Affects of criticality on the light nuclei yields

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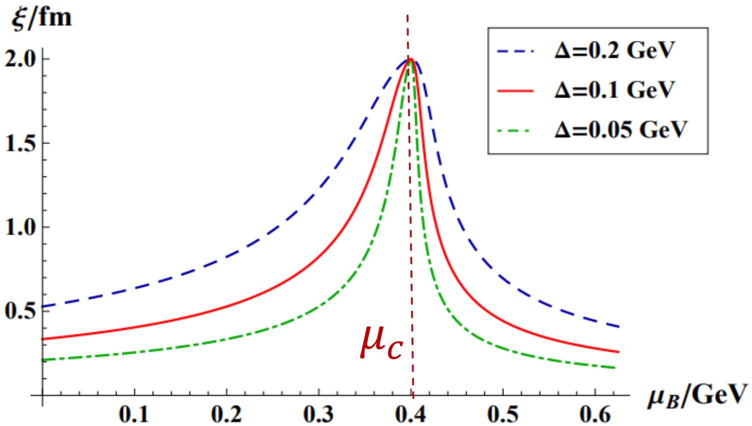
Main Logic

At chemical freeze-out:



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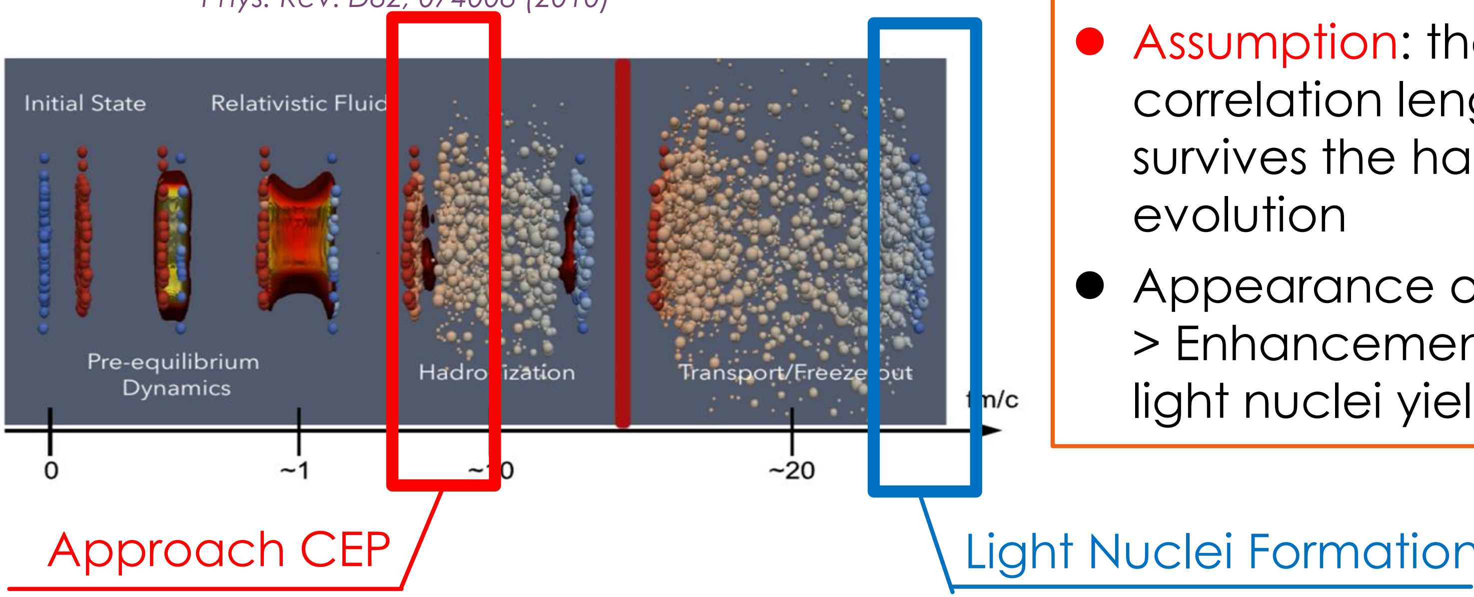


