Science & Technology Facilities Council

CLARA & VELA Progress

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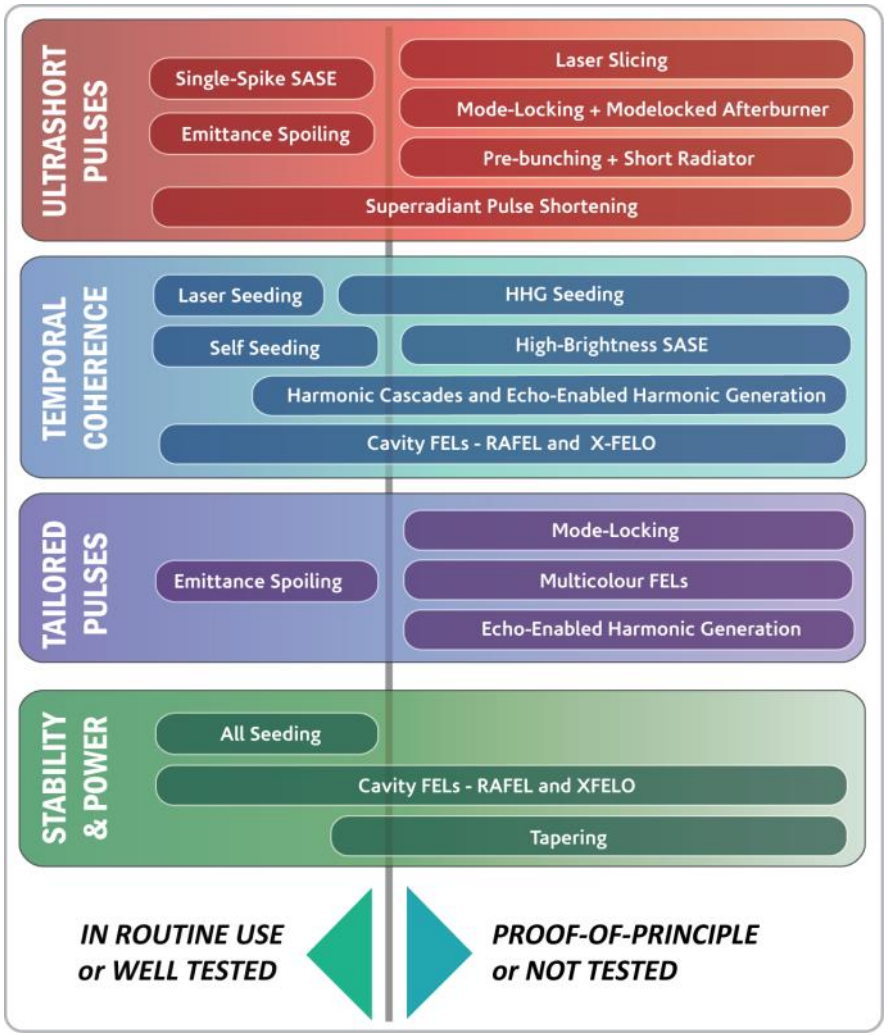
STFC Daresbury Laboratory and The Cockcroft Institute

on behalf of the CLARA & VELA Project Teams

Octoberfest at JAI, 3rd October 2014

The 'FEL Case' for an FEL Test Facility



- Free-Electron Lasers (FELs) are remarkable scientific tools
- Short-wavelength FELs are operating for users around the world, for example LCLS (USA), SACLA (Japan), FLASH (Germany) and FERMI@Elettra (Italy).
- There are still many ways their output could be improved:
  - ***Shorter Pulses***
  - ***Improved Temporal Coherence***
  - ***Tailored Pulse Structures***
  - ***Stability & Power***
- There are many ideas for achieving these aims, ***but many of these ideas are untested***
- ***Beamtime on FELs is over subscribed by users and so little time for R&D***

The CLARA Concept

CLARA

Compact Linear Accelerator for Research and Applications

An upgrade of the existing VELA Photoinjector Facility at Daresbury Laboratory to a 250MeV Free-Electron Laser Test Facility

Proof-of-principle demonstrations of novel FEL concepts

Emphasis is ***ULTRA-SHORT PULSE GENERATION***

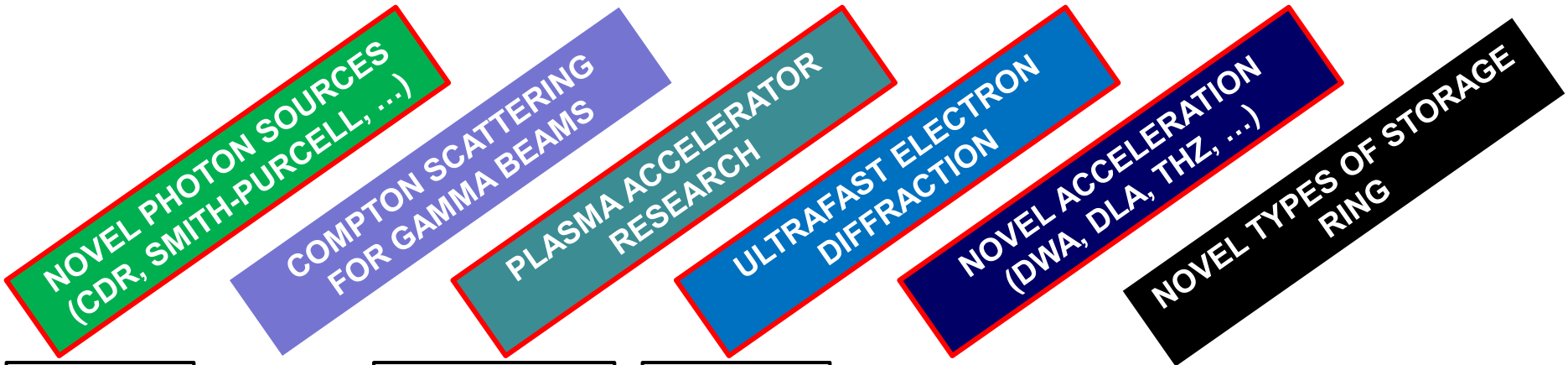
ASTeC
Strathclyde
INFN Frascati
SwissFEL
DLS
Oxford
Liverpool
Imperial

