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

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(based on N. Armesto, M.A. Escobedo, E.G. Ferreiro and **V. López-Pardo** (2024). "A potential approach to the $X(3872)$ thermal behavior". Physics Letters B, **854**, 138760 || arXiv:2401.10125 [hep-ph])

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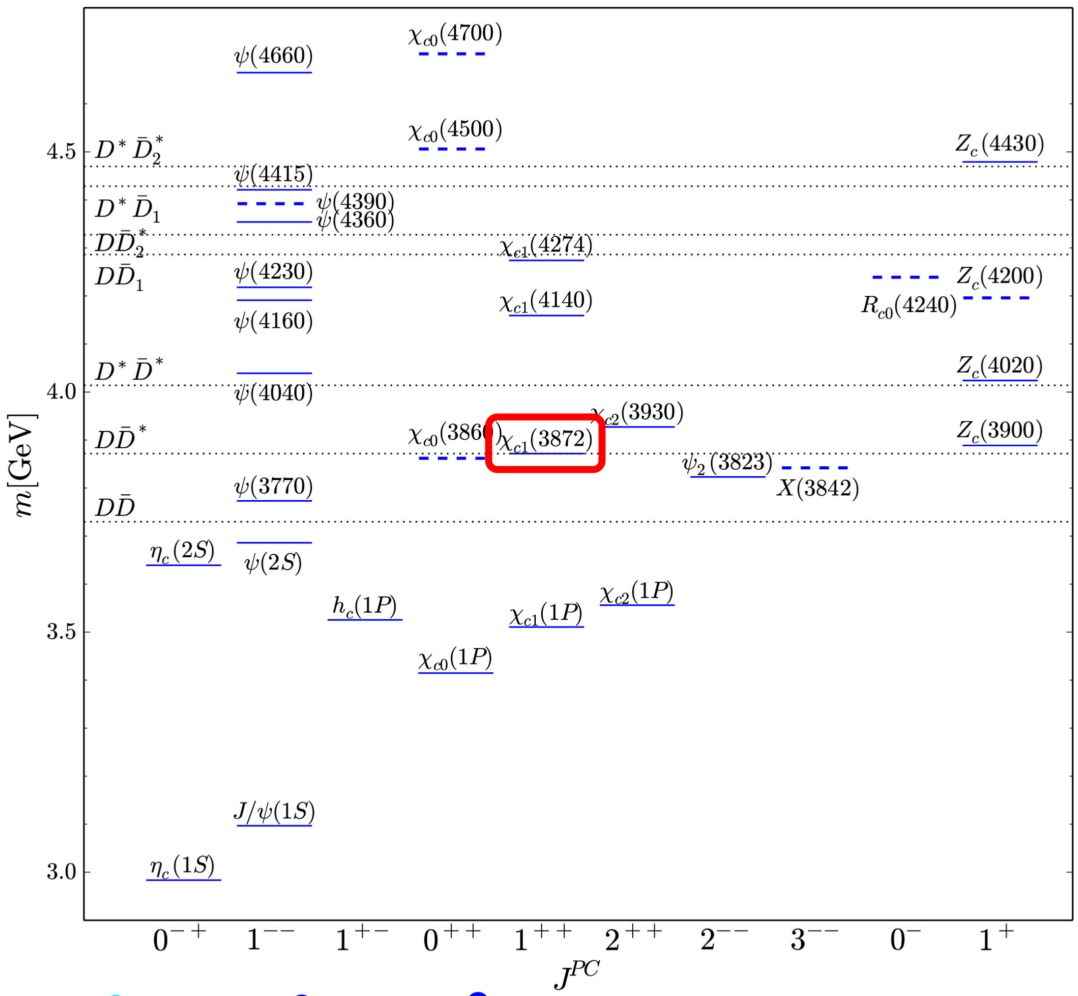
Exotic quarkonia

[PR 873 (2020)]

- Quarkonia-like particles not explained by the quark model.
- We focus on the $\chi_{c1}(3872)$ also known as $X(3872)$:
  - discovered by Belle in 2003,
  - confirmed by BaBar, LHCb, CDF, DØ, CMS, ATLAS and BES III,
  - one of the firsts,
  - still unknown structure.



