Inclusive Strange-Particle Production by νp Interactions in the 10–200-GeV Region*

J. P. Berge, D. Bogert, D. C. Cundy,† F. A. DiBianca, A. Dunaitsev,‡ V. Efremenko,§
P. Ermolov,‡ W. Fowler, R. Hanft, G. Harigel,† F. R. Huson, V. Kolganov,§ A. Mukhin,‡
F. A. Nezrick, Y. Rjabov,‡ W. G. Scott, and W. Smart
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

C. T. Coffin, R. N. Diamond, H. French, W. Louis, B. P. Roe, A. A. Seidl, and J. C. Vander Velde
University of Michigan, Ann Arbor, Michigan 48104

(Received 17 November 1975)

Data are presented on charged-current inclusive strange-particle production in 10–200-GeV/c νp interactions. Final states with V^0 decay topologies are reported: $K_s^{\,0}$, Λ^0 (Σ^0), $\overline{\Lambda}^0$ ($\overline{\Sigma}^0$). Neutrino energy, charged multiplicity, Q^2, W, x, and y distributions are shown. The corrected relative V^0 production rate is 0.16 ± 0.03 per event. The first example of neutrino-induced antibaryon ($\overline{\Lambda}$) production is observed. The 90%-confidence upper limit on $\Delta S = -\Delta Q$ inclusive Λ production is 0.036 of all charged-current νp interactions above 10 GeV/c.

Strange-particle production by neutrinos is expected to provide considerable information on the nature of the weak interaction. Indeed the *raison d'etre* of the Glashow-Iliopoulos-Maiani[1] charm hypothesis is to suppress adequately strangeness-changing weak neutral currents.

We present results on V^0 strange-particle production in νp interactions from a 62 000-photograph exposure of the Fermilab 15-ft bubble chamber to a wide-band neutrino beam. To select the charged-current sample we take as muon the highest-transverse-momentum negative track, which we require to lie on the opposite side of the neutrino direction from the vector sum of all remaining track momenta. The total background in the V^0 sample is approximately 15% and arises from interactions of neutrons, $K_L^{\,0}$, $\overline{\nu}$, ν neutral currents, and charged-current events in which the muon is misidentified. To estimate (to about ± 10%) the neutrino energy E_ν we take the total hadron direction as that of the visible hadrons projected onto the μ-ν plane and use transverse-momentum balance. Further experimental details and discussions of the analysis procedures are given elsewhere.[2]

Using this prescription, we restrict the final event sample to have visible longitudinal momentum greater than 7 GeV/c and E_ν greater than 10 GeV. The yields of V^0 events in this sample of 543 charged-current events are given in Table I. The corrected relative V^0 production rate is 0.16 ± 0.03 per event. Contributions from non-V^0 topologies (e.g., K^+, K^+K^-, $\Sigma^\pm K^+$) are not included in this determination. The observed rate appears to exceed earlier theoretical estimates.[3] In the low-energy neutrino experiment of Barish *et al.*,[4] the rate $\sigma(\nu n \to \mu^- \Lambda K^+)/\sigma(\nu N \to \mu^- N + \text{pion})$ equaled 0.04 ± 0.03.

The distributions in reconstructed neutrino energy and in charged-particle multiplicity are given in Figs. 1(a) and 1(b), respectively. The smooth curves represent the total charged-current distributions normalized to the V^0 data.

The inclusive deep inelastic parameters of the V^0 data are shown in Figs. 1(c)–1(f). The W, Q^2,

TABLE I. Yields of events with V^0 decays.

V^0 decay	No. events observed with visible V^0 decays	Inclusive No. events corrected[a]	No. events corrected[a,b]
$K_s^{\,0}$	16	61.2 ± 14.0	43.8 ± 11.0
Λ^0 (Σ^0)	17[c]	36.0 ± 8.0	18.6 ± 4.5
$K_s^{\,0}\Lambda^0$ (Σ^0)	3	∘••	17.4 ± 10.0[d]
$\overline{\Lambda}^0$ (Σ^0)	1	1.6	1.6
$3V^0$	1	•••	7
Total	38	•••	88.4 ± 17.0

[a] We assume that the numbers of $K_s^{\,0}$ and $K_L^{\,0}$ decays are equal and correct for invisible decays, finite chamber size, and $1V^0$-$2V^0$ mixing for invisible decays. No $K_s^{\,0}K_s^{\,0}$ correction has been applied.

[b] This means, for example, the corrected number of events with K^0 and no Λ (detected or undetected).

[c] Including one $\Sigma^0 \to \Lambda\gamma$ decay with both Λ and γ visible.

[d] This channel has contributions from both of the above listed channels.

