Impacts of heavy-flavor probes in small colliding systems
Weiyao Ke & Ivan Vitev, Los Alamos National Laboratory, arXiv:2204.00634

**Bottom line up front**

- Dynamical CNM effects for no-QGP baselines.
- QGP-modified splitting functions from SCET$_G$ + modified DGLAP evolution.
- Collisional energy loss more important in small systems.

![Graphs showing $R_{pPb}$ and $R_{O-O}$ as functions of $p_T$]
Challenges of identifying QGP signals in small systems with high-$p_T$ hadrons

- Potential cold nuclear matter (CNM) effects distort the baseline.  
  **This work** → dynamical calculations of CNM modifications [1].

- Nuclear geometry / centrality definition:  
  **This work** → study both $p$-$Pb$, $d$-$Au$ and light-ion systems O-O.

- Is there a QGP? How it evolves in small systems?  
  **This work** → test two extremes:
  - No QGP formation, color density=0 (medium scattering centers=0).
  - QGP formation with maximum color density $\propto T^3$, given by hydrodynamic simulation [2].

### Max. $T$ of QGP using lattice EoS [3]

<table>
<thead>
<tr>
<th>Systems</th>
<th>$p$-$Pb$ 5 TeV</th>
<th>O-O 7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-1%</td>
<td>60-90%</td>
</tr>
<tr>
<td>$T_{max}$ [GeV]</td>
<td>0.315</td>
<td>0.174</td>
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</tbody>
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Dynamical cold nuclear matter (CNM) effects

- Cronin (broadening) effect: $\Delta k_\perp^2 \propto \mu^2 A^{1/3}$; 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]

\[ \frac{\Delta x_a}{x_a} \approx \frac{\alpha_s C_R L_B}{\pi^2 \lambda_g} \int_0^{\mu B^+} d^2 q_\perp \frac{\mu^2}{\pi (q_\perp^2 + \mu^2)^2} \left[ \frac{q_\perp^2}{k_\perp^2 (q_\perp - q_\perp \cdot k_\perp)^2} - \frac{2(q_\perp^2 - q_\perp \cdot k_\perp)}{k_\perp^2 (q_\perp - q_\perp)^2} \frac{\sin \frac{k_\perp^2 L_B}{xp^+}}{k_\perp^2 L_B / xp^+} \right] \]

Hard

\[
\begin{align*}
T'_A(b) &\propto A^{1/3} - 1 \\
T'_B(b) &\propto B^{1/3} - 1
\end{align*}
\]

\[
\begin{align*}
\frac{d\sigma^{AA}_{\text{pp}}}{dp_T^{AA}} &\approx \frac{d\sigma^{\text{pp}}}{dp_T^{\text{pp}}} \\
\text{Cronin + Power Corr.} &\quad \text{Cronin + Power Corr. + e loss}
\end{align*}
\]

\[ q+\bar{q}, \text{Au+Au 0.2 TeV, 30-50%} \]

\[ \triangle \text{Dynamical approach compared to nNNPDF [6]} \]
QGP effects in large and small systems

- HTL collisional energy loss of hard parton [7]:
  \[
  \frac{dE_{\text{el}}}{d\Delta z} = \frac{C_R}{4} \alpha_s(\hat{T}) m_D^2 \ln\left(\frac{\hat{T}}{m_D^2}\right) \left(\frac{1}{v} - \frac{1-v^2}{2v^2} \ln \frac{1+v}{1-v}\right)
  \]
  More important in small systems

- QGP-modified fragmentation functions:
  \[
  \partial_{\ln Q^2} D_{h/i} = [P_{ji}^{\text{vac}} + \Delta P_{ji}^{\text{med}}] \otimes D_{h/j}
  \]
  obtained in SCET [8]

\[Q = p_T = 30 \text{ GeV} \]
\[p-\text{Pb} 5.02 \text{ TeV}, 0-1\%\]

\[p_T [\text{GeV}/c] \]
\[p_T [\text{GeV}/c] \]
**Scenario I: no QGP formation, only cold nuclear matter effects**

- 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.

**Scenario II: QGP formed with a local-thermal color charged density**
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 $R_{AA}^h$ 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: