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**Production of π^0 mesons and charged hadrons
in $\bar{\nu}$ Neon and ν Neon charged current interactions**

BEBC WA59 Collaboration

W. WITTEK⁹, M. ADERHOLZ⁹, P. ALLPORT^{10,+}, N. ARMENISE¹, J.P. BATON¹²,
M. BERGGREN^{13,++}, F.W. BULLOCK¹⁴, M. CALICCHIO¹, E.F. CLAYTON⁷,
T. COGHEN⁸, A.M. COOPER-SARKAR¹¹, O. ERRIQUEZ¹, P. FITCH¹⁴,
N. GIANNAKOPOULOS⁵, J. GUY¹¹, E. HOFFMANN⁹, P.O. HULTH¹³,
G.T. JONES², P. KASPER^{12,+++}, U.F. KATZ⁹, J. KERN⁹, H. KLEIN⁴,
P. MARAGE³, E. MATSINOS⁵, D.R.O. MORRISON⁴, M. NEVEU¹²,
M.A. PARKER⁴, N. SCHMITZ⁹, E. SIMOPOULOU⁵, K. VARVELL², A. VAYAKI⁵,
W. VENUS¹¹, H. WACHSMUTH⁴

- 1) Dipartimento di Fisica dell'Universita e Sezione INFN, Bari, Italy
- 2) University of Birmingham, UK
- 3) Inter-University Institute for High Energies, ULB-VUB, Brussels, Belgium
- 4) CERN, European Laboratory for Particle Physics, Geneva, Switzerland
- 5) Nuclear Research Centre Demokritos, Athens, Greece
- 6) LPNHE, Ecole Polytechnique, Palaiseau, France
- 7) Imperial College of Science and Technology, London, UK
- 8) Institute of Nuclear Physics, Cracow, Poland
- 9) Max-Planck-Institut für Physik und Astrophysik, München, Germany
- 10) Department of Nuclear Physics, Oxford, UK
- 11) Rutherford Appleton Laboratory, Chilton, Didcot, UK
- 12) DPhPE, Centre d'Etudes Nucleaires, Saclay, France
- 13) Institute of Physics, University of Stockholm, Sweden
- 14) Department of Physics and Astronomy, University College London, UK

+ Now at Rutherford Appleton Laboratory, UK

++ Now at CERN, Switzerland

+++ Now at FNAL, USA

8000 MÜNCHEN 40 - FÖHRINGER RING 6

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Max-Planck-Institut für Physik und Astrophysik, München.

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Abstract

The average multiplicities of charged hadrons and of π^+ , π^- and π^0 mesons, produced in $\bar{\nu}\text{Ne}$ and νNe charged current interactions in the forward and backward hemispheres of the $W^\pm$ -nucleon center of mass system, are studied with data from BEBC. The dependence of the multiplicities on the hadronic mass (W) and on the laboratory rapidity (y_{Lab}) and the energy fraction (z) of the pion is also investigated. Special care is taken to determine the π^0 multiplicity accurately. The ratio of average π multiplicities $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ is consistent with 1. In the backward hemisphere $\langle n_{\pi^0} \rangle$ is positively correlated with the charged multiplicity. This correlation, as well as differences in multiplicities between $\bar{\nu}\text{Ne}$ and $\bar{\nu}\text{p}$, $\bar{\nu}\text{n}$ scattering, is attributed to reinteractions inside the neon nucleus of the hadrons produced in the initial $\bar{\nu}$ interaction.

1. Introduction

The main aim of the present analysis is to measure and compare the average multiplicities of all positive and negative hadrons and separately of π^0 , π^+ and π^- mesons in the forward and backward regions of the $W^\pm$ -nucleon center of mass system ($W^\pm$ being the exchanged $W^\pm$ -boson). The π^0 multiplicities are determined independently of the π^+ and π^- multiplicities by reconstructing π^0 mesons from the observed electron-positron pairs. The reconstruction method is described in detail. The multiplicities are studied as a function of the $W^\pm$ -nucleon effective mass and of the laboratory rapidity y_{Lab} and the energy fraction z of the pion. Correlations between the average π^0 multiplicity and the charged multiplicity are investigated. Comparisons are made with experiments on hydrogen and deuterium targets and with experiments using pion beams and also with quark parton model predictions. The analysis uses 16068 $\bar{\nu}\text{Ne}$ and 9196 νNe charged current events in the energy region 5 to 200 GeV.

Properties of hadrons produced in reactions on nuclei and their comparison with those produced in reactions on free nucleons give information on nuclear effects and on the space-time development of hadron production within small distances and short times. Data from neutrino experiments are of particular interest since nuclear effects in neutrino-induced reactions are expected to be different from and simpler than those in hadron-induced reactions, where soft multi-quark collisions probably dominate.

Data with incident $\bar{\nu}$'s and ν 's have been published so far only from an $\bar{\nu}\text{Ne}$ experiment at FNAL [1, 2] with 783 events in the energy range from 10 to 200 GeV, from a νNe and $\bar{\nu}\text{Ne}$ experiment at FNAL [3] with 289 ν and 263 $\bar{\nu}$ events in the same energy range

and, at lower energy (< 30 GeV), from a ν and $\bar{\nu}$ experiment on freon at Serpukhov [4,5] with 2835 ν and 709 $\bar{\nu}$ events. Only one of these experiments [2] has published results for π^0 mesons.

2. Experimental procedure

a) The data sample

The data used in this paper come from an experiment at CERN in which the Big European Bubble Chamber (BEBC), filled with a mixture of neon (75 mole %) and hydrogen, was exposed to the horn-focussed $\bar{\nu}$ and ν wide band beams. The source of the neutrinos was the decay of charged pions and kaons which were produced from a beryllium target by 400 GeV protons from the SPS. In total 61 000 pictures with incident $\bar{\nu}$ and 36 000 pictures with incident ν have been taken.

At the working temperature of the bubble chamber the neon-hydrogen mixture has a density of 0.71 g/cm^3 , a hadronic collision length of 92 cm and a radiation length of 41.6 cm.

BEBC was equipped with an external muon identifier (EMI) consisting of two planes of multiwire proportional chambers [6]. The geometrical acceptance of the EMI was 84% at a momentum of 5 GeV/c and increased to $\sim 100\%$ for momenta above 10 GeV/c. Low momentum protons ($\lesssim 1$ GeV/c) were identified using their range and energy loss in Ne-H₂. Practically none of the charged pions and kaons were identified. Unidentified charged particles were provisionally called pions.

The film from BEBC was scanned twice in the normal fashion. The antineutrino film was then scanned two further times by following all leaving tracks back to where they either originated in an interaction or entered the chamber; this enabled 1-prong and 2-prong charged current interactions to be detected efficiently. Finally, 10 % of the pictures distributed throughout the film were scanned painstakingly two more times in a restricted fiducial volume where visibility was particularly good; this final scan was highly efficient and was used to determine the overall efficiency of the previous scans as a function of multiplicity. The result for the final efficiencies, which include all losses during measurement and reconstruction, is given in Tab. 1.

In events with a muon of momentum above 5 GeV/c, all tracks were measured, including those from secondary interactions of neutrons and neutral kaons, decays of Λ hyperons and kaons, and photon conversions into electron-positron (e^+e^-) pairs, which

appeared to be associated to the primary vertex. The average track length, used for momentum measurement, of charged hadrons in accepted neutrino interactions was 65 cm. The average relative measurement error on the momentum is $\Delta p/p = \pm 5\%$ for charged hadrons and $\pm 10\%$ for photons (from their conversion into e^+e^- pairs). For 10 % of the charged particles $\Delta p/p$ exceeds 30 %, in which case the particle charge has been set undefined.

Protons (or heavier charged particles) travelling backwards in the laboratory system or having a momentum less than 350 MeV/c are rejected. They are considered to be evaporation fragments not taking part in the ' $\bar{\nu}$ ' nucleon interaction.

The direction of the incident ' $\bar{\nu}$ ' is well known from the geometry of the ν beam and the position of the ' $\bar{\nu}$ 'Ne interaction point. Its energy is unknown and was estimated from the momenta of the observed particles according to

$$E_\nu = p_L^\mu + S \cdot f(S) \quad \text{with} \quad S = \left| \sum_i p_L^i \right| \quad (1)$$

where p_L^i denotes the longitudinal momentum (relative to the beam direction) of particle i in the laboratory system and the sum extends over all observed hadrons and photons. The function f was determined using the Monte Carlo program described below. The four-momentum of the $W^\pm$ -nucleon system was calculated as the difference between the ' $\bar{\nu}$ ' and μ four-momenta plus the four-momentum of a nucleon at rest.

The analysis uses only events containing a muon of the right charge (positive for $\bar{\nu}$ and negative for ν) and with a momentum greater than 5 GeV/c. The maximum accepted value of W is 15 GeV. The resulting sizes of the event samples are given in Tab. 2, together with the mean values of the ' $\bar{\nu}$ ' energy E_ν , of the hadronic mass W ($=W^\pm$ -nucleon mass) and of Q^2 , the four-momentum transfer squared between the ' $\bar{\nu}$ ' and the muon.

b) Monte Carlo simulation and corrections

Extensive Monte Carlo (MC) calculations have been performed mainly for the following purposes:

- to study effects due to experimental errors and deficiencies,
- to determine the efficiency of the π^0 reconstruction method, and
- to provide weights to correct the data.

An *initial* set of MC events was generated by

- simulating the energy spectrum of the incident neutrino,
- generating the leptonic variables of an event using standard sets of structure functions,
- producing hadrons according to longitudinal phase space; the types of hadrons produced are nucleons, π , K , ρ and η mesons, Λ and Σ hyperons; after the decays of the ρ and η mesons the average numbers per event of π^+ , K^+ , protons of momentum above 350 MeV/c, π^- and K^- particles were 0.90, 0.098, 0.63, 1.57 and 0.077 respectively for $\bar{\nu}\text{Ne}$ scattering and 2.15, 0.133, 0.86, 1.49 and 0.079 for νNe scattering;
- including Fermi motion, and
- simulating nuclear reinteractions within the target neon nucleus.

