Science & Technology Facilities Council

Recent ALICE Achievements

Alice
Accelerators and Lasers In Combined Experiments

Peter Williams

Daresbury Laboratory & Cockcroft Institute

ESLS XVIII, Elettra, Trieste 26th Nov 2010

The Cockcroft Institute of Accelerator Science and Technology

Susan Smith sends apologies

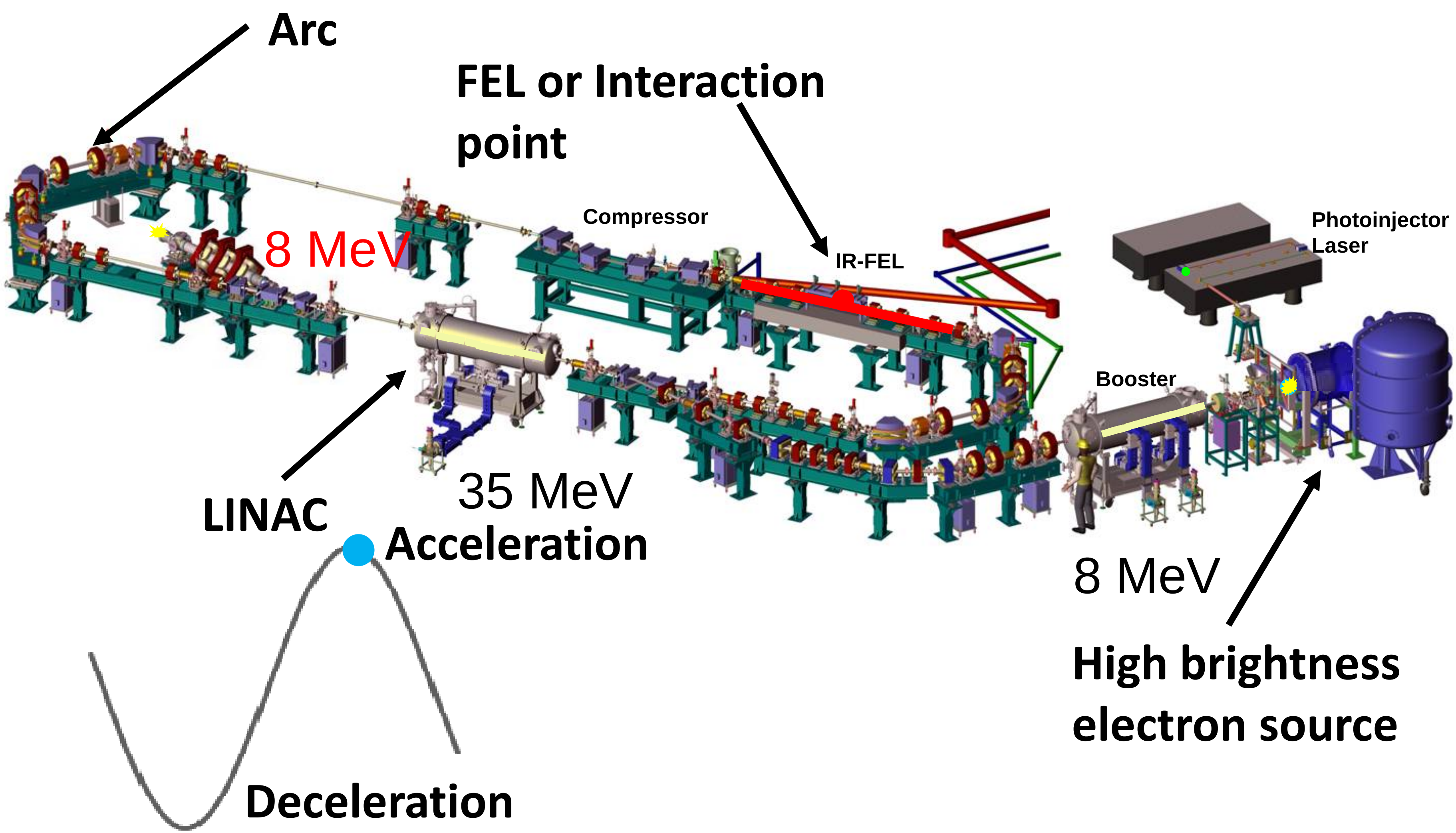
Contents

ALICE: Introduction

- Accelerators & Lasers In Combined Experiments
  - » Formally known as ERLP (Energy Recovery Linac Prototype)

- ALICE is an R&D facility dedicated to accelerator science and technology
  - Offers a unique combination of accelerator, laser and FEL based sources
  - Enables studies of electron and photon beam combination techniques
  - Development of scientific programmes and techniques
  - Injector for EMMA

ALICE: An Energy Recovery Linac



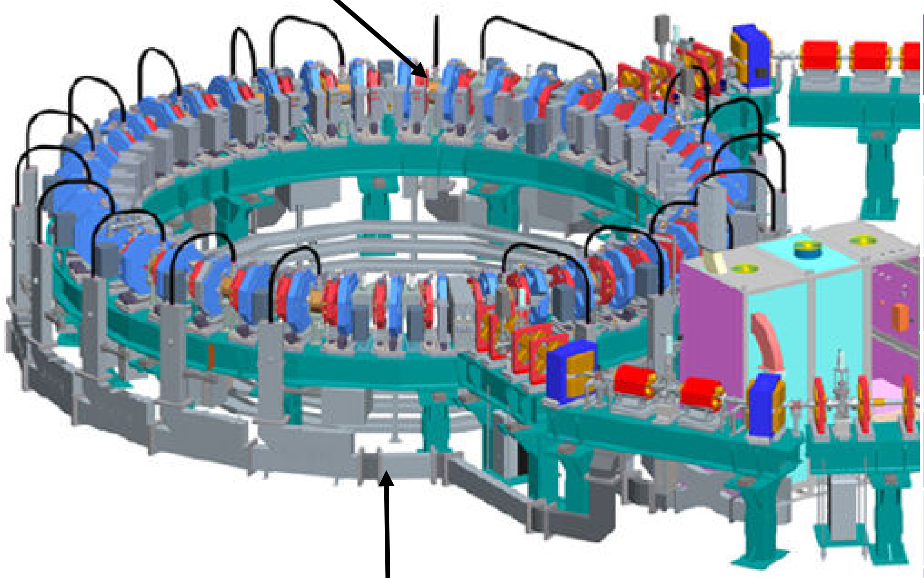
ALICE: Parameters

Parameter	**Design Value**	**Achieved Value**
Injector Energy	8.35 MeV	6.5 MeV
Total beam energy	35 MeV	27.5 MeV
RF frequency	1.3 GHz	1.3 GHZ
Bunch repetition frequency	81.25 MHz	81.25 MHz
Train Length	0 - 100 s	0 - 100 ms (with 40pC bunches)
Train repetition frequency	1 - 20 Hz	1 - 20 Hz
Compressed bunch length	<1 ps rms	<1 ps rms (measured)
Bunch charge	80 pC	40 pC @ 81.25MHz, 60pC @ 16MHz, >100 pC achieved
Energy Recovery Rate	>99%	>99% (measured)

