Modeling the Impact Parameter Dependence of the nPDFs With EKS98 and EPS09 Global Fits

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Introduction

Collinear factorization framework: Number of hard processes at impact parameter $\mathbf{b}$ in A+B collision from

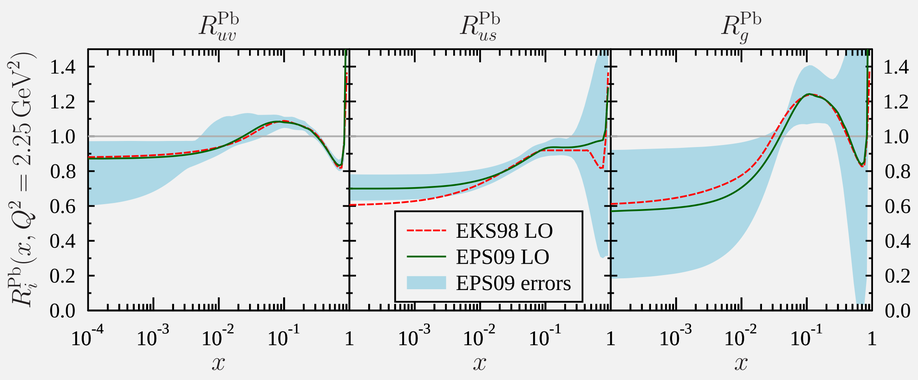
$$\mathrm{d}N^{AB\to k+X}(\mathbf{b}) = T_{AB}(\mathbf{b}) \sum_{i,j,X'} f_i^A(x,Q^2) \otimes f_j^B(x,Q^2) \otimes \mathrm{d}\hat{\sigma}^{ij\to k+X'},$$

- $\mathrm{d}\hat{\sigma}^{ij\to k+X'}$ are the partonic pieces calculable from pQCD.
- $f_i^A(x,Q^2)$ are the universal nuclear parton distribution functions (nPDFs), determined via global analysis, defined in terms of the free proton PDFs:

$$f_i^A(x,Q^2) = R_i^A(x,Q^2) \cdot f_i^N(x,Q^2)$$

Here we consider two sets of globally analysed $R_i^A(x,Q^2)$:

- EKS98 (LO DGLAP evolution) [1]
- EPS09 (LO and NLO + error sets) [2]



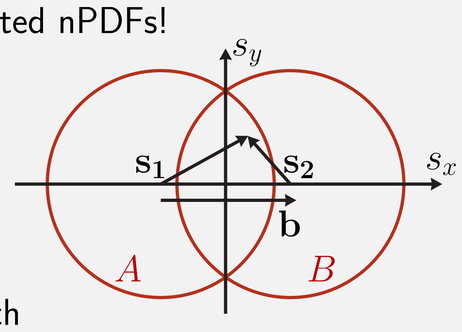
So far, no spatial dependence in the globally fitted nPDFs!

- $T_{AB}(\mathbf{b})$ is the nuclear overlap function

$$T_{AB}(\mathbf{b}) = \int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s}_1) T_B(\mathbf{s}_2),$$

where $\mathbf{s}_1 = \mathbf{s} + \mathbf{b}/2$, $\mathbf{s}_2 = \mathbf{s} - \mathbf{b}/2$ and for the thickness function $T_A(\mathbf{s})$ we use Woods-Saxon density distribution

$$T_A(\mathbf{s}) = \int_{-\infty}^{\infty} \mathrm{d}z \frac{n_0}{1+\exp[\frac{\sqrt{\mathbf{s}^2+z^2}-R_A}{d}]}$$



with

- $d = 0.54$ fm
- $R_A = 1.12A^{1/3} - 0.86A^{-1/3}$ fm
- $n_0 = \frac{3}{4}\frac{A}{\pi R_A^3}\frac{1}{(1+(\frac{\pi d}{R_A})^2)}$
- $A = \int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s})$

Framework

- We introduce a spatially dependent nuclear modification of the PDFs [3],

$$R_i^A(x,Q^2) \to r_i^A(x,Q^2,\mathbf{s}),$$

defined as

$$R_i^A(x,Q^2) \equiv \frac{1}{A}\int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s})\, r_i^A(x,Q^2,\mathbf{s}),$$

where $R_i^A(x,Q^2)$ is taken from EKS98 or EPS09 global analyses.

