Production of light nuclei in Au+Au collisions at STAR

Rishabh Sharma (*for the STAR Collaboration*)
Indian Institute of Science Education and Research (IISER) Tirupati, India

International Conference on Physics and Astrophysics of Quark Gluon Plasma
(ICPAQGP-2023)
February 7-10, 2023

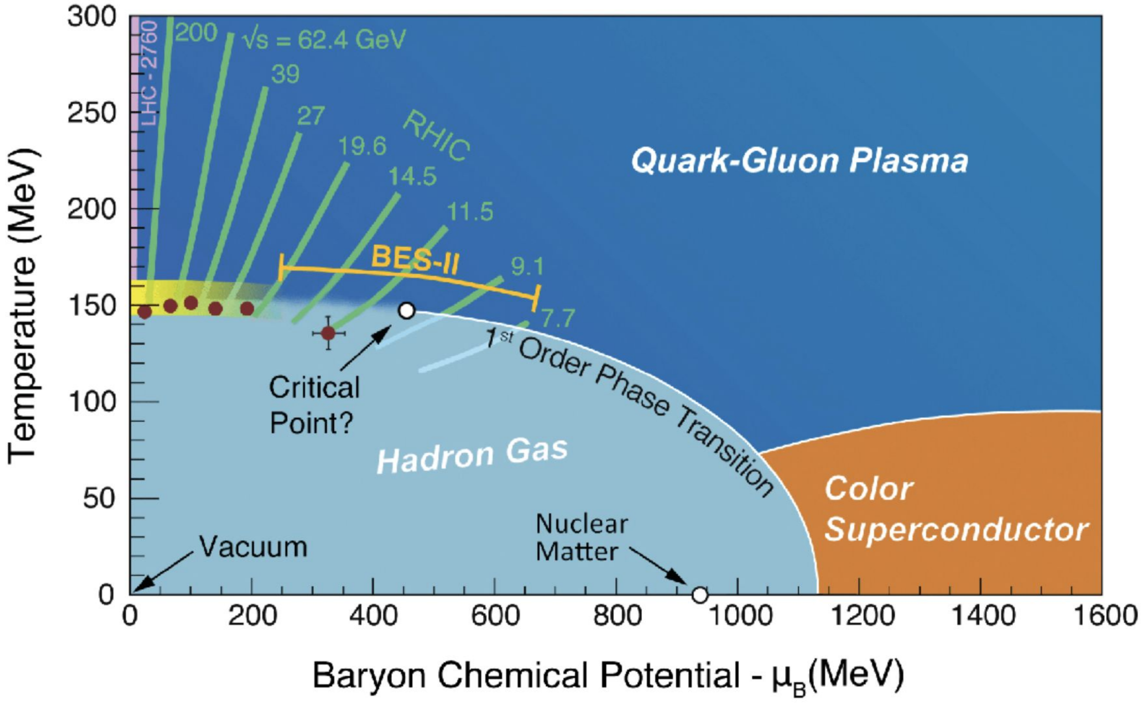
Supported in part by:
U.S. DEPARTMENT OF ENERGY | Office of Science

STAR Presentations: https://drupal.star.bnl.gov/STAR/presentations

Outline

- ➔ Motivation
- ➔ The STAR Experiment
- ➔ Light nuclei identification
- ➔ Results
  - ◆ Transverse momentum spectra
  - ◆ dN/dy and $\langle p_T \rangle$
  - ◆ Light nuclei yield ratios
- ➔ Summary

Motivation



Courtesy: S Mukherjee/BNL

➔ **Aim of Beam Energy Scan (BES) program at STAR:**

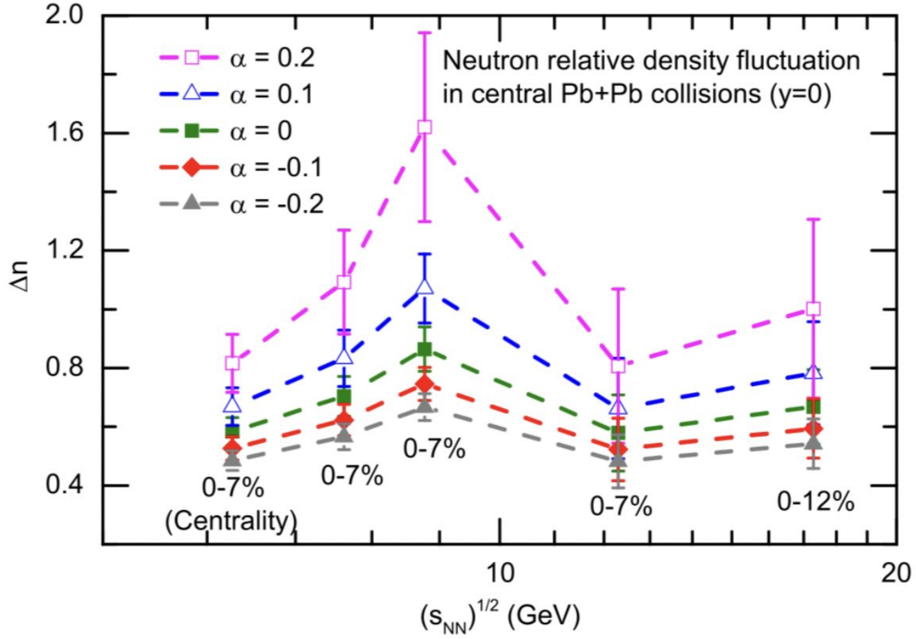
- **Experimentally scan the QCD phase diagram**
- **Search for the predicted first-order phase transition**
- **Search for QCD critical end-point**

Motivation

Light nuclei production mechanism:

➔ **Thermal → produced at the chemical freeze-out**

➔ **Coalescence → produced at the later stage of the collision by the coalescence of nucleons**



KJ Sun *et al.*, PLB 774 103–107 (2017)

$$N_d = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T_{eff}}\right)^{3/2} N_p \langle n\rangle (1+\alpha\Delta n),$$

$$N_{^3H} = \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T_{eff}}\right)^{3} N_p \langle n\rangle^2 [1+(1+2\alpha)\Delta n],$$

