Conserved number fluctuations under global rotation in a hadron resonance gas model

Overview: QCD phases, critical behaviour

- **QCD matter** in ultrarelativistic heavy-ion collisions (HIC)
- Phase diagram expected to have a critical point (CP), characterized by large correlation lengths and fluctuations
- Moments of fluctuations sensitive indicators of a transition between hadronic and quark–gluon matter, key to CP search

Fluctuations and Freeze-out

- Event-by-event analysis of fluctuations in baryon number (B), electric charge (Q) and strangeness (S) may help find CP
- Hyperon polarization measured in HIC
- Angular velocity, $\omega \sim 0.1\ \mathrm{fm}^{-1} \sim 0.02$ GeV

Global Rotation in the HRG model

- Causality condition: $R \leqslant 1/\omega$, where R=radius,
- **Free energy density** for neutral baryons(b) and mesons(m) is given by

$$f_{i,n}^{b/m} = \mp\frac{T}{8\pi^2}\int_{(\Lambda_l^{\mathrm{IR}})^2} dp_r^2 \int dp_z \sum_{l=-\infty}^{\infty}\sum_{\nu=l}^{l+2s_i} J_\nu^2(p_r r)$$

$$\boxed{\varepsilon_n=\sqrt{p_z^2+p_r^2+m^2}} \qquad \times \ln\left(1 \pm e^{-(\varepsilon_{i,n}-(l+s_i)\omega-\mu_i)/T}\right),$$

Susceptibilities and Moments

- Susceptibilities are related to the cumulants of the event-by-event multiplicity distributions thus

$$\chi^1 = \frac{1}{VT^3}\langle N\rangle,\ \chi^2 = \frac{1}{VT^3}\langle(\Delta N)^2\rangle,\ \chi^3 = \frac{1}{VT^3}\langle(\Delta N)^3\rangle,$$

$$\chi^4 = \frac{1}{VT^3}\langle(\Delta N)^4_c\rangle \equiv (\langle(\Delta N)^4\rangle - 3\langle(\Delta N)^2\rangle^2),$$

$$\chi^5 = \frac{1}{VT^3}\langle(\Delta N)^5_c\rangle \equiv \langle(\Delta N)^5\rangle - 10\langle(\Delta N)^3\rangle\langle(\Delta N)^2\rangle,$$

$$\chi^6 = \frac{1}{VT^3}\langle(\Delta N)^6_c\rangle \equiv \langle(\Delta N)^6\rangle - 15\langle(\Delta N)^4\rangle\langle(\Delta N)^2\rangle - 10\langle(\Delta N)^3\rangle^2 + 30\langle(\Delta N)^2\rangle^3\,.$$

- Susceptibilities' ratios yield products of moments

$$\frac{\chi^2}{\chi^1} = \frac{\sigma^2}{M},\quad \frac{\chi^3}{\chi^2} = S\sigma,\quad \frac{\chi^4}{\chi^2} = \kappa\sigma^2,\quad \frac{\chi^6}{\chi^2} = \kappa^H\sigma^4$$

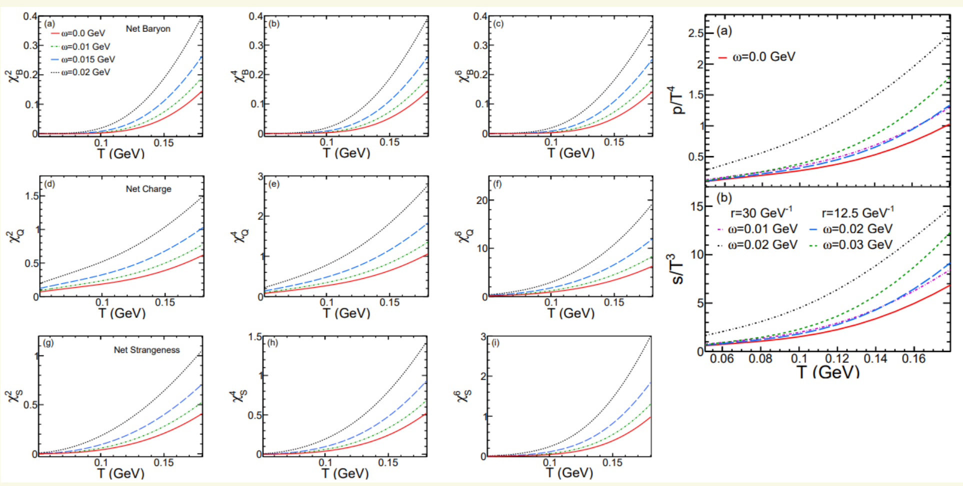

Figure: Left three columns: Susceptibilities as a function of T
Right: Equation of state: scaled pressure and entropy density

