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MAGNETIZED GRIDDED THERMIONIC ELECTRON SOURCE

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Abstract

A crucial part of achieving JLab's proposed electron ion collider (JLEIC) design luminosity is the application of electron cooling to reduce the ion emittance. One required cooling method is Bunched Beam Cooling (BBC). This cooling process requires beam characteristics that are difficult to achieve. In particular, a high current magnetized electron beam. Here we present a magnetized gridded cathode thermionic electron source, deigned and built by Xelera Research LLC as part of the DOE SBIR program, that could represent the correct technology to use in achieving BBC, as well as a beamline at JLab that will be used to characterize the source.

INTRODUCTION

Thermionic sources operate under the effect of thermionic emission. Applying a current that heats the cathode increases the thermal energy of electrons to the point of overcoming the work function of emission from the cathode to free space. Gridded cathodes driven by RF sources are able to form bunched electrons from an otherwise continuously emitting cathode. One main advantage of the thermionic sources are their robustness and longevity even at high current as opposed to sources like photoelectron guns. Photoguns are highly flexible and offer control over the phase space of the bunch, but have not been proven continuously at very high currents for extended periods. A thermionic gun could be a viable low risk plan; being a robust platform capable of producing the current required for effective BBC [1]. To demonstrate this, JLab has partnered with Xelera Research LLC to design and build a thermionic electron gun as part of the DOE SBIR program [2].

It is likely a thermionic source will be the most viable option to achieve the high average current for the JLEIC design can be achieved with the appropriate bunch charge and repetition rate controlled by the RF gated, gridded thermionic electron gun.

Gridding near the edge of the cathode creates gradients within the E-field that suppress the thermionic emission of electrons. By modulating this field, pulsed electron bunches can be generated. The mechanism of the electron "gating" is straightforward. Have a DC bias voltage from the grid that restricts emission of electrons and drive this bias with an RF at which the peaks above the cut-off voltage allow for electron emission [3,4]. This is illustrated in Figs. 1 and 2.

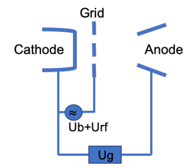

Figure 1: Conceptual cathode, grid, anode diagram. U_g: gun voltage.

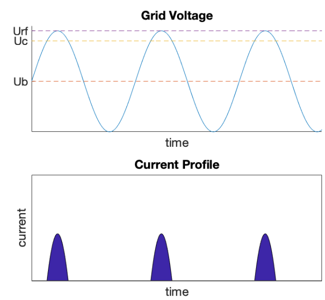

Figure 2: Illustration relating grid voltages to current profile of bunches.

The current emitted as a function of time is given by

$$I(t) = g\left[U_{\mathrm{b}} + U_{\mathrm{rf}}\cos(\omega_{\mathrm{rf}}\, t) - U_{\mathrm{c}}\right], \tag{1}$$

where U_{b} is the grid bias voltage, U_{rf} is the peak RF voltage, U_{c} is the cutoff voltage, ω_{rf} is the angular frequency of the RF signal, and g is the transconductance.

This gun was designed with the potential for magnetization. Magnetization is achieved by immersing the cathode in a magnetic field perpendicular to the cathode surface. By powering a large solenoid at the gun, electrons leaving the solenoid field are imparted with an angular momentum:

$$\langle L\rangle = \frac{eB_z}{2}\left\langle r_c^2\right\rangle, \tag{2}$$

where r_c is the radius of the beam on the cathode, and B_z is the longitudinal magnetic field on the cathode, thus creating a 'magnetized beam'. This is important for JLEIC cooling as this angular momentum cancels fringe field Lorentz force when entering the cooling solenoid, increasing the cooling efficiency [5]. The larger emission radius of a thermionic gun means effective magnetization can be achieved at smaller magnetic field strengths, but the field must be uniform over the emitting area.

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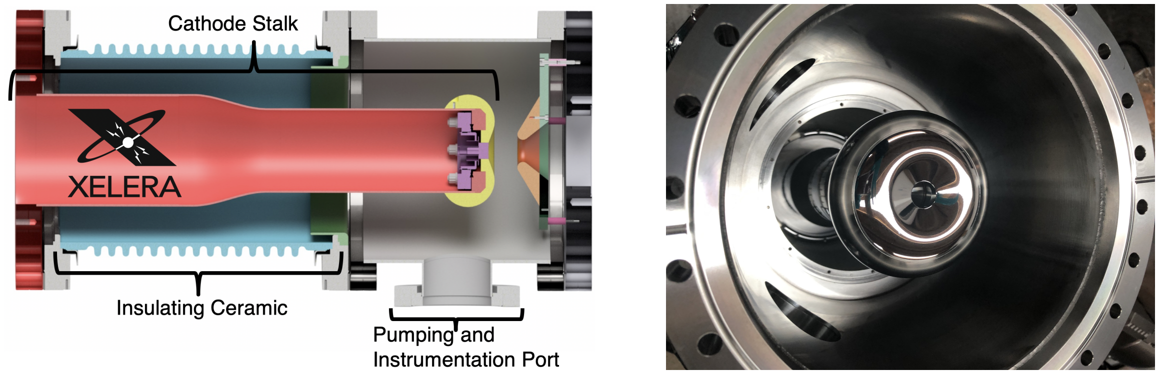

Figure 3: Thermionic electron source design, and assembly at Xelera's facility.

