DEVELOPMENTS IN THE CLARA FEL TEST FACILITY ACCELERATOR DESIGN AND SIMULATIONS

P. H. Williams*, D. Angal-Kalinin, A. D. Brynes, J. A. Clarke,
F. Jackson, J. K. Jones, J. W. McKenzie, B. L. Militsyn, N. R. Thompson,
STFC Daresbury Laboratory & Cockcroft Institute, Warrington, UK
R. B. Appleby, B. Kyle, University of Manchester & Cockcroft Institute, UK

Abstract

We present recent developments in the accelerator design of CLARA (Compact Linear Accelerator for Research and Applications), the proposed UK FEL test facility at Daresbury Laboratory. In order to prioritise FEL schemes requiring the shortest electron bunches, the layout has changed significantly to enable compression at higher energy. Four proposed modes of operation are defined and tracked from cathode to FEL using ASTRA. Supplementing these baseline mode definitions with CSR-enabled codes (such as CSRTRACK) where appropriate is in progress. The FEL layout is re-optimised to include shorter undulators with delay chicanes between each radiator.

FEL SCHEMES PRIORITISATION

CLARA will be primarily an FEL R&D facility [1] and will inform the aims and design of a future UK-XFEL. It is intended to be flexible such that different FEL schemes can be investigated, nevertheless in 2015 a priority order of envisaged FEL research programmes was developed to inform the accelerator design and layout. The prioritisation considered both the current status of worldwide FEL research, to ensure CLARA work is complementary and addresses some unique topics, as well as the anticipated requirements of a future UK-XFEL. The revised CLARA beam modes in priority thus determined are:

- Ultrashort Mode: for the demonstration of single spike SASE where the bunch length should be less than the SASE spike spacing.
- Short Mode: to achieve saturation at the shortest wavelength (100 nm). Schemes demonstrating temporal coherence can be diagnosed at this wavelength and short pulse schemes will produce the shortest pulse durations in absolute terms at this wavelength.
- Long Mode: for short pulse schemes involving a long wavelength energy modulation of the beam, such as mode-locking and slice-and-taper. These schemes are best diagnosed at 266 nm.
- Flat Mode: for stable seeded harmonic generation to reduce shot to shot output power jitter caused by electron bunch to seed laser timing jitter.

* peter.williams@stfc.ac.uk

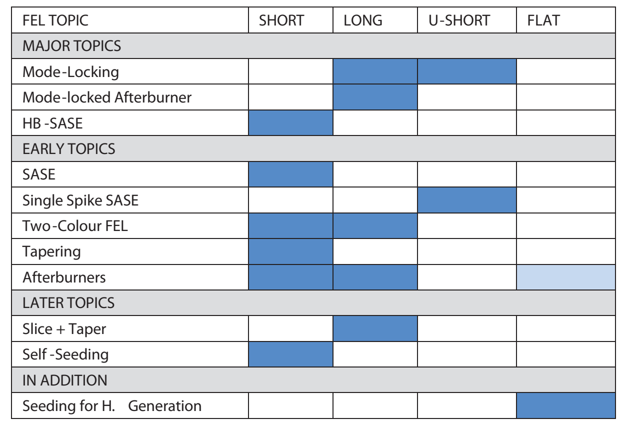

Figure 1: CLARA FEL schemes showing required beam mode(s) for each scheme.

Fig. 1 shows a summary of the prioritisation of CLARA FEL schemes and the required beam mode(s) for each scheme. The FEL prioritisation dictates the requirements on beam parameters as shown in Tab. 1. For the short and long mode it may be advantageous to demonstrate schemes at both 100 nm and 266 nm, therefore we define two target final energies required for these modes, these being 150 MeV and 240 MeV.

In summary, since the publication of the CDR the emphasis for the electron beam modes has switched away from a mildly compressed, chirpless *flat bunch* mode towards better optimisation of the more highly compressed *short* and *ultrashort* modes. This reflects an intention to cancel regenerative amplifier FEL work and give lower priority to seeded harmonic generation. Instead the initial emphasis will be on single spike SASE with the more challenging HB-SASE and Mode-Locking, which do not require flat top bunches.

