Constraining nuclear PDFs with forward photons and charm: EPPS

Low-x gluon structure of nuclei and signals of saturation at LHC

Ilkka Helenius

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Tübingen University
Insititute for Theoretical Physics

With Hannu Paukkunen

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

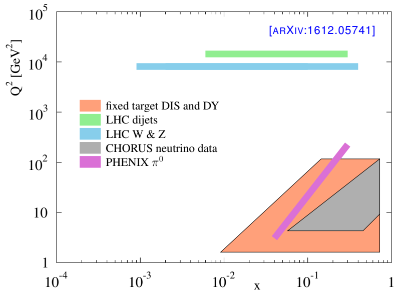
Outline

1. Nuclear parton distribution functions (nPDFs)
2. Direct Photons at forward rapidities
3. Heavy quark production
4. Summary

Based on:

- K. J. Eskola, I. Helenius, H. Paukkunen, JHEP 1409 (2014) 138 [arXiv:1406.1689 [hep-ph]]
- I. Helenius, H. Paukkunen, *in preparation*

Nuclear parton distribution functions (nPDFs)



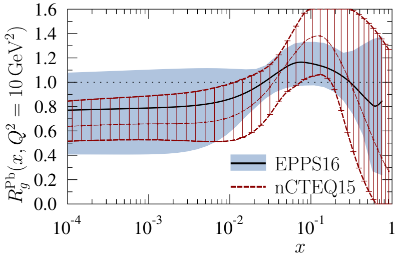
⇒ Large uncertainties especially for gluon nPDFs

⇒ Uncertainty in the pQCD baseline for heavy-ion physics at the LHC

Data available for nPDF fits

- Fixed-target (ν)DIS and DY
- Pions in dAu at RHIC
- Dijets in pPb at the LHC
- EW bosons at the LHC

⇒ Limited kinematic reach

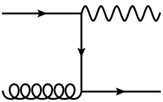


[Figures from EPPS16: Eur.Phys.J. C77 (2017) no.3, 163]

Direct photon production

Direct photon production

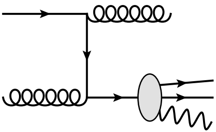
Prompt photons



- Calculable from pQCD
- Provides a direct probe to the gluon PDFs
- LO kinematics:

$$x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-y_\gamma} + e^{-y_q}\right)$$

Fragmentation photons



- Convolute partonic spectra with non-perturbative FFs

$$p^\gamma = z \cdot p^i \quad (\langle z \rangle \sim 0.5)$$

$\Rightarrow$ Less sensitive to small x

- Two components experimentally indistinguishable
- At NLO the relative fractions depend on μ_{frag}
- Also NNLO calculation available for direct part [PRL 118 222001]

Calculation framework

Isolation cut

- Reject photons with

  $\Sigma E_T^{had} > E_T^{max}$ (or αE_T^{γ})

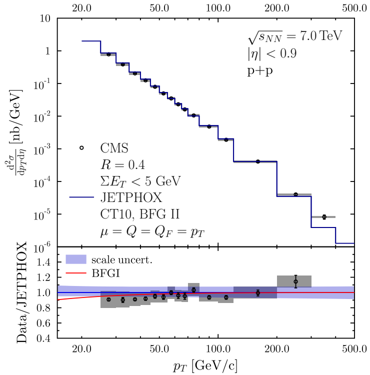
  within cone

  $$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

- Experiments: Suppresses background from hadron decays
- Theory: Reduce the fragmentation contribution

⇒ Increases small-x sensitivity

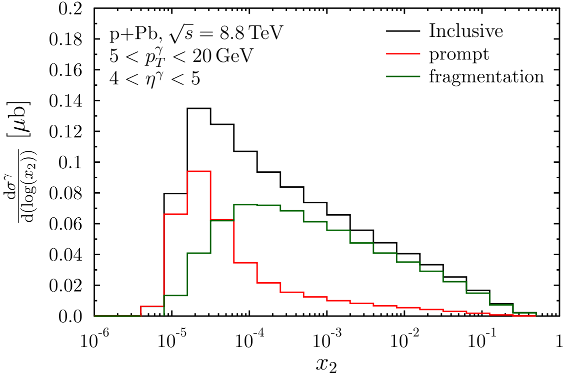
[CMS: Phys.Rev. D84 (2011) 052011]



