Light Nuclei Production in Relativistic Heavy-Ion Collisions and QCD Critical Endpoint

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- QCD Critical Endpoint (CEP)
- Baryon density fluctuation and coalescence production of light nuclei in HIC
- $O = \frac{N_{^3\mathrm{H}} N_p}{N_d^2}$ as a probe of QCD CEP
- Summary and Outlook

Main References:

[1] Kai-Jia Sun (孙开佳) & LWC, PRC95, 044905 (2017) [arXiv:1701.01935]

[2] Kai-Jia Sun (孙开佳), LWC, C. M. Ko, and Z. Xu, arXiv:1702.07620

Workshop on AMPT for Relativistic Heavy Ion Collisions (AMPT2017), Sichuan University, Chengdu, China, July 24-27, 2017

Outline

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- Baryon density fluctuation and coalescence production of light nuclei in HIC
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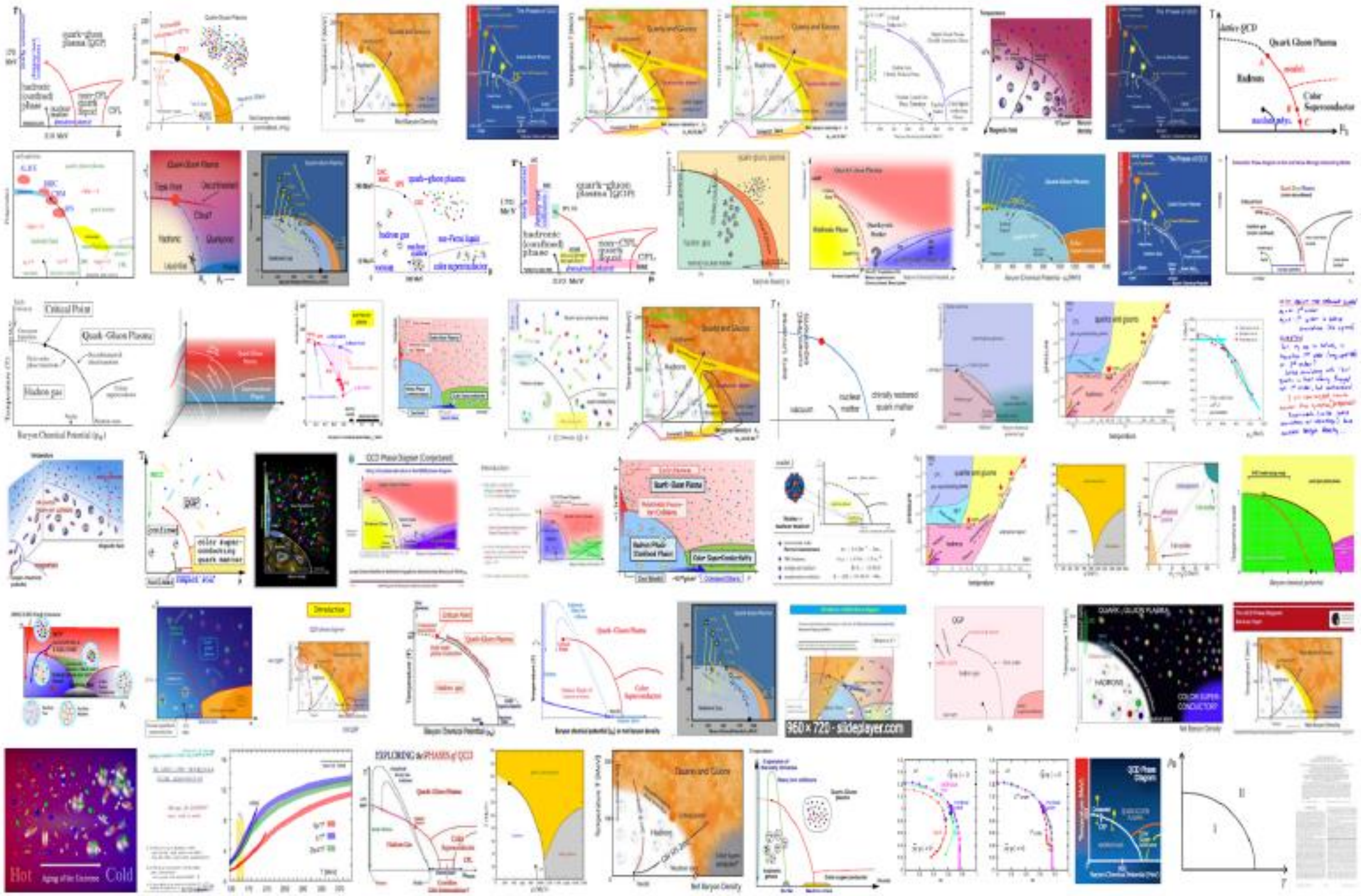
QCD Phase Diagram

A selection of representations of the QCD phase diagram in the (μ_B, T) plane

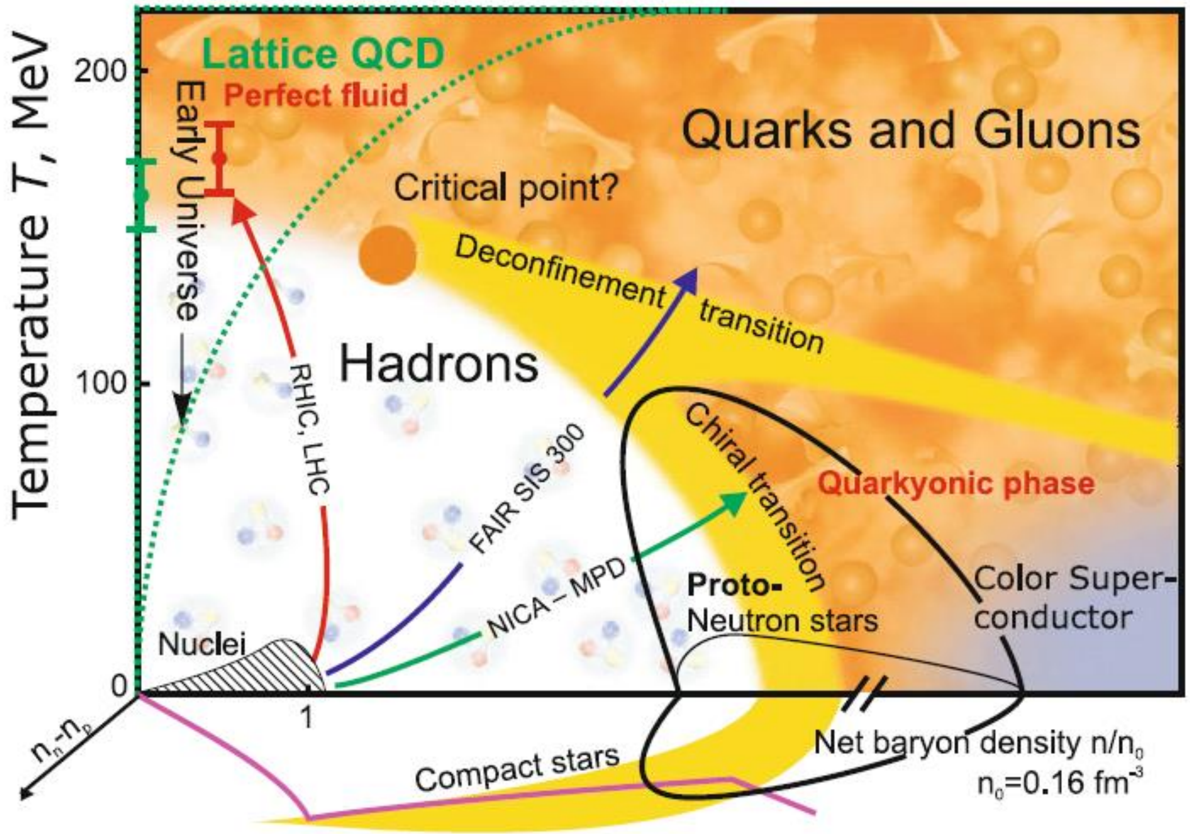


"All science is either physics or stamp collecting." --- Ernest Rutherford

"The Way Forward – Closing Remarks at Quark Matter 2017", W.A. Zajc, [arXiv:1707.01993]