MACHINE LAYOUT REVISIONS

Until recently [2], initial optics matching was defined using Mad8.23dl and Elegant [3], then tracking was performed using ASTRA [4] in the injector (from cathode to exit of Linac 1) and Elegant in the remainder of the machine. This enabled fast matching and optimisation, but neglected space-charge effects. However, it is now possible to track the entirety of CLARA using ASTRA in 3-D space-charge mode. When this was performed it revealed an undesirable feature of the matching that was not apparent previously. At least one optics crossover occured within each linac, this

ISBN 978-3-95450-147-2

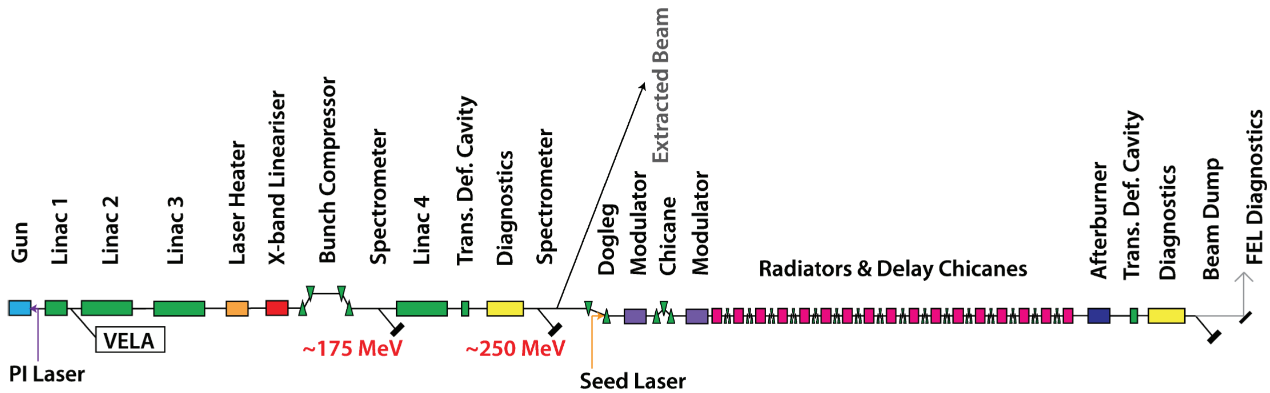

Figure 2: CLARA layout. The total length is ~ 90 m.

Table 1: CLARA beam modes for FEL R&D

Param.	Unit	Beam Mode			
		Short	Long	U. Sh.	Flat
Energy	MeV	240 150	150 240	240	240
Δt_{FWHM}	fs	585	1875	40	250
Charge	pC	250	250	20	250
Slice	fs	25	25	5	15
I_{peak}	A	400	125	1000	400
ε_N target	μm	0.5	0.5	1.0	0.5
ε_N max	μm	1.0	0.8	1.5	1.0
σ_δ target	keV	25	25	100	25
σ_δ max	keV	120	75	150	100
E. Chirp	MeV/ps	n/a	n/a	n/a	<1
E. Var.	keV	n/a	n/a	n/a	< 240

led to large transverse emittance increases each time as the beam size becomes small at relatively low energy. Therefore we concluded that it is important to not only perform tracking studies using a space-charge code, but also match the lattice with one. A decision has therefore been taken to conduct all matching, optimisation and tracking using ASTRA with appropriate switchover to a CSR-enabled code (such as CSRTRACK) while tracking the beam through the variable bunch compressor (in the modes where this is used) and the seeding dogleg.

Tracking using 3D space-charge in ASTRA with a candidate ultrashort mode generated via velocity bunching also indicated noticeable increase in bunch length between Linac 2 and 3 due to space charge at ~ 70 MeV, shown in Fig.3. In the case where Linac 3 is placed directly after Linac 2, the short bunch length is preserved.

