at this wavelength comes from the determination of T_{01} determined from the weighted average of all the stellar CN lines, notably those in ζ Ophiuchus and ζ Perseus. This conclusion has been strengthened by our demonstration of the essential equivalence of T_{01} and T_{bg} in the cloud we have investigated. However, the possibility of a small amount of excitation, to a temperature of the order of 0.1 K above the background must be considered. Such an excitation could be accomplished by collisions with neutral hydrogen atoms if their density were of the order of 10^4 cm^{-3}.[3] Such a density is consistent with our CO data on a number of dark interstellar clouds.[13] It should be noted, though, that the cloud in front of BD +66°1675 has highest optically observed CN column density. If this reflects a higher volume density than the ζ Ophiuchus cloud, say, then the effect of collisional excitation would be proportionally less in the latter case. It is perhaps significant that we have not been able to observe $^{12}C^{16}O$ line emission in the direction of ζ Ophiuchus. From the ratios of equivalent widths in the optical CN lines, we would expect a $^{12}C^{16}O$ column density toward ζ Ophiuchus about one tenth that toward BD +66°1675. That such a column density is normally observable is demonstrated by our ability to detect the corresponding $^{13}C^{16}O$ line in the latter star. The absence of a CO detection toward ζ Ophiuchus could, of course, also be due to small angular size of the cloud, i.e., filling only a small part of our antenna beam, rather than a lack of sufficient collisional excitation.

It is a pleasure to acknowledge the many contributions of P. Thaddeus to this work.

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*A*3 Region of the Three-Pion Mass Spectrum in the Reaction $\pi^- p \to p\pi^+\pi^-\pi^-$ at 13 and 20 GeV/c*

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We report an investigation of the production channels of the *A*3 region of the $\pi^+\pi^-\pi^-$ mass spectrum from the reaction $\pi^- p \to p\pi^+\pi^-\pi^-$ at 13 and 20 GeV/c. Evidence that the *A*3 has a substantial branching ratio to 3π is obtained; its mass and width are measured as 1658 ± 8 MeV and 53^{+20}_{-16} MeV, respectively. To satisfactorily describe the data an additional peak is required with mass 1830 MeV and width 130 MeV.

A peak at about 1650 MeV in the $\pi^+\pi^\pm\pi^-$ mass from the reaction $\pi^\pm p \to p\pi^+\pi^\pm\pi^-$ has been reported in several experiments,[1] the majority of which interpret the peak as a resonance, the *A*3, with a width of more than 100 MeV. Crennell *et al.*,[2] in a study of this reaction in $\pi^- p$ scattering at 6 GeV/c, observed a broad (130 ± 30 MeV) enhancement in the *A*3 region which they find can be explained entirely as an $f^0\pi^-$ kinematical effect.[3] Our data for the $A3$ region of the $\pi^+\pi^-\pi^-$ mass spectrum are inconsistent with a single broad $f^0\pi^-$ enhancement and suggest that we may be dealing with a mixture of resonances or a kinematical effect plus resonances. Although the $A3$ peak in our data appears to be strongly associated with an $f^0\pi^-$ decay mode, we also see a persistence of signal in the $A3$ region when we look at the 3π mass spectrum with events in the f^0 band removed.[4] This Letter describes our investigation of the production channels of the 3π mass spectrum in the $A3$ region, the measurement of the mass and width of the $A3$, and reports on the possible existence of an additional peak at about 1830 MeV.

