J/ψ in Quark-Gluon Plasma

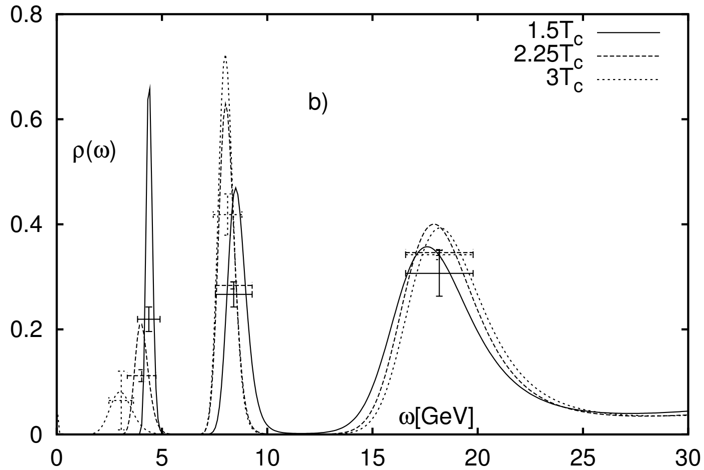
Cheuk-Yin Wong
(Oak Ridge National Laboratory)

- Introduction
- Color Singlet C-$\bar{C}$ Potential in Quark-Gluon Plasma
- Binding energy of J/ψ in Quark-Gluon Plasma
- $\sigma(g + J/\psi \to C + \bar{C})$ and $\sigma(C + \bar{C} \to g + J/\psi)$
- Dissociation and Production of J/ψ
  in Quark-Gluon Plasma
- Conclusions

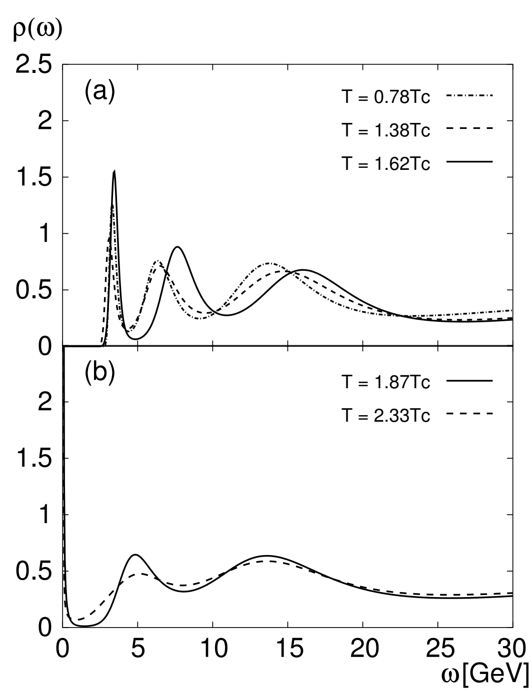
Introduction

Recent lattice gauge results indicate that the width of J/ψ remains relatively narrow up to $T \sim 1.6T_c$.

S. Datta, F. Karsch, P. Petreczky, I. Wetzorke, hep-lat/0312037
P. Petreczky, S. Datta, F. Karsch, I. Wetzorke, hep-lat/0309012
P. Petreczky, J.Phys. G30 (2004) S431-S440, hep-ph/0305189



M. Asakawa, T. Hatsuda, Phys. Rev. Lett. **92**, 012001 (2004)
M. Asakawa, T. Hatsuda, Y. Nakahara Nucl.Phys. A715 863 (2003)



Further Questions

- How does the presence of dynamical quarks affect the stability of J/ψ?
- If J/ψ is stable for $T < T_{J/\psi}$, how strongly bound is it. Is χ_c bound?
- How easy is it for J/ψ to be dissociated by collision with gluons? We need $g + J/\psi \rightarrow C + \bar{C}$ cross section, as a function of temperature.
- How easy is it to produce J/ψ by collision of $C + \bar{C}$? What is the cross section for the inverse process of $C + \bar{C} \rightarrow J/\psi + g$?

Effects of Dynamical Quarks

Effects of dynamical quarks were studied by Kaczmarek, Karsch, Petreczky, and Zantow.

O. Kaczmarek, F. Karsch, P. Petreczky, F. Zantow hep-lat/0309121

They calculate color-singlet $\langle TrL(x)L^\dagger(0)\rangle$ at $T > T_c$ and obtain $F_1(x,T)$ from

$$\langle TrL(x)L^\dagger(0)\rangle = e^{-F_1(x,T)/T}.$$

$TrL(x)L^\dagger(0)$ represents a quark line and an anti-quark line which does not form a close loop. Thus, $\langle TrL(x)L^\dagger(0)\rangle$ is not gauge independent. Calculations has been carried out in the Coulomb gauge.