EMMA

Electron Machine of Many Applications

- World's first Non-Scaling Fixed Field Alternating Gradient Accelerator



Machine Parameters	Value	Units
Frequency	1.3	GHz
Number of Straights	21	
Number of Cavities	19	
Total Acc per Turn	2.3	MV
Upgrade Acc per Turn	3.4	MV
Beam Aperture	40	mm
Pulse Length	1.6	mS
RF Repetition Rate	5-20	Hz
Phase Control	0.3	°
Amplitude Control	0.3	%

ALICE: Introduction

- ALICE is not a user facility per se, but there are competing demands
  - How we operate: It varies – in 2010 three commissioning periods of ~2 months each, generally 2 shifts per day 08:00 – 16:00 & 16:00 to 00:00. Some 00:00 – 08:00 for “users” when staff available. No operators, all AP
  - Below is plan for first operating period of 2011

ALICE/EMMA Schedule January-March 2011

154 Shifts available

Shutdown
EMMA
FEL
THz/AP/EI

January

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M
Shift 2	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI
Shift 3	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	Shutdown	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI

February

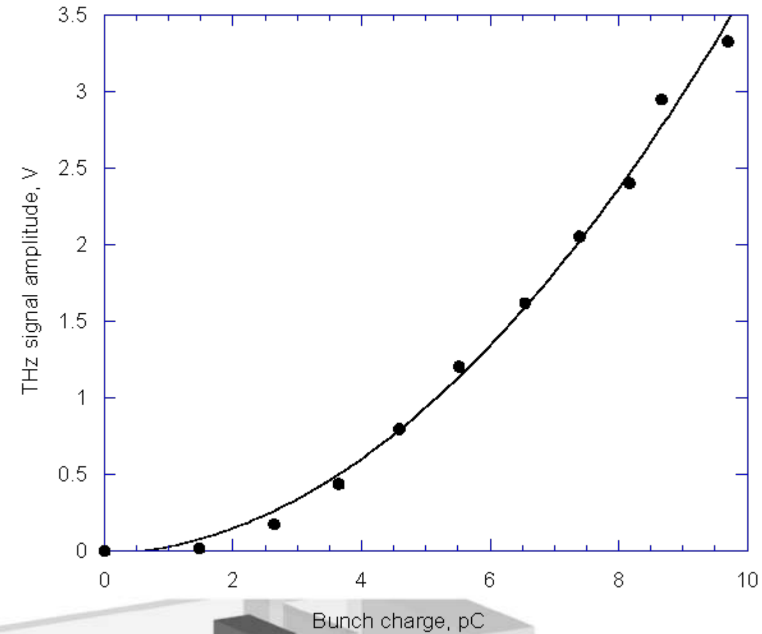
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M
Shift 2	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI
Shift 3	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI

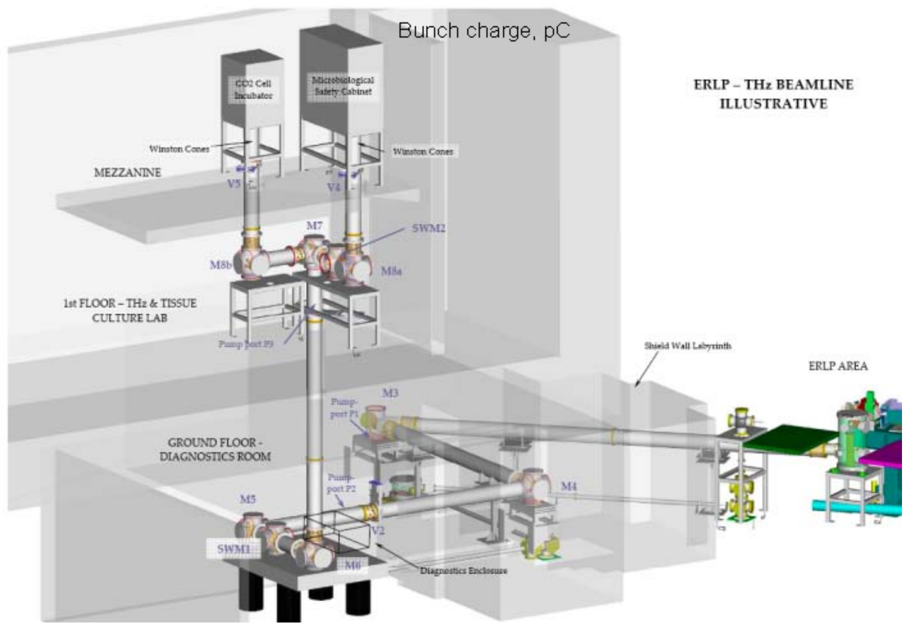
March/April

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3
	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S
Shift 2	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL
Shift 3	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL	EMMA	EMMA	EMMA	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	THz/AP/EI	FEL	FEL

Coherent THz Production

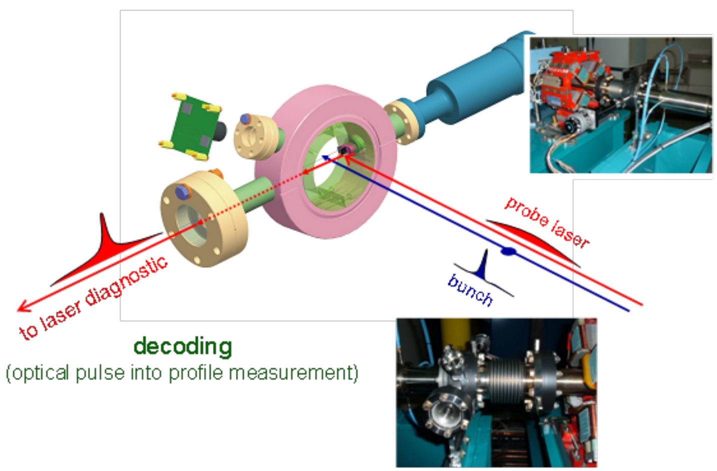
- CSR generated in THz region because bunch length ~1 ps FWHM
- Output enhanced by many orders of magnitude (N^2)
- Dedicated tissue culture lab
- Effect of THz on living cells being studied
- Because of our timing structure source has very high peak power (10's kW) but very low average power (~ 1 mW) – so no thermal effects!
- So far completed ~20 separate exposures of many hours (overnight)