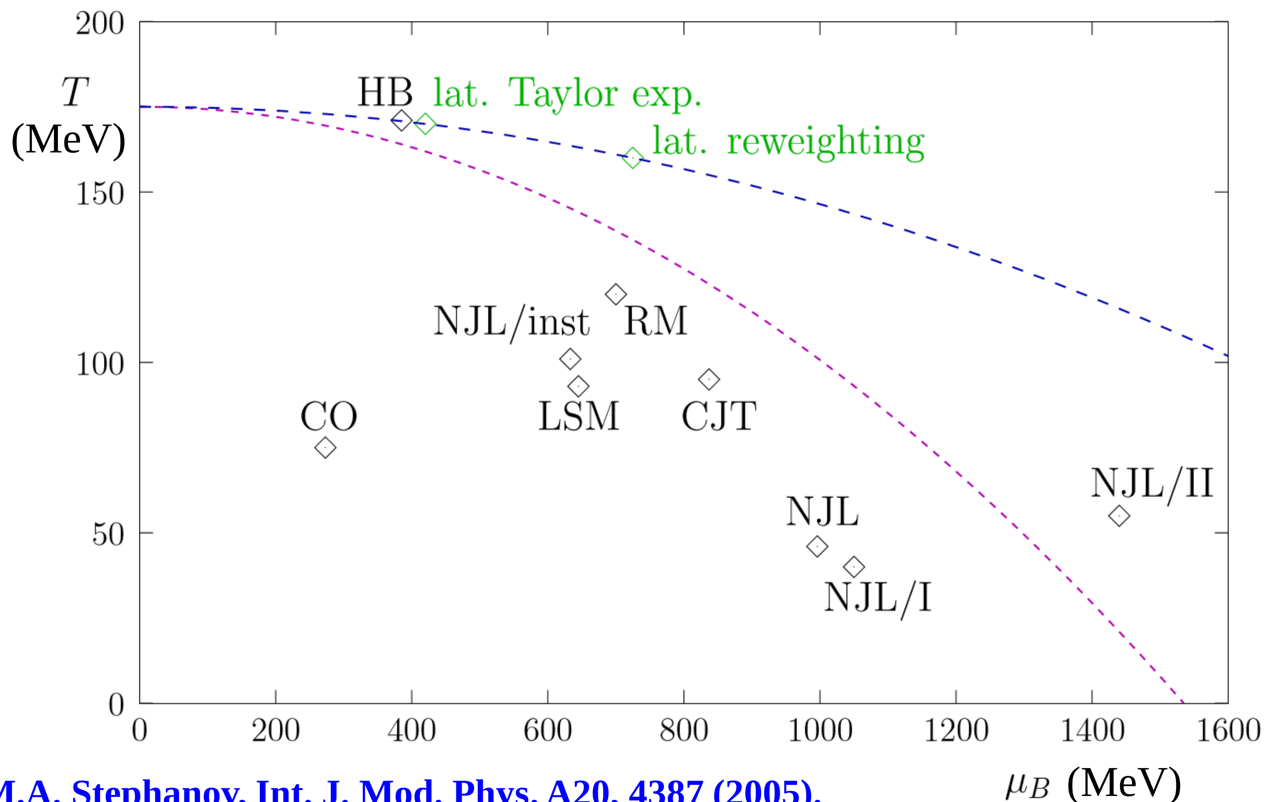
QCD Phase Diagram

V.E. Fortov, Extreme States of Matter – on Earth and in the Cosmos, Springer-Verlag, 2011



- Small baryon chemical potential: Smooth Crossover Transition
- Large baryon chemical potential: First-order Phase Transition
- QCD Critical Endpoint: where the first-order phase transition ends

CEP from Lattice and effective field theories



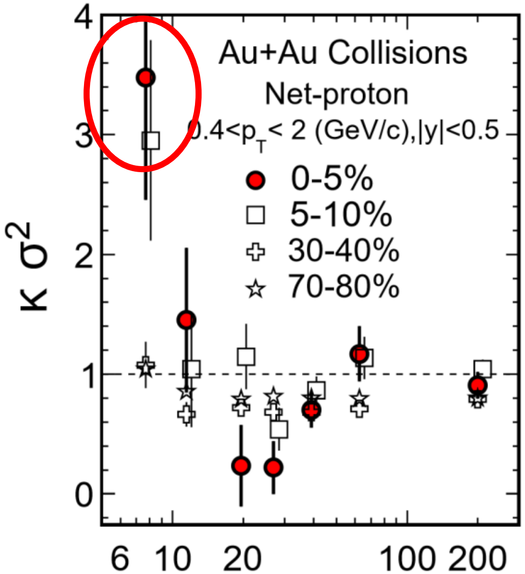
M.A. Stephanov, Int. J. Mod. Phys. A20, 4387 (2005).

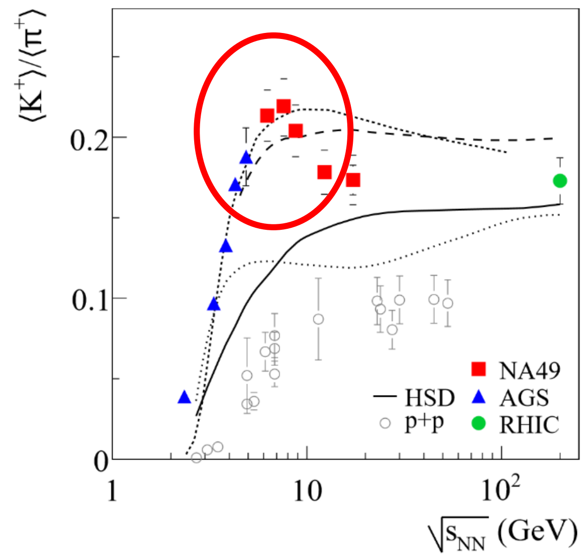
TABLE I: Locations of the QCD critical point from Lattice QCD and DSE, respectively.

	Lattice			DSE		
(μ_B^E, T^E)	I [33]	II [34, 35]	III [36–39]	I [40]	II [41]	III [42]
MeV	(360,162)	(285,155)	$\mu_B^E/T^E > 2$	(372,129)	(405,127)	(504,115)

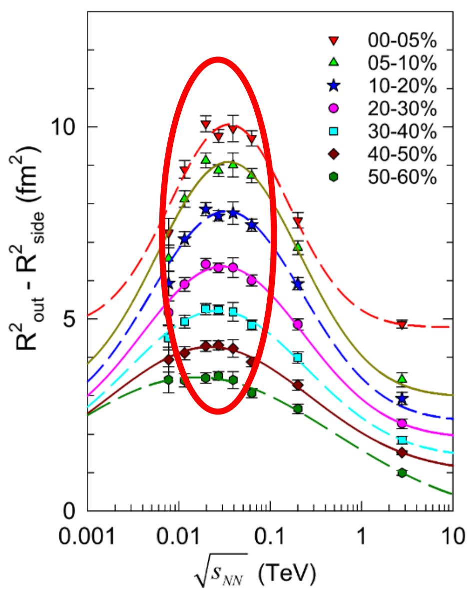
X.F. Luo and N. Xu, Nucl. Sci. Tech. 28, 112 (2017).

