Study of central nucleus-nucleus collisions with a new approach

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Abstract: Using a new approach which is based on Random Matrix Theory, the results for the nearest-neighbor momentum spacing distributions obtained from simulation data on ^{12}CC collisions at 4.2 A GeV/c produced with the aid of the ultra relativistic Quantum Molecular Dynamics model has been studied. The results shows that the observed changes in the nearest-neighbor momentum spacing distributions for different multiplicities can be associated with the central collisions.

Keywords: random matrix theory, nearest neighbor momentum spacing distributions, ultra relativistic Quantum Molecular Dynamics

The nuclear matter under extreme conditions produced is one of the main subjects in experimental high energy physics. To see the phase evolution, one analyses various characteristics of particle production at nuclear-nuclear collisions depending on the centrality of collisions [1–6]. However, there is problem to define the centrality experimentally. Therefore, in different experiments [1-6] the centrality is defined as a number of identified protons, projectile and target fragments, slow particles, all particles, as the energy flow of the particles with emission angles equal 0◦ or 90◦, etc. Glauber modeling [7] which contains some theoretical approximations enables one to establish approximately the centrality with the aid of the impact parameter b and the multiplicity of identified secondary charged particles in experiments. But, in this case, however, there is a model dependent definition of the centrality. Evidently, the absence of an unique criterion for the centrality may significantly affect the interpretation of experimental results and, therefore, to hide a true signal on the onset of a new phase of the hadronic matter. In a preliminary report [8] one has suggested that tools from Random Matrix Theory (RMT) [9, 10] might be useful in illuminating the presence of correlations in the spectral (momentum) distribution of secondary particles produced in nucleus-nucleus collisions at high energy. Indeed, one have found a good agreement between the results obtained in this way and a standard analysis based on the method of effective mass spectra and two-pair correlation function often used in high energy physics [11]. It have been demonstrated that the RMT approach does not depend on the background of measurements and relies only on fundamental symmetries preserved in nucleus-nucleus collisions. The purpose of the present paper is to suggest novel criteria for the centrality of collision, using a new method which is based on Random Matrix Theory (RMT)[8-11] that was originally introduced to explain the statistical fluctuations of neutron resonances in compound nuclei [16]. The theory assumes that the Hamiltonian belongs to an ensemble of random matrices that are consistent with the fundamental symmetries of the system. Besides these general symmetry considerations; there is no need in other properties of the system under consideration. It is assumed that the momentum distribution of secondary particles produced in nucleus-nucleus collisions may be associated with eigenstates (quantum levels) of a composite system. It is, therefore, natural to use the momentum as a proper variable for the analysis in order to avoid possible errors at the transformation from the momentum to the energy, which requires an accurate determination of the corresponding mass value.

In general, this procedure does not involve any uncertainty or spurious contributions and deals with a direct processing of physical data. If the "events" $\{x_i\}$ are independent, i.e., correlations in the system under consideration are absent, the form of the histogram must follow p(s) = exp (-s) known as the Poisson density. The Poisson spectrum corresponds to the dominance of many crossings between different energies (momenta). On the other hand, if the levels are repelled, the density is approximately given by the Wigner surmise form $p(s) = \frac{\pi}{2} s \exp(-\frac{\pi}{4} s^2)$. In turn, the crossings are usually observed when there is no mixing between states that are characterized by different good quantum numbers, while the anti crossings signal about a strong mixing due to a perturbation brought about by either external or internal sources. In other words, any correlations that produce the deviation from the regular pattern (Poisson distribution): production of a collective state (resonance), or some structural changes in the system under consideration would be uniquely identified from the change of the histogram shape.

To clearly recognize correlations the total set of spacings $\{s_i\}$ has been divided on three sets, in correspondence with three regions of the measured momenta: a) 0.1 < |p| < 1.14 GeV/c (region I); b) 1.14 < |p| < 4.0 GeV/c (region II); c) 4.0 < |p| < 7.5 GeV/c (region III) (see Fig.1). The region boundaries were determined with the requirement that the shape of the spacing density P(S) does not change in the region under consideration. Note that there is no a prescribed procedure how to define such regions. However, the empirical approach described above proved to be useful in data processing for various systems at the RMT analysis [9, 12]. In the present paper the nearest-neighbor momentum spacing distribution P(S), related to all secondary particles are considered.

