Xelera Research LLC

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Contents

1 Significance, Background Information, and Technical Approach

1.1 Identification and Significance of the Problem or Opportunity, and Technical Approach

A number of electron-ion collider facilities for nuclear physics research are under consideration in the US. At Brookhaven National Lab (BNL), the eRHIC (electron Relativistic Heavy Ion Collider) facility would use the existing ion/proton facility (RHIC) and augment it with an electron accelerator. At Thomas Jefferson National Accelerator Facility (JLab), they plan to use the existing CEBAF machine and add an ion/proton accelerator, as part of the Jefferson Lab Electron-Ion Collider (JLEIC). All such facilities require that the ion beams be cooled in order to reach the luminosity goals. Different methods of cooling the ions using an electron beam are envisaged. BNL is pursuing coherent electron cooling and non-magnetized, bunched-beam cooling, while Jefferson Lab is considering magnetized cooling.

A good review of all types of cooling is described in reference [1]. Low energy cooling using a DC electron beam has been in use for many decades, and is well understood [2]. More recently, Fermilab demonstrated relativistic cooling using a high energy (4.3 MeV) beam from a Van de Graaff [3]. Neither relativistic magnetized cooling nor bunched beam cooling have yet been demonstrated. A system for cooling using non-magnetized bunched beams is currently being constructed at Brookhaven National Lab for the next series of experiments at RHIC [4]. At Jefferson Lab, an energy recovery linac (ERL)-based design is used to produce the high average beam currents needed for their magnetized cooling scheme [5].

The JLab scheme has evolved over the last few years into a Circulator Cooler Ring (CCR) for bunched-beam electron cooling [6]. A diagram of the system is shown in Fig. 1.1. This relies on a generating very high charge, magnetized bunches, accelerating in an ERL to 55 MeV, then transfer to a recirculating ring. It is then transported to a recirculating ring and matched into a long, 1 Tesla cooling solenoid where it co-propagates with the ion beam. After cooling for 11 passes, the electron beam is energy recovered. In such a machine, the angular momentum of the beam exiting the gun must cancel the angular momentum induced in the fringe field of the main cooling solenoid (after the beam has been accelerated to 55 MeV).

In Phase I of this project, Xelera Research LLC (Xelera) performed detailed simulations and optimizations of the electron source and injector, known as the "magnetized injector". This work demonstrated that the injector requirements can be met, and also pointed the way towards simplifying the design to reduce costs and enhance

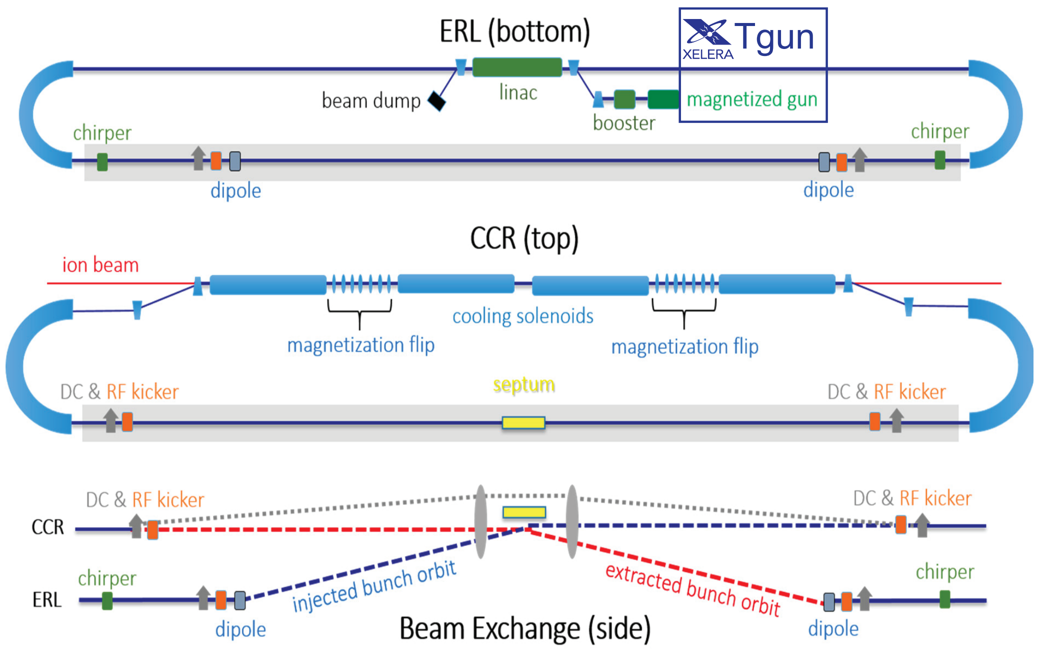


Figure 1.1: The current design for a Circulator Cooler Ring for bunched-beam electron cooling from [6], annotated with the Xelera Thermionic Gun (Tgun).

reliability. The Xelera solution uses a thermionic cathode solution based on low-risk, proven technology. Jefferson Lab is also pursing a more technically challenging solution using a photocathode electron source. Either source can be substituted into the final injector design. The details of the Phase I solution using a thermionic gun are described in §1.3.1.

In the Phase II project (still in progress), we designed and built a thermionic gun immersed in a magnetic field based on the results of the Phase I work. It will soon be transported to JLab and tested in their gun test facility (GTF). There, the operation of the gun can be demonstrated and beam properties characterized. The details of the gun design and experimental plans are described in §1.3.2.

For this proposal, Phase IIB, we propose to extend the work in Phase II to build a system that will be close to what is needed for the final CCR and lead to a commercial product that can be sold to national labs for future cooling, or other, projects.