A corresponding *final* set of MC events was generated by also

- simulating reinteractions of hadrons in the Ne–H₂ mixture within a distance of 4 mm from the primary interaction vertex, which produce tracks indistinguishable from tracks from the primary vertex,
- simulating ρ , η , π^0 and Σ^0 decays,
- simulating further decays and γ conversions in the Ne–H₂ mixture, and
- simulating scanning losses, experimental resolution and lack of particle identification.

The *final* set of MC events reproduces the measured distributions of W and Q^2 , the average multiplicity of charged hadrons as a function of W^2 , the rate of ρ^0 and K^0 mesons, the rate of identified protons and the distributions of momenta and transverse momenta of charged hadrons.

For each experimental distribution, the corresponding distributions from *initial* and *final* MC events were also produced. The kinematical quantities were calculated for the *initial* set using the initially generated E_ν value and for the *final* set using the E_ν value estimated as for the data (eq. (1)). By dividing the *initial* and *final* distributions bin by bin correction factors were obtained, which were then applied to the experimental distribution. Thus the correction factors account for the smearing effects due to measurement errors, particle misidentification, non-observation of a certain fraction of neutral secondaries, scanning inefficiencies, ' $\bar{\nu}$ ' energy estimation errors and rescattering in the Ne–H₂ mixture. They do not correct for Fermi motion or for rescattering within the neon nucleus.

c) Determination of average π^+ , π^- and proton multiplicities

The average multiplicities of charged pions $\langle n_{\pi\pm} \rangle$ in the experimental data are determined from the multiplicities of those charged hadrons ($h^\pm$) which have not been identified as $K^\pm$ or proton. Since practically none of the $K^\pm$ and only $\sim 50\%$ of the protons are identified, the corrected $\langle n_{\pi\pm} \rangle$ depends on the multiplicities of the $K^\pm$ mesons and protons ($\langle n_p \rangle^{MC}$) generated in the MC program. This causes a small systematic error ($\pm 2\%$) in the corrected $\langle n_{\pi-} \rangle$ and a rather large systematic error in the corrected $\langle n_{\pi+} \rangle$, mainly due to the uncertainty in the proton multiplicity. A change of $\langle n_p \rangle^{MC}$ by a certain amount will cause a change of $\langle n_{\pi+} \rangle$ of the same size but with opposite sign.

An estimate of the proton multiplicity ($\langle n_p \rangle^{CS}$) can be obtained by assuming charge symmetry to hold exactly, which implies the relations

$$\langle n_{\pi+} \rangle_{\bar{\nu}} = \langle n_{\pi-} \rangle_{\nu} \quad \text{and} \quad \langle n_{\pi+} \rangle_{\nu} = \langle n_{\pi-} \rangle_{\bar{\nu}} \quad (2)$$

for interactions on an isoscalar target. $\langle n_p \rangle^{CS}$ is then calculated from the experimental $\langle n_{h+} \rangle$ by removing the contribution from K^+ mesons and subtracting $\langle n_{\pi+} \rangle^{CS}$, which is determined from the experimental $\langle n_{\pi-} \rangle$ according to (2). $\langle n_p \rangle^{CS}$ will be discussed in section 3a. The difference between $\langle n_p \rangle^{MC}$ and $\langle n_p \rangle^{CS}$, which by definition is equal to $\langle n_{\pi+} \rangle^{CS} - \langle n_{\pi+} \rangle$, can be computed from the data in Tab. 5 : it is different for $\bar{\nu}\text{Ne}$ and νNe scattering, W^2 dependent and ranges from -0.10 to 0.30 . These results suggest a systematic error of $\pm 15\%$ for $\langle n_{\pi+} \rangle$, if one assumes that charge symmetry is approximately fulfilled.

d) Selection of photons

The original sample of electron–positron pairs (called photons (γ) in the following) consists of those scanned and measured γ 's which give an acceptable kinematic fit to the hypothesis that the γ comes from the primary vertex. In this sample the following contaminations and losses have to be taken into account :

- Contamination by 'brems'– γ 's, i.e. γ 's which are due to bremsstrahlung from electrons or positrons. These γ 's have predominantly lower momenta and larger distances from the primary vertex. Moreover the effective mass formed by the brems– γ (γ_b) and the 'mother'– γ (γ_m) tends to be small. The bulk of the brems– γ 's is removed by rejecting those γ_b 's for which the 'horizontal' and 'vertical' $\gamma_b\gamma_m$ masses, formed with another γ_m in the same event, are below certain

values (solid line in Fig. 1), provided γ_m is more energetic and converts closer to the primary vertex than γ_b . The horizontal and vertical $\gamma\gamma$ masses are defined as

$$\begin{aligned} M_{hor} &= [2p_1p_2(1 - \cos\Delta\phi)]^{\frac{1}{2}} \\ M_{ver} &= [2p_1p_2(1 - \cos\Delta\lambda)]^{\frac{1}{2}} \end{aligned} \quad (3)$$

where p_1 and p_2 are the momenta and $\Delta\phi$ and $\Delta\lambda$ are the differences in the azimuthal and dip angles of the two photons in the laboratory system. The angle ϕ is counted in a plane perpendicular to the direction of the magnetic field and λ is the angle relative to this plane. Scatter plots of M_{ver} versus M_{hor} are shown in Fig. 1 for a subsample of photons in the $\bar{\nu}\text{Ne}$ reaction. The area where photons are rejected has been chosen wider in M_{hor} than in M_{ver} since the brems γ 's are spread in ϕ , due to the magnetic field, but not in λ . MC calculations show that due to this cut $\sim 4.5\%$ of genuine (i.e. non-brems) γ 's are rejected.

- Photons due to internal bremsstrahlung from muons. The distribution of $\cos\Theta_{\mu\gamma}$, where $\Theta_{\mu\gamma}$ is the laboratory angle between the muon and a photon, exhibits a spike near $\cos\Theta_{\mu\gamma} = 1$, which is attributed to internal bremsstrahlung from muons [7,8]. A cut $\cos\Theta_{\mu\gamma} < 0.9985$ has been applied, which eliminates $\sim 75\%$ of these photons.
- Confusion with γ 's originating from a secondary interaction. About 40 % of all γ 's, which give an acceptable fit for an association to the primary vertex, have also an acceptable fit for a different origin. In 50 % of the cases the χ^2 -probability for the latter fit is found to be better than that of the former. The primary vertex was finally accepted as the right origin of the γ , if the corresponding fit was not significantly worse (difference in χ^2 less than 2 for 3 degrees of freedom) than any other fit with a physical origin. With these criteria $\sim 80\%$ of all γ 's with ambiguous origin are associated to the primary vertex. The criteria tend to minimize the loss of γ 's coming from the primary vertex, however they lead to a contamination of the photon sample by γ 's from a different vertex of the order of 10 % (see section 2e).
- Scanning losses. Part of the film has been rescanned for γ 's so that in principle a scanning efficiency can be calculated. However the above mentioned ambiguity with respect to the origin of the γ makes it difficult to calculate a scanning efficiency in the usual way: due to the finite experimental resolution a given γ may be associated to the primary vertex in one scan and to a different vertex in the other scan, which leads to an apparent scanning efficiency of less than 100 % although the γ was found in both scans. Since the ambiguity vanishes as the distance d between

the photon conversion point and the primary vertex approaches zero, the global scanning efficiency ϵ can be determined by extrapolating the apparent scanning efficiency to $d = 0$. This has been done for a subsample of photons, for which the data suggest a uniform detection efficiency. The subsample is defined by: photon momentum p_γ greater than 200 MeV/c, production angle Θ_γ relative to the beam direction less than 40° and d less than 80 cm. For this subsample good agreement is found between the data and the MC sample, in particular for the distribution of the conversion distance d . The resulting scanning efficiencies are $\epsilon_1 = 0.95 \pm 0.01$ and 0.94 ± 0.01 for the $\bar{\nu}$ and ν data samples respectively.

The losses of photons with p_γ below 200 MeV/c or Θ_γ above 40° were estimated by comparing the experimental data with MC events. On average the corresponding scanning efficiencies, which were determined as a function of p_γ , Θ_γ and the charged multiplicity, are $\epsilon_2 = 88\%$ and 90% (relative to the total photon sample) for the $\bar{\nu}$ and ν data sample respectively.

The scanning efficiencies have been taken into account in the analysis by applying appropriate weights to the photons in the *final* sample of MC events (see section 2b).

The total number of accepted photons (called 'observed' photons in the following), i.e. after the cuts described in this section, is listed in Tab. 2.

Fig. 2 shows the distribution of the photon laboratory momentum for the data and for the *final* set of MC events, normalized to the same area. The photon multiplicity distribution is displayed in Fig. 3. The number of events with 1 or 3 observed photons is larger than in the MC sample. This suggests that photon sources other than π^0 's and η 's, both of which decay only to an even number of photons, are stronger in the data than in the MC sample. Important sources are the brems- γ 's and γ 's from secondary interaction vertices discussed above. Another source may be the internal bremsstrahlung from quarks. An estimate of contributions from these additional sources to the experimental sample of observed photons is given in the next section. The contamination of the experimental photon sample by misidentified K^0 mesons or Λ hyperons is negligible.

The distribution of the effective mass $M_{\gamma\gamma}$ of all $\gamma\gamma$ combinations (Fig. 4) exhibits a peak at the π^0 mass with a full width at half maximum of 32 MeV or a σ of 14 MeV. The enhancement, below the π^0 mass region, of the experimental distribution as compared to the MC distribution is largely attributed to a residual contamination of the photon sample by brems- γ 's.

e) Reconstruction of π^0 mesons

The principle of the method used is the following. Let us consider an event with an even number N of observed γ 's originating from the primary vertex. By forming pairs of γ 's, all possible 'solutions' are generated in which each γ is combined with one and only one other γ , thus obtaining $N/2$ $\gamma\gamma$ pairs per solution. One of these solutions is then selected using certain criteria (see below). Those $\gamma\gamma$ pairs within the selected solution with an effective $\gamma\gamma$ mass ($M_{\gamma\gamma}$) sufficiently close to the π^0 mass are considered as π^0 mesons.

