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

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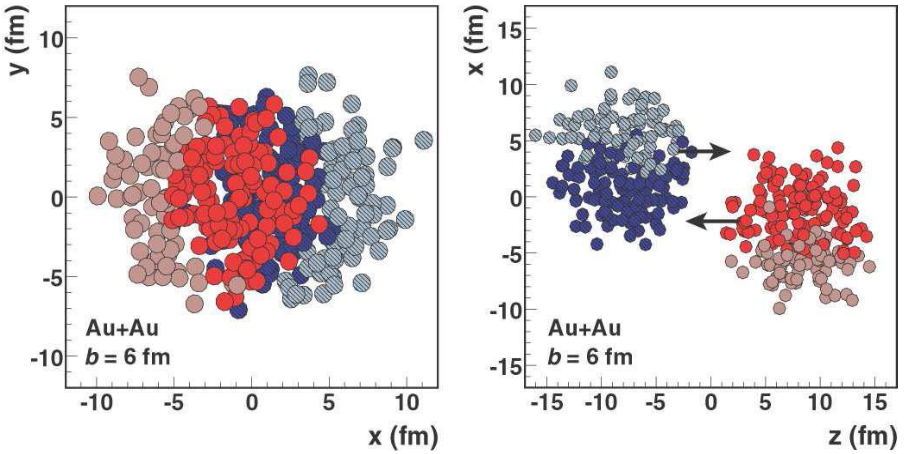
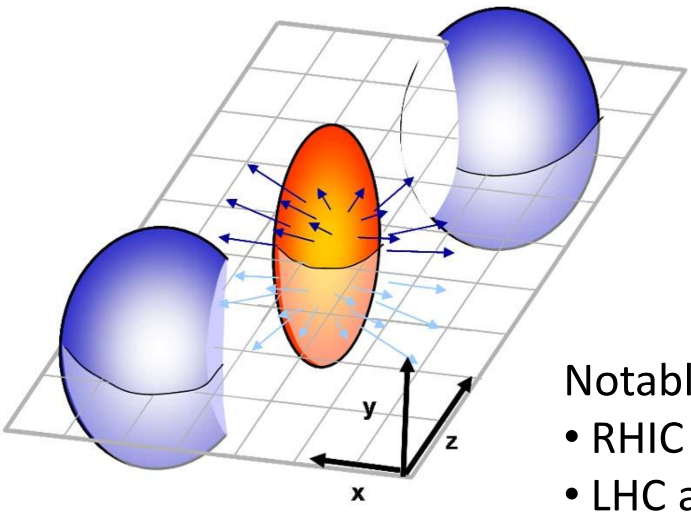
Overview

- 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

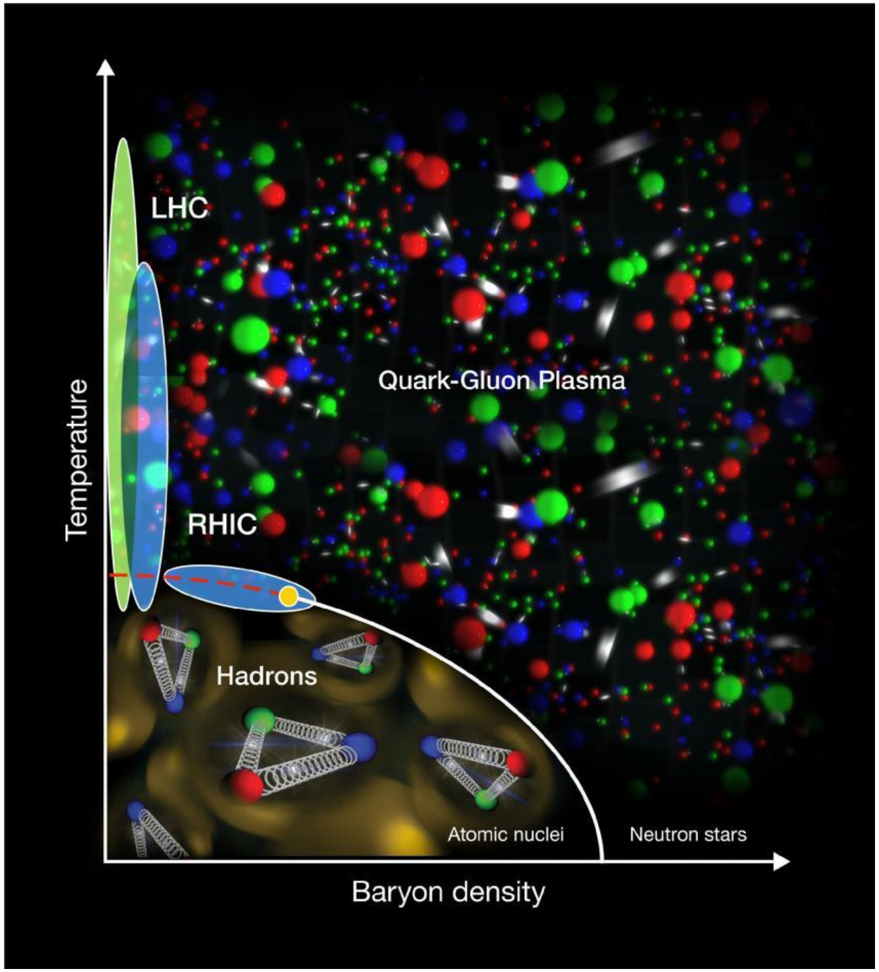




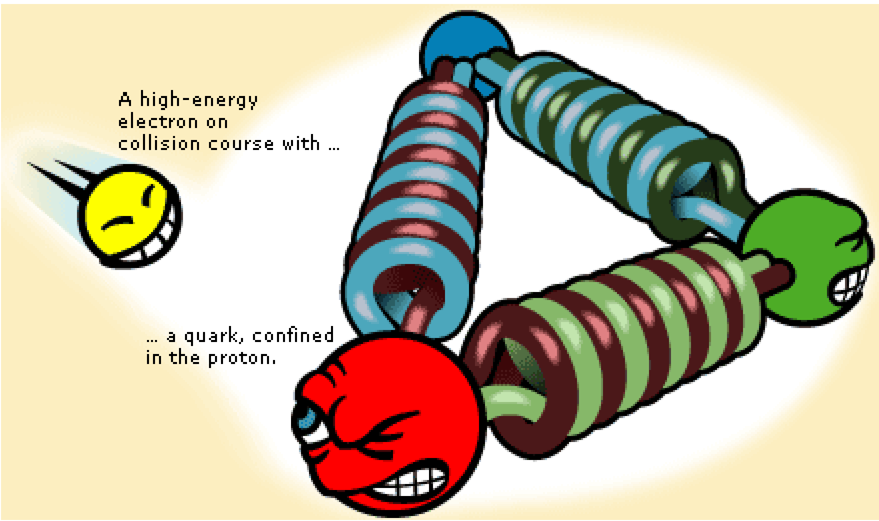
Notable experiments:

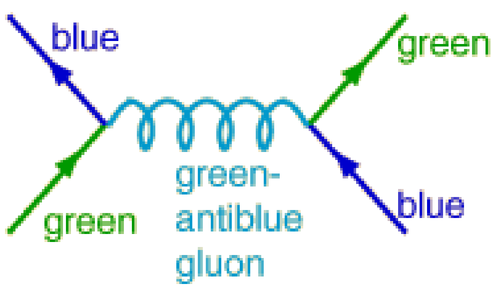
- RHIC at Brookhaven
- LHC at CERN

Quark Gluon Plasma



What is QCD

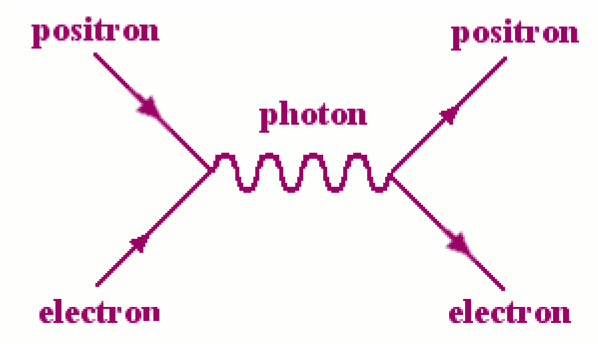


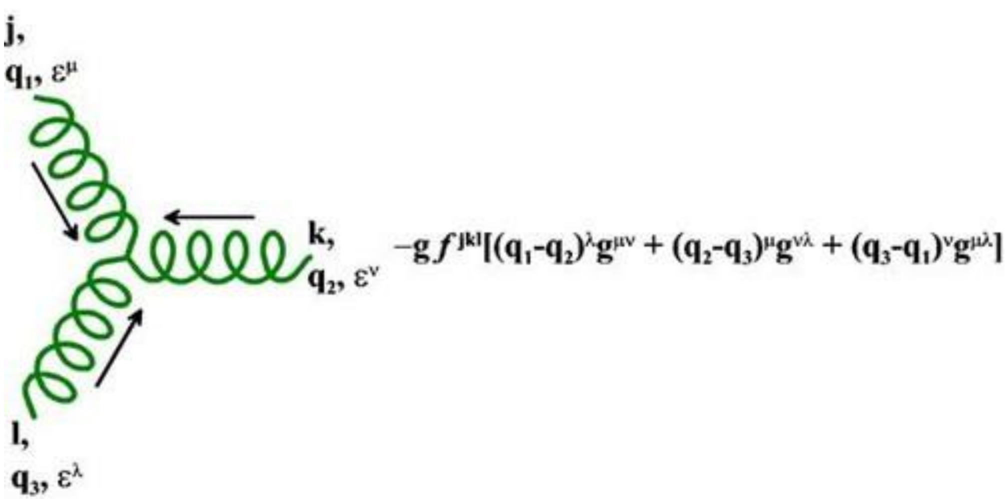


Feynman diagram for an interaction between quarks generated by a gluon.

- 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

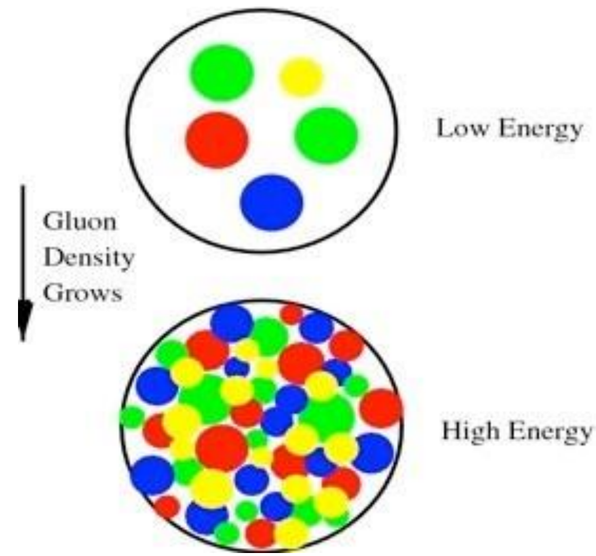




- SU(3) vs U(1)
- Gluons vs Photons
- Quarks vs Leptons
  - Color charge and flavors
  - Confinement
  - Asymptotic Freedom

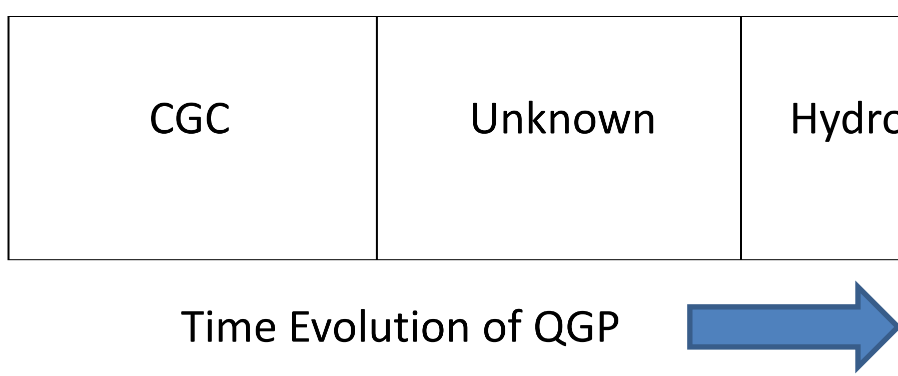
Color Glass Condensate (CGC)