1.2 Anticipated Public Benefits

Constructing the next generation of electron-ion colliders for nuclear physics research is an important goal for the U.S. scientific community [7]. Cooling the ion beams to increase the luminosity for the physics program is vital to the success of these machines. Magnetized electron cooling has been chosen as the method to use at the Jefferson Lab Electron-Ion Collider (JLEIC) currently being designed in Newport News, VA.

During this project, an effective magnetized injector for electron cooling of ion beams will be designed and optimized. In addition, a process will be developed for the design which can be applied to any similar accelerator system, thus extending the usefulness of the project beyond one particular machine. Other industrial and research accelerators that require a sophisticated electron source will also benefit from these design methodologies.

In addition to electron cooling, magnetized electron beams are of interest for other applications such as flat beam klystrons, and novel means for producing bright beams for micro-undulators and compact X-ray sources. For example, flat beams generated from a magnetized injector (using emittance exchange techniques), in conjunction with low emittance, enable RF sources with frequencies above 100 GHz [8]. While the market for high performance machines for electron cooling is limited, the market for high frequency RF sources and compact X-ray systems is considerable. Thus, the design methodologies and hardware developed in this project will have a wide range of applicability.

Future accelerator projects at national labs and universities, and for industrial uses, often require novel particle sources and injectors to achieve their full performance and scientific goals. In many ways the performance of the next generation of particle accelerators depends on the performance of the source of their particles, the 'injector'. By advancing the technology of the source, we can also advance the capabilities and science achieved with the next generation of accelerators, enabling new types of research. Accelerator designers require these novel injectors but often do not have all of the skills necessary to build them. Xelera Research LLC was founded by a team of researchers from Cornell University where the world's highest brightness electron injector was built, thus has the skills and experience to fill this need.

Accelerator labs typically build their own injectors or work collaboratively with each other to build them. For example, both Cornell University and JLab maintain a healthy injector group of 5–6 staff full time and have the capability to build their own injectors. Maintaining these staffing levels is expensive considering that only one injector is built perhaps every three to five years. There is a burden to maintain these staff members whether they are currently building an injector or not. Funding cutbacks have led to reduction in the capability of some of these groups, so that commercial solutions are increasingly attractive, assuming a company with the required skills exists and has alternate lines of work for periods between injector projects.

In addition to being one of the few potential commercial suppliers, Xelera utilizes massively parallel computing and genetic optimization codes written by Xelera to design these injectors for maximal performance. Without these optimization and physics modeling capabilities the performance of these injectors could not be determined in advance of commissioning. In fact, the design tools have improved greatly in the last few years and new designs typically work as promised right out of the box. In addition we are unique in offering everything from the physics design, mechanical design, vacuum and high voltage design, to fabrication and testing within a single company, because we have experience with all aspects of the design and construction of these injectors.

At the conclusion of this Phase IIB project, we will have demonstrated our ability to deliver an outstanding product to meet the needs of the accelerator community. We can then expand on these results in a future commercial projects and become the company of choice around the world for the design and construction of complex injector facilities, whether for research needs or industrial applications.

1.3 Degree to which Technical Feasibility has been Demonstrated

1.3.1 Phase I

In our Phase I project, Xelera Research LLC performed simulations and calculations to develop a prototype design for a magnetized electron injector that can be used as a source for cooling an ion beam [9] .

To enable the design work, we first developed our own software optimization framework using genetic algorithms to drive the most reliable and well-known space charge simulation codes. These types of optimizations are massively parallel, and so we chose to utilize cloud computing services of the Google Computer Engine [10], rather than to build our own local cluster, which would have been prohibitively expensive. With this cluster we were able to get speedups of a factor of 50–100 over what could be done on a single computer.

We then used this framework to study various magnetized injector layouts. The injector consists of an electron gun with an external solenoid, bunching/debunching cavities, and superconducting RF (SRF) or normal conducting RF (NCRF) booster cavities to accelerate to energies around about 5 MeV. We produced optimized de-

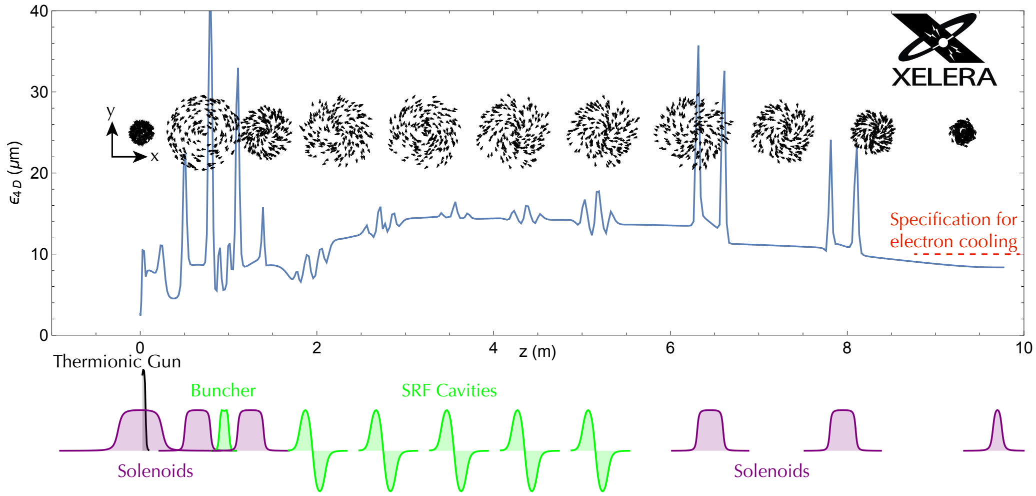


Figure 1.2: The uncorrelated emittance along one of our optimized magnetized injector layouts.

signs for various combinations. With constraints, we primarily optimized for the tradeoff between the dechirped relative energy spread and the 4D (uncorrelated) emittance ϵ_{4D}. Limiting this emittance is the key to delivering a well-preserved magnetized beam into a strong solenoid for ion cooling, which we justified in a theory section of the final report. The specification for the magnetized beam in the Jefferson Lab machine is $\epsilon_{4D} < 10\,\mu$m. The dechirped energy spread is that which remains when removing the linear correlation in the longitudinal phase space, and must be less than 0.02. This constraint was easily satisfied. We primarily used the space charge code GPT [11] and two-dimensional (cylindrically symmetric) field maps.

