D mesons in hot nuclear matter

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Outline

1. Motivation

2. Model: Self-consistent coupled-channel approach for DN scattering
→ Λ_c(2593) and Σ_c(2800) are dynamically generated

3. Open-charm mesons in hot dense matter

4. Conclusions & Outlook

Motivation I (experimental facts)

1. J/Ψ suppression: it has been advocated as signature of QGP due to color screening

T.Matsui and H. Satz, PLB 178 (1986) 416
NA50 Collaboration, M.Gonin et al., NPA 610 (1996) 404c

but there are alternative explanations in terms of conventional hadronic models:

→ "comover" scattering:

$$J/\Psi\ \pi,\rho \rightarrow D\ \bar{D}$$

N. Armesto, A. Capella, PLB430 (1998) 23
B.Zhang, C.M.Ko, B.A.Li, Z.W.Lin, S.Pal, PRC65 (2002) 054909
W. Cassing, E.L. Bratkovskaya, S. Juchem, NPA674 (2000) 249
O. Lynnyk,E.L. Bratkovskaya,W. Cassing, H.Stöcker, NPA786 (2007) 183

→ statistical hadronization model:

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel. PLB571 (2003) 36; NPA789 (2007) 334; nucl-th/0701079

2. Open-charm enhancement: $NN \rightarrow NND^+D^- \quad E_{\rm th} = 2.8\ {\rm GeV}$

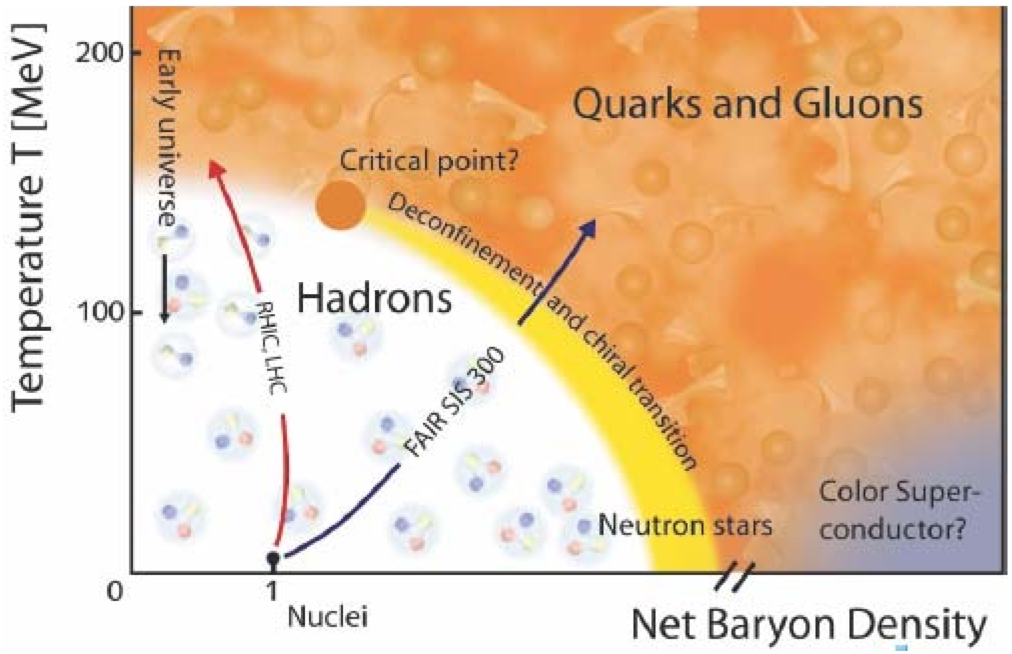
NA50 Collaboration, M.C.Abreu et al., EPJ C14 (2000) 443

it would facilitate J/Ψ suppression but … recent debate because of different interpretation using the improved data of the NA60 collaboration

NA60 Collaboration, E.Scomparin, talk @ QM2005

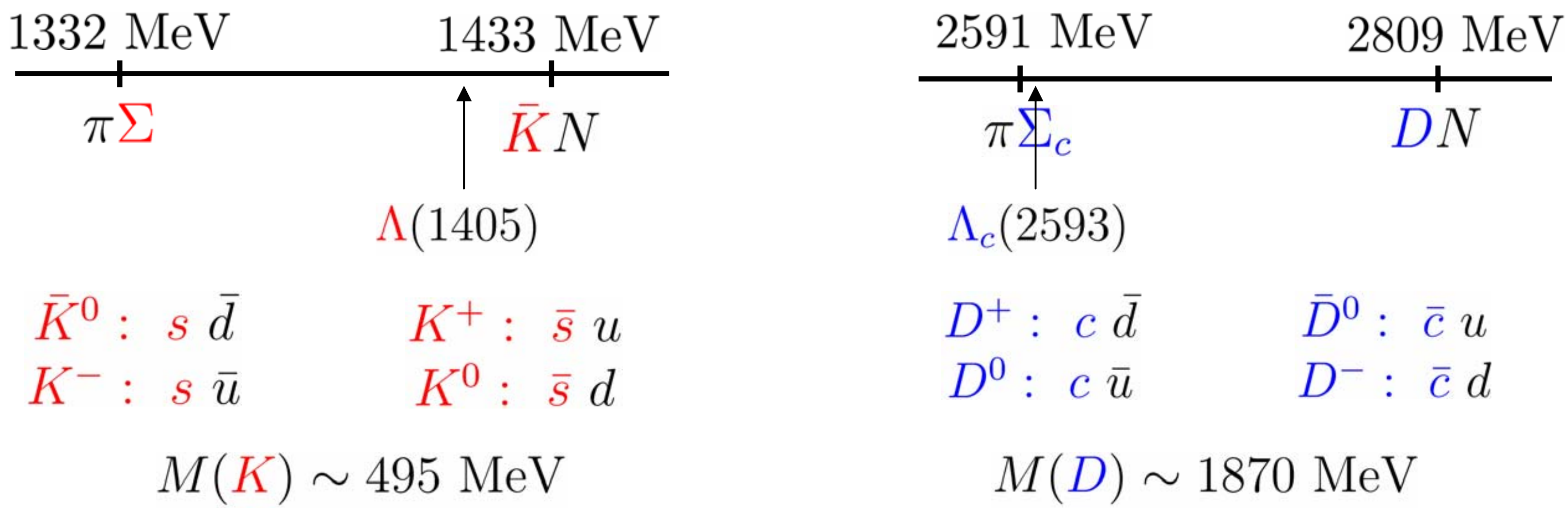
To understand these issues it is imperative to have a realistic picture of the properties of charmonia and open charm mesons in a hot nuclear environment.

