

Nucleon participants or quark participants?

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We show that centrality dependence of charged particle pseudorapidity density at midrapidity in Au+Au collisions at the RHIC is well described as proportional to the number of participating constituent quarks. In this approach there is no need for an additional contribution from hard processes usually considered in the models based on the number of the nucleon participants.

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I. INTRODUCTION

Charged particle multiplicity densities near midrapidity in high energy nuclear collisions depend strongly on collision centrality. In order to better understand this dependence and to disentangle pure nuclear effects, this density is often plotted as per nucleon participant pair [1]. Participants are the nucleons that have encountered at least one inelastic collision. The number of participants at a given centrality is usually calculated in the Glauber model either analytically or with the help of a Monte Carlo algorithm. The charged particle density per participant increases with increasing centrality. In the 5% most central Au+Au collisions it is about 20% larger than that in semiperipheral collisions (50–70% centrality region), and it is about 50% larger compared to pp collisions at the same energy.

The reason for this increase in the number of produced particles per participant at midrapidity is still not well understood. The most common explanation of the phenomena involves particle production in hard processes. Hard processes have much smaller cross sections than soft collisions and depend differently on collision centrality. They scale with the number of binary collisions (the number of collisions the incident nucleon would experience if it were not altered at all while passing through the nucleus). The number of binary collisions increases with centrality faster than the number of participants; this results in an increase of particle production per participant nucleon as centrality increases. In such approaches the particle density is often presented simply as [2]

$$\frac{dN_{ch}}{dy} \propto \alpha N_{N-part} + (1 - \alpha) N_{N-coll}, \quad (1)$$

where the parameter α is the relative fraction of particles produced in the soft collisions, and $(1 - \alpha)$ is the relative fraction produced in hard collisions. With proper parameters, this fits the data fairly well; see Ref. [1]. Note, however, that in such models, the relative contribution of hard processes is expected to increase with the collision energy. The data seem inconsistent with such an energy dependence.

In the approach proposed in this paper, both nuclei and single nucleons are considered as a superposition of constituent quarks (also often called as “dressed” quarks or valons); there are three such dressed quarks per nucleon. The concept of the constituent quarks has been known for many years

(see Refs. [3,4] and references therein). The constituent quark approach is able to explain many features of hadron-hadron and hadron-nucleus collisions [5]. QCD calculations support the statement that inside a nucleon there are three objects of size of 0.1–0.3 fm (see Ref. [6] and references therein); for some recent works using or discussing constituent quarks, see also Refs. [7,8].

In the constituent quark picture, a NN collision looks like a collision of two light nuclei. Most often only one qq pair interacts, with other quarks being *spectators*. Only part of the entire nucleon energy is spent for particle production at midrapidity (as $\sqrt{s_{qq}} \sim \sqrt{s_{NN}}/3$). The quark spectators form hadrons in the nucleon fragmentation region. In the case of AA collisions, more than one quark per nucleon interacts due to the large nucleus size and the possibility for quarks from the same projectile nucleon to interact with different target nucleons. The goal of this study is to find the number of produced particles per participant quark (pair) and to check for its centrality dependence.

II. CALCULATIONS OF THE NUMBER OF PARTICIPANTS

We calculate mean number of nucleon/quark participants using a Monte Carlo based implementation [9] of the nuclear overlap model [10]. We use Woods-Saxon nuclear density profile,

$$n_A(r) = \frac{n_0}{1 + \exp[(r - R)/d]}, \quad (2)$$

with parameters $n_0 = 0.17 \text{ fm}^{-3}$, $R = (1.12A)^{1/3} - 0.86^{1/3} \text{ fm}$, and $d = 0.54 \text{ fm}$.

In the nuclear overlap model, the mean number of participants in the $A + B$ collision at impact parameter b is given by

$$N_{part,AB} = \int d^2s T_A(\vec{s}) \left\{ 1 - \left[1 - \frac{\sigma_{NN} T_B(\vec{s} - \vec{b})}{B} \right] B \right\} + \int d^2s T_B(\vec{s}) \left\{ 1 - \left[1 - \frac{\sigma_{NN} T_A(\vec{s} - \vec{b})}{A} \right] A \right\}, \quad (3)$$

where $T(b) = \int_{-\infty}^{\infty} dz n_A(\sqrt{b^2 + z^2})$ is the thickness function; then $[1 - \sigma_{NN} T_A(b)/A]^A$ is the probability for a nucleon to

