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The progress of funneling gun high voltage condition and beam test

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THE PROGRESS OF FUNNELLING GUN HIGH VOLTAGE CONDITION AND BEAM TEST

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Abstract

A prototype of a high average current polarized electron funneling gun as an eRHIC injector has been built at BNL. The gun was assembled and tested at Stangenes Incorporated. Two beams were generated from two GaAs photocathodes and combined by a switched combiner field. We observed the combined beams on a YAG crystal and measured the photocurrent by a Faraday cup. The gun has been shipped to Stony Brook University and is being tested there. In this paper we will describe the major components of the gun and recent beam test results. High voltage conditioning is discussed as well.

INTRODUCTION

In order to construct a future electron ion collider with high luminosity, a high average current and high bunch charge polarized electron source is under R&D at Brookhaven National Laboratory. Currently, the highest average current of polarized electron source was 4 mA achieved at JLab. The cathode lifetime is limited by ion back bombardment. To obtain average current of 50 mA and increase the lifetime, enlarging the photocathode emission area is a straight forward method. However, there are technical difficulties to get uniform photoemission and polarization from large superlattice GaAs photocathode. Uniform electrical field on the large cathode is another challenge as well. Alternatively, we developed a DC gun with multiple cathodes. Funneling the multiple electron bunches generated from several photocathodes to a single common axis could increase the total average current and single-cathode-lifetime. Here, we have to assume the individual cathode performance will not be affected by the rest of cathodes. The first step of the R&D program is proof of this principle.

The gun and beam parameters for eRHIC were described in reference [1]. To carry out the proof of principle test in a short time, we simplified the gun setup and started test with lower current to meet radiation limits. Our first gun conditioning and beam combining test was carried out at Stangenes Industries. Two beams were emitted from two cathodes positioned radially opposite to each other and combined by a switched combiner magnet. Beam current, cathode QE and lifetime was measured.

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GUN SETUP

The detailed gun design with beam optics was described earlier [2]. The depressed collector was replaced by a faraday cup which placed at the end of the beam line. It was biased to 500V to eliminate the secondary electron and back-scattering electrons. A pico-ammeter was connected in series to the Faraday cup. A fixed YAG crystal monitor was placed between the combiner magnet and Faraday cup for monitoring the beam profile and beam position. The YAG crystal has a hole at the centre which allows the beam pass through and reaches the Faraday cup. Figure 1 is the schematic layout of funnelling gun in this first beam test.

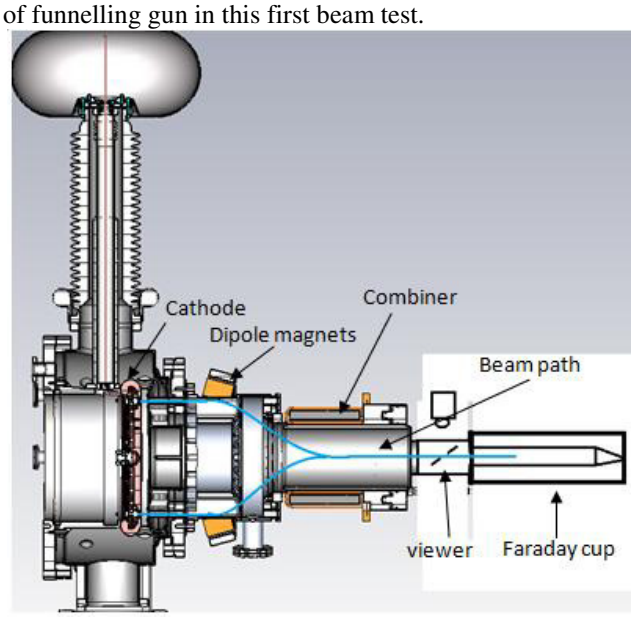


Figure 1: The schematic layout of the funnelling gun with beam measurement instruments

Two dipole magnets and combiner magnets were placed downstream of anode. The combiner was designed to have 20 coils with Sine distribution of the current. In our first beam test, it was simplified to six pairs of coils with constant current and driven by single power supply. Figure 2 shows the field distribution of measured magnetic field compared with the designed ideal field.

