KLF Final Beam Focusing (Draft)

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This is a short technical note to evaluate the feasibility of certain beam parameters for the K-Long Factory (KLF) experiment proposal from Sean Dobbs and Igor Strakovsky on 17 Apr 2020. In particular, this note evaluates the feasibility of a 95% full width beam size of 1–2 cm (horizontal) and 5 mm (vertical) at the CPS, with a projected beam minimum beam size at the Be production target in the collimator cave ≈67 m downstream of the CPS.

The document [1] identifies typical beam parameters for CEBAF 12 GeV operations. The relevant parameters for this note are the geometric transverse rms emittances of $\epsilon \approx 6 \times 10^{-9}$ m rad, and the beam energy of ≈12 GeV. The emittances in both transverse planes are dominated by synchrotron radiation driven emittance growth in the CEBAF arcs at energies above 9–10 GeV, so they are unlikely to be significantly different than this estimate.

1 Baseline GlueX

The beta functions at the radiator in nominal GlueX tuning are about $\beta_x \approx$250 m and $\beta_y \approx$170 m. The rms beam sizes σ can then be calculated via $\sigma = \sqrt{\beta\epsilon}$ [2].

$$\sigma_x = \sqrt{\beta_x \epsilon_x} = \sqrt{(250\,\mathrm{m})(7\times 10^{-9}\,\mathrm{m\,rad})} \tag{1.1}$$

$$= 1.3\,\mathrm{mm} \tag{1.2}$$

and

$$\sigma_7 = \sqrt{\beta_y \epsilon_y} = \sqrt{(170\,\mathrm{m})(5\times 10^{-9}\,\mathrm{m\,rad})} \tag{1.3}$$

$$= 0.9\,\mathrm{mm} \tag{1.4}$$

These are relatively consistent with observed beam spot sizes on the GlueX diamond radiator.

2 KLF Request

The effective emittance of 95% of a beam is 6π larger than the rms emittance [2]. For the conservative 95% horizontal total beam size of 1 cm, the horizontal beta function required at the CPS is therefore

$$\beta_x = \sigma_{95}^2/(6\pi\epsilon) \tag{2.5}$$

$$= (5\times 10^{-3}\,\mathrm{m})^2/(6\pi(6\times 10^{-9}\,\mathrm{m\,rad})) \tag{2.6}$$

$$= 221\,\mathrm{m} \tag{2.7}$$

This is a reasonable number, in fact not so different than the existing horizontal beta function at the GlueX diamond radiator. The projected beta function at the target is 21.1 m.

For the 95% vertical total beam size of 5 mm, the vertical beta function required at the CPS is therefore

$$\beta_y = \sigma_{95}^2/(6\pi\epsilon) \tag{2.8}$$

$$= (2.5\times 10^{-3}\,\mathrm{m})^2/(6\pi(6\times 10^{-9}\,\mathrm{m\,rad})) \tag{2.9}$$

$$= 55\,\mathrm{m} \tag{2.10}$$

This number is too small to provide a focus at the target L =65 m downstream. The minimum beta function should be ≈130 m. Presumably the collaboration does not have a problem with making the beam larger at the CPS. An even larger beta function at the CPS would be better to provide smaller beam at the target, since the relationship between the CPS beta function β_c and target beta function β_t is

$$\beta_c = \beta_t + L^2/\beta_t \ . \tag{2.11}$$

The required beta function scales with the beam size squared, so pushing the 95% full width beam size to 2 cm requires a beta function of ≈880 m. As can be seen in the next section on convergence, this is quite large, and would require substantial rework of the beamline including installation of large-aperture quadrupoles. This would also produce an extremely small beta function at the target of β_t =4.8 m, with correspondingly high divergence necessary at the CPS.

The space between the CPS and Be production target is a drift space. The beam convergence, $\alpha_c \equiv -\beta_c'/2$, required at the CPS to produce a waist at the Be production target is

$$\alpha_c = L/\beta_t \tag{2.12}$$

In the horizontal plane this implies $\alpha_c \approx 3$ at the CPS. This convergence is quite steep. Careful checks in upstream optics are necessary to determine whether such a steep convergence is feasible for the 1 cm 95% full width beam case.

