Multiplicity distribution of final-state particles and different contributions of related sources in nucleus-nucleus collisions at high energies*

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Abstract The final state particle multiplicity distributions in high-energy nucleus-nucleus collisions are described by two different sub-distributions contributed by a single nucleon. The Monte Carlo calculated results from the two sub-distributions and the participant-spectator model are compared and found to be in agreement with the experimental data of Au-Au collisions at $\sqrt{s}=130$ AGeV and Pb-Pb collisions at 158 AGeV.

Key words multiplicity distribution, sub-distributions contributed by a single nucleon, nucleus-nucleus collisions

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1 Introduction

The final state particle multiplicity is defined as the number of particles produced in an event in high-energy collisions. Particle multiplicity distribution in high-energy collisions is an important quantity which can be measured in experiment. Not only in light particle-particle collisions such as e^+e^- and $p\bar{p}$ annihilations[1—5] but also in heavy nuclear collisions[6—10] such as Au-Au and Pb-Pb collisions[11—13], the multiplicity distribution is interesting for us to understand the evolution of interacting system.

In e^+e^- and $p\bar{p}$ collisions, the particle multiplicity distribution can be described usually by a simple formula[14, 15]. If one use the Koba-Nielsen-Olesen (KNO) scaling[16] to describe the multiplicity distribution, the multiplicities at different energies and in different (pseudo) rapidity ranges distribute around a curve. Because the interacting systems in e^+e^- and $p\bar{p}$ collisions are simple and small, the multiplicity distribution does not show a complex structure. Even if for the evaporated fragments produced in nucleus-nucleus collisions[17—20], the multiplicity distribution does not show a complex structure[21, 22].

However, the situation is different for the multiproduction process in nucleus-nucleus collisions at high energy. The investigations since 1980's show that nuclear geometry plays an important role in multiplicity distribution[23, 24]. In nucleus-nucleus collisions, the basic participants are nucleons. If we consider exactly the nuclear geometry, the different multiplicity distributions contributed by a single nucleon does not effect greatly the final state multiplicity distribution. We hope to give a test for this idea.

In a previous work[25], we have used an exponential distribution describing the multiplicity distribution contributed by a single nucleon and given a description of multiplicity distributions in Au-Au collisions at the Relativistic Heavy Ion Collider (RHIC) energy (with the center-of-mass energy $\sqrt{s}$ being 130 AGeV)[26, 27] and in Pb-Pb collisions at the Super Proton Synchrotron (SPS) energy (with the beam energy being 158 AGeV)[28]. In this paper, we shall use a different multiplicity distribution contributed by a single nucleon to describe the multiplicity distributions in Au-Au collisions at the RHIC energy and Pb-Pb collisions at the SPS energy. A comparison between the two different sub-distributions will be given.

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2 The model

The distribution of nucleon number density in a nucleus can be regarded as even one or Woods-Saxon shape[29]. According to the participant-spectator model[30], for a given impact parameter, the participant nucleon number can be obtained. In our previous work[25], we have given a description for the nuclear geometry and confirmed that the two distributions of nucleon number density do not show an obvious difference in the description of multiplicity distribution in nucleus-nucleus collisions. For the purpose of convenience, in this paper, we shall use only the even distribution of nucleon number density to give calculations and comparisons.

Let us structure the multiplicity distribution contributed by a single nucleon. We assume that three quarks in a nucleon contribute independently to the multiplicity. Each quark contributes an even multiplicity distribution in $[0,2m_i]$, where i denotes the i-th nucleon and $2m_i$ denotes the maximum multiplicity contributed by a quark. The sum of contributions of the three quarks will be in the range $[0,6m_i]$ with a peak at $3m_i$. Then, the distribution is moved to $[-3m_i,3m_i]$. The multiplicity distribution contributed by a single nucleon is taken as the distribution in the range from 0 to $3m_i$, and the normalization in $[0,3m_i]$ is considered. According to the knowledge of probability theory, the distribution in $[0,3m_i]$ can be given by two formulas with different ranges. Because the multiplicity distribution in nucleus-nucleus collisions will be calculated by the Monte Carlo method, the multiplicity distribution contributed by a single nucleon is treated by the Monte Carlo method, too.

