

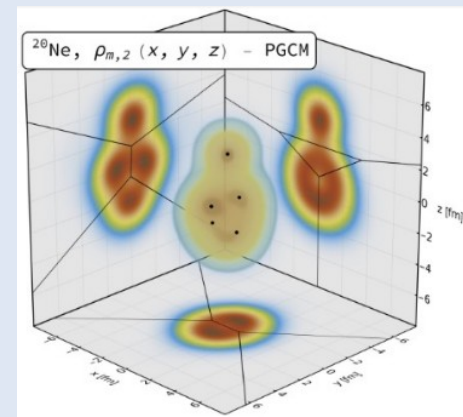
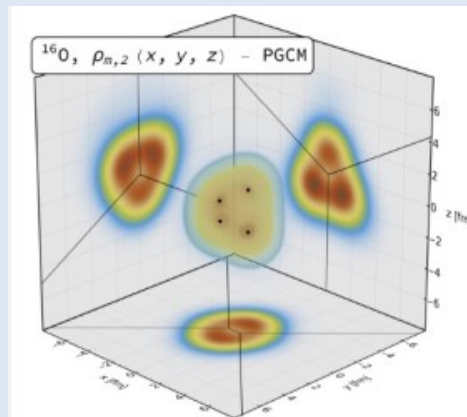
VM photoproduction at the LHC as a probe of nuclear structure

Olga Bessidskaia Bylund

IJCLab Orsay, Université Paris-Saclay, IN2P3/CNRS



The author acknowledges the support of the French Agence Nationale de la Recherche (ANR) under reference ANR-22-CE31-0005 MALICE



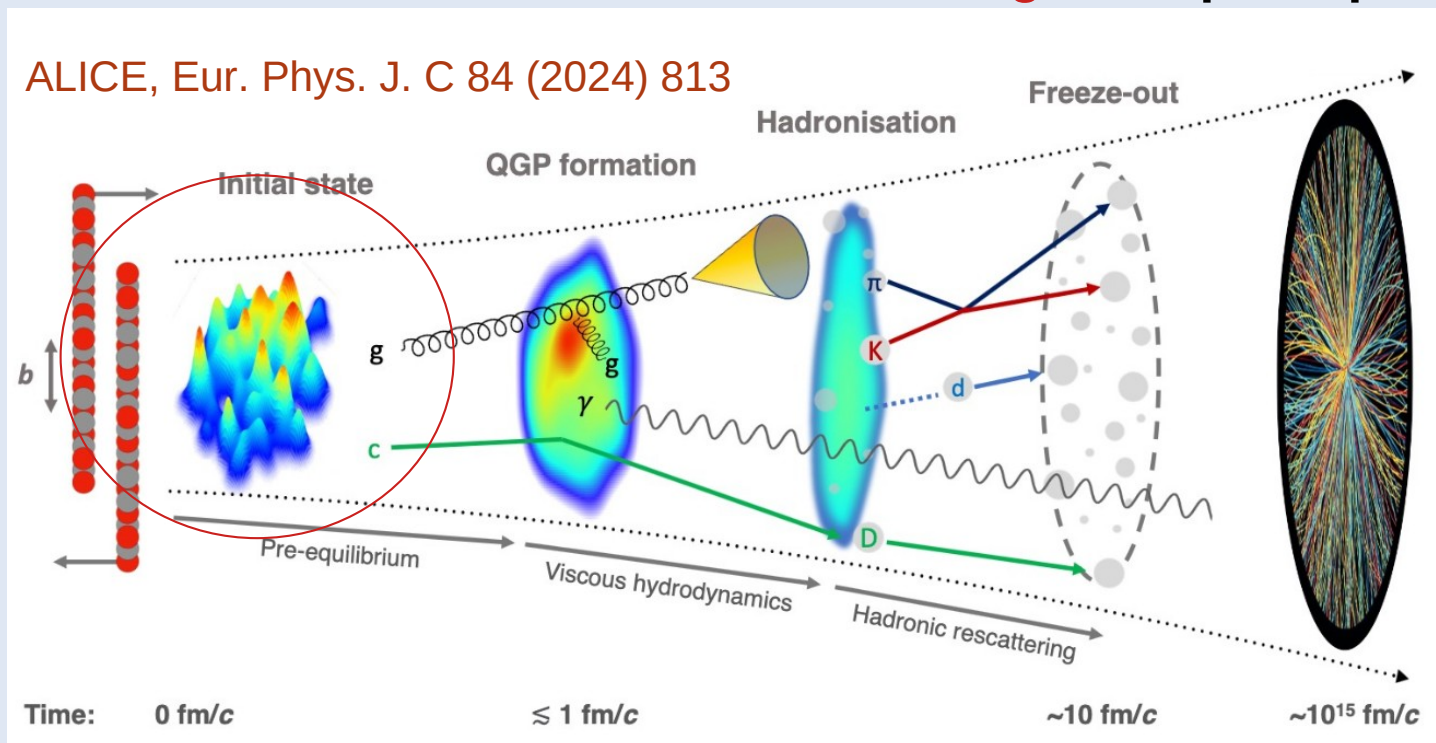
ESNT workshop on clustering and correlations, CEA Saclay

Outline

- A very brief introduction and summary of **flow** observables at the LHC
- **Theoretical** background for **vector meson** (VM) **photoproduction**
- My simulation study: can we see effects of **clustering** in VM photoproduction measurements at the LHC?
- New Ions: what could the LHC do in the **future**?

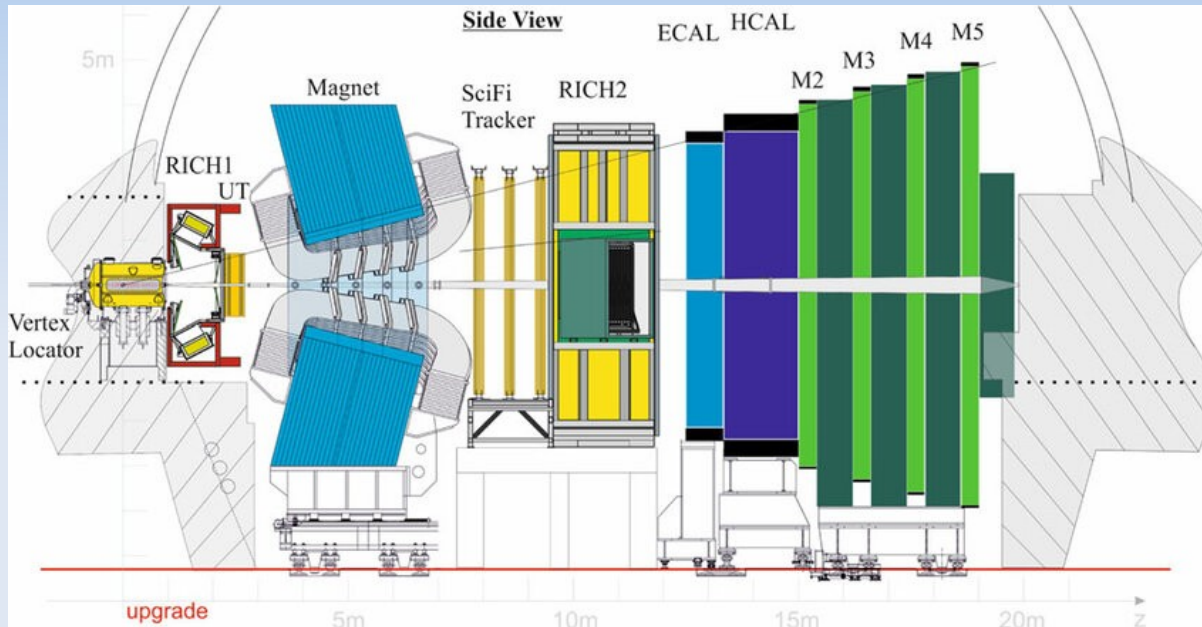
Hadronic ion collisions at the LHC

- Access to nuclear structure from high-energy ion collisions:
 - Very **short time scales** (~ 10 fm/c for QGP) allow probing a **specific nuclear configuration** rather than the long time orientation-averaged distribution
 - Infer **indirect information** from **final state** particles: **flow**
 - Direct** information inferred from **initial stages** via **photoproduction**



The LHCb experiment

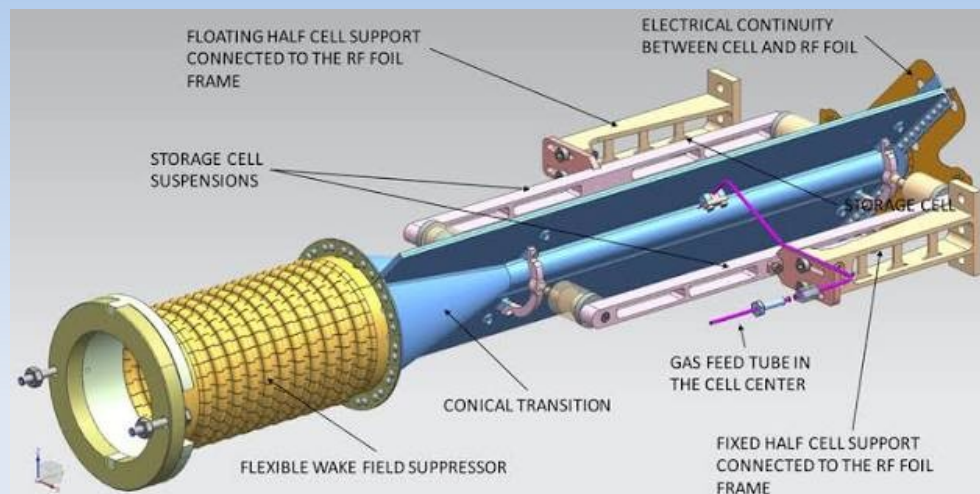
LHCb is a forward single-arm spectrometer, covering $2 < \eta < 5$



Typical collision energies ~ 5 TeV per nucleon pair

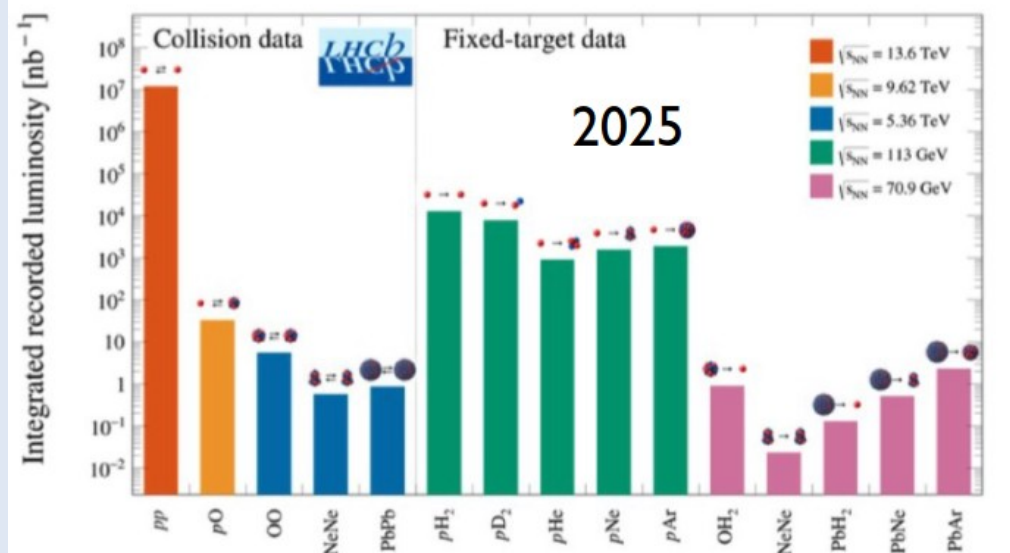
- Provides excellent p_T resolution (momentum in transverse plane)
- Vertex locator registers where the collision occurs and decays
- Muons detected in spectrometer (M2-M5)
- Other charged particles measured by tracker and calorimeters

The LHCb experiment with SMOG2



Fixed target mode enabled by SMOG2

- **Lower energy**, ~ 70 GeV per nucleon pair
- **Flexibility** to inject gas target of choice



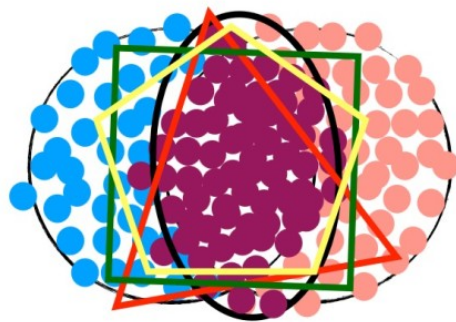
Flow in heavy ion collisions

$$E \frac{d^3N}{dp^3} = \frac{1}{2\pi p_T dp_T dy} (1 + 2v_1 \cos(\phi - \Psi_R) + 2v_2 \cos[2(\phi - \Psi_{RP})] + 2v_3 \cos[3(\phi - \Psi_{RP})] + \dots)$$