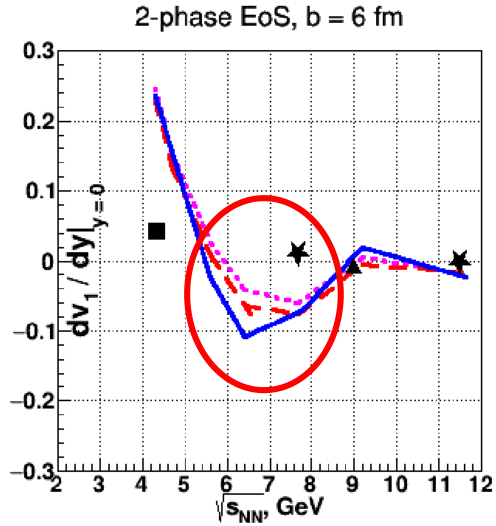
Strategy for locating CEP in experiments





Searching for non-monotonic behaviors of quantities with energy





X. F. Luo et al. [STAR Collaboration], PoS CPOD2014, 019 (2015).

C. Alt et al, (NA49 Collaboration), Phys. Rev. C 77, 024903 (2008).

R. A. Lacey, Phys. Rev. Lett. 114, 142301 (2015).

N. -U. Bastian et al, arXiv: 1608.02851 (2016).

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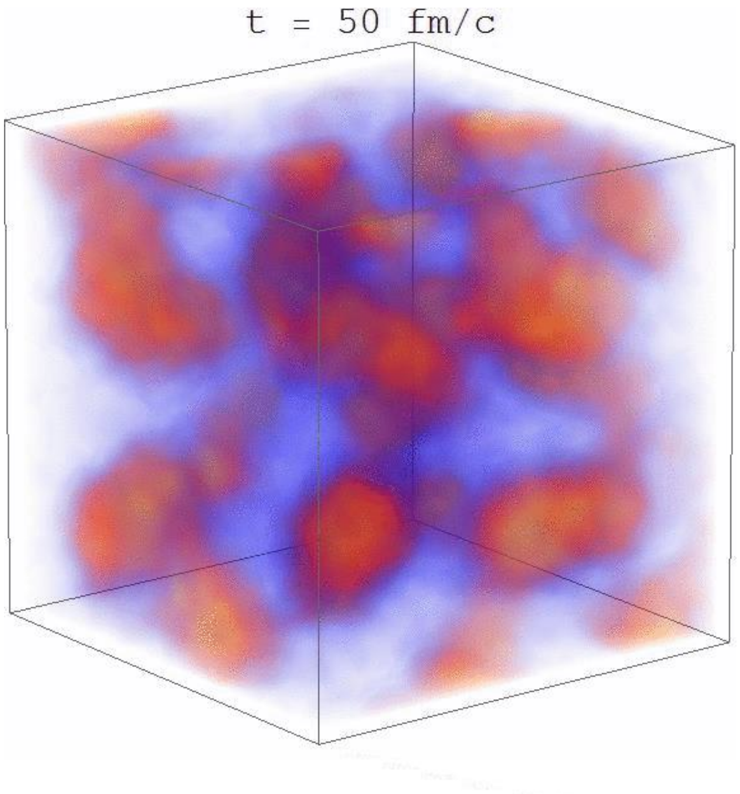
First-order phase transition and baryon density fluctuation

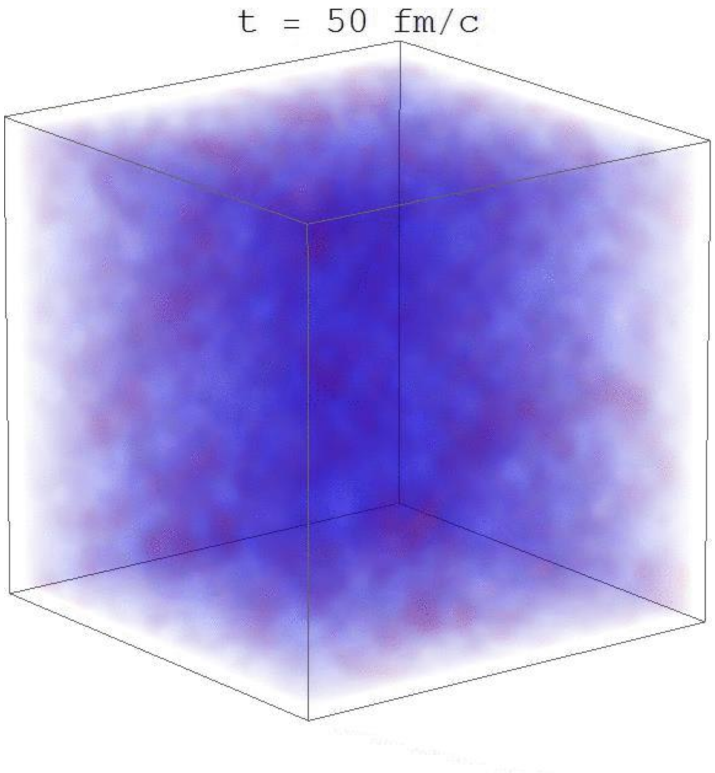
Transport Model + NJL

With first-order phase transition



$$T = 20\ \mathrm{MeV} \qquad n = 0.5\ \mathrm{fm}^{-3}$$

No first-order phase transition



$$T = 45\ \mathrm{MeV} \qquad n = 0.7\ \mathrm{fm}^{-3}$$

Taken from Feng Li's talk at Shanghai, 01/2017

F. Li and C.M. Ko, Phys. Rev. C 93, 035205 (2016).

Basic idea

Baryon density fluctuation vs light nuclei production

**Baryon density fluctuation
is closely related to
the correlation between nucleons.**

**The correlation between nucleons
determines
the production of light nuclei**

**Baryon density fluctuation in vicinity
of first-order phase transition
could be deciphered from
the production of light nuclei**

Cluster Production: Coalescence?

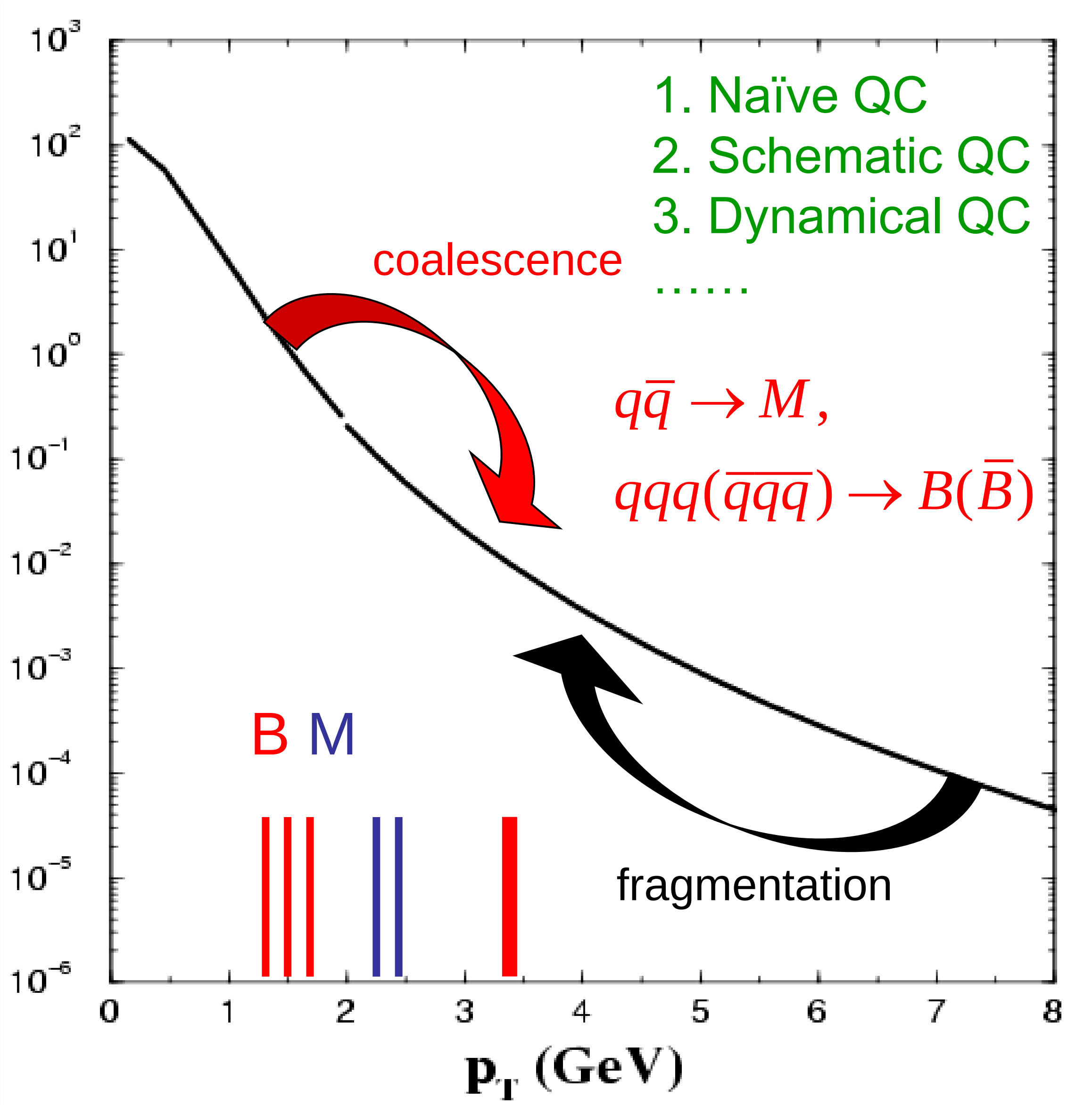
Coalescence model provides a useful approach to describe light cluster production in HIC

