Impact of fully coherent energy loss on nPDF extraction

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Hard Probes 11th edition
Aschaffenburg, Germany

Parton Distribution Functions

Universal objects:

- Can be used to compute observables <u>independent</u> of the collision system

PDF are not computable from QCD first principles:

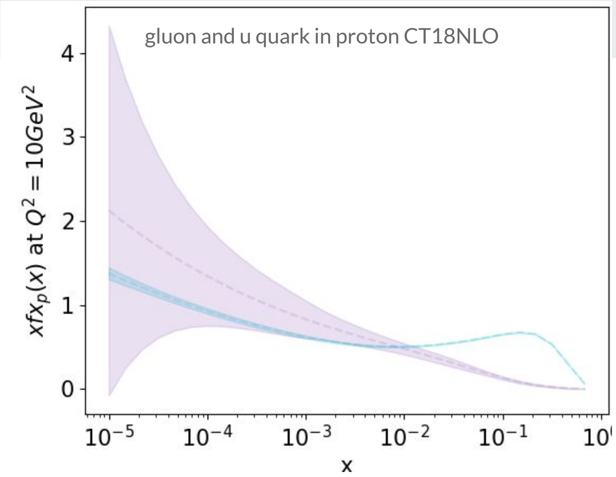
- obtained from global fits on data

Collaborations :

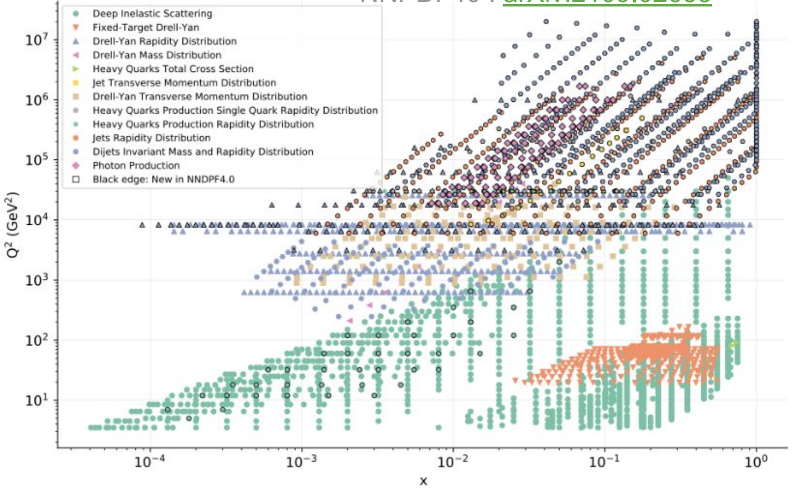
- NNPDF
- MMHT
- CTEQ
- EPPS
- …

Main observables :

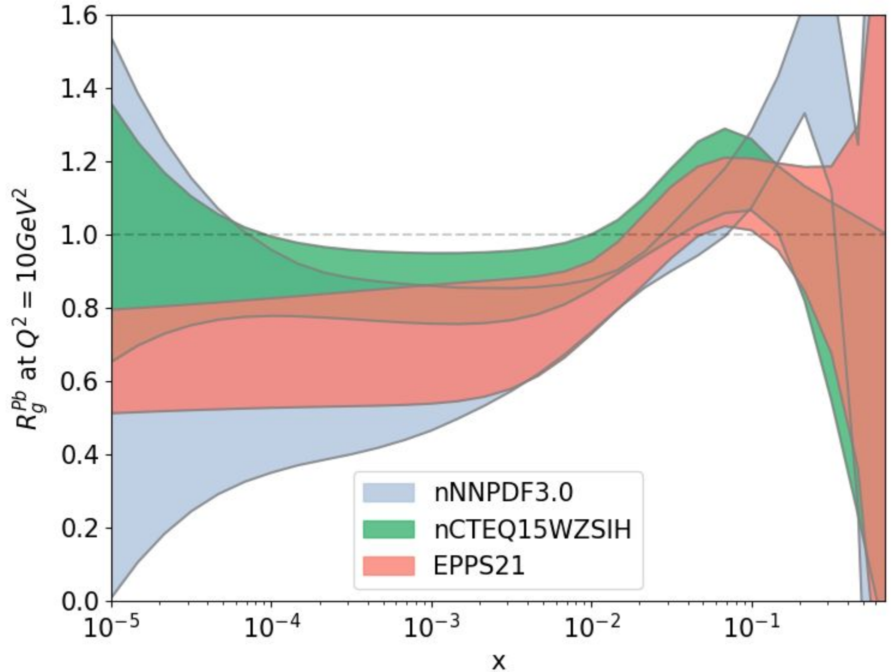
- F_2 in DIS
- Drell-Yan
- Jets / dijets
- Weak bosons
- …



NNPDF40 : arXiv:2109.02653



Nuclear PDFs



- Nuclear medium affects parton distributions in nucleons
- Requires additional data of nuclear collisions to be extracted

EPPS21 : arXiv:2112.12462
nCTEQ15WZSIH : arXiv:2105.09873
nNNPDF30 : arXiv:2201.12363

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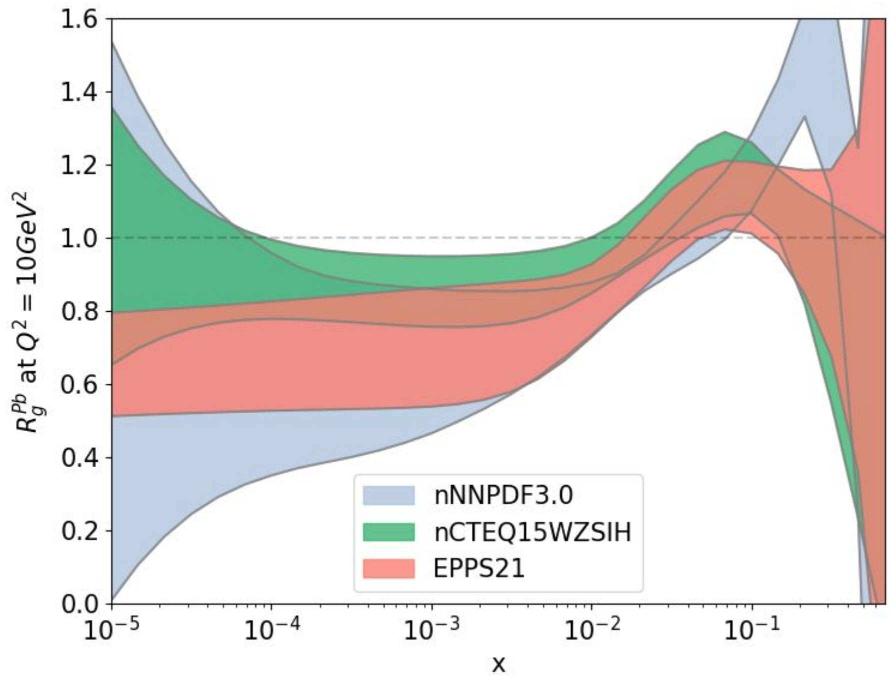

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- Recent proposals to use heavy flavour data (ψ, D, B) at high energy provide additional constraints on gluons at small x
  - nNNPDF3.0 with D meson
  - nCTEQHQ with ψ, D, B…
  - EPPS21 with D meson

