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Collision system size dependence of light (anti-)nuclei and (anti-)hypertriton production in high energy nuclear collisions

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on behalf of

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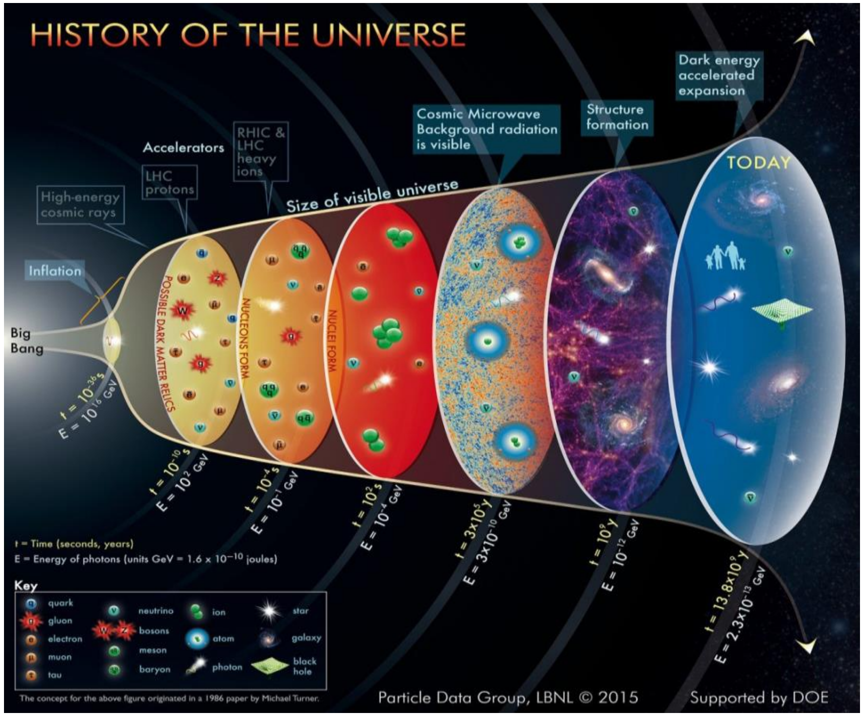
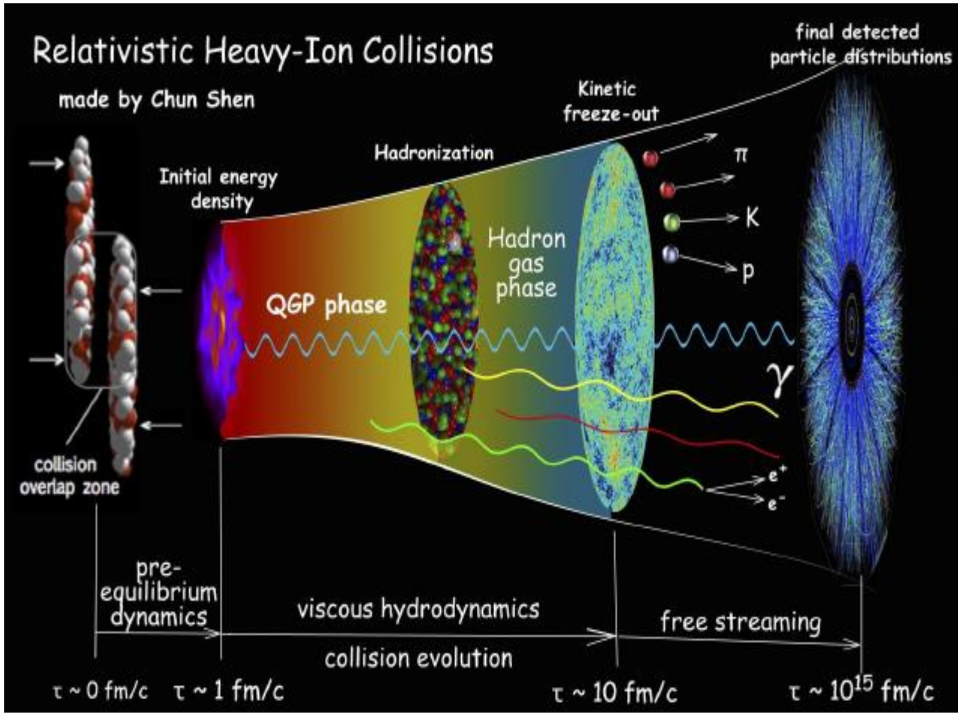
Outline

