Multiplicity Measurement in High Energy Neutrino-Emulsion and Antineutrino-Emulsion Interactions in the CHORUS Experiment

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We present preliminary results from the CHORUS experiment on the production of charged particles in charged current neutrino-emulsion and antineutrino-emulsion interactions. Data are collected on an event-by-event basis by recording the particle emission angle as well as ionization features observed in the target emulsion detector, in connection with event parameters reconstructed by the CHORUS electronic detectors. Average multiplicities for charged tracks, pseudorapidity distributions, the dispersion D_c and the KNO scaling are studied in different kinematical regions.

1. INTRODUCTION

Multiparticle production is an interesting phenomenon in high energy neutrino nucleus collisions. One can use multiplicity, pseudorapidity, transverse momentum, transverse energy distributions to describe the characteristics of the multiparticle production process.

Characteristics of charged particle multiplicity distributions have been studied in detail in lepton-induced interactions [1,4], in high energy hadronic collisions and in e^-e^+ annihilation [5,6]. It is very important to compare lepton-lepton, lepton-nucleus, lepton-hadron and hadron-hadron interactions in order to elucidate similarities or differences on the characteristictics of multiparticle productions.

we present a study of charged particle multiplicities in high energy charged current neutrino-emulsion and antineutrino-emulsion interactions

$\nu_\mu N \rightarrow \mu^- Hadrons$

$\overline{\nu}_\mu N \rightarrow \mu^+ Hadrons$

The behavior of the mean multiplicity $\langle n_c \rangle$ as a function of W^2 and the dispersion of these multiplicities is investigated and compared with the results of other experiments. And also KNO scaling are investigated.

2. THE EXPERIMENTAL APPARARUS

CHORUS was designed to search for $\nu_\mu \rightarrow \nu_\tau$ oscillation through the detection of the characteristic topology of the τ-lepton decay in ν_τ CC events. The CHORUS detector [7] is a hybrid setup that combines a nuclear emulsion target with various electronic detectors. The nuclear emulsion is used as target for neutrino interactions, allowing three-dimensional reconstruction of short-lived particles like the τ lepton and any charmed hadron. The emulsion target, which is segmented into four stacks, has an overall mass of 770 kg, each of the stacks consisting of eight modules of 36 plates of size 36x72 cm^2. Each plate has a 90 μm plastic support coated on both sides with a 350 μm emulsion layer [8]. Each stack is followed by three interface emulsion sheets with a 90 μm emulsion layer on both sides of an 800 μm thick plastic base and by a set of scintillating fibre tracker planes. The interface sheets and the fibre trackers provide accurate predictions of particle trajectories into the emulsion stack for the location of the vertex positions. The accuracy of the fibre tracker prediction is about 150 μm in position and 2 mrad in the track angle.

The emulsion scanning has been performed by fully automatic microscopes equipped with CCD cameras and a read-out system, called *Track Selector* [9]. In order to recognize track segments in an emulsion, a series of tomographic images are taken by focusing at different depths in the emulsion thickness. The digitized images are shifted according to the predicted track angle and then added. The presence of aligned grains forming a track is detected as a local peak of the grey level of the summed image. The track finding efficiency of the track selector is higher than 98% for track slopes less than 400 mrad.

The electronic detectors downstream of the emulsion target include a hadron spectrometer which measures the bending of charged particles in an aircore magnet, a calorimeter where the energy and direction of showers are measured and a muon spectrometer which determines the charge and momentum of muons.

The West Area Neutrino Facility (WANF) at CERN provides a beam of 27 GeV average energy consisting mainly of ν_μ with a 6% $\overline{\nu}_\mu$ contamination. During the four years of operation the emulsion target was exposed to the beam with an integrated intensity which corresponds to 5.06x10^{19} protons on target. The data from the electronic detectors were analysed and the set of events possibly originating from the emulsion stacks was identified and searched in emulsion target.

3. ANALYSIS

The location of the plate containing the interaction vertex is based on the following back of the selected negative tracks, assumed to be the τ daughters. The track is first located in the interface emulsion sheets (CC and SS) with a search initially based on the track parameters measured by the scintillating fiber trackers. A track which is found in the interface emulsion sheets is followed upstream in the target emulsion stack, using track segments reconstructed in the most upstream 100 μm of each plate, until it disappears. The corresponding plate is defined as the vertex plate, since it should contain the primary neutrino vertex or the secondary (decay) vertex, or both, from which the track originates. The three most downstream plates of each stack are used to validate the matching with the interface emulsion sheets and are not considered as possible vertex plates. The efficiency of this scan-back procedure is almost independent from the track momentum and angle. The number of located events for charged current interactions is 143742 [10].