Anisotropy

Elliptic flow

Triangular flow



=

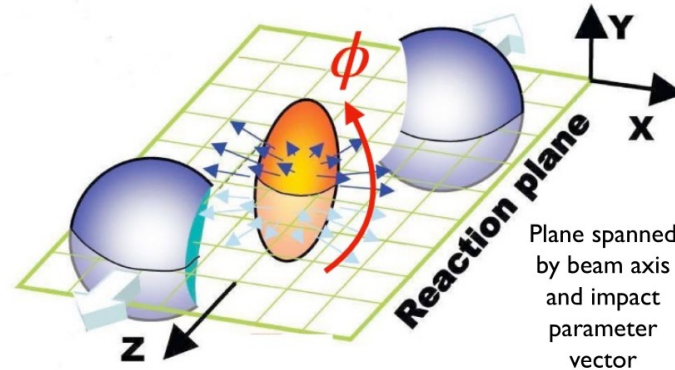
$\epsilon_2 \rightarrow$ elliptical deformation in source

+

$\epsilon_3 \rightarrow$ triangular deformation in source

+

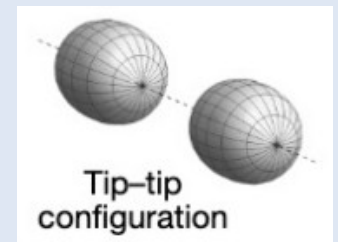
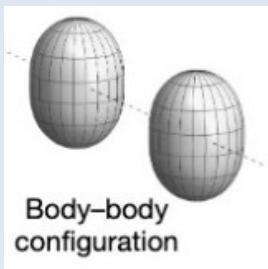
$\epsilon_4 \rightarrow \dots$



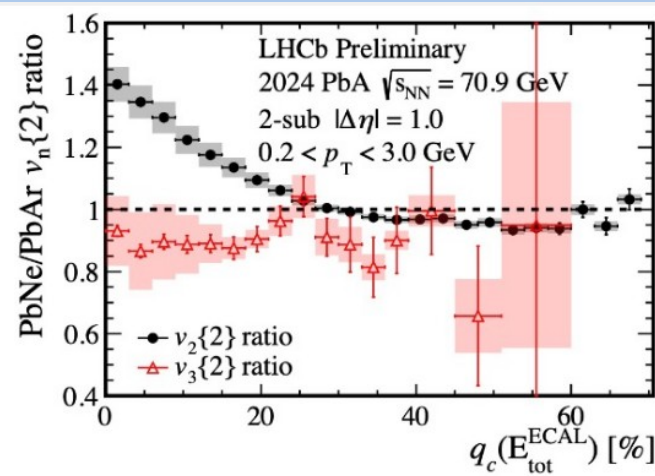
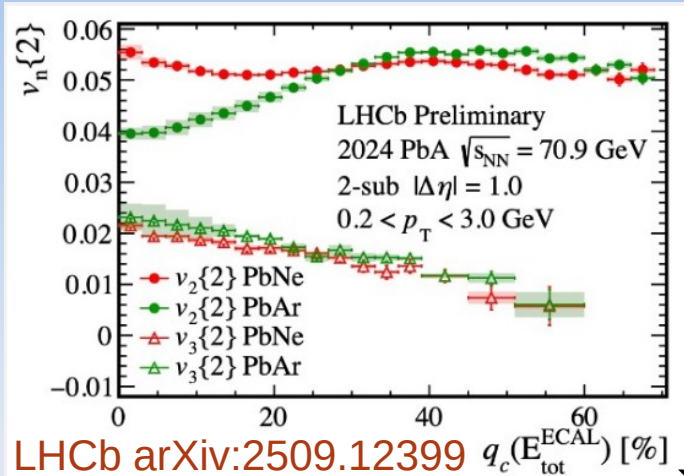
Courtesy H. Zbroszczyk, QM2023

- The collision gives a **snapshot** of spatial **matter distribution**, imprinted on final state particles through hydrodynamic expansion
- In central collisions: no spatial anisotropy for spherical nuclei
- Deformed nuclei: even small **deformations** can lead to sizable v_n

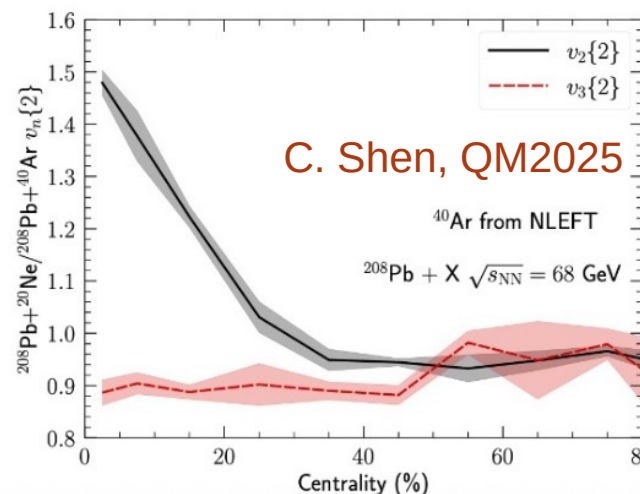
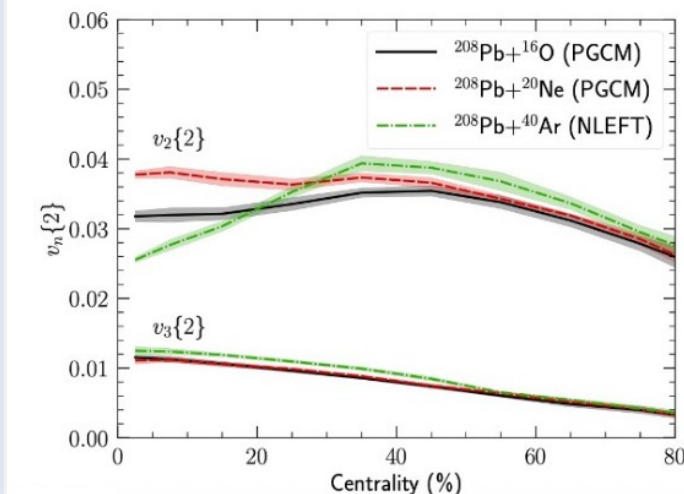
- v_n built from multiparticle correlations (and cumulants)
- Different v_2 for body-body and tip-tip configurations
- Different harmonics ($v_2, v_3 \dots$) probe different aspects of deformation (quadropole, octupole...)



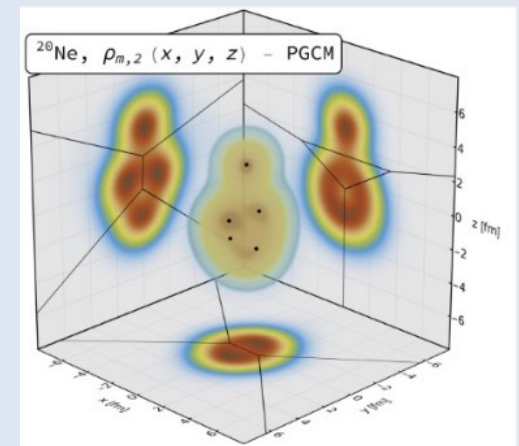
Flow measurements by LHCb



Significant **difference** between $v_2\{2\}$ of **PbNe** and **PbAr** in **central** collisions, confirmed in PbNe/PbAr $v_2\{2\}$ ratio



Suggests **bowling-pin** shape of ^{20}Ne nucleus



G. Giacalone et al., Phys. Rev. Lett. 134 (2025) 082301

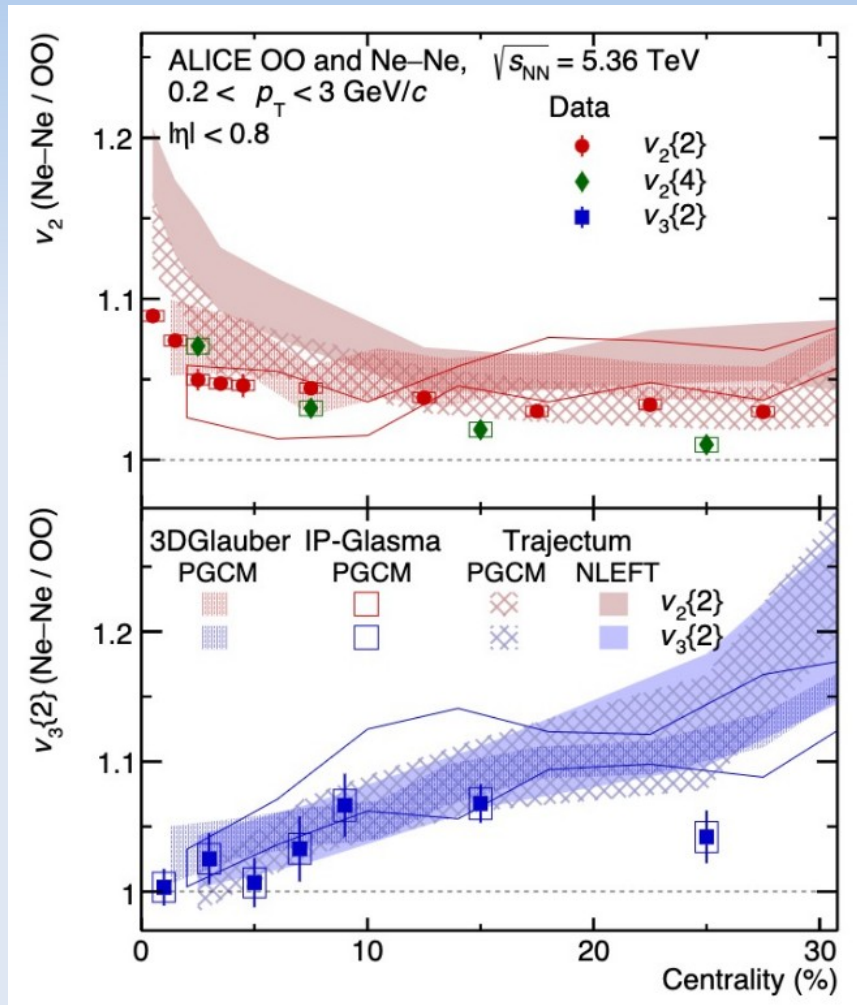
Qualitative **agreement** with 3+1D hydro model
with ab-initio nuclear structure (PGCM, NLEFT)

Olga Bessidskaia Bylund, IJCLab (Orsay)

G. Giacalone et al.,
arXiv 2402.05995

Flow measurements by ALICE

High energy OO and NeNe data

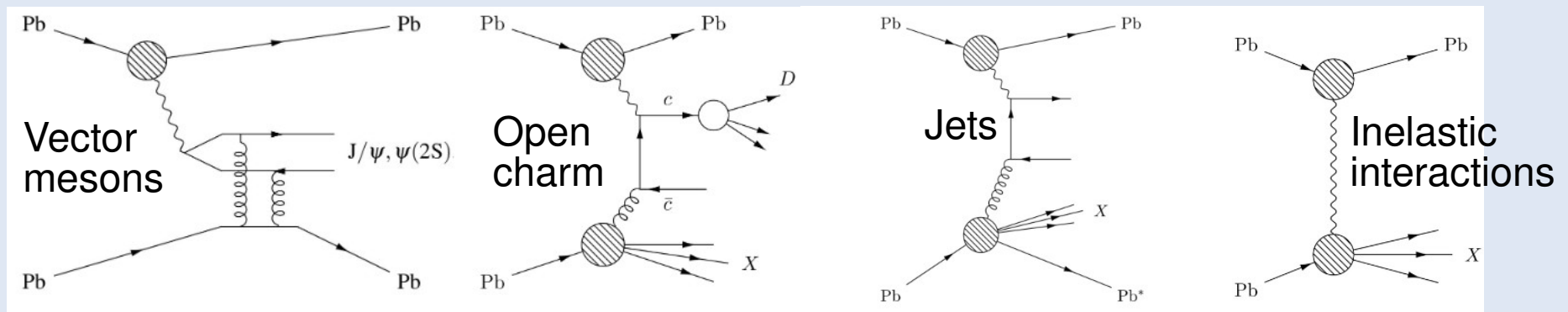
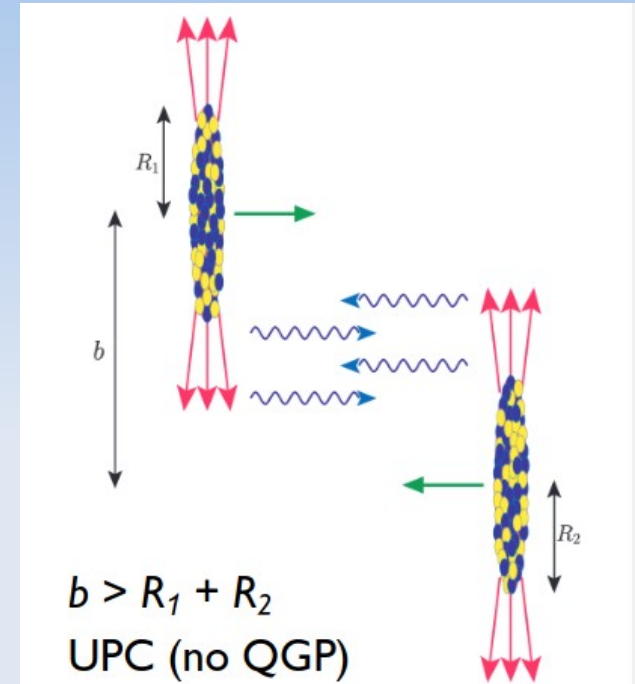