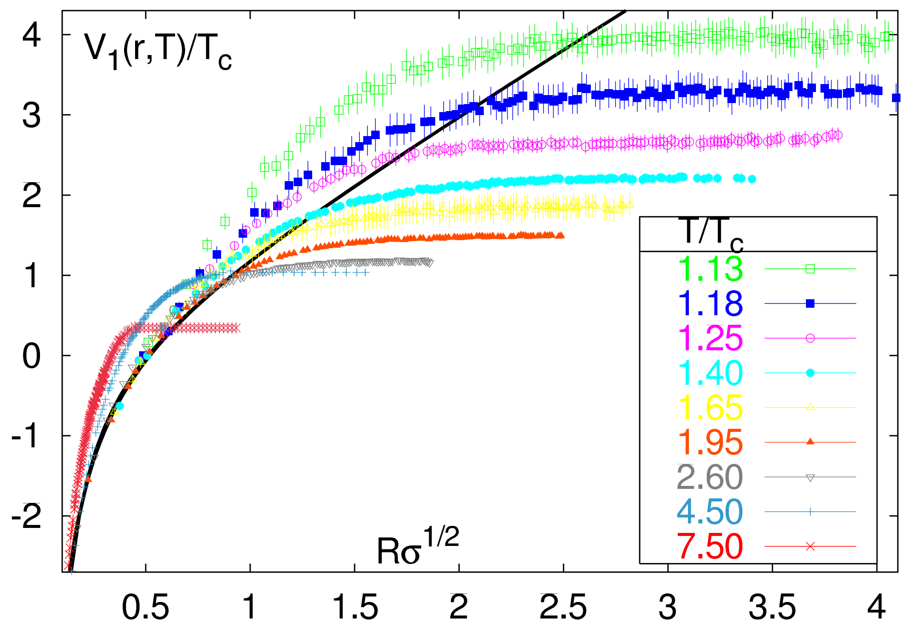
They obtained from F_1 the internal energy $V_1(r,T)$

$$V_1(r,T) = -T^2\frac{\partial[F_1(R,T)/T]}{\partial T}$$

This is the color-singlet potential which need to be solved for the state of J/ψ.

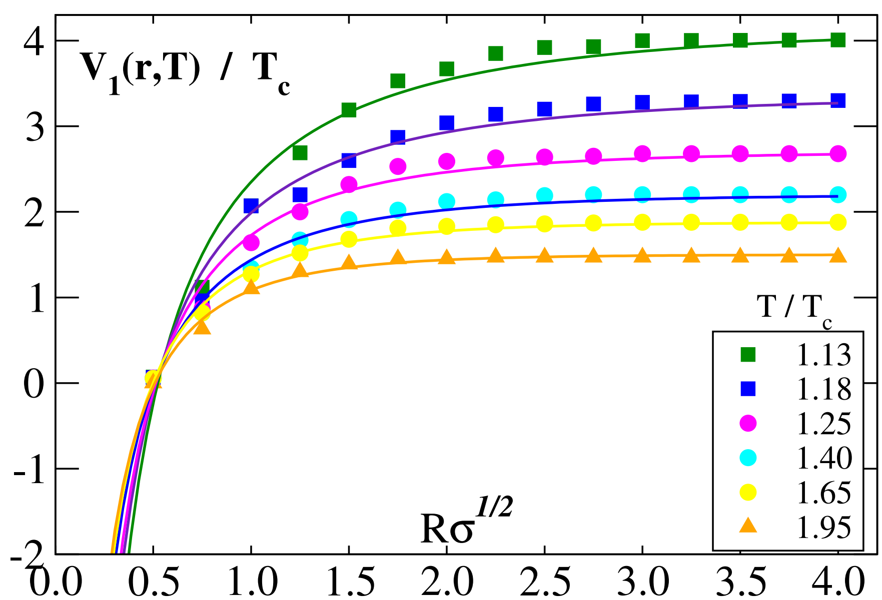
Lattice gauge results

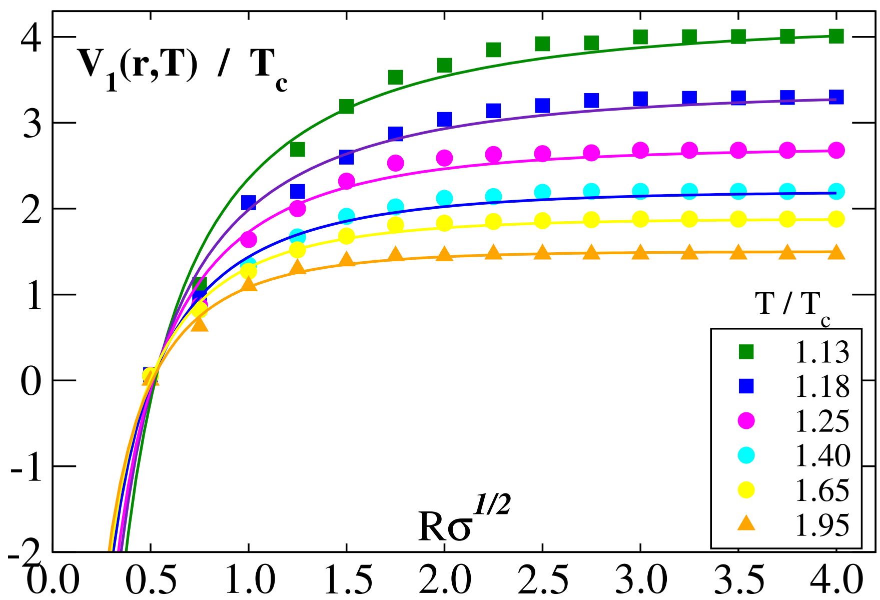
O. Kaczmarek, F. Karsch, P. Petreczky, F. Zantow hep-lat/0309121