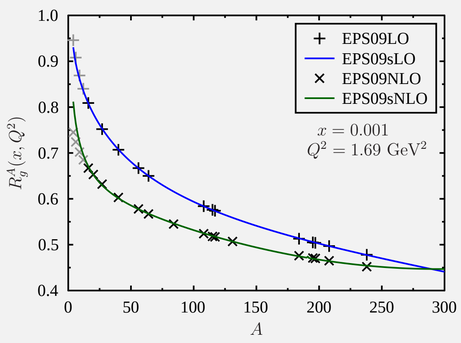
- Assumption: the spatial dependence is related to $T_A(\mathbf{s})$ as follows:

$$r_i^A(x,Q^2,\mathbf{s}) = 1 + \sum_{j=1}^{n} c_j^i(x,Q^2)\,[T_A(\mathbf{s})]^j$$

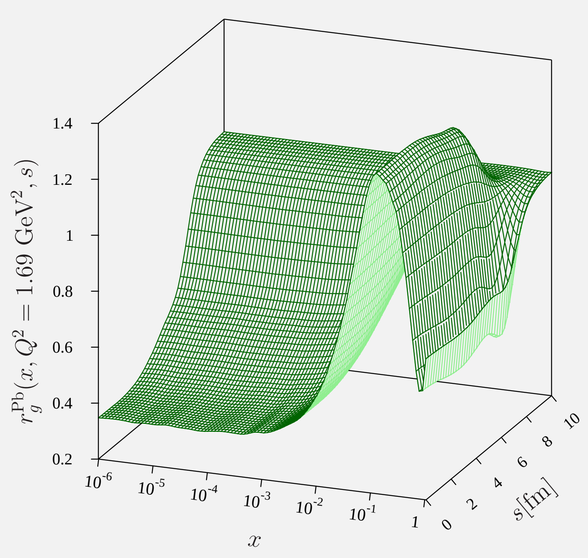
- No A-dependence in the fit parameters $c_j^i(x,Q^2)$
  $\Rightarrow$ Values for the fit parameters over a (x,Q^2)-grid can be obtained by fitting to the A-dependence of the globally fitted $R_i^A(x,Q^2)$, i.e. by minimizing the χ^2 defined as

$$\chi_i^2(x,Q^2) = \sum_A \left[\frac{R_i^A(x,Q^2) - \frac{1}{A}\int \mathrm{d}^2\mathbf{s}\, T_A(\mathbf{s}) r_i^A(x,Q^2,\mathbf{s})}{W_i^A(x,Q^2)}\right]^2$$

- A-dependence of $R_i^A(x,Q^2)$ is well reproduced with $n = 4$:



- Fitting is done also for the error sets of EPS09, both LO and NLO.



$\Rightarrow$Outcome: Spatially dependent nPDF sets EPS09s and EKS98s, now available†!

