A potential approach to the $X(3872)$ thermal behavior

Miguel Ángel Escobedo

Universitat de Barcelona

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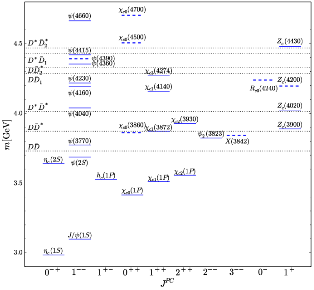
Work done in collaboration with N. Armesto, E. Ferreiro and V. López-Pardo. Phys.Lett.B 854 (2024) 138760.

Outline

Quarkonia exotics

- There are Quarkonium-like particles that can not be explained by the simple quark-antiquark model.



Picture taken from Physics Reports 873 (2020)

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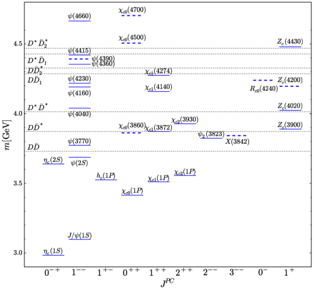

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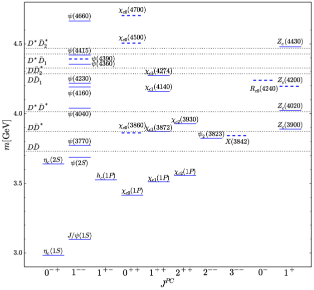
- There are two competing models. The tetraquark and the hadronic molecule.



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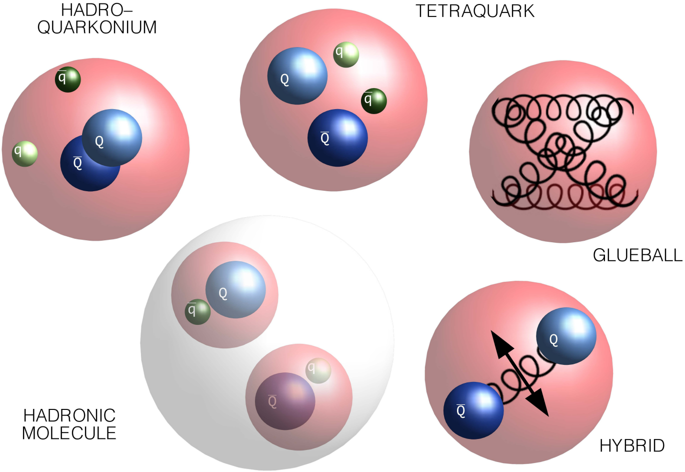

Picture taken from `https://www.fz-juelich.de/en/ias/ias-4/research/exotic-hadrons/exotics_pad.jpg`.

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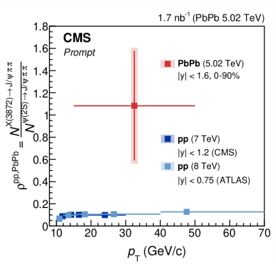
The $X(3872)$ in heavy-ion collisions



Picture taken from Phys.Rev.Lett. 128 (2022) 3, 032001

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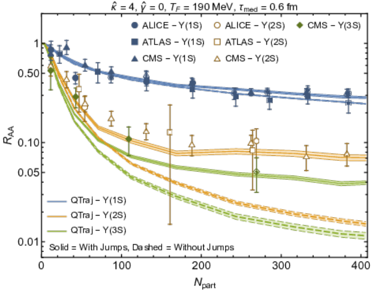

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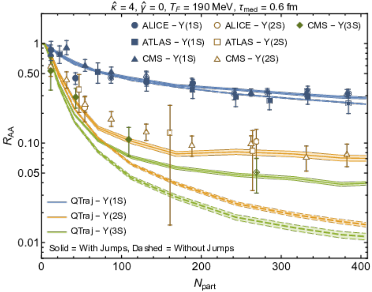

