Diffusion of charm hadrons and the Search of the QCD Critical Point

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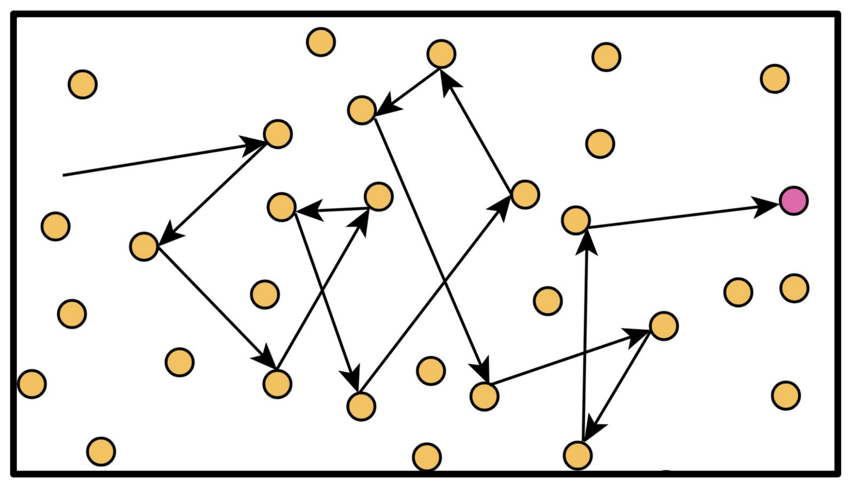
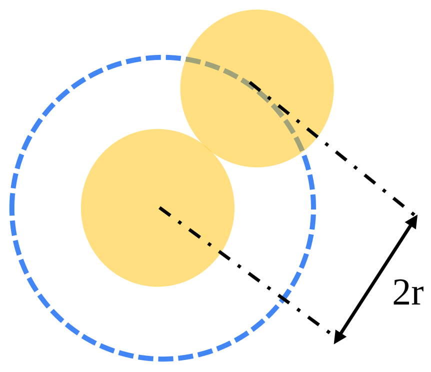
Based on: **Phys. Rev. D 111, 014029 (2025)**

Introduction



- Heavy quarks are an excellent probe to study the deconfined medium of quarks and gluons.
- Due to their much heavier mass, they undergo Brownian motion in a medium of lighter constituents.
- We employ the relativistic Fick's law and estimate the diffusion matric coefficient related to the conserved charges
- We use the Van der Waals hadron resonance gas model (VDWHRG) to estimate the diffusion matrix coefficient for baryon, strange, electric charge, and charm charges.

Van der Waals hadron resonance gas model (VDWHRG)



- Ideal hadron resonance gas (HRG) is a non-interacting statistical model consisting of hadrons and resonances.
- The agreement between ideal HRG results and the lattice observable in the crossover region deteriorates.
- The pressure in the ideal HRG model is given as,

$$P^{id}(\mu_i,T) = \Sigma_i \pm \frac{T g_i}{2\pi^2}\int_0^\infty p^2 dp\, \ln\left\{1+\exp\left[-\left(\frac{E_i-\mu_i}{T}\right)\right]\right\}$$

- The VDWHRG model introduces attractive and repulsive forces between the hadron species, using two parameters *a* and *b*.

$$\mathrm{a} = 0.926\ \mathrm{GeV\ fm^3},\ \mathrm{b} = \frac{16}{3}\pi \mathrm{r}^3$$
$$\mathrm{r_m} = 0.2\ \mathrm{fm\ and\ r_{B,\bar{B}}} = 0.62\ \mathrm{fm}$$

- The baryon-antibaryon interactions and attractive interaction among mesons have been neglected.
- The pressure and number density in the VDWHRG model are given as,

$$P_{VDW} = P_M + P_B + P_{\bar{B}}$$
$$P_{B,\bar{B}}(T,\mu) = P^{id}_{B,\bar{B}}(T,\mu^*) - a n^2_{B,\bar{B}}(T,\mu)$$

