CEBAF INJECTOR MODEL FOR K-LONG BUNCH CHARGE AT 200 kV*

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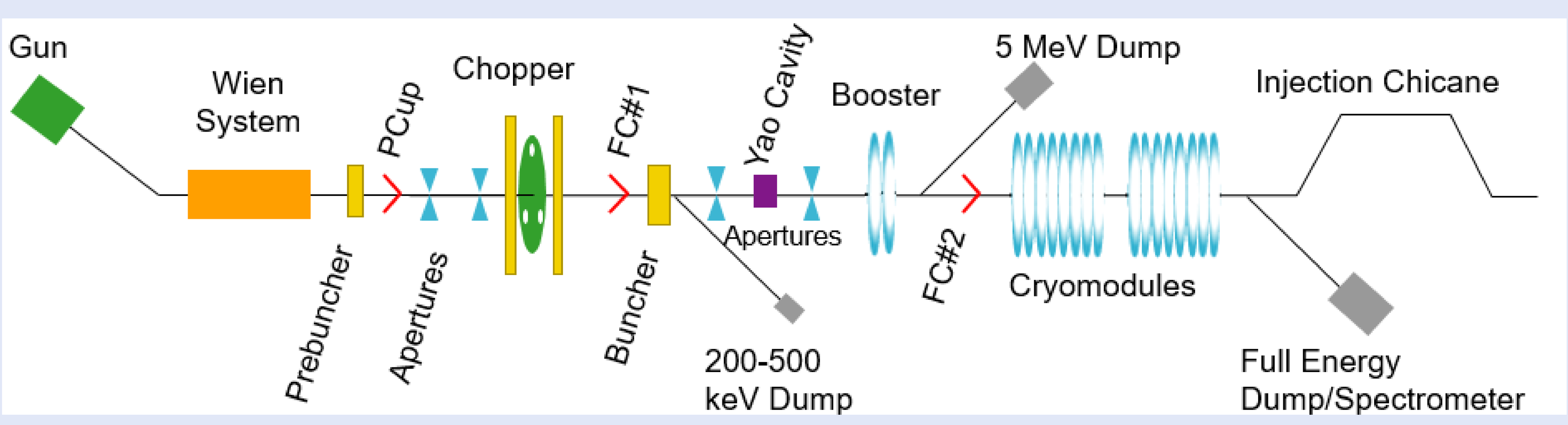
ABSTRACT

The upcoming Jefferson Lab K-Long experiment at Hall D will require unique beam conditions with much lower bunch repetition rates and atypically high bunch charge. To optimize the Continuous Electron Beam Accelerator Facility (CEBAF) injector for this experiment, we performed Multi-Objective Genetic Optimization (MGO) using General Particle Tracer (GPT) to determine the magnetic elements and RF setting necessary for the K-long bunch charge (0.64 pC) at 200 kV. We also investigated the transmission and beam characteristics for low to high charge per bunch electron beam through the CEBAF injector for simultaneous operations of four CEBAF Halls and characterized the transmission as a function of laser spot size and pulse length. Our findings provide valuable insights into optimizing the CEBAF injector for the Jefferson Lab K-Long experiment, as well as for other experiments with similar beam conditions.

INTRODUCTION

- Jefferson Lab CEBAF has the ability to deliver polarized electron beams of different specifications to four experimental Halls simultaneously.
- Transmitting the beams of different specifications simultaneously for the same injector optics is difficult.
- Computer Modeling provides suitable settings to satisfy the beam requirements at different Halls.
- This work is a continuation and expansion of the CEBAF Injector modeling activities.
- In this work, we performed the Multi-objective Genetic Optimizations to get the optimized settings of magnetic elements and RF system for K-long bunch charge (0.64 pC) at 200 kV.
- Using the optimized settings for K-long bunch charge, performed a simulation to get the beam characteristics for various charges per bunch through the CEBAF injector.

BEAMLINE SETUP AND SIMULATION DETAILS



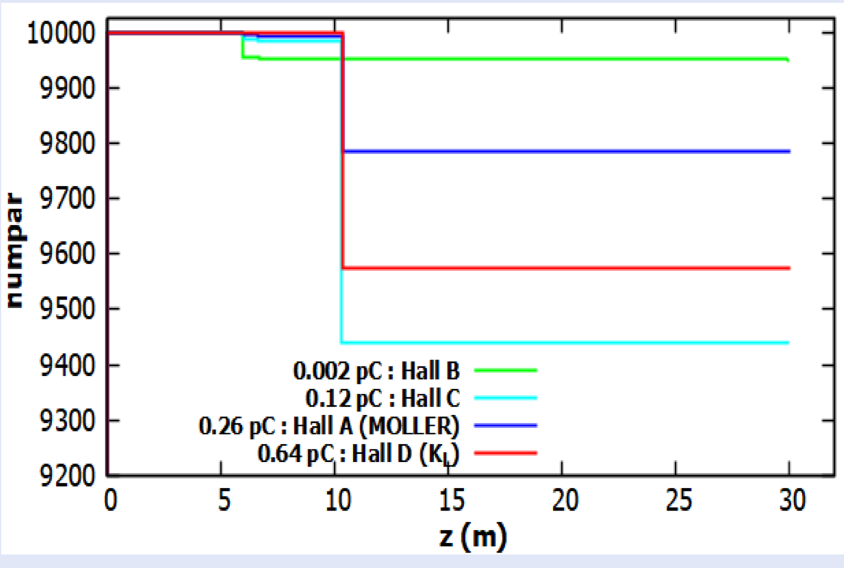
The layout of the CEBAF Injector with upgraded beamline elements (solenoids, quads, correctors, etc. not shown).

- The beamline elements are a 200 kV DC gun, 15° bend dipole, 11 solenoids including spin solenoids set for 0°, 12 quads excluding Wiens quads, 1 pre-buncher, 1 buncher, and quarter cryomodules (2-7 cell SC cavities), extends from the gun to 30 m upstream of full first cryomodules.
- These all elements are incorporated into the General particle Tracer (GPT) model.
- Used a straight beamline, 15°dipole, RF choppers, beam diagnostics, Wiens are OFF.
- The beam of Gaussian distribution in t, x, y, p_x, p_y following the profile of the laser. The transverse beam size is 0.55 mm, the laser pulse length (FWHM) is 45 ps.
- The transverse emittance is given by, $\epsilon_{n,\perp} = \sigma_{\perp}\sqrt{\frac{MTE}{mc^2}}$, 0.1348 mm-mrad, MTE = 30.691 meV for GaAs photocathode.

