Coherent processes on light nuclei at the EIC

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in collaboration with

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Istituto Nazionale di Fisica Nucleare

STRONG 2020

Outline

1. Coherent processes from Ultraperipheral Collisions (UPC) @ LHC to the EIC: from shadowing effects on nuclear gluon PDFs (t = 0) to shadowing effects on gluon GPDs and 3D-imaging of gluons in nuclei

2. Role of light ion beams at the EIC

3. Results for coherent J/Ψ production on ^{3}He, ^{4}He using realistic treatments: counting the active nucleons selecting the kinematics
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4. Conclusions

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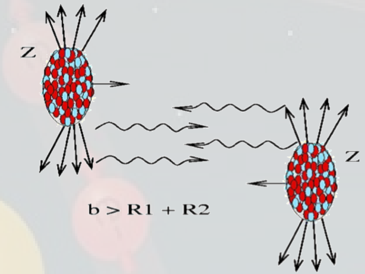
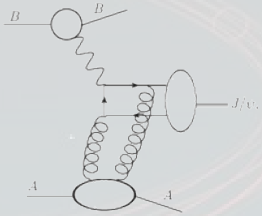
Gluon shadowing in UPC collisions @ LHC

- Large (up to 40%) Leading twist (LT) shadowing in:
  $\gamma + \mathrm{Pb/Au} \rightarrow \rho(\mathrm{J}/\Psi) + \mathrm{Pb/Au}$ Explained/predicted
  (**Frankfurt, Guzey, Strikman Phys. Rep. 512 (2012) 255**)





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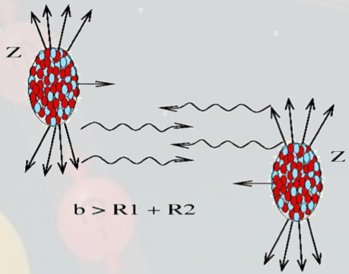

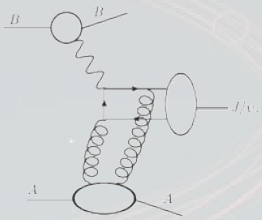

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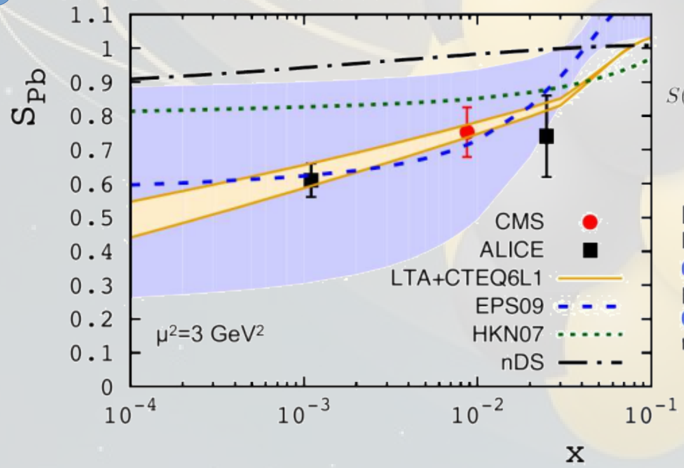
- Abbas *et al.* [ALICE], EPJ C 73 (2013) 2617; CMS Collab., PLB 772 (2017) 489 → suppression factor S_{Pb}



$$S(W_{\gamma p}) = \left[\frac{\sigma_{\gamma Pb \to J/\psi Pb}}{\sigma^{IA}_{\gamma Pb \to J/\psi Pb}}\right]^{1/2} = \kappa_{A/N} \frac{G_A(x,\mu^2)}{A G_N(x,\mu^2)}$$

LTA: Guzey, Zhalov JHEP 1310 (2013) 207
EPS09: Eskola, Paukkunen, Salgado, JHEP 0904 (2009) 065
HKN07: Hirai, Kumano, Nagai, PRC 76 (2007) 065207
nDS: de Florian, Sassot, PRD 69 (2004) 074028

Learning from light nuclei - I

- Problem:
@ EIC/LHC it is challenging to measure coherent scattering at $t \neq 0$ for $A \simeq 200$; Large coherence length: information on interactions with many nucleons, in average

- Solution:
use the lightest nuclei, especially ^3He and ^4He, to study coherent effects for interactions with exactly 2 nucleons in the range of $0 < -t < 0.5$ GeV2 .