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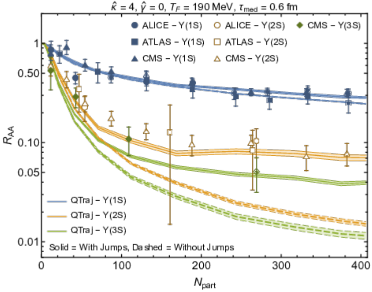

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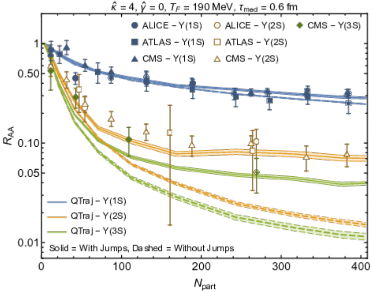
- In some limits, it is a good approximation to model quarkonium using a Schrödinger equation with a complex potential.



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- We assume that it is a tetraquark. In the future, we plan to do a similar study assuming that it is an hadronic molecule.
- It is challenging because non-perturbative physics has a prominent role in exotic quarkonia.
- Due to this, our aim is to obtain qualitative results. We use as insights results from perturbative computations, lattice QCD and the large N_c limit.

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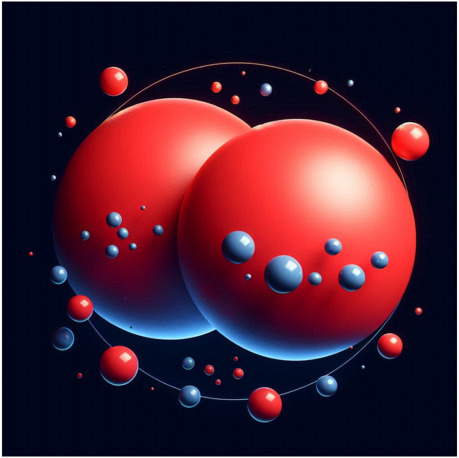
- The effect of light particles and gluons can be encoded in a potential computed assuming that the heavy quarks are frozen and separated a given distance r.
- Two step-approximation:
  - Compute the potential taking the heavy quarks as static color sources.
  - Solve the Schrödinger equation.

The Born-Oppenheimer approximation



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- We use data taken from Phys. Rev. D 99(3), 034502 (2019).

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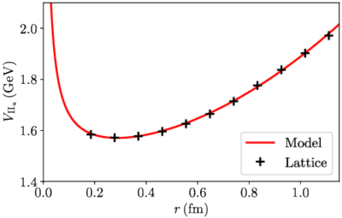

This potential is well fitted by the formula

$$V(r,0) = \frac{A_{-1}}{r} + A_0 + A_2 r^2\,.$$

Lattice data is not sensitive to large r behavior. But, using Effective String Theory results, we know that at very large r it only grows linearly.

The finite T potential

The real part

We use the following assumption

$$V(\mathbf{p}) = \frac{V_{vac}(\mathbf{p})}{\epsilon(\mathbf{p}, m_D)}\,,$$

where ϵ is the medium permittivity in the HTL approximation and m_D is the Debye mass.

$$\Re[V(r, m_D)] = A_{-1}\left(m_D + \frac{e^{-m_D r}}{r}\right) + A_0$$
$$+A_2\left[\frac{6}{m_D^2}(1 - e^{-m_D r}) - \left(2r^2 + \frac{6r}{m_D}\right)e^{-m_D r}\right]$$

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Rationale

This model was able to describe lattice quarkonium potential at finite T using m_D as a fitting parameter (Phys. Rev. D 101(5), 056010 (2020)).

