Beam energy dependence of d and $\bar{d}$ production in Au + Au collisions at RHIC

Ning Yu (Central China Normal University), *for the STAR Collaboration*

2015 KOBE JAPAN

Abstract

The production of light nuclei with small binding energy such as (anti)deuterons, can be used to study the freeze-out properties and local baryon density in high-energy nuclear collisions. The azimuthal anisotropic results of protons and deuterons have shown that the coalescence is the dominant process for the light nuclei production at later stage of the evolution.

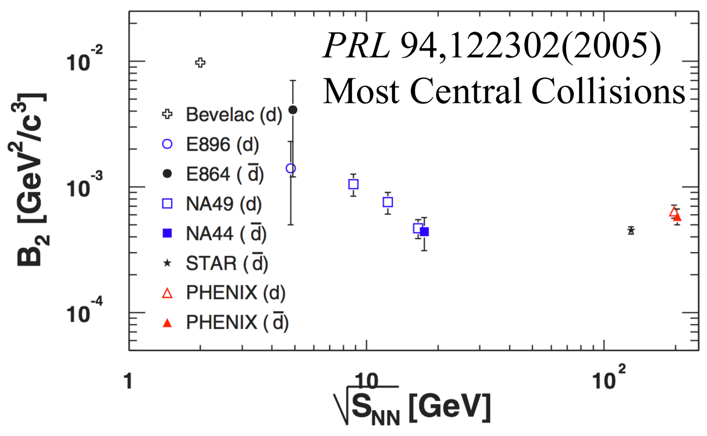
In this talk we present a systematic study of colliding energy, centrality, and transverse momentum dependence of mid-rapidity deuteron and anti-deuteron production, measured by the STAR experiment, from Au + Au collisions at RHIC at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, and 200 GeV. Deuterons, 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 $\bar{d}$ (ε = 2.2 MeV), are formed through final-state coalescence.

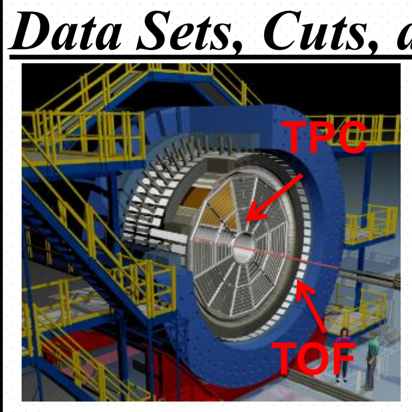
$$E_A\frac{d^3N_A}{d^3p_A} = B_A\left(\frac{d^3N_p}{d^3p_p}\right)^Z\left(\frac{d^3N_n}{d^3p_n}\right)^{A-Z} \approx B_A\left(\frac{d^3N_p}{d^3p_p}\right)^A$$

- The coalescence parameter B_A reflects the local nucleon density.
- In thermal mode, $B_A \propto V_f^{1-A}$, V_f is freeze-out volume. *Phys. Reps.* **131,223(1986)**
- The production of light nuclei provides a tool to measure the freeze-out properties.



- Is there any structure in energy dependence of B_2 from high energy to low energy?
- Is there any centrality dependence of B_2?
- Is there any difference between $B_2(d)$ and $B_2(\bar{d})$?

Data Sets, Cuts, and Pariticle Identification



$\sqrt{s_{NN}}$ (GeV)	N_{events}
7.7	4M
11.5	11M
14.5	27M
19.6	40M
27	71M
39	133M
62.4	67M
200	481M