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Complementary measurements with light ion beams @ the EIC:

- Scattering off 2 and 3 nucleons can be separately probed

- no excited states -> easy to select coherent events

Here:

- Results on J/Ψ diffractive electro-production off ^{3}He – ^{4}He
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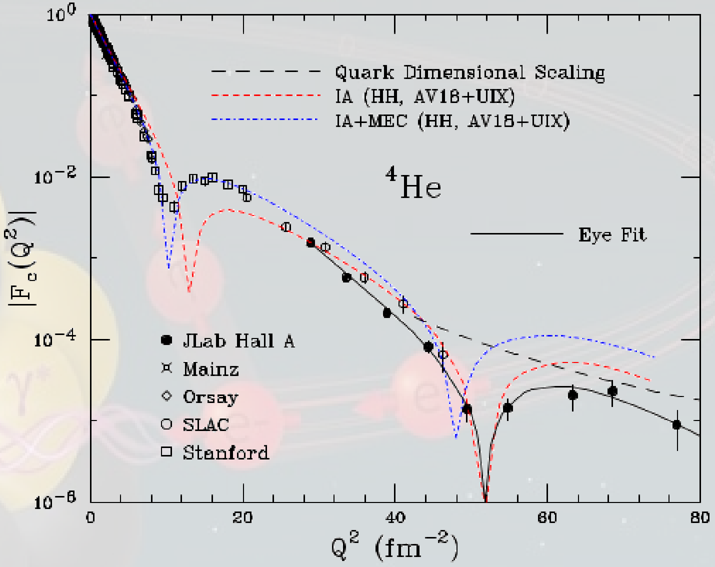
Learning from light nuclei - II

- State of the art of realistic calculations (exact solutions of the Schrödinger equation with realistic potentials).
  Example:
  ^{4}He ff (JLab data from Camsonne et al. PRL 119 (2017) ; HH calculation by M. Viviani, INFN Pisa).



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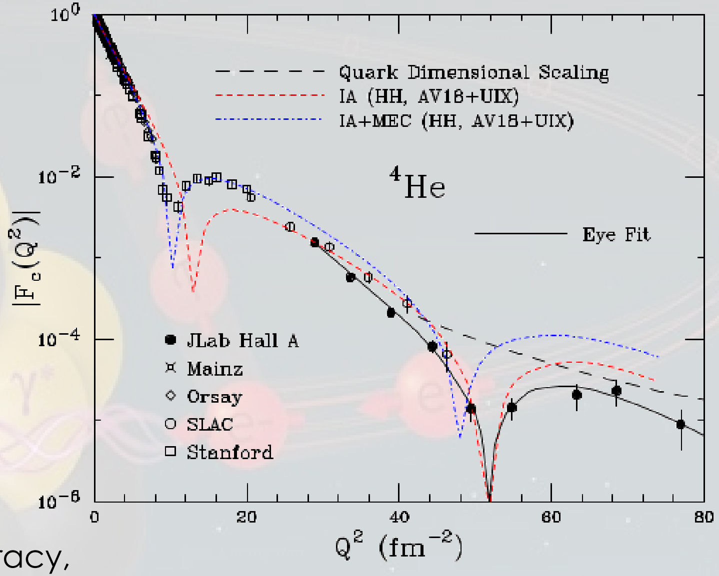
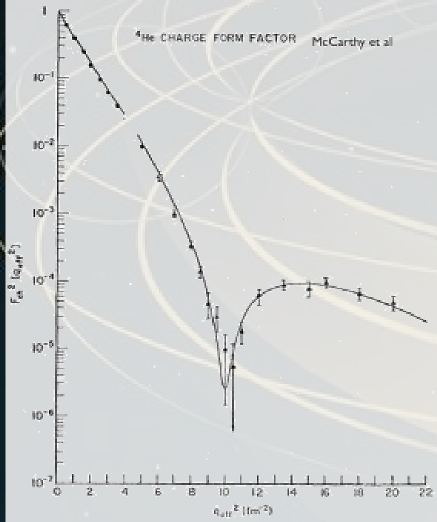


