Many thanks to A. Mazeliauskas, C. A. Salgado, H. Paukkunen, K. J. Eskola and C. Andrés for discussions

Current status of nPDFs and prospects for pO and OO collisions

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Opportunities of OO and pO collisions at the LHC
8 Feb 2021

Section 1

nPDF overview

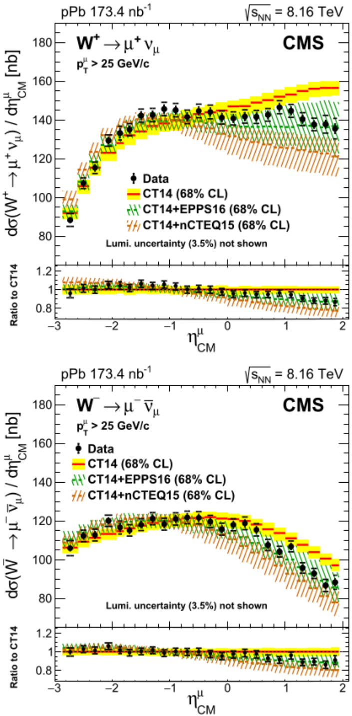
Latest nPDF global analyses

	EPPS16	nNNPDF2.0	nCTEQ15WZ	nNNPDF1.0	TuJu19	KSASG20
Order in α_s	NLO	NLO	NLO	NNLO	NNLO	NNLO
lA NC DIS	✓	✓	✓	✓	✓	✓
νA CC DIS	✓	✓			✓	✓
pA DY	✓		✓			
πA DY	✓					
RHIC dAu/pp π	✓		✓			
LHC pPb W, Z	✓	✓	✓			
LHC pPb jets	✓					
Q cut in DIS	1.3 GeV	1.87 GeV	2 GeV	1.87 GeV	1.87 GeV	1.3 GeV
Data points	1811	1467	828	451	2336	4525
Free parameters	20	256	19	183	16	9
Error analysis	Hessian	Monte Carlo	Hessian	Monte Carlo	Hessian	Hessian
Error tolerance $\Delta\chi^2$	52	N/A	35	N/A	50	10
Free-proton PDFs	CT14	NNPDF3.1	~CTEQ6M	NNPDF3.1	own fit	CT18
HQ treatment	GM-VFNS	GM-VFNS	GM-VFNS	GM-VFNS	GM-VFNS	GM-VFNS
Indep. flavours	6	6	5	3	4	3
Year	2016	2020	2020	2019	2019	2020
Reference	EPJC 77, 163	JHEP 09, 183	EPJC 80, 968	EPJC 79, 471	PRD 100, 096015	arXiv:2010.00555

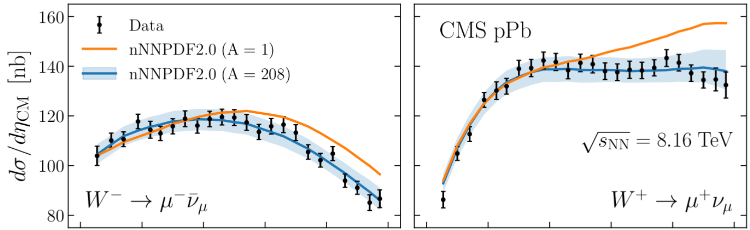
State of the art (EPPS16, nNNPDF2.0, nCTEQ15WZ)

W bosons in pPb at 8.16 TeV

[CMS, Phys.Lett.B 800 (2020) 135048]



[Abdul Khalek, Ethier, Rojo & van Weelden, JHEP 09 (2020) 183]



Potential probes of the flavour separation (and strangeness):

- $u\bar{d}$ $(u\bar{s}, c\bar{s}) \rightarrow W^{+}$
- $d\bar{u}$ $(s\bar{u}, s\bar{c}) \rightarrow W^{-}$

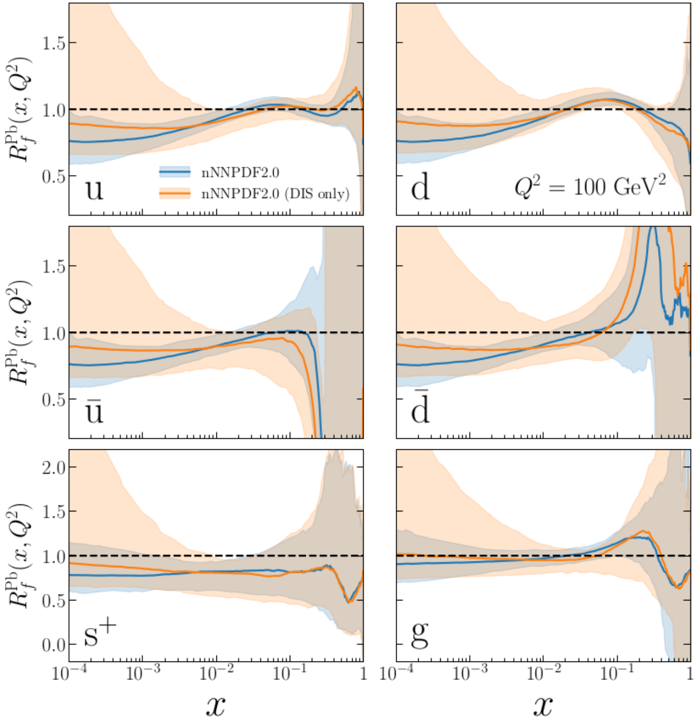
Remember: small-x, high-Q^2 quarks and gluons correlated by DGLAP evolution ➔ constraints for gluons

Increased statistics for W bosons in the 8.16 TeV data set

➔ Included in nNNPDF2.0 and nCTEQ15WZ

W/Z bosons in pPb at 5.02 TeV and 8.16 TeV – impact in nNNPDF2.0

[Abdul Khalek, Ethier, Rojo & van Weelden, JHEP 09 (2020) 183]



Flexible neural-network parametrization (256 free parameters)

Includes CMS and ATLAS W/Z data

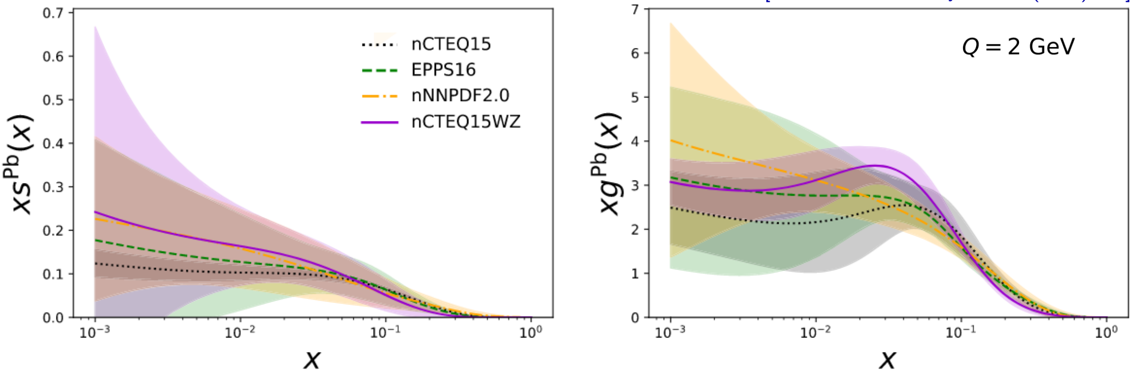
Compared to DIS-only fit:

- Preference for EMC effect both in u and d
- Enhanced shadowing for all quarks
- Some preference for gluon shadowing & antishadowing

Here:

$$R_f^A(x,Q^2) = \frac{Z f_f^{p/A}(x,Q^2) + (A-Z) f_f^{n/A}(x,Q^2)}{Z f_f^{p}(x,Q^2) + (A-Z) f_f^{n}(x,Q^2)}$$

[Kusina *et al.*, Eur.Phys.J.C 80 (2020) 968]



Includes also ALICE & LHCb W/Z data

- → Most extensive EW-boson data set to date

Compared to nCTEQ15:

- Additional freedom for s needed to describe the data
  - much larger uncertainty
- Less gluon shadowing

			$\sqrt{s_{NN}}$ [TeV]
Data overview			
ATLAS	Run I	$W^{\pm}$	5.02
ATLAS	Run I	Z	5.02
CMS	Run I	$W^{\pm}$	5.02
CMS	Run I	Z	5.02
CMS	Run II	$W^{\pm}$	8.16
ALICE	Run I	$W^{\pm}$	5.02
LHCb	Run I	Z	5.02

u and d valence quark modifications (in lead)

Most nuclei are close to isoscalar

- ➔ Nearly equal amout of u and d quarks

For example, we can write

$$f^A_{u_V} = R^A_{u_V+d_V}\left(1 - \frac{A-2Z}{A}\mathcal{A}^A_{u_V-d_V}\right)\frac{A}{2}(f^p_{u_V} + f^p_{d_V})$$

$$f^A_{d_V} = R^A_{u_V+d_V}\left(1 + \frac{A-2Z}{A}\mathcal{A}^A_{u_V-d_V}\right)\frac{A}{2}(f^p_{u_V} + f^p_{d_V})$$

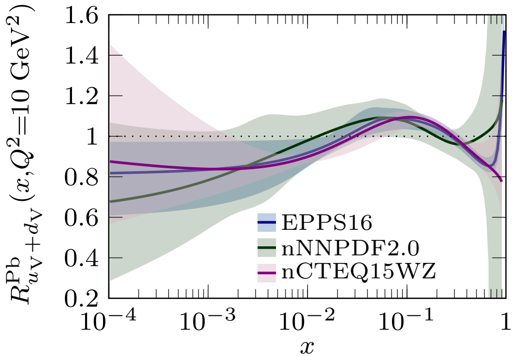
where

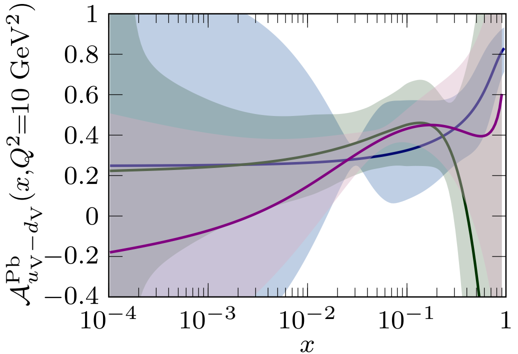
$$R^A_{u_V+d_V} = \frac{f^{p/A}_{u_V} + f^{p/A}_{d_V}}{f^p_{u_V} + f^p_{d_V}} \qquad \mathcal{A}^A_{u_V-d_V} = \frac{f^{p/A}_{u_V} - f^{p/A}_{d_V}}{f^{p/A}_{u_V} + f^{p/A}_{d_V}}$$

and neutron excess $\dfrac{A-2Z}{A} \approx 0.2$ for Pb

- ➔ Need high-precision data on non-isoscalar nuclei to constrain the asymmetry

Important for studying the physical origin of the EMC effect





u and d sea quark modifications (in lead)

Most nuclei are close to isoscalar

- ➔ Nearly equal amout of $\bar{u}$ and $\bar{d}$ quarks

Here

$$f^A_{\bar{u}} = R^A_{\bar{u}+\bar{d}}\left(1 - \frac{A-2Z}{A}\mathcal{A}^A_{\bar{u}-\bar{d}}\right)\frac{A}{2}(f^p_{\bar{u}} + f^p_{\bar{d}})$$

$$f^A_{\bar{d}} = R^A_{\bar{u}+\bar{d}}\left(1 + \frac{A-2Z}{A}\mathcal{A}^A_{\bar{u}-\bar{d}}\right)\frac{A}{2}(f^p_{\bar{u}} + f^p_{\bar{d}})$$

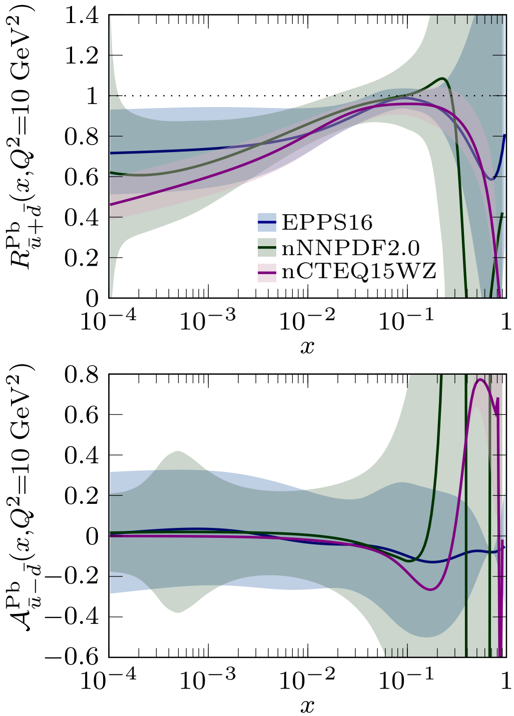
with

$$R^A_{\bar{u}+\bar{d}} = \frac{f^{p/A}_{\bar{u}} + f^{p/A}_{\bar{d}}}{f^p_{\bar{u}} + f^p_{\bar{d}}} \qquad \mathcal{A}^A_{\bar{u}-\bar{d}} = \frac{f^{p/A}_{\bar{u}} - f^{p/A}_{\bar{d}}}{f^{p/A}_{\bar{u}} + f^{p/A}_{\bar{d}}}$$

Flavour asymmetry only a small correction

nNNPDF2.0 does not use fixed-target DY data

- ➔ less constraints for valence/sea separation compared to EPPS16 & nCTEQ15WZ



Gluon and strange modifications (in lead)

$R_i^A(x,Q^2) = f_i^{\mathrm{p}/A}(x,Q^2) \;/\; f_i^{\mathrm{p}}(x,Q^2)$

bound-proton PDF   free-proton PDF

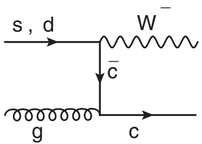
The gluon and strange modifications are poorly constrained in the current nPDF releases

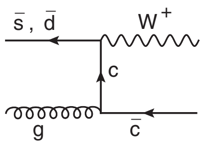
- Better gluon constraints are available from LHC pPb dijets and D-mesons, but these need to be included in the global analyses (in progress)

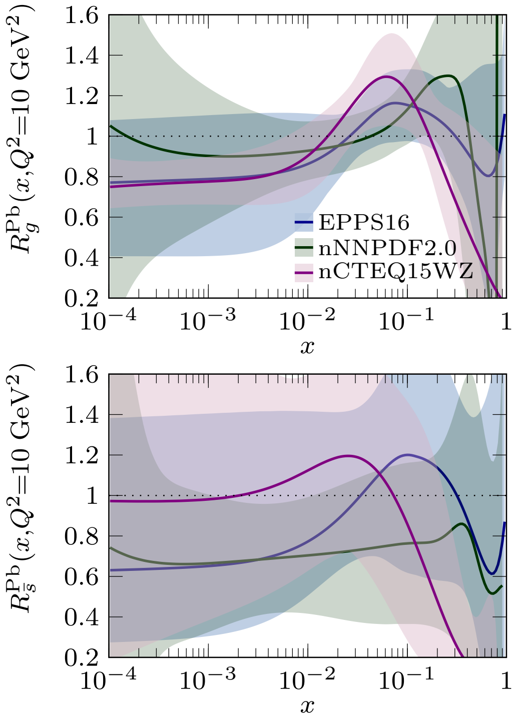
The existing LHC pPb W/Z data did not give strong constraints for the strangeness

→ Additional data needed

- W+charm measured in pp, doable in pPb?



