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CROSS SECTION MEASUREMENTS FOR THE REACTIONS $\nu p \rightarrow \mu^- \pi^+ p$ and $\nu p \rightarrow \mu^- K^+ p$ at HIGH ENERGIES

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Abstract

We present results for the reactions (1) $\nu p \to \mu^- \pi^+ p$ and (2) $\nu p \to \mu^- K^+ p$ at energies above 5 GeV. The average cross section for the first reaction between 15 and 40 GeV is $(0.80 \pm .12) \times 10^{-38}$ cm^2 and for events with $M_{\pi^+ p} < 1.4$ GeV is $(0.55 \pm .08) \times 10^{-38}$ cm^2. The ratio of the cross sections for reactions (2) to (1) is $0.017 \pm .010$.

We present results for the reactions $\nu p \to \mu^- \pi^+ p$ and $\nu p \to \mu^- K^+ p$ 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 peaks at about 15 GeV with ~ 90% of the spectrum 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 fit to the reactions:

$$\nu p \to \mu^- \pi^+ p \qquad (1)$$
$$\nu p \to \mu^- K^+ p \qquad (2)$$
$$np \to \pi^- pp \qquad (3)$$
$$K^\circ p \to K^+ p \pi^- \qquad (4)$$
$$\bar{K}^\circ p \to K^- p \pi^+ \qquad (5)$$

using both the Fermilab HYDRA and LBL SQUAW kinematics programs.[2a] Events appearing to come from upstream events in the chamber or chamber wall were rejected. Reactions (1) and (2) are 3 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. To obtain a purer sample and facilitate background estimation the additional selections $|E_D| < 0.04$ GeV, (where $E_D = P_L - (E_c - m_p)$ with P_L and E_c being the sum of the outgoing charged longitudinal momentum and energy) and $|P_z| < .120$ GeV where P_z is the sum of the momentum transverse to the ν-μ plane, were made. Since E_D and P_z should be zero for a perfectly measured event, these cuts remove those events where the fitted quantities are considerably different from the measured values. To remove a small contamination from $\bar{\nu}$ events the selection $E_\pi < 7\, E_\mu$ was also applied.

The E_D and P_z distributions from the samples: (a) events with an accepted 3-C fit to reaction (1), (b) 3 prong events with no 3-C fits, (c) 3 prong events with an associated V° or γ, (d) 5 prong events with a random positive and negative charged track discarded, were compared. Samples

(c) and (d) did not cluster at low values of E_D and P_z whereas (a) did so strongly and (b) showed some residual clustering, which we attribute to 3-C events failing to obtain a kinematics fit. We estimate that 13±5% of true $\nu p \to \mu^- p \pi^+$ events failed to obtain a kinematic fit with $P(\chi^2) > 1\%$.[2b] Also from the above comparison we estimate the background to the selected 3-C fits from events with missing neutrals to be negligible. Any background to reaction (1) from reaction (2) is also negligible. Backgrounds from hadronic induced reactions were studied by comparing the fitted direction of the incoming neutral from reactions (3)-(5) with the distribution for the 3-C fits. The conclusions from all these studies are that the background to the selected sample of fits to reaction (1) is < 2% overall, and < 1% for events with $\pi^+ p$ invariant mass $M_{\pi^+ p} < 1.4$ GeV. The effects of the cuts and correction factors are summarized in Table I.

The $\pi^+ p$ mass distribution from the events fitting $\nu p \to \mu^- \pi^+ p$ (Fig. 1) shows this reaction is dominated by Δ^{++} (1236) production, but the accumulation of events with $M_{\pi^+ p}$ 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 succeeding letter[6].

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[3]. Fig. 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 $(0.80 \pm .12) \times 10^{-38}$ cm^2, and for events with $M_{\pi^+ p} < 1.4$ GeV the cross section is $(0.55 \pm .08) \times 10^{-38}$ 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 $(.63 \pm .09) \times 10^{-38}$ cm^2, assuming 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 previously been observed at these energies.[7] To obtain a sample of events for this reaction a slightly different procedure was used. The three prong events were fit 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. 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 $\nu p \to \mu^- p K^+$ and the background is small. 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 $(1.4 \pm .8) \times 10^{-40}$ cm^2 for reaction (2) averaged over the neutrino energy spectrum above 5 GeV. In the quark parton model this can be estimated assuming 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. Using Field and Feynman[4] 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 $(0.80 \pm .12) \times 10^{-38}$ cm^2 and for events with $M_{\pi^+ p} < 1.4$ GeV is $(0.55 \pm .08) \times 10^{-38}$ cm^2. The ratio of the cross sections for reactions (2) to (1) is $0.017 \pm .010$.

