Comparison of Inclusive Production of $\Delta^{++}(1236)$ at 15 and 303 GeV/c*†

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(Received 16 July 1973)

We have studied the inclusive reaction $\pi^- + p \rightarrow \Delta^{++} + X^{--}$ at 15 GeV/c and have compared our data with the data from the reaction $p+p \rightarrow \Delta^{++} + X^0$ at 303 GeV/c. We find that the Δ^{++} in these reactions is a decay product of a diffractively produced higher-mass object, a main component of which is a low-mass $\Delta^{++}\pi^-$ system.

A recent paper[1] studied the inclusive spectra of the $\Delta^{++}(1236)$ produced by 303-GeV/c protons incident on a hydrogen bubble chamber. We report here a similar analysis of the Δ^{++} produced by 15-GeV/c π^- incident on the SLAC 82-in. bubble chamber filled with hydrogen.

Our data were selected from a sample of 56 616 events measured with precision encoding and pattern recognition. The data selection was similar to Ref. 1. The basic difference between the two methods was that protons whose laboratory momentum was 1 GeV/c or less were chosen rather than 1.4 GeV/c or less, guaranteeing the positive identification of protons. The cut on the proton momentum resulted in a sample of 18 518 events.

It is important to know the detection efficiency for seeing a Δ^{++}. From simple kinematics, we can calculate our detection efficiency to be 100% for all Δ^{++} which have a $|t| < 0.5$ (GeV/c)$^{-2}$. By examining the t distribution for all the Δ^{++} in our sample, we conclude that we have at *least* a 90% detection efficiency for all Δ^{++} with $|t| < 1.0$ (GeV/c)^2.

Figure 1 compares the 15-GeV/c data with the 303-GeV/c data. Figures 1(a) and 1(a′) contain protons with $P_{\text{lab}} < 1.0$ GeV/c and $P_{\text{lab}} < 1.4$ GeV/c, respectively, while the pions have $P_{\text{lab}} < 1.4$ GeV/c. The solid curves on Figs. 1(a) and 1(a′) are the same as the hand-drawn curve of Ref. 1. The ordinates of these two figures have been chosen to give roughly the same figure height. Figures 1(b) and 1(b′) have the added restriction that the $p\pi^+$ system has $|t| < 1.0$ (GeV/c)^2, while Figs. 1(c) and 1(c′) have in addition the restriction that $P_\perp^2$ of the $p\pi^+$ system be less than 0.1 (GeV/c)^2. We conclude from these first six figures that the 15-GeV/c $p\pi^+$ system, selected in a manner similar to the 303-GeV/c sample, has almost identical characteristic, including background, as the 303-GeV/c sample.

Figures 1(d)-1(f) and 1(d′)-1(f′) are concerned with the $p\pi^-$ system. In order to have final states that contain as many $p\pi^-$ combinations as $p\pi^+$ combinations, we have plotted in the 15-GeV/c figures data only from events that contained one π^- whose laboratory momentum was greater than 3.0 GeV/c. The shapes of the curves and number of events displayed are insensitive to this cut.

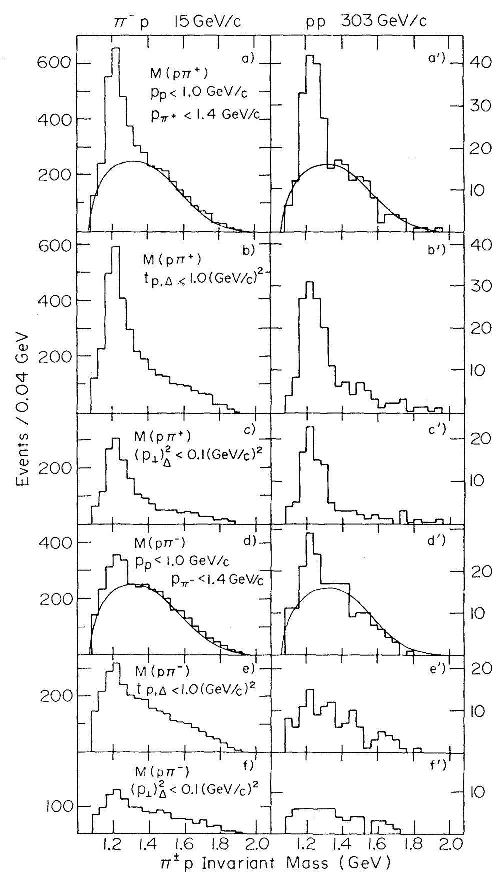

FIG. 1. (a′)-(f′) Copied from Ref. 1. (a)-(f) The equivalent data from this experiment. The solid lines are hand drawn, copied from Ref. 1. The cuts on the data are on the figures and explained in the text. The side-by-side figures refer to the same data, but from the two different experiments. See text for details.

