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A Comparative Study of Multiplicity Scaling in Nuclear Collisions at High Energies

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Abstract: **Koba-Nielsen-Olesen (KNO) and generalized KNO (KNO-G) scalings are examined in n_s and n_c distributions by studying the behaviours of $\psi(z)$ and $S_n(z)$ versus z plots. A distinct departure from the KNO predictions is observed in the present study involving 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions and 4.5, 14.5A GeV/c ^{28}Si- nucleus interactions. However, KNO-G predictions are found to be essentially consistent with the results obtained by us for different projectiles in both n_s and n_c distributions.**

Keywords- **Heavy-Ion Collisions, Nucleus-Nucleus Collisions, Multiplicity Scaling and KNO Scaling**

I. INTRODUCTION

Several workers [1-8] have made attempt to investigate multiplicity distributions of particles produced in hadron-hadron (h-h), hadron-nucleus (h-A) and nucleus-nucleus (A-A) collisions at relativistic energies. Koba-Nielsen-Olesen (KNO) scaling has been a dominant framework to study the behaviour of multiplicity distribution of charged particles produced in high-energy hadronic collisions. Multiplicity distributions in p-nucleus interactions in emulsion experiments are found to be consistent with the KNO scaling [6-8]. The applicability of the scaling of multiplicities was extended to Fermi National Laboratory (FNL) energies by earlier group of scientists [3-5]. Slattery [3] has shown that KNO scaling is in agreement with the data on pp interactions over a wide-range of energies. The KNO scaling framework, which satisfieses the normalization condition: $\int_0^\infty z\psi(z)=1$, assumes that at a given energy the following relationships:

$$P_N = 1/(<n>)\ \Psi(n/<n>) \quad (1)$$

$$\text{Where } <n> = \sum n P_n \quad (2)$$

are valid, where n and < n > denote respectively the number of secondary charged particles produced in an interaction and their mean for a particular sample and P_n represents the probability of producing n secondaries in the final state of the collision; $\psi(z)$, where $z = n/<n>$ is energy independent function.

There are two ways of testing the validity of KNO scaling. In the first approach, there will be an overlap of the data at different projectile energies in $<n>\ P_n$ versus $n/<n>$ plots. In the second, the data at different incident energies should overlap, if sums $S_n(z)$, $S_n(z) = \sum_{i=n}^{\infty} P_i$ are plotted against z.

The results reported by the earlier workers [4-8] showed that the data obey approximately the KNO scaling at various beam energies. Nevertheless, the agreement between the data and KNO predictions was not perfect. The shape of the scaling function $\psi(z)$ when plotted against z, has to change with energy in order to obtain the best fit to the data. A sincere effort was made to generalize KNO scaling to KNO-G scaling by Glokhvastov [9]; KNO-G scaling assumes that there exists a probability distribution function, $P(\bar{n})$ which is related to P_n in the following way:

$$P_n = \int_n^{n+1} P(\bar{n})\, d\bar{n} \text{ and} \quad (3)$$

$$<\bar{n}> = \sum \bar{n}\ P(\bar{n}) \quad (4)$$

Where $<\bar{n}> = <n> + 0.5$ and scaling function in the modified form is expressed as:

$\Psi(\bar{z}) = <\bar{n}>P(\bar{n})$ and $\bar{z} = \bar{n}/<\bar{n}>$. In order to test the validity of KNO-G scaling, behaviour of parameters, $\Psi(\bar{z})$ and $S_n(\bar{z})$ are studied at different projectile energies. In the present work, an attempt is made to investigate the validity of KNO and KNO-G scalings in the multiplicity distributions of secondary charged particles produced in 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions and 4.5, 14.5A GeV/c ^{28}Si- nucleus interactions.

II. EXPERIMENTAL DETAILS

In the present study, data on 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions from Super Proton Synchrotron (SPS), European Centre for Nuclear Research (CERN) with $n_h \geq 0$, where n_h represents the number of charged particles produced in an interactions with relative velocity, $\beta \le 0.7$, are analyzed. The number of relativistic charged particles having $\beta > 0.7$ in a collision is represented by n_s; the number of compound multiplicity is denoted by $n_{c\,(=n_s+n_g)}$ where n_g is the number of charged particles emitted with relative velocity, β, lying in the interval $0.3 \le \beta \le 0.7$. In order to compare the results of the present study with the results of other experiment, two stacks of ILFORD G5 emulsion exposed to 4.5 and 14.5A GeV/c ^{28}Si nuclei from Joint Institute of Nuclear Research (JINR), Dubna and Alternating Gradient Synchrotron (AGS), Brookheaven National Laboratory (BNL) respectively are also analyzed.

