System size scan of D meson $R_{AA}$ and $\nu_n$ using PbPb, XeXe, ArAr, and OO collisions at LHC

Jacquelyn Noronha-Hostler
Collaborators: Roland Katz, Caio A.G. Prado, Alexandre A.P. Suaide
Motivation 1:
What makes theory match data?

What is the data actually telling us?

(Bayesian) Yingru Xe et al, Phys.Rev. C97 (2018) no.1, 014907
DAB-MOD


- Heavy flavor (D and B mesons) package that allows for a variety of parameterized energy loss models or relativistic Langevin models.

- Coalescence

- Event-by-event relativistic viscous hydrodynamics v-USPhydro  JNH et al, PRC88(2013)no.4,044916; PRC90(2014)no.3,034907

- pQCD FONLL calculations for initial quark distributions

New additions
Initial conditions: Trento/mckln

Heavy Quark Sampling: pOCD FONLL

Oversampling of heavy quarks
No cold nuclear matter effects or shadowing

Minimum 1000 initial conditions/centrality
Hydro evolution: v-USPhydro

Heavy quark evolution: Either parameterized energy loss or relativistic Langevin model

Hydrodynamic parameters tuned to reproduce soft observables
Trento+v-USPhydro


- Trento initial conditions

- v-USPhydro

- Equation of State: EOS2+1 from Lattice QCD

- Viscosity $\eta/s = 0.047$

- Freeze-out $T_{FO} = 150\,\text{MeV}$

- PDG16+
Heavy Quarks in a hot QGP


- **Parameterized Energy loss model**
  \[
  \frac{dE}{dL} = -f(T, p, L)\zeta \Gamma_{\text{flow}}
  \]

- **Parameterized Energy loss fluctuations** $\zeta$
  Betz&Gyulassy JHEP 1408 (2014) 090

- **Medium contribution**
  \[
  \Gamma_{\text{flow}} = \gamma \left[ 1 - v_{\text{flow}} \cos(\phi_q - \phi_{\text{flow}}) \right]
  \]

- **Langevin Model** (QCD+HTL)
  \[
  dp_i = -\Gamma(\vec{p})p_i dt + \sqrt{dt\kappa \rho_i}
  \]
  \[
  \kappa = 2T^2/D
  \]
  Diffusion coefficients from:
  - **M&T** $D \propto 1/(2\pi T)$
  - **G&A running coupling**
**Hydro particlization:** Cooper-Frye+decays

**Heavy quark fragmentation:** Petersen fragmentation function+light/heavy quark coalescence

Semi-leptonic decays done in Pythia8
$R_{AA}$: “Best Fit” PbPb 5.02 TeV results


$D^0$ meson, 0-10%, Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV

$T_d = 160$ MeV
Azimuthal anisotropies (hard/heavy)

Scalar Product [1] - 1 soft+1 hard particle correlation

\[ v_n\{SP\}(\rho_T) = \frac{\langle v_n^{\text{soft}} v_n^{\text{hard}}(\rho_T) \cos(n[\psi_n^{\text{soft}} - \psi_n^{\text{hard}}(\rho_T)])\rangle}{\sqrt{\langle (v_n^{\text{soft}})^2 \rangle}} \]

Rapidity gap to suppress non-flow

Averaging over events [2] (∼ 5% effect theoretically [3])

- Calculated in 0.5% centrality bins
- \(\langle \cdots \rangle \rightarrow \) multiplicity weighing
- 0.5% rebinned into 5% or 10%


$v_2 \{2\}$: “Best Fit” PbPb 5.02 TeV

Motivation 2: D meson scaling with system size

Can we understand system size dependence of energy loss?
Comparisons between soft and hard sector?
PROPOSAL FOR COLLISIONS

$^{40}\text{Ar}^{40}\text{Ar} \quad ^{16}\text{O}^{16}\text{O}$

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams

Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

Hydro already worked well with XeXe collisions

$R_{AA}$ across system size


- $R_{AA} \to 1$ as the system size decreases
- $R_{AA}$ from energy loss less than from Langevin
SOFT SECTOR: UNIVERSAL SCALING VS. HIERARCHY

Sievert, JNH, Phys.Rev.C 100 (2019) 2, 024904

Size Hierarchy

Universal Scaling
TYPICAL EVENTS

PbPb and XeXe events larger, more elliptical.

ArAr and OO smaller and rounder.

Small systems are hotter

Sievert, JNH, Phys.Rev.C 100 (2019) 2, 024904
Geometry and system size


- Central collisions: as size ↓ system is more elliptical
- Mid-central collisions: as size ↓ system, shape is nearly constant
Mid-Central collisions


- **0-10% centrality**: $v_2 \sim \text{const}$ across system size ($\uparrow$ in $\varepsilon_2$ with $\downarrow$ R)
- **30-50% centrality**: $v_2 \downarrow$ with $\downarrow$ system size ($\varepsilon_2 \sim \text{const.}$)
Sources of uncertainty

- **Soft sector**: overall normalization constant tuned to $dN/dy$

- **Heavy flavor sector**: overall normalization constant tuned to $R_{AA}$

Here we assume both remain constant across system size, but we really need experimental data to be sure!!
Conclusions and Outlook

- DAB-MOD is a modular heavy flavor code that can compare energy loss vs. Langevin directly with the same hydrodynamic backgrounds
  
- Langevin works best at low pT and Energy loss at high pT

- Comparing PbPb, XeXe, ArAr, OO collisions:
  
  - $v_2$ of D mesons $\sim$const in 0-10% and sensitive to system size in 30-50%

  - More suppression of D mesons from Energy loss than Langevin

- More RHIC/sPHENIX results to come.