Science & Technology Facilities Council

First Lasing of the ALICE IR-FEL at Daresbury Laboratory

David Dunning

Neil Thompson, Jim Clarke, Mark Surman, Andy Smith, Yuri Saveliev

On behalf of the ALICE team

22nd August 2011

ASTeC

Alice
Accelerators and Lasers In Combined Experiments

The Cockcroft Institute of Accelerator Science and Technology

FEL 2011 SHANGHAI

33rd International Free Electron Laser Conference

22-26 AUGUST 2011 SHANGHAI, CHINA

Introduction/History

- The ALICE IR-FEL is a UK project based at STFC's Daresbury Laboratory.
- Daresbury Laboratory operated a 2nd generation synchrotron light source (SRS) from 1981-2008.
- Proposals were made for a new ERL-based FEL facility at Daresbury (4GLS).
- As part of the proposal, funding was provided to construct a prototype ERL machine (ERLP → now ALICE).
- A FEL was included to test energy recovery with a disrupted beam.
- Decided on IR oscillator FEL – suitable parameters and established technique.
- First lasing in October 2010 makes this the first FEL to successfully operate in the UK.

Daresbury Laboratory

FEL '09 Conference visit to the ALICE facility

ALICE facility

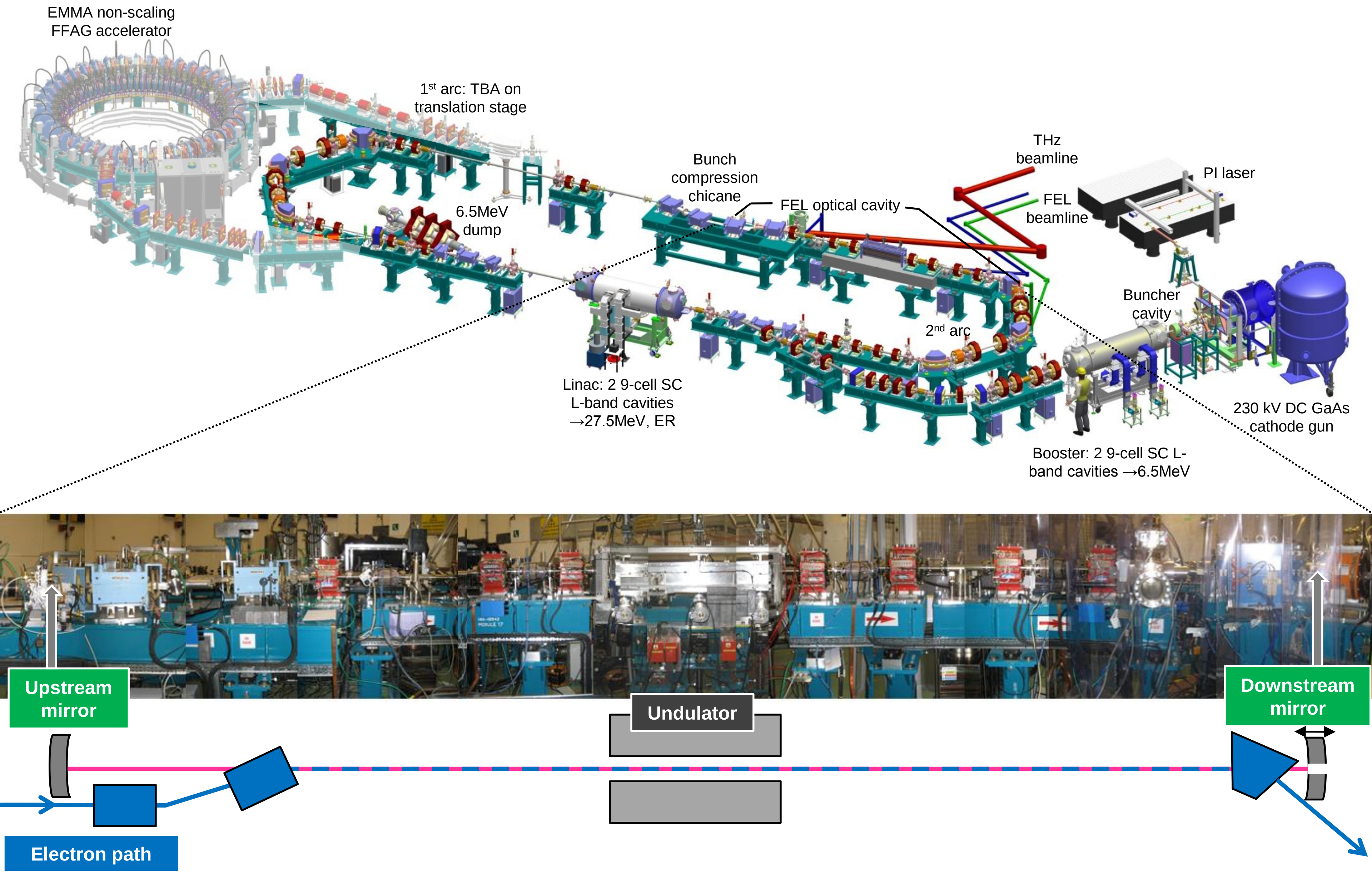
Motivation

The motivation for the project has evolved over time:

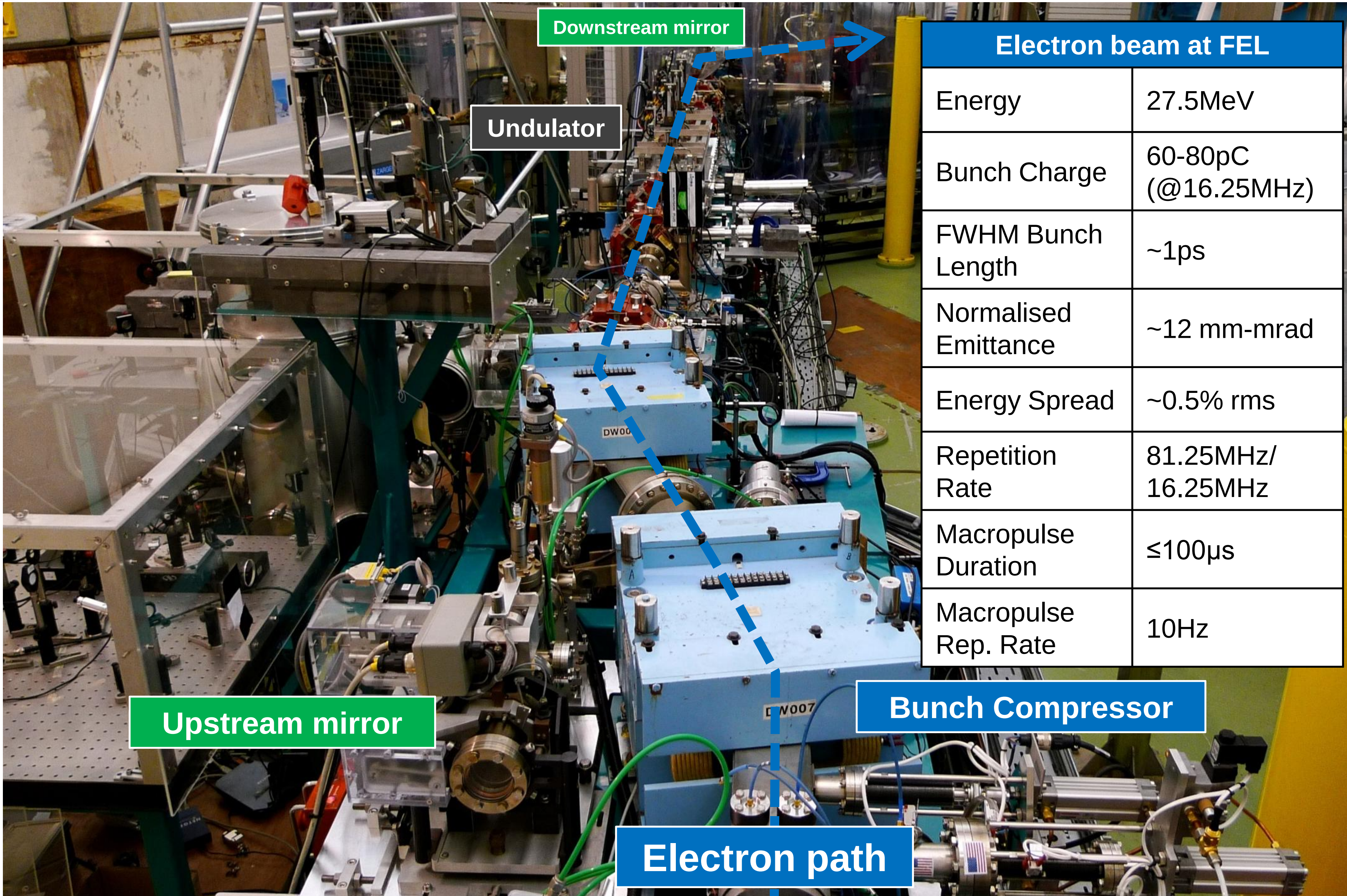
- New UK FEL projects have been proposed which use single pass linacs rather than ERLs.
- The ALICE FEL project now serves to develop the modelling and experimental skills necessary for these future projects.
- ERLP re-named ALICE (Accelerators and Lasers in Combined Experiments) to reflect its purpose as a test-bed for accelerator technologies and experiments:
  - FEL
  - Compton back-scattering
  - THz user experiments
  - Electro-optic diagnostic
  - EMMA non-scaling FFAG