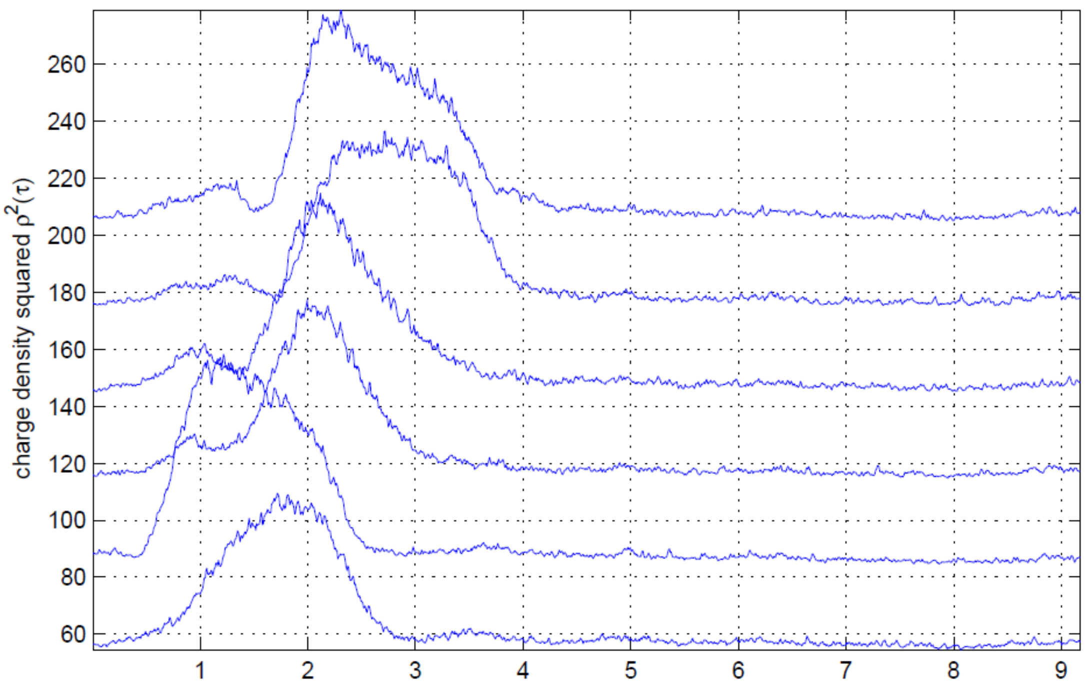




Electro-Optic Measurements

- Installed and commissioned during 2010
- Preliminary measurements appear to confirm expected bunch lengths (FWHM ~1 to 2 ps)
- More beam time needed to fully develop diagnostic and to try new concepts for better resolution

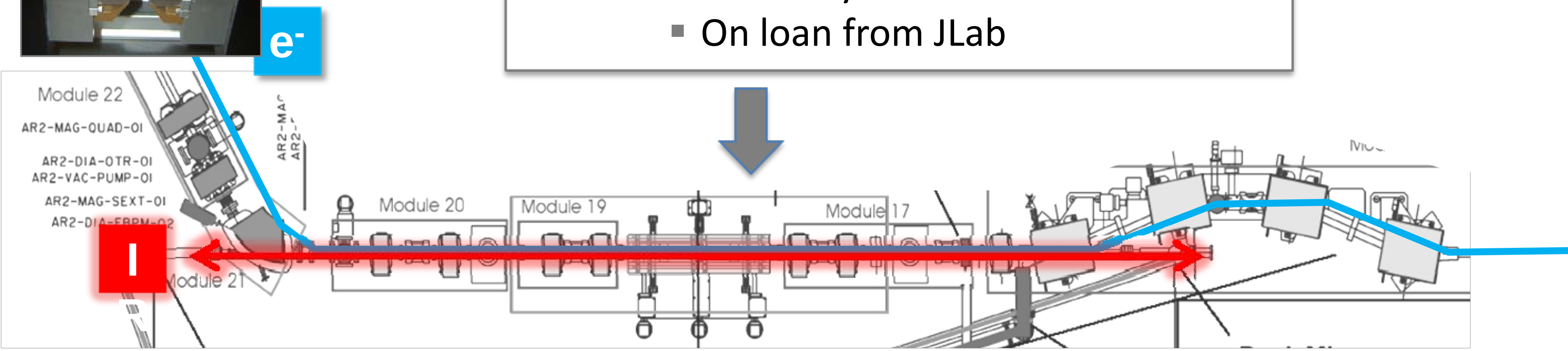




ALICE FEL: Layout & Parameters

WIGGLER

- 40 Periods of 27mm
- Planar hybrid
- On loan from JLab



ELECTRON BUNCH

- 27.5 MeV
- < 1 ps bunch duration (RMS)
- Steered to < 200µm of wiggler axis
- Focussed to 250µm waist
  - at wiggler entrance (horizontally)
  - at wiggler centre (vertically)

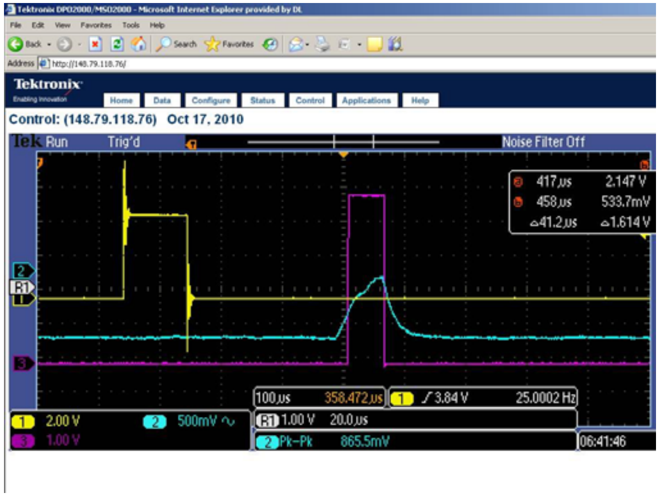
INFRA-RED

- 4-12 µm wavelength
- ≈ 1 ps pulse duration (FHWM)
- Mirrors Cu/Au with 4.85m ROC
- Mirrors transversely aligned to ≈100 µrad
- Length of 9m optical cavity set to < 20 µm

ALICE FEL: Troubleshooting

• Summer 2010: We had THz from bunch compressor & EO measurements = short bunches, cavity alignment confirmed, good beam focusing & steering (or so we thought). And we saw lots of spontaneous radiation. But no lasing – why?

• BPM system not calibrated, therefore relying on screens = short trains and inaccurate steering When withdraw screens and increase train see beam loading on booster -> energy droop over train



• Also bunch charge limited to only 40pC, again because of booster beam loading and also cathode lifetime -> sitting on the edge FEL gain of 20% (cavity losses of 15% per round trip)

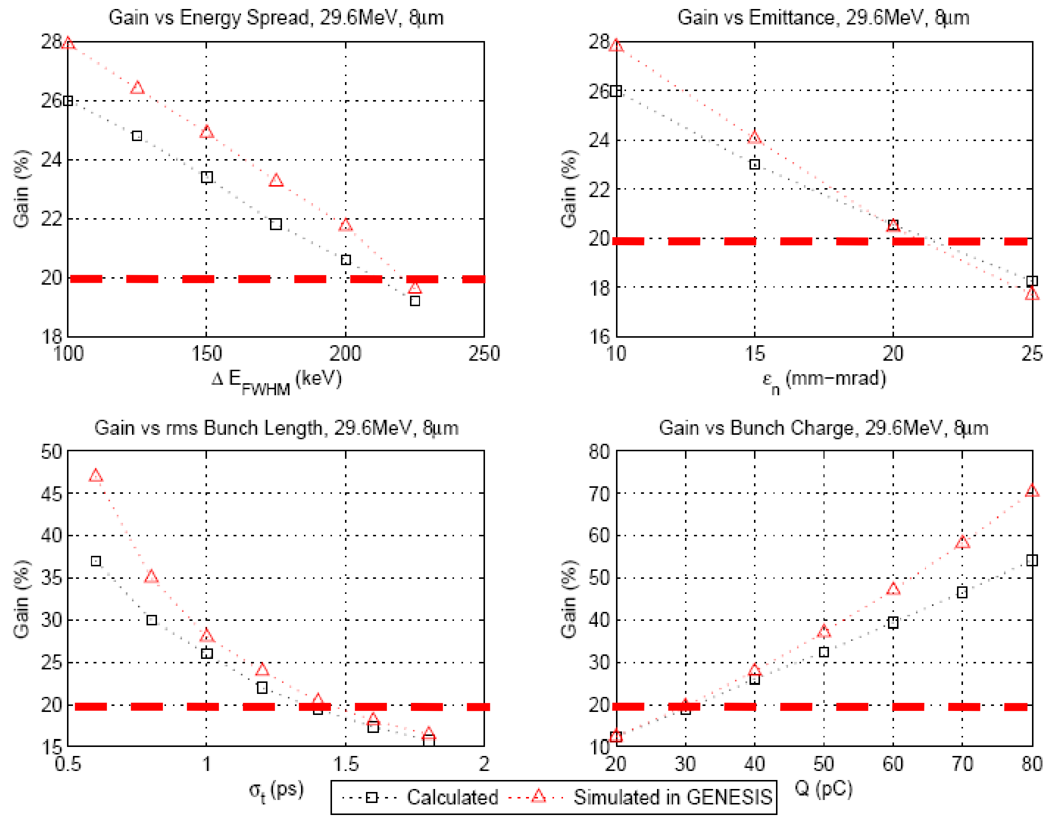
• We are developing digital LLRF system to counteract this beam loading, but long development time

