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

Jim Clarke, ASTeC, Daresbury Laboratory
on behalf of the 4GLS Design Team

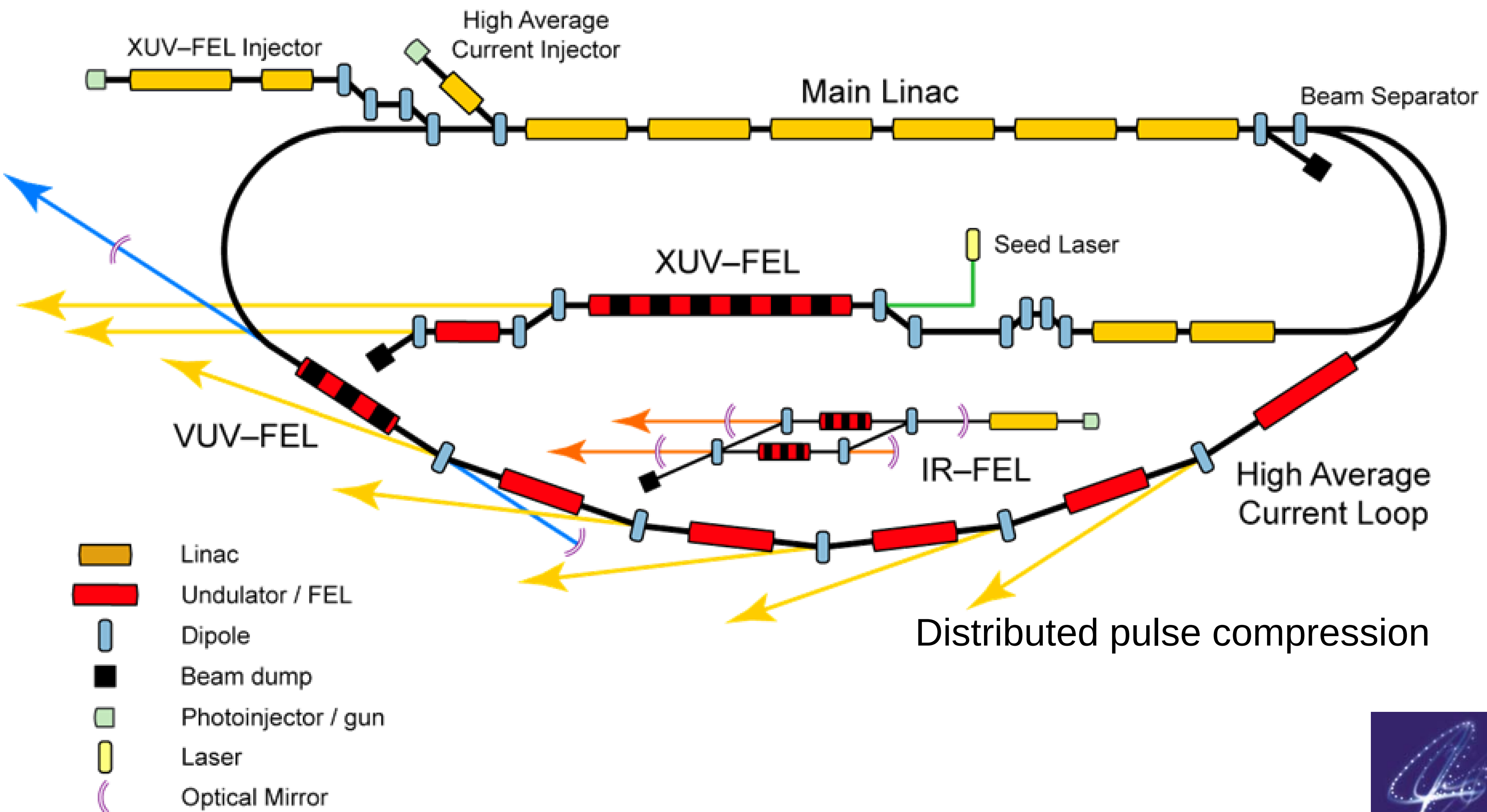
FEL 2006, Berlin

4GLS

Contents

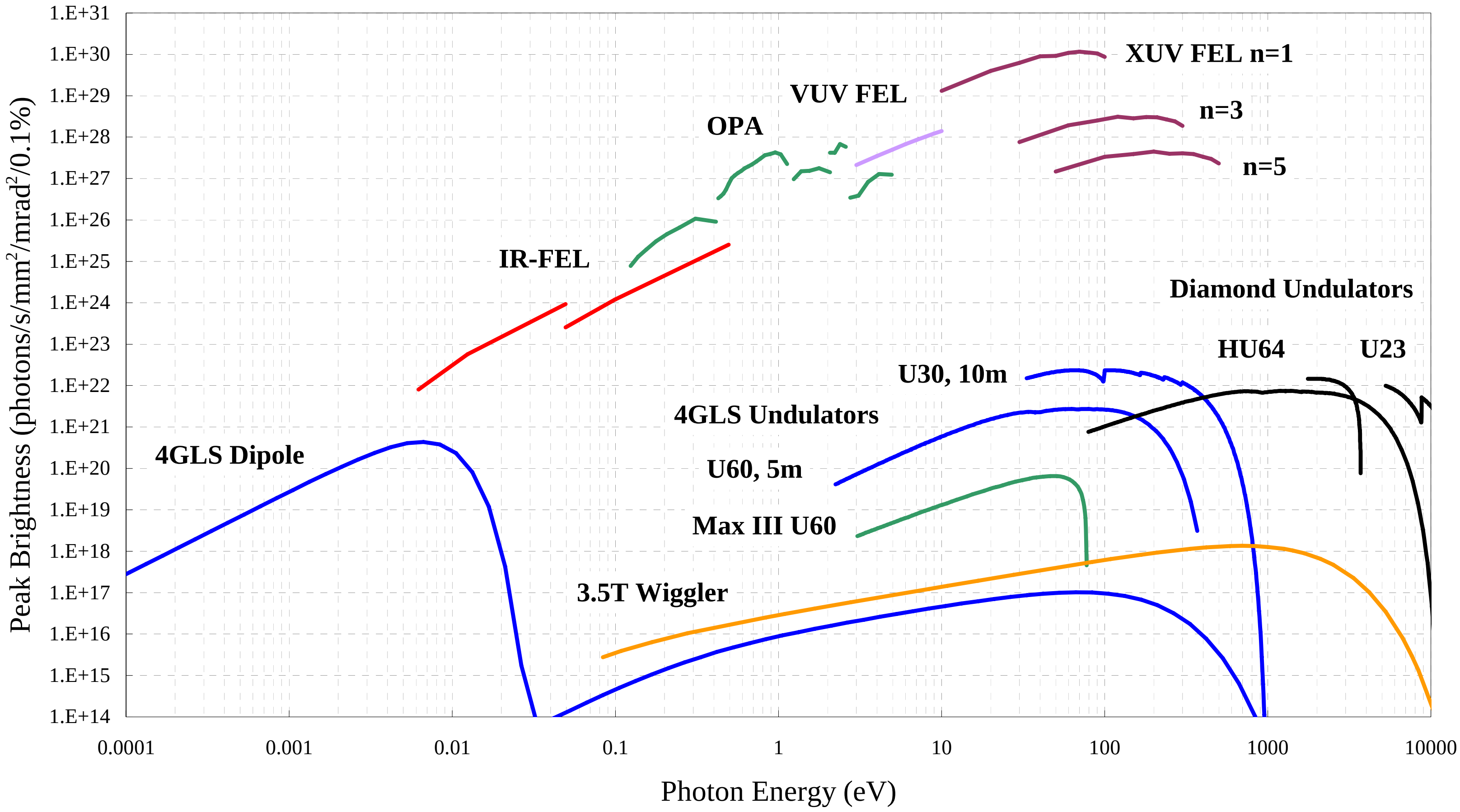
- What is 4GLS?
- What is it for?
- How will it work?
- What do the FELs look like?
- What R & D are we doing?
- What is the status of 4GLS?

4GLS combines superconducting ERL, SR, laser and FEL technology in a fully integrated multi-source, multi-user facility



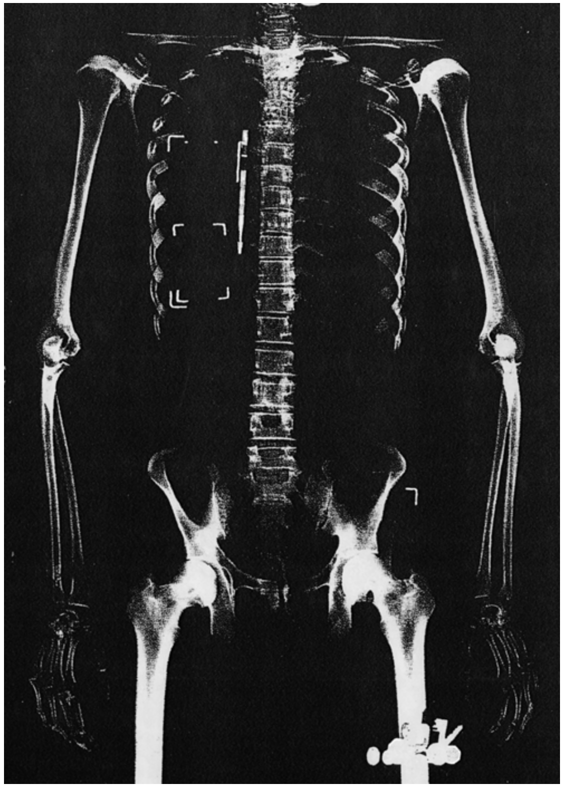
Peak Brightness

Optimised from THz to 100 eV

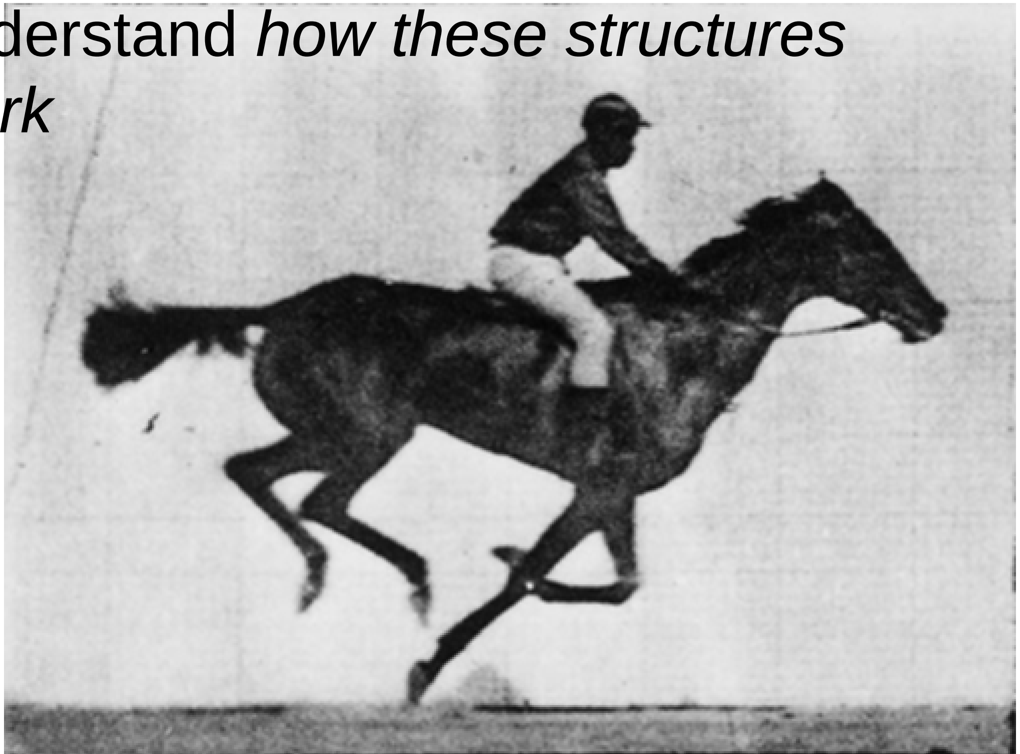


The Science Need...