- **Coalescence model** provides a useful tool to describe light nuclei production in HIC
- **Coalescence model** also provides a useful tool to describe hadron production from partonic matter (hadronization)
- ……

Butler, Pearson, Sato, Yazaki, Gyulassy, Frankel, Remler, Dove, Scheibl, Heinz, Schnedermann, Mattiello, Nagle, Polleri, …

Biro, Zimanyi, Levai, Csizmadia, Hwa, Yang, Ko, Lin , Greco, Chen, Fries, Muller, Nonaka, Bass, Voloshin, Molnar, Xie, Shao, …

Parton coalescence mechanism at RHIC



Lin/Ko
PRL89, 202302 (2002);

S.A. Voloshin,
NPA715, 379(2003);

Greco/Ko/Levai,
PRL90, 202302 (2003);

Fries/Muller/Nonaka/Bass
PRL90, 202303 (2003);

Hwa/Yang
PRC67, 034902 (2003);
064902 (2003);

Molnar/Voloshin
PRL91, 092301 (2003)

$$B(p_T) \Leftarrow 3q(p_T/3)$$

$$M(p_T) \Leftarrow 2q(p_T/2)$$

Deuteron production in HIC

The correlation between neutron and proton with small relative momentum and deuteron formation both appear due to the final state interaction (S. Mrowczynsky, PLB248 (1990), P. Danielewicz et al., PLB274 (1992))

⇕

The n-p pair in a scattering state with small relative momentum and deuteron (n-p pair in a bound state) should provide the same space-time information about the size of an emission source

⇕

Using stiff symmetry energy will produce more deuterons than using soft symmetry energy?

Similarly to the n-p correlation function (HBT), deuteron yield in HIC's induced by neutron-rich nuclei is also a sensitive probe of the nuclear symmetry energy!!!

n-p HBT: Chen/Greco/Ko/Li, PRL90, 162701(2003); PRC68, 014605 (2003)

Deuteron: Chen/Ko/Li, PRC68, 017601 (2003); NPA729, 809 (2003)

Coalescence model

Covariant coalescence model

Dover/Heinz/Schnedermann/Zimanyi, PRC44, 1636 (1991)

$$1+2+\cdots+M \to C$$

$$N_C = g_C \int \prod_{i=1}^{M} p_i \cdot d\sigma_i \frac{d^3 p_i}{(2\pi)^3 E_i} f_i(x_i; p_i) \rho_C^W (x_1, \cdots, x_M; p_1, \cdots, p_M)$$

Statistical factor

Phase-space distribution function

Invariant phase-space factor

Wigner function

- **Depends on constituents' space-time structure at freeze-out (Reaction Dynamics)**
- **Neglecting the binding energy effect (T or E >>$E_{binding}$),**

  Coalescence probability: Semi-classical Wigner function. (Wave Function, Correlation)
- **Rare process has been assumed (the coalescence process can be treated perturbatively).**

  Higher energy collisions and higher energy cluster/particle production!

Freeze-out: Blast-Wave-Like Parametrization

Anisotropic Blast-Wave Model

F. Retiere and M.A. Lisa, PRC70, 044907 (2004)

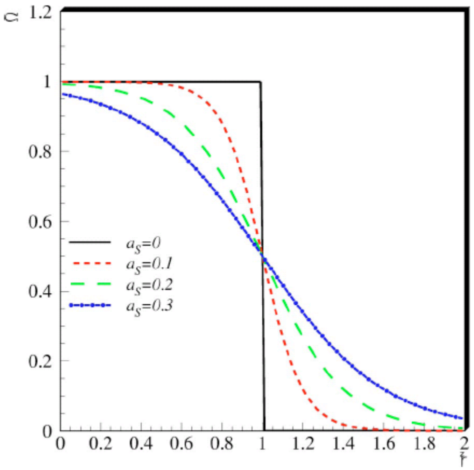


FIG. 1. (Color online) The source weighting function Ω as a function of the normalized elliptical radius $\tilde{r}$ for several values of the surface diffuseness parameter a_s.

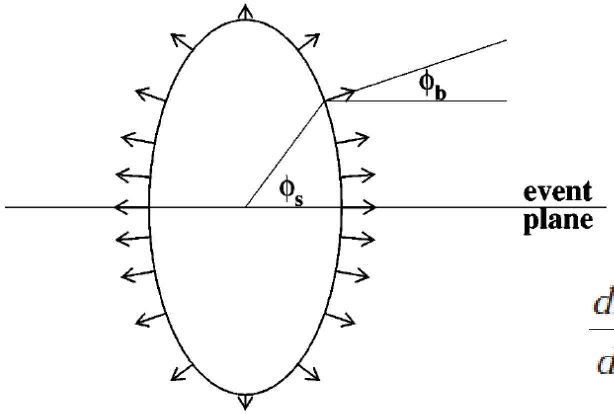
The freeze-out distribution is infinite in the beam (z) direction and elliptical in the transverse (x-y) plane. (The x-z plane is the reaction plane.) The transverse shape is controlled by the radii R_y and R_x, and the spatial weighting of source elements is given by

$$\Omega(r,\phi_s)=\Omega(\tilde{r})=\frac{1}{1+e^{(\tilde{r}-1)/a_s}}, \qquad (1)$$

where a fixed value of the "normalized elliptical radius,"

$$\tilde{r}(r,\phi_s)\equiv\sqrt{\frac{[r\cos(\phi_s)]^2}{R_x^2}+\frac{[r\sin(\phi_s)]^2}{R_y^2}}, \qquad (2)$$

corresponds to a given elliptical subshell within the solid volume of the freeze-out distribution.



$$\frac{dN}{d\tau}\sim\exp\left(-\frac{(\tau-\tau_0)^2}{2\Delta\tau^2}\right)$$

FIG. 2. Schematic illustration of an elliptical subshell of the source. Here, the source is extended out of the reaction plane ($R_y>R_x$). Arrows represent the direction and magnitude of the flow boost. In this example, $\rho_2>0$ [see Eq. (4)].

Boosted by the transverse rapidity

$$\rho(r,\phi_s)=\tilde{r}[\rho_0+\rho_2\cos(2\phi_b)]. \qquad (4)$$

8 parameters: T, ρ_0, ρ_2, R, s_2, a_s τ_0, $\Delta\tau$

Light (Anti-)(Hyper-)Nuclei Production:
Sun/Chen, PLB751, 272 (2015); PRC93, 064909 (2016); PRC94, 064908 (2016)

Analytical Coalescence Formula

Analytical coalescence formula: COAL-SH

Sun/LWC, PRC95, 044905 (2017)

$$N_c = g_{\rm rel} g_{\rm size} g_c M^{3/2} \left[\prod_{i=1}^{A} \frac{N_i}{m_i^{3/2}} \right] \times \prod_{i=1}^{A-1} \frac{(4\pi/\omega)^{3/2}}{Vx(1+x^2)} \left(\frac{x^2}{1+x^2} \right)^{l_i} G(l_i, x).$$

$$x^2 = \frac{2T_{\rm eff}}{w}$$

$$g_{\rm rel} \approx 1, g_{\rm size} \approx 1, l_i = 0$$

$$N_{\rm d} = g_{\rm d} \frac{(m_n + m_p)^{3/2}}{m_p^{3/2} m_n^{3/2}} \frac{N_p N_n}{V} \frac{(4\pi/\omega_{\rm d})^{3/2}}{x_{\rm d}(1+x_{\rm d}^2)},$$

$$N_{^3{\rm H}} = g_{^3{\rm H}} \frac{(2m_n + m_p)^{3/2}}{m_p^{3/2} m_n^3} \frac{N_p N_n^2}{V^2} \frac{(4\pi/\omega_{^3{\rm H}})^3}{x_{^3{\rm H}}^2(1+x_{^3{\rm H}}^2)^2},$$

$$w_d = 8.1 \text{ MeV}$$

$$w_{^3{\rm H}} = 13.4 \text{ MeV}$$

$$x_d \gg 1, x_{^3{\rm H}} \gg 1$$

$$N_{\rm d} = \frac{3}{2^{1/2}} \left(\frac{2\pi}{m_0 T_{\rm eff}} \right)^{3/2} \frac{N_p N_n}{V},$$

$$N_{^3{\rm H}} = \frac{3^{3/2}}{4} \left(\frac{2\pi}{m_0 T_{\rm eff}} \right)^{3} \frac{N_p N_n^2}{V^2}.$$

$$m_n = m_p = m_0$$

K. J. Sun, LWC, C.M. Ko, and Z. Xu, arXiv:1702.07620 (2017).

Cluster Yields w/o density fluctuation

$$N_{\rm d} = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T_{\rm eff}}\right)^{3/2}\frac{N_p N_n}{V},$$

$$N_{^3{\rm H}} = \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T_{\rm eff}}\right)^{3}\frac{N_p N_n^2}{V^2}.$$

