Vol. 39 (2008) *ACTA PHYSICA POLONICA B* No 7

GLAUBER MONTE CARLO PREDICTIONS FOR LHC*

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(Received May 14, 2007)

In the framework of various Glauber-like models we compute several correlation observables in nuclear collisions at the SPS, RHIC, and LHC energies. We analyze fluctuations of the eccentricity of the fireball created in the collision, in particular the variable-axes harmonic moments ε^*, as well as the fluctuations of multiplicity of charged particles. We find moderate model dependence of the scaled standard deviation $\sigma(\varepsilon^*)/\varepsilon^*$ on the choice of the particular Glauber model. For all considered models the values of $\sigma(\varepsilon^*)/\varepsilon^*$ range from ~ 0.5 for central collisions to ~ 0.3–0.4 for peripheral collisions. The results are confronted to the recent measurement of the elliptic-flow fluctuations at RHIC. We also find that the dependence of multiplicity fluctuations on the centrality of the collision is too weak to explain the measurements at the SPS energies. The magnitude of the Glauber multiplicity fluctuations increases by about 20% from the RHIC to LHC energies.

PACS numbers: 25.75.–q

1. Introduction

Studies of correlations and fluctuations have become a major part of the heavy-ion-collisions physics program, as these observables may carry valuable information on the dynamics of the system. While the dynamical

* Presented at the Cracow Epiphany Conference on LHC Physics, Cracow, Poland, 4–6 January 2008.

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nature of correlations is of great theoretical interest, a part of the observed effect originates from purely statistical phenomena, such as the fluctuation of the number of participants in a given centrality class, fluctuations of the shape and orientation of the fireball, *etc.* It is thus important to understand in detail the "background" of these non-dynamical fluctuations.

In this talk we present predictions of a variety of Glauber-like models of the initial stage of a heavy-ion reaction for several correlation observables studied at SPS and RHIC, which can also be measured in the forthcoming LHC experiments. We analyze fluctuations of the eccentricity in the transverse plane of the initial fireball, including the *variable-axes* harmonic moments, ε^*. The predictions are compared to the recent measurements of the fluctuations of the elliptic-flow coefficient at RHIC.

New results are shown for the fluctuations of multiplicity of charged particles, and compared to the NA49 results. It is found that the fluctuations induced by the Glauber-model are not sufficient to explain these data, leaving room for dynamical effects.

The formalism used in this talk is described in detail in Refs. [1, 2]. In particular, all details concerning the statistical methods and the variants of the Glauber models may be found there.

2. Simulations in Glauber-like models

With the help of a computer program GLISSANDO [2] we have analyzed several variants of Glauber-like Monte Carlo models:

- The standard *wounded nucleon model* [3]. The wounding cross section $\sigma_{\rm w}$ is equal to 32 mb, 42 mb, and 65 mb [4] for SPS, RHIC, and LHC energies, respectively.

- The *mixed* model, amending wounded nucleons with some admixture α of binary collisions [5,6]. The successful fits to particle multiplicities (see Ref. [6]) give $\alpha = 0.145$ at $\sqrt{s_{NN}} = 200$ GeV and $\alpha = 0.12$ at $\sqrt{s_{NN}} = 17.3$ GeV. For LHC energy $\sqrt{s_{NN}} = 5.5$ TeV we made an educated guess for the mixing parameter, $\alpha = 0.2$.

- We also analyze a model with *hot spots* (see Ref. [7]), assuming that the cross section for a semi-hard binary collisions producing a hot-spot is tiny, $\sigma_{\rm hot-spot} = 0.5$ mb for all energies, however when such a rare collision occurs it produces on the average a very large amount of the transverse energy equal to $\alpha\sigma_{\rm w}/\sigma_{\rm hot-spot}$.

- Each source from the previously described models may deposit the transverse energy with a certain probability distribution. Thus, we superimpose the Γ distribution, $g(w, \kappa)$, over the distribution of sources

$g(w,\kappa) = w^{\kappa-1}\kappa^\kappa \exp(-\kappa w)/\Gamma(\kappa)$. Here we do this superposition on the hot-spot model, labeled *hot-spot+Γ*. We set $\kappa = 0.5$, which gives $\mathrm{var}(w) = 2$ for the analysis of elliptic flow fluctuations. In order to reproduce multiplicity distribution in $p+p$ collisions at SPS energies, we set $\kappa = 1$, which gives $\mathrm{var}(w) = 1$ for analysis of multiplicity fluctuations.

The four considered models (wounded-nucleon, mixed, hot-spot, and hot-spot+Γ) differ substantially in the number of sources and the amount of the built-in fluctuations.

