# FUTURE LIGHT SOURCES: INTEGRATION OF LASERS, FELS AND ACCELERATORS AT 4GLS

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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 flux photon sources (undulators and bending magnets) and three high peak brightness 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. The conceptual design is now completed and a CDR recently published [1]. The 4GLS concept will be summarised, highlighting how the significant design challenges have been addressed, and the project status and plans explained.

## INTRODUCTION

The 4GLS project design takes advantage of the very latest advances in accelerator science and technology incorporated in a unique scheme to provide state-of-the-art research facilities. This will enable a broad range of outstanding science to be undertaken by the UK and international communities.

4GLS will enable the study of real time molecular processes and reactions on timescales down to tens of femtoseconds in short-lived, nano-structured or ultra-dilute systems. The emphasis is on molecular and device function, rather than the largely 'static' structural focus of work on 3rd generation synchrotron radiation sources and X-ray FELs. Key areas where 4GLS will make unique contributions are in:

- understanding the function of single biomolecules in living systems and membrane transport;
- determining reaction pathways in areas as diverse as enzyme processes, reactions contributing to atmospheric pollution or reactions occurring in the interstellar medium;
- studies of electron motion in atoms/molecules and developing 'coherent control' of reactions and intense laser-matter interaction leading to new physics;
- developing new nano-scale devices through understanding electron charge and spin transport; and
- development of new dynamic imaging techniques to improve early diagnosis of conditions such as cancer and prion based diseases.

The major themes of the science case are time-resolved measurements in the life sciences and nanoscience. Particular areas of strength are high resolution pump-probe spectroscopy of atoms, molecules and clusters, including high field dynamics, dynamics at surfaces and interfaces, many-body problems in condensed matter, and studies of the dynamics of biomolecules in 'real' environments.

The science requirement is for an ultra-high brightness facility that allows the use of short pulsed sources in combination, and where the energy range is optimised to allow the extraction of electronic and vibrational information. The 4GLS suite of synchronised sources, operating from the THz to the soft X-ray range is designed to meet this science need.

The 4GLS facility is planned from the outset to be a multi-source, multi-user facility. This is achieved by superconducting radio-frequency (SCRF) accelerator technology, operating using energy recovery, to provide short pulse spontaneous radiation with pulse length variable from ps to < 100 fs. At long wavelengths this allows the condition for coherent synchrotron radiation (CSR) production to be met, with the result that 4GLS will provide enormously bright THz radiation. The high quality low emittance electron beam provided by the photoinjectors additionally provides an ideal source with which to operate free electron lasers (FELs). In the 4GLS conceptual design these are embedded within the facility, delivering ultra-high brightness short-pulse radiation in the IR, VUV and XUV energy ranges, with pulse lengths as short as 50 fs FWHM. In world terms, this gives a unique suite of synchrotron radiation (SR) and FEL sources covering the THz to the soft X-ray range. Many of the light pulses originate from the same electron bunch, thus offering potential levels of internal synchronization at the tens of femtoseconds level. All the 4GLS sources are offered with variable polarization, while the flexibility of SCRF technology allows the repetition rates of the sources to be varied. The peak brightness of the 4GLS sources is given in Figure 1. There is a typical enhancement of eight orders of magnitude when compared with 3rd generation light sources.

The 4GLS accelerator design concept consists of three inter-related accelerator systems [2, 3]. The high average current loop uses energy recovery as an essential element to deliver a 600 MeV electron beam of 77 pC bunches at repetition rates of up to 1.3 GHz. Distributed bunch compression allows for SR pulse lengths from a few ps to approximately 100 fs (RMS) to be delivered according to user requirements. A low-Q cavity VUV-FEL device is incorporated at the end of this loop. The most challenging area of accelerator design for 4GLS is in transporting and accelerating an extremely high quality high-average current (100 mA) beam to this loop, while simultaneously providing extremely high peak current (1.5 kA) at 750 – 950 MeV for the second accelerator system, the XUV-FEL branch. This beam is derived from 1 nC bunches produced by a normal conducting RF photoinjector operating at 1 kHz and it is dumped after traversing a final spontaneous undulator source. The XUV-FEL uses an HHG (high harmonic generation) seed, offering considerable advantages in pulse quality over a SASE (self-amplification of spontaneous emission) design. The third accelerator system is required for the IR-FEL. SCRF linac technology is used to accelerate electrons to 25 – 60 MeV to provide a fully integrated and synchronized IR-FEL facility.

