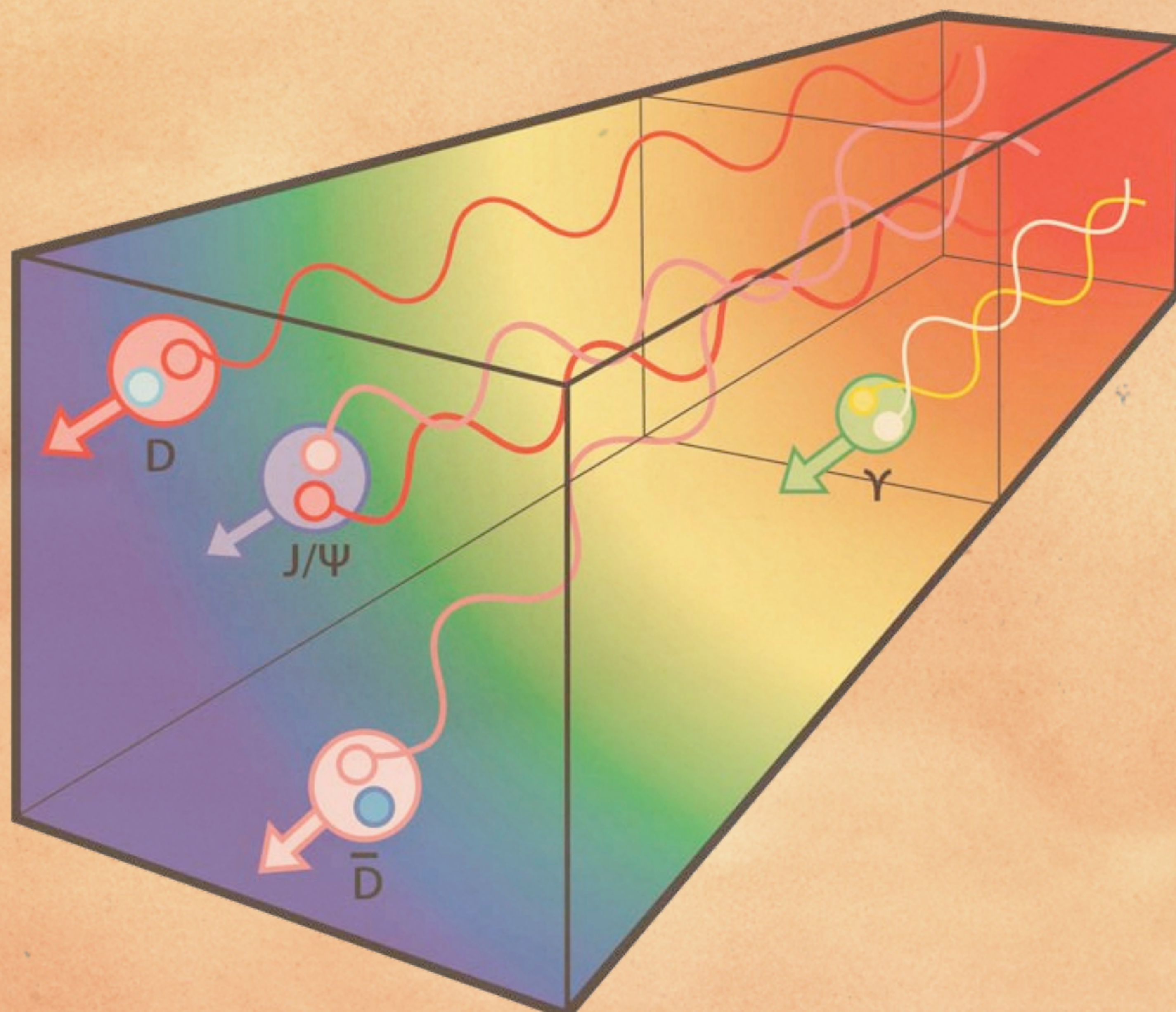
QWG Meeting, Fermilab
May 2010

Potential in Anisotropic Plasma



Ágnes Mócsy
Pratt Institute, Brooklyn, NY

Pratt

Motivation

"Little bangs"

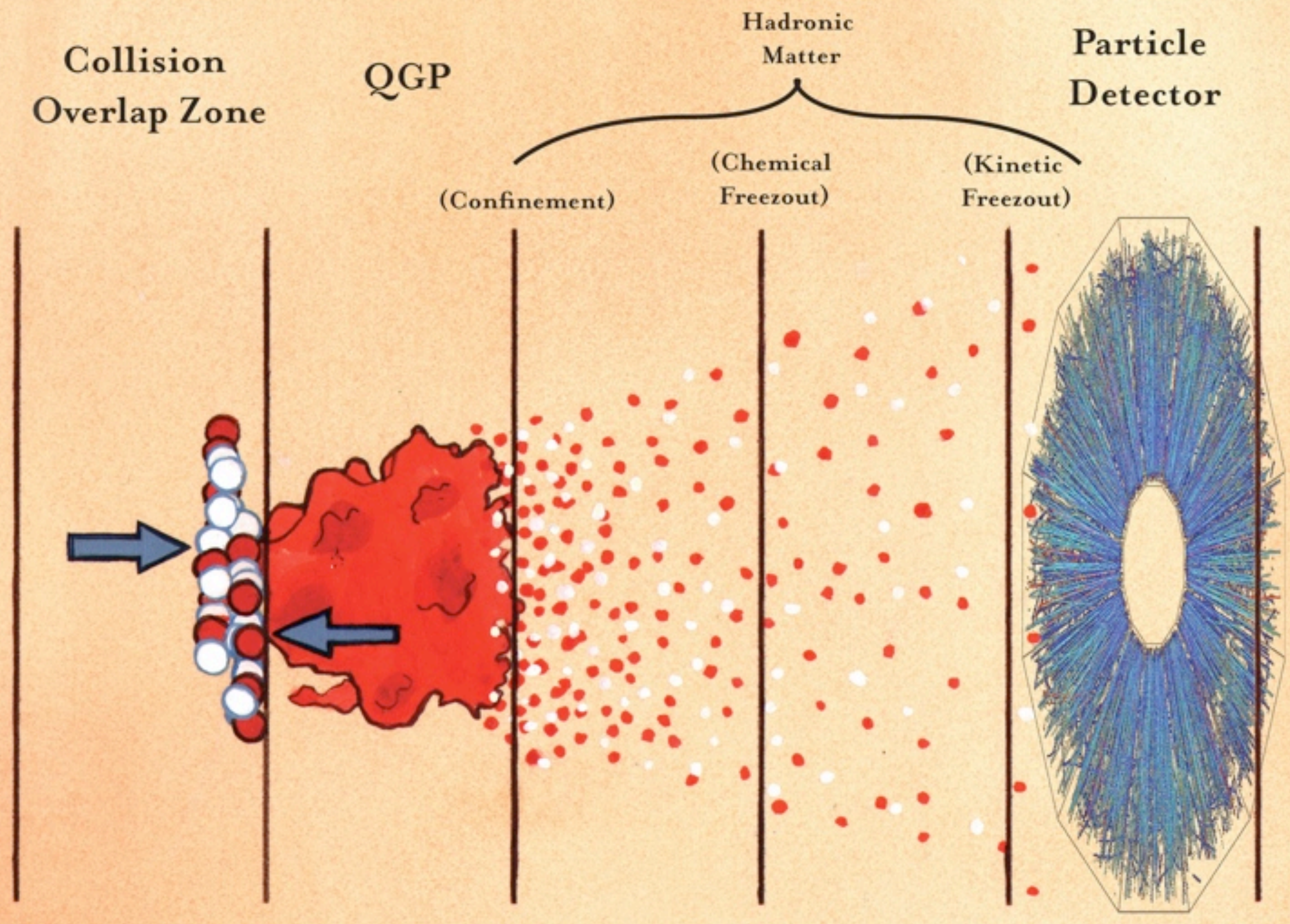
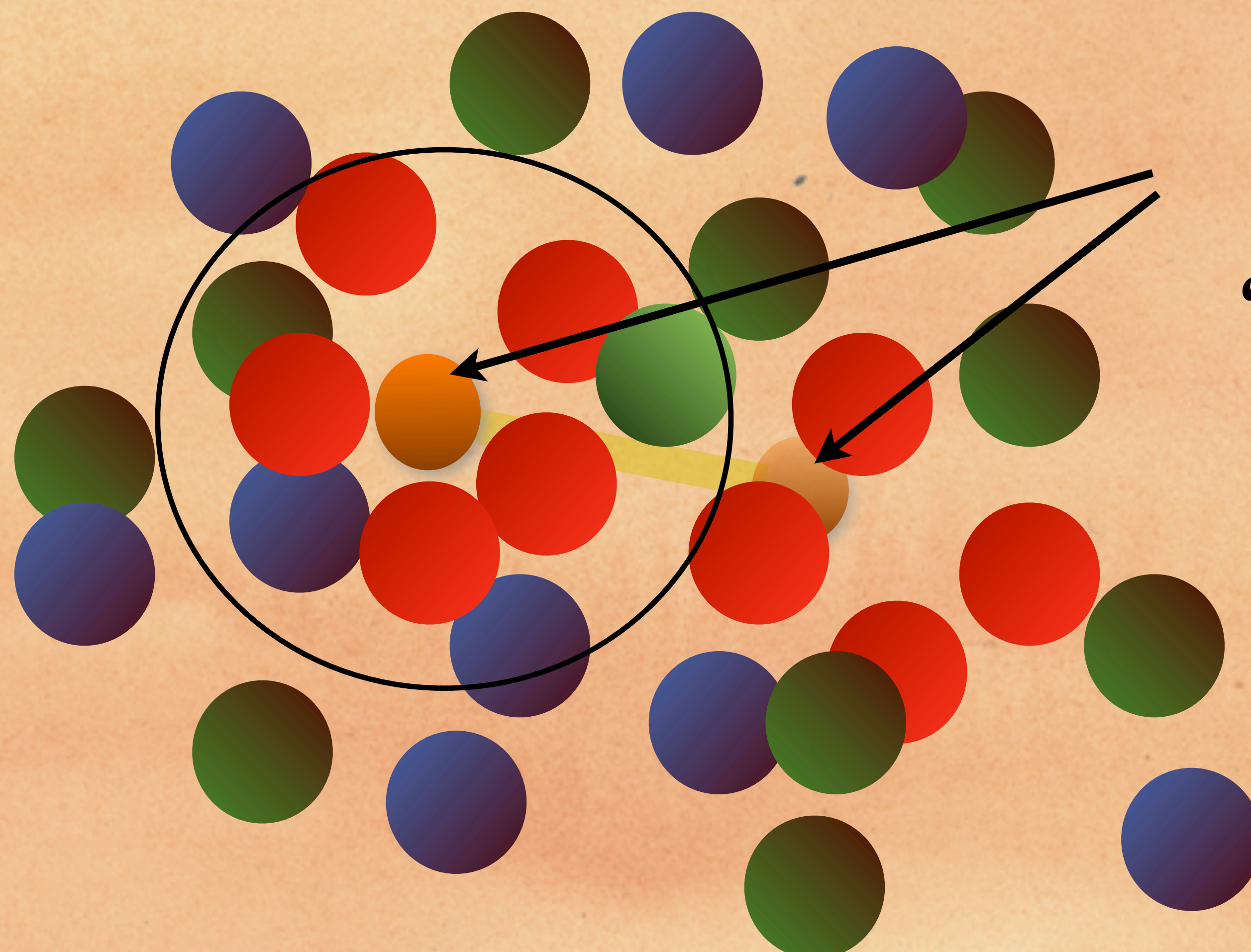


illustration: Alex Doig

Motivation

Testing the plasma with quarkonium



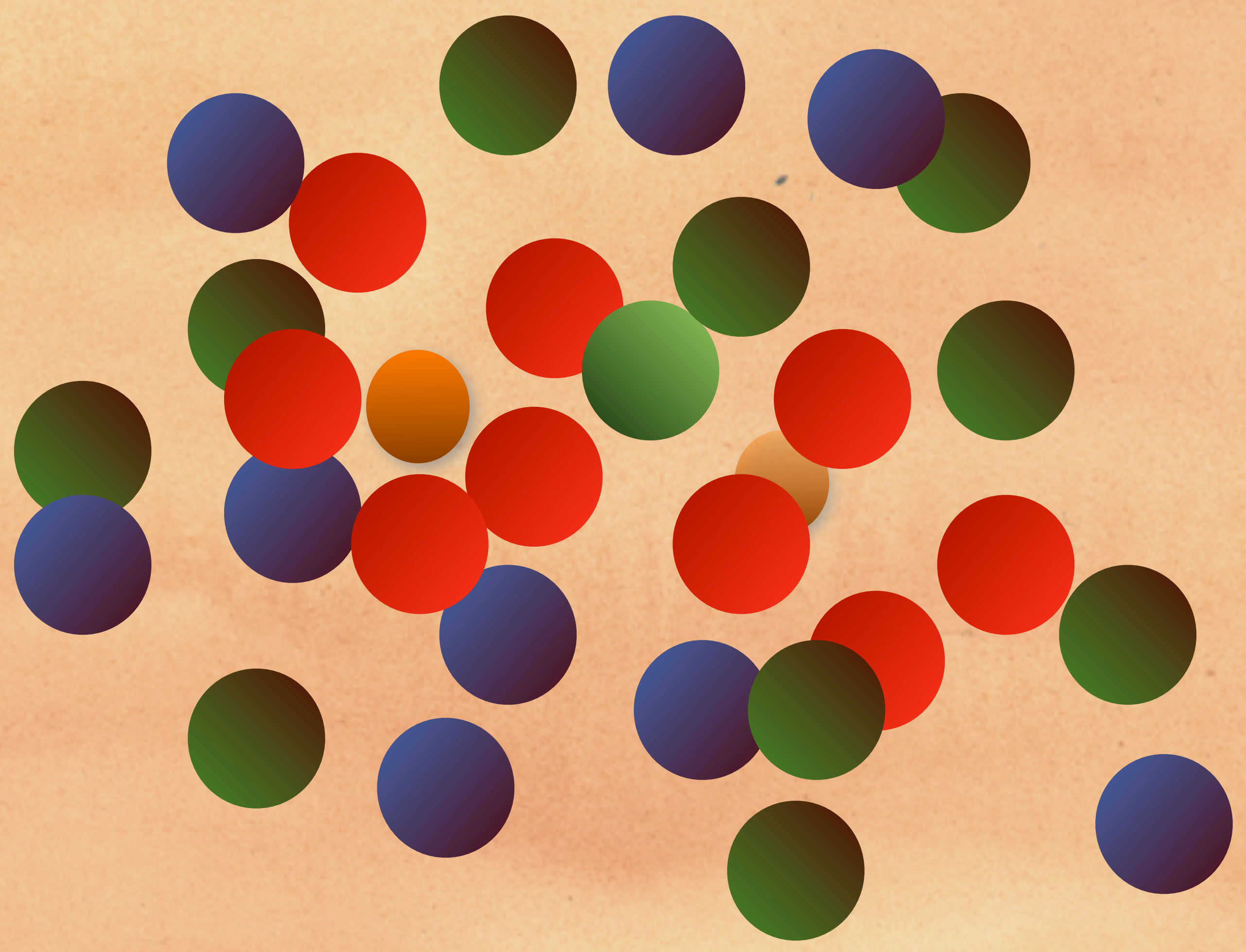
for $r_D < r_{Q\bar{Q}}$

Q and $\bar{Q}$ cannot "see" each other

Matsui, Satz, PLB 1986

Motivation

Testing the plasma with quarkonium



Matsui, Satz, PLB 1986

Consequence of screening: quarkonium states do not form and suppressed J/psi yield

