$T_{cc}(3875)^+$ AND $T_{\bar{c}\bar{c}}(3875)^-$ IN NUCLEAR MATTER

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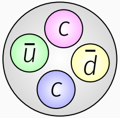
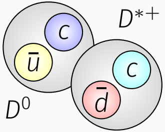
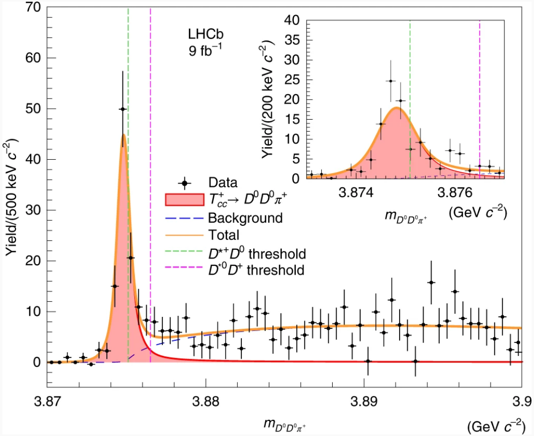
Generalities about $T_{cc}(3875)^+$

- First reported by LHCb in 2021
- Very narrow state, very close to $D^{*+}D^0$ and $D^{*0}D^+$ thresholds
  - $m_{D^{*+}} + m_{D^0} - m_{T_{cc}^+} = 360 \pm 40$ keV
  - $\Gamma_{T_{cc}^+} = 48 \pm 2$ keV
- Most probably an isoscalar state
- Quark content: $cc\bar{u}\bar{d}$. Exotic!
- Internal structure? Ongoing debate



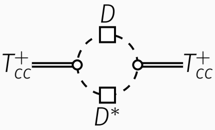




$D^0D^0\pi^+$ spectrum showing the T_{cc}^+ signal from LHCb. [Nat.Phys. 18, 751 ('22)]

$T_{cc}(3875)^+$ IN NUCLEAR MEDIUM: OVERVIEW

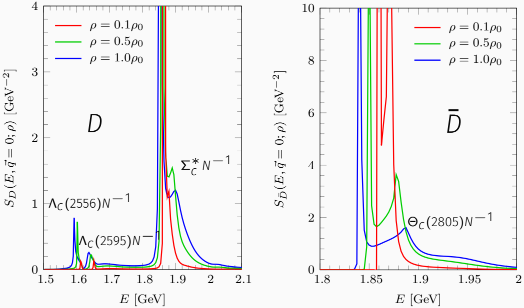
- The nuclear medium changes the properties of $D^{(*)}$ and $\bar{D}^{(*)}$ mesons
- T_{cc}^+ couples to the $D^{*+}D^0$ and $D^{*0}D^+$ channels



- The D^*D meson loop renormalizes the T_{cc}^+ propagator
- The T_{cc}^+ and $T_{\bar{c}\bar{c}}^-$ may behave very differently

L. Tolos, C. Garcia-Recio, J. Nieves, PRC 80, 065202 ('09)
C. Garcia-Recio, J. Nieves, L.L. Salcedo, L. Tolos, PRC 85, 025203 ('12)

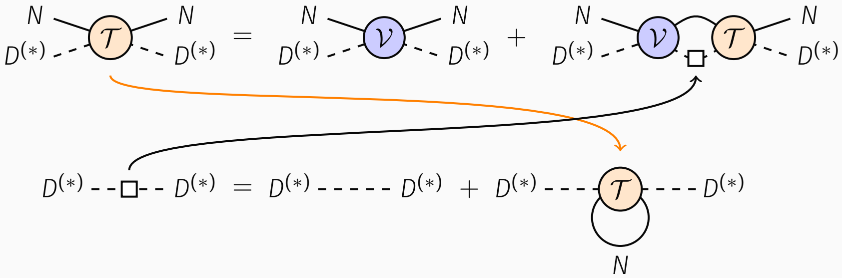
Spectral functions



$$\Delta_D(q\,;\rho) = \int_0^\infty d\omega \left(\frac{S_D(\omega,|\vec{q}\,|)}{q^0 - \omega + i\varepsilon} - \frac{S_{\bar{D}}(\omega,|\vec{q}\,|)}{q^0 + \omega - i\varepsilon} \right)$$

D and D^* mesons in nuclear matter

More details on the DN and D^*N interaction: L. Tolos, C. Garcia-Recio, J. Nieves, PRC 80, 065202 ('09)