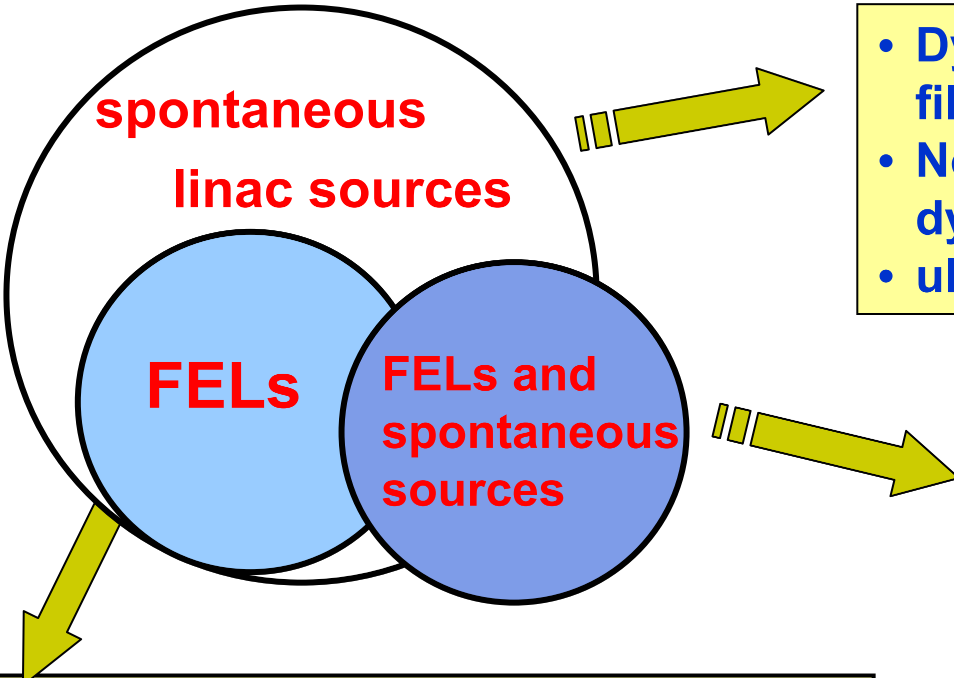
Fundamental requirement to understand the *dynamic* behaviour of matter, often in very small (nm) units, on very fast (fs) timescales



Need not just to determine *structure* with high precision, but to understand *how these structures work*



4GLS: Greater than the sum of the parts



- Dynamics of adsorbates and films
- Nondestructive biosystem dynamics
- ultra-high spectral resolution

+

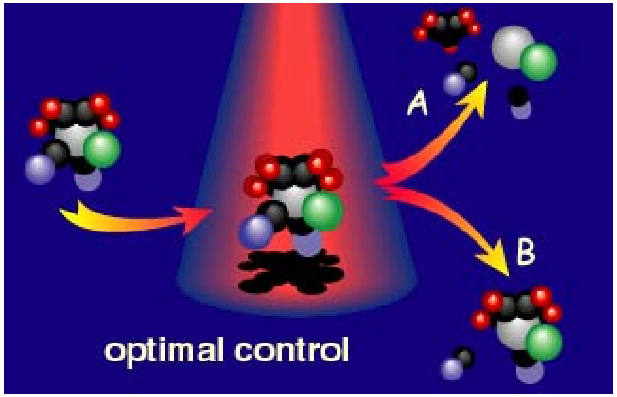
- Pump-probe
  FEL+ spontaneous SR (THz>)
- Dynamics in nanoparticles and microdevices, spintronics
- Energy transfer in biomolecules

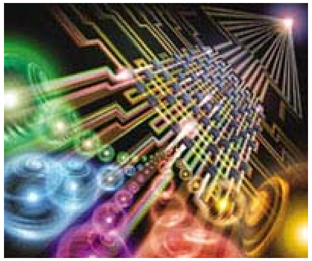
+

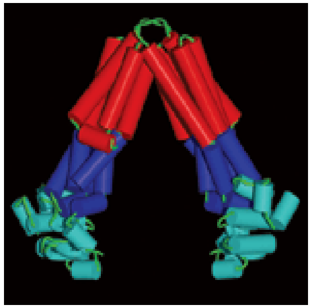
- bio and chemical fs dynamics
- materials under extreme conditions
- nonlinear processes
- plasma physics
- nano spectromicroscopy
- nano electronic structure and magnetism

Overview

- Unprecedented probe of electron motion in atoms and molecules
- Capability to pioneer a new generation of ultra-fast time resolved experiments revealing short lived intermediates in catalytic reaction pathways

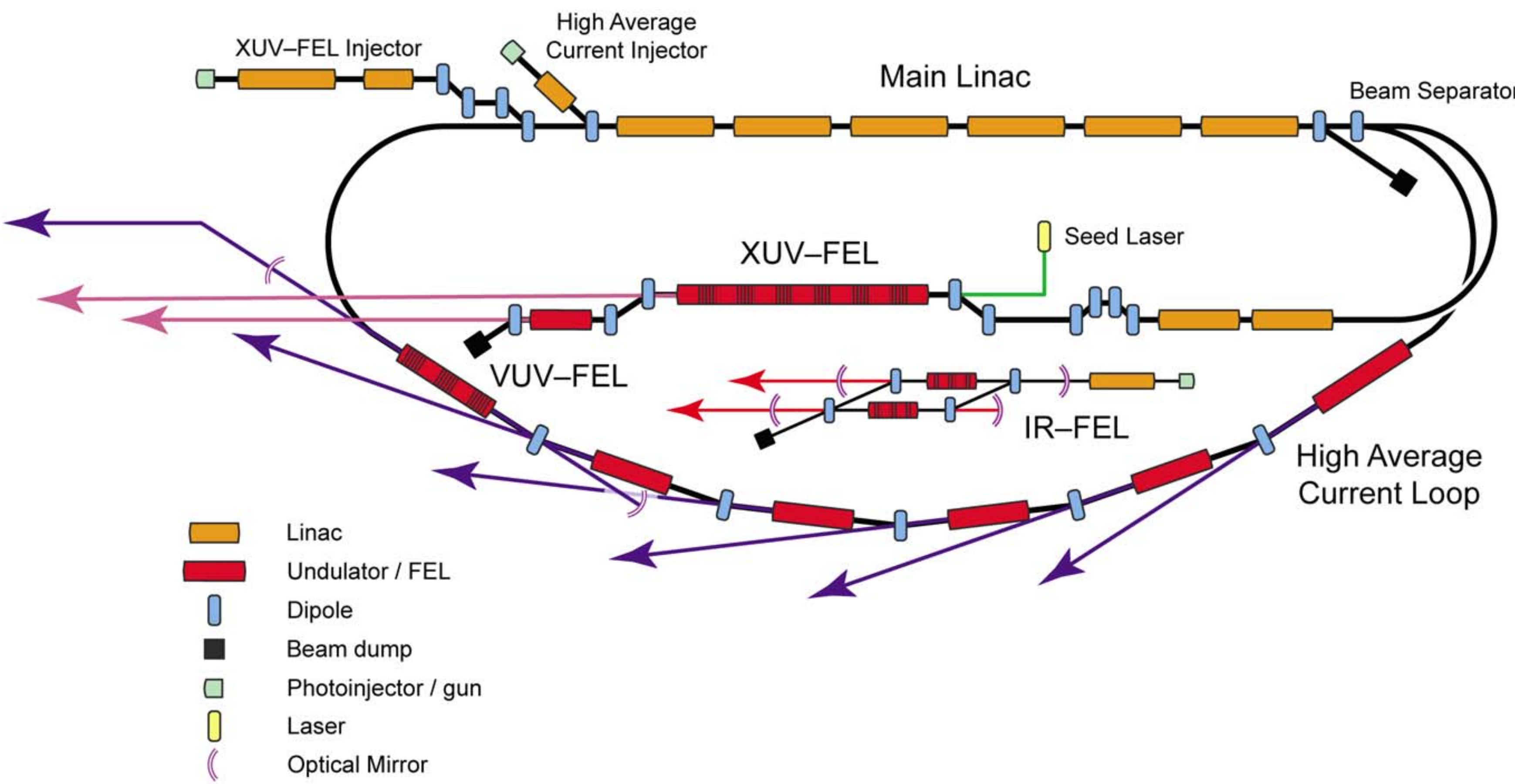






- The technology to underpin the development of the next generation of electronic devices: spintronics
- Development of innovative dynamic imaging techniques
  - on large scale for disease recognition
  - on nanoscale for biomolecular function in live cells

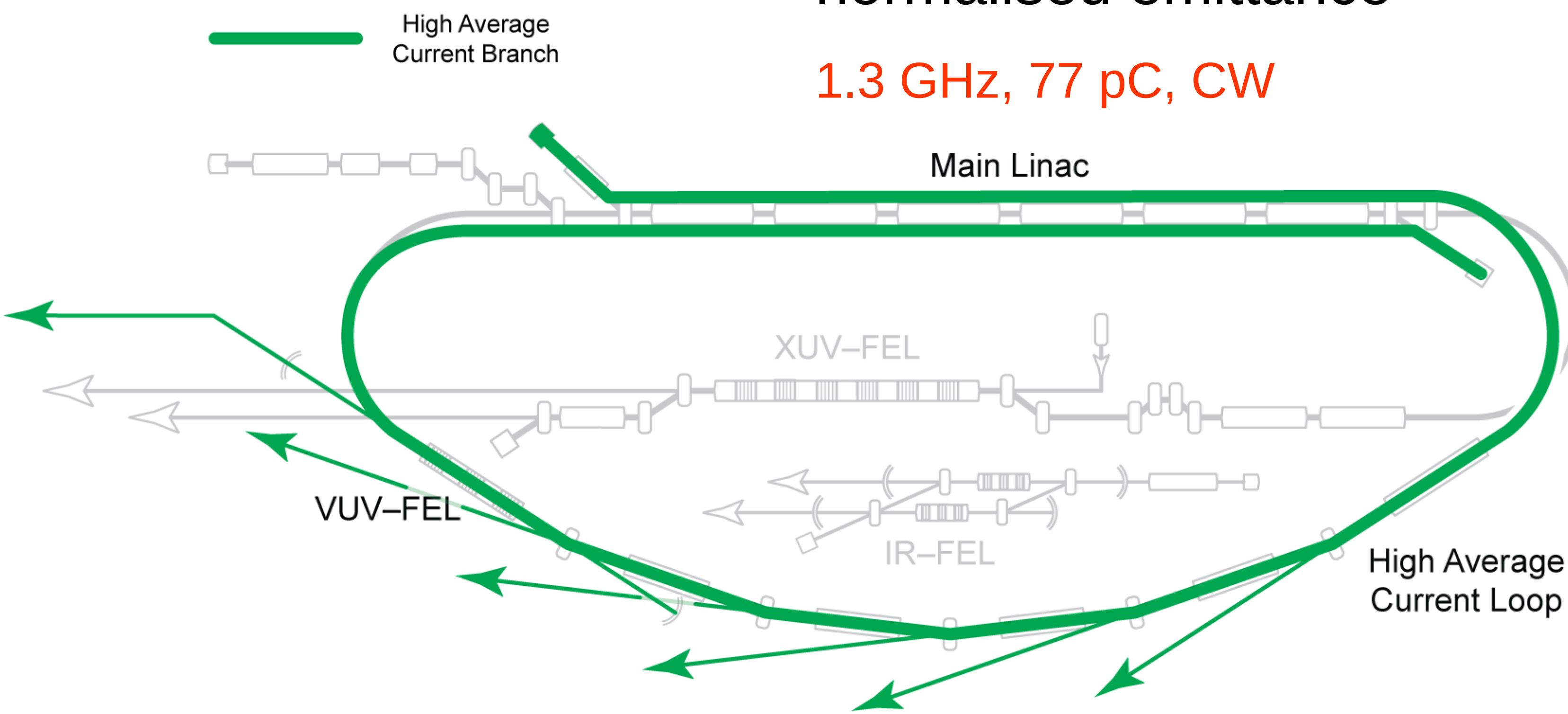
The Concept


XUV–FEL Injector
High Average
Current Injector
Main Linac
Beam Separator
Seed Laser
XUV–FEL
VUV–FEL
IR–FEL
High Average
Current Loop
Linac
Undulator / FEL
Dipole
Beam dump
Photoinjector / gun
Laser
Optical Mirror

