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Diffractive dissociation using nuclear targets

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We have compared our data for nuclear coherent dissociation of neutrons into $(p\pi^-)$ systems with a production model which was used previously to investigate the nature of the diffractive process on a hydrogen target. The decay and production characteristics observed for $(p\pi^-)$ systems produced on nuclear targets at Fermilab energies are in qualitative agreement with the predictions of the model.

INTRODUCTION

In previous publications we presented results on the coherent dissociation of neutrons into $(p\pi^-)$ systems using nuclear targets[1] and using hydrogen.[2] Our emphasis in the case of the nuclear targets was on the extraction of total cross sections (σ^*) for scattering of the $(p\pi^-)$ systems on nucleons. This was achieved using a model that incorporated contributions from both electromagnetic (Primakoff) and hadronic production, integrating over the decay angles of the $(p\pi^-)$ systems. An earlier investigation of the decay properties of $(p\pi^-)$ systems produced on hydrogen[3] revealed an unusually strong correlation between the square of the four-momentum transfer from the incident neutron to the $(p\pi^-)$ system (t) and the polar decay angle of the $p\pi^-$ system. This correlation was compared to predictions of a Deck-type model, and it was found that, although the model provided a reasonable general description of the experimental results (especially in the kinematic regime where the one-pion-exchange Deck diagram was important), in detail it had serious difficulty in accounting for the rich structure in the data. In the present paper we will compare the decay properties of $(p\pi^-)$ systems produced off nuclear targets with the same Deck model that we used in the analysis of the hydrogen data.

THE DATA

The data are from an experiment performed in the Meson Area of Fermilab. A forward spectrometer, described in previous publications,[2] was utilized in the M-3 neutral beam to study the following reaction:

$$n + A \to (p\pi^-) + A\,, \tag{1}$$

where A is the atomic number of the target material. Possible backgrounds to this reaction, and the reconstruction efficiency and resolution of the spectrometer have been described elsewhere.[1] The data we will present are derived from the same sample that was used in extracting total cross sections (σ^*) for scattering of $(p\pi^-)$ systems on nucleons.

Figure 1 displays decay-angular distributions of $(p\pi^-)$ systems produced on a carbon (C) and on a copper (Cu) target. The data, for neutron momenta between 150 and 300 GeV/c and for $t < 0.05$ GeV^2, are presented for four intervals of $(p\pi^-)$ mass (M). The angle θ refers to the polar angle of the proton in the Gottfried-Jackson frame. (The curves are predictions from a model to be discussed in the next section.) Two rather unusual features are apparent in the data of Fig. 1: First is that steep enhancements at large negative $\cos\theta$ appear for all masses; second is that the distributions in $\cos\theta$ shift to more positive values as the masses of the $(p\pi^-)$ systems increase. These features are similar to previous observations reported for reaction (1) at lower energies. In particular, the data of Mühlemann *et al.*,[4] which are available only for $\cos\theta \gtrsim -0.2$, and the data of Vander Velde *et al.*,[5] which are for $\cos\theta < 0.0$, are both in general agreement with our measurements in regions of mutual overlap. For comparison, we display in Fig. 2 previously unpublished data for reaction (1) on a hydrogen target, for the smallest available interval in t.[2] The trend of these data with increasing M is similar to that noted for

