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BACKWARD RHO PRODUCTION IN $\pi^- p$ REACTIONS AT 2.3 BeV/c*†

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In a sample of 8300 events of the type $\pi^-p\to\pi^-\pi^+n$ and 6800 events of the type $\pi^-p\to\pi^-\pi^0p$ obtained with 2.3-BeV/c incident π^-, substantial backward ρ^0 production is seen. The decay angular distribution of these backward ρ^0 events was found to be anisotropic. The u distribution for the backward ρ^0's is compared with the theoretical predictions of the strong-cut Reggeized absorption model. A small amount of backward ρ^- production is also seen.

Recent experimental work has shown indications of backward ρ production in πN interactions.[1] We present data on the reactions

$$\pi^-p\to\pi^-\pi^+n \text{ (8300 events)} \tag{1}$$

and

$$\pi^-p\to\pi^-\pi^0p \text{ (6800 events)} \tag{2}$$

at 2.3 BeV/c, where we have studied in detail the very backward-produced di-pions, i.e., those events for which the center-of-mass scattering angle θ_{pN} between the incoming proton and the outgoing nucleon is near 180°. We observe substantial ρ^0 production and a small amount of ρ^- production.

The data were obtained from an exposure of 2.3-BeV/c π^- in hydrogen in the Princeton-Pennsylvania Accelerator's 15-in. bubble chamber. About 50 000 two-prong events were measured using the flying-spot digitizer (Hough-Powell device) at the University of Pennsylvania in the minimum-guidance mode (i.e., the film was prescanned and the event vertices digitized). These events were then processed through the University of Pennsylvania automatic track-following and minimum-guidance events-recognition computer programs.[2,3] The failures (about 10%) were remeasured using conventional measuring machines. The standard CERN bubble-chamber analysis programs THRESH-GRIND were used to reconstruct and kinematically fit the events.

Because of the very accurate nature of the measuring technique,[3] the fraction of misidentified events due to poor measurement was less than 1% for Reaction (1) and less than 2% for Reaction (2). Also no more than 1% of the single-