ALICE, arXiv:2509.06428

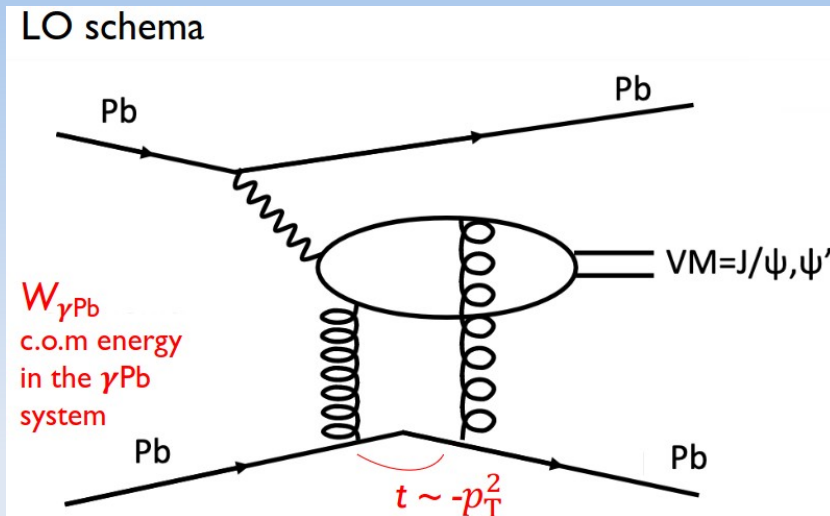
- $v_2\{2\}$ (NeNe/OO) : benefit from reduced uncertainties + **cancellation** of part of final state effects
- **Enhancement** of the v_2 ratio in the most **central** events attributed to stronger **quadrupole** deformation of ^{20}Ne compared to tetrahedral ^{16}O
- $v_3\{2\}$ (NeNe/OO) : **decrease** towards **central** events consistent with tetrahedral structure of ^{16}O (**octupole** deformation)
- Same ab-initio nuclear structure input for two different hydro calculations
 → constraints to early time dynamics of the QGP

Photon-induced processes at the LHC

- The nuclei can interact **electromagnetically**
 - Extremely strong EM fields from ultra-relativistic highly charged ions
 - Separation of pair of nuclei $>$ sum of their radii = **ultra-peripheral collisions** (UPC)
- **Transverse structure** from **diffraction** pattern
- The EM field of a nucleus described as beam of quasi-real **photons**, number of photons $\propto Z^2$
- The LHC as a photon-hadron collider (**QCD**)



Vector meson photoproduction: some definitions



$$\gamma + A \rightarrow VM + A$$

- E.g. for J/ψ: Quasi-real photon fluctuates into a quark-antiquark pair (colour dipole)
- Interaction with the target nucleus via gluon exchange
- Dipole rescatters → on-shell VM

- The rapidity y (“forwardness”) of the VM is related to **Bjorken-x** (longitudinal momentum fraction of nucleon momentum carried by the struck gluons)

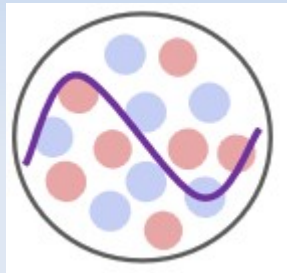
$$x_{\pm} = \frac{m_{J/\psi}}{\sqrt{s_{NN}}} e^{\pm y}$$

- Probing Bjorken-x range 10^{-2} - 10^{-5} at the LHC
 - $m_{J/\psi} = 3.1 \text{ GeV}$, $\sqrt{s_{NN}} = 70 \text{ GeV}$ - 5.36 TeV , y : 0-5 (2-5 in this talk)

Coherence of VM photoproduction

Coherent VM photoproduction

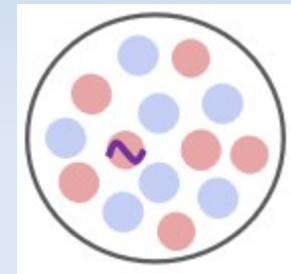
- The photon interacts coherently with the whole target nucleus



- $\langle p_T^{VM} \rangle \sim 1/\text{Radius} \sim 60 \text{ MeV}$ for Pb
- Usually no breaking of target nucleus
- Sensitive to **nuclear parton distribution functions**

Incoherent VM photoproduction

- A single nucleon emits the gluon



- **Higher** $\langle p_T^{VM} \rangle \sim 500 \text{ MeV}$
- Usually breaks the target nucleus
- Sensitive to nuclear **geometry**

p_T : projection of the momentum on the plane transverse to the beam axis

Nuclear imaging with VM photoproduction

Transverse target profile

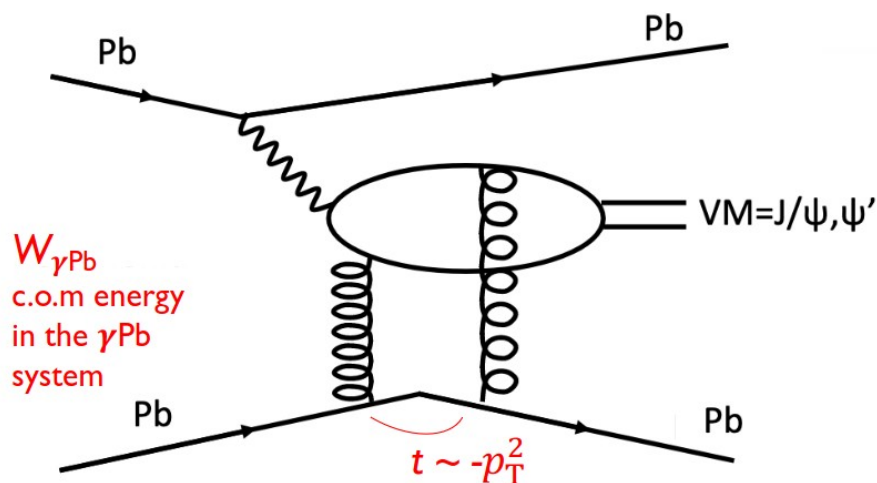
vector meson amplitude

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

Impact parameter-dependent
dipole-nucleus cross section

t-dependent
UPC cross section

LO schema



- The **nuclear structure** inprints on the **t**-distribution
 - Related to momentum transfer to the target ion
 - Evaluated as $|t| \sim p_T^2$ of the VM

Nuclear imaging with VMs: target profile

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

Transverse target profile

In the hot spot model, the transverse profile of the gluonic **colour field** is constructed from **nucleons** and **sub-nucleonic hot spots** (localised regions of enhanced density):

transverse position w.r.t
center of target nucleus

nucleons

transverse position of nucleon i

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

hot spot width

hot spots

transverse position
of hot spot j

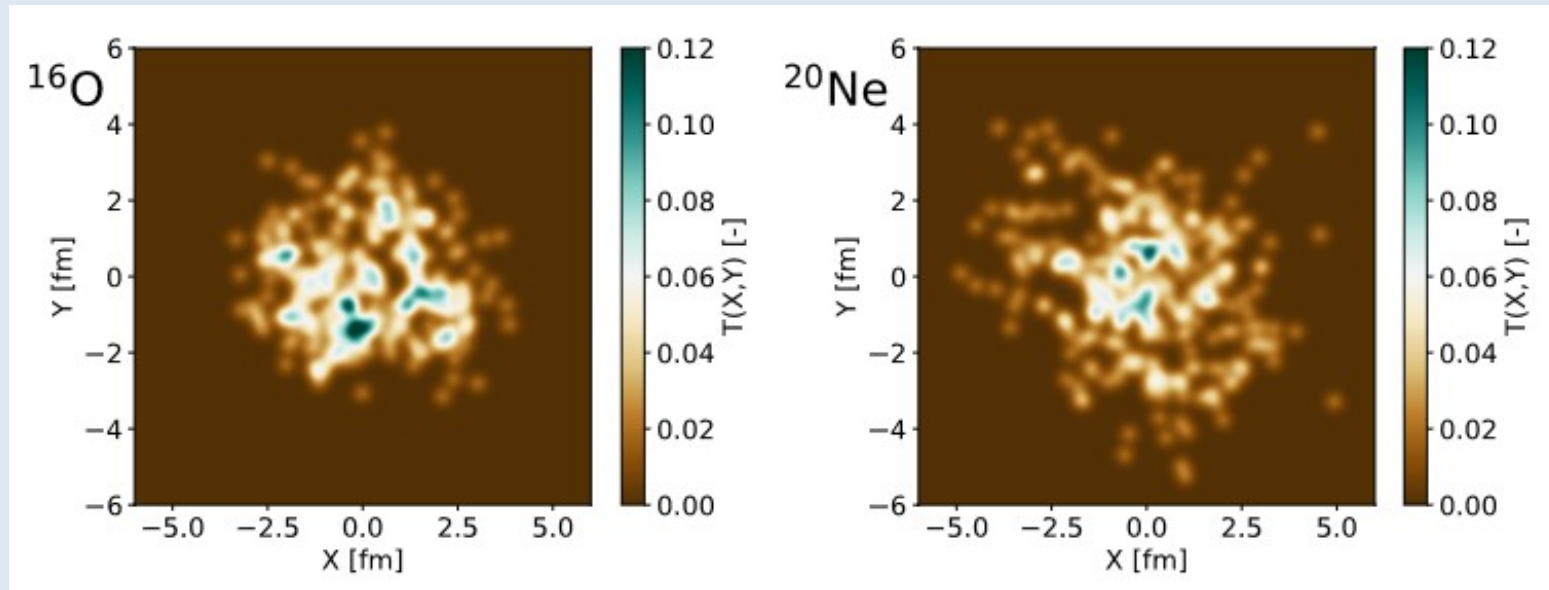
J. Cepila et al., Phys. Rev. C. 113 (2026) 2, 025202

Nuclear imaging with VMs: hot spot distributions

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

Transverse target profile

Example **hot spot configuration** in the cluster model for ^{16}O and ^{20}Ne (PGCM formalism), evaluated at Bjorken- $x=10^{-5}$.



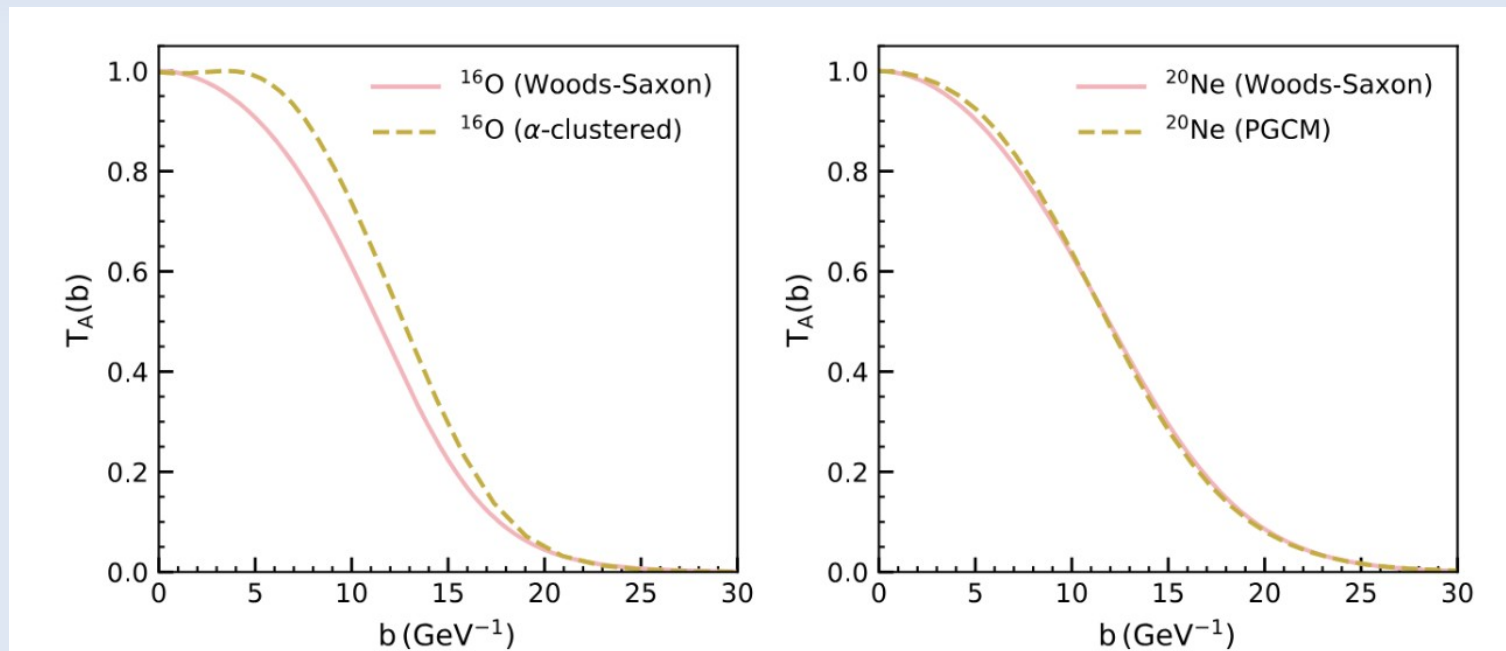
J. Cepila et al., Phys. Rev. C. 113 (2026) 2, 025202

