4GLS: AN ADVANCED MULTI-SOURCE LOW ENERGY PHOTON FACILITY FOR THE UK

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Abstract

Despite the need for optimised sources of low energy photons being well established, especially in the areas of fast dynamics and nanoscience, all of the latest 3rd generation light sources are now being increasingly targeted at the higher energy (x-ray) regime. This paper presents the integrated concept of an alternative low energy multiple source facility with unique properties, based on a 600 MeV superconducting energy recovery linac (ERL) that can deliver both high average or peak beam currents. A flexible suite of spontaneous emission undulators will exceed the capabilities of any existing storage ring in the photon energy range below 100 eV, including provision of femtosecond output pulses. In addition there will be three FELs: an infrared device, a VUV oscillator (up to 10 eV) and an XUV single pass (SASE or seeded) one with output energy up to or beyond 100 eV. The various photon source outputs will be highly synchronised and fed to shared experimental areas. The project is outlined and its key features explained, including the associated accelerator physics and technology challenges. Feasibility studies are continuing and it is planned to initiate a full Design Study during 2003.

1 BACKGROUND

The UK has had a long investment in advanced radiation sources based on particle accelerators and as long ago as 1993 concluded that successors were needed to the existing national light source, the SRS, the world's first dedicated 2nd generation source [1,2]. Since then the 3 GeV x-ray source DIAMOND has been funded and is now under construction [3]. Attention has now been turned to the provision of a complementary source at low energy and early ideas were that this should be a storage ring, although the alternative linac-based solution has been under consideration for some time [4].

Any such examination of storage rings, especially for low energies below about 1 GeV, reveals their severe limitations. Although in principle low transverse emittance can be achieved this leads to serious issues of beam dynamics, stability and enhanced losses. Touschek lifetime is a particularly important case and collapses so rapidly that even modern concepts of top-up injection are unlikely to be applicable. In addition it seems impossible to operate such a ring with sub-picosecond bunch lengths whereas the user case for short pulse (fs) exploitation is very compelling.

This need for a combination of very high transverse and longitudinal brightness leads inevitably to the conclusion that the storage ring must be abandoned and replaced by a linac system. This concept was first pursued in the development of free electron lasers (FELs), but these have usually required high peak but modest average brightnesses whereas a national light source will also need to deliver high average fluxes. The only solution is then to adopt the Energy Recovery Linac (ERL) principle, an idea experimentally demonstrated some time ago [5] but only recently coming to fruition with the results of the Jefferson Laboratory high average power FEL [6,7] since 1998. These results have stimulated a series of other project proposals together with an interest in pushing ERL technology to higher limits. Use of these concepts for an upgraded light source has been pursued at the NSLS (Brookhaven) [8], but their PERL source is aimed at generating high energy x-rays; similar high energy schemes are also being investigated at Cornell [9] and a multi-pass variant has been proposed at Berkeley [10]. The first such proposal for a multi-pass x-ray source was actually proposed at an earlier time [11].

Once the ERL is adopted for a spontaneous light source its superior properties also become attractive for advanced FEL development. The greatly enhanced peak beam currents in a linac can be exploited in a high gain FEL that removes the mirror technology limitations of a more conventional optical cavity; much progress has also been made recently with this new technology [12]. The combination of spontaneous and stimulated (coherent) sources at a single facility then becomes extremely attractive and is the unique feature of this 4GLS proposal.

2 IDEAL SOURCE

The quest by light source users for brighter beams can be expected to continue for the forseeable future, allowing for example the study of nanoscale objects and the development of novel imaging techniques, but there are also other features that determine the effective scientific exploitation of such advanced sources. It is usual for the source cross-section in existing 3rd generation sources to have a high aspect ratio whereas some experiments would benefit from a round beam. An ideal light source would incorporate a great deal of flexibility in its settings, not a ready possibility in existing sources.

The requirement for ultra-short pulses has already been mentioned and this is still true even at more modest brightness levels: very basic scientific processes such as chemical reactions and the initiation of molecular conformational change (eg protein folding) are only accessible in this fs time domain. Associated with such time domain exploitation will be the demand for variable pulse patterns, ranging from radio-frequency repetition times out to multi-microsecond bunch separation to study long relaxation time processes. The ability to make rapid pulse structure changes, impossible in a storage ring source, will be a further attraction in satisfying the widely different needs of the light source user community. Of particular importance will be to establish multiple synchronised sources so as to allow a broad class of ‘pump-probe’ experiments to be undertaken.

