

# Gluo-dissociation and quasi-free dissociation in the EFT framework

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Nora Brambilla, MAE, Jacopo Ghiglieri, Antonio Vairo. [arxiv:1109.5826]  
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# Outline

- 1 Motivation
- 2 Gluo-dissociation
- 3 Quasi-free dissociation
- 4 Conclusions

# Motivation

# What has been found until now using EFTs in Quarkonia?

- EFT provide a systematic way to extract information from the fact that  $m_Q \gg \frac{1}{r} \gg E$  in Quarkonia. Computations are easier and it is more difficult to neglect a needed resummation.
- For  $T \gg \frac{1}{r} \sim m_D$  we recover the perturbative potential with an imaginary part found by Laine, Philipsen, Romatschke and Tassler (2007).
- For  $T \lesssim \frac{1}{r}$  we were able to compute thermal corrections to the binding energies and the decay width.
- For the decay width we found two different mechanism. Gluo-dissociation and Landau damping (or quasi-free dissociation).

## Other approach to quarkonia decay width

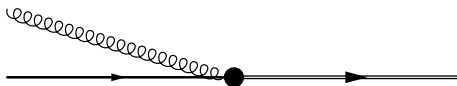
- Use a cross-section computed at  $T = 0$ ,  $\sigma(k)$ .
- Convolute with the thermal distribution

$$\Gamma = \int \frac{d^3k}{(2\pi)^3} f(k) \sigma(k)$$

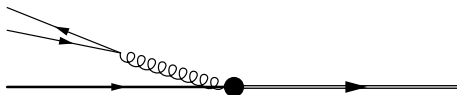
- These cross-sections are computed in perturbation theory and later they are "adapted" to strong coupling by using  $\alpha_s$  as a free parameter, introducing thermal masses...
- This information is used as an input to predict the observed suppression in nowadays experiments. See for example Zhao and Rapp (2010).

# Perturbative computations of cross-section for quarkonia in the literature

Gluo-dissociation



Bhanot and Peskin (1979)  
Quasi-free dissociation



Combridge (1978), Park, Kim, Song, Lee and Wong (2007)

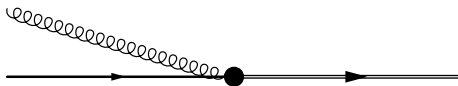
# Motivation

- Translate the EFT results that have been found to cross-sections convoluted with distribution function "language".
- Analyze the assumptions made by previous perturbative computations and check if they agree or disagree with the EFT framework.

# Gluo-dissociation

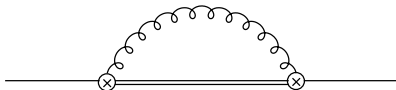


# Glue-dissociation in Bhanot and Peskin



- They use OPE. The interaction between the singlet, the octet and the gluon is a color dipole interaction. Similar to what is done in pNRQCD.
- They use the large  $N_c$  limit approximation. In this limit  $V_o = 0$  and computations are simplified.
- We are going to see that the large  $N_c$  limit is a good approximation for  $T \gg E$  but not for  $T \sim E$ .

# Glue-dissociation in pNRQCD



- Computed for  $T \gg E$  in HQ. Brambilla, MAE, Ghiglieri, Soto and Vairo (2010)

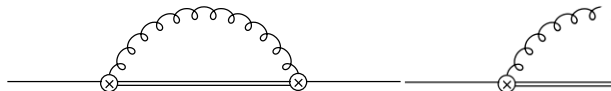
$$\delta\Gamma_n = \frac{1}{3}N_C^2 C_F \alpha_s^3 T - \frac{16}{3m} C_F \alpha_s T E_n + \frac{4}{3}N_C C_F \alpha_s^2 T \frac{2}{mn^2 a_0}$$

where  $E_n$  is the binding energy and  $a_0$  the Bohr radius.

