Langevin approach to heavy-quark diffusion and quarkonium formation in the QGP

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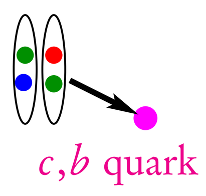
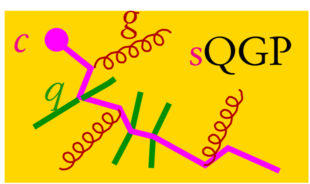
Introduction

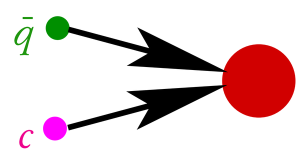
- Strongly coupled quark-gluon plasma (QGP)
  - ultrarelativistic heavy-ion collsions: medium well described by hydrodynamics
  - collective radial and elliptic flow (v_2); constituent-quark number scaling of v_2
  - low-viscosity strongly coupled quark-gluon plasma
- heavy-quark probes
  - heavy charm and bottom quarks produced in primordial hard collisions
  - calibrated initial conditions from pp collisions
  - conserved in strong interactions with bulk medium of light quarks and gluons
  - R_{AA} and v_2 of D, B mesons and non-photonic single electrons ⟺ transport properties of the sQGP
  - can be described in relativistic Fokker-Planck/Langevin model
- theory scheme for heavy quarks



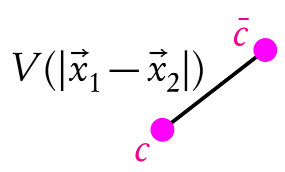
initial collisions: UrQMD + (3+1) hydro; Glauber model
hard production of HQs
described by PDF's + pQCD (PYTHIA)



HQ rescattering in QGP: Langevin simulation
drag and diffusion coefficients from
microscopic model for HQ interactions in the sQGP
description of bulk matter: UrQMD + (3+1)-dim hydro



Hadronization to D,B mesons via
quark coalescence + fragmentation



$c\bar{c}$-pair can form (classical) bound state ⟷ quarkonia

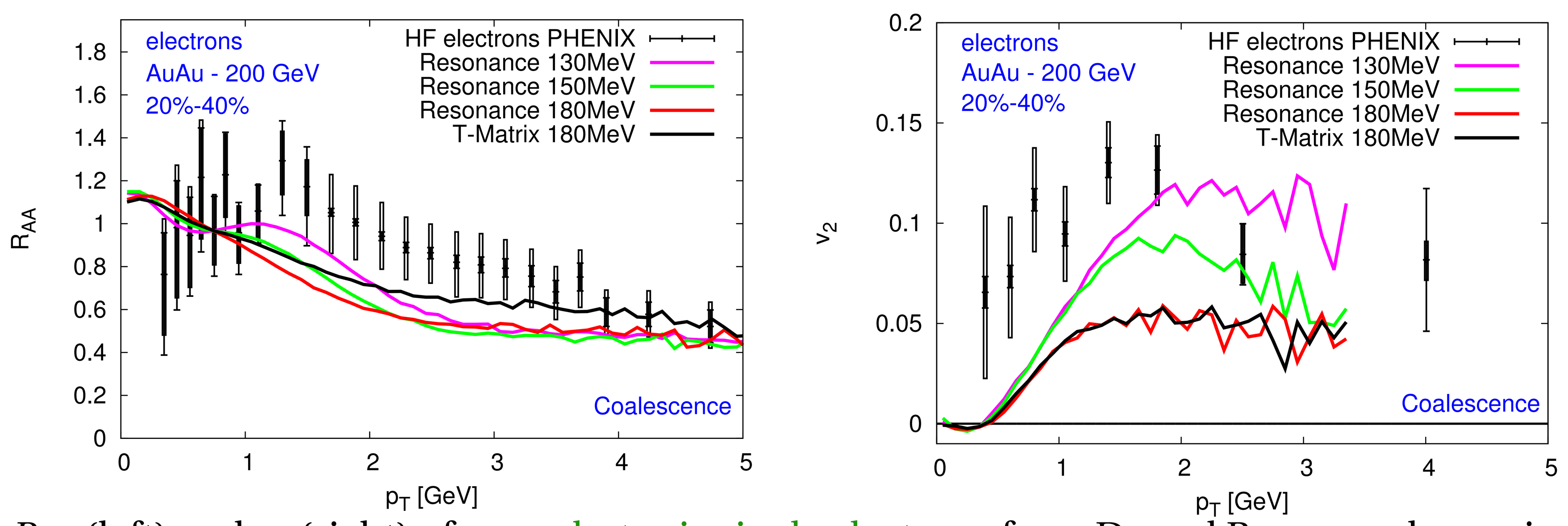
Heavy-quark diffusion

- Relativistic Langevin simulation
  - heavy-quark diffusion in hydrodynamic background