- Good agreement with CMS data and JETPHOX

Sensivity to small-x

Direct photons in pPb collisions at $\sqrt{s} = 8.8$ TeV with JETPHOX



- Prompt peaked at $\sim 10^{-5}$, fragmentation extends to high-x_2

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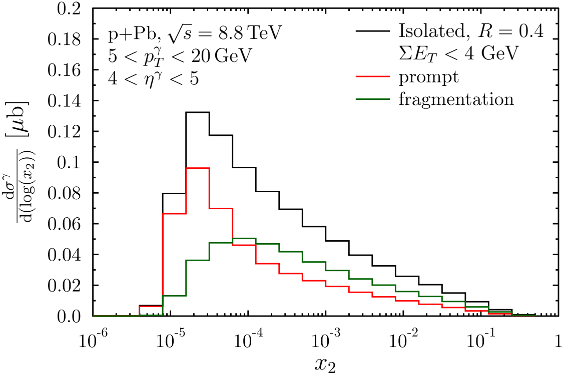

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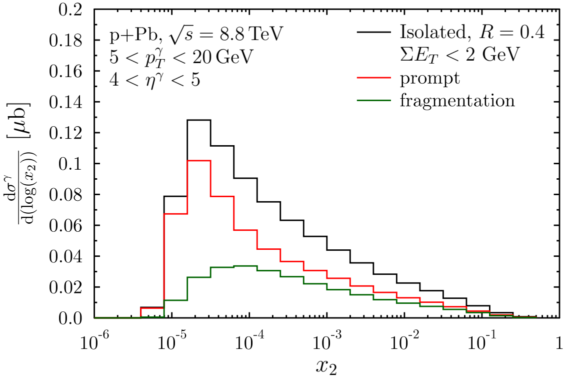

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- Tighter cut further suppresses fragmentation contribution

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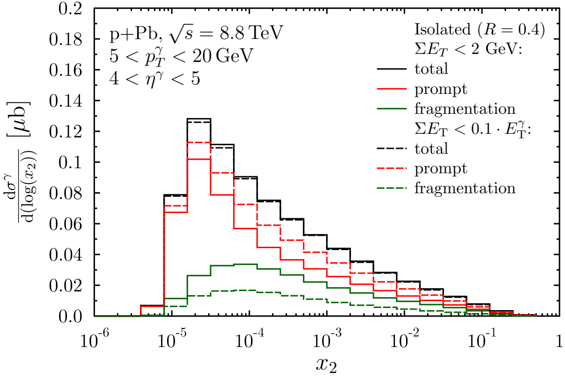
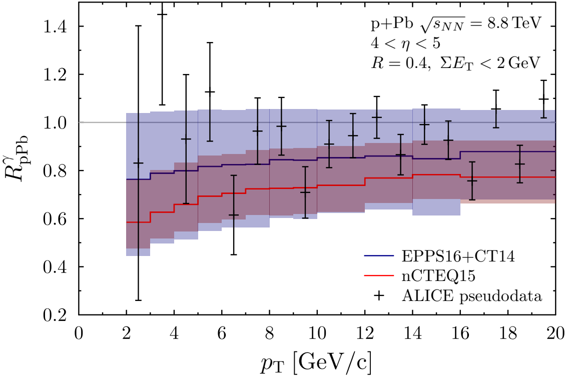


- Prompt peaked at $\sim 10^{-5}$, fragmentation extends to high-x_2
- Isolation cut suppress high-x_2 tail
- Tighter cut further suppresses fragmentation contribution
- However, total x_2 sensitivity similar

ALICE FoCal capability

- Expected FoCal data precision compared to current nPDFs

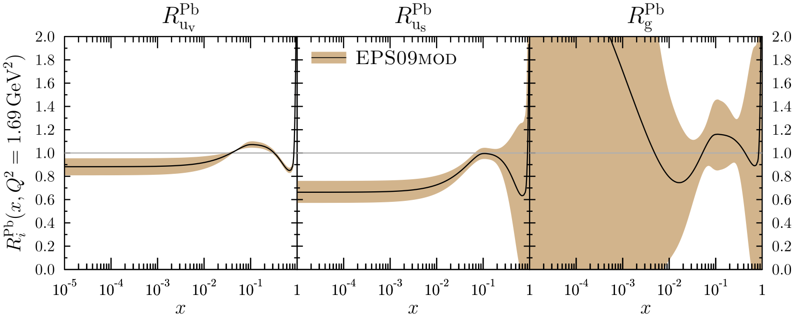


- EPPS16 and nCTEQ15 compatible within uncertainties
- Error sets depend on nPDF parametrization
- No data constraints at $x < 10^{-3}$
  $\Rightarrow$ Uncertainties somewhat underestimated

