An Electron-Ion Collider at CEBAF

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Electron-ion colliders with a center of mass energy between 15 and 100 GeV, a luminosity of at least 10^{33} cm^{-2}s^{-1}, and a polarization of both beams at or above 80% have been proposed for future studies of hadronic structure. The scheme proposed here would accelerate the electron beam using the CEBAF recirculating linac with energy recovery. If all accelerating structures presently installed in the CEBAF tunnel are replaced by ones with a $\sim$ 20 MV/m gradient, then a single recirculation results in an electron beam energy of about 5 GeV. After colliding with protons/light ions circulating in a figure-of-eight storage ring (for flexibility of spin manipulation) at an energy of up to 100 GeV, the electrons are re-injected into the CEBAF accelerator for deceleration and energy recovery. In this report several lay-out options and their respective feasibilities will be presented and discussed, together with parameters which would provide a luminosity of up to $1 \cdot 10^{35}$ cm^{-2}s^{-1}. The feasibility of combining such a collider at a center-of-mass energy $\sqrt{s}$ of up to 43 GeV with a fixed target facility at 25 GeV is also explored.

1. INTRODUCTION

At present extensive research programs are executed at a variety of facilities (JLab, HERMES, COMPASS, RHIC-spin) to study the spin, flavor and chiral structure of the nucleon through deep inelastic scattering. Semi-inclusive and exclusive reactions are needed to separate contributions from different flavors. Also the Q^2- and x-ranges have to be extended significantly to investigate the evolution and factorization of generalized parton distributions. The ability to control both electron and hadron polarizations would provide an important component in extracting information on partonic correlations. An accurate decomposition of the components of the nucleon spin would become feasible. It is clear that a future extension to a higher center-of-mass energy $\sqrt{s}$ is required[1]. Such a facility should provide a high luminosity, a high duty factor, a high polarization and a large range of $\sqrt{s}$. An electron-ion collider could meet those design requirements.

2. THE ELIC PROPOSAL

The ELIC (Electron Light-Ion Collider) proposal is based on the following elements:

- The CEBAF accelerator is used in energy recovery mode (for RF power savings and ease of beam dump requirements) for the acceleration of electrons.
- "Figure 8"[2] booster and storage rings are used for the ions for spin preservation and flexible manipulation of all ion species of interest.

