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MULTIPLICITIES IN (ANTI-)NEUTRINO INTERACTIONS

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Abstract

We present an analysis of charged particle multiplicities in charged-current neutrino– and anti-neutrino–nucleus interactions at high energy. Owing to its high spatial resolution and isotropic sensitivity nuclear emulsion is well suited for the investigation of the multiplicity of the production of charged particles. A study of quasi-elastic topologies performed for the first time in nuclear emulsions is also reported. The results of the analysis can be used for tuning Monte Carlo generators of (anti-)neutrino–nucleus interactions.

1 Introduction

The multiplicity of charged particle is an important parameter for investigating particle production mechanism. Therefore, it has been studied in many experiments with different energy and particle beams [1]. The nuclear emulsion with micrometric spatial resolution is very suitable for investigating charged particle multiplicity in (anti-)neutrino interactions. However, only few measurements on neutrino-nucleon interactions in nuclear emulsion are reported. Indeed, there is no measurement on anti-neutrino-nucleus interactions in nuclear emulsion.

A study of charged-particle multiplicities produced in high-energy charged-current (anti-)neutrino interactions in a nuclear emulsion target is performed by the CHORUS collaboration. In this paper, we present the results on the multiplicity of charged particles and a first study of quasi-elastic topologies in ν_μ–A and $\overline{\nu}_\mu$–A interactions. Such measurements can be useful in order to tune interaction models in Monte Carlo event generators. Further details of the analysis can be found in Ref. [2].

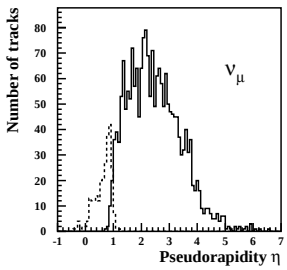

Figure 1: Pseudo-rapidity distributions for tracks classified as shower (full histogram) and grey (dashed histogram) by the scanner.

2 The experimental set-up

The experimental set-up and the characteristics of the CERN wide band neutrino beam are described in more detail in Ref. [3]. The CHORUS detector is a hybrid setup that combines a nuclear emulsion target with several electronic detectors. The target, consisting of *Fuji ET-7B* [4] nuclear emulsions, is segmented into four stacks with overall mass of 770 kg. Each of the stacks consists of eight modules of 36 plates of size 36 cm $\times$ 72 cm. Each plate has a 90 μm plastic support coated on both sides with a 350 μm emulsion layer. Each target stack is followed by three interface emulsion sheets with 90 μm emulsion layers on both sides of an 800 μm thick plastic base and by a set of scintillating-fibre tracker planes. The emulsion target was exposed perpendicular to the neutrino beam. This allows fast automatic scanning of the emulsion sheets.

3 Analysis

The first step of the event location is to search the tracks reconstructed by the electronic detector in the interface emulsion sheets. Once, a track is found in the interface sheets, it is followed upstream into the emulsion stacks plate by plate. If it is not found in two subsequent plates, the first one is defined as the vertex plate. For this analysis a sample of 1208 events was randomly selected over 150000 located neutrino interactions. These events are scanned visually in order to measure the charged track parameters at the (anti-)neutrino vertex. 627(581) of the selected events contain a leading muon of negative(positive) sign reconstructed by the muon spectrometer.

The sample of events with positive muon has contamination due to ν_μ CC events with the μ^- and punch-through hadrons reconstructed as positive muons in the spectrometer. These contaminations are reduced by applying quality cuts [2] on the muon reconstruction. After the quality selection the sample is reduced to 529 events with positive muon. Finally, We require that square of the invariant mass of the hadronic system, W^2, of (anti-)neutrino events is greater than 1 GeV^2/c^4. After this selection the number of ν_μ–A ($\overline{\nu}_\mu$–A) interactions is 496 (369).

