PREDICTIONS IN MODIFIED GLAUBER MODEL OF TOTAL CHARGED-PARTICLE YIELDS CENTRALITY DEPENDENCE IN O+O AND NE+NE COLLISIONS AT LHC

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Simak Svetlana*
Laboratory of Ultra High Energy Physics
Saint-Petersburg State University
Saint-Petersburg, Russia
s.simak@spbu.ru

Feofilov Grigory
Laboratory of Ultra High Energy Physics
Saint-Petersburg State University
Saint-Petersburg, Russia
g.feofilov@spbu.ru

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ABSTRACT

In this article we present the results of application of the Monte Carlo modified Glauber model [1, 2, 3] for the predictions of collision centrality dependence of the total charged-particle yields for 16O +16O and 20Ne+20Ne colliding systems at the LHC.

Our model differs from the Standard Glauber model by the effective account of the energy losses in successive inelastic nucleon-nucleon collisions. For this purpose, a single model parameter k is defined as a mean fraction of the momentum loss that happens in any binary nucleon collision due to the production of multiple particles. Therefore, the decrease of the nucleon momentum after each inelastic collision leads to a corresponding reduction of the inelastic cross section and the mean multiplicity yield in the subsequent interaction. All these effects are taken into account in the MC model in each of the subsequent inelastic binary interactions.

We discuss the purely geometrical effects for these light colliding systems that could be considered useful in future studies of QGP properties in energy density scanning. Predictions in this single parameter model are based on the previous successful analysis [3] of non-linear centrality dependence of charged particle yields observed in Pb+Pb collisions by ALICE at the LHC.

Keywords **relativistic heavy-ion collisions, modified Glauber model, total multiplicity yield, centrality dependence, non-linear effects**

1 Introduction

Studies of light-ion collisions at the LHC energies aim to explore the properties of hot, strongly interacting matter created in case of small systems. For O+O and Ne+Ne interactions, of primary interest are the centrality dependence of charged-particle multiplicity, rapidity distributions, collective flow and parton energy losses. The initial conditions in small systems are described, as in heavy-ion collisions, by centrality, linked to the impact parameter b or the number of participating nucleons N_{part}. These quantities cannot be measured directly and are estimated through Glauber-type approaches.

In the Standard Glauber Model (SGM), the total charged-particle multiplicity $\langle N_{ch}^{tot} \rangle$ is initially taken as the sum of contributions $\langle N_{ch}^{pp} \rangle$ from each binary collision. This naive approach, however, substantially overestimates yields. The improved descriptions employ two-component models with "soft" (N_{part}) and "hard" (N_{coll}) contributions, where multiplicity distributions are simulated via Negative Binomial Distributions fitted to experimental data, one can find more details in Ref. [4, 5].

* Corresponding author

Nevertheless, SGM assumptions ignore energy–momentum conservation law and are therefore overestimates the number of nucleon-nucleon collisions $\langle N_{coll}\rangle$. Contrary to SGM, the Modified Glauber Model (MGM) incorporates an effective energy loss in successive inelastic collisions via a single parameter k, the mean momentum fraction lost per nucleon-nucleon inelastic interaction. This reduces, step-by-step, both the effective inelastic cross-section and subsequent charged particle production, providing a more realistic description of nonlinear effects in heavy-ion and light-ion collisions at RHIC and LHC. At the LHC energies, the value of k is estimated by fitting Pb+Pb and Xe+Xe multiplicity data across centralities. The MGM reproduces observed yields and significantly lowers the estimated number of binary collisions compared to SGM.

In this work, we present the MGM predictions for O+O and Ne+Ne collisions at the LHC, emphasizing the role of initial-state geometry and conservation laws. These results may be useful for future studies of QGP properties through system-size and energy-density scans.

2 Event simulation and analysis procedure

In this section, we will describe the generation of the nucleons configuration in the colliding nuclei and the calculations for each nucleon-nucleon collision in our MC codes of SGM and MGM.

