Considerations for a New UK Light Source

R.P. Walker, Diamond Light Source

As stated earlier, a future NLS facility for the UK -

- will be science driven
- should fit within the international coherent light source landscape
- is likely to be a coupled set of facilities including both state of the art conventional lasers and free electron laser(s)
- should have unique and world leading capabilities, compared to other projects under construction around the world
- might achieve uniqueness through, for example, a combination of:

  - new ranges and combinations of photon energy

  - a superior short pulse and synchronisation capability

  - simultaneous access to a wider range of laser and other facilities
- must be upgradable
- could be a staged approach, to minimise initial investment

Conventional Lasers: state-of-the-art

- Few-cycle, carrier-envelope stabilised (kHz rep-rate/ 1mJ pulse) lasers (1-3 eV): attoscience
- Ultra-high field, fast (< 30 fs), high contrast, (few Hz rep-rate) lasers (1.55 eV): drive relativistic electron motion
- Ultra-fast (~ 10 fs), tuneable OPA (kHz-100kHz/ 1mJ pulse), 0.3-2 eV): femtosecond spectroscopy
- Ultra-fast lasers + phase amplitude pulse shaping: coherent control
- Ultra-fast fast UV-XUV (via NLO/HHG down to 100eV with $>10^8$ photons/pulse): attosecond XUV pulses

Courtesy of Jon Marangos

Critical areas of R&D to expand scientific capabilities, which could be exploited in later stages of NLS

- Higher pulse energy (multi-mJ), higher rep. rate (1kHz-100kHz) few-cycle laser pulses
- Higher rep. rate (>1kHz) ultra-high power lasers for relativistic electrons
- Extend ultra-fast tuneable OPA towards Far-IR/THz
- Pulse shaping in UV/VUV and IR
- Higher power sub-femtosecond pulses
- Higher efficiency HHG (e.g. via surface harmonics) for $>10^9$ photons pulse at 1keV (e.g. for FEL seeding)

Courtesy of Jon Marangos

Free-Electron Lasers: Main Issues/Options

Accelerator Technology

- Superconducting linac:

  complex and expensive, but allows operation with long macro-pulses (e.g. FLASH), or in cw operation permits high repetition rate single pulses (kHz-MHz).

- Normal conducting linac:

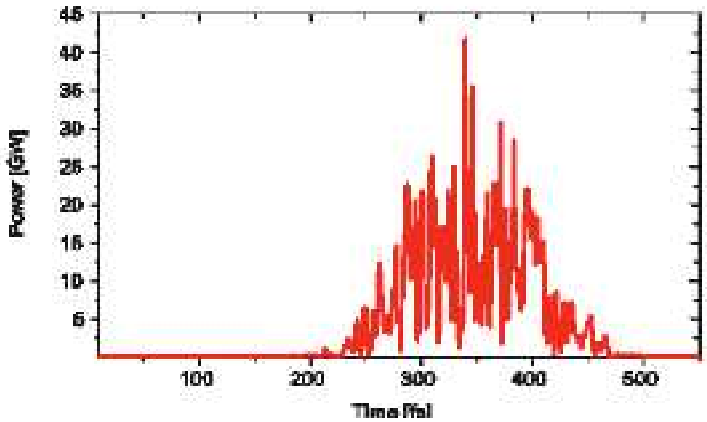
  cheaper, and higher effective accelerating gradient, therefore provides higher energy for given cost, but is limited in rep. rate to a few 100 Hz.

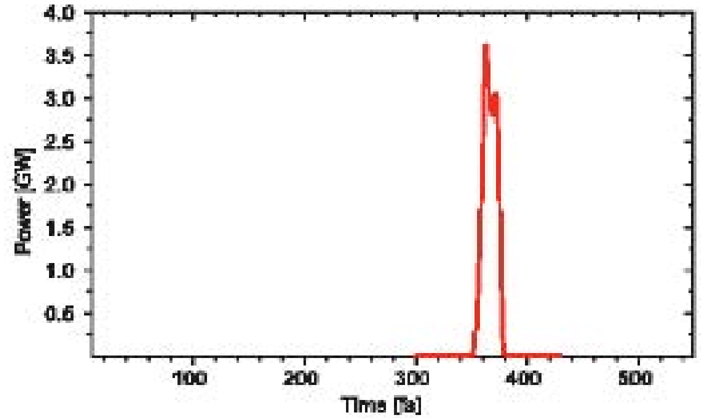
(Note: max. photon energy scales as linac energy squared)

Pulse Coherence and Seeding

- The basic Self-Amplified Spontaneous Emission (SASE) mode of FEL operation, since it starts from noise, results in a spiky output pulse in both time and spectral domains.

- More complicated schemes can be used to “seed” the FEL with a coherent signal in order to produce a smooth output pulse with the coherence of the input signal and adjustable pulse length/bandwidth.