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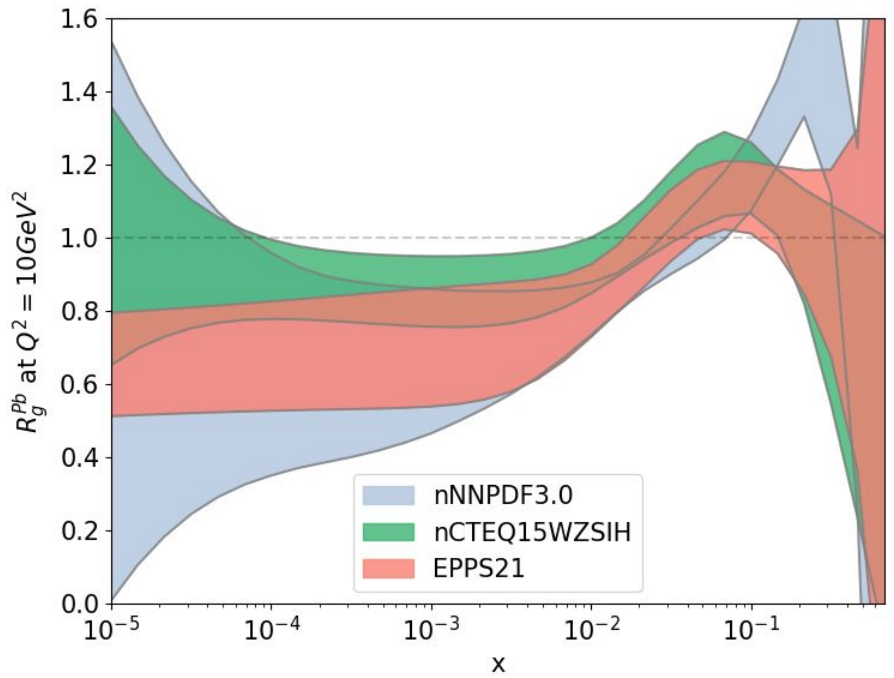

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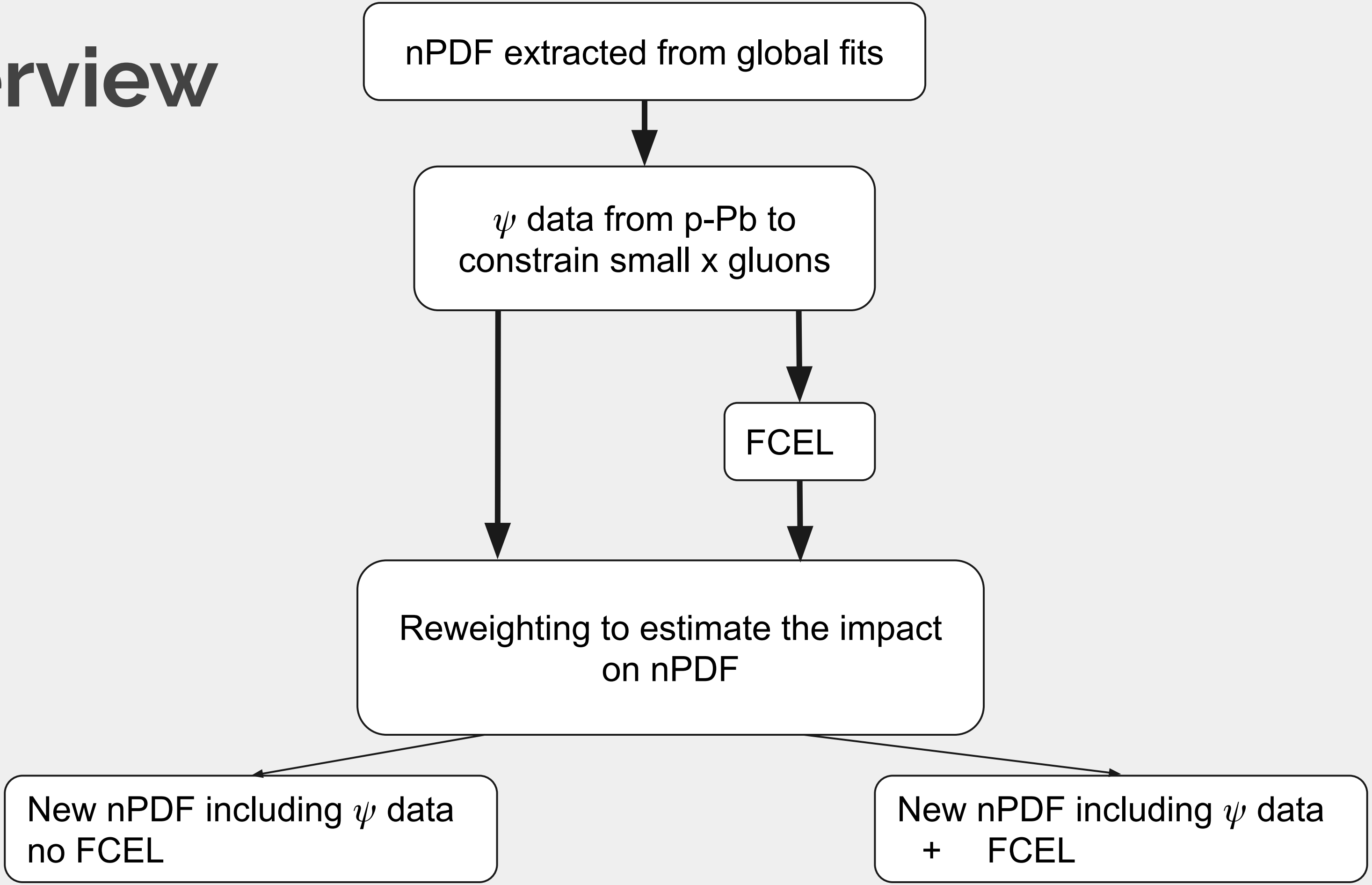
Caveat : heavy flavour data sensitive to fully coherent energy loss (FCEL)

Overview


nPDF extracted from global fits
ψ data from p-Pb to constrain small x gluons
FCEL
Reweighting to estimate the impact on nPDF
New nPDF including ψ data no FCEL
New nPDF including ψ data + FCEL