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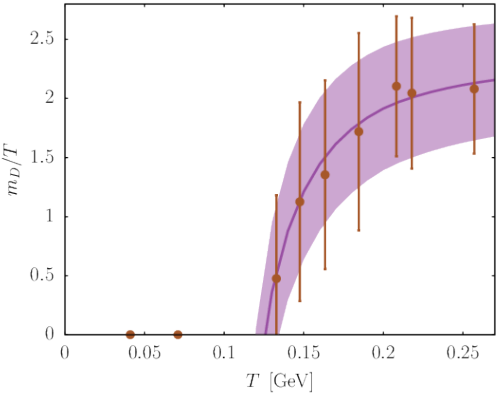

Plot taken from Phys. Rev. D 101(5), 056010 (2020)

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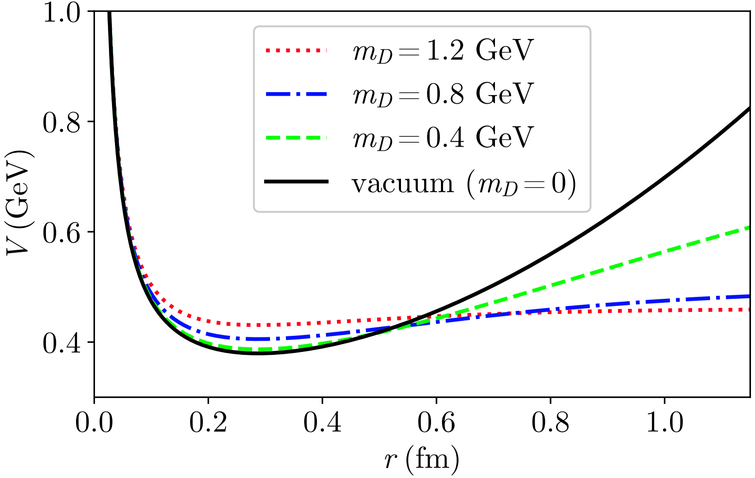

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- Between these two limits it is a smoothly increasing function.

The imaginary part

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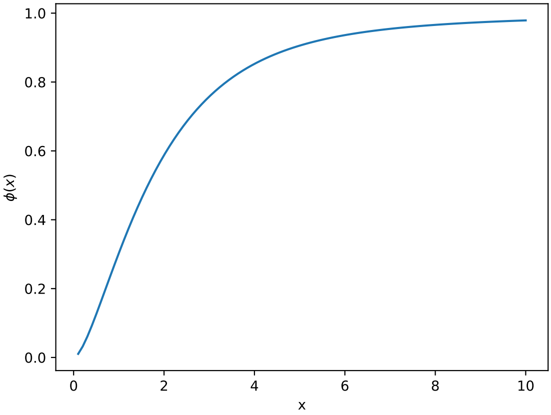
For example, in the HTL approximation

$$\Im V(r) = -\alpha_s C_F T \phi(m_D r)\,.$$



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In a tetraquark state treated in the BO approximation, the heavy quarks are in an octet state.

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- At intermediate distances we expect that the imaginary part of the potential is a smooth function that interpolates between the two regimes.
- In the large N_c limit the decay width of a heavy gluon is equal to that of two heavy quarks.
- Therefore, we can take the imaginary part of the potential to be a constant.

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- It is a educated guess. However, note that our aim is to get a qualitative understanding.

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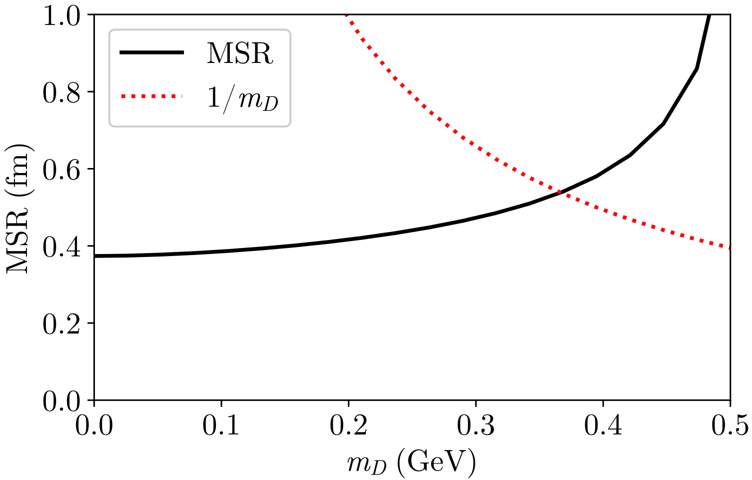
- The dissociation temperature is the one in which we can no longer find bound state solutions. In our case, we obtain $T_d \sim 250\,\mathrm{MeV}$.

