Possibilities of Precision Electroweak and Beyond the Standard Model Physics with the Electron Ion Collider

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Over the last decade, the Electron Ion Collider (EIC) has been considered in the US nuclear science community as a possible future experimental facility (beyond 12 GeV upgrade of the CEBAF at Jefferson Laboratory, and the FRIB at MSU) [1] for the study of QCD. The EIC will help us explore and understand some of the most fundamental and universal aspects of QCD [1, 2]. It will enable the most precise measurements yet of gluons and sea quarks, which are critical to our understanding of constitution of the matter in the visible universe, including its fundamental properties such as mass and spin. If realized, the physics program at the EIC will allow us to map out the 3D tomographic picture (position correlated momentum distribution of partons) inside the nucleons and the nuclei. This physics program requires the EIC to have a variable center-of-mass energy from about $\sqrt{s} = 30 - 140$ GeV, and the luminosities of $\sim 10^{33}-34$ cm$^{-2}$ sec$^{-1}$ for e-p collisions (100-1000 times that achieved at HERA), and polarization in both beams, and a wide range in nuclear species. The planned precision studies of QCD and the partonic dynamics also require the construction of a comprehensive detector system capable of excellent particle identification over a large momentum range, high momentum & energy resolution and almost full (4$\pi$) acceptance. Currently there are two designs under consideration for the EIC in the US:

1. eRHIC [3] at Brookhaven National Laboratory (BNL) which will use the hadron & nuclear beams of the existing Relativistic Heavy Ion Collider (RHIC). The plan is to build an ERL based electron beam facility of variable energy 5-30 GeV in the existing RHIC tunnel to collide with one of the RHIC beams.

2. ELIC at Jefferson Laboratory (JLab) [4] which will use the electron beam from the 12 GeV upgraded CEBAF under construction now. This will require construction of a hadron/nuclear beam facility to be built next to the upgraded CEBAF complex to enable such collisions.

With the experimental conditions available at the EIC: a) center of mass energy ($\sim 100-140$ GeV), b) $\sim 100-1000$ times larger luminosity in e-p collisions than HERA, c) polarization in electron and proton/deuteron/helium beams, and d) a comprehensive detector system, it is only natural to explore what measurements would be possible at the EIC in the Electro-Weak physics sector and of possible physics beyond the Standard Model (BSM). Three possible physics topics were considered so far:

1. Precision measurement of $\sin^2 \theta_W$ as a function of Q, the momentum transfer, in e-p collisions [5]. This would be the next generation experiment beyond the SLAC-E158, 6 GeV PVDIS and the currently planned 12 GeV experiments (Moller [6] & SoLID-PVDIS [7]) and would be complementary to atomic parity violation searches planned in the future. The Q range of the EIC would be between the fixed target experiments and the measurements from LEP at the Z-pole. Any deviation from the expected running of the $\sin^2 \theta_W$ would be a hint of physics beyond the SM.

2. Possible exploration of charged lepton flavor violation, particularly transitions between the 1$^{st}$ and the 3$^{rd}$ generation leptons ($e - \tau$) [8] at the highest energy and highest luminosity e-p collisions [9] at the EIC. This would extend searches made at HERA, in different ranges of the lepto-quark couplings and masses, and will be complementary to future searches at the LHC, LHeC and the Super-B factories. The $\sim 100-1000$ times more luminous collisions compared to HERA will be key to success in these searches. The angular correlations in the final state decay particles in the known Standard Model interactions involving $\tau$’s in the final state and those in which $\tau$’s are created in a leptoquark interaction will form the tell-tale signs of the existence of leptoquarks interactions. Such studies were performed at HERA in the last decade, as such the requirements of detector acceptance and the methods of analyses are fairly well defined[10].

3. Exploration of nucleon spin structure using the electroweak probes i.e. Z (and its interference with $\gamma$) and $W^{+/-}$[12]. Due to their different couplings to the quarks and anti-quarks, these measurements will enable us to explore different combinations of partons and hence allow a determination of parton distribution functions different from those which are accessible through conventional deep inelastic scattering with virtual photons. There is ample experience with W production in e-p scattering from HERA, where detailed studies of the structure function $xF_3$ have been performed. Since the HERA proton beam was unpolarized, only unpolarized
quark-anti-quark distributions were ever measured. With the polarized proton and neutron (via either deuteron or helium) beams at the EIC, these studies can be extended to include not only the quark-anti-quark polarization but one could also study in detail their possible charge symmetry relations.

The above studies and considerations are preliminary. Detailed detector simulations are needed to confirm feasibility of these, and are underway. There might be other topics of interest to the high-energy physics community possible with a machine like EIC. We welcome your input and thoughts on this.

[7] The Solenoidal Large Intensity Device (SoLID) at Jefferson Lab: http://hallaweb.jlab.org/12GeV/SoLID/
[12] Electroweak structure functions at the EIC, A. Deshpande et al. in arXiv:1108.1713