

Overview of vector meson photoproduction in UPCs at the LHC: from small-x gluons to nuclear imaging

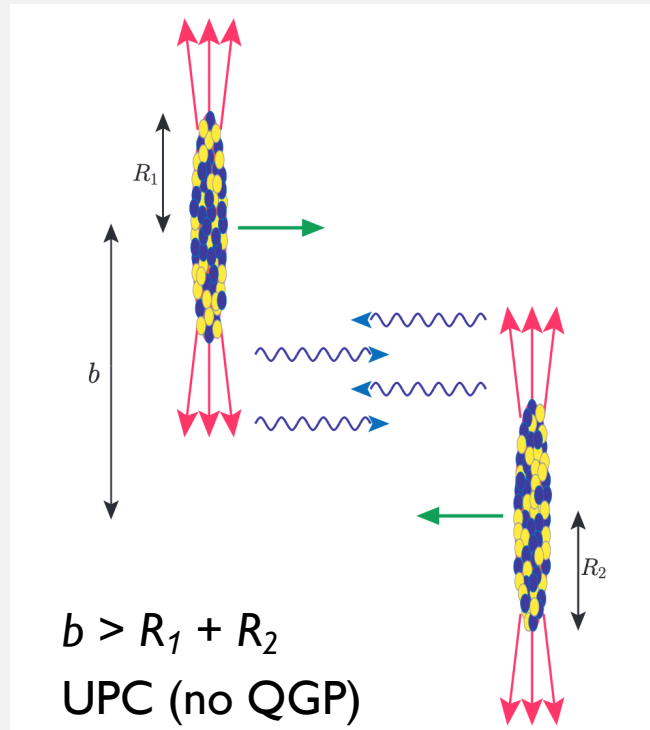
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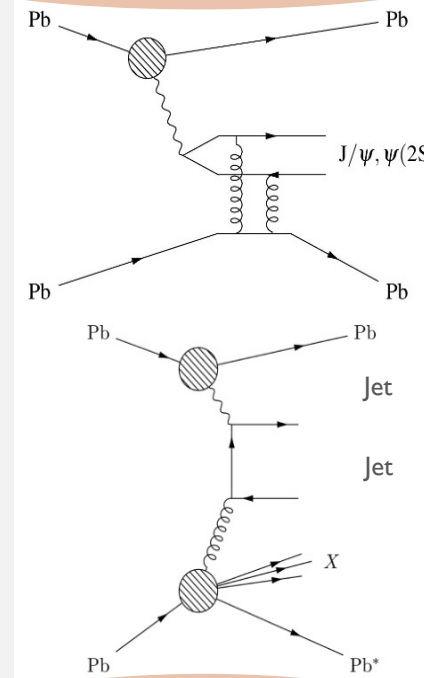
Photon-induced processes at the LHC

- ❑ The EM field of a nuclei can be described as beam of **quasi-real photons** (number of photons proportional to Z^2)
- ❑ Use LHC as photon-photon (QED) or photon-hadron collider (QCD)



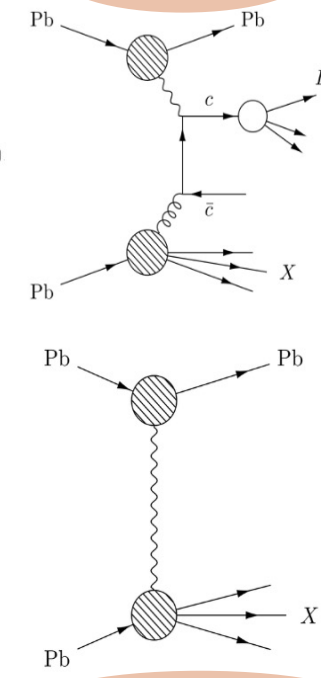
QCD (γA interactions)

Vector meson photoproduction



Jet photoproduction

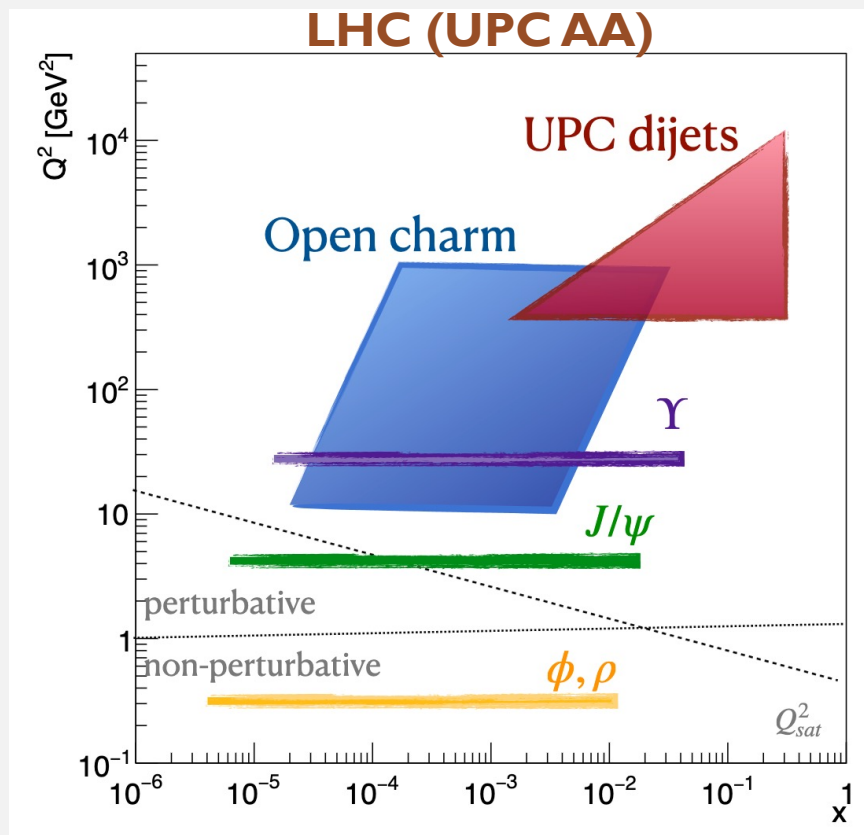
Open charm



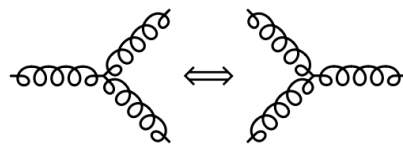
Inelastic interactions

Probing small-x gluons with UPCs at the LHC

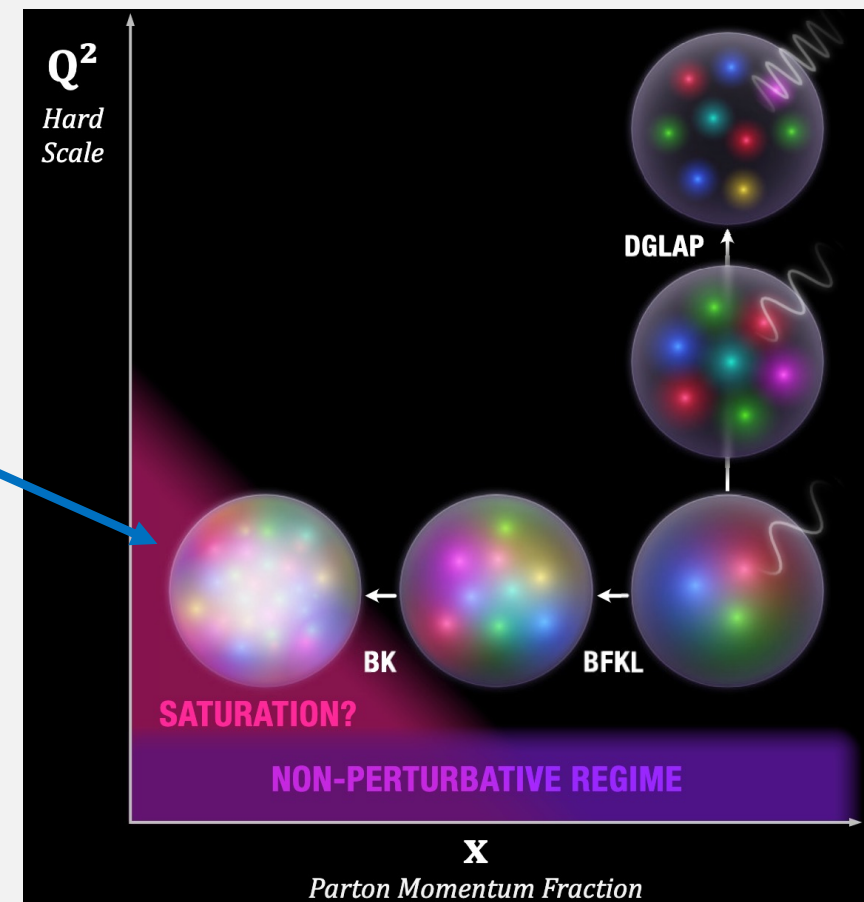
- UPCs to probe parton distributions in nuclei in a broad (x, Q^2) kinematic range and search for parton saturation



At small- x , large
gluon densities $\rightarrow$
gluon recombination
+ non-linear effects



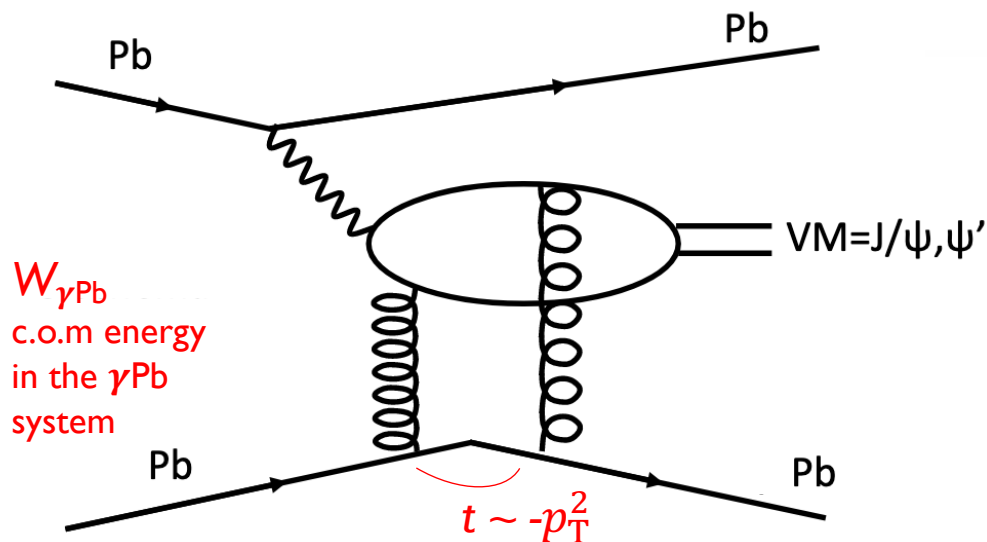
$$Q_s^2(x, A) \sim A^{1/3} x^{-\lambda}$$



- Quasi real photons
- Extreme energies, huge $W_{\gamma A}$ reach, very low- $x \rightarrow$ access to saturation region
- Fixed/moderate Q^2

Vector meson (VM) photoproduction : few definitions

LO schema



$$\gamma + A \rightarrow V + A$$

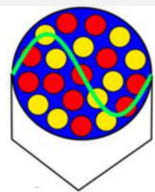
Eg. the J/ψ case:

- ❑ Quasi-real photon fluctuates into a $q\bar{q}$ pair (the color dipole)
- ❑ Interaction with the target nucleus via gluon exchange
- ❑ Dipole recombine into a VM
- ❑ Probed Bjorken- x at LHC energies $10^{-5} < x < 10^{-2}$

$$x_{\pm} = \frac{m_{J/\psi}}{\sqrt{s_{NN}}} e^{(\pm y)}$$

❑ Coherent photoproduction of VM

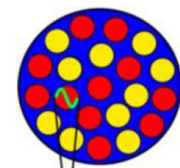
- χ couples coherently to all nucleons
- $\langle p_T \rangle_{J/\psi} \sim 1/\text{Radius} \sim 60 \text{ MeV}$
- Usually no breaking of target nucleus



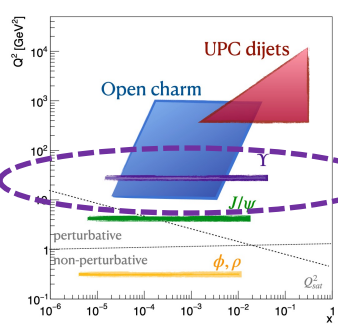
$\lambda_{\text{coherent}}$

❑ Incoherent photoproduction of VM

- χ couples to a nucleon (or subnucleonic structure)
- $\langle p_T \rangle_{J/\psi} \sim 500 \text{ MeV}$
- Usually target nucleus breaks

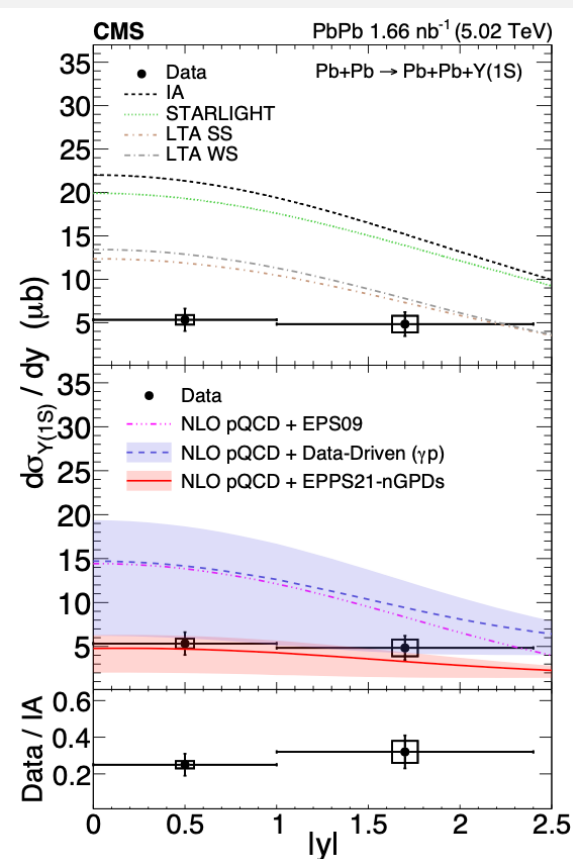
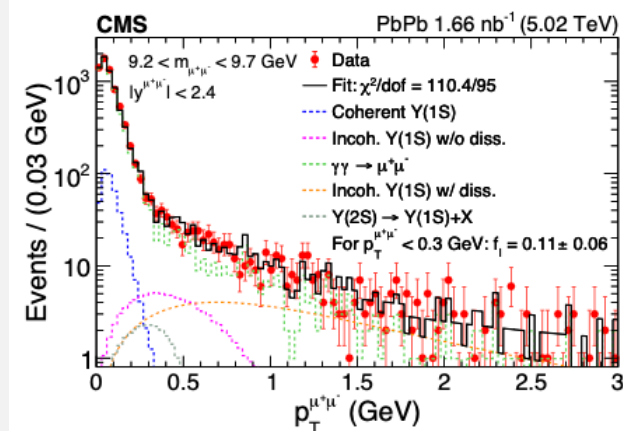
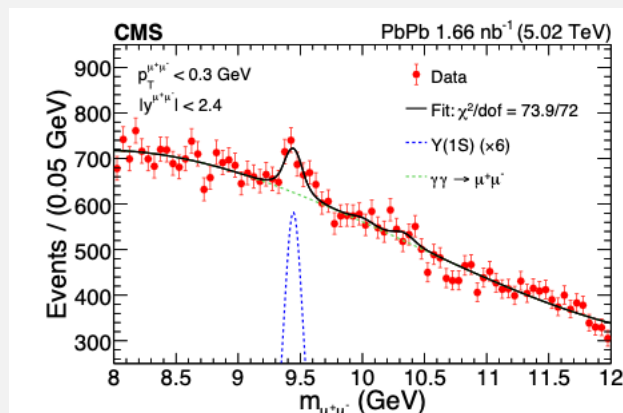