This is especially important for the conditions of the CBM@FAIR heavy ion experiment, where both density (ρ~1-2 fm^{-3}) and temperature (T~100 MeV) are relevant parameters.



Motivation II (theoretical issues)

1. DN interaction: similar features as the thoroughly studied KbarN interaction. In the charm sector we also find a subthreshold I=0 resonance, the Λ_c(2593) (udc), that bears a strong resemblance to the Λ(1405) (uds).



May the Λ_c(2593) be generated also dynamically, through a coupled-channel unitarized model?

2. Mean-field models: → predict the D^+,D^- mass shift

QCD sum rule: The in-medium mass shift is propotional to the mass of the charmed quark (m_c) and the light meson q-qbar condensate:

A. Hayashigashi, Phys. Let. B487, 96 (2000)
P. Morath, W. Weise, S.H. Lee, 17 Autumn school on QCD, Lisbon 1999 (World Scientific, SIngapore, 2001) 2001

$$\rightarrow \delta M_D \sim \delta M_{\bar{D}} \sim -50 \text{ MeV}$$

Quark Meson Coupling approach: Hadron interactions mediated by the exchange of scalar-isoscalar (σ) and vector (ρ and ω) medium modified mesons among the light constituent quarks.

$$\delta M_{D+} = U_s + U_v \sim -140 \text{ MeV}$$
$$\delta M_{D-} = U_s - U_v \sim +25 \text{ MeV}$$

A.Sibirtsev, K.Tsushima, and A.W.Thomas, Eur. Phys. J. A6, 351 (1999)

Nuclear Mean Field approach (NMFA): $\sigma-\omega$ model supplemented by chiral terms (of vector and scalar-isoscalar nature)

$$\delta M_{D+} = -250 \text{ to } -70 \text{ MeV}$$
$$\delta M_{D-} = -100 \text{ to } -20 \text{ MeV}$$

A.Mishra, E.L. Brakovskaya, J. Schaffner-Bielich, S. Schramm, and H. Stoecker, PRC 70, 044904 (2004)

3. Spectral function models: → predict the full energy distribution of the D^+ meson strength in a self-consistent coupled channel approach

D self-energy with a SU(3) separable DN interaction with u, d, c content

L. Tolós, J. Schaffner-Bielich, and A. Mishra, Phys. Rev.C 70, 025203 (2004) **(T=0 MeV)**
L. Tolós, J. Schaffner-Bielich, and H. Stöcker, Phys. Lett. B635, 85 (2006) **(finite T)**

D and Dbar self-energy with an improved SU(4) and chiral DN interaction

J.Hofmann and M.F.M.Lutz, Nucl. Phys. A763, 90 (2005)
M.F.M.Lutz, and C.L.Korpa, Phys. Lett. B 633,43 (2006)

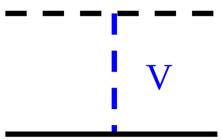
D self-energy using a revised SU(4) and chiral DN interaction, supplemented by an attractive scalar-isoscalar Σ_{DN}

T. Mizutani, A. Ramos, Phys. Rev. C74, 065201 (2006)

HERE: we extend the model to Dbar mesons and implement finite T effects

Model:

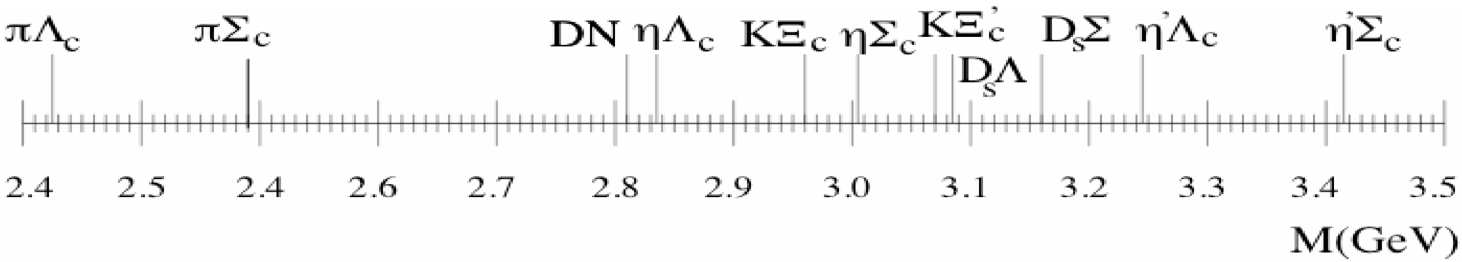
1. Transition potential **V** built from the meson-baryon Lagrangian at lowest order



$$V_{ij} = -\kappa C_{ij} \frac{1}{4f^2}(2\sqrt{s} - M_i - M_j)\left(\frac{M_i + E}{2M_i}\right)^{1/2} \left(\frac{M_j + E'}{2M_j}\right)^{1/2}$$