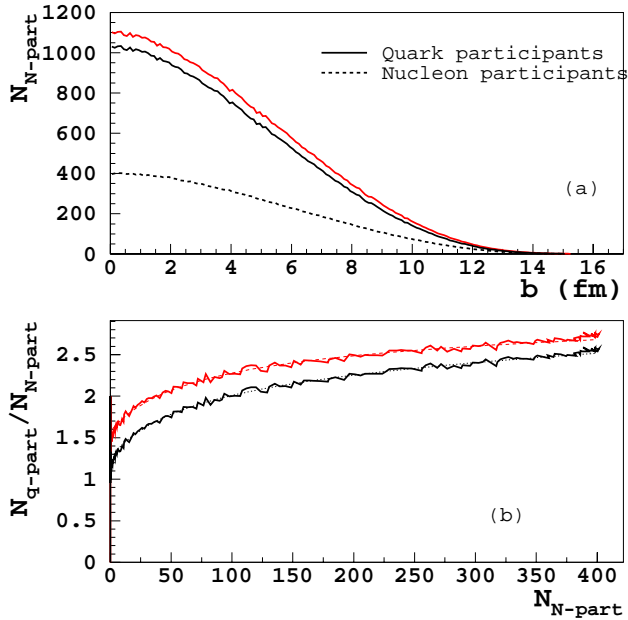


FIG. 1. (Color online) Impact parameter dependence of (a) the number of the nucleon and the quark participants, and (b) the ratio of N_{q-part}/N_{N-part} . The quark participant curves are shown for $\sigma_{qq} = 4.56$ mb (lower) and 6 mb (upper curve).

pass through the nucleus without any collision. We use the inelastic NN cross section $\sigma_{NN} = 41$ mb at $\sqrt{s_{NN}} = 130$ GeV.

The number of participating nucleons for a given centrality can be determined directly using the web interface [9]. In order to calculate the number of participating quarks we downloaded the FORTRAN code and modified it by increasing the density three times ($n_0^q = 3n_0 = 51 \text{ fm}^{-3}$) and changing σ_{NN} to σ_{qq} . For the quark-quark cross section in our calculation, we use two values, $\sigma_{qq} = \sigma_{NN}/9 = 4.56$ mb, and a somewhat arbitrary value of $\sigma_{qq} = 6$ mb; the latter was used mostly to illustrate the sensitivity of the results to the value of σ_{qq} . The choice of $\sigma_{qq} = 6$ mb is not unreasonable since at the RHIC energies, approximately 1.2–1.3 quarks per nucleon can participate in a single NN collision [5]. In principle, σ_{qq} could be probably as high as 8 mb based on the early estimates of $(r_q/R_N)^2 \sim 1/5$ [4].

Figure 1(a) shows the number of the nucleon and quark participants vs impact parameter. Fig. 1(b) presents the centrality dependence of the ratio of N_{q-part}/N_{N-part} . Smooth curves are the polynomial fits to the Monte Carlo results to smooth out the statistical fluctuations. The ratio N_{q-part}/N_{N-part} is used later for the renormalization of the particle pseudorapidity distributions from per nucleon participant to per quark participant.

Figure 2 presents the comparison of our calculation of N_{N-part} in the nuclear overlap model with PHOBOS calculations [1] based on the HIJING model. The number of participants is plotted as a function of a given fraction of the total cross section. Open circles represent the PHOBOS calculations. The nuclear overlap model results (using the Woods-Saxon density profile, the same as used in the HIJING model) are shown by solid symbols. Note a small deviation

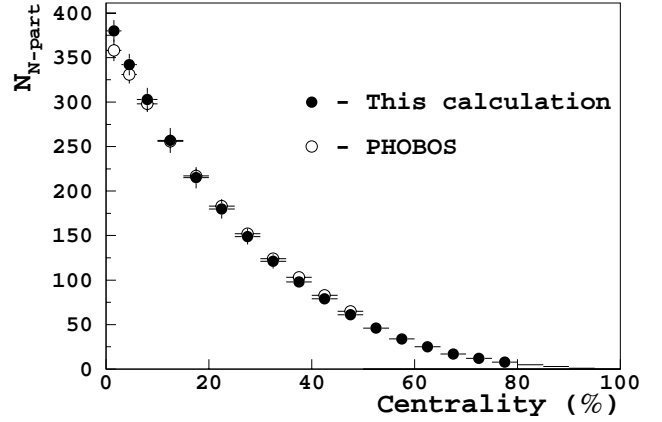


FIG. 2. (Color online) Mean number of nucleon participants vs centrality in the nuclear overlap model (solid symbols) and from PHOBOS calculations (open circles).

of our calculations from that of the PHOBOS in very central region; this is not important for the conclusion of the current study.

The PHOBOS Collaboration presents their results on centrality dependence of the charged particle pseudorapidity density by plotting it vs the number of the nucleon participant pairs. In this paper, we continue to use the same quantity for the centrality characterization, but note that in the constituent quark picture, the number of the nucleon participants no longer has the meaning of the number of the particle production sources.

