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ERLP and 4GLS at Daresbury

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STFC Daresbury Laboratory
SRF2007, Beijing
15th – 19th October 2007

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Daresbury Laboratory

Overview

- ERLP Overview
  - Construction Status
  - Commissioning Status
  - RF System
    - SRF Module Commissioning
  - Status and Plans
- 4GLS Overview
  - RF System Specifications
  - 4GLS SRF Module R&D
- Conclusions

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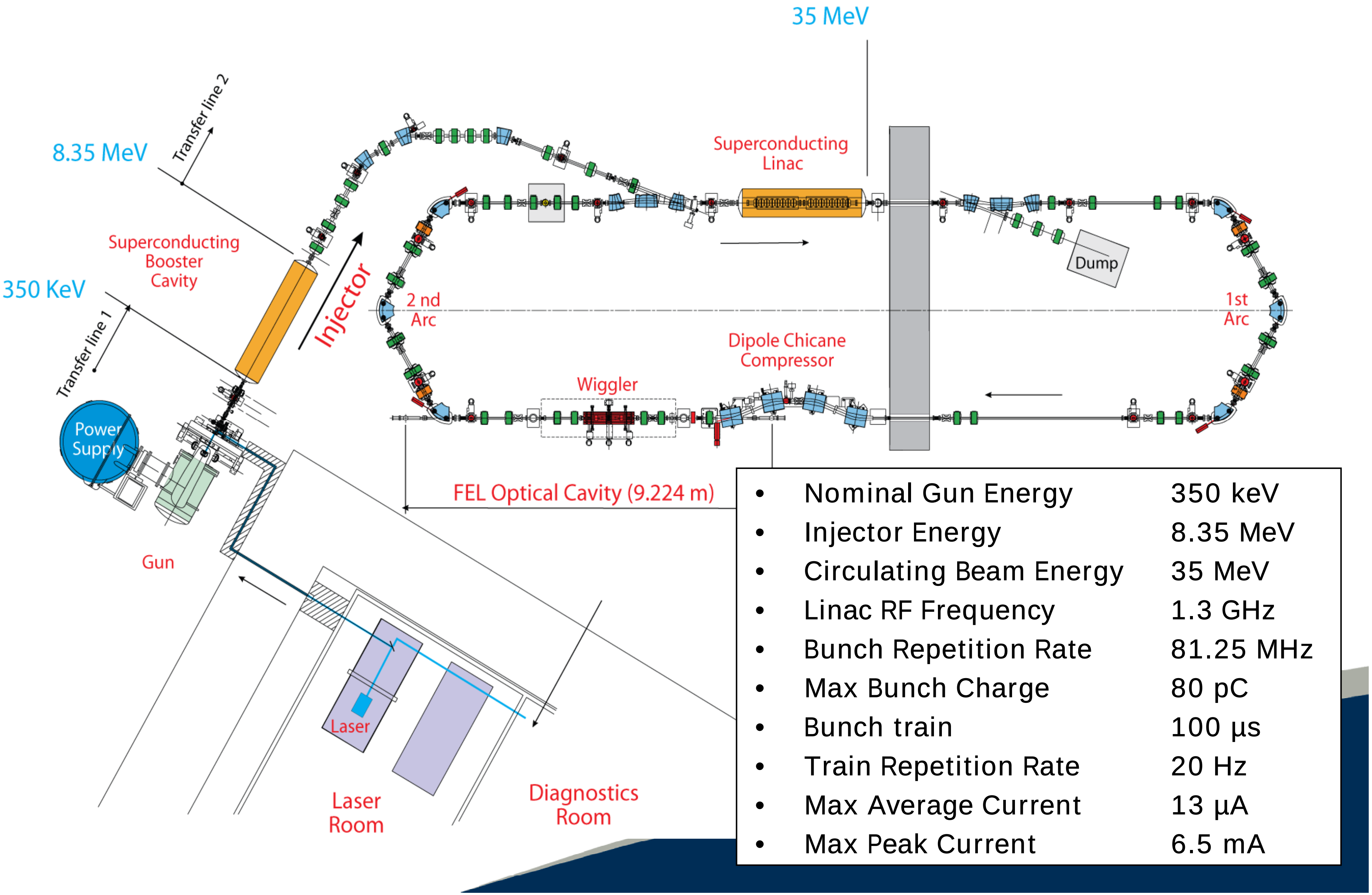
Technical Priorities for the ERL Prototype

- Operate a superconducting linac.
- Produce and maintain bright electron bunches from a photoinjector.
- 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 ERLP Complex



• Nominal Gun Energy	350 keV
• Injector Energy	8.35 MeV
• Circulating Beam Energy	35 MeV
• Linac RF Frequency	1.3 GHz
• Bunch Repetition Rate	81.25 MHz
• Max Bunch Charge	80 pC
• Bunch train	100 µs
• Train Repetition Rate	20 Hz
• Max Average Current	13 µA
• Max Peak Current	6.5 mA

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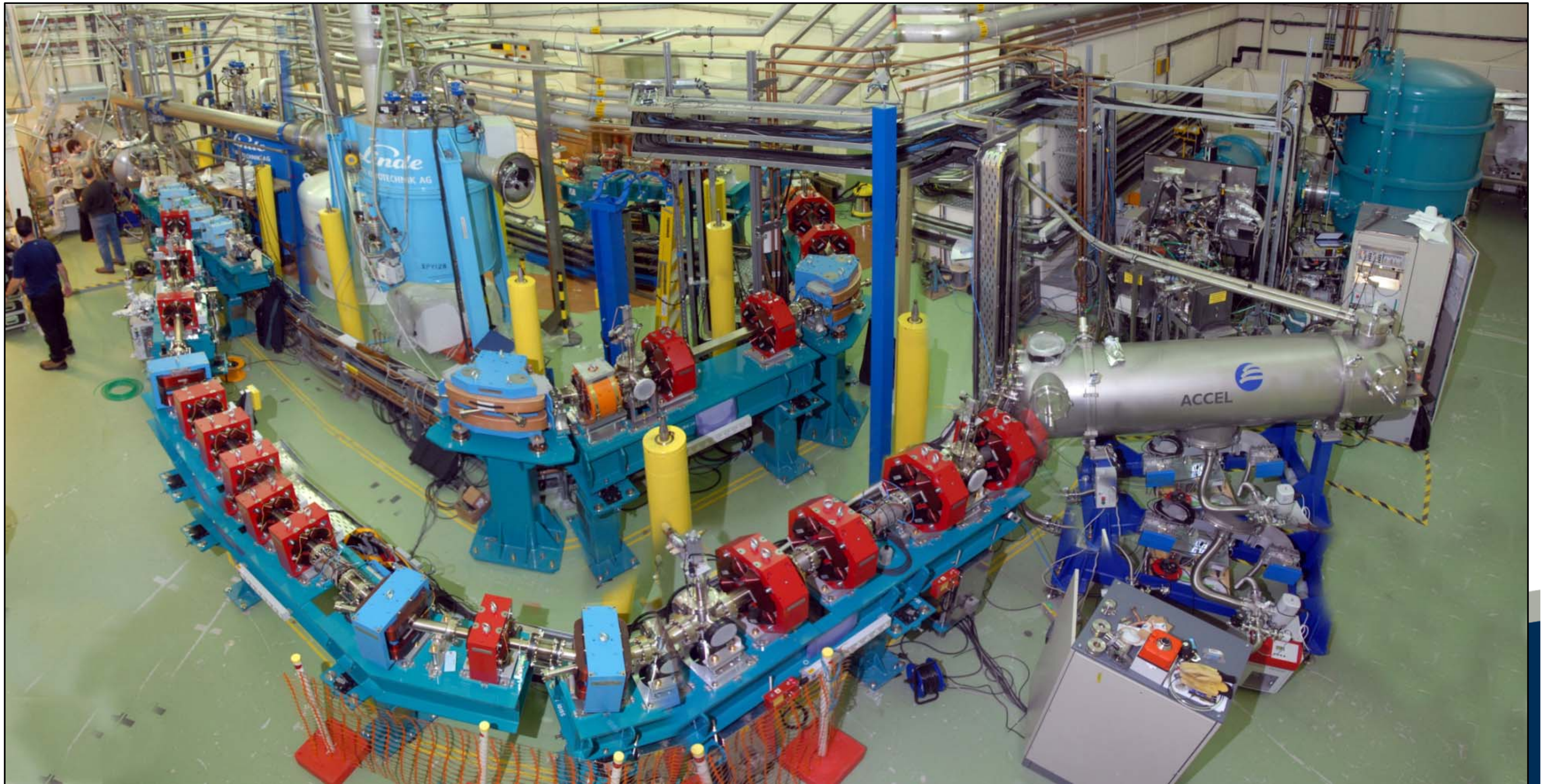
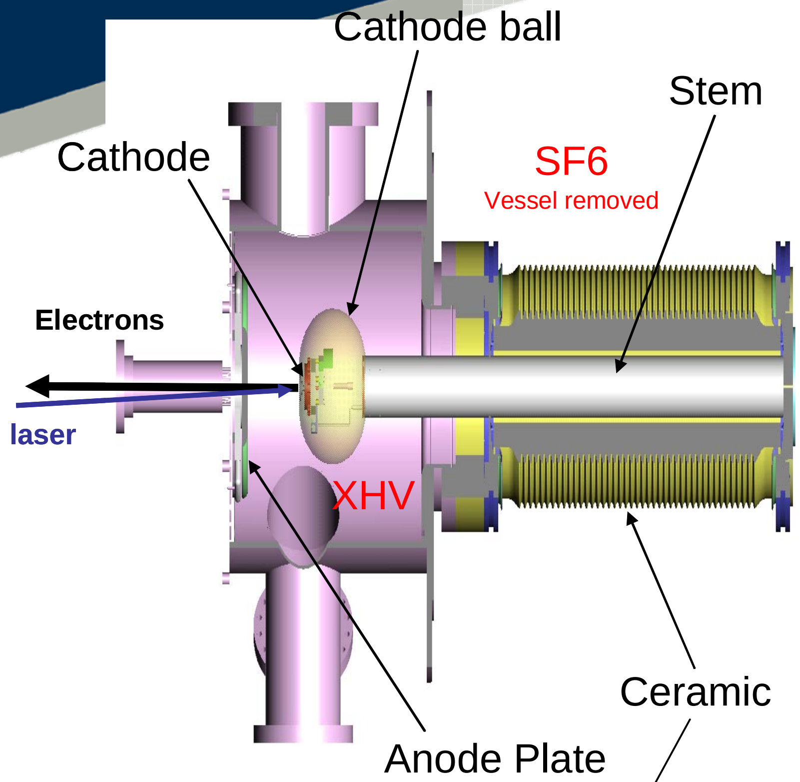
Construction Status

- Photoinjector laser operating since April '06.
- Both 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).
- Cryosystem installed and used to cool accelerating modules down to 2K (May 07).
- SRF modules validated to high power (Sept 07).

