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WOUNDED-QUARK EMISSION FUNCTION IN ASYMMETRIC HEAVY-ION COLLISIONS*

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The wounded-nucleon and -quark models are compared using d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The shape of the wounded-quark emission function seems to be universal for different centralities, in contrast to the wounded-nucleon emission function. Predictions for $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distributions for various centrality classes in p+Al, p+Au, d+Au, and ^{3}He+Au collisions are presented and compared to recent PHENIX results.

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1. Introduction

The wounded-nucleon and -quark models (WNM, WQM), among others, are frequently used [1–14] to describe soft particle production in relativistic heavy-ion collisions. In WNM, nucleus–nucleus collision is considered as multiple nucleon–nucleon interactions [1]. Any nucleon from one nucleus colliding inelastically with at least one nucleon from another nucleus is called a "wounded" nucleon and is assumed to populate charged particles independently of the number of collisions it undergoes. On the other hand, in WQM, it is postulated that a heavy-ion collision consists of quark–quark interactions [2]. By analogy, the wounded quarks produce particles independently of the number of collisions.

Deuteron–gold (d+Au) collisions at $\sqrt{s_{NN}} = 200$ GeV measured by the PHOBOS Collaboration at the Relativistic Heavy Ion Collider (RHIC) [15] were used to compare both models. The wounded-source emission functions $F(\eta)$ (pseudorapidity single particle density originating from one wounded source) for different centralities were extracted using the PHOBOS data and our Monte Carlo Glauber simulations.

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2. Two models

As described in detail in Ref. [16], WNM and WQM were taken into consideration. In both cases, the charged particle multiplicity distribution is given by

$$\frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta} = w_{\mathrm{L}} F(\eta) + w_{\mathrm{R}} F(-\eta)\,, \tag{1}$$

where in the wounded-nucleon (-quark) model, $F(\eta)$ is the wounded-nucleon (-quark) emission function, w_{L} and w_{R} are the average numbers of the left-going and the right-going wounded nucleons (quarks), respectively. If $w_{\mathrm{L}} \neq w_{\mathrm{R}}$, the wounded-source emission function can be extracted separately for each centrality

$$F(\eta) = \frac{1}{2}\left[\frac{N(\eta)+N(-\eta)}{w_{\mathrm{L}}+w_{\mathrm{R}}} + \frac{N(\eta)-N(-\eta)}{w_{\mathrm{L}}-w_{\mathrm{R}}}\right], \tag{2}$$

where $N(\eta) := \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ is taken from the PHOBOS measurement on d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [15].

In our Monte Carlo Glauber simulation, the positions of nucleons in the gold nucleus are drawn according to the Woods–Saxon distribution [17, 18], whereas in the deuteron, the proton's position is taken from the Hulthen distribution and the neutron is placed opposite to the proton [17, 19]. Two nucleons collide if a transverse distance, d, between them is $d \leq \sqrt{\sigma_{nn}/\pi}$. The inelastic nucleon–nucleon cross section $\sigma_{nn} = 41$ mb corresponds to $\sqrt{s_{NN}} = 200$ GeV [17].

Wounded nucleons populate particles according to a negative binomial distribution (NBD) with $\langle n\rangle = 5$ and $k = 1$ [20], where k measures the deviation from the Poisson distribution. For each centrality bin, w_{L} and w_{R}, were calculated to complete Eq. (2).

In WQM, the positions of three constituent quarks around the center of each nucleon were drawn using $\varrho(\vec{r}) = \varrho_0 \exp(-r/a)$, where $a = r_p/\sqrt{12}$ with $r_p = 0.81$ fm being the proton's radius [6, 21][1].

Quarks collide if $d \leq \sqrt{\sigma_{qq}/\pi}$, where σ_{qq} is the inelastic quark–quark cross section. We took $\sigma_{qq} \simeq 7$ mb to reproduce $\sigma_{nn} = 41$ mb [16]. Each wounded quark emits charged particles according to NBD with $k_q = k_p/1.3$ and $\langle n_q\rangle = \langle n_p\rangle/1.3$, where $k_p = 1$ and $\langle n_p\rangle = 5$ are the parameters of NBD used in our WNM calculations.

[1] Quarks are shifted so that their center of mass is the center of a nucleon and we actually used $\widetilde{\varrho}(\vec{r}) = \varrho_0 \exp(-Cr/a)$. $C = 0.82$ was determined by the trial and error method.

3. Results

Using Eq. (2), the wounded-nucleon emission function was extracted for different centrality bins and is shown in Fig. 1 (left)[2]. Apparently, the shape of $F(\eta)$ is different for various centralities.