The data for this experiment come from exposures of Brookhaven National Laboratory's 80-in. hydrogen bubble chamber to a π^- beam at 13 and 20 GeV/c. After the data reduction[5] for the four-prong events, we obtained 5834 events (2151 at 13 GeV/c and 3683 at 20 GeV/c) corresponding to the reaction

$$\pi^- p \to p\pi^+\pi^-\pi^-. \qquad (1)$$

Figure 1(a) shows the uncut $\pi^+\pi^-\pi^-$ spectrum for these events together with the prediction of the Wolf one-pion-exchange model (OPEM)[6] normalized to the data between 2 and 3 GeV. In addition to the well-known $A1$, $A2$ peak, which we ignore here, there is a clear excess of events in the region 1.6 to 1.9 GeV which we initially assume to be our $A3$ signal. In order to reduce the background under the $A3$ peak we have imposed a cut on the four-momentum transfer squared from the target to the outgoing proton, $0.05 \leq |t_{pp}| \leq 0.25$ (GeV/c)^2, and in addition have removed events associated with a strong $\Delta^{++}(1236)$ signal, $1.15 < m(p\pi^+) < 1.35$ GeV. The 3π mass spectrum for events selected in this way is shown in Fig. 1(b). This sample of events was then used in an attempt to investigate the various possible decay modes in the $A3$ region. The Dalitz plots of $M^2(\pi^+\pi_1^-)$ versus $M^2(\pi^+\pi_2^-)$ for each of a set of 3π invariant mass intervals, 80 MeV in width, were partitioned by the ρ^0 and f^0 bands into six distinct regions, $A_{3\pi}$, $A_{\rho 3\pi}$, $A_{f3\pi}$, $A_{ff3\pi}$, $A_{\rho\rho 3\pi}$, and $A_{\rho f 3\pi}$,[7] from which we determined $N_{3\pi}$, $N_{\rho\pi}$, and $N_{f\pi}$, the numbers of 3π, ρ^0, and f^0 events corresponding to each 3π mass interval. The analysis was then repeated with the 3π mass intervals shifted by one-half interval width (40 MeV). This procedure requires several crude assumptions which appear to be consistent with the distribution of events, within the statistical limitations of the data, viz., that there are no interference effects and that pure 3π events are isotropically distributed over the entire Dalitz plot. The numbers $N_{\rho\pi}$, $N_{3\pi}$, and $N_{f\pi}$, are plotted in Fig. 2(a)–2(f) for the two different 3π mass binnings.

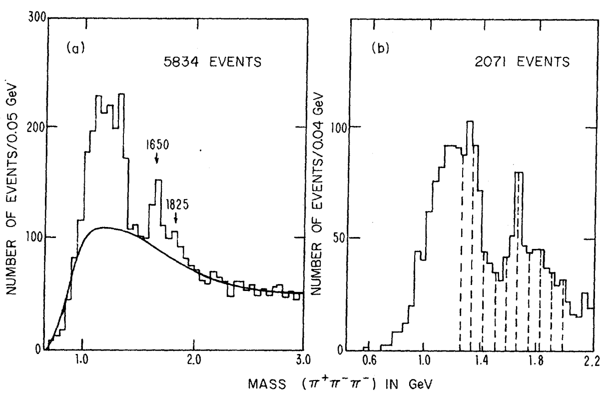

FIG. 1. (a) The uncut $\pi^+\pi^-\pi^-$ mass spectrum. The solid curve is the OPEM normalized to the data between 2.0 and 3.0 GeV. (b) The $\pi^+\pi^-\pi^-$ mass spectrum for events with no $\Delta^{++}(1236)$ [$1.15 < m(p\pi^+) < 1.35$ GeV] and with the four-momentum transfer squared from the target to the outgoing proton in the range $0.05 \leq |t_{pp}| \leq 0.25$ (GeV/c)^2. The dashed lines define the first set of 3π mass intervals used in the Dalitz-plot analysis.

The $N_{\rho\pi}$ plots [Figs. 2(a), 2(b)] show the decline from the $A2$, but no enhancement in the $A3$ region. However, in the $N_{3\pi}$ plots of Figs. 2(c) and 2(d), there is indication of a 3π effect centered at 1660 MeV. The $f^0\pi^-$ part of the cross section [Figs. 2(e), 2(f)] shows a broad peak in the region of 1.6–1.7 GeV. Since a threshold enhancement may be anticipated in the πf^0 cross section, we cannot, on the basis of this analysis, comment on the existence or size of a πf^0 resonance in this region. Although better statistics are clearly required for a definitive demonstration, we find some evidence for the existence of a pure 3π decay of the $A3$. This is in contrast to the results obtained from three similar analyses at lower energies[2,10,11] where the $f^0\pi$ mode was found to dominate. We can only comment that, because of the lower incident beam momentum,[12] the problem of background under the $A3$ peak is considerably worse in these cases [of the order of 3/1, background/signal, as opposed to approximately 1/1 in our sample of Fig. 1(b)]. However, a recent publication by Bassler *et al.*,[13] on 12-GeV/c π^+p interactions, tends to confirm our observation of a narrow 3π peak in addition to the