Nuclear imaging with VMs: target profile

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

Transverse target profile

The impact of nuclear structure (deformed Woods-Saxon vs α -clustering) on the nuclear profile $T_A(b)$ in the hot spot model:



J. Cepila et al., Phys. Rev. C. 113 (2026) 2, 025202

collapsed to 1D for the figure

Nuclear imaging with VMs: dipole-nucleus cross section

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

dipole-nucleus cross section

target profile, encoding
nuclear structure

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

dipole scattering amplitude related to small-x QCD dynamics

- depends on Bjorken-x and the transverse size of the dipole
- Includes cold nuclear matter effects (shadowing, saturation)

Nuclear imaging with VMs: vector meson amplitude

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

dipole extension

VM wave function

Dipole-nucleus interaction profile

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

VM production amplitude,
dependent on Bjorken- x ,
photon virtuality Q^2 and t

dipole wave function

Momentum transfer
to target ion, $\Delta^2 = |t|$

The **spatial structure** in $\vec{b}$ is related to the
momentum transfer $\vec{\Delta}$ via a Fourier transform

Nuclear imaging with VMs: t-diferential UPC cross section

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

Good-Walker approach

Coherent VM cross section

- Proportional to the **average** over possible configurations of the colour field

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

- Gives **average transverse nuclear structure**
- Encodes the nucleon **one body density**

Incoherent VM cross section

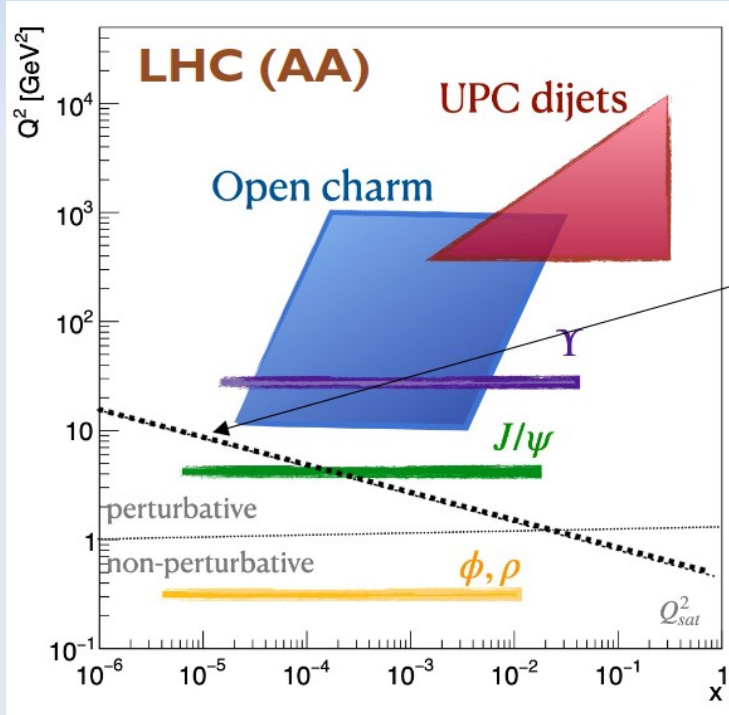
- Proportional to the **variance** of possible configurations of the colour field

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

- Probes internal gluonic **fluctuations** and the **substructure** of nuclei
- Contains the **two-body density**

Complementarity of VM photoproduction measurements

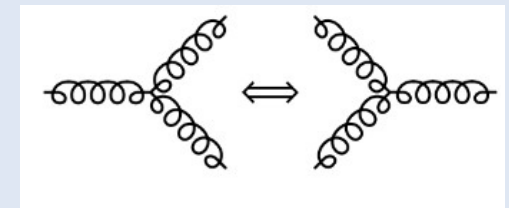
- Using **different VMs** changes the spatial resolution of the probe
 - Same nuclear geometry, hotspot model, formalism
 - But different VM wave function, different dipole sizes, pdf sensitivity



N. Burmasov LHCP 2026

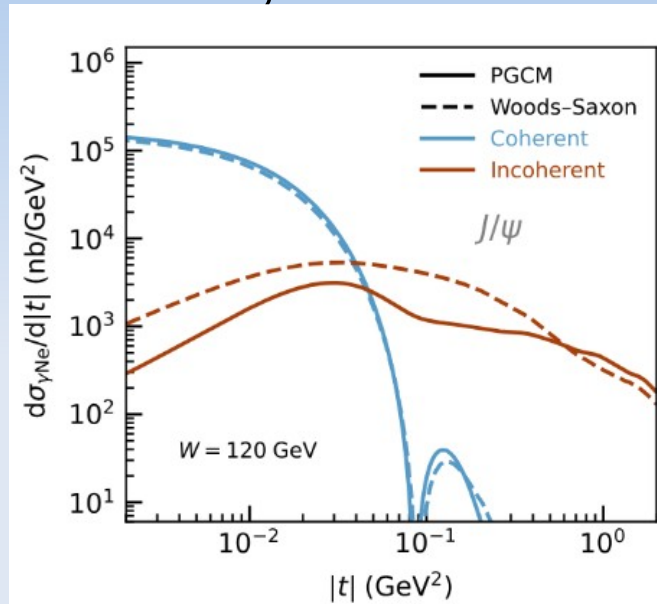
Vector meson	ρ^0	J/ψ
Quark content	light (u, d)	charm pair ($c\bar{c}$)
Mass	0.77 GeV	3.1 GeV
Dipole size	large	small
Typical Q^2	small $\sim 0.3 \text{ GeV}^2$	larger $\sim 4 \text{ GeV}^2$
Typical x range	$7 \cdot 10^{-5} - 10^{-2}$	$5 \cdot 10^{-5} - 10^{-2}$
Interaction regime	Non-perturbative	More perturbative
Saturation sensitivity	Stronger	Weaker; non-negligible small x

Saturation: (hypothetical) stop of growth of gluon density with decreasing x

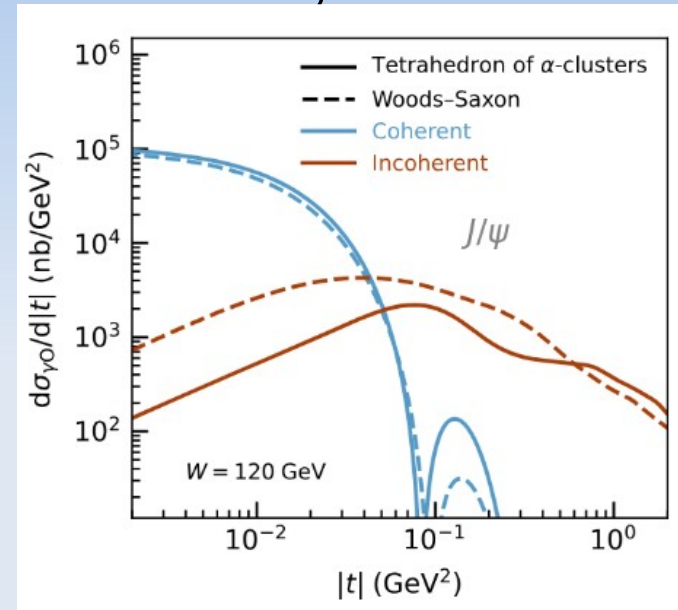


How does nuclear structure affect the VM cross section?

O-O, 5.36 TeV



Ne-Ne, 5.36 TeV

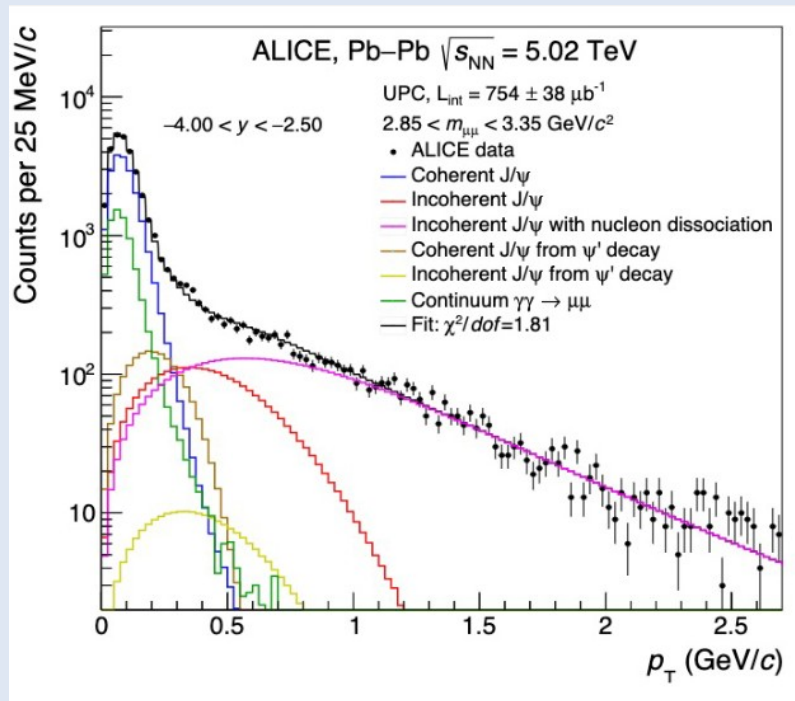


J. Cepila et al., Phys. Rev. C. 113 (2026) 2, 025202

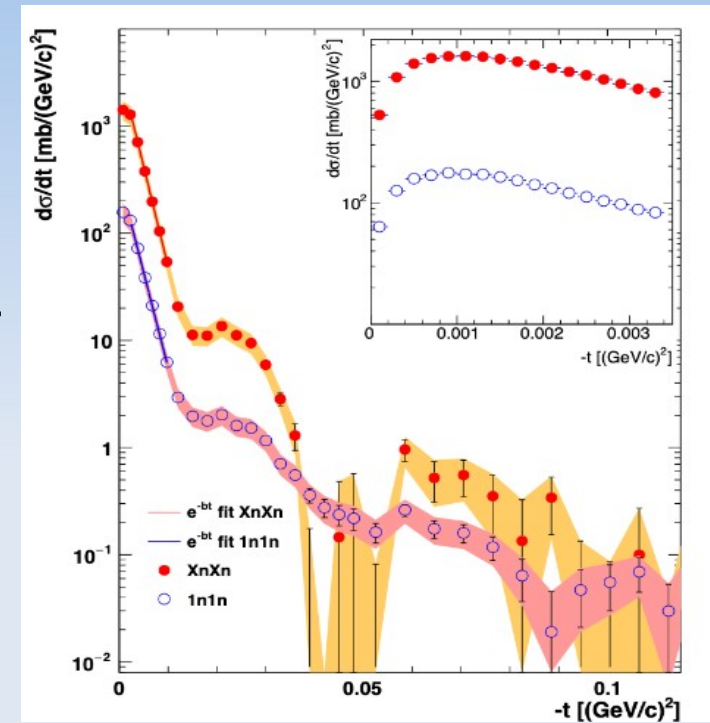
- **Coherent** process: main impact from nuclear structure is on the magnitude of the **second diffractive peak**
- **Incoherent** process: change in **shape** of the t-differential cross section and the **position** of the **dips**

Feasibility to constrain nuclear structure with VMs in UPC

- Extraction of second peak challenging in coherent VM photoproduction.
 - Measurements exist for the abundant ρ^0
- Clean coherent/incoherent separation (p_T cut or template fits of p_T distributions). Requires good $p_T(t)$ **resolution**



ALICE, Phys. Lett. B798 (2019) 134926



STAR, Phys. Rev. C. 96 054904

- I perform **projections** for some of the many available systems available at **LHCb**
 - **fixed target** and **collision** modes

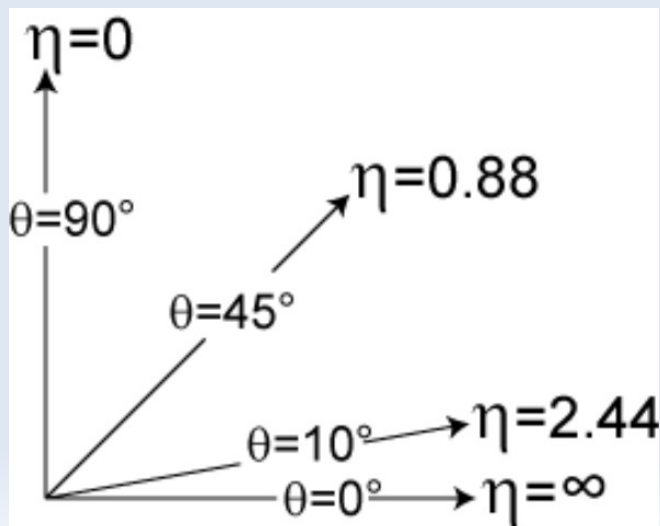
Angular coordinates and variables

Pseudorapidity η

- Coordinate in the lab, related to polar angle **w.r.t. beam**

$$\eta = -\ln[\tan(\theta/2)] = \frac{1}{2} \ln \left(\frac{|\mathbf{p}| + p_L}{|\mathbf{p}| - p_L} \right)$$

- Applied to final state particles that we measure (μ , π etc.)
- $2 < \eta < 5$ at LHCb



Rapidity y

- Intrinsic coordinate, used in theoretical predictions

$$y = \frac{1}{2} \ln \left(\frac{E + p_L}{E - p_L} \right)$$

- In the lab frame y coincides with η for ultra-relativistic particles:
 $E \sim |\mathbf{p}| \rightarrow \eta \sim y$

Outline for feasibility study

- **Feasibility** study of $\rho \rightarrow \pi^+\pi^-$ and $J/\psi \rightarrow \mu^+\mu^-$ photoproduction in UPC events at LHCb
 - Acceptance cuts: $2 < \eta(\pi, \mu) < 5$, $p_T(\pi, \mu) > 0.2$ GeV, $2 < y(VM) < 5$
- Using the STARLIGHT event generator: applying the LHCb selection and estimating the number of events
 - **Fixed target** mode, $\sqrt{s_{NN}} = 71$ GeV with SMOG2 in Run 3
 - Light ions in **collision** mode, $\sqrt{s_{NN}} = 5.36$ TeV in Run 3, including predictions from the hotspot model including variations of **geometrical structure**
 - Ideas for extension to LHC Run 4 (2029-) for possible **New Ions** to be collided, looking for **input!**

Cross sections in fixed target mode

^{208}Pb beam on ^{40}Ar or ^{20}Ne target. Most interactions **probe** the **lighter nucleus**, with the heavier nucleus emitting the photon.