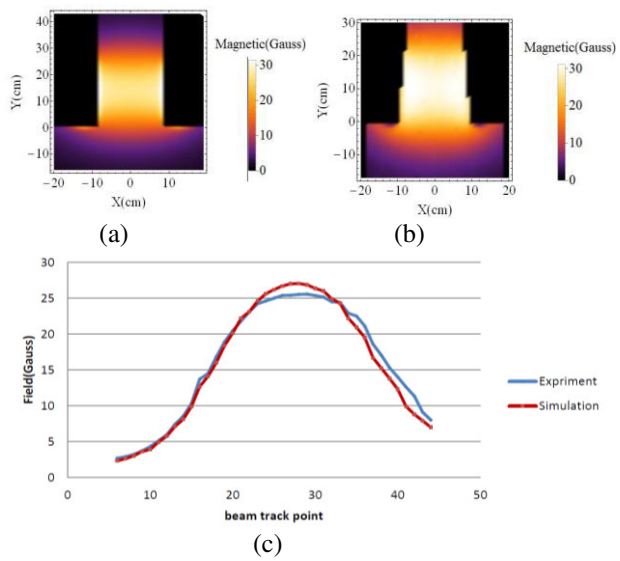


Figure 2: Comparison the field of the 20 coils with current sine distribution magnets (a) and 6 pairs' coils with constant current (b). (c) Comparison of the field on the beam path between two set up of combiner.

We used 5 mW green laser to drive the photocathodes. The laser was split into two beams with identical power, modulated by two shutters to illuminate two cathodes. The shutters' frequency was synchronized to the combiner switch and camera frequency. The incident laser power on each cathode is 1.2 mW.

The photocathode preparation chamber is connected to the gun through a gate valve. The two GaAs cathodes were activated and transported to the gun. Besides the two GaAs photocathodes, rest of cathode positions were filled with copper blanks. The details of the cathode preparation system and performance are described in reference [3].

HIGH VOLTAGE CONDITIONING

Our first gun conditioning and beam test were performed at Stangenes Industries, CA. Under the operating conditions in Stangenes, in order to keep the radiation under the state law, the maximum allowed current is 80 uA. In order to stay below this limit, for 250 kV maximum output voltage, 2.88 GOhm current limiting resistors were connected in series between power supply and DC gun high voltage feed-thru. This also functioned as the DC gap protector to avoid arcing. Once the field emission happened between the DC gap, the resistor could hold the voltage and reduce the voltage across the DC gap. We connected a 100 kOhm resistor in series to high voltage circuit. Current through the 100 kOhm resistor could be calculated by measuring the voltage across it. This could be the field emission current as well as photocurrent.

Due to time constraints, we condition the gun only twice for a total of four hours. Two Geiger counter were placed, one near the high voltage feed-thru and another below the DC gap. We found very strong radiation near the feed-thru during our first conditioning while the bottom Geiger counter receives orders of magnitude lower radiation which indicates there are field emitters at top of the DC gap. Figure 3 shows a radiation curve with increasing the high voltage across the DC gun.

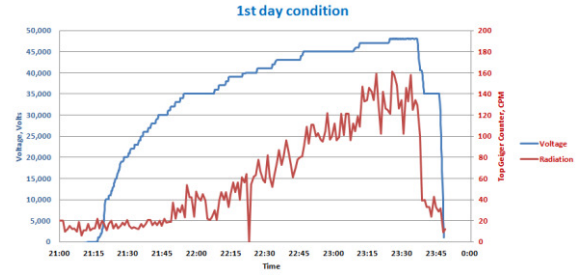


Figure 3: A conditioning process with radiation curve. The red curve is the radiation received by the top Geiger counter and blue curve is the voltage across the DC gap

By measuring the voltage across 100 kOhm resistor, we found the 30 kV is our first hard barrier. However, the large voltage drop across the 2.8 GOhm resistors limited our maximum conditioning current. The maximum field emission current is 10 uA which is much less than we expected. Figure 4 shows the DC gap voltage as a function of power supply out-put voltage. The difference between them was held across the resistor. The beam tests were performed below the field emission threshold of 14 kV.

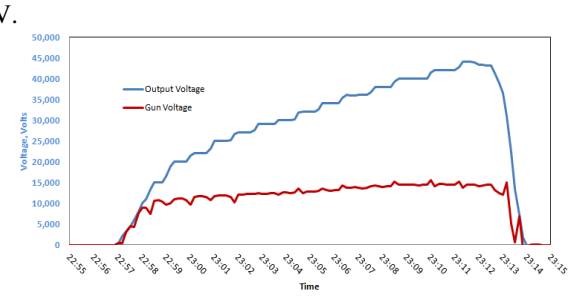


Figure 4: Red curve is the gun gap voltage while the blue curve is the power supply output voltage.

After this beam test, we opened the gun vessel and found multiple sharp edges and points at high voltage feed-thru connections. All these defects were filleted and polished. Recently, the gun easily went up to 50 kV without any radiation. The conditioning process is still ongoing.

BEAM COMBINING TEST

Table 1 lists the beam parameters and bunch structure of our first beam combining test.

