Dynamical Quarkonia Suppression in a QGP-Brick

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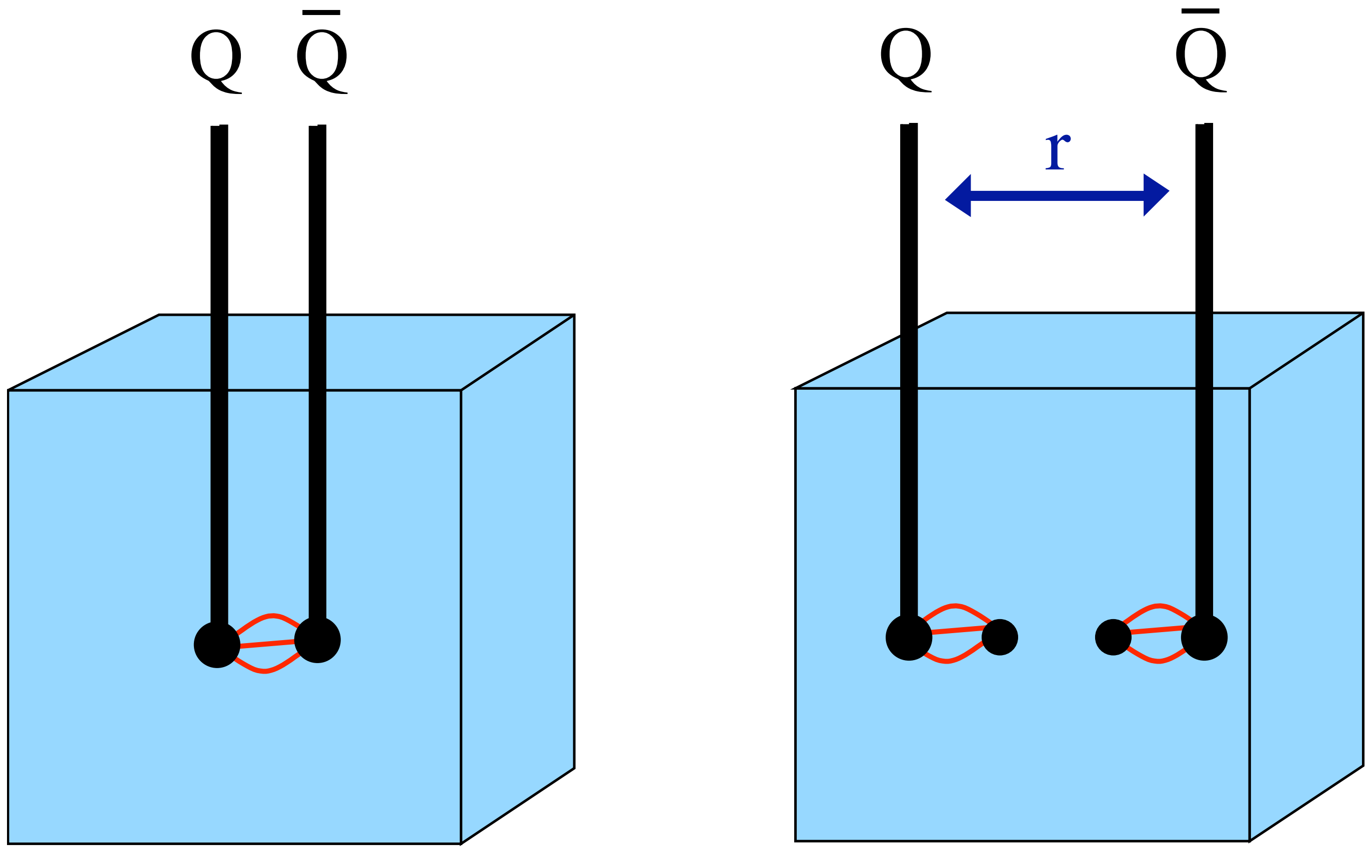
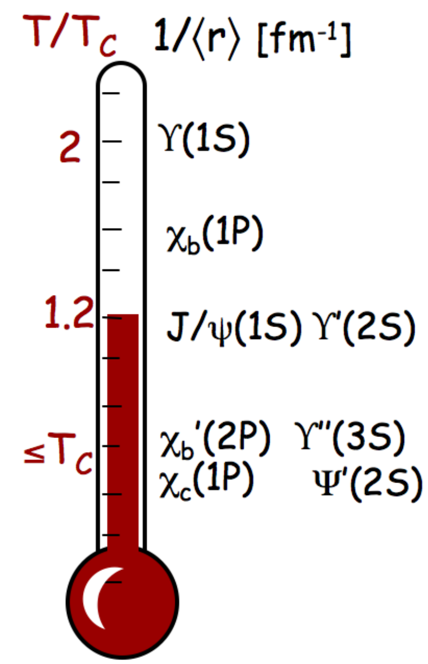
Introduction

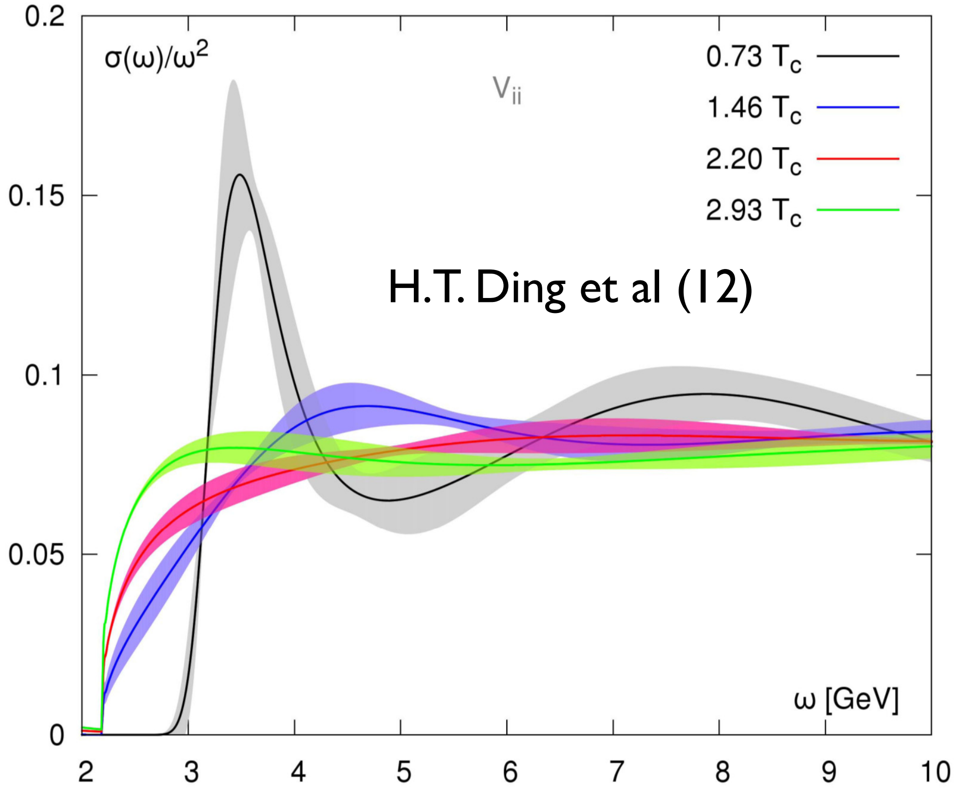


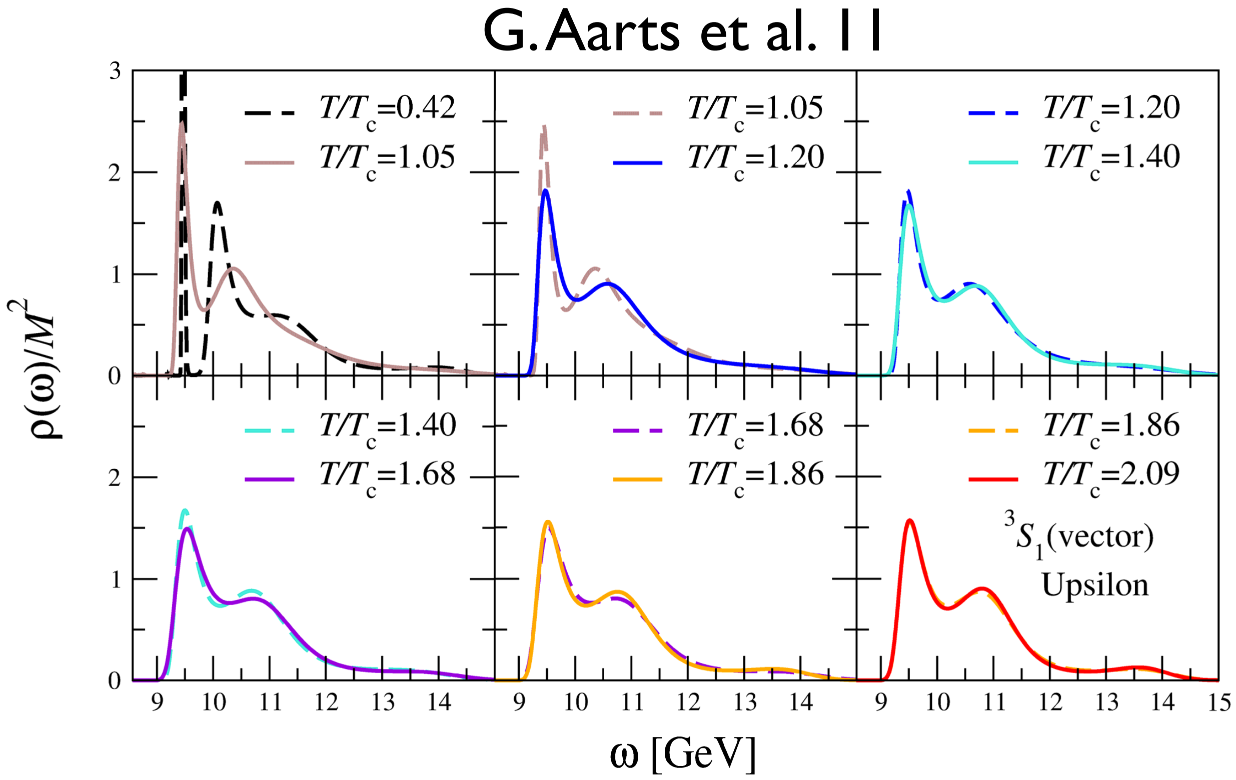


Mocsy,
EPJ C 61 (2009) 705

- Quarkonia suppression is one of the earliest heavy probes in HI
- Basic idea: Matsui and Satz 86
  - Free color charges in plasma screen the QQ interactions
  - States with a Bohr radius larger than μ_D are disolved
- Quarkonia states act as a “thermometer” of the plasma

Spectral Functions from Lattice





- Efforts to extract spectral functions from lattice:
  - Υ survives to relatively high temperatures
  - J/ψ dissolves at T<1.5 Tc
  - 2S states are suppressed at lower temperatures.
- How are these calculations related to suppression in HIC?
  - What happens in a medium with a finite life-time
  - How does expansion affect the in-medium production?

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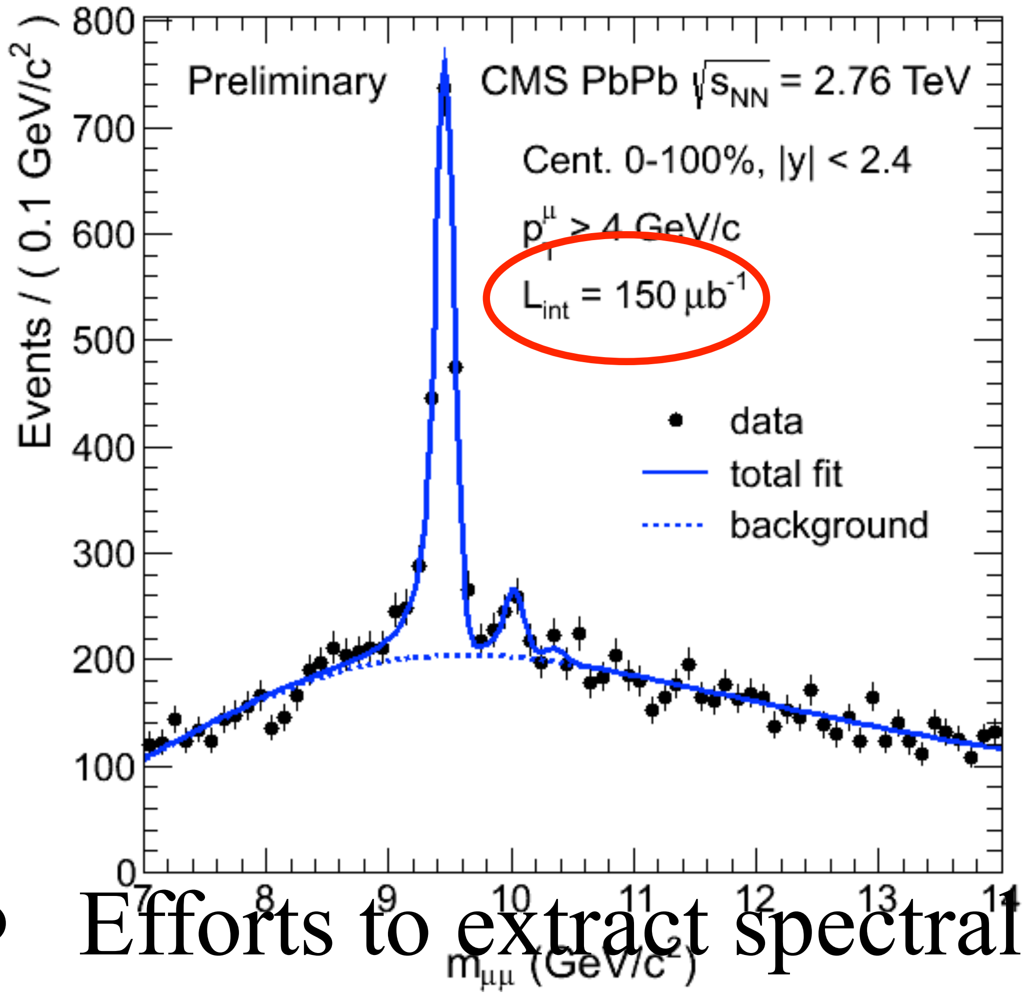

