Towards EPPS21 nuclear PDFs

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Short intro to EPPS framework

- Define nuclear PDFs in terms of

$$\underbrace{f_i^{p/A}(x,Q^2)}_{\text{bound-proton PDF}} = \overbrace{R_i^{p/A}(x,Q^2)}^{\text{nuclear modification}}\,\underbrace{f_i^{p}(x,Q^2)}_{\text{free-proton PDF}}$$

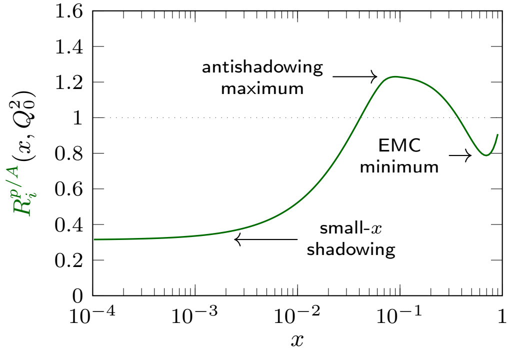
- PDFs of the full nucleus are then constructed with

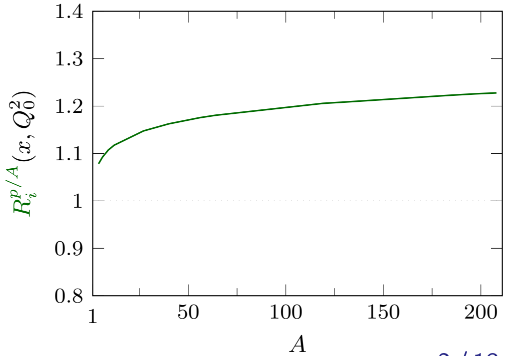
$$f_i^{A}(x,Q^2) = Z f_i^{p/A}(x,Q^2) + N f_i^{n/A}(x,Q^2),$$

and assuming $f_i^{p/A} \xleftrightarrow{\text{isospin}} f_j^{n/A}$

- Parametrize the x and A dependence of $R_i^{p/A}(x,Q_0^2)$ at $Q_0 = m_{\mathrm{charm}} = 1.3\ \mathrm{GeV}$
  - Use a phenomenologically motivated piecewise function in x
  - Use a power-law type function in A

We are currently exploring the best fit functions for our next ‘EPPS21’ fit





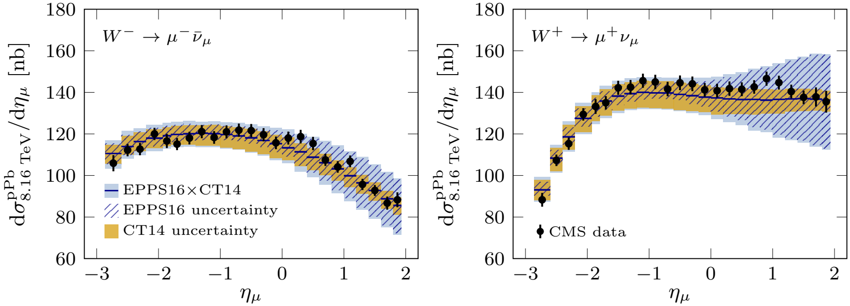
Comparison with other NLO nPDF global fits

	EPPS16	nNNPDF2.0	nCTEQ15WZ	nCTEQ15HIX	EPPS21 prelim.
lA NC DIS	✓	✓	✓	✓	✓
+ JLab NC DIS				✓	✓ new!
νA CC DIS	✓	✓			✓
pA DY	✓		✓	✓	✓
πA DY	✓				✓
RHIC dAu/pp π^0	✓		✓		✓
LHC pPb dijet R_{FB}	✓				
$\rightarrow$ dijet R_{pPb}					✓ new!
LHC pPb D^0					✓ new!
LHC pPb W,Z Run 1	✓	✓	✓		✓
+ Run 2 pPb W		✓	✓		✓ new!
Q cut in DIS	1.3 GeV	1.87 GeV	2 GeV	1.3 GeV	1.3 GeV
Data points	1811	1467	828	1564	2023 prelim.
Free parameters	20	256	19	19	24 prelim.
Error analysis	Hessian	Monte Carlo	Hessian	Hessian	Hessian
Error tolerance $\Delta\chi^2$	52	N/A	35	35	35 prelim.
Free-proton PDFs	CT14	NNPDF3.1	~CTEQ6M	~CTEQ6M	CT18A prelim.
HQ treatment	S-ACOT	FONLL	S-ACOT	S-ACOT	S-ACOT
Indep. flavours	6	6	5	4	6
Reference	EPJC 77, 163	JHEP 09, 183	EPJC 80, 968	arXiv:2012.11566	TBA

Need to mitigate free-proton PDF uncertainty

Absolute cross sections carry large proton-PDF uncertainty!

Should not be neglected when fitting the nPDFs!

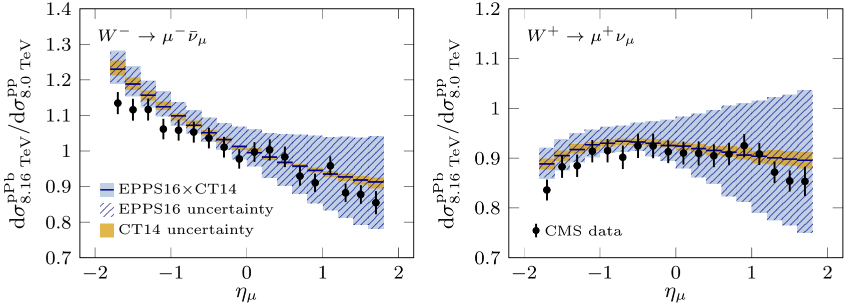


↓ Cancel proton-PDF uncertainty ↓

Wherever possible, we use nuclear modification ratios to cancel the free-proton PDF uncertainty

