Quarkonia production and dissociation in a Langevin approach

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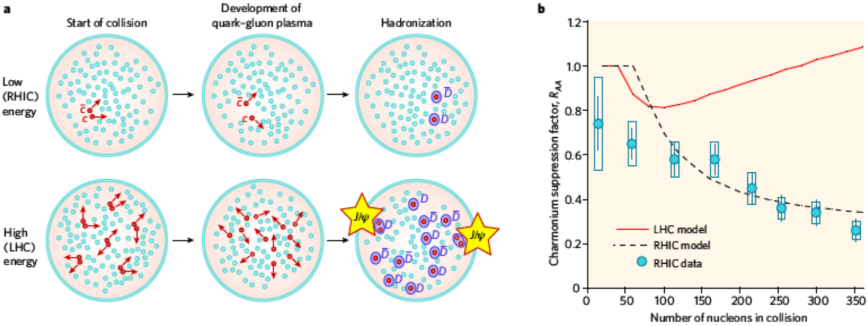
Outline

Motivation

- develop a classical model for J/ψ dissociation and recombination
- quarkonia are an important tool for the investigation of the QGP
- signal for deconfinement [T. Matsui and H. Satz 1986 *Phys. Lett.* B **178** 416]
- dissociation due to collisions and color screening
- recombination at higher beam energies

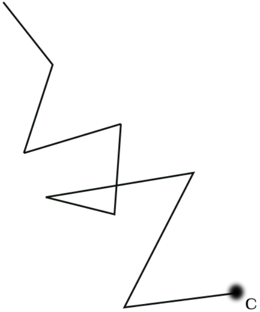


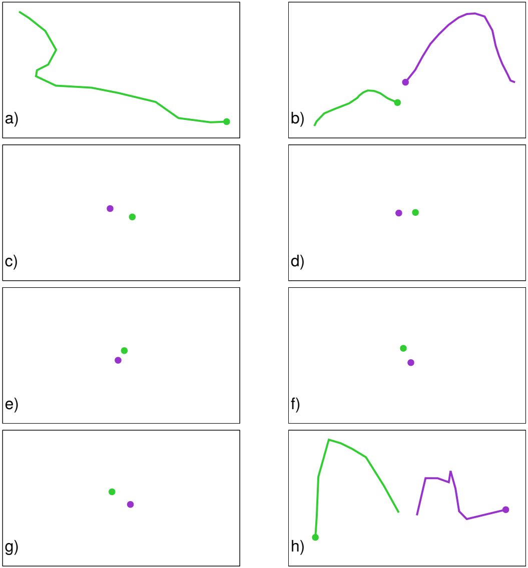
[from J. Stachel, Talk at EMMI workshop Feb/13/18]

Langevin equation

Langevin equation

- Langevin equation describes Brownian motion
  (heavy particles in a light medium)
- particle performs a 'random walk'
- $\frac{\mathrm{d}\mathbf{p}}{\mathrm{d}t} = -\gamma \mathbf{p} + F(\mathbf{r}) + \zeta$
- $\frac{\mathrm{d}\mathbf{x}}{\mathrm{d}t} = \frac{\mathbf{p}}{m}$



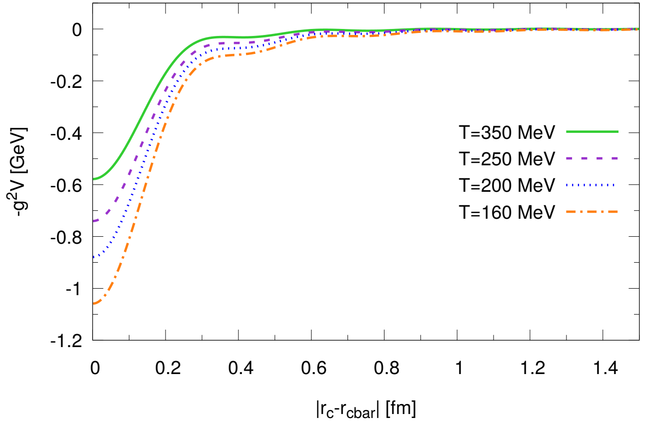


- (a) trajectory of single c quark
- (b) trajectory of a $c\bar{c}$ pair
- (c-g) time sequence of a bound $c\bar{c}$ pair
- (h) trajectory of a dissociating bound state