Exotic quarkonia

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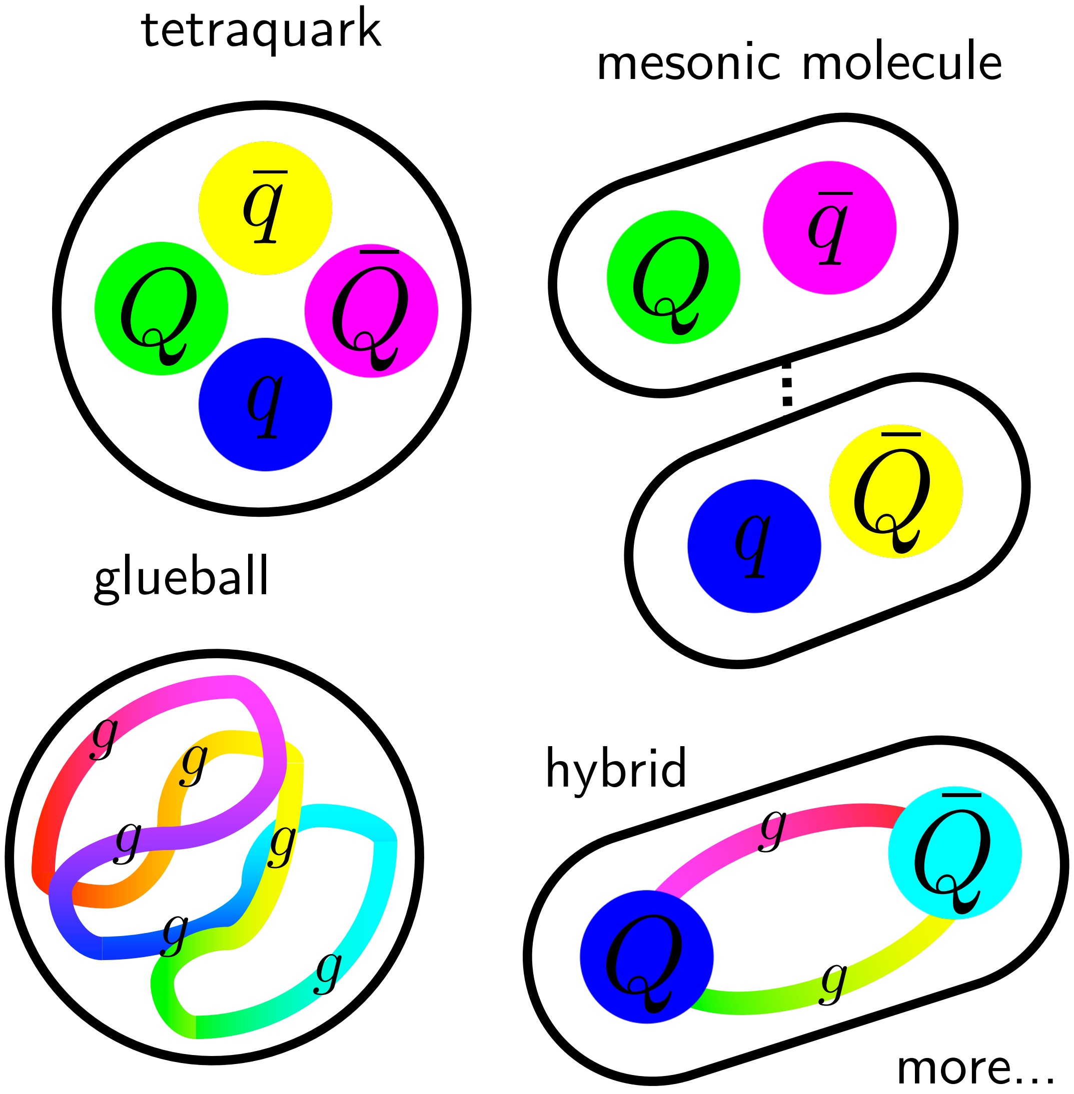
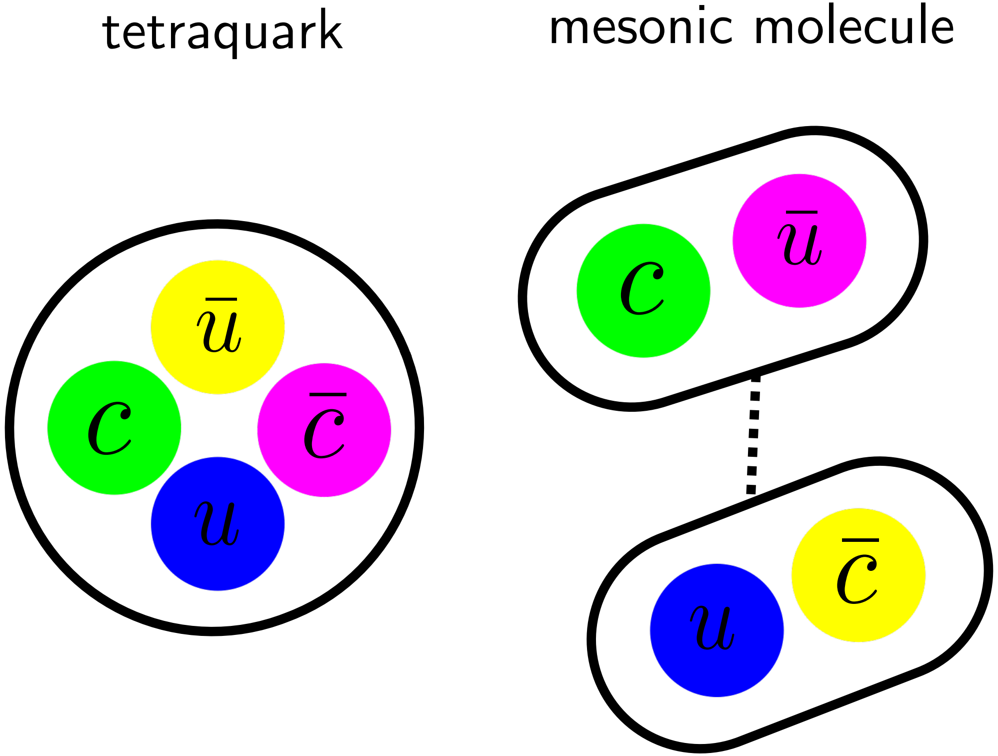