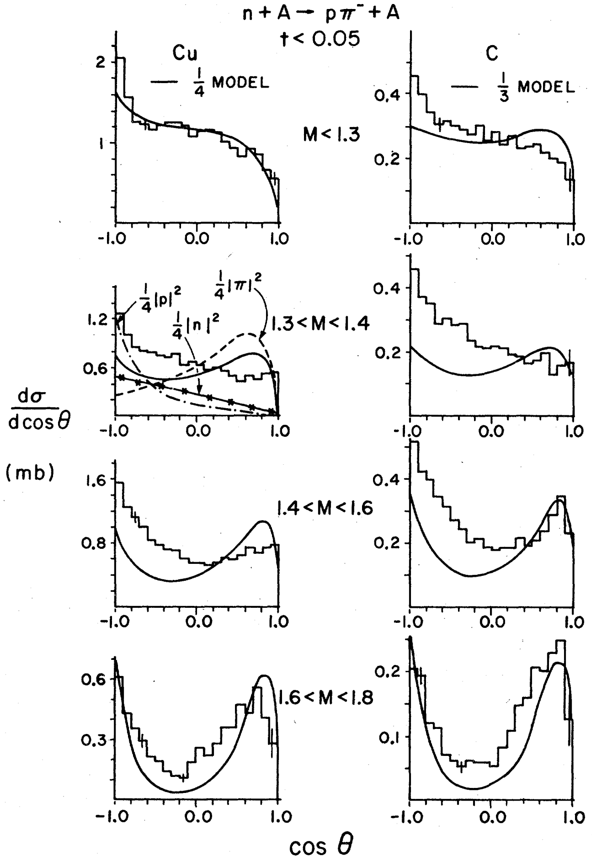


FIG. 1. Gottfried-Jackson polar-angle distributions for the proton in the decay of $(p\pi^-)$ systems produced coherently off Cu and C targets. The predictions of a Deck-type model (Fig. 5) are shown renormalized to the data at small masses. Magnitudes of the contributions from the three (interfering) terms in Fig. 5 are shown on the Cu results for $1.3 < M < 1.4$ GeV.

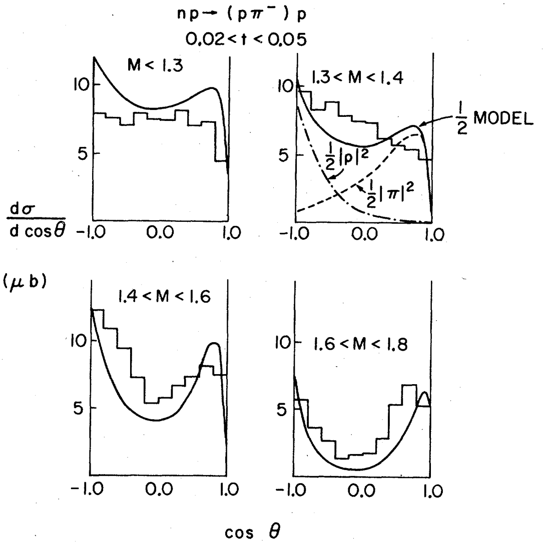


FIG. 2. Comparison of predictions for θ distributions from the production model (reduced by a factor of 2) with data off a hydrogen target, at small values of t.

Fig. 1. In fact, there also appears to be a smooth trend in the θ distributions as a function of the average value of t. From the Cu data, where t values are typically ~ 0.006 GeV^2, to the C data, where the average t values are ~ 0.015 GeV^2, through the hydrogen data in Fig. 2, to the largest t values for hydrogen,[2] the trend is for the distributions to become more forward peaked as t increases.

The data for reaction (1) on hydrogen revealed a strong correlation between the t distributions and the decay angles θ.[3] Our results for nuclear targets also show a striking dependence of t on θ.[6] In Figs. 3 and 4 we display our t' spectra [t' being defined as the square of the transverse momentum of the $(p\pi^-)$ system] for a copper target for two ranges of M. Ignoring the first several bins in t' (dominantly Coulomb production[1]), we see that the shapes for $t' \leq 0.01$ GeV^2 range from $\exp(-265\,t')$ for data at $|\cos\theta| < 0.3$ in Fig. 3 to $\exp(-140\,t')$ for data at $\cos\theta < -0.9$ in Fig. 4. In the region of $\cos\theta > 0.9$ (where our data are statistically rather weak) there appears to be an exceedingly rapid initial drop in the cross section for $t' < 0.003$ GeV^2 (again, similar to what might be expected for Coulomb production); after this drop the spectrum shows only a weak falloff in t'. (The expected Coulomb contribution in Fig. 4 is substantially smaller than in Fig. 3.) The weak t' dependence observed in the data with small values of θ suggests that substantial helicity-flip terms are contributing in this region of phase space.[7] A similar variation of the t'

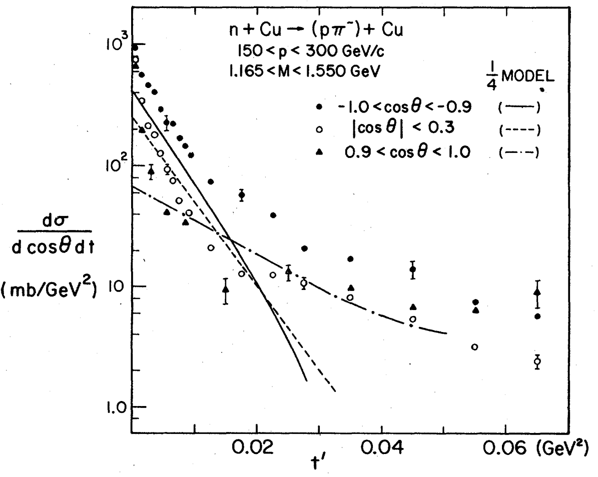


FIG. 3. Comparison of t distributions for the Cu data of Fig. 1 with the model of Fig. 5. (The theoretical predictions have been reduced by an arbitrary factor of 4.) The comparison is for small M.