Other Goals and Benefits of CLARA

- The opportunity for R&D on advanced technologies:
  - New photoinjector technologies
  - Novel undulators (short period, cryogenic, superconducting….)
  - New accelerating structures: X-Band etc...
  - Advanced diagnostics

ASTeC
CERN
FERMI@Elettra
RHUL
INFN Frascati
SwissFEL
DLS
Lancaster
INR Moscow

- The enhancement of VELA beam power and repetition rate, enabling additional industrial applications.
- The possibility to ***use the electron beam*** for other scientific research applications:



ASTeC
RHUL
Oxford

ASTeC
Strathclyde
Manchester
INFN Frascati

ASTeC
York
Swansea
UCL

ASTeC
RHUL
Liverpool

Lancaster
Manchester
Oxford

Design Philosophy and Parameters

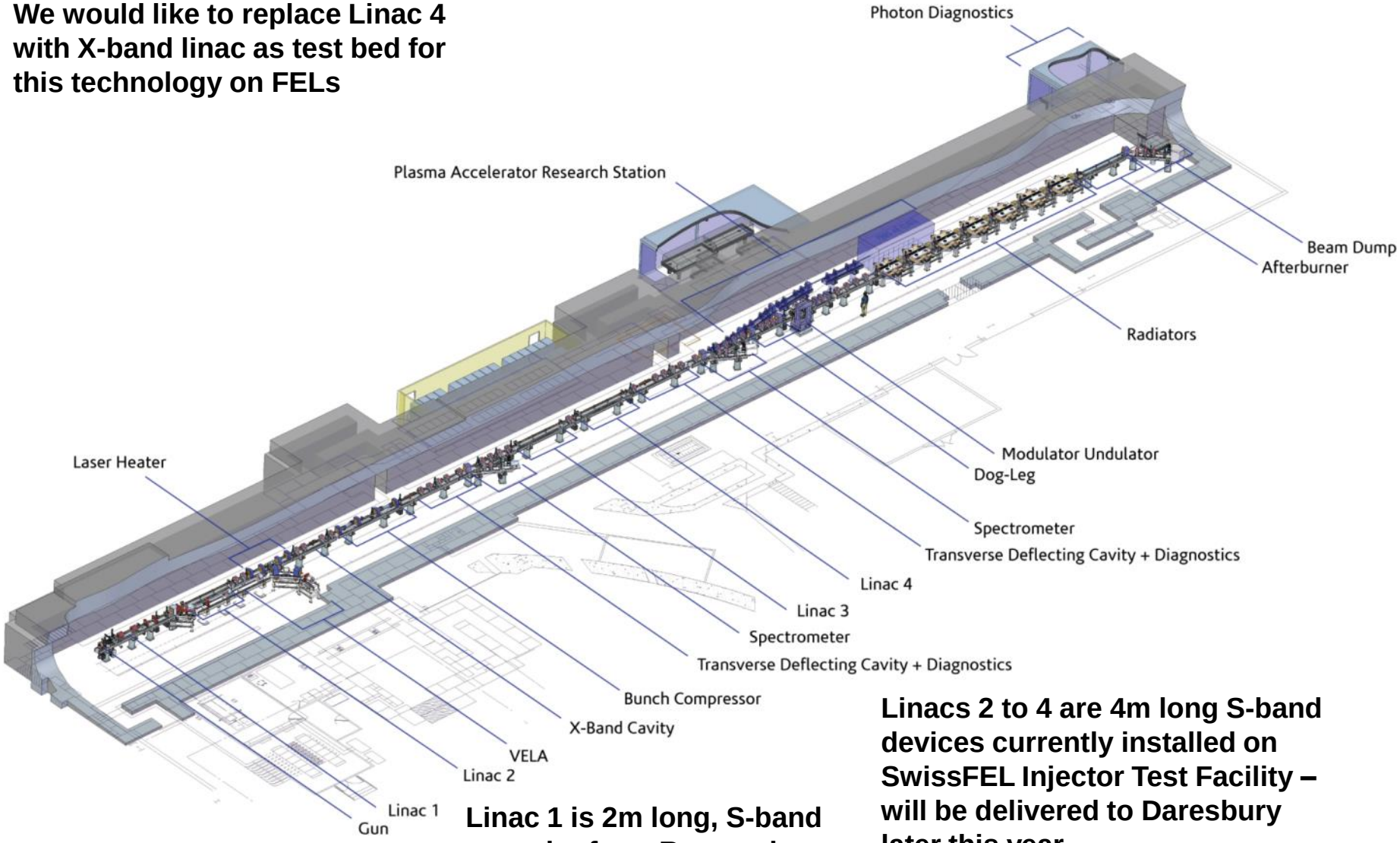
- CLARA will be a flexible test facility allowing the broad range of accelerator and FEL R&D necessary to ensure a future UK FEL facility is world leading.
- Many of the FEL research topics are in two main areas which are intended to demonstrate improvement of FEL output beyond that available from SASE
  - ***The generation of ultra-short pulses***
    - Our emphasis for the short pulse schemes ***is to generate pulses with as few optical cycles as possible*** with durations of the order of, or shorter than, the FEL cooperation length.
    - ***For these schemes we will lase at 400–250 nm***, where suitable nonlinear materials for single shot pulse profile characterisation are available.
    - A suitable wavelength range for seed sources to manipulate the electron beam longitudinal phase space is 30 – 120 μm
  - ***Improvement of temporal coherence.***
    - ***For these schemes we will lase at 266-100nm*** because here only spectral characterisation is required.
    - A suitable seed source for harmonic upconversion, if required, is an 800nm Ti:S.
- In all cases, we aim to study the essential physics of the schemes which can often ***be independent of the FEL wavelength.***
- Using a hybrid planar undulator, with minimum gap 6mm, and gap tuning range of 400–100 nm, the required electron beam energy is ~230 MeV.