High Average Current Loop

100mA, 600 MeV, 2 mm mrad normalised emittance

1.3 GHz, 77 pC, CW

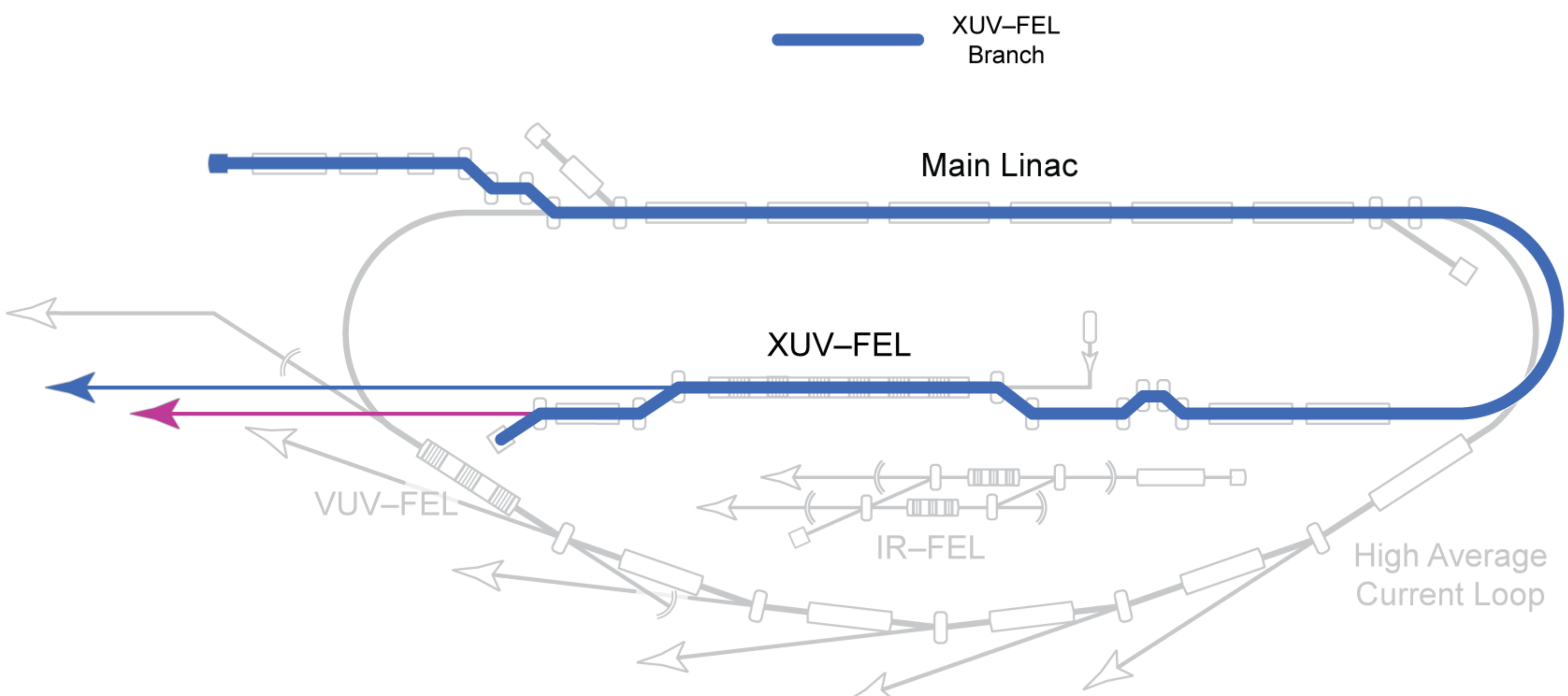


Undulator sources and VUV-FEL

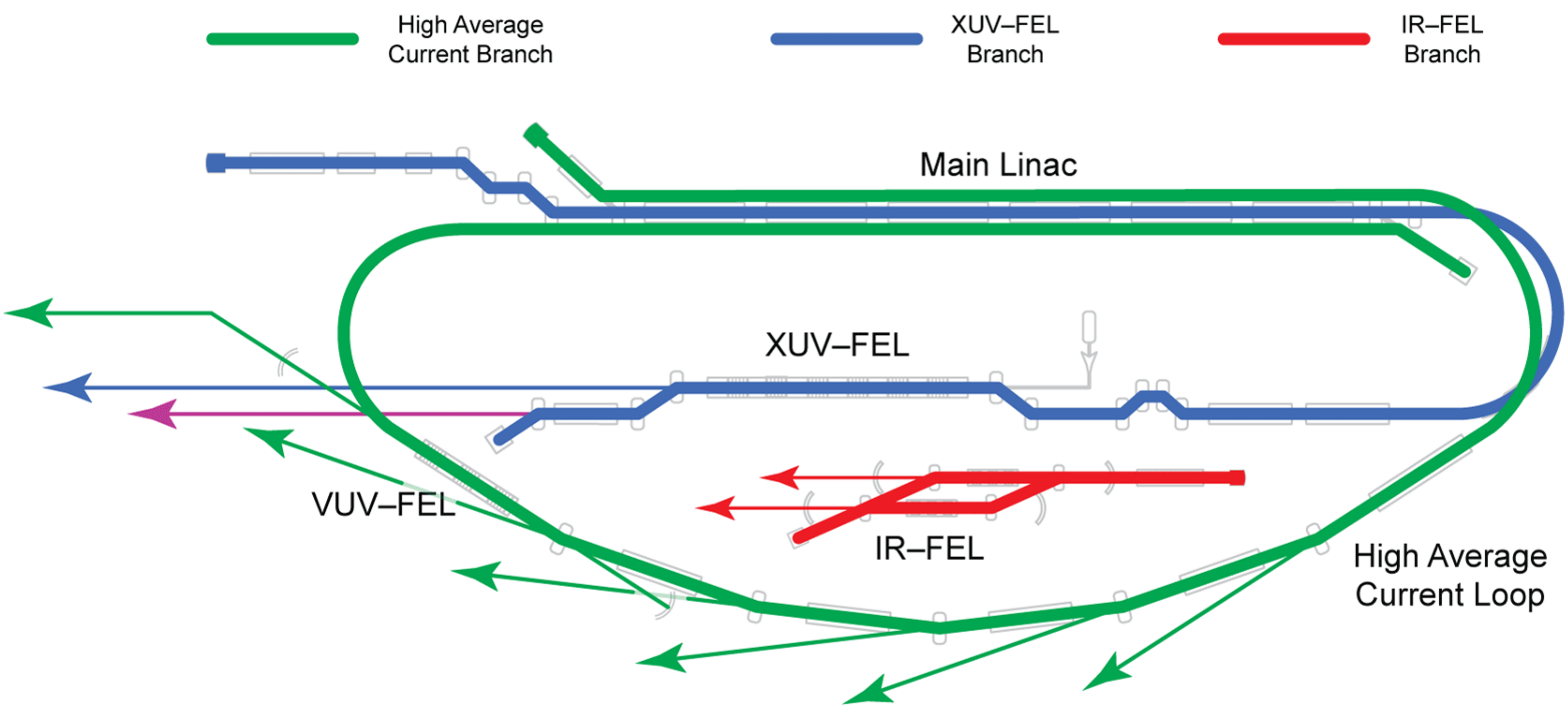
Progressive compression, ~1 ps to 100 fs