3 Optics Evaluation

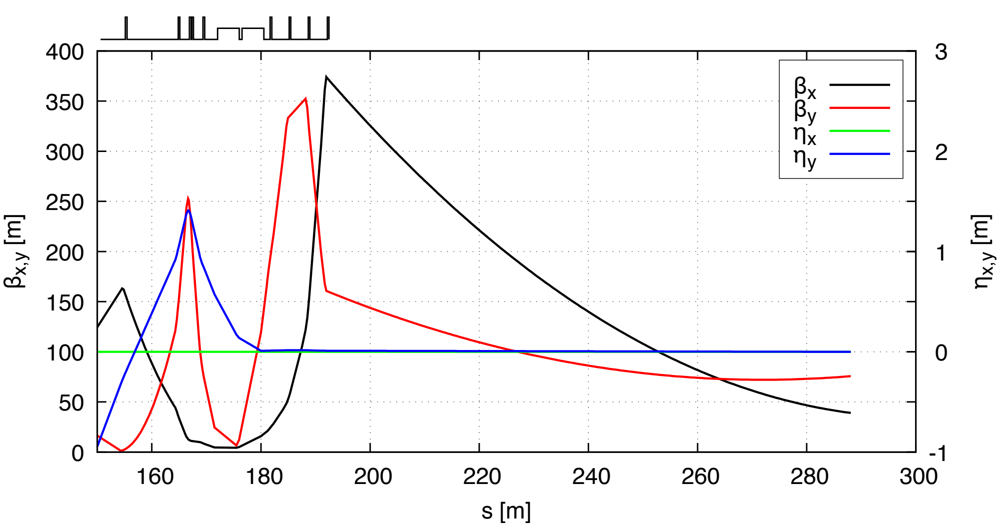

Figure 1: Nominal final focus optics for GlueX. The KLF CPS front face would be located near s = 220 m.

Figure 1 shows close to the nominal GlueX optics. The location of the KLF CPS front face would be around s = 220 m. The top of the plot shows quadrupoles (tall thin lines) and dipoles (short, wider rectangles). Quadrupoles are numbered Q4 through Q11 proceeding left to right. The Q8-11 quadrupole quadrupolet is typical of optical systems used to focus both horizontal and vertical planes of a beam to a common waist, as is typically desired in GlueX operations to “focus” the projected photon beam to a small spot at the collimator to maximize photon polarization transmission efficiency.

Figure 2 shows slightly modified optics to produce beta functions at the CPS radiator front face of about β_x=220 m and β_y=130 m. This corresponds to the conservative 95% horizontal total beam size of 1 cm at the CPS. This is achievable with no modifications of the GlueX/HallD beamline.

Figure 3 shows slightly modified optics to produce beta functions at the CPS radiator front face of about β_x=440 m and β_y=130 m. This is an incrementally more aggressive horizontal beam size at the CPS radiator

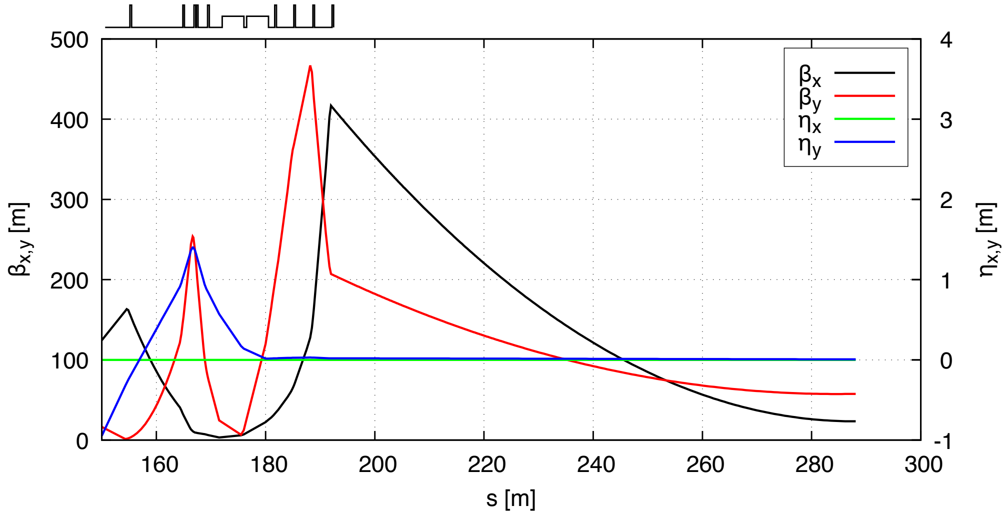

Figure 2: Final focus optics to produce β_x=220 m and β_y=130 m at the CPS front face.

