ISSN 2347-3487

CHARACTERISTICS OF PARTICLES PRODUCED IN HADRON-NUCLEUS COLLISIONS

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ABSTRACT

A detailed study on mean multiplicities of secondary charged particles is presented. The average number of grey, black and heavy particles are found to be independent of energy in proton-nucleus interactions whereas for pion-nucleus collisions the data deviates from its independence with energy. The ratio of mean number of charged particles produced in pion-nucleus collisions to its number in proton-nucleus interactions at almost the same energy is found to be similar at different energies.

Keywords: Multiparticle production; secondary charged particles; hadron-nucleus interactions and mean values of black; grey and shower particles

Subject classification

PACS 13.85 – Hadron – induced high – and superhigh – energy interactions, energy > 10 GeV

Council for Innovative Research
Peer Review Research Publishing System

Journal: JOURNAL OF ADVANCES IN PHYSICS

Vol. 6, No.1

www.cirjap.com , japeditor@gmail.com

ISSN 2347-3487

1. INTRODUCTION

The high energy hadron-nucleus (hA) collisions have been studied by several workers [1-7]. An important feature noticed in these interactions is that the nucleus plays the role of the target for the incident hadron as well as the newly produced hadronic systems. It is expected that an experimental investigation of hA interactions will not only help to explain the multiparticle production process but also reveal hadron structure. In the present paper nuclear emulsion detector (NED) has been used to detect the interactions/events. NED is one of the oldest detector technologies used for such studies. Nuclear emulsion is a material which memorises the tracks of charged particles. Emulsion consists of various elements like hydrogen (H), carbon (C), nitrogen (N), oxygen (O), silver (Ag) and bromine (Br). When a high energetic particle say hadron is incident on a target say emulsion, it interacts with the nuclei of emulsion and secondary charged particles are produced, this is called multiparticle production. The produced particles appear as tracks in emulsion and are named as black, grey and shower particles.The number of black, grey and shower particles in an event are written as N_b, N_g and N_s. The sum of black and grey particles are called heavily ionizing particles and their number is written by N_h.

When a hadron hits a nucleus it may interact in two ways with the nucleons of the target nucleus. Firstly independent reactions may take place between the incident hadron and the nucleons present in the target nucleus. Secondly the incident hadron may react coherently with the nucleons of the target nucleus. The latter picture emerges from the consideration that the time required for the formation of multibody final states in hadron-hadron (hh) interactions is so large that in the multiparticle production process, the nucleons which lie in the path of the colliding hadron inside the target nucleus may be taken as acting collectively. In the first order approximation it may be considered as collision with a single object, let us call it as "effective nuclear target". The collision between the hadron and the effective target may be considered by the same picture which is used for the description of two colliding hadrons. Such a collision may be called either a fragmentation type or a violent type collision.

In the study of multiparticle production, multiplicity is one of the most important parameters. This paper mainly deals with mean multiplicities of different particles at different energies. The mean multiplicities of slow and relativistic charged particles for pion and proton projectiles at different energies have been discussed in detail. We have also discussed some results on compound particle multiplicity (N_c) which is defined as the sum of grey and shower particles in an event as reported by [8], i. e., $N_c(=N_g+N_s)$. Here, we define the compound particle in a different way, i. e., by taking black and shower particles together and we write this as $N_{c1}(=N_b+N_s)$. The variation of mean shower and compound particles with energy is presented. The values of the ratios $<N_s>_{\pi^- A}/<N_s>_{pA}$, $<N_c>_{\pi^- A}/<N_c>_{pA}$ and $<N_{c1}>_{\pi^- A}/<N_{c1}>_{pA}$ at almost the same energy of pion and proton projectiles have been calculated and their variation with energy is studied.

2. EXPERIMENTAL PROCEDURE

The data was collected by using a stack of Ilford-G5 emulsion pellicles exposed to a 340 GeV negative pion beam at CERN SPS. Only those interactions lying 3 mm from the leading edges of the pellicles were picked up. The interactions which were produced within 35 µm from the top or the bottom surfaces of the pellicles have been excluded from the data. To avoid any contamination of primary events with secondary interactions, the primaries of all the interactions were followed back up to the edge of the plates and only those events whose primary remained parallel to the main direction of the beam and which did not show any significant change in their ionization, were finally picked up as genuine primary events.

The secondary tracks coming out from each detected event were classified according to emulsion experiment terminology [9] on the basis of their specific ionization $g^*(=g/g_o)$, where g is the ionization of the track and g_o is the ionization of the primary. The tracks with $g^*<1.4$, $1.4 \le g^* \le 10$ and $g^*>10$ were named as shower, grey and black tracks respectively. Shower tracks are relativistic charged particles whereas grey and black tracks are slow particles. The other details regarding the size of the plates, flux and the total number of interactions in the data sample are given in our earlier publications [4-7].

3. RESULTS AND DISCUSSION

The particle multiplicity is defined as the number of particles produced in the interaction. However, most of the detecting devices record only the charged particles which are produced during the interaction process. Therefore only the charged particle multiplicity is used in various analyses. The black, grey and shower tracks are supposed to be produced due to particles emitted during different stages of the multiparticle production process.

