# Azimuthal anisotropy from quantum interference in $\rho^0$ photoproduction in UPCs with ALICE

Andrea Giovanni Riffero[1] on behalf of the ALICE Collaboration

1. University and INFN Torino

DIS 2024, Grenoble, France, April 10th 2024

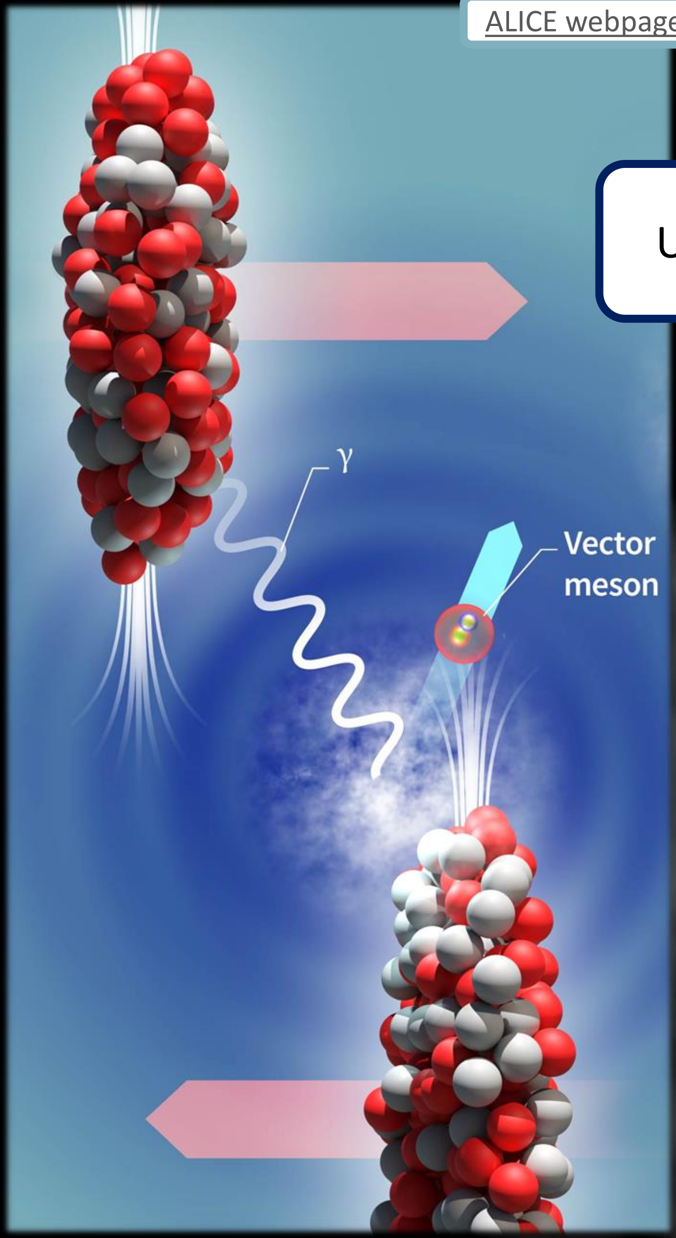
# OUTLINE

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

# PHYSICS MOTIVATIONS

# ULTRA-PERIPHERAL COLLISIONS (UPCs)

ALICE webpage

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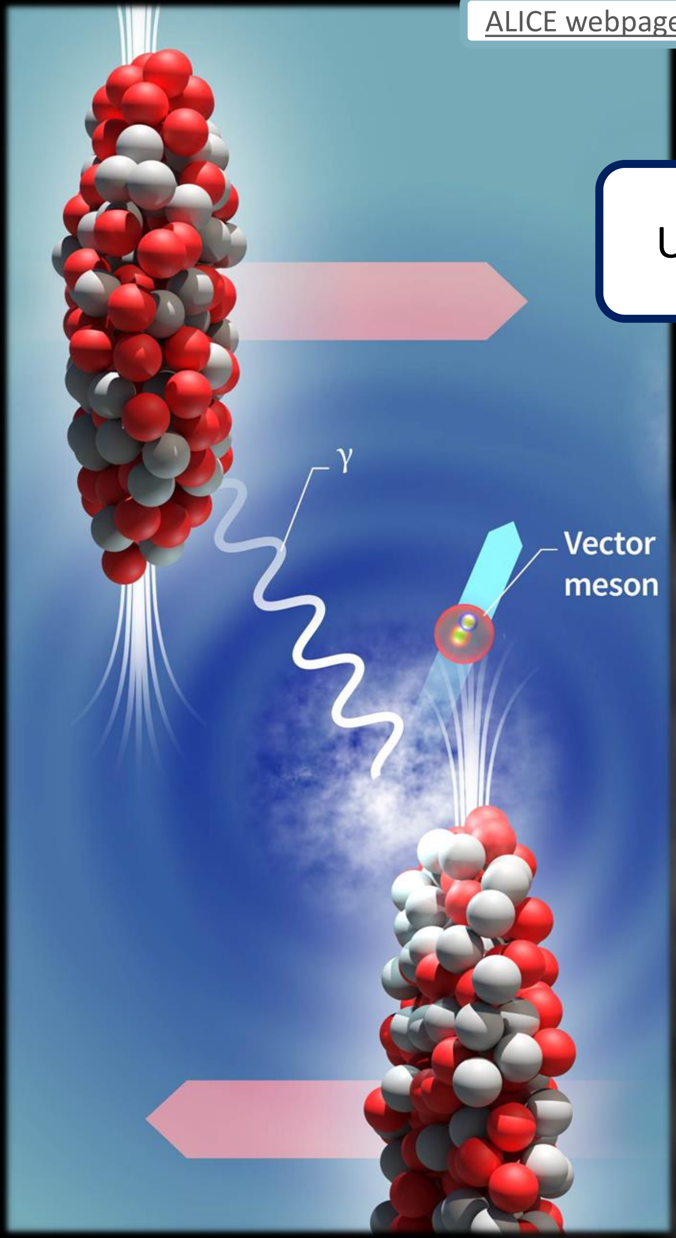


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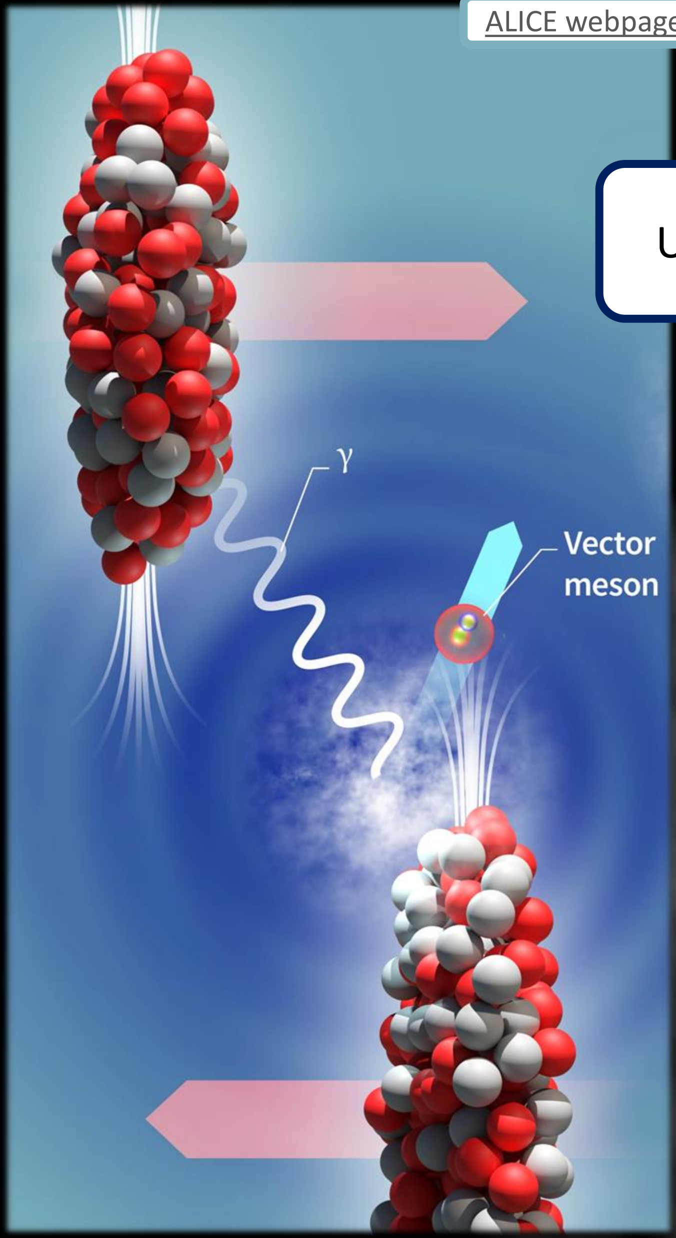


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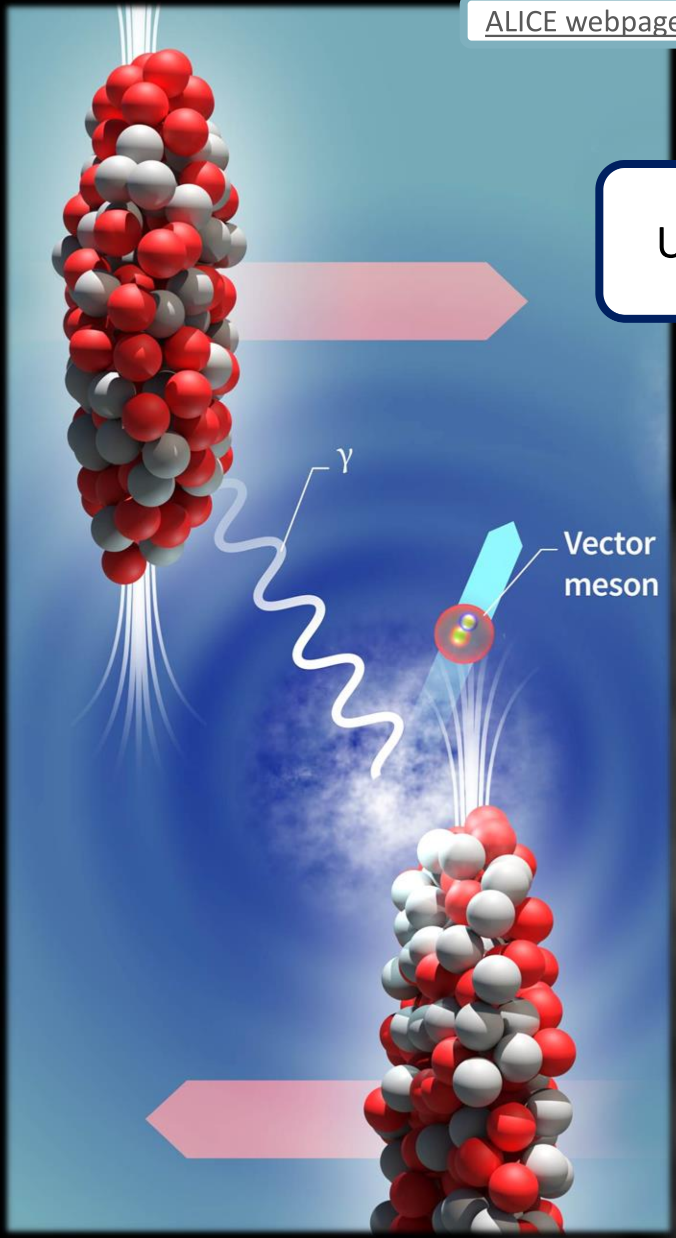


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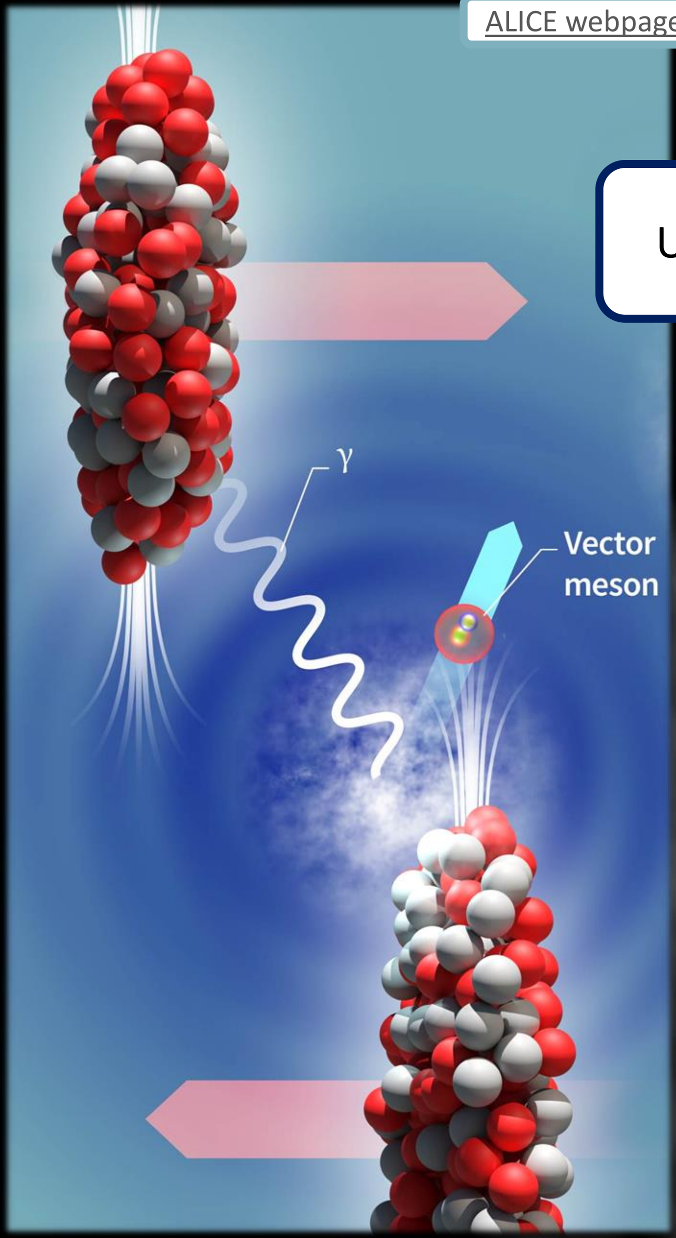


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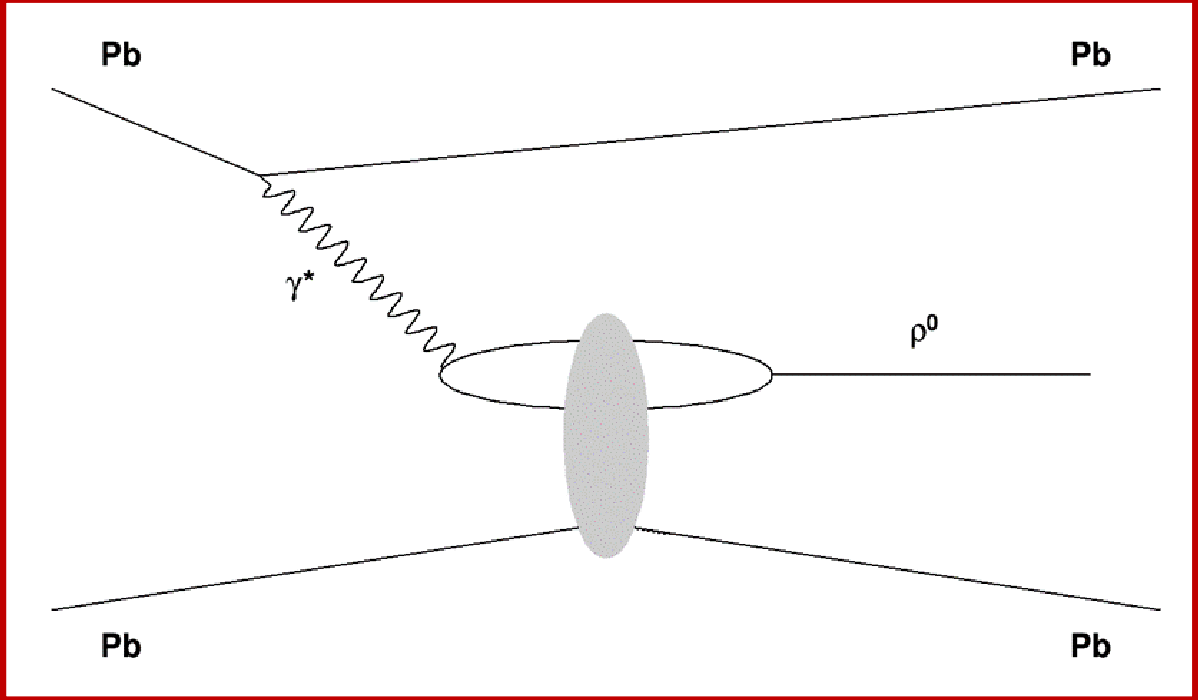
Coherent: the photon interacts with the nucleus as a whole
Incoherent: the photon interacts with one nucleon

# COHERENT PHOTOPRODUCTION

Interesting process:
coherent photoproduction of a vector meson (e.g. $\rho^0$)



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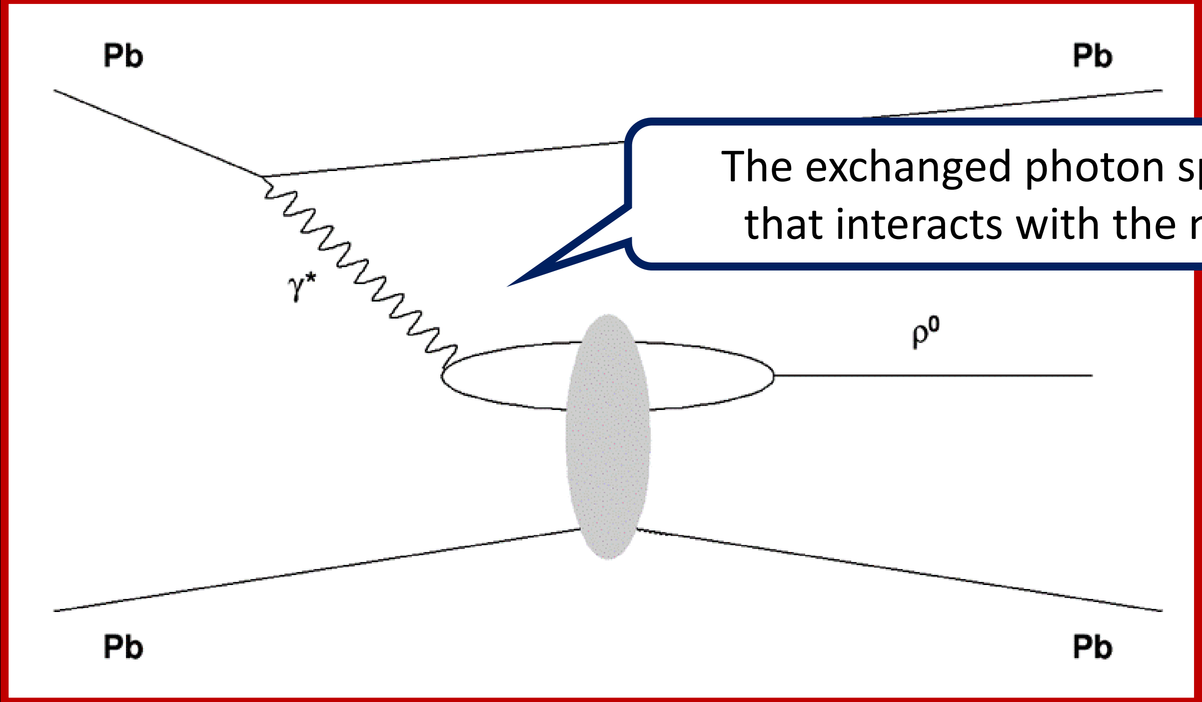


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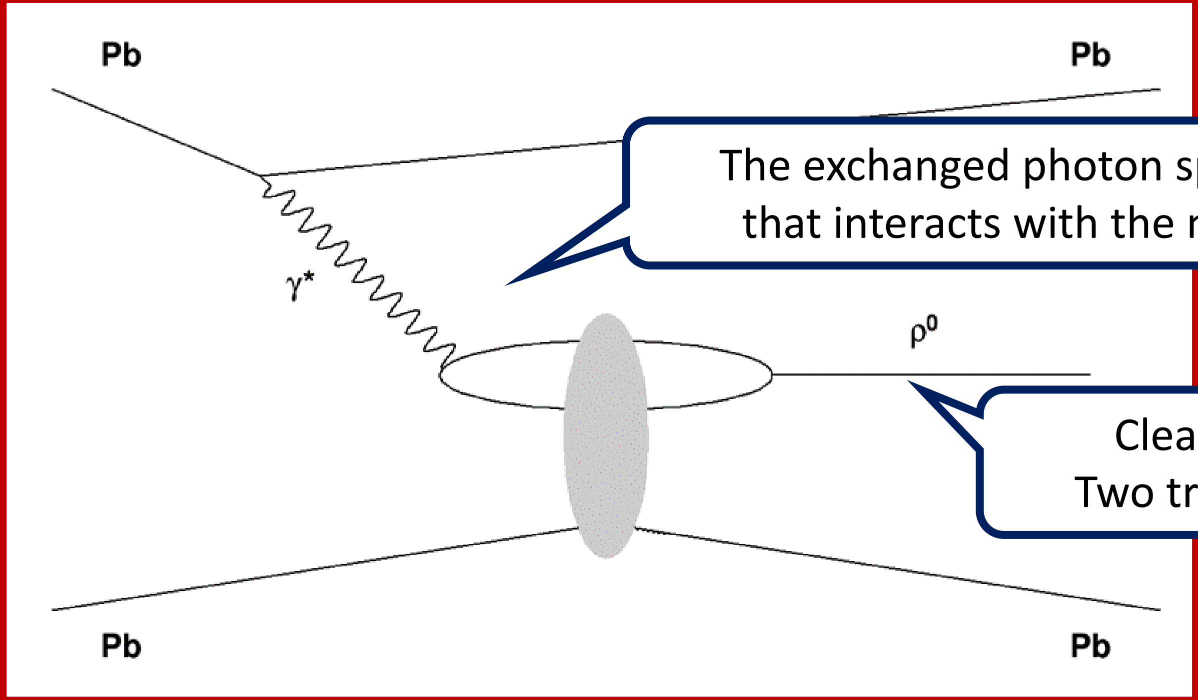