XUV-FEL Branch

1 nC, 750 to 950 MeV, 2 mm mrad normalised emittance, 1 kHz, 1.5 kA

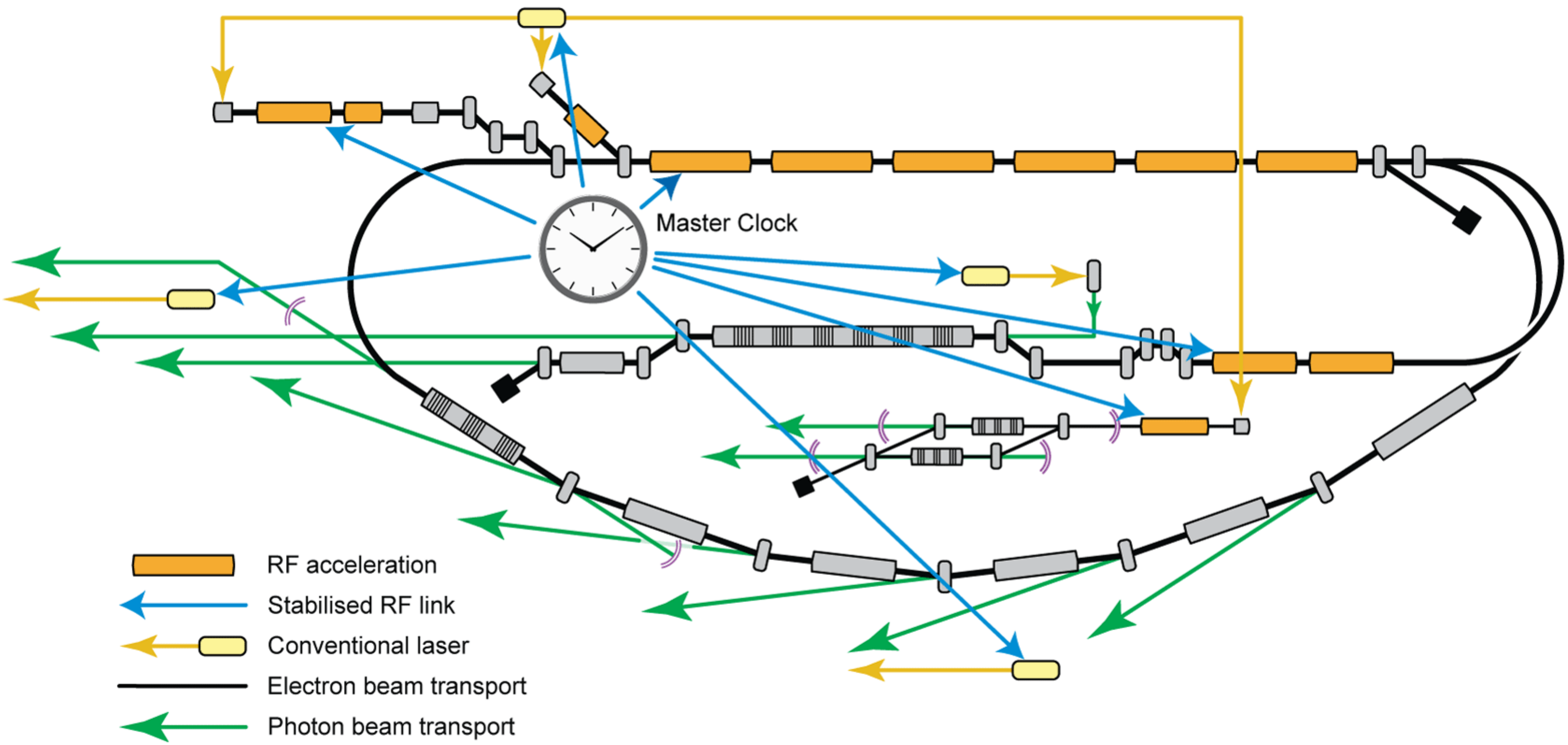


Simultaneous Operation



Short pulses and combined sources are key to 4GLS

Synchronisation

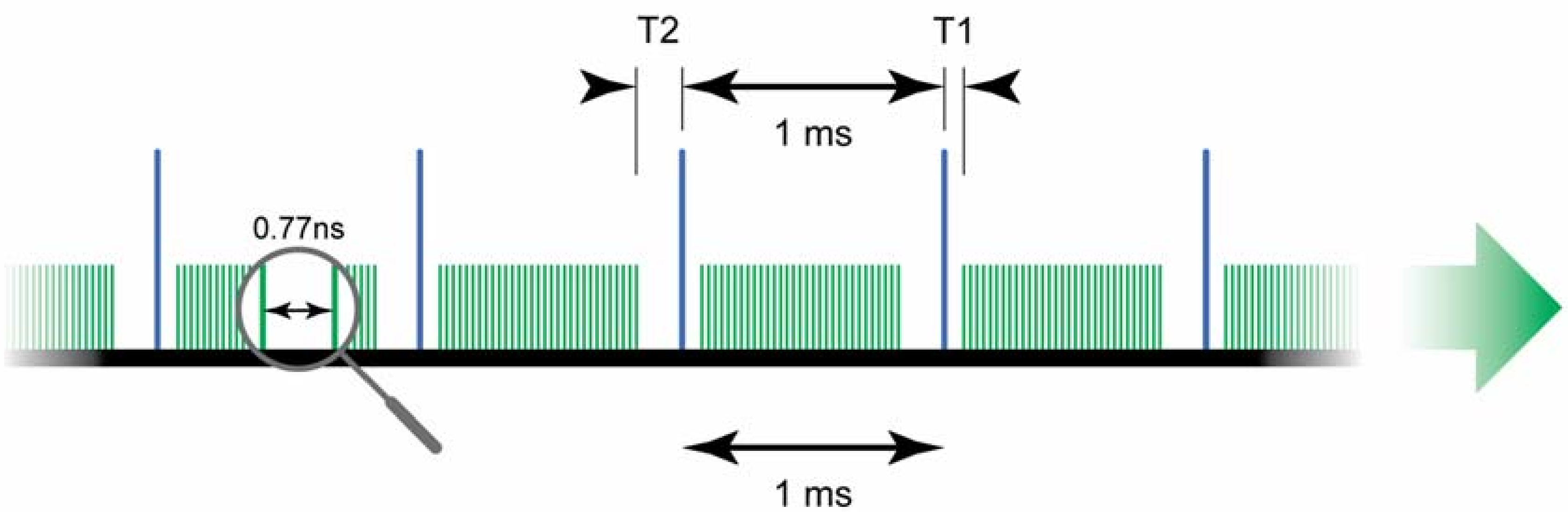


Combining sources requires excellent synchronisation

~100 fs 'standard', ~10 fs target for key experiments

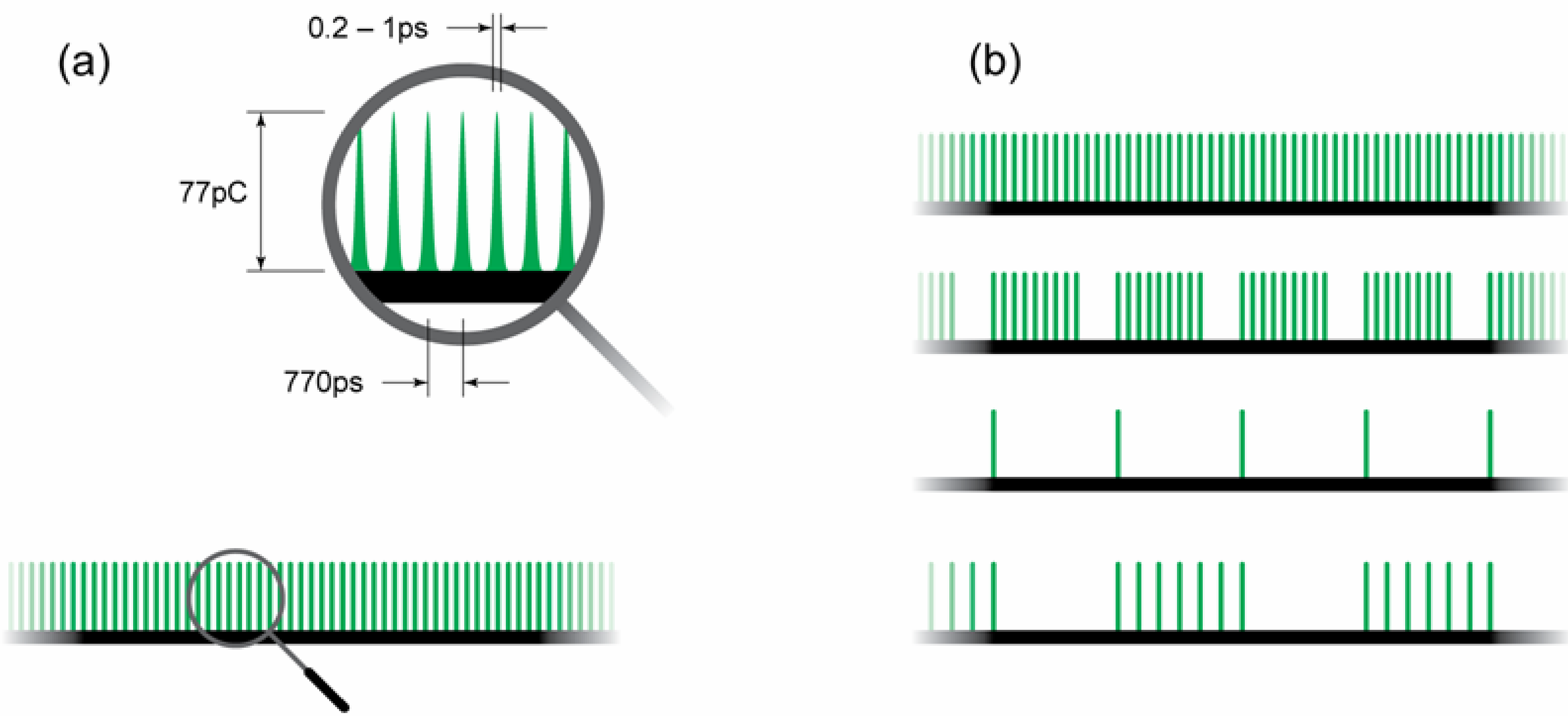
Main Linac Bunch Trains

- Standard operation mode
- High average current (77pC, 1.3GHz)
- XUV FEL bunches every 1ms
- Use energy difference to separate them