Accelerator installation



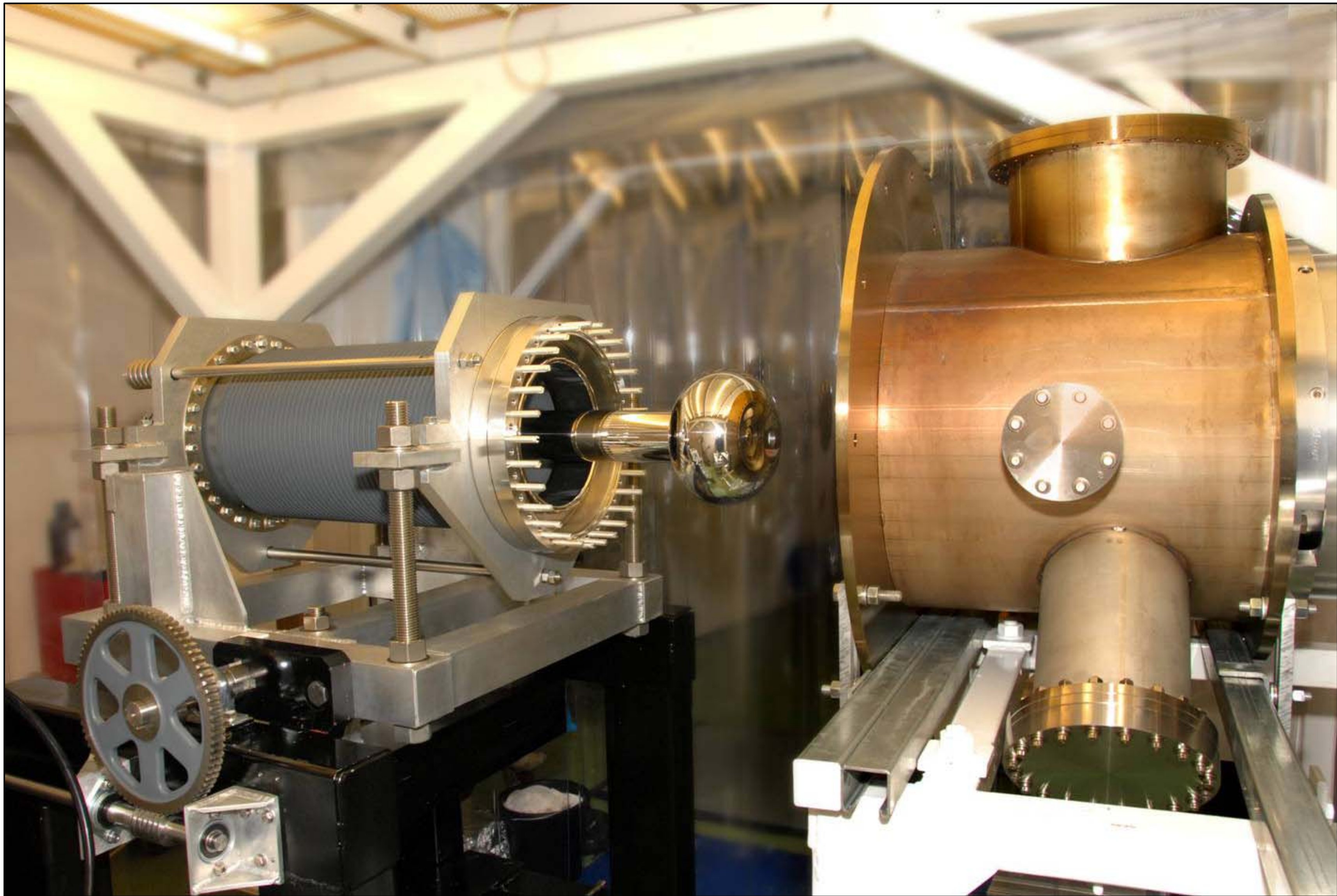
Gun Assembly



- 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



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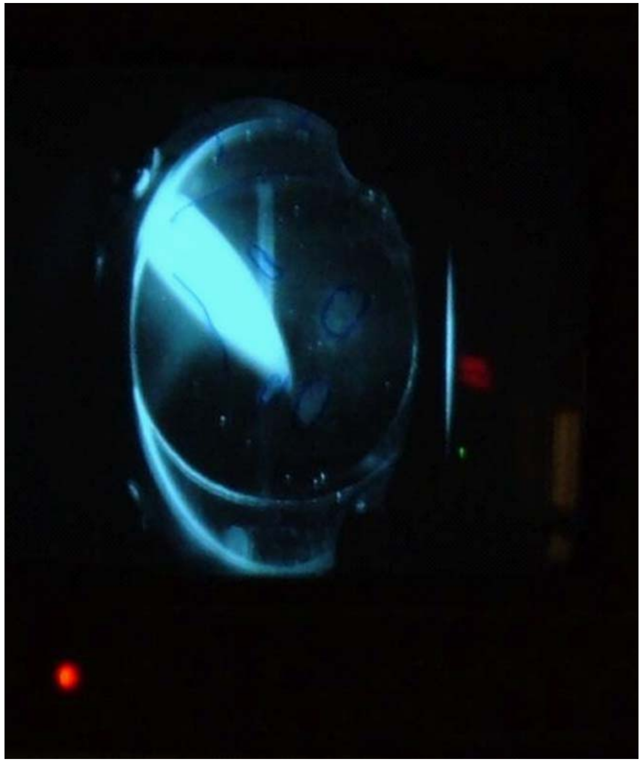
Gun Commissioning Status

- 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.
- Gun unable to support high voltage following cathode re-caesiation at the end of Aug 06.
- Gun was rebaked and still exhibited similar breakdown.
- Gun stripped down and cleaned.
- Electron gun reassembled operating at 350 kV in Jan 07.
- Limited by field emission to lower volts.
- Gun bake temperature increased to 250 C.
- Cathode change after mechanical damage to flap, operation @ 350 keV & 250 keV.
- Diagnostic, buncher and kicker commissioned at low charge.
- Cathode lifetime very poor, halo problems some field emission from flap during conditioning.
- Changed cathode, "solved" DC ion current problem, tightened handling methods, changed vacuum criteria, increased uniformity of bake, changed to NF3.
- Gun ceramic braze failure Aug 07.
- Gun bake temperature reduced to 230 C.
- Spare ceramic installed and baking right now.

First Beam!



01:08 AM on Wednesday 16th August 06

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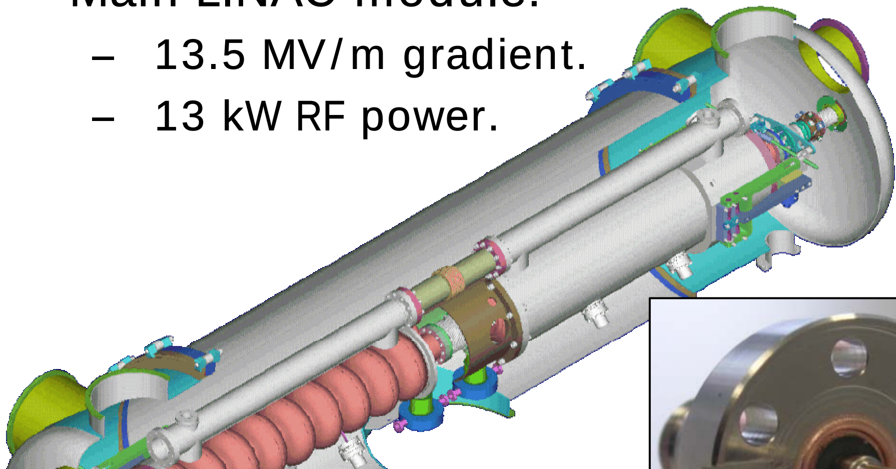
Performance Achieved To Date

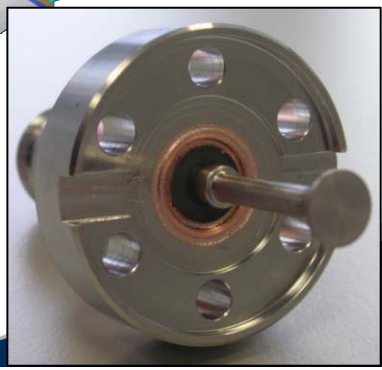
- Beam energy
  - 350 keV (spec value) ✓
- Bunch charge
  - 22 pC (ultimate target 80 pC)
- Quantum efficiency
  - measured in the gun 1.2 %,
  - measured in the lab 3.5 % (ultimate target ~ up to 10 %)
- Bunch train length
  - 6 ps pulse @ 100 μs (spec value) ✓
- Train repetition rate
  - 20 Hz (spec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

SRF Modules

- 2 x Stanford/Rossendorf cryomodules
  - 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.



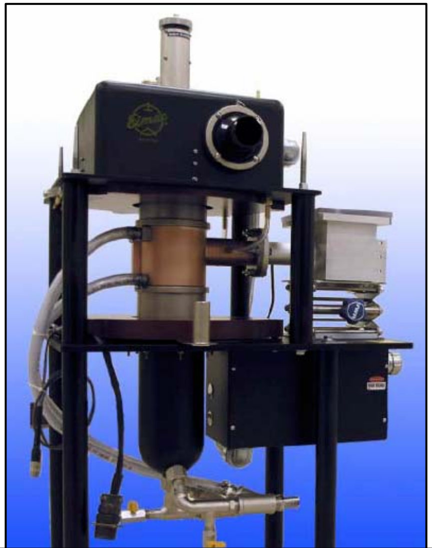
- JLab HOM coupler feedthrough design adopted for the LINAC module:
  - Sapphire loaded ceramic.
  - Higher power handling capability.



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	20
Gain (dB)	>20	21	20.9
Beam Voltage (kV)	25	34	34
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

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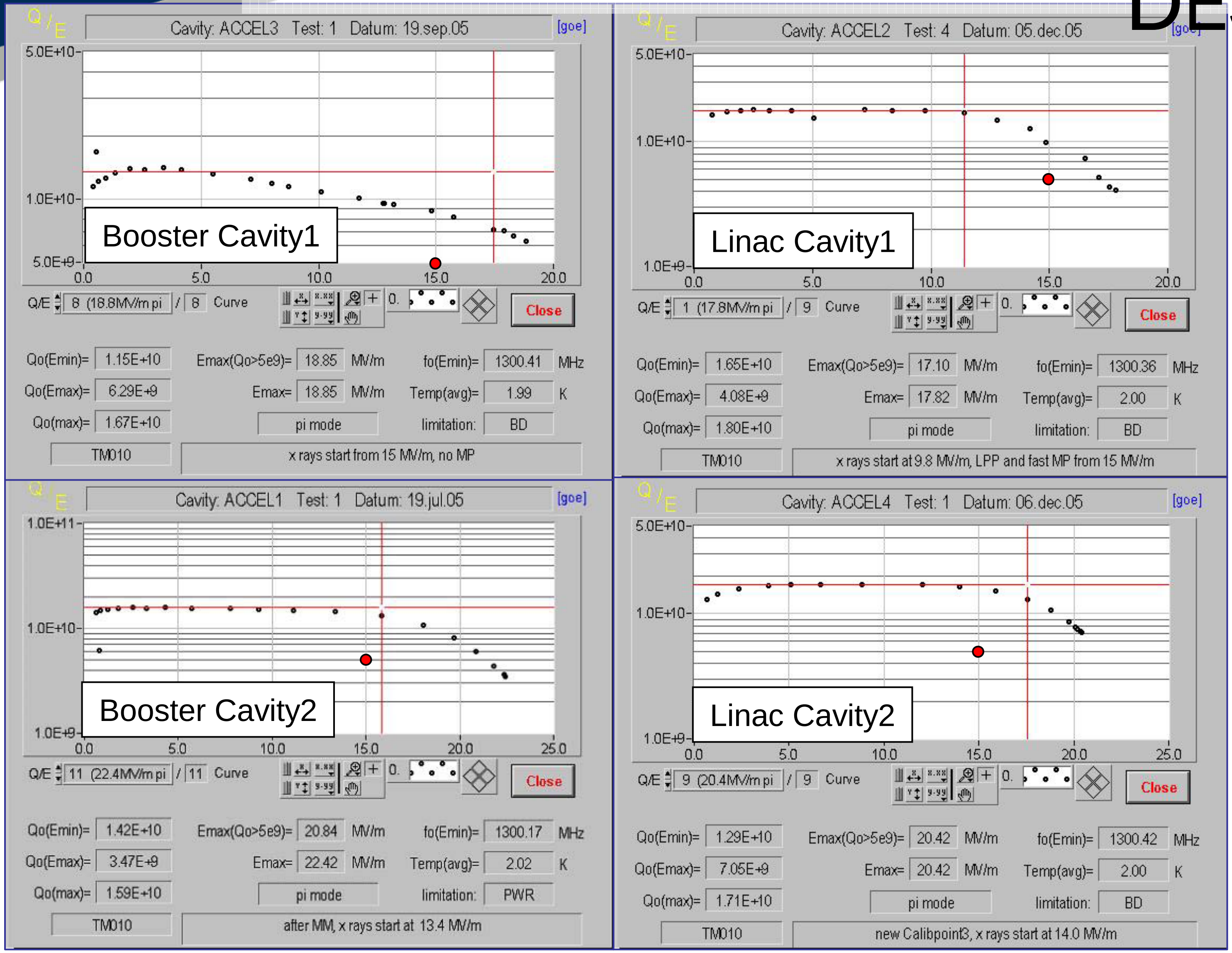
Cavity Vertical Tests at DESY



Jul – Dec 2005

High Power Tests

Vertical Tests at DESY (Jul – Dec 2005)

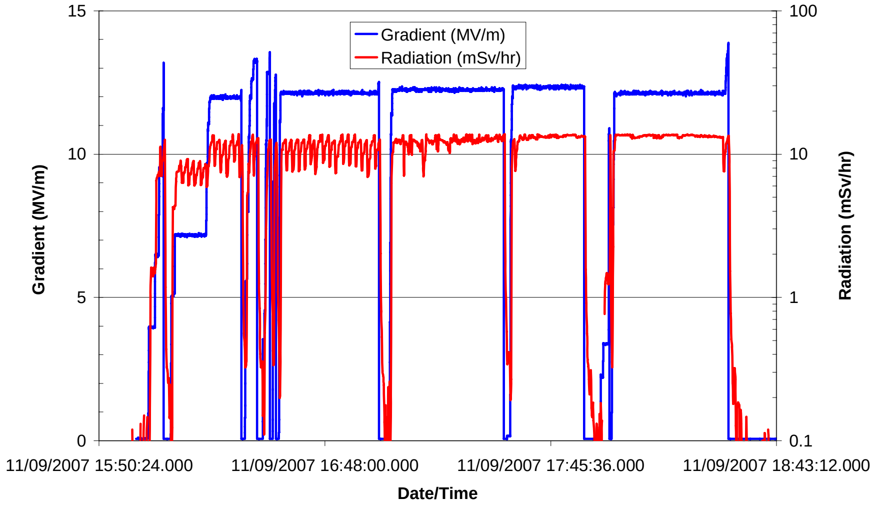
	Booster		Linac	
	Cavity 1	Cavity 2	Cavity 1	Cavity 2
E_{acc} (MV/m)	18.9	20.8	17.1	20.4
Q_o	5×10^9	5×10^9	5×10^9	5×10^9

