Monte Carlo Simulation of Partons and Gluon Fields in Ultra-Relativistic Heavy Ion Collisions

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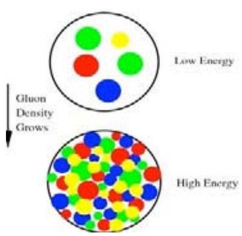
Introduction

The theory behind the interaction of quarks and gluons through the strong nuclear force is known as Quantum Chromodynamics (QCD). Hydrodynamics is a transport theory which describes the flow of these partons when they are in a state known as Quark Gluon Plasma (QGP). QGP is produced in high energy collisions of large nuclei. This project focused on creating appropriate initial conditions from nuclear collisions which would be used in further hydrodynamic evolution. This was done by modeling quarks and gluons in a nucleus and calculating the color charge density. Then using the theory of Color Glass Condensate (CGC), the energy density and other components of the energy-momentum tensor were calculated and compared to empirical data.

Color Glass Condensate

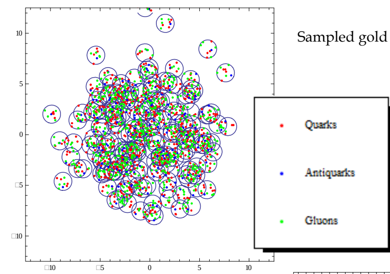
Color Glass Condensate (CGC) describes the state of partons inside high energy nuclei. "Color" represents the color charge of the quarks and gluons. "Glass" is used to describe the slow evolution of gluon fields. "Condensate" characterizes the high density of gluons inside the nucleons. As their energy increases, the number of gluons increases, but the coupling strength decreases.



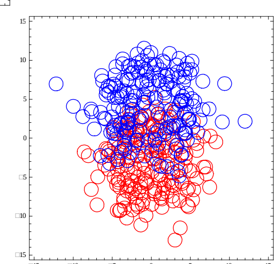
Initial Conditions

For consistency with experiments, gold nuclei were used in the model. Protons and neutrons were positioned in the nucleus through the Woods-Saxon distribution. Inside the nucleons, valence quarks as well as quark-antiquark pairs and gluons are uniformly distributed. However, because they are traveling at velocities comparable to the speed of light, the spherical nuclei are severely Lorentz-contracted into pancake-like objects. Therefore the spherical distribution functions must be transformed into areal density functions.

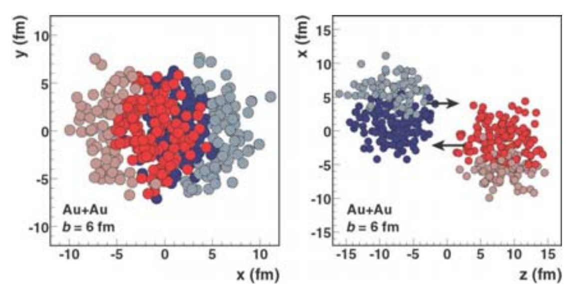
The MTSW parton distribution function was integrated from a Bjorken X value of 0.01 to 1 to determine the number of large-X partons inside each nucleon initially. These partons are the source of color charge for the gluon field and production of softer (small-X) partons. From this, the three valence quarks, one quark-antiquark pair, and four gluons were placed in each of the 197 nucleons in each gold nucleus.



Sampled gold nucleus



Colliding nuclei with impact parameter of 7 fm



Bold-colored circles represent the colliding nucleons of each nucleus

Calculation of Energy-Momentum Tensor

The color charge density, μ^2, was calculated, and the components of the energy-momentum tensor were determined. The energy density is found by

$$\varepsilon_o = c_1\, \mu_1^2(X)\mu_2^2(X)\left[c_2 + c_3\left(\frac{\Delta\mu_1^2(X)}{\mu_1^2(X)} + \frac{\Delta\mu_2^2(X)}{\mu_2^2(X)}\right)\right]$$

Then the components of the Poynting vector are computed by

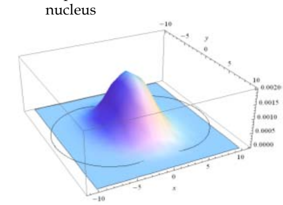
$$S^i = \alpha^i \cosh\eta + \beta^i \sinh\eta$$

Where

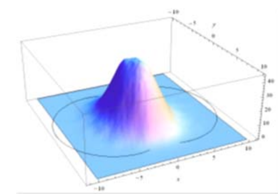
$$\alpha^i = \nabla^i \varepsilon_o$$

$$\beta^i = c_3\left(\nabla^i\mu_1(X)\mu_2(X) - \mu_1(X)\nabla^i\mu_2(X)\right)$$

Impact Parameter = 7 fm; Plotted in arbitrary units; Red lines represent nucleus

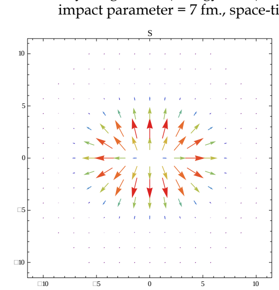


Averaged Energy Density

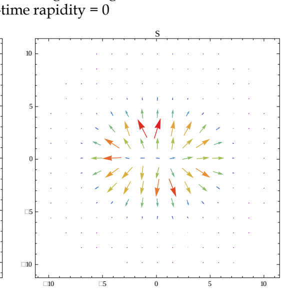


Sampled Energy Density (1000 trials)

Poynting Vector (Energy Flow) for averaged charge densities with impact parameter = 7 fm., space-time rapidity = 0



Averaged Flow



Sampled Flow (1000 trials)

Summary

This project focused on calculating the averaged and sampled energy density and flow of two colliding gold nuclei. These values may be used in further Hydrodynamic calculations.