Light Nuclei ($d, t$) Production in Au + Au Collisions at
\[ \sqrt{s_{NN}} = 7.7 – 200 \text{ GeV} \]

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In part supported by

U.S. Department of Energy
Office of Science

STAR
Outline

- Introduction and Motivation

- The STAR Experiment
  - Dataset and Particle Identification
  - Data Corrections

- Results and Discussions
  - Particle Production
  - Particle Ratios

- Summary
Introduction and Motivation – QCD Phase Diagram

RHIC STAR Beam Energy Scan\textsuperscript{[1, 2]}

<table>
<thead>
<tr>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
<th>Year</th>
<th>Events ($10^6$)</th>
<th>$\mu_B$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>2010</td>
<td>4</td>
<td>420</td>
</tr>
<tr>
<td>11.5</td>
<td>2010</td>
<td>11</td>
<td>315</td>
</tr>
<tr>
<td>14.5</td>
<td>2014</td>
<td>27</td>
<td>260</td>
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<tr>
<td>19.6</td>
<td>2011</td>
<td>40</td>
<td>205</td>
</tr>
<tr>
<td>27</td>
<td>2011</td>
<td>71</td>
<td>155</td>
</tr>
<tr>
<td>39</td>
<td>2010</td>
<td>133</td>
<td>115</td>
</tr>
<tr>
<td>54.4</td>
<td>2017</td>
<td>1200</td>
<td>83</td>
</tr>
<tr>
<td>62.4</td>
<td>2010</td>
<td>67</td>
<td>72</td>
</tr>
<tr>
<td>200</td>
<td>2011</td>
<td>480</td>
<td>20</td>
</tr>
</tbody>
</table>

\textsuperscript{[1]} M.M. Aggarwal et al. (STAR Collaboration), arXiv: 1007.2613

\textsuperscript{[2]} BES-II whitepaper:

Quark Matter 2019, Wuhan, Nov. 4–9, 2019
Light Nuclei Production – HIC

- **Coalescence picture**: Production of light nuclei with small binding energy, such as triton (8.48 MeV), deuteron (2.2 MeV), formed via final-state coalescence, are sensitive to the local nucleon density [3].

\[ E_A \frac{d^3N_A}{d^3p_A} = B_A \left( E_p \frac{d^3N_p}{d^3p_p} \right)^Z \left( E_n \frac{d^3N_n}{d^3p_n} \right)^{A-Z} \approx B_A \left( E_p \frac{d^3N_p}{d^3p_p} \right)^A \]

\[ B_A = \frac{4\pi}{3} p_0^3 (A-1) \frac{1}{A! m^A} M \]

- The coalescence parameter, \( B_A \), reflects the local nucleon density
- In thermal model, \( B_A \propto V_f^{1-A} \), \( V_f \) is freeze-out volume [4]


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In the vicinity of the critical point or the first order phase transition, density fluctuations become larger.

\[ N_d = \frac{3}{2^{1/2}} \left( \frac{2\pi}{m_0 T_{eff}} \right)^{3/2} N_p \langle n \rangle (1 + C_{np}) \]

\[ N_t = \frac{3^2}{4} \left( \frac{2\pi}{m_0 T_{eff}} \right)^3 N_p \langle n \rangle^2 (1 + \Delta n + 2C_{np}) \]

\( C_{np} \) characterizes the neutron and proton density correlation. When \( C_{np} = 0 \), \( N_t \cdot N_p/N_d^2 = g(1 + \Delta n) \) [5].

Experimentally, one can measure the light nuclei yield ratio to probe the QCD critical point or first order phase transition.

