Measurement of the impact-parameter dependent azimuthal anisotropy in coherent ρ^0 photoproduction with ALICE

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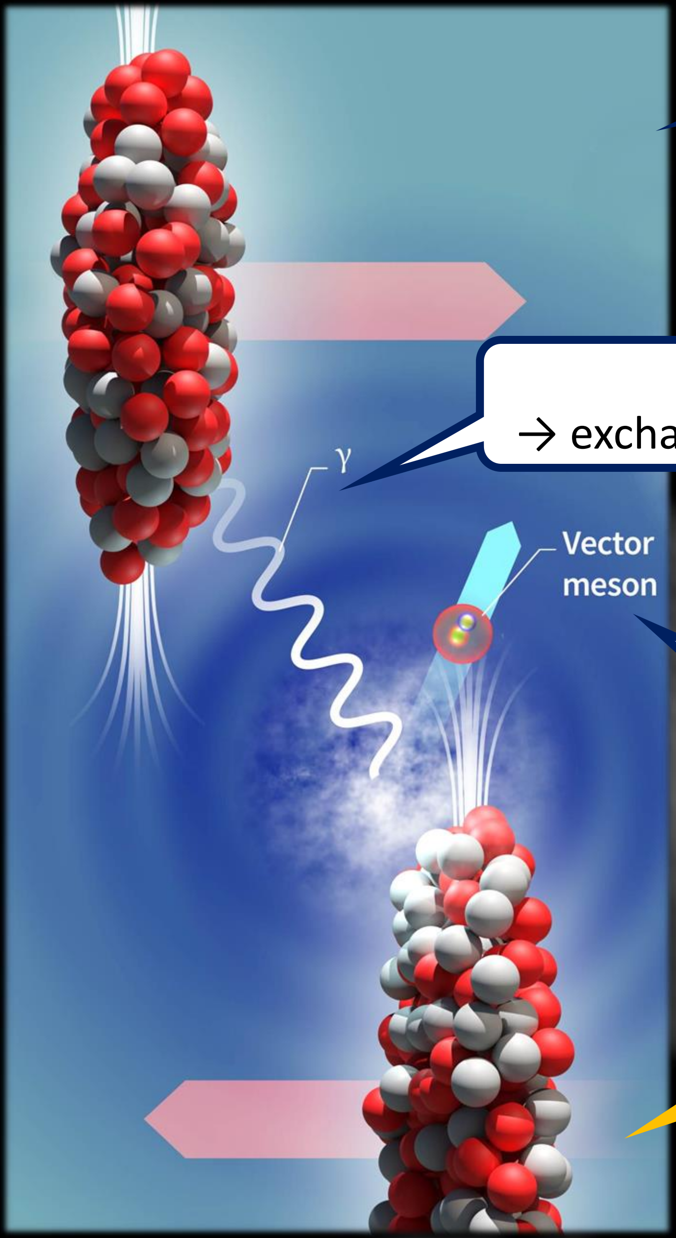
OUTLINE

- PHYSICS MOTIVATION
- DETECTOR AND DATA SAMPLE
- DATA ANALYSIS
- RESULTS
- TAKE HOME AND OUTLOOK

PHYSICS MOTIVATIONS

COHERENT PHOTOPRODUCTION

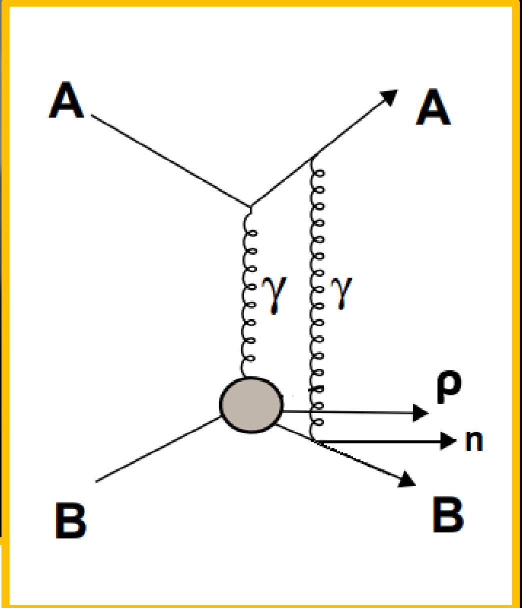


The process studied is the **coherent photoproduction of the ρ^0**

Clear signal: $\rho^0 \rightarrow \pi^+\pi^-$ at midrapidity in an otherwise empty detector

EM fields treated as flux of quasi-real photons
→ exchanged photons can fluctuate into a quark-antiquark pair

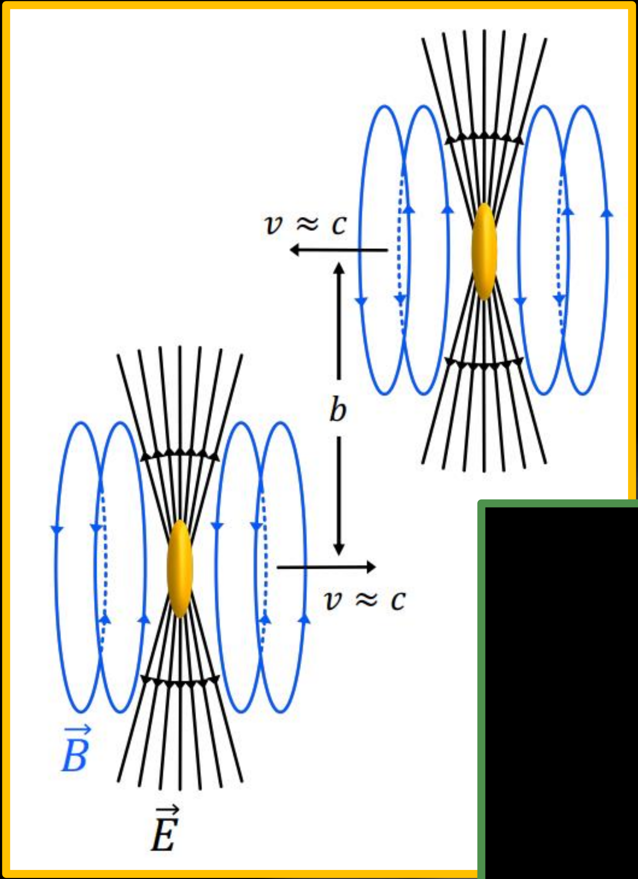
The pair interacts strongly with the other nucleus via pomeron exchange
→ emerges as a real vector meson