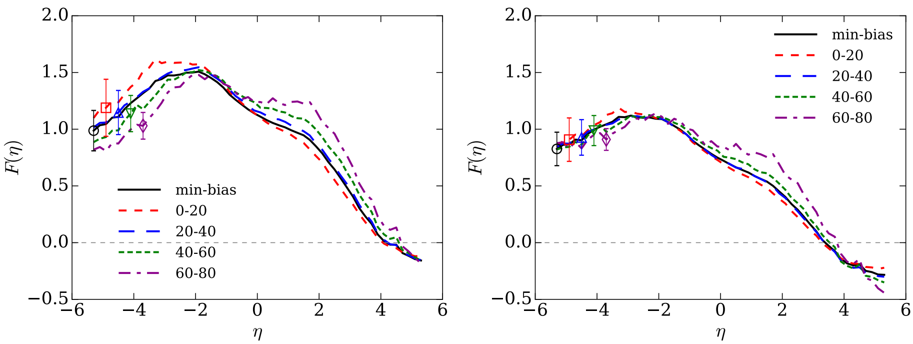

Fig. 1. The wounded-nucleon (left) and -quark (right) emission functions extracted from PHOBOS d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. For clarity, the uncertainty bars are shown only for a limited number of points.

The extracted wounded-quark emission function, shown in Fig. 1 (right), is virtually universal for different centrality classes, see Ref. [16] for details. This observation was also verified recently in Ref. [22]. This could imply that the soft particle production in d+Au collisions is better described by WQM rather than WNM. Note that the wounded-quark emission function is physically meaningful for $|\eta| \leq 3$ because in the fragmentation regions, other effects should be taken into account, *e.g.* contributions from unwounded quarks (within wounded nucleons) [5].

These results encouraged us to make predictions for p+Al, p+Au, d+Au, and ^{3}He+Au collisions at the same energy for various centralities (as requested by the PHENIX Collaboration). We assumed that the wounded-quark emission function $F(\eta)$ is universal also for various asymmetric systems at the same energy. Then, we determined $w_{\rm L}$ and $w_{\rm R}$ for each centrality class and using Eq. (1) we computed $\mathrm{d}N_{\rm ch}/\mathrm{d}\eta$ distributions for all colliding systems. The minimum-bias wounded-quark emission function $F(\eta)$ has been used. The results are presented in Fig. 2. A very recent paper by the PHENIX Collaboration shows that the wounded-quark model with its universal wounded-quark emission function can reasonably well describe all measured asymmetric collisions [23].

[2] The errors represent the systematic uncertainties of $N(\eta)$. Thus, they are not expected to influence the shape of $F(\eta)$.

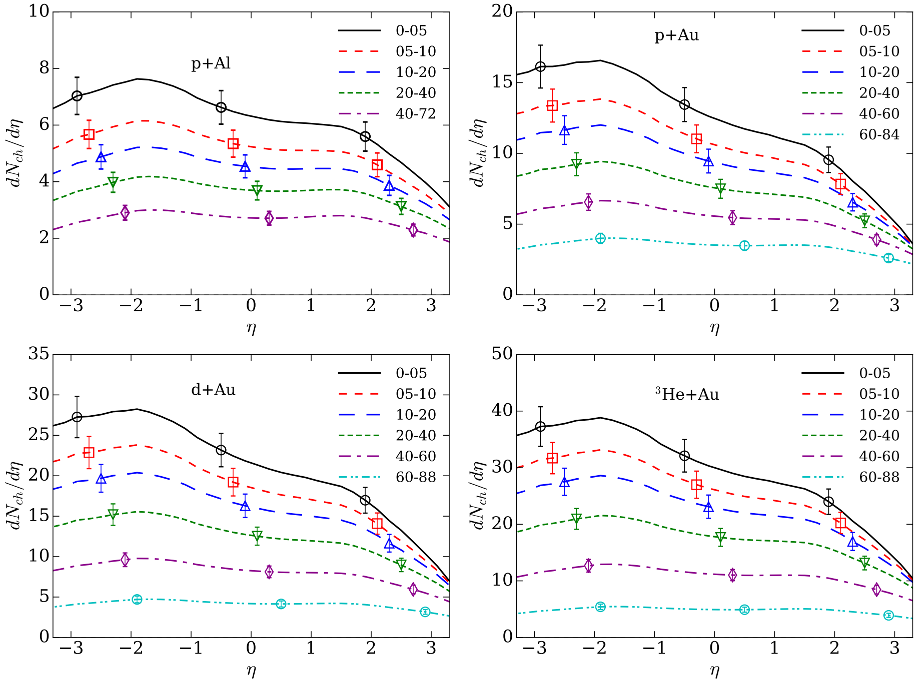

Fig. 2. Predicted charged particle $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distributions as functions of pseudorapidity for p+Al, p+Au, d+Au, and ^{3}He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for different centralities according to the wounded-quark model.

4. Conclusions

To summarize, we argued that the wounded-quark emission function has a universal shape for various centrality classes (within uncertainties) in the range of $|\eta| \leq 3$, whereas the wounded-nucleon emission function differs across centralities [16]. The latest PHENIX results show that just one common wounded-quark emission function can successfully describe different systems (p+Al, p+Au, d+Au, and ^{3}He+Au) at $\sqrt{s_{NN}} = 200$ GeV as our predictions are in reasonably good agreement with their measurement [23]. It suggests that the considered heavy-ion collisions and soft particle production are quite well described by the wounded-quark model. As a next step, we plan to take unwounded quarks from wounded nucleons into account for regions $|\eta| > 3$ and also to study larger colliding systems such as Au+Au or Cu+Cu. For further research, it would be valuable to study event-by-event fluctuations of $F(\eta)$ as well as to verify the model at different energies.

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