Timing and Synchronisation Considerations for the NLS Project

G. J. Hirst, STFC Central Laser Facility
S. P. Jamison, L. B. Jones, A. J. Moss, ASTeC
P. J. Phillips, University of Dundee

The NLS Project

A *science-driven* proposal for an integrated suite of sources delivering ~20fs FWHM pulses tuneable from THz to soft X-ray

Progress:

Launched	April ’08
Science case	October ’08
Developed science case and outline facility design	July ’09
Conceptual design	End of ’09

NLS

NLS Project:
Science Case &
Outline Facility Design

www.newlightsource.org

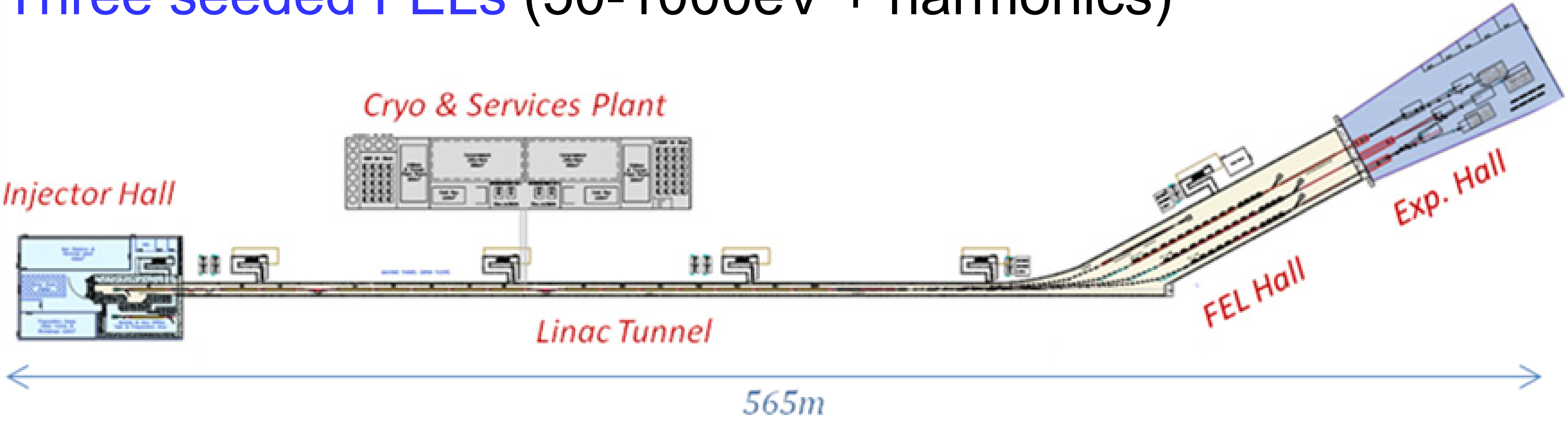
July 2009

http://www.newlightsource.org/documents/NLS_Sci_Case.pdf

The NLS Project

A *science-driven* proposal for an integrated suite of sources delivering ~20fs FWHM pulses tuneable from THz to soft X-ray

BMs and undulators (2.5-60meV)
Conventional lasers + NLO (60meV-6eV), Laser HHG (6-50eV)
Three seeded FELs (50-1000eV + harmonics)



200pC electron bunches from a photoinjector accelerated to 2.25GeV in a cw SC 1.3GHz linac and compressed to ~200fs

Timing

Output pulses will be equispaced with a nominal baseline pulse rate of 1kHz, rising to 10kHz, 100kHz and 1MHz

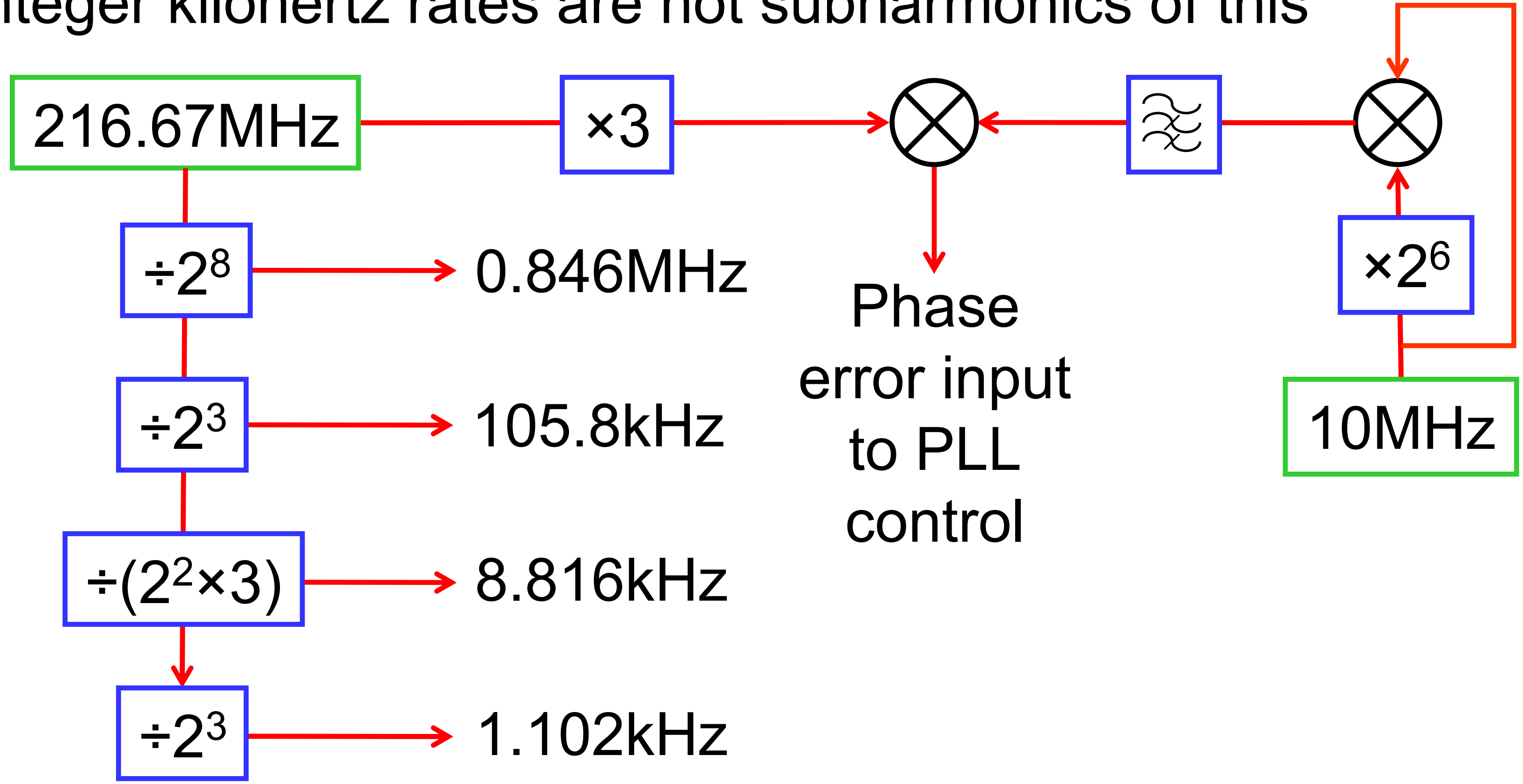
Factors affecting the exact rates will include:

- Use of integer fractions of the master clock frequency which will be an integer fraction of the 1.3GHz RF
- 1kHz-1MHz rates will be integer fractions of one another
- Preference for the products of small primes ($2^n \times 3^m$) allowing simple subdivision and compatibility with a wide range of resonant subsystems
- Cooperation with international partners to allow the development of common commercial components

Clock Frequency and Bunch Rates

Clocks based on fibre laser oscillators work best at ~200MHz

216.67MHz is a convenient (6th) subharmonic of 1.3GHz but integer kilohertz rates are not subharmonics of this

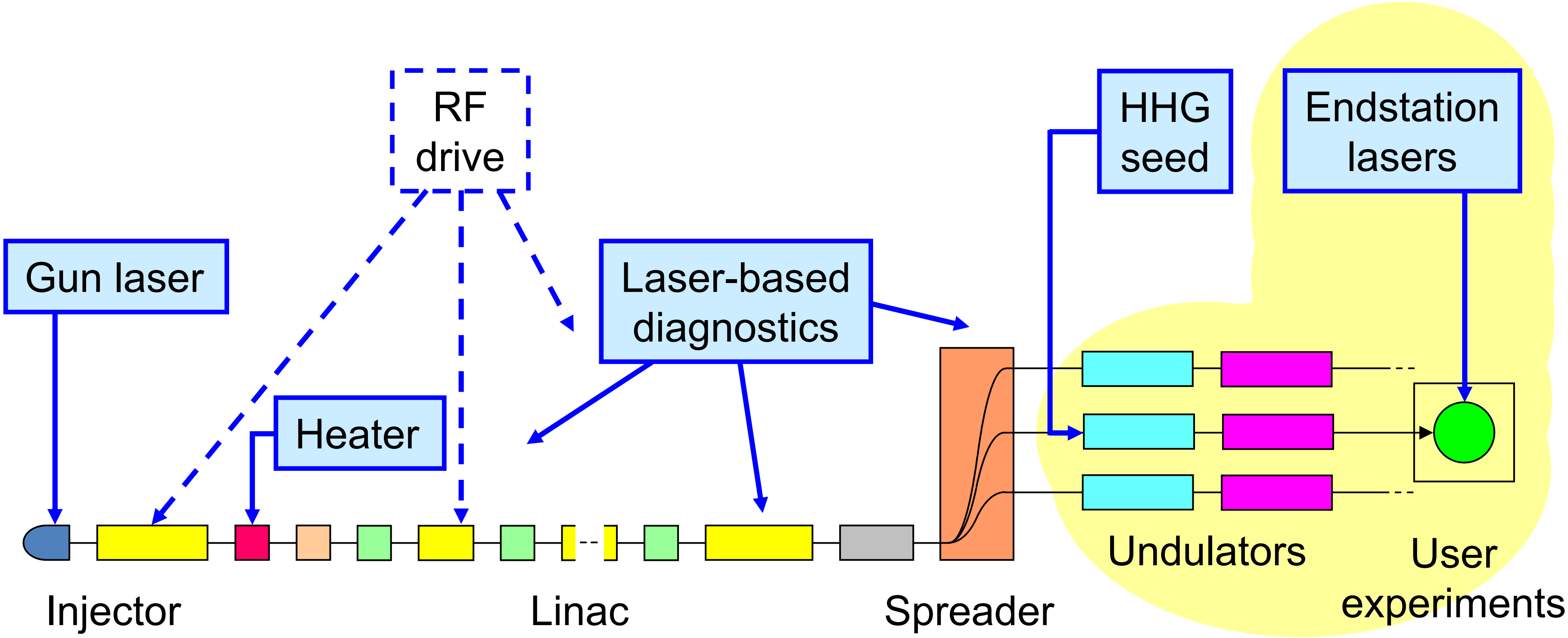


Timing Summary

- NLS time structures are *science-driven*

  Implementation details need careful thought but are not expected to present serious challenges

