Commissioning of the ALICE SRF Systems at Daresbury Laboratory

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ESLS – RF

1st – 2nd October 2008

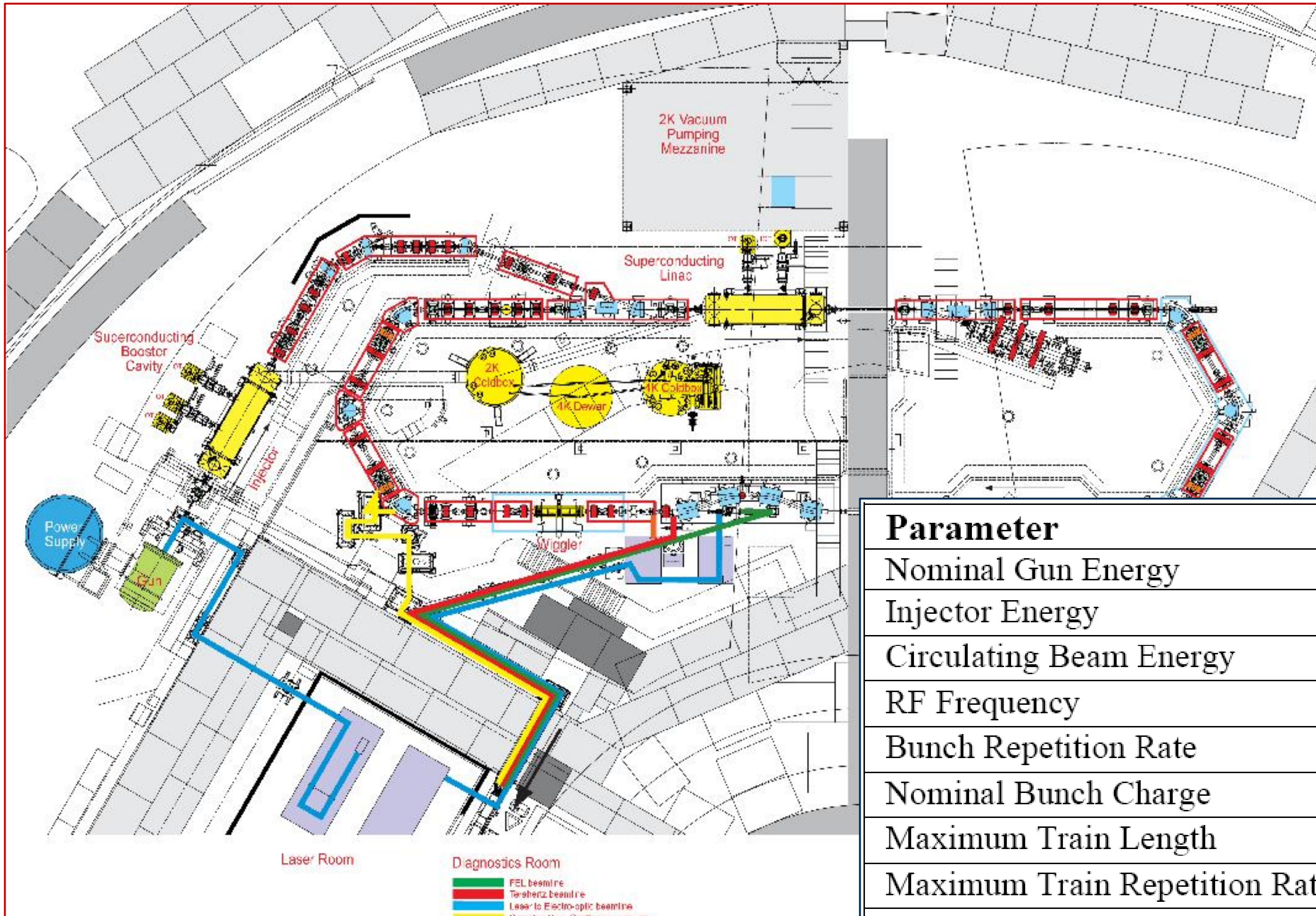
Overview

- ALICE (Accelerators and Lasers In Combined Experiments)
  - Construction Status
  - Commissioning Status
  - RF System
    - SRF Module Commissioning
  - Status and Plans
- Summary

Technical Priorities for the ERL Prototype

- Operate a superconducting linac.
- Produce and maintain bright electron bunches from a photo-injector.
- Produce short electron bunches from a compressor.
- Demonstrate energy recovery.
- Demonstrate energy recovery (with an insertion device that significantly disrupts the electron beam).
- Have an FEL activity that is suitable for the synchronisation needs.
- Produce simultaneous photon pulses from a laser and a photon source of the ERL Prototype that are synchronised at or below the 1 ps level.

The ALICE Complex

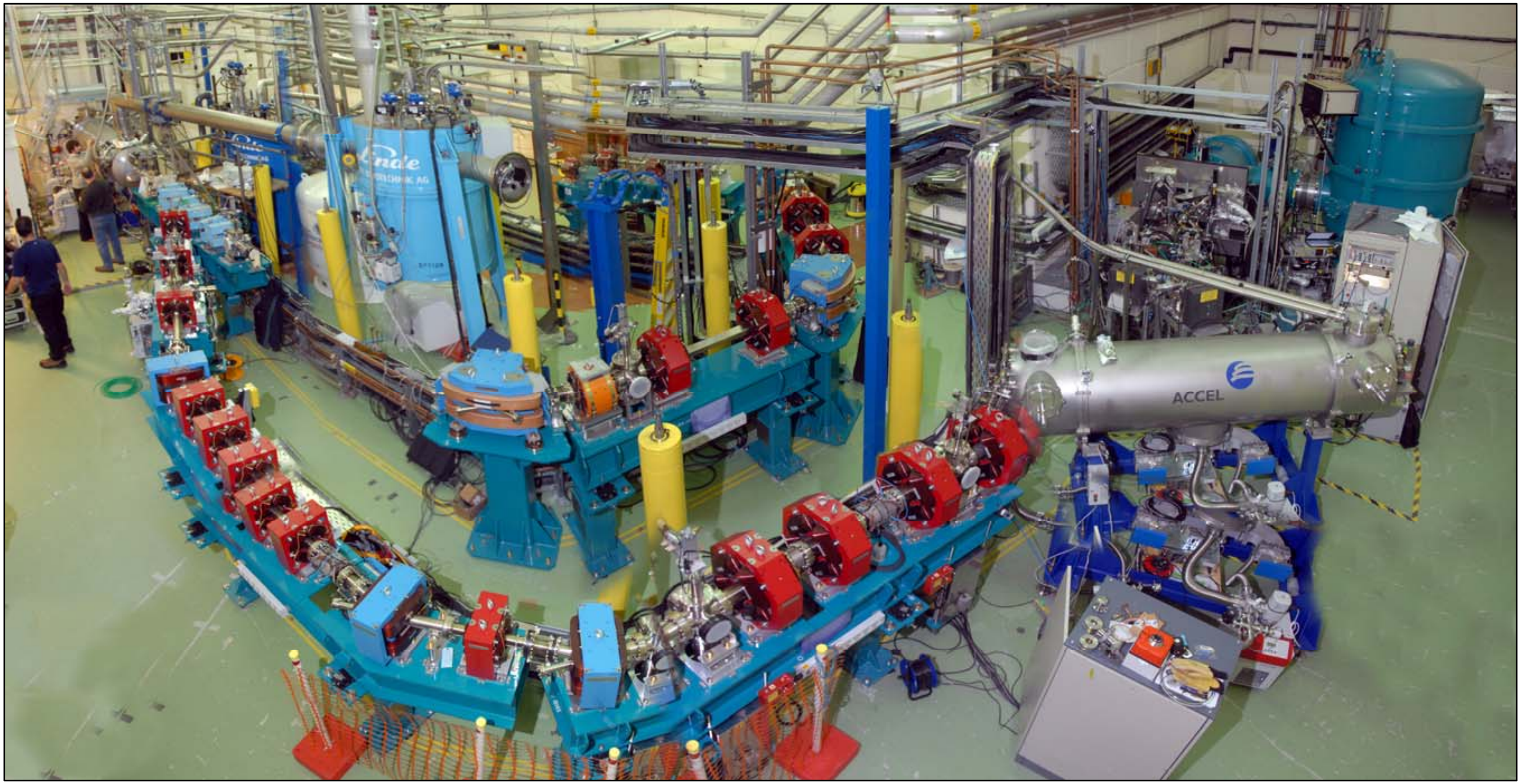


Parameter		Units
Nominal Gun Energy	350	keV
Injector Energy	8.35	MeV
Circulating Beam Energy	35	MeV
RF Frequency	1.3	GHz
Bunch Repetition Rate	81.25	MHz
Nominal Bunch Charge	80	pC
Maximum Train Length	100	µs
Maximum Train Repetition Rate	20	Hz
Maximum Average Current	13	µA

