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MULTIPLICITY CHARACTERISTICS OF MUON-NUCLEUS INTERACTION AT 400 GeV

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We present new data on the multiplicity of charged particles produced in muon-nucleus interactions at 400 GeV in a freon bubble-chamber experiment. The observed multiplicity distributions for charged particles producing both light and dark tracks have been compared with the negative binomial distribution. Multiplicity correlation between the light and dark tracks has also been studied.

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1. Introduction

The charged-particle multiplicities at various energies in hadron-nucleus and lepton-nucleus interaction have attracted much attention for a long time. In the study of the multiparticle production process, multiplicity is one of the most important parameters. With the help of this parameter, different phenomenological and theoretical models can be tested and modified. A deeper insight into the dynamics of the high-energy nuclear interaction and the particle-production process is provided by the multiplicity distribution. Confining the analysis only to charged particles, the charged-particle multiplicity distribution is denoted by p_n. The normalization condition and the average value of the number of tracks are

$$\sum p_n = 1, \qquad \langle n \rangle = \sum n p_n \,. \tag{1}$$

The Koba, Nielsen and Olesen (KNO) scaling law [1], which found its basis in the Feynman's analysis of the limits of particle production [2], successfully depicted the charged-particle multiplicity distribution. The relation is

$$\langle n \rangle p_n = \Psi(n/\langle n \rangle)\,. \tag{2}$$

The KNO scaling is valid for nucleon-nucleon and hadron–nucleus interactions with the centre of mass energy $\sqrt{s}$ up to 20 GeV. With the availability of higher energies, the violation of the KNO scaling has been revealed [3].

From several experiments done during recent years on μ^-p, e$^+$e$^-$, p$\bar{\rm p}$, π^+p and pA [4-9] interactions over an energy range 10 to 1000 GeV, it has been observed that the multiplicity distribution of charged secondaries attained a different form.

The multiplicity distributions, both in the limited pseudo-rapidity regions and in the whole phase space, have been observed to follow the negative binomial (NB) distribution. It has been seen that the NB distribution is statistically equivalent to the combination of Poisson and logarithmic distributions.

The NB distribution for n charged secondaries has two parameters, $\bar{n}$ and k, and enegy dependence of the distribution is described by the energy dependent parameter k. The distribution is expressed as:

$$p(n;k,\bar{n}) = \frac{k(k+1)\ldots(k+n-1)}{n!}\frac{\bar{n}^n k^k}{(\bar{n}+k)^{n+k}}\,. \tag{3}$$

The average multiplicity $\langle n \rangle$ and the dispersion D of the statistics are related to the parameters as follows,

$$\langle n \rangle = \bar{n} \qquad \text{and} \qquad D^2 = \bar{n} + \frac{\bar{n}^2}{k}\,. \tag{4}$$

It is well known that in the case of strong interaction, the experimental points fit well with the NB distribution curve, i.e., this distribution is widely accepted as a good representation of the charged-particle multiplicity distribution in high-energy interactions. The physical process involved in the interaction mechanism can be reasonably well explained by the cascade model [10]. We have studied the multiplicity distribution of light and dark tracks in muon-nucleus interactions at 400 GeV in a freon bubble chamber experiment.

Our main objective has been to see whether multiplicity distribution in the case of the weak interaction, like the muon-nucleus interaction, follows NB distribution or not. We have also studied the multiplicity correlation between the light and dark tracks.

2. *Experimental details*

E-782 was a unique bubble-chamber muon experiment [11]. It was done in collaboration with Tohoku University (Japan) and Fermilab (USA). It also involved the University of Tennessee (USA) and the Institute of High Energy Physics, China.

The Tohoku Bubble Chamber was exposed to the 400-GeV muon beam at Fermilab. Muon interaction in the bubble chamber liquid (freon) had been recorded and was available for the analysis in the form of a 2-view 70 mm film for event identification and scanning, and as a 3-view 35 mm film for scalping and measurement.