UPCs with independent electromagnetic dissociation
→ nuclear break-up with emission of forward neutrons

Left figure from Ref. [1], right figure from Ref. [2],

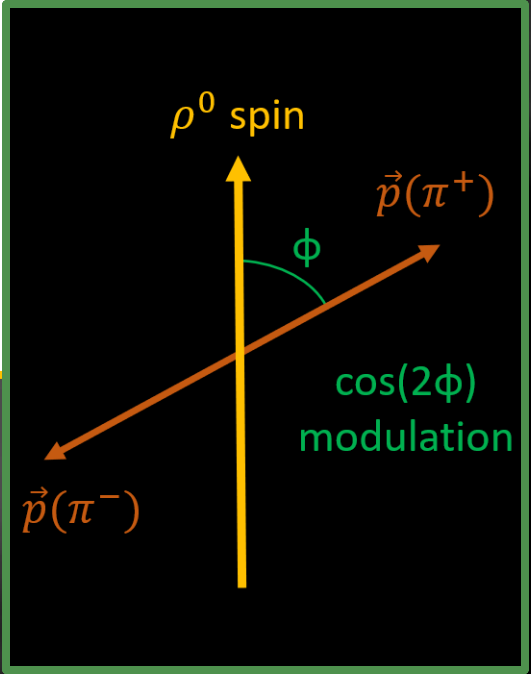
AZIMUTHAL ANISOTROPY



EM field of the nuclei highly Lorentz contracted
→ exchanged photons are fully linearly polarized along the impact parameter

The polarization is transferred to the ρ^0 and, upon decay, to the orbital angular momentum of the pions

The angular distribution of the pions is determined by the conservation of the total angular momentum



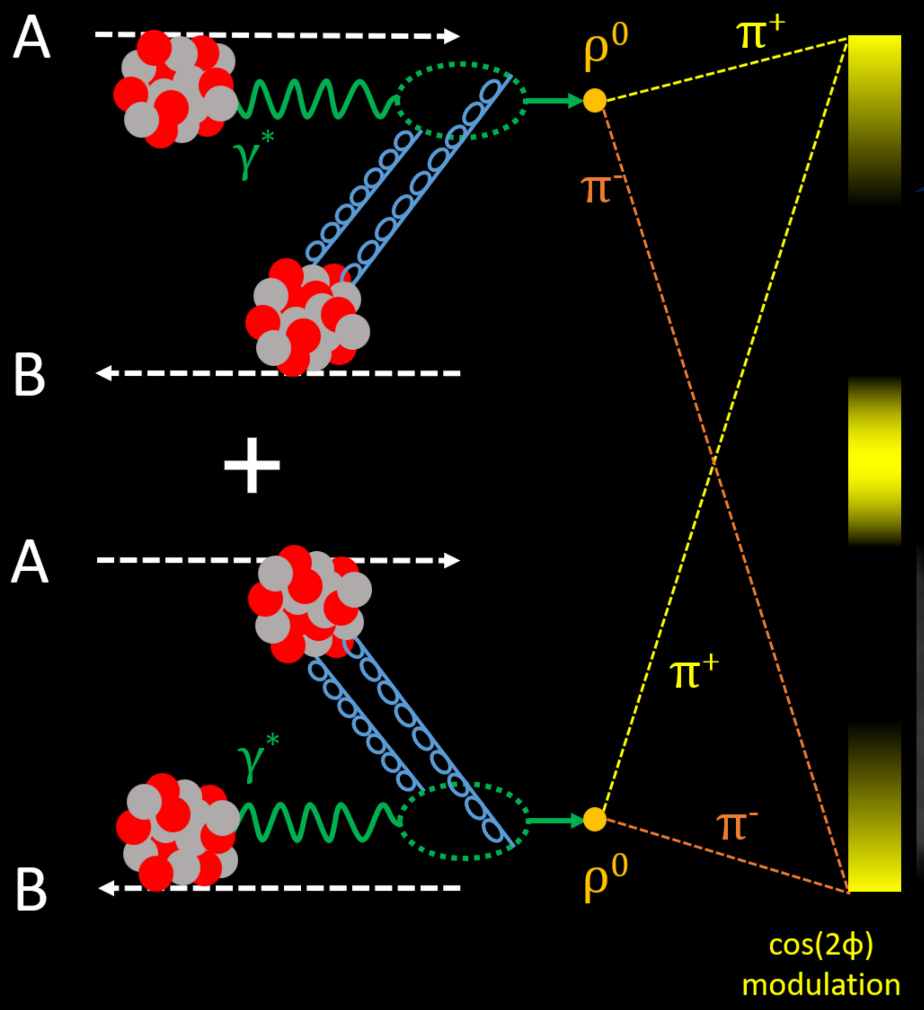
It results in an azimuthal modulation in the momentum distribution wrt the polarization direction

BUT… the impact parameter is random event-by-event
→ the anisotropy vanishes :(

We need another ingredient…
…let's look at the photoproduction process!