Mean radius vs Debye mass



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$$S(t) = \exp[-\int_{t_0}^{t} d\tau \Gamma(T(\tau),\tau)] \ ,$$

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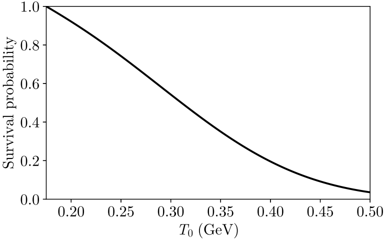

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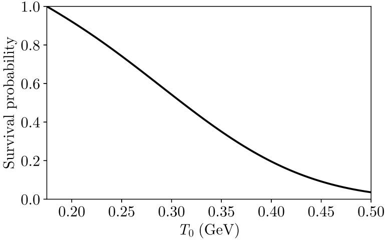

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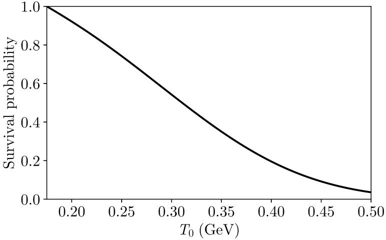

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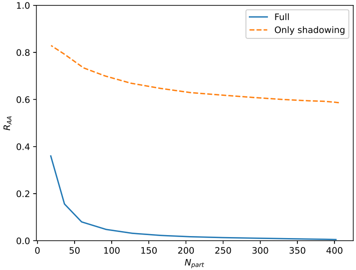
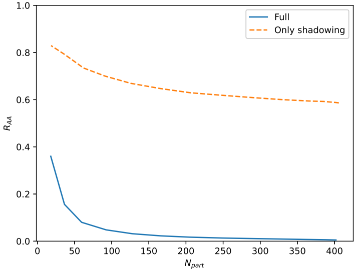
- If $T \gtrsim 250\,\mathrm{MeV}$ the state melts.

R_{AA}


1.0
0.8
0.6
0.4
0.2
0.0
R_{AA}
0
50
100
150
200
250
300
350
400
N_{part}
Full
Only shadowing

R_{AA}



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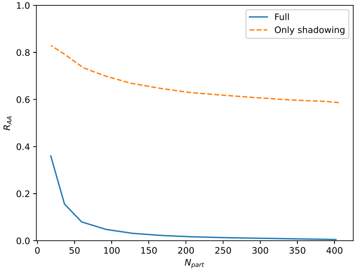

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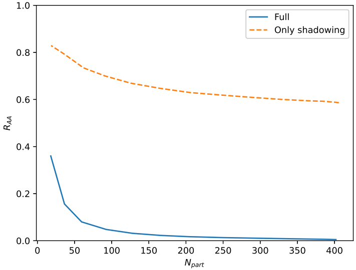

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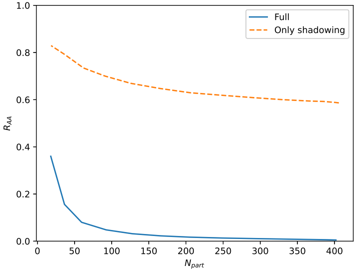

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- We have developed a qualitative model for the potential of the $X(3872)$.
- Our results indicates that it melts around $250\,\mathrm{MeV}$. The effect of the decay width is mild in heavy-ion collisions.