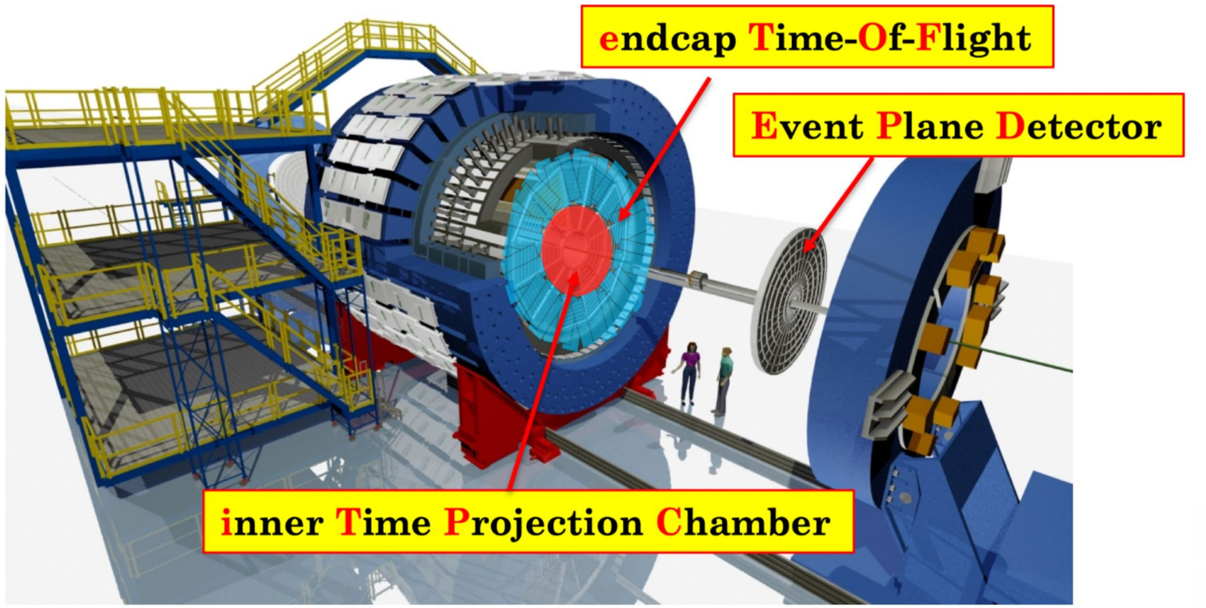
$$\mathcal{O}_{\text{p-d-t}} = \frac{N_{^3H} N_p}{N_d^2} = g\frac{1+(1+2\alpha)\Delta n}{(1+\alpha\Delta n)^2}$$

➔ **Fluctuations of conserved quantities in heavy-ion collisions can be used as potential signatures of critical end-point and 1st-order phase transition**

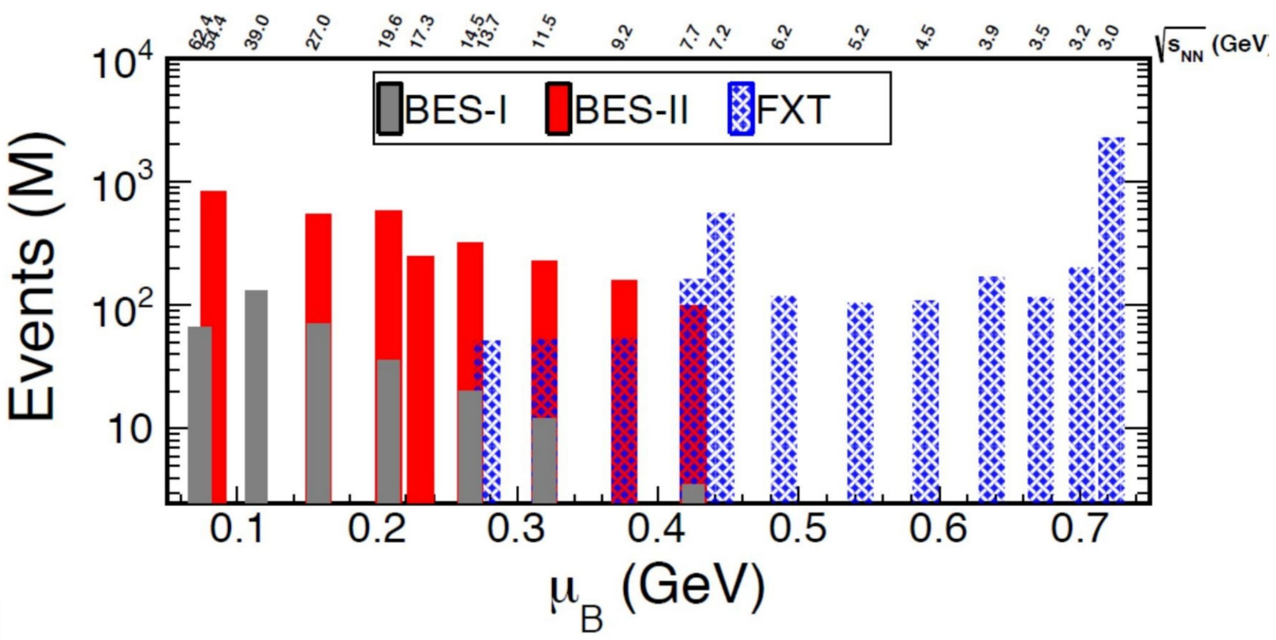
➔ **Based on the coalescence model, the ratio $O_{p\text{-}d\text{-}t}$ is sensitive to the neutron relative density fluctuation at kinetic freeze-out**

➔ **Light nuclei yields and ratios provide important insights into the understanding of QCD phase diagram**

The STAR Experiment



C. Yang *et al.*, JINST 15 C07040 (2020)



- ➔ Light nuclei identification is performed 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 ($-1.6 < \eta < 1.5$)
  - ◆ Better tracking and event plane resolution

BES-I energies:

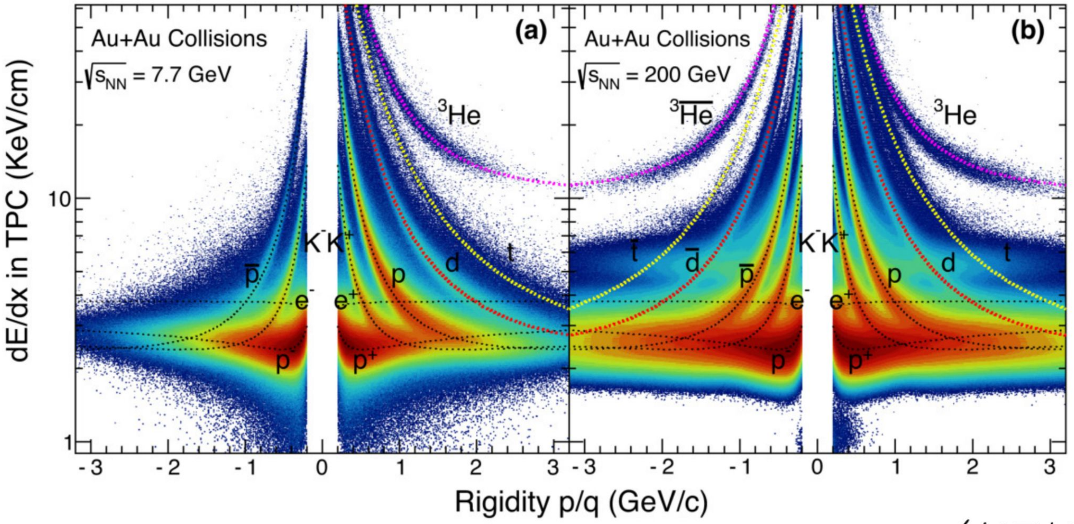
$\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, and 62.4 GeV