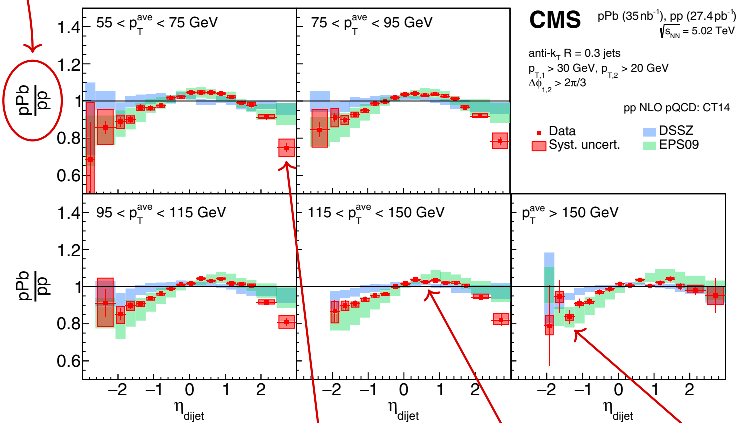




Better gluon constraints: Dijets in pPb at 5.02 TeV

Ratio of ratios: $R^{\mathrm{norm.}}_{\mathrm{pPb}} = \dfrac{\mathrm{d}^2\sigma^{\mathbf{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}}{\mathrm{d}\sigma^{\mathbf{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}} \Big/ \dfrac{\mathrm{d}^2\sigma^{\mathbf{pp}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}}{\mathrm{d}\sigma^{\mathbf{pp}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}}$

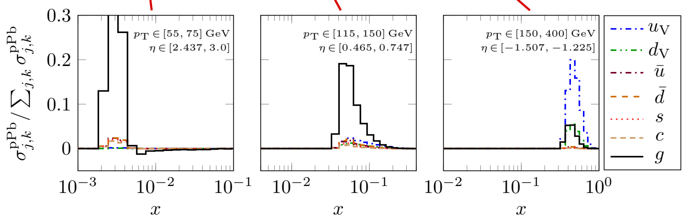
[CMS Collaboration, Phys.Rev.Lett. 121 (2018) 062002]



Double ratio convenient for:

- Cancellation of hadronization and luminosity uncertainties separately for pPb and pp
  - do not expect strong final-state effects
- Cancellation of free-proton PDF uncertainties in pPb/pp
  - direct access to nuclear modifications

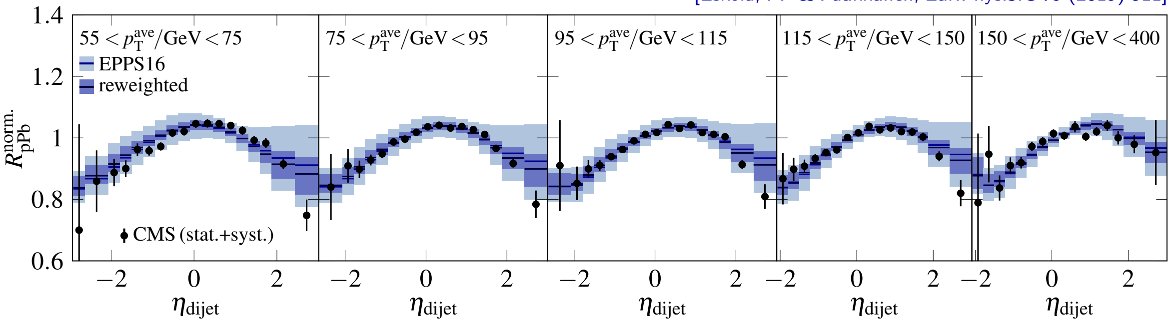
NLO pQCD:



Good resolution to gluon nuclear modifications for $10^{-3} < x < 0.5$

Dijets in pPb at 5.02 TeV – EPPS16 reweighted

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

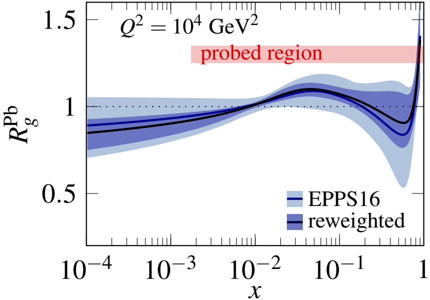


A Hessian PDF reweighting study shows that these data can put stringent constraints on the gluon modifications

- Drastic reduction in EPPS16 gluon uncertainties
- Support for mid-x antishadowing and small-x shadowing
- Probes the onset of shadowing down to $x > 10^{-3}$

Remaining questions:

- Is there EMC suppression for gluons?
- What happens at $x < 10^{-3}$?

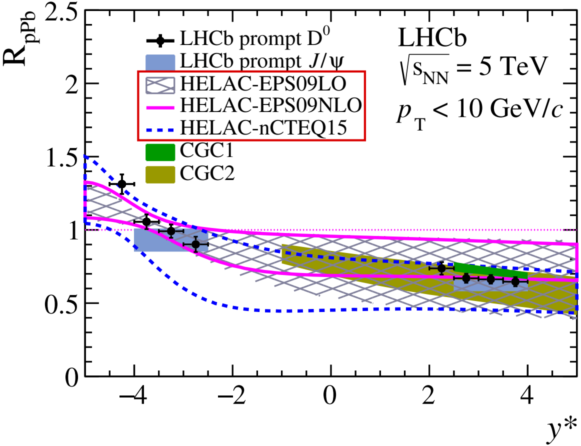


$$R_i^A(x, Q^2) = f_i^{p/A}(x, Q^2) \; / \; f_i^{p}(x, Q^2)$$

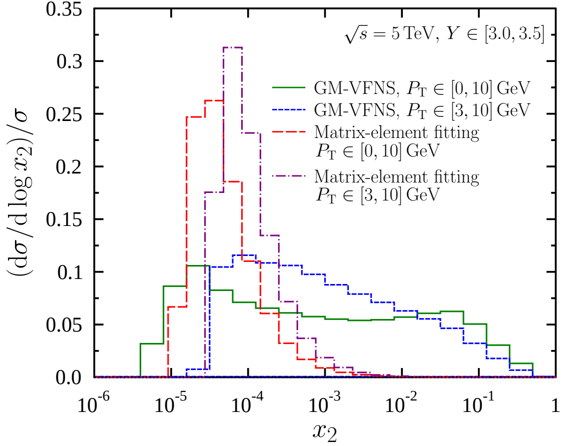
bound-proton PDF free-proton PDF

D-mesons in pPb at 5.02 TeV – differences in theoretical descriptions

[LHCb Collaboration, JHEP 10 (2017) 090]



[Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]



Data can probe nPDFs down to $x \sim 10^{-5}$, but x sensitivity differs between theoretical approaches:

- The HELAC framework [Lansberg & Shao, EPJ C77 (2017) 1] uses a matrix-element fitting method with $2 \to 2$ kinematics producing a narrow distribution in x (can be used also for quarkonia)
- The SACOT-m_T scheme [Helenius & Paukkunen, JHEP 1805 (2018) 196] of GM-VFNS NLO pQCD gives a much wider x-distribution due to taking into account the gluon-to-HQ fragmentation

D-mesons in pPb at 5.02 TeV – nPDFs reweighted

$R_{\rm pPb}$ mostly insensitive to the differences

- → Reweighting with the two methods give compatible results for $R_g^{\rm Pb}$

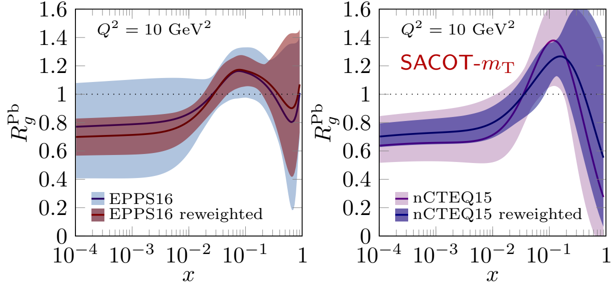
  see the refs. for comparison with POWHEG+PYTHIA, FONLL

- ■ Large reduction in small-x uncertainties, probed down to $x \sim 10^{-5}$
- ■ EPPS16 and nCTEQ15 brought to a closer mutual agreement