- “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



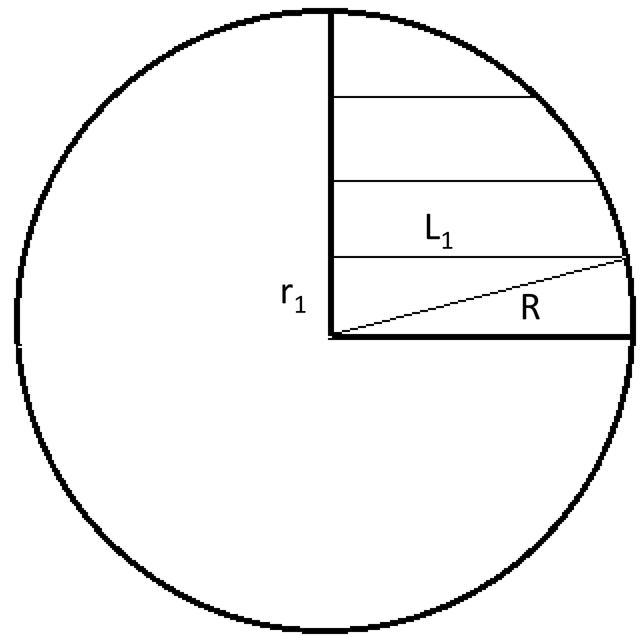
Motivation

- 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

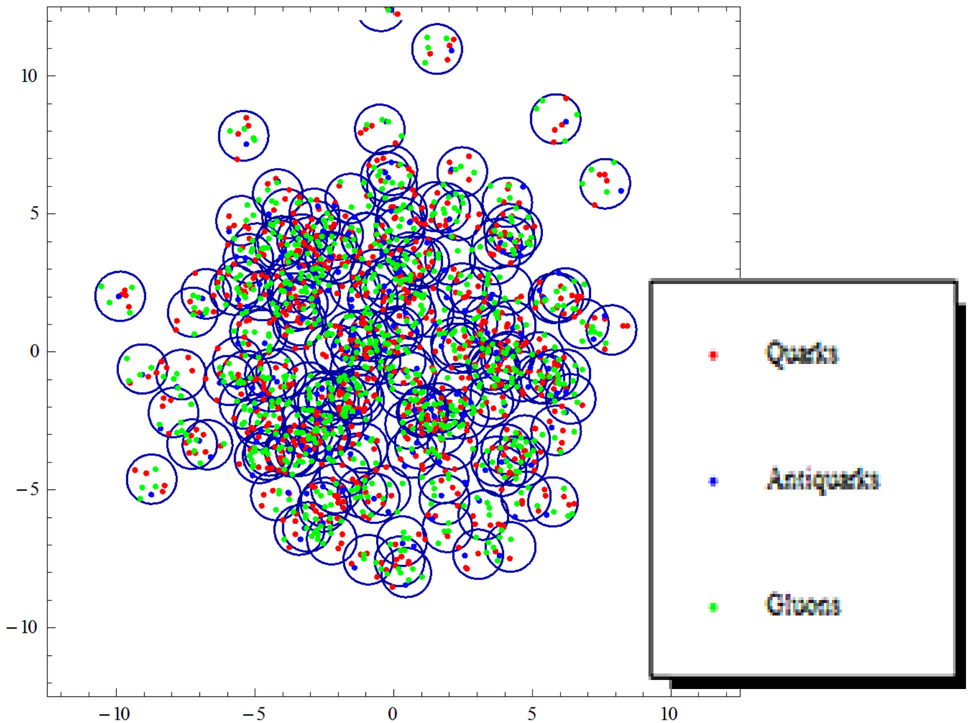


Probability Density Functions

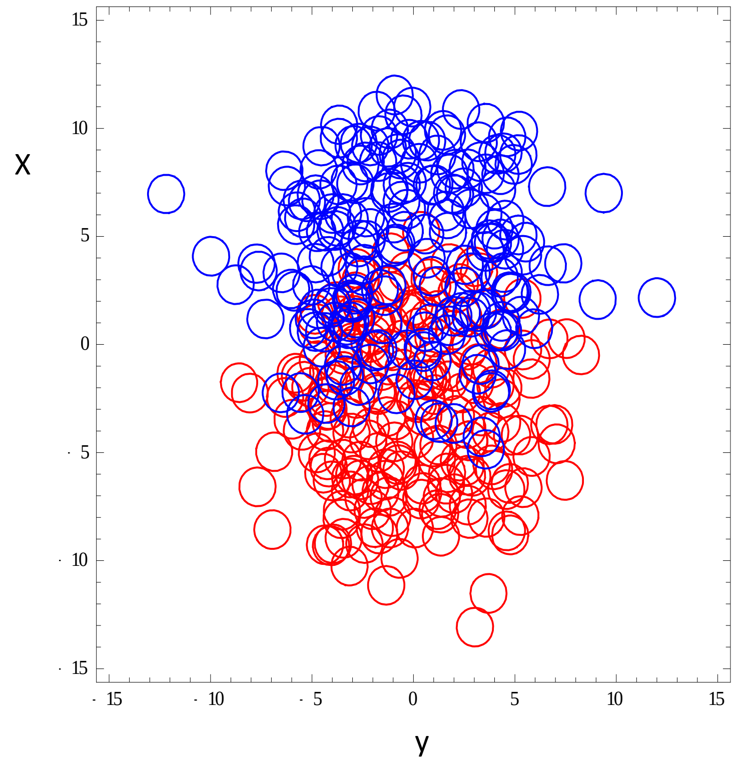
- Nucleons positioned through Woods-Saxon distribution
- Partons distributed uniformly in each nucleon
- Lorentz contraction and effect on distributions