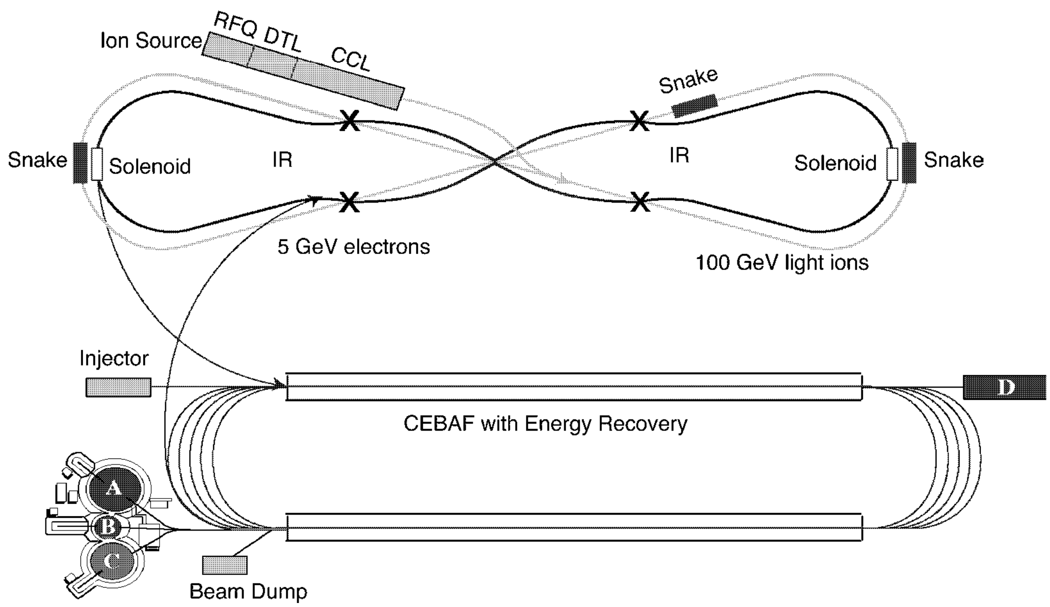

Figure 1. Proposed lay-out for the ELIC facility.

- In order to ease the high current polarized photoinjector and ERL requirements electrons are stacked into a circulator ring[2], in which they circulate for a small number of revolutions (about 100) while colliding with the ion beam.

Figure 2 displays a schematic layout of ELIC. Longitudinally polarized electrons generated from a high current polarized source are injected into the CEBAF accelerator. With only CEBAF Upgrade-style cavities, operating at a gradient of 18 MV/m installed in the tunnel, a single-pass recirculation through CEBAF results in an electron beam energy of $\sim$ 5 GeV. The 5 GeV electrons are stacked into the circulator ring (CR) where they stay for $\sim$ 100 turns while they continuously collide with the ions. They are subsequently extracted, transported back to CEBAF for deceleration and energy recovery, and are dumped at approximately their injection energy. If the polarized source development should become so advanced that the CR does not offer any advantages, the electrons can still follow the same transport, but now circulate only once before being reinjected to CEBAF for energy recovery.

The CR concept greatly eases the requirements on the polarized electron source and the ERL: the injector produces current macropulses of length equal to the ring circumference. Each macropulse is then injected into the CR for $\sim$ 100 revolutions. During this time the injector current is turned off. After $\sim$ 100 revolutions, the macropulse is extracted and reinjected into the linac for energy recovery. At the same time a new pulse is being injected into the linac for acceleration, in perfect synchronism with the decelerating pulse for energy recovery to work. The average current requirement on the polarized injector is lower by the number of revolutions in the CR. Different filling patterns of the CR are being considered[3].

All ion species are injected longitudinally polarized and accelerated in a conventional ion RF Linac. The circulator ring can also be used as a booster ring bringing the ion energy to 10-20 GeV. The ions are then injected and accelerated up to 100 GeV in the "Figure-8" storage ring housed in the same tunnel as the CR. The "Figure-8" storage ring is used for the ions for its zero spin tune, thus intrinsic spin resonances and spin resonance crossings are avoided. Longitudinal polarization for all ion species is possible at all energies by introducing solenoids in the straight sections or horizontal dipoles in the arcs. Spin rotators around the interaction points would not be needed. For protons (^{2}H and ^{3}He), up to 4 (2) simultaneous interaction regions (IR's) can be provided with longitudinal polarization. To ensure that the electron spin remains longitudinal at the IR's, a Wien filter in the injector or a Siberian snake is required for two IR's, and a Wien filter plus 2 Siberian snakes, or three Siberian snakes without the Wien filter for 4 IR's.

Table 1
ELIC parameters for different Point Designs.

