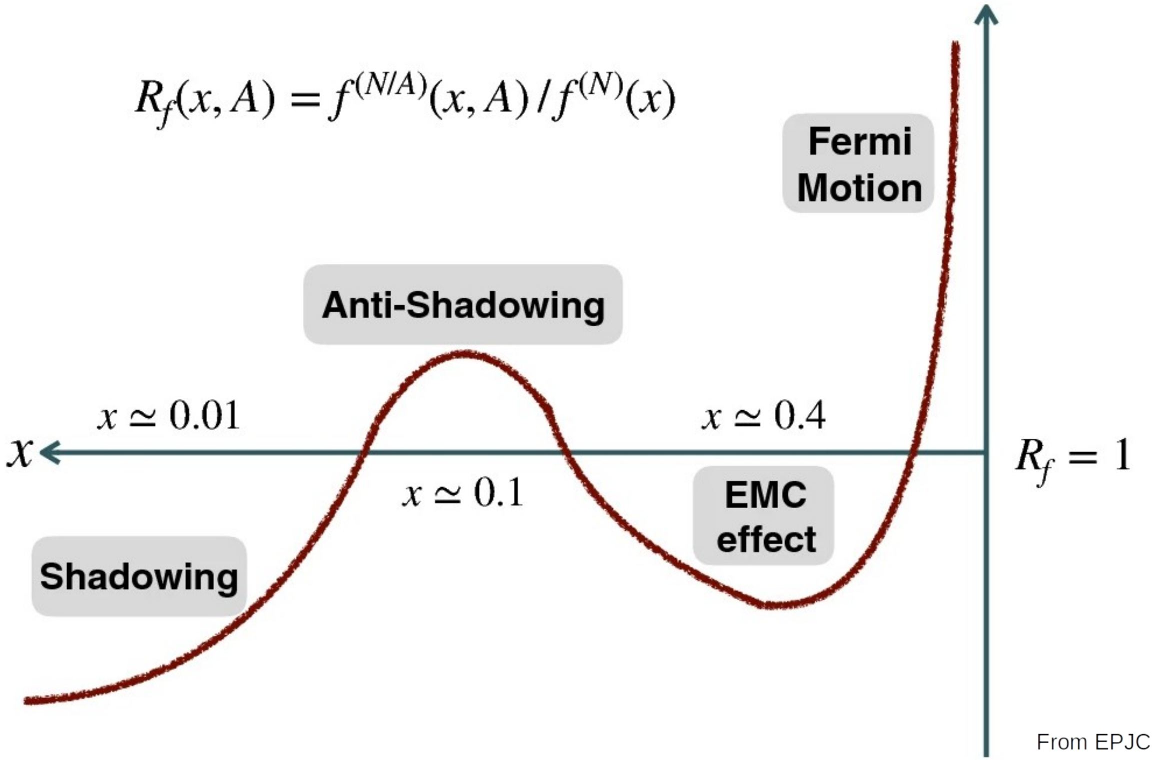
Probing nuclear parton distribution functions with heavy-flavour production (HQ4nPDF)

Jean-Philippe Lansberg and Aleksander Kusina

IFJ PAN - IJCLab Workshop 2024
Kraków, 24 October 2024

Goals of the project

$$R_f(x,A) = f^{(N/A)}(x,A)\,/\,f^{(N)}(x)$$



From EPJC 79 471(2019)

Before our collaboration: French side

Physics Letters B 680 (2009) 50–55

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Cold nuclear matter effects on J/ψ production: Intrinsic and extrinsic transverse momentum effects

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A R T I C L E   I N F O

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A B S T R A C T

Cold nuclear matter effects on J/ψ production in proton–nucleus and nucleus–nucleus collisions are evaluated taking into account the specific J/ψ-production kinematics at the partonic level, the shadowing of the initial parton distributions and the absorption in the nuclear matter. We consider two different parton processes for the $c\bar{c}$-pair production: one with collinear gluons and a recoiling gluon in the final state and the other with initial gluons carrying intrinsic transverse momentum. Our results are compared to RHIC observables. The smaller values of the nuclear modification factor R_{AA} in the forward rapidity region (with respect to the mid rapidity region) are partially explained, therefore potentially reducing the need for recombination effects.

Before our collaboration: Polish side

PHYSICAL REVIEW D **93,** 085037 (2016)

nCTEQ15: Global analysis of nuclear parton distributions with uncertainties in the CTEQ framework

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We present the new nCTEQ15 set of nuclear parton distribution functions (PDFs) with uncertainties. This fit extends the CTEQ proton PDFs to include the nuclear dependence using data on nuclei all the way up to ^{208}Pb. The uncertainties are determined using the Hessian method with an optimal rescaling of the eigenvectors to accurately represent the uncertainties for the chosen tolerance criteria. In addition to the deep inelastic scattering and Drell-Yan processes, we also include inclusive pion production data from the Relativistic Heavy Ion Collider to help constrain the nuclear gluon PDF. Furthermore, we investigate the correlation of the data sets with specific nuclear PDF flavor components and asses the impact of individual experiments. We also provide comparisons of the nCTEQ15 set with recent fits from other groups.