This work demonstrated the viability of our parallel genetic optimization software and cloud computing solutions. Three magnetized injector designs were created, optimized, and evaluated. In particular, the uncorrelated emittances between 3 to $5\,\mu$m have been produced using a 350 kV DC photo-gun coupled to both a SRF and NCRF linac.

Similar performance can be achieved using a thermionic gun followed by the same SRF linac when operating the gun at 350 kV. Lowering the gun voltage does degrade the performance, however uncorrelated emittances of around 7 μm can be achieved at voltages as low as 200 kV, making the thermionic gun a candidate for a low risk source option. Figure 1.2 shows an optimized layout for this case.

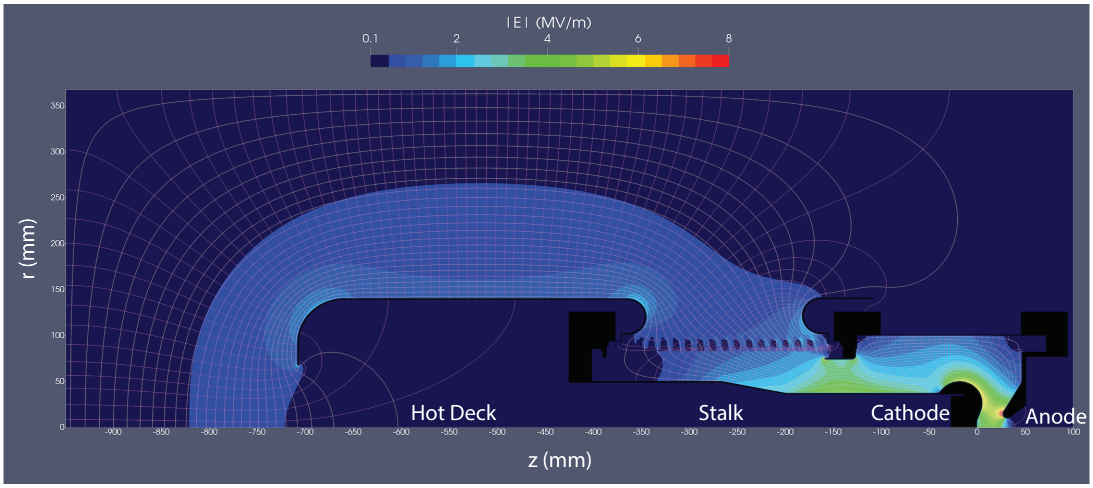


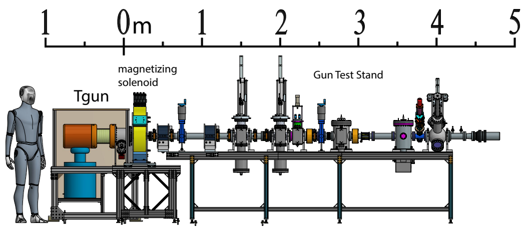
Figure 1.3: Full axisymmetric Tgun electrostatic design. The cathode and anode shapes were optimized for beam emittance preservation. Off-axis surfaces were also optimized to have a field of less than 7 MV/m to reduce the chance for field emission. This was calculated by Poisson [13].

1.3.2 Phase II

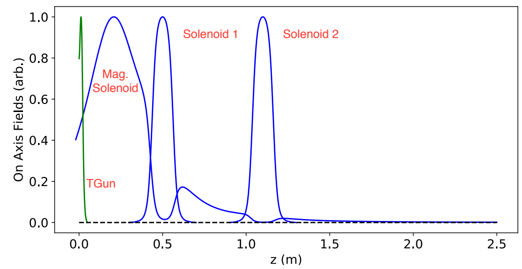
For the initial Phase II project, in progress, Xelera is building a proof-of-concept thermionic gun operating at 100 kV, with a maximum current of 50 mA. This device is nearly complete, and will soon be shipped to JLab for for initial beam characterization. This work has been done from the beginning in close collaboration with the JLab injector group.

For the electrostatic design, we further developed the genetic optimization tools from Phase I to use Poisson [13] optimize the gun geometry for magnetized beam emittance preservation. Figure 1.3 shows the full electrostatic design. In addition to beam considerations, the geometry was optimized for reasonably low cathode surface fields, and corona ring protection around the insulator triple points. To show that emittance and magnetization can be preserved from this device, we modeled it completely using the Gun Test Stand (GTS) layout at JLab. Figure 1.4 shows this setup and optimized simulations.

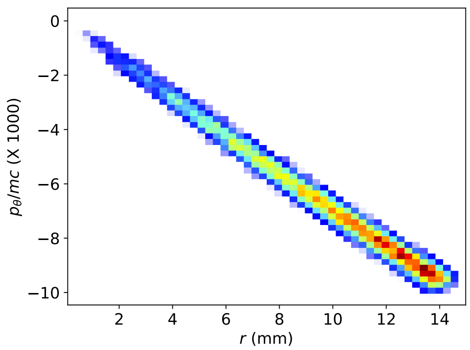
The vacuum system design is shown in Fig. 1.5. The layout of the JLab Gun Test Stand, with its grounded cage, isolation transformer, and RF components hot deck are shown in Fig. 1.6. Finally, Fig. 1.7 shows photographs of the assembly at Xelera's facilities.



