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Transverse Energy Density of Produced Charged Prticles at $\sqrt{s_{NN}}$ =193 GeV

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Abstract: In this research article, a particular attention has been paid to the Uranium-Uranium collisions at 193 GeV c.m. energy in MC Glauber model by implementing some modifications. The larger size and prolate shape of Uranium nuclei gives us oppurtunity to have different angular orientations and 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 performed using modified MCGM calculations and analysis performed is presented here. Centrality dependence of Transverse energy density of produced particles in Uranium-Uranium collisions is studied. The simulation results obtained reproduce the observed correlation between the measurable quantities and initial geometrical configurations as observed in collision experiments.

Keywords: Quantum chromo dynamics, deformed Uranium nuclei, Glauber model, angular orientation, geometrical configuration.

1. Introduction

The characterization of the nuclear interaction in terms of measurable quantities in the collision experiments plays vital role in understanding the dynamics of relativistic nuclear collisions such as the energy produced transverse to the beam direction and/or the number of charged particles produced in an interaction are very crucial. These experimental measurements are directly related to the initial geometry of colliding nuclei and provide crucial information in understanding properties of the system formed during nuclear collisions.

The study of the evolution of Quantum chromodynamics (QCD) matter and study of the properties of QCD matter[1-7] can be performed by analysing the properties of charged particles produced in the final stage of the collision process. The production of charged particles in these collider experiments is affected by the properties of the initial state geometrical configurations of the overlap region formed during the collision. It also has 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[8–15] to correctly replicate the different collision events in theoretical model simulations and to 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 bulk observables and their dependence on impact parameter i.e., the centrality of collision events are of prime interest. In heavy-ion collision experiments, the centrality dependence of physically measurable quantities such as multiplicity density, mean multiplicities, transverse energy density etc. provide us much needed insight to see the dependence of these observables on the initial state spatial anisotropy. Prolate shape of Uranium nuclei makes available to us all the possible angular orientations[16-18] to mimic the possible collision processes at 193 GeV c.m. energy. Different geometrical configurations of the collision event such as body-body, side-side, tip-tip, tip-body configurations are possible to simulate by using different angular orientations of the colliding uranium nuclei. These different orientations are also possible in central most collision events. The initial state geometry configurations of the overlap region affects the charged particles production in central nuclear collision events. These effects can be well understood by carrying out the analysis of the anisotropy measured in the experiments. In order to see their after effects, It is always preferable to carry out the analysis measured observable in the central most collision events. We simulated different orientations of the collision events in Uranium-Uranium collisions at 193 GeV c.m. energy and then calculated the derived transverse energy density as a function of the centrality using the two component approach in MCGM for the various configurations of U-U collisions. Finally, we give a summary of the results obtained from the analysis performed in the present work.

2. Model Formalism

The Monte Carlo Glauber Model (MCGM) simulation is used in the present work to generate a set of Uranium-Uranium collisions events, a detailed description can be found in Ref.[8,19]. 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 (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 subnucleon 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[8] 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[19]. 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, for determining the position of each nucleon inside the nucleus, one commonly requires a minimum inter-nucleon separation (d_{min}) to determine of the nucleon. Discrete nucleons are generated for both the nuclei using the nuclear density distribution, then the nuclei were collided depending on the inelastic nucleon-nucleon cross section (σ_{NN}) as the parameter. The geometric quantities from each collision event were recorded. Transverse energy distribution of charged particles were calculated using the two-component model.

