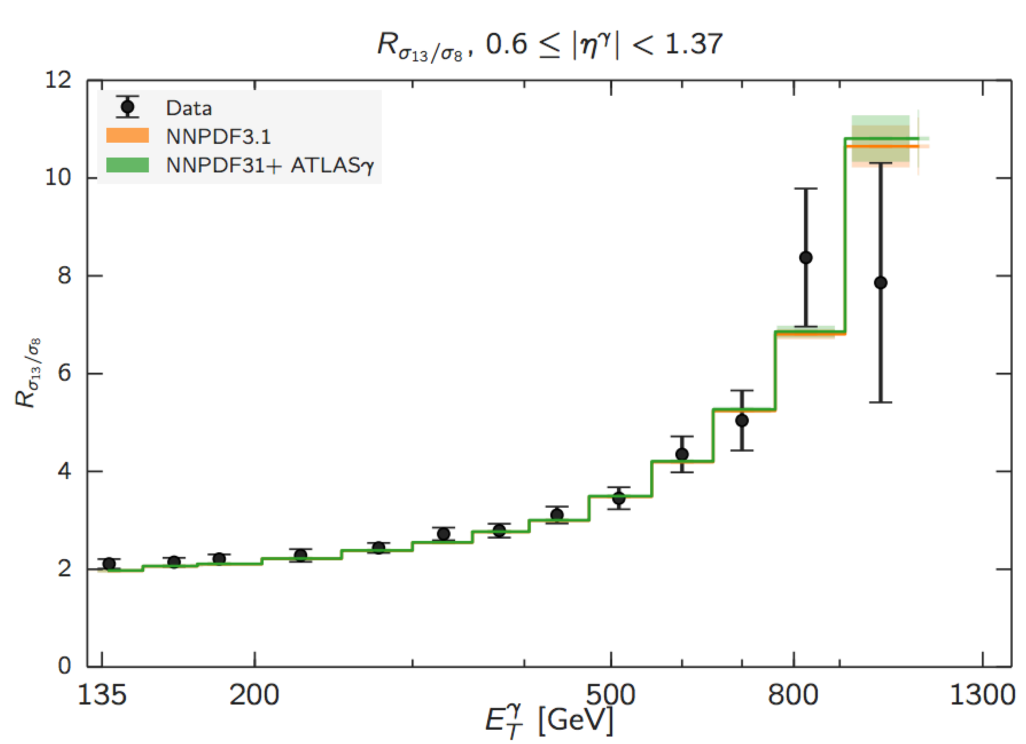
- Good agreement between theory and data **also at 13 TeV …**





- … as well as for the **ratio of cross-sections between 13 TeV and 8 TeV**





The role of the fragmentation component

- In addition to hard-scattering, collinear photons can be radiated off final-state quarks, leading to the **poorly understood fragmentation component** (depending on non-perturbative effects)

$$\mathrm{d}\sigma = \mathrm{d}\sigma_{\mathrm{dir}} + \mathrm{d}\sigma_{\mathrm{frag}} = \sum_{a,b=q,\bar{q},g} \int \mathrm{d}x_a \mathrm{d}x_b f_a(x_a;\mu_F^2) f_b(x_b;\mu_F^2) \times$$

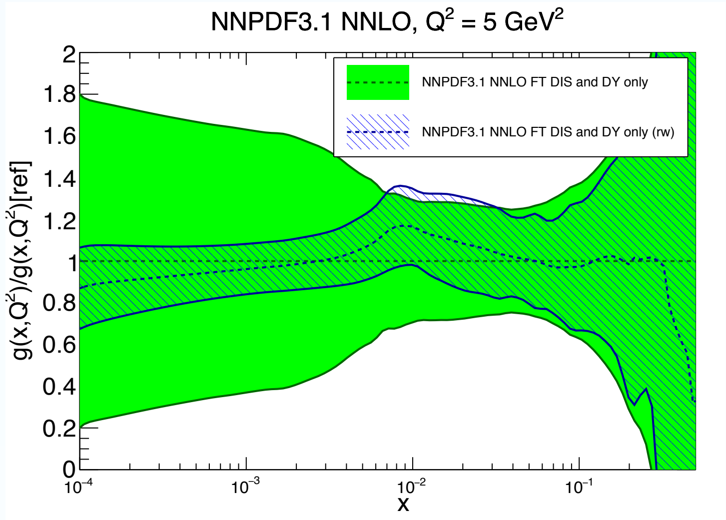
$$\left[\mathrm{d}\hat{\sigma}^{\gamma}_{ab}(p_\gamma, x_a, x_b; \mu_R, \mu_F, \mu_{\mathrm{ff}}) + \sum_{c=q,\bar{q},g} \int_{z_{\min}}^{1} \frac{\mathrm{d}z}{z^2} \mathrm{d}\hat{\sigma}^{c}_{ab}(p_\gamma, x_a, x_b, z; \mu_R, \mu_F, \mu_{\mathrm{ff}}) D_c^{\gamma}(z;\mu_{\mathrm{ff}}^2) \right]$$

direct component *fragmentation component*

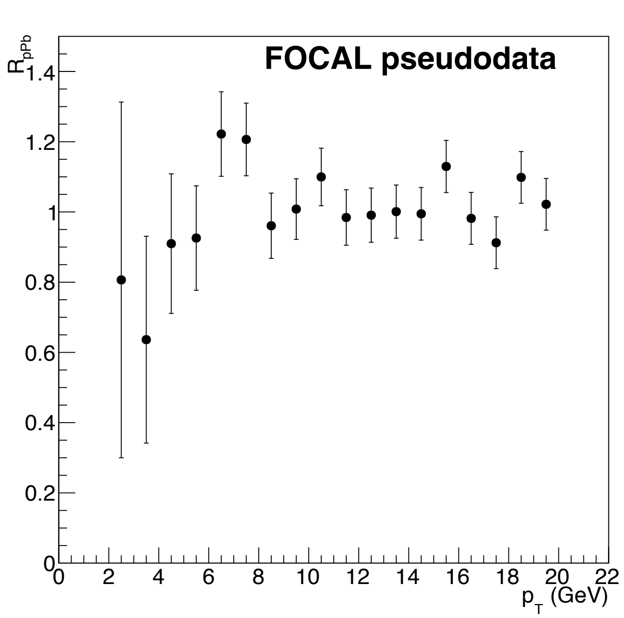
- The need to model the fragmentation component is avoided if the **smooth cone (Frixione) isolation criterion** is used. Its parameters can be tuned to match the experimental isolation used

$$\sum E_T^{\mathrm{had}}(R) < \epsilon_\gamma E_T^{\gamma} \left(\frac{1-\cos R}{1-\cos R_0} \right)^n$$

- Understanding the **isolation and fragmentation of photons in the forward region** is required in order to fully exploit the potential of the FoCal measurements.



