Letter of Intent for Snowmass 2020 on Lepton-Hadron colliders at Multi-TeV Scale

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Deep inelastic scattering of high energy leptons and hadrons has been pivotal in exploring structure of proton and nuclei. It can realize accumulation of unprecedentedly large amount of experimental data for enabling theoretical and computational studies of strong interaction between quarks and gluons.

In the medium center-of-mass (CM) energy range up to ~140 GeV, after twenty years of diligent studies in the science programs, machine designs and technology development, and several community-wide reviews, a polarized electron-ion collider was finally selected by the US Department of Energy in January, 2020 as the next major facility for advancing nuclear physics.[1] This collider, at an estimated construction cost between 1.6 and 2.6 billion US dollars, will be built at Brookhaven National Laboratory and will reuse the existing RHIC facility for cost efficiency and fast construction cycle.

In the CM energy range beyond 1 TeV, there is another set of fundamental physics questions waiting to be answered by deep inelastic scattering experiments. A lepton-hadron collider in this CM energy range offers rich opportunities within and beyond standard model, therefore it is an ideal laboratory to study the properties of new particles that couple to electrons and quarks. In fact, a TeV scale lepton-hadron collider could also be operated as a Higgs factory as an alternate to the *e+e-* collision based factory machine. To support these high energy physics programs, at least four advance concepts have been proposed for a TeV scale lepton-hadron collider by various groups worldwide over the last decade. They are

1. *LHeC*: A lepton-hadron collider based on LHC (HL-LHC or HE-LHC), it collides 7 TeV proton beam in LHC (or 14 TeV in HE-LHC) with a 60 GeV electron beam from a recirculating energy recovery linac (ERL), achieves up to 1.3 TeV CM energy (or 1.8 TeV with HE-LHC) [2]. A collaboration has already been formed between CERN and Jefferson Lab for the development of the ERL.

2. *FCC-he*: A lepton-hadron collider based on the proposed future energy frontier circular *hadron-hadron* collider *FCC-hh* at CERN, with proton energy up to 50 TeV; the electron beam will be from a recirculating ERL similar to that of *LHeC*, thus the electron beam energy is up to 60 GeV; such a facility could achieve 3.5 TeV CM energy [3]

3. *CEPC-SPPC-he:* A lepton-hadron collider similar to *FCC-he*, based on the proposed future energy frontier circular lepton-lepton collider CEPC and circular *hadron-hadron* collider *SPPC* at IHEP in China, with proton energy up to 75 TeV and the electron energy up to 120 GeV, thus such an *ep* facility could reach 6 TeV CM energy [4]

4. *VHEeP*: A lepton-hadron collider with CM energies as high as 9 TeV based on advanced acceleration technology, it utilizes one 7 TeV *LHC* proton beam as a driven beam to accelerate an electron beam to 3 TeV energy by a method of plasma wakefield acceleration, and collides this electron beam with the other 7 TeV *LHC* beam. The CM energy of this collider could be made even higher if energy upgrade of LHC is finally realized. [5]

Substantial accelerator conceptual design studies and technology R&D have been carried out over the last decade, such as ERL for *LHeC,* several conceptual design reports have been released summarizing the conceptual studies and R&D.

In this letter of intent, we propose studies of the energy frontier TeV-class lepton-hadron collider. The study should covers both machine design and optimization, and key accelerator technology R&D. We propose the following activities

1. Continuing the collaboration with the *LHeC/FCC-he* group at CERN on development of TeV scale lepton-hadron colliders, contributing design optimization;
2. Seeking opportunities in collaboration with the *CEPC-SPPC-he* group at IHEP and the *VHEeP* group at MPI, Munich/UCL/DESY, on development of TeV scale lepton-hadron colliders, contributing design optimization;
3. Performing R&D on accelerator technologies which enables the TeV scale hadron-ion colliders

Reference:

1. *US Electron-Ion collider Conceptual Design Report* (To be published, 2020)
2. *A Large Hadron Electron Collider at CERN: Report on the Physics and Design Concepts for Machine and Detector* https://arxiv.org/abs/1206.2913 (2012)
3. *"Future Circular Collider Study FCC-he Baseline Parameters"* by O. Bruning, J. Jowett, M. Klein, D. Pellegrini, D. Schulte, F. Zimmermann, FCC-ACC-RPT-0012 V1.0 (2017)
4. *CEPC Conceptual Design Report: Volume 1 Accelerator*, https://arxiv.org/abs/1809.00285 (2018)
5. *VHEeP: A very high energy electron-proton collider*, https://arxiv.org/abs/1606.00783 (2016)