Charged Hadron Multiplicities in High Energy $\bar{\nu}_n$ and $\bar{\nu}_p$ Interactions

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Abstract. Charged hadron multiplicity distributions in $\bar{\nu}_n$ and $\bar{\nu}_p$ interactions in the energy range $5 < E_\nu < 150$ GeV are presented. They are obtained from about 6000 $\bar{\nu}_\mu$ charged current events produced in BEBC filled with deuterium. Multiplicity moments are studied as a function of the invariant mass of the hadronic system $W$. Results on multiplicity distributions in the forward and backward directions in the hadronic c.m.s. are presented and discussed within the framework of the quark parton model. Values for the average charge of the forward jet are also determined and compared with other experimental data.

1. Introduction

Charged particle multiplicities have been studied extensively in hadron hadron interactions. Some results from deep inelastic lepton scattering experiments have recently become available [1–4]. We report here the first results, obtained with high statistics, of processes induced by high energy antineutrinos colliding with quasi free protons or neutrons in a deuterium filled bubble chamber. The purpose of this paper is twofold. Firstly results will be given on multiplicity distributions for charged hadrons produced in $\bar{\nu}_n$ and $\bar{\nu}_p$ interactions. The logarithmic increase of the mean charged multiplicity $\langle n_{\text{ch}} \rangle$ as a function of energy will be compared with other neutrino experiments [1–4] and with multiplicity distributions observed in hadronic experiments, mainly in $\pi^- p$ interactions [5]. Secondly the multiplicities will be discussed in the framework of the quark parton model QPM, and we will attempt to establish what is referred to as the “net charge” of the quark jet. The different behaviour for $\bar{\nu}_n$ and $\bar{\nu}_p$ reactions will be emphasized whenever observed.

2. Experimental Procedure

The experiment was carried out by exposing the BEBC bubble chamber filled with deuterium to the CERN–SPS wide band antineutrino beam. The beam was produced by 400 GeV protons incident on a 110 cm long and 3 mm thick beryllium target. A horn-reflector system focussed negatively charged particles; a narrow beam stopper placed immediately before the first horn improved the ratio of antineutrino to neutrino flux by absorbing fast forward hadrons.
The remaining neutrino flux over all energies was 11% of the total flux.

The present data are based on the analysis of 125,000 pictures. A fiducial volume of 18.9 m$^3$, corresponding to a mass of 2.65 tons of deuterium, was used.

The selection of charged current (CC) events was based on the two-plane External Muon Identifier (EMI). Only events with a muon with a momentum larger than 4 GeV/c were used in the present analysis. With this cut the overall efficiency, electronic and geometric, of the EMI was $\sim 95\%$. The contamination from accidental events, hadron punch through and decays in flight was estimated to be of the order of 1%.

The entire film was scanned twice for all topologies, except for one prong events without a $V^0$. A special scan for one prong events was performed on part of the film. The overall scanning efficiency, after two scans, was 99%; it was 80% for one prong plus $V^0$, 91% for two prongs and 95% for the special scan for one prongs. Some 13,000 events were measured on film plane digitizers and were reconstructed using the standard chain of CERN Hydra programs. The processing efficiency was 98% for topologies with less than 10 charged tracks, and 96% for higher topologies.

Besides scanning and measuring efficiencies, the raw data have been corrected for the following effects:

a) the EMI geometrical inefficiency which depends essentially on the momentum $p_\mu$ and on the angle $\theta_\mu$ between the muon and the beam direction. Each event was multiplied by a Monte-Carlo computed weighting factor correcting for the EMI geometrical inefficiency which decreases from about 40% at 4 GeV/c to less than 1% at 10 GeV/c. The effect of the $p_\mu > 4$ GeV/c cut was studied by a Monte-Carlo method and corrections were applied whenever useful.

b) events with unbalanced charge. In about 1% of the events the total charge in the final state was different from 0 or 1; in general the total charge was $-1$ or $+2$ for odd at even prong respectively. This fact was mainly due to the loss of very short tracks (stopping protons or absorbed $\pi^-$), to secondary interactions near the primary vertex or to strongly asymmetric Dalitz pairs. These events were rejected and in the computation of the passing rate events with missing positive track were assigned to the next higher topology (i.e. one prong was added); events with positive track excess were assigned equally among neighbouring topologies.

Finally, before determining the multiplicities, possible effects arising from Dalitz pairs or $V^0$ decays close to the vertex were considered. Dalitz pairs were removed from the sample of the charged hadron prongs. Moreover when a single electron or positron was identified it was assumed to be a member of a Dalitz pair and another track (with opposite sign) was removed from the final state. The estimated fraction of unrecognized Dalitz pairs was $\lesssim 1\%$ of the total sample of events and no further correction was applied.

No correction was applied for $V^0$ decays very close to the vertex since from a study of all $V^0$s this possible contamination was estimated to be negligible.

A total of 5823 CC antineutrino and 1435 CC neutrino events was obtained. The sample of antineutrino CC events was divided into two categories according to whether the target particle was a neutron or a proton in the primary collision in order to study the following inclusive CC reactions:

\begin{align}
\bar{\nu}_\mu n &\rightarrow \mu^- X^- , \\
\bar{\nu}_\mu p &\rightarrow \mu^+ X^0.
\end{align}

All even-prong events are clean $\bar{\nu}_n$ interactions. The odd-prong events may arise from: i) interactions on the proton, ii) interactions on the neutron where the spectator proton is visible and iii) interactions followed by rescattering inside the deuteron. In first approximation the odd prong events having a visible proton with momentum smaller than 300 MeV/c are considered as interactions on the neutron. The remaining odd prong events are considered as interactions on the proton. However this separation is not fully reliable since the cut on the proton momentum is to some extent arbitrary and does not completely separate neutron and proton events. Although these are second order effects for the purpose of our study, a different method to separate neutron from proton events was used whenever possible. If $N$ and $P$ denote the true number of $\bar{\nu}_n$ and $\bar{\nu}_p$ events respectively, and $f$ the fraction of events involving rescattering, then:

\begin{align}
N &= (N_{\text{even}} + N_{sp})(1 - f) , \\
P &= (N_{\text{odd}} - N_{sp}) - N \cdot f \\
&= (N_{\text{odd}} - N_{sp}) - (N_{\text{even}} + N_{sp}) \cdot \frac{f}{(1 - f)} ,
\end{align}

where:

i) $N_{\text{even}}(N_{\text{odd}})$ is the number of even (odd) prong events;

ii) $N_{sp}$ is the number of events with a spectator proton and its value is computed as $N_{sp} = B_{sp} + F_{sp}$ where $B_{sp}(F_{sp})$ denotes the number of events with a spectator proton in the backward (forward) direction with respect to the beam. $F_{sp}$ was calculated from $B_{sp}$ taking into account the effects due to the Fermi motion of the nucleons inside the target: a) the target neutron flux variation with their momentum and direction in the laboratory system, and b) the antineutrino-neutron cross section variation with the total energy of the reaction;

iii) the value of the rescattering parameter $f$ is taken to be $0.12 \pm 0.03$ (see [6]).