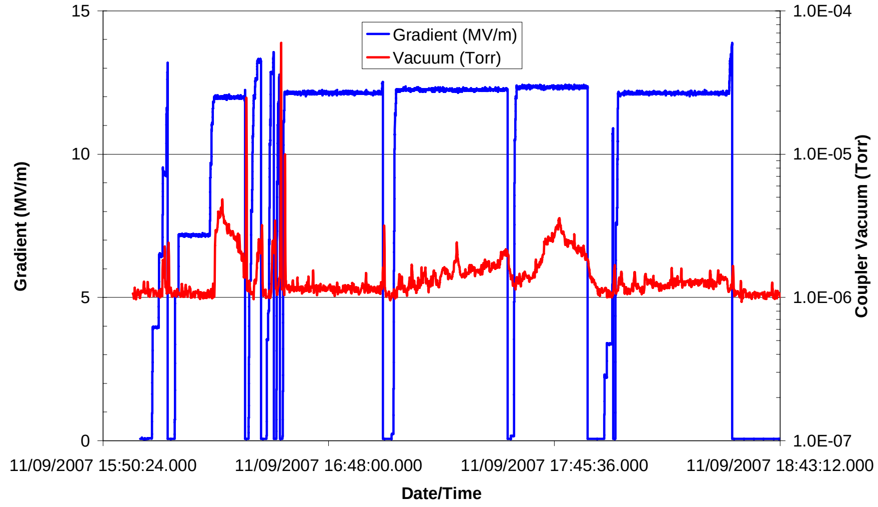
Module Acceptance Tests at Daresbury (May – Sept 2007)

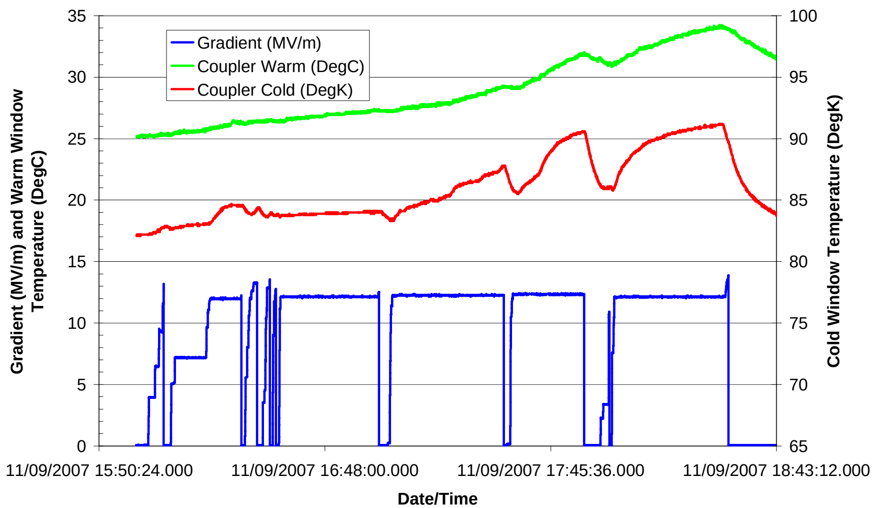
Max E_{acc} (MV/m)	10.8	13.5	16.4	12.8
Q_o	3.5×10^9 @ 8.2 MV/m	1.3×10^9 @ 11 MV/m	1.9×10^9 @ 14.8 MV/m	7.0×10^9 @ 9.8 MV/m
Limitation	FE Quench	FE Quench	RF Power	FE Quench

See Poster: TUP63

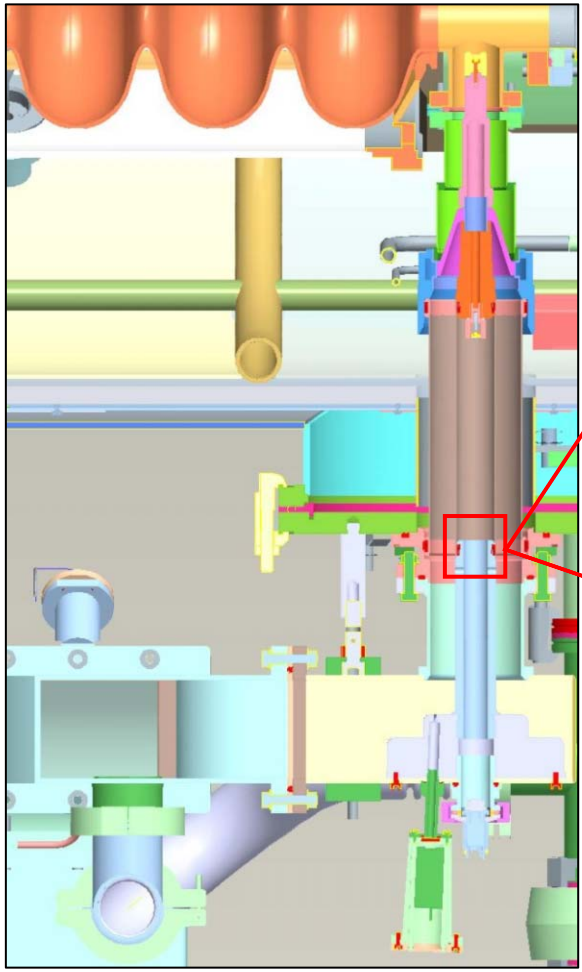
Cavity Processing (Linac – Cav1)

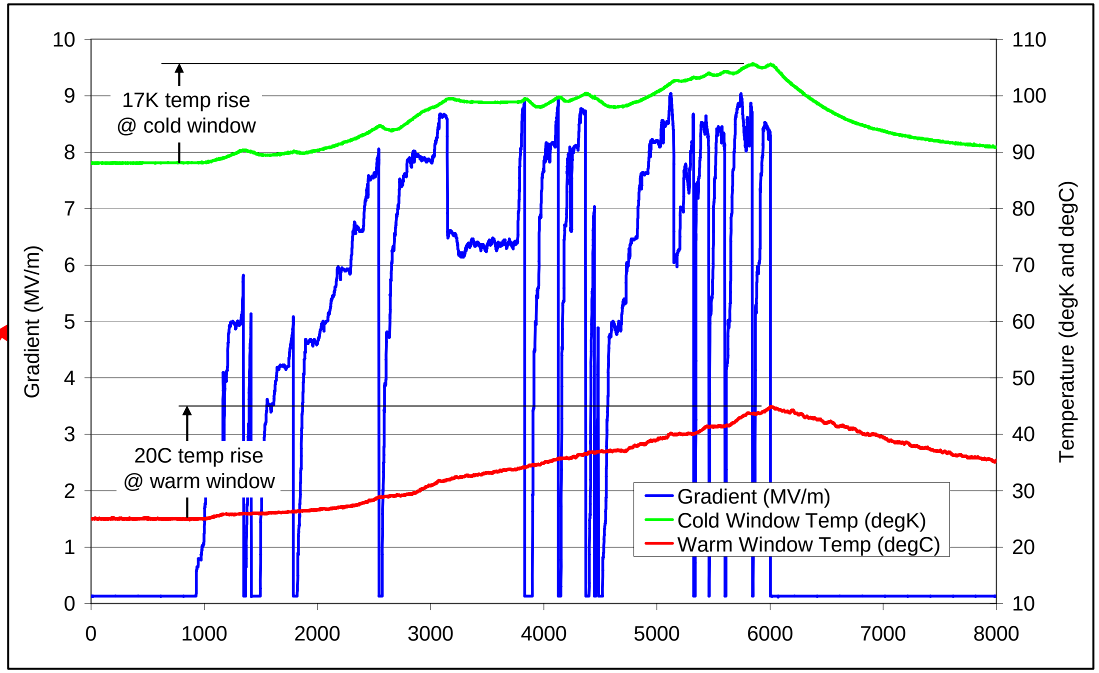


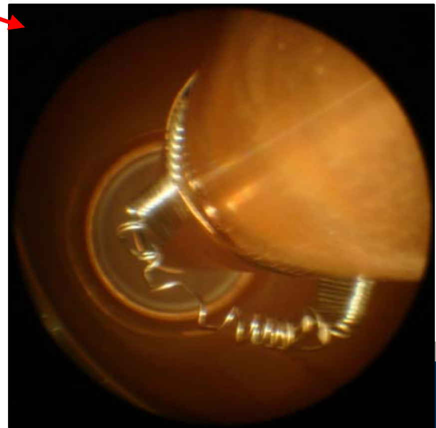


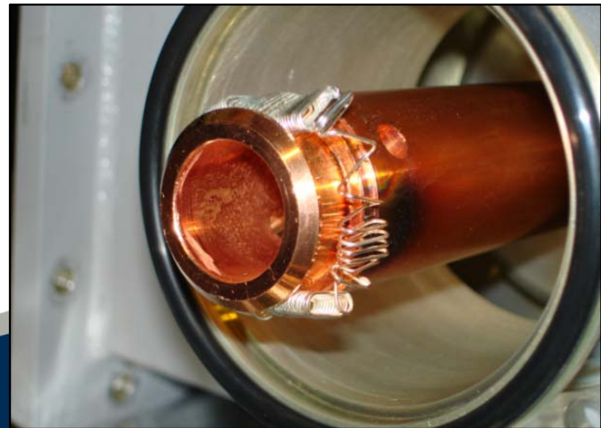


Coupler Heating (Linac – Cav2)



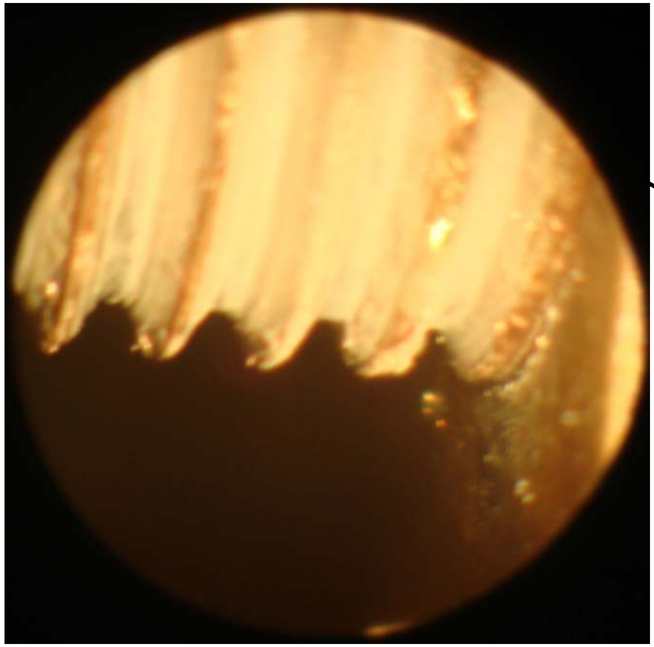


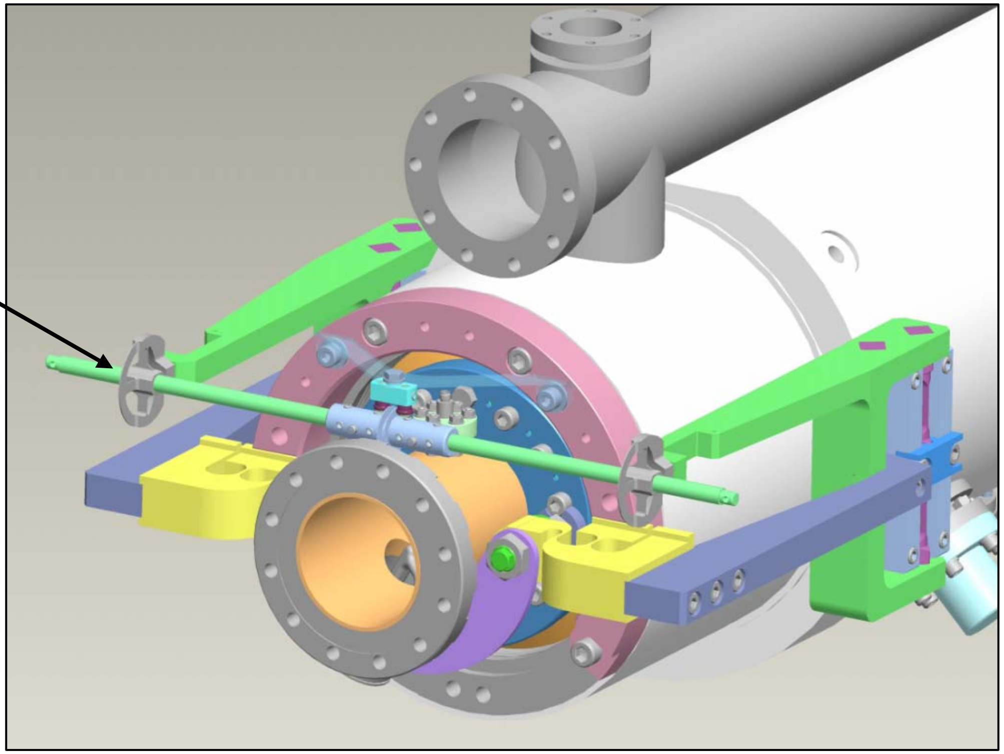




Stuck Tuner (Linac – Cav1)

Worn drive mechanism





Cryosystem 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 $\pm$ 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 – needs optimising.

