Jet studies as a probe for the Gluon Structure Function in heavy nuclei

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ABSTRACT It has been shown that there is a sea of low momentum elementary particles known as partons that make up hadrons. Present theories indicate that this is something called a "Color Glass Condensate" - a new form of matter in which the momentum of the partons is so low, that their positions are highly uncertain, and seemingly "overla" each other. By using Jets as a probe of simulated collisions of protons on heavy nuclei, I will determine how well measurements can be made under detailed simulations of detectors that would support current Color Glass Gluonic Structure Functions.

I. INTRODUCTION

In particle physics the parton model was first proposed by Richard Feynman in 1969 [1]. It served as a method to describe High Energy particle collisions of Hadrons (Protons, Neutrons, etc). The bulk of the model revolves around Hadrons being composed of partons; now known as quarks, antiquarks, and gluons.

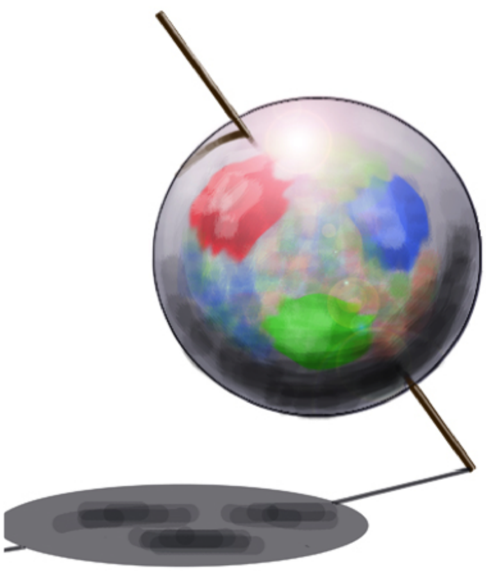

Figure 1. Artistic rendering of quarks depicted with their respective color charges, with sea quarks providing a colorful backdrop, inside a proton.

Experimentally, it has been shown that there is a sea of low momentum partons in addition to the stable quarks that make up a Hadron. Every parton contains a fraction of their corresponding Hadron's momentum. The sea's characteristics are not well understood. Present theories suggest that this sea is a "Color Glass Condensate" (CGC). In experiments at the Relativistic Heavy Ion Collider, when the Quark Gluon Plasma has been formed and seen in collisions of heavy nuclei, the CGC would be the precursor initial state [4][5].

The CGC is matter in which the momentum of the partons is so low, that the position is uncertain over a large area as required by the Heisenberg uncertainty principle [2][3]. One can visualize these partons as being spread out so that they overlap. This overlap is enhanced in a large nucleus where many nucleons are involved, and it can happen over many protons and neutrons. The overlap changes the momentum distribution of a Hadron. This distribution is not well understood.

To get the maximum overlap of low momentum partons, I will look at the collisions of protons on heavy nuclei. At this point, it then becomes important to measure the momentum fraction carried by the partons. This project aims to determine how well the "low" momentum fraction of partons can be measured in regions in which the current Gluonic Structure Functions (GSF) extend in to. To do this, I will use Jets to probe simulated heavy ion particle collisions in a detailed simulation of a detector.

II. DESCRIPTION

Due to the importance of low momenta partons to GCG, this project will attempt to quantify how well these partons can be measured under a detailed simulation of a detector.

The data obtained thus far is composed entirely of measurements drawn from simulated proton-proton collisions. The data was gathered from the highly powerful physics software known as Pythia. Pythia, is a program used to generate High-Energy-Physics events where the "objective is to provide as accurate as possible a representation of event properties in a wide range of reaction, within and beyond the standard model"[6]. The Gluon Structure Function (GSF) in (1) below is the main guide for my analysis. X_2 is the parton's momentum fraction

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and is exactly what is needed. To compute this momentum fraction from this function one simply needs the other parameters, $P_{T\gamma}$, $\sqrt{s}$, η_γ, and η_J. $\sqrt{s}$ is the beam energy and is set in Pythia.