THERMIONIC GUN DESIGN

The thermionic gun geometry was designed and built by Xelera Research LLC, and shown in Fig. 3. Table 1 gives the gun's major design features.

Table 1: Thermionic Electron Source Design Features

Max. Average Current:	65 mA	
Maximum gun Voltage:	125 kV	
RF Frequency:	500 MHz	
Cathode:	CPI Y-845	$R = 0.4$ cm
Nominal bunch charges:	20 pC, 130 pC	
Cathode/Anode Gap:	26 mm	
Cathode Angle:	20 deg	
Anode Angle:	31 deg	
Thermal Emittance:	~ 4 micron	at 130 pC
Magnetized Emittance:	~ 36 micron	

DIAGNOSTIC BEAMLINE

In order to accurately characterize the gun and confirm it matches the design goals, a diagnostic beamline has been constructed with the aim of measuring the main properties of interest. These properties include: longitudinal current profile (Eq. 1), angular momentum (Eq. 2), normalized rms emittance:

$$\epsilon_n = \frac{1}{m_e c}\sqrt{\langle x^2 \rangle \langle p_x^2 \rangle - \langle x p_x \rangle^2}, \tag{3}$$

and uncorrelated emittance (ϵ_{un}). Here m_e is the electron rest mass, c is the speed of light, x is a position coordinate, and p_x is the associated momentum to that coordinate.The uncorrelated emittance being the resulting emittance after correlation from magnetization between coordinates and the corresponding orthogonal momentum is removed. The removal of this correlation numerically is equivalent to

$$p_x' = p_x - C_{yp_x} y, \tag{4}$$

where C_{yp_x} is the linear fit of the correlation in (y, p_x) phase space.

The beamline itself is shown in Fig. 4 and consists of three viewers for steering and measurements, the magnetizing solenoid, five focusing solenoids and seven steering corrector magnets. Current can be measured at the dump and from gun power supply. The viewers also contain a slit and diagnostic tool termed a 1-Dimensional Pepper-Pot (1DPP). The beamline also includes a deflecting cavity that when used with the 1DPP allows for accurate measurement of the longitudinal current profile.

Beamline Simulations

A large number of simulations have been performed using General Particle Tracer (GPT) [6] at various bunch charges and magnetizing solenoid current to have a strong understanding of possible behaviors we may encounter when using this diagnostic beamline. Some of these simulation results are shown in Figs. 5-6. These depict maximum transverse bunch size along the length of the beamline to ensure clean transportation and emittance values for various levels of magnetization.

Figure 7 shows simulations of measurements, and Fig. 8 illustrates promising results demonstrating a good match between simulated measurements and predictive theory of gun characteristics related to the previously mentioned properties of interest.

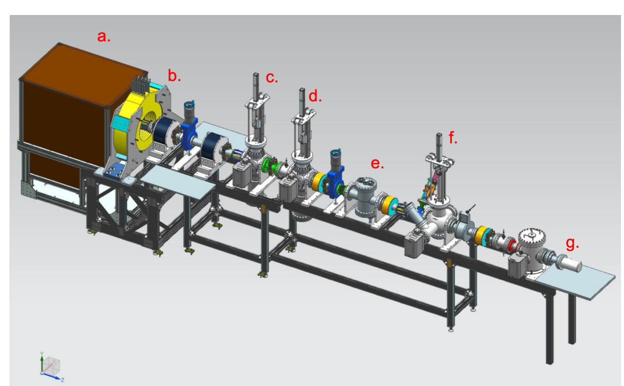

Figure 4: Diagnostic beamline: (a) Gun in faraday cage, (b) Magnetizing solenoid, (c) Viewer 1, (d) Viewer 2/1DPP, (e) DQW Cavity, (f) Viewer 3, (g) Beam dump.

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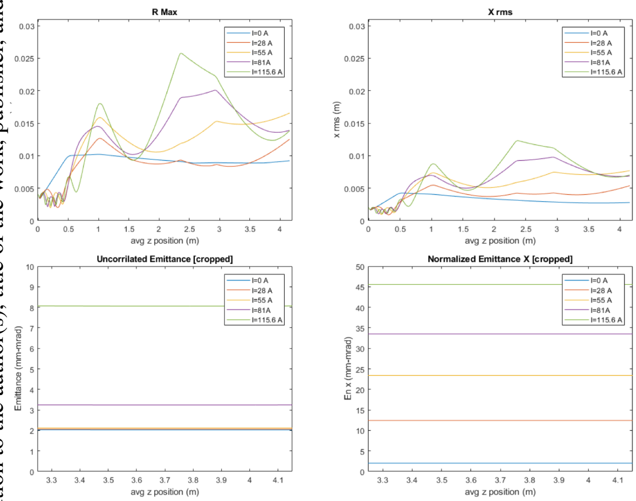

Figure 5: Simulations of transverse size and emittance for 1 pC bunch charges at various magnetizations.