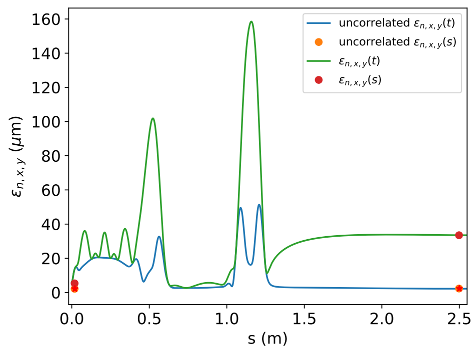
(a) Gun Test Stand layout



(b) On-axis E_z and B_z in the GTS



(c) Magnetization preservation



(d) Emittance preservation

Figure 1.4: Simulation of the preservation of the magnetized beam the first 2.5 meters of the JLab Gun Test Stand (GTS). (a) GTS beamline (b) On-axis accelerating field E_z (green) and solenoid fields B_z (blue). (c) The correlation between rotational momentum and radius (the magnetization) at the end (d) The correlated emittance at the end is 36 μm,

2 The Phase IIB Project

2.1 Technical Objectives

The design of the CCR for bunch beam electron cooling at the Jlab electron-ion collider has continued to evolve over the past several years, as was described earlier and in reference [6]. Our Phase I and Phase II awards, wecarried out initial design and then construction and testing of a thermionic gun that could eventually be used as the electron source for the ring. As the gun parameters are quite challenging, we proposed a staged approach that could be extended later to reach the final, desired

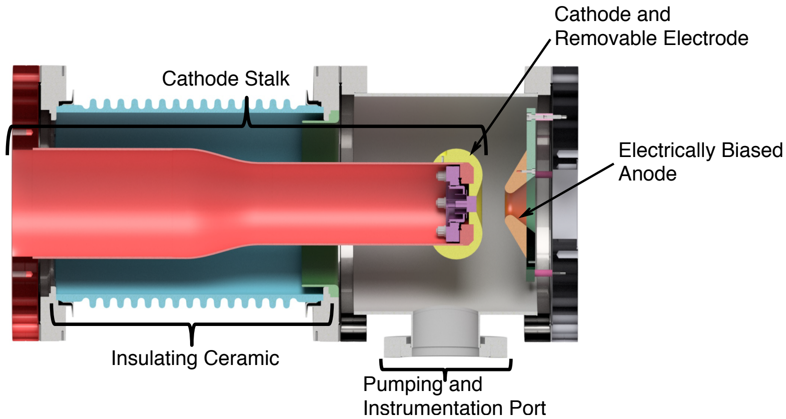


Figure 1.5: The Tgun vacuum system design.

Table 2.1: Electron source parameters for the existing Phase II project, this Phase IIB proposal, and a potential Phase III commercial item that satisfies the needs of the JLEIC electron cooler.

Parameter	Phase II	Phase IIB	(Phase III)	Unit
Voltage	100	350	450	kV
Bunch Charge	0.100	3.2	3.2	nC
frequency	500	43.3	43.3	MHz
Duty Factor	100	5	100	%
Max Average Current	50	7	130	mA
Magnetized (drift) emittance	< 36	< 36	< 36	μm
Thermal emittance	< 10	< 19	< 19	μm

parameters.

At the beginning of Phase I, it was suggested that an electron gun with 350 kV and 200 mA average current would be needed to meet the cooling requirements. While building a gun with this high power level is possible, the cost would exceed amounts typically available to Phase II SBIR grants. Thus, as part of the Phase I simulations, we investigated the possibility of using a lower voltage gun to determine if the beam parameters could still be met by a less complex and cheaper device. As discussed in §1.3.1, Phase I results indicated that with voltages as low as 200 kV the required 4D beam emittance could still be achieved. During Phase IIB, we will continue optimizing for high bunch charge, with the goal of meeting ion cooling emittance requirements.