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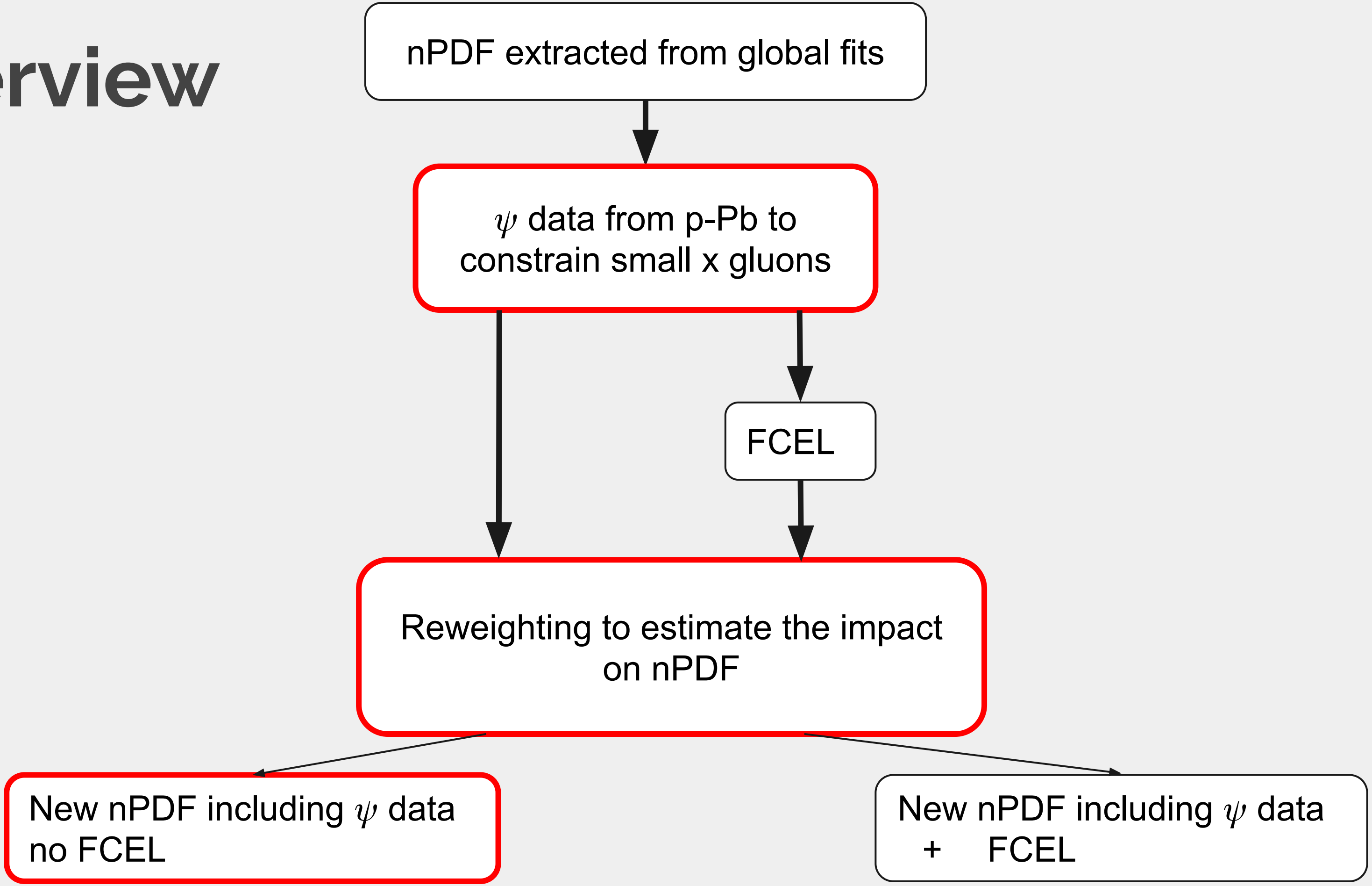
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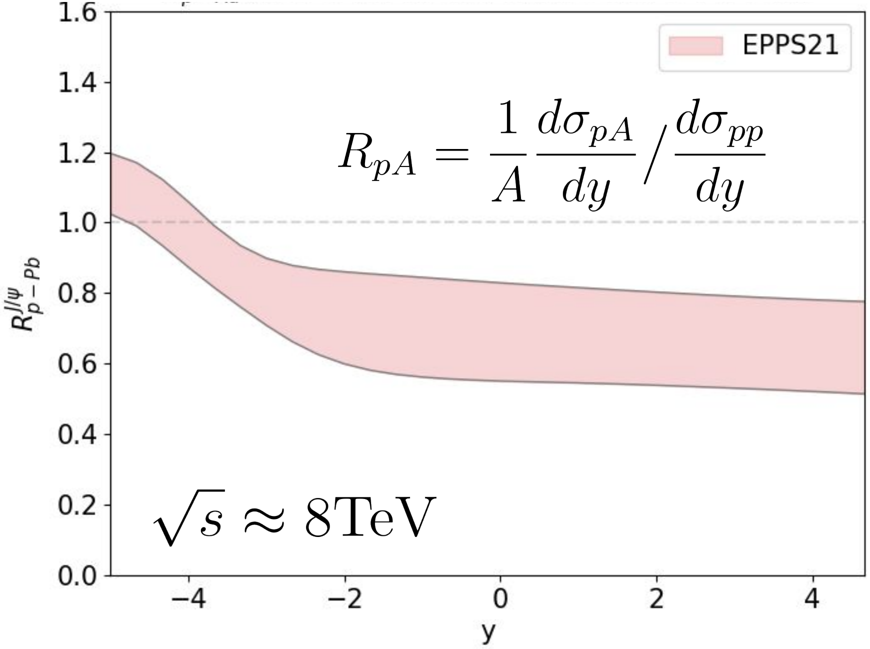
ψ hadroproduction model

Color evaporation model:

$c\bar{c}$ pair hadronises with fixed probability to a ψ state as long as its invariant mass is in range:

$$\frac{d\sigma_{p+A\to\psi}}{dy} = 2F_\psi \int_{2m_c}^{2m_D} dm\, m \frac{d\sigma_{p+A\to c\bar{c}}}{dm^2 dy}$$

$$\frac{d\sigma_{p+A\to c\bar{c}}}{dm^2 dy} \equiv \sum_{i,j=g,q,\bar{q}} f_i^p(x_1,\mu^2) \otimes f_j^A(x_2,\mu^2) \otimes \hat{\sigma}_{ij\to c\bar{c}}$$

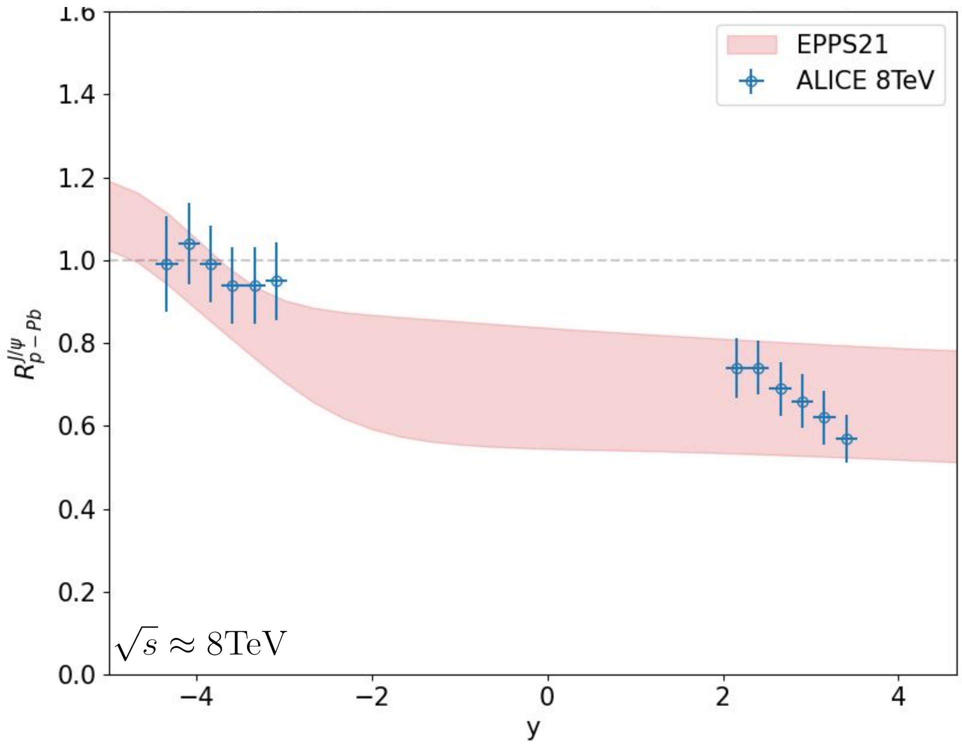


Reweighting nPDF

- Uncertainties are characterised by a set of equally likely replicas
- Behave like a statistical sample
- Comparison to ψ data in p-Pb collisions:
  ALICE 5 TeV
  ALICE 8 TeV
  LHCb 8 TeV

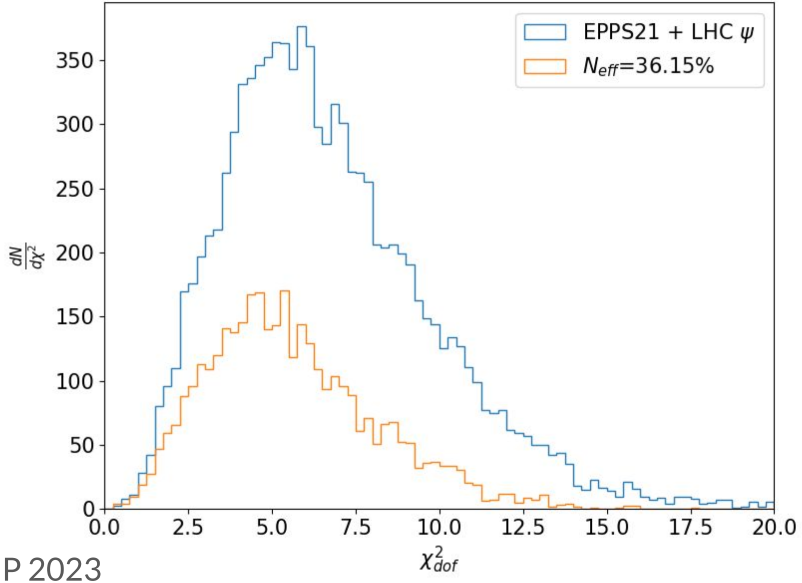
Replicas are given weights according to:

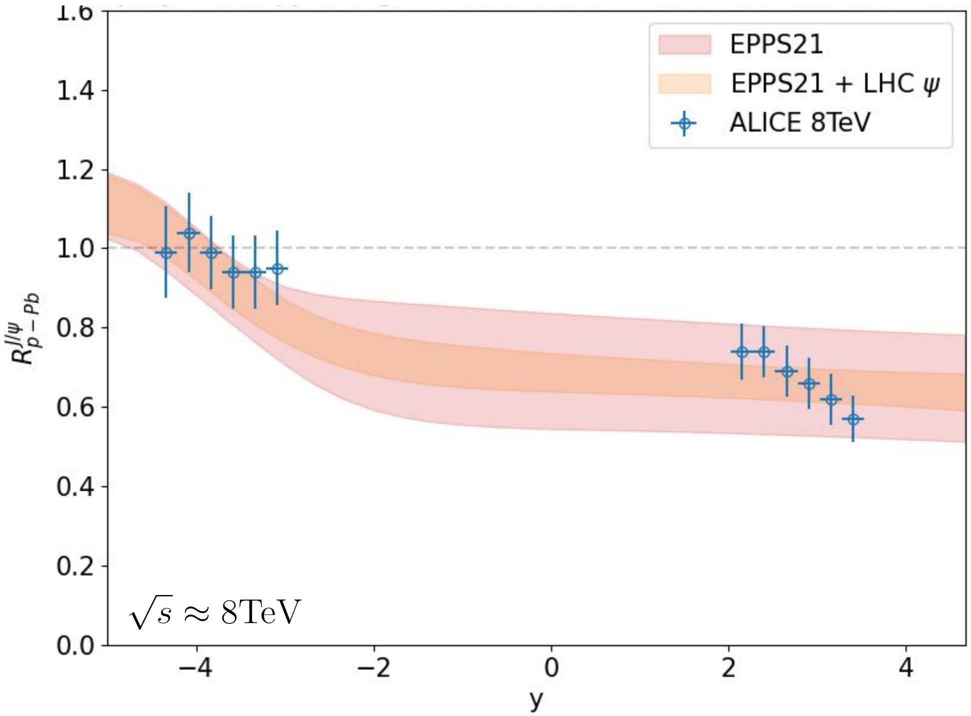
$$w_k = f(\chi_k^2)$$



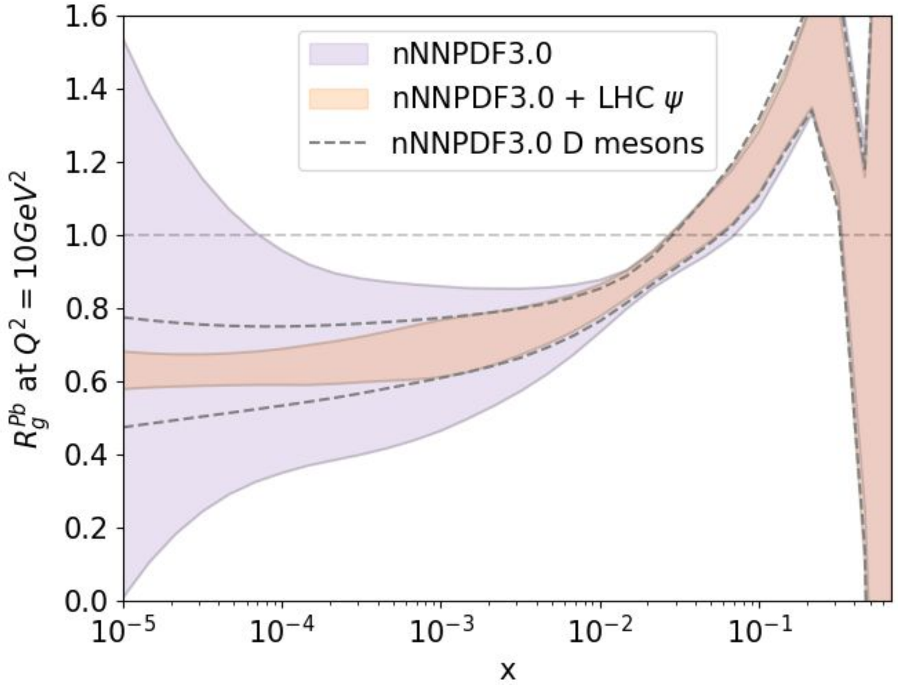
Reweighting nPDF

- Uncertainty narrowing at forward rapidity
- χ^2 distribution tail is suppressed



