ISSN 1330–0016
CODEN FIZBE7

# STUDY OF MULTIPLICITY DISTRIBUTION IN FULL PHASE SPACE IN ULTRA RELATIVISTIC NUCLEAR COLLISION

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Received 11 April 1996

Revised manuscript received 7 February 1997

UDC 539.171, 539.1.073

PACS 25.70.Np, 25.75.+r

A comparative study has been made among three distributions - the negative binomial distribution (NBD), the generalised multiplicity distribution (GMD) and the distribution followed by the two mechanism model (TMM), in order to describe the multiplicity distribution of charged secondary particles produced in 200 200 $A$ GeV $^{32}$S – AgBr interaction.

## 1. Introduction

The studies of multiplicity distribution in high energy hadronic, leptonic, semileptonic and nuclear interactions have revealed some striking phenomena which can be described by various models [1-4]. Among them, the most spectacular and well known is the negative binomial distribution (NBD) model [2]. Various experimental data covering a wide range of reactants and energies including $p\bar{p}$ data at $\sqrt{s} = 200$ GeV [5] show that multiplicity distribution of the charged secondary particles could be well described by NBD. However, UA5 Collaboration observed a failure of NBD in describing multiplicity distribution at $\sqrt{s} = 900$ GeV in $p\bar{p}$ data [5]. Recently, UA5 data on $p\bar{p}$ collisions at $\sqrt{s} = 546$ Gev and 900 Gev [6] have been successfully described in terms of another interesting model named the two mechanism model (TMM) [7]. This model assumes that the mechanism by which secondary particles are produced can be separated into two phases. In the first phase, secondary particles are produced by the decays of primarily produced resonances (clans), and in the second phase, particles are produced by the inverse processes of merging of pairs of particles into one particle.

In this paper, an effort has been made to describe the data by comparing them with the three independent distributions (NBD, GMD and TMM).

## 2. Description of multiplicity distributions

Mathematically, the law of NBD can be expressed by

$$P_n(\bar{n},k) = \begin{pmatrix} k+n-1 \\ k-1 \end{pmatrix} \left(\frac{\bar{n}}{\bar{n}+k}\right)^n \left(\frac{k}{\bar{n}+k}\right)^k . \tag{1}$$

Here $\bar{n}$ and $k$ are two parameters of NBD. $\bar{n}$ is the average multiplicity of the distribution and $k$ is related to the dispersion of the distribution by the following relation:

$$D^2 = \bar{n} + \frac{\bar{n}^2}{k} . \qquad 2$$

It was argued [2] that NBD arises due to the formation of clans by the secondary particles produced in the final state of the reaction. The clans form by the decay of a common ancestor. An originally produced particle, which has not emitted any additional particle, forms a single particle cluster or clan. These ancestors and, therefore, clusters, are assumed to be produced independently, which ultimately results in NBD in the final state.

Following this picture, another interesting distribution was proposed by some authors [3], in which they predict that their ancestors are actually initiated either by the quarks or by the gluons. They also claimed the distribution to be more fundamental rather than NBD, hence they named it the general multiplicity distribution (GMD). The form of the distribution is given by

$$P_n(\bar{n},k,k') = \begin{pmatrix} n+k-1 \\ k+k'-1 \end{pmatrix} \left(\frac{\bar{n}-k'}{\bar{n}+k}\right)^{n-k'} \left(\frac{k+k'}{\bar{n}+k}\right)^{k+k'} . \tag{3}$$

Here $\bar{n}, k$ and $k'$ are the three parameters of GMD. $\bar{n}$ is the average multiplicity of the distribution. $k$ and $k'$ actually determine whether the reaction is initiated by the quarks or by the gluons., If $k \to 0$, then, according to this model, one might conclude that the reaction process is dominated by the gluons, while if it is observed that $k' \to 0$, then that would indicate that the reaction process is dominated by the quarks. Again, from the Eq.

(3), it is also clear that under the assumption $k' \to 0$, Eq. (3) reduces to the form of Eq. (1), i.e. to NBD.

At very high energy, the distribution expressed in Eq. (1) can be reduced to the form

$$P_n(\bar{n},k) = \frac{k^k}{\bar{n}\Gamma(k)} Z^{k-1} \exp(-kZ). \tag{4}$$

Here $Z = n/\bar{n}$. According to the two mechanism model [7], experimetal multiplicity distribution of the charged secondary particles could be expressed as the sum of two distributions of the form (4) with two different parameters $k_1$ and $k_2$ such that the total probability

$$P_n = P_{1,n} + P_{2,n}, \tag{5}$$

under the condition that the sum of the probabilities over $n$ is equal to unity, i.e.:

$$\int_0^\infty P_{1,n} \mathrm{d}n + \int_0^\infty P_{2,n} \mathrm{d}n = 1. \tag{6}$$