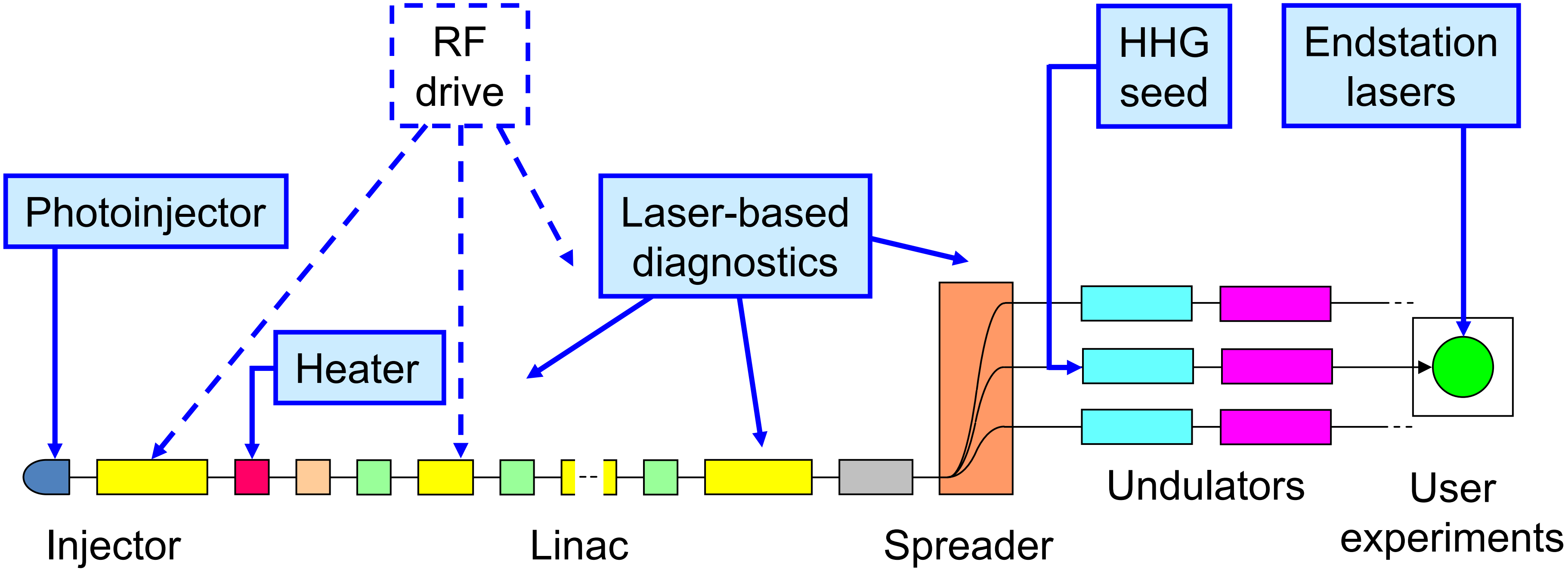
NLS Synchronisation Requirements



PRIMARY: ~10 fs rms between FELs, lasers and THz/IR at the experiment

🟦	Gun	🟨	Linac module	🟥	Heater	🟩	Bunch compressor
🟧	3ω cavity	⬜	Collimator	🟦	FEL	🟪	THz/IR undulator

