

J/ Ψ mass shift and J/ Ψ -nuclear bound state [(D, \bar{D}) (D^* , \bar{D}^*) and J/ Ψ]

XXII RETINA, IFT Sao Paulo, 21, Feb. 2011

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PLB 697, 136 (2011), arXiv:1101.3389 [nucl-th]

PRC 59, 2824 (1999)

Review of QMC, PPNP, 58, 1 (2007)

Outline

- Introduction: **others** and **our** approaches (color **octet** and **singlet**)
 - Nuclear matter, Nuclei in **QMC**
 - **D, \bar{D}** in a nuclear medium (**QMC**)
 - **J/Ψ** in **nuclear matter**
(in **Finite nuclei** preliminary results)
 - Summary, outlook

J/ Ψ in nuclei (historical)

S. J. Brodsky, I. Schmidt, Guy F. de Téramond:

QCD van der Waals potential

A=9, η_c binding energy ~ 400 [MeV] !!!

PRL 64, 1011 (1990)



Corrected by folding nuclear density dist.

D. A. Wasson:

at most ~ 30 [MeV] !!! PRL 67, 2237 (1991)

J/Ψ pot. at ρ_0 (color octet)

$$\alpha_\Psi/2 \langle N | \vec{E}_a \cdot \vec{E}_a | N \rangle$$

M.B. Voloshin: chromo-polarizability

at ρ_0 , $V < -21$ ($\alpha_\Psi/2$ GeV $^{-3}$) [MeV],

Prog. Part. Nucl. Phys. 61, 455 (2008)

S.H. Lee, C.M. Ko: QCD Stark effect

$V = -8 + 3$ (D-loop) [MeV], PRC 67, 038202 (2003)

M. Luke, A.V. Manohar, M.J. Savage: EFT

$V = -11 \sim -8$ [MeV], PLB 288, 355 (1992)

QCD sum rules

Klingl et. al, PRL 82, 3396 (1999), Err-ibid 83, 4224 (1999).

A. Hayashigaki, Prog. Theor. Phys. 101, 923 (1999).

S. Kim and S. H. Lee, NPA 679, 517 (2001).

(mass shift)

V = - 4 ~ - 7 [MeV]

Recent A=2,3 few-body calculations

V.B. Belyaev et. al, **NPA 780, 100 (2006)**

η_c - d and η_c - 3He (local Yukawa type pot.)

$E_B =$ a few ~ ten [MeV]

Lattice (quenched)

T. Kawanai, S. Sasaki, **PRD 82, 09151 (2010)**

Equal-time BS amplitudes → potential

η_c - N and J/Ψ - N potentials: attraction !

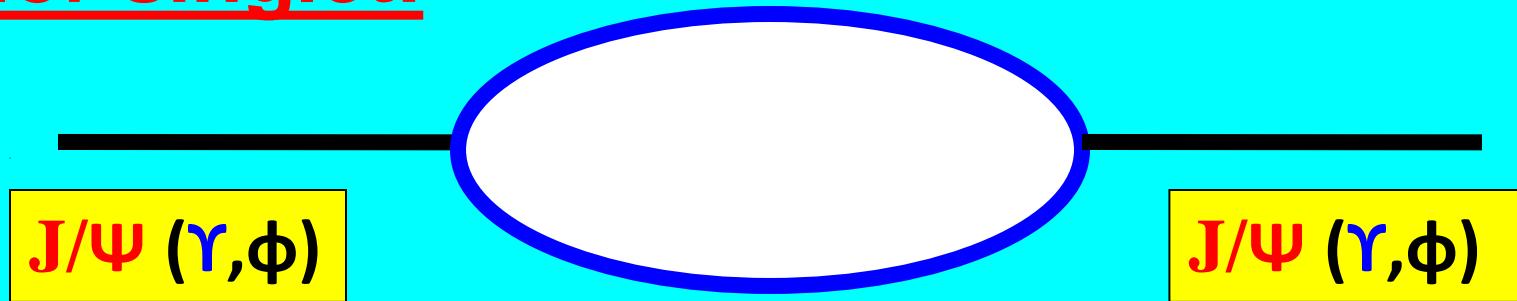
V = - 30 ~ - 40 [MeV] at r ~ 0.2 fm

J/Ψ (Υ,Φ) mass in medium (loop!)

J/Ψ bound in large nuclei ?

D, B, K (also vector mesons in medium!)

Color singlet!



Ȑ, Ȑ, Ȑ (also vector mesons in medium!)

N and D, \bar{D} in medium (QMC)

- (Large) nuclei, and nuclear matter in terms of quarks and gluons
(eventually by QCD) ???!!!
- NN, NNN, NNNN... interactions →
Nucleus ? ← shell model, MF model,...
- Lattice QCD: still extracting NN and NY interactions, [Y=hyperons: Λ, Σ, Ξ]
- Quark model based description of nucleus
- Hadron properties in a nuclear medium

The QMC model

P. Guichon, PLB 200, 235 (1988)

Light (u,d) quarks interact self-consistently with mean σ and ω fields

$$m^*_q = m_q - g_\sigma^q \sigma = m_q - V_\sigma^q$$

↓ nonlinear in σ

$$M^*_N \approx M_N - g_\sigma^N \sigma + \underline{(d/2) (g_\sigma^N \sigma)^2}$$

$$[i \gamma \cdot \partial - (m_q - V_\sigma^q) + \gamma_0 V_\omega^q] q = 0$$

1. Start

$$[i \gamma \cdot \partial - M_N^* + \gamma_0 V_\omega^N] N = 0$$

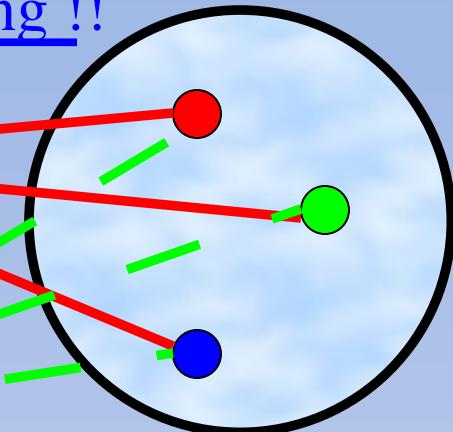
(Applied quark model !)

K. Tsushima

Nuclear Binding !!

$$\langle \sigma \rangle$$

$$\langle \omega \rangle$$



$$M_N^* = M_N - V_\sigma^N$$

$$V_\omega^N = 3 V_\omega^q$$

Self-consistent !

At Nucleon Level Response to the Applied Scalar Field is the **Scalar Polarizability**

Nucleon response to **a chiral invariant scalar field** is then a nucleon property of great interest...

$$\vec{M}^*(R) \approx M - g_\sigma \vec{\sigma}(R) + (d/2) (\vec{g}_\sigma \vec{\sigma}(R))^{**2}$$

Non-linear dependence **scalar polarizability**
0.22 $d^{**1/4}$ R in original QMC (MIT bag)

Indeed, in nuclear matter at mean-field level (e.g. QMC),
this is the **ONLY place the response of the internal
structure of the nucleon enters.**

Nuclear (Neutron) matter, E/A

Novel saturation mechanism !

