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Simak Svetlana Grigory Feofilov

Violation of scaling of total charged-particle multiplicity normalized by the number of nucleons-participants in central Xe-Xe and Pb-Pb collisions

Abstract. We present the results of the updated Monte Carlo code of the modified Glauber model (MGM) [1], [2]. In our work, the code is extended to the collisions of deformed relativistic nuclei and it provides also the possibility to differentiate the contributions to the total yields of charged particles relevant to some definite number of binary nucleon-nucleon collisions. Contrary to the standard Glauber model (SGM) code [3], in the MGM we take into account the energy and momentum conservation laws in the relevant processes of multiple production of particles in nucleus-nucleus collisions at high energies. A single parameter (k) is responsible in the MGM for the nucleon momentum loss in each inelastic collisions. It allows us to describe the total yields of charged particles produced in heavy nuclei collision at the LHC energies and to explain the the observed deviation from scaling with the number of participating nucleons.

Terminology:

- N_{part} - nucleons that have collided at least once;
- N_{coll} - number of binary nucleon-nucleon collisions;
- N_{spect} - nucleons that have not experienced a single collision;
- N_{ch} - output of charged particles;
- b - impact parameter;
- $\sqrt{s}$ - energy per pair of nucleons in the CMS

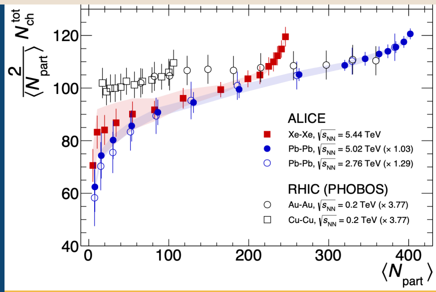

Fig. 1: The 'uptick' effect (the increase in the charged particle yield normalized by the nucleon-participant pair), see [4]

Nuclei generation.

See [3], [5]

For undeformed nuclei: $\rho(r) = \rho_0 \cdot \frac{1}{1+exp(\frac{r-R}{a})}$

For deformed nuclei:

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

$$Y_{20} = \sqrt{\frac{5}{16\pi}} \cdot (3 \cdot cos^2(\theta) - 1)$$

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

Calculation of charged particle yield

A parameterization is used to calculate $< N_{ch} >$ in each collision:

$$< N_{ch}^{pp} > = a + b \cdot ln(s) + c \cdot ln^2(s),$$

where a = 16.65, b = -3.147, c = 0.334 from [6].

The final $< N_{ch} >$ is the sum from each binary collisions.

Collisions.

Nucleons are said to collide if their impact parameter (b) satisfies:

$$b < \sqrt{\frac{\sigma_{NN}}{\pi}}, \quad \sigma_{NN} = a + b \cdot ln^n s,$$ see [7], [8]

The first collision is calculated as follows:

1. Initial momentum of nucleons:

$$P_1 = -P_2 = \sqrt{(\frac{\sqrt{s}}{2})^2 - m^2},$$ where P_1, P_2 are the momenta of nucleons moving counter-directionally.

2. Impulses after the collision:

$$P'_1 = k \cdot P_1, \; P'_2 = k \cdot P_2$$

In further collisions the momentum is recalculated as follows when (otherwise the variables are renamed):

1. Nucleons energy:

$$E_1 = \sqrt{(P'_1)^2 + m^2}, \; E_2 = \sqrt{(P'_2)^2 + m^2}$$

2. Energy per pair of nucleons and energy of each nucleon in the center-of-mass system (CM):

$$\sqrt{s} = \sqrt{(E_1+E_2)^2 - (P'_1 + P'_2)^2}, \; E_{CM} = \frac{\sqrt{s}}{2}$$

3. The momentum modulus of nucleons in the center-of-mass system:

$$P_{CM} = \sqrt{E_{CM}^2 - m^2}$$

4. Momentums recalculation:

$$\beta = \frac{P_{CM} \cdot E_1 - E_{CM} \cdot P_1}{P_{CM} \cdot P_1 - E_{CM} \cdot E_1}, \; P_{CM}^{new} = k \cdot P_{CM}, \; E_{CM}^{new} = \sqrt{(P_{CM}^{new})^2 + m^2}, \; P_1^{new} = \frac{P_{CM}^{new} + \beta \cdot E_{CM}^{new}}{\sqrt{1-\beta^2}}, \; P_2^{new} = \frac{-P_{CM}^{new} + \beta \cdot E_{CM}^{new}}{\sqrt{1-\beta^2}}$$

where P_{CM}^{new} is the momentum modulus in CM after the collision, E_{CM}^{new} is the energy of the nucleons in CM after the collision, P_1^{new}, P_2^{new} are the momenta of the nucleons after the collision.