DOI: 10.1103/PhysRevD.93.085037

Methodology (2017)

Abstract We propose a simple and model-independen procedure to account for the impact of the nuclear modi fication of the gluon density as encoded in nuclear collinea PDF sets on two-to-two partonic hard processes in proton-nucleus collisions. This applies to a good approximation t quarkonium, *D* and *B* meson production, generically referre to $\mathcal{H}$. Our procedure consists in parametrising the square o the parton scattering amplitude, $\mathcal{A}_{gg\to\mathcal{H}X}$ and constraining it from the proton–proton data. Doing so, we have been able to compute the corresponding nuclear modification factors for J/ψ, Υ and D^0 as a function of y and P_T at $\sqrt{s_{NN}} = 5$ and 8 TeV in the kinematics of the various LHC experiments in a model independent way. It is of course justified since the most important ingredient in such evaluations is the probability of each kinematical configuration. Our computations for *D* mesons can also be extended to *B* meson production. To further illustrate the potentiality of the tool, we provide – for the first time – predictions for the nuclear modification factor for η_c production in *p*Pb collisions at the LHC.

Eur. Phys. J. C (2017) 77:1
DOI 10.1140/epjc/s10052-016-4575-x

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Special Article - Tools for Experiment and Theory

Towards an automated tool to evaluate the impact of the nuclear modification of the gluon density on quarkonium, *D* and *B* meson production in proton–nucleus collisions

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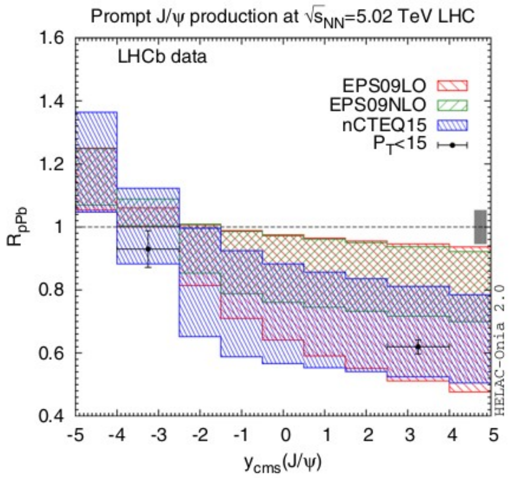

Evidence for gluon shadowing in HF data (2018)

PHYSICAL REVIEW LETTERS **121,** 052004 (2018)

Gluon Shadowing in Heavy-Flavor Production at the LHC

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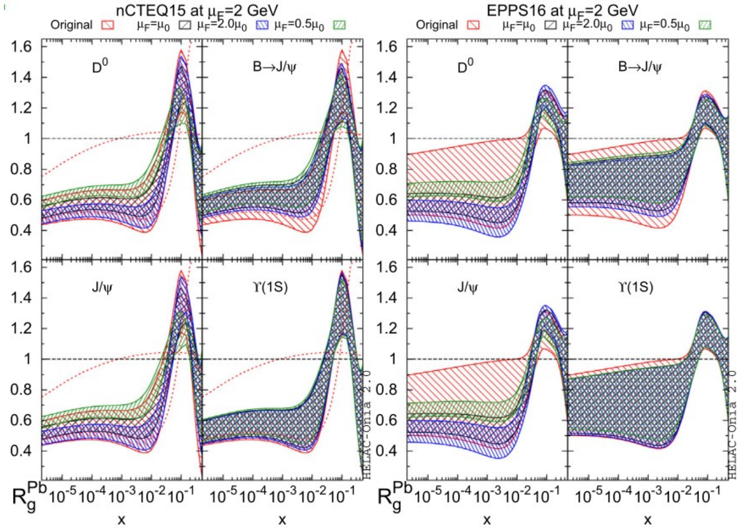
We study the relevance of experimental data on heavy-flavor [D^0, J/ψ, $B \to J/\psi$ and $\Upsilon(1S)$ mesons] production in proton-lead collisions at the LHC to improve our knowledge of the gluon-momentum distribution inside heavy nuclei. We observe that the nuclear effects encoded in both most recent global fits of nuclear parton densities at next-to-leading order (nCTEQ15 and EPPS16) provide a good overall description of the LHC data. We interpret this as a hint that these are the dominant ones. In turn, we perform a Bayesian-reweighting analysis for each particle data sample which shows that each of the existing heavy-quark(onium) data set clearly points—with a minimal statistical significance of 7σ—to a shadowed gluon distribution at small x in the lead. Moreover, our analysis corroborates the existence of gluon antishadowing. Overall, the inclusion of such heavy-flavor data in a global fit would significantly reduce the uncertainty on the gluon density down to $x \simeq 7 \times 10^{-6}$—where no other data exist—while keeping an agreement with the other data of the global fits. Our study accounts for the factorization-scale uncertainties which dominate for the charm(onium) sector.