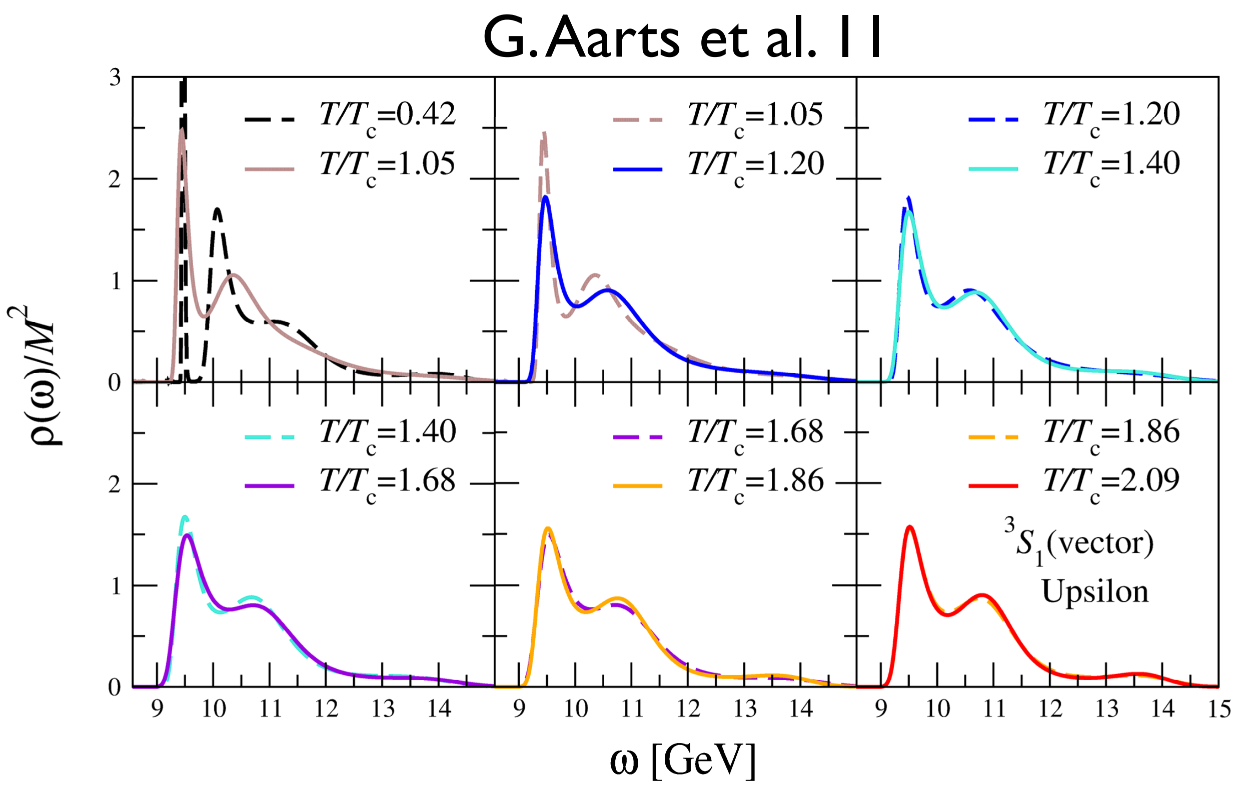

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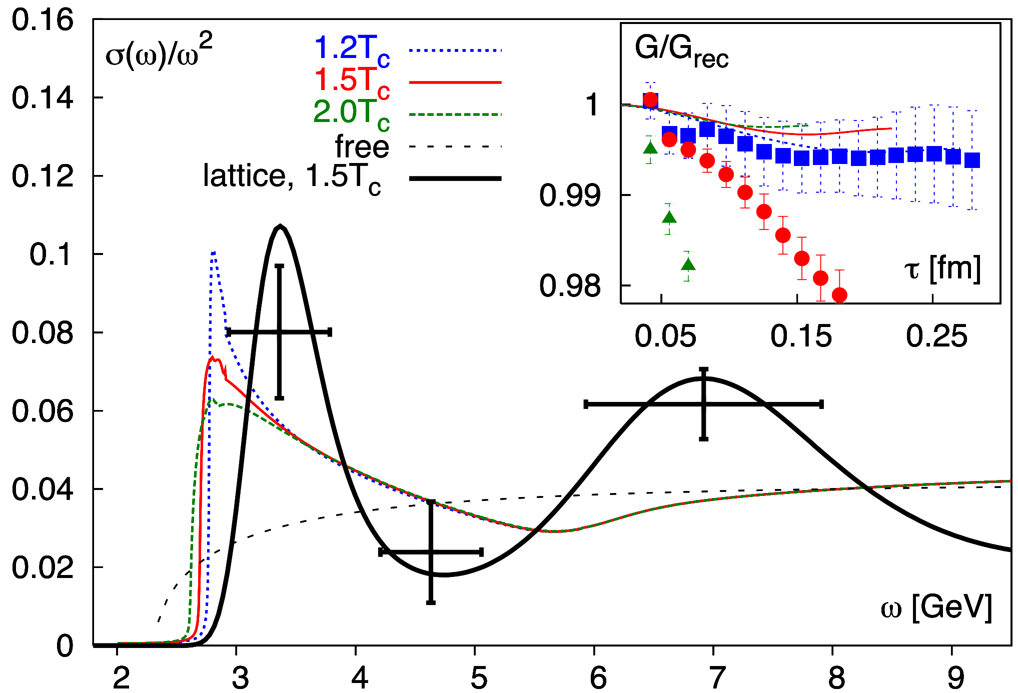
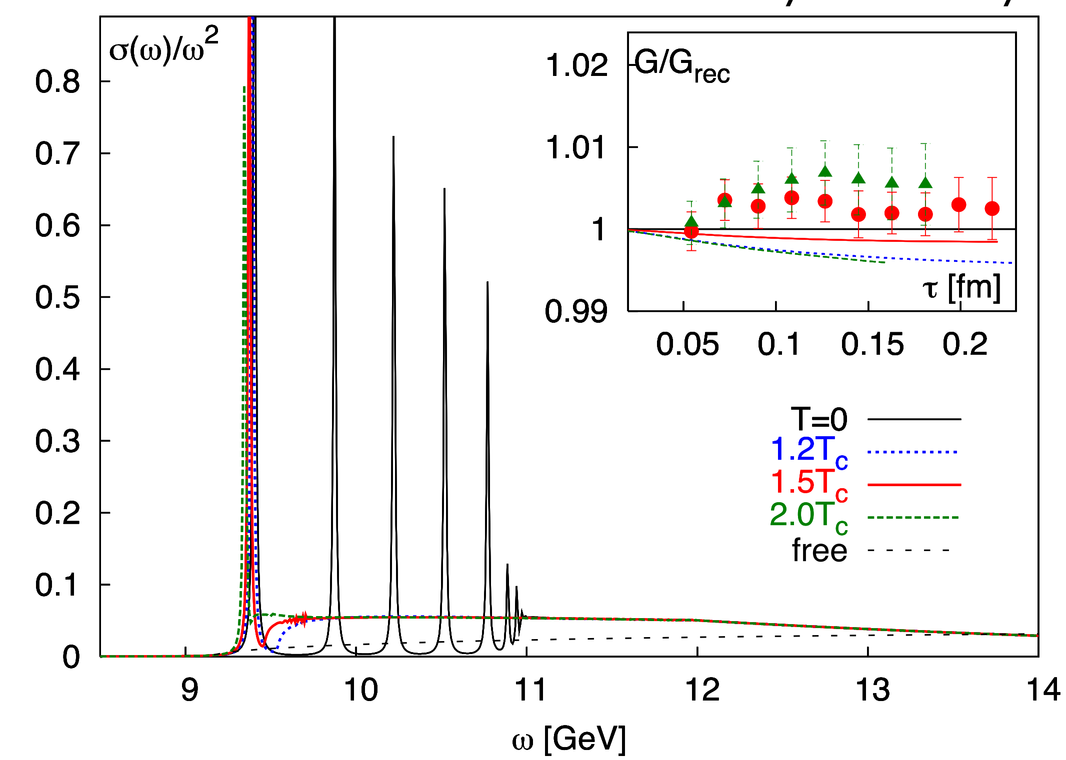
Potential Models

Mocsy & Petreczky 07





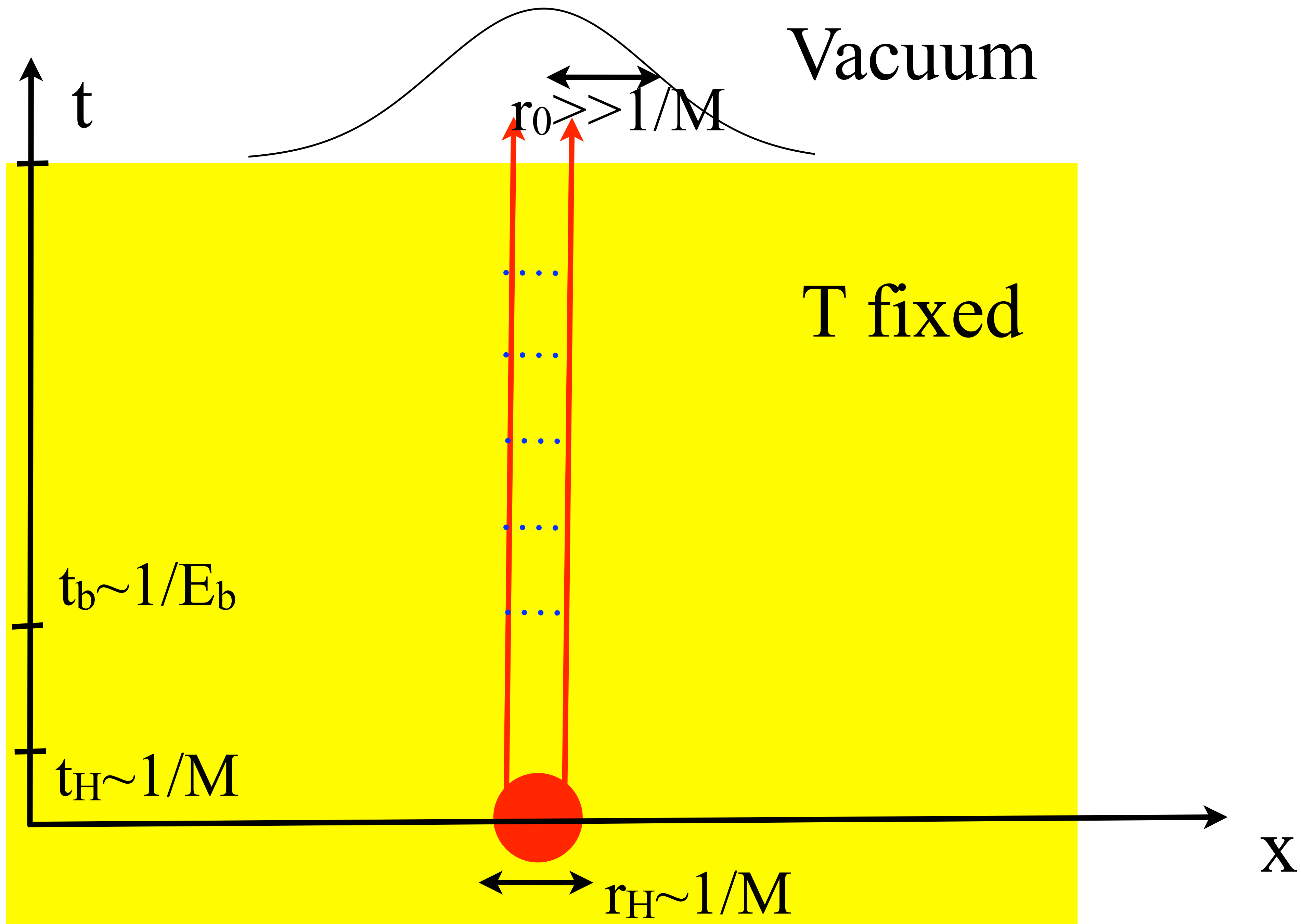
- Quarkonia is described via an in-medium (singlet) potential
  - Well theoretically justified for very heavy quarks via EFT

    Escobedo & Soto 08, Brambilla et al 10
  - OK for bottomonium, not so good for chamonium
- Simple dynamical model to address time dependent problems.
- Uncertainty in the potential:
  - Hard to extract from the lattice
  - Phenomenological real potential describe lattice data

    Mocsy & Petreczky 07
  - Perturbative calculations lead to complex potentials

    Laine et al 07, Beraudo et al 07

The QGP-Brick set up



Suppression from Schrödinger eq.