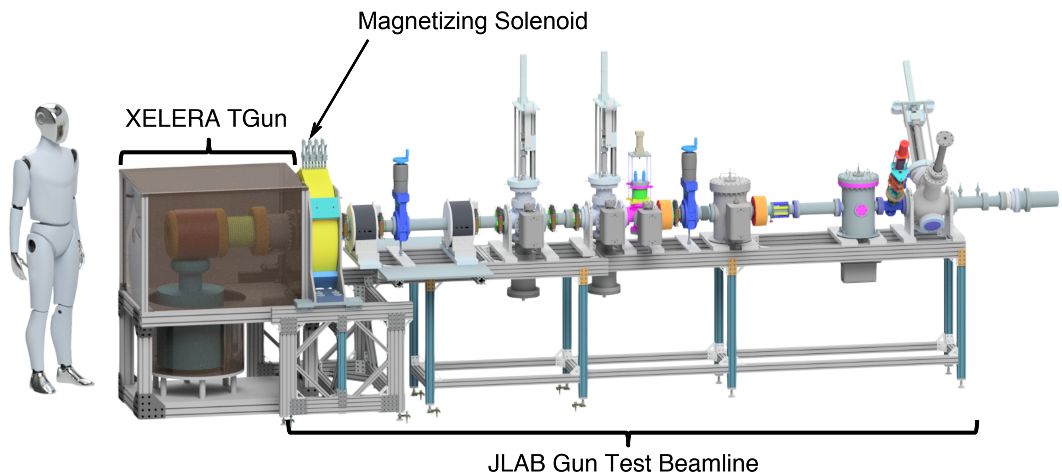


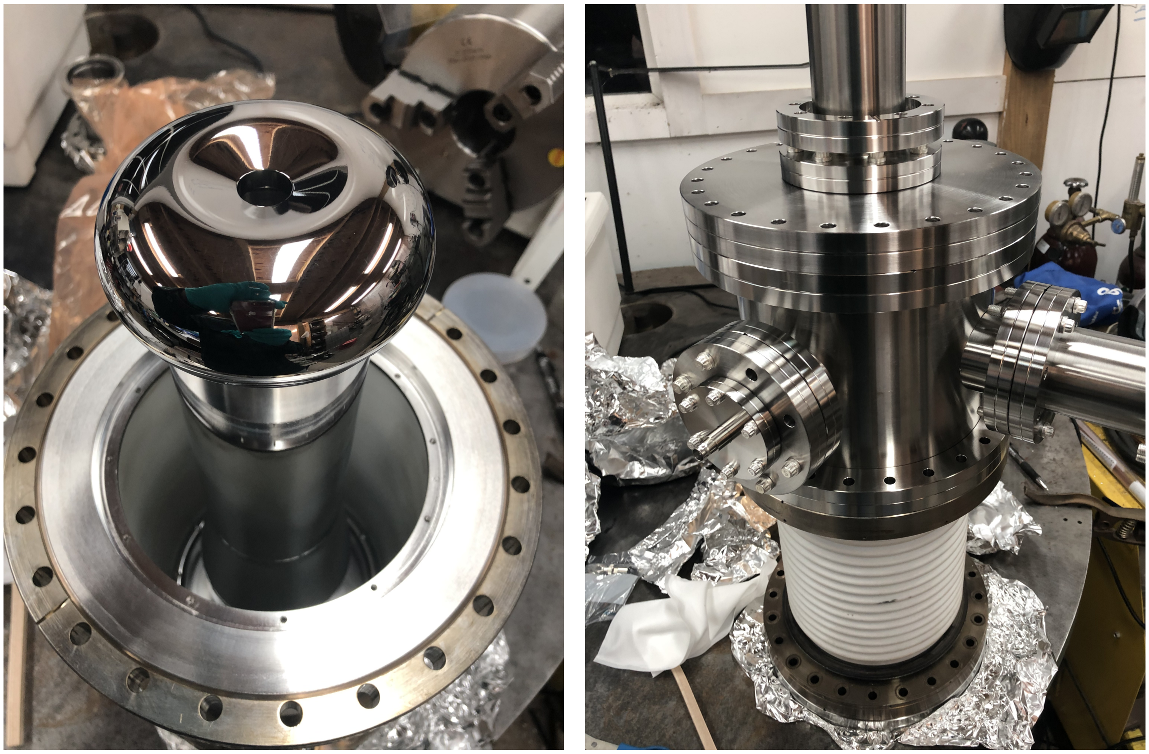
Figure 1.6: The Xelera Tgun in the Gun Test Stand (GTS) at JLab.

In the Phase II project, in order to keep the costs to a reasonable level (and after consultation with JLab scientists) we decided to use a gridded-thermionic gun with a 100 kV beam energy and 50 mA average current, as a first step towards the final goal. These levels are chosen for specific reasons, mainly to reduce cost and to increase the chance for success in the short time period of this project. A 125 kV, 50 mA DC power supply is commercially available, again reducing costs and allowing for quicker project initiation, and 100 kV insulator bushings are readily available. The progress towards this in the Phase II project was discussed earlier.

For Phase IIB, we are proposing to build a new electron source whose parameters come much closer to meeting the final requirements, and may, with some modifications, fulfill the final design parameters. Similar to the Phase II project, it would be difficult to build a system to meet all the requirements in the time given and finances available, so we plan to design and build a gun with reduced functionality that can still be used to provide experimental verification for the latest CCR design, and be upgradable to the final state in the future. The following sections will provide technical details for the system.

2.2 Work Plan

The work done in Phase I and II was described earlier. We plan to continue the simulations and optimizations of the gun and injection system, incorporating the latest parameters for the CCR in Phase IIB. The Phase II electron gun was a 100 kV, 50 mA gun to be used as a proof-of-concept device, and for initial beam character-



(a) Cathode and stalk (b) Tgun vacuum assembly

Figure 1.7

ization at JLab. For Phase IIB, we plan to build a new gun with a higher voltage (approximately 350 kV, with the final voltage to be determined from simulations), using a similar design to the 100 kV gun for the RF drive and gridding.

The parameter table for the progression of electron sources (Tab. 2.1) shows a 450 kV gun with an equivalent average current of 130 mA as the ultimate source. The team from Xelera has designed and built photocathode guns with operating values near this, but it is still a very challenging task. For example, purchasing a HV power supply for 450 kV/130 mA would be a custom design with a price tag of at least $600k, and a long lead time, far beyond what we could do in an SBIR. As JLab has power supplies in the 400 kV range, but with currents limited to below 10 mA, we propose to make a system that runs at a reduced duty factor. Thus, we can meet the bunch charge requirements, but not the full average current needs. Additionally, we have designs for HV insulators that can operate above 400 kV in an SF_6 atmosphere, but plan to keep the voltage at or below 350 kV so we can run the system in air without a SF_6 pressure vessel. All of the components will be designed to be compatible with a future upgrade of the power supply and voltage capability. Details of the various components will be described in the following sections.

All design and construction will be centered at Xelera's facility in Ithaca, NY, and led by V.O. Kostroun with the same team responsible for the design and fabrication of numerous previous injector projects. Beam testing will be performed at JLab in the Gun Test Facility with Xelera's experienced staff present. The success of this project will position Xelera as a unique commercial supplier of injector components for worldwide accelerator projects.