Parameter	**Units**	**Point Design 0**		**Point Design 1**		**Point Design 2**		**Point Design 3**	
		e^-	Ions	e^-	Ions	e^-	Ions	e^-	Ions
Energy	GeV	5	50	5	50	5	50	5	50
Cooling	-	-	No	-	Yes	-	Yes	-	Yes
Luminosity	$cm^{-2}s^{-1}$	$1 \cdot 10^{32}$		$1 \cdot 10^{33}$		$1 \cdot 10^{34}$		$1 \cdot 10^{35}$	
N_{bunch}	ppb	$1 \cdot 10^{10}$	$2.5 \cdot 10^{10}$	$1 \cdot 10^{10}$	$2.5 \cdot 10^{10}$	$2 \cdot 10^{10}$	$5 \cdot 10^{9}$	$1 \cdot 10^{10}$	$1 \cdot 10^{10}$
f_c	MHz	150		150		500		1500	
I_{ave}	A	0.24	0.6	0.24	0.6	1.6	0.4	2.5	2.5
σ^*	μm	45	45	14	14	6	6	3.2	3.2
ϵ_n	μm	10	2	10	0.2	10	0.2	10	0.1
β^*	cm	200	5	20	5	4	1	1	1
σ_z	cm	0.1	5	0.1	5	0.1	1	0.1	1
ξ_e/ξ_i	-	0.5	0.0006	0.5	0.006	0.1	0.01	0.2	0.01
$\Delta\nu_L$	-	-	0.005	-	0.05	-	0.05	-	0.09

Consistent sets of parameters have been developed for four point designs for ELIC (Table 1). Point Design 0 (PD0) is a baseline design based on presently achieved parameters (not necessarily simultaneously) assuming no electron cooling of the ions. Under these assumptions, the maximum achieved luminosity is 10^{32} cm^{-2}s^{-1}. PD1 assumes electron cooling, which would result in a luminosity at 10^{33} cm^{-2}s^{-1}. PD2 provides a luminosity of 10^{34} cm^{-2}s^{-1}. This solution requires, in addition to electron cooling and the associated short ion bunches[2], a circulator ring and the use of crab crossings to increase the collision frequency and reduce parasitic collisions. The final design (PD3) gives the maximally attainable luminosity. We found that 10^{35} cm^{-2}s^{-1} is feasible only if the ion energy is 100 GeV or above. Each point design should be viewed as an evolutionary upgrade.

3. ACCELERATOR PHYSICS AND TECHNOLOGY ISSUES

To achieve a luminosity $\geq 10^{32}$ cm^{-2}s^{-1} electron cooling is required to overcome intra-beam scattering, in both the transverse and the longitudinal phase space. An electron beam energy of $\sim$ 50 MeV will be required at a beam current of up to 100 mA. Electron cooling at such a high energy can only be achieved with a superconducting RF ERL, such as routinely used in the Jefferson Lab FEL.

Operation of CEBAF in energy-recovery mode implies the ability to confine two beams of different energies in the same beam line. An energy recovery experiment has been scheduled at CEBAF for March 2003 to investigate such issues. Additional ERL issues include beam loss, single and multiple collective effects, multi-pass beam breakup and higher-order mode power dissipation.

IR issues include integration of Its design with the detector geometry, incorporating crab crossings and beam-beam head-tail instabilities. Extensive simulations are being pursued to investigate these effects.

Technology issues for the realization of ELIC include the high-current polarized electron source and RF control and operation of SRF cavities at high gradient.

4. INTEGRATION WITH 25 GEV FIXED TARGET FACILITY

With a single pass in CEBAF accelerating the electron beam by 5 GeV, the proposed facility could deliver up to 25 GeV to the existing experimental halls. The emittance growth due to synchrotron radiation in the arcs has been studied. A new optics design[4] will limit the beam size at the interaction points to ≤ 0.5 mm at 25 GeV. Future studies will address the issue whether the collider and fixed-target modes could run simultaneously.

5. CONCLUSION

An electron-ion collider at CEBAF yielding a luminosity of up to 10^{35} $\text{cm}^{-2}\text{s}^{-1}$ is shown to be feasible. Electron cooling is required in all scenarios presented. The concept of a circulator ring is being studied, since it promises to ease the requirements on the polarized electron source and on high average current issues in the ERL. The strategy for future R&D includes the study of high average current effects in the JLab IR FEL, the Cornell/JLab prototype and the BNL electron cooling prototype. An energy recovery experiment in CEBAF will address ERL issues in large systems. Integrating the electron-ion collider with a 25 GeV fixed-target facility also appears feasible.

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