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K_1/K^* enhancement as a signature of chiral symmetry restoration in heavy ion collisions

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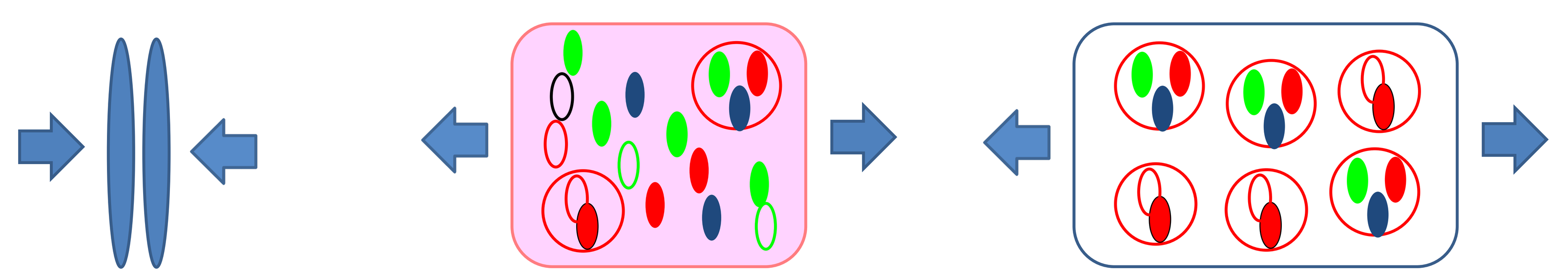
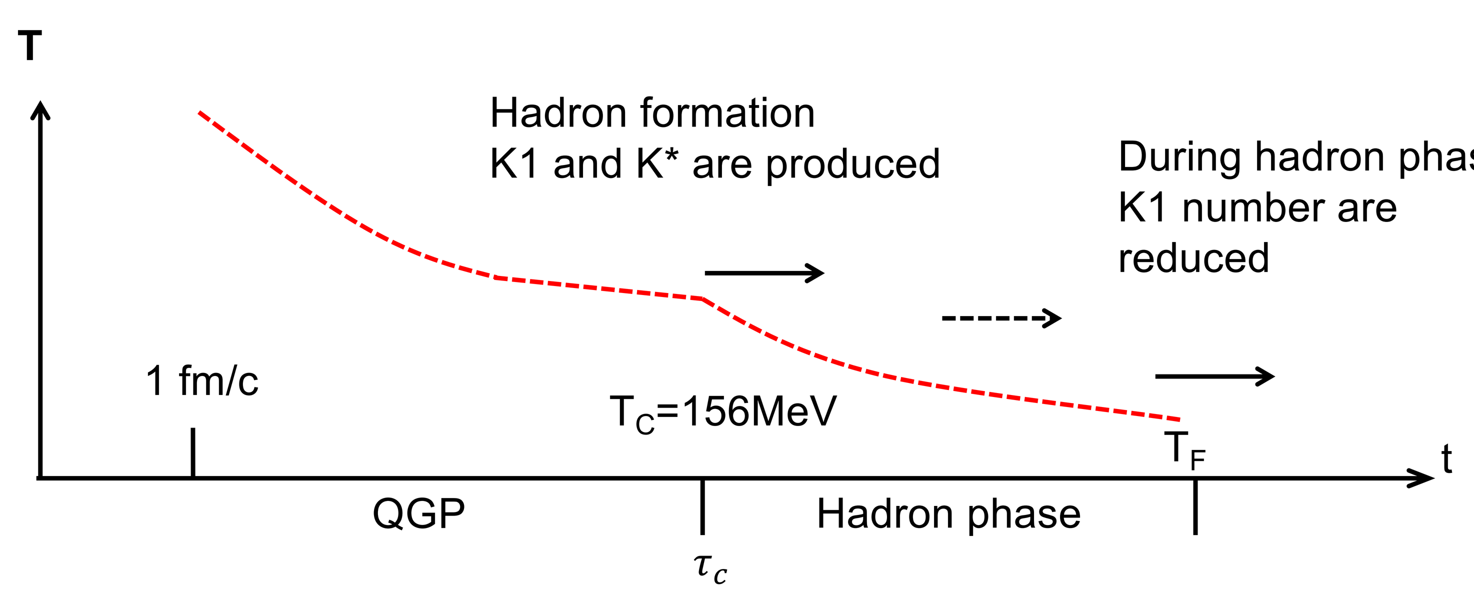
Abstract