By means of MC events, various implementations of this method were tried out. The following procedure turned out to yield rather clean π^0 samples with tolerable losses of genuine π^0 's. For each $\gamma\gamma$ pair, a χ^2 -value and a corresponding χ^2 -probability $P(\chi^2)$ are calculated, which measure the compatibility of the measured $M_{\gamma\gamma}$ with the π^0 mass :

$$\chi^2 = \left[\frac{M_{\gamma\gamma} - M_{\pi^0}}{\Delta M_{\gamma\gamma}} \right]^2 \quad (4)$$

$\Delta M_{\gamma\gamma}$ is the experimental error of $M_{\gamma\gamma}$. A $\gamma\gamma$ pair is called a π^0 candidate if $P(\chi^2)$ is greater than 1 %. Amongst the solutions with the maximum number of π^0 candidates, the solution with the smallest $\sum \chi^2$, where the sum extends over all π^0 candidates within the solution, is selected. Within the selected solution, the π^0 candidates with $P(\chi^2)$ above 5% are finally accepted as π^0 's. They will be called 'reconstructed' π^0 's in the following.

The case with an odd number N of observed γ 's is reduced to the case with an even number by adding a fake γ and assigning a very large χ^2 -value to all $\gamma\gamma$ pairs containing the fake γ .

Similar algorithms for reconstructing π^0 's were applied in a K_L^0 decay experiment [9], in a ' $\bar{\nu}$ ' proton experiment [10] using the Ne-H₂ filled BEBC with a track sensitive H₂ target, and in a ν Ne experiment [11] at FNAL.

The efficiency of the π^0 reconstruction method can be seen from Tab. 3, which shows the results from applying the method to MC events. The table contains various ratios between the number of produced and observed photons, the number of produced and reconstructed π^0 's, the number of π^0 's with both decay γ 's seen and the number of correctly reconstructed π^0 's. It is seen that roughly 66% of all produced photons are observed; that 42% of all produced π^0 's can in principle be reconstructed, because both decay γ 's are seen; and that 78% of the reconstructed π^0 's are reconstructed correctly, which corresponds to 81% of the π^0 's with both γ 's seen.

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The contamination of the photon sample by γ 's from additional sources (see section 2d above) can be estimated by comparing the ratios h_{data} and h_{MC} (Tab. 3) as determined in the data sample and in the MC sample. One finds a contamination $1 - \frac{h_{data}}{h_{MC}}$ of $\sim 12\%$. It is to be expected that the contamination of the π^0 sample is much lower, because it is very unlikely that both decay γ 's of a π^0 from a secondary vertex are assigned to the primary vertex.

The number of reconstructed π^0 's rises linearly with the number of observed photons in an event, and the increase is identical in the data and in the MC sample (see Fig. 5).

The distribution of $P(\chi^2)$ of the π^0 candidates in the selected solutions is shown in Fig. 6. The flatness of this distribution for the MC events in the range $P(\chi^2)$ above 10% confirms that the π^0 selection criteria are reasonable. The contamination by wrong $\gamma\gamma$ combinations is reflected in the enhancement at $P(\chi^2)$ below 5% both in the experimental and the MC distributions. Note that only the combinations with $P(\chi^2)$ above 5% have finally been accepted as π^0 's.

The momentum distribution of the reconstructed π^0 's is in excellent agreement with the corresponding distribution for the set of *final* MC events (see Fig. 7), as was the case for the observed photons (Fig. 2).

Due to the larger corrections at low photon momenta, the systematic error in the average π^0 multiplicity $\langle n_{\pi^0} \rangle$ is expected to increase with decreasing π^0 momentum; its average value is determined to be $\pm 5\%$, including an error in the photon scanning efficiency of $\pm 2\%$ (discussed in section 2d).

3. Results

All experimental results given below are fully corrected, as described above. Data points which are based on less than 10 events are not shown. The errors quoted in the Tables and drawn in the Figures are only statistical.

a) Multiplicities of charged hadrons

Fig. 8 and Fig. 9 show the distributions of the charged hadron multiplicity (n_{ch}) and of the total charge (Q_T) of all particles (including the μ) in an event. For scattering off single protons or neutrons, Q_T would have the value 1 or 0 respectively. Many events

(29% in $\bar{\nu}\text{Ne}$, 17% in νNe scattering) have higher Q_T values, due to rescattering of hadrons in the neon nucleus (see below). The lower fraction in νNe scattering is expected since in νNe scattering a larger fraction of events with rescattering is contained in the $Q_T = 1$ sample than in $\bar{\nu}\text{Ne}$ scattering, since $\sigma(\nu n)/\sigma(\nu p) \simeq \sigma(\bar{\nu}p)/\sigma(\bar{\nu}n) \simeq 2$. The rejection of protons with momentum below 350 MeV/c (see section 2a) causes a loss of some positive particles, which explains the tails of the distributions at low Q_T .

The average multiplicities of positive (h^+), of negative (h^-) and of all charged hadrons ($n_{ch} = n_{h^+} + n_{h^-}$) are plotted as functions of W^2 in Fig. 10, for the forward region (F), for the backward region (B) and for the total sample ($F + B$). The forward region is defined by the current direction in the $W^\pm$ -nucleon center of mass system (for the definition of this system see section 2a).

In $\bar{\nu}\text{Ne}$ scattering, $\langle n_{h^+}^F \rangle$ is smaller than $\langle n_{h^-}^F \rangle$ and $\langle n_{h^+}^B \rangle$ exceeds $\langle n_{h^-}^B \rangle$, whereas in νNe scattering $\langle n_{h^+} \rangle$ exceeds $\langle n_{h^-} \rangle$ both in the forward and in the backward region. This can be seen more clearly in Fig. 11, which shows the average hadronic charges $Q^F = \langle n_{h^+}^F \rangle - \langle n_{h^-}^F \rangle$, $Q^B = \langle n_{h^+}^B \rangle - \langle n_{h^-}^B \rangle$ and $Q^{F+B} = Q^F + Q^B$ as a function of W^2 . The behaviour in the forward region can be qualitatively understood in the framework of the quark parton model (QPM) because the emitted quark is negative in $\bar{\nu}$ scattering and positive in ν scattering. In the backward region, the QPM (with scattering only on valence quarks) predicts average hadronic charges of 0 and 2/3 respectively, when the charge leakage term [12] is neglected :

$$Q_{\bar{\nu}\text{Ne}}^{QPM} = \frac{1}{3} \cdot (r_{\bar{\nu}} \cdot Q_{\bar{\nu}p} + Q_{\bar{\nu}n}) \quad Q_{\nu\text{Ne}}^{QPM} = \frac{1}{3} \cdot (Q_{\nu p} + r_{\nu} \cdot Q_{\nu n}) \quad (5)$$

$$r_{\bar{\nu}} = r_{\nu} = \sigma(\bar{\nu}p)/\sigma(\bar{\nu}n) = \sigma(\nu n)/\sigma(\nu p) = 2 \quad (6)$$

$$Q_{\bar{\nu}p} = 1/3 \quad Q_{\bar{\nu}n} = -2/3 \quad Q_{\nu p} = 4/3 \quad Q_{\nu n} = 1/3 \quad (7)$$

These numbers have to be compared with observed values for Q^B of ~ 0.5 and 1.2 (see Fig. 11). The excess of positive hadrons in both reactions, which is related to the tail of the Q_T distribution at $Q_T > 1$ ($\langle Q_T \rangle = Q^F + Q^B + \text{charge of muon}$), can be explained by rescattering of hadrons in the neon nucleus. Since the rescattering takes place on a proton or neutron, any change of the net charge can only be positive.

In order to allow a quantitative comparison of the various multiplicities, the expression

$$\langle n \rangle = a + b \cdot (\ln W^2 - \ln W_0^2) \quad (8)$$

has been fitted to the average multiplicities for W^2 between 4 GeV² and 160 GeV². The W_0^2 term (with $W_0^2 = 20$ GeV²) has been introduced in order to reduce the correlation between the parameters a and b , whose fitted values are given in Tab. 4. The value of a represents the average multiplicity at $W^2 = W_0^2 = 20$ GeV².

The increase of $\langle n_{h-} \rangle$ with $\ln W^2$ is weaker in the backward than in the forward region. Within one hemisphere the increase is similar for positive and negative hadrons, which implies that Q^F and Q^B depend only weakly on $\ln W^2$ (see Fig. 11 and parameter b in Tab. 4).

The parameters a and b for $\langle n_{h-} \rangle_{\bar{\nu}Ne}$ ($a = 2.10 \pm 0.02, b = 0.72 \pm 0.02$) can be compared to the measurement from a previous $\bar{\nu}Ne$ experiment [1] ($a = 2.03 \pm 0.04, b = 0.76 \pm 0.01$), which finds a slightly higher value for b .

In Fig. 12 the average proton multiplicities $\langle n_p \rangle^{CS}$, obtained under the assumption of charge symmetry (cf. section 2c), are displayed as functions of W^2 and compared with $\langle n_{h+} \rangle$. Above $W^2 \sim 4$ GeV² $\langle n_p \rangle^{CS}$ decreases as W^2 increases in the forward hemisphere and is rather independent of W^2 in the backward hemisphere. At $W^2 = 20$ and 100 GeV² the protons represent, respectively, 29 and 16 % of all positive hadrons in $\bar{\nu}Ne$ scattering and 36 and 28 % in νNe scattering.

b) Multiplicities of neutral and charged pions

The results of fits of (8) to the average π multiplicities are given in Tab. 5. Within the errors the parameters a and b for $\langle n_{\pi 0} \rangle_{\bar{\nu}Ne}$ ($a = 1.61 \pm 0.02, b = 0.58 \pm 0.02$) agree with those from a previous $\bar{\nu}Ne$ experiment [2]: $a = 1.58 \pm 0.08, b = 0.65 \pm 0.07$.