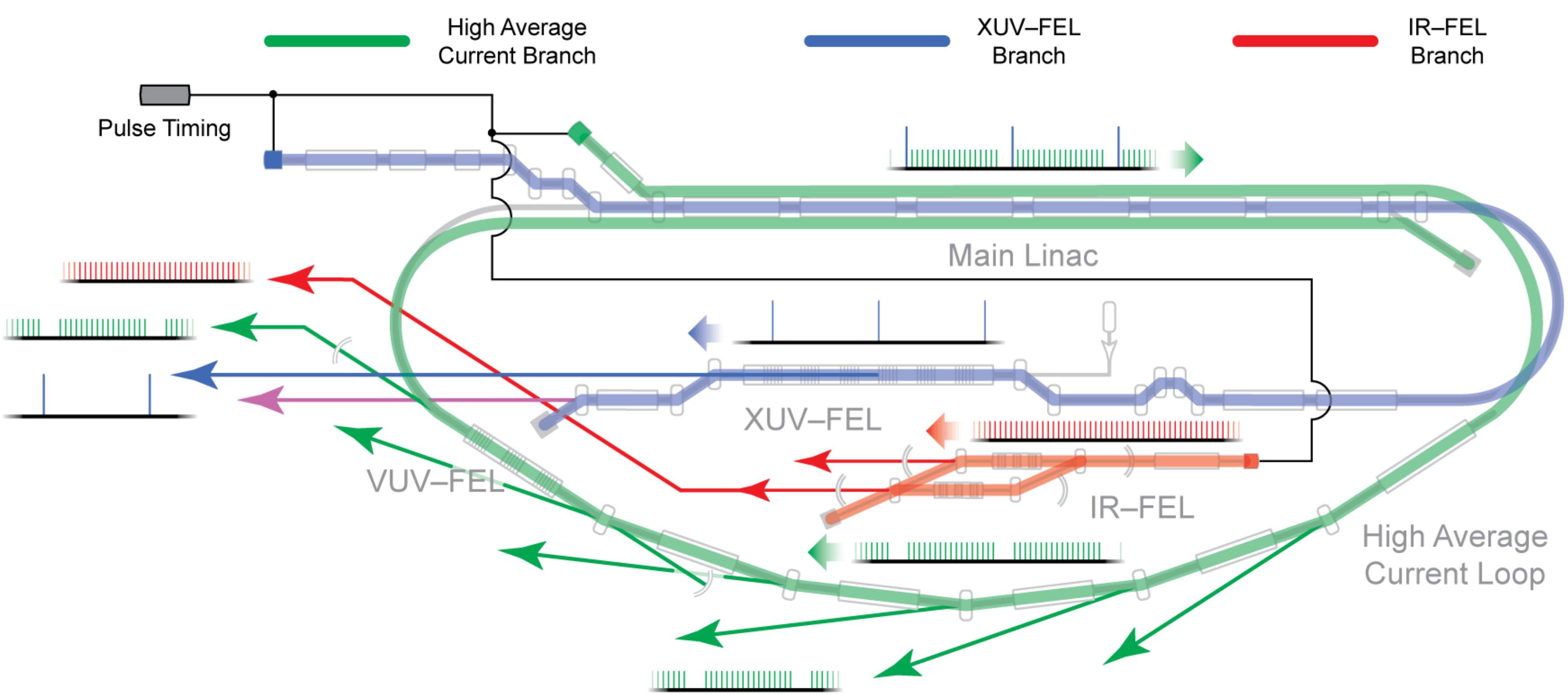


Other Possible Bunch Modes

- Considerable flexibility in bunch patterns



Bunch Pattern Example

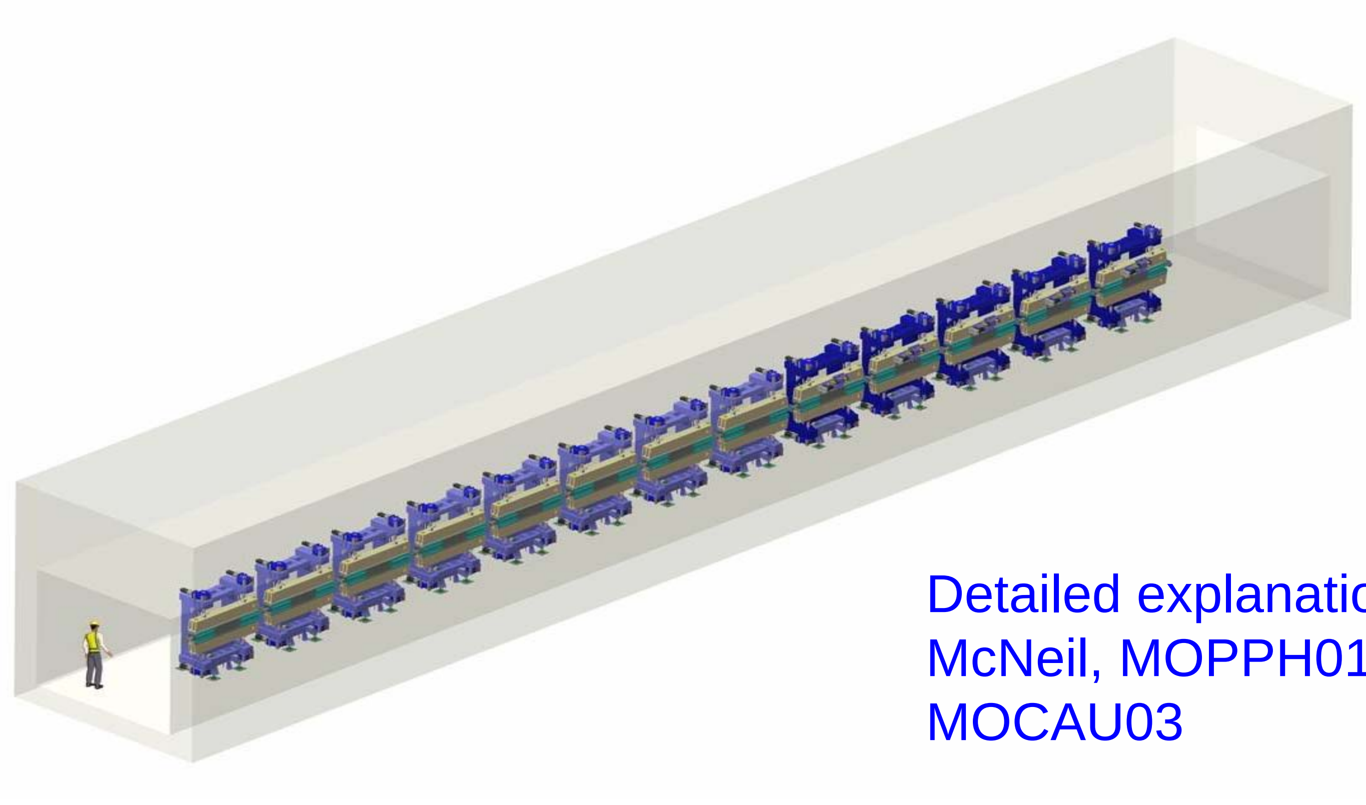


Main Parameters

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**

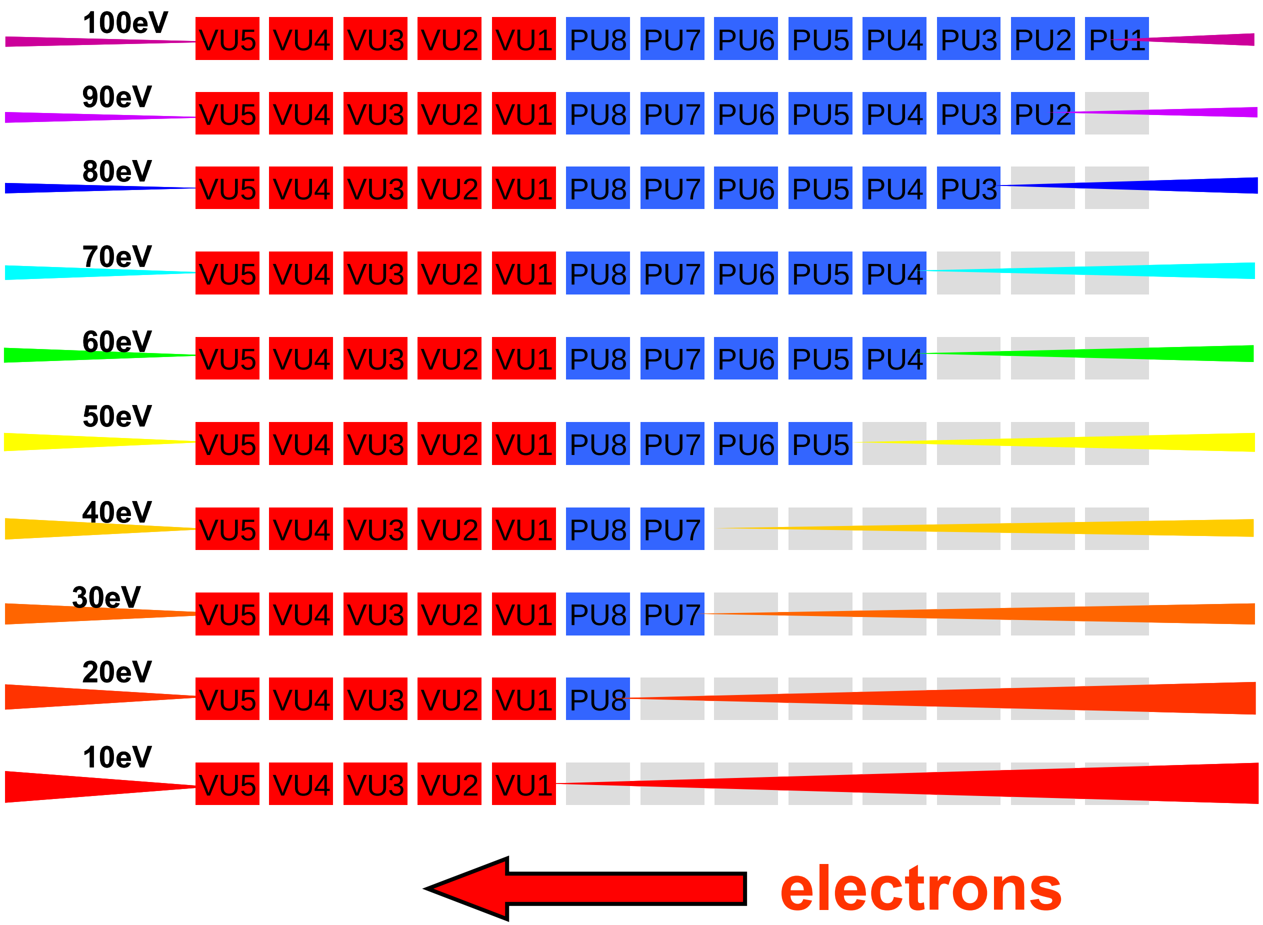
XUV-FEL

- 8 to 100 eV, multi-GW output
- Amplifier of seed pulse derived from conventional laser
- Ensures high quality output since mimics input pulse
- ~30 m long undulator system



Detailed explanation in B McNeil, MOPPH012 and MOCAU03

XUV FEL Operation



HHG seed source, fully tunable from 8 to 100 eV.