Proposed signal of deconfinement

Motivation

Testing the plasma with quarkonium

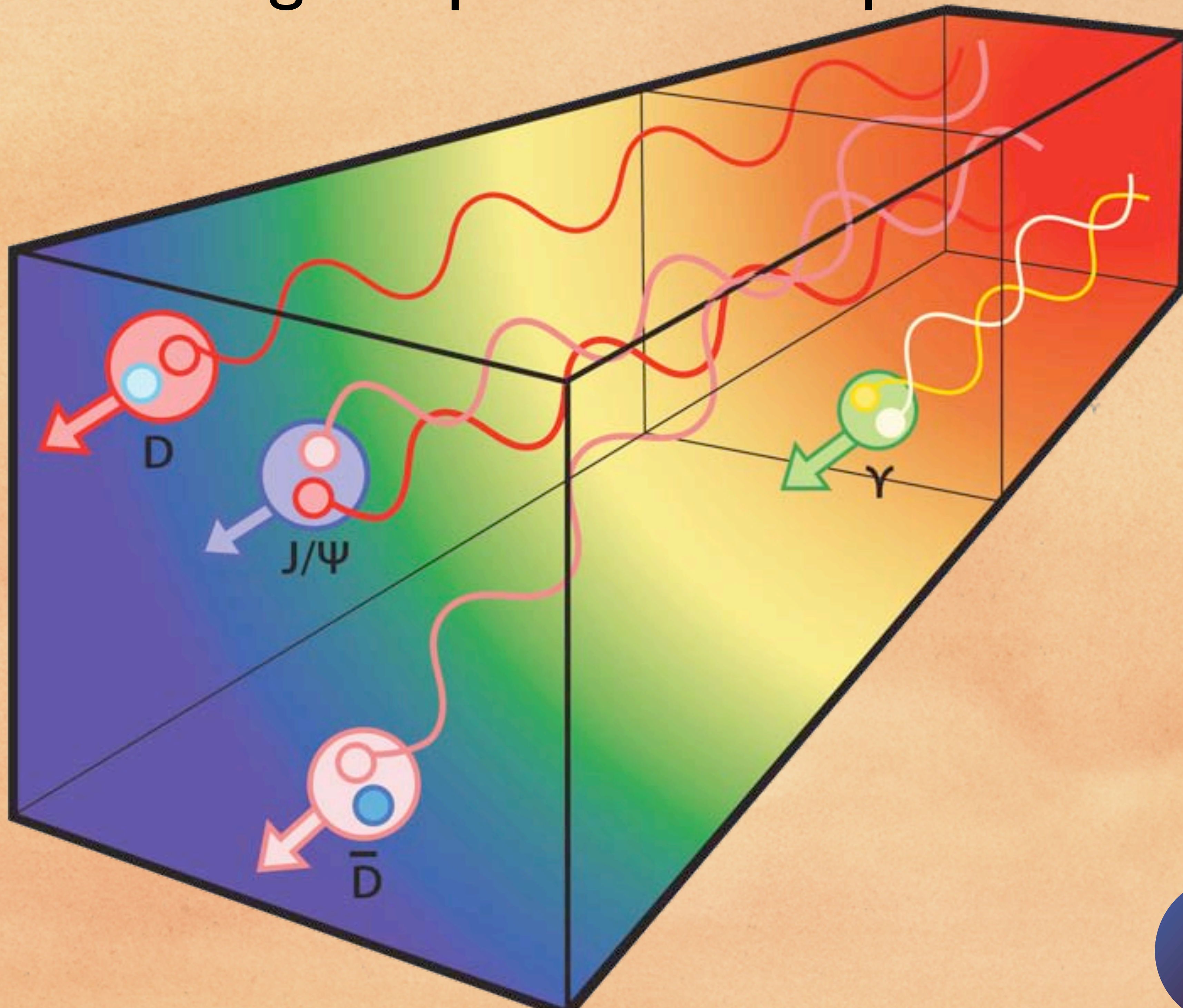


illustration: Alex Doig

QGP Thermometer

Motivation

Testing the plasma with quarkonium

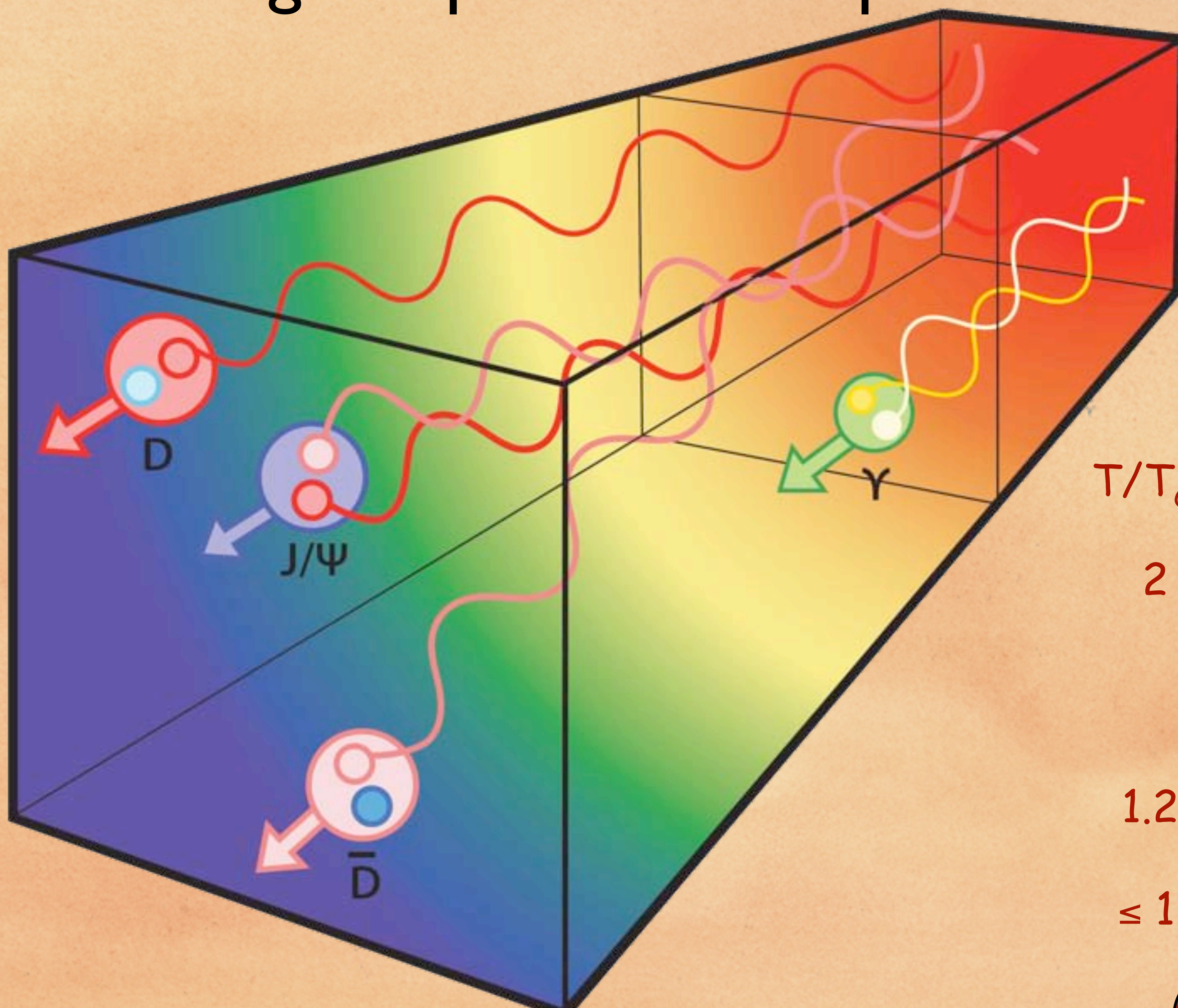
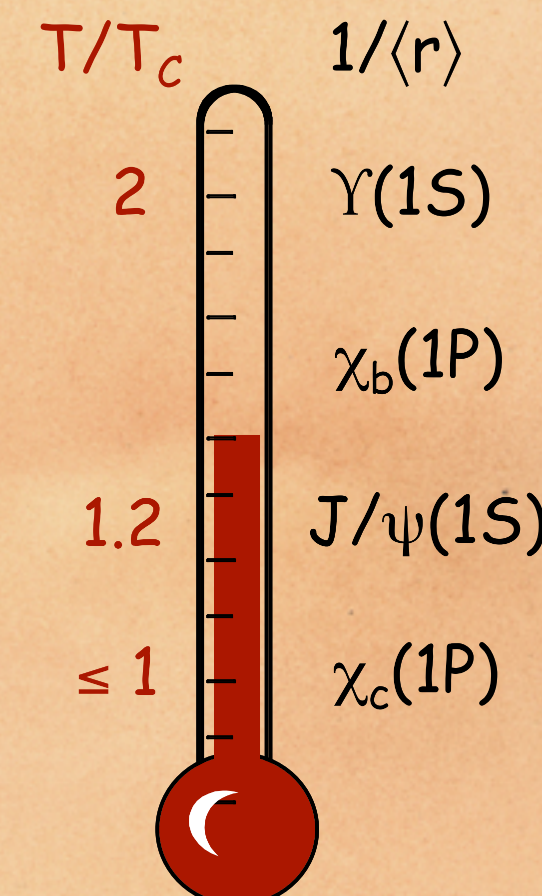


illustration: Alex Doig



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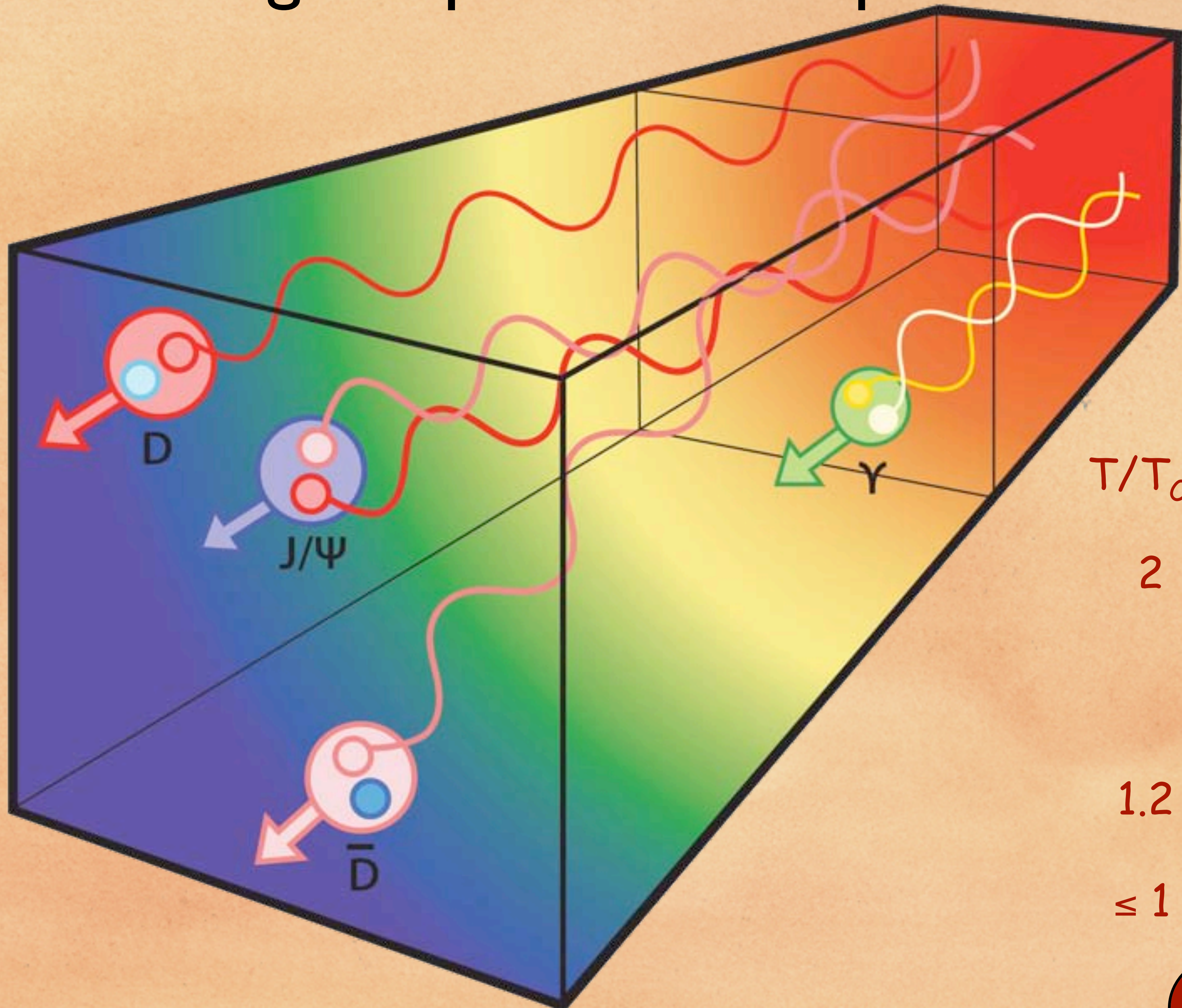
Testing the plasma with quarkonium



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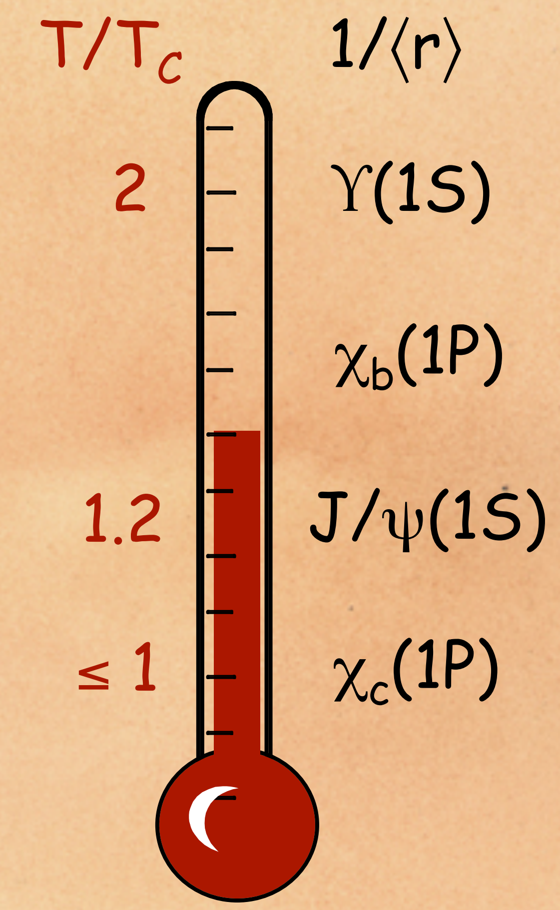
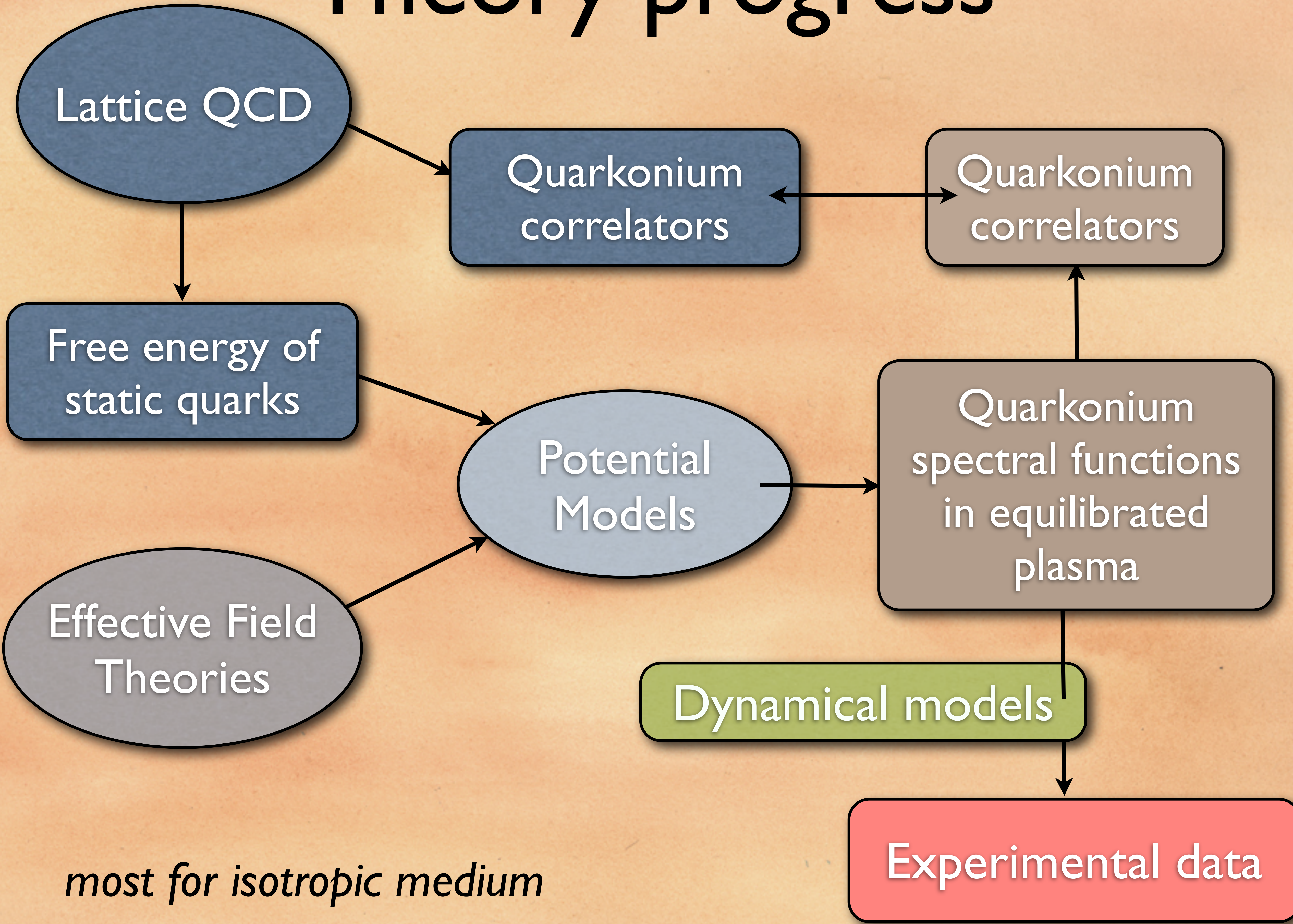


Important diagnostic (LHC, RHICII): The Upsilon

Theory progress



most for isotropic medium

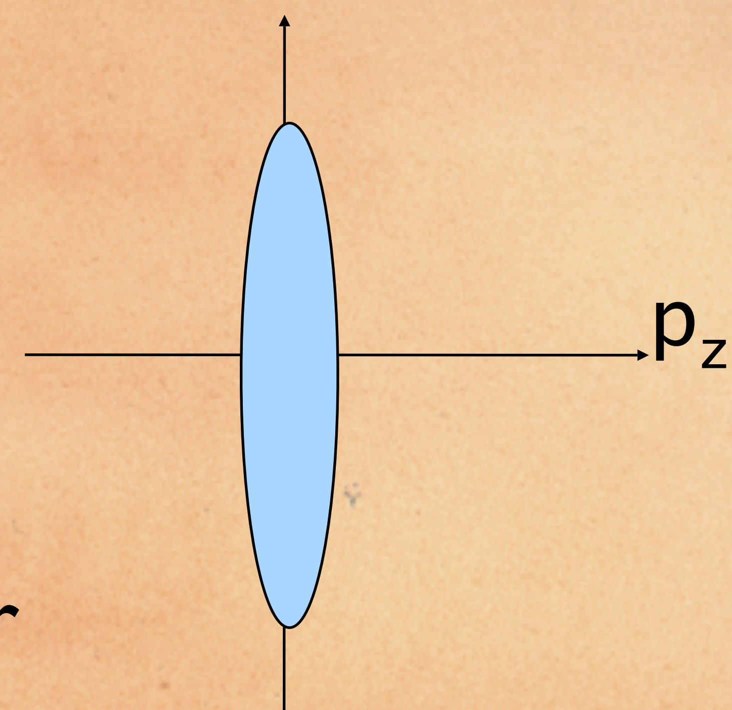
Why anisotropic plasma?

