Analysis of shower particle pseudorapidity spectra in interactions of relativistic Au and Pb ions with emulsion nuclei*

B. Z. Belashev[1] M. K. Suleymanov[2,3;1)] S. Vokál[4] J. Vrláková[4] M. Ajaz[2]
Ali Zaman[2] K. H. Khan[2] Z. Wazir[2]

[1] Institute of Geology, Karelian Research Center, Russian Academy of Sciences, St. Petrozavodsk, Russia
[2] COMSATS Institute of Information Technology, Department of Physics, Islamabad 44000, Pakistan
[3] Veksler and Baldin Laboratory of High Energy Physics, JINR, Dubna 141980, Russia
[4] P. J. Šafárik University, Košice, Slovakia

Abstract: The pseudorapidity spectra of fast particles (with $\beta > 0.7$) produced in Au (at 11.6 A GeV) and Pb (at 158 A GeV) induced collisions with emulsion (Em) nuclei contain some visual plateaus and shoulders. The plateau is wider for Pb+Em reactions compared with the Au+Em ones. The existence of a plateau is expected for parton models. The Fourier transformation and maximum entropy methods were used to get additional information about the plateaus. The dependence of the plateaus on the centrality of the collisions was also studied using the number of g-particles to fix centrality. It shows that the maximum entropy method could confirm the existence of the plateau and the shoulder on distributions.

Key words: pseudorapidity spectra, s-particles, g-particles, centrality, Fourier transformation maximum entropy

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1 Introduction

According to the modern understanding of the collision of high energy hadrons and nuclei, a majority of particles could be produced as a result of hadronization of fast quark-partons to the hadron jets. As a consequence, we could observe the short range correlations on the behavior of some characteristics of produced hadrons. These correlations could be easily studied using rapidity y (or pseudorapidity η) distributions of the hadrons because in the case of jet production the produced particles have to be grouped around some selected values of y or η and could form some peaks. In high energy hadron-nuclear and nuclear-nuclear experiments some plateaus for the central area were observed. The existence of a plateau is very important for theoretical estimation. For example, in paper [1] the space-time evaluation of the hadronic matter produced in the central rapidity region in extreme nucleus-nucleus collisions has been described. It is found that quark-gluon plasma is produced at a temperature ⩾200–300 MeV, which is in agreement with previous studies. The authors commented that the description relies on the existence of a flat central plateau and on the applicability of hydrodynamics. The experimentally observed plateau could be the sum of different contributions connected, for example, with the fragments of various dynamics. In the framework of the thermalized cylinder model [2] it is a natural result of longitudinal extension. So the new results which could confirm the existence of the plateau are required. The main goal of this paper is to investigate whether some theoretical approaches can confirm the existence of a plateau. We discuss some methods of a posteriori increasing resolution of the spectral lines. In this paper, the Fourier transfor-

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1) E-mail: mais_suleymanov@comsats.edu.pk

mation method [3] and the maximum entropy one [4] are applied to confirm the existence of the plateau. The methods of analysis are described in Sec. 2. To observe more detailed information on rapidity distribution of π^--mesons produced in π^-p- and π^{-12}C-reactions at 40 GeV/c a new method was applied on the basis of the Fourier algorithm (regularization of the width of the spectral lines) [3]. The complex structures were identified by this method. Fig. 1 illustrates the results. One can see that at least two selected points are indicated by the method. The experimental data of the CERN SPS/EMU12 [5] and BNL AGS/E863 experiments [6] are used for our analysis. Some information about experimental data is given in Sec. 3. The obtained results are discussed in Sec. 4. The final part of this paper is the conclusion.