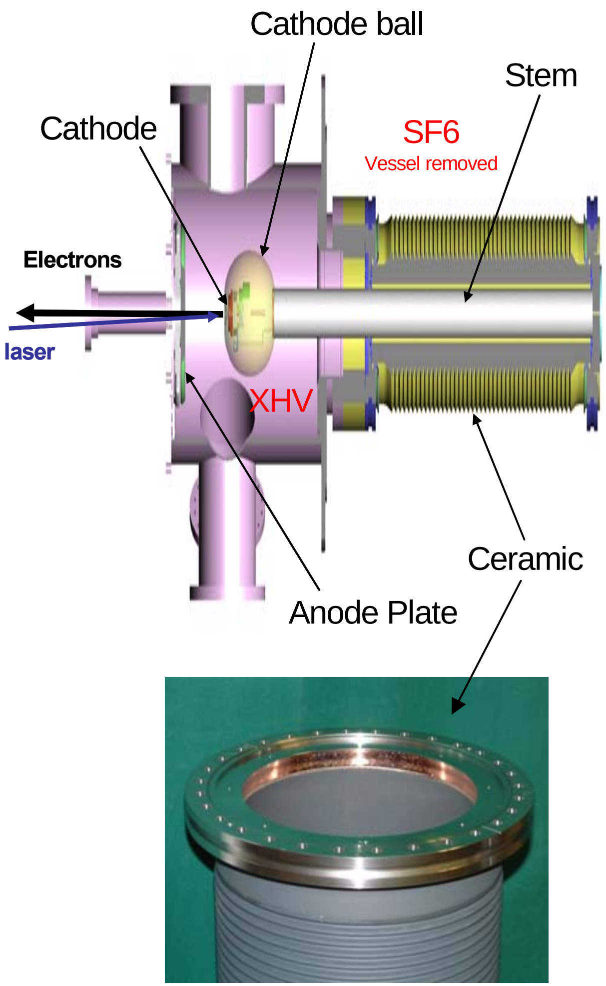
Construction Status

- Photo-injector laser operating since April ’06.
- Superconducting modules installed (July 06).
- Gun installed with a dedicated gun diagnostic beamline (Aug 06).
- First beam achieved from photocathode (Aug 06).
- Beam transport system installed and under vacuum (Feb 07).
- Cryo-system installed and used to cool accelerating modules down to 2K (May 07).
- SRF modules validated to high power (Sept 07).

Accelerator Installation



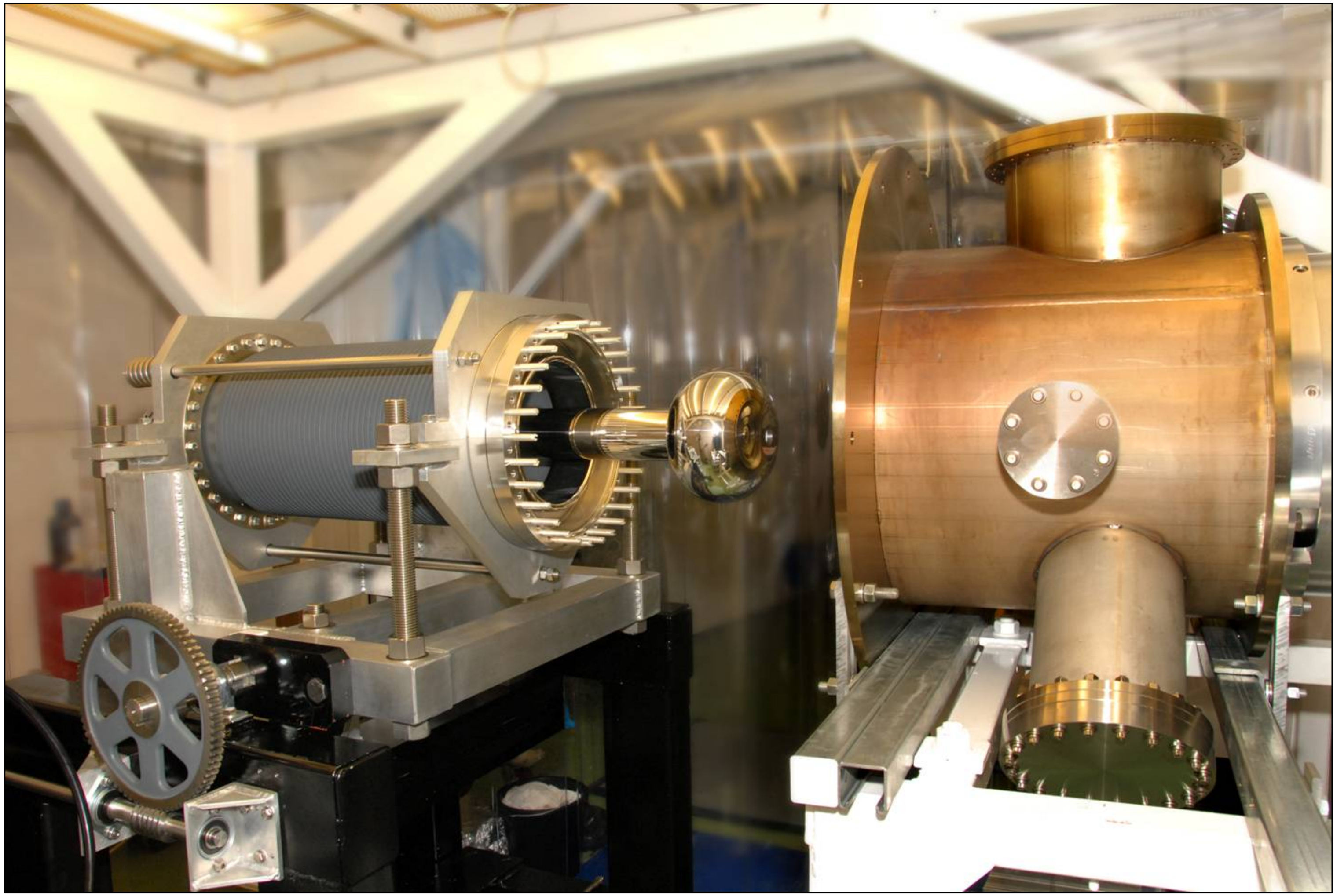
Gun Assembly



- JLab design GaAs cathode.
- 500 kV DC supply.
- Transverse emittance ~3 mm mrad.

- Power supply commissioned '05.
- Ceramic delivered March '06.
- Spare ceramic delivered Nov '06.

Ceramic, Cathode Ball and Gun



Gun Commissioning Status

- Electron gun operated July and August 06.
- First beam from the gun recorded at 01:08 on Wednesday 16th August 06 with the gun operating at 250 kV
  - Encouraging results obtained.
- Physical problems
  - Voltage breakdown issues
  - Field emission issues
  - Vacuum leaks at brazed joints, valves or vacuum flanges
  - Current leakage along the ceramic surface due to contamination from braze particles
- Presently the gun is being prepared for commissioning using a ceramic with a lower voltage capability

First Beam!