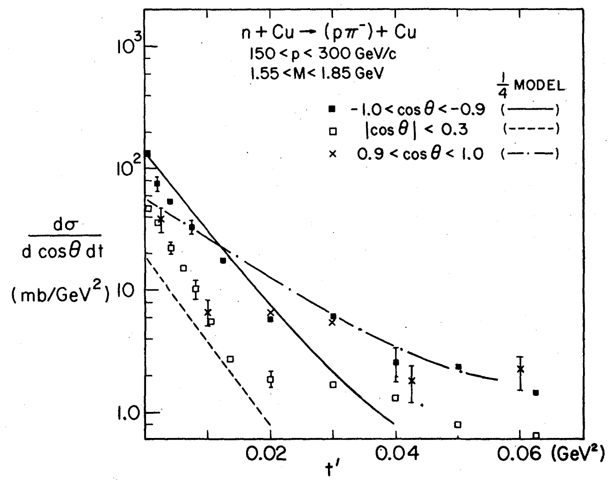


FIG. 4. Comparison of t distributions for the Cu data of Fig. 1 with the model of Fig. 5. (The theoretical predictions have been reduced by an arbitrary factor of 4.) The comparison is for large M.

spectra with changing θ is observed for nuclei with small atomic number.[6]

Several interesting implications emerge from the large variations observed in the shapes of the t' distributions.[8] First is that extraction of the σ^* values[1] through an averaging over such differing t spectra must certainly be suspect to some extent. Second is that production on nuclear targets must be quite sensitive to the details of the diffraction mechanism. In particular, the steep minima observed in the t' distributions in hydrogen[3] for $|\cos\theta| < 0.3$ and the sharp peaks for $\cos\theta < -0.9$ appear to be present in the nuclear data, but just at smaller values of t. Similarly, the data for $\cos\theta > 0.9$ display a relatively weak t dependence for nuclei, as was also the case for hydrogen. In the following section we will apply to the nuclear data an extension of the Deck-type model which we used as a framework for understanding the features of our hydrogen data.[3]

THE MODEL

The model we employ is based on the Deck mechanism. Three amplitudes contribute to the production; the graphs for these are shown in Fig. 5. Although in our calculation we used the explicit expressions provided by Babaev *et al.*,[9] the formulation is essentially the same as that of other similar models.[10] The only substantive change we made in extending the model to nuclear targets involved the substitution of the elastic scattering amplitude for the exchanged object on hydrogen by that on a nucleus. For this we used the elastic scattering data of Blieden *et al.*[8] (ignoring the elastic Coulomb contribution).

In previous applications of this model[11] we found that the general features of the hydrogen data were described quite adequately by adding the three amplitudes for the graphs in Fig. 5. Although the predicted normalization was found to be too high by about a factor of 2, the shapes of the t distributions, particularly for small θ, where the π-exchange diagram (a) dominates, were in surprisingly good agreement with the measurements.[3] Figure 2 illustrates the kind of agreement that can be achieved for θ distributions on hydrogen. At smallest masses all the terms in Fig. 5 are large and their interference terms are important. As the M values increase, the contribution from the neutron-pole ("direct production") term becomes small, the π-exchange and p-exchange contributions separate in phase space, and the interference terms become far less significant. The predicted normalizations for the calculations shown in Fig. 2 have been reduced by a factor of 2; for the $1.3 < M < 1.4$ GeV region we have also shown the contributions to the cross section from the π-exchange and p-exchange terms. (The interference terms and the contributions from the neutron pole are unimportant at these values of t, even for masses as low as 1.3 to 1.4 GeV.)

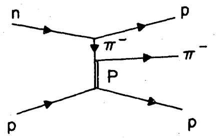
In Fig. 1 we show the results of applying the model to nuclear data. The model again provides a good framework for understanding the source of asymmetries and anisotropies in θ at all M values. As was the case for hydrogen, the predicted normalizations are too high—quite possibly due to neglect of absorption.[12] In Fig. 1 we display the calculations reduced by a factor of 4 for Cu and by a factor of 3 for C. For any fixed M in the nuclear data (small t), the neutron-pole contribution which interferes destructively with proton exchange appears more important than in the case of hydrogen. (See the results in Fig. 1, for $1.3 < M < 1.4$ GeV, where we show the absolute square of the separate contributions from Fig. 5.)