SU(4) symmetry broken by the use of physical masses.

$$\begin{aligned} \kappa &= 1 \qquad \text{(non-charm exchange)} \quad DN \to DN,\ D_s Y \\ &= \left(\frac{m_\rho}{m_D}\right)^2 \sim 1/4 \quad \text{(charm exchange)} \quad DN \to \pi\Sigma_c,\ K\Xi_c \end{aligned}$$



V is also supplemented by a scalar-isoscalar interaction (Σ_{DN} term)

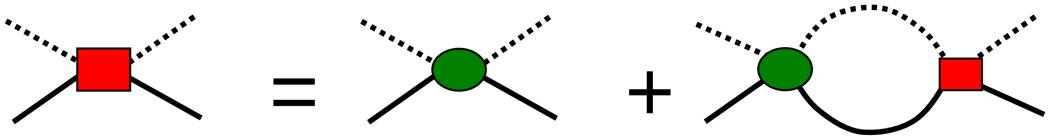
$$\mathcal{L}_\Sigma \equiv \frac{\Sigma_{DN}}{f_D^2} \bar{N} N \bar{D} D \longrightarrow \quad V_\Sigma(\sqrt{s}) = -\frac{\Sigma_{DN}}{f_D^2} \left(\frac{M_N + E}{2 M_N} \right) \sim -0.05 \text{ MeV}^{-1}$$

$$f_D \sim 200 \text{ MeV}$$

$$\Sigma_{DN} \sim 2000 \text{ MeV}$$ (from QCDSR)

2. Unitarization: N/D method

→ equivalent to Bethe-Salpeter coupled-channel equations with on-shell amplitudes



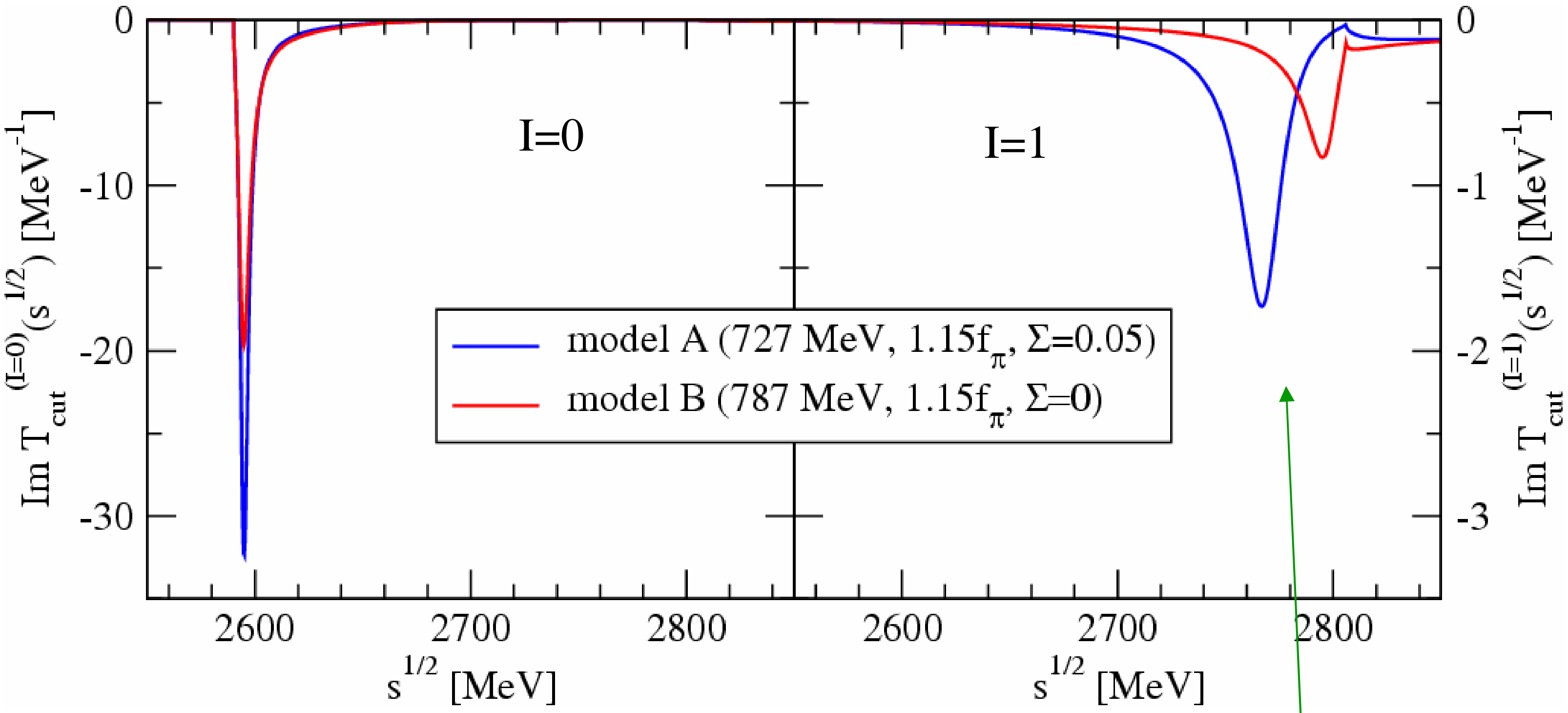
$$T_{ij} = V_{ij} + V_{il} G_l T_{lj}$$

The loop function **G** is regularized with a cut-off Λ [adjusted to reproduce Λ_c(2593)]

