ELIC: AN ELECTRON-LIGHT ION COLLIDER BASED AT CEBAF*

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Abstract

Electron-ion colliders with center of mass energy between 20 and 100 GeV, luminosity at or above 10^{33} cm^{-2} sec^{-1}, and polarization of both beams at or above 80% have been proposed for the study of hadronic structure. The proposed scheme would accelerate the electron beam using the CEBAF recirculating linac with energy recovery. If ~20 MV/m accelerating structures are installed in the CEBAF tunnel, then a single recirculation can result in an electron beam energy of about 5 GeV. After colliding with protons/light ions circulating in a storage ring at an energy of 50-100 GeV, the electrons are re-injected into the CEBAF accelerator for deceleration and energy recovery. In this report several point designs and their respective feasibilities are discussed, parameters for the required luminosity presented and accelerator physics issues discussed for both protons/ions and electrons. The feasibility of an integrated fixed target program at 25 GeV and collider program with a center-of-mass energy between 20 and 100 GeV is also explored.

1 INTRODUCTION

Electron - light ion colliders have recently been proposed as a means to study hadronic structure. The center-of-mass energy of interest is between 20 and 100 GeV with energy asymmetry ratio of approximately 10, yielding collision of 3 GeV electrons on 30 GeV ions, up to that of 10 GeV electrons on 250 GeV ions. The required luminosity is 10^{33} cm^{-2} sec^{-1} or higher with both beams longitudinally polarized at 80% in the interaction region. Spin-flip of both beams is extremely desirable for exclusive measurements. The ion species of interest include protons, deuterons and He^3. Two design scenarios have been proposed: colliding storage rings [1] and energy recovering linac-on-ring [1,2]. Although linac-ring is not as well understood as ring-ring, comparable, if not higher luminosities appear feasible, while the linac-ring option presents a significant advantage in spin manipulation. Feasibility of an energy recovering linac-ring collider has been studied and presented. This paper describes a proposal for a CEBAF-based electron-light ion collider. We first present the basic elements of the proposal and the machine layout, followed by accelerator technology and physics issues of electrons and ions and the feasibility of integration of the collider with a 25 GeV fixed target program at CEBAF. We conclude with the R&D strategy we plan to follow in order to address the significant issues of this proposal.

2 THE ELIC PROPOSAL

The ELIC (Electron Light-Ion Collider) proposal is based on the following elements: The CEBAF accelerator in energy recovery mode (for rf power savings and ease of beam dump requirements) is used for the acceleration of electrons. "Figure 8" [3] booster and storage rings are used for the ions for spin preservation and flexible manipulation of all ion species of interest. A circulator ring [3], in which electrons are injected after acceleration in the Energy Recovering Linac (ERL) and circulate for a small number of revolutions (about 100) while colliding with the ion beam, may be used to ease the high current polarized photoinjector and ERL requirements.

Figure 1 displays a schematic layout of ELIC. Longitudinally polarized electrons generated from a high current polarized source are injected into the CEBAF accelerator. With CEBAF Upgrade-style cavities, operating at a gradient of ~20 MV/m installed in the tunnel, a single pass recirculation through CEBAF results in electron beam energy of ~5 GeV. In the scenarios that include a circulator ring (CR), the 5 GeV electrons are then injected into the CR where they stay for ~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 ERL injector produces current macropulses of length equal to the ring circumference. Each macropulse is then injected into the CR for ~100 revolutions. During this time the injector current is turned off. After ~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 [4,5].

All ion species are injected longitudinally polarized and accelerated in a conventional ion RF Linac. The circulated ring can also be used as a booster ring bringing the ion energy to 10-20 GeV. The ions are then injected and stored in the "Figure 8" storage ring housed in the same tunnel with the CR. The "Figure-8" storage ring is used for the ions for its zero spin tune, thus intrinsic spin resonances and spin resonance-crossing are avoided. Longitudinal polarization for all ion species at all energies is possible by introducing solenoids in the straight sections or horizontal dipoles in the arcs. Spin rotators