Significant aspects of the 4GLS design have been informed by experience gained on the 4GLS Energy Recovery Linac Prototype (ERLP) currently approaching completion at CCLRC Daresbury Laboratory [4, 5]. In considering detailed 4GLS design decisions considerable attention has been given to ensuring that future upgrade options are not designed out at this early stage. These possibilities include various routes to higher energy operation, increased repetition rate for the XUV-FEL and decreased photon pulse lengths.

4GLS is thus the leading energy recovery proposal in Europe and the most comprehensive in terms of utilisation of combined sources. In terms of multi-user capability it is currently the most advanced energy recovery linac (ERL) proposal in the world. 4GLS is complementary to XFEL, to table-top lasers and to 3rd generation sources.

The unique advantages of 4GLS are:

- Combinations of sources. The fully integrated capability to utilize both short pulse SR(ERL) and the FEL sources for pump-probe and two colour dynamics experiments. This results in both experimental flexibility and cost effective delivery.
- Intense, tuneable, variable polarisation FEL sources optimized for spectroscopy and imaging in the frequency ranges of XUV, VUV and IR-THz.
- Energy recovery linac spontaneous light sources available from soft X-ray to THz. This gives short pulse, high repetition rate operation, the capability to 'pulse tailor', and low probability of sample damage.
- Europe's most intense broadband source of coherent THz radiation.

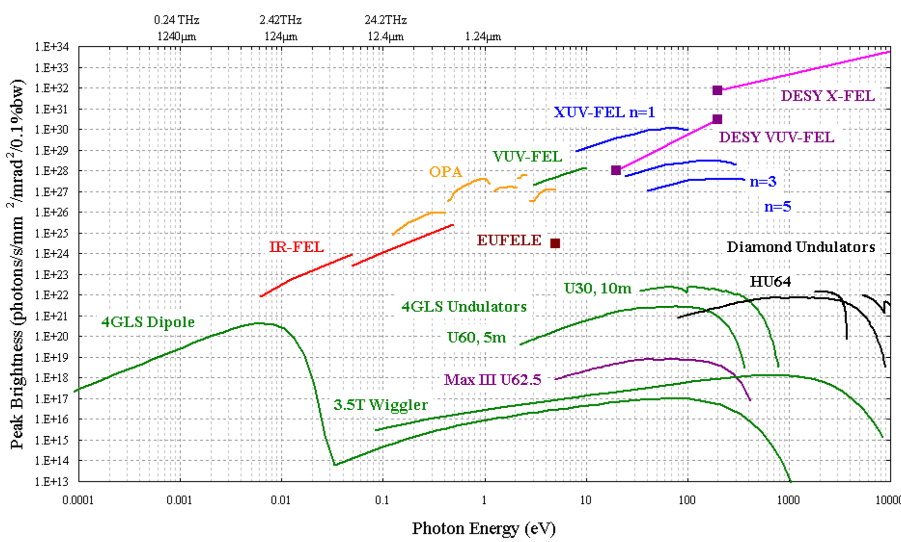


Figure 1. Peak brightness for 4GLS FELs, undulators, wiggler, OPA and dipoles compared with EUFELE, XFEL, Diamond and Max III undulators.

## OVERVIEW

The 4GLS project design takes advantage of the very latest advances in accelerator science and technology incorporated in a unique scheme to provide state-of-the-art facilities. This has been made possible by a number of parallel developments at leading international laboratories, including successful demonstrations of technical solutions. The proposed design builds on current world achievements and in some cases extrapolates beyond them. In the most challenging areas an active R&D programme is already underway world-wide and the 4GLS team has augmented this, not least because to do so enhances the necessary skill base for detailed design, construction and operations.

The provision of high intensity electron beams has been revolutionised in the last decade by the successful development of a new variant of accelerator: the Energy Recovery Linac (ERL). Traditionally beam currents in linear accelerators can have high instantaneous values but are restricted to pulses with low repetition rates because the average power dissipation must be kept to manageable levels. For a light source high average flux emission is highly desirable and this output has been possible so far only by the widespread application of the electron storage ring (e.g. Diamond and other 3rd generation sources) that achieves average currents of hundreds of milliamperes by recirculating the same electrons many times (and for many hours). This solution has serious drawbacks, in particular the ring defines the beam properties and they are dominated by the very emission of synchrotron radiation that the ring is built to deliver. If long-term storage of the electron beam can be avoided then greatly superior properties can be provided and this is one of the principal features of the ERL.

The ERL delivers high average currents without beam storage, since electrons are injected, accelerated and circulated only once before the system recovers their energy, dumps them and replaces them with new electrons. This means that if the beam is injected with superior brightness properties it maintains these during its radiation emission phase. The 4GLS project has an ERL at its heart in a generational leap from storage ring sources. Globally, pioneering work on ERLs has been undertaken at the Jefferson Laboratory in the USA where a low energy proof-of-principle ERL has been successfully demonstrated.

4GLS is best thought of in terms of three inter-related accelerator systems (see Figure 2). The first is the high average current loop. In this a 600 MeV beam of 77 pC bunches is delivered at repetition rates of up to 1.3 GHz and energy recovery is an essential element. Progressive compression of the electron bunches in this loop allows for photon pulse lengths from a few ps to approximately 100 fs (RMS). The VUV-FEL is placed towards the end of the high-average current loop.

The second major accelerator system is the XUV-FEL branch. The XUV-FEL requires a peak current of ~ 1.5 kA at beam energies from 750 to 950 MeV. This beam is derived from 1 nC bunches produced by a normal conducting RF photo injector operating at 1 kHz. At this repetition rate the 1 kW of beam can be safely dumped after traversing a final spontaneous undulator source.

Although the XUV-FEL beam and the high average-current beam discussed above are derived from separate electron sources after suitable low energy acceleration they are merged and accelerated in a single superconducting linac. The two beams are then separated using magnetic, energy dispersion for delivery to their respective devices.

The third accelerator system is that required for the IR-FEL. The same linac technology is used to accelerate electrons to between 25 and 60 MeV to provide a fully integrated and synchronised IR-FEL facility. The main electron beam parameters for 4GLS are given in Table 1.

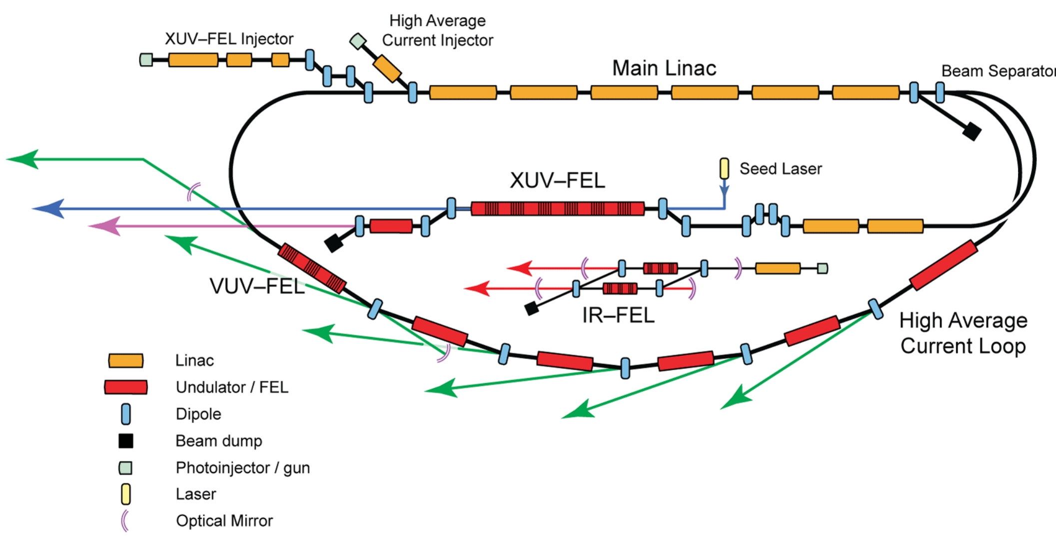


Figure 2. The conceptual layout of 4GLS.

Table 1. Main electron beam parameters of 4GLS

| *Bunch Parameter* | *XUV-FEL* | *100 mA HACL Operation* | *VUV-FEL HACL Operation* | *IR-FEL* |
|---|---|---|---|---|
| Electron Energy | 750 to 950 MeV | 600 MeV | 600 MeV | 25 to 60 MeV |
| Normalised Emittance | 2 mm mrad | 2 mm mrad | 2 mm mrad | 10 mm mrad |
| RMS Projected Energy Spread | 0.1 % | 0.1 % | 0.1 % | 0.1 % |
| RMS Bunch Length | < 270 fs | 100 to 900 fs | 100 fs | 1 to 10 ps |
| Bunch Charge | 1 nC | 77 pC | 77 pC | 200 pC |
| Bunch Repetition Rate | 1 kHz | 1.3 GHz | n x 4.33 MHz | 13 MHz |
| Electron Beam Average Power | 1 kW | 60 MW | n x 200 kW | 156 kW |

## SUPERCONDUCTING LINACS

The 4GLS design utilises superconducting linacs to accelerate and manipulate the three beams required to drive the photon sources. The accelerating structures are all based on a fundamental RF frequency of 1.3 GHz and a modified TESLA type cavity design operating at 2 K or below [6, 7]. The chosen RF frequency takes advantage of extensive development and operating experience of such systems (including the fact that industrialisation of the production and processing of such cavities is already well underway in preparation for the international linear collider ILC and superconducting XFEL).