$$X_2 = \frac{P_{T\gamma}}{\sqrt{s}}(e^{\eta_\gamma} + e^{\eta_J}) \tag{1}$$

In defining the other observables, we must turn our attention to the Feynman diagram in Figure 2. The diagram depicts the interaction we are interested in. A parton from each proton undergoes a 2→2 process to a photon and a "free quark." The quark then, unable to be by itself due to postulated Color Confinement, pulls a quark-antiquark pair out of the vacuum and pairs with one [8]. This pairing creates a composite particle, a hadron. This "hadronization" process is precisely what creates the conic shower of particles that is actually detected and what we call a Jet. Now, since this event is a 2→2 process at its core, one expects ideally, due to conservation of momentum, that the quark-jet and the direct photon have equal and opposite momentum. For this reason, we see the photons momentum written explicitly in the GSF as $P_{T\gamma}$. The next two parameters of interest, η_γ, and η_J are the photon and quark-jet's angular position respective to the beam line and are not depicted in the figure.

In reflection, equation (1) resembles a result we would obtain in a classical collision, a function of angle and energy. After having laid the framework, the next step in the analysis is to quantify what is meant by "how well something is measured."

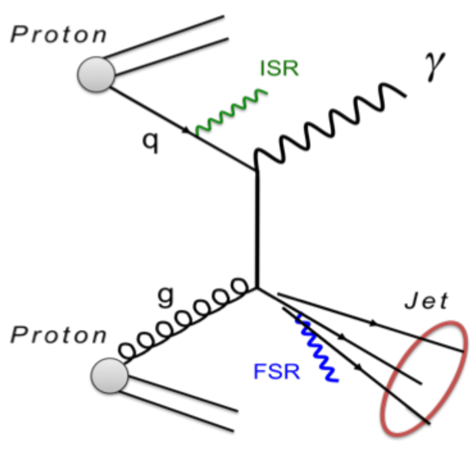

Figure 2. A Feynman diagram of a 2→2 process (two particles generating two particles) illustrating processes implemented in analysis.

To do this I start with an assumption of a "perfect" measurement. Then, once we have decided what this is, we simply compare all succeeding measurements to this base measurement. This base measurement is the X_2 value the Pythia program has given to the parton of interest. From here, I can compare the X_2 value that the GSF gives to the default value of the Pythia program. The analysis continues as more physical realities are implemented onto the simulations, thereby constructing a more realistic picture of detecting particles in an actual detector. Realities already implemented and analyzed are as follows:

- Initial State Radiation (ISR) and Final State Radiation (FSR) depicted in Figure 2. are modeled as a photon being radiated by the proton prior to the event, and as a photon radiated by the free quark after the event, respectively.

- Fermi momentum was added to the partons in the proton.

- Direct photon energy was then smeared to account for detector resolution. Equation (2) below is the factor by which I smeared the photons energy. The E parameter is the photons energy prior to smearing. The first numeric parameter is the calibration of the detector. Experience has shown that this can be brought down to as low as 1% (0.01). The second parameter is the lowest amount of energy we can measure for a given particle.

$$\sigma = E\left(0.01 + \frac{0.1}{\sqrt{E}}\right) \tag{2}$$

- Then, in later steps I use the Jet reconstruction software FastJet to reconstruct Jets from particle showers to indirectly measure X_2 because in reality quarks cannot be observed by themselves [7][8].

The next large step in this project will be to move up to a much more detailed simulation of a detector. In these new simulations the project will move up from proton-proton collision to proton-heavy ion collisions and will involve the use of new software. The new simulation software goes by the names GEANT and PISA. GEANT (GEometry ANd Tracking) achieves more detail by simulating particles passing through matter, while PISA (PHENIX Integrated Simulation Application) "models the ensemble performance of a dozen different detector technologies" [9][10].

III. POTENTIAL IMPLICATIONS

The implications would be twofold. First, if the data supports the CGC theory, then it would allow an ab-intio theory of the Gluon Structure Functions. These functions have previously been measured in experiments as empirical fits and thus only describe the data [11][12][13]. And secondly, since the GCG describes the state of the Hadron prior to the event, this would tell us the initial conditions for the formation of the Quark Gluon Plasma [4][5].

VI. REFERENCES

[1] R. P. Feynman, Phys. Rev. Lett. **23**, 1415 (1969).

[2] L. D. McLerran, Lect. Notes Phys. **583**, 291 (2002) [hep-ph/0104285].

[3] F. Gelis, Int. J. Mod. Phys. **A 28**, 1330001 (2013) [arXiv:1211.3327 [hep-ph]].

