ERL 2005

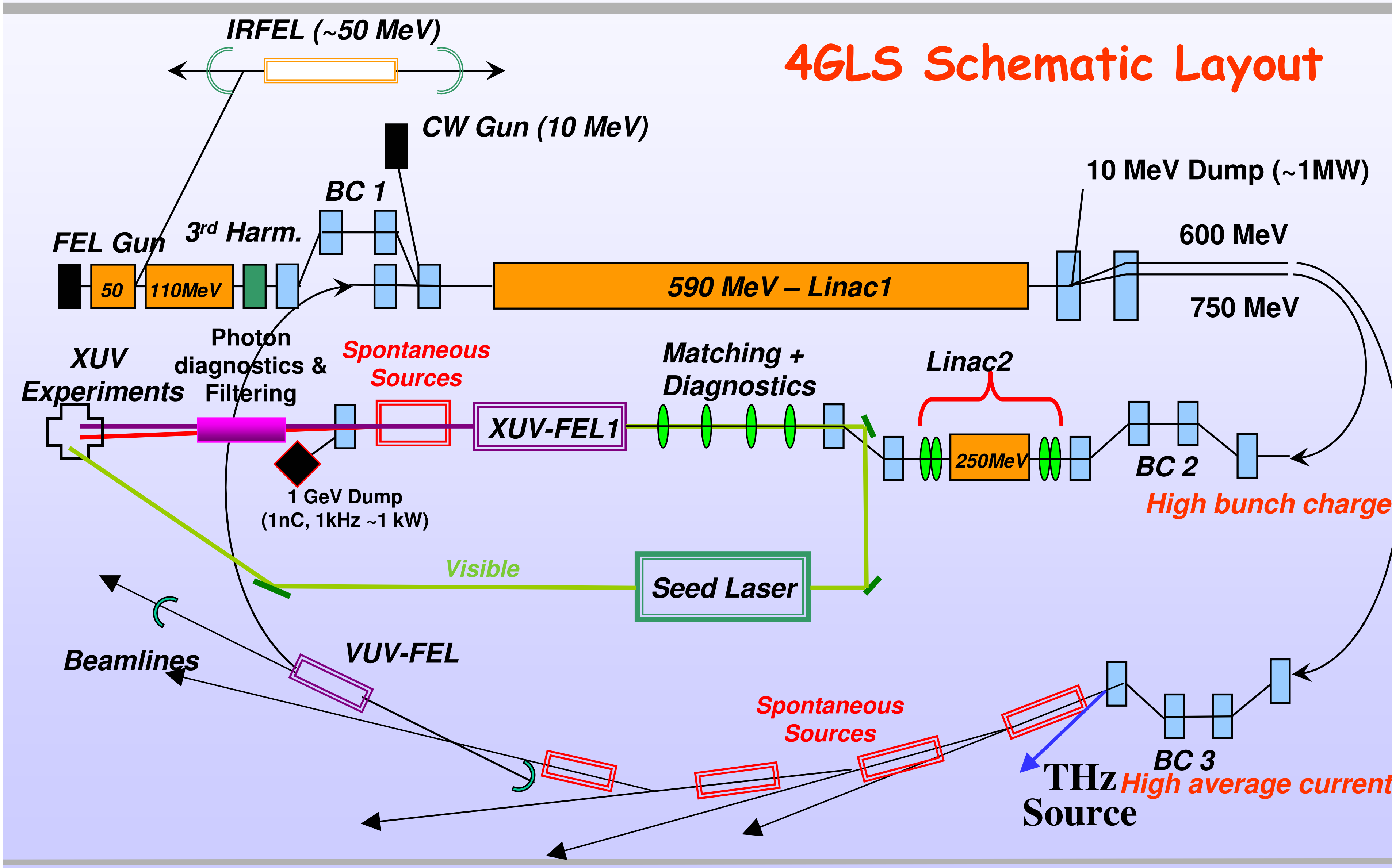
ERL Workshop Review

Mike Dykes

ASTeC, Daresbury Laboratory

What is an ERL?

4GLS Schematic Layout



ASTeC
accelerator science and technology centre

1 Plenary

4 Working Groups

1. Electron Guns and Injector Designs
2. Optics and Beam Transport
3. Superconducting RF and RF Control
4. Synchronization and Diagnostics/Instrumentation

http://www.jlab.org/intralab/calendar/archive04/erl/program.html

Contents

- Acknowledgements
- Charge
- Programme
- Highlights and Recommendations
- Conclusions

Acknowledgements

All 25 people who made presentations, and whose work I am reporting; I also thank them for the material used in this presentation

Charge

- …to identify critical SRF related items for the construction of ERLs, evaluate the readiness of the related science and technology, and to lay out an R&D path for solving remaining open issues.