Due to expansion and non-zero viscosity the plasma exhibits a local anisotropy

$$f(\mathbf{p}) = f_{iso}(\sqrt{\mathbf{p}^2 + \xi p_z^2})$$

Mrowczynski,Romatschke,Strickland 2003/04

anisotropy parameter



Relation to shear viscosity for 1D Bjorken expansion $\xi = \frac{10}{T\tau}\frac{\eta}{s}$

Asakawa,Bass,Muller 2007

With η/s ~ 0.1 -- 0.2 and τT ~ 1 -- 3 we expect ξ ~ 1

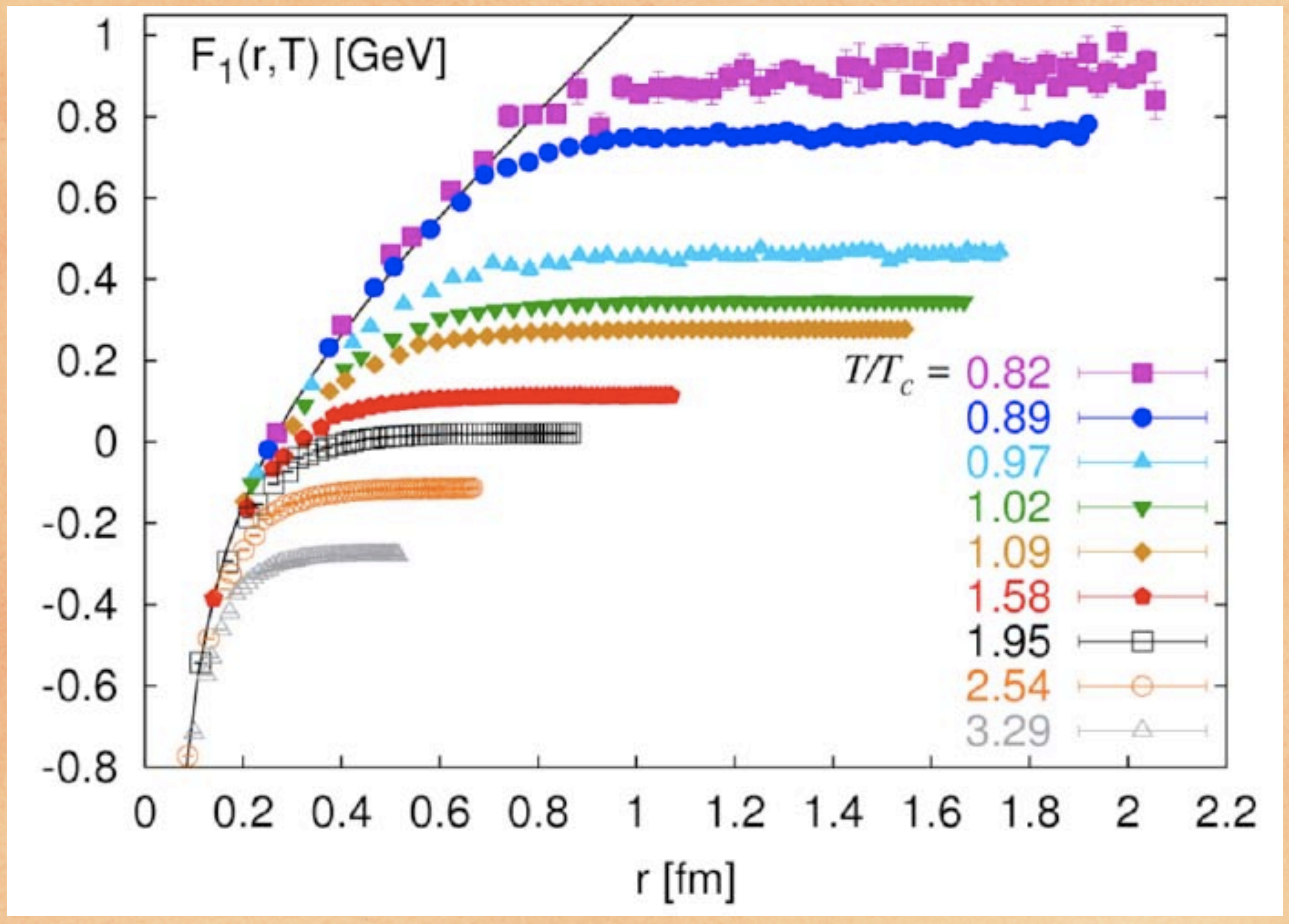
Our goal: how quarkonium states may be affected by the anisotropy of the medium Dumitru,Guo,Mocsy,Strickland, PRD 2009

Potential *in isotropic medium*

(Historically) underlying assumption for potential-models:
all medium effects given by a T-dependent potential V(r,T)

Phenomenological potentials, "lattice-based" potentials

Free energy from lattice QCD RBC-Bielefeld 2008



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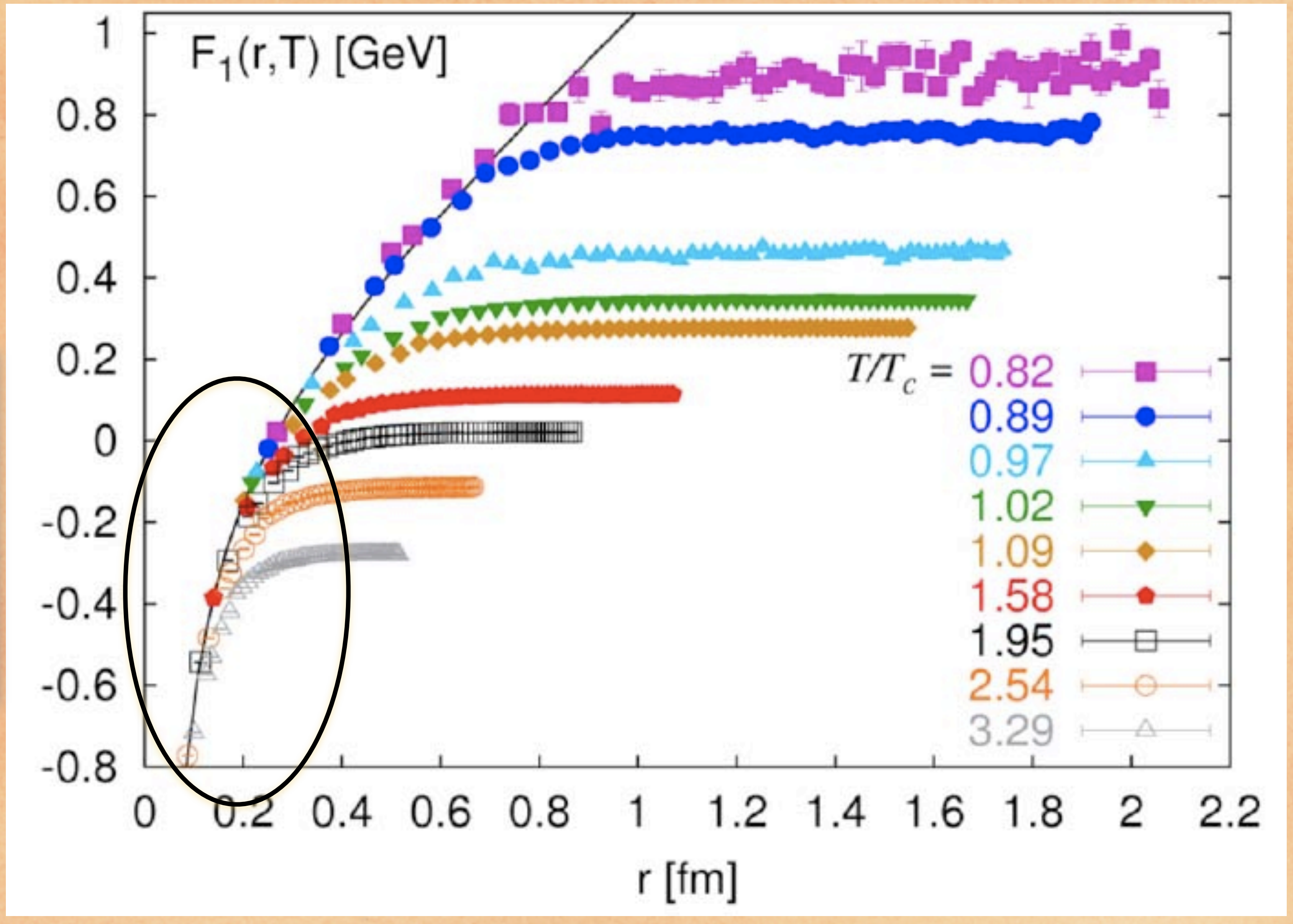

$r < r_{med}(T) \sim 1/m_D$

F(r,T) = F(r)

vacuum physics

Potential *in isotropic medium*

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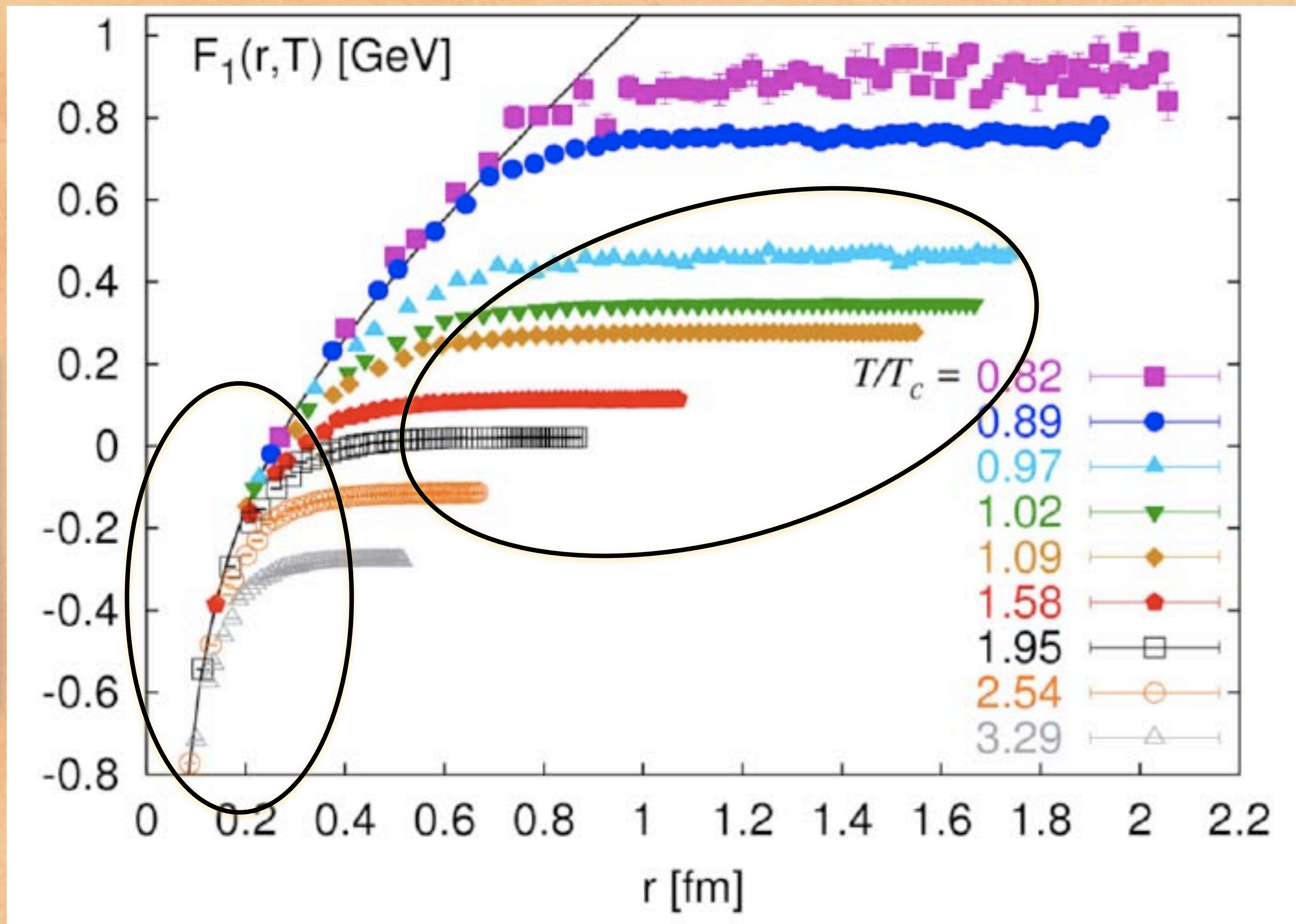


$r > r_{scr}(T)$

$F(r,T) = F(T)$

screening

Potential *in isotropic medium*

phenomenological KMS potential

$$F(r,T) = -\frac{\alpha}{r}\exp(-r\,m_D) + \frac{\sigma}{m_D}\left[1-\exp(-r\,m_D)\right]$$

Karsch,Mehr,Satz 1988

interpolates between
short distance Coulomb and long distance string

Note: it can be obtained as Fourier-transform of the static propagator with an added non-perturbative contribution to the HTL resummed

