

A TWO-NUCLEON MODEL OF COHERENT PION PRODUCTION IN PROTON-NUCLEUS COLLISIONS NEAR THE PION THRESHOLD

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In this annual report we present the first applications of our microscopic, meson exchange model for nuclear pion production, which has been under development at IUCF and Erlangen for a number of years.¹ Based on effective Lagrangians, it includes pion stripping from the incoming proton (the so-called one-nucleon term) as well as s-wave and both resonant and non-resonant p-wave rescattering (the two-nucleon term). Initial state interactions and corrections for higher order rescattering of the outgoing pion are included via proton-nucleus and pion-nucleus optical potentials. We summarize here the philosophy and main features of the model.

Most previous theoretical approaches have focused on specific aspects of the production process, in order to avoid the computational difficulties associated with a comprehensive microscopic model. Only recently have systematic and comprehensive theoretical analyses of the (p, π) reaction been attempted. Whereas Keister and Kisslinger,² as well as Iqbal and Walker,³ focused on scattering energies close to the 33 -resonance (to study primarily Δ -isobar excitation and propagation in nuclei), the present approach concentrates on energies close to the pion production threshold, where extensive data on both the cross section and the analyzing power of the (p, π) reaction are available.

For energies close to threshold, the complexity of the elementary πN amplitude implies a fairly complicated microscopic model for the nuclear (p, π) dynamics. The unpleasant consequences of this are that

microscopic models involve a good deal of phenomenology, and numerical calculations are technically rather complicated. On the other hand, a complex model which is reasonably complete and also flexible, allows one to address in a consistent manner a variety of interesting questions, such as the role of mesonic and baryonic degrees of freedom, and the importance of cooperative or collective phenomena in nuclei. Detailed information about such questions will emerge only from systematic and consistent analyses of a large amount of data with a microscopic model which has the flexibility to be extended, with minor modifications, to other medium energy, large momentum transfer processes. It is crucial for the practical application of any model to keep the technicalities simple.

Guided by the above philosophy, we start out with what we expect to be a sound though still rather transparent microscopic model and apply it initially to low-energy pion production. After developing a qualitative understanding of the important physics input and the various parameters of the model, it is planned to extend the model step by step to higher energies and to the study of specific questions such as those mentioned above. The aim is to obtain not only a detailed understanding of proton-induced pion-production, but ultimately a coherent description of exclusive high-momentum transfer reactions in general.

The formulation of our model is based on previous

investigations of the (p, π) reaction as well as true pion absorption on nuclei at low energies. Even though the interpretation of earlier results is not unambiguous, they indicate that:

- at energies well below the 33 -resonance, the pion is produced predominantly in a single "hard" nucleon-nucleon collision (Fig. 1a), i.e., the primary production or absorption process involves dynamically only two nucleons;
- the modifications from "soft" proton-nucleus and pion-nucleus interactions before and after the genuine production process can be included in a global fashion via local mean-field corrections;
- the bremsstrahlung process (Fig. 1b), in which the pion is produced directly from the projectile in a stripping-like manner, supplements the production process as a moderate correction (except for very light nuclei).

These conclusions are drawn from analyses of high momentum transfer reactions in general, which consistently map out the two-nucleon subamplitude as the dominant dynamical substructure, and the interplay of the kinematics of the (p, π) reaction at threshold with the strength of the πN interaction at these

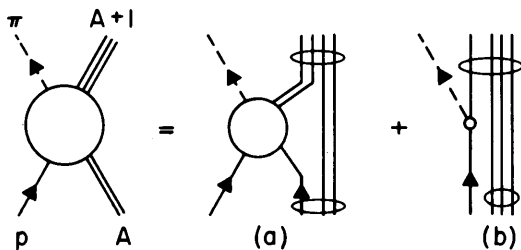


Figure 1. Decomposition of the (p, π) amplitude into a rescattering (a) and a bremsstrahlung (b) amplitude.

energies and the momentum distribution of bound nucleons.