Charge

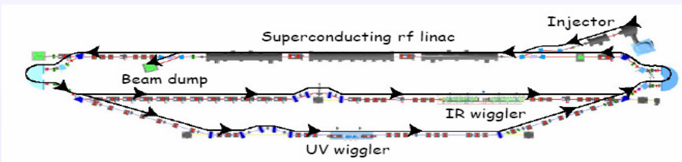
- Review parameter space covered by ERLs, concentrate on the difficult ones
- What are the SRF-related ERL-specific challenges?
- What solutions have already been developed?
- Which components still need more R&D work?
- Organise R&D effort, develop a roadmap to coordinate studies and identify collaborative possibilities

C. Beard, DL

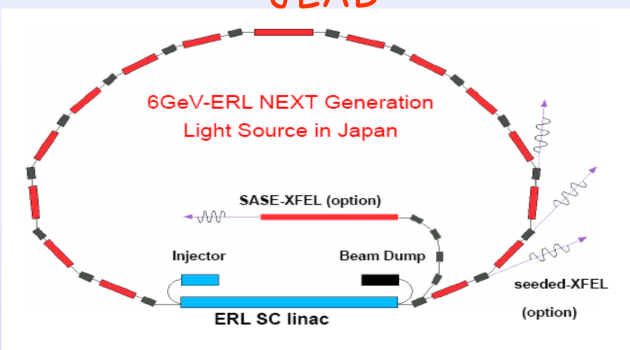
Program

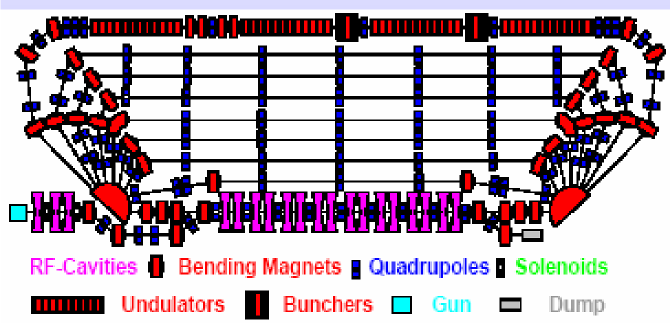
1. Introduction and Overview
2. Cavities/Modules
3. Cavity Cell Shape/Design
4. HOM Damping and Power Requirements
5. High Q Operation
6. Microphonics
7. Tuners
8. RF Control
9. Couplers
10. RF Power Sources and Transmission
11. Assembly – Transfer to Industry
12. Cryogenics
13. Injector Modules