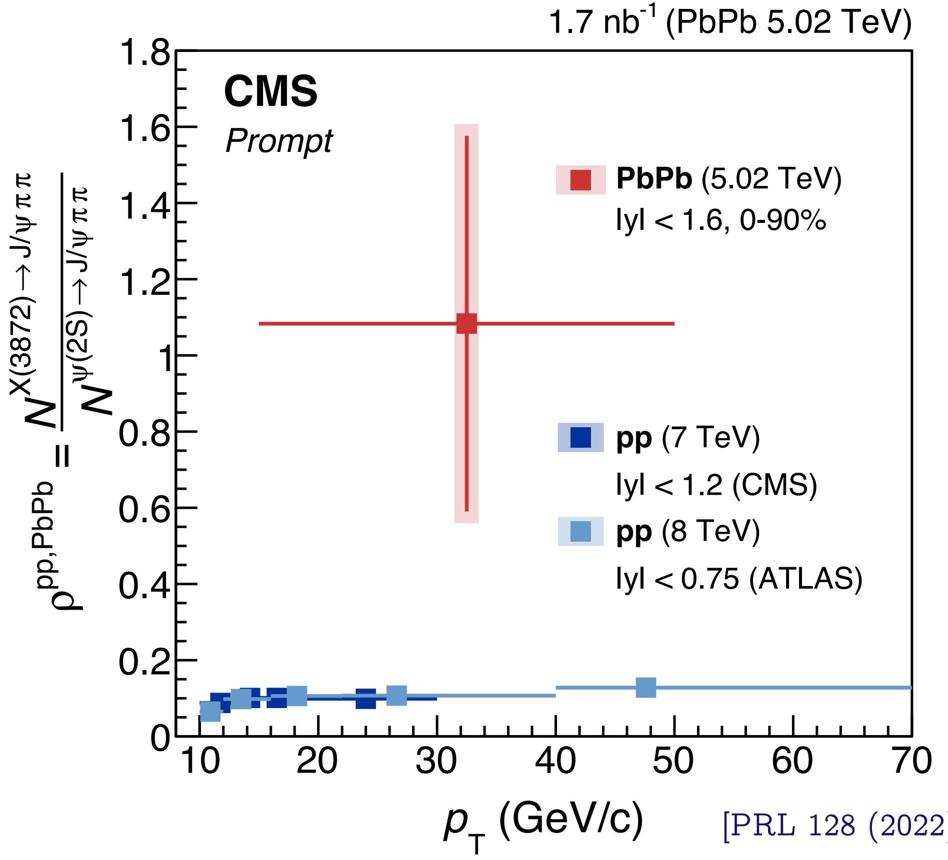
The $X(3872)$

- Exotic quarkonium:
  - $I^G(J^{PC}) = 0^+(1^{++})$
- Mass of 3871.64 MeV.
- $c\bar{c}u\bar{u}$
- Unknown structure:
  - mesonic molecule ($D^0\overline{D^0}$),
  - compact tetraquark.



How can we get information about the internal structure of the the $X(3872)$?

- Quantum numbers.
- Spectroscopy.
- Decays.
- **Studying how a thermal medium modifies its properties.**



[PRL 128 (2022) 032001]

Outline

- Study how the potential of the $X(3872)$ is modified in a thermal medium.
- Assume it is a **tetraquark** (similar study possible for a molecule).
- Non-perturbative physics only allows us to get **qualitative** results.
- Perturbative non-relativistic QCD, lattice QCD, large N_c limit...
- Two steps:
  - compute the potential taking the heavy quarks as static color sources using **lattice**,
  - solve the Schrödinger equation for the heavy quarks.