- Introduction
- PACIAE model and DCPC model
- Results on (anti-)nuclei and (anti-)hypertriton production
- Summary and Outlook

Big Bang and Little Bang

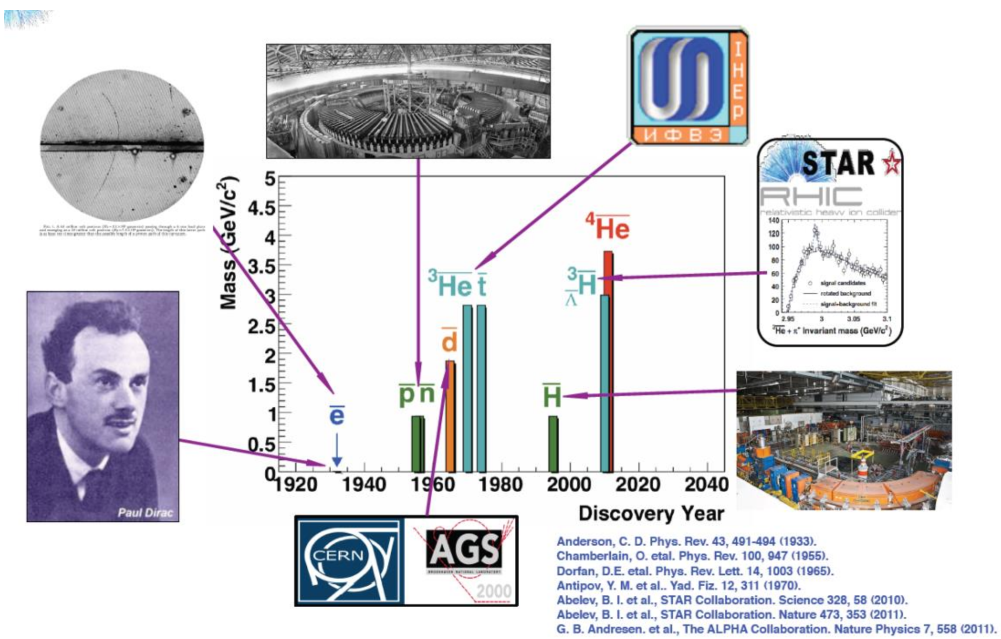
High-energy heavy-ion collisions（the Little Bang）at RHIC & LHC can create a circumstance similar to that of the Universe microseconds after the Big Bang.

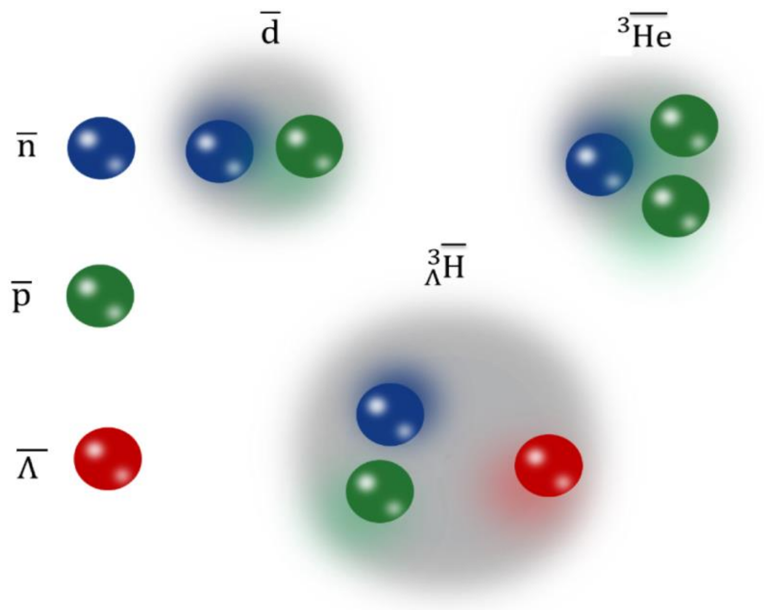




Antimatter factories

High-energy heavy-ion collisions provide an excellent chance for the discovery and study of light antinuclei and antihypernuclei.

