ISSN 0974 - 9373

Vol. 23 No. 4 (2019) **Journal of International Academy of Physical Sciences** pp. 395- 402

Global Properties of Uranium-Uranium Collisions at $\sqrt{s_{NN}}$ =193 GeV

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(Received October 11, 2019)

Abstract: In this research article, the particular attention has been paid to the Uranium-Uranium collisions in MC Glauber model by implementing some modifications. The larger size and deformed shape of Uranium nuclei is utilized here to better understand the properties of Quantum chromodnamics (QCD) matter through charged particle production. To analyse the charged particle production in collisions of deformed Uranium nuclei at $\sqrt{s_{NN}}$ = 193 GeV, a simulation study is performed in the context of modified MC Glauber model (MCGM). The study of various possible configurations of Uranium nuclei in a collision event is presented here using modified MCG Model simulation. The variations of number of binary collisions as a function of number of participating nucleons in U-U collisions is studied in modified MC Glauber Model calculations. The simulation results reproduce the correlation between the measurable quantities and initial geometrical configurations as observed in collision experiments.

Keywords: Quantum chromo dynamics, deformed, Uranium nuclei, Glauber model, correlation, initial configuration.

1. Introduction

The purpose of the investigations carried out through heavy ion collision experiments at relativistic ion colliders is to find a way to search for QCD matter and characterize its properties under extreme conditions of temperatures and densities. In these heavy-ion collision experiments, The QCD matter produced in the collision process is not directly available for measurements and also the measurement of experimental quantities have their own limitations due to complexity involved in these sophisticated experiments. The study of the evolution of the QCD matter and their properties can be done by the analysis of the properties of the charged particles produced in the final state of the collision process[1–4]. The production of charged particles in these experiments is greatly affected and altered by the properties of the initial state geometrical configurations of the overlap region formed during the collision and its path length dependence. It is observed recently in Collider experiments at RHIC energies that the initial state geometry and its fluctuations is indirectly reflected into the final state anisotropies. Therefore, it becomes necessary to correctly incorporate the geometrical configurations of colliding nuclei[5–11] to correctly replicate the collision events in theoretical model calculations and see their after effects on measured quantities. In this regard, Nucleon-nucleon interactions based models are being extensively used in the study of the properties of the initial state in high-energy nuclear collisions. The properties of the initial state N_{part}, N_{coll}, eccentricity[12] etc. and their dependence on impact parameter i.e., centrality are of prime significance. In heavy-ion collision experiments, the centrality dependence of physically measurable quantities such as multiplicity density, mean multiplicities, transverse energy density etc provide us a much needed insight into the dependence of these bulk observables on the initial state spatial anisotropy. Owing to prolate shape of Uranium nuclei, different angular orientations[13-15] of the Uranium during the collision are possible. Different orientations results with different geometrical configurations of the collision event i.e., body-body, side-side, tip-tip, tip-body configurations. These different orientations are also possible in collisions of nuclei with complete overlap i.e., central most collisions. The initial state geometry configurations of the overlap region significantly affects the production of charged particles in central collisions of these nuclei. These effects can be well understood by carrying out the analysis of the initial anisotropy measured in the experiments. In order to see their after effects caused by the initial geometry configurations i.e., due to the different orientations of colliding Uranium nuclei, It is always preferable to carry out the analyze of the central most collision events so that the effects due to the centrality can be reduced. To meet these requirements, we first studied different orientations of the collision events in U-U collisions at 193 GeV c.m. energy and then aim for the pseudorapidity density and transverse energy density as a function of the centrality using modified MCG model for the various configurations of U-U collisions. Finally, we give a summary of the results obtained from the analysis performed in this work.

2. Model Formalism

Here, the Monte Carlo Glauber Model (MCGM) is used to generate the events, a detailed description can be found in Ref.[14]. In the MC Glauber model, nuclei consists of a set of nucleons and the nuclear reaction is approximated by successive independent nucleon nucleon (NN) interactions is performed using the assumption of straight line motion of nucleons along the beam axis using eikonal approximation such that nucleons are tagged as wounded (participating) or spectator. Glauber model gives a generalized description of the collision process by taking into account effective sub nucleonic degrees of freedom. It obviously does not take into account the partonic structure of the nucleons like the constituent quark models. The optical Glauber calculations[14] assume a smooth matter density distribution for the makeup of the nuclei, while in Monte Carlo (MC) implementation individual nucleons are distributed on event by event basis. For both the cases, a Fermi distribution is used for the radial direction and a uniform distribution for the solid angle. In the context of the MC Glauber model, the position of each nucleon inside the nucleus commonly requires a minimum inter-nucleon separation (d_{min}). Individual nucleons are generated for both the colliding nuclei using the nuclear density distribution, then the nuclei were collided taking the inelastic nucleon-nucleon cross section (σ_{NN}) as the parameter. The geometric quantities from each event were calculated. Charged particle multiplicity and Transverse energy distribution were calculated using the two-component model.