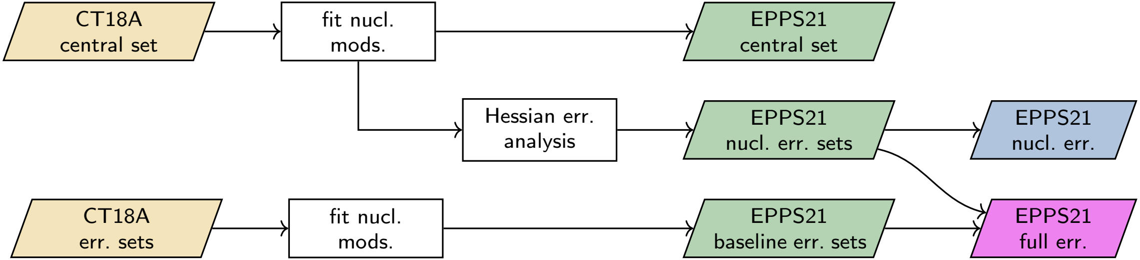
For Ws at 8.16 TeV, we formulate a mixed-energy nuclear modification ratio

$$R_{\rm pPb} = \frac{d\sigma^{\rm pPb}_{8.16\ \rm TeV}/d\eta_\mu}{d\sigma^{\rm pp}_{8.0\ \rm TeV}/d\eta_\mu}$$

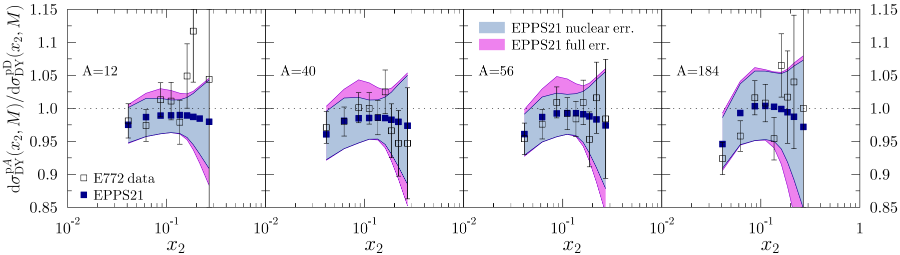


Charting the baseline proton-PDF uncertainty *new!*

We study baseline-PDF sensitivity by fitting nuclear modifications <u>separately</u> for each CT18A error set



Baseline error mostly subdominant in the observables we fit, but shows up e.g. in the fixed-target DY



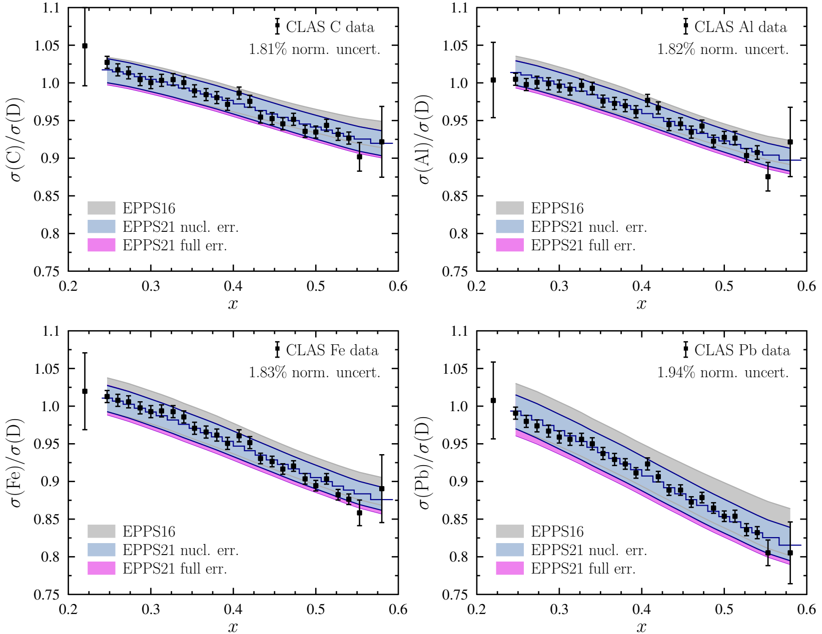
data from: [CLAS Collaboration, Nature 566 (2019) 354-358]

Excellent fit!

Results in line with the reweighting study
[Paukkunen & Zurita, Eur.Phys.J.C 80 (2020) 381]

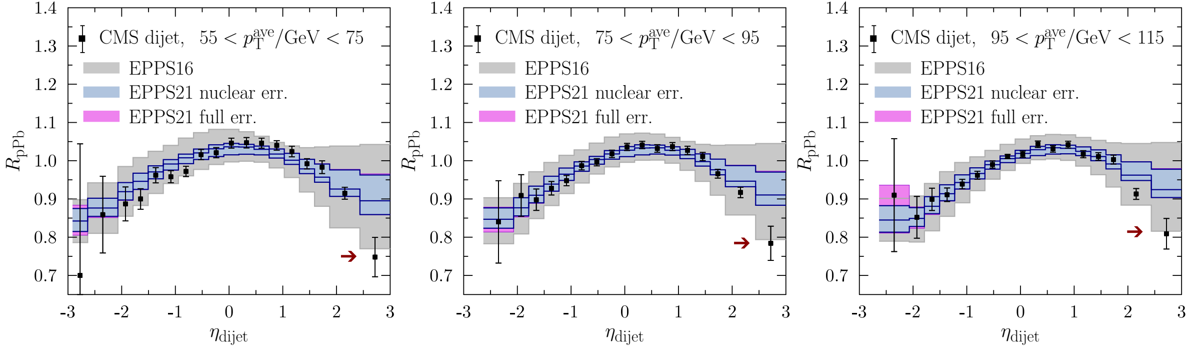
We take into account the leading target-mass corrections

