A hybrid transport model for heavy quarks

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Introduction

- A hybrid transport model of heavy quark evolution in a QGP medium:
  - Scattering with medium partons using LO pQCD.
  - Non-perturbative interactions missing from the LO pQCD picture are treated via a diffusion equation.
- Calibrate model and extract transport properties.
- Validate model and predict novel observables.

Leading order pQCD scattering

Linearized Boltzmann equation \( \frac{df}{dt} = C^{+2+2}[f] + C^{+2+2}[f] \).
- Elastic: \( Qg(q) \to Qg(q) \)
- Radiation (Gunion-Bertsch): \( Qg(q) \to Qg(q) + g \)
- Absorption: \( Qg(q) + g \to Qg(q) \)
- Matrix-elements screened by \( m_g, m_q \).
- Model Landau-Pomeranchuk-Migdal effect by modifying radiated/absorbed gluon phase space,
  \[ \int \frac{dk^3}{2k} \int \frac{dk^3}{2k} \left[ 1 - \cos \left( \frac{t - t_0}{\tau_f} \right) \right], \]
  \( t_0 \): time of last radiation/absorption, \( \tau_f \): gluon formation time. Suppress inelastic channel for \( \Delta t < \tau_f \).

*Parameters of the pQCD interactions:
- \( \mu \): medium scale parameter controls the minimum \( Q \) in the running coupling constant \( \alpha_s(\mu Q T) \).

Diffusion

Langevin equations govern non-perturbative and soft interactions between heavy quarks and the QGP medium,

\[ \Delta p_{t} = -\eta_\rho \Delta t + \sqrt{\kappa_\Delta \xi_{t,i}(t), \xi_{t,i}(t)} = \delta_{ij}, \]

- Empirical diffusion coefficients parameterization,
  \[ \kappa_D \equiv \frac{\kappa}{\tau_f} = \kappa_D \left( x_D + (1-x_D) \frac{1}{2} E T \right) . \eta_D = \kappa - \frac{d\kappa}{dE} \]

*Parameters of the diffusion coefficients:
- \( \kappa_D \): the magnitude of diffusion at \( ET = 1 \text{ GeV}^2 \).
- \( x_D \): \( E \)-independent fraction of \( \kappa \) at \( ET = 1 \text{ GeV}^2 \).

Coupling to medium evolution

Medium evolution model was calibrated to \( dN_{qs}/d\eta, \eta_\rho, (\rho_T), (\rho_T) \) fluctuation at the LHC.

\[ \tau = 0^+ \]
\[ \tau < \tau_{\text{H}} \]
\[ \tau_{\text{H}} < \tau < 1.2 \]
\[ \tau > 1.5 \text{ MeV} \]
\[ \tau < 154 \text{ MeV} \]
\[ \tau > 154 \text{ MeV} \]

*Additional parameter:
- \( \tau_{\text{H}} \): heavy quark energy loss starting time.

Summary

- New hybrid transport model for heavy quark evolution in a QGP medium. Heavy quarks undergo perturbative scattering and non-perturbative diffusion.
- The calibrated model describes the experimental data at the RHIC and the LHC.
- The extracted transport coefficients overlap with previous work and static lattice calculations.

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Bayesian parameter calibration at 5.02 TeV Pb+Pb

Calibrate on \( R_{AA}^{A*} \) event-engineered \( v_P^2 \) and \( R_{AA}^{A*} \) nuclear PDFs: EPPS and nCTEQ.

- Different nuclear PDF barely affects parameter extraction.
- Relatively large \( \alpha_s(0.65 T) \). \( \alpha_s(Q = 0.65 T) \sim 0.5 \sim 1.0 \)
- A small non-perturbative diffusion.

- \( q = q[\text{el. scatter}] + q[NP], \)
  \[ 2\pi T \Delta_s = 8\pi T^2/(q|NP|) \]

- Comparison to earlier extraction (Xu et al) and lattice calculations. This work overlaps with lattice calculations in the static limit.*

Validation and predictions

Pick high-probability parameter set, \( \tau_{H} = 0.9 \text{ fm}/c, \mu = 0.6, \kappa_D = 0.4, x_D = 0.5 \).

- Validation: compare to experimental data that are not calibrated on. ALICE \( R_{AA}^{pPb}, \) CMS \( v_P^2, \) STAR \( R_{AA}^{pPb}, \) and STAR \( v_P^2. \)
- Predictions: \( v_1^2, v_3^2, R_{AA}^{A*} \) and D-meson \( v_1 \) relative to event-plane \( \Psi_3. \)

- \( v_T \) - \( \Psi_3 \) at mid-rapidity.

References

ALICE: PRL 113, 232301; PRL 120, 102301; EPJ 17, 13401; arXiv:1804.09683.