Separation of the (p, π) process into hard and soft collisions is favored by both the kinematics and the πN dynamics near the pion threshold. With a typical momentum transfer to the residual nucleus of about 450 MeV/c, momentum sharing in a hard collision can bring the pion close to its mass shell with a momentum transfer to each participating nuclear wave function of only 150 MeV/c (see Fig. 2), which is close to the maximum of the momentum distribution of a bound nucleon. Combined with the dominance of momentum components around 400 MeV/c in the tensor part of the pion exchange potential, this strongly favors a two-nucleon mechanism. The weak πN interaction at low energies results in a large mean free path for pions in nuclei (~ 2 fm); consequently the multiple scattering series should converge rather rapidly for pions close to their mass shell.

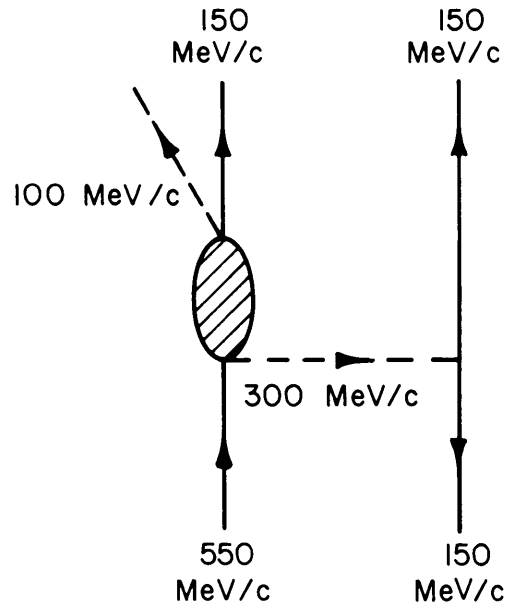


Figure 2. Typical momentum sharing in the (p, π) reaction around the production threshold in the rescattering model.

For the practical formulation of the rescattering term, which involves at low energies s-wave and both resonant (Δ -dominated) and nonresonant p-wave parts of the πN amplitude, we are immediately confronted with the complexities of isobar-dynamics in nuclei. Recent studies in the isobar-doorway approach have demonstrated clearly the dominant role of the Δ -isobar in the pion-nucleus interaction. Particularly for pion scattering around the 33-resonance, medium corrections for the isobar are an essential part of the nuclear dynamics. To treat them properly requires the full Δ -nucleus Greens-function instead of the conventional closure approximation. Including the Δ -dynamics in full generality requires - due to the presence of nonlocalities in the isobar propagator - a rather specific technical apparatus. Its detailed incorporation in the present approach would very likely make the code impracticable for systematic applications. Being interested in energies well below the 33-resonance, we feel that it is justifiable to treat the Δ -isobar in the closure approximation, including medium corrections very qualitatively as a local self energy term. It is certainly necessary to test this approximation by studying the energy dependence in our model, by comparing with other approaches^{2,3} which treat the isobar Greens function in the local limit, and by comparing (through charge symmetry and detailed balance) with a very recent calculation of ${}^4\text{He}(\pi^-, n){}^3\text{H}$ around the resonance energy based on the isobar doorway model.⁴

Our model lacks the simplicity of the earlier bremsstrahlung models, but avoids the full technicalities of the isobar-doorway approach. It is fairly complete and flexible enough to address questions beyond those related to the basic (p, π)

reaction mechanism. Keeping the whole approach in momentum space allows a convenient study of recoil effects, nonstatic corrections, the influence of time-ordering, etc.. Similarly, the influence of different parametrizations for the off-shell continuation of the various vertices - such as dipole form versus Bessel type structures - or its interplay with other poorly known ingredients in the interaction (heavy meson exchanges, short range correlations) can be easily investigated. Furthermore, including a complete set of time ordered diagrams allows one to study the influence of both real as well as virtual degrees of freedom in nuclei. For example, it is easily realized that the target-emission diagram is directly related to the content of virtual pions in the nuclear ground state or excited states. Similarly, the existence of virtual Δ -isobar components in nuclei is easily traced back to the pre-emission piece of the target emission diagram. Beyond that, an extension of our model to other one-nucleon transfer reactions or to doubly coherent phenomena like pionic fusion induced by (light) heavy ions should be feasible. We hope that it ultimately can provide a basis for a unifying description of high-momentum transfer reactions in general around the pion threshold.

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- 4) K. Sakamoto, M. Hirata, A. Matsuyama and K. Yazaki, Phys. Rev. C 31, 1987 (1985).