

Charmonium in a hot medium: melting vs absorption

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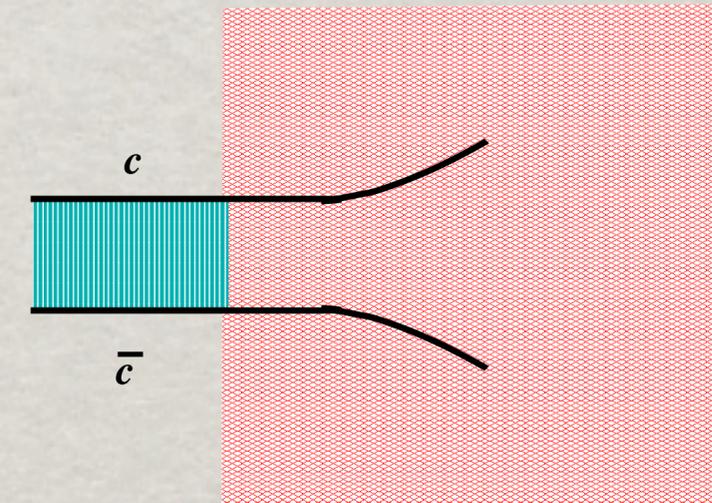
J/ Ψ melting vs absorption

Two sources of J/ Ψ suppression in a hot medium:

- (i) Debye screening, i.e. weakening of the binding potential, which can lead to disappearance of the bound level (**melting**)
- (ii) Color-exchange interactions of the c - \bar{c} dipole with the medium, leading to a break-up of the colorless dipole (**absorption**).

Melting

A bound c - \bar{c} state can be dissolved by Debye screening in a hot medium.