Nucleon/Parton Positioning



Sampled gold nucleus



Two colliding gold nuclei with impact parameter =7 fm

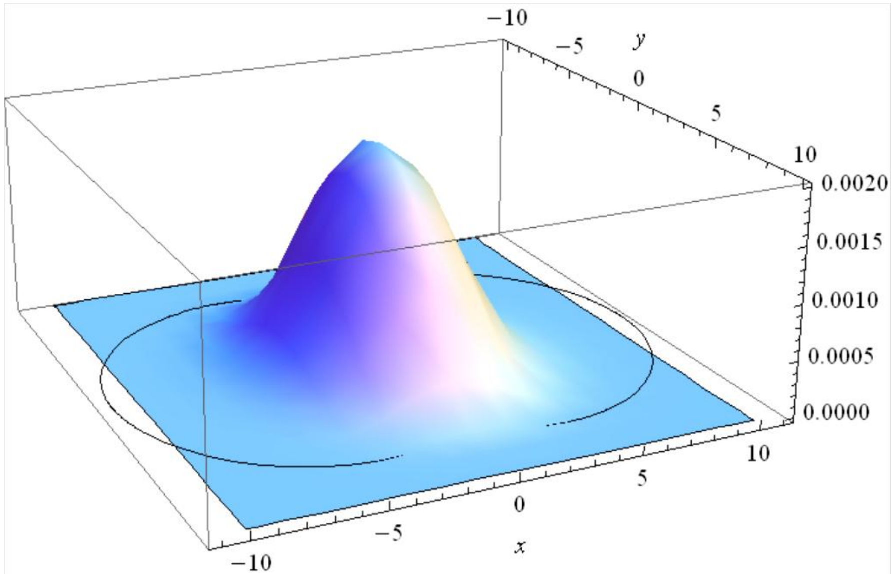
Energy Density

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

Averaged nucleon and parton positions

Each nucleus has a Woods-Saxon color charge density, μ^2

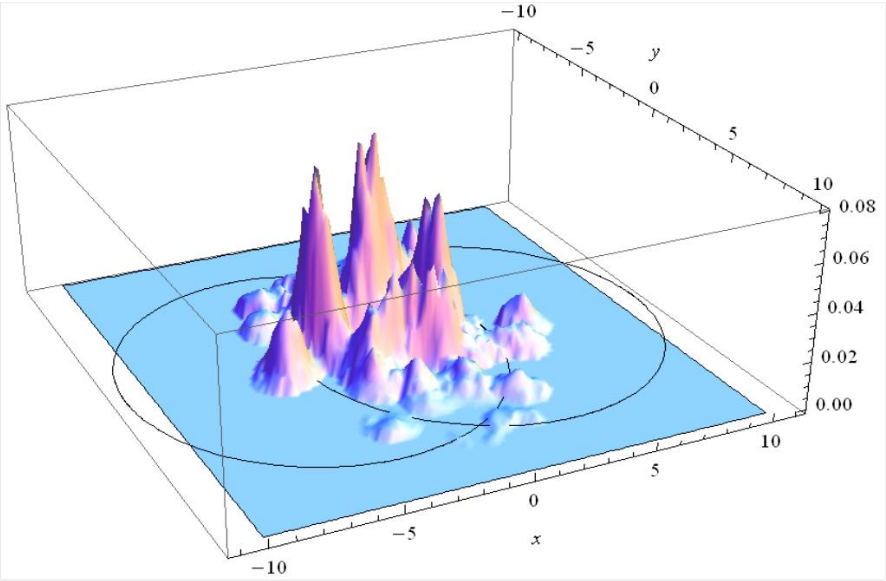
Two colliding nuclei (shown in black) with impact parameter = 7



