# Exclusive vector meson production as a probe of nuclear geometry at high energy

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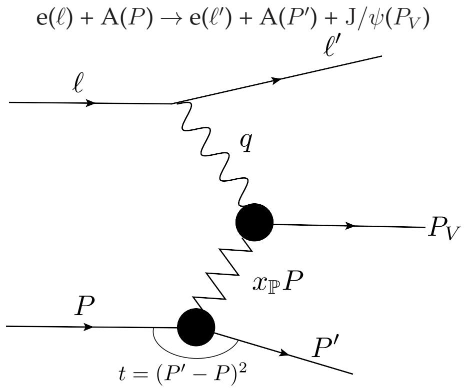
ABSTRACT

- Saturation effects change the nuclear spatial density profile at small-$x$
- Exclusive vector meson production in UPCs and at the EIC can probe that
- $J/\psi$ spectra from LHC sensitive to this effect
- EIC can also access the potentially deformed structure of light and nuclei at small-$x$

## 1 Diffractive DIS

No exchange of quantum numbers (color)

$$e(\ell) + A(P) \to e(\ell') + A(P') + J/\psi(P_V)$$



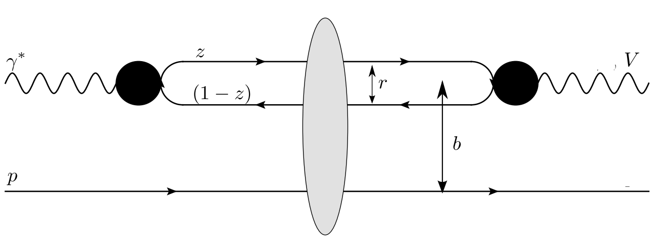

Divide events into two categories:

- Coherent diffraction
  Nucleus remains intact, probes average structure
  $$\frac{d\sigma}{dt} \sim |\langle \mathcal{A}(x_{\mathbb{P}}, Q^2, t)\rangle_N|^2$$
- Incoherent diffraction
  Nucleus breaks up, sensitive to structure fluctuations
  $$\frac{d\sigma}{dt} \sim \langle |\mathcal{A}(x_{\mathbb{P}}, Q^2, t)|^2\rangle_N - |\langle \mathcal{A}(x_{\mathbb{P}}, Q^2, t)\rangle_N|^2$$

$\mathcal{A}$: Diffractive scattering amplitude
$\langle\rangle_N$: Average over target configurations

*Can be measured in Ultra Peripheral Collisions and at the EIC*

## 2 Diffraction in dipole picture




1. $\gamma^* \to q\bar{q}$ splitting: QED, photon wave function $\Psi$
2. Dipole-target scattering (QCD): $\sigma_{dip}$
3. Dipole $\to J/\psi$ (QED+modeling), $J/\psi$ wave function $\Psi_V$

$$\mathcal{A} = i\int d^2r\, d^2b\, dz\, [\Psi_V^*\Psi](r,z,Q) e^{-i[b-(\frac{1}{2}-z)r]\cdot\Delta} \frac{d\sigma_{dip}}{d^2b}(b,r,x_{\mathbb{P}})$$

$\Delta = \sqrt{-t}$: Transverse momentum transfer, conjugate to $b$

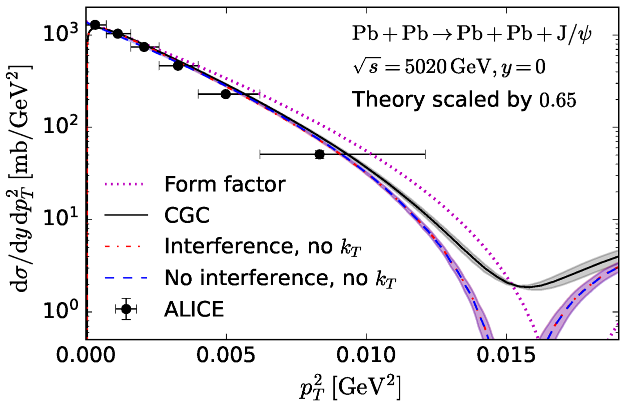


## References

[1] H. Mäntysaari, F. Salazar and B. Schenke, Phys. Rev. D **106** (2022) no.7, 074019, arXiv:2207.03712 [hep-ph].

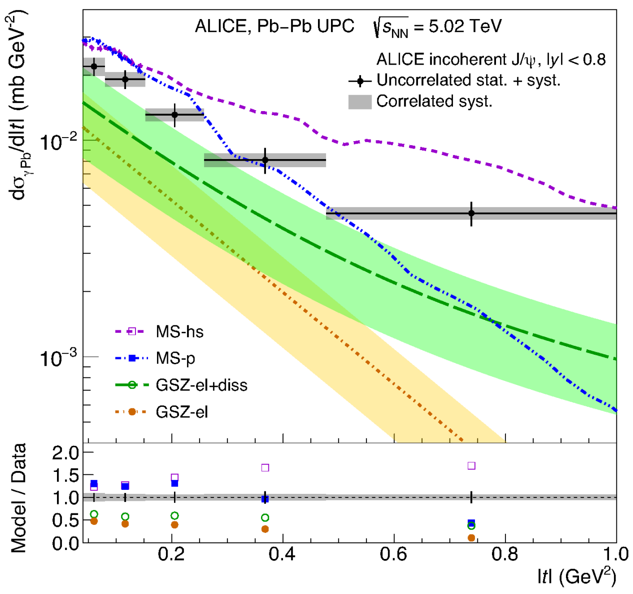
[2] H. Mäntysaari, B. Schenke, C. Shen and W. Zhao, arXiv:2303.04866 [nucl-th].