To shed light on the production of the all secondary particles, a fully integrated Monte Carlo simulation package UrQMD (Ultra relativistic Quantum Molecular Dynamics model) have been employed [13]. The UrQMD model is aimed for simulation of nucleus-nucleus collisions at relativistic energies. Simulating the all secondary particles production in $^{12}C+^{12}C$ collisions at a momentum of 4.2A GeV/c.

To see the behavior of the nearest neighbor spacing momentum distributions P(S) with multiplicity, the events has been separated in three groups: i) the events with N_{all} = 10 − 20 all secondary particles; ii) the events with N_{all} = 21 − 30 all secondary particles; iii) the events with N_{all} = 31 − 40 all secondary particles.

One evidently recognizes the onset of correlations for N_{all} = 10 – 20 all secondary particles with the increase of the absolute value of the momentum distribution (see Fig.1, top row, from left to right). The presence of the sharp peak in the third interval 4.0 < |p| < 7.5 GeV/c (the region III) can be attributed to the interaction between stripping protons in the final state, which dominate in the peripheral collisions. Indeed, one could found that strong correlations are brought about by the protons pairs with zero angle in the momentum distribution interval 4.0 < |p| < 7.5 GeV/c. This interpretation becomes even more convincing with the increase of all secondary particles number (N_{all} = 21−30; see Fig.1, right column). With the increase of the multiplicity of all secondary particles, the number of the stripping protons decreases as shown in Fig.1. As a result, the correlations, brought about by these proton pairs, decreases as well. For the multiplicity N_{all} = 31−40 the distribution is neither the Poisson nor the Wigner surmise. Note, however, that the number of participants is increased, which can be associated with the onset of the central collisions.

The model results show the existing of some peaks in the region II and their transformation to the Wigner distribution in the region III. Evidently, the model results demonstrate the existing of some non-trivial non-kinematic correlations for the all secondary particles in the regions II and III. This analysis provides the basis to identify the critical multiplicity that would signal on the onset of central collisions. Indeed, the UrQMD model enables us to solve several problems of practical importance. Namely, altering the impact parameter, one can trace the evolution of the multiplicity with the variation of the momentum distribution.