2.1 Nucleus generation

To determine the distribution of nucleon density in the Pb, Xe, O and Ne nuclei, we will use the standard three-parameter Fermi (3pF) distribution:

$$\rho = \frac{\rho_0(1+\omega(\frac{z}{R})^2)}{1+\exp\frac{r-R}{a}} \tag{1}$$

The parameters for 3pF distribution were taken from Ref. [6, 7, 8] and are shown in the table:

Table 1: parameters of 3pF distribution

	a, fm	R, fm	ω
^{208}Pb	0.546	6.62	0
^{16}O	0.513	2.608	-0.051
^{20}Ne	0.698	2.791	-0.168

For the ^{129}Xe nucleus we used [9]:

$$\rho(x,y,z) = \rho_0 \cdot \frac{1}{1+exp(\frac{r-R\cdot(1+\beta_2\cdot Y_{20}+\beta_4\cdot Y_{40})}{a})} \tag{2}$$

$$Y_{20} = \sqrt{\frac{5}{16\pi}}\cdot(3\cdot cos^2(\theta)-1),\ Y_{40} = \frac{3}{16\sqrt{\pi}}\cdot(35\cdot cos^4(\theta)-30\cdot cos^2(\theta)+3)$$

with $R = 5.36,\ a = 0.59,\ \beta_2 = 0.18,\ \beta_4 = 0.$

2.2 Calculation of each nucleon-nucleon collision in Modified Glauber Model

The key difference between the MGM presented in this work and the SGM lies in the consistent application of energy and momentum conservation laws for each binary nucleon-nucleon collision.

To account for energy loss due to the multiple particle production, we introduce a single parameter, k, analogous to the approaches in Refs. [1, 2, 3]. This parameter is universal for all nucleon-nucleon collisions and represents the average fraction of momentum retained by a nucleon in the center-of-mass (CM) frame of the colliding nucleon pair. Consequently, in any binary collision, a nucleon loses a fraction $(1-k)$ of its momentum in the CM frame.

The sequence of nucleon-nucleon collisions is determined by the distances between nucleons, meaning the closest pairs collide first. Two nucleons are considered to interact if their impact parameter b satisfies the condition $b < \sqrt{\sigma_{NN}^{inel}/\pi}$. The nucleon-nucleon cross-section σ_{NN}^{inel} is parameterized as a function of the CM energy $\sqrt{s}$:

$$\sigma_{NN}^{inel}(s) = a + b\cdot\ln^n(s), \tag{3}$$

with the parameters taken from Ref. [10]: $a = 28.84 \pm 0.52$ mb, $b = 0.05 \pm 0.02$ mb, $n = 2.37 \pm 0.12$.

Further, we move to the center-of-mass system of two nucleons and recalculate the momenta after the collision as follows:

$$P_1' = k \cdot P_1, \quad P_2' = k \cdot P_2. \tag{4}$$

One can see a more complete description of the calculations in Ref. [3]

For a given impact parameter, the average number of participant nucleons $\langle N_{part} \rangle$ and the average number of binary nucleon-nucleon collisions $\langle N_{coll} \rangle$ are determined by direct Monte Carlo counting during the sequence of collisions.

The average multiplicity of charged particles $\langle N_{ch}^{tot} \rangle$ is calculated by summing the contributions from each binary collision $\langle N_{ch}^{pp} \rangle$:

$$\langle N_{ch}^{pp} \rangle = a + b \cdot \ln(s) + c \cdot \ln^2(s), \quad a = 16.65,\ b = -3.147,\ c = 0.334 \tag{5}$$

with parameters from Ref. [11]. For every nucleon-nucleon collision, the average charged particle multiplicity $\langle N_{ch}^{pp} \rangle$ is determined using a parameterization Eq. (4) as a function of the CM energy $\sqrt{s_{NN}}$ of that specific colliding nucleon pair. The total $\langle N_{ch} \rangle$ is then the sum of these contributions over all collisions in the event.

To select the parameter k for O+O and Ne+Ne collisions at LHC energies, the already known, published experimental data on Pb+Pb and Xe+Xe collisions were used to fit the parameter k. For our predictions of total multiplicity for light nuclei collisions at the LHC, we obtained a mean value of the parameter k in the analysis of centrality dependence of charged particle multiplicity normalized to the pair of nucleons - participants in Pb+Pb and Xe+Xe collisions at the LHC. The following data were used: in Pb+Pb collisions at $\sqrt{s_{NN}}$ =2.76 [12], at $\sqrt{s_{NN}}$ =5.02 TeV[13] and in Xe+Xe collisions [14] at $\sqrt{s_{NN}}$ =5.44 TeV.We show the results of fits in Figure 1. The relevant values of k are presented in Table 2. we choose the mean value $k = 0.19 \pm 0.05$.

