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Measurement of the Coherent Dissociation Reaction $p + A \to p\pi^+\pi^- + A$†

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The coherent reaction $p + A \to p\pi^+\pi^- + A$ was measured at 22.5 and 15.3 GeV in order to study diffraction dissociation free from normal Regge exchange background. Glauber-model analysis yields a $pN \to N^*N$ signal in good agreement with pp scattering. Through the model it is found that $\sigma_T(N^*N)$ decreases rapidly from 36 ± 3 mb for $M(N^*) = 1.4$ GeV to 18 ± 4 mb for $M \geq 1.7$ GeV and that $\alpha(N^*N) \sim -0.5$ for $M < 1.7$ GeV.

We report results of an experiment to measure the coherent dissociation reaction[1]

$$p + A \to p\pi^+\pi^- + A,$$

where, in our restricted definition of coherence, both the initial and final nucleus, A, are in the ground state. Data were taken at 22.5 GeV with nuclear targets Be, C, Al, Ti, Cu, Ag, Ta, Pb, and U and at 15.3 GeV with C, Cu, and Pb using the Brookhaven National Laboratory Mark I magnetic spectrometer.[2] A total of 2×10^5 coherent events were observed.

Broadly, the purpose of the experiment was twofold: (1) To study diffraction dissociation, or Pomeron exchange, in a reaction which is relatively free of background from normal Regge exchange because of the coherence requirement. The following properties of diffraction dissociation were measured: the mass spectra both for the three-body diffractive system (hereafter referred to as N^*) and for its two-body constituents; the angular momentum decomposition of its decay products; and, through extensive comparison to a Glauber nuclear scattering model,[3] the energy dependence of the cross section for $pN \to N^*N$. (2) To study the interaction of the diffractive system (N^*) with nuclear matter. Through the Glauber-model fits we have measured $\sigma_T(N^*N)$, the total N^*N cross section, and $\alpha(N^*N)$, the ratio of the real to imaginary part of the forward N^*N elastic scattering amplitude.

For this experiment, the Mark I spectrometer was supplemented by a Pb-scintillator–sandwich veto box[4] surrounding the target to reject events with nuclear break-up and γ rays from excited nuclei and π^0's. Tagging by a segmented atmospheric-pressure Cherenkov counter downstream of the system was used to separate pions from

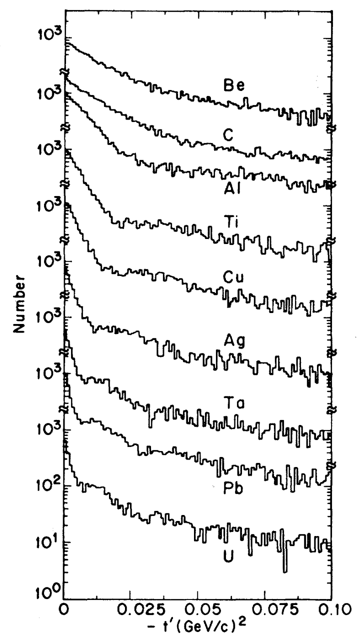

FIG. 1. t' distributions for $p+A\rightarrow p\pi^+\pi^- +A$ at 22.5 GeV/c, with the raw data summed over all masses.

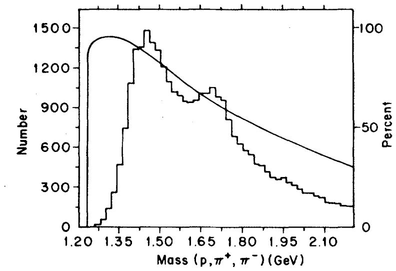

FIG. 2. Uncorrected $p\pi^+\pi^-$ mass spectrum for $p+\mathrm{C}\rightarrow p\pi^+\pi^-+\mathrm{C}$ at 22.5 GeV with $-t' < 0.04$ (Gev/c)^2. Geometrical acceptance of the spectrometer vs mass is superimposed.

protons in the analysis. Studies of reconstructed events show the following resolution uncertainties: for the N^* mass, ± 5 MeV; the N^* transverse-momentum resolution, ± 10 MeV/c; and for the missing mass to the unobserved recoil nucleus, ± 110 MeV (averaged over all data). The overall detection and reconstruction efficiency was 95%, excluding geometrical acceptance (the latter varied almost imperceptibly over the range $-0 < |t'| < 1$ (GeV/c)^2.

Figure 1 shows t' distributions for the cumulative data[5] at 22.5 GeV. The sharp forward peaks seen for all targets are characteristic of nuclear form factors. Their t' slopes vary from ~ 50 to ~ 500 (GeV/c)$^{-2}$ for the range Be to U. Note that secondary and even tertiary maxima are evident for the heavier nuclei. Coherent scattering is identified from these patterns, rather than on an event-by-event basis. Data at the larger $|t'|$ values indicate the level of the incoherent background.