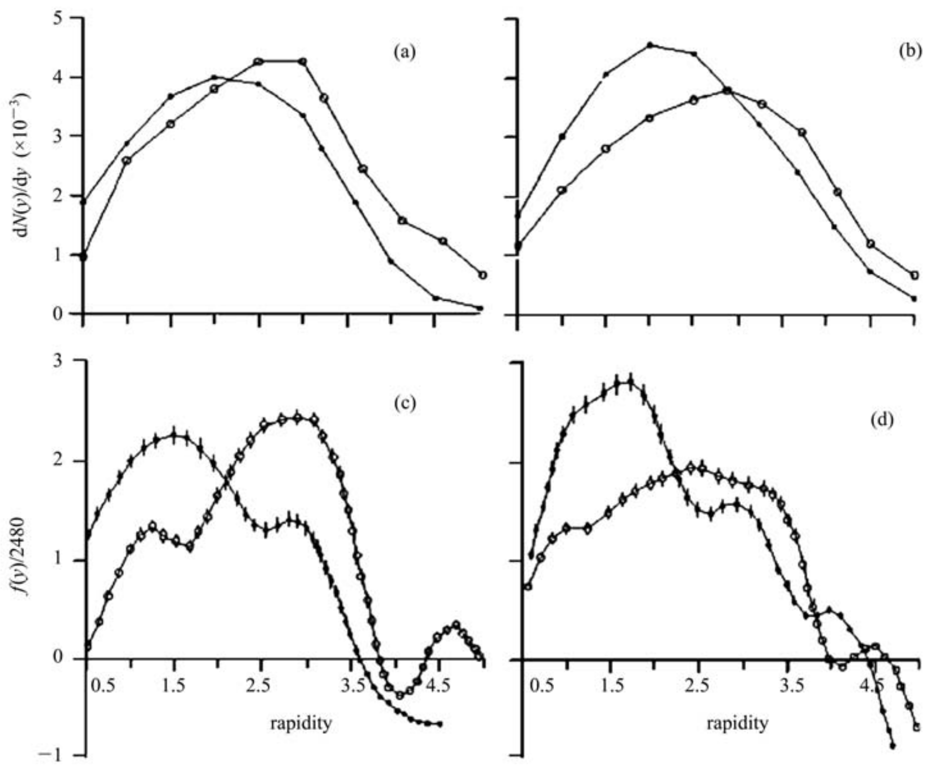

Fig. 1. The rapidity distributions (top panels) and their Fourier transformations (bottom panels) for the π^+- (close symbols) and π^-- (open symbols) mesons produced in $\pi^- p$ (left panels) and π^{-12}C - (right panels) reactions at 40 GeV/c [3].

2 The methods and procedures of data analysis

Pseudorapidity distributions were considered in the framework of the $s = hf + n$ model, where h is the blurring function, n is the additive noise, and f is the estimation of distribution which defines the structure of a distribution.

Reconstruction of the structure for pseudorapidity distributions of secondary particles was done by a posteriori decreasing the widths of its components [7]. As a result of artificial decreasing of the widths at constant positions, the resolution, contrast and self-descriptiveness of estimations grow. The methods of Fourier-transformation [3] and maximum entropy [4] were applied to decrease the widths for the distribution components of the given values. Such data processing is especially evident for the case of Gaussian or Lorentz (Breit-Wigner) forms of components. In Fourier-algorithms they pass from initial distribution to the Fourier-image, which is divided into the module of the Fourier-image of the components with a given width and do inverse transitions. The method of maximum entropy removes the given blurring function from the distribution and maximizes the entropy of estimation at performance of models restrictions.

The influence of noise on the maximum entropy method is less than that for the Fourier-transformation method and could give stable estimations at levels of additive noise of 25%. It works with narrow and wide, space-invariant and no space-invariant blurring functions [4]. Narrow blurring functions could detect deeper details of structure, wide functions leave in estimations of distributions of wide intensive components. To analyse the pseudorapidity distributions of the secondary particles and search for the existence of a central plateau the maximum entropy approach seems to be preferable.

The statistical fluctuations of the spectra were deleted using wavelet-transformation of distributions [8] at the first stage of the processing. This is equivalent to the removal of high-frequency parts of the signal from the spectrum. This procedure is effective at high noise levels and differs considerably from the traditional averaging of histograms on counting, and maintains in estimations smoothed fluctuations. The algorithm was realized in the Wavelet Toolbox of the computer mathematics system MATLAB by means of a wdcbm command, approximating c and detailing l factors of wavelet decomposition of distribution and parameters $alpha = 1.02$ and $m = l(1)$ [8]. To avoid the occurrence of small (on absolute values) negative values in the estimation, those smaller than 30 were attributed to the initial given histogram data.

