Light nuclei production in Au+Au collisions at BES-II energies at RHIC-STAR

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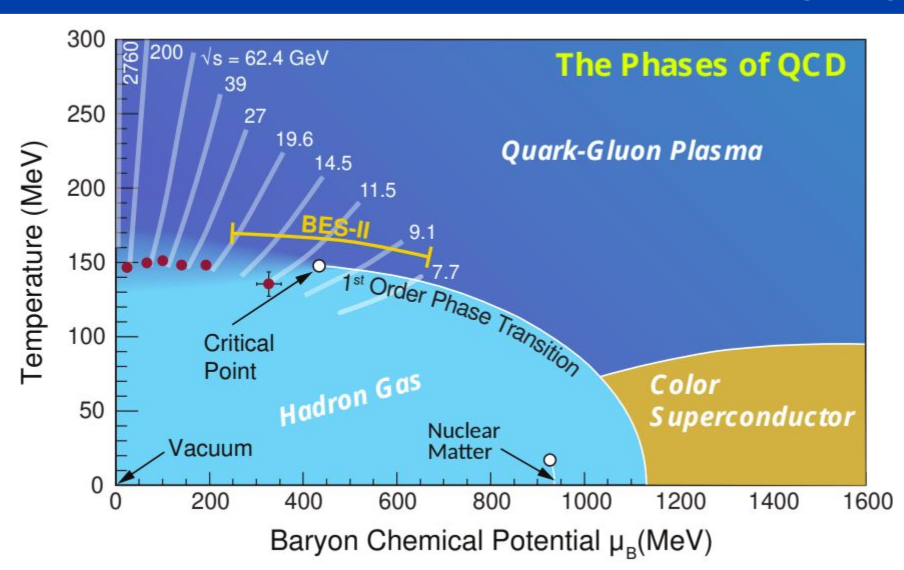
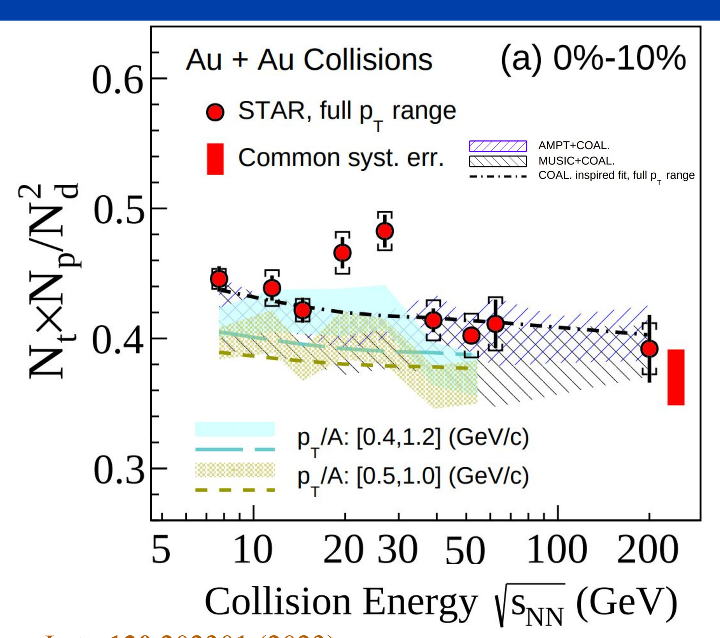
Abstract

In high-energy heavy-ion collisions, light nuclei serve as a powerful probe to investigate the phase structure of Quantum Chromodynamics (QCD). The production of light nuclei is influenced by the temperature and phase-space density of the system at freeze-out. Moreover, a phase transition can lead to significant baryon density fluctuations, which may be reflected in the yields of light nuclei at freeze-out. For instance, the yield ratio involving proton (N_p), triton (N_t), and deuteron (N_d) expressed as $N_p \times N_t / N_d^2$, can act as a sensitive observable for identifying the QCD critical point. The precision of the new measurements will be significantly improved by the large data sets (~10× BES-I) obtained by the STAR BES-II with upgraded detector capabilities. In this poster, we report the transverse momentum spectra of light nuclei in Au+Au collisions at $\sqrt{s_{NN}}$ =7.7 - 27 GeV measured by the STAR BES-II. We will also report on the centrality and energy dependence of integrated particle yields (dN/dy) of light nuclei. Furthermore, we will discuss the effect of collective expansion by studying the centrality and p_T dependence of the coalescence parameters (B_2 (d) and B_3 (^{3}He)) with their broader physics implications.