3 Results and comparisons

Using the numerical calculated result about the relation between impact parameter and participant nucleon, and the multiplicity distribution contributed by a single nucleon, we can calculate the multiplicity distribution in nucleus-nucleus collisions. Fig. 1 presents the multiplicity distribution of negative charged particles produced in Au-Au collisions at $\sqrt{s}$ = 130 AGeV. The circles are the experimental data quoted in Refs. [26, 27] and the negatives with transverse momentum p_{T} > 100 MeV/c and pseudorapidity $|\eta|$ < 0.5. The thick solid and dotted curves are our calculated results corresponding to the present and previous sub-multiplicity distributions respectively. The three thin solid curves and the three thin dotted curves are our calculated results for three different centrality cuts respectively. In the calculation, we take $m_i = 0.970$ for the present sub-distribution. The parameter value used in the previous sub-distribution is $\langle N_i\rangle = 0.785$, where $\langle N_i\rangle$ is the mean sub-multiplicity. We can see that the calculated results corresponding to both the sub-distributions are in agreement with the experimental data[26, 27], and for the three centrality cuts the two results are similar.

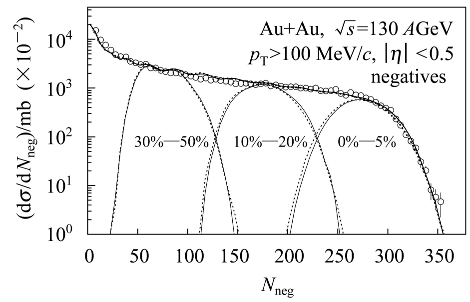

Fig. 1. Multiplicity distribution of negative charged particles produced in Au-Au collisions at $\sqrt{s} = 130$ AGeV. The circles are the experimental data quoted in Refs. [26, 27] and the curves are our calculated results.

The multiplicity distribution of charged particles produced in Pb-Pb collisions at 158 AGeV are given in Fig. 2. The circles are the experimental data quoted in Ref. [28] and the charged particles with $2.35 < \eta < 3.75$. The thick solid and dotted curves are our calculated results corresponding to the present and previous sub-multiplicity distributions respectively. The three thin solid curves and the three thin dotted curves are our calculated results for three different centrality cuts respectively. In the calculation, we take $m_i = 2.210$ for the present sub-distribution, and $\langle N_i\rangle = 1.780$ for the previous sub-distribution. The calculated results corresponding to both the sub-distributions are in agreement with the experimental data[28], and for the three centrality cuts the two results are similar.

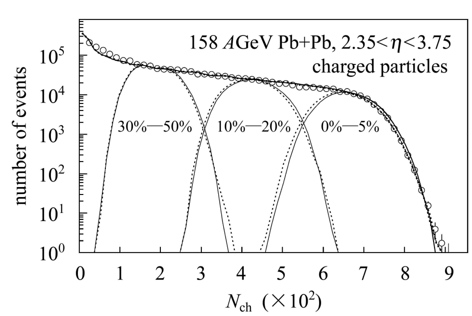

Fig. 2. Multiplicity distribution of charged particles produced in Pb-Pb collisions at 158 AGeV. The circles are the experimental data quoted in Ref. [28] and the curves are our calculated results.

Figure 3 shows the multiplicity distribution of γ-like clusters produced in Pb-Pb collisions at 158 AGeV. The circles are the experimental data quoted in Ref. [28] and the γ-like clusters with $2.8 < \eta < 4.4$. The thick solid and dotted curves are our calculated results corresponding to the present and previous sub-multiplicity distributions respectively. The three thin solid curves and the three thin dotted curves are our calculated results for three different centrality cuts respectively. In the calculation, we take $m_i = 1.540$ and $\langle N_i \rangle = 1.242$. The calculated results corresponding to both the sub-distributions are in agreement with the experimental data[28], and for the three centrality cuts the two results are similar.

