Near-future prospects for nuclear PDFs

Hannu Paukkunen

University of Jyväskylä, Finland
Helsinki Institute of Physics, Finland

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Latest available nPDF parametrizations in 2018

	EPS09	DSSZ12	KA15	NCTEQ15	EPPS16
Order in α_s	NLO	NLO	NNLO	NLO	NLO
DIS in ℓ^-+A	✓	✓	✓	✓	✓
Drell-Yan in p+A	✓	✓	✓	✓	✓
RHIC pions d+Au	✓	✓		✓	✓
Neutrino-nucleus DIS		✓			✓
Drell-Yan in π+A					✓
LHC p+Pb dijets					✓
LHC p+Pb W, Z					✓
Q cut in DIS	$1.3\,\mathrm{GeV}$	$1\,\mathrm{GeV}$	$1\,\mathrm{GeV}$	$2\,\mathrm{GeV}$	$1.3\,\mathrm{GeV}$
datapoints	929	1579	1479	708	1811
free parameters	15	25	16	16	20
error analysis	Hessian	Hessian	Hessian	Hessian	Hessian
error tolerance $\Delta\chi^2$	50	30	N.N	35	52
proton baseline PDFs	CTEQ6.1	MSTW2008	JR09	CTEQ6M-like	CT14NLO
Heavy-quark effects		✓		✓	✓
Flavour separation				partial	full
Reference	JHEP 0904 065	PR D85 074028	PR D93, 014026	PR D93 085037	EPJ C77 163

Expect "soon": Andrés-Zurita NNLO nPDFs [https://indico.cern.ch/event/639067/contributions/2642447/]

This talk restricted to:

- **CMS $\sqrt{s} = 5\,\mathrm{TeV}$ p-p and p-Pb dijets**
- **Towards including LHCb D-meson measurements**

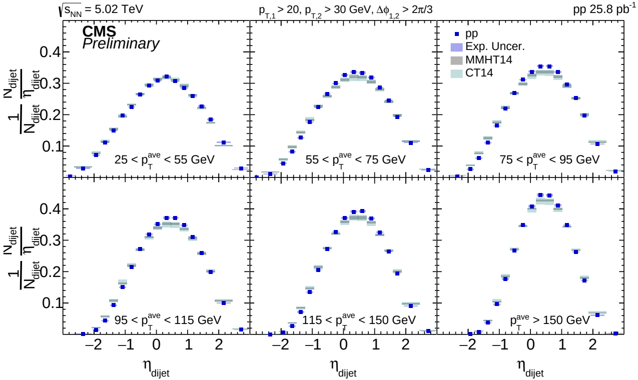
CMS p-p and p-Pb dijets

- Normalized dijet cross sections at $\sqrt{s} = 5\,\mathrm{TeV}$ in p-p [CMS PAS HIN-16-003]

$$\frac{d\sigma^{\mathrm{pp}}(\eta_{\mathrm{dijet}}, p_{\mathrm{T}}^{\mathrm{average}})}{\int d\sigma^{\mathrm{pp}}(\eta_{\mathrm{dijet}}, p_{\mathrm{T}}^{\mathrm{average}}) d\eta_{\mathrm{dijet}}}$$

$$p_{\mathrm{T}}^{\mathrm{average}} = (p_{\mathrm{T}}^{\mathrm{leading}} + p_{\mathrm{T}}^{\mathrm{subleading}})/2$$

$$\eta = (\eta^{\mathrm{leading}} + \eta^{\mathrm{subleading}})/2$$



- The preliminary data not well reproduced by the current PDFs

CMS p-p and p-Pb dijets

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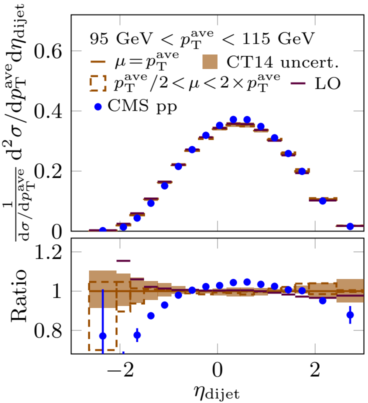
- Normalization apparently suppresses the experimental systematic uncertainties
- NLO calculations are wider in η_{dijet} than the (preliminary) data
- The scale uncertainty is very small for $\eta_{\mathrm{dijet}} \in [-1, 2]$ — would not expect large NNLO effects. Already NLO to LO difference is small near $\eta_{\mathrm{dijet}} \sim 0$



CMS p-p and p-Pb dijets

- Normalized dijet cross sections at $\sqrt{s} = 5\,\mathrm{TeV}$ in p-Pb [CMS PAS HIN-16-003]

$$\frac{d\sigma^{\mathrm{pPb}}(\eta_{\mathrm{dijet}}, p_{\mathrm{T}}^{\mathrm{average}})}{\int d\sigma^{\mathrm{pPb}}(\eta_{\mathrm{dijet}}, p_{\mathrm{T}}^{\mathrm{average}}) d\eta_{\mathrm{dijet}}}$$