The **Solenoidal Tracker At RHIC (STAR)**

- **Time Projection Chamber (TPC)**
  - Charged Particle Tracking
  - Momentum reconstruction
  - Particle identification from ionization energy loss ($dE/dx$)
  - Pseudorapidity coverage $|\eta| < 1.0$

- **Time-of-Flight (TOF)**
  - Particle identification $m^2$
  - Pseudorapidity coverage $|\eta| < 0.9$

- **Excellent Particle Identification**
- **Large, Uniform Acceptance at Midrapidity**
Particle Identification
Data Corrections

- TPC tracking efficiency
- TOF matching efficiency
- Energy loss corrections
- Absorption corrections
- Background subtraction

\[
\varepsilon_{TPC}(p_T) = p_0 \cdot e^{-(p_1/p_T)p^2_T} + \frac{1}{2}(p_T-p_4)^2 + p_3 \cdot e^{-p_5/p_T^2}
\]

\[
\varepsilon_{TOF}(p_T) = p_0 \cdot e^{-(p_1/p_T)p^2_T}
\]

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Transverse Momentum Spectra for Tritons (BES - I)

[Image of plots showing transverse momentum spectra for different energies and rapidity intervals.]

- Midrapidity ($|y| \leq 0.5$) transverse momentum distributions of triton
- Vertical lines and boxes represent statistical and systematic errors respectively
- Dash lines: blast-wave function fits [6]

$$\frac{d^2N}{p_T dp_T dy} \propto \int_0^R r dr m_T l_0 \left( \frac{p_T sinh \rho}{T} \right) K_1 \left( \frac{m_T cosh \rho}{T} \right)$$


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Transverse Momentum Spectra for 54.4 GeV

Midrapidity transverse momentum distribution of proton, (anti)deuteron and triton

Hui Liu, Poster #389 (CP9)
$B_3$ decreases from peripheral to central collisions and with increasing collision energy.
At energies below 20 GeV the $B_2$ and $\sqrt{B_3}$ decreases with increasing collision energy. For $\sqrt{s_{NN}} > 20$ GeV the rate of decrease seems to change and saturate up to 62.4 GeV. The $B_2$ values at 200 GeV is found to be larger than the BES saturation values [7].

\( \frac{dN}{dy} \) increases with decreasing energy: baryon stopping.

\( \frac{dN}{dy} \) increases from peripheral to central collisions.
The Thermal model can describe the d/p ratios [7], but can not describe the t/p, t/d ratios.

\[ T_{cl} = T_{cl}^\ast \frac{M}{1 + \exp(2.60 - \ln(\sqrt{s})/0.45)} \]

\[ \mu_B' = a/(1 + 0.288\sqrt{s}) \]

With \( \sqrt{s}_{NN} \) in GeV and \( T_{CF}^{lim} = 158.4 \) MeV and \( a = 1307.5 \) MeV [8].

The Yield Ratio – Neutron Density Fluctuations

The yield ratio is related to neutron density fluctuations.

\[ N_t \cdot \frac{N_p}{N_d^2} = g(1 + \Delta n), \]

\textit{with} \( g = 0.29 \)

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\textit{with} \( g = 0.29 \)

The yield ratio is related to neutron density fluctuations.

☆ Yield ratio shows a non-monotonic dependence on collision energy in 0-10% Au + Au collisions. A peak is around 20-30 GeV.

☆ JAM model shows a flat energy dependence of yield ratio and disagrees with the data [9].

Summary and Outlook

- We present STAR results of light nuclei ($d$, $\bar{d}$, and $t$) from Au + Au collisions at $\sqrt{s_{\text{NN}}} = 7.7$, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.4, and 200 GeV.

- Coalescence parameters, $B_2^d$ and $B_3^t$, are extracted for $d$ and $t$, respectively. $B_2^d$ and $\sqrt{B_3^t}$ are consistent within uncertainties except for 200 GeV.

- The thermal model can describe the $d/p$ ratio but not $t/p$ or $t/d$ ratios.

- The collision-energy dependence of yield ratios shows a non-monotonic behavior at central collisions. A peak is observed around 20-30 GeV.

- Study the QCD phase structure with more statistics in BES-II at RHIC (2019-2021) …
Thank you!
Back Up


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