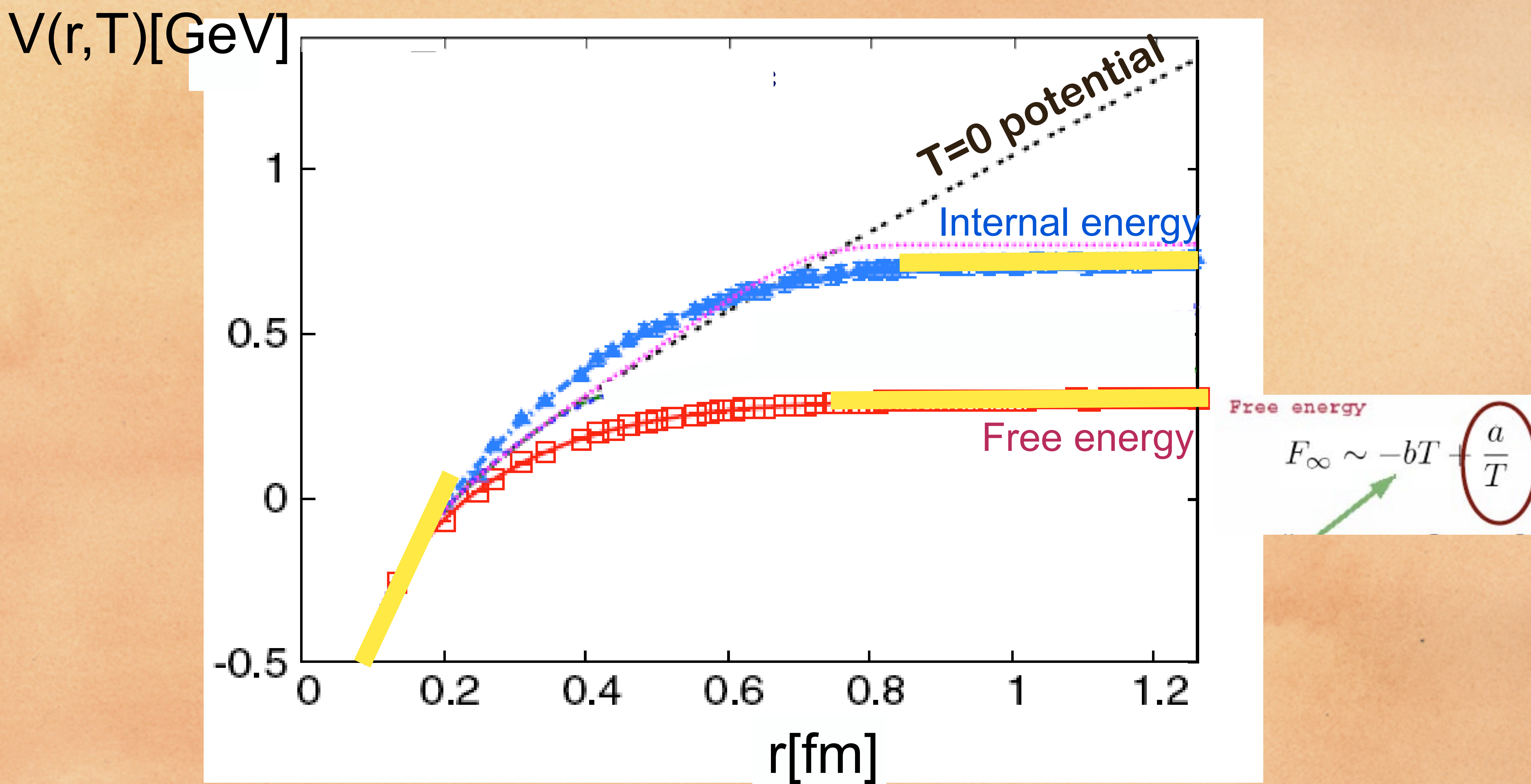
$$\Delta^{00}(\omega=0,\mathbf{k}) = \frac{1}{\mathbf{k}^2+m_D^2} + \frac{m_G^2}{(\mathbf{k}^2+m_D^2)^2}$$

Megias et al PRD07

m_G^2 dimension 2 constant that can be related to the string tension by matching onto Cornell pot. at small $m_D r$

Potential *in isotropic medium*

"lattice-based" potentials



Potential *in isotropic medium*

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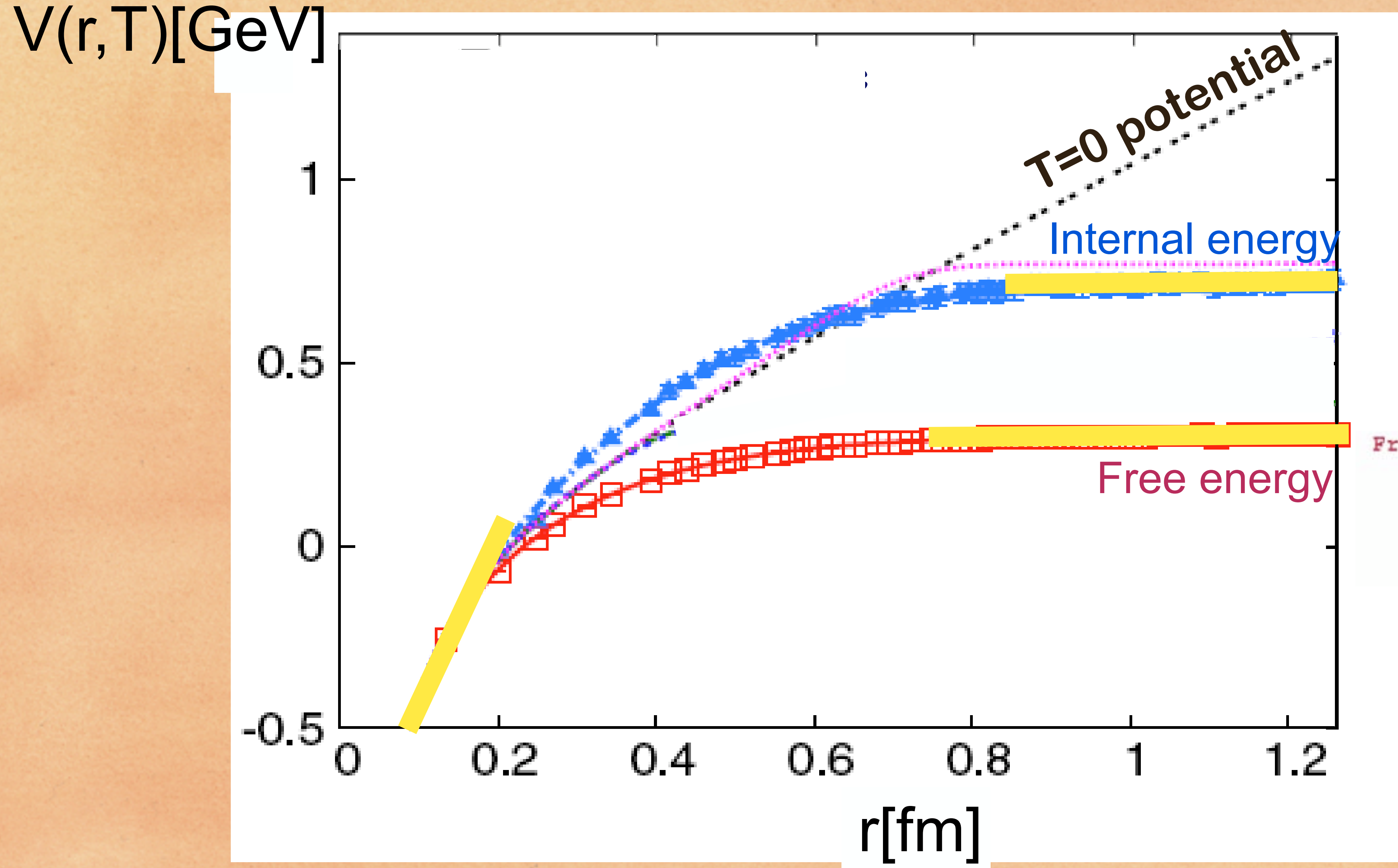


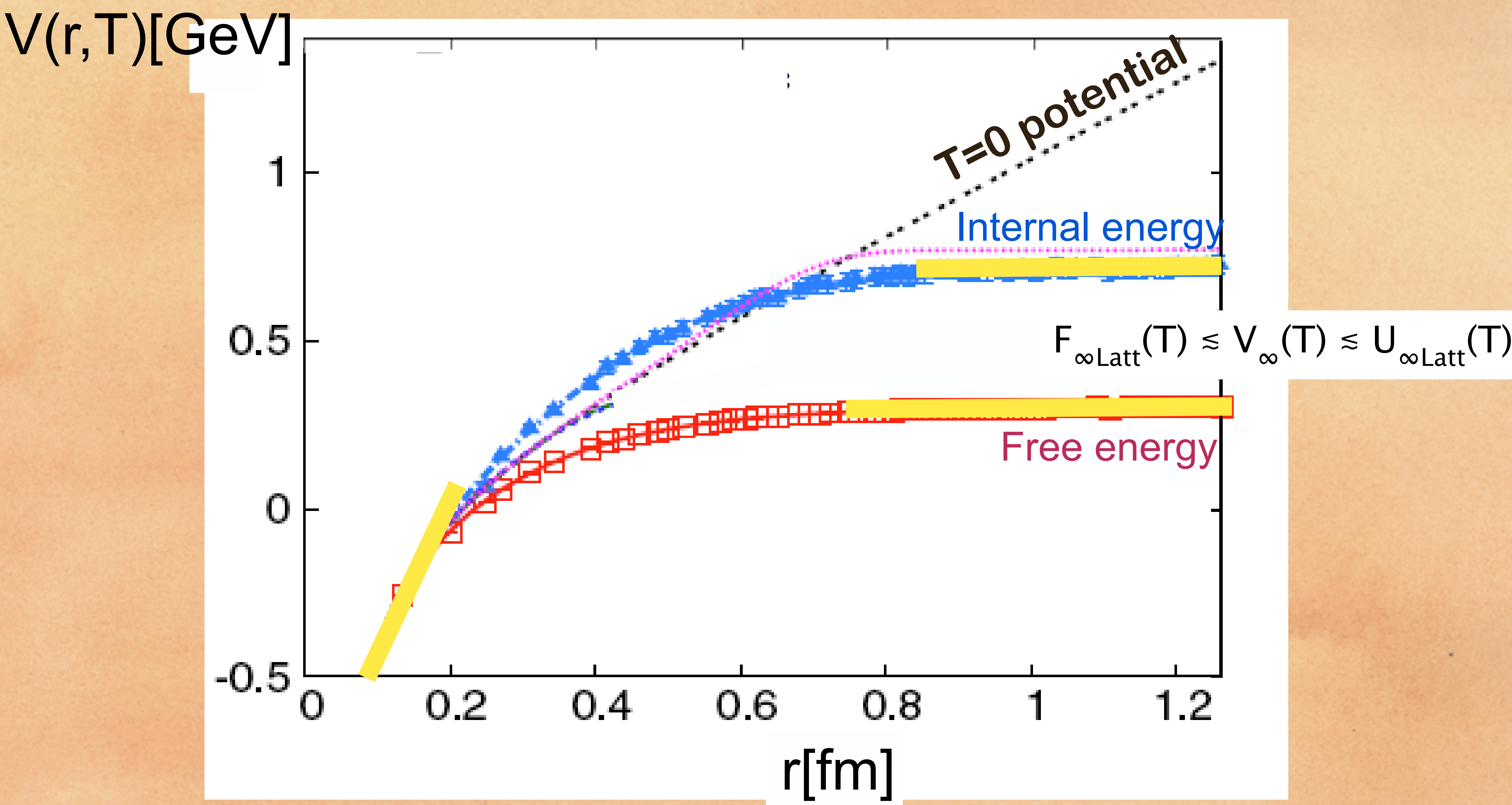
$$
\begin{aligned}
U &= F + TS \\
&= F - T\frac{\partial F}{\partial T}
\end{aligned}
$$

Free energy

$$F_\infty \sim -bT + \frac{a}{T}$$

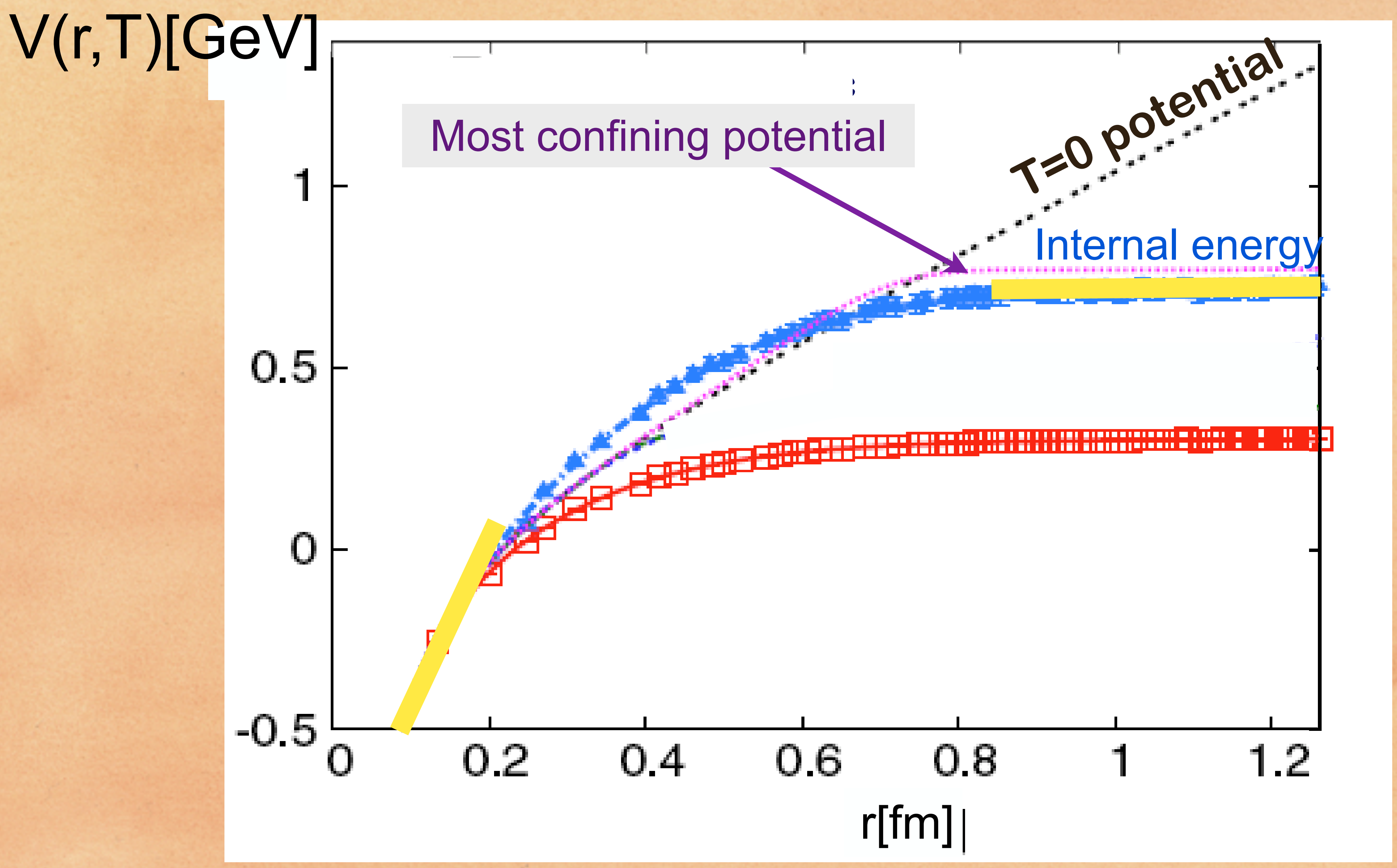
Potential *in isotropic medium*

“lattice-based” potentials



Potential *in isotropic medium*

"lattice-based" potentials



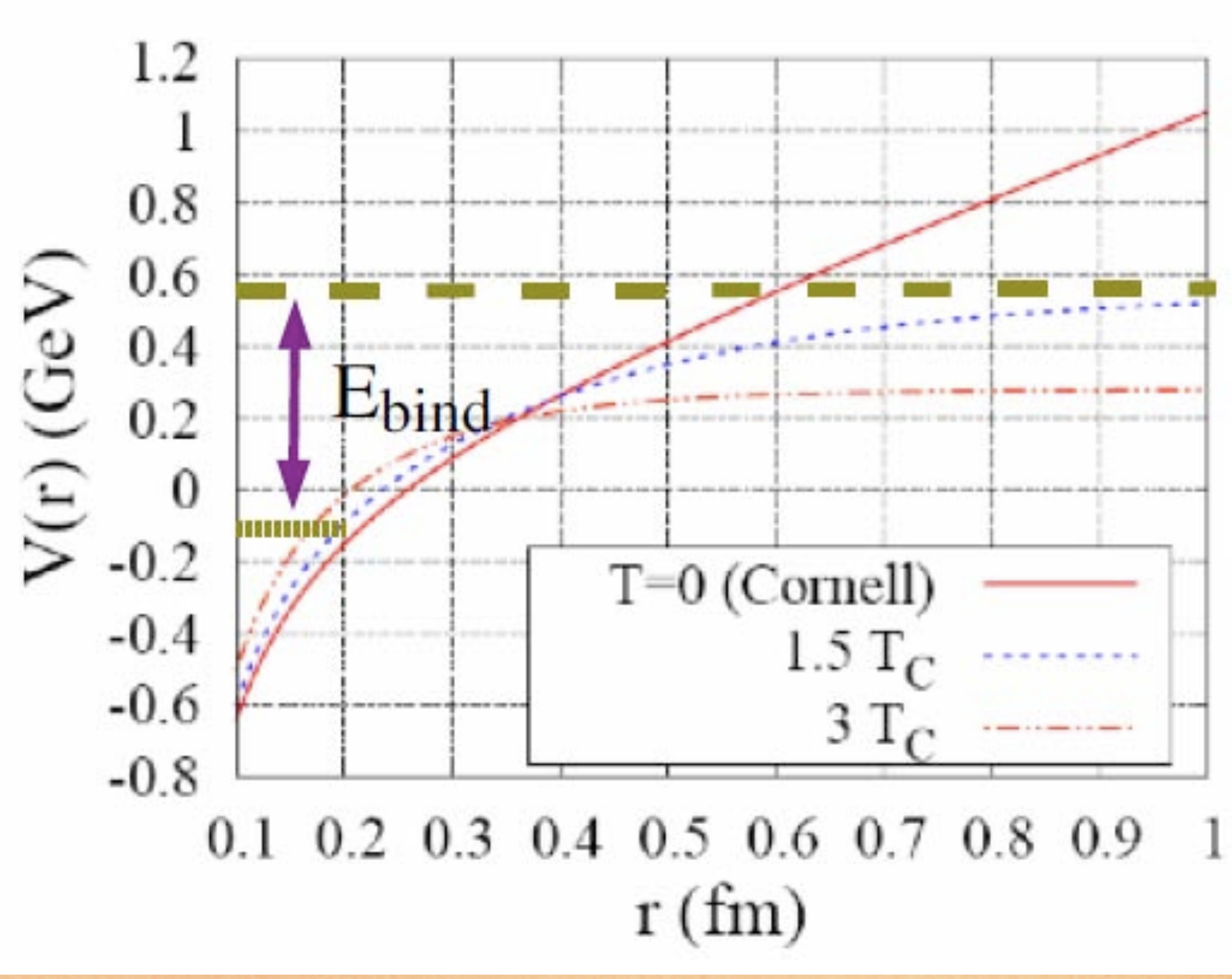
Mocsy, Petreczky, PRL07, PRD 08

Potential *in isotropic medium*

starting from the KMS potential

$$
\begin{aligned}
V(r,T) &= F(r,T) - T\frac{\partial F(r,T)}{\partial T} \\
&\approx \left\{ -\frac{\alpha}{r}\left(1+\hat{r}\right) + 2\frac{\sigma}{m_D}\left(e^{\hat{r}}-1\right) - \sigma\, r \right\} e^{-\hat{r}}
\end{aligned}
$$

$$\hat{r} \equiv r\, m_D$$



$$
\begin{aligned}
V_\infty(T) &= 2\frac{\sigma}{m_D} \simeq \frac{0.16\ \mathrm{GeV}^2}{T} \\
&\approx U_\infty^{\mathrm{Latt}}(T)
\end{aligned}
$$

model for
"most confining potential"