The above C-$\bar{C}$ potential can be parametrized as

$$V_1(r,T) = C(T) - \frac{4\alpha_{\rm eff}(T)}{3}\frac{e^{-\mu(T)r}}{r}$$





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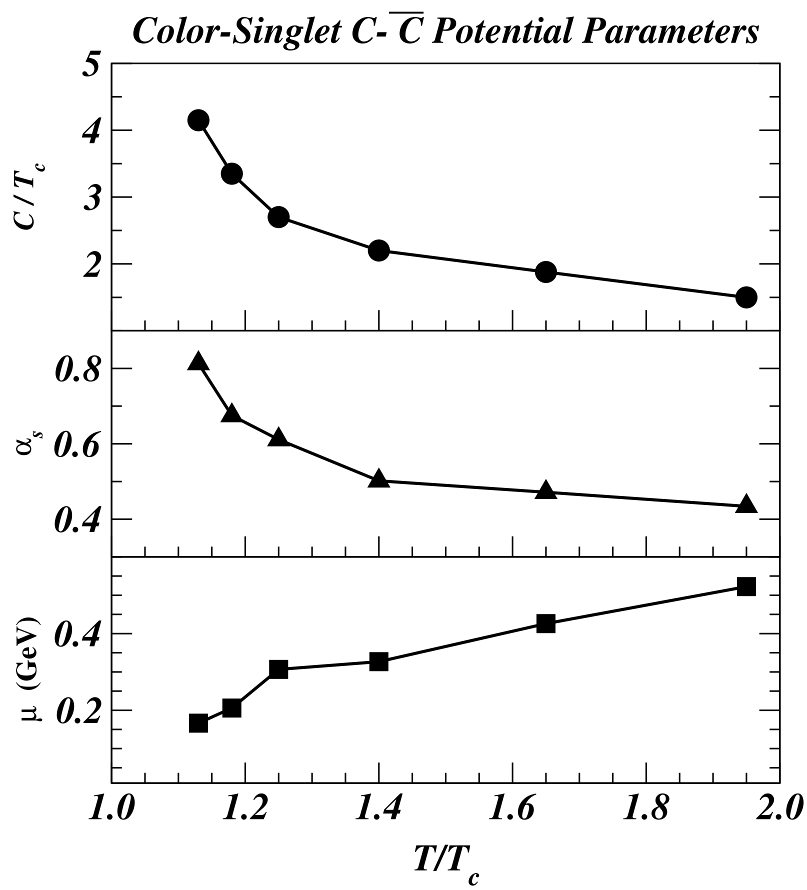
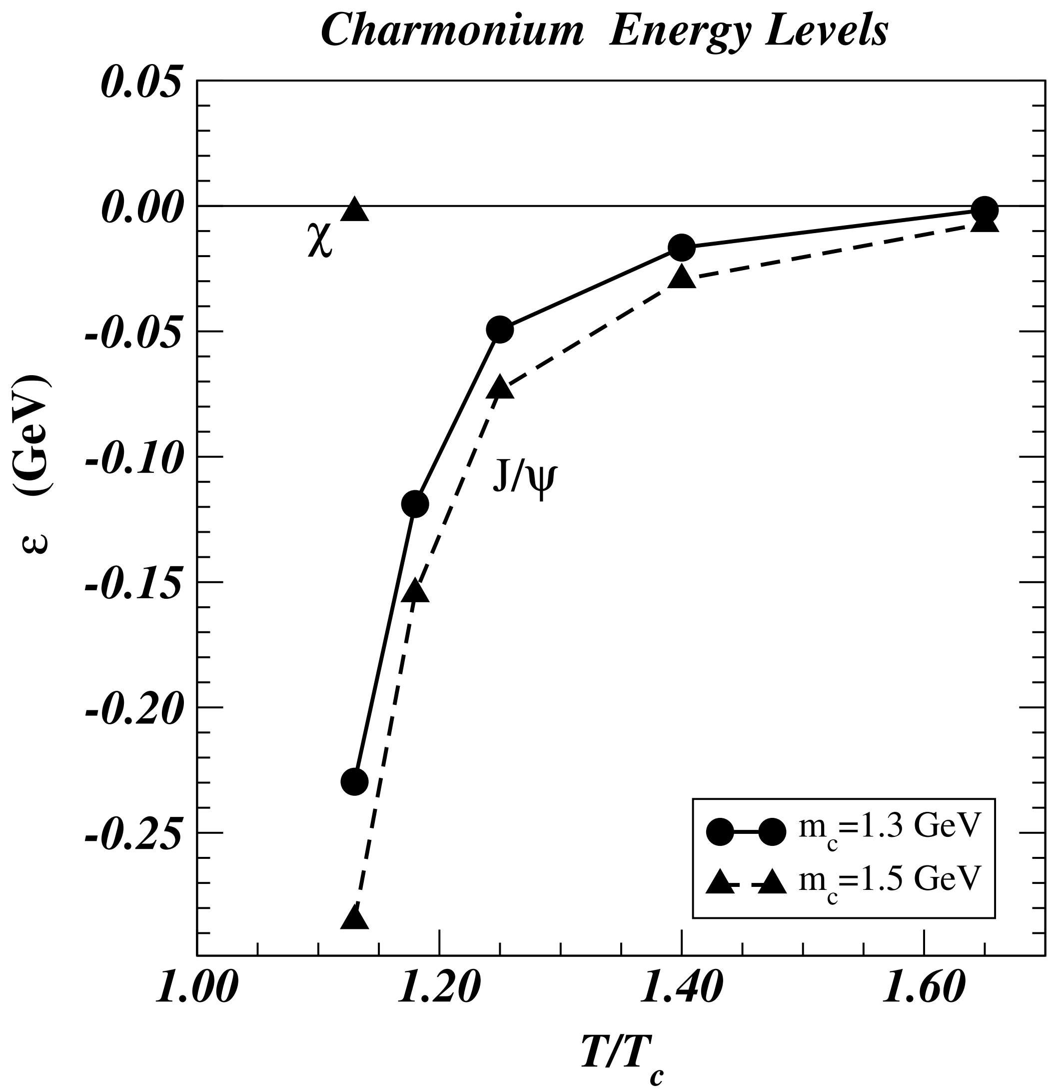