- **A step towards developing a leading FEL facility in the UK.**

ALICE accelerator and FEL layout



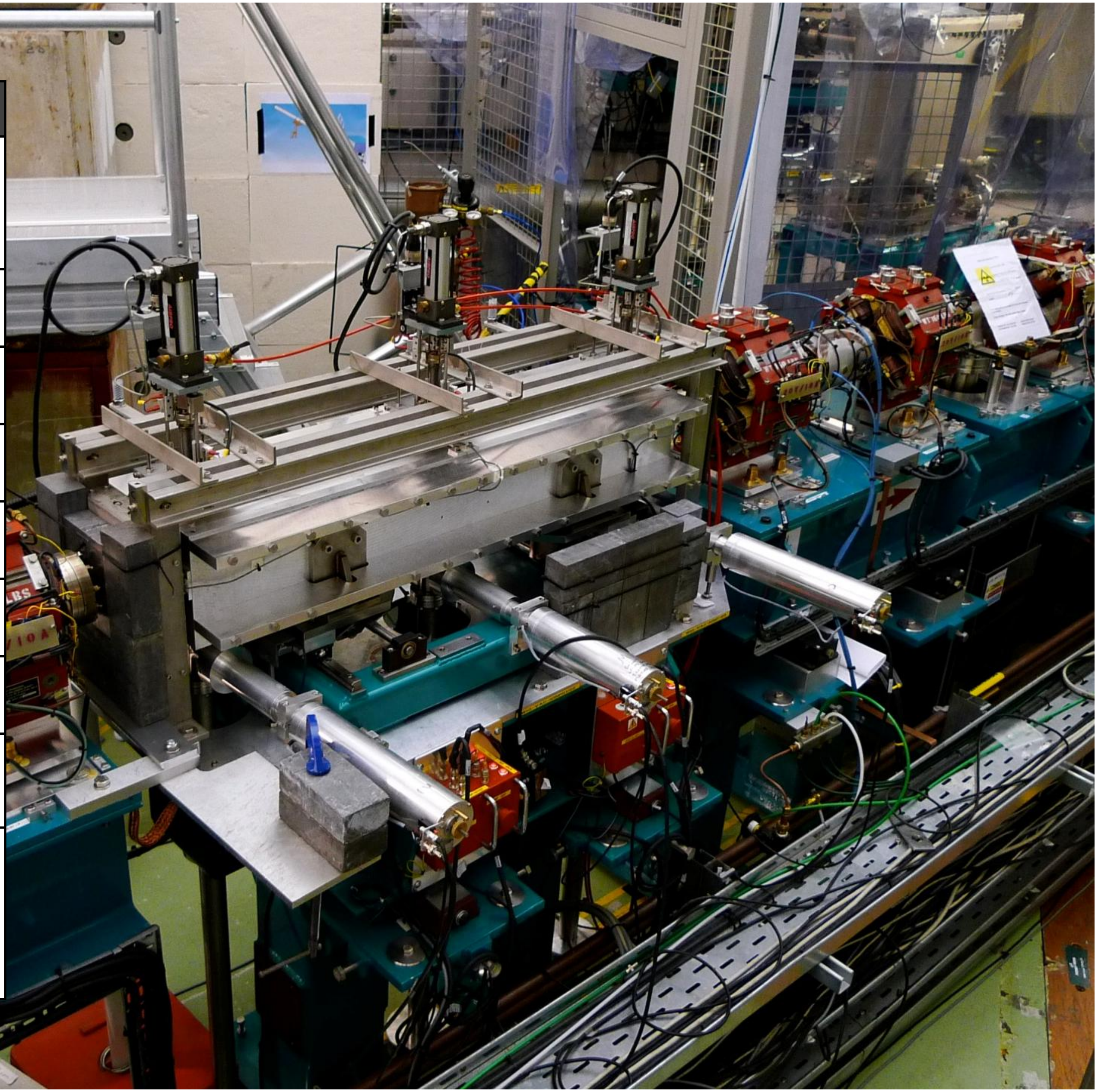
Electron Beam



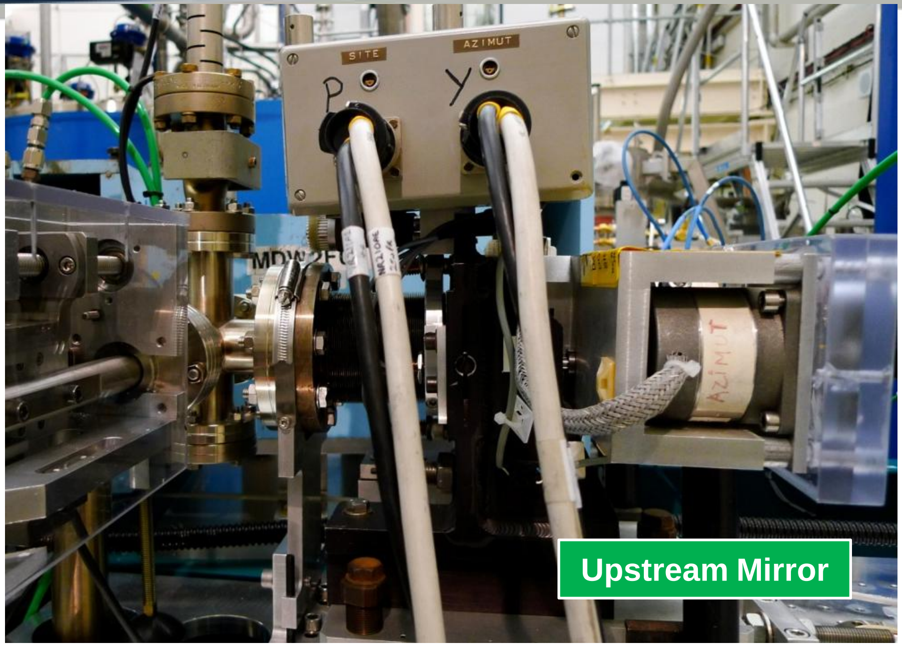
Electron beam at FEL	
Energy	27.5MeV
Bunch Charge	60-80pC (@16.25MHz)
FWHM Bunch Length	~1ps
Normalised Emittance	~12 mm-mrad
Energy Spread	~0.5% rms
Repetition Rate	81.25MHz/ 16.25MHz
Macropulse Duration	≤100μs
Macropulse Rep. Rate	10Hz