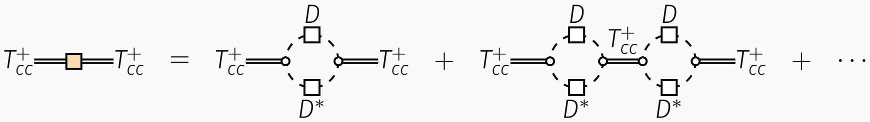


- Self-consistent procedure for computing the D and D^* self-energies
- In the isospin limit, $\Pi_{D^{0(*)}} = \Pi_{D^{+(*)}} \equiv \Pi_{D^{(*)}}$
- However $\Pi_{D^{(*)}} \neq \Pi_{\bar{D}^{(*)}}$
- Note that $\Pi_{D^{(*)}}(q;\, \rho = 0) = 0$

$$\Delta_{D^{(*)}}(q;\, \rho) = \frac{1}{q^2 - m^2_{D^{(*)}} - \Pi_{D^{(*)}}(q;\, \rho)}$$

T_{cc}^+ SELF-ENERGY IN NUCLEAR MATTER

M. Albaladejo, J. Nieves, L. Tolos, PRC 104, 03520 ('21)



- Renormalized T_{cc}^+ propagator in terms of the bare mass ($\hat{m}$) and coupling ($\hat{g}$)

$$\Delta^{-1}_{T_{cc}^+}(p;\,\rho) = p^2 - \hat{m}^2 - \hat{g}^2\Sigma(p;\,\rho) \quad \leftarrow \quad \Sigma(p;\,\rho) = i\int \frac{d^4q}{(2\pi)^4}\underbrace{\Delta_{D^*}(p-q;\,\rho)\Delta_D(q;\,\rho)}_{\Delta_{D^*}\text{ and }\Delta_D\text{ in nuclear medium}}$$

- We introduce a sharp cutoff $\Lambda = 0.7$ GeV in the d^3q integral to regularize $\Sigma(p;\,\rho)$
- The T_{cc}^+ mass for finite density in terms of the vacuum mass (m_0) and coupling (g_0)

$$m^2(\rho) = m_0^2 + \frac{g_0^2}{1+g_0^2\Sigma'(m_0;\,0)}\left\{\Sigma[m(\rho);\,\rho] - \Sigma(m_0;\,0)\right\}$$

- $\Sigma(p;\,\rho)$ develops an imaginary part, and so does $m^2(\rho)$

D^*D SCATTERING IN NUCLEAR MATTER

- We solve the Bethe-Salpeter Equation in the on-shell approximation to obtain the $I = 0$ D^*D $T-$matrix

$$T^{-1}(s;\,\rho) = V^{-1}(s) - \Sigma(s;\,\rho)$$

- We consider two families of potentials

$$\begin{cases} V_A(s) = C_1 + C_2 s \\ V_B(s) = (C_1' + c_2' s)^{-1} \end{cases}$$

- $C_1^{(\prime)}$ and $C_2^{(\prime)}$ constants fixed by imposing

$$\begin{cases} T^{-1}(m_0^2;\,0) = 0 \\ \left.\dfrac{dT^{-1}(s\,;0)}{ds}\right|_{s=m_0^2} = \dfrac{1}{g_0^2} \end{cases}$$

- The loop function contains the medium effects
- Weinberg compositeness condition:

$$P_0 = -g_0^2 \Sigma'(m_0;\,0)$$

S. Weinberg, Phys.Rev. 137, B672 ('65)
D. Gamermann, J. Nieves, E. Oset, E. Ruiz Arriola, PRD 81, 014029 ('10)

- P_0 is interpreted as the D^*D molecular component in the T_{cc}^+ wavefunction
- We use P_0 instead of g_0

Preliminary results: D^*D Loop Function

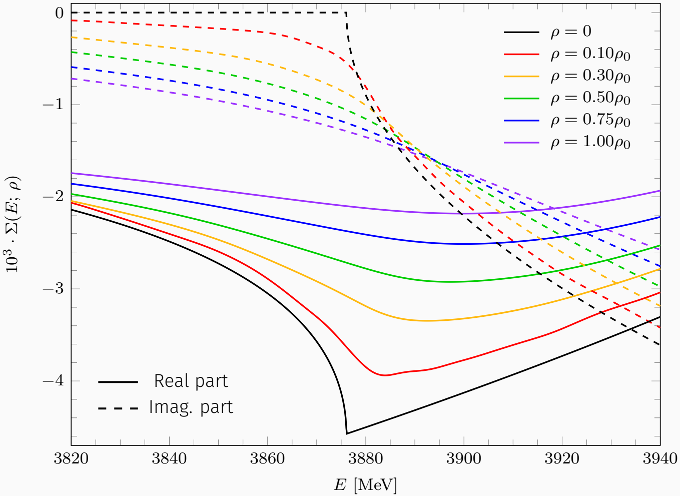


Figure: D^*D loop function for different values of ρ.