In the eikonal limit, the nucleons of colliding nuclei were assumed to have a straight line motion along the collision beam axis. All the binary nucleonic collisions were assumed to be independent of previous binary collisions. In this regard, the impact parameter was generated using the distribution dN/db ∝ b, where the impact parameter b were generated according to the centrality bin. The centre of the two uranium 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. The value used for σ_{NN} used here to be 41.67 mb corresponding to $\sqrt{s_{NN}}$ = 193 GeV. Collision event was recorded only if each binary nucleonic collision was observed as per criterion. The total number of participating (or wounded) nucleons, N_{part}, was calculated by counting the nucleons which suffered the binary collision and the total number of such binary collisions, N_{coll}, was calculated. The modified nuclear density chosen for present work is expressed by following expression:

(2.1)
$$\rho = \frac{\rho_0}{1 + \exp\left(\frac{r - R\left(1 + \beta_2 Y_{20} + \beta_4 Y_{40}\right)}{a}\right)} .$$

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[19], The normalization ρ_0 is irrelevant to the Glauber calculations and the value of the parameters was taken from the Ref[8, 19]. The centre of the nucleons were assumed to be at least 0.4 fm apart in this calculation. 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 beam axis i.e., z-axis. In this manner both the target and the projectile nuclei were given a rotation along the z axis to randomize the angular configuration of Uranium nuclei. By using the modified nuclear density profile, the number of participating nucleons and the number of binary collisions are simulated. For estimating transverse energy density, the two component approach is used in the calculations and finally the transverse energy density of collision events with individual angular orientation is simulated.

(2.2)
$$\frac{dE_T^{AA}}{d\eta} = \frac{dE_T^{pp}}{d\eta}\left[\left(1-x\right)N_{\text{part}} + xN_{\text{coll}}\right],$$

where x is the fraction of hard processes and n pp is the factor relating to proton-proton collision.

The soft and hard processes in particle collision scale directly with the wounded nucleons and binary collisions respectively.

$$\frac{dE_T^{AA}}{d\eta} = \frac{dE_T^{pp}}{d\eta}\left[(1-x)N_{\text{part}} + xC\left(N_{\text{coll}}\right)^{\alpha}\right]. \quad (2.3)$$

The value of both these parameters (x and α) can be evaluated by fitting the experimental data with the equation.

3. Results and Discussion

The mean transverse energy per unit pseudorapidity $\langle dE_T/d\eta \rangle$ basically gives us the informations about the part of initial longitudinal energy carried by the incoming nuclei which after collision is getting converted and being imparted to the outgoing particles perpendicular to the beam axis. Transverse energy distribution of the charged particles is most basic and important measurements that can be made in heavy ion collision experiments and is dependent upon the initial energy and entropy densities of the QCD matter produced during the collision. The centrality dependence of transverse-energy production and at midrapidity is also useful to characterize the nuclear geometry of the reaction and is sensitive to the dynamics of the collision system.

In Figure 1, the model results for the variation of normalized transverse energy density as a function of number of participating nucleon (N_{part}). The model results are fitted with the function used in (2.3) and a reasonably good fit is obtained by using the values of the parameters as mentioned in the Figure.

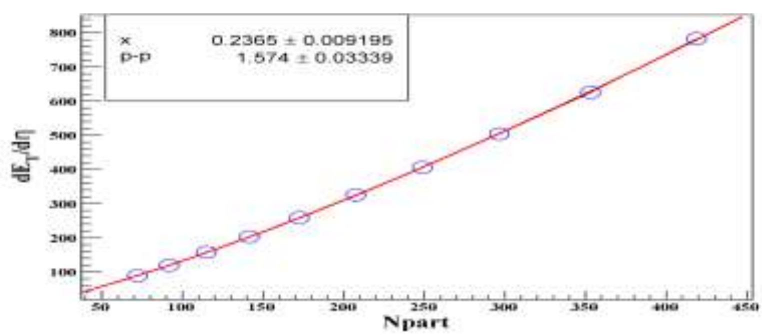

Figure 1. The variation of Tanseverse energy density scaled by <Npart> as a function of <Npart> at 193 GeV c.m. energy.

