MIT-Bates Linear Accelerator Center

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Introduction

The MIT-Bates Laboratory has brought into operation the South Hall Ring for high duty-factor experiments with energies up to 1 GeV. Extracted beams of order 10 μA and stored beams of order 150 ma have been routinely delivered. Stored polarized beam development has demonstrated that the necessary 80 mA average intensity and 60% polarization will be routinely delivered. Ongoing development of lasers and crystals for extracted polarized beam delivery indicate that 5 μA intensity at 80% polarization should be routine.

In Fall 2000, extracted beam of intensity 8 μA was used to carry out experiment 97-03, a measurement of virtual Compton scattering from the proton. The complete OOPS spectrometer system was used. The BLAST detector is in the final stages of construction and assembly in the south Hall Ring will take place this year.

New Research Initiatives

The institutional plan at Bates is to principally focus on BLAST after 2001. This would allow one experiment per year on OOPS. There are no new research initiatives associated with the South Hall Ring envisaged at this time. The present research program has a lifetime of order five years.

With a finite lifetime to the present research program around the SHR in view, the Laboratory has begun to consider options for the longer term future. In particular, over the last year physicists from Bates and the MIT Medium Energy Group have had a leadership role in the Electron Ion Collider. A feasibility study of a machine has been carried out in collaboration with physicists from the Budker Institute at Novosibirsk, Russia. It is intended to request R&D funds for EIC in the coming years. The requests are described in the accompanying document.

Funding Level

In FY2002 Bates must commission BLAST and carry out the first experiment with this new instrument. A constant level of effort will require a facility operations budget of $11.9 million. This will keep the staff level constant at the FY01 level (down 15% from FY97 level); will allow commissioning and 2000 hours of data taking with BLAST; will permit completion of the transmitter and controls upgrades and some improvements on OOPS and the extracted beam. The minimum reduced effort facility operating budget which would bring BLAST into operation without delay is estimated at $11.2 million. This will delay completion of the necessary upgrades to the transmitters and control system and prevent any work on OOPS and extracted beam.

In FT2002, Capital Equipment funds of $1.5 million; AIP funds of $0.5 million; GPP funds of $0.2 million; and Research Operations of $0.3 million will also be required. These represent constant dollar levels from FY2001.

The requested information is tabulated below.

Nuclear Science Program at MIT-Bates Linear Accelerator Center

Funding	FY2000: 10185k$		FY2001: 10930k$*		
Staffing:	Perm Ph.D.	Tech/Admin	Postdocs	G.S.	Undergraduate
FY2000:	9	56	0	0	2

Users:	110	Ph.D.	G.S.	Other	DOE	NSF	Other US	Foreign
FY2000:		78%	16%	5%	40%	36%	1%	23%

* includes 480k$ for SAMPLE run

Research and Development at MIT-Bates for the Electron Ion Collider

Introduction

Over the last two years, consideration of an electron proton/nucleus collider for hadronic physics in the United States has been the focus of workshops at IUCF (April 99), BNL (December 99) and Yale (April 00). Two independent efforts (EPIC: focussed on the proton and light nuclei up to center-of-mass energy of 30 GeV and eRHIC: focussed on the proton and heavy nuclei with center-of-mass energy up to 100 GeV) were joined in summer 2000. It was decided to hold a workshop at MIT which would unify all the scientific interest for a collider. At the MIT workshop, the Electron-Ion Collider was born and a steering committee was established to guide the effort through the Long Range Planning Exercise.

With the support of the MIT Dean of Science, a feasibility study of the ring-ring machine option was carried out during 2000 in collaboration with physicists from the Budker Institute for Nuclear Physics (BINP), Novosibirsk, Russia. In this design, 7 GeV electrons collide with 32 GeV protons in a 1.4 km circumference ring configuration. Polarization of the electrons is an important question. One approach is to use wigglers to enhance the Sokolov-Ternov self-polarization mechanism. With this scheme, electrons can be injected at relatively low energy and accelerated to 7 GeV and self-polarized, as at HERA. This technique would be very cost-effective. Thus, it is highly desirable to pursue this avenue and the Bates SHR with its excellent polarized beam characteristics can be an important test-bench to experimentally study self-polarization at low energies.

In addition, physics simulations and detector design are underway involving physicists at Bates and at MIT in the Medium Energy Group. Of particular interest are spin-dependent charm production to study the spin structure of the proton and exclusive process such as DVCS to access generalized parton distributions. A major area of study is to produce an optimized detector design which will be consistent with the high luminosity constraints in the interaction region.