Left figure from Ref. [3]

AZIMUTHAL ANISOTROPY



Each nucleus can act as the source of the photon or as the target in the interaction
→ two indistinguishable amplitudes contribute to the cross-section

Interference between the amplitudes!

$$\sigma(p_\mathrm{T}, b, y=0) = \left| \, A(p_\mathrm{T}, b) - A(p_\mathrm{T}, b) \, e^{i\,\vec{p}\cdot\vec{b}} \, \right|^2$$

Correlation between ρ^0 momentum and polarization (aligned along *b*)
→ preserves the anisotropy!

ρ^0 is short lived: $c\tau \ll b$ → decay length too short for amplitudes to overlap

Interference involves the pions, which need to be emitted in an entangled state [4]

WHY STUDY THIS ANISOTROPY ?

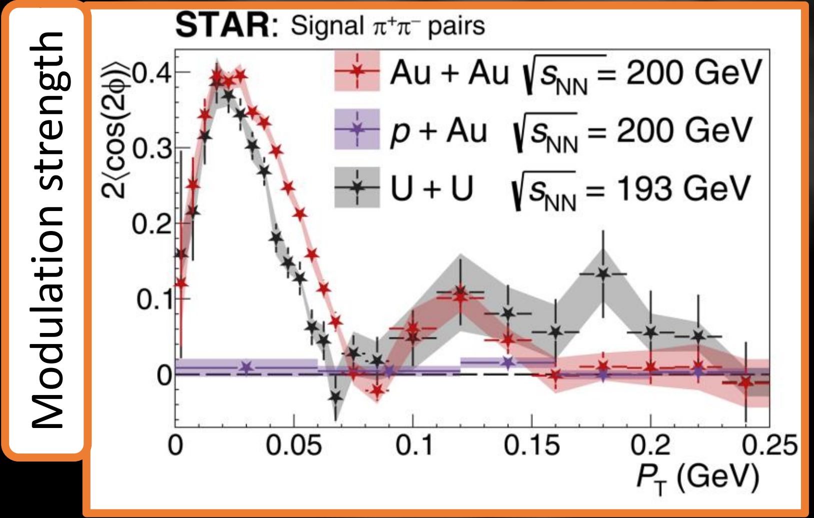
Why is it interesting?

The pomeron exchange restricts the ρ^0 production site within one of the nuclei

Double-slit experiment at fm scale [5]
→ *b* = distance between the openings

The interference is sensitive to the gluon distribution and to the size of the nuclei

Possibility to do gluon tomography in the future



There are theoretical models available

H. Xing *et al.* [6]: color-dipole model + scattering with gluons from color glass condensate inside nuclei

W. Zhao *et al.* [7]: same formalism of [6], but:
1) interaction dipole/target → Wilson lines
2) event-by-event variation of Wilson lines → account for different color charge configurations

Both models implement a correlation between the incoming photon's spin and momentum

Predict a cos(2ϕ) modulation of the ρ^0 yield

ϕ~azimuthal angle between the ρ^0 and one of its daughters' momentum (def. in slide 6)

Depends on p_T → STAR [8,9]

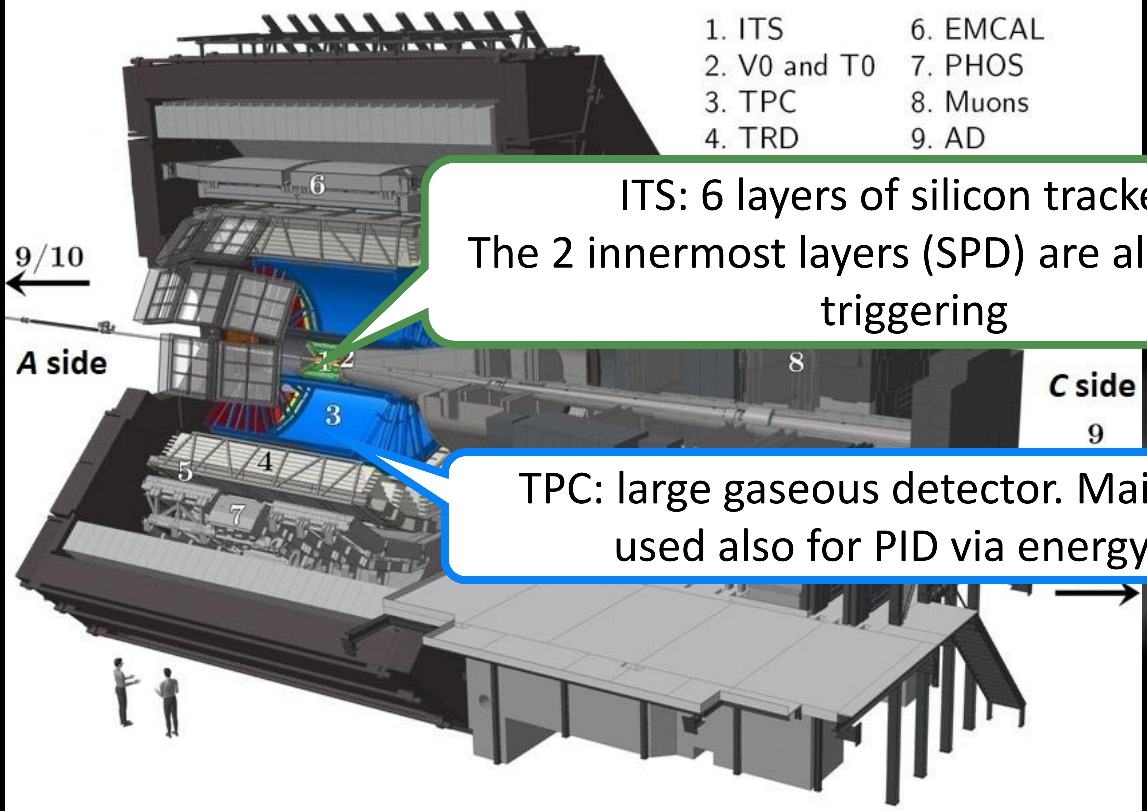
Depends on *b* → ALICE

This talk! And paper in preparation!