ALICE FEL: Calculated Tolerances

- Bunch-to-bunch energy jitter should be less than rms energy spread, giving **$\Delta E_{(jitter)} < 42$keV**

- Energy droop over saturation time should be less than energy bandwidth, giving $\Delta E_{droop} \ll 30$keV/μs

- From simulations get $\Delta E_{droop} \ll 8$keV/μs



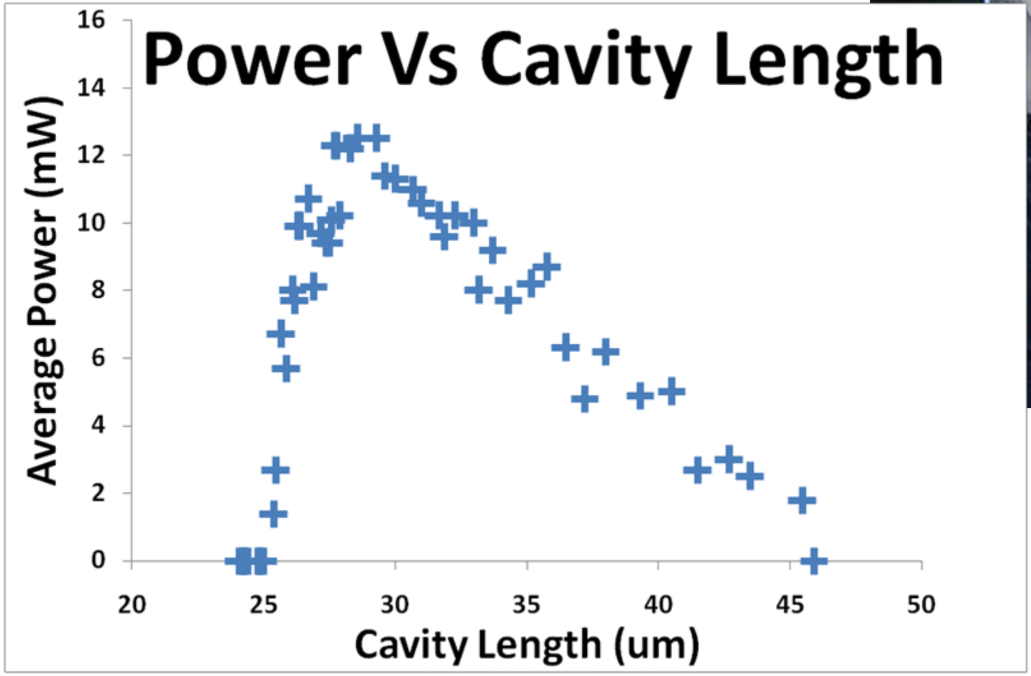
$$\Delta_x < 250\mu\text{m} \quad \theta_x < 650\mu\text{rad} \quad \Delta_y < 400\mu\text{m} \quad \theta_y < 400\mu\text{rad}$$

- Some combination of these (need further studies to confirm) dropped us below 20% FEL gain (vs ~15% losses)

ALICE FEL: First Lasing

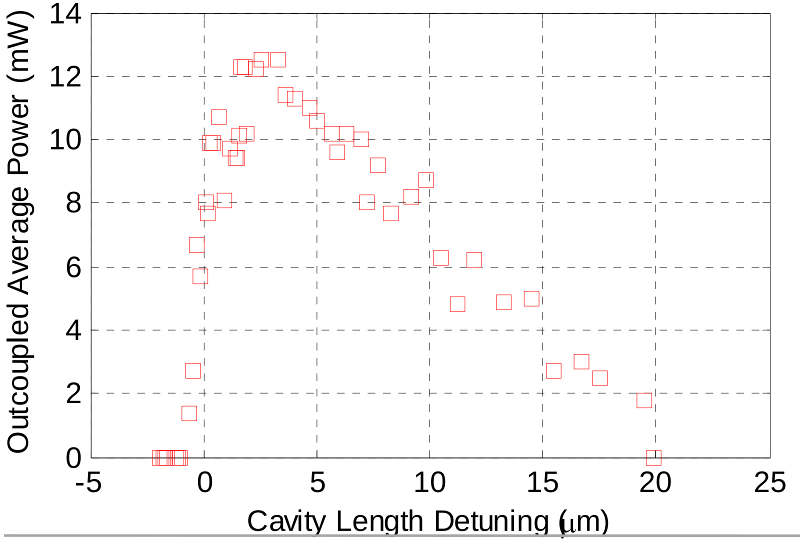
• Interim solution – install burst generator on photoinjector laser, cut out 4 out of 5 pulses (cavity only sees every 5th pulse) – go from 81 MHz to 13 MHz rep. rate . Allows reduction of beam loading and increase of bunch charge to ~100 pC

• First lasing achieved 23rd October 2010 !

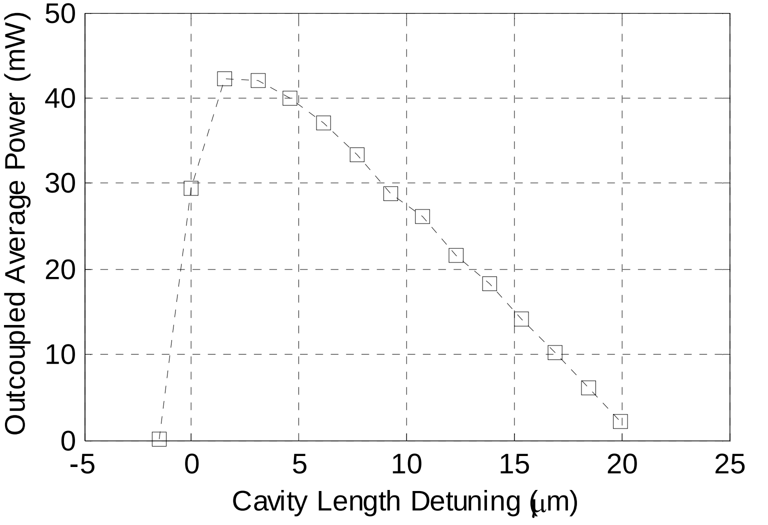


ALICE IR-FEL: First Lasing on 23/10/10

First Lasing Data:23/10/10



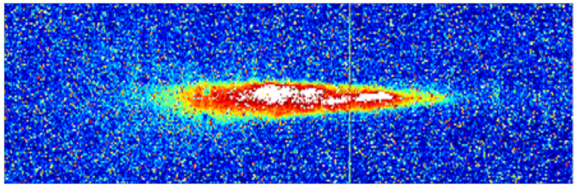
Simulation (FELO)