Event Cuts

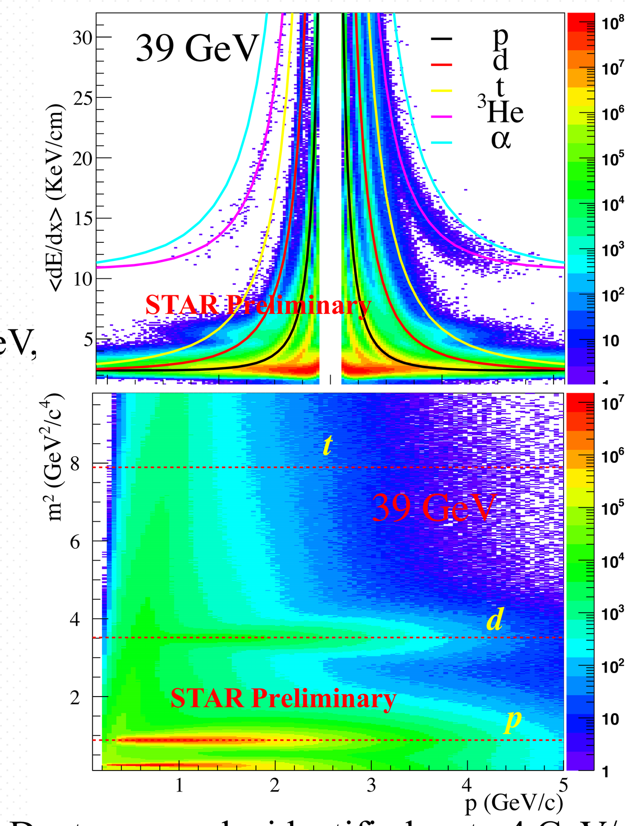
$|V_z| < 70$ cm for 7.7, 14.5, 19.6 GeV,
< 50 cm for 11.5 GeV,
< 40 cm for 39, 62.4 GeV,
< 30 cm for 200 GeV;
$|V_r - (0\mathrm{cm}, -0.89\mathrm{cm})| < 1$ cm for 14.5 GeV,
$|V_r| < 2$ cm otherwise.

Track Cuts

$p_T > 0.6$ GeV/c
$N_{HitFits} > 25$,
$N_{HitDedx} > 15$,
DCA < 1 cm
$|y| < 0.3$

Centrality

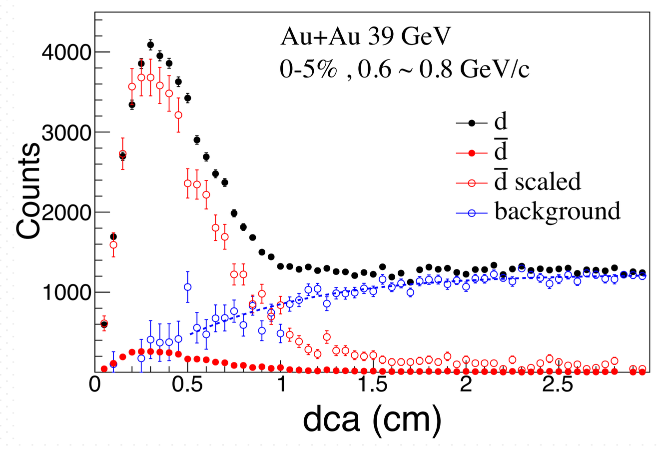
Multiplicity with $|\eta| < 0.5$



Deuteron can be identified up to 4 GeV/c

Detector Corrections

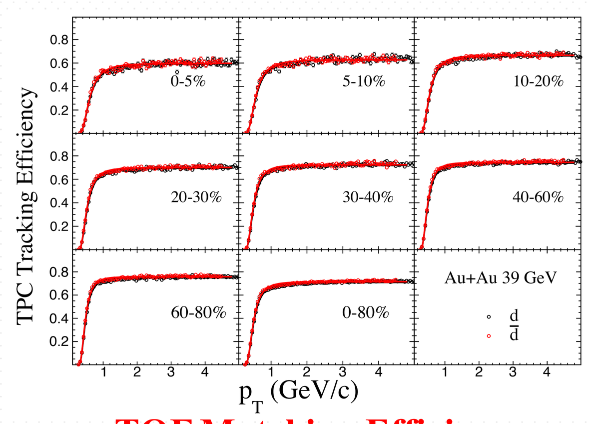
- Secondary particle contamination from beam pipe. This effect will be vanished at high p_T. It is assumed d and $\bar{d}$ have similar DCA distribution. The contamination for d can be extracted from the difference of these two distributions.