Overview

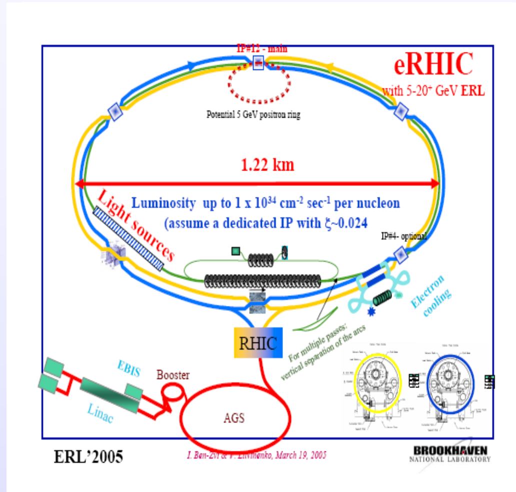


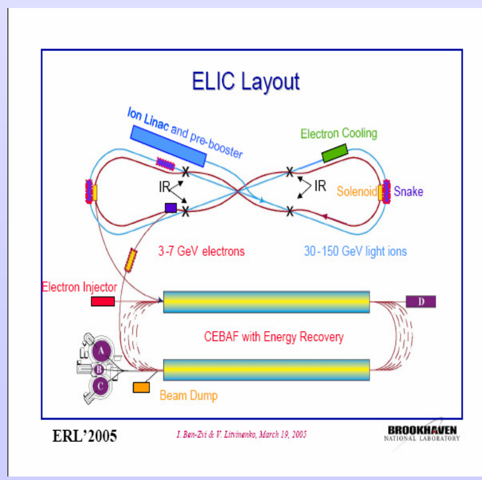
JLAB

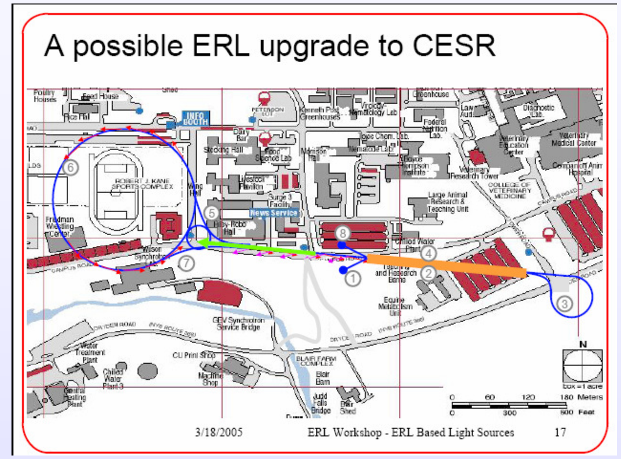


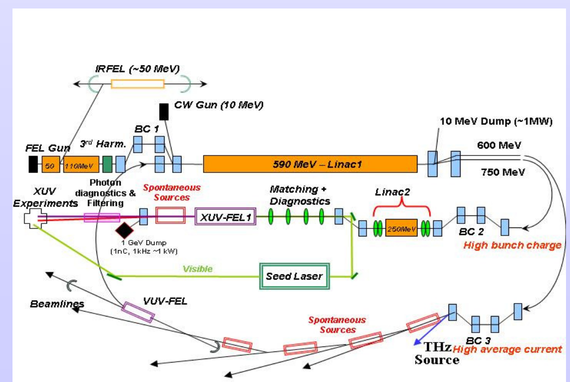


BINP



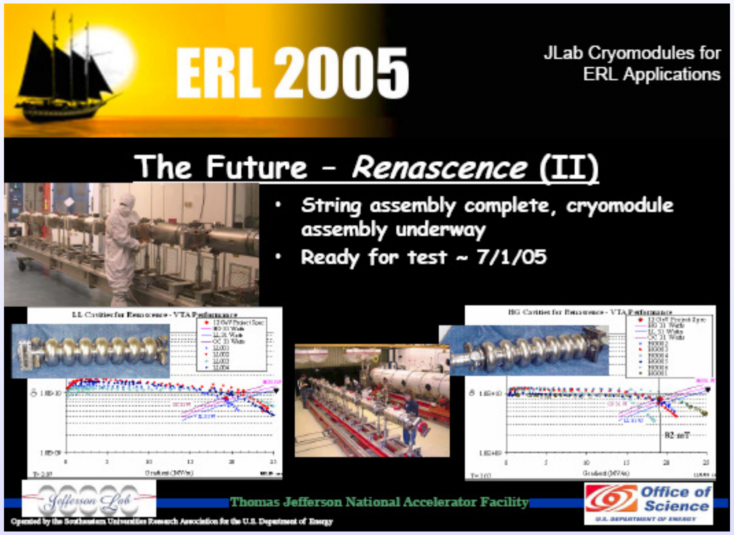


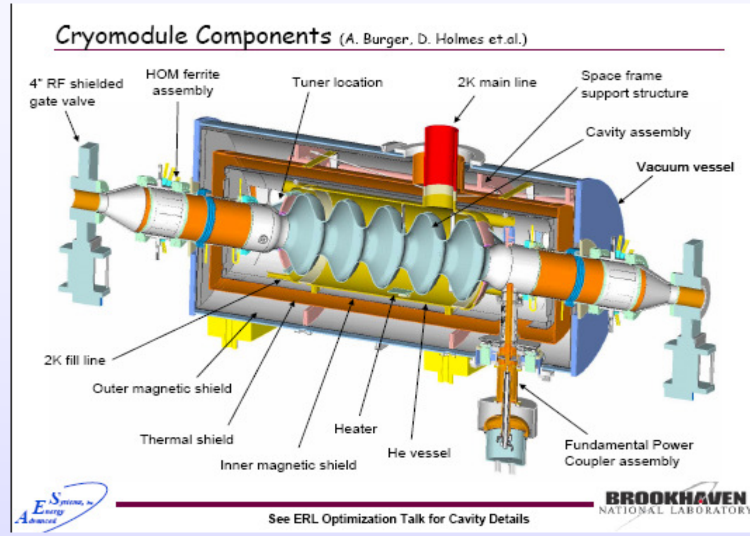


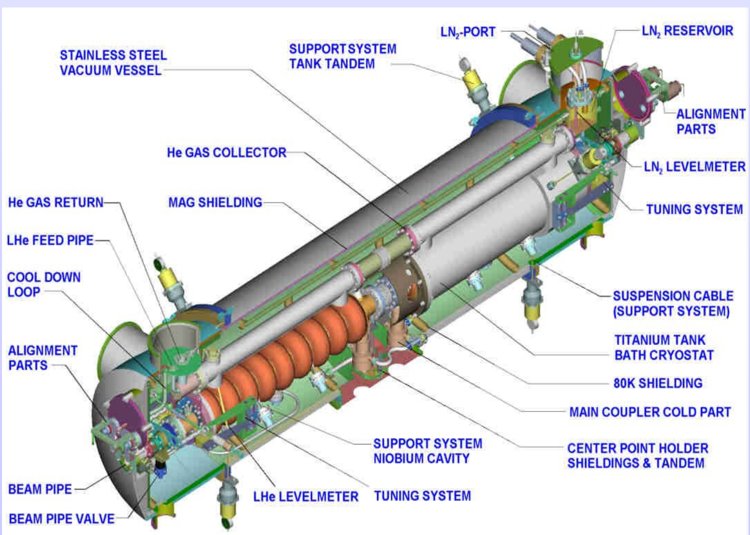


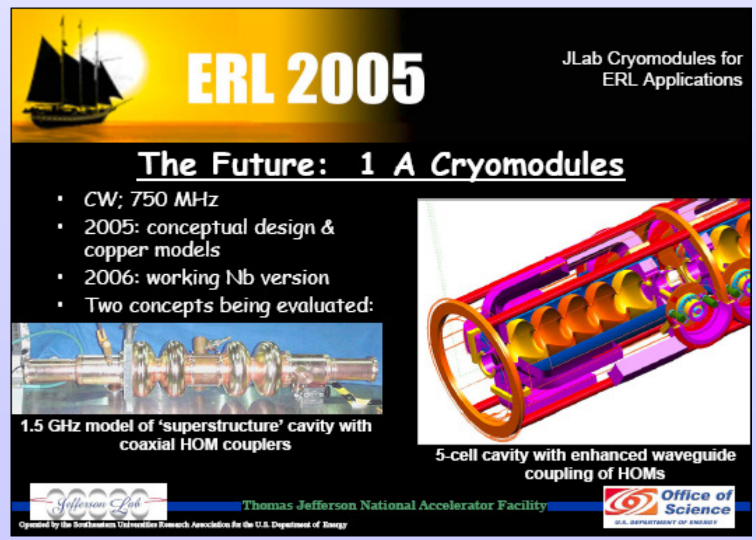
4GLS

Highlights and Recommendations
Cryomodules







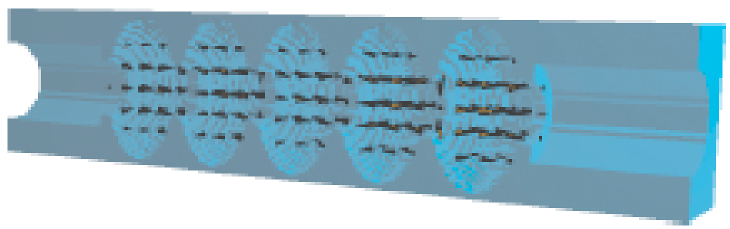


Highlights and Recommendations
Cavity Shape

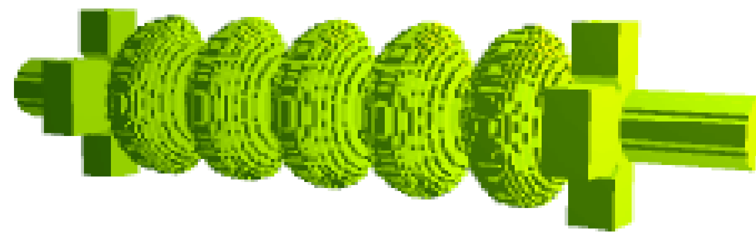