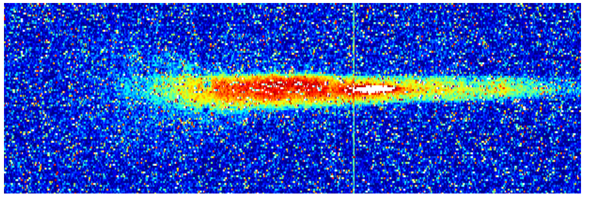
Effect of Lasing on Electron Beam

Beam transverse profile observed post-FEL in ARC-2

High Energy Low Energy



NO LASING



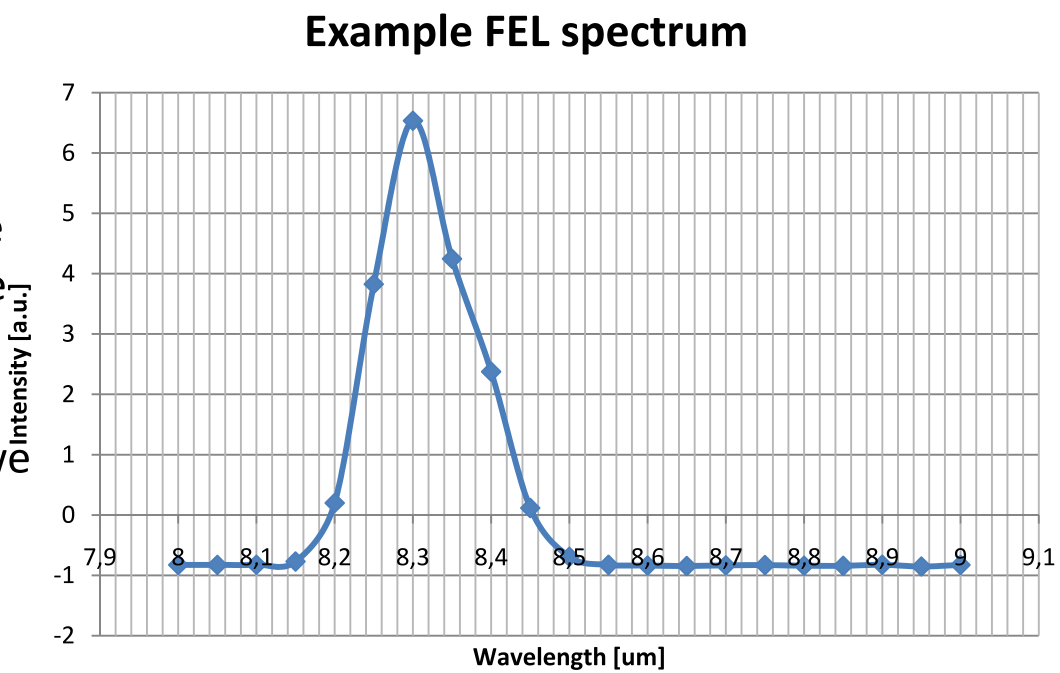
LASING
Increased energy spread and drop in mean energy

ALICE IR-FEL: First Lasing on 23/10/10

- Maximum power observed so far is 30mW (3μJ pulse energy)
  - ALICE timing structure is pulsed: 100us/10Hz trains of 16MHz electron bunches, so *average power within train is 30W*
  - Setup for first lasing used low cavity outcoupling to maximise cavity Q *at the expense of output power*
  - Expect to get significantly higher output power and pulse energy in future runs with optimised outcoupler.

- Lasing spectrum indicates FEL pulse length as short as 600 fs (FWHM)

- Once we are lasing, we are able progressively reduce the charge and resteer (beam & cavity mirrors) to re-establish lasing. Following this process, we can lase down to 28 pc! (but it takes the full 100 us to saturate)

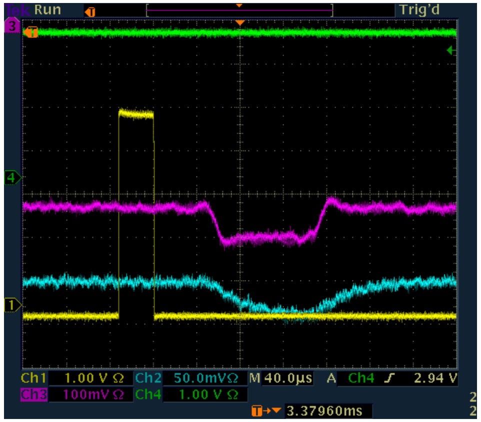


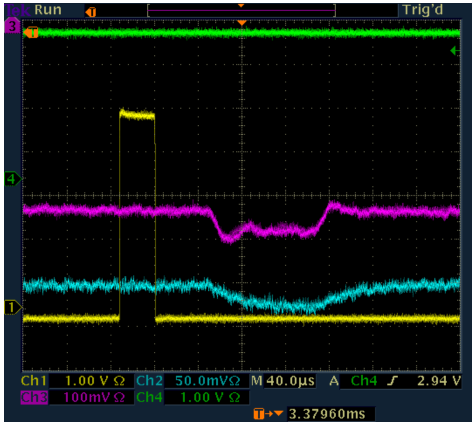
ALICE FEL: Status & Next Steps

- Once lasing was observed it was straightforward to re-establish on successive days (we lased 5 times within 1 week, then shutdown). Once set up FEL will lase for hours with no intervention

- Effect of lasing on energy recovery is not significant at current FEL power

- Linac cavity 1 (blue), 2(pink) gradient set traces with cavity blocked (left) and cavity open (right)