NLS Synchronisation Requirements



RF drive

HHG seed

Endstation lasers

Photoinjector

Laser-based diagnostics

Heater

Undulators

User experiments

Injector

Linac

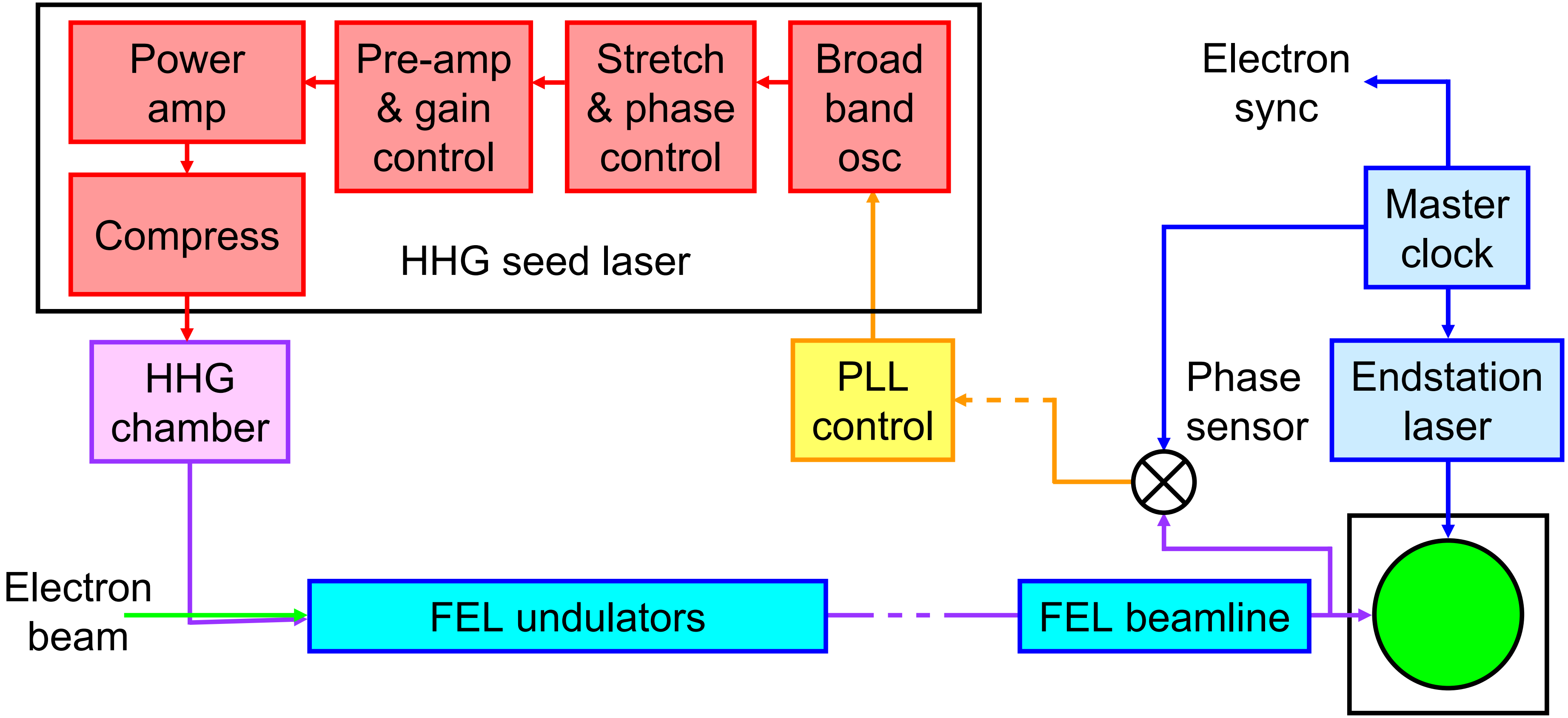
Spreader

SECONDARY: Individual subsystem jitters low enough for stable source operation

🟦 Gun 🟨 Linac module 🟥 Heater 🟩 Bunch compressor

🟧 3ω cavity ⬜ Collimator 🟦 FEL 🟪 THz/IR undulator

Synchronisation of Lasers and FELs

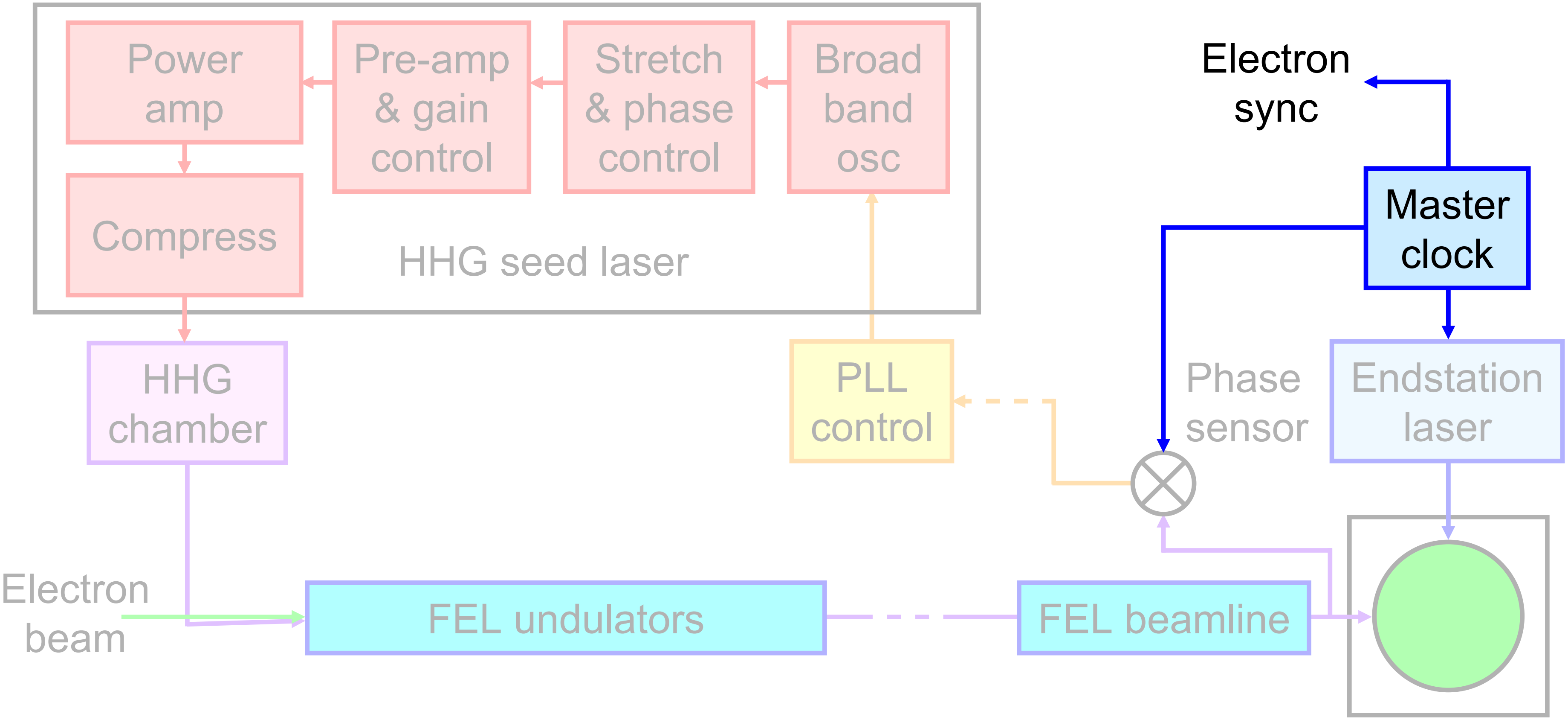


Clock distribution
HHG seed laser locking
Endstation laser locking
Differential transport