- Can optimize cavity shape for losses and HOM extraction simultaneously.
- 500 MHz cavities are not option at present.
- For up to 100 mA, present L-Band technology works. Residual losses (at low Tbath) push up frequency.

HOMs

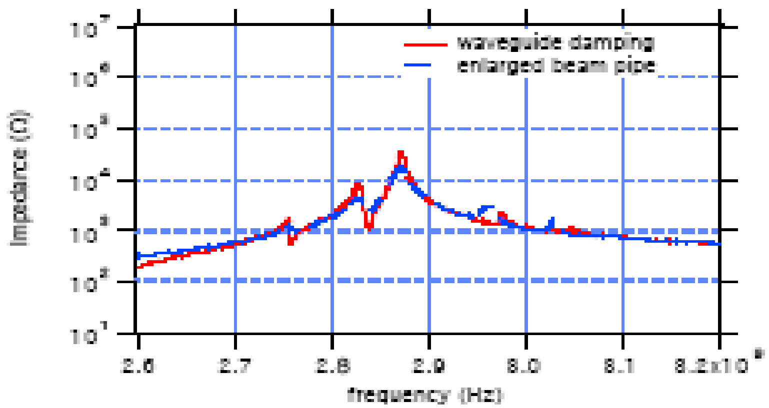
Compare waveguides with beam pipe loading:



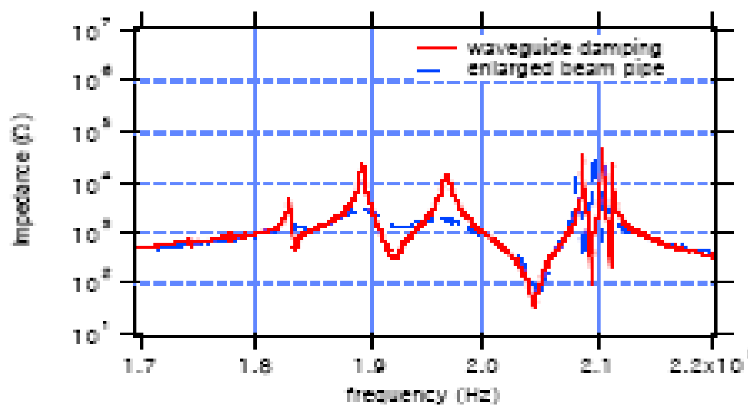
5-cell cavity with beam-pipe loads.



5-cell cavity with waveguide loads.



TM_{011}, 5-cells, wg and beam-pipe loads.



Dipole, 5-cells, wg and beam-pipe loads.

Impedance is good in either case, real estate gradient is better for waveguides.