Dumitru,Guo,Mocsy,Strickland, PRD 2009

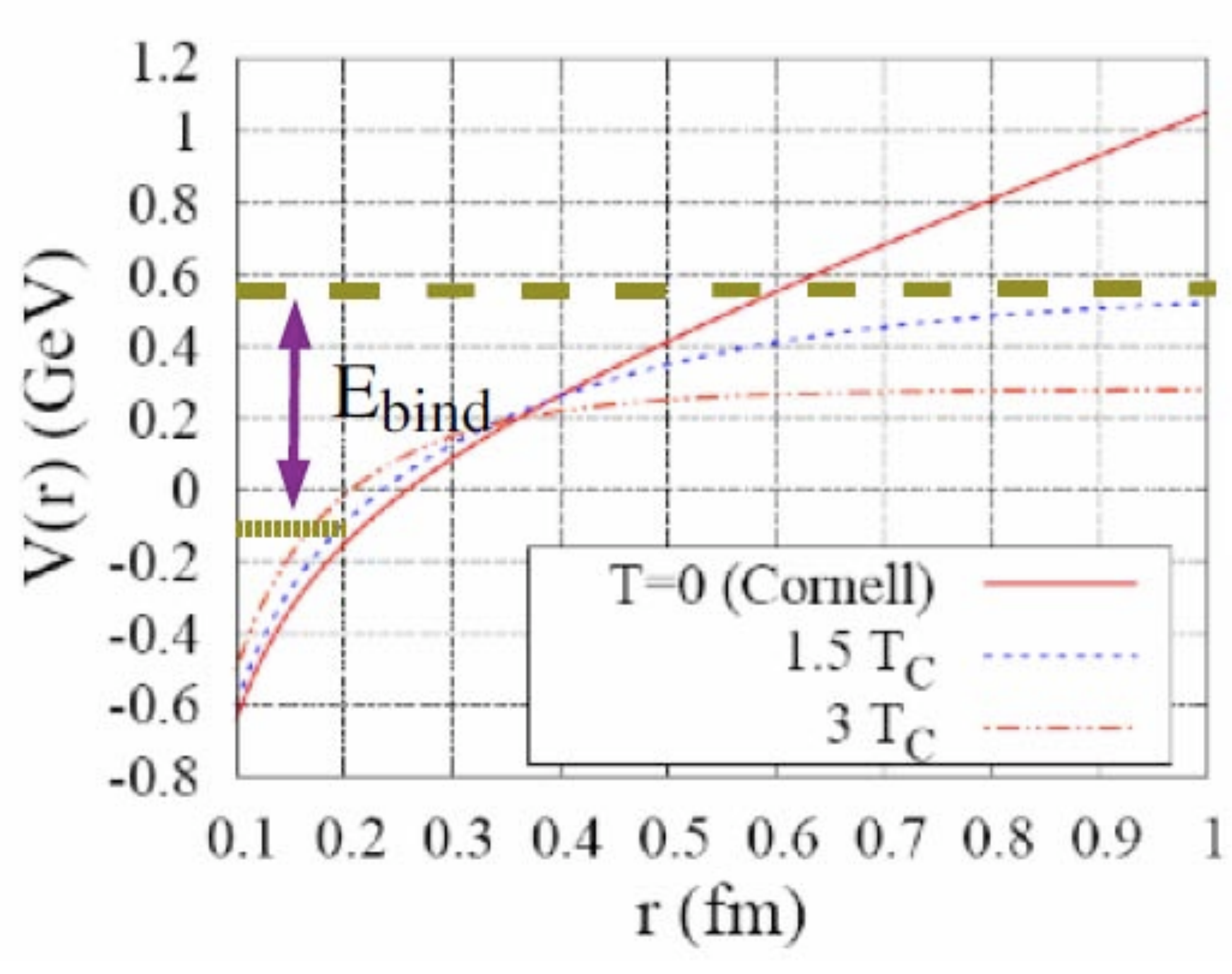
Potential *in isotropic medium*

starting from the KMS potential

$$\begin{aligned} V(r,T) &= F(r,T) - T\frac{\partial F(r,T)}{\partial T} \\ &\approx \left\{-\frac{\alpha}{r}(1+\hat{r}) + 2\frac{\sigma}{m_D}(e^{\hat{r}}-1) - \sigma\, r\right\} e^{-\hat{r}} \end{aligned}$$

V_∞

$$\hat{r} \equiv r\, m_D$$



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model for
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Dumitru,Guo,Mocsy,Strickland, PRD 2009

Anisotropic Potential

We re-spin the old KMS potential. No new parameters!

$$F(r,T) = -\frac{\alpha}{r}\exp(-r\,m_D) + \frac{\sigma}{m_D}\left[1-\exp(-r\,m_D)\right]$$

Karsch,Mehr,Satz 1988

HTL resummed propagator carries angular dependence >> angular-dependent Debye-screening

$$m_D \to \mu(\theta;\xi,T) = m_D\left(1-\xi\frac{3+\cos 2\theta}{16}\right)$$

Dumitru,Guo,Strickland PLB 2008

anisotropy parameter

ξ>0: smaller screening mass

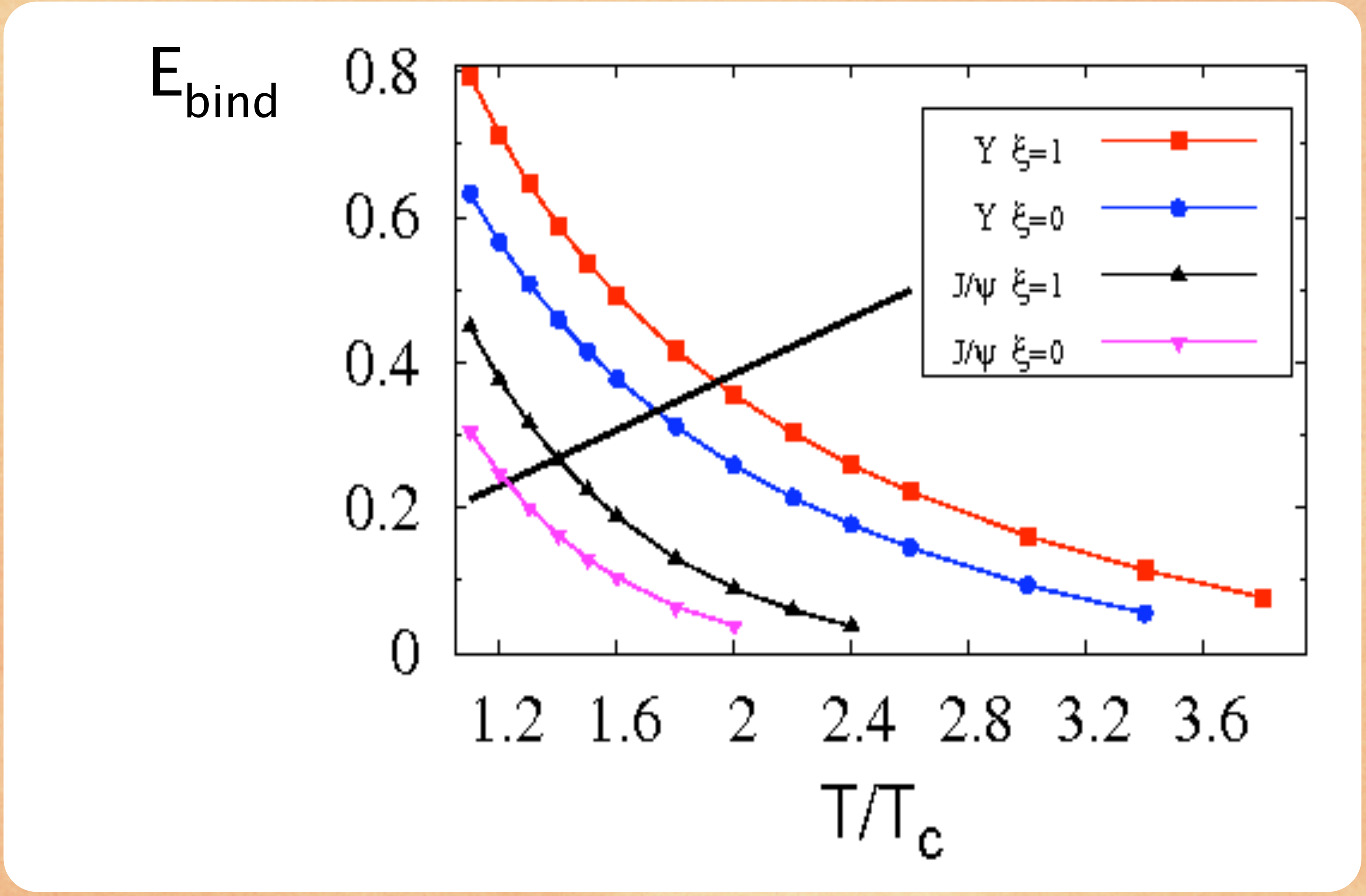
Potential depends on
distance, temperature, anisotropy, direction of anisotropy

Dumitru, Guo, Mocsy, Strickland, PRD 2009

Solutions of 3D Schroedinger equation in a weakly anisotropic medium

Binding Energies

with the most binding potential



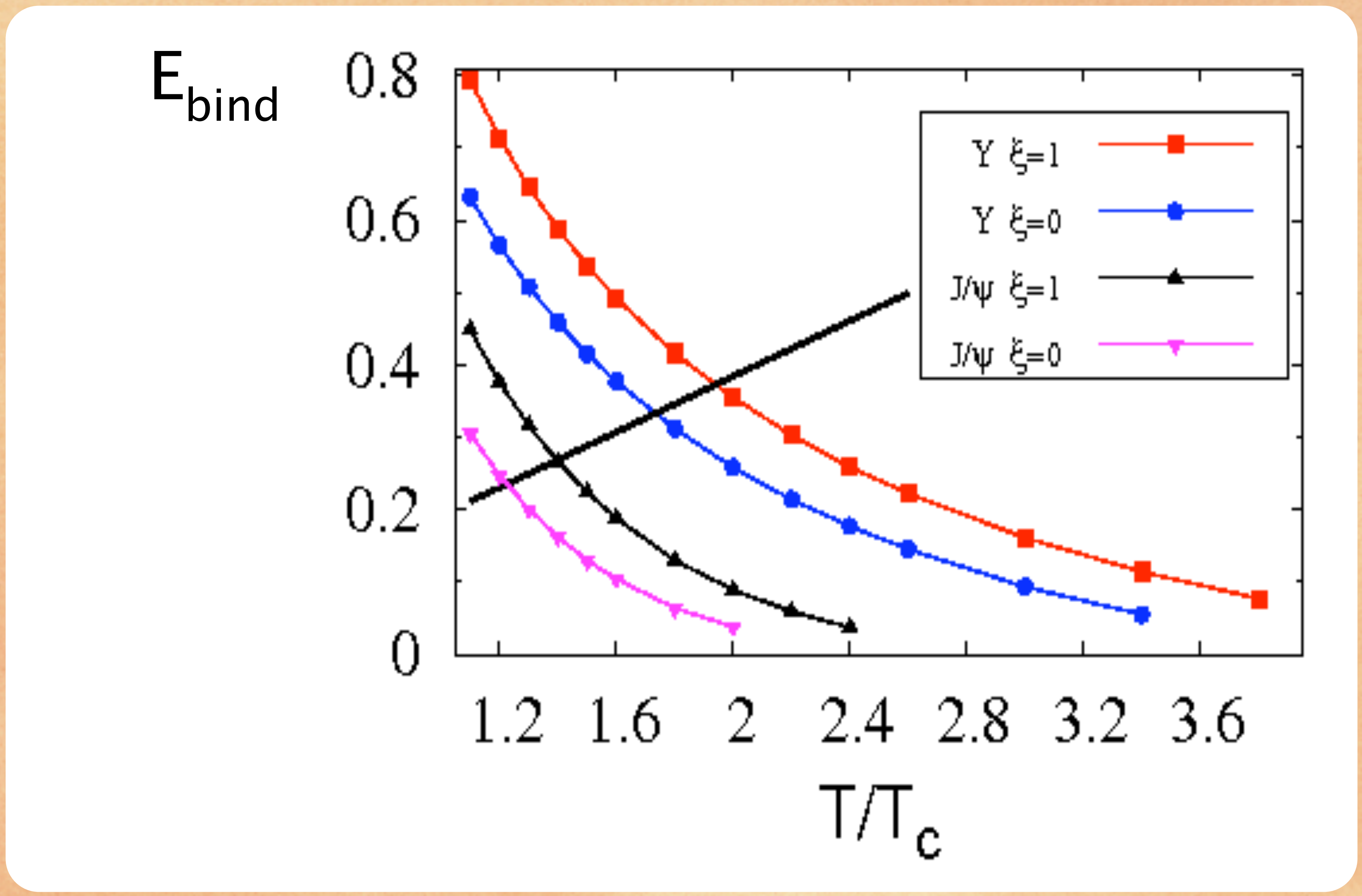
Dumitru, Guo, Mocsy, Strickland, PRD 2009