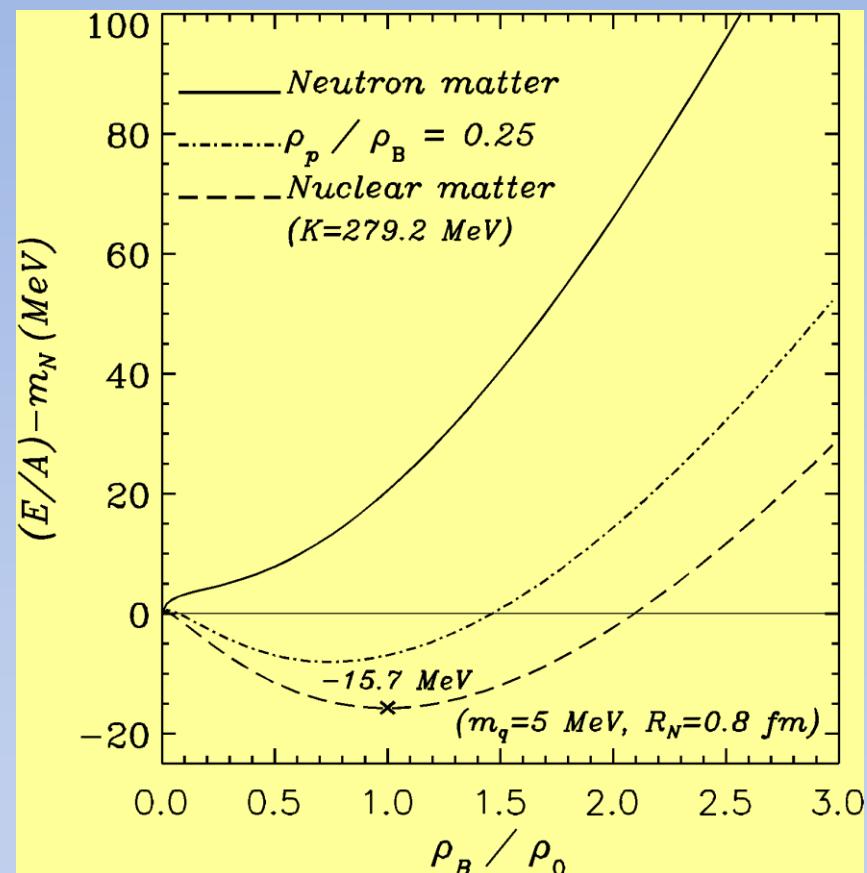
Incompressibility

QHD: $K \approx 500$ MeV

QMC: $K \approx 280$ MeV

(Exp. 200 ~ 300 MeV)

PLB 429, 239 (1998)



Finite nuclei (^{208}Pb energy levels)

NPA 609, 339 (1996)

Large mass nuclei
Nuclear matter

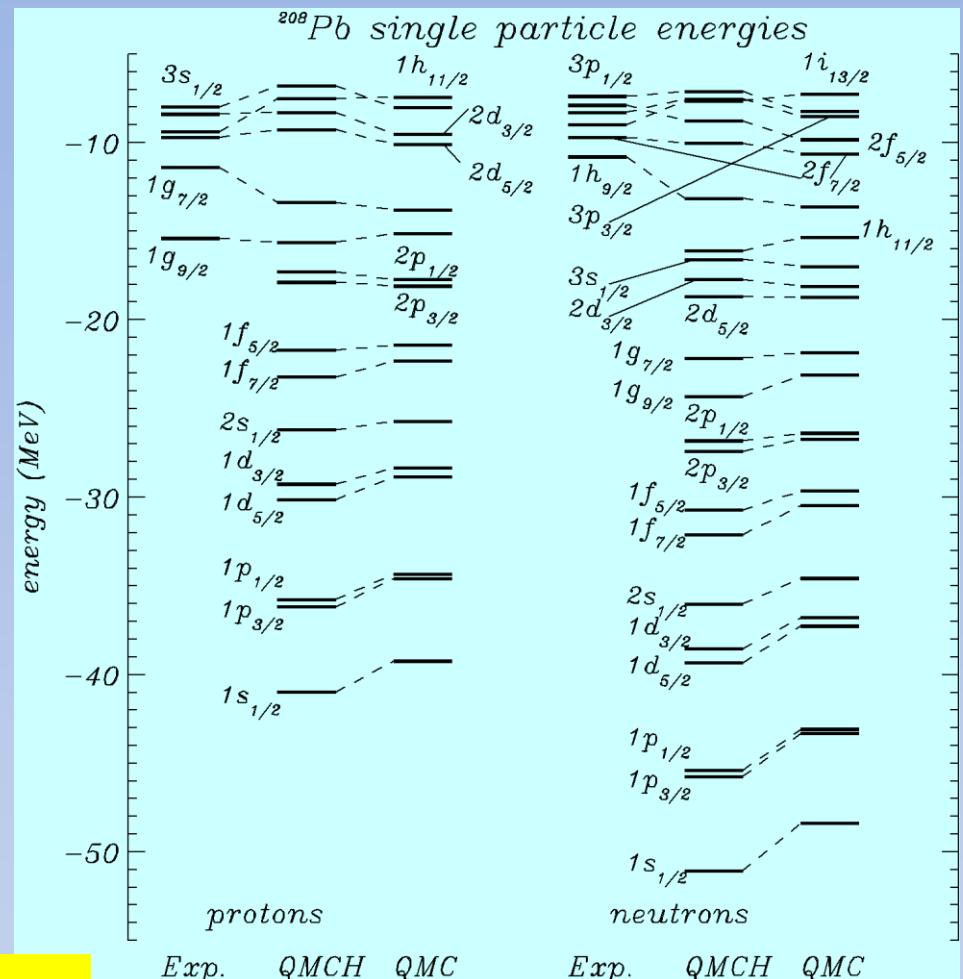
Based on quarks !



Hadrons

Hypernuclei

latest QMC, NPA 814, 66 (2008)



Mesons in nuclear medium in QMC

(For a review, PPNP 58, 1 (2007))

Light (**u,d**) quarks interact self-consistently with mean **σ** and **ω** fields

$$m^*_q = m_q - g_\sigma^\sigma \sigma = m_q - V_\sigma^\sigma$$

↓ nonlinear in **σ**

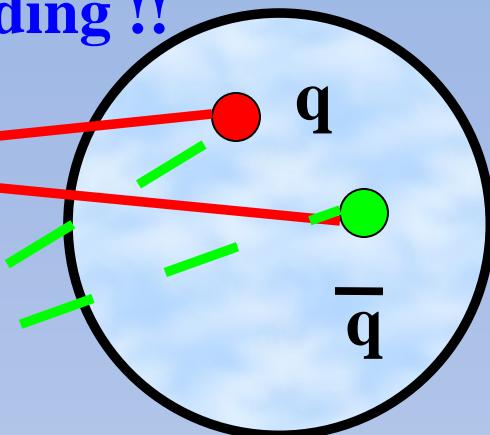
$$M^*_M \approx M_M - g_\sigma^M \sigma + (d^M/2) (g_\sigma^M \sigma)^2$$

$$[i \gamma \cdot \partial - (m_q - V_\sigma^\sigma) + \gamma_0 V_\omega^\sigma] q = 0$$

Nuclear Binding !!