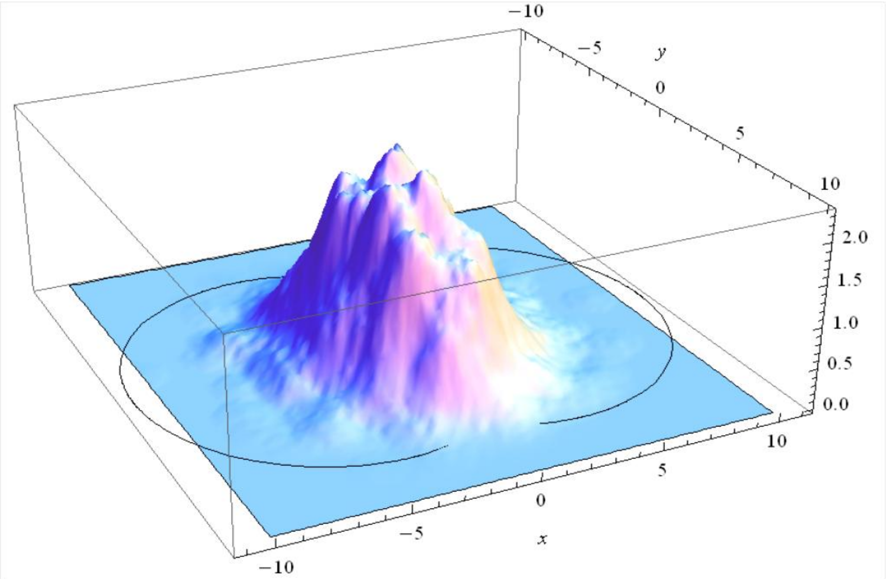
Sampled Energy Densities

- 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



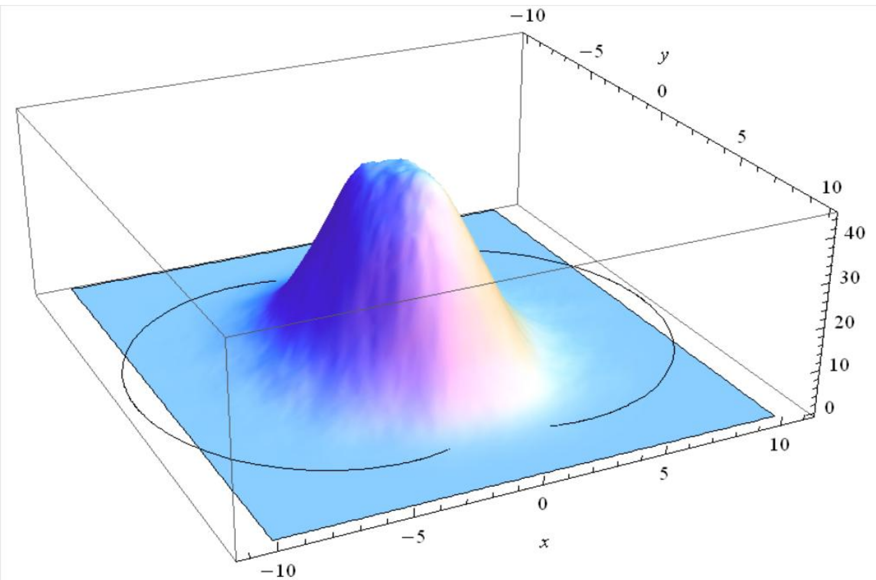
1 Trial



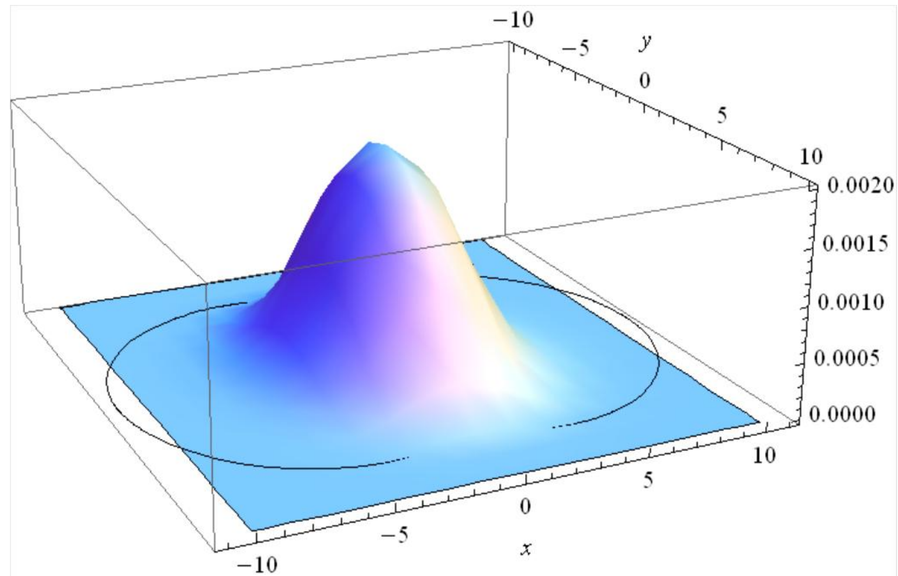
50 Trials

Sampled Energy Densities

1000 trials



Averaged



Almost identical results!