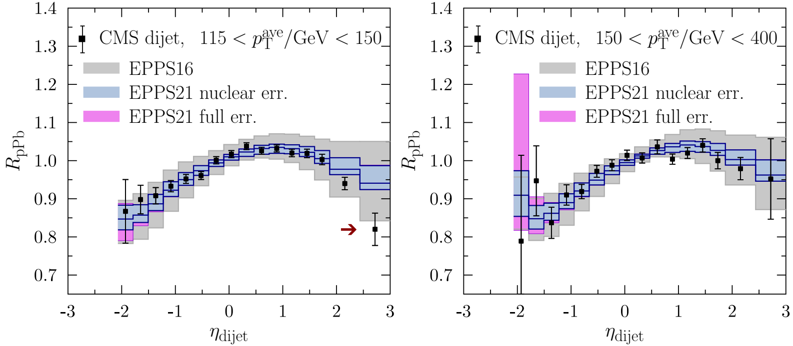
No sign of isospin-dependence in the bound-proton nuclear modifications $R_i^{p/A}$



Dijets at 5.02 TeV *new!*

data from: [CMS Collaboration, Phys.Rev.Lett. 121 (2018) 062002]





Results in line with the reweighting study

[Eskola, PP & Paukkunen, Eur.Phys.J.C 79 (2019) 511]

Still finding it difficult to fit the forwardmost data points

➔ currently excluded from the fit

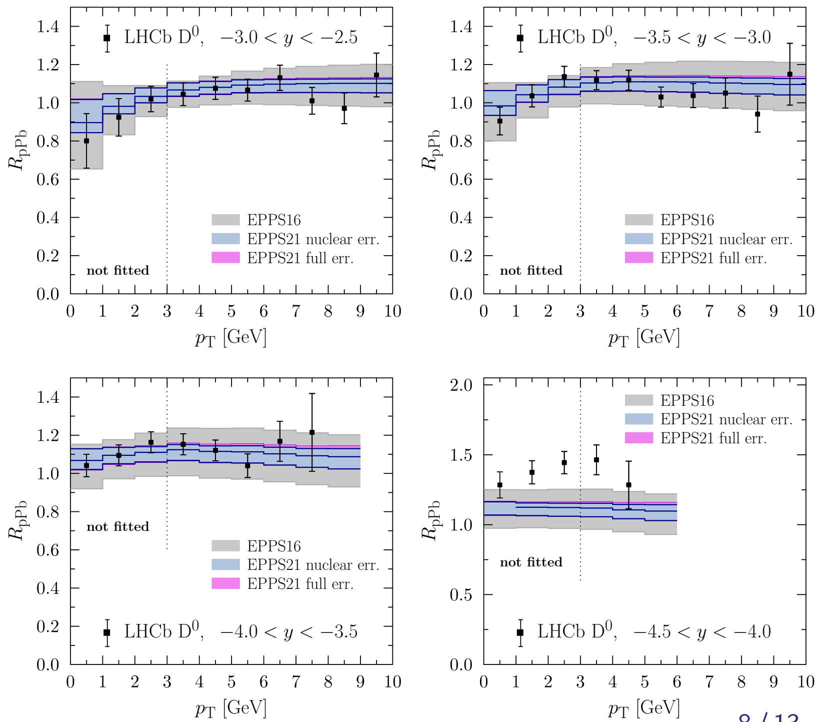
data from: [LHCb Collaboration, JHEP 10 (2017) 090]

Excellent fit!

Results in line with the reweighting study
[Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]

Using the NLO pQCD S-ACOT-m_T GM-VFNS
[Helenius & Paukkunen, JHEP 05 (2018) 196]

Using a $p_T > 3$ GeV cut to reduce theoretical uncertainties



D^0s at 5.02 TeV – forward *new!*

data from: [LHCb Collaboration, JHEP 10 (2017) 090]

Excellent fit!

Results in line with the reweighting study
[Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]

Using the NLO pQCD S-ACOT-m_{T} GM-VFNS
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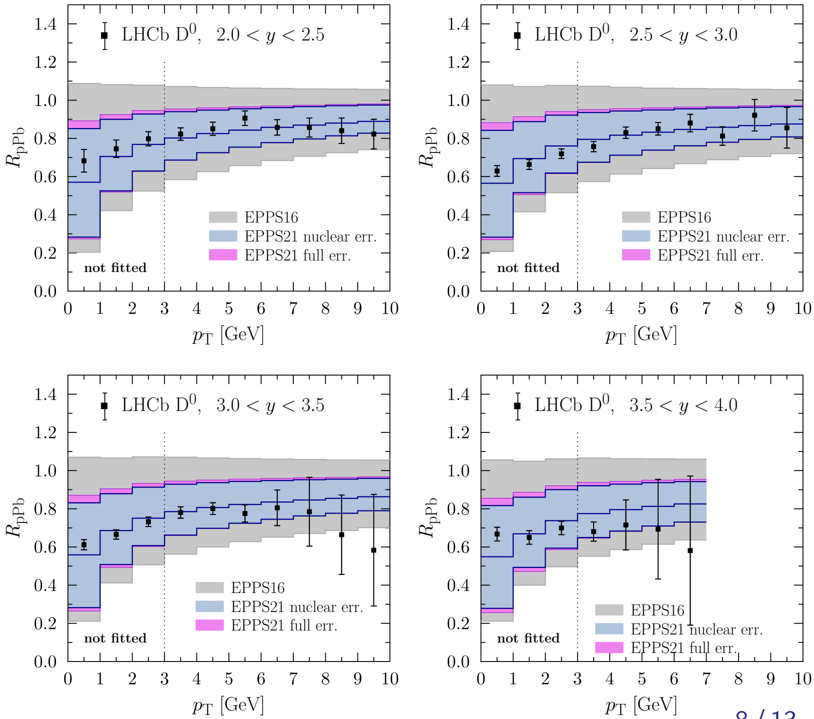
Using a $p_{\mathrm{T}} > 3$ GeV cut to reduce theoretical uncertainties