$\lambda_{\text{incoherent}}$



Coherent $\Upsilon(1S)$ photoproduction in Pb-Pb UPC (Run 2)

- ❑ First coherent $\Upsilon(1S)$ photoproduction measurement in Pb-Pb UPC at LHC
- ❑ $Q^2 \sim M^2_{\Upsilon}/4 \sim 22 \text{ GeV}^2$, $x \sim 10^{-3} \rightarrow$ minimal non linear QCD effects

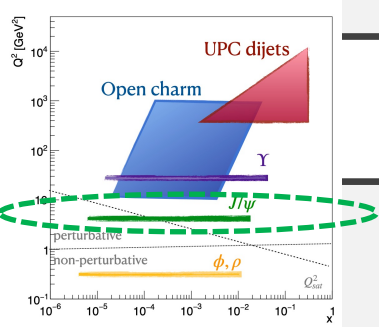


- ❑ Outside saturation region, but strong suppression of the yield w.r.t IA hypothesis («baseline» model neglecting nuclear effects; nucleus = collection of free nucleons)

$$S_{Y(1S)} = 0.25 \pm 0.07 \text{ (tot) at } |y| < 1.0$$

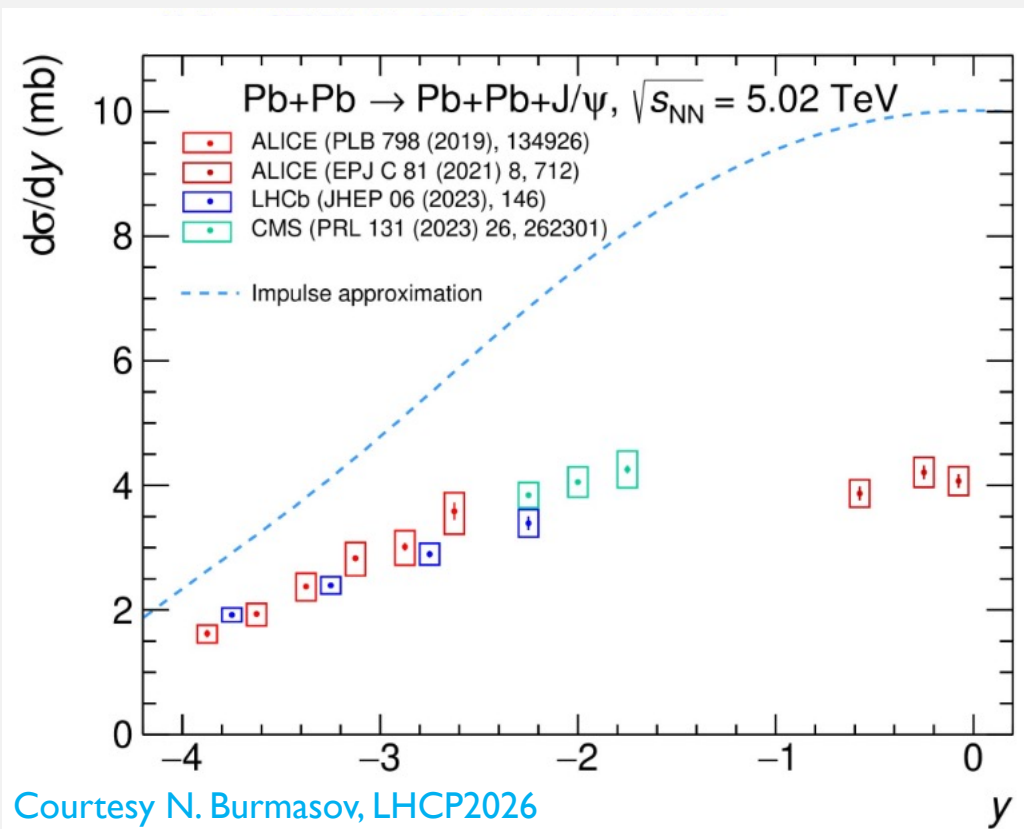
$$S_{Y(1S)} = 0.32 \pm 0.11 \text{ (tot) at } 1.0 < |y| < 2.4$$

- ❑ Calculations with NLO pQCD consistent with data when large uncertainties on nPDFs considered
*EPPS21-nGPDs consider **nGPDs** modeled via Shuvaev transform of nPDFs*



Coherent J/ψ photoproduction in Pb-Pb UPC (Run 2)

☐ Measurements from the 4 LHC Collaboration spanning a wide y range $\rightarrow \sim (10^{-5} < x < 3 \times 10^{-2})$



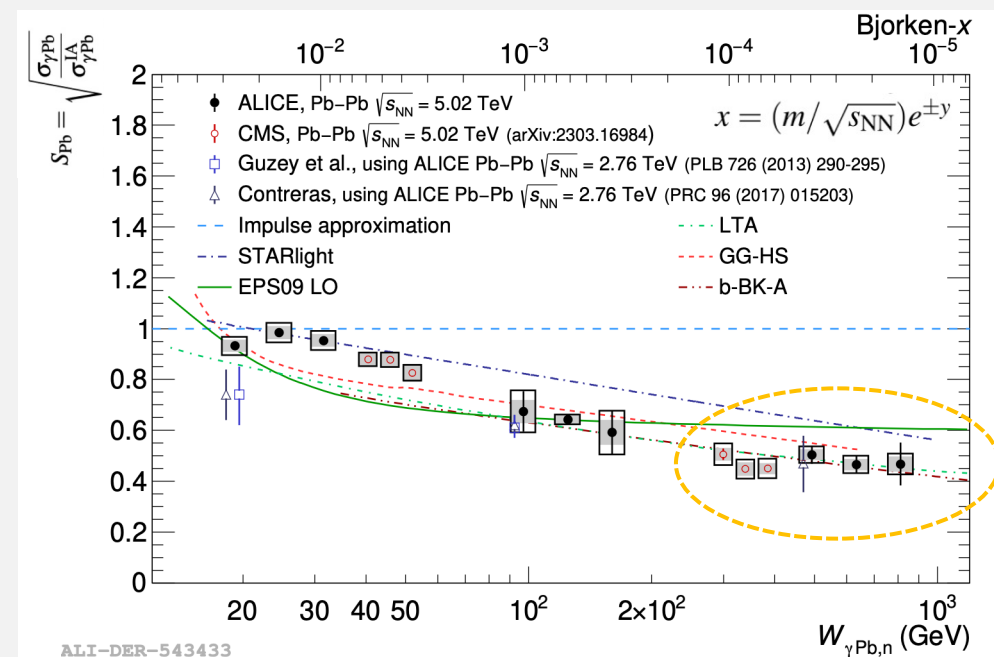
Courtesy N. Burmasov, LHCP2026

Compilation of Run 2 measurements

☐ Consistent physics picture : strong suppression of the cross section w.r.t Impulse Approximation for all rapidities
 $\rightarrow$ Indications of strong nuclear effects

[ALICE, JHEP 10 \(2023\) 119](#)

[CMS, PRL 131 \(2023\) 262301](#)

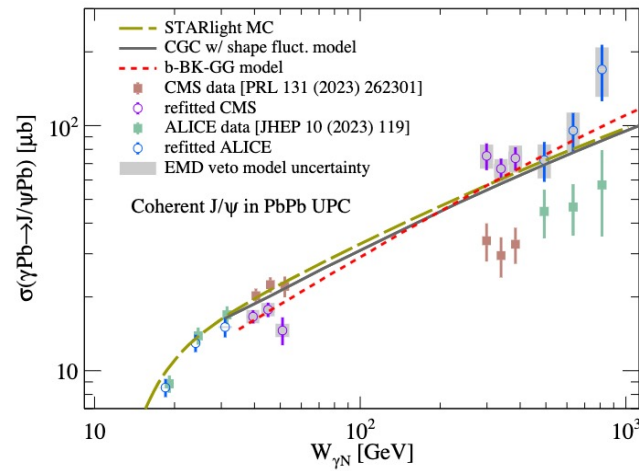
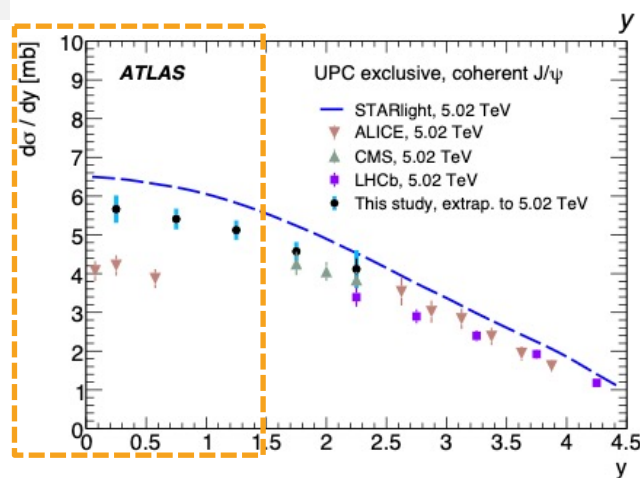
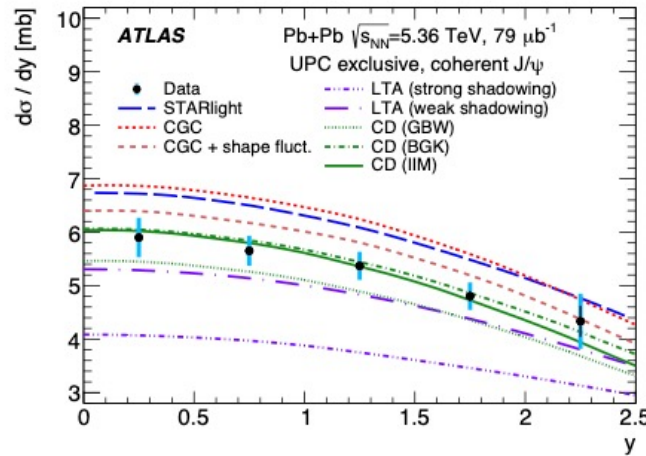
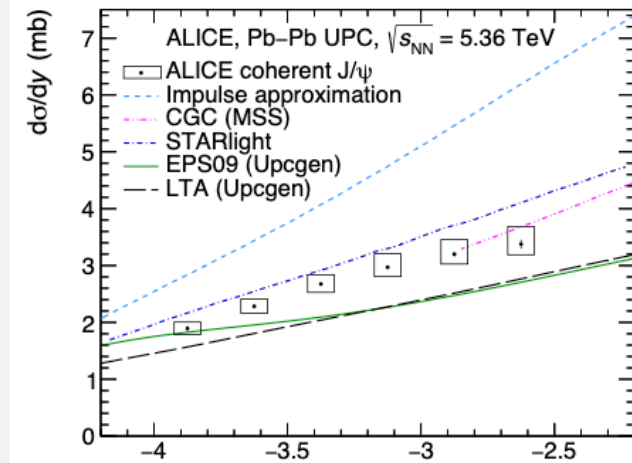


☐ Suppression at small- x reasonably described by shadowing or saturation models

Coherent J/ψ photoproduction in Pb-Pb UPC (Run 3)

[ALICE, arXiv:2605.13569](#)

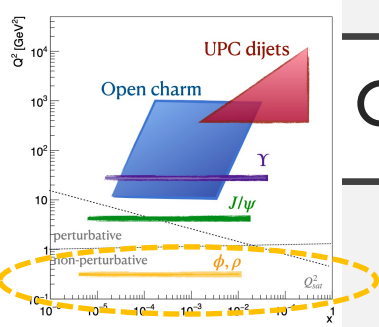
[ATLAS, JHEP 04 \(2026\) 020](#)



[ATLAS, JHEP 04 \(2026\) 020](#)

[M. Dyndal et al., arXiv:2604.19879](#)

- ❑ Similar physics picture in Run 3 : strong suppression of the cross section w.r.t Impulse Approximation
- ❑ Complementary measurement by ALICE (forward) and ATLAS (mid-rapidity)
- ❑ ATLAS results extrapolated to Run 2 energy (correction ~4-5%) in tension with ALICE Run 2 results at mid-y
- Investigation ongoing to understand the source of discrepancy (additional photon exchanges, VETO conditions?)
- ❑ Recent study shows the possible bias introduced by EDM on VETO conditions in the ALICE and CMS measurements
- Also new coherent $\psi(2S)$ measurements (see backup). Difference dipole size w.r.t J/ψ hence different sensitivity to nuclear effects