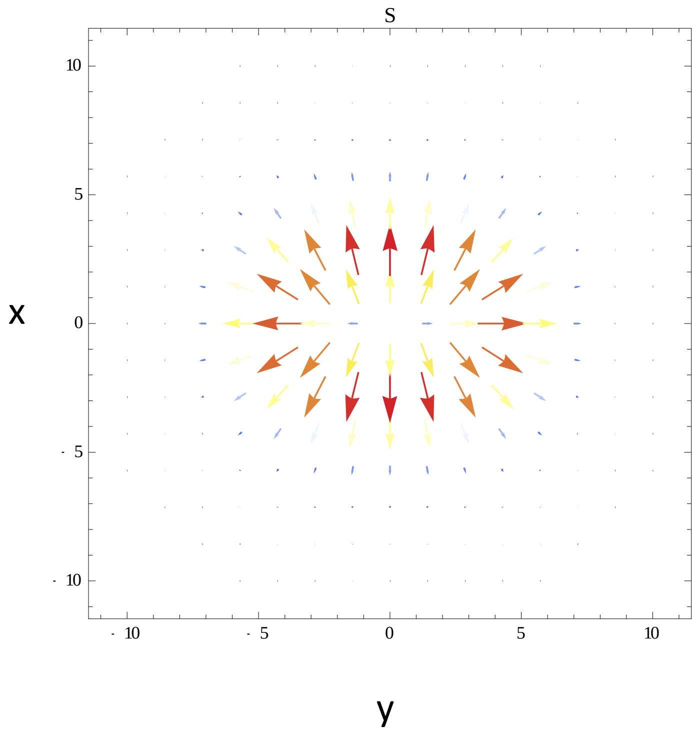
Energy-Momentum Tensor

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

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

Poynting Vector with averaged nucleon positions

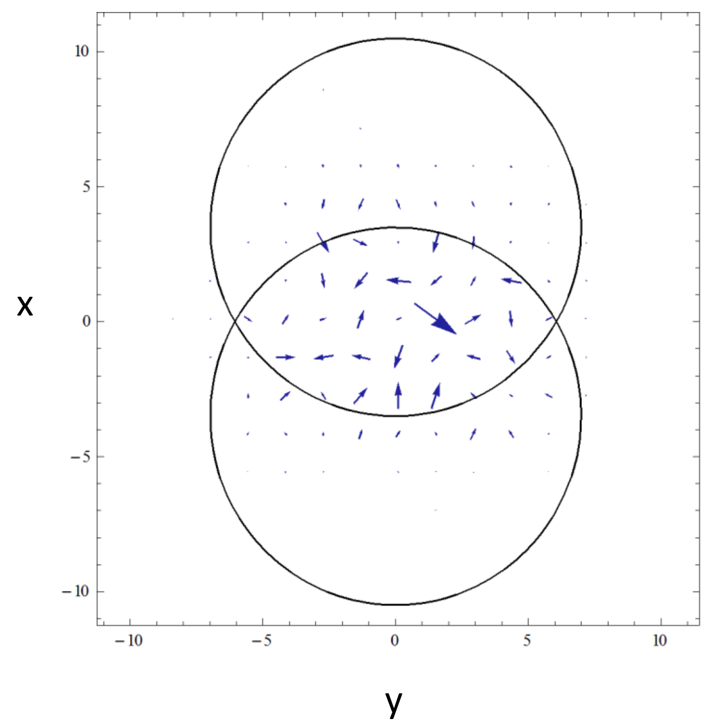
Rapidity = 0



b=7

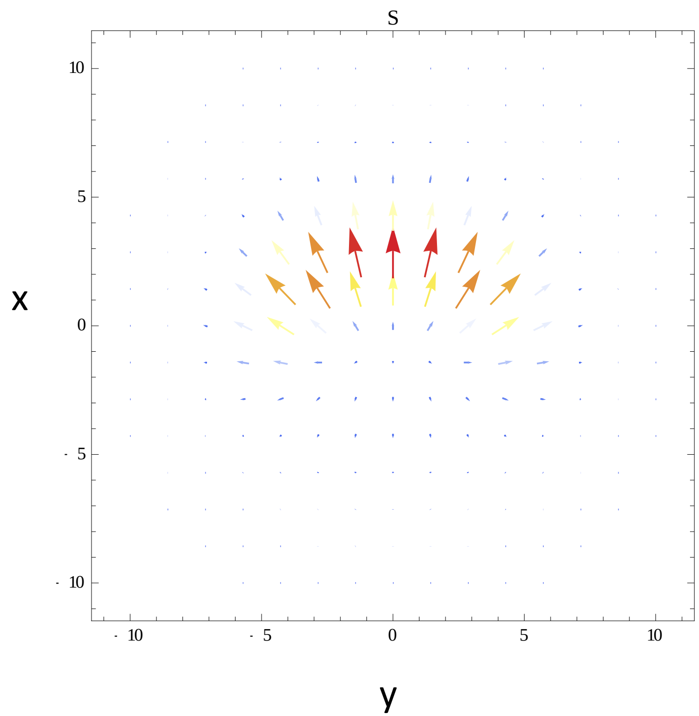
Poynting Vector with sampled nucleon positions (1000 trials)

Rapidity = 0



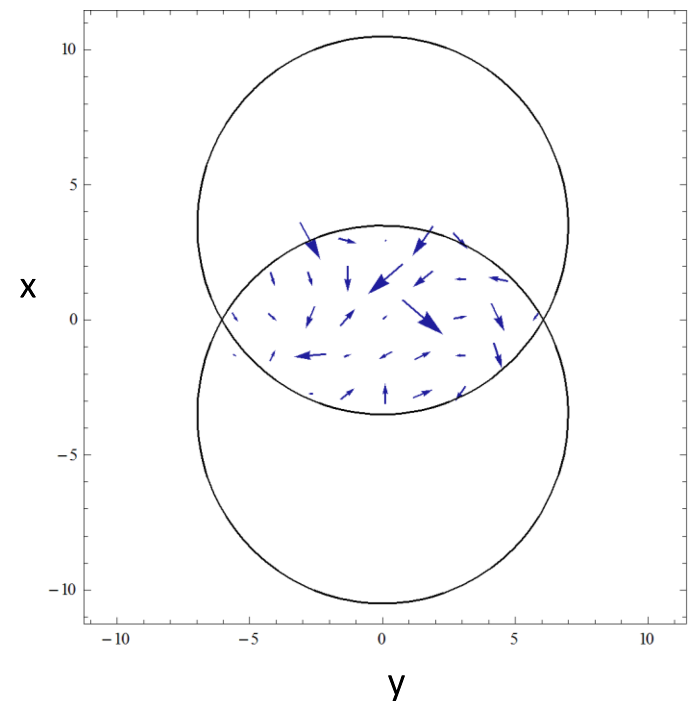
Energy-Momentum Tensor

Spacetime Rapidity = 1



b=7

Spacetime Rapidity = 1



Future Work

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

Acknowledgments

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- Guangyao Chen
- A&M Cyclotron Institute

References

- E. Iancu, A. Leonidov, L. McLerran, *The Colour Glass Condensate: An Introduction*, hep-ph/0202270v1
- H. Kowaiski, D. Teaney, *An Impact Parameter Dipole Saturation Model*, hep-ph/0304189
- M. Miller, K. Reygers, S. Sanders, P. Steinberg, *Glauber Modeling in High Energy Nuclear Collisions*, nucl-ex/0701025v1
- P. Sahu, S. Phatak, Y. Viyogi, *Quark Gluon Plasma and Hadron Physics*
- http://www.quantumdiaries.org/author/zoe/
- http://phys.org/news/2012-07-physicists-primordial-soup.html
- http://www.spontaneoussymmetry.com/blog/archives/17
- http://vi.sualize.us/3_gluon_coupling_feynman_diagram_picture_u7nE.html