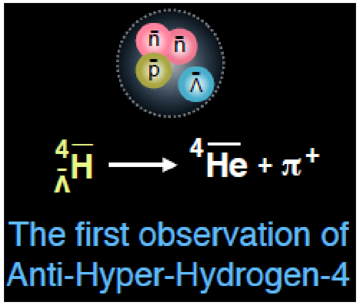




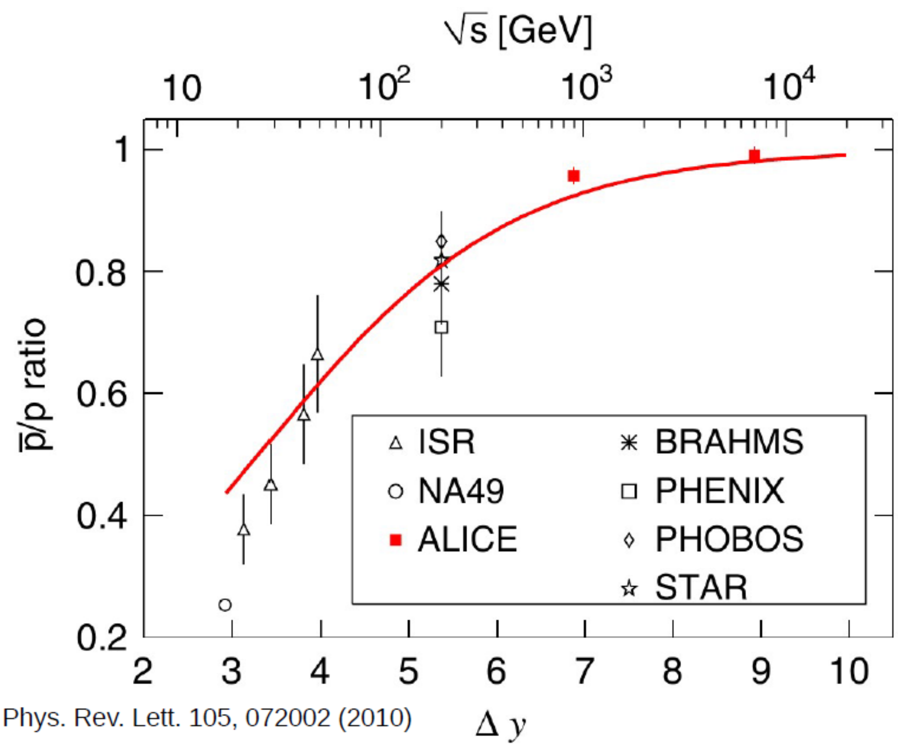
Phys. Rep. 760 (2018) 1

The first observation of Anti-Hyper-Hydrogen-4 by STAR

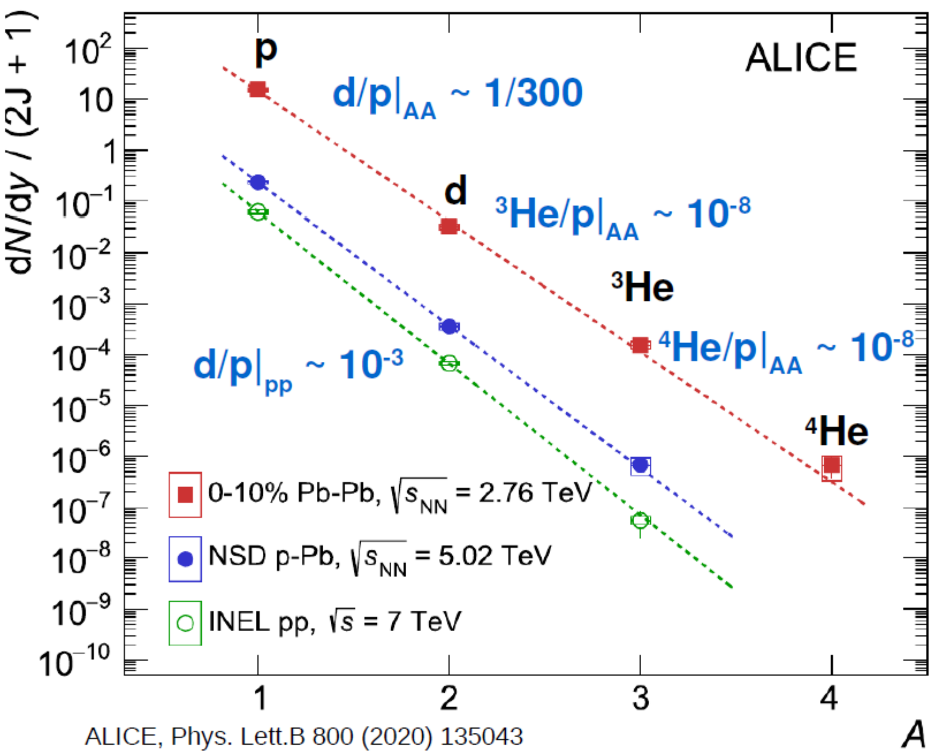
Quark Matter 2022



Research Status of Light (Anti-)cluster



Phys. Rev. Lett. 105, 072002 (2010)