Results

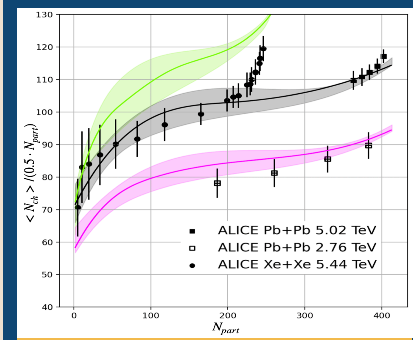

Figure 2: Results of MGM for Pb+Pb 5.02 TeV, Pb+Pb 2.76 TeV, Xe+Xe 5.44 TeV
k = 0.23

Conclusions

(1) Collisions of both spherical (Pb-Pb) and deformed (Xe-Xe) relativistic nuclei at the LHC energies show the general deviation from scaling of charged particle yield with the number of participation nucleons (N_{part}) and "the uptick" effect — a sharp increase in the multiplicity in the very central collisions at the LHC. The efficient account of the energy-momentum conservation in multiparticle production, taken by a single model parameter (k), allows to explain the observed deviation from scaling with the number N_{part} observed at the LHC energies.

(2) In the MGM, the effects of scaling violation are found to be related to the collision geometry:

· Fig.4 shows that for two close central classes of Pb-Pb collisions at 2.76 TeV appearance of the "the uptick" effect in case of very central class ($N_{part} = 359$ is provided by the increased contribution of 6 nucleon-nucleon collisions)

· Fig.5 and Fig.6 provide similar but more detailed explanations for Pb-Pb collisions at 5.02 TeV and Xe-Xe at 5.44 TeV: "the uptick" effect in the most central classes is provided by the increased contribution of 5 and 6 nucleon-nucleon collisions for Pb-Pb and 4,5,6 for Xe-Xe collisions

· At the same time, Fig.5 and Fig.6 show that the general violation of scaling with N_{part} is produced by the dominating 5 nucleon-nucleon collisions for Pb-Pb at 5.02 TeV and by dominating 7 nucleon-nucleon collisions for Xe-Xe collisions at 5.44 TeV

(3) Comparison of the results of SGM and MGM (k = 0.24) for estimates of the total mean number of binary nucleon-nucleon collisions ($< N_{coll} >$) for the case of Pb+Pb 5.02 TeV shows striking difference (see Fig.3). A similar kind difference was shown previously [1,2] and also confirmed by the non-Glauber calculations [9] pointing at the definite considerable bias in the values of $< N_{coll} >$ extracted in the widely applied Standard Glauber approach.

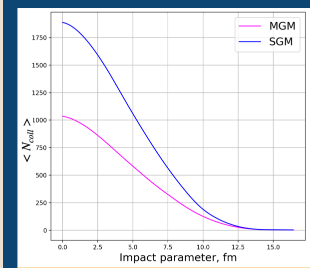

Figure 3: Comparison of the results of SGM and MGM estimates of the number of binary nucleon-nucleon collisions for the case of Pb+Pb 5.02 TeV;
for MGM k = 0.24

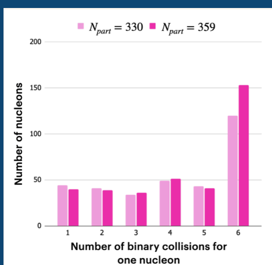

Figure 4: MGM results for the distributions on the number of binary collisions for one nucleon for two cases of close classes of the most central events of Pb+Pb collisions at energy 2.76 TeV

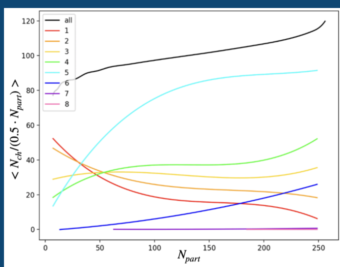

Figure 5: The colored curves show the N_ch that have been produced in binary collisions of nucleons that collided a certain number of times for **Pb+Pb 5.02 TeV**

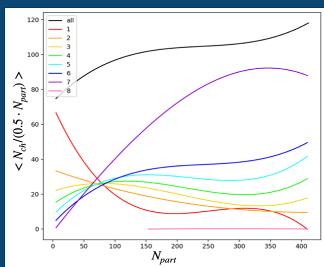

Figure 6: The colored curves show the N_ch that have been produced in binary collisions of nucleons that collided a certain number of times for **Xe+Xe 5.44 TeV**

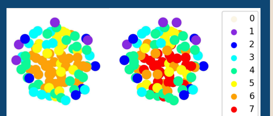

Figure 7: Nuclei in section: on the left in the Pb+Pb collision **2.76 TeV**, on the right **5.02 TeV**; The colors represent the number of binary collisions experienced by each nucleon

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