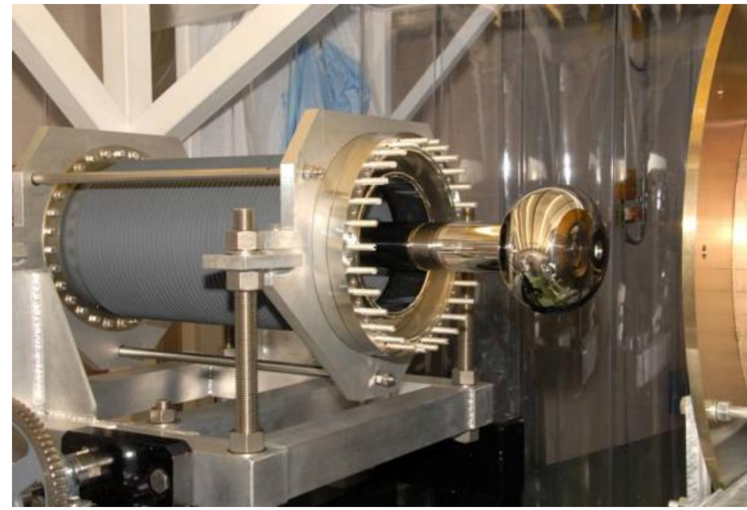


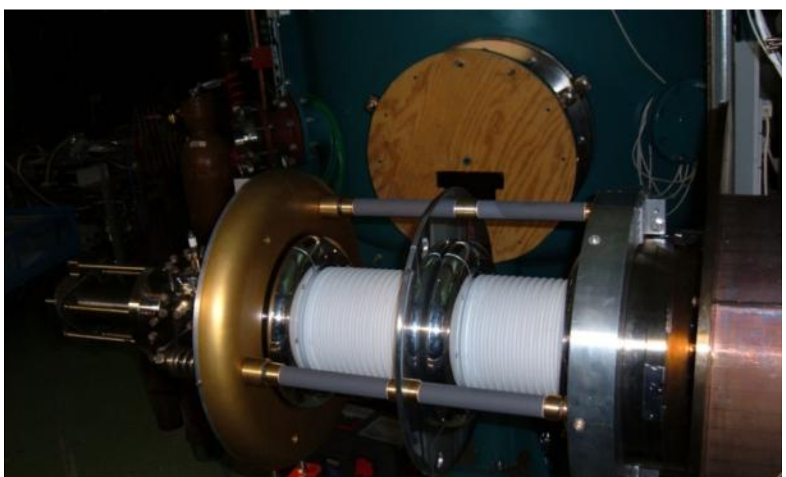


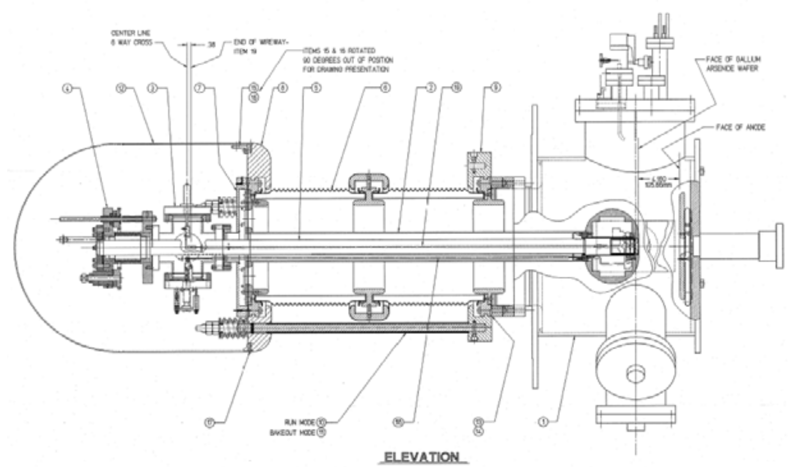
- Next Steps
  - Wavelength tuning by changing undulator gap
  - Full characterisation at all wavelengths
  - Transport of FEL radiation to ALICE photon diagnostics room

2011/12 Improvement: Photoinjector

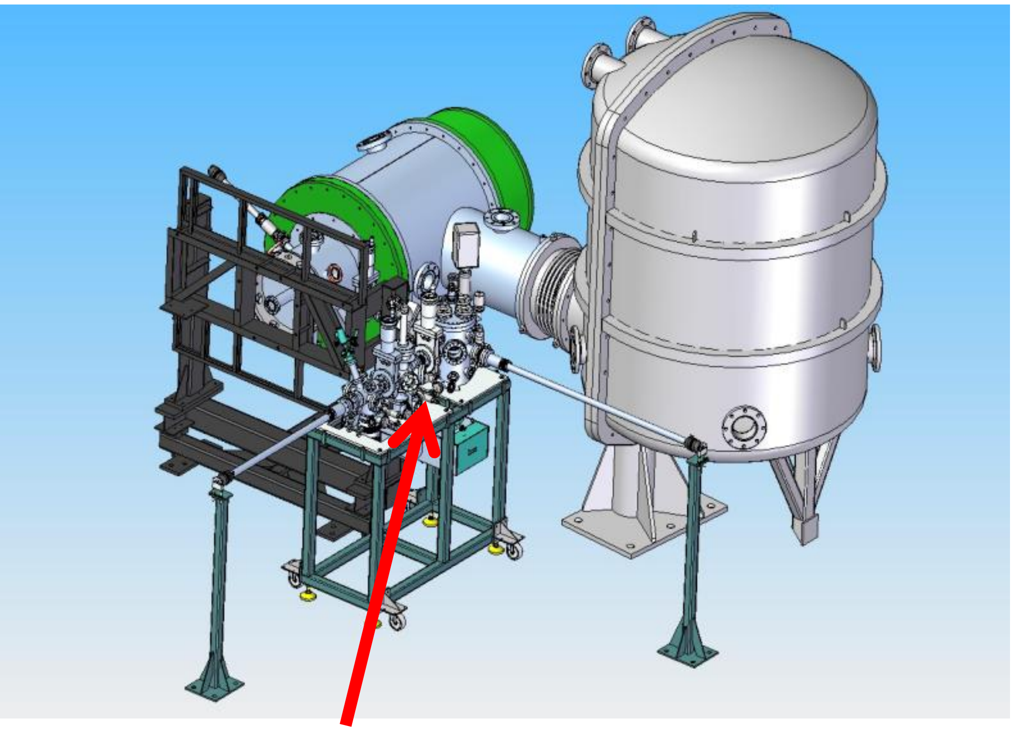
• Gun ceramic was major source of delay (~1 year)
• Alternative ceramic on loan from Stanford was installed to get us started – still in use today!
• Limits gun voltage to 230 kV (cf 350 kV)
• Original ceramic is on shelf waiting for opportunity to be re-installed