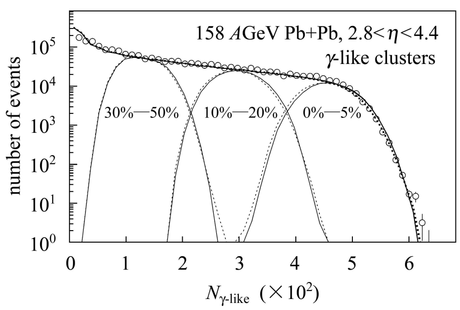

Fig. 3. Multiplicity distribution of γ-like clusters produced in Pb-Pb collisions at 158 AGeV. The circles are the experimental data quoted in Ref. [28] and the curves are our calculated results.

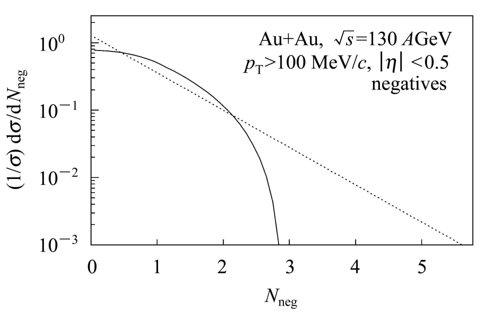

Fig. 4. Comparison between the two sub-distributions. The solid and dotted curves correspond to the sub-distributions used in the present and previous work[25] respectively.

Although the calculated results based on the two sub-distributions are similar, the two sub-distributions are different. In order to see the difference between them, Fig. 4 shows the two sub-distributions using the parameter values as used in Fig. 1. The solid curve is for the sub-distribution used in the present work, and the dotted curve is for the exponential distribution used in a previous work[25]. One can see an obvious difference between the two sub-distributions. The distribution region of sub-distribution used in the present work is narrower than that of previous work; the sub-distribution used in the previous work has a long tail in the high multiplicity region. However, the two sub-distributions give similar results of multiplicity distributions in Au-Au and Pb-Pb collisions at the RHIC and SPS energies respectively.

To compare the two sub-distributions in detail, Fig. 5 gives the results contributed by two, six, ten, twenty, thirty, and forty nucleons, respectively. The nucleon numbers are given on the curve tops in the figure. The solid and dotted curves correspond to the results of present and previous sub-distributions respectively. One can see that the difference between the two results are very small even if for only two nucleons taking part in the collisions. Although the two sub-distributions are different, the fold of two even distributions and the fold of two exponential distributions are similar. In fact, the fold of many even distributions is a Gaussian distribution, and that of many exponential distributions is an Erlang distribution. Both the Gaussian and Erlang distributions are similar in the shape.

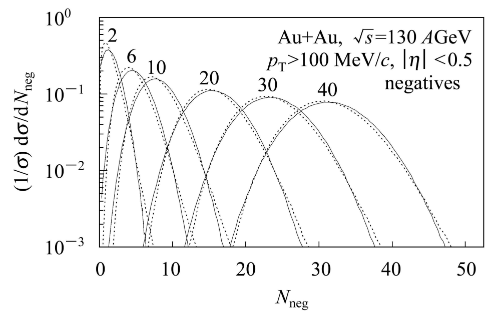

Fig. 5. Further comparison between the two sub-distributions. The solid and dotted curves correspond to the results of multi-nucleon contributions based on the sub-distributions used in the present and previous work[25] respectively.

4 Discussion and conclusion

The parameters m_i and $\langle N_i \rangle$ are related to the cut condition. For Au-Au collisions at $\sqrt{s} = 130$ AGeV (Fig. 1), the cut condition is the negatives with $p_{\mathrm{T}} > 100$ MeV/c and $|\eta| < 0.5$. For Pb-Pb collisions at 158 AGeV (Figs. 2 or 3), the cut condition is the charged particles with $2.35 < \eta < 3.75$ or the γ-like clusters with $2.8 < \eta < 4.4$. It is obvious that the cut condition for Au-Au collisions is tighter than that for Pb-Pb collisions. This renders that the parameters m_i and $\langle N_i \rangle$ have small values in the case of Au-Au collisions. As the basic multiplicity distribution contributed by a single nucleon, the two sub-distributions are normalized to 1 for the i-th nucleon in the participant, respectively. In our calculation, we have taken the parameters m_i and $\langle N_i \rangle$ to be unrelated to i.