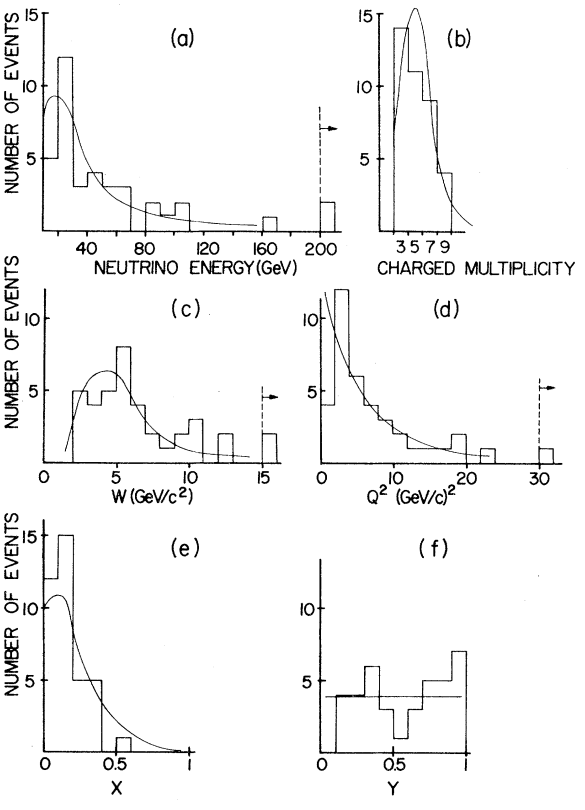

FIG. 1. Inclusive distributions for charged-current events with V^0 decays: (a) reconstructed neutrion energy, (b) charged multiplicity, (c) W, (d) Q^2, (e) x, (f) y.

x, and y distributions agree within statistics with the normalized total charged-current data. We compare in Fig. 2 the W dependence of the relative V^0 rates from neutrino production, electroproduction,[5] and photoproduction.[6] Again, no significant differences are evident.

An example of antibaryon production by neutrinos has been observed. The event topology is five charged prongs with an associated unambiguous $\bar{\Lambda}$ as well as an associated single-prong recoil. Two γ's are associated with the single-prong recoil. The visible longitudinal momentum is 19.1 GeV/c so that production by a hadron is improbable. [The relative event density is

$$\frac{dN(\text{hadrons})/dE}{dN(\text{neutrinos})/dE} < 0.02$$

near 19 GeV/c.] The probability of production by an antineutrino is two orders of magnitude lower than for a neutrino. Since the event satisfies the charged-current reconstruction procedure, we assume it to be such but cannot rule out a neutral-current interpretation.

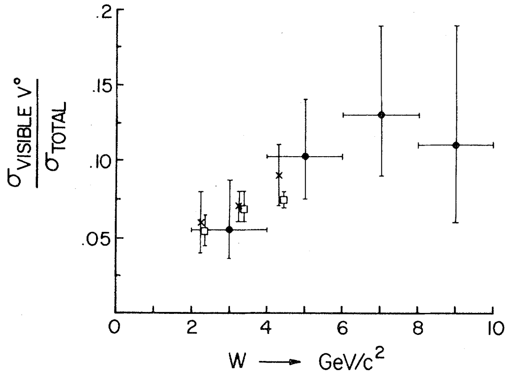

FIG. 2. Comparison of V^0 decay yields versus W for, circles, neutrino-production (νp data corrected for decay length but not for neutral modes); crosses, electroproduction; and, squares, photoproduction.

On the basis of this single event, the relative rate $N_{\bar{\Lambda}}/N_\nu$(charged current) is approximately 0.003. Other parameters of the event are $E_\nu = 24.3$ GeV, $Q^2 = 12.6$ (GeV/c)^2, $W = 5.6$ GeV/c^2, $x = 0.30$, and $y = 0.94$.

Finally, we use the seventeen Λ^0 and three $\Lambda^0 K_s^0$ events observed to set an upper limit on $\Delta S = -\Delta Q$ inclusive Λ^0 production, an example of which has been reported by Cazzoli *et al.*[7] We take $N_\Lambda(\text{observed}) = N_\Lambda + N_{\Lambda K_s^0}$, where $N_\Lambda = N_\Lambda(\Delta S = -\Delta Q) + N_{\Lambda[K]}$. Here $N_{\Lambda[K]}$ is the number of ΛK^+ events plus the number of ΛK^0 events with undetected K^0 decays. If we assume that the rates for $\nu p \to \mu^- \Lambda K^0 X^{++}$ and $\nu p \to \mu^- \Lambda K^+ X^+$ are equal (the result is insensitive to this ratio), then $N_\Lambda(\Delta S = -\Delta Q) = N_\Lambda - 5.4 N_{\Lambda K_s^0} = 17 - 5.4 \times 3$ events. The 90%-confidence upper limit on $N_\Lambda(\Delta S = -\Delta Q)/N_{\text{tot}}$(charged current) is 3.6% for E_ν above 10 GeV. The final number includes all corrections for undetected Λ and K^0 decays.