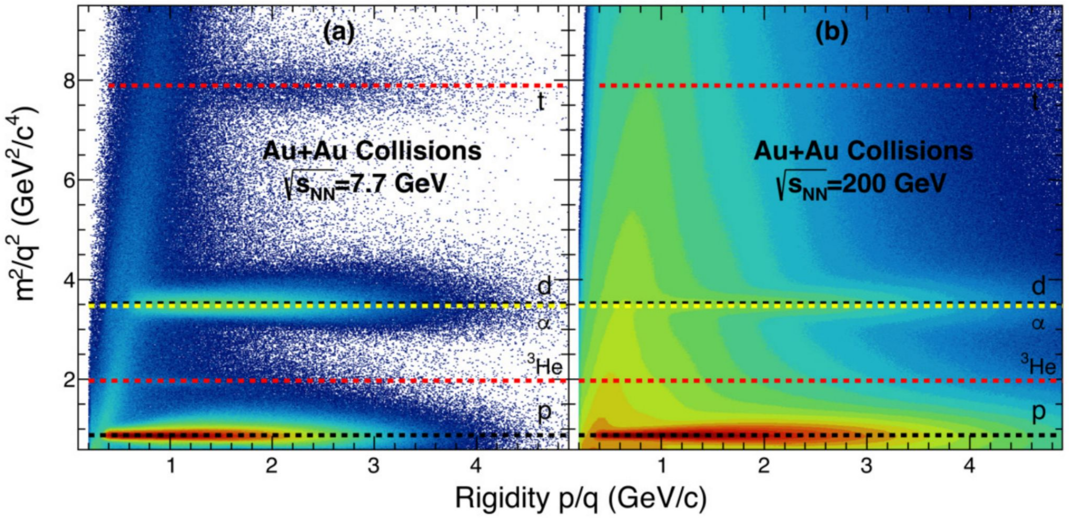
BES-II energies:

$\sqrt{s_{NN}}$ = 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)

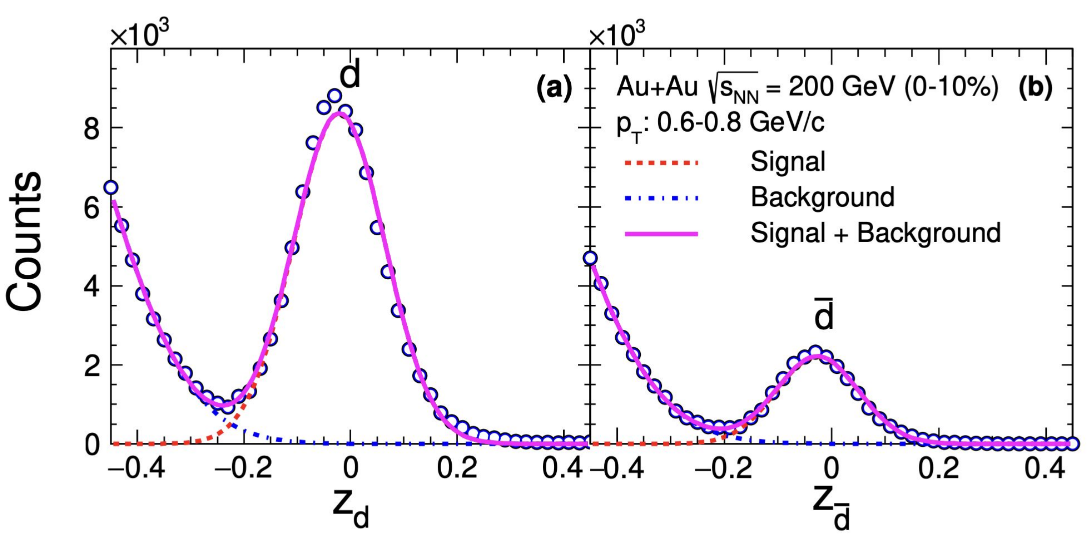
Light nuclei identification

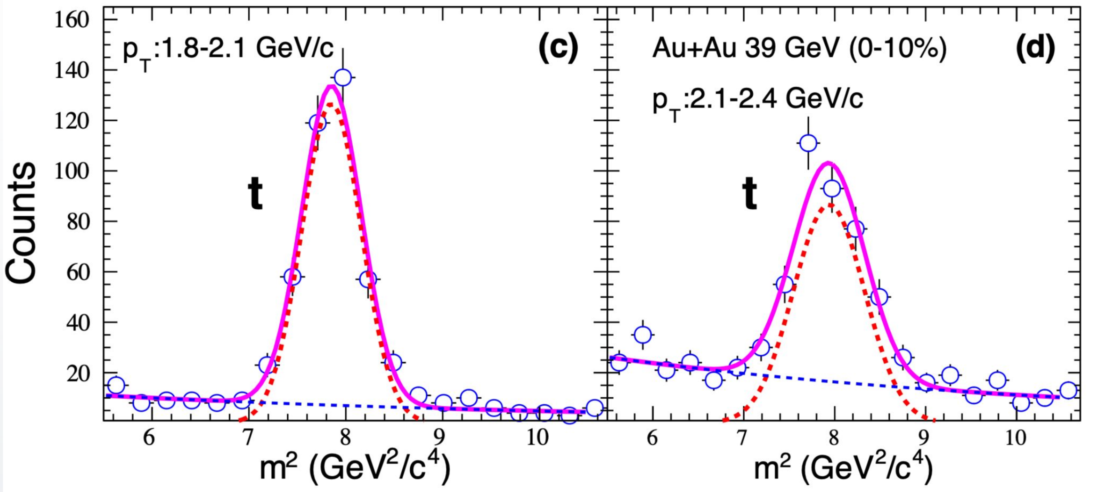




➔ **PID using dE/dx information from TPC at low p_T** $z_i = \ln\left(\frac{\langle dE/dx\rangle_{measured}}{\langle dE/dx\rangle_{theory}}\right)$

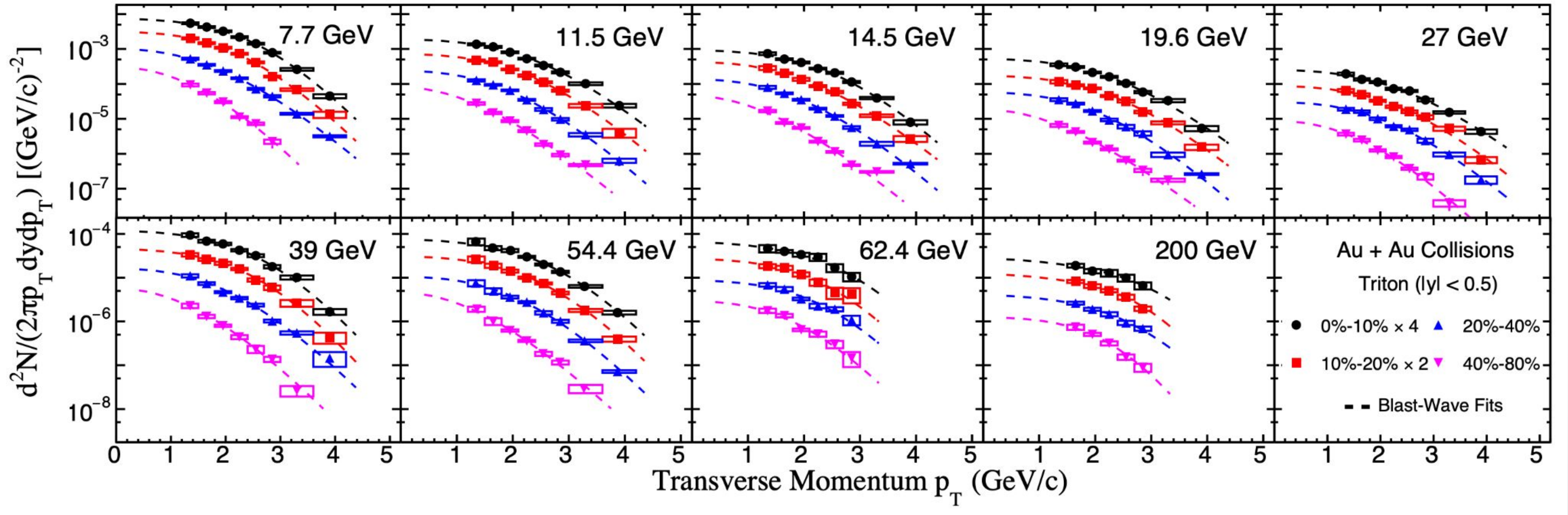
➔ **PID using TOF at intermediate p_T** $m^2 = p^2(1/\beta^2 - 1)$