Pb-Ar, 71 GeV, 2 nb^{-1}			
	σ	σ_{LHCb}	N_{LHCb}
$\rho \rightarrow \pi^+ \pi^-$ coherent	40.1 mb	25.8 mb	52M
$\rho \rightarrow \pi^+ \pi^-$ incoherent	60.7 mb	15.5 mb	31M
$J/\psi \rightarrow \mu^+ \mu^-$ coherent	84.1 nb	52 nb	100
$J/\psi \rightarrow \mu^+ \mu^-$ incoherent	449.0 nb	119 nb	400
Pb-Ne, 71 GeV, 0.06 nb^{-1}			
$\rho \rightarrow \pi^+ \pi^-$ coherent	26.4 mb	16.3 mb	1.5M
$\rho \rightarrow \pi^+ \pi^-$ incoherent	37.3 mb	9.9 mb	0.7M
$J/\psi \rightarrow \mu^+ \mu^-$ coherent	58 nb	38 nb	2
$J/\psi \rightarrow \mu^+ \mu^-$ incoherent	255 nb	123 nb	7

- **High statistics** for ρ photoproduction expected from collected data
- A J/ψ photoproduction measurement in **Pb-Ar** looks **feasible**

Cross sections in collision mode

Symmetrical collisions of ^{16}O - ^{16}O and ^{20}Ne - ^{20}Ne at **5.36 TeV**

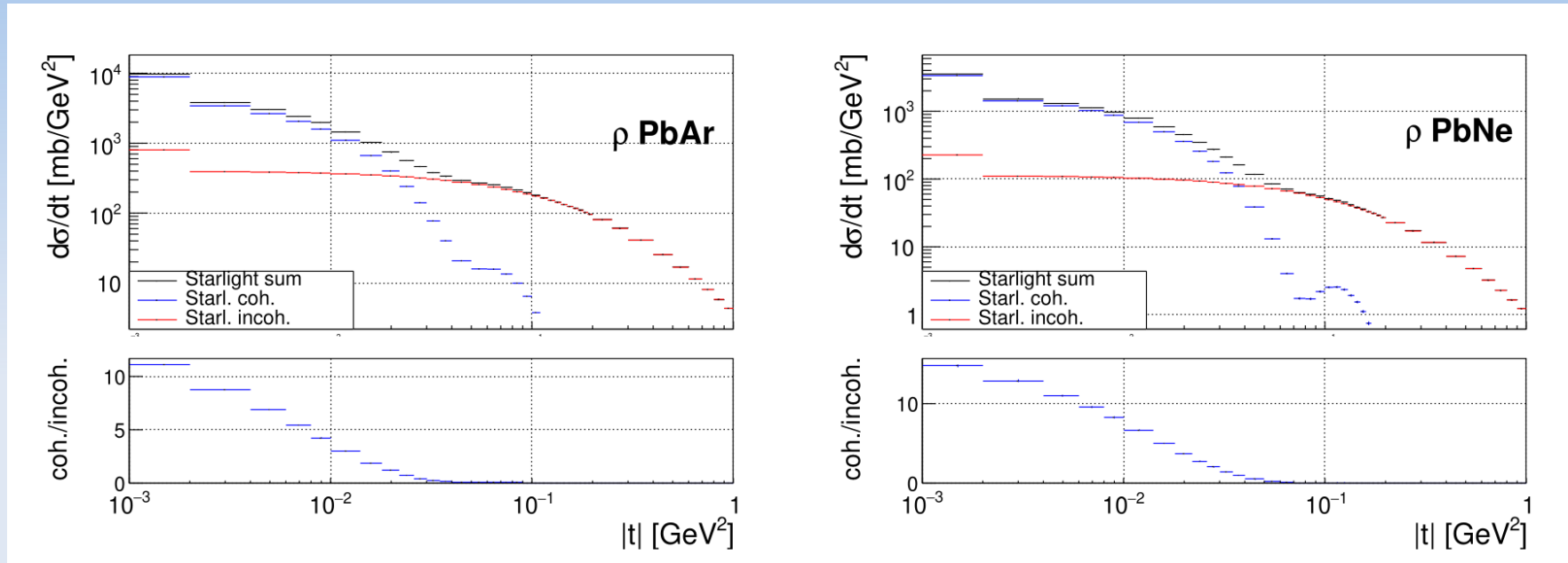
O-O, 5.36 TeV, 5.5 nb^{-1}			
	σ	σ_{LHCb}	N_{LHCb}
$\rho \rightarrow \pi^+\pi^-$ coherent	8.65 mb	1.31 mb	7.2M
$\rho \rightarrow \pi^+\pi^-$ incoherent	6.62 mb	0.69 mb	3.8M
$J/\psi \rightarrow \mu^+\mu^-$ coherent	$1.34 \mu\text{b}$	$0.14 \mu\text{b}$	790
$J/\psi \rightarrow \mu^+\mu^-$ incoherent	449.0 nb	119 nb	400
Ne-Ne, 5.36 TeV, 0.6 nb^{-1}			
$\rho \rightarrow \pi^+\pi^-$ coherent	15.9 mb	2.4 mb	980k
$\rho \rightarrow \pi^+\pi^-$ incoherent	11.8 mb	1.2 mb	590k
$J/\psi \rightarrow \mu^+\mu^-$ coherent	$2.6 \mu\text{b}$	$0.28 \mu\text{b}$	170
$J/\psi \rightarrow \mu^+\mu^-$ incoherent	$2.8 \mu\text{b}$	$0.29 \mu\text{b}$	170

- Higher energy and **smaller system size** (competing effects on σ)
 - Different energy dependence for ρ and J/ψ photoproduction
- High statistics for ρ and J/ψ measurements are feasible

Strategy for feasibility study

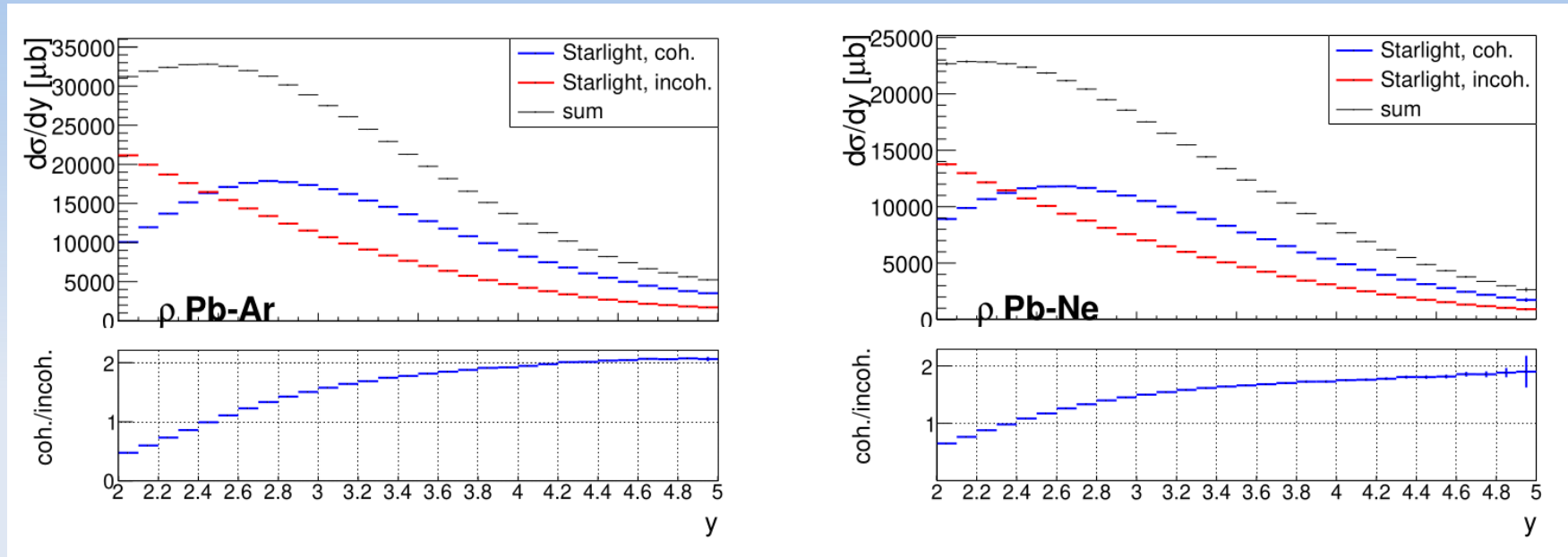
- Studying distributions in VM **rapidity** y (in lab frame) and $|t| \sim p_T^2$
- Assigning a **statistical uncertainty** of $\sqrt{N_{\text{LHCb}}}$ bin-wise
- The uncertainty is propagated to the cross section
 - Assuming that the statistical uncertainty dominates the uncertainty on the cross section
- Add predictions from the **hot spot model** in light ion collisions with:
 - Deformed Woods-Saxon
 - α -clustering for ^{16}O and ^{20}Ne (PGCM framework for Ne)
- Compare the difference in prediction when assuming **2 different geometrical structures** to the expected **statistical precision**

t in fixed target events



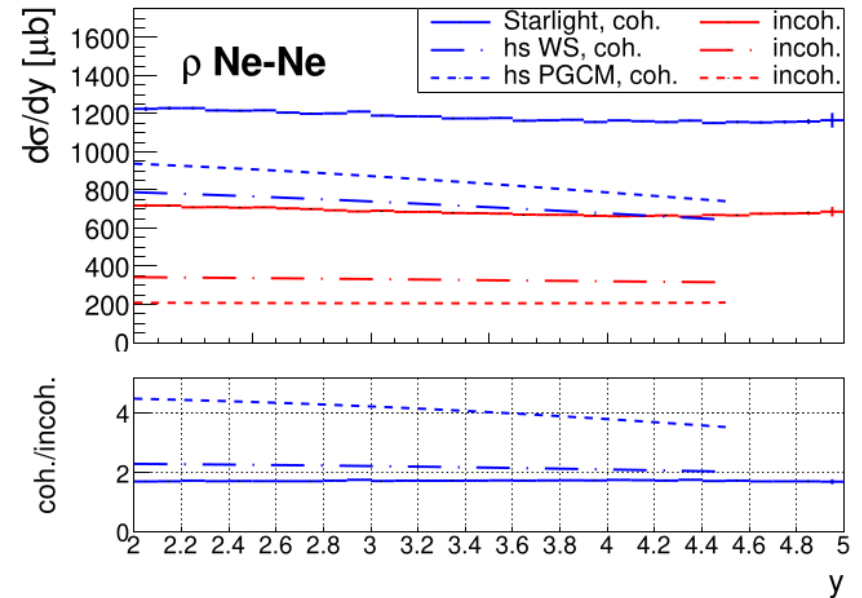
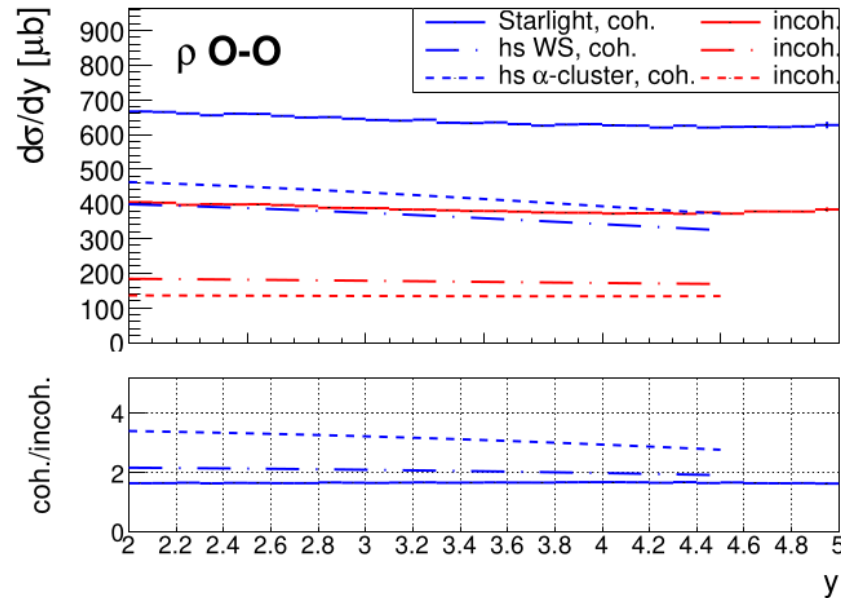
- As expected, **coherently** photoproduced VMs have a much **lower average transverse momentum** than incoherently produced
- The **diffractive** structure simulated
- The second coherent diffractive peak is in a region dominated by the incoherent process