$$\mathrm{d}\vec{x} = \frac{\vec{p}}{E}\mathrm{d}t, \quad \mathrm{d}\vec{p} = -\Gamma\vec{p}\,\mathrm{d}t + \sqrt{\mathrm{d}t}\,\hat{C}\vec{\rho}$$

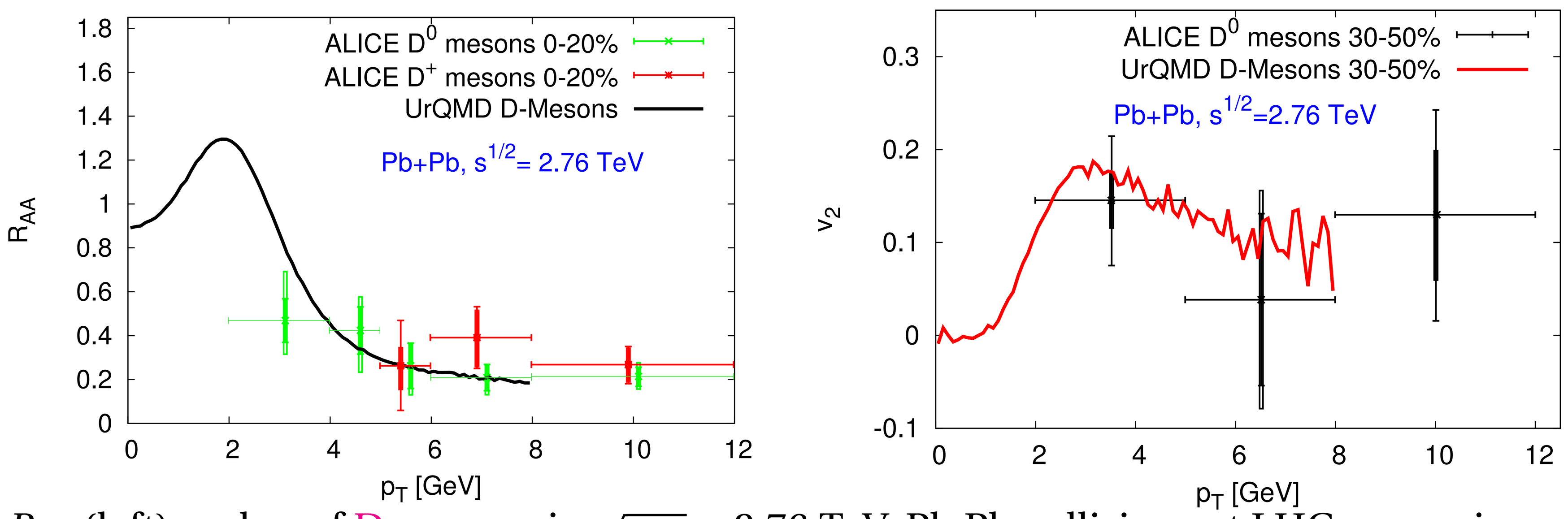
  - $\vec{\rho}$: Gaussian noise, Γ: drag coefficient, $\hat{C} = \sqrt{\hat{D}}$ with $\hat{D}$: diffusion coefficient
  - use post-point Ito realization of stochastic process [1] with diffusion coefficient $D_{\|} = E\Gamma T$ ⇒ ensures correct relativistic equilibrium limit
  - drag and diffusion coefficients: from microscopic models for elastic HQ scattering
  - assume D/B-like resonance formation above T_c [2, 3] or T-matrix approach with lQCD in-medium qQ potentials [4]
  - extrapolate cross sections into hadronic phase
- hadronization
  - use coalescence description at decoupling temperature T_{dec} to recombine c/b quarks with light antiquarks to D/B mesons
  - use PYTHIA for semileptonic decay of D/B mesons to "non-photonic" electrons
- background medium: UrQMD+hydro model or elliptic-fireball parametrization

Non-photonic single electrons at RHIC



R_{AA} (left) and v_2 (right) of non-photonic single electrons from D- and B-meson decays in $\sqrt{s_{\mathrm{NN}}} = 200$ GeV-Au Au collisions at RHIC, assuming different decoupling temperatures. Using coalescence for hadronization process crucial for consistency between R_{AA} and v_2 (data from the PHENIX collaboration [5]).