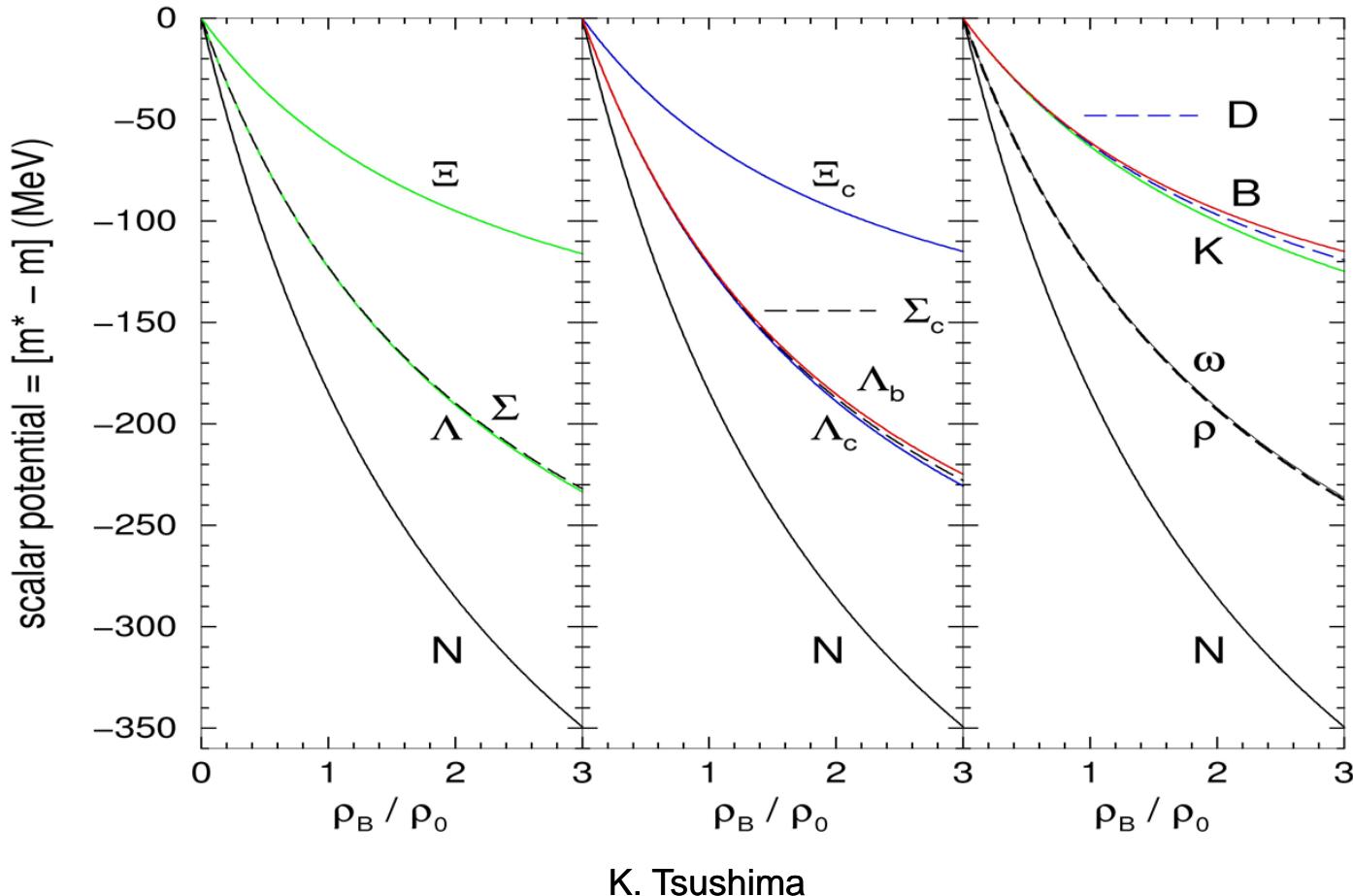
$$\langle \sigma \rangle$$

$$\langle \omega \rangle$$

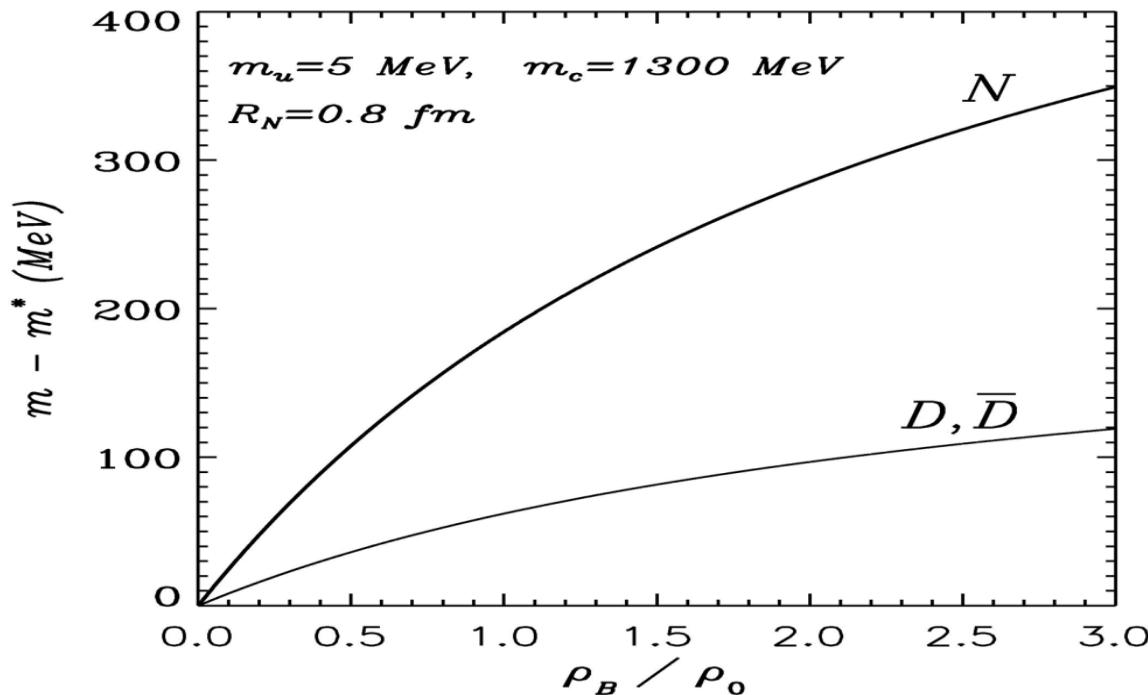


σ, ω fields: no couplings with **s,c,b** quarks!!

