(Anti-)deuteron production and anisotropic flow measured with ALICE at the LHC

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Overview

- Motivation
- Deuteron identification with the ALICE detector
- Deuteron elliptic flow measurement
- Comparison of the measured deuteron $v_2$ with other identified particles and scaling tests
Elliptic flow ($v_2$) is sensitive to the system evolution:

- Constrains initial conditions and particle production mechanisms

Identified particle $v_2$ vs transverse momentum allows for the study of:

- Rate of hydrodynamic radial expansion (mass dependence of $v_n$ vs $p_T$)
- Properties of the deconfined phase (e.g. viscosity)
- Details of hadronization mechanism (e.g. coalescence)
Motivation – Deuteron

- The measurement of light nuclei $v_2$ will help in the understanding of particle production mechanisms
Motivation – Deuteron

- The measurement of light nuclei $v_2$ will help in the understanding of particle production mechanisms

- Do deuterons follow the mass ordering observed for lighter particles?
- Do deuterons follow a mass scaling or are better described by hydrodynamical based models?
ALICE Detector

**Inner Tracking System (ITS):**
- Primary vertex
- Tracking
- Particle identification via dE/dx

**Time Projection Chamber (TPC):**
- Tracking
- Particle identification via dE/dx

**Time Of Flight (TOF):**
- Particle identification via velocity measurement

**V0A and VOC:**
- Centrality classes
- Symmetry plane determination

Deuteron identification

**Low momenta**

Nuclei identification via $dE/dx$ measurement in the TPC:

- $dE/dx$ resolution in central Pb-Pb collisions: 7%
- Excellent separation of (anti-)nuclei from other particles over a wide range of momentum

**Higher Momenta**

Velocity measurement with the Time Of Flight detector is used to evaluate the $m^2$ distribution.

- Excellent TOF performance: $\sigma_{\text{TOF}} \approx 85$ ps in Pb-Pb collisions.
- $\pm 3\sigma$-cut around expected TPC $dE/dx$ for deuterons reduces drastically the background from TPC and TOF mismatch.
Flow analysis details

**Analyzed data samples**
- Pb - Pb at $\sqrt{s_{_{NN}}}$ = 2.76 TeV (~ 35M events)
- Events are classified into 6 different centrality intervals

**Deuteron identification**
Identical to spectra analyses:
1) Energy loss in TPC: require $dE/dx$ signal to be within 3σ of expected value for all $p_T$
2) Time of flight: fit to mass signal of TOF for $p_T > 1$ GeV/c

**Track selections:**
- $0.5 < p_T < 5$ GeV/c
- $-0.8 < \eta < 0.8$

**Fit function**: Total : Gauss + Exponential tail + Exponential
Flow analysis method

- $v_2$ is measured using the scalar product method
  - Hits measured by V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta <-1.7$) are used as reference particles
  - Deuteron candidates are the particles of interest ($|\eta|<0.8$)

- The contribution to the measured elliptic flow ($v_2^{\text{Tot}}$) due to misidentified deuterons ($v_2^{\text{Bkg}}$) was removed by studying the azimuthal correlations versus $\Delta M$ ($\Delta M = m_{\text{TOF}} - m_d$)

$$v_2^{\text{Tot}}(\Delta M) = v_2^{\text{Sig}}(\Delta M) \frac{N^{\text{Sig}}}{N^{\text{Tot}}(\Delta M)} + v_2^{\text{Bkg}}(\Delta M) \frac{N^{\text{Bkg}}}{N^{\text{Tot}}(\Delta M)}$$

- The yields $N^{\text{Sig}}$ and $N^{\text{Bkg}}$ are extracted from fits of the invariant mass distribution obtained with the TOF detector
The value of $v_2(p_T)$ increases progressively from central to semi-central collisions.
Comparison with $\pi$ and $p$

$\pi^+ (p+\bar{p})$ from: JHEP 06 (2015) 190 (arXiv:1405.4632)

ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV 10-20%

10-20%

ALI-PREL-97023
Comparison with $\pi$ and $p$


30-40%
Comparison with $\pi$ and $p$

$\pi^+$ and $(p+\bar{p})$ from: JHEP 06 (2015) 190 (arXiv:1405.4632)

30-40%

ALICE Preliminary

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV 30-40%

Low $p_T$: deuterons follow mass ordering $\rightarrow$ Radial Flow

ALICE-PREL-97027
$p_T/A$ scaling


Compare deuteron and proton: $p_T/A$ scaling

- For $p_T/A > 1$ GeV/c: A scaling deviations of the order of ~20%
- Similar magnitude for all measured centrality classes
\[ \frac{p_T}{n_q} \text{ scaling} \]