DETECTOR AND DATA SAMPLE

Run 2 ALICE DETECTOR & DATA SAMPLE

AD/V0: arrays of scintillators at forward rapidities. Used for triggering



ITS: 6 layers of silicon trackers. The 2 innermost layers (SPD) are also used for triggering

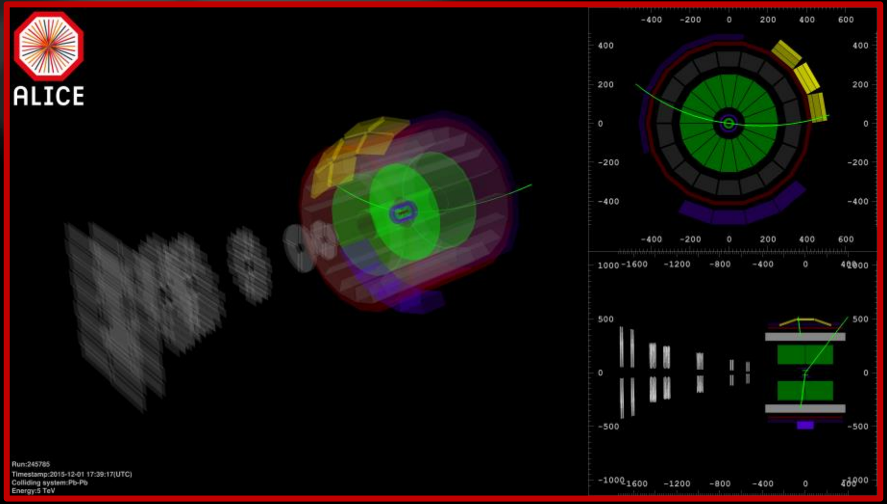
TPC: large gaseous detector. Main tracker, used also for PID via energy loss

ZDC: sampling Cherenkov calorimeters. Used to detect forward neutrons and protons

Data: $\mathcal{L}_{int}$=0.485 μb^{-1} from Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

Trigger

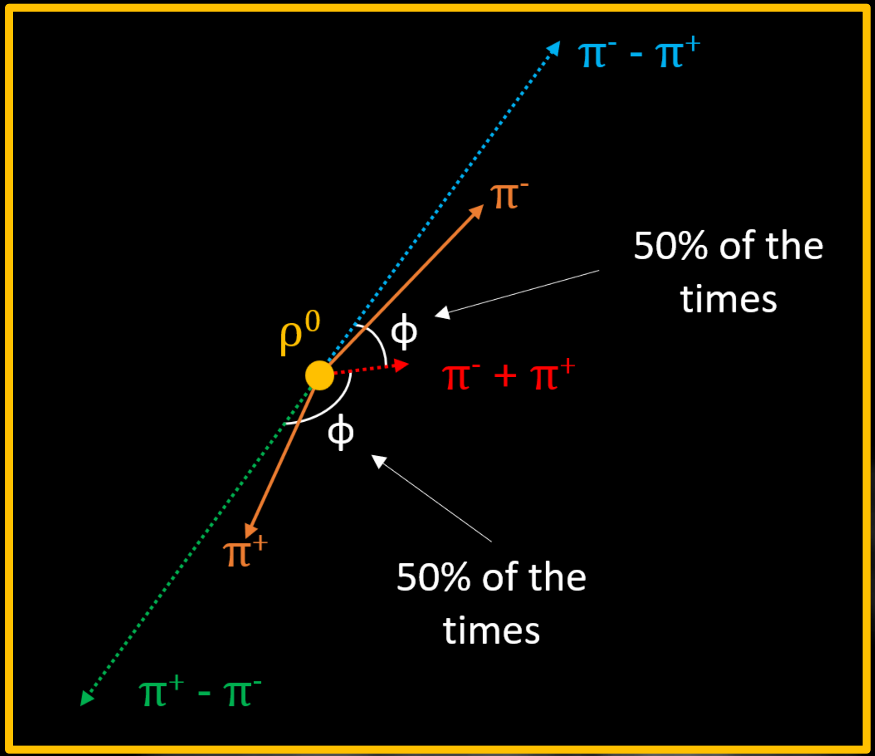
- AD and V0 used as veto → suppression of purely hadronic interactions
- Topological trigger: events with at least two track segments in the ITS SPD with an opening angle θ>153°



Figures from Ref. [1]

DATA ANALYSIS

DEFINITIONS

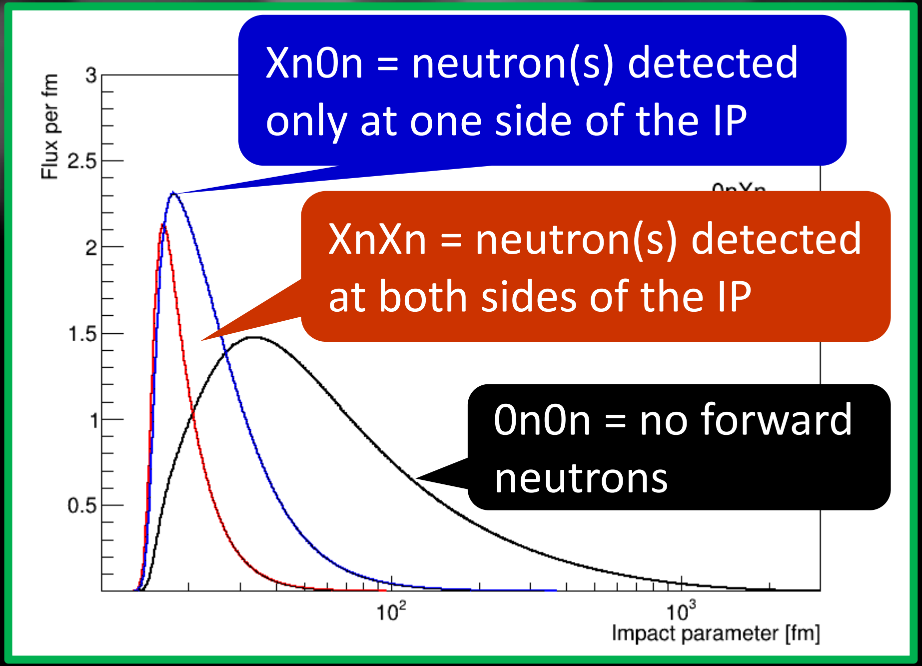


ϕ = azimuth angle between p_+ and p_-

$p_\pm = \pi_1 \pm \pi_2$

π_1 (π_2) = 4-momentum of track 1(2), randomly assigned to the positive and negative tracks