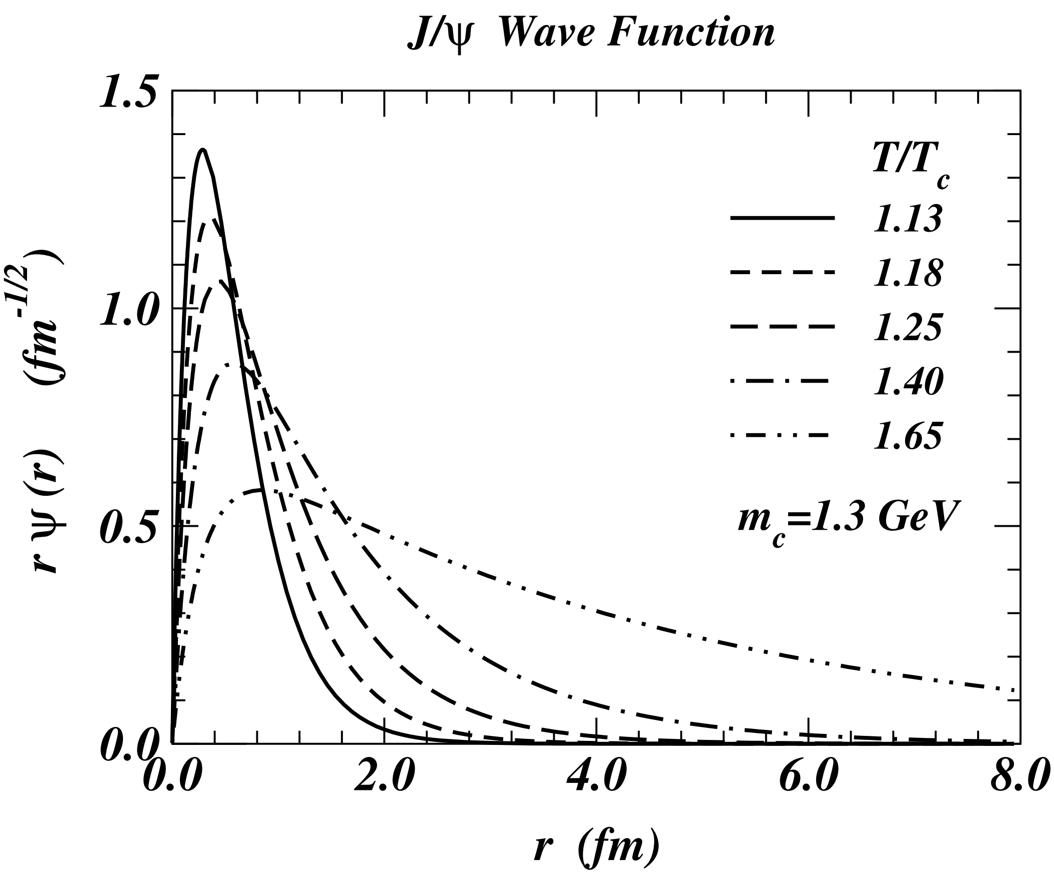
J/ψ energy level in Quark-Gluon Plasma



The dissociation temperature of color-singlet J/ψ is about 1.65 T_c, which agrees with the spectral function analysis.

The χ state is unbound at about $1.13T_c$.

J/ψ Wave Function in Quark-Gluon Plasma



The wave function extends farther out at large distances as temperature increases.

Evaluation of $\sigma(g + J/\psi \to C + \bar{C})$

Bhanot and Peskin (Nucl. Phys. B156, 391 (1977)):

- Operator product expansion
- Large N_c limit

  $\alpha_{\text{singlet}} = -\frac{N_c^2-1}{2N_c}\alpha_s \sim -\frac{N_c}{2}\alpha_s$
- Sum over a large set of diagrams
- Hydrogenic wave function and states