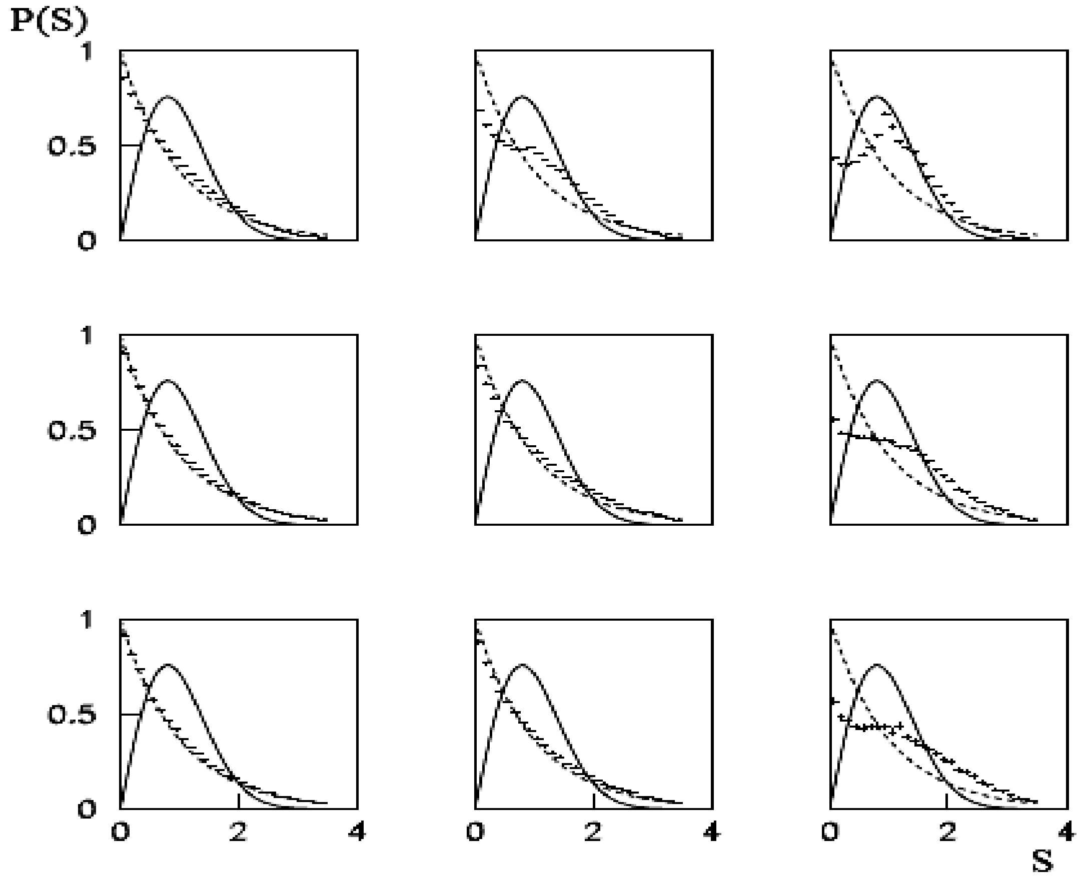

FIG. 1: The P(S) distributions, based on the UrQMD results, for different regions of the momentum: the first column corresponds to 0.15 < |p| < 1.14 GeV/c; the second column corresponds to 1.14 < |p| < 4.0 GeV/c; the third column correspond to 4.0 < |p| <7.5 GeV/c. The P(S) distribution for different values of the all secondary particles: the top row corresponds to N_{all}=10–20; the middle row corresponds to N_{all} =21–30: the bottom row corresponds to N_{all} =31–40. The Poisson and the Wigner surmise distributions are connected by dashed and solid lines, respectively.

In conclusion, one has proposed novel criteria to define the centrality of the nucleus-nucleus collisions, using the procedure developed in the framework of the RMT approach. The transition from the Poisson distribution to the Wigner surmise distribution signals on the onset of correlations. In turn, the centrality of nucleus-nucleus collisions is associated with the absence of correlations.

[1] Aichelin J and Werner K 2009 Phys. Rev. C 79 064907 %DOI: 10.1103/PhysRevC.79.064907

[2] Arsene I C 2009 J. Phys. G: Nucl. Part. Phys. 36 064004 %DOI: 10.1088/0954-3899/36/6/064004

[3] Masui H 2009 Eur. Phys. J. C 62 169 %DOI: 10.1140/epjc/s10052-009-1019-x

[4] Soltz R A , Newby R J, Klay J L, Heffner M, Beaulieu L, Lefort T, Kwiatkowski K and Viola V E 2009 Phys. Rev. C 79 034607 %DOI:10.1103/PhysRevC.79.034607

[5] Gburek T 2008 J. Phys. G: Nucl. Part. Phys. 35 104131 %DOI: 10.1088/0954-3899/35/10/104131

[6] Masui H 2009 J. Phys. G: Nucl. Part. Phys. 36 064047 %DOI: 10.1088/0954-3899/36/6/064047

[7] Miller M L, Reygers K, Sanders S J and Steinberg P 2007 Annu. Rev. Nucl. Part. Sci. 57 205 %DOI: 10.1146/annurev.nucl.57.090506.123020

[8] Shahaliev E I, Nazmitdinov R G, Kuznetsov A A, Syleymanov M K, and Teryaev O V 2006 Physics of Atomic Nuclei 69 142 %DOI:10.1134/S1063778806010182

[9] Brody T A, Flores J, French J B, Mello P A, Pandy A and Wong S S M 1981 Rev. Mod.Phys. 53 385 %DOI: 10.1103/RevModPhys.53.385

[10] Mehta M L 2004 Random Matrices (Elsevier, Amsterdam) Third Edition.

[11] Nazmitdinov R G, Shahaliev E I, Syleymanov M K, and Tomsovic S 2009 Phys. Rev. C 79 054905 %DOI:10.1103/PhysRevC.79.054905

[12] Weidenmuller H A and Mitchell G E 2009 Rev. Mod. Phys. 81, 539 %DOI: 10.1103/RevModPhys.81.539

1 [13] Bass S A 1998 Prog. Part. Nucl. Phys. 41 255 %DOI :10.1016/S0146-6410(98)00058-1