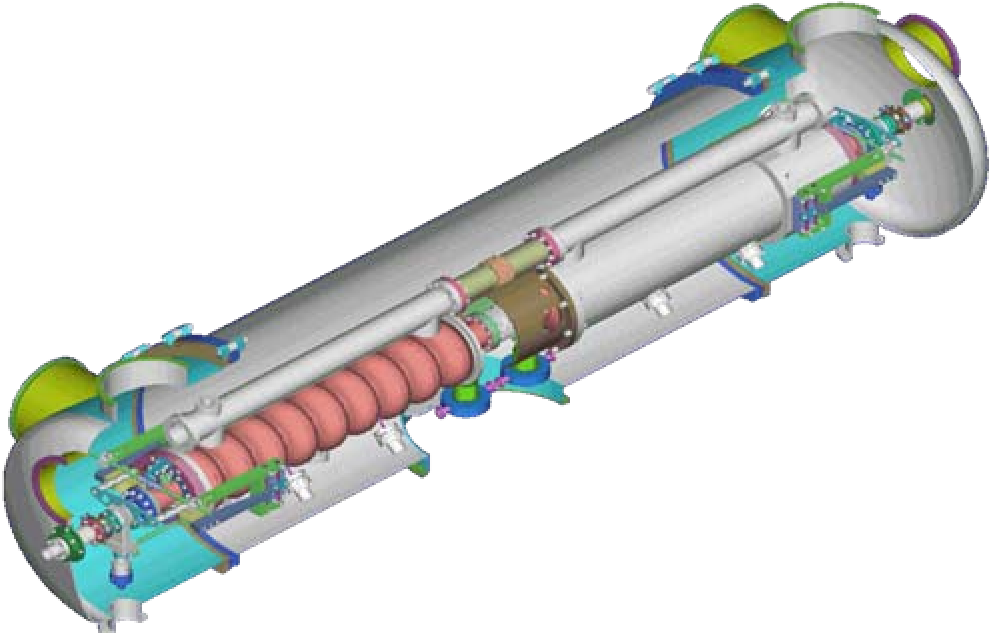
01:08 AM on Wednesday 16th August 06

Performance Achieved To Date

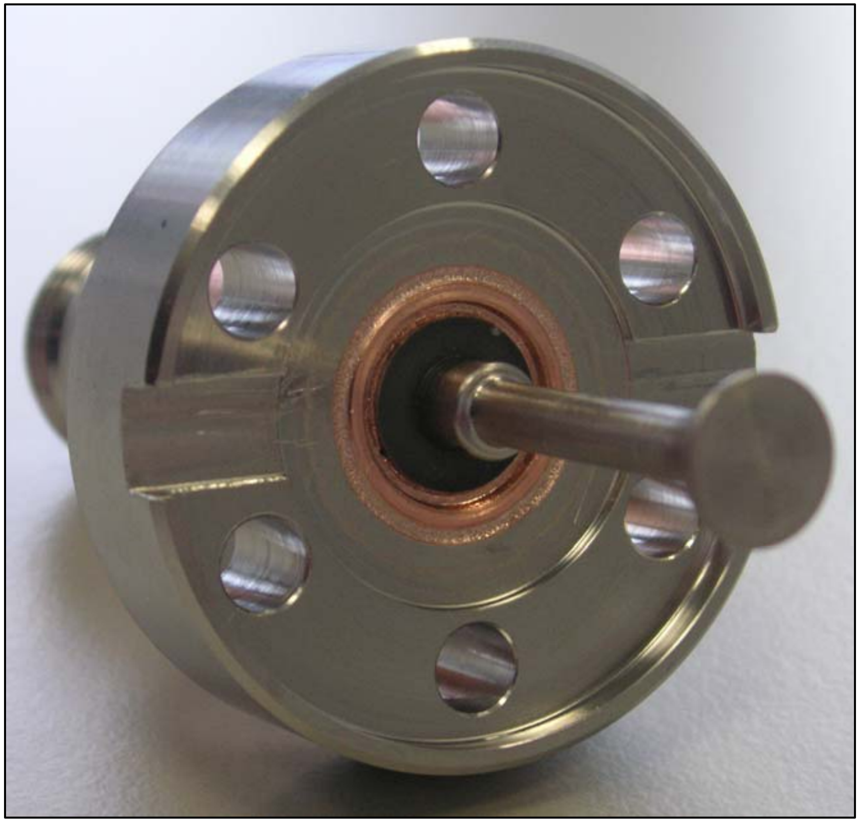
- Beam energy
  - 350 keV (spec value) ✓
- Bunch charge
  - 22 pC (ultimate target 80 pC)
- Quantum efficiency
  - Measured in the gun 1.2 %,
  - Measured in the lab 3.5 % (ultimate target ~ up to 10 %)
- Bunch train length
  - 6 pS pulse at 100 µs (spec value) ✓
- Train repetition rate
  - 20 Hz (spec value) ✓

SRF Modules

- 2 x Stanford/Rossendorf cryo-modules
  - 1 Booster and 1 Main LINAC.
- Fabricated by ACCEL.
- Booster module:
  - 4 MV/m gradient.
  - 52 kW RF power.
- Main LINAC module:
  - 13.5 MV/m gradient.
  - 13 kW RF power.

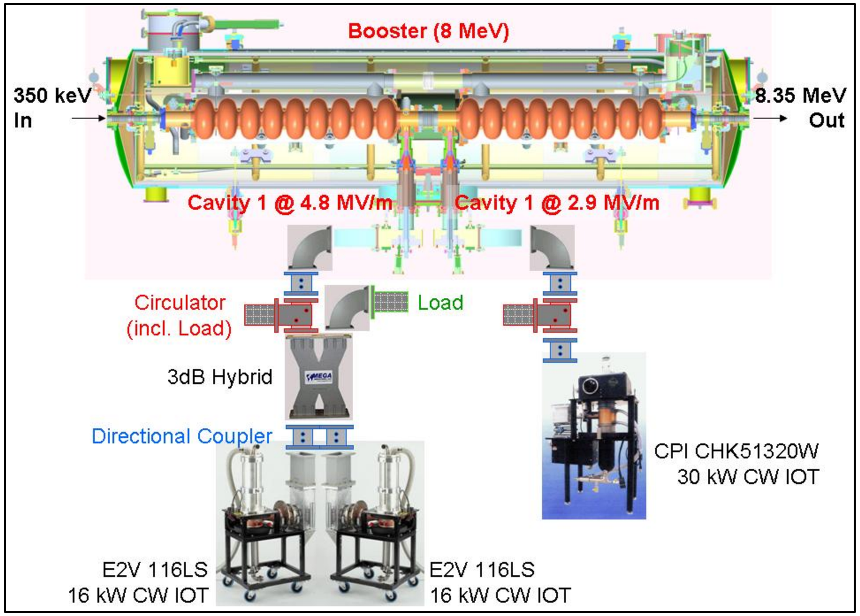


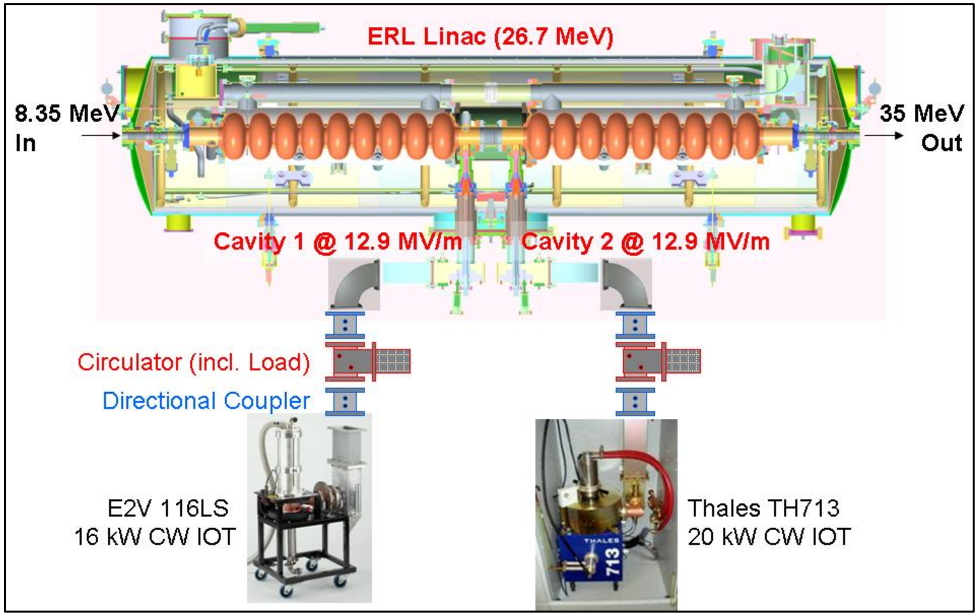
SRF Modules (Cont)



- JLab HOM coupler feed-through design adopted for the LINAC module:
  - Sapphire loaded ceramic.
  - Higher power handling capability.

SRF Modules (Cont)