  (1S binding energy) $= B = \frac{1}{2}\alpha_{\text{singlet}}^2\mu = 0.076$ GeV

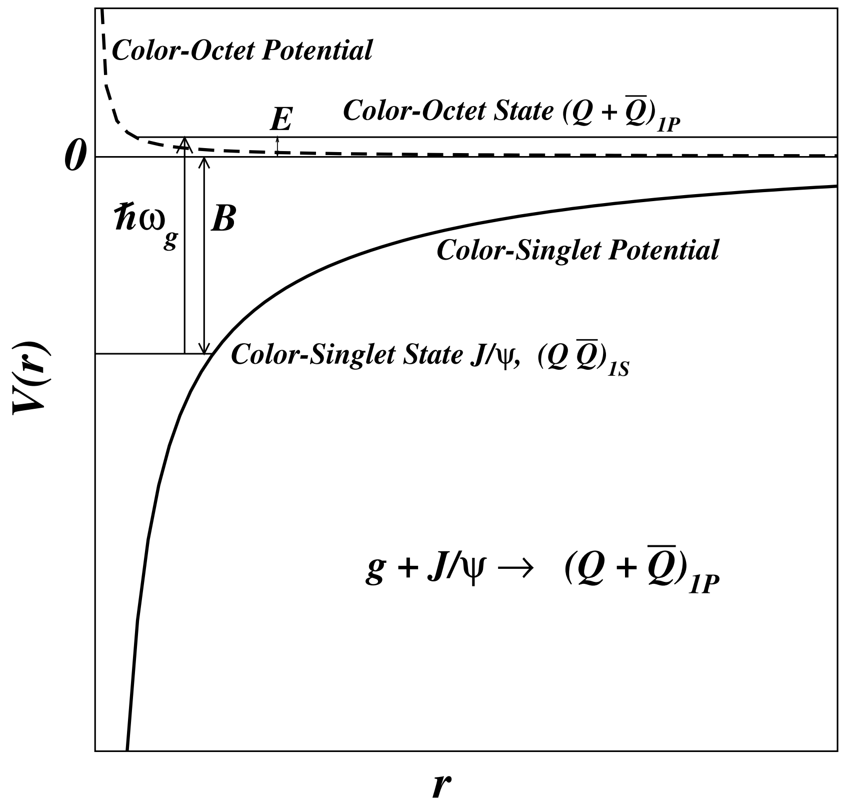
Bhanot and Peskin obtain

$$\sigma(g + (Q\bar{Q})_{1S} \to Q + \bar{Q}) = \frac{2}{3}\pi \left(\frac{32}{3}\right)^2 \left(\frac{4}{3\alpha_s^2}\right) \frac{1}{m_Q^2} \frac{(E/B)^{3/2}}{(E/B+1)^5}$$

E is the non-relativistic kinetic energy of the dissociated $Q + \bar{Q}$.

Potential Model to evaluate $\sigma(g + J/\psi \to C + \bar{C})$

C. Y. Wong, J. Phys. G28, 2349 (2002)



The dissociation cross section $\sigma(g + J/\psi \to C + \bar{C})$ can be obtained by using the potential model:

$$\sigma_{\rm dis}^{E1}(E_{\rm gluon}) = 4 \times \frac{\pi}{3}\alpha_{\rm gQ}(k^2 + \gamma^2)k^{-1}I^2,$$

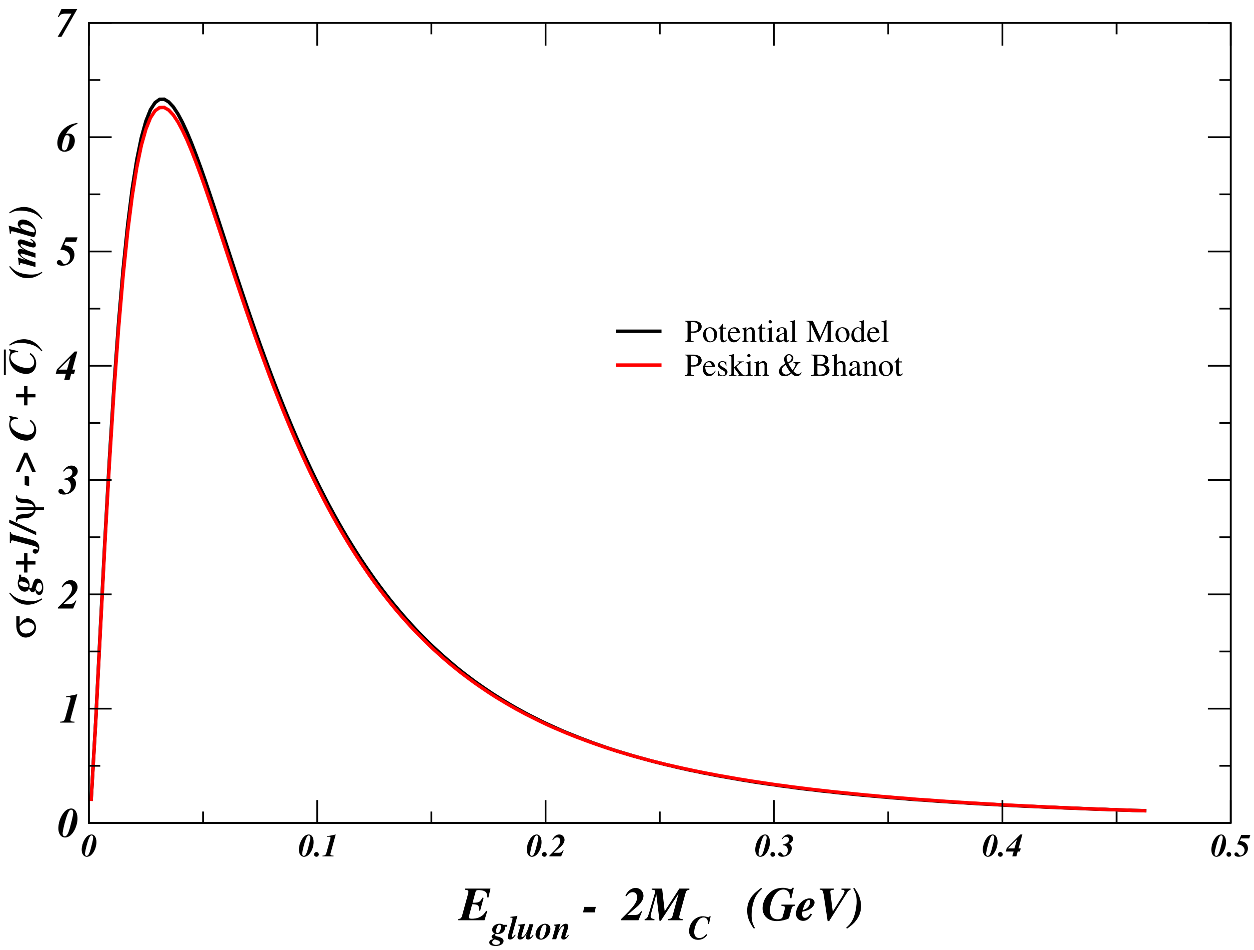
$$E_{\rm gluon} = B + E, \qquad \gamma^2 = 2\mu B, \qquad k^2 = 2\mu E$$

$$I = \int_0^\infty u_{1P}(r)\ r\ u_{1S}(r)dr.$$

$$\alpha_{\rm gQ} = \alpha_s |\langle 8c|\frac{\lambda^c}{2}|1\rangle|^2 = \alpha_s\ \times\ \frac{1}{6}$$

Comparison of Potential Model with the Peskin-Bhanot Model

The result from the potential model agrees with the analytical results of Bhanot and Peskin for the case considered (hydrogenic wave function, large N_c limit,...).



