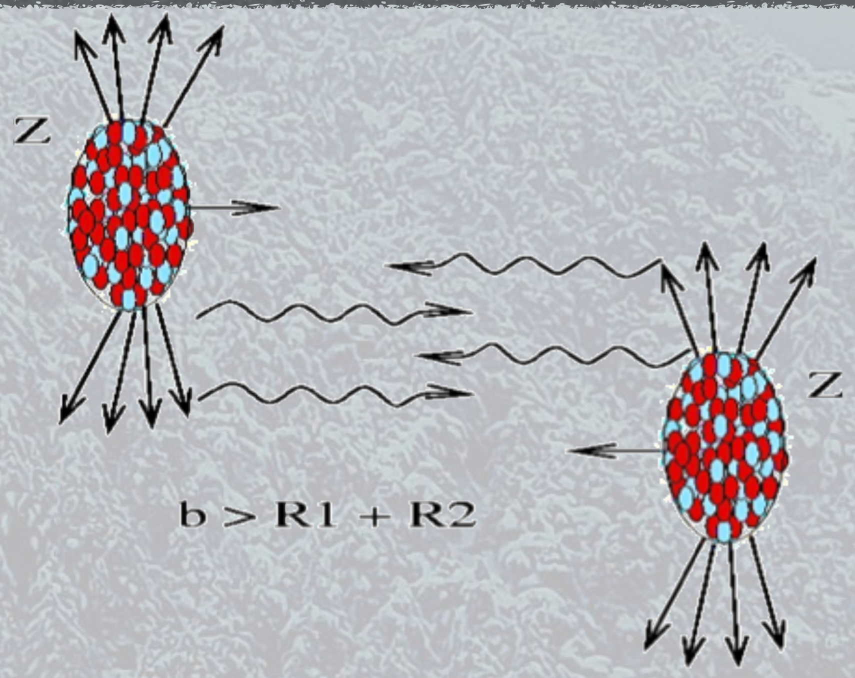
J/ψ electroproduction on light-nuclei at the EIC

Matteo Rinaldi

INFN sezione di Perugia

J/ψ electroproduction on light-nuclei

Gluon shadowing in UPC collisions @ LHC

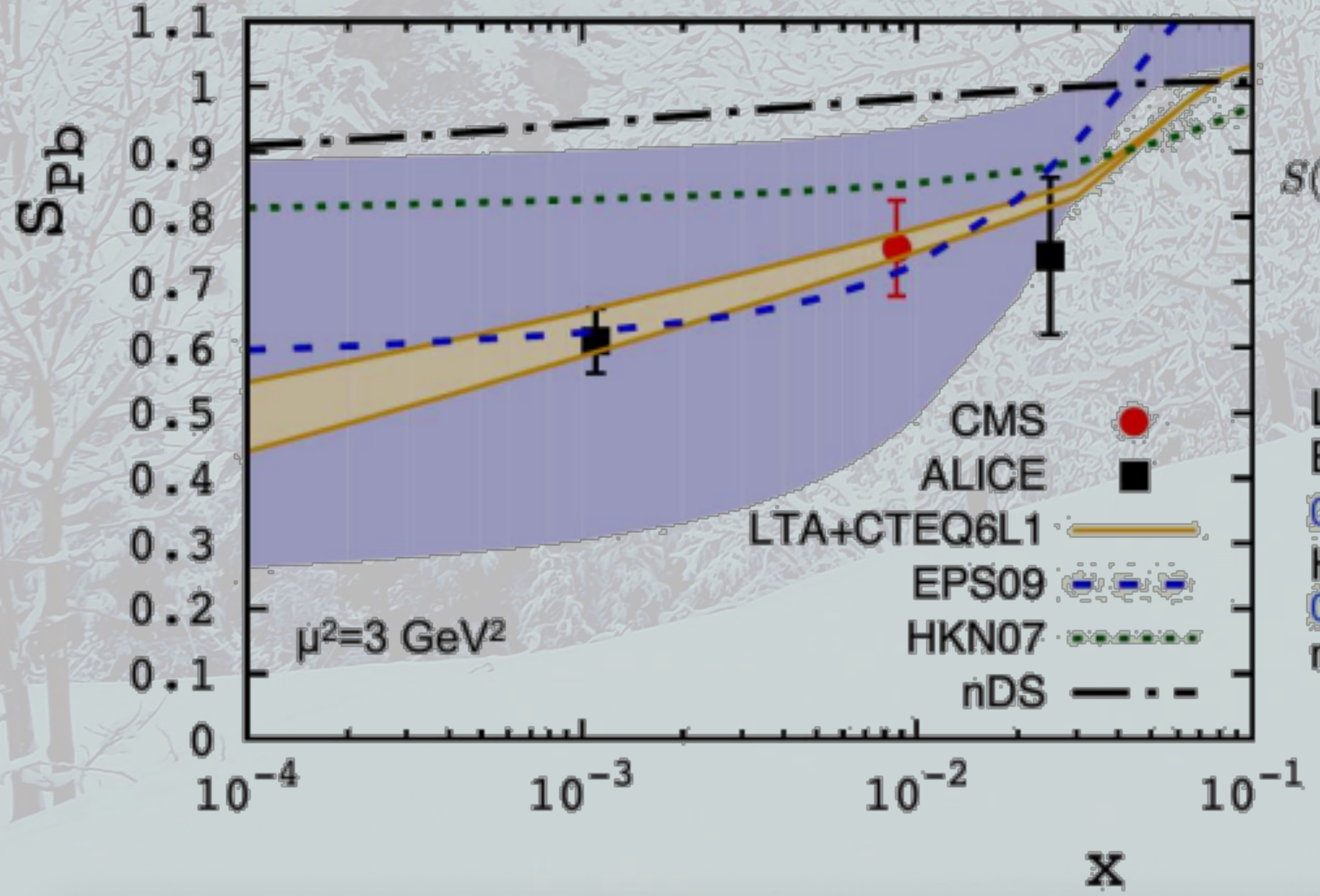


Large (up to 40%) Leading twist (LT) shadowing in:

$\gamma + \mathrm{Pb/Au} \to \rho(\mathrm{J}/\Psi) + \mathrm{Pb/Au}$ Explained/predicted

(**Frankfurt, Guzey, Strikman Phys. Rep. 512 (2012) 255**)

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



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

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

Introduction. Studies of nuclear shadowing have a long history [1–5]. In quantum mechanics and in the eikonal limit, it is manifested in the total hadron-nucleus cross section being smaller than the sum of individual hadron-nucleon cross sections. In essence, this is due to simultaneous interactions of the projectile with $k \geq 2$ nucleons of the nuclear target, leading to a reduction (shadowing) of the total cross section. In this frame-

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 .