Table 2: Values of parameter k in fits to the data in Pb+Pb collisions at $\sqrt{s_{NN}}$ =2.76 [12], 5.02 TeV[13] and in Xe+Xe collisions [14]

Colliding system	$\sqrt{s_{NN}}$, TeV	k
^{208}Pb	2.76	$0.22^{+0.01}_{-0.02}$
^{208}Pb	5.02	$0.21^{+0.002}_{-0.01}$
^{129}Xe	5.44	$0.16^{+0.01}_{-0.002}$

3 Results and discussions

We demonstrate in Figure 1 our results obtained in the MGM analysis of data from heavy ion collisions at the LHC: for Pb+Pb at $\sqrt{s_{NN}}$ =2.76 [12], 5.02 TeV[13] and for Xe+Xe [14] at $\sqrt{s_{NN}}$ =5.44 TeV. As we see, a single parameter Modified Glauber model is capable to describe the observed non-linear effects of total multiplicity yields in the whole region of centralities.

So, these results, obtained with a single efficient parameter k in the Modified Glauber model approach, are indicating the importance of energy-momentum account in the multiparticle production in heavy-ion collisions at the LHC. It should also be noted that in this case of total multiplicity yields, the role of deformation of colliding nuclei is not very important even in the region of so-called "up-tick" effects observed by ALICE for very central Pb+Pb and in Xe+Xe collisions [14].

In Figure 1 we show also our predictions of the total multiplicity normalized to the number of participating nucleon pairs for O+O at $\sqrt{s_{NN}}$ = 5.36 TeV. Parameter $k = 0.19$. The same value of parameter k is used for the prediction of centrality dependence of yields in Ne+Ne collisions – the results are presented in the relevant expanded region of N_{part} in Figure 2 – along with the repeated predictions for O+O collisions. We see that in both cases of central O+O and Ne+Ne collisions, the total multiplicity yields, normalized to the number of participant nucleons, is very close to the relevant values measured in semi-central Pb+Pb and Xe+Xe collisions at the LHC.

The shaded areas in Fig. 1 and Fig. 2 show the Monte Carlo data dispersion, solid lines are the results of data splines.

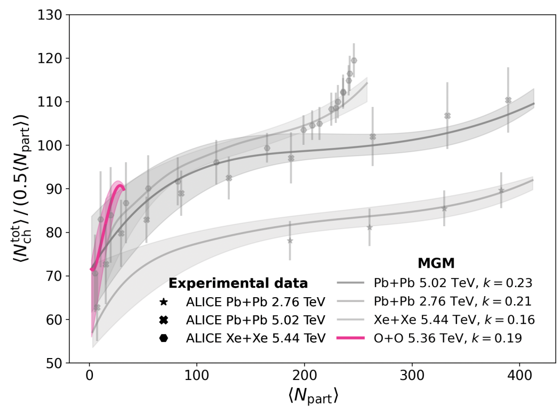


Figure 1: Lines – are the MGM analysis of the experimental data on heavy ion collisions at the LHC for the total multiplicity normalized to the number of participating nucleon pairs. Experimental points are: Pb+Pb collisions at $\sqrt{s_{NN}}$ =2.76 [12], 5.02 TeV[13] and Xe+Xe collisions [14] at $\sqrt{s_{NN}}$ =5.44 TeV. Red line – is the result of our prediction for O16+O16 collisions at $\sqrt{s_{NN}}$=5.36 TeV. The shaded areas are indicating the uncertainties of the MGM calculations.