Formalism

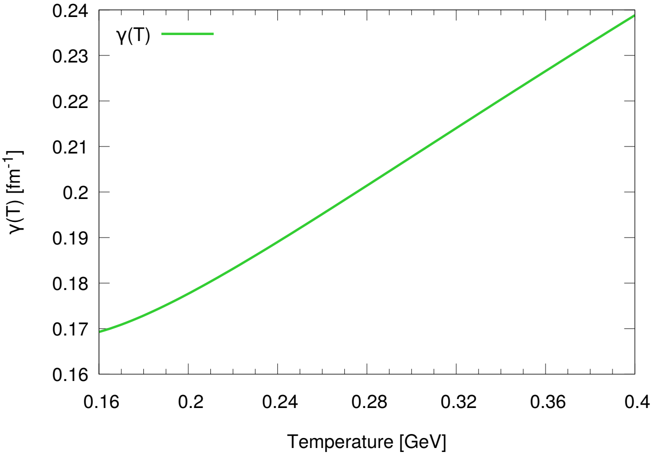
$c\bar{c}$-potential with cut-off $\Lambda = 4$ GeV

- drag coefficient γ and potential for $F(\mathbf{r}) = -\nabla V(r)$ from [J. P. Blaizot, D. De Boni, P. Faccioli, and G. Garberoglio 2016 *Nucl. Phys.* A **946** 49]
- $g^2 = 4\pi\alpha_s = \frac{4\pi\alpha_s(T_C)}{1+C\ln\left(\frac{T}{T_C}\right)}$ $\quad C = 0.76, \quad T_C = 160\mathrm{MeV}, \quad \alpha_s(T_C) = 0.5$



Friction coefficient

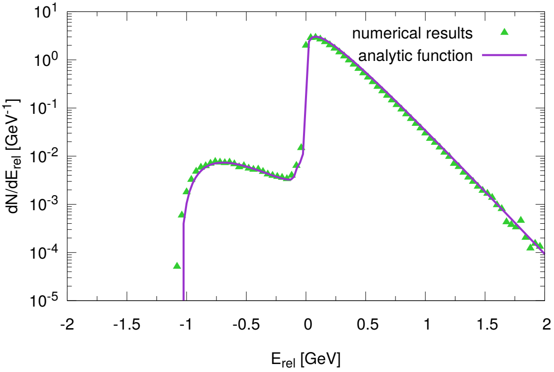
- $\gamma = \frac{m_D^2 g^2}{24\pi m_Q} \left(\ln\left(1 + \frac{\Lambda^2}{m_D^2}\right) - \frac{\frac{\Lambda^2}{m_D^2}}{\frac{\Lambda^2}{m_D^2}+1} \right)^{-1}$