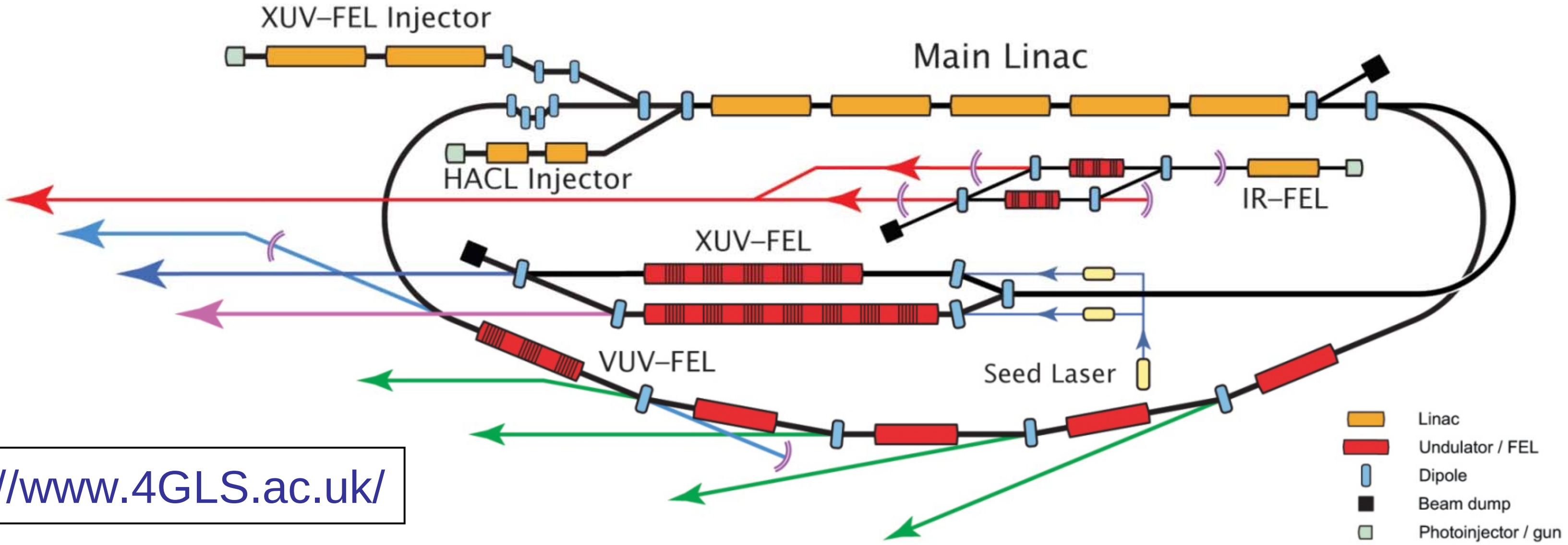
ERLP Plans and Schedule

- 2007:
  - Gun & diagnostics line studies finished — end Nov
  - Booster repositioned — mid Dec
  - Beam through booster — mid Jan
- 2008:
  - Beam through the linac — mid Feb
  - Beam through booster, linac and arcs — end Feb
  - Energy recovery demonstrated — end Mar

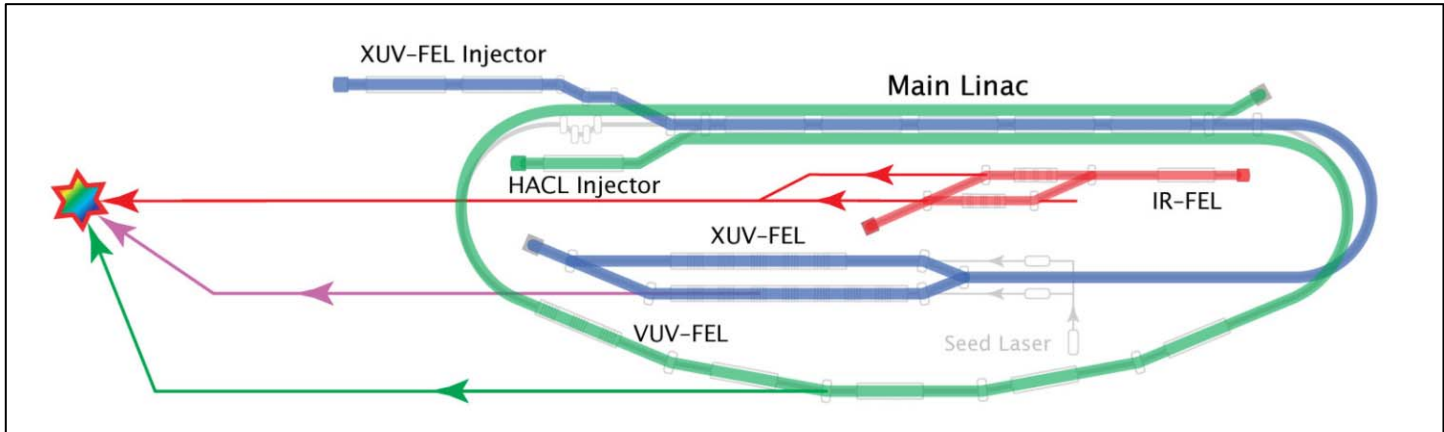
- Longer term:
  - Exploit THz radiation from compressor
  - Compton backscatter phase 1
  - Install wiggler
  - Energy recovery from FEL-disrupted beam
  - Produce output from the FEL

The 4GLS Facility

ERLP is the educational and technical demonstrator for 4GLS.