IOT RF Power Sources

e2v IOT116LS

CPI CHK51320W

Thales TH713

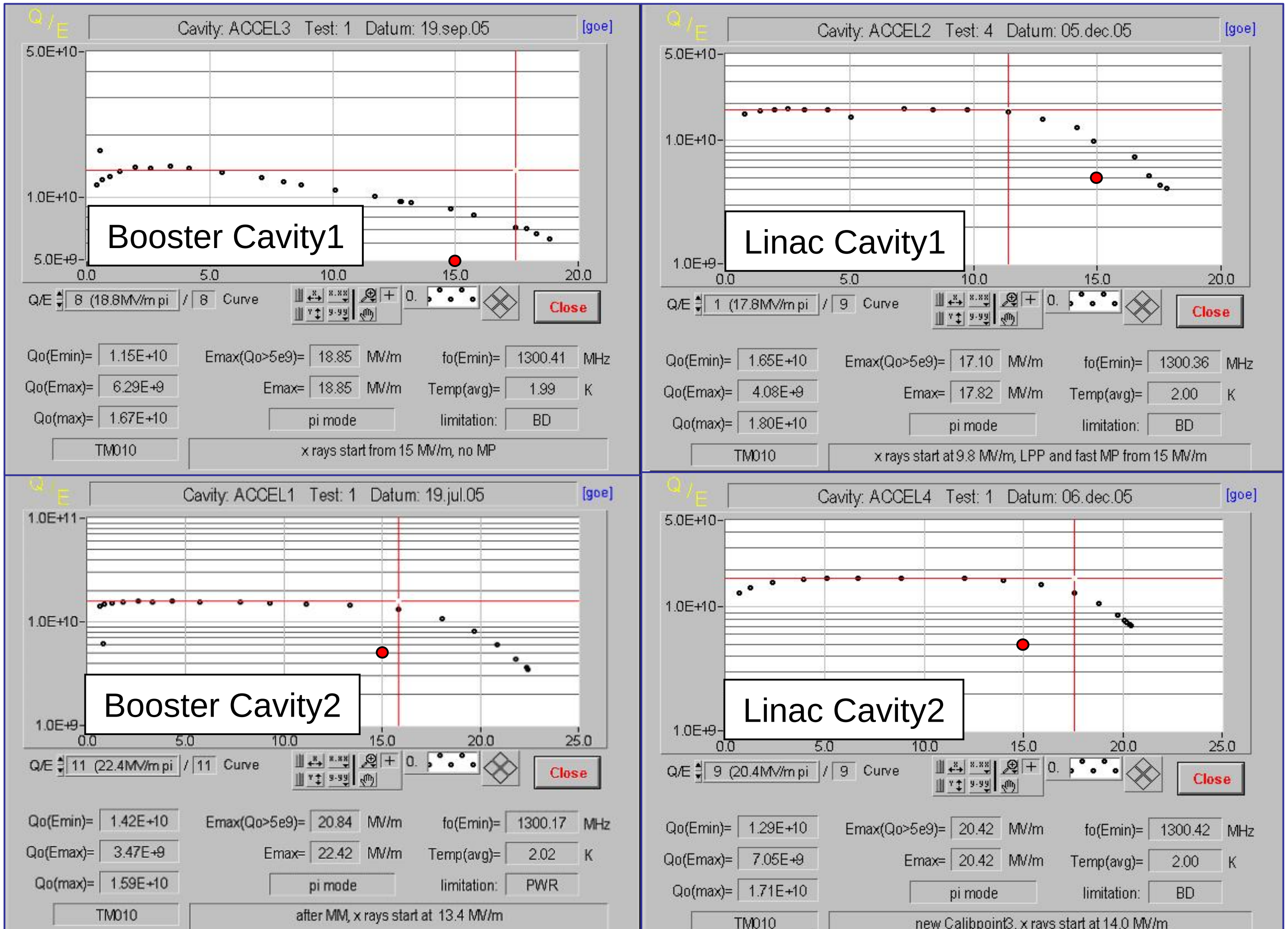
	e2v	CPI	Thales
Frequency (GHz)	1.3	1.3	1.3
Max CW Power (kW)	16	30	16
Gain (dB)	>20	21	20.9
Beam Voltage (kV)	25	34	25
Bandwidth (MHz)	>4	4.5	>5
Efficiency (%)	>60	63.8	60.4

RF System Specifications

	Booster		ERL Linac	
	Cav1	Cav2	Cav1	Cav2
Gradient (MV/m)	5	3	13.5	13.5
Q_o	5×10^{10}	5×10^{10}	5×10^{10}	5×10^{10}
Q_e	3×10^{6}	3×10^{6}	7×10^{6}	7×10^{6}
Power (kW)	32	20	6.7	6.7
Power Source	2 x e2v	CPI	e2v	Thales

0.1ms bunch trains @ 20 Hz repetition rate

Cavity Vertical Tests at DESY



● Specification

Jul – Dec 2005

Cryo-system Operation

- Partial system procured from Linde.
- 4 K commissioning completed May 06.
- SRF Module delivery April and July 06.
- Problems with excessive system heat leaks and heater failure.
- Cryo specification 118 W at 2 K with 1 mbar stability.
- Actually achieved 118 W at 2 K with ± 0.03 mbar stability in May 07.
- Measured 5 W static load for both modules (i.e. ~2.5 W each)
  - Specification < 15 W per module!
- System has operated successfully at 1.8 K with poor stability.

High Power Tests

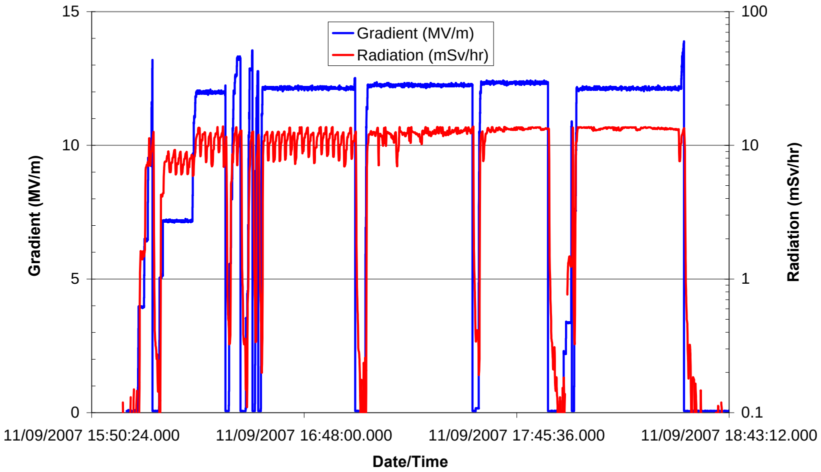
Vertical Tests at DESY (Jul – Dec 2005)

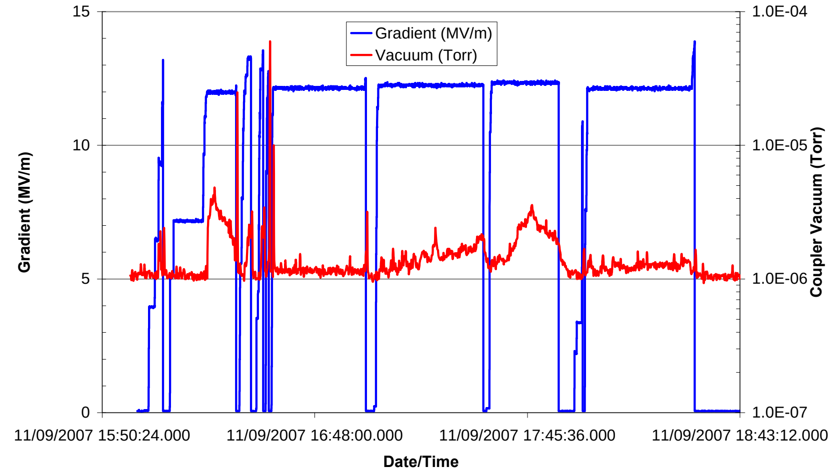
	Booster		Linac	
	Cavity 1	Cavity 2	Cavity 1	Cavity 2
E_{acc} (MV/m)	18.9	20.8	17.1	20.4
Q_o	5×10^9	5×10^9	5×10^9	5×10^9

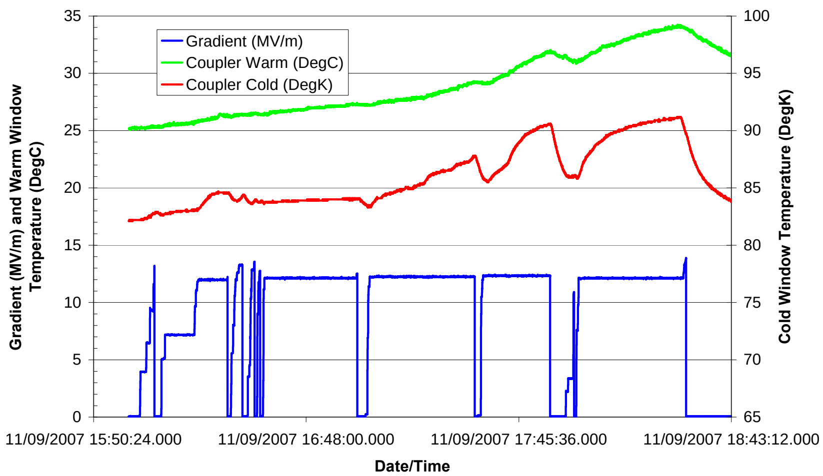
Module Acceptance Tests at Daresbury (May – Sept 2007)

Max E_{acc} (MV/m)	10.8	13.5	16.4	12.8
Q_o	3.5×10^9 @ 8.2 MV/m	1.3×10^9 @ 11 MV/m	1.9×10^9 @ 14.8 MV/m	7.0×10^9 @ 9.8 MV/m
Limitation	FE Quench	FE Quench	RF Power	FE Quench