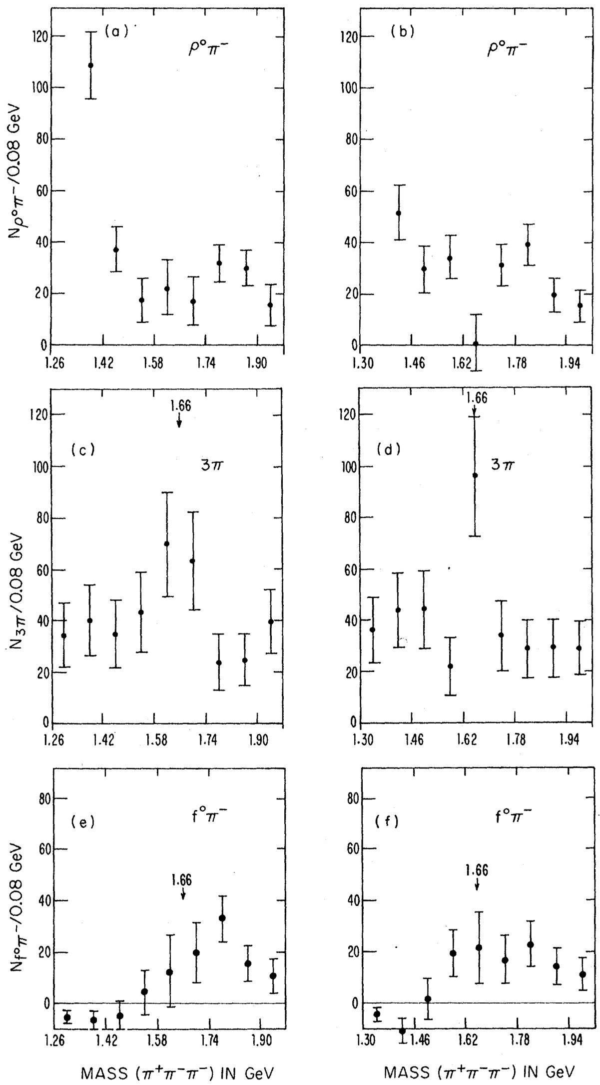

FIG. 2. (a), (b) Number of $\rho^0\pi^-$ events; (c), (d) number of $\pi^+\pi^-\pi^-$ events; (e), (f) number of $f^0\pi^-$ events from the Dalitz-plot analysis for each of the two sets of 3π mass intervals for events with no $\Delta^{++}(1236)$ [$1.15 < m(p\pi^+) < 1.35$ GeV] and with the four-momentum transfer squared from the target to the outgoing proton in the range $0.05 \leq |t_{pp}| \leq 0.25$ $(\text{GeV}/c)^2$.

broad $f^0\pi$ enhancement.

In attempting to obtain reliable measurements of the mass and width of the $A3$ from our total sample of data, we found the shoulder at about 1.8 GeV, which is evident in both Figs. 1(a) and 1(b), troublesome. The 3π mass was fitted in 25-MeV bins by a single Breit-Wigner term plus the OPEM background; the fit was poor. A second fit was made using two Breit-Wigner terms, which resulted in a much more acceptable χ^2. In all cases the simple relativistic form of the