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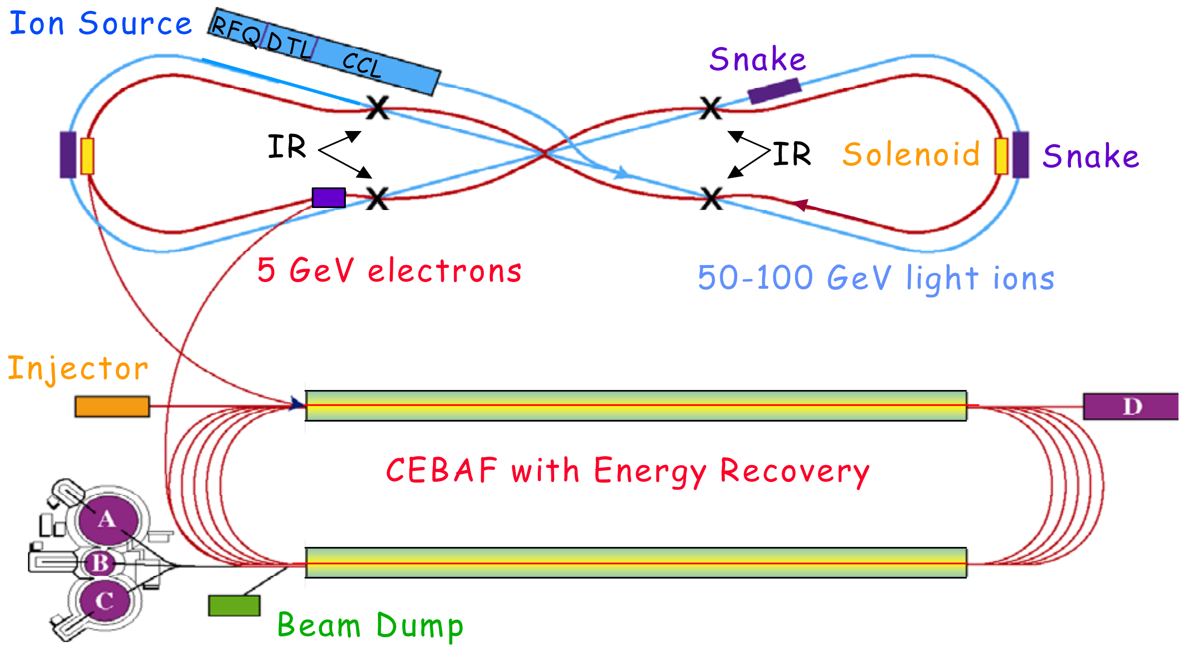

Figure 1: ELIC layout

Table 1: ELIC Parameter Table

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	50/100
Cooling	-	-	No	-	Yes	-	Yes	-	Yes
Luminosity	$cm^{-2}\ sec^{-1}$	**1 x 10^{32}**		**1 x 10^{33}**		**1x 10^{34}**		**6x10^{34} / 1x10^{35}**	
N_{bunch}	ppb	1x10^{10}	2.5x10^{10}	1x10^{10}	2.5x10^{10}	2x10^{10}	5x10^{9}	1x10^{10}	1x10^{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	4.5	4.5
ε_n	μm	10	2	10	0.2	10	0.2	10	0.1
β^*	cm	200	5	20	5	4	1	2	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

around the interaction points would not be needed. For protons, up to 4 simultaneous interaction regions (IRs) can exist with longitudinal polarization. For D and He up to 2 simultaneous IRs can exist with longitudinal spin. To ensure that the electron spin remains longitudinal at the IRs, a Wien filter in the injector plus one or two Siberian snakes is required for two IRs, and a Wien filter plus 2 Siberian snakes, or three Siberian snakes without the Wien filter for 4 IRs.

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} sec^{-1}. PD1 assumes electron cooling. Luminosity at 10^{33} cm^{-2} sec^{-1} appears feasible. PD2 gives maximal luminosity of 10^{34} cm^{-2} sec^{-1}. This solution requires, in addition to electron cooling and the associated short ion bunches [3], a circulator ring and the use of crab crossing for increase of collision frequency and reduction of parasitic collisions. The final design (PD3) gives the maximally attainable luminosity. We found that 10^{35} is feasible only if the ion energy is 100 GeV or above. Each point design should be viewed as an evolutionary upgrade to the previous design.