CLARA Layout

The existing VELA RF Photoinjector Facility

CLARA Layout

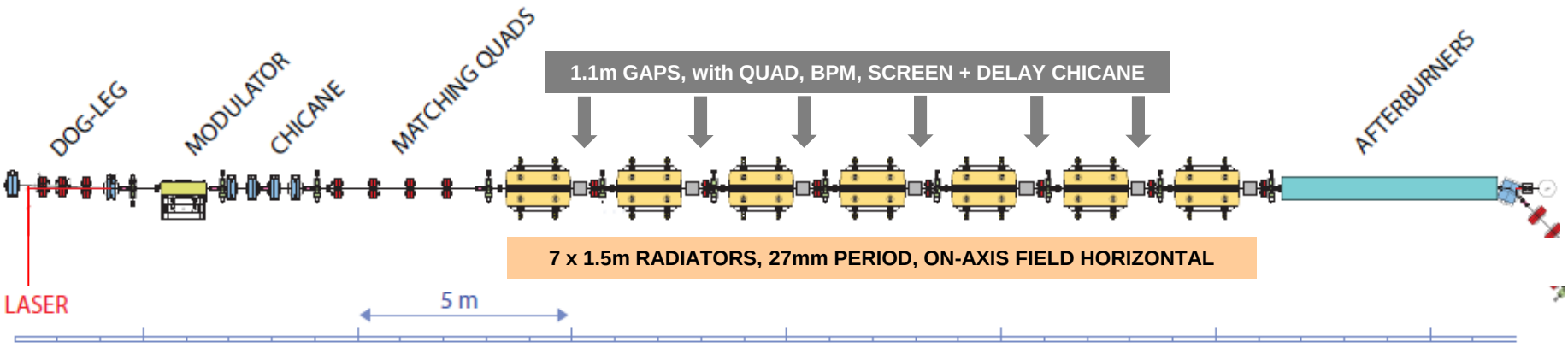
We would like to replace Linac 4 with X-band linac as test bed for this technology on FELs



Linac 1 is 2m long, S-band on order from Research Instruments

Linacs 2 to 4 are 4m long S-band devices currently installed on SwissFEL Injector Test Facility – will be delivered to Daresbury later this year

FEL Layout + Operating Modes



	Operating Modes			
Parameter	**Seeding**	**SASE**	**Ultra-short**	**Multibunch**
Max Energy (MeV)	250	250	250	250
Macropulse Rep Rate (Hz)	1–100	1–100	1–100	1–100
Bunches/macropulse	1	1	1	16
Bunch Charge (pC)	250	250	20–100	25
Peak Current (A)	125–400	400	~1000	25
Bunch length (fs)	850–250 (flat-top)	250 (rms)	<25 (rms)	300 (rms)
Norm. Emittance (mm-mrad)	≤ 1	≤ 1	≤ 1	≤ 1
rms Energy Spread (keV)	25	100	150	100
Radiator Period (mm)	27	27	27	27

Table 3.1: Main parameters for CLARA operating modes.

Seeding Mode is for

Short Pulse Schemes
FEL lasing: 400-250nm
(Seed: 30-120μm)
+
Temporal Coherence Schemes
FEL lasing: 266-100nm
(Seed: 800nm)

CLARA Short Pulse Schemes:

Predicted Pulse Durations

			FWHM Pulse Duration			
Scheme	**Pulse Type**	**Wavelength (nm)**	fs	μm	#cycles	$\#I_c$
Slice/Taper	Single	266	50	15	56	2.2
EEHG	Single	100	25	8	75	2.6
Single-Spike SASE	Single	100	23	7	70	2.3
Mode-Locking Phase I	Train	266	43	13	49	1.9
	Train	100	18	5.3	50	1.8
Mode-Locking Phase II	Train	266	17	5.1	20	0.7
	Single	100	14	4.1	41	1.4
Mode-Locked Afterburner	Train	100	1.6	0.5	5	0.16

Table 3.2: Predicted pulse durations for CLARA Short Pulse Schemes.