Parametrization dependence

Quantify the total small-x uncertainty

- A global analysis based on EPS09 but more flexibility for small-x gluon parametrization (EPS09MOD)
- Resulting uncertainties larger than in published analyses
- However, theoretically $R_g(x < 10^{-3}) \leq 1$ is expected



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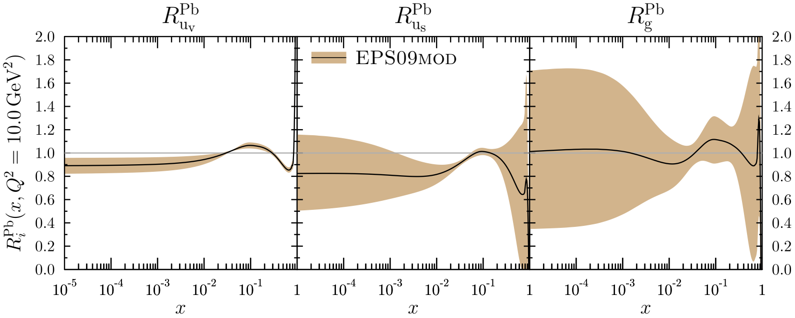
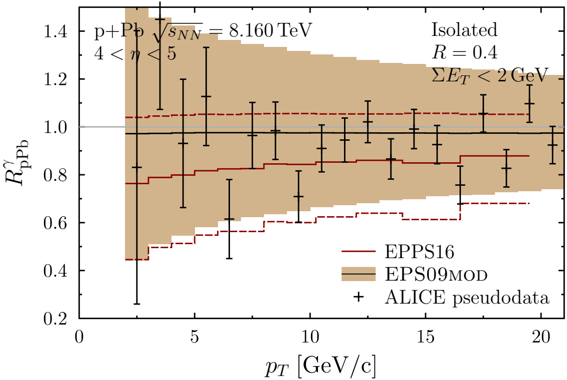


- R_g uncertainties shrink with Q^2, some transmitted to q_S

Parametrization dependence

- Comparison to expected FoCal precision



- Almost a factor of 2 larger uncertainties than EPPS16 (EPPS16 result and pseudodata at $\sqrt{s_{\mathrm{NN}}} = 8.8$ TeV)
- Direct photons at forward rapidities would constrain small-*x* gluon nPDFs

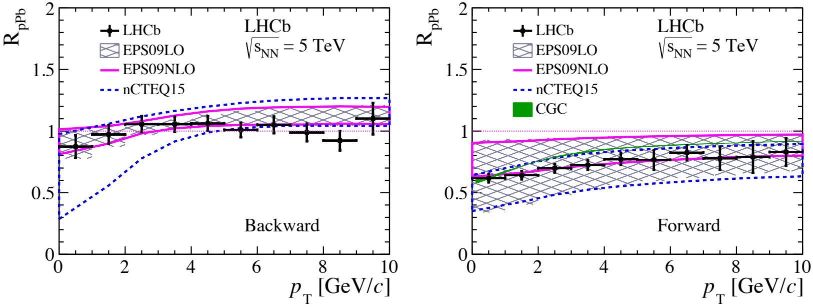
Heavy quark production

Motivation

Recent data from LHCb for D^0 meson production in pPb show clear suppression at forward rapidities

⇒ Constraints for small-x gluons?

[JHEP 1710 (2017) 090]



- D-meson data from pp has potential to constrain small-x gluons in proton [PRL 118 072001, EPJ C75 396]
- Impact of pPb data studied with data-driven method [arXiv:1712.07024]

Theoretical framework

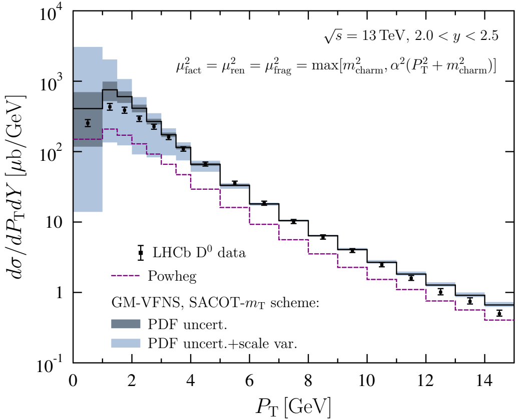
To study the realistic potential of the D-meson data we have set up a NLO calculation based on GM-VFNS

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

- Proton PDFs from NNPDF_NLO_PCH_AS_0118 [EPJ C 77 (2017) 663]
- Heavy meson FFs from KKKS08 [Nucl. Phys. B 799 (2008) 34]
- The NLO coefficient functions behave as in FFNS at low p_T and as zero-mass matrix elements at high-p_T
- Sum over all partonic subprocesses, significant contribution also from $g \to D$ FFs
- $\mu^2_{\text{ren}} = \mu^2_{\text{fact}} = \mu^2_{\text{frag}} = \max(\alpha^2(P_T^2 + m_c^2), m_c^2)$, $\alpha = 0.5, 1, 2$