FCS Implementation Principles

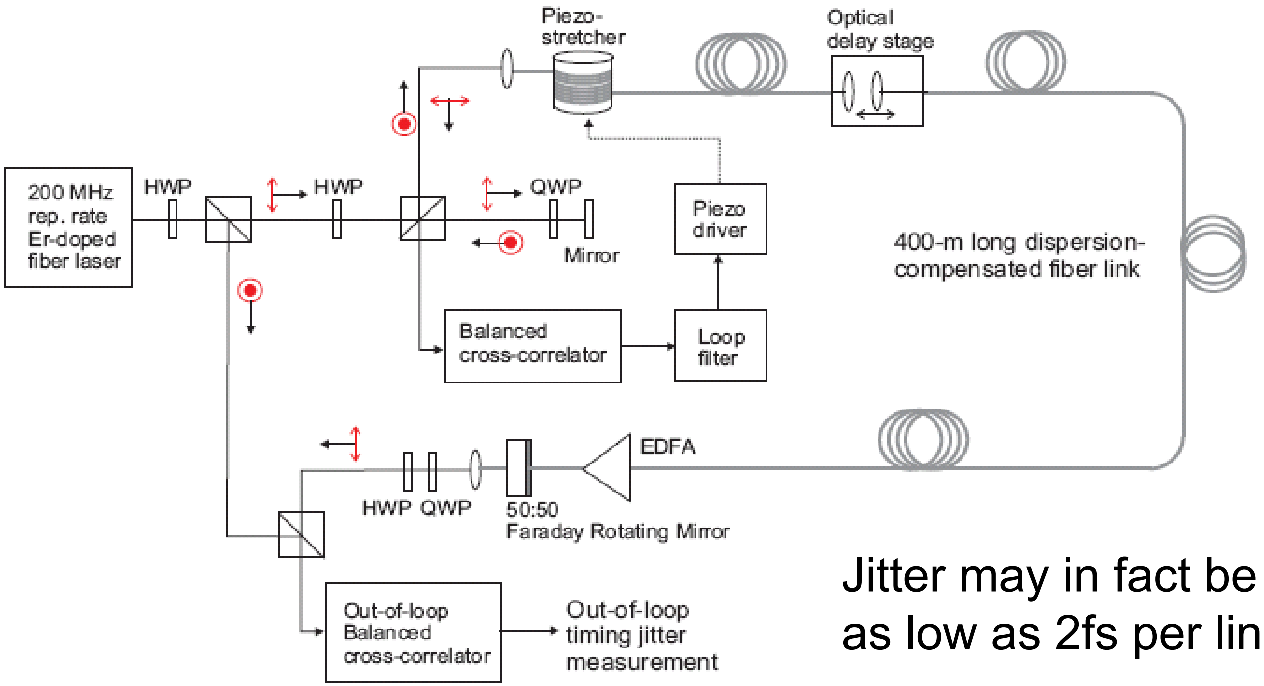
- Sensors as close as possible to point-of-use
- Actuators as close as possible to sources of noise
- Sensing and control of the parameters of interest
- Paths for fast, low-amplitude signals as short as possible
- Burden on feedback control system minimised
  (e.g. passive stability maximised, deterministic variations removed into separate feed-forward systems)

Clock Distribution



Clock Distribution

- Two femtosecond-jitter schemes have been demonstrated*, both distributing laser light (pulsed or cw) over optical fibres
- At this stage it will suffice if at least one of these meets the NLS specification. Consider the pulsed laser scheme:



Low noise clock, based on Er fibre laser locked to Rb/OCXO RF source below a few kHz

