# OPTICS LAYOUT FOR THE ERL PROTOTYPE AT DARESBURY LABORATORY

B. Muratori, H.L. Owen, J.A. Varley
ASTeC, CCLRC Daresbury Laboratory, Warrington WA4 4AD, United Kingdom

*Abstract*

The design of the electron beam transport system for the Energy Recovery Linac Prototype (ERLP) at Daresbury Laboratory is described; in particular we discuss the arc design, matching and adjustment of the compression options for the facility, and the layout constraints that affect the choices made.

## INTRODUCTION

The Energy Recovery Linac Prototype (ERLP) is presently under construction at Daresbury Laboratory [1]. It will study issues such as compression, synchronisation, energy recovery and coherent synchrotron radiation, which in conjunction with experiments planned elsewhere are needed to validate design choices for the proposed 4th Generation Light Source. ERLP will consist of a single-pass superconducting linac driving an infra-red oscillator FEL [2], circulating 80pC electron bunches at up to 35MeV; deceleration through the same linac 180 degrees out of phase with acceleration will provide energy recovery, with injection and extraction occurring at nominally 8.35MeV. The design of the injector, which consists of a 350keV photocathode gun followed by a superconducting module composed of 2 TESLA-type 9-cell cavities, is described elsewhere [3]. Although the expected normalised emittance is small ($<$ 5mm-mrad), the design allows for operation at larger normalised emittance values of up to 15mm-mrad.

The re-use of an existing building demands a compact layout with two arcs to recirculate the electron bunches for energy recovery, placing the FEL opposite the main linac. The two 4-dipole chicanes used for bunch compression/decompression will be placed close to optimise the FEL gain [2]; due to the their geometry (and the requirement to place mirror vessels in them) the chicanes have an effectively static $R_{56}$ of 0.28m (positive in our sign convention). Two triple-bend achromat arcs (plus matching quadrupoles) provide the rest of the beam transport system, and are able to provide a large negative $R_{56}$ by changing the dispersion in the centre dipole [4]. In combination with the chicanes this allows significant adjustment of $R_{56}$ both upstream and downstream of the FEL to allow both optimum compression and flexible experiments in energy recovery. The overall layout is shown in Figure 1. Building constraints (see Figure 2) require a relatively long transfer line between the injector and the injection chicane. However, emittance growth from space charge is not predicted to be excessive [5]; space charge can be neglected at full energy (35 MeV).

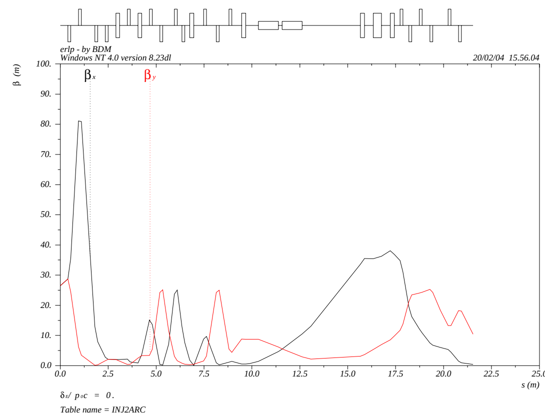


Figure 3: Twiss functions in the transfer line from injector, through ERL and extraction chicane to start of first arc.

## OPTICAL DESIGN

### *Transfer Line*

The transfer line, which transports bunches from the injector to the 3-dipole injection merging chicane of the ERL, consists of a double-bend achromat (DBA) followed by a 2-dipole achromatic dog-leg. The $R_{56}$ arising from this system is small and easily accommodated by adjusting the RF phase in the main linac from its nominal 9 degrees off-crest chirp. To allow variation of the injector setup (up to $\beta_{x,y}$ of 60m and a divergence of $\alpha_{x,y}$ up to -6), we require a large diameter aperture of 71mm upstream of the DBA and a four-quadrupole telescope to match into the DBA. An energy bandwidth of +/-1% is budgeted prior to the FEL. A second four-quadrupole telescope between the DBA and dog-leg matches the Twiss functions into the main linac. Twiss functions are shown in Figure 3.

### *ERL Design*

Triple-bend achromat (TBA) and Bates bend designs were considered and have comparable predicted performance [4]; the TBA option was chosen as it is a simpler engineering solution. By varying the dispersion in the central TBA dipole, $R_{56}$ either side of the FEL is adjustable from a large negative to large positive value, whilst $T_{566}$ can be adjusted using sextupoles in the arcs. Sextupoles are required in the first arc to linearise the compression at