In Figs. 3 and 4 we present the t predictions of the model for copper data. Although the agreement is far from quantitative, it is clear that the data tend to follow the trend of the model. Again, as in the case of hydrogen, the shapes of the t distributions (apart from the very smallest t values) appear to be in consonance with the model at small θ (dominantly π exchange), less so in the region of largest θ (where the neutron pole and p exchange dominate), and hardly at all in regions of $\cos\theta \sim 0$.

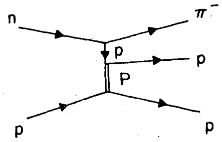
CONCLUSION

From our investigation we conclude that Deck-type models provide an excellent first-order des-

(a) pion-exchange Deck



(b) proton-exchange Deck



(c) neutron pole

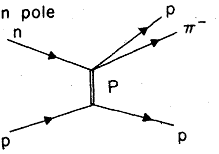


FIG. 5. Diagrams contributing to neutron dissociation into ($p\pi^-$) systems. The symbol P represents the exchange of a Pomeranchukon.

cription of diffractive dissociation at high energies on both hydrogen and nuclear targets. Our nuclear data exhibit great asymmetries and anisotropies in the decay angles of the dissociated systems[13]; this is true even at small values of invariant mass. In the context of a Deck model, our results indicate the need for contributions from all three graphs shown in Fig. 5. The nuclear data, involving production at smallest t values, appear to be relatively more sensitive than the hydrogen data to contributions from baryon exchange. The fact that the model and data agree only qualitatively at large values of M is not surprising because at larger masses resonance contributions, in addition to Deck processes, must be considered. However, the fact that there is considerable discrepancy between data and model for $M < 1.4$ GeV is more important. The unusual steepness in t observed for the interference region $|\cos\theta| < 0.3$ must be related to a similarly puzzling effect in the hydrogen data.[3] The fact that the model predictions do not drop off rapidly enough in θ, both for the π-exchange and p-exchange terms, suggests that both propagators must have more drastic form factors than are afforded by present phenomenology. Consequently, as stated earlier, although Deck models provide a qualitative framework for understanding diffractive dissociation, there are many striking features in the data that at present defy simple explanation and must await clarification in the future.[14]

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[2] J. Biel *et al.*, Phys. Rev. D 18, 3079 (1978).

[3] J. Biel *et al.*, Phys. Lett. 65B, 291 (1976).

[4] P. Mühlemann *et al.*, Nucl. Phys. B133, 189 (1978).

[5] J. Vander Velde *et al.*, Nucl. Phys. B45, 1 (1972).

[6] W. Mollet *et al.*, University of Rochester Report No. UR-635, 1977 (unpublished).

[7] See G. Fäldt and P. Osland, Nucl. Phys. 126, 22 (1977), for a discussion of the effect of helicity-flip amplitudes on the extraction of σ^*.

[8] The shape of the elastic scattering distribution for protons on Cu can be represented approximately as $\exp(-180t)$. See H. R. Blieden *et al.*, Phys. Rev. D 11, 14 (1975).

[9] A. Babaev *et al.*, Nucl. Phys. B116, 28 (1976). As in Ref. 3, we did not use the small Regge corrections to the amplitudes suggested by these authors.

[10] See, for example, M. Uehara, Prog. Theor. Phys. 55, 146 (1976); R. Cutler and E. L. Berger, Phys. Rev. D 15, 1903 (1977).

[11] See Ref. 3 and T. Ferbel, in *Proceedings of the International Meeting on Frontier of Physics, Singapore, 1978*, edited by K. K. Phua (Nanyang Univ., Singapore, 1979).

[12] Absorptive effects have been studied for pion-exchange Deck graphs by E. L. Berger and P. Pirilä, Phys. Rev. D 11, 3448 (1975), and by V. A. Tsarev, *ibid.* 11, 1864 (1975). These corrections are clearly of importance in that they provide a reduction of the overall cross section for dissociation. Absorption also has substantial impact on the shapes of t distributions. The calculation of a fully absorbed model involving all the diagrams in Fig. 5 is of great interest, but beyond the scope of the present paper.

[13] In this regard see the work of A. Minaka and H. Sumiyoshi [Report No. KYUSHU-78-HE-7, 1978 (unpublished)], wherein coherent production is treated in the framework of ideas pertaining to inclusive production on nuclear targets.

[14] For a discussion of other shortcomings of Deck-type models as applied to nuclei see P. Osland, Harvard Report No. HUTP-78/BOOZ, 1978 (unpublished).