3. Event by event fluctuations of the elliptic flow

The proper description of the mechanism of the fluctuations of the elliptic flow may be very helpful in understanding the dynamics of heavy-ion collision, especially in its early stage [8]. Moreover, for the first time the elliptic-flow fluctuations have recently been measured at RHIC [9–11]. The interpretation of these results connects the fluctuations of the eccentricity coefficient, ε^*, with the fluctuations of the variable-axes flow coefficient, denoted in this talk as v_2^*. For sufficiently small elliptic asymmetry, which is an experimental fact, one expects on purely hydrodynamic grounds the relation

$$\frac{\sigma(v_2^*)}{v_2^*} = \frac{\sigma(\varepsilon^*)}{\varepsilon^*}\,. \tag{1}$$

Comparison of the data to our Glauber calculations is made in Fig. 1. For central collisions we expect the result following from the central limit theorem [1] for uncorrelated sources,

$$\sigma(v_2^*)/v_2^* \simeq \sigma(\varepsilon^*)/\varepsilon^* = \sqrt{4/\pi - 1} \simeq 0.52 \qquad (b=0)\,, \tag{2}$$

which is compatible with the data, although the error bars are large. We note that, with the identification (1), the Glauber models reproduce properly the data for not-too-peripheral collisions, where the approach is credible. Other variants fall between the wounded-nucleon model, which has the lowest amount of fluctuation, and the hot-spot+Γ model, which has the strongest fluctuations. More accurate measurements are needed to discriminate the model predictions. We note, however, that the statistical fluctuations built in the Glauber model are sufficient to explain the data.

In Fig. 2 we compare the results of simulations of the elliptic-flow fluctuations at SPS and RHIC with the predictions for the LHC energies. The calculation is done for two extreme variants of Glauber-like models, namely

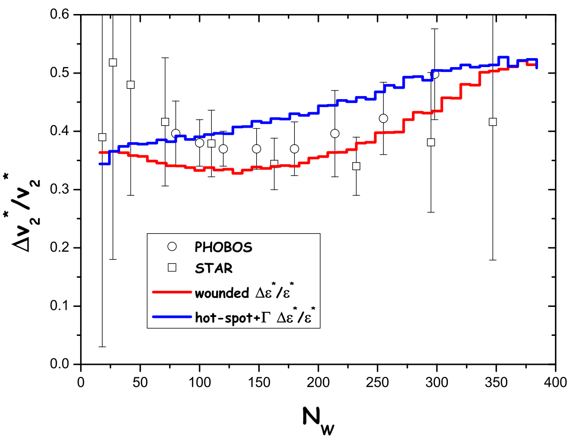

Fig. 1. (Color online) Fluctuations of ϵ^* in two variants of the Glauber models, compared to the data from Refs. [9–11]. See the text for details.

the wounded nucleon model, where the fluctuations of initial shape are smallest, and the model with hot-spots+Γ, where the initial shape fluctuations are most prominent. For the most central and most peripheral collisions the results are very similar for both models at all energies, however at intermediate centralities there are much higher fluctuations for the LHC energies with the hot-spots+Γ model than in other cases, as expected.

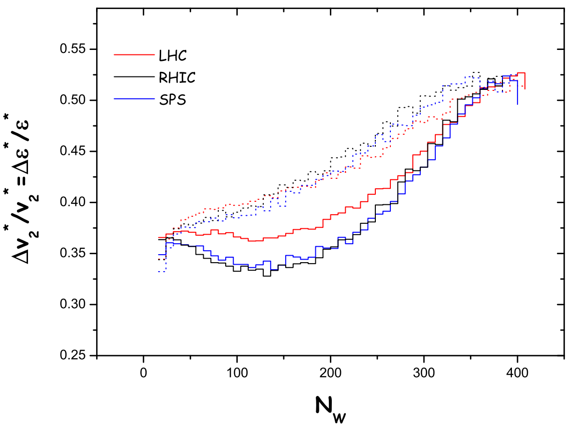

Fig. 2. (Color online) Fluctuations of v_2^* at SPS, RHIC, and LHC energies from the Glauber model with wounded nucleons only (full lines) and the hot-spot+Γ model (dotted lines).