We extend the recent study of K_1/K^* enhancement as a signature of chiral symmetry restoration in heavy ion collisions at the Large Hadron Collider (LHC) via the kinetic approach to include the effects due to non-unity hadron fugacity during the evolution of produced hadronic matter and the temperature-dependent K_1 mass. Although the non-unity fugacity effect is found to reduce slightly the K_1/K^* enhancement due to chiral symmetry restoration, including the temperature-dependent K_1mass leads to a substantial reduction in the K_1/K^* enhancement. However, the final K_1/K^* ratio in peripheral collisions still shows a more than factor of two enhancement compared to the case without chiral symmetry restoration and thus remains a good signature for chiral symmetry restoration in the hot dense matter produced in relativistic heavy ion collisions.

Introduction

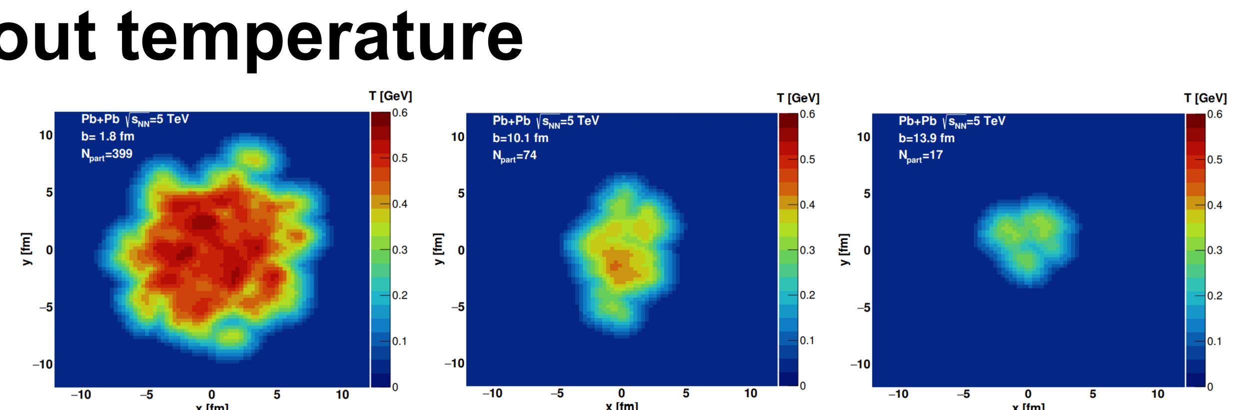




- Kinetic freeze-out temperature

M. L. Miller et al, Ann. Rev. Nucl. Part. Sci. 57, 205 (2007).

S. Acharya et al. [ALICE], Phys. Rev. C 101, no.4, 044907 (2020).[arXiv:1910.07678v2]

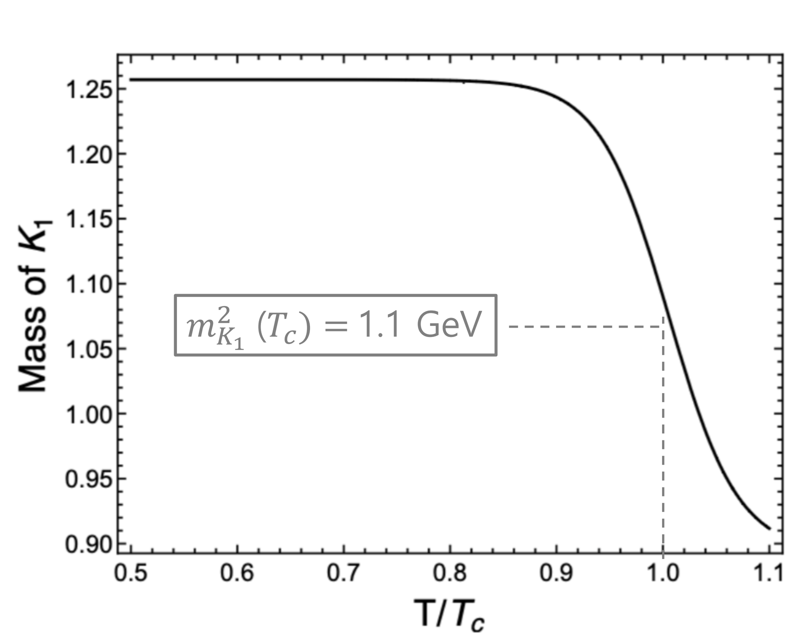


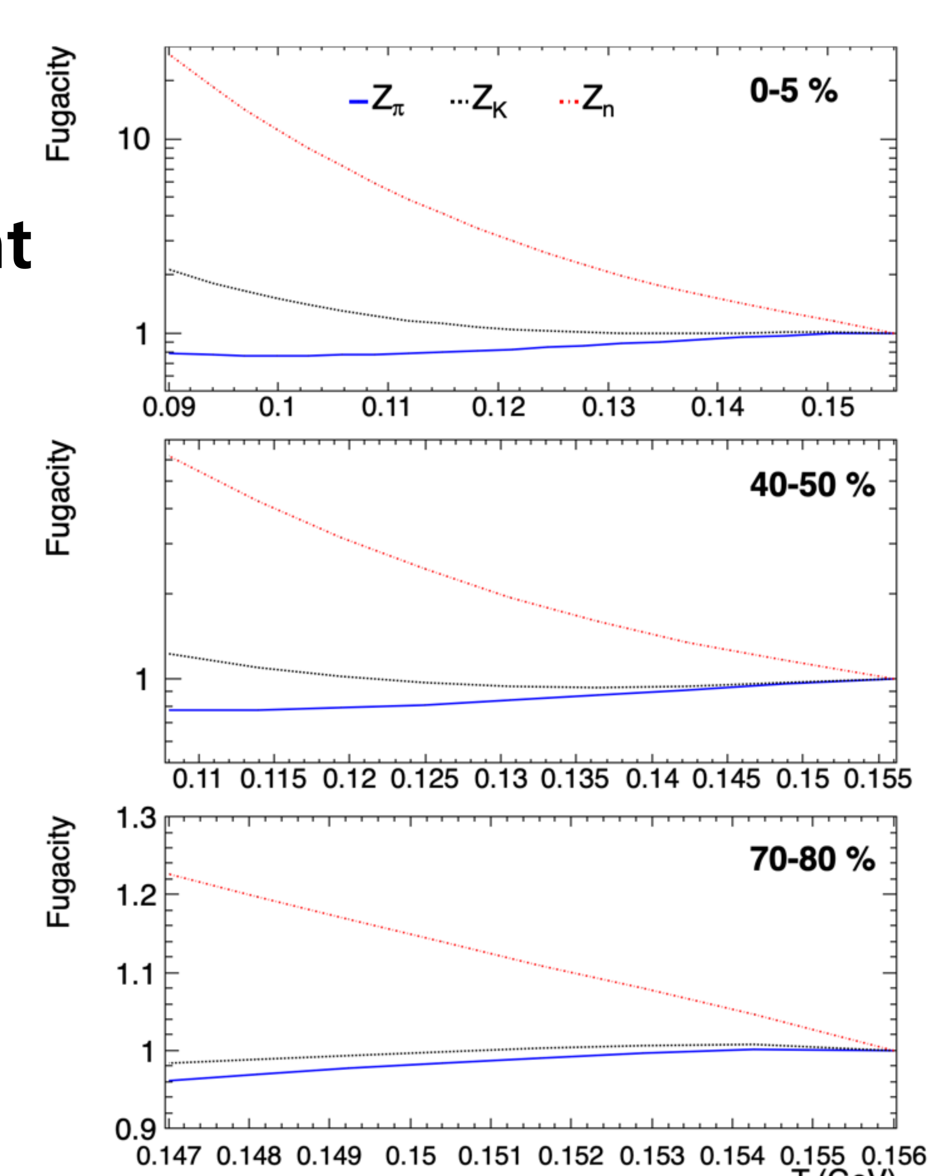
0 – 5 % : T_{kin} = 90MeV
40-50% : T_{kin} = 108MeV
70-80% : T_{kin} = 147MeV

The fraction of initial energy where the temperature is higher than **156MeV** is larger than **98%** in all three centrality ranges.