- Hard production leads to a density matrix of quarkonia states

$$\rho_H\left(\mathbf{r}-\frac{\mathbf{y}}{2},\mathbf{r}+\frac{\mathbf{y}}{2};t_0\right)=\rho_0(\mathbf{r})\delta\left(\mathbf{y}\right)\ .$$

short distance hard relative momenta

- The production yield is obtained by projecting with $\rho_s = |S\rangle\langle S|$

$$Y_S \propto \mathrm{Tr}\left(\rho_H(t)\rho_s\right)=\mathrm{Tr}\left(\rho_H(t_0)\rho_s(t-t_0)\right)$$

- Time evolution with the soft H $\Rightarrow$ transmuted to the final state

$$\rho_s(t-t_0)=\left(e^{-iH(t-t_0)}\right)^\dagger|S\rangle\langle S|\left(e^{-iH(t-t_0)}\right)=\left|\tilde{S}\right\rangle\left\langle\tilde{S}\right|$$

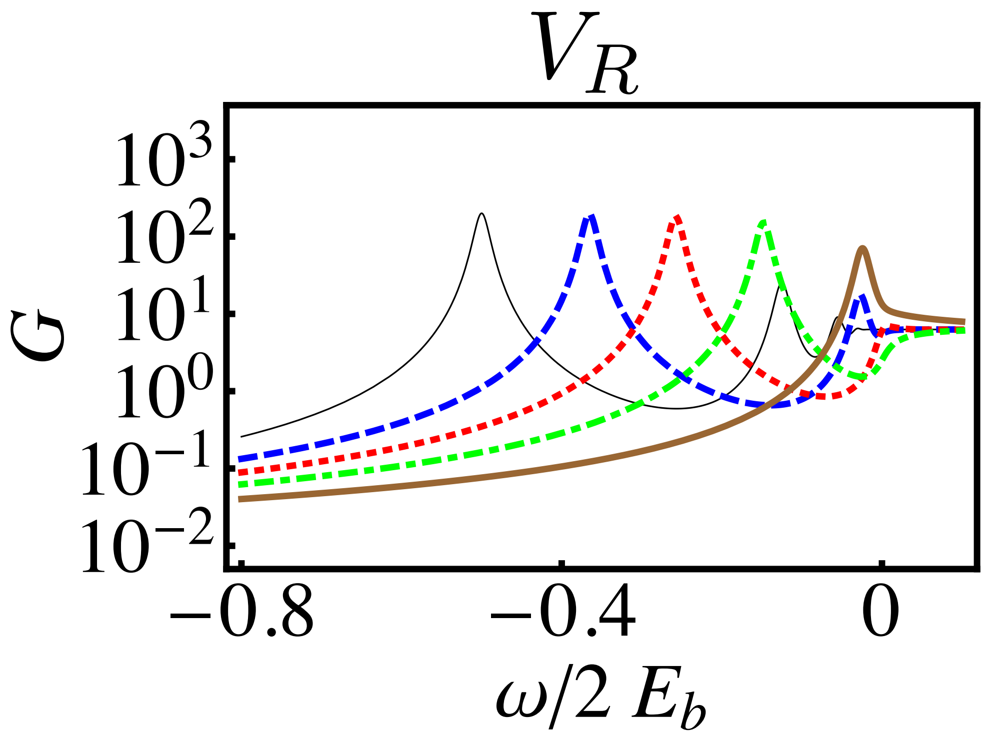
- From the time reverted evolution of the final wave function

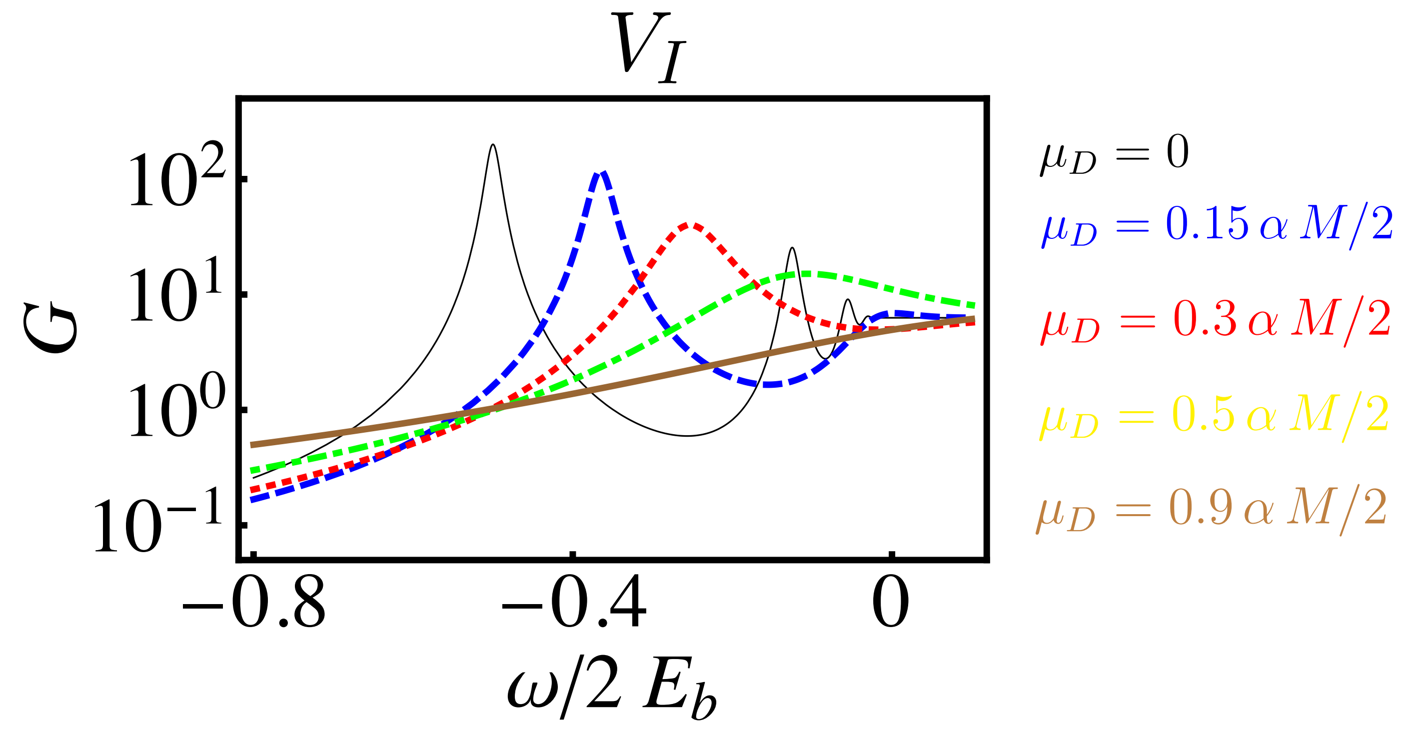
$$-i\partial_{\tilde{t}}\tilde{\psi}(\tilde{t},\mathrm{r})=-\frac{\nabla^2}{M_q}\tilde{\psi}(\tilde{t},\mathrm{r})+V^\dagger(r)\tilde{\psi}(\tilde{t},\mathrm{r})\qquad (\tilde{t}=t-t_0)$$

- The final yield:

$$Y_S\propto\left|\tilde{\psi}(t-t_0,\mathbf{r}=0)\right|^2\qquad \text{(color singlet model)}$$

Potential(s)





- I model the medium QQ potential by

  1) Yukawa: $$V_R(r) = -\alpha\frac{e^{-\mu_D r}}{r}$$

  Laine et al 07, Beraudo et al 07

  2) Complex potential: $$V_I(r) = -\alpha\left(\frac{e^{-\mu_D r}}{r} + i\mu_D\,\phi(\mu_D r)\right).$$

- Vacuum states models by μ_D=0 (no linear rise!)
- For each potential, the suppression factor is defined as

$$R_S = \frac{Y_S(\mu_D)}{Y_S(\mu_D = 0)}$$

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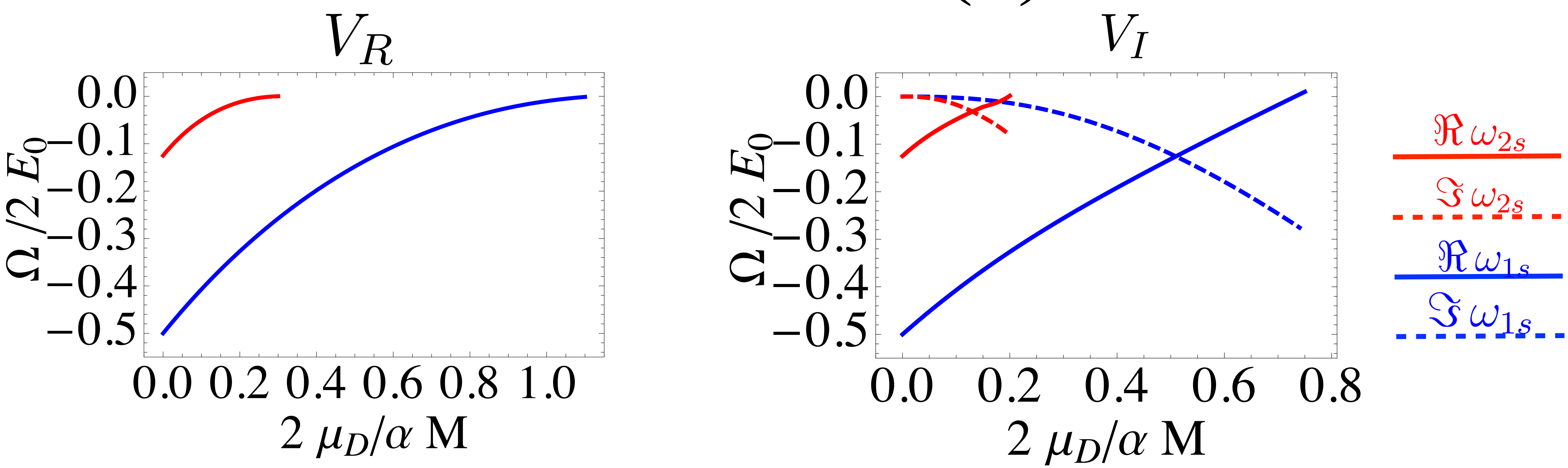

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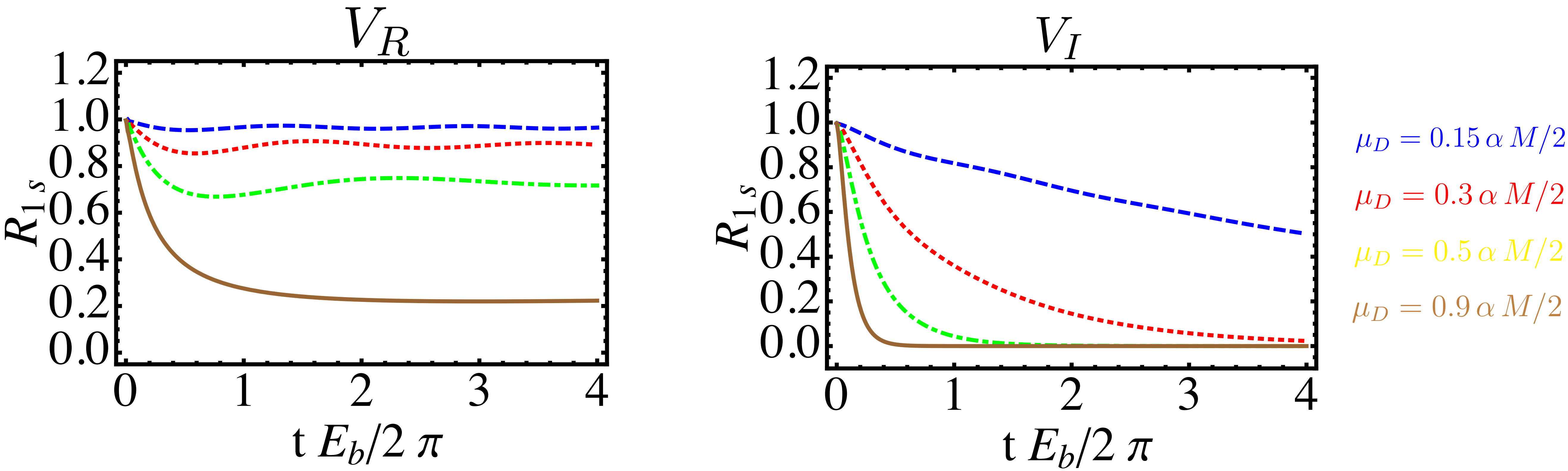
Suppression of 1S States



- Ground state suppression is larger for the complex potential
- The late time suppression:
  - Saturates to a fixed value for V_R (ground state survival)
  - Decay with the width of the state for V_I.
  - Suppression is dominated by the imaginary component.
- Characteristic time scale: ground state period $\mathcal{T} = 2\pi/E_b$