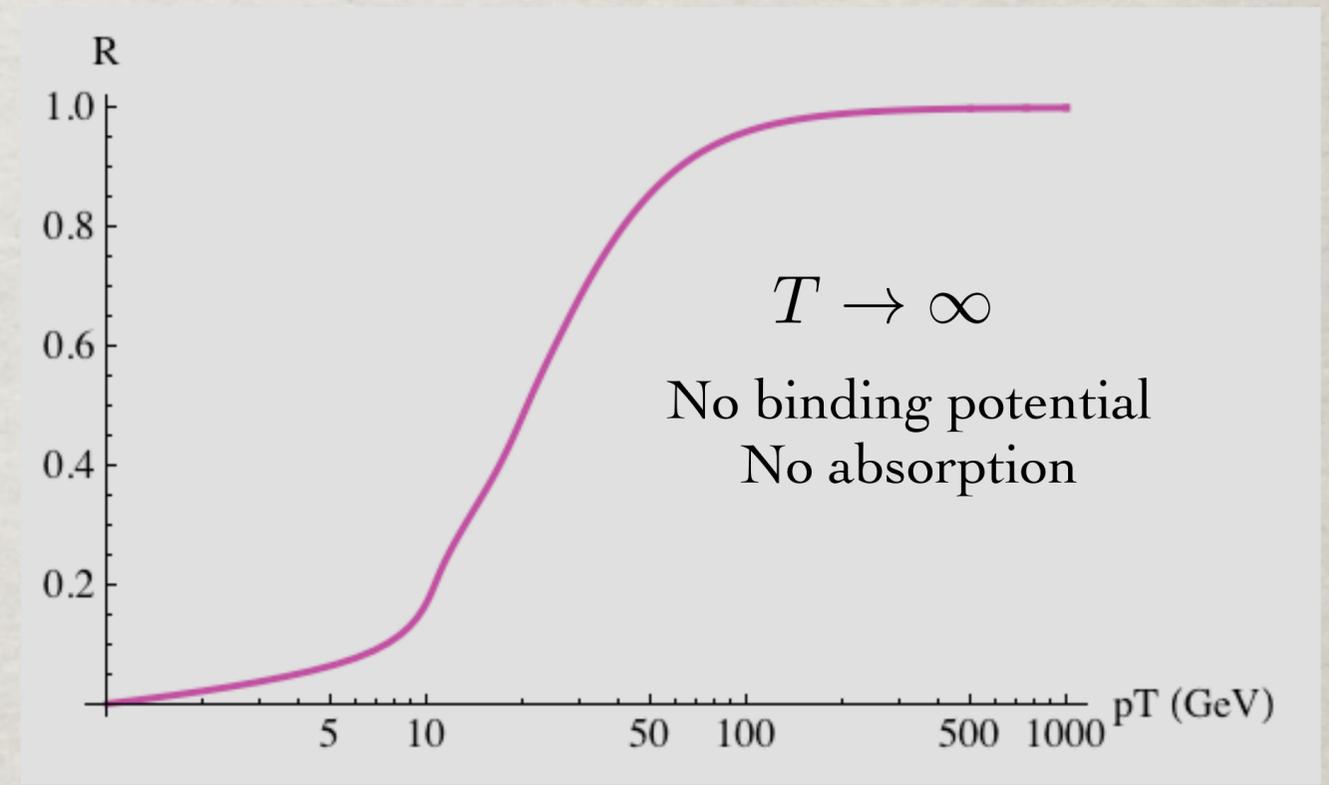
T.Matsui & H.Satz, PLB 178 (1986) 416

No clear signal of J/ Ψ melting has been observed so far

Where is J/Ψ melting?

The melting scenario assumes that lacking a bound level the quarks fly away, resulting in disappearance of J/Ψ . However, the quark distribution amplitude still can be projected to the charmonium wave function.

Even in the extreme case of lacking any potential between c and c -bar ($T \rightarrow \infty$), still the J/Ψ can survive.

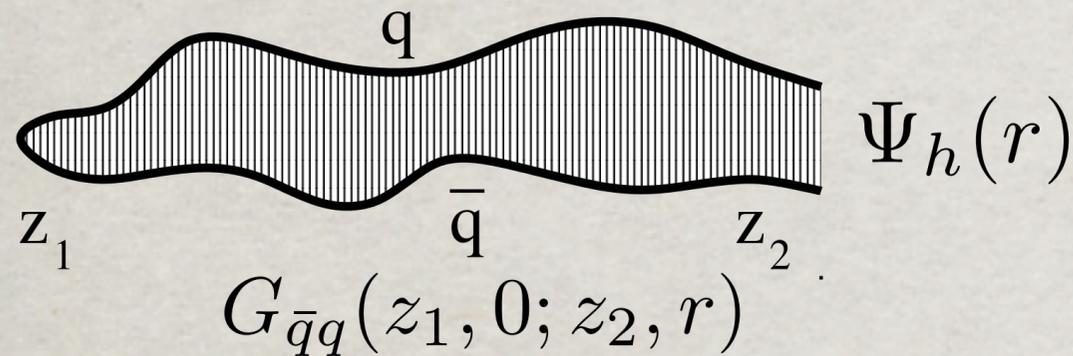


At large p_T the medium becomes fully transparent, because the initial dipole size is “frozen”, and the projection to the J/Ψ wave function remains the same as in pp .

Charmonium propagation through a hot medium

Path integral technique

B.G.Zakharov & B.K. PRD44(1991)3466



$$\left[i \frac{d}{dz} - \frac{m_c^2 - \Delta_{r_\perp}}{E_\Psi/2} - V_{\bar{q}q}(z, r_\perp) \right] G_{\bar{q}q}(z_1, r_{\perp 1}; z, r_\perp) = 0$$

The Green function $G_{\bar{q}q}(z_1, r_1; z_2, r_2)$ describes propagation of the dipole between longitudinal coordinates $z_{1,2}$ with initial and final transverse (2D) separations $r_{1,2}$.

The imaginary part of the light-cone potential describes absorption,

$$\text{Im} V_{\bar{q}q}(z, r_\perp) = -\frac{v}{4} \hat{q}(z) r_\perp^2$$

Transport coefficient \hat{q} , the rate of broadening, is related to the medium temperature, $\hat{q} \approx 3.6 T^3$ ($T > T_c$) and is to be adjusted to data.

$\text{Re} V_{\bar{q}q}(z, r)$ corresponding to the binding potential, is known only in the rest frame of the dipole, and it also depends on longitudinal dipole separation r_L

It cannot be properly described with this 2-dimensional Schrödinger equation. Debye screening corrections make it even more challenging.

Lorentz boosted binding potential

Debye screening of the potential for J/Ψ produced at rest can be modeled,

However, most of J/Ψ s are fast moving, at the LHC $\langle p_\psi^2 \rangle = 8 \text{ GeV}^2$

$V(\mathbf{r})$ is not Lorentz invariant \mathbf{r} is 3-dimensional

Boosting the Schrödinger equation to a moving reference frame is a challenge.