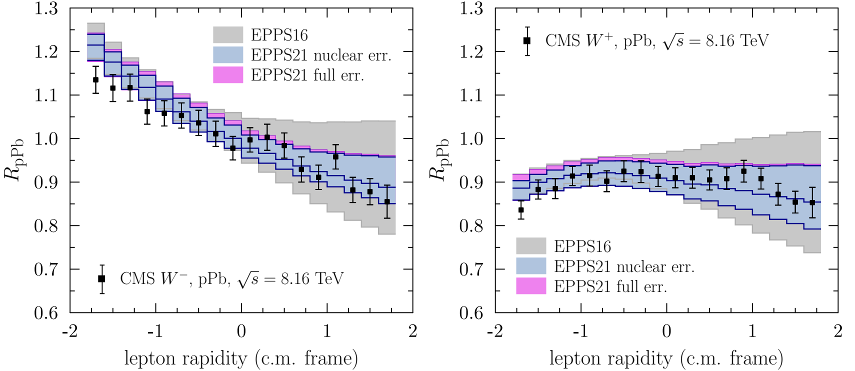
data from: [CMS Collaboration, Phys.Lett.B 800 (2020) 135048, Eur.Phys.J.C 76 (2016) 469]

Excellent fit!

Using the mixed-energy nuclear modification ratio

$$R_{\rm pPb} = \frac{d\sigma^{\rm pPb}_{8.16\ {\rm TeV}}/d\eta_\mu}{d\sigma^{\rm pp}_{8.0\ {\rm TeV}}/d\eta_\mu}$$

to cancel the free-proton PDF uncertainty



Fully consistent with the dijets and D^0s

- Important check on the nPDF universality & factorization

These data do not appear to give additional flavour-separation constraints on top of those we had already in EPPS16

