4GLS AND THE ENERGY RECOVERY LINAC PROTOTYPE PROJECT AT DARESBURY LABORATORY

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Abstract

4GLS is a novel next generation proposal for a UK national light source to be sited at Daresbury Laboratory, based on a superconducting energy recovery linac (ERL) with both high average current photon sources (undulators and bending magnets) and high peak current free electron lasers. Key features are a high gain, seeded FEL amplifier to generate XUV radiation and the prospect of advanced research arising from unique combinations of sources with femtosecond pulse structure. An R&D programme is addressing the challenging accelerator technology involved and a major part of this is a 35 MeV demonstrator, the ERL Prototype (ERLP) currently under construction. The 4GLS design activities are summarised, the ERLP described in detail and the 4GLS project status and plans explained.

THE PROPOSED 4GLS FACILITY

4GLS embraces an advanced concept for a 4th generation light source for the UK. It is proposed as a low energy source providing unique output for that scientific user community and complementing other higher energy 3rd generation sources such as Diamond and the ESRF as part of a national portfolio. From its original concept at Daresbury [1,2,3] the linac based source has been considerably developed and a prototype energy recovery linac project was also approved in 2003 [4].

A key feature of 4GLS is its multi-source nature, allowing advanced two-colour pump-probe experiments. The project team is now undertaking design studies and recent progress is reported here. The target is to produce by March 2006 a mature proposal, including a CDR, to support a funding bid. Development of the Scientific Case is proceeding in parallel with the technical source studies, consolidating the formal specification.

THE ERL PROTOTYPE PROJECT

The Energy Recovery Linac Prototype (ERLP) is a precursor to 4GLS. It is designed as a demonstrator of the beam physics and some of the technologies that will be needed for 4GLS, albeit at a much smaller scale. It is nevertheless important that it delivers its initial objectives during 2006 in order to underpin the anticipated 4GLS funding bid process.

The complete layout of ERLP is given in Fig. 1. Restrictions on the available building require the recirculation beam transport system to straddle an existing shielding wall as is shown in the figure. However this building does provide excellent ancillary space for adjacent laser and diagnostics areas, power supply locations and a control room.

All parts of the beam transport system have been matched using MAD8. It comprises a 350 keV DC gun, a buncher, an 8 MeV injector linac and a 35 MeV ERL configuration. One of the two TBA arcs can be translated up to 70 mm by a drive mechanism on its support girders to achieve an optimised phase setting for energy recovery.

One important ERLP deliverable will be the successful demonstration of compression of electron bunches to below 1 ps. This will be achieved with a combination of chirping by off-crest RF phasing and a 4-dipole magnetic chicane shown in Fig. 1. This chicane has a fixed R_{56} of 0.28 m. The first arc is approximately isochronous but the second is set nominally to R_{56} = -0.28 m to compensate the action of the chicane before the second beam pass through the linac. A pair of sextupoles has been included in the first arc to adjust its T_{566} in order to reduce non-linear chirping effects. Wide compression variability can be achieved through a combination of RF phase setting (limited by linac gradient and non-linear effects) and arc tuning (R_{56} range from 0 to -0.5 m).

Downstream of the compression chicane is an infrared FEL that utilises a planar wiggler magnet loaned from Jefferson Laboratory. It has 40 periods of 27 mm. The FEL optical cavity length is 9.22 m, one of its mirrors being within the chicane and the other outside the second arc. This FEL has been included in order to demonstrate effective ERL operation in the presence of a resulting major impact on electron beam quality: both analytic and GENESIS predictions suggest that for a mean energy loss of 0.8 % an energy spread in excess of 4 % will have to be transmitted around the second arc.

A complete Start-to-End (S2E) simulation has now been undertaken [5], combining the low energy injector, modelled with the ASTRA and GPT codes [6], the high energy transport (ELEGANT) and FEL interaction (GENESIS 1.3). Bunch compression to well below 1 ps is predicted, approaching 200 fs if the sextupoles are employed. Space charge effects contribute to the injector line beam dynamics and will also need assessment in the 35 MeV transport lines [6]. Overall this very comprehensive and integrated simulation exercise has already given confidence in the ERLP performance.

Construction of ERLP is now well advanced. The DC gun is a copy of the Jefferson Laboratory one [7], employing a GaAs cathode and 81 MHz CW mode locked drive laser, frequency doubled to 530 nm. In combination a chopper and shutter ensure that the drive system will be capable of delivering three basic

 0-7803-8859-3/05/$20.00

photoinjector operating modes: single bunches at 20 Hz; and short (20 μs) or long (100 μs) pulse trains. In each case the bunch charge will be up to 80 pC, equivalent to a CW current of 6.5 mA although the actual average current is limited to about 13 μA due to the 0.2 % duty cycle. The laser pulses will be about 10 ps duration but the GaAs response will lengthen this figure for the resultant electron bunches. The 5 W laser system is already in place and fully tested. A 500 kV power supply has been operated, the gun itself is being assembled and beam commissioning should start in July.