J. Adam *et al.*, (STAR) PRC 99, 064905 (2019)

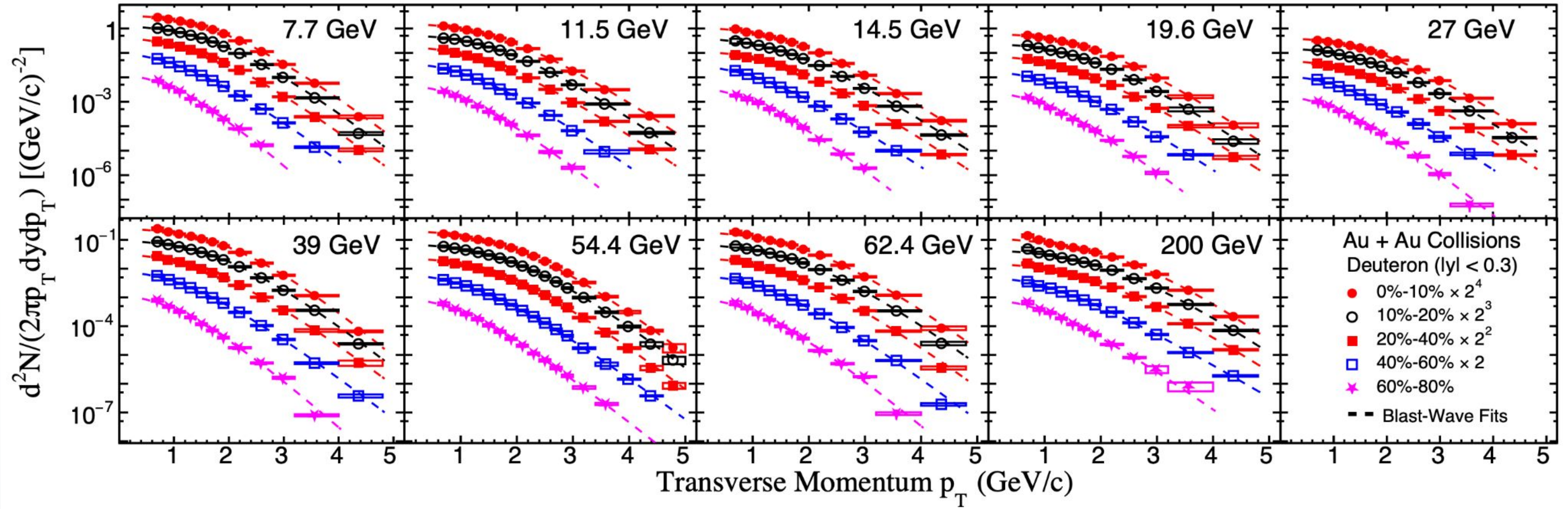
p_T-spectra (tritons)



- ➔ Midrapidity p_T spectra of tritons ($|y|<0.5$) in BES-I energies
- ➔ Dashed lines represent blast wave fits

STAR: arXiv:2209.08058

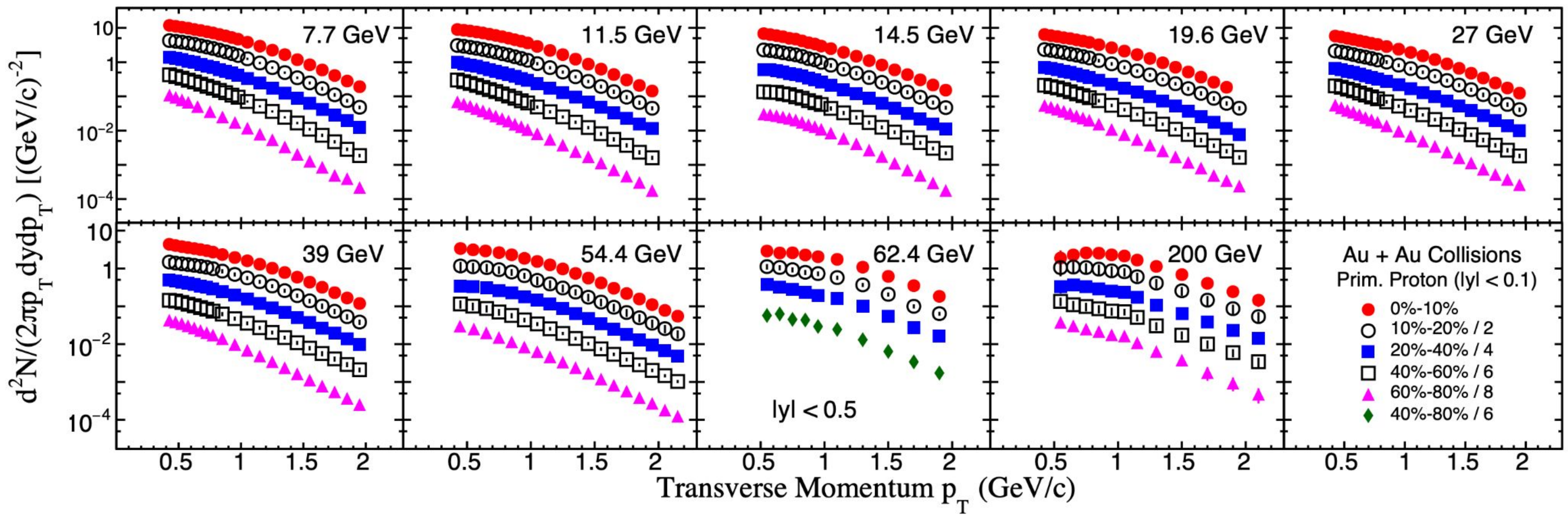
p_T-spectra (deuteron)



- ➔ Midrapidity p_T spectra of deuteron (|y|<0.3) in BES-I energies
- ➔ Dashed lines represent blast wave fits