(e) nCTEQ15 nPDF (f) EPPS16 nPDF

Physics case for the LHC in the FT mode (2020)

Physics Reports 911 (2021) 1–83

Contents lists available at ScienceDirect

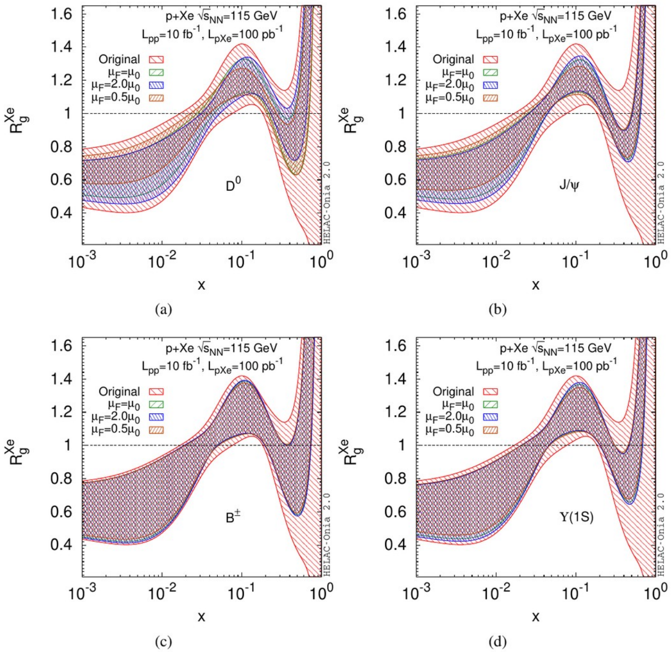
Physics Reports

journal homepage: www.elsevier.com/locate/physrep

ELSEVIER

A fixed-target programme at the LHC: Physics case and projected performances for heavy-ion, hadron, spin and astroparticle studies

C. Hadjidakis [1,a], D. Kikoła [2,a], J.P. Lansberg [1,*,a], L. Massacrier [1,a], M.G. Echevarria [3,4,b], A. Kusina [5,b], I. Schienbein [6,b], J. Seixas [7,8,9,b], H.S. Shao [10,b], A. Signori [11,3,12,b], B. Trzeciak [13,14,b], S.J. Brodsky [15], G. Cavoto [16], C. Da Silva [17], F. Donato [18], E.G. Ferreiro [19,20], I. Hřivnáčová [1], A. Klein [17], A. Kurepin [21], C. Lorcé [22], F. Lyonnet [23], Y. Makdisi [24], S. Porteboeuf Houssais [25], C. Quintans [8], A. Rakotozafindrabe [26], P. Robbe [1], W. Scandale [27], N. Topilskaya [21], A. Uras [28], J. Wagner [29], N. Yamanaka [1,32,30,31], Z. Yang [33], A. Zelenski [24]



Confirmation and diffusion via LHAPDF (2021)

PHYSICAL REVIEW D **104,** 014010 (2021)

Reweighted nuclear PDFs using heavy-flavor production data at the LHC

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We present the reweighting of two sets of nuclear parton distribution functions (PDFs), nCTEQ15 and EPPS16, using a selection of experimental data on heavy-flavor meson [D^0, J/ψ, $B \to J/\psi$ and $\Upsilon(1S)$] production in proton-lead collisions at the LHC which were not used in the original determination of these nuclear PDFs. The reweighted PDFs exhibit significantly smaller uncertainties thanks to these new heavy-flavor constraints. We present a comparison with another selection of data from the LHC and relativistic heavy ion collider (RHIC) which were not included in our reweighting procedure. The comparison is overall very good and serves as a validation of these reweighted nuclear PDF sets, which we dub $\text{nCTEQ15}_{\text{rwHF}}$ and $\text{EPPS16}_{\text{rwHF}}$. This indicates that the LHC and forward RHIC heavy-flavor data can be described within the standard collinear factorization framework with the same (universal) small-x gluon distribution. We discuss how we believe such reweighted PDFs should be used as well as the limitations of our procedure.

nCTEQ adopts our methodology for quarkonia (2022)

PHYSICAL REVIEW D **105,** 114043 (2022)

