Open quantum systems for quarkonium dynamics

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virtual Quarkonia As Tools 2021

Collaborators:

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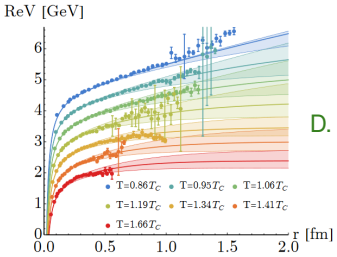
- Thierry Gousset (Ph.D supervisor)
- Roland Katz (Post-doc)

Quarkonium in heavy-ion collisions

Static screening

$T \neq 0 \rightarrow$ Suppression of color attraction

Melting of pairs at high T
$\Rightarrow$ Suppression

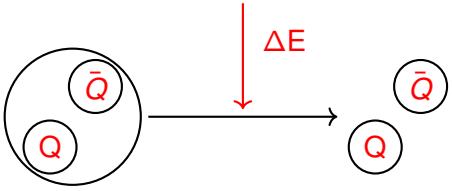


D. Lafferty, A. Rothkopf

Dynamical screening

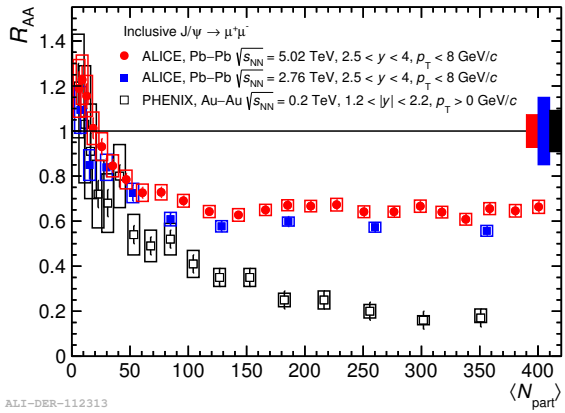
Dynamical processes (collisions...)
$\rightarrow$ Pair dissociation

$\Rightarrow$ Suppression



Described by an imaginary potential

Quarkonium in heavy-ion collisions



Recombination

Initially uncorrelated heavy quarks form a quarkonium

Can happen below the dissociation temperature

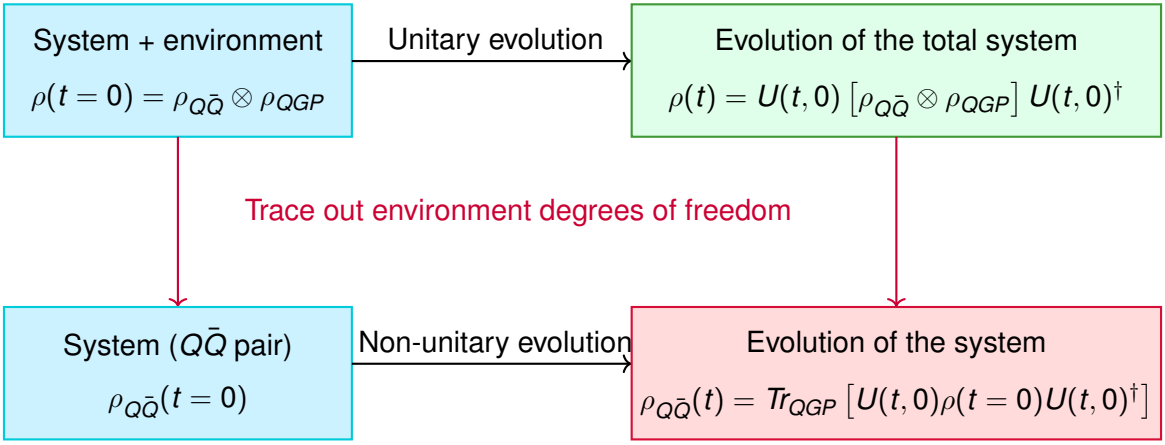
Essential to have a formalism that can treat this effect