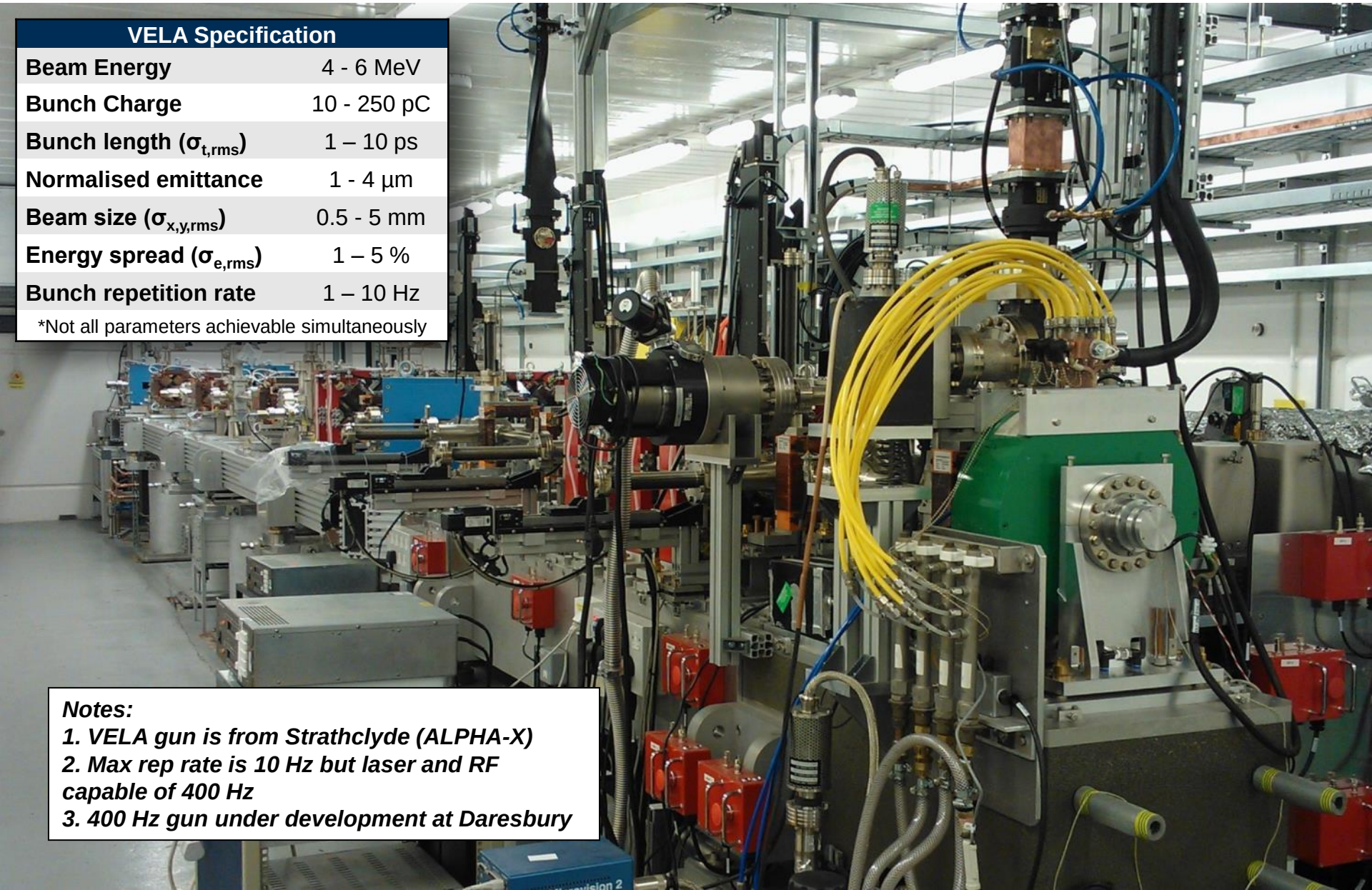
Typical SASE output is ~100,000 cycles

CLARA Status

JINST 9 (2014) T05001

- The CDR was published in July 2013
- SwissFEL are providing required 3 linacs, together with a number of quadrupoles and solenoids (available Q4 2014)
- The project has now been split into ***Two Phases***
- ***PHASE 1 – Front End, 50 MeV***
  - This is happening now, with procurement progressing, and installation in 2015.
  - Will enable access to bright, short, up to ~50 MeV electron bunches for UK accelerator science and technology community
  - Will enable new high rep rate photoinjector to be characterised with beam whilst VELA/CLARA ***Phase 1*** still operational (i.e. two guns)
  - Potential for early exploitation of 20 TW laser
- ***PHASE 2a – 150 MeV, up to bunch compression section***
  - ***Funded, procurement starting this year***
- ***PHASE 2b – 250 MeV FEL Test Facility***
  - ***Not Yet Funded –*** Part of Ongoing UK Capital Consultation Exercise – CLARA is a priority for STFC