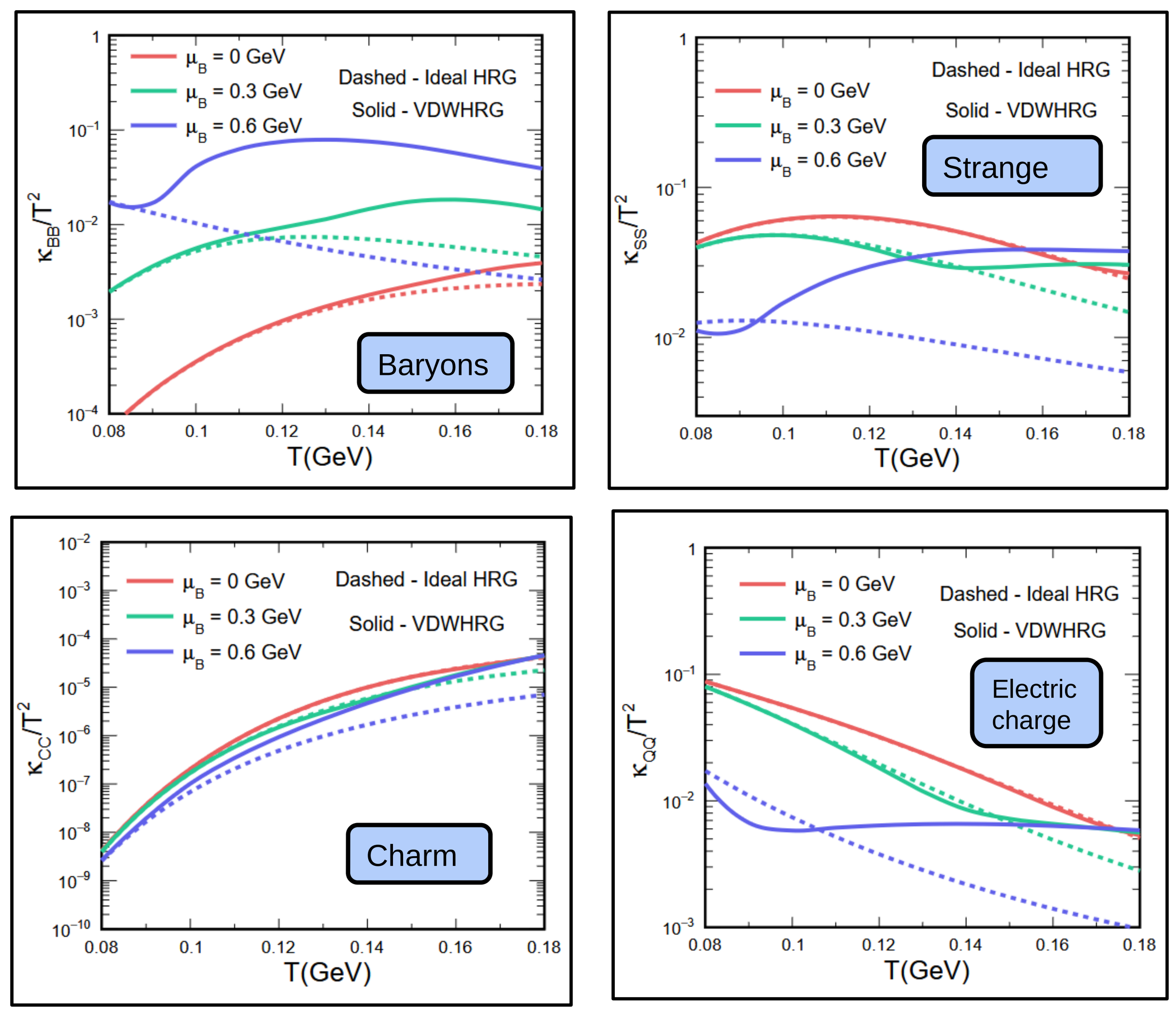
$$n(T,\mu) = \frac{\sum_i n_i^{id}(T,\mu^*)}{1+b\sum_i n_i^{id}(T,\mu^*)}$$

$$\mu^* = \mu - bP(T,\mu) - abn^2(T,\mu) + 2an(T,\mu)$$

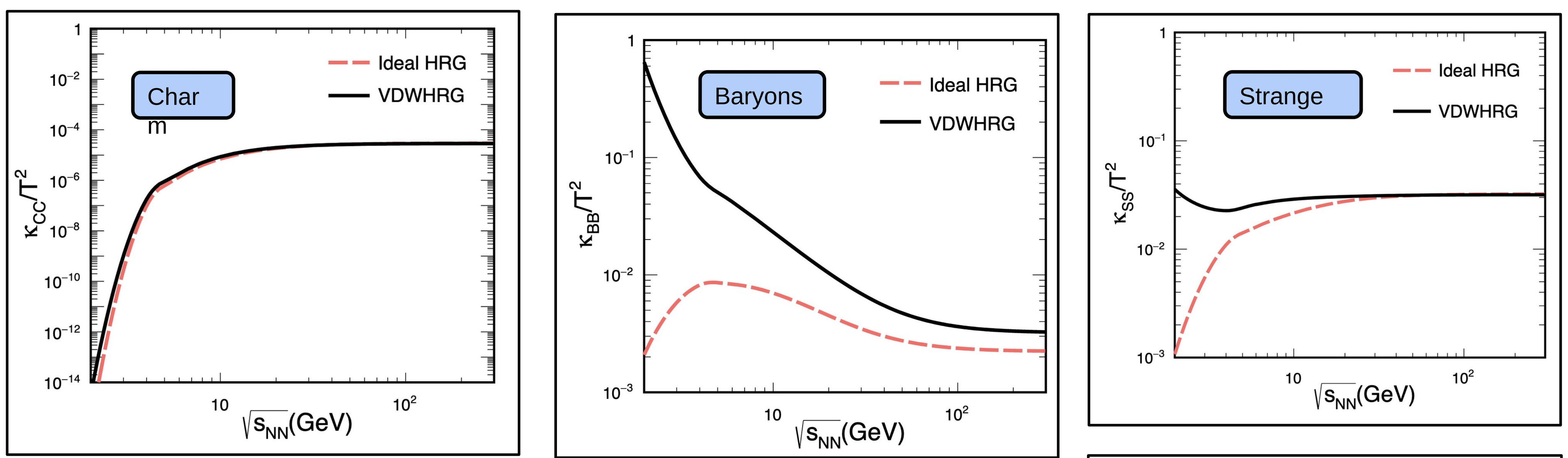
Results

- The diffusion matrix coefficient is estimated as:

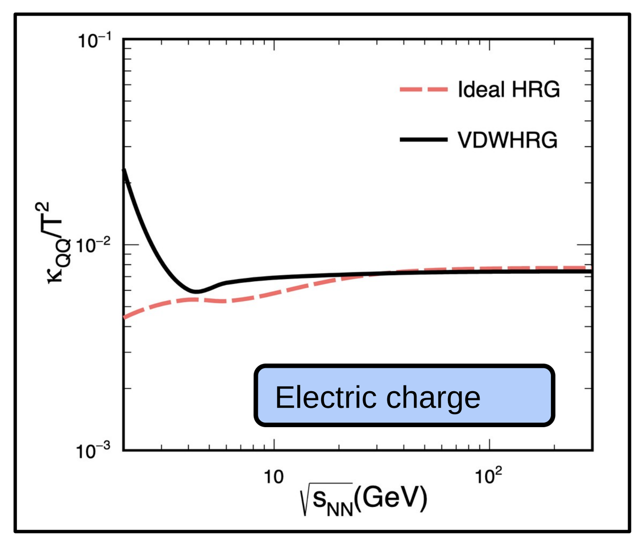
$$\kappa_{qq'} = \sum_i \int \frac{d^3p_i}{(2\pi)^3}\frac{p_i^2}{3E_i}\left(q_i - \frac{n_q E_i}{\omega}\right)\frac{\tau_i}{E_i}\left(q_i' - \frac{n_q' E_i}{\omega}\right) f_i^0$$



- We plot the diffusion matrix coefficient as a function of temperature for three different baryo-chemical potential.
- The VDWHRG results deviates more from the ideal HRG results at higher baryo-chemical potential and temperature.
- Due to the interaction in the VDWHRG model, the diffusion matrix coefficient values is comparatively higher than the ideal HRG model.



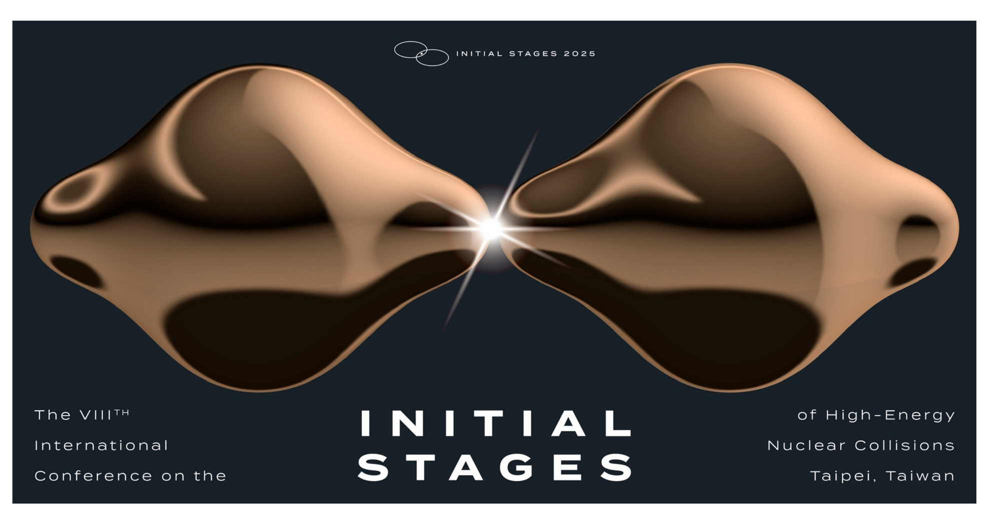
- We plot the diffusion coefficient matrix as a function of center of mass energy ($\sqrt{s_{NN}}$)
- We observe that, $\kappa_{CC} \ll \kappa_{BB}$, specifically at lower center of mass energy
- The proton number cumulants, which is a proxy for baryon number cumulants, are studied as a function of $\sqrt{s_{NN}}$, to estimate the location of the QCD critical point.
- For low center of mass energy, the baryon diffusion is maximum, which means the baryon number susceptibilities will be maximally affected.
- The charm hadrons are relatively less diffused as compared to baryons



A possibility to explore the QCD critical point with the net charm fluctuations instead of net proton fluctuations!

Summary

- We expand the 3X3 diffusion matrix to a 4X4 matrix by considering the contribution coming from charm sector
- We estimate the diagonal component of the diffusion coefficient as a function of center-of-mass energy
- A very small diffusion of the charm sector hints towards that they might be an effective probe to study the QCD critical point



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