- Looking forward to increased precision at LHC Run 3

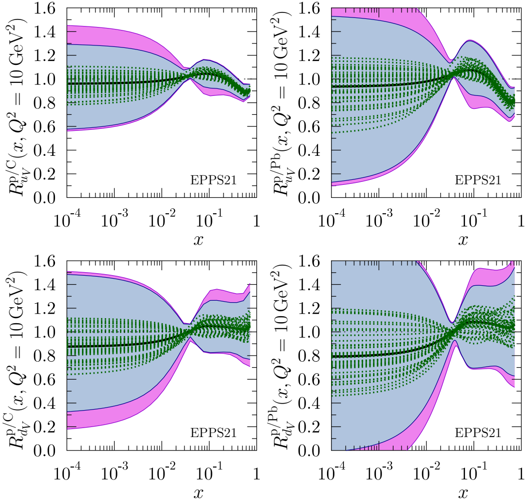
Fit results – valence

Bound-proton modifications *prelim.*

Carbon | Lead

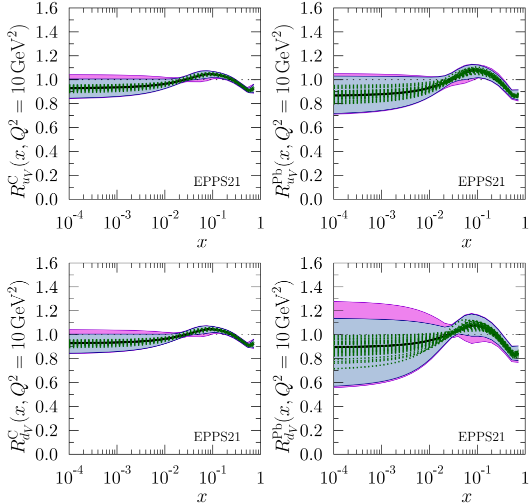
u_V

d_V



Full-nucleus modifications *prelim.*

Carbon | Lead



$$R_i^{p/A} = \frac{f_i^{p/A}}{f_i^p}$$

$$R_i^A = \frac{Z f_i^{p/A} + N f_i^{n/A}}{Z f_i^p + N f_i^n}$$

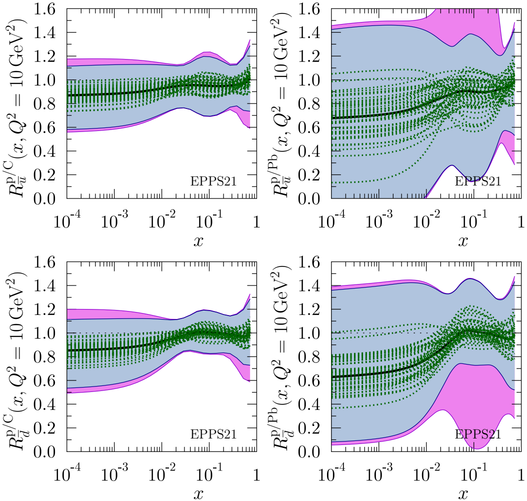
Fit results – sea

Bound-proton modifications *prelim.*

Carbon   Lead

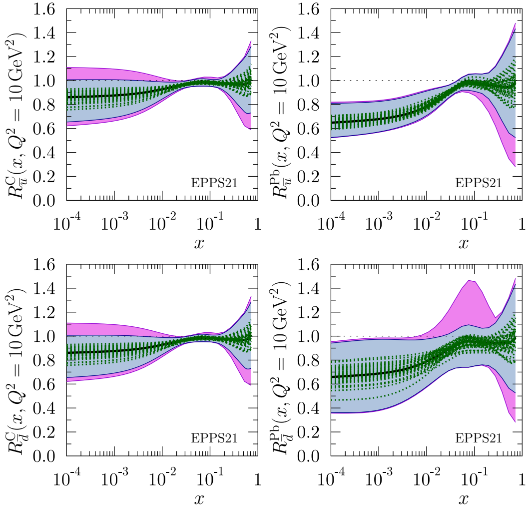
$\bar{u}$

$\bar{d}$



Full-nucleus modifications *prelim.*

Carbon   Lead



$$R_i^{p/A} = \frac{f_i^{p/A}}{f_i^p}$$

$$R_i^A = \frac{Z f_i^{p/A} + N f_i^{n/A}}{Z f_i^p + N f_i^n}$$

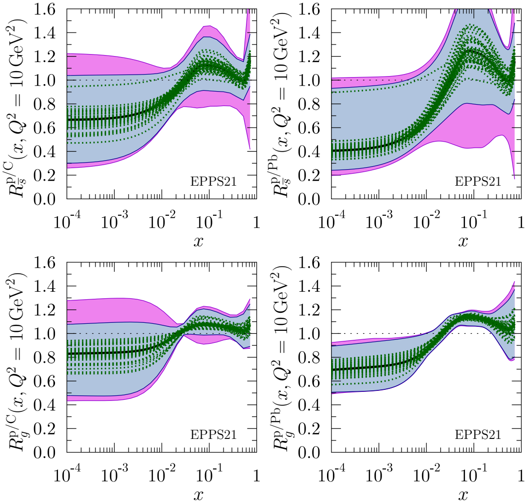
Fit results – strange and glue

Bound-proton modifications *prelim.*

Carbon | Lead

$\bar{s}$

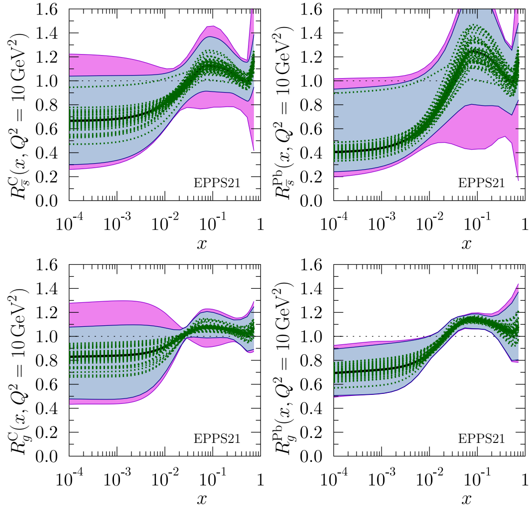
g



$$R_i^{p/A} = \frac{f_i^{p/A}}{f_i^p}$$

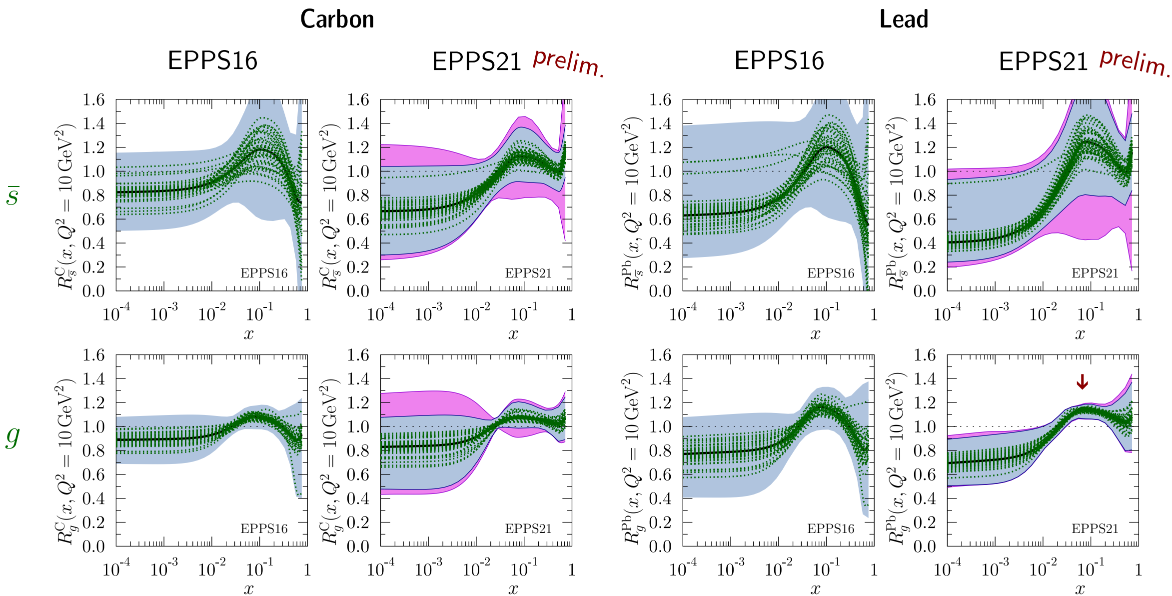
Full-nucleus modifications *prelim.*

Carbon | Lead



$$R_i^{A} = \frac{Z f_i^{p/A} + N f_i^{n/A}}{Z f_i^p + N f_i^n}$$

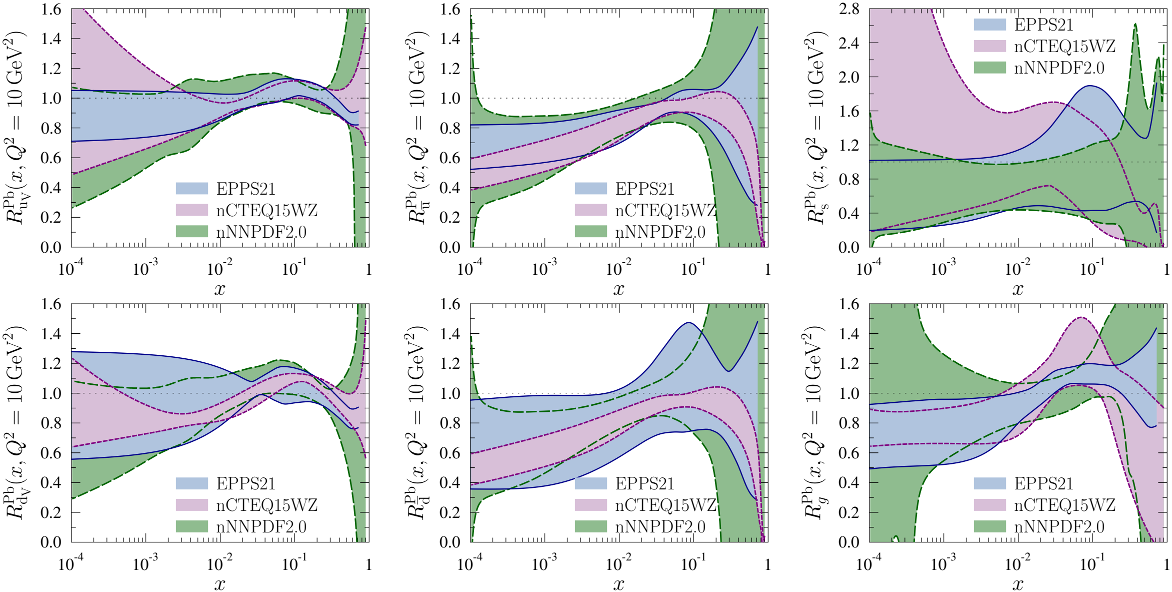
Comparison with EPPS16



- Better control over gluon (anti)shadowing ➔ sub-10% level uncertainties at mid-x!