From vacuum to finite temperature

- We want a way to transform a vacuum potential into a medium potential:

$$V(\mathbf{p}, m_D) = \frac{V(\mathbf{p}, 0)}{\varepsilon(\mathbf{p}, m_D)}$$

- In position space:

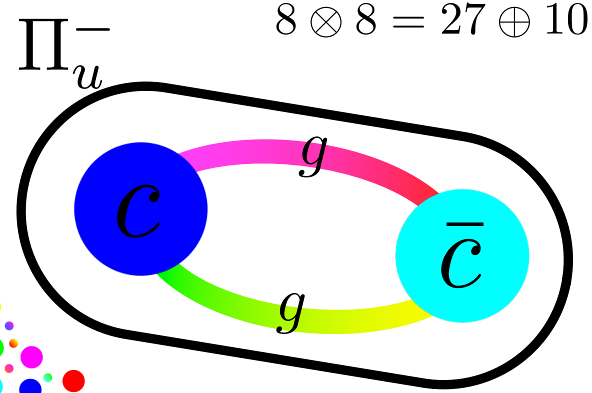
$$V(r, m_D) = C(m_D) + 4\pi \int^{r} dr' \frac{\partial V(r', 0)}{\partial r'} \int^{r'} dr'' r''^2 \varepsilon^{-1}(r'', m_D)$$

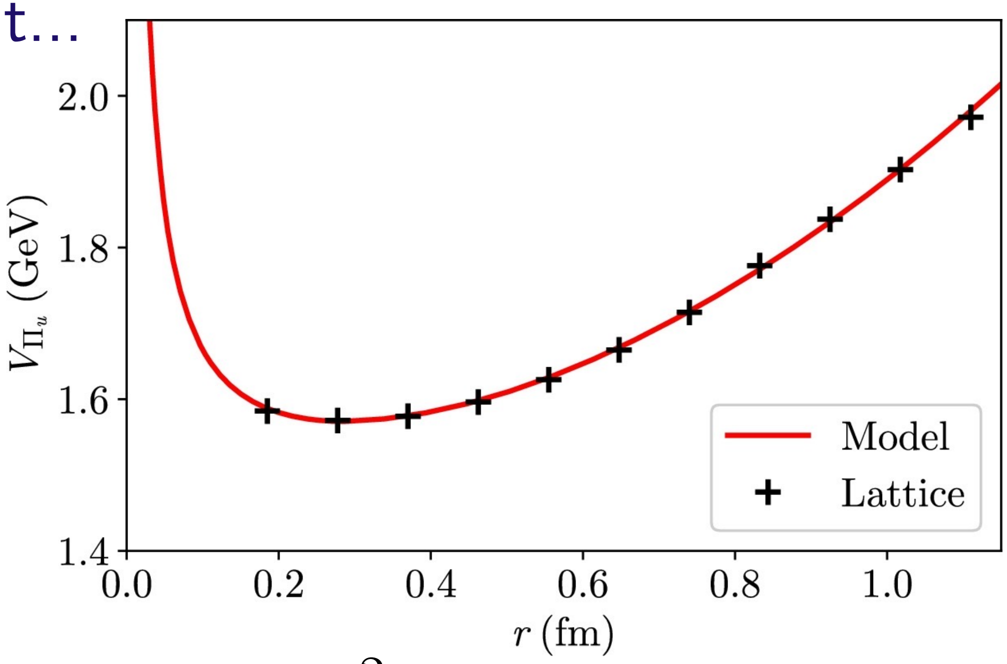
with the $C(m_D)$ such that $V(r,m_D)=V(r,0)$ up to linear order.

The $X(3872)$ vacuum potential

- No lattice results for tetraquarks, but...
- Heavy hybrid mesons:
  - heavy quark-antiquark pair,
  - light **degrees of freedom** (gluons),
  - similar color algebra:

$$3 \otimes \bar{3} = 8 \oplus 1$$
$$8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$$





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

[PRD 99 (2019) 034502]
[PLB 854 (2024) 138760]