Figures 1(d) and 1(d′) have the same additional restrictions as Figs. 1(a) and 1(a′). Again, the solid curves come from the 303-GeV/c paper.[1] There seems to be a small Δ^0 signal in both figures, but the main point we wish to emphasize here is that the 15- and the 303-GeV/c data display a remarkable similarity. Figures 1(e) and 1(e′) have the same additional restrictions as Figs. 1(b) and 1(b′), and 1(f) and 1(f′) have the same $P_\perp^2$ cut as Figs. 1(c) and 1(c′).

We will define our Δ^{++} sample by taking a mass cut on Fig. 1(b) such that $1.16 < m_{p\pi^+} < 1.32$ GeV and $|t_{p,p\pi^+}| < 1.0$ (GeV/c)^2, as was done in Ref. 1. Using this definition of the Δ^{++} we calculate the Δ^{++} cross section to be 0.91 mb. This number has an uncertainty of about 10% due to the normalization of our data to the total cross section and the estimate of our detection efficiency. This cross section is considerably lower than the 10 mb quoted for $p+p \to \Delta^{++}+X$ at 6.6 GeV/c.[1] The reduction by only a factor of 2 in the $p+p\to\Delta^{++}+X$ cross section in going from 6.6 to 303 GeV/c suggests a diffractive production mechanism.

Figures 2(a)–2(d) give the comparison of our Δ^{++} characteristics with those obtained in the 303-GeV/c experiment. Figures 2(a) and 2(b) compare the distributions of the Feynman variable x. These two distributions are quite similar, both peaking at $x \sim -0.8$. In Figs. 2(c) and 2(d) we compare the distribution of the $(P_\perp)_\Delta^2$. In Fig. 2(c) we make a fit to the first six points and calculate a slope of 8.2 ± 0.4 (GeV/c)$^{-2}$. This slope is consistent with the value of 6.75 ± 0.40 found for $\pi^- + p \to \Delta^{++}+X$ at 11.2 GeV/c.[2] In Fig. 2(d) we show the 303-GeV/c data with our slope of 8.2 (GeV/c)$^{-2}$ indicated by the solid line.

In both the 303- and the 15-GeV/c data, the missing-mass distribution of X peaks at about half of the respective center-of-mass energy. As indicated in Ref. 1, these facts can be the result of the Δ^{++} being a decay product of a heavier system.

We believe that Fig. 1, Figs. 2(a)–2(d), and the peaking of the invariant-mass distribution recoiling against the Δ^{++} are all convincing evidence that the mechanisms producing the Δ^{++} at 15 GeV/c are the same as those at 303 GeV/c.

Since we can measure the momentum of all charged tracks at 15 GeV/c, we can try to determine the origin of the Δ^{++} events at this energy. We have concluded that the Δ^{++} is almost always produced in association with a π^- as part of a low-mass system, which has all the characteristics of diffraction dissociation of the target