III. RESULTS AND DISCUSSION

Validity of KNO scaling for n_s and n_c distributions is tested by studying the behaviours of $\psi(z)$ versus z and $S_n(z)$ versus z plots. The KNO scaling plots for n_s and n_c distributions for 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions and 4.5 and 14.5A GeV/c ^{28}Si- nucleus interactions and are displayed in Figs. 1-2. It may be noted from the figures that the data at different projectile energies lie approximately closer to the solid curves, obtained by carrying out best fits to the data using:

$$\psi(z) = A \times ze^{-Bz}$$
(5),

where A and B are constants. The values of the constants along with their corresponding, χ^2 / D.F. obtained for the best fits to the data using CERN standard program, MINUTE are presented in Table1.

TABLE 1. Values of the constants occurring in Eq. (5) for the best fits to the data corresponding to KNO-G scaling function, $\psi(z)$

Collision type	Types of distribution	Fit parameters		χ^2 / D.F.
		A	B	
^{28}Si-Em	n_s	6.16±0.55	1.79±0.10	0.34
	n_c	4.79±0.28	1.57±0.91	0.33
^{16}O-Em	n_s	2.11±0.38	1.35±0.21	0.52
	n_c	1.46±0.72	1.13±0.72	0.53

It may be noted from Table 1 that parameter A has higher values for both n_s and n_c distributions for 4.5 and 14.5A GeV/c ^{28}Si-nucleus collisions than those for 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions. However, the values of parameter B are found to be almost identical for both n_s and n_c distributions.

The validity of KNO scaling is also tested by the examining behaviour of $S_n(z)$ versus z plot. The variations of $S_n(z)$ with z for both n_s and n_c distributions for 4.5 and 14.5A GeV/c ^{28}Si-nucleus and 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions are exhibited in Figs. 3-4. It may be interesting to note from the figures that data points at different energies approximately overlap over each other.

TABLE 2. Values of the constants occurring in Eq. (5) for the best fits to the data corresponding to KNO-G scaling function, $\Psi(\bar{z})$.

Collision type	Types of distribution	Fit parameters		χ^2 / D.F.
		A	B	
^{28}Si-Em	n_s	5.47±0.28	1.61±0.44	0.12
	n_c	4.79±0.48	1.52±0.80	0.06
^{16}O-Em	n_s	6.82±0.58	1.83±0.88	0.07
	n_c	9.83±0.53	2.18±0.84	0.51

The validity of generalized KNO scaling, KNO-G, for n_s and n_c distributions is also tested by studying the behaviours of the variations of $\Psi(\bar{z})$ and $S_n(\bar{z})$ plots with $\bar{z}$. The KNO-G scaling plots for 4.5 and 14.5A GeV/c ^{28}Si-nucleus interactions and 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions are shown in Figs. 5-6. It is clear from the figures that both n_s and n_c distributions are nicely reproduced by the energy-independent function, $\Psi(\bar{z})$ .The solid curves in each plot are the best fits to the data obtained by MINUTE program using Eq. (5). Values of the fit parameters along with the χ^2 / D.F., obtained for the best fits to the data, are listed in Table 2. It may be of interest to note from the Table 2 that parameters A and B acquire slightly higher values for the data on 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions in comparison to those for the data on 4.5 and 14.5A GeV/c ^{28}Si-nucleus collisions.

Shown in Figs. 7-8 are the variations of scaling parameter $S_n(\bar{z})$ with $\bar{z}$ for both n_s and n_c distributions in 4.5 and 14.5A GeV/c ^{28}Si-nucleus collisions and 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions. Figs. 7-8 show that the experimental results on $S_n(\bar{z})$ corresponding to different projectile energies overlap and scattering is not observed in the case of both of the n_s and n_c distributions. Thus, a graphical test of the KNO-G scaling is displayed in Figs. 5-8. It may be noticed from these plots that all the data points lie on a single curve and deviations are observed around the tails of the distributions, where larger experimental errors are expected to occur.

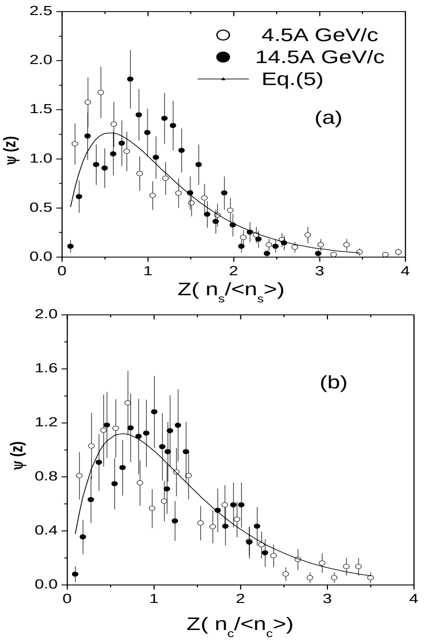

Fig. 1 Variations of $\psi(z)$ with z for n_s and n_c in ^{28}Si-nucleus collisions