Theoretical models

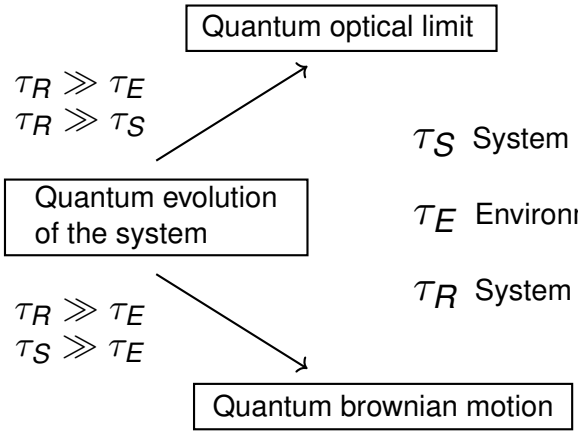
- Statistical Recombination:
  - Quasi-stationnary medium
  - $Q\bar{Q}$ dissociated
  - Recombination at freeze-out
- Transport:
  - Based on dilute medium approximation
  - Transition rates given by cross-sections
  - Cross-sections can't treat everything
- Open Quantum Systems:
  - Allow to treat screening and recombination
  - Dynamic medium
  - Recombination of $c\bar{c}$ still problematic
    $\Rightarrow$ Semi-classical approximations

Need to understand the domain of validity of semi-classical approximations

Open quantum systems



Overwiew of open quantum systems studies



X. Yao, T. Mehen

τ_S System intrinsic timescale

τ_E Environment correlation timescale

τ_R System relaxation timescale

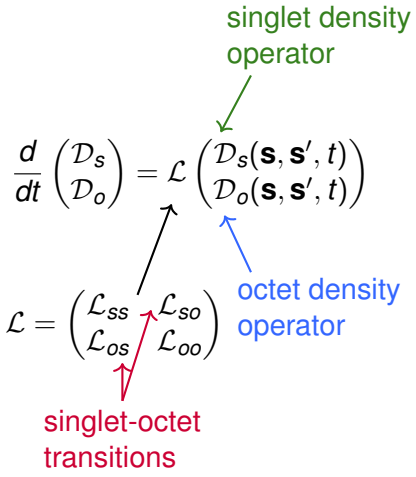
J.P. Blaizot, M.A. Escobedo

Y. Akamatsu, A. Rothkopf, M. Asakawa...

N. Brambilla, M.A. Escobedo, A. Vairo...

R. Katz, P.B. Gossiaux

3D Quantum Master Equation



J.P. Blaizot, M.A. Escobedo, J. High Energy Phys. 06 (2018) 034.

- Weak coupling between heavy quarks and plasma particles
- Resolved through a semi-classical approximation
- Pioneering work on the use of semi-classical approximations to be explored

3D Quantum Master Equation

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 + \mathcal{L}_2 + \mathcal{L}_3$

$\mathcal{L}_0$: Kinetic terms

$\mathcal{L}_1$: Static screening (V)

$\mathcal{L}_2$: Fluctuations (W)

$\mathcal{L}_3$: Dissipation (W'/W")

Singlet⇔octet, octet⇔octet transitions and dissipation effects

Complex potential V + iW

↑

Derived from HTL perturbation theory

M. Laine, O. Philipsen, P. Romatschke, M. Tassler

A. Beraudo, J.P. Blaizot, C. Ratti

In our case:

V: 1D linear potential with T-dependent screening

W: 1D HTL-inspired potential

Our work

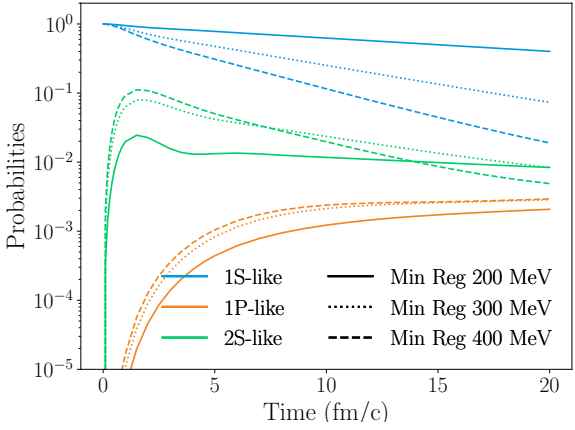
GOAL: Resolve the equations in the 1D case to gain insight on the dynamics

LAST YEAR: Only partial results, with only the singlet-singlet terms.