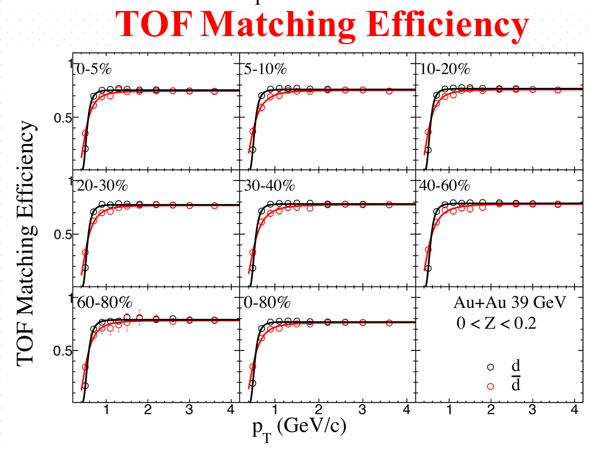
$$d(\mathrm{DCA}) = A \cdot \bar{d}(\mathrm{DCA}) + d_{\mathrm{bkgd}}(\mathrm{DCA})$$

$$d_{\mathrm{bkgd}}(\mathrm{DCA}) = B \cdot (1 - \exp(\mathrm{DCA}/\mathrm{DCA}_0))^C$$