Figure 2 shows an N^* mass plot for the uncorrected coherent data in carbon [$-t' < 0.04$ (GeV/c)^2] at 22.5 GeV. Also shown is a Monte Carlo calculation of the mass dependence of the geometrical acceptance. The mass plot is quite similar to comparable data on dissociation in pp scattering[6] in that both the enhancement at ~ 1450 MeV and a shoulder at ~ 1690 MeV (the position of the $J^P = \frac{5}{2}^+$ nucleon recurrence) are evident. Studies of two-body submass systems show that while $\Delta^{++}\pi^-$ production is a large fraction of low N^* mass production, as expected, it is a modest fraction of the high-mass data [$\sim 20\%$ of the signal for $1.8 < M(N^*) < 2.2$ GeV]. There is no evidence of ρ^0 production.

Decay angular distributions show a small but clear violation of both s- and t-channel helicity conservation, regardless of mass.

The Glauber model was fitted to the data at each energy for all targets simultaneously, and for several discrete N^* mass intervals. (See Ref. 1 for details of the fitting procedure.) The basic form of the differential cross section is

$$\frac{d^2\sigma}{dq_\perp dM} = C_0 \exp(B_1 t') 2q_\perp |F_A(\vec{q})|^2 + C_I \exp(B_2 t') 2q_\perp G_A(\vec{q}).$$

The first term represents coherent scattering. A simple form, $C_0 \exp(B_1 t')$, was used for the elemental reaction $pN \rightarrow N^*N$ off a single nucleon. F_A is the nuclear form factor modified by attenuation of the incoming proton and outgoing N^*. It is thus a sensitive function of the pN and N^*N forward elastic scattering amplitudes. The form factor is further modified by the phase change of the incoming and outgoing waves due to the Coulomb field of the nucleus. However, explicit dissociation in the Coulomb field is expected to be small and was not included. Woods-Saxon nuclear density distributions, $\rho(r)$, were used with parameters taken from electron scattering data.[7] These were modified to account for shell-model effects (Be and C) and quadrupole moments (Ta and U). The second term is the incoherent background, i.e., the incoherent sum of scattering from all nucleons in a target nucleus modified by attenuation of the beam proton and N^* in the nucleus and by closure. Before fitting, the model was further

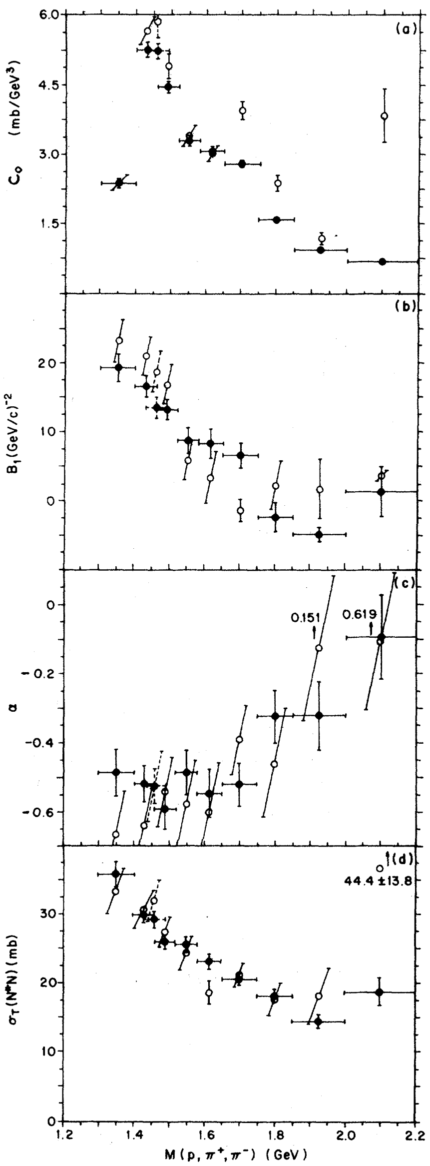

FIG. 3. Results of Glauber-model fits for the coherent signal at 22.5 (●) and 15.3 GeV (○). Mass dependence of (a) C_0, (b) B_1, (c) $\alpha(N^*N)$, and (d) $\sigma_T(N^*N)$. (See text for definitions.)

modified to account for incoherent recoil nucleons and δ rays striking the veto box, for resolution smearing of $q_\perp$, and for $M(N^*)$ and $q_\perp$ dependent geometrical acceptance. Beam proton attenuation parameters were taken from published data[8] on $\sigma_T(pp)$ and $\alpha(pp) = \mathrm{Re}f_0(pp)/\mathrm{Im}f_0(pp)$. The remaining parameters, C_0, B_1, B_2, $\sigma_T(N^*N)$, $\alpha(N^*N)$, and the incoherent intercepts, C_I, were found with a least-squares fitting procedure using the range $0\ \mathrm{GeV}/c < q_\perp < 0.8\ \mathrm{GeV}/c$. The fits are excellent in general. Typically, χ^2/degree of freedom $= \sim 1.1-1.2$.

Comparisons of the coherent data to analogous pp scattering results test the validity of the diffraction-dissociation interpretation of the published pp data because of the coherent filter. Alternatively, they test the nuclear model.