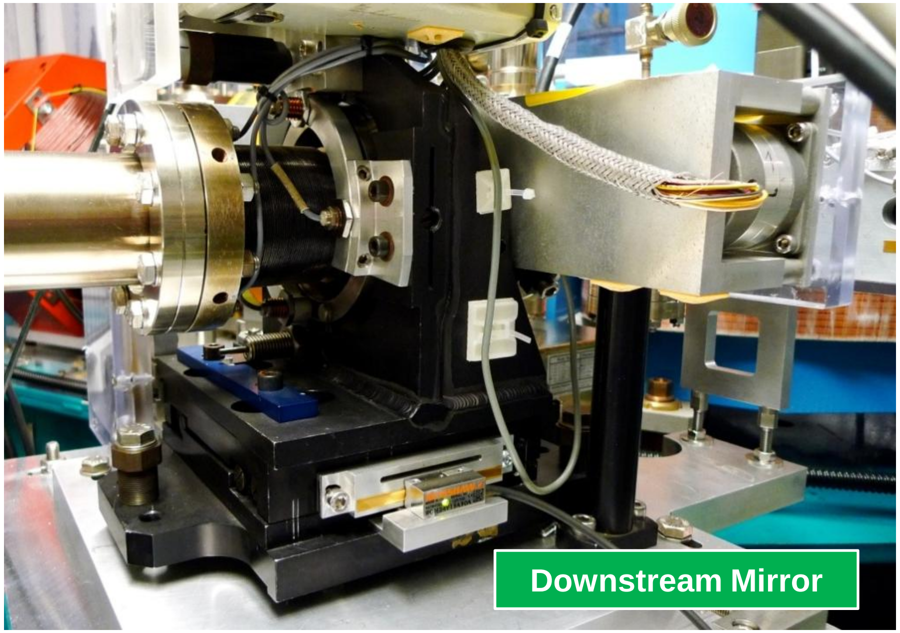
Undulator

Undulator	
On loan from JLAB where previously used on IR-DEMO FEL	
Now converted to variable gap	
PARAMETERS	
Type	Hybrid planar
Period	27mm
No of Periods	40
Minimum gap	12mm
Maximum K (rms)	0.9
Resonant wavelength at minimum gap and 27.5 MeV	8μm