The above equations are consistent with conventional thermal model:

$$N^{\rm th} = \frac{gV}{(2\pi)^3}4\pi T m^2 K_2(\frac{m}{T})e^{\frac{\mu}{T}}$$

$$T = T_{\rm eff}$$

K_2 is modified Bessel function

$$N_p^{\rm th} = \frac{g_p V}{(2\pi)^3}(2\pi m_0 T)^{\frac{3}{2}}e^{\frac{\mu_p - m_0}{T}},$$

$$N_d^{\rm th} = \frac{g_d V}{(2\pi)^3}(4\pi m_0 T)^{\frac{3}{2}}e^{\frac{2\mu_p - 2m_0}{T}},$$

$$N_{^3{\rm He}}^{\rm th} = \frac{g_{^3{\rm He}} V}{(2\pi)^3}(6\pi m_0 T)^{\frac{3}{2}}e^{\frac{3\mu_p - 3m_0}{T}},$$

$$K_\nu(x) \to \sqrt{\frac{\pi}{2x}}e^{-x}(1 + \frac{4\nu^2 - 1}{8x} + \mathcal{O}(\frac{1}{x^2}))$$

K. J. Sun, LWC, C.M. Ko, and Z. Xu, arXiv:1702.07620 (2017).

Cluster Yields with density fluctuation

Density fluctuation over space:

$$n(\vec{r}) = \frac{1}{V}\int n(\vec{r})\mathrm{d}\vec{r} + \delta n(\vec{r}) = \langle n\rangle + \delta n(\vec{r})$$

Neutron:
Proton:

$$\begin{aligned} n(\vec{r}) &= \langle n\rangle + \delta n(\vec{r}), \\ n_p(\vec{r}) &= \langle n_p\rangle + \delta n_p(\vec{r}), \end{aligned}$$

$$\langle \delta n\rangle = 0,\ \langle \delta n_p\rangle = 0,$$

$$N_n = \int d\vec{r}\, n = V\langle n\rangle,\ N_p = \int d\vec{r}\, n_p = V\langle n_p\rangle.$$

Strictly speaking, one needs to introduce fluctuation from the beginning in coalescence formulism

Approximately:

$$N_\mathrm{d} = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T_\mathrm{eff}}\right)^{3/2}\frac{N_p N_n}{V}$$

$$\sim \int \mathrm{d}\vec{r} n(\vec{r}) n_p(\vec{r})$$

$$\begin{aligned} N_\mathrm{d} &= \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2}\int d\vec{r}\, n(\vec{r}) n_p(\vec{r}) \\ &= \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2}\int d\vec{r}\, (\langle n\rangle + \delta n(\vec{r}))(\langle n_p\rangle + \delta n_p(\vec{r})) \\ &= \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2}\int d\vec{r}\, (\langle n\rangle\langle n_p\rangle + \delta n(\vec{r})\delta n_p(\vec{r})) \\ &= \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2}(N_p\langle n\rangle + \int d\vec{r}\, \delta n(\vec{r})\delta n_p(\vec{r})). \end{aligned}$$

Cross terms vanish

Cluster Yields with density fluctuation

$$N_{^3\mathrm{H}} = \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T_{\mathrm{eff}}}\right)^3 \frac{N_p N_n^2}{V^2}$$
$$\sim \int \mathrm{d}\vec{r} n(\vec{r})^2 n_p(\vec{r})$$

$$\begin{aligned}
N_{^3\mathrm{H}} &= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T}\right)^3 \int d\vec{r}\, n(\vec{r})^2 n_p(\vec{r}) \\
&= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T}\right)^3 \int d\vec{r}\, (\langle n\rangle + \delta n(\vec{r}))^2 (\langle n_p\rangle + \delta n_p(\vec{r})) \\
&= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T}\right)^3 \int d\vec{r}\, \{(\langle n\rangle^2 + (\delta n(\vec{r}))^2)\langle n_p\rangle + (2\langle n\rangle \delta n(\vec{r}) + (\delta n(\vec{r}))^2)\delta n_p(\vec{r})\} \\
&= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T}\right)^3 \{(\langle n\rangle^2 + \langle(\delta n(\vec{r}))^2\rangle)\langle n_p\rangle V + \int d\vec{r}\, (2\langle n\rangle \delta n(\vec{r}) + (\delta n(\vec{r}))^2)\delta n_p(\vec{r})\}
\end{aligned}$$

$$N_{\mathrm{d}} = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2} \left(N_p \langle n\rangle + \int d\vec{r}\, \delta n(\vec{r}) \delta n_p(\vec{r})\right)$$

$$\langle n(\vec{r})\rangle = \frac{1}{V}\int d\vec{r} n(\vec{r}) \qquad \langle(\delta n(\vec{r}))^2\rangle = \frac{1}{V}\int d\vec{r} (\delta n(\vec{r}))^2$$

Cluster Yields with density fluctuation

Neglecting correlation: $\int d\vec{r}\,\delta n(\vec{r})\delta n_p(\vec{r}) = 0.$ $\int d\vec{r}\,\delta n(\vec{r})^2\delta n_p(\vec{r}) = 0.$

$$N_{\mathrm{d}} = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T}\right)^{3/2} N_p\langle n\rangle,$$

$$N_{^3\mathrm{H}} = \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T}\right)^{3} N_p\langle n\rangle^2(1+\Delta n),$$

$$\Delta n = \frac{<(\delta n)^2>}{<n>^2}$$ Relative neutron density fluctuation

$$\langle n(\vec{r})\rangle = \frac{1}{V}\int d\vec{r} n(\vec{r}) \qquad \langle(\delta n(\vec{r}))^2\rangle = \frac{1}{V}\int d\vec{r}(\delta n(\vec{r}))^2$$

^{3}H yield is proportional to the relative density fluctuation!

However, their yields also depend on T and neutron average density <n>.

Let's take ratio to cancel out the T and <n> !

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Observable

The observable we propose to probe density fluctuation is:

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

$$g = 4/9 \times (3/4)^{3/2} \approx 0.29$$

$$\Delta n = \frac{<(\delta n)^2>}{<n>^2}$$

$$\langle n(\vec{r}) \rangle = \frac{1}{V} \int d\vec{r} n(\vec{r})$$

$$\langle (\delta n(\vec{r}))^2 \rangle = \frac{1}{V} \int d\vec{r} (\delta n(\vec{r}))^2$$

One can see that it has a linear dependence on neutron relative density fluctuation and it has no dependence on T, V, or other parameters.

This is different from what has been done in the measurements of fluctuation of yields of net protons within a specific phase-space in momentum so far.