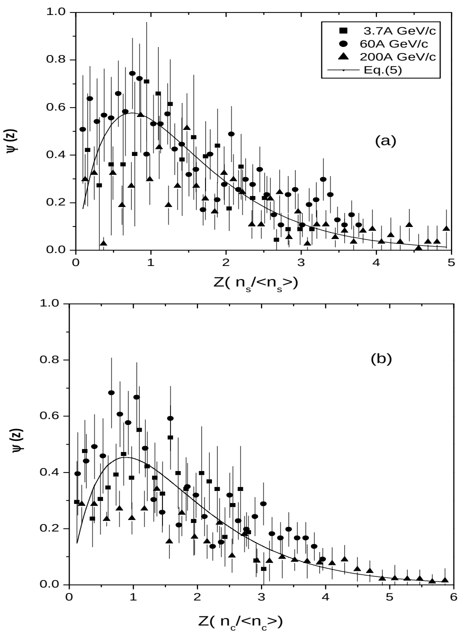

Fig. 2 $\psi(z)$ versus z plots for n_s and n_c in ^{16}O-nucleus collisions.

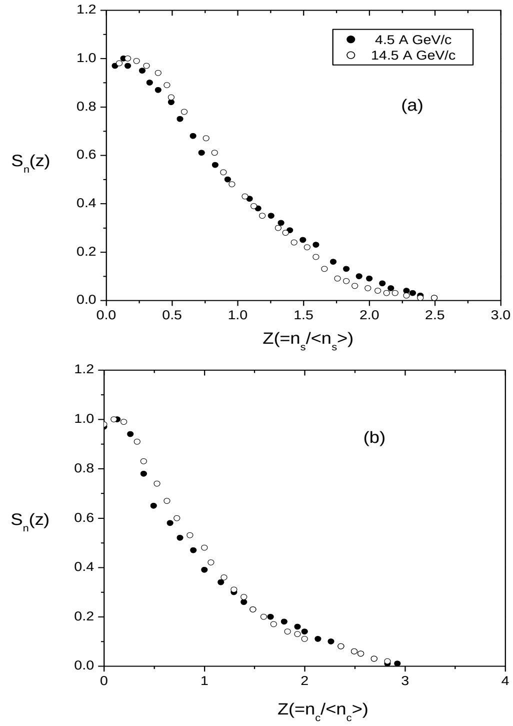

Fig. 3 Dependence of $S_n(z)$ on z for n_s and n_c in ^{28}Si-nucleus collisions.

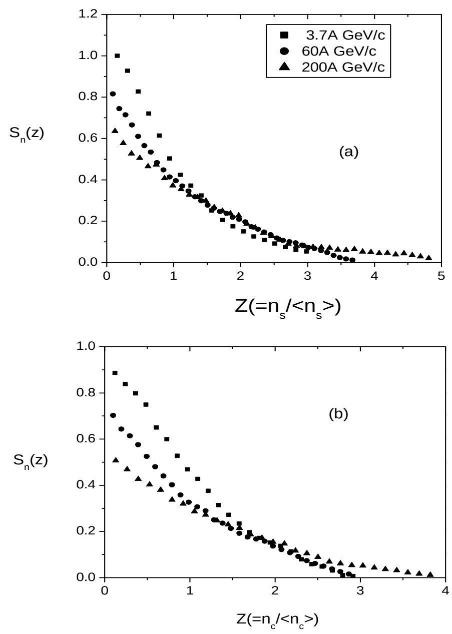

Fig. 4 Variations of $S_n(z)$ with z for n_s and n_c in ^{16}O-nucleus collisions

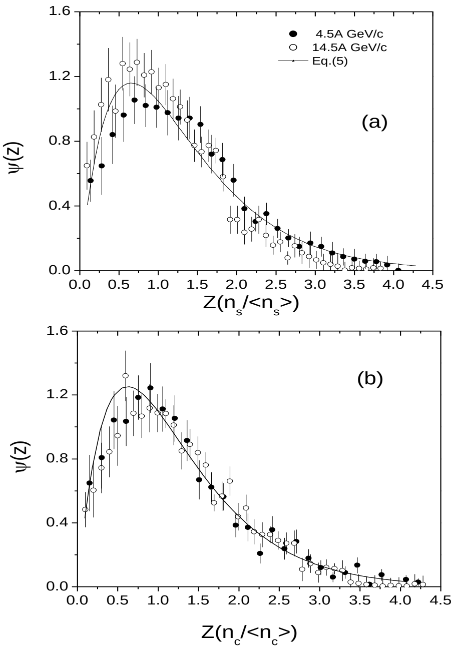

Fig. 5 Dependence of $\psi(z)$ on z for n_s and n_c in ^{28}Si-nucleus collisions