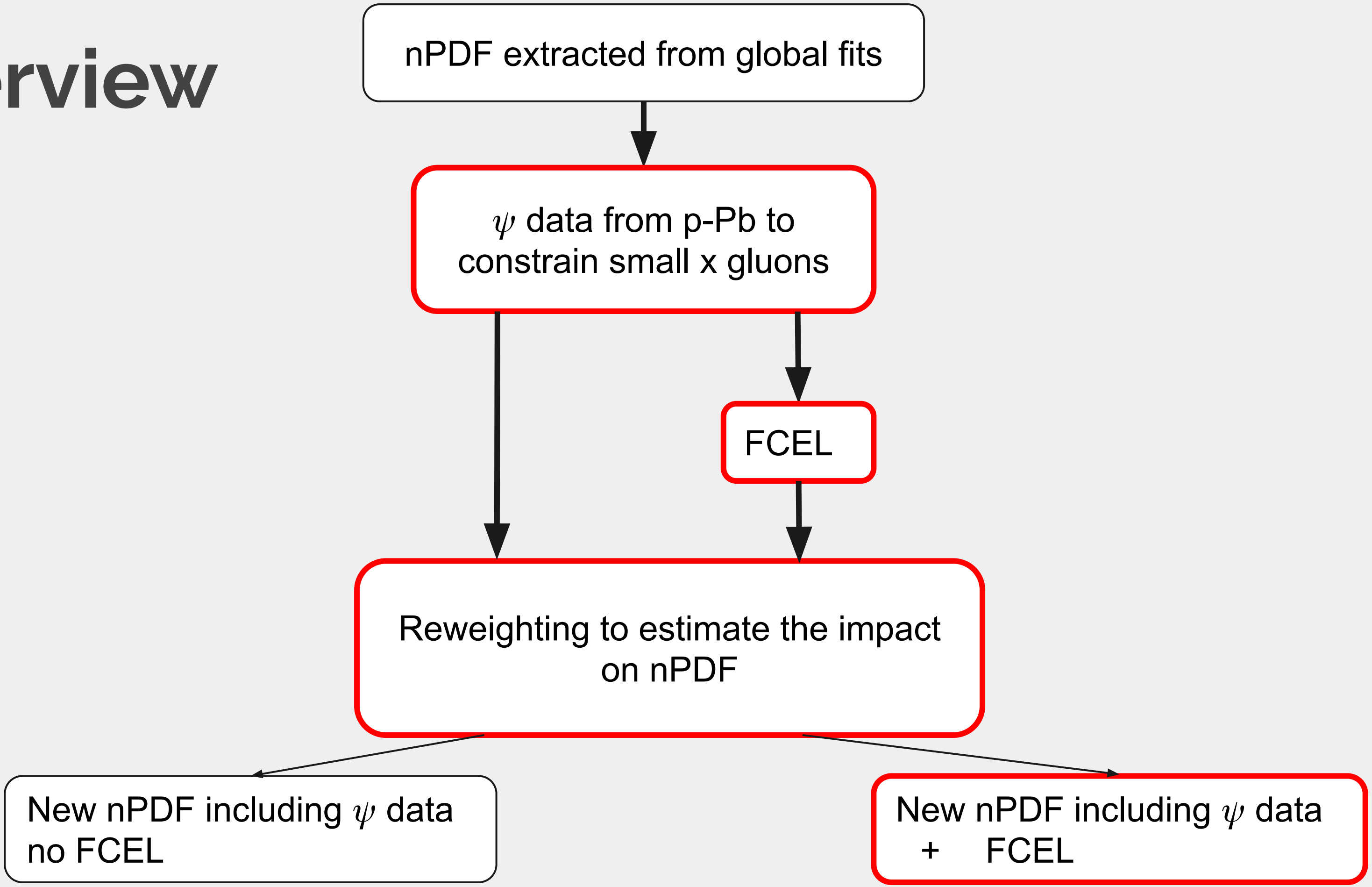


Effect gluon nPDF ratios



- Reduction of uncertainties similar to results from D mesons by nNNPDF3.0
- Validates the procedure
- Only a few data points which constrain at x down to ~10^{-5}

Overview



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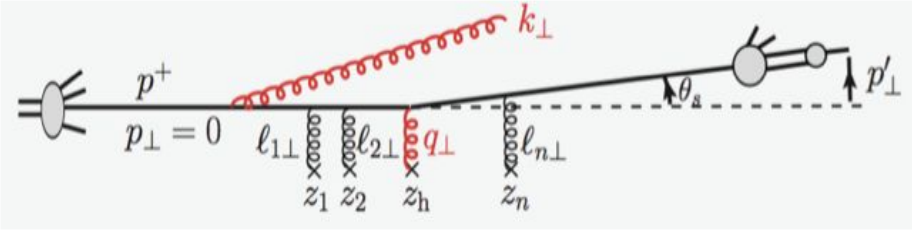
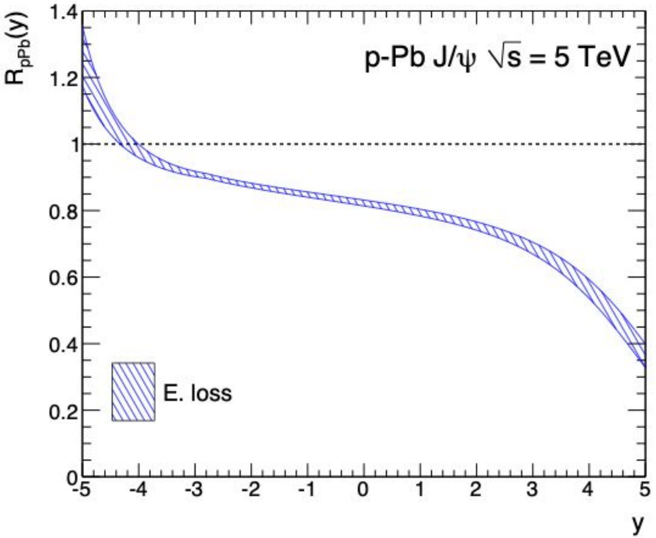
arXiv:2107.05871

Phenomenology



- Affects hadrons in p-A collisions
- Absent in DIS and W/Z in p-A



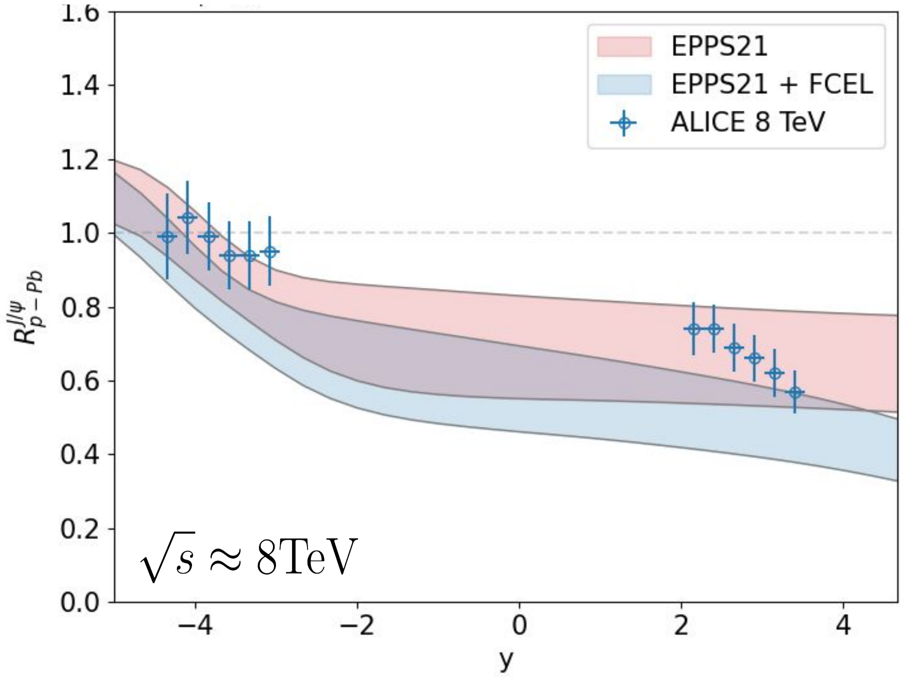
$$\frac{d\sigma^{J/\psi}_{FCEL}}{dE}(E) = \int_0^{\epsilon_{\max}} d\epsilon \mathcal{P}(\epsilon, E) \frac{d\sigma^{J/\psi}}{dE}(E+\epsilon)$$

with quenching weight : $\mathcal{P}(\epsilon) = f\left(\frac{dI}{d\omega}\right)$

$$\Delta E \simeq N_c \alpha_s \frac{\sqrt{\hat{q}L}}{M_\perp} E$$

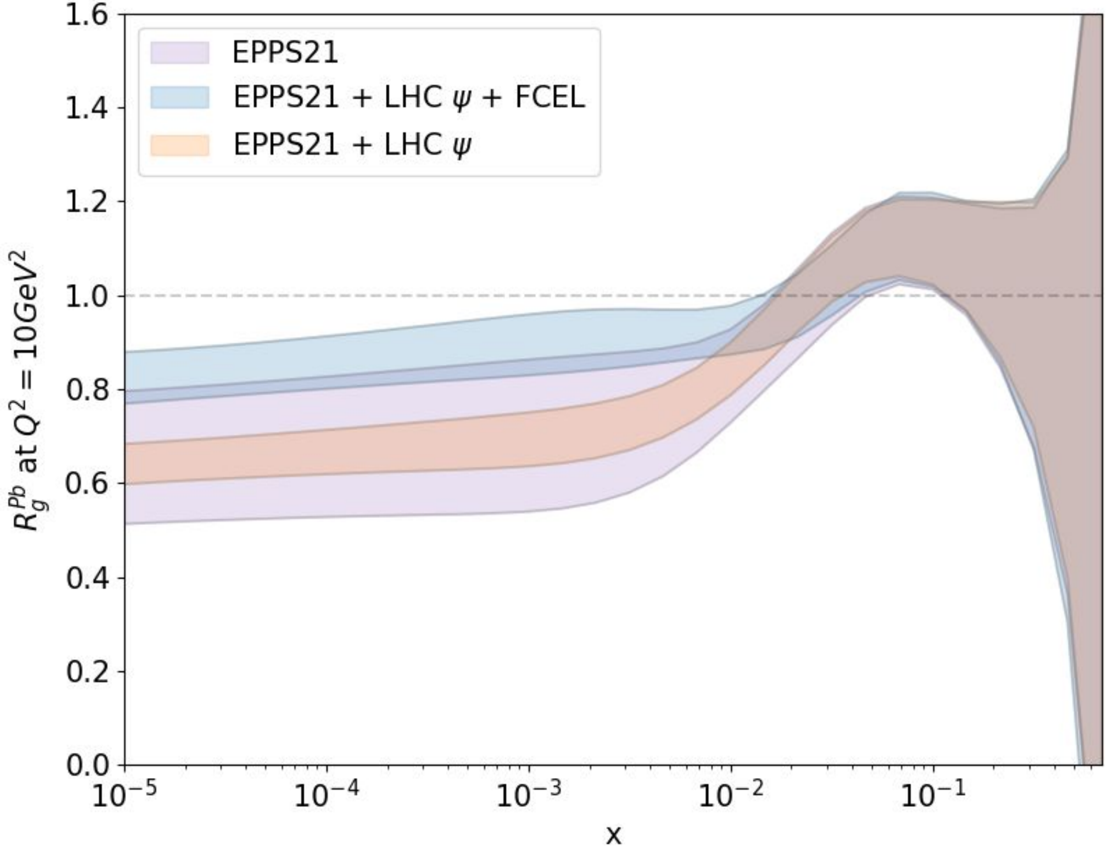
With q the nuclear matter transport coefficient: only free parameter