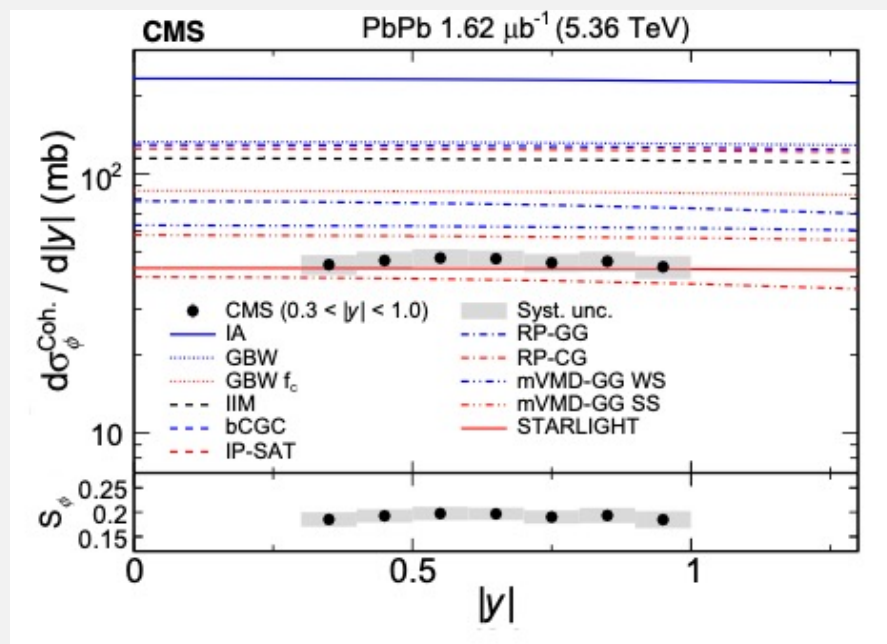


Coherent ϕ and ρ^0 photoproduction in Pb-Pb UPC (Run 3)

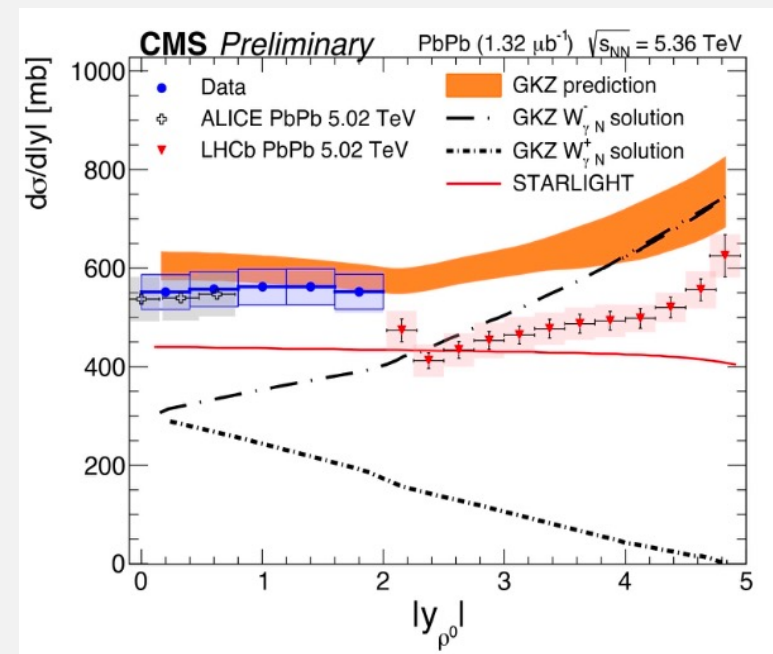
□ ϕ : intermediate scale between perturbative J/ψ and non-perturbative ρ

□ ρ : non-perturbative regime, LHCb measurement extends down to $x \sim 10^{-6}$

[CMS, Phys. Rev. Lett. 135 \(2025\) 262301](#)

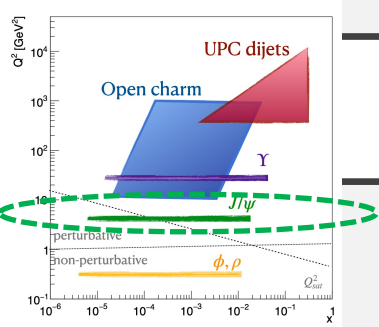


- Suppression of the cross section by a factor ~ 5 w.r.t IA
- Current data tend to favour shadowing-based calculations over available saturation-based predictions



- Strong suppression w.r.t IA : 0.05 ± 0.11 (high energy γ , low x)
- Important effect from elastic and inelastic nuclear shadowing, but still room for additional suppression especially at low- x (saturation?)

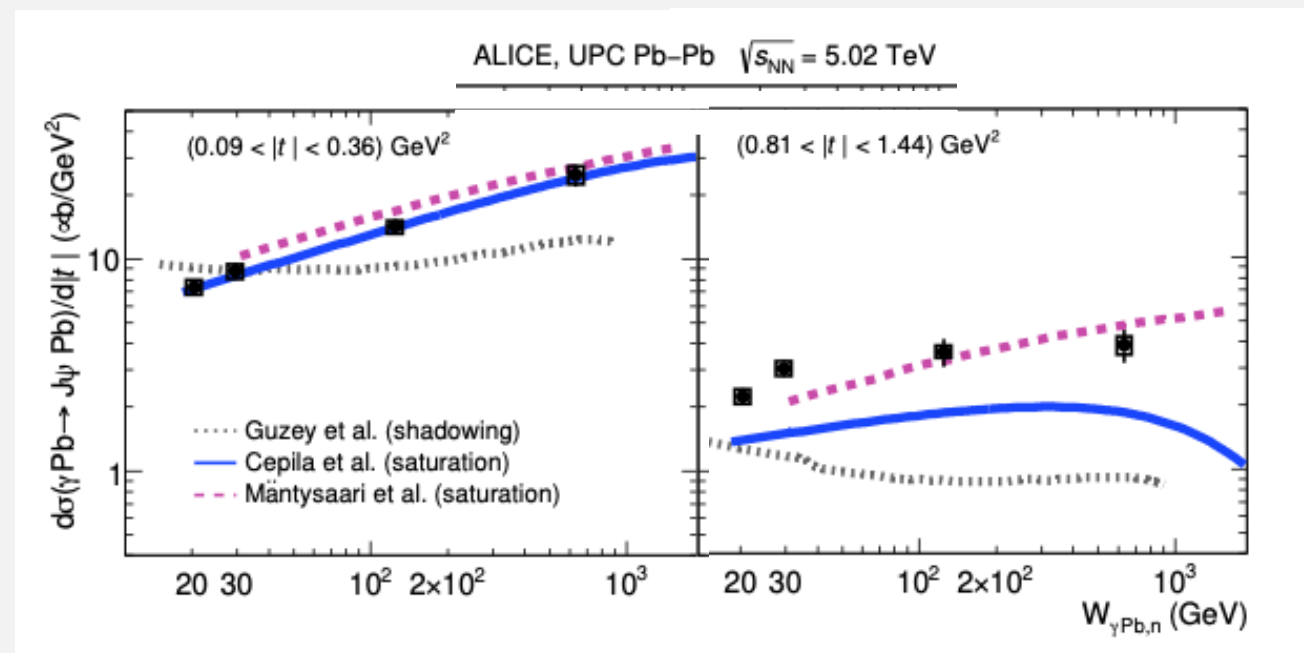
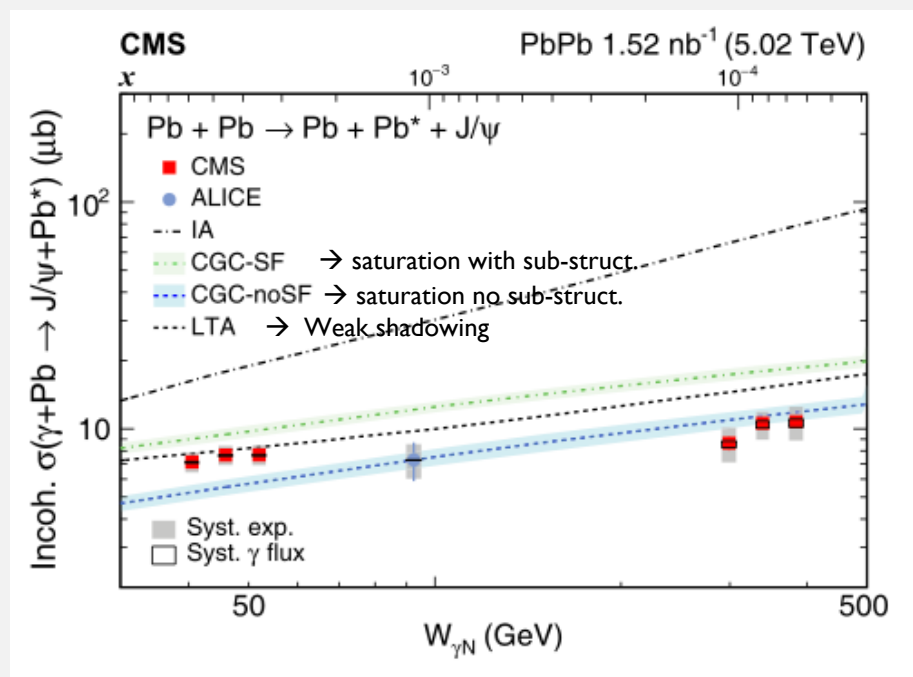
[ALICE, Phys. Lett. B 820 \(2021\) 136481](#)
[LHCb, JHEP 11 \(2025\) 103](#)
[CMS-PAS-HIN-24-020](#)



Incoherent J/ψ photoproduction in Pb-Pb UPC (Run 2)

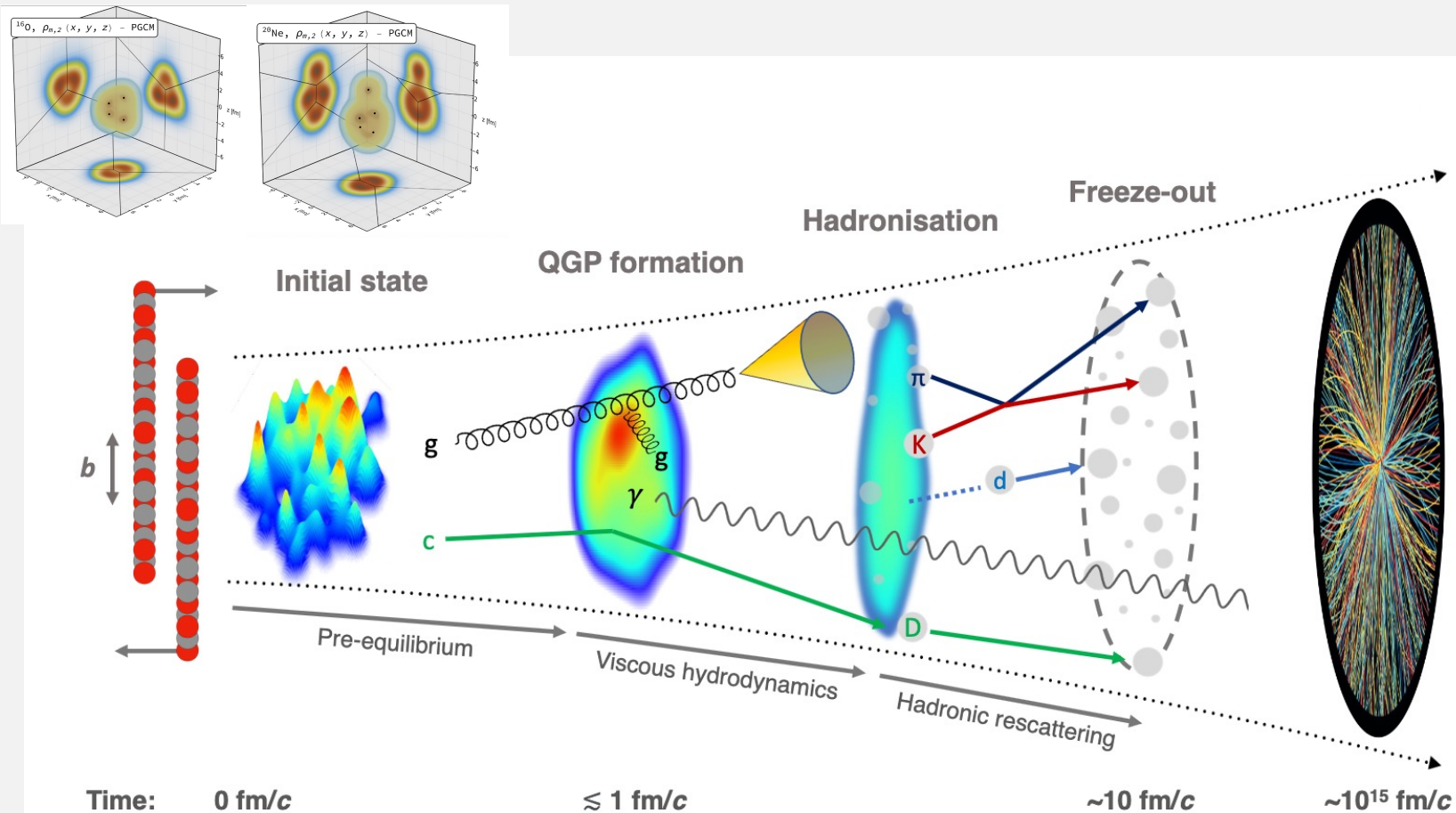
- Probe internal gluonic fluctuations and substructure of nucleus

CMS, PRL 135, 112301 (2025)



- First measurement of energy dependence of incoherent J/ψ photonuclear cross section ($\sigma \sim 6.5 \times 10^{-5}$ for $W_{\gamma N} \sim 400$ GeV)
 - Strong suppression w.r.t IA. No description of low W and high W data by a single model for nuclear effects
- First double differential measurement as a function of $W_{\gamma N}$ and $|t|$:
 - Rise of the incoherent cross section with energy shows evidence of suppression as $|t|$ increases
 - Energy dependence of the suppression better described by saturation-based calculations

VM photoproduction as a new tool to probe nuclear structure ?



Can nuclear structure information survive in high-energy observables from HIC?