ξ=0 in agreement with most confining isotropic potential results

Mocsy, Petreczky, PRL 2007

Binding Energies

with the most binding potential



Dumitru, Guo, Mocsy, Strickland, PRD 2009

ξ=0 in agreement with most confining isotropic potential results

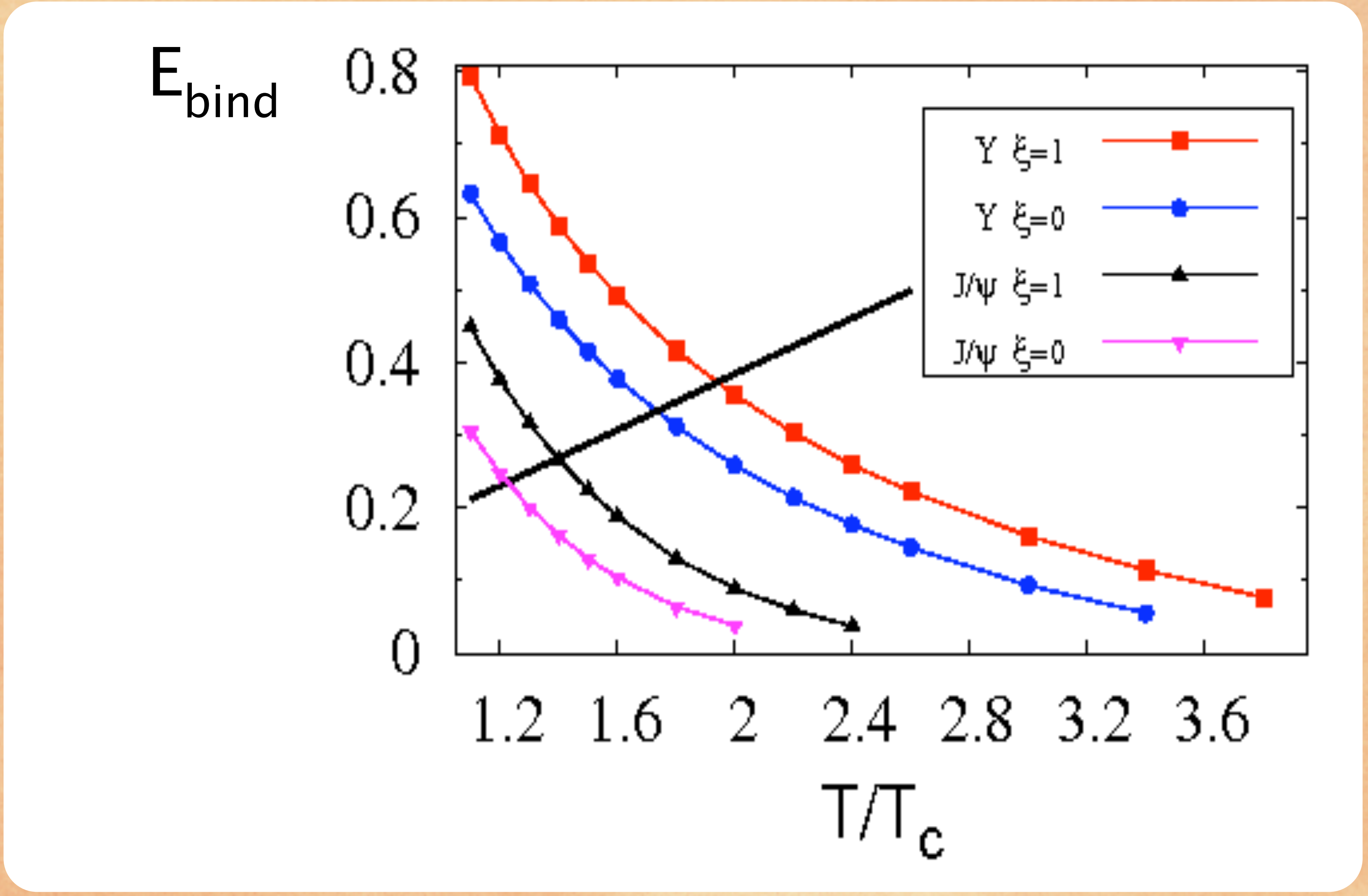
Mocsy, Petreczky, PRL 2007

ξ>0 smaller screening mass leads to stronger binding

$$\mu(\theta;\xi,T) = m_D\left(1 - \xi\frac{3+\cos 2\theta}{16}\right)$$

Binding Energies

with the most binding potential



Dumitru, Guo, Mocsy, Strickland, PRD 2009

ξ=0 in agreement with most confining isotropic potential results

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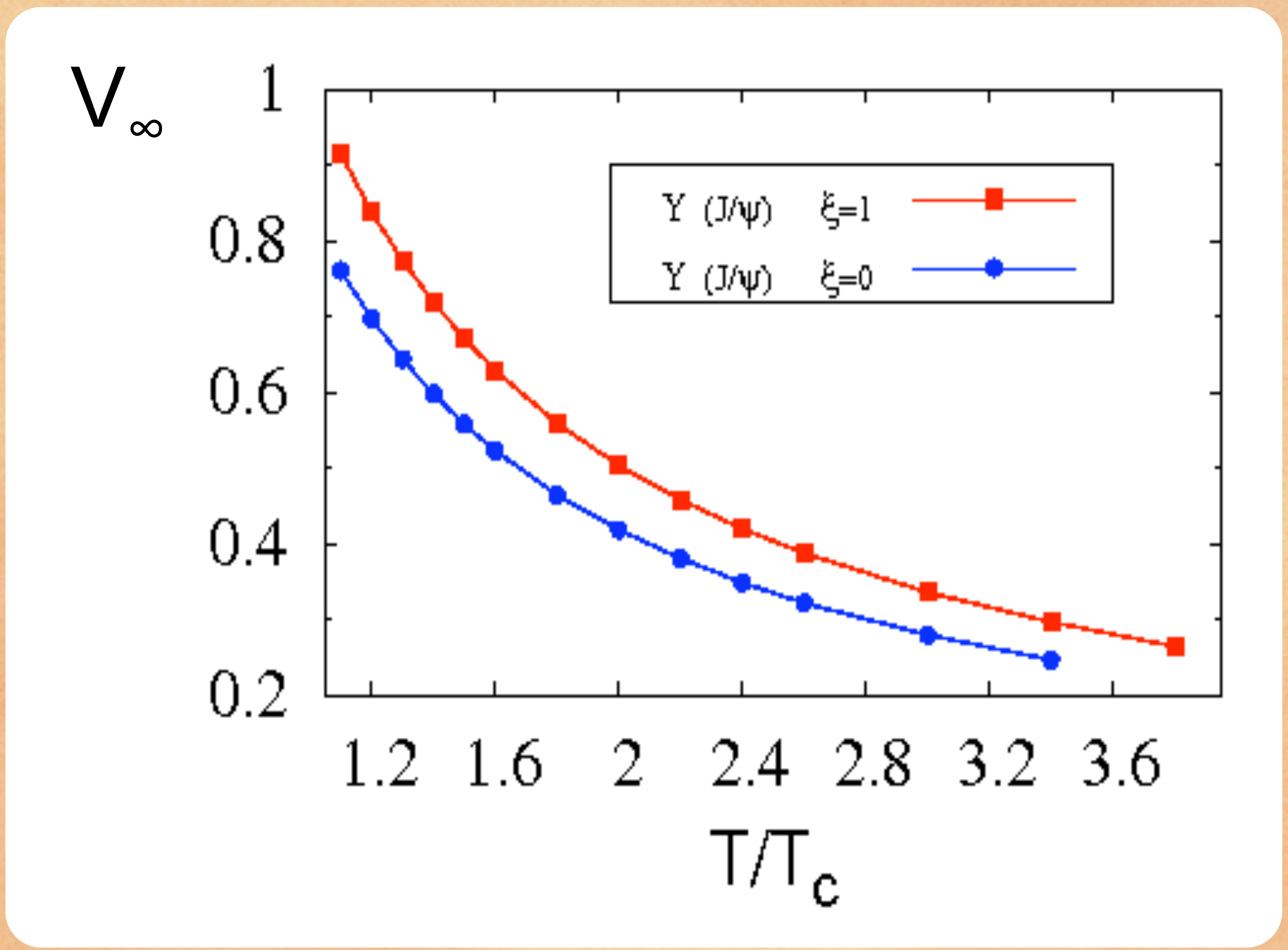
ξ>0 smaller screening mass leads to stronger binding

E_{bin} near Tc of J/Ψ increases 50% and Υ about 30%

Asymptotic value of the potential

another effect of screening

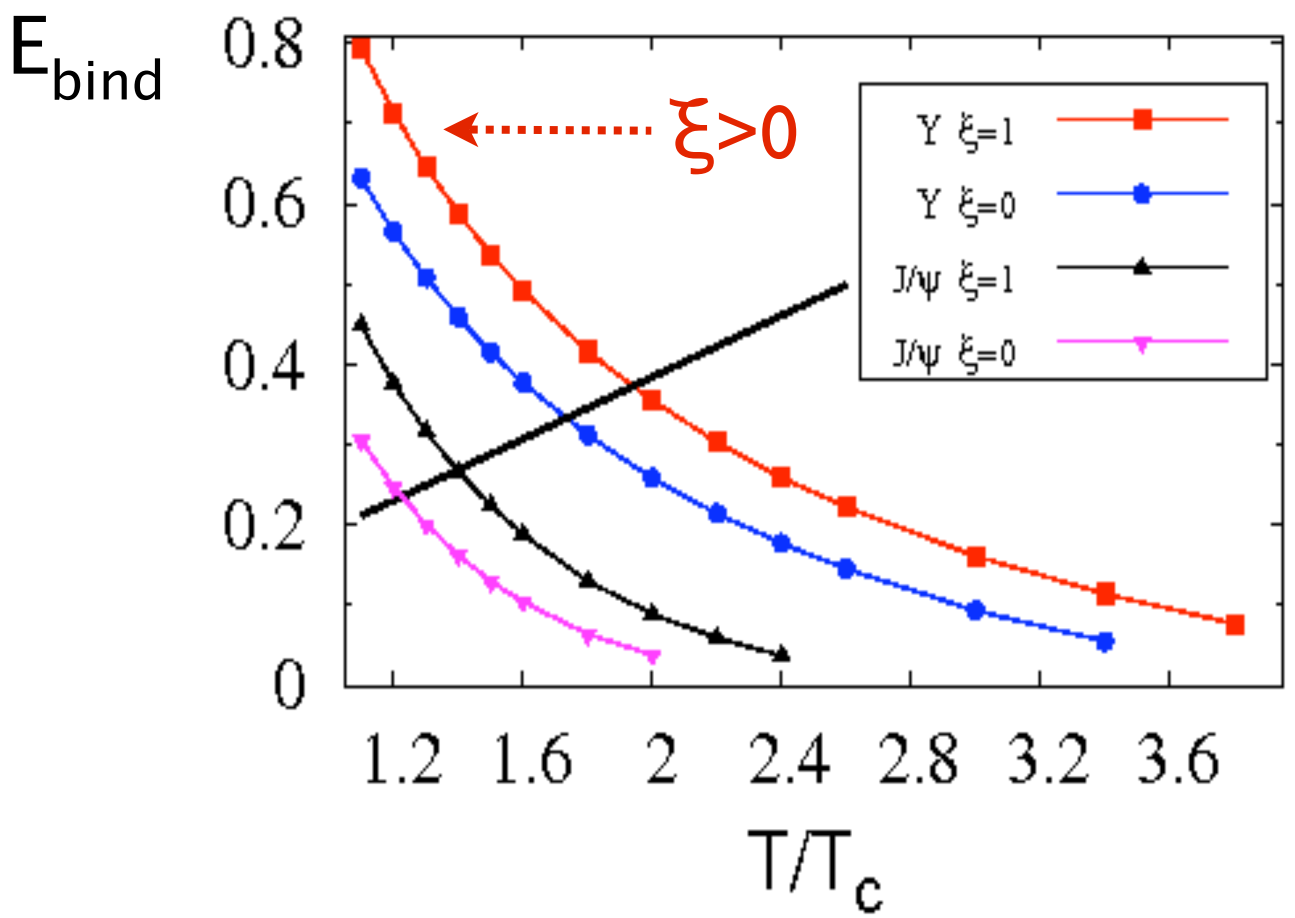


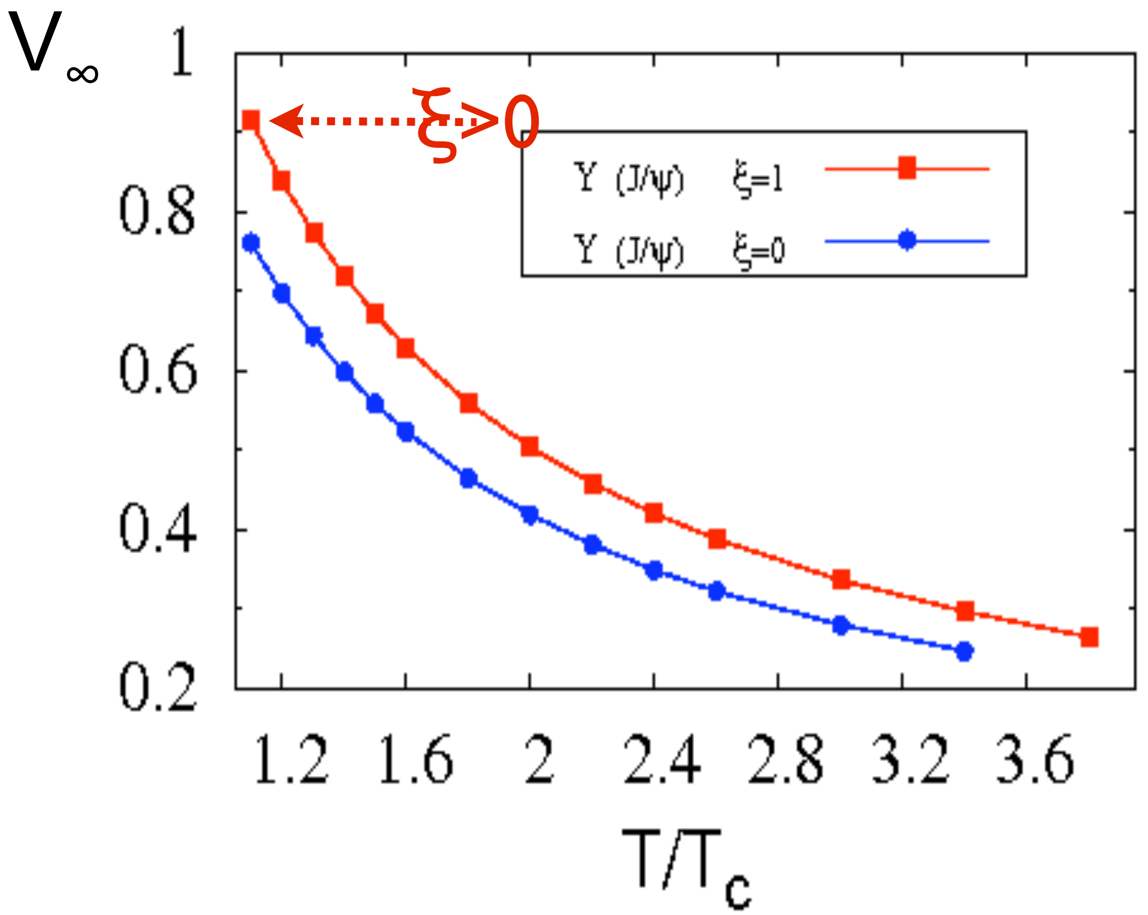
Dumitru, Guo, Mocsy, Strickland, PRD 2009

$$V_\infty(\theta) \sim 1/\mu(\theta;\xi,T)$$

Smaller screening >> larger Vinf >> larger continuum threshold than in isotropic case

