Production of light nuclei in Au+Au collisions from STAR BES-II

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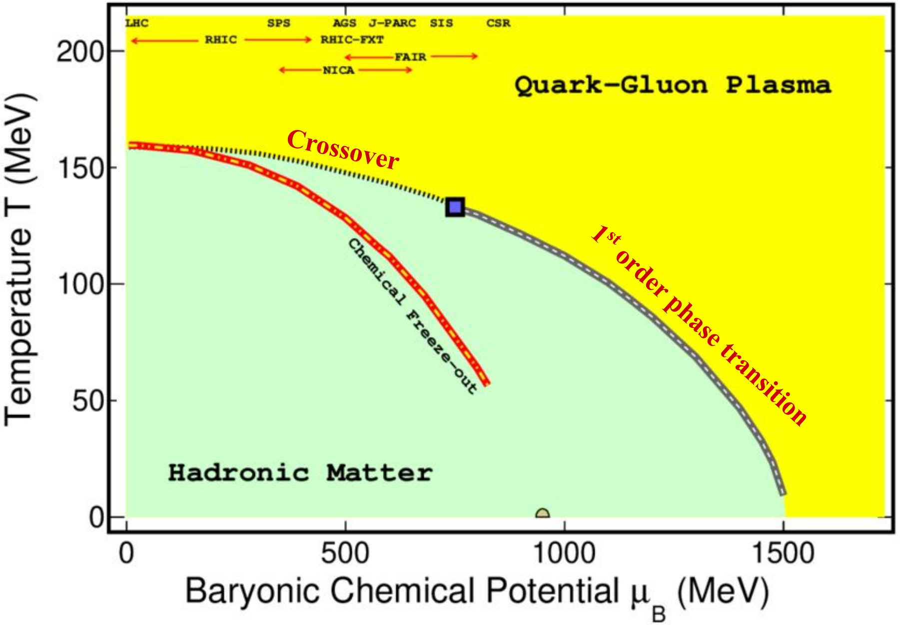
- Introduction
- The STAR experiment
- Analysis details
- Results:
  - Transverse momentum (p_T) spectra
  - Yield and mean p_T of light nuclei
  - Coalescence parameters (B_A)
- Summary

Introduction: Highlights from the STAR BES-I

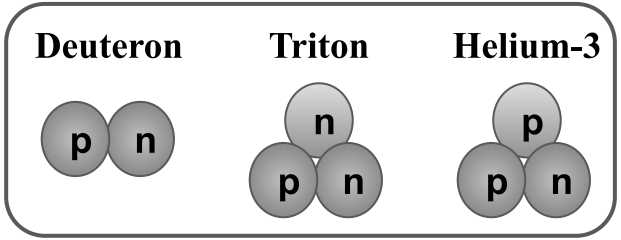


Progress in Particle and Nuclear Physics **125**, 103960 (2022)

- ➢ Goal of Beam Energy Scan (BES) program is to explore **QCD phase diagram**
  1. **QGP** to **hadronic matter** phase transition ➡ crossover at low μ_B & 1^{st} order at higher μ_B
  2. Search for **critical point**
  3. **Turn off** of QGP signatures

Why light nuclei?