- Access to very short timescales (QGP ~ 10 fm/c at the LHC) $\rightarrow$ collision samples a specific nuclear configuration rather than the long-time orientation-averaged distribution
- Indirect information inferred from final state particles (flow)
- Direct information inferred from initial stages (via photoproduction)

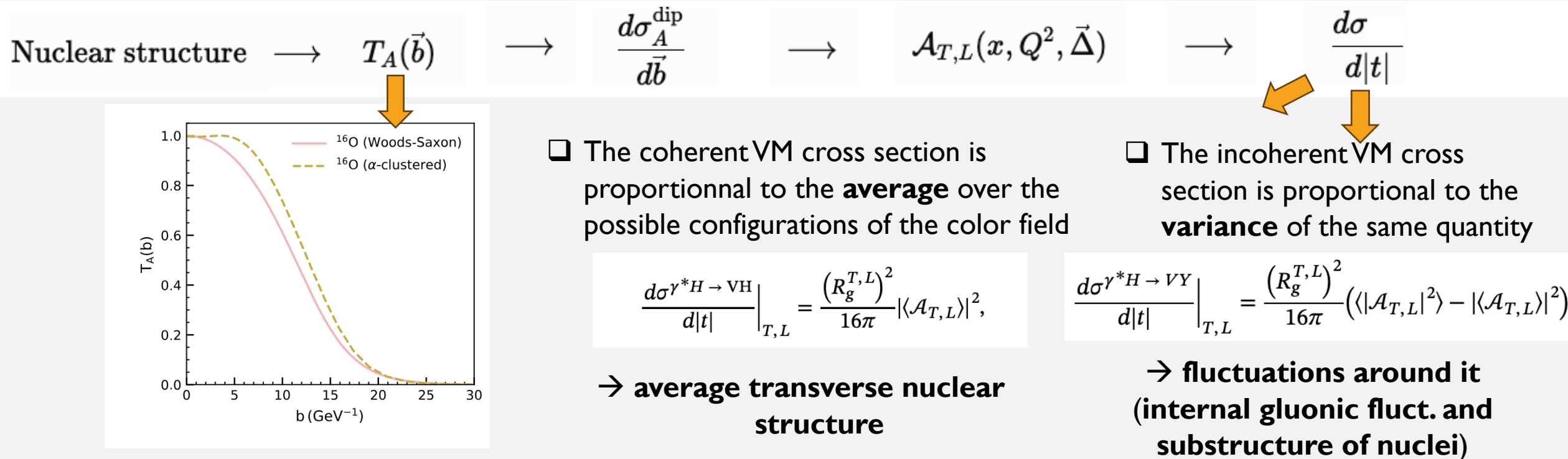
[ALICE, Eur. Phys. J. C 84 \(2024\) 813](#)

Nuclear imaging with VM photoproduction

- From nuclear structure to the measured t-dependent photoproduction cross section of VM (using the formalism from the hotspot* model as an example):

[J. Cepila et al., Phys. Rev. C. 113 \(2026\) 2, 025202](#)

Nuclear structure → **Transverse target profile** → **dipole interaction** → **vector meson amplitude** → **t-dependent cross section**

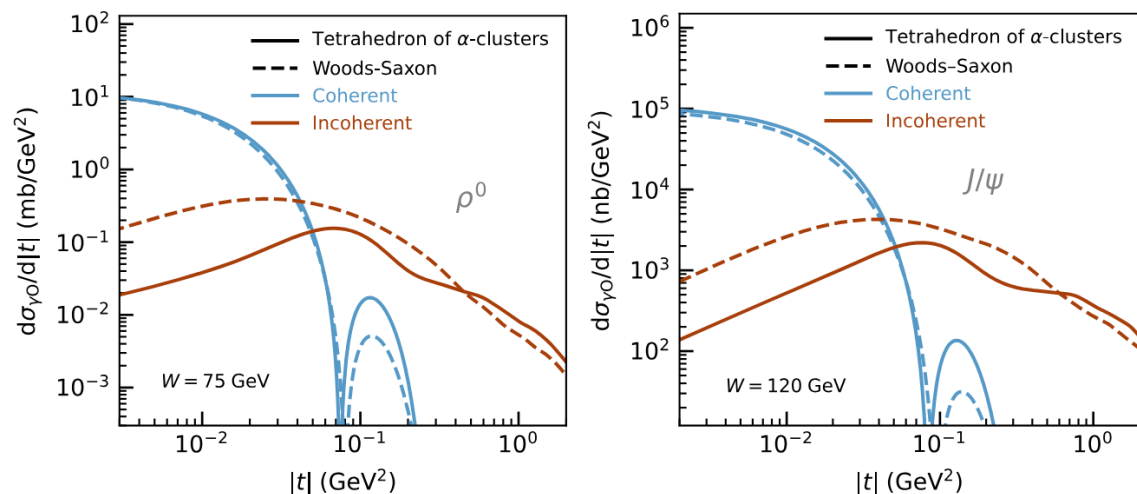


* **Hotspot** : a localized region of enhanced gluon/color-field density used to model subnucleonic fluctuations of the nucleon's transverse structure

How does nuclear structure affect the VM cross section ?

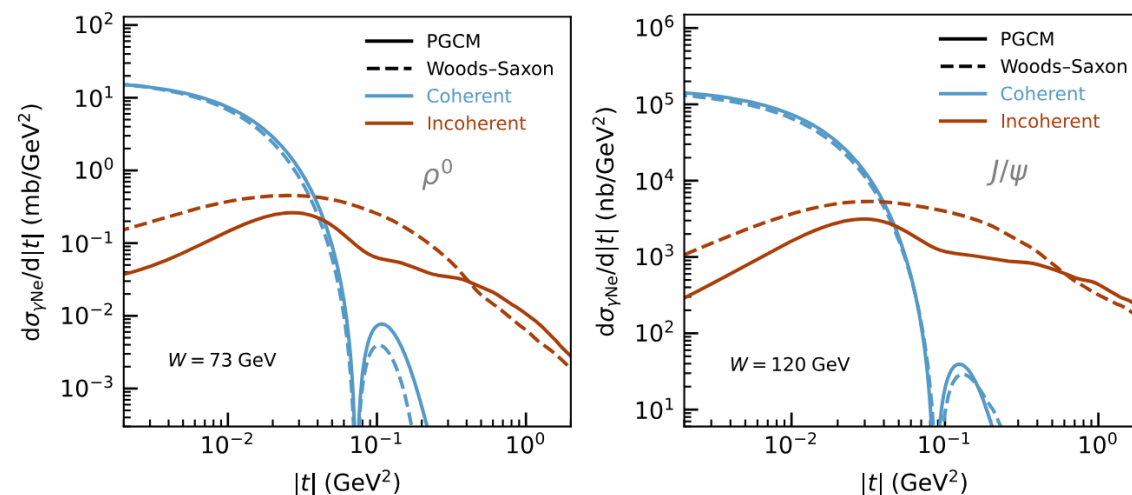
- ❑ Using different vector meson changes the spatial resolution of the probe (for the same underlying nuclear config.)
→ Same nuclear structure probed but different sensitivity to nuclear geometry, gluon field fluctuation and saturation

OO collisions, LHC energies, mid-rapidity



[J. Cepila et al., Phys. Rev. C. 113 \(2026\) 2, 025202](#)

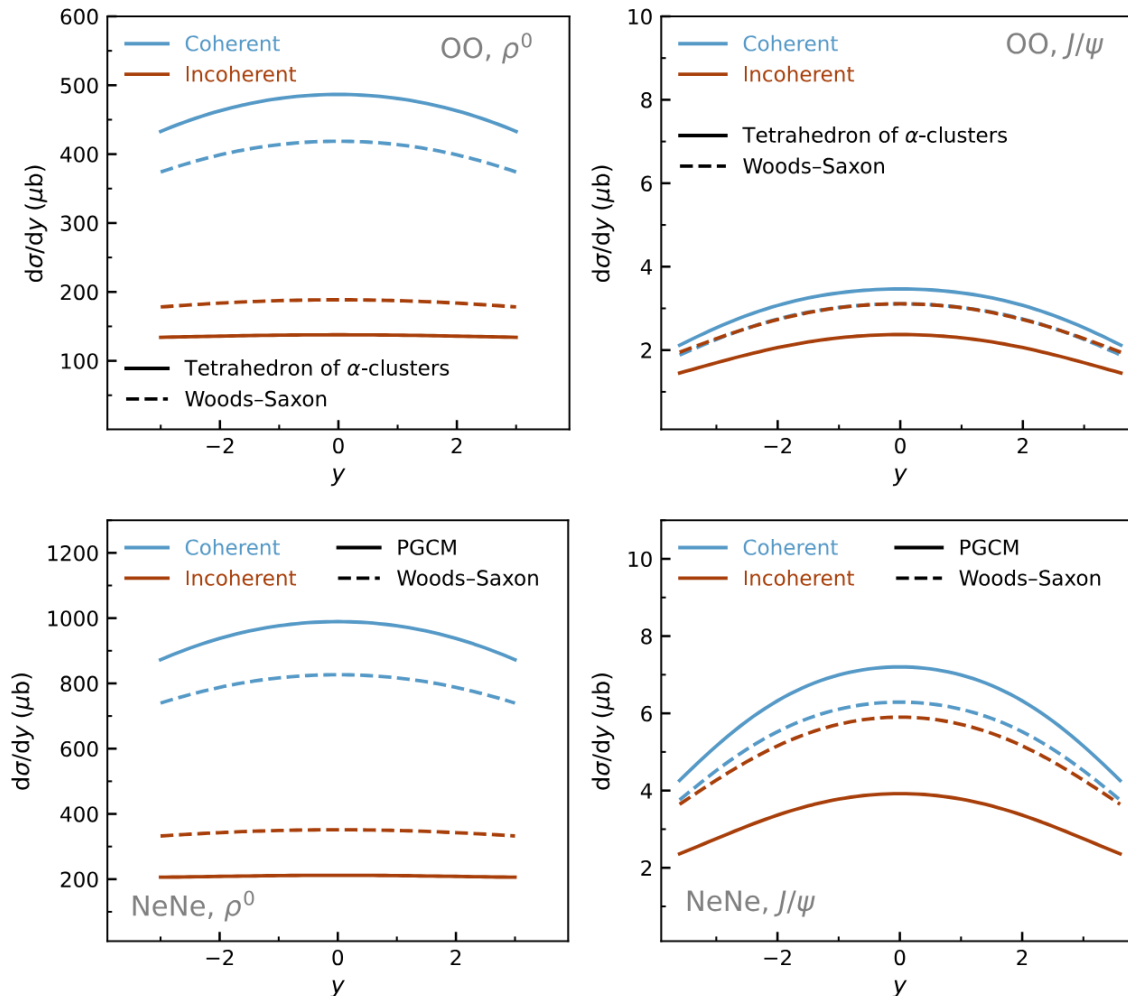
NeNe collisions, LHC energies, mid-rapidity



- ❑ In coherent production, main impact from nuclear structure on the position of the diffractive dip and magnitude of the 2nd diffractive peak
→ Coherent : nuclear structure moves the diffraction pattern
- ❑ In incoherent production, change in shape of the t-differential cross section, especially in the $|t|$ range where incoherent production mechanism dominates ($0.1 < |t| < 2$)
→ Incoherent : nuclear structure changes the fluctuation pattern

How does nuclear structure affect the VM cross section ?

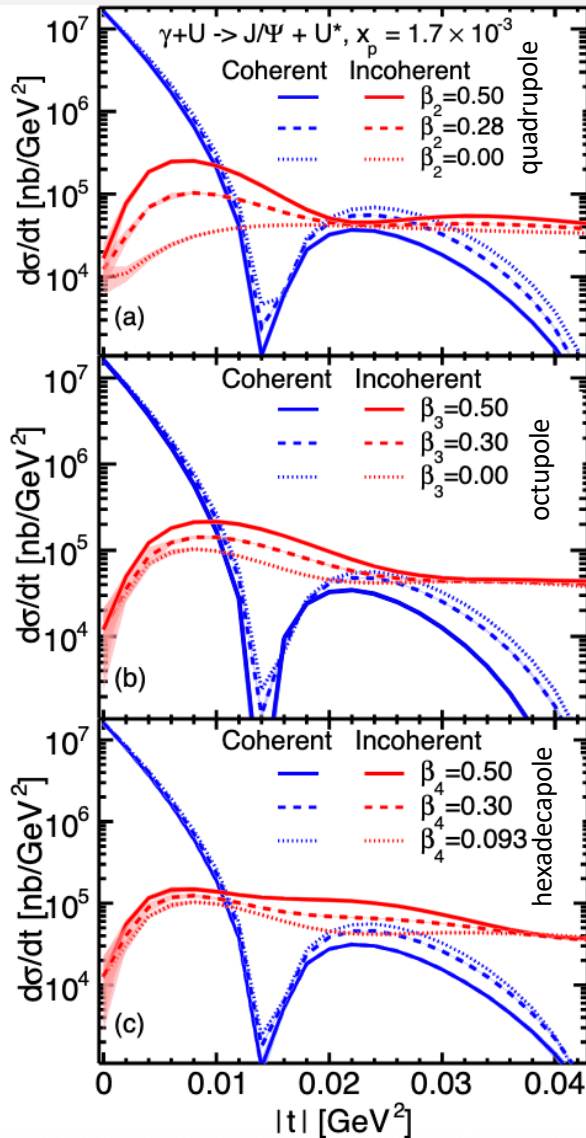
LHC energies, mid-rapidity



Interesting pattern for J/ψ

- WS models predict similar cross section for coherent and incoherent photoproduction
- α -cluster predictions for coherent and incoherent production strongly differ (especially in NeNe)

How does nuclear structure affect the VM cross section ?