PDF fits with FoCal direct photon production pseudo-data



Fit settings

- Using the same theory settings as those used for the ATLAS measurements, include **FoCal pseudo-data in proton PDF fit**

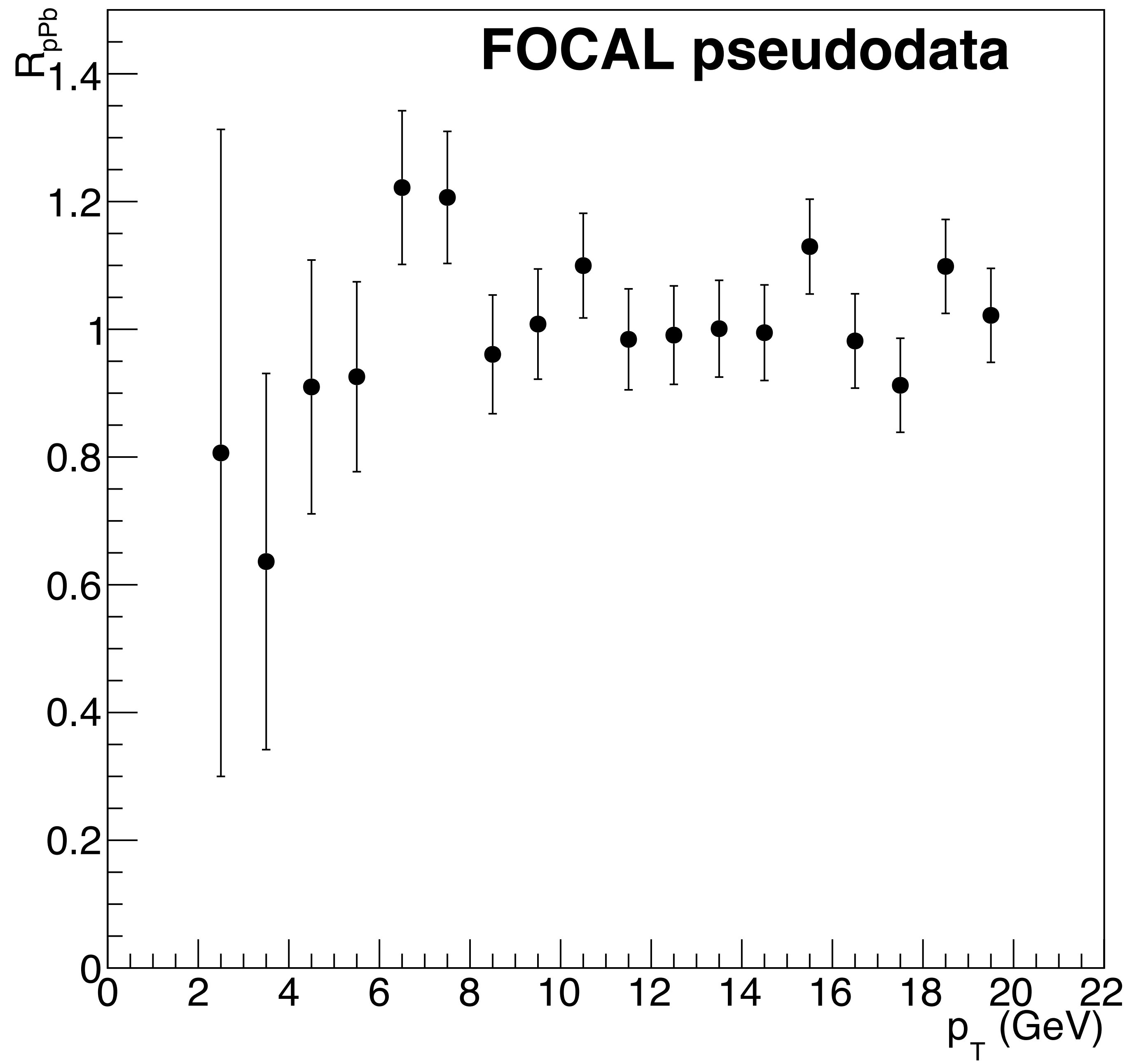
- Assume a given proton PDF central value as ``truth'': main goal is ti assess impact on the PDF uncertainties

- Assess impact of FoCal measurements for **different prior datasets:**

  - *i)* a **global dataset:** NNPDF3.1

  - *ii)* a **fixed-target DIS and Drell-Yan dataset:** similar to nuclear PDF fits

- Use the **Monte Carlo PDF reweighting method,** no limitations of principle for carrying out a full-fledged fit