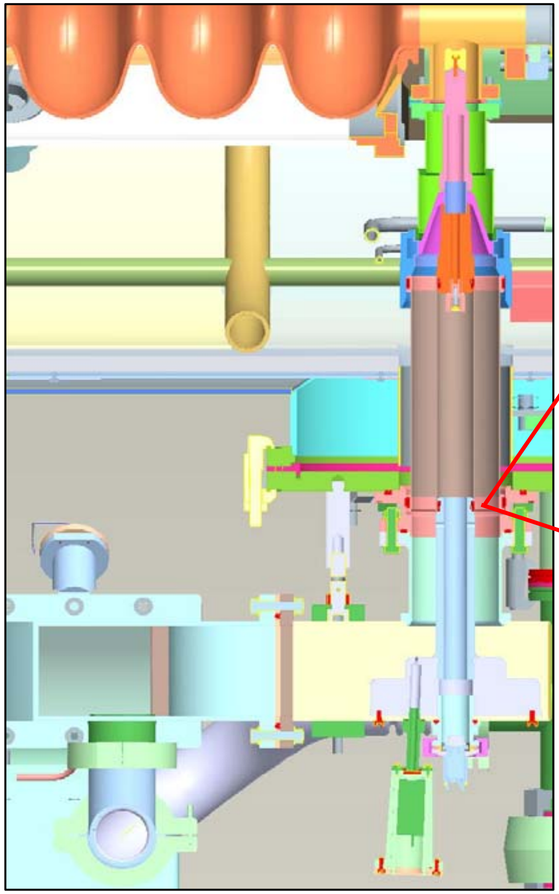
Cavity Processing (Linac – Cav1)

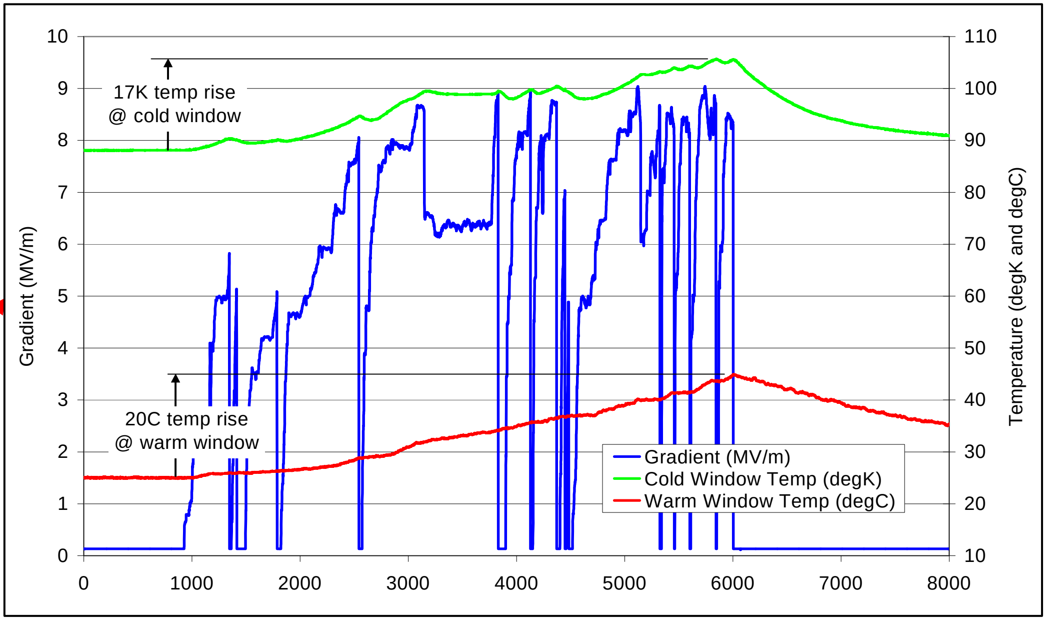


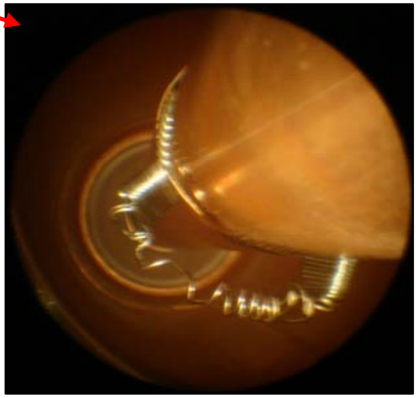


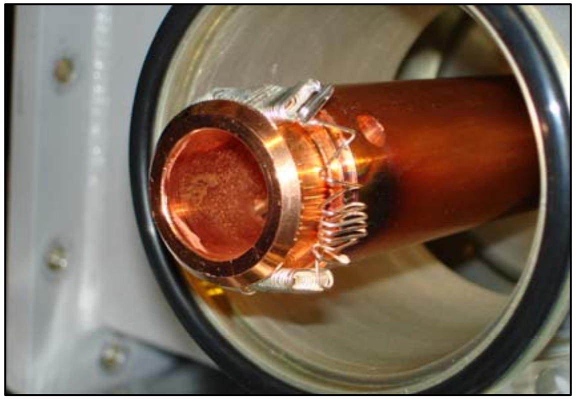


Coupler Heating (Linac – Cav2)