We appreciate the efforts of Fermilab personnel for making this exposure possible and thank our respective scanning staffs. Discussions with C. Albright, M. Einhorn, B. Lee, J. Rosner, R. Shrock, and C. Quigg have been very helpful.

---

*Work supported by the Energy Research and Development Administration.

†Permanent address: CERN, Geneva, Switzerland.

‡Permanent address: Institute of High Energy Physics, Serpukhov, U. S. S. R.

§Permanent address: Institute of Theoretical and Experimental Physics, Moscow, U. S. S. R.

[1] S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D $\underline{2}$, 1285 (1970).

[2] J. P. Berge *et al.*, to be published.

[3] C. H. Albright, to be published.

[4] S. J. Barish *et al.*, Phys. Rev. Lett. $\underline{33}$, 1446 (1974).

[5] J. Ballam *et al.*, Phys. Lett. $\underline{56B}$, 193 (1975).

[6] J. Ballam *et al.*, Phys. Rev. D $\underline{5}$, 545 (1972); H. H. Bingham *et al.*, Phys. Rev. D $\underline{8}$, 1277 (1973).

[7] E. G. Cazzoli *et al.*, Phys. Rev. Lett. $\underline{34}$, 1125 (1975).

Charge Distribution of ^{208}Pb and the Difference in $\rho(r)$ for Pb and Tl Investigated by by Elastic Electron Scattering

H. Euteneuer, J. Friedrich, and N. Voegler
Institut für Kernphysik der Johannes Gutenberg Universität, 65 Mainz, Federal Republic of Germany

(Received 29 September 1975)

Elastic electron-scattering cross sections from ^{208}Pb have been measured for $0.5\ \mathrm{fm}^{-1} < q < 2.24\ \mathrm{fm}^{-1}$. The charge distribution for this nucleus is determined by a "model-independent" method; it exhibits a bump in the center of the nucleus which is also a characteristic feature of Hartree-Fock calculations. The influence of the 3*s* protons on $\rho(r)$ has been investigated by a difference measurement between lead and thallium isotones.

As a characteristic result of previous electron-scattering experiments on ^{208}Pb the extracted charge distribution exhibited a depression in the center of the nucleus.[1-3] In the following years it was not possible to reproduce this central dip with Hartree-Fock (HF) calculations.[4-6] On the contrary, all calculations yield a central bump, which is mainly due to the 3*s* protons. More recent model-independent evaluations[7,8] of the data from Ref. 2 demonstrated that the cross sections are compatible with a bump, but there remained a discrepancy with HF calculations as well as with muonic data.[12] Because of the importance of this problem the measurement has been repeated with the Mainz electron-scattering facility. In order to get some additional information on the contribution of the last single nucleons (in particular the 3*s* protons), we also measured cross-section ratios between ^{208}Pb and the neighboring nuclei ^{203,205}Tl, ^{204,206,207}Pb, and ^{209}Bi.

The scattering facility has been described in detail by Ehrenberg *et al.*,[9] and therefore only the data of this experiment are given here. The measurements were performed with incident energies of 119.7, 199.5, and 289.0 MeV in a q range from 0.5 to 2.24 fm^{-1}. The heavy nuclei have been measured "simultaneously" with a fast target-exchange equipment; thus errors due to drifts in the scattering apparatus should cancel. The absolute cross-section values have been measured relative to ^{12}C, where the reference carbon cross sections were computed with a charge distribution determined recently in Mainz from new absolute measurements.[10] Many of the points were reproduced several times. In addition to the error from counting statistics we estimated an uncertainty of ±0.5% for the cross-section ratios and of ±0.8% for the cross sections relative to carbon. This uncertainty was added quadratically to the statistical error.

The evaluation of the data has been done with the Fourier-Bessel (FB) method described in detail in Ref. 7. The charge distribution is represented by the series

$$\rho_{\mathrm{FB}}(r) = \begin{cases} \sum_{1}^{N} a_\nu j_0(q_\nu r), & r \leqslant R, \\ 0, & r > R, \end{cases} \tag{1}$$

where the values q_ν are given by $\pi\nu/R$ and the coefficients a_ν are related to the Fourier-Bessel transform $F(q_\nu)$ of $\rho(r)$ (i.e., to the form factor if the Born approximation were valid) by

$$a_\nu = F(q_\nu)/2\pi R^3 j_1^{\,2}(q_\nu R). \tag{2}$$

[Here $\rho(r)$ is normalized such that $4\pi\int\rho(r)r^2\,dr = 1$.] In practice the coefficients a_ν are fitted to the cross sections by a phase-shift code.[11] In the large-q region, where they are not determined by measurement, the range of possible values is limited by the estimate

$$|F(q_\nu)| \leqslant c q_\nu^{-4} F_p(q_\nu) \tag{3}$$

(F_p is the proton form factor). The constant c is matched to the last measured cross-section maximum. The error in $\rho(r)$ results from the error