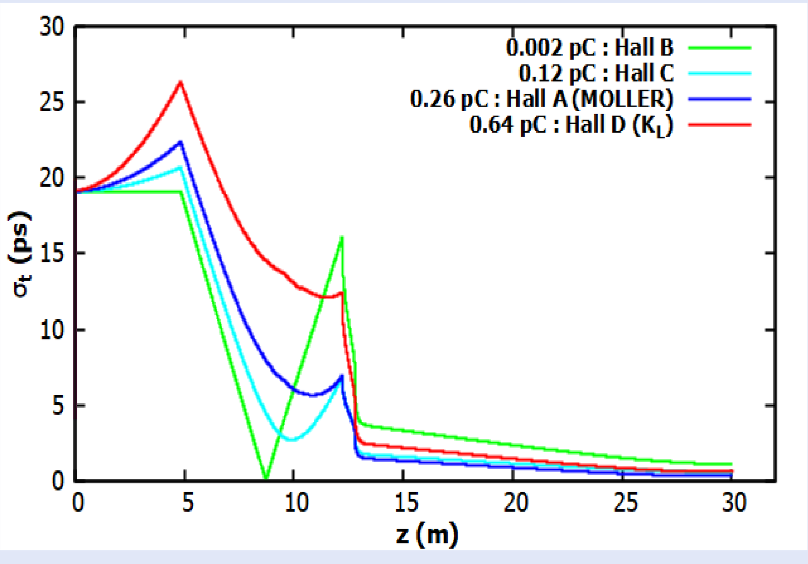
OPTIMIZATION AND SIMULATION

- Performed using GDFMGO multi-objective global optimizer implemented in GPT.
- The optimizations were performed for K-long bunch charge (0.64 pC), at 320 µA beam current at a laser frequency of 499 MHz for 200 keV beams.
- A population size of 120 with 1000 generations was used for 120000 runs, resulting in 120 sets of optimal settings for magnetic elements and RF, with a goal of achieving 99.9% beam transmission, $\epsilon_{n,x,y} \leq 0.25$ mm mrad, $\sigma_t \leq 0.5$ ps, kinetic energy 5.0 to 8.0 MeV upstream of the first full cryomodules.
- The number of macroparticles was 250, for 28 variables (magnetic elements and RF settings), 62 objectives, and constraints.
- The optima obtained from MGO were tested with increasing the number of macroparticles.
- The increase in macroparticles causes the degradation of beam characteristics.
- After optimization, one of the optimal solutions on the Pareto front was chosen for the injector's simulation.
- The optimal solution was selected based on the attainment of beam transmission greater than 90%, $\epsilon_{n,x,y} \leq 1.0$ mm mrad, $\sigma_t \leq 1.1$ ps.

SIMULATION RESULTS



Transmission for various bunch charge specifications for the CEBAF four Halls.



Evolution of bunch length along the beamline for various charges per bunch.