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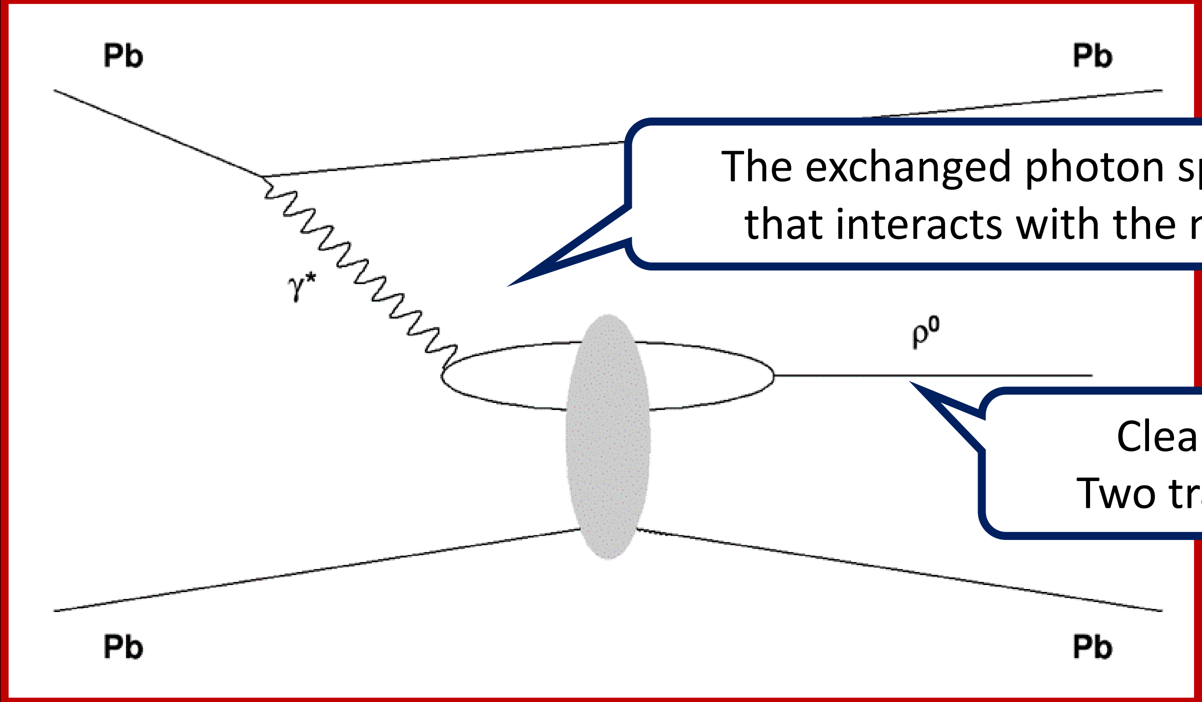


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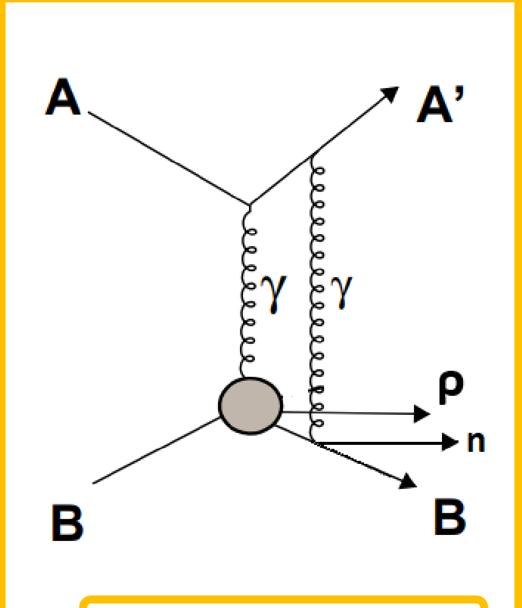


Phys.Rept. 458 (2008) 1171

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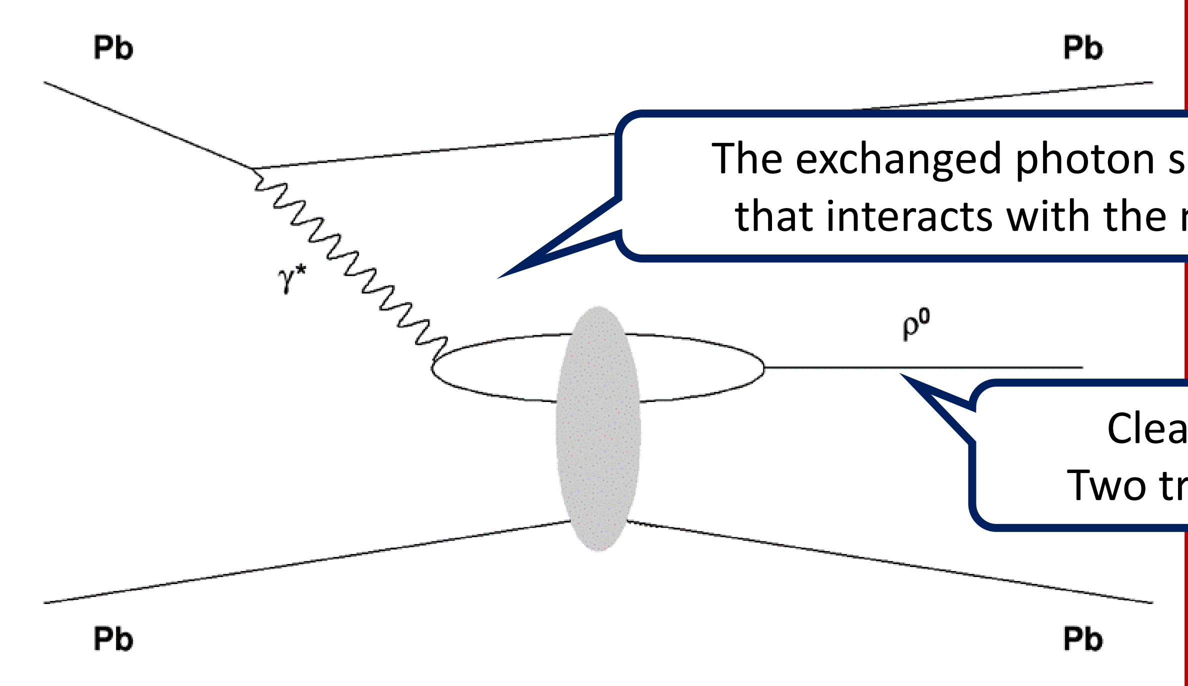


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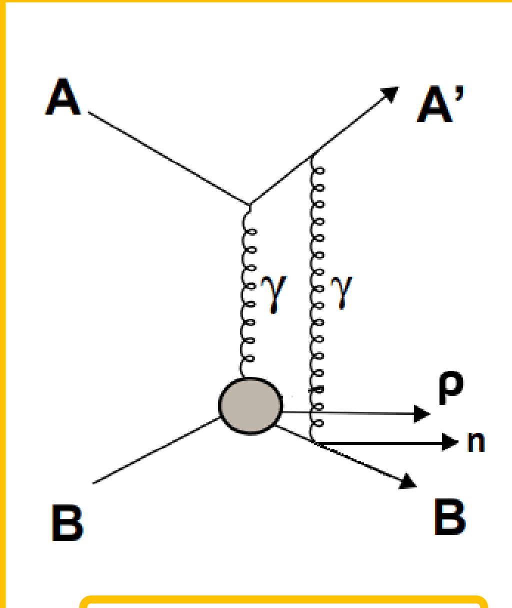


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UPCs with independent electromagnetic dissociation
→ nuclear break-up with emission of forward neutrons

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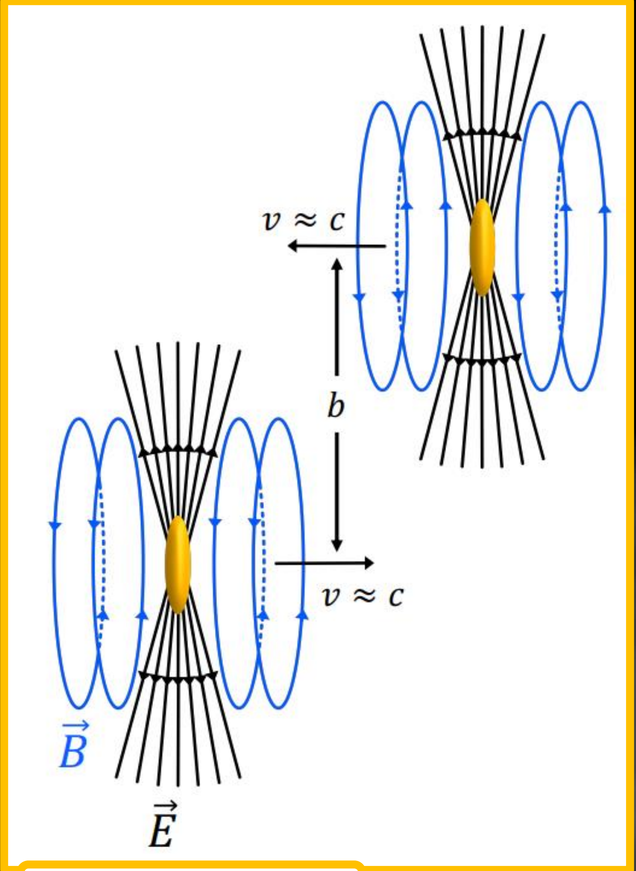


Talk by D. Brandenburg

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

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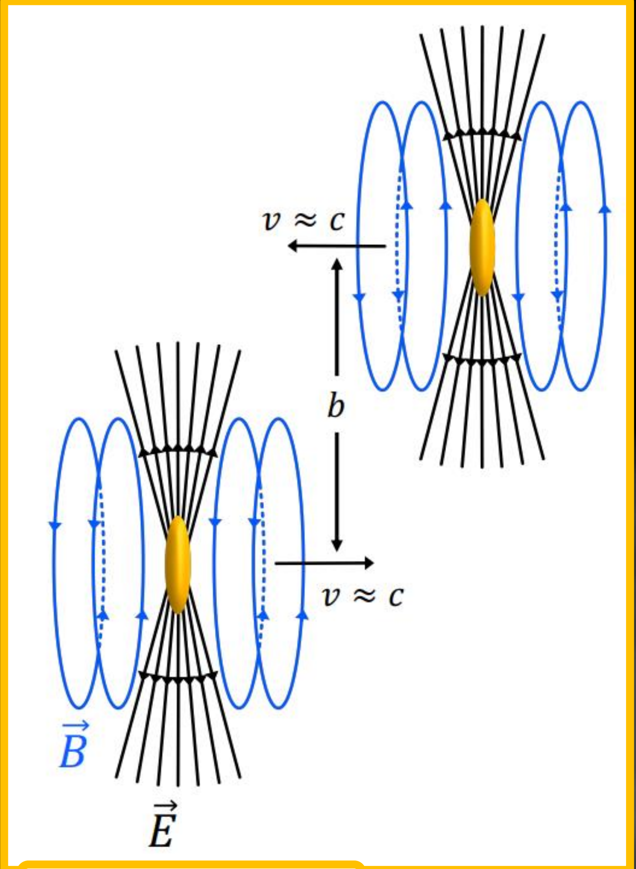


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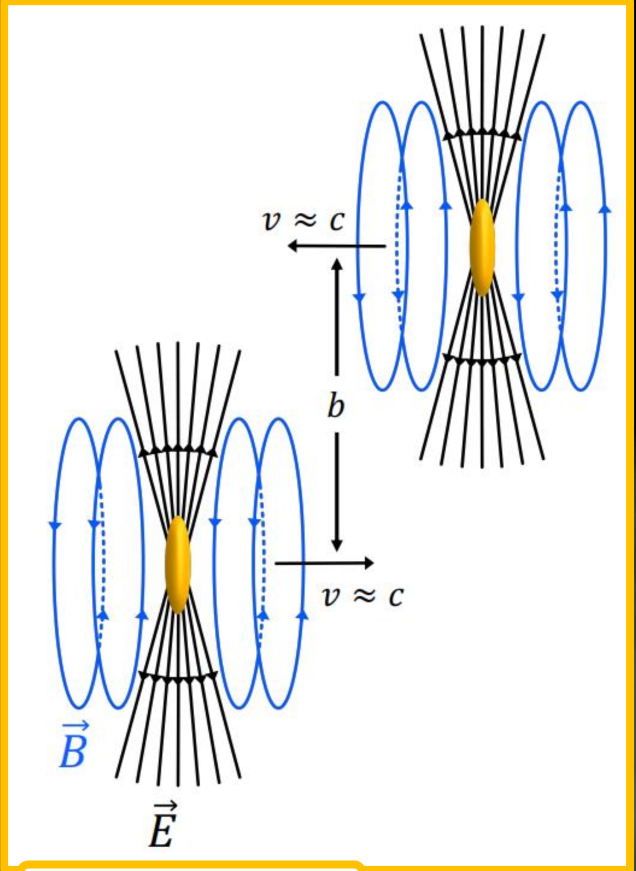


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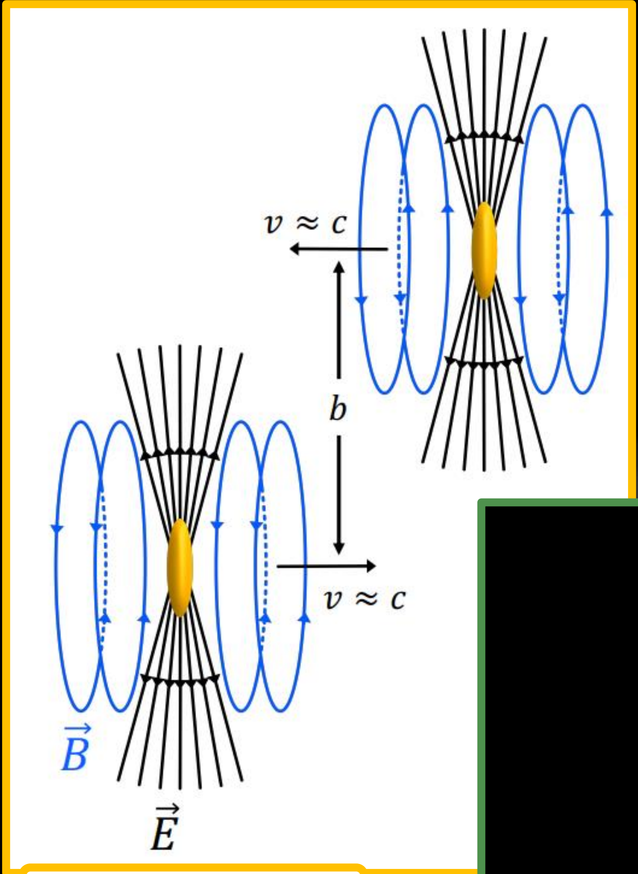


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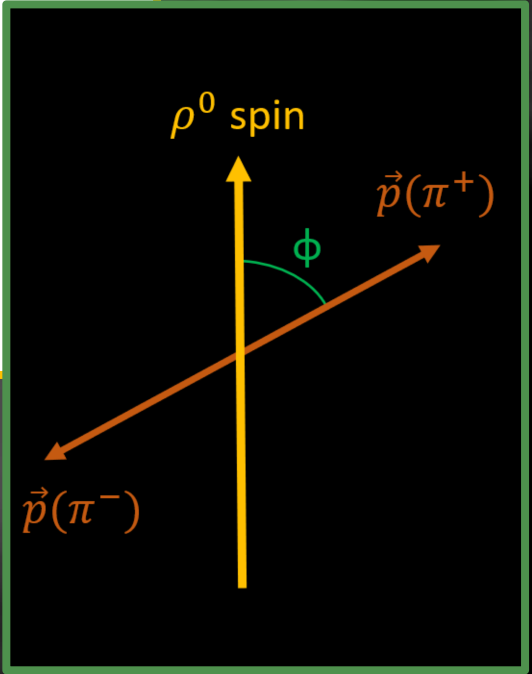


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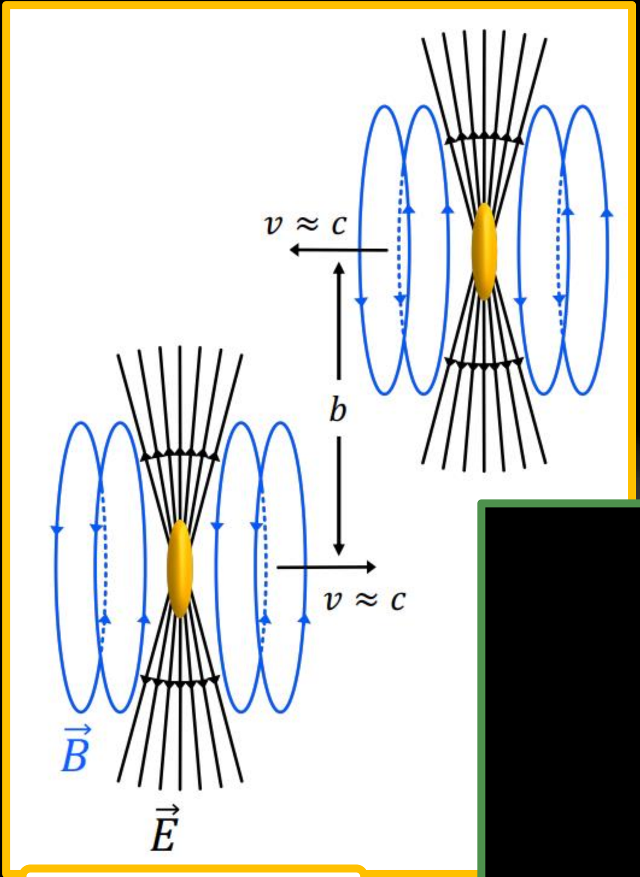

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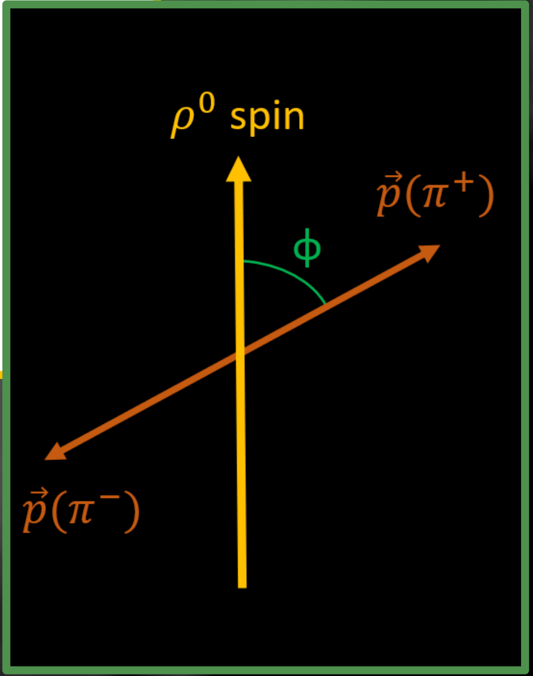


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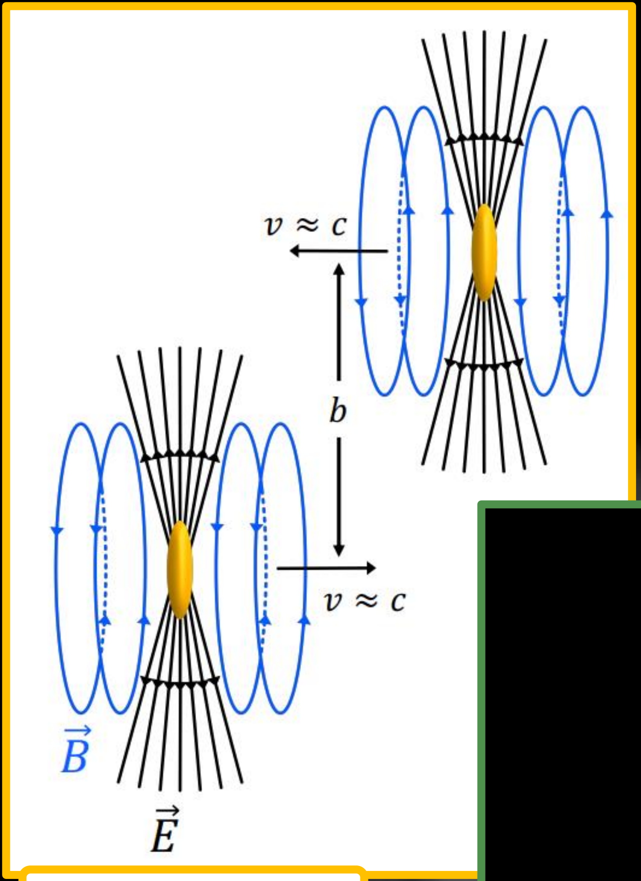


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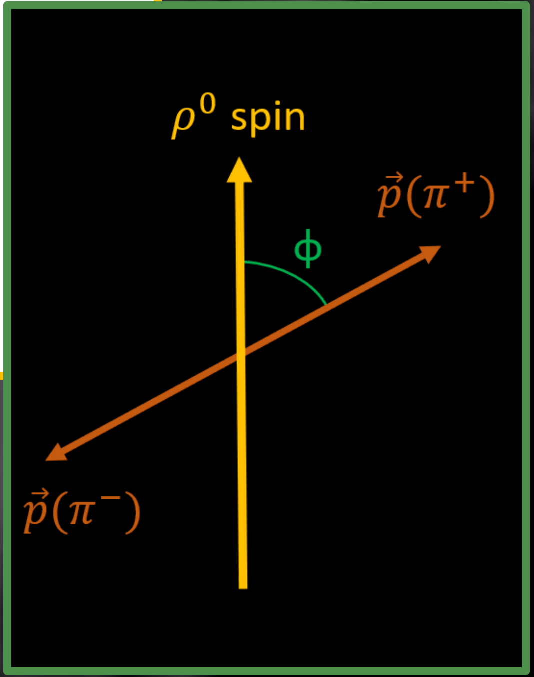


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We need another ingredient…
…let's look at the photoproduction process in UPCs!