J. Adam *et al.*, (STAR) PRC 99, 064905 (2019)

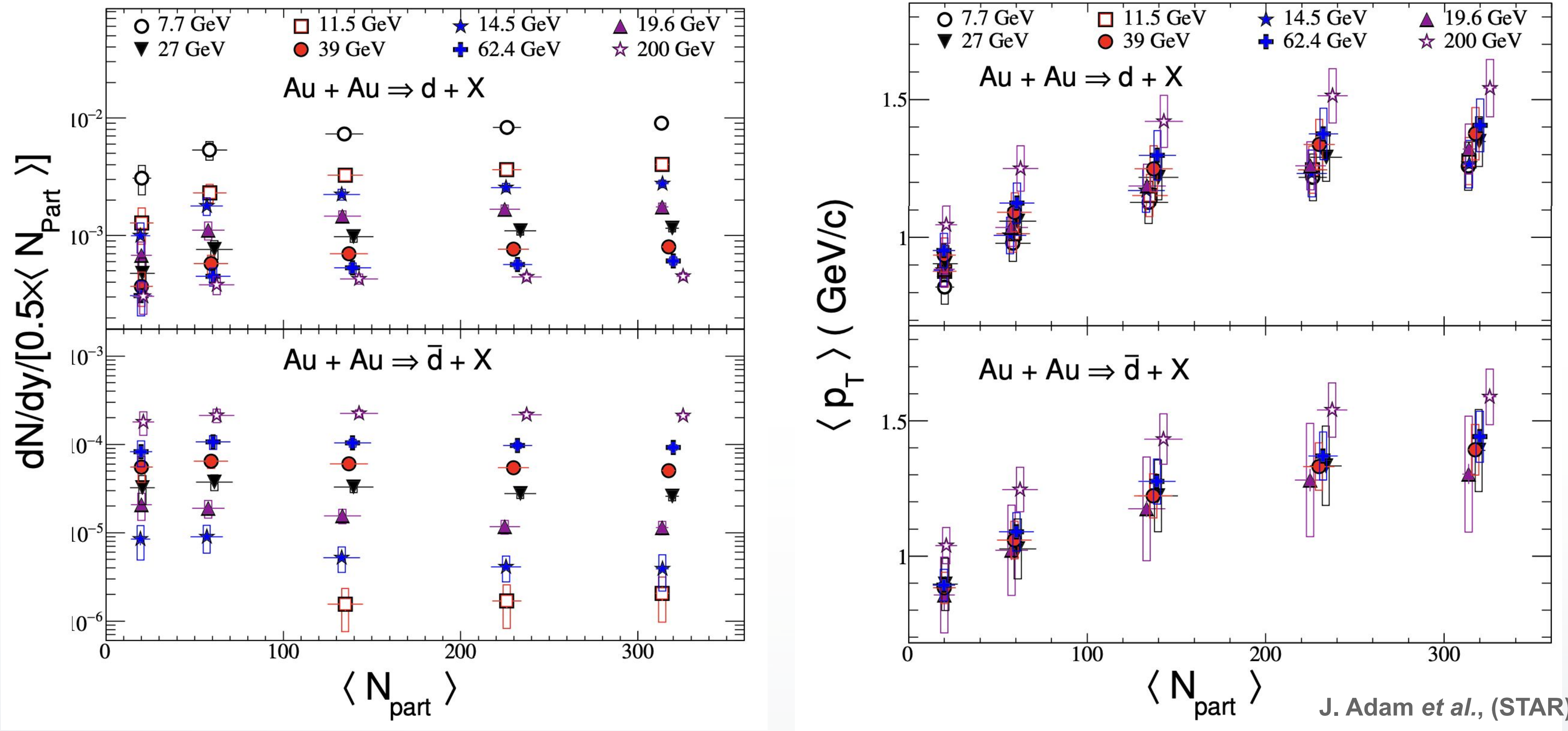
p_T-spectra (primordial protons)



- ➔ **Midrapidity p_T spectra of protons ($|y|<0.1$) in BES-I energies**
- ➔ **Feed-down contribution from weak decays of hyperons have been subtracted using a data-driven method**

STAR: arXiv:2209.08058

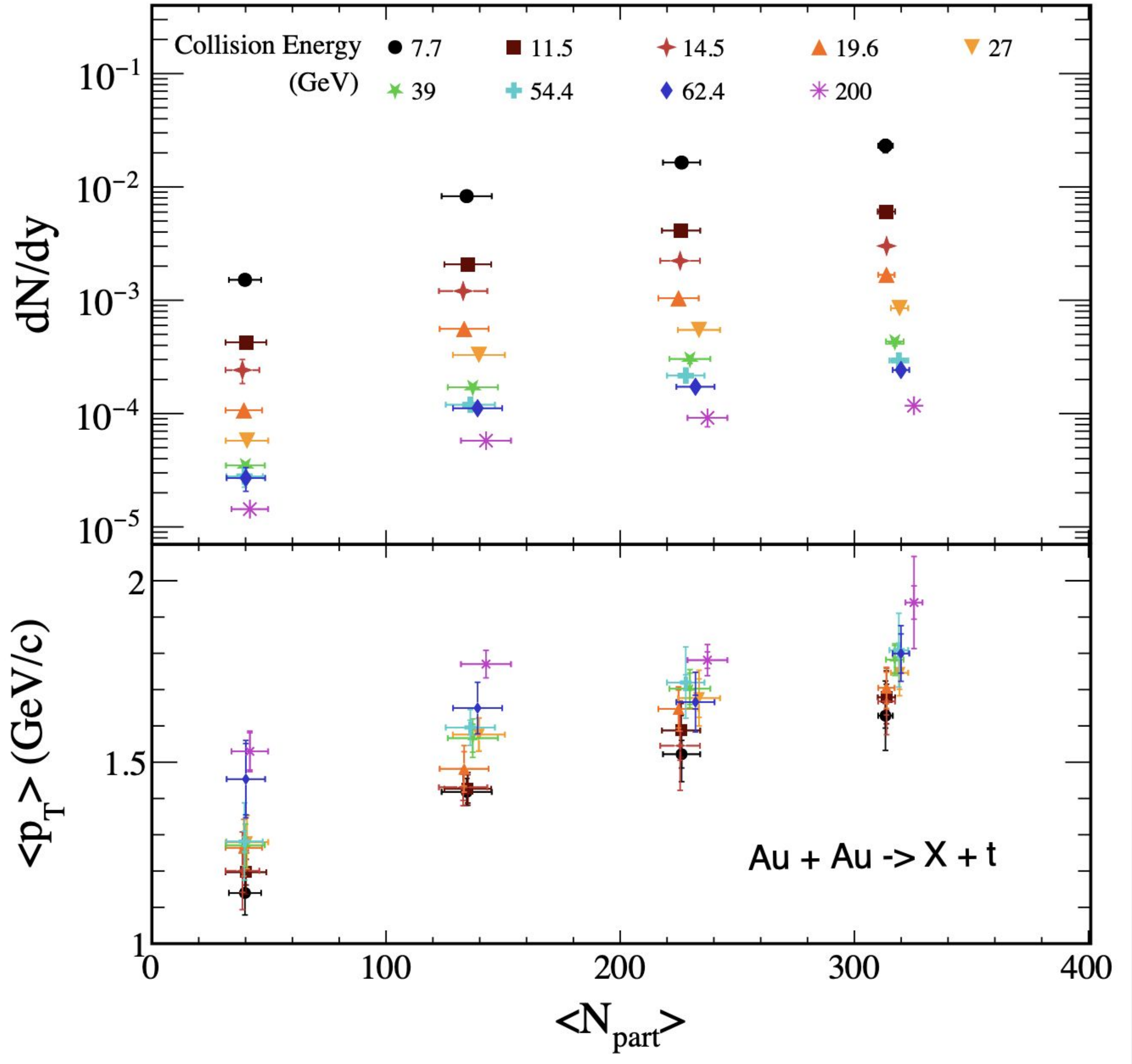
Centrality dependence of *dN/dy* and $<p_T>$