Neutron emission probability decreases with the impact parameter ***b***
→ different neutron emission classes corresponds to different average values of ***b***



Right image from Ref. [10]

CORRECTIONS

Data (invariant mass distributions) need to be corrected for acceptance and efficiency

Use of STARlight [11] MC (ρ^0 + continuum pion pair production)

p_T of the ρ^0 not perfectly reproduced → re-weighting needed!

Re-weighting procedure

Fit the MC generated p_T^2 distribution using the square of the nuclear form factor (1) to extract a_{Pb} and R_{Pb}

$$\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}^2} = c \mid F(t, a_{\mathrm{Pb}}, R_{\mathrm{Pb}}) \mid^2 \quad (1)$$

Compute the weights using (2), where R_X is chosen to minimize discrepancies between data and reconstructed MC p_T distributions

$$\mathrm{w}(p_{\mathrm{T}}) = \frac{\mid F(\mid t \mid, a_{\mathrm{Pb}}, R_{\mathrm{X}}) \mid^2}{\mid F(\mid t \mid, a_{\mathrm{Pb}}, R_{\mathrm{Pb}}) \mid^2} \quad (2)$$

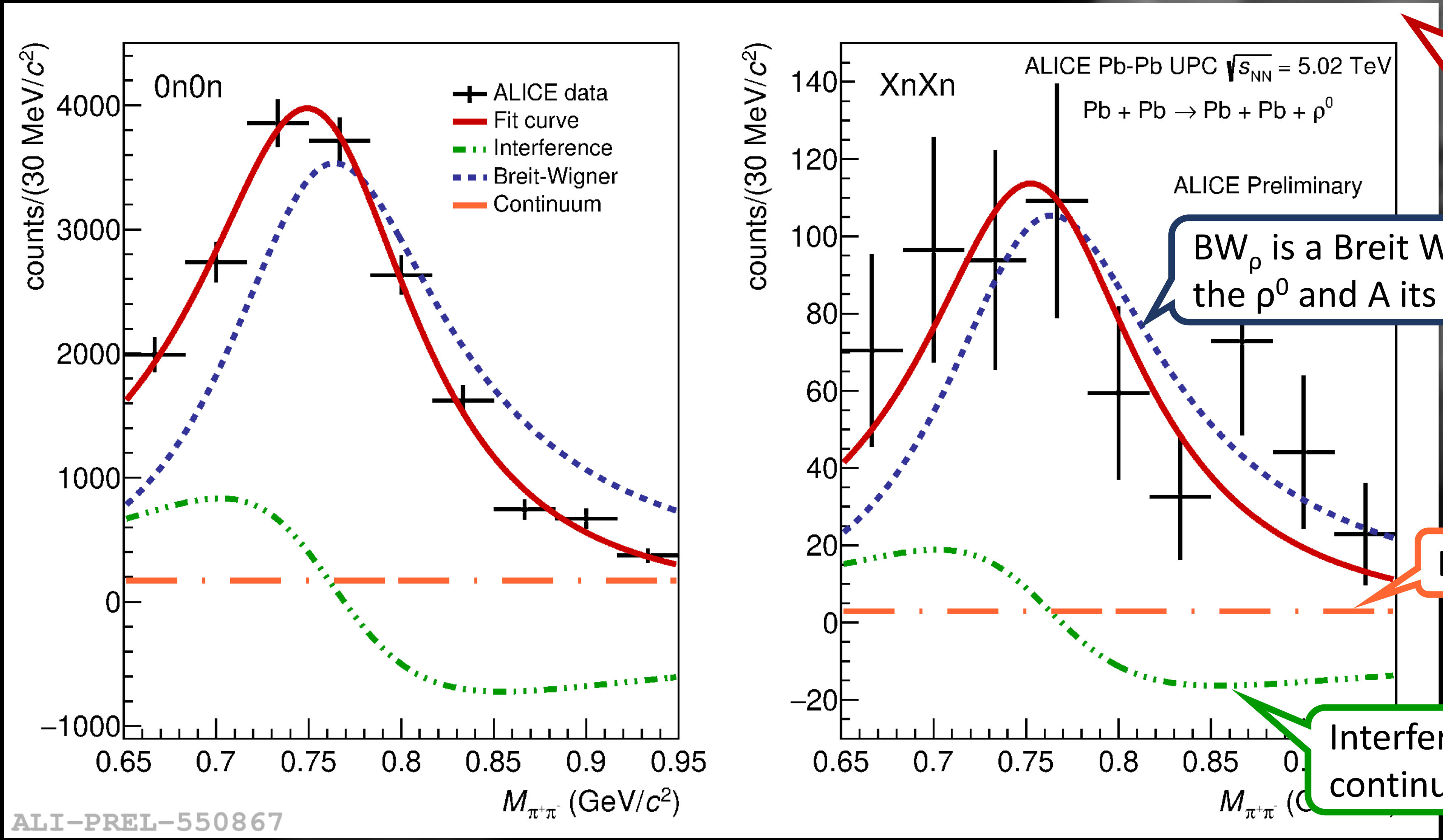
Build the MC mass distributions by weighting each event with $w(p_T)$ applied to the generated p_T