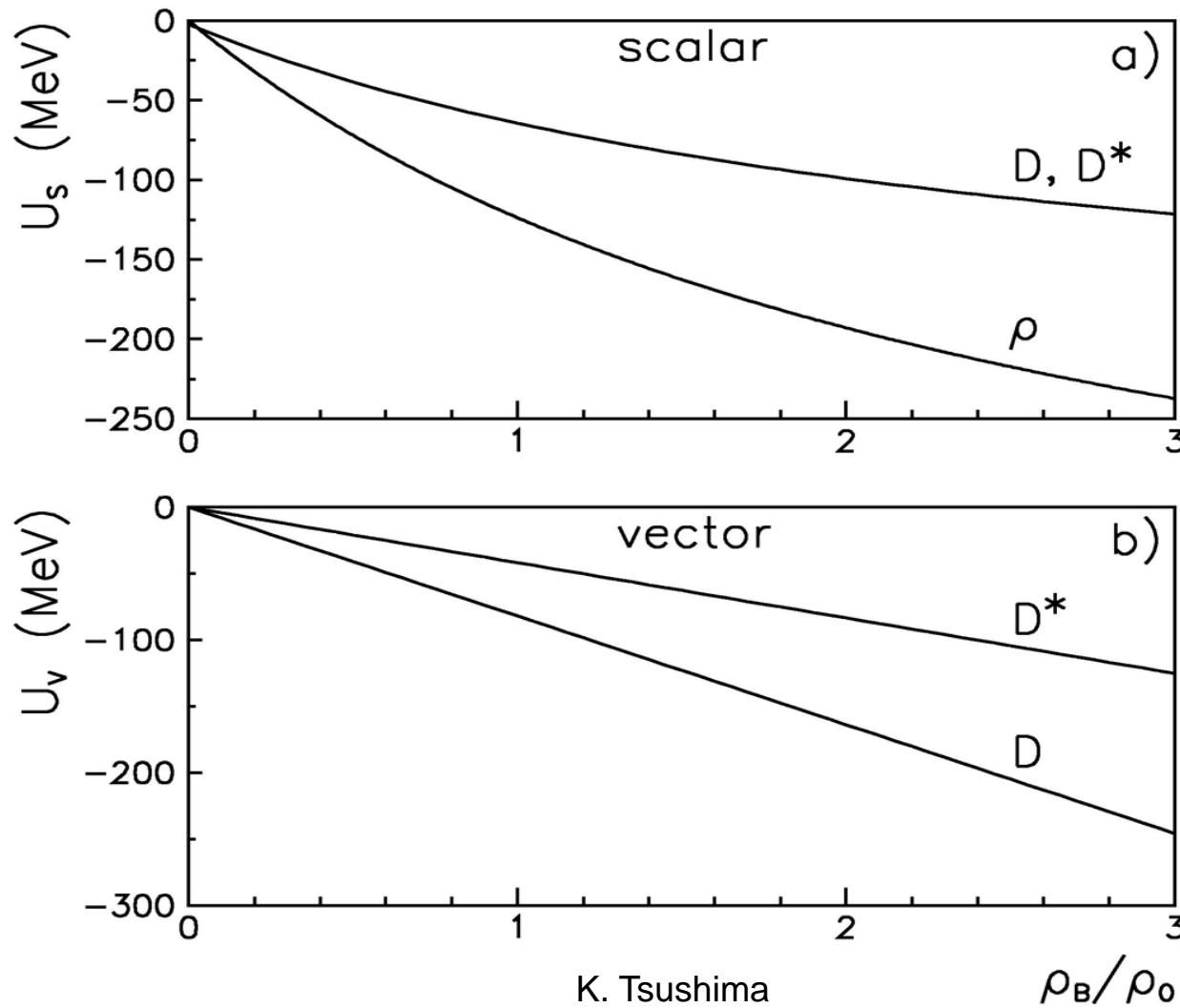
Scalar potentials in QMC respects $SU(3)$ (light quark # !)