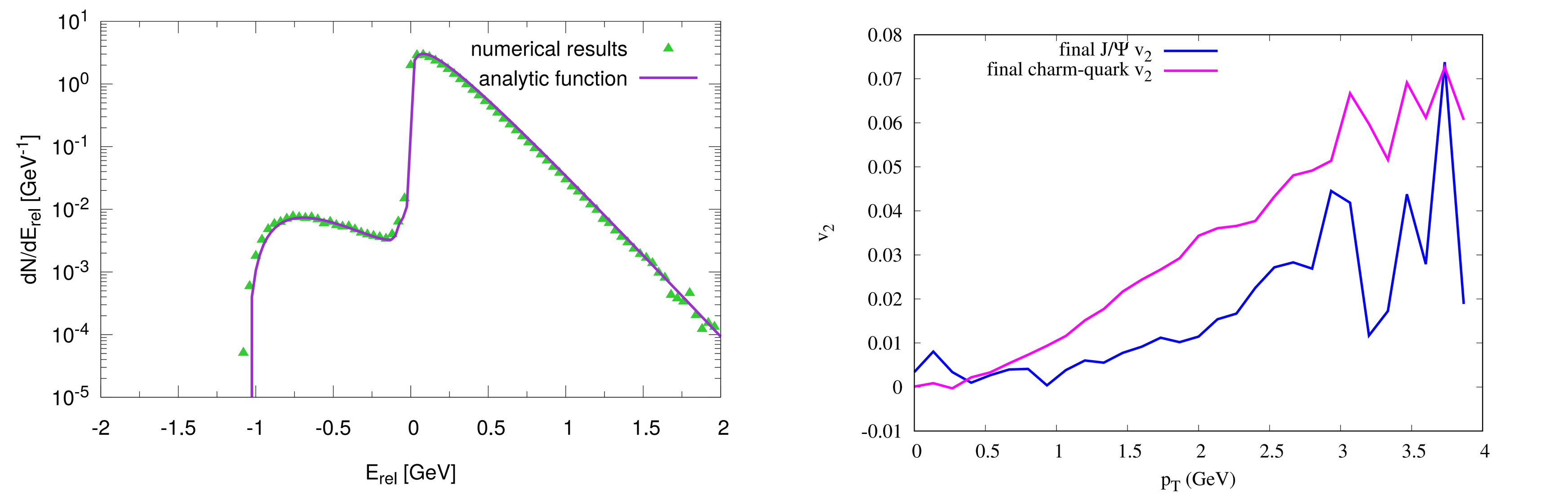
D-mesons at LHC



R_{AA} (left) and v_2 of D mesons in $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV-Pb Pb collisions at LHC, assuming a decoupling temperature of $T_{\mathrm{dec}} = 130$ MeV (data from the ALICE collaboration [6, 7]).

Quarkonium-bound states

- Langevin simulation of 1 or several $c\bar{c}$ pairs [8, 9]
- additional interaction via a $c\bar{c}$ in-medium UV-regularized screened color-Coulomb potential [10]



Left: "Box test" $c\bar{c}$-pair-energy distribution in thermal medium with $T = 160$ MeV; **Right:** v_2 of heavy-quarkonia ("J/Ψ") and c-quarks in semi-central Au+Au collisions at RHIC.

Conclusions and outlook

- medium modifications of heavy-quark spectra
  - used UrQMD+hydro hybrid model for realistic description of the bulk medium
  - includes initial-state fluctuations
  - heavy c+b-quark diffusion via Langevin process
  - elastic resonance scattering of heavy quarks in strongly interacting matter
  - coalescence crucial for consistency of R_{AA} and v_2
  - also used to evaluate dilepton production from correlated D$\bar{\text{D}}$-pair decays
- Quarkonia as classical $c\bar{c}$-pair bound states
  - additional in-medium $c\bar{c}$-potential in Langevin simulation
  - bound-state formation ⟷ dissociation via interaction with medium
- outlook
  - implement proper quantum description of bound-state formation
  - possible approaches:
    in-medium T-matrix
    Lindhard equation for open quantum systems
    Schrödinger-Langevin equation
  - also for open-heavy flavor meson formation within the same potential approach?!?

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