Forward spectrometer upgrade of the PHENIX experiment

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The PHENIX experiment proposes substantial detector upgrade for long-term enhancement of major physics programs using full luminosity of the recently upgraded RHIC accelerator.[1] The proposed midrapidity upgrade replaces the present magnet with a solenoid, and removes the large iron yoke at forward rapidity that provides the hadron absorber for the muon detectors. The open geometry of the forward direction of the proposed upgrade will allow for addition of a forward spectrometer covering forward rapidity region, $1 < \eta < 4$, with capability of measuring hadrons, photons, electrons, muons and jets. We have been investigating requirements for detector design and performance of the forward upgrade consisting of charged-particle tracking, particle identification, electromagnetic and hadronic calorimeters as shown in Fig. 1.

A physics topic regarding the forward upgrade is Cold Nuclear Matter (CNM) effects in proton- and deuteron-nucleus collisions. We aim to measure nuclear gluon distribution, $G_A(x)$, to know initial state of heavy-ion collisions and to understand the strongly coupled Quark-Gluon Plasma. It is important to investigate gluon suppression, or suppression of $G_A(x)$, at small-x and verify the Color Glass Condensation framework, which is an effective field theory for describing saturated gluon.[2] We also aim to know the perturbative-QCD (pQCD) mechanism of the energy loss of partons in the CNM, its relation to transverse momentum broadening, and detailed hadronization and time scales.

Another physics topic is measurements of single transverse-spin asymmetry. The asymmetries have been measured in the Fermilab fixed-target experiment with transversely polarized proton beams[3] and in the RHIC transversely polarized proton collider experiments at much higher energies.[4] pQCD models have been developed to explain the asymmetries. At small transverse momenta, the asymmetries have been explained using transverse-momentum dependent (TMD) factorization framework.[5] They have been explained with correlations between the transverse spin of the target proton and intrinsic transverse momentum of quarks in the initial state, which is called the Sivers effect[6] and described by the Sivers function. They have also been explained with correlations between quark spin and the transverse momentum of hadrons in the final state, which is called the Collins effect[7] and described by the Collins fragmentation function. At larger transverse momenta, higher-twist effect explains the asymmetries with spin-dependent transverse momentum components generated through quark-gluon and multi-gluon correlations using the collinear factorization framework.[8]

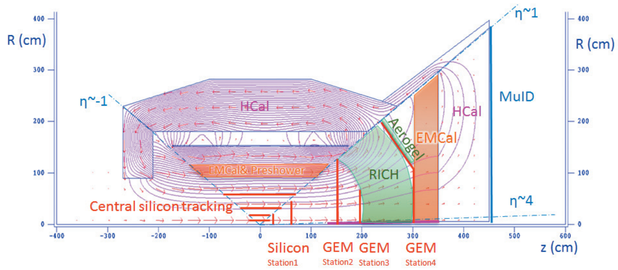

Fig. 1. Conceptual configuration of the forward spectrometer upgrade.

The Sivers function contributes with opposite sign to the transverse-spin asymmetries in the semi-inclusive DIS process and the Drell-Yan process due to non-universality of the TMD factorization framework.[9] This is a fundamental QCD prediction based on gauge invariance and its verification is an important milestone in the field of hadron physics. The verification allows testing of non-perturbative aspects of QCD and the concept of factorization. The forward upgrade will enable us to measure the Sivers function in the Drell-Yan process.

The Collins effect will be investigated through an azimuthal anisotropy in the distribution of hadrons in final-state jets with the forward upgrade detectors. The asymmetry of single identified hadrons described by the Collins fragmentation function will give a measurement of quark transversity distribution at large x which will determine the tensor charge of the nucleon.

There is a new possibility in collisions of polarized protons and nuclei. Transverse single-spin asymmetries in $p\uparrow + A$ collisions may have a sensitivity to the saturation scale in the nucleus. This link between the physics of the CNM and spin structure of the nucleon is one of the most interesting recent developments.

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