Preliminary results: D^*D amplitude

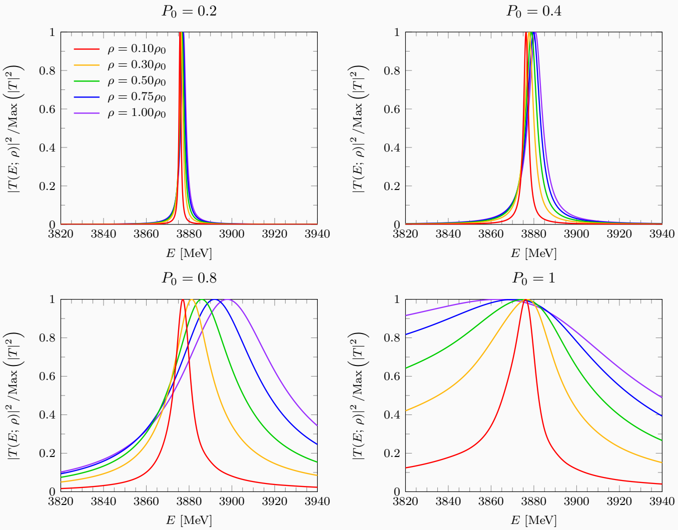


Figure: D^*D scattering T—matrix for different values of P_0 and ρ.

Preliminary results: $T_{\bar{c}\bar{c}}^{-}$ vs T_{cc}^{+}: loop function

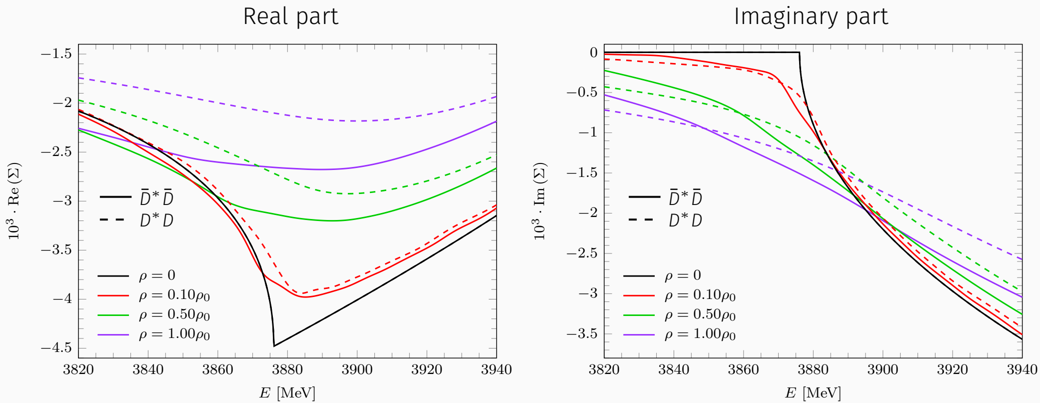


Figure: $\bar{D}^*\bar{D}$ vs D^*D scattering loop functions for different values of ρ.

Preliminary results: $T_{\bar{c}\bar{c}}^{-}$ vs T_{cc}^{+}: amplitudes

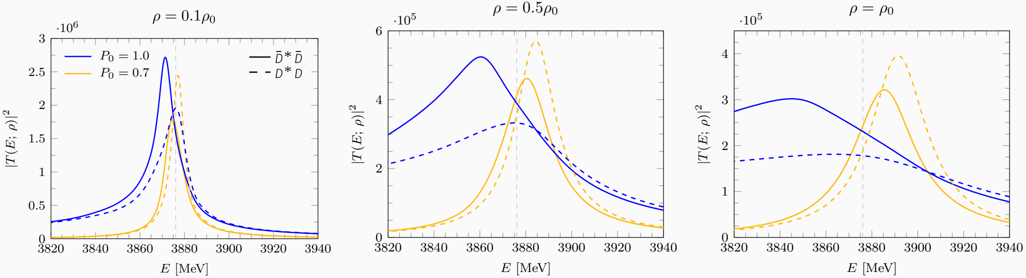


Figure: $\bar{D}^*\bar{D}$ vs D^*D amplitude for different values of P_0 and ρ.

