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

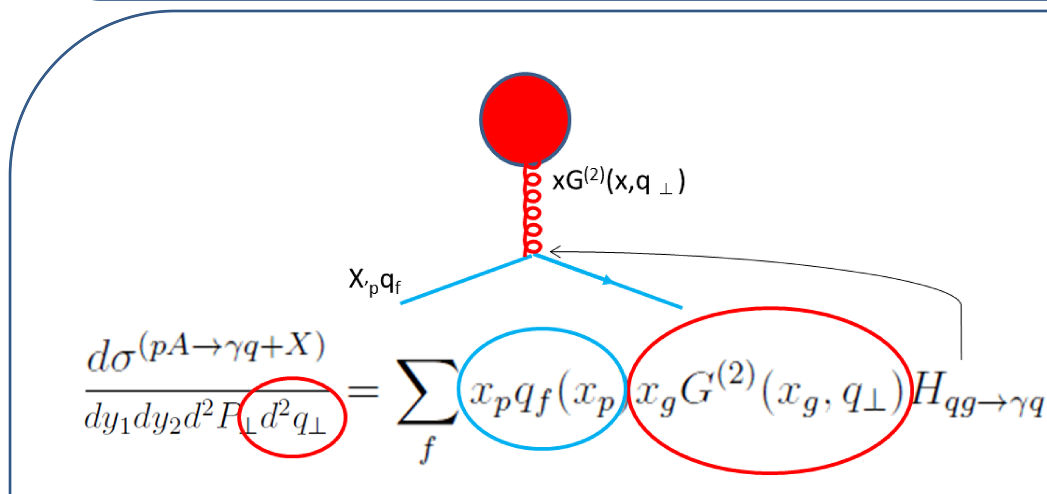
Why Measure Cold Nuclear Matter (CNM)?

- 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 Momentum Dependent Gluon PDFs, $G^{(1)}$ and $G^{(2)}$ in p+A



Cross section factorized in terms of:

- perterbatively calculable hard part (H)
- nonpertubative quark PDF (q_f)
- transverse momentum (q_T) dependent gluon PDF (G)