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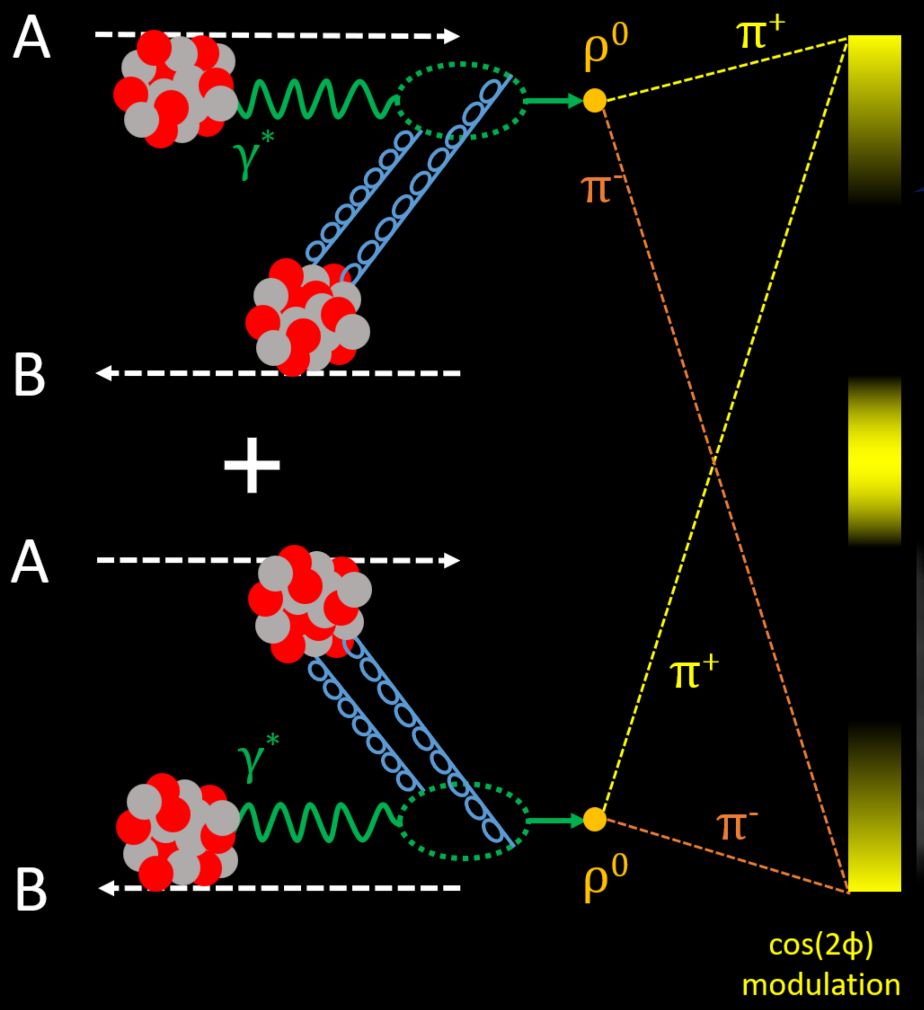


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→ two indistinguishable amplitudes contribute to the cross section

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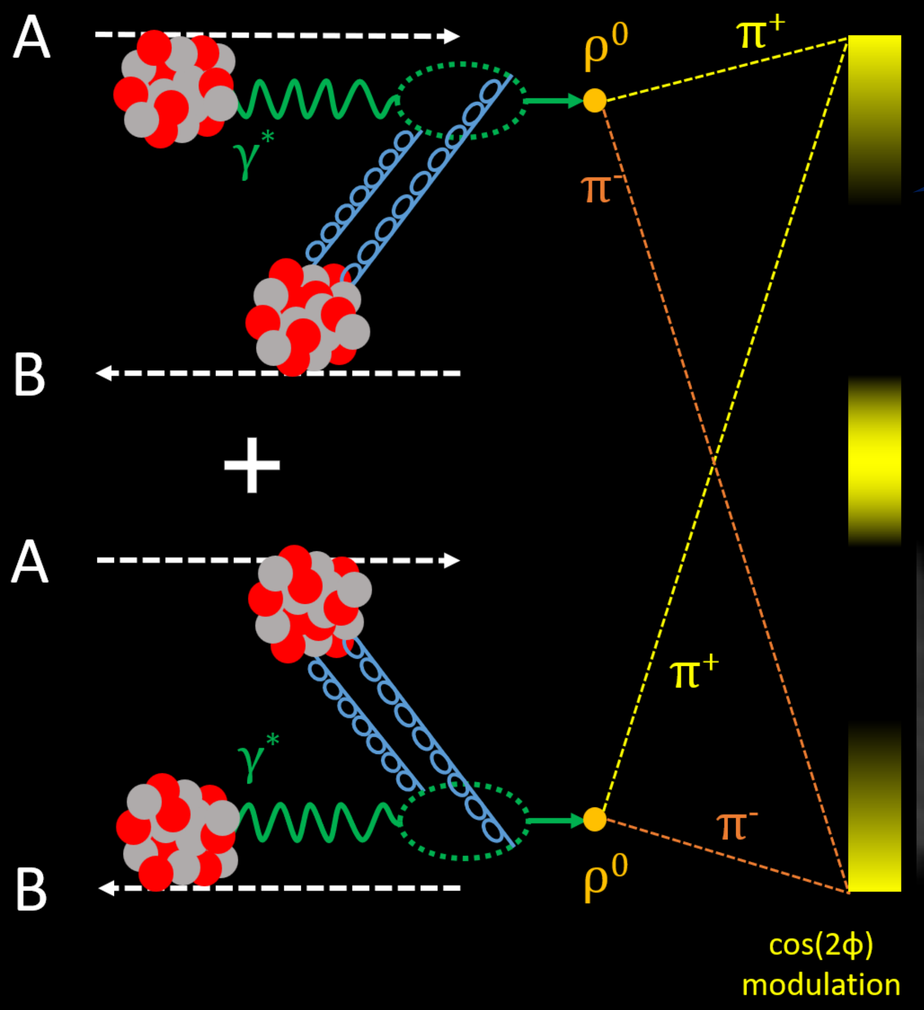


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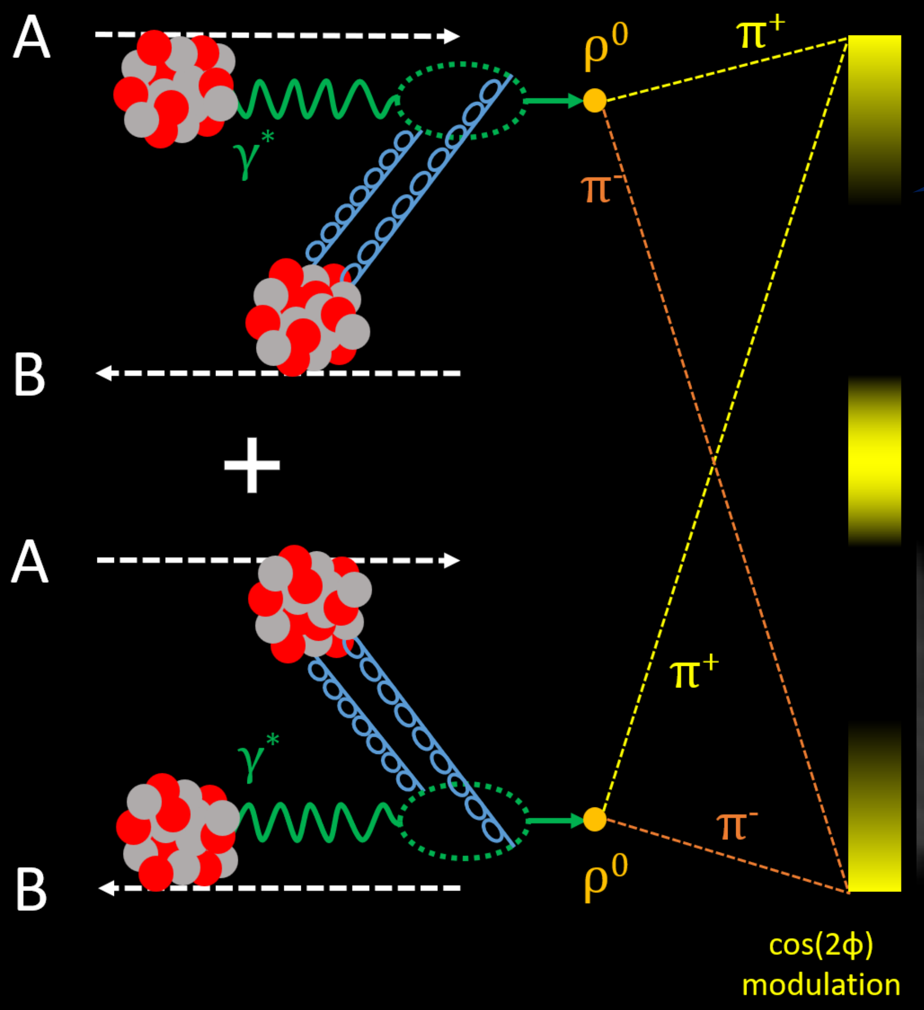


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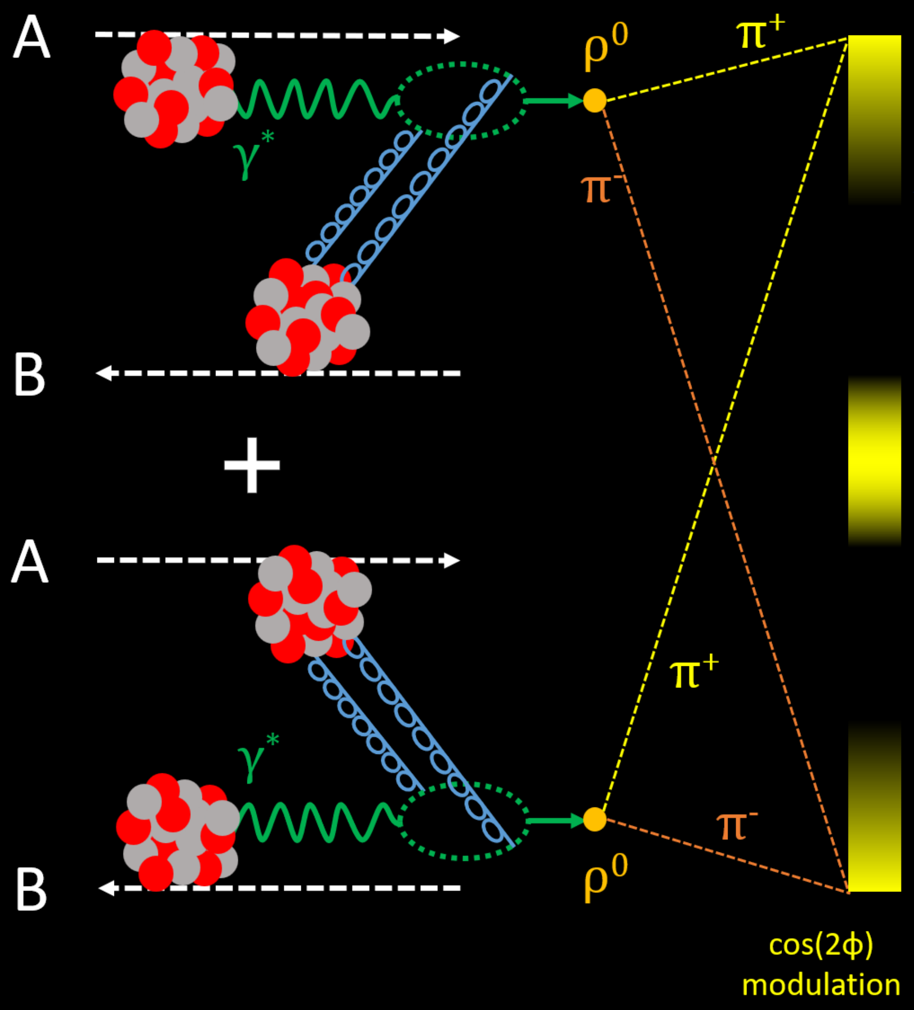


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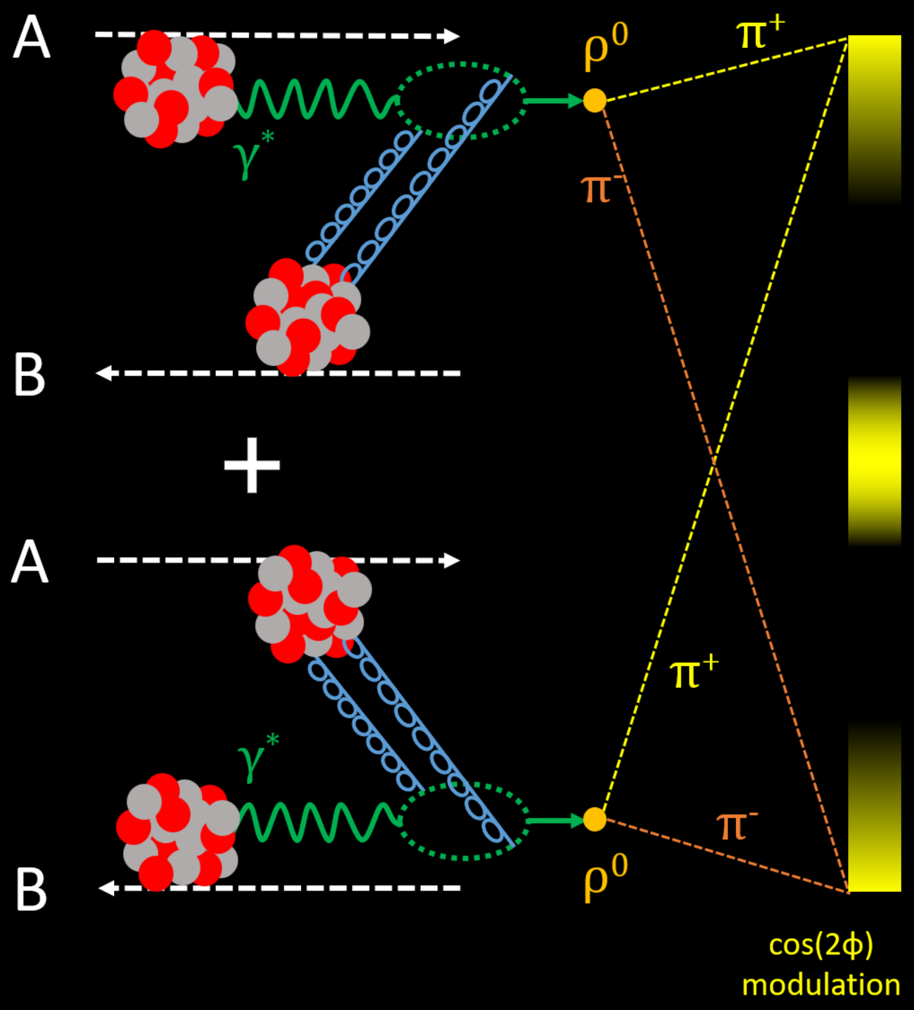


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Interference involves the pions, which need
to be emitted in an entangled state [4]

[4] PRL 84 (2000) 2330-2333

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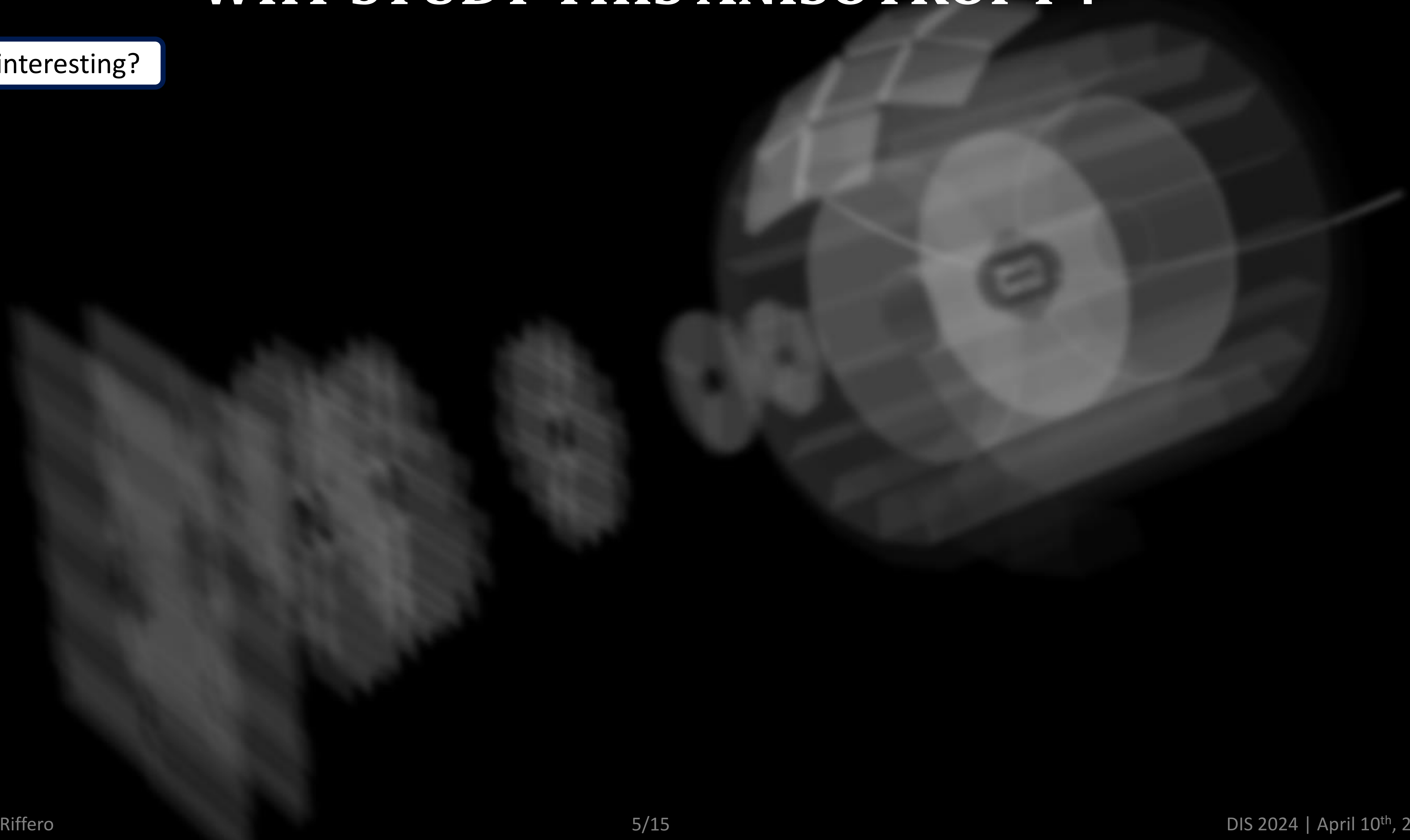
Why is it interesting?



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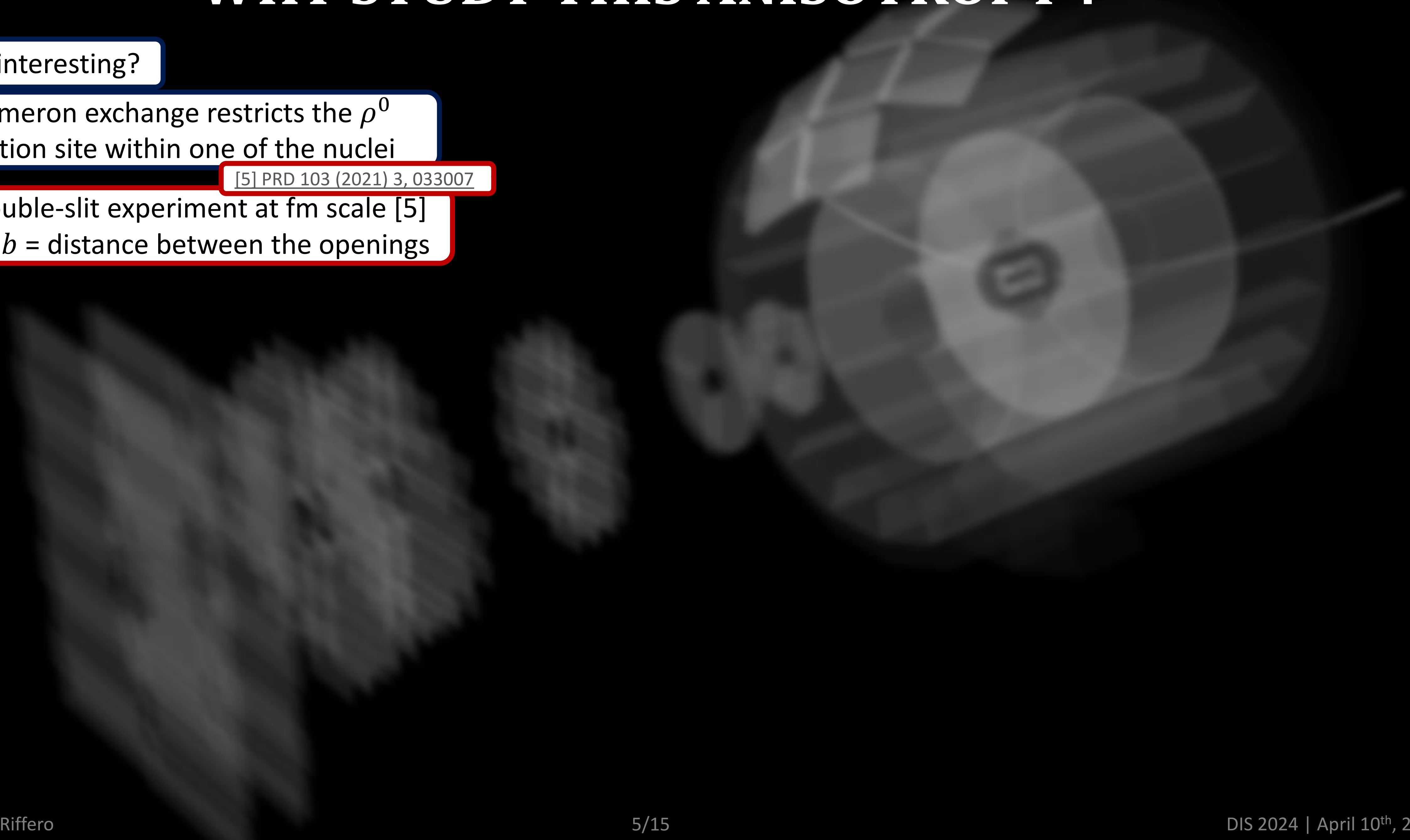
The pomeron exchange restricts the $\rho^0$ production site within one of the nuclei

[5] PRD 103 (2021) 3, 033007

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



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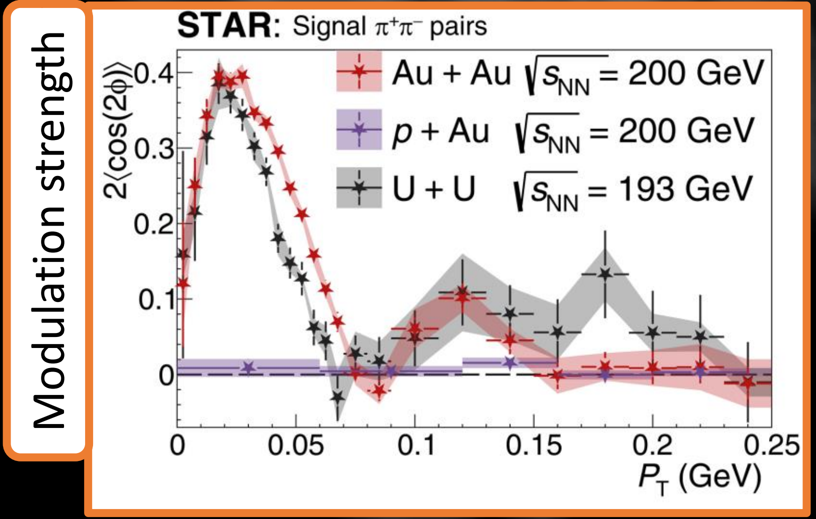


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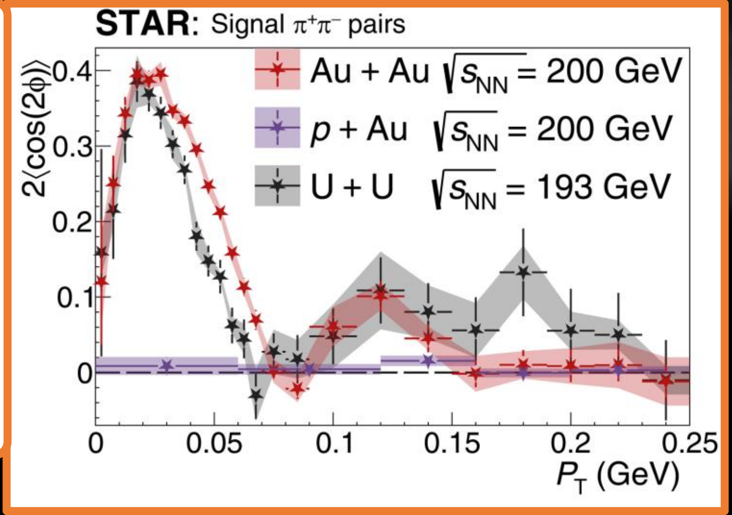


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This talk! And paper in preparation!

