SIMULATIONS FOR PRELIMINARY DESIGN OF A MULTI-CATHODE DC ELECTRON GUN FOR eRHIC *

Q. Wu#, I. Ben-Zvi, X. Chang, J. Skaritka, BNL, Upton, NY 11973, U.S.A.

Abstract

The proposed electron ion collider, eRHIC, requires a large average polarized electron current of 50 mA, which is more than 20 times higher than the present experimental output of a single, highly polarized electron source, based on cesiated super-lattice GaAs. To meet eRHIC's requirement for current, we designed a multi-cathode DC electron gun for injection. The twenty-four GaAs cathodes emit electrons in sequence, then are combined on axis by a rotating field (or "funnelled"). In addition to its ultra-high vacuum requirements, the multi-cathode DC electron gun will place high demand on the electric field symmetry, the magnetic field shielding, and on preventing arcing. In this paper, we discuss our results from a 3D simulation of the latest model for this gun. The findings will guide the actual design in future.

INTRODUCTION

eRHIC requires a 90% polarized electron beam with an average current of 50 mA, more than an order of magnitude higher than the latest achievement in polarized electron sources [1]. As a potential solution, we proposed a multi-cathode design to combine multiple sources for a 50 mA total current. Using what is called as "funnelling", electric and magnetic fields combine the 24 separate streams coming from individual cathodes into one train of bunches exactly on axis. Thus the gun's output current becomes much larger then each single cathode. Figure 1 shows a view of the full setup in its preliminary design. Along with the understanding of the details of this structure that we gain, changes will be made for the final version.

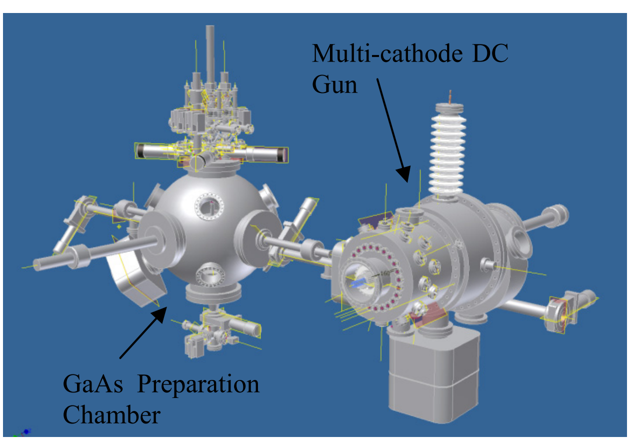

Figure 1: Preliminary design of the multi-cathode electron gun with its preparation chamber.

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#qiowu@bnl.gov

PRELIMINARY DESIGN

With GaAs cathodes, a practically realizable average current is ~2mA [1]. In our design, we have put 24 cathodes together symmetrically on one circular cathode tray. Twenty-four individual laser beams will illuminate them from the front. Figure 2 shows the layout of the cathode tray.

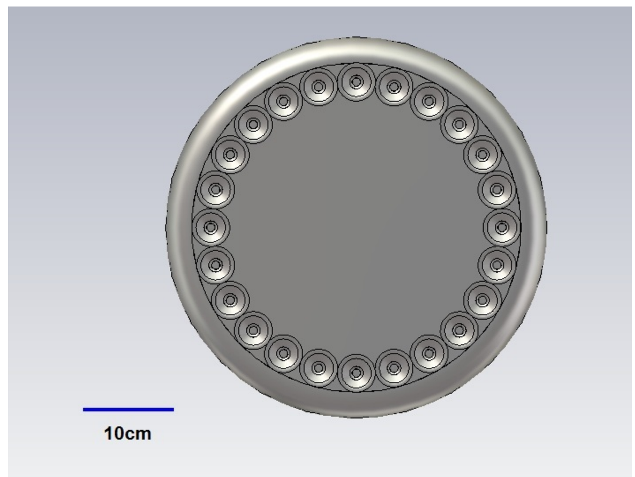

Figure 2: Layout of cathode tray with 24 GaAs sources.