TMD Factorization

- Violated in p+p dijet processes
- *reestablished* in low-x p+A processes

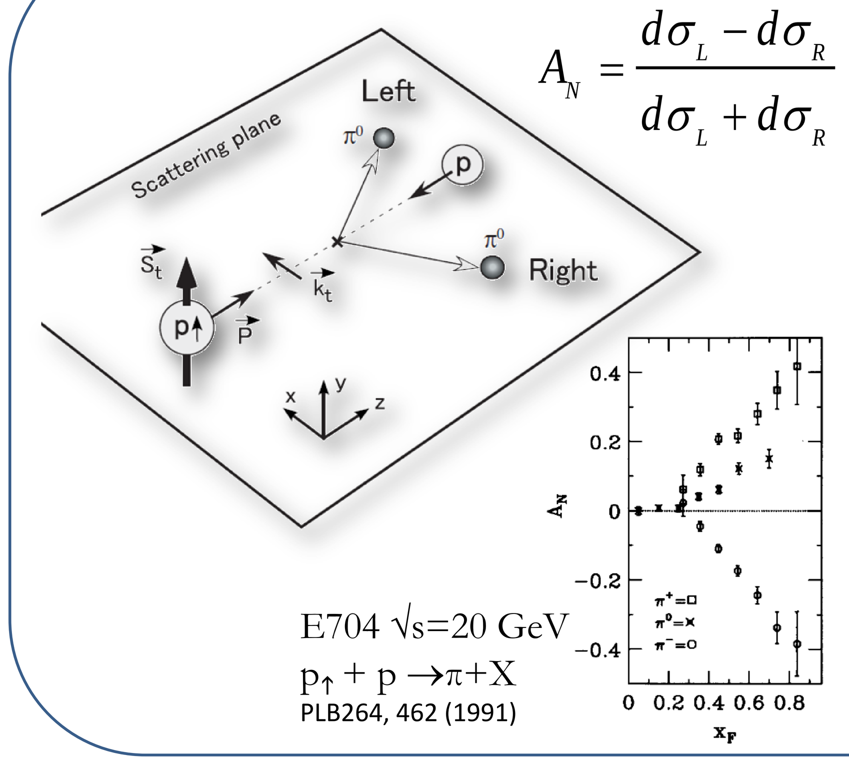
Gluon distribution G

- not universal
- *Split into two which are universal*
  $G^{(1)}$ - Weizsacker- Williams (WW)
  $G^{(2)}$ - Diplole

$G^{(1)}$ and $G^{(2)}$ are identical in CGC and TMD frameworks
➔Equivalence of GCG and TMD framework at low-x

Transverse Spin Asymmetries

$$A_N = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$



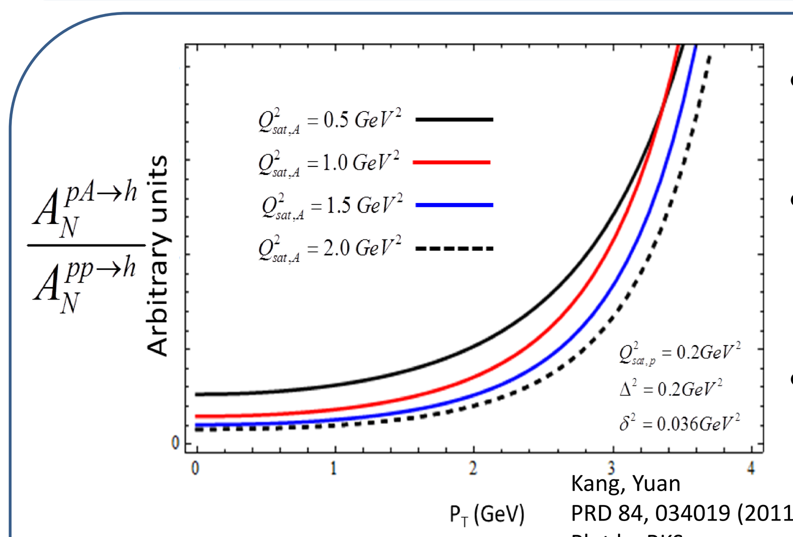
- Large single spin asymmetries (SSA) are seen in transversely polarized p+ unpolarized p collisions at high $x_F=x_1-x_2$
- One possibility is that the transverse momentum dependent fragmentation function "remembers" the spin of the incoming projectile (Collins function)
- In polarized p+A collisions, 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 (see panel below)

What should we measure in fsPHENIX?

	Hadron in p+A	γ-jet in p+A	Dijet in p+A	Drell-Yan in p+A
$G^{(1)}$ WW	×	×	✓	×
$G^{(2)}$ diplole	✓	✓	×	✓

Processes are dependent one or both gluon distributions
Hence Measure: 1) γ-jet to extract $G^{(2)}$ at low-x
2) dijet + $G^{(2)}$ allows for the extraction of $G^{(1)}$

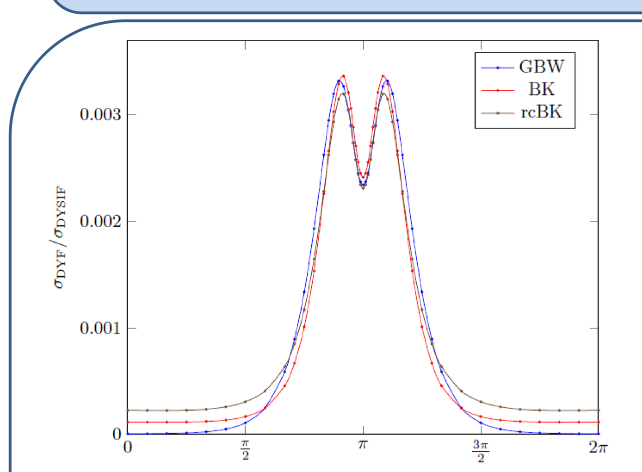
Transversely Polarized p+A collisions as a measure of Q_S



$$\frac{A_N^{pA\to h}}{A_N^{pp\to h}} \sim f(Q^2_{sat,p}, Q^2_{sat,A}, P^2_{h,\perp}) \sim \lim_{P_{h,\perp}\to 0} \frac{Q^2_{sat,p}}{Q^2_{sat,A}}$$