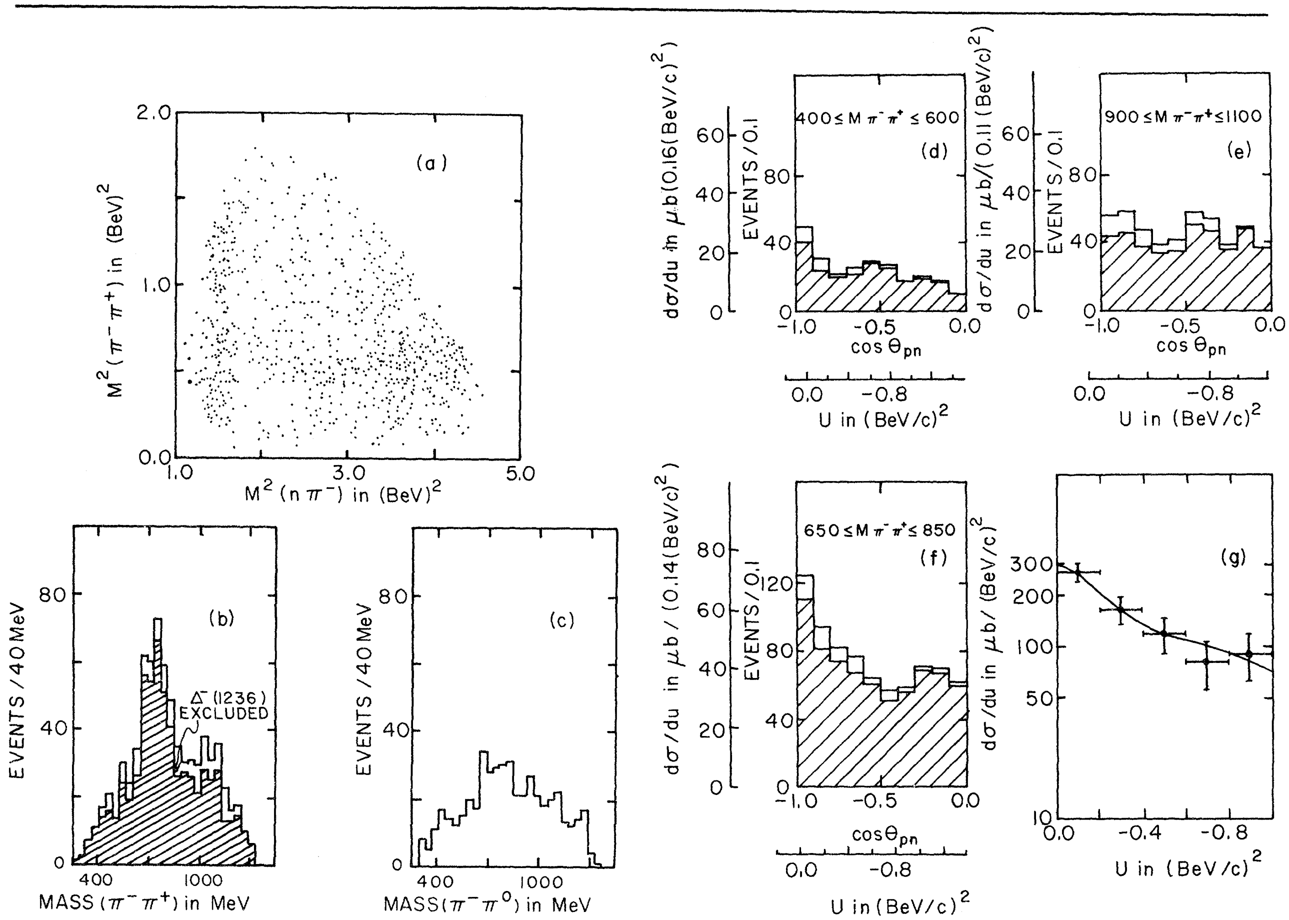

FIG. 1. (a) Dalitz plot for Reaction (1), and (b) the $\pi^-\pi^+$ mass distribution for Reaction (1), both for $\cos\theta_{pn} \le -0.7$; 767 events. (c) The $\pi^-\pi^0$ mass distribution for Reaction (2), $\cos\theta_{pp} \le -0.7$; 482 events. (d)-(f) $d\sigma/du$ for Reaction (1) for three mass intervals. Shaded region is for $\Delta^-(1236)$ excluded. The numbers of events for (d), (e), and (f) are 253, 482, and 763, respectively (before the Δ^- cut). (g) $d\sigma/du$ for 380 ρ^0 events of Reaction (1) (background subtracted; see text). The theoretical curve is the calculation of Kelly, Kane, and Henyey using the strong-cut Reggeized absorption model (see Ref. 4).

pion-production events were lost. The unique identification of the various event types, using kinematical constraints and ionization, was also better than 99%, because of the relatively low incident π^- momentum. In order to study the very backward-produced di-pions, we have selected those events for which $\cos\theta_{pN}$ is between -1.0 and -0.7. The Dalitz plot for Reaction (1) with this $\cos\theta_{pN}$ selection is shown in Fig. 1(a). A clear ρ^0 band is seen, centered at 0.56 BeV^2, and a $\Delta^-(1236)$ band is seen, centered at 1.54 BeV^2. We estimate the contamination of $\Delta^-(1236)$ events in the backward ρ^0 region (650-850 MeV) to be less than 10%. To remove the $\Delta^-(1236)$, events with π^-n mass in the range 1185-1285 MeV are deleted from the sample. Of these excluded events, 80% are true Δ^-, as determined from a mass plot of $M(n\pi^-)$ (not shown). Subsequent plots will be shown with and without this $\Delta^-(1236)$ cut.

The $\pi^-\pi^+$ invariant-mass spectrum for the very backward-produced di-pions of Reaction (1) is shown in Fig. 1(b). A ρ^0 peak is seen with a central value of 745 ± 10 MeV and a width of 150 ± 25 MeV. From this mass plot we estimate that about 50% of the events in the ρ^0 mass range of 650 to 850 MeV with $-1.0 \le \cos\theta_{pn} \le -0.7$ are background. The shaded histogram, corresponding to events with $\Delta^-(1236)$ excluded, also shows the same ρ^0 peak with about the same central mass and width.