The anode, located 2.66cm away from the cathode's surface, will have 24 cylindrical openings each lined up with one cathode. Inside the anode, each opening will have a solenoid coil with proper shielding and a cooling mechanism for focusing the beam. The opening of solenoid is a compromise between leaving a clear passage for the laser and electron beams, meanwhile affording limited shielding, so that the magnetic field on the GaAs's surface is lowered to a very small value. The cathode tray will be at -200kV, with the anode grounded for electron acceleration.

The electron beam is bent in a simple way by two coaxial circular electrodes as shown in Figure 3. The inner electrode will be grounded, and the outer electrode will have a voltage of -40kV. After acceleration by the anode, the electron bunches from each cathode will be bent towards the gun's central axis.

The anode is designed with a hollowed central area, which will be filled with non-evaporable getter (NEG) material. NEG panels will also be installed on the prominence of the anode after the bending electrodes, as shown in Figure 4. These NEG pumps are essential to maintain the ultra-high vacuum in the chamber in addition to ion pumps.

Combining the emission from all cathodes is a challenge, because of the high total bunch repetition rate of 9.4 MHz. Therefore, bunches from individual cathodes will be combined by an electric or magnetic field with fast, accurate alternating phases. To maintain the polarization of the electrons, we will consider having the same method used for bending and combining the beam. At present, we are working along both paths to compare the two approaches.

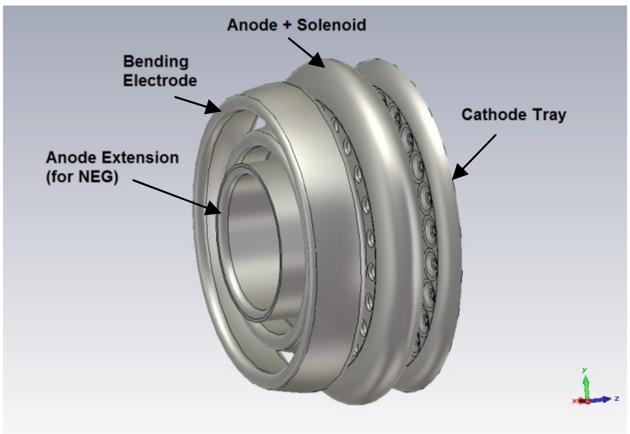

Figure 3: Layout of the cathode, anode, and bending electrodes.

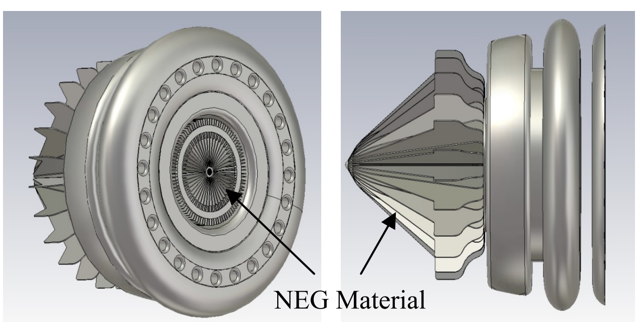

Figure 4: Locations of the NEG materials. Left: NEG cartridge inside the anode. Right: NEG material in front of anode.

The combiner is more difficult to design. For both electric and magnetic approaches, the direction of the combiner field should be changing accordingly to the direction of the electron bunch. This requires fixing pairs of electrodes or coils in a cylindrical tube which operating under high frequency and with phase difference between each pair. Because of the high field and fast rotating frequency, the design of the control circuit and field shielding is the dominant issue. The design is now in process.

FIELD SIMULATION

In this paper, we discuss only our simulation of electric bending. Following the above design, we used CST EM Studio to simulate the electric field. Before tracking the particles, it is important to prevent possible electric arcing. Hence, the design must be changed in accord with the field emission limit under the chamber's vacuum level, which should be better than 10^{-11} Torr.