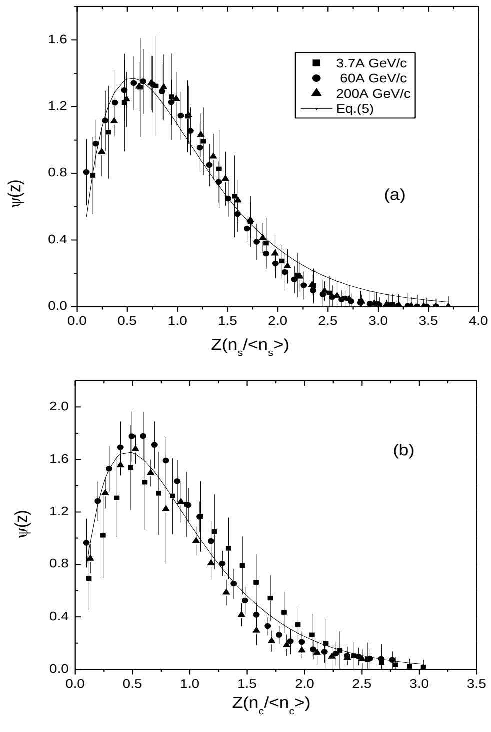

Fig. 6 Variations of $\psi(z)$ with z for n_s and n_c in ^{16}O-nucleus collision

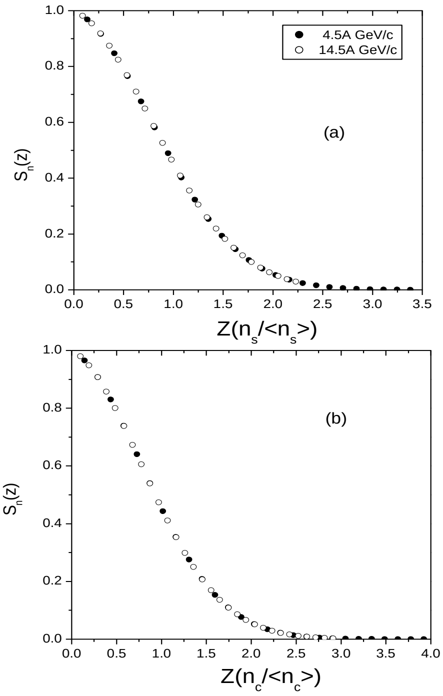

Fig. 7 $S_n(z)$ versus z plots for n_s and n_c in ^{28}Si-nucleus collisions.

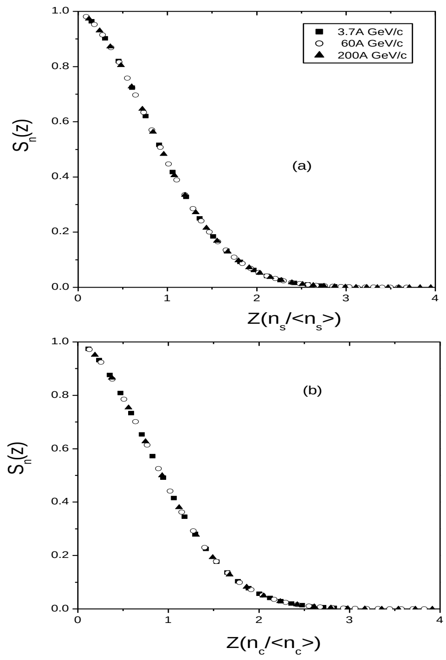

Fig. 8 Variations of $S_n(z)$ with z for n_s and n_c in ^{16}O-nucleus collisions

IV. CONCLUSIONS

Scaling of charged particles multiplicities, n_s and n_c, is examined for the data 3.7, 60 and 200A GeV/c ^{16}O-nucleus collisions and 4.5 and 14.5A GeV/c ^{28}Si-nucleus collisions . Validity of the KNO and KNO-G scalings is also tested by studying the behaviours of variations of $S_n(z)$ versus z and $S_n(\bar{z})$ versus $\bar{z}$ plots. A clear departure from the KNO predictions is discernible. However, KNO-G predictions are nearly consistent with the results extracted from the variations of $\Psi(\bar{z})$ and $S_n(\bar{z})$ with $\bar{z}$ for different projectile energies for both n_s and n_c . It may be pointed out that a confirmatory test of the KNO-G validity at LHC energies requires a further analysis of multiplicity data measured in the full phase space.

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