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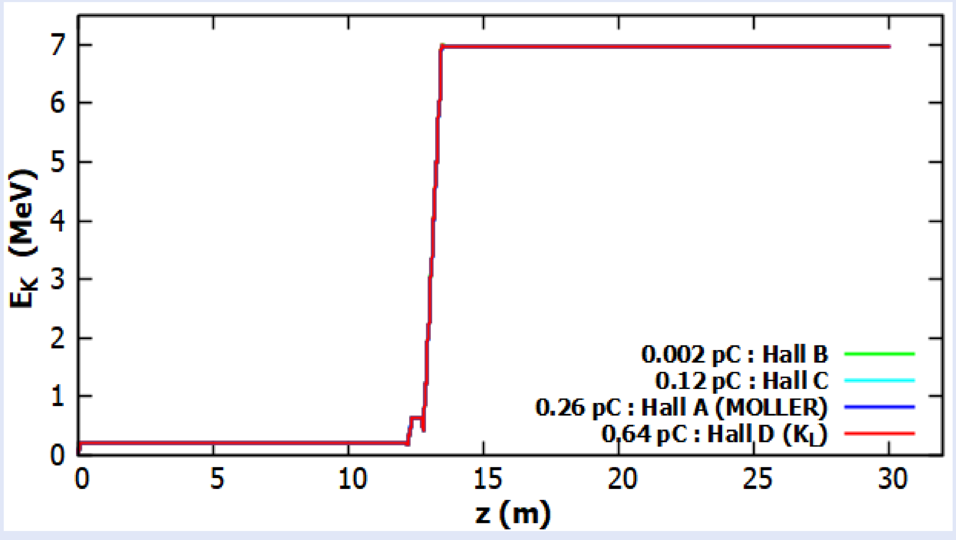
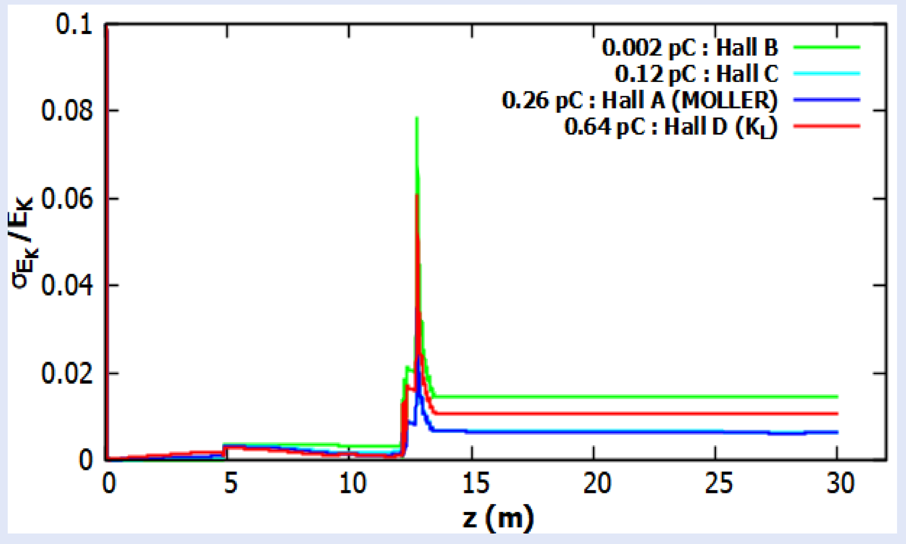
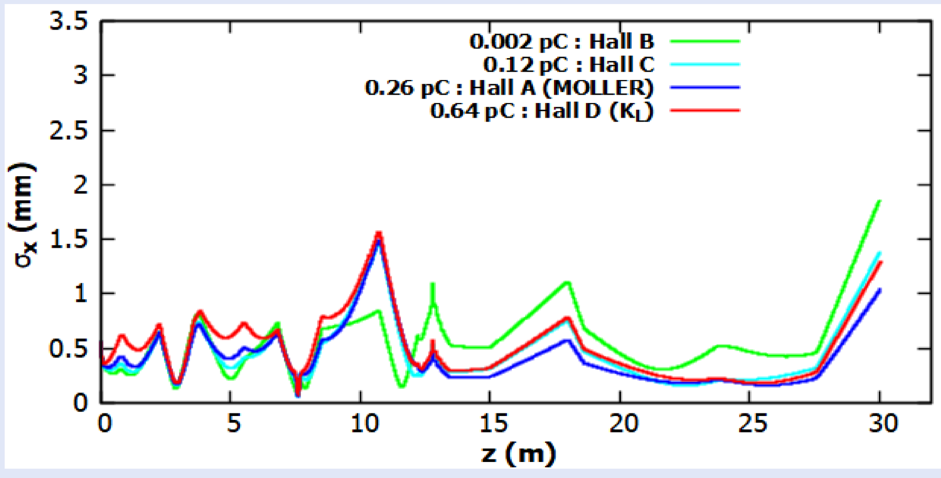
SIMULATED BEAM CHARACTERISTICS



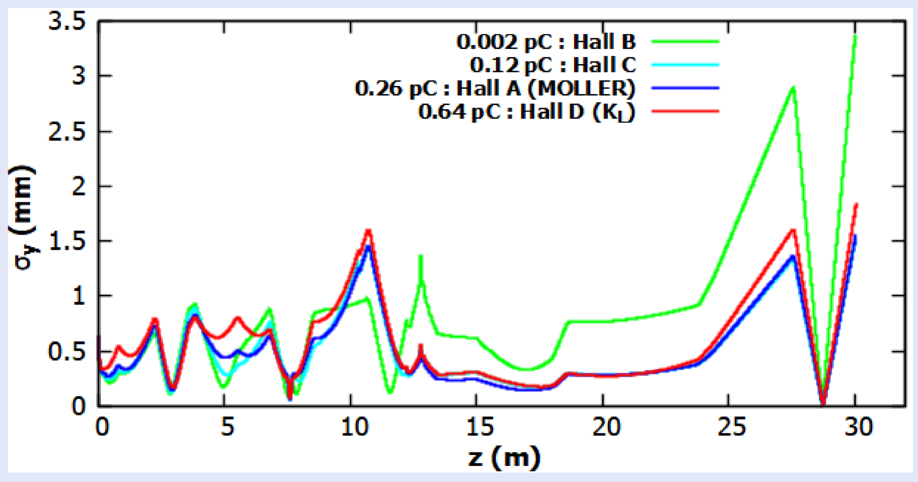
The average Kinetic energy for different bunch charges, its value is around 6.98 MeV.