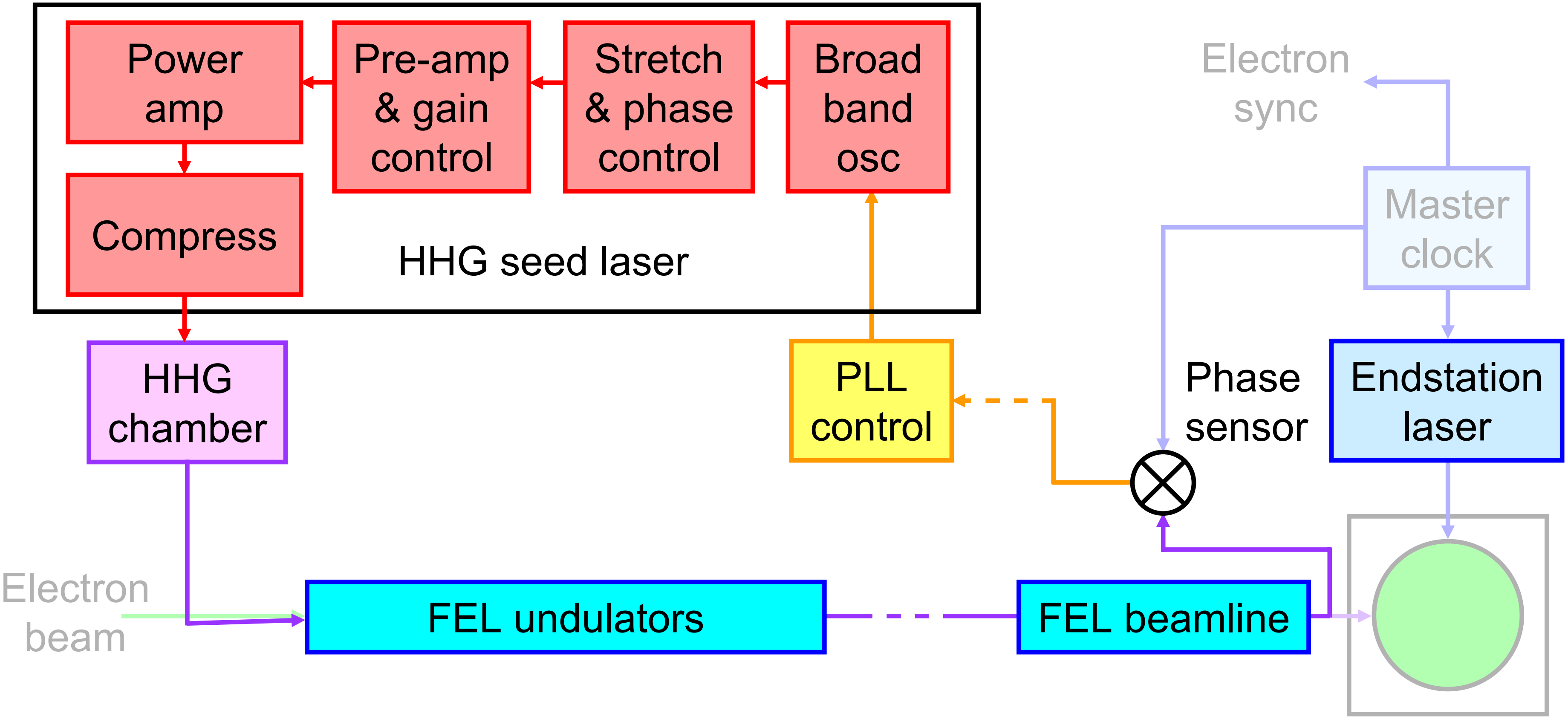
Distribution fibre length stabilised by optical cross-correlation of retro-reflected signal

Jitter may in fact be as low as 2fs per link

3 fs overall for 2 links

*F Loehl et al, *First prototype of an optical cross-correlation based fibre-link stabilization*, DIPAC ’07 (2007)
J W Staples et al, *Demonstration of femtosecond-phase stabilization in 2km optical fiber*, PAC ’07 (2007)