D meson scalar potential

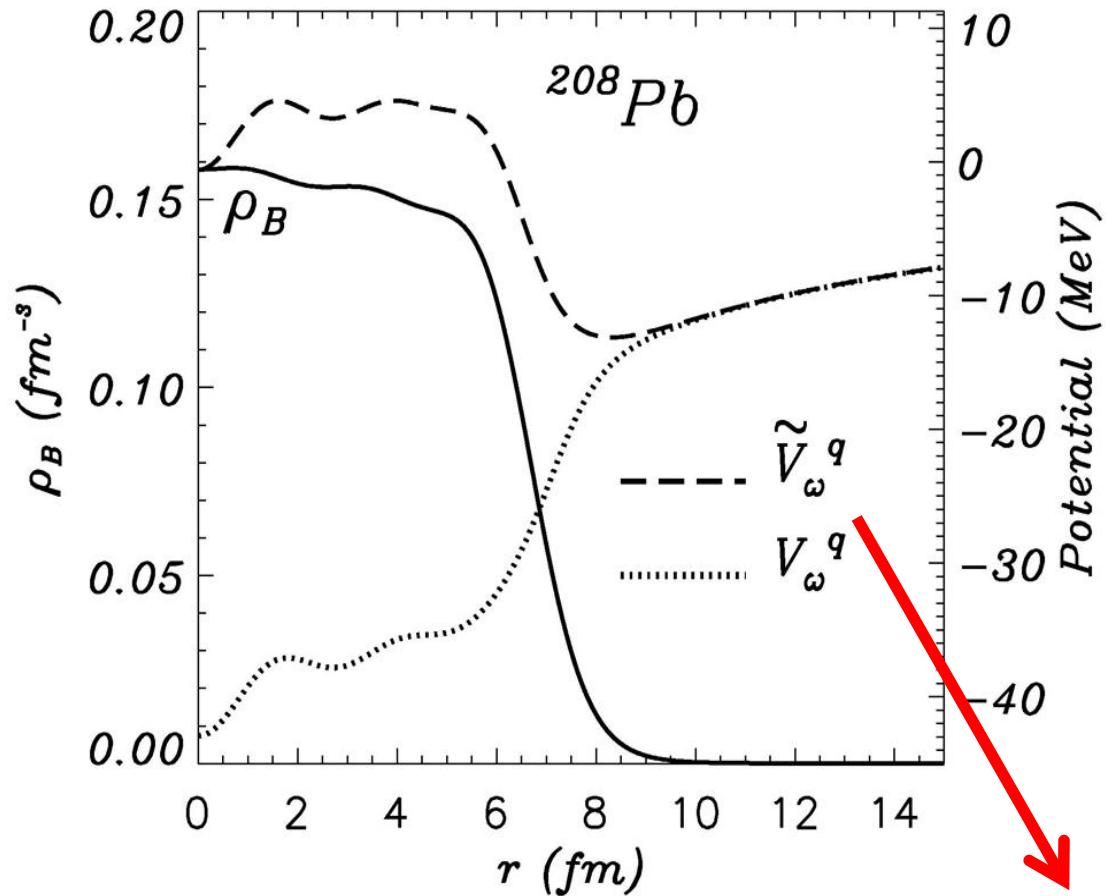


D and D* potentials in nuclear matter



1.96* V_{ω}
 $D^+ = c \bar{d}$
 $D^0 = c \bar{u}$

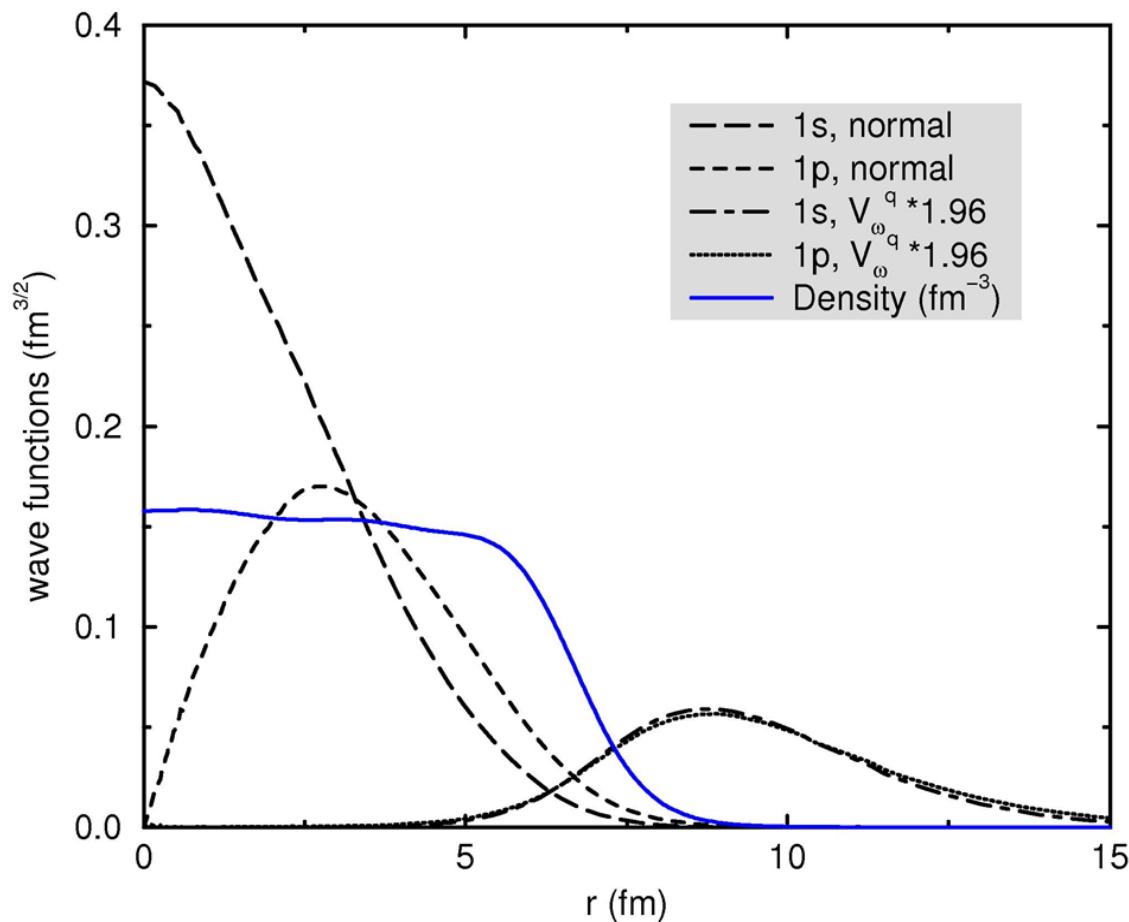
D^- ($\bar{c}d$) total potential in Pb



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$$1.96 * V_\omega^q$$

D^- ($\bar{c}d$) bound state wave functions in Pb

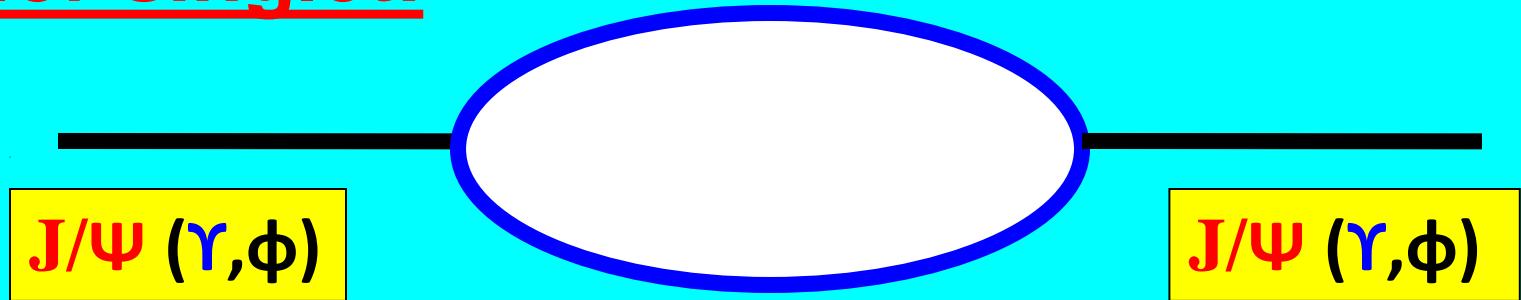


J/Ψ (Υ,Φ) mass in medium (loop!)

J/Ψ bound in large nuclei ?

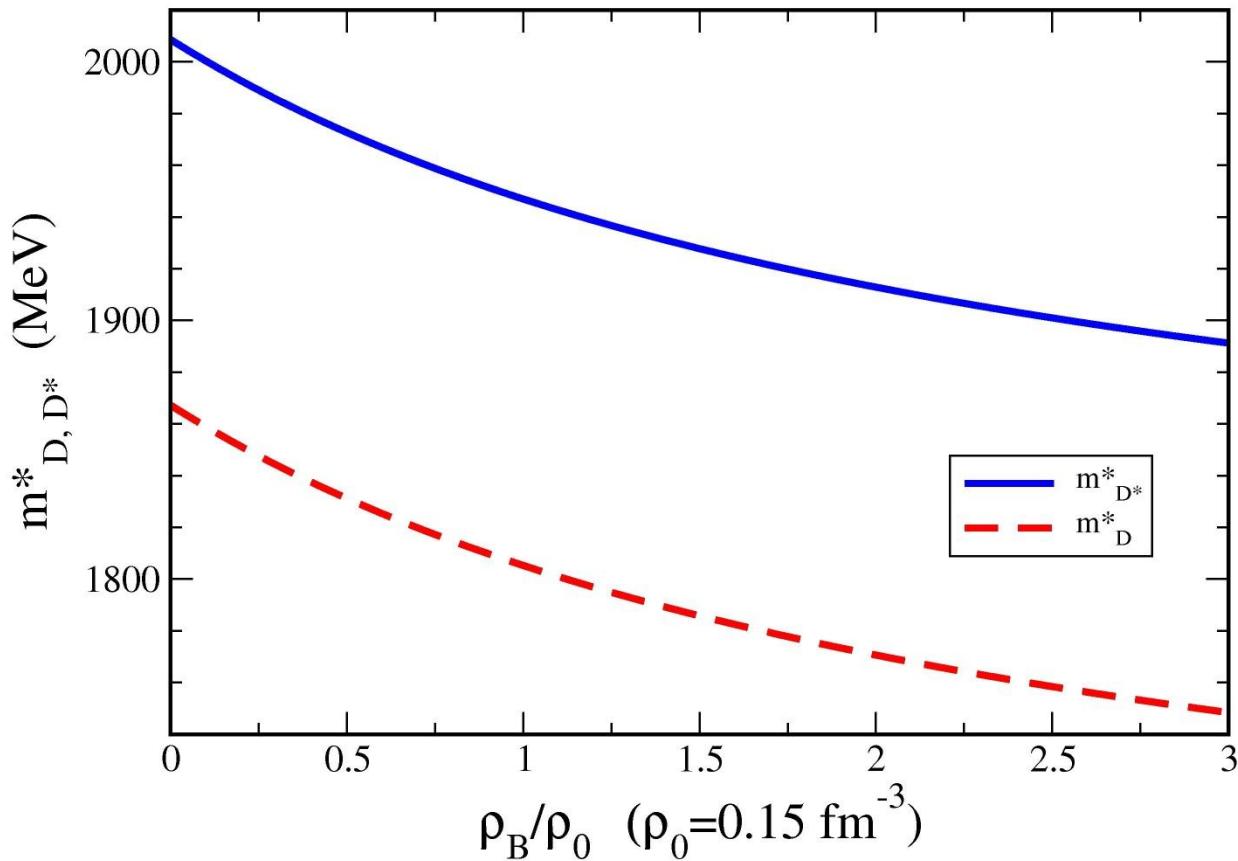
D, B, K (also vector mesons in medium!)

Color singlet!



̄D, ̄B, ̄K (also vector mesons in medium!)

