CEBAF INJECTOR FOR K_L BEAM CONDITIONS*

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Abstract

The Jefferson Lab K_L experiment [1] will run at the Continuous Electron Beam Accelerator Facility with a much lower bunch repetition rate (7.80 MHz or 15.59 MHz) than nominally used (249.5 MHz or 499 MHz). While the proposed average current of 2.5 - 5.0 µA is relatively low compared to the maximum CEBAF current of approximately 180 µA, the corresponding bunch charge is atypically high for CEBAF injector operation. In this work, we investigated the evolution and transmission of low-rep-rate, high-bunch-charge (0.32 to 0.64 pC) beams through the CEBAF injector. Using the commercial software General Particle Tracer, we have simulated and analyzed the beam characteristics for both values of bunch charge. We performed these simulations with the existing injector using a 130 kV gun voltage. We have calculated and measured the transmission as a function of the photocathode laser spot size and pulse length. We report on the findings of these simulations and optimum parameters for operating the experiment.

INTRODUCTION

The K_L experiment (a new nuclear physics experiment) at Jefferson Lab in Hall D requires time-of-flight measurements which in turn requires substantially lower bunch repetition rates in Continuous Electron Beam Accelerator Facility (CEBAF) than the nominal 249.5 MHz or 499 MHz. The momenta of K_L particles will be measured using the time-of-flight between RF signal of CEBAF accelerator and start counters surrounding LH_2 target. A schematic view of beamline is presented in Fig. 1. At 12 GeV an average current of 2.5 - 5.0 µA corresponds to 30 - 60 kW of beam power, which will converted by the CPS to illuminate the Be target. Table 1 summarizes the individual bunch charges corresponding to these beam requirements for the K_L experiment.

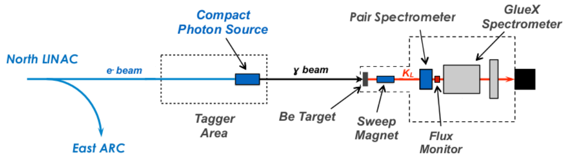

Figure 1: Schematic view of Hall D beamline on the way $e \to \gamma \to K_L$. Electrons first hit the copper radiator inside the Compact Photon Source (CPS). Then photons illuminate the Be target, and finally, neutral kaons hit the LH_2/LD_2 cryogenic target. Beam goes from left to right [1].

Table 1: CEBAF Injector bunch currents and repetition rates for K_L experiment [1].

Current (A)	Repetition Rate (MHz)	Subharmonic of 499 MHz	Bunch Charge (pC)	Equivalent 249.5 MHz current (A)
2.5	15.59	32nd	0.16	40
2.5	7.80	64th	0.32	80
5.0	15.59	32nd	0.32	80
5.0	7.80	64th	0.64	160

We are developing new operating parameters of the CEBAF injector for the K_L experiment. This experiment requires relatively low rep rate but the bunch charge at the high end of what CEBAF delivers to achieve its goals. This paper describes the evolution and transmission of low-rep-rate, high-bunch-charge (0.32 to 0.64 pC) beams through the CEBAF injector. Using the computational software packages, we will describe designed beam size, the initial electron beam distribution, and analyze the beam characteristics for both values of bunch charge for 130 kV gun voltage. We characterize the transmission as a function of the photocathode laser spot size and pulse length. Finally, we describe measurement for two injector laser drive frequency modes : one with 500 MHz, and another with 250 MHz.

BEAMLINE SETUP AND SIMULATION DETAILS

Figure 2 shows the general layout of the CEBAF injector, showing the elements related to bunching, timing and focusing the beam. Our injector model for K_L beam conditions focuses on the beam line between the gun and the captured solenoid S6 (MFA0I03) upstream of the Chopper 1 RF cavity and retains the pre-upgraded injector beam line downstream from S6 (MFA0I03) onward [2]. The beam originates on a 130 keV photocathode. Then the beam transits through the elements of a 30 m beamline which consist of 1 pre-buncher cavity, 1 buncher cavity, 5-cell capture section, 1/4 cryomodule booster (2 Cornell-style 5-cell cavities), focusing solenoids, and quadrupoles. We performed the simulations using the commercial software General Particle Tracer (GPT) [3].