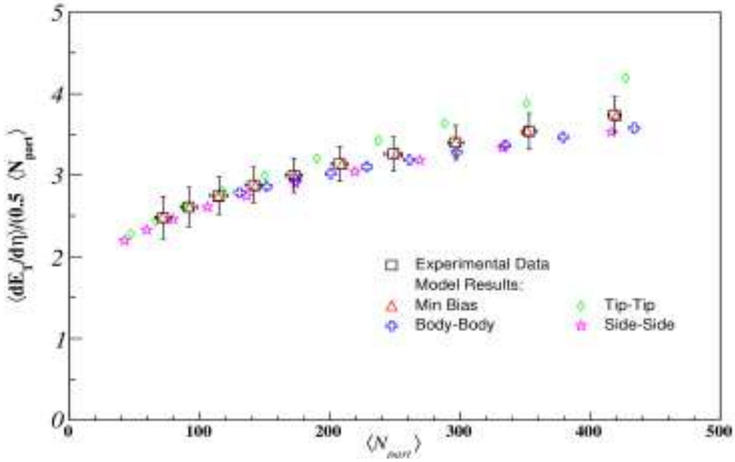

Figure 2. The variation of Tanseverse energy density scaled by <Npart> as a function of <Npart> at 193 GeV c.m. energy.

Figure 2, depicts the model results for the centrality variation of transverse energy density of the charged particles produced in min-bias, tip-tip, body-body and side-side configurations. Model results are compared with the available experimental data and are found to agree reasonably well within statistical error. Figure 3, depicts the model results for the centrality variation of mean transverse energy density per participating nucleon pair of the charged hadrons produced in minimum-bias, tip-tip, body-body and side-side configurations. Model results are compared with the experimental data. The model results of the modified MC Glauber results for the Tip-Tip configuration shows higher values than all other configurations. Which is due to the fact that the availability of larger travel path during the collision in Tip-Tip configuration causes increase in the number of binary collisions than the collisions with other configurations. Due to this increase in the number of binary collisions, more and more energy is deposited in the fireball during the collision. Which causes a higher value of the scaled $dE_T/d\eta$ in Tip-Tip configuration as observed in the figure.

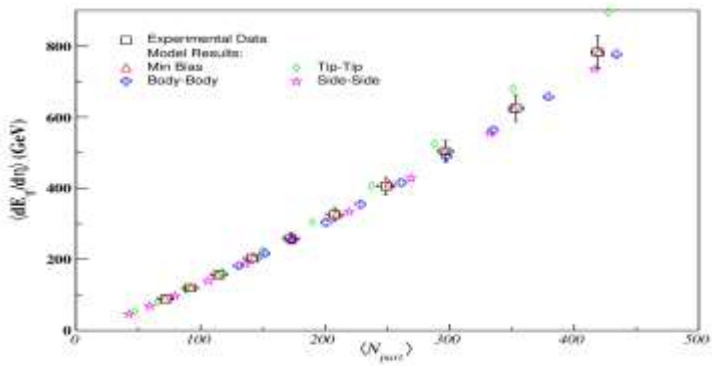

Figure 3. The variation of Tanseverse energy density scaled by <Npart> as a function of <Npart> at 193 GeV c.m. energy.

4. Summary

The simulation results based on 100,000 events for individual Uranaium configuration at different centralities obtained by modifying the wood-saxon nuclear density profile as used in the calculations presented. Simulated results for different configurations of Uranium nuclei are compared with the available experimental data measured at RHIC energy 193 GeV. It is evident from the analysis that the charge particle yield in tip-tip configurations is comparable to experimental measurements at lower centralities but have more pronounced values at higher centralities. Whereas the results based on min-bias events simulated by MCGM calculations shows good agreement with the available experimental data. Experimental results for charge particle production have contributions from all the possible geometrical orientations of the colliding Uranium nuclei at 193 GeV c.m. energy. Our present work describes the properties of charged particle production in the collisions of deformed Uranium nuclei at 193 GeV and their dependence on the initial state configurations and show reasonable agreement with the available experimental results. Furthermore calculate-ons are required to better understand the dependence of initial state aniso-tropy and their effects as observed in the experimentally measurable quant-ities.