Model A: $\Lambda = 727 \text{ MeV}, \; f = 1.15 f_\pi, \; V_\Sigma = -0.05 \text{ MeV}^{-1}$

Model B: $\Lambda = 787 \text{ MeV}, \; f = 1.15 f_\pi, \; V_\Sigma = 0$

Free space DN amplitudes



R. Mizuk et al. [Belle Collaboration]
Phys.Rev.Lett.94, 122002(2005)
Σ_c(2800), Γ~60 MeV

The model generates the I=0 Λ_c(2595) and another resonance in I=1 around the nominal Σ_c(2800)!

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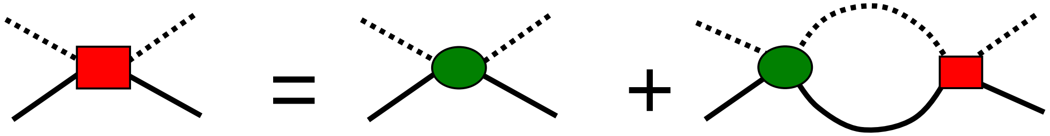
Self-consistent coupled channels procedure

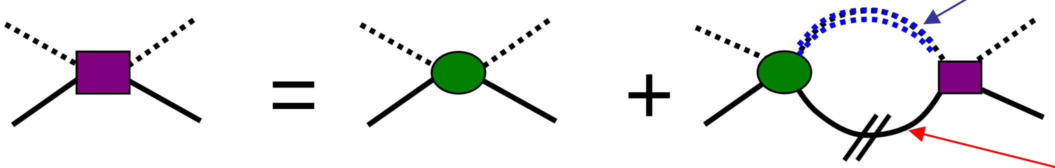
Free space



$$T_{ij} = V_{ij} + V_{il}\, G_l\, T_{lj}$$

meson dressing

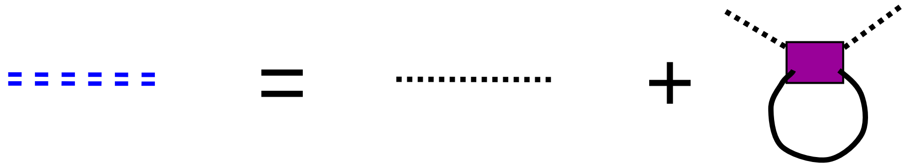
Medium



Pauli blocking
and
baryon dressing

$$T_{ij}(\rho) = V_{ij} + V_{il}\, G_l(\rho)\, T_{lj}(\rho)$$

Dressed D meson:



Loop function (depends on ρ and T)

$$n(k) = \frac{1}{1 + e^{(\varepsilon(k)-\mu)/T}}$$

$$\tilde{G}_{DN}(P_0, \vec{P}, \rho) = \int_{|\vec{q}|<\Lambda} \frac{d^3q}{(2\pi)^3} \frac{M_N}{E_N(\vec{P}-\vec{q})} \times \left[\int_0^\infty d\omega S_D(\omega, \vec{q}) \frac{1 - n(\vec{P}-\vec{q})}{P_0 - \omega - E_N(\vec{P}-\vec{q}) + i\varepsilon} + \int_0^\infty d\omega S_{\bar{D}}(\omega, \vec{q}) \frac{n(\vec{P}-\vec{q})}{P_0 + \omega - E_N(\vec{P}-\vec{q}) - i\varepsilon}\right]$$