For the particle distribution at cathode in simulation, the beam is assumed to have a Gaussian distribution in t, x, y

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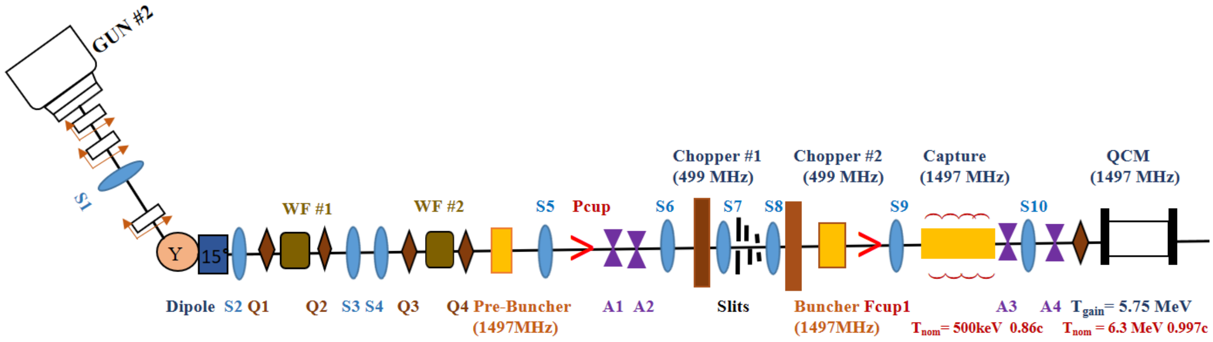

Figure 2: Layout of the CEBAF injector upto quarter cryomodule (QCM) at JLab. The more detailed information can be found at [2].

p_x and p_y following the profile of the laser. Initially, the transverse beam sizes are, 4_x = 2.237 mm, and 4_y = 2.093 mm, laser pulse length (FWHM) is 45 ps, the transverse emittance is 0.061 mmmrad. The beam current is varied from 5 µA to 160 µA for 250 MHz laser frequency. Thus, the bunch charge is calculated by using the relation: $q = I \times f$. For the high bunch charge, the space charge effect is incorporated using the space charge3Dmesh algorithm [4]. The applied macro particle number in the simulation is 10000. Also, we varied the laser spot size and the laser pulse length at cathode to see the transmission as the function of these parameters.

RESULTS AND DISCUSSION

In this section, we present the results of simulation, measurements and the comparison between them.

Simulation Results

Figure 3 shows the beam transmission through the apertures as a function of the bunch charge. It shows that the transmission decreases with increase is bunch charge. For 64 ns bunch spacing, 0.32 pC bunch charge, the beam transmission is about 92% but the transmission decreases to about 82% for 128 ns bunch spacing, 0.64 pC bunch charge. Figures 4 and 5 show the beam transmission versus laser spot size and laser pulse length at the cathode for two different bunch spacing; 128 ns and 64 ns respectively.

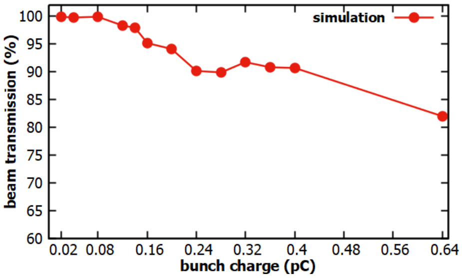

Figure 3: Beam transmission through the apertures A1 and A2 as a function of bunch charge.

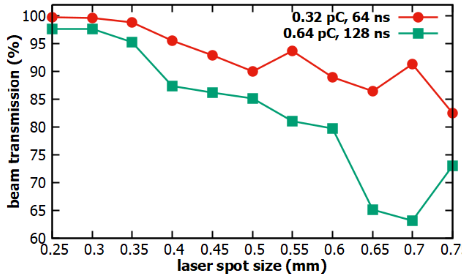

Figure 4: Beam transmission through the apertures A1 and A2 with variation of laser spot size at cathode for 64 ns and 128 ns beam.

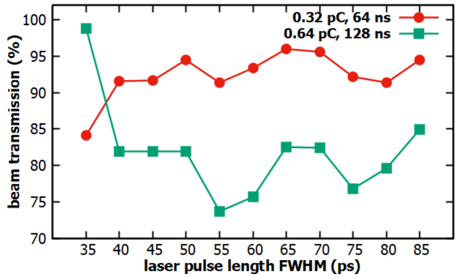

Figure 5: Beam transmission through the apertures A1 and A2 with variation of laser pulse length at cathode size for 64 ns and 128 ns beam.

Measurements

We measured the bunch charge versus transmission for different beam frequencies : one for 250 MHz and another for 500 MHz. Figure 6 shows that for 500 MHz drive frequency, we can get only 0.4 pC of charge from the gun and the beam loss is about 10% for it. For the 250 MHz laser drive frequency, we can get more charge than K-Long beam requirement, but the losses in the apertures (A1, A2 and MS) is very high. For 0.65 pC of bunch charge from the gun, the loss is about 39%.