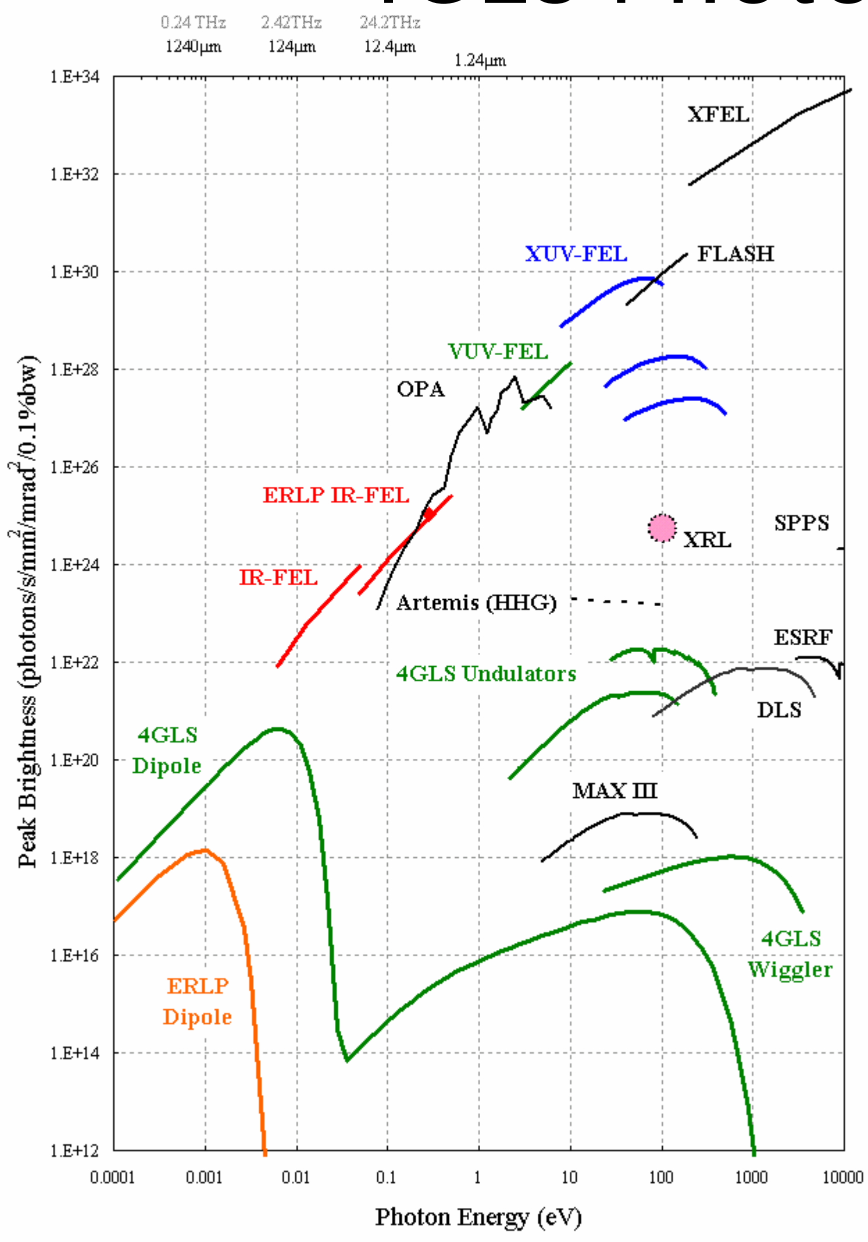


https://www.4GLS.ac.uk/



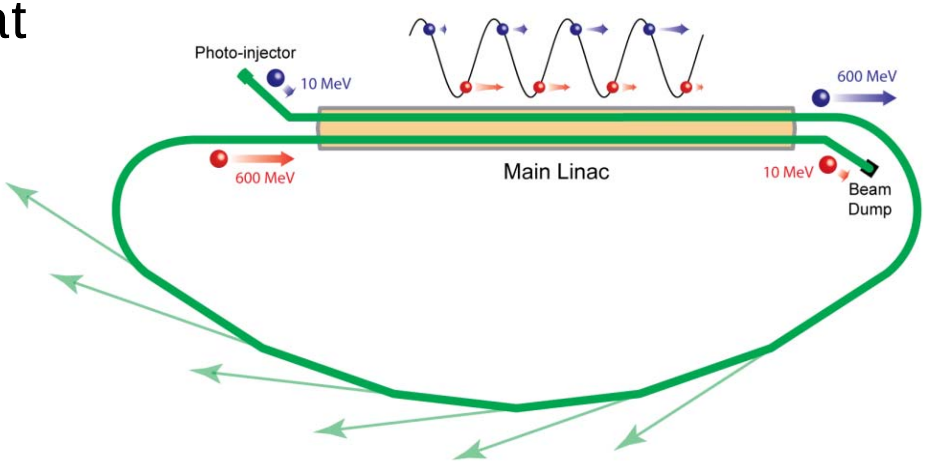
XUV, VUV and IR Source Combination

4GLS Photon Output



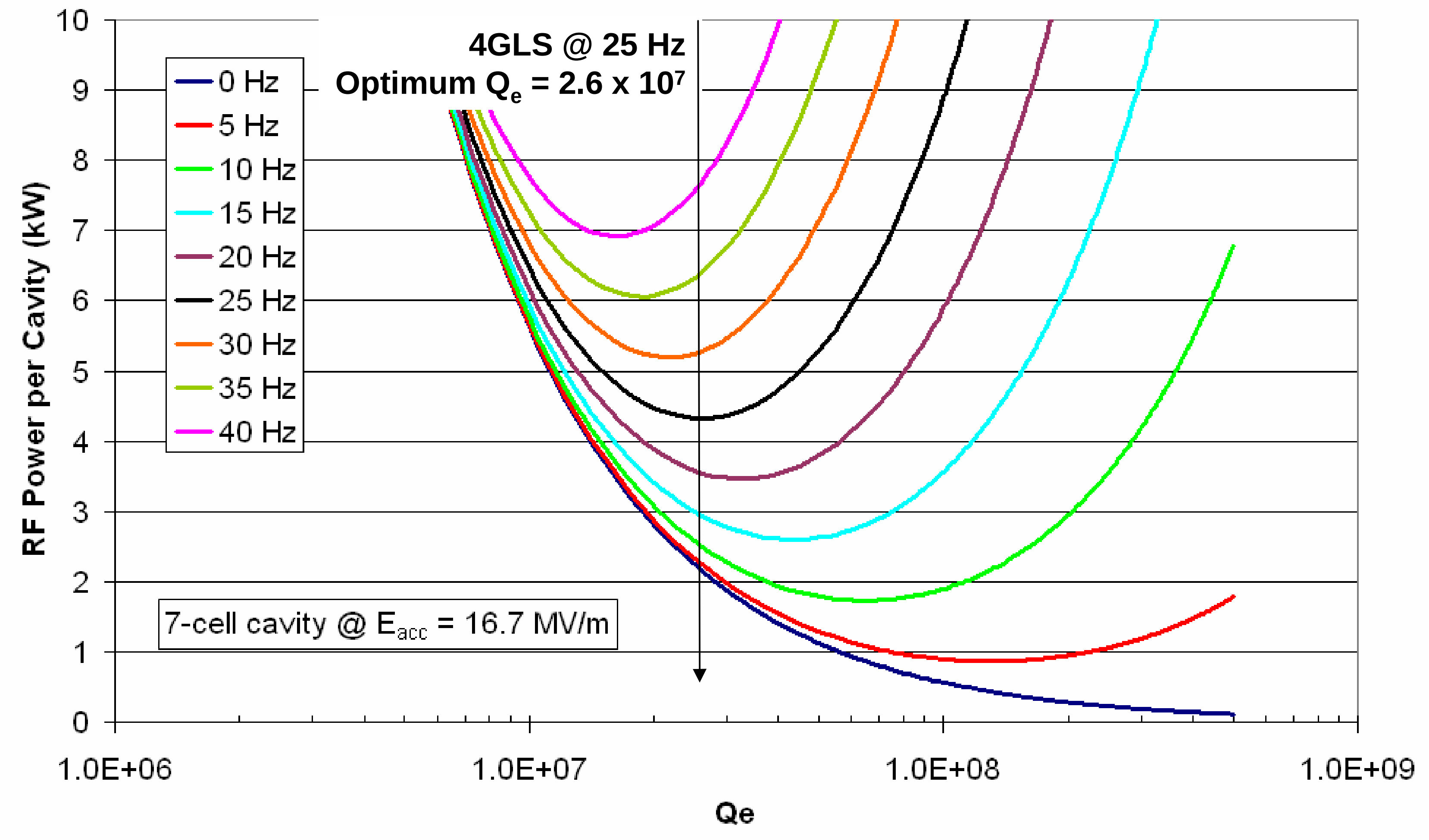
The Energy Recovery Process

- Injcted beam accelerated normally and arrives back at the Main Linac 180º out of phase.
- Beam then decelerated and energy recovered and simultaneously used to accelerate more injected beam.
- For operation in ER mode, net beam loading is zero.
- Generator power (P_g) defined by peak microphonics ($\Delta\varpi$) sensitivity of cryomodules.
- For 4GLS modules have assumed 25 Hz as a conservative expectation.

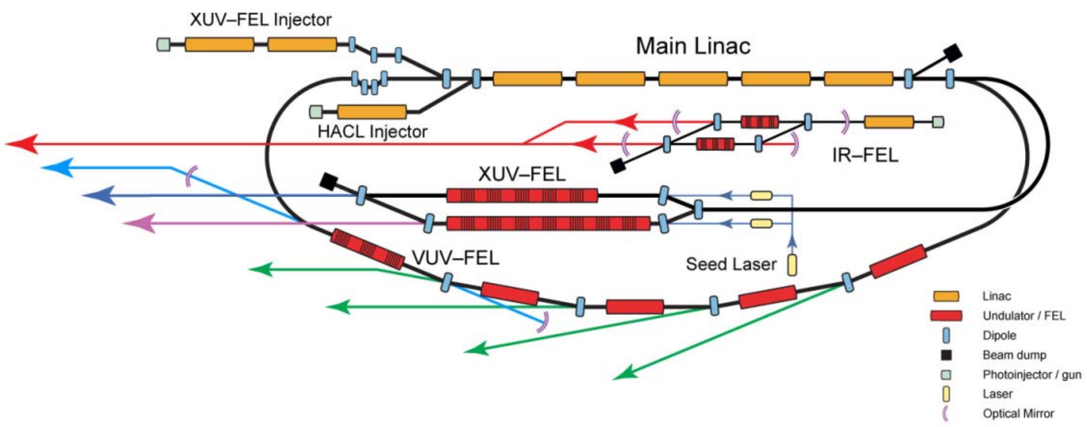


$$P_g = \frac{V_{acc}^2}{4\frac{R}{Q}Q_e}\left\{1+\left(\frac{2\Delta\varpi Q_e}{\varpi_c}\right)^2\right\}$$

Microphonics Sensitivity



4GLS RF Requirements



4GLS CDR completed April 2006.

4GLS Linacs:

- 10 MeV HACL Linac
- 210 MeV XUV-FEL Injector
- 540 MeV ERL Linac
- 60 MeV IR-FEL Linac

Mods from CDR:

- XUV-FEL 3rd Harmonic Linac removed
- ERL modules reduced from 6 to 5
- XUV-FEL booster Linac removed
- XUV-FEL injector energy increased
- ERL Linac energy reduced

4GLS TDR expected April 2008.

	HACL Injector	XUV-FEL Injector	ERL Linac	IR-FEL
Number of Cells/Cavity	2	7	7	7
Number of Cavities/Module	5	8	8	8
Number of Modules	2	2	5	1
Energy Gain (MeV)	10	210	540	60
E_{acc} (MV/m)	4.3	16.3	16.7	9.3
Q_e	4.7×10^4	1.3×10^7	2.6×10^7	1.3×10^7
Total RF Power/Cavity (kW)	100	16.5	12.8*	19.5

Same Linac design

*includes CSR losses

4GLS Cryomodule R&D Collaboration

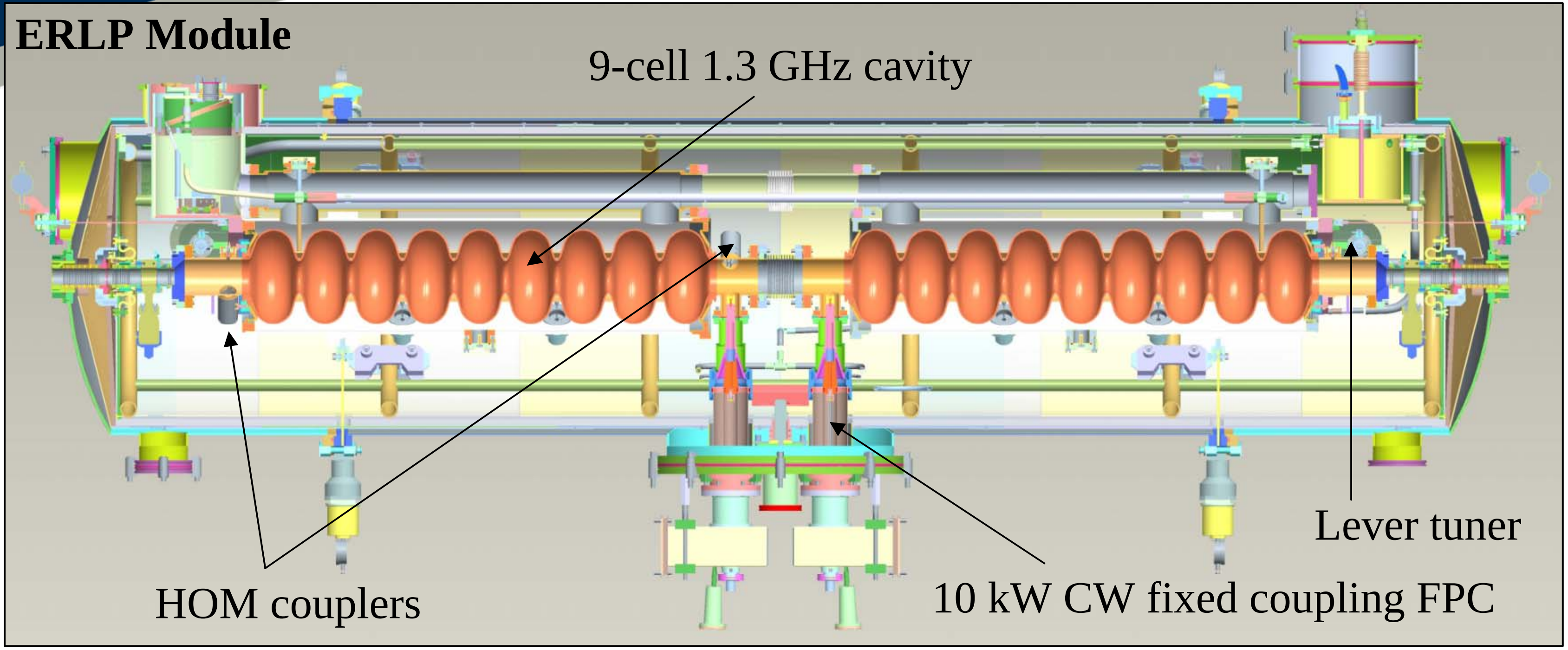
- 5 collaborating institutes:
  - ASTeC (UK):
    - Bob Bate (Module cryogenics, assembly)
    - Carl Beard (Cavity, coupler)
    - Mike Cordwell (Integration, coupler, tuner)
    - Mike Dykes (Cavity, tuner, coupler, integration)
    - Peter McIntosh (ASTeC overview)
    - Shrikant Pattalwar (Module cryogenics)
    - John Strachan (Integration, tuner, project management)
    - Emma Wooldridge (Cavity)
  - Cornell University (USA):
    - Sergey Belomestnykh (Cavity, tuner, coupler, absorber, integrati
    - Matthais Liepe (Cavity, tuner, coupler, absorber, integration)
    - Hasan Padamsee (Cornell overview)
  - Stanford University (USA):
    - Todd Smith (Stanford overview)
    - Takuji Kimura (Tuner, coupler, assembly)
  - Lawrence Berkeley Laboratory (USA):
    - John Corlett (LBNL overview)
    - Derun Li (Cavity)
    - Steve Lidia (Cavity)
  - FZD Rossendorf (Germany):
    - Frank Gabriel (Rossendorf Overview)
    - Andree Buechner (Coupler, tuner, integration)

See Poster: WEP33

Cryomodule Goals

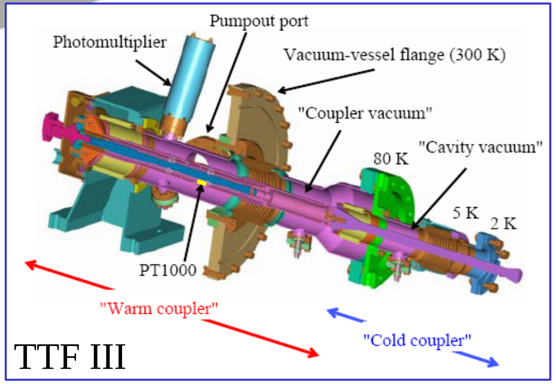
- Design requirements:
  - E_{acc} > 20 MV/m @ $Q_o > 10^{10}$
  - $Q_{ext} \approx 1 \times 10^7$ to 1×10^8
  - Couplers capable of up to 25 kW CW SW
  - Large HOM damping capability
- Issues to be resolved include:
  - Effective HOM Damping (up to 200W/cavity)
  - Microphonics sensitivity (< 25 Hz peak)
  - Fast Tuning (microphonics compensation)
  - Input Power Delivery (25 kW CW SW)
  - Cryomodule Design (< 2.5 W static loss)
- A 2-cavity cryomodule to be validated with beam:
  - On ERLP in 2009
  - On Cornell ERL injector in 2010

Collaborative Development



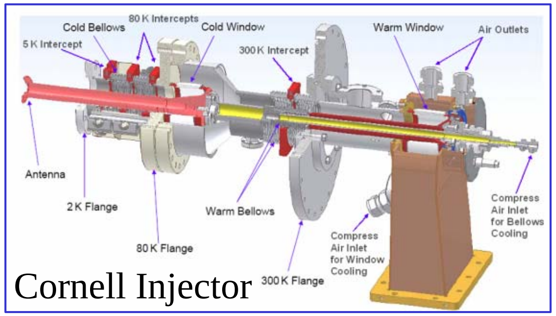
- Stanford has provided a 2-cavity cryomodule (incl. some internals).
- Cornell will provide and modify the 2 x 7-cell cavities.
- DL will provide the HOM absorbers and couplers.
- FZD have provided the 3D cryomodule drawings.
- LBNL have provided cavity design expertise.
- Engineering and design effort split across the 5 institutes.