TPC Tracking Efficiency and Acceptance

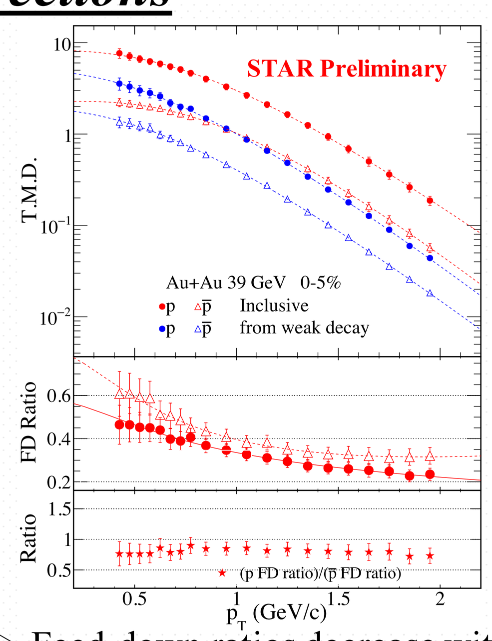


TOF Matching Efficiency



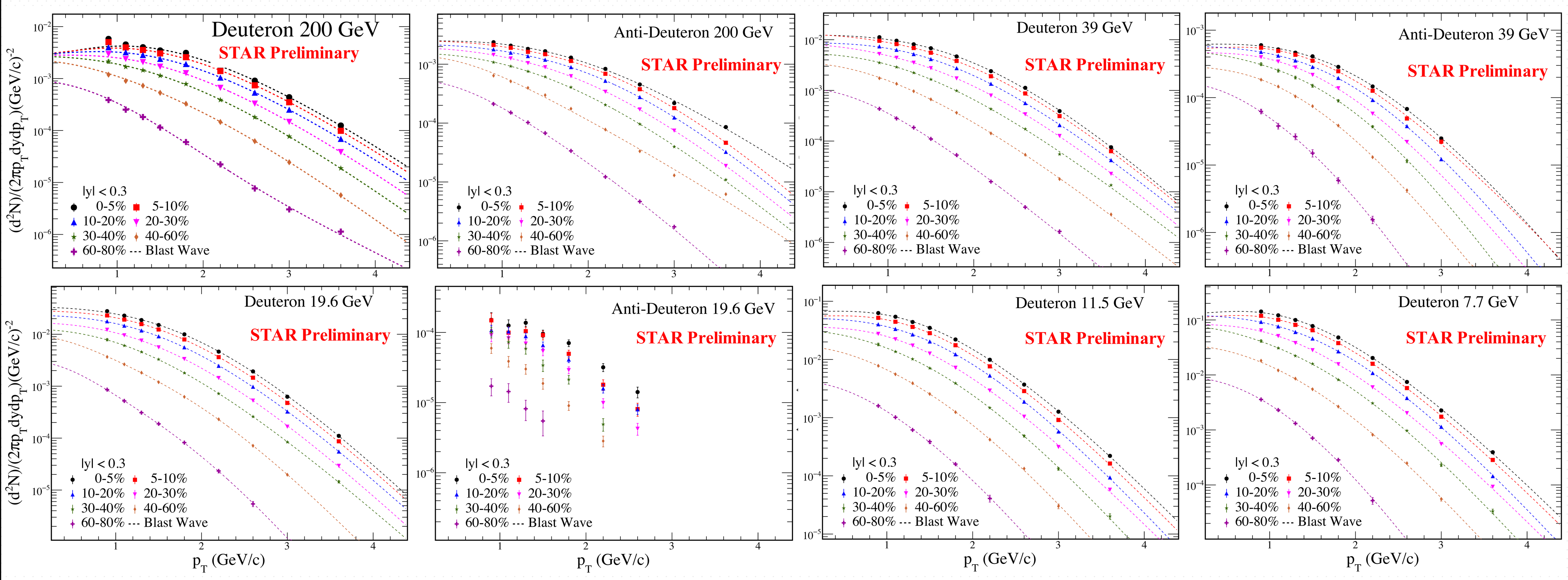
Proton Feed-down Corrections

- 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 Λ, Ξ^-, Ω^- and their anti-particles can be measured. For Ξ^0, it is assumed the spectra of Ξ^- and Ξ^0 are the same. For these particles, corrected spectra and the embedding detector simulation are used to get the weak decay protons.
- For Σ^+, it is assumed the ratio $\Sigma^+/\Lambda \approx 0.27$ and p_T independent.

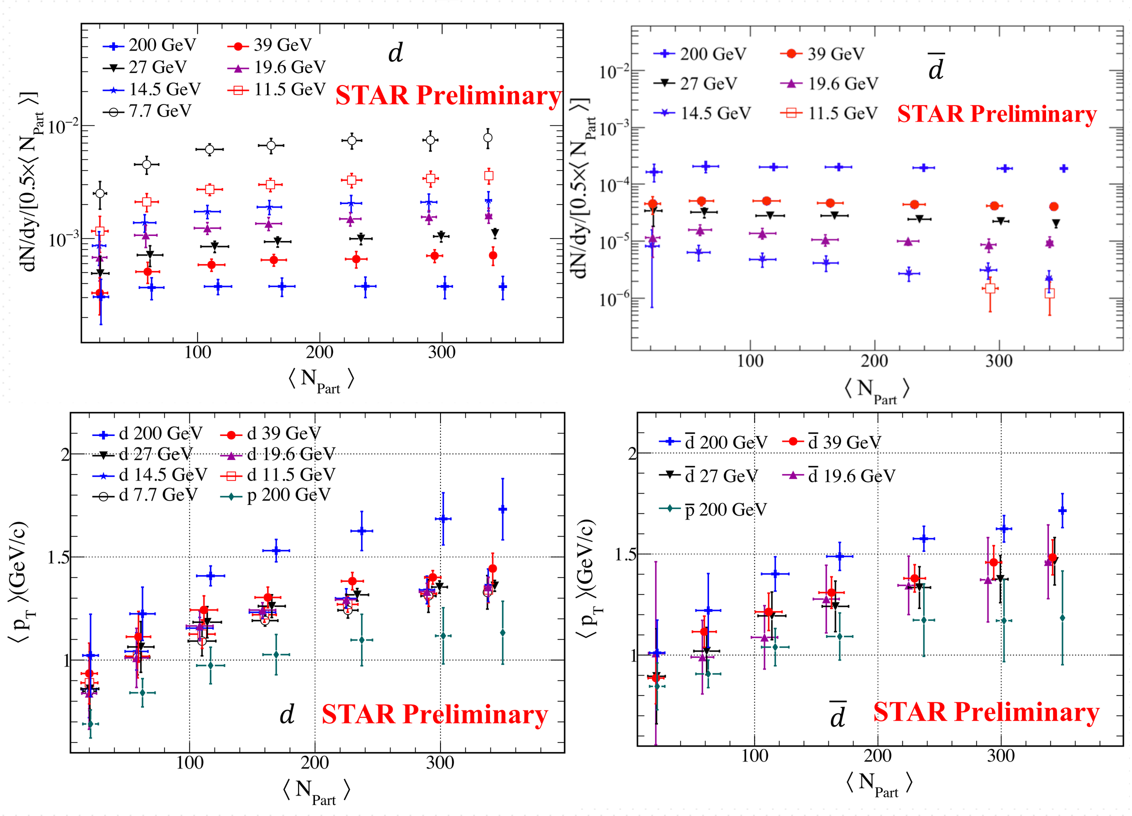


- Feed-down ratios decrease with increasing p_T and saturate at high p_T.
- Feed-down ratios for $\bar{p}$ are larger than p.