# DETECTOR AND DATA SAMPLE

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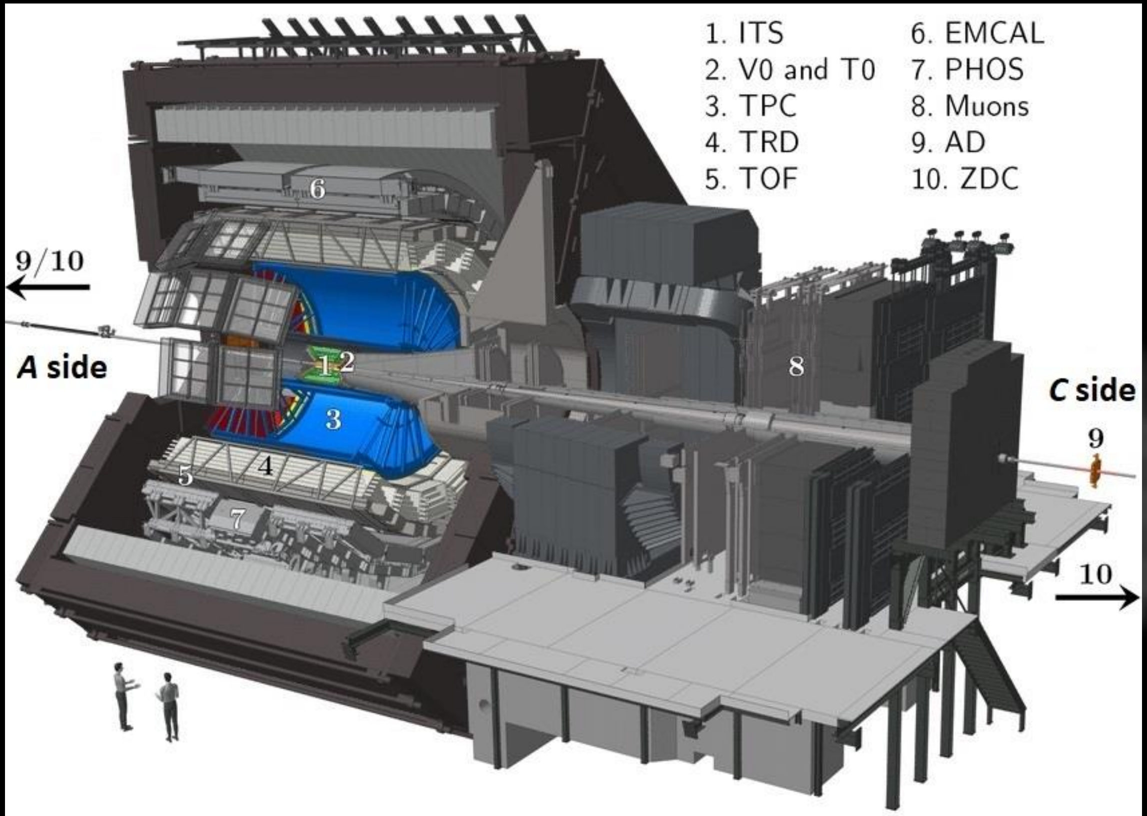

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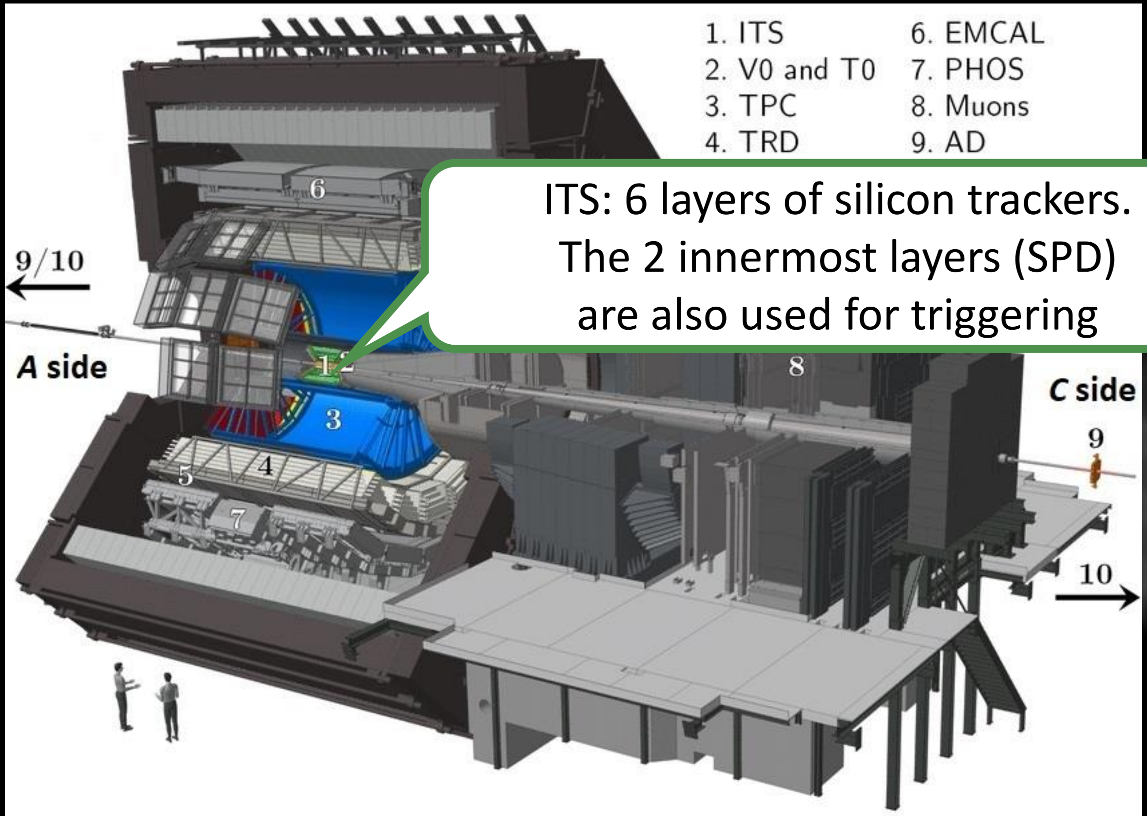


ITS: 6 layers of silicon trackers.
The 2 innermost layers (SPD)
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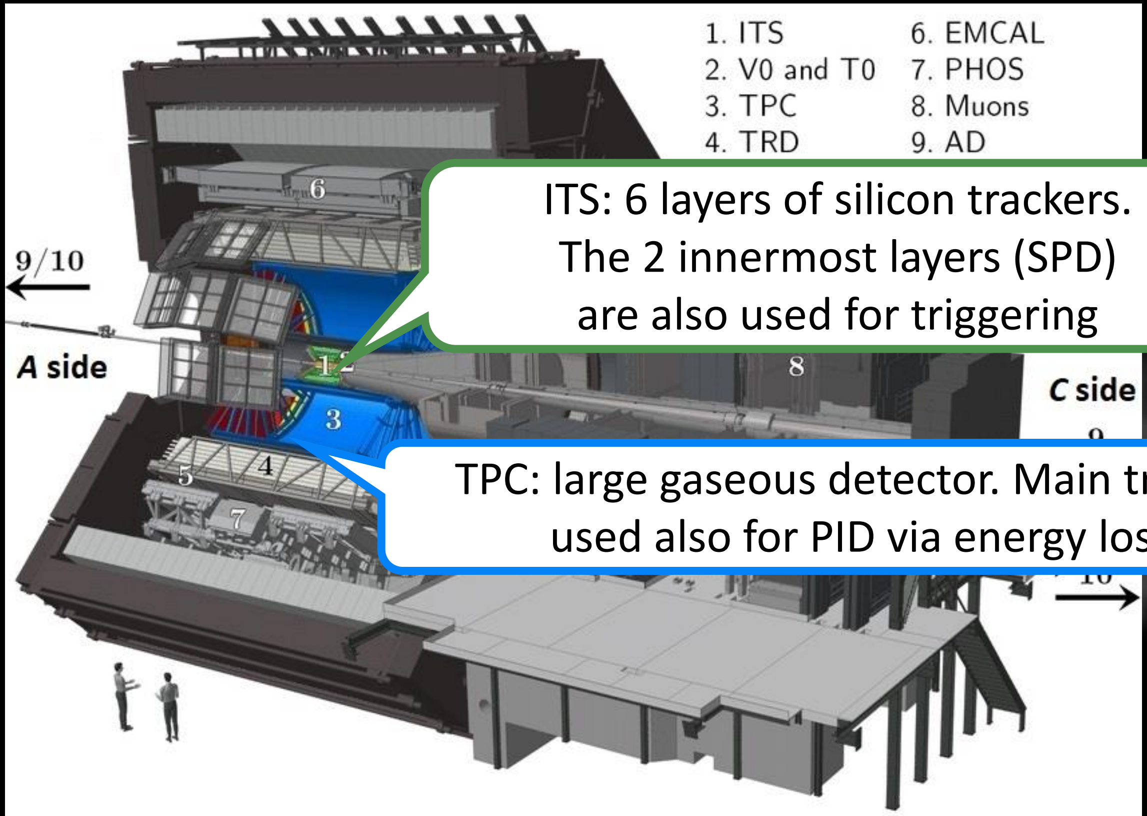


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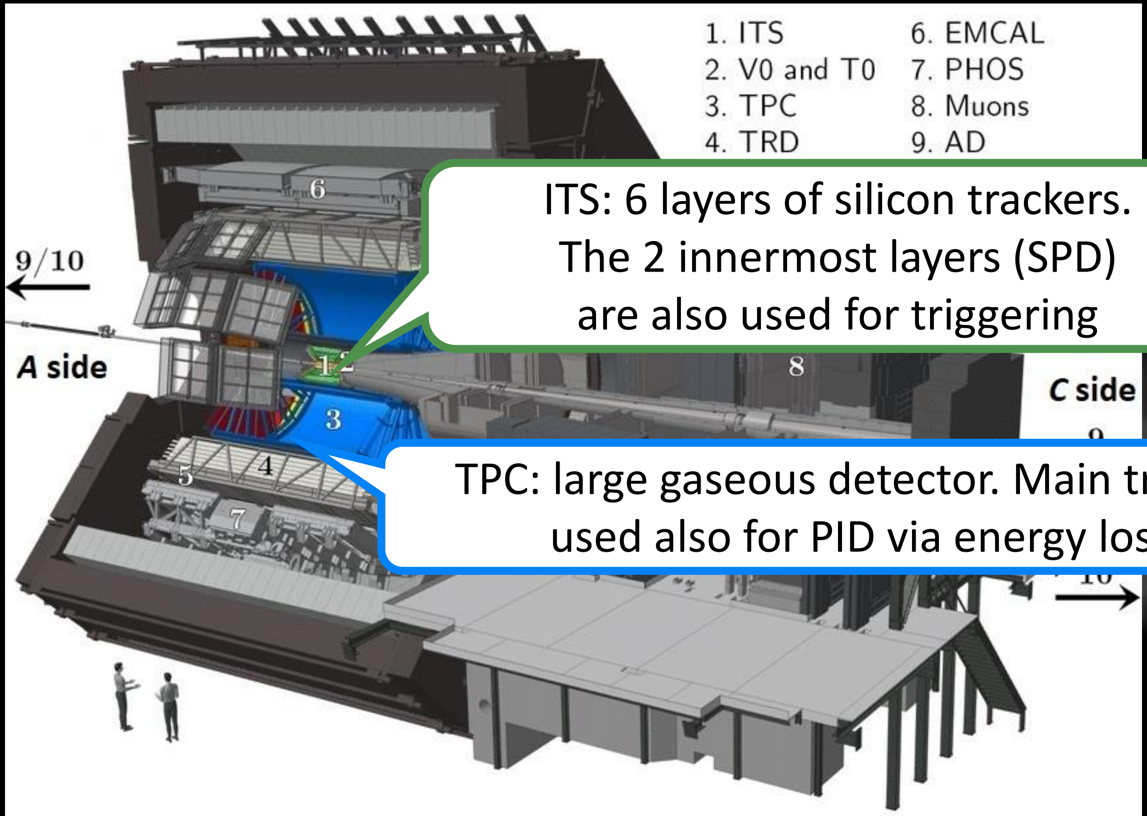
TPC: large gaseous detector. Main tracker, used also for PID via energy loss

# Run 2 ALICE DETECTOR & DATA SAMPLE

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

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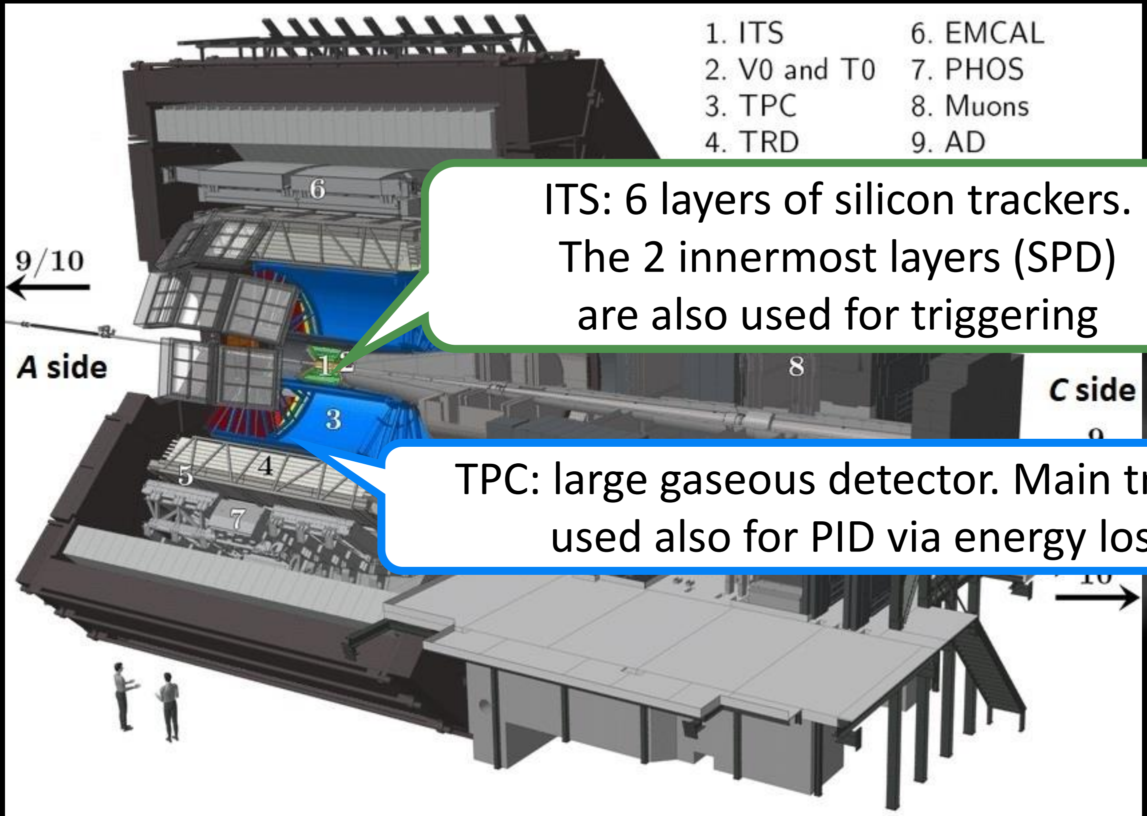


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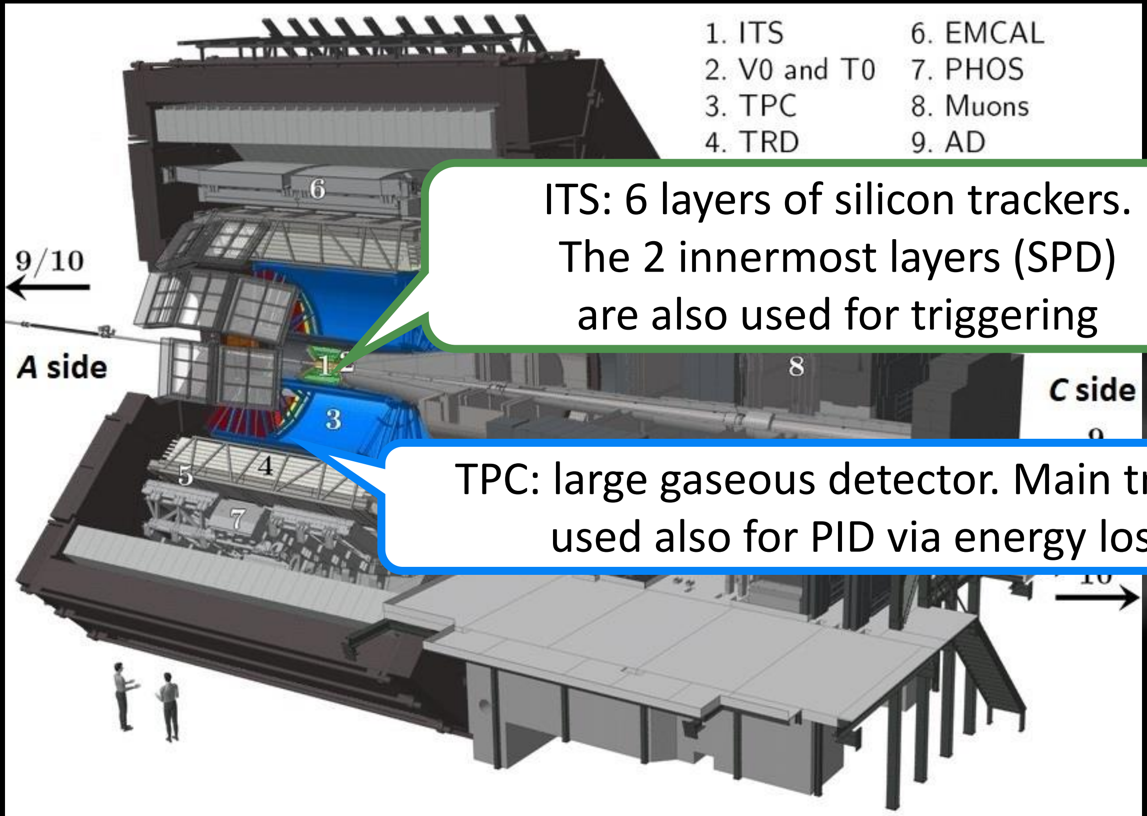


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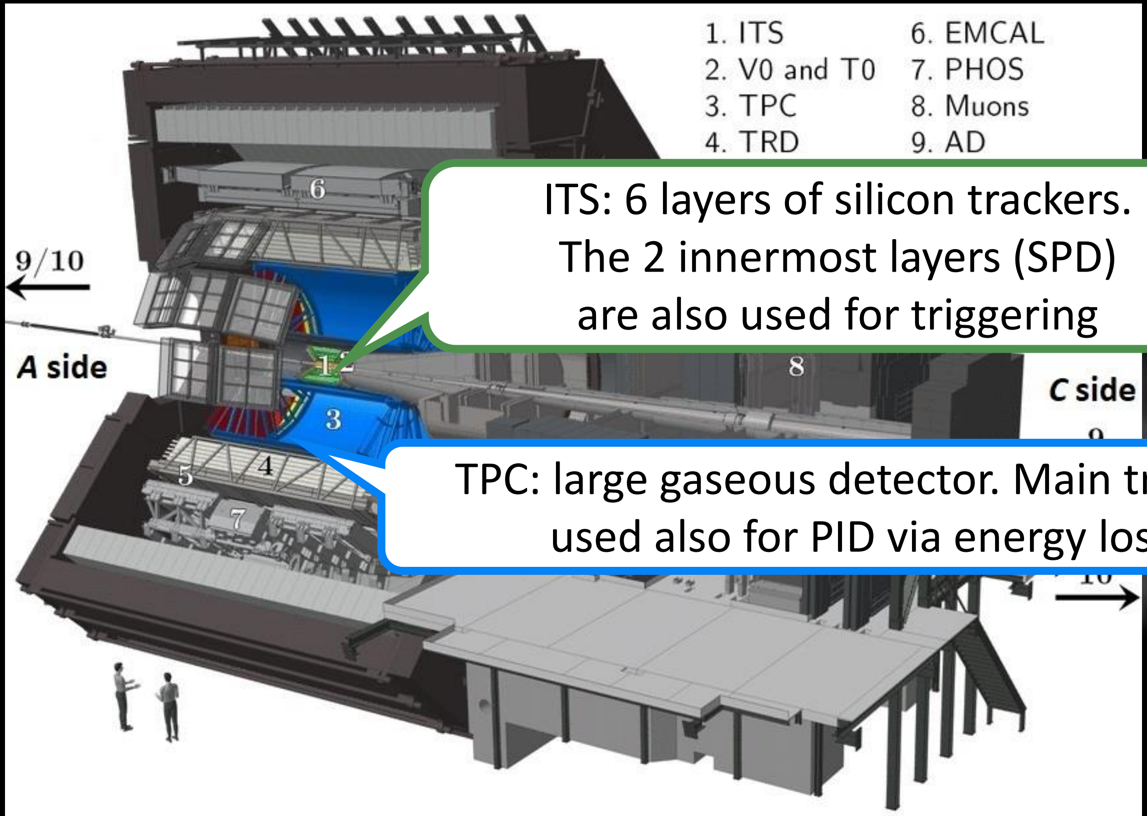