The events which were simple and had fallen in the fiducial (reference) volume were taken into account. For the analysis, we considered all events with:

1. an outgoing fast muon that was not deflected from the beam direction by more than ±4 cm/metre,

2. more than one light hadrom track or a single light hadron track having momentum greater than 0.6 GeV/c.

We were not interested in: 1) events from non-beam tracks, 2) events from crowded frames (> 200 tracks/prix) and 3) two prong events having an electron or positron track.

A large number of frames were scanned and 2146 confirmed events were selected. For each event, corresponding multiplicities were noted and categorized into dark or light tracks.

3. Results and discussion

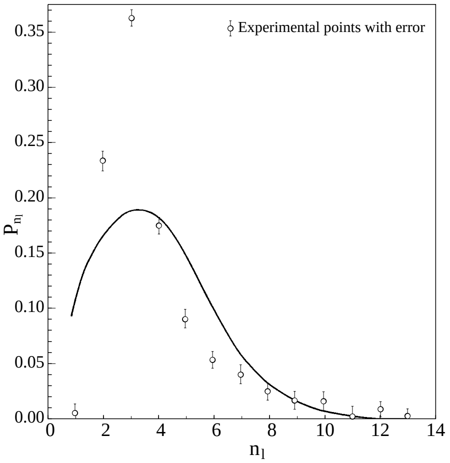
We have studied multiplicity distribution and multiplicity correlation in 400-GeV muon–nucleus interaction. In contrast to the hadron probes, which are complicated by their strong interaction form factors, lepton probes are structureless projectiles. However, it is precisely for this leptonic nature that the multiplicity is very low.

We observed the interactions in a freon (CCl_2F_2) bubble chamber. So, the target nuclei were carbon, chlorine and fluorine, which have a large number of nucleons. That is an advantage over some traditional bubble chambers. Thus, muons, being subject to weak interaction, can produce significant events as there is a large number of target nucleous. The results obtained from NB parameterization of muon–nucleus interaction are summarized in Table 1. The best NB fitted curves for light and dark tracks are shown in Figs. 1 and 2, respectively. Corresponding experimental points are given with error bars. Within experimental and statistical error, data obtained for light and dark tracks are in agreement with NB distribution. This is evident from their corresponding χ^2(d.o.f) values. The agreement in the case of dark tracks is quite remarkable. In the case of light tracks, experimental values of different points deviate with respect to NB distribution curve for the region $n = 2, 3$ (events with $n = 1$ with momentum less than 6 GeV, as mentioned already in the selection criteria were not considered in our sample). Experimetal values of different parameters using the multiplicity data, are shown in Table 2. These parameters are average multiplicity $\langle n \rangle$, dispersion (D) and multiplicity moments C_2, C_3 and C_4 for both the light and dark tracks. Multiplicity moments are obtained by using the formulae,

$$C_q(q = 2, 3, 4) = \frac{\langle n^q \rangle}{\langle n \rangle^q} \, . \tag{5}$$

TABLE 1. Results obtained from the best fitted negative binomial distribution using the multiplicity data of muon-nucleus interaction at 400 GeV.

Tracks	$\bar{n}$	k	D	χ^2
Light	4.00	20.00	2.19	6.182 (13)
Dark	1.18	3.59	1.57	0.179 (7)



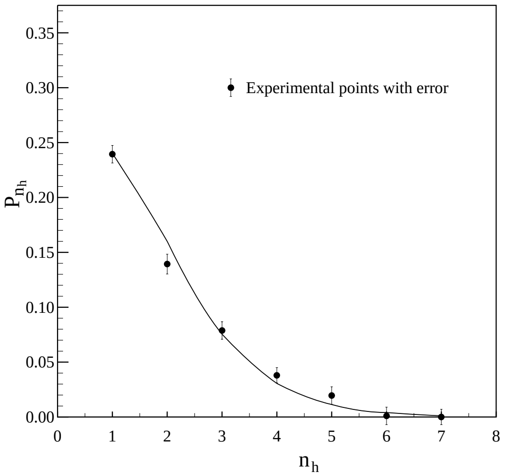


Fig. 1. Best NB fitted curve for light tracks using data from muon-nucleus interaction at 400 GeV *in a freon bubble chamber. Experimental points are shown with error bars.*