Importantly the 4GLS design team at Daresbury are currently close to completing construction of an energy recovery prototype, ERLP, based on commercially procured linac modules incorporating TESLA 9-cell cavities which will provide a valuable test bed for the critical cavity and module developments required to produce linacs capable of operating in CW mode with the high-average beam currents.

For the high average current injector linac the major challenge is the delivery of the beam power required to accelerate a beam of up to 100 mA to 10 MeV without energy recovery. A cavity and coupler scheme similar to the two-cell geometry with symmetric couplers currently being developed at Cornell for the Cornell ERL prototype will be adopted for 4GLS. Two modules consisting of five of these two-cell cavities will suffice to provide the requirements of the ~ 10 MeV high average current injector system.

The main linac will be made up of six cryomodules each containing eight, seven-cell cavities which are currently under development within an international collaboration that includes CCLRC. This development is designed to meet the extreme demands of CW high-average current operation. The choice of six accelerating modules for the main linac is a balance between capital and operating costs which also provides a reasonable overhead in accelerating voltage. Another five similar accelerating modules are required within the accelerator system, two within the XUV-FEL injector system, two for the XUV-FEL linac to take this beam from 750 MeV to 950 MeV and one to give the 60 MeV requirement for the IR-FEL. Development and verification of this challenging module design will be a major activity during the technical design phase of 4GLS. A prototype 2 cavity cryomodule is currently being developed at Daresbury Laboratory [8].

## INJECTORS

For linac-based light sources the injectors are an essential element in the delivery of high performance, high quality beams. The requirements for the three injectors proposed for 4GLS come directly from the challenging demands of the FEL and spontaneous sources. Unlike storage rings light sources where the beam properties are essentially decoupled from the properties of the injector beam, the performance of ERL-based sources are directly dependent on the quality of the electron beam as produced by the injector and preserved during transport and acceleration.

The IR-FEL of 4GLS makes relatively modest demands of the injector and the source envisaged requires 200 pC, 1 ps electron bunches with a normalised emittance of around 10 mm mrad. This can be delivered in a cost-effective and reliable way by mature thermionic gun technology. In contrast, the proposed injectors for both the high-average current loop and the high brightness XUV-FEL branch are based on developments of existing injectors.

The XUV-FEL injector source is required to deliver 1.5 kA peak current at 1 kHz repetition rate, the normalised emittance required to drive the device is 2 mm mrad. Normal conducting RF photoinjectors today already exceed the bunch charge (1 nC) and emittance requirements and are a proven mature technology but they are typically low duty-cycle systems operating at a few Hz and require development to meet the 4GLS target repetition rate. Development of the PITZ gun is already underway that would increase the demonstrated 0.9 % duty cycle to 2.5 %, a slightly higher duty cycle than that required for 1 kHz operation of the XUV-FEL. Simulations using well developed particle codes have shown that a normalised emittance of 1.7 mm mrad can still be delivered whilst using relatively modest accelerating gradients, producing acceptable thermal loads in a gun engineered to supply additional cooling. This design is an effective starting point for the technical design of the XUV-FEL gun-cavity.

The photoinjector chosen for the high average current loop is required to deliver an unprecedented 100 mA beam with an emittance of 2 mm mrad. With such a high current demand an optimal choice of cathode material is a high quantum efficiency semiconductor which limits the laser power required to reasonable levels. From the experience of the JLAB DC photo-injector, that has been utilised on the ERLP photo-injector, caesiated gallium arsenide may provide a suitable option for the cathode material. To meet the 4GLS requirements this gun will be driven by a simple stable 160 W, Yb-doped fibre laser operating at 1.3 GHz. Whilst the TJNAF DC and ERLP photo-injectors are already designed to achieve the 77 pC bunch charge required, the emittance of these guns is limited to around 5 – 10 mm mrad and the maximum, average current achieved at JLAB is only 9.1 mA. Further development is clearly required to meet the requirements of 4GLS and verification of such performance goes beyond the scope and capability of the current ERLP. Evolving from JLAB DC photoinjector developments, Cornell University is currently building a prototype injector which will produce a 100 mA beam of 77pC bunches. Extensive simulations of this gun based on the use of particle tracking codes predict that the emittance requirements for 4GLS would be fully met by this design.