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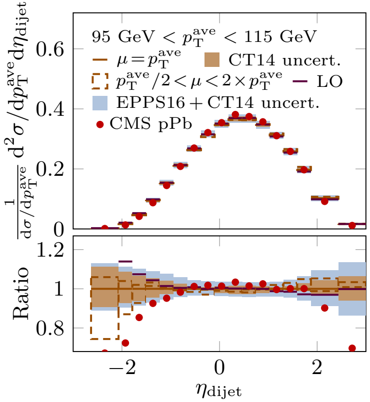
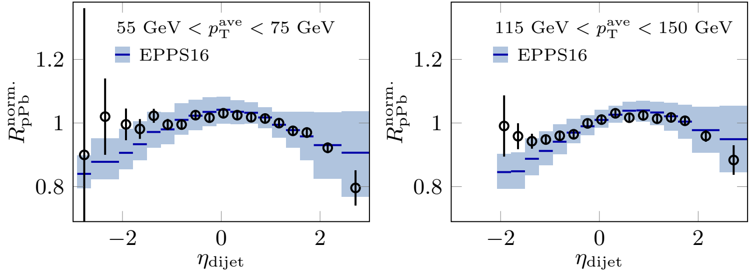
- Similar situation in p-Pb measurements



CMS p-p and p-Pb dijets

- Nuclear modification — a ratio of ratios

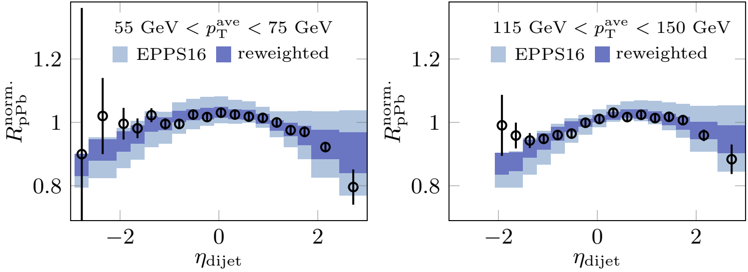
$$R_{\rm pPb}^{\rm norm.} \equiv \frac{d\sigma^{\rm pPb}(\eta_{\rm dijet}, p_{\rm T}^{\rm average})}{\int d\sigma^{\rm pPb}(\eta_{\rm dijet}, p_{\rm T}^{\rm average}) d\eta_{\rm dijet}} \Bigg/ \frac{d\sigma^{\rm pp}(\eta_{\rm dijet}, p_{\rm T}^{\rm average})}{\int d\sigma^{\rm pp}(\eta_{\rm dijet}, p_{\rm T}^{\rm average}) d\eta_{\rm dijet}}$$



- The preliminary $R_{\rm pPb}^{\rm norm.}$ data decently described by EPPS16
- The data uncertainties beat EPPS16 by far
- Some deviations in the backward direction (probing **very** large-$x_{\rm Pb}$ region)

CMS p-p and p-Pb dijets

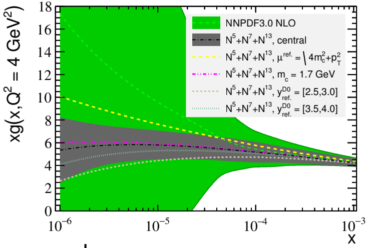
- The effect of these CMS preliminary data estimated by an **improved PDF-reweighting/profiling method** (check out P. Paakkinen in DIS'18)



- The preliminary data promise a **major effect** in EPPS16 — even more dramatic for nCTEQ15 which has larger gluon uncertainties at large x.
- Have to settle down the issues (discussed in the previous slides) with the normalized spectra before can include these data in global nPDF fits.

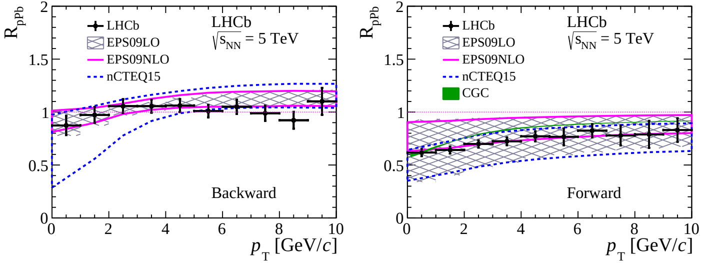
Towards including LHCb D-meson measurements

- The potential of D (and B) meson production has been demonstrated in p-p [PRL 118 072001, EPJ C75 396]



- Good gluon resolution based on including data down to $p_T^D = 0$

- Recent R_{pPb} data from LHCb [JHEP 1710 (2017) 090] show **compelling evidence** of small-x shadowing