- Enhancement of correlation length (of order parameter) around CEP
- Larger correlation length leads to larger light nuclei yield ratio
- Assumption: the large correlation length survives the hadronic evolution
- Appearance of CEP -> Enhancement of light nuclei yield ratio

Coalescence Model

- Deuteron abundance:

$$N_d = g_d \int dx_1 dx_2 dp_1 dp_2 f_{np}(x_1, p_1; x_2, p_2) W_d(\frac{x_1 - x_2}{\sqrt{2}}, \frac{p_1 - p_2}{\sqrt{2}}; \sigma_d)$$

Joint probability: $f_{np}(x_1, p_1; x_2, p_2) \sim \rho_{np}(x_1, x_2) e^{-\frac{p_1^2 + p_2^2}{2mT}}$

$$\rho_{np}(x_1, x_2) = \rho_n(x_1)\rho_p(x_2) + C_2(|x_1 - x_2|)$$

Long-range Cor.: $C_2^*(r) = \langle \delta\rho_B(r)\delta\rho_B(0)\rangle \approx \left(\frac{\partial \rho_B}{\partial \phi}\right)^2 \langle \delta\phi(r)\delta\phi(0)\rangle$

$$\sim \frac{\zeta_2 \langle \rho_n\rangle\langle\rho_p\rangle e^{-r/\xi}}{r} \qquad \zeta_2 = \frac{T}{\pi \rho_B^2}\left(\frac{\partial \rho_B}{\partial \phi}\right)^2 > 0$$

- Triton abundance:

$$N_t = g_t \int dx_1 dx_2 dx_3 dp_1 dp_2 dp_3 f_{nnp}(x_1, p_1; x_2, p_2; x_3, p_3) W_t(\sigma_t)$$

Joint probability: $f_{nnp}(x_1, p_1; x_2, p_2; x_3, p_3) \sim \rho_{nnp}(x_1, x_2, x_3) e^{-\frac{p_1^2 + p_2^2 + p_3^3}{2mT}}$

$$\rho_{nnp}(x_1, x_2, x_3) = \rho_n(x_1)\rho_n(x_2)\ \rho_p(x_3) + \rho_n(x_1) C_2(x_2, x_3) + \rho_n(x_2) C_2(x_1, x_3) + \rho_p(x_3) C_2(x_1, x_2) + C_3(x_1, x_2, x_3)$$

Long-range Cor.: $\widetilde{C_3^*}(k_1, k_2) \approx \frac{\zeta_3}{(k_1^2 + \xi^{-2})(k_2^2 + \xi^{-2})\left((\vec{k_1} + \vec{k_2})^2 + \xi^{-2}\right)}$ $\qquad \zeta_3 = \frac{-3 g_3 T^2}{\pi^4 \rho_B^3}\left(\frac{\partial \rho_B}{\partial \phi}\right)^3 > 0$

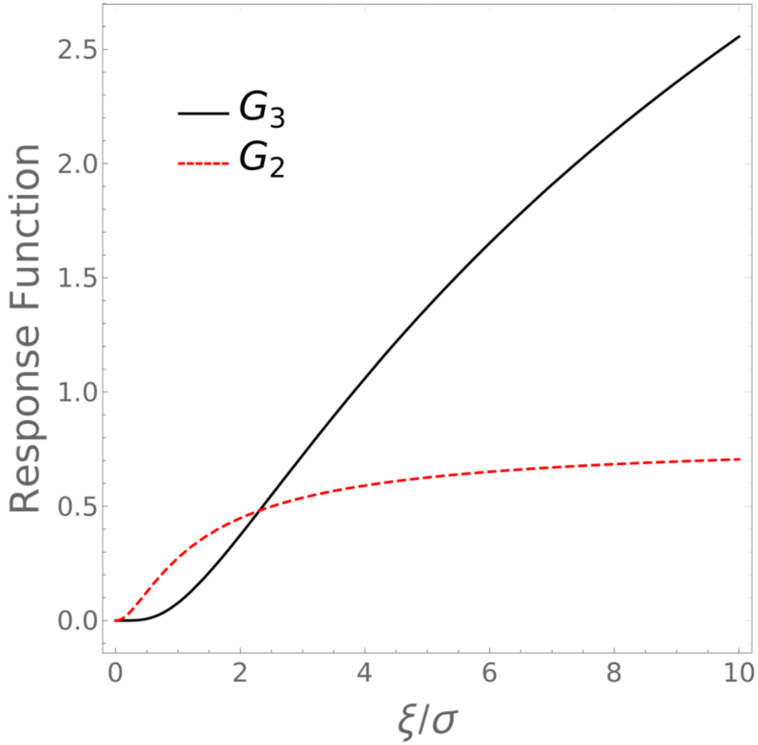
① Nucleons are emitted from a thermalized source
② Neglect the correlation among momenta
③ Dominated by the singular term around CEP