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References

1. K. Fukushima and T. Hatsuda, The Phase Diagram of Dense QCD, *Reports on Progress in Physics*, **74** (2011), 014001.

2. C. P. Singh, Signals of Quark-Gluon Plasma, *Phys. Rep.*, **236** (1993), 147.

3. Ashwini Kumar, B. K. Singh, P. K. Srivastava and C. P. Singh, Wounded Quarks and Multiplicity at Relativistic Ion Colliders, *Eur. Phys. J. Plus,* **128** (2013), 45.

4. J. W. Harris and B. Muller, The Search for the Quark-Gluon Plasma, *Ann. Rev. Nucl. Part. Sci.,* **46** (1996), 71.

5. P. Braun-Munzinger and J. Stachel, The Quest for the Quark–Gluon Plasma, *Nature,* **448** (2007), 302.

6. B. Mohanty, Exploring the Quantum Chromodynamics Landscape with High-Energy Nuclear Collisions, *New Journal of Physics*, **13 (**2011), 065031.

7. B. Mohanty, QCD Phase Diagram: Phase Transition, Critical Point and Fluctuations, *Nuclear Physics A,* **830 (**2009), 899C–907.

8. Miller, R. Snellings, *arXiv: nucl-ex/0312008,* (2003).

9. B. Alver, B. B. Back and M. D. Baker et al., Importance of Correlations and Fluctuations on the Initial Source Eccentricity in High-Energy Nucleus-Nucleus Collisions, *Phys. Rev.C,* **77** (2008), 014906.

10. S. Bhalerao and J. Y. Ollitrault, Eccentricity Fluctuations and Elliptic Flow at RHIC, *Physics Letters B,* **641** (2006), 260.

11. Broniowski, P. Bozek and M. Rybczynski, Fluctuating Initial Conditions in Heavy Ion Collisions from the Glauber Approach, *Phys. Rev. C,* **76** (2007), 054905.

12. P. Sorensen, Implications of Space–Momentum Correlations and Geometric Fluctuations in Heavy-Ion Collisions, *J. Phys. G: Nucl. Part. Phys.,* **37** (2010), 094011.

13. P. Sorensen, B. Bolliet, A. Mocsy, Y. Pandit and N. Pruthi, *Physics Letters B,* **705** (2011), 71.

14. Agakishiev et al., STAR Collaboration, Energy and System-Size Dependence of Two- and Four-Particle V2measurements in Heavy-Ion Collisions at $\sqrt{S_{nn}}$ =62.4 and 200 Gev and their Implications on Flow Fluctuations and Nonflow, *Phys. Rev. C,* **86** (2012), 014904.

15. B. Alver et al., System Size, Energy, Pseudorapidity and Centrality Dependence of Elliptic Flow, *Phys. Rev. Lett.,* **98** (2007), 242302.

16. Q. Y. Shou, Y. G. Ma, P. Sorensen, A. H. Tang, F. Videbæk and H. Wang, Parameterization of Deformed Nuclei for Glauber Modeling in Relativistic Heavy Ion Collisions, *Physics Letters B,* **749** (2015), 215.

17. Michael L. Miller, Klaus Reygers, Stephen J. Sanders and Peter Steinberg, Glauber Modeling in High Energy Nuclear Collisions, *Review of Nuclear and Particle Science*, **57** (2007), 205.

18. Md. Rihan, Lin, Zi-Wei, Mohanty and Bedangadas, Multiplicity, Average Transverse Momentum and Azimuthal Anisotropy in U+U Collisions at $\sqrt{S_{nn}}$ = 200 Gev using AMPT Model, *Phys. Rev. C*, **85** (2012), 034905.

19. C. Loizides, J. Nagle, and P. Steinberg, Improved Version of the PHOBOS Glauber Monte Carlo, *Software X*, **1-2** (2015), 13.