2.2.1 Thermionic Cathode Selection

Gridded, thermionic dispenser cathodes are commercially available, (from CPI for example [12]) and mounted on conflat flanges for ease of replacement. In the gun design, the cathode flange can easily be exchanged by removing the hot deck assembly mounted on the HV insulator flange. Forced air circulation into the bore of the insulator will cool the cathode.

It is important to determine if a cathode is available for the full beam current expected by the ultimate gun which will provide ~130 mA. For this target beam current there is basically only one choice of cathode: the Eimac-CPI YU-156. The grid has to be negatively biased with ~200 V (DC) and modulated by a 220 V radio frequency signal. The RF power is expected to be 50 to 100 W depending on the details of the feed design, all of which are routinely feasible.

Preliminary emission model calculation show that the Eimac-CPI YU-156 cathode, operated at 43.3 MHz would deliver 3.2 nC bunch charge with an emission angle of $\sim 26°$ applying voltages of less than 200 V (RF and bias) assuming a small signal gain of 65 mA/V. The peak current in this scenario is 1.3 A which is well below the YU-156 cathode rating of 18 A.

2.2.2 Electrostatic Design of Gun Electrode Structure

The electrode structure, with a Pierce-type configuration, will be analyzed using Poisson-Superfish [13] and optimized using our genetic optimizer code. The electrostatic design of the cathode and anode shapes and spacing will be driven by the optimizer and Xelera HV design rules, and refined with field maps used by the injector modeler utilizing the same design process as in Phase I. We expect the Phase IIB gun geometry to be similar to the Phase II system, but scaled up to accommodate the higher voltage and potentially a larger dispenser cathode. We will apply our design expertise to determine a reliable, trouble-free geometry.

2.2.3 High Voltage, Vacuum and Mechanical Design of Gun

To simplify the HV design and the magnetic coil design, we plan to use a scheme as shown in Fig. 1.5. By moving the cathode and anode into the chamber downstream of the insulator, it will be simple to generate a uniform magnetic field around that region. In addition, any material evaporated from the cathode will be shielded from the insulator body, reducing any chance of eventually shorting the insulator. The main design limitation with this scheme is that a large central tube must be used, which is at HV, and the ID of the tube must be large enough to fit the cathode assembly.

Besides these considerations, the gun and vacuum system are constructed using commercial components. The vacuum chamber, at ground, will be procured early in the project and will be pumped by a combination ion-NEG pump. This is beneficial because it can maintain vacuum during transportation to JLab. The gun will have a gate-valve downstream of the chamber so that it can be attached to existing diagnostics without breaking gun vacuum. All internal HV surfaces will be machined to a surface finish of 1.6 μm, then polished using standard techniques. All parts will be cleaned for ultra-high vacuum conditions and rinsed with high pressure DI water. Assembly will take place in a small clean room to prevent particulate contamination.

The Xelera team has designed and built several HV insulator stacks that have operated at or above 350 kV. The main difficulty with insulators is procurement, as there are only a few vendors that can manufacture them. As we have proven designs ready we will need to begin the procurement process as soon as possible.

2.2.4 Magnetic Modeling and Mechanical Design of Solenoid

The key defining feature of this injector is the magnetic field imparted on the cathode and thus the angular momentum of the emitted electrons. The solenoid is mounted to the exterior of the vacuum chamber and is movable, to allow for vacuum bakeouts of the chamber. Because the gun vacuum space is terminated with a beamline gate valve, the solenoid is trapped and the chamber needs to allow for the solenoid to move far enough to access the chamber for baking without adversely heating the solenoid magnet. We will re-use the solenoid from Phase-II.

2.2.5 RF Drive Design and Implementation

For this Phase IIB proposal we will follow the principle of getting pulsed emission from a gridded cathode as in Phase II. Like in a triode, emission is controlled by the grid voltage. To obtain a pulsed emission with angle of 26°, the harmonic drive

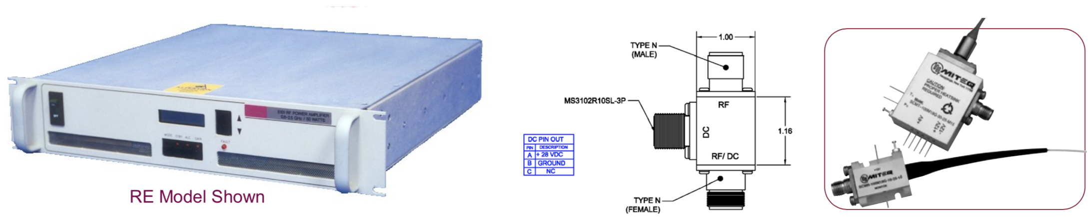


Figure 2.1: Identified RF hardware: 40 MHz, 100 W (saturated) amplifier from OPHIR-RF (Model 5044) on the left to be used for the harmonic drive. In the middle the 50 Ω Bias-T from Metropole Products (FTP-14BH) is shown that can add up to 200 V bias to a 200 W RF signal. On the right is the fibre optic link, available from MITEQ that was also used in the Phase II: It will be used to prove the RF low level drive to the hot deck, bridging the high voltage gap

plus a bias voltage has to be applied to the grid. During the Phase II work, we have gained detailed insight on how to do this which allows us now to calculate the RF requirements with high confidence. All parameters, already laid out above, are well within state-of-art technology.

To provide the RF power to the grid, we will follow our Phase II approach: The 50–100 W RF power, including the bias voltage and grid matching, will be located on the hot deck. Due to the lower frequency in this proposal we cannot use a coaxial RF feed to match the cathode impedance and to provide the biasing. Instead, we will use a Bias-T commercially available (which limits us to stay under 200 V for the bias) and add a resonant circuit to match the impedance which needs to be designed within this proposal.