- *n-body* " form factors" can be evaluated with great accuracy, in particular IA (1-body), very important in our project

- predictions can be tested at $x_B \simeq 0.05$ for the 1-body sector, which should dominate in a broad range of t

An old Idea (Levin and Strikman 1975)



- ^{4}He charge FF, dominated by one-body dynamics (IA) presents the first diffraction minimum at: $-t \simeq 0.4$ GeV^2

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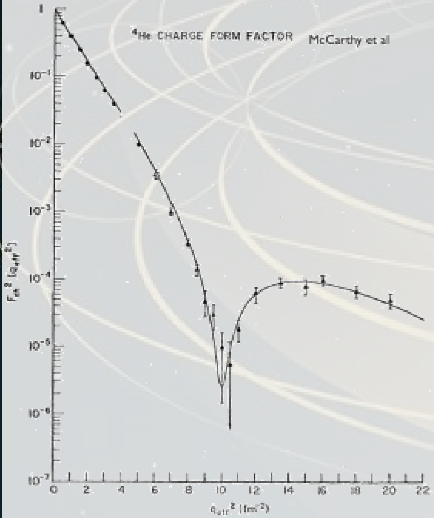

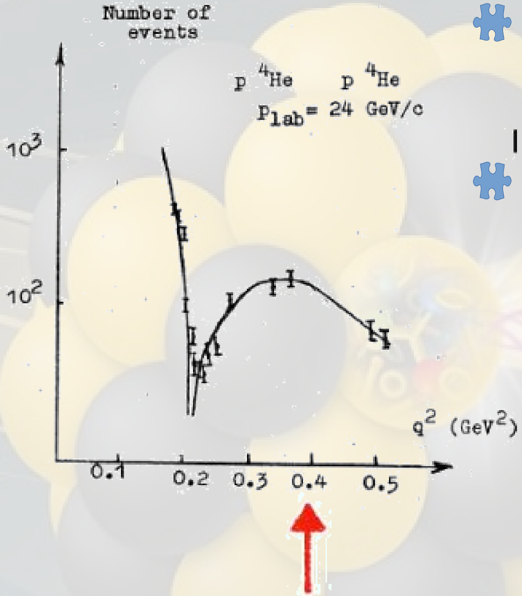

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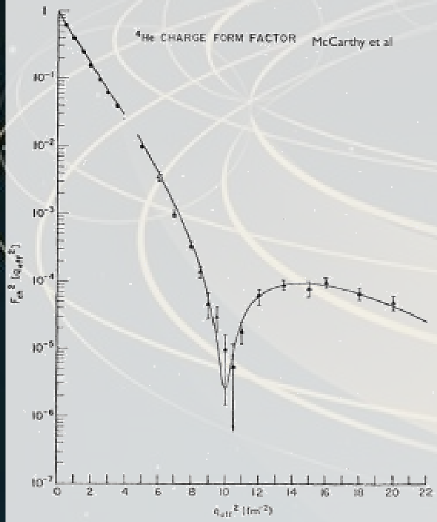

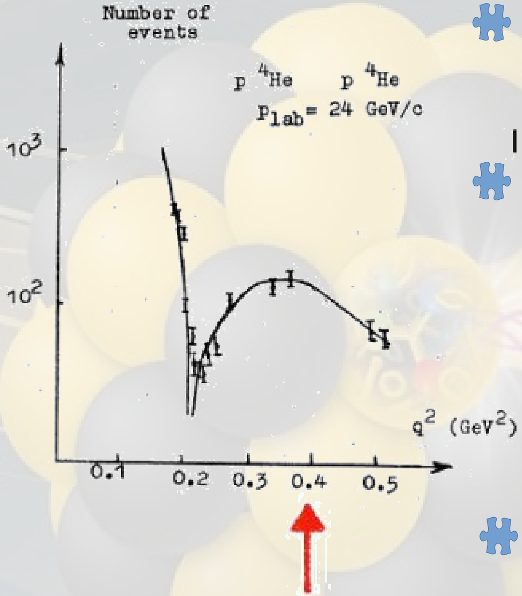

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- We study diffractive VM production to expose gluon shadowing at the EIC ($t \neq 0$).

