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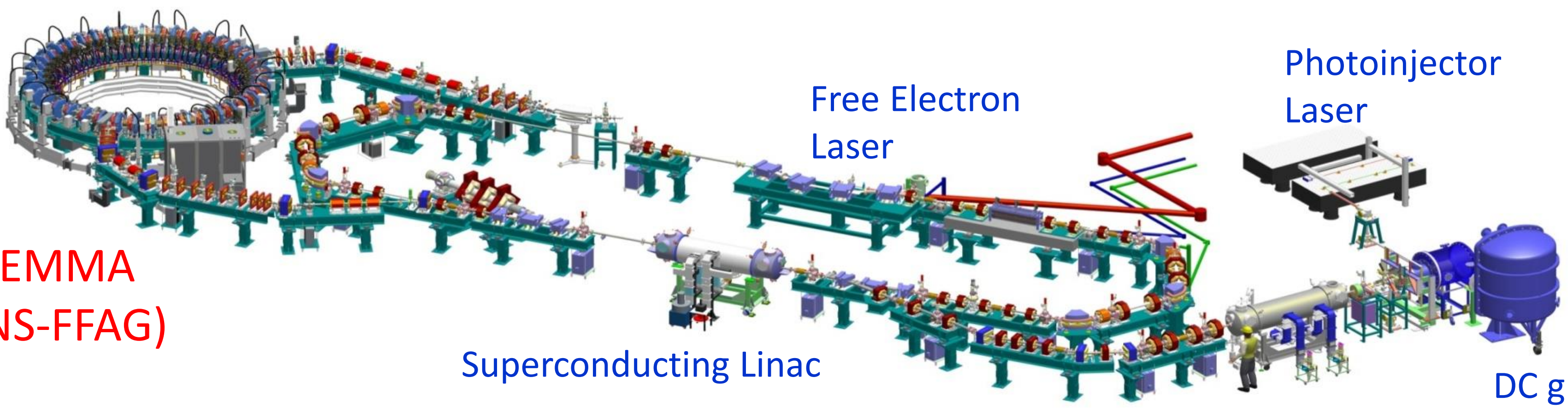
The ALICE Facility @ Daresbury

Status & Plans

Peter McIntosh (STFC Daresbury Laboratory)

LHeC Workshop 20 – 21 Jan 2014

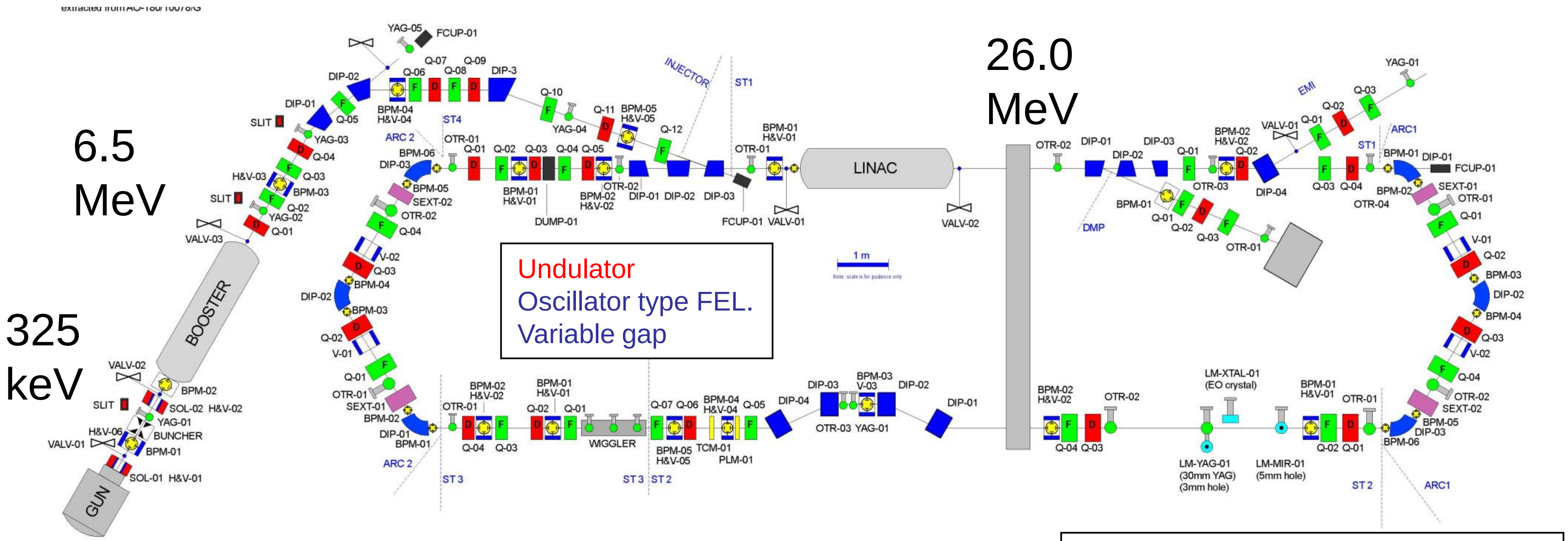


Accelerators & Lasers In Combined Experiments

ALICE Machine Overview

RF System
Superconducting booster + linac
2 x 9-cell cavities. 1.3 GHz, ~10 MV/m.
Pulsed up to 10 Hz, 100 μS bunch trains

Beam transport system.
Triple bend achromatic arcs.
First arc isochronous
Bunch compression chicane ~1ps bunches



Undulator
Oscillator type FEL.
Variable gap

DC Gun + Photo Injector Laser
325 kV
GaAs cathode; QE=2.5-3.0%
Up to 100 pC bunch charge
Up to 81.25 MHz rep rate

TW laser
For Compton Backscattering and EO
~70 fS duration, 10 Hz
Ti Sapphire

Diagnostics
YAG/OTR screens
BPMs (stripline / button)
Slits
Energy spectrometers
Electro-optic bunch profile monitor

Operating since Dec 2008

ALICE Parameters (Current)

Parameter	Operating Value	Comments
Injector Energy	6.5 MeV	Limited only by the required ratio of full/injector beam energies
Total beam energy	12.0 – 26.0 (27.5) MeV	Various setups; upper value limited by FE in the main linac cavities.
RF frequency	1.3 GHZ	
Bunch repetition frequency	up to 81.25 MHz (variable)	Use of burst generator in PI laser system;
Train Length	0 - 100 μs	
Train repetition frequency	1 - 20 Hz	
Compressed bunch length	<1 ps rms	Measured with EO technique
Bunch charge (standard)	40 pC @ 81.25MHz, 60pC @ 16MHz and 40MHz	Limited by beam loading; Q=60pC is a standard bunch charge for FEL and THz operation.
Bunch charge (potential)	~200pC	Allowed by achievable QE of 2.5-3.0%; requires digital LLRF with feed-forward ability in buncher/booster systems
Energy Recovery Rate	>99%	Measured