VELA



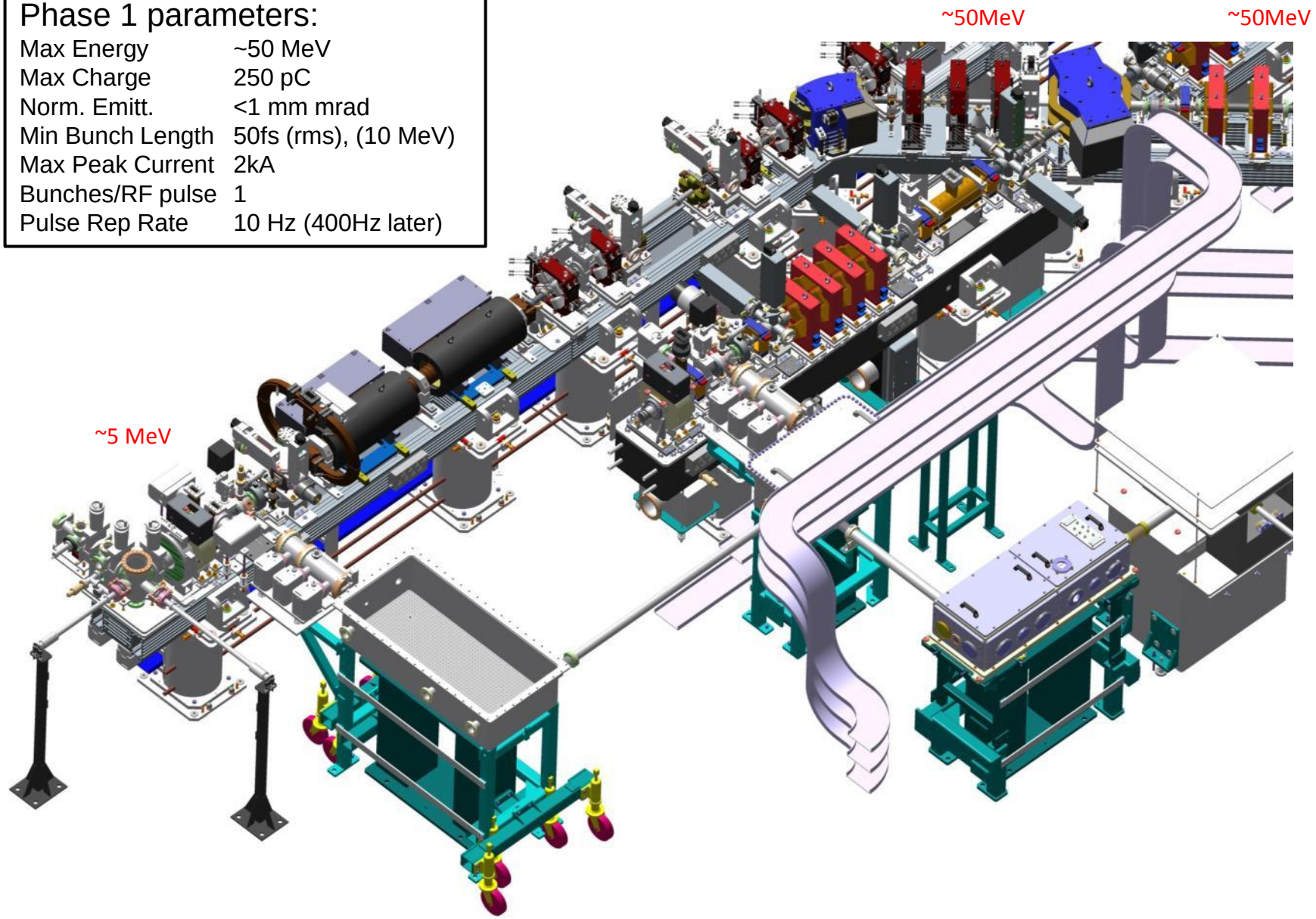
VELA Specification	
Beam Energy	4 - 6 MeV
Bunch Charge	10 - 250 pC
Bunch length ($\sigma_{t,rms}$)	1 – 10 ps
Normalised emittance	1 - 4 µm
Beam size ($\sigma_{x,y,rms}$)	0.5 - 5 mm
Energy spread ($\sigma_{e,rms}$)	1 – 5 %
Bunch repetition rate	1 – 10 Hz

*Not all parameters achievable simultaneously

Notes:
1. VELA gun is from Strathclyde (ALPHA-X)
2. Max rep rate is 10 Hz but laser and RF capable of 400 Hz
3. 400 Hz gun under development at Daresbury

VELA + CLARA Phase 1 (2015)

Phase 1 parameters:	
Max Energy	~50 MeV
Max Charge	250 pC
Norm. Emitt.	<1 mm mrad
Min Bunch Length	50fs (rms), (10 MeV)
Max Peak Current	2kA
Bunches/RF pulse	1
Pulse Rep Rate	10 Hz (400Hz later)