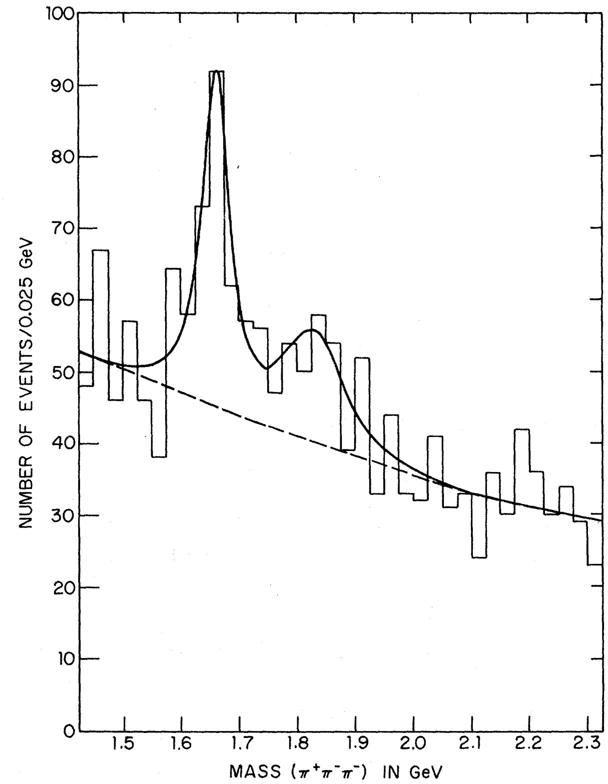

FIG. 3. The $\pi^+\pi^-\pi^-$ mass spectrum in the $A3$ region with the fit by an OPEM background plus two Breit-Wigner shapes.

Breit-Wigner term was used, and the mass, width, and percentage contribution allowed to vary. The results of these fits are shown in Table I and the second one is displayed in the data in Fig. 3. The shoulder at 1.8 GeV is some 4 standard deviations above the OPEM background. We repeated the fits using both a different background, hand drawn by interpolating from the regions on either side of the peaks, and different binnings of the data; in all cases we obtained essentially the same results. Comparable results were also obtained from fitting the 13- and 20-GeV/c data separately. From these separate fits we deduced the cross section for $A3$ production in Reaction (1) to be 36 ± 13 μb at 13 GeV/c and 24 ± 6 μb at 20 GeV/c.

Regardless of whether or not we adopt the hypothesis of a second peak, the $A3$ mass and width resulting from the fits are relatively stable at about 1658 and 55 MeV, respectively. Taking our best fit, which requires the addition of a second Breit-Wigner term with a fitted mass and width of 1829 and 127 MeV, respectively, we can quote

TABLE I. Least-squares fit to the 3π mass spectrum between 1.425 and 2.325 GeV.

Description of fit	A3 parameters M_0 (MeV)	A3 parameters Γ_0 (MeV)	A4 parameters M_0 (MeV)	A4 parameters Γ_0 (MeV)	$P(\chi^2)$
OPEM background plus one Breit-Wigner term	1660 ± 7	60 ± 20	···	···	0.066
OPEM background plus two Breit-Wigner terms	1658 ± 6	53 ± 16	1829 ± 20	127 ± 69	0.402

the mass and width of the $A3$ as

$$M_0 = 1658 \pm 8 \text{ MeV}, \quad \Gamma_0 = 53^{+20}_{-16} \text{ MeV},$$

where we have added to the statistical error derived from the fit an estimate of possible systematic shifts due to binning and choice of background. We note that since our observations[13] of well-known resonances (particularly ω^0) in this experiment occur at their accepted mass values, we expect systematic shifts in our mass determination to be negligible. The measurement of the width of the $A3$ has not been corrected for experimental resolution which we estimate to be about 20 MeV. While our value for the mass of the $A3$ is completely compatible with other current measurements,[1] the width that we obtain is substantially smaller than the world average of 107.7 ± 18.7 MeV.[1] Again it should be pointed out that this world value is based on experiments with an incident beam momentum less than 11 GeV/c.

