Interpretation of the Breakup Reaction $dp \rightarrow ppn$ in the Incident-Deuteron-Momentum Range 2.0–3.7 GeV/c in Terms of Free Np Scattering

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The breakup reaction $dp \rightarrow ppn$ was studied at ten momenta in the incident-deuteron-momentum range 2.0–3.7 GeV/c. The magnitudes of the differential cross sections for quasielastic scattering of protons and neutrons are lower by 10%–20% than those of the free pp and np elastic cross sections. However, the shapes of the quasielastic and free elastic differential cross sections are quite similar except possibly in the very forward region.

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Since the deuteron is the simplest nuclear system and its binding is loose, the dp interaction can be, to a large extent, considered to be the superposition of pp and np interactions, which are relatively well known. The breakup reaction $dp \rightarrow ppn$ is particularly amenable to various theoretical analyses such as the impulse-approximation and final-state-interaction models.[1]

In our momentum range there is only one measurement of the breakup cross section, by Aladashvili *et al.*[2] Data are available on various distributions such as spectator-nucleon distributions for restricted kinematical configurations of the reaction $dp \rightarrow ppn$ at the equivalent deuteron momenta of 2.2,[3] 2.40 and 2.93,[4] 2.44,[5] 2.56,[6] and 3.3 GeV/c.[7]

The aim of this experiment is to study the dp breakup reaction systematically and to compare quasielastic cross sections directly with free Np elastic-scattering cross sections to check the validity of the impulse approximation. This momentum region was chosen because of the availability of a good Np phase-shift analysis[8] in the equivalent nucleon momentum region.

This Letter is based on a part of a 200 000-picture exposure of the National Laboratory for High Energy

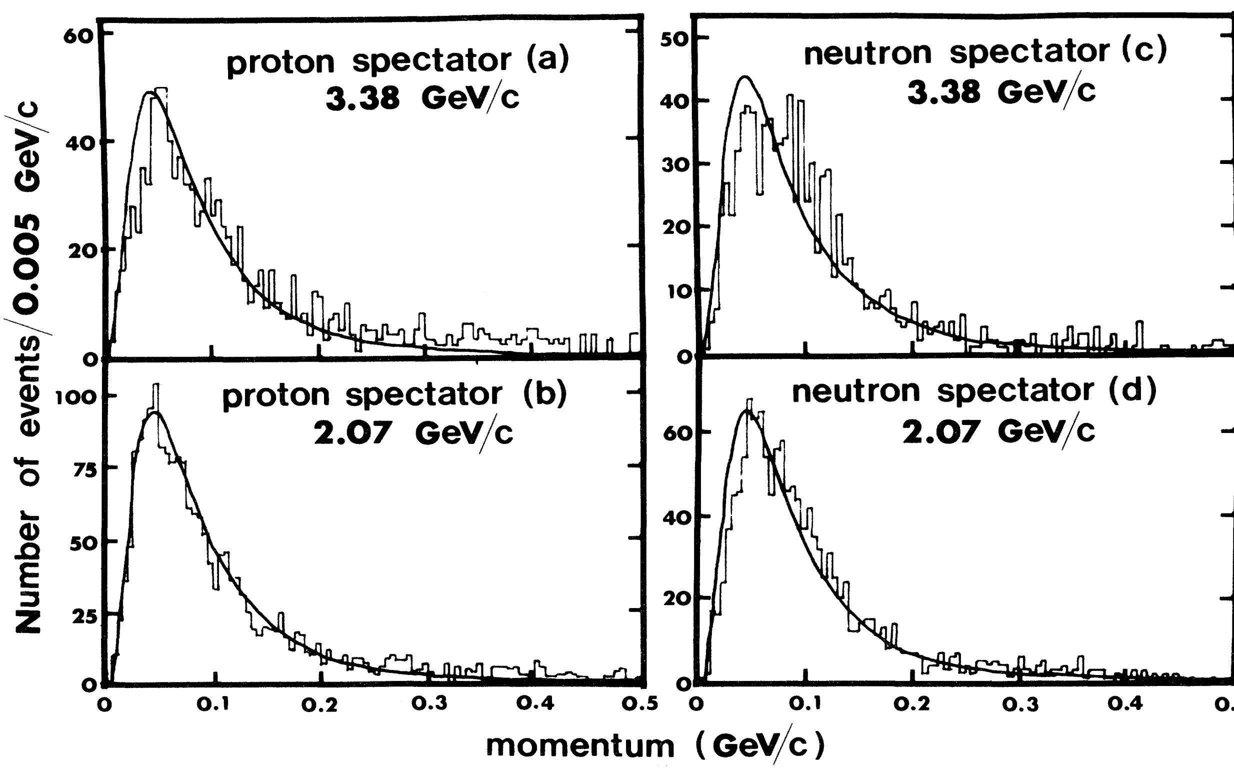

FIG. 1. The momentum distributions of the proton and neutron spectators in the deuteron c.m. system for the incident momenta of 2.07 and 3.38 GeV/c. The solid curves are theoretical distributions based on the Hulthén deuteron wave function (Ref. 10).