J. Adam *et al.*, (STAR) PRC 99, 064905 (2019)

- ➔ Deuteron yield decreases w/ increasing $\sqrt{s_{NN}}$ → **baryon stopping** plays dominant role in deuteron production
- ➔ Deuteron yield increases w/ increasing centrality → effect of **baryon stopping** is stronger in central collisions
- ➔ Anti-deuteron yield increases w/ increasing $\sqrt{s_{NN}}$ → **pair production** plays the dominant role
- ➔ $<p_T>$ increases w/ increasing energy & centrality → **radial flow** increases with collision energy & centrality

Centrality dependence of *dN/dy* and $<p_T>$

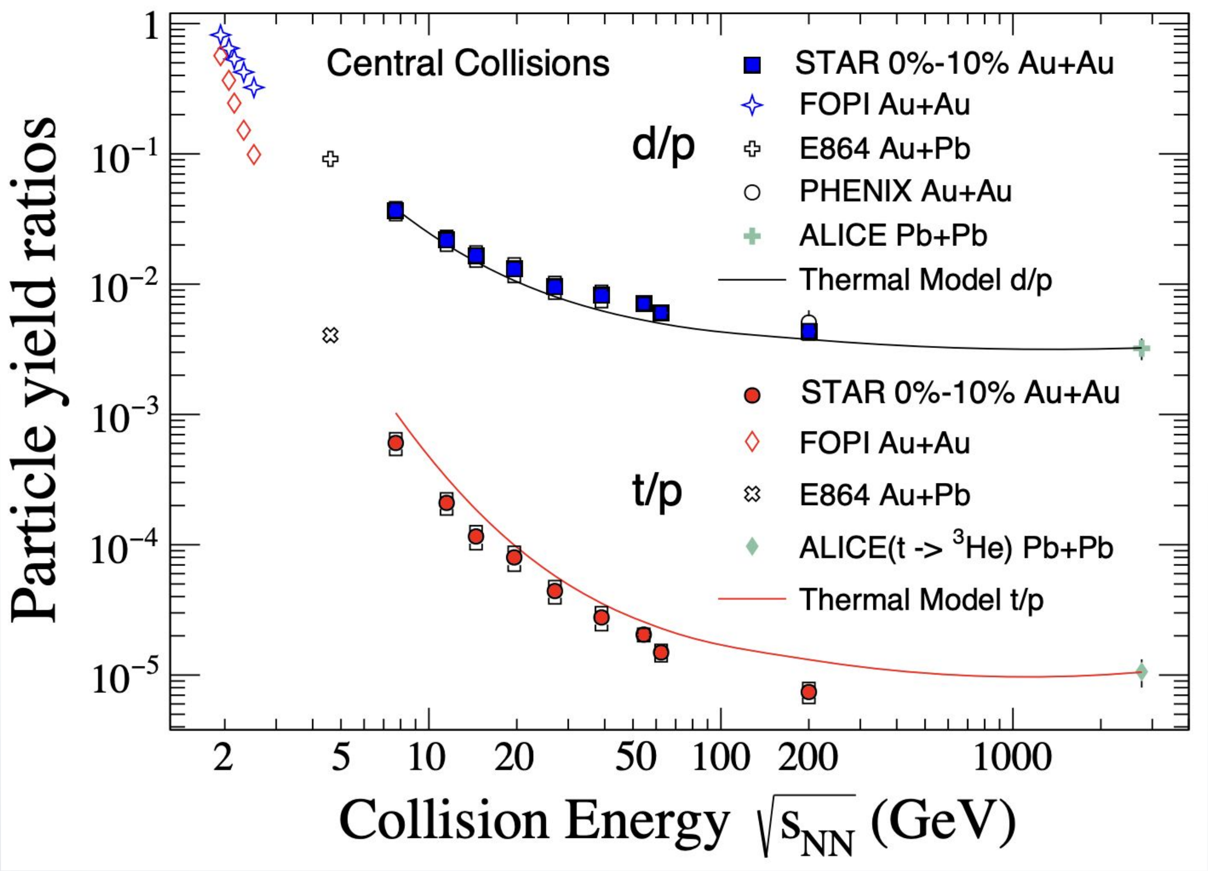


★ Triton dN/dy increases with decreasing energy → **baryon stopping** plays dominant role