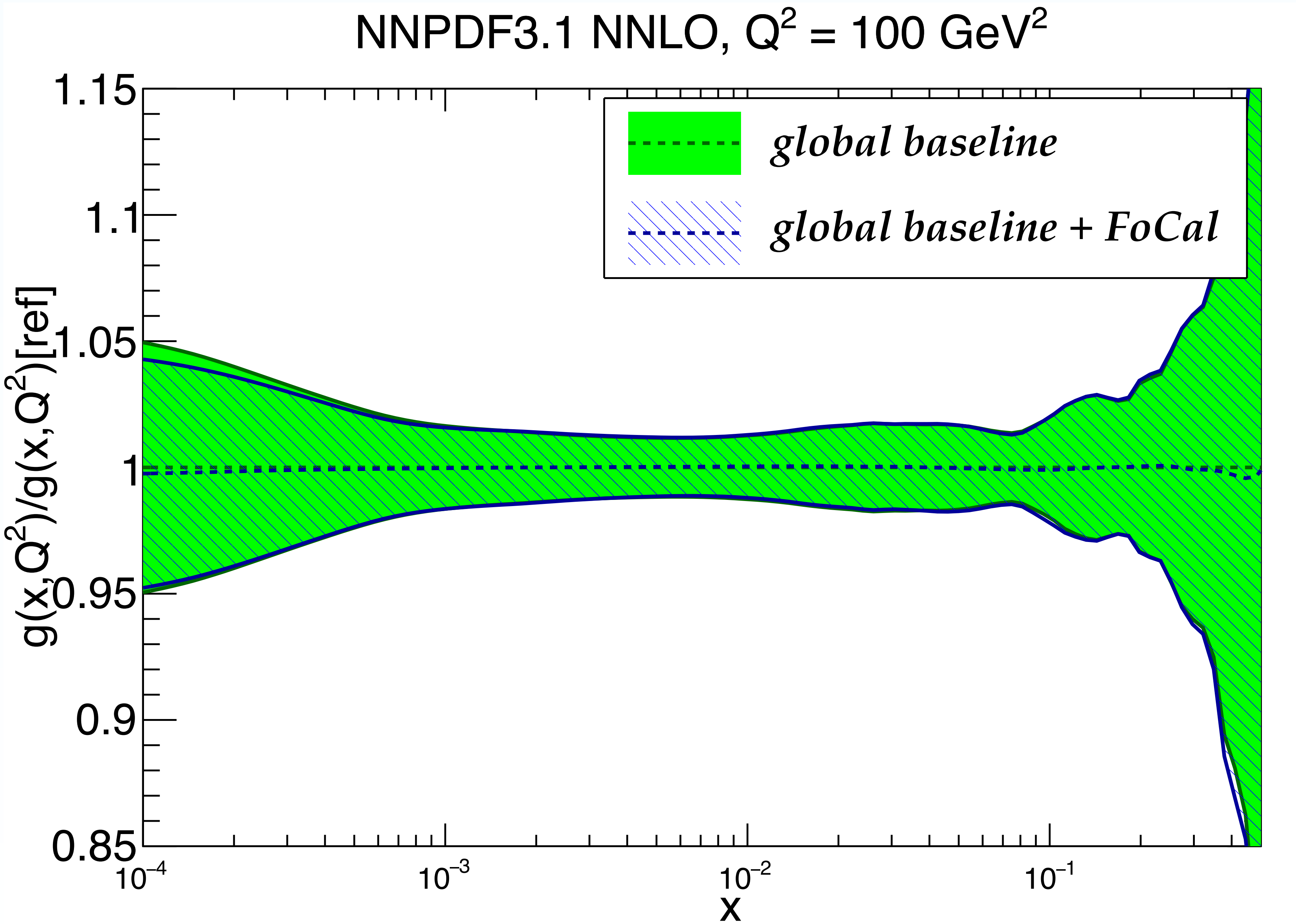


look only at experimental uncertainties, central values arbitrary here

Impact on a global dataset

When added on top of a **proton global dataset** (NNPDF3.1) the impact of the FoCal data is small

The reason is that **other experiments already constrain the gluon PDF**, in particular at small-x the HERA structure function data



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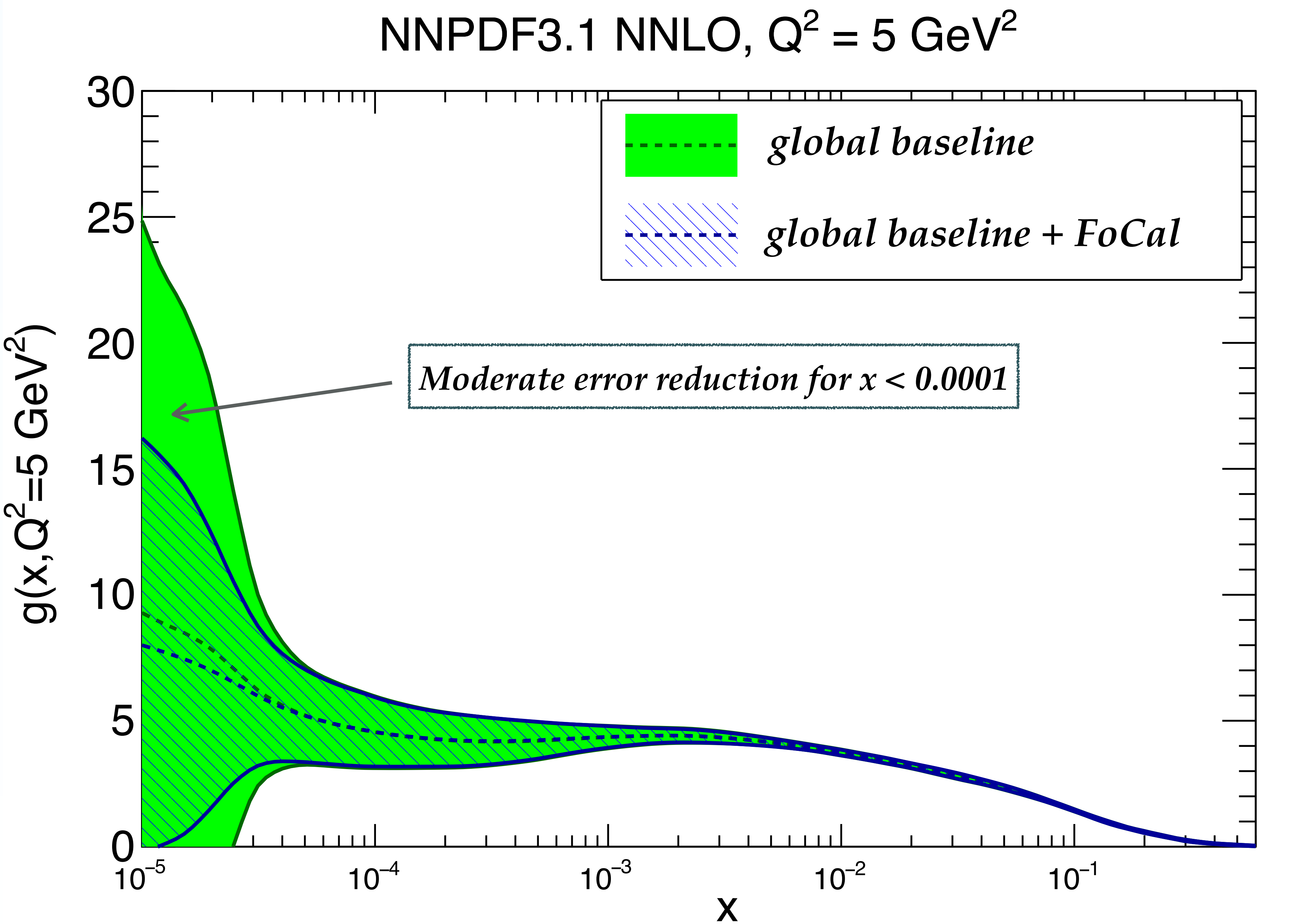
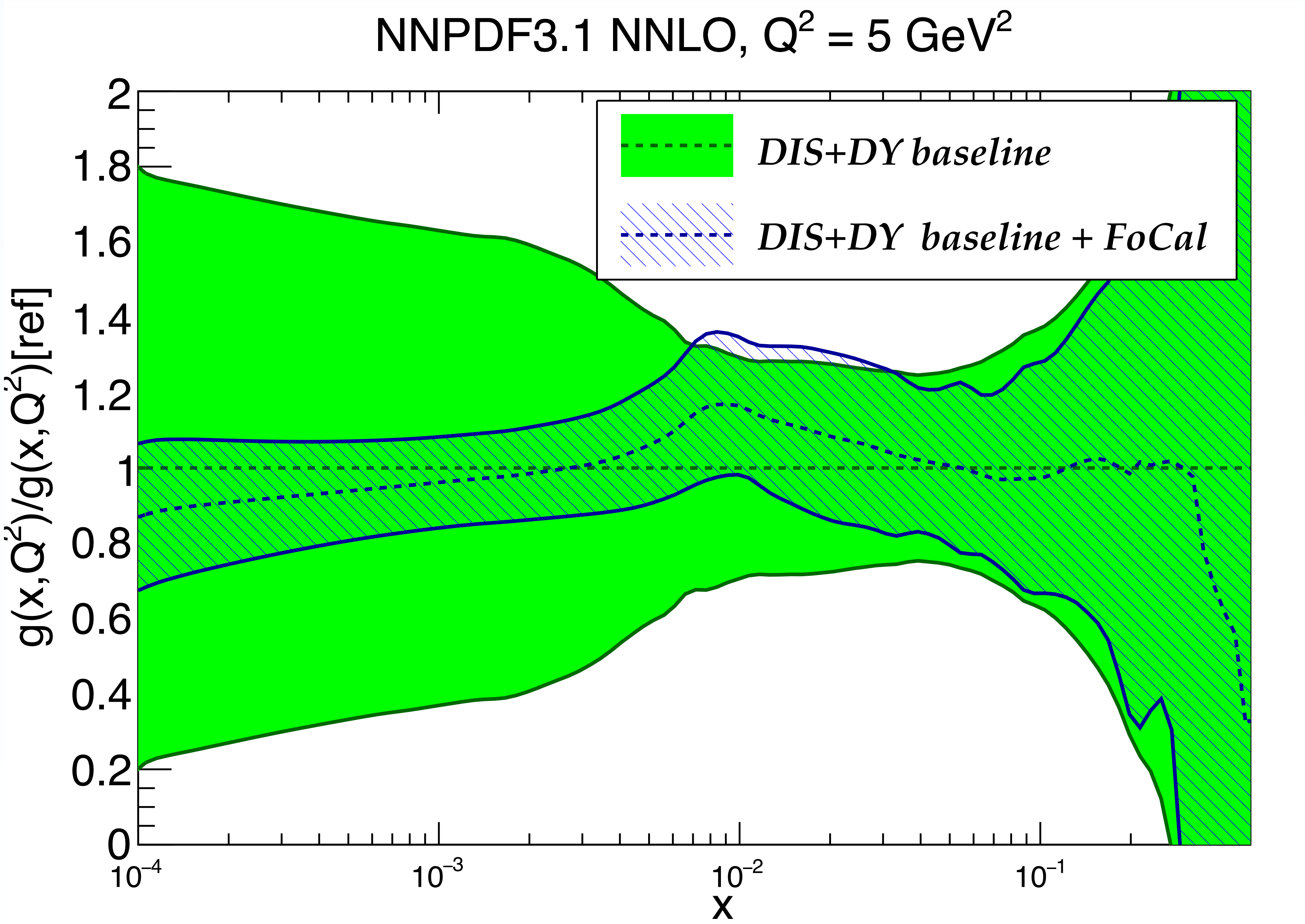