Fig. 13 shows $\langle n_{ch} \rangle$ and $\langle n_{\pi 0} \rangle$ as functions of W^2 . The ratio $\frac{\langle n_{\pi 0} \rangle}{\langle n_{ch} \rangle}$ is very similar in $\bar{\nu}Ne$ and νNe scattering and is practically independent of W^2 . This is clear from Tab. 6, which lists ratios of average multiplicities of π^+, π^-, π^0 mesons and of charged hadrons at $W^2 = 20$ and 100 GeV². On average $\langle n_{\pi 0} \rangle \simeq 0.45 \cdot \langle n_{ch} \rangle$ in the forward region, $\langle n_{\pi 0} \rangle \simeq 0.30 \cdot \langle n_{ch} \rangle$ in the backward region and $\langle n_{\pi 0} \rangle \simeq 0.37 \cdot \langle n_{ch} \rangle$ for the total sample (Tab. 6). The π^0/π^- ratios are also given in Tab. 6.

Fig. 14 shows $\langle n_{\pi 0} \rangle$ together with $\langle n_{\pi+} \rangle$ and $\langle n_{\pi-} \rangle$ as functions of W^2 . With very few exceptions, $\langle n_{\pi 0} \rangle$ lies always between $\langle n_{\pi+} \rangle$ and $\langle n_{\pi-} \rangle$. From Fig. 15, in which $\langle n_{\pi 0} \rangle$ is compared with $\frac{1}{2} \cdot [\langle n_{\pi+} \rangle + \langle n_{\pi-} \rangle]$, and from Tab. 5 and Tab. 6, it can be seen that $\langle n_{\pi 0} \rangle$ and $\frac{1}{2} \cdot [\langle n_{\pi+} \rangle + \langle n_{\pi-} \rangle]$ are very similar both in size and in W dependence. For $\bar{\nu}Ne$

and ν Ne scattering the ratio $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ is found to be $0.97 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})$ and $0.96 \pm 0.02(\text{stat.}) \pm 0.10(\text{syst.})$ respectively, with no significant difference between $W^2 = 20$ and 100 GeV^2 . The systematic errors have been calculated from the systematic error of 5% on $\langle n_{\pi^0} \rangle$ (see section 2e), of 2% on $\langle n_{\pi^-} \rangle$ and of 15% on $\langle n_{\pi^+} \rangle$ (see section 2c). At $W^2 = 100 \text{ GeV}^2$ the ratio tends to be smaller in the backward than in the forward region (see Tab. 6).

The relation $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]} = 1$ has been derived for hadronic interactions by several authors under certain assumptions, although it does not follow from general symmetry arguments alone [13–16]. If some of the π^0 's result from electromagnetic decays, such as $\eta \rightarrow \pi^0 \pi^0 \pi^0$, the ratio should be higher. At low W π^0 production may be suppressed because of charge and energy conservation, leading to a lower ratio. A special example for a reaction on an isoscalar target where a low ratio is expected is exclusive production of the $\Delta(1232)$ resonance by neutrinos, for which a ratio of 0.4 is predicted [17]. Within the errors, the ratios observed in our data are consistent with unity.

In the framework of the QPM, and considering only u and d quarks, isospin and charge conjugation invariance imply the following relations for the fragmentation functions $D_q(\pi)$ of a quark q fragmenting into a π

$$\begin{aligned} D_u(\pi^0) &= D_d(\pi^0) = D_{\bar{d}}(\pi^0) = D_{\bar{u}}(\pi^0) \\ D_u(\pi^0) &= \frac{1}{2} \cdot [D_u(\pi^+) + D_u(\pi^-)] \\ D_u(\pi^+) &= D_d(\pi^-) = D_{\bar{d}}(\pi^+) = D_{\bar{u}}(\pi^-) \\ D_u(\pi^-) &= D_d(\pi^+) = D_{\bar{d}}(\pi^-) = D_{\bar{u}}(\pi^+) \end{aligned} \quad (9)$$

If the fragments of the struck quark are emitted into the forward hemisphere and the fragments of the target remnant into the backward hemisphere then one obtains from (9), provided nuclear effects can be neglected, the following relations between the average forward multiplicities or between the average backward multiplicities in $\bar{\nu}$ Ne scattering

$$\langle n_{\pi^0} \rangle_{\bar{\nu}} = \langle n_{\pi^0} \rangle_{\nu} \quad (10)$$

$$\langle n_{\pi^+} \rangle_{\bar{\nu}} = \langle n_{\pi^-} \rangle_{\nu} \quad \langle n_{\pi^+} \rangle_{\nu} = \langle n_{\pi^-} \rangle_{\bar{\nu}} \quad (11)$$

$$\langle n_{\pi^0} \rangle_{\bar{\nu}} = \frac{1}{2} \cdot [\langle n_{\pi^+} \rangle_{\bar{\nu}} + \langle n_{\pi^-} \rangle_{\bar{\nu}}] \quad \langle n_{\pi^0} \rangle_{\nu} = \frac{1}{2} \cdot [\langle n_{\pi^+} \rangle_{\nu} + \langle n_{\pi^-} \rangle_{\nu}] \quad (12)$$

From Tab. 5 it is seen that relation (10) is well fulfilled in the forward region but not in the backward region, where at $W^2 = 20 \text{ GeV}^2$ $\langle n_{\pi^0} \rangle_{\nu Ne}$ exceeds $\langle n_{\pi^0} \rangle_{\bar{\nu} Ne}$ by

$[18 \pm 4(\text{stat.}) \pm 5(\text{syst.})]\%$. The sum $0.5 \cdot [\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]$ behaves similarly, so that the ratios $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ for $\bar{\nu}Ne$ and νNe scattering agree within errors, both in the forward and backward region (see Tab. 6).

There are deviations from (11) both in the forward and backward region (see Tab. 5). However, as explained in section 2c, this may be due to a wrong proton multiplicity $\langle n_p \rangle^{MC}$ being generated in the Monte Carlo model. The average proton multiplicity $\langle n_p \rangle^{CS}$, which would yield average π^+ multiplicities satisfying (11), and which would still be compatible with the data, was displayed in Fig. 12 and discussed in section 3a. If (11) is assumed to be valid the sum $\langle n_{\pi^+} \rangle_{\bar{\nu}Ne} + \langle n_{\pi^-} \rangle_{\bar{\nu}Ne}$ becomes equal to $\langle n_{\pi^+} \rangle_{\nu Ne} + \langle n_{\pi^-} \rangle_{\nu Ne} = \langle n_{\pi^-} \rangle_{\bar{\nu}Ne} + \langle n_{\pi^-} \rangle_{\nu Ne}$, which is also given in Tab. 5 (marked with *). Differences between $\bar{\nu}Ne$ and νNe scattering in the corresponding ratios $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ (see Tab. 6) reflect directly the differences in $\langle n_{\pi^0} \rangle$ between $\bar{\nu}Ne$ and νNe scattering.

Many experiments with nuclear targets measure the multiplicities of 'shower' particles, i.e. of particles with velocity $\beta \geq 0.7$ [18]. Fig. 16 shows the average multiplicities of π^0 , π^+ and π^- mesons with $\beta \geq 0.7$. For these fast pions the ratio $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ is found to be $0.97 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})$ and $0.96 \pm 0.02(\text{stat.}) \pm 0.10(\text{syst.})$ for $\bar{\nu}Ne$ and νNe scattering respectively, independent of W (see Tab. 6).

c) Correlations of average π^0 multiplicities with charged multiplicities

Fig. 17 shows $\langle n_{\pi^0} \rangle$ as a function of n_{ch} in three bins of W , for the forward region, for the backward region and for both hemispheres together. There is a clear difference between the two hemispheres: in the forward region $\langle n_{\pi^0} \rangle$ is independent of or rather decreasing with n_{ch} , whereas in the backward region $\langle n_{\pi^0} \rangle$ increases with increasing n_{ch} .

A quantitative measure of the correlation is the value of the slope parameter d in the expression

$$\langle n_{\pi^0} \rangle = c + d \cdot n \quad . \quad (13)$$

The results of fitting this expression to the data points with $n = n_{ch}$ and $n = n_{h-}$ are listed in Tab. 7. The slope parameter d for $n = n_{ch}$ has a value of $\sim 0.14 \pm 0.02$ in the backward region and of $\sim 0.12 \pm 0.02$ for the total sample, rather independent of W^2 . No significant difference is seen between $\bar{\nu}Ne$ and νNe scattering.

The correlation between $\langle n_{\pi^0}^B \rangle$ and n_{ch}^B seen in the experimental data can be related to nuclear effects, because it is also present in the MC data when nuclear reinteractions are included, and is strongly reduced when nuclear reinteractions are switched off. The

MC model for a single interaction contains (at fixed W) no explicit correlation between $\langle n_{\pi^0} \rangle$ and n_{ch} .

d) Distributions of the laboratory rapidity y_{Lab} and of the energy fraction z for neutral and charged pions

The rapidity in the laboratory system y_{Lab} and the energy fraction z of a hadron are defined as

$$y_{Lab} = \frac{1}{2} \cdot \ln \frac{E^h + p_L^h}{E^h - p_L^h} \quad z = \frac{E^h}{\nu} \quad (14)$$

where E^h is the energy and p_L the longitudinal momentum of the hadron (relative to the direction of the $W^\pm$) and ν the energy transfer $\nu = E_\nu - E_\mu$ in the laboratory system. The rapidity y_{Lab} has the advantage of being less sensitive to experimental smearing and to the definition of the $W^\pm$ -nucleon center of mass system than the Feynman x_F or the z variable.

