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A NORMAL CONDUCTING RF GUN AS AN ELECTRON SOURCE FOR JLEIC COOLING

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Abstract

The baseline design for a magnetized injector for the bunched-beam electron cooler ring, as part of the Jefferson Lab Electron Ion Collider (JLEIC) uses a DC photocathode electron gun as the source. A challenging aspect of this concept is transporting a 3.2nC electron bunch at low energy and preserving the angular momentum. An RF gun source has been investigated to gauge the potential advantages of high gradient on the photocathode and higher exit energy. The design is presented and compared with the baseline results.

INTRODUCTION

Jefferson Lab is currently in the process of designing an electron ion collider, JLEIC, to be built on-site utilizing existing accelerator facilities. The proposal for this machine is to have unprecedented luminosity of 10^{33}–10^{34}cm^{-2}sec^{-1}. The luminosity is heavily dependent on ion cooling in both the booster and the storage ring of the accelerator, shown in Figure 1 [1].

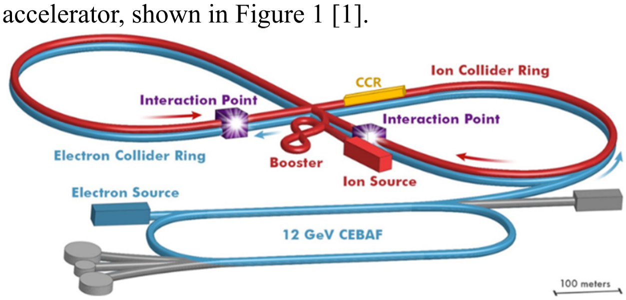

Figure 1: A schematic of the JLEIC accelerator complex.

To counter the effects of emittance growth from intra-beam scattering in the ion beam, electron cooling is employed. The cooling in the booster will be a conventional DC cooler of a similar design to COSY. The high-energy storage ring will require novel bunched beam cooling to achieve the required luminosity. The JLEIC design considered and investigated two concepts for the cooling. The first is based on a standard Energy Recovery Linac (ERL) [2], the second uses a Circulating Cooling Ring (CCR) [3], which also leverages energy recovery and a harmonic kicker cavity to reduce source current [4]. This is due to the electron bunch making several passes through the cooler loop before being energy recovered. This paper discusses the injector design utilizing an RF gun source as shown in Figure 2.

To achieve the high luminosity, the ion beam must be continuously cooled [5]. To improve the cooling efficiency, a magnetized electron beam is used. In this scenario, the electron bunches are produced in the presence of a uniform longitudinal magnetic field. When the electrons exit this field they acquire angular momentum, which if preserved throughout the CCR will be removed as the beam enters the fringe field of the cooling solenoid. Hence, the usual Larmor rotation inside the cooling solenoid is no longer present and electrons are forced to travel along magnetic field lines with smaller helical motion, supressing the electron-ion recombination, thus increasing cooling efficiency.

INJECTOR DESIGN

The baseline design assumes that beam current is delivered from a multi-alkali photocathode inside a 400kV DC electron gun [6]. The typical gradient on the cathode is ~4.3MV/m in this gun. The complete beam parameters for the injector are listed in Table 1. Previously reported results from this design indicate that in order to deliver 3.2nC, the transverse emitting area should be large and the bunch length long, 1cm diameter and 143ps rms respectively. It was also noted that while the bunch is at low energy, below ~2 MeV, space charge forces dominate both transversally and longitudinally, whereas after this soft limit, angular momentum dominates transverse properties. The supposition with substituting the DC gun for an RF gun is that the higher cathode gradient and exit energy will both allow for greater flexibility and performance of the injector.

Table 1: CCR Operating Specification

Parameter	
Energy at the cooler	20-55 MeV
Bunch charge	3.2 nC
CCR bunch frequency	476 MHz
Bunch length at cooler (full)	2 cm
Injector bunch frequency	43.3 MHz
Drift emittance	36 mm mrad

A schematic layout of the RF based injector is shown in Figure 2. For this initial study, rather than designing a new RF gun, geometry very similar to the Boeing photoinjector was utilized. The Boeing gun operated at 433MHz with a cathode gradient of 26MV/m, delivering 2MeV beam. For many years, this gun was a world record holder of 32mA current at 25% duty factor [7]. The gun itself comprised of two short cavities that could be operated independently of one another. We roughly recreated the gun design using the dimensions found in reference [8], and tweaked the design to achieve the correct frequency. It should be noted that with modern simulation tools, we believe we could optimize a similar gun concept for much higher efficiency. This gun has a solenoid between the two cells and a bucking coil behind the cathode. These can be set to provide the magnetized beam with the desired drift emittance. The gun is

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followed by a series of solenoids and single cell cavities aimed at producing beam in excess of 5MeV. The fundamental frequency of the RF is 433MHz to be compatible with the circulating cooling ring frequency of 952MHz.