For the multiplicity study 953 ν_μ and 581 $\overline{\nu}_\mu$ located charged current interactions have been visually inspected.

3.1. Charged track classification in nuclear emulsions

The major constituents of the nuclear emulsion are hydrogen, carbon, nitrogen, oxygen, bromine and silver (Table 1 shows the composition of the CHORUS emulsion [11]). The silver bromide (AgBr) crystals in emulsion behave as a sensitive device dispersed in a thin gelatin layer. When charged particle passes through nuclear emulsion ionizes a AgBr crystal by the Coulomb force, and this ion acts as an imager, After development of emulsion this ion changes into a Ag particle along the trace of the charged particle. These images of tracks are classified according to grain density as shower, grey and black tracks as follows [12–14]; Shower particles correspond to relativistic singly charged particle with a velocity $\beta > 0.7$. The grain density is $g < 1.4g_0$ (g_0 represents the plateau density of a singly charged particles and equals 29.6 *grains* per 100*micron*). Grey particles correspond to charged particles with velocity $0.25 \leq \beta < 0.7$. They are recoil nucleons emitted during the nuclear cascade model and the grain density is $1.4g_0 < g < 10g_0$. The black particles are produced by comparatively slower particles emitted from the target with a velocity $\beta \leq 0.25$. The grain density is $g > 10g_0$. The black tracks are produced by low energy fragments -protons,deutrons,alphas and heavier fregments- emitted from the excited target nucleus.

In the visual inspection it is not easy to classify charged tracks according to above criteria. Since the emulsion sheets were exposed perpendicular to the beam direction, for most of the tracks it is very difficult to obtain the grain density. Moreover, energy and momentum measurements of every charged particles are not feasible. Instead, we follow the following procedure: when the neutrino interaction vertex is found in the emulsion, the number of tracks at vertex is counted. Then

Table 1
Atomic composition of nuclear emulsions (Fuji-EB7) used in the CHORUS experiment.

Element	Atomic number	Weight (%)	Mole fraction (%)
Iodine (I)	53	0.3	0.06
Silver (Ag)	47	45.5	11.2
Bromine (Br)	36	33.4	11.1
Sulfur (S)	16	0.2	0.2
Oxygen (O)	8	6.8	11.3
Nitrogen (N)	7	3.1	5.9
Carbon (C)	6	9.3	20.6
Hydrogen (H)	1	1.5	40.0

Quark contents:48% up,52% down
Mean nucleus: 36 protons, 45 neutrons
Density = $3.73 g/cm^3$
Radiation length = 2.94 cm
Nuclear interaction mean free path = 38 cm
Concentration of AgBr = 45.5% in volume

they are classified as black and MIP (shower and grey) according to their ionizations in emulsion. The black tracks, heavy ionizing particles, appear as continues lines. They have short lengths; often stop in the plate. For the MIP tracks, the emission angle are measured. The neutrino emulsion interaction points is shown in Figure 1. In emulsion experiments, the emission angles, θ, of particles can be measured ,the behavior of the pseudorapidity variable for MIP tracks is shown in Figure 2. The pseudorapidity variable is given by

$$\eta = -\ln \tan \frac{\theta}{2} \quad (1)$$

where the θ is the emmision angle of the charged tracks with respect to the neutrino direction. In (anti)neutrino-induced reactions, there is no contribution of leading hadrons. The charged particle pseudorapidity distribution is qualitatively symmetrical. The pseudorapidity distribution, as seen in Figure 2, has a peak or long tail in the high pseudorapidity region. The pseudorapidity distribution of MIP particles in (anti)neutrino-emulsion collisions is approximately of Gaussian type.

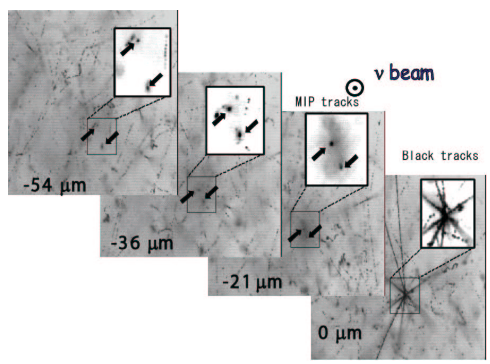

Figure 1. Neutrino interaction in emulsion. At the first screen ($0\mu m$) the black tracks at focus, at the others MIP tracks seen