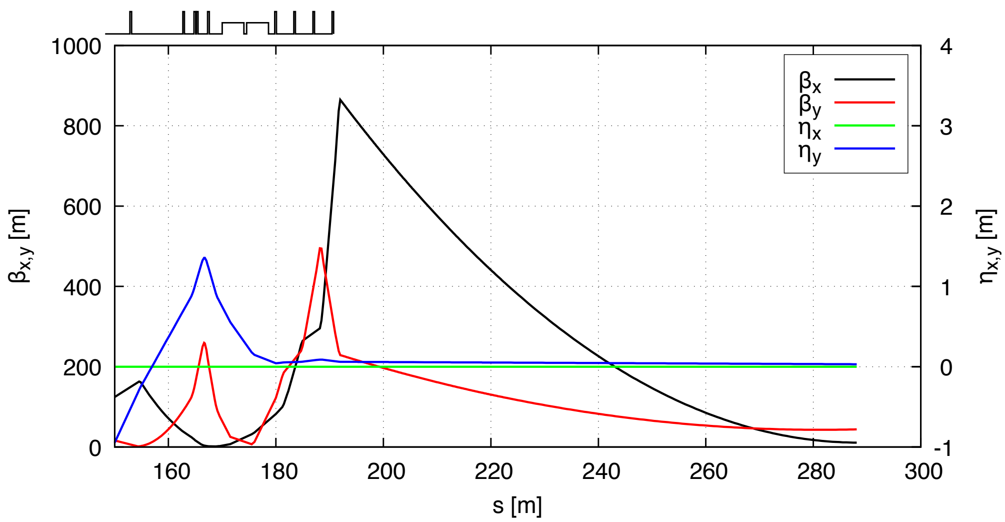

Figure 3: Final focus optics to produce β_x=440 m and β_y=130 m at the CPS front face.

front face, corresponding to a 95% horizontal total beam size of 1.4 cm at the CPS. The maximum horizontal beta function at the Q11 quadrupole is 864 m, giving a 95% rms beam radius of

$$\sigma_{95} = \sqrt{6\pi\epsilon\beta_x} = 10\,\text{mm} \tag{3.13}$$

The existing Q11 quadrupole has a bore radius of 16 mm. These optics are tight and would require tight steering and optics correction and stability tolerances for sustained GlueX operation. Alternatively, the Q8-Q11 magnets may be replaced with newly-designed larger-bore magnets for KLF operations.

Figure 4 shows slightly modified optics to produce beta functions at the CPS radiator front face of about β_x=660 m and β_y=130 m. This is a significantly more aggressive horizontal beam size at the CPS radiator front face, corresponding to a 95% horizontal total beam size of 1.7 cm at the CPS. The maximum horizontal beta function at the Q11 quadrupole is 1315 m, giving a 95% rms beam radius of

$$\sigma_{95} = \sqrt{6\pi\epsilon\beta_x} = 12\,\text{mm} \tag{3.14}$$

The existing Q11 quadrupole has a bore radius of 16 mm. These optics are quite tight and would likely require replacement of the Q8-Q11 magnets with newly-designed larger-bore magnets for KLF operations.

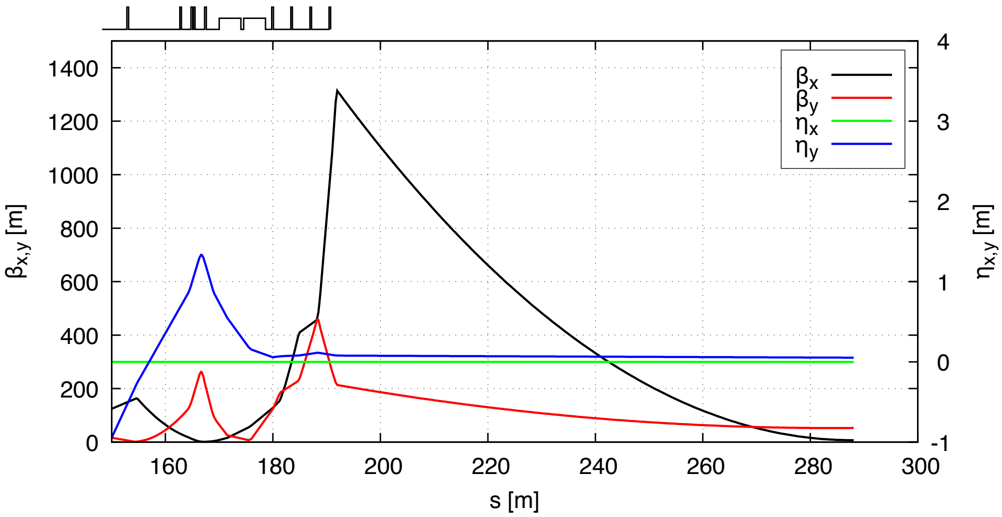

Figure 4: Final focus optics to produce β_x=660 m and β_y=130 m at the CPS front face.

A similar argument applies for 95% horizontal total beam size of 2 cm at the CPS. At that level, the required quadrupole apertures and strengths are sufficiently large that the new quadrupoles would certainly have to be designed and installed for these optics. The field quality and stability requirements would also be tight, as the very large beta functions would make beam quality very sensitive to small energy and steering variations.

References

[1] J. Benesch *et al.*, "12 GeV CEBAF Beam Parameter Tables", JLAB-TN-18-022, 31 March 2018.

[2] A. Chao and M. Tigner, eds., "Handbook of Accelerator Physics and Engineering", 3rd printing, p. 66.