Constraints for nuclear PDFs from the LHCb D-meson data

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Eskola, Helenius, Paakkinen, Paukkunen, arXiv:1904.XXXXX

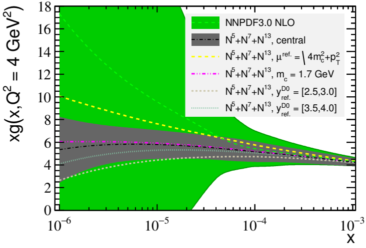
JYVÄSKYLÄN YLIOPISTO

SUOMEN AKATEMIA

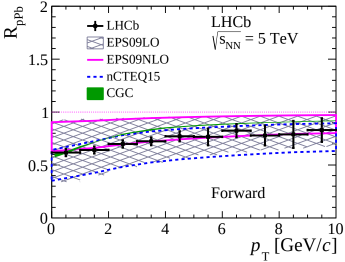
Open heavy-flavour measurements promising PDF constraints

- The potential of D (and B) meson production as a PDF constraint has been actively investigated [Gauld, Rojo, PRL 118, 072001 ; PROSA, EPJ C75, 396 ; Kusina et.al. PRL 121,052004]

reduction of NNPD3.0 gluon uncertainty upon including LHCb D-meson data



large y nuclear modification in p-Pb from LHCb [JHEP 10 (2017) 090]



- Theoretical description typically based on fixed-order QCD (e.g. the MNR code [Mangano et.al. NP B373, 295]), FONLL [Cacciari et.al. JHEP 9805, 007], or Powheg+Pythia [Frixione et.al. JHEP 0709, 126]

- We use a full **general-mass variable-flavour-number scheme (GM-VFNS)** approach [Kniehl et.al PRD71, 014018, Helenius, Paukkunen, JHEP 1805 (2018) 196]

The GM-VFNS framework

- The master formula for D-meson production in GM-VFNS:

sum over all partonic subprocesses

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

$$f_i^{h_1}(x_1, \mu^2_{\text{fact}}) \quad \frac{d\hat{\sigma}^{ij\to k+X}(x_1, x_2, m^2, \mu^2_{\text{ren}}, \mu^2_{\text{fact}}, \mu^2_{\text{frag}})}{dp_T dy} \quad f_j^{h_2}(x_2, \mu^2_{\text{fact}}) \quad D_{k\to D}(z, \mu^2_{\text{frag}})$$

here $z \equiv E_D/E_k$, but generally not unique!

Coefficient functions behave as FFNS at low p_T, but as zero-mass $\overline{\text{MS}}$ matrix elements at high p_T

Scale-dependent, universal fragmentation functions (FFs)

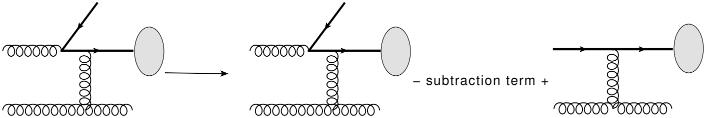
- In comparison, fixed flavour-number scheme (FFNS) produces heavy quarks only in three partonic processes

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

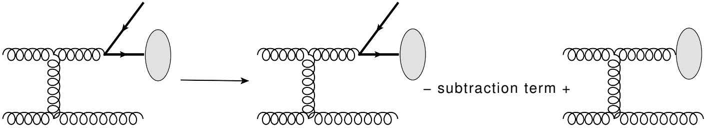
the $Q \to D$ FFs are scale independent, and it's applicable only at "low" p_T

The GM-VFNS framework

- In GM-VFNS the contributions **initiated by heavy-quarks**...



...and those in which a **light quark/gluon fragments** into a D meson...