3.2. Multiplicity Distributions

For this study about 953 and 581 CC interaction have been scanned for $\nu - Emulsion$ and $\overline{\nu} - Emulsion$ interactions. The average (anti)neutrino energy $E_\nu = 33GeV, E_{\overline{\nu}} = 37GeV$ and the average invariant mass of the hadronic final state $W^2(\nu - Em) = 21GeV^2$, $W^2(\overline{\nu} - Em) =$

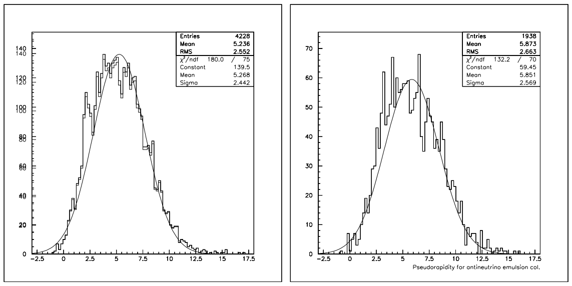

Figure 2. Pseudorapidity distributions for (left) neutrino emulsion, (right) antineutrino emulsion interactions.

$20GeV^2$. The MIP (shower + grey) and black tracks multiplicity distributions are shown in Figure 3. The average number of MIP and black track particles are $\langle n_c(\nu - Em)\rangle = 3.4 \pm 0.1$, $\langle n_c(\overline{\nu} - Em)\rangle = 2.35 \pm 0.03$ and $\langle n_b(\nu - Em)\rangle = 4.1 \pm 0.2$, $\langle n_b(\overline{\nu} - Em)\rangle = 2.35 \pm 0.04$ respectively. The average charged particle multiplicities n_c for

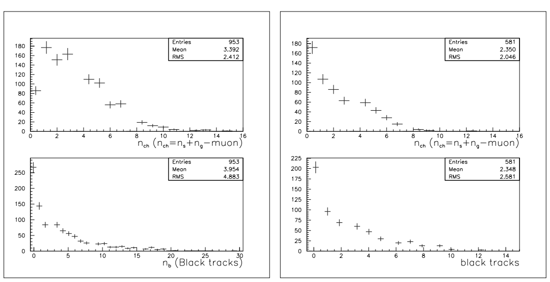

Figure 3. MIP and black tracks multiplicity distributions.Left: ν_μ-emulsion, Right: $\overline{\nu}_\mu$-emulsion interactions

$\nu - Em$ and $\overline{\nu} - Em$ interactions are plotted as a functions of W^2 given in Figure 4. The mean multiplicities are in very good agreement with a linear dependence on $ln\langle W^2\rangle$, that is

$$\langle n_c\rangle = A + Bln\langle W^2\rangle \tag{2}$$

. This expression has been fitted tyo the average for W^2 between $1GeV^2$ and $200GeV^2$. The values for the fitted parameters A and B are given below and compared with the results from other experiments in Figure 4 and shows good agreement with other experiment results.
ν-Em (Chorus)
$(0.8 \pm 0.1) + (1.08 \pm 0.06)ln\langle W^2\rangle$
ν-Em [15] $(1.9 \pm 0.7) + (1.2 \pm 0.2)ln\langle W^2\rangle$
ν-Em [16] $(1.07 \pm 0.05) + (1.3 \pm 0.1)ln\langle W^2\rangle$
ν-$freon$ [17] $(-0.3 \pm 0.1) + (1.47 \pm 0.04)ln\langle W^2\rangle$
and
$\overline{\nu}$-Em (Chorus)
$(-1.36 \pm 0.09) + (1.42 \pm 0.05)ln\langle W^2\rangle$

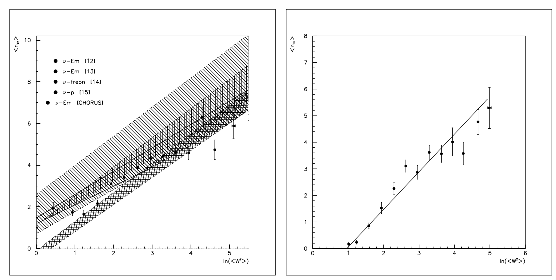

Figure 4. Charged multiplicity distributions as a function of lnW^2 for (left) neutrino emulsion, and (right) antineutrino emulsion interactions.