☐ Predictions from Color Glass Condensate + hotspot model

☐ Coherent VM photoproduction

- $|t|$ -differential VM photoproduction cross section also affected by nuclear deformation at large $|t|$ (2nd diffractive peak)

☐ Incoherent VM photoproduction

- Cross section increases with increasing degree of deformation
- Different types of deformation manifest in different $|t|$ regions

→ Would be interesting to have similar calculations for LHC

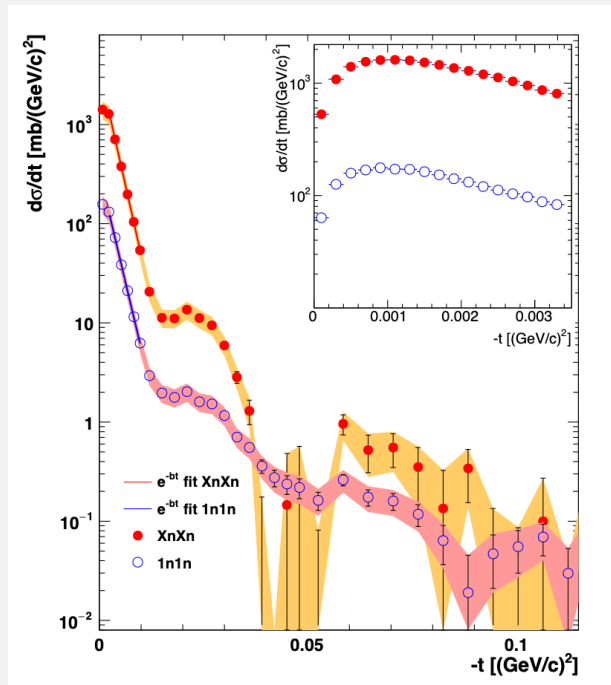
→ Measurements require good experimental precision in order to constrain nuclear models. Feasibility?

e+U collisions, EIC energy

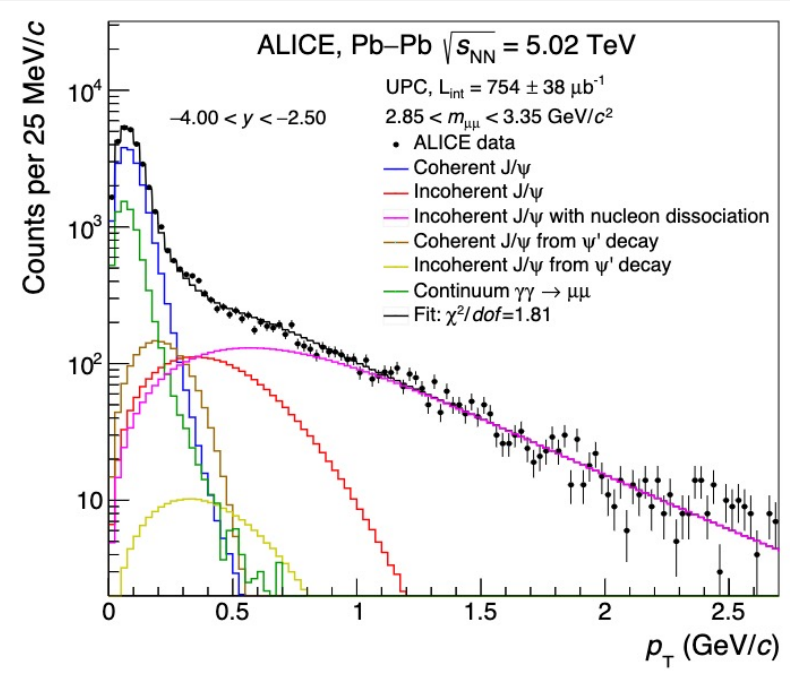
Feasibility of photoproduction measurement to constrain nuclear structure (?)

- ❑ Extraction of second diffractive peak challenging in coherent VM photoproduction, but measurements exist for the abundant ρ^0 (at RHIC and the LHC)
- ❑ Clean coherent/incoherent separation (p_T cut or template fits of p_T distributions)
- ❑ Requires good p_T/t resolution
- ❑ Sufficient statistics needed to also measure higher mass vector mesons to get a global picture

[STAR, Phys. Rev. C. 96 054904](#)



[ALICE, Phys. Lett. B798 \(2019\) 134926](#)

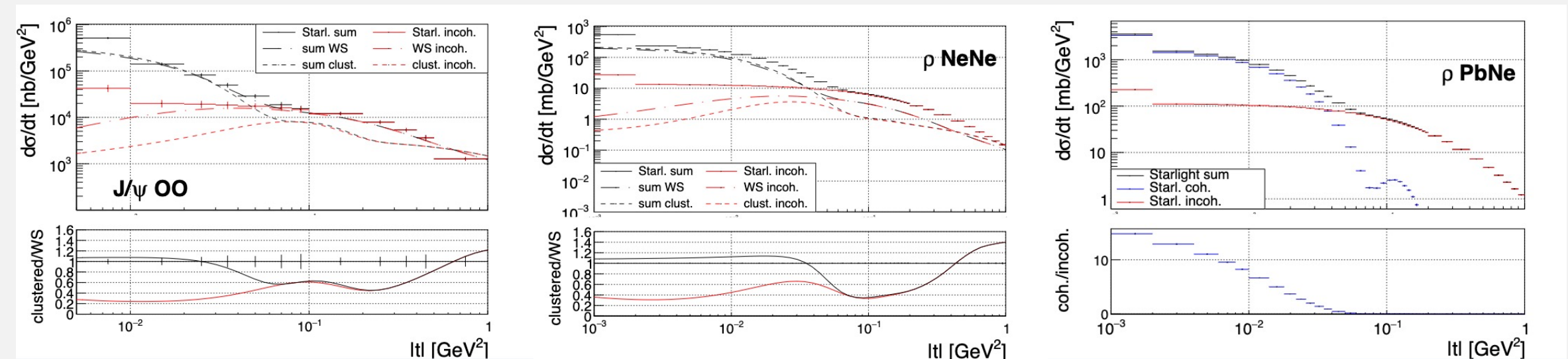


Prospects for measurements in LHCb (STARLIGHT MC simulation)

fid: $2 < y_{VM} < 5$, $p_{T, \text{daughters}} > 0.2 \text{ GeV}$ $2 < \eta_{\text{daughters}} < 5$	Pb-Ar, 71 GeV 2 nb^{-1}		Pb-Ne, 71 GeV 0.02 nb^{-1}		O-O, 5.36 TeV 5.5 nb^{-1}		Ne-Ne, 5.36 TeV 0.6 nb^{-1}	
	$\sigma_{\text{fid.}} \cdot \text{Br}$	N_{LHCb}	$\sigma_{\text{fid.}} \cdot \text{Br}$	N_{LHCb}	$\sigma_{\text{fid.}} \cdot \text{Br}$	N_{LHCb}	$\sigma_{\text{fid.}} \cdot \text{Br}$	N_{LHCb}
$\rho \rightarrow \pi\pi \text{ coh.}$	25.8 mb	52M	16.3 mb	980k	1.31 mb	7.2M	2.44 mb	1.5M
$\rho \rightarrow \pi\pi \text{ incoh.}$	15.5 mb	31M	10.1 mb	610k	0.69 mb	3.8M	1.23 mb	0.7M
$J/\psi \rightarrow \mu\mu \text{ coh.}$	52 nb	100	38 nb	2	145 nb	790	276 nb	170
$J/\psi \rightarrow \mu\mu \text{ incoh.}$	199 nb	400	125 nb	7	160 nb	860	285 nb	170

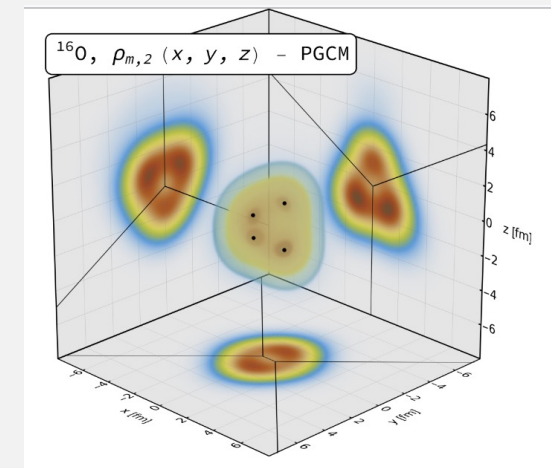
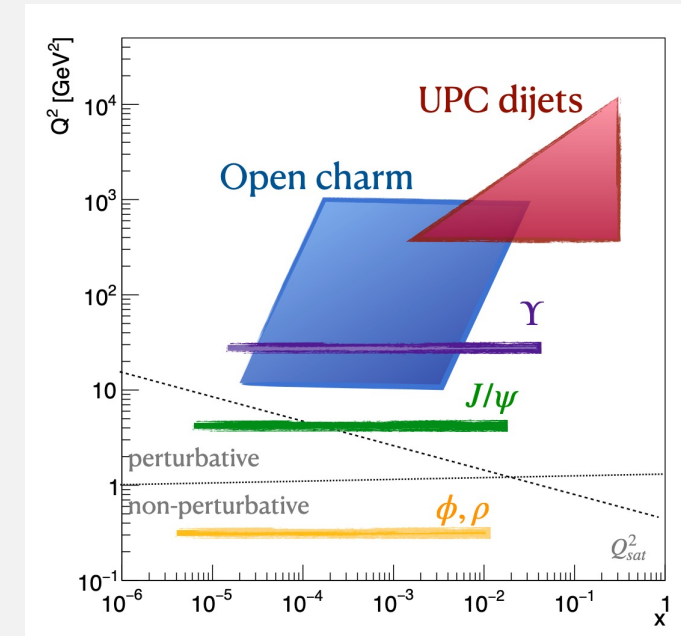
- ❑ Large number of collided nuclei thanks to collider and fixed target modes in LHCb
- ❑ ρ^0 yield expected in LHCb in OO/NeNe/PbAr/PbNe collisions large enough to probe nuclear structure
- ❑ Statistics more scarce for J/ψ , $|t|$ differential-measurement might be possible in OO

Courtesy O. Bylund, presentation at GDR QCD 2026



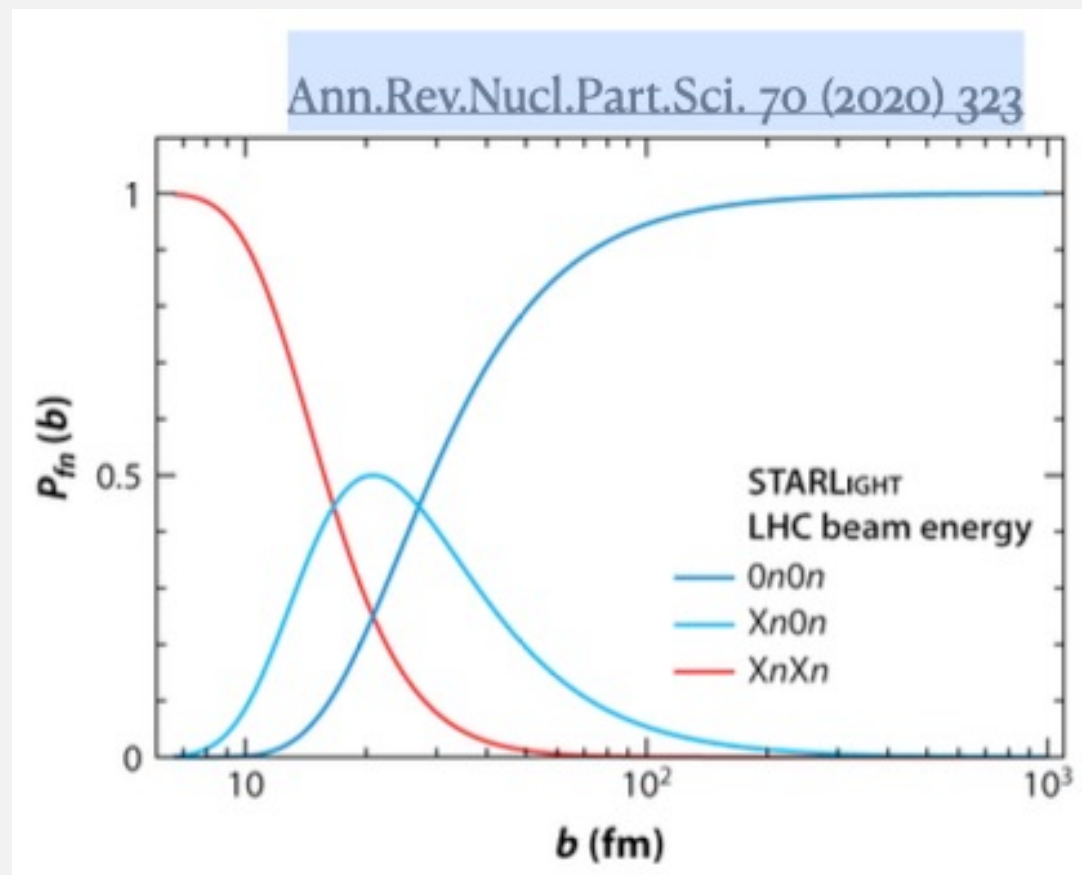
Conclusion

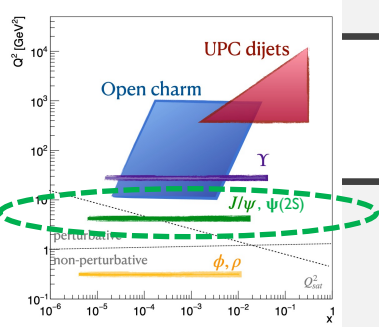
- ❑ Rich variety of UPC results from the 4 LHC experiments
- ❑ Nuclear effects extensively probed with VM photoproduction, now further extended to open-heavy flavours and jets, leading to extended kinematic coverage
- ❑ High energy collisions offer new unique ways to image the nucleus:
 - In particular via photonuclear diffraction:
 - Coherent photoproduction probes average nuclear structure
 - Incoherent photoproduction probes sub-nucleonic structure/fluctuations
 - By scanning x , t and the VM species, we turn complementary photoproduction measurements into a multidimensional image of the nucleus



Back up

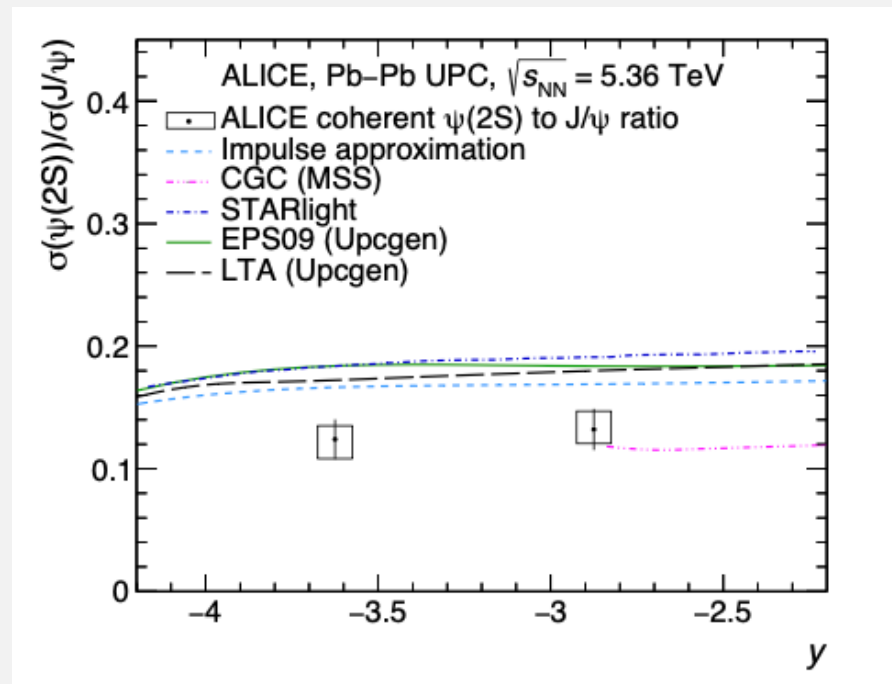
Probability of neutron emission versus b