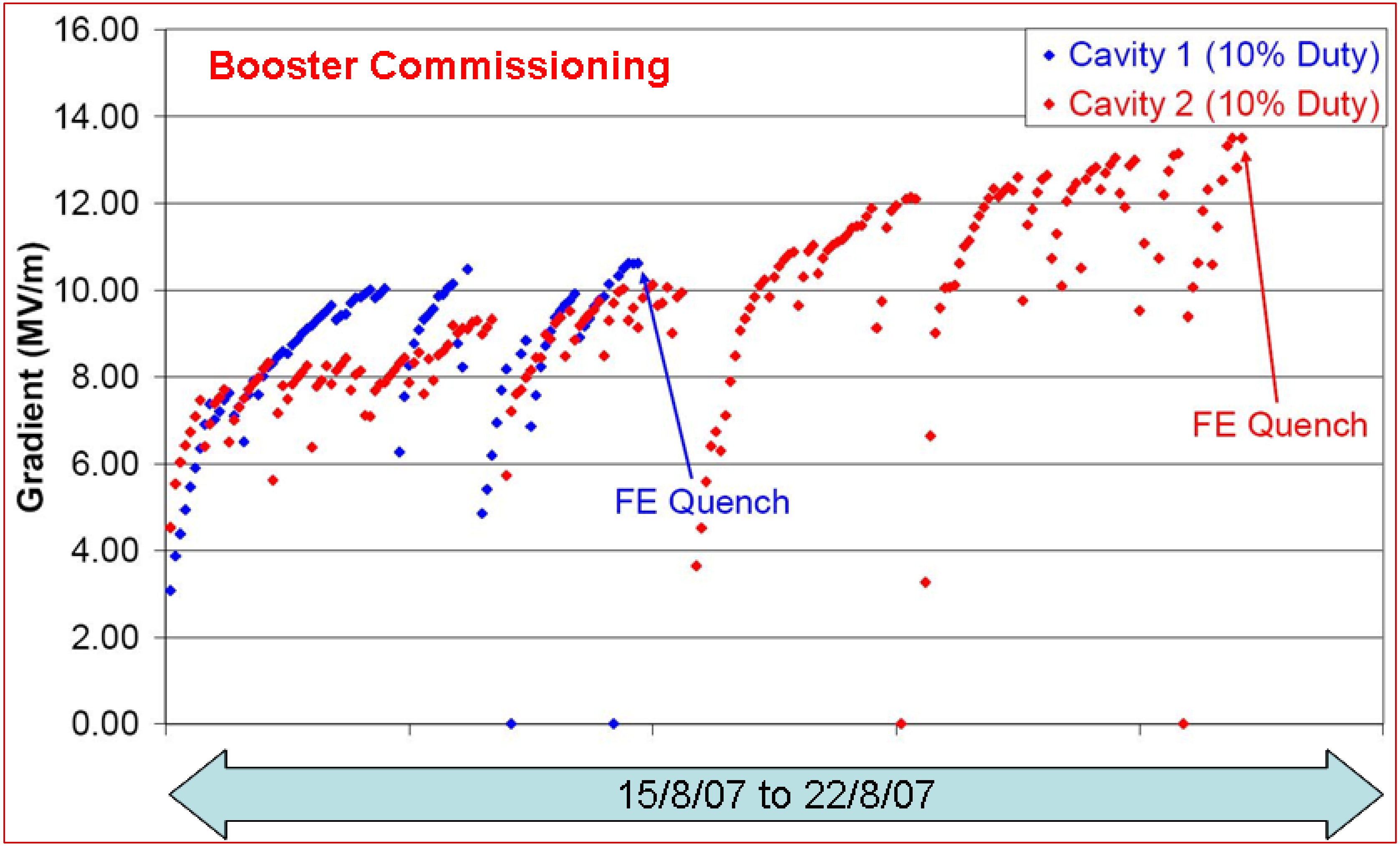




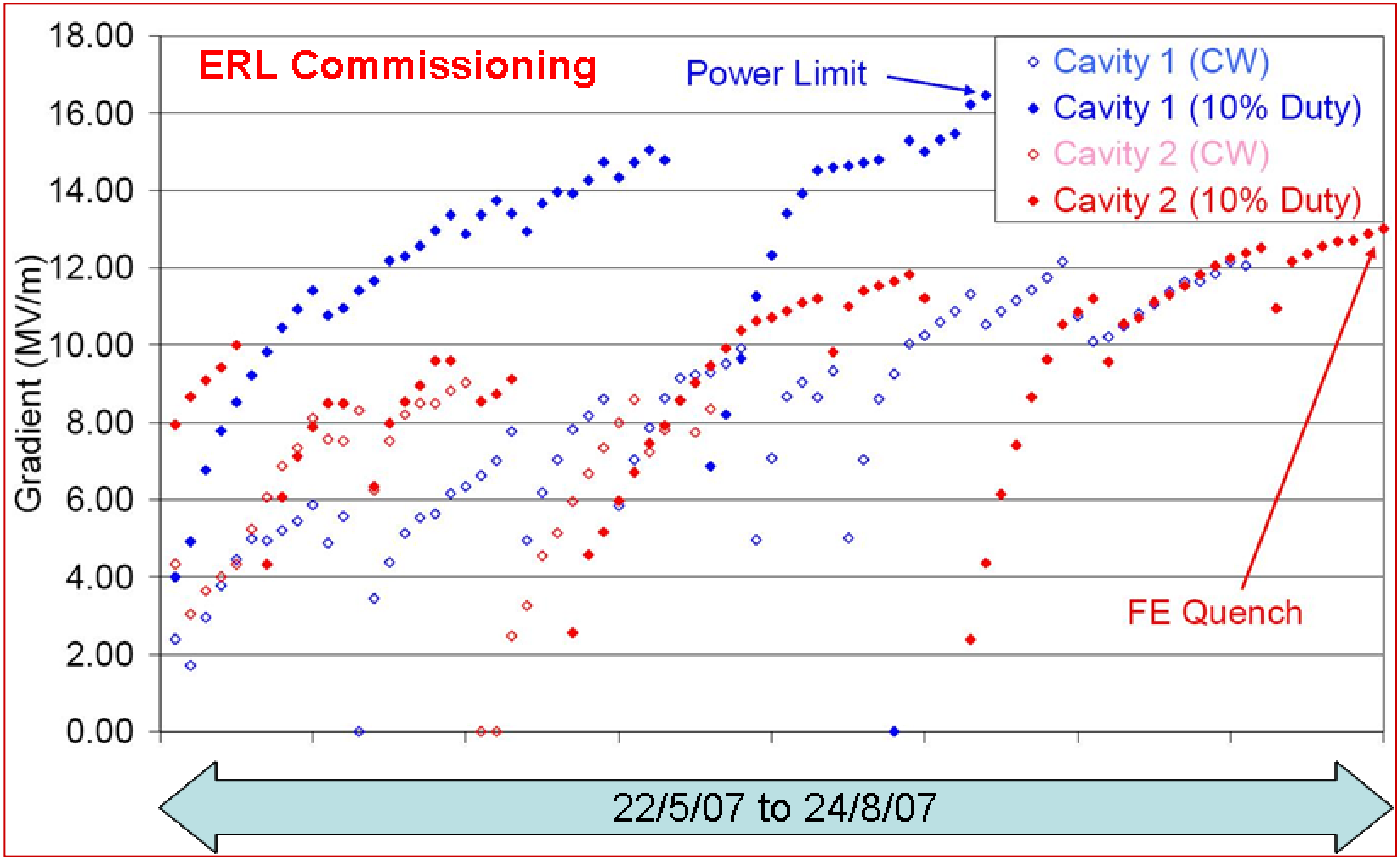




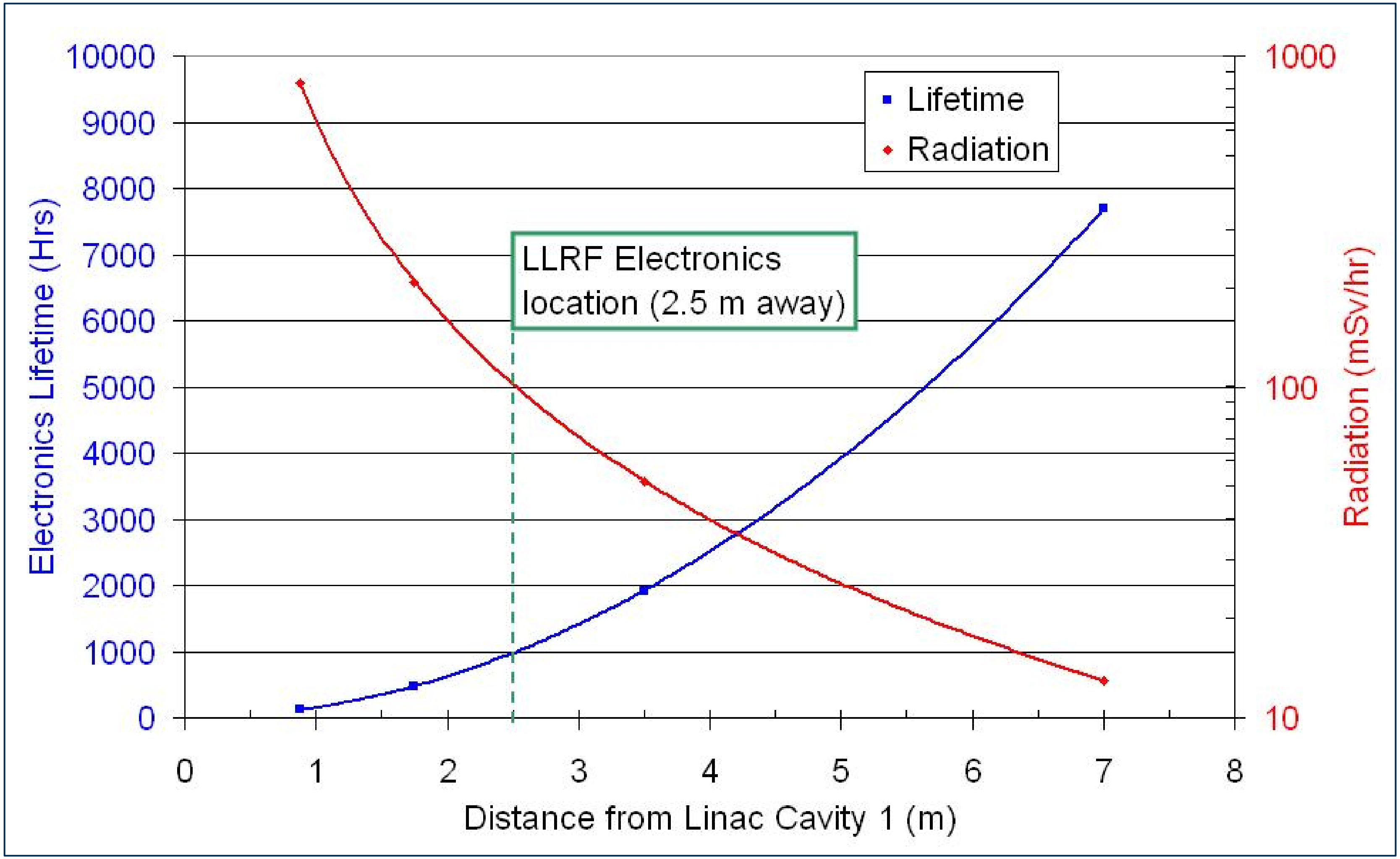
Booster Commissioning



Linac Commissioning



Predicted LLRF Electronics Lifetime at 9 MV/m



Further Cavity Conditioning

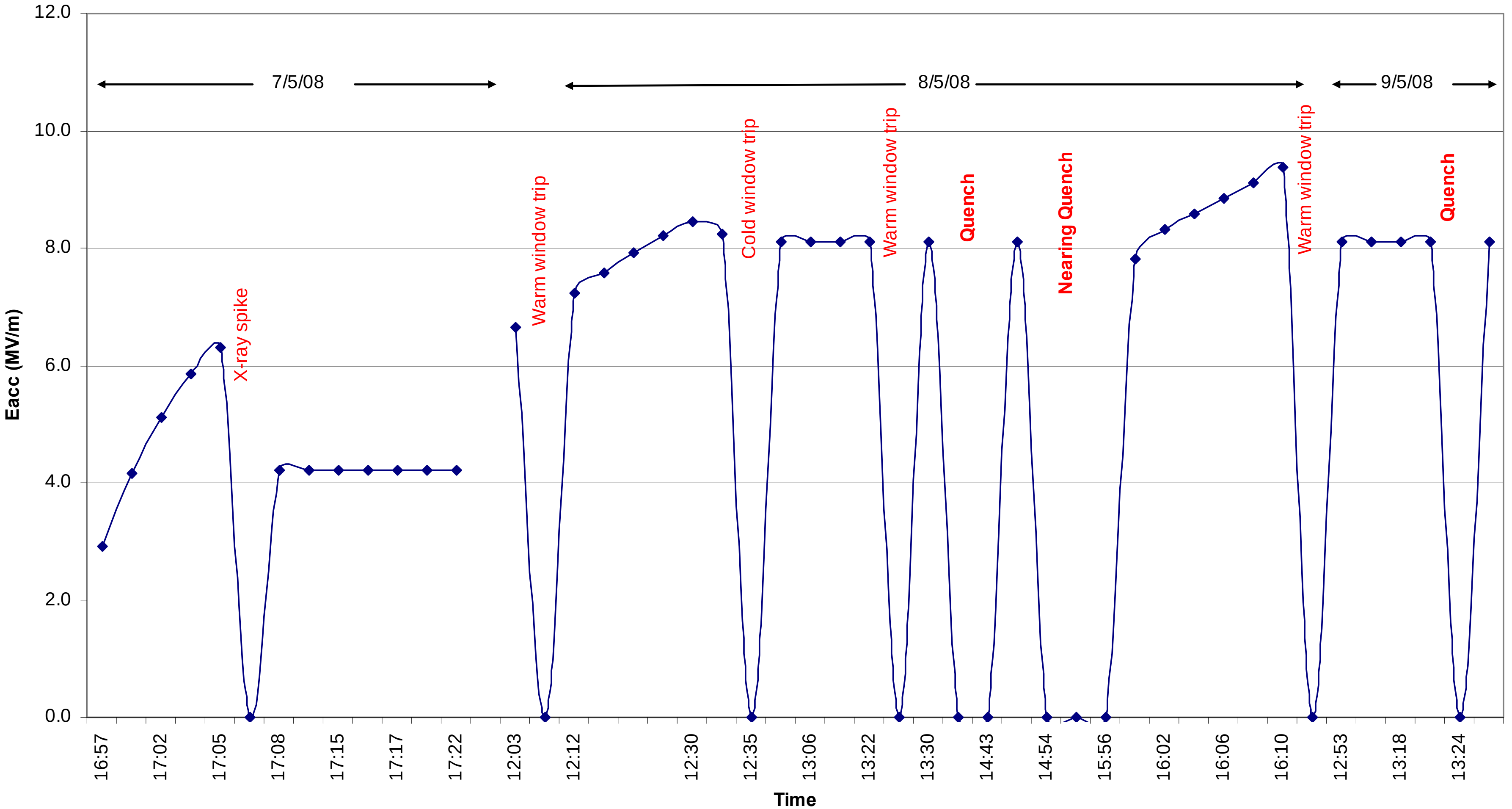
Booster

- Cavity 1
  - E_{acc} = 9.4 MV/m
  - Conditioned for 7:10 hrs
- Cavity 2
  - E_{acc} = 8.8 MV/m
  - Conditioned for 7:30 hrs