The $\pi^-\pi^0$ mass spectrum for events of Reaction (2) with $\cos\theta_{pp}$ between -1.0 and -0.7 is shown in Fig. 1(c). A small ρ^- peak is seen with a central value of 745 ± 30 MeV and a width of 200 ± 60 MeV. There is about 70% background in the ρ^- region, i.e., $\pi^-\pi^0$ mass between 650 and 850 MeV. Because of the large background and reflections of πp resonances, no statistically significant study of backward ρ^- production can be made with these data.

Backward resonance production can be interpreted in terms of baryon exchange. We proceed to discuss the present data from the viewpoint that baryon exchange is in fact the primary mechanism responsible for the backward ρ. (We note that the fact that the backward ρ^- is much weaker than the backward ρ^0 is consistent with the interpretation that $T=\frac{3}{2}$ baryon exchange for backward ρ production is weaker than $T=\frac{1}{2}$ exchange.)

For baryon exchange, the significant variable is the momentum transfer u, the square of the four-momentum transfer from the initial π^- to the final nucleon. u is linearly related to $\cos\theta_{pN}$ for a definite $M(\pi\pi)$. In Figs. 1(d)-1(f) we show $d\sigma/du$ for backward di-pions in the ρ mass region and, to find out what the background looks like, we also show $d\sigma/du$ for mass regions above and below the ρ. These plots indicate that the non-ρ background has a relatively flat u distribution in the backward region, while the $d\sigma/du$ distribution for the ρ^0 region has a clear backward peak.

The determination of the true magnitude of $d\sigma/du$ for the backward ρ^0 events is not easy, as the size of the peak is about equal to the background. A simple subtraction of background would give the correct intensity for baryon-exchange production of backward ρ^0's only if there is no interference between the amplitude for that process and the amplitude for all other mechanisms producing events in this mass and angle range. An assumption of no interference cannot be justified. For example, at our incident momentum there may be an appreciable interference effect at "backward ρ^0" angles coming from di-pions produced by π exchange ("forward" di-pions). Nevertheless, in the absence of any explicit model, a simple background subtraction was made for the $d\sigma/du$ distribution in the ρ^0 mass region, using a flat background which was the approximate shape of $d\sigma/du$ averaged for masses above and below the ρ^0. The resulting $d\sigma/du$ distribution for the "ρ^0 events" is shown in Fig. 1(g). We have not plotted points for u greater than 0, since $u\simeq 0$ is the kinematical limit for $M(\pi^-\pi^+)=850$ MeV, the upper bound of our ρ mass region.

Kelly, Kane, and Henyey[4] have calculated $d\sigma/du$ for the reaction $\pi^-+p\to n+\rho^0$ using the strong-cut Reggeized absorption model with N and Δ trajectories. Their theoretical curve[5] for our momentum, with predicted absolute normalization, is plotted with our data in Fig. 1(g).

In order to study further the backward-produced di-pion state, the $\pi^-\pi^+$ decay angles have been plotted. The coordinate system chosen, which is illustrated in Fig. 2(a), is the convenient one for the study of the baryon-exchange hypothesis. The outgoing angle of the final π^- with respect to the incident proton in the di-pion center-of-mass system is denoted by $\theta_{\pi^- p}$, and the Treiman-Yang angle between the plane of the final π^- and the incident proton and the plane of the incident π^- and the final nucleon, in the di-pion center-of-mass system, is denoted by α_{TY}. The second of these planes is the same as the plane of the initial proton and the final nucleon. α_{TY} is defined in this coordinate system by

$$\cos\alpha_{TY}=\hat{n}_{21}\cdot\hat{n}_{14},$$

where $\hat{n}_{21}=\vec{p}_2\times\vec{p}_1/|\vec{p}_2\times\vec{p}_1|$ and $\hat{n}_{14}=\vec{p}_1\times\vec{p}_4/|\vec{p}_1\times\vec{p}_4|$,