## BEAM DYNAMICS

The most challenging area of accelerator design for 4GLS is in meeting the requirements of extremely high peak current, (1.5 kA) for the XUV-FEL branch whilst simultaneously transporting and accelerating very high quality high-average current (100 mA) beam to the energy recovery loop. The conceptual solutions to the dynamics challenges for delivering the two most challenging beams are discussed below.

These two beams originate from separate photo-injectors, a high brightness RF photoinjector operating at 1 kHz delivering 2 mm mrad normalised emittance, 1 nC bunches for the XUV-FEL and a low emittance 100 mA, normal conducting DC injector. At relatively low injector energies these high quality beams are susceptible to intense space charge effects. Within the RF gun, the 1 nC beam undergoes rapid acceleration to a few MeV and is then injected into a superconducting linac which quickly boosts the energy to 220 MeV. Rapid acceleration of the 100 mA beam is achieved through the use of a high DC voltage followed closely by two superconducting booster modules delivering the ~1 MW power required to accelerate the beam to 10 MeV.

The bunches within both of these beams have to undergo a significant amount of compression to deliver the required peak currents to drive the XUV- and VUV-FELs and to meet the requirements of the science case for different pulse lengths from undulators in the high-average current loop. An innovative, integrated acceleration and compression scheme is proposed which meets the unique requirements for each of the two beams whilst using the same main superconducting accelerator [9]. By defining appropriate accelerating phases within the linacs, the high compression demands of the XUV-FEL are met using a two-stage compression scheme including a higher harmonic RF system for flexible non-linear correction, whilst progressive compression through the undulator arc delivers the high peak current in the 77pC bunches required to drive the VUV-FEL. An important part of this design is the optimisation of the scheme to maintain a high quality beam throughout the transport. Wakefield effects in the accelerator are reduced by performing the final compression stage at full energy so that the bunches around the arcs are kept relatively long to control the disruptive effects of coherent synchrotron radiation (CSR) emission which if uncontrolled can produce unacceptable energy loss and emittance growth. Acceleration of a 100 mA beam is very challenging; to accelerate and decelerate such a beam requires that the linac transport design is tailored to give a high threshold for the disruptive beam break-up instability. This is achieved through a combination of techniques including substantial damping of HOMs in an advanced design of RF cavity, tight control of beam focussing throughout the linac and optimisation of coupling and overall transport properties in the energy recovery loop [10, 11].

For the 4GLS XUV- and VUV-FELs, very high peak current is demanded simultaneously with narrow magnet gaps. These high peak currents are vulnerable to disruption by associated strong wakefields in nearby metallic chamber walls. This wakefield interaction and its undesirable consequences will be controlled through the use of appropriate vacuum materials and an optimisation of the FEL design which maintains vessel apertures that are compatible with delivering the required high quality beam.

## FREE ELECTRON LASERS

The characteristics of 4GLS and its central ERL will be optimally exploited by the inclusion of three FELs, each covering a distinct photon energy range matched to the science needs of the UK and each offering excellent performance levels. The three designs are all state-of-the-art with key advantages over other designs being proposed elsewhere.

### *XUV-FEL*

A simple yet robust seeded design for the XUV-FEL is proposed to ensure that ultra-high quality, reproducible, tunable radiation is available in the 8 to 100 eV photon range [12, 13].

A tunable laser seed pulse from a High Harmonic Generation source, that covers the full photon energy range, is amplified within the FEL. The FEL undulator consists of a lattice of individual undulator modules allowing electron beam focusing elements and diagnostics to be placed in between. The final undulator modules of the FEL will be of APPLE-II design that will enable the generation of variable elliptically polarised radiation. Figure 3 shows a schematic layout for the undulator modules and illustrates that for the low energy photons only the APPLE-II modules are in use whilst at high energy all of the modules are required.

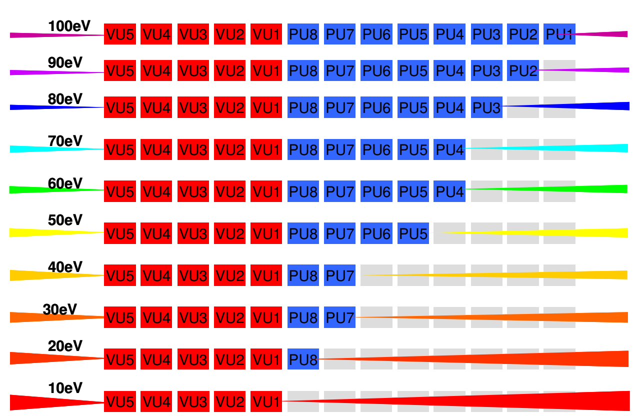


Figure 3. Schematic of the modular undulator system of the XUV-FEL demonstrating the different modes of operation across the photon energy range 10-100 eV. Electron beam transport is right to left. The minimum required undulator gap decreases in gradual steps from 28 mm for PU1 down to 10 mm for PU8 and the variable polarisation modules VU1-VU5.