Impact on a ``nuclear" dataset

When added on top of a **nuclear-like dataset** (DIS and DY data only) the impact of the FoCal data becomes much more significant, since there is no "nuclear HERA"

Assuming that **collinear DGLAP factorisation** works, a determination of the **nuclear modifications of the gluon PDF at the 10% level down to x=10^{-4}** would be possible



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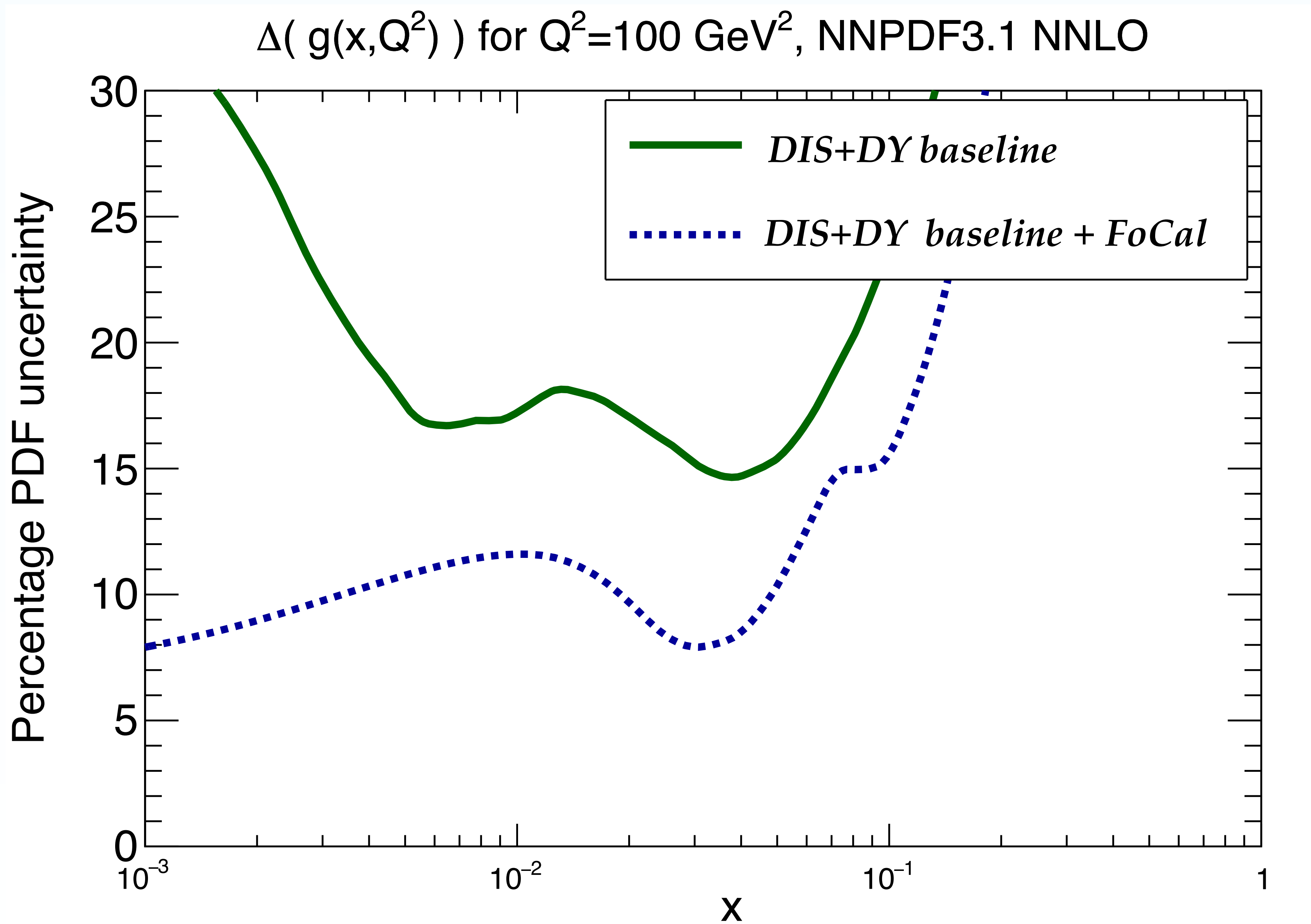