[4] *'Perfect' Liquid Hot Enough to be Quark Soup* `http://www.bnl.gov/rhic/news2/news.asp?a=1074&t=pr`

[5] H. Song, S. A. Bass, U. Heinz, T. Hirano and C. Shen, Phys. Rev. Lett. **106**, 192301 (2011) [Erratum-ibid. **109**, 139904 (2012)] [arXiv:1011.2783 [nucl-th]].

[6] Torbjorn Sjostrand, Stephen Mrenna, & Peter Skands, *PYTHIA 6.4 Physics and Manual* (2006).

[7] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C **72**, 1896 (2012) [arXiv:1111.6097 [hep-ph]].

[8] V. Barger, R. Phillips *Collider Physics. AddisonWesley* (1997).

[9] S. Agostinelli, J. Allison, K. Amako, et al.. Nucl. Instrum. Meth. A: Accelerators, Spectrometers, Detectors and Associated Equipment, **250-303**, (2003) 506(3).

[10] C. F. Maguire, A. Trivedi, A. Rose, et al.. *PISA The PHENIX Experiment Simulation Packages* (1997).

[11] K. J. Eskola, Nucl. Phys. A **910-911**, 163 (2013) [arXiv:1209.1546 [hep-ph]].

[12] I. Helenius, K. J. Eskola, H. Honkanen and C. A. Salgado, arXiv:1207.6869 [hep-ph].

[13] I. Helenius, K. J. Eskola, H. Honkanen and C. A. Salgado, Nucl. Phys. A **904-905**, 999c (2013) [arXiv:1211.2130 [hep-ph]].

IV. IMPLEMENTAION TIMELINE

Implementation Timeline
Summer Quarter (if included in proposal):
• Working 12 hours or more per week • Trip to Brookhaven National Laboratory to work with mentor and meet with collaborators/ start project (Mid July) • Start to use GEANT and PISA simulation software • Run high statistics simulations • Begin analysis of simulation data • Write and submit Summer quarterly reflection
Fall Quarter:
• Working 9 hours or more per week • Analysis: Determine resolution of Jets • Create poster of project thus far for the 2014 Division of Nuclear Physics (DNP) Fall Meeting /Conference Experience for Undergraduates (CEU) • Attend and present poster at DNP/CEU • Write and submit Fall quarterly reflection
Winter Quarter:
• Working 9 hours or more per week • Analysis: Determine Jet acceptance • Begin to finalize analysis • Write and Submit Winter quarterly reflection
Spring Quarter:
• Working 9 hours or more per week • Write up final analysis conclusions • Create and Print Poster for Symposium. • Present Poster at UCR's Undergraduate Research Symposium 2015 • Write and submit Spring quarterly reflection

V. BUDGET DEVELOPMENT

A. Travel

Travel Description / Justification	Amount ($)
Airfare (LAX to New York, round-trip. Meet and work w/ collaborators at BNL)	500.00
Food expenses ($30/day)	210.00
Room and Board (1 week on site, 40/night w/ tax)	280.00
Ground transportation (Rental car, $250/week)	250.00
2014 Division of Nuclear Physics (DNP) Fall Meeting/ Conference Experience for Undergraduates (CEU) Registration	~100.00
Airfare (Flight to Hawaii for DNP/CEU Conference, round-trip)	600.00
Room and Board (4 nights in a hotel at $215/night w/ tax for DNP/CEU Conference)	~860.00.
Food expenses (For 5 days at $25/day for DNP/CEU Conference)	~125.00
Travel Subtotal	$2,925.00
Amount asking from CRF	$1,840.00
Amount covered by external sources (denoted with a " ~ ")	$1,085.00

B. Stipend

Stipend requested	Description / Justification	Amount ($)
Summer stipend	Working 12 hours or more per week during summer quarter	880.00
Fall stipend 2014	Working 9 hours or more per week during Fall quarter	700.00
Winter stipend 2015	Working 9 hours or more per week during Winter quarter	700.00
Spring stipend 2015	Working 9 hours or more per week during Spring quarter	700.00
	Stipends Subtotal	$ 2,980.00

C. Other

Item(s) requested	Description / Justification	$/unit	Quantity	Amount ($)
Poster	For Symposium	90	1	90.00
Poster	For CEU	90	1	90.00
			Other Expenses Subtotal	$ 180.00
			Amount asking from CRF	$180.00

*My project will have no "Materials & Supplies" expenses.