- Flavour separation (esp. strangeness) remains a difficult beast to tame

Comparison with nNNPDF2.0 and nCTEQ15WZ

prelim.



- All three consistent within uncertainties, but significant differences in the uncertainty estimates
- Best constrained gluons in the (prelim.) EPPS21 fit!

Summary

A new EPPS nPDF fit on its way...

- Obtained a good fit for multiple new nuclear data from LHC (Ws, D^0s and dijets) and JLab
- Strong new constraints on gluon modifications in lead → sub-10% level mid-x uncertainties!
- Flavour separation uncertainties remain large, esp. for the sea quarks

Study the baseline free-proton PDF sensitivity / error

- We use data as nuclear modification ratios to decorrelate nuclear-modification and free-proton d.o.f.s to best possible extent
- Residual baseline free-proton PDF uncertainty still relevant where direct data constraints are scarce (sea-quark flavour separation, light-nuclei gluons)

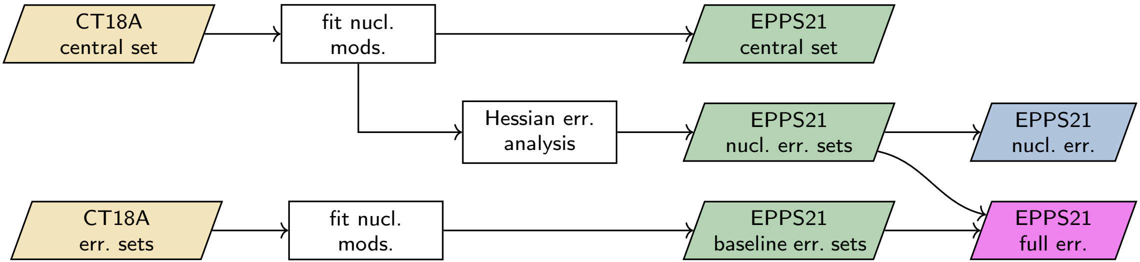
TODO:

- Still charting the possible parametrization choices

Backup

Charting the baseline proton-PDF uncertainty *new!*

We study baseline-PDF sensitivity by fitting nuclear modifications separately for each CT18A error set

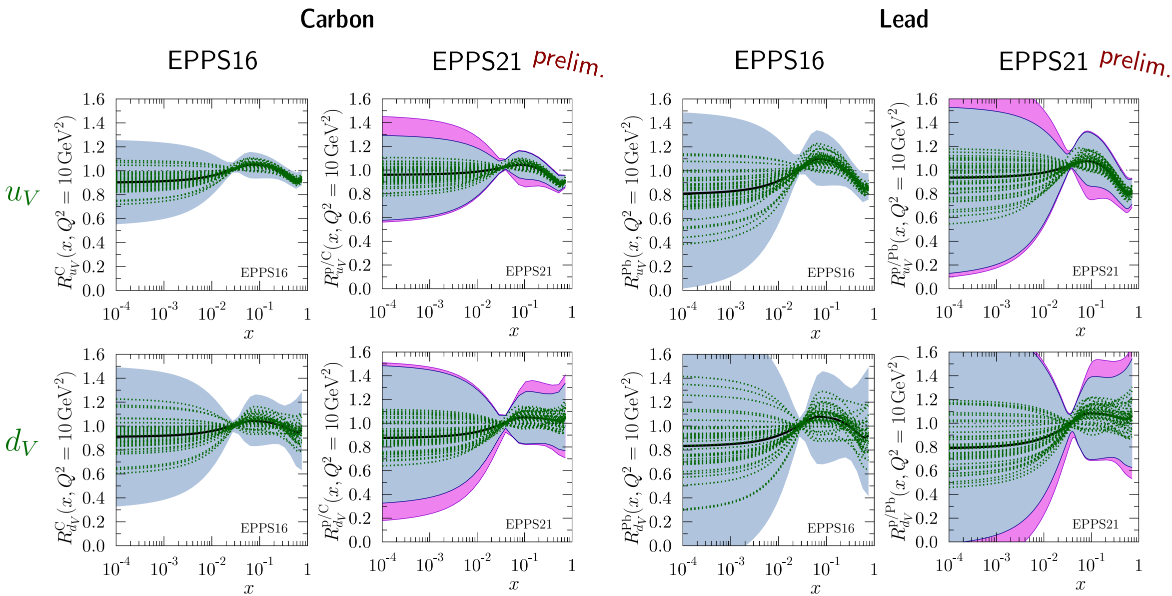


The full error is calculated with:

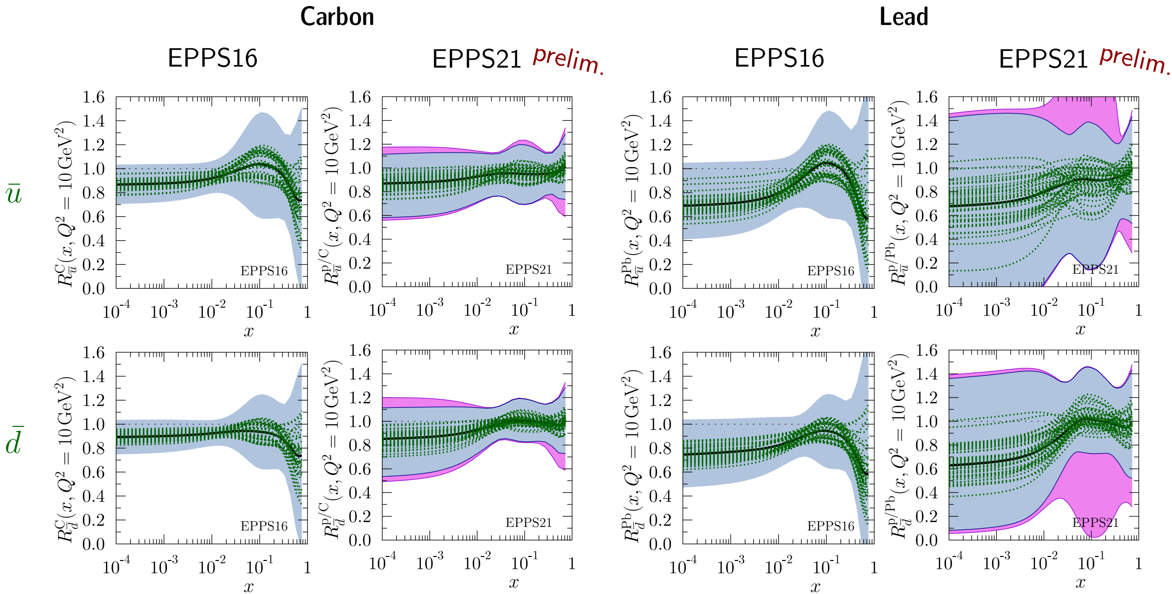
$$(\delta X^{\pm}_{\mathrm{full}})^2 = (\delta X^{\pm}_{\mathrm{nucl.}})^2 + \underbrace{(\delta X^{\pm}_{\mathrm{baseline}})^2}$$

$$= \sum_{k}^{N_{\mathrm{baseline\ param.}}} \Big({\textstyle\substack{\max \\ \min}} \{ \underbrace{X[S_k^+]}_{\text{calculate with } f_i^{p/A}[S_k^+] = \underbrace{R_i^{p/A}[S_k^+]}_{\text{fitted using the } f_i^p[S_k^+] \text{ proton PDFs}} f_i^p[S_k^+]} - X[S_0], X[S_k^-] - X[S_0], 0 \} \Big)^2$$