Complementary measurements with light ion beams @ the EIC:

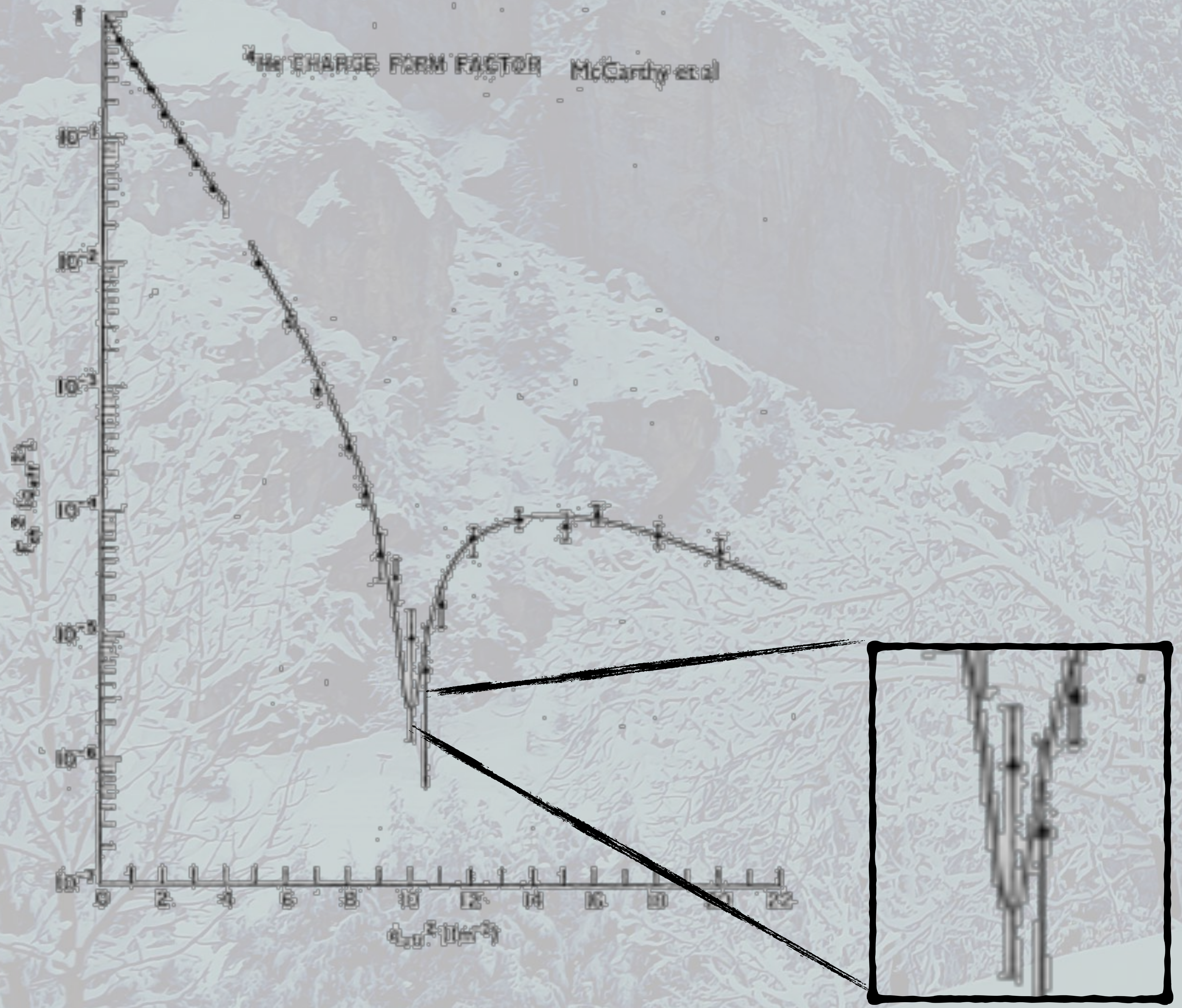
- Scattering off 2 and 3 nucleons can be separately probed
- no excited states -> easy to select coherent events

Here:

Results on J/Ψ diffractive electro-production off ^3He – ^4He

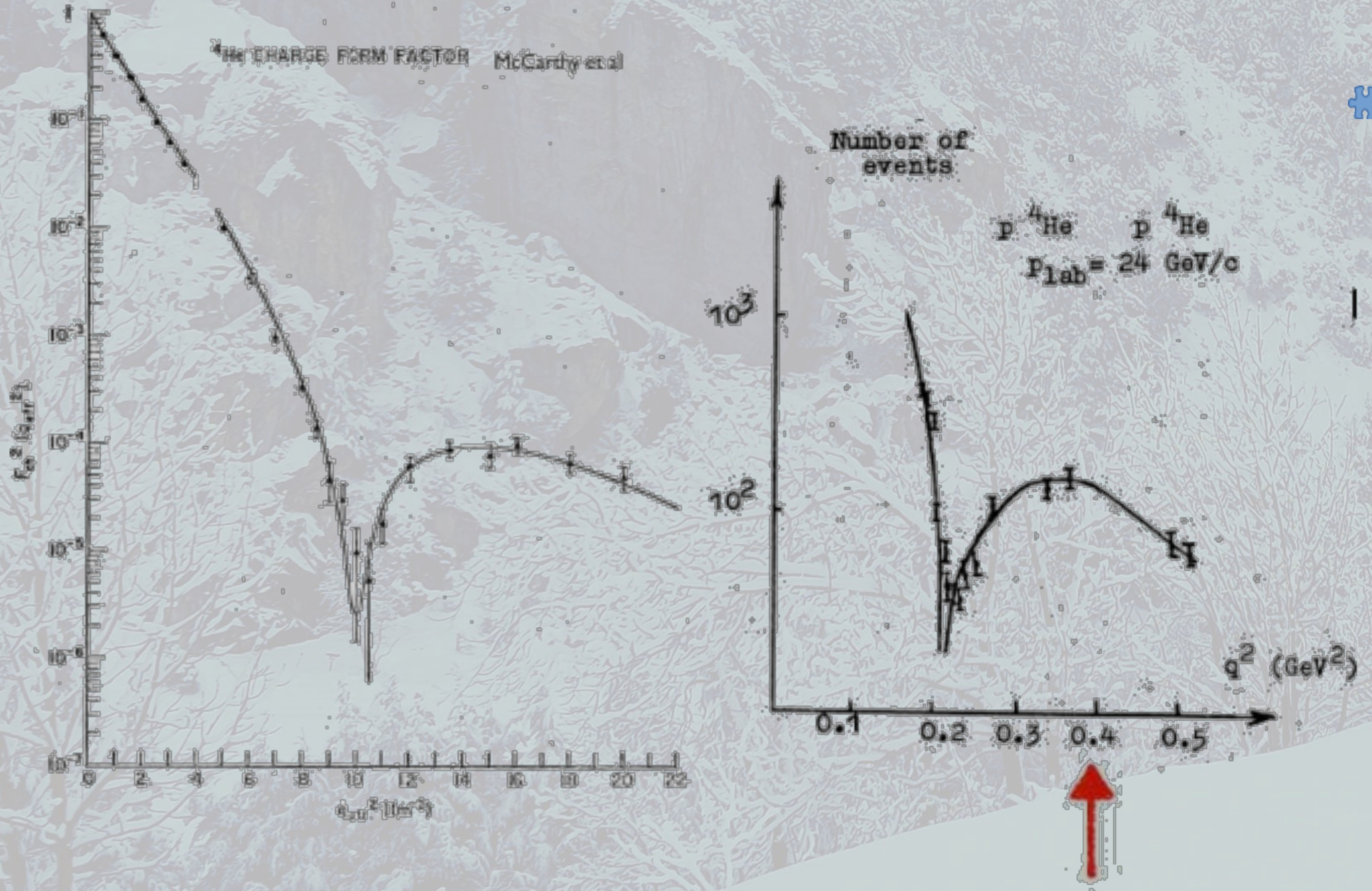
V. Guzey, M. R., S. Scopetta, M. Strikman and M. Viviani, PRL 129 (2022) 24, 24503

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

An old idea (Levin and Strikman 1975)



no contribution of impulse approximation term

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

- around this value of t, the cross section in p +^{4}He -> p +^{4}He is dominated by effects beyond IA: multinucleon interactions, gluon shadowing for hard processes

The X-section for J/ψ exclusive production @ EIC

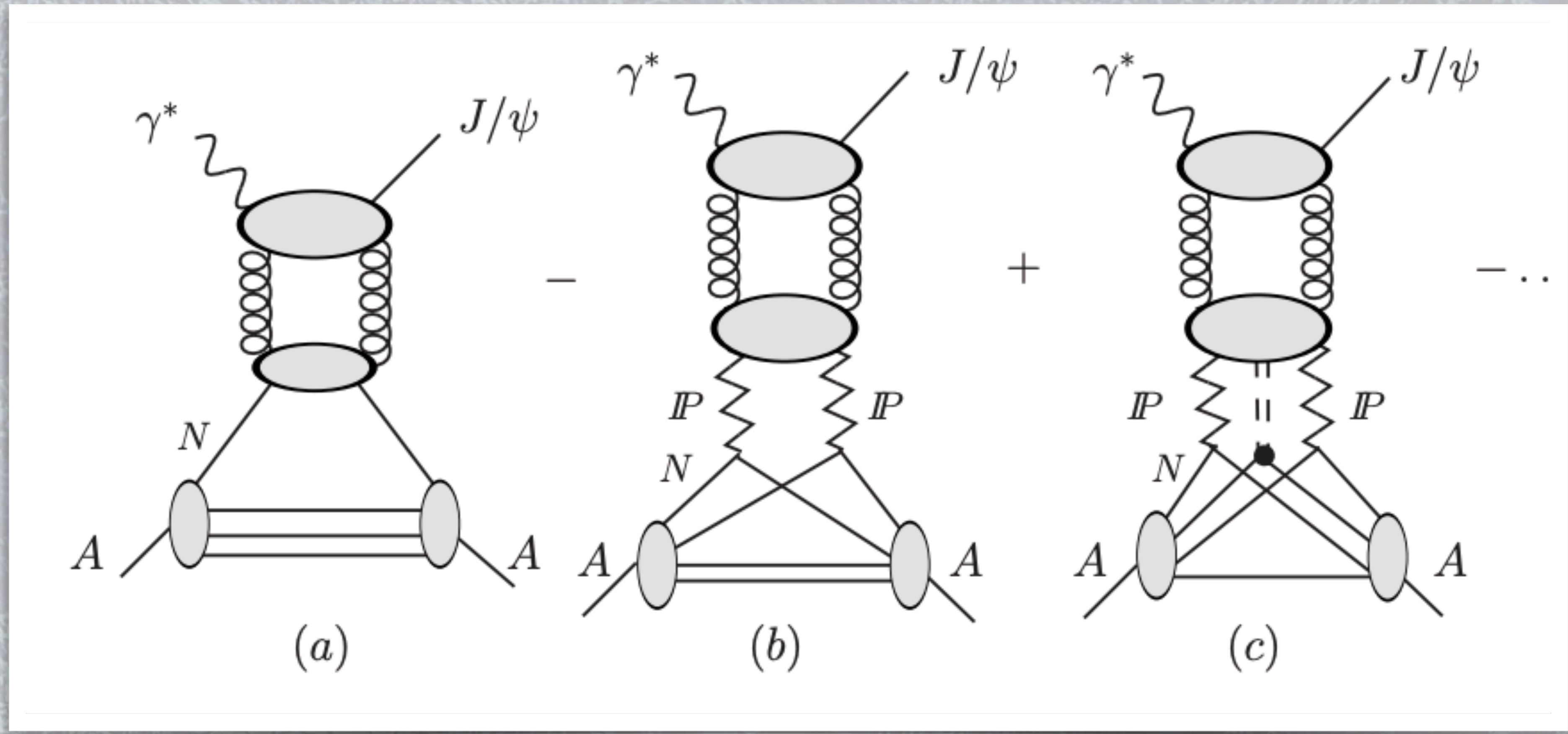
LT parton shadowing for J/Ψ coherent production off He (gluon GPDs in He)
(**Frankfurt, Guzey, Strikman Phys. Rep. 512 (2012) 255**)