The average π^0 , π^+ and π^- multiplicities are shown as functions of y_{Lab} in Fig. 18; for the pions travelling forward in the $W^\pm$ -nucleon center of mass frame they are shown as functions of z in Fig. 19. The data show that for W below 10 GeV the height of the rapidity distribution for pions is still rising and no rapidity plateau has yet developed. As in the case of the global average pion multiplicities, $\langle n_{\pi^0} \rangle$ lies in general between $\langle n_{\pi^+} \rangle$ and $\langle n_{\pi^-} \rangle$. In particular at high z ($z > 0.6$), $\langle n_{\pi^0} \rangle$ is consistent with $\frac{1}{2} \cdot [\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]$.

e) Comparison with (anti-)neutrino nucleon scattering

In order to compare interactions on nuclei (A) with interactions on nucleons (N), frequent use is made of the multiplicity ratios $R_{A,N} = \frac{\langle n \rangle_A}{\langle n \rangle_N}$ [18]. With the results for the neon target in Tab. 4 and those for p and n targets from [19] one obtains at W^2 values of 20 and 100 GeV² the $R_{Ne,N}$ values listed in Tab. 8. It should be mentioned that the average multiplicities from [19] are for a cut $Q^2 > 1$ GeV². Also applying this cut to the neon data yielded $R_{Ne,N}$ values which differed insignificantly from those in Tab. 8. The ratios $R_{Ne,p}$ have also been determined with the data from a ν and $\bar{\nu}$ experiment on hydrogen [20]. Within two standard deviations the results were identical to those given in Tab. 8.

In Tab. 9 the ratios $R_{Ne,I} = \langle n \rangle_{Ne} / \langle n \rangle_I$ and the differences of average hadronic charges $D_{Ne,I} = Q_{Ne} - Q_I$ are given, where the subscript I denotes an isoscalar nucleon. $\langle n \rangle_I$ has been calculated from $\langle n \rangle_p$ and $\langle n \rangle_n$ of [19] according to the QPM relation

$$\begin{aligned}\langle n \rangle_{\bar{\nu}I} &= \frac{1}{3} \cdot [r_{\bar{\nu}} \cdot \langle n \rangle_{\bar{\nu}p} + \langle n \rangle_{\bar{\nu}n}] \\ \langle n \rangle_{\nu I} &= \frac{1}{3} \cdot [\langle n \rangle_{\nu p} + r_{\nu} \cdot \langle n \rangle_{\nu n}] \quad ,\end{aligned}\tag{15}$$

with $r_{\bar{\nu}}$ and r_{ν} taken from the same experiment [21] : $r_{\bar{\nu}} = 1.96 \pm 0.04(\text{stat.}) \pm 0.12(\text{syst.})$, $r_{\nu} = 2.10 \pm 0.08(\text{stat.}) \pm 0.22(\text{syst.})$. In the same way Q_I was determined from Q_p and Q_n .

In the forward region the multiplicities for the neon target are lower than those for the isoscalar nucleon target, whereas in the backward region they are higher (Tab. 9). This reduction and excess hold for both positive and negative hadrons. Within errors the ratios are equal at $W^2 = 20$ and 100 GeV^2 . With two exceptions in the forward region, a reduction and an excess are also seen in the ratios $R_{Ne,N}$ (Tab. 8).

As to the average hadronic charges, in the forward hemisphere, fair agreement is found between the neon and the isoscalar nucleon target, both at $W^2 = 20$ and 100 GeV^2 . However, in the backward hemisphere, the average hadronic charges in $\bar{\nu}\text{Ne}$ and νNe scattering exceed the expectations by 0.47 ± 0.08 , with no significant change between $W^2 = 20$ and 100 GeV^2 (Tab. 9). This excess is of similar size to that of the average hadronic backward charge discussed in section 3a, since the average backward charges in $\bar{\nu}p$ and $\bar{\nu}n$ scattering agree approximately with the QPM predictions (7).

The reduction and the excess of the multiplicities, as well as the excess of the hadronic backward charges, seen in the data are attributed to reinteractions inside the nucleus of the hadrons produced in the initial $W^\pm$ -nucleon interaction [22].

The average charged multiplicity $\langle n_{ch} \rangle_{\nu Ne}$ can also be compared with $\langle n_{ch} \rangle_{\nu D}$ from a further ν deuterium experiment [23]: at $W^2 = 20$ and 100 GeV^2 one obtains for the ratio $\frac{\langle n_{ch} \rangle_{\nu Ne}}{\langle n_{ch} \rangle_{\nu D}}$ the values 1.11 ± 0.02 and 1.08 ± 0.02 respectively. These ratios are 5% below the $R_{Ne,I}$ values given in Tab. 9 : 1.16 ± 0.02 and 1.13 ± 0.02 . The discrepancy may be partly due to the fact that rescattering events are contained in $\langle n_{ch} \rangle_{\nu D}$ but not in $\langle n_{ch} \rangle_{\nu I}$.

f) Comparison with $\pi^\pm$ scattering

Some comparisons with the results from $\pi^\pm\text{Ne}$ experiments [24, 25] are shown in Tab. 10. Assuming a target nucleon at rest, the laboratory momentum of $10.5 \text{ GeV}/c$ corresponds to $W^2 = 20 \text{ GeV}^2$. In terms of $\langle n_{h-} \rangle$, $\langle n_{\pi^0} \rangle$ and $\langle n_{\pi^+} \rangle$ $\bar{\nu}\text{Ne}$ scattering resembles $\pi^-\text{Ne}$ and νNe resembles $\pi^+\text{Ne}$ scattering. This confirms a previous observation [3] that $W^\pm\text{Ne}$ interactions are similar to $\pi^\pm\text{Ne}$ interactions.

In pion scattering the ratio $\frac{\langle n_{h-} \rangle_{\pi Ne}}{\langle n_{h-} \rangle_{\pi p}}$ is estimated to lie between 1.25 and 1.4 [18]. This is higher than the corresponding ratio in $\bar{\nu}$ scattering (see Tab. 8) : $\frac{\langle n_{h-} \rangle_{\bar{\nu} Ne}}{\langle n_{h-} \rangle_{\bar{\nu} p}} = 1.11 \pm 0.05$ and 1.08 ± 0.04 , and $\frac{\langle n_{h-} \rangle_{\nu Ne}}{\langle n_{h-} \rangle_{\nu p}} = 1.24 \pm 0.06$ and 1.10 ± 0.04 , at W^2 values of 20 and 100 GeV^2 respectively. This difference is expected since in $\bar{\nu}$ nucleus scattering intra-nuclear cascading is the only source of a surplus multiplicity, whereas in hadron nucleus scattering the main contribution to the extra multiplicity is expected to come from multiquark collisions [22].

Some data on the $\langle n_{\pi^0} \rangle - n_{ch}$ correlation in hadronic reactions and in $\bar{\nu}$ proton scattering are listed in Tab. 11. In π^-p scattering the correlation is known to increase with the center of mass energy W [26], starting to become positive at $W^2 \sim 30 \text{ GeV}^2$ and with a value of the parameter d (eq. (13)) of 0.14 ± 0.02 at $W^2 = 76 \text{ GeV}^2$ [27, 28]. This correlation is comparable to, possibly slightly lower than, the one in π^-C scattering at the same W^2 [18, 29].

In $\bar{\nu}p$ scattering [20], on the other hand, no correlation is observed in the W^2 range $25 < W^2 < 100 \text{ GeV}^2$. The correlation measured in $\bar{\nu}Ne$ scattering (Tab. 7) is similar to the one in π^-p scattering and seems to be slightly lower than in π^-C scattering.

The increase of the correlation in $\bar{\nu}$ scattering when replacing the proton by a neon target can be qualitatively understood by reinteractions inside the neon nucleus. The slightly higher correlation in π^-C scattering as compared to $\bar{\nu}Ne$ scattering could be due to additional multiquark collisions in π^-C scattering.

4. Summary

The multiplicities of secondary hadrons produced in $\bar{\nu}Ne$ and νNe interactions are investigated for W^2 below $\sim 100 \text{ GeV}^2$. The results can be summarized as follows :

- The average multiplicities of positive and negative hadrons and of neutral and charged pions rise approximately linearly with $\ln W^2$. For negative hadrons the increase is steeper in the forward hemisphere (defined by the direction of the exchanged $W^\pm$ -boson in the $W^\pm$ - nucleon center of mass system) than in the backward hemisphere. The average hadronic charges in the forward and backward hemispheres depend only weakly on W .
- The average multiplicity of π^0 mesons is $\sim 0.45 \cdot \langle n_{ch} \rangle$ in the forward region, $\sim 0.30 \cdot \langle n_{ch} \rangle$ in the backward region and $\sim 0.37 \cdot \langle n_{ch} \rangle$ for the total sample.
- The average multiplicity $\langle n_{\pi^0} \rangle_{\nu Ne}$ agrees with $\langle n_{\pi^0} \rangle_{\bar{\nu} Ne}$ in the forward region but

exceeds $\langle n_{\pi^0} \rangle_{\bar{\nu}Ne}$ in the backward region by $[18 \pm 4(\text{stat.}) \pm 5(\text{syst.})]\%$. This is in contrast to the expectation from charge symmetry, which would predict equal average π^0 multiplicities in $\bar{\nu}Ne$ and νNe scattering (see below).