Laser Locking

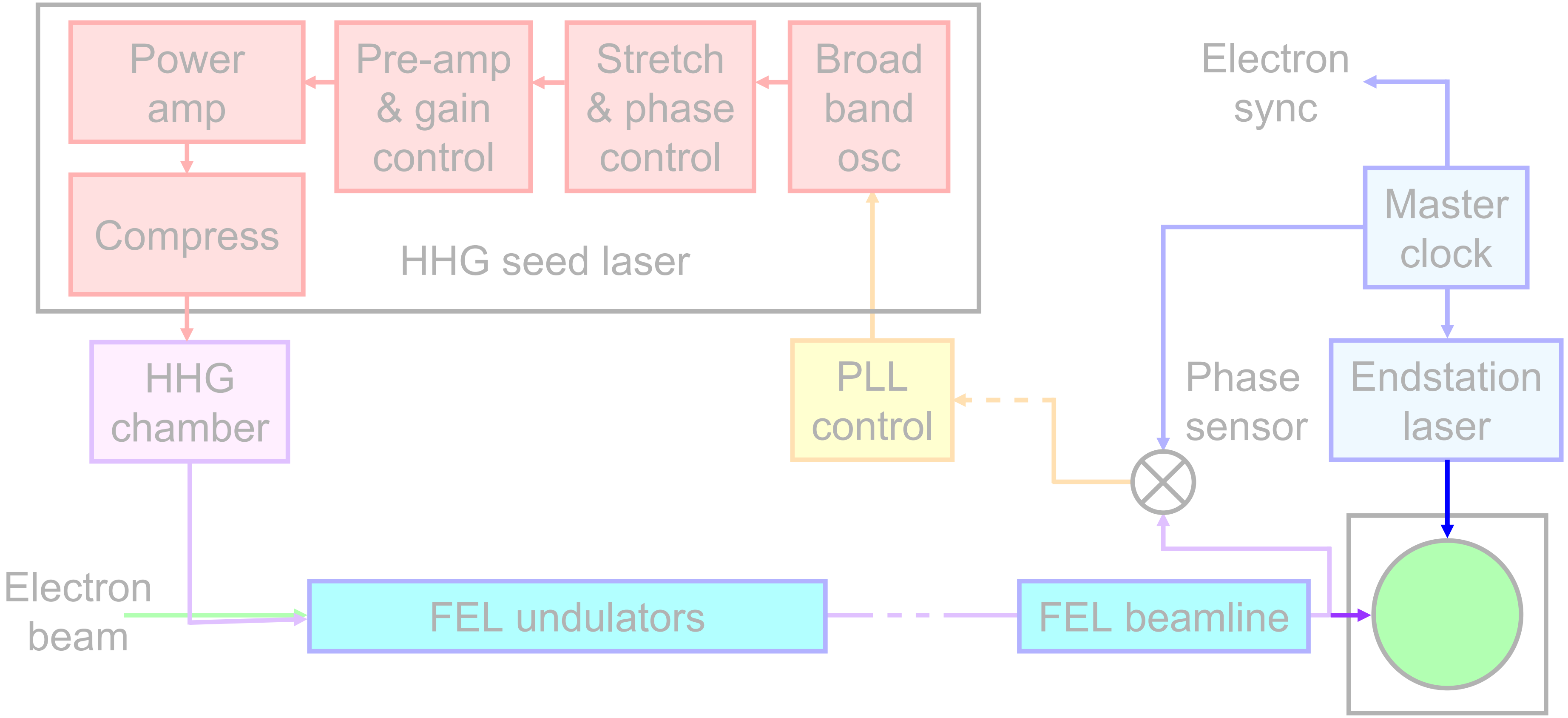


Laser Locking

- Ti:Sapphire laser oscillators have already been locked both to RF and to optical sources with ~1 fs jitter*
- Complications in the NLS laser chains include:
  - Wavelength tuning effects on the timing itself and on the sensor (should be deterministic)
  - Noise from long paths, large pump lasers, cooling plant ...
  - The Nyquist limit for noise sensing at low pulse rate
  - Reconciling timing control with CEP stabilisation
- Complications in the FEL amplification include:
  - Bunch timing stability through the cascade chicane(s)
  - **5 fs target for endstation laser, 7 fs for HHG seed**

*R K Shelton et al, *Subfemtosecond timing jitter between two independent, actively synchronized mode-locked lasers*, Opt Letts **27** 312 (2002), T R Schibli et al, *Attosecond active synchronization of passively mode-locked lasers by balanced cross correlation*, Opt Letts **28** 947 (2003)

Differential Transport



Differential Transport

- Direct feedback control is no longer possible, so stability must be passive (or maintained by a proxy probe)

- Beam path “ends” will vary from experiment to experiment,

  $\Rightarrow$ defined engineering standards

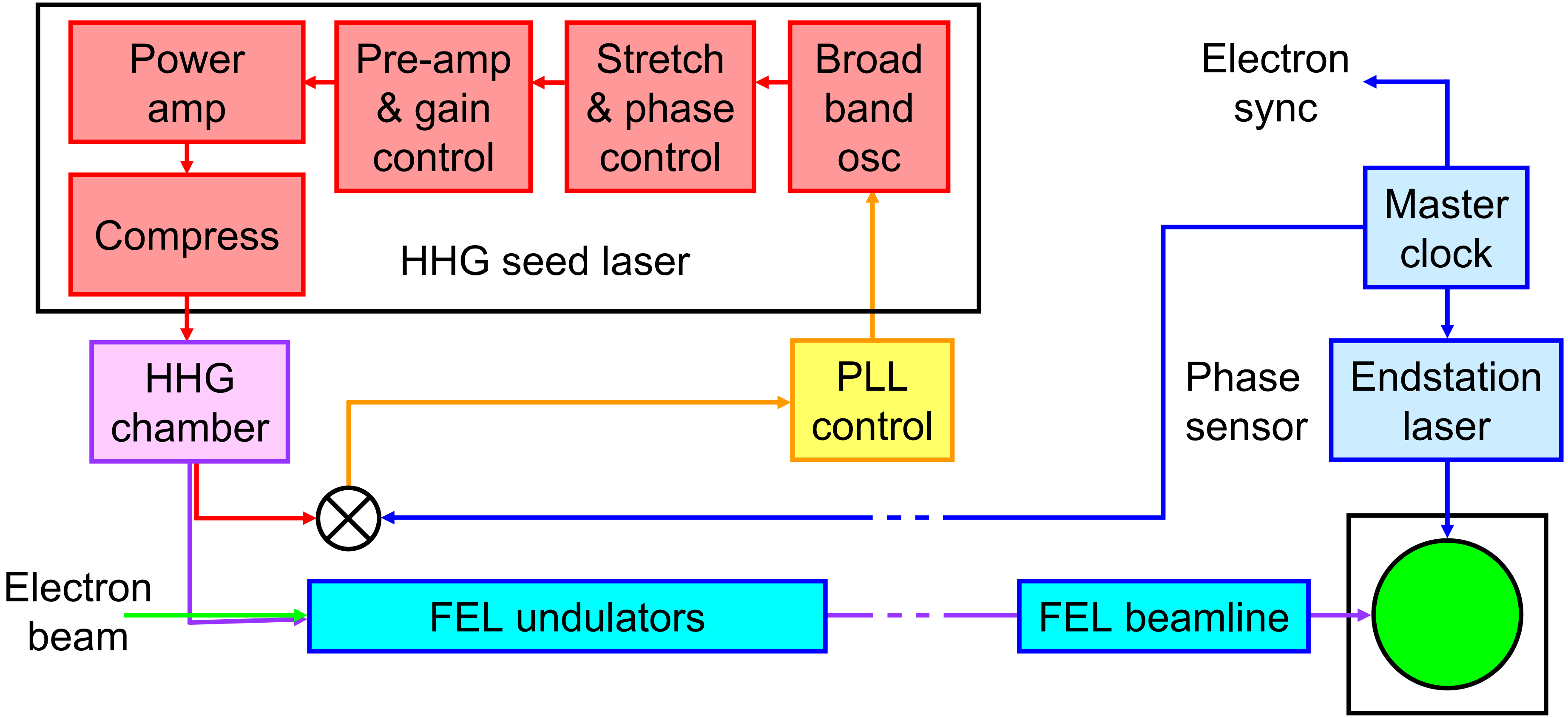
  off-line test facilities

  stability verification in advance

- Stable few-metre interferometers are not uncommon and this is beyond the NLS stability requirement

- But it is important to prevent final sensor “creep” back along the beam path

Synchronisation of Lasers and FELs



INITIAL SETUP

Proven technology, will be needed to establish seeded operation

Removes the need for a new sensor, but results in a long unstabilised path

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3 fs on each path (~1 optical wave)
4 fs for 2 links