Summary

- Nuclear medium effects greatly modify the $T_{cc}(3875)^+$ properties, and are strongly dependent on the D^*D component
- Nuclear medium effects allow us to tell apart the $T_{\overline{c}\overline{c}}(3875)^-$ from the $T_{cc}(3875)^+$ in the high molecular component scenarios
- Measuring these amplitudes in nuclear matter should help in understanding the $T_{cc}(3875)^+$ and $T_{\overline{c}\overline{c}}(3875)^-$ in vacuum

Backup: Effective Loop functions

- In order to get how the mass gets modified in the medium we take

$$\Sigma(E;\,\rho) \simeq G\left[E;\, m_{D^*}^{(\mathrm{eff})}(\rho),\, m_{D}^{(\mathrm{eff})}(\rho)\right] \equiv G^{(\mathrm{eff})}\left(E;\,\rho\right),$$

where

$$m_{D}^{(\mathrm{eff})}(\rho) = m_D + \Delta m(\rho) - i\frac{\Delta\Gamma(\rho)}{2},$$

$$m_{D^*}^{(\mathrm{eff})}(\rho) = m_{D^*} + \Delta m(\rho) - i\frac{\Delta\Gamma(\rho)}{2}.$$

- We fit the Δm and $\Delta\Gamma$ parameters of the $G^{(\mathrm{eff})}$ loop function to best reproduce the exact Σ function

Backup: T_{cc}^+ mass in the medium

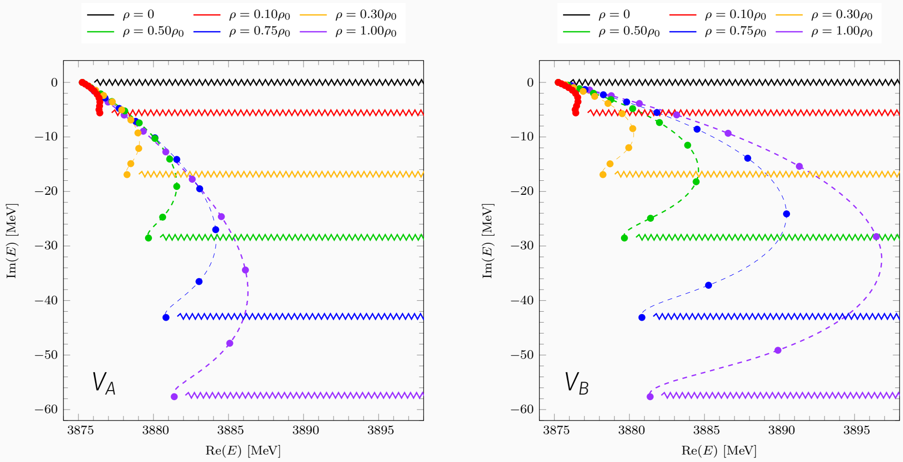


Figure: Mass of the $T_{cc}(3875)^+$ for different values of ρ and P_0.

Backup: $T_{\bar{c}\bar{c}}^{-}$ mass in the medium

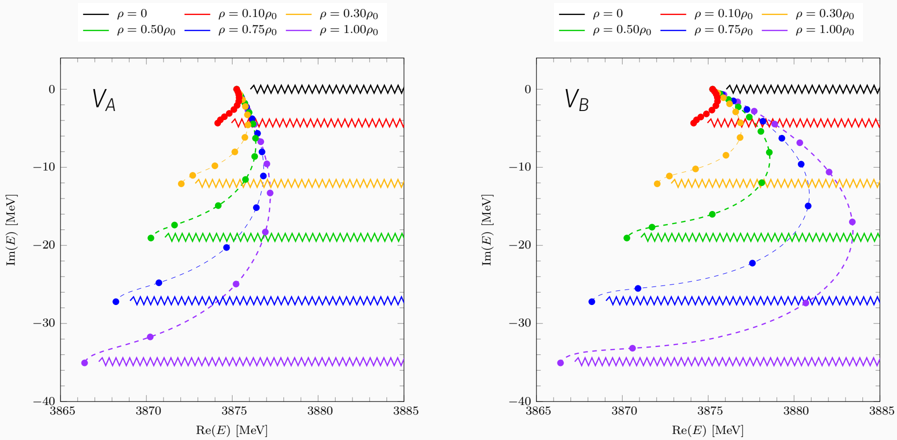


Figure: Mass of the $T_{\bar{c}\bar{c}}(3875)^{-}$ for different values of ρ and P_0.

Backup: T_{cc}^{+} and $T_{\bar{c}\bar{c}}^{-}$ mass and width

D^*D				$\bar{D}^*\bar{D}$			
ρ/ρ_0	Δm [MeV]	$\Delta\Gamma/2$ [MeV]	χ^2	ρ/ρ_0	Δm [MeV]	$\Delta\Gamma/2$ [MeV]	χ^2
0.10	0.58	2.8	1.0	0.10	−0.55	2.2	4.2
0.30	1.48	8.4	2.4	0.30	−1.61	6.0	13.4
0.50	2.19	14.2	3.1	0.50	−2.48	9.5	18.4
0.75	2.77	21.5	4.0	0.75	−3.50	13.5	21.4
1.00	3.03	28.7	5.6	1.00	−4.41	17.4	23.9

Table: Fitted Δm and $\Delta\Gamma$ parameters.