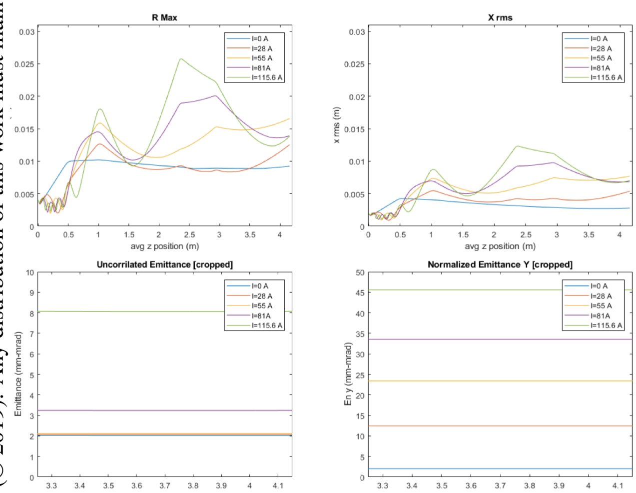

Figure 6: Simulations of transverse size and emittance for 130 pC bunch charges at various magnetizations.

Specifically: $\langle L \rangle$: measurement error < 0.5%, $I(t)$: true 227 ps, calculated 232 ps, error 2.16%, ϵ_n: true value 36.08 µm, calculated 36.24 µm, error < 0.5%, ϵ_{un}: true value 4.91 µm, calculated 5.03 µm, error 2.5%.

CONCLUSION

The diagnostic beamline is complete, and measurements will be made soon to confirm predicted behavior of the design. Validating a reason to continue pursuing this work to develop a gun that will match JLIEC design parameters. In simulation all possible information about the beam properties are directly available and can therefore be compared to the values calculate from virtual measurement as validation of these devices and techniques. All virtual measurements performed for the properties of interest agreed well with theoretical prediction and the values directly from simulation.

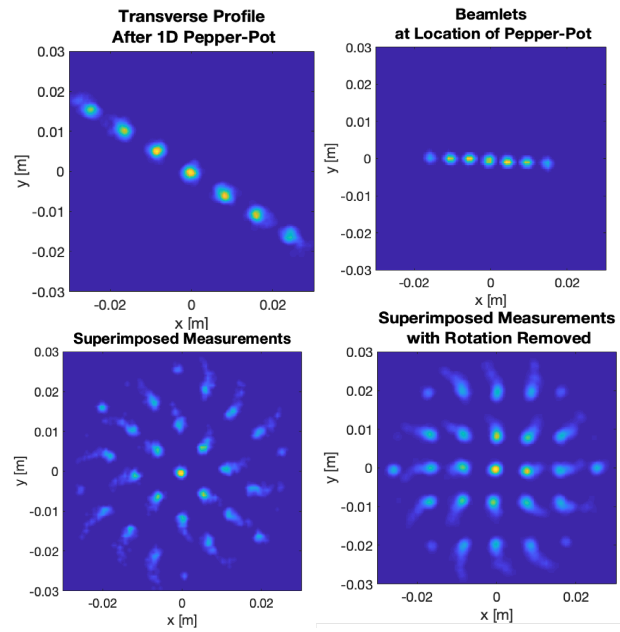

Figure 7: Example of simulated measurement as would be seen on viewer screen.

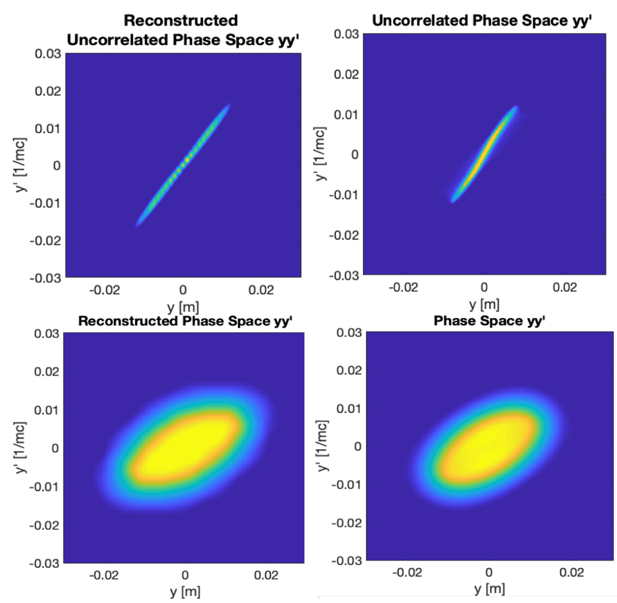

Figure 8: Recreated phase space from simulated measurements.

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