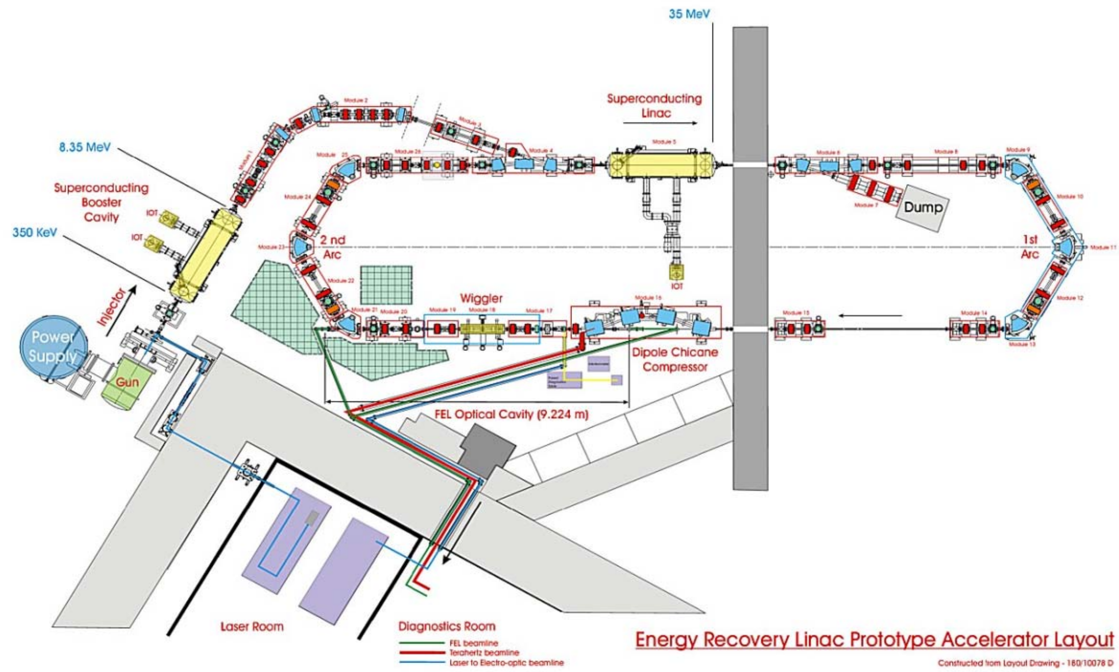

Figure 1: 35 MeV ERLP layout at Daresbury

The two superconducting linac modules are under manufacture by ACCEL and scheduled for delivery late in 2005. Before then the Linde TCF50 4K cryoplant and associated cryogenic systems will be commissioned; final 2K cool down commissioning will take place together with the two linac modules early in 2006. The 1.3 GHz linac structures will be driven by 16 kW IOTs jointly developed with e2v for the purpose.

The beam transport system has a total of 56 magnets, including a major fraction on order from Danfysik due for delivery in late Summer. The full ERLP assembly will be completed by February 2006 and high energy beam commissioning will follow immediately afterwards.

4GLS DESIGN STUDIES

In parallel with the design and construction of ERLP the project team has commenced a more detailed exercise on 4GLS itself. The aim is to agree and to finalise major key parameters in the near future in order to allow the projected CDR timescale to be met. In addition resources have recently been made available to proceed with a Technical Design Report, to be delivered by end of 2006; in principle the funded project could then start in 2007.

The scientific case for 4GLS has already been made, although user consultation is still being undertaken and this has some impact on the source specification. The suite of sources must cover the whole range from THz to soft x-ray output and be synchronised for pump-probe and dynamic imaging studies. Recent progress world wide on femtosecond synchronisation suggests that with care a general level of 100 fs can be attained, including jitter contributions from both accelerator and optical systems; it also seems that pairs of pulses can probably be synchronised to about a factor 10 better than this general figure. Generation of sub-100fs pulses is a definite aim of the 4GLS project. Such short bunches will also be needed for the planned XUV-FEL device.

Detailed assessment of bunch compression schemes has reached similar conclusions to other projects: that a third harmonic RF system is an essential feature and that probably compression should be performed in two stages. The alternative method of T566 adjustment with sextupoles in the arc is less attractive because of the impact on overall optics, but has not yet been abandoned. Present computations suggest that an accelerated bunch of length initially below about 2 ps and 0.02 % uncorrelated energy spread can be compressed to well below 100 fs. Checking with arc bending fields in the range 0.5-1.0 T reveals CSR energy loss below 0.1 % and no significant CSR micro-bunching problems up to 1 nC charge levels. For the low charge CW branch of 4GLS increased pre-compression bunch length and energy spread can be tolerated since post-compression energy spread has less importance than for the XUV-FEL. However an upper limit of 7 ps should not be exceeded to avoid severe beam transport non-linearities.