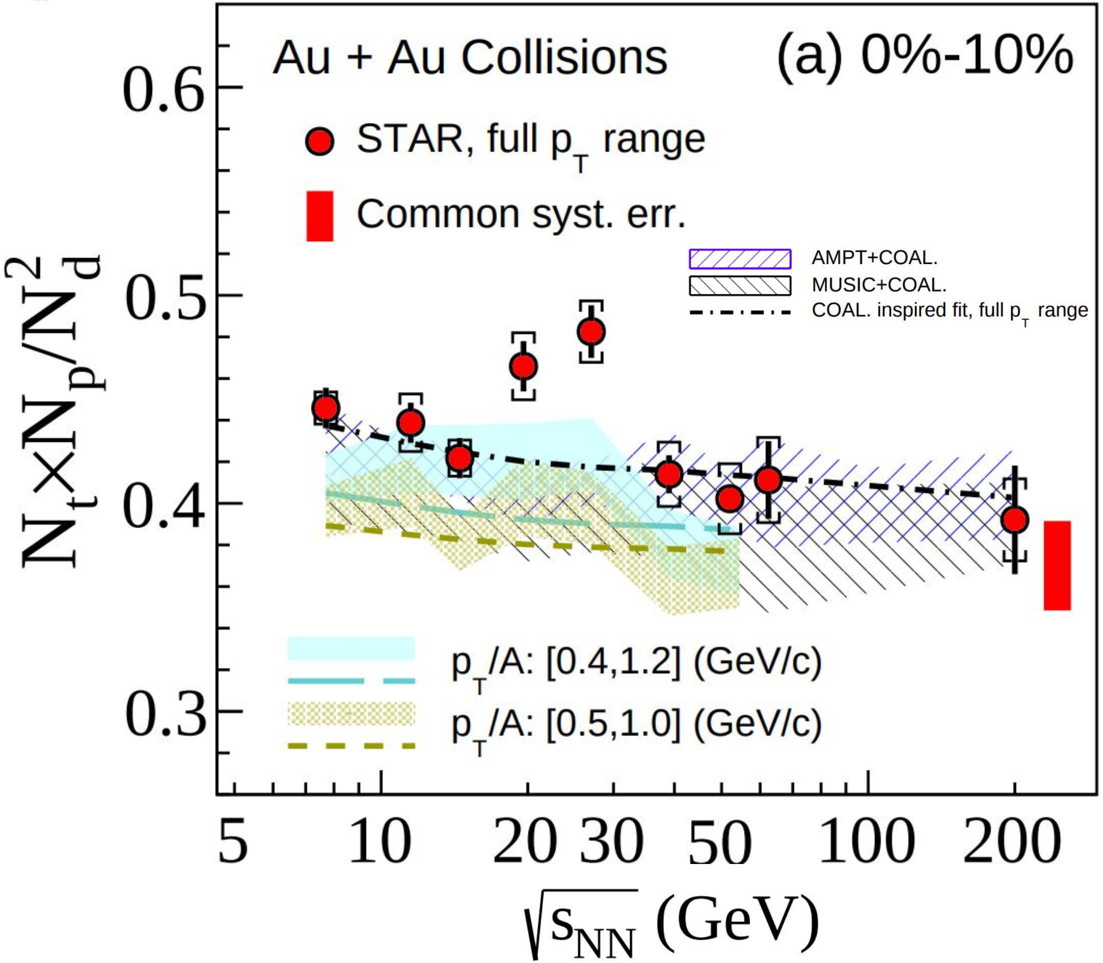
- ➢ Understand the production mechanism of light nuclei
- ➢ Light nuclei may carry information about the local baryon density fluctuations ➡ can be used as a tool to probe the QCD phase diagram



Choice of observable: compound light nuclei ratio ➡ $\frac{N_t \times N_p}{N_d^2} \propto (1 + \Delta n)$

Δn : Neutron fluctuation density

PLB **774** 103-107 (2017)
PLB **781** 499-504 (2018)
EPJA **57** 11313 (2021)

