π^0 production.[8] Unfortunately, the small solid angle of the LGW does not permit direct observation of η^0's.

In conclusion, there is no evidence that π^0 production is significantly different from π^+ or π^- production. There may be some excess production of γ's over what is predicted from the measured π^0 production cross section.

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[1]R. F. Schwitters, in *Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California, 1975,* edited by W. T. Kirk (Stanford Linear Accelerator Center, Stanford, Calif., 1975), p. 5.

[2]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 764 (1975).

[3]J. M. Feller *et al.*, IEEE Trans. Nucl. Sci. 25, 304 (1977).

[4]D. L. Scharre *et al.*, Phys. Rev. Lett. 40, 74 (1978).

[5]G. Goldhaber *et al.*, Phys. Rev. Lett. 37, 255 (1976).

[6]The relative insensitivity of the acceptance and trigger efficiency to major changes in the Monte Carlo calculation gives confidence in these corrections. The major uncertainty arises from the correction for events with zero or two produced prongs which are not in the data sample.

[7]This measurement is similar to previous measurements of the inclusive charged-particle spectrum {see G. G. Hanson, SLAC Report No. SLAC-PUB-2118, [in Proceedings of the Thirteenth Recontre de Moriond on High-Energy Leptonic Interactions and High-Energy Hadronic Interactions, 1978 (to be published)]}. The major change involves elimination of tracks which are not pions. K's and p's are eliminated by time-of-flight separation. (At higher momentum, the separation is based on extrapolation from the lower-momentum data.) Muon and electron contamination (on the order of a few percent) is corrected for in the Monte Carlo acceptance calculation.

[8]One of us (D.L.S.) has addressed the question of whether all of the center-of-mass energy can be accounted for by extrapolation of the observed inclusive particle cross sections to low momentum. This extrapolation was done using a jet-model Monte Carlo which includes effects due to the rest masses of heavy particles (kaons and nucleons), missing neutral kaons, neutrinos from τ, and charmed-particle decays, and we have made the additional, untested assumption that there is η^0 production on the order of 50% or more of the π^0 production. With these assumptions, this model can account for both the charged and neutral inclusive cross sections with no unaccounted-for energy.

Cross-Section Measurements for the Reactions $\nu p \to \mu^- \pi^+ p$ and $\nu p \to \mu^- K^+ p$ at High Energies

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We present results for the reactions $\nu p \to \mu^- \pi^+ p$ and $\nu p \to \mu^- K^+ p$ at energies above 5 GeV. The average cross section for the first reaction between 15 and 40 GeV is $(0.80 \pm 0.12) \times 10^{-38}$ cm^2 and for events with $M_{\pi^+ p} < 1.4$ GeV is $(0.55 \pm 0.08) \times 10^{-38}$ cm^2. The ratio of the cross section for the second reaction to that for the first is 0.017 ± 0.010.

We present results for the reactions $\nu p \to \mu^- \pi^+ p$ and $\nu p \to \pi^- K^+ p$ obtained from a 150 000-picture exposure of the Fermilab 15-ft bubble chamber, filled with hydrogen, to a wide-band horn-focused neutrino beam. The neutrino-event energy spectrum is roughly flat between 10 and 30 GeV then falls off such that ~90% of the spectrum is below 100 GeV. Details of the scanning, measurement, and reconstruction procedures will be given elsewhere.[1]

Events within a restricted fiducial volume and more than 50 cm from the downstream wall of the bubble chamber were fitted to the reactions

$$\nu p \to \mu^- \pi^+ p, \quad (1)$$

$$\nu p \to \mu^- K^+ p, \quad (2)$$

$$n p \to \pi^- p p, \quad (3)$$

$$K^0 p \to K^+ p \pi^-, \quad (4)$$

$$\bar{K}^0 p \to K^- p \pi^+, \quad (5)$$

using both the Fermilab HYDRA and Lawrence Berkeley Laboratory SQUAW kinematics programs. Events appearing to come from upstream events in the chamber or chamber wall were rejected. Reactions (1) and (2) are three-constraint (3-C) fits because the ν beam direction is known to better than 1 mr. A total of 225 events with $E_\nu > 5$ GeV obtained a fit to Reaction (1) with χ^2 confidence level $P(\chi^2) > 10^{-2}$. The $P(\chi^2)$ distribution was flat above this value. In all but four of the events the proton was uniquely identified either by stopping (seventy events) or by kinematic fitting.[2]