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Alice
Accelerators and Lasers In Combined Experiments

Historical ALICE Achievements

Milestone	Date
First ALICE (ERLP) meeting held	May 2003
500kV DC HVPS delivered	Dec
4K cryoplant commissioning starts	
First gun operation starts	
SRF cryomodules arrive	
First electron beam gen	
2K cryoplant c	
SRF	2006
	Oct 2007
	Dec 2008
	Feb 2009
Radiation produced	Nov 2009
nts with cell exposure to THz radiation	Apr 2010
IR FEL radiation produced	**Oct 2010**
First EMMA acceleration demonstrated	Apr 2011

Technical problems overcome:

HV ceramic failures due to brazing problems (re-design & vendor change)

SRF linac cavity tuner failure (removal and repair on-site)

SRF booster helium vessel EB-weld failure (return to factory for repair)

Excessive beam-loading in Booster SRF cavities (reduced rep-rate & DLLRF)

Field emission in SRF linac cavities (reduced gradient & new SRF CM)

http://stfc.ac.uk/ASTeC/Programmes/Alice/General/36020.aspx

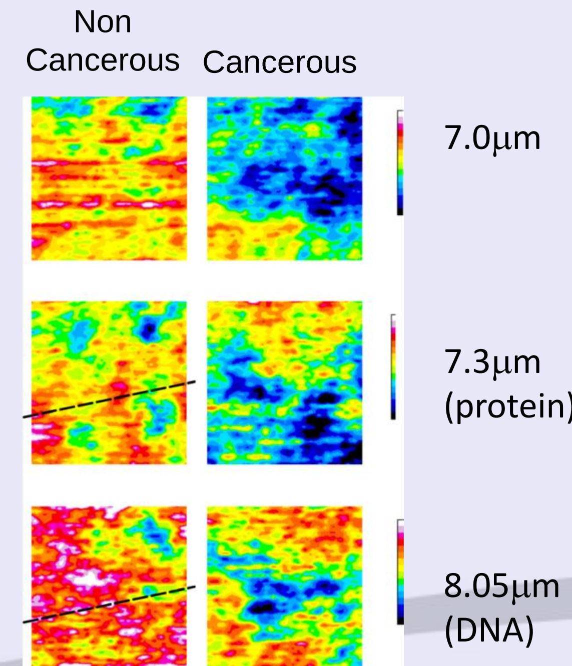
ALICE Current Status

- Last main accelerator physics and science programme on ALICE was successfully completed at the end of 2012.

Scanning Near-Field Optical Microscopy (SNOM) with IR FEL applied to cancer research

Spatial resolution ~0.1um
With sufficient intensity from FEL
can get below the diffraction limit at which
conventional IR microscopes on SR sources operate.

Current tuning range of Alice FEL 5.5 – 11 μm covers most of the "fingerprint" region in molecular spectroscopy.

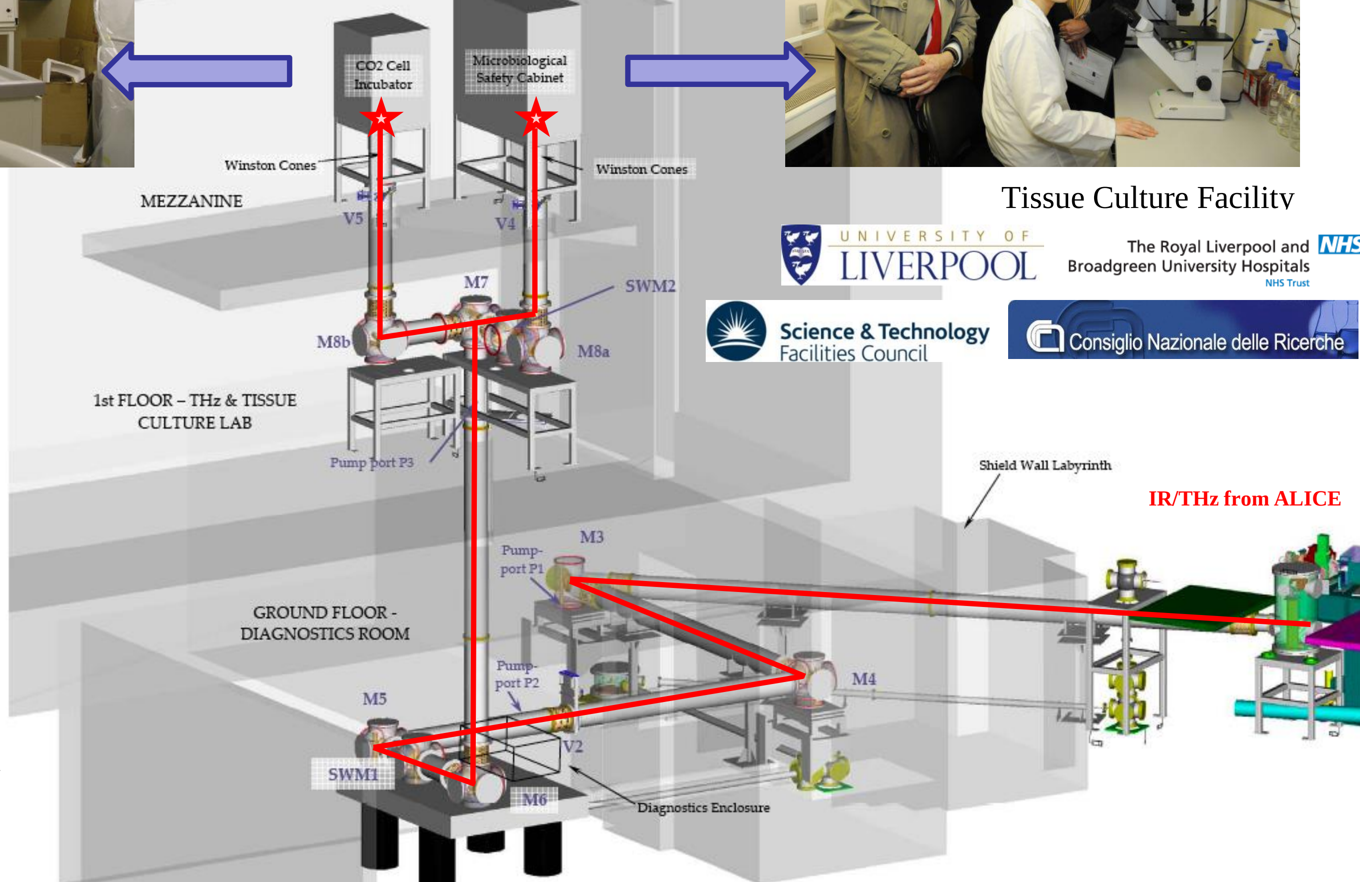


Peter Weightman (Liverpool Univ) leads a programme using SNOM on ALICE FEL to study oesophageal & prostate cancers,
Ref: A D Smith et al, Appl. Phys. Lett, 102, 053701 (2013)