- Stronger nuclear effects in the center of the nucleus than at the edges

†https://www.jyu.fi/fysiikka/en/research/highenergy/urhic/nPDFs

Applications

- Observable: Nuclear Modification Factor

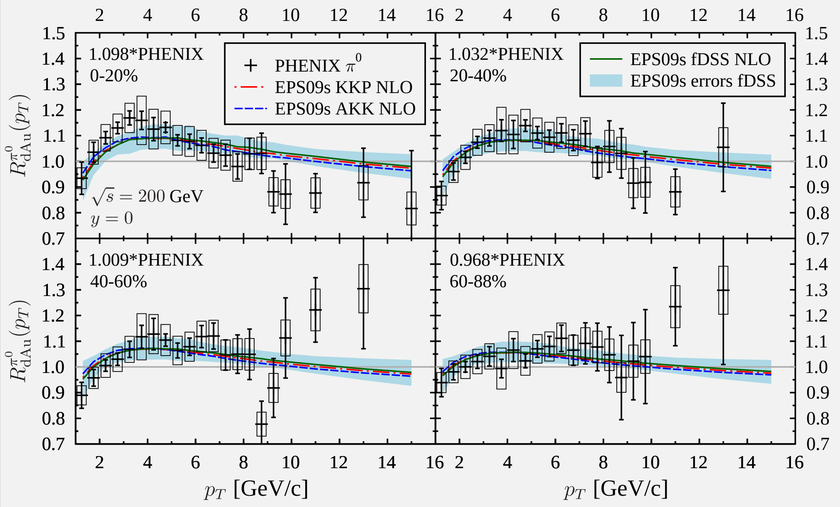
$$R_{AB}^k(b_1,b_2) = \frac{\left\langle \frac{\mathrm{d}^2N_{AB}^k}{\mathrm{d}p_T\mathrm{d}y}\right\rangle_{b_1,b_2}}{\frac{\langle N_{bin}\rangle_{b_1,b_2}}{\sigma_{inel}^{NN}}\frac{\mathrm{d}^2\sigma_{pp}^k}{\mathrm{d}p_T\mathrm{d}y}} = \frac{\int_{b_1}^{b_2}\mathrm{d}^2\mathbf{b}\frac{\mathrm{d}^2N_{AB}^k(\mathbf{b})}{\mathrm{d}p_T\mathrm{d}y}}{\int_{b_1}^{b_2}\mathrm{d}^2\mathbf{b}\, T_{AB}(\mathbf{b})\frac{\mathrm{d}^2\sigma_{pp}^k}{\mathrm{d}p_T\mathrm{d}y}}$$

  Centrality classes b_1, b_2 and $\langle N_{bin}\rangle_{b_1,b_2}$ from optical Glauber model
- Implementation of the new nPDFs (most straightforward)

$$\mathrm{d}N_{AB}^k(\mathbf{b}) = \sum_{n,m}\int \mathrm{d}^2\mathbf{s}\,[T_A(\mathbf{s_1})]^{n+1}\,[T_B(\mathbf{s_2})]^{m+1}\sum_{i,j} c_i^n\, f_i^N \otimes c_j^m\, f_j^N \otimes \mathrm{d}\hat{\sigma}^{ij\to k+X}$$

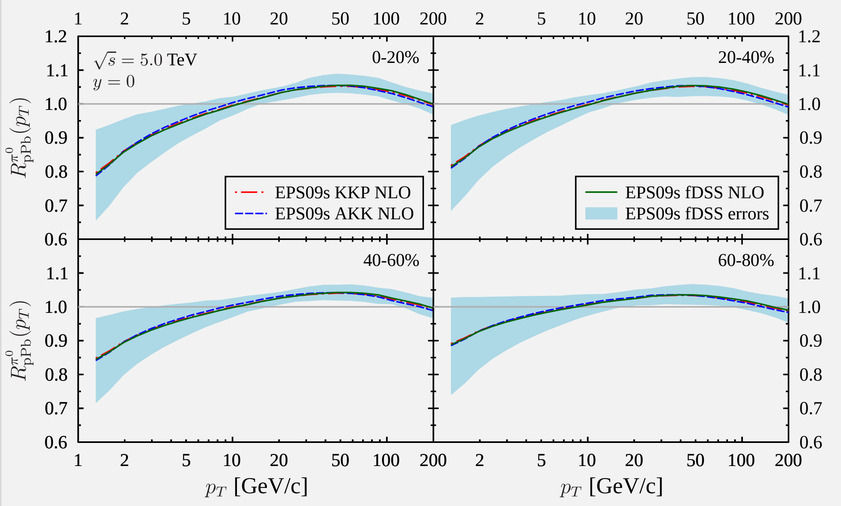
  Geometric and momentum integrals can be done separately
  $\Rightarrow$ No need to recode old computations, just replace $R_i^A(x,Q^2)$ with $c_i^n(x,Q^2)$.
- Below: Numerical NLO calculations are done using the `INCNLO`-package [4]. The error bands are calculated using the error sets of EPS09s.