Correction from correlation

Correlation between density fluctuation of proton and neutron

$$\begin{aligned}\langle \delta n \delta n_p \rangle &= \frac{1}{V}\int \mathrm{d}\vec{r}\,\delta n(\vec{r})\delta n_p(\vec{r}) \\ &= \frac{1}{V}\int \mathrm{d}\vec{r}\; c(\vec{r})(\delta n(\vec{r}))^2\end{aligned}$$

with $\delta n_p(\vec{r}) = c(\vec{r})\delta n(\vec{r})$

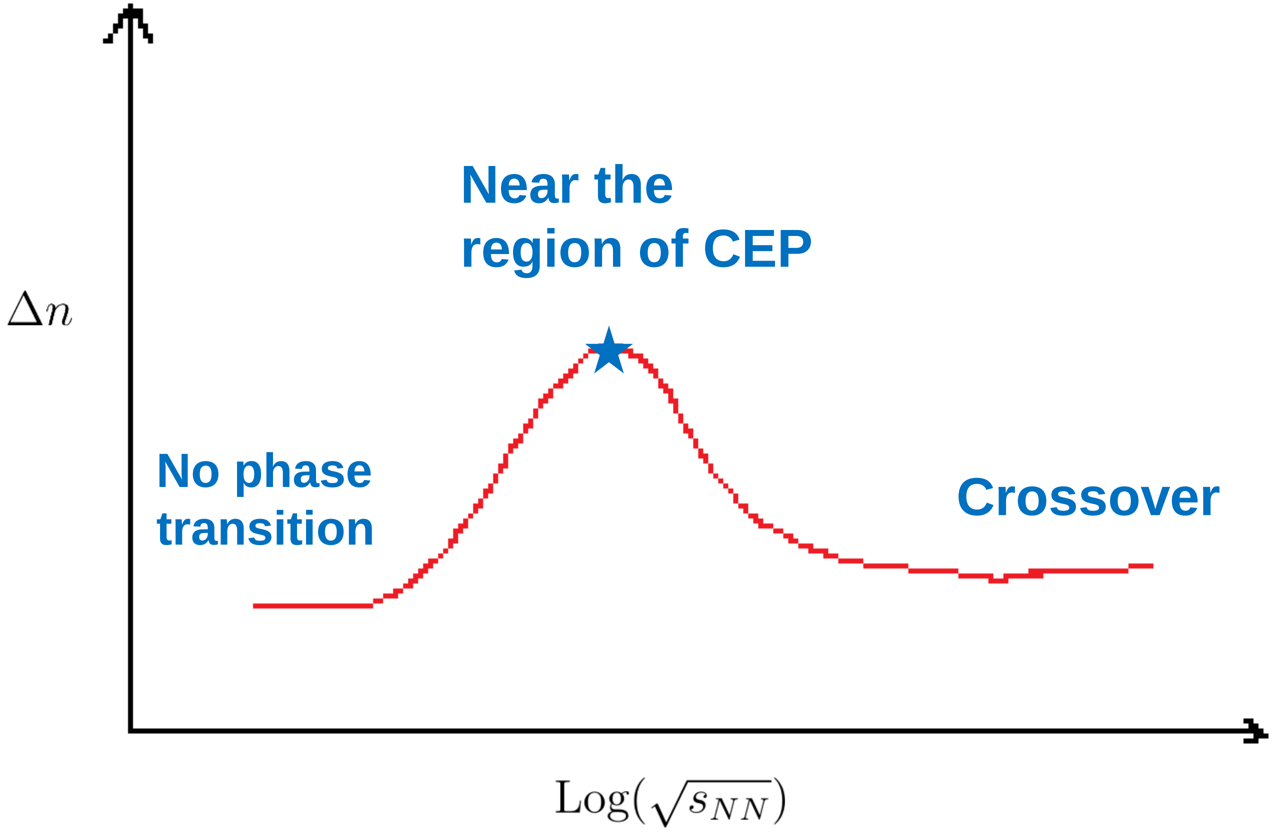
One can always express: $\langle \delta n \delta n_p \rangle = \alpha \frac{\langle n_p \rangle}{\langle n \rangle}\langle (\delta n)^2 \rangle$

$$\begin{aligned}N_{\mathrm{d}} &= \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T_{\mathrm{eff}}}\right)^{3/2} N_p \langle n \rangle (1+\alpha\Delta n), \\ N_{^3\mathrm{H}} &= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T_{\mathrm{eff}}}\right)^{3} N_p \langle n \rangle^2 (1+(1+2\alpha)\Delta n)\end{aligned}$$

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

$$\begin{aligned}N_{^3\mathrm{He}} &= \frac{3^{3/2}}{4}\left(\frac{2\pi}{m_0 T_{\mathrm{eff}}}\right)^{3} N_n \langle n_p \rangle^2 (1+\Delta n_p + 2\alpha\Delta n) \\ N_{^4\mathrm{He}} &= \frac{1}{2}\left(\frac{2\pi}{m_0 T_{\mathrm{eff}}}\right)^{9/2} N_p \langle n_p \rangle \langle n \rangle^2 \\ &\times \left[1+(1+4\alpha)\Delta n + \Delta n_p + \frac{\langle (\delta n \delta n_p)^2 \rangle}{\langle n \rangle^2 \langle n_p \rangle^2}\right]\end{aligned}$$

Naive expectation



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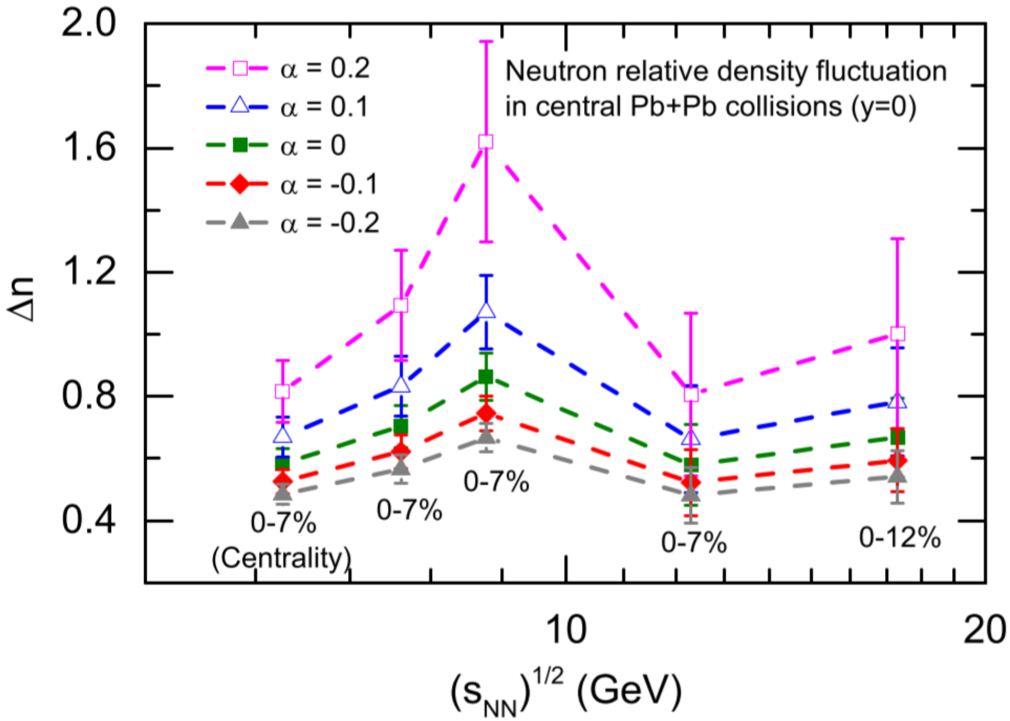
Circumstantial evidence of peak structure