FCEL impact on RpA



- FCEL should account for part of the suppression
- Reweighting with FCEL should reduce shadowing

Effect on nPDF gluon ratios



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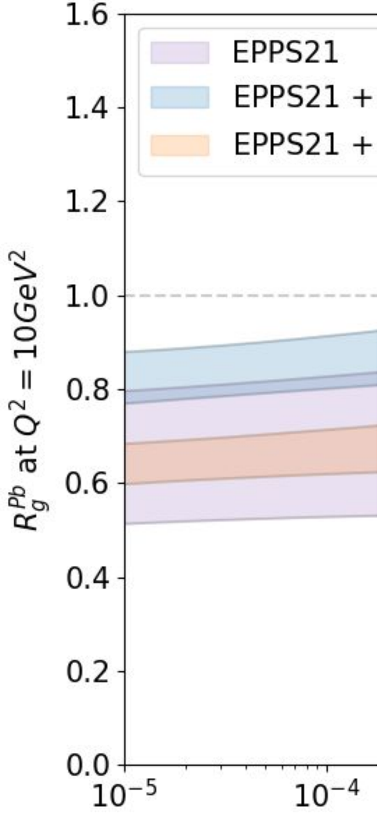

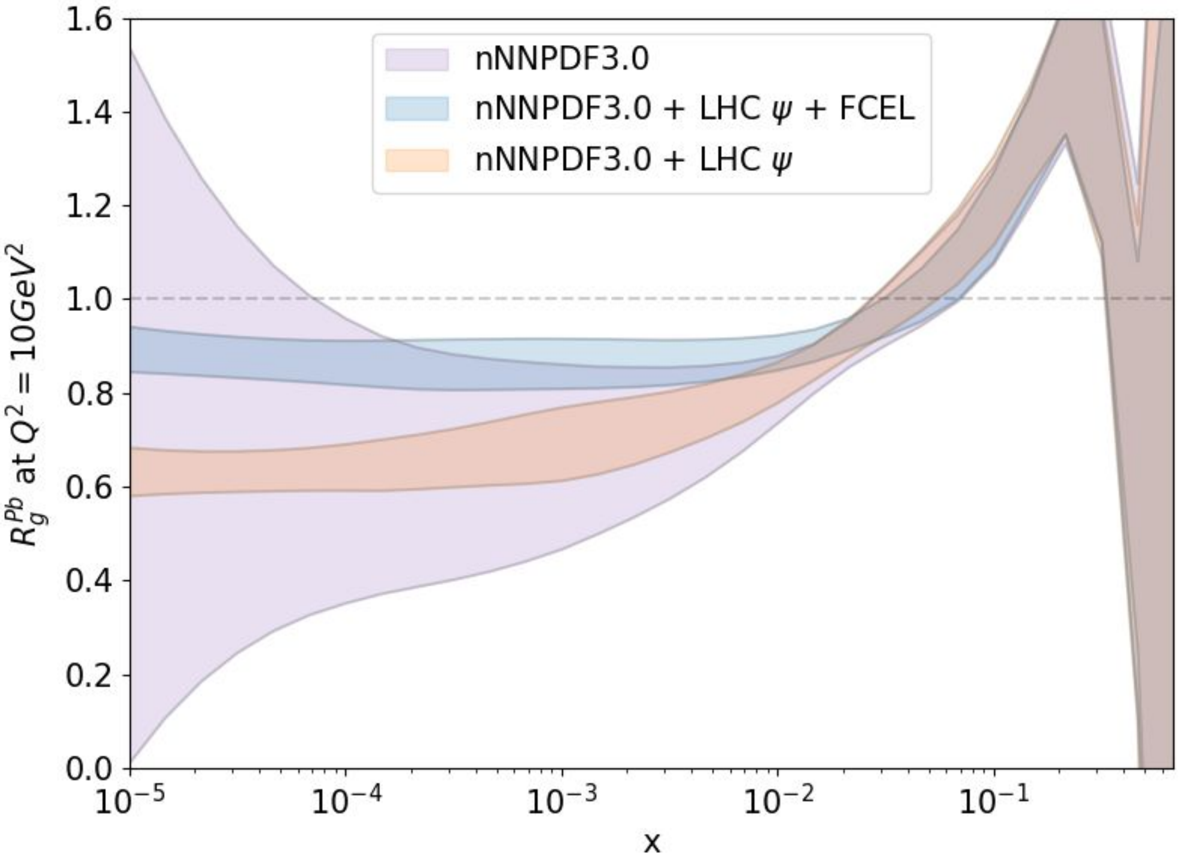

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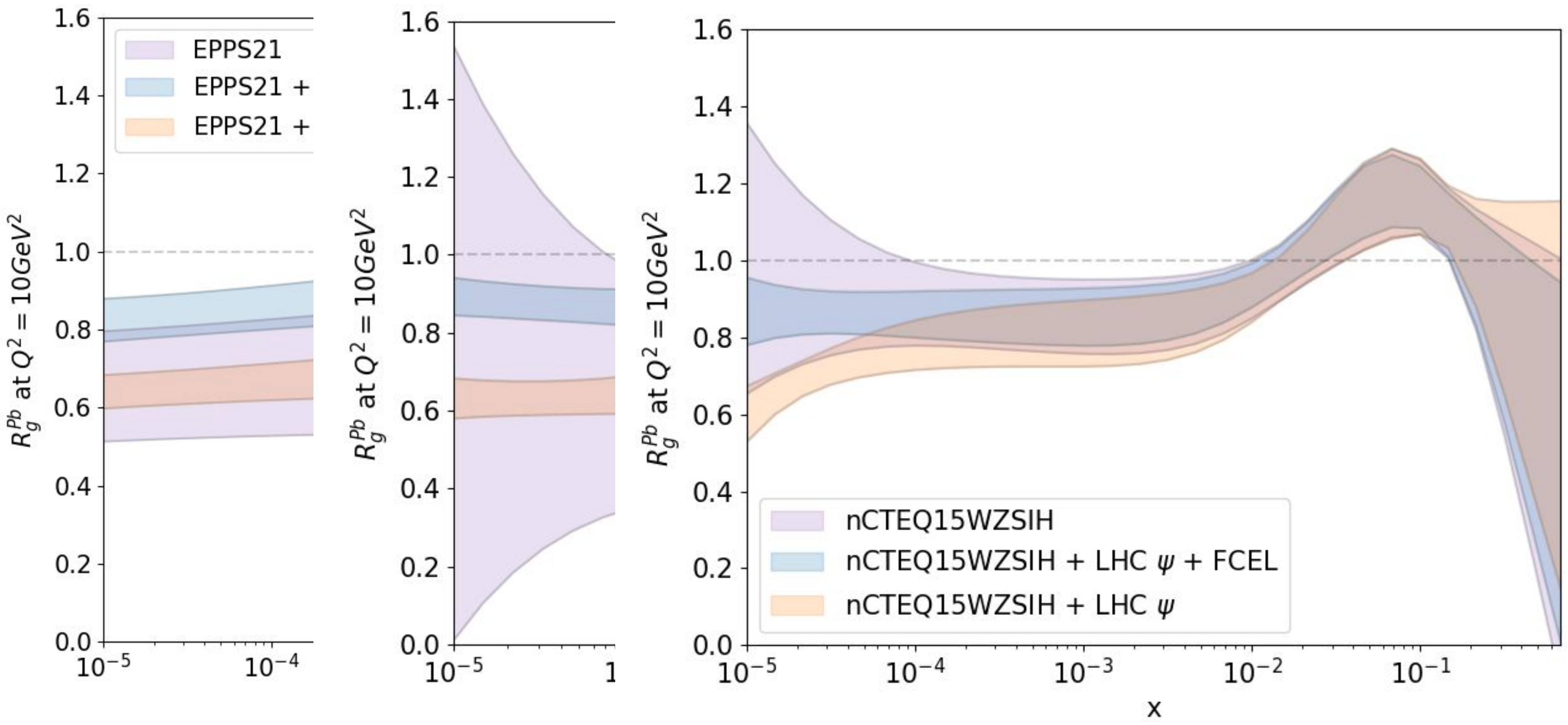