Binding Energies



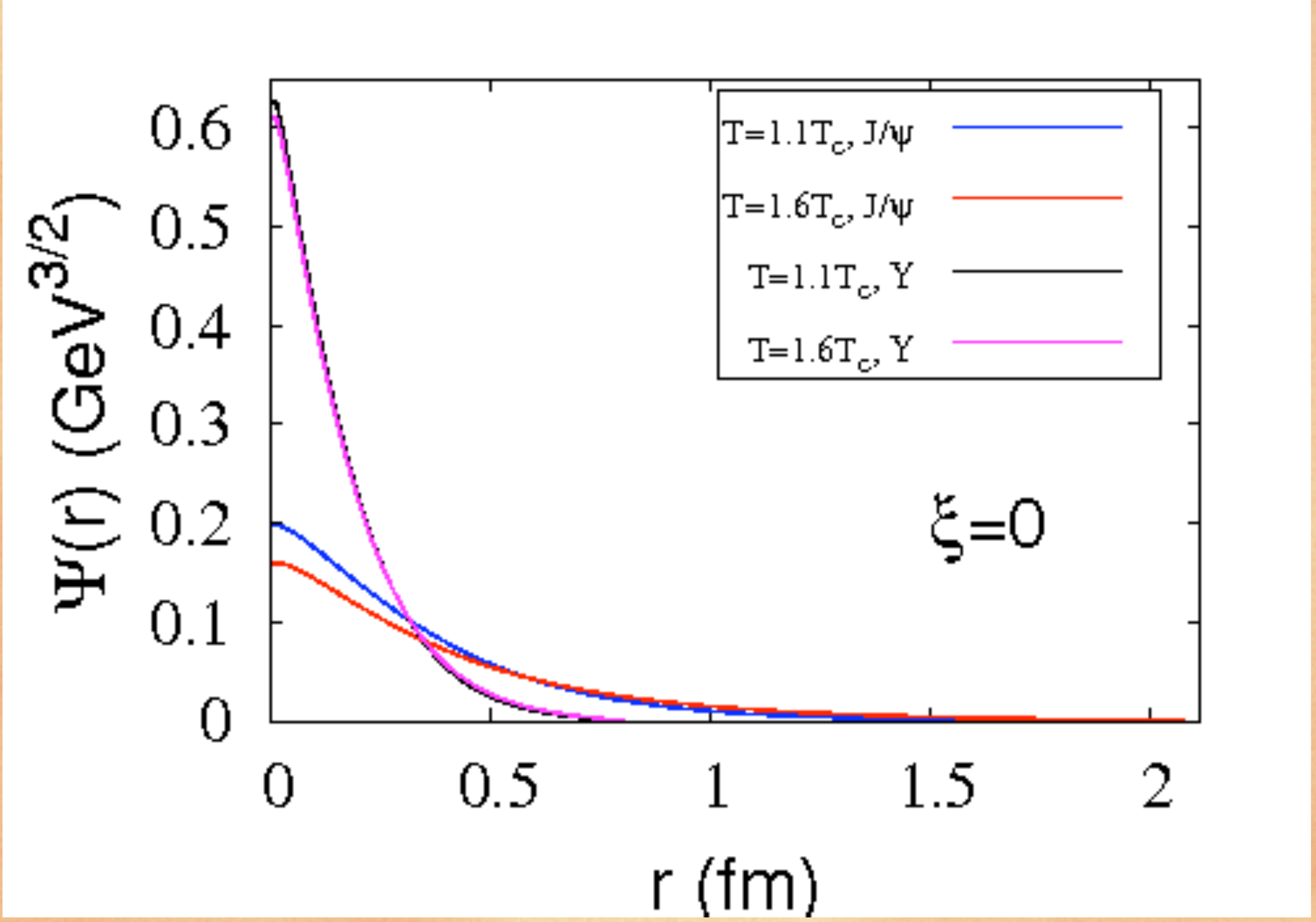


T, ξ - dependence of E_{bind} dominated by V_∞

\- especially for the Υ -

Dumitru, Guo, Mocsy, Strickland, PRD 2009

Wave functions

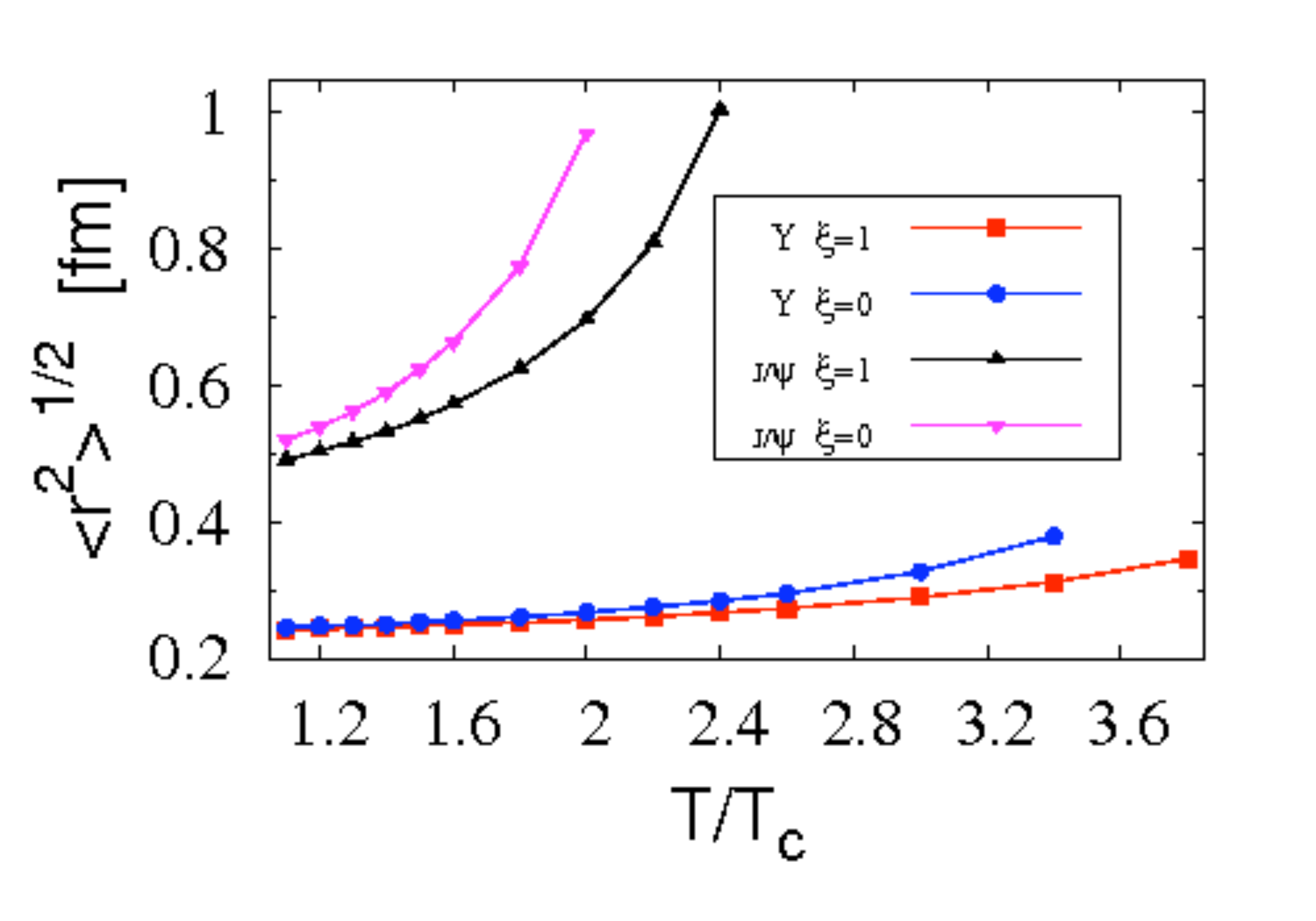


Dumitru, Guo, Mocsy, Strickland, 2009

The wave function of the Upsilon is essentially unaffected by the slightly anisotropic medium until 2Tc (Y is too small)

The larger states (Jpsi) gets modified due to screening

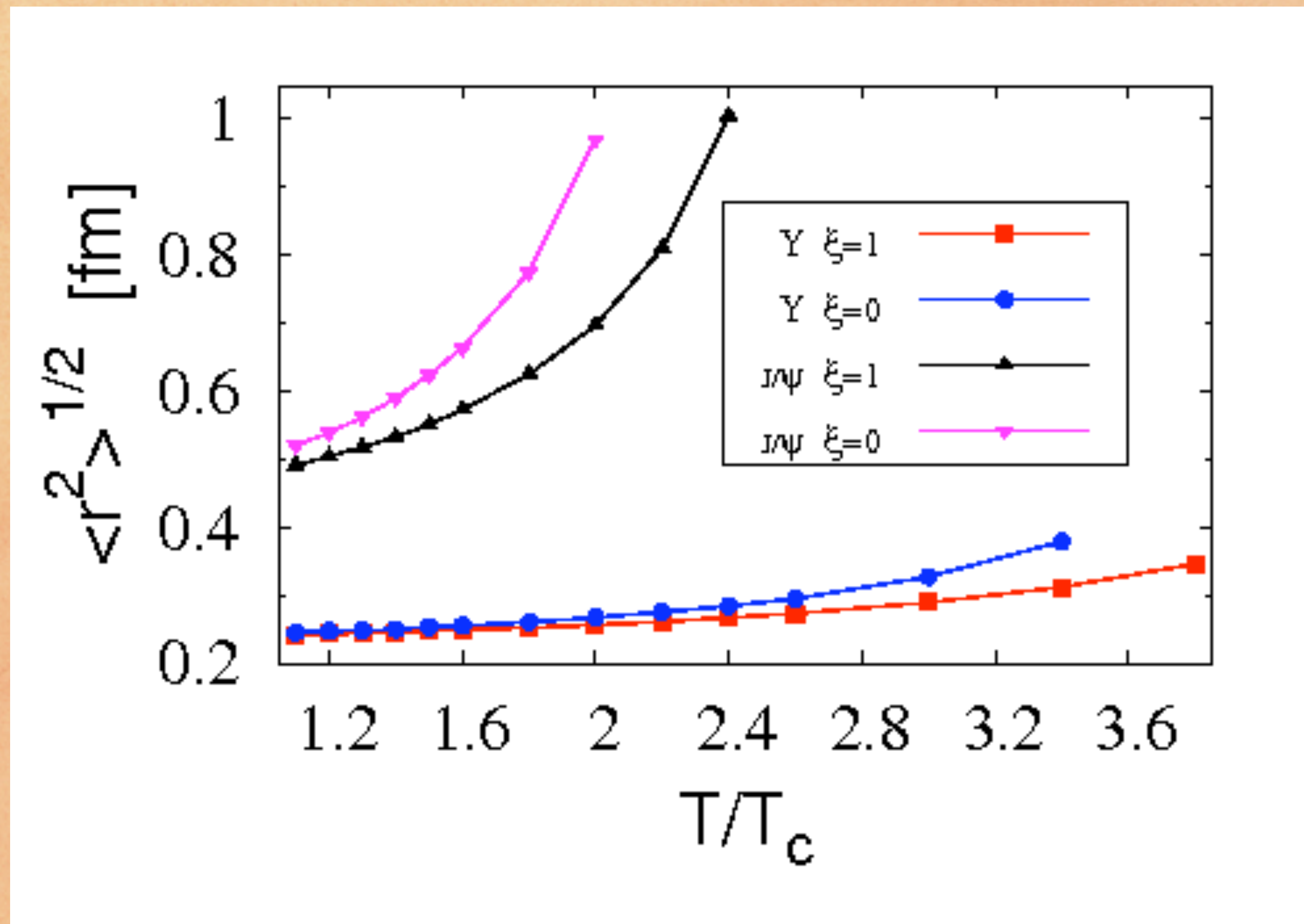
Radii



Dumitru, Guo, Mocsy, Strickland, PRD 2009

J/Ψ grows rapidly with temperature
ϒ essentially unaffected by the medium

Radii



Dumitru, Guo, Mocsy, Strickland, PRD 2009

J/Ψ grows rapidly with temperature >> J/Ψ dominated by string

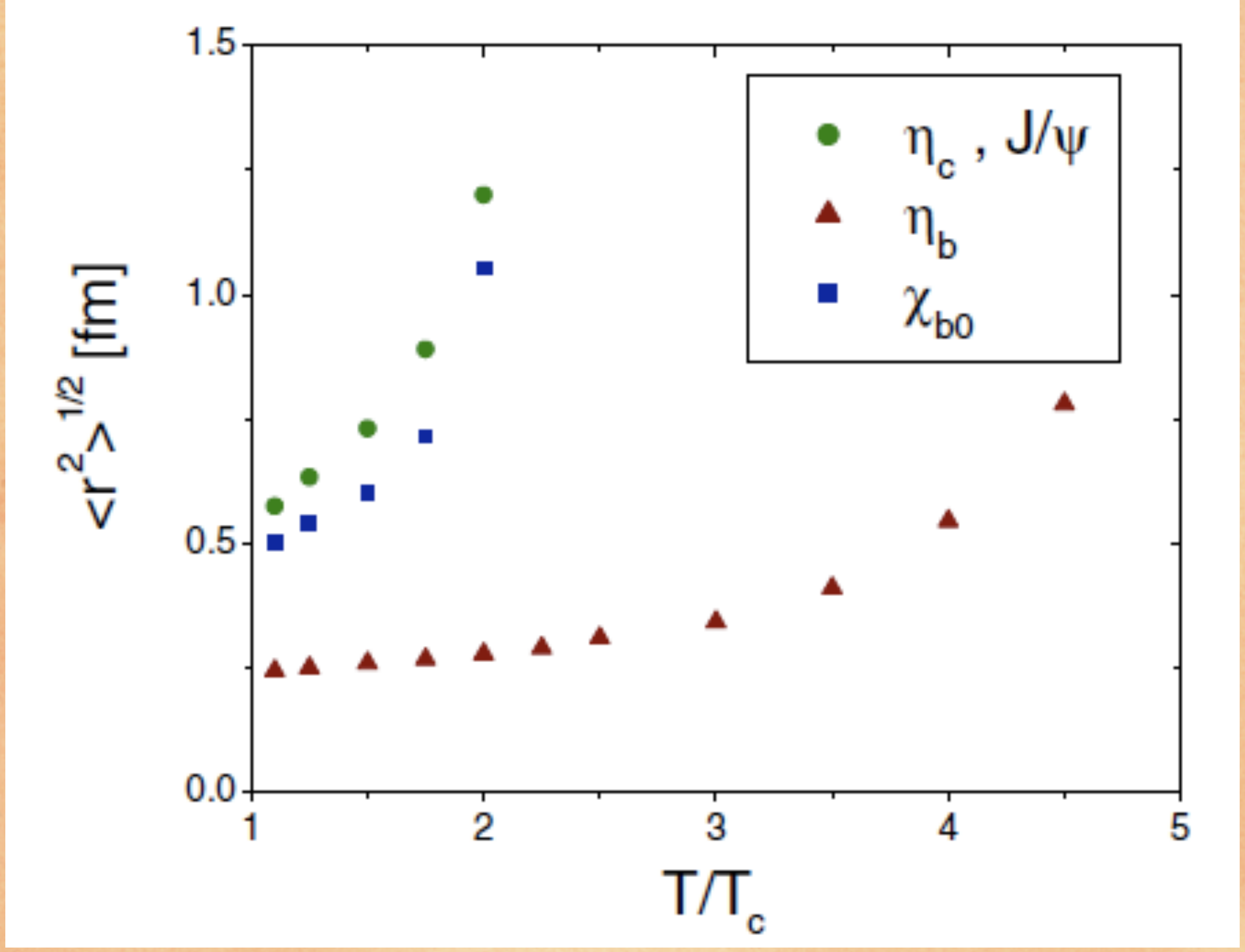
ϒ essentially unaffected by the medium >> ϒ Coulomb state

$$\left\{ -\frac{\alpha}{r}\,(1+\hat{r}) + 2\,\frac{\sigma}{m_D}\,(e^{\hat{r}}-1) - \sigma\, r \right\}\, e^{-\hat{r}}$$