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

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

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

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



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 < σ^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)**)

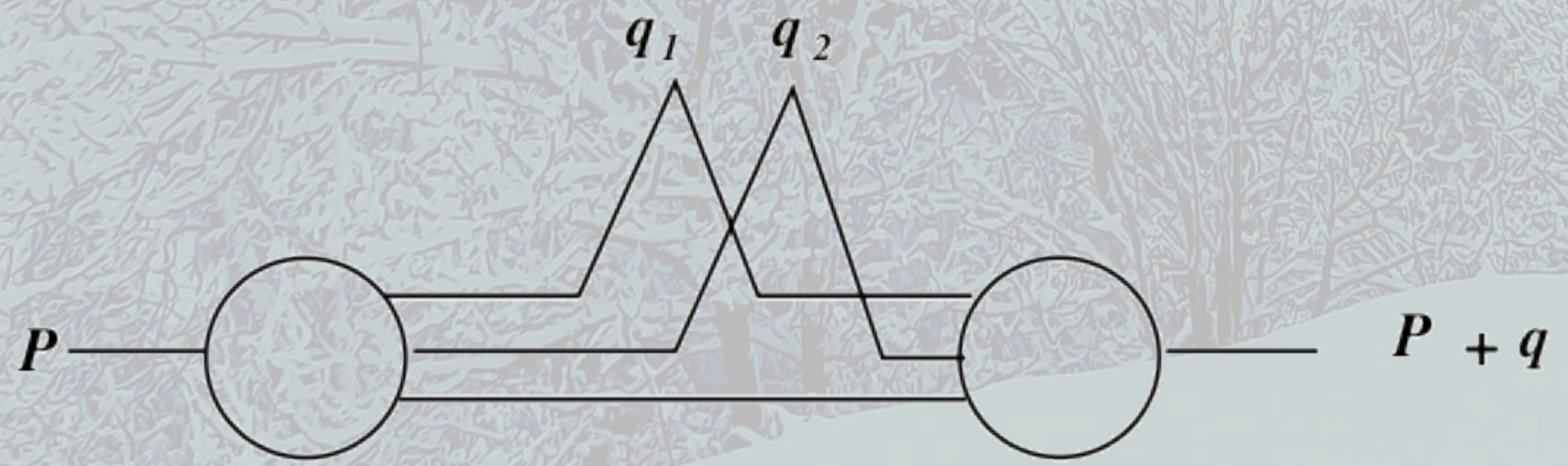
- Φ_k "k-body form factor", is the nuclear input