The length and shape of a 10 fC electron bunch at 250 MHz and 500 MHz frequency is measured at the location of 499 MHz chopper. This is done by using a chopper scanning technique and as shown in Fig. 7. The Fig. 7 shows the

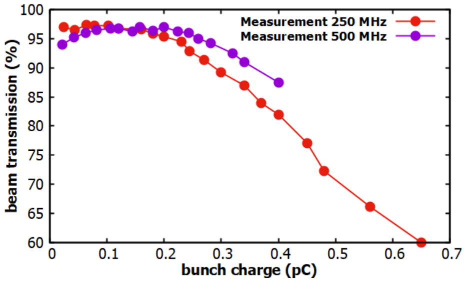

Figure 6: Beam transmission through the apertures A1, A2 and Master slit vs. bunch charge from the gun for different laser drive frequency.

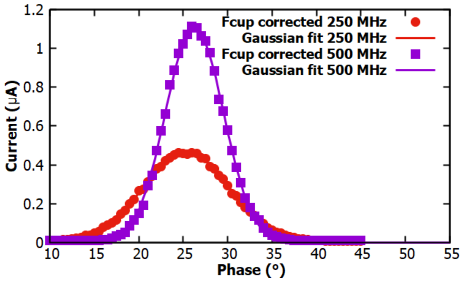

Figure 7: Chopper Scan for measuring beam pulse length for different beam frequency created by the drive laser.

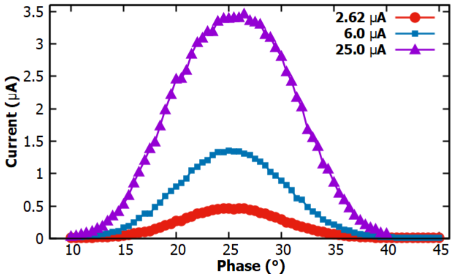

Figure 8: Chopper scan at various beam current from the gun for 250 MHz drive frequency.

measurement data and corresponding Gaussian fit for finding the pulse length of the beam for different drive frequency of the laser. The frequency of the chopper used is 499 MHz. So, the pulse length of the beam at different drive frequencies is calculated by 5.6 ps per degree. The length of the bunch is about 42.50 ± 0.22 ps full width at half maximum (FWHM) for 500 MHz drive frequency and about 63.83 ± 0.27 ps FWHM for 250 MHz drive frequency. It shows that the different mode of drive frequency has beam of different pulse length. Compared to the pulse length at low current the electron bunch length is much longer for higher currents as shown in Fig. 8. The reference [5] explains the bunch length growth.

Comparison Measurements and Simulations

Figure 9 represents the comparison between measurement and simulations for various bunch charge studied for 500 MHz frequency. Our simulation results are in good agreement with the measurement. The beam transmission decreases with increasing charge/bunch due to the space charge effect. Space charge forces can degrade the beam quality and cause resulting in emittance growth, energy spread, halo formation, particle losses and even can set up upper limit for the beam current. The self induced forces due to space charge are always defocusing in either in x or the y directions [6].

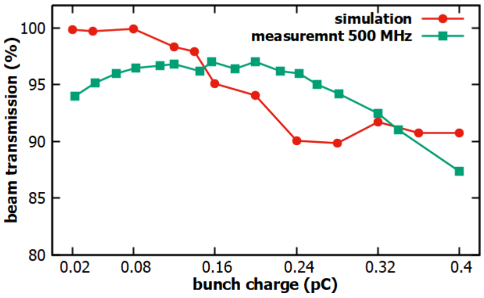

Figure 9: Comparison between simulation and measurement for beam transmission vs. bunch charge

OUTOOK

With existing gun (130 kV), we have simulated the CEBAF upgraded injector model for K-Long experiment for low and high charge/bunch using General Particle Tracer (GPT). During the simulations, the laser pulse length and laser spot size at cathode were varied to see the effects of these parameters in the beam interception though the apertures. Measurements were done for low and high charge for two different laser drive frequency mode and compared with the simulation results. From the measurements, we found that maximum bunch charge from the gun that is transmitted through the apertures is 0.4 pC at 500 MHz drive frequency with about 12% loss and in good agreement with the simulations. However, for the 250 MHz drive frequency the maximum bunch charge from the gun met the K-Long experiment requirement but the losses in the apertures are high, about 39%. This shows that the charge that can be transmitted from the injector is about 0.35 pC for 500 MHz drive frequency and 0.40 pC for 250 MHz drive frequency. From the chopper scanning technique, we have found that for different drive frequency modes of the laser, the pulse lengths are different. The FWHM pulse length for 500 MHz drive frequency 42.50 ± 0.22 ps and is close to the simulated pulse length. But, the FWHM pulse length for 250 MHz drive frequency is 63.83 ± 0.27 ps and is larger than the simulated pulse length.

FUTURE WORKS

A planned injector upgrade with a 200 kV gun and new RF acceleration scheme is planned for 2023. This upgrade is expected to further benefit the K-Long experiment. New simulations for this experiment and studies with the K-Long drive laser are planned.

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