3 ACCELERATOR PHYSICS AND TECHNOLOGY ISSUES

3.1 Accelerator Physics Issues of the Ion Ring

To achieve luminosities above roughly 10^{32} cm^{-1} sec^{-1} electron cooling is required to overwhelm intrabeam scattering, in both transverse and longitudinal degrees of freedom. Cooling of the intense ion bunches contemplated here requires high electron beam current (hundreds of mA). Electron cooling at such high energy can only be conceived in the context of superconducting rf ERLs demonstrated and routinely used in the Jefferson Lab IR FEL. The BNL/BINP collaboration, in cooperation with Jlab, is seriously pursuing the design and prototyping of an ERL-based electron cooling device for RHIC [6]. The electron beam energy will be 50 MeV and the electron beam current will be approximately 50 mA.

Collective instabilities in the ion ring must be analyzed. Based on previous results, it is expected that the longitudinal mode coupling, or microwave instability, and the transverse mode coupling instability will exhibit the lowest thresholds, but no showstoppers are anticipated.

3.2 Accelerator Physics Issues of the ERLs

Operation of CEBAF in energy recovery mode implies the ability to confine two beams of different energies in the same focusing channel. This imposes a constraint on the ratio of injected to final beam energies. An energy recovery experiment at CEBAF has been proposed and is being planned for March 2003. CEBAF-ER aims to investigate the ability for phase space management and to quantify beam quality degradation in large scale ERLs. The injected to final beam energy ratio will be varied between 20-80, from 11-45 MeV to about 800 MeV.

Additional issues of the ERL include understanding the origin of and ability to control beam loss, single and multibunch collective effects, multipass Beam Breakup (BBU) instability and Higher Order Mode power dissipation [7,8]. The JLab FEL Upgrade, designed to energy recover 10 mA, the BNL electron cooling prototype to energy recover 10 mA, and the Cornell/JLab ERL prototype to energy recover 100 mA will experimentally address these high current effects.

3.3 Accelerator Physics Issues of the Collisions

Physics issues of the collisions include: a) integration of the IR design with real detector geometry, b) investigation of crab crossing for the ions for luminosity enhancement, and c) beam-beam head-tail instability. The beam-beam force due to the relative offset between the head of the ion bunch and the electron beam will deflect the electrons, subsequently interacting with the tail of the ion bunch through the beam-beam kick. The electron beam acts as transverse impedance to the ion bunch and can drive the ions unstable. We are pursuing extensive simulation and analytical studies to evaluate and mitigate this effect [9,10]. We expect that Landau damping caused by the electron beam-induced tune spread, and perhaps chromaticity, to increase the threshold current of this instability.

3.4 Accelerator Technology Issues

The major technology issue for the realization of ELIC is the high average current polarized electron source. The highest average current that has been demonstrated to date is approximately 1 mA [11]. The circulator ring concept appears promising in easing this requirement. Other technology issues include rf control of high loaded Q superconducting cavities, operation of SRF cavities at high gradient (18 MV/m) with high CW current, and cryogenics. At $Q_0=1\text{x}10^{10}$, the dynamic load for ELIC is about 10 kW, which requires about 20 kW installed cryogenic power. This is twice the amount planned for the CEBAF 12 GeV Upgrade program.

4 INTEGRATION WITH 25 GEV FIXED TARGET PROGRAM

It appears feasible to integrate ELIC with a CEBAF-based fixed target program, in which five accelerating passes deliver up to 25 GeV electron beam to the experimental halls. It is a subject of further investigation whether the collider and fixed target modes could run simultaneously or in alternating modes. The emittance growth due to synchrotron radiation in the CEBAF arcs at the higher energies has been addressed. A novel optics design for the higher arcs results in reduction in emittance growth by a factor of 10 compared to the present optics. The beta functions in arc 9 are ~ 70 m and the spot sizes at the IP are between 0.3-0.5 mm at 25 GeV [12].

5 CONCLUSIONS AND R&D STRATEGY

An electron-ion collider based at CEBAF yielding 10^{33} to 10^{35} cm^{-2} sec^{-1} luminosity appears feasible. Electron cooling is required in all scenarios. We are investigating the concept of circulator ring, as it promises to ease requirements on polarized electron source as well as high average current issues in the ERL. Other conceptual improvements are being explored [3]. The R&D strategy includes experimental investigation of high average current effects in the JLab IRFEL, Cornell/JLab ERL prototype and BNL electron cooling prototype. Complementary to these efforts is the energy recovery experiment at CEBAF to address ERL issues in large systems. Electron-ion collider program integrated with a 25-GeV CEBAF-based fixed target program appears feasible.

6 REFERENCES

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