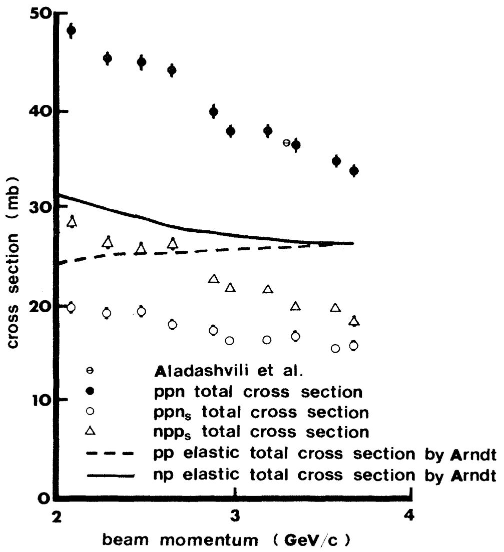

FIG. 2. The $pp(n_s)$, $np(p_s)$, and breakup total cross sections as functions of incident deuteron momentum together with the datum of Aladashvili *et al.* (Ref. 2). The dashed curves are *pp* and *np* elastic total cross sections obtained from the phase-shift analysis of Arndt *et al.* (Ref. 8).

Physics (KEK) 1-m liquid-hydrogen bubble chamber to a doubly separated beam of deuterons from the 12-GeV proton synchrotron at KEK. Approximately 20 000 pictures were taken at each of the following momenta: 2.07, 2.26, 2.46, 2.64, 2.88, 2.96, 3.16, 3.38, 3.56, and 3.67 GeV/*c*. A detailed description of the experimental procedure has been given by Katayama *et al.*[9]

Approximately 55 000 two-prong events were measured and fitted by the following kinematical hypotheses: $d+p\rightarrow d+p$, $d+p\rightarrow d+p+\pi^0$, $d+p\rightarrow p+p+n$, and $d+p\rightarrow d+\pi^+ +n$. The elastic-scattering data have already been reported.[9] The identication of $dp\rightarrow ppn$ events was made by first eliminating events with a π^+ in the final state on the basis of track ionization. Then events which were fitted by only the breakup hypothesis with a χ^2 probability > 0.1% were accepted as belonging to the this hypothesis without further ionization checks. Events with multiple fits, all with χ^2 probabilities > 0.1%, were identified on the basis of track ionization.

Most of the breakup events can be interpreted as quasielastic scattering of the target proton and a constituent nucleon in the incident deuteron. Quasielastic scattering can be studied in terms of the impulse approximation, which assumes that the deuteron breakup occurs when the target proton interacts with one of the constituent nucleons (the projectile nucleon), while the other nucleon (the spectator nucleon) does not receive any momentum transfer. In the rest frame of the incident deuteron, the particle with the lowest momentum among the outgoing three nucleons is considered to be the spectator, which is designated as N_s. The momentum distributions of the proton (p_s) and neutron (n_s) spectators in the deuteron c.m. system for the incident momenta of 2.07 and 3.38 GeV/*c* are shown in Fig. 1. The solid curves are theoretical distributions based on the Hulthén deuteron wave function[10] normalized to the number of events with momenta less than 0.3 GeV/*c*. The momentum distributions of the spectator nucleons agree fairly well with the Hulthen-function distributions, indicating that most of the breakup events can be interpreted as quasielastic *Np* events.

The $pp(n_s)$, $np(p_s)$, and breakup total cross sections as functions of incident-deuteron momentum, together with the datum of Aladashvili *et al.*,[2] are shown in Fig. 2. The dashed and solid curves are *pp* and *np* elastic total cross sections obtained from the phase-shift analysis of Arndt *et al.*[8] The $pp(n_s)$ and $np(p_s)$ quasielastic differential cross sections in the c.m. system of the projectile nucleon and the target proton are shown in Figs. 3 and 4. This is the first set of differential cross sections for quasielastic scattering obtained from the deuteron breakup reaction in this momentum range. Some events were lost in the two most forward bins of these differential cross sections because of very short proton tracks which could not be measured. The error bars indicate statistical errors only.