In the next step, component widths were reduced assuming that the forms of components were Gaussian or Lorentz functions in the case of a Fourier algorithm method, and Gaussian in the case of a maximum entropy method. The Fourier algorithm method was carried out using the computer mathematics system MATLAB with the command FFT (Fast Fourier Transformation). For the Gaussian forms the following multiplicative functions of the Fourier-image were used:

$$\mathrm{e}^{(0.0001(w_i/\delta w))^2};\ \mathrm{e}^{(0.0002(w_i/\delta w)^2)},$$

and for the Lorentz forms the function

$$\mathrm{e}^{[0.04|w_i/\delta w|-0.0001(w_i/\delta w)^2]},$$

where w_i is the cyclic frequency of the i-th counting of the Fourier -image of distribution, δw - a step of the cyclic frequency.

In the maximum entropy method the computing program MEMFR [9] and the blurring function $h(i,j) = \mathrm{e}^{[-(0.078(\eta(i)-\eta(j))/\delta\eta)2]}$ were taken in the next analysis of the pseudorapidity spectra. For the convenience of interpretation of the processing results the maximum from the estimations was matched to the maximal value of the initial histogram.

3 Experimental data

The stacks of NIKFI BR-2 nuclear emulsions were irradiated horizontally by ^{208}Pb beam at 158 A GeV/c (Experiment EMU12 at the CERN SPS) and by ^{197}Au beam at 11.6 A GeV/c (Experiment E863 at BNL AGS). The projectile and target nuclei are disintegrated in the interactions of relativistic nuclei. According to the geometrical picture, in such collisions there is an interaction area, and non-overlapping parts of both nuclei disintegrated into fragments due to the obtained excitation. As a result of an impact parameter variation, events occur with the emission of secondaries of different types and energies within a wide range of multiplicity. The used emulsion method allows you to measure multiplicities and angles of any charged particles, and the charge of projectile fragments. Secondary charged particles used in this study were classified into the following groups:

(1) Relativistic (shower) s-particles (N_s), fast singly charged particles with $\beta \geqslant 0.7$. This group includes particles produced in the interactions (mainly pions), relativistic singly charged projectile fragments as well as those singly charged particles knocked-out from the target nucleus.

(2) Fast target fragments, g-particles (N_g), with $0.23 \leqslant \beta < 0.7$. They consist mainly of recoil protons from the target.

In this work we have analyzed 628 Pb+Em collisions and 1185 Au+Em collisions found by along-the-track scanning. Further details on experiments, measurements and experimental criteria can be found in [5, 6].

4 The results

Usually the rapidity (or pseudorapidity) spectra of relativistic particles emitted at high energies are smooth without any singularities. Apparently it is not simple to extract any information on jet production or other effects. The pseudorapidity distributions of charged particles with $\beta > 0.7$ measured in Au+Em and Pb+Em collisions at AGS and SPS energies are shown in Fig. 2.

The vertical lines indicate the points which could correspond to the boundaries of plateaus and some shoulders. The values of η corresponding to plateaus and shoulders were taken visually. So we can say that, visually, the distributions contain at least three selected points.