- π, K, and nucleon Fugacity &
- Temperature dependent K_1 Mass

$$m^2_{K_1}(T) = m^2_{K^*} + \frac{<\bar{q}q>_T}{<\bar{q}q>_0}(m^2_{K_1} - m^2_{K^*})$$





Method

- Kinematic Equation for K_1, K^*, and K

$$\frac{dN_{K_1}(\tau)}{d\tau} = \gamma_{K_1,K_1}(\tau)N_{K_1}(\tau) + \gamma_{K_1,K^*}(\tau)N_{K^*}(\tau) + \gamma_{K_1,K}N_K(\tau)$$

$$\frac{dN_{K^*}(\tau)}{d\tau} = \gamma_{K^*,K_1}(\tau)N_{K_1}(\tau) + \gamma_{K^*,K^*}(\tau)N_{K^*}(\tau) + \gamma_{K^*,K}N_K(\tau)$$

where

$$\begin{aligned}\gamma_{K_1,K_1} =& -(\langle\sigma_{K_1\pi\to K\pi}\rangle + \langle\sigma_{K_1\pi\to K^*\rho}v\rangle)z_\pi n_\pi^T \\ & -(\langle\sigma_{K_1\rho\to K^*\pi}v\rangle + \langle\sigma_{K_1\rho\to K\rho}v\rangle)z_\pi^2 n_\rho^T \\ & -\langle\Gamma_{K_1\to K^*\pi}\rangle - \langle\Gamma_{K_1\to K\rho}\rangle, \end{aligned} \tag{5}$$

$$\begin{aligned}\gamma_{K_1,K^*} =& (\langle\sigma_{K_1\pi\to K^*\rho}v\rangle n_\pi^T + \langle\sigma_{K_1\rho\to K^*\pi}v\rangle z_\pi n_\rho^T)\frac{n_{K_1}^T}{n_{K^*}^T} \\ & +\langle\Gamma_{K_1\to K^*\pi}\rangle\frac{n_{K_1}^T}{z_\pi n_{K^*}^T}, \end{aligned} \tag{6}$$

$$\begin{aligned}\gamma_{K_1,K} =& (\langle\sigma_{K_1\pi\to K\pi}v\rangle n_\pi^T + \langle\sigma_{K_1\rho\to K\rho}v\rangle z_\pi n_\rho^T)\frac{z_\pi^2 n_{K_1}^T}{n_K^T} \\ & +\langle\Gamma_{K_1\to K\rho}\rangle\frac{z_\pi n_{K_1}^T}{n_K^T}. \end{aligned} \tag{7}$$

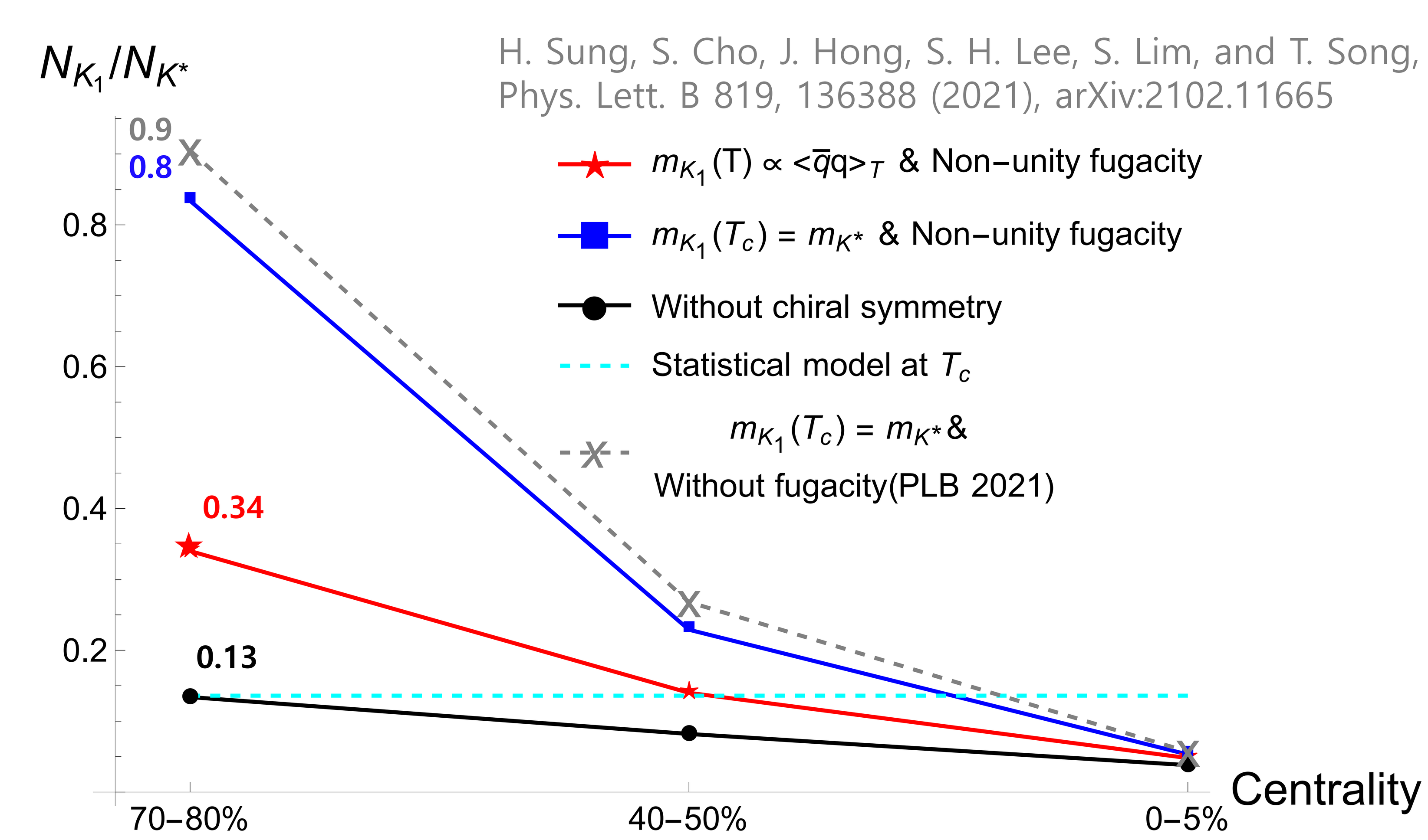
$$\begin{aligned}\gamma_{K^*,K_1} =& \langle\sigma_{K_1\pi\to K^*\rho}v\rangle z_\pi n_\pi^T + \langle\sigma_{K_1\rho\to K^*\pi}v\rangle z_\pi^2 n_\rho^T \\ & +\langle\Gamma_{K_1\to K^*\pi}\rangle, \end{aligned} \tag{9}$$

