PHENIX Upgrade Plans for the Next Decade

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DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/158`

Over its first twelve years, the PHENIX experiment has studied the spin structure of the proton, cold nuclear matter (CNM) in d+Au and discovered a strongly coupled quark gluon plasma in Au+Au collisions. We present the near- and long-term upgrades planned for PHENIX. The MPC-EX, a preshower for the forward calorimeter, is expected to be installed by 2014. A larger upgrade of PHENIX, envisions replacing the central arm with a compact jet detector, as well as adding a forward arm spectrometer to study the source of large single spin asymmetries in $p^{\uparrow}+p$ collisions, as well as measure Drell-Yan, to study both the proton spin structure and CNM effects in d+Au collision.

1 Introduction

During 12 years of operations, the PHENIX experiment has studied many aspects of QCD by utilizing the flexibility of RHIC, which can collide transversely and longitudinally polarized protons, an array of nuclei such as Au, Cu and U, and also have asymmetric collisions, such as d+Au and Cu+Au. Asymmetry measurements in longitudinally polarized proton collisions have significantly constrained the gluon spin contribution to the proton [1]. Unexpectedly large single spin asymmetries (SSA) have been measured in transversely polarized proton collisions at high $x_F = p_z/(\sqrt{s}/2)$ [2, 3, 4]. In Au+Au collisions, PHENIX has discovered a strongly-coupled quark-gluon plasma (sQGP) [5], and is continuing to study its properties. One of the requirements to understand the behavior of this hot, dense matter is to understand the initial state of cold nuclear matter (CNM), which has been probed in d+Au [6].

2 Completed and Near-Term Upgrades

Over the past several years, PHENIX has implemented an upgrade program to both extend and enhance our physics reach. A GEM-based Čerenkov detector, the Hadron Blind Detector, was installed in 2009-2010 to understand the background in the dielectron spectrum in Au+Au. In 2011, this was removed, and a barrel and (in 2012) endcap vertex detectors (VTX) were installed to separate charm and beauty quarks to understand how the mass of heavy quarks affects the suppression of related mesons in the sQGP.

Trigger electronics have been added to the existing muon tracker. These, along with recently installed resistive plate chambers, have extended the trigger capabilities of PHENIX so that it can record a sizable W-boson sample in longitudinally polarized $p+p$ at $\sqrt{s} = 500$ GeV. With this data, PHENIX will be able to access the poorly known sea quark helicities through a parity violating single spin asymmetry. The first results were shown at this conference [7].

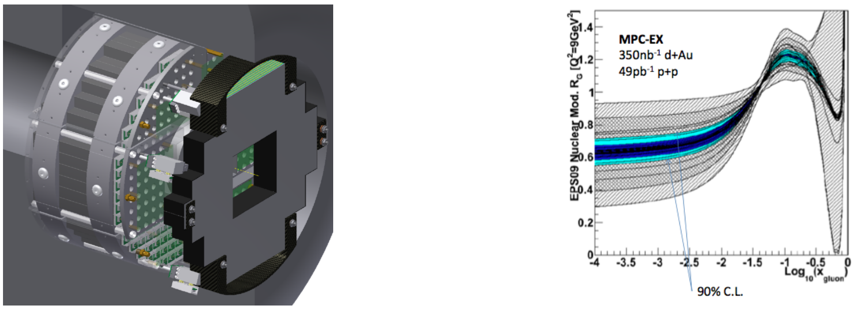

Figure 1: (Left) Drawing of MPC-EX. (Right) Nuclear modification factor for the gluon from EPS09. Grey band shows current uncertainty. Highlighted band shows uncertainty discriminating power of expected direct photon measurement from the MPC-EX based on the EPS09 best fit as input.

The final upgrade of the current PHENIX detector in this program is the MPC extention (MPC-EX). This detector (see Fig. 1), currently in the proposal stage, is a Si-W preshower which will be installed in front of an existing calorimeter, the MPC, which covers $3.0 < \eta < 3.8$. The detector is made of eight layers of Si “minipad” sensors between layers of tungsten absorber, allowing for π^0 identification separation up to 80 GeV. This then enables separation of π^0 and direct photons up to similar energies. Direct photons are primarily produced in photon-gluon Compton scattering, and, in d+Au, in the deuteron-going direction can probe the low x gluon distribution in the target Au nuclei. Measurements of the nuclear suppression factor, R_{dAu}, with identified π^0s and direct photons will be used to study gluon saturation in nuclei at low x, providing strong constraints on gluon parton distribution functions (PDF) in nuclei, as seen in Fig. 1. Assuming the best fit result from the EPS nuclear PDF [8], the expected sensitivity is shown in the highlighted region, as compared to the current uncertainty (larger shaded region).

3 sPHENIX

Over the last decade, PHENIX has answered many of the questions for which it was designed. However, many of these answers have generated further questions, such as what the source of the large transverse SSA is, or how the sQGP affects quarks traversing it. In order to fully address these and other important questions, PHENIX is planning a significant upgrade of it’s detector capabilities for the latter half of this decade. This upgrade, named sPHENIX, consists of new azimuthally symmetric barrel covering $|\eta| < 1$ for measuring jet asymmetries in nuclei collisions, and a forward spectrometer ($1 < \eta < 4$) for measuring electrons and hadrons/jets in d+Au and transversely polarized $p + p$. The detector is also being designed with a possible upgrade path to an electron-ion collider detector at eRHIC [9].