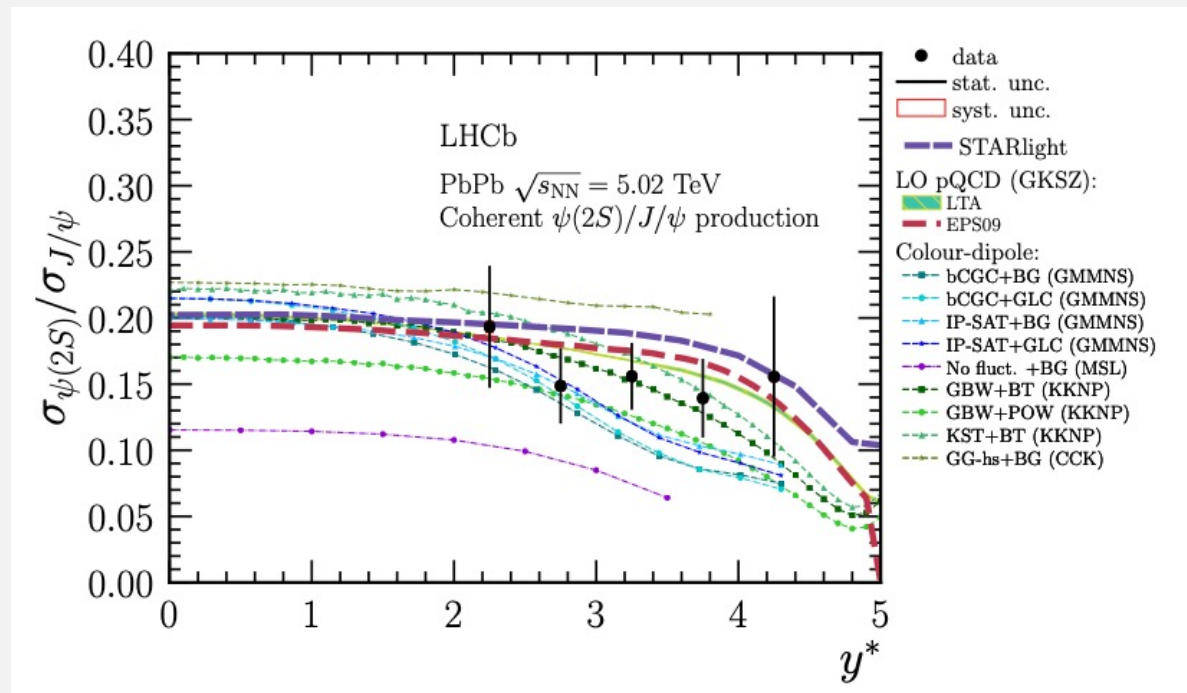


Coherent $\psi(2S)$ photoproduction in Pb-Pb UPC (Run 2&3)

- Probe different dipole size w.r.t J/ψ , hence different sensitivity to nuclear effects
- VM ratio : reduced uncertainties in theoretical predictions (meson wave function, factorization scale)

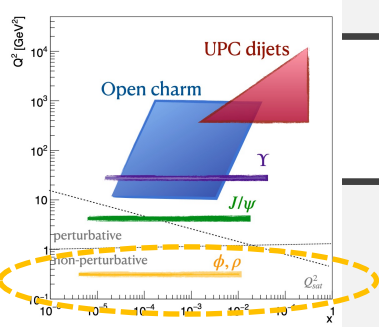


ALICE, arXiv:2605.13569



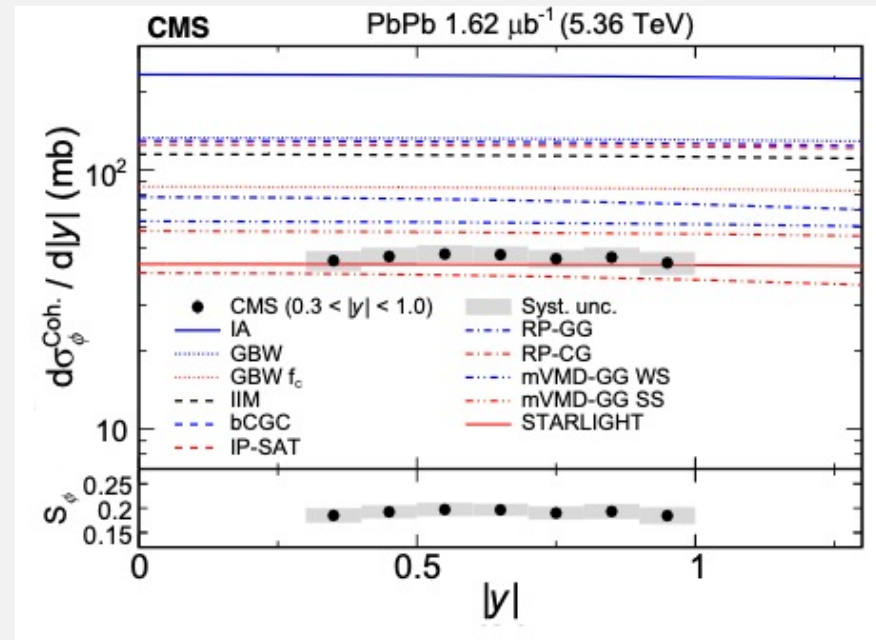
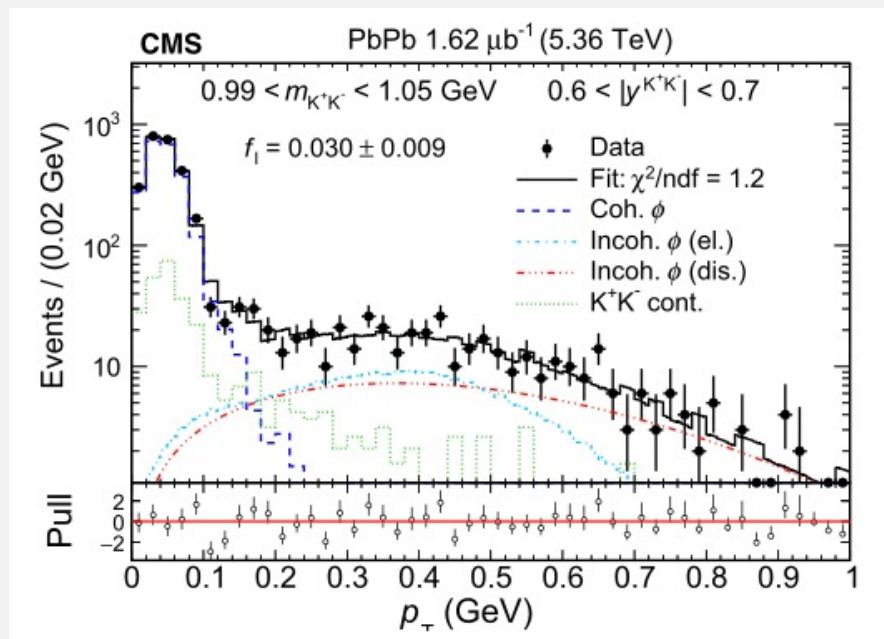
LHCb, JHEP 2023, 146 (2023)

- ALICE: First Run 3 result with improved precision, agreement within 1σ with ALICE/LHCb Run 2 data
- New Run 3 data remain compatible within current uncertainties with all models ($< 2\sigma$)



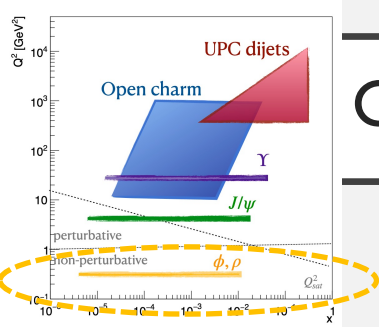
Coherent ϕ photoproduction in Pb-Pb UPC (Run 3)

- ❑ First observation of ϕ coherent photoproduction off heavy nuclei in Run 3
- ❑ Intermediate scale between perturbative J/ψ and non-perturbative ρ



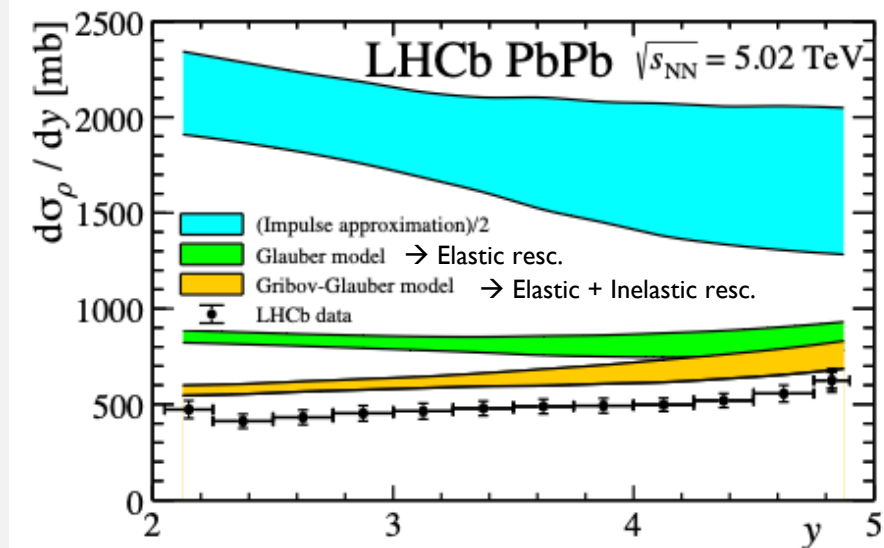
[CMS, Phys. Rev. Lett. 135 \(2025\) 262301](#)

- ❑ Very little dependence of the cross section with rapidity
- ❑ Suppression of the cross section by a factor ~ 5 w.r.t IA
- ❑ Current data tend to favour shadowing-based calculations over available saturation-based predictions
- ❑ Nuclear gluon suppression factor only slightly lower than the $\Upsilon(1S)$ one despite two orders of magnitude in Q^2 , but much lower than the J/ψ one at mid-rapidity

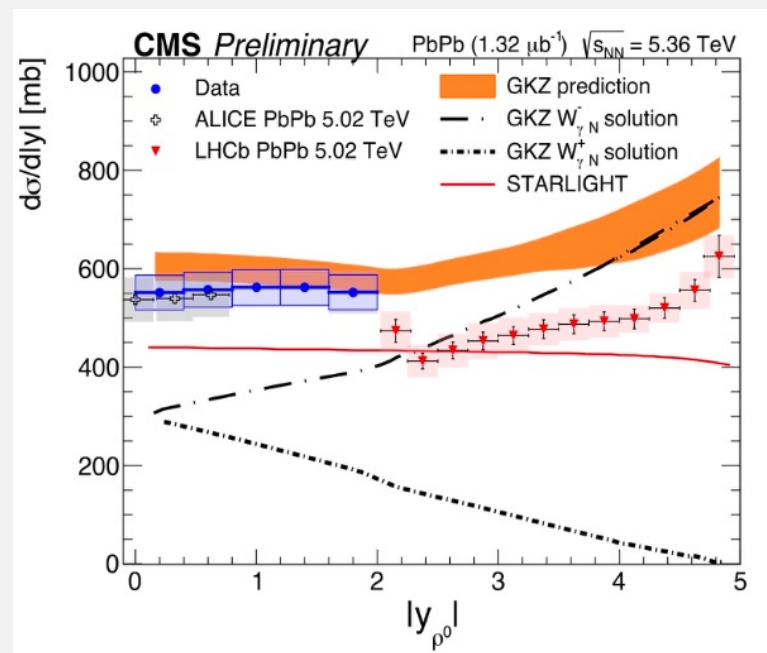


Coherent ρ^0 photoproduction in Pb-Pb UPC (Run 2 & 3)

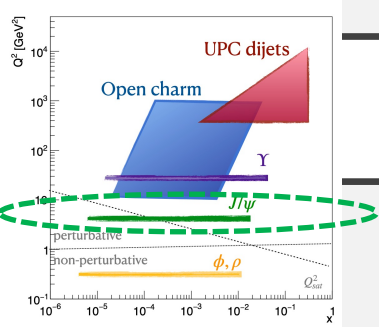
- ❑ Non perturbative regime, LHCb measurement extends down to $x \sim 10^{-6}$
- ❑ ρ^0 produced before interaction with the target $\rightarrow$ strong sensitivity to multiple scattering with nucleons



[LHCb, JHEP 11 \(2025\) 103](#)

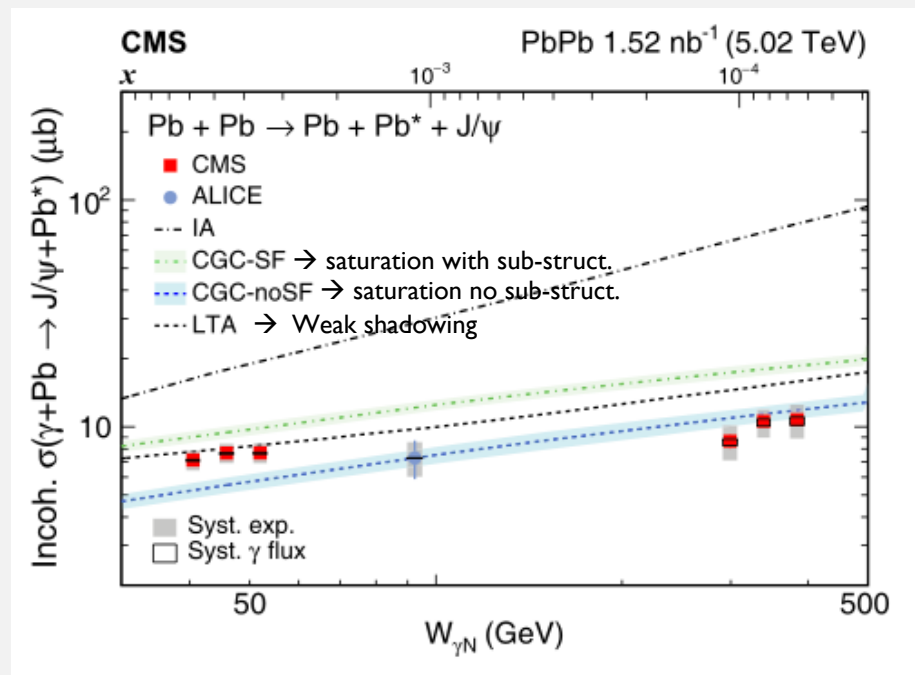


- ❑ Strong suppression w.r.t IA : 0.39 ± 0.03 (low energy γ , large x); 0.05 ± 0.11 (high energy γ , low x)
- ❑ Important effect from elastic and inelastic rescatterings, but still room for additional suppression (saturation?)
- ❑ New CMS preliminary result from Run 3 compatible with mid-rapidity ALICE results (suppression not fully explained by GZK nuclear shadowing)