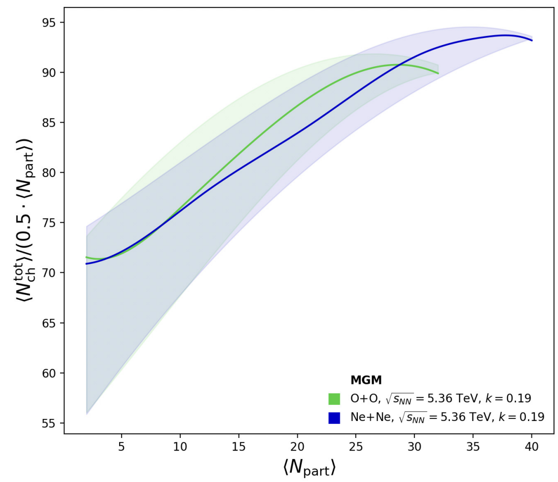
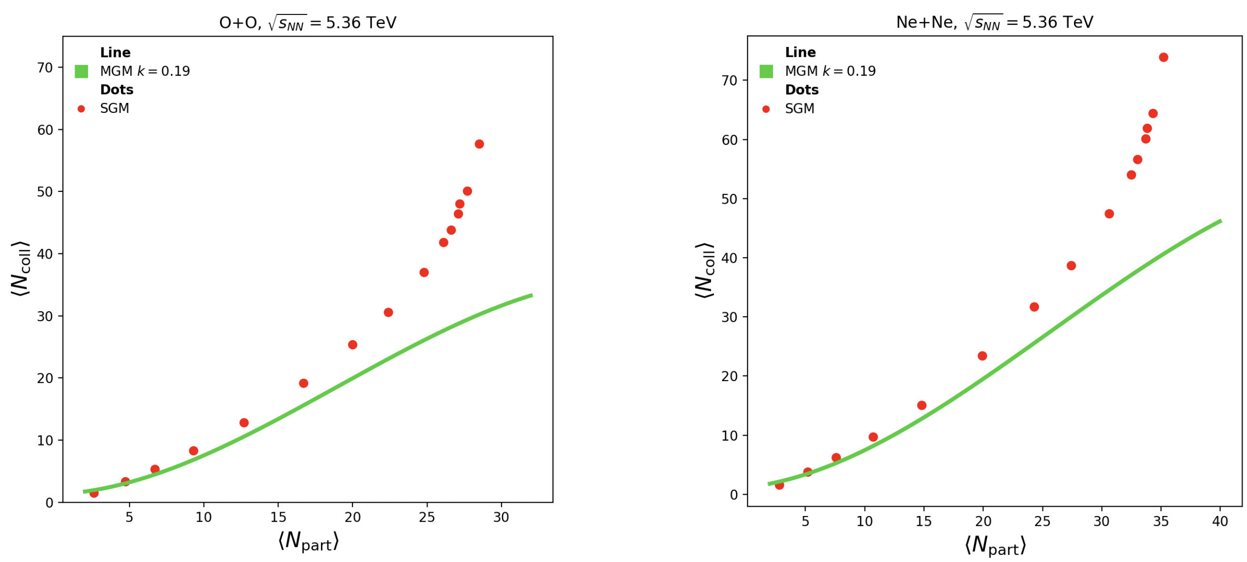


Figure 2: Predictions of the total multiplicity normalized to the number of participating nucleon pairs for O+O and Ne+Ne collisions at $\sqrt{s_{NN}}$ =5.36 TeV. Parameter $k = 0.19$.

When discussing the number of participating nucleons $\langle N_{part}\rangle$, it should be noted that it is approximately the same in all models, as shown in Ref. [15]. At the same time, comparison of the MGM results for $\langle N_{coll}\rangle$ as a function of centrality, to the SGM predictions Ref. [8], shows a factor of ~ 2 decrease both for very central O+O and Ne+Ne collisions at $\sqrt{s_{NN}} = 5.36$ TeV, see in Figure 3a and in Figure 3b (green lines for the MGM).



(a) (b)

Figure 3: Values of $\langle N_{coll}\rangle$ as a function of $\langle N_{part}\rangle$ at $\sqrt{s_{NN}} = 5.36$ TeV for O+O (a) and Ne+Ne (b) collisions: comparison of MGM (green lines) to the SGM predictions (red dots). Ref. [8].

4 Conclusion

We make predictions in the framework of the Modified Glauber model for the centrality dependence of total multiplicity yields of charged particles produced in O+O and Ne+Ne collisions at the LHC energies. The efficient account of the energy-momentum conservation in multiparticle production in collisions of light nuclei is taken by a single model parameter (k), that is considered to be universal for all nucleon-nucleon collisions at the LHC energies. For predictions, we fixed the average value $k = 0.19 \pm 0.05$ as defined from our analysis of data for Pb+Pb and Xe+Xe collisions at LHC. We obtain with the MGM, that in the case of O+O and Ne+Ne collisions at $\sqrt{s_{NN}} = 5.36$ TeV, the total multiplicity yields, normalized to the number of participant nucleons, is expected to be very close to the relevant values measured in semi-central Pb+Pb and Xe+Xe collisions at the LHC.