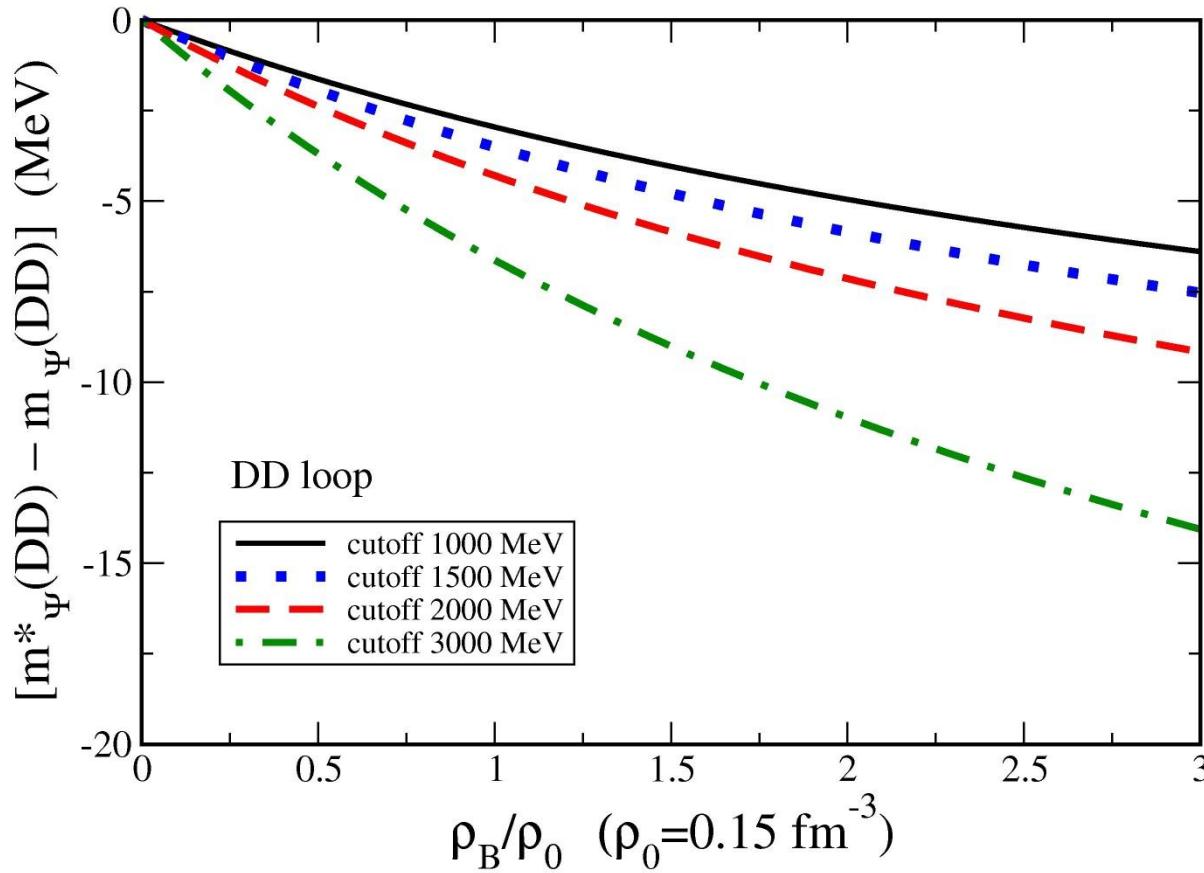
D and D* masses in matter



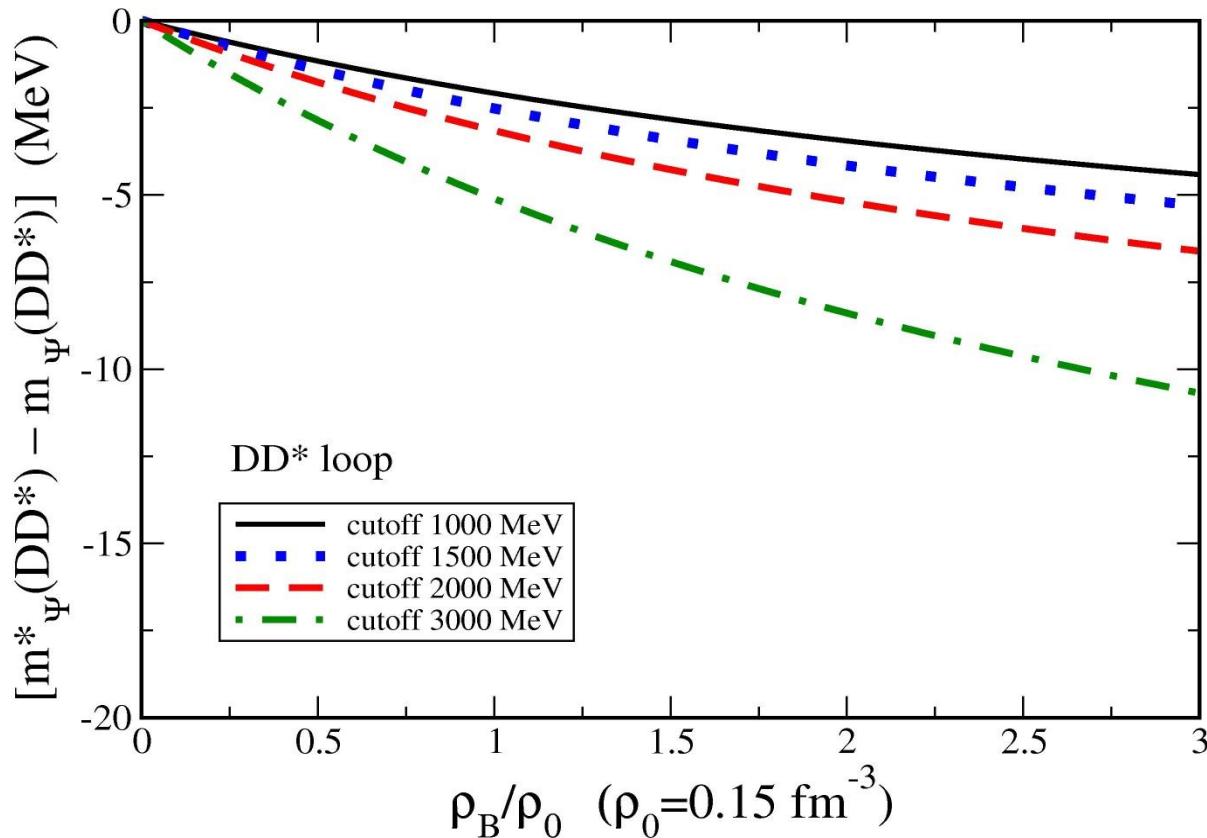
Vertex form factor

$$U_{D,D^*}(\vec{q}^2) = \left[\frac{\Lambda^2_{D,D^*} + m_{J/\Psi}^{*2}}{\Lambda^2_{D,D^*} + 4\omega_{D,D^*}^{*2}(\vec{q}^2)} \right]^2$$