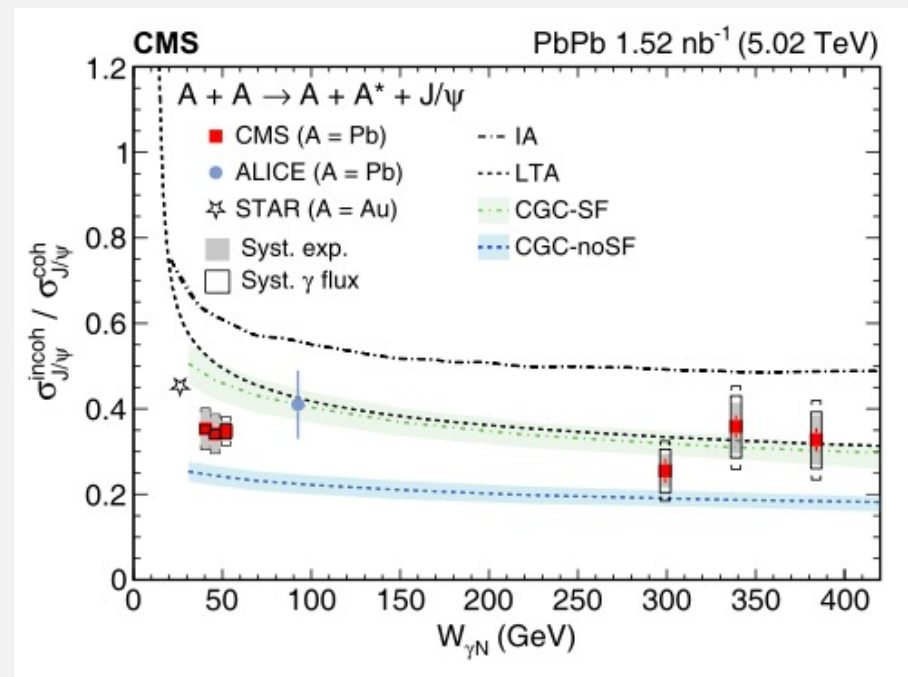


Incoherent J/ψ photoproduction in Pb-Pb UPC (Run 2)

- ❑ Probe internal gluonic fluctuations and substructure of nucleus
- ❑ At low- x , also a good test of the black disk limit



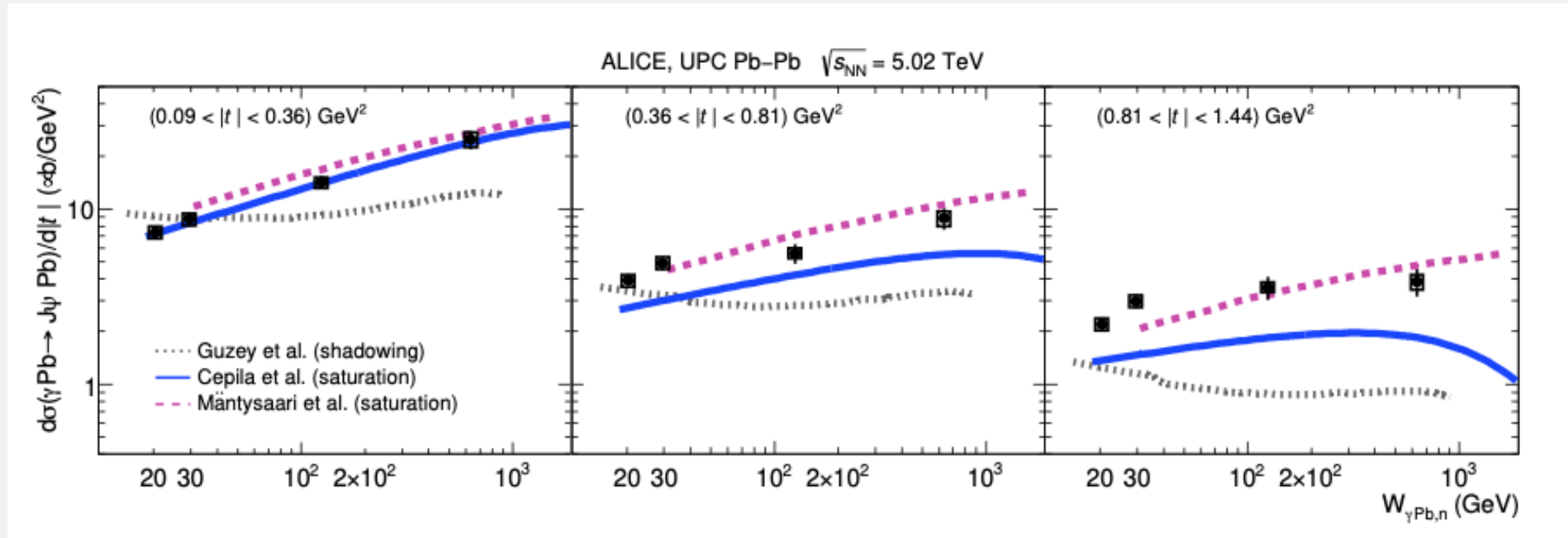
CMS, PRL 135, 112301 (2025)



- ❑ First measurement of energy dependence of incoherent J/ψ photonuclear cross section ($x \sim 6.5 \times 10^{-5}$ for $W_{\gamma N} \sim 400$ GeV)
- ❑ Strong suppression w.r.t IA. No description of low W and high W data by a single model for nuclear effects
- ❑ Incoherent/coherent ratio $\rightarrow$ more suppressed than IA. CGC-SF captures rather well the ratio across $W_{\gamma N}$. Doesn't follow expectations from black disk limit

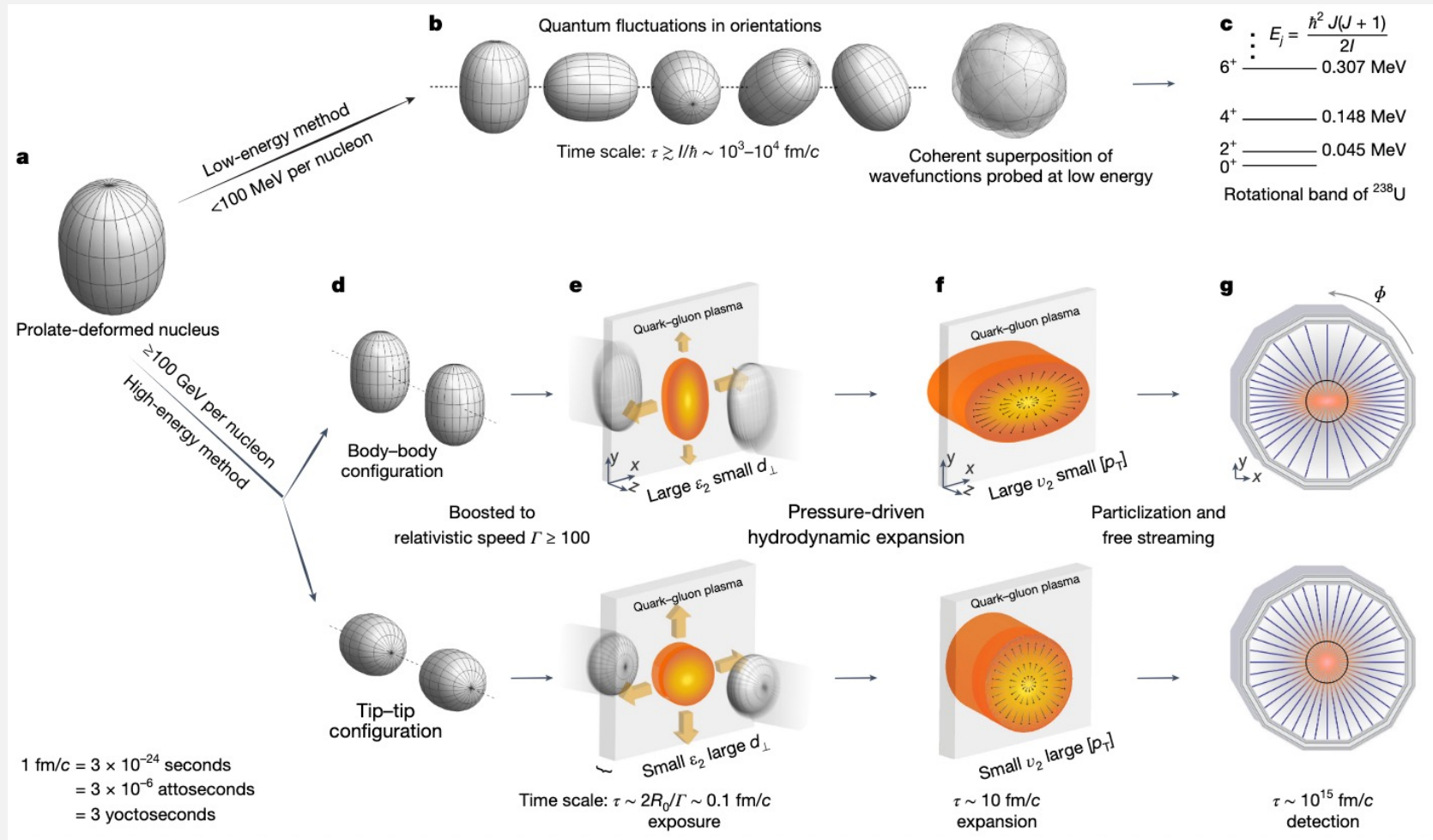
Incoherent J/ψ photoproduction in Pb-Pb UPC (Run 2)

[ALICE, arXiv:2503.18708](https://arxiv.org/abs/2503.18708)



- ❑ First double differential measurement as a function of $W_{\gamma N}$ and $|t|$
- ❑ Rise of the incoherent cross section with energy shows evidence of suppression as $|t|$ increases
- ❑ The observed energy dependence of the suppression is better described by saturation-based calculations than by the shadowing model of Guzey et al.

From flow measurements to the imaging of the nucleus

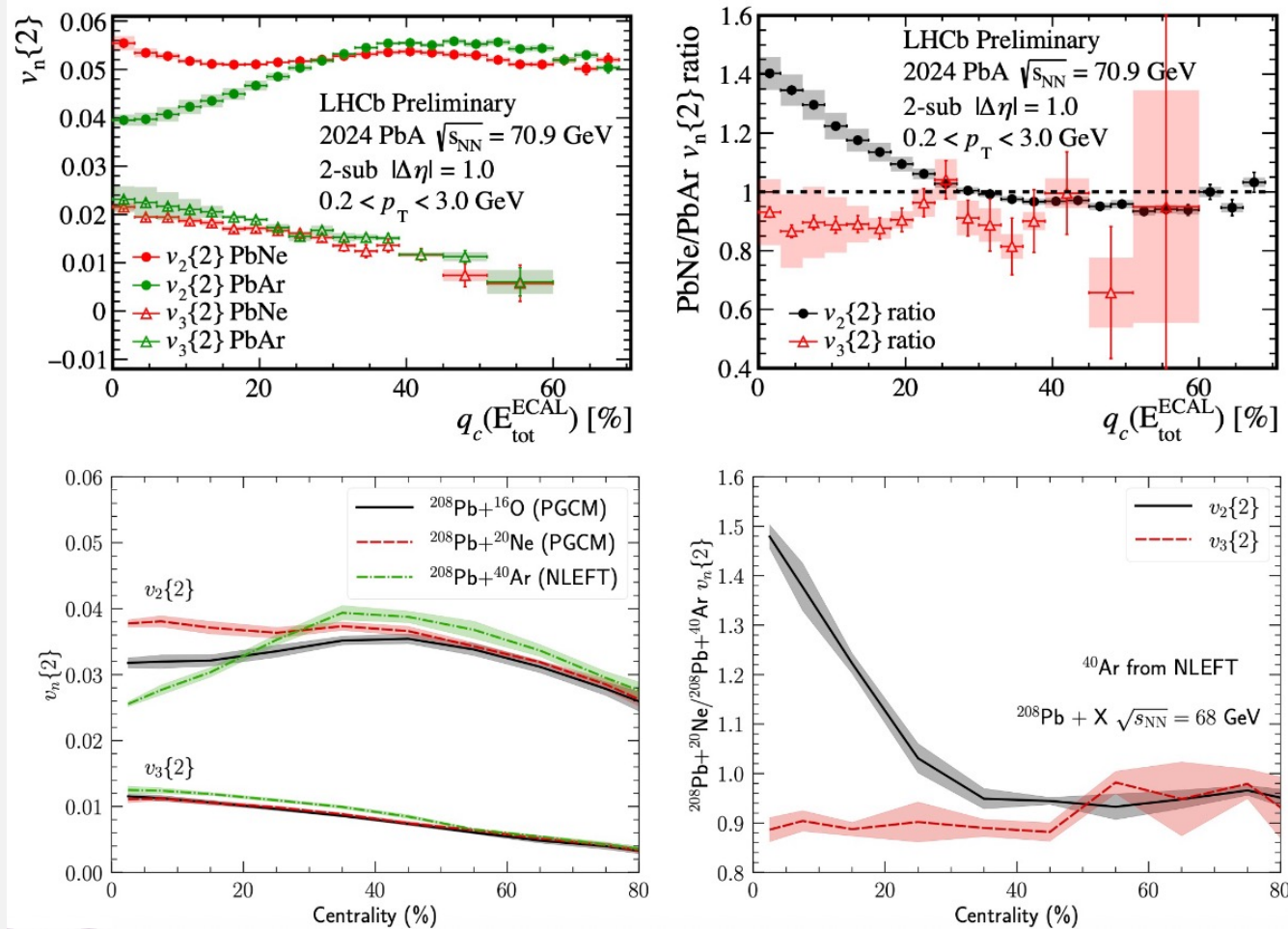


[STAR, Nature 635, 67-72 \(2024\)](#)

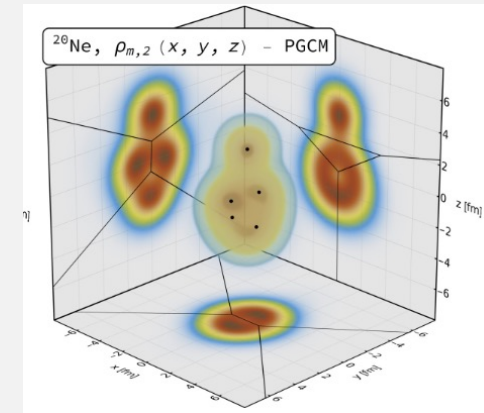
- ☐ Toward $b = 0$, no spatial anisotropy for spheric nucleus
- ☐ The collision snapshot of spatial matter distribution is imprinted in final state particles through hydro expansion
- ☐ Expect different v_2 magnitude for tip-tip and body-body nucleus configurations
- ☐ Even small deformation can lead to sizable v_n
- ☐ Different harmonics ($v_2, v_3 \dots$) probe different aspects of deformation (quadrupole, octupole...)