1. Introduction: Highlights from STAR BES-I





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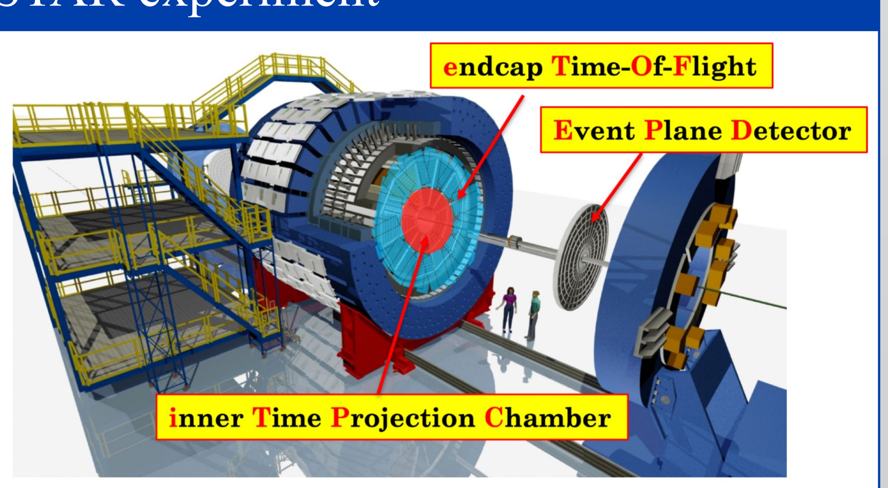
- **QGP** to **Hadronic matter** transition is crossover at low μ_B and 1st order at higher μ_B
- **Main goal**: Search for **Critical Point (CP)** in QCD phase diagram
- Light nuclei may carry information about local baryon density fluctuations
- Choice of observable: **Compound light nuclei yield ratio** provides an effective probe to study the 1st order phase boundary and QCD CP
- Based on coalescence model: $\frac{N_t \times N_p}{N_d^2} \propto (1+\Delta n)$ where, Δn: Neutron fluctuation density

Phys. Lett. B **774** 103-107 (2017)
Phys. Lett. B **781** 499-504 (2018)
Eur. Phys. J. A **57** 11313 (2021)

Beam Energy Scan program (BES-II) collider mode:
Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, 14.6, 17.3, 19.6 , 27 GeV

2. Introduction: The STAR experiment

- Solenoidal Tracker at RHIC (STAR) is one of the large detector systems at RHIC consisting of several sub-detectors
- Time Projection Chamber (TPC) and Time of Flight (TOF) are two sub-detectors used for particle identification at STAR
- The upgrade to iTPC provides better momentum resolution, better dE/dx resolution, and improved acceptance at large rapidity
- Particles are identified using dE/dx information from TPC
- m^2 cut has been used whenever TOF information is available