The authors in Ref. 6 pointed that the empirical probalities suggest a kind of ”break” at $n = n_0 \approx \bar{n}/2$ at $\sqrt{s} = 546$ GeV and 900 GeV, and suppose that

$$P_{1,n} = N_1 Z^{k_1 - 1} \exp(-k_1 Z) \mathrm{at} n \geq n_0,$$

and

$$P_{2,n} = N_2 Z^{k_2 - 1} \exp(-k_2 Z) \mathrm{at} n \leq n_0, \tag{7}$$

under the condition

$$P_{1,n=n_0} = P_{2,n=n_0}, \tag{8}$$

where $N_1$ and $N_2$ are normalization parameters. It was found at $\sqrt{s} = 546$ GeV and 900 GeV that the multiplicity distribution of the charged secondary particles for $\mathrm{p}\bar{\mathrm{p}}$ collision could be uniquely described by Eq. (7). The parameters $k_1$ and $k_2$ were calculated by minimising the $\chi^2$.

This paper reports a first analysis of the multiplicity distribution of $^{32}$S – AgBr interaction at 200 *A* GeV in terms of the three models, NBD, GMD and TMM.

## *3. Experimetal procedure*

Stacks of G5 nuclear emulsion plates were used, with dimensions of 20 cm × 10 cm × 600 $\mu$m. The plates were irradiated by the $^{32}$S 200 GeV per nucleon beam at CERN, Geneva. The scanning of the plates was performed by the Leitz Metalloplan microscopes with semi-automatic scanning stage. Plates were scanned by using the optics: 10× objectives and 20× ocular lenses, and for measurement 100× oil immersion objective was used in conjunction with 20× ocular lens. The events were chosen utilizing the following criteria:

a) beam tracks which make an angle greater than 3° to the mean beam direction were not taken for measurement,

b) the interaction should not be within 20 $\mu$m from the top or bottom surface of the pellicle,

c) all the primary beam tracks were followed back to ensure that the events chosen do not include interactions from the secondary tracks of other interactions. When they were observed to do so the corresponding events were removed from the sample.

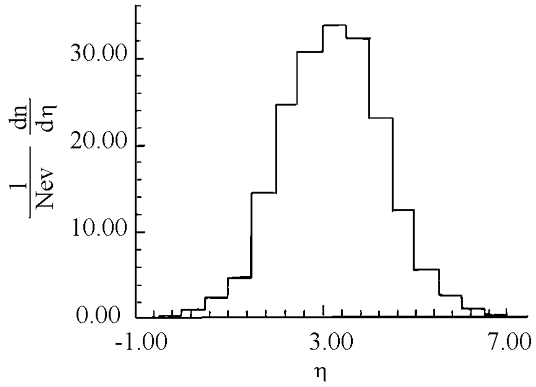

*Fig. 1. Normalised single particle rapidity distribution of* $^{32}$*S interactions at 200 A GeV.*

The scanning was done by five independent observers to increase the scanning efficiency which turned out to be 98 %. With these criteria, 140 primary events of $^{32}$S – AgBr interactions [8] were selected for the purpose of analysis. All the tracks of the charged secondaries in these events are classified in accordance with the emulsion terminology as follows:

1) Black tracks (b), having range $L < 3$ mm and ionisation $I > 6I_0$;

2) Grey tracks (g), having range $L > 3$ mm and ionisation $1.41I_0 < I < 6I_0$, where $I_0$ is the plateau ionisation for singly charged minimum ionising tracks.

3) Shower tracks (s), having very long range and ionisation $I < 1.41I_0$.

In order to ensure the target in the emulsion to be Ag/Br only, those events were chosen in which the number of heavily ionizing tracks $(n_h = n_b + n_g)$ is greater than eight. In the present analysis, we further made a selection of events with the criterion $n_h > 12$.

In order to find the pseudo-rapidity values of the relativistic charged secondary particles (shower tracks), the space angles θ of the tracks were calculated. The space angles were measured by taking the space coordinates of a point on the track, the space coordinates of the productiton point and space coordinates of a point on the incident beam track. The pseudo-rapidity value was than calculated using the formula,

$$\eta = -\ln\tan(\theta/2). \tag{9}$$

The pseudo-rapidity distribution of the relativistic particles produced in $^{32}$S – AgBr are constructed by considering all the $^{32}$S – AgBr interactions at 200 *A* GeV. It is shown in Fig. l.