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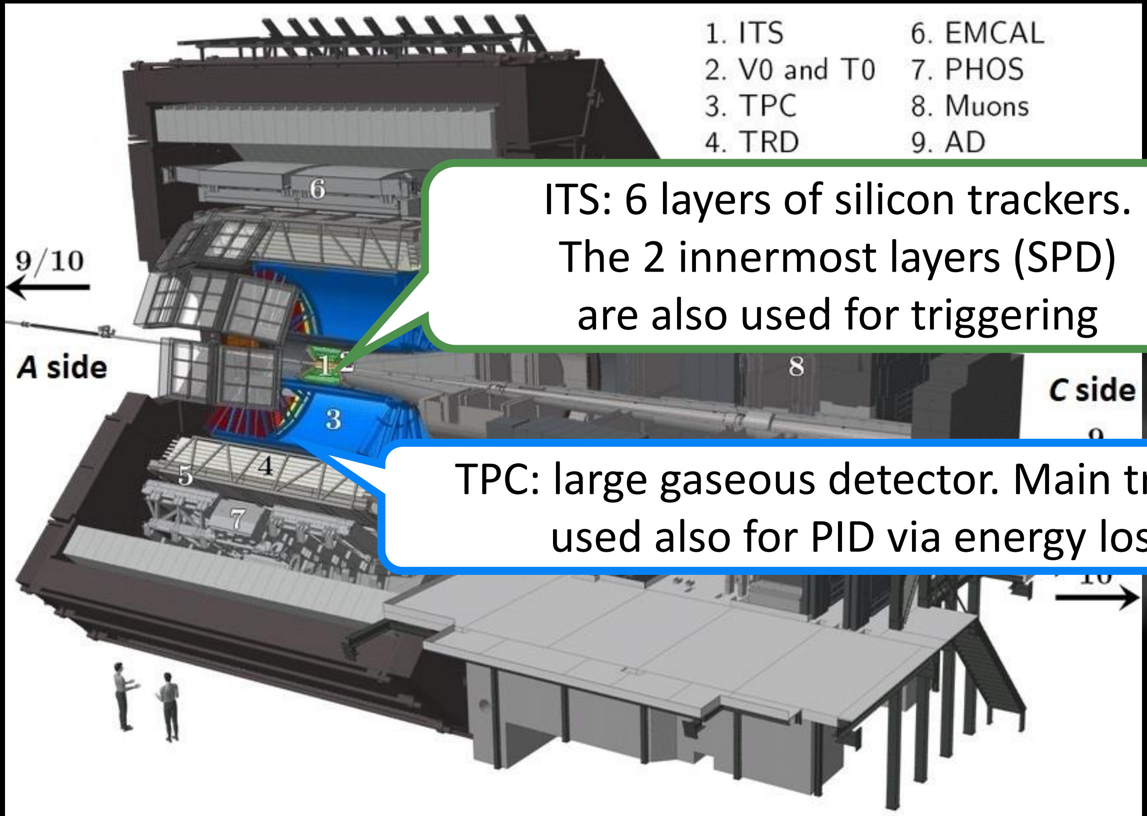


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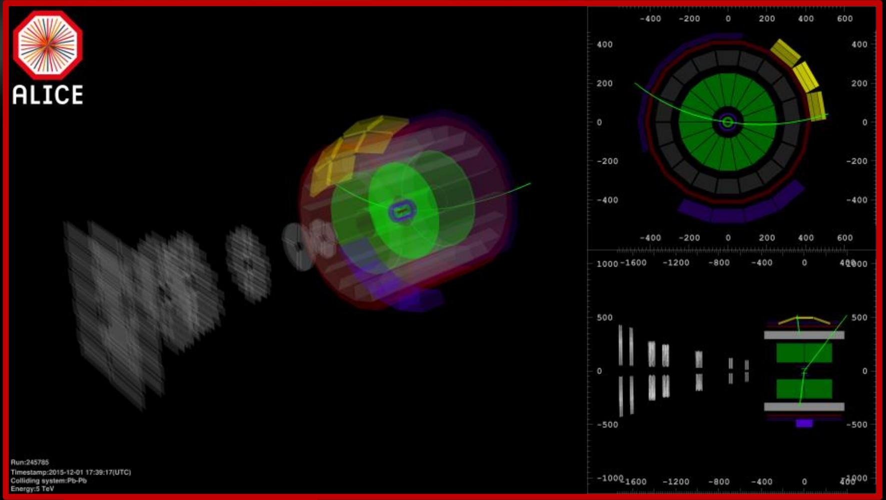
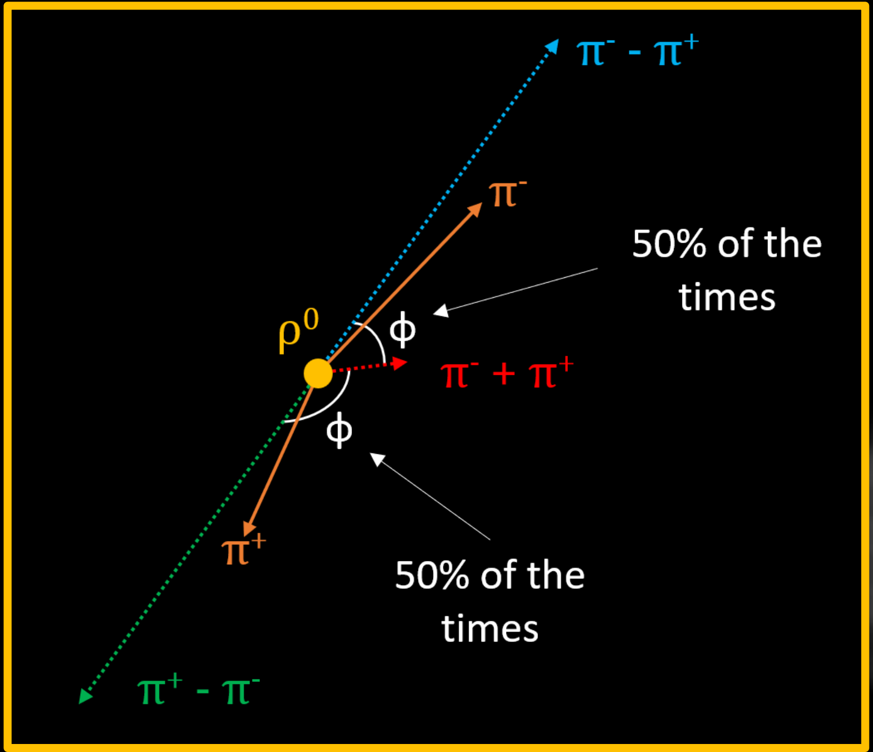
Topological trigger: events with at least two track segments in the ITS SPD with an opening angle θ>153°




ALICE webpage

# DATA ANALYSIS

# DEFINITIONS




**$\boldsymbol{\phi}$ = angle between $\vec{\boldsymbol{p}}_+$ and $\vec{\boldsymbol{p}}_-$**

$$\vec{p}_\pm = \vec{p}_{\mathrm{T},1} \pm \vec{p}_{\mathrm{T},2}$$

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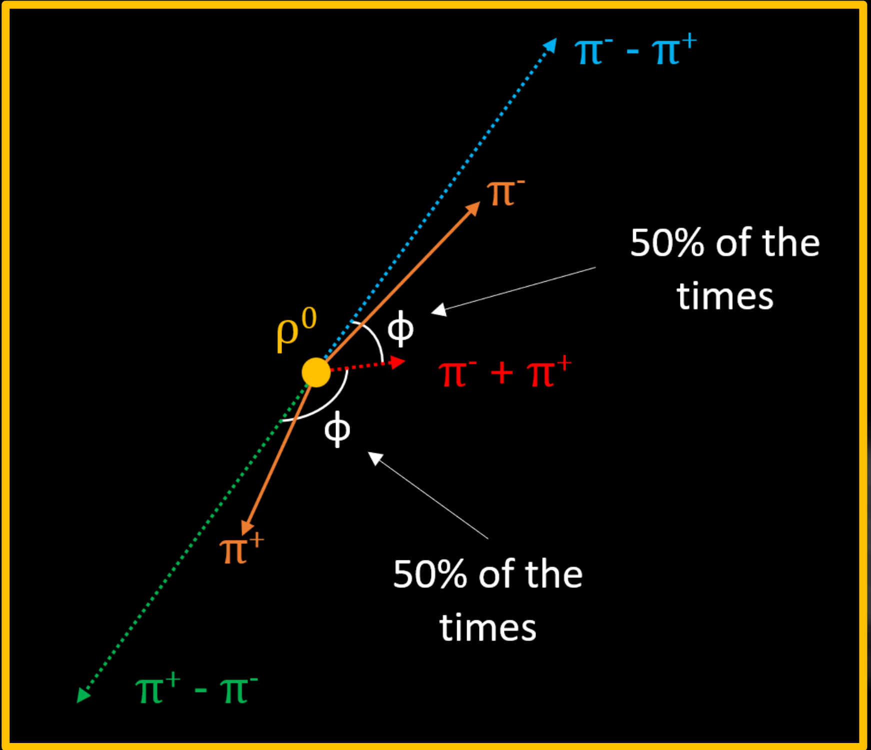


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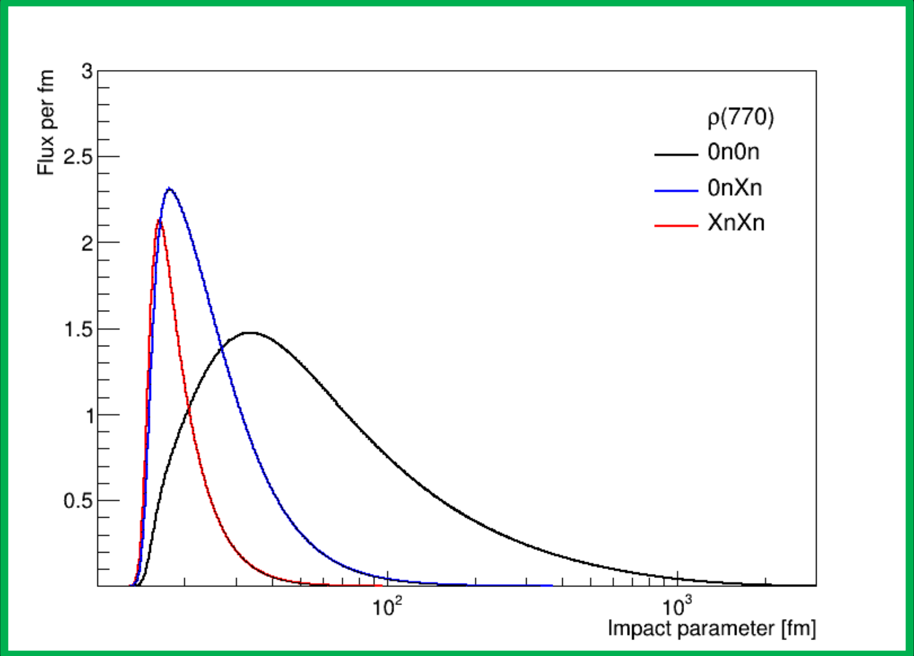
→ different neutron emission classes correspond to different average values of $\boldsymbol{b}$

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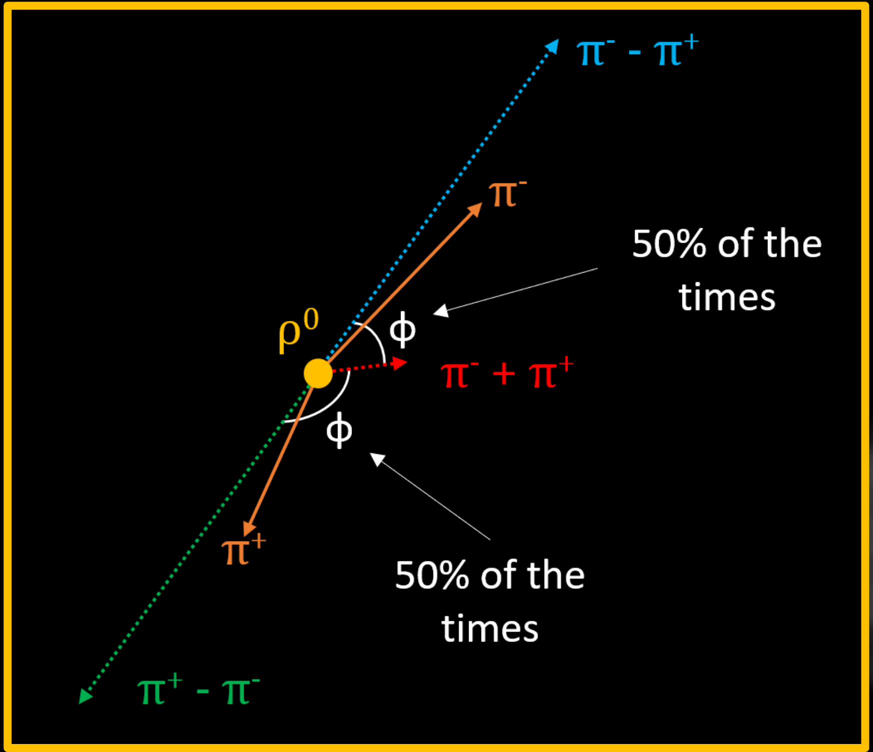


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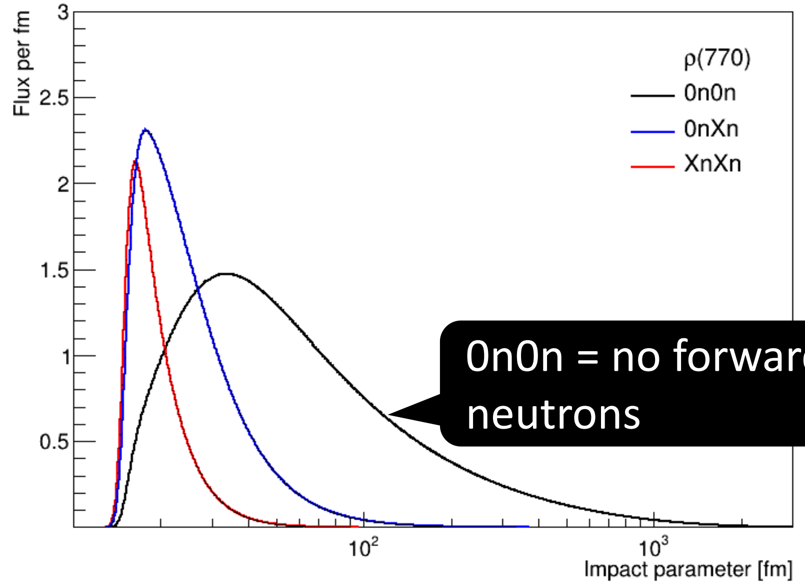


0n0n = no forward neutrons

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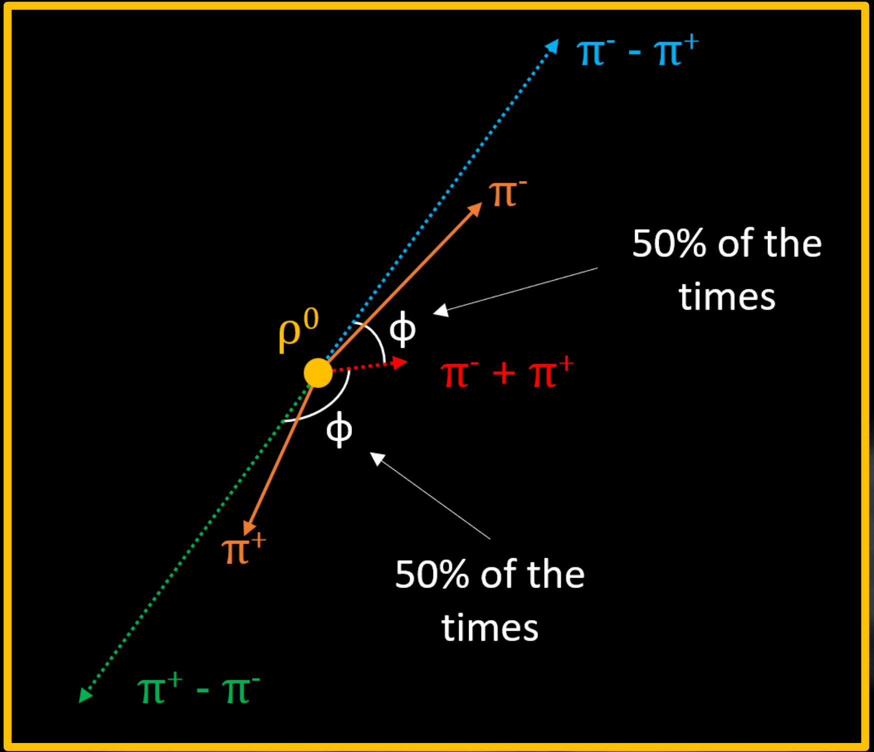


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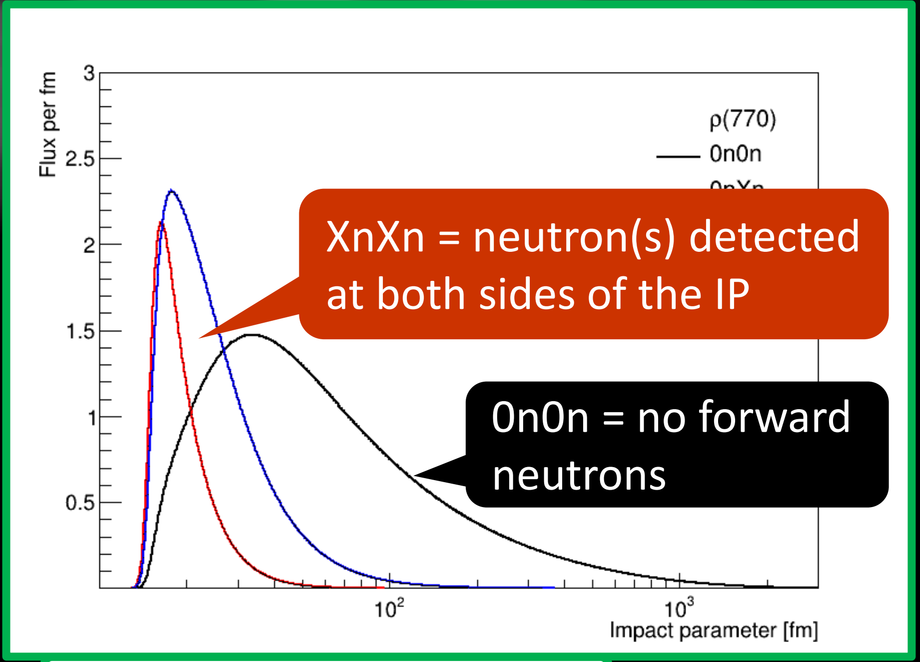


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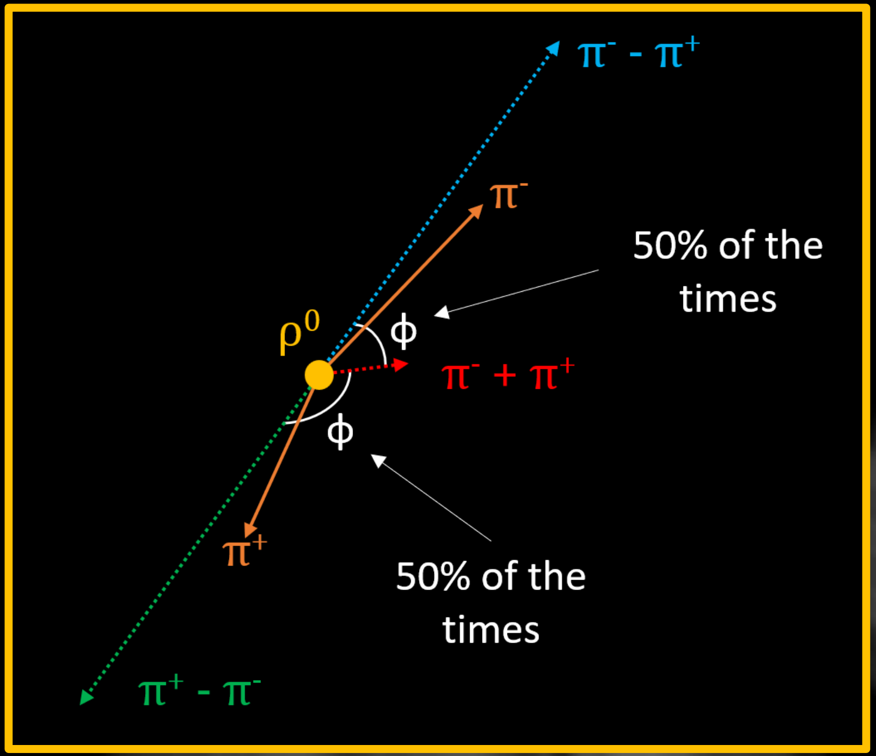


