Migdal's short range correlations in a covariant model

M.F.M. Lutz[1,2]
[1]GSI, [2]TU-Darmstadt

A faithful evaluation of the pion self energy in nuclear matter requires a relativistic treatment at least in the vicinity of $\omega \sim |\vec{q}|$ [1]. The purpose of this work is to demonstrate that previous works [1, 2] did not completely succeed in constructing a covariant model for Migdal's short range correlations [3]. The necessary modifications to Dmitriev's model [1] lead to significant effects in the pion self energy for $\omega \sim |\vec{q}|$ missed so far [4].

Following Dmitriev's original work [1] we consider the interaction of pions with nucleons and isobars in terms of the leading order vertices

$$\mathcal{L} = i\,\frac{f_N}{m_\pi}\,\bar{\psi}\,\gamma_5\,\gamma^\mu\,\vec{\tau}\,\partial_\mu\vec{\phi}_\pi\,\psi + \frac{f_\Delta}{m_\pi}\left(\bar{\psi}^\mu\,\vec{T}\,\psi\,\partial_\mu\vec{\phi}_\pi + \text{h.c}\right), \quad (1)$$

as predicted by the chiral Lagrangian. A covariant from of the short range correlations was introduced explicitly by Nakano et al. [2]

$$\begin{aligned}\mathcal{L}_{\text{Migdal}} &= g'_{11}\,\frac{f_N^2}{m_\pi^2}\left(\bar{\psi}\,\gamma_5\,\gamma_\mu\,\vec{\tau}\,\psi\right)\left(\bar{\psi}\,\gamma_5\,\gamma^\mu\,\vec{\tau}\,\psi\right)\\ &+ g'_{12}\,\frac{f_N\,f_\Delta}{m_\pi^2}\left(\bar{\psi}\,\gamma_5\,\gamma_\mu\,\vec{\tau}\,\psi\right)\left(\left(\bar{\psi}^\mu\,\vec{T}\,\psi\right) + \text{h.c.}\right)\\ &+ g'_{22}\,\frac{f_\Delta^2}{m_\pi^2}\Bigg(\left(\bar{\psi}_\mu\,\vec{T}\,\psi\right)\left(\bar{\psi}\,\vec{T}\,\psi^\mu\right)\\ &\qquad + \left(\left(\bar{\psi}_\mu\,\vec{T}\,\psi\right)\left(\bar{\psi}^\mu\,\vec{T}\,\psi\right) + \text{h.c.}\right)\Bigg), \quad (2)\end{aligned}$$

where it is understood that the local vertices are to be used at the Hartree level. The Fock contribution can be cast into the form of a Hartee contribution by a simple Fierz transformation. Therefore it only renormalizes the coupling strength in (2) and can be omitted here. The terms proportional to $\bar{\psi}_\mu\,\bar{\psi}^\mu$ and $\psi_\mu\,\psi^\mu$ of (2) were missed in [2]. They are required to recover the proper non relativistic limit of the short range correlations as introduced by Migdal [3].

In previous works [1, 2] the short range correlation effects were introduced in a form which were correct if the generic nucleon-hole loop and isobar-hole loop, had contributions proportional to $g_{\mu\nu}$ and $q_\mu\,q_\nu$ only. However, the most general decomposition of the loop functions involves additional structures proportional to $u_\mu\,q_\nu$ and $q_\mu\,u_\nu$ where u_μ specifies the nuclear matter frame. This leads to an additional 2×2 matrix structure of the nucleon-hole and also the isobar-hole loop function. We write $\Pi_{ij}^{(Nh)}$ and $\Pi_{ij}^{(\Delta h)}$ with $i,j = 1,2$. The self energy can be cast into the form of a sum of 11, 33 and 13, 31 components of an appropriate 4×4 matrix that incorporates the additional 2×2 matrix structure

$$\begin{aligned}\frac{\Pi}{q^2} &= -\Big[\Big(1 - J\,G\Big)^{-1} J\Big]_{11} - \Big[\Big(1 - J\,G\Big)^{-1} J\Big]_{33}\\ &- \Big[\Big(1 - J\,G\Big)^{-1} J\Big]_{13} - \Big[\Big(1 - J\,G\Big)^{-1} J\Big]_{31}. \quad (3)\end{aligned}$$

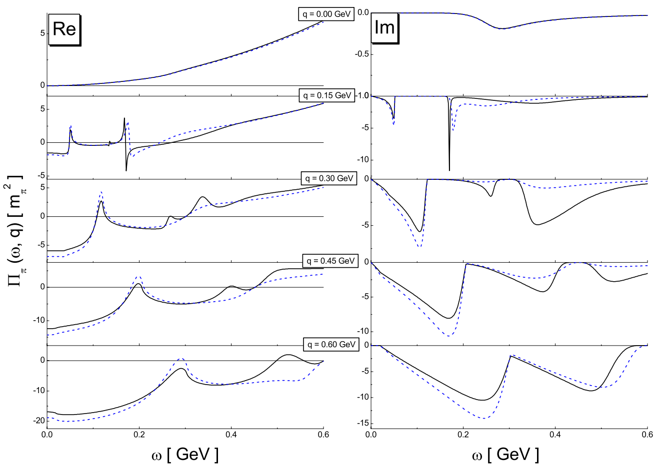

Figure 1: The pion self energy as a function of ω and $|\vec{q}|$ evaluated at nuclear saturation density. The solid line shows the full result (3), the dashed line follows with $\Pi_{12}^{(\Delta h)} \to 0$.

where the coupling matrix, G, and loop matrix, J, are specified in [4]. Explicit calculations show $\Pi_{12}^{(Nh)} = 0$ but $\Pi_{12}^{(\Delta h)} \neq 0$.

In Fig. 1) we present the pion self energy (3) for the choice of parameters $g'_{11} = 0.585$ and $g'_{12} = 0.191 + 0.051\,g'_{22}$ with $g'_{22} = 0.6$ as suggested in [2]. A realistic isobar spectral function is used. The figure clearly illustrates significant effects in certain kinematical regions as the result of a proper treatment of all coupled channels. Most striking is the enhancement by about a factor 5 found for the imaginary part of the pion self energy at $\omega \sim 350$ MeV and $|\vec{q}| = 300$ MeV. The inclusion of the transition loop function $\Pi_{12}^{(\Delta h)}$ together with $\Pi_{22}^{(\Delta h)}$ and $\Pi_{22}^{(Nh)}$ is crucial here. From the form of $\Pi_{12}^{(\Delta h)}$ (see [4]) it follows directly that at $\omega \neq 0$ and $|\vec{q}| = 0$, the kinematical region probed by the quenching of the Gamow-Teller resonance, the coupled channel structure discussed here is superficial. In this case the additional 2×2 matrix structure of the loop functions in (3) can be dropped. A further interesting limit is $\omega = 0$ with $\vec{q} \neq 0$ as is probed by a possible pion condensate. Here one recovers the algebraic form of the non-relativistic scheme of Migdal [3] for $|\vec{q}| \ll m_N$ and $|\vec{p}| \ll m_N$.

References

[1] V.F. Dmitriev and T. Suzuki, Nucl. Phys. **A 438** (1985) 697.
[2] M. Nakano et al., Int. J. Mod. Phys. **E 10** (2001) 459.
[3] A.B. Migdal et al., Phys. Rep. **192** (1990) 181.
[4] M.F.M. Lutz, Phys. Lett. **B 552** (2003) 159.