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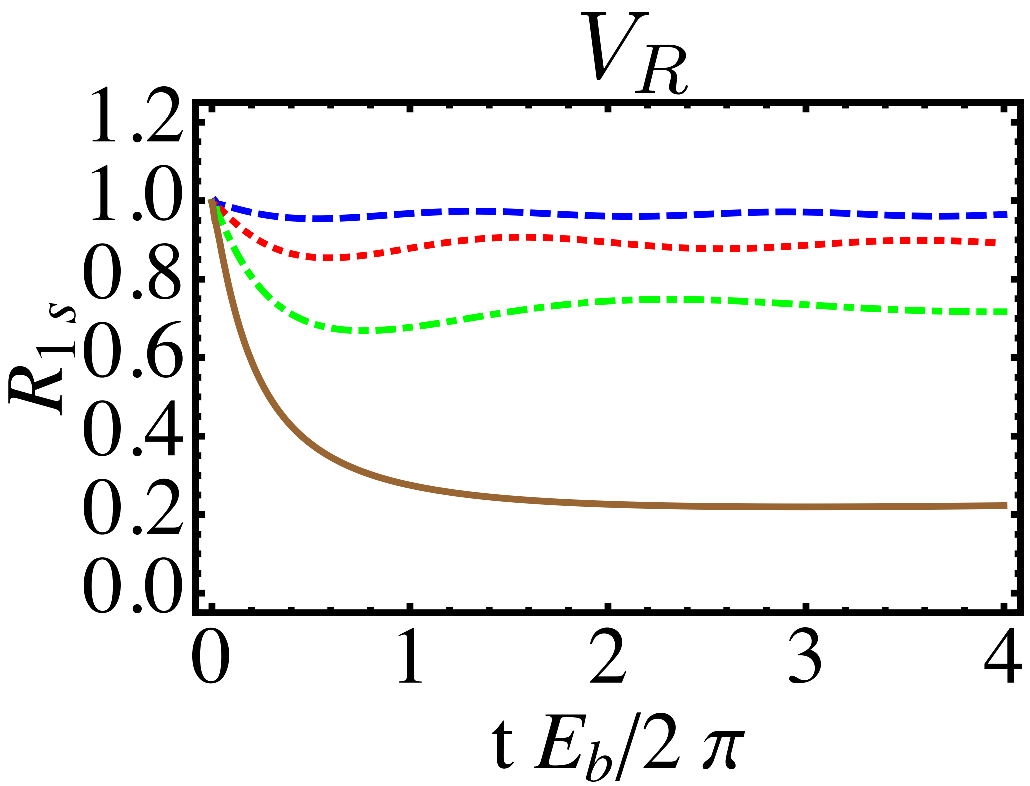

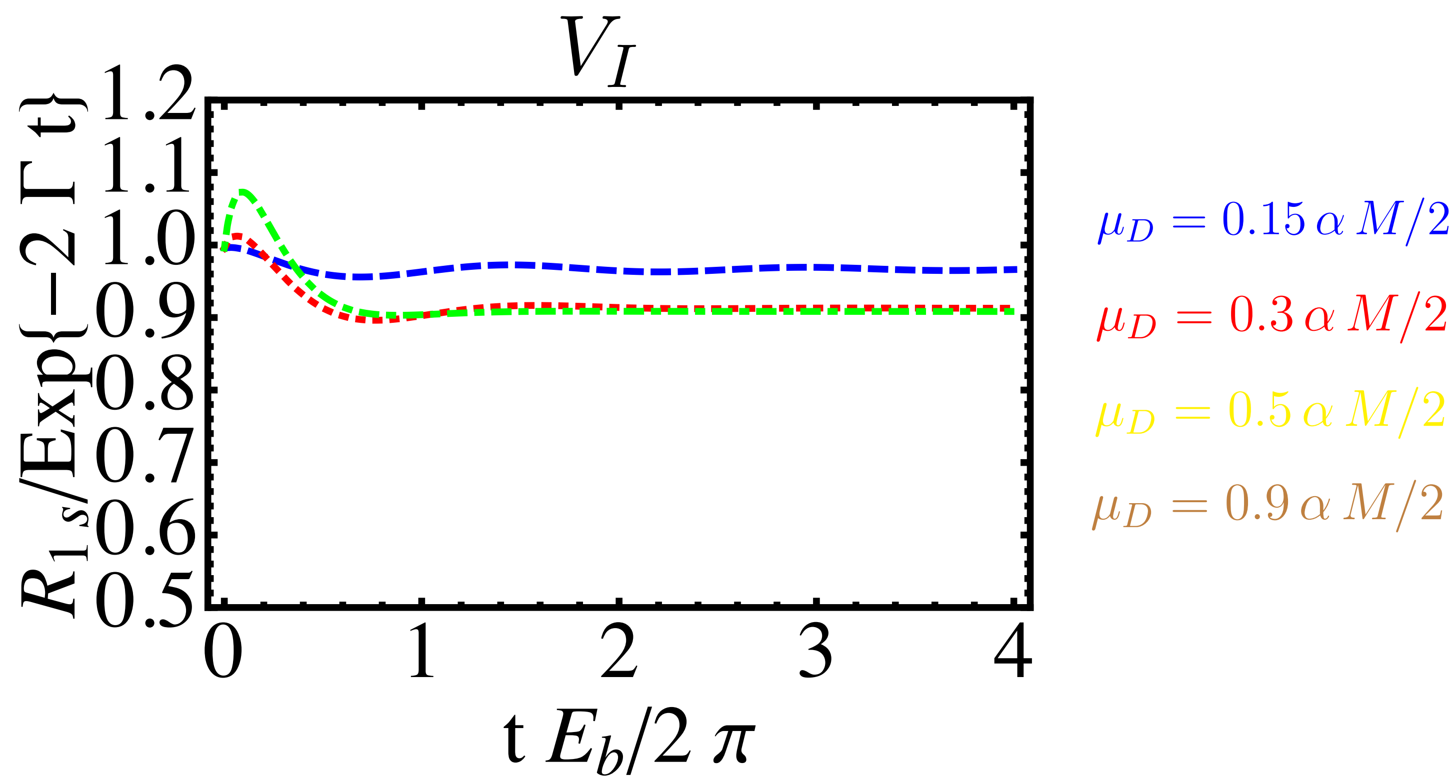

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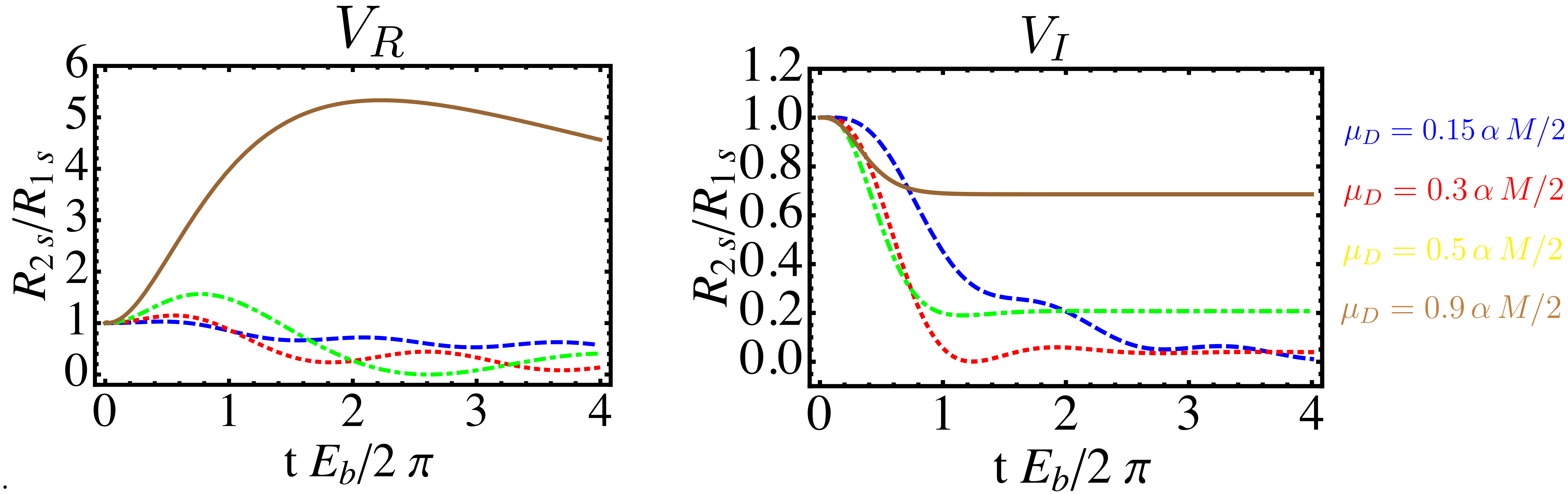
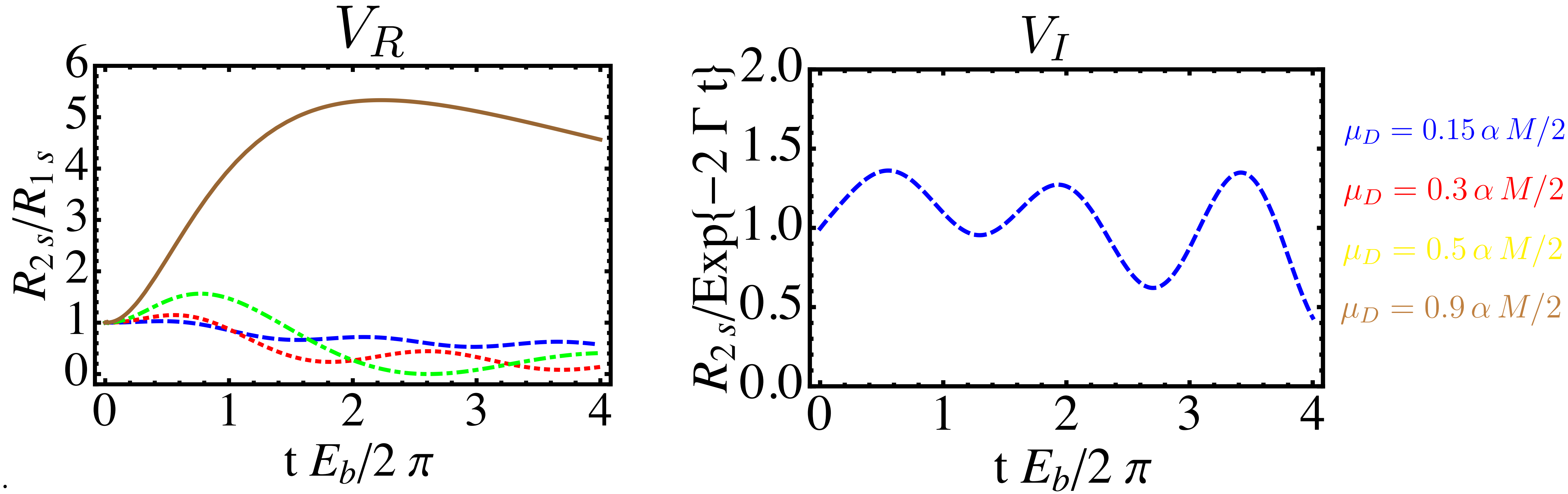
Suppression of 2S States



- 2S formation is strongly influenced by in-medium ground state
    - The oscillations are due to interference with 1S states
    - Late time suppression for V_I falls with the 1S width.
- 2S suppression smaller than 1S one at high T due to:
    - Contribution of in-medium 1S (if bound)
    - Wider vacuum wave function (if 1S is unbound)
- If no states survive in a large fraction of medium evolution

$$R_{2S}/R_{1S} > 1$$

Suppression of 2S States



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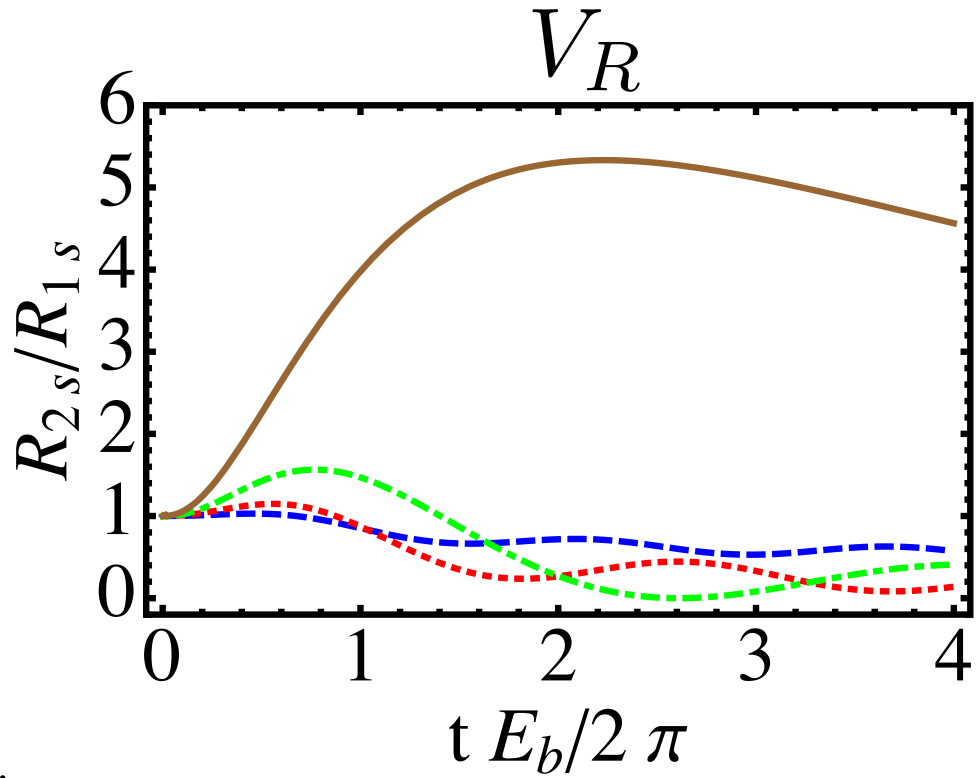