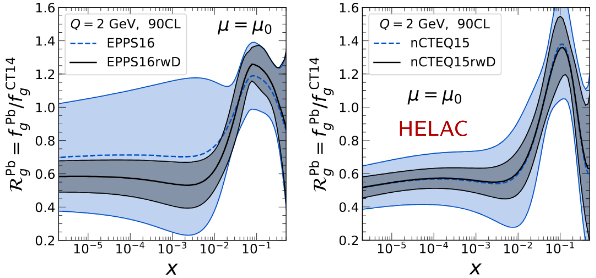
Striking similarity with the results with dijets

- → Supports the validity of collinear factorization in pPb and the universality of nPDFs

[Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]



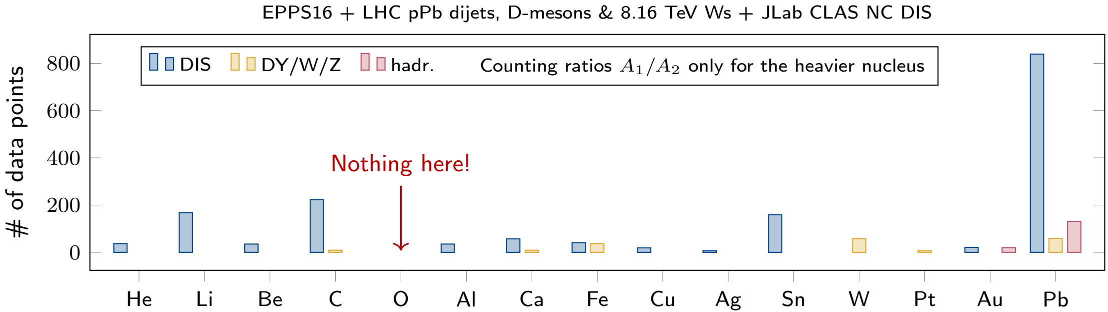
[Kusina, Lansberg, Schienbein & Shao, PRL 121 (2018) 052004, fig. from arXiv:2012.11462]



Section 2

Opportunities with lighter ions

Data availability w.r.t. A



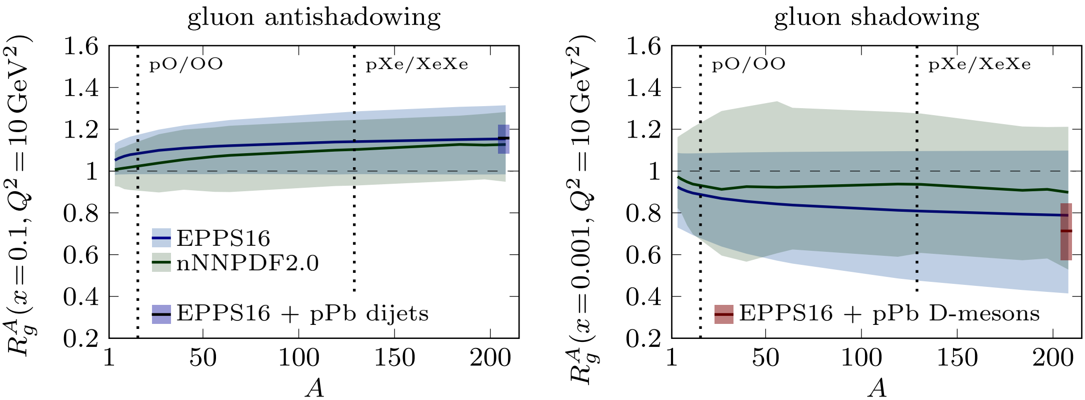
$\sim 50\%$ of the data points are for Pb!

- ☺ Good coverage of DIS measurements for different A
- 😐 DY data more scarce, but OK A coverage
- ☹ Hadronic observables available only for heavy nuclei!

Light-ion runs at LHC could:

- Complement other light-nuclei DY data with W and Z production (strangeness!)
- Give first direct constraints (e.g. dijets, D-mesons) on light-nuclei gluon distributions!

A-dependence of gluon modifications



Direct gluon constraints available only for heavy nuclei (most constraining: pPb dijets & D-mesons)

- ➔ Gluons and small-x quarks poorly constrained for lighter nuclei
- ➔ Significant parametrization dependence

How confidently can we interpolate the light-nuclei gluons from measurements at large A?

- ■ SMOG@LHCb can help for the large x
- ➔ Need for lighter-ion pA runs!

The average u and d valence and sea modifications

$$R^A_{u_V+d_V} = \frac{f^{p/A}_{u_V} + f^{p/A}_{d_V}}{f^{p}_{u_V} + f^{p}_{d_V}} \qquad R^A_{\bar{u}+\bar{d}} = \frac{f^{p/A}_{\bar{u}} + f^{p/A}_{\bar{d}}}{f^{p}_{\bar{u}} + f^{p}_{\bar{d}}}$$

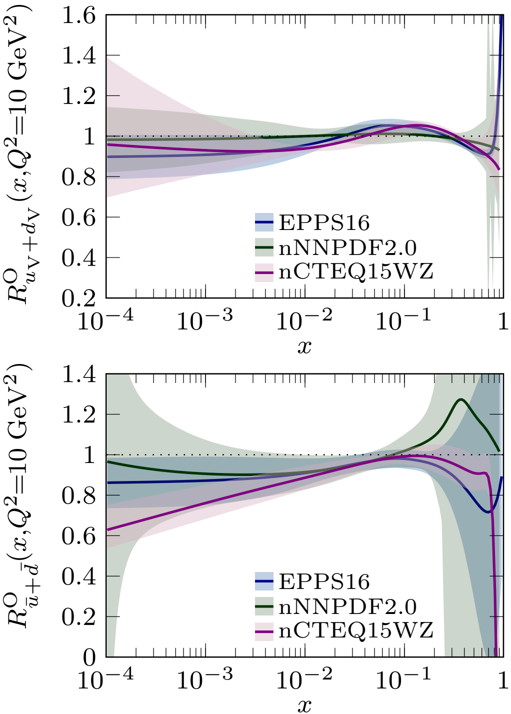
are under control (from interpolation)

Oxygen fully isoscalar

- ➔ No contribution from flavour asymmetry!
- From nPDF point of view, oxygen is "simpler" than lead

nNNPDF2.0 differs (again) from EPPS16 and nCTEQ15WZ due to not having fixed-target DY data

- Data from E772 indicate that there should be antishadowing for valence, but not for sea quarks



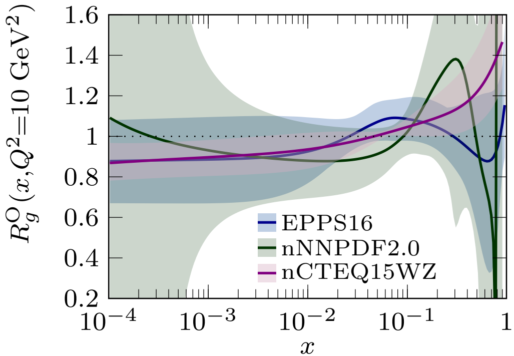
Gluon and strange modifications (in oxygen)

$R_i^A(x,Q^2) = f_i^{p/A}(x,Q^2) \; / \; f_i^{p}(x,Q^2)$

bound-proton PDF   free-proton PDF

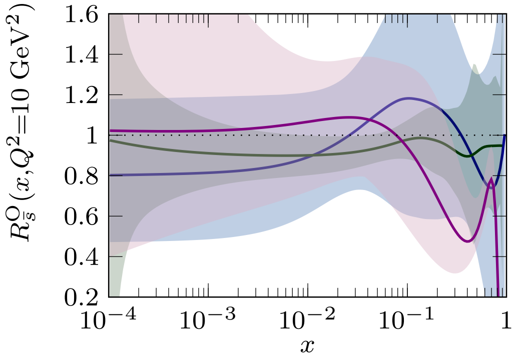
No agreement for the shape of gluon modifications!