The $X(3872)$ in-medium potential

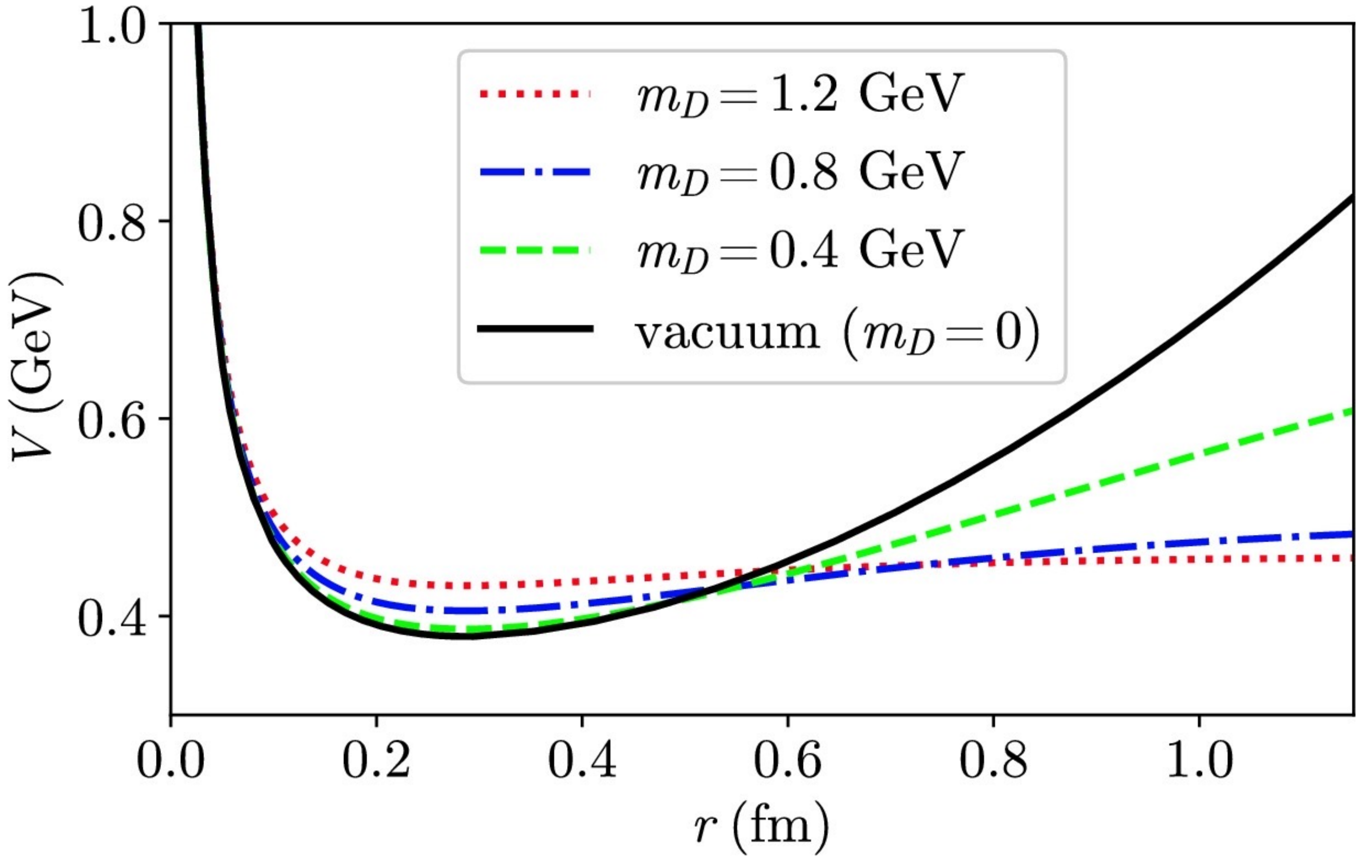
- Real part of the potential:

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

- Imaginary part of the potential:

$$\mathrm{Im}[V(r,m_D)] = A_{-1}T + \frac{A_2 T}{m_D^3}\frac{6\pi}{\Delta}$$

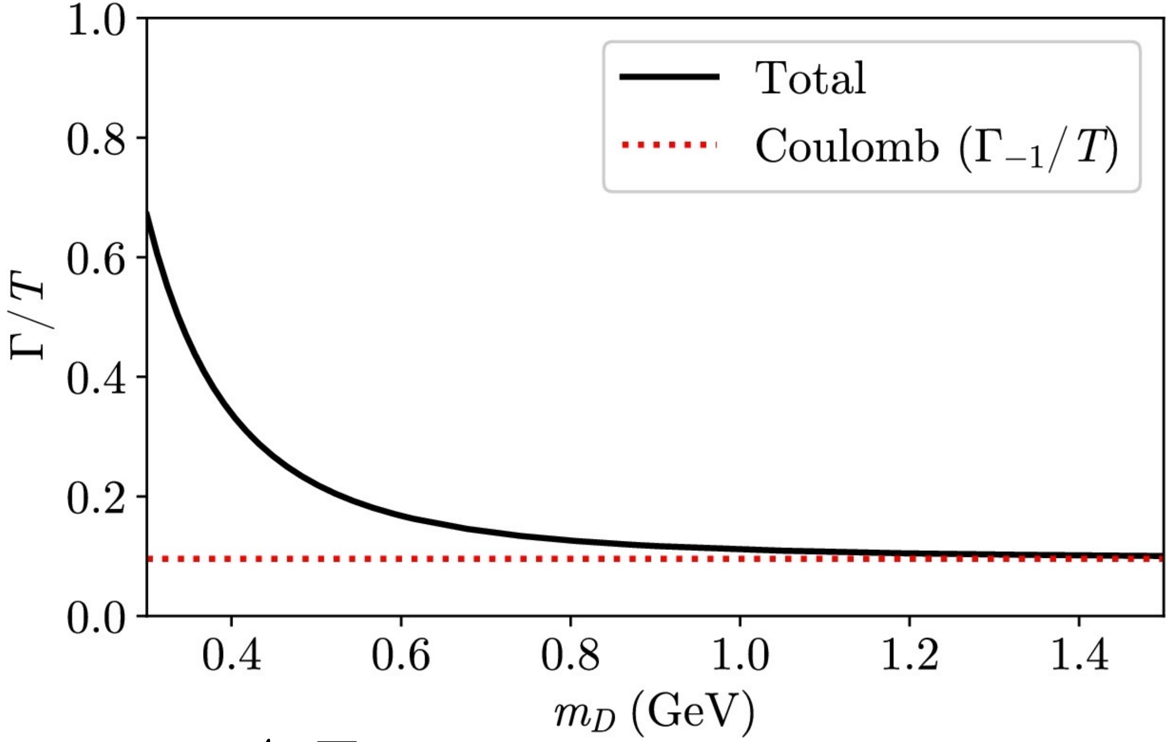
Real part of the potential



[PLB 854 (2024) 138760]

Imaginary part of the potential

- It is an **octet** potential.
- Needs regularization.
- Large N_c.



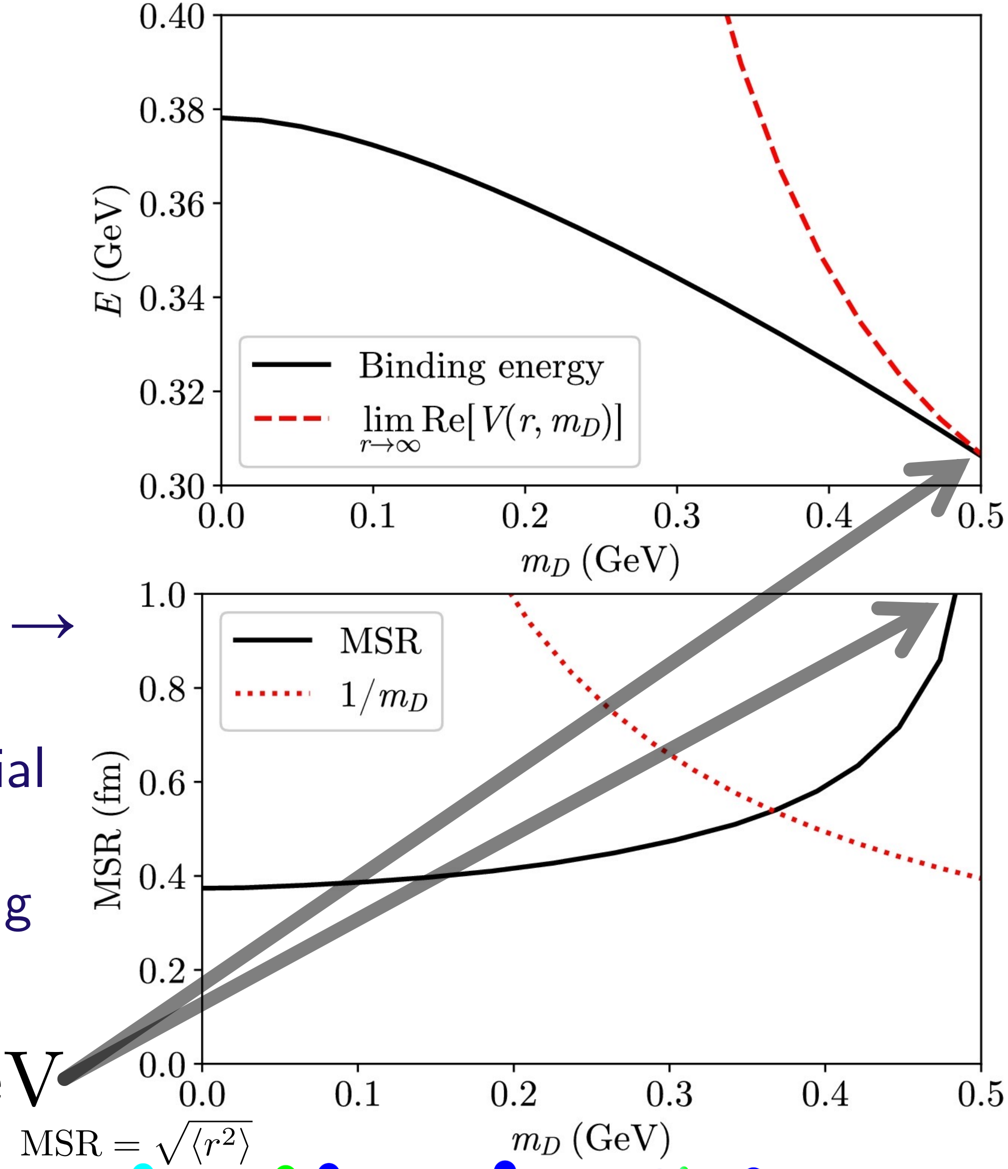
$$\mathrm{Im}[V(r, m_D)] = \Gamma(m_D) = A_{-1}T + \frac{A_2 T}{m_D^3}\frac{6\pi}{\Delta}$$