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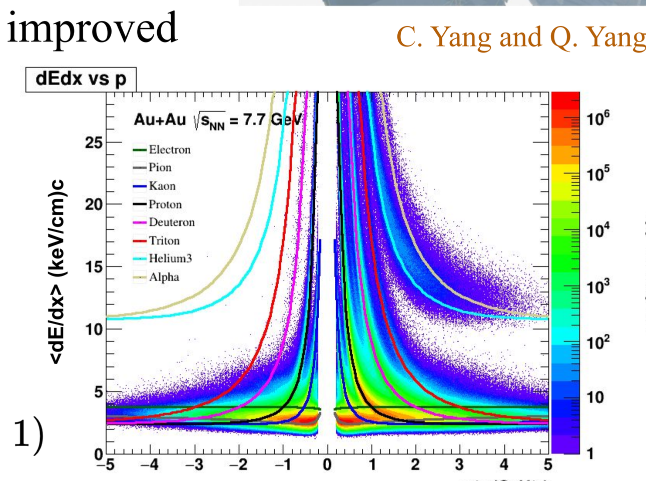
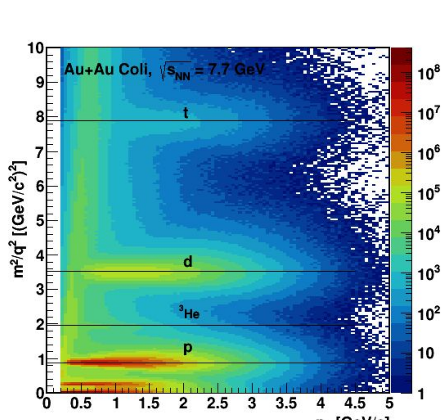
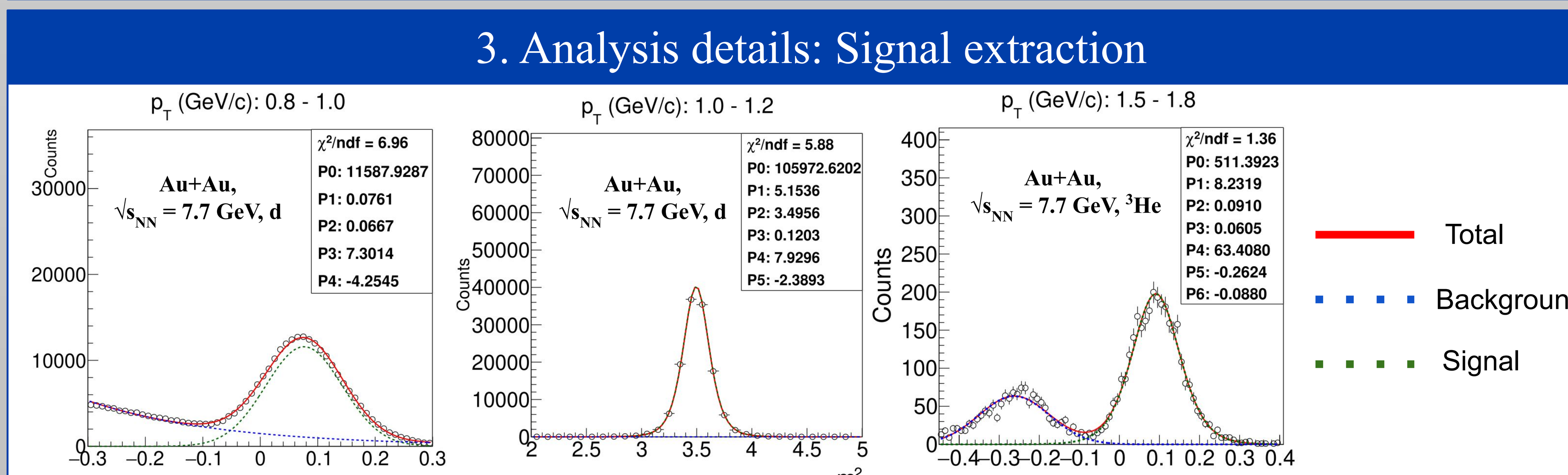




$$z_i = \ln\left(\frac{<dE/dx>_{measured}}{<dE/dx>_{i,theory}}\right) \quad m^2 = p^2(1/\beta^2 - 1)$$

3. Analysis details: Signal extraction



- At low p_T (0. 5 - 1.0 GeV/c) (Gaussian + Exponential):