We wish to thank the members of the Neutrino Laboratory at Fermilab and the scanning, measuring and secretarial staff at our respective laboratories for their contribution to this experiment.

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References and footnotes

1) Experimental details will be given in "Experimental study of hadrons produced in high energy neutrino proton interactions," J. Bell et al., (submitted to Phys. Rev. D).

2a) There is no significant difference between the results of the two kinematic programs.

2b) The 13±5% estimated kinematic fit loss includes 4% of the events that obtain fits with $10^{-4} < P(\chi^2) < 10^{-2}$.

3) B.C. Barish et al., Phys. Rev. Lett 39, 1595 (1977) and P.C. Bosetti et al., Phys. Lett. 70B, 273 (1977). The cross-section measurements were parameterized as $\sigma^{tot}_{\nu N} = [0.77 - 0.085 \log_{10}(E)] \times E \times 10^{-38}$ cm^2 (E in GeV). $\sigma_{\nu p}$ was obtained with $\sigma_n/\sigma_p = 1.93 \pm .05$ as calculated using quark distributions of Ref. 4.

4) R.D. Field and R.P. Feynman, Phys. Rev. D15, 2590 (1977).

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

6) J. Bell et al., A Study of the reaction $\nu p \to \mu^- \Delta^{++}$ at high energies and comparison with theory. (following paper)

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

Figure Captions

1. The π^+p mass distribution from $\nu p \to \mu^-\pi^+p$.
2. The Q^2 distribution (a) for $M_{\pi^+p} > 1.4$ GeV, (b) for $M_{\pi^+p} < 1.4$ GeV.
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, assuming 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[6] with $M_A = 1.0$ GeV.
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, $\Delta M^2 < .03$ GeV^2.

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	fract true[a] events lost	Number of events	fract true events lost	Number of events	fract 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%

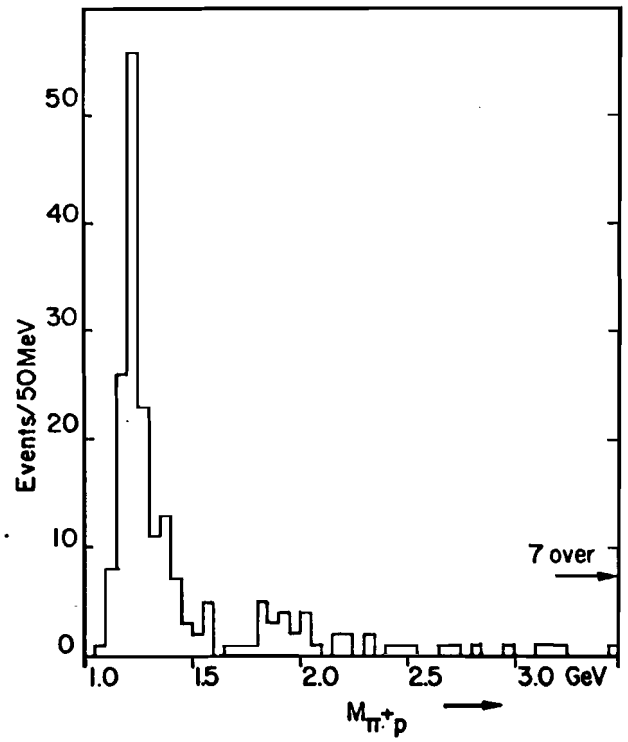
Events/50MeV
50
40
30
20
10
0
7 over
1.0
1.5
2.0
2.5
3.0 GeV
M_{π^+p}

Fig. 1

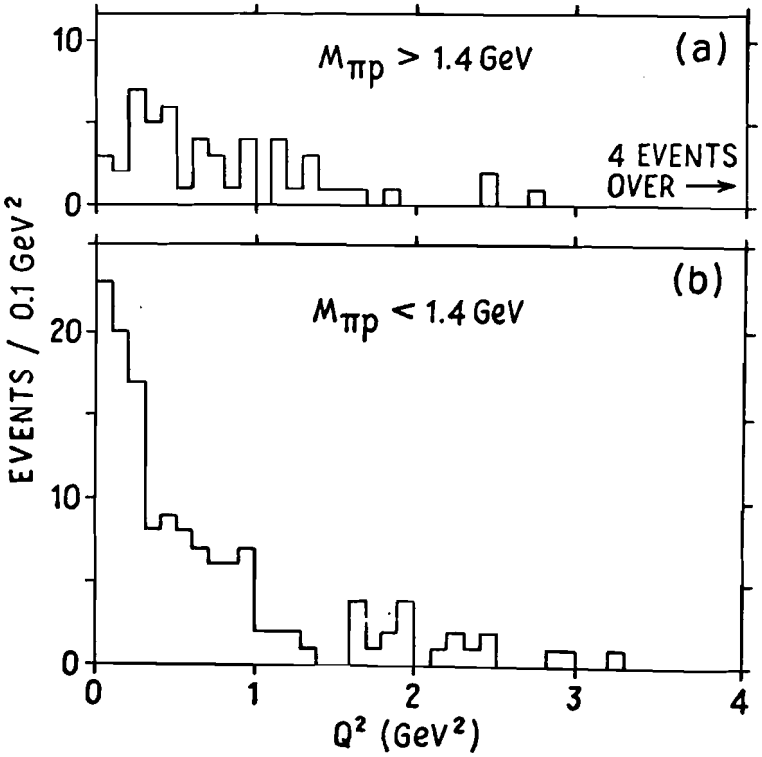
$M_{\pi p} > 1.4$ GeV
(a)
4 EVENTS OVER
$M_{\pi p} < 1.4$ GeV
(b)
EVENTS / 0.1 GeV²
10
0
20
10
0
1
2
3
4
Q^2 (GeV²)