These factors led to a decision to move Linac 3 from its originally intended position downstream of the bunch compressor to upstream, immediately following Linac 2. As the ultrashort mode suffers from emittance increase in long sections at relatively low energy, the choice made is to put only a short section with one quadrupole in between Linac

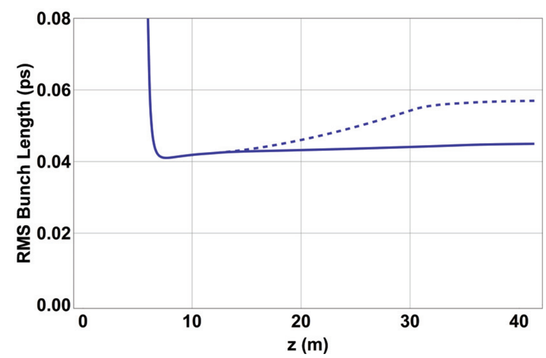

Figure 3: RMS bunch length for the case of a long drift after Linac 2 (dashed) and with Linac 3 directly after Linac 2 (solid).

2 and Linac 3. This provides some flexibility in matching without significant additional length. This revised layout is shown in Fig. 2.

The layout of the FEL radiator section was also revised following the FEL prioritisation. The radiator section has been revised from eight 1.5 m radiators to seventeen 0.75 m radiators with delay chicanes inserted between each radiator. This was driven partly by the identification of Mode-Locking and HB-SASE as core topics—both of these schemes perform progressively better as the length of individual undulator modules is reduced and the number of delays is increased. However, by also reducing the inter-undulator gap length to maintain the same packing factor (ratio of undulator length to gap length) the gain length for all schemes is also reduced because a smaller average β-function can be achieved. Re-optimisation of the intra-undulator components is underway.

EXAMPLE TRACKING SIMULATIONS

Presently, simulations for the ultrashort mode use velocity bunching in Linac 1 to achieve the necessary compression, whereas all other modes use magnetic compression in a variable chicane. There is scope to mix-and-match these approaches as operational experience develops.

For reason of brevity, we present only two of the highest priority beam modes here as examples.

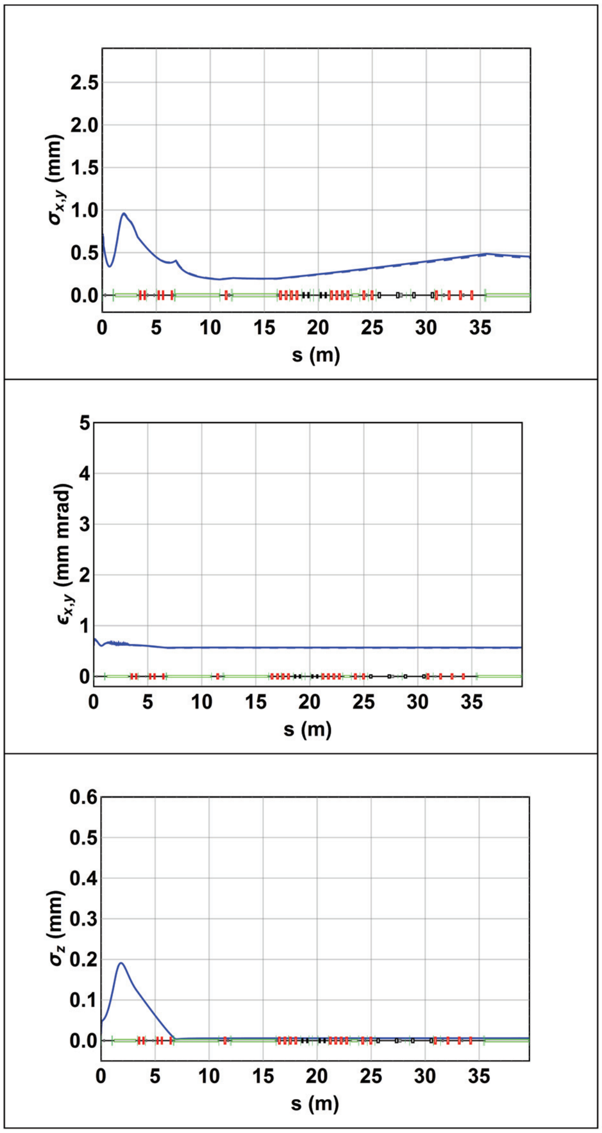

Figure 4: Bunch evolution up to the end of Linac 4 in the 20 pC ultrashort bunch mode at 240 MeV.

