The Jefferson Lab's injector has a photo-cathode source operating at 130 kV with GaAs [1] as the photo-cathode material to provide polarized beams to nuclear physics experiments in Jefferson Lab's experimental halls. After bunching at 130 keV, the beam is accelerated to 500 keV with a low Q graded β 5-cell radiofrequency (RF) cavity before being accelerated to relativistic energies (or nearly relativistic energies as required) in 2 5-cell superconducting RF cavities known as the quarter cryomodule. Downstream of the quarter cryomodule is a transport section with four beamlines served by a common dipole: a straight ahead line (0L) to deliver beam to the next stage of accleration before the beam is merged into the main CEBAF accelerator and three spectrometer dump lines (2D, 3D, and 5D). The 2D and 5D dump lines form -30° and 25° angles, respectively, with the straight ahead 0L line. The bubble chamber was installed on the 5D line. Setting and measuring the electron beam characteristics for the experiment used the 0L, 5D, and 2D lines.

Throughout the experiment, the cavities in the quarter cryomodule were operated on-crest providing maximum energy gain from each cavity, and the gradient setpoints of the two cavities were adjusted to set the momentum of the beam to match the calculated spectrometer dipole setting for the desired beam momentum in the 5D line. Beam position monitor (BPM) readbacks in the 5D line determined when the momentum matched the dipole setting. The momentum was measured using both the 2D and 5D lines under the assumptions that the momentum of the beam coming into the spectrometer dipole is fixed and proprotional to the angle (and therefore dipole setting) required to bend the beam into the respective dump line. The beam momenta measured using this method and associated errors are summarized in Tables 1 and 2.

Table 1: Beam Momenta

Design p (MeV/c)	**Design K.E (MeV)**	**2D line dipole setting (G cm)**	**5D line dipole setting (G cm)**	**Measured p (MeV/c)**
5.24	4.75	-8957.675	7338.900	5.299
5.34	4.85	-9135.993	7490.000	5.406
5.44	4.95	-9320.700	7646.800	5.517
5.54	5.05	-9468.500	7771.400	5.605
5.64	5.15	-9632.300	7909.200	5.703
5.74	5.25	-9865.500	8099.000	5.840
5.84	5.35	-9937.637	8168.800	5.887

Table 2: Beam Momenta Errors

Contribution	**Value (%)**
Power Supply Calibration (2 mA)	0.06
Power Supply Regulation (1.5 mA)	0.04
Spectrometer dipole field map offset (7 G-cm)	0.08
Spectrometer dipole model	0.10
Tracking model (0.006 MeV/c)	0.11
Total	0.18

In addition to transport optics, the 0L line is instrumented with BPMs and a wire scanner for measuring the beam centroid and size. The 2D line has a wire scanner and BPM, and the 5D line has transport optics, BPMs, and a wire scanner upstream of the radiator. Using an `elegant` [2] model for the optics in the individual lines and measurements from the wire scanners, simulations provide the momentum or energy spread of the beam (Table 3) and the beam size at the radiator (Tables 4 and 5).

Table 3: Momentum or Energy spread (dp/p)

Measured p (MeV/c)	**dp/p** ($\times 10^{-3}$)
5.299	1.76
5.406	1.72
5.517	1.27
5.605	1.17
5.703	1.28
5.840	1.50
5.887	1.88

With a beamline model of the 5D beamline elements between the spectrometer dipole and the radiator (3 corrector pairs, 2 quadrupoles, and 2 BPMs) including the background earth's field, General Particle Tracer (`gpt`) [3] simulations provide estimates of the position and angle of the beam on the radiator in Table 6. The simulations used the measured beam positions from the BPMs and the control system setpoints for the corrector and quadrupole magnets to determine the likely beam orbit at the radiator.

References

[1] CIS photocathode paper.

[2] M. Borland, Advanced Photon Source LS-287 (September 2000).

[3] S.B. van der Geer and M.J. de Loos, General Particle Tracer, `http://www.pulsar.nl.gpt`, 2018.

Table 4: Horizontal beam size at wire scanner and extrapolated beam size at the radiator

Measured p (MeV/c)	**Wire Scanner RMS size (mm)**	**RMS size (mm)**	**Note**
5.299	1.312	1.698	05142018 22:35:00 measurement prior to data taking is different from 05162018 13:21:51 re-measurement after data taking (latter reported)
5.406	0.7528	0.8670	05132018 22:39:02
5.517	0.4907	0.3093	05162018 19:01:44
5.517	1.11	1.51	05172018 11:28:02 (larger spot size)
5.605	0.1532	0.4092	05122018 16:11:48
5.703	0.6809	0.6575	05152018 23:29:41 poor beam position on radiator
5.703	0.9079	1.023	05162018 09:45:50 centered on radiator
5.840	0.7493	0.7416	05112018 22:04:10
5.840	0.5721	0.5100	05132018 15:34:03
5.887	1.342	1.623	05172018 23:59:19

Table 5: Vertical beam size at wire scanner and extrapolated beam size at the radiator

Measured p (MeV/c)	**Wire Scanner RMS size (mm)**	**RMS size (mm)**	**Note**
5.299	0.6964	0.5736	05142018 22:35:00 measurement prior to data taking is different from 05162018 13:21:51 re-measurement after data taking (latter reported)
5.406	0.9905	1.224	05132018 22:39:02
5.517	1.001	1.220	05162018 19:01:44
5.517	2.296	2.793	05172018 11:28:02 (larger spot size)
5.605	1.013	1.261	05122018 16:11:48
5.703	0.9945	1.190	05152018 23:29:41 poor beam position on radiator
5.703	1.137	1.180	05162018 09:45:50 centered on radiator
5.840	0.5956	0.7936	05112018 22:04:10
5.840	0.4482	0.5249	05132018 15:34:03
5.887	0.405	0.4781	05172018 23:59:19

Table 6: Beam Positions and Angles at the radiator (RHCS) listed in the same order as Tables 4 and 5

Measured p (MeV/c)	**Horizontal angle (mrad)**	**Horizontal position (mm)**	**Vertical angle (mrad)**	**Vertical position (mm)**
5.299	-0.64	2.26	-1.06	-1.15
5.406	-1.90	0.99	-3.42	-5.24
5.517	-1.61	-0.26	0.00	0.66
5.517	-1.63	-0.29	-0.38	0.10
5.605	-3.67	-0.78	-1.17	-1.17
5.703	-3.73	-2.36	0.20	1.03
5.703	-2.36	0.45	-0.39	0.23
5.840	-2.60	0.32	-0.96	-0.91
5.840	-2.30	1.02	-0.66	-0.46
5.887	-3.58	0.95	4.02	0.86