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Scaling of multiplicity distribution in high energy hadron-nucleus interactions

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Abstract: *Analysis of 50 and 340 GeV pion-nucleus and 400 GeV proton- nucleus interactions data for multiplicity scaling study has been carried out. The multiplicity distribution of compound(sum of shower and grey particles in an event), slow (black tracks) particles and target protons (grey tracks) are found to obey a KNO type scaling law.*
Keywords: *Multiplicity scaling, compound multiplicity, relativistic charged particles, multiparticle production, multiplicity distribution Subject classification PACS 13.85 – Hadron – induced high – and superhigh – energy interactions, energy > 10 GeV.*

I. Introduction

During the last many years, the work on high energy experiments was carried out by several workers[1-8] mostly for shower particles which are fast moving charged particles or we can say that relativistic charged particles in hadron-nucleus (hA) and nucleus-nucleus (AA) collisions. The investigation of hA collisions is fundamental for understanding the nature of the interaction process. It is believed that these interactions may provide some very useful information about the dynamics of multiparticle production. An important feature noticed in these interactions is that the nucleus plays the role of target for the incident hadron.

For the present study nuclear emulsion technique has been used to collect the data. Nuclear emulsion is a material which memorises the tracks of charged particles. When a particle, let us call it as a primary particle, is incident on the nuclei of the emulsion, secondary particles are produced in the form of tracks. These particles are termed as shower, grey and black particles; and their number in an event/interaction is given as n_s, n_g and n_b.

We have tried to study the compound particle (n_c) multiplicity distribution also. A compound particle is defined as the sum of number of shower (n_s) and grey (n_g) particles in an event, i.e., $n_c=n_s+n_g$. The study on compound particle multiplicity was first done by Jurak and Linscheid [9]. We studied some aspects of compound multiplicity distribution in our earlier publication [10], this paper is in continuation to that [10]. Many workers [12-20] have studied various characteristics of compound multiplicity distributions for high energy interactions. An attempt has also been made to study the multiplicity distributions of the slow particles (black tracks) and target protons (grey particles).

In the present paper an effort is made to test the validity of hypothesis of Koba, Neilsen and Olesen [11] which is referred to as KNO scaling in the case of compound as well as slow particles.

II. Experimental details

In order to collect the experimental data, a stack of Ilford-G5 emulsion pellicles exposed to a 340 GeV negative pion beam was used. The events/interactions were picked up after leaving 3 mm from the leading edges of the pellicles to avoid any distortion effects. The measurement was carried out using an oil immersion objective of 100X magnification. To rule out any contamination of primary events with secondary interactions, the primaries of all the events 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.

In these interactions the secondary particles appear in the form of a track. The particles associated with different tracks were classified according to emulsion terminology [21] 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 $g^*<1.4$ are shower tracks. Shower tracks are relativistic charged particles which are mostly produced in the forward cone. The tracks with $1.4\leq g^*\leq 10$ and $g^*>10$ were named as grey and black tracks respectively. The particles associated with grey and black tracks are also called as slow particles, grey tracks are mostly target protons. In this study two more data sets were used, one at 50 GeV [18] pion-nucleus interactions and the other at 400 GeV [18] proton-nucleus interactions. Thus the analysis is based at three energies i.e., 50, 340 and 400 GeV. Other details may be found in our earlier publications[10,18].

III. Results and discussion

The studies on the multiplicity distribution of charged shower particles produced in hadron-hadron (hh) interactions show that the multiplicity distributions change with energy. However, it is observed that if one plots the distribution in terms of a variable $z=n_s/<n_s>$, then the multiplicity distributions at various energies may be represented by the same mathematical function $\psi(z)$. This fact is observed in hA interactions as well. This means that the multiplicity distribution exhibits a universal behaviour when plotted with z as the variable. This behaviour of the distribution is known as KNO scaling after Koba, Nielsen and Olesen [11] who first put forward the hypothesis. According to the KNO scaling the probability of observing n_s charged particles in pp collisions may be related to a function by

$$P_n(s)=\sigma_n(s)/\sigma_{inel}(s)=(1/<n_s>)\ \psi\ (n_s/<n_s>)=1/<n_s>\psi(z) \quad (1)$$

where $\sigma_{inel}(s)$ is the total inelastic cross section at a given centre of mass energy, $\sqrt{s}$ and $\sigma_n(s)$ is the partial cross section for the production of n_s charged particles and $\psi(z)$ is an energy independent function at sufficiently high energies. The KNO scaling thus implies that the multiplicity distribution is universal and the function $<n_s>P_n(s)$ has no dependence on energy when expressed in terms of a scaling variable z.