Nuclear Physics input

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

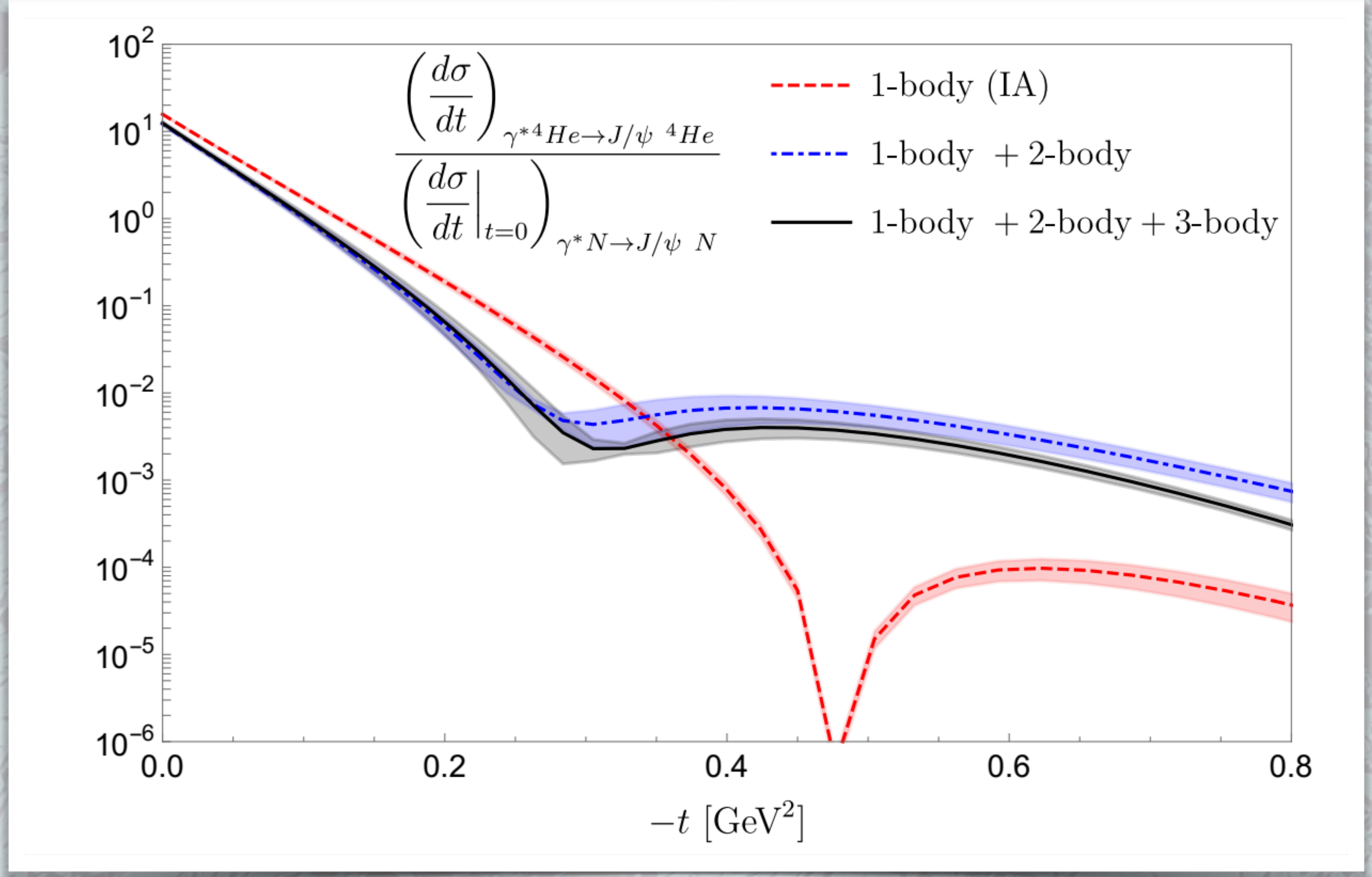
- Φ_1 (IA, very important here), Φ_2 and Φ_3 evaluated using the realistic w. f. obtained by the Pisa group using: *a)* Av18 for ^{3}He *b)* the N4LO chiral potential (D. R. Entem, R. Machleidt, Y. Nosyk, Phys. Rev. C 96, 024004 (2017)) for ^{4}He

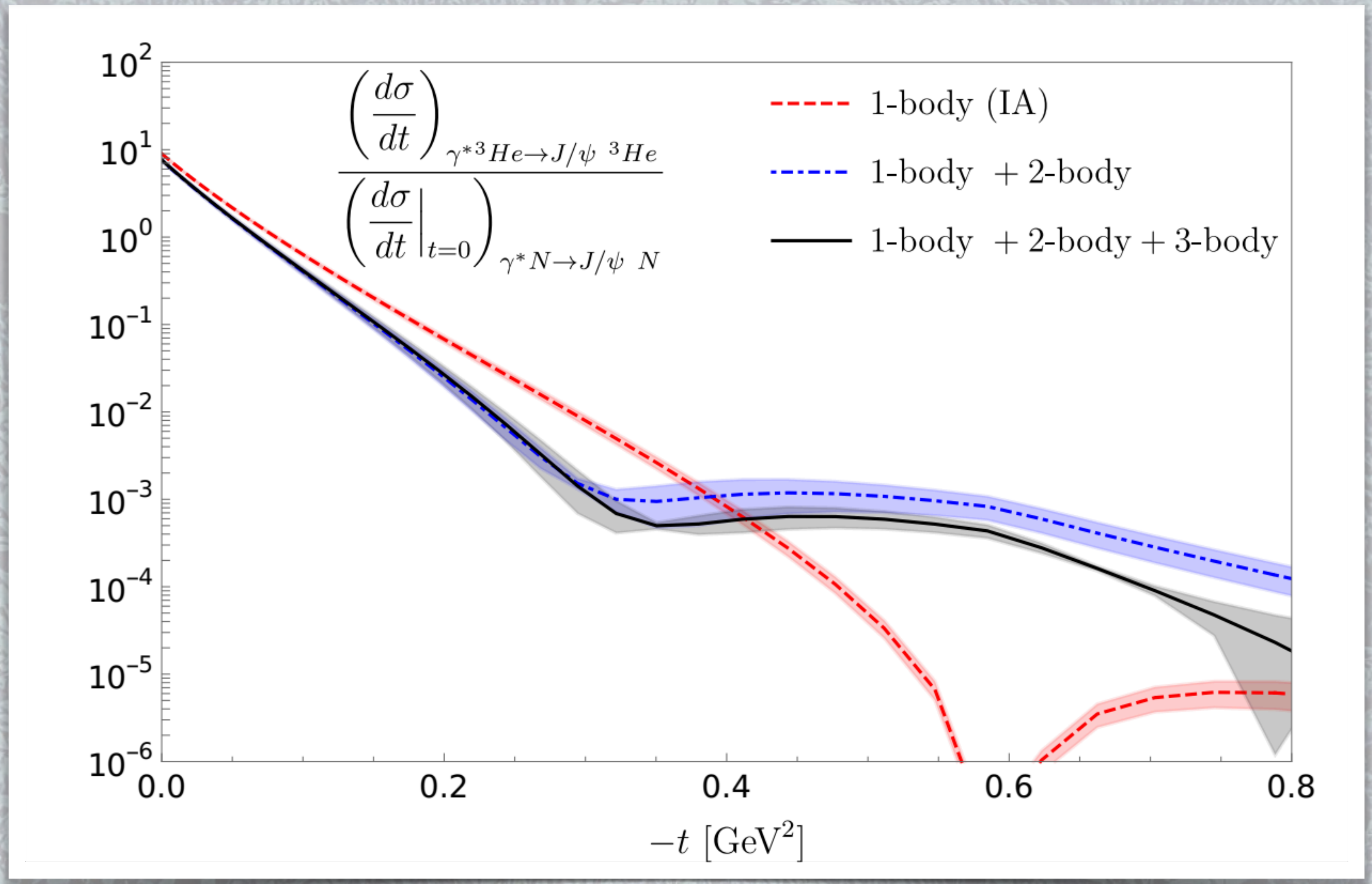
- Example of Φ_2 :