For additional controls and macro-pulsing we can copy substantial parts of our Phase II design. However, we will look into the RF-over-Fibre technology to streamline the design which might allow us to reduce the hot deck equipment significantly, which is a significant due to the higher gun voltage.

Fig. 2.1 shows the key RF components that have already been identified.

2.2.6 High Voltage Power Supply and Hot Deck Implementation

As mentioned before, high voltage power supplies with high average currents are not readily available, and would be a custom design with a cost of at least $600k. For Phase IIB tests, we propose to use an existing supply at Jefferson Lab which can provide the high voltage but only at currents <10 mA, and run the beam tests at a reduced duty factor. By taking this path, we can provide the majority of the beam parameters, but not at 100% duty factor.

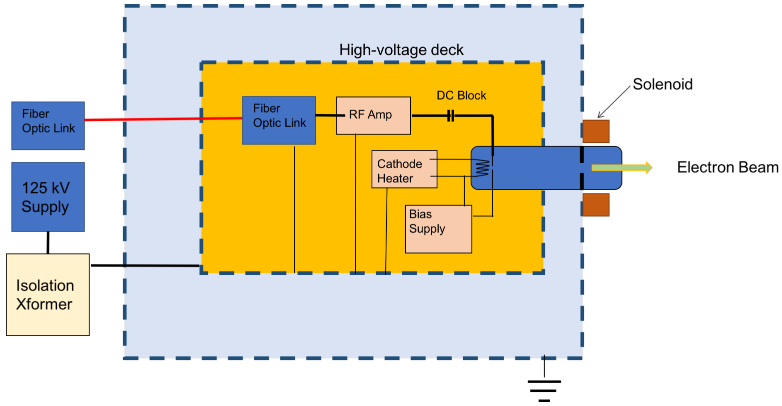


Figure 2.2: Schematic of the cathode RF drive system: An isolation transformer allows AC power to be provided to the RF amplifier, the DC biasing power supply and the cathode heater on the high voltage deck.

In order to provide power to the cathode heater and RF drive amplifier, an isolation transformer is needed. The isolation transformer allows AC power to be floated on top of the DC HV platform, and then connected to the gun. For Phase II we purchased a 150 kV isolation transformer using solid insulation from Stangenes Industries, and are in discussions with them to design a higher voltage device for this project.

For safety reasons, the gun insulator, filament power supply, and RF amplifier are mounted inside a grounded, interlocked box. The ground from the isolation transformer cable is connected to the outer box, the common conductor to the gun insulator and the AC power cables to the filament and RF power supplies. The HV power supply is interlocked to the box, and will shut down if any side of the box is opened. The entire box is mounted on robust HV insulators used by the power industry. This is all shown in Fig. 2.2.

2.2.7 Testing

Initial tests will be performed at Xelera's facility in Ithaca, NY. All of the hardware will be built and prepared for assembly. Once the gun is assembled, a lengthy bake-out will be performed in order to minimize chamber out-gassing rates and to achieve a suitably low pressure. A series of vacuum tests will be performed to verify the vacuum integrity of the chamber, cathode, and insulator. In addition to a simple leak check, residual gas analysis will be used to ensure the absence of any unwanted vacuum contamination. Once an acceptable vacuum level has been achieved, the hot deck will be installed on the back of the gun along with the RF drive and filament power supply.

In the first phase of testing, the gun will be processed using the high voltage power supply with a progressively increasing voltage. Typically this step can be extremely laborious, but our polishing, vacuum cleaning, and high pressure rinsing processes have been optimized to reduce the difficulty of processing HV structures at high field strengths. Still, the processing can consume many tens of hours in order to reach full field. The gun will be processed to a voltage roughly 25% beyond its operation point in order to eliminate stray field emission and to minimize random trips during routine operation. An electron source for an EIC would be in continuous operation 24/7, and long term testing of the proposed source is not possible in the short term of the grant. Reliability tests will be done for an extended period of time, 24–48 hours, to determine if there are any unexpected drift or warm-up effects in the high voltage system, the RF drive amplifiers, or progressive vacuum degradation during cathode emission. The primary operational concern will be adequate cathode cooling by the fan mounted on the hot deck.

The second phase of testing will be done at JLab in Newport News, VA where the gun will be installed on a diagnostic beamline at the Gun Test Facility. Xelera staff will work alongside JLab staff to install and test the gun at their facility. Transporting an electron gun can generate internal particulate contamination as particles are generated and migrate during vibrations, thus it is expected that a period of basic processing will be required at JLab to recover gun high voltage performance. After processing, basic checks of the cathode and RF drive will be performed. We expect that 2 to 4 weeks will be required to get the gun up and running at JLab.

The JLab gun test facility includes a beam line with diagnostics to quantify the performance of the gun. Measurements to verify the beam current and bunch charge will be repeated. Transverse emittance will be measured and compared with expected values from a beamline simulation. The energy spread of the beam will be measured using a dipole followed by a slit scan and Faraday cup, and the degree of magnetization will be checked using a slit and a viewscreen.