ALICE, Phys. Lett.B 800 (2020) 135043

Antimatter-to-matter ratio at LHC ~ 1 independently on the collision system

Production rates strongly depend on the mass number and collision system

Production Mechanisms of Light Cluster

Their detailed production mechanism is, however, not fully understood.
NPA 987 (2019) 144

Statistical thermal model: Nature 561 (7723) (2018) 321; PLB 809 (2020) 135746

- Thermodynamically equilibrium system;
- Chemical freeze-out tempecture T_{ch} and baryo-chemical potential μ_{B}.

$$N_A \approx g_A V (2\pi m_A T)^{3/2} e^{(A\mu_B - m_A)/T}$$

Transport model: PRC 99 (2019) 044907; arXiv:2106.12742

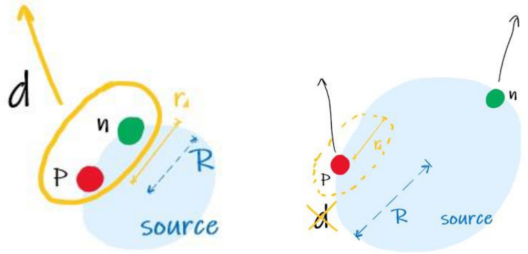
- Light cluster produced on hyper-surface, then break up and re-form during the chemical freeze-out and the kinetic freeze-out.

$$\pi NN \Leftrightarrow \pi d, NNN \Leftrightarrow Nd, NN \Leftrightarrow \pi d.$$

Coalescence model: PLB 808 (2020) 135668; PRC 102 (2020) 044912

- The process occure at kinetic freeze-out and instantaneously;
- Proximity of constituent nucleons in momentum and(or) coordinate space.

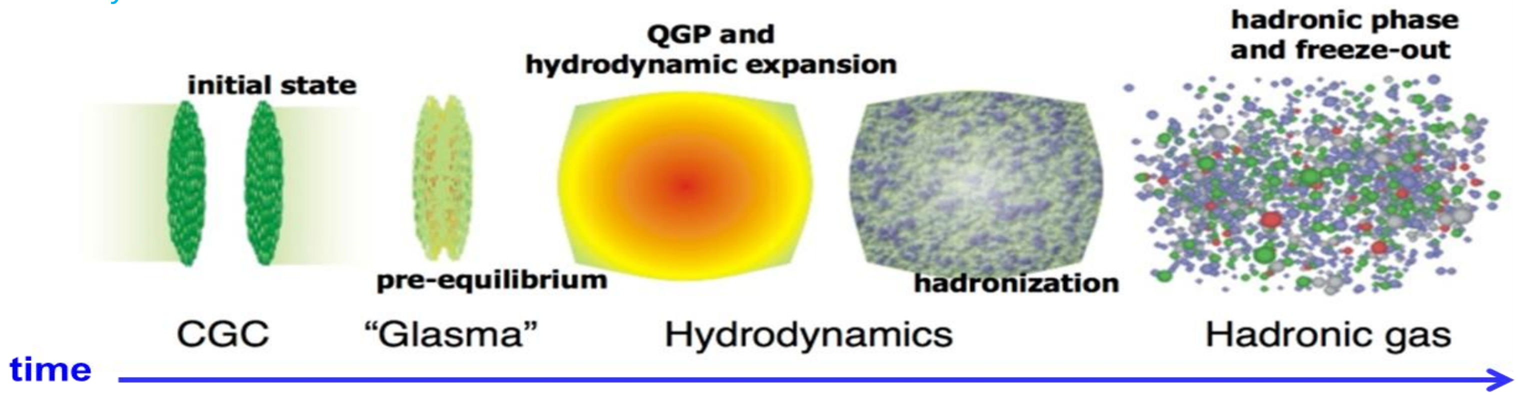
$$E_A \frac{dN_A}{d^3p_A} = B_A (E_p \frac{dN_p}{d^3p_p})^Z (E_n \frac{dN_n}{d^3p_n})^N$$



PACIAE model

Parton and hadron cascade model is based on PYTHIA 6.4 model, is a Monte-Carlo event generator in high energy collisions.

made by S. A. Bass



1. The parton initial state is obtained.
2. The parton rescattering is proceeded until partonic freeze-out.
3. The hadronization is followed.
4. The hadronic rescattering is proceeded until hadronic freeze-out.