Ultrafast Electron Diffraction

Studying structural evolution in fs regime
Synergy with XFEL Structural Science

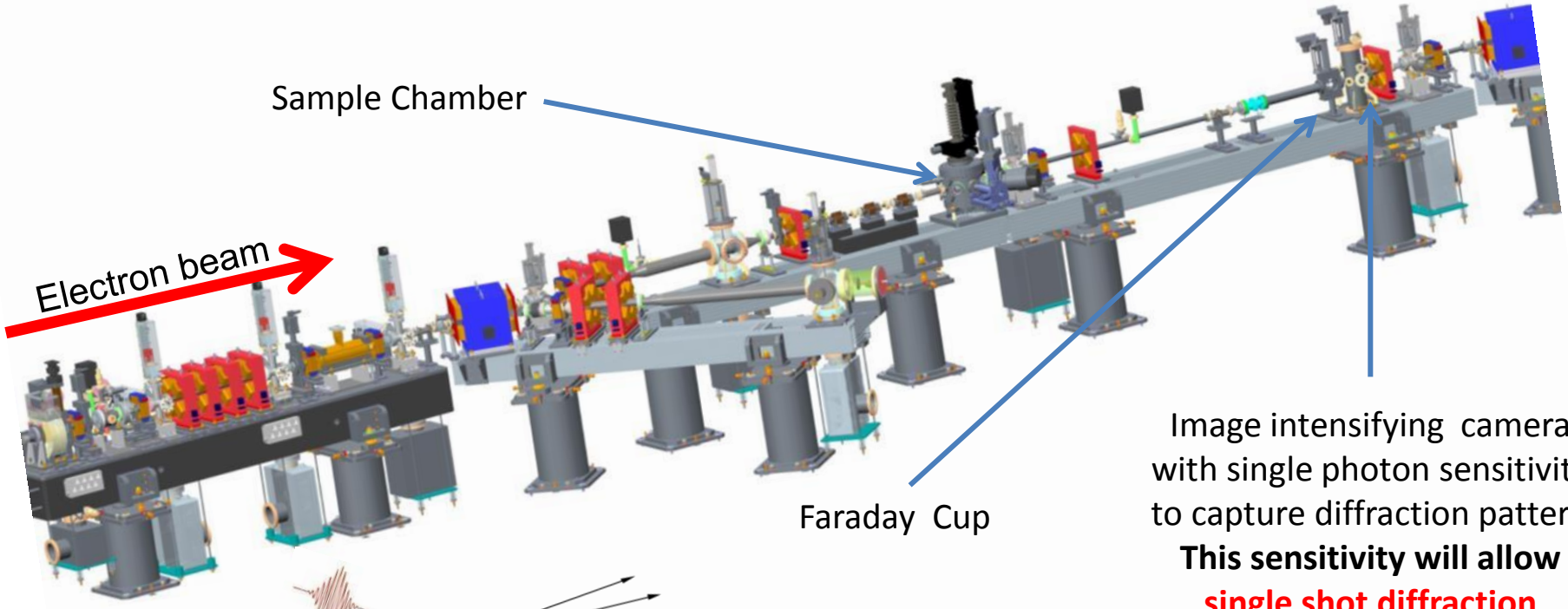
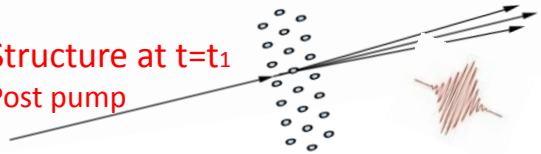


Image intensifying camera with single photon sensitivity to capture diffraction pattern
This sensitivity will allow single shot diffraction pattern to be recorded with a 1 pC ultrashort bunch

Structure at t=0
Pre-pump

Monitor change to single shot diffraction pattern



Structure at t=t_1
Post pump

Ultrafast Electron Diffraction

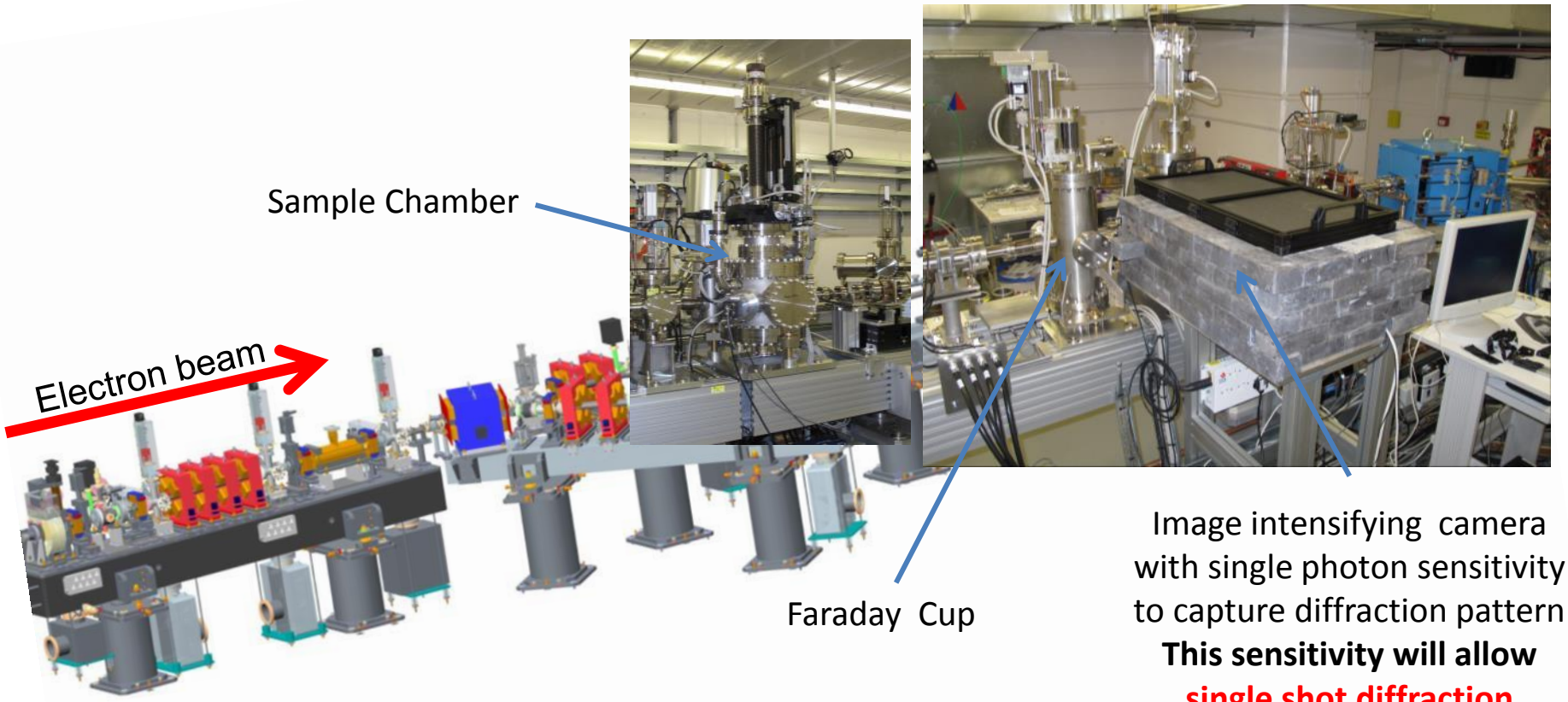


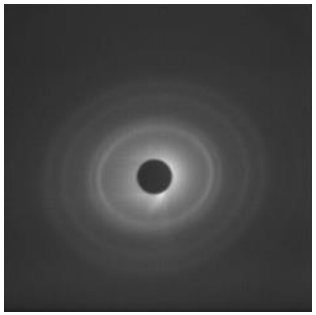
Image intensifying camera with single photon sensitivity to capture diffraction pattern

