OVERVIEW OF ELECTRON-ION COLLIDER INITIATIVES

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Abstract

Over the last decade, there has been growing interest in the U.S. and Europe in realizing a high luminosity electron-ion collider as the next generation accelerator to study QCD and to probe the limits of the Standard Model. In the U.S., the Electron-Ion Collider (EIC) initiative is considering such a collider at both Brookhaven National Laboratory using RHIC and at Jefferson Laboratory using CEBAF. At CERN, a 70 GeV electron beam in collision with the LHC hadron beams, so-called LHeC, is under consideration. Recently, hadron physicists in Europe have started to consider a multi-Gev electron beam in collision with the planned 15 GeV proton beam at the FAIR facility at GSI. Here the accelerator concepts are summarized and the R&D outlined.

INTRODUCTION

In considering the necessary new accelerator capabilities to explore the Standard Model, physicists have developed the concept of an electron-ion collider (EIC) [1] possessing high luminosity and having polarized beam capability. Over many decades, it has been established that lepton-hadron scattering is the technique of choice to cleanly study the strong interaction. The collider offers the possibility of a large kinematic range in parton momentum x and momentum transfer Q^2, which are essential to deconvolute the effects of the virtual photon-quark interaction from those of hadron structure. The value of x determines whether valence or sea partons are probed and Q^2 determines the resolution of the scattering. In the U.S., EIC would probe down to values of x of 10^{-4} and would span a range in Q^2 from 1 to 1000 $(\mathrm{GeV/c})^2$. The collider also provides a large range in center-of-mass energy which again extends the kinematic range. The polarized beam capability is demanded by the desire to understand how the spin-½ of the proton arises from the quark and gluon constituents. In Fig. 1, EIC is shown [2] together with a representative example of existing machines on a plot of luminosity vs. center-of-mass energy. The electron-ion collider would provide a new capability far beyond that which is available at any present or planned accelerator. In the last several years, interest in the electron-ion collider has increased beyond the U.S. with two such accelerators under consideration in Europe: one at higher center-of-mass energies than EIC using the LHC at CERN [5] and a second at lower center-of-mass energies at the next generation nuclear physics accelerator FAIR at GSI [6].

With its center-of-mass energy over 1 TeV, LHeC is is motivated by a search for new physics such as SUSY, Technicolor or lepton flavor number violation.

The EIC machine design is driven by desire to comprehensively explore the virtual fields of QCD. It demands a luminosity of at least 10^{33} cm^{-2}s^{-1} with highly

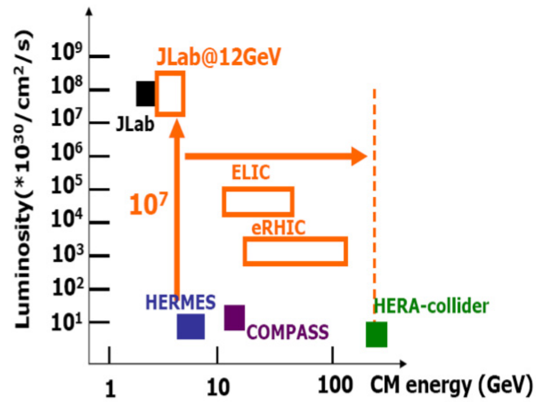

Figure 1: EIC (both JLAB/ELIC [3] and BNL/eRHIC [4]) together with a representative sample of existing capabilities on a plot of luminosity vs. center-of-mass energy.

polarized e± and nucleon beams and the full range of nuclear beams from deuterium to uranium. Tests of the electroweak interaction demand a significantly higher luminosity of order 10^{34} cm^{-2}s^{-1}. The center of mass energy should span the onset of deep inelastic scattering (~10 GeV) to ~100 GeV. The design of the EIC electron-ion interaction region is intimately connected with the design of the collider detector.

Accelerator physicists [3,4] have developed several concepts for EIC in the U.S. based around existing capabilities at BNL/RHIC and JLab/CEBAF. They fall into two distinct categories: a ring-ring machine and a linac-ring machine, where the electron beam is produced by a linac.