Results: Possible role of Rotation

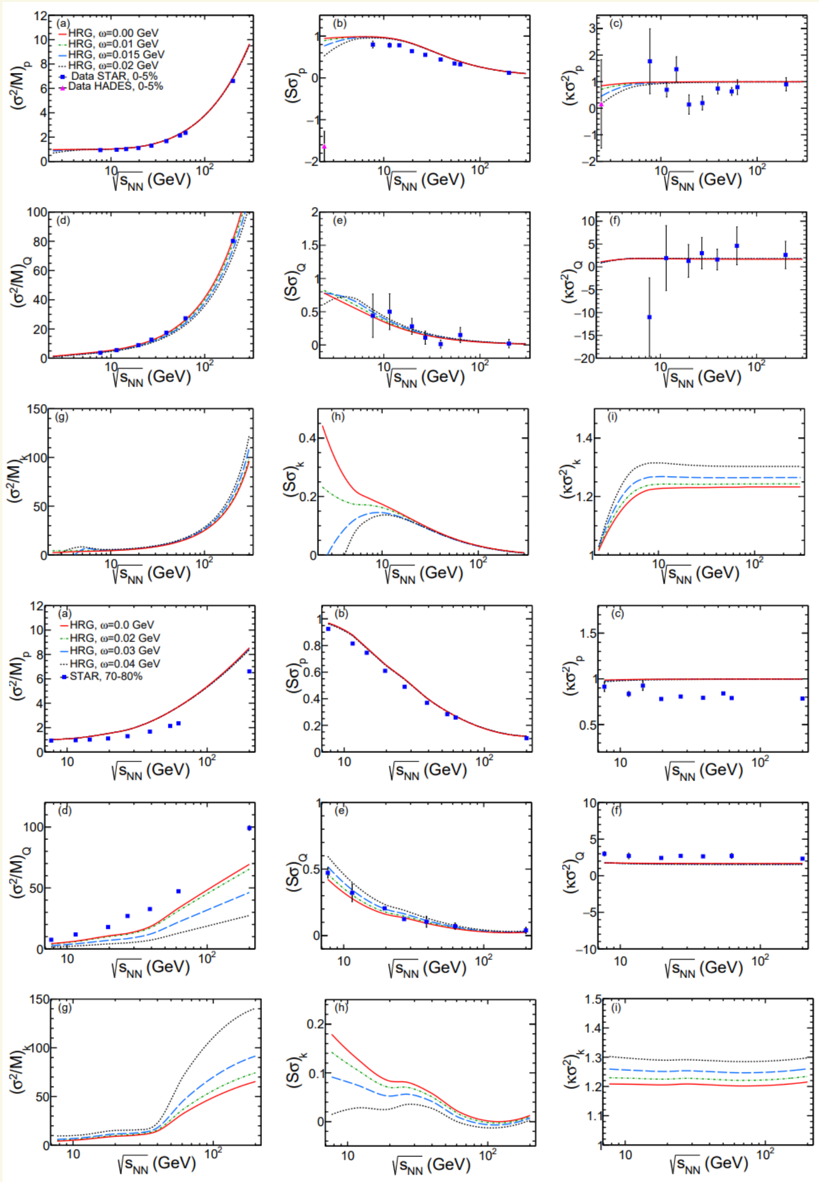

Figure: Top three rows: Products of moments of net-proton, net-charge and net-kaon as functions of the centre-of-mass energy for different angular velocity. Bottom three rows: Same as above but with parameters possibly relevant for peripheral collisions.

- Model results may serve as baseline predictions for the thermal system at chemical freeze-out
- If deviations are found it may signal that some memory of the actual phase transition is retained even at freeze-out
- Critical fluctuations may help to locate CP and determine quark-gluon plasma to hadron gas phase transitions
- References: Fujimoto etal, Phys.Lett.B 816(2021)136184; **Also see:** arXiv:2304.14658, arXiv:2304.12643

Conclusion and Scope

- Rotation does not seem to strongly affect HRG results on moments of conserved charge fluctuations in the parameter range applicable for present/upcoming colliders. Accompanying magnetic field may amplify the effects.

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