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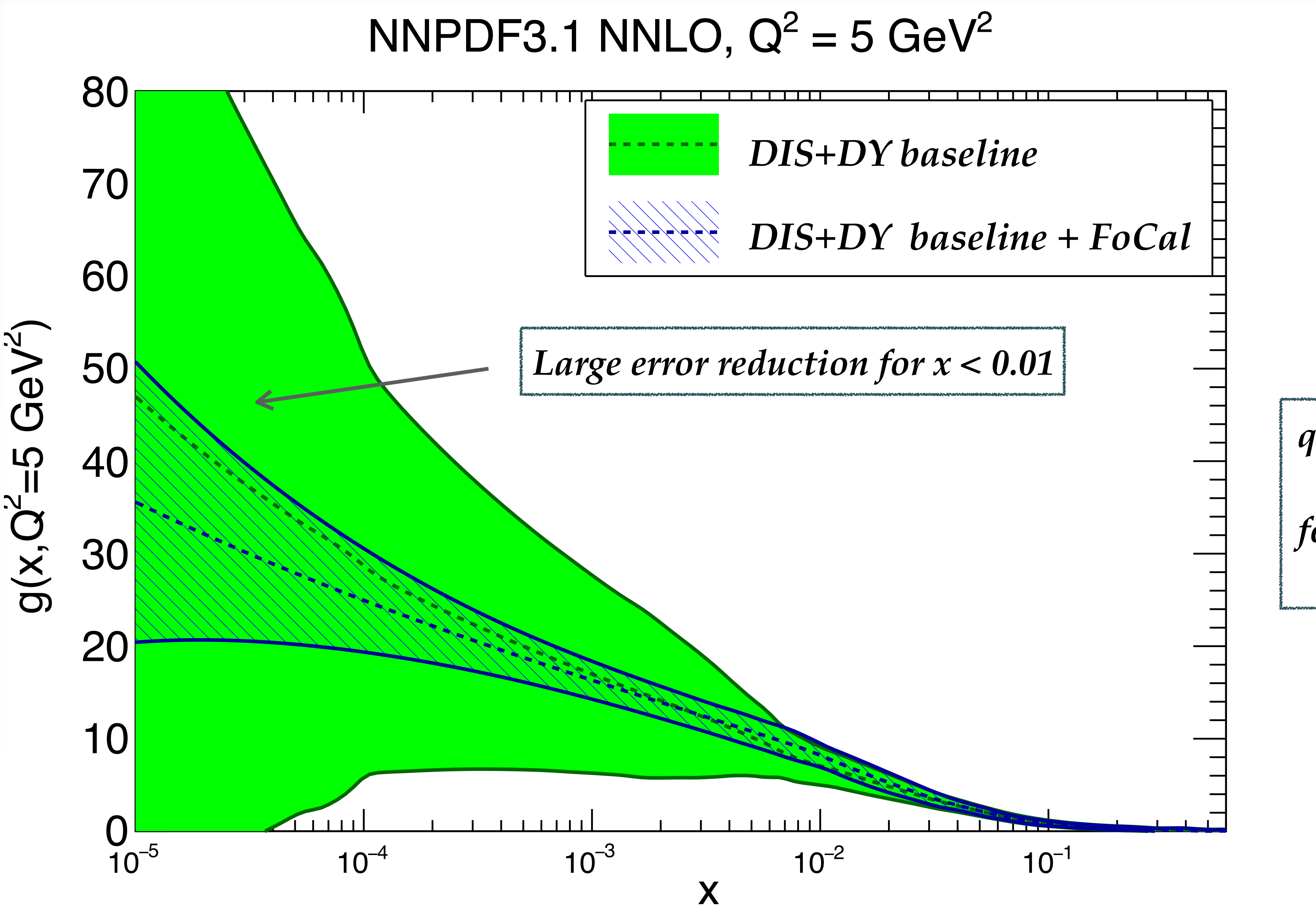
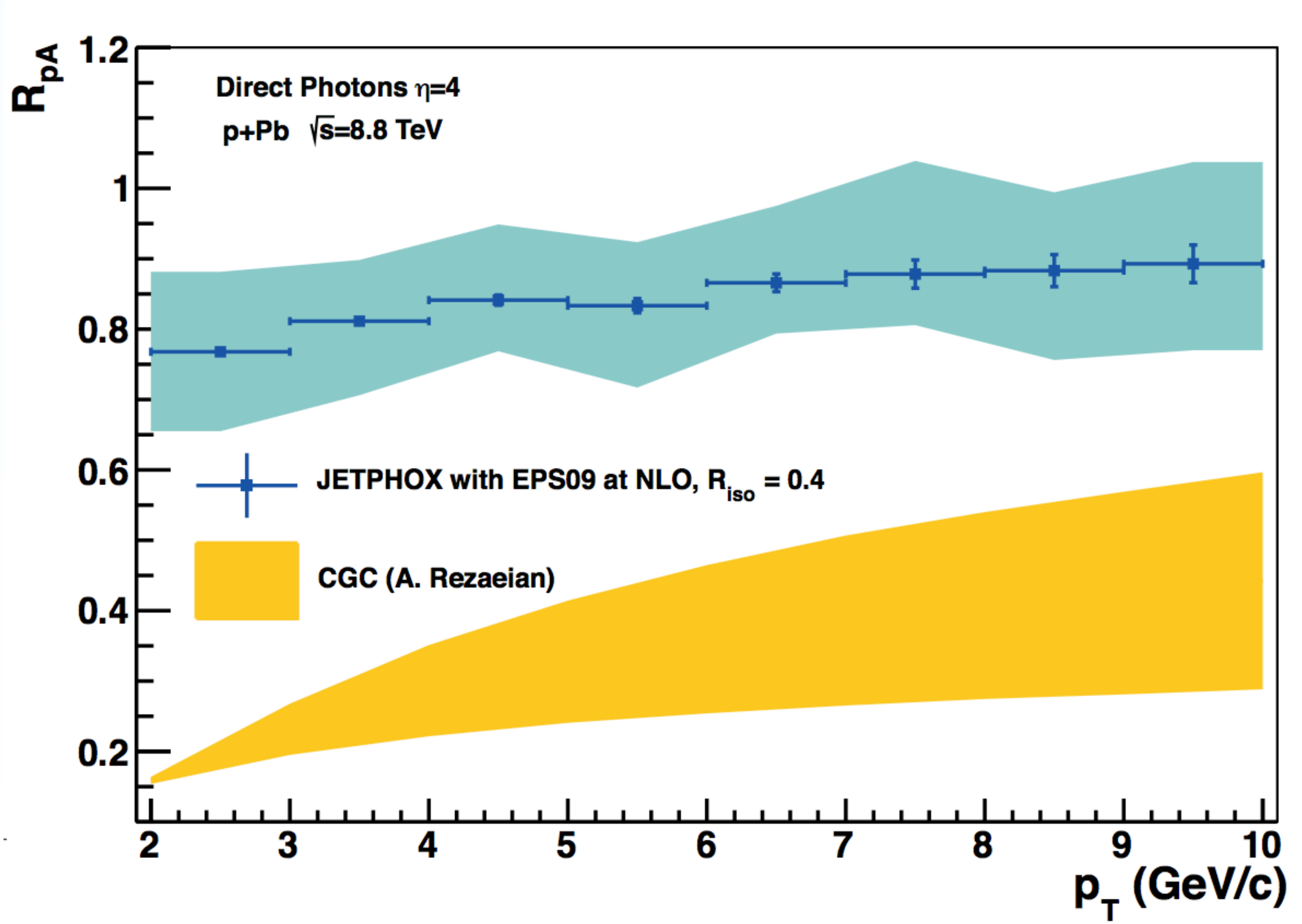