★ Triton $<p_T>$ increases with increasing collision centrality and energy

STAR: arXiv:2209.08058

Particle yield ratios

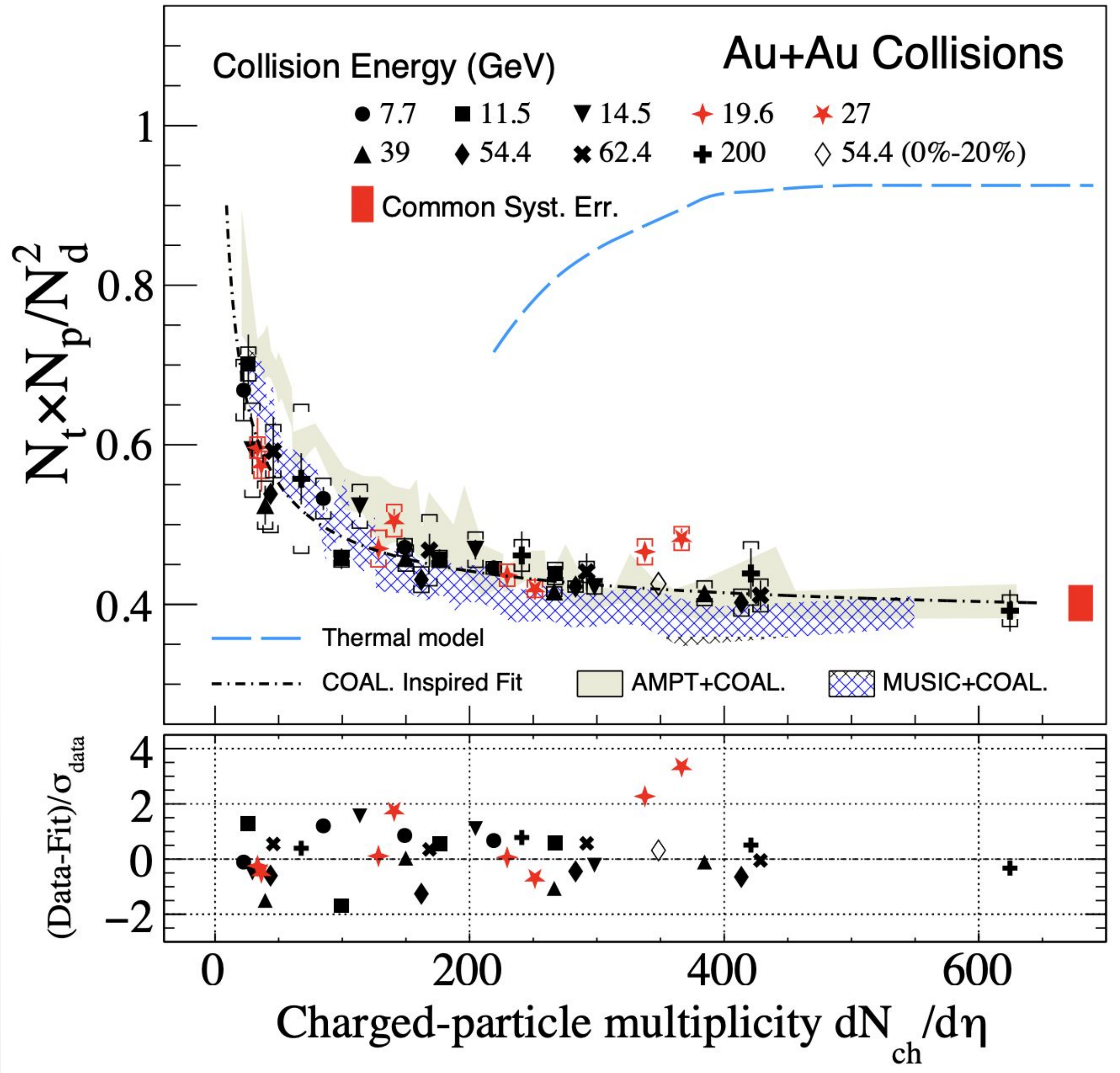


★ N_t/N_p ratios follow the world data trend

★ **Thermal model** seems to overestimate the t/p data

V. Vovchenko, *et al.*, PLB 135746 (2020)
STAR: arXiv:2209.08058
W. Reisdorf *et al.* (FOPI), Nucl. Phys. A 781, 459 (2007)
T. A. Armstrong *et al.* (E864), Phys. Rev. C 61, 064908 (2000)
S. S. Adler *et al.* (PHENIX), Phys. Rev. Lett. 94 , 122302 (2005)
S. S. Adler *et al.* (PHENIX), Phys. Rev. C 69, 034909 (2004)
J. Adam *et al.* (ALICE), Phys. Rev. C 93, 024917 (2016)

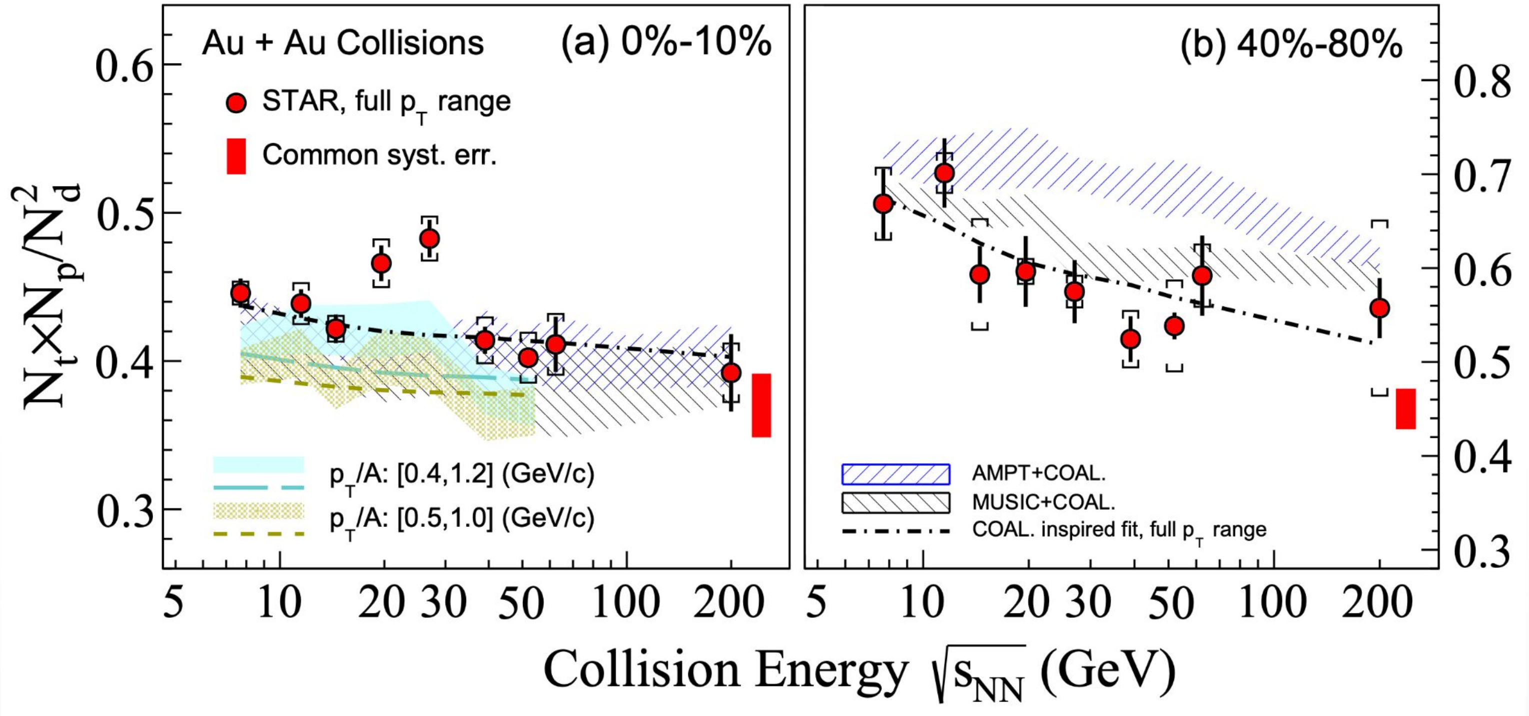
Multiplicity dependence of light nuclei ratio



- ★ Light nuclei ratio decreases with increasing charged particle multiplicity and exhibits a scaling behaviour
- ★ **Coalescence model** seems to describe the data
- ★ **Thermal model** overestimates the data
- ★ The ratios at 19.6 and 27 GeV exhibit an enhancement from coalescence baseline with a combined significance of 4.1σ

STAR: arXiv:2209.08058

Energy dependence of light nuclei ratio



★ **Non-monotonic behaviour is observed around 19.6 and 27 GeV for 0-10% central collisions**