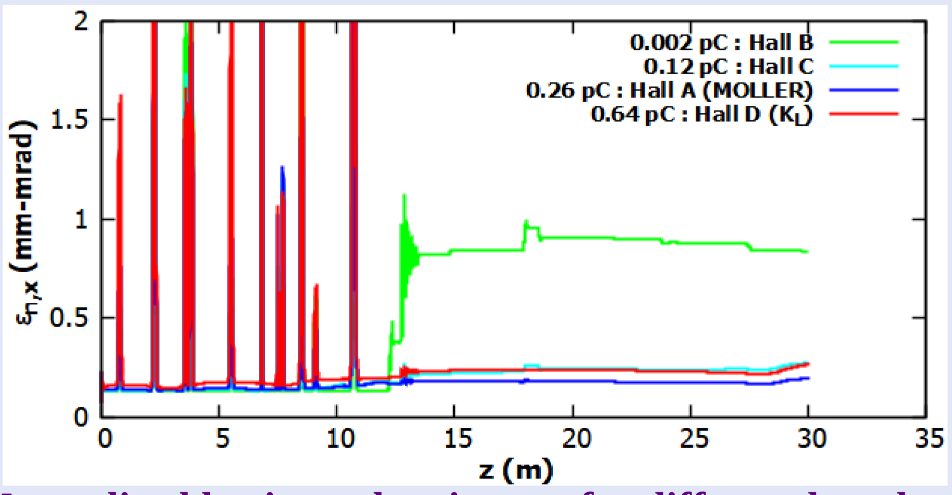
Energy spread σ_{E_k}/E_k for different charge per bunch.



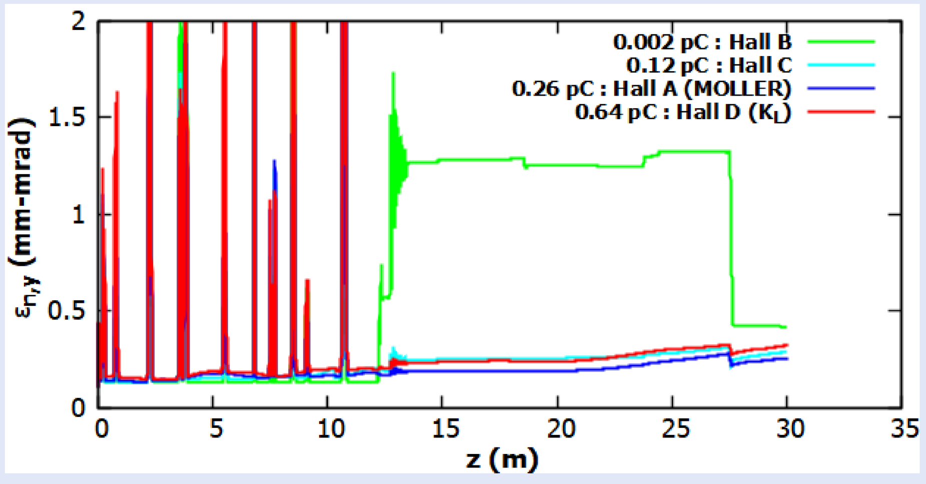
Transverse horizontal beam sizes for different bunch charges along the beamline.