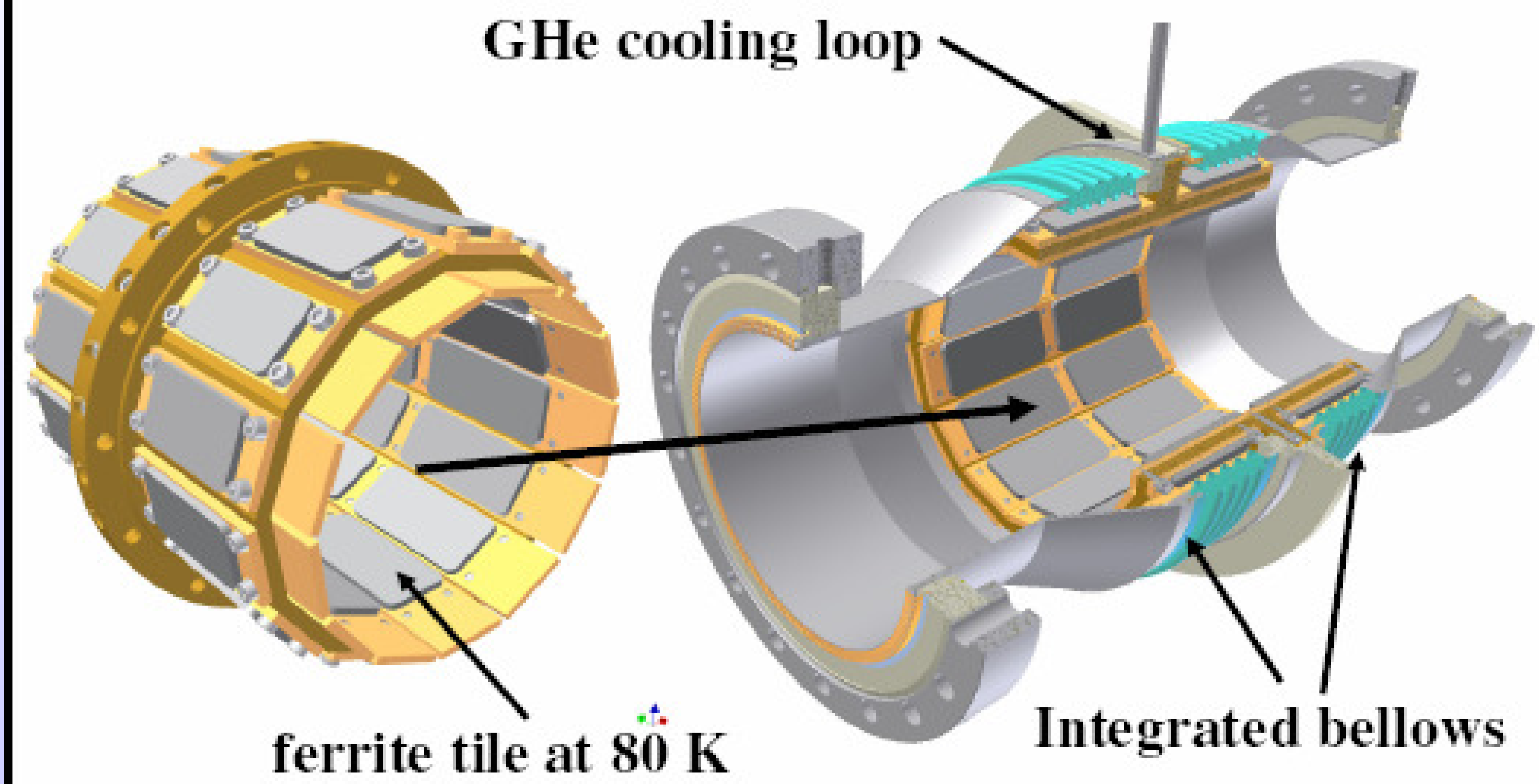
Highlights and Recommendations
HOM Damping

- Many schemes will work equally well, (except for loop couplers). Based on simulation and initial experiments
- Q = 10^3 to 10^4 which is good enough for 1 A machines.
- HOM power is a concern

