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Rapidity density distributions and their fluctuations in violent Au-induced nuclear interactions at 11.6 A GeV/c

EMU01 Collaboration

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The first rapidity density distributions from relativistic collisions between truly heavy nuclei are presented. The distributions are compared with expectations from a linear extrapolation of results obtained from collisions with lighter nuclei. Fluctuations are essentially described by a simple scenario with stochastic emission.

With gold ions at the BNL/AGS, a further step in the search for new states of matter, e.g. the quark–gluon plasma, is taken. The ultimate proof of such new states requires a good understanding of the soft processes responsible for the bulk of particle production. Although several phenomenological models describe quite successfully many of the features of the existing experimental data, their predictions may differ quite substantially when the energy and mass ranges increase [1]. Non-linear effects which are essentially negligible at present energies ($E_{\text{proj}} \leqslant 200\,A$ GeV) and masses ($A_{\text{proj}} \leqslant 32$), may eventually become important as energies and masses are increased.

In this letter we will present the first pseudo-rapidity density distributions of charged particles from central Au+Au and Au+Ag collisions at $11.6\,A$ GeV/c observed in experiment E863 by the emulsion technique using the Au beam at the BNL/AGS. The distributions and their fluctuations will be compared with linear extrapolations from experimental data for lighter projectiles, i.e. oxygen, silicon and sulfur projectiles, to see if there are deviations from this simplified approach.

The Au+Au sample is obtained using perpendicularly exposed emulsion chambers equipped with thin gold foils (250 μm thick) as target material, the same technique previously successfully utilized by the EMU01 Collaboration. The emulsion chambers consist of several emulsion layers placed with increasing distances in between. The measurements of the emission angles are facilitated by semi-automatic devices [2]. The total number of events so far found in scanning is 215. The Au+Ag sample is obtained by the standard emulsion technique, and 367 events are found in the scanning. Only singly charged particles with velocity $v \geqslant 0.7\,c$ are recorded (shower particles). As in earlier work the centrality is estimated, based on the number of projectile charges, Q_{ZD}, that continue along the beam direction throughout the collision and are to be found in a narrow forward cone [3]. At the present incident energy this cone has an opening angle of 2.98° corresponding to a pseudorapidity ($\eta = -\ln\tan\frac{1}{2}\theta$) of 3.65. Due to the target foils, particles with emission angles larger than 30° ($\eta < 1.32$) are not measured in the emulsion chambers. Among the singly charged particles there is a small contamination of e^+e^- pairs from gamma-conversion in the gold foil and Dalitz-production. The observed particle densities may thus be overestimated by approximately 5% in the central region. A similar contamination is also inherent in the data used for comparison and no efforts have been made to correct the present data.

In fig. 1a we exhibit the particle density as a function of pseudo-rapidity for Au+Au interactions in which the projectile nucleus is totally disintegrated into single nucleons, at most two alpha-particles and no fragments with $Z \geqslant 3$. This corresponds to central collisions and constitutes around 13% of the total production cross section. As can be seen in the figure

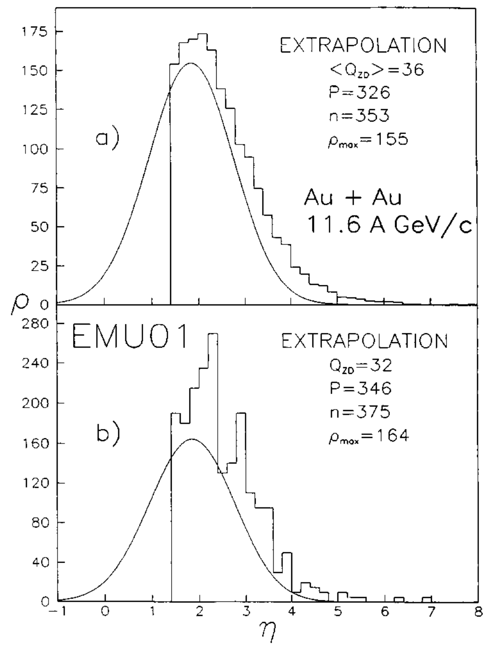

Fig. 1. (a) Charged particle density distribution obtained from central Au+Au interactions. The Gaussian curve is obtained by an extrapolation from interactions with lighter projectiles. (b) Charged particle density obtained for a single Au+Au event.

the particle density reaches 175 charged particles per rapidity unit in the central region.