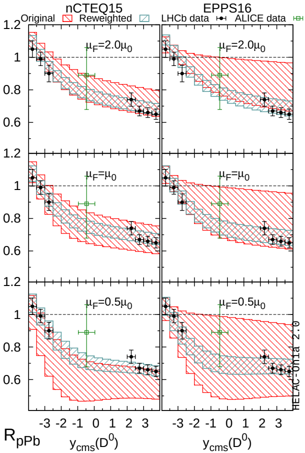
Towards including LHCb D-meson measurements

- Idea introduced in [EPJ C77 (2017) 1] and then applied in [arXiv:1712.07024]:

$$d\sigma(\mathrm{D}^0) = f_g(x_1, Q_f^2) \otimes d\sigma_{gg}^{\mathrm{D}^0}(Q_f^2, Q_r^2) \otimes f_g(x_2, Q_f^2)$$

Fit the coefficient functions to p-p data

- Neglects all but the gluon-gluon channel
  - Close to fixed-flavour number scheme (FFNS)
  - EPPS16/nCTEQ15 are not FFNS PDFs...
- Based on $2 \to 2$ kinematics
  - May bias the x_2 distributions to overly low x
- I would say a more appropriate treatment requires a general-mass variable flavour number (GM-VFNS) approach



Towards including LHCb D-meson measurements

- In FFNS, the heavy quarks are produced in three partonic processes

$$g + g \to Q, \quad q + \overline{q} \to Q, \quad q + g \to Q$$

  Phenomenological fragmentation functions (FFs) for $Q \to D$ transition
- FFNS cross sections diverge as $\sim \log(p_\mathrm{T}^2/m^2)$. In GM-VFNS these logs are resummed into heavy-quark PDFs and scale-dependent FFs

Includes ALL partonic subprocesses (unlike FFNS)

$$\frac{d\sigma(h_1 + h_2 \to D^0 + X)}{dP_\mathrm{T} dY} = \sum_{ijk} \int_{z^\mathrm{min}}^1 \frac{dz}{z} \int_{x_1^\mathrm{min}}^1 dx_1 \int_{x_2^\mathrm{min}}^1 dx_2$$

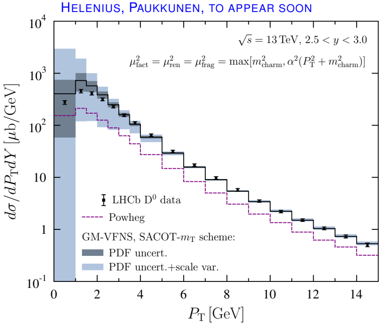
$$f_i^{h_1}(x_1, \mu^2_\mathrm{fact}) \; \frac{d\hat{\sigma}^{ij\to k}(x_1,x_2,m,\mu^2_\mathrm{ren},\mu^2_\mathrm{fact},\mu^2_\mathrm{frag})}{dp_\mathrm{T}\, dy} \; f_j^{h_2}(x_2, \mu^2_\mathrm{fact}) \; D_{k\to D^0}(z, \mu^2_\mathrm{frag})$$

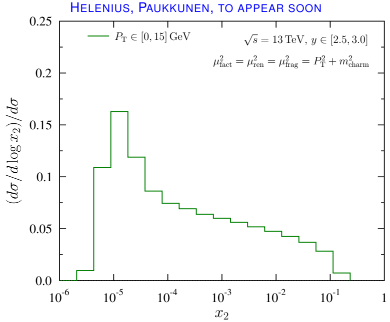
Coefficient functions behave as FFNS at low p_T, as zero-mass matrix elements at high p_T

Scale-dependent, universal FFs

Towards including LHCb D-meson measurements

- LHCb p-p cross sections fairly well reproduced by GM-VFNS approach in **SACOT-$m_{\rm T}$ scheme** — a generalization of SACOT-χ to hadroproduction





- x_2 distributions in GM-VFNS peaked at low x — a long tail towards large x
- Sizable theory uncertainties at low $p_{\rm T}$: GM-VFNS scheme dependence, ambiguous fragmentation variable z, scale uncertainties, etc...

  $\Rightarrow$ Will need to set a cut $p_{\rm T} \gtrsim 5\,\mathrm{GeV}$ or so

Summary

- The (preliminary) CMS $\sqrt{s} = 5\,\mathrm{TeV}$ dijet R_{pPb} data promises a huge potential to constrain nuclear gluons at large-x

  However, the η, p_{T} dependence of the (preliminary) p-p and p-Pb spectra are not well reproduced — only the ratio seems OK

  $\Rightarrow$ Have to sort out these discrepancies before one can confidently include the data in global fits

- Potential of LHCb D-meson measurements in p-Pb are significant at small-x

  GM-VFNS approach can describe the p-p data down to $p_{\mathrm{T}} = 0$ but the theory uncertainties are huge — requires a cut $p_{\mathrm{T}} \gtrsim 5\,\mathrm{GeV}$ or so

  $\Rightarrow$ Retain sensitivity to small-x but at higher interaction scale