- ➔ Can cause significant uncertainties e.g. for jet R_{OO}
- ! No direct data constraints available
- ➔ We could expect major improvement from a LHC pO run



Large uncertainties also for the strange quark

- nNNPDF2.0 has smaller uncertainties here likely due to including NuTeV νFe CC DIS data (interpolation, again)
- Measuring EW bosons in pO/OO might be able to test these



A case study: Dijet production in pO at 9.9 TeV

Similar setup as in the CMS 5.02 TeV pPb measurement

Total integrated pO cross section of ~ 80 μb

- Grows with larger $\sqrt{s_{\mathrm{NN}}}$, decreases with smaller A
- Compare with ~ 330 μb in pPb at 5.02 TeV
- Sufficient to give reasonable statistics even at relatively low luminosities

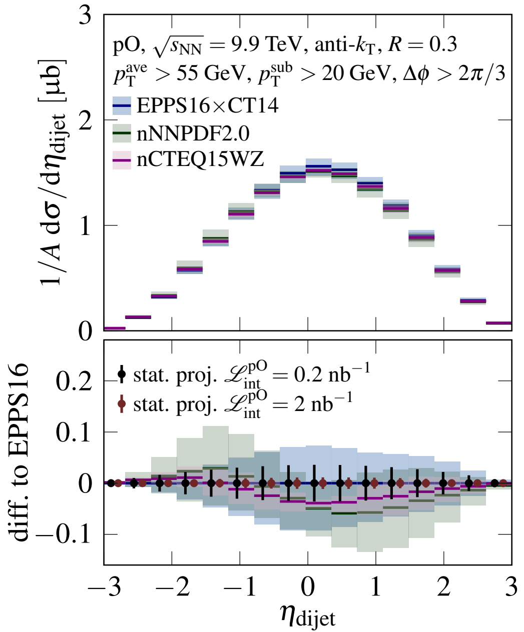
Here only single-differential

- Going multi-differential would improve locality in x and Q^2 (requires more luminosity)

Question: Systematic uncertainties?

N.B. For each nPDF, I am using the corresponding baseline free-proton PDF

→ Calculations with nCTEQ15WZ do not include free-proton PDF uncertainties



*not corrected for hadronization effects
*not corrected for efficiency

Problem: absolute cross sections very sensitive to the used free-proton PDFs

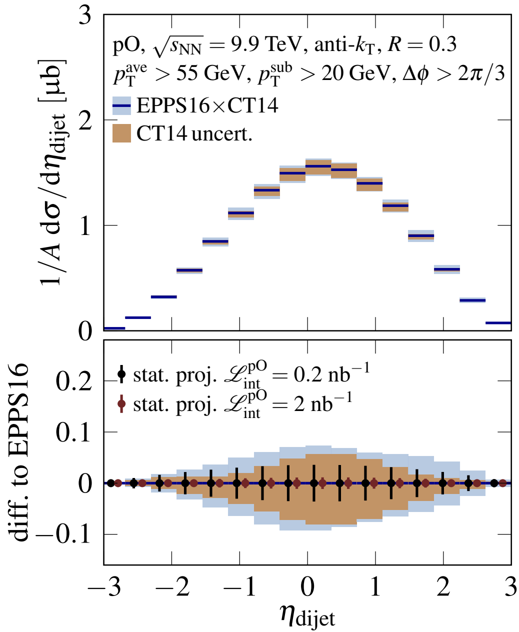
- Difficult to disentangle nuclear modifications from the free-proton d.o.f.s

N.B. In the EPPS framework, free-proton uncertainties enter both from the

- incoming proton PDFs: f_i^p
- incoming bound-nucleon PDFs: $f_i^{p/A} = R_i^A f_i^p$

Possible ways to mitigate the problem:

- Take forward-to-backward ratio (R_{FB})
- Take nuclear modification ratio ($R_{\mathrm{pPb}}^{(\mathrm{norm.})}$)
  - requires a pp reference measurement at the same collision energy



*not corrected for hadronization effects
*not corrected for efficiency

Dijet $R_{\rm FB}$ in pO at 9.9 TeV

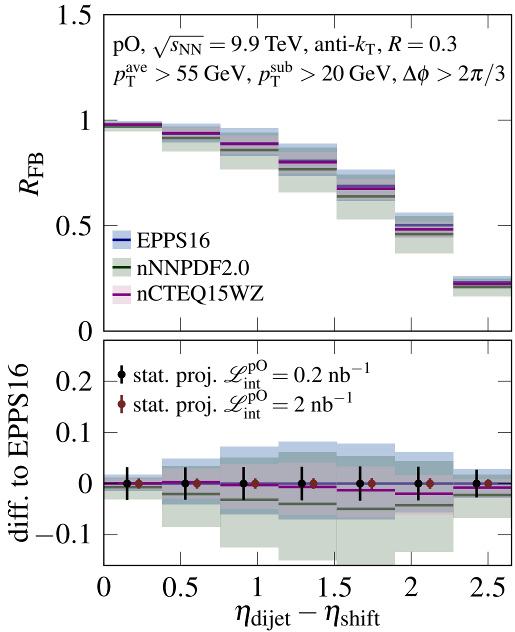
Excellent cancellation of free-proton PDFs

Luminosity (and hadronization) uncertainties also (expected to) cancel!

Already $\sim 1\ \mathrm{nb}^{-1}$ can be expected to be enough to put new constraints on nPDFs

Problem: access only to nPDF small v.s. large x correlations – mixing different effects

- Forward shadowing and backward antishadowing pull to the same direction
- Even rather different nuclear modifications can yield similar shape for $R_{\rm FB}$



Dijet $R^{\mathrm{norm.}}_{\mathrm{pO}}$ in pO at 9.9 TeV

Excellent cancellation of free-proton PDFs

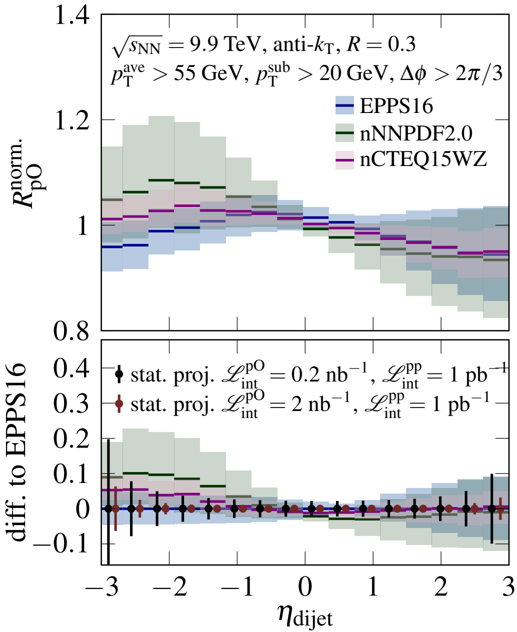
- → Direct access to nuclear modifications

Luminosity (and hadronization) uncertainties also (expected to) cancel!

Already $\sim 1\ \mathrm{nb}^{-1}$ can be expected to be enough to put new constraints on nPDFs (if we have sufficient statistics for the pp reference)

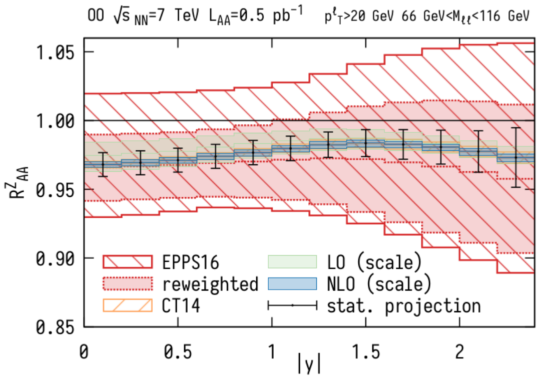
- → Can resolve different nPDF parametrisations!
- → We would heavily benefit from having the pp reference!

The expected $2\ \mathrm{nb}^{-1}$ for LHCb should be enough to give small-x gluon constraints also from forward D-meson production!



EW bosons in pO and OO?