- Conditioning
  - 18mS pulse width at 10Hz
  - Some CW conditioning at low power levels

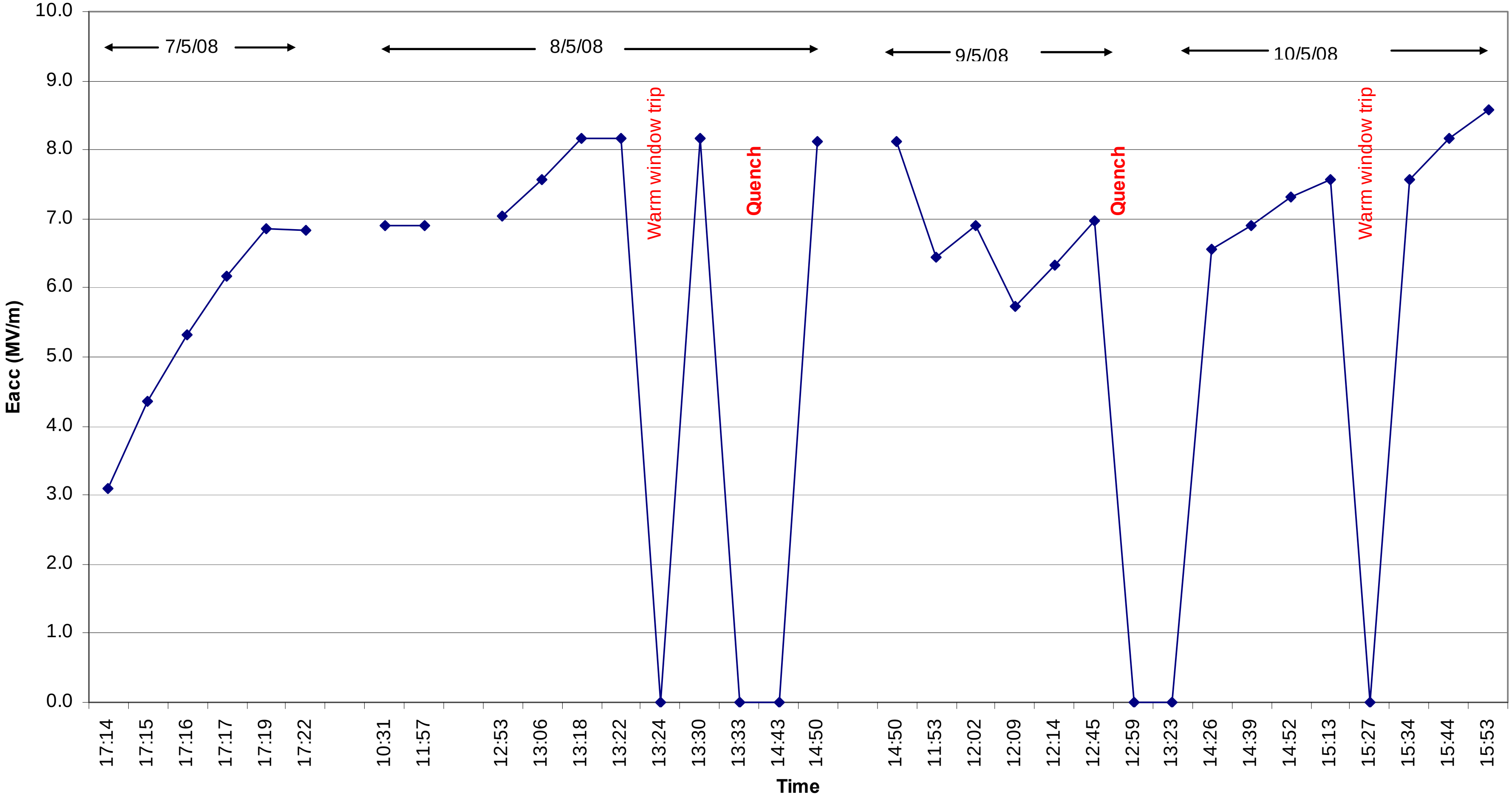
Linac (with lead wall)

- Cavity 1
  - E_{acc} = 10.7 MV/m
  - Conditioned for 5:30 + 5:50 + 4:30
  - Total 10:50hrs
- Cavity 2
  - E_{acc} = 10.8 MV/m
  - Conditioned for 7:10 hrs
- Conditioning
  - 18mS pulse width at 10Hz
  - Some conditioning at narrower pulse widths 1.6mS