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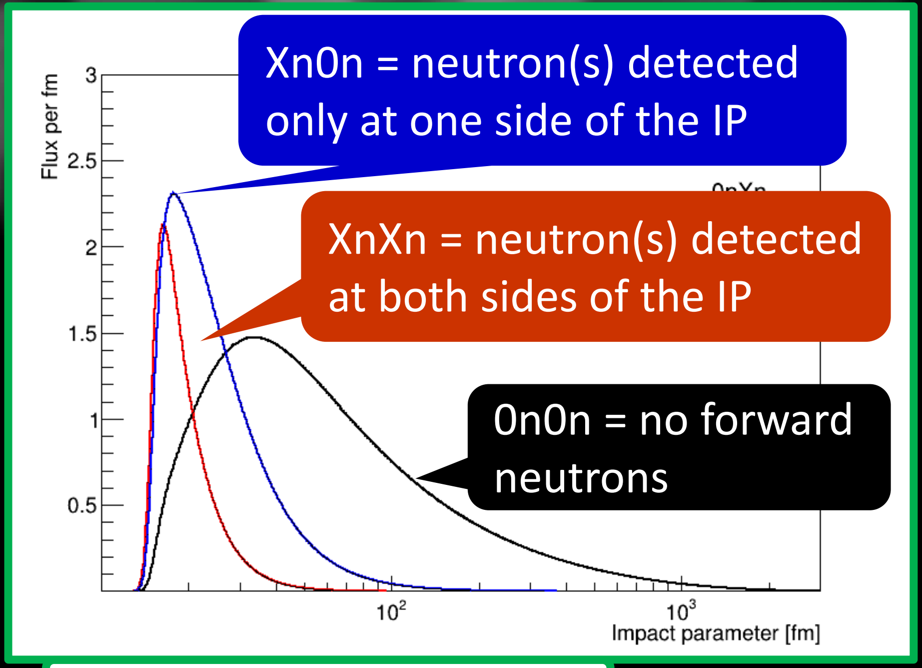


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# CORRECTIONS

[11] Comput. Phys. Commun. 212 (2017) 258–268

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

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Build the MC mass distributions by weighting each event with $w(p_T)$ evaluated at the generated $p_\mathrm{T}$

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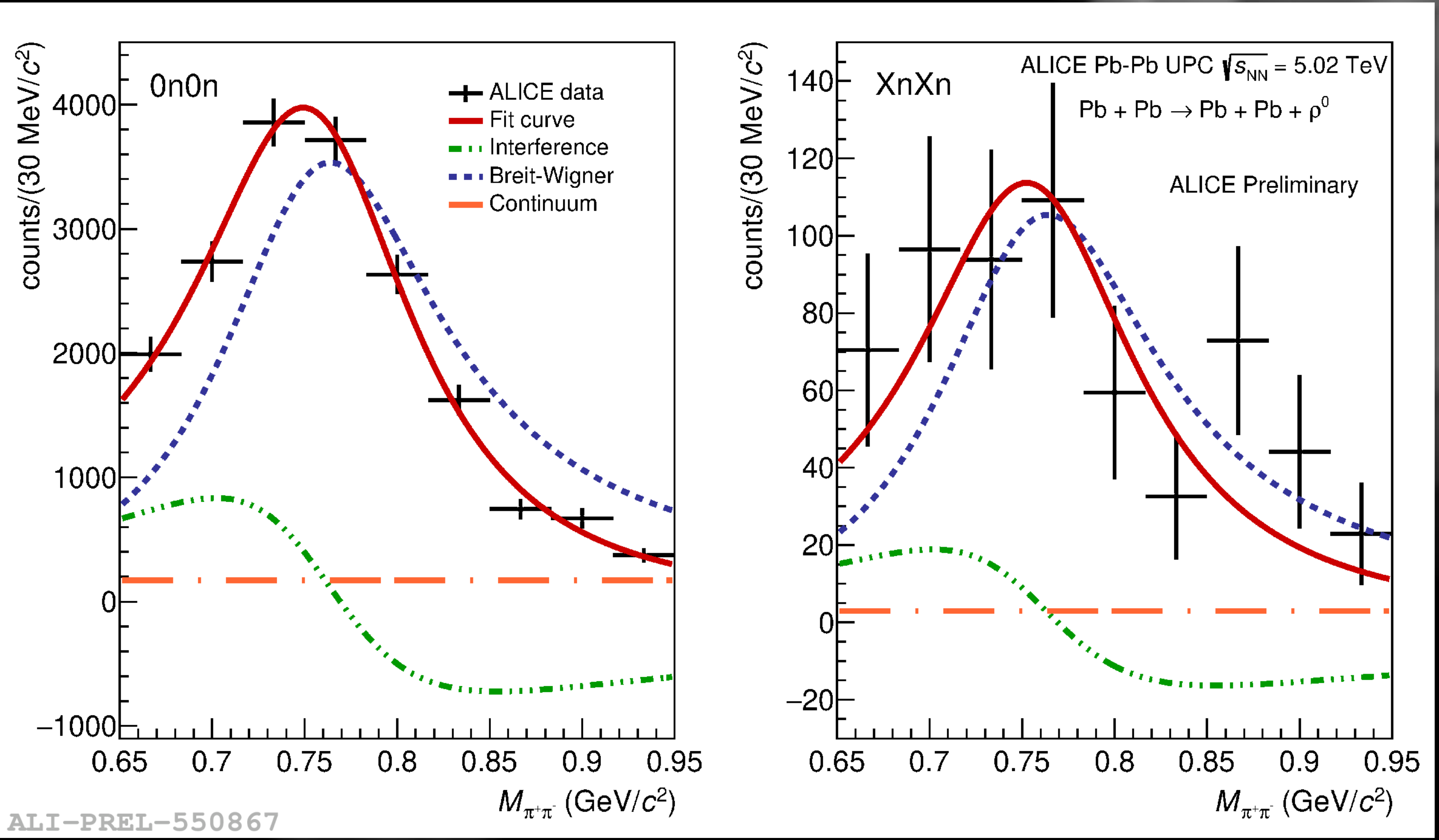

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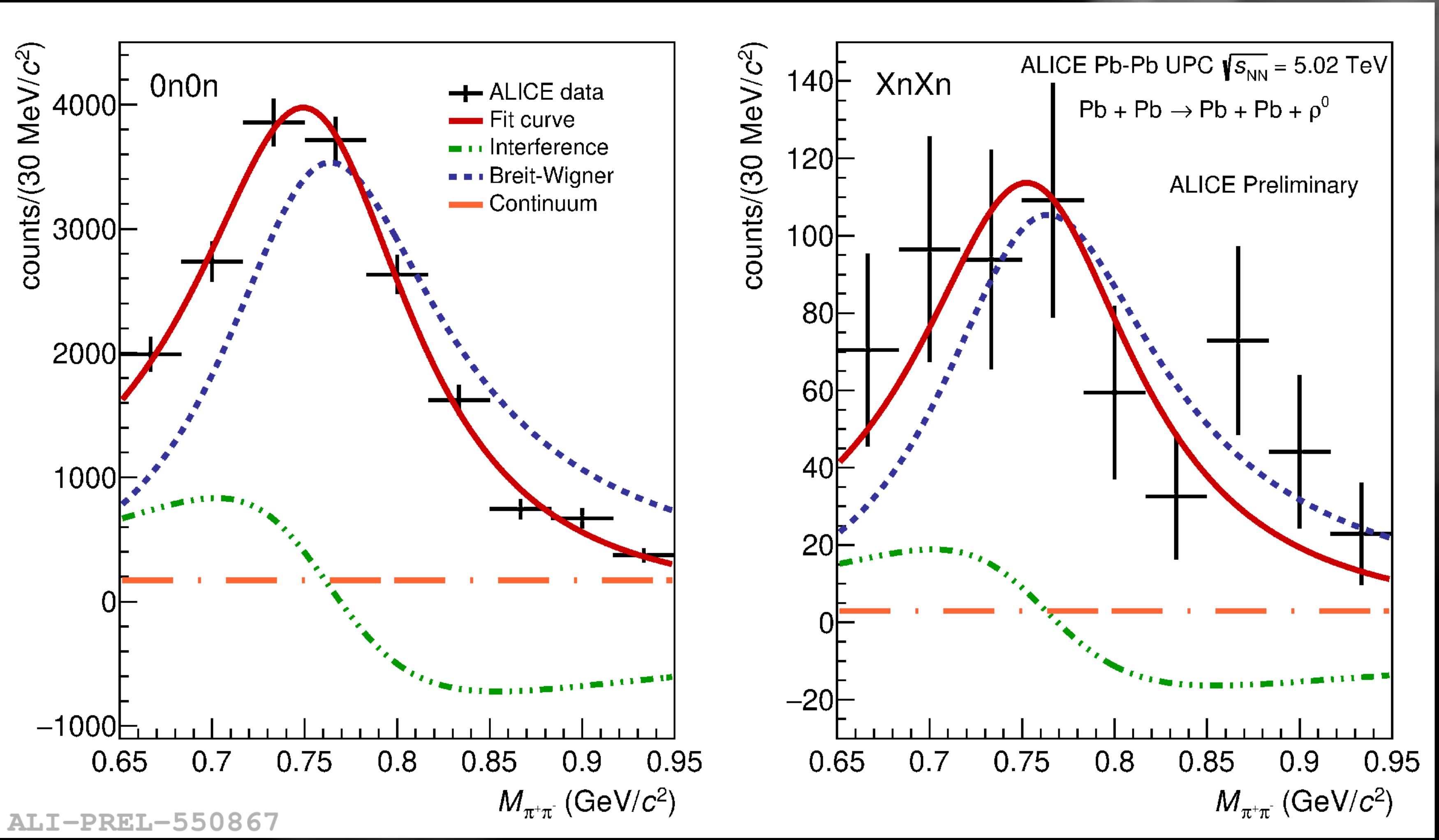
The corrected mass spectra in each $\phi$ bin are fitted using the Söding model

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



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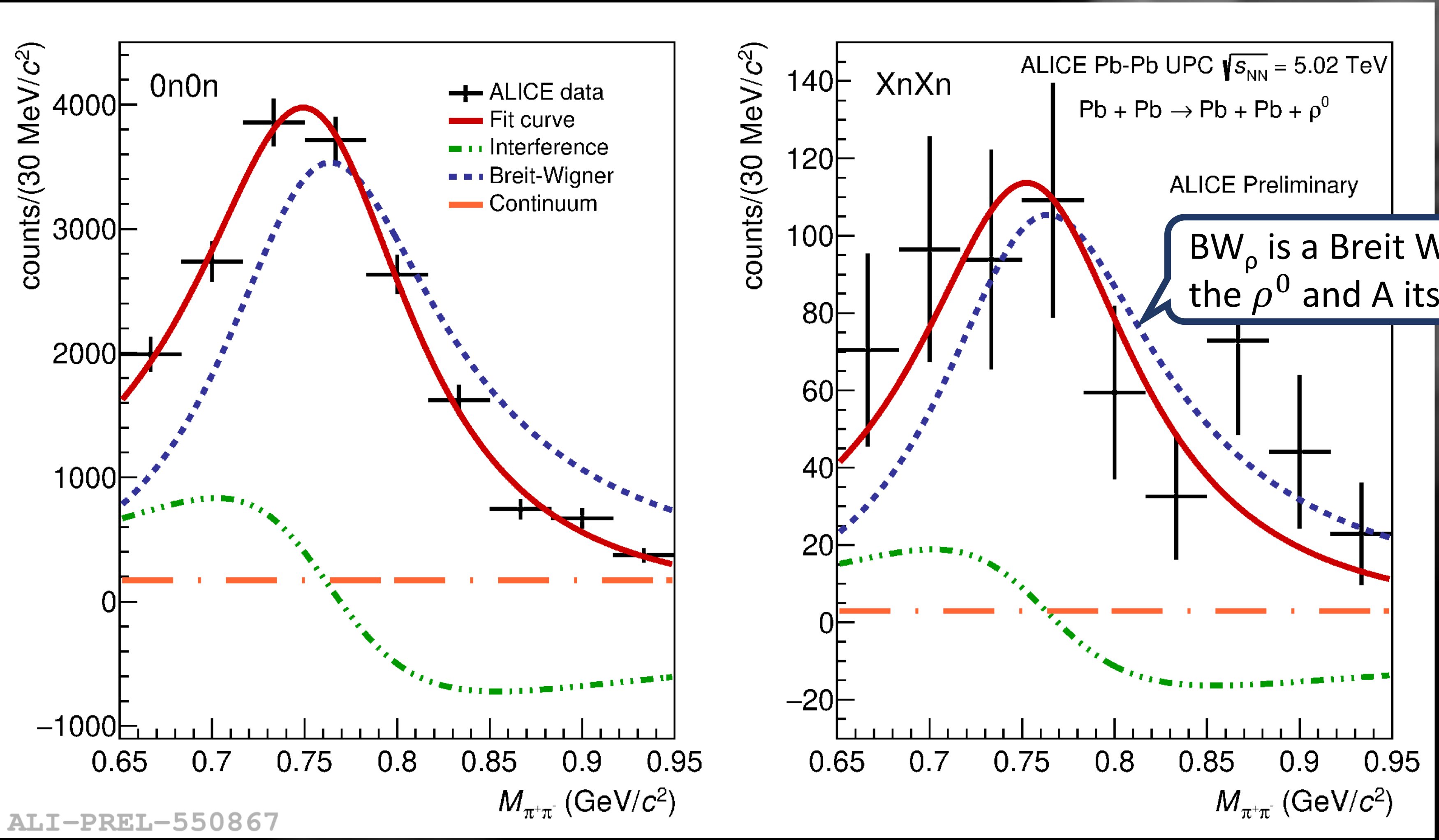


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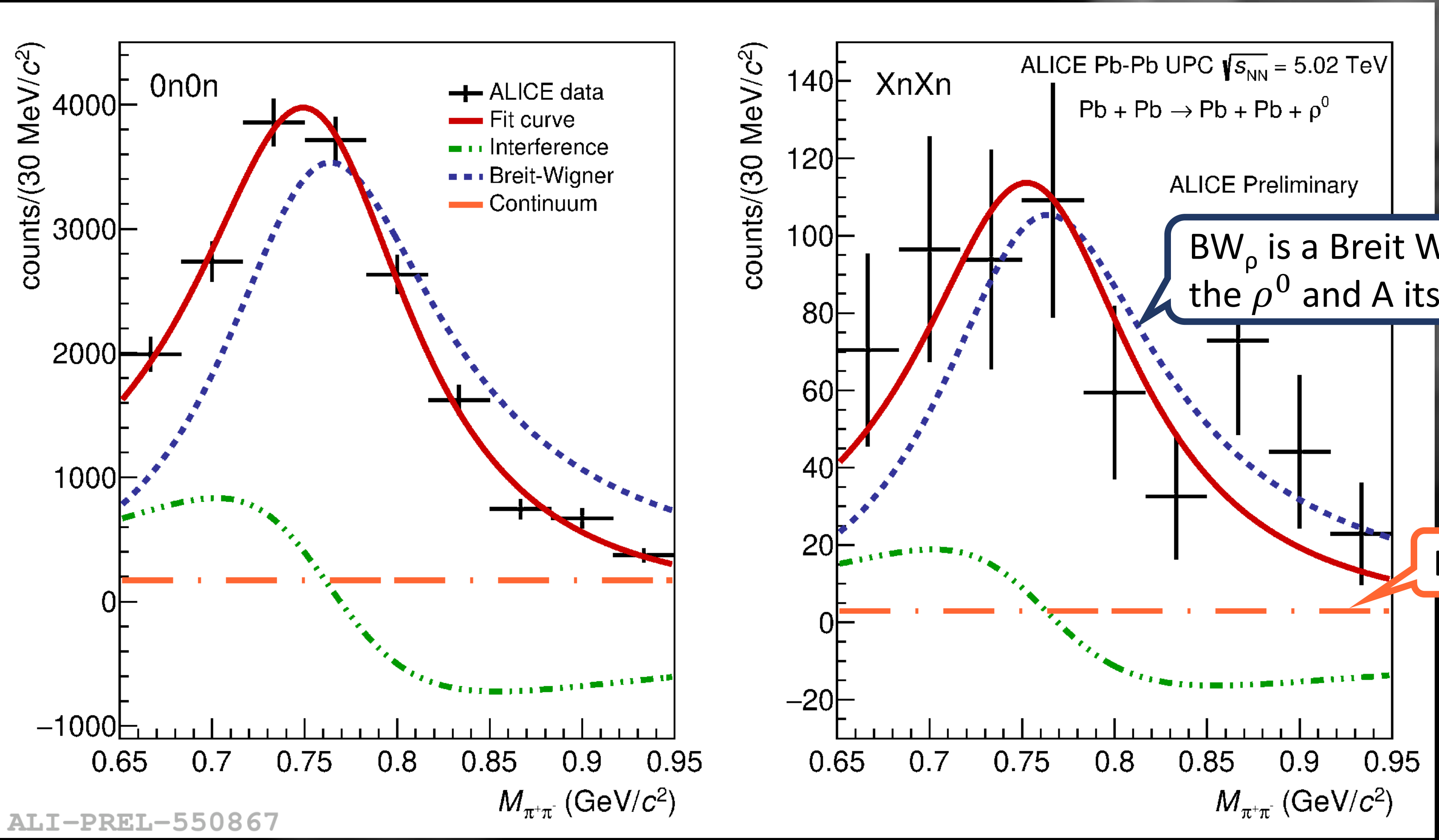


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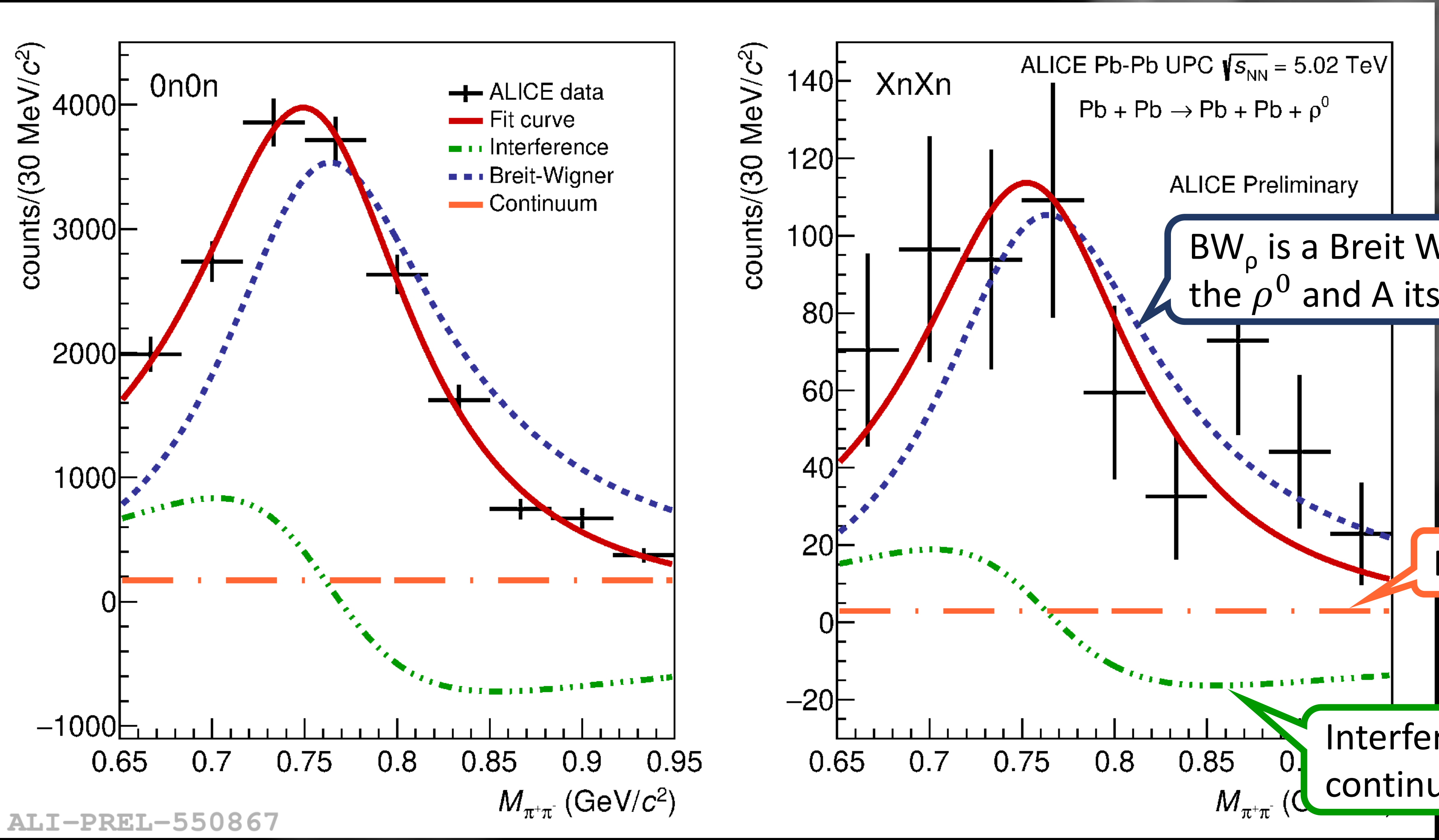