S.Brodsky, G.De Teramond, H.G.Dosch, A.Travinski & S.Glazek (2014)

$$U_{\text{eff}}(\mathbf{r}, \mathbf{p}) = V_{\text{eff}}^2(\mathbf{r}) + 2\sqrt{\mathbf{p}^2 + m_c^2} V_{\text{eff}}(\mathbf{r}) + V_{\text{eff}}(\mathbf{r})\sqrt{\mathbf{p}^2 + m_c^2}$$

$$\mathbf{p} \Rightarrow \nabla_{\mathbf{r}}$$

This is a non-linear non-local operator, which makes practical applications difficult.

Lorentz boosted Schrödinger equation

E.Levin, I.Schmidt, M.Siddikov & B.K. (2014)

The light cone fractional momentum distribution of quarks in a charmonium sharply peaks around $x=1/2$. With a realistic potential

$$\langle \lambda^2 \rangle \equiv \left\langle \left(\mathbf{x} - \frac{1}{2} \right)^2 \right\rangle = \frac{\langle \mathbf{p}_L^2 \rangle}{4m_c^2} = \frac{1}{4} \langle v_L^2 \rangle \approx 0.017$$

Introducing a variable ζ Fourier conjugate to λ ,

$$\tilde{\Psi}_{\bar{c}c}(\zeta, \mathbf{r}_\perp) = \int_0^1 \frac{d\mathbf{x}}{2\pi} \Psi_{\bar{c}c}(\mathbf{x}, \mathbf{r}_\perp) e^{2im_c \zeta (\mathbf{x} - 1/2)}$$

and making use of smallness of λ and of the binding energy, we arrive at the boost-invariant Schrödinger equation for the Green function

$$\left[\frac{\partial}{\partial z^+} + \frac{\Delta_\perp + (\partial/\partial\zeta)^2 - m_c^2}{\mathbf{p}_\psi^+ / 2} - \mathbf{U}(\mathbf{r}_\perp, \zeta) \right] \mathbf{G}(z^+, \zeta, \mathbf{r}_\perp; z_1^+, \zeta_1, \mathbf{r}_{1\perp}) = 0$$

Solving the equation

$$\text{Re}U_{\bar{q}q}(\mathbf{r}_{\perp}, \zeta) = \frac{M_{\psi}}{p_{\psi}^{+}} V \left(\sqrt{r_{\perp}^2 + \zeta^2} \right) \quad - \text{rest frame potential}$$

This is the main result, a simple replacement: $\mathbf{r}_{\perp} \Rightarrow \zeta$

In the rest frame the usual Schrödinger equation is recovered.

$$\text{Im}U_{\bar{q}q}(\mathbf{r}_{\perp}, \zeta) = -\frac{1}{4} v \hat{q} r_{\perp}^2 \quad \text{controls absorption and is independent of } \zeta$$

Screened potential.

$$V_{\bar{c}c} \left(r = \sqrt{r_{\perp}^2 + \zeta^2} \right) = \frac{\sigma}{\mu(\mathbf{T})} \left(1 - e^{-\mu(\mathbf{T})r} \right) - \frac{\alpha}{r} e^{-\mu(\mathbf{T})r}$$

$$\mu(\mathbf{T}) = g(\mathbf{T})\mathbf{T} \sqrt{1 + \frac{N_f}{6}}, \quad g^2(\mathbf{T}) = \frac{24\pi^2}{33 \ln(19\mathbf{T}/\Lambda_{\overline{MS}})}$$

F. Karsch, M. T. Mehr and H. Satz, Z. Phys. C 37, 617 (1988)

The equation is solved numerically with $\hat{q} = q_0 \frac{n_{\text{part}}(\tilde{\tau}, \tilde{\mathbf{b}})}{n_{\text{part}}(0, 0)} \frac{t_0}{t}; \quad q_0 = 1 \text{ fm}$