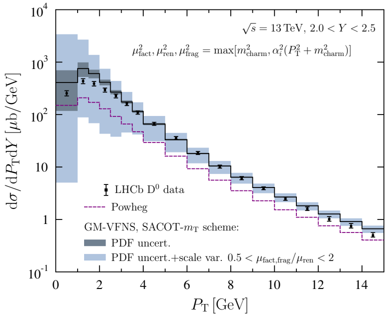
...are scheme dependent

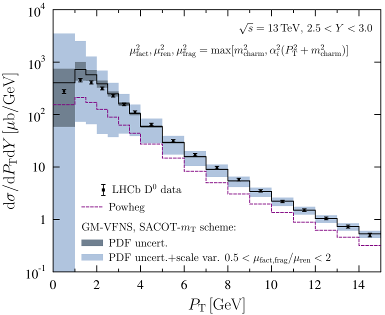
- We adopt the **SACOT-m_{T}** prescription [Helenius, Paukkunen, JHEP 1805 (2018) 196] for these contributions: zero-mass partonic cross sections but with $Q\overline{Q}$-pair kinematics

- Well-behaved cross sections from zero to high p_{T}

Comparison with the LHCb 13 TeV p-p data

- LHCb p-p cross sections well reproduced by the SACOT-m_{T} approach





PDF = NNPDF3.1NLO (pch)
FF = KKKS08

- Sizable theory uncertainties at low p_{T}: scale-choice and proton-PDF uncertainties shown, but there are others too (scheme dependence, fragmentation variable z,...)
- Powheg+Pythia setup down by a factor of two with a large scale uncertainty (very similar to FONLL/FFNS)
- For more on GM-VFNS, see my talk in WG5 after the next coffee break!

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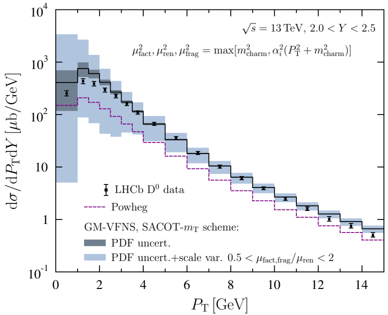

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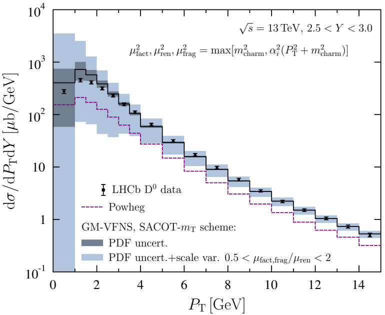

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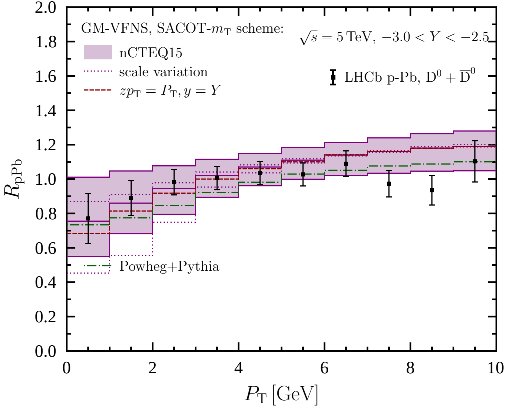
Theory uncertainties in nuclear modifications $\sigma_{\mathrm{pPb}}/\sigma_{\mathrm{pp}}$