To produce a detailed proposal for EIC within about five years, an aggressive program of R&D is required. BNL plans to develop the necessary electron cooling capabilities for EIC. At MIT-Bates, the focus is on the ring-ring machine option. Over the next three years, (FY02, 03, 04) approximately $2.2 million per year is required to pursue the ring-ring design to the level of a Conceptual Design Report. A central aspect of the MIT-Bates effort on EIC is focussed on studying forced self-polarization at an energy of ~ 1.5 GeV in the South Hall Ring. Conceptual design of a number of detectors is included in this effort. In addition, it is proposed to carry out polarized source R&D relevant to the linac-ring option at the level of $200,000 per year for FY 02, 03, 04.

In this document, we detail the resources required to pursue R&D for EIC at MIT-Bates over the next three years.

Funds Required for EIC R&D at MIT-Bates (in M$)

	FY02	FY03	FY04	Total
Ring-Ring Machine Design	0.3	0.3	0.3	0.9
Polarization Study in SHR	1.6	1.6	1.5	4.7
Detector Design	0.3	0.3	0.3	0.9
Polarized Source R&D	0.2	0.2	0.2	0.6
Total	2.4	2.4	2.3	7.1

Ring-Ring Machine Design

One of the most promising machine designs to attain a luminosity of 10^{33} $cm^{-2}s^{-1}$ involves counter-circulating rings of electrons and protons (or nuclei). The circulating beams would collide at a number of interaction points. A feasibility study was developed in 2000 in collaboration with the BINP group. It is proposed to continue this collaborative effort over the next three years in the framework of EIC and to realize a Conceptual Design Report for such a machine. There are a number of central elements to this effort:

- implementation of electron cooling
- positron beams
- forced self-polarization of electron beam
- spin manipulation for both electron and proton/deuteron/^{3}He beams
- nuclear beams
- optimization of interaction region in the presence of a realistic detector

It is estimated that $300,000 per year for the fiscal years 02, 03, and 04 would be required to support a combination of additional Bates personnel as well as physicists from BINP.

Study of Self Polarization at South Hall Ring

The recently proposed high-luminosity ring-ring e-p and e-A colliders projects could avoid the cost for full-energy injection linacs for the e-ring by injecting unpolarized electrons at lower energies, ramping the e-ring to full energy and then letting the beam polarize spontaneously via the Sokolov-Ternov effect. In most scenarios, the polarizing times are too long. Theoretical proposals exist to shorten them by superconducting wigglers inserted in the electron ring.

We propose to test those theories by inserting wigglers into the SHR and ramping its energy to 1.5 GeV. Thus, the performance of the wigglers and associated spin rotators could be thoroughly tested at low electron energy where wiggler enhanced polarization is most needed. In particular, depolarization effects and equilibrium polarizations could be studied.

The SHR is well suited for these studies due to its open lattice design. As a bonus, the polarized 1.5 GeV electron beam could be used for internal target experiments.

The following table shows the estimated costs to raise the SHR energy from 1.0 to 1.5 GeV and to install wigglers and spin rotators.. The total cost of about 5M$ is a very modest fraction of the potential savings from scaling down the injector linacs from 7 to about 1 GeV.

Budget Table (M$)

Additional 2856 MHz cavity and hybrid for existing RF system	0.5	
Additional RF System 2856 MHz, with 2 cavities, total 300 kV	1.6	
New power supplies and ramping control	0.2	
Wiggler, 10 Tesla × 0.2m, superconducting	0.5	
2 spin rotators (superconducting solenoid with correction quads)	0.5	
Polarimeter	0.1	
Total procurement		3.4
Layout for 1.5 GeV SHR (1 man year Acc. Phys.)	.16	
Wiggler and Spin rotation engineering (1 man year)	.16	
Ramping studies and modeling (0.5 man years)	.08	
Total manpower		0.4
Contingency 24%		0.9
Total for Polarization R&D on SHR		4.7

Detector Design Optimization

Considerable preparation is required to design experiments and detectors to best exploit the physics potential of a polarized electron – polarized ion collider. To achieve high luminosities the collider will necessarily have machine components close to the interaction region and the experiment and machine groups must work together to minimize the interference and maximize the performance of both detector and collider. While the energies are not large compared to other colliders, background rates will be a problem. Detectors need to be designed to withstand these rates and the data acquisition and trigger systems must be able to filter out the interesting physics from the noise.

The collider will be asymmetric in beam energies (e.g. 7 GeV electrons on 32 GeV protons). This implies an asymmetric detector to handle the differences in energy and momentum of the reaction products. However, the accelerator elements will likely be symmetric about the interaction point to steer and focus the entering and exiting beams. Thus, the interface between detector and machine will be different in the forward (proton direction) and rear (electron direction) sectors and require different solutions to best match physics and machine requirements.