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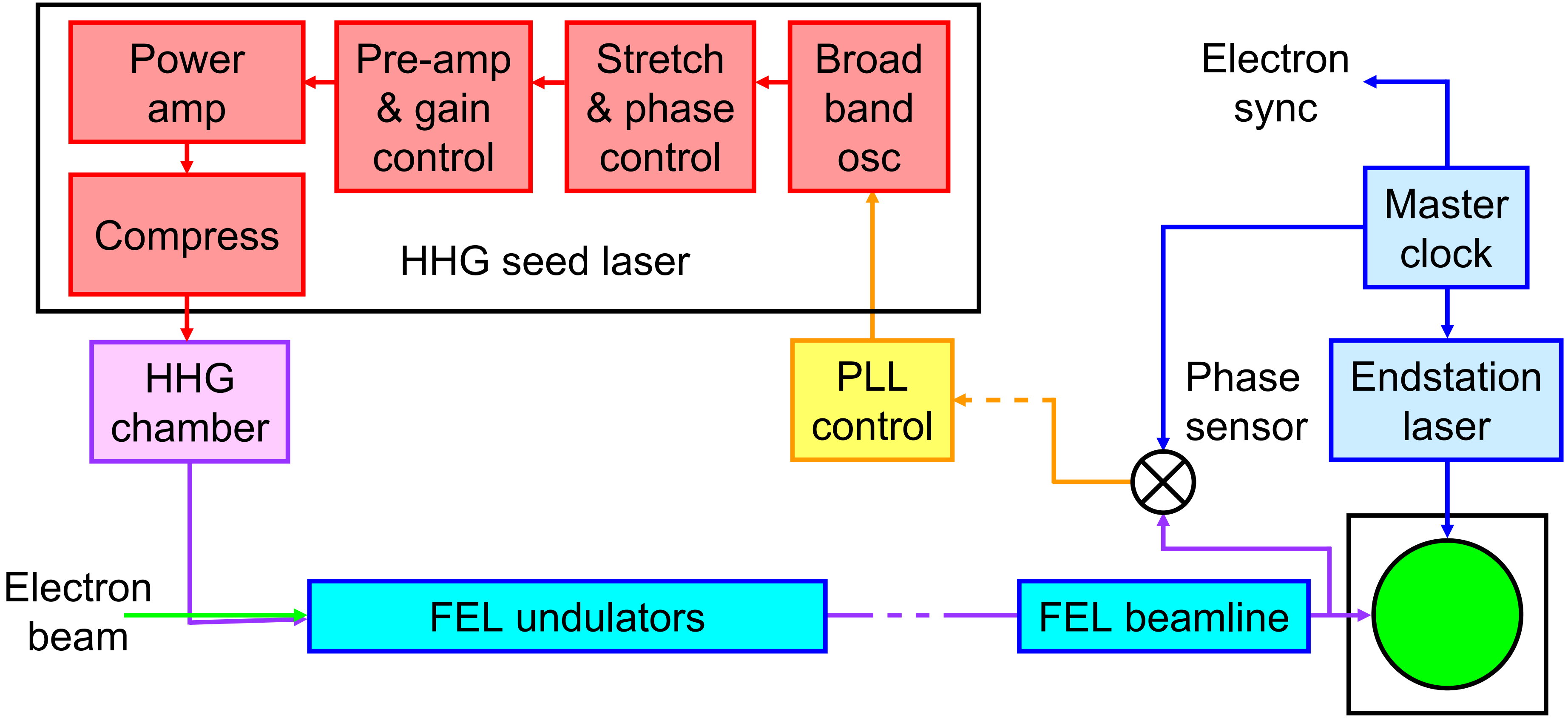

Clock distribution	3fs (demonstrated)
HHG seed laser locking	7fs (target)
Endstation laser locking	5fs (target)
Differential transport	4fs (target)

BUT

Needs high-resolution, single-shot soft X-ray phase sensor

QUADRATURE SUM ~10fs

Electron Beam Jitter Sources and Results

Reducing the two main contributors to the jitter by

- independently powering the RF cavities in each cryomodule
- reducing the power supply jitter in the bunch compressors to 10^{-5}

Gun Jitter Parameters (rms)

Solenoid Field	0.02e-3	T
Gun Phase	0.1	degrees
Gun Voltage	0.1%	
Charge	1%	
X Offset	0.025	mm

Main linac cavities

Phase (P)	0.01 degrees
Bunch Comp. (B)	1e-5 fractional
Voltage (V)	1-e4 fractional

RF gun (P and V)	7 fs	7 fs
Injector (RF gun + ACC01)	**21 fs**	**11 fs**
Main linac RF P	3 fs	3 fs
Main linac RF V	9 fs	9 fs
BCs power supplies	**20 fs**	**4 fs**
P + V + B combined	20 fs	10 fs
P + V + B + I combined	**30 fs**	**14 fs**

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P + V + B combined	20 fs	10 fs
P + V + B + I combined	**30 fs**	**14 fs**
Fibre links and RF recovery		7 fs
HHG seed laser (undulator)		5 fs
Clock + electrons + laser		**17 fs**

Summary

- NLS time structures are *science-driven*

  Implementation details need careful thought but are not expected to present serious challenges

- Photon pulse synchronisation at the experiment will be *key* to the success of NLS

  Many subsystems already meet specification, or are close

  Areas receiving attention include:

  - Arrival time sensing for tuneable XUV pulses
  - Laser pulse locking over extended paths with tuning
  - Beam-based feedback for electron bunch arrival time
  - Specifying and delivering stability at noise frequencies above the kilohertz Nyquist limit