- As an example, LHCb data w.r.t. nCTEQ15

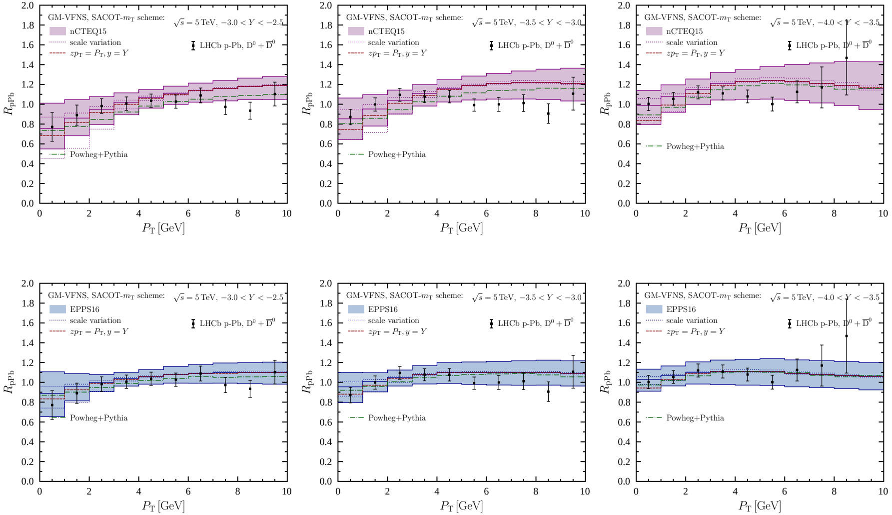


$$\mu = \sqrt{P_T^2 + m_{\mathrm{charm}}^2}$$

- Uncertainties due to scale choices and fragmentation variable z in $D_{k \to D}(z, \mu_{\mathrm{frag}}^2)$ grow towards low p_T
- Powheg+Pythia biased to overly low x and therefore systematically below GM-VFNS

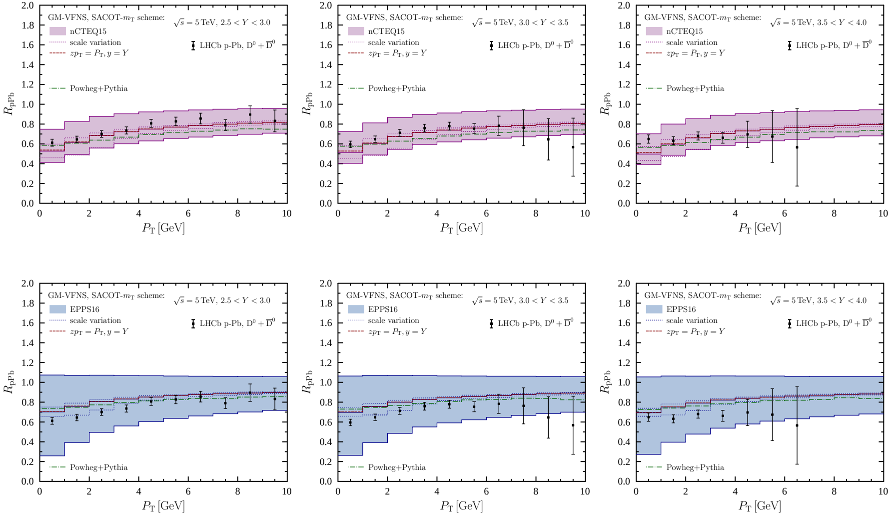
LHCb data vs. EPPS16 and nCTEQ15

- Nuclear modification at $Y < 0$ with nCTEQ15 and EPPS16



LHCb data vs. EPPS16 and nCTEQ15

- Nuclear modification at $Y > 0$ with nCTEQ15 and EPPS16



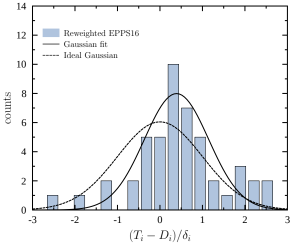
Tuning nuclear PDFs to the LHCb data

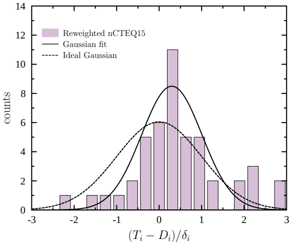
- Use the Hessian PDF reweighting [Paukkunen, Zurita, JHEP 1412, 100; Eskola et.al. arXiv:1903.09832, Schmidt et.al. PRD98, 094005] to check the impact of LHCb data
- For $N_{\rm data} = 48$, excluding the region $p_{\rm T} < 3\,{\rm GeV}$