Comput. Phys. Commun. 183 (2012) 333; 184(2013)1476; 193(2015)89; 224(2018)417; 274 (2022) 108289

DCPC model

Dynamically constrained phase-space coalescence model, is developed to estimate light nuclei production in high energy collisions.

As the uncertainty principle

$$\Delta \vec{q} \Delta \vec{p} \approx h^3$$

we can estimate the yield of a single particle by

$$Y_1 = \int_{H \le E} \frac{d\vec{q}d\vec{p}}{h^3}.$$

Similarly, for the yield of N particles cluster

$$Y_N = \int \ldots \int_{H \le E} \frac{d\vec{q_1}d\vec{p_1}\ldots d\vec{q_N}d\vec{p_N}}{h^{3N}}.$$

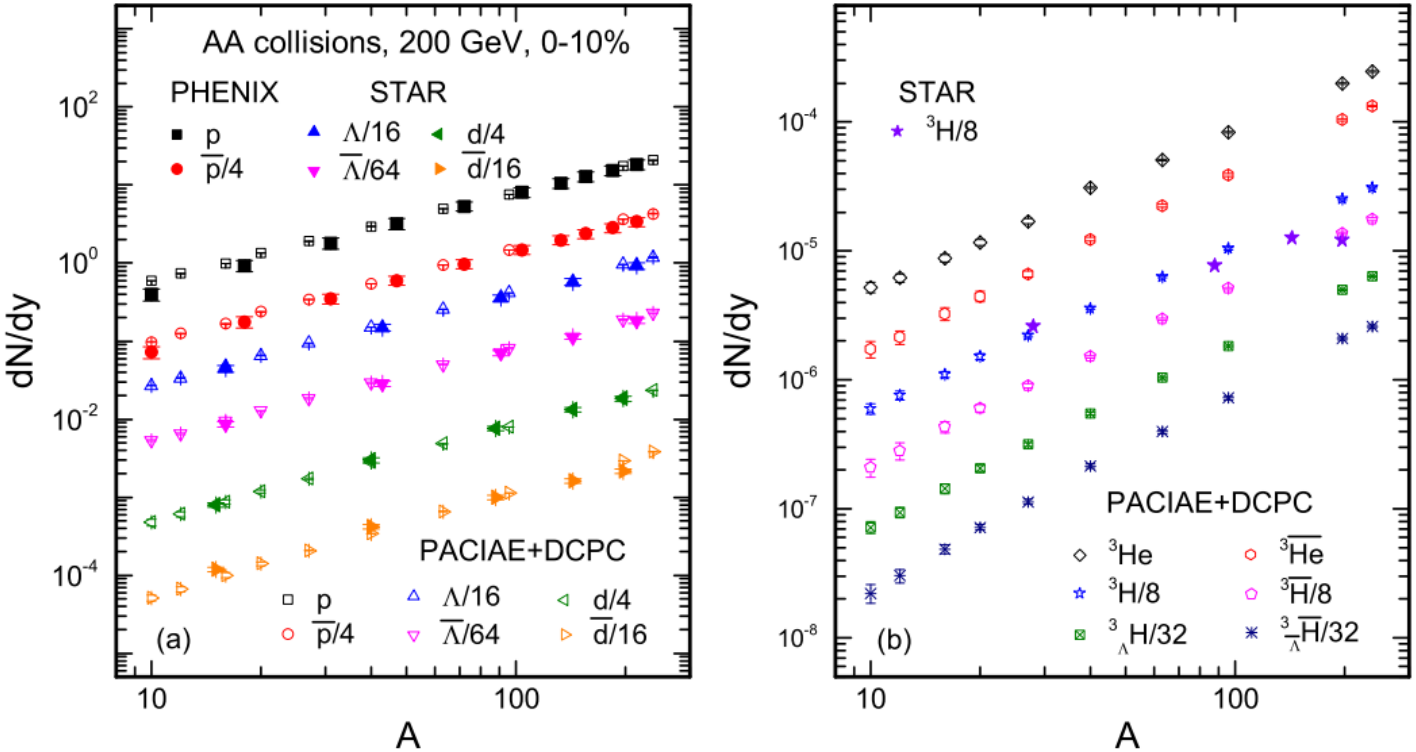
Equation must satisfy these constraint conditions:

$$\begin{cases} m_0 \le m_{inv} \le m_0 + \Delta m; \\ q_{ij} \le D_0, (i \ne j; i, j = 1,2\ldots N); \\ m_{inv} = \left[\left(\sum_{i=1}^{N} E_i \right)^2 - \left(\sum_{i=1}^{N} \vec{p}_i \right)^2 \right]^{1/2}. \end{cases}$$

*PRC **85** (2012) 024907; 99(2019)034904; PRC 103 (2021) 014906*

Yields of Light Cluster

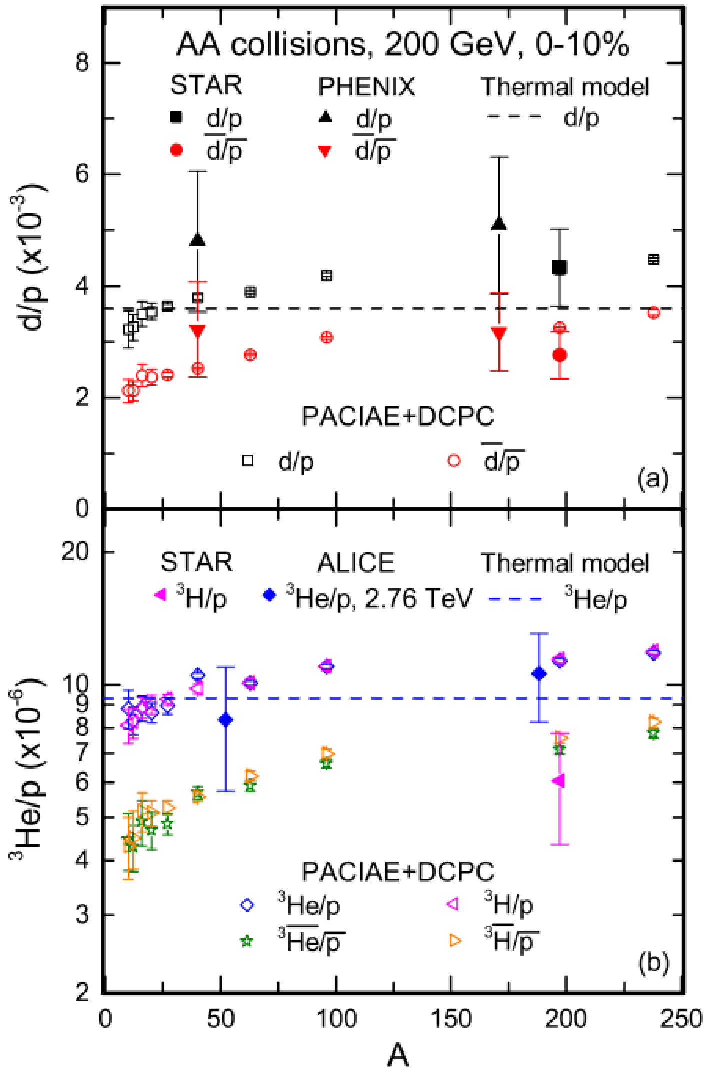
Nuclear system size scans: B+B(Boron), C+C, O+O, Ne+Ne, Al+Al, Ca+Ca, Cu+Cu, Ru+Ru, Au+Au, U+U(Uranium) collisions at RHIC energy.



The yield for each particle species appears to increase linearly with atomic mass number A.

Z.L. She et al., Eur. Phys. J. A 58, 15 (2022).