$$\frac{1}{\sqrt{2\pi\sigma^2}} e^{(x-\mu)^2/2\sigma^2} + ae^{bx}$$

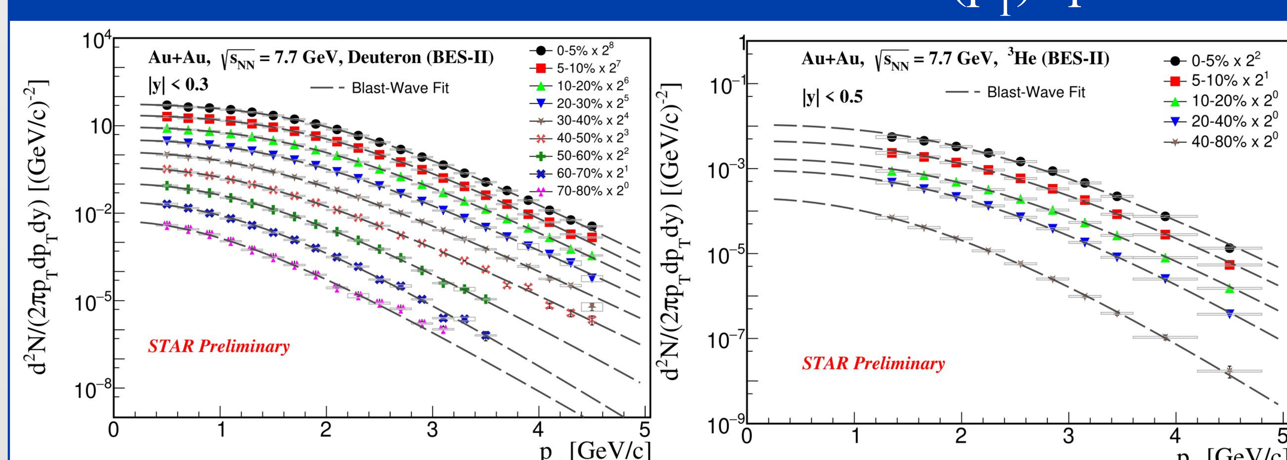
- At intermediate p_T (1.0 - 5.0 GeV/c) (StudentT + Exponential / Gaussian):

$$\frac{\Gamma(\frac{\nu+1}{2})}{\Gamma(\frac{\nu}{2}\sqrt{\pi\nu\sigma^2})}[1+\frac{1}{\nu}(\frac{x-\mu}{\sigma})^2]^{-\frac{\nu+1}{2}} + ae^{bx}$$

Corrections

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

4. Results: Transverse momentum (p_T) spectra & Yield of light nuclei



Blast-Wave model

$$\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho}{T}\right) K_1\left(\frac{m_T \cosh\rho}{T}\right)$$