EPPS16: $\chi^2/N_{\rm data}$ (before reweighting) = 1.56
$\chi^2/N_{\rm data}$ (after reweighting) = 1.02

nCTEQ15: $\chi^2/N_{\rm data}$ (before reweighting) = 2.09
$\chi^2/N_{\rm data}$ (after reweighting) = 1.12

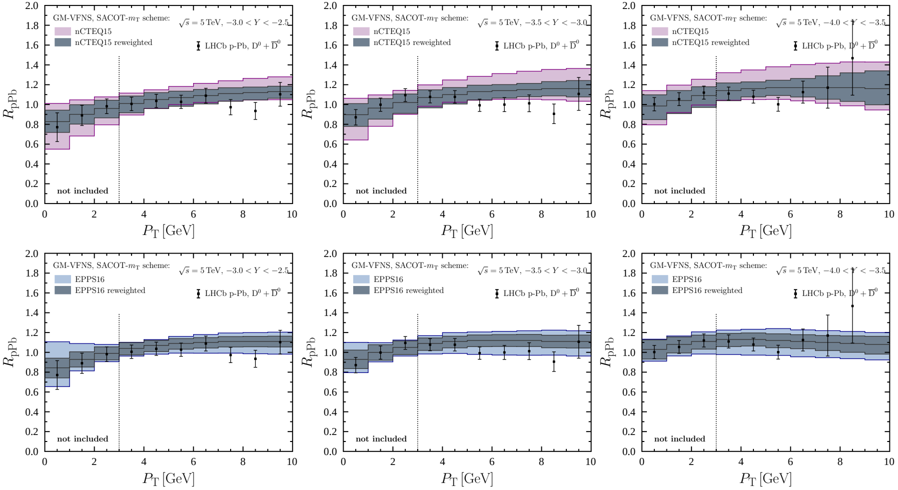
- Distributions of data "residuals" $r = \dfrac{\rm data - theory}{\rm error}$ also reasonably Gaussian





Tuning nuclear PDFs to the LHCb data

- Nuclear modification at $Y < 0$ with nCTEQ15 and EPPS16 after reweighting



- Data well reproduced down to $P_T = 0$ — no sign of non-linear (beyond DGLAP) effects

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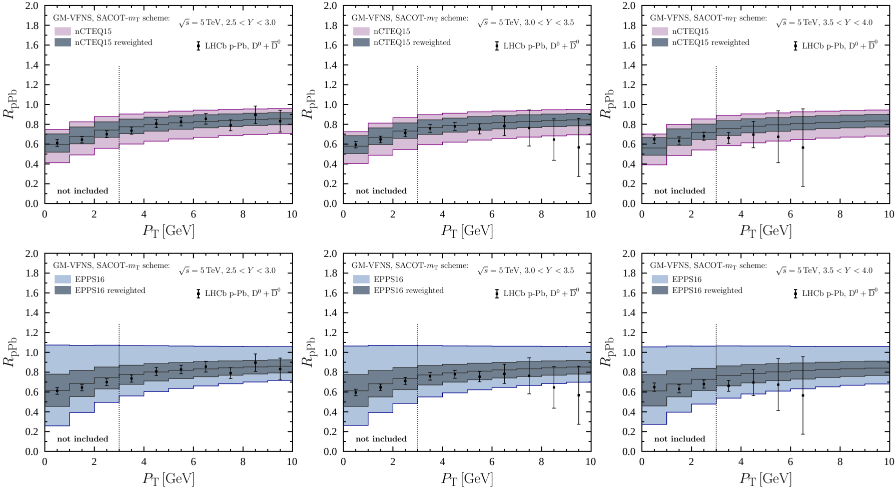