3.1 Understanding the sQGP: Central Barrel Upgrade

Now that we know an sQGP is produced in heavy nuclei collisions, it is important to understand its behavior. By studying jets produced in hard scattering, and the energy asymmetries in back-to-back jets, we can learn how a colored particle is effected by the medium produced, as well

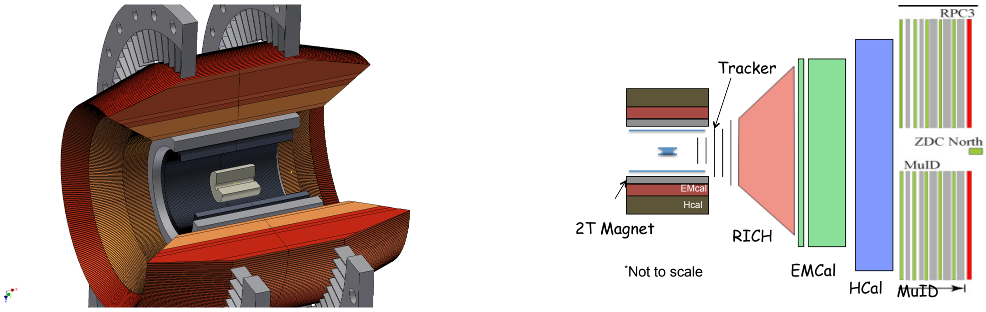

Figure 2: (Left) Engineering drawing of central barrel in sPHENIX. (Right) Conceptual design plan for sPHENIX forward upgrade.

as how the medium itself changes as it expands. In order to measure jets, one must fully reconstruct the jet energy. This requires full calorimetry, both hadronic and electromagnetic, over a sizable rapidity range. Therefore, the barrel upgrade will have full azimuthally symmetric calorimetry covering $|\eta| < 1$, as shown in the engineering drawing in Fig. 2. The detector will also retain the VTX detector in conjunction with a 2 T solenoidal magnet to continue the study of heavy flavor, with the added ability to study heavy flavor jets. The detector is being designed with possible upgrade paths, such as a possible preshower detector to select direct photons for γ-jet events, which are less sensitive to surface bias in heavy nuclei collisions.

3.2 Nucleon Transverse Spin Structure

The large transverse SSA found at RHIC can be generated by coupling between the proton spin and (1) the quark orbital motion, as in the Sivers effect, or (2) the quark transverse spin, as in transversity. In the case of transversity, a nonzero result requires a spin dependent fragmentation function (FF), such as the Collins FF. To understand how these two sources lead to the measured hadron SSA, it is important to separate jet asymmetries, which would be due to Sivers, from hadron asymmetries about the jet axis, which would be due to Collins. Therefore, we need to measure forward jets at RHIC. As the Collins effect can differ by hadron, it is also necessary to have particle identification (PID) in the forward region. As discussed below, the planned forward spectrometer will achieve both of these goals.

A second transverse spin measurement we are planning is polarized Drell-Yan (DY) production. DY is similar to Semi-Inclusive Deep Inelastic Scattering (SIDIS), but with the $\gamma*$ and quark legs interchanged. When color exchange between the remnant and the quark legs are considered, it is found that factorization is broken in the case of the Sivers distribution. However, it is broken in a unique way, namely that the Sivers function in DY has the same magnitude, but opposite sign, to the Sivers function in SIDIS. A number of experiments have plans to test this theory over the next several years. With sPHENIX, we expect to measure the Sivers function in polarized DY over a wide range in rapidity, and therefore determine the Sivers function over a wide range at large x currently not measured in SIDIS.

3.3 Cold nuclear matter (CNM) and low x gluons

A well known signal of the QGP is the suppression of quarkonia such as J/ψ due to color screening. However, separating the effects from cold nuclear matter and screening is not simple. The d+Au program at PHENIX, and the planned program with sPHENIX, will help unravel this puzzle. The first piece is to understand parton energy loss in CNM, which can be done by measuring DY. As the leptons do not interact strongly, they should exit the nuclei unaffected, and so any energy loss would be from the initial parton. The second piece is to understand quarkonia breakup in CNM, which can be done by comparing expected rates of $c\bar{c}$ vs. J/ψ production. However, to fully understand these results, the gluon and quark nuclear PDF (nPDF) must be know. The quark nPDF can be obtained from DY, while the gluon nPDF can be measured in direct photon production. Finally, effects of gluon shadowing can be studied by varying the $\sqrt{s}$ and measuring different quarkonia states. It is important to make these measurements over a wide range in η to fully understand the CNM effects.

3.4 Forward Spectrometer

A conceptual plan for the forward spectrometer is shown in Fig. 2. We envision both hadronic and electromagnetic calorimetry, required for jet reconstruction. For the electromagnetic calorimeter, we will restack our current central and forward arm calorimeters, which will give us coverage from $1 < \eta < 4$. For a number of the planned measurements, tracking will be required. We are investigating whether the central barrel magnetic field can be shaped to optimize particle bend without the need for additional magnets, though it is possible that one will be required for $\eta > 3$. Gas Electron Multiplier (GEM) detectors will provide charged particle tracking, required for both hadron asymmetries and DY measurements. Due to the high momenta of particles in this rapidity region, we expect to use Čerenkov based PID, and are looking at possible options. GEANT4 studies are underway to better define the detector requirements to achieve the ambitious physics goals described above.

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