In order to analyze our data in the impulse approximation we assumed that the free *Np* differential cross sections, $d\sigma_{Np}/dz$, were represented by the phase-shift analysis of Arndt *et al.*,[8] and fitted them to our data by minimizing the χ^2 defined as

$$\chi^2=\sum_i[N_i-(f_N/q)\int_{i\text{th bin}}(d\sigma_{Np}/dz)\,dz]^2/N_i,$$

where z is the cosine of the scattering angle in the c.m. system, N_i is the number of events in the ith bin, f_N is the parameter to be fitted and represents the ratio of the quasielastic *Np* scattering cross section to the free *Np* elastic cross section, and q is the conversion factor from the number of events to the differential cross section. The fitting was done over the range $0.0\leq z\leq 0.85$ for quasielastic *pp* scattering, and $-1.0\leq z\leq 0.85$ for quasielastic *np* scattering. The average χ^2/d.o.f. was about 1.1 for f_p and 1.5 for f_n. Extending the angular ranges to $z=0.9$ increases χ^2/d.o.f. significantly at some momenta for both reactions, but on the whole good agreement was obtained up to $z=0.9$. The fitted curves are shown in Figs. 3 and 4 as dashed curves. The parameters f_p and f_n obtained for the above angular ranges, are shown in Fig. 5 as functions of incident momentum. The statistical uncertainties in the values of f_p and f_n were all about 3%, based on the statistical uncertainties of the data. There are also uncertainties arising from the consider-

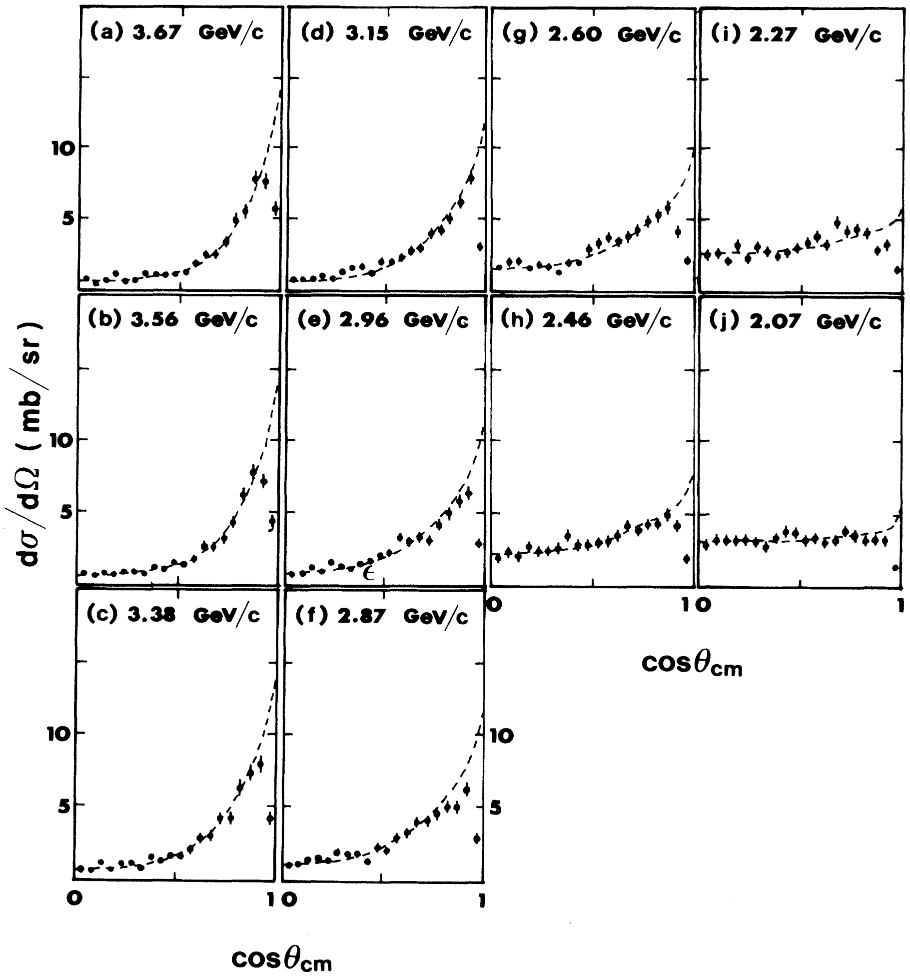

FIG. 3. The $pp(n_s)$ quasielastic differential cross sections in the c.m. system of the projectile nucleon and the target proton. The dashed curves represent the results of the fit described in the text.

able spread in the incident nucleon momentum due to Fermi motion. We estimated these uncertainties to be less than 0.1% by fitting the free Np differential cross sections averaged over the momentum spread to the data. Finally there are uncertainties due to the possible differences between real and phase-shift data. The experimentally measured total pp elastic cross sections in our momentum range[11] agree well with the phase-shift analysis at low momenta, but gradually become smaller with increasing momentum. The difference is about 20% at 1.8 GeV/c. No such comparison is possible for np scattering.