Also shown in fig. 1a, as a Gaussian curve, is the extrapolation obtained from interactions with smaller projectiles. The average Q_{ZD} for the sample is 36, corresponding to a total of 324 participating nucleons, from both projectile and target; a result obtained from calculations of the nuclear geometry using the FRITIOF model [4]. From the energy dependence of the number of produced particles per participating nucleon it is expected that, at 11.6 *A* GeV/*c*, each participant emits on the average 1.085 charged mesons (produced particles) [5]. This number is in good agreement with the experimental observation of approximately 1 charged meson per participant in the most central Au+Au interactions at 11.6 *A* GeV/*c* [6]. Extrapolation of the result to the Au+Au system predicts a multiplicity of 352 charged mesons. It is furthermore found [5] that the width of the distribution is 0.91 units of rapidity, again based on the findings from experiments with lighter projectiles. Due to the symmetry we expect the peak to occur half-way between the projectile and the target rapidity, i.e. $y_{\text{peak}} = \frac{1}{2}y_p$, and using the phenomenological relation [5,7] $\eta \simeq y + 0.25$, we finally obtain $\eta_{\text{peak}} = 1.85$. As can be seen in the figure there is an excess of observed particles over the extrapolation in the whole region. The excess of particles shows a broad distribution with a maximum around 3 in pseudorapidity. If the excess is integrated there are approximately 75 particles not accounted for; a number which is close to the number of projectile protons.

Fig. 1b exhibits the density distribution from a single event with a very large multiplicity of charged particles and with a complete disintegration of the projectile into nucleons. The peak density is about 50% larger than expected from the extrapolation. The event is also characterized by large bin-to-bin fluctuations. The question whether such fluctuations can be expected to occur from purely statistical considerations is addressed below.

The particle density distribution for central Au+Ag interactions is shown in fig. 2a. In this case the centrality criterion was a total disintegration of the projectile into singly charged fragments, i.e. the absence of fragments with $Z \geqslant 2$. This corresponds to the most central 1% of the total cross section. The contamination of e^+e^- pairs is smaller in this sample ($\simeq 2\%$)

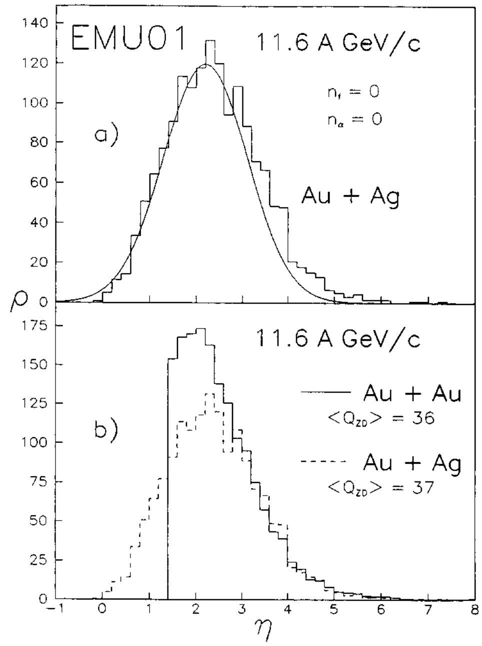

Fig. 2. (a) Charged particle density distribution obtained from central Au+Ag interactions (no fragments with $Z \geqslant 3$; $n_f = 0$, and no He fragments; $n_\alpha = 0$). The Gaussian curve is obtained by the extrapolation procedure. (b) Comparison between central Au+Au and Au+Ag interactions having the same average Q_{ZD}.

and the full rapidity space is covered. The number of participating nucleons is estimated to be 142 from the projectile and all 108 from the target. These numbers are obtained from a purely geometric picture of two overlapping spheres with zero impact parameter. As in fig. 1 the Gaussian curve represents the linear extrapolation with η_{peak} obtained as $\frac{142}{250}y_p + 0.25 = 2.07$. This value is somewhat larger than the value 1.98 obtained when a compound system (fireball) of 142+108 nucleons is considered. As in the case with Au+Au interactions there is an excess of particles with $\eta > \eta_{\text{peak}}$. The observed distribution and the extrapolation agree well in the region $\eta < \eta_{\text{peak}}$. In this region, however, the distribution is affected by the velocity cut, rejecting protons with an energy less than about 400 MeV. A possible explanation for the excess is thus that protons from the projectiles show up in the region $\eta > \eta_{\text{peak}}$, whereas most target protons are rejected by the velocity cut, i.e. $\beta > 0.7$.