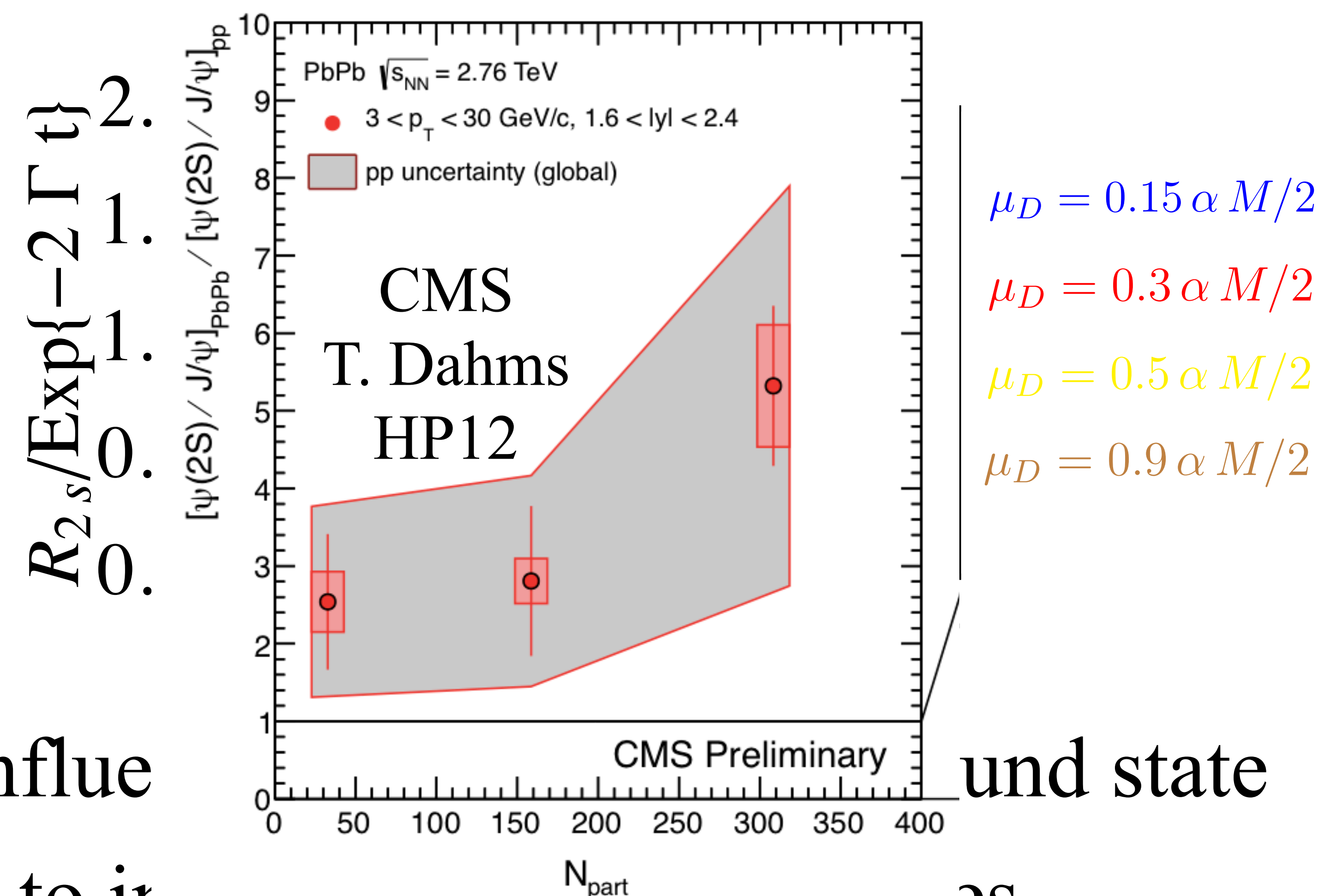

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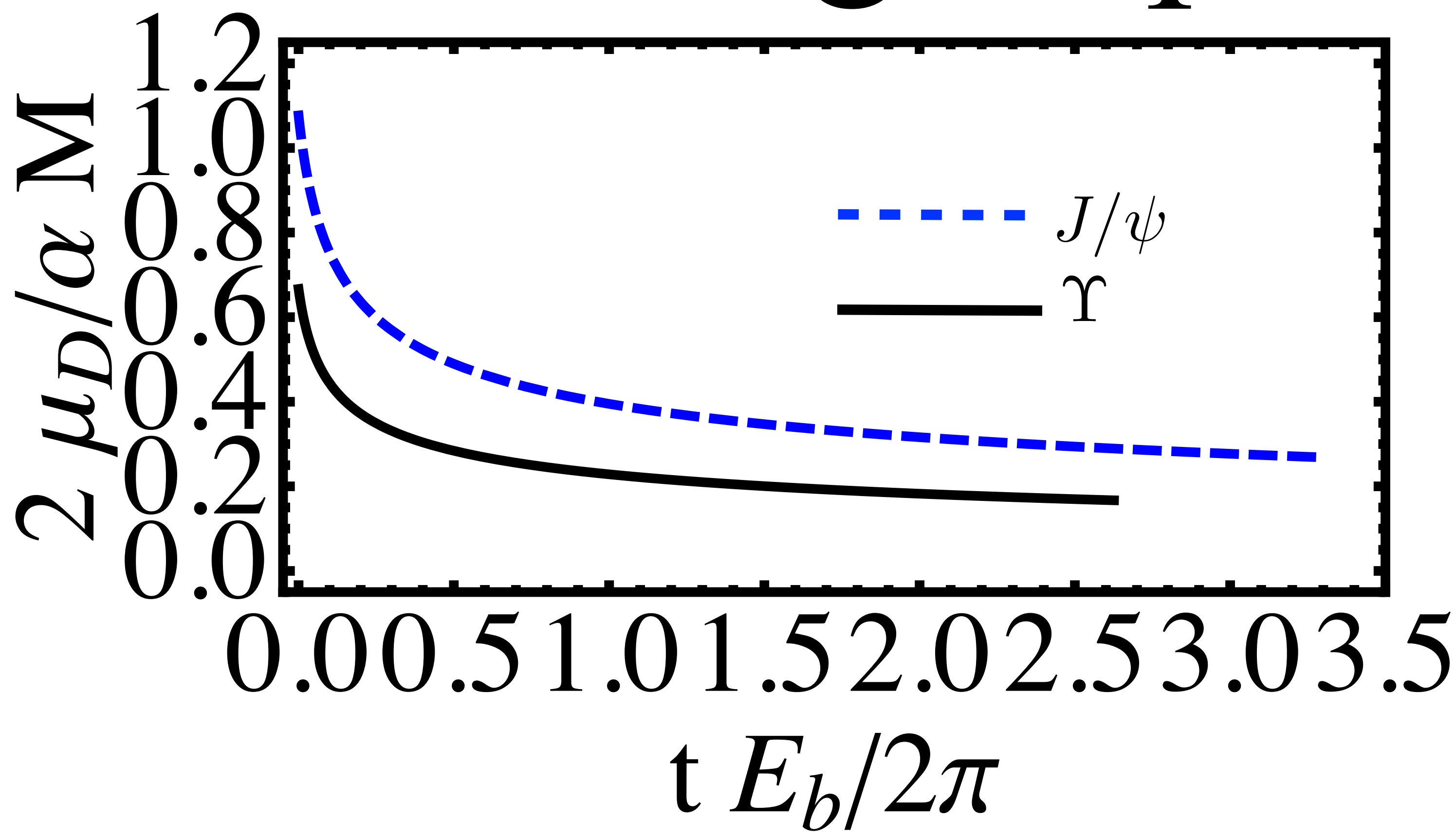
Introducing Expansion

μ_{D0}=0.7 GeV



- Inspired by Bjorken expansion, we vary

$$\mu_D(t) = \mu_{D0} \left(\frac{\tau_0}{t+\tau_0} \right)^{1/3} \quad \tau_0 = 0.4 \text{ fm}$$

- At Tc= 175 MeV, the pair is projected into vacuum states

- For each meson, α is fixed in the vacuum by fitting r_0

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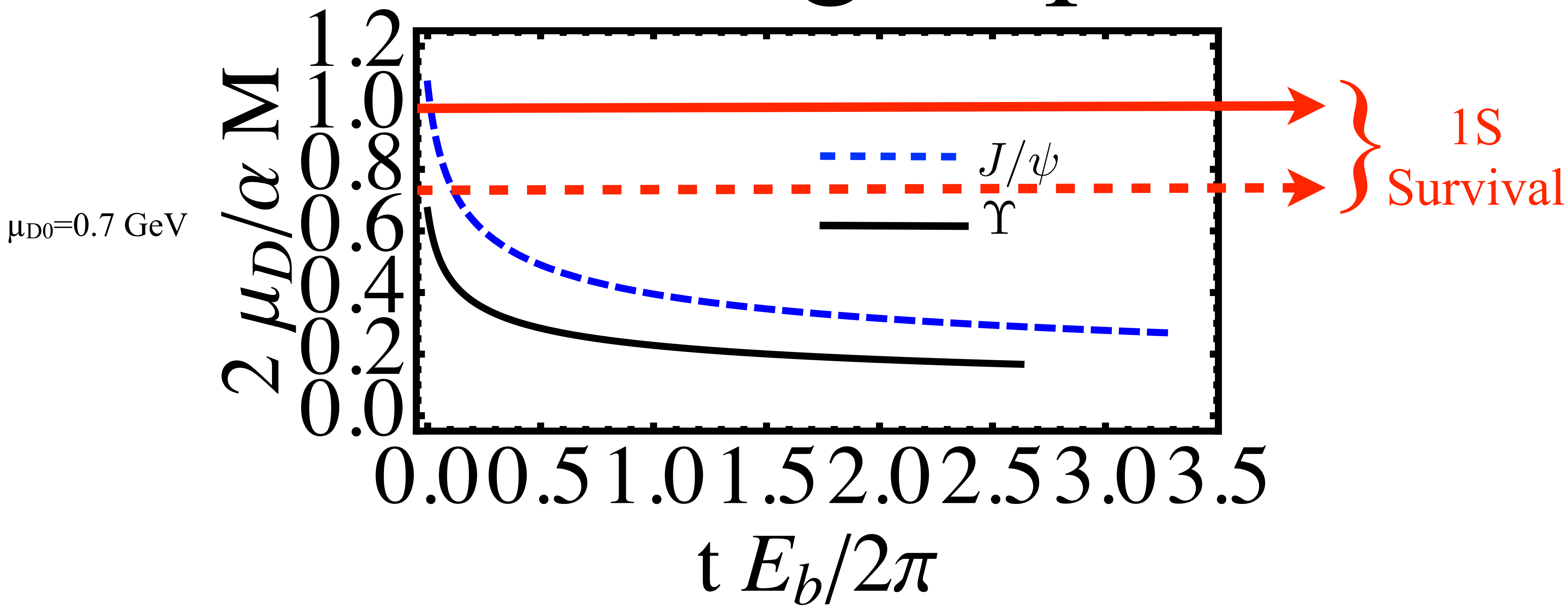