Rapidity in fixed target events



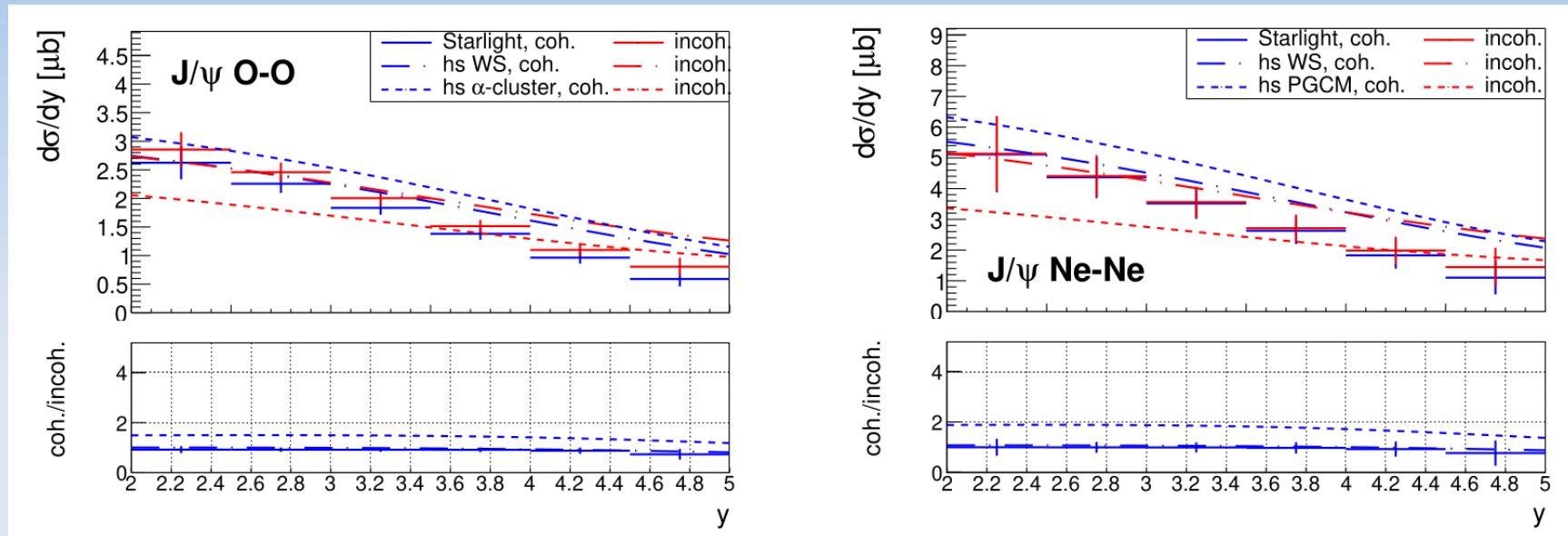
- The **coherent** process, which has lower p_T , and is **boosted** to **higher rapidity** than the incoherent one
- The LHCb acceptance cuts result in an enrichment of coherent events for fixed target interactions

y distributions for ρ , light ions



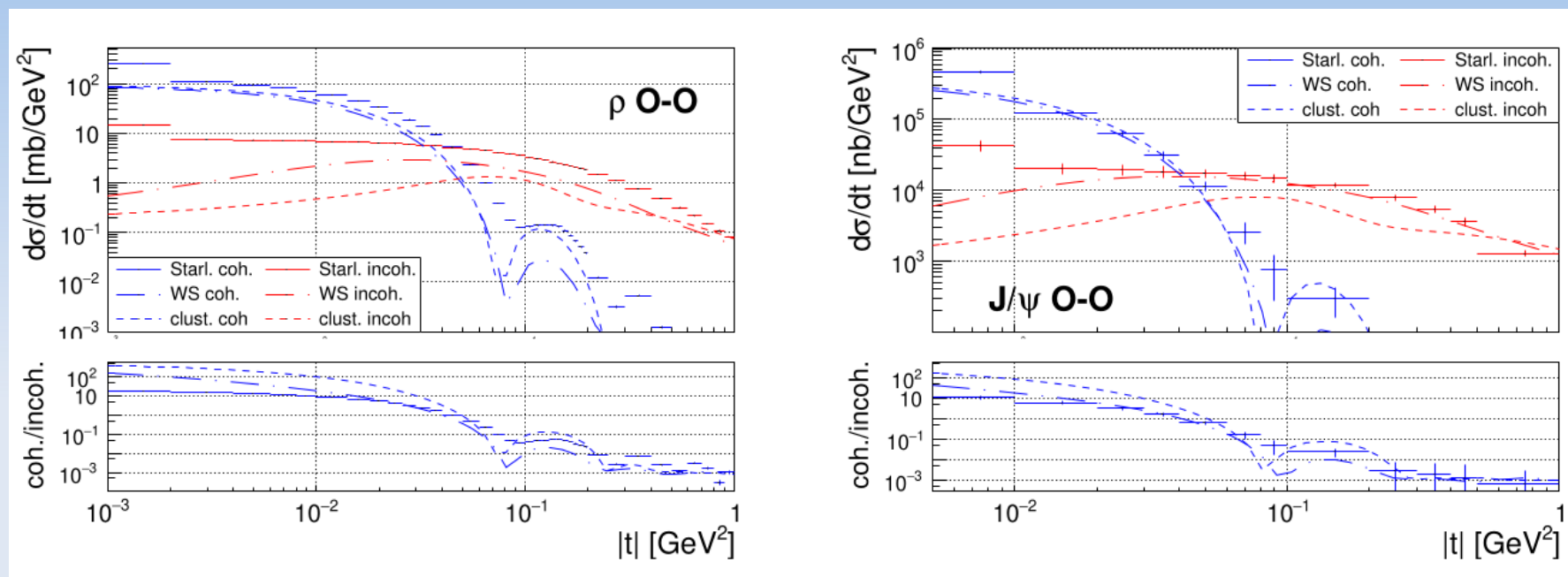
- Again, a **small statistical uncertainty** on the ρ cross sections.
- In collider mode with the same nuclei in both beams, we do not profit from the boost to separate the two processes in rapidity.
- The Woods-Saxon and clustered predictions result in **different yields**, with no major impact on shape in y .

γ distributions for J/ψ , light ions



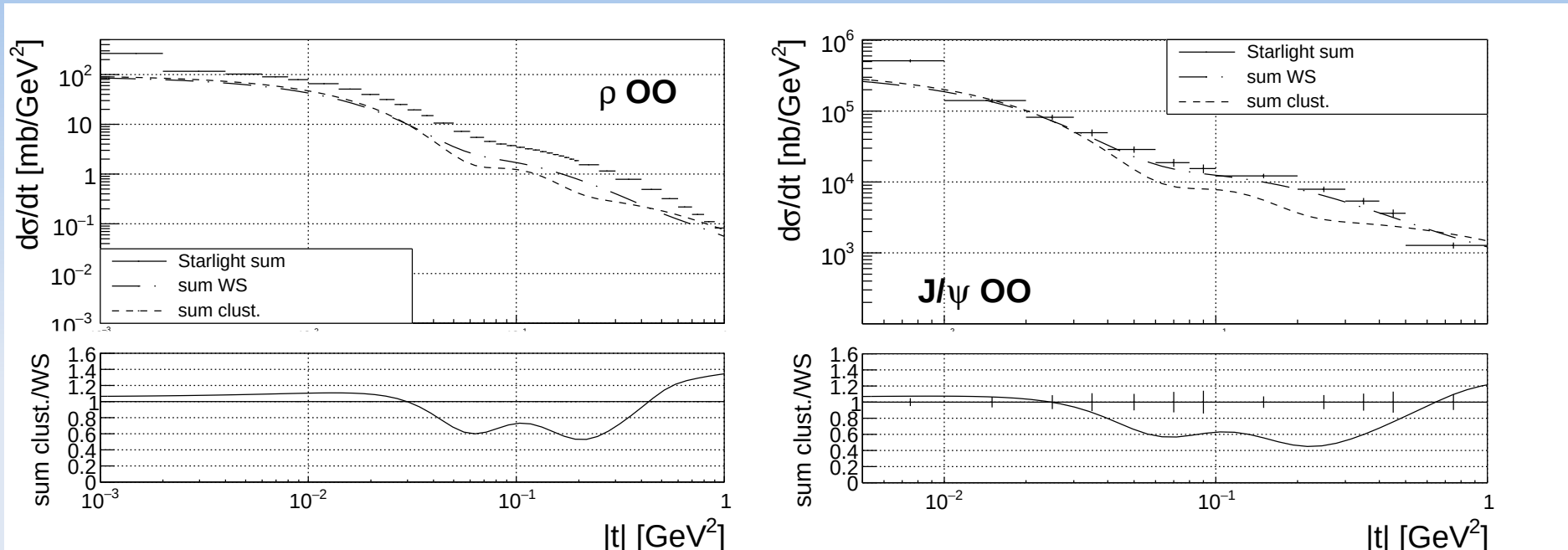
- Smaller statistical precision for J/ψ
- The coherent and incoherent predictions are very similar in the clustered case
- **Higher slope** than for ρ photoproduction