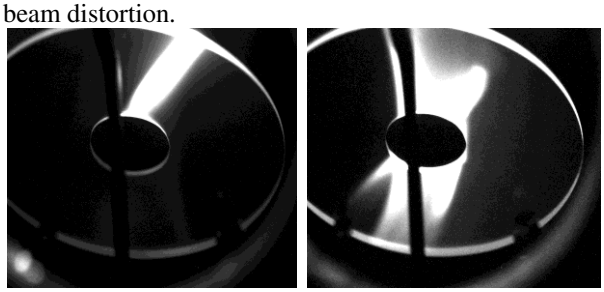
Table 1: Beam parameters and bunch structure

Parameter	Value
Cathodes' QE	0.34% / 0.07%
Shutter trigger Freq.	1Hz
Bunch length	0.1s
Beam Repetition Freq.	2Hz
Beam energy	14 keV
Laser beam size	1.2mm rms

The steps of our beam combining test are listed below:

1. Preset the dipole magnets and combiner magnets current to bend 14keV beam by 29 degrees.
2. Increased the power supply output voltage to 14 kV and made sure the field emission current was eliminated.
3. Illuminated the laser beam on one photocathode.
4. Tuned the single beam to the centre of the YAG crystal.
5. Measured the photocurrent and QE decay time constant.
6. Opened the second shutter and let the laser shine on opposite cathode.
7. Tuned the dipole magnet to move the second beam to overlap with first beam spot.
8. Measured the combined photocurrent and both cathodes QE decay time constant.

We obtained two beam spots on the YAG crystal. Part of the beam spots are overlapped and passed through the hole of YAG screen. The single beam spot and two overlapped beam spots are shown on figure 5. The slot shape of the beams indicates the beam has large energy dispersion which comes from large resistor distorted gap voltage. Nonlinear combiner field also contributed to the beam distortion.



(a) (b)

Figure 5: The beam spots on the YAG crystal. a) The single beam. b) The overlapped two beams from opposite GaAs photocathode

We observed that the cathode QE dropped almost 90% in first 30 seconds and then stabilized in both single beam test and beam combining test. When the electrons started emitting from the cathode, the current through the HV circuit simultaneously jumped up. For 4.8 uA average photocurrent, the voltage across 2.88 GOhm resistor is 14 kV resulting in the DC gap voltage of zero. Because all the beam optics were tuned for 14 keV beam, the initial 20~30 bunches hit on the beam pipe and desorbed the gas which poisoned the cathodes and reduced the QE dramatically. Figure 6 shows the anticorrelation between the gap voltage and the photocurrent. Once the cathode QE dropped by a factor of 10, the beam spot appeared on the YAG screen and the QE stabilized. Then, we started to measure the photocathode cathode lifetime. Figure 7 shows the two cathodes photocurrent measurement after two beams combined. The scatter in the data is caused due to timing asynchronism between the pico-ampere meter and master clock. The top edges of the dots are the full photocurrent received by the Faraday cup.

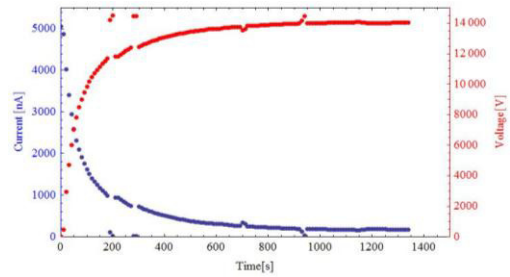


Figure 6: The gap voltage and photocurrent change at first 20 minutes. The blue dots train is photocurrent and the red dots train is gap voltage.

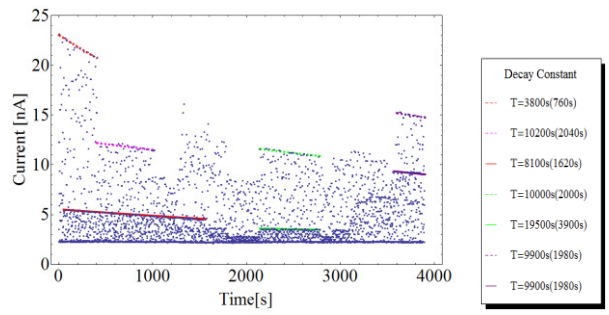


Figure 7: Photocurrent from two cathode were measured by Faraday cup. The QE decay is fitted by a exponential function. The decay constants are listed at legend.

The 1/e lifetime of both cathodes after beam combined is 1980 s which is longer than single cathode lifetime (1520 s). It indicates QE of one cathode was not reduced by emission from another cathode. Meanwhile, when one beam from #1 cathode hit to the beam pipe, only #1 cathode lifetime reduced. Thus, At 10s nano-amper average current, we didn't see any lifetime cross-talk between two operational photocathodes.

CONCLUSION

We carried out the first beam combining test of funneling gun. Two beams from two GaAs photocathodes were combined and measured the photocurrent as well as lifetime. At low average current, one cathode operation will not affect another cathodes lifetime.

We moved the funneling gun to SBU experimental hall with concrete shielding. In the future, we will remove the 2.88 GOhm resistors and carry out a high current test.

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