Commissioning of the new SRF cryomodule on ALICE is underway

Photon Beam Exploitation

Tissue Culture Facility



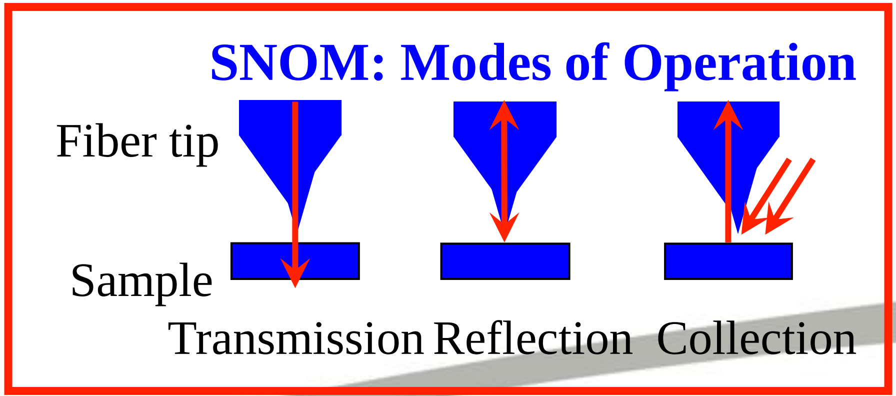
- CSR generated in THz Region as bunch length ~1 ps.
- Output enhanced by many orders of magnitude.
- Dedicated tissue culture laboratory.
- Effect of IR/THz on living cells being studied.
- Source has very high peak intensities but very low average power:
  - no thermal effects!

ALICE in 2014 & Beyond

- New grant for using ALICE IR FEL in cancer diagnostic studies has been received - SCANCAN (Critical Mass Award from EPSRC):
  - June 2013 – May 2016
- SNOM based programme led by Liverpool University:

"Towards disease diagnosis through spectrochemical imaging of tissue architecture"

- The grant allows ALICE operation for 3 years (three months per year).
- Opportunity for other project applications to increase the length of ALICE operation.

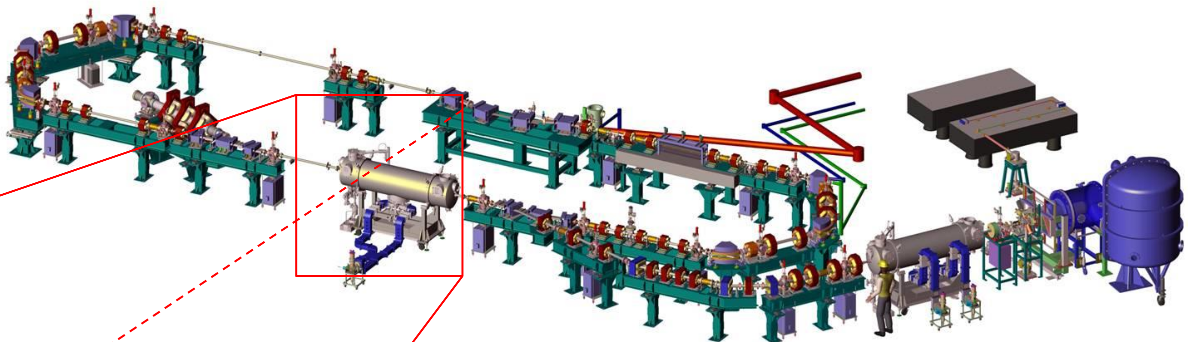


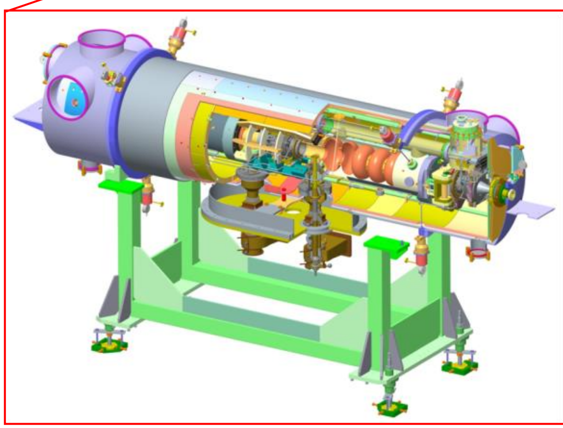
ALICE Near Term Developments

- New feedback system to ensure stability of FEL wavelength during SNOM scans.
- Improved diagnostic system for ALICE orbit monitoring and correction.
- Upgrade of the LLRF system to improve short-term and long-term machine stability.
- Efforts to extend the IR wavelengths range towards longer ~20µm wavelength:
  - Opens up more opportunities.
- Upgrade IR FEL transport beamline to improve efficiency at longer wavelengths.
- New SRF cryomodule is expected to allow ALICE operation at higher beam energy of up to 35 MeV:
  - Extension to shorter IR FEL wavelengths range.

New SRF Cryomodule Integration on ALICE

Accelerator and **L**asers
in **C**ombined **E**xperiment





- Dimensioned to fit on the ALICE ERL facility at Daresbury:
  - Same cryomodule footprint.
  - Same cryo/RF interconnects.
  - ‘Plug Compatible’ with existing cryomodule.

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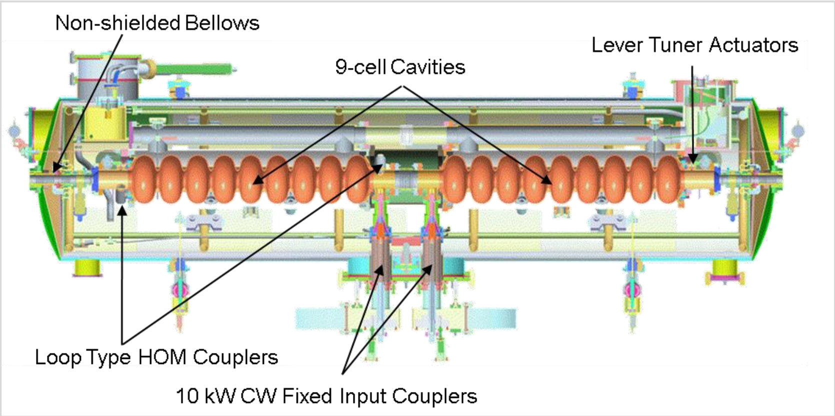
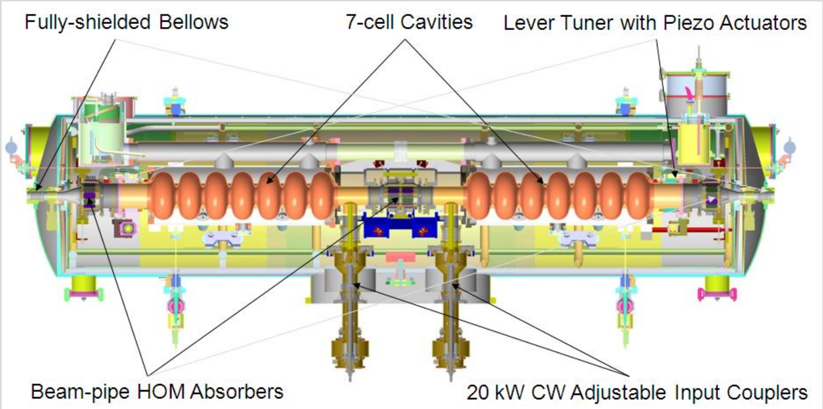
New SRF Cryomodule