The output pulses will have selectable polarisation and a pulse repetition rate of 1 kHz is set by the seed laser and the electron beam. Established FEL theory and state-of-the-art simulation codes predict this FEL will generate photon energies at multi giga-watt power levels in pulses of duration 40 - 60 fs FWHM. The pulses will have excellent temporal and spatial coherence with time-bandwidth products close to the Fourier transform limit for a Gaussian pulse. Unlike the self amplified spontaneous emission mode of operation, which effectively self-starts from intrinsic noise, the FEL interaction here is acting as a true amplifier. The high quality spectral properties of the radiation input seed pulses are maintained by the amplified output radiation pulses, as illustrated in Figure 4. Recent advances in High Harmonic Generation seed sources mean that the seed requirements for the XUV-FEL already exist and clearly future advances in conventional lasers can be readily harnessed. Further details on the issues raised by the use of HHG seeding can be found in [14].

The 4GLS design also incorporates an undulator after the XUV-FEL which enables the generation of spontaneous SR light with natural synchronisation to the XUV-FEL radiation

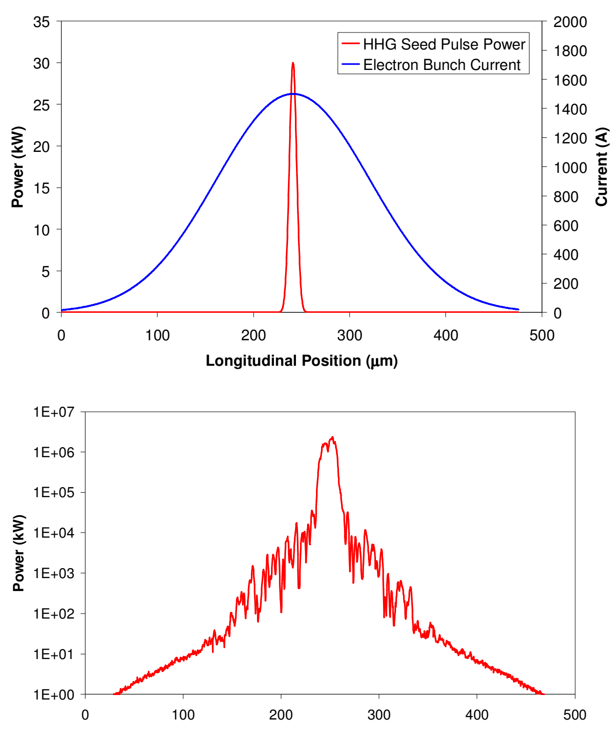


Figure 4. (a) Input HHG seed power (FWHM 30 fs) and electron bunch current as a function of longitudinal position (linear scale) and (b) radiation power (FWHM ~50 fs) at the exit of the XUV-FEL (log scale).

## *VUV-FEL*

The VUV-FEL will be a Regenerative Amplifier FEL (RAFEL) which is a high gain system that is of insufficient length to achieve saturation in SASE mode. A small fraction of the radiation emitted by an electron pulse at the end of the undulator is fed back to the beginning of the undulator to act as a seed field to a subsequent electron pulse. The radiation feedback may readily be achieved by placing the undulator into a low-Q cavity. This self-seeding process rapidly builds up and allows the RAFEL to achieve saturation after only a few electron pulses have propagated through the undulator. Figure 5 shows the intracavity pulse power for a cavity length detuning of ~ 12 µm after the first and eighth pass. After the first pass, the pulse power has a noisy profile characteristic of SASE. However, after only eight passes saturation occurs and the intracavity peak power is 290 MW, equivalent to an output power of 218 MW. The corresponding spectrum, also shown in Figure 5, is seen to be noisy after the first pass. On subsequent passes however the spectrum narrows about a single wavelength. At saturation the spectrum has FWHM bandwidth of 0.26% giving a time-bandwidth product of ~1.0. This is just over a factor two greater than a Fourier transform limited gaussian pulse and indicative of excellent longitudinal coherence.

The FEL will offer high repetition rates (multiples of 4.33 MHz) with giga-watt peak power and > 100 W average power [15]. Here advantage is taken of mirrors (with hole out-coupling) that are able to operate over the photon energy range of 3 to 10 eV. Photon pulse lengths of ~ 170 fs (FWHM) will be obtained in standard mode and simulations suggest that pulses as short as ~ 25 fs will be generated in a super-radiant mode. The output pulses will have selectable polarisation and be fully tunable.