- we remark that $\Phi_2(k_\perp, -k_\perp)$ is the same quantity appearing in the DPS2 mechanism

Results for J/Ψ exclusive production @EIC: xB ≈ 10-3





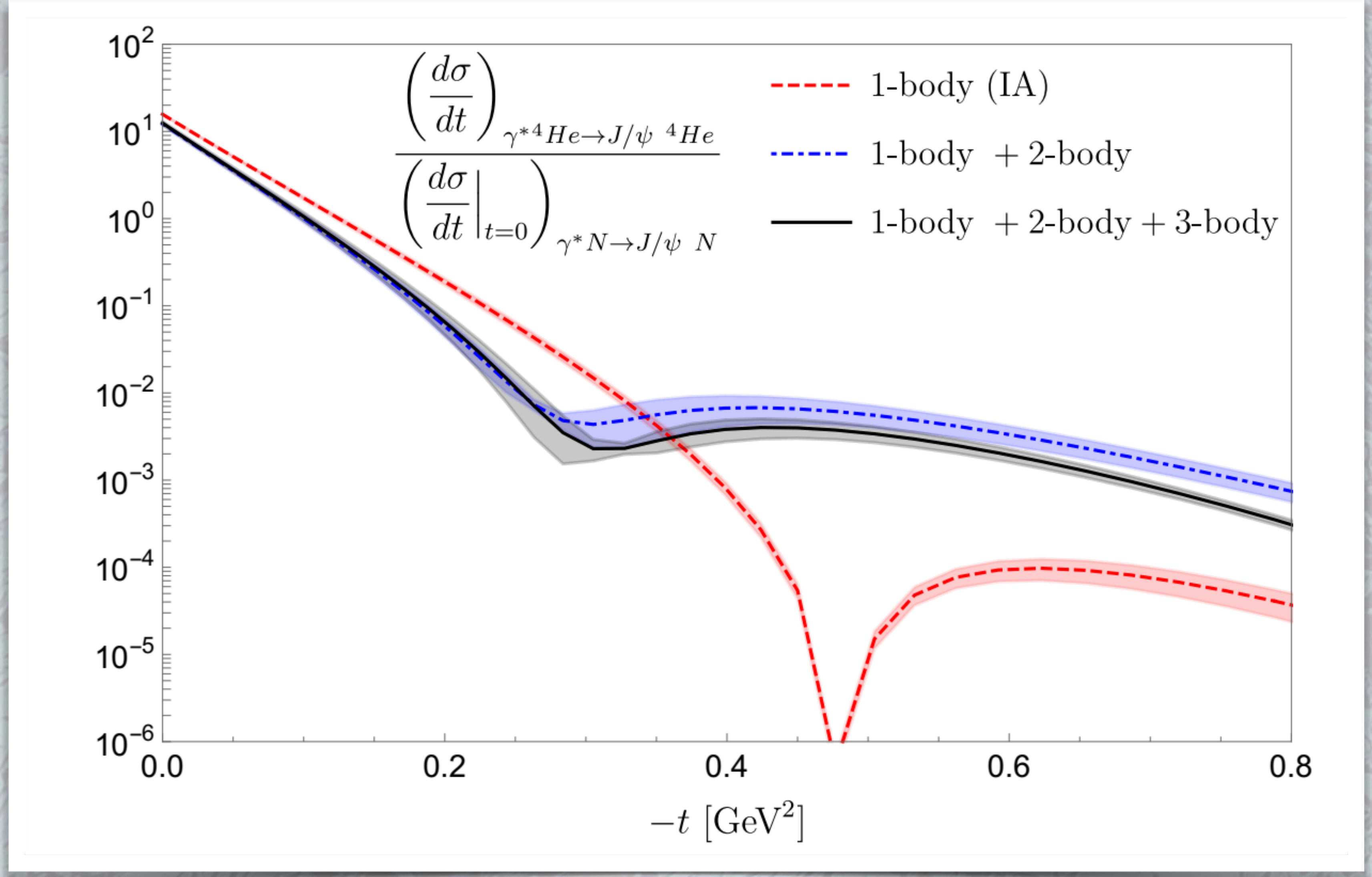
Error bars account:

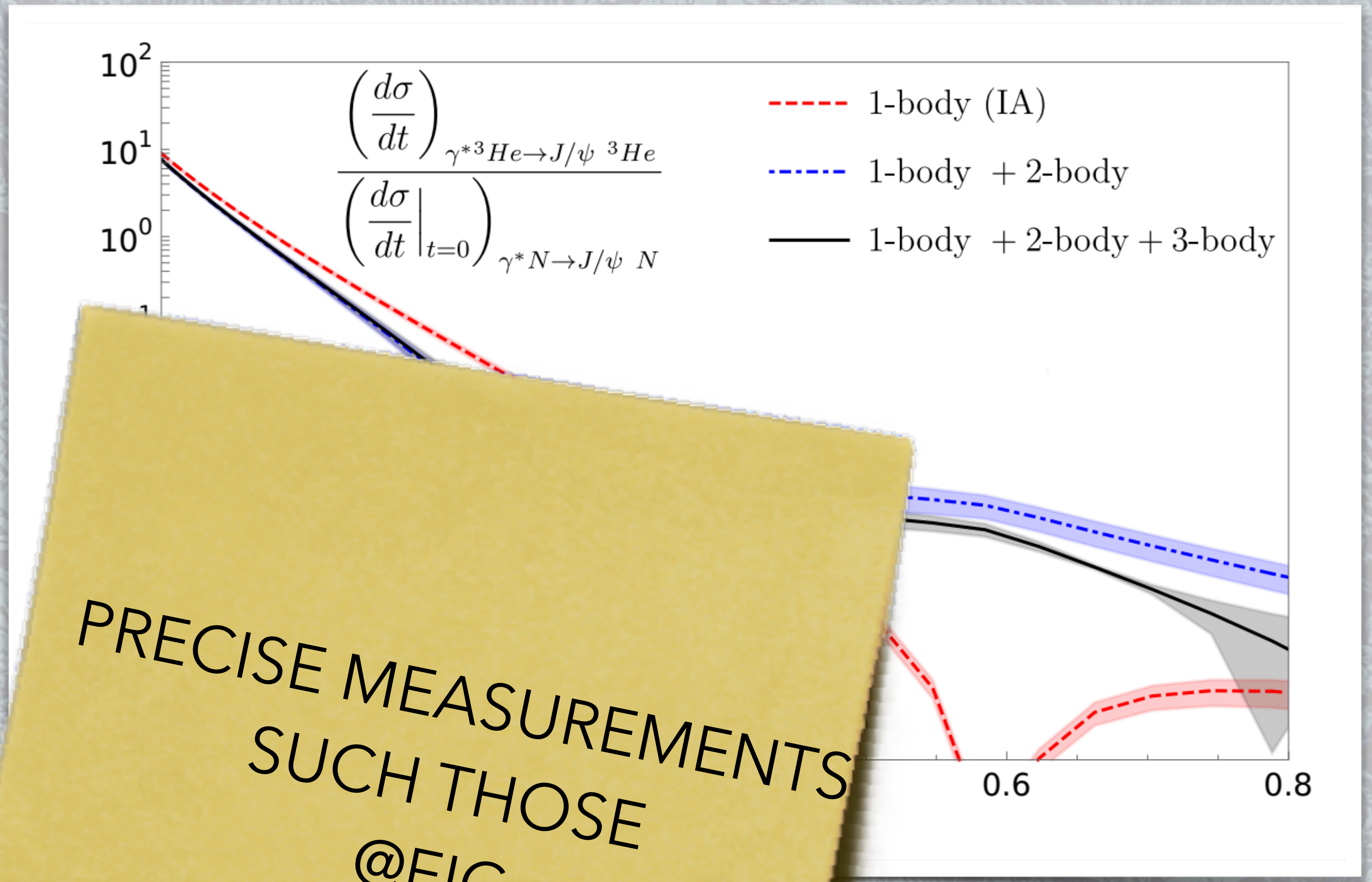
-10% of variation for B_0

-15 of variation in < σ^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!

Results for J/Ψ exclusive production @EIC: xB ≈ 10-3





PRECISE MEASUREMENTS SUCH THOSE @EIC ARE NECESSARY!

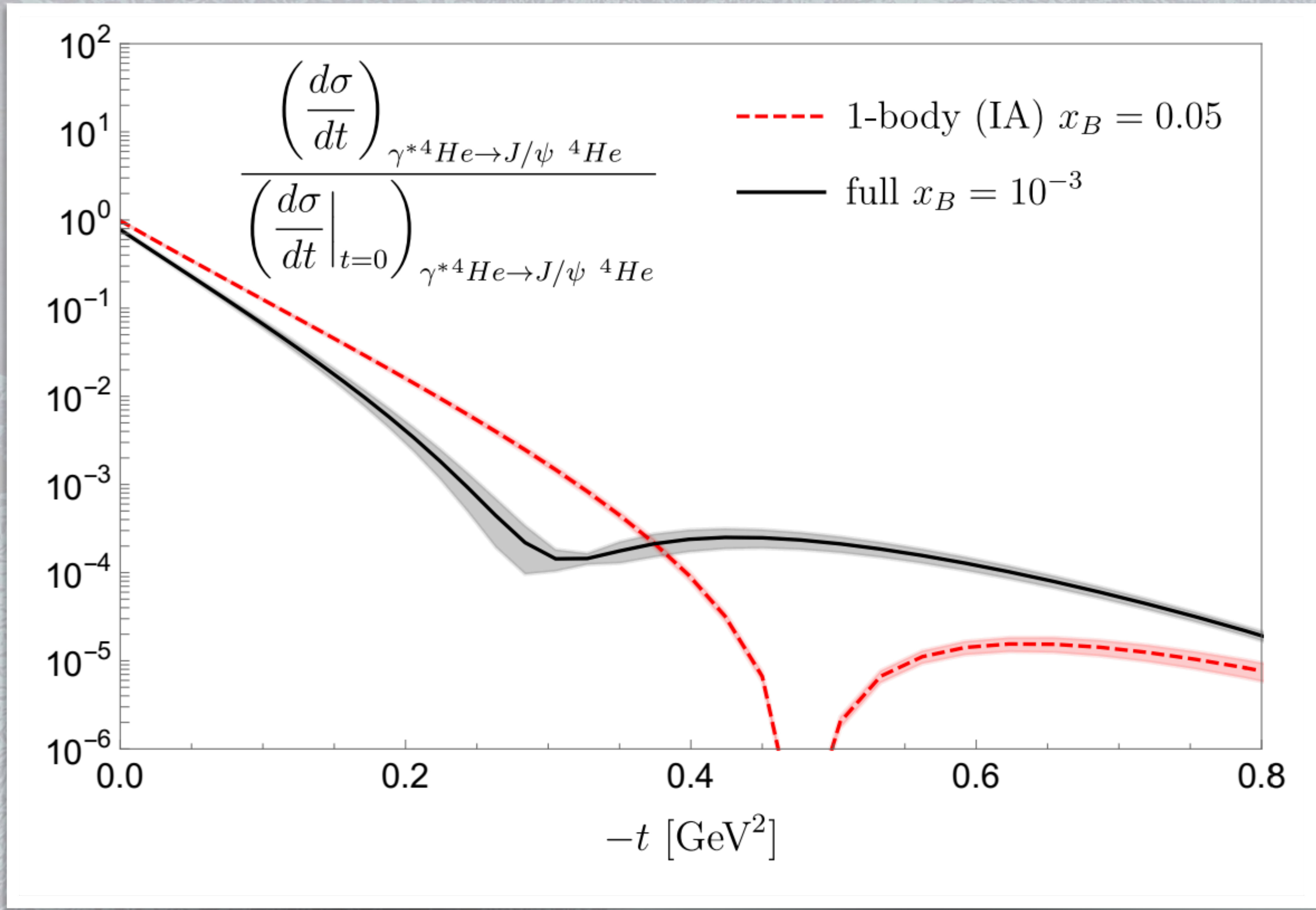
Error bars account:

-10% of variation for B_0

-15 of variation in < σ^2 >

- ✔ 1-body + 2-body re-scatterings dominate the cross-se … body dynamics
- ✔ 1-body dynamics under theoretical control: very good chances …
- ✔ 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!

Results for J/Ψ exclusive production @EIC: xB ≈ 0.05 (xB-evolution)



Error bars account:

-10% of variation for B_0

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

✔ 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)

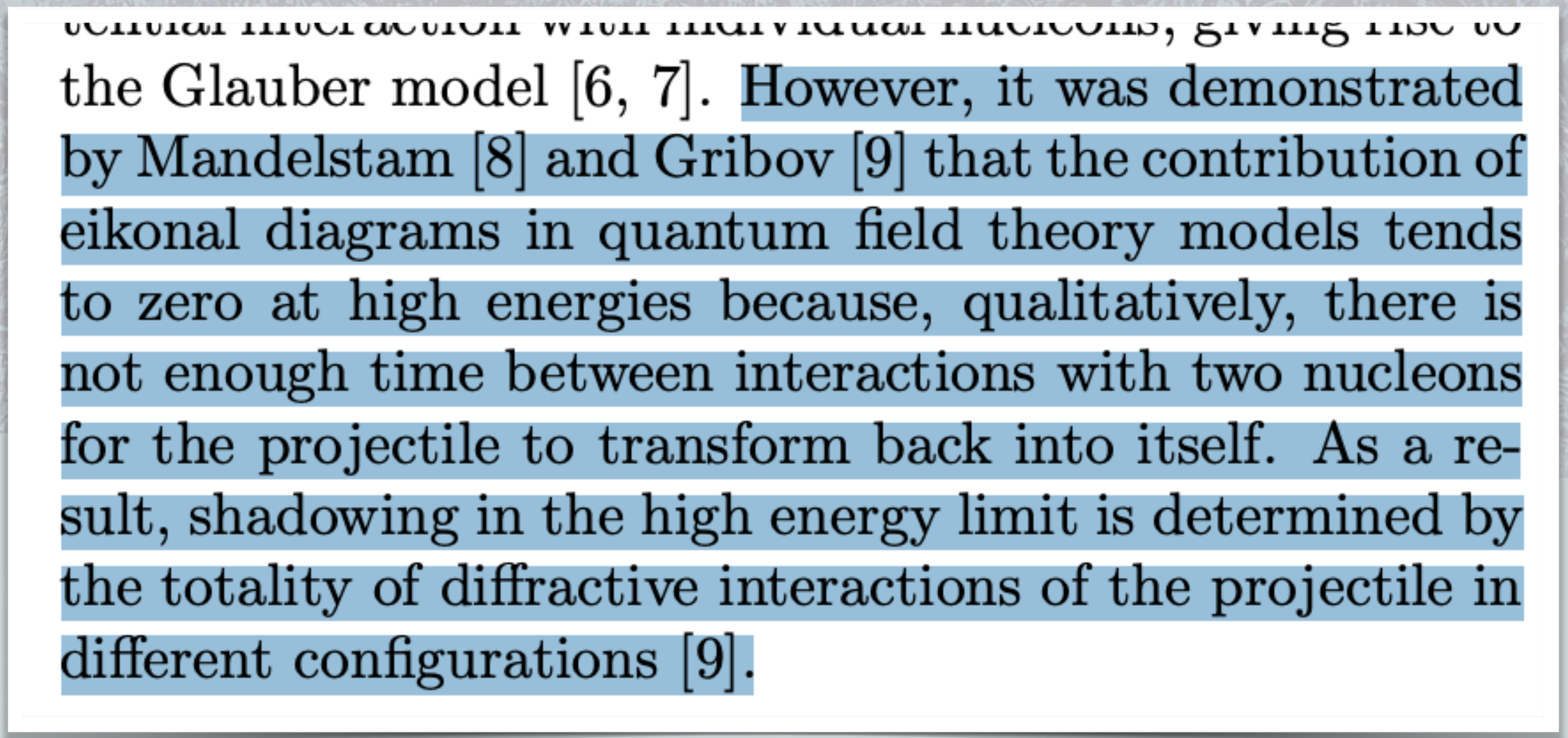
Backup

Good-Walker formalism of eigenstates of the scattering operator which allows one to characterize the interaction with k nucleons by the kth moment $\langle \sigma^k \rangle$

M. L. Good and W. D. Walker, Phys. Rev. 120, 1857- 1860 (1960)
B. Blaettel, et al, Phys. Rev. D 47, 2761-2772 (1993)

$$\langle \sigma^k \rangle = \int d\sigma \, P(\sigma) \sigma^k$$

parametrizes the hadronic structure of the virtual photon and gives the probability for the photon to interact with a nucleon with the cross section σ


the Glauber model [6, 7]. However, it was demonstrated by Mandelstam [8] and Gribov [9] that the contribution of eikonal diagrams in quantum field theory models tends to zero at high energies because, qualitatively, there is not enough time between interactions with two nucleons for the projectile to transform back into itself. As a result, shadowing in the high energy limit is determined by the totality of diffractive interactions of the projectile in different configurations [9].