QUARK MATTER KRAKÓW 2022

Onset of light & heavy meson quenching in small systems

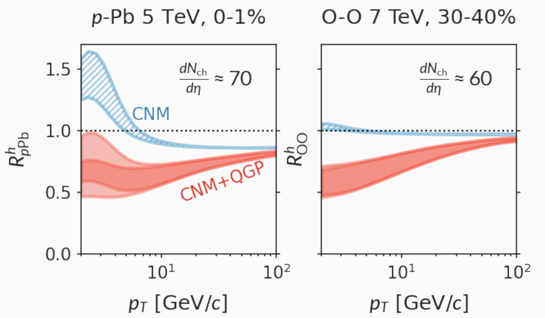
Weiyao Ke and Ivan Vitev, Los Alamos National Laboratory

Bottom line up front

Predictions of QGP signals in small systems ▷

- Include dynamical CNM effects to better understand the baseline.
- QGP-modified splitting functions from $\mathrm{SCET_G}$ + modified DGLAP evolution.
- HTL collisional energy loss (more important in small systems).

Based on W. Ke, I. Vitev arXiv:2204.00634

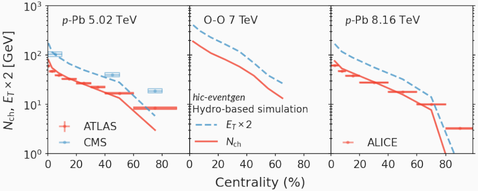


Challenges of identifying QGP signals in small systems with high-p_T hadrons

- Potential cold nuclear matter (CNM) effects distort the baseline
  This work $\rightarrow$ dynamical calculations of CNM modifications [1].
- Nuclear geometry / centrality definition:
  This work $\rightarrow$ study both *p*-Pb, *d*-Au and light-ion systems O-O.
- Is there a QGP? How it evolves in small systems?
  This work $\rightarrow$ test two extremes:
  - No QGP formation, color density=0 (or, the medium scattering centers).
  - QGP formation with maximum color density $\propto T^3$, given by hydrodynamic simulation [2] $\triangledown$.

Max. T of QGP using lattice EoS [3]

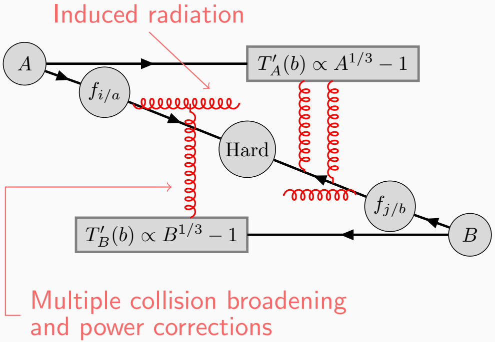
Systems	*p*-Pb 5 TeV		O-O 7 TeV	
	0-1%	60-90%	0-10%	30-50%
$T_{\max}$ [GeV]	0.315	0.174	0.325	0.263

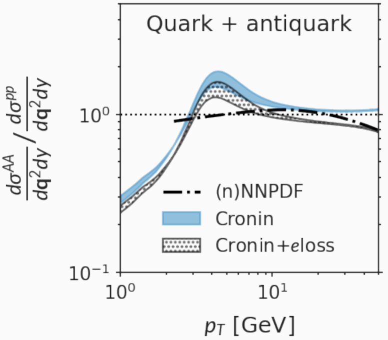


Dynamical cold nuclear matter (CNM) effects

- Cronin (broadening) effect: $\Delta \mathbf{k}_\perp^2 \propto \mu^2 A^{1/3}$; dynamical shadowing: $\delta x_a / x_a \propto \frac{\mu^2 B^{1/3}}{-u}$ [4]
- Cold nuclear matter energy loss from collision-induced soft gluon emission [5]

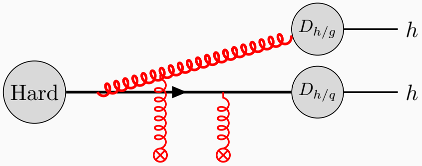
$$\frac{\Delta x_a}{x_a} \approx \frac{\alpha_s C_R}{\pi^2} \frac{L_B}{\lambda_g} \int_0^{\frac{\mu p^+}{4}} d^2\mathbf{q}_\perp \frac{\mu^2}{\pi(\mathbf{q}_\perp^2 + \mu^2)^2} \left[\frac{\mathbf{q}_\perp^2}{\mathbf{k}_\perp^2 (\mathbf{k}_\perp - \mathbf{q}_\perp)^2} - \frac{2(\mathbf{q}_\perp^2 - \mathbf{q}_\perp \cdot \mathbf{k}_\perp)}{\mathbf{k}_\perp^2 (\mathbf{k}_\perp - \mathbf{q}_\perp)^2} \frac{\sin \frac{\mathbf{k}_\perp^2 L_B}{x p^+}}{\frac{\mathbf{k}_\perp^2 L_B}{x p^+}} \right]$$





△ Dynamical approach compared to nNNPDF [6]