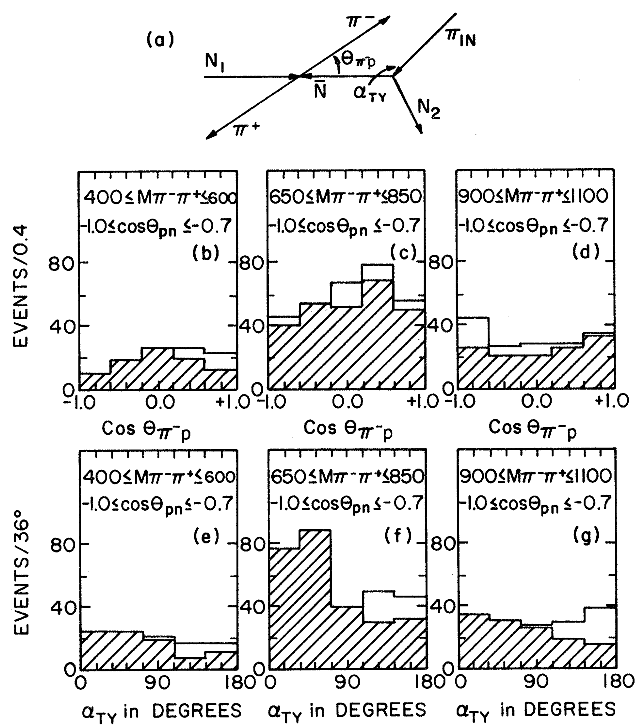

FIG. 2. (a) Illustration of two angles in the di-pion center of mass: $\theta_{\pi^- p}$, the production angle between the outgoing π^- and the incident p, and α_{TY}, the Treiman-Yang angle. (b)-(d) $\text{Cos}\theta_{\pi^- p}$ distributions; (e)-(g) α_{TY} distributions. Shaded region is for $\Delta^-(1236)$ excluded. For the three mass intervals shown, the number of events are, respectively, 103, 303, and 163 total (85, 268, and 128 with the Δ^- cut).

with $\vec{p}_1$, $\vec{p}_2$, and $\vec{p}_4$ equal, respectively, to the three-momentum of the initial proton, the outgoing π^-, and the outgoing neutron.

Figure 2(c) shows the $\cos\theta_{\pi^- p}$ distribution for events in the ρ-mass region 650-850 MeV, while Figs. 2(b) and 2(d) show the $\cos\theta_{\pi^- p}$ distribution for mass regions below and above the ρ. A small $\sin^2\theta_{\pi^- p}$ effect is seen for the ρ region, while the distributions averaged for masses above and below the ρ are approximately isotropic. The Treiman-Yang angular distributions for the same mass regions are shown in Figs. 2(e)-2(g). The Treiman-Yang angular distribution for the ρ region is very anisotropic and peaked toward 0°. For the regions above and below ρ, the Treiman-Yang distributions are approximately isotropic, becoming slightly anisotropic when the $\Delta^-(1236)$ events are removed (shaded area of graph).

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UPPER LIMIT FOR ELASTIC SCATTERING OF ELECTRON ANTINEUTRINOS BY ELECTRONS*

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A conservative upper limit of 4 times the prediction of $V-A$ theory has been determined for the process $\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$. The target detector used in a fission $\bar{\nu}_e$ flux of 2.8×10^{13} cm^{-2} sec^{-1} was a 7.84-kg plastic scintillator arrangement enclosed by 330 kg of NaI and a 2200-liter liquid detector, the latter two operated in anticoincidence with the plastic.

Experimental information regarding the antineutrino-electron scattering process $\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$ is of great interest to weak-interaction physics because it is a collision between two elementary particles which do not possess the strong interaction. Furthermore, the particles involved are in some sense nature's simplest, since they are stable end products of the weak interaction. The purpose of the present communication is to report recent progress in a program to test the predictions of the $V-A$ theory in this so far experimentally unchecked case.[2] The $\bar{\nu}_e$ source is one of the large fission reactors at the Savannah River Plant.

The experimental design is dictated by the requirement to discriminate against all reactions but the one of interest in the face of the fact that the expected cross section—assuming the theory of Feynman and Gell-Mann[3]—is so small and the resultant reaction seemingly nondescript. It early became clear that an overwhelming source of background promised to be due to gamma rays