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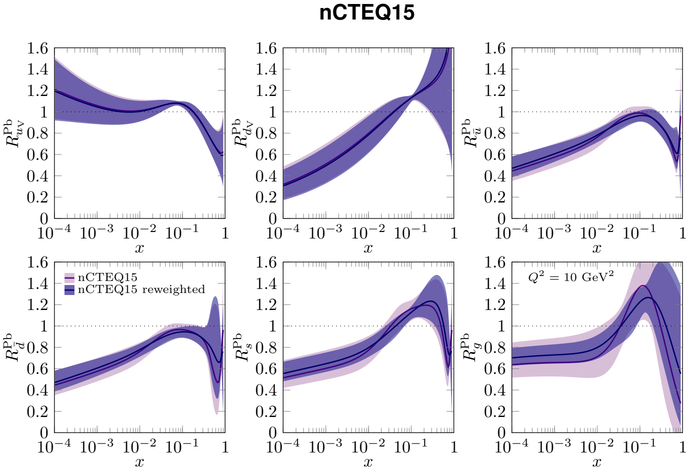
Tuning nuclear PDFs to the LHCb data

- Effect for PDF nuclear modifictions $f_i^{\rm p,Pb}(x,Q^2)/f_i^{\rm p}(x,Q^2)$, at $Q^2 = 10\,{\rm GeV}^2$:



- Significant effect for gluons, the sea quarks follow

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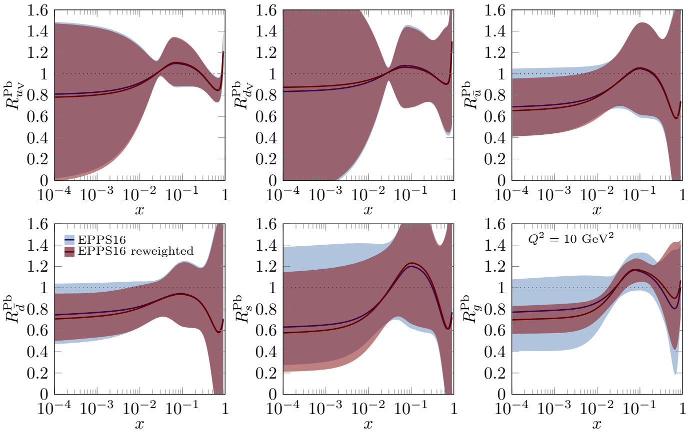
EPPS16



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Summary

- Studied the compatibility and impact of LHCb D-meson data on nuclear PDFs within a realistic GM-VFNS scheme (SACOT-$m_{\rm T}$)

  - GM-VFNS facilitates a controlled description across all $p_{\rm T}$

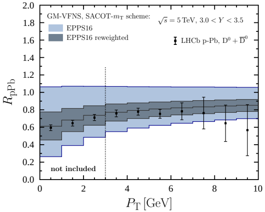
- Theoretical uncertainties below $P_{\rm T} \sim 3\,{\rm GeV}$ quickly grow, so we excluded this region from our main analysis

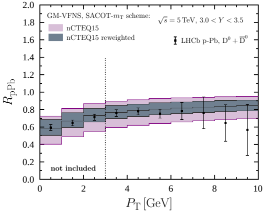
- EPPS16 and nCTEQ15 nPDFs can be brought to an excellent agreement with the LHCb data by Hessian PDF reweighting

  - Only mild changes (very little for EPPS16, more for nCTEQ15) in the original central values — the D-meson data thus compatible with the rest in the global analysis

  - Significant decrease in uncertainties

- The agreement with the data remains very good down to $P_{\rm T} = 0$ — no obvious need for invoking BFKL, non-linear evolution, intrinsic $k_{\rm t}$ kicks, etc...





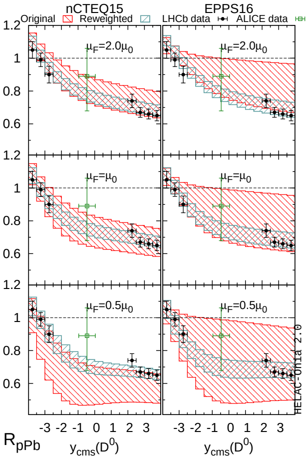
Matrix-element fitting study

- Method in [KUSINA ET.AL. PRL 121,052004]:

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

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
  - Biases the x_2 distributions to overly low x



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