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

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PHYSICS MOTIVATIONS
The process studied is the **coherent photoproduction of the $\rho^0$**

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

The polarization is transferred to the $\rho^0$ 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!

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!

\[ \sigma(p_T, b, y = 0) = |A(p_T, b) - A(p_T, b)|^2 e^{i \vec{p} \cdot \vec{b}} \]

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

\( \rho^0 \) is short lived: \( c \tau < \langle b \rangle \) → 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 $\rho^0$ production site within one of the nuclei
- 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 $\rightarrow$ Wilson lines
  2) event-by-event variation of Wilson lines $\rightarrow$ account for different color charge configurations

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

Predict a $\cos(2\phi)$ modulation of the $\rho^0$ yield

Depends on $p_T \rightarrow$ STAR [8,9]

$\phi \sim$ azimuthal angle between the $\rho^0$ and one of its daughters’ momentum (def. in slide 6)

Depends on $b \rightarrow$ 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: $\mathcal{L}_{int}=0.485 \mu b^{-1}$ from Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Trigger
AD and V0 used as veto $\rightarrow$ suppression of purely hadronic interactions
Topological trigger: events with at least two track segments in the ITS SPD with an opening angle $\theta>153^\circ$
Neutron emission probability decreases with the impact parameter $b$ 
→ different neutron emission classes corresponds to different average values of $b$

DEFINITIONS

$\phi = \text{azimuth angle between } p_+ \text{ and } p_-$

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

$\pi_1 (\pi_2) = 4\text{-momentum of track 1(2), randomly assigned to the positive and negative tracks}$

$X_{n0n} = \text{neutron(s) detected only at one side of the IP}$

$X_{nXn} = \text{neutron(s) detected at both sides of the IP}$

$0n0n = \text{no forward neutrons}$
Data (invariant mass distributions) need to be corrected for acceptance and efficiency.

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

$\rho_T$ of the $\rho^0$ 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 $R_{Pb}$

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

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

$$\frac{dN}{dp_T^2} = c \left| F(t, a_{Pb}, R_{Pb}) \right|^2$$ (1)

$$w(p_T) = \frac{|F(|t|, a_{Pb}, R_{X})|^2}{|F(|t|, a_{Pb}, R_{Pb})|^2}$$ (2)
The corrected mass spectra in each $\phi$ bin are fitted using the Söding model.

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

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

$BW_\rho$ is a Breit Wigner that represents the $\rho^0$ and $A$ its amplitude.

$B$ is the non-resonant amplitude.

Interference between resonant and continuum pion pair production.
Fit to $\rho^0$ yields as a function of $\phi$ in each neutron emission class to extract the anisotropy

$\cos(2\phi)$ modulation with $b$ dependent amplitude

$b \leftrightarrow$ neutron emission classes
Migrations across neutron classes need to be considered!

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

$\alpha_2$ = true amplitudes of the modulation
The modulation is very different in different neutron emission classes.

The effect of migrations is important especially in Xn0n and XnXn.
RESULTS
The modulation strength strongly increases as $b$ decreases.


Medan values, less sensitive wrt the mean to the tail of other interactions at large $b$.

First measurement of the azimuthal anisotropy of the $\rho^0$ yield as a function of the impact parameter.

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

We measured for the first time the azimuthal anisotropy of the $\rho^0$ 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. $J/\psi$) where the models predictions are more precise.
REFERENCES

[1] ALICE webpage


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


[12] ALICE Collaboration, *Coherent photoproduction of ρ0 vector mesons in ultra-peripheral Pb-Pb collisions at √sNN = 5.02 TeV*, JHEP 06 (2020) 035
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Check them out!
THANK YOU FOR YOUR ATTENTION!