The scalar-isoscalar mode in matter

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It is well established that the mid-range attraction of the NN force is an important part of the nuclear binding and is believed to be mediated to a large extent by correlated two pion-pairs in the scalar-isoscalar channel. This has been implemented in the OBEP potential by the exchange of the fictitious "σ" meson [1]. According to most model calculations, the latter is a broad resonance of about 500 MeV decaying hadronically mostly into two pions [2]. In nuclear medium, where chiral symmetry is partially restored, the σ, as the chiral partner of the pion, is strongly modified. Hence a closer look at the dynamics of the sigma meson in nuclear medium is certainly very much needed.
Starting from the linear σ model in the large-N limit which reproduces the phaseshifts in $\pi\pi$-scattering and preserves the constraints from chiral symmetry, one finds for the σ meson in the vacuum a mass of 600 MeV and several hundred MeV width [3].
In the nuclear medium the σ-meson undergoes a strong mean-field renormalization as well as direct coupling to particle-hole $(p-h)$ excitations. These couplings is examined using the standard σ-ω model where the ω meson provides the repulsion necessary for the stabilization of the system against two-pion condensation. The full sigma meson in this approach is given by [3]:

$$D_\sigma(E,\vec{p}) = \Big[E^2 - \vec{p}^2 - \epsilon_\sigma^2 - g_{\sigma N}\frac{I_N}{\langle\sigma\rangle} - \frac{2\lambda^2\langle\sigma\rangle^2\Sigma_{\pi\pi}(E,\vec{p})}{1-\lambda^2\Sigma_{\pi\pi}(E,\vec{p})} - \frac{g_{\sigma N}^2\Pi_0(E,\vec{p})}{1+g_{\omega N}^2 D_\omega(E,\vec{p}\Pi_0(E,\vec{p})}\Big]^{-1} \quad (1)$$

The propagator is shown for two sets of g_ω and g_σ taken from [5]

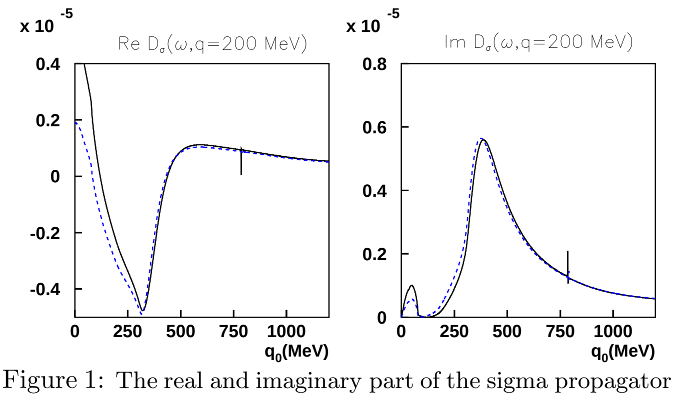

Figure 1: The real and imaginary part of the sigma propagator for finite momentum at nuclear matter density. Two sets for the parameters are shown.

In order to fix the unknown parameters further, we have looked at the scalar longitudinal response of nuclear matter. It can be calculated following a semiclassical approach and making use of local density approximation and RPA [4]. Instead of using a phenomenological potential for the isoscalar part we take for the potential

$$V_{ph}^{\tau=0} = (g_\sigma^2 D_\sigma^0(\omega,\vec{q}) - g_\omega^2 D_\omega^0(\omega,\vec{q}) - g_{NN}^2 F(q^2)), \quad (2)$$

where we have added a further source of repulsion to the potential in the form of the four-point interaction with the coupling strength g_{NN}. The σ propagator entering here is the one without the coupling to the particle-hole excitations. Their effect is already taken into account in S_L.
The coupling parameter g_{NN} is fixed by the condition that the scalar Potential is repulsive at nuclear matter saturation density. Indeed, it can be seen that one needs the additional repulsion coming from the four-point interaction in order to describe the data as shown below.

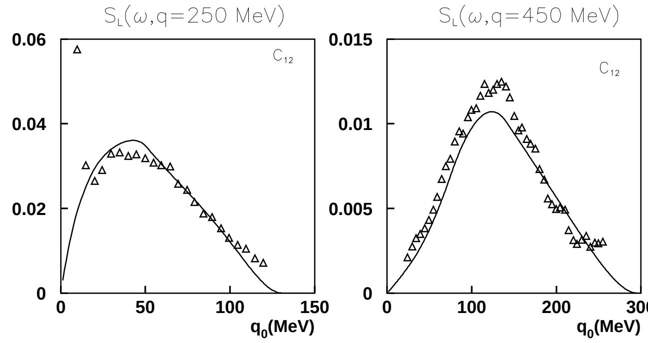

Figure 2: The scalar longitudinal response for different nuclei and momenta.

At low energy as well as low momenta the experiment shows a peak in the response which can not be explained with our parameter set. Further investigations showed a more attractive potential at the surface could explain this peak [6]. This can be accomplished by decreasing the repulsion coming from the four-nucleon term. On the other hand, this peak might be a sign of collective modes in finite nuclei which are not included in our local-density treatment such that the absence of this peak can be understood.
Unfortunately, the addition of another source of repulsion to the sigma propagator results in a very strong particle-hole peak appearing in the sigma propagator. The task which remains to be done is to find a set of the coupling parameters g_σ,g_ω and g_{NN} which fits the experimental data of the scalar longitudinal response and at the same time preserves the properties of the sigma meson as shown in [3].

References

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