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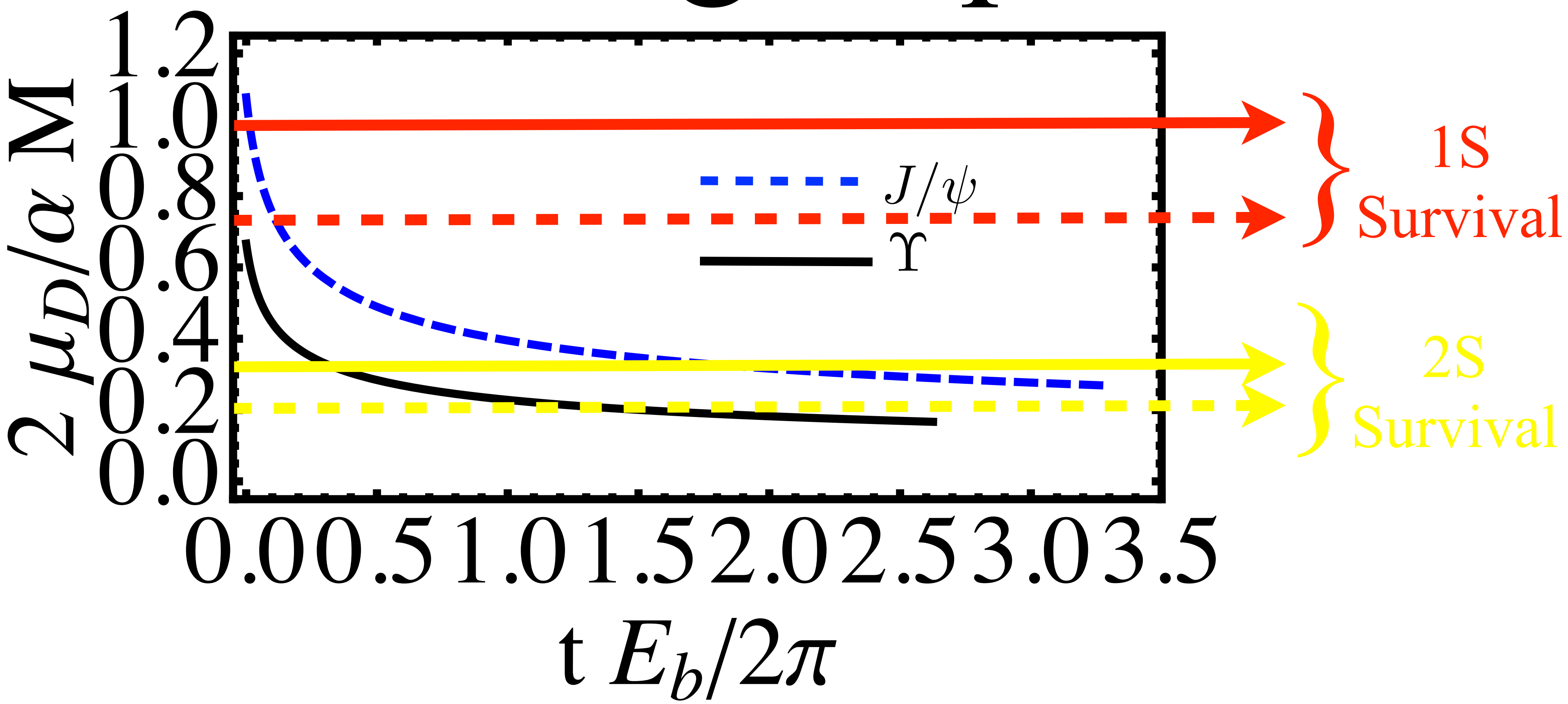

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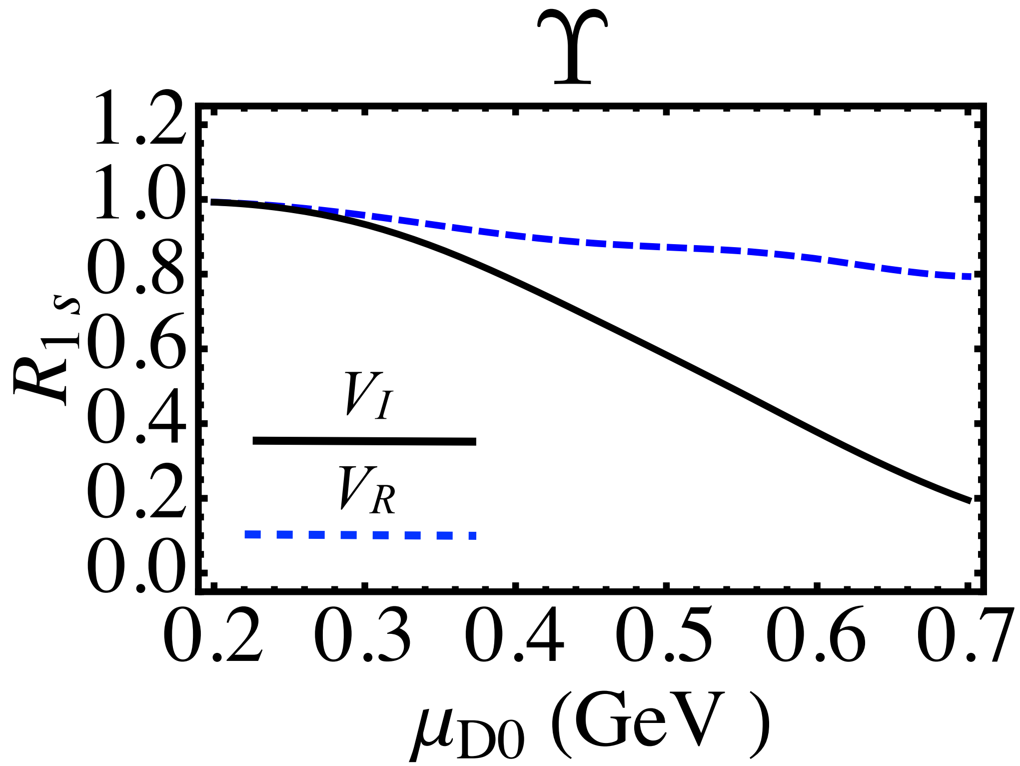
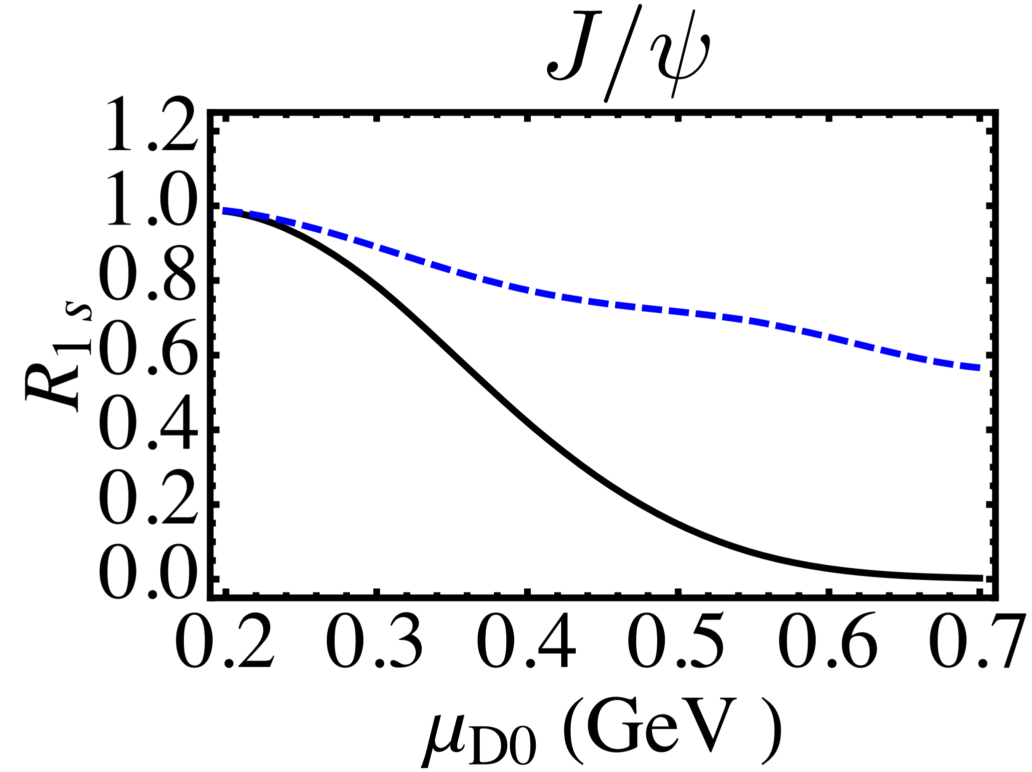
Varying the Initial μ_{D0}





- V_I leads to a strong suppression of 1S states.
- Most of the suppression happens in the pre-formation stage
  - $t_{TC} < 2\pi/E_b$ for $\mu_{D0} < 0.5$ GeV
- The suppression of the 2S states shows non monotonic behavior
  - For V_R, it reflects the oscillations at fixed μ_D
- The suppression is insensitive to the hottest part of the evolution.

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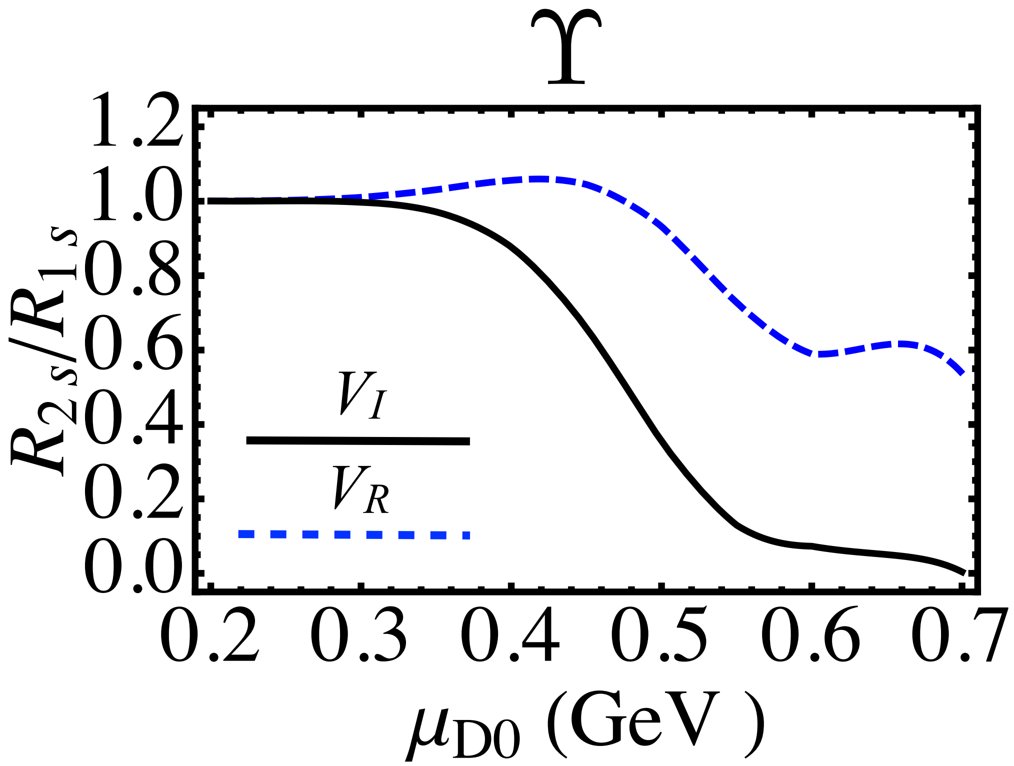