- Computed for  $T \sim E$  in the hydrogen atom. MAE and Soto (2008).

$$\delta\Gamma_n = \frac{4}{3}\alpha_s C_F T \langle n | r_i \frac{|E_n - h_o|^3}{e^{\beta|E_n - h_o|} - 1} r_i | n \rangle$$

# Cutting rules at finite temperature

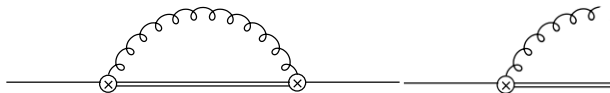


Similar to what is found at  $T = 0$ .

- Multiply by  $n_B(k)$  ( $n_F(k)$ ) for in-coming bosons (fermions).
- Multiply by  $1 + n_B(k)$  ( $1 - n_F(k)$ ) for out-going bosons (fermions).

Kobes and Semenoff (1986)

## Cutting rules at finite temperature



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- Multiply by  $n_B(k)$  ( $n_F(k)$ ) for in-coming bosons (fermions).
- Multiply by  $1 + n_B(k)$  ( $1 - n_F(k)$ ) for out-going bosons (fermions).

In this case we get a structure

$$\delta\Gamma_n = \int \frac{d^3k}{(2\pi)^3} n_B(k) \langle n | h_\sigma(r, p, k) | n \rangle$$

## A choice

$$\delta\Gamma_n = \int \frac{d^3k}{(2\pi)^3} n_B(k) \langle n | h_\sigma(r, p, k) | n \rangle$$

- If we integrate out  $k$  first we recover the pNRQCD result
- If we choose for example  $n = 1S$  and compute the matrix element.

$$\delta\Gamma_{1S} = \int \frac{d^3k}{(2\pi)^3} n_B(k) \sigma_{gd}(k)$$

# pNRQCD gluo-dissociation $\sigma_{gd}$ for $1S$

- If we do the same approximations as Bhanot and Peskin (large  $N_c$  limit) we recover their result.
- Without doing this approximation we get

$$\sigma_{gd}(k) = \frac{8\pi^2 C_F \alpha_s m a_0^2 k}{3} |\langle 1S | r_i | m a_0^2 (k + E_1) \rangle_o|^2 \Theta(k + E_1)$$

$|\epsilon\rangle_o$  are the octet wave function taking into account the octet potential.

$$\int_0^\infty d\epsilon \langle \epsilon | \epsilon \rangle_o = 1$$

## pNRQCD gluo-dissociation $\sigma_{gd}$ for $1S$

The Coulomb wave-function with a repulsive potential (as the one of the octet) were taken from Abramowitz and Stegun (1972)

$$\sigma_{gd}(k) = \frac{32\pi C_F \alpha_s m a_0^3 k \left( C_1 \left( \frac{1}{8\sqrt{\tau}} \right) \right)^2 \left( f \left( \frac{1}{\sqrt{\tau}} \right) \right)^2}{3\tau^{7/2}} \Theta(\tau)$$

where

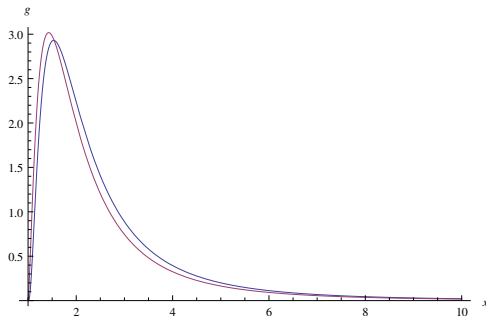
$$\begin{aligned}\tau &= m a_0^2 (k + E_1) \\ C_1(x) &= \frac{\sqrt{1+x^2}}{3} \sqrt{\frac{2\pi x}{e^{2\pi x} - 1}} \\ f(x) &= \frac{51}{2} \frac{x e^{\frac{x}{4} \operatorname{arccot}(x)}}{(x+1)^3}\end{aligned}$$

Agrees with Brezinski and Wolschin (2011)