[Huss *et al.*, arXiv:2007.13754]



EW probes are more luminosity hungry

- We would need $\sim 2\ \mathrm{pb}^{-1}$ for pO to get the same statistics as in the 8.16 TeV pPb run
- Larger cross section in OO → less luminosity needed
  - Accurate determination of the luminosity uncertainty important

Large part of the uncertainties in these observables come from the poorly known gluons

- These we can constrain already with the hadronic observables in pO

  (EW bosons still an important check for factorization / nPDF universality)

Since u/d flavour asymmetry does not contribute (isoscalarity), measuring W/Z bosons in pO/OO could provide unique constraints for strangeness nuclear modifications

→ Requires a further study

Summary

Where are we now with the nPDF global analyses?

- We have good understanding of the average valence and sea quark nuclear modifications, but flavour separation remains difficult to constrain
- Strong evidence from LHC (both hadronic & EW probes) for gluon shadowing & antishadowing
  - Lot of activity by different groups to include LHC data in their analyses

What can we learn from lighter-ion runs at the LHC?

- Already few nb^{-1} in pO could help us better understand gluon modifications in light nuclei
  - Important for setting the baseline for energy-loss studies in OO!
- W/Z production in pO/OO could serve as a test-bench for nuclear strangeness

Points for discussion:

- Can we expect a pp reference at the same energy as the pO run?
  - If we are expecting higher luminosity pPb and pp runs at 8.8 or 8.0 TeV, should we "tune" the pO run to that?
  - Does this impact the plans for "tuning" the OO collision energy?

Backup

What the nPDFs are?

Based on the collinear factorization of QCD:

$$\mathrm{d}\sigma^{AB\to k+X} \overset{Q\gg\Lambda_{\rm QCD}}{=} \sum_{i,j,X'} f_i^A(Q^2)\otimes \mathrm{d}\hat{\sigma}^{ij\to k+X'}(Q^2)\otimes f_j^B(Q^2) \ + \ \mathcal{O}(1/Q^2)$$

The coefficient functions $\mathrm{d}\hat{\sigma}^{ij\to k+X'}$ are calculable from perturbative QCD...

PDFs are *universal*, process independent, and obey the DGLAP equations

$$Q^2\frac{\partial f_i^A}{\partial Q^2} = \sum_j P_{ij}\otimes f_j^A$$

...but the parton distribution functions f_i^A, f_j^B contain long-range physics and cannot be obtained by perturbative means

For a nucleus A, one can decompose

$$f_i^A(x,Q^2) = Z\underbrace{f_i^{\mathrm{p}/A}}_{\text{bound-proton PDF}}(x,Q^2)+(A-Z)\underbrace{f_i^{\mathrm{n}/A}}_{\text{bound-neutron PDF}}(x,Q^2),$$

and assume $f_i^{\mathrm{p}/A} \overset{\text{isospin}}{\longleftrightarrow} f_j^{\mathrm{n}/A}$

How do we get the $f_i^{\mathrm{p}/A}$?

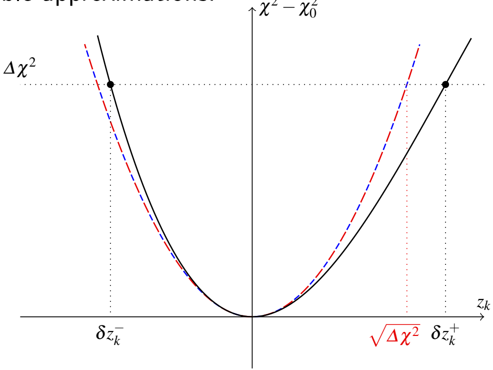
- Physical models: too numerous to cite here – 'Everybody's Model is Cool'
- Extract from lattice: not an easy task
- Fit to data: parametrize the x- and A-dependence – *the global analysis approach*

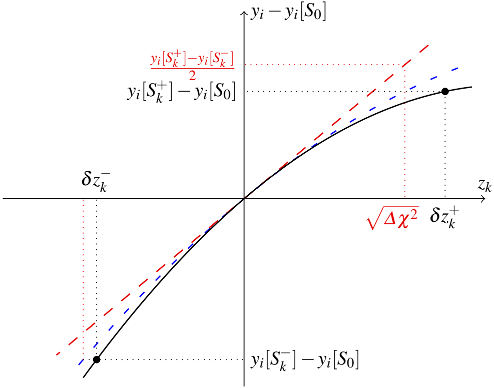
PDF reweighting: different approximations [Eskola, PP & Paukkunen, Eur.Phys.J.C 79 (2019) 511]

The Hessian reweighting is a method to study the impact of a new set of data on the PDFs without performing a full global fit

$$\chi^2_{\text{new}}(\mathbf{z}) = \chi^2_{\text{old}}(\mathbf{z}) + \sum_{ij} \left(y_i(\mathbf{z}) - y_i^{\text{data}}\right) C_{ij}^{-1} \left(y_j(\mathbf{z}) - y_j^{\text{data}}\right)$$

Possible approximations:





quadratic–linear: $\chi^2_{\text{old}} \approx \chi^2_0 + \sum_k z_k^2,$ $\quad y_i \approx y_i[S_0] + \sum_k d_{ik} z_k$

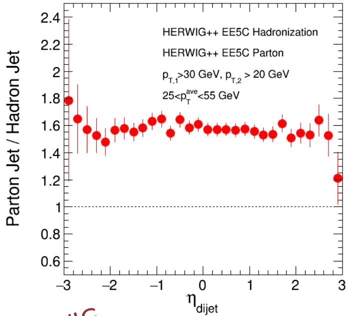
quadratic–quadratic: $\chi^2_{\text{old}} \approx \chi^2_0 + \sum_k z_k^2,$ $\quad y_i \approx y_i[S_0] + \sum_k (d_{ik} z_k + e_{ik} z_k^2)$

cubic–quadratic: $\chi^2_{\text{old}} \approx \chi^2_0 + \sum_k (a_k z_k^2 + b_k z_k^3),$ $\quad y_i \approx y_i[S_0] + \sum_k (d_{ik} z_k + e_{ik} z_k^2)$

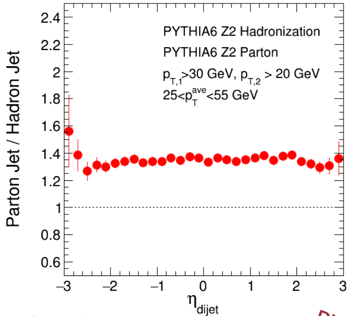
slide from: Doga Gulhan, HI Jet Workshop, July 2016

Cross-section ratios

HERWIG

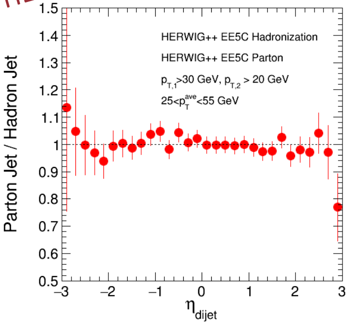


PYTHIA

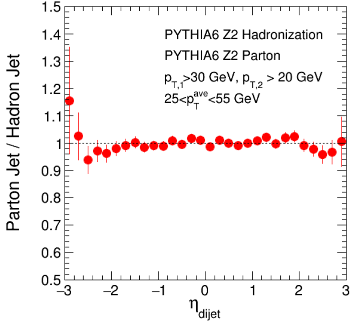


Area normalized ratios

HERWIG



PYTHIA



Hadronization uncertainty

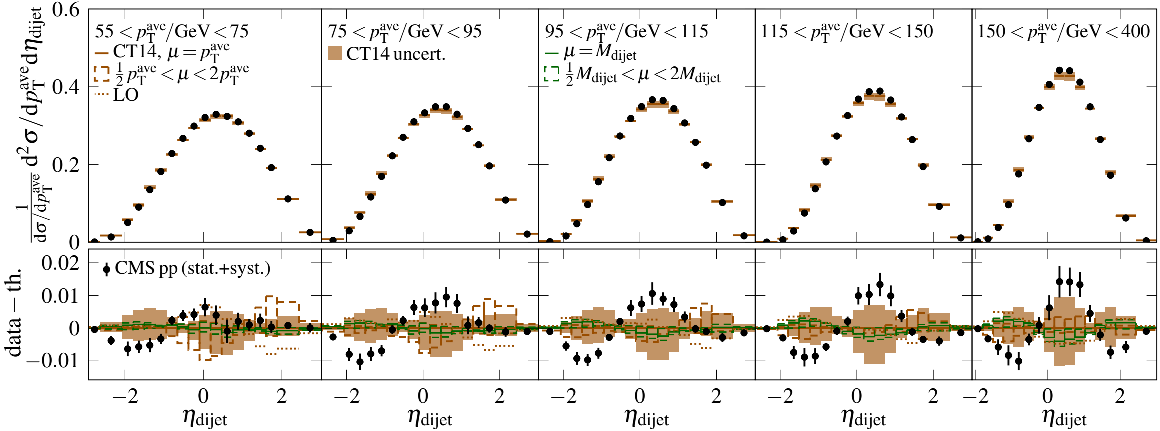
Parton jets have higher cross section for R = 0.3 jets with same kinematic selections compared to hadron jets