To restrict the sample to well-measured events only those where the fitted quantities are close to the measured quantities were kept. This was done by selecting events with $|P_z| < 0.12$ GeV and $|E_D| < 0.04$ GeV, where P_z is the net seen momentum out of the ν-μ plane and $E_D = P_L - (E_c - m_p)$ with P_L and E_c being the sum of the outgoing charged longitudinal momentum and energy, calculated with the mass assignment corresponding to the fit. To remove a small contamination from $\bar{\nu}$ events the selection $E_\pi < 7E_\mu$ was applied.

By comparing the $|E_D|$ and $|P_z|$ distributions from various samples we can estimate the background and losses for Reaction (1). The samples are as follows: (a) 3-C fit events to Reaction (1) with $P(\chi^2) > 10^{-2}$, (b) three-prong events with no 3-C fit with $P(\chi^2) > 10^{-4}$, (c) three-prong events with an associated V^0 or γ, and (d) five-prong events with a random positive and negative track discarded. For each event E_D and P_z were calculated using the mass assignment of Reaction (1) for the three charged tracks. For samples (b)–(d), if one positive track stopped it was assigned as the proton, otherwise the assignment giving the lower value of $|E_D|$ was used. The 3-C–fit sample (a) has 92% of the events with $|E_D| < 0.04$ GeV and $|P_z| < 0.12$ GeV, whereas samples (b), (c), and (d) have 5%, 3%, and 1%, respectively. From samples (c) and (d) (that have known missing particles) we can estimate the backgrounds to the selected 3-C–fit events from reactions such as $\nu p \to \mu^- \pi^+ p + m\pi^0$ and $\nu p \to \mu^- \pi^+ \pi^+ n$ $(+m\pi^0)$. However, since the clustering of $|E_D|$ and $|P_z|$ in the selected region is greater for sample (b) than for samples (c) and (d), we conclude after detailed examination of the forty sample-(b) events in this region that 25 ± 11 of them can be attributed to reactions with missing neutrals, and the remainder are classified as failed 3-C fits. Further, we conclude that the background to the selected 3-C–fit events from ν reactions with missing neutrals is <2% overall and <1% for events with $M_{\pi^+ p} < 1.4$ GeV. By comparing the fitted direction of the incoming neutral from Reactions (3)–(5) with that from Reaction (1) we conclude that backgrounds to Reaction (1) from hadron-induced reactions is negligible as is any background from Reaction (2). We obtain correction factors for true Reaction-(1) events with $|E_D|$ and $|P_z|$ in the selected region that fail to obtain a 3-C fit with $P(\chi^2) > 10^{-2}$ of 6% for the approximately fifteen events in sample (b) not attributed to backgrounds, 4% for fits with $10^{-4} < P(\chi^2) < 10^{-2}$, and 3% for overall processing losses, yielding a final

TABLE I. Numbers of fits to $\nu p \to \mu^- p \pi^+$ and fraction of true events lost by each successive cut.

	All		$M_{\pi^+ p} < 1.4$ GeV		$M_{\pi^+ p} > 1.4$ GeV	
	Number of events	Fraction of true events lost (%)	Number of events	Fraction of true events lost (%)	Number of events	Fraction of true events lost (%)
Fit to (1) $[P(\chi^2) > 1\%]$	225	13 ± 5	148	13 ± 5	77	14 ± 5
After E_D, P_Z cut	206	5 ± 3	138	4 ± 2	68	6 ± 3
After $\bar{\nu}$ cut = final clean sample	201	<1	138	0	63	<1
Corrected for all losses	245 ± 27	18 ± 7	166 ± 17	17 ± 5	79 ± 13	20 ± 9

correction factor of $(13\pm 5)\%$ where the error takes into account the systematic uncertainties in the estimates. The effects of the cuts and correction factors are summarized in Table I.