Input Coupler Options



TTF III

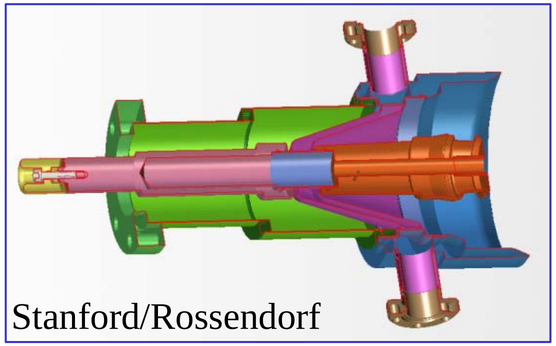
TTF III:
- Adjustable coupling (16 mm)
- Long (minor mods needed)
- 5 kW CW SW (BESSY)



Cornell Injector

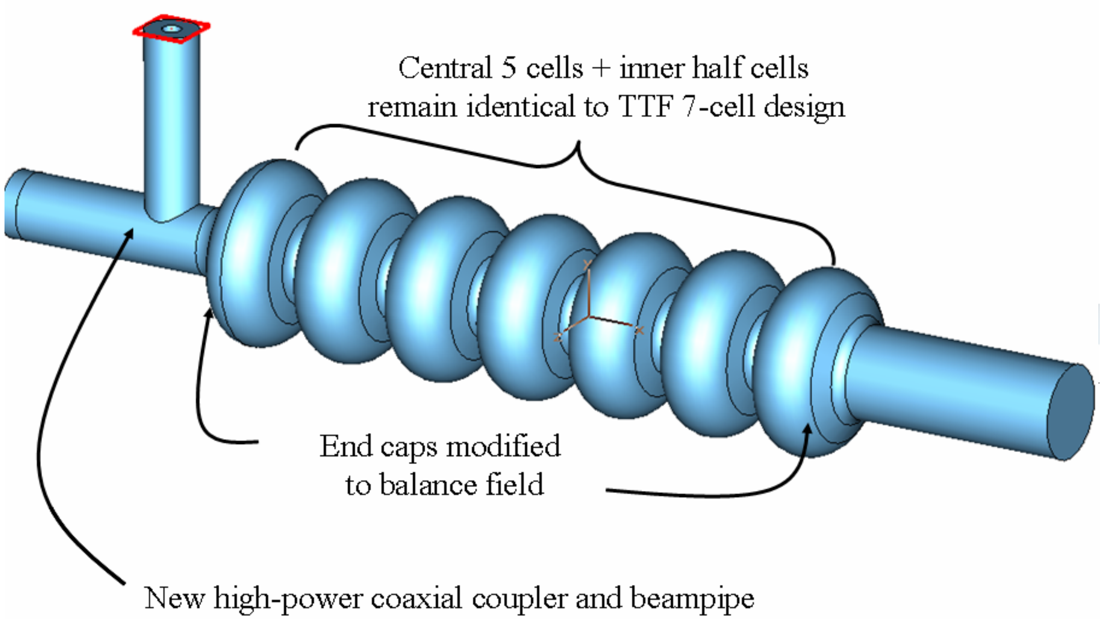
Cornell Injector:
- Adjustable coupling (16 mm)
- Longer (modest mods needed)
- Up to 50 kW CW SW (Cornell)

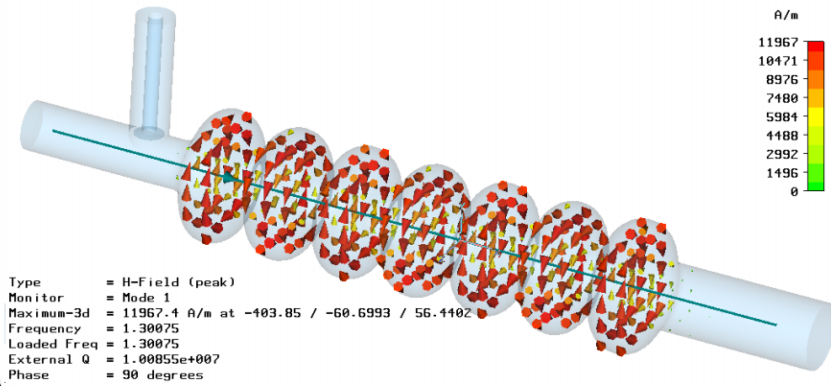
Chosen solution


Stanford/Rossendorf

Stanford/Rossendorf:
- Fixed coupling
- Compact (no mods needed)
- 10 kW CW SW (Rossendorf)

Cavity Optimisation



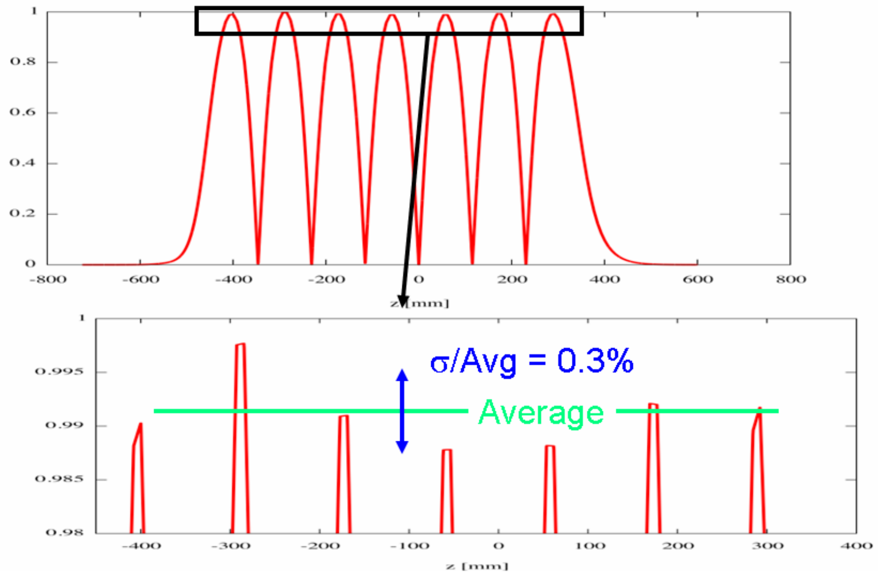


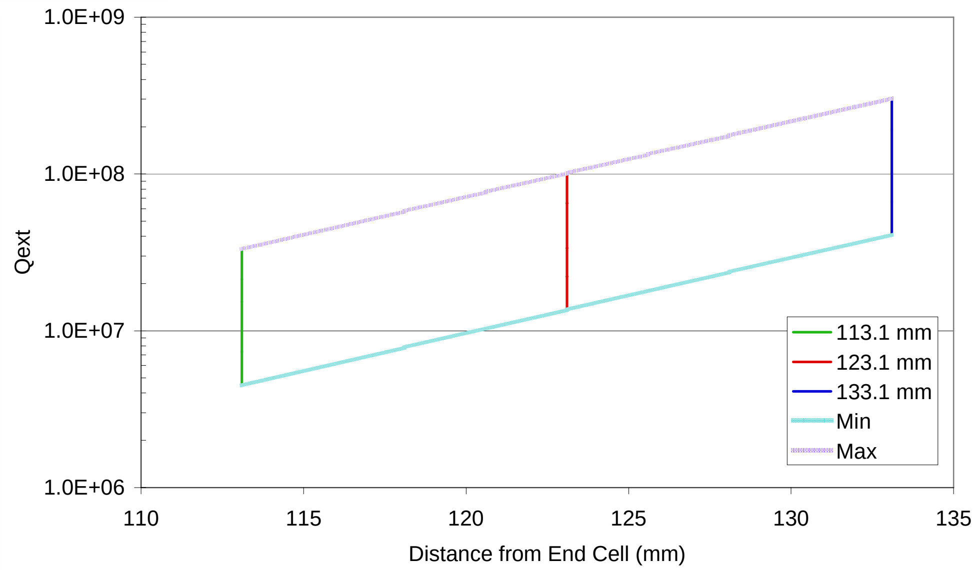
f_{π} = 1300.75 MHz

Q_e = 1 x 10^7

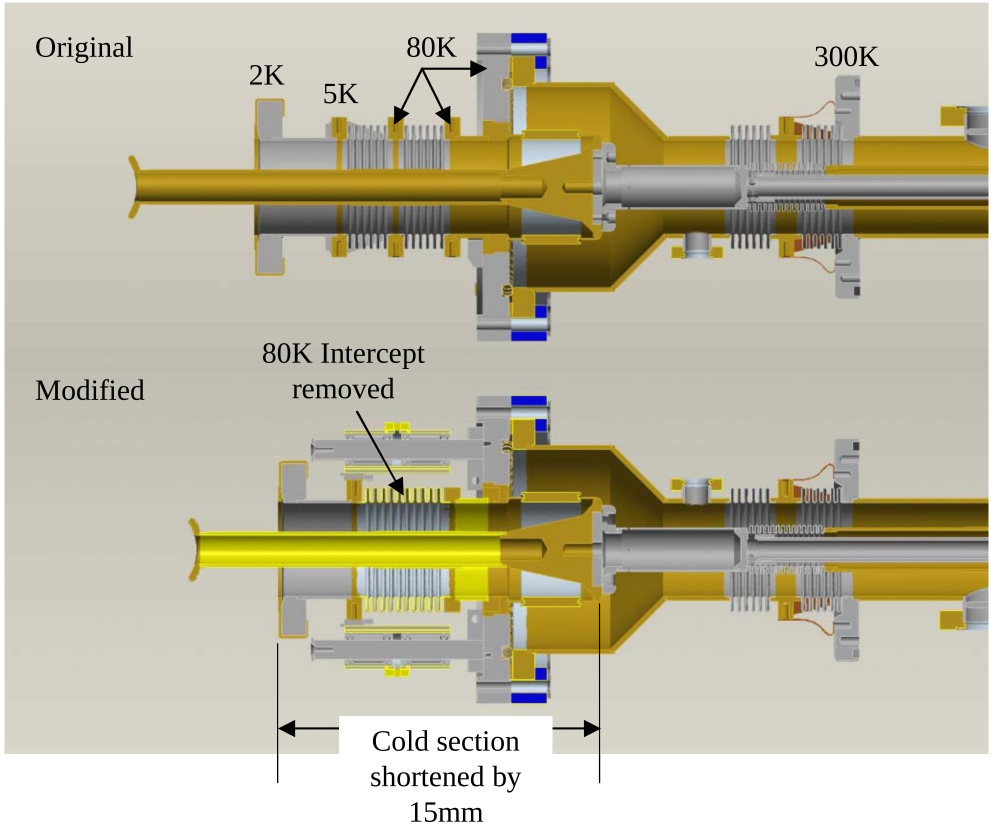
E_{pk}/E_{acc} = 2.9

H_{pk}/E_{acc} = 59.5 Oe/(MV/m)





Cornell ERL Injector Coupler Modifications



- Cold section of the Cornell injector coupler too long to load into the module.
- Removed 80 K intercept ring and two bellows convolutions.
- Reduced the 2 K to 5 K transition tube.
- At 25 kW SW, mods should not affect performance.

Parameter	Original	Modified
Max Power (kW)	50 TW	20 SW
Antenna Stroke (mm)	>15	<15
Heat Leak to 2K (W)	0.23	0.13
Heat Leak to 5K (W)	1.7	2.5*
Heat Leak to 80K (W)	43	34

- Shortened the cold section by 15 mm in total.
- Still conflicts with LN2 skeleton.