Slattery [22] was the first to test the proposed KNO scaling by plotting $<n_s>P_n(s)$ as a function of $z=n_s/<n_s>$ for the experimental data on pp collisions in two different ranges of energies, viz., 19 to 28.5 GeV and 50 to 303 GeV . Slattery [22] represented the scaling function as follows,

$$\psi(z)=(Az+Bz^3+Cz^5+Dz^7)\ \exp(-Ez) \quad (2)$$

The data was fitted by taking the values of the parameters which appears in the functional form as:

$$\psi(z)=(3.79z+33.7z^3-6.64z^5+0.033z^7)\ \exp(-3.04z) \quad (3)$$

The above function was found to give good fit to the pp collision data with χ^2/dof(degree of freedom)=1.00 in the energy range 50 to 303 GeV but the fit was poor in the energy range 19 to 28.5 GeV with χ^2/dof=2.92.

Olesen [23] has also observed that KNO scaling law is not well satisfied at very low energies atleast in pp scattering. Buras et al. [24] gave a modified scaling variable,

$$z'=(n_s-\alpha)/(<n_s>-\alpha) \quad (4)$$

which provides an extension of KNO scaling at low energies, i. e., Elab<50 GeV. Here α is an energy independent parameter. The value of α is determined in such a way that the modified KNO scaling function

$$\psi(z')= (<n_s>-\alpha)\ (\sigma_n\ (s)/\sigma_{inel}\ (s)) \quad (5)$$

weakly depends on energy. They [24] gave the following function,

$$\psi(z')=A(z' + B)\ \exp\ (Cz' + Dz'^2) \quad (6)$$

which they have used to fit the data on pp collisions in the energy range 5.5 to 300 GeV with the values of the parameters as A=2.30, B=0.142, C=-0.058 and D=-0.659. They have taken the value of α as 0.90.

Martin et al. [25] have tested the KNO scaling in the case of hA interactions taking proton as the projectile. They [25] have shown that the multiplicity distribution of charged particles in proton-nucleus interactions at 30, 67 and 300 GeV obeys KNO scaling law. The functional form given by them is as follows,

$$\psi(z)= (6.84\ z + 26.6\ z^3 - 2.12\ z^5 + 0.16\ z^7)\ \exp\ (-3.28z) \quad (7)$$

the above function was fitted to the data with χ^2/dof=0.79.

Anzon [2] et al. have also used the same function as given by Slattery [22] but with different values of the parameters for pion-nucleus interactions at 200 GeV. The values of the fitted parameters in the functional form appear as

$$\psi(z)= (3.0z + 26.0z^3 + 4.6z^5 + 0.18z^7)\ \exp\ (-4.0z) \quad (8)$$

El-Nadi et al. [3] have also tested KNO scaling in pion-nucleus interactions using the function given by Buras et al. [24]. They took the value of α as zero and found the values of the parameters A, B, C and D as 1.15, 0.14, 0.059 and -0.659 respectively.

We [7] have also studied KNO scaling for pion-nucleus interactions at 17.2, 50, 200, 300 and 340 GeV in the case of relativistic charged shower particles and tried to fit the function given by Buras et al. We also took the value of α as zero. The values of the parameters obtained by us are A=1.50±0.29, B=-0.007±0.03, C=0.17±0.13 and D=-0.95±0.13 with χ^2/dof=0.64.

Many workers [13,15,17,20,26-28] have tested the KNO scaling law for AA interactions data as well. In the present investigation, we have made an attempt to study KNO scaling in pion-nucleus interactions at 50 and 340 GeV, and proton-nucleus interactions at 400 GeV for compound multiplicity distribution. We have already defined the compound particle in section 1. In order to test the KNO scaling of multiplicity distribution of compound particles, we have calculated the function $\psi(z)$ and the variable z which has already been defined. We have tried to fit the experimental data at three different energies mentioned above with a scaling function

$$\psi(z) = Az \exp(-Bz) \quad (9)$$

The variation of $\psi(z)$ with z for compound multiplicity distribution is shown in Figure.1. The solid curve in the figure is due to the above equation with A = 2.97 ± 0.12 and B= 1.92 ± 0.32. The values of the parameters A and B were calculated using the CERN standard programme MINUIT and errors as given in MINOS. The value of χ^2/dof is 0.95. All the experimental points are almost close to the universal curve. Thus we say that the function fits the data quite well. One may conclude here that KNO scaling exists in the given energy range 50-400 GeV for compound particle multiplicity distribution.