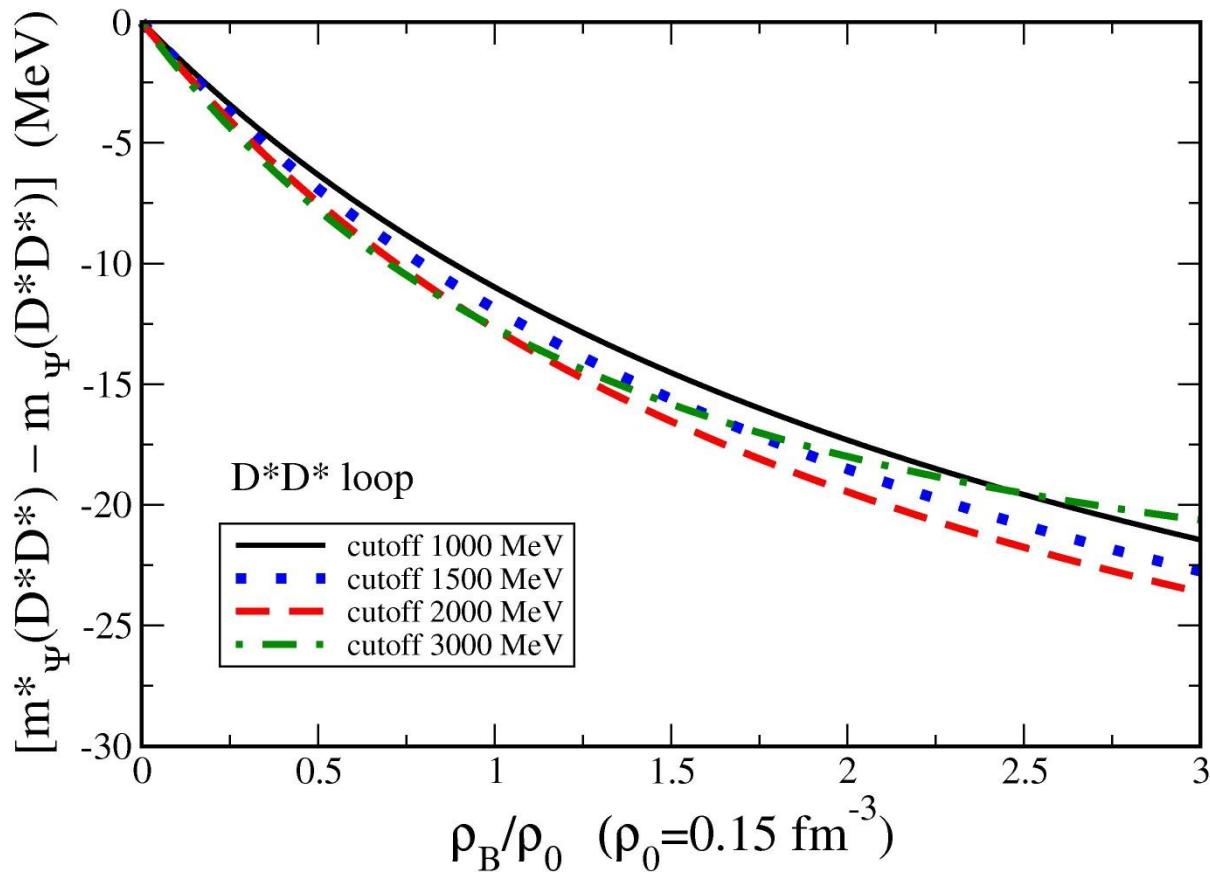
D- \bar{D} loop: J/Ψ potential in matter



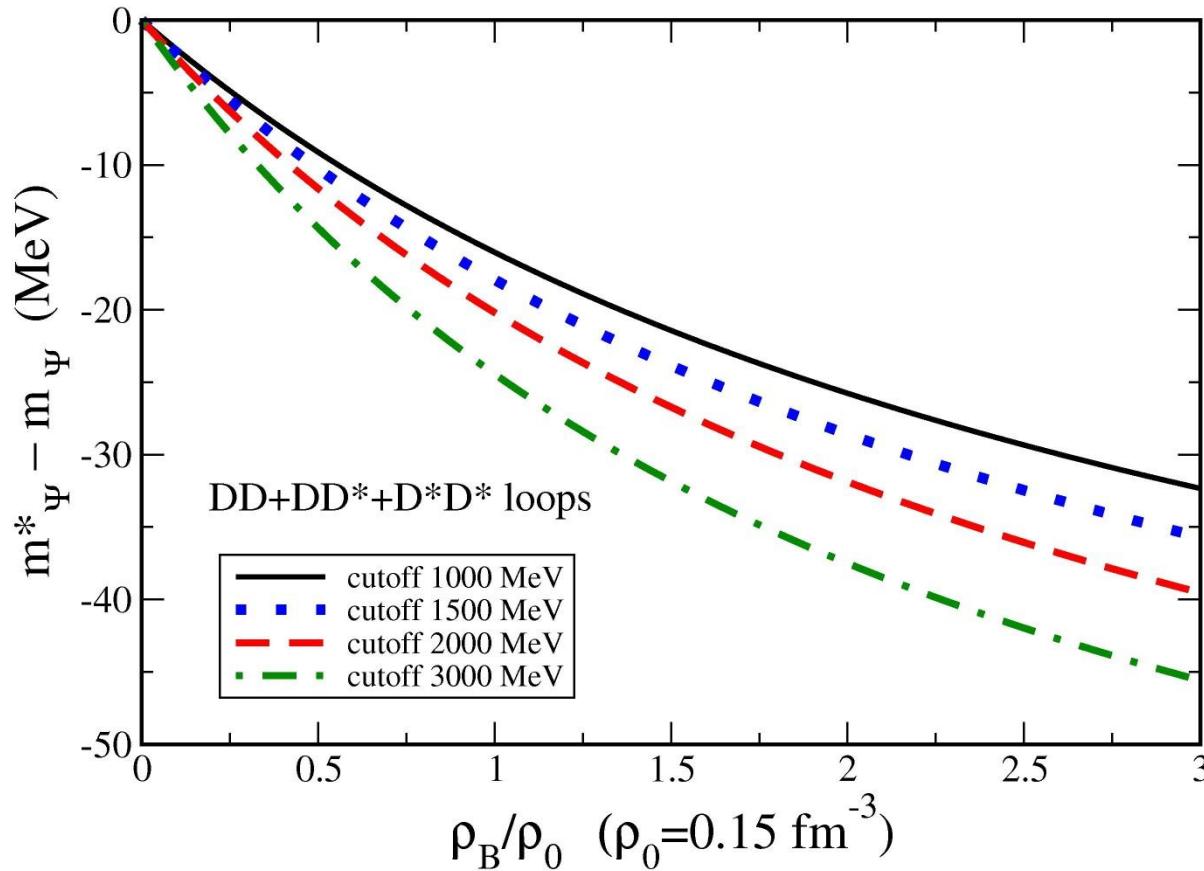
$D\bar{D}^* + D^*\bar{D}$: J/Ψ potential in matter