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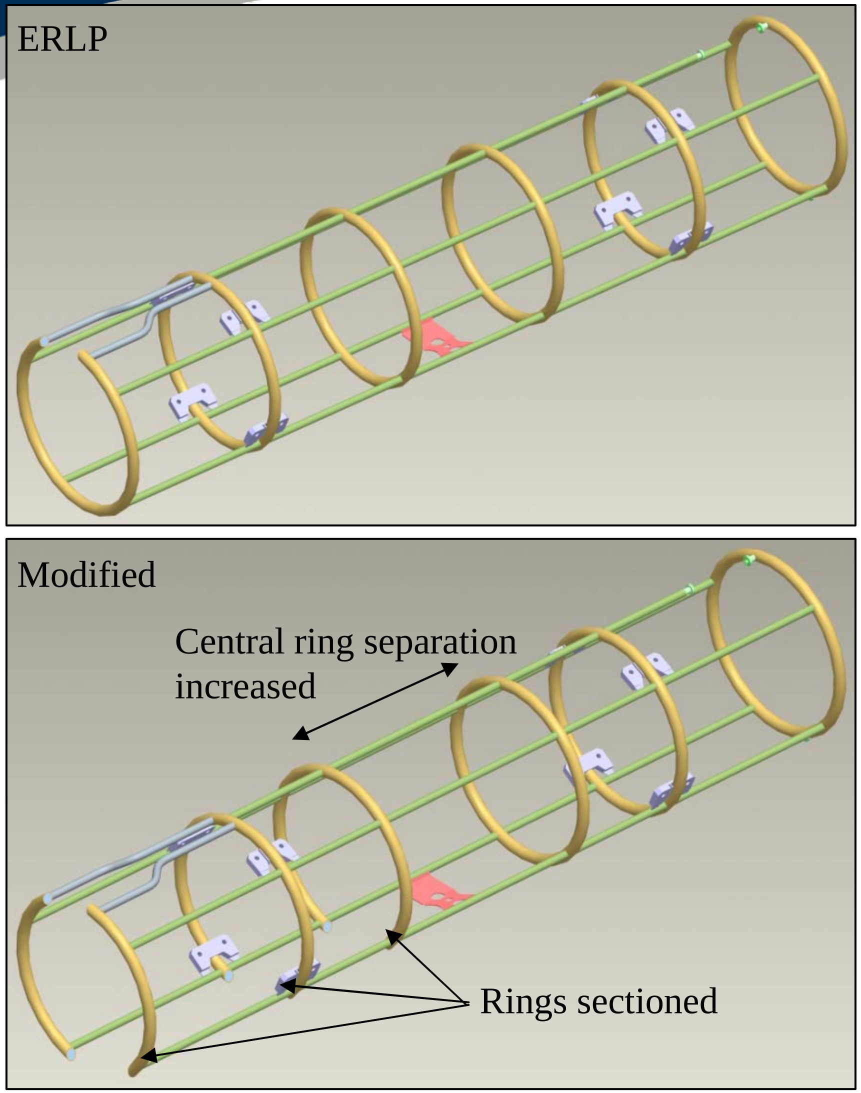
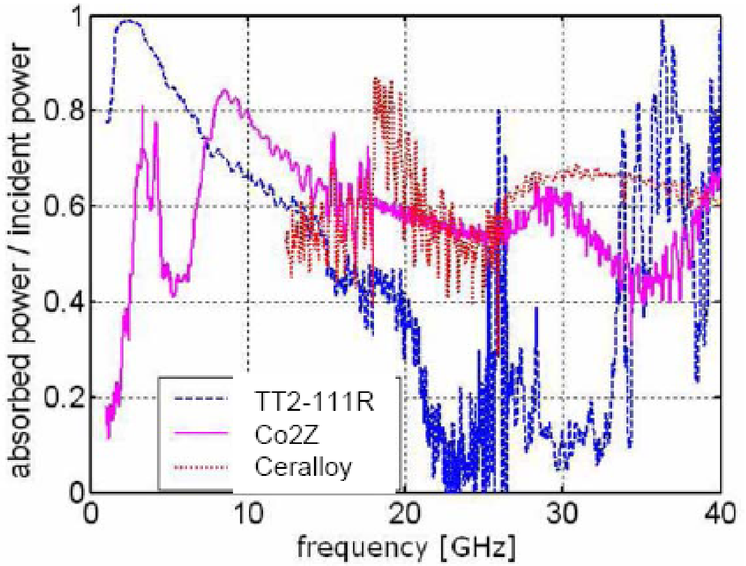
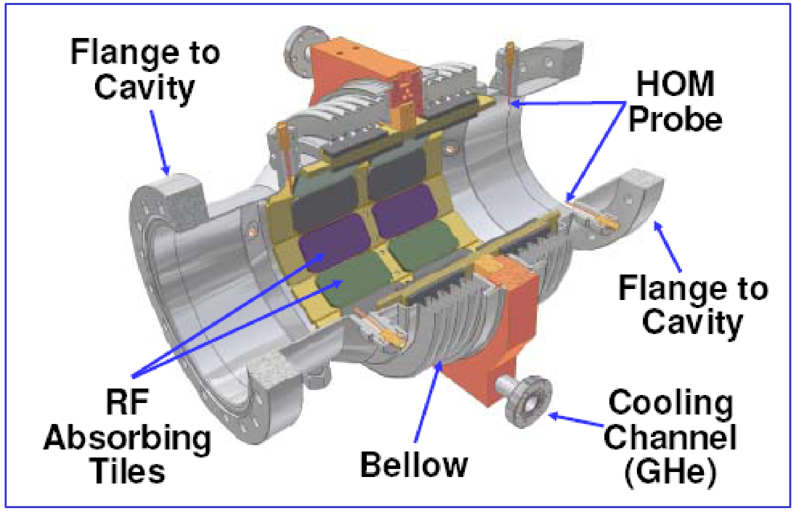
LN2 Skeleton Modifications



- Coupler cold section still too long to insert cavity string through LN2 skeleton.
- Sectioned 3 x rings to allow for insertion from one side only.
- Both central rings pushed further apart to accommodate larger coupler.
- Modifications are not anticipated to cause excessive differential 80 K cooling.

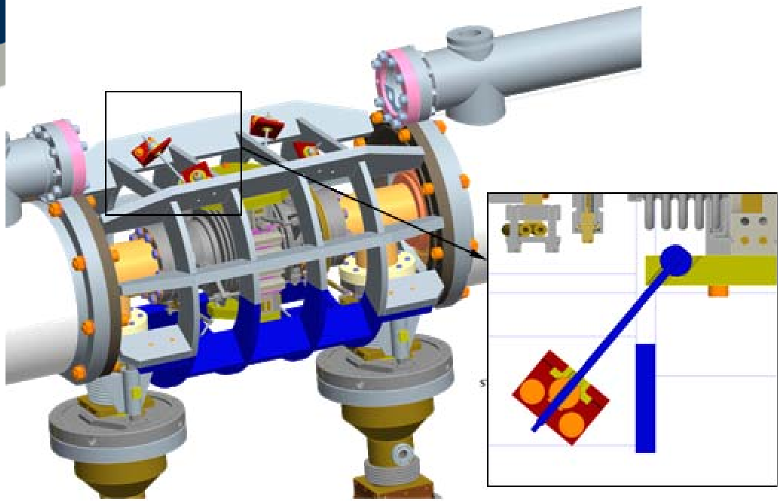
Cornell HOM Absorbers

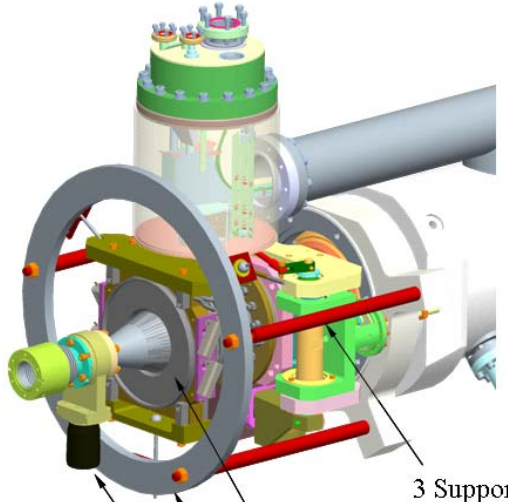




Power per load (W)	Up to 100 (max 200)
HOM frequency range (GHz)	1.4 to 100
Operating temperature (K)	80
Coolant	GHe
RF absorbing tiles	TT2, Co2Z, Ceralloy

HOM Absorber Integration



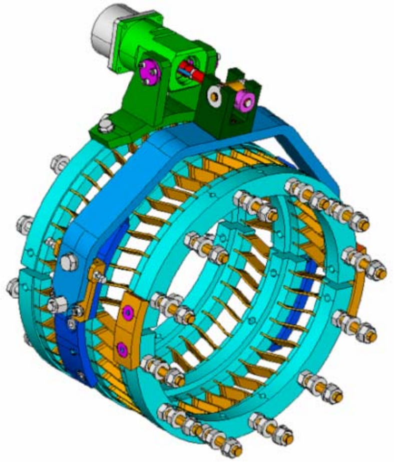


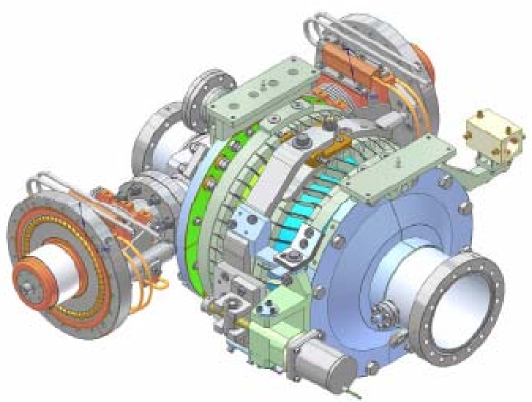
- Central HOM absorber surrounded by rigid support cage.
- Restricts longitudinal movement of both input couplers.
- Absorber thermally isolated by thin titanium support rods/cables.

- End HOM absorbers uses similar rod/cable support.
- Support ring mounted from cavity LHe vessel at 2 K.

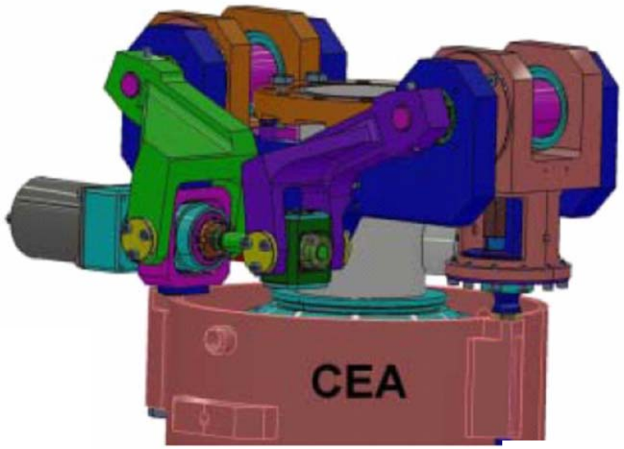
Tuner Options

Blade





Lever

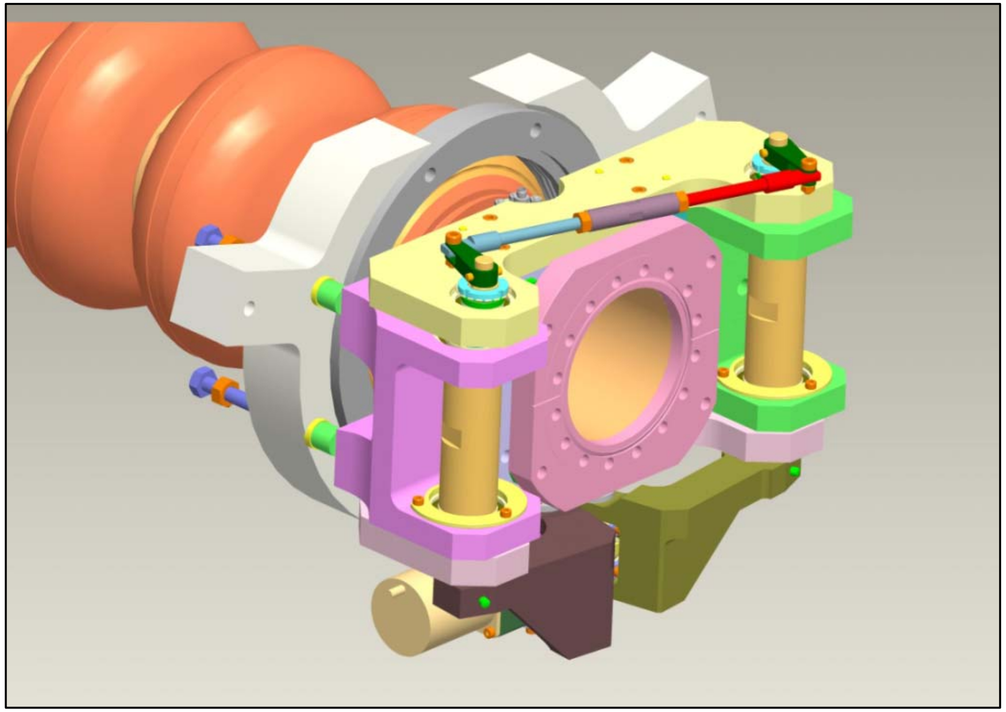


Chosen solution

- Blade tuner:
  - Compact
  - Good sensitivity
- Lever tuner:
  - Large tuning range
- Both incorporate piezo actuators.
- Blade tuner extremely difficult to incorporate into existing module:
  - substantial modifications required!