(1) Elemental intercept parameters, C_0. Figure 3(a) shows the values of C_0 vs $M(N^*)$ for both beam energies. Errors are statistical only. Note that the enhancements at 1450 and 1690 MeV are clearly indicated. The agreement of the 22.5-GeV data with corresponding pp data[6] is remarkably good except for $M(N^*) > 1.9$ GeV, where these results lie substantially above the pp data. This may indicate that here a substantial part of the pp data is non-Pomeron exchange. The energy dependence in our data is slight except in the 1690-MeV mass region. For $C_0 \propto p^{-n}$, $n = 0.19 \pm 0.17$ and 0.90 ± 0.15 at 1450 and 1690 MeV, respectively. [The unusual values of C_0 and σ_T for $M(N^*) = 2.1$ GeV at 15 GeV may be due to inaccuracies in the model coupled with a relatively weak coherent signal due to the t_{min} effect.]

(2) Elemental t slopes, B_1. Figure 3(b) shows the mass dependence of B_1. Below $M(N^*) \sim 1.7$ GeV, the behavior is similar to pp data[9] for which the slope decreases from $\sim 18\ (\mathrm{GeV}/c)^{-2}$ near threshold to $\sim 6\ (\mathrm{GeV}/c)^{-2}$ at $M(N^*) \sim 1.7$ GeV. It is nearly constant beyond this point. One might expect such a qualitative feature, but the quantitative agreement for $M(N^*) < 1.7$ GeV is remarkable, considering the small values of B_1 relative to typical nuclear form factors and, therefore, the expected insensitivity of the model to this parameter. The disagreement with pp data for $M(N^*) > 1.7$ GeV is not well understood.

(3) The most noteworthy result from this analysis is the measurement of the mass dependence of the N^*N forward elastic scattering amplitude. The fitted values of $\alpha(N^*N)$ and $\sigma_T(N^*N)$ are given in Figs. 3(c) and 3(d). Whereas $\alpha(pp) \approx -0.2$ in this energy region, $\alpha(N^*N) \sim -0.5$ for $M(N^*) \leq 1.7$ GeV where the sensitivity is greatest. Previously, it had been suggested that either σ_T for a dissociated system is similar to the sum of the total cross sections for its constituents or that σ_T is similar to the parent-particle cross section. The total cross sections that we find are close to $\sigma_T(pp)$ near threshold, but decrease rapidly to $\sim \frac{1}{2}\sigma_T(pp)$ by the point $M(N^*) \sim 1.7$ GeV beyond which they are essentially independent of $M(N^*)$. Complex behavior reminiscent of this has also been seen in coherent pion dissociation[10] wherein $\sigma_T(5\pi, N) < \sigma_T(3\pi, N)$. In addition, recent partial

wave analyses of the 3π data[11] show $\sigma_T(J^P=1^+,N) \lesssim \sigma_T(\pi, N)$, whereas $\sigma_T(J^P=0^-,N) \sim 2\sigma_T(\pi, N)$. It should be noted that the fits for σ_T depend substantially on the ratio of the N^* yields from heavy nuclei to light nuclei, since the attenuation of the signal depends dominantly on $\sigma_T(N^*N)$. Thus, for example, fits to the data with fixed $\alpha(N^*N) = -0.2$ yielded results little different from those in Fig. 3(d).

Qualitatively the behavior of $\sigma_T(N^*N)$ with $M(N^*)$ is remarkably similar to the t slope data for $pp \rightarrow pN^*$. Fäldt[12] has discussed possible refinements to the Glauber model for multiple N^* scattering and helicity flip which would give rise to an "apparent" decrease in $\sigma_T(N^*N)$ with $M(N^*)$.

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Extracting Hadron-Neutron Scattering Amplitudes from Hadron-Proton and Hadron-Deuteron Measurements*

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I present a method to extract hadron-neutron scattering amplitudes from hadron-proton and hadron-deuteron measurements within the framework of the Glauber approximation. This method, which involves the solution of a linear integral equation, is applied to pn collisions between 15 and 275 GeV/c, and effects arising from inelastic intermediate states are estimated.

One of the earliest applications of the Glauber approximation[1] was to the scattering of hadrons by deuterium.[2] It was sufficient, at that time, to assume identical black-sphere interactions for the free hadron-neutron (xn) and hadron-proton (xp) collisions in order to calculate the cross-section defect $\delta\sigma \equiv \sigma_n + \sigma_p - \sigma_d$, i.e., the difference between the free xn plus xp total cross sections and the hadron-deuteron (xd) total cross section. An expression for the xd scattering amplitude, f_d, in terms of the free xn and xp elastic scattering amplitudes, f_n and f_p, and the deuteron form factor, S, was later presented.[3,4] Since neutron targets are unavailable, this result has often been used in attempts to extract the xn total cross section, elastic scattering amplitude, or other information regarding xn scattering from a knowledge of the xp and xd amplitudes and the deuteron form factor, these latter quantities being easier to measure directly. However, in order to extract this information some assumptions are made regard-