Our value of $f_n = 0.86 \pm 0.03$ at 3.38 GeV/c compares favorably with the value of 0.9 of Aladashvili *et al.*[7] at 3.3 GeV/c obtained from the proton-spectator distribution for limited kinematical ranges. Felder *et al.*[4] obtained $f_p \sim 0.9 \pm 0.1$ and $f_n \sim 1.3 \pm 0.3$ at the equivalent deuteron momenta of 2.2 and 2.4 GeV/c from the spectator momentum distributions for various fixed kinematical configurations. Our values are 0.84 ± 0.02 and 0.92 ± 0.03, respectively. Thus, our values of f_p and f_n obtained for a nearly full kinematical region are in reasonable agreement with the previous values.

We conclude that the impulse approximation seems to work quite well for the dp breakup reaction in reproducing the shapes of quasielastic differential cross sections, but mechanisms such as screening, double scattering, and final-state interactions may have to be invoked to explain the magnitudes of quasielastic differential cross sections and the possible falloff in the very forward region.

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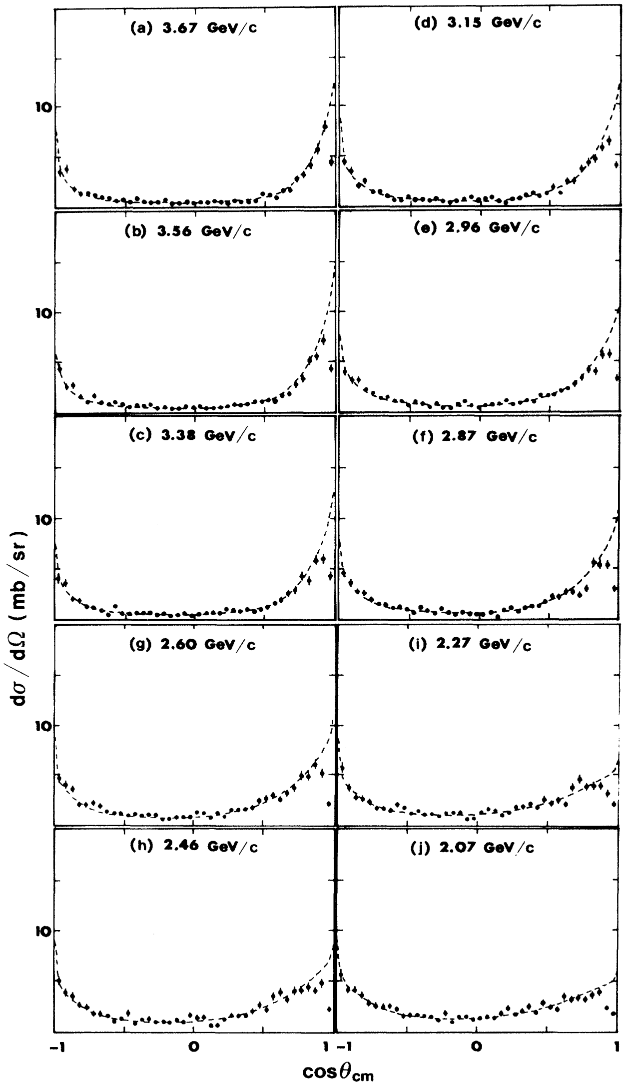

FIG. 4. The same as Fig. 3, expect that the reaction is $np(p_s)$ quasielastic scattering.

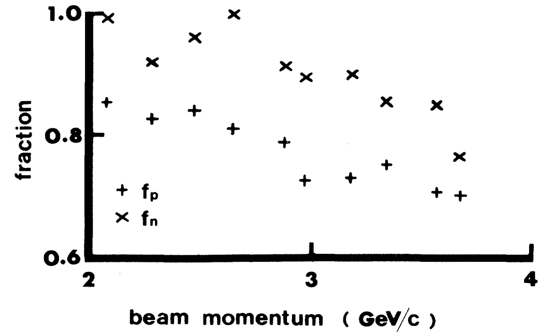

FIG. 5. The momentum dependence of the parameters f_p and f_n.

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