## 4. Results and discussion

As the experimental multiplicity values are spread over a wide range (up to 230), to get a realistic multiplicity distribution, multiplicity bins of size twenty were considered. With this multiplicity binning, the experimental probability distribution of the relativistic charged secondary particles in $^{32}$S – AgBr interaction at 200 *A* Gev has been fitted with the predictions of NBD, GMD and TMM. The parameters of these fits (using MINUIT programme of CERN library) are shown in Table I. Figures 2a, b and c show the experimental as well as the best fit multi-

*TABLE I. Values of different parameters of negative binomial distribution (NBD), generalised multiplicity distribution (GMD), and two-mechanism model (TMM).*$\nu$ *is the number of degrees of freedom.*

| | $k$ | $n$ | $\nu$ | $\chi^2$ | Confid. level |
|---|---|---|---|---|---|
| NBD | 6.615±1.126 | 84.8±3.96 | 8 | 8.8 | 40% |

| | $k$ | $k'$ | $n$ | $\nu$ | $\chi^2$ | Confid. level |
|---|---|---|---|---|---|---|
| GMD | 6.603±1.128 | 0.01±0.006 | 84.8±3.95 | 7 | 7.7 | 40% |

| | $k_1$ | $k_2$ | $\nu$ | $\chi^2$ | Confid. level |
|---|---|---|---|---|---|
| TMM | 2.89±0.246 | 2.88±1.04 | 8 | 6.16 | 60% |

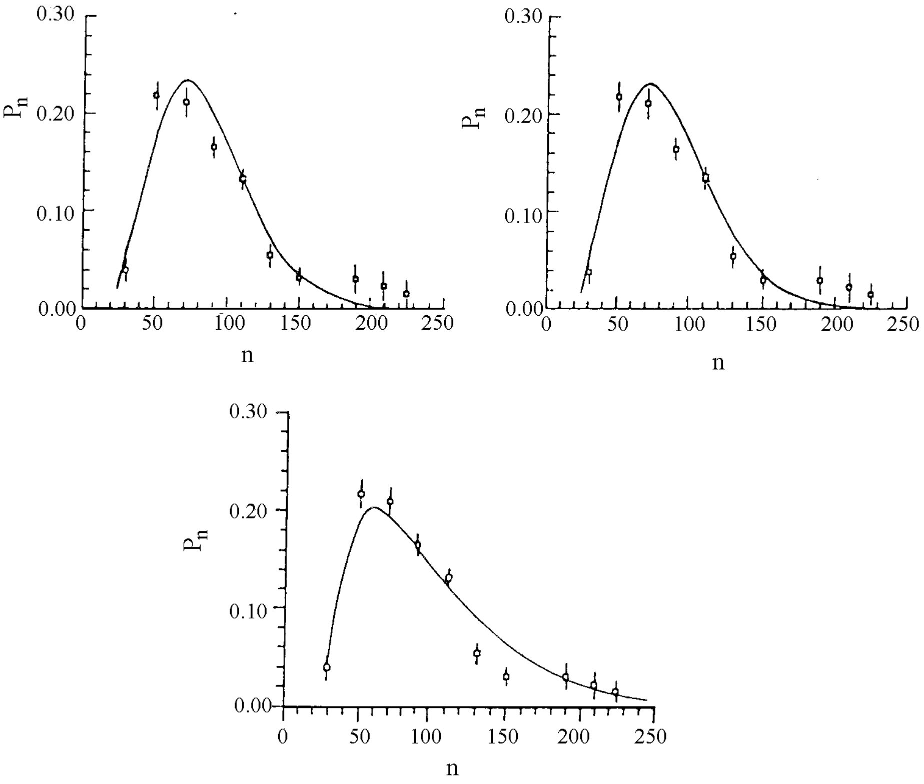

*Fig. 2. Best fits to the multiplicity distribution in full phase space, for* $^{32}S$ *– AgBr interactions at 200 A GeV: (a) with negative binomial distribution (NBD), (b) with generalised multiplicity distribution (GMD) and (c) with two mechanism model (TMM).*

plicity distributions due to NBD, GMD and TMM, respectively. The theoretical curves, as presented by the models, are shown as smooth curves, whereas the discrete points represent the experimental values. Table I shows that $\chi^2$ per degree of freedom is nearly unity for each of the three models. So, we cannot discard any one of them. However, if we consider also the level of confidence of the fits, there is an inclination towards the two mechanism model. It is evident that the parameters $k_1$ and $k_2$ of TMM are almost identical, which may indicate that the probability of resonance decay and probability of recombination to form a single state for the production of final state particles are almost identical. Further comparative analyses are suggested for other data in order to test the superiority of the two mechanism model.

## Acknowledgements

We are thankful to Prof. P. L. Jain of Buffalo State University for providing us with the exposed and developed emulsion plates. We acknowledge the financial help sanctioned by University Grants Commision, Government. of India under COSIST programme.

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## PROUČAVANJE RASPODJELE MNOGOSTRUKOSTI U CIJELOM FAZNOM PROSTORU PRI RELATIVISTIČKIM NUKLEARNIM SUDARIMA

Načinili smo usporedbu triju raspodjela: negativne binomijalne raspodjele, poopćene raspodjele mnogostrukosti i raspodjele prema modelu dvaju mehanizama, radi opisa raspodjela mnogostrukosti nabijenih čestica koje su bile proizvedene u sudarima iona $^{32}$S energije 200 *A* GeV u AgBr emulziji.