NOW: Equations fully resolved
Positivity preserved (not the case in the original equations)
We have now a robust tool to explore the dynamics

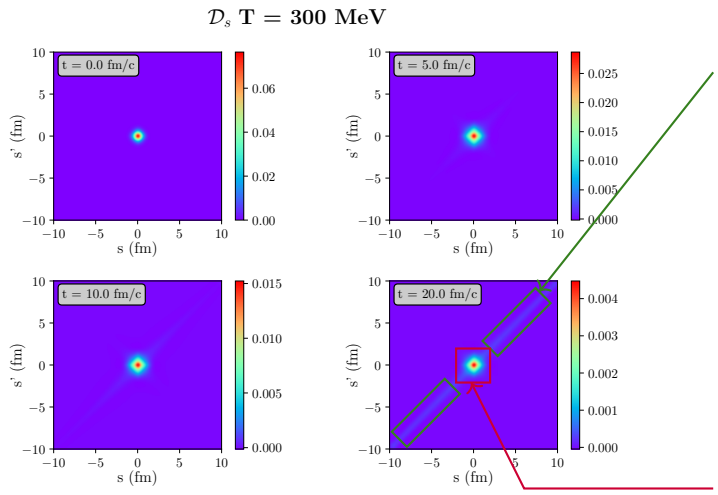
Results for the charmonium system only

1D equations resolution: State probabilities

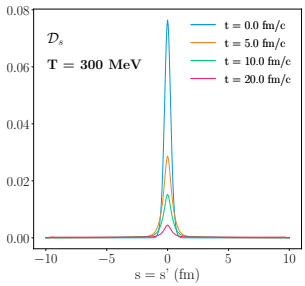


- 1S-like initial state
- Transient phase: re-equilibration
- Same late-time evolution for S-like states at a given temperature
- Higher suppression at higher temperatures

1D equations resolution: Singlet density operator



Dissociated component



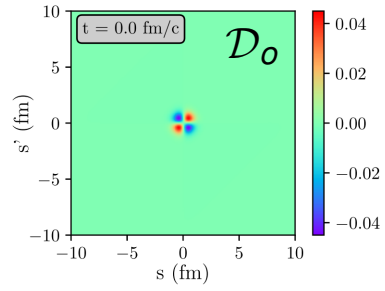
Bound core to be studied

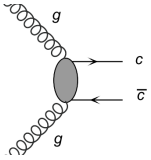
Quantum coherences?

Initial state remnant?

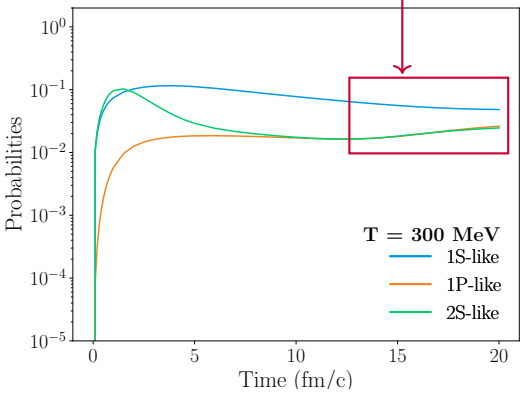
More realistic initial state

- 1P-like octet initial state



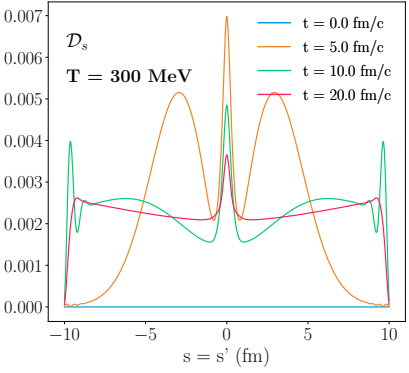


Finite grid size effect?

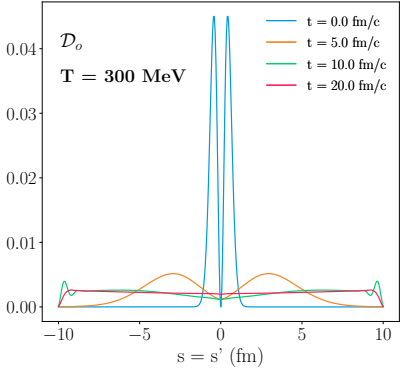


- Interplay between binding, diffusion and transitions between states

More realistic initial state



Central core forms rapidly and then slowly vanishes



Dissociated octet component

Conclusion & Perspectives

- Open quantum systems formalism widely used to study quarkonium dynamics
- We have a fully functionnal tool to explore the 1D dynamics
- Semi-classical approximations may be valid, but further investigations required

- Further study the validity of semi-classical approximations
- Implement a more realistic 1D potential
- Add a realistic temperature dependence
- Study the bottomonium system
- Go to 3D