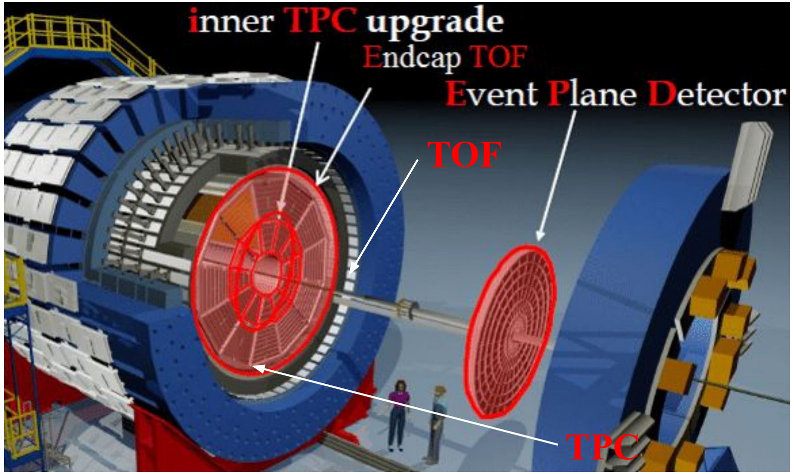


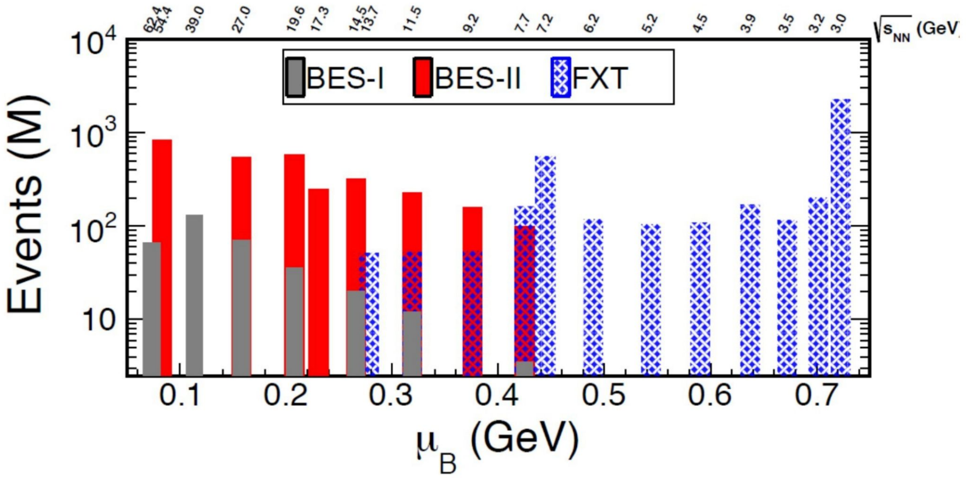
Beam Energy Scan program (BES-I) collider mode:

7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, and 200 GeV

- Total deviation of N_tN_p/N_d^2 ratio from coalescence baseline is 4.2 sigma (19.6 and 27 GeV)
- Light nuclei yields and ratios could provide a probe to search for signature of critical phenomena

STAR, PRL **130** 202301 (2023)





➢ Particle identification is done using:
- *<dE/dx>* information from **Time Projection Chamber (TPC)**
- m^2 information from **Time of Flight (TOF)**

➢ BES-II upgrades:
- iTPC & eTOF: Large pseudorapidity coverage ($-1.5 < \eta < 1.5$)
- Better momentum and *dE/dx* resolution

JPCS **742** 012022 (2016)

BES-I energies:

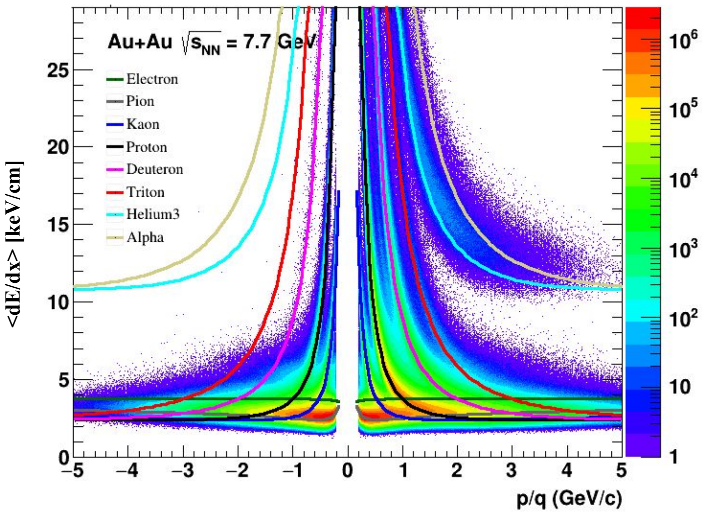
$\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, and 62.4 GeV

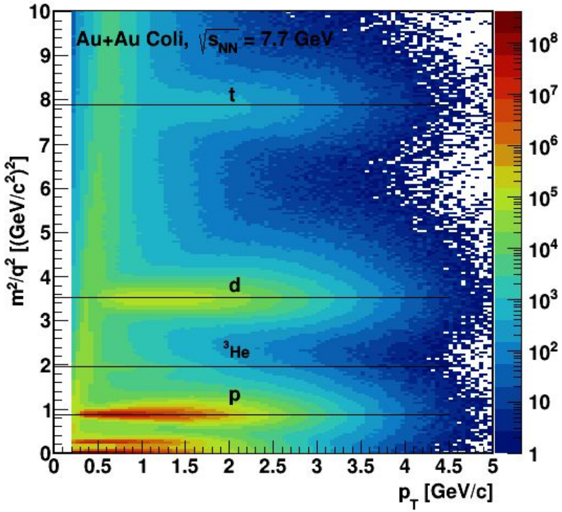
BES-II energies:

$\sqrt{s_{NN}}$ = **7.7**, 9.2, 11.5, **14.6** ,17.3, **19.6, 27**, and 54.4 GeV

$\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7, 9.2, 11.5, and 13.7 GeV (**FXT**)