[PLB 854 (2024) 138760]

Solving Schrödinger equation

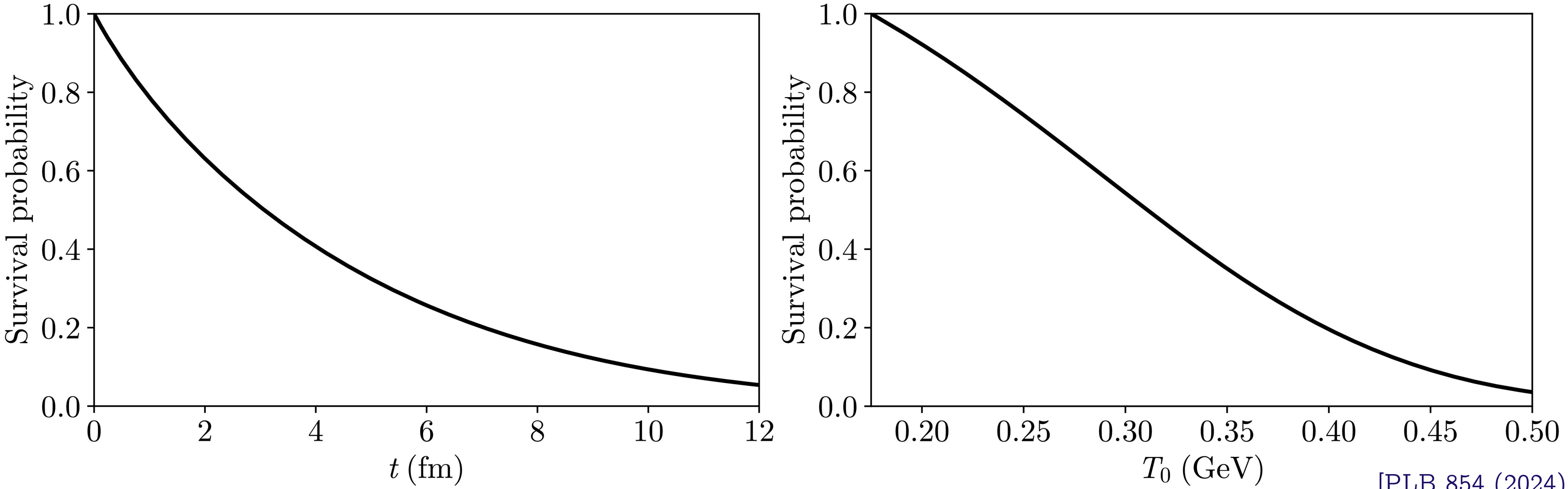
- Eigenenergies → binding energy
- Eigenfunctions → size of the particle
- Dependence on the temperature → dissociation temperature:
  - binding energy higher than potential barrier,
  - particle much bigger than screening length.