The average Q_{ZD} for the Au+Ag sample ($\langle Q_{ZD} \rangle = 37$) almost coincides with the corre-

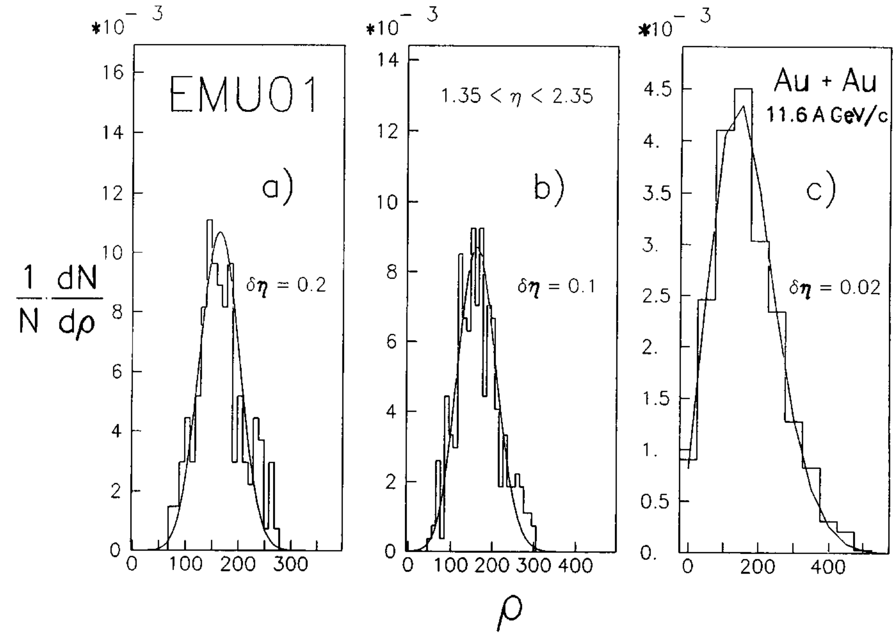

Fig. 3. The distribution of particle densities in η-bins of various sizes. The curves are obtained from an estimate considering fluctuations due to stochastic emission and variations in the number of participants.

sponding value for the earlier discussed Au+Au sample ($\langle Q_{ZD} \rangle = 36$). In fig. 2b η-distributions from both samples are compared showing that in the forward hemisphere the two distributions coincide. This is expected since here the particle production essentially is governed by the projectile participants. In the central region however we expect the densities to be roughly proportional to the total number of participants, and a ratio close to $\frac{324}{250} \simeq 1.3$ is indeed observed.

The discussion so far has been focused on the average behaviour of the particle densities, which is found to behave basically as would be expected by a linear extrapolation from data with lighter projectiles. A question which naturally arises is if the fluctuations around the mean also can be understood in a similar way. In hadron–hadron collisions, i.e. a system with two participants, the widths of multiplicity distributions are found to be roughly half the average multiplicity [8]. A scenario with independent emission from each participant would lead to a corresponding value of only 4% if a system of 300 participants is considered. This value is considerably smaller than the variation in the number of participants in the central Au+Au sample, estimated to be around 10%. We can thus safely neglect the fluctuations from each participant and only take the fluctuations in the total number of participants into account. In a picture with a larger amount of collectivity one would naively expect the effective number of independent sources to decrease, and thus the relative fluctuations to increase.

In fig. 3 the rapidity window $1.35 < \eta < 2.35$, i.e. the central region, is divided into bins of $\delta\eta = 0.2$, 0.1 and 0.02 units or rapidity and the distributions of particle density in each such bin are displayed. The curves are calculated using a 10% variation in the number of participants together with an assumption of stochastic emission [9]. Stochastic emission simply assumes that the particles are emitted independently with a probability to end up in a given bin equal to the average bin content divided by the average global multiplicity. In the calculation the average number of charged particles per participant is given the value 1.20 in order to account for the excess of projectile protons in the central region as observed in fig. 1a. As can be seen in the figure this approach fully describes the experimental observations, especially for the very small bins. The fluctuations observed are thus consistent with the statistical approach and does not suggest any other mechanisms producing large fluctuations.

We conclude that the particle production in Au-induced nuclear interactions essentially behaves as can be expected from a linear extrapolation of data from interactions with lighter projectiles, both regarding particle densities and fluctuations in the central region. The observed excess of particles compared to the extrapolated yields of produced shower particles appears predominantly with $\eta > \eta_{peak}$, both for Au and Ag targets. This excess seems to be attributed to projectile protons, participants as well as spectators.

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