Light nuclei identification using TPC and TOF





- **PID** using **dE/dx** information from **TPC** at low p_T (0.5 - 1.0 GeV/c)

$$Z = ln(\frac{<dE/dx>}{<dE/dx>_{theory}})$$

- **PID** using $\mathbf{m^2/q^2}$ information from **TOF** at intermediate p_T (1.0 - 5.0 GeV/c)

$$\frac{m^2}{q^2} = \frac{p^2}{q^2}(1/\beta^2 - 1)$$

NIMA **562** 154-197 (2006)

Signal extraction using TPC and TOF

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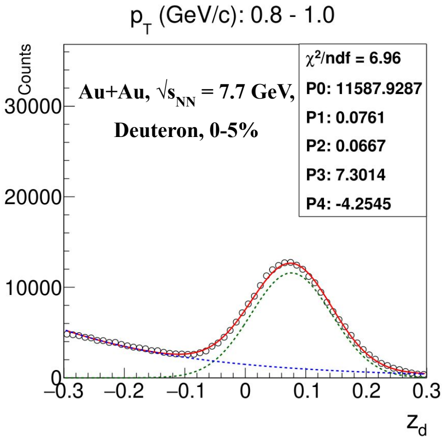
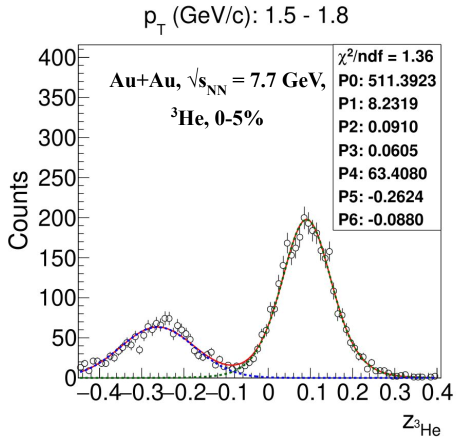
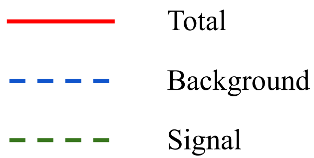
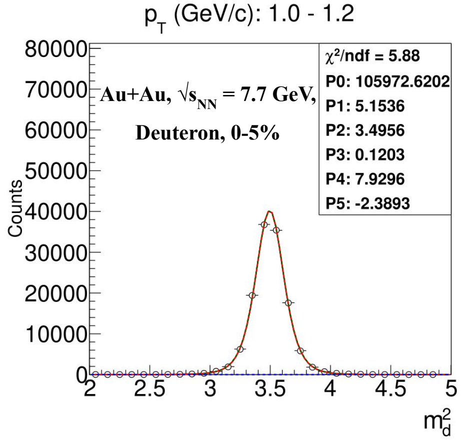
$$Z_i = ln\left(\frac{<dE/dx>}{<dE/dx>^{i}_{theory}}\right)$$

$$\frac{m^2}{q^2} = \frac{p^2}{q^2}(1/\beta^2 - 1)$$









- At low p_T (Gaussian+Exponential) [0.5 - 1.0 GeV/c]:

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

- At intermediate p_T (Student-t+Exponential/Gaussian) [1.0 - 5.0 GeV/c] :