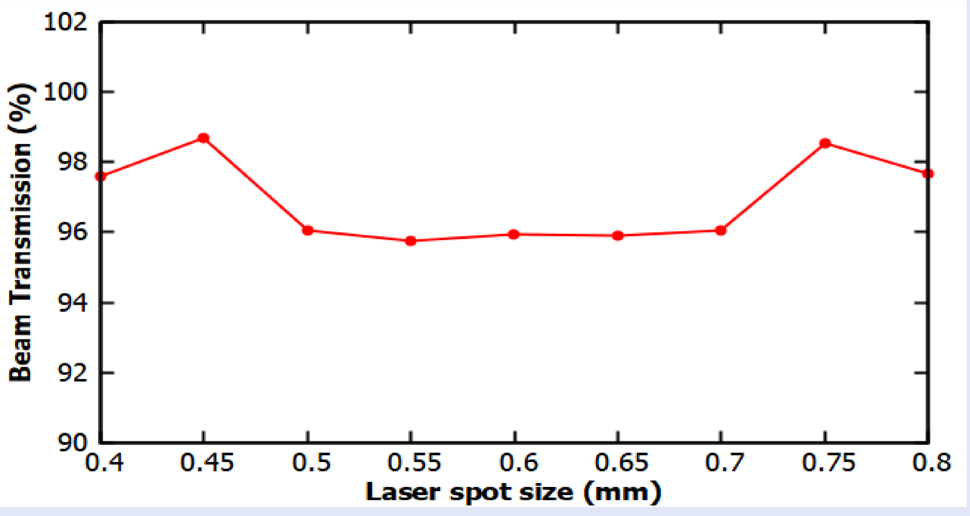
Transverse vertical beam sizes for different bunch charges along the beamline.



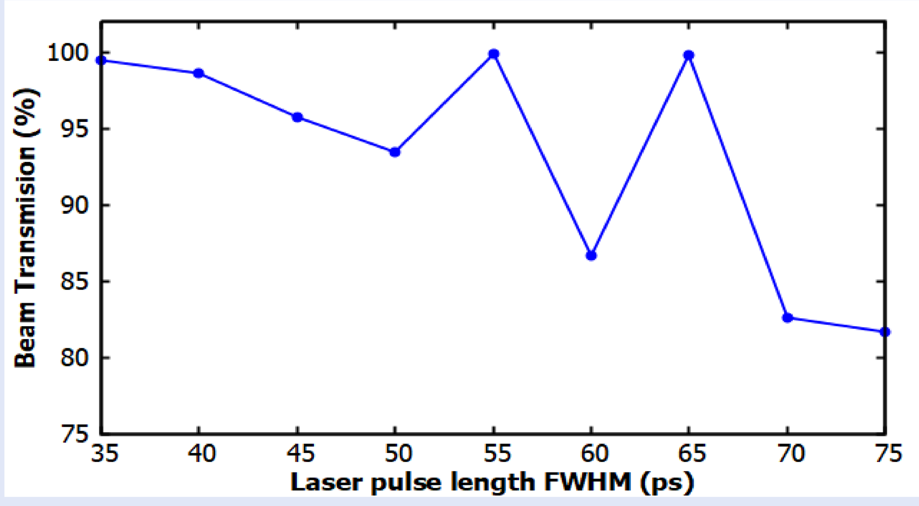
Normalized horizontal emittance for different bunch charges along the beamline.



Normalized vertical emittance for different bunch charges along the beamline.



Beam transmission vs. laser spot size at cathode for K-Long bunch charge (0.64 pC).



Beam transmission vs. laser pulse length for K-long bunch charge (0.64 pC).

OUTLOOK AND FUTURE WORK

- we have presented the optimization and simulation of the upgraded CEBAF injector model for the K-Long experiment at 200 kV using General Particle Tracer.
- By varying the laser pulse length and laser spot size at the cathode, we investigated the effects of these parameters on the beam characteristics and interception through the injector.
- The obtained simulated beam characteristics for various bunch charges from the optimized settings for K-Long bunch charge were also presented.
- A plan has been made for testing the upgraded injector with a 200 kV gun during the Scheduled Accelerator Down (SAD) 2023 for the K-long experiment.
- An injector simulation with the spin rotator/Wien system ON is planned for the low-energy 200 keV beam to Hall D, which will run simultaneously with MOLLER at Hall A in CEBAF.

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