Fig. 2

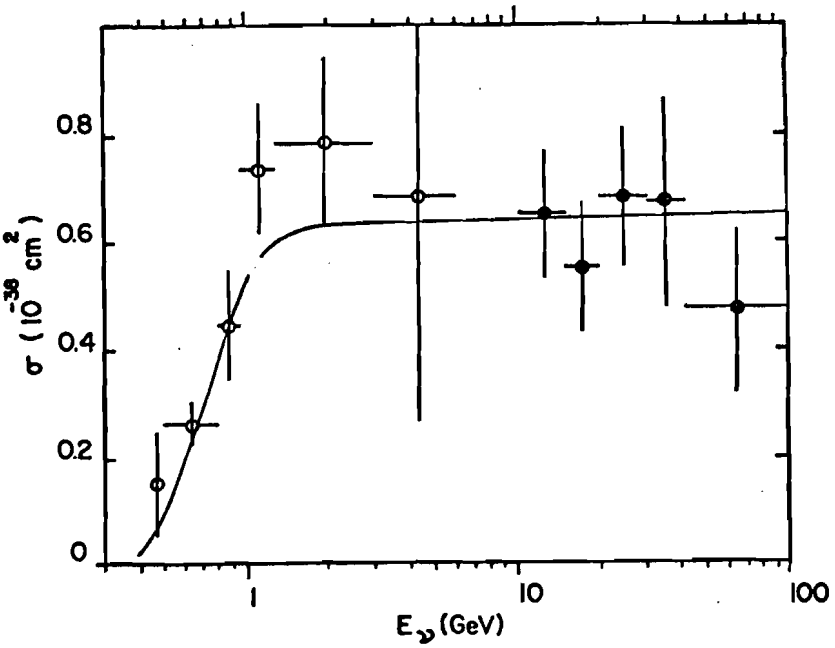
0.8
0.6
0.4
0.2
0
σ (10^-38 cm^2)
1
10
100
E_ν (GeV)

Fig. 3

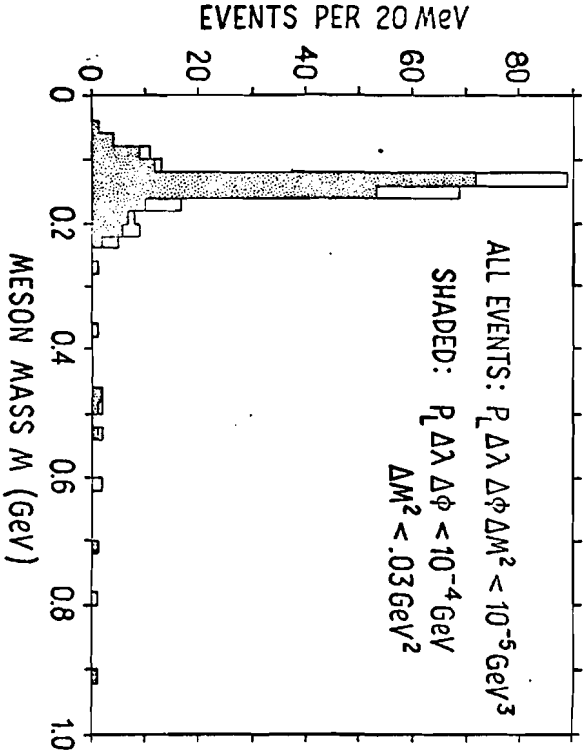
EVENTS PER 20 MeV
0
20
40
60
80
0
0.2
0.4
0.6
0.8
1.0
MESON MASS M (GeV)
ALL EVENTS: P_L Δλ ΔΦ ΔM² < 10⁻⁵ GeV³
SHADED: P_L Δλ ΔΦ < 10⁻⁴ GeV
ΔM² < .03 GeV²

Fig. 4