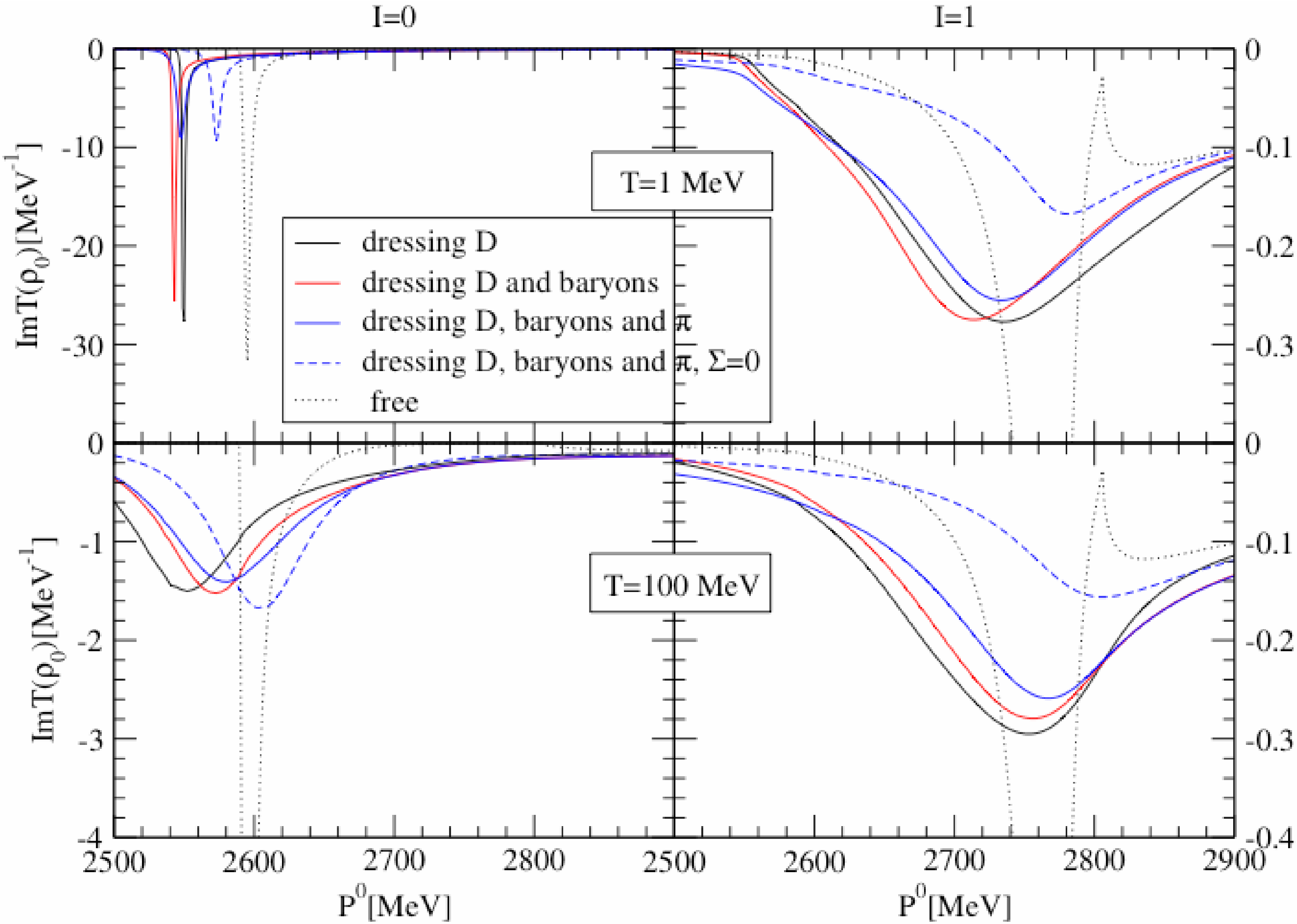
spectral density

$$S_D(q_0, \vec{q}) = -\frac{1}{\pi} \mathrm{Im}\, D_D(q_0, \vec{q}) = -\frac{1}{\pi} \frac{\mathrm{Im}\, \Pi_D(q_0, \vec{q})}{|\, q_0^2 - \vec{q}^{\,2} - m_D^2 - \Pi_D(q_0, \vec{q})\,|^2}$$