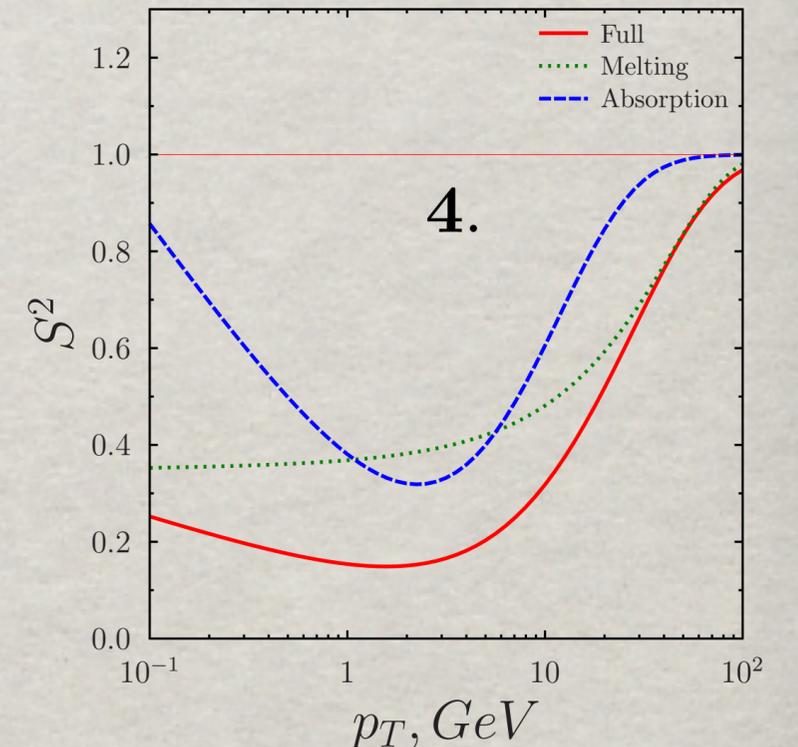
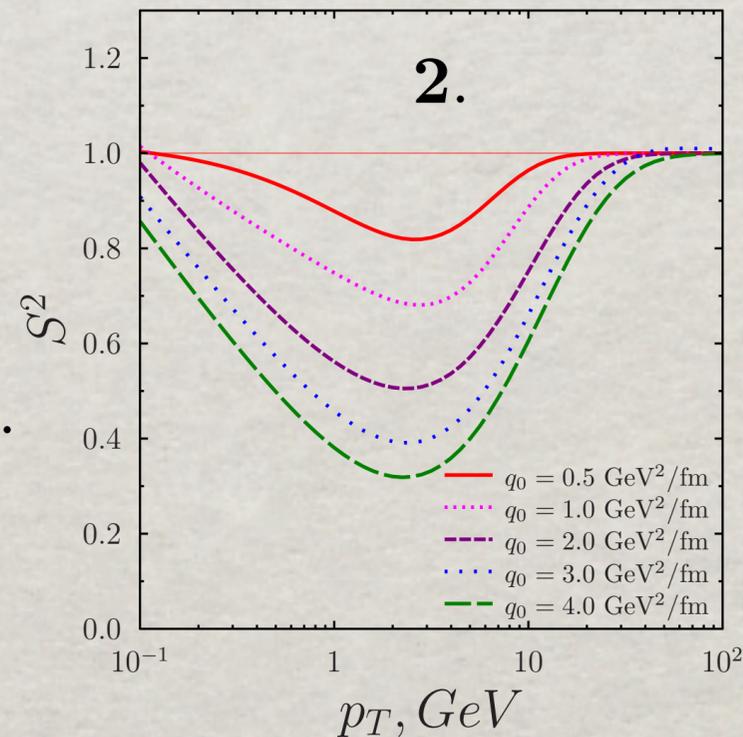
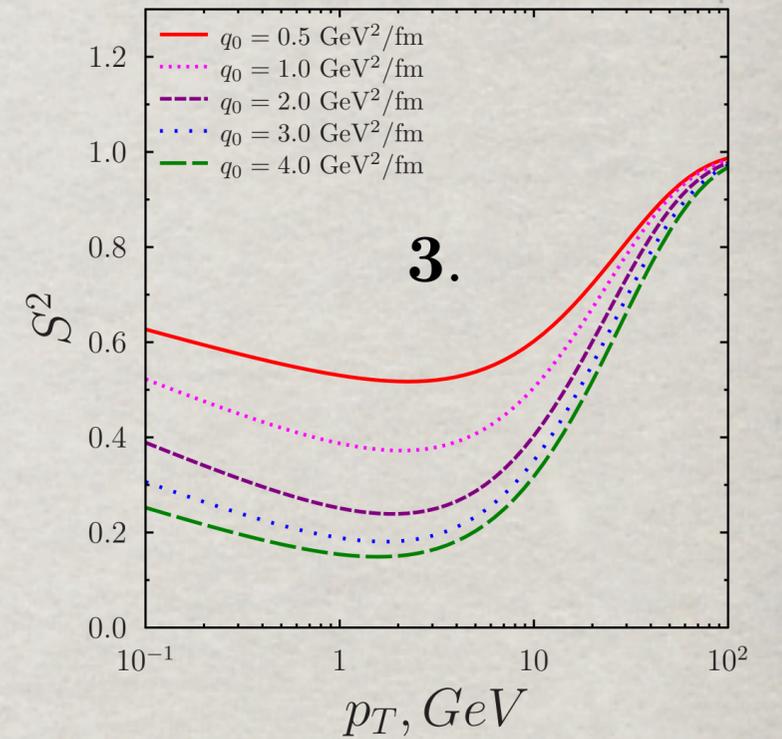
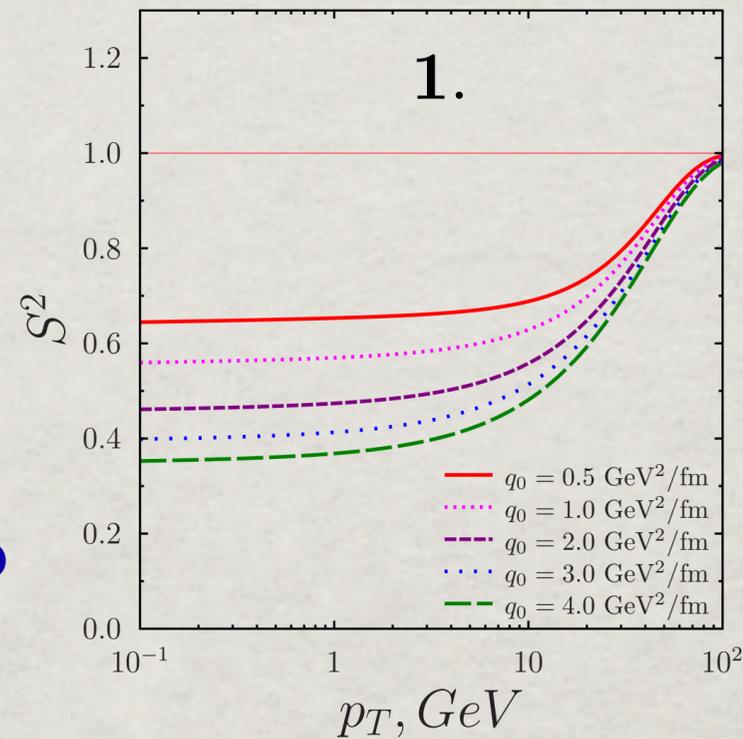
Results