Flow data (LHCb) confrontation to nuclear models

Low energy fixed target PbNe and PbAr data



- ❑ Significant difference between $v_2\{2\}$ of PbNe and PbAr towards most central collisions
- ❑ Confirmed in the PbNe/PbAr $v_2\{2\}$ ratio plot greater than unity
- ❑ Qualitative agreement with 3+1D hydro model with ab-initio nuclear structure (PGCM, NLEFT)
- ❑ Suggest bowling-pin shape of ^{20}Ne nucleus and validity of the hydrodynamic description of the hot medium



[LHCb, arXiv:2509.12399v1](https://arxiv.org/abs/2509.12399v1)

[G. Giacalone et al., Phys. Rev. Lett. 134 \(2025\) 082301](https://arxiv.org/abs/2509.12399v1)

[C. Shen, QM2025](https://arxiv.org/abs/2509.12399v1)

[G. Giacalone et al., arXiv 2402.05995](https://arxiv.org/abs/2402.05995)

Nuclear imaging with VM photoproduction

- ❑ From nuclear structure to the measured t -dependent photoproduction cross section of VM (using the formalism from the hotspot* model as an example):

[J. Cepila et al., Phys. Rev. C. 113 \(2026\) 2, 025202](#)

Nuclear structure $\rightarrow$ Transverse target profile $\rightarrow$ dipole interaction $\rightarrow$ vector meson amplitude $\rightarrow$ t -dependent cross section

$$\text{Nuclear structure} \longrightarrow T_A(\vec{b}) \longrightarrow \frac{d\sigma_A^{\text{dip}}}{d\vec{b}} \longrightarrow \mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) \longrightarrow \frac{d\sigma}{d|t|}$$

I. From the nuclear structure to the transverse target profile

- ❑ Different nuclear configurations give different nuclear transverse profile
- ❑ In the hotspot model, the transverse profile of the gluonic color field is constructed from nucleons and hotspots

A : mass number;
 $\vec{b}$: transverse position;
 $\vec{b}_i$: transverse position of nucleon i ;

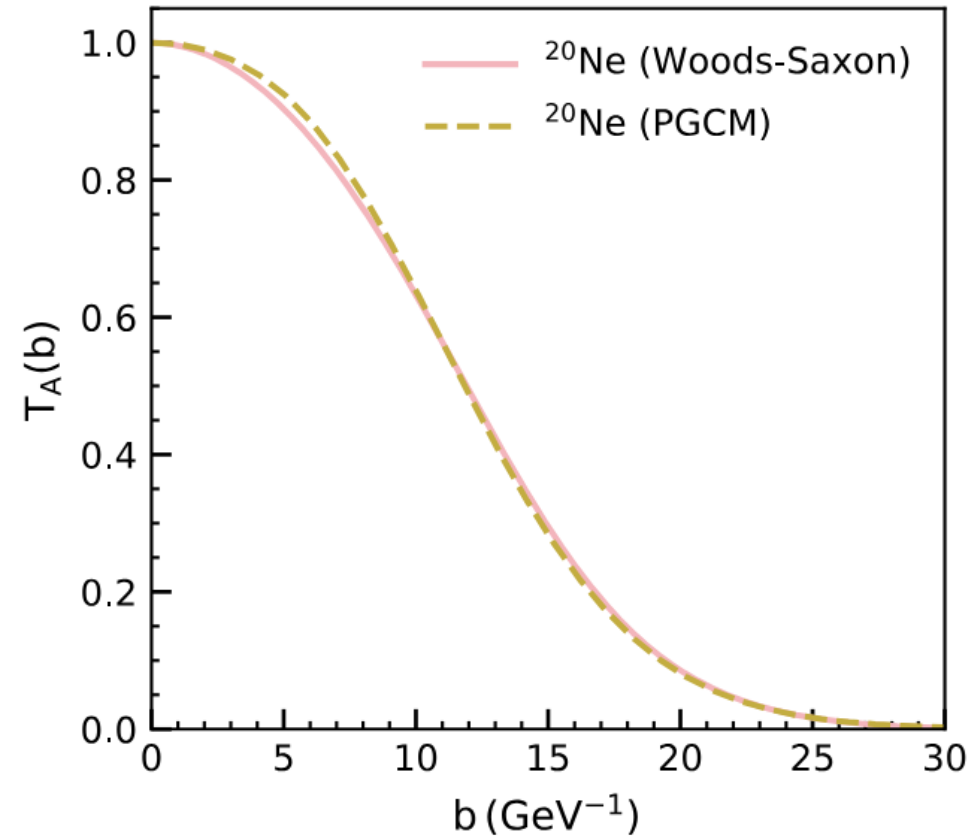
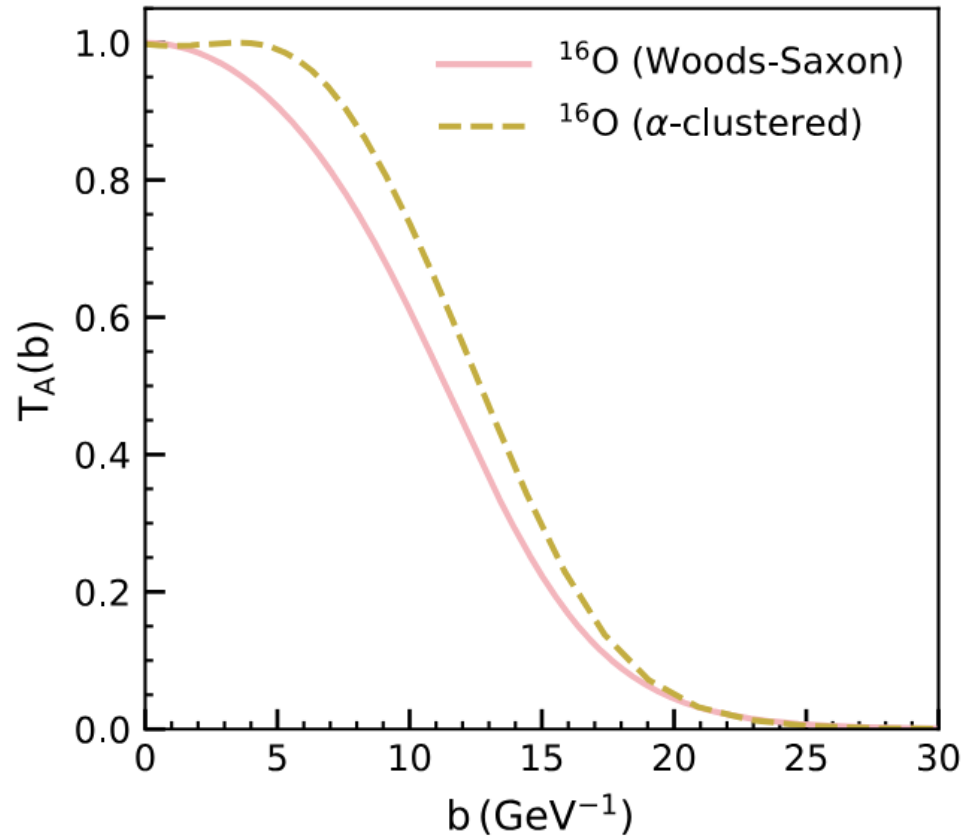
$$T_A(\vec{b}) = \frac{1}{2\pi B_{\text{hs}}} \sum_{i=1}^A \frac{1}{N_{\text{hs}}} \sum_{j=1}^{N_{\text{hs}}} \exp \left[-\frac{(\vec{b} - \vec{b}_i - \vec{b}_j)^2}{2B_{\text{hs}}} \right]$$

$\vec{b}_j$: transverse position of hotspot j inside the nucleon;
 N_{hs} : number of hotspots per nucleon;
 B_{hs} : width of an individual hotspot.

* **Hotspot** : a localized region of enhanced gluon/color-field density used to model subnucleonic fluctuations of the nucleon's transverse structure

Nuclear imaging with VM photoproduction

- Impact of different nuclear structure assumption on $T_A(\vec{b})$



[J. Cepila et al., Phys. Rev. C. 113 \(2026\) 2, 025202](#)

Nuclear imaging with VM photoproduction

2. From $T_A(\vec{b})$ to the dipole-nucleus interaction

$$\frac{d\sigma_A^{\text{dip}}}{d\vec{b}} = 2 \left[1 - \left(1 - \frac{1}{2A} \sigma_0 N(x, r) T_A(\vec{b}) \right)^A \right].$$

dipole scattering amplitude related to small-x QCD dynamics
(depends on Bjorken-x and the transverse size of the dipole)

Transverse profile related to nuclear structure

3. From dipole-nucleus interaction to VM amplitude

$$\mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) = i \int d\vec{r} \int_0^1 \frac{dz}{4\pi} \int d\vec{b} |\Psi_V^* \Psi_{\gamma^*}|_{T,L} e^{-i[\vec{b} - (\frac{1}{2} - z)\vec{r}] \cdot \vec{\Delta}} \frac{d\sigma_A^{\text{dip}}}{d\vec{b}}.$$

Nuclear imaging with VM photoproduction

$$\mathcal{A}_{T,L}(x, Q^2, \vec{\Delta}) = i \int d\vec{r} \int_0^1 \frac{dz}{4\pi} \int d\vec{b} |\Psi_V^* \Psi_{\gamma^*}|_{T,L} e^{-i[\vec{b} - (\frac{1}{2} - z)\vec{r}] \cdot \vec{\Delta}} \frac{d\sigma_A^{\text{dip}}}{d\vec{b}}.$$

Vector meson production
amplitude dependent on Bjorken-
x, photon virtuality and t

Vector meson wave function

Photon wave function

dipole nucleus
interaction profile

Schematically :

$$\int d^2b e^{-i\vec{b} \cdot \vec{\Delta}} [\text{interaction profile}] \sim \mathcal{A}(\vec{\Delta})$$

$$\boxed{\text{spatial structure in } \vec{b} \quad \xleftrightarrow{\text{Fourier}} \quad \text{momentum transfer } \vec{\Delta}}$$

with

$$|t| = \Delta^2$$

Nuclear imaging with VM photoproduction

4. From VM amplitude to t-dependent coherent and incoherent VM photoproduction cross section

In the Good-Walker approach :

- The coherent VM cross section is proportionnal to the **average** over the possible configurations of the color field

$$\left. \frac{d\sigma^{\gamma^*H \rightarrow VH}}{d|t|} \right|_{T,L} = \frac{(R_g^{T,L})^2}{16\pi} |\langle \mathcal{A}_{T,L} \rangle|^2,$$

- The incoherent VM cross section is proportional to the **variance** of the same quantity

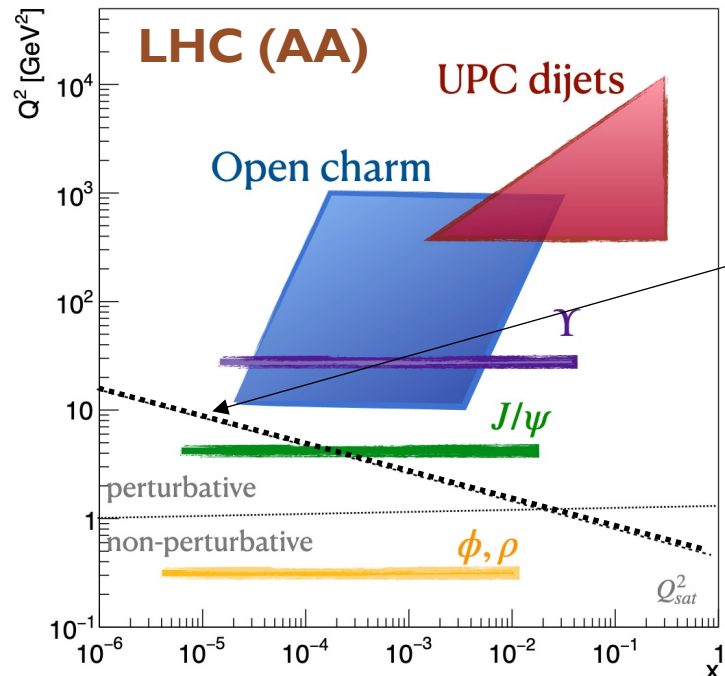
$$\left. \frac{d\sigma^{\gamma^*H \rightarrow VY}}{d|t|} \right|_{T,L} = \frac{(R_g^{T,L})^2}{16\pi} (\langle |\mathcal{A}_{T,L}|^2 \rangle - |\langle \mathcal{A}_{T,L} \rangle|^2)$$

- Hence **t-dependent coherent** VM photoproduction studies the **average transverse nuclear structure**, while the **incoherent** VM photoproduction studies the fluctuations around it (**internal gluonic fluct. and substructure of nuclei**)
- The y -dependence scans Bjorken- x , probing the evolution of the transverse gluon structure as a function of x

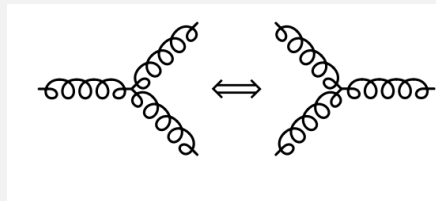
Complementarity of VM photoproduction measurements

- ❑ Using different vector meson changes the spatial resolution of the probe (for the same underlying nuclear config.)
 - Same nuclear geometry, hotspot model, dipole formalism, Good-Walker treatment
 - But different VM wave function, different dipole sizes

→ Same nuclear structure probed but different sensitivity to nuclear geometry, gluon field fluctuation and saturation



At small- x , large gluon densities → gluon recombination + non-linear effects → gluon saturation



Property	ρ^0	J/ψ
Quarks	Light u, d	Charm c
Mass	$m_\rho \simeq 0.77$ GeV	$m_{J/\psi} \simeq 3.10$ GeV
Typical dipole size r	Large	Small
Typical Q^2	Small, ~ 0.3 GeV ²	Larger, ~ 4 GeV ²
x range at typical Q^2	$7 \times 10^{-5} \sim 10^{-2}$	$5 \times 10^{-5} \sim 10^{-2}$
Interaction regime	Non-perturbative	More perturbative
Saturation sensitivity	Stronger	Weaker, but not negligible at small x

Courtesy N. Burasov, LHCP2026