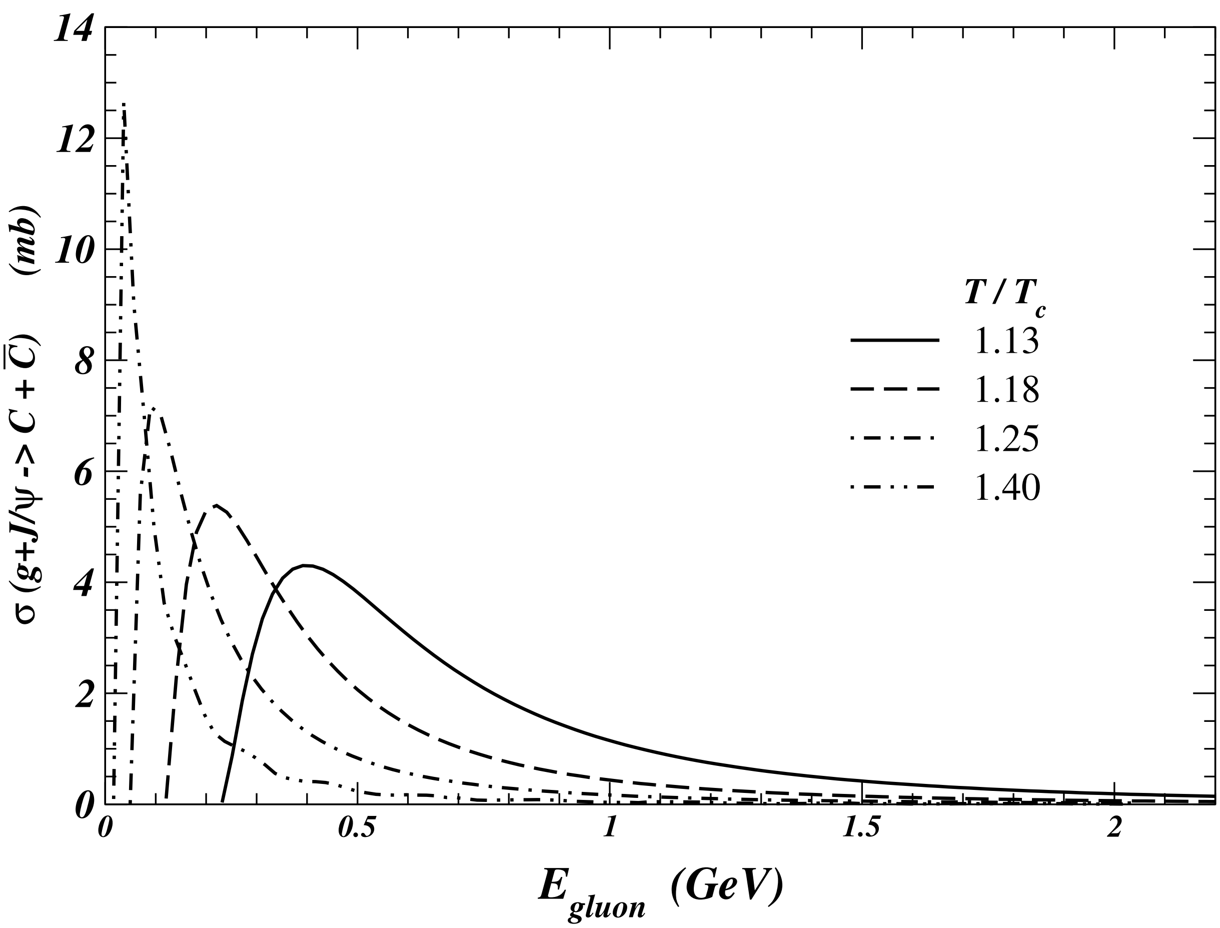
The potential model has the advantage that it can be generalized to other C-$\bar{C}$ potentials.