t distributions, O-O



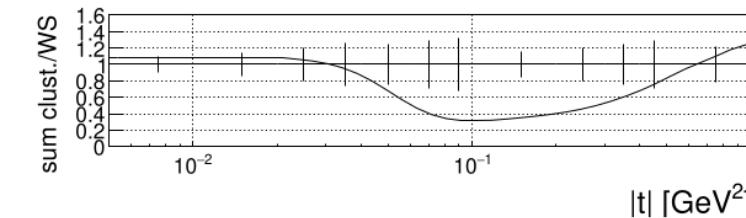
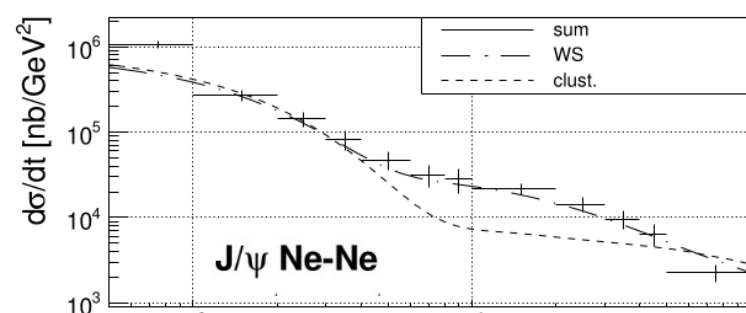
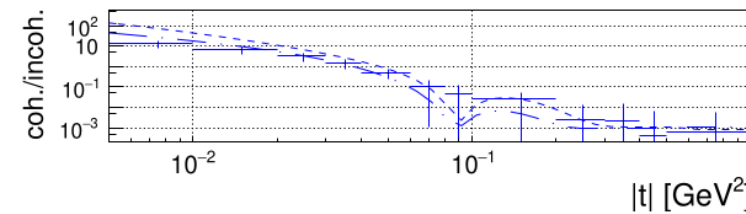
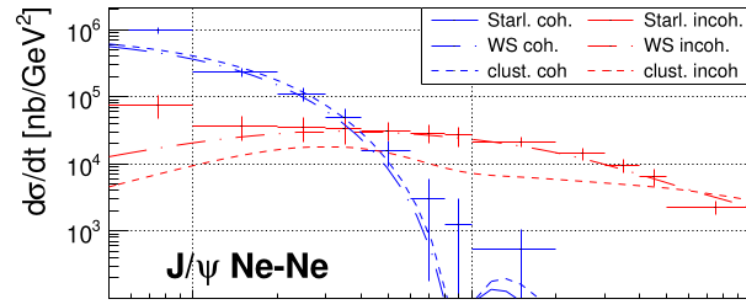
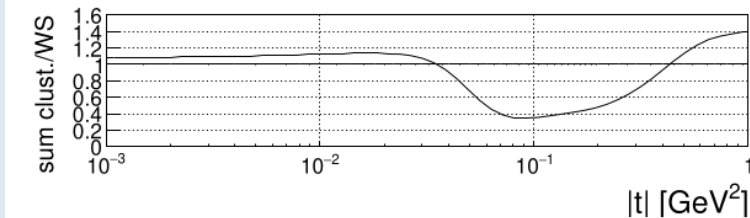
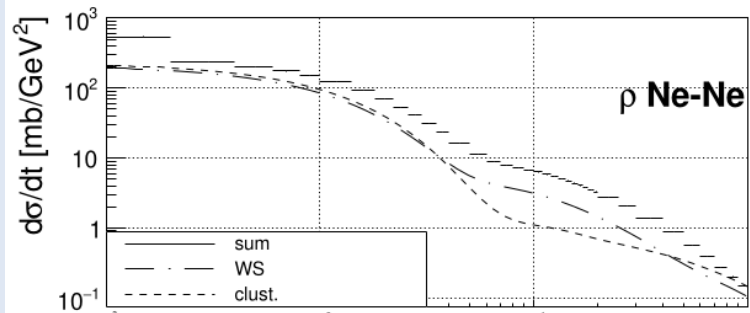
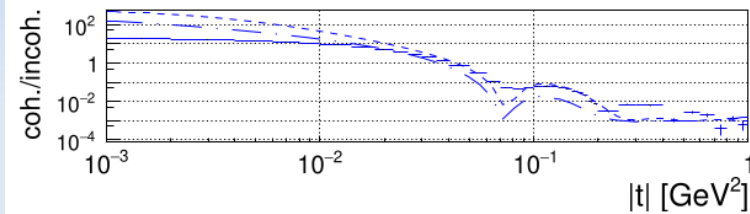
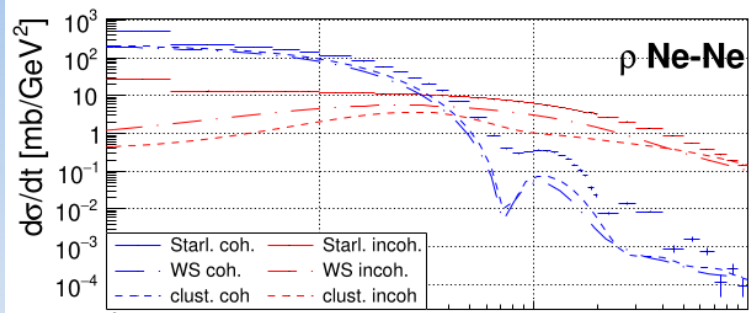
- Cold nuclear matter effects (shadowing, saturation) are included in the hotspot model and are prominent at low $|t|$, resulting in a lower cross section than in the STARLIGHT simulation
- Second diffractive coherent peak buried under the incoherent process
- Sizeable **impact** from **structure** in the **incoherent prediction**
 - Better **separated** from the coherent process at **higher $|t|$**

Adding the coherent and incoherent cross sections, O-O



- By looking at the **sum** of the **coherent and incoherent** processes one can avoid making assumptions on the two contributions
- The statistical uncertainty is shown as errorbars in both panels
- Differences on the total clustered vs. non-clustered cross section:
 - **30-40% lower clustered** prediction at **intermediate $|t| \sim 10^{-1}$**
 - 30% higher at high $|t| \sim 1$

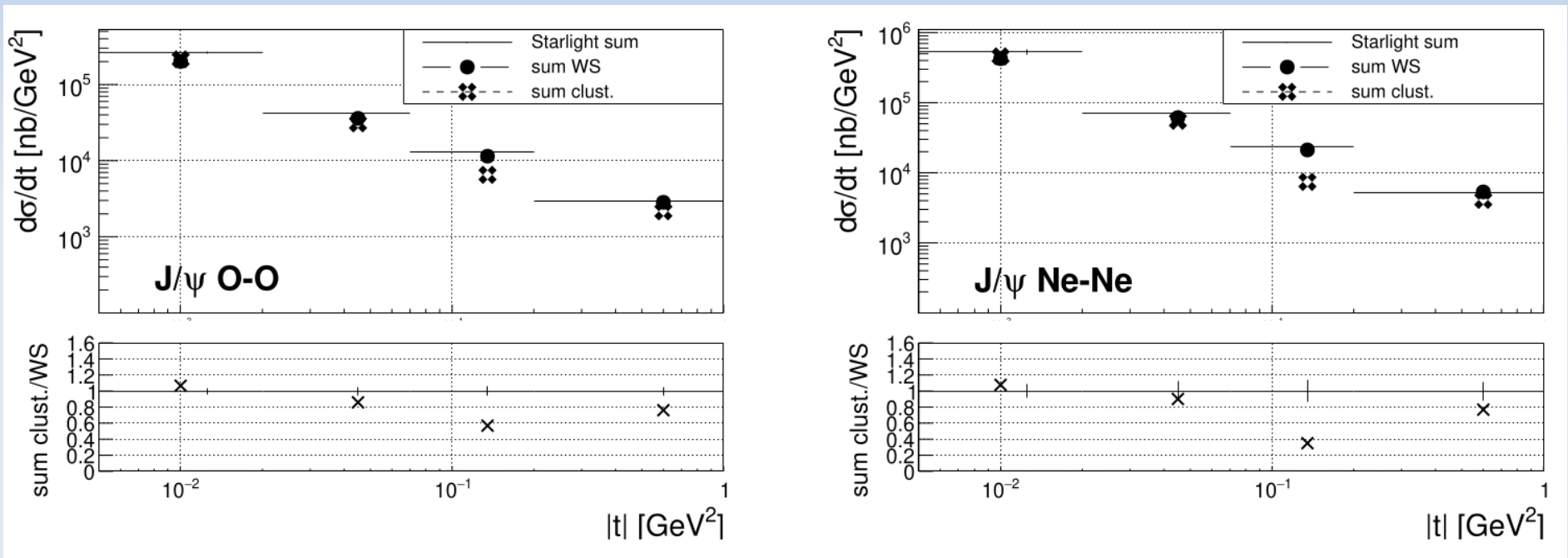
Adding the coherent and incoherent cross sections, Ne-Ne



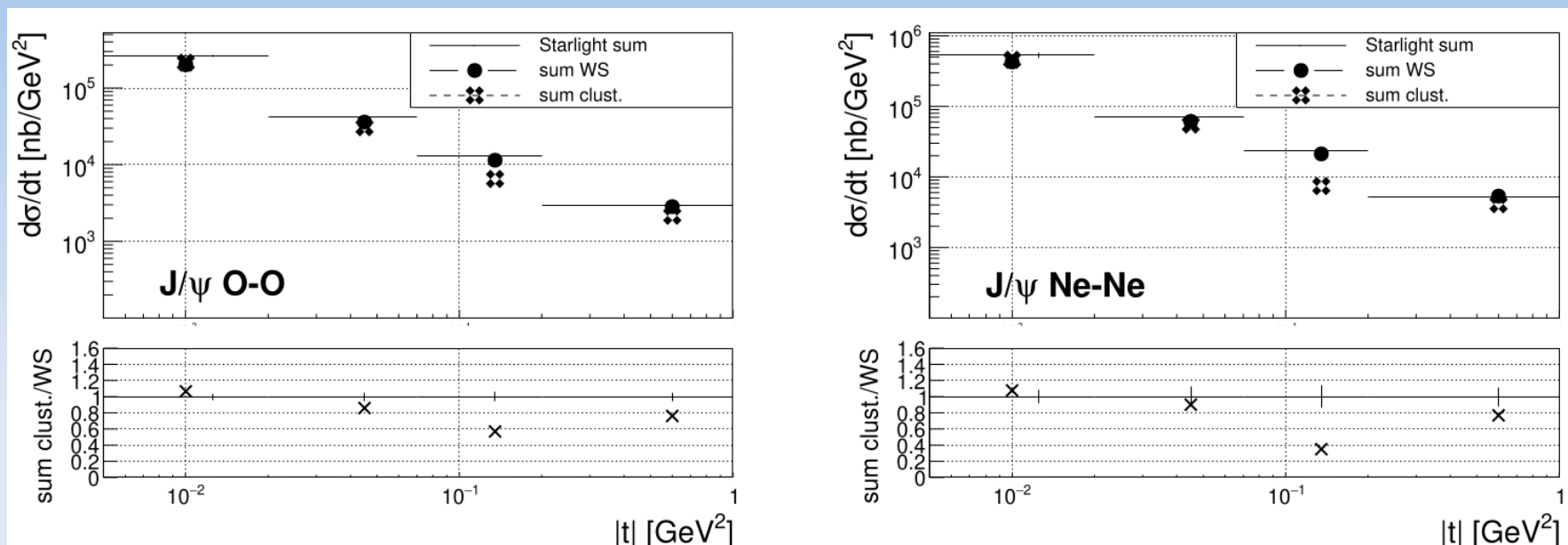
60-70% lower clustered prediction at $|t| \sim 10^{-1}$, 20-40% higher at $|t| \sim 1$

Ratios

In reality, the **luminosity** (normalisation) **uncertainty** is sizeable (targeting ~6% in O-O, Ne-Ne and 10% for SMOG2) → consider **ratios**!



Ratios



	ρ O-O	ρ Ne-Ne	J/ψ O-O	J/ψ Ne-Ne
ratio bin3/bin1 WS R_{WS}	0.030	0.027	0.057	0.050
ratio bin3/bin1 clustered R_{cl}	0.018	0.0095	0.030	0.016
difference in ratio $(R_{cl} - R_{WS})/R_{WS}$	40%	65%	47%	67%
precision bin3/bin1 STARLIGHT	0.10%	0.22%	7%	16%
difference in ratio / stat. precision	400	290	6.5	4.2

Difference in bin3/bin1 ratio well exceeds the statistical precision

Summary so far

- Investigating **feasibility** to measure VM photoproduction with in light ion collisions and with SMOG2 in collected Run 3 data with LHCb
 - Millions of p events are expected in both modes
 - Hundreds of J/ψ events expected in O-O, Ne-Ne and Pb-Ar runs
- **Diffraction** structure simulated in $|t|$, with a **softer spectrum** for the **coherent** process
- Probing the **sensitivity to clustering** in O-O and Ne-Ne collisions, in the framework of the hot spot model
 - Looks **promising** in a region enriched in **incoherent** events
 - By evaluating ratios once can cancel out the luminosity uncertainty
 - The uncertainty on the **modelling** should be kept in mind

Complementarity low-high energy

Low energy measurements

- Great **flexibility** in choice of nuclei to probe
- Ground and excited **states accessible**
- More **contamination** of the probed state from excitations
- Need to construct Kumar invariant by exciting to all states, measure and sum over results (not all states available)

T. Duguet, slide 37-39

Heavy ions at LHC

- Very **short interaction times** → clean ground state
 - Possible contamination from excited states if they are close in energy?
- **Expensive** beam time, with priority to pp/PbPb/pPb
 - Still, **new collision systems** possible for Run 4
 - Fixed (gas) target mode with **SMOG2** can provide larger **variety** of systems

Will we see the same thing at low and high energy?

Complementarity flow – photoproduction in UPC

Flow

- Measure **correlations** between charged particles in hadronic collisions
- Can get useful measurements even from very short runs
- **Indirect** measurement: how do final state particles imprint on the QGP?
- Relies on **hydrodynamic modelling** and well-calibrated **centrality**

VM photoproduction

- Probes the **initial state** (more direct measurement)
- Ultra-peripheral collisions
 - Clean signature
 - Less statistics than for hadronic events
- **Theoretical modelling** of the process needs to be well understood

Will the measurements give a consistent picture?

New Ions @ LHC

What ions should we collide in **LHC Run 4** (2029-)? Science case?
Syneries?