The hard sphere wounding approach was used. In the eikonal limit, the nucleons were assumed to move in straight line along the direction beam. All the binary collisions were taken independent of any previous binary collision. Firstly, the impact parameter was generated using the distribution $dN/db \propto b$, where the limits on b were set according to the centrality bin. The centre of the two nuclei were then shifted to (-b/2, 0, 0) and (b/2, 0, 0).

The transverse distance between nucleons from the two nuclei, d, was calculated. Two nucleons from nuclei are supposed to collide if, d < $\sqrt{\frac{\sigma_{NN}}{\pi}}$ π [5]. The value used for σ_{NN} was taken 41.67 mb corresponding to $\sqrt{s_{NN}}$ = 193GeV. An event was recorded if one such binary collision was observed. The total number of participating (or wounded) nucleons, Npart, was calculated by counting the nucleons that underwent the binary collision and the total number of binary collisions, Ncoll, was also calculated.

In case of spherical nuclei, the nuclear density is generally determined by using the woods-saxon density function

(1.1) $$\rho = \frac{\rho_o}{1 + \exp(\frac{r-R}{a})} .$$

Here R is the nuclear radius and a is the skin depth. ρ_0 is normalization constant in the Glauber calculations. In the present work, For U-U collisions, we have incorporated deformed Woods-Saxon density function[15],

(1.2) $$\rho = \frac{\rho_o}{1 + \exp\left(\frac{r - R(1 + \beta_2 Y_{20} + \beta_4 Y_{40})}{a}\right)} ,$$

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

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

Here θ is the polar angle and Y_{20}, Y_{40} denote the spherical harmonics. β_2 and β_4 are the deformation parameters responsible for the deformed shape of Uranium nuclei. The normalization ρ_0 is irrelevant to the Glauber calculations and the value of the parameters was taken from the Ref.[13]. The position of the centre of nucleon in one nucleus was drawn at random from the distribution $4\pi r^2 \rho(r) \sin\theta dr d\theta$. The centre of the nucleons were taken to be at least 0.4 fm apart. The radius increases when θ goes to 0 and decreases when θ goes to π/2, giving rise to a prolate shaped nucleus whose major axis is aligned along the z axis. Thus, both the target and the projectile nuclei were given a rotation along the z axis to randomize the configuration

3. Results and Discussion

In Figure 1, Body-body configuration of the collisions events for U-U collision at 193 GeV c.m. energy is shown. Here, the major axis of both the Uranium nucleus is perpendicular to the direction of colliding beam and are parallel to each other.

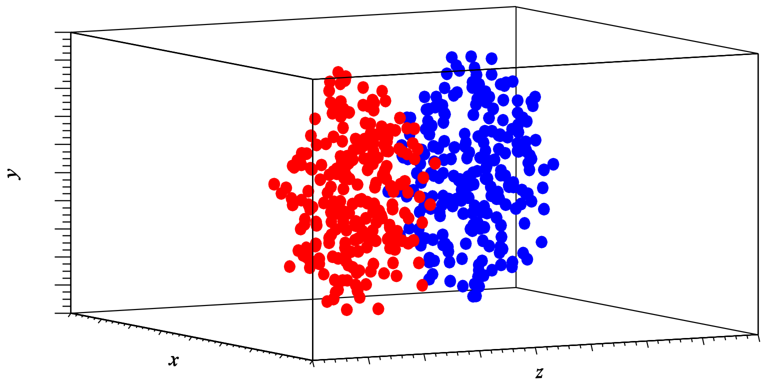

Figure 1. Body-body configuration of collisions of Uranium nuclei at 193 GeV c.m. energy.

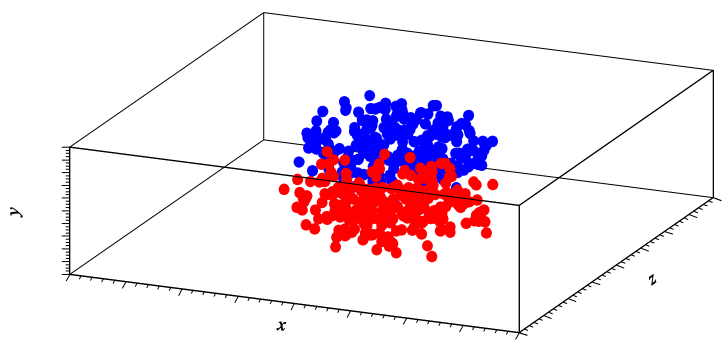

Figure 2. Side-Side configuration of collisions of Uranium nuclei at 193 GeV c.m. energy

In Figure 2, Side-side configuration of the collisions events for U-U collision at 193 GeV c.m. energy is shown.