Application of the Potential Model

We use potential

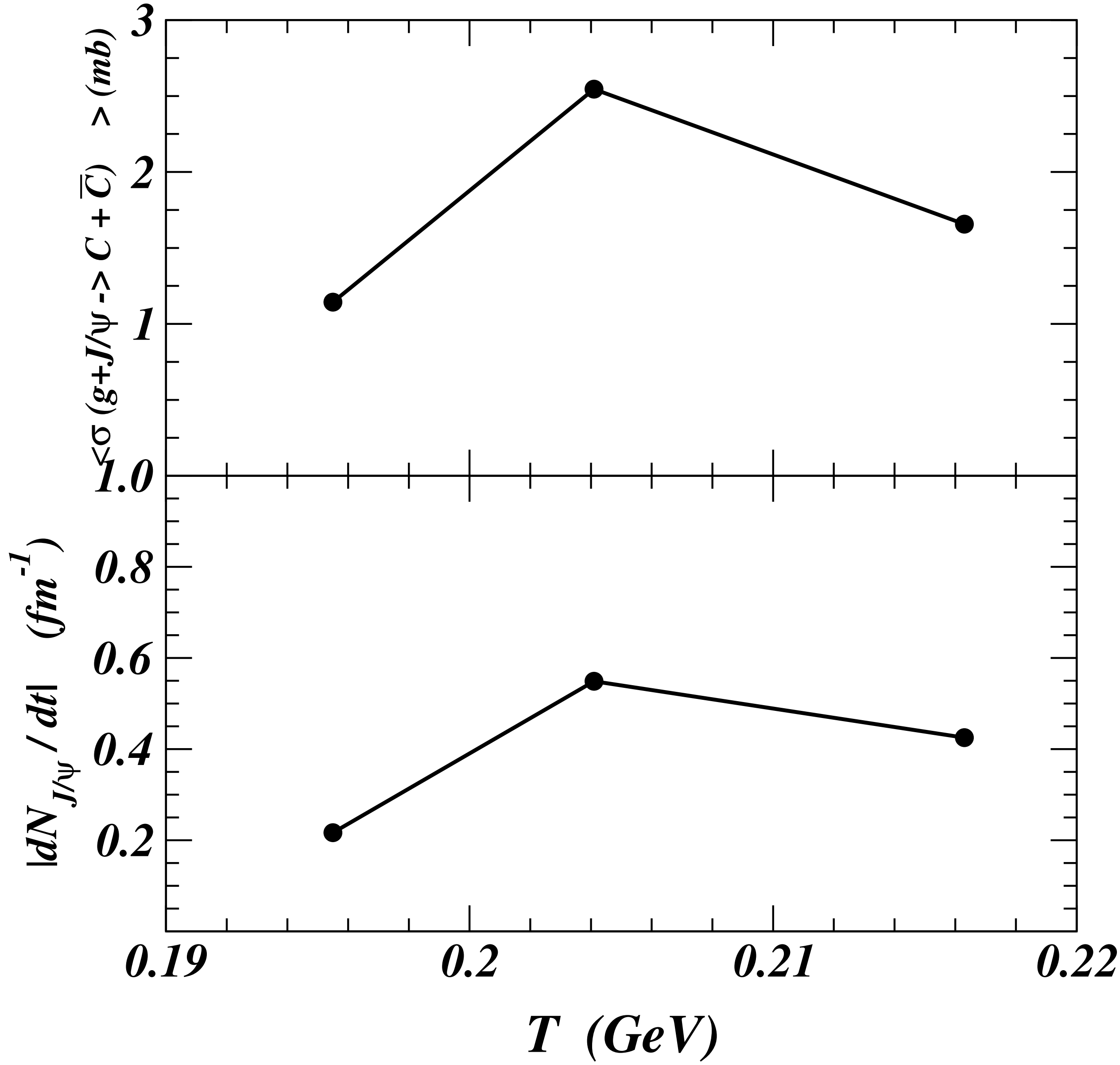
$$V(r) = C_f \frac{\alpha_s(T)\, e^{-\mu(T)\, r}}{r}$$

$$C_f = \begin{cases} -4/3 & \text{(singlet)} \\ 1/6 & \text{(octet)} \end{cases}$$



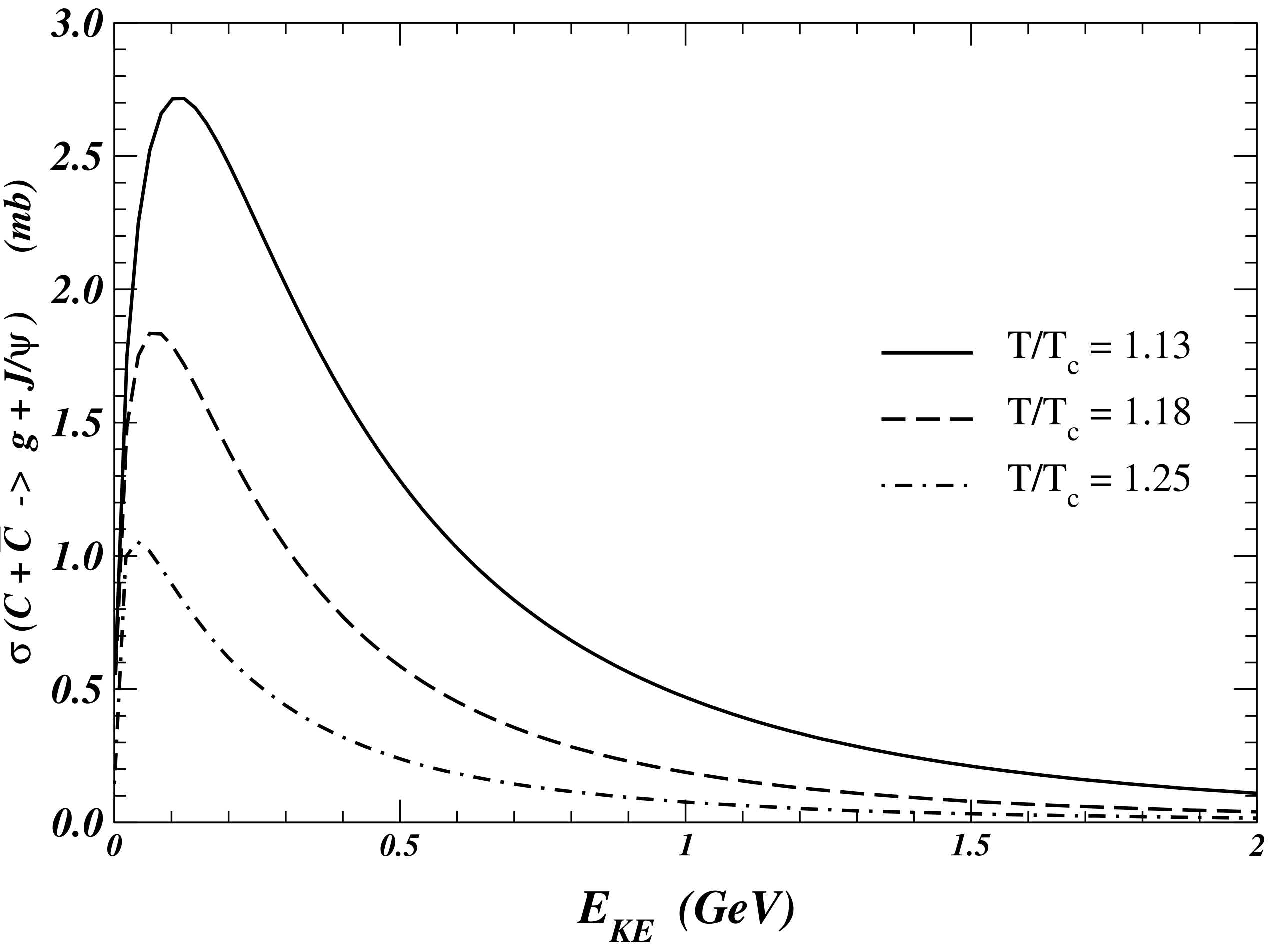
The dissociation cross section depends on energy and temperature.