To conclude, we have used a new sub-distribution for a single nucleon to give a description of multiplicity distribution of particles produced in Au-Au collisions at the RHIC energy and Pb-Pb collisions at the SPS energy. The two sub-distributions, one used in the present work and the other used in a previous work[25], have been compared and found that consistent results are obtained even if only two nucleons taking part in the collisions. Although the two sub-distributions are different, the difference between the results of two sub-distributions is very small. From the multiplicity distribution in nucleus-nucleus collisions we cannot say which sub-distribution is more correct. Even if in pp and p$\bar{\text{p}}$ collisions, we cannot distinguish the two sub-distributions due to two nucleons taking part in the collisions.

References

1 Abe F et al. Phys. Rev. Lett., 1993, **70**: 4042

2 Alexopoulos T et al. Phys. Rev. Lett., 1988, **60**: 1622

3 Bogert D et al. Phys. Rev. Lett., 1973, **31**: 1271

4 Suzuki N, Biyajima M, Nakajima N. Phys. Rev. D, 1993, **54**: 3653

5 Biyajima M, Osada T, Takei K. Phys. Rev. D, 1998, **58**: 037505

6 Singh G, Sengupta K, Jain P L. Phys. Rev. Lett., 1988, **61**: 1073

7 Ahle L et al. Phys. Rev. C, 1999, **59**: 2173

8 Aggarwal M M. Phys. Rev. C, 1998, **58**: 1146

9 Deines-Jones P et al. Phys. Rev. C, 1996, **53**: 3044

10 Barrette J et al. Phys. Rev. C, 1995, **52**: 2028

11 Steinberg P A. Nucl. Phys. A, 2002, **698**: 314

12 Adcox K et al. Phys. Rev. Lett., 2001, **86**: 3500

13 Back B B et al. Phys. Rev. Lett., 2000, **85**: 3100

14 Matinian S G, Walker W D. Phys. Rev. D, 1999, **59**: 034022

15 Calucci G, Treleani D. Phys. Rev. D, 1998, **57**: 602

16 Koba Z, Nielsen H B, Olesen P. Nucl. Phys. B, 1972, **40**: 317

17 Singh G, Ismail A Z M, Jain P L, Phys. Rev. C, 1991, **43**: 2417

18 Jain P L, Aggarwal M M. Phys. Rev. C, 1986, **33**: 1790

19 El-Nadi M et al. Int. J. Mod. Phys. E, 1996, **5**: 617

20 REN G X, JING G R. J. Phys. G, 1993, **19**: 1211

21 LIU F H, Panebratsev Y A. Nuovo Cimento A, 1998, **111**: 1219

22 LIU F H. Phys. Rev. C, 2000, **62**: 024613

23 DING L K, Stenlund E. Comput. Phys. Commun., 1990, **59**: 313

24 CHAO W Q, REN J L. Europhys. Lett., 1989, **8**: 123

25 LIU F H, ZHANG D H, DUAN M Y, Abd Allah N N. Chin. J. Phys., 2003, **41**: 618

26 Adler C et al. Phys. Rev. Lett., 2001, **87**: 112303

27 Calderón de la Barca Sánchez M (STAR Collaboration). Nucl. Phys. A, 2002, **698**: 503

28 Steinberg P for the WA98 Collaboration. Nucl. Phys. B, 1990, **71**(PS): 335

29 Bialas A, Bleszynski M, Czyz W. Nucl. Phys. B, 1976, **111**: 461

30 Glauber R J. in Lectures of Theoretical Physics. Ed by Brittin W E, Dungam L G. New York: Interscience, 1959. 315