Yields & Correlation Length

$$N_d \approx N_d^{(0)}\left[1 + C_{np} + \frac{\lambda_2}{\sigma_d} G_2\left(\frac{\xi}{\sigma_d}\right)\right]$$

$$N_t \approx N_t^{(0)}\left[1 + \Delta\rho_B + 2C_{np} + \frac{3\lambda_2}{\sigma_t} G_2\left(\frac{\xi}{\sigma_t}\right) + \lambda_3 G_3\left(\frac{\xi}{\sigma_t}\right)\right]$$

$$\frac{N_t N_p}{N_d^2} \approx \frac{1}{2\sqrt{3}}\left[1 + \Delta\rho_B + \frac{\lambda_2}{\sigma_t} G_2\left(\frac{\xi}{\sigma_t}\right) + \lambda_3 G_3\left(\frac{\xi}{\sigma_t}\right)\right]$$



- Light nuclei yields (and their ratios) increase with the correlation length

  can thus be employed as a 'ruler' measuring the correlation length

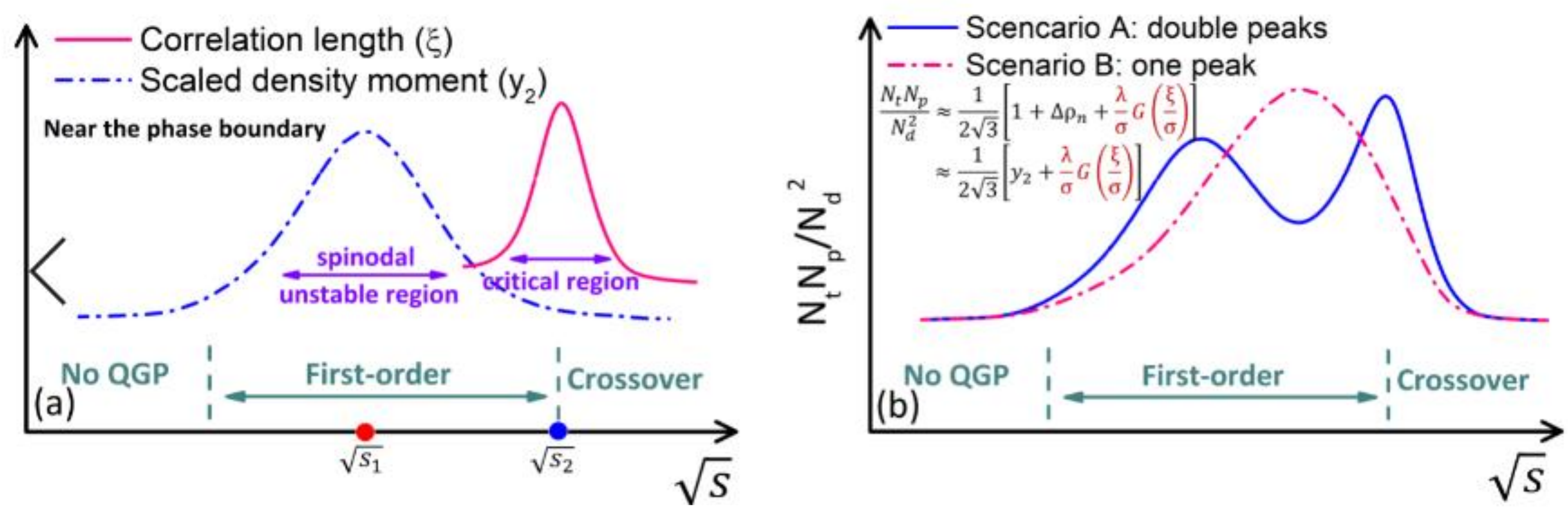
- The resolution of such a 'ruler' is the size of the light nuclei (2-3 fm)