\( \pi^+ \) and \((p+\bar{p})\) from: JHEP 06 (2015) 190 (arXiv:1405.4632)

Compare deuteron with \(\pi\) and protons: \( \frac{p_T}{n_q} \) scaling

- For \( \frac{p_T}{n_q} > \sim 0.5 \text{ GeV}/c \): \( n_q \) scaling deviations of the order of \( \sim 20\% \)
- Similar magnitude for all measured centrality classes

ALICE Preliminary
Pb-Pb \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) 30-40%
$KE_T/n_q$ scaling

$\pi^+$ and $(p+\bar{p})$ from: JHEP 06 (2015) 190 (arXiv:1405.4632)

$KE_T = m_T - m_0 \quad m_T = \sqrt{p_T^2 + m_0^2}$

For $KE_T/n_q < 0.6$ GeV/$c^2$: significant deviations from NCQ scaling are seen in data for d

- Similar magnitude for all measured centrality classes

ALICE Preliminary

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV 30-40%

29/09/15

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Blast-Wave model

- Hydrodynamical calculations are able reproduce the main features of $v_2$ for $p_T<2$ GeV/$c$

- A simple model based on hydrodynamics is the Blast-Wave model [1,2]:

$$v_2(p_T) = \frac{\int_0^{2\pi} d\phi_s \cos(2\phi_s) I_2[\alpha_t(\phi_s)] K_1[\beta_t(\phi_s)][1 + 2s_2 \cos(2\phi_s)]}{\int_0^{2\pi} d\phi_s I_0[\alpha_t(\phi_s)] K_1[\beta_t(\phi_s)][1 + 2s_2 \cos(2\phi_s)]}.$$  

Where $I_0$, $K_1$ and $I_2$ are modified Bessel function, and the function has 4 free parameters + the mass of the particle

- Measured $\pi$, $K$, $p$ $p_T$ spectra and $v_2(p_T)$ were fitted, and the parameters were used to predict deuteron $v_2(p_T)$

Blast-Wave model:
Blast-Wave model

$v_2$ Blast-Wave curve for deuteron is predicted from combined fit of $\pi, K, p$ $p_T$ spectra and $v_2(p_T)$

- Good description of the data in the measured $p_T$ range
$v_2$ Blast-Wave curve for deuteron is predicted from combined fit of $\pi, K, p$ $p_T$ spectra and $v_2(p_T)$

- Good description of the data in the measured $p_T$ range and for all the measured centralities
Blast-wave vs Coalescence

10-20%

How does the Blast-Wave prediction differ from expectations from coalescence?

- The measured $v_2$ of protons was used to compute the expected $v_2$ of deuterons (reverse $n_n$ scaling = both $p_T$ and $v_2$ of measured $p$ was multiplied by 2) and the results were compared to data and Blast-Wave curves:
How does the Blast-Wave prediction differ from expectations from coalescence?

- The measured $v_2$ of protons was used to compute the expected $v_2$ of deuterons (reverse $n_q$ scaling = both $p_T$ and $v_2$ of measured $p$ was multiplied by 2) and the results were compared to data and Blast-Wave curves:
  - simple coalescence model does not describe deuteron $v_2$, while the Blast-Wave model gives a good description of the measured elliptic flow of deuterons
Conclusions

- Deuteron $v_2$ was measured up to 5 GeV/c using the scalar product technique:
  - At low $p_T$, deuteron $v_2$ follows mass ordering, indicating a more pronounced radial flow in most central collisions, as observed also for lighter particles
  - A deviation from $A$ (number of mass) and NCQ scaling at the level of $\pm 20\%$ was observed
  - The Blast-Wave model gives a good description of the measured elliptic flow of deuterons
$p_T/n_q$ scaling: measured identified particle
$KE_T/n_q$ scaling: measured identified particle
Comparison with $\pi$, $k$ and $p$

ALICE Preliminary

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV 10-20%

10-20%
Comparison with $\pi$, $k$ and $p$

ALICE Preliminary

Pb-Pb $\sqrt{s_{\text{NN}}} = 2.76$ TeV 30-40%

30-40%
Combined Blast-Wave

ALICE Coll.: arXiv:1506.08951 [nucl-ex]

All particle spectra are described well with the BW fit.

Results from (anti-)(hyper-)Nuclei Production and Searches for Exotic Bound States with ALICE at the LHC
N. Sharma
28/09/15