The mean values of black, grey and shower tracks/particles i. e., $<N_b>$, $<N_g>$ and $<N_s>$ are calculated and given in table1, the values reported by other workers are also listed in the same table for an exhaustive comparison for particles produced in pion-nucleus (π^-A) and proton-nucleus (pA) interactions. The mean values of heavily ionizing particles, $<N_h>$, are also calculated and displayed in table1.

Table 1. Values of $\langle N_b \rangle$, $\langle N_g \rangle$ and $\langle N_h \rangle$ for π^- A and pA interactions data at various energies

Energy GeV	Type of Interaction	$\langle N_b \rangle$	$\langle N_g \rangle$	$\langle N_h \rangle$	Reference
50	π^- A	4.48±0.09	2.71±0.07	7.19±0.09	10
50	π^- A	4.02±0.15	2.61±0.13	6.63±0.16	11
200	π^- A	4.52±0.07	2.38±0.04	6.90±0.07	12
200	π^- A	4.25±0.14	2.86±0.11	7.11±0.15	11
300	π^- A	4.71±0.25	2.89±0.20	7.60±0.29	13
340	π^- A	5.69±0.11	2.25±0.10	7.94±0.12	2
340	π^- A	5.64±0.13	2.18±0.06	7.82±0.13	Present Work
24	p A	4.45±0.13	3.16±0.11	7.61±0.14	11
50	p A	4.34±0.13	3.19±0.12	7.53±0.14	11
67	p A	4.70±0.10	2.85±0.09	7.55±0.11	14
200	p A	5.03±0.10	2.70±0.06	7.73±0.10	14
200	p A	4.09±0.18	2.96±0.15	7.05±0.20	11
300	p A	4.78±0.39	3.24±0.17	8.02±0.39	13
400	p A	4.92±0.15	2.52±0.09	7.44±0.16	15
400	p A	4.87±0.20	2.39±0.21	7.26±0.24	16
400	p A	4.22±0.16	3.14±0.14	7.36±0.18	11
800	p A	4.62±0.12	2.90±0.09	7.52±0.19	17

We have studied the variation $\langle N_b \rangle$, $\langle N_g \rangle$, $\langle N_h \rangle$ and $\langle N_s \rangle$ with energy in one of our earlier publications [4] but here we are reporting the exact values of these quantities at different energies which may be very useful for future workers in the field. From the table it is clear that the values of $\langle N_b \rangle$, $\langle N_g \rangle$ and $\langle N_h \rangle$ are almost constant within the statistical error at different energies in pA interactions but the situation is not similar in the case of π^- A interactions.

The values of $\langle N_s \rangle$, $\langle N_c \rangle$ and $\langle N_{c1} \rangle$ for both the projectiles i. e. pion and proton are given in table 2. The variations of $\langle N_c \rangle$ and $\langle N_{c1} \rangle$ with energy for proton and pion beams are shown in figures 1 & 2. It is clear that a linear dependence is observed. Least square fits to the data have been performed and the following equations are obtained.

$$\langle N_c \rangle_{\pi^- A} = -0.06 + 2.81 \ln E$$

$$\langle N_c \rangle_{pA} = -4.83 + 4.07 \ln E$$

$$\langle N_{c1} \rangle_{\pi^- A} = -1.01 + 3.46 \ln E$$

$$\langle N_{c1} \rangle_{pA} = -2.96 + 4.11 \ln E$$

ISSN 2347-3487

Table 2. Values of <Ns>, <Nc> and <Nc1> for π^- A and pA interactions data at various energies

Energy (GeV)	Type of Interaction	<Ns>	<Nc>	<Nc1>	Reference
50	π^- A	8.27±0.12	10.98±0.08	12.75±0.10	10
200	π^- A	12.01±0.10	14.39±0.05	16.53±0.08	12
300	π^- A	14.09±0.44	16.98±0.39	18.80±0.44	13
340	π^- A	13.38±0.18	15.63±0.13	19.07±0.14	2
340	π^- A	14.18±0.16	16.36±0.08	19.82±0.15	Present work
67	p A	9.73±0.23	12.58±0.14	14.43±0.15	14
200	p A	13.31±0.28	16.01±0.14	18.34±0.18	14
300	p A	16.50±1.20	19.74±1.61	21.28±1.83	13
400	p A	16.10±0.10	18.62±0.10	21.02±0.16	15
400	p A	16.86±0.51	19.25±0.47	21.73±0.46	16
800	p A	20.02±0.29	22.92±0.17	24.67±0.20	17

It may be noted from the table 2 that at nearly the same energy of incident particle the value of $<N_s>$, $<N_c>$ and $<N_{c1}>$ in pA interactions is greater than that for π^-A interactions. This difference in the values may be attributed to the fact that the inelastic cross-section in proton-nucleon interactions is greater than the inelastic cross-section in pion-nucleon interactions.