HOMs

Cornell University

Beam-pipe absorber
Example: Cornell ERL Prototype



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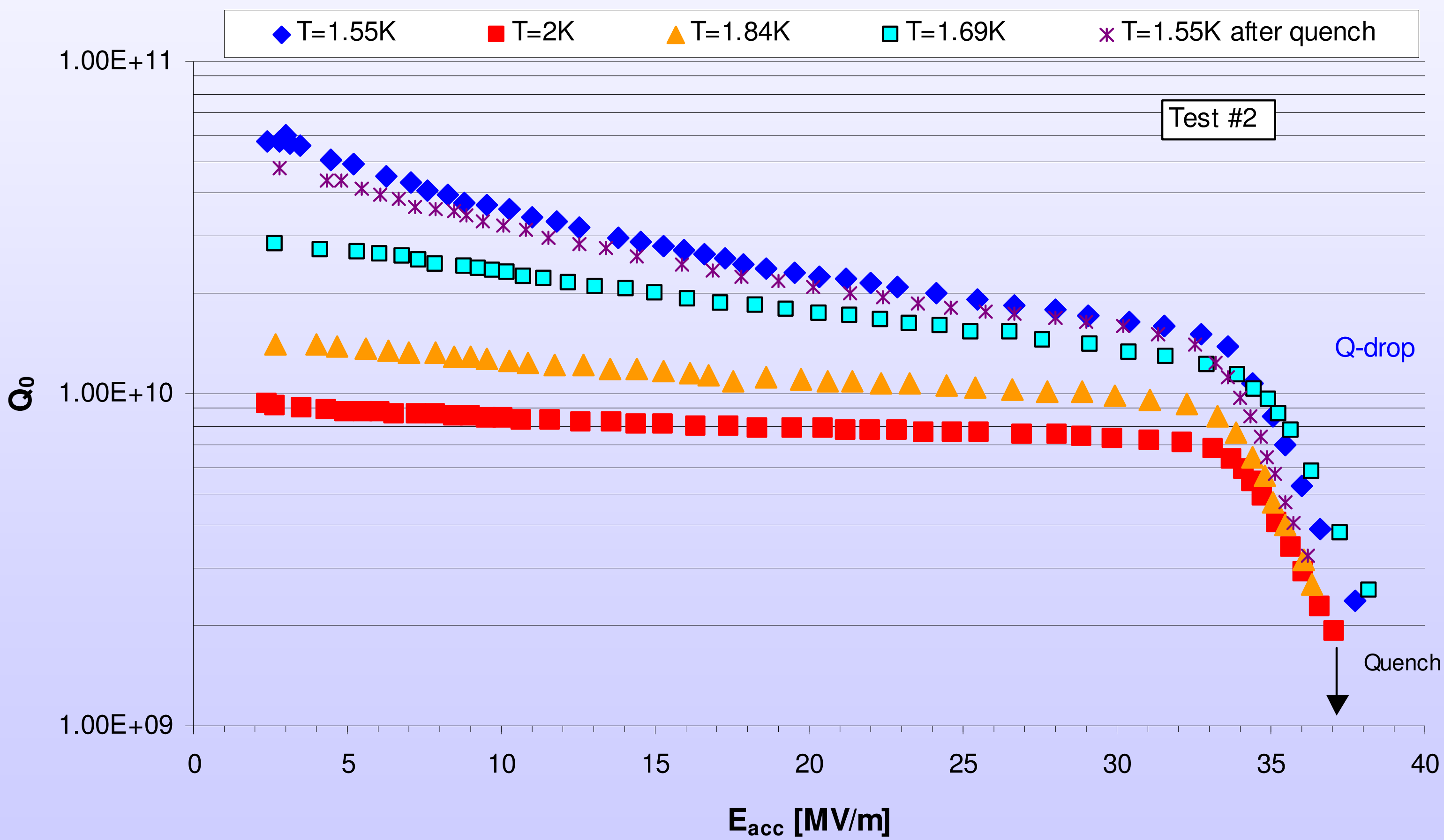
Highlights and Recommendations
Cavity Preparation

- Eddy CurrentScanning, Squid Scanning
  (successfully used at DESY on TTF cavities)
- Degreasing (ultrasound + soap+water, solvents)
- BCP (HF:HNO_3 :H_3PO_4 as 1:1:1, 1:1:2,1:1:4)
  (room temperature or below to avoid excessive hydrogen pick-up)
- Electropolishing (HF/H_2SO_4 Siemens-KEK-Recipes)
- Barrel Polishing
- High pressure Ultrapure Water Rinsing
- High Temperature Heat Treatment (600C to 1400C for Hydrogen degassing, Post Purification)
- "In-situ" baking (typically 120C for> 24 hrs)
- Alternative Cleaning:CO_2 Snow, Megasonic, UV Ozon..

Highlights and Recommendations
Single Crystal Cavity

2.2 GHz Single crystal single cell cavity after post-purification, 70μm BCP 1:1:1, 30min HPR

Q_0 vs. E_{acc}



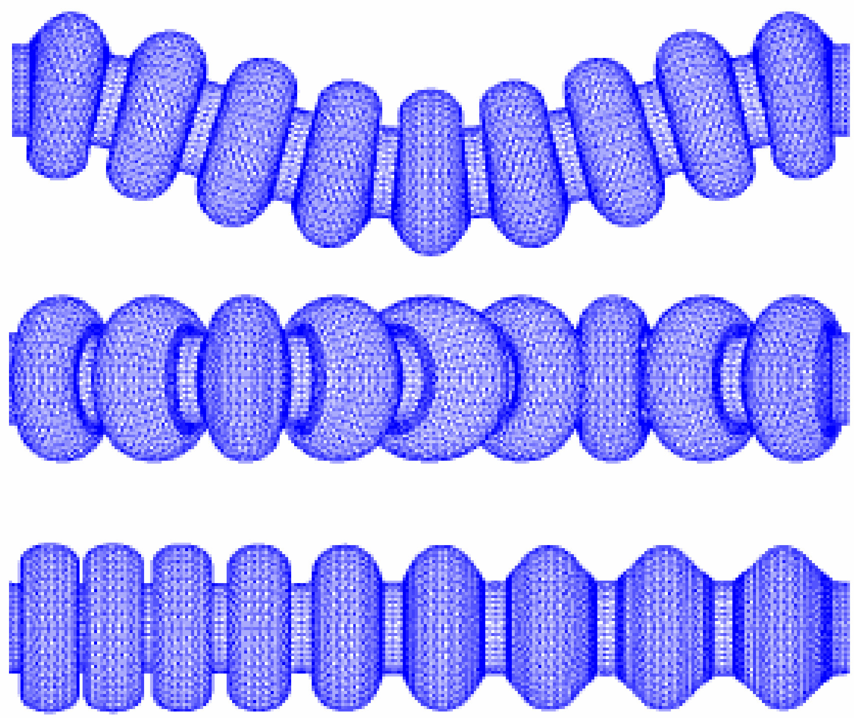
Highlights and Recommendations
Cavity Preparation

- Q research still needed,
- Q 10^{10}, 20 MV/m
- EP not necessary, but may help
- Single crystal cavities are proving very promising and may be cheaper. Needs more research!
- Also magnetic shielding in modules needs to be investigated and possibly improved!!!