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

Corrected p_T spectra: Deuteron

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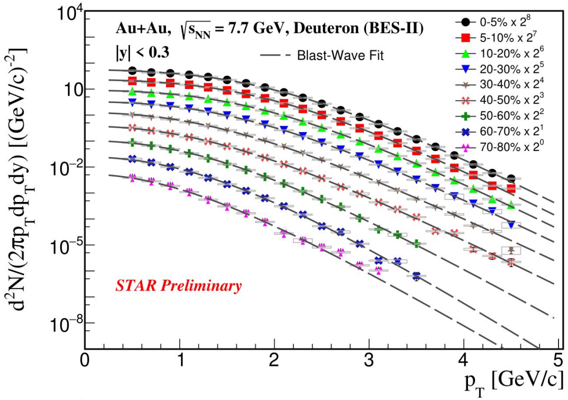
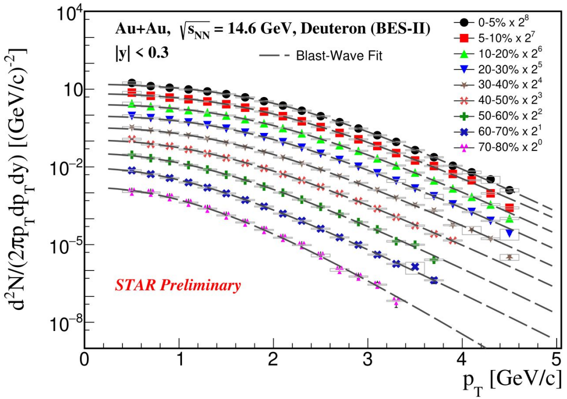
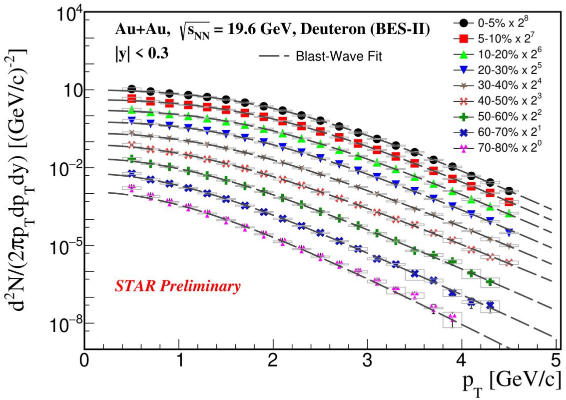
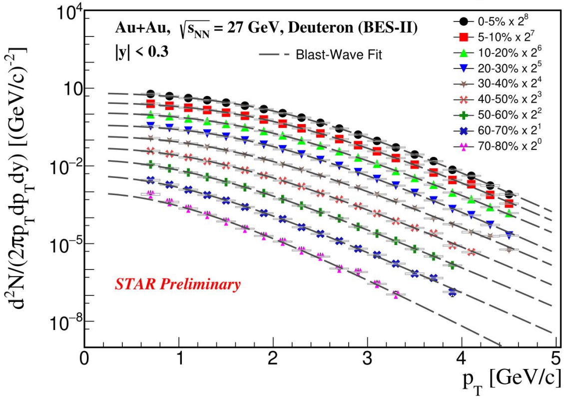








Blast-Wave fit function

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

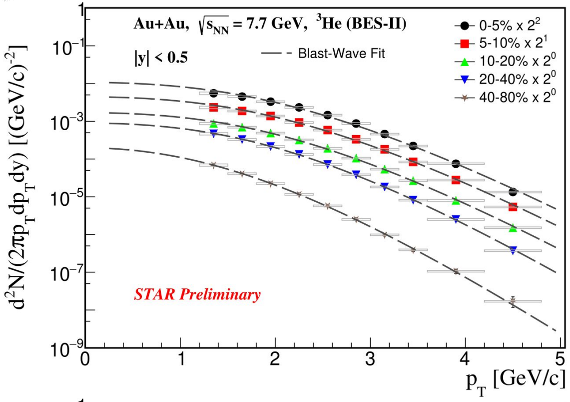
$$\rho = \tanh^{-1}\beta_r \, , \, \beta_r(r) = \beta_s\left(\frac{r}{R}\right)^n$$

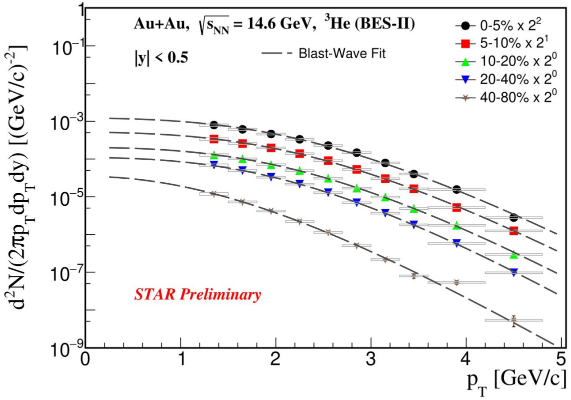
PRC **99**, 064905 (2019)

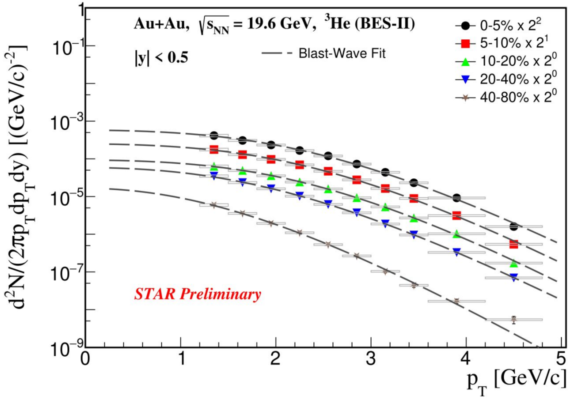
- ❏ Energy loss correction (✅)
- ❏ TPC efficiency and acceptance (✅)
- ❏ TOF efficiency (✅)
- ❏ Absorption correction (✅)
- ❏ Background subtraction (✅)