In conclusion, we have shown that the $A3$ appears to have a substantial decay into 3π as well as into $f^0\pi^-$ and have measured its mass and width, obtaining for the latter a value distinctly less than the majority of the published values from lower-energy experiments. The data are best described by the addition of another peak at 1830 MeV, the precise nature of which is still in doubt.

It is a pleasure to acknowledge the assistance of the Brookhaven National Laboratory staff and the operating crews of the alternating gradient synchrotron and the 80-in. bubble chamber. We also wish to thank J. C. Street and K. Strauch for their continued help and encouragement. Finally we are indebted to our staff of scanning personnel for their diligent efforts.

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the reduced available phase space but also because of the higher cross section for $A2$ production and the resulting contribution from the $A2$ tail under the $A3$.

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Antiproton-Neutron Elastic Scattering near 1.8 GeV/c*

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Antiprotron-deuteron inelastic-scattering differential cross sections have been measured near 1.8 GeV/c. An impulse approximation is employed to extract antiproton-neutron differential cross sections. The technique allows us to study this reaction in a low-momentum-transfer region ($0.03 < |t| < 0.15$ GeV^2) never explored before. Our data indicate that the real part of the antiproton-neutron forward scattering amplitude is consistent with zero. A comparison of antiproton-proton and anitproton-neutron differential cross sections confirms the previously reported crossover phenomenon in the region of the first diffraction minimum.

The subject of hadron-hadron elastic scattering has long been of great experimental as well as theoretical interest in terms of exploring the strongly interacting structure of particles. It is known that hadronic elastic scattering on nucleon targets is mediated by an exchange of $I=0$ or $I=1$ particles in the t channel. Although Pomeranchukon exchange is believed to dominate in the asymptotic energy region, the importance of $I=1$ exchange cannot be neglected, particularly at energies currently available at accelerators. In the antiproton-nucleon system, the signs of the $I=1$ exchange amplitudes are different for proton and neutron targets. Therefore, the presence of an $I=1$ exchange amplitude would evidence itself as a difference in differential cross sections for proton and neutron targets. A survey of existing data reveals that, while elastic differential cross sections involving a proton target have been measured over a wide range of energies and momentum transfers, there exist very little data involving neutron targets. In some cases, for example $\pi^{\pm}n$ scattering, this problem can be avoided by substituting information from charge-symmetry-related $\pi^{\mp}p$ reactions. A similar argument can be made for pn scattering, which is identical to np scattering. But for reactions such as $K^{\pm}n$ and $\bar{p}n$, experiments on their charge-symmetry-related reactions are equally difficult to perform.

Traditionally, deuterons have been used to provide quasifree neutron targets. For χn elastic scattering, one would study the deuteron breakup reaction $\chi d \rightarrow \chi pn$. In the spirit of the impulse approximation, the deuteron breakup reaction has two components, that is, an elastic scattering against the proton and against the neutron. The momentum spectrum of the struck nucleon is mainly determined by the momentum transfer $|t|$ from the incident particle χ, and the spectator nucleon momentum may be calculated from the deuteron wave function. Overlapping between these two distributions is considerable and increases with decreasing $|t|$. The usual procedure employed to distinguish between collisions against the proton and those against the neutron is to call the slower nucleon in the laboratory the spectator. However, this procedure breaks down in the low $|t|$ region because of severely overlapping momentum distributions. Consequently, no reliable data on the low $|t|$ behavior of the elastic differential cross section can be obtained using this method. In this paper, we present a new approach, which has permitted a measurement of $\bar{p}n$ elastic scattering down to a momentum transfer squared of -0.03 GeV^2, using Glauber multiple-diffraction theory.[1] Presumably this approach could be applied to a variety of elastic scattering processes with a neutron as target.

The experiment was carried out using the Argonne National Laboratory zero-gradient synchrotron and the 30-in. liquid-deuterium bubble chamber. A total of 125 000 picutres were taken and the pictures were roughly evenly divided among antiproton momenta of 1.60, 1.75, 1.85, and 2.00 GeV/c. Approximately 85% of the film was used