The π^+p mass distribution from the events fitting $\nu p\to\mu^-\pi^+p$ (Fig. 1) shows that this reaction is dominated by $\Delta^{++}(1236)$ production, but the accumulation of events with M_{π^+p} between 1.8 and 2.1 GeV could indicate the production of higher-mass Δ's. The Q^2 distribution $[Q^2=-(p_\nu-p_\mu)^2]$ from events with $M_{\pi^+p}<1.4$ GeV and $M_{\pi^+p}>1.4$ GeV (corresponding to a significantly broader distribution) are shown in Fig. 2. Details of the Δ^{++} production and comparisons with theoretical models will be presented in the following Letter.[3]

Cross-section measurements were obtained by comparing the data to the overall charged-current (CC) event sample (about 2000 events with $E_\nu>10$ GeV after cuts[1] normalized to recent total CC cross-section measurements.[4] Figure 3 shows the cross section for $M_{\pi^+p}<1.4$ GeV calculated for various energy intervals between 10 and 100 GeV, compared with results from a lower-energy experiment.[5] Our results are consistent with the lower-energy results, and consistent with an energy-independent cross section above 1 GeV. Over the energy range 15 to 40 GeV (where the normalization is least sensitive to the corrections made for hadronic backgrounds or the rapidly falling high-energy flux distribution), the average cross section for the reaction $\nu p\to\mu^-p\pi^+$ is $(0.80\pm 0.12)\times 10^{-38}$ cm^2, and for events with $M_{\pi^+p}<1.4$ GeV the cross section is $(0.55\pm 0.08)\times 10^{-38}$ cm^2. After one corrects for Δ^{++} events with $M_{\pi^+p}>1.4$ GeV, the average cross section for $\nu p\to\mu^-\Delta^{++}$ over the same energy range is $(0.63\pm 0.09)\times 10^{-38}$ cm^2, if we assume that the contribution from non-Δ background is negligible below 1.4 GeV.

The reaction (2), $\nu p\to\mu^-K^+p$, corresponds to an allowed $\Delta S=\Delta Q$ reaction which has not previ-

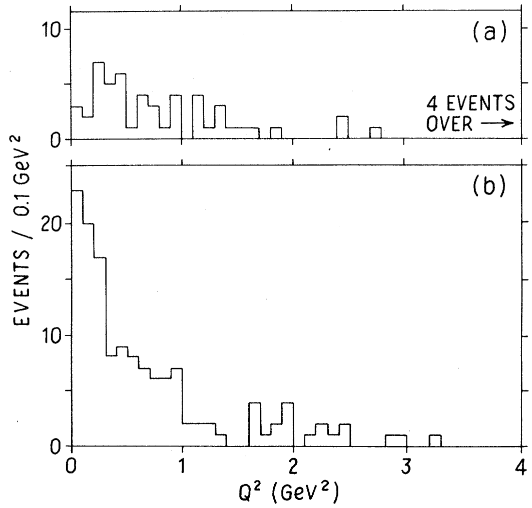

FIG. 2. The Q^2 distribution (a) for $M_{\pi^+p}>1.4$ GeV, and (b) for $M_{\pi^+p}<1.4$ GeV.

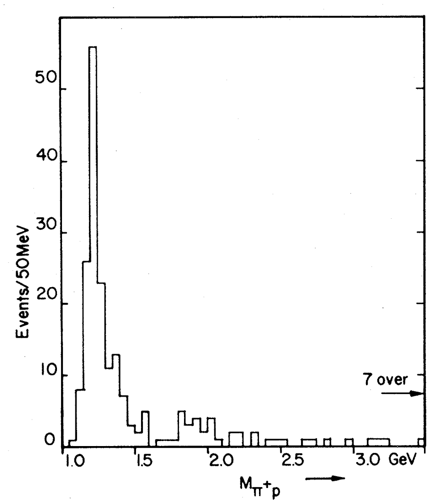

FIG. 1. The π^+p mass distribution from $\nu p\to\mu^-\pi^+p$.