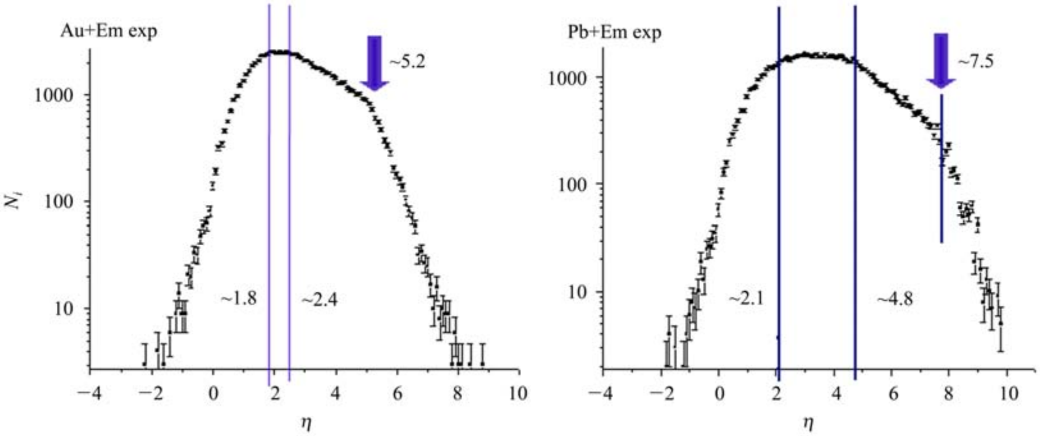

Fig. 2. (color online) The pseudorapidity distributions for the secondary charged particles emitted in: the Pb+Em reactions at SPS energies (right) and in the Au+Em reactions at AGS energies (left).

The spectra were analyzed using different Fourier transformations (see Section 3). This method can indicate some fluctuations but it is impossible to fix any selected points. For illustration in Fig. 3(a, b) one can see the picture after applying the Fourier algorithm with multiplicative function $e^{[0.04|w_i/\delta w|-0.0001(w_i/\delta w)^2]}$.

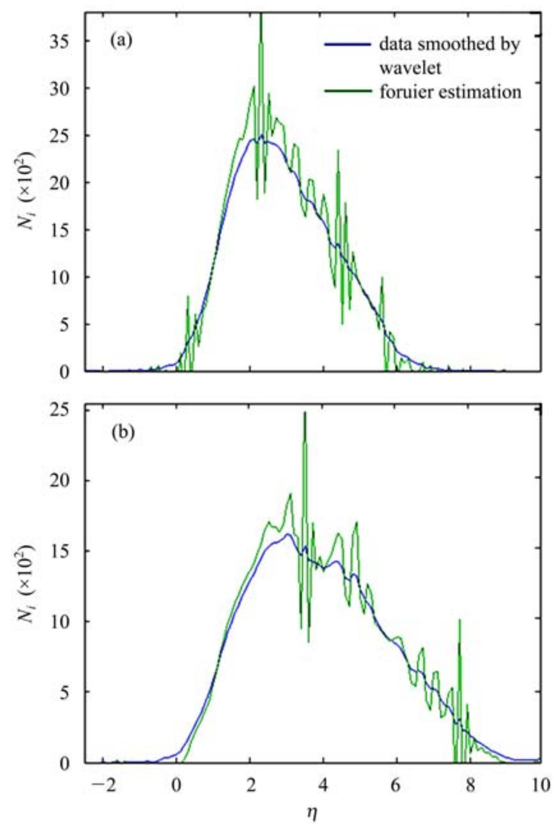

Fig. 3. (color online) The pseudorapidity distributions after applying one of the Fourier transformations (see text) to the secondary charged particles emitted in the Au+Em reactions at AGS energies and in the Pb+Em reactions at SPS energies.

Figure 4 shows the results after applying the maximum entropy method. One can see that the method indicates several selected points. Some of them correspond to the visually observed ones.