2.3 Performance Schedule

The project plan is given in the Gantt chart in Fig. 2.3 and will be completed in 24 months. The first budget period will focus on the mechanical and vacuum design and verification modeling of the gun. The design will be finalized with a design review with our JLab collaborators at roughly month 8. The vacuum chamber will be procured in the first budget period after completion of the design review. The design

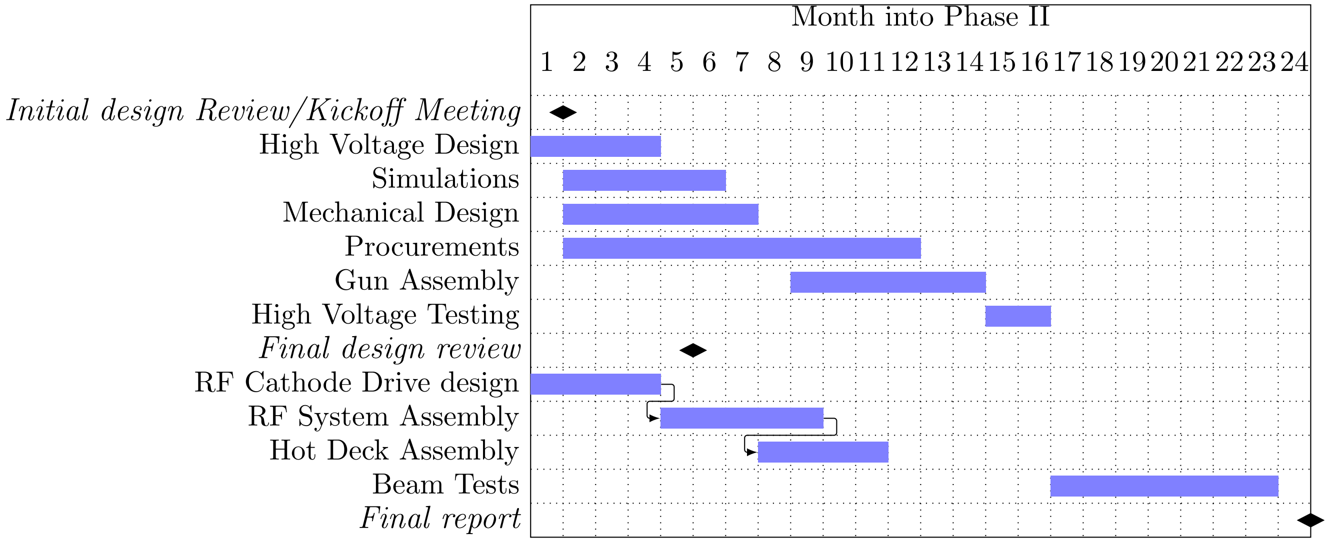


Figure 2.3: Timelines for the items described in §2.2

of the cathode RF drive will commence at the beginning of the project. Some initial testing of the RF drive can start as soon as commercial components are received. At the close of the first budget period, all design documentation will be completed and much of the procurements will have begun, so that components will be on hand for the second period.

The second budget period will focus on completing the assembly of the gun early in the period. Testing at Xelera will begin in this second period and the project will finish with final testing at JLab. The exact timing of the final testing with our laboratory collaborators at JLab is impossible to determine, so we have allowed for 1 month of float in the schedule so that we can complete testing within the 2 year budgetary period.

2.4 Facilities/Equipment

Xelera has adequate computing resources for the design and modeling of the gun. For beam dynamics simulations we augment our internal computing resources with cloud based parallel computing provided by Google [10]. Additional computing resources may be provided by JLab for beam dynamics simulations specific to their EIC design work through a CRADA agreement.

Xelera maintains a workshop of 2000 sq. ft. with adequate working space for the construction of the gun. While we intend to rely on outside machine shops and vacuum fabricators for the bulk of manufacturing of the gun and related components, Xelera has its own machine shop for light duty, short run machining. Our shop equipment includes a 2 and 3-axis Bridgeport CNC milling machines, a Monarch 10EE tool room lathe, and two TIG welders (ESAB 250 amp and Miller 150 amp) for precision vacuum welding. In addition our shop has typical supporting tools: horizontal and vertical band saws, surface grinder, belt sander, and standard metrology equipment.

An existing portable clean room will be used for the vacuum assembly of the gun, providing a particle free environment for reduced processing time at high voltages. Our experience with past projects has shown that modern portable cleanrooms can be very effective in reducing the contamination of the gun, without the great expense of a full scale clean room facility. We will add additional vacuum cleaning equipment, in particular chemical storage cabinets and larger ultrasonic baths for the preparation of parts for assembly into the gun. It is critical to have full control over all aspects of the cleaning and preparation of the components that are assembled into an electron gun.

3 Consultants and Subcontractors

No consultants or subcontractors other than our research collaborators at JLab will be involved in the Phase IIB project.

3.1 Research Institution

A substantial portion (totalling $300,000) of the project will be carried out in collaboration with staff at the Thomas Jefferson National Accelerator Facility (JLab). The certifying official is Joe Scarcello, CFO; Jefferson Lab; 12000 Jefferson Avenue; Newport News,VA 23606-4468; Phone: (757) 269-7027; Fax: (757) 269-7398; email: `Scarcell@JLab.org`. Our technical contact at JLab is Dr. Fay Hannon, email: `FHannon@JLab.org`. She is coordinating our collaboration and testing there. A commitment letter from JLab is attached in Field 12 of this application.

JLab will receive $300,000 total over the budget period which will support the staff working with us to develop the gun and prepare the test cave and carry out gun commissioning and experiments. A design review will be held at JLab late in the first budget period where we will finalize the design of the gun, ensuring that its parameters fulfill the needs of their EIC design program. These funds will cover not only the staff time, but the costs of supporting the test facility infrastructure and diagnostics.

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[9] Grant No. DE-SC0015186, for a Small Business Innovation Research project entitled "A Magnetized Injector for Electron Cooling Applications" to Xelera Research LLC, DOE-XELERA-0015186, (February 2016 – November 2016).

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[11] GPT - General Particle Tracer, Pulser Physics, http://www.pulsar.nl

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