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

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Overview

• Introduction to QCD and CGC
• Motivation of project
• Distribution of partons in nuclei
• Calculation of color charge density
• Computation of energy-momentum tensor
• Future work
Heavy Ion Collisions

Notable experiments:
- RHIC at Brookhaven
- LHC at CERN

Quark Gluon Plasma
What is QCD

- Quantum Chromodynamics - theory behind interactions of quarks and gluons through strong nuclear force
- Studied experimentally through heavy ion collisions, deep inelastic scattering, etc
QCD vs QED

- SU(3) vs U(1)
- Gluons vs Photons
- Quarks vs Leptons
  - Color charge and flavors
  - Confinement
  - Asymptotic Freedom
Color Glass Condensate (CGC)

- “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
Motivation

• One outstanding problem in QCD is the determination of initial conditions for QGP dynamics

• Results of this project can be implemented in hydrodynamics code as initial conditions for the transport of QGP

<table>
<thead>
<tr>
<th>CGC</th>
<th>Unknown</th>
<th>Hydrodynamics</th>
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Time Evolution of QGP
Probability Density Functions

- Nucleons positioned through Woods-Saxon distribution
- Partons distributed uniformly in each nucleon
- Lorentz contraction and effect on distributions
Nucleon/Parton Positioning

Sampled gold nucleus

Two colliding gold nuclei with impact parameter =7 fm
Energy Density

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

Averaged nucleon and parton positions

Each nucleus has a Woods-Saxon color charge density, \( \mu^2 \)

Two colliding nuclei (shown in black) with impact parameter = 7
Sampled Energy Densities

- Color Charge calculated by giving each nucleon a Gaussian color charge with $\sigma = 0.6$ fm.
- Color charge density is then the sum of individual nucleon color charges.

Energy Densities with $b = 7$ fm

1 Trial

50 Trials
Sampled Energy Densities

1000 trials

Averaged

Almost identical results!
Energy-Momentum Tensor

\[ S^i = \alpha^i \cosh \eta + \beta^i \sinh \eta \]

\[ \alpha^i = \nabla^i \varepsilon_0 \quad \beta^i = c_3 \left( \nabla^i \mu_1(X)\mu_2(X) - \mu_1(X)\nabla^i \mu_2(X) \right) \]

Poynting Vector with averaged nucleon positions

Poynting Vector with sampled nucleon positions (1000 trials)
Energy-Momentum Tensor

Spacetime Rapidity = 1

b=7
Future Work

• Calculate energy density and flow with sampled parton positions
• Exploring other ways of sampling for more accurate results
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