Original Cryomodule on ALICE



New ERL Cryomodule

Parameter	ALICE	Target
Frequency (GHz)	1.3	1.3
Number of cavities	2	2
Number of Cells per Cavity	9	7
Cavity Length (m)	1.038	0.807
Cryomodule Length (m)	3.6	3.6
R/Q (Ω)	1036	762
E_{acc} (MV/m)	12 - 15	>20
CM Energy Gain (MeV)	26	>32
Q_o	$<5 \times 10^9$	$>1 \times 10^{10}$
Q_{ext}	4×10^6	$4 \times 10^6 – 10^8$
Max Cavity Fwd Power (kW)	10 SW	20 SW

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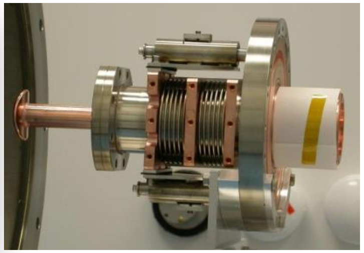
Cryomodule Integration

Cavity

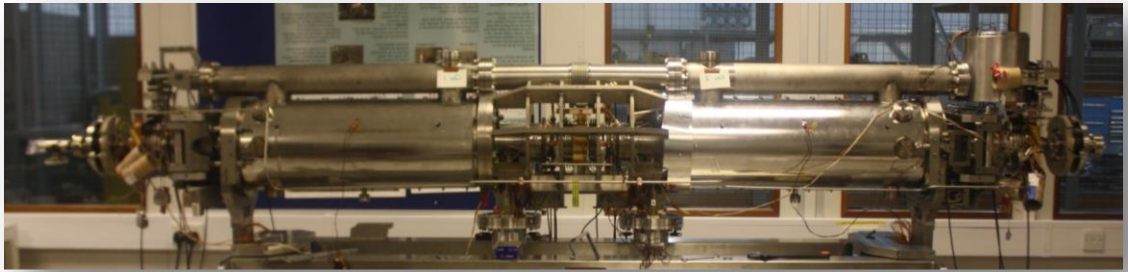
HOM Absorber

Tuner



FPC

String Integration



Offline Testing

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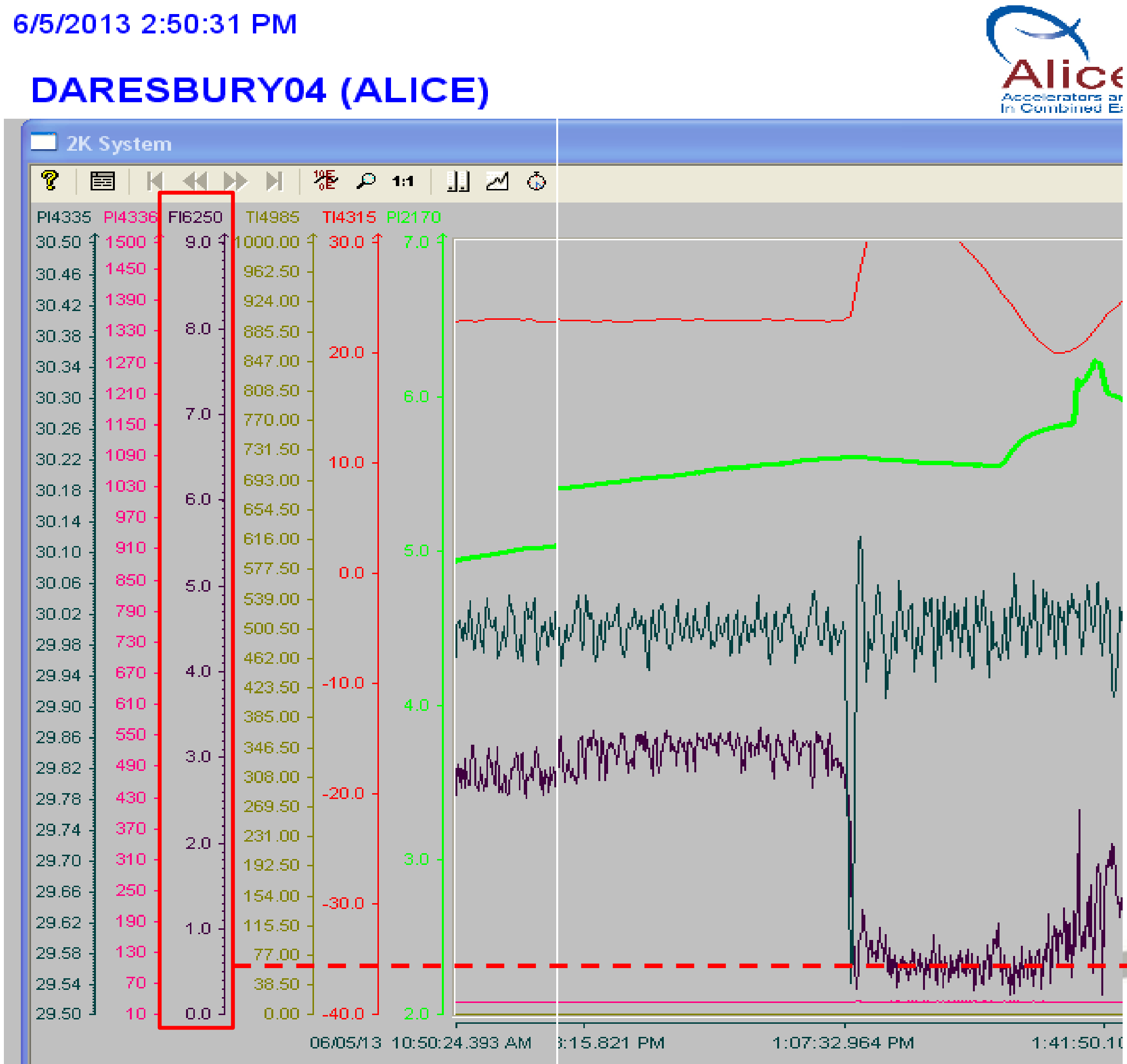
Cryomodule Implementation on ALICE

CM Static Heat Load at 2K



- Static heat load measured with all the input valves closed to ensure that only the boil off from the cryostat is measured.
- 0.6 g/S total mass flow Linac + Booster.