Survival probability amplitude

$$S(\mathbf{z}_2, \mathbf{z}_1) = \int d\zeta_2 d\zeta_1 d^2r_2 d^2r_1 \Psi_{J/\psi}(\mathbf{r}_2, \zeta_2) \times \mathbf{G}(\mathbf{r}_2, \zeta_2, \mathbf{z}_2; \mathbf{r}_1, \zeta_1, \mathbf{z}_1) \Psi_{\text{in}}(\mathbf{r}_1, \zeta_1)$$

Calculations are done for central Pb-Pb collisions with realistic nuclear density.
No ISI effects are added.

1. Net melting: $\text{Re}U \neq 0; \text{Im}U = 0$.
2. Net absorption: $\text{Re}U = 0; \text{Im}U \neq 0$.
3. Total suppression: $\text{Re}U \neq 0; \text{Im}U \neq 0$.
4. $q_0 = 2 \text{ GeV}^2/\text{fm}$



Summary

- Melting of a charmonium in QGP does not lead to its disappearance. The survival probability is still high and rises with p_T .
- Another source of charmonium suppression is color-exchange interaction with the medium, which breaks-up the colorless dipole.
- A novel procedure for boosting the Schrödinger equation to a moving reference frame is proposed. It is based on the small intrinsic velocity expansion. The resulting equation is linear and does not contain any nonlocal operators.
- This is the first calculation of the melting effect for a moving charmonium. The two suppression mechanisms have similar magnitudes.



In collaboration with

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