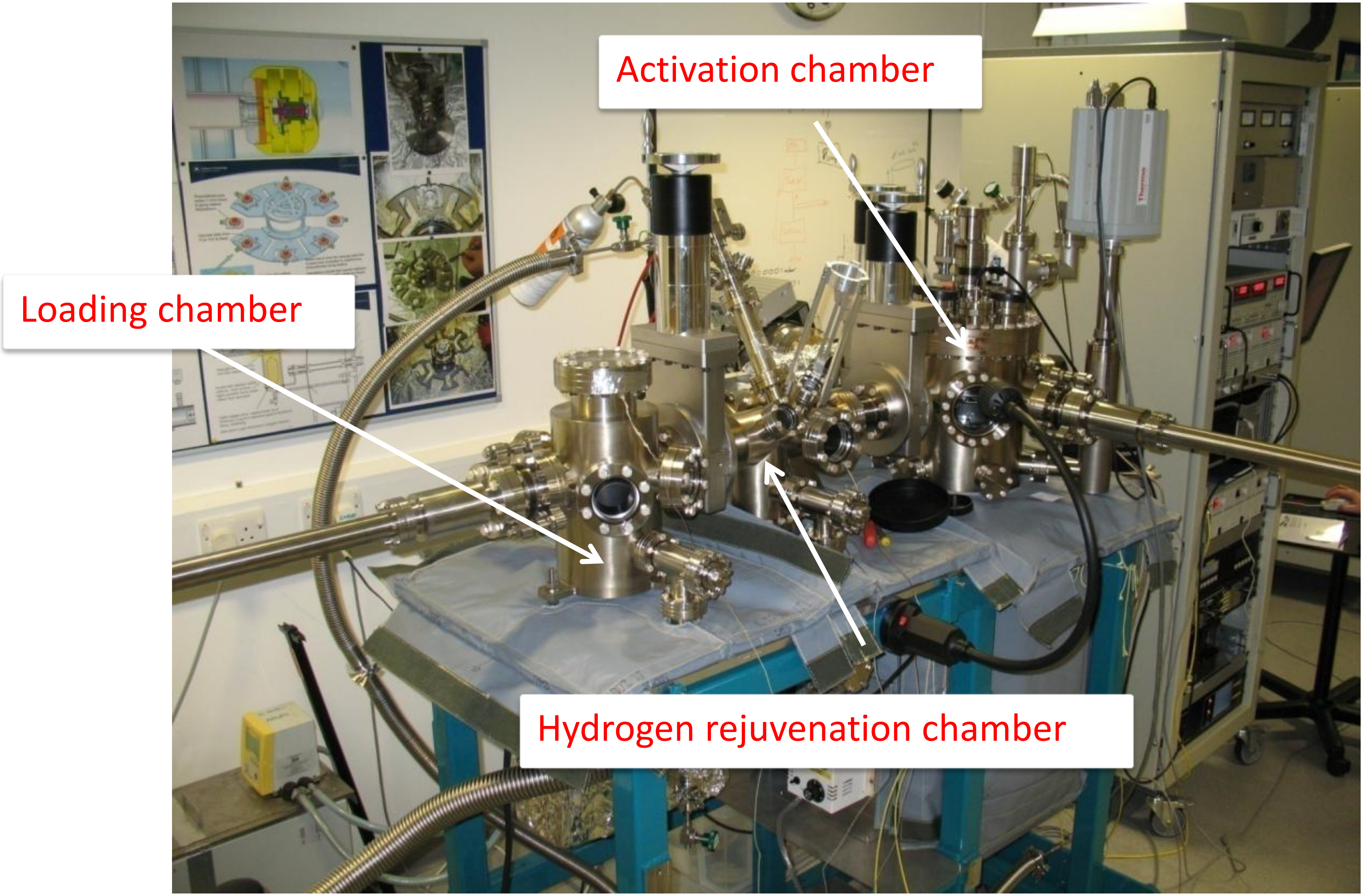
2011/12 Improvement: Photoinjector



Photocathode preparation facility

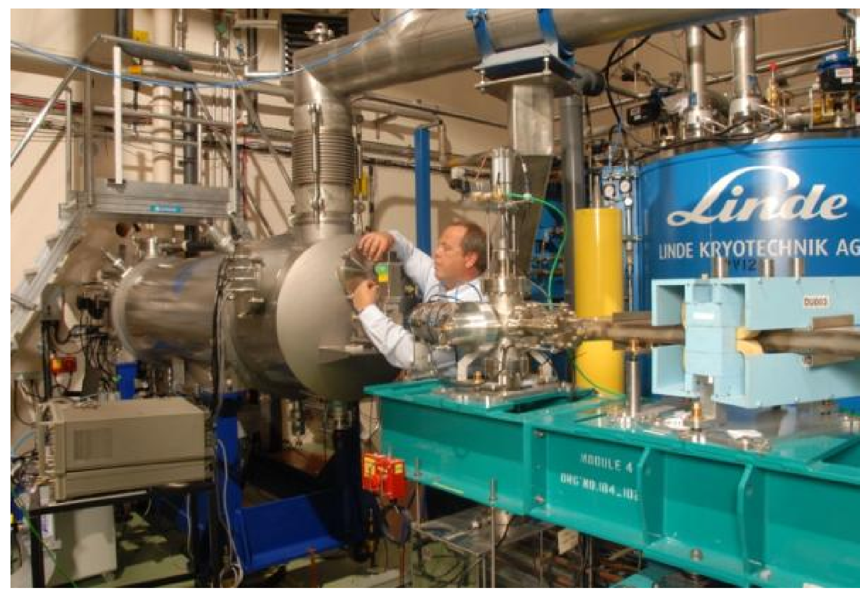
- Load lock system complete and under evaluation
- Improved vacuum conditions
- Photocathode activated offline
- Reduced time for photocathode changeover, from **weeks to mins**
- Higher quantum efficiency
  - Allows practical experiments with photocathodes activated to different electron affinity levels
  - 15% QE achieved in offline tests (red light)
- Allows tests of innovative photocathodes
- **Will be installed in 2011**

2011/12 Improvement: Photoinjector



2011/12 Improvement: SC Linacs

- Both linacs were procured from ACCEL
- They each contain two 9-cell ILC type cavities (as used by XFEL) – 1.3 GHz
- Linacs only designed to operate in pulsed mode (20Hz)
- Would not be suitable for NLS type, high-rep rate facilities
- Due to poor cavity rinsing (we believe), there is large X-ray field emission
- Necessitated building of lead shield wall to protect electronics

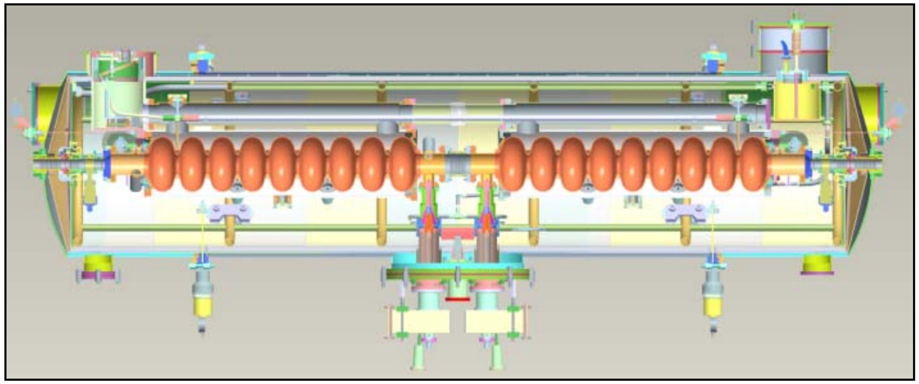


2011/12 Improvement: SC Linacs

- International initiative led by ASTeC to develop linac module suitable for **CW operation** as required by a high rep rate facility (eg NLS)
  - Higher power and adjustable input couplers
  - Higher beam currents, CW operation
  - Piezo actuators provide improved stability control
  - Improved thermal and magnetic shielding
  - Better HOM handling
  - 7 cell cavities so space for HOM absorbers
  - Same footprint as ACCEL linac so can install in ALICE easily
  - Validation with beam