RING-RING CONCEPTS

The best understood EIC machine configuration is where a ~10 GeV electron storage ring is arranged to collide with the existing RHIC complex at BNL [4], as shown schematically in Fig. 2. This design takes advantage of the investment and capabilities of RHIC. Polarized positron beams can be straightforwardly produced. However, the present ring-ring machine design is limited in luminosity to ~ 3 x 10^{32} cm^{-2}s^{-1}. There are no significant R&D issues associated with this concept.

A more ambitiouos EIC concept [3] is based around the existing CEBAF at Jefferson Lab and would require a new ion complex, as shown schematically in Fig. 3. This concept aims for a luminosity in excess of 10^{34} cm^{-2}s^{1} accomplished with a high collision frequency. With optimization of the IP final focusing design, the ELIC luminosity is able to reach 10^{35} cm^{-1}s^{-1} at the collision frequency of 499 MHz.

The LHeC accelerator concept [5] has a design luminosity of 10^{33} cm^{-2} s^{-1} and has been developed for

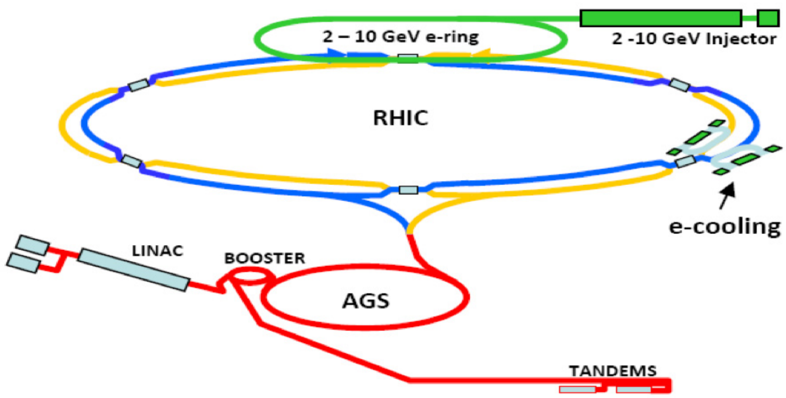

Figure 2: Schematic layout of the eRHIC ring-ring electron-ion collider [4].

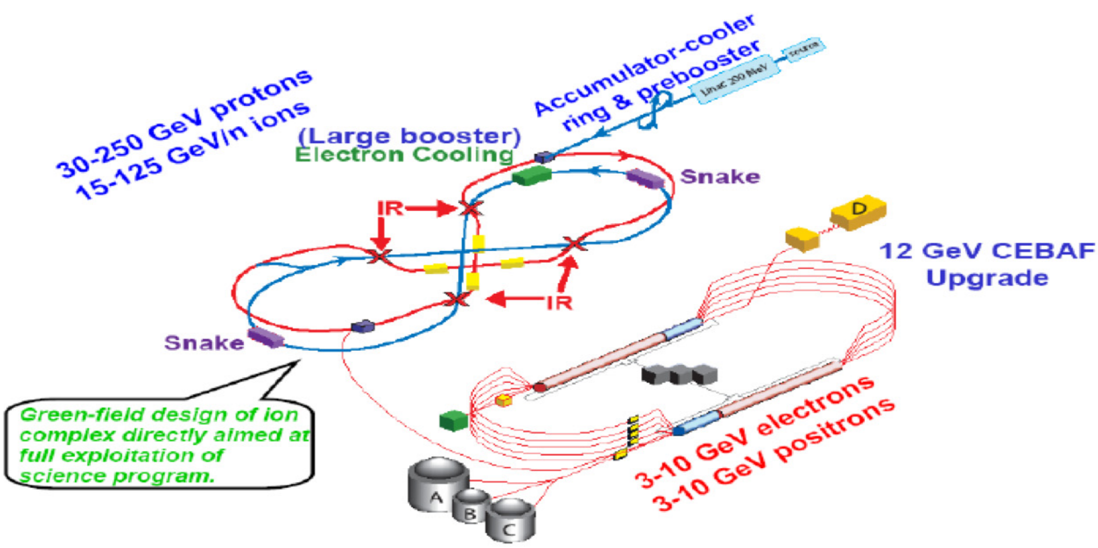

Figure 3: Schematic layout of the ELIC ring-ring electron-ion collider [3].