1. Neutral pion production in d+Au collisions at RHIC at midrapidity



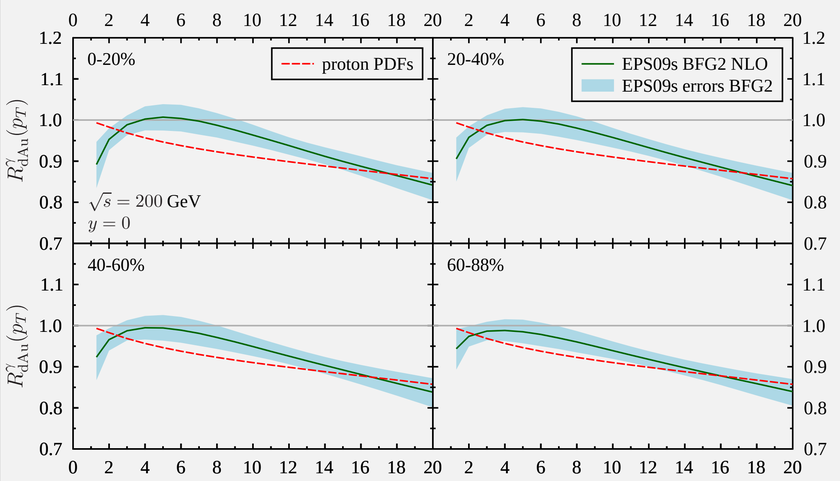
- Data points multiplied by a factor which is within the total experimental overall normalization uncertainties [5]
- Good agreement with the data in all centrality classes
- Difference due to different fragmentation functions is small

2. Neutral pion production in p+Pb collisions at LHC at midrapidity



- More shadowing in the low p_T region than at RHIC due to larger $\sqrt{s_{NN}}$
- Small enhancement around $p_T \sim 50$ GeV/c
- Nuclear effects decrease when going from central to more peripheral collisions

3. Inclusive photon production in d+Au collisions at RHIC at midrapidity



- Preliminary results [6]
- Two components:
  - Direct photons
  - Fragmentation photons
- Isospin effect:
  - Also neutrons in nuclei

  $\Rightarrow$ Less charge to couple with
  $\Rightarrow$ R_{dAu} not normalized to unity!

Summary

- We have determined and published new spatially dependent nPDF sets EPS09s and EKS98s based on
  - A-dependence of the globally fitted nPDFs (EPS09 and EKS98)
  - Power series ansatz in $T_A(\mathbf{s})$
- We have calculated R_{dAu} for neutral pion and inclusive photon production at RHIC and R_{pPb} for neutral pion production at LHC in different centrality classes.

References

[1] K. J. Eskola, V. J. Kolhinen and C. A. Salgado, *Eur. Phys. J.* C9 (1999) 61-68
[2] K. J. Eskola, H. Paukkunen and C. A. Salgado, *JHEP* 0904 (2009) 065
[3] I. Helenius, K. J. Eskola, H. Honkanen and C. A. Salgado, *JHEP* 1207 (2012) 073
[4] `http://lapth.in2p3.fr/PHOX_FAMILY/readme_inc.html`
[5] PHENIX Collaboration *Phys. Rev. Lett. 98 (2007) 172302*
[6] I. Helenius and K. J. Eskola, *Work in progress*

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