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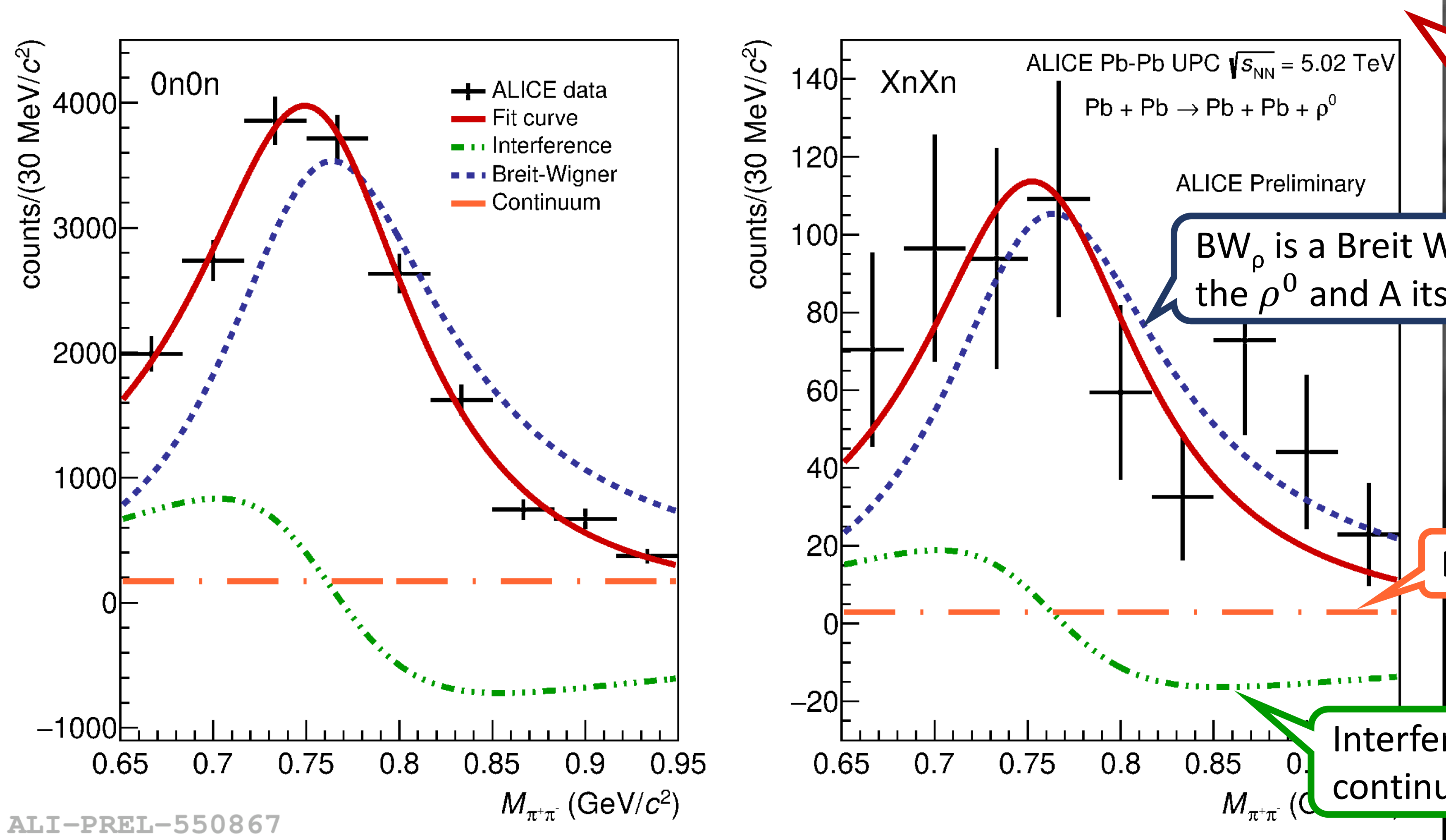
Extraction of the $\rho^0$ yield in each neutron emission class, as a function of $\phi$

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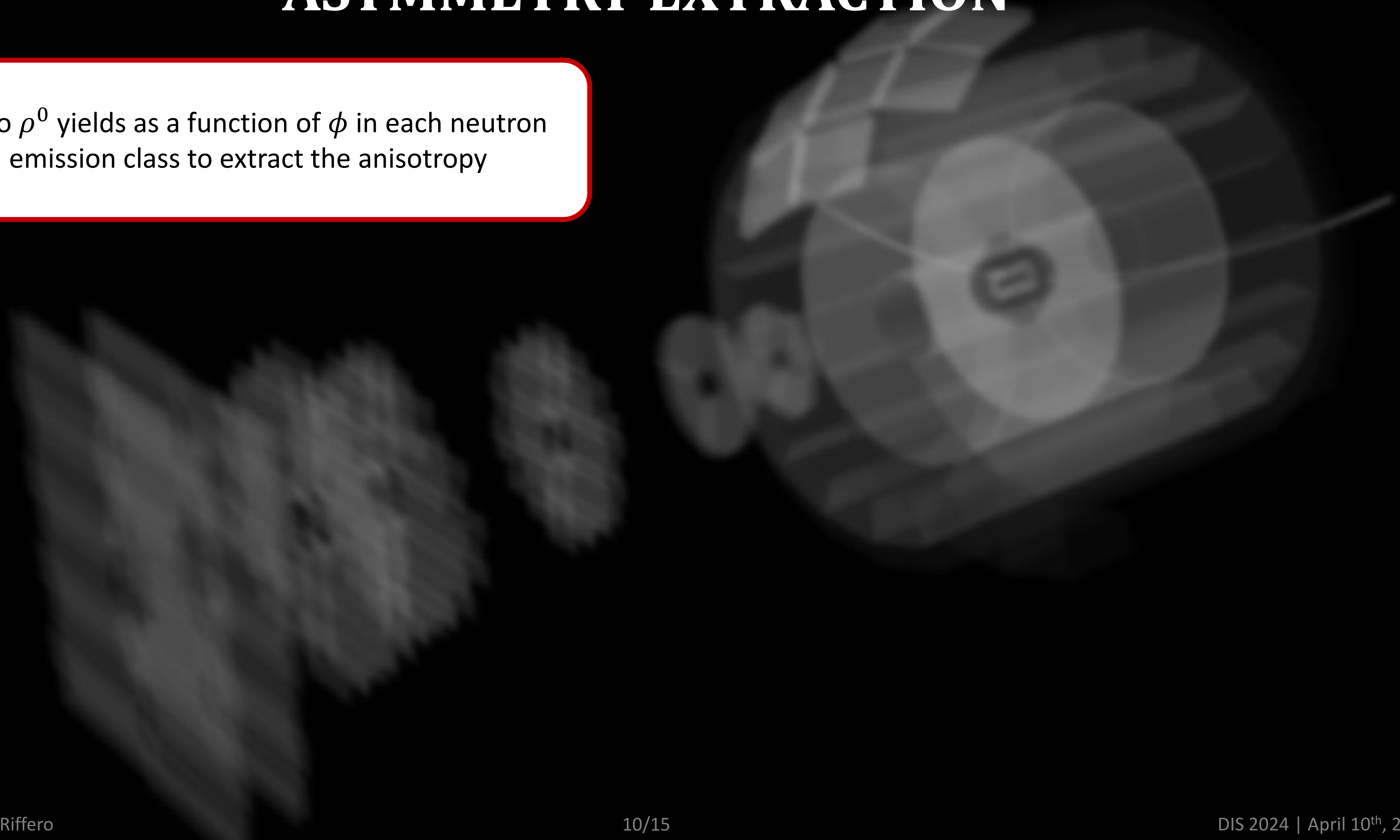
Fit to $\rho^0$ yields as a function of $\phi$ in each neutron emission class to extract the anisotropy



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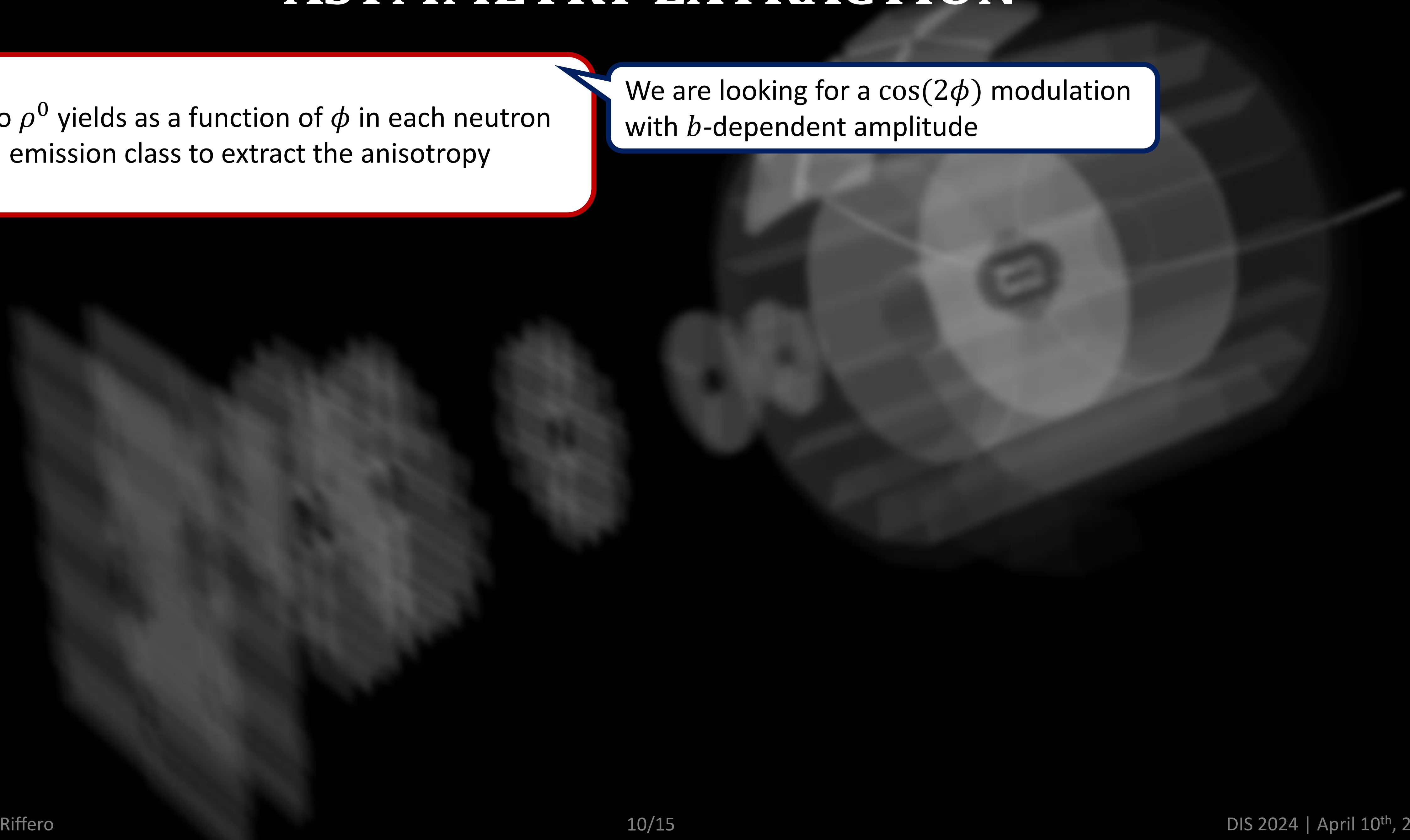
We are looking for a $\cos(2\phi)$ modulation with $b$-dependent amplitude



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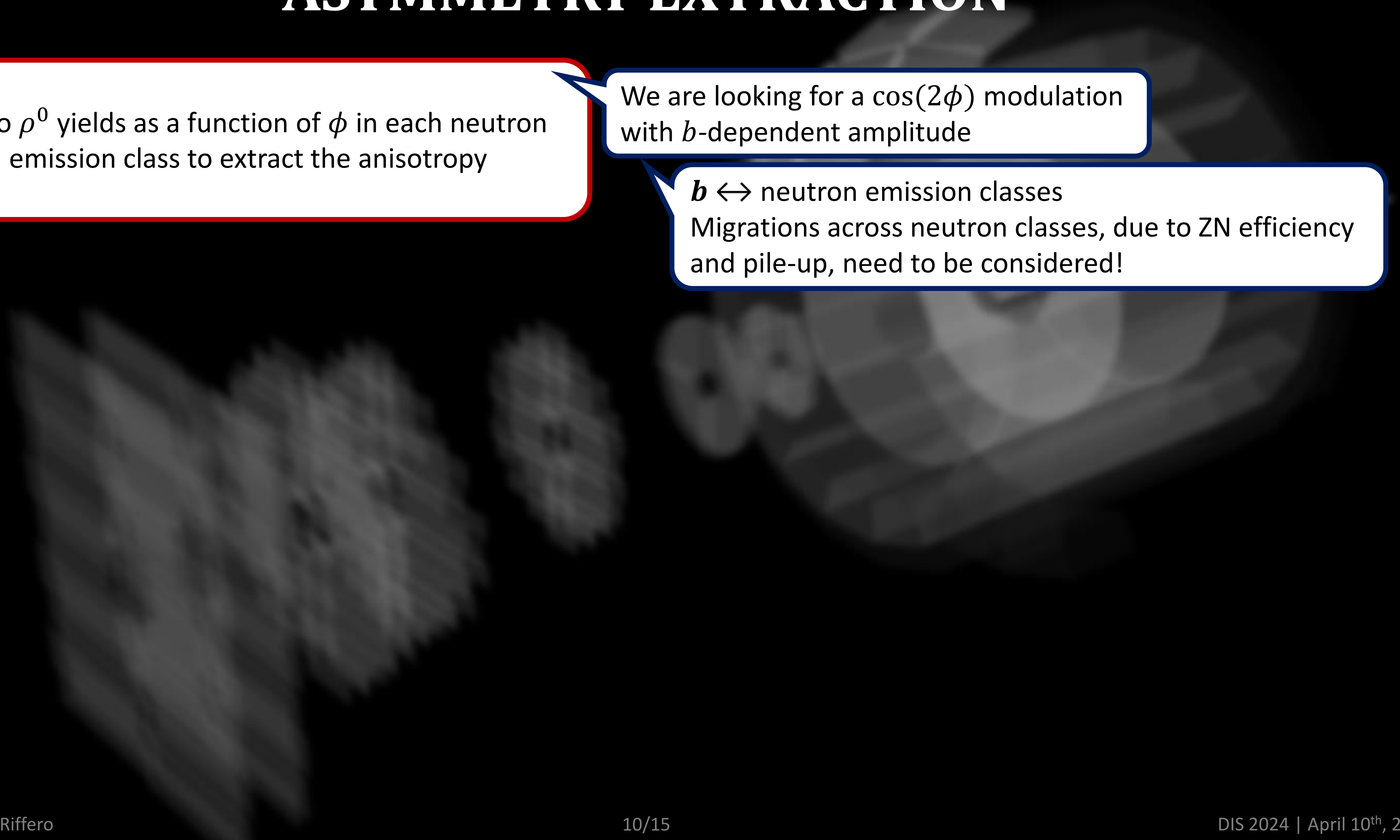

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$w_{Y \to Z}$ = contribution of the physical class Y to the yield in the experimental class Z.
Computed from measured cross sections ratios and migration probabilities [12].

[12] JHEP 06 (2020) 035

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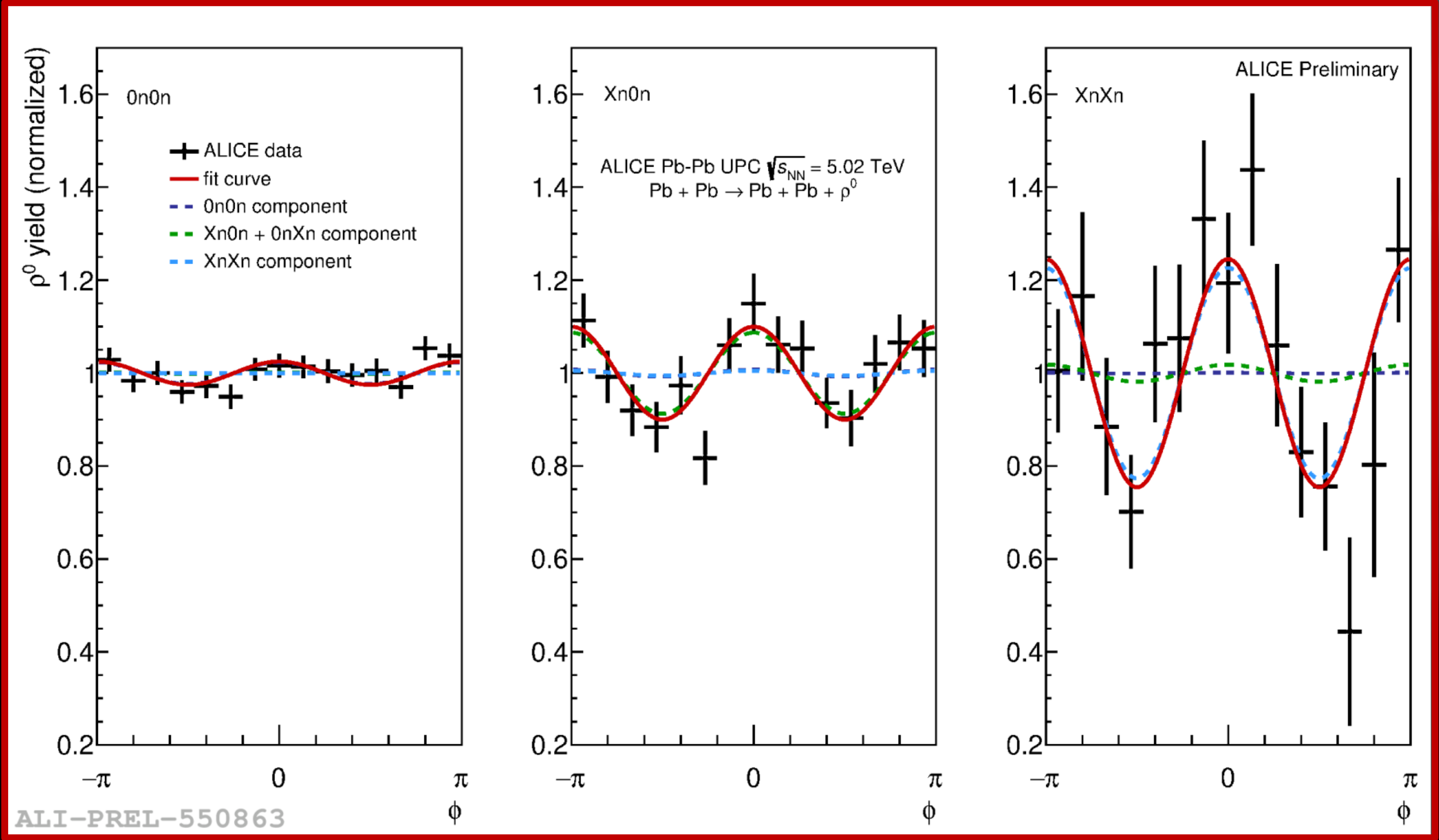


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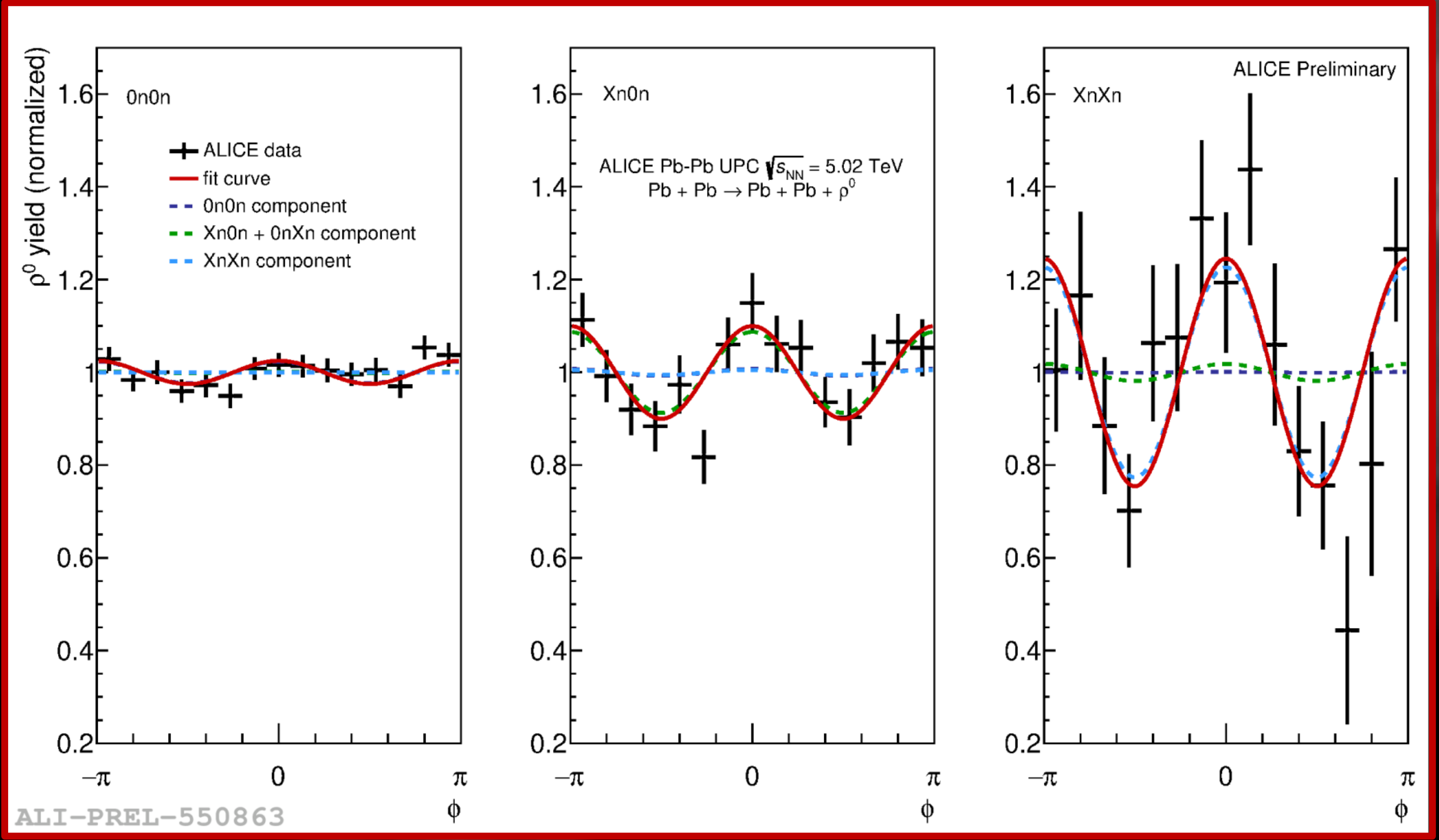


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The effect of migrations is important especially in Xn0n and XnXn