For the most part, the physics to be studied can be classified as deep inelastic scattering (DIS) though other processes must also be taken into account. The 7+32 GeV option implies a maximum Q^2 of about 900 GeV^2. At these energies the processes will be primarily neutral current DIS as the charged current channel will be negligible being suppressed by the $W^{\pm}$ masses. Consequently, there will almost always be a scattered electron which, if accurately measured, will give the x and Q^2 of the reaction. The first physics to be studied, corresponding to the highest event rates, will be in the backward region where the electron is scattered just slightly from its incident path. Q^2's less than 10 GeV^2 correspond to electron angles within 30º of the rear beam line and span the entire range of x. In this regime, the scattered electron energy is a few GeV. Thus, the rear detector should have good angular and energy resolution for electrons to measure the low Q^2 and low x physics. Significant event rates extend to Q^2's of a few 100 GeV^2 with corresponding electron scattering angles nearly perpendicular to the beam and energies still below 10 GeV. To access higher Q^2 requires electron detection in the proton direction and would be complimented by simultaneous measurement of the proton or hadron jet in the forward direction.

Colliders typically have large 4π detectors with sizable magnetic fields for momentum measurements but some consideration should also be given to smaller dedicated experiments and non-magnetic detector options. A small experiment covering a limited region of space could be simpler to build and could be interchangeable with other detectors. For example, in deeply virtual Compton scattering (DVCS) the scattered electron and photon can be detected generally at angles away from the beamlines and can thus avoid conflicts with the accelerator components. A dedicated fine granularity electromagnetic calorimeter spanning the angles 30º-150º would cover the interesting DVCS region. Of course, competing processes might require a small angle (< 1.5º) proton tag which would have to be incorporated into the machine lattice but this could be investigated with Monte Carlo studies. The proton tag would necessarily be limited in azimuthal coverage but the electron-photon calorimeter could cover all the azimuthal angles and benefit from not requiring a magnetic field.

The data acquisition and analysis for an electron – ion collider detector a decade from now will be a solvable but non-trivial task. With a luminosity of 10^{33}, we should expect the complexity of the events will be more like that of high energy physics. This means event sizes an order of magnitude larger than currently at JLab, and the rates higher than FermiLab.

Fortunately there are a number of new developments in data acquisition and computing which can facilitate this. Firstly, front-end electronics are becoming fully functional computers. Secondly, mass storage and CPU power continue to follow Moore's law; mass storage doubling every two years, and CPU every eighteen months. The task will be to design a system utilizing the power of the CPU embedded in the front-end electronics and taking advantage of the technological advances.

The experimental considerations will be intimately tied to the accelerator and ring design. Much as the mechanical design of the detector is enmeshed with the components of a ring, the data acquisition and the ring control/monitoring system will be more enmeshed than any present experiment. Crucial for the operation of the accelerator and for the physics will be luminosity monitors and polarimeters with active feedback to both machine and data acquisition.

To fully explore the detector options considerable Monte Carlo studies and detector simulations will be required over the broad range of physics processes open to an electron – ion collider. This work must be done in collaboration with the machine design as the detector will be integral with the machine. The work is not purely one of the physics involved but also requires engineering and design to optimize the active detector and machine elements and minimize the necessary but dead areas required for mechanical support and construction. In the future, prototype detector development and testing will also be necessary when the type of detector components are chosen.

To begin this work we propose two post-doctorate research associates, an engineer, and a designer/draftsperson that would require additional resources of about $300,000 per year for three years. The work will be to identify the physics goals, simulate these processes, and define the detector required to achieve the goals. Then, with a specific detector strategy, integrate this with the machine design and data acquisition and control system.

Polarized Source Development for a Linac-Ring Collider

The Linac-Ring e-A collider option has very demanding requirements for a polarized source. A CW source with 100-200 mA polarized beam is needed. The existing state of the art polarized sources today at best provide average currents of the order of ~100-200 μA. These injectors include the polarized sources at Jefferson Laboratory, MIT-Bates Center and Mainz. In order to achieve an increase of the order of ~1000 in the average current requires a substantial level of R&D and effort in polarized source technology. Specifically, high power CW laser systems such as new generations of fiber coupled diode array lasers are needed. In addition, the lifetime of photocathodes under these extremely high average currents would be very short unless the UHV conditions in the polarized sources are also improved one or two orders of magnitude. Another limitation on the maximum current from high polarization photocathodes will be the surface charge saturation of the GaAs based samples. The surface charge limit is a strong function of the laser power density. One way of reducing the laser power density is to increase the active area of the photocathode by about an order of magnitude over the existing ~1cm photocathodes. This increase would require a major modification in the design of the gun geometry as well as in the injector beam optics. The polarized source R&D for EIC will require approx. $200,000 per year for three years. All the funds are for Capital Equipment.