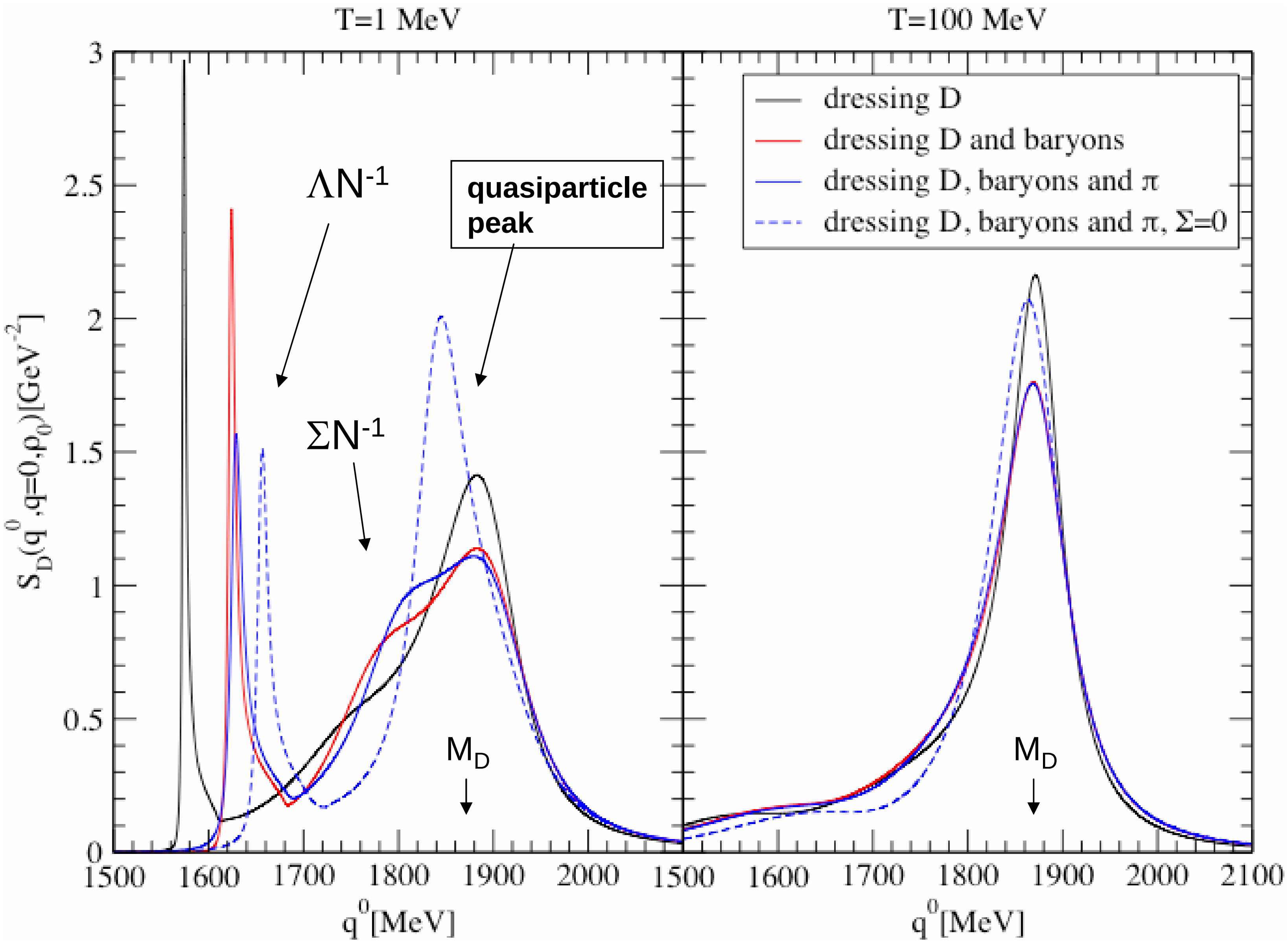
D-meson self-energy

$$\Pi_D(q_0, \vec{q}) = \int \frac{d^3p}{(2\pi)^3} n(\vec{p}) \, [\tilde{T}_{DN}^{(I=0)}(P_0, \vec{P}) + 3\tilde{T}_{DN}^{(I=1)}(P_0, \vec{P})]$$

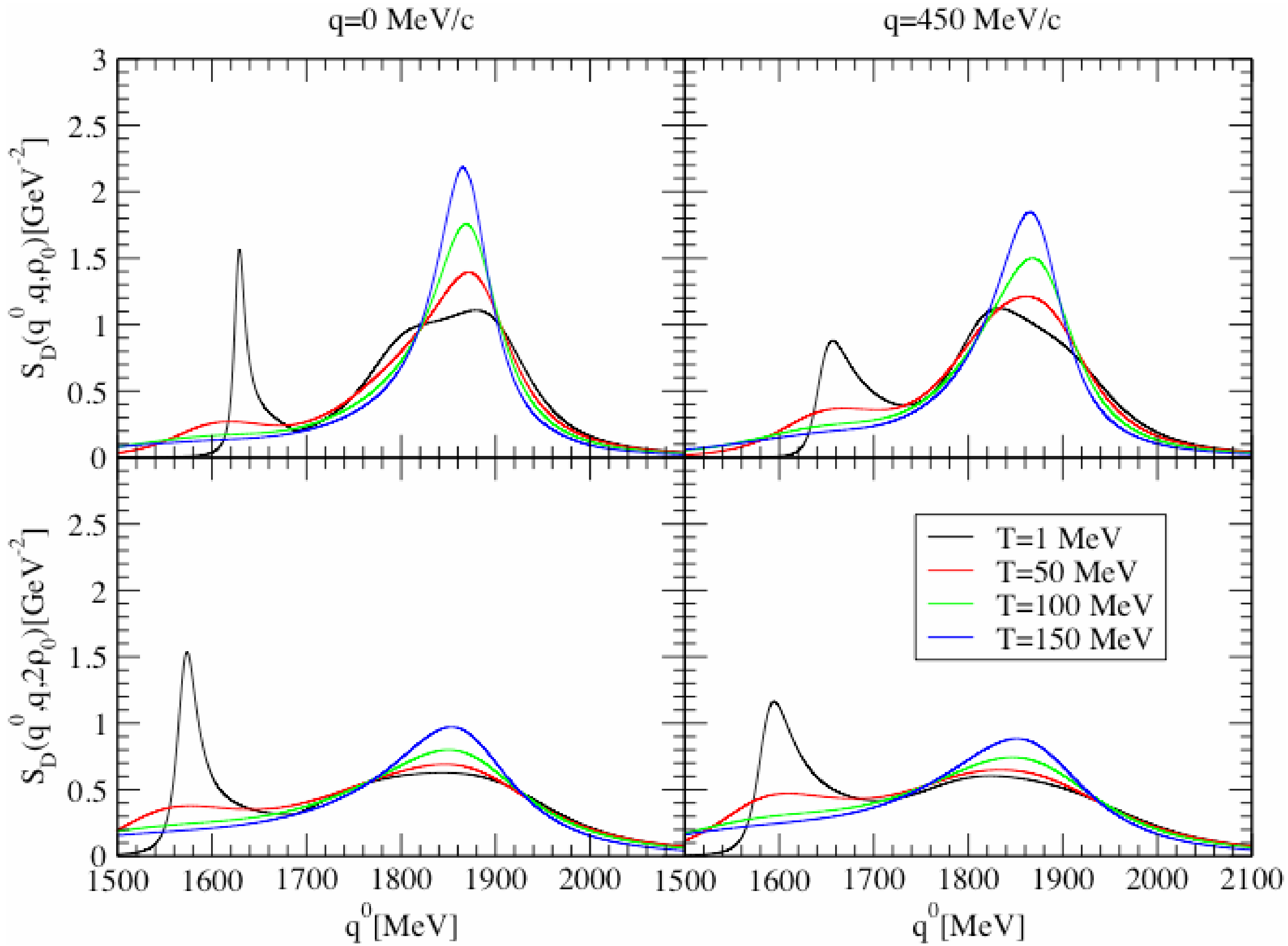
DN amplitudes in hot dense matter ($\rho=\rho_0$)