By using a pair of mirrors to reflect light emitted by the FEL back to the entrance of the device it becomes, in effect, self-seeding and no external conventional laser system is required. Hence high quality, stable light is ensured through a rather simple optical feedback loop. A particular feature of this FEL when compared with similar designs covering the same wavelength range is the tolerance to low mirror reflectivity. Extensive simulations have shown that mirror reflectivities in the range 40 to 60 % are acceptable for this design [16].

Detailed modelling has been used to study the effect of timing jitter in the electron bunch arrival time [17]. Figure 6 shows the build up of saturation with no timing jitter and with a jitter of ±80 fs, calculated using the 1D time dependent code FELO [18]. Statistical analysis of the peak output power during saturation suggests that the RMS variation in the peak output power increases from 2.5% for the no jitter case to 8% for a jitter of ±80 fs.

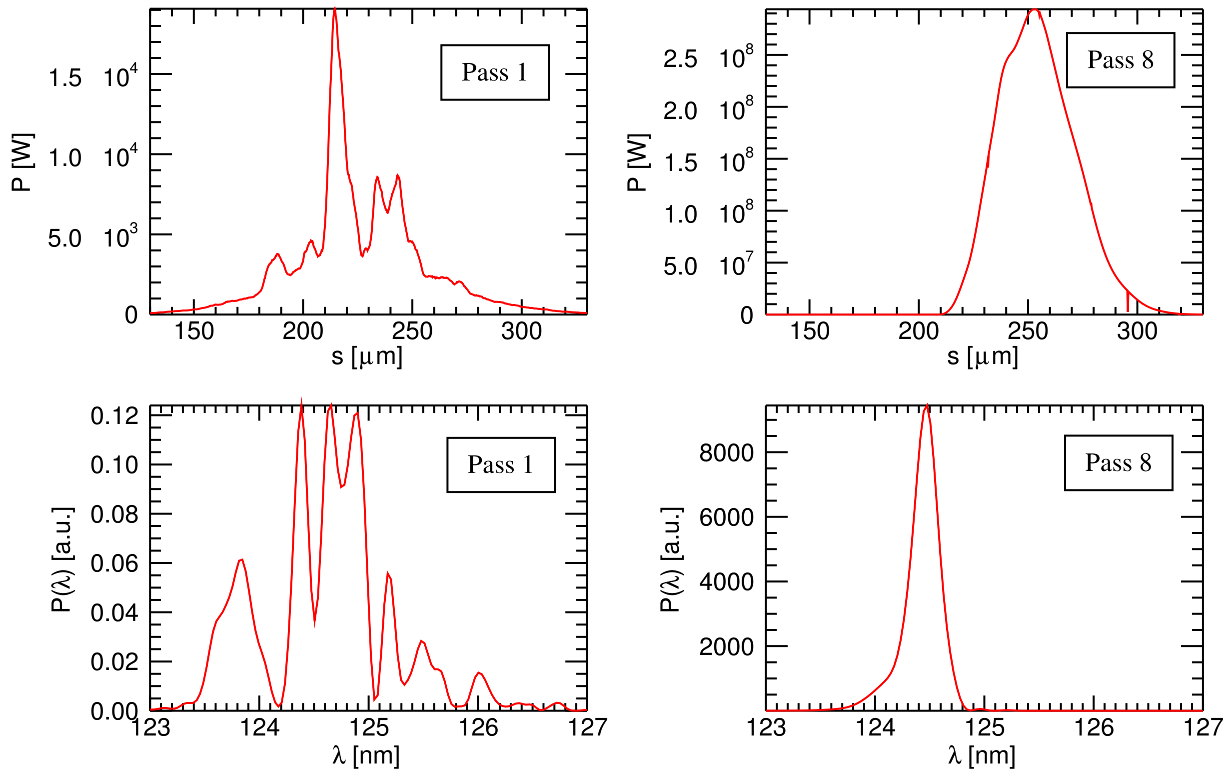


Figure 5. Genesis 1.3 [19] simulation of the radiation pulse power and the radiation spectrum after one and eight passes through the VUV-FEL for a cavity detune of 12µm.