QGP effects in large and small systems



- HTL collisional energy loss of hard parton [7]:

$$\frac{dE_{\mathrm{el}}}{d\Delta z} = \frac{C_R}{4}\alpha_s(ET)m_D^2 \ln\left(\frac{ET}{m_D^2}\right)\left(\frac{1}{v} - \frac{1-v^2}{2v^2}\ln\frac{1+v}{1-v}\right)$$

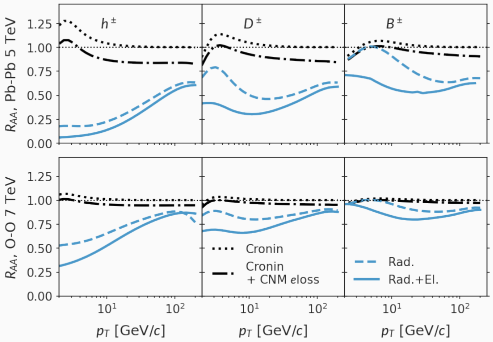
- QGP-modified fragmentation functions:

$$\frac{\partial D_{h/i}}{\partial \ln Q^2} = [P_{ji}^{\mathrm{vac}} + \Delta P_{ji}^{\mathrm{med}}(E - \Delta E_{\mathrm{el}})] \otimes D_{h/j}$$

obtained in SCET$_{\mathrm{G}}$ [8]

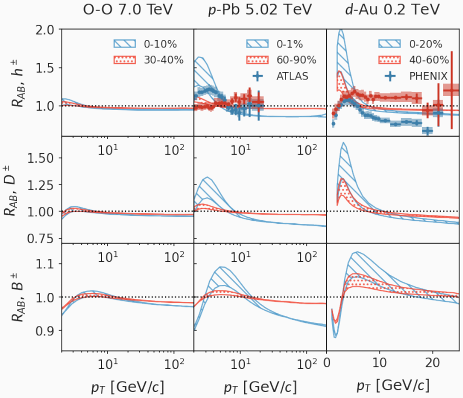
In small systems:

- Collisional energy loss becomes more important. For example $T^3 \propto \tau^{-\alpha}$: $\Delta E_{\mathrm{rad}} \propto L^{2-\alpha}$ v.s. $\Delta E_{\mathrm{el}} \propto L^{1-\frac{2}{3}\alpha}$
- Use heavy flavor to further suppress radiation to study collisional process.

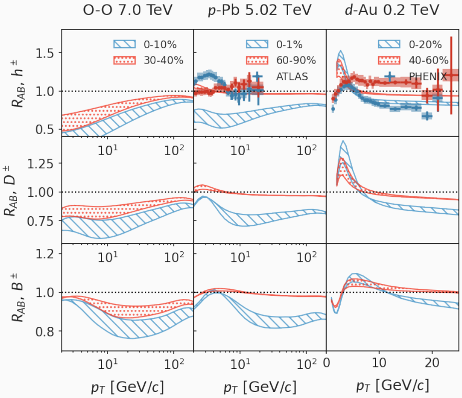


Results

Scenario I: no QGP formation, only cold nuclear matter effects



Scenario II: QGP formed with a local-thermal color charged density



- *d*-Au data: PHENIX [9]; *p*-Pb data: ATLAS [10] (with $\langle T_{pA} \rangle$ from the Glauber-Gribov model)
- Compare to *d*-Au & *p*-Pb, CNM effects in O-O are small → ideal to searching for QGP.
- QGP effects in *d*-Au at RHIC energy is small.
- In *p*-Pb at LHC energy, QGP effects with color density $\propto T^3$ is inconsistent with data.

Conclusion & references

CNM effects

- are strong in small asymmetry systems such as p-Pb and d-Au;
- are much weaker in light-ion system O-O;
- can introduce centrality-dependent suppression at large p_T due to CNM energy loss.

QGP effects?

- QGP effects with color-source density give by hydrodynamics ($\propto T^3$) is inconsistent with R^h_{AA} in p-Pb.
- $\Delta E^{el}/\Delta E^{rad}$ increases in small systems: a change in the flavor separation of R_{AA}.
- Future scenario III: jet quenching with non-equilibrium color charged density.

References:

[1] Z.-B. Kang, I. Vitev, H. Xing, Phys. Lett. B 718, 482–487 (2012). [2] Jonah E. Bernhard, 1804.06469; H. Song, U. Heinz, Phys. Rev. C. 77, 064901 (2008). [3] A. Bazavov et al.,Phys. RevD. 90, 094503 (2014). [4] J.-W. Qiu, I. Vitev, Phys. Let. B 632, 507-511 (2006). [5] I. Vitev, Phys. Rev. C 75, 064906 (2007). [6] R. A. Khalek et al. (nNNPDF3.0), arXiv:2201.12363. [7] E. Braaten, M. H. Thoma, Phys. Rev. D 44, R2625(R)(1991). [8] G. Ovanesyan, I. Vitev, JHEP 06, 080 (2011). [9] PHENIX, Phys. Rev. C. 96, 064905 (2017). [10] ATLAS, Phys. Lett. B. 763, 313-336 (2016).