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

$$g = 4/9 \times (3/4)^{3/2} \approx 0.29$$

$$\Delta n = \frac{<(\delta n)^2>}{<n>^2}$$

From NA49 Collaboration

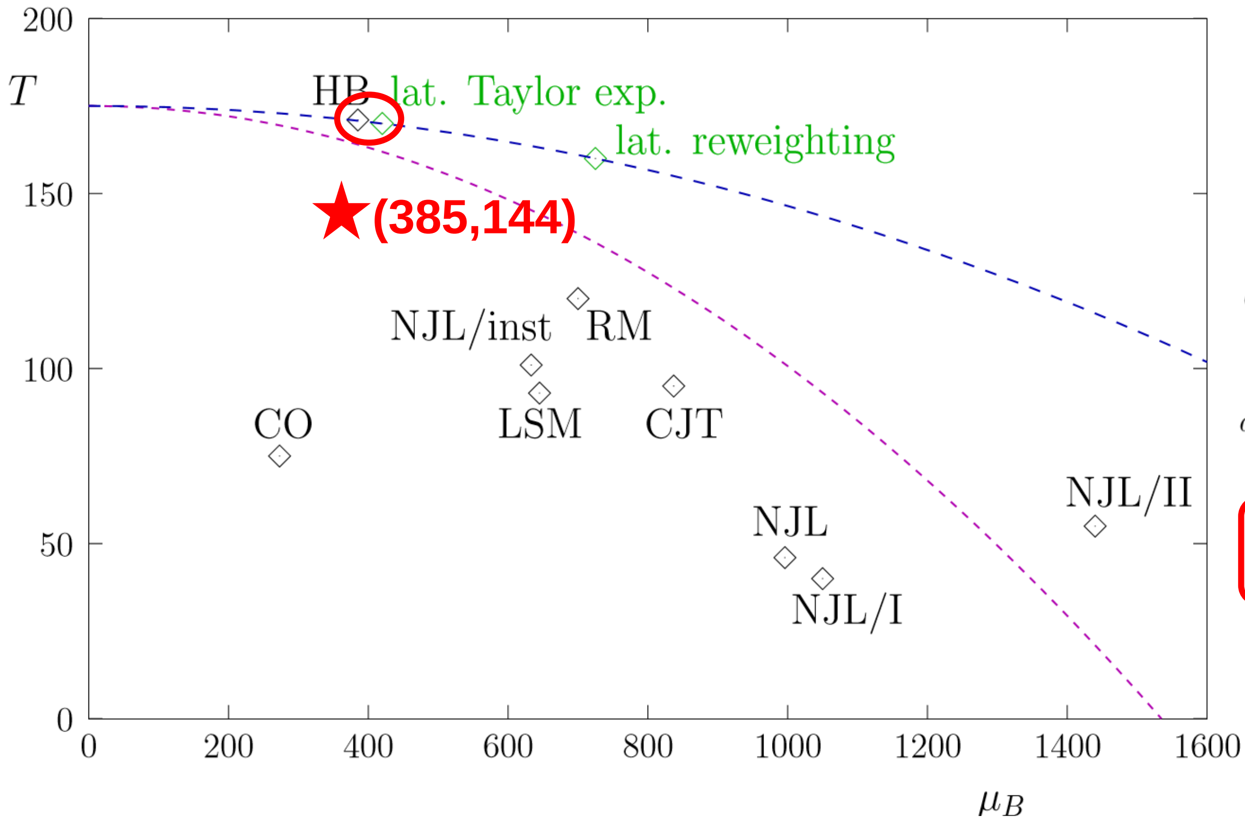
T. Anticic et al. (NA49 Collaboration), Phys. Rev. C 94, 044906 (2016).

TABLE I: Yields (dN/dy at midrapidity) of p, d, ^{3}He and ^{3}H as well as the yield ratio ^{3}H/^{3}He measured in Pb+Pb collisions at SPS energies [47] together with the derived yield ratio $\mathcal{O}_{\text{p-d-t}}$. The units for E and $\sqrt{s_{NN}}$ are AGeV and GeV, respectively.

E	$\sqrt{s_{NN}}$	centrality	p	d	^{3}He	^{3}H/^{3}He	^{3}H	$\mathcal{O}_{\text{p-d-t}}$
20	6.3	0 − 7%	46.1±2.1	2.094±0.168	$3.58(\pm0.43) \times 10^{-2}$	1.22±0.10	$4.37(\pm0.64) \times 10^{-2}$	0.459±0.014
30	7.6	0 − 7%	42.1±2.0	1.379±0.111	$1.89(\pm0.23) \times 10^{-2}$	1.18±0.11	$2.23(\pm0.34) \times 10^{-2}$	0.494±0.020
40	8.8	0 − 7%	41.3±1.1	1.065±0.086	$1.28(\pm0.15) \times 10^{-2}$	1.16±0.15	$1.48(\pm0.26) \times 10^{-2}$	0.541±0.022
80	12.3	0 − 7%	30.1±1.0	0.543±0.044	$3.90(\pm0.50) \times 10^{-3}$	1.15±0.19	$4.49(\pm0.94) \times 10^{-3}$	0.458±0.038
158	17.3	0 − 12%	23.9±1.0	0.279±0.023	$1.50(\pm0.20) \times 10^{-3}$	1.05±0.15	$1.58(\pm0.31) \times 10^{-3}$	0.484±0.037

Estimation of location of CEP

J. Cleymans et al, Phys. Rev. C 73, 034905 (2006).



$$T(\mu_B) = a - b\mu_B^2 - c\mu_B^4$$

$$\mu_B(\sqrt{s}) = \frac{d}{1 + e\sqrt{s}}$$

$a = 0.166 \pm 0.002$ GeV, $b = 0.139 \pm 0.016$ GeV^{-1}

$c = 0.053 \pm 0.021$ GeV^{-3}

$d = 1.308 \pm 0.028$ GeV and $e = 0.273 \pm 0.008$ GeV^{-1}

$\sqrt{s_{NN}} = 8.8$ GeV

$T \sim 144$ MeV and $\mu_B \sim 385$ MeV

TABLE I: Locations of the QCD critical point from Lattice QCD and DSE, respectively.

	Lattice			DSE		
(μ_B^E, T^E)	I [33]	II [34, 35]	III [36–39]	I [40]	II [41]	III [42]
MeV	(360,162)	(285,155)	$\mu_B^E/T^E > 2$	(372,129)	(405,127)	(504,115)

M.A. Stephanov, Int. J. Mod. Phys. A20, 4387 (2005).

X.F. Luo and N. Xu, Nucl. Sci. Tech. 28, 112 (2017).