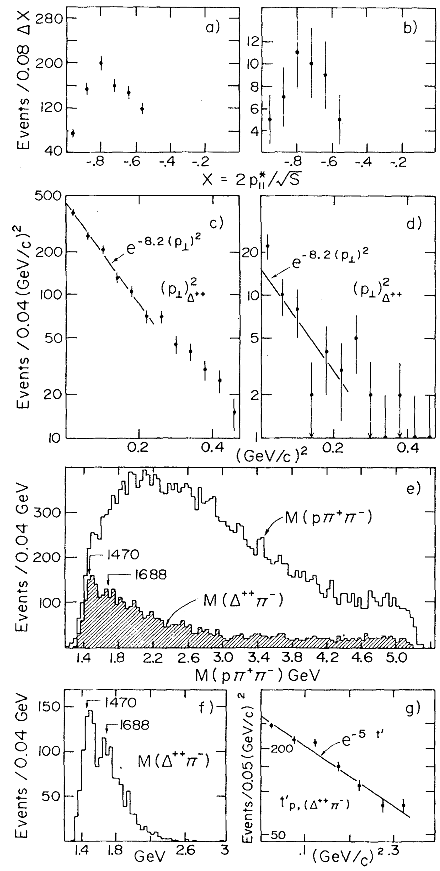

FIG. 2. (a), (b) Comparison of the x distributions for Δ^{++} produced at 16 and 303 GeV/c, respectively. (c), (d) Comparison of the $(P_\perp)_\Delta{}^2$ for 16 and 303 GeV/c, respectively. (e) Invariant mass of the $p\pi^+\pi^-$ system. The shaded area is the invariant mass of the $\Delta^{++}\pi^-$ system. See text for definition of the Δ^{++}. (f) Invariant mass of $\Delta^{++}\pi^-$ where the x of the π^- is between -0.2 and $+0.05$. (g) t' distribution for the events in (h).

nucleon. Figures 2(e)–2(g) display the results of our studies.

Figure 2(e) shows the invariant mass of the $p\pi^+\pi^-$ for all our data. The shaded area is the invariant mass of the $\Delta^{++}\pi^-$ combination. The main conclusion one can draw from this figure is that the Δ^{++} is predominantly produced in a low-mass system with a π^-. In order to isolate and study this low-mass system, we have calculated the Feynman variable x for all the π^+ and π^- mesons in our sample. Most of the mesons have an x close to zero, and the distribution in x is peaked near zero for both π^+ and π^-. Hence, we have chosen a cut on the x of the π^- such that $-0.2 < x < 0.05$. The width of the cut was determined by requiring that we account for our total

Δ^{++} sample, and the asymmetry of the cut was adjusted so that the invariant-mass distribution of the $\Delta^{++}\pi^-$ resembles the low-mass enhancement of Fig. 2(e). This shape, however, is not very sensitive to the cut chosen. Figure 2(f) is the invariant mass of $\Delta^{++}\pi^-$ combination where the π^- is in this x cut. As can be seen, this invariant-mass distribution faithfully reproduces the low-mass enhancement of the shaded part of Fig. 2(e). It is important to observe that there are clear $N^*(1470)$ and $N^*(1688)$ signals in this invariant-mass distribution. Both are $I=\frac{1}{2}$ resonances that are known to be diffractively produced. In addition, as expected, this cut has eliminated all the higher masses. This shape is very similar to shapes previously published[3,4] for nucleon diffraction dissociation.

Figure 2(g) is the $t'=|t-t_{\rm min}|$ distribution for the events in Fig. 2(f). The slope is 5.0 ± 0.5 $(\text{GeV}/c)^{-2}$ which is suggestive of a diffractive process. This slope is consistent with information known about the quasielastic diffractive production by 16-GeV/c π^- on protons of the $N^*(1470)$ and the $N^*(1688)$.[5] As a separate check on these ideas, we examined the four-prong, four-constraint class of our events.[6] In these events, the Δ^{++} is always produced with a π^- forming a low-mass enhancement similar to that shown in Fig. 2(f). Complete results on this study will be published elsewhere.

Given the above data, we conclude that the Δ^{++} seen here is produced with a π^- as part of a higher-mass diffractively produced system. The diffractive system in Fig. 2(f) may itself be part of a still higher-mass system but, given the t' distribution of these events as shown in Fig. 2(g), one would assume that such a higher-mass system was itself a diffraction product of the target. We therefore believe that for both momenta, the Δ^{++} is the decay product of a diffractively produced system whose major cascade component is represented by Fig. 2(f). This conclusion might modify some recent theoretical calculations[7] which try to explain the data in Ref. 1.

We wish to thank the bubble-chamber crew of the SLAC 82-in. chamber. We also wish to especially thank our scanning and measuring personnel.

*Accepted without review under policy announced in Editorial of 20 July 1964 [Phys. Rev. Lett. 13, 79 (1964)].

†Work supported by the U. S. Atomic Energy Commission.

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