Chiral Fluctuations in Nuclei

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The near-threshold enhancement in the $\pi^+\pi^-$ invariant mass distribution in nuclei, observed by CHAOS collaboration [1] and for $\pi^0\pi^0$ pairs by the Crystal Ball collaboration [2], offers the interesting possibility of directly observing a signal for partial restoration of chiral symmetry in a dense medium. There seems to be theoretical consensus on a strong in-medium reshaping of the s-wave isoscalar pion-pair correlations as a direct consequence of increased fluctuations of the chiral order parameter. This translates into a significant downward shift of the strength in the $\pi\pi$ T-matrix in the scalar-isoscalar channel as seen in Fig. 1.

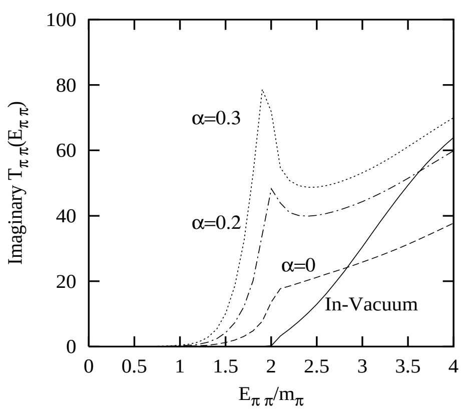

Figure 1: The imaginary part of the in-medium $\pi\pi$ T-matrix at normal nuclear density. The parameter α represents the medium effects on the mean field sigma-mass. See ref. [3] for details.

The reaction theory for the $A(\pi, 2\pi)$ knockout process has been thoroughly studied in the past [4], but only recently has the in-medium $\pi\pi$ final-state interaction (FSI) been seriously considered [5]. Taking into account the elementary $\pi\pi$ production process on the nucleon, the experimental acceptance, the Pauli constrained phase-space, and the nuclear absorption of the incoming and outgoing pions, the total cross-section for the $A(\pi, 2\pi)$ process in local density approximation reads

$$\begin{aligned}\sigma &= \frac{\pi}{q}\int d^2bdzA_{in}(\rho(\vec{r}))A^+_{out}(\rho(\vec{r}_1))A^-_{out}(\rho(\vec{r}_2)) \\ &\int \frac{d^3k}{(2\pi)^3}\frac{d^3q_1}{(2\pi)^3}\frac{d^3q_2}{(2\pi)^3}n(\vec{k})[1-n(\vec{q}+\vec{q}-\vec{q}_1-\vec{q}_2)] \\ &\delta(q_0+\varepsilon_{\vec{k}}-\omega_{\vec{q}_1}-\omega_{\vec{q}_2}-\varepsilon_{\vec{k}+\vec{q}-\vec{q}_1-\vec{q}_2})\frac{1}{2\omega_{\vec{q}_1}}\frac{1}{2\omega_{\vec{q}_2}} \\ &|T_{(\pi N\to\pi\pi N)}|^2\left|\frac{T_{\pi\pi}}{V_{\pi\pi}}\right|^2_{FSI}\times Acceptance\,. \qquad (1)\end{aligned}$$

To remove both experimental and theoretical uncertainties in the reaction dynamics, the CHAOS collaboration has considered the composite ratio, $C^A_{\pi\pi} = \frac{\sigma^A(M_{\pi\pi})}{\sigma^A_T}/\frac{\sigma^N(M_{\pi\pi})}{\sigma^N_T}$, where $\sigma^A(M_{\pi\pi})$ ($\sigma^N(M_{\pi\pi})$) denotes the invariant mass distribution in the nucleus (nucleon), while σ^A_T (σ^N_T) is the corresponding total cross section for the $A(\pi, 2\pi)$ process [6]. Comparing this ratio for both $\pi^+\pi^-$ and $\pi^+\pi^+$ final states, one can argue that the observed near-threshold enhancement must be an $I = 0$ effect. The theoretical pre-

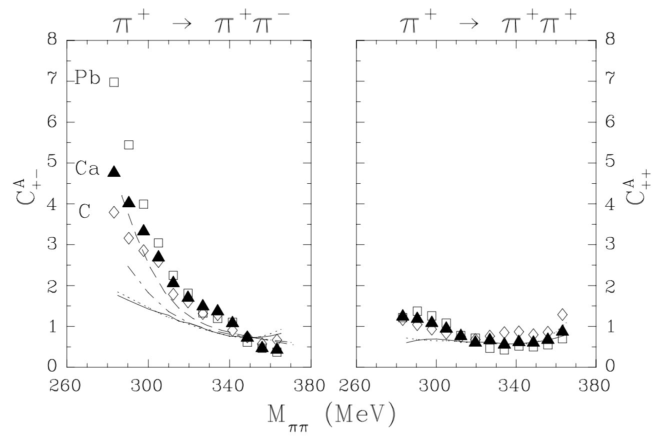

Figure 2: The ratio $C^A_{\pi\pi}$ for various nuclear targets [6].

dictions shown on Fig. 2 assume the effect of the FSI as appearing in Fig. 1. The various curves reflect the current state-of-the-art calculations by different groups (see [7] for details). The dashed curve uses the model in [3].
However, improvements in the reaction calculations are needed. The kinematical analysis of the 3-body final state, for instance, reveals that the average momentum of the pion-pair is about 200 MeV/c. Therefore the back-to-back kinematics assumption used in all previous calculations needs to be revised [8].
On the experimental side, a very exciting possibility which circumvents the strong absorption in the initial state is the photoproduction $A(\gamma, 2\pi^0)$. Such experiments have been conducted at MAMI in Mainz and are currently analyzed [9]. A theoretical description is also in progress [8].

References

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