Parton jets are harder fragmenting

After self normalization effect of hadronization is negligible

CMS dijets at pp

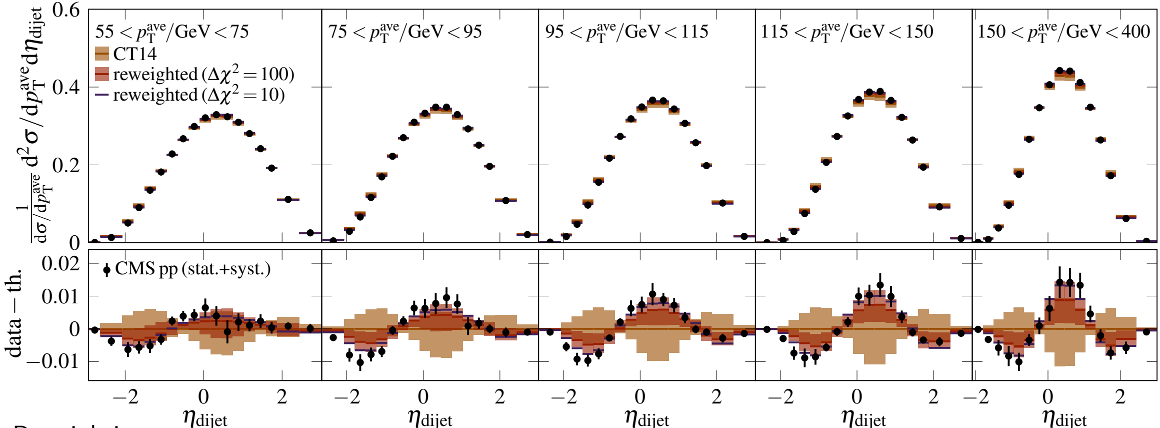
[Eskola, PP & Paukkunen, Eur.Phys.J.C 79 (2019) 511]



- Predicted NLO distributions somewhat wider than the measured spectra
- High-p_T^{ave} midrapidity robust against scale variations and LO-to-NLO effects
  - → can expect NNLO corrections to be small in this region
  - → observed discrepancy seems to be a PDF related issue
- Refitting might be needed to improve agreement with data
  - → study the impact with the reweighting method

CMS dijets at pp – CT14 reweighted

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

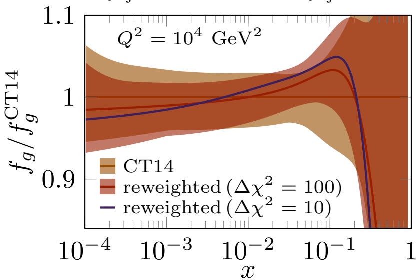


Reweighting:

- improves midrapidity description
- is not able to fully reproduce data at large rapidities even when applied with additional weight ($\Delta\chi^2 = 10$) (high-x parametrization issue? NNLO? data systematics?)

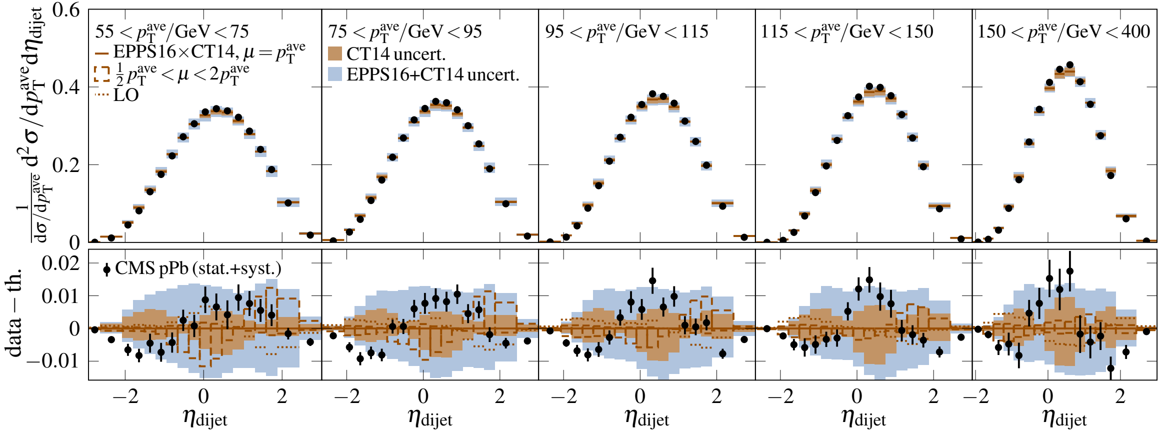
Significant gluon modifications needed especially at large x

- also valence quarks get modified



CMS dijets at pPb

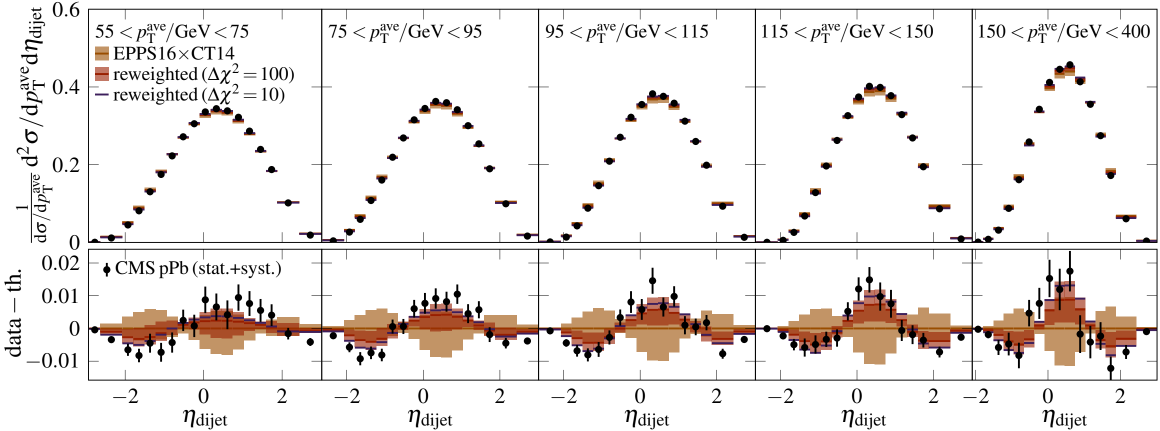
[Eskola, PP & Paukkunen, Eur.Phys.J.C 79 (2019) 511]



- pPb data deviates from NLO calculations *almost the same way* as the pp data
  - ➔ had we not seen the same deviations in pp, we might have interpreted this as a fault in our nuclear PDFs
- Compared to pp case we have additional suppression in data compared to theory at forward rapidities
  - ➔ implication of deeper gluon shadowing

CMS dijets at pPb after CT14 reweighting

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



- Modifications needed in CT14 to describe pp data have large impact on pPb predictions
  - → it is imperative to understand the pp baseline before making far-reaching conclusions from pPb data
- Using these data directly in nuclear PDF analysis with CT14 proton PDFs would lead to
  - overestimating nuclear effects
  - large scale-choice bias