$T \approx 250$ MeV



The survival probability

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



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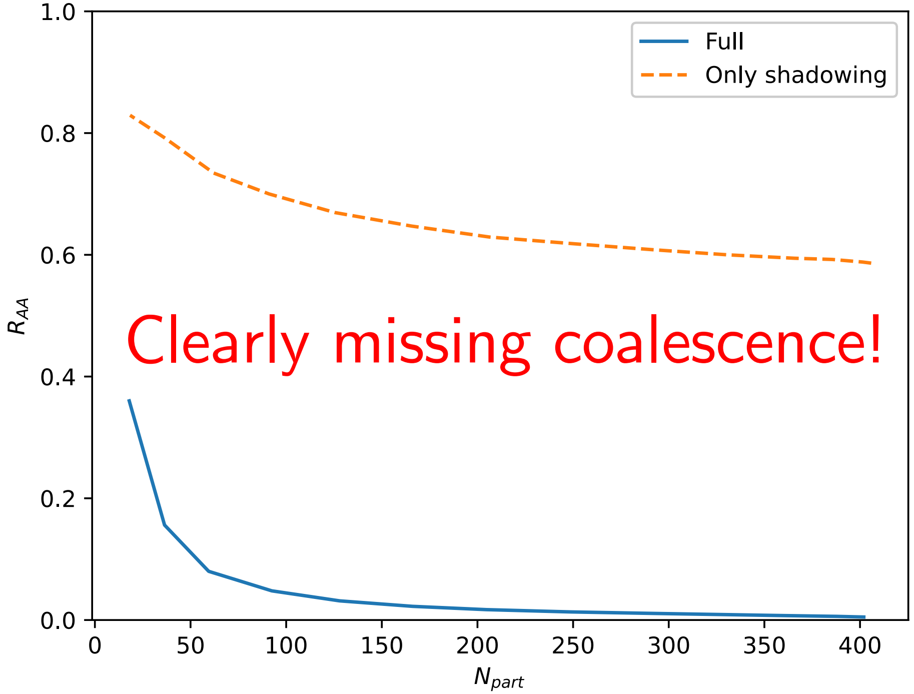
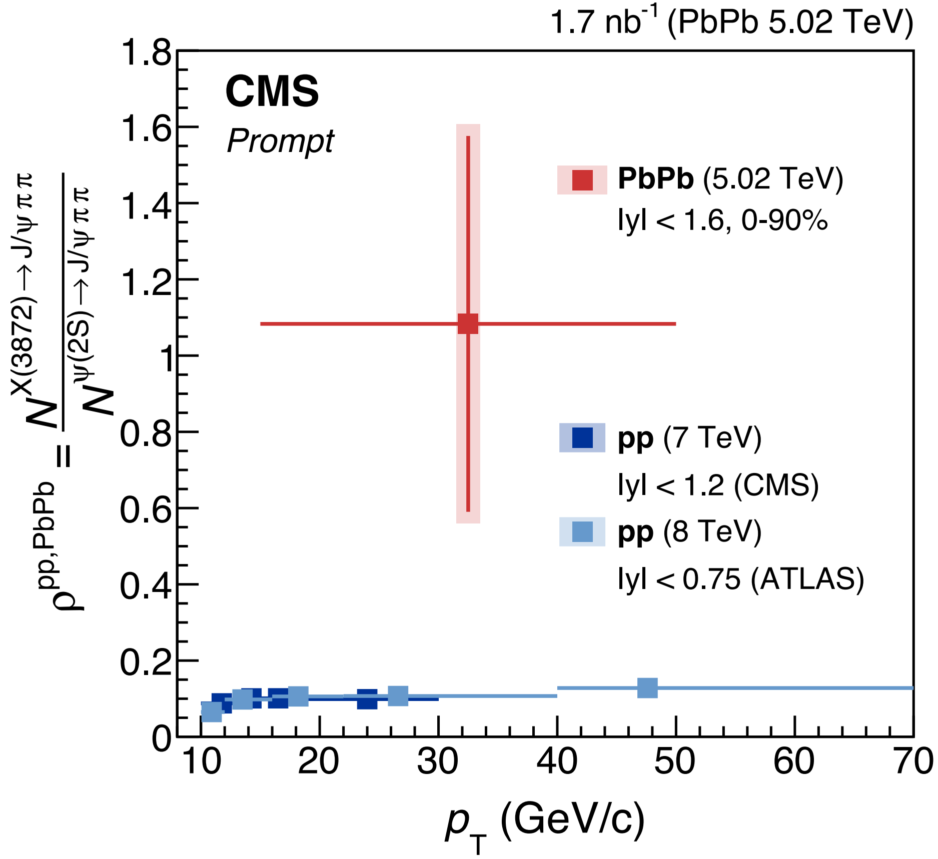
Something missing





[N Armesto, MA Escobedo, E Ferreiro & **V López-Pardo**, in preparation]

[PRL 128 (2022) 032001]

Conclusions and outlook

- If the initial temperature is larger than 250 MeV, the $X(3872)$ does not form in the medium.
- If the initial temperature is smaller than 250 MeV, the system does form but it quickly decays.
- We must estimate other effects like recombination, coalescence...
- Our approach can be applied to other potential models for the $X(3872)$ (such as the molecular hypothesis), even to **other particles**.

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Thank you for listening!

ご清聴ありがとうございました！

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