SIGNAL EXTRACTION

The corrected mass spectra in each ϕ bin are fitted using the Söding model

$$dN/dm_{\pi\pi} = |A \cdot BW_\rho + B|^2$$

Extraction of the ρ^0 yield in each neutron emission class, as a function of ϕ



BW_ρ is a Breit Wigner that represents the ρ^0 and A its amplitude

B is the non-resonant amplitude

Interference between resonant and continuum pion pair production

ASYMMETRY EXTRACTION

Fit to ρ^0 yields as a function of ϕ in each neutron emission class to extract the anisotropy

cos(2ϕ) modulation with *b* dependent amplitude

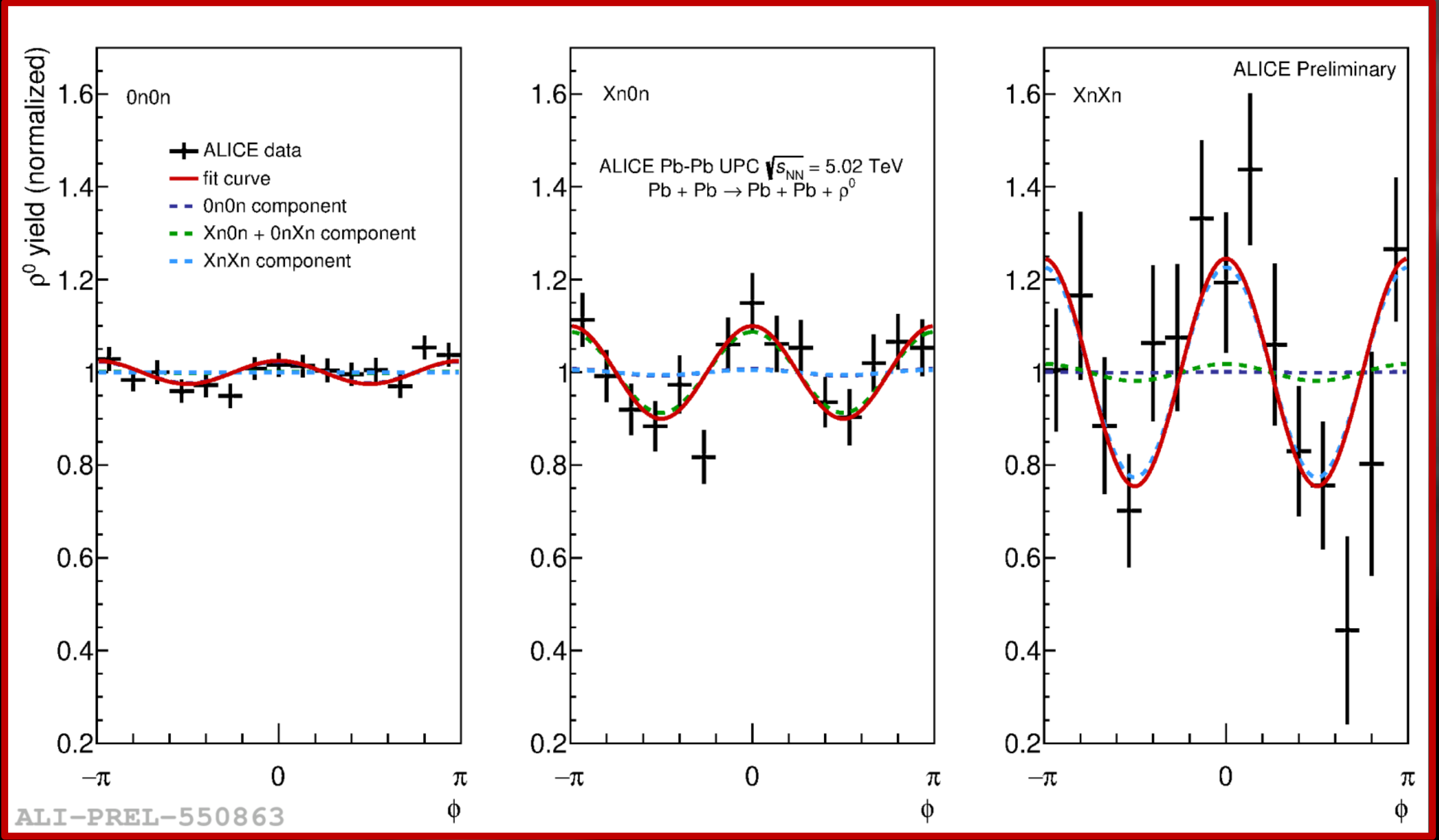
b ↔ neutron emission classes
Migrations across neutron classes need to be considered!

$$\begin{pmatrix} n_{\rho\,\mathrm{0n0n}} \\ n_{\rho\,\mathrm{Xn0n}} \\ n_{\rho\,\mathrm{XnXn}} \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} + \begin{pmatrix} w_{\mathrm{0n0n} \to \mathrm{0n0n}} & w_{\mathrm{Xn0n} \to \mathrm{0n0n}} & w_{\mathrm{XnXn} \to \mathrm{0n0n}} \\ w_{\mathrm{0n0n} \to \mathrm{Xn0n}} & w_{\mathrm{Xn0n} \to \mathrm{Xn0n}} & w_{\mathrm{XnXn} \to \mathrm{Xn0n}} \\ w_{\mathrm{0n0n} \to \mathrm{XnXn}} & w_{\mathrm{Xn0n} \to \mathrm{XnXn}} & w_{\mathrm{XnXn} \to \mathrm{XnXn}} \end{pmatrix} \begin{pmatrix} a_{2\,\mathrm{0n0n}} \\ a_{2\,\mathrm{Xn0n}} \\ a_{2\,\mathrm{XnXn}} \end{pmatrix} \cos(2\phi)$$