3 THE 4GLS PROJECT

The feasibility of this new light source philosophy has been studied by a project team based on a core group at Daresbury, together with strong scientific input from the potential user base in the UK academic community. It has also benefitted from advice and assistance from other major laboratories that have similar interests in ERL solutions. The outcome of an attempt to match the ideal source specification of the user community leads to an overall 4GLS concept as illustrated in fig 1. This is schematic and omits many details.

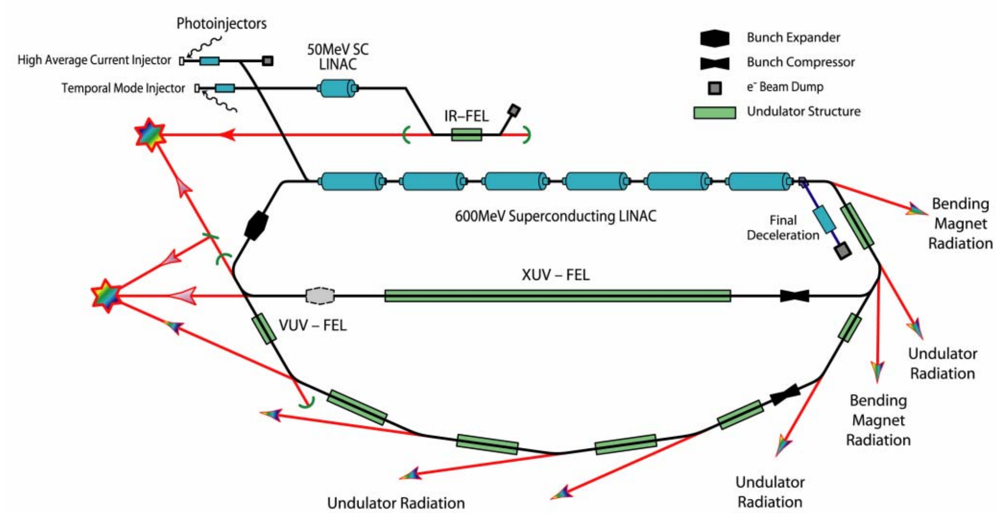

Figure 1: Schematic Layout of 4GLS Light Source Concept

The main accelerating structure is a superconducting linac and that selected for the feasibility study is the TESLA solution from DESY [13]. Although this structure has successfully achieved accelerating gradients of 20-25 MeV/m at the 1.3 GHz operating frequency this was at the 1 % pulsed duty cycle appropriate to its particle physics application. For 4GLS purposes a more conservative figure of around 15 MeV/m is assumed and this has the added advantage of greatly reducing the power dissipation faced by the cryogenics system in its 2 K operation, although dynamic losses may still exceed 100 W per cryomodule. To achieve the desired 600 MeV suggests a total of five of these 8 m modules and an overall length of some 60 m, with an incident CW RF power of about 350 kW to produce the required gradient. A major issue will be the potentially damaging additional HOM losses and it will be essential to couple these out into external loads. The losses will be reduced by choice of a bunch length greater than 1 ps, with further compression only at the full energy in the external beam transport lines. HOM couplers will be a topic for future development work. The associated cryogenic plant will clearly need to be rated to at least 1 kW at 2 K (ie nearly 1 MW AC power installation). Attention will need to be paid to suppression of the BBU instability and its threshold can be raised above 100 mA by HOM damping and by optimised transport line optics [14]; active feedback systems must also be incorporated.

The sources of electrons will be two alternative photocathode guns. The CW high average current gun will need considerable development to give confidence in its long lifetime at 100 mA level. The second gun will provide high charge per bunch output for either large bunch spacing patterns in the ERL or for FEL operations, but at much lower average current levels. It will be more similar to the specifications being achieved in the latest linear collider and SASE FEL projects, probably based on metallic cathodes. Selection of the 100 mA CW gun will follow on from an R&D programme comparing high and low quantum efficiency cathode solutions, including the associated high power mode-locked laser technology. Initial estimates suggest that a cesiated GaAs cathode, embedded in a 500 kV DC gun and driven by a Ti-sapphire laser as in the Jefferson system [15], could be developed to deliver the required beams. However alternative RF and superconducting gun options will also be assessed.