➪ 0.3 g/S per module.

➪ ~6.2 W per cryomodule

Cryogenic Performance

Parameter	Unit	Spec	Measured Value	
Base temperature	K	2.0	2.0	
Static heat load	W	15	6.2	Single shot mode at 2K
Static base heat load	g/S	1.5	2.5	With flash gas (additional heat leak from external components)
Pressure stability	mbar	±1.0	±0.05	at 2K
HOM Intercepts	K	< 20	13.5 < T < 15.5	CKT -1 at GHe 2.0 barA
HOM Intercepts	K	< 90	89 < T < 99	CKT -2 at GHe 2.0 barA
Shield	K	< 90	89 < T < 99	CKT -2 at GHe 2.0 barA
Cavity Frequency	GHz	1.3	1.3	
Tuning range	KHz	±350	±350	
Dynamic performance to be measured				
Static performance similar to original ALICE LINAC				

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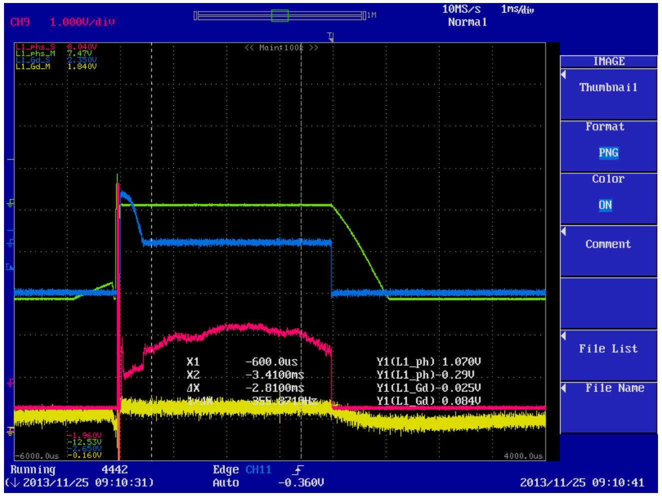
Alice Accelerators and Lasers In Combined Experiments

Cavity Conditioning

Pink – Phase set
Green – Phase measure
Blue – Gradient set
Yellow – Gradient measure

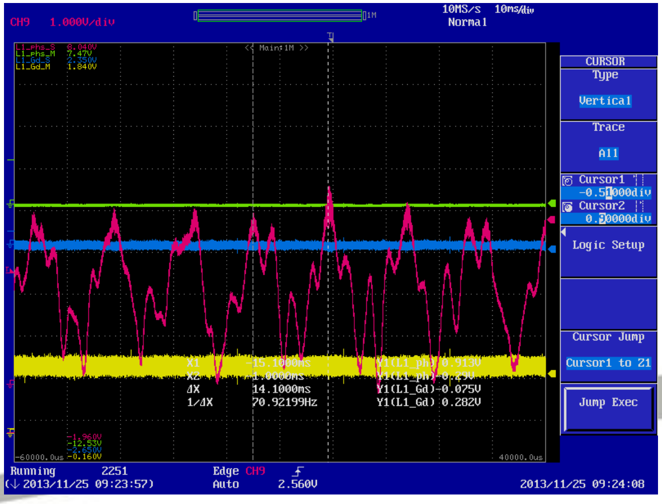
- Q_{ext} set to original Linac settings:
  - LC1 – 6.4 x 10^6
  - LC2 – 8.3 x 10^6
- Initial conditioning reached:
  - LC1 – 10.8 MV/m
  - LC2 – 12.5 MV/m
- 16 MV/m min gradient required

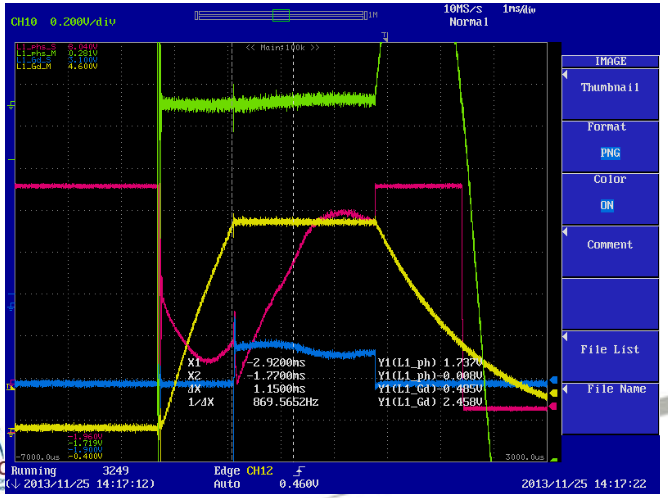
LC1
Gradient ~0.8MV/m
Phase set 40^0



- Microphonic issues discovered with analogue LLRF:
  - Phase set limit of 60⁰ reached at low gradients
  - 71Hz oscillation seen on the phase set under CW conditions

LC1 (CW)
Gradient ~0.8MV/m
71Hz oscillation





LC2
Gradient 7MV/m
Phase set 60^0

No FE radiation observed!