$$\begin{aligned}\gamma_{K^*,K^*} =& -\langle\sigma_{K^*\pi\to K\rho}v\rangle z_\pi n_\pi^T - \langle\sigma_{K^*\rho\to K\pi}v\rangle z_\pi^2 n_\rho^T \\ & -(\langle\sigma_{K_1\pi\to K^*\rho}v\rangle n_\pi^T + \langle\sigma_{K_1\rho\to K^*\pi}v\rangle z_\pi n_\rho^T)\frac{z_\pi^2 n_{K_1}^T}{n_{K^*}^T} \\ & -\langle\Gamma_{K^*\to K\pi}\rangle - \langle\Gamma_{K_1\to K^*\pi}\rangle\frac{z_\pi n_{K_1}^T}{n_{K^*}^T}, \end{aligned} \tag{10}$$

$$\begin{aligned}\gamma_{K^*,K} =& (\langle\sigma_{K^*\pi\to K\rho}v\rangle n_\pi^T + \langle\sigma_{K^*\rho\to K\pi}v\rangle z_\pi n_\rho^T)\frac{z_\pi^2 n_{K^*}^T}{n_K^T} \\ & +\langle\Gamma_{K^*\to K\pi}\rangle\frac{z_\pi n_{K^*}^T}{n_K^T}. \end{aligned} \tag{11}$$

Results

H. Sung, S. Cho, J. Hong, S. H. Lee, S. Lim, and T. Song, Phys. Lett. B 819, 136388 (2021), arXiv:2102.11665



Conclusion

- The effect of non-unity pion and kaon fugacity and the temperature dependent K_1 mass reduce the K_1/K^* enhancement due to chiral symmetry restoration
- However, the K_1 production will be about 2.6 times greater than that of the thermal prediction in Pb-Pb peripheral collisions(70-80%) at the energy $\sqrt{s} = 5.02TeV$.
- Therefore, the chiral symmetry restoration in heavy-ion collisions can be seen through centrality dependence of K_1 and K^* production.

$$K_1^- \to \begin{cases}\rho^0 K^- \\ \rho^- \bar{K}^0 \\ \pi^0 K^{*-} \\ \pi^- \bar{K}^{*0}\end{cases}, \quad \bar{K}_1^0 \to \begin{cases}\rho^+ K^- \\ \rho^0 \bar{K}^0 \\ \pi^+ K^{*-} \\ \pi^0 \bar{K}^{*0}\end{cases}$$

$$K^{*-} \to \begin{cases}\pi^0 K^- \\ \pi^- \bar{K}^0\end{cases}, \quad \bar{K}^{*0} \to \begin{cases}\pi^+ K^- \\ \pi^0 \bar{K}^0\end{cases}$$