Comparison to pp data from LHCb

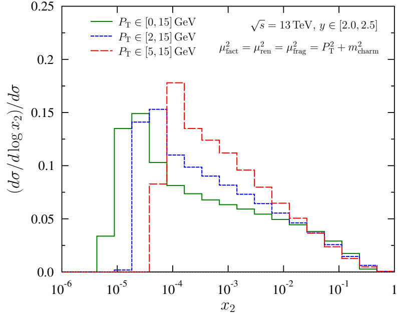
[I. Helenius, H. Paukkunen, *to appear*]



[LHCb: JHEP 1603 (2016) 159, *Erratum* JHEP 1705 (2017) 074]

- Good agreement between GM-VFNS calculation
- Compared also to FFNS calculation using POWHEG+PYTHIA
- Large theory uncertainty at $P_{\rm T} < 4$ GeV

D-meson sensitivity to small-x



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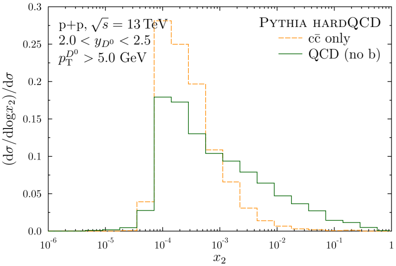
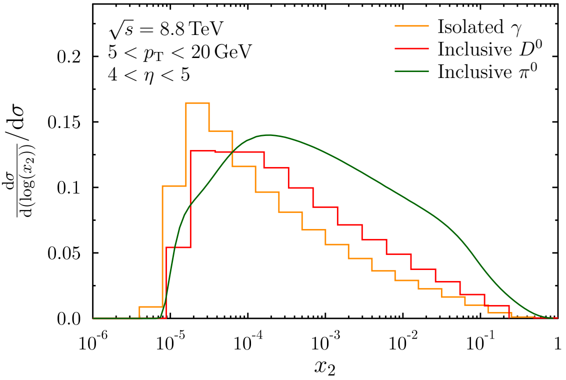


- x_2 peaked at low-x, still contribution from $x > 10^{-2}$
- Similar distribution from PYTHIA 8 when all partonic subprocesses included, including only $c\bar{c}$ channels overestimates the sensitivity to small-x

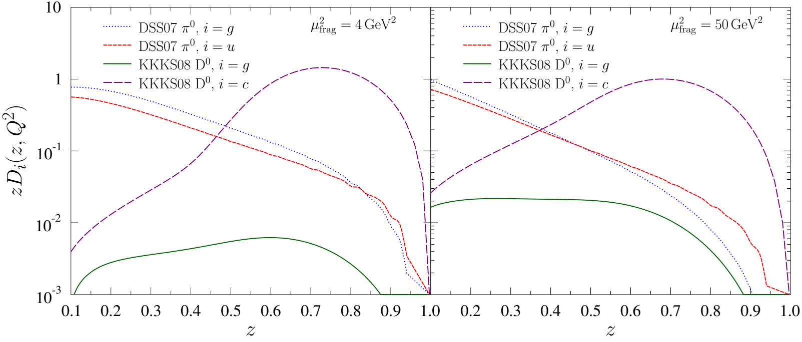
Isolated photons vs. hadrons



- Isolated photons most sensitive to small-*x*
- Heavy-quark mesons have some contribution from large *x* but less than light mesons
- Slight differences in kinematics but comparable

Pions vs. D-mesons

D-meson FFs (KKKS08) compared to pion FFs (DSS07)



- Pion FFs grow towards $z \to 0$
- D-meson FFs peaked around $z \sim 0.6$

  $\Rightarrow$ Provides increased sensitivity to small-x PDFs

Summary

Direct photons

- Isolation cut increases sensitivity to low-x region
- nPDFs uncertainties somewhat underestimated where no data constraints ($x \lesssim 10^{-3}$)
- FoCal pseudodata show potential to constrain low-x nPDFs

D-mesons

- Good description of LHCb pp data with GM-VFNS based NLO calculation
- More sensitivity to small-x region than with light hadrons due to different behaviour of FFs
- Not quite as sensitive as isolated photons and more theoretical uncertainties
- Application to pPb collisions to follow

Backup slides

Direct photons in pPb by ATLAS

[ATLAS-CONF-2017-072]