The charged tracks are usually classified according to their grain density (number of Ag grains per unit length) as shower, grey and black prongs in the nuclear emulsion as described in Ref. [5]. Since the emulsion sheets were exposed perpendicular to the beam direction in the CHORUS experiment, the track classification based on the grain density is not applied. Instead, ionization features and pseudo-rapidity variable are used for the charged track classification. The black prongs have short path lengths and usually stop within one emulsion plate so that they can be recognized. For the remaining mixture of shower and grey prongs, we measured the particle directions and calculated the pseudo-rapidity variable [6]: $\eta = -\ln\tan\frac{\theta}{2}$ where θ is the emission angle of the prong with respect to the neutrino direction. This has the advantage of being independent of the scanner and of the microscope optics, allowing us to compare in a straightforward manner the multiplicity measurements with the theoretical models. Figure 1 shows the pseudo-rapidity distributions for tracks classified as shower and grey by the scanner, both for neutrino and anti-neutrino interactions. Based on these plots, one can insists that a scanner-independent classification is possible and it is consistent with the traditional one. In the following, all prongs with $\eta \geq 1$ are classified as shower particles. The multiplicities of shower, grey and heavy (grey+black) prongs are denoted by n_{sh}, n_{gr} and n_h, respectively. The total number of charged hadrons classified as shower particles in an event is defined to be $n_{ch} = n_{sh} - 1$, namely the number of shower tracks minus the muon track.

Based on the the pseudo-rapidity selection the average number of shower and heavy prongs in ν_μ–A interactions are $\langle n_{ch}(\nu\text{–A})\rangle = 3.4 \pm 0.1$ and $\langle n_h(\nu\text{–A})\rangle = 4.7 \pm 0.2$, respectively. And in the $\overline{\nu}_\mu$–A induced events are measured to be $\langle n_{ch}(\overline{\nu}\text{–A})\rangle = 2.8 \pm 0.1$ and $\langle n_h(\overline{\nu}\text{–A})\rangle = 3.5 \pm 0.2$, respectively. These are the first measurements in nuclear emulsion for anti-neutrino interactions.

The average charged particle multiplicities in $\overline{\nu}$–A and $\overline{\nu}$–A interactions have been investigated as a function of W^2. It is found that the mean multiplicity is in good agreement with a linear dependence of $\ln W^2$ as shown in

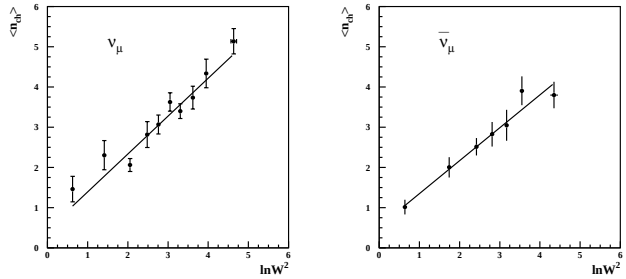

Figure 2: The hadronic shower prong multiplicity distributions as a function of lnW^2 for ν_μ-A, and $\overline{\nu_\mu}$-A interactions.

Fig. 2. The parameters of the fitted lines were found to be

$$n_{ch}(\overline{\nu}\text{–A}) = (0.45 \pm 0.24) + (0.94 \pm 0.08) lnW^2$$

$$n_{ch}(\overline{\nu}\text{–A}) = (0.53 \pm 0.20) + (0.82 \pm 0.08) lnW^2.$$

For the first time a sample of (anti-)neutrino events measured in emulsions is large enough to study (QE+RES)-like topologies. In order to have a minimum bias sample of (QE+RES)-like events, the $W^2 \geq 1\ GeV^2/c^4$ cut was not applied to the located events. Hence, the starting sample of $\nu_\mu - A$ ($\overline{\nu_\mu} - A$) interactions becomes 627 (529). An event is defined as being (QE+RES)-like, if the number of shower prongs is zero or one and the number grey prongs zero or one for for ν-A interactions regardless of the number of black tracks. In order to obtain (QE+RES)-like enriched sample in ν-A interactions, the sum of shower prongs and grey prongs is required to be one or zero regardless of the number of black tracks. After applying the efficiency and background corrections, the fraction of (QE+RES)-like events is found to be (13.4±1.0±2.0)% for ν_μ and (26.3±1.4±3.9)% for $\overline{\nu_\mu}$ interactions, respectively.

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