quantifies impact of FoCal for a nuclear PDF analysis!

next steps

Of course, this exercise assumes that **collinear DGLAP is the whole story**. What if the data contains effects beyond this framework, such as **small-*x* / BFKL** corrections, or **saturation/CGC/higher-twists** effects? We don't want *eg* to absorb BGC effects into the fitted nuclear gluon PDF ….



Parton distributions with BFKL resummation

- **Perturbative fixed-order QCD calculations** have been extremely successful in describing a wealth of data from proton-proton and electron-proton collisions

- There are theoretical reasons that eventually we need to go beyond DGLAP: at small-x, **logarithmically enhanced terms in *1/x* become dominant** and need to be resummed to all orders

- ***BFKL/high-energy/small-x resummation*** can be matched to the **DGLAP collinear framework**, and thus be included into a standard PDF analysis

DGLAP Evolution in Q²

$$\mu^2 \frac{\partial}{\partial \mu^2} f_i(x,\mu^2) = \int_x^1 \frac{dz}{z} P_{ij}\left(\frac{x}{z}, \alpha_s(\mu^2)\right) f_j(z,\mu^2),$$

BFKL Evolution in x

$$-x\frac{d}{dx} f_+(x,\mu^2) = \int_0^\infty \frac{d\nu^2}{\nu^2} K\left(\frac{\mu^2}{\nu^2}, \alpha_s\right) f_+(x,\nu^2)$$

Within small-x resummation, the **N^{k}LO fixed-order DGLAP splitting functions** are complemented with the **N^{h}LLx contributions from BKFL**

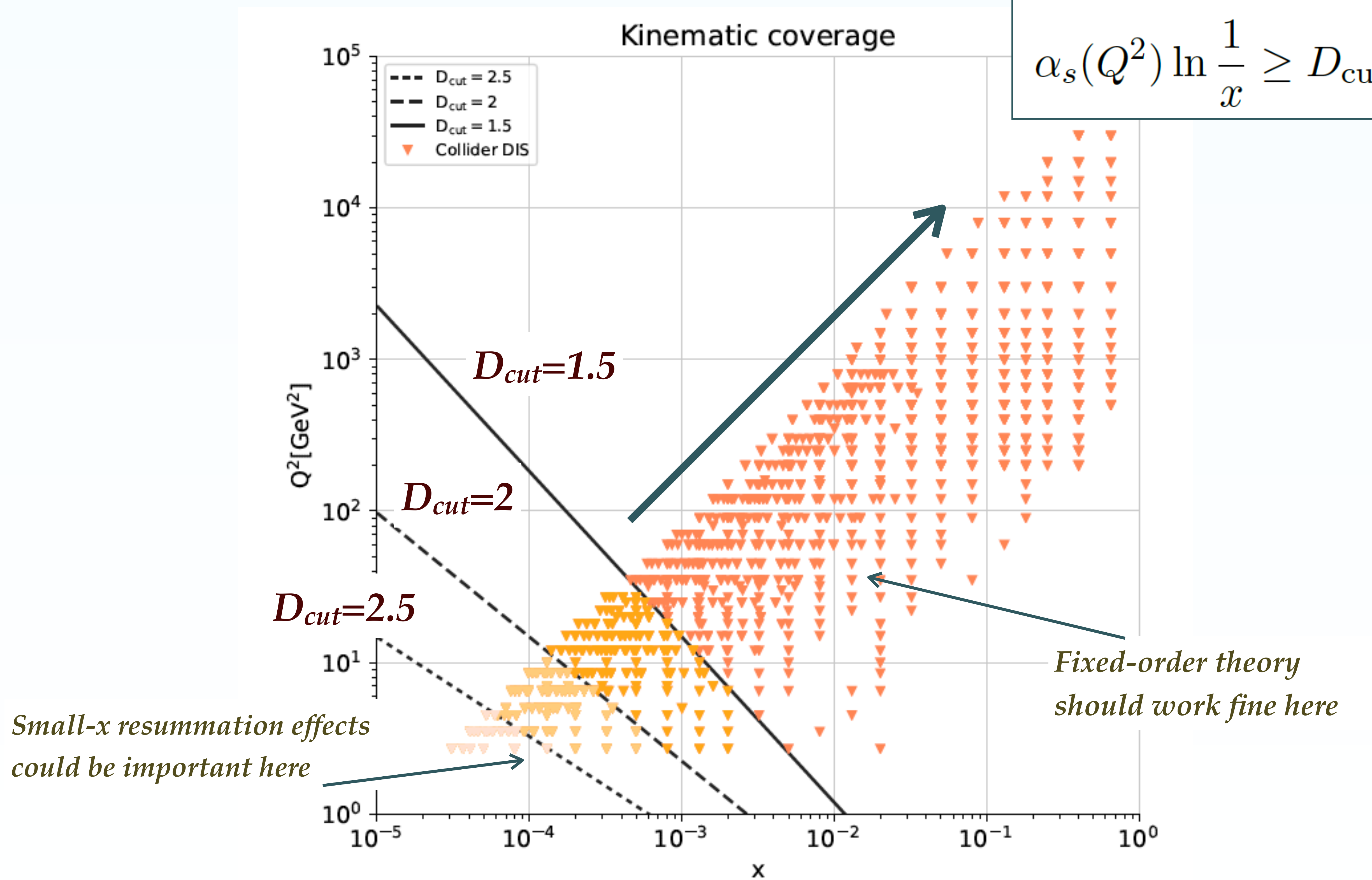
ABF, CCSS, TW + others, 94-08

$$P_{ij}^{\mathrm{N}^k\mathrm{LO}+\mathrm{N}^h\mathrm{LL}x}(x) = P_{ij}^{\mathrm{N}^k\mathrm{LO}}(x) + \Delta_k P_{ij}^{\mathrm{N}^h\mathrm{LL}x}(x),$$