We argue that the purely geometrical effects and the energy-momentum conservation laws are driving the predictions of the total multiplicity yields – both in collisions of heavy and of light ion systems at the LHC. The numbers of binary nucleon-nucleon collisions $\langle N_{coll} \rangle$, obtained in a single parameter Modified Glauber model, are found to be remarkably different from the Standard Glauber model approach, that neglects energy-momentum conservation laws and overestimates $\langle N_{coll} \rangle$.

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5 Attachment: Modified Glauber Model data

Table 3: Ne+Ne at $\sqrt{s_{NN}} = 5.36$ TeV, $k = 0.19$

b range (fm)	$\langle N_{\text{part}} \rangle$	$\langle N_{\text{coll}} \rangle$	$\langle N_{\text{ch}} \rangle$
0.0–1.0	33.6	40.3	40.6
1.0–2.0	31.6	37.4	37.6
2.0–3.0	27.7	32.3	32.4
3.0–4.0	22.8	26.2	26.1
4.0–5.0	17.4	19.2	19.0
5.0–6.0	12.3	12.7	12.5
6.0–7.0	7.9	7.4	7.2
7.0–8.0	4.8	4.0	3.8
8.0–9.0	2.9	2.2	2.0
9.0–10.0	2.2	1.6	1.4

Table 4: O+O at $\sqrt{s_{NN}} = 5.36$ TeV, $k = 0.19$

b range (fm)	$\langle N_{\text{part}} \rangle$	$\langle N_{\text{coll}} \rangle$	$\langle N_{\text{ch}} \rangle$
0.0–1.0	25.7	28.4	28.6
1.0–2.0	24.2	26.5	26.5
2.0–3.0	20.8	22.7	22.6
3.0–4.0	16.7	17.7	17.5
4.0–5.0	12.6	12.7	12.5
5.0–6.0	8.8	8.2	8.0
6.0–7.0	5.7	4.9	4.7
7.0–8.0	3.6	2.8	2.6
8.0–9.0	2.4	1.7	1.6
9.0–10.0	2.1	1.4	1.3

References

[1] G. A. Feofilov and A. A. Ivanov, *J. Phys. G: Nucl. Part. Phys.* **31** (2005) 230, doi:10.1088/0954-3899/31/5/001.

[2] G. A. Feofilov and A. Yu. Seryakov, *AIP Conf. Proc.* **1701** (2016) 070001, doi:10.1063/1.4938686.

[3] S. Simak and G. A. Feofilov, *Phys. Part. Nucl.* **56** (2025) 877, doi:10.1134/S1063779624702447.

[4] D. Kharzeev and M. Nardi, *Phys. Lett. B* **507** (2001) 121, doi:10.1016/S0370-2693(01)00457-9.

[5] ALICE Collaboration, *ALICE-PUBLIC-2018-003* (2018), CERN Document Server.

[6] H. De Vries, C. W. De Jager, and C. De Vries, At. Data Nucl. Data Tables **36**, 495 (1987), doi:10.1016/0092-640X(87)90013-1.

[7] D. Behera *et al.*, Eur. Phys. J. A **58**, 23 (2022), doi:10.1140/epja/s10050-022-00823-6.

[8] C. Loizides, arXiv:2507.05853.

[9] C. Loizides, J. Nagle, and P. Steinberg, arXiv:1408.2549 [nucl-ex].

[10] C. Loizides, Phys. Rev. C **94**, 024914 (2016), doi:10.1103/PhysRevC.94.024914.

[11] J. F. Grosse-Oetringhaus and K. Reygers, *J. Phys. G: Nucl. Part. Phys.* **37** (2010) 083001, doi:10.1088/0954-3899/37/8/083001.

[12] ALICE Collaboration, Phys. Lett. B **726**, 610 (2013), doi:10.1016/j.physletb.2013.09.022, arXiv:1304.0347.

[13] ALICE Collaboration, Phys. Lett. B **772**, 567 (2017), doi:10.1016/j.physletb.2017.07.017, arXiv:1612.08966.

[14] ALICE Collaboration, arXiv:1805.04432 [nucl-ex].

[15] T. A. Drozhzhova, V. N. Kovalenko, A. Yu. Seryakov and G. A. Feofilov, *Phys. At. Nucl.* **79** (2016) 737, doi:10.1134/S1063778816040074.