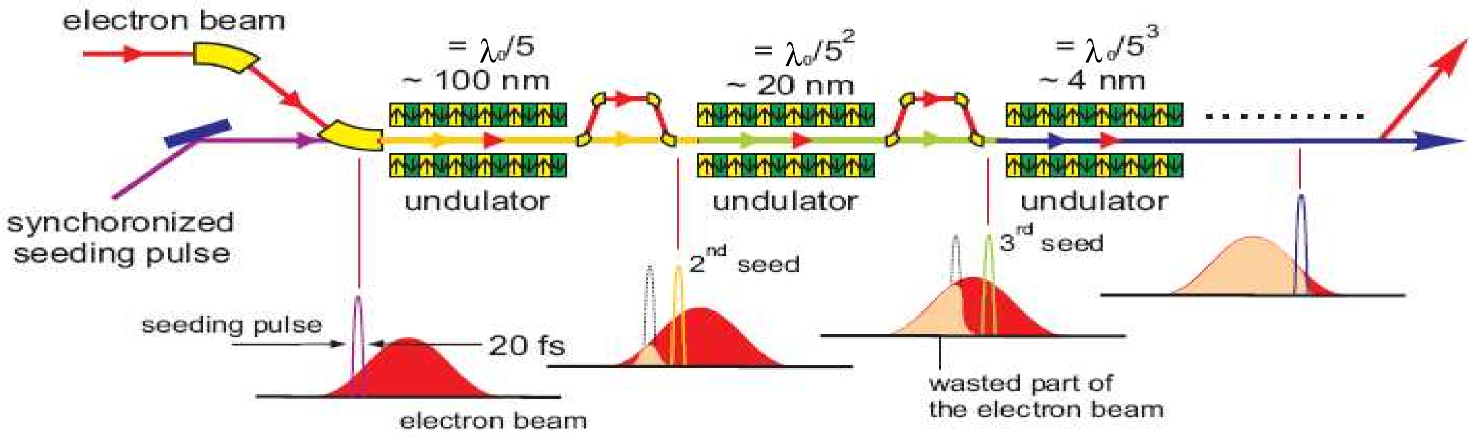




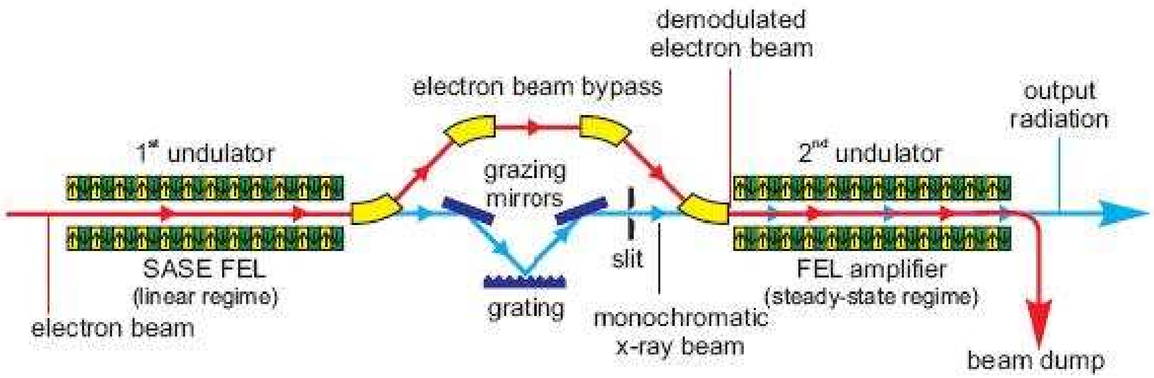
Seeding can in principle be achieved using either:

- a conventional laser, or HHG source

- to reach shorter wavelength this can be combined with FEL frequency multiplication, in the HGHG or cascaded HGHG scheme:



- a "self-seeding scheme":



The World-wide Short Wavelength FEL Scene

	Electron energy (Gev)	λ_{min} (nm)	Rep. rate	Linac type	FEL type
FLASH	1	6.5	5 Hz, 1 MHz	SC- pulsed	SASE
LCLS	13.6	0.15	120 Hz	NC	SASE
SCSS	8	0.1	60 Hz	NC	SASE
Euro-XFEL	17.5	0.1	10 Hz, 5 MHz	SC-pulsed	SASE
FERMI (i)	1.2	20	10 (50) Hz	NC	HGHG
SPARX (i)	1.0	15	50 Hz	NC	Seeded
PSI-XFEL	5.8	0.1	100 Hz	NC	SASE
Arc-en-Ciel	1.2, 3	2.5, 0.8	1-10 kHz	SC-cw	HHG Seeded
BESSY-FEL	2.25	1.2	1 (25) kHz	SC-cw	Cascaded HGHG
LBL-FEL	2.0	1.0	100 kHz	SC-cw	SASE/ seeded
Wi-FEL	2.2	1.4	1 MHz	SC-cw	HHG seeded