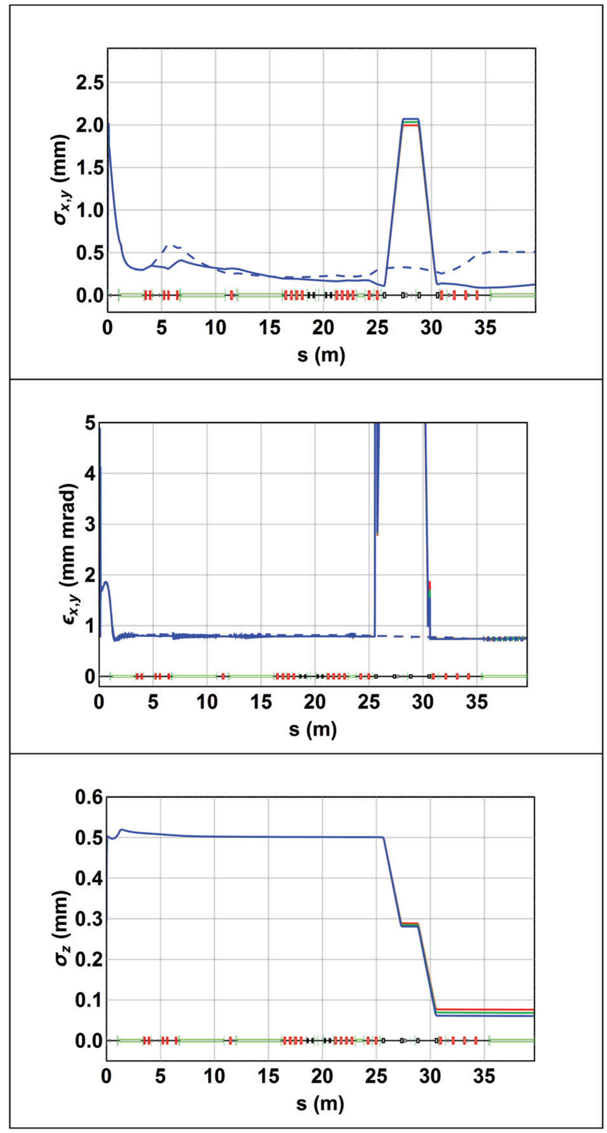

Figure 5: Bunch evolution up to the end of Linac 4 in the 250 pC short bunch mode at 240 MeV. Linac-X phase setting of 185°, 186°, 187° are marked as blue, green and red respectively.

20 pC Ultrashort Mode at 240 MeV

We set Linac 1 to velocity bunching mode (close to zero-cross phase), turn off the magnetic chicane, X-band harmonic RF and all quadrupoles to the end of Linac 4. Focusing is achieved using two solenoids encasing Linac 1, together with the RF-focusing. Figure 4 shows that the beam properties as they evolve along the machine, we conclude that the specifications can be met.

250 pC Short Mode at 240 MeV

We set Linac 1 to booster mode (20° from crest), activate the variable bunch compressor, harmonic RF and provide matching focusing through to Linac 4. Shown here is an estimation of the effect of the X-band phase jitter by performing three runs, incrementing the phase by one degree. Fig. 5 shows the beam properties as they evolve along the machine, we conclude that the specifications can be met.

FUTURE WORK

In order to completely specify the layout a number of issues are outstanding, namely revisiting the previously designed diagnostics sections incorporating transverse deflecting cavities to measure the longitudinal phase space before and after the FEL, confirmation of BPM and screen positions, the required components in the four spectrometer beamlines, and assessment of any additional collimation.

CLARA is able to satisfy the many beam modes required of this uniquely flexible test facility. The revised layout has successfully mitigated the risk of space charge mediated emittance growth at the variable bunch compressor.

ISBN 978-3-95450-147-2

REFERENCES

[1] J. A. Clarke *et al,* CLARA Conceptual Design Report, *JINST*, 9:T05001, 2014.

[2] P. Williams, D. Angal-Kalinin, A. D. Brynes et al, "Developments in CLARA Accelerator Design and Simulations", Proceedings of International Particle Accelerator Conference, 2015.

[3] M. Borland, "elegant: A flexible SDDS-Compliant Code for Accelerator Simulation", Advanced Photon Source LS-287, 2000.

[4] K. Floetmann, ASTRA, `http://www.desy.de/~mpyflo`