J/ψ Dissociation Length in QGP

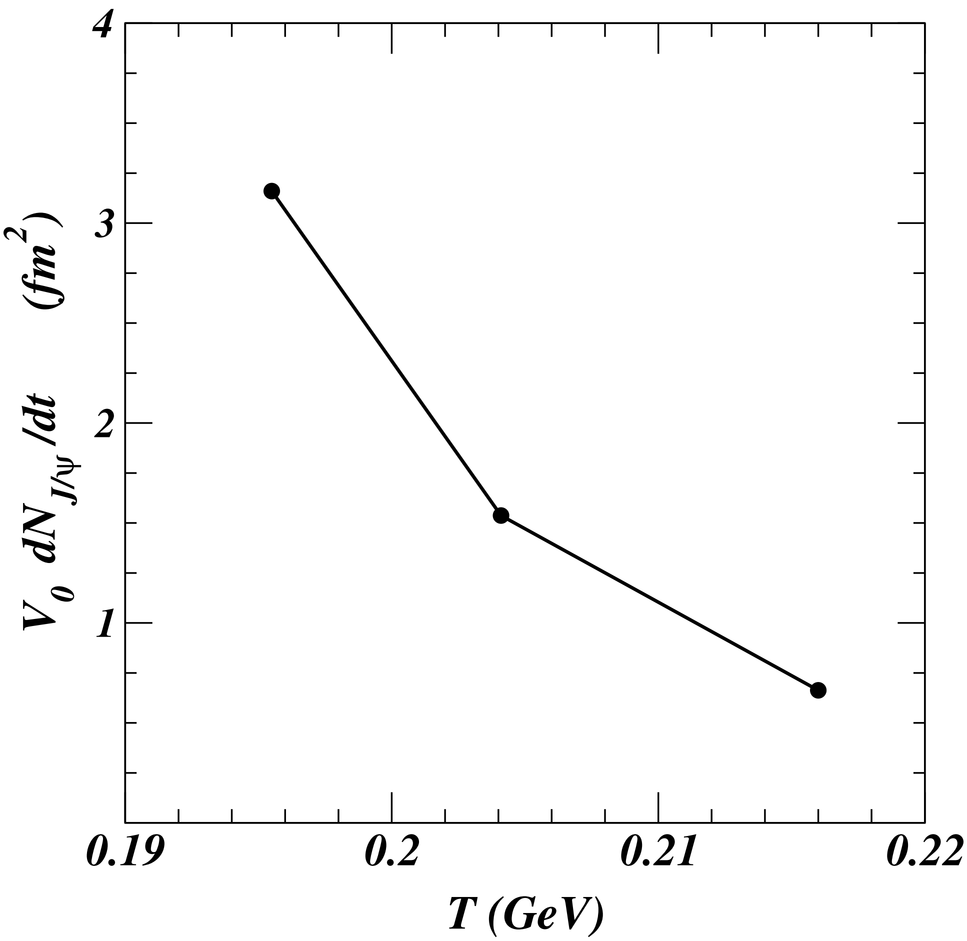


$|dN_{J/\psi}/dt|$ is the rate of J/ψ loss per unit time.

J/ψ Production by C-$\bar{C}$ in QGP



Rate of J/ψ Production by C-$\bar{C}$ in QGP



V_0 is the volume which contains the re-interacting C and $\bar{C}$.

Conclusions

- Lattice gauge theory results of Kaczmarek *et al.* is consistent with the binding of J/ψ below $T/T_c \sim 1.65$ in quark-gluon plasma.
- The binding energy of J/ψ decreases from about 250 MeV at $T/T_c = 1.13$ to zero at $T/Tc = 1.65$.
- The χ state becomes unbound at $T/T_c \sim 1.13$.
- The J/ψ dissociation cross section depends on energy and temperature. The peak cross section ranges from a few mb to ∼10 mb.
- The J/ψ dissociation rate in the quark-gluon plasma is 0.2 - 0.5 /(fm/c) for $T/T_c \sim 1.13 - 1.25$.
- The J/ψ production rate depends on the volume which contains C and $\bar{C}$ and decreases as temperature increases.