$$\rho = \tanh^{-1}\beta_r, \; \beta_r(r) = \beta_s\left(\frac{r}{R}\right)^n$$

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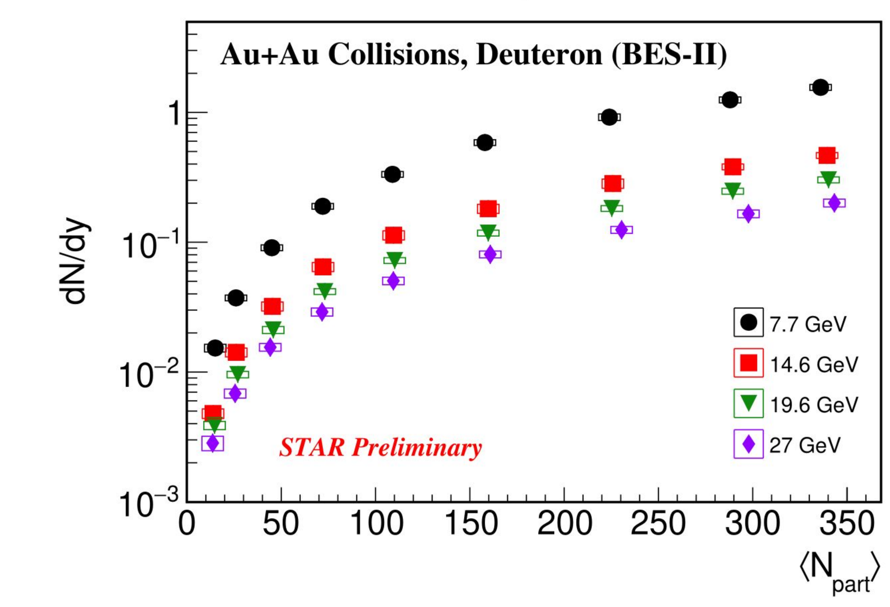
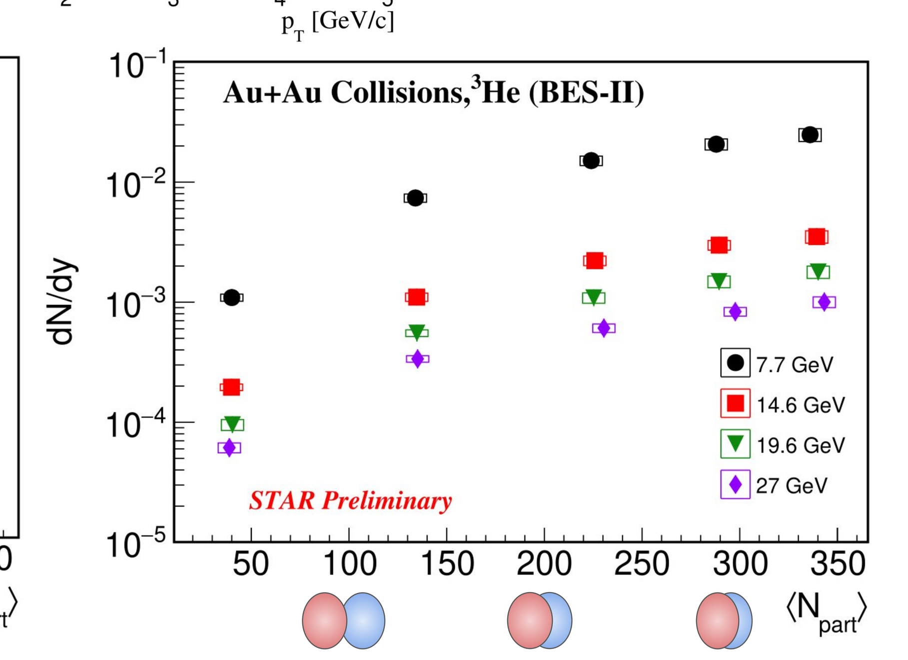
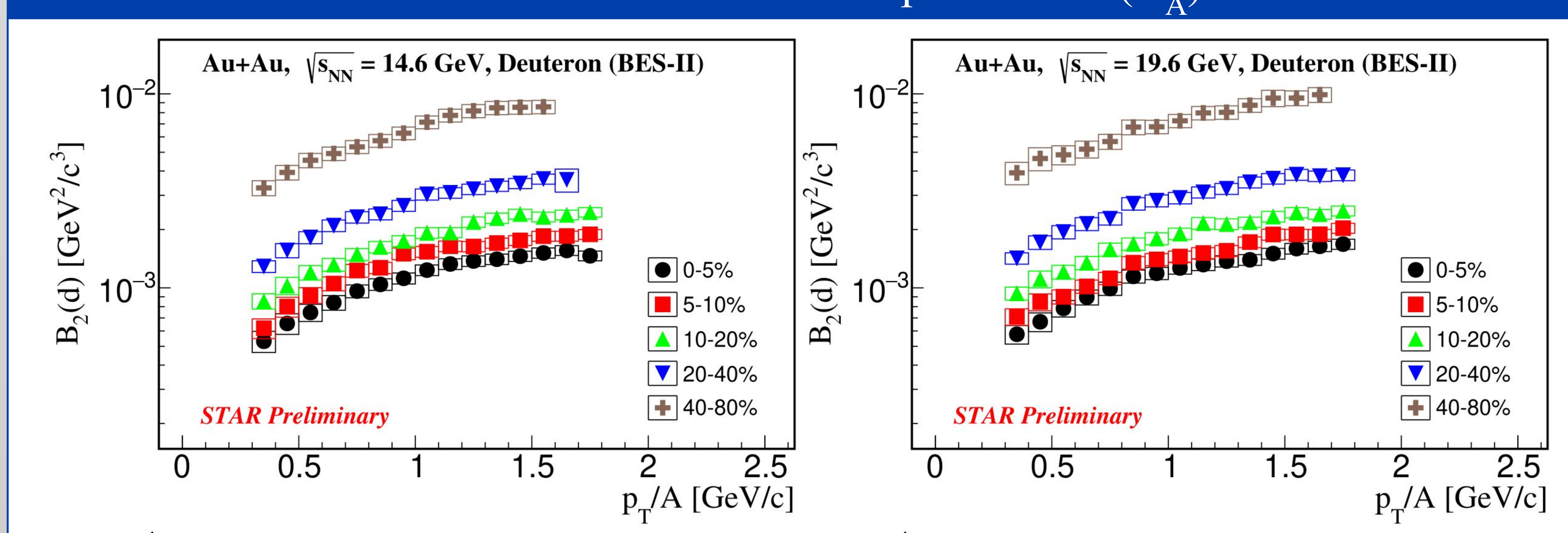
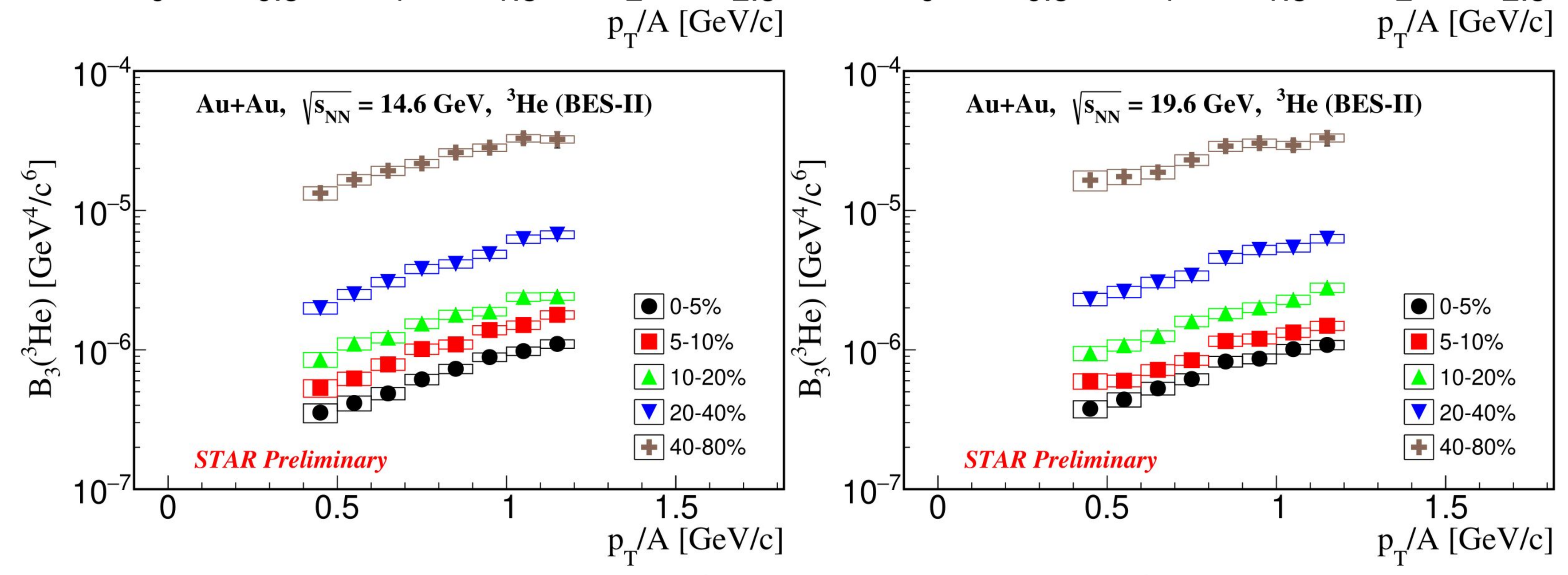




- Yield of light nuclei increases from peripheral to central collisions
- Light nuclei yield increases with decreasing $\sqrt{s_{NN}}$ (Baryon stopping effect)

5. Results: Coalescence parameters (B_A)





$$E_A\frac{d^3N_A}{dp_A^3} = B_A\left(E_p\frac{d^3N_p}{dp_p^3}\right)^Z\left(E_n\frac{d^3N_n}{dp_n^3}\right)^{A-Z} \simeq B_A\left(E_p\frac{d^3N_p}{dp_p^3}\right)^A$$

- B_A reflects the probability of nucleon coalescence
- B_A increases with p_T (Collective flow of hadrons)
- B_A increases from central to peripheral (Decrease in source volume)

Phys. Rev. C **99** 064905 (2019)

6. Summary & Outlook

- We presented the p_T spectra of d and ^{3}He in Au+Au collisions at $\sqrt{s_{NN}}$= 7.7 - 27 GeV
- Yield of light nuclei increases with decreasing beam energy due to baryon stopping effect
- B_A increases with increasing p_T and from central to peripheral

Outlook: Estimate the compound light nuclei ratios as a function of center-of-mass energy to understand critical phenomena

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