## 3 Coherent $J/\psi$ spectra at the LHC



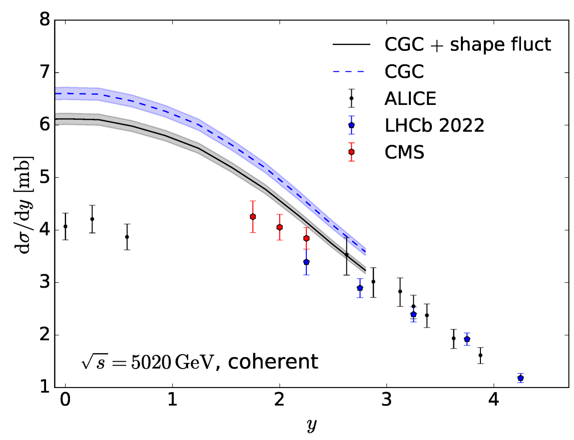

- Non-linearities (saturation) significantly modify the shape measured by the $p_T^2$ distribution
  - Preferred by the ALICE data
  - *Form factor* = linearized calculation (no saturation)
- Interference important only at very low $p_T^2$
- Non-zero photon $k_T$ removes the diffractive minima

## 4 Incoherent $J/\psi$ spectra at the LHC



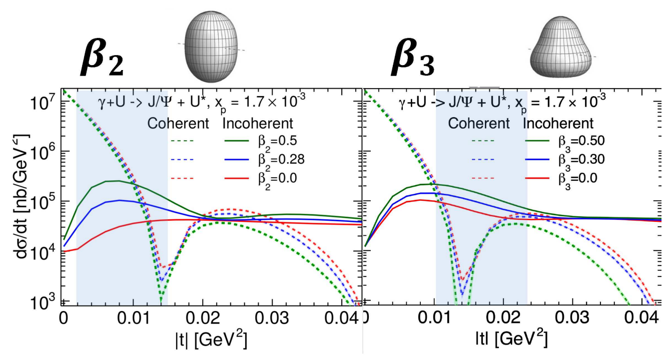

- ALICE $|t|$ spectra (2305.060169) prefers fluctuating nucleon substructure (MS-hs), not round nucleons (MS-p)

## 5 Large nuclear suppression



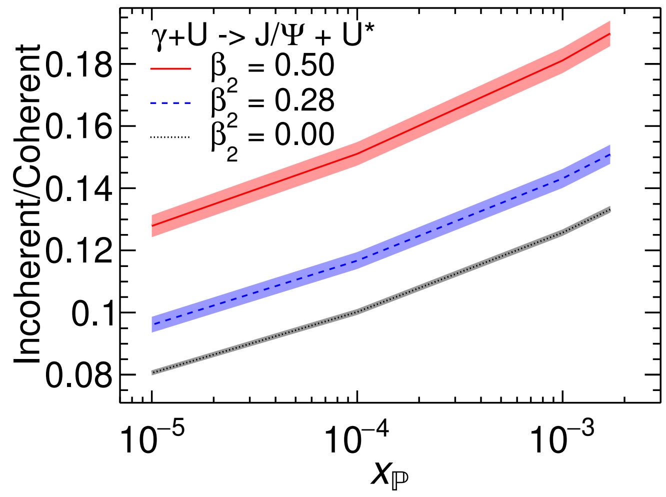

- Significant nuclear suppression: linearized calculation at $y=0$ predicts $d\sigma/dy \sim 10$ mb
- CGC calculation: less suppression at $y=0$ ($x_p \approx 6\cdot 10^{-4}$)
- With substructure overlapping hot spots $\Rightarrow$ stronger suppression (more saturation)

## 6 Deformations at the EIC: Uranium



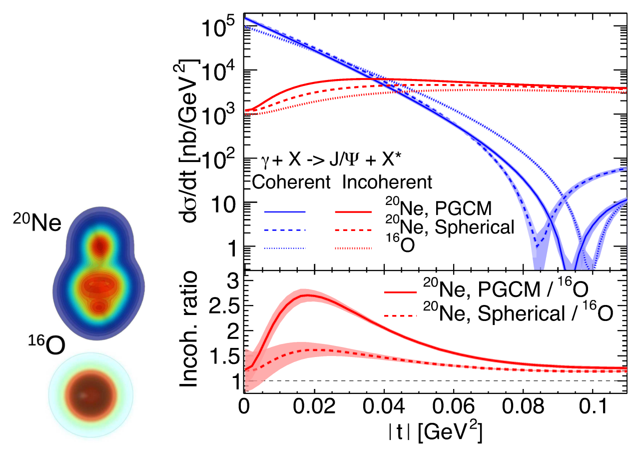

- Deformed nucleus:
  $R(\theta) = R_0[1 + \beta_2 Y_2^0(\theta) + \beta_3 Y_3^0(\theta) + \beta_4 Y_4^0(\theta)]$
- Is the small-$x$ gluon distribution similarly deformed? Necessary input e.g. to simulate U+U
- Incoherent $\gamma + U \to J/\psi + U^*$ at the EIC:
  Different $t$ ranges sensitive to different $\beta_i$
- EIC can extract small-$x$ deformations!

## 7 Deformations survive to small-$x$




- Cross section ratios initialized with different $\beta_2$ differ after 2 orders of magnitude of JIMWLK evolution
- Expect deformations to survive to small-$x$

## 8 Deformations at the EIC: light ions




- Neon $\approx$ O + $\alpha$
- Extra alpha cluster increases long distance scale fluctuations $\Rightarrow \sigma^{incoh}$ around $-t \sim 0.02 \ldots 0.06$ GeV$^2$
- Much larger effect than simple $A$ scaling visible at large $-t \sim$ short-scale fluctuations
- EIC can constrain the non-trivial shape of light ions!