→ Consider nuclear modification factor instead

Heavy-flavour production mass schemes

FFNS

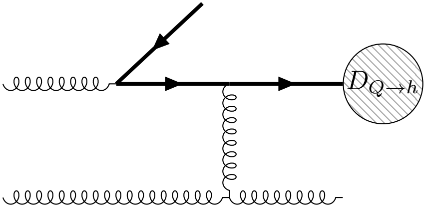
In *fixed flavour number scheme*, valid at small p_{T}, heavy quarks are produced only at the matrix element level

Contains $\log(p_{\mathrm{T}}/m)$ and m/p_{T} terms

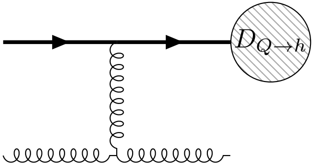
ZM-VFNS

In *zero-mass variable flavour number scheme*, valid at large p_{T}, heavy quarks are treated as massless particles produced also in ISR/FSR

Resums $\log(p_{\mathrm{T}}/m)$ but ignores m/p_{T} terms



$-$ subtraction term $+$



GM-VFNS

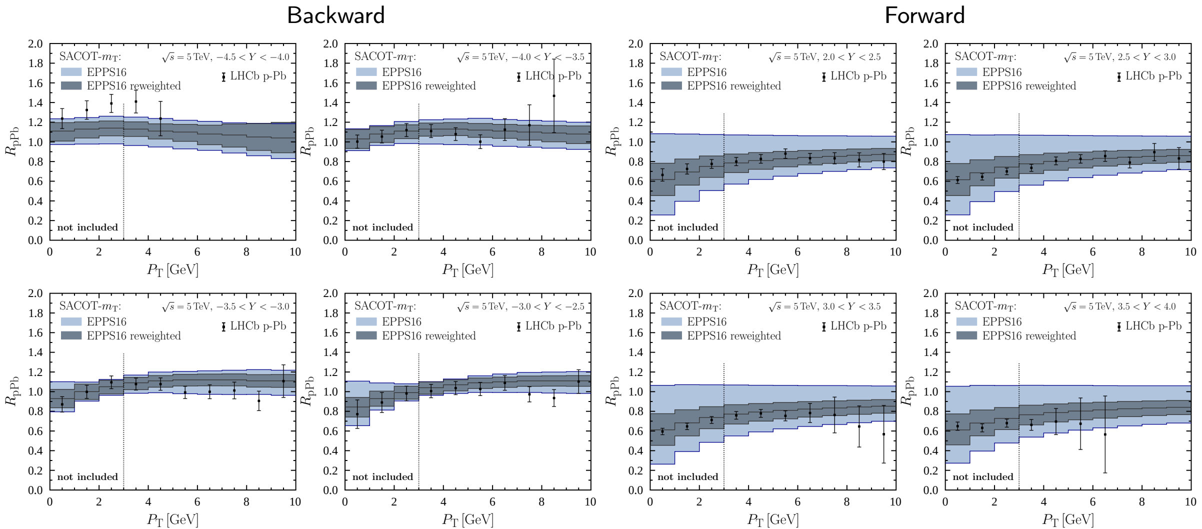
A *general-mass variable flavour number scheme* combines the two by supplementing subtraction terms to prevent double counting of the resummed splittings, valid at all p_{T}

Resums $\log(p_{\mathrm{T}}/m)$ and includes m/p_{T} terms in the FFNS matrix elements

Important: includes also gluon-to-HF fragmentation – large contribution to the cross section!

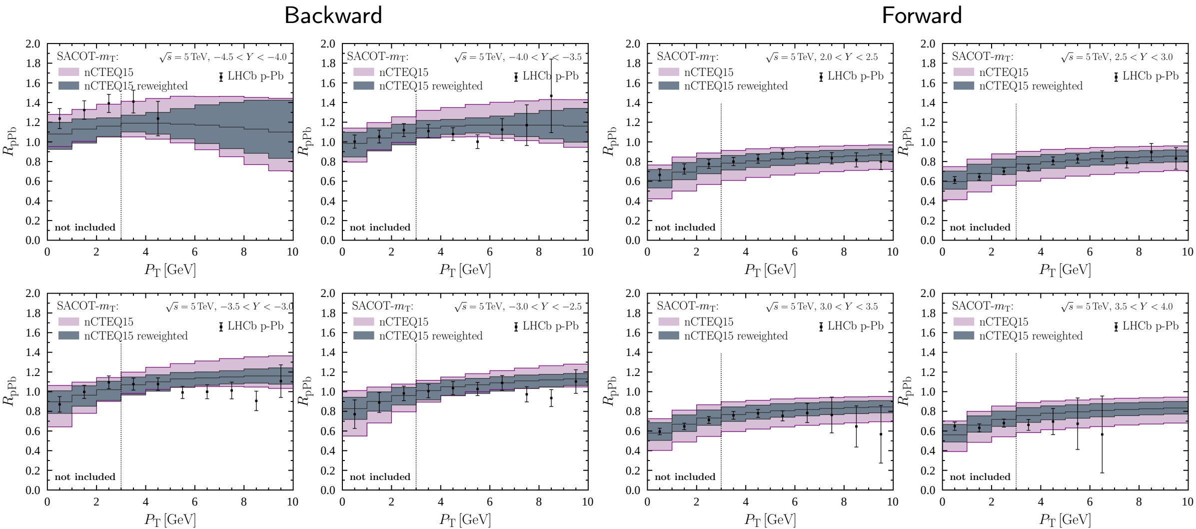
EPPS16 reweighted LHCb D-meson R_{pPb}

[Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]



- Data well reproduced with the reweighted results
- Significant reduction in EPPS16 uncertainties especially in forward bins
- Good agreement with data below cut – no physics beyond collinear factorization needed

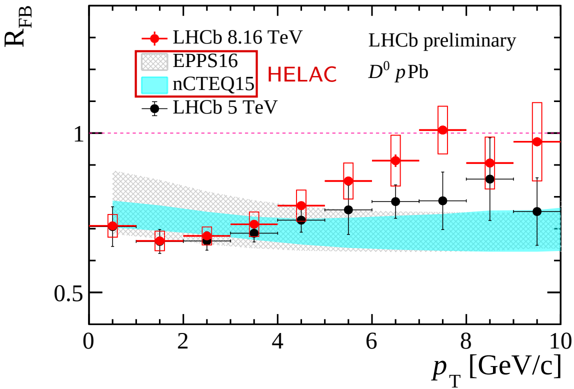
nCTEQ15 reweighted LHCb D-meson R_{pPb} [Eskola, Helenius, PP & Paukkunen, JHEP 05 (2020) 037]



- Uncertainties smaller to begin with in the forward direction (less flexible small-x parametrization) while larger in backward – almost identical results
- Data well reproduced

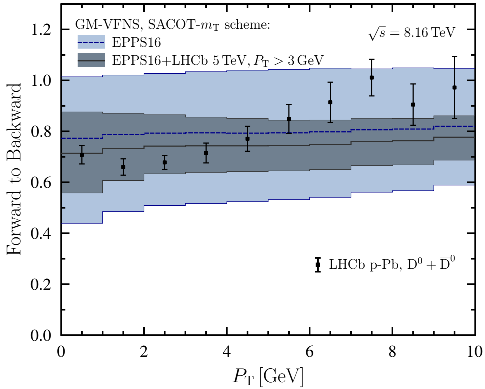
D-mesons at 8.16 TeV – do we have tension?

[LHCb Collaboration, LHCb-CONF-2019-004]



→

[Eskola, Helenius, PP & Paukkunen, unpublished]



QM2019 LHCb summary talk:

~~*"Tension between data and nPDFs predictions. Additional effects required."*~~

→ *Theoretical description matters, HELAC predicts much smaller nPDF uncertainties for R_{FB} than SACOT-m_{T}!*

The slope of the 8.16 TeV data still differs from that in nPDF predictions and in 5.02 TeV data

→ How can we explain the difference?