- Ratio decreases with increasing in Q_s
- Measure in several channels $\pi^{\pm 0}$, jets, direct photons
- Same value as measured by other methods (e.g. γ-h) to validate the theory
- Measurement is unique to RHIC

Drell Yan hadron correlations in d+A

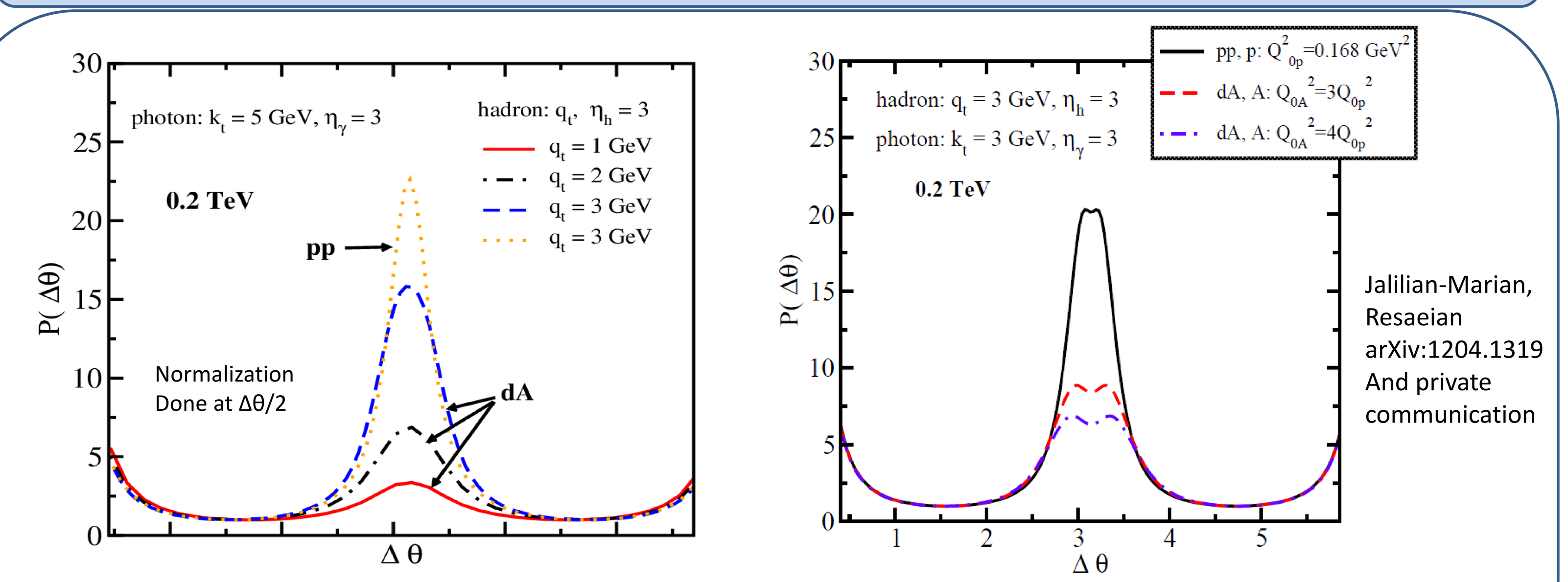


√s=200 GeV
η_γ=2.5
η_h=2.5
M_{DY}=4GeV
Central collisions

Stasto, Xiao, Zaslavsky
PRD 86, 014009 (2012)