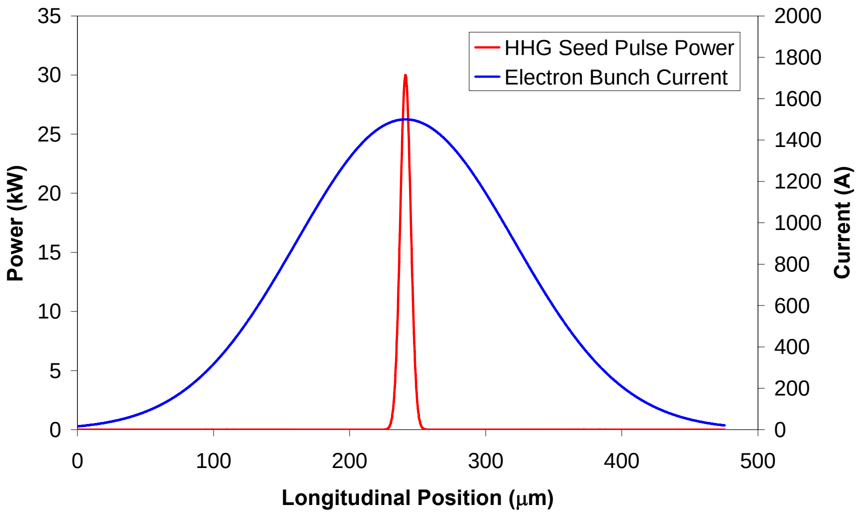
HHG details in B Sheehy et al MOPPH067

Stepped vacuum chamber for seed injection

Pulse Amplification, 100eV example

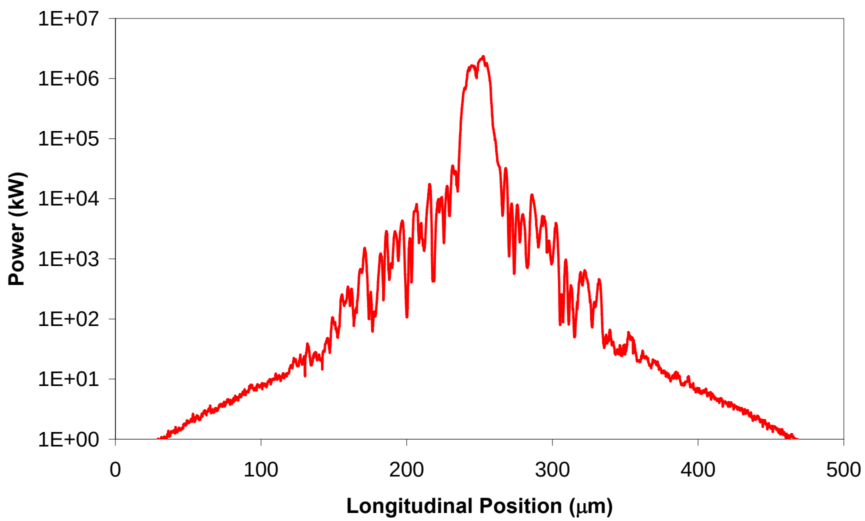
Entrance to FEL

30 kW seed, 100eV, 30fs

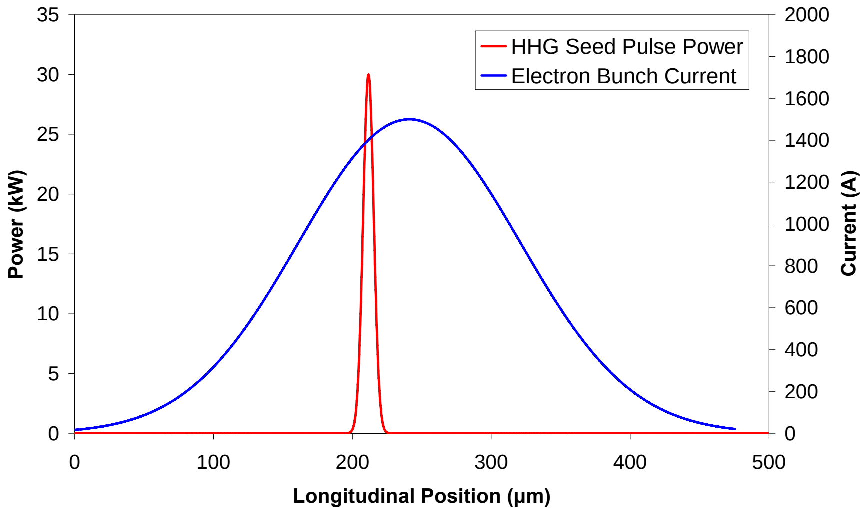


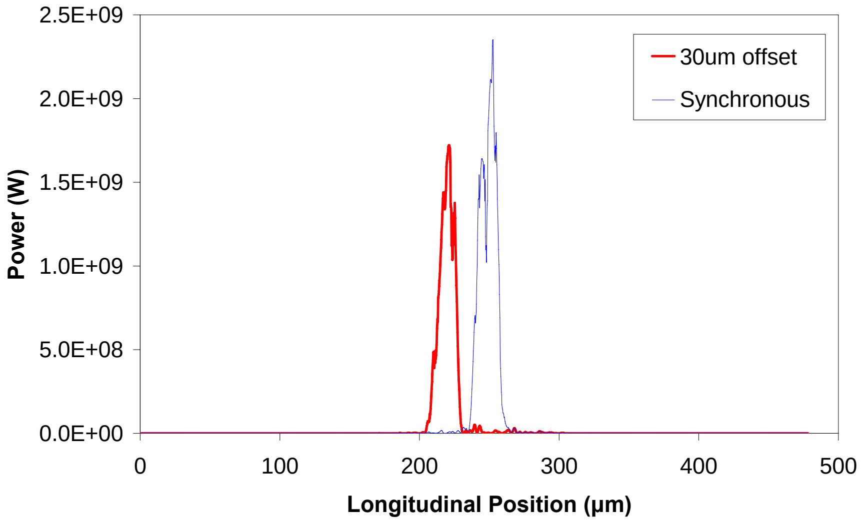
Exit of FEL

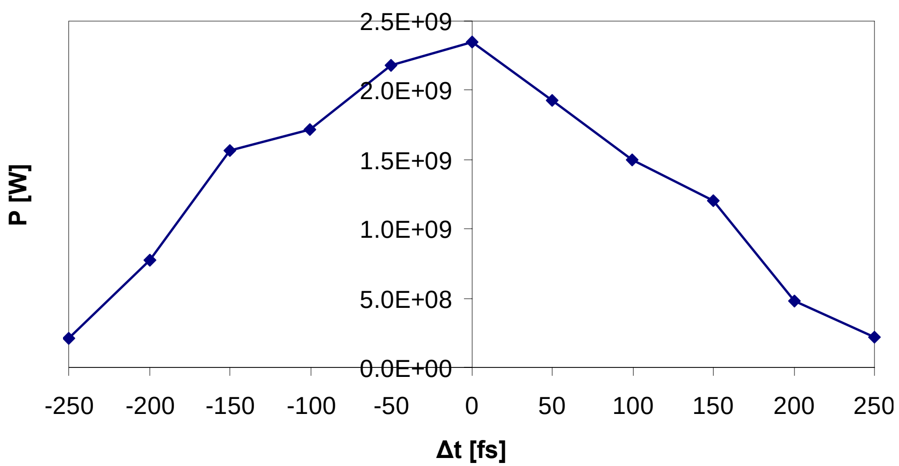
>2 GW, 100eV, 50fs



XUV-FEL Initial Jitter Simulations





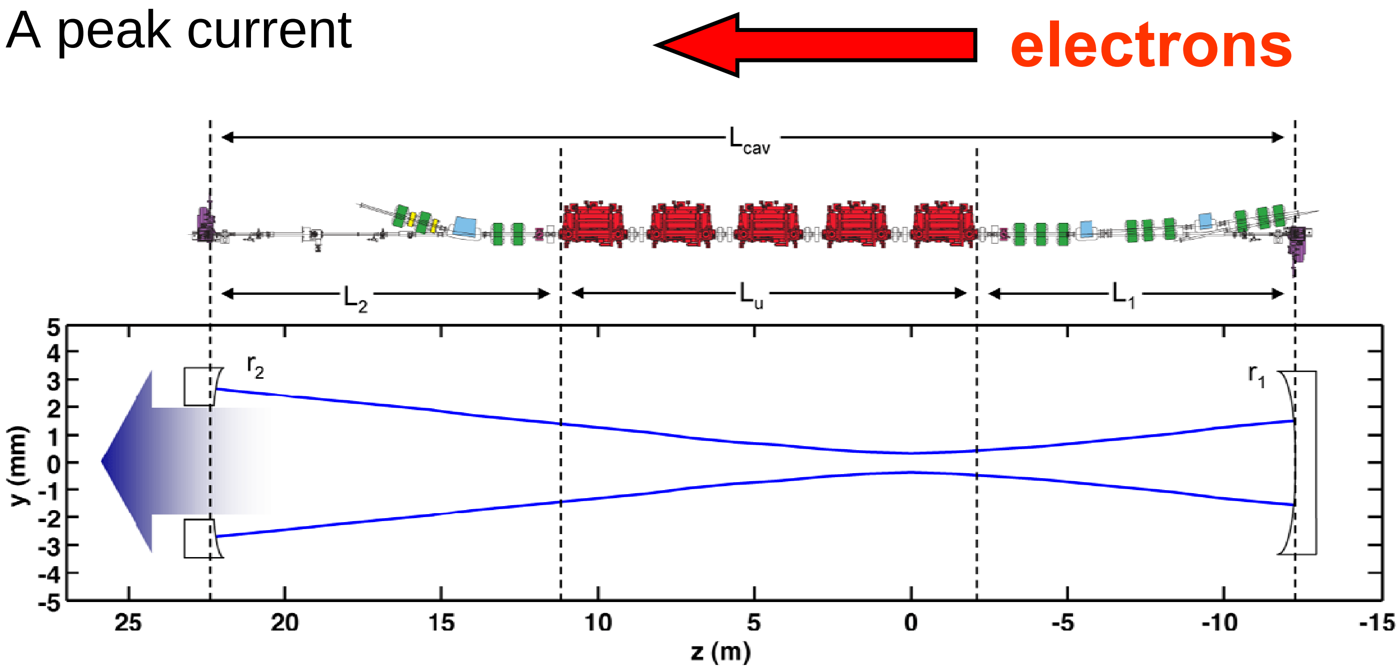


To keep output power within 90% need jitter < **± 45 fs**

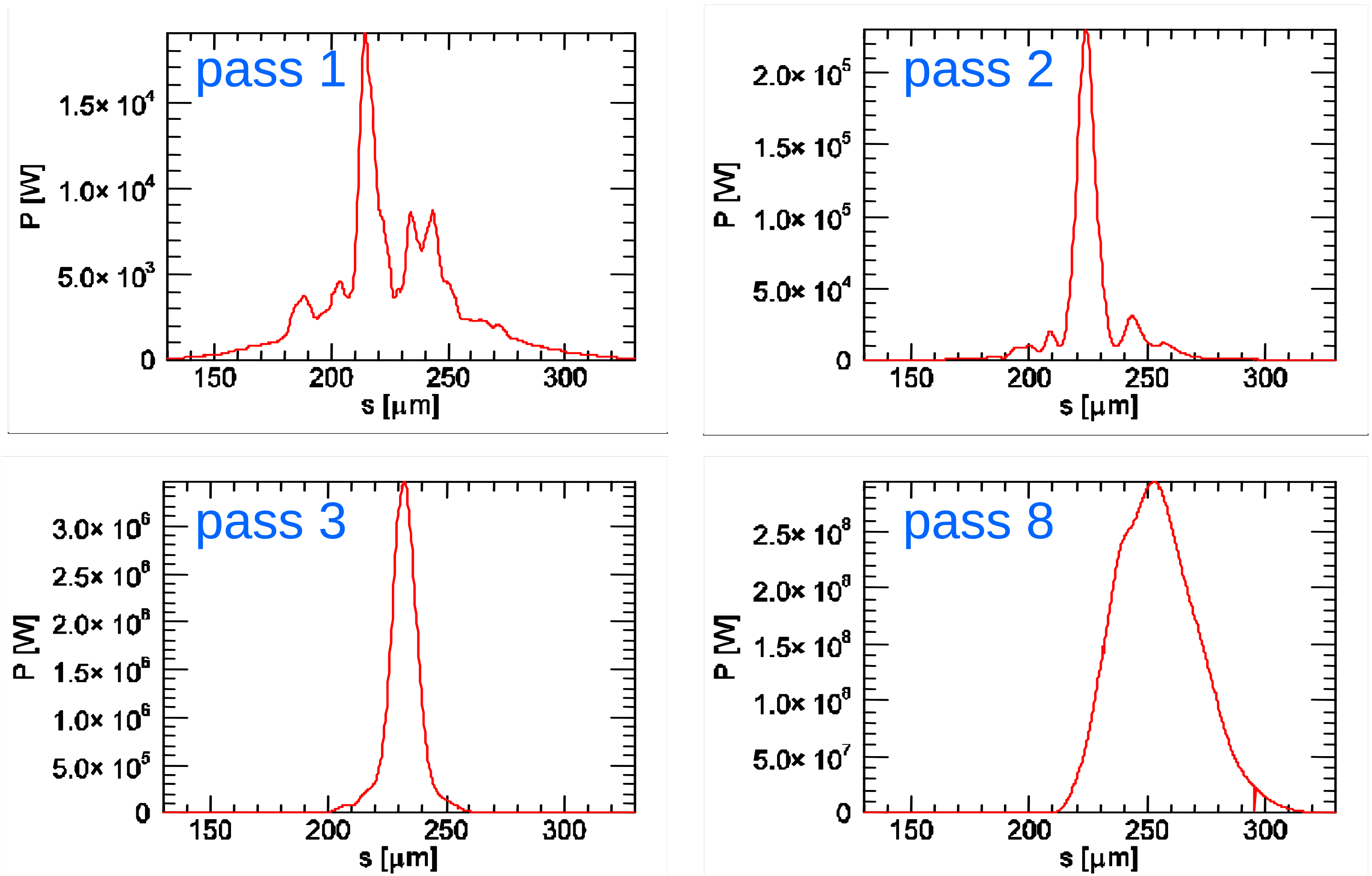
More details in D Dunning et al, TUPPH057

VUV-FEL

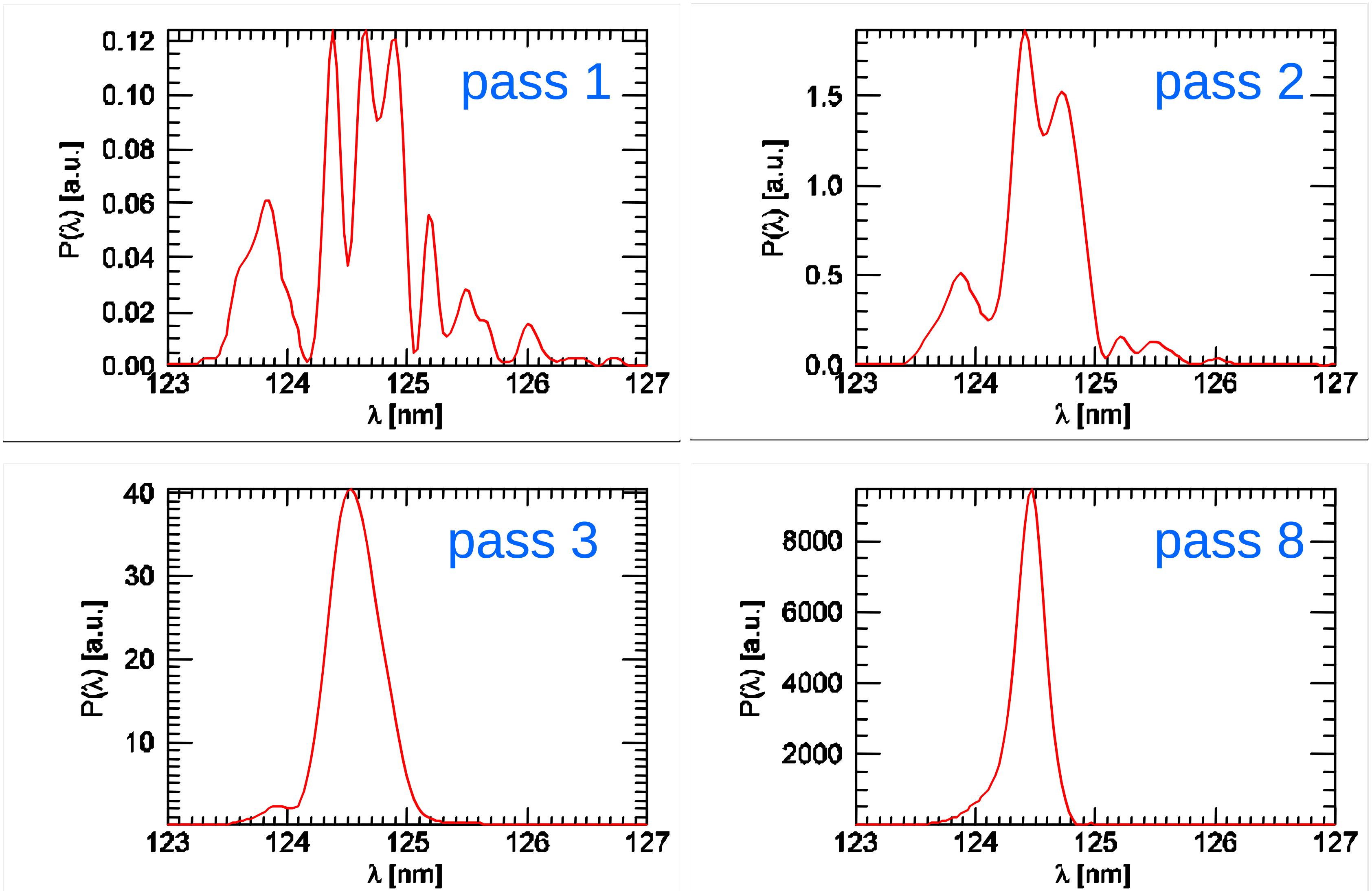
- 3 to 10 eV, ~500MW output
- Regenerative Amplifier system
- 4.33 MHz compared with 1 kHz XUV FEL
- Very tolerant to mirror degradation
- Reflectivity only 40 to 60% needed
- No seed
- 300 A peak current