Quantifying BFKL effects in HERA data

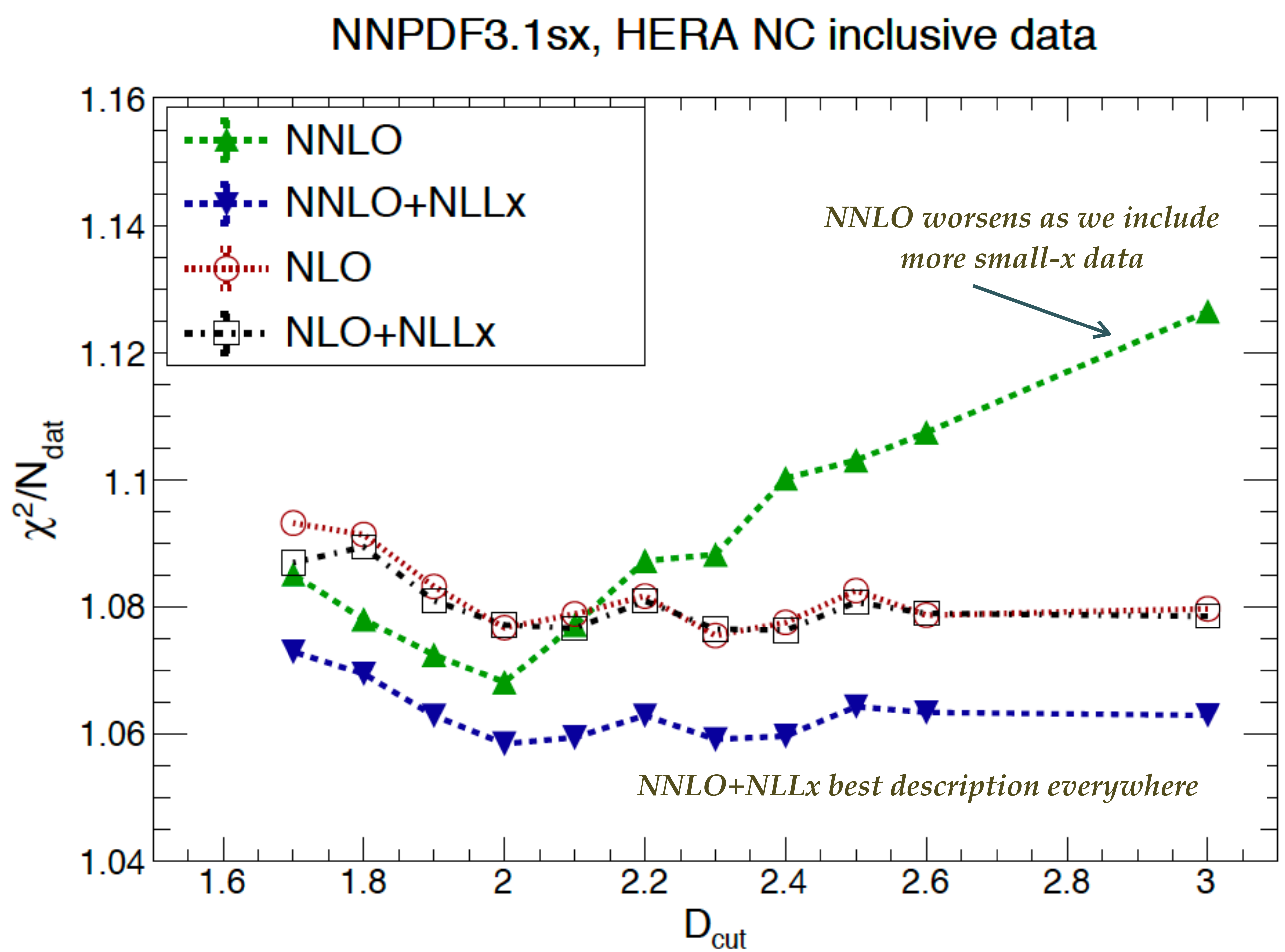
In order to assess the impact of small-x resummation for the description of the small-x and Q^2 HERA data, compute the χ^2 **removing data points in the region where resummation effects are expected**