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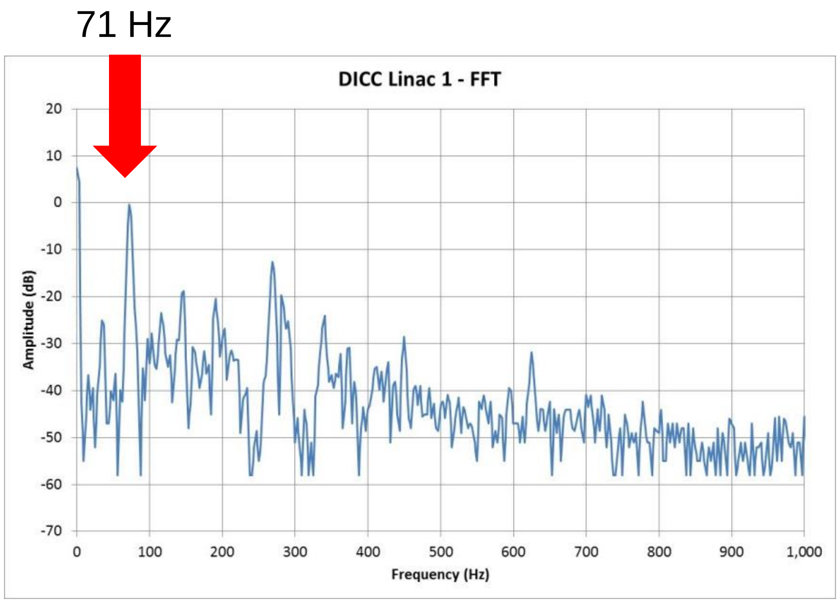
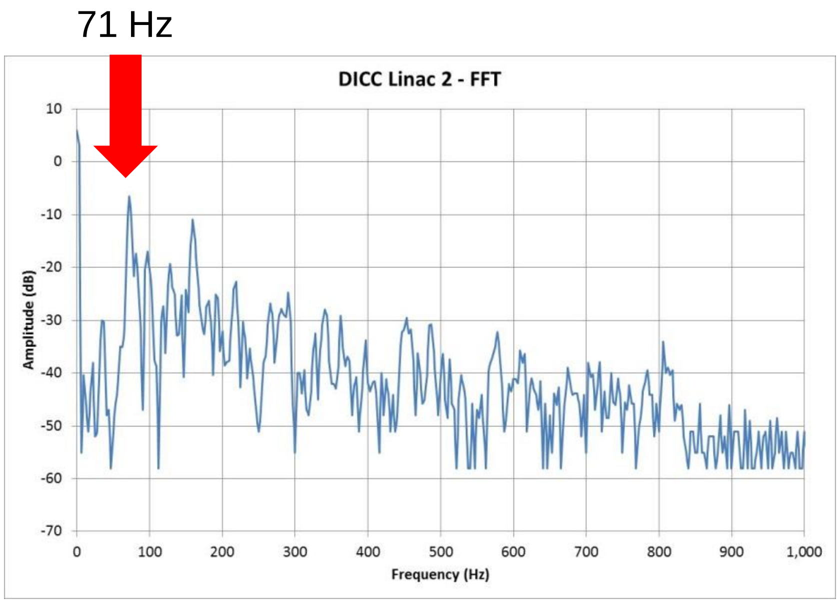
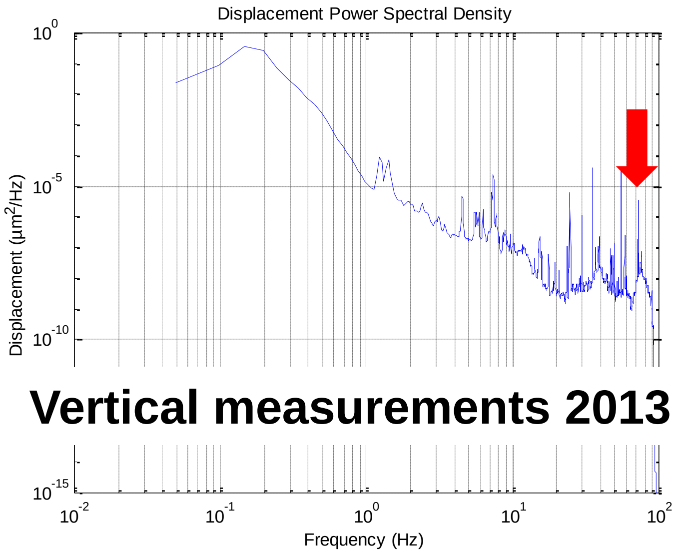
Microphonic Analysis – LC1 and LC2



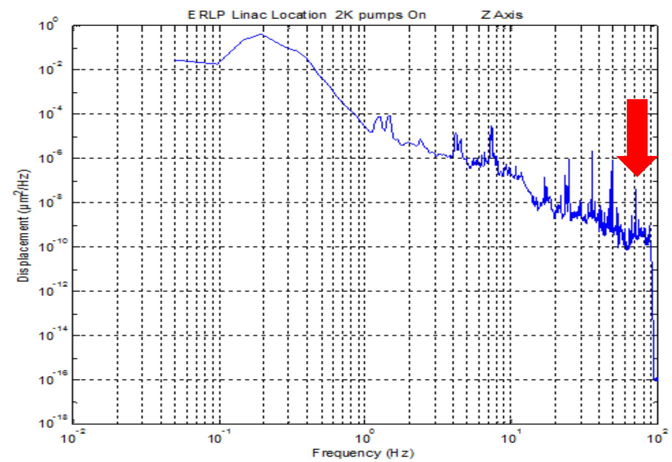


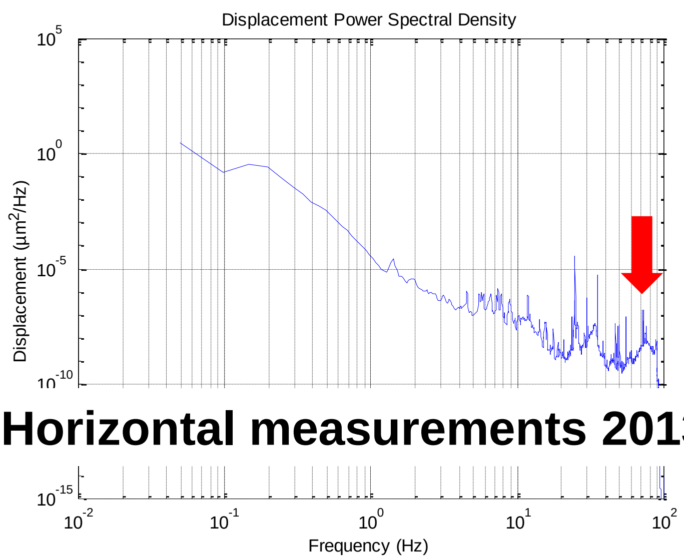
Seismic Ground Tests



Vertical measurements 2013

Vertical measurements 2005





Horizontal measurements 2013

- Seismic measurements performed next to the Linac and 2K pump platform.
- Greater than an order of magnitude degradation seen for modes >20 Hz (including 71Hz):
  - 2013 – Vertical displacement 10^{-6}µm^2/Hz
  - 2005 – Vertical displacement <10^{-7}µm^2/Hz