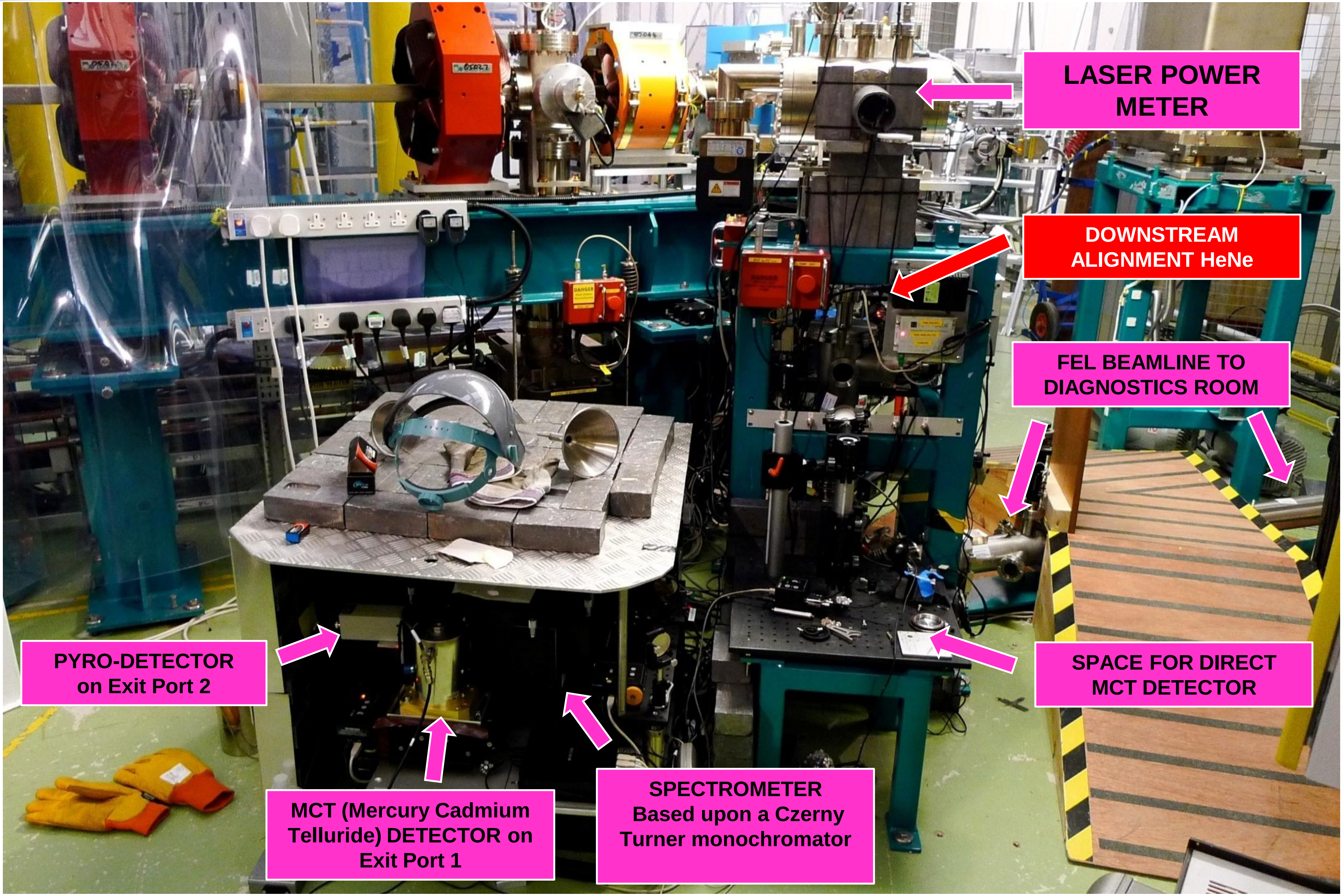
Optical Cavity





Optical Cavity	
Mirror cavities on loan from CLIO.	
PARAMETERS	
Type	Near Concentric
Resonator Length	9.2234m
Mirror ROC	4.85m
Mirror Diameter	38mm
Mirror Type	Cu/Au
Outcoupling	Hole
Rayleigh Length	1.05m
Upstream Mirror Motion	Pitch, Yaw
Downstream Mirror Motion	Pitch, Yaw, Trans.

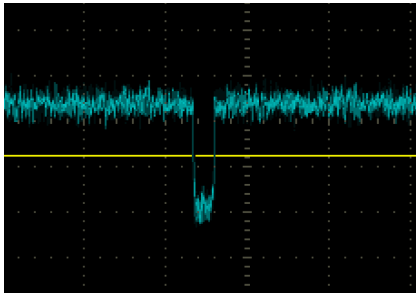
Diagnostics for IR radiation



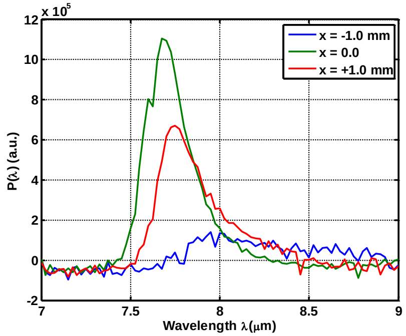
Commissioning Timeline

- November 2009 - Undulator installation.
- January 2010 - Cavity mirrors installed and aligned, all hardware in place.
  - Initially we were limited to 40pC bunch charge due to beam loading in the booster.
  - Throughout 2010 the FEL programme proceeded in parallel with installation of EMMA leaving one shift per day for commissioning. ~15% of ALICE beam time was dedicated to the FEL programme (approximately 5-6 weeks integrated time).
- February 2010 - First observation of undulator spontaneous emission. Radiation was stored in the cavity immediately, indicating the transverse pre-alignment was reasonable.
- May/June 2010 - Spectrometer installed and tested. Analysis of spontaneous emission used to optimise electron beam steering and focussing.
- June 2010 - Strong coherent emission with dependence on cavity length but no lasing.