The cross-section for J/Ψ exclusive production @EIC

LT parton shadowing for J/Ψ coherent production off He (gluon GPDs in He)
(**Frankfurt, Guzey, Strikman Phys. Rep. 512 (2012) 255**)

$$\frac{d\sigma_{\gamma^* A\to VA}}{dt} = \frac{d\sigma_{\gamma^* N\to VN}}{dt}(t=0)\left|F_1(t)e^{(B_o/2)t} + \sum_{k=2}^{4} F_k(t)\right|^2$$

$$F_k(q) = \left(\frac{i}{8\pi^2}\right)^{k-1} C_n^k\, A_k \int \prod_{l=1}^{k} d^2q_l\, f(q_l)\Phi_k(q,q_l)\,\delta\left(\sum_l q_l - q\right) \quad k=2,3,4$$

$$F_1(q) = 4\Phi_1(q) \qquad f(q_l) = scattering\ amplitude\ for\ J/\Psi N \to J/\Psi N$$

$$A_{k>1} = \frac{<\sigma^k>}{<\sigma>}\frac{(1-i\eta)^k}{1-i\eta_0};\ the\ \ same\ used\ in\ UPC\ studies!$$

Parameters:

- B_0
- η (η_0)=$Re(f)/Im(f)$ for $\gamma p \to J/\psi p$ ($J/\psi p \to J/\psi p$)
- moments $<\sigma^i>$ chosen for the specific final state and the specific kinematics **(Guzey et al. PRC 93 (2016) 055206).**

The model has been tested in J/Ψ photoproduction in Pb-Pb UPCs at the LHC(**V. Guzey and M. Zhalov, JHEP 10, 207 (2013)**)

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- Φ_k "k-body form factor", is the nuclear input

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Nuclear Physics input

$$\Phi_k(\vec{q}_1,\dots\vec{q}_k) = \int \prod_{i=N}^{4} \left\{ \frac{d\vec{p}_i}{(2\pi)^3} \right\} \psi^*_{P'}(\vec{p}_1+\vec{q}_1,\dots\vec{p}_k+\vec{q}_k,\dots,\vec{p}_N) \underbrace{\psi_P(\vec{p}_1,\dots,\vec{p}_k,\dots\vec{p}_N)}_{\text{Nuclear w.f.}} \delta\left(\sum_{i=1}^{N}\vec{p}_i\right)$$

- Φ_1 (IA, very important here), Φ_2 and Φ_3 evaluated using the realistic w. f. obtained by the Pisa group using: *a)* Av18 for ^{3}He *b)* the N4LO chiral potential (D. R. Entem, R. Machleidt, Y. Nosyk, Phys. Rev. C 96, 024004 (2017)) for ^{4}He

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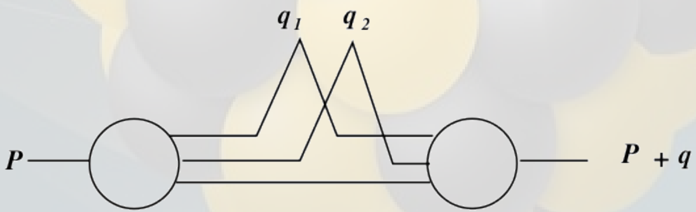
- Example of Φ_2 :