This sensitivity will allow single shot diffraction pattern to be recorded with a 1 pC ultrashort bunch

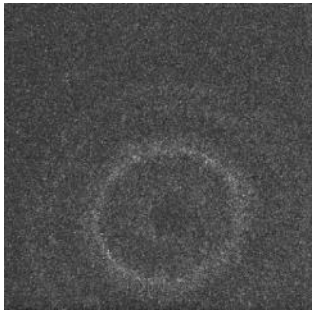
Faraday Cup chamber and Lanex screen detection chamber. Screen located 3.4 m downstream of sample

First Results: September 2014

Charge at detector <<1 pC



Al sample
1000 shots



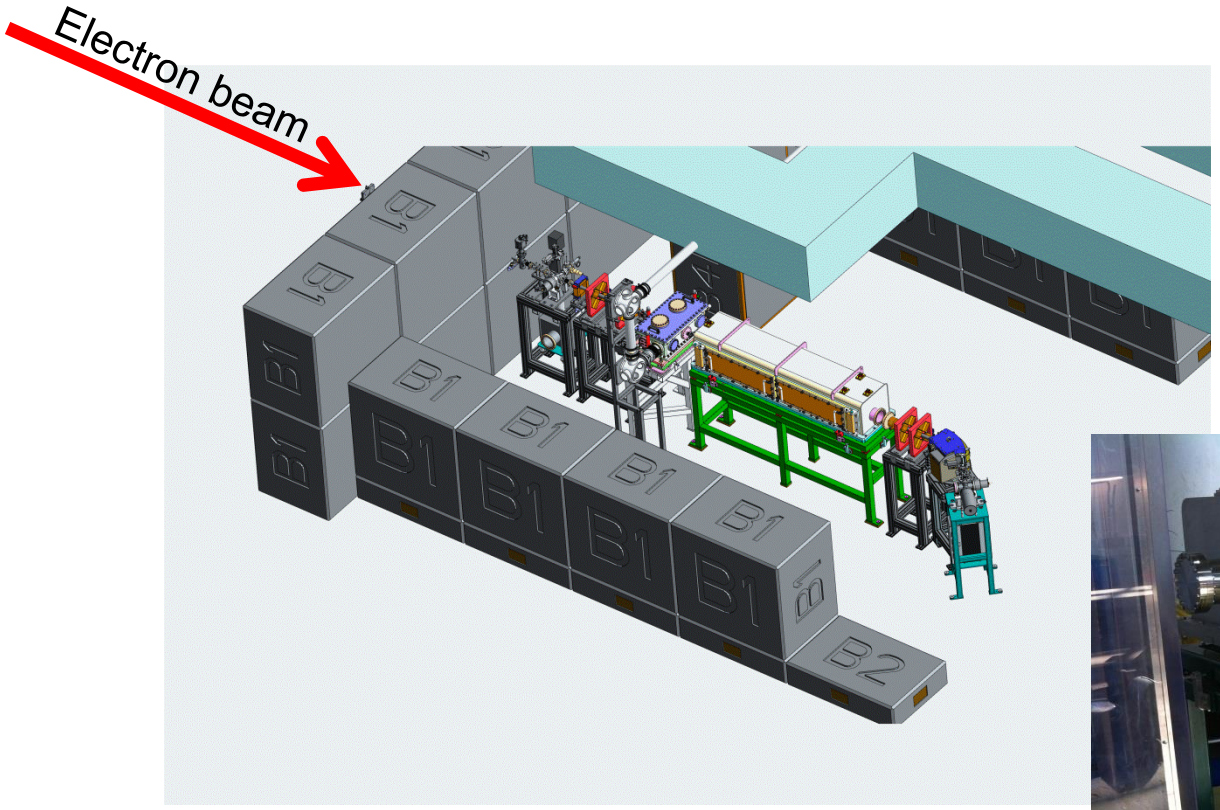
Pt sample
Single shot

Reconfiguring VELA in future will allow <100 fs time resolution.

Already have sufficient information in single shot to follow sample melting (order – disorder transition)