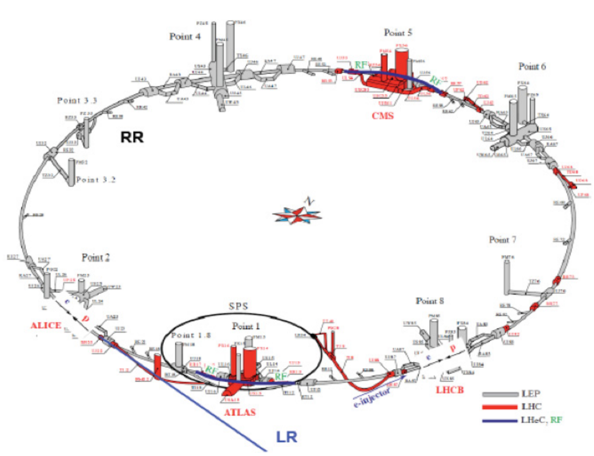

Figure 4: Layout of the LHeC concept [5].

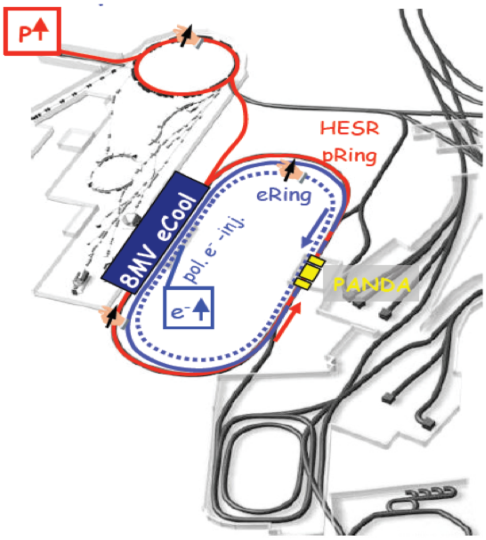

Figure 5: Layout of the ENC concept at FAIR [6].

both a ring and linac. In the ring design, the electron beam would be contained in the LHeC tunnel. It could be installed in 1-2 years during LHC shutdowns. Polarized beams are not available in the present LHeC design.

In the Electron-Nucleon Collider (ENC) considered at GSI [6], a 3 GeV electron ring would be collided with the planned 15 GeV HESR of FAIR. The 14 GeV center-of-mass energy with polarized electron and nucleon beams at a collision luminosity of 10^{33} cm^{-2} s^{-1} would allow access to the sea quarks and gluons of the nucleon. Nuclear beams are not envisaged for ENC at this time.

LINAC-RING CONCEPTS

High energy (~10 GeV), high intensity (~100 mA) electron linear accelerators will require recovery of the energy due to the high power in the beam. There have been significant advances in this technology using superconducting RF. Thus, it is conceivable that the electron beam for an electron-ion collider can be realized with an ERL. Indeed, the luminosity possible

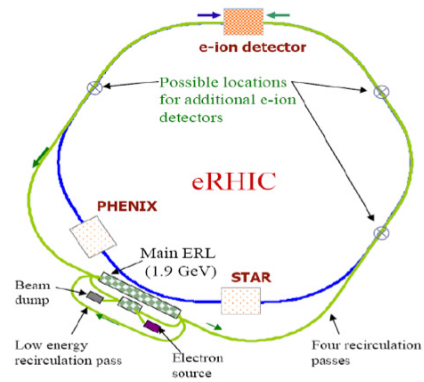

Figure 6: Schematic layout of the eRHIC linac-ring electron-ion collider [4].

could substantially exceed that of the ring-ring design. Also, the linac-ring allows more space for the detectors in the interaction region. However, with the requirement that the electron beam be polarized, the intensity of the polarized electron source is much larger than exists with current technology.

Figure 6 shows the layout for a linac-ring concept [4] using the RHIC complex. The beam is recirculated four times in the RHIC tunnel. Collision luminosities of ~ 3 x 10^{33} $cm^{-2}s^{-1}$are expected with this design. A staged implementation of this concept is under development at present.