Fig. 2. Best NB fitted curve for dark tracks obtained from 400 GeV *muon-nucleus interaction in Tohoku bubble chamber (right).*

For the best fit NB curve, NB distribution parameter $\bar{n}$ is actually $< n >$. For both the light and dark tracks, this criterion is satisfied, and the dispersion is calculated from the relation (4). It is seen that, for the light tracks, the value of D from experimental data deviates a little from the theoretical NB distribution value, while for the dark tracks, the agreement is much better.

NB distribution can be interpreted [12] as a geometric distribution having k number of independent stochastic sources. But our data set for the best agreement with the NB distribution requires k to assume fractional values. The physical interpretation of such values of k are still an open question.

Figure 3 is the scatter diagram used to analyze the correlation between $\langle n_L \rangle$ and n_h. n_L and n_h are the light and dark track multiplicities, respectively. It is transparent from the figure that the correlation is positive but low. The data are

TABLE 2. Experimental velues of different parameters using the multiplicity data of muon-nucleus interaction at 400 GeV.

Interactions μ-freon	$< n >$	$< D >$	C_2	C_3	C_4	Reference
Light tracks	3.81	1.97	1.26	2.07	4.01	present work
Dark tracks	1.11	1.55	2.38	7.17	25.71	present work

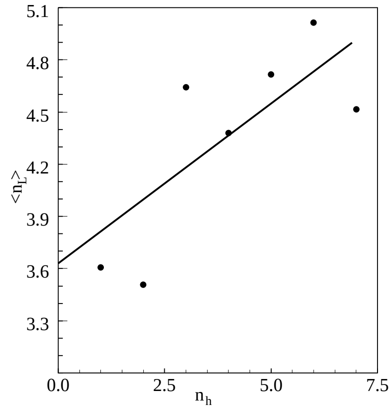


Fig. 3. Distribution of the average number of light tracks $\langle n_L \rangle$ *associated with a fixed number of dark track events.*

fitted with a linear curve. Table 3 shows the gradient (a) and the intercept (b) of the linear fit. We compute the coefficient of determination, r^2, using the following formula:

$$r^2 = \frac{b \sum n_{Li} + a \sum n_{Li} n_{hi} - n \bar{n}_L^2}{\sum n_{Li}^2 - n n_L^2} \,. \tag{6}$$

Here a and b are correlation parameters and their values are:

$$a = 0.18 \qquad \text{and} \qquad b = 3.63 \,.$$

After computation, we get $r^2 = 0.025$. Hence, we get the coefficient of correlation $r = 0.158$. From these results, we can conclude that the number of light tracks and the number of dark tracks are not correlated to a high degree.

4. *Conclusions*

The investigation and analysis carried out in this work provides new data on the multiplicity characteristics of muon-nucleus interactions at ultra high energy. It is observed that:

(1) The experimental multiplicity distribution agrees well with NB distribution for both light and dark tracks.

(2) However, in the case of light tracks, the agreement is poor for $n = 2$ and $n = 3$ (events with $n = 1$ having momentum less than 0.6 GeV, as mentioned already in the selection criteria, were not taken in our sample).

(3) There is a very weak correlation between light- and dark-track producing particles.

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ZNAČAJKE VIŠESTRUKOSTI U MEĐUDJELOVANJU MION-JEZGRA NA 400 GeV

Izlažemo nove podatke o višestrukosti nabijenih čestica proizvedenih u međudjelovanju miona s jezgrama na 400 GeV u freonskoj komori na mjehuriće. Opažene raspodjele višestrukosti za svjetle i tamne tragove su se usporedile s negativnom binomnom raspodjelom. Istraživala se i korelacija među višestrukosti svjetlih i tamnih tragova.