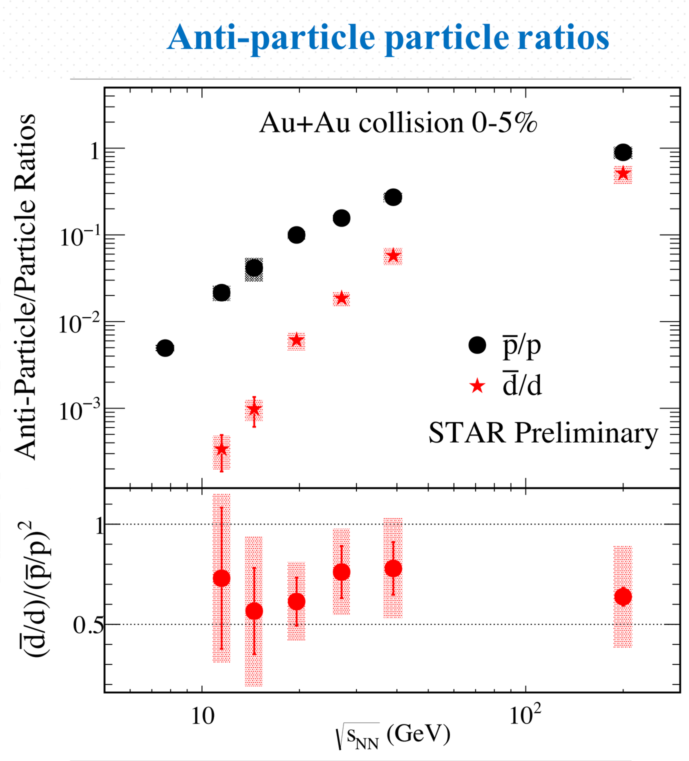
Deuteron Transverse Momentum Distribution



dN/dy and Mean p_T

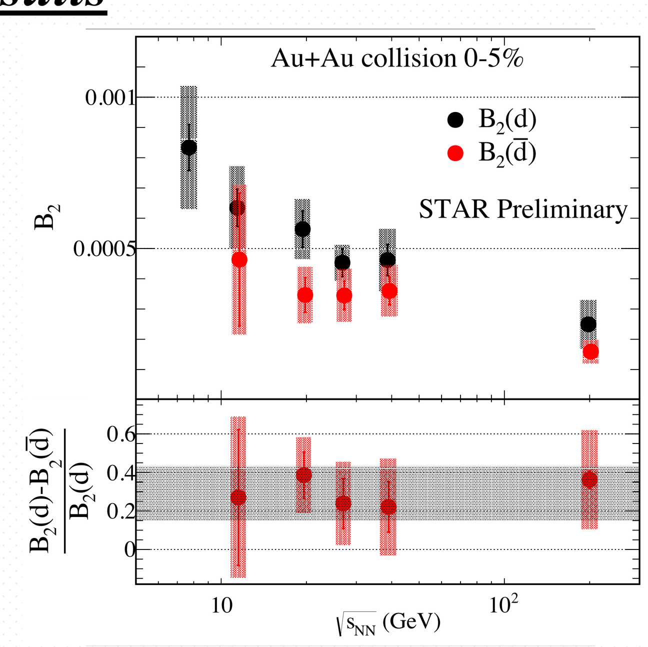


Anti-particle particle ratios



- Yield of d is smaller at higher energy, which suggests baryon density at mid-rapidity decreases with increasing energy.
- Yield of $\bar{d}$ increases with increasing energy.
- N_{part} scaled dN/dy for $\bar{d}$ shows weak centrality dependence, for d increase slightly from peripheral to central collision.
- $\langle p_T \rangle$ increase from peripheral to central collision.
- $\langle p_T \rangle$ show weak energy dependence.
- The $\langle p_T \rangle$ difference between d and $\bar{d}$ are small.
- $\bar{d}/d$ and $\bar{p}/p$ increase with increasing energy. $\bar{d}/d$ and $(\bar{p}/p)^2$ are in the same order of magnitude.

Results



- Because B_2 is not p_T independent, we study the energy dependent 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

$$\frac{B_2(d) - B_2(\bar{d})}{B_2(d)} \approx 0.29 \pm 0.14$$

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.

Summary

- We report STAR new results on d and $\bar{d}$ productions in Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, and 200 GeV.
- Both the N_{part} scaled yields (dN/dy) and mean transverse momenta ($\langle p_T \rangle$) of d and $\bar{d}$ 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: $(B_2(d) - B_2(\bar{d}))/B_2(d)$, show little energy dependence, the averaged valued is 0.29 ± 0.14, 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.

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