An attempt has been made to test the validity of KNO scaling for slow particles i.e. black particles and target protons (grey particles). These are shown in Figures 2 and 3. Same function as appearing in equation (9) was tried to fit the data and the values of the parameters and χ^2/dof obtained are as under

A=3.37 ± 0.43, B=2.18 ± 0.13, χ^2/dof = 0.65 for grey particle multiplicity distribution.

A=2.52 ± 0.85, B=1.76 ± 0.27, χ^2/dof = 1.20 for black particle multiplicity distribution.

It is seen from the figure as well from χ^2/dof that the data is quite well represented by the function with the above values of A and B. Hence the KNO scaling is observed in the energy range 50-400 GeV for slow particles and target protons as well. Similar findings have been reported by other workers [26,27] also in AA interactions.

IV. Concluding remarks :

On the basis of the results discussed in the present investigation, we conclude the following.

The multiplicity distributions of compound particles, slow particles (black tracks) and target protons (grey tracks) are well represented by a single scaling function which indicates the presence of KNO scaling in hA collisions in the energy range 50-400 GeV.

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Figure Captions

Fig. 1 Scaling of compound particle multiplicity distribution in pion-nucleus and prton- nucleus interactions.

Fig. 2 Scaling of multiplicity distribution of target protons(grey tracks) in pion-nucleus and proton-nucleus interactions.

Fig. 3 Scaling of multiplicity distribution of slow particles(black tracks) in pion-nucleus and proton-nucleus interactions.

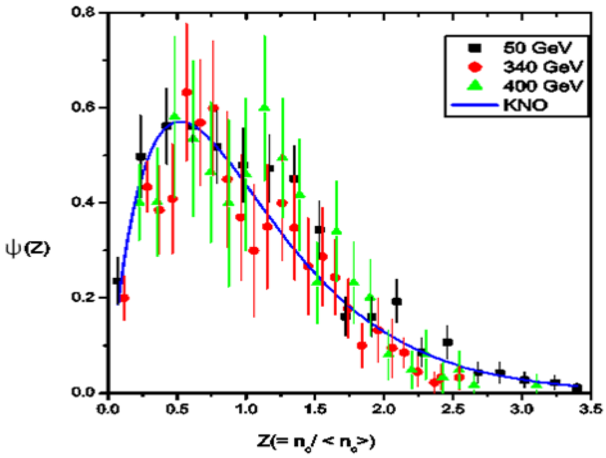

Fig. 1

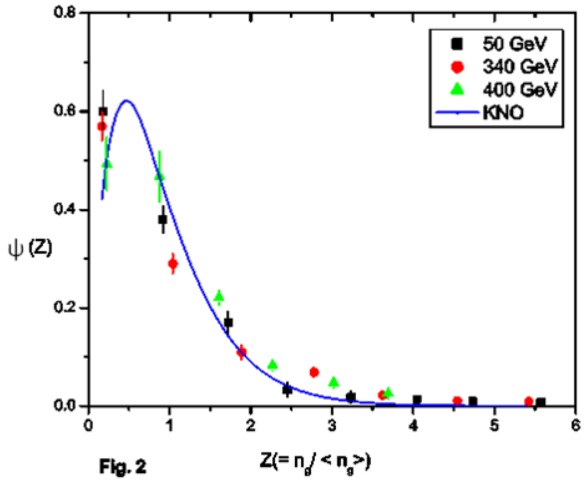

Fig. 2

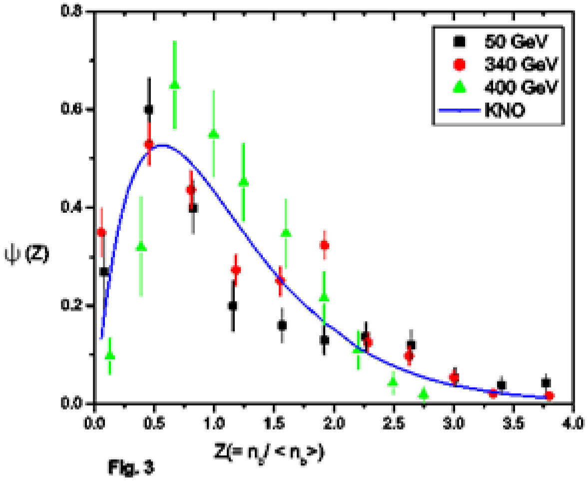

Fig. 3