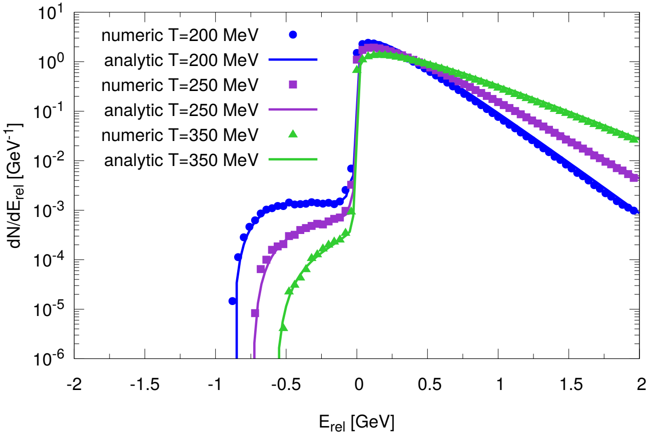
Numerical calculations

Energy distribution T=160 MeV

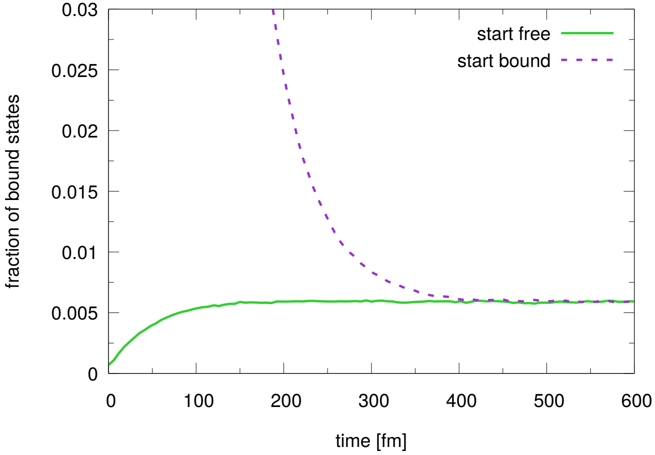
$$\frac{\mathrm{d}N}{\mathrm{d}E_{\mathrm{rel}}} = C\int_{\mathbb{R}^3}\mathrm{d}^3\mathbf{r}\int_{\mathbb{R}^3}\mathrm{d}^3\mathbf{p}_{\mathrm{rel}}\delta(E_{\mathrm{rel}}-H_{\mathrm{rel}})\exp\left(-\frac{H_{\mathrm{rel}}}{T}\right)$$
$$= (4\pi)^2(2\mu)^{3/2}C\int_0^R \mathrm{d}r r^2\sqrt{E_{rel}-V(r)}\exp\left(-\frac{E_{rel}}{T}\right)$$



Energy distribution at different temperatures

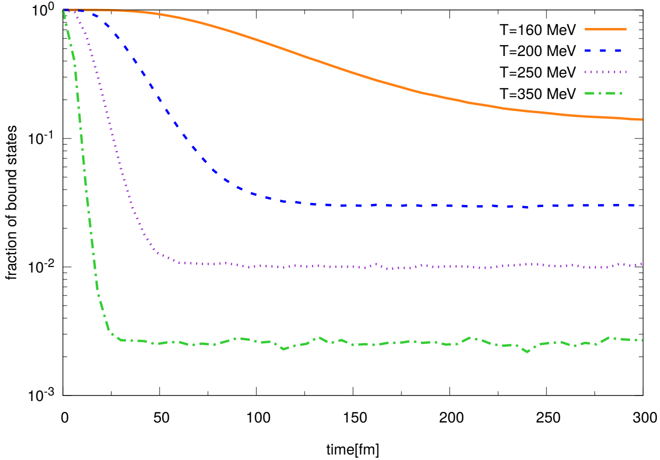


Comparison of initial conditions



- $T = 160$ MeV, single pair, $m_c = 1.8$ GeV, rigid box

Fraction of bound states at different temperatures



- $T = 160$ MeV, five $c\bar{c}$ pairs, $m_c = 1.8$ GeV, rigid box

Comparison with an equilibrated thermodynamic system

- number of J/ψ in the system can be calculated with the grand canonical partition function
- $T = 160$ MeV, single pair, $m_c = 1.8$ GeV, rigid box

Volume	grand canonical fraction of J/ψ	numerical fraction of J/ψ
8^3 fm^3	0.0066	0.0059
10^3 fm^3	0.0035	0.0029
12^3 fm^3	0.002	0.0017

Summary and Outlook

- Summary
  - model for J/ψ dissociation and recombination
  - motion of heavy quarks realized via Langevin equation
  - model passes all equilibrium box tests
  - great scope for further research
- Outlook
  - expanding fireball
  - include distance-dependence in γ
  - use different potential models (confinement)
  - include quantum effects for example using Wigner function
    [C., Young and E. Shuryak 2009 *Phys. Rev.* C **79** 034907]
  - long-time goal: full in-medium quantum Langevin treatment