Results for J/Ψ exclusive production @EIC: $x_B \approx 10^{-3}$

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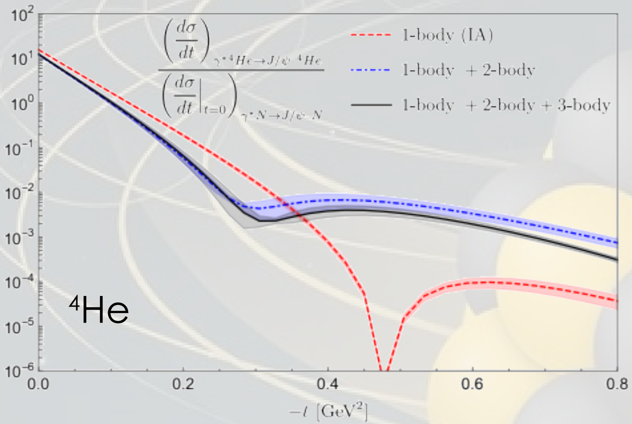

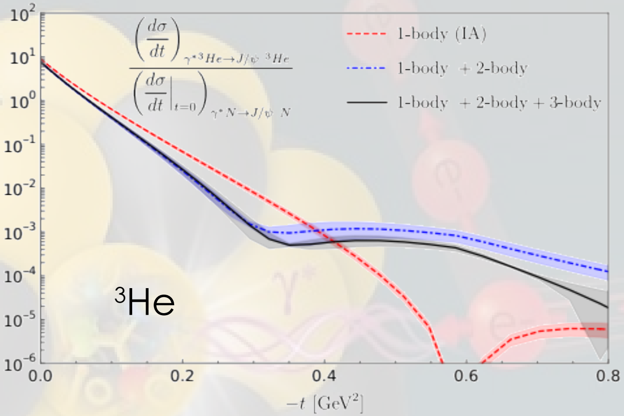

Error bars account:

-10% of variation for B_0

-15 of variation in $< \sigma^2 >$

- ✔ 1-body + 2-body re-scatterings dominate the cross-sections shift of the minimum due to 2-body dynamics
- ✔ 1-body dynamics under theoretical control: very good chances to disentangle
- ✔ 2-body dynamics (LT gluon shadowing)
- ✔ unique opportunity to access the real part of the scattering amplitudes in a wide range of t
- ✔ The position of the minimum is extremely sensitive to dynamics and the structure!

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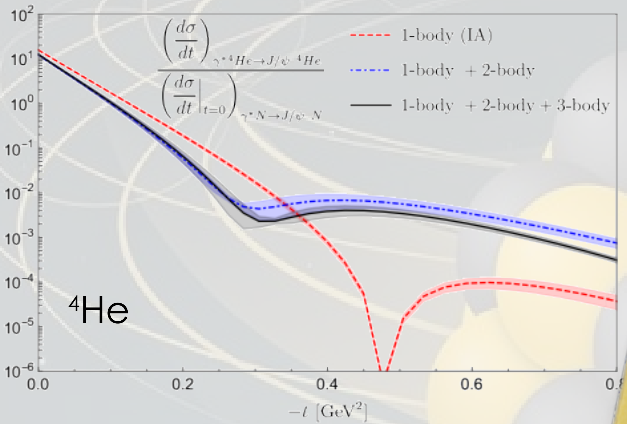