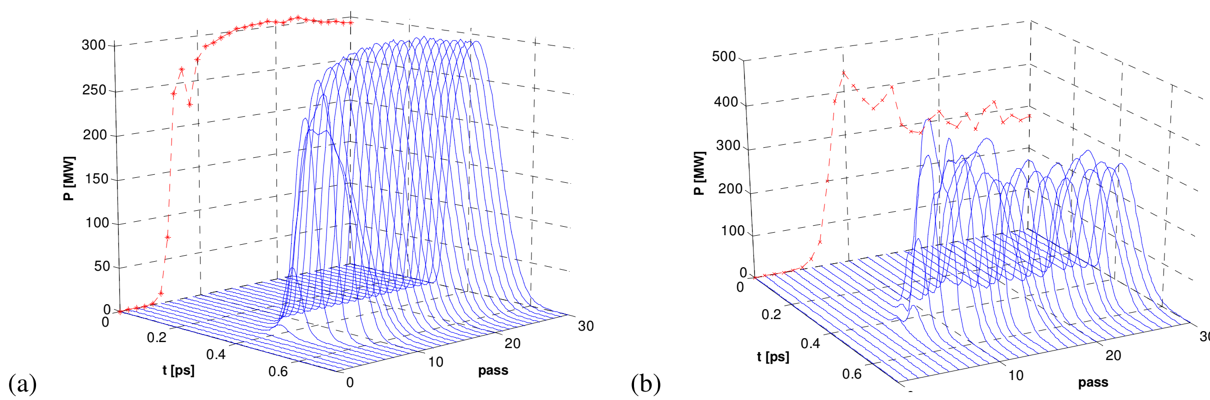


Figure 6. FELO simulation of the VUV-FEL at 10eV and cavity length detuning of 18µm with (a) zero electron bunch arrival time jitter and (b) jitter of ±80 fs. The red points show the peak intensity of the pulse at each pass.

### *IR-FEL*

The IR-FEL has been designed to produce high intensity, spatially and temporally coherent radiation with variable pulse lengths, flexible output pulse patterns and variable polarisation over the wavelength range 2.5 - 200 µm. The high-Q cavity-based design employs two undulators in parallel and hence can serve two user experiments simultaneously. The provision of short electron bunches offers the potential to operate the FEL in super-radiant mode to produce shorter FEL pulses with higher peak intensities than available in normal operation: simulations predict FWHM pulse lengths of only a few optical cycles can be produced in this way. The implementation of a superconducting RF linac with the IR-FEL will offer highly stable operation and also high average powers (> 100 W) though the option of running in modes that reduce the average power for sensitive samples will also be available.

## SPONTANEOUS SOURCES

There are six insertion device straights in the high average current loop, one of which is allocated to the VUV-FEL. The remaining five will be used to generate spontaneous radiation. To maximise the potential of the spontaneous sources three different undulator straight lengths have been chosen; two 14 m straights; two 10 m straights and two 8 m straights. Thus the total space available for undulators is ~ 64 m, which exceeds all other existing low energy 3rd generation light sources. More than one insertion device can be placed in each straight with a small corrector magnet between them so as to angularly separate the photon output. Distributed pulse compression will be employed in the high average current loop in order to deliver to users pulse lengths optimised for their experiments ranging from a few ps down to 100 fs (RMS).

It is well known that electrons in a bunch radiate coherently at wavelengths of the order of, and longer than, the bunch length. Since 4GLS has very short bunch lengths this so-called Coherent Synchrotron Radiation (CSR) is emitted over a broad wavelength range. Calculations indicate that the onset of the CSR for 4GLS is at around 40 µm and hence it will be an extremely intense source THz radiation.

## TABLE TOP LASERS

In order to make full use of 4GLS it is important to allow integration of its sources with conventional lasers. Continuous coverage of the visible and near-IR parts of the spectrum is provided by the spontaneous sources as illustrated in Figure 1. However, there are currently no plans to provide FEL radiation in the spectral range from 0.5 – 3 eV, as this is covered more cost-effectively by tabletop laser systems. These wavelengths will be made available by using continuously tuneable mid-infrared laser systems, such as mid-infrared Optical Parametric Oscillator and Optical Parametric Amplifier systems, Difference Frequency Generators and diode lasers. Ability to synchronise the additional lasers to within the temporal profile of the 4GLS sources is required. Current synchronisation is achievable to within < 100 fs, and is the subject of a vigorous worldwide research and development programme.

## STATUS

The conceptual design of 4GLS is now complete and reported in [1]. The project is now entering the technical design phase which includes a substantial R & D element. The Energy Recovery Linac Prototype at Daresbury Laboratory is presently being commissioned and the results from this will be fed into the technical design of 4GLS. In addition to this a superconducting RF linac module prototype is under construction that will be capable of operating CW at a high average beam current of 100mA. It is intended that this will be installed into ERLP at a later date for electron beam trials. In addition to this a high current photoinjector project is being initiated at Daresbury Laboratory to ensure that the target current of 100 mA can be delivered with the required electron beam parameters.

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