$w_{Y \to Z}$ = contribution of the physical class Y to the yield in the experimental class Z.
Computed from measured cross-sections and migrations probabilities [12].

a_2 = true amplitudes of the modulation

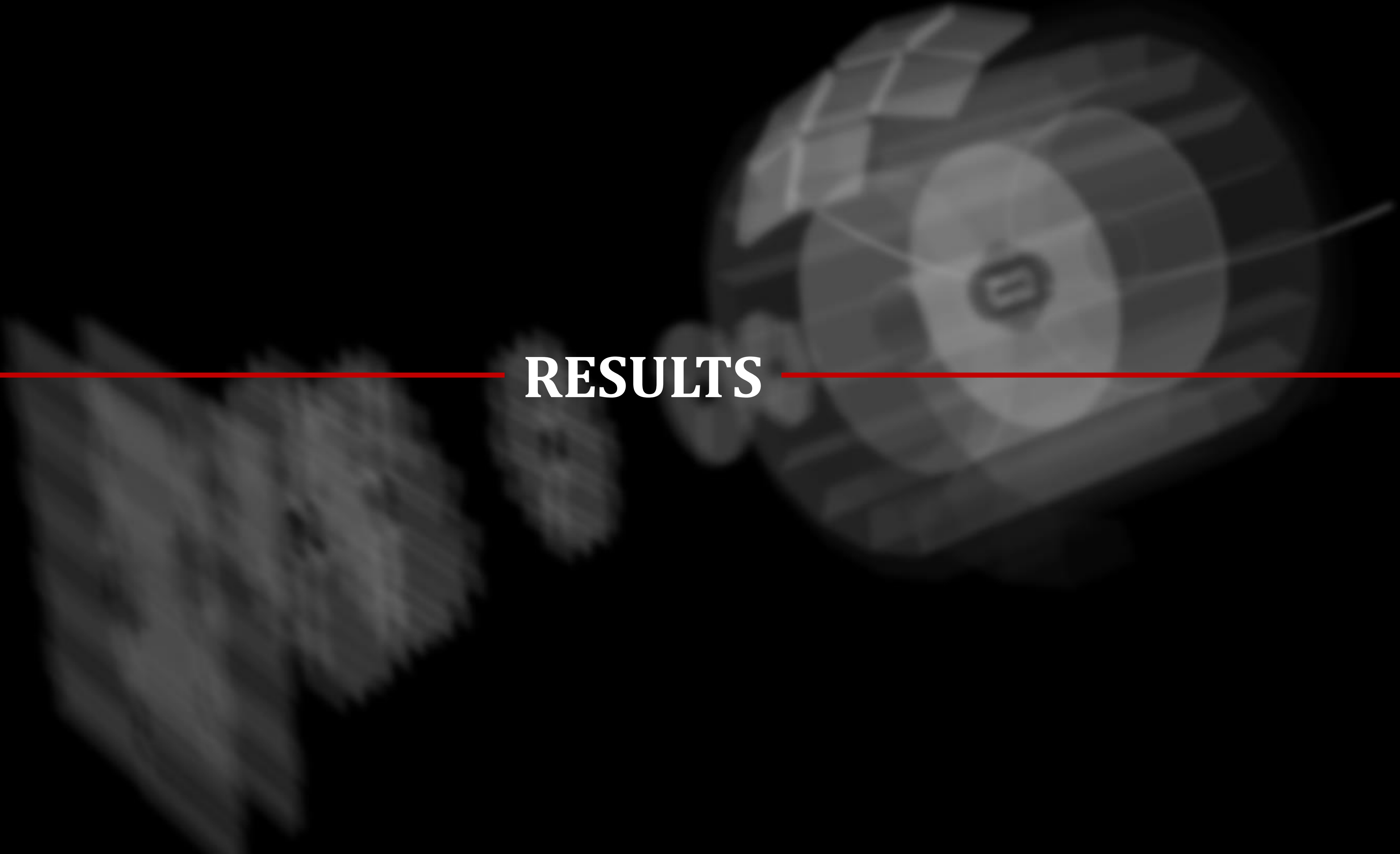
ASYMMETRY EXTRACTION



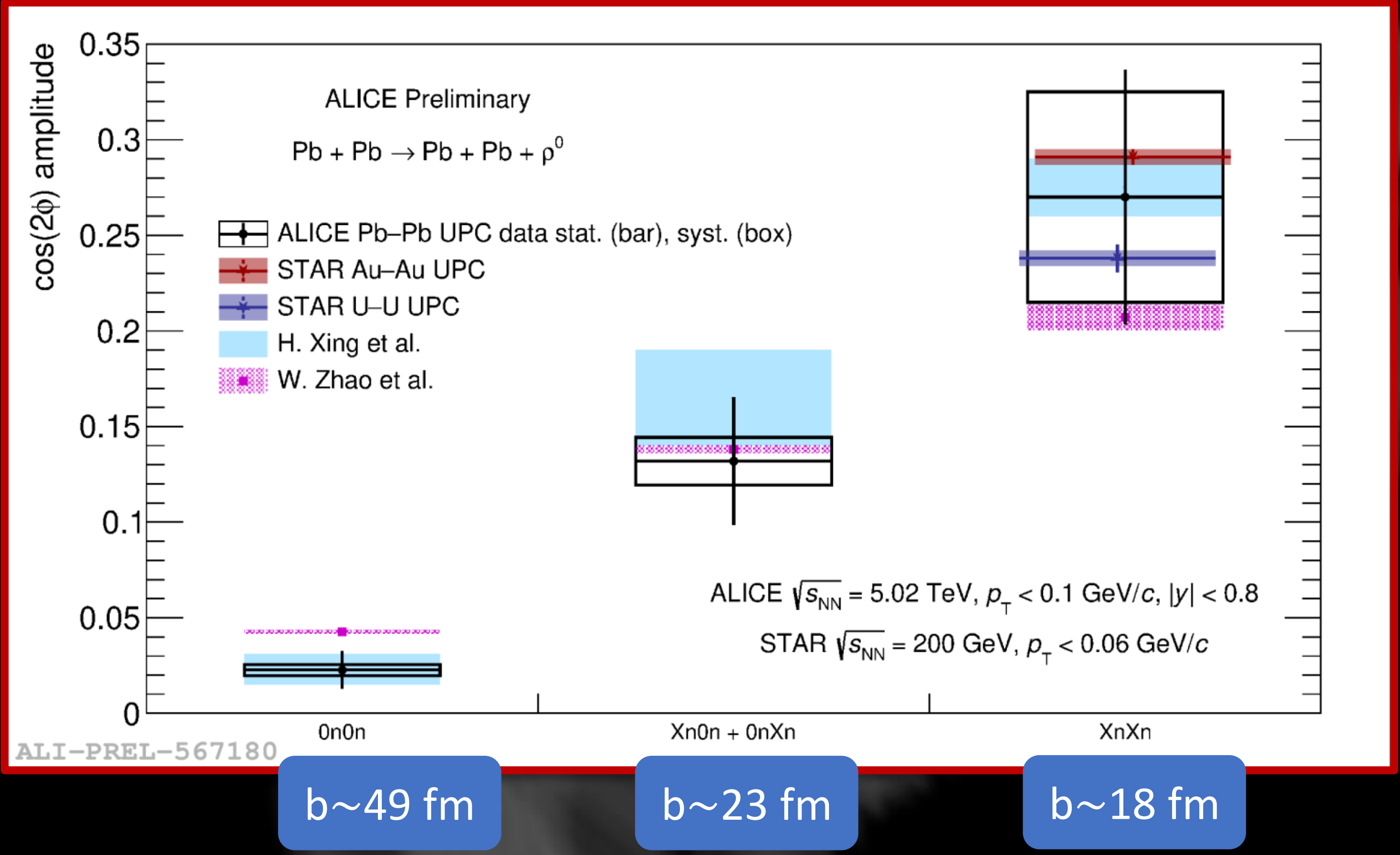
The modulation is very different in different neutron emission classes

The effect of migrations is important especially in Xn0n and XnXn

RESULTS



ASYMMETRY RESULTS



First measurement of the azimuthal anisotropy of the ρ^0 yield as a function of the impact parameter

The **modulation strength strongly increases as *b* decreases**

Compatible with **theory** [6,7], XnXn amplitude compatible with **STAR** results [8] for Au-Au and U-U collisions at lower energy

It is not possible to constrain models yet → goal with Run 3 data!

Median values, less sensitive wrt the mean to the tail of other interactions at large *b*

TAKE HOME AND OUTLOOK

TAKE HOME & OUTLOOK

Take home

We measured for the first time the azimuthal anisotropy of the ρ^0 yield as a function of the impact parameter

The effect varies by more than one order of magnitude as a function of *b*

Results compatible with available theoretical predictions [6,7] and with STAR [8] for the same neutron emission requirement

Outlook

Run 3 data will allow one to constrain models and to perform more differential studies

The effect depends on the nuclear structure [6,7] → useful to repeat the analysis for other colliding systems (e.g. OO)

The same effect can be studied with other particles (e.g. J/ψ) where the models predictions are more precise

REFERENCES

[1] ALICE webpage

[2] A. Baltz *et al. The Physics of Ultraperipheral Collisions at the LHC,* Phys.Rept. 458 (2008) 1171

[3] Talk by Daniel Brandenburg *Linearly polarized photon-gluon collisions*