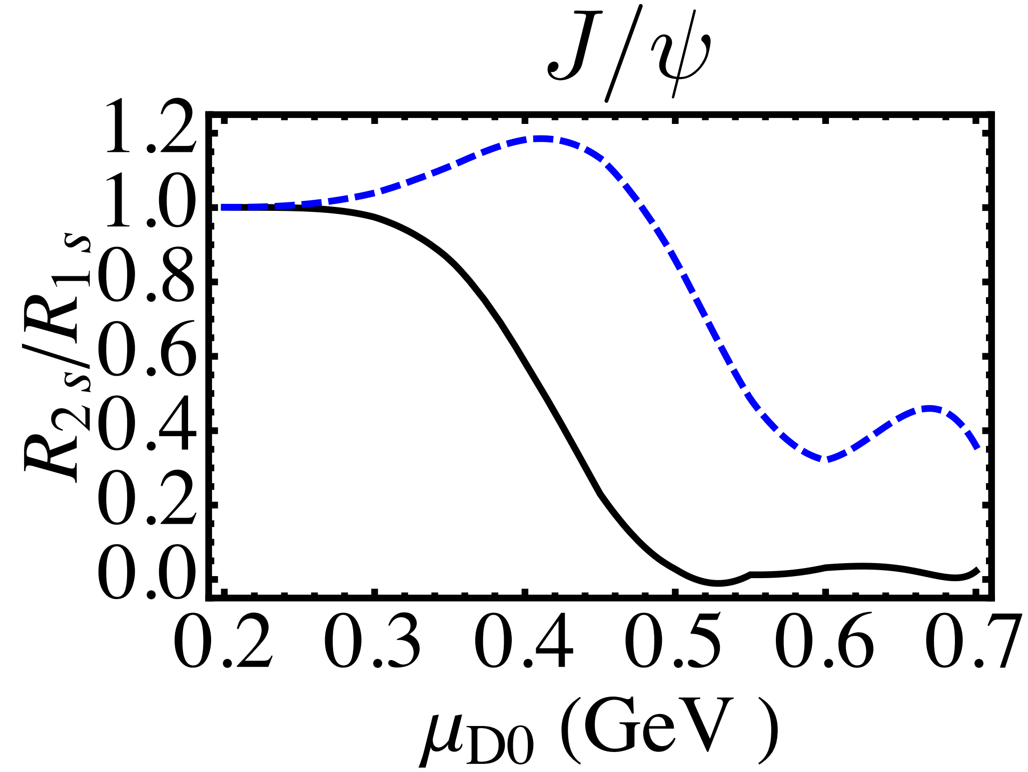

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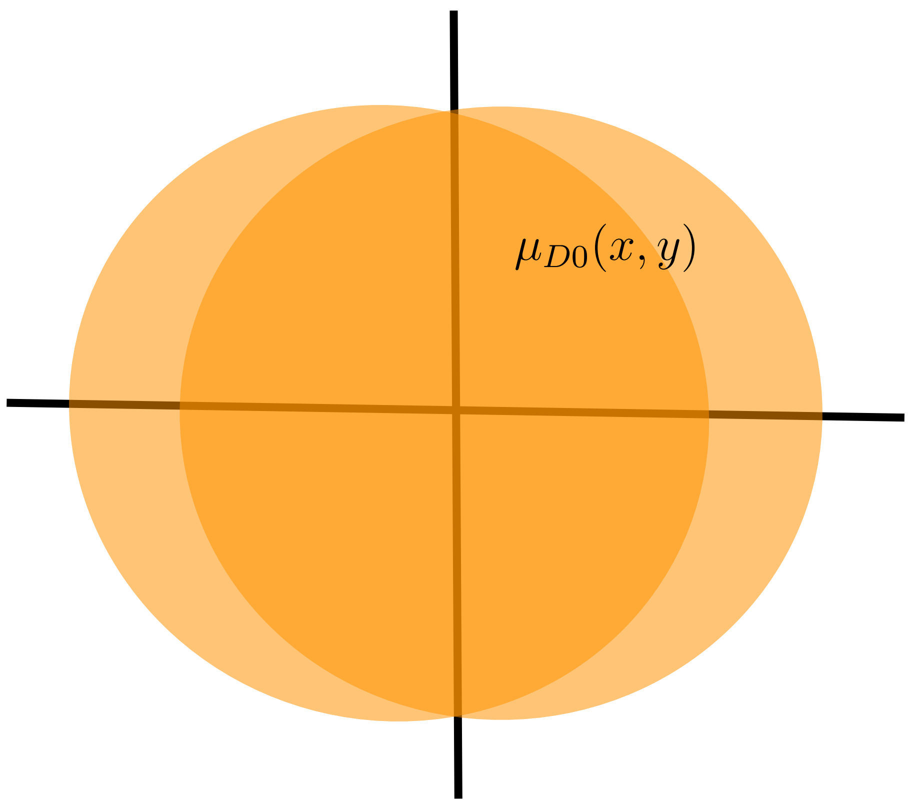
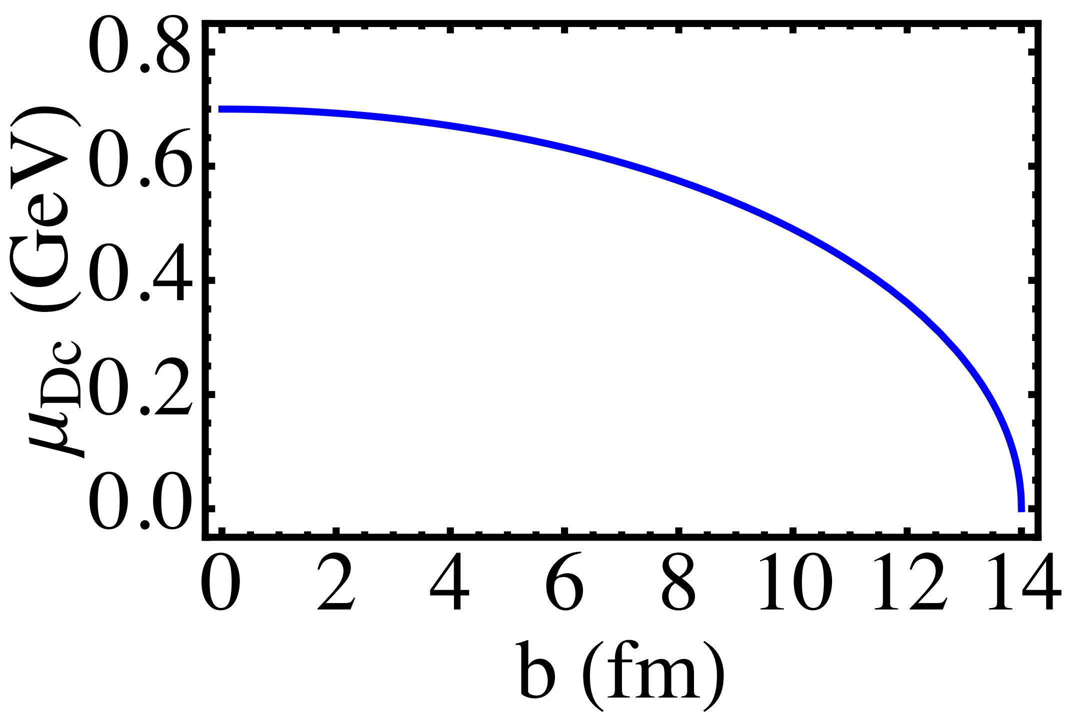
Collision Geometry





- Initial μ_{D0} changes in the transverse plane.

$$\mu_D \propto T_A((x-b/2),y) + T_A((x+b/2),y)$$ (Hard Spheres)

- If $\mu_D < T_c$, we assume no quarkonia suppression
- Increasing b decreases the maximum available μ_D, μ_{DC}
- 1S states survive most of the evolution.
- 2S are dissolved.

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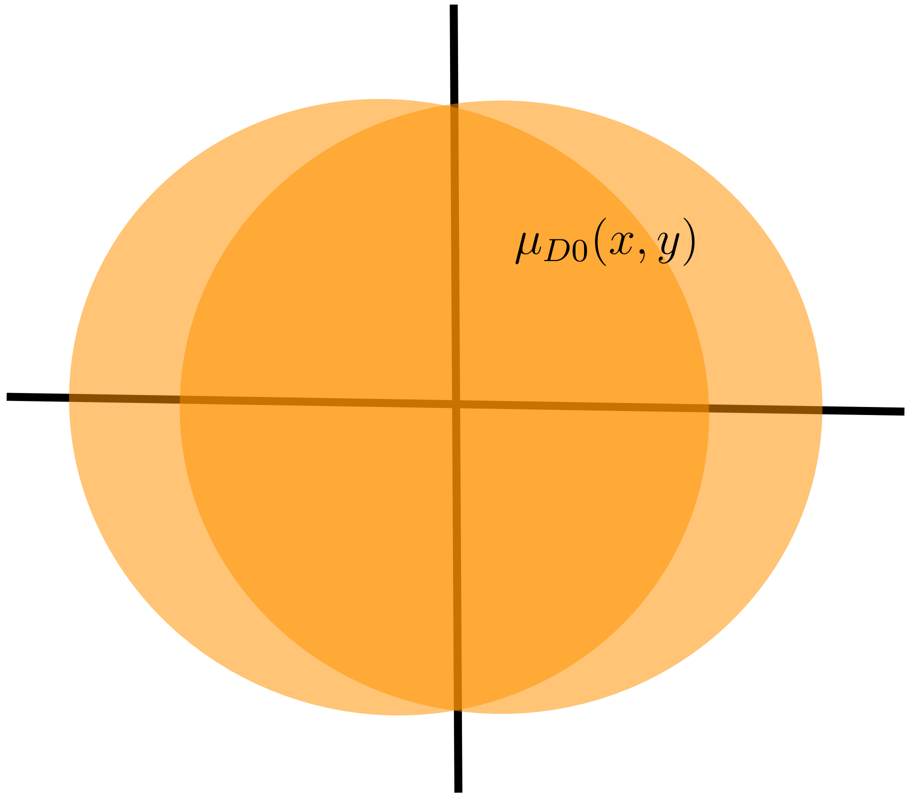

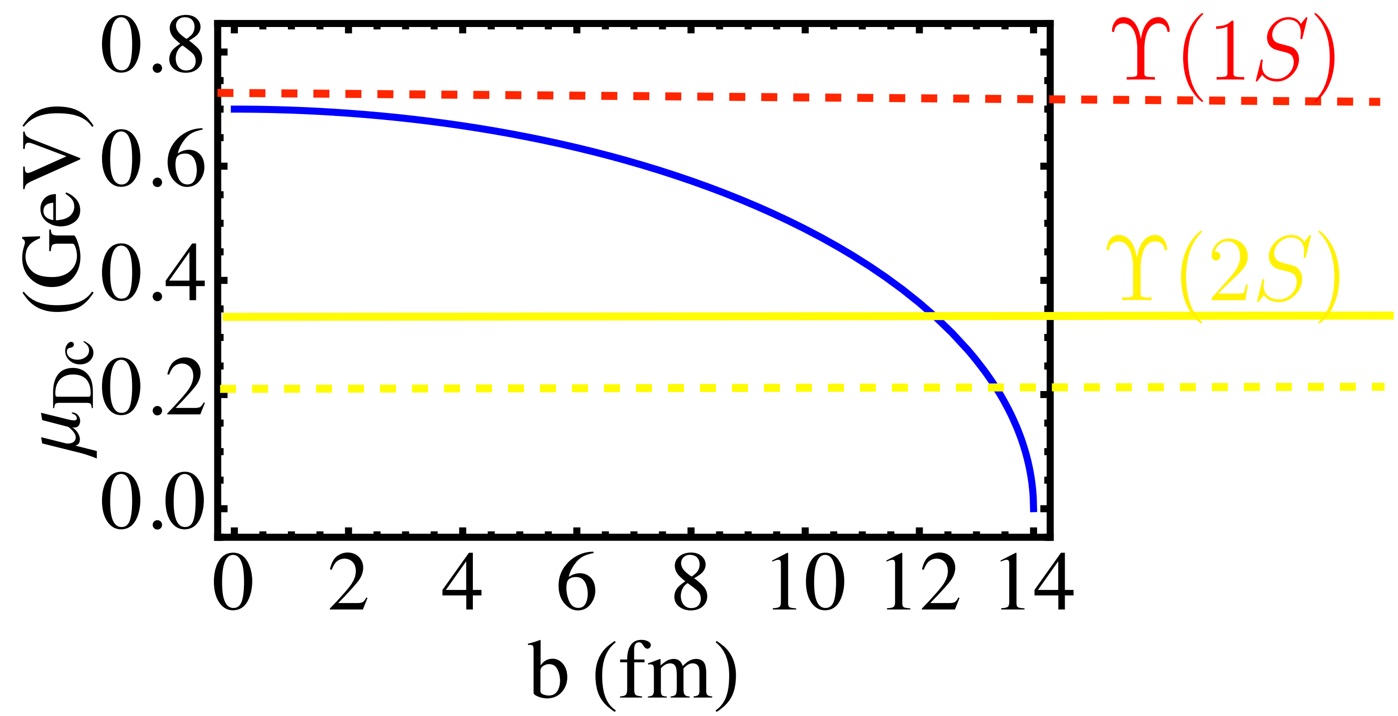

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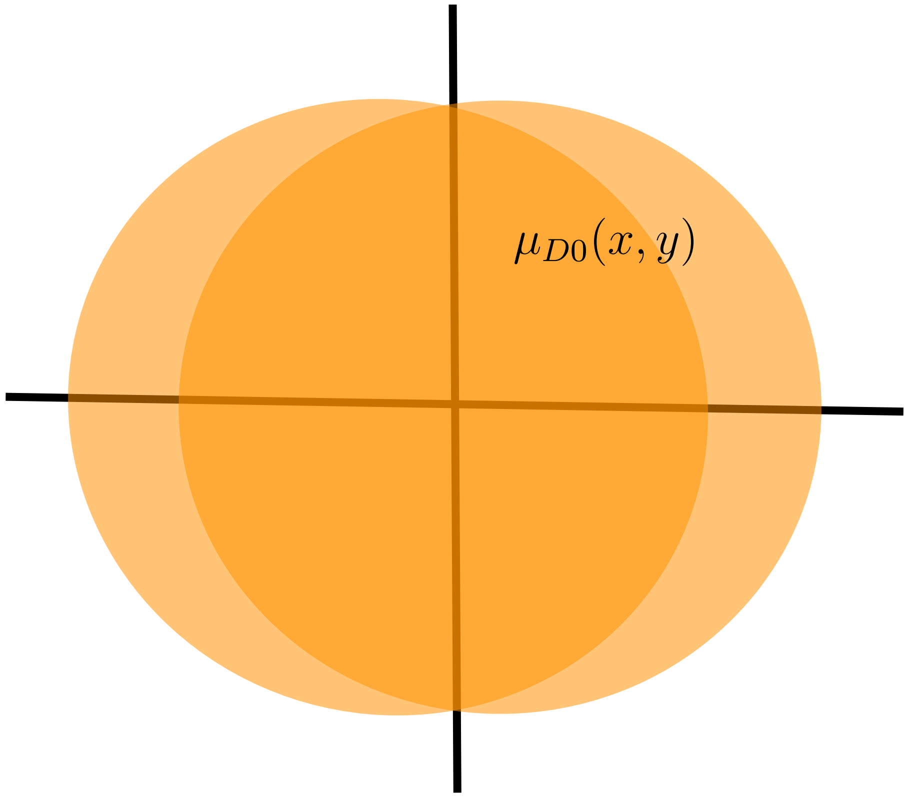