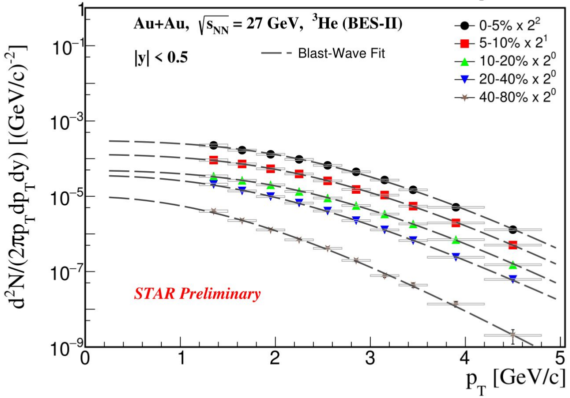
- ➢ More precise measurements compared to BES-I due to larger statistics (~10x increase)
- ➢ p_T spectra is used to calculate the yield and mean p_T of light nuclei

Corrected p_T spectra: ^{3}He









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

PRC **99**, 064905 (2019)

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- ➢ More precise measurements compared to BES-I due to larger statistics (~10x increase)
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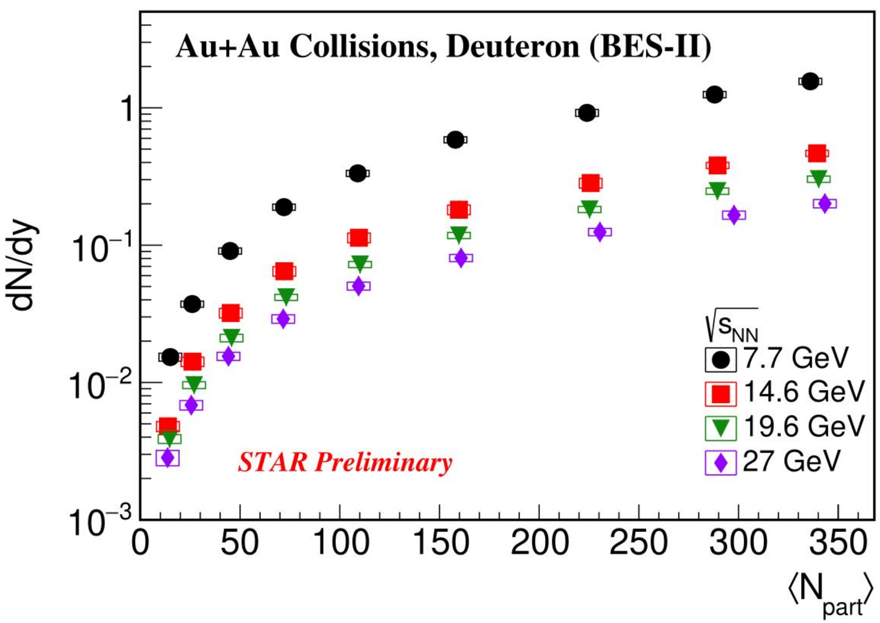
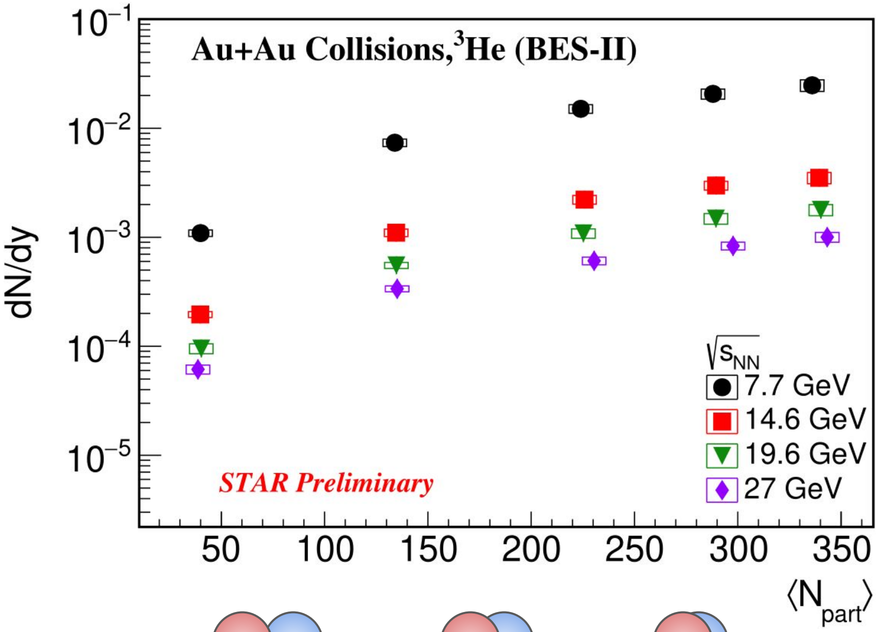
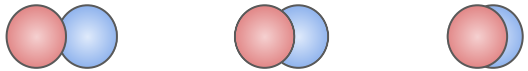
Integrated yield (dN/dy)