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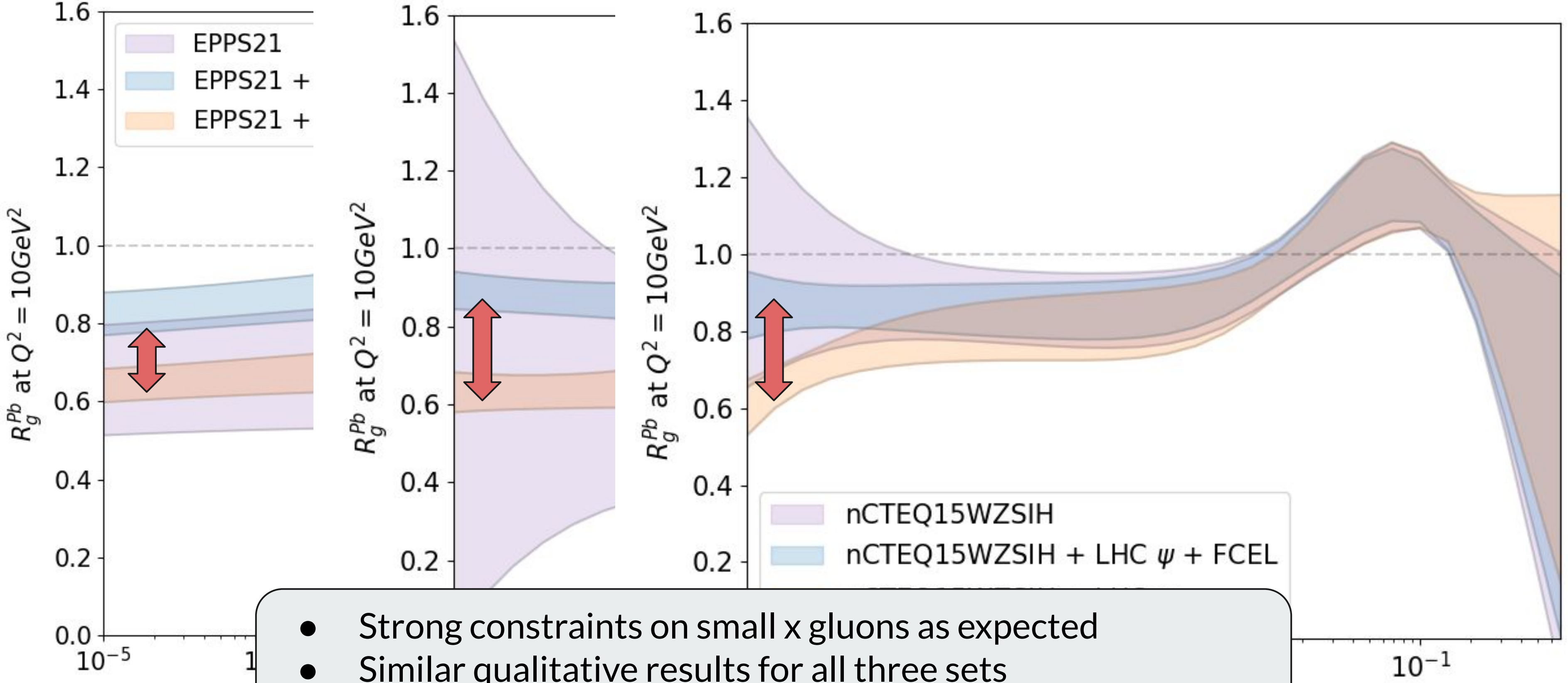
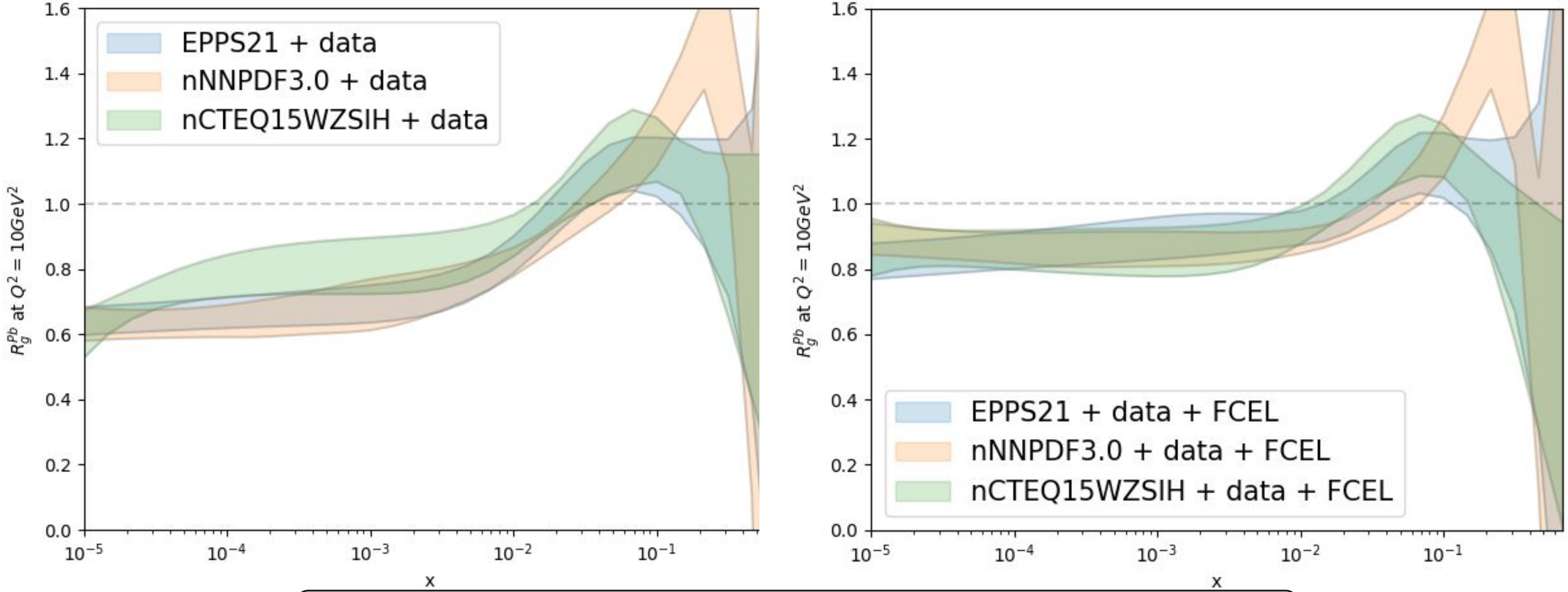


