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DETERMINING PROPERTIES OF BARYON RESONANCES IN NUCLEI

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Meson-nucleus and photon-nucleus interactions are important sources of information about the medium modifications of baryon resonances in nuclei. Indications of how large the medium effects are for resonances above the $\Delta_{33}(1232)$ are provided by a combined analysis of photonuclear and pion cross sections in the GeV range of energies. The existing data indicate a possible 10–20% renormalization of the pion coupling to higher-lying resonances in nuclei.

When a projectile strikes a nucleon in the nucleus forming a resonance, the mass and width of this baryon resonance may be different from the corresponding values in free space. The simplest way to picture this is in the isobar-doorway model,[1] in which the properties of the resonance appearing, say in Eq. (2), are parameterized and deduced from experiment. This was done long ago for the Δ_{33}, and in the mean time the empirical values have been understood based on microscopic theory. For example, a combination of medium effects,[2,3] including the binding of the nucleon, the mean field acting on the Δ_{33}, Pauli blocking, fermi averaging, and correlation corrections are required to understand the shifts in the mass and width of the Δ_{33}. In a more modern context, the modified resonance properties reflect the behavior of quark and gluon condensates in nuclei.

To make the connection to quark and gluon condensates,[4] it is of course first necessary to determine empirically the masses and coupling constants of baryon resonances in nuclei. The problem of determining these properties for the massive baryon resonances is more complicated than it is for the Δ_{33} itself, because at higher energies the resonances are overlapping. Consequently, one needs to consider all sources of information available. Photonuclear and pionic reactions are complementary for this purpose, since the resonances are mixed differently in different reactions. In this talk, we will indicate what existing data are saying about the properties of baryon resonances in nuclei following our Ref. 5 and briefly discuss the prospects for obtaining additional information at new facilities.

The basic element of meson-nucleus and photon-nucleus scattering is the corresponding scattering t-matrix, which may be divided into resonance and background parts,

$$t = t_{nr} + \sum t_{res,j} \quad , \tag{1}$$

where t_{nr} is the nonresonant background amplitude and $t_{res,j}$ is the resonant on-shell amplitude for resonance j. The latter may be expressed in a Breit-Wigner form, e.g.,. for pions,

$$t_{res,j} = \sum \frac{g^2_{\pi NN^*,j}}{(k+p)^2 - M_j^2 + iM_j\Gamma_j} \, , \tag{2}$$

characterized by a free-space elastic width (proportional to $g_{\pi NN^*,j}$), a free-space mass M_j, and a free-space total width Γ_j. Here k is the pion and p is the nucleon four momentum.

Measurements of total cross sections with energetic photons have been used for an empirical study of baryon resonances in nuclei above the $\Delta(1232)$.[6] In the case of photonuclear measurements, the prominent peaks for the $D_{13}(1520)$ and $F_{15}(1680)$ resonances, present for the free nucleon, have been found to disappear for a nuclear target. This result is interpreted in Ref. 6 as the combined effect of fermi averaging plus additional collision broadening. Various attempts have been made to understand pion scattering data above the Δ_{33} resonance; see e.g., Refs. 5 and 7–13. There is general quantitative agreement among the different approaches, and it is found that in the absence of medium modifications the experimental data is generally in disagreement with theory.

The work in Ref. 5 was done in the covariant theory of Ref. 3. Fermi motion was included, but it was assumed that the conventional second-order correlation corrections and mesonic-current corrections are negligible. The medium modifications to the self-energies of the baryon resonances were incorporated in the spirit of Ref. 6. That is, $t_{res,j}$ is assumed to be modified in the medium by the fermi motion of the nucleons plus additional collision broadening.

First, $g_{\pi NN^*,j}$ is adjusted to fit the free pion-nucleon elastic amplitudes[14] and the total cross sections are calculated from these using the eikonal theory. The results are presented in Fig. 1 as a function of pion laboratory kinetic energy for π^+ on ^{12}C and compared to data.[15,16] (The new KEK data[17] were not available when the study in Ref. 5 was made.) The medium-dash line is the result of the calculation in the absence of collision broadening, showing the combined effect of fermi averaging and multiple scattering. When the collision broadening is added as determined from the photon total cross section in Ref. 6, the dash-dotted curve is obtained. Although the increase in widths has a noticeable effect on the predicted cross sections, the result is strikingly small and the effect of the wrong sign. Changes in the masses of the resonances will have little additional effect since the resonances in our final model are quite broad.