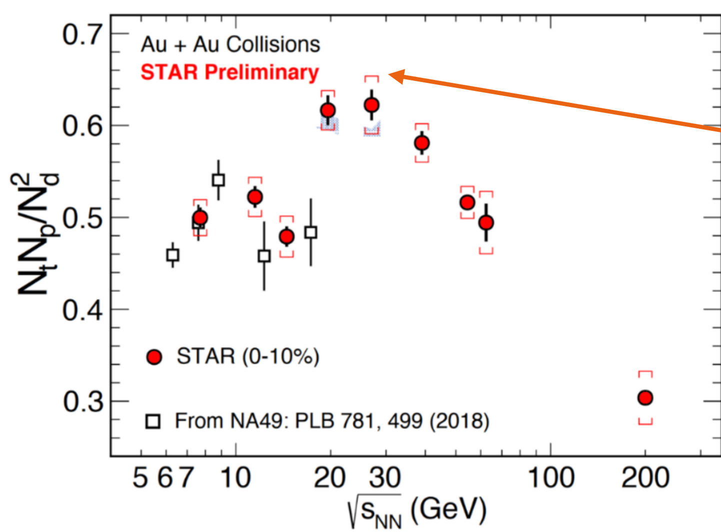
  close to ξ_{max}

- G-functions saturates at large ξ

  a broad peak in BES

Two Scenarios in BES





Signal from critical point?

A dynamical simulation (maybe via hydro+) is necessary to see whether the long-range correlation survives during the hadronic evolution

Appendix: Sign of ζ3

Quark-Meson Model: $H = H_{kin} + H_{q-m} + \frac{\lambda}{4}\left(\sigma^2 + \pi^2 - v^2\right)^2 - c\sigma$

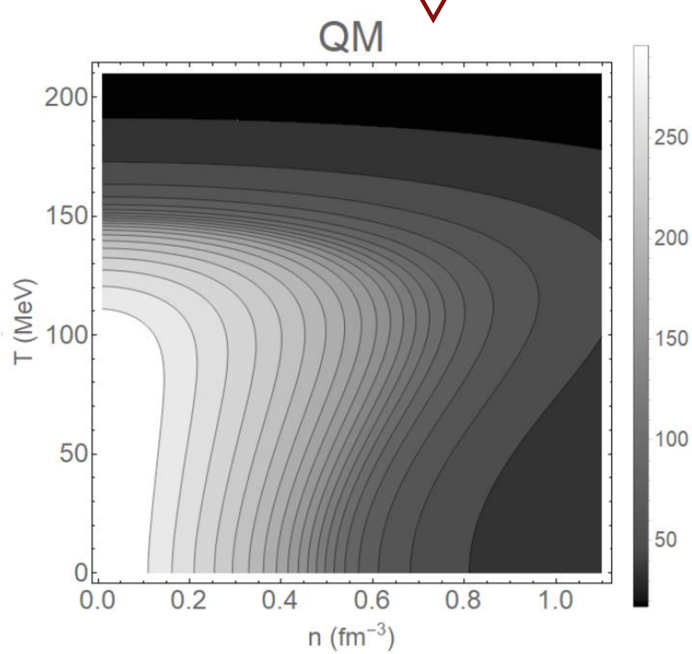
$$\langle \delta\rho_B(x)\delta\rho_B(y)\delta\rho_B(z)\rangle \sim \left(\frac{\partial \rho_B}{\partial \sigma^*}\right)_T^3 \langle \sigma'(x)\sigma'(y)\sigma'(z)\rangle$$

Order parameter for chiral phase transition: $\sigma = \sigma^* + \sigma'$

Expectation value of q-condensate: $\sigma^* = \frac{M_Q}{g_{Q\sigma}} > 0$

$H = \cdots + \lambda\sigma^*\sigma'^3 + \cdots$

$g_3 \approx \lambda\sigma^* + O(\hbar) > 0$



M_u MeV → $\left(\frac{\partial \rho_B}{\partial \sigma^*}\right)_T < 0$

$$\zeta_3 = \frac{-3g_3T^2}{\pi^4\rho_B^3}\left(\frac{\partial \rho_B}{\partial \phi}\right)^3 > 0\,!$$