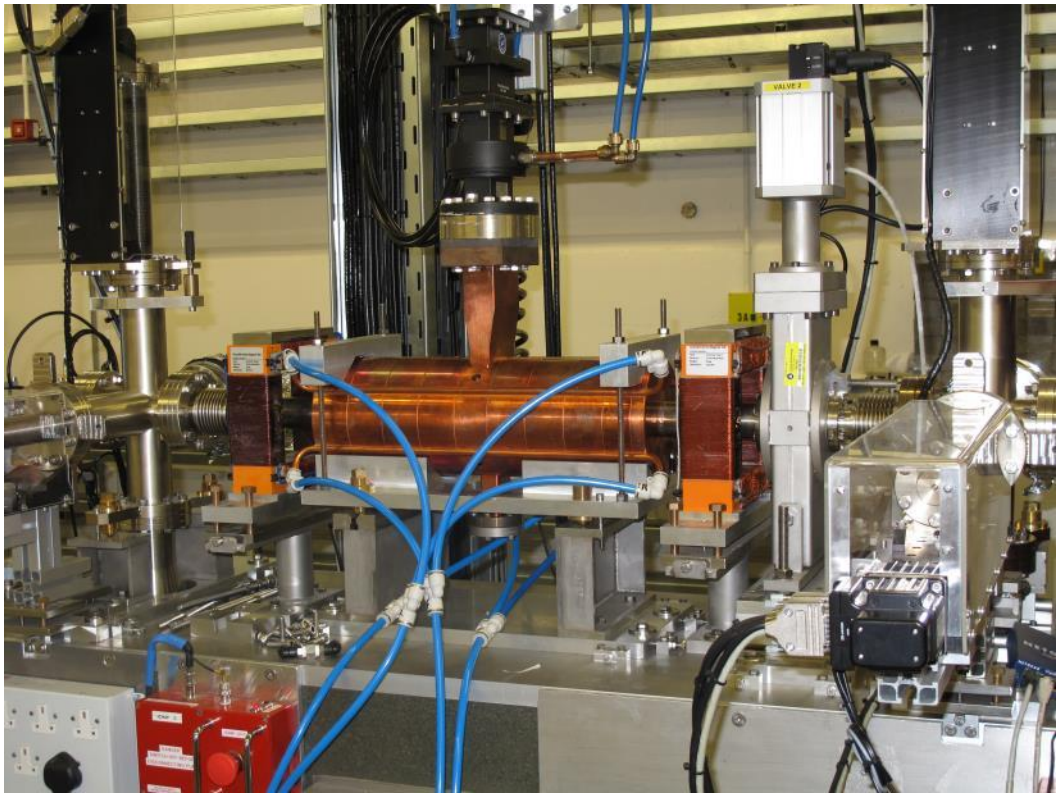
Multi User Station

- Flexible end station being installed at the end of 2014 to allow rapid reconfiguration of experiments on optical breadboard inside large vacuum vessel
- Combining electron beam with lasers will also be new capability

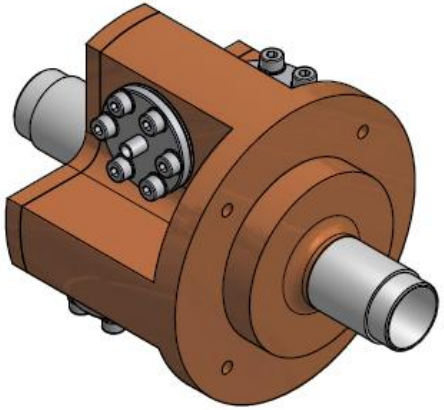


TDC

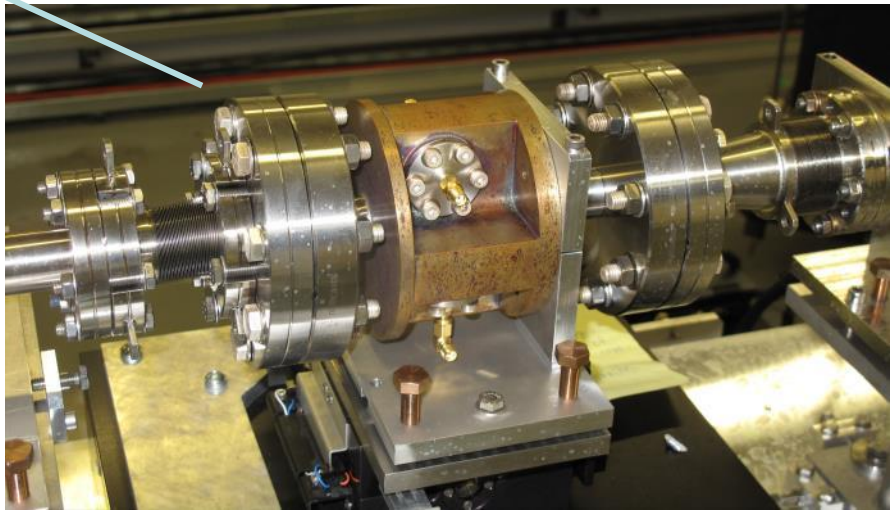
- Transverse Deflecting Cavity now installed and ready to be conditioned with RF – scheduled for 1st Nov 14
- Will allow much more detailed diagnosis of bunches (slice properties, bunch length with fs resolution)



Cavity BPMs



Industrialisation of technology – supported by STFC IPS Grant



Installed and ready for first tests – scheduled for 27th Oct 14

3 CBPM setup + Reference Cavity to be installed next year

Summary

- **CLARA** is an FEL Test Facility for the UK Accelerator Community
  - NC RF (up to 400 Hz)
  - Emphasis on ultra short pulse generation
  - Enabling other electron beam applications
  - Major upgrade to VELA
- **VELA** is an RF Photoinjector with two user areas
  - Generating ~4.5 MeV bunches for use by industry and academia
  - First industrial users already
  - Electron diffraction station taking data now
  - Transverse Deflecting Cavity commissioning November
  - Cavity BPM tests October
  - Multi-User Station installed December
- **CLARA** Phase 1 (Front End) is due for installation in 2015
  - Will enable even more accelerator/light source R&D
  - Phase 2 not yet fully funded
- Many active collaborations already on **CLARA** & **VELA** with leading UK and European accelerator and FEL teams – room for more!