4. Multiplicity fluctuations

Recently the NA49 Collaboration published results [12] on centrality and system-size dependence of multiplicity fluctuations observed in Pb+Pb minimum bias and in $p+p$ collisions. Unexpectedly, the scaled variance $\mathrm{Var}(N)/\langle N\rangle$, where $\mathrm{Var}(N)$ is the variance and $\langle N\rangle$ the average multiplicity of the observed charged particles, changes non-monotonically when the number of wounded nucleons grows. The scaled variance is close to unity in peripheral and central collisions, however it shows a very prominent peak at $N_w \approx 70$. The measurement has been performed at the top SPS collision energy $\sqrt{s_{NN}} = 17.3$ GeV in the transverse momentum and pion rapidity intervals $(0.005, 1.5)$ GeV and $(1.1, 2.6)$, respectively. The azimuthal acceptance has been also limited, and only about 20% of all produced negative particles have been used in the analysis. In Fig. 3 we show NA49 results for the negatively-charged particles compared to the Glauber-like simulation of the model hot-spots+Γ in the NA49 azimuthal acceptance. The experimental acceptance of 20% has been implemented in the simulation. Despite the fact that the fluctuations in the hot-spot+Γ model are the highest of all considered Glauber models, it is evident from the plot that the Glauber calculation alone cannot describe the non-monotonic dependence of scaled variance on centrality. Near the peak the model falls below the data, while

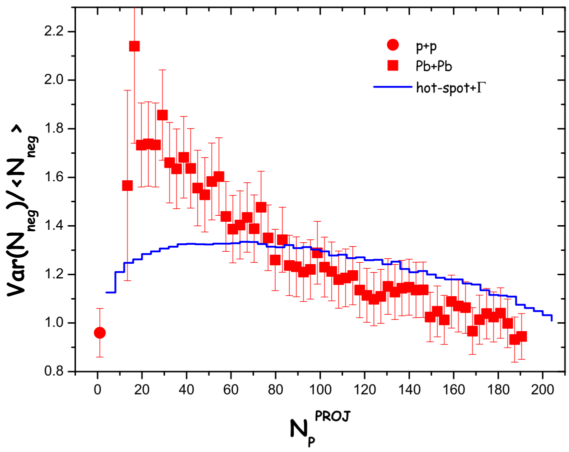

Fig. 3. (Color online) Scaled variance of the multiplicity distribution of negatively charged hadrons produced in $p+p$ and Pb+Pb collisions at the top SPS energy, plotted as a function of centrality determined by the number of projectile participants measured by NA49 experiment. The line is obtained with the hot-spot+Γ model with proper implementation of the experimental acceptance. The data are from Ref. [12].

at larger N_w it goes above the data. For other models the obtained curve is even lower. In our opinion dynamical effects must be incorporated in order to understand the phenomenon [13, 14].

In Fig. 4 we compare the centrality dependence of the model multiplicity fluctuations for the SPS, RHIC, and LHC energies in the full acceptance. Here we use scaled standard deviation of multiplicity distribution as a measure of multiplicity fluctuations. Multiplicity fluctuations at SPS and RHIC energies are very close to each other, however we notice an increase at the LHC by about 20%. This effect is due to the larger value of the wounding cross section σ_w. The conclusion is qualitative, since as mentioned above, the Glauber models do not explain the details of the SPS measurement of the multiplicity fluctuations.

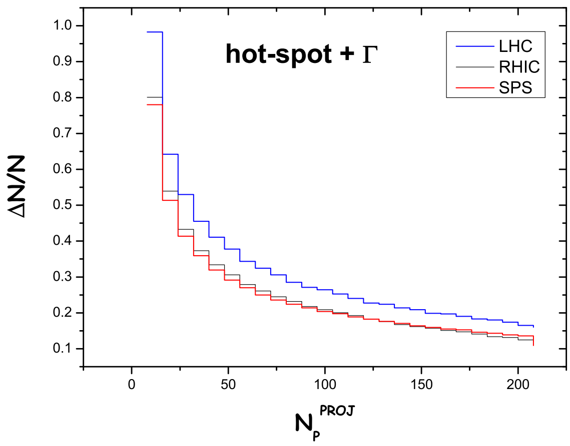

Fig. 4. (Color online) Scaled standard deviation of the multiplicity distribution of negatively charged hadrons plotted as a function of the number of projectile participants for SPS, RHIC and LHC energies, all results for the Glauber Monte Carlo hot-spot+Γ model.

5. Conclusions

Our main results are as follows:

- The fluctuations of the eccentricity of the fireball are related to the fluctuations of the elliptic flow coefficient. They depend rather moderately on the chosen Glauber model. Our results agree with the recent PHOBOS and STAR measurements of the v_2 fluctuations. The agreement indicates that this quantity is dominated by the Glauber-model statistics.

- The Glauber-model predictions for the multiplicity fluctuations fail short of the experimental results of Ref. [12], leaving room for strictly dynamical effects [13, 14]. Such effects should be introduced in order to understand the non-monotonic dependence of the scaled variance of multiplicity on the number of produced particles.

This research has been supported by the Polish Ministry of Science and Higher Education under grants N202 034 32/0918 and 1 P03B 127 30.

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