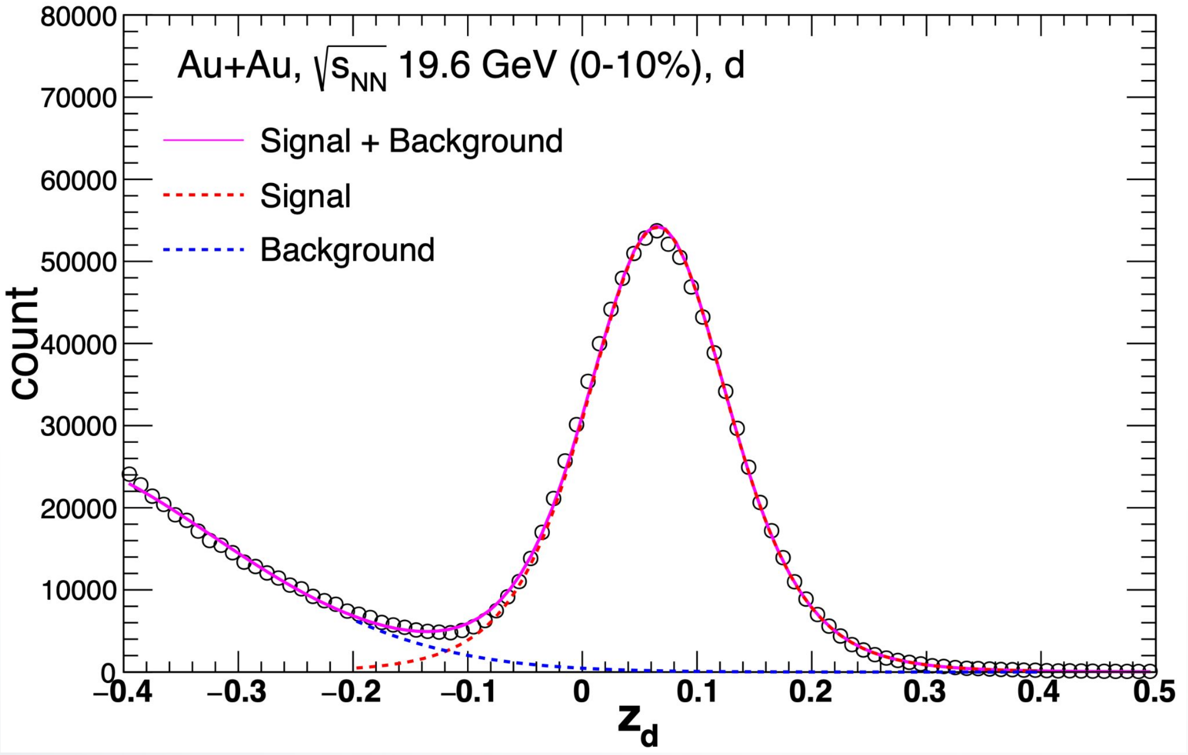
★ **Monotonic behaviour is observed for 40-80% collisions**

★ **The significance of the enhancements decreases with decreasing p_T acceptance in the region of interest**

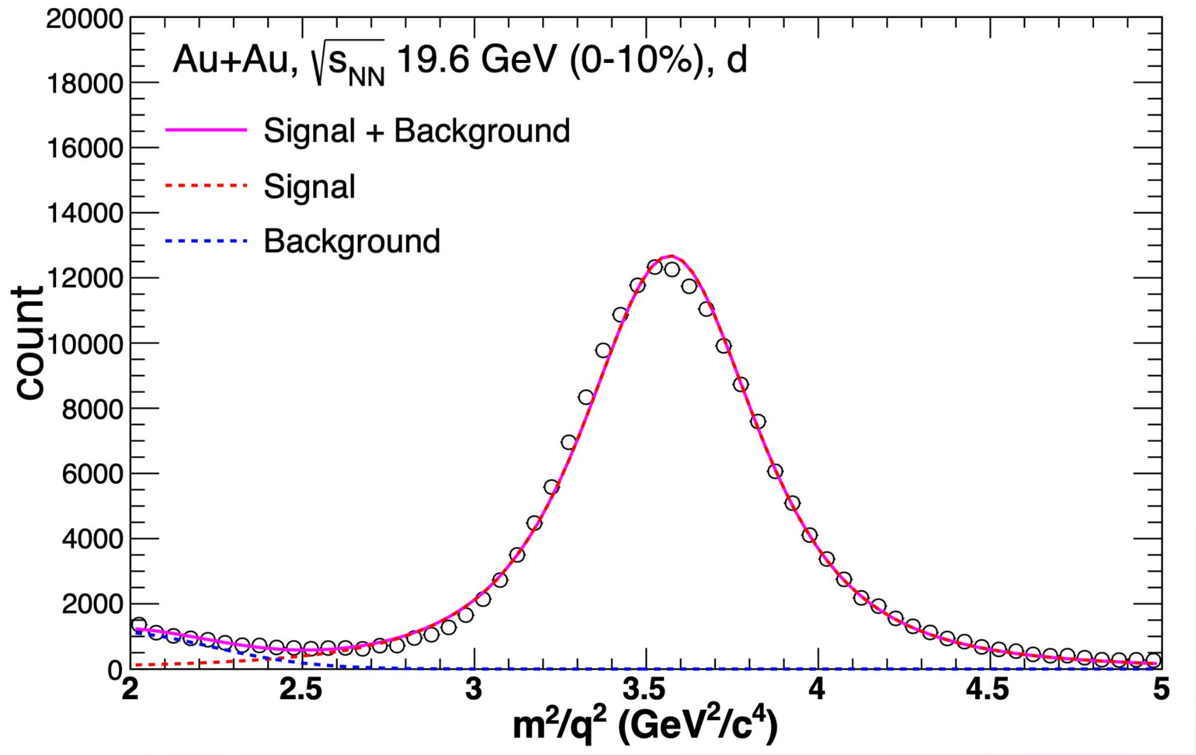
STAR: arXiv:2209.08058

Signal extraction in BES-II energies

$0.6 \leq p_T < 0.8$ (GeV/c)



$2.8 \leq p_T < 3.2$ (GeV/c)



- ★ **Fit function: Student-t (Signal) + Gaussian (Background)**
- ★ **Enhanced statistics and wider detector acceptance in the BES-II program at STAR will allow to measure light nuclei yields with better precision**

Summary and outlook

- ★ p_T-spectra of primordial protons, deuterons and tritons are presented for BES-I energies
- ★ Increase of dN/dy of light nuclei with decreasing collision energy suggests that baryon stopping plays an important role in their production
- ★ Increase of $\langle p_T \rangle$ with collision centrality and energy suggests radial flow gets stronger with increasing centrality and energy
- ★ Light nuclei ratios are consistent with the coalescence model whereas thermal model overpredicts these ratios
- ★ $(N_t \times N_p)/N_d^2$ ratio at 19.6 and 27 GeV exhibit an enhancement from coalescence baseline with a combined significance of 4.1σ
- ★ Non-monotonic behaviour is observed in the energy dependence of the yield ratio $(N_t \times N_p)/N_d^2$ in 0-10% central Au+Au collisions

Outlook

- ★ Stay tuned for more exciting results from BES-II energies

Thank you