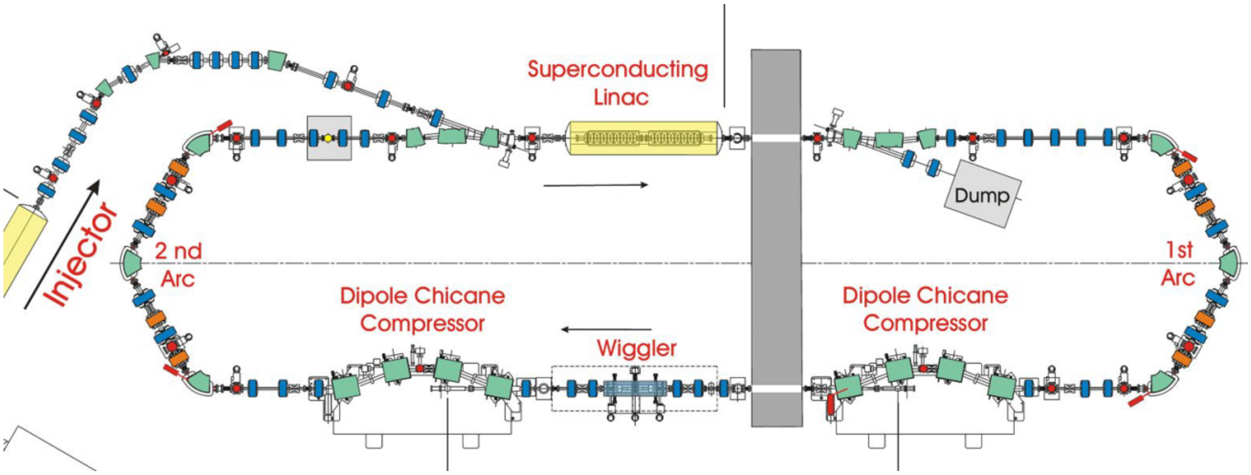


Figure 1: The layout of the ERL Prototype.

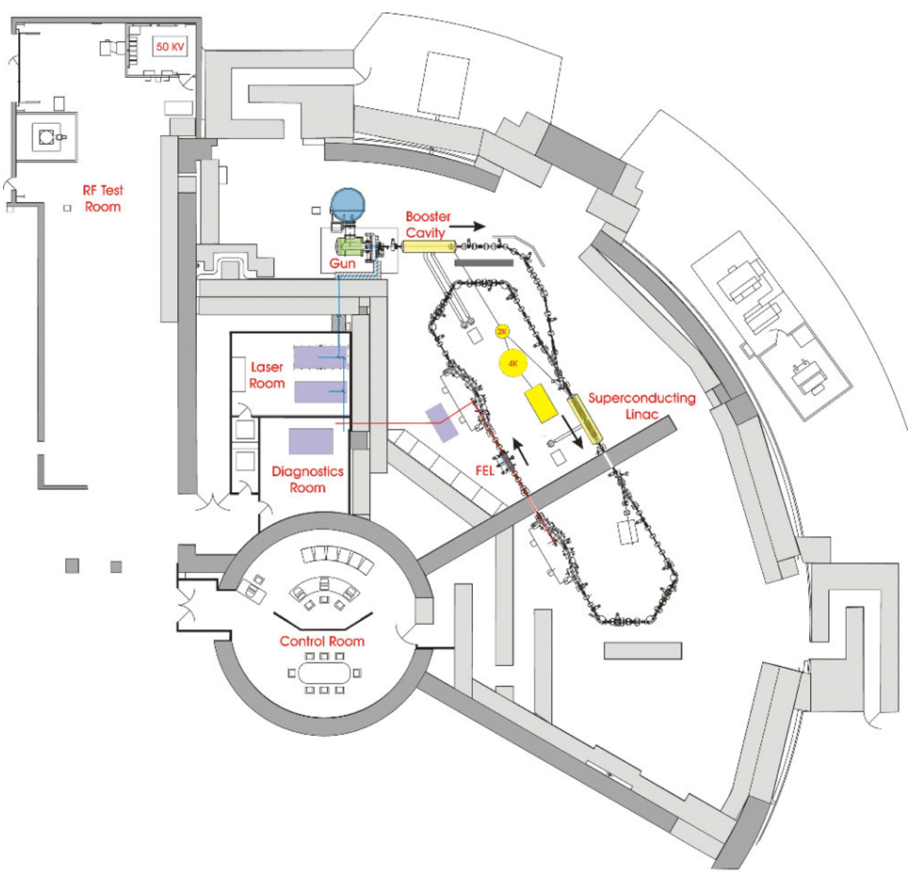


Figure 2: Position of ERLP in existing building. Space is very limited around the injector and Arc 2. Existing building walls are shown in dark grey, and new additional shielding is shown in light grey.

the FEL (removing the lowest-order curvature from the sinusoidal RF in the linac), whilst those in the second arc minimise the energy spread after deceleration so that the disrupted electron bunches may be cleanly extracted to the beam dump. A building wall between the main linac and extraction chicane makes the beam transport sensitive but still operable. Two example modes of $R_{56}$ operation are illustrated in Figure 4: in the second mode (shown dashed) the return arc is used to overcompensate the $R_{56}$ induced by the $2^{nd}$ chicane to reverse the longitudinal phase space for energy recovery.