III. RESULTS

The centrality dependence of the charged particle multiplicity per participant pair is shown in Fig. 3. The results per

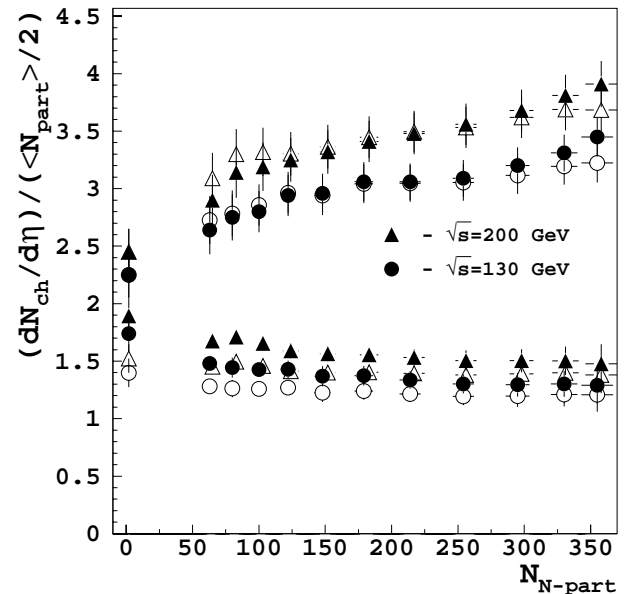


FIG. 3. (Color online) N_{ch} per nucleon and quark participant pair vs centrality. The results for quark participant pair are shown for $\sigma_{qq} = 4.56$ mb (solid symbols) and $\sigma_{qq} = 6$ mb (open symbols).

nucleon participant pair are in the upper part of the figure, and the results per quark participant pair are shown in the lower part. The original PHOBOS results [1] on $dN_{ch}/d\eta$ per nucleon participant pair (calculated using HIJING) for $\sqrt{s_{NN}}=130$ GeV and 200 GeV are shown in solid symbols. In open symbols we also show the same results renormalized for the number of the nucleon participant pairs from our calculations using the nuclear overlap model. Our main result—the centrality dependence of the charged particle pseudorapidity density per quark participant pair—is presented in the same plot.

We observe no, or even slightly decreasing, dependence of $(dN_{ch}/dy)/N_{q-part}$ on centrality, with the ratio being dependent only on the energy of the collision. The slight decrease in particle production at midrapidity with increasing centrality could be due either to low values of the constituent quark inelastic cross section used in our calculations or to parton saturation effects.

Note that in the constituent quark picture, $(dN_{ch}/dy)/N_{q-part}$ as a function of centrality depends very weakly on the collision energy, as the change in the inelastic cross section is probably less than 5% between $\sqrt{s_{NN}}=130$ GeV and 200 GeV.

Hard processes scale with the number of binary collisions. Although it was not necessary to include the contribution of hard processes into our calculation in order to describe the centrality dependence of the charged particle density at midrapidity, we have calculated the number of binary collisions as well: see Fig. 4. Note that the number of binary collisions per participant has a much weaker centrality dependence in the constituent quark approach than it has in the the nucleon participant model.

IV. SUMMARY

We have shown that the particle multiplicity density near midrapidity scales linearly with the number of constituent

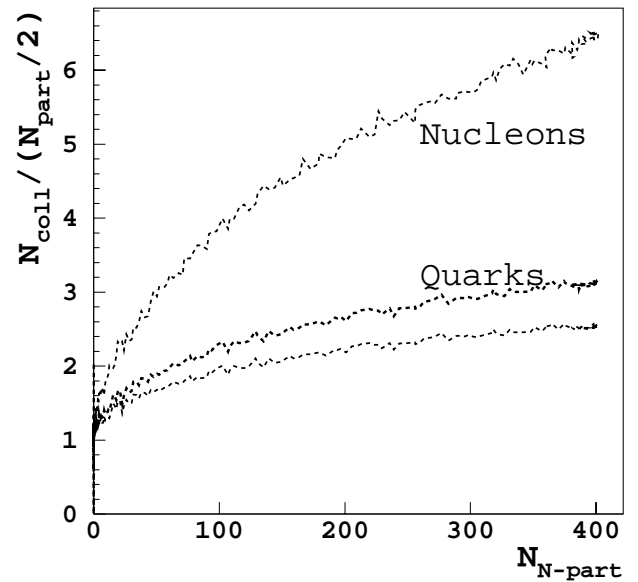


FIG. 4. (Color online) Centrality dependence of the ratio of binary collisions to the number of nucleon and quark (upper curve corresponds to $\sigma_{qq}=6$ mb and lower to $\sigma_{qq}=4.56$ mb) participants.

quark participant pairs. The experimentally observed increase of $dN_{ch}/d\eta$ per nucleon participant pair with centrality in this picture is explained by the relative increase in the number of interacting constituent quarks in more central collisions.

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