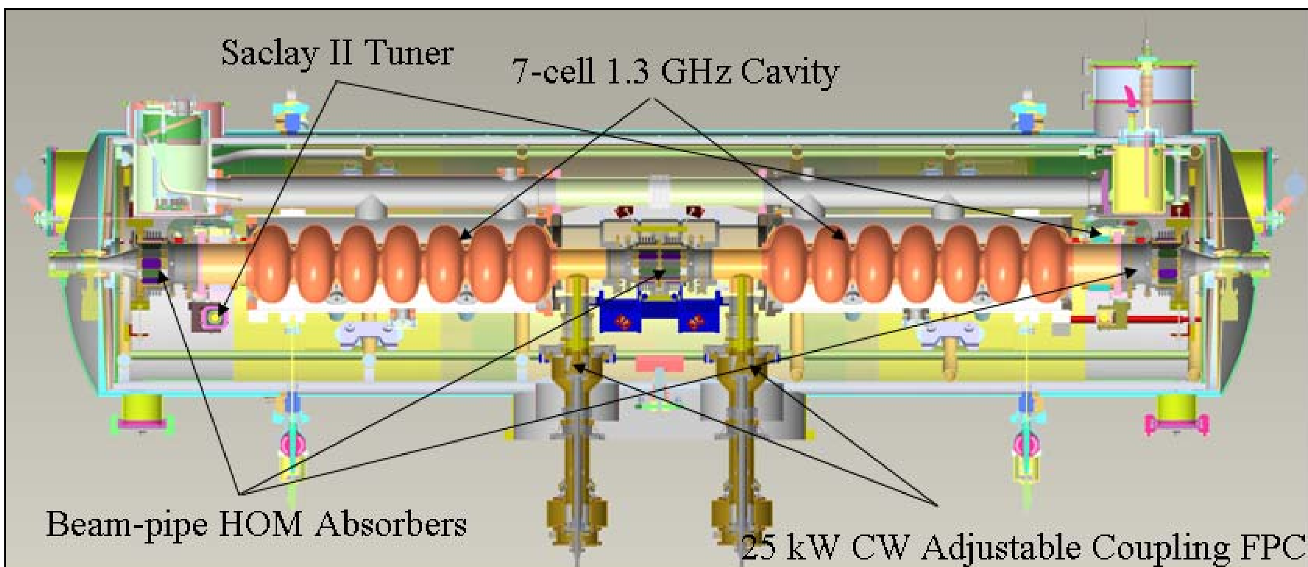
2011/12 Improvement: SC Linacs

Current Module



- Will be installed into ALICE in 2011

New Module



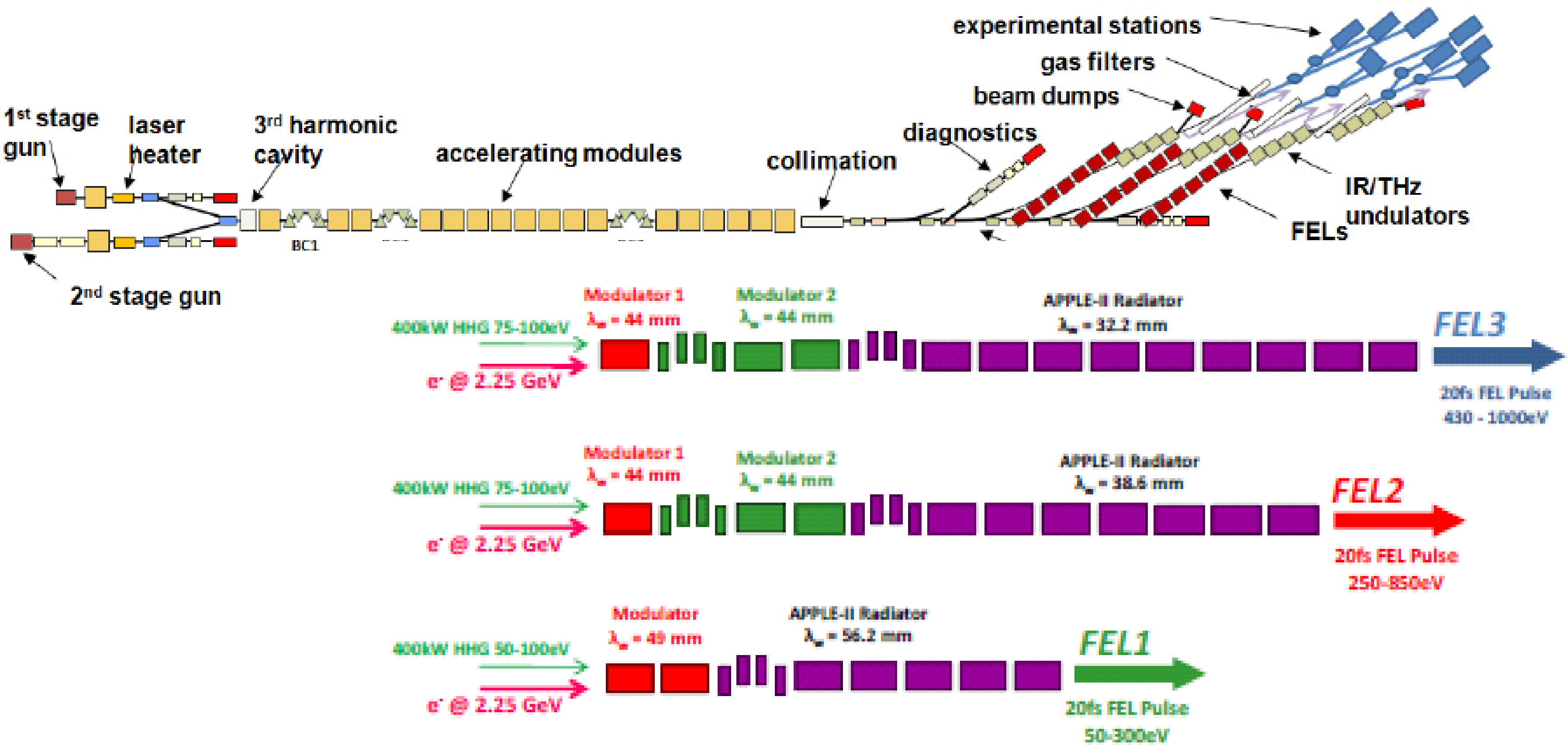
ALICE Future Planning

- ASTeC is currently updating its vision for electron test accelerators
- Proposals have been solicited from UK scientists and engineers with an interest in accelerators or the use of accelerators
- We have received a very enthusiastic response! 45 proposals

ALICE Upgrade	CW or ~kHz operation of ALICE	Yuri Saveliev	Larger average power from FEL and THz	Operate ALICE at higher rep rate if possible when new cryomodule installed (at lower energy perhaps)
ALICE Upgrade	FEMTO-X	Elaine Seddon	Generate 14keV x-rays, 30fs pulse duration for science (EXAFS and pump-probe)	Transverse CBS geometry with TW laser
ALICE Upgrade	Intra-Cavity X	Elaine Seddon	Generate low intensity ~ps x-ray pulses at high rep rates. Helpful diagnostic for FEL.	Generating X-rays by interacting the relativistic electron beam of ALICE with counter-propagating FEL light
ALICE Upgrade	Plasma accelerator studies on ALICE	Yuri Saveliev	Research into plasma accelerators	Use TW laser
ALICE Upgrade	ALICE Beam Loss Monitor system using CVD diamond	Yuri Saveliev	A detailed mapping of the radiation generated by beam losses using different beam configurations can improve our understanding of the physics and lead us to better configurations that will minimise losses and improve beam current	Use CVD radiation detectors to monitor local beam losses
ALICE Upgrade	To enhance the Cooling Power of the cryosystem	Shrikant Pattalwar	Enable cavities to operate in CW mode by increasing cooling power at 2K	replace the existing 2K system by developing a new one with an aim to improve the cooling power at 2K to at least 120W (currently 70W)

New Light Source Layout & Specs

- 2.25 GeV 1.3 GHz SC linac, 1 kHz rep rate increasing in phases to 1 MHz
- 3 independent HHG seeded FELs with variable gap undulators 50 eV – 1 keV
- 20 fs FWHM photon pulse length at all photon energies with 10^{11} photons/pulse at 1 keV – (upgrade path to sub-fs pulses)



New Light Source Status

- The Science Case was very well received
- The CDR was published in May 2010
- STFC (UK Government funding agency) has put the project on hold for 3 years due to financial constraints
- NLS was singled out as **the** project (out of many) that should be pursued in the future
- A good result given the circumstances in the UK