D meson spectral in hot and dense matter ($\rho=\rho_0$)



Evolution with density and temperature



$\rho=\rho_0$

$\rho=2\rho_0$

Similar trend to previous finite temperature results:

LT, J. Schaffner-Bielich and H. Stoecker PLB 635 (2006) 85

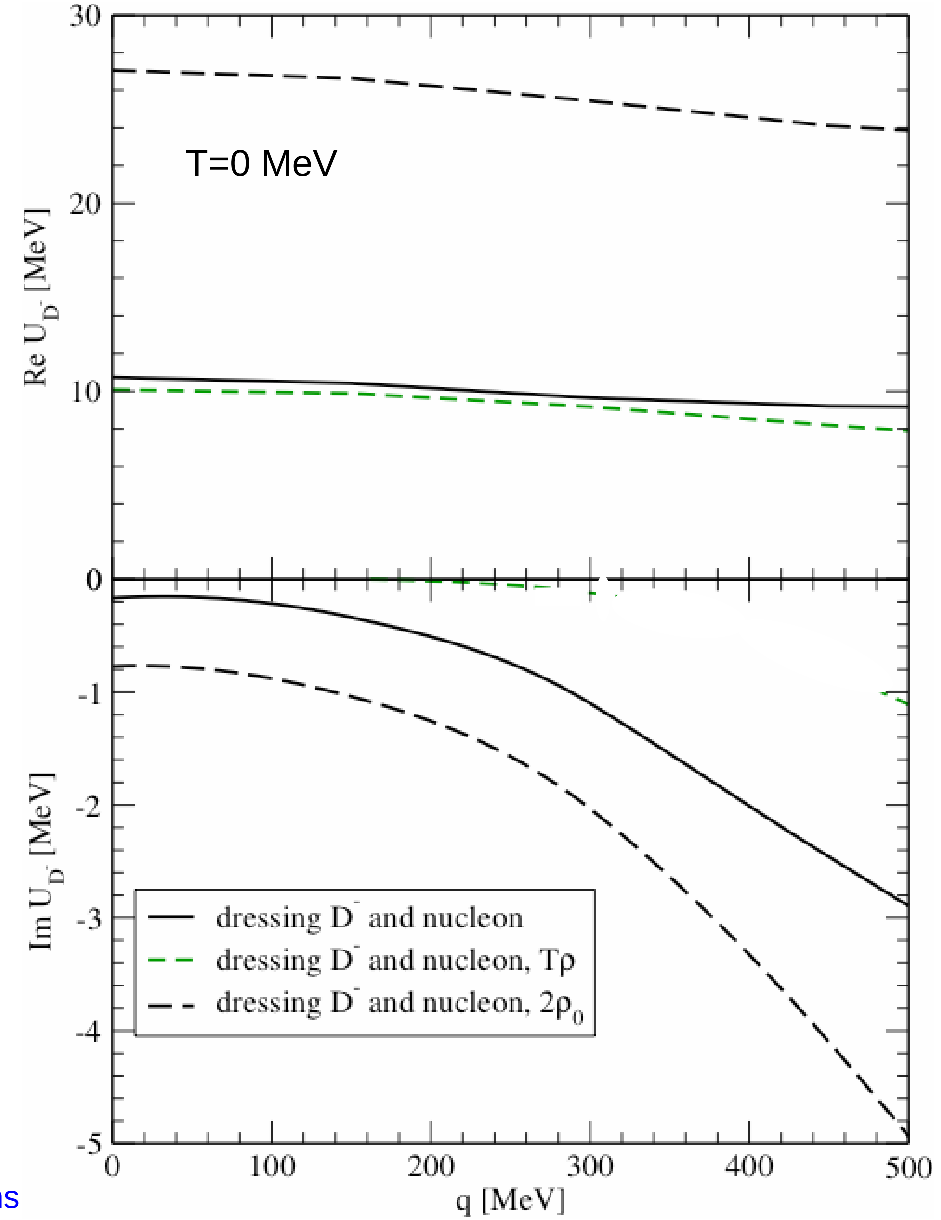
$\bar{D}$N interaction

$$a_{\bar{D}N} = -\frac{1}{4\pi}\frac{M_{\bar{D}N}}{\sqrt{s}} T_{\bar{D}N\to\bar{D}N}$$