3.3. Dispersion and Kobe-Nielsen-Olensen Distributions

We have also investigated the dependence of the multiplicity distribution width, dispersion D_{ch}, on the average multiplicity. D_{ch} is defined as

$$D_c \overset{def}{=} \sqrt{\langle n_c^2\rangle - \langle n_c\rangle^2}. \tag{3}$$

For independent particle production the multiplicity is distributed Poisson like. Therefore, one gets

$$D_c = \sqrt{\langle n_c\rangle}. \tag{4}$$

For charged particle production in hadronic interactions, however, the empirical relation is found as

$$D_c = A + B\langle n_c\rangle \quad (5)$$

In Figure 5 D_{ch} as a function of $\langle n_c\rangle$ is given. As one can see our data behave much more Poisson-like than those from the isoscalar target of free nucleons. This might be explained by the intranuclear cascade processes which could destroy possible correlations in the primary interaction. The values for the fit parameters to the data gives
ν-Em $(1.1 \pm 0.1) + (0.22 \pm 0.03)\langle n_c\rangle$
$\overline{\nu}$-Em $(0.11 \pm 0.06) + (0.52 \pm 0.03)\langle n_c\rangle$

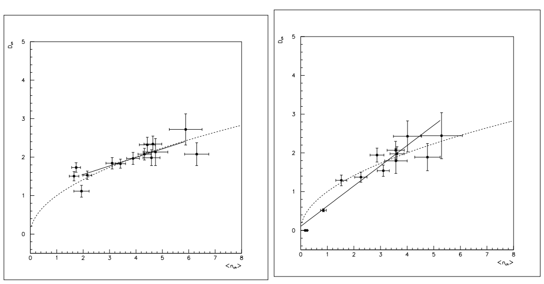

Figure 5. Shower multiplicity dispersion as a function of the $\langle n_c\rangle$ (left) for $\nu - Em$ and (right) $\overline{\nu} - Em$ interactions.

The linear dependence of the D_c on $\langle n_c\rangle$ would imply that the shape of the distribution of the normalized multiplicity is independent of the hadronic effective mass W. This is called Koba-Nielsen-Olensen (KNO) scaling [18]. Koba, Nielsen and Olesen have shown that at asymptotically high energies the scaled multiplicity distribution should become independent of the energy and a function of $z = \frac{n_c}{\langle n_c\rangle}$ only, i.e.

$$K = \langle n_c\rangle \cdot P(n_c) = \Psi(z) \quad (6)$$

where $P(n_c)$ is the probability to produce in an interaction a multiplicity n_c. Exact KNO-scaling demands, that in the linear dependence of the dispersion on the average multiplicity, Eq.5, the intercept parameter A is exactly equal to zero. From Figure 5 we observe for our data $A \neq 0$. In this case one introduces usually a new variable z' defined as

$$z' = \frac{n_c - \alpha}{\langle n_c - \alpha\rangle}. \quad (7)$$

Here $\alpha = -\langle n_0\rangle$ and $\langle n_0\rangle$ is the extrapolated point where the fitted dispersion crosses the average multiplicity axis. The KNO-scaling law now reads

$$K' = (\langle n_c\rangle - \alpha)P(n_c) = \Psi(z'). \quad (8)$$

It is clear that asymptotically it makes no difference whether one uses z or z', so this statement is a way of describing the approach to KNO scaling. The KNO distribution for shower particles is shown in Figure 6. In Figure is shown that data on neutrino-emulsion interactions follow the same kind scaling, with the same curve as for the other type of collisions but with different values of α. α is reaction dependent, and may be a measure of the average number of leading particles in the reactions.

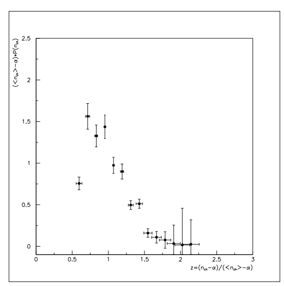

Figure 6. KNO distribution for MIP particles

4. CONCLUSION

The multiplicity structure of neutrino-emulsion, antineutrino-emulsion interactions

$$\begin{array}{l} \nu_\mu N \rightarrow \mu^- Hadrons \\ \overline{\nu}_\mu N \rightarrow \mu^+ Hadrons \end{array} \quad (9)$$

have been investigated, and compared with other experimental results. The results can be summarized as:

- The pseudorapidity distribution of charged particles like other experimental results (pion-emulsion, proton-emulsion, nucleus-emulsion collisions) are approximatelly of the Gaussian type [19–21].

- The average multiplicity $\langle n_c \rangle$ shows a linear dependence on $\ln W^2$.

- The dispersion D_c of the multiplicity distribution shows a linear dependence with mean multiplicity $\langle n_c \rangle$.

- The emulsion data is consistent with the KNO scaling.

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