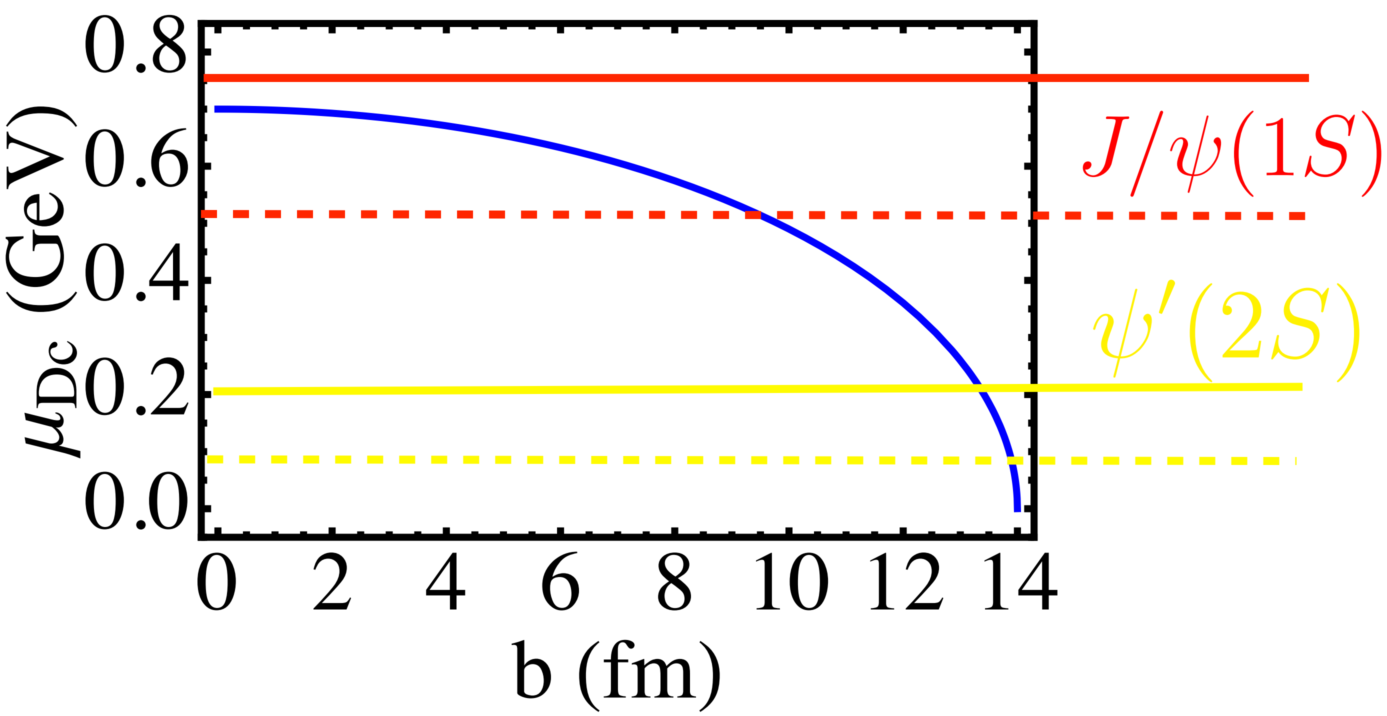

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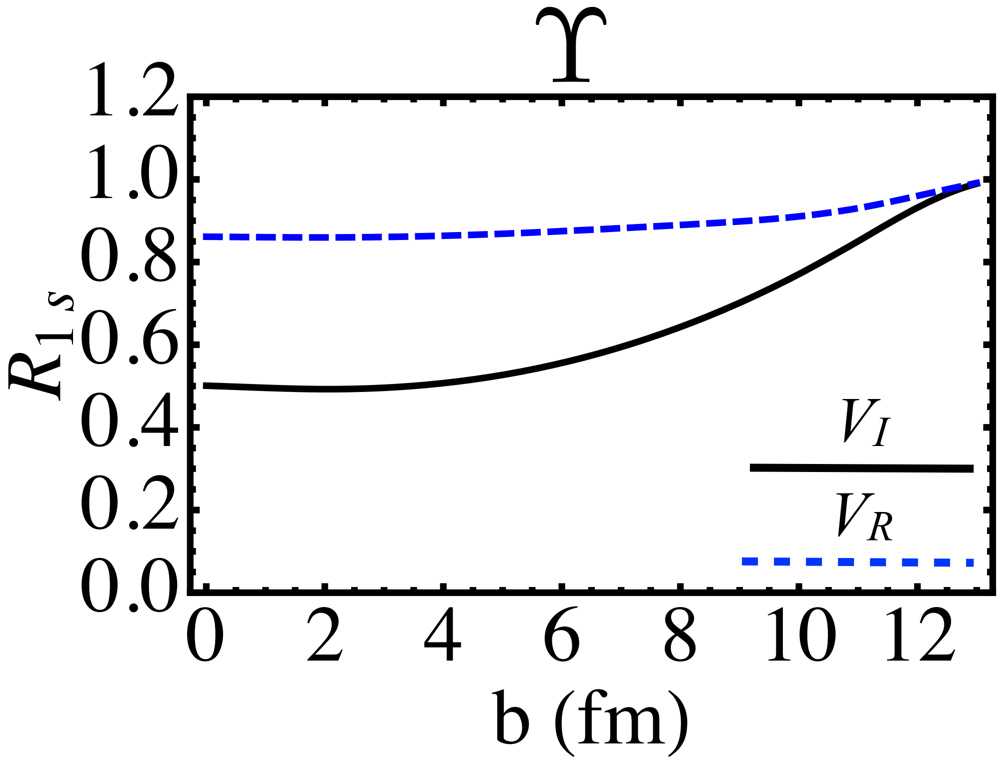
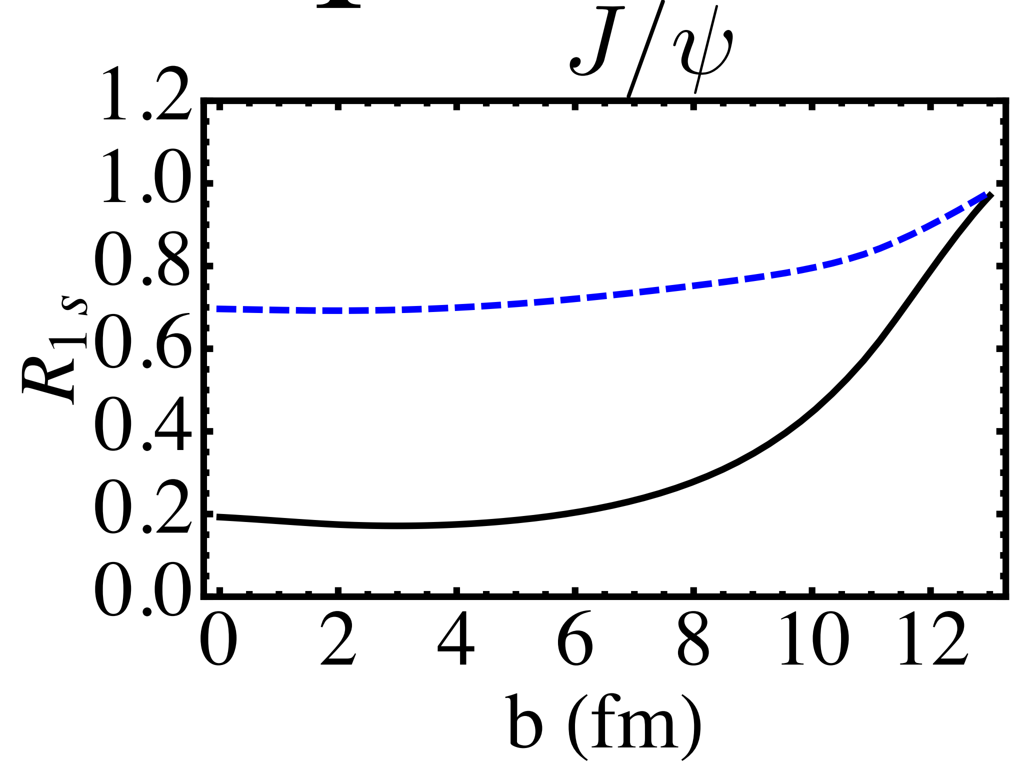
Nuclear Absorption





- 1S: smooth b dependence with a strong rise for b>8 fm
  - In-medium 1S state is present for all temperatures
  - The rise is due to a fireball lifetime less than $2\pi/E_b$
- 2S: some structure remains after transverse plane average
  - In-medium 2S state is dissolved for all temperatures
  - The rise persists around b=8 fm
  - No excess of 2S to 1S since in-medium 1S survives
  - Yet, at small b, the double ratio decreases with b.

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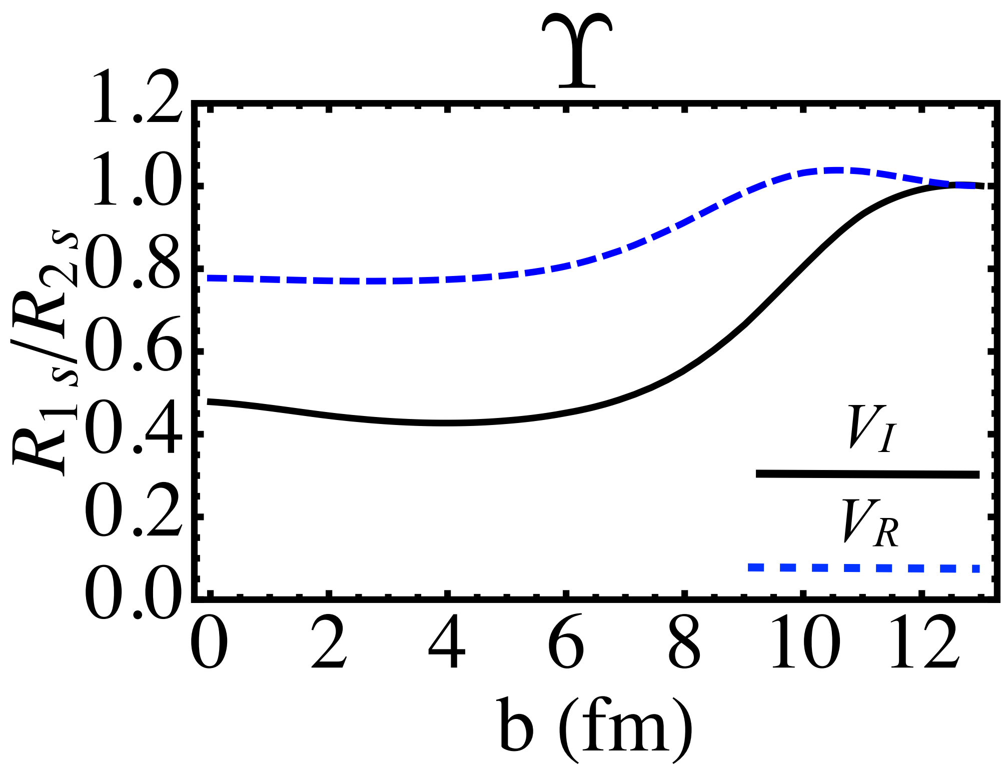

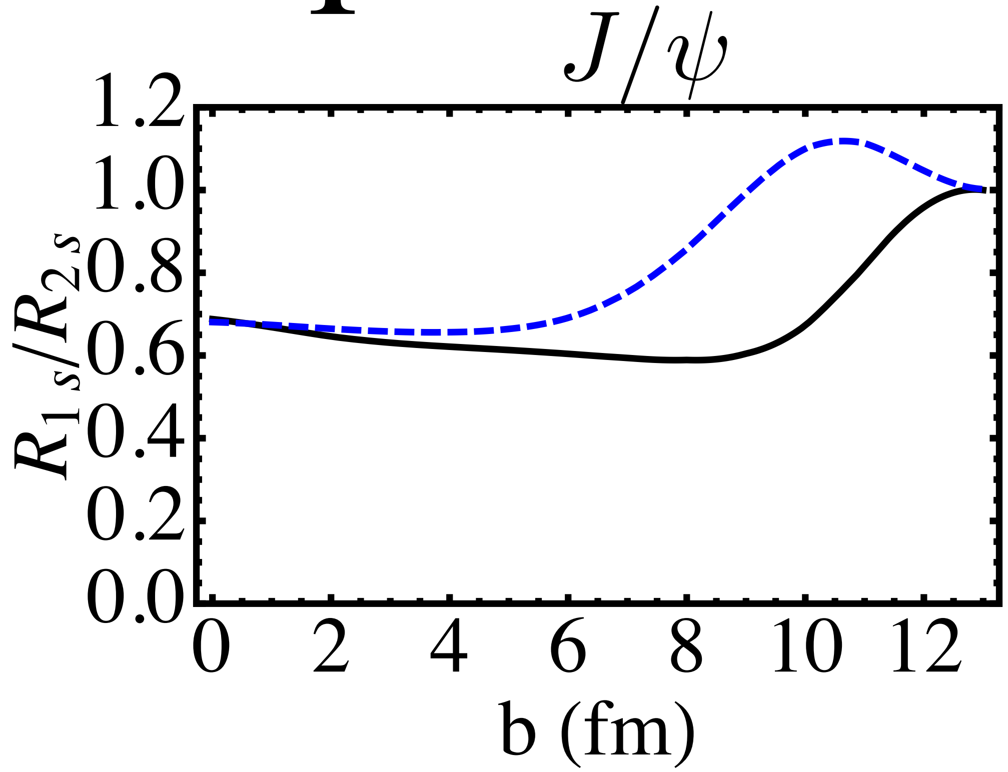

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Conclusions

- Suppression of 1S states is dominated by in-medium 1S states
- Production of 2S states are also influence by in-medium 1S
- Interplay between 2S and 1S leads to non-trivial structure
- An enhancement of 2S states can occur
  - For close to threshold in-medium 1S states
  - Absence of states in plasma
- Relevant formation times of quarkonia states are long.
  - Expansion reduces the sensitivity to the early very high temperature part of the evolution
  - Production of quarkonia in HI have limited sensitivity to in medium potential