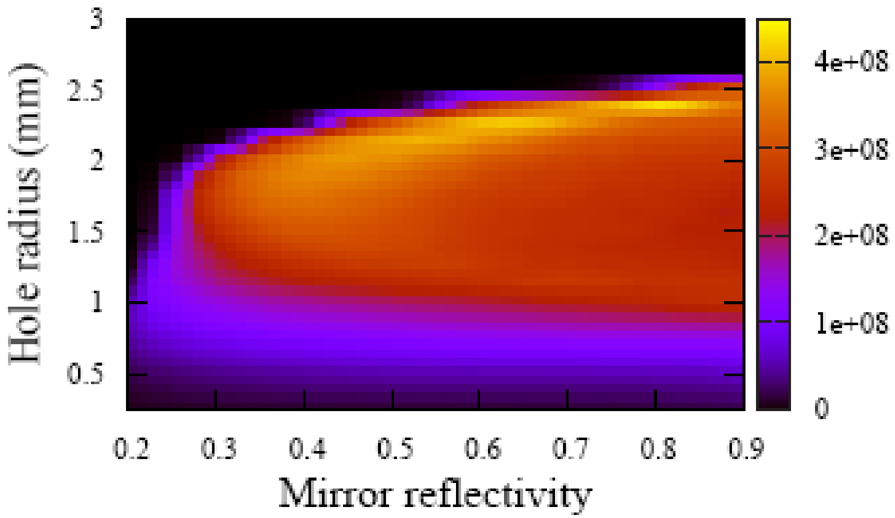
Radiation Pulse Power Build-Up

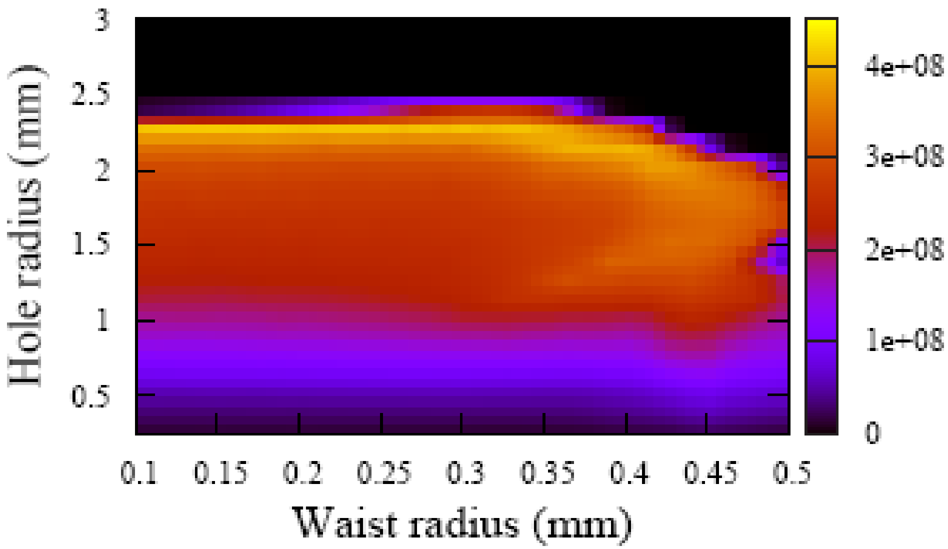


Radiation Spectrum Build-Up



3D simulations of VUV FEL



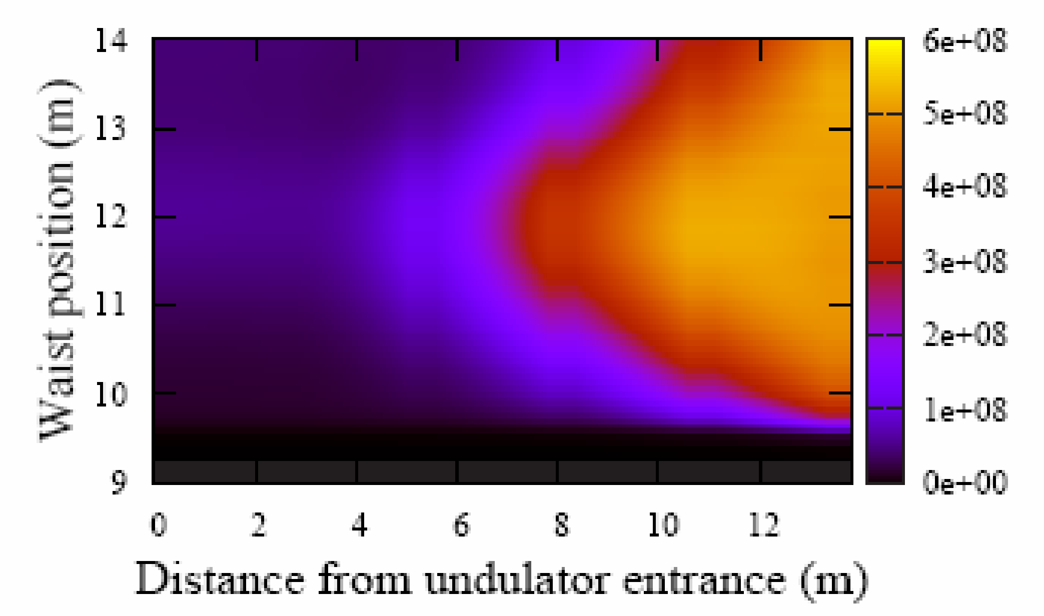


Code developed which incorporates Genesis 1.3 by Twente University.

3D simulation of optical components and radiation propogation within the optical cavity

Results confirm cavity parameters found from 1D model and demonstrate broad tolerance of the cavity system

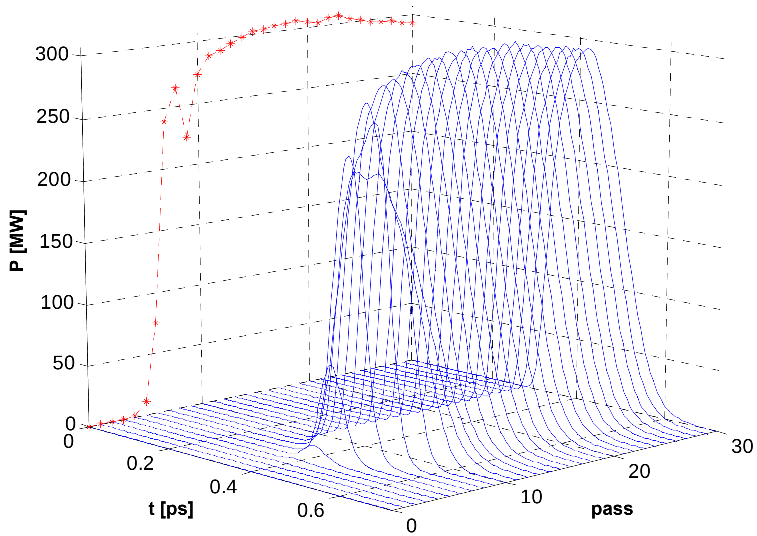
Power build up

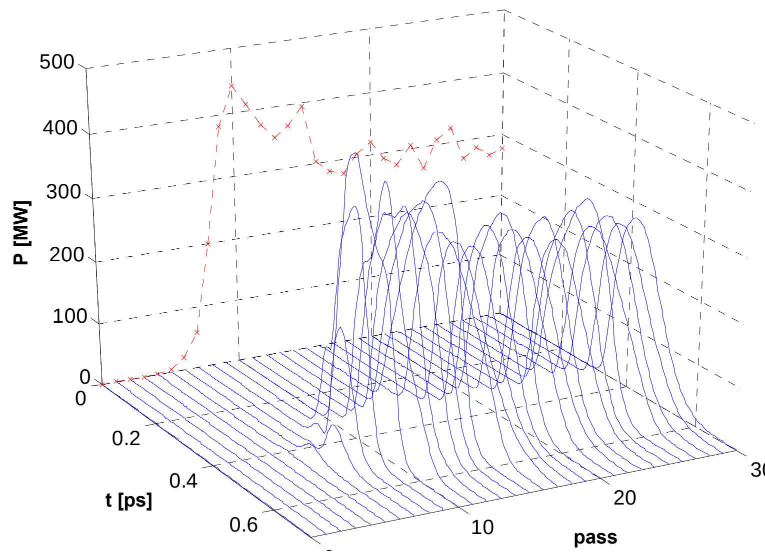


Power at exit largely intolerant to cavity waist position

More details of 3D studies in N Thompson et al, TUPPH001

VUV-FEL Jitter Simulations



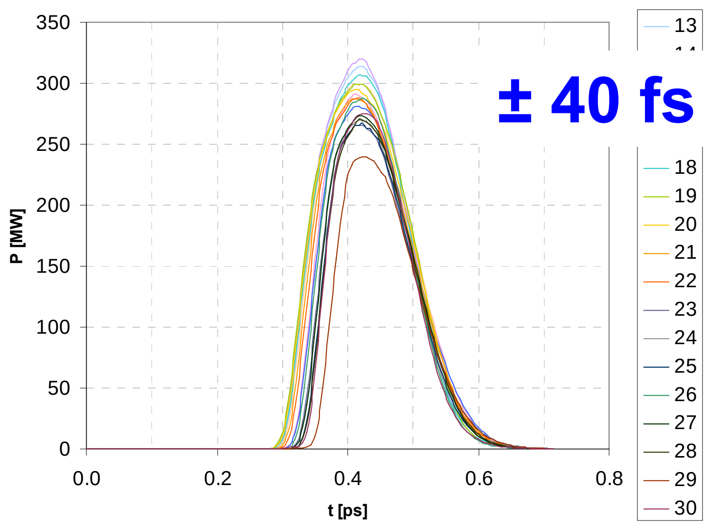


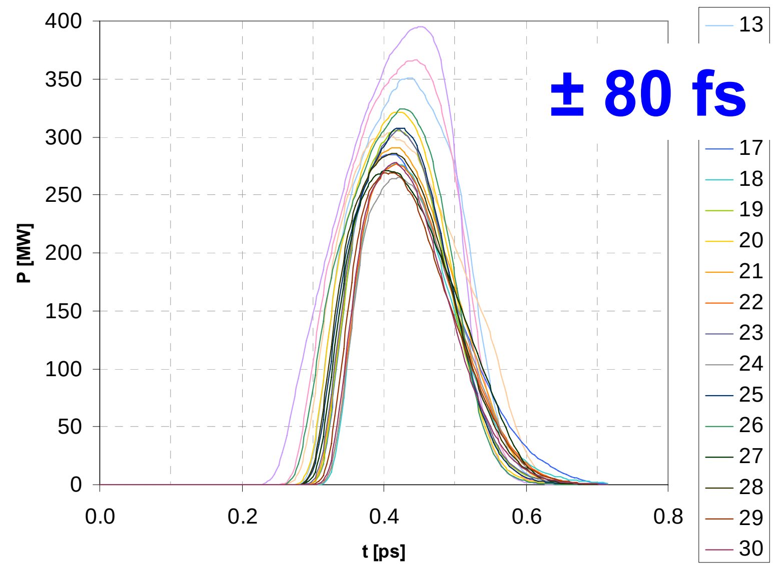
Zero jitter **± 80 fs jitter**

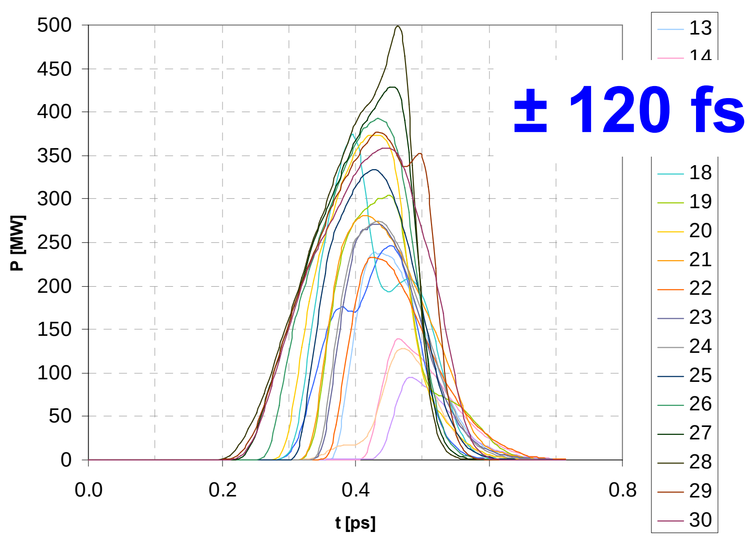
Output power **300MW ± 8%** if jitter in electron bunch arrival time **± 80 fs**