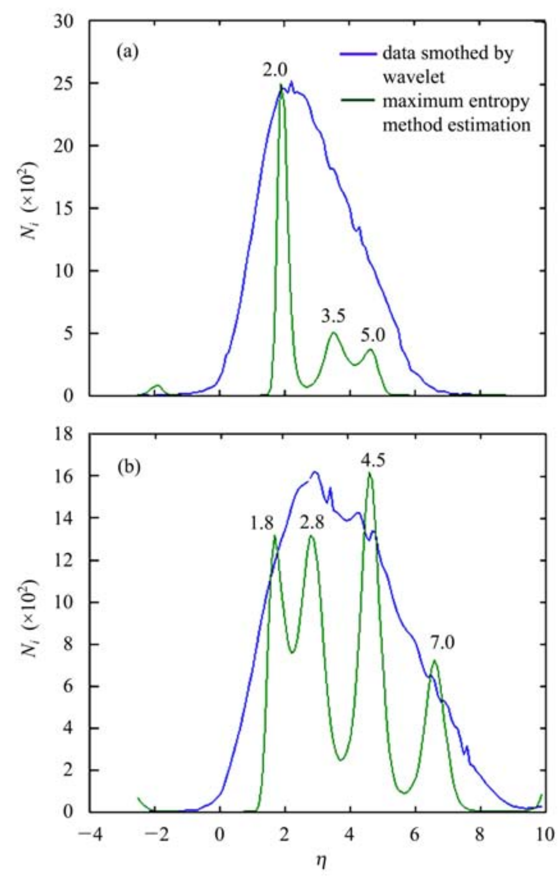

Fig. 4. (color online) The pseudorapidity distributions after applying the maximum entropy method (see text) for the secondary charged particles emitted in the Au+Em reactions at AGS energies and in the Pb+Em reactions at SPS energies.

All the above-mentioned methods were applied to the pseudorapidity spectra of charged relativistic particles with $\beta > 0.7$ measured in Au+Em and Pb+Em collisions at AGS and SPS energies with different numbers of g-particles. Non-statistical significant points were selected by the Fourier transformation method. On the other side the maximum entropy approach can determine some selected points of these distributions. The results of selected pseudorapidity values are shown in Table 1 together with the visually observed ones. One can see that the numbers of selected points are different for Au+Em and Pb+Em reactions, for Pb+Em there are more than for Au+Em. The results of this method are closed to the visually observed values. The points connected to a shoulder disappeared for the Au+Em reactions in the cases of $N_{\rm g} = 15-19$ and $N_{\rm g} \geqslant 20$. This would be connected to the suppression of the stripping effect in the central collisions. The shoulder is a natural result of leading nucleon effects in the thermalized cylinder model [2]. The presented data confirm the existence of a plateau in the central region.

Table 1. The pseudorapidity values for Au+Em and Pb+Em interactions with different number of g-particles obtained by the maximum entropy method. The η-values determined visually for all $N_{\rm g}$ from the experiment and from the maximum entropy method are shown here for comparison.

$N_{\rm g}$		Au+Em			Pb+Em		
All $N_{\rm g}$(visually from the experiment)	1.8	2.4	5.2	2.1	–	4.8	7.5
All $N_{\rm g}$(visually from the method)	2.0	3.5	5.0	1.8	2.8	4.5	7.5
$N_{\rm g} = 0-1$	2.0	–	5.0	1.8	–	4.5	7.0
$N_{\rm g} = 2-4$	1.8	3.2	5.2	2.2	–	4.5	7.0
$N_{\rm g} = 5-9$	2.0	–	4.0	2.0	–	4.2	7.0
$N_{\rm g} = 10-14$	2.0	–	4.5	2.0	–	4.2	7.0
$N_{\rm g} = 15-19$	1.8	–	–	1.8	3.2	5.0	7.0
$N_{\rm g} \geqslant 20$	1.8	3.7	–	2.2	–	4.5	7.0

5 Conclusion

(1) The methods of a posteriori increase the resolution of the spectral lines - Fourier transformation and maximum entropy methods were applied to obtain more detailed information on the structure of pseudorapidity spectra of relativistic particles emitted in Au and Pb induced reactions at high energies.

(2) The central plateau and shoulder are seen visually on the pseudorapidity spectra.

(3) Both methods demonstrate the complex structure of the spectra.

(4) Non-significant pseudorapidity values of particle distributions have been obtained by the Fourier transformation method.

(5) The maximum entropy method can confirm the existence of some pseudorapidity values which would be connected with the boundary values of the central plateau and the values of the pseudorapidity shoulder.

(6) This method has extracted some selected values of pseudorapidity which could not be observed visually; the numbers of selected points are different for Au+Em and Pb+Em reactions, there are more selected points for Pb+Em than for Au+Em.

(7) The results of analysis confirm the existence of a plateau in the central region.

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