The most interesting feature is not the effect of the medium modifications *per se*, but rather the large discrepancy that stands out in comparing the dash-dotted curve in Fig. 1 with the data. Ignoring for the moment the KEK data, the discrepancy is about 20% and is approximately energy independent. One interesting possible explanation is that the coupling of the pion to the resonances is modified in the nucleus. In the eikonal theory, a phenomenological increase of the pion-nucleon interaction in the medium by 20% will reproduce the older data, as is shown by the solid curve in Fig. 1.

This corresponds to a 10% increase in the pion-nucleon-resonance coupling constant, $g_{\pi NN^*,j}$, in all channels (including the non-resonant channels) and would be a significant additional piece of information for constraining the four-quark condensates in nuclei. The coupling constant renormalization needed in the optical model theory[5] is about twice this size, but in both approaches an enhanced interaction is clearly indicated. This situation is reminiscent of what has been seen[18] in K^+-nucleus scattering. There one also finds that the theoretical cross sections lie consistently, and of the order of 20%, below the data. An explanation suggested[19] here is an increased coupling of mesons to the nucleon.

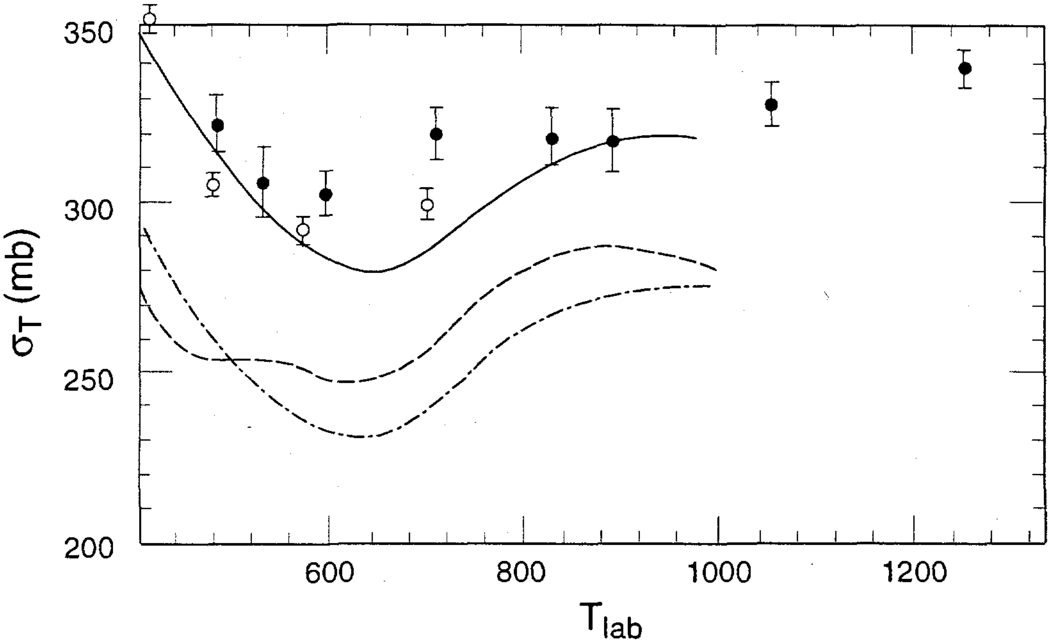

Fig. 1. Total cross section for π on ^{12}C. Data are from Refs. 15 and 16, and the calculations are described in the text.

To refine the theory, angular distribution data are very useful. The reason is that angular distributions in the vicinity of their minima (which we have found to differ somewhat from the theory), depend strongly on the real part of the amplitude[20] and are therefore particularly sensitive to the masses of the resonances in the nucleus.

Available angular distribution[17,21] data support the interpretation[5] for an enhanced pion coupling to the higher baryon resonances in nuclei, which has important implications for quark condensates in nuclei. However, the required enhancement is no longer independent of energy, since the total cross sections extracted from the KEK data[17] are smaller than the older data below 600 MeV where the $\Delta(1232)$ begins to dominate. It is also likely that shifts in the masses of the baryon resonances in nuclei will be required in order to understand the angular distributions in the vicinity of their minima, and it will be interesting to see what values the data require for these.

In the longer-term future, an experimental effort to separate the contributions from the (overlapping) resonances would be quite desirable. Such measurements might be made by doing coincidence measurements in which the outgoing pion or eta meson is detected in coincidence with the outgoing proton arising from decay of excited baryon resonances.[22] CEBAF or the AGS would be very attractive for such experiments.

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