Yield Ratios of Light Nuclei



A. Andronic et al, Phys. Lett. B 697, 203 (2011)

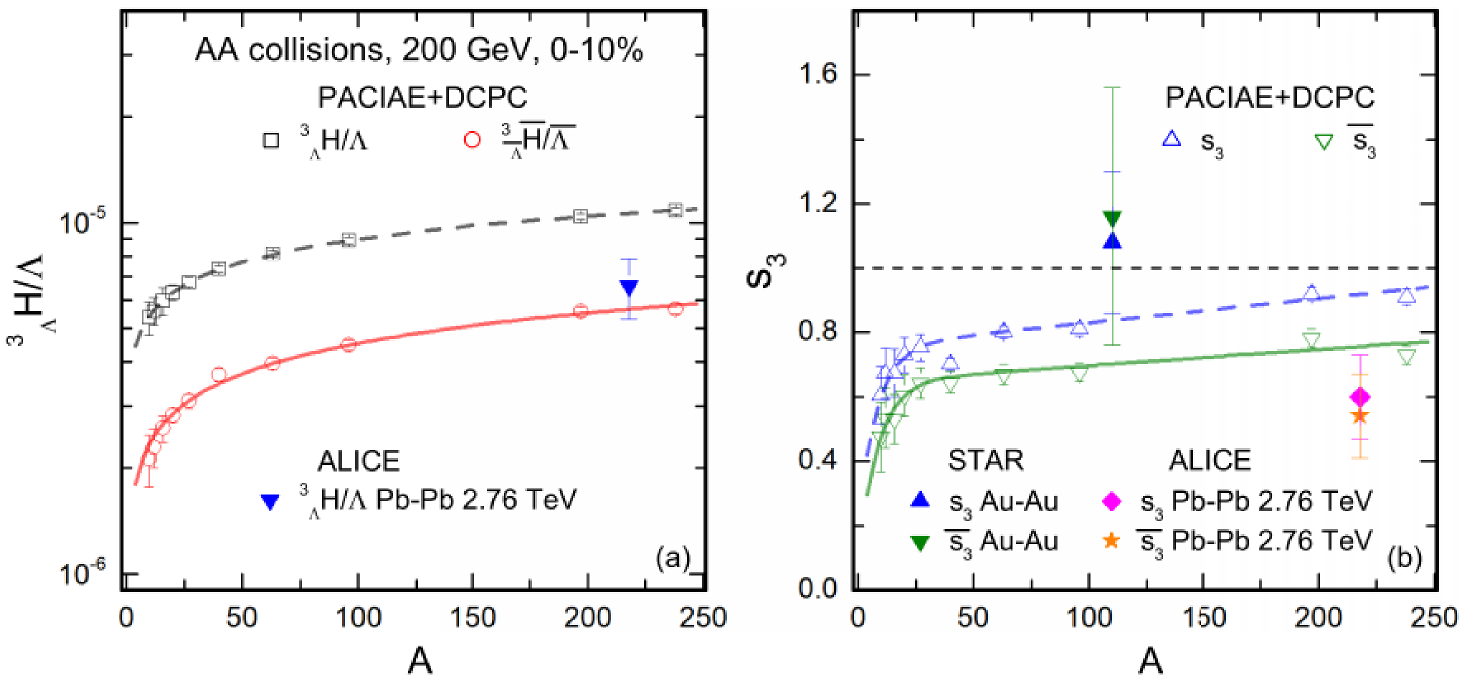
Three-body nuclei is more sensitive than two-body nuclei to the spatial distribution of nucleons in the emission source.

The significant difference between nuclei and antipartners are due to non-zero baryo-chemical potential at RHIC energy.

Z.L. She et al., Eur. Phys. J. A 58, 15 (2022).

Yield Ratios of Hypertriton

$$s_3 = ({}^3_\Lambda\mathrm{H} \times \mathrm{p})/({}^3\mathrm{He} \times \Lambda)$$



The suppression of (anti-)hypertriton is more significant than three-body (anti-)nuclei.

The non-smooth A-dependence may be mainly related to a size effect of source.

Z.L. She et al., Eur. Phys. J. A 58, 15 (2022).

Summary& Outlook

The Collision system size dependence of light (anti-)nuclei and (anti-)hypertriton production is calculated in high-energy nuclear collisions at RHIC energy, based on PACIAE + DCPC models.

1, The yield of each particle species appears to increase linearly with atomic mass number A.

2, Three-body nuclei is more sensitive than two-body nuclei to the spatial distribution of nucleons in the emission source.

3, The non-smooth A-dependence of (anti)hypercluster-to-(anti)hyperon may be mainly related to a size effect.

4, The present study can provide a reference for a upcoming collision system scan program at RHIC.

Thank you for your attention!