$$\alpha_s(Q^2) \ln \frac{1}{x} \geq D_{\rm cut}$$



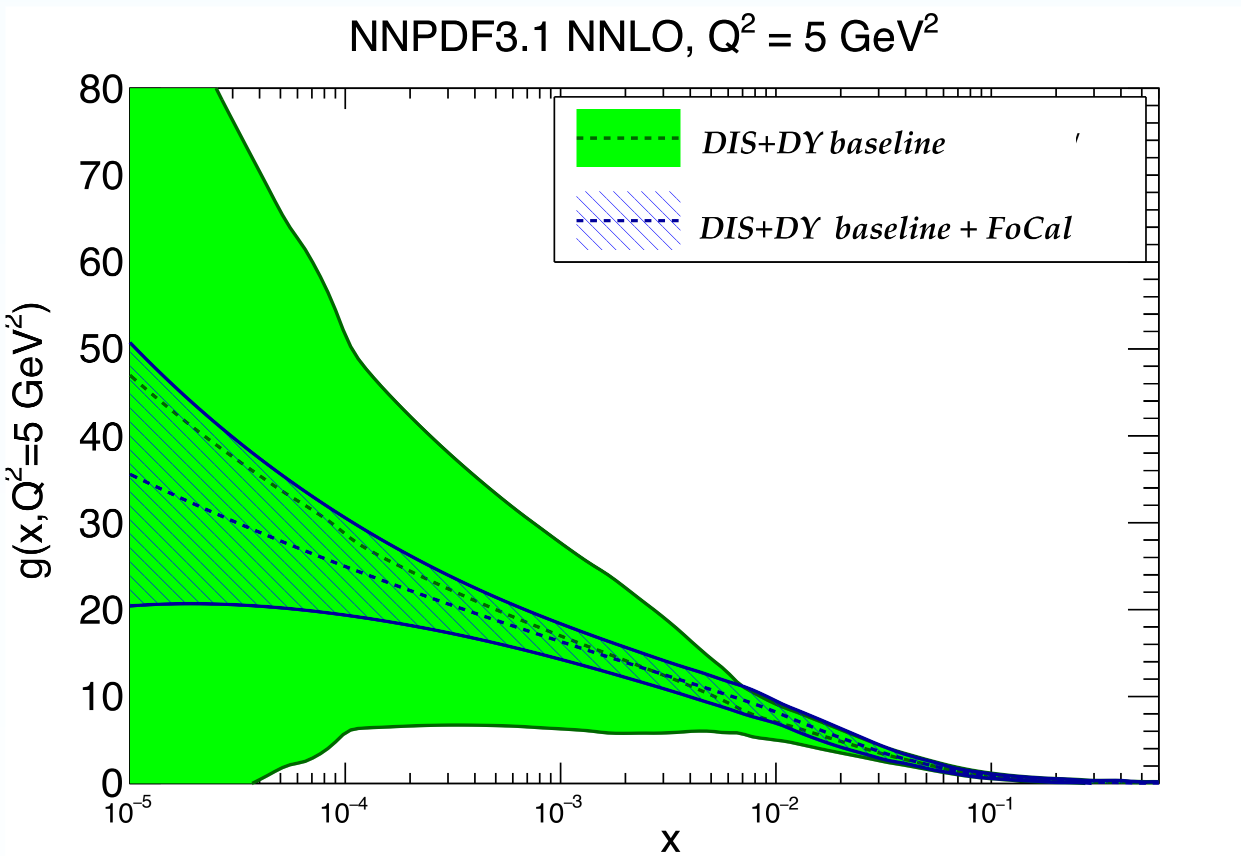
Quantifying BFKL effects in HERA data

By smoothly probing the **transition region between DGLAP and small-x**, we can quantify the onset of **novel QCD dynamics in HERA data** - the same could be done for FoCal *eg* varying $\mathbf{p_T^{cut}}$

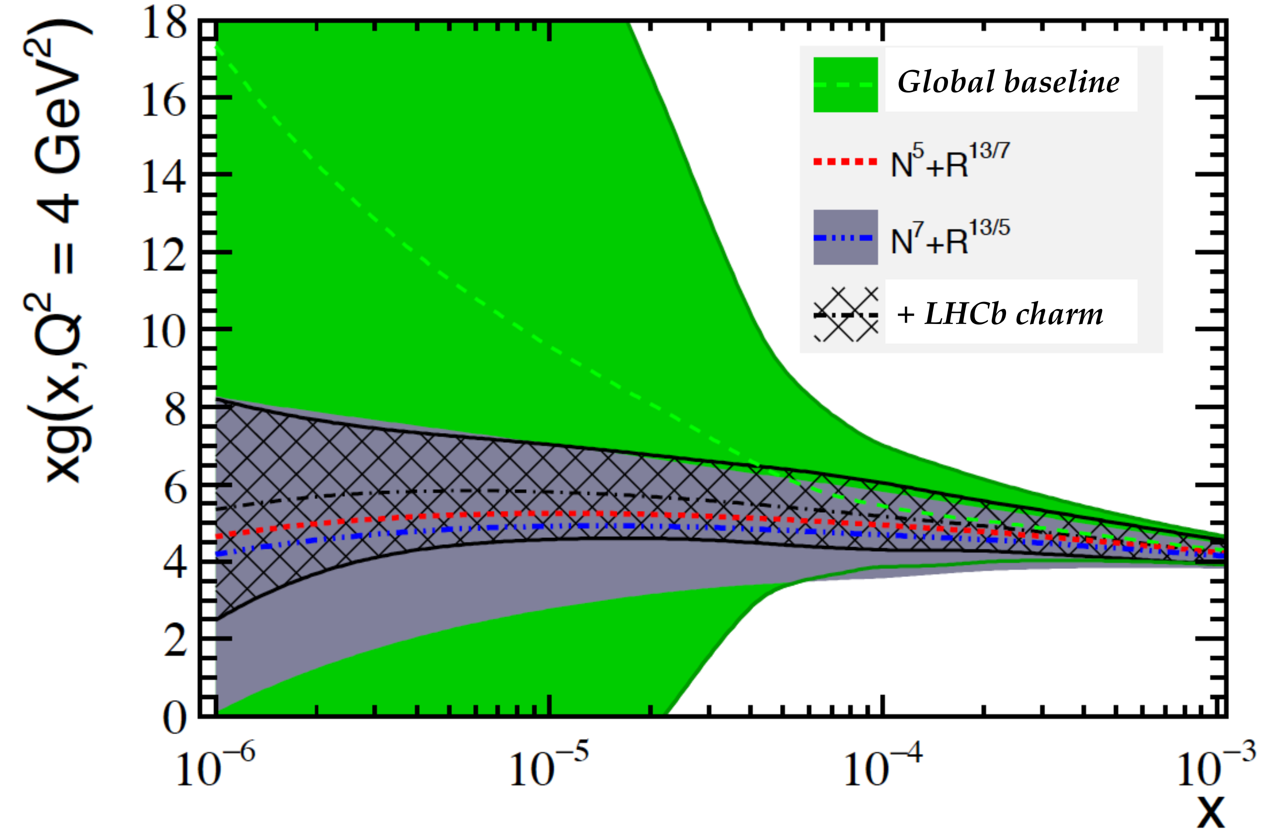


Comparison with charm production

Impact of FoCal photon data when added to a DIS+DY fit



Impact of LHCb charm data when added to a global fit



D **meson** and **direct photon production** have very different systematic errors, both from the theory and from the experimental point of view: they are **fully complementary** to test nuclear PDFs at small-x

Disclaimer: *a fully consistent comparison would require fitting the LHCb charm measurements in p+Pb collisions, which afaik it has never been carried out …*

Summary and outlook

- **Direct photon production** is an important process in hadron collisions. State of the art theory is NNLO QCD with LL electroweak corrections

- The ATLAS 8 TeV photon measurements have been successfully **included in the NNPDF3.1 global analysis**, good overall consistent with other data in the global fit

- Photon production in the forward region (FoCal) offers a **sensitive prove of small-x QCD in proton-lead collisions**, allowing us to **constrain the nuclear gluon modifications** and to test **deviations wrt the collinear DGLAP framework**

- The production of **photons** is characterised by very different theory and experimental errors than that of ***D* mesons**, so imho the two measurements are fully complementary