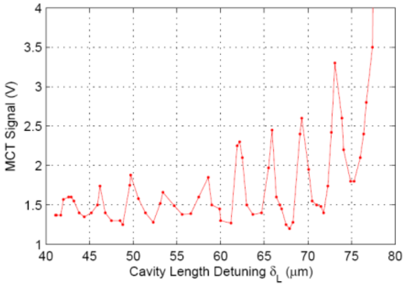
Undulator installation



First spontaneous signal detected with MCT



Spontaneous spectra used to set steering

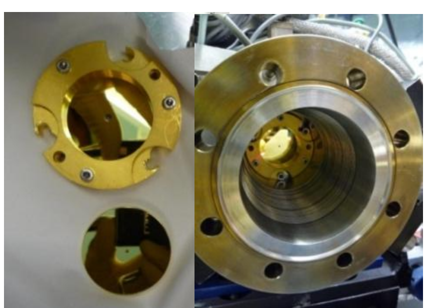


Beginning to see cavity effects

Modifications and Further Commissioning

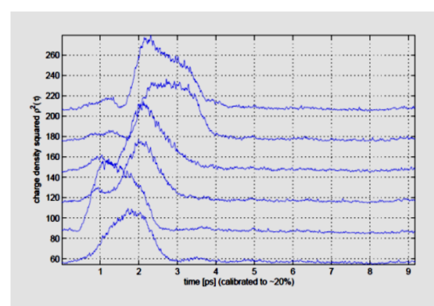
A number of modifications and measurements were made to improve prospects for establishing lasing:

- July 2010 - Changed outcoupling mirror from 1.5mm radius hole to 0.75mm to reduce losses.
- Installed an encoder to get a reliable relative cavity length measurement.
- Optical cavity mirror radius of curvature were tested - matched specification.
- EO measurements indicated correct bunch compression.
- Re-gained cavity enhancement with new mirror but lasing was not established over several attempts.
- 17th October: installed a Burst Generator to reduce the photo-injector laser repetition rate by a factor of 5, from 81.25MHz to 16.25MHz. This enabled us to avoid beam loading and increase the bunch charge from 40pC up to 100pC $\rightarrow$ resulted in lasing within a few shifts.



Changed mirror for smaller hole radius

Encoder for relative cavity length measurement



EO measurements

Burst mode Pockels cell mounted on optical table

23rd October 2010: ALICE FEL First Lasing

Output and Performance

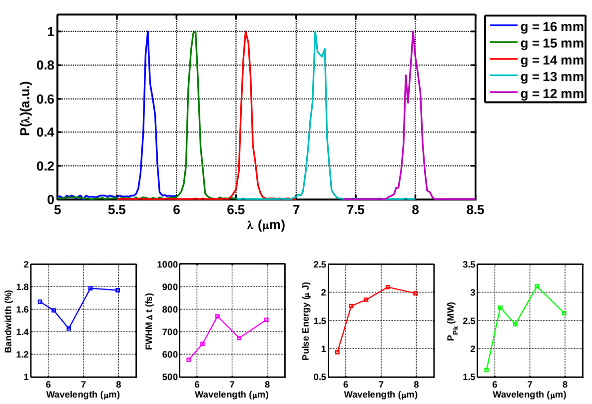
- The highest recorded average power on the power meter is 32 mW.
- Taking into account the efficiency of vacuum window = 0.7, gives 45 mW in-vacuum immediately behind downstream mirror.
- From the pulse structure, the energy per pulse is calculated to be ~3µJ.
- Average power within a macropulse = 53 W.
- The FEL pulse duration has been inferred from the spectral width to be ~1 ps The peak power is therefore inferred to be ~3 MW.
- The maximum net gain achieved so far is ~20% per pass, with ~6% loss. Given the measured parameters, this agrees well with simulation. Increasing the outcoupling hole size should allow us to increase the power. The gain could be further increased with lower energy spread.

