Finite Momentum of the $\pi\pi$-Pair in the $A(\pi\ ,2\pi)$ Reaction

C. Isselhorst , Z. Aouissat, J. Wambach
Institut für Kernphysik, Technische Universität Darmstadt

The knockout reaction $\pi A \rightarrow \pi\pi A$ has been thoroughly studied in the past [1]. However, only recently the inclusion of final-state interactions has been discussed [2]. This was motivated by the experimental findings of both CHAOS collaboration [3] and Crystal Ball collaboration [4], where a strong enhancement of the $\pi\pi$ mass distribution is observed around 2π threshold.
Indeed, the $\pi\pi$ interaction is known to be strongly attractive and might even lead in nuclear medium to a 2π bound-state, which could provide an explanation of the experimental results. For a thorough investigation of this conjecture, one needs to develop a model for interacting pions. This is being undertaken in the framework of the linear-sigma model which is treated in the large N limit approach [5]. Besides, the usual p-wave coupling of the pion to the nuclear medium, in this context, the σ-meson undergoes as well a strong mean-field renormalization and a direct coupling to particle-hole ($p{-}h$) excitations. Indeed for a finite total momentum of the $\pi\pi$-pair or equivalently of the σ mode, the direct coupling to $p-h$ excitations is very important. The magnitude of this coupling is traced back through the experimentally accessible scalar polarization propagator [7]. In a recent work we addressed this question using the standard σ-ω model [6], and fine tuning the σNN and ωNN couplings to ensure the nuclear matter stability (see [6] for details).
The effect of the above on the $\pi\pi$ scattering S-matrix and the σ propagator is shown below. One notice in particular the strong downward shift of both the σ pole and the strength in the $\pi\pi$ scattering matrix. At finite momentum of the $\pi\pi$ pair, the strength is dramatically weakened at threshold in the scattering matrix while an important build up of strength is seen in the imaginary part of the sigma propagator at very low energy due to the $p-h$ coupling.

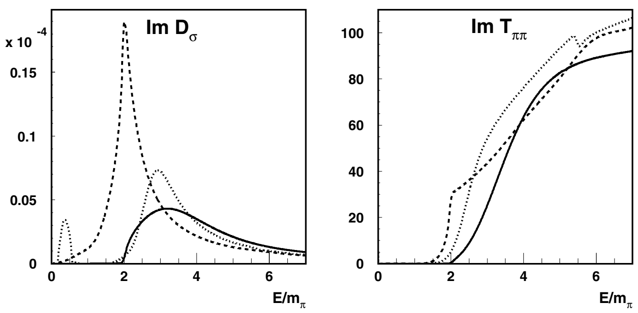

Figure 1: Imaginary part of the σ propagator (left panel), and the $T_{\pi\pi}$ matrix (right panel). The full lines denote the vacuum case. The dashed lines are for normal nuclear matter density and the zero three-momentum case . The dash-dotted lines are for nuclear matter density and a three-momentum of the pair of 200 MeV.

Regarding the knockout reaction, a closer investigation of the phase-space for the produced $\pi\pi$-pair, precisely in the 2π threshold region, reveals that most events contributing to the total cross-section of the process

$$\begin{aligned}\sigma \;=\;& \tfrac{\pi}{q}\int d^2\mathbf{b}\, dz\, A_{in}(\rho(\vec{r}))\, A^{+}_{out}(\rho(\vec{r}_1))\, A^{-}_{out}(\rho(\vec{r}_2))\\ &\int \tfrac{d\vec{k}}{(2\pi)^3}\tfrac{d\vec{q}_1}{(2\pi)^3}\tfrac{d\vec{q}_2}{(2\pi)^3}\, n(\vec{k})\,\Big[1-n(\vec{q}+\vec{k}-\vec{q}_1-\vec{q}_2)\Big]\\ &\delta(q^0+\mathcal{E}_{\vec{k}}-\omega_{\vec{q}_1}-\omega_{\vec{q}_2}-\mathcal{E}_{\vec{q}+\vec{k}-\vec{q}_1-\vec{q}_1})\\ &\tfrac{1}{2\omega(q_1)}\tfrac{1}{2\omega(q_2)}\,\overline{|T|^2}_{(\pi N\rightarrow\pi\pi N)}\big|\tfrac{T_{\pi\pi}}{V_{\pi\pi}}\big|^2\times acceptance\end{aligned} \quad (1)$$

carry an average total momentum of about 260 MeV [6]. In the light of what we have learned earlier concerning the behavior of the in-medium $\pi\pi$ scattering at finite total momentum Fig. 1, one expects weak final state interaction (FSI) reversing the conclusion of an old result [2] which attributed the near-threshold enhancement observed in CHAOS data to the strong 2π FSI.

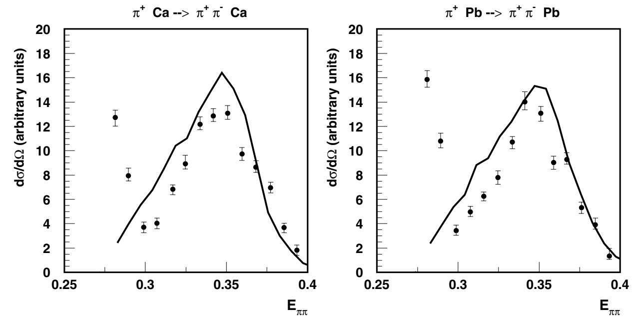

Figure 2: Differential cross-section for the knockout process off Ca and Pb. At threshold the experimental data show a strong enhancement missing in the theoretical (solid) curve due to the finite three momentum of the pair as explained in the text.

As shown in Fig. 2, the theoretical calculations fail to account for CHAOS data in the near-threshold region. It should be mentioned also that the strong nuclear absorption plays an important role in moderating the FSI effects. More work is therefore needed to understand the mechanism behind the experimental findings.

References

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