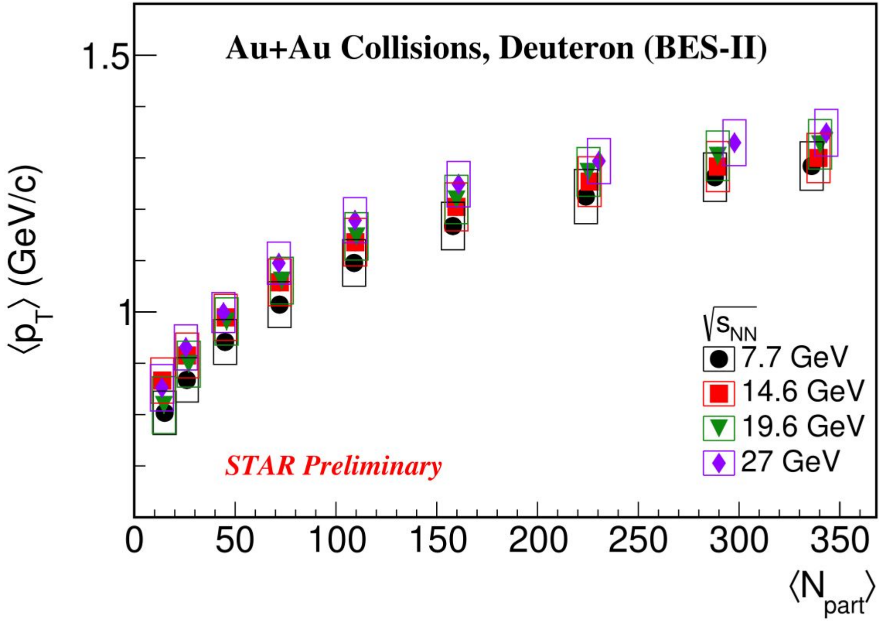


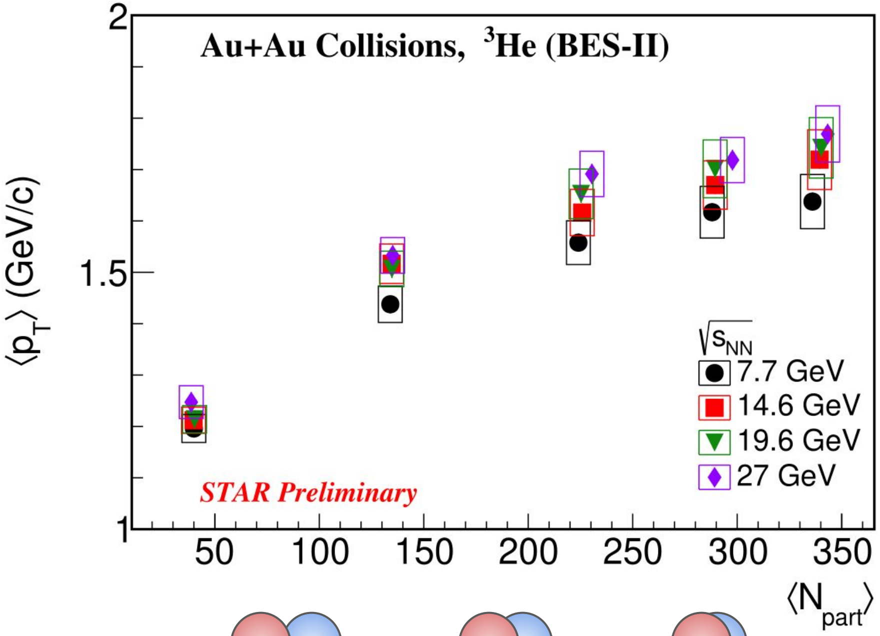


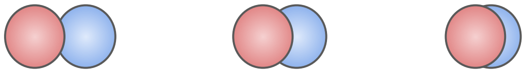


- ➢ dN/dy increases with increasing centrality ➡ energy density is larger in central collisions
- ➢ dN/dy increases with decreasing collision energy ➡ baryon stopping effect is dominant at lower collision energy

Mean p_T ($\langle p_T \rangle$)





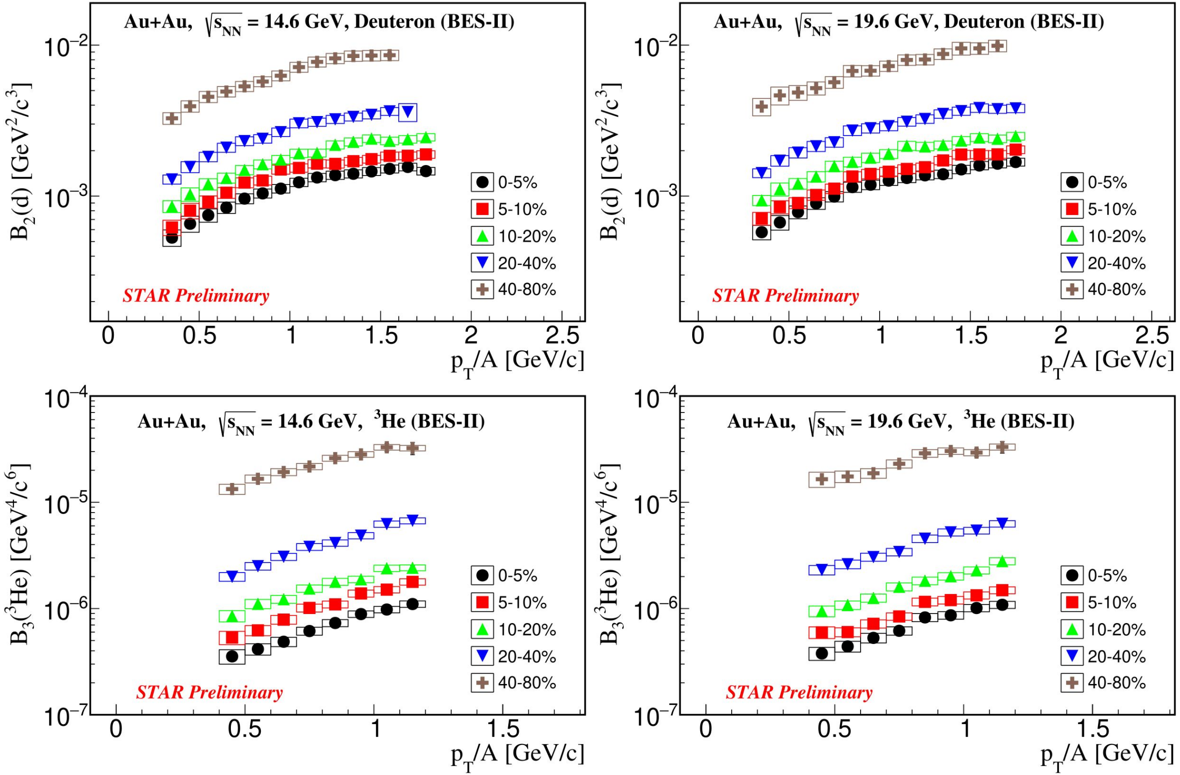


- $\langle p_T \rangle$ increases with increasing centrality ➡ large radial flow in central collisions
- Comparable $\langle p_T \rangle$ is observed at a given centrality in various collision energies

Coalescence parameters (B_A)

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

- 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

Summary

- Transverse momentum spectra of d and ^{3}He measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 27 GeV
- Yield of light nuclei is observed to increases with increasing centrality
- Light nuclei yield increases with decreasing beam energy due to baryon stopping effect
- Mean p_T increases with centrality due to large radial flow
- B_A increases with increasing p_T and also from central to peripheral collisions

Thank you all!

Backup slides