Search for the QCD Critical Point by Transverse Velocity Dependence of Anti-deuteron to Deuteron Ratio

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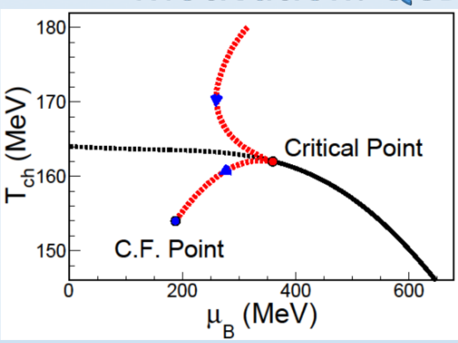
We propose the transverse velocity (β_T) dependence of anti-deuteron to deuteron ratio as a new observable to search for the QCD critical point in heavy-ion collisions. The QCD critical point can attract the system evolution trajectory in the QCD phase diagram, which is known as focusing effect. To quantify this effect, we employ thermal model and hadronic transport model to simulate the dynamical particle emission along a hypothetical focusing trajectory near critical point. It is found that the focusing effect can lead to anomalous β_T dependence of $\bar{p}/p, \bar{d}/d$ and $^3\overline{\text{He}}/^3\text{He}$ ratios. The heavier light anti-nuclei to light nuclei ratios are more sensitive to the focusing effect in the vicinity of critical point. We examined the β_T dependence of $\bar{p}/p$ and $\bar{d}/d$ ratios of central Au-Au collisions at $\sqrt{s_{NN}}$ = 7.7 to 200 GeV measured by the STAR experiment at RHIC. Surprisingly, we only observe a negative slope in β_T dependence of $\bar{d}/d$ ratio at $\sqrt{s_{NN}}$ = 19.6 GeV, which indicates the trajectory evolution has passed through the critical region. In the future, we could constrain the location of the critical point and/or width of the critical region by making precise measurements on the β_T or p_T dependence of $\bar{d}/d$ ratio at different energies and rapidity. **Chin. Phys. C44,014002, arXiv1812.04291**

Motivation: QCD Focusing Effect

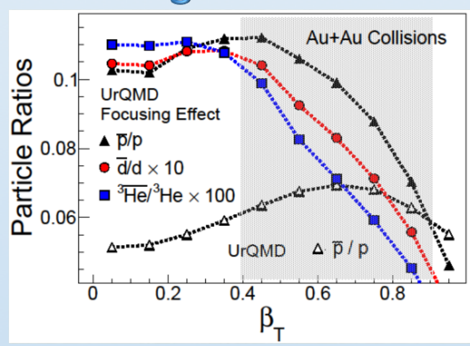


QCD phase diagram with crossover (black dashed line), 1*st* order phase transition boundary (black solid lines) and QCD critical point (red solid circle). Red dashed lines is a hypothetical system evolution trajectory and ended with the chemical freeze-out point (blue solid circle).

- QCD critical point will serve as an attractor of the trajectory evolution in $T-\mu_B$ plane.
- Thermal production of light nuclei and protons along the system evolution trajectory.
- The production of light nuclei is more sensitive to the system evolution trajectory.

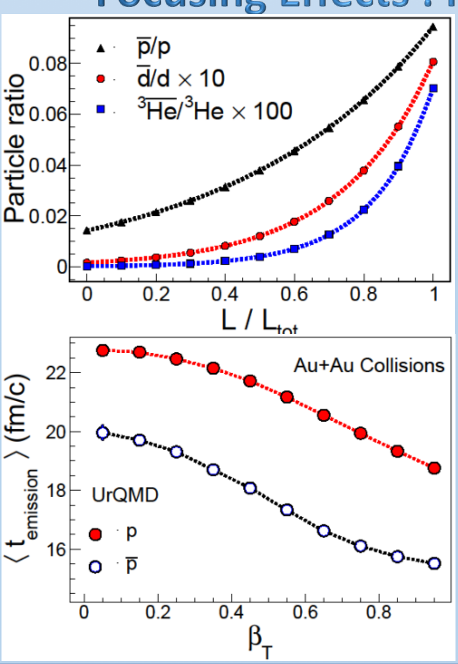
$$\bar{p}/p \propto e^{-2\mu_B/T}, \qquad \bar{d}/d \propto e^{-4\mu_B/T}$$

Focusing Effect: Ratios



- QCP focusing effect can lead to anomaly in β_T dependence of anti-particle to particle ratio.
- The heavier the particle is, the steeper slope we can observe.

Focusing Effects : Model Simulation

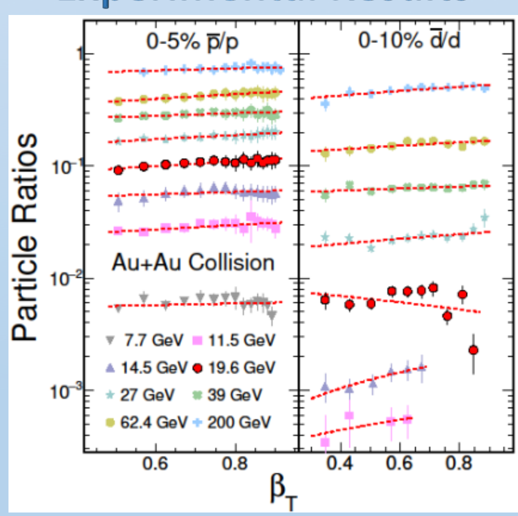


- L_{tot}: the length of the trajectory from critical point to C. F. Point. L : the length of the trajectory from critical point to considered point.
- $t = L/L_{tot}$: the time scale of the isentropic trajectory on the QCD phase diagram.
- Numbers of particle A emitted at time t, $(D_A(t))$ along the trajectory is calculated from THERUS with the T and μ_B $(Y_A(t))$ and normalized to the yield at chemical freeze-out $Y_A(t=1)$.

$$D_A(t) = \frac{Y_A[T(t), \mu_B(t)]}{\int_0^1 Y_A(t)dt} Y_A(t=1)$$

- $t-\beta_T$ is calculated from UrQMD.
- The particles with larger transverse velocity are freeze-out at earlier time.

Experimental Results



- The β_T dependence of 0-5% collision centrality for $\bar{p}/p$ and 0-10% for $\bar{d}/d$
- Positive slopes for β_T dependence of $\bar{d}/d$ are observed for all energies except 19.6 GeV.

Summary

- We studied the QCP focusing effect on β_T dependence of $\bar{p}/p, \bar{d}/d$ and $^3\overline{\text{He}}/^3$He ratios.
- The focusing effect will lead to a decreasing anti-particle to particle ratio when increasing β_T .
- The fitting slope of $\bar{d}/d$ at $\sqrt{s_{NN}}$ = 19.6 GeV is negative, which might indicate system evolution trajectory has passed through the critical region.

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