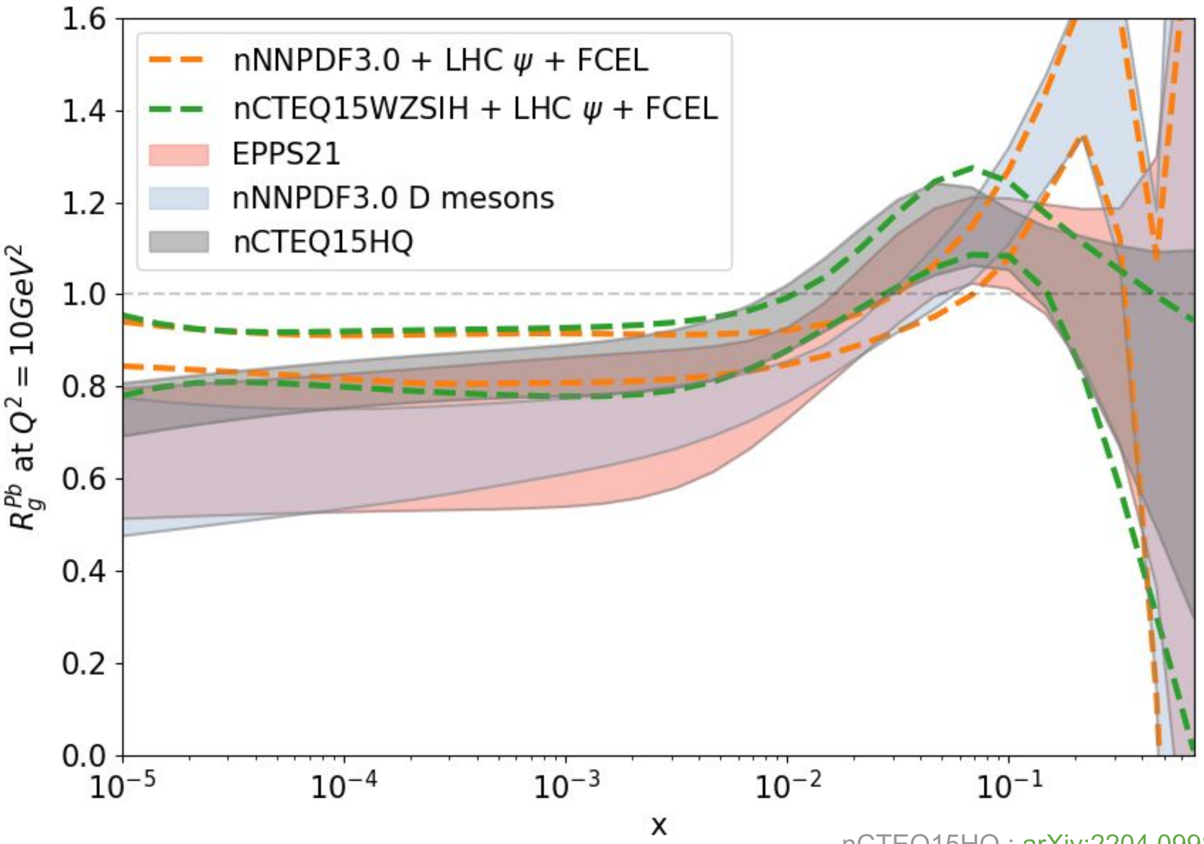
- Strong constraints on small x gluons as expected
- Similar qualitative results for all three sets
- Large difference between nPDF alone and nPDF + FCEL

Gluon ratios

- Convergence of all sets due to constraining data
- Uncertainties greatly reduced



Large difference with and without FCEL at very small x



nCTEQ15HQ : arXiv:2204.09982

Conclusion

- reweighting nPDFs using ψ measurements with and without FCEL

New sets show large constraints on (small x) nuclear gluon distributions

- First time inclusion of FCEL
- Using FCEL impact nPDF extractions
- Visible differences between ψ + FCEL and other extractions without FCEL

Outlooks:

- Other ψ production models
- Similar study with D mesons data
- Global fits using HF data and accounting for FCEL

Thank you

Phenomenology

$$\frac{d\sigma^{J/\psi}_{FCEL}}{dE}(E) = \int_0^{\epsilon_{\max}} d\epsilon \mathcal{P}(\epsilon, E)\frac{d\sigma^{J/\psi}}{dE}(E+\epsilon)$$

The cross section is shifted by radiated gluon, with probability density function of gluon energy:

$$\mathcal{P}(\varepsilon, E) = \frac{\mathrm{d}I}{\mathrm{d}\varepsilon}\exp\left\{-\int_\varepsilon^\infty \mathrm{d}\omega \frac{\mathrm{d}I}{\mathrm{d}\omega}\right\}$$

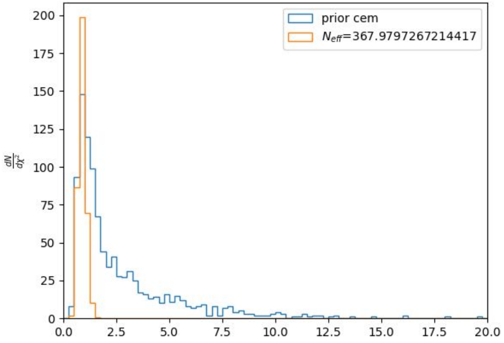
Only parametric dependence of the model:

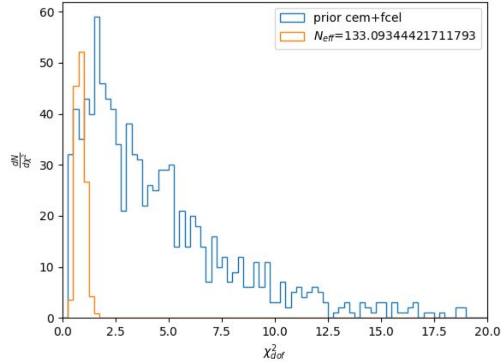
$$l_\perp^2 = \hat{q}L$$ with $$\hat{q}(x) \equiv \hat{q}_0\left(\frac{10^{-2}}{x}\right)^{0.3}$$

$$\omega\frac{\mathrm{d}I}{\mathrm{d}\omega} = \frac{N_c\alpha_s}{\pi}\left\{\ln\left(1+\frac{\ell_{\perp A}^2 E^2}{M_\perp^2\omega^2}\right) - \ln\left(1+\frac{l_{\perp p}^2 E^2}{M_\perp^2\omega^2}\right)\right\}\Theta\left(\ell_{\perp A}^2 - \Lambda_B^2\right)$$

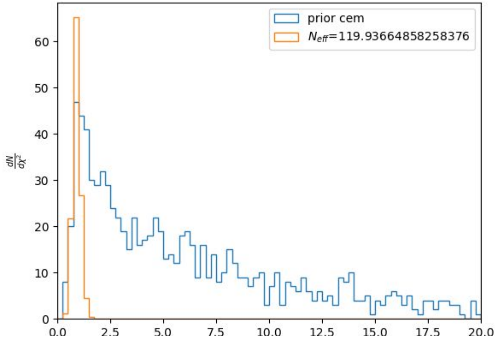
χ^2 Distributions

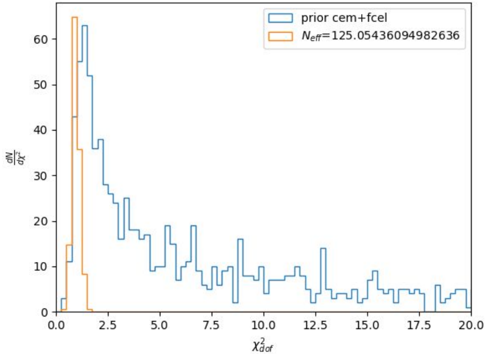
EPPS21





nNNPD3.0





nCTEQ15WZ