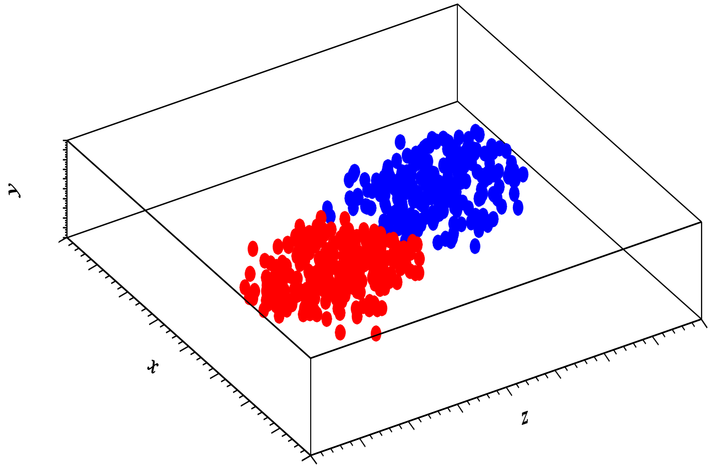

Figure 3. Tip-tip configuration of collisions of Uranium nuclei at 193 GeV c.m. energy

In Figure 3, Tip-tip configuration of the collisions events for U-U collision at 193 GeV c.m. energy is shown. Here the major axis of both the Uranium nucleus is parallel to the direction of colliding beam. It is expected that multiplicity in tip-tip configuration will be higher than other configurations.

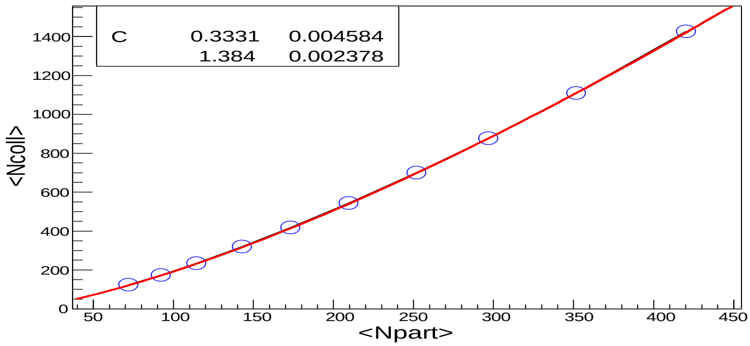

Figure 4. The total number of binary collisions, Ncoll, as a function of wounded nucleons, Npart. The values as obtained from the model are represented by circles. The bold line represents is curve obtained by fitting the data obtained by MCG model calculation

The multiplicity produced charged particles in the final stage of collision directly depend upon number of binary collisions of nucleons, and is also dependent on the orientations of the two colliding nuclei i.e, body-body, tip-tip, side-side, body-tip. Therefore, it is important to study the variation of N_{coll} as a function of N_{part} i.e, overlapping region of the two nuclei. It is observed that with increasing Npart the number of binary collisions increases non-linearly. In Figure 4, the variation of average number of binary collisions as a function of the average number of nucleons is plotted by using MCGM simulation calculations. It is clearly observed in Figure 4 that with increasing centrality the no. of binary collisions increases rapidly. It causes the higher deposition of energy with increasing centrality in mid rapidity region which is responsible for higher production of charged particle in central collisions.

4. Summary

Using modified wood-saxon nuclear density profile for Uranium nuclei, 100,000 events were simulated for each configuration at different centralities. The measurement of charged particle production as a function of centrality was performed which is quite helpful to quantify the role of soft and hard processes in the particle production mechanism. The study of properties of charged particle production requires the study of correlation between the number of participant nucleons and the number of binary collisions. Analysis of these correlations are necessary to understand the role of collision energy, size of colliding nuclei and the role of orientation of colliding nuclei. These quantities directly affect the production of charged particles. It will be useful to implement modified nuclear density to study the role of initial nuclear matter density in Uranium-Uranium collision in order to explain the available experimental data at RHIC energies. The multiplicity density and transverse energy density are another important quantities which needs to be calculated and compared with the experimental data in this analysis to draw any firm conclusion.

Acknowledgment: One of authors A. K. sincerely thanks Department of Physics and Electronics, Dr. Rammanohar Lohia Avadh University, Ayodhya for research facilities provided by the department.

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