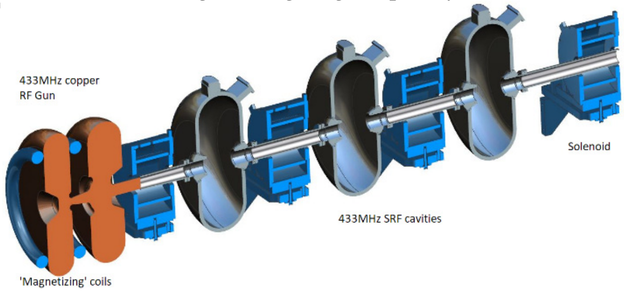

Figure 2: Conceptual design of the RF Gun based injector.

Multi-objective genetic algorithms are commonly used to optimize the performance of injectors, and was employed here. Particle tracking tools are typically excellent predictors for beams that are both travelling close to the ideal axis and small transversely. In this situation, with beams dominated by the angular momentum imparted from the magnetizing solenoid, the beam is large transversely throughout the transport of the injector. Extra care is required that any field maps used are representative and valid at the extremes of the beam. The tracking code General Particle Tracer [9] was used for the optimisation of this injector, and to avoid discrepancies in the off-axis field computation at large radius, 2D or 3D field maps were employed wherever possible in the simulation.

Simulation Results

The objectives of the optimization were to minimize both longitudinal and transverse emittance. Specifically the aim was to minimize the uncorrelated portion of transverse emittance whilst maintaining the correlated drift emittance of 36µm. The Pareto front is shown in Figure 3, depicting a minimum achievable transverse uncorrelated emittance of ~5µm and a low longitudinal emittance in the range of 10-50keV mm.

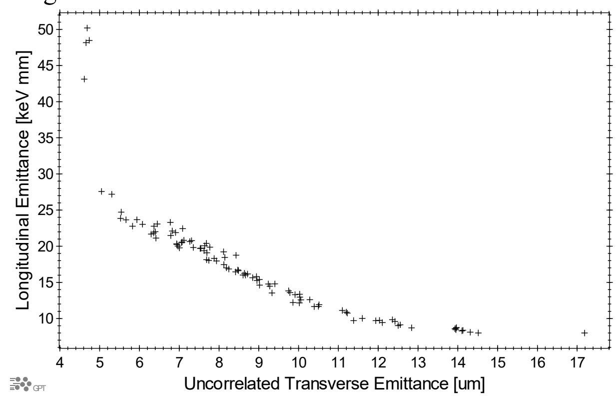

Figure 3: Pareto front of the optimization.

The beam properties of a solution chosen for low transverse emittance are shown in Figure 4, as the bunch evolves through the injector beamline. The beam exits the injector with a kinetic energy of 6MeV, and a longitudinal emittance of 27keV mm, shown in Figure 5d. Additionally,