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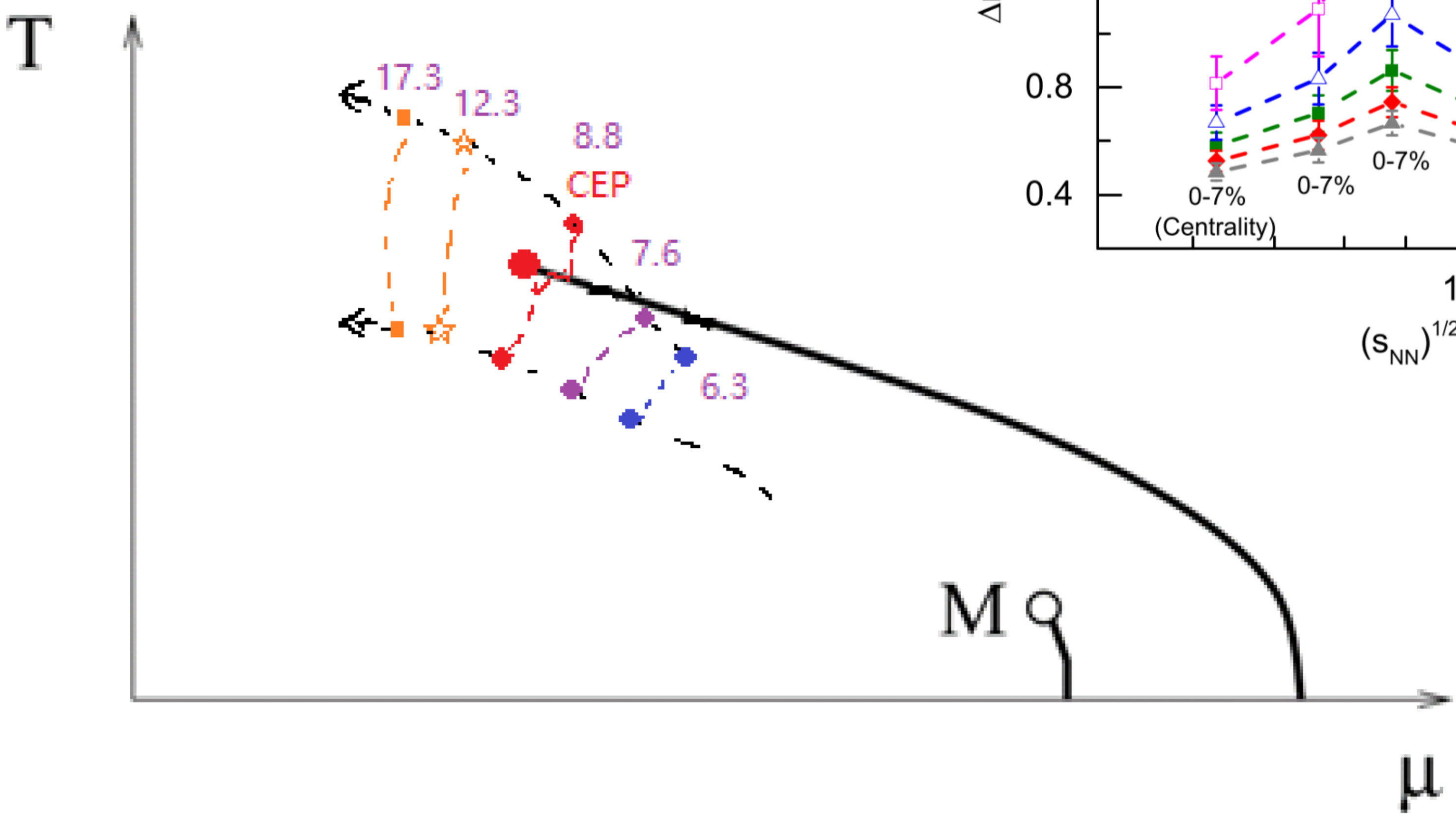
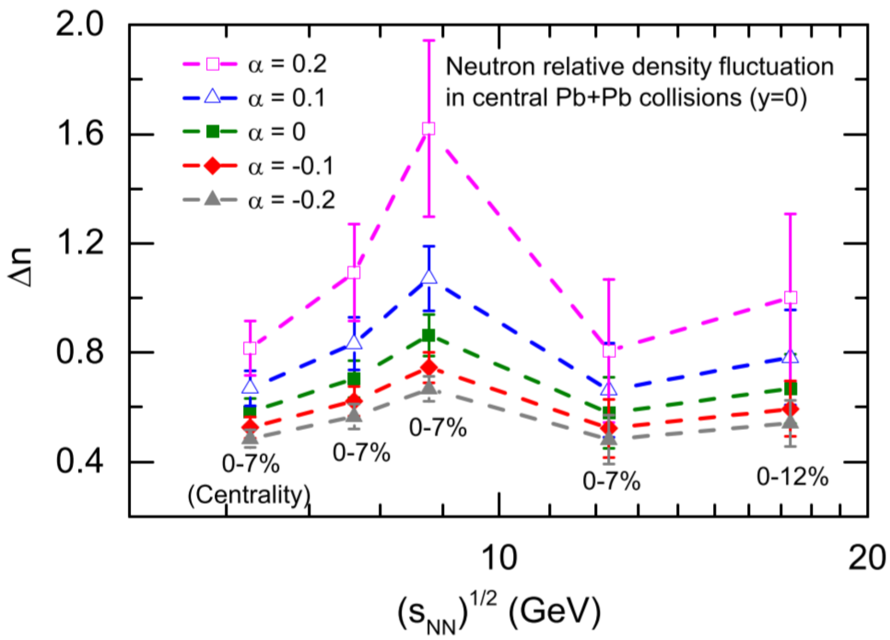
Peak structure and CEP

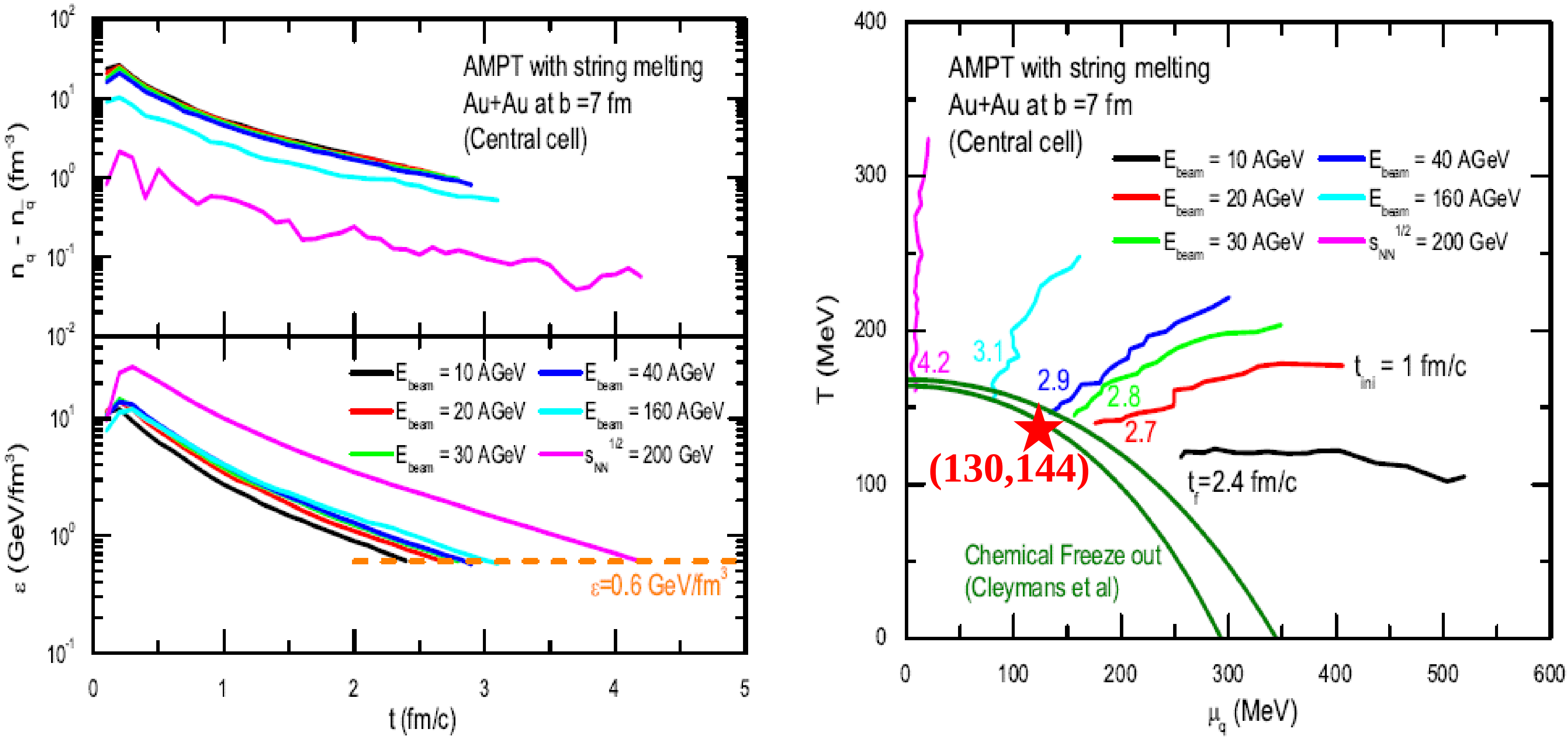




Peak structure and CEP

AMPT prediction for Trajectories of heavy ion collisions in the QCD phase diagram of temperature and net quark chemical potential.

Lower of the energy is, shorter (smaller) the QGP lifetime (size) is?



L. W. Chen, C. M. Ko, W. Liu, and B.W. Zhang, PoS (CPOD2009) 034 [arXiv:1103.0916].

Outline

- **QCD Critical Endpoint (CEP)**
- **Baryon density fluctuation and coalescence production of light nuclei in HIC**
- $O = \frac{N_{^3\mathrm{H}} N_p}{N_d^2}$ **as a probe of QCD CEP**
- **Summary and Outlook**

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Summary and Outlook

- $O = \frac{N_{^3\mathrm{H}} N_p}{N_d^2}$ provides a potentially useful probe for QCD critical fluctuations and to locate the position of CEP in QCD phase diagram.
- The extracted relative neutron density fluctuation in central Pb+Pb collisions at CERN SPS energies measured by NA49 collaboration exhibits circumstantially a non-monotonic behavior with a peak at sqrt(s_{NN})=8.8 GeV, suggesting that the CEP in the QCD phase diagram may have been reached in these collisions with its temperature and baryon chemical potential estimated to be about T=144 MeV and μ_B=385 MeV.
- Further investigations from experiments, such as the BES program at RHIC, and theoretical modeling of light nuclei production and its connection to baryon density fluctuations are required.

谢 谢！

Thanks！