The voltage difference between the cathode tray and the anode is 200kV for electron acceleration. The anode and both NEG cartridges will be set at ground potential. This design will decrease the field in the center of the cathode tray and reduce the possibility of field emission and arcing.

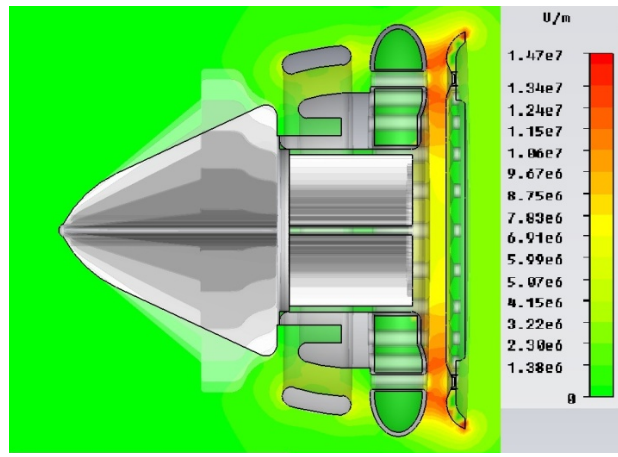

Figure 5: Electric field of the components before the combiner with the cathode tray at the limit of 250kV voltage.

Figure 5 is the 2D projection of the electric field near the components before the combiner. The cathode tray is set at 250kV for this simulation that is the limit of the feedthrough chosen for the chamber. A maximum field of ~14 MV/m is generated around the entrance of the solenoid tubes on the anode. Although this field is tolerable for such an ultra-high vacuum environment, it is not difficult to enhance the field by further smoothing its edges.

The most important information we can gain from the electric field simulation would be the parameters of the field along the beam's trajectory. Figure 6 shows the tangential electric field that the electrons experience, starting from the surface of the cathode to after the bending electrodes.

The semi-Pierce shaped cathode cap exerted a strong effect, weakening the electric field for acceleration. Nevertheless, the maximum electric field for acceleration still was more than 10 MV/m within a 2.66 cm space.

The electric field was evaluated along two trajectories; the center of the components, and 5 mm offset outwards in radial direction. The difference between them at these two trajectories can be as high as 40% before the bending electrodes. This difference will cause the electrons to experience a different acceleration and will degrade the longitudinal emittance of the bunch. This effect can be cancelled partially at the exit of the bending electrodes.

We designed two sets of NEG fins. The larger set lies between the cathodes, while the shorter set is sited below the trajectory of the electron bunch. By specially shaping the fins, the disturbance of the electric field due to the NEG cartridge is negligible.