The other major feature of the ERL system is the return path transport line. This will need careful application of the lessons learned from Jefferson experiments [7]. It will include two 180° arcs, employing either the MIT-Bates solution [16] or more standard tunable achromats [17] to achieve achromatic and isochronous transport over a broad energy spread. Also indicated schematically in fig. 1 are the important bunch compressors and expanders that produce fs lengths but only over parts of the transport system where they are needed. These chicanes will need great care in design, as is already known from linear collider studies; in particular coherent synchrotron radiation (CSR) effects must be minimised. Two return paths are shown. In the first are a series of undulators feeding user stations, in some cases from fs source points. The transport focusing optics will also be able to be locally optimised for beam dimensions at individual undulators. The second return path transmits the electron beam through a long undulator intended for a high gain FEL system, with maximum compression immediately upstream of its undulator entrance. Finally the electrons return to the linac suitably phase shifted for deceleration (energy recovery) and subsequent dumping. The dump line might conveniently be exploited for a pulse radiolysis programme.

Three FELs are also illustrated in fig. 1. The infra-red IR-FEL is fed from a separate superconducting linac and will provide high quality, stable output over a range from perhaps 3-75 µm. Energy recovery will be unnecessary unless very high average powers (1 kW ?) are required at some stage. In the standard ERL return path is situated a cavity FEL operating in the VUV range (3-10 eV). Finally the high energy (XUV) FEL should achieve 5-100 eV output from the 600 MeV electron beam.

As can be seen, a feature of the 4GLS proposal is the linking of the outputs from these various sources to permit a range of pump-probe experiments to be undertaken. Source brightness from typical undulators is presented in fig. 2 and the excellent complementarity with ESRF and DIAMOND is also shown. When the FEL sources are added to this portfolio the brightness is greatly enhanced, as shown in fig. 3.

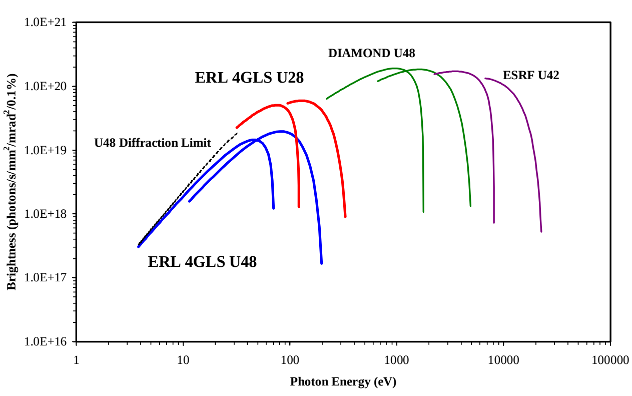

Figure 2: Average Brightness from 4GLS Undulators

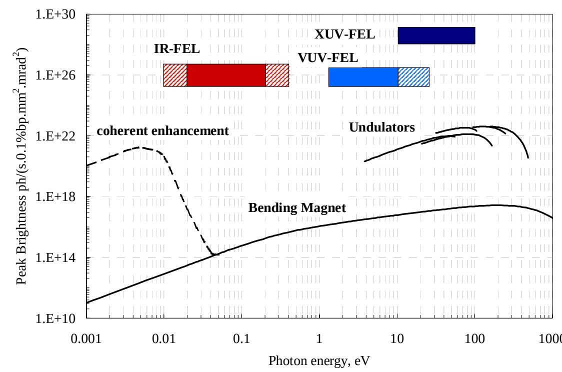

Figure 3: Peak Brightness of 4GLS Sources

4 PROJECT STATUS

The 4GLS proposal is underpinned by an extensive scientific case prepared by over 200 members of the UK science community. After recently passing scientific peer review an immediate start is to be made on a business case. In parallel an extensive R&D programme is planned. Final project approval by 2005 after a full Design Study could lead to first operations 2-3 years later.

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