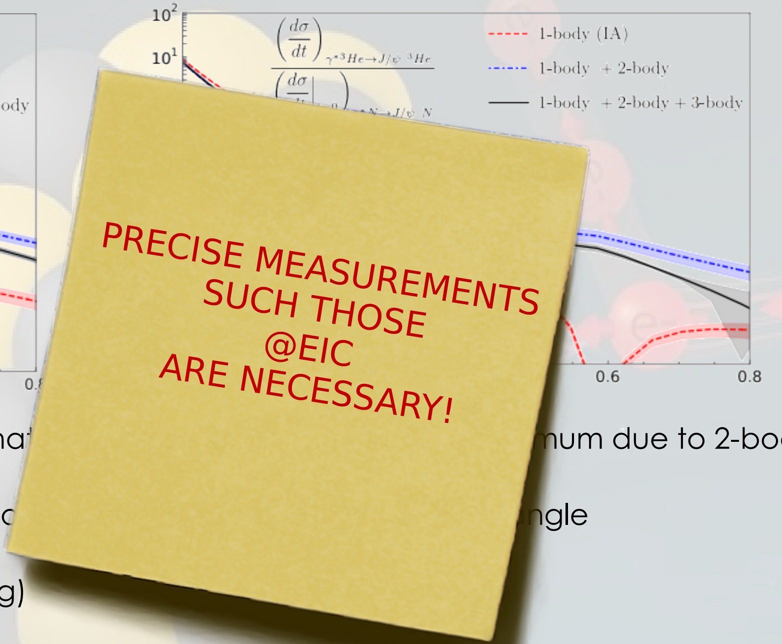

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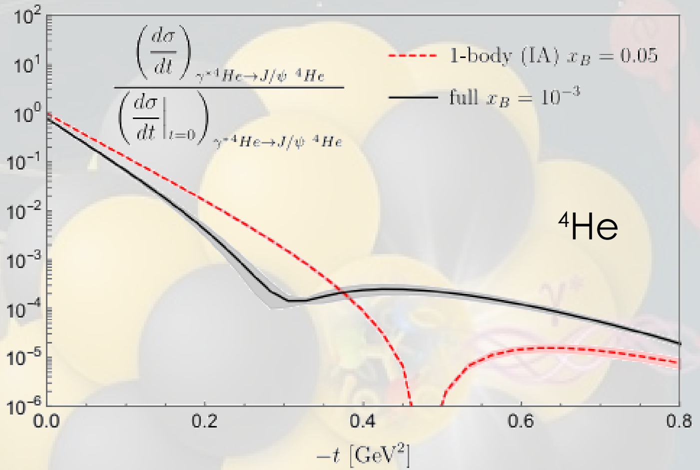

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- ✔ x_B-evolution of the t-dependence predicted in **Frankfurt, Strikman, Weiss PRD 83 (2011) 054012** , considering HERA data: possible check of the model at the EIC
- ✔ 1-body dominates the cross-section at $x_B \simeq 0.05$; no shadowing at $t = 0$
- ✔ possible interpretation: at low x_B , significant broadening in the impact parameter space of the nuclear gluon distribution (see Guzey, Strikman, Zhalov PRC 95 (2017) 2,025204 for heavy nuclei)

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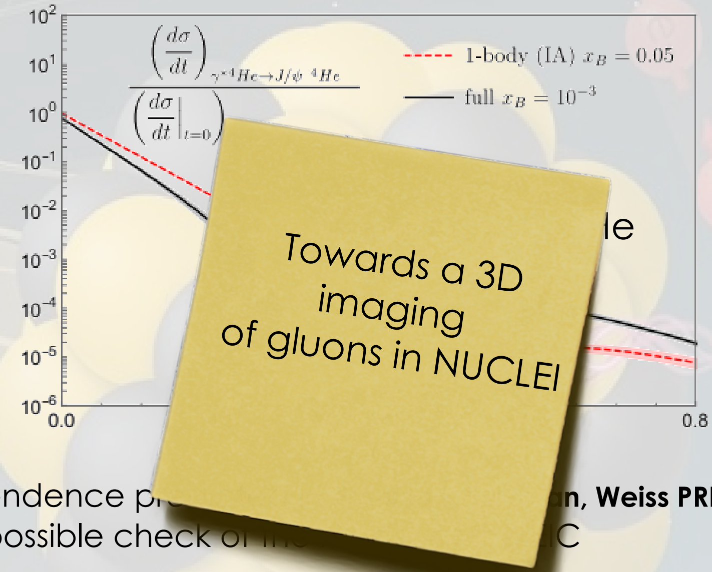

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CONCLUSIONS

Dynamics of small and large configurations: one of the EIC objectives

Leading-twist gluon shadowing for heavy nuclei:

- ✔ predicted for both DIS and coherent heavy meson (e.g. J/Ψ) production
- ✔ tested in UPC @ the LHC
- ✔ @ the EIC, expected stringent tests, together with the study of gluon pdfs

Complementary measurements with light ion beams @ the EIC:

- ✔ Scattering off 2 and 3 nucleons can be separately probed
- ✔ Successfully tested in J/Ψ diffractive electro-production off ^{3}He and ^{4}He @ EIC kinematics

What's next:

? Other final states: ρ

? DVCS…

? Double parton Scattering