Highlights and Recommendations
Microphonics

Cornell University **Microphonics**

Example: TTF 9-cell cavity



H.Gassot et al.

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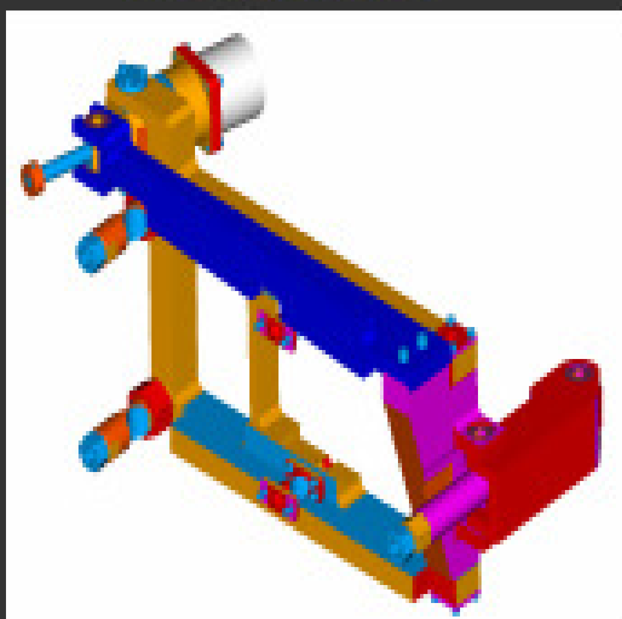
Highlights and Recommendations
Microphonics

- Proof of principle that low (10Hz pk) microphonics modules exists.
- But even high-microphonics can be controlled so again this is a cost issue!
- Microphonics fluctuate from cavity to cavity and this must be investigated with big statistics at JLAB or SNS.
- Also correlations must be investigated.

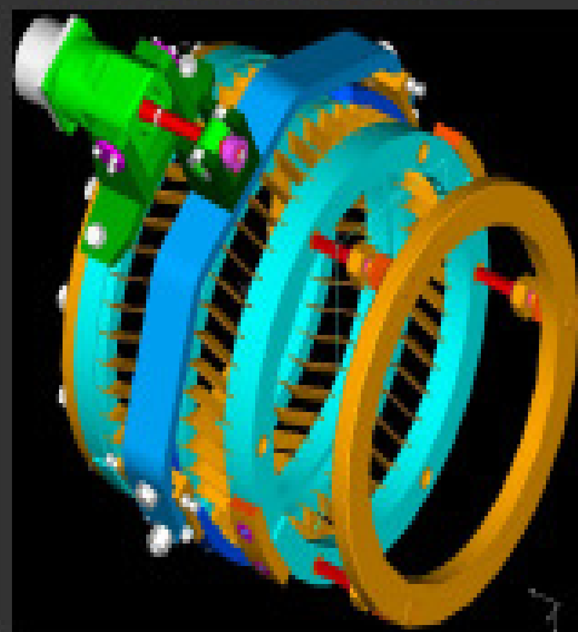
Highlights and Recommendations
Tuners

- Several designs with integrated piezos have been tested:

SNS tuner



TTF blade tuner



JLAB tuner

Highlights and Recommendations
Tuners

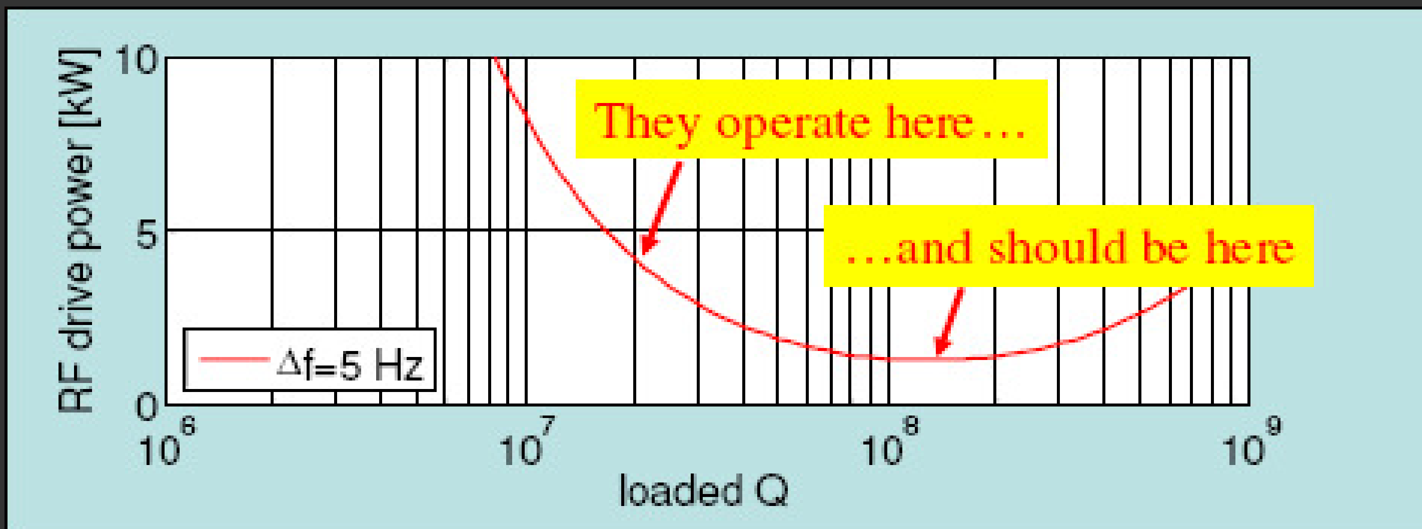
- Piezo element is required for fine tuner control
- Several designs have been tested (RIA has shown active control)
- Reliability is still a concern

Highlights and Recommendations
RF Control

Cornell University

Where are we today?
State of the Art (II)

JLAB FEL:



⇒ A good mechanical design results in very low microphonics levels, and would allow to run at a $Q_L \approx 10^8$!

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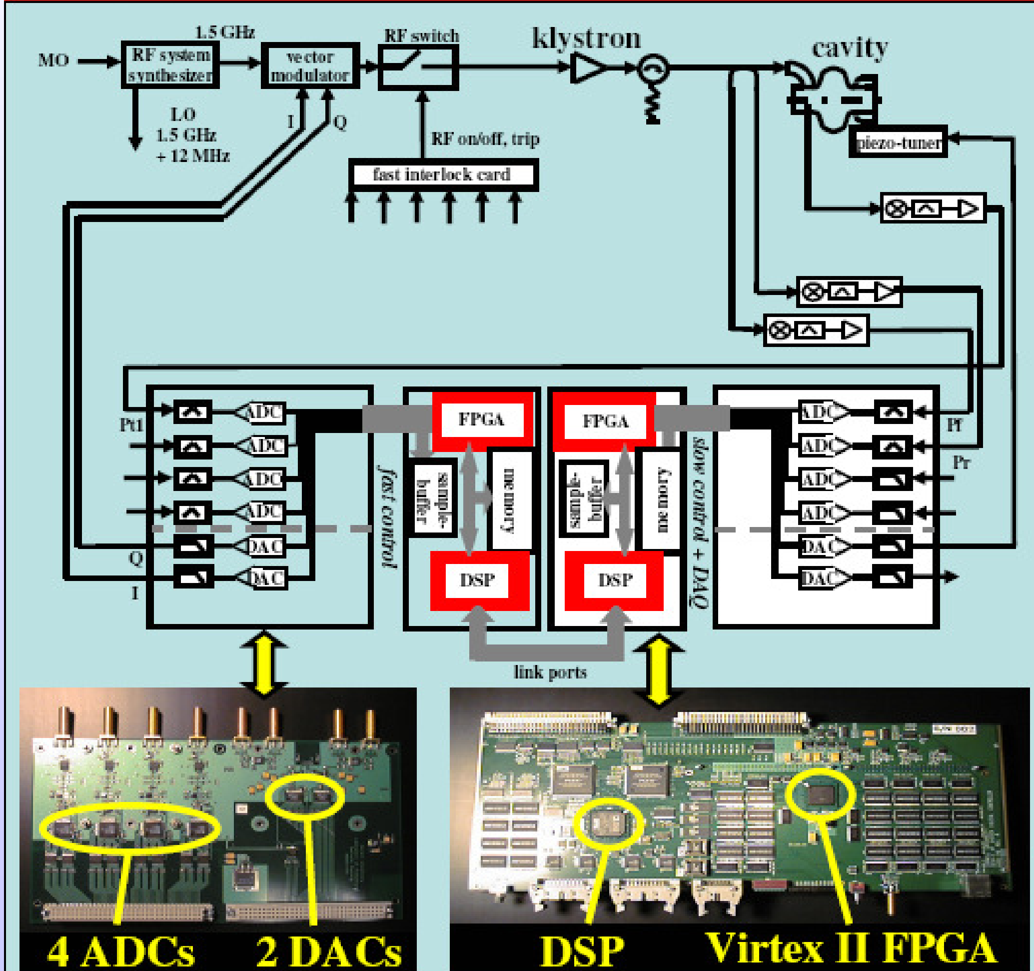
Highlights and Recommendations
RF Control

Cornell University

Where are we today?
Cornell RF control hardware



- *very low delay in the control loop*
- *Field Programmable Gate Array (FPGA) design combines the speed of an analog system and the flexibility of a digital system*
- *high computation power allows advanced control algorithms*
- *all boards have been designed in house*

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