- in operation - under construction - proposal/conceptual

Possibilities for producing short pulses

- Compressing the electron beam allows a FEL pulse length of ~ 10 fs to be produced (e.g FLASH)
- Alternatively, using a short-pulse seed laser allows a similarly short FEL pulse to be produced, ~ 10 fs in length.
- To produce sub-fs pulses many schemes have been proposed, the majority of which make use a few optical cycle laser pulse to modulate the electron energy distribution and then arrange that only the electrons that interact with a particular part of one optical cycle have the necessary conditions to lase in the FEL.
- An alternative scheme makes use of a very highly compressed, very low charge, electron bunch, which is short enough to produce only a single spike in the output (rather than the many spikes of a typical SASE pulse).
- NB] None of these schemes are included in any of the FEL projects currently under construction

Preliminary comparison of sub-fs schemes

(R. Bartolini, DLS)

	Emittance spoiler	Slicing wavelength	Slicing current	HC FEL seed	Energy chirp	Single spike
Pulse length	< 1fs	300 as	250 as	100 as	200 as	300 as
Photons per pulse	10^{10}	10^{8}	10^{9}	10^{6}	10^{10}	10^{8}
Contrast	poor	poor	poor	good	good	excellent
Rep. rate	LINAC	Laser seed pulse	Laser seed pulse	Laser seed pulse	Laser seed pulse	LINAC
Synchro-nisation	NO	YES	YES	YES	YES	NO
Stability	poor	-	-	-	-	poor
Diagnostics	OK	OK	OK	OK	OK	difficult

How will NLS Design Proceed ?

1. Set-up integrated design team to exploit the wide range of expertise in the UK : STFC (ASTeC, PSD, TD) + DLS + Institutes (CI, JAI) + Universities *(in progress)*

2. Apr. – Oct. ’08

   Consider technical options and relative advantages/disadvantages, including costs

3. Oct. ’08 – Jan. ’09

   Define the facility solution that best meets the NLS science case

   Determine any R&D needs

4. Jan. – Oct. ’09

   Detailed design and costing of selected option

Input to this Process

1. Science Workshops and Working Groups must address and define the desired source parameters for each science area:

   - photon energy range(s)
   - pulse energy
   - pulse length/bandwidth
   - pulse/macropulse repetition rate
   - average flux/brightness
   - degree of coherence
   - polarization
   - stability in energy, intensity, timing, position
   - contrast against background
   - requirement for combinations of sources (e.g. THz, IR, SR, electrons etc.) and degree of synchronisation …. etc.

2. Workshop on Advanced Photon Sources, June 3rd

3. International Machine Advisory Committee being considered

Workshop on Advanced Photon Sources

June 3rd, Cockcroft Institute/Daresbury Laboratory

09:00 – 09:10	Welcome – R.P. Walker (DLS)
09:10 – 09:30	NLS Overview - J. Marangos (Imperial Coll.)

Status, future potential and challenges of laser-based photon sources:

09:30 – 09:55	High power, high rep. rate lasers - J. Collier (CLF)
09:55 – 10:20	HHG in gases - TBA
10:20 – 10:45	HHG on surfaces - TBA
10:45 – 11:00	*Coffee*
11:00 – 11:25	Laser-plasma accelerator based photon sources – D. Jaroszynski (Strathclyde)
11:25 – 11:50	Compton scattering photon sources – G. Priebe (STFC)

Status, future potential and challenges of FEL-based photon sources

11:50 – 12:15	Potential and challenges of normal-conducting Linac-based FELs - P. Emma (SLAC)
12:15 – 12:40	Potential and challenges of super-conducting Linac-based FELs – TBA
12:40 – 14:00	*Lunch*
14:00 – 14:25	Self-Seeding schemes - TBA
14:25 – 14:50	HHG seeding - M.E. Couprie (SOLEIL)
14:50 – 15:15	Cascaded HGHG - B. Kuske (BESSY)
15:15 – 15:30	*Coffee*
15:30 – 15:55	Generation of attosecond X-ray pulses using FELs - A. Zholents (LBL)
15:55 – 16:20	Single-spike SASE - S. Reiche (UCLA)
16:20 – 16:45	Mode-locked FELs and attosecond pulse trains – B. McNeil (Strathclyde)
16:45 - 17:10	Femtosecond synchronization for Free Electron Lasers – H. Schlarb (DESY)
17:10 – 17:20	*Break*
17:20 – 18:30	General Discussion
18:30	Close of Workshop

Conclusion

1. NLS design will draw together the considerable amount of relevant laser, accelerator and FEL expertise in the UK (and possibly abroad) and also benefit from the significant amount of work carried out on previous projects (e.g. 4GLS, Sapphire).

2. There is no doubt however that a considerable amount of work has to be done – starting now - to be in a position to select options at the end of this year and produce a design report by Autumn ’09.

3. A clear definition of source requirements matched to the science case is, of course, essential to this process.

4. As a favoured solution emerges, R&D needs will become clearer, and will need to be addressed.