- The ratio $\frac{2\langle n_{\pi^0} \rangle}{[\langle n_{\pi^+} \rangle + \langle n_{\pi^-} \rangle]}$ is consistent with unity in both the forward and the backward region. Its average value is $0.97 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})$ and $0.96 \pm 0.02(\text{stat.}) \pm 0.10(\text{syst.})$ for $\bar{\nu}Ne$ and νNe scattering respectively. At $W^2 = 100 \text{ GeV}^2$ the ratio tends to be smaller in the backward than in the forward region.
- In the W^2 region below $\sim 100 \text{ GeV}^2$ the height of the rapidity distribution of pions is still increasing and no plateau has yet developed.
- $\langle n_{\pi^0} \rangle$ and n_{ch} are positively correlated in the backward region and nearly uncorrelated in the forward region. The correlation for the total sample does not depend significantly on W and the correlation parameter d has a value of 0.12 ± 0.02 .
- A comparison with data on $\bar{\nu}p$ and $\bar{\nu}n$ scattering reveals a reduction of the forward multiplicities and an excess of backward multiplicities in $\bar{\nu}Ne$ scattering; both are independent of W^2 in the region $20 \text{ GeV}^2 < W^2 < 100 \text{ GeV}^2$.
- The average hadronic charge in $\bar{\nu}Ne$ scattering is close to that expected for an isoscalar nucleon target in the forward region but it exceeds the expected value by 0.47 ± 0.08 in the backward region, independently of W^2 .
- The average multiplicity of protons (with laboratory momentum above $350 \text{ MeV}/c$) is estimated under the assumption of charge symmetry. For $W^2 \gtrsim 4 \text{ GeV}^2$ $\langle n_p \rangle$ decreases as W^2 increases in the forward hemisphere and is rather independent of W^2 in the backward hemisphere. At $W^2 = 20$ and 100 GeV^2 the protons represent, respectively, 29 and 16% of all positive hadrons in $\bar{\nu}Ne$ scattering and 36 and 28% respectively in νNe scattering.
- The average multiplicities in $\bar{\nu}Ne$ and νNe scattering are similar to those in π^-Ne and π^+Ne scattering respectively, but the value of $\frac{\langle n_{h^-} \rangle_{\pi Ne}}{\langle n_{h^-} \rangle_{\pi p}}$ is larger than $\frac{\langle n_{h^-} \rangle_{\bar{\nu} Ne}}{\langle n_{h^-} \rangle_{\bar{\nu} p}}$.

Several of these experimental observations show that $\bar{\nu}$ scattering on a neon target differs from scattering on free nucleons. Examples are the $\langle n_{\pi^0} \rangle - n_{ch}$ correlation in $\bar{\nu}Ne$ scattering, the reduction of average forward multiplicities and the excess of average backward multiplicities as compared to $\bar{\nu}p$ and $\bar{\nu}n$ scattering, and the excess of the average hadronic backward charge in $\bar{\nu}Ne$ as compared to scattering off an isoscalar nucleon. A natural explanation is provided by reinteractions inside the neon nucleus of the hadrons produced in the initial $W^\pm$ -nucleon interaction. The larger value of $\frac{\langle n_{h^-} \rangle_{\pi Ne}}{\langle n_{h^-} \rangle_{\pi p}}$ as compared to $\frac{\langle n_{h^-} \rangle_{\bar{\nu} Ne}}{\langle n_{h^-} \rangle_{\bar{\nu} p}}$ suggests that in π -nucleus scattering there are additional mechanisms for particle production, e.g. multi-quark collisions, as expected.

Concerning the comparison of the average π^0 multiplicities between $\bar{\nu}\text{Ne}$ and νNe scattering, deviations from charge symmetry are expected due to the presence of charm or strangeness changing currents only in the forward but not in the backward hemisphere. Effects which depend on the leptonic energy transfer ν ($= E_\nu - E_\mu$) could cause an asymmetry between $\bar{\nu}\text{Ne}$ and νNe scattering. However, this asymmetry should be small, since the average value of ν in νNe scattering exceeds that in $\bar{\nu}\text{Ne}$ scattering only by $\sim 10\%$. The observed difference between $\langle n_{\pi^0} \rangle_{\bar{\nu}\text{Ne}}$ and $\langle n_{\pi^0} \rangle_{\nu\text{Ne}}$ in the backward region is therefore more likely due to the statistical and systematic errors.

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Tab. 1: Throughput efficiency as a function of the number of charged secondaries (prongs) in an event; first and third row for events without associated neutrals, second and fourth row for events with associated neutrals

	1	2	3	4	≥ 5 prongs
$\bar{\nu}\text{Ne}$	0.77 ± 0.04	0.91 ± 0.03	0.92 ± 0.03	0.97 ± 0.02	0.97 ± 0.02
	0.89 ± 0.03	0.97 ± 0.02	0.97 ± 0.01	0.96 ± 0.02	0.97 ± 0.01
νNe	0.19 ± 0.09	0.67 ± 0.04	0.90 ± 0.03	0.97 ± 0.02	0.97 ± 0.02
	0.57 ± 0.05	0.85 ± 0.02	0.98 ± 0.01	0.97 ± 0.02	0.97 ± 0.01

Tab. 2: Experimental samples used ($p_\mu > 5$ GeV/c, $W < 15$ GeV)

	$\bar{\nu}\text{Ne}$	νNe
Total no. of events	16068	9196
Total no. of accepted photons	31327	24834
Total no. of reconstr. π^0 's	8645	7191
Total no. of well measured negative hadrons	23914	12645
$\langle E_\nu \rangle$	39 GeV	54 GeV
$\langle W \rangle$	3.8 GeV	5.1 GeV
$\langle Q^2 \rangle$	3.8 GeV ²	6.3 GeV ²

Tab. 3: Summary on the π^0 reconstruction. For all quoted numbers the statistical error is less than 0.01

	MC events	$\bar{\nu}\text{Ne}$	νNe
a	$\frac{\text{no. of observed } \gamma}{\text{no. of produced } \gamma}$	0.65	0.67
b	$\frac{\text{no. of } \pi^0 \text{ with both } \gamma \text{ obs.}}{\text{no. of produced } \pi^0}$	0.41	0.43
c	$\frac{\text{no. of reconstructed } \pi^0}{\text{no. of } \pi^0 \text{ with both } \gamma \text{ obs.}}$	1.03	1.04
d	$\frac{\text{no. of correctly reconstructed } \pi^0}{\text{no. of reconstructed } \pi^0}$	0.80	0.77
e	$\frac{\text{no. of correctly reconstructed } \pi^0}{\text{no. of } \pi^0 \text{ with both } \gamma \text{ obs.}}$	0.83	0.80
f_{MC}	$\frac{\text{no. of observed } \gamma}{\text{no. of events}}$	1.79	2.50
g_{MC}	$\frac{\text{no. of reconstructed } \pi^0}{\text{no. of events}}$	0.58	0.83
h_{MC}	$\frac{\text{no. of reconstructed } \pi^0}{\text{no. of observed } \gamma}$	0.32	0.33
	experimental data	$\bar{\nu}\text{Ne}$	νNe
f_{data}	$\frac{\text{no. of observed } \gamma}{\text{no. of events}}$	1.95	2.70
g_{data}	$\frac{\text{no. of reconstructed } \pi^0}{\text{no. of events}}$	0.54	0.78
h_{data}	$\frac{\text{no. of reconstructed } \pi^0}{\text{no. of observed } \gamma}$	0.28	0.29

Tab. 4: Fitted values of the parameters a and b in the expression $\langle n \rangle = a + b \cdot (\ln W^2 - \ln W_0^2)$ for the average multiplicities of charged hadrons. The data points were fitted in the interval $4 \text{ GeV}^2 < W^2 < 160 \text{ GeV}^2$ and W_0^2 has been set to 20 GeV^2 .

		$\bar{\nu}Ne$		νNe	
		a	b	a	b
h^+	forward	0.80 ± 0.02	0.31 ± 0.02	1.31 ± 0.02	0.38 ± 0.02
h^-		1.14 ± 0.02	0.48 ± 0.02	0.73 ± 0.02	0.41 ± 0.02
$h^+ + h^-$		1.94 ± 0.04	0.79 ± 0.05	2.04 ± 0.04	0.80 ± 0.04
$h^+ - h^-$		-0.34 ± 0.01	-0.17 ± 0.02	0.59 ± 0.02	-0.03 ± 0.02
h^+	backward	1.44 ± 0.04	0.33 ± 0.04	1.99 ± 0.02	0.33 ± 0.02
h^-		0.95 ± 0.04	0.23 ± 0.04	0.79 ± 0.01	0.32 ± 0.01
$h^+ + h^-$		2.39 ± 0.08	0.56 ± 0.09	2.78 ± 0.03	0.64 ± 0.03
$h^+ - h^-$		0.49 ± 0.02	0.11 ± 0.02	1.20 ± 0.03	0.02 ± 0.03
h^+	total	2.24 ± 0.02	0.66 ± 0.02	3.30 ± 0.02	0.72 ± 0.02
h^-		2.10 ± 0.02	0.72 ± 0.02	1.52 ± 0.02	0.72 ± 0.02
$h^+ + h^-$		4.34 ± 0.04	1.38 ± 0.04	4.82 ± 0.03	1.44 ± 0.04
$h^+ - h^-$		0.15 ± 0.02	-0.06 ± 0.02	1.78 ± 0.03	-0.00 ± 0.03

Tab. 5: Fitted values of the parameters a and b in the expression $\langle n \rangle = a + b \cdot (\ln W^2 - \ln W_0^2)$ for the average multiplicities of π mesons. The data points were fitted in the interval $4 \text{ GeV}^2 < W^2 < 160 \text{ GeV}^2$ and W_0^2 has been set to 20 GeV^2 .