STAGED EIC

A staged concept for eRHIC, so-called MeRHIC, is under consideration [7]. This is motivated by the recognition that it may be possible to realize this on a significantly faster timescale compared to the full eRHIC. It takes advantage of a significant transverse size to the RHIC tunnel in the vicinity of IP2. A 4 GeV electron linac in collision with the 250 GeV RHIC beam at a luminosity of ~ 3 x 1032 cm-2 s-1 is being studied. Figure 7 shows the layout. There is a sizable experimental hall where the detector can be located. A staged ELIC design is also under consideration [8].

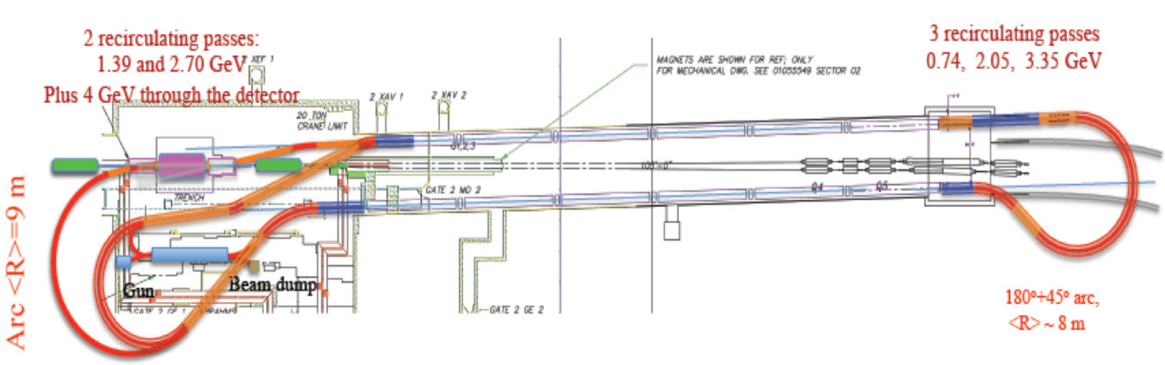

Figure 7: Layout of the MeRHIC concept [7].

With a momentum range up to 60 GeV/c for proton and 11 GeV for electrons, with a figure-8 ring of circumference 630 m, the luminosity reaches up to 10^{34} $cm^{-2}s^{-1}$ per detector, over multiple IPs (up to 3 for medium energy and 1 for low energy). Some new ideas for suppressing space charge effects at extremely low proton energy are being considered.

ACCELERATOR R&D

R&D for electron-ion colliders is a major activity at present. A test energy recovery linac (ERL) facility is under construction at BNL. Development of a high intensity polarized electron source is being carried out at MIT-Bates. To increase the output intensity, the laser spot size on the GaAs crystal must be scaled up and this will necessitate active thermal cooling of the crystal. Development of cooling techniques for the ion beam is a major focus of effort as this is essential to attaining high luminosity. At Jefferson Lab, crab cavities are being studied as well as the ability to attain high collision frequencies. At present the scientific reach and the cost of the different design concepts are being studied in detail. It is anticipated that within three years the most optimal design will be identified and costed.

DETECTOR CONSIDERATION

A successful science program at an electron-ion collider will require a suite of optimized detectors. The conceptual design of these detectors is in progress. A solenoidal central detector will likely be required to detect the final state particles from $\sim 10^o$ to $\sim 170^o$ with respect to the incoming electron. In the forward and backward directions a dipole magnet looks like an attractive option. Indeed, a detailed design has been developed for this configuration [9]. Although the collision luminosity is high, the electroweak cross section is small so the trigger rate is not beyond state of the art. Particle identification is important as well as the ability to detect jets.

In the collider configuration many important experiments require the detection of final-state particles with momentum close to the beam momentum and at very forward angles. This requires specialized detectors located to the beam line.

Beam polarimetry is important for an electron-ion collider as the precise knowledge of the beam polarization is essential for a number of important experiments. The electron and ion polarimeters must be designed as integral elements of the interaction region. Work on this has started [10].

ACKNOWLEDGEMENTS

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