# Comparison between Bhanot and Peskin and pNRQCD gluo-dissociation

$$\sigma_{gd}(k) = \sigma_R g(x)$$

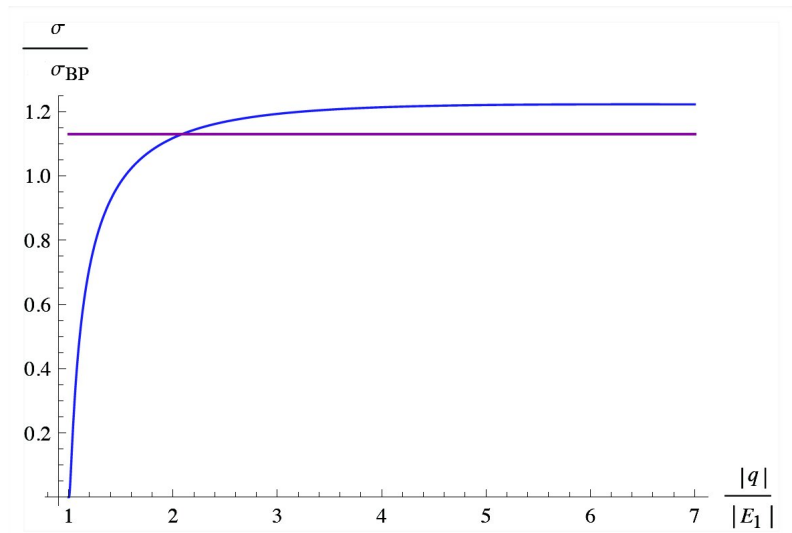
$$\text{with } \sigma_R = \frac{32\pi C_F \alpha_s a_0^2}{3} \text{ and } x = \frac{k}{|E_1|}$$



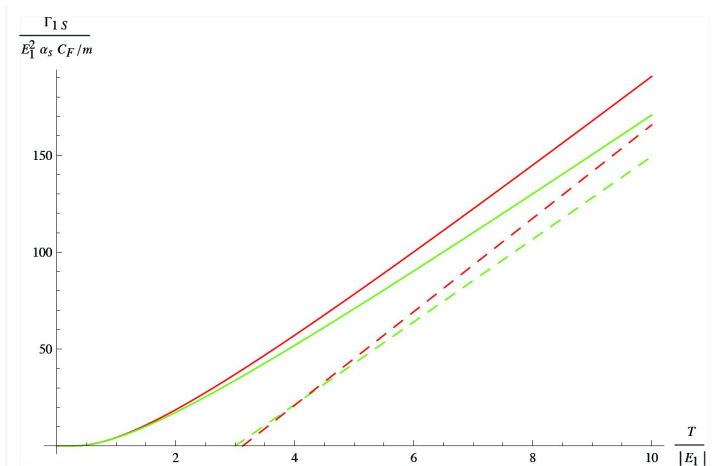
Bhanot and Peskin large  $N_c$  limit  
pNRQCD



# Comparison between Bhanot and Peskin and pNRQCD gluo-dissociation

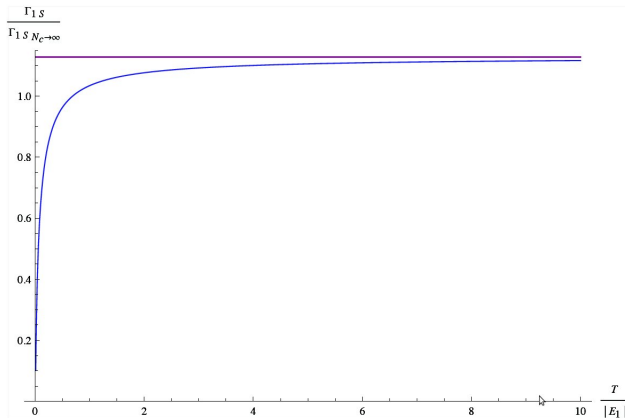


# Comparison between Bhanot and Peskin and pNRQCD gluo-dissociation



Bhanot and Peskin, pNRQCD

# Comparison between Bhanot and Peskin and pNRQCD gluo-dissociation



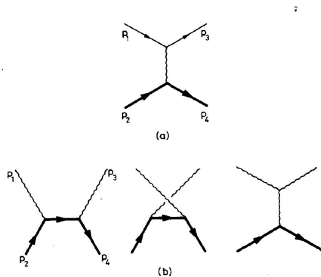
At asymptotically high values of  $T$  the ratio tends to the constant  $\frac{289}{256}$ .

# Quasi-free dissociation

## (Or Landau damping)

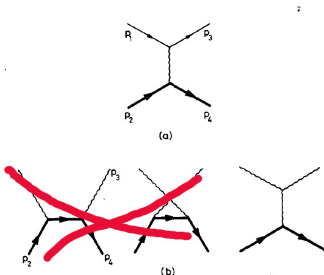
# Quasi-free in Cambridge

He computed the process  $qc \rightarrow qc$  for a charm quark, no information of the bound state is included.



## Quasi-free in Cambridge

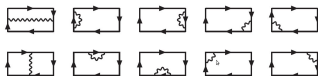
He computed the process  $qc \rightarrow qc$  for a charm quark, no information of the bound state is included.



Note that in NRQCD (valid for  $m_Q \gg T$ ) and using the Coulomb gauge the crossed diagrams are subleading.

HQ potential for  $T \gg \frac{1}{r} \sim m_D$

Laine, Philipsen, Romatschke and Tassler



pNRQCD



# Imaginary part of the potential

$$Im \left( \begin{array}{c} \text{Diagram 1: Two horizontal lines with a wavy line connecting them at the top, with a black dot at the vertex.} \\ \text{Diagram 2: Two horizontal lines with a wavy line connecting them at the bottom, with a black dot at the vertex.} \\ \text{Diagram 3: Two horizontal lines with a vertical wavy line connecting them in the middle, with a black dot at the vertex.} \end{array} \right)$$

By the optical theorem

$$\begin{aligned} & \left| \begin{array}{c} \text{Diagram 1} \\ \text{Diagram 2} \end{array} \right|^2 + \left| \begin{array}{c} \text{Diagram 3} \\ \text{Diagram 4} \end{array} \right|^2 = \\ & \left| \begin{array}{c} \text{Diagram 1} \\ \text{Diagram 2} \end{array} \right|^2 + \left| \begin{array}{c} \text{Diagram 3} \\ \text{Diagram 4} \end{array} \right|^2 + 2Re \left( \left( \begin{array}{c} \text{Diagram 1} \\ \text{Diagram 2} \end{array} \right)^* \begin{array}{c} \text{Diagram 3} \\ \text{Diagram 4} \end{array} \right) \end{aligned}$$



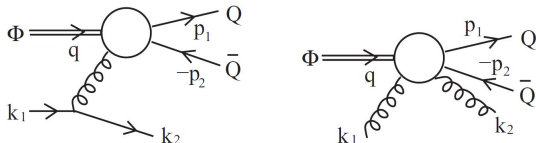
## Imaginary part of the potential

$$Im \left( \begin{array}{c} \text{Diagram 1} \\ \text{Diagram 2} \\ \text{Diagram 3} \end{array} \right) + \left| \begin{array}{c} \text{Diagram 4} \\ \text{Diagram 5} \end{array} \right|^2 = \left| \begin{array}{c} \text{Diagram 6} \\ \text{Diagram 7} \end{array} \right|^2 + 2Re \left( \left( \begin{array}{c} \text{Diagram 8} \end{array} \right)^* \begin{array}{c} \text{Diagram 9} \end{array} \right)$$

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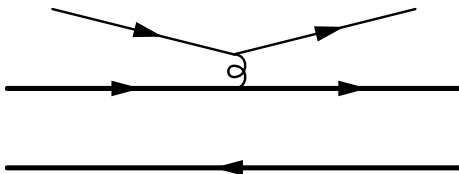
6th of october

# Quasi-free in Park, Kim, Song, Lee and Wong



- For the interaction of the HQ with partons they use vertex computed in Bethe-Salpeter approach and large  $N_C$  limit by Song and Lee (2005).
- They assume  $q, p_1, p_2 \sim m\alpha_s \gg k_1, k_2$ . Colour dipole approximation.