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

Measuring Q_S in γ+hadron correlations in p+A

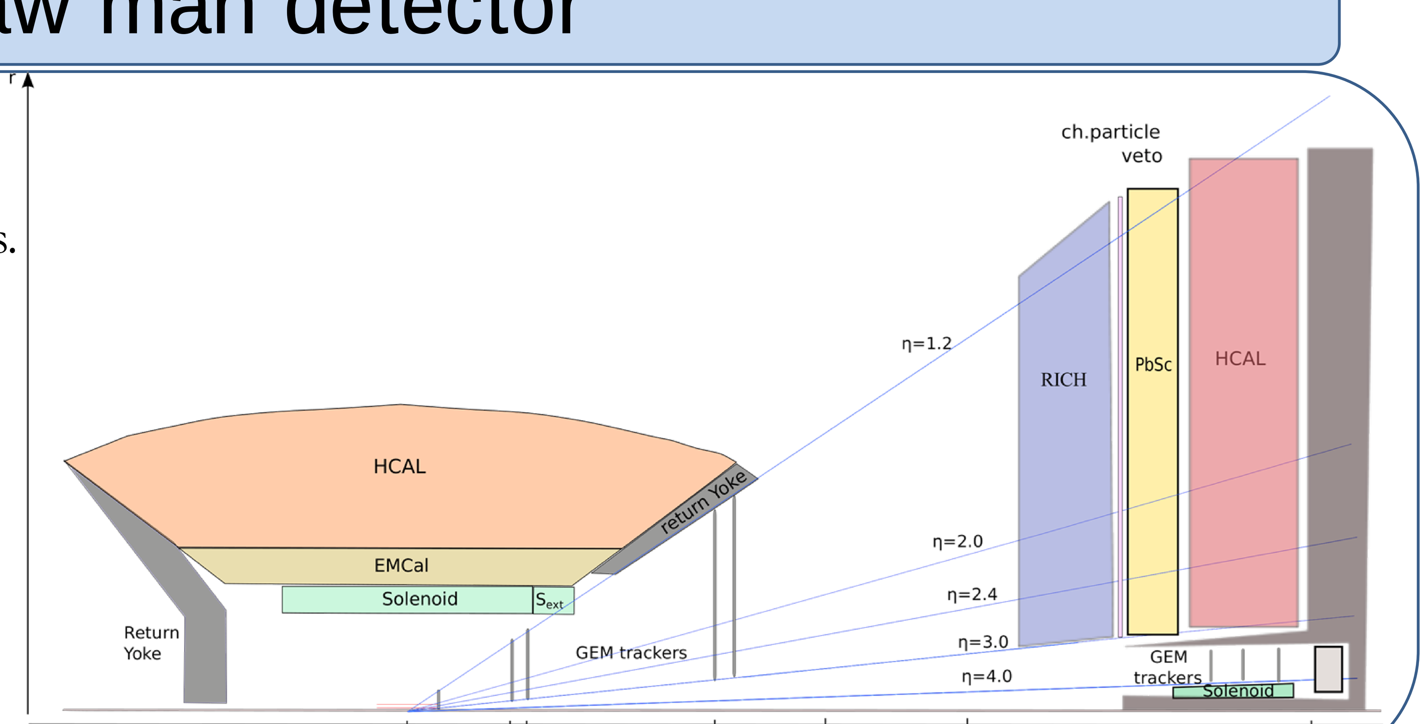


γ_{prompt}-hadron correlations are theoretically cleaner than hadron-hadron correlations
P_T dependent behavior of away side peak gives a measure of Q_s

A straw man detector

Detector requirements stem from the needs of the Spin, Heavy Ion and Cold Nuclear Matter programs. These demand large acceptance (to η=4, i.e. low-x)
A straw man proposal has the following elements

- EMCAL: photon and Drell Yan
- HCAL: Jet measurements
- Magnetic Field and high precision tracking; special instrumentation for η>4
- Hadron P ID for the spin program



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.