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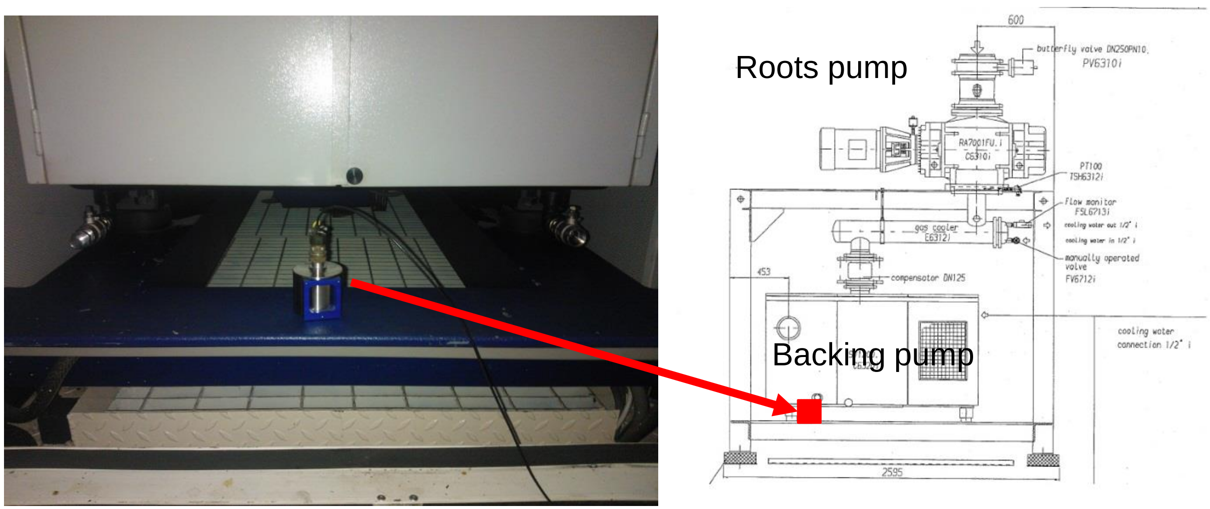
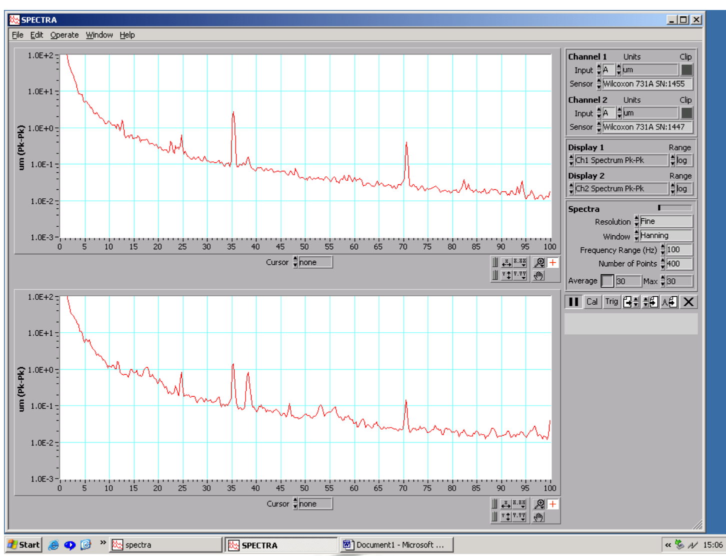
Accelerometer Measurements

Accelerometer located on pump mount

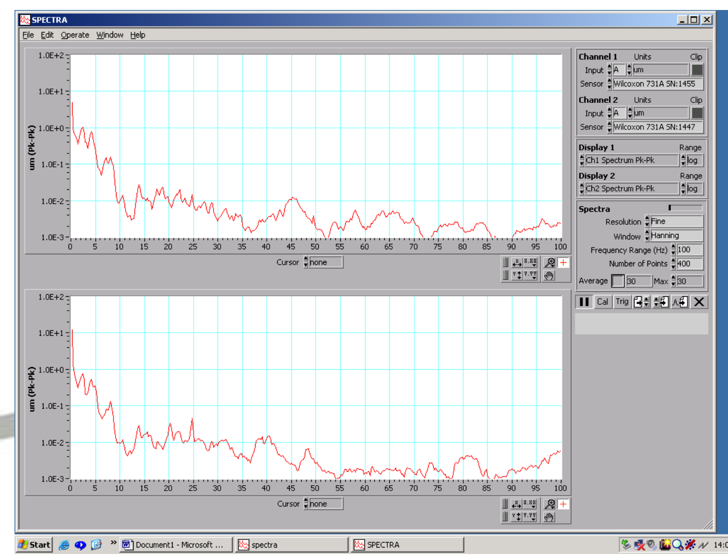


- Accelerometer measurements of the 2K pump system:
  - ⇨ Confirmed the source of the 71Hz vibrations from the backing pumps.
  - ⇨ Cryo roots pumps not the source.