		$\bar{\nu}Ne$		νNe	
		a	b	a	b
π^0	forward	0.88 ± 0.01	0.37 ± 0.02	0.90 ± 0.02	0.39 ± 0.02
π^+		0.66 ± 0.02	0.26 ± 0.02	1.16 ± 0.01	0.35 ± 0.02
π^-		1.06 ± 0.02	0.44 ± 0.02	0.68 ± 0.02	0.38 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)$		0.86 ± 0.02	0.35 ± 0.02	0.92 ± 0.02	0.37 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)^*$		0.87 ± 0.02	0.41 ± 0.02	0.87 ± 0.02	0.41 ± 0.02
π^0	backward	0.72 ± 0.02	0.14 ± 0.02	0.86 ± 0.02	0.18 ± 0.03
π^+		0.71 ± 0.02	0.25 ± 0.02	1.06 ± 0.01	0.28 ± 0.02
π^-		0.87 ± 0.03	0.21 ± 0.03	0.73 ± 0.01	0.29 ± 0.01
$\frac{1}{2} (\pi^+ + \pi^-)$		0.79 ± 0.03	0.23 ± 0.03	0.90 ± 0.01	0.28 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)^*$		0.80 ± 0.02	0.25 ± 0.03	0.80 ± 0.02	0.25 ± 0.03
π^0	total	1.61 ± 0.02	0.58 ± 0.02	1.75 ± 0.03	0.62 ± 0.03
π^+		1.37 ± 0.01	0.52 ± 0.01	2.21 ± 0.02	0.63 ± 0.02
π^-		1.94 ± 0.01	0.66 ± 0.01	1.42 ± 0.01	0.66 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)$		1.66 ± 0.01	0.59 ± 0.01	1.82 ± 0.01	0.65 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)^*$		1.68 ± 0.01	0.66 ± 0.01	1.68 ± 0.01	0.66 ± 0.01
π^0	$\beta \geq 0.7$	1.55 ± 0.02	0.57 ± 0.02	1.69 ± 0.03	0.62 ± 0.03
π^+		1.33 ± 0.01	0.51 ± 0.02	2.16 ± 0.01	0.63 ± 0.02
π^-		1.88 ± 0.01	0.66 ± 0.01	1.37 ± 0.01	0.66 ± 0.02
$\frac{1}{2} (\pi^+ + \pi^-)$		1.61 ± 0.01	0.59 ± 0.01	1.76 ± 0.01	0.65 ± 0.01
$\frac{1}{2} (\pi^+ + \pi^-)^*$		1.63 ± 0.01	0.66 ± 0.01	1.63 ± 0.01	0.66 ± 0.01

* For the evaluation of this expression $\langle n_{\pi^+} \rangle_{\bar{\nu}Ne}$ was replaced by $\langle n_{\pi^-} \rangle_{\nu Ne}$ and $\langle n_{\pi^+} \rangle_{\nu Ne}$ by $\langle n_{\pi^-} \rangle_{\bar{\nu}Ne}$ respectively. The values of a and b are therefore identical in $\bar{\nu}Ne$ and νNe scattering and are equal to those for $0.5 \cdot [\langle n_{\pi^-} \rangle_{\bar{\nu}Ne} + \langle n_{\pi^-} \rangle_{\nu Ne}]$.

Tab. 6: Ratios of average multiplicities of π^0, π^+, π^- mesons and of charged hadrons (h^+, h^-) at $W^2 = 20$ and (in brackets) at 100 GeV² for $\bar{\nu}Ne$ and νNe scattering.

		$\bar{\nu}Ne$	νNe
$\frac{\pi^0}{h^+ + h^-}$	forward	0.45 ± 0.01 (0.46 ± 0.02)	0.44 ± 0.01 (0.46 ± 0.02)
	backward	0.30 ± 0.01 (0.29 ± 0.02)	0.31 ± 0.01 (0.30 ± 0.01)
	total	0.37 ± 0.01 (0.39 ± 0.01)	0.36 ± 0.01 (0.39 ± 0.01)
$\frac{\pi^0}{\pi^-}$	forward	0.83 ± 0.02 (0.83 ± 0.02)	1.32 ± 0.04 (1.19 ± 0.04)
	backward	0.83 ± 0.03 (0.78 ± 0.05)	1.18 ± 0.04 (0.97 ± 0.04)
	total	0.83 ± 0.01 (0.84 ± 0.02)	1.23 ± 0.02 (1.11 ± 0.03)
$\frac{2\pi^0}{(\pi^+ + \pi^-)}$	forward	1.02 ± 0.03 (1.03 ± 0.04)	0.98 ± 0.02 (1.02 ± 0.03)
	backward	0.91 ± 0.04 (0.81 ± 0.05)	0.96 ± 0.03 (0.86 ± 0.04)
	total	0.97 ± 0.02 (0.97 ± 0.02)	0.96 ± 0.02 (0.96 ± 0.02)
$\frac{2\pi^0}{(\pi^+ + \pi^-)}^*$	forward	1.01 ± 0.03 (0.96 ± 0.03)	1.03 ± 0.03 (1.00 ± 0.04)
	backward	0.90 ± 0.03 (0.78 ± 0.04)	1.08 ± 0.04 (0.97 ± 0.05)
	total	0.95 ± 0.02 (0.92 ± 0.02)	1.04 ± 0.02 (1.01 ± 0.02)
$\frac{2\pi^0}{(\pi^+ + \pi^-)}$	$\beta \geq 0.7$	0.97 ± 0.01 (0.97 ± 0.02)	0.96 ± 0.02 (0.96 ± 0.02)
$\frac{2\pi^0}{(\pi^+ + \pi^-)}^*$	$\beta \geq 0.7$	0.95 ± 0.01 (0.92 ± 0.02)	1.04 ± 0.02 (1.00 ± 0.02)

* For the evaluation of this expression $\langle n_{\pi^+} \rangle_{\bar{\nu}Ne}$ was replaced by $\langle n_{\pi^-} \rangle_{\nu Ne}$ and $\langle n_{\pi^+} \rangle_{\nu Ne}$ by $\langle n_{\pi^-} \rangle_{\bar{\nu}Ne}$ respectively.

Tab. 7: Fitted values of the parameters c and d in the expression $\langle n_{\pi^0} \rangle = c + d \cdot n$. For each case the results for the W intervals $W < 4$ GeV, $4 \text{ GeV} < W < 8$ GeV and $8 \text{ GeV} < W < 15$ GeV are given in three consecutive lines.

n		$\bar{\nu}Ne$		νNe	
		c	d	c	d
$n_{h+} + n_{h-}$	forward	0.48 ± 0.02	-0.03 ± 0.01	0.50 ± 0.03	-0.03 ± 0.02
		1.12 ± 0.04	-0.06 ± 0.02	1.24 ± 0.11	-0.07 ± 0.04
		1.74 ± 0.15	-0.10 ± 0.04	1.36 ± 0.11	0.02 ± 0.03
	backward	0.24 ± 0.02	0.14 ± 0.01	0.32 ± 0.03	0.11 ± 0.02
		0.33 ± 0.03	0.16 ± 0.01	0.46 ± 0.04	0.16 ± 0.02
		0.52 ± 0.09	0.10 ± 0.03	0.51 ± 0.09	0.16 ± 0.03
	total	0.54 ± 0.05	0.13 ± 0.02	0.66 ± 0.07	0.10 ± 0.02
		1.16 ± 0.14	0.13 ± 0.03	1.33 ± 0.08	0.12 ± 0.02
		2.01 ± 0.24	0.05 ± 0.04	1.77 ± 0.18	0.12 ± 0.03
n_{h-}	forward	0.46 ± 0.02	-0.03 ± 0.02	0.46 ± 0.06	0.02 ± 0.10
		1.12 ± 0.04	-0.08 ± 0.03	1.12 ± 0.11	-0.04 ± 0.10
		1.75 ± 0.16	-0.19 ± 0.07	1.40 ± 0.09	0.06 ± 0.06
	backward	0.36 ± 0.04	0.15 ± 0.06	0.44 ± 0.03	0.27 ± 0.05
		0.50 ± 0.06	0.23 ± 0.07	0.67 ± 0.04	0.29 ± 0.04
		0.61 ± 0.12	0.17 ± 0.10	0.79 ± 0.07	0.26 ± 0.05
	total	0.60 ± 0.03	0.20 ± 0.02	0.76 ± 0.03	0.27 ± 0.04
		1.30 ± 0.06	0.19 ± 0.03	1.63 ± 0.06	0.20 ± 0.04
		2.03 ± 0.24	0.08 ± 0.08	1.99 ± 0.13	0.23 ± 0.05

Tab. 8: Ratios $R_{Ne,N}$ of average multiplicities at $W^2 = 20$ and (in brackets) at $W^2 = 100$ GeV² with a neon target (this experiment) and with proton and neutron targets [19].

	$\bar{\nu}$		ν	
type of particles	$\frac{\langle n \rangle_{\bar{\nu}Ne}}{\langle n \rangle_{\bar{\nu}p}}$	$\frac{\langle n \rangle_{\bar{\nu}Ne}}{\langle n \rangle_{\bar{\nu}n}}$	$\frac{\langle n \rangle_{\nu Ne}}{\langle n \rangle_{\nu p}}$	$\frac{\langle n \rangle_{\nu Ne}}{\langle n \rangle_{\nu n}}$
h^+	0.90 ± 0.06 (0.80 ± 0.04)	1.05 ± 0.10 (0.89 ± 0.06)	0.94 ± 0.04 (0.94 ± 0.04)	0.96 ± 0.04 (0.96 ± 0.04)
h^-	0.91 ± 0.05 (0.95 ± 0.04)	0.87 ± 0.06 (0.98 ± 0.06)	1.01 ± 0.06 (0.93 ± 0.04)	0.88 ± 0.04 (0.94 ± 0.04)
$h^+ + h^-$	0.91 ± 0.04 (0.88 ± 0.04)	0.94 ± 0.06 (0.94 ± 0.05)	0.96 ± 0.04 (0.94 ± 0.03)	0.93 ± 0.03 (0.95 ± 0.03)
h^+	1.40 ± 0.10 (1.44 ± 0.10)	3.07 ± 0.27 (2.86 ± 0.28)	1.10 ± 0.05 (1.11 ± 0.05)	1.74 ± 0.07 (1.63 ± 0.07)
h^-	1.46 ± 0.13 (1.32 ± 0.12)	1.03 ± 0.07 (1.22 ± 0.10)	1.55 ± 0.13 (1.38 ± 0.09)	1.16 ± 0.06 (1.19 ± 0.06)
$h^+ + h^-$	1.43 ± 0.09 (1.39 ± 0.09)	1.72 ± 0.10 (1.86 ± 0.14)	1.20 ± 0.05 (1.18 ± 0.04)	1.52 ± 0.05 (1.45 ± 0.05)
h^+	1.17 ± 0.06 (1.10 ± 0.04)	1.83 ± 0.12 (1.53 ± 0.08)	1.03 ± 0.03 (1.03 ± 0.03)	1.31 ± 0.04 (1.25 ± 0.03)
h^-	1.11 ± 0.05 (1.08 ± 0.04)	0.94 ± 0.05 (1.07 ± 0.05)	1.24 ± 0.06 (1.10 ± 0.04)	1.01 ± 0.04 (1.04 ± 0.03)
$h^+ + h^-$	1.14 ± 0.04 (1.09 ± 0.03)	1.26 ± 0.05 (1.26 ± 0.04)	1.09 ± 0.03 (1.06 ± 0.03)	1.20 ± 0.03 (1.17 ± 0.02)

Tab. 9: Ratios $R_{Ne,I}$ of average multiplicities and differences $D_{Ne,I}$ of average hadronic charges at $W^2 = 20$ and (in brackets) at $W^2 = 100$ GeV² with a neon target (this experiment) and with an isoscalar nucleon target [19].