Achieved ALICE FEL output parameters, in-vacuum immediately behind the downstream mirror:

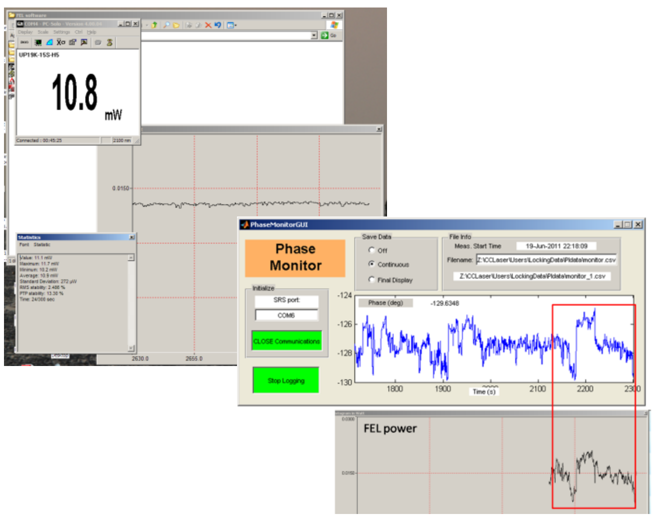
Parameter	**Notation**	**Value**
Wavelength	λ_r	5.0–8.0 μm
FWHM Bandwidth	$\Delta\lambda/\lambda$	0.9–1.8 %
Pulse Energy	E_{pulse}	$\leq$ 3.3 μJ
Peak Power	P_{peak}	$\leq$ 3.6 MW
Average Power	P_{avg}	$\leq$ 45 mW
Average Power (within macropulse)	$P_{\text{avg,pulse}}$	$\leq$ 53 W

Further developments

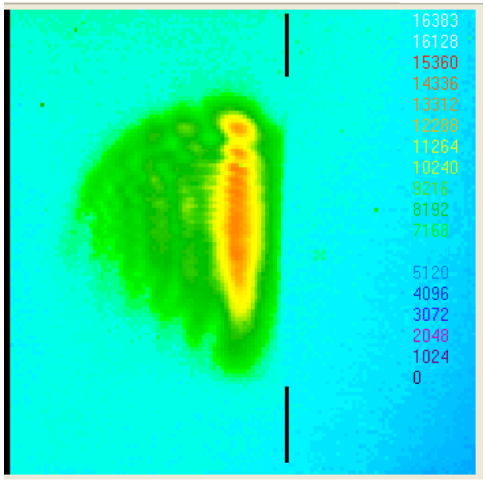
- Established a reliable lasing setup at 60pC, and characterised output and performance.
- Demonstrated wavelength tuning (mainly gap tuning 5-8µm, but also energy tuning).
- Assessed stability and identified some causes of instabilities that we are working to improve (best stability so far ~2.5% rms over several hours) .
- Higher harmonics measured (2nd and 3rd, at ~0.1% fundamental).
- Beamline commissioned through to optics box in diagnostics room.
- Lasing with electron bunch arrival frequency at half the cavity roundtrip frequency.



Results from first demonstration of wavelength tuning



2.5% stability, and correlation of instability to PI laser phase



Transverse profile of FEL output in diagnostics room

What comes next?

- We plan to reduce the optical cavity ROC to 4.75 m to increase the gain, and to use a larger hole in the outcoupling mirror to optimise the power and decrease losses due to overfilling mirrors in the beamline.
- Characterisation of the output in the diagnostics room - upgrades are planned to the diagnostics to enable single macropulse FEL spectra and single-shot FEL pulse length measurements.
- Installation of a scanning near-field optical microscope (SNOM) previously used on the Vanderbilt FEL, for a select user programme.
- We're investigating the feasibility of several FEL physics experiments.

- Ultimately, the skills and knowledge gained from the ALICE FEL project are being used in the development of a new test accelerator: CLARA (Compact Linear Advanced Research Accelerator). This will be a single pass FEL for short pulses – see poster tomorrow (TUPB28) for further details.

Acknowledgements

Thanks to everyone who has contributed to the project.
All of the ALICE team. JLab and CLIO for equipment loans.
Thanks to the FEL community for helpful advice along the way.

Thank you for your attention.