Possible candidates for symmetrical collisions:

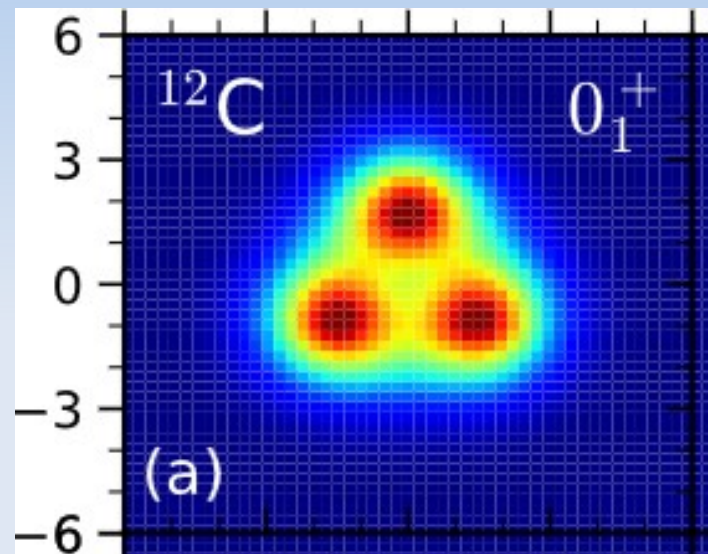
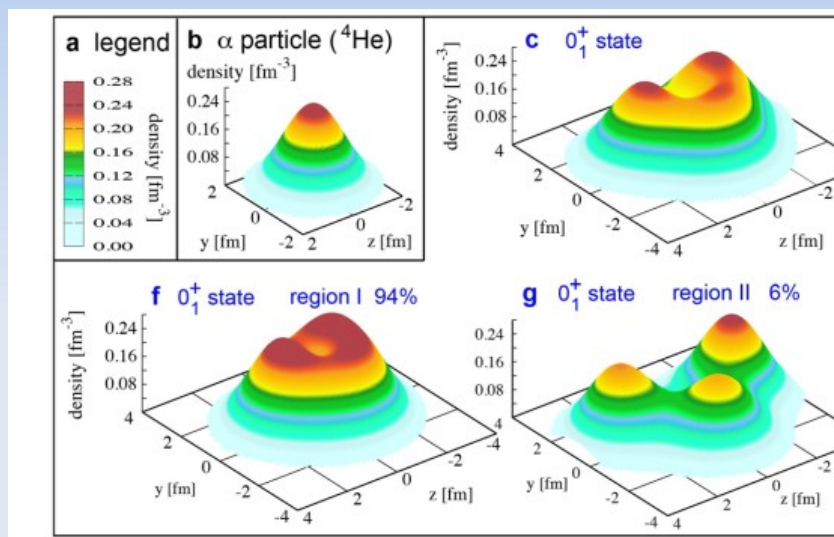
Species $\rightarrow$ ^4He , ^{12}C , ^{16}O , ^{24}Mg , ^{40}Ar , $^{40,44,48}\text{Ca}$, $^{76}\text{Ge-Se}$, ^{86}Kr , $^{136}\text{Ba-Xe}$

- Abstract submissions to White Paper by 31st of October
- Contributions to New Ions White Paper by October 2028. Results can also appear as standalone publications

<https://indico.cern.ch/event/1697777/>

Motivation for ^{12}C

- Recent simulation studies suggest **clustering** component in the **ground state** of ^{12}C



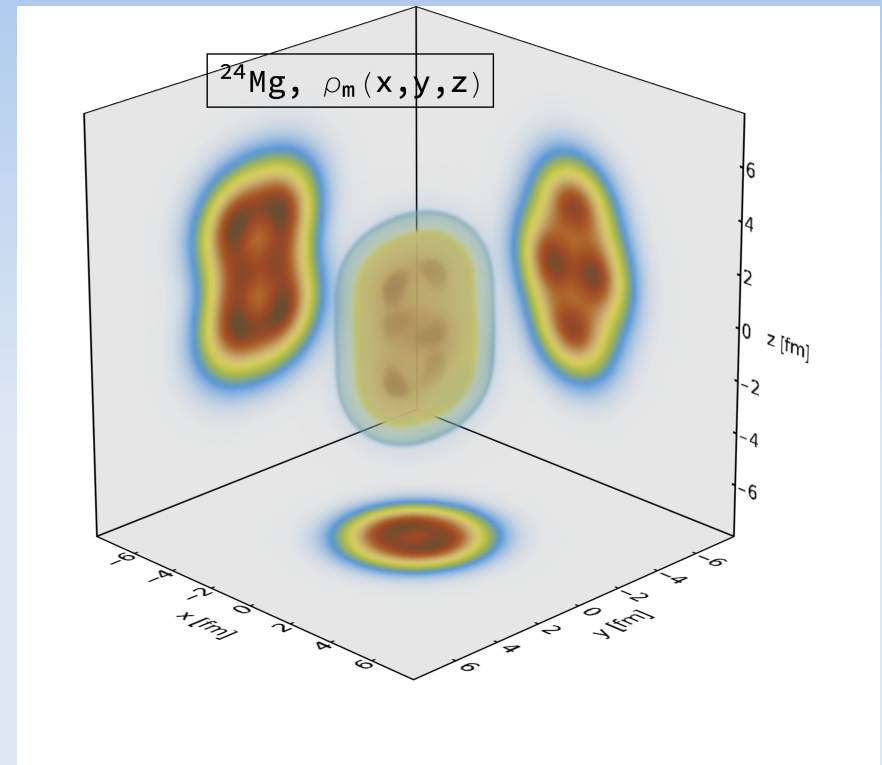
T. Otsuka et al, Nat Commun 13, 2234 (2022)

S. Shen et al, Nat. Commun. 14 (2023) 2777

- Recent **analyses** of low-energy ^{12}C reactions suggest presence of **clustering** K. Yoshida, M. Kimura arXiv:2606.31437
W. Horiuchi, N. Itagaki Phys.Rev.C 107 (2023) 2
- Motivation: Improving understanding of **transitions** to **Hoyle** state and ^{24}Mg synthesis in **supernovae**. Possible synergy with LHCb – investigating CH_2 target

Motivation for ^{24}Mg

- ^{24}Mg is **intermediate in size** between deformed clustered ^{16}O , ^{20}Ne and heavier, more collective systems
- Test models for $^{12}\text{C}+^{12}\text{C} \rightarrow ^{24}\text{Mg}$ fusion in Type I **supernovae**
- Possible synergies with SPS and ISOLDE

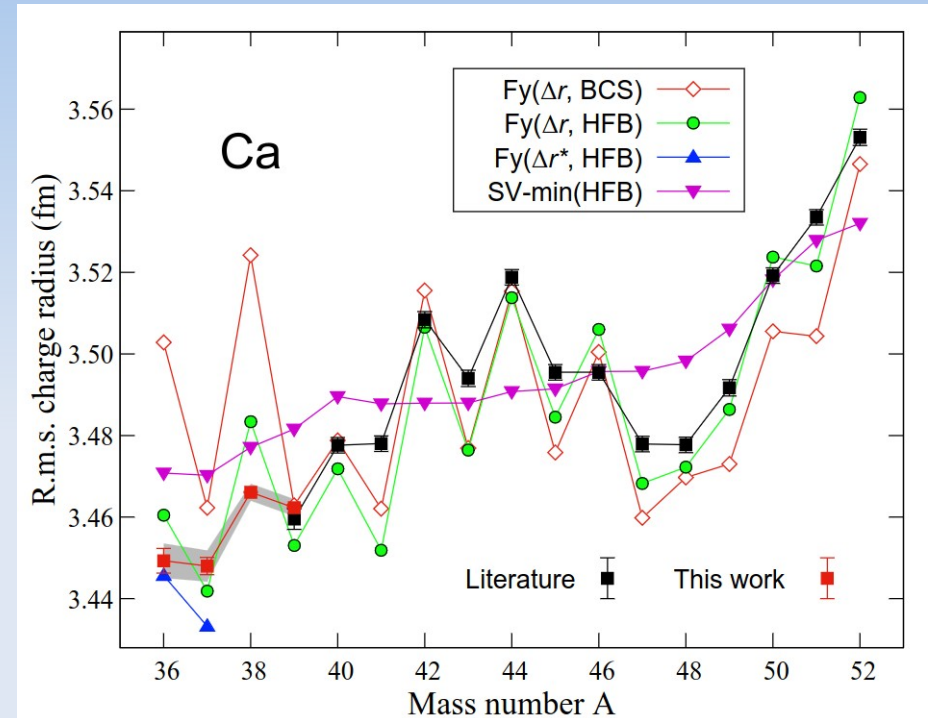


3D density recently obtained
from Benjamin Bally :D

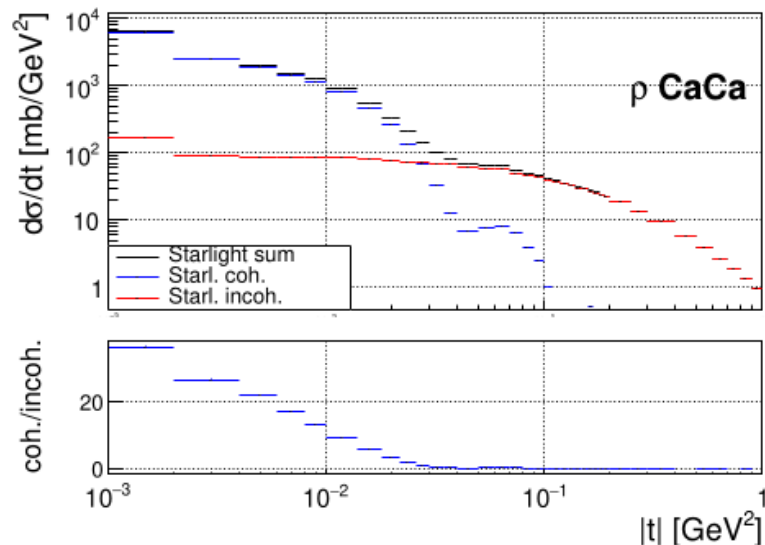
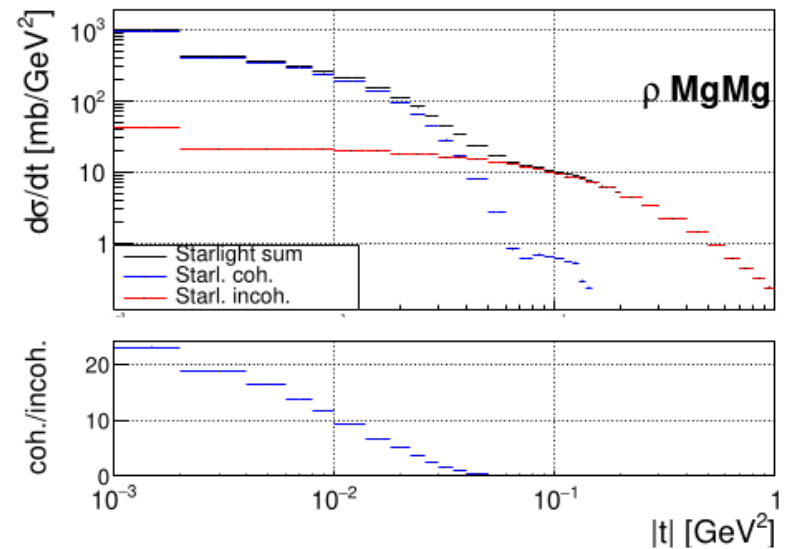
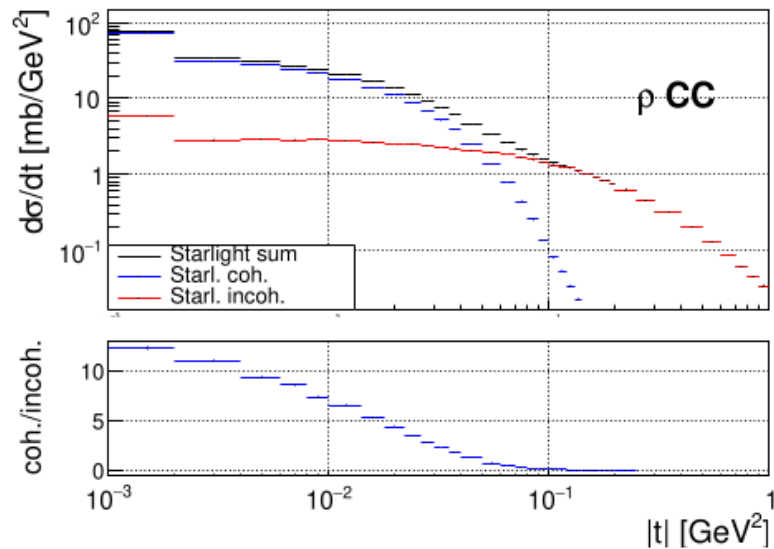
→ compare to Woods-Saxon?

Motivation for Ca

- Strange trend in **calcium charge radii**: similar size for $A=40$, $A=48$, and larger radii for intermediate even-even isotopes
- **Ideally** would like to measure at least **2-3 isotopes** and explore differences
- But it currently looks like we will get **at most one**, with a preference for $A=48$ to measure the neutron skin and use as input to equation of state for **neutron stars**
 - Is it still worth it?



A first look at the t-distributions



$\langle p_T^{VM} \rangle$ decreases with **system size** for the **coherent** process (pattern moves left) → better access to **incoherent** process at **lower $|t|$** at high A

Incoherent cross sections for potential New Ions

At 5.36 TeV and assuming an integrated **luminosity** of **5.5nb⁻¹**, while waiting for luminosity estimates (that may well be lower):

species	$\sigma^{\text{incoh.}}(\rho)$	N_{ρ}^{LHCb}	$\sigma^{\text{incoh.}}(J/\psi)$	$N_{J/\psi}^{LHCb}$
¹² C- ¹² C	2.66 mb	1.5M	586 nb	340
¹⁶ O- ¹⁶ O	6.62 mb	3.8 M	1.52 μ b	880
²⁴ Mg- ²⁴ Mg	19.0 mb	10M	4.50 μ b	2500
⁴⁸ Ca- ⁴⁸ Ca	81 mb	44M	20.8 μ b	11k

But what is our **sensitivity** to **geometrical shape**? Need **input densities** for ¹²C and possibly ^xCa, ⁷⁶Ge

olga.bylund@cern.ch

Thank you for your attention!