agreement with

Radii

in isotropic plasma



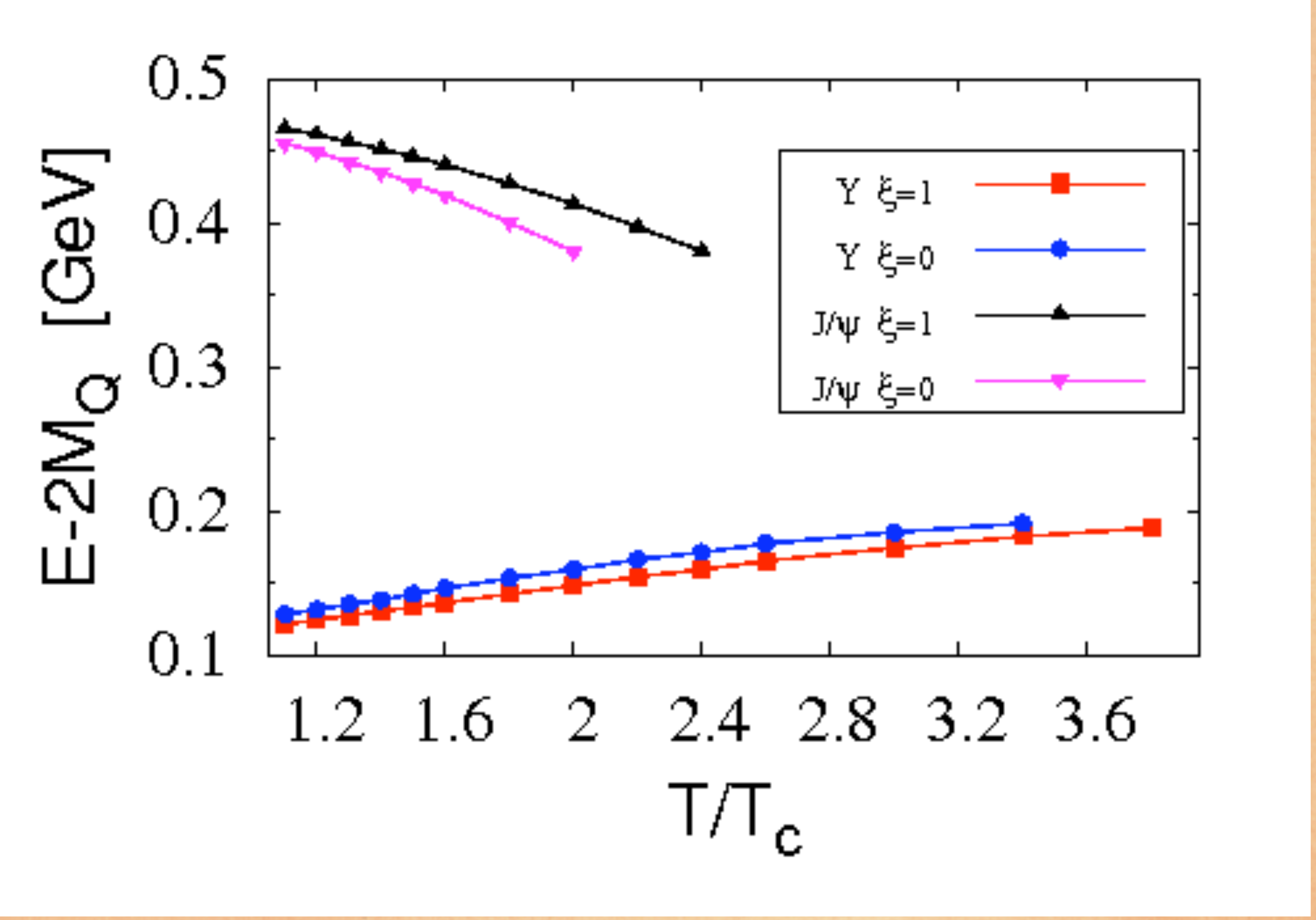
Mocsy, Petreczky, PRD 2006

J/Ψ grows rapidly with temperature >> J/Ψ dominated by string

ϒ essentially unaffected by the medium >> ϒ Coulomb state

Energies

$E_{bind} + V_{\infty}$



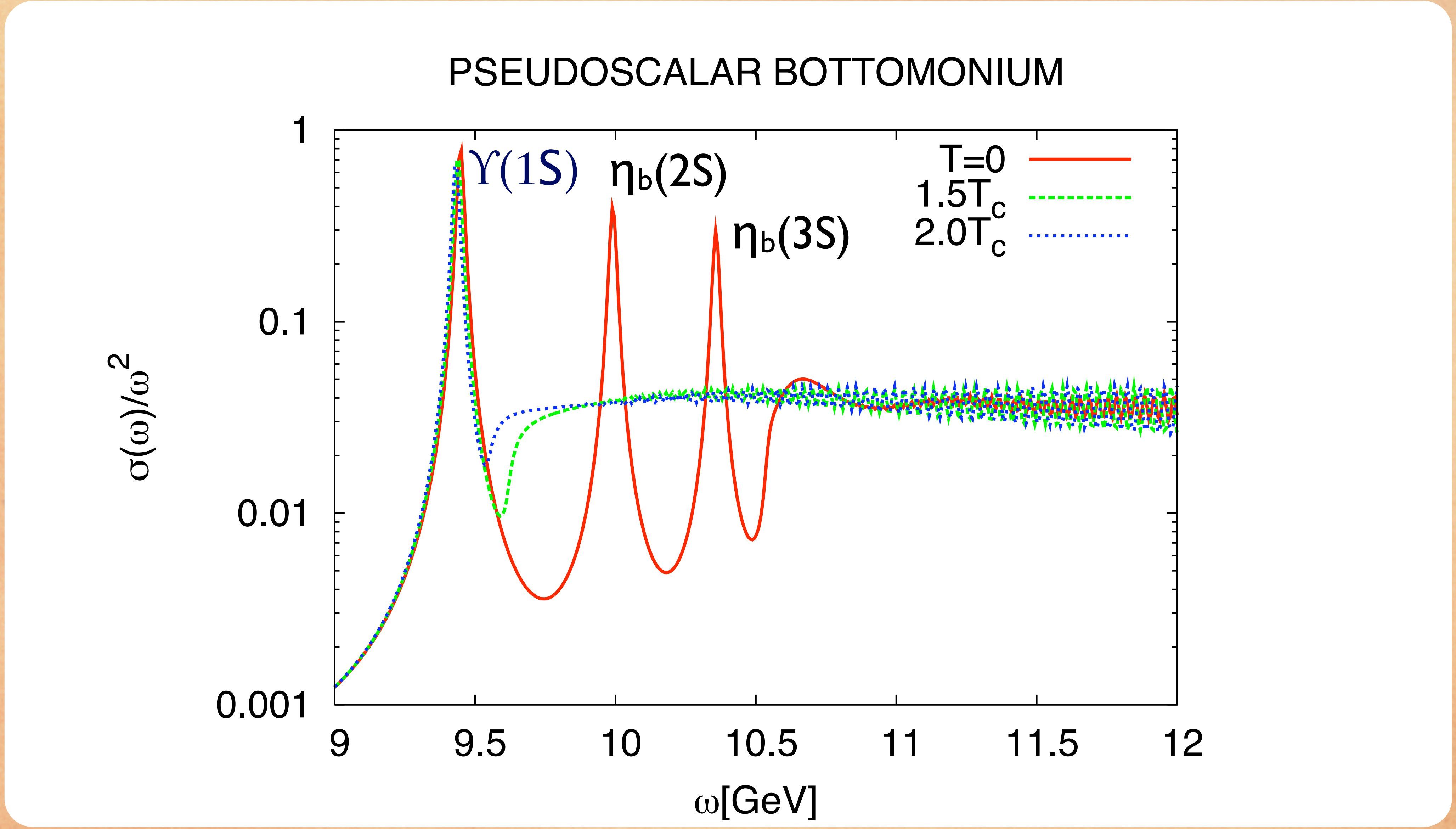
Dumitru, Guo, Mocsy, Strickland, PRD 2009

J/Ψ dominated by string (decreases)
ϒ by Coulomb (increases)

$$V(\mathbf{r}) = -\frac{\alpha}{r}(1+\mu r)\exp(-\mu r) + \frac{2\sigma}{\mu}[1-\exp(-\mu r)]$$

Spectral functions

in isotropic medium full Greens' fct calculation

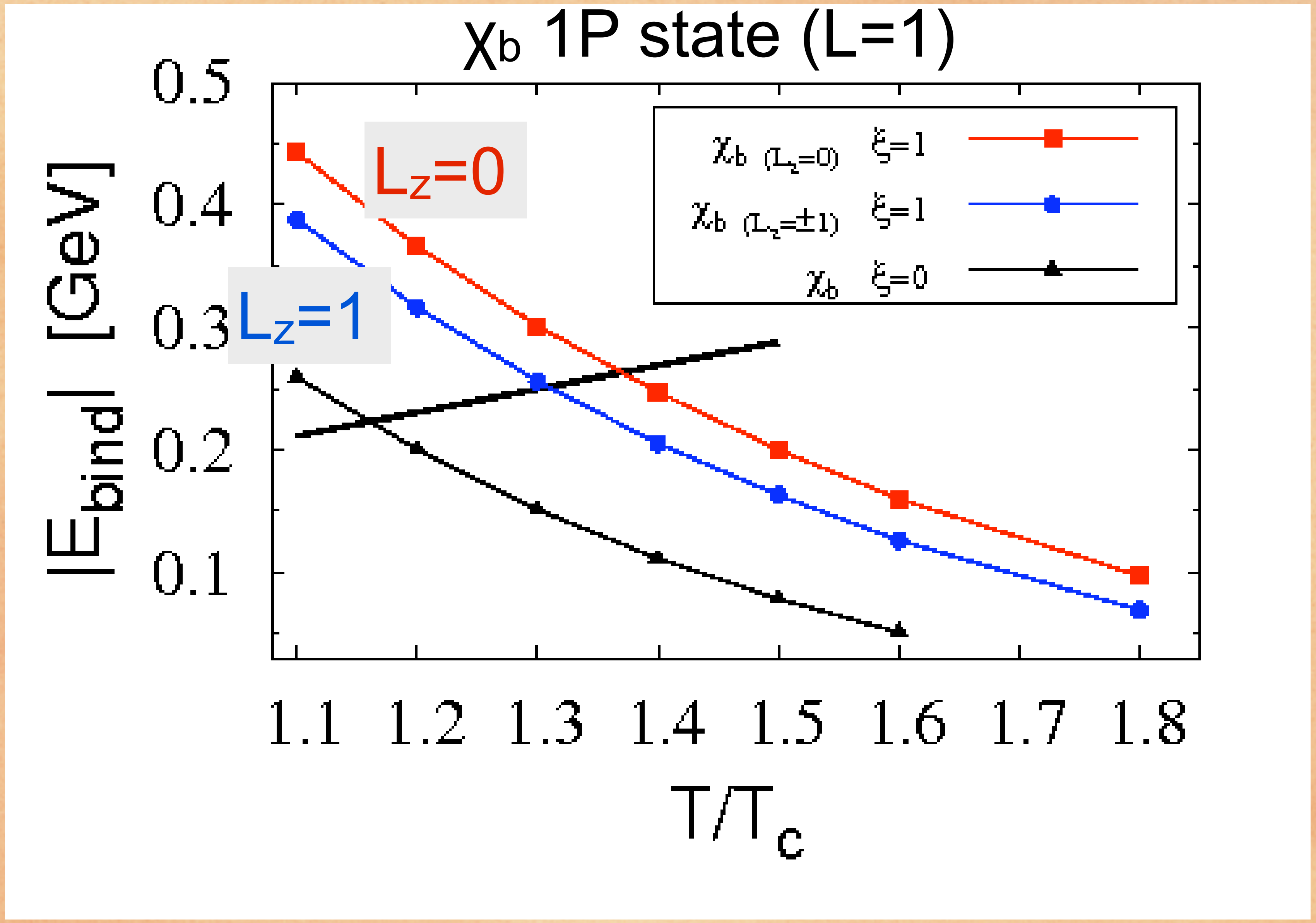


Mocsy, Petreczky, PRL 2007

The Υ peak very little affected by T

The continuum rapidly approaches the peak as T increases

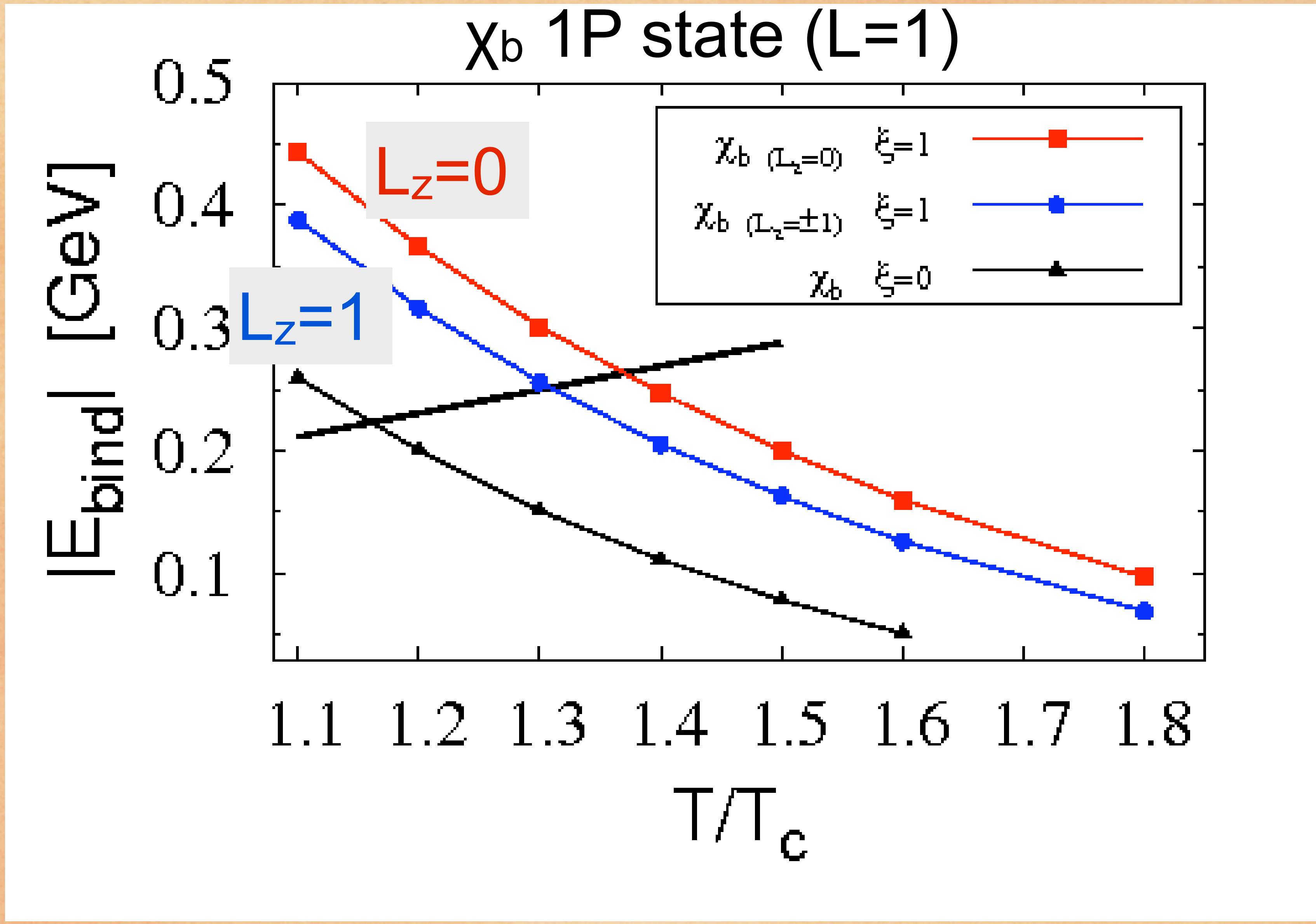
The P States



Dumitru, Guo, Mocsy, Strickland, PRD 2009

Anisotropy leads to about 50% increase

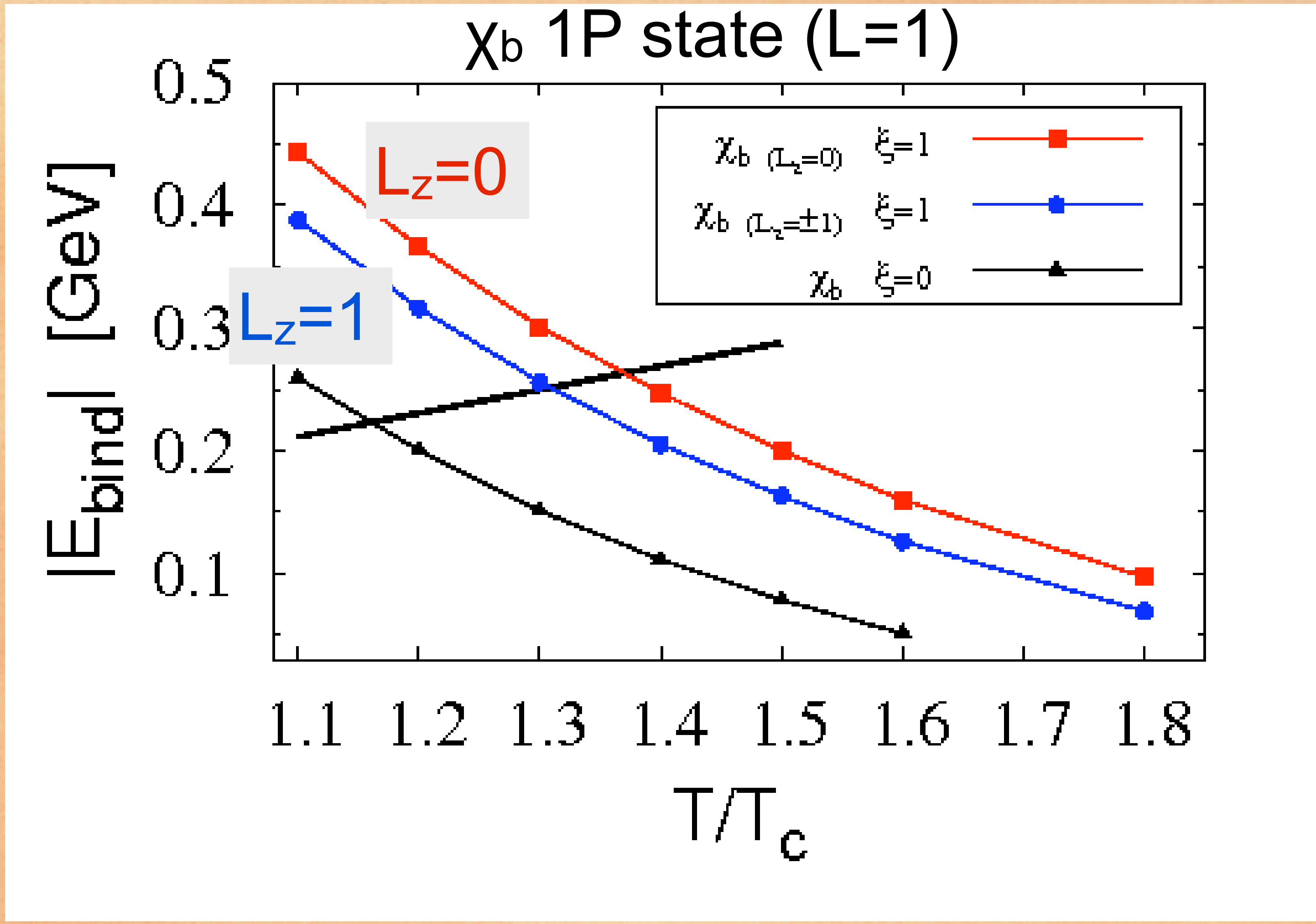
The P States



Dumitru, Guo, Mocsy, Strickland, PRD 2009

Polarization of P-state (L_z=0 is preferred) induced by the angular dependence of the potential (~50 MeV splitting)

The P States



Dumitru, Guo, Mocsy, Strickland, PRD 2009

At T=200MeV the population of L_z=0 enhanced by ~exp(-E_{bind}/T) = 30% compared to states along the anisotropy direction

Summary/Conclusions

First analysis of quarkonium in anisotropic medium

Quarkonium binding energies larger than in isotropic plasma

Screening effects seen only on larger states

Υ radius, energy, wave fct unchanged and its binding energy decreases due to Vinf - “melting” due to deconfinement

We found polarization of P states - could signal viscosity experimental detection?!

*** The End ***