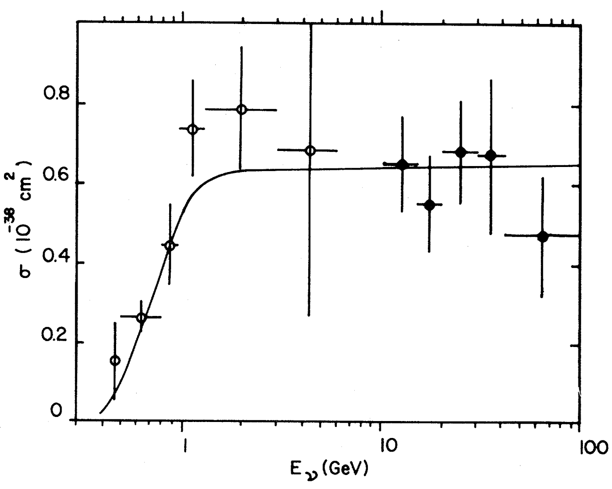

FIG. 3. The cross section for $\nu p\to\mu^-\Delta^{++}$ from this experiment (solid circles) and Ref. 5 (open circles) as a function of neutrino energy. The results from this experiment were obtained from the measured cross section for $\nu p\to\mu^-\pi^+p$ with $M_{\pi^+p}<1.4$ GeV corrected by 14% for Δ^{++} events with $M_{\pi^+p}>1.4$ GeV, on the assumption that the background from non-Δ^{++} events with $M_{\pi^+p}<1.4$ GeV is negligible. The curve is the prediction from a parametrized Adler dipole model (Ref. 3) with $M_A=1.0$ GeV.

ously been observed at these energies.[6] To obtain a sample of events for this reaction a slightly different procedure was used. The three-prong events were fitted with the 2-C hypothesis $\nu p \to \mu^- p M^+$, with the mass of the meson M^+ being a variable of the fit. Well-measured events were selected by the requirement $F \equiv P_L \Delta\lambda \Delta\varphi \Delta M^2 < 10^{-5}$ GeV^3, where $\Delta\lambda$ and $\Delta\varphi$ are the dip and azimuth uncertainty for the sum of all the measured tracks and ΔM^2 is the error on the square of the meson mass obtained from the 2-C fit. The distribution of M from 2-C fits with $F < 10^{-5}$ and $P(\chi^2) > 0.005$ is shown in Fig. 4.[7] For the bulk of the events the mass resolution is less than 20 MeV. The shaded events in Fig. 4 correspond to an even cleaner sample for which $P_L \Delta\lambda \Delta\varphi < 10^{-4}$ GeV and $\Delta M^2 < 0.03$ GeV^2. The three events at the K mass yield good 3-C fits to $\nu p \to \mu^- p K^+$ but no fits to Reaction (1). The proton assignment is unique from the 3-C fit and confirmed by ionization. We conclude that any background to these events is small,[8] well within the statistical errors quoted. Normalizing to the number of events that satisfy the same sample selection and get a 3-C fit to Reaction (1), we obtain the ratio of the cross sections $\sigma(\nu p \to \mu^- p K^+)/\sigma(\nu p \to \mu^- p \pi^+) = 0.017 \pm 0.010$, corresponding to a cross section of $(1.4 \pm 0.8) \times 10^{-40}$ cm^2 for Reaction (2) averaged over the neutrino energy spectrum above 5 GeV. In the quark parton model this can be estimated if we assume that it is of a similar magnitude to the inclusive $(\Delta S = \Delta Q)/(\Delta S = 0)$ ratio. Production of K^+ would be from $\bar{u}$ or s quarks in the sea and also suppressed by the Cabbibo angle. With the use of Field and Feynman[9] quark distributions (ignoring the effects of resonances), a ratio of about 1% is expected, which is consistent with our result.