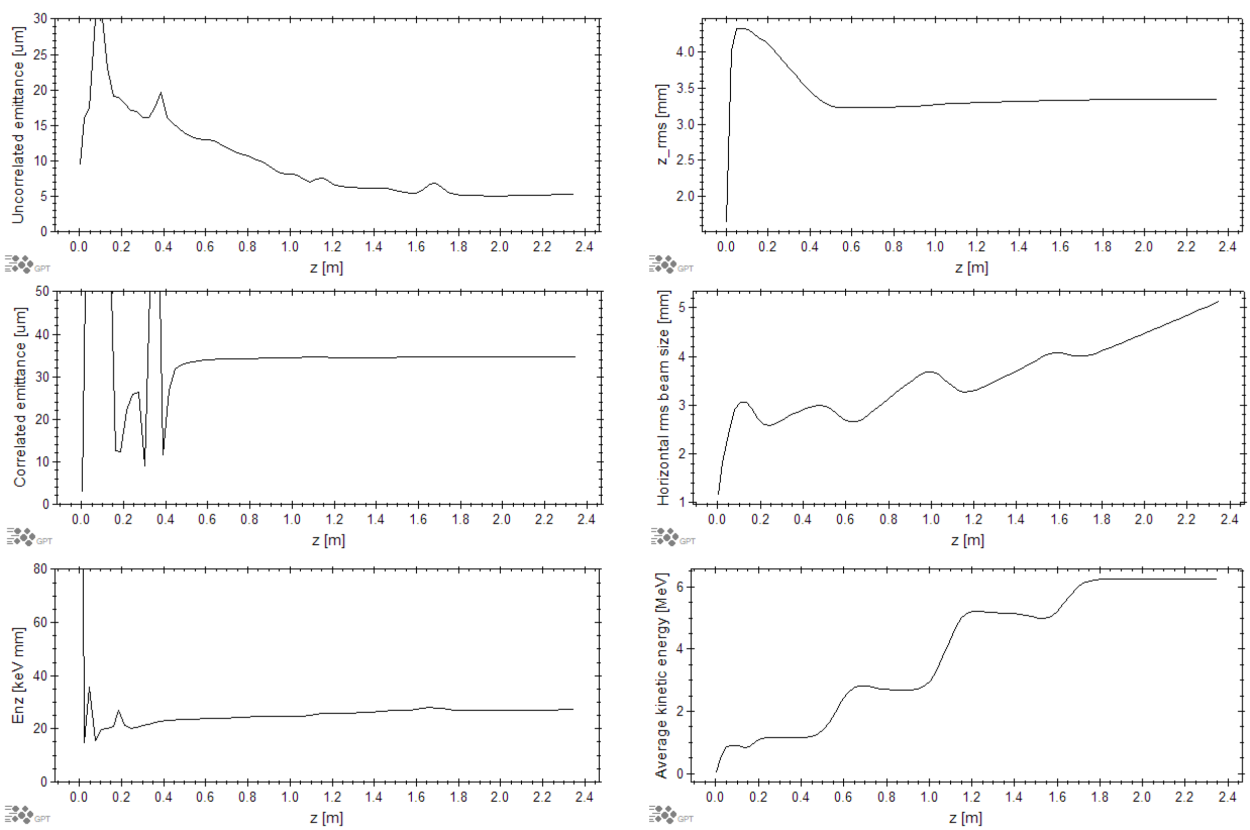

Figure 4: Beam evolution along the injector beamline.

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as the beam is emittance dominated after the first accelerating cavity, the longitudinal pulse shape is well defined as shown in Figure 6. The transverse phase space is shown in figure 5a, which indicates that emittance compensation has been achieved. Furthermore, with simulation is it possible to view the uncorrelated transverse emittance, Figure 5c. This is the emittance that would be evident in the cooling solenoid. Figure 5b, depicting the radius versus angular momentum shows that the magnetization is well preserved through the beamline as this is both narrow and linear.

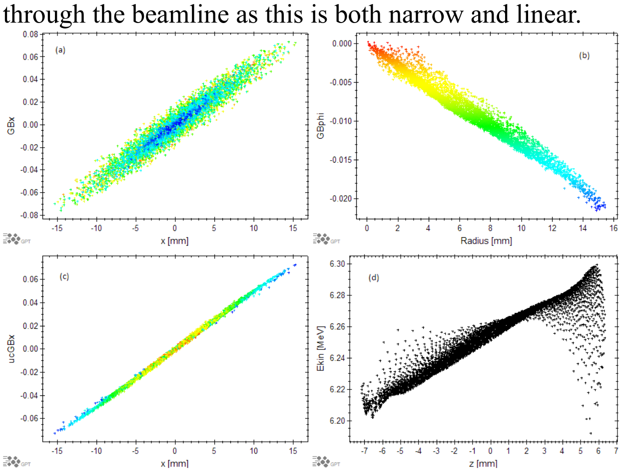

Figure 5: Phase Space at the injector exit, color-coded on angular momentum as shown in (b). (a) Horizontal phase space, (b) radial phase space, (c) Horizontal uncorrelated phase space, (d) longitudinal phase space.

The longitudinal bunch profile is shown in Figure 6, which follows the truncated Gaussian temporal shape of the assumed laser on the cathode. This suggests that with a temporal uniform distribution that there is the potential to maintain this desirable shape, which improves cooling and CSR degradation in the CCR.

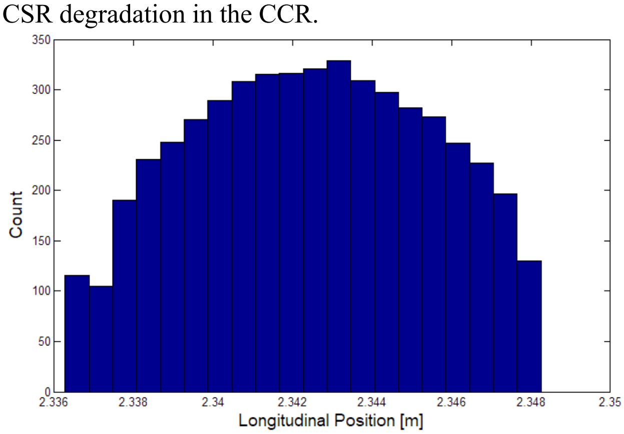

Figure 6: Longitudinal bunch profile at the injector exit.

A comparison of the performance of this injector with the most recent results from the DC gun based injector described in [6] is shown in Table 2. The figures of merit for both injectors are very similar. However, not described in these values, the bunch from the RF gun is more uniform longitudinally and has a more linear angular momentum vs. radius distribution that would improve the matching into the cooling solenoid.

Table 2: Comparison of RF and Baseline Injector Schemes

Parameter	RF Gun	DC Gun
Injector energy	5.84MeV	6.8 MeV
Bunch charge	3.2nC	3.2 nC
Uncorrelated transverse emittance	6.8mm mrad	7mm mrad
Bunch length rms	4.4mm	4.03mm
Longitudinal emittance	27keV mm	26keV mm
Injector length	2m	5m

DISCUSSION & CONCLUSION

The results of this preliminary investigation do not show a clear-cut advantage to using an RF photoinjector source over DC guns. There is benefit to fewer components required and a shorter injector length. The acceleration to MeV range energy in the RF gun offers improvements to the longitudinal profile and magnetization, but these must be quantified and propagated through the CCR to see possible gains globally. Further research will include the effects of uniform laser distributions and higher gun voltage.

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