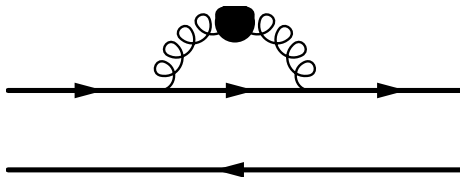
## From the cross-section to the decay width



- Apart from the heavy quarks that are not thermalized, there is an in-coming parton and an out-going parton.
- The decay width then has the structure

$$\Gamma = \int \frac{d^3k}{(2\pi)^3} f(k)(1 + f(k))\sigma(k)$$

## From the cross-section to the decay width



This is consistent with EFT result. For example, the part related with fermion loops is

$$\Pi_{00}^S(q \gg q_0) = \frac{4ig^2 T_F N_F}{\pi q} \int_{k > \frac{q}{2}} dk k^2 \left(1 - \frac{q^2}{4k^2}\right) n_F(k)(1 - n_F(k))$$

# From the cross-section to the decay width

In conclusion, thermal field theory does not justify in this case

$$\Gamma = \int \frac{d^3k}{(2\pi)^3} f(k) \sigma(k)$$

but instead

$$\Gamma = \int \frac{d^3k}{(2\pi)^3} f(k) (1 + f(k)) \sigma(k)$$

## Cross-section for the $1S$ state

We proceed in a similar way to what is done for the gluo-dissociation. We start by our previous EFT computations and "translate" them

- In gluo-dissociation only a energy scale was relevant. This is not the case now.
- As we need information of the scale  $m_D$  the HTL has to be performed at some part of the computation.  $\sigma$  is going to depend also on the temperature due to this.
- Because we are doing a perturbative computation  $T \gg m_D$  which is not the case for quarkonia. However, we still can analyze up to which temperature the color dipole approximation is valid (relation with the Park, Kim, Song , Lee and Wong computation) and at which temperature the Laine et al. potential gives the correct results.

## Some notation

$$\sigma(k, m_D) = \sigma_R f(x, y)$$

where

$$\sigma_R = 16\pi C_F \alpha_s^2 T_F N_F a_0^2$$

$$x = m_D a_0$$

$$y = k a_0$$

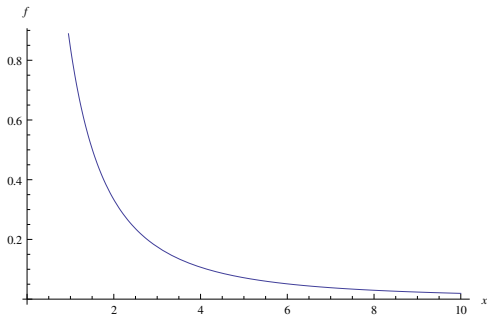
I will only show the result for the fermion part, the boson part is quantitatively and qualitatively very similar.



$T \gg \frac{1}{r} \sim m_D$  cross-section for 1S

$$f(x, y) = 2 \left( 1 - 4 \frac{x^4 - 16 + 8x^2 \log\left(\frac{4}{x^2}\right)}{(x^2 - 4)^3} \right)$$