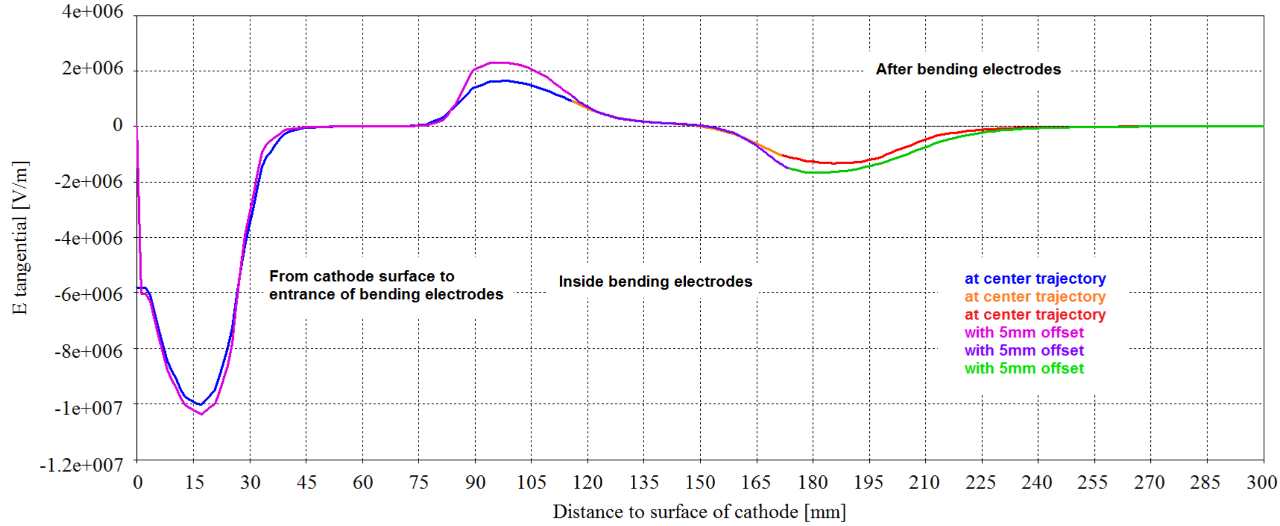

Figure 6: Electric field along the beam's trajectory through the center of the components, and with 5mm offset outwards in the radial direction.

Figure 7 depicts the radial field between the two bending electrodes. Because of the system's curvature, electrons further away from the center experience stronger bending force. Meanwhile, they travel a longer distance in the bending region. The combination of the two circumstances results in their becoming focused in the vertical direction. Thus, the beam will be asymmetric after bending.

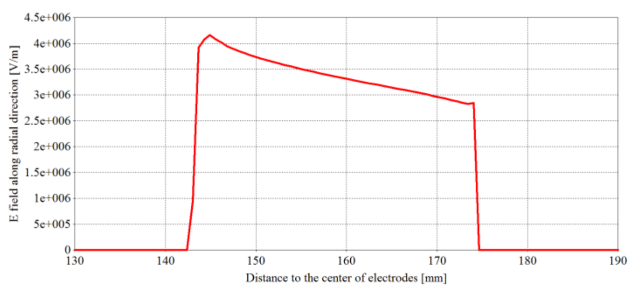

Figure 7: Electric field in radial direction between bending electrodes.

With a small change in the details of the bending electrodes, we should be able to reduce this transverse asymmetry for electron bunches.

PARTICLE SIMULATION

The particle simulation of the setup was done with CST Particle Studio. The parameters for the simulation, listed in Table 1, were chosen according to the requirements of eRHIC and the characteristics of the GaAs cathode.

Figure 8 shows the phase space plot of x direction, which indicates that the nonlinear field deforms the transverse distribution. The normalized emittance reaches ~20mm-mrad.

Compared to the eRHIC's goal of 7 mm-mrad, we are still working on the improvement.

Table 1: Parameters for particle simulation.

Parameter	Value	Unit
Initial Energy	0.4	eV
Energy Spread	0.04	eV
Charge per Bunch	5	nC
Bunch Length	2.056	ns
Bunch Distance	106.5	ns

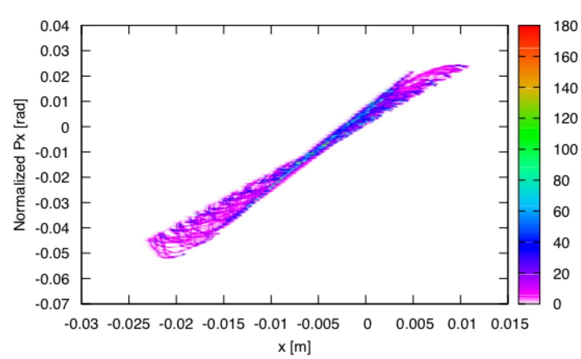

Figure 8: Phase space of x direction after bending.

CONCLUSION

Our preliminary design of a multi-cathode electron source for eRHIC demonstrated tolerable fields and reasonable results in both field and particle simulations.

REFERENCES

[1] M.L. Stutzman, P. Adderley, J. Brittian, J. Clark, J. Grames, J. Hansknecht, G.R. Myneni and M. Poelker, Nucl. Instr. and Meth. A 574 (2007) 213-220.