D^*-D^* loop: J/Ψ potential in matter



Total: J/Ψ potential in matter



At nuclear matter density ρ_0

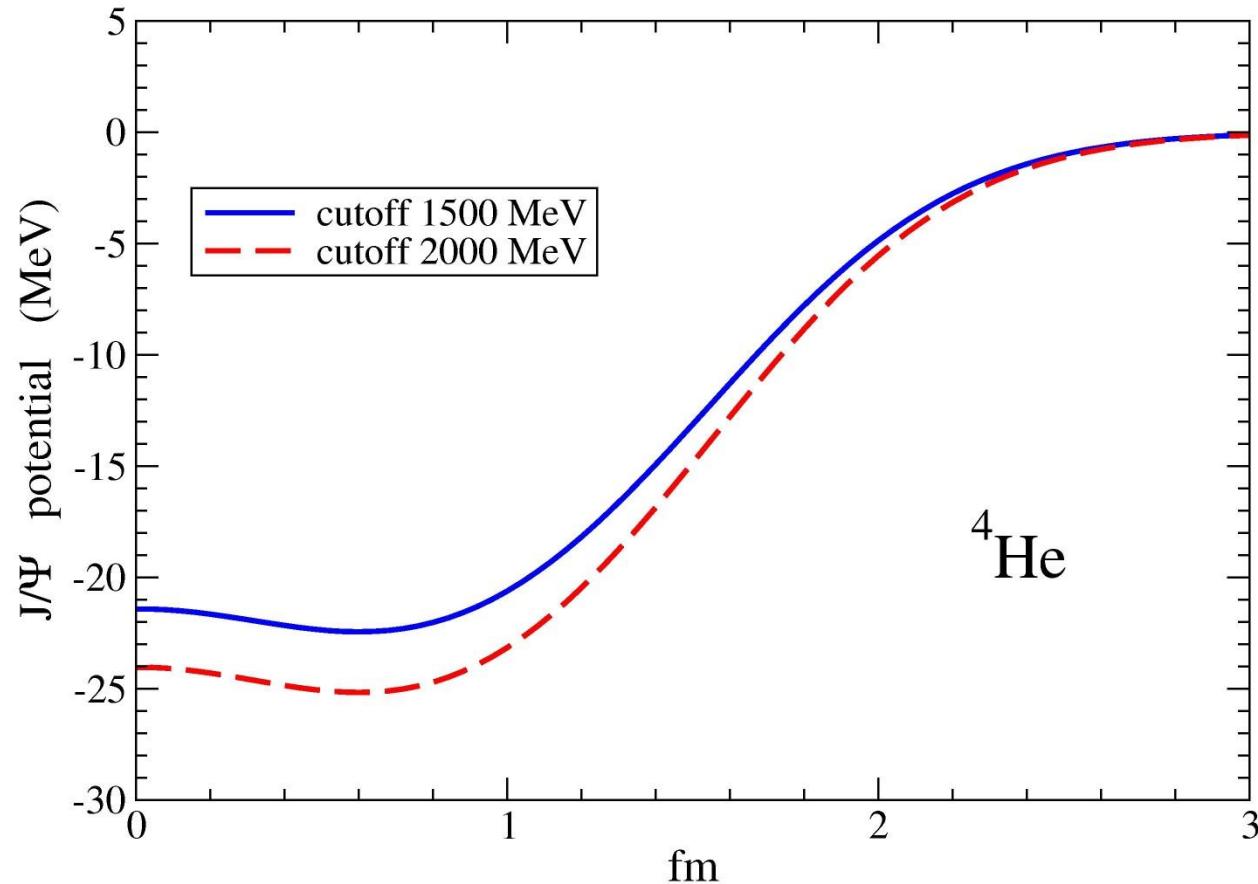
Cut-off	$m^*(J/\Psi)$	DD loop	DD* loop	D*D* loop	$\Delta m(J/\Psi)$
1000	3081	-3	-2	-11	-16
1500	3079	-3.5	-2.5	-12	-18
2000	3077	-4	-3	-13	-20
3000	3072	-6.5	-5	-12.5	-24

- All loops give attraction ! (nongauged J/Ψ) (all in MeV)
- c.f. DD: S.H. Lee, C.M. Ko, PRC 67, 038202 (2003)
- D^*D^* loop insensitive of cut-off
(G. Krein, A. W. Thomas, KT, arXiv:1007.2220)

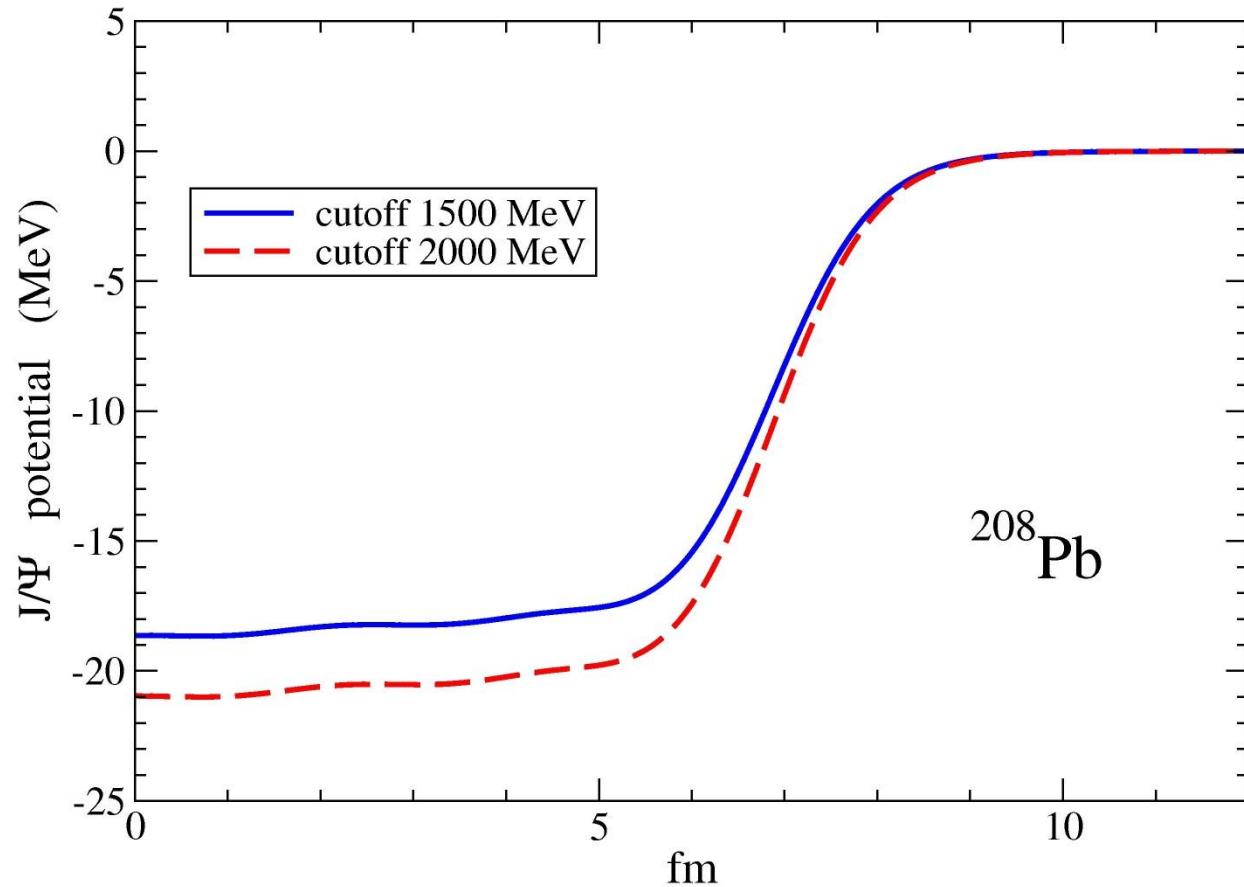
J/ Ψ binding in finite nuclei

Potentials and single-particle
energies (Preliminary !!!)

J/ Ψ potential in ${}^4\text{He}$



J/Ψ potential in ^{208}Pb



J/ Ψ single-particle energies

		$\Lambda = 1500$ MeV	$\Lambda = 2000$ MeV
4He	1s	-8.71 (preliminary !!)	-10.74 (preliminary !!)
^{208}Pb	1s	-16.80	-19.06
	1p	-15.34	-17.57
	1d	-13.62	-15.81
	2s	-13.08	-15.27

Kinematics: J/ Ψ is produced nearly at rest !!

4He : c.m. or reduced mass for K.G. equation !!

Summary, outlook

- **J/Ψ** potential in nuclear matter
 - Color octet, QCD Stark → attraction!
 - Color singlet, DD, DD*, D*D* loops
 - all give attraction! (nongauged J/Ψ)
- **J/Ψ** will be bound in (large mass) nuclei
 - (nearly stopped production of J/Ψ)
- Widths of D and D* ?!
- Φ and Υ in future ?!