# RESULTS

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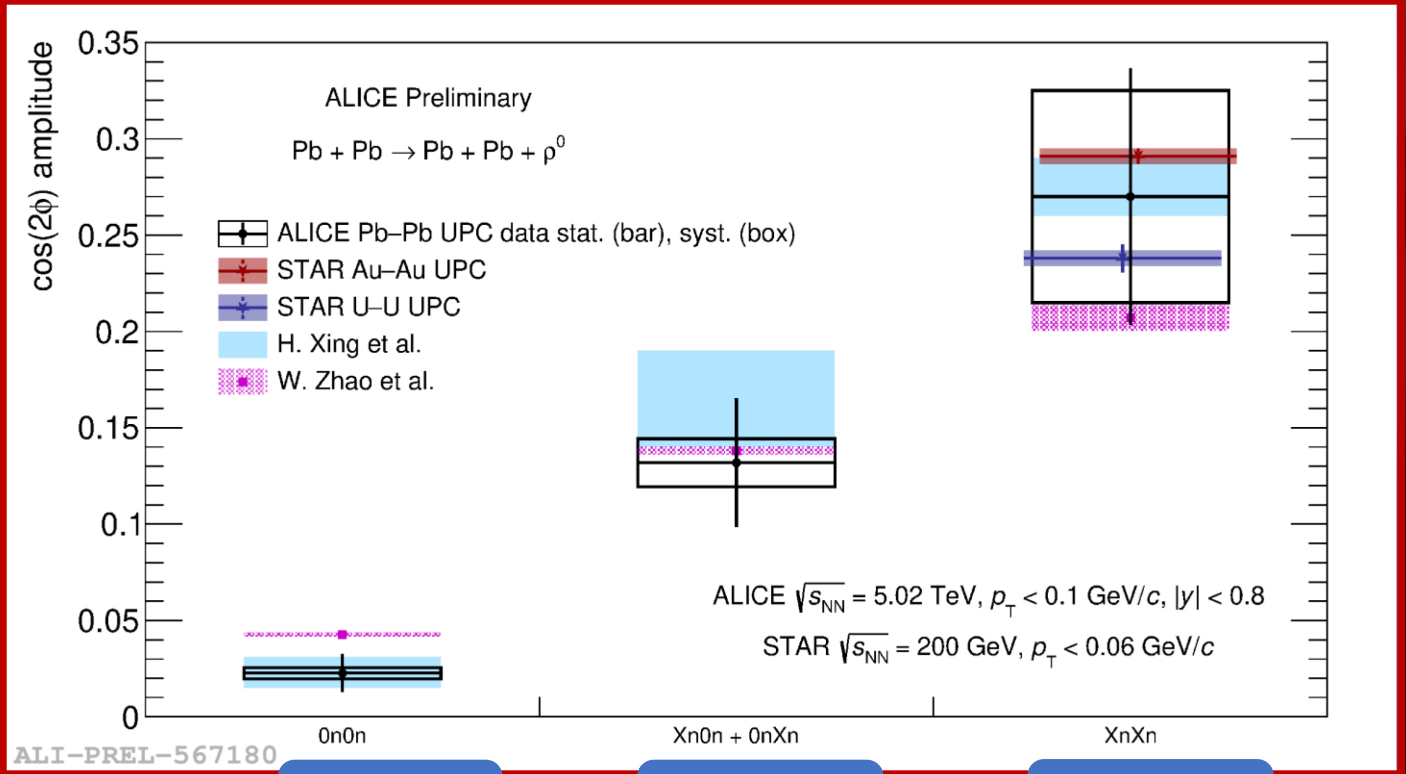
**First measurement of the impact-parameter dependent angular anisotropy in the decay of coherently photoproduced $\rho^0$**




$b$~49 fm

$b$ ~23 fm

$b$ ~18 fm

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

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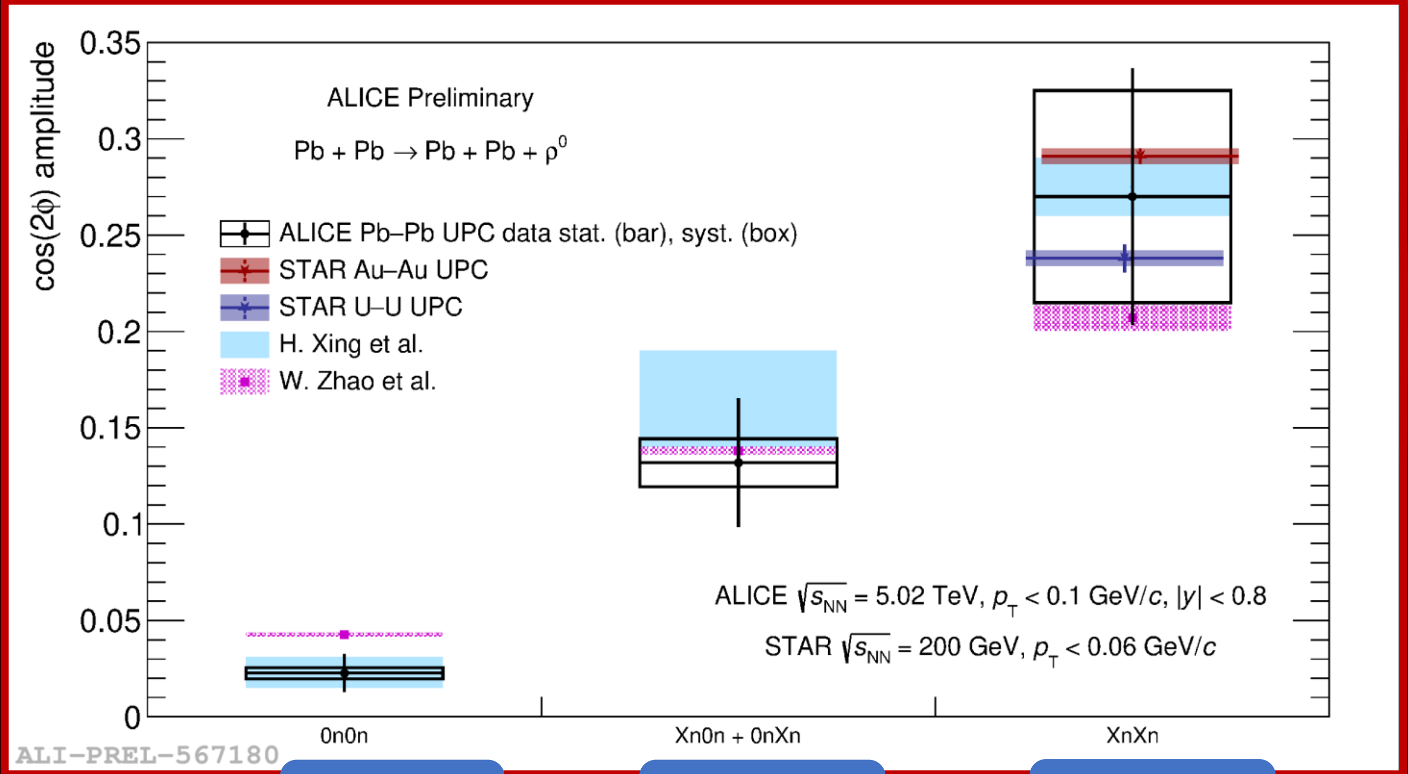


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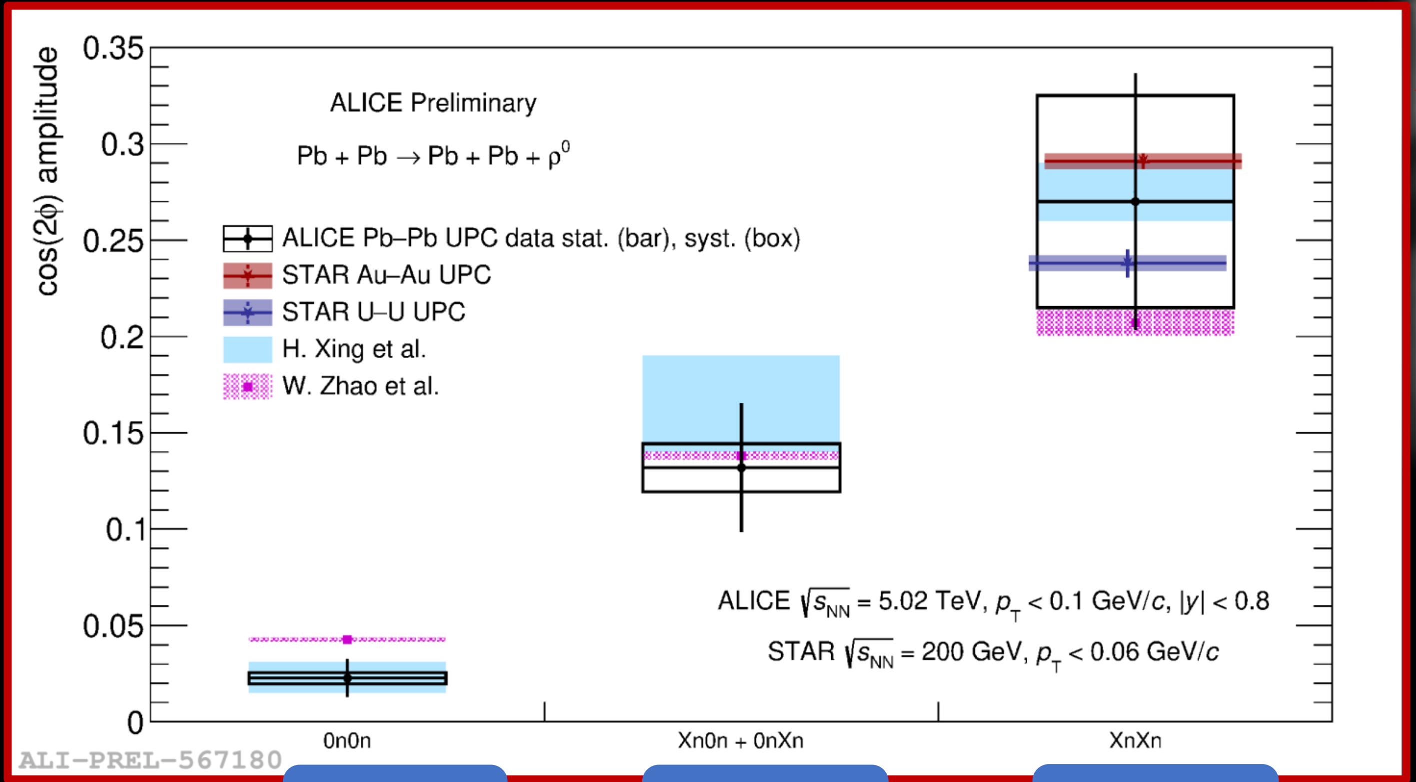


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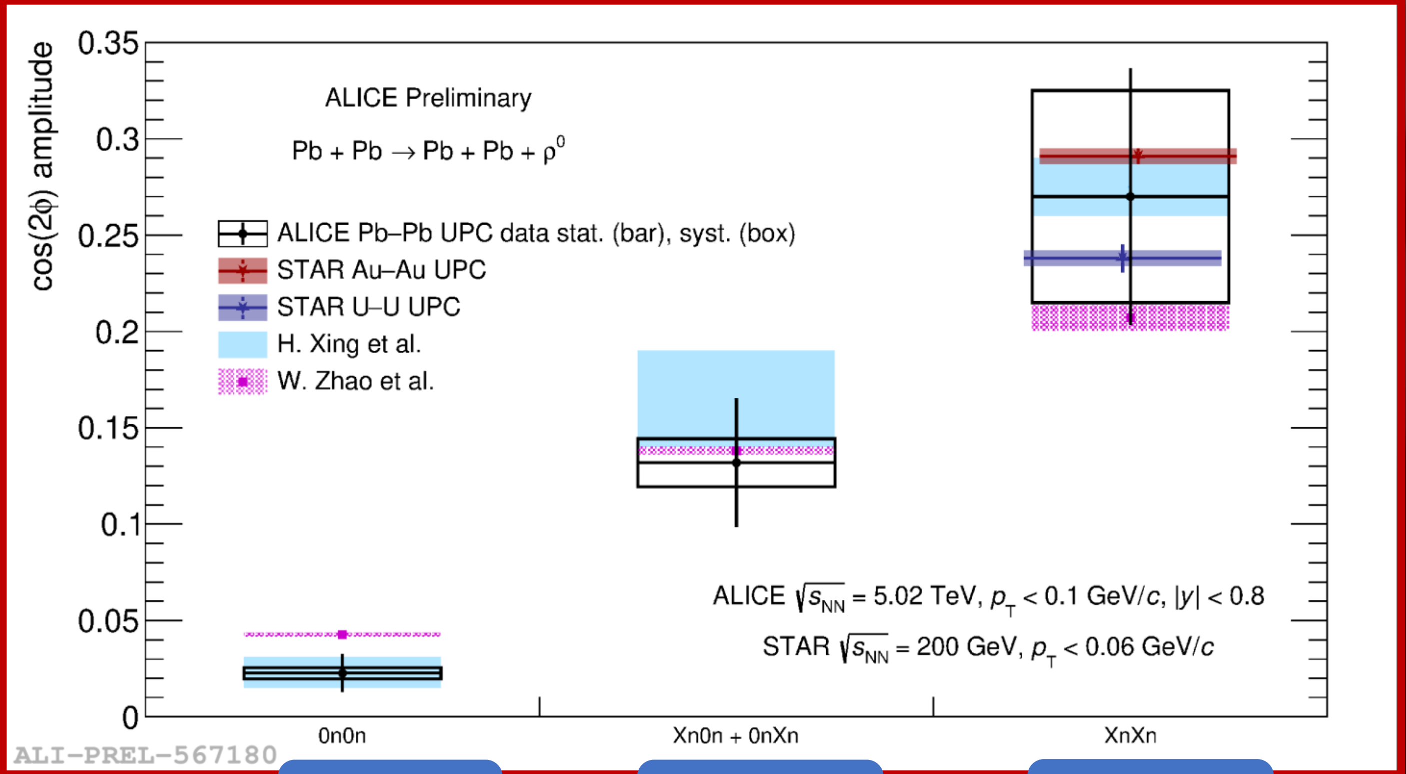


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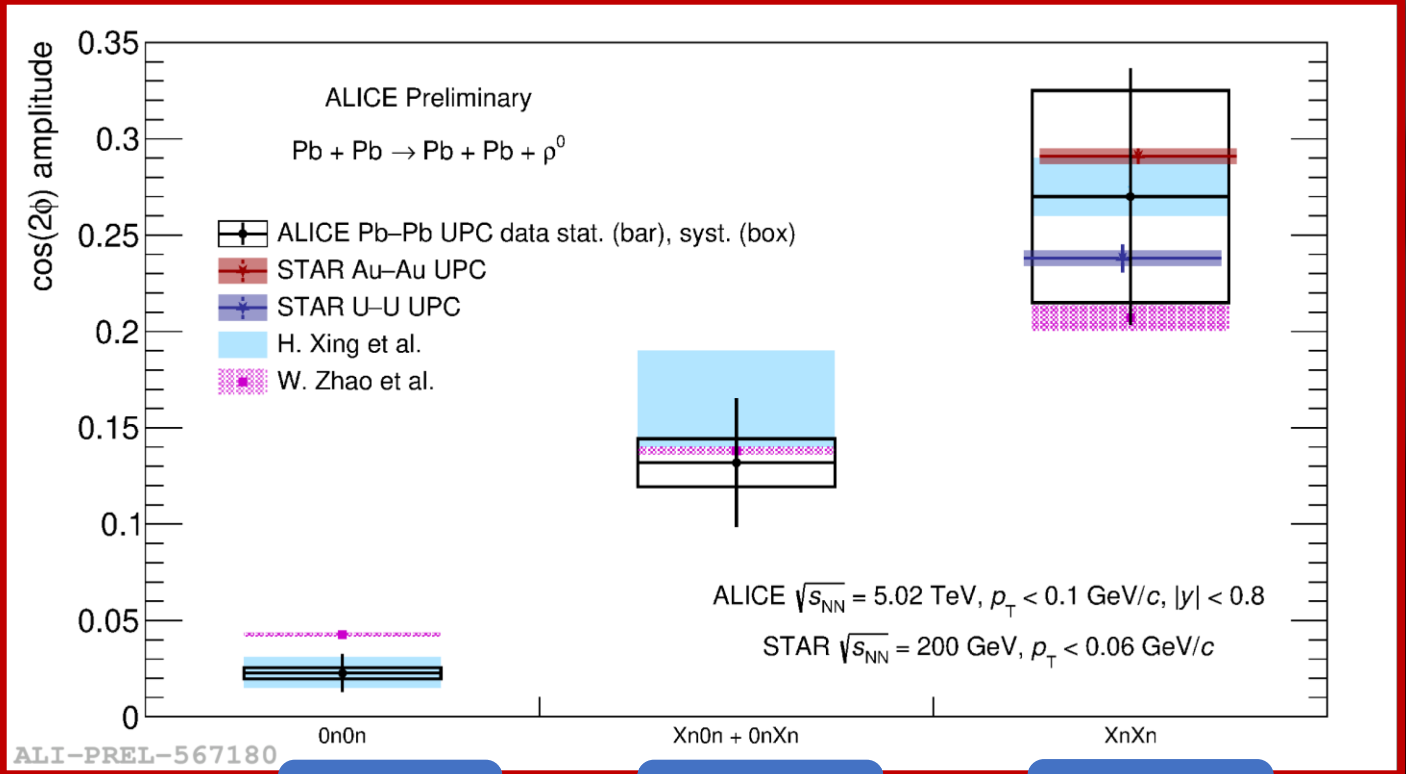


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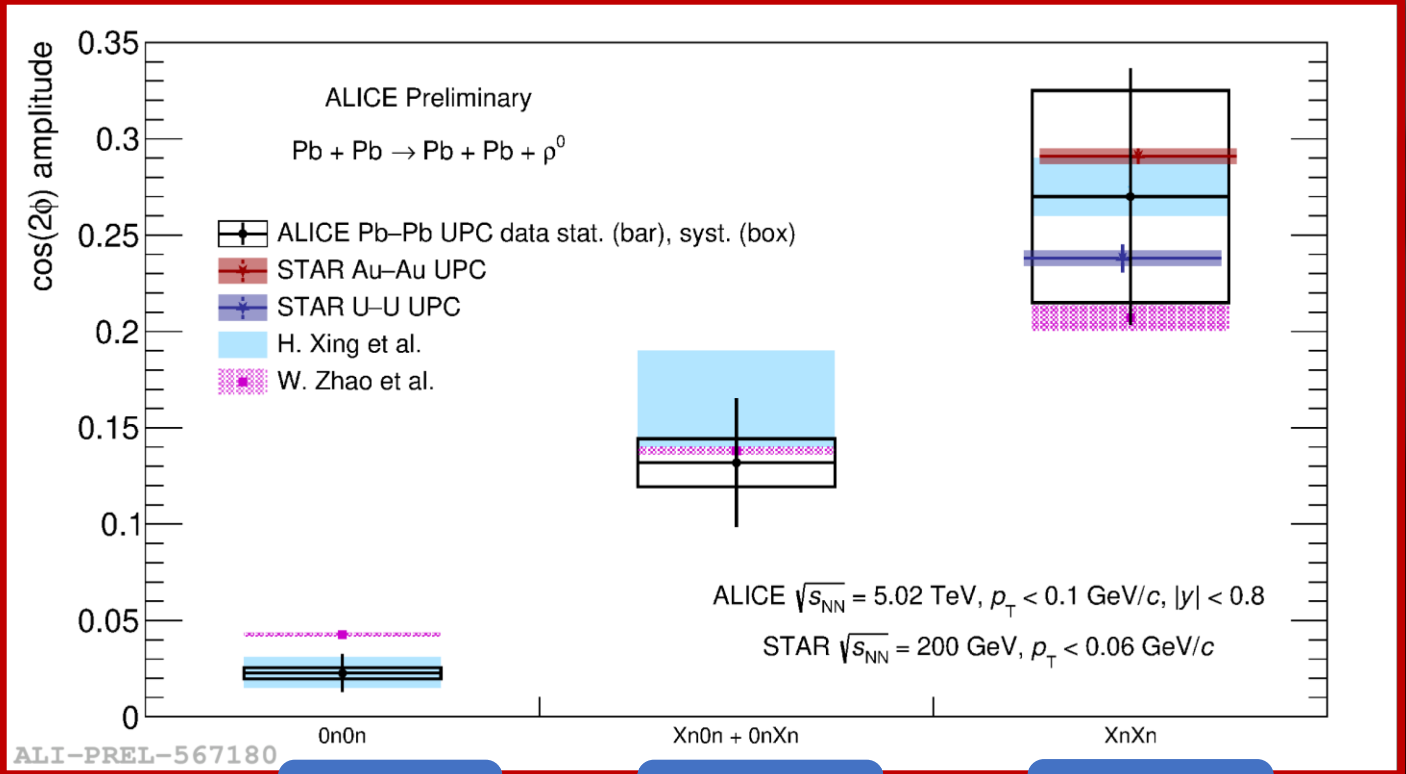
**Compatible** with **theory** [6,7], XnXn amplitude compatible with **STAR** results [8] for Au-Au and U-U collisions at lower energy

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


[6] JHEP 10 (2020) 064
[7] arXiv:2310.15300 [nucl-th] (2023)
[8] Sci.Adv. 9 (2023) eabq3903
Comput. Phys. Commun. (2020) 107181

# ASYMMETRY RESULTS

**First measurement of the impact-parameter dependent angular anisotropy in the decay of coherently photoproduced $\rho^0$**




$b$~49 fm | $b$ ~23 fm | $b$ ~18 fm

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

Comput. Phys. Commun. (2020) 107181

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

The **anisotropy** comes from **linearly polarized photons + quantum interference**

Main systematic uncertainties: signal extraction, acceptance x efficiency, and $\phi$ angle definition

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

# TAKE HOME AND OUTLOOK

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Take home

**We measured for the first time the angular anisotropy in the decay of coherently photoproduced $\rho^0$ as a function of the impact parameter**

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Outlook

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

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


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

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[7] arXiv:2310.15300 [nucl-th] (2023)
STAR results:
[8] Sci.Adv. 9 (2023) eabq3903

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[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: $n_0^0n$, *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

| | | | | |
|---|---|---|---|---|
| Tue | 09/04 | 09:50 | A. Bylinkin | Exclusive four pion photoproduction in ultra-peripheral Pb–Pb collisions at √sNN = 5.02 TeV at ALICE |
| Tue | 09/04 | 11:20 | J. Park | Reacent heavy flavour measurements from ALICE |
| Tue | 09/04 | 14:00 | R. Guernane | Overview of ALICE Upgrades |
| Tue | 09/04 | 14:20 | L. Huhta | ALICE Forward Calorimeter upgrade (FoCal): Physics program and performance |
| Tue | 09/04 | 16:00 | A. Shatat | Coherent vector meson photoproduction and polarization in heavy-ion collisions with nuclear overlap in ALICE |
| Tue | 09/04 | 16:20 | G. Contreras | Energy dependence of coherent J/psi production off lead with ALICE |
| Wed | 10/04 | 11:40 | D. Grund | First study of the initial gluonic fluctuations using UPCs with ALICE |
| Wed | 10/04 | 12:20 | M. Kim | K+K– photoproduction in ultra-peripheral Pb–Pb collisions with ALICE |

**Check them out!**

# THANK YOU FOR YOUR ATTENTION!