Impact of heavy quark and quarkonium data on nuclear gluon PDFs

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A clear understanding of nuclear parton distribution functions (nPDFs) plays a crucial role in the interpretation of collider data taken at the Relativistic Heavy Ion Collider, the Large Hadron Collider (LHC), and in the near future at the Electron-Ion Collider. Even with the recent inclusions of vector boson and light meson production data, the uncertainty of the gluon PDF remains substantial and limits the interpretation of heavy ion collision data. To obtain new constraints on the nuclear gluon PDF, we extend our recent nCTEQ15WZ + SIH analysis to inclusive quarkonium and open heavy-flavor meson production data from the LHC. This vast new data set covers a wide kinematic range and puts strong constraints on the nuclear gluon PDF down to $x \lesssim 10^{-5}$. The theoretical predictions for these data sets are obtained from a data-driven approach, where proton-proton data are used to determine effective scattering matrix elements. This approach is validated with detailed comparisons to existing next-to-leading order calculations in nonrelativistic QCD for quarkonia and in the general-mass variable-flavor-number scheme for the open heavy-flavored mesons. In addition, the uncertainties from the data-driven approach are determined using the Hessian method and accounted for in the PDF fits. This extension of our previous analyses represents an important step toward the next generation of PDFs not only by including new data sets, but also by exploring new methods for future analyses.

DOI: 10.1103/PhysRevD.105.114043

SRC and nPDF (2023/24)

PHYSICAL REVIEW LETTERS **133,** 152502 (2024)

Modification of Quark-Gluon Distributions in Nuclei by Correlated Nucleon Pairs

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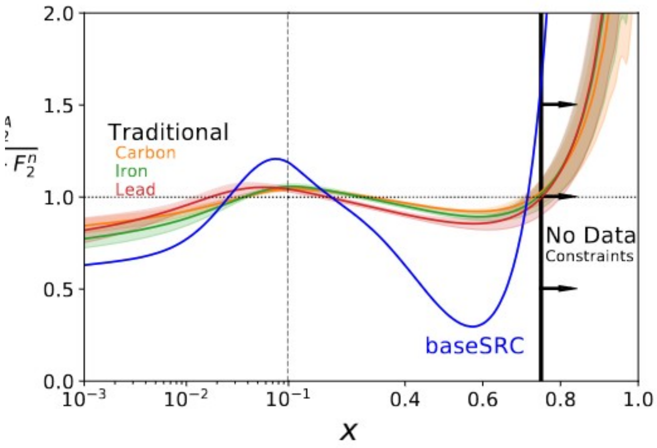
We extend the QCD Parton Model analysis using a factorized nuclear structure model incorporating individual nucleons and pairs of correlated nucleons. Our analysis of high-energy data from lepton deep-inelastic scattering, Drell-Yan, and W and Z boson production simultaneously extracts the universal effective distribution of quarks and gluons inside correlated nucleon pairs, and their nucleus-specific fractions. Such successful extraction of these universal distributions marks a significant advance in our understanding of nuclear structure properties connecting nucleon- and parton-level quantities.

DOI: 10.1103/PhysRevLett.133.152502



Plan for Co-PhD

- **1.5 years** in **IJCLab** and **1.5 years** in **IFJ PAN**
- Geometry of the nPDFs and connection with SRC
- Constraints from exclusive quarkonium production and on meson PDFs
- Dissemination via the EU VA NLOAccess and preparation for the future of Strong 2020 as an EU INFRASERV

In October Dimitrios Daskalas started as the first joined PhD between IFJ PAN and IJCLab

- Travel money for visits between IJCLab & IFJ PAN expected from the COPIN-IN2P3 agreement #12-147:
  - to be seen?
  - is there possibility for money directly from the IFJ PAN - IJCLab collaboration?

Plan for Co-PhD

Year 1-2 @ IJCLab

- Study the literature on PDFs and nPDFs;
- Study the literature on SRC and EMC;
- Study the impact-parameter dependence of nPDFs (using the set up developed by H.S. Shao based on HELAC-Onia and the centrality-dependent data of the LHC (ALICE) and RHIC (PHENIX));
- Propose a realistic model of b-dependent gluon densities and confront it with data;

Year 2-3 @ IFJ PAN

- Study the literature on meson PDFs;
- Perform a reweighting study of π PDFs for different nPDFs from πA data;
- Revisit the prospects to measure gluon nPDF via exclusive quarkonium data on Pb;
- Revisit the prospects to measure π and K PDF via meson-induced quarkonium data;
- PhD writing

Possible Future projects

- proposal: **MARIE Skłodowska-CURIE ACTIONS Doctoral Networks**
  (Call: HORIZON-MSCA-2024-DN-01-01)
  - Joint Doctoral Network proposal on Heavy Quark physics:
    Unravelling Partonic Structure of Matter using Heavy Quarks
  - incl. UP Saclay (FR), IFJ (PL), WUT (PL), NCBJ (PL), UCD (IE), UG (NL), LU (UK), USC (SP), UCA (IT), CTU (CZ)