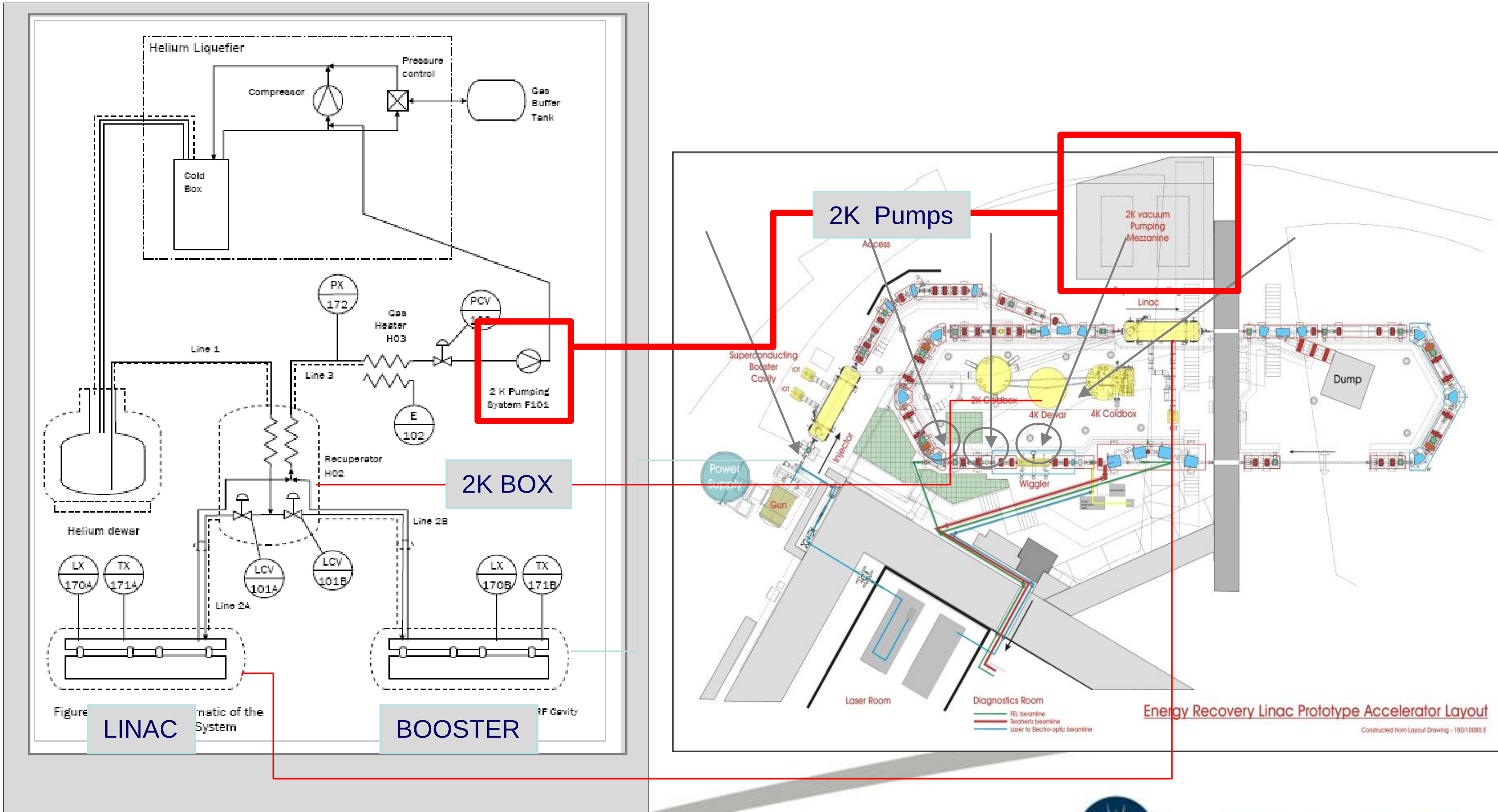
2K cryo backing pumps ON



2K cryo backing pumps OFF

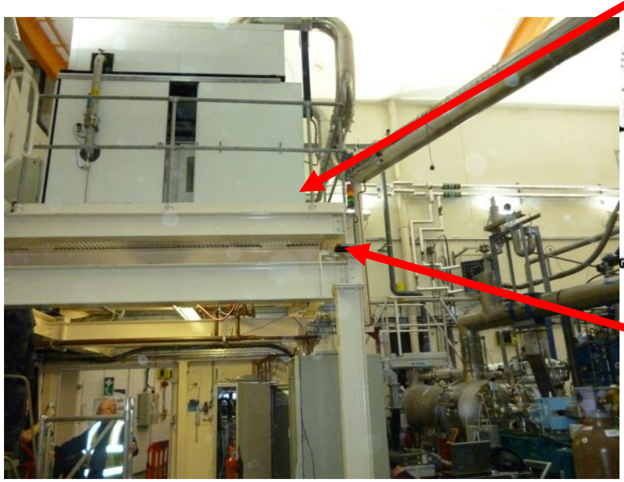


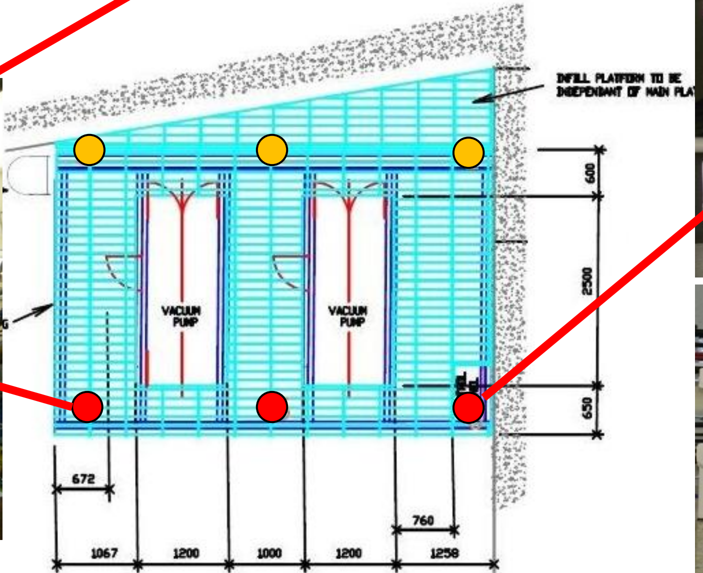
ALICE Cryogenic Pump Configuration



Pump Investigations

- Low pressure in pump frame shock absorbers:
  - Pressure had reduced to 4 Bar
  - ⇨ Increased to max – 6 Bar
- Distortion of platform shock absorbers observed:
  - Absorbers nearest the Linac had deformed likely due to radiation damage.
  - ⇨ Presently being replaced.





● Undamaged platform shock absorbers

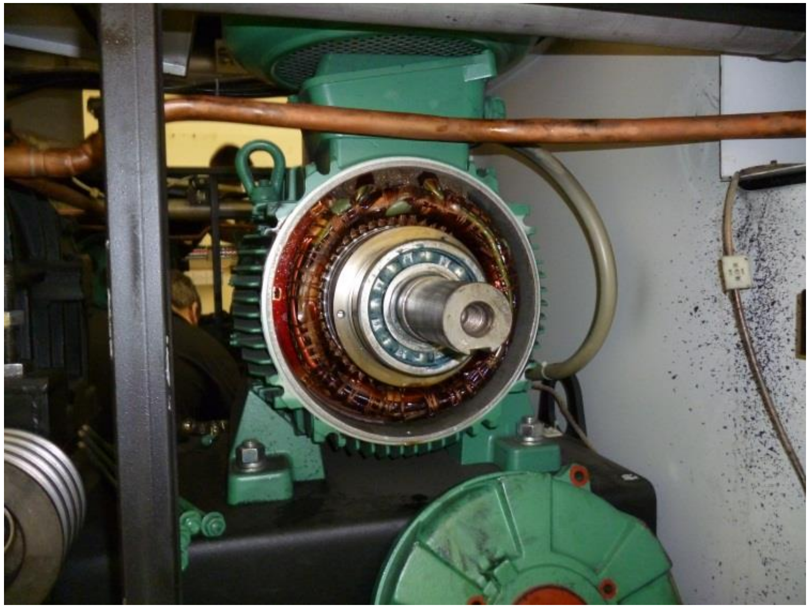
● Damaged platform shock absorbers

Pump Investigation (Cont)

- Investigation of pumps revealed a horizontal vibration due to backing pumps.

⇨ Bearings have been replaced:
  - Pump bearings
  - Pulley bearings
  - Motor bearings

- Pump system appears to be much quieter.
- Seismic and accelerometer measurements to be repeated once the system has been returned to a full operational status.
- **Cryomodule retesting expected to restart this week.**



Summary

- ALICE remains Europe’s only operating ERL test facility, employing:
  - DC photo-injector
  - SRF linacs
  - IR-FEL
- Facility has recently secured a new ‘lease of life’, with a 3-year grant award for cancer diagnostic studies.
- Beam stability improvements being made to improve FEL capability.
- New SRF cryomodule undergoing validation, to increase beam energy, efficiency and operability.

As a dedicated ERL test facility, ALICE maintains a unique capability globally for ERL scientific and technology R&D.

LHeC R&D Opportunities Using ALICE

- DC HV gun based injector physics:
    - Photocathode development
    - Low energy beam transport optimisation
- Energy recovery with various energy spreads and spectra:
    - Emulate e-beam disruption at IP
- Beam halo effects and mitigation
- Synchronisation R&D:
    - DLLRF systems
    - Optical distribution system
- BBU studies:
    - Induce BBU with small time constant ~ 10 -100us
- Instrumentation and beam diagnostics development:
    - EO profile monitors
    - Beam arrival monitors
    - Beam phase and position monitors