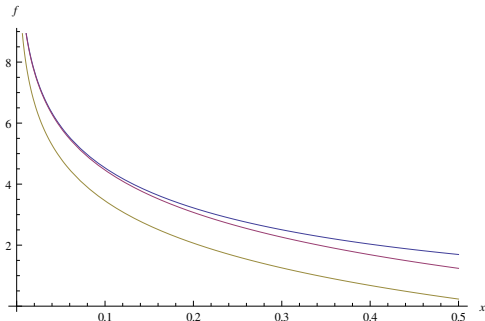
$x \sim 1$  and  $y \gg 1$



$T \sim \frac{1}{r} \gg m_D$  cross-section for 1S

$$f(x, y) = -\frac{3}{2} + 2 \log \left( \frac{2}{x} \right) + \log \left( \frac{y^2}{1 + y^2} \right) - \frac{1}{y^2} \log(1 + y^2)$$

$x \ll 1$  and  $y \sim 1$ .

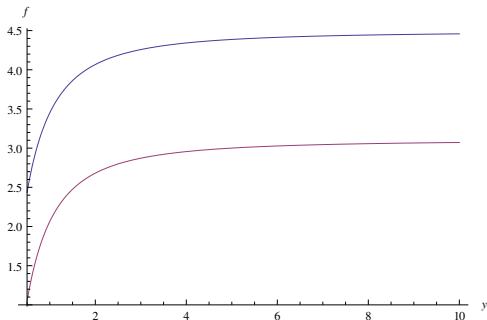


$T \gg \frac{1}{r} \sim m_D$ ,  $ka_0 = 10$  and  $ka_0 = 1$ . Discrepancy between the blue and red line signals the need for HTL resummation.

$T \sim \frac{1}{r} \gg m_D$  cross-section for 1S

$$f(x, y) = -\frac{3}{2} + 2 \log\left(\frac{2}{x}\right) + \log\left(\frac{y^2}{1+y^2}\right) - \frac{1}{y^2} \log(1+y^2)$$

$x \ll 1$  and  $y \sim 1$ .

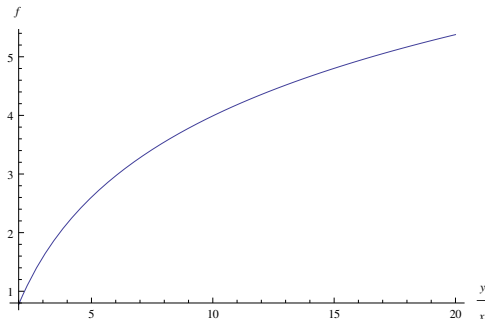


$m_D a_0 = 0.1$  and  $m_D a_0 = 0.2$ .

$\frac{1}{r} \gg T \gg m_D \gg E$  cross-section for 1S

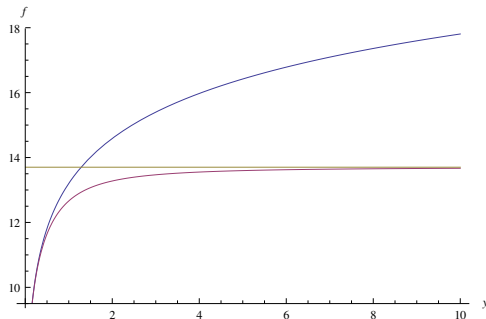
$$f(x, y) = 2 \left( \log \left( \frac{2y}{x} \right) - 1 \right)$$

$1 \gg y \gg x$ .



# Summary cross-section for 1S

$$m_D a_0 = 0.001$$



$\frac{1}{r} \gg T \gg m_D$ ,  $T \sim \frac{1}{r} \gg m_D$  and  $T \gg \frac{1}{r} \sim m_D$ . Discrepancy between blue and red lines signals a failure of color dipole approximation.

# Conclusions

- Large  $N_c$  limit for gluo-dissociation is a good approximation for  $T \gg E$  but it is not so good for  $T \sim E$ .
- The imaginary part of the potential and the quasi-free dissociation describe the same physical process at different temperatures.
- Just using perturbation theory one can not say *a priori* that quasi-free dissociation would be more important than gluo-dissociation for  $m_D \gg E$ . This piece of information is given by EFT power counting.