	$\bar{\nu}$	ν
type of particles	$\frac{\langle n \rangle_{\bar{\nu}Ne}}{\langle n \rangle_{\bar{\nu}I}}$	$\frac{\langle n \rangle_{\nu Ne}}{\langle n \rangle_{\nu I}}$
$\left. \begin{array}{l} h^+ \\ h^- \\ h^+ + h^- \end{array} \right\} \text{ forward}$	0.94 ± 0.05 (0.83 ± 0.04) 0.90 ± 0.04 (0.96 ± 0.04) 0.92 ± 0.04 (0.90 ± 0.03)	0.96 ± 0.03 (0.95 ± 0.03) 0.92 ± 0.04 (0.93 ± 0.03) 0.94 ± 0.03 (0.95 ± 0.03)
$\left. \begin{array}{l} h^+ \\ h^- \\ h^+ + h^- \end{array} \right\} \text{ backward}$	1.72 ± 0.11 (1.73 ± 0.11) 1.28 ± 0.08 (1.28 ± 0.10) 1.51 ± 0.08 (1.52 ± 0.09)	1.46 ± 0.05 (1.41 ± 0.05) 1.26 ± 0.06 (1.25 ± 0.05) 1.40 ± 0.04 (1.35 ± 0.04)
$\left. \begin{array}{l} h^+ \\ h^- \\ h^+ + h^- \end{array} \right\} \text{ total}$	1.33 ± 0.05 (1.22 ± 0.04) 1.04 ± 0.04 (1.08 ± 0.03) 1.17 ± 0.03 (1.14 ± 0.03)	1.20 ± 0.03 (1.17 ± 0.02) 1.07 ± 0.03 (1.06 ± 0.03) 1.16 ± 0.02 (1.13 ± 0.02)
	$Q_{\bar{\nu}Ne} - Q_{\bar{\nu}I}$	$Q_{\nu Ne} - Q_{\nu I}$
forward	0.08 ± 0.07 $(-.18 \pm 0.09)$	0.01 ± 0.05 $(-.00 \pm 0.06)$
backward	0.39 ± 0.07 (0.55 ± 0.09)	0.46 ± 0.05 (0.49 ± 0.08)
total	0.49 ± 0.02 (0.40 ± 0.04)	0.46 ± 0.03 (0.46 ± 0.05)

Tab. 10: Comparisons of average multiplicities between ' $\bar{\nu}$ 'Ne and $\pi^\pm$ Ne scattering.

	$\bar{\nu}, \nu$ Ne at $W^2 = 20 \text{ GeV}^2$	$\pi^\pm$ Ne at 10.5 GeV/c [24]
$\langle n_{h-} \rangle$	$\bar{\nu}Ne : 2.10 \pm 0.02$ $\nu Ne : 1.52 \pm 0.02$	$\pi^- Ne : 2.08 \pm 0.02^{(b)}$ $\pi^+ Ne : 1.37 \pm 0.02^{(b)}$
$\langle n_{\pi^0} \rangle$	$\bar{\nu}Ne : 1.61 \pm 0.02$ $\nu Ne : 1.75 \pm 0.03$	$\pi^\pm Ne : 1.77 \pm 0.05^{(c)}$
$\frac{\langle n_{\pi^0} \rangle_{Ne}}{\langle n_{\pi^0} \rangle_p}$	$\bar{\nu}Ne : 0.91 \pm 0.12^{(a)}$ $\nu Ne : 1.07 \pm 0.14^{(a)}$	$\pi^\pm Ne : 1.09 \pm 0.06$
$\langle n_{\pi^+} \rangle$	$\bar{\nu}Ne : 1.37 \pm 0.01$ $\bar{\nu}Ne : 1.42 \pm 0.01^{(e)}$ $\nu Ne : 2.21 \pm 0.02$ $\nu Ne : 1.94 \pm 0.01^{(e)}$	$\pi^- Ne : 1.37 \pm 0.02$ $\pi^+ Ne : 2.08 \pm 0.02$
		$\pi^- Ne$ at 10.5 GeV/c [25]
$\langle n_{\pi^+} + n_{\pi^-} \rangle$	$\bar{\nu}Ne : 3.32 \pm 0.02$ $\nu Ne : 3.64 \pm 0.02$ $\bar{\nu}Ne, \nu Ne : 3.36 \pm 0.02^{(e)}$	$\pi^- Ne : 3.74 \pm 0.06^{(d)}$

(a) $\langle n_{\pi^0} \rangle_{\bar{\nu}p}$ and $\langle n_{\pi^0} \rangle_{\nu p}$ have been taken from [20].

(b) In [24], $\langle n_{h-} \rangle$ has been assumed to be equal to $\langle n_{\pi^-} \rangle$.

(c) In [24], $\langle n_{\pi^0} \rangle$ has been determined under the assumption that all observed photons come from π^0 decays.

(d) There is an inconsistency between the two experiments of [24] and [25], due to different deductions of $\langle n_{\pi^+} \rangle$ from $\langle n_{h^+} \rangle$.

(e) $\langle n_{\pi^+} \rangle_{\bar{\nu}Ne}$ is taken to be equal to $\langle n_{\pi^-} \rangle_{\nu Ne}$ and $\langle n_{\pi^+} \rangle_{\nu Ne}$ equal to $\langle n_{\pi^-} \rangle_{\bar{\nu}Ne}$.

Tab. 11: Correlations between $\langle n_{\pi^0} \rangle$ and n_{ch} in $\bar{\nu}p$, π^-p and π^-C interactions. c and d are the parameters in the expression $\langle n_{\pi^0} \rangle = c + d \cdot n_{ch}$.

reaction	atomic number of target nucleus	W^2 [GeV ²]	c	d
$\bar{\nu}p$ [20]	1	25-100	2.37 ± 0.22	$-.05 \pm 0.07$
νp [20]	1	25-100	2.17 ± 0.16	$-.04 \pm 0.04$
π^-p [27]	1	76	1.57 ± 0.16	0.14 ± 0.02
π^-p [28]	1	76		0.13 ± 0.02
π^-p [18, 29]	1	76	1.85 ± 0.15	0.16 ± 0.02
π^-C [18, 29]	12	76	1.64 ± 0.11	0.16 ± 0.02
π^-C [18, 29] ^(a)	12	76	1.54 ± 0.17	0.18 ± 0.02

^(a) Events with interactions between π^- mesons and quasifree nucleons are excluded.

FIGURE CAPTIONS

1. Scatter plot of the vertical (M_{ver}) and horizontal (M_{hor}) $\gamma_b\gamma_m$ mass in the $\bar{\nu}\text{Ne}$ reaction. Upper plot: before, and lower plot: after removing the brems- γ 's by the cuts described in section 2d. The solid line represents the upper limit of M_{hor} and M_{ver} of the area in which photons (γ_b) are rejected. The accumulation of points along a circular band, crossing the axes at $M_{hor} = M_{ver} = \text{mass of the } \pi^0 = 0.135 \text{ GeV}$, is due to π^0 decays.
2. Distribution of the laboratory momentum of photons. Squares: data; solid line: final set of MC events.
3. Distribution of the multiplicity of photons. Squares: data; solid line: final set of MC events.
4. Distribution of the effective mass $M_{\gamma\gamma}$ of all $\gamma\gamma$ combinations. Squares: data; solid line: final set of MC events.
5. The average number of reconstructed π^0 mesons as a function of the number of observed photons in an event. Squares: data; crosses: final set of MC events.
6. Distribution of the χ^2 -probability $P(\chi^2)$ (see eq. (4)) of the π^0 candidates in the selected solutions. Squares: data; solid line: final set of MC events.
7. Distribution of the laboratory momentum of the reconstructed π^0 mesons. Squares: data; solid line: final set of MC events.
8. Distribution of the multiplicity of charged hadrons n_{ch} .
9. Distribution of the total charge Q_T of all secondaries in an event.
10. Average multiplicity of positive hadrons (open squares), negative hadrons (full squares) and of all charged hadrons (stars), plotted versus W^2 .
11. Average hadronic charge plotted versus W^2 .
12. Average multiplicity of protons $\langle n_p \rangle^{CS}$ (open triangles) and of all positive hadrons (open squares) plotted versus W^2 .
13. Average multiplicity of π^0 mesons (crosses) and of all charged hadrons (stars), plotted versus W^2 .
14. Average multiplicity of π^0 mesons (crosses), π^+ (open circles) and π^- mesons

(full circles), plotted versus W^2 .

15. Average multiplicity of π^0 mesons (crosses) and half the sum of the average multiplicities of π^+ and π^- mesons (squares), plotted versus W^2 .
16. Average multiplicity of π^0 mesons (crosses), π^+ (open circles) and π^- mesons (full circles) with $\beta \geq 0.7$, plotted versus W^2 .
17. Average multiplicity of π^0 mesons as a function of the charged multiplicity, separately for the forward and backward hemisphere and for the total sample, and for three bins of W .
18. Normalized distribution $\frac{1}{N_{ev}} \cdot \frac{dN_{\pi}}{dy_{Lab}}$ of the laboratory rapidity y_{Lab} of π^0 mesons (crosses), π^+ (open circles) and π^- mesons (full circles), in three bins of W .
19. Normalized distribution $\frac{1}{N_{ev}} \cdot \frac{dN_{\pi}}{dz}$ of the energy fraction z of π^0 mesons (crosses), π^+ (open circles) and π^- mesons (full circles) travelling forward in the $W^{\pm}$ -nucleon center of mass system, in three bins of W .

Fig. 1

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Fig. 19