Future Cold Nuclear Matter Studies at RHIC with a sPHENIX Forward Spectrometer

Richard Seto, Lucas Flores and Tim Hester
University of California, Riverside for the PHENIX Collaboration

sPHENIX is a major upgrade proposed for the PHENIX detector at RHIC. As part of this proposal, a forward spectrometer to cover the rapidity range \(1 < \eta < 4\) is in a conceptual design stage to complement the detectors in the central region. One of the primary goals of the forward sPHENIX spectrometer (fsPHENIX) is the study of high density gluons in a nucleus. Several possible measurements are described and a preliminary detector design is presented.

### Cold Nuclear Matter

**Why Measure Cold Nuclear Matter (CNM)?**
- To understand the behavior of low-\(x\) gluons in the nucleus
- To determine the initial state which leads to the formation of the sQGP

**The Color Glass Condensate (CGC): A non-perturbative theory of gluons saturation**
- Can we definitively “prove” that the CGC is the correct description?
- Probably not with one measurement, even at the LHC. Like other things in QCD, it will take many measurements all explained in a unified framework to substantiate the theory.
- CGC and other ways of describing the phenomena (shadowing, energy loss coherence, higher twist, TMD PDFs) may be equivalent descriptions of the same physics sometimes in different kinematic regimes.
- Two advances with input from the spin community
  - Transverse Momentum Dependent PDF framework
  - Transverse spin as a tool for measurement

### Transverse Spin Asymmetries

- Large single spin asymmetries (SSA) are seen in transversely polarized \(p+u\) unpolarized \(p\) collisions at high \(x_F\).
- One possibility is that the transverse momentum dependent fragmentation function “remembers” the spin of the incoming projectile (Collins function)
- In polarized \(p+A\) collisions, the SSA can be calculated using the unintegrated gluon distribution (dipole) from CGC calculations and the Collins fragmentation function.
- SSA in transversely polarized \(p+A\) collisions can be used to measure \(Q_S\)

### Transversely Polarized \(p+A\) collisions as a measure of \(Q_S\)

- Ratio decreases with increasing in \(Q_S\)
- Measure in several channels \(\pi\)\^\(\pm\) jets, direct photons
- Same value as measured by other methods (e.g. \(\gamma-h\)) to validate the theory
- Measurement is unique to RHIC

### Drell Yan hadron correlations in \(d+A\)

- Drell-Yan hadron correlations from a calculation assuming a gluon distribution given by the CGC (dipole). The mass imparted to the virtual photons produce the characteristic double peak structure

### What should we measure in fsPHENIX?

<table>
<thead>
<tr>
<th>Hadron in (p+A)</th>
<th>(\gamma)-jet in (p+A)</th>
<th>Dijet in (p+A)</th>
<th>Drell-Yan in (p+A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G(1)^{WW})</td>
<td>(\times)</td>
<td>(\times)</td>
<td>(\checkmark)</td>
</tr>
<tr>
<td>(G(2)^{dipole})</td>
<td>(\checkmark)</td>
<td>(\checkmark)</td>
<td>(\times)</td>
</tr>
</tbody>
</table>

Processes are dependent one or both gluon distributions

Hence Measure: 1) \(\gamma\)-jet to extract \(G(0)\) at low-\(x\)

2) Dijet + \(G(2)^{dipole}\) allows for the extraction of \(G(1)^{\gamma-h}\)

### Measuring \(Q_S\) in \(\gamma\)+hadron correlations in \(p+A\)

- \(Q_S\) in \(\gamma\)-hadron correlations are theoretically cleaner than hadron-hadron correlations
- \(P_T\) dependent behavior of away side peak gives a measure of \(Q_S\)

### QCD connections

- One of the highlights of recent developments in QCD theory and experiment, is our understanding of the extent to which relativistic heavy ion physics, the study Cold Nuclear Matter, and the spin physics of the nucleon, are related
- Transverse momentum dependent methods first used in the study of nucleon spin have given insight into gluon saturation
- Transversely polarized \(p+Au\) collisions may be a means of measuring \(Q_S\)
- In turn, high density gluons as described by the Color Glass Condensate model are probably the best candidate for the initial state of the strongly interacting Quark Gluon Plasma.