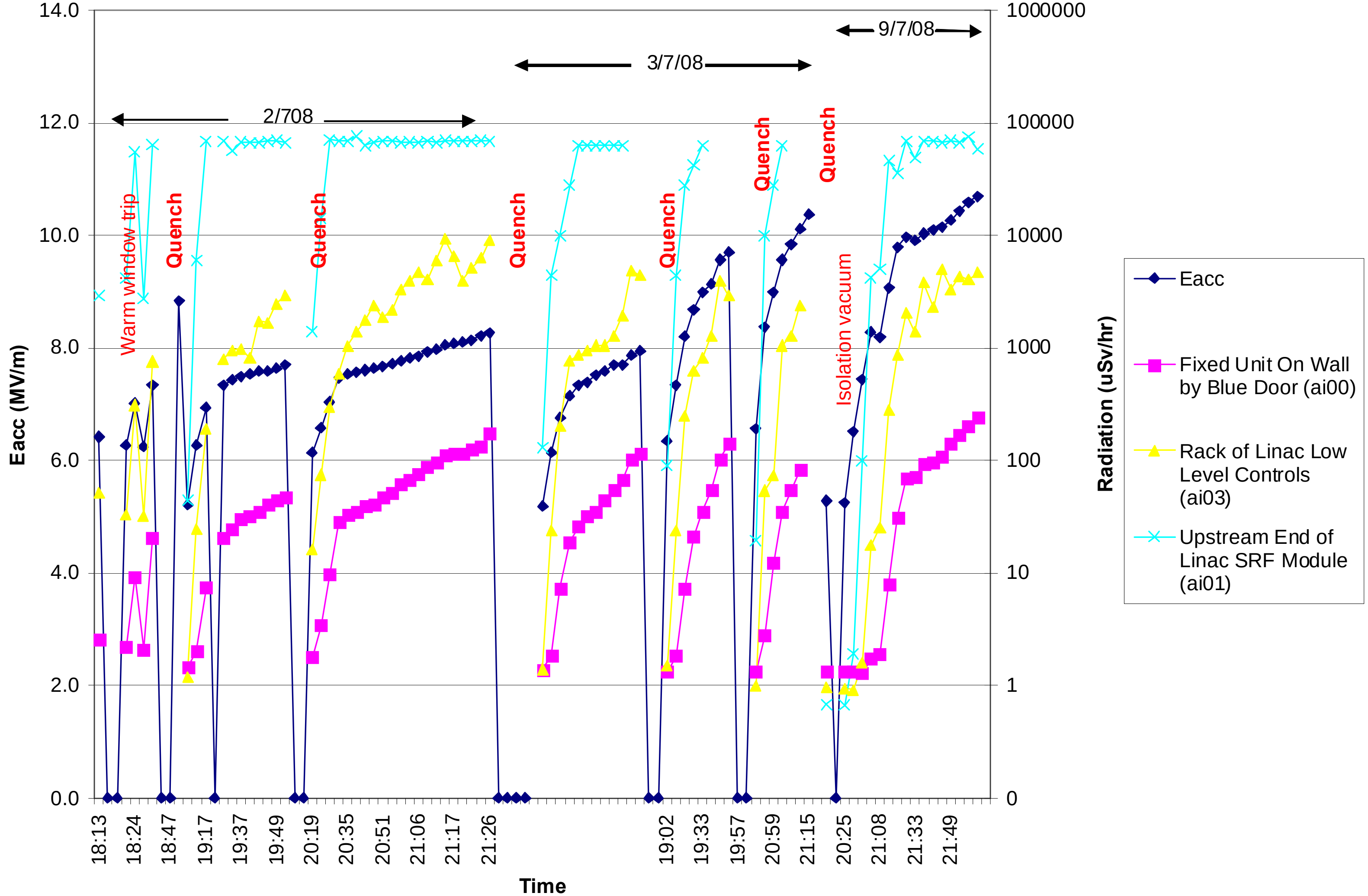
Further Booster Cavity 1 Commissioning



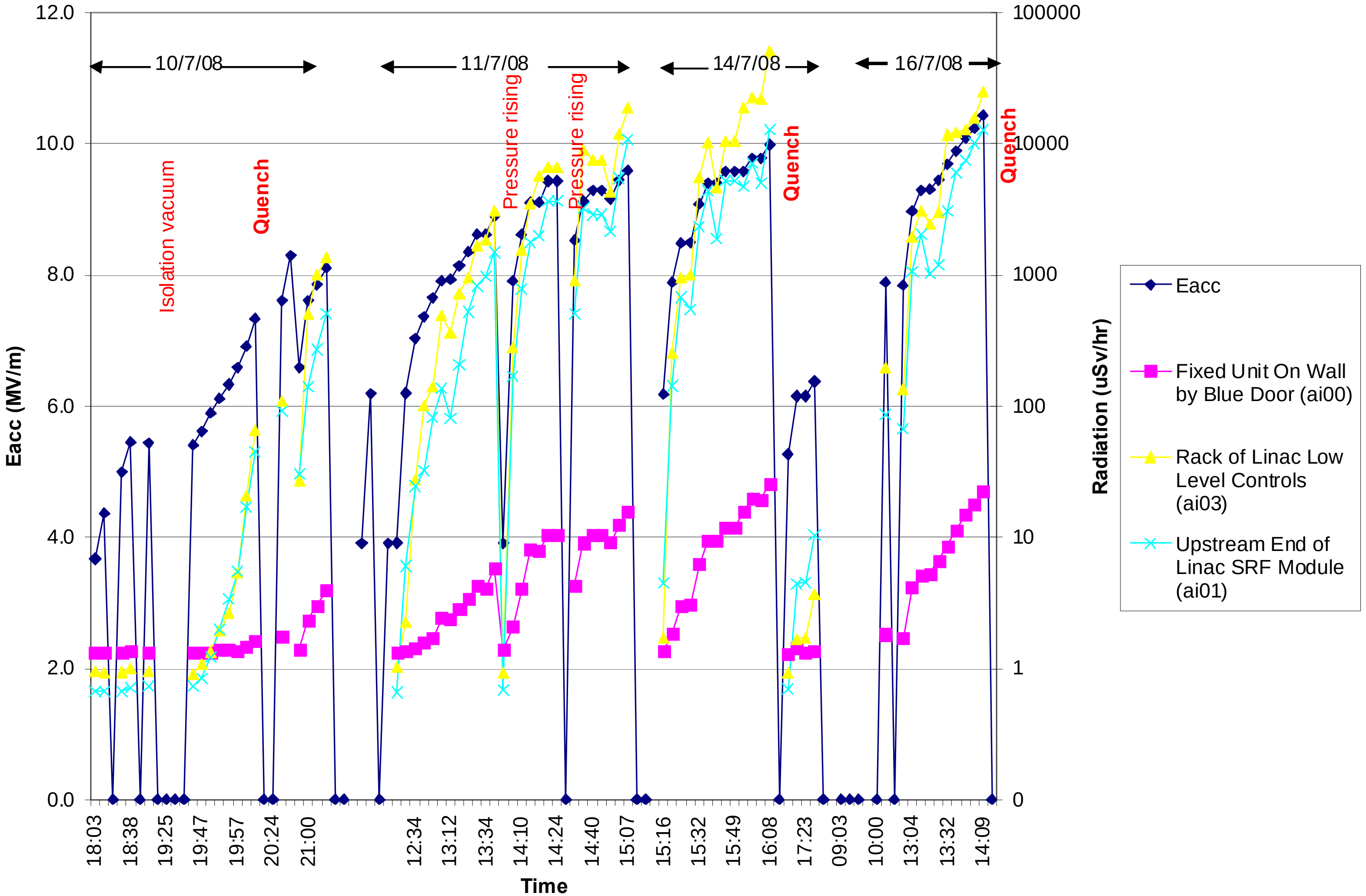
Further Booster Cavity 2 Commissioning



Further Linac Cavity 1 Commissioning

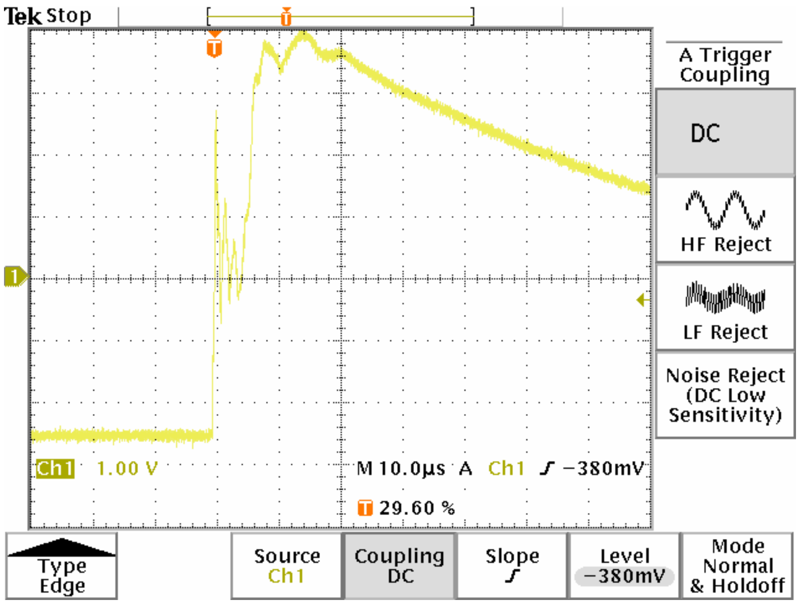


Further Linac Cavity 2 Commissioning



Power Supply Testing

- Failure of auxiliary power supplies during system trips
  - Extensive crowbar testing of the HV system
  - Issue mainly due to the inductance in the long lengths of HV cable
  - Earthing issue discovered
  - Resolved by referencing the return paths for each of the auxiliary power supplies at the power supply



Commissioning Status

- Very high levels of field emission
  - High radiation levels reduced by lead wall around Linac
  - Gradients less for Booster - No lead required
- Auxiliary power supply failures
  - Cable re-wiring proof tested through comprehensive crowbar testing
- All IOTs powered into dummy loads at the same time
- Reduction in performance between the vertical tests and when they are installed in ALICE
  - Further cavity conditioning commencing

ALICE Plans and Schedule

- 2008:
  - Gun commissioning — mid Oct
  - Beam through booster — end Oct
  - Beam through the linac — early Dec
- 2009:
  - Beam through booster, linac and arcs — end Feb
  - Energy recovery demonstrated — end Mar
- Longer term:
  - Exploit THz radiation from compressor
  - Compton backscatter phase 1
  - Install wiggler
  - Energy recovery from FEL-disrupted beam
  - Produce output from the FEL

Summary

- Gun conditioning
  - Numerous issues
  - Conditioning commencing with a lower voltage gun
- SRF Module Commissioning
  - Gradient reduction seen
  - High field emission levels
    - Limited by a lead wall
  - Conditioning commencing