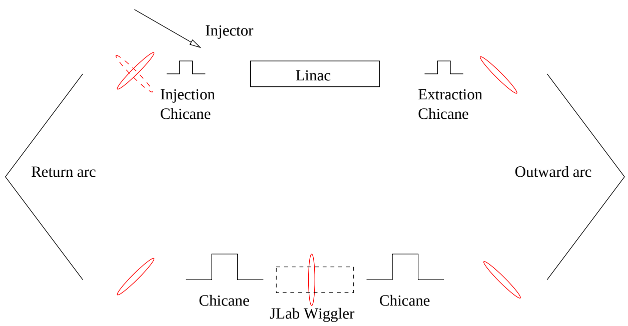


Figure 4: Illustrative longitudinal phase space for two modes of operation - solid line: $R_{56}(\text{arc1\&2}) = 0$, dashed: $R_{56}(\text{arc2}) = -2R_{56}(\text{chicane})$.

A compact layout of quadrupoles and correction either side of the FEL enables a movable beam waist of $\beta_x = \beta_y = 0.5$ m. Twiss functions for the ERL are shown in Figure 5.

Re-using the existing building means that shielding is limited, and losses from beam halo must be minimised as far as possible over a wide range of optics tunings. Similar to the specification used at Jefferson Laboratory [6], apertures are defined to allow a wide range of operating modes, using 50mm diameter apertures in the (non-dispersive)

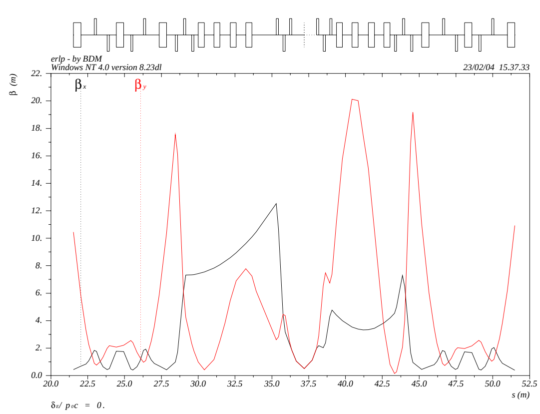

Figure 5: Beta functions behaviour in the arcs and through the wiggler ($R_{56}(\text{arc}) = 0$). The $R_{56}(\text{chicane}) = -R_{56}(\text{arc})$ mode is only slightly different.

straight sections and 80x40mm apertures in the dispersion-dominated arcs. This will provide a bandwidth of around +/-2.5%, sufficient to transport the fully-disrupted bunches from the FEL [2]. Magnet specifications are modest at these apertures [7], with many being provided from the JLab IR-Demo [6].

Each section of the accelerator will have either optical transition radiation (OTR) or YAG-based screens, with 1/4-$\lambda$ electron beam position monitors (EBPMs) at regular spacing. In particular, the arcs have symmetrically-placed OTRs and EBPMs to enable optical setup and absolute and relative energy spread measurement. Trajectory correction studies indicate that the maximum corrected trajectory can be kept under 5mm everywhere, with sufficient steering accuracy at the FEL. Alignment tolerances are fairly loose, e.g. 0.5mm transverse tolerance on quadrupoles. Bunch lengths at the FEL, which are expected to be less than 1ps with Arc 1 sextupoles energised, will be measured using either an electro-optic crystal technique [8, 9] or via an interferometer-based autocorrelation technique [10].

## ACKNOWLEDGEMENTS

The authors would like to thank the FEL staff at Jefferson Laboratory for many collaborative discussions and the provision of many magnet systems, and Ivan Bazarov and Georg Hofstätter at Cornell University, for useful discussions.

## REFERENCES

[1] M.W. Poole *et al* "4GLS and the Prototype Energy Recovery Linac Project at Daresbury", EPAC'04, Lucerne, July 2004.

[2] N. Thompson, "Design for an Infra-Red Oscillator FEL for the 4GLS Energy Recovery Linac Prototype", Proceedings of the 2003 Free-Electron Laser Conference.

[3] C. Gerth, F.E. Hannon, "Injector Design for the 4GLS Energy Recovery Linac Protype", EPAC'04, Lucerne, July 2004.

[4] H. L. Owen, B. Muratori, "Choice of Arc Design for the ERL Prototype at Daresbury Laboratory", EPAC'04, Lucerne, July 2004.

[5] B. Muratori *et al*, "Space Charge Effects for the ERL Prototype at Daresbury Laboratory", EPAC'04, Lucerne, July 2004.

[6] D. R. Douglas, "Lattice Design for a High-Power Infrared FEL", PAC'97, Vancouver, May 1997.

[7] N. Marks, N. R. Thompson, "Magnet Specification for the Daresbury Laboratory ERL Prototype", EPAC'04, Lucerne, July 2004.

[8] I. Wilke *et al*, "Single-Shot Electron-Beam Bunch Length Measurements", *Phys.Rev.Lett.* **88 (12)**, 124801 (2002).

[9] G. Berden *et al*, "High Temporal Resolution, Single-Shot Electron Bunch-Length Measurements", EPAC'04, Lucerne, July 2004.

[10] G. A. Krafft *et al*, "Measuring and Characterising Ultra-short Bunches in The Jefferson Lab Free Electron Laser", EPAC'98, Stockholm, June 1998.