	Lever	Blade
Tuning range (mm)	1.9	1.0
Tuning range (kHz)	820	440
Sensitivity (Hz/step)	0.74	0.38
Δf. warm/cold (MHz)	2.3	2.3
ΔF (4.2K/2K) (kHz)	30	70

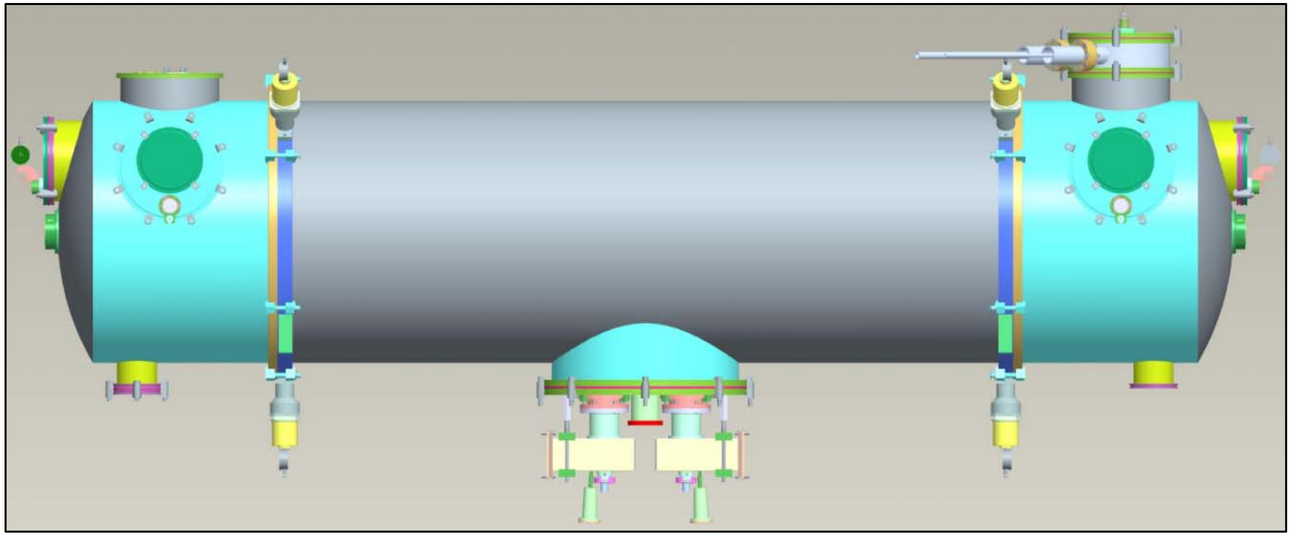
Adapting Saclay II Tuner



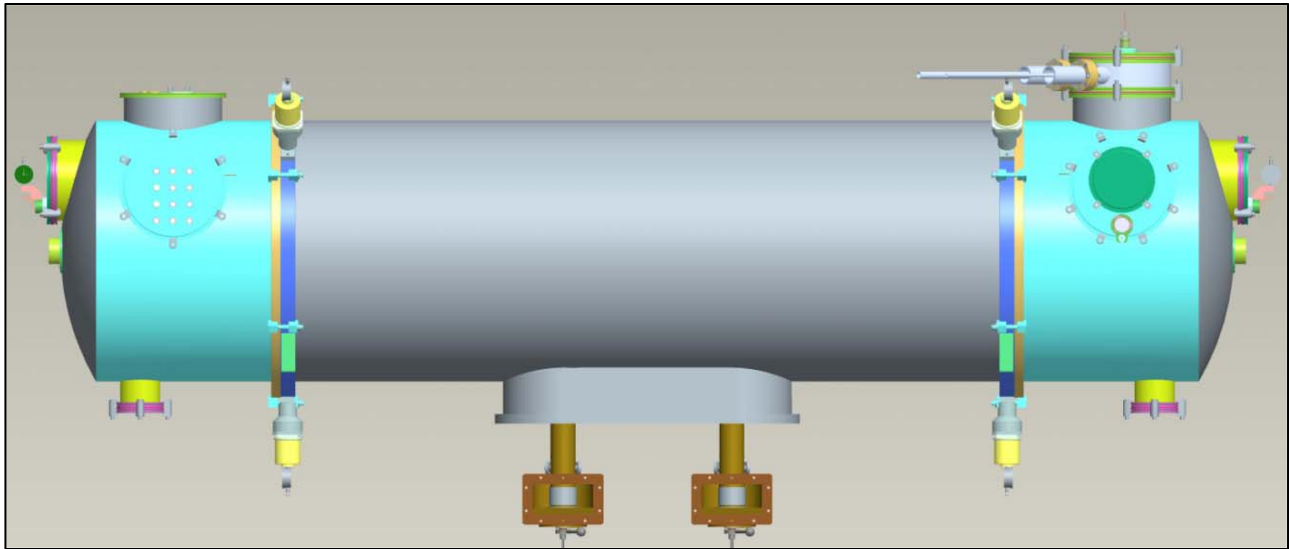
- Enlarged to accommodate larger 106 mm beam pipe diameter.
- Piezo cartridge modified to be pre-compressed so as to not rely on cavity tuning for compression.
- Low voltage piezo stack to be replaced by high voltage stack to improve stiffness.

Cryomodule Evolution (External)

ERLP



Modified



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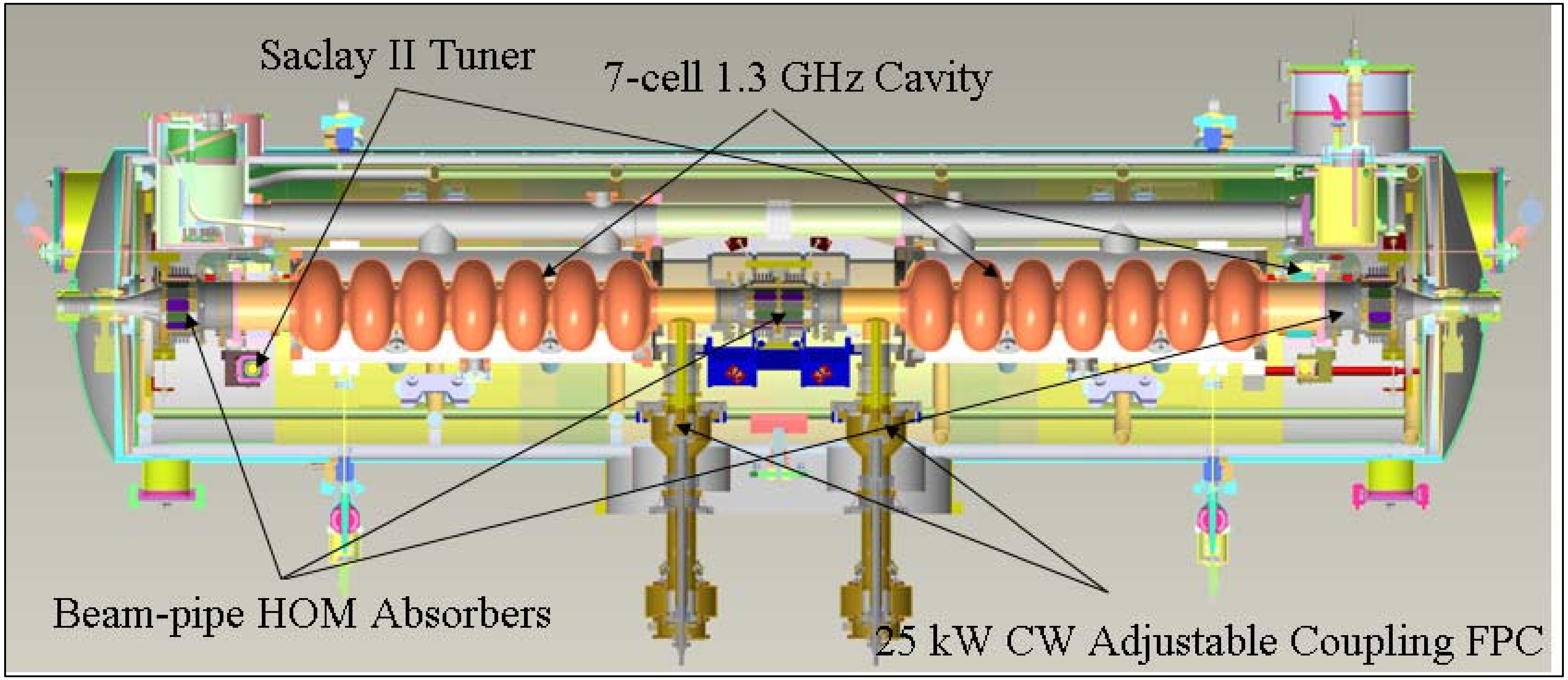
ASTeC

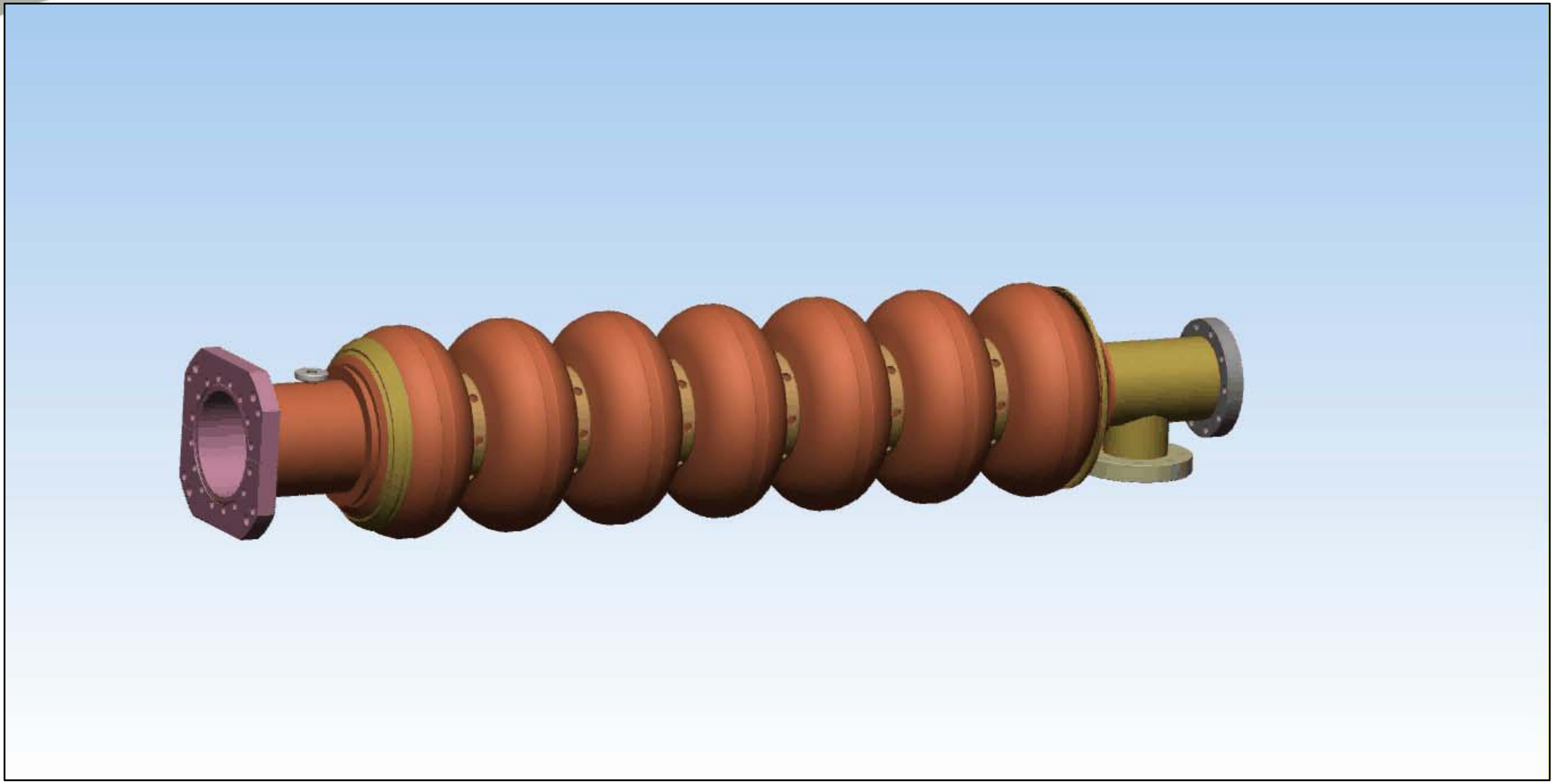
Cryomodule Evolution (Internal)



Schedule

• ACCEL HOM absorbers delivered	Dec 2007
• Module internal drawings complete	Dec 2007
• Saclay II tuners delivered	Feb 2008
• Module centre section modified	Feb 2008
• CPI Couplers delivered	Mar 2008
• Tooling and fixtures fabricated	Mar 2008
• All module components available	Jul 2008
• Module assembled	Dec 2008
• Installation on ERLP	Early 2009
• Installation on Cornell ERL Injector	Early 2010

Cryomodule Assembly



Conclusions

- ERLP and 4GLS are taking advantage of the vast amount of R&D already performed as part of the TESLA Technology Collaboration (TTC) at 1.3 GHz.
- ERLP is an educational R&D project giving DL staff the ability to demonstrate competencies in SRF, XUHV and FEL technologies.
- ERLP will be the workhorse to demonstrate viable system solutions for 4GLS.
  - Struggled this last year with repeated gun vacuum problems.
  - Commissioning right now!
- 4GLS being designed and technical solutions identified:
  - CDR completed April 2006.
  - TDR expected April 2008.
- SRF module development well underway to prove required 4GLS performance in 2009-2010.