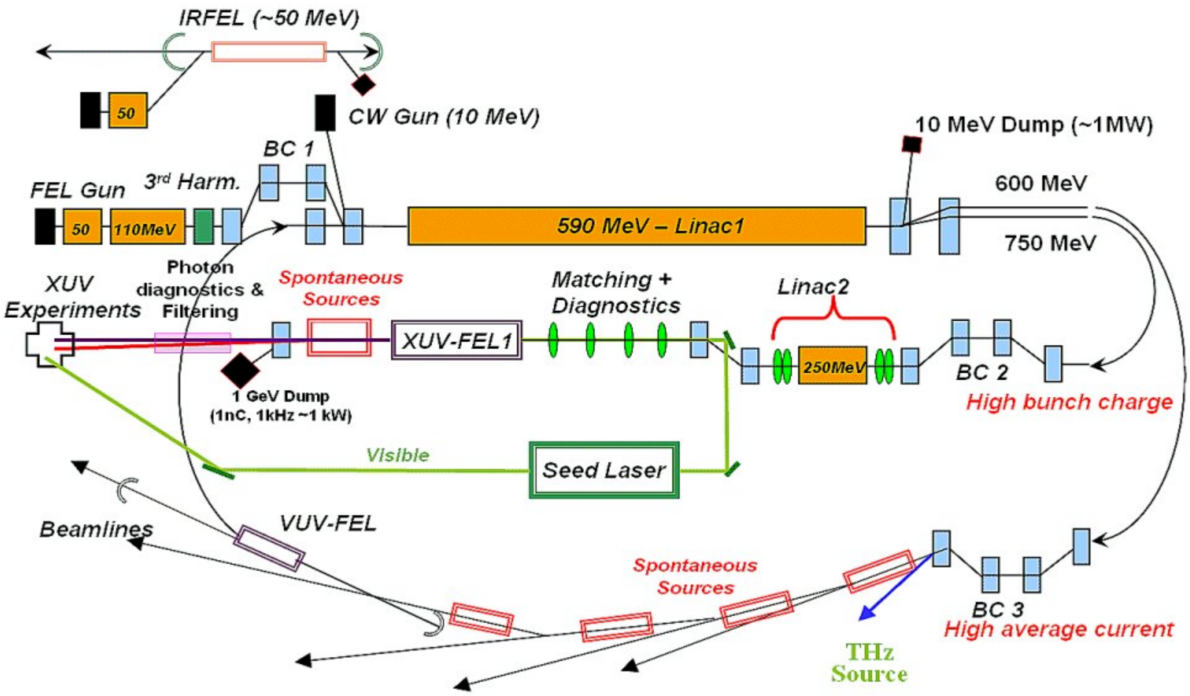

Figure 2: Possible baseline layout scheme for 4GLS

The proposed layout of 4GLS has now progressed from its earlier conceptual level [3] to one that is a realistic scheme that can be simulated and that matches the scientific needs of users. Figure 2 presents a recent version that contains the essential new features, although arc design has still to be finalised. A 10 MeV superconducting gun injects CW beam into the 590 MeV linac and the 600 MeV output beam at 100 mA traverses the outer path, via various undulator sources and a VUV-FEL, before returning for energy recovery in a second pass. In parallel a beam from a high charge (1 nC) RF gun operating at 1 kHz can be accelerated to 160 MeV and then compressed before entering the high energy linac; a third harmonic (3 GHz) structure is also inserted at this intermediate energy. The emerging 750 MeV beam is separated from the 600 MeV one by a fixed magnetic chicane and directed through an alternative arc to a further variable energy linac of final output up to 1 GeV. A seeded XUV-FEL is located downstream of this, followed by a long undulator for high energy spontaneous radiation. The source portfolio is completed by an IRFEL fed from a separate 50 MeV linac that is nevertheless synchronised to the high energy ones via its photocathode gun. The team is now investigating a modified layout including cascaded injection to reduce the recirculated beam dump power by additional recovery, perhaps including the IRFEL in this new leg. A further possible upgrade would be a second acceleration pass feeding another FEL at 1.6 GeV.

The XUV-FEL (10-100 eV) performance has been simulated and a baseline solution determined, assuming a 1.5 kA beam and a seeded configuration. Saturation lengths of less than 30 m are predicted. Initial studies of possible HGHG operation to extend the operating range have also been initiated. For the VUV-FEL (3-10 eV) a seeded amplifier option delivers 350 MW for a 20-25 m undulator, but an alternative is to employ a high gain, low Q oscillator (regenerative amplifier: RAFEL) that saturates in a few passes in a 9 m long cavity, producing similar output power levels, assuming 300 A bunch current.

ACKNOWLEDGEMENTS

This report represents the work of very many project staff at Daresbury. We have benefited from many UK and international advisors to the project. Work is funded by CCLRC and the UK Office of Science and Technology.

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