More details in D Dunning et al, TUPPH057

VUV-FEL Jitter Simulations, pulse shape



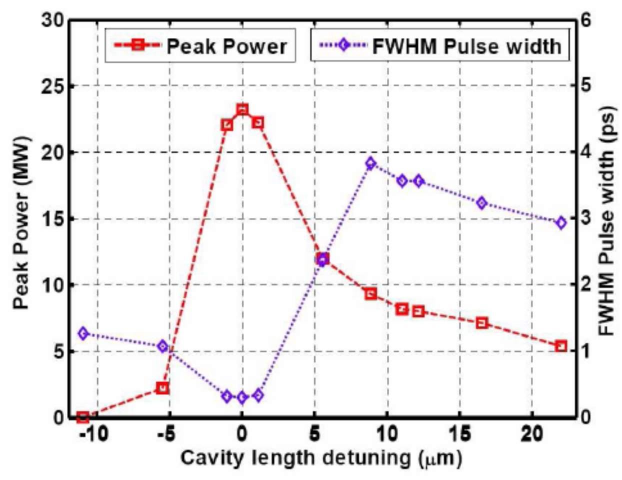


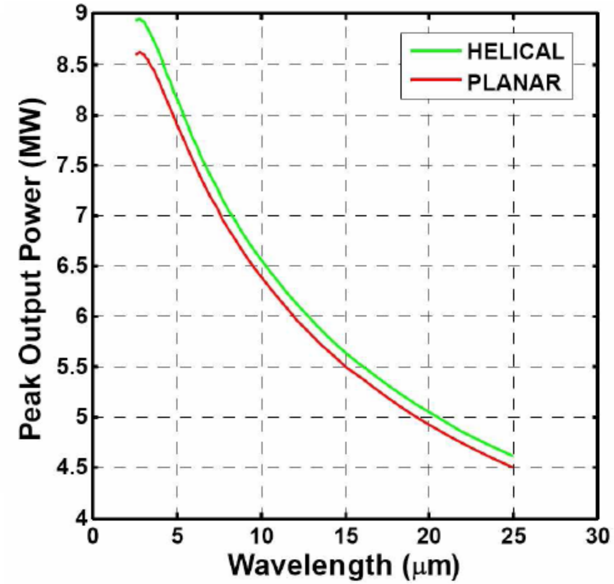


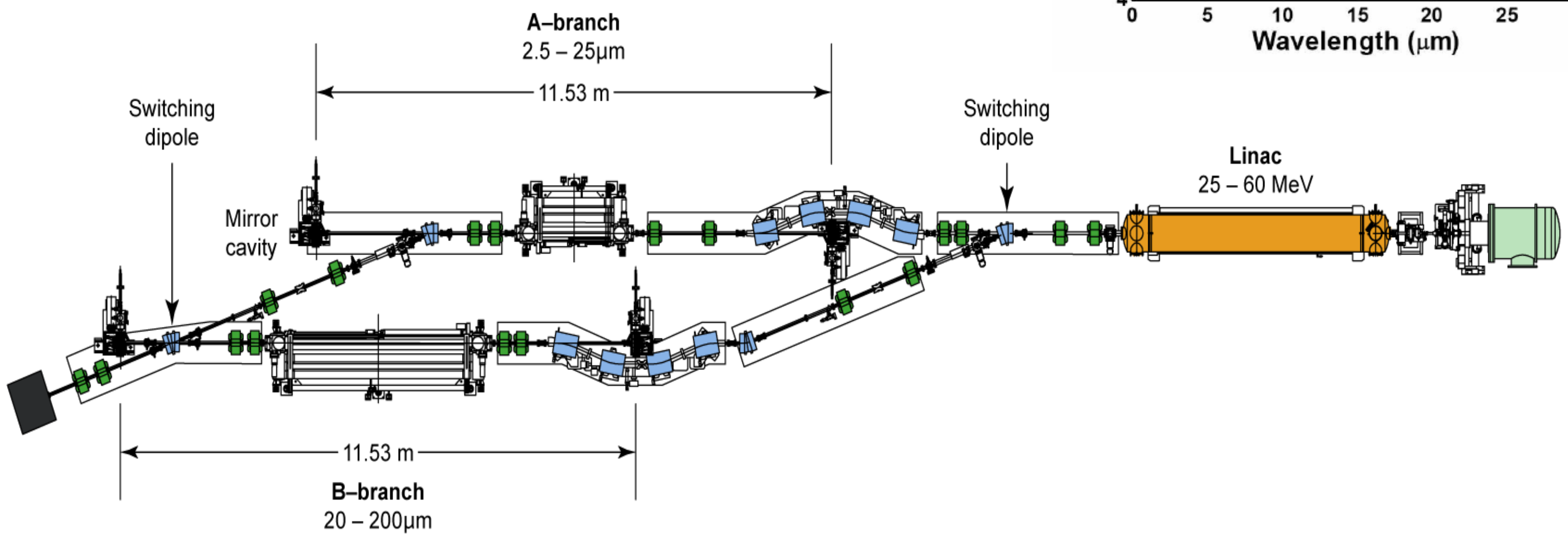
Jitter (fs)	Saturation Power (MW)
± 0.0	300 ± 2.5%
± 20	300 ± 4.1%
± 40	300 ± 6.0%
± 80	300 ± 8.0%
± 120	300 ± 18.8%

IR-FEL

- 2.5 to 200 μm
- Oscillator FEL
- SCRF for stability
- 25 to 60 MeV





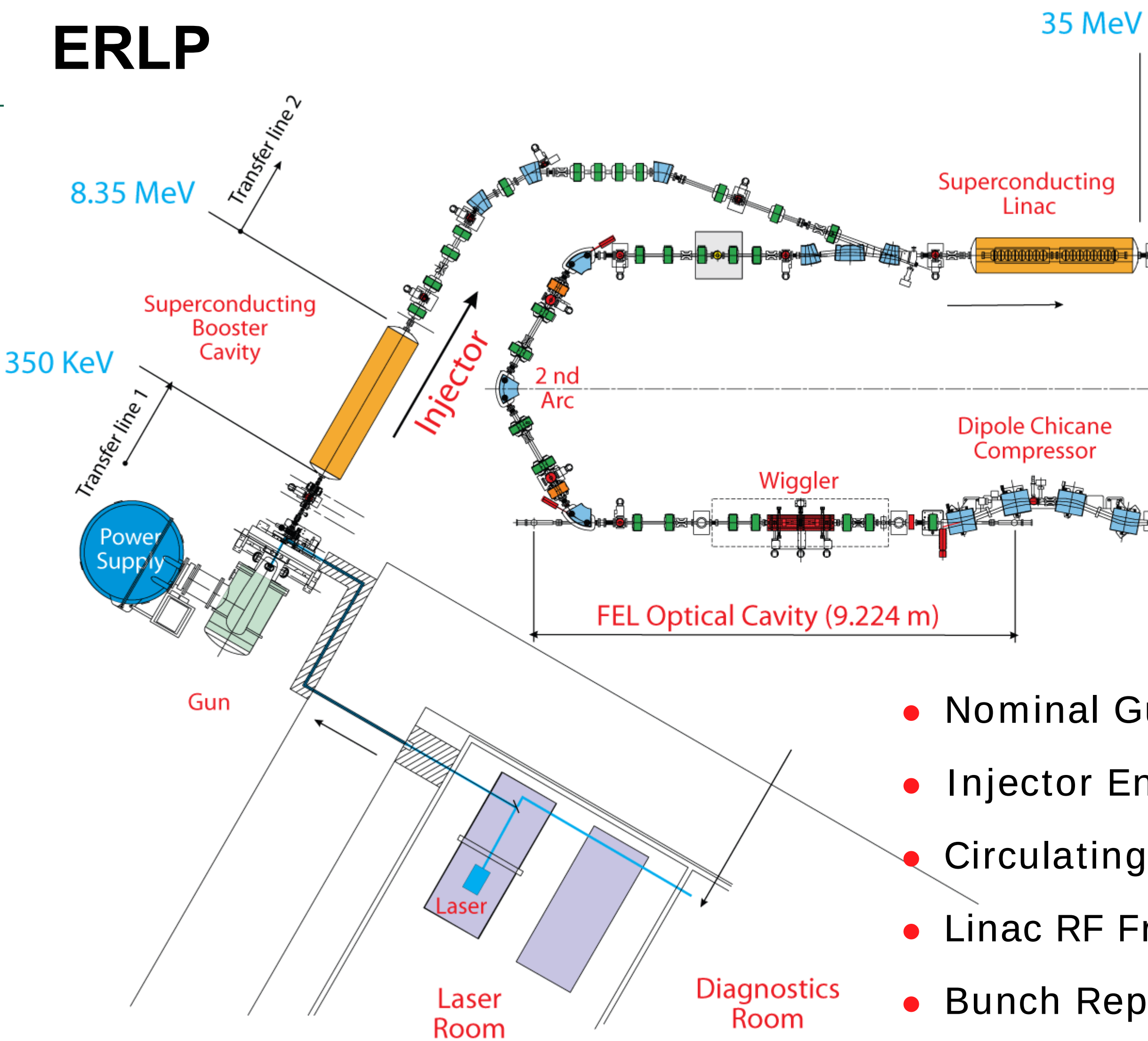


R & D Studies

- In preparation for 4GLS we have constructed a prototype ERL
- This has given us direct experience of photoinjectors, SC linacs, energy recovery, FELs, single pass diagnostics, etc
- Commissioning of the photoinjector has recently started

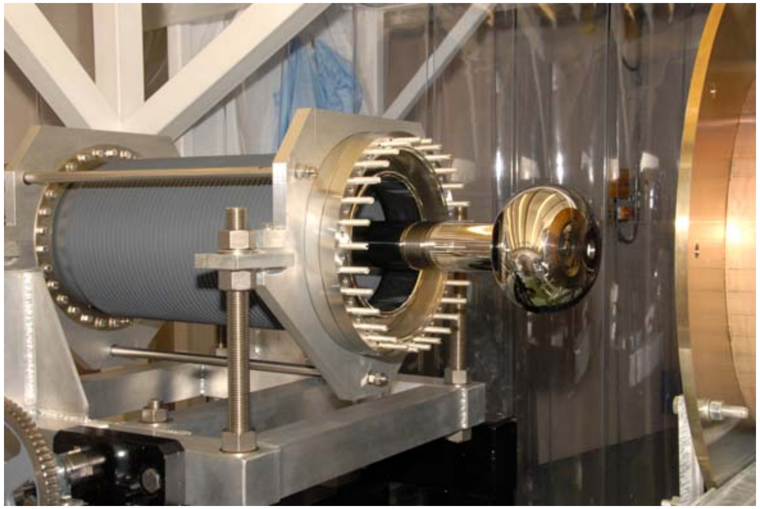
- In addition to this we have started the design and construction of a prototype SC linac suitable for CW-mode operation
  - → Reduced HOM contribution
  - → Larger HOM dissipation capacity
  - → Larger RF power capability
- We are also planning to prototype a high average current photoinjector capable of 100mA operation

ERLP



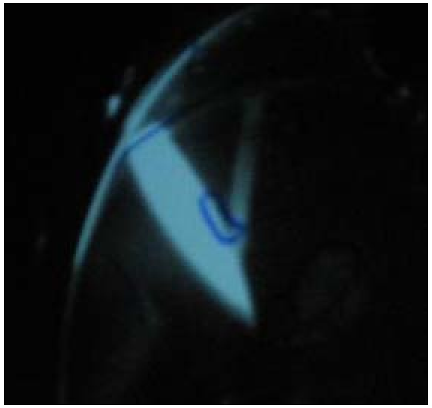
• Nominal Gun Energy	350 keV
• Injector Energy	8.35 MeV
• Circulating Beam Energy	35 MeV
• Linac RF Frequency	1.3 GHz
• Bunch Repetition Rate	81.25 MHz
• Max Bunch Charge	80 pC
• Max Average Current	13 μA

ERLP Photos



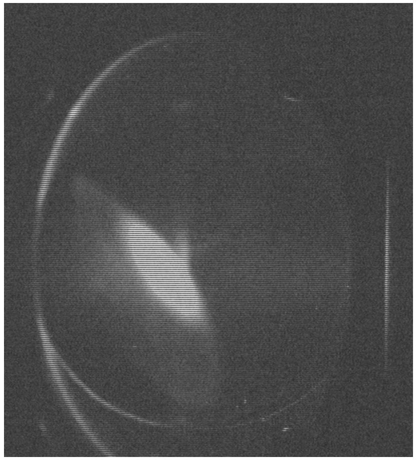
ERLP Commissioning

First electrons from photoinjector on **16th August 2006** at 01:08am. Gun voltage 250 kV, QE ~0.05%.



By 22nd August,

Gun voltage 350kV and QE ~0.5%.



Status & Future Plans

- CDR published April 2006
- Available from http://www.4gls.ac.uk/

- Technical design phase has now started
- TDR to be published in 2007
- Prototyping of high average current SC linac commenced
- Prototyping of high average current gun planned

- ERLP Commissioning starting to get interesting!
- Expect energy recovery in ERLP, Spring 2007
- Aim for first lasing in ERLP IR-FEL by FEL '07

Thanks

- To everyone who has contributed to the design of 4GLS and the construction of ERLP
- Special thanks to our international collaborators, without you we could not have got this far!

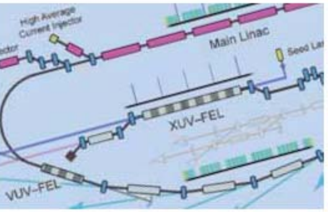
4GLS DARESBURY

4GLS – the UK's 4th Generation Light Source

4GLS: the next steps

An information and interaction meeting for potential users following publication of the Conceptual Design Report

Daresbury Laboratory
Friday 8th September 2006



Invited speakers:

Markus Drescher (Universität Hamburg & DESY, Germany)
Gwyn P Williams (Jefferson Laboratory, USA)
John Sutherland (East Carolina University, USA)
Normal H Tolk (Vanderbilt University, USA)
Antonio Cricenti (ISM-CNR Roma, Italy)
Cheuk-Yiu Ng (University of California, Davis, USA)

- The purpose of the meeting is to inform, and consult with, potential users on the design of 4GLS, following the recent publication of the Conceptual Design Report.
- A number of international experts will give presentations describing the key science that will be achieved
- Discussion sessions will ensure that the evolving aspirations of the user community continue to be met as the detailed design parameters are confirmed.

The meeting will take place at CCLRC Daresbury Laboratory, Warrington, WA4 4AD, Cheshire, in the Merrison Lecture Theatre, starting at 10 am and ending at 5.30 pm. Delegates should report to laboratory reception. Refreshments and lunch will be provided.

There is no meeting fee. Registration and further information is available at http://www.srs.ac.uk/meetings/4GLS_nextsteps/.

CCLRC Daresbury Laboratory

If you are interested in using 4GLS or learning more about it you are invited to our one-day workshop

http://www.4gls.ac.uk/