To summarize, we have obtained a sample of events from the reactions (1) $\nu p \to \mu^- \pi^+ p$ and (2) $\nu p \to \mu^- K^+ p$ at energies between 5 and 100 GeV. Reaction (1) is dominated by production of $\Delta(1236)$ and the cross section for $\nu p \to \mu^- \Delta^{++}$ is consistent with being energy independent above 1 GeV. The average cross section for Reaction (1) between 15 and 40 GeV is $(0.80 \pm 0.12) \times 10^{-38}$ cm^2 and for events with $M_{\pi^+ p} > 1.4$ GeV is $(0.55 \pm 0.08) \times 10^{-38}$ cm^2. The ratio of the cross sections for Reactions (2) to (1) is 0.017 ± 0.010.

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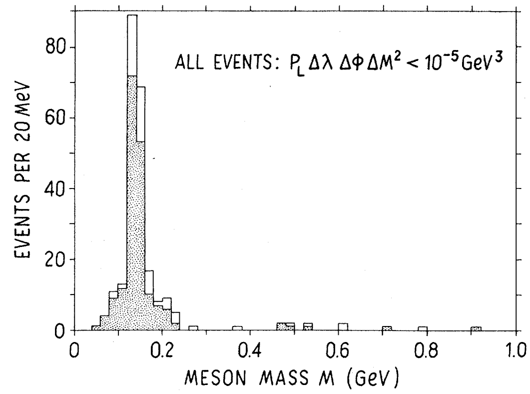

FIG. 4. The meson mass distribution from events that fit $\nu p \to \mu^- p\, M^+$, as described in text. The shaded area is with the additional selections $P_L \Delta\Phi\ \Delta\lambda < 10^{-4}$ GeV, $\Delta M^2 < 0.03$ GeV^2.

[1]Experimental details will be given in J. Bell *et al.*, "Experimental Study of Hadrons Produced in High Energy Neutrino Proton Interactions" (to be published).

[2]Three of the four ambiguous events are removed by the subsequent cuts. For the other event the fit with the maximum $P(\chi^2)$ was kept.

[3]J. Bell *et al.*, following Letter [Phys. Rev. Lett. 41, 1012 (1978)].

[4]B. C. Barish *et al.*, Phys. Rev. Lett. 39, 1595 (1977); P. C. Bosetti *et al.*, Phys. Lett. 70B, 273 (1977). The cross-section measurements were parametrized as $\sigma_{\nu N}{}^{\text{tot}} = [0.77 - 0.085 \log_{10}(E)]E \times 10^{-38}$ cm^2 (E in GeV). $\sigma_{\nu p}$ was obtained with $\sigma_n/\sigma_p = 1.93 \pm 0.05$ as calculated using quark distributions of R. D. Field and R. P. Feynman, Phys. Rev. D 15, 2590 (1977).

[5]J. Campbell *et al.* Phys. Rev. Lett. 30, 335 (1973).

[6]One event of this type has been reported at lower energies in S. J. Barish *et al.*, Phys. Rev. Lett. 33, 1466 (1974).

[7]Some events fit either track assigned as proton, in which case the solution with M^+ closest to the π mass is plotted.

[8]The event with M^+ at 522 MeV does not fit Reaction (2), M^+ being 4 standard deviations from the K^+ mass, and also one track is a $\pi\mu e$ decay. All three events obtain 1-C fits to Reaction (4), but in two cases the negative track is identified as a μ^- in the external muon identifier and the other event has $y = 0.02$, indicating that reaction (2) is the correct fit. Each event is consistent with being $\nu p \to \mu^- p\ \pi^+ \pi^0$, but this background is ruled out by the lack of events with M^+ between the π and K mass in Fig. 4.

[9]Field and Feynman, Ref. 4.