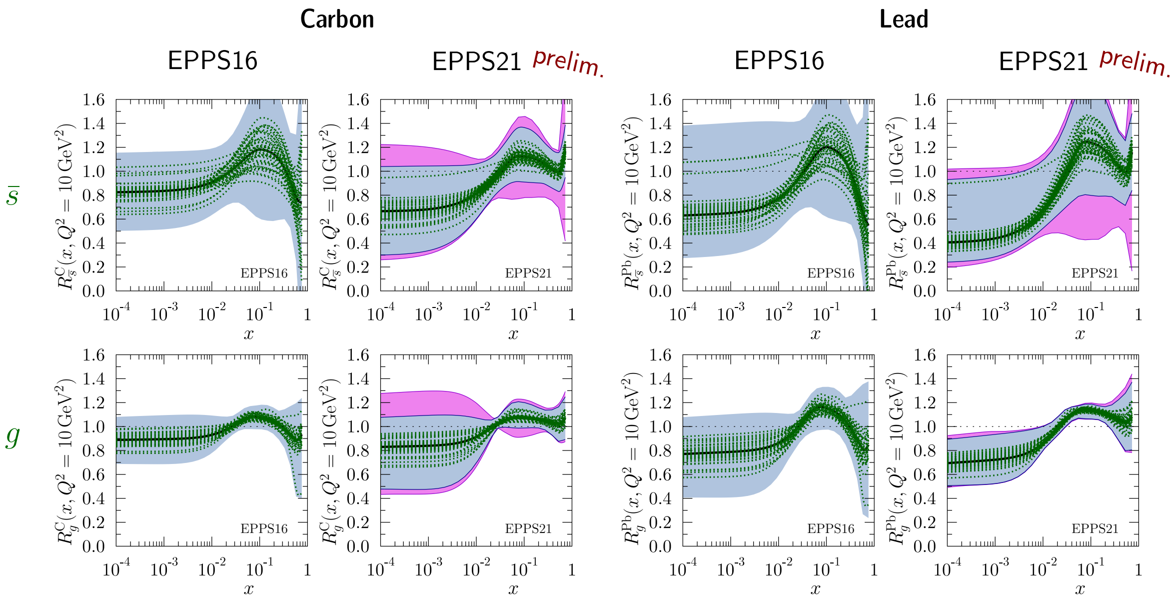
Comparison with EPPS16 – valence



Comparison with EPPS16 – sea



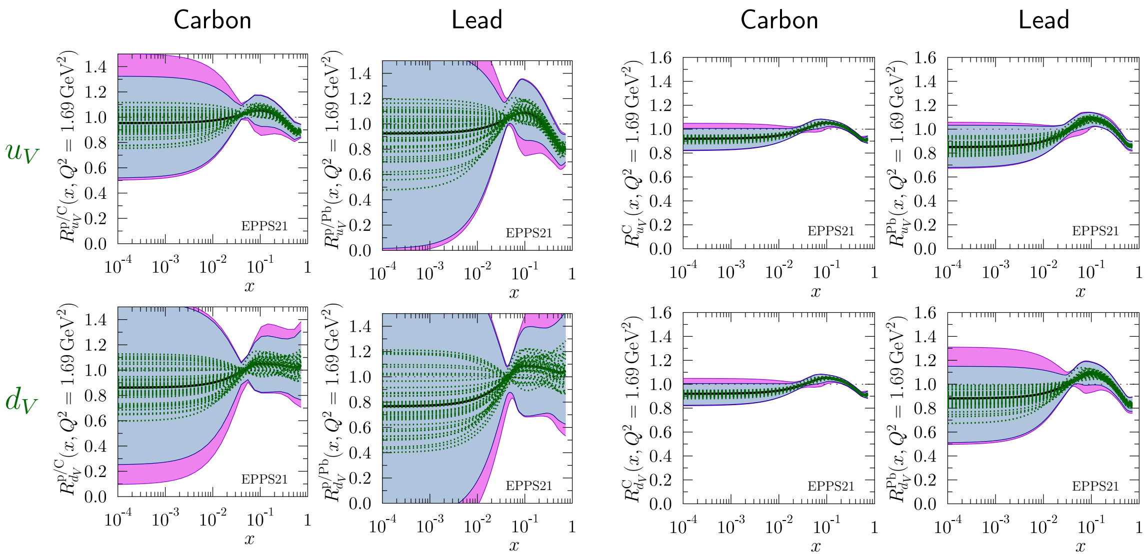
Comparison with EPPS16 – strange and glue



Fit results at parametrization scale – valence

Bound-proton modifications *prelim.*

Full-nucleus modifications *prelim.*



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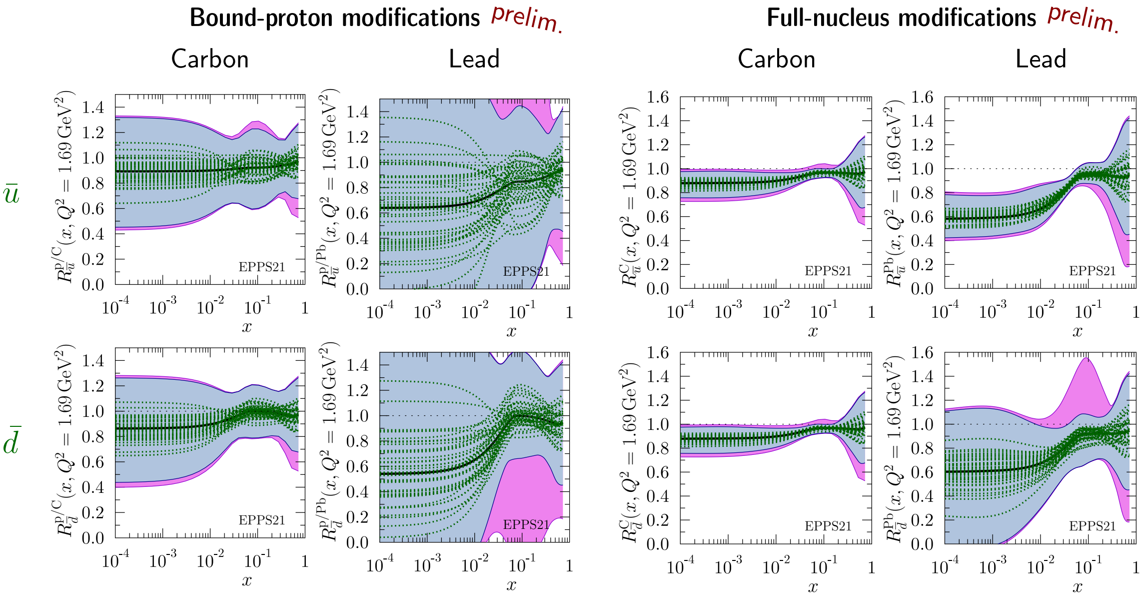
Fit results at parametrization scale – sea



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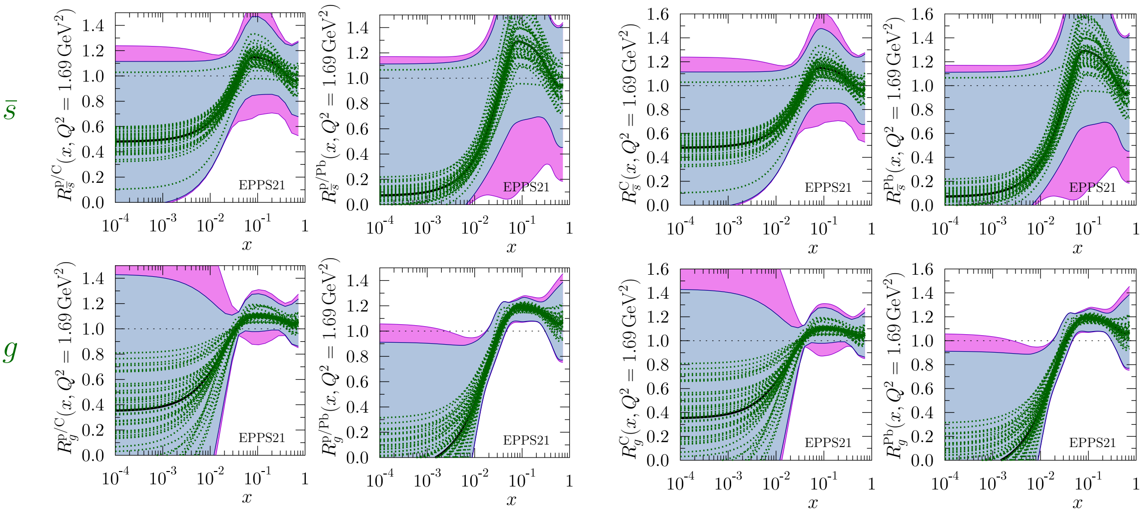
Fit results at parametrization scale – strange and glue

Bound-proton modifications *prelim.* | **Full-nucleus modifications** *prelim.*

Carbon | Lead | Carbon | Lead



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