[4] S. Klein, J. Nystrand, *Interference in exclusive vector meson production in heavy ion collisions*, Phys.Rev.Lett. 84 (2000) 2330-2333

[5] W. Zha et al. *Exploring the double-slit interference with linearly polarized photons*, Phys.Rev.D 103 (2021) 3, 033007

[6] H. Xing et al. *The cos 2φ azimuthal asymmetry in ρ0 meson production in ultraperipheral heavy ion collisions,* JHEP 10 (2020) 064

[7] W. Zhao et al. *Effects of nuclear structure and quantum interference on diffractive vector meson production in ultra-peripheral nuclear collisions*, arXiv:2310.15300 [nucl-th] (2023)

[8] STAR Collaboration, *Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions*, Sci.Adv. 9 (2023) eabq3903

[9] Talk by Ashik Ikbal (STAR), *Exclusive J/ψ Photoproduction and Entanglement-Enabled Spin Interference in Ultra-Peripheral Collisions at STAR*

[10] M. Broz et al. A generator of forward neutrons for ultra-peripheral collisions: $\boldsymbol{n_0^0 n}$, *Comput. Phys. Commun. (2020) 107181*

[11] *S. Klein, et al. STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions,* Comput. Phys. Commun. 212 (2017) 258–268

[12] ALICE Collaboration, *Coherent photoproduction of ρ0 vector mesons in ultra-peripheral Pb-Pb collisions at √sNN = 5.02 TeV,* JHEP 06 (2020) 035

OTHER ALICE TALKS

Mon 11/12	10:10	D. Grund	*Recent results on ultra-peripheral collisions with the ALICE experiment*
Mon 11/12	10:10	M. Winn	Energy dependence of J/ψ in UPCs at the LHC
Mon 11/12	18:45	M. Kim	*K+K- photoproduction in ultra-peripheral Pb-Pb collisions with ALICE*
Thu 11/12	17:30	N. Bizé	Photoproduction of J/ψ and dileptons in events with nuclear overlap with ALICE
Ven 15/12	16:30	I. Arsene	*A Forward Calorimeter in ALICE*
Ven 15/12	18:00	A. Khatun	*UPC physics with ALICE in Run 3*

Check them out!

THANK YOU FOR YOUR ATTENTION!