Abstract

The production of light nuclei with small binding energy such as d and $\bar{d}$, can be used to study the freeze-out properties and local baryon density in high-energy nuclear collisions. The azimuthal anisotropy results of protons and deuterons have shown that the coalescence is the dominant process for the light nucleus production at later stage of the evolution.

In this talk we present a systematic study of colliding energy, centrality, and transverse momentum dependence of mid-rapidity deuteron and anti-deuteron production, measured by the STAR experiment, from Au + Au collisions at RHIC at $\sqrt{s_{NN}} = 7, 11.5, 14.5, 19.6, 27, 39,$ and $200$ GeV. Deuterons, protons and their anti-particles are identified using the time projection chamber (TPC) and time-of-flight detector (TOF). Proton and anti-proton yields are corrected for weak decays. The $B_2$ parameters, defined as $N(d)/(N^2(p))$, which measure the phase space density for nucleons show a difference between $B_2(d)$ and $B_2(\bar{d})$. These observations may imply that baryon and anti-baryon freeze-out at different densities.

Introduction and Motivation

- Light (anti)nuclei with small binding energy, such as d and $\bar{d}$ ($\varepsilon = 2$ MeV), are formed through final-state coalescence:
  $$B_2\rho^4 = B_2\left(\frac{\rho^4}{\rho_0^4}\right) = B_2\left(\frac{\rho^4}{\rho_0^4}\right).$$
- The coalescence parameter $B_2$ reflects the local nucleon density.
- In thermal model, $B_2 = T^4/N^2(p)$ is freeze-out volume. Phys. Rev. 131, 223(1966)
- The production of light nuclei provides a tool to measure the freeze-out properties.

Data Sets, Cuts, and Particle Identification

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<th>Data Set</th>
<th>Cuts</th>
<th>Particle Identification</th>
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| Event Cuts | $|\eta| < 0.3$ | |}
| Track Cuts | $p_T > 0.6$ GeV | Deuterons can be identified up to 4 GeV |
| | $p_T > 0.6$ GeV | |
| | $|\eta| < 0.3$ | |
| | | |

Proton Feed-down Corrections

- Protons have many contributions from weak decay of multi-strange particles. These contributions should be removed to get the primary proton.
- In STAR experiment, for the proton parent particles, only A, $\Sigma^+$, $\Lambda^+$ and their anti-particles can be measured. These $\Sigma$ and $\Lambda$ are the same. For $\Sigma^+$, it is assumed the spectra of $\Sigma^+$ and $\Sigma^-$ are the same. For $\Lambda$, it is assumed $\Lambda = 0.27$ and $p_T$ independent.
- Feed-down ratios decrease with increasing $p_T$ and saturate at high $p_T$.
- Feed-down ratios for $\Xi$ are larger than $p$. |

Deuteron Transverse Momentum Distribution

- $N_{dN}$ scaled $dN/dy$ for $\Xi$ shows weak centrality dependence, for $d$ increase slightly from peripheral to central collision.
- $\rho^4$ increases from peripheral to central collision.
- $\rho^4$ shows weak energy dependence.
- $\rho^4$ differ between $d$ and $\bar{d}$ are small.
- $\Xi$ and $\Xi^*$ increase with increasing energy. $\Xi/\Xi^*$ are in the same order of magnitude.

nN/dy and Mean $p_T$

- Yield of d is smaller at higher energy, which suggest baryon density at mid-rapidity decreases with increasing energy.
- Yield of $\Xi$ increases with increasing energy.

Results

- Because $B_2$ is not $p_T$ independent, we study the energy dependence of $p_T$ integrated $B_2 = N(d)/N^2(p)$.
- In thermal model grand canonical ensemble (GCE), integral $B_2(d)$ and $B_2(\bar{d})$ should be the same if iso-spin effect can be neglected.
- For the most 5% collision centrality $B_2(d) = B_2(\bar{d}) = 0.29 \pm 0.14$ with a straight line fit, which might represent the iso-spin effect is not negligible in heavy-ion collision or particle and antiparticle have different freeze-out volume.
- High statistics data are needed for future studies, especially at the high net-baryon, i.e. low collision energy, region.

Summary

- We report STAR new results on d and $\Xi$ productions in Au + Au collisions at $\sqrt{s_{NN}} = 7, 11.5, 14.5, 19.6, 27, 39,$ and $200$ GeV.
- Both the $N_{dN}$ scaled yields ($dN/dy$) and mean transverse momenta ($p_T$) of d and $\Xi$ show collision energy dependence. Blast Wave function fits to deuteron spectra well.
- The coalescence parameter $B_2 = N(d)/N^2(p)$ decrease as collision energy increases, which shows that as energy decreases, the freeze-out volume for nucleons becomes smaller. The relative change of the $B_2$ decreases with increasing energy, which might represent the iso-spin effect is not negligible in heavy-ion collision or particle and antiparticle have different freeze-out volume.
- High statistics data are needed for future studies, especially at the high net-baryon, i.e. low collision energy, region.