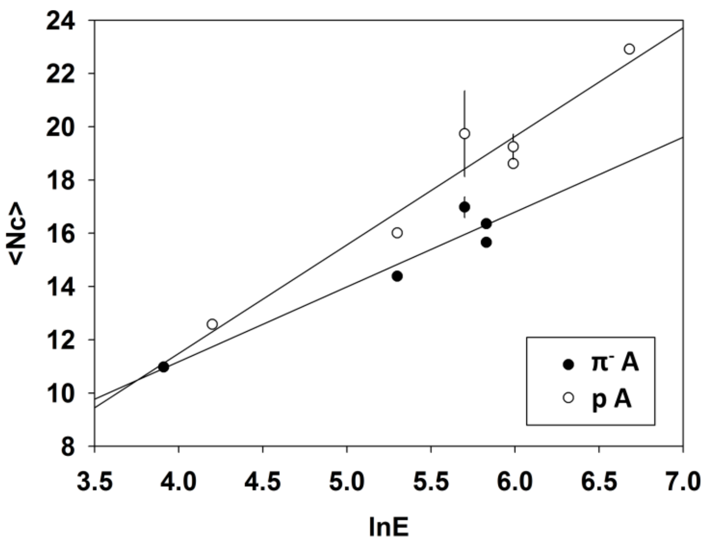

Fig 1: Variation of <Nc> with natural log of energy

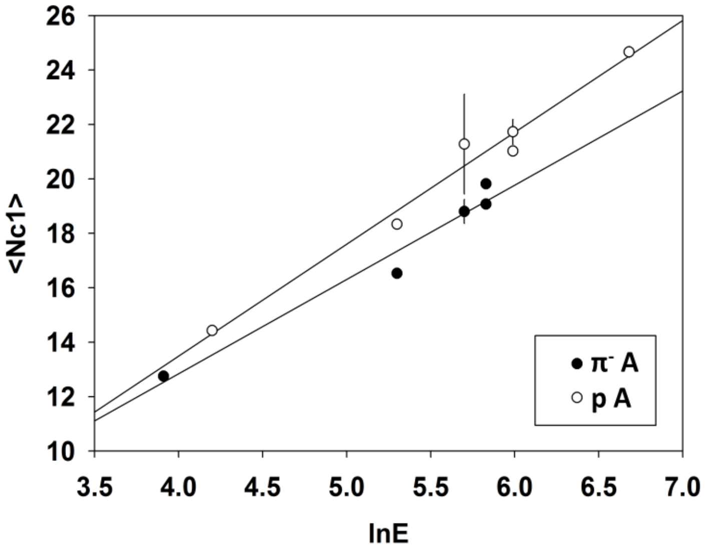

Fig 2: Variation of <Nc1> with natural log of energy

The values of the ratios $<N_s>_{\pi^- A}/<N_s>_{pA}$, $<N_c>_{\pi^- A}/<N_c>_{pA}$ and $<N_{c1}>_{\pi^- A}/<N_{c1}>_{pA}$ at almost the same energy of pion and proton projectiles were calculated and given in table 3. One may notice from the table that the ratios do not depend upon energy.

Table 3. Values of $<N_s>_{\pi^- A}/<N_s>_{pA}$, $<N_c>_{\pi^- A}/<N_c>_{pA}$ and $<N_{c1}>_{\pi^- A}/<N_{c1}>_{pA}$ at various energies

Energy (GeV)	$<N_s>_{\pi^- A}/<N_s>_{pA}$	$<N_c>_{\pi^- A}/<N_c>_{pA}$	$<N_{c1}>_{\pi^- A}/<N_{c1}>_{pA}$
50	0.85±0.02	0.87±0.01	0.88±0.01
200	0.90±0.02	0.90±0.01	0.90±0.01
300	0.85±0.07	0.86±0.01	0.88±0.08
340	0.86±0.06	0.83±0.07	0.93±0.08
400	0.88±0.01	0.88±0.01	0.94±0.01

4. CONCLUDING REMARKS

On the basis of the results presented in the paper, we conclude the following:

(i) The mean values $<N_g>$, $<N_b>$ and $<N_h>$ are almost constant for pA collisions in the entire energy range but in the case of $\pi^- A$ collisions it is something different.

(ii) A linear dependence is observed in the variation of $<N_c>$ and $<N_{c1}>$ with the natural log of energy.

(iii) The ratios $<N_s>_{\pi^- A}/<N_s>_{pA}$, $<N_c>_{\pi^- A}/<N_c>_{pA}$ and $<N_{c1}>_{\pi^- A}/<N_{c1}>_{pA}$ are independent of energy.

ISSN 2347-3487

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Dr. Tufail Ahmad obtained his PhD degree in the year 1989 in Experimental High Energy Physics from the Aligarh Muslim University, Aligarh, India. From 1990 to 1991, he worked as Research Associate of the University Grants Commission (UGC), Government of India. Presently, he is working as Associate Professor of Physics in the Aligarh Muslim University. Dr. Ahmad has published twenty two research papers in the journals of international repute like Physical Review D, Journal of Physical Society of Japan, Nuovo Cimento, International Journal of Modern Physics, ISRN High Energy Physics and Indian Journal of Pure & Applied Physics etc. He has participated in many symposia and conferences and presented papers also. His area of research is high energy hadronic collisions and relativistic heavy ion collisions.