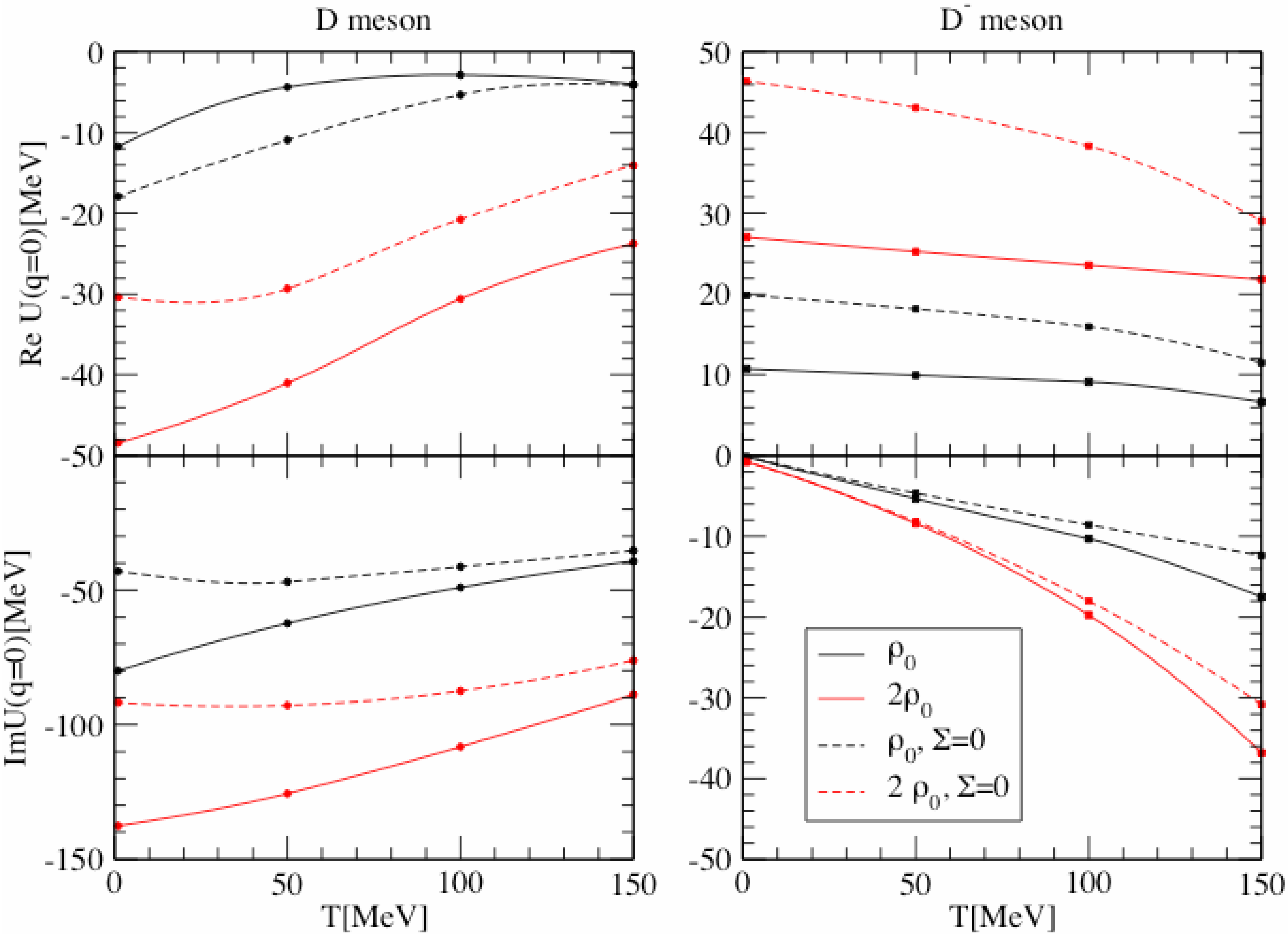
Table 1: $\bar{D}N$ scattering lengths (fm)

	Model A	Model B
$I = 0$	0.607	0
(Born approx.)	0.262	0
$I = 1$	-0.264	-0.289
(Born approx.)	-0.614	-0.876

$\bar{D}$ optical potential



D and $\bar{D}$ meson potentials



Conclusions & Outlook

We have performed a self-consistent coupled-channel calculation of the D and $\bar{D}$ self-energies in symmetric nuclear matter at finite temperature taking, as bare interaction, the SU(4) TW contribution supplemented by a Σ_{DN} term

✓In hot dense matter, Λ_c(2593) and Σ_c(2800) stay close to their free position but develop a remarkable width

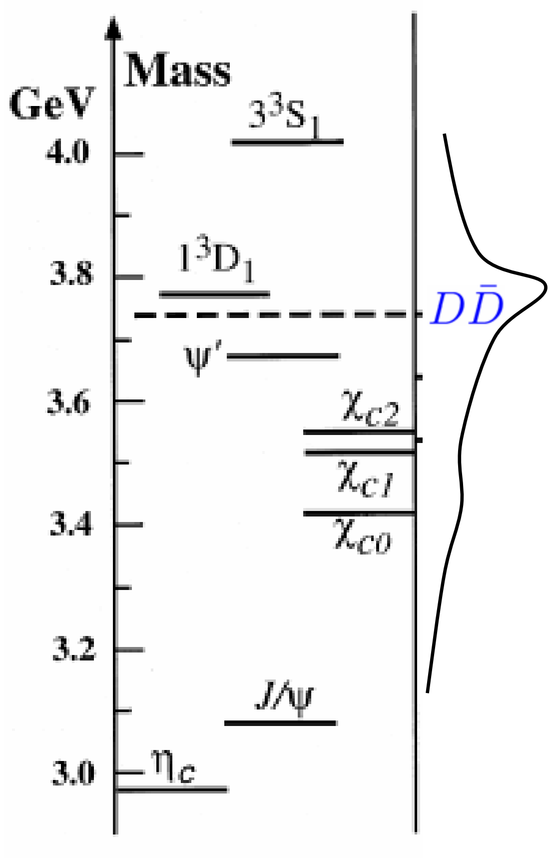
✓The D meson spectral density shows a single pronounced peak at finite temperature that melts with increasing density

✓Up to ρ_0 the low-density theorem is a good approximation for the $\bar{D}$N, where the repulsive I=1 component dominates

✓ Due to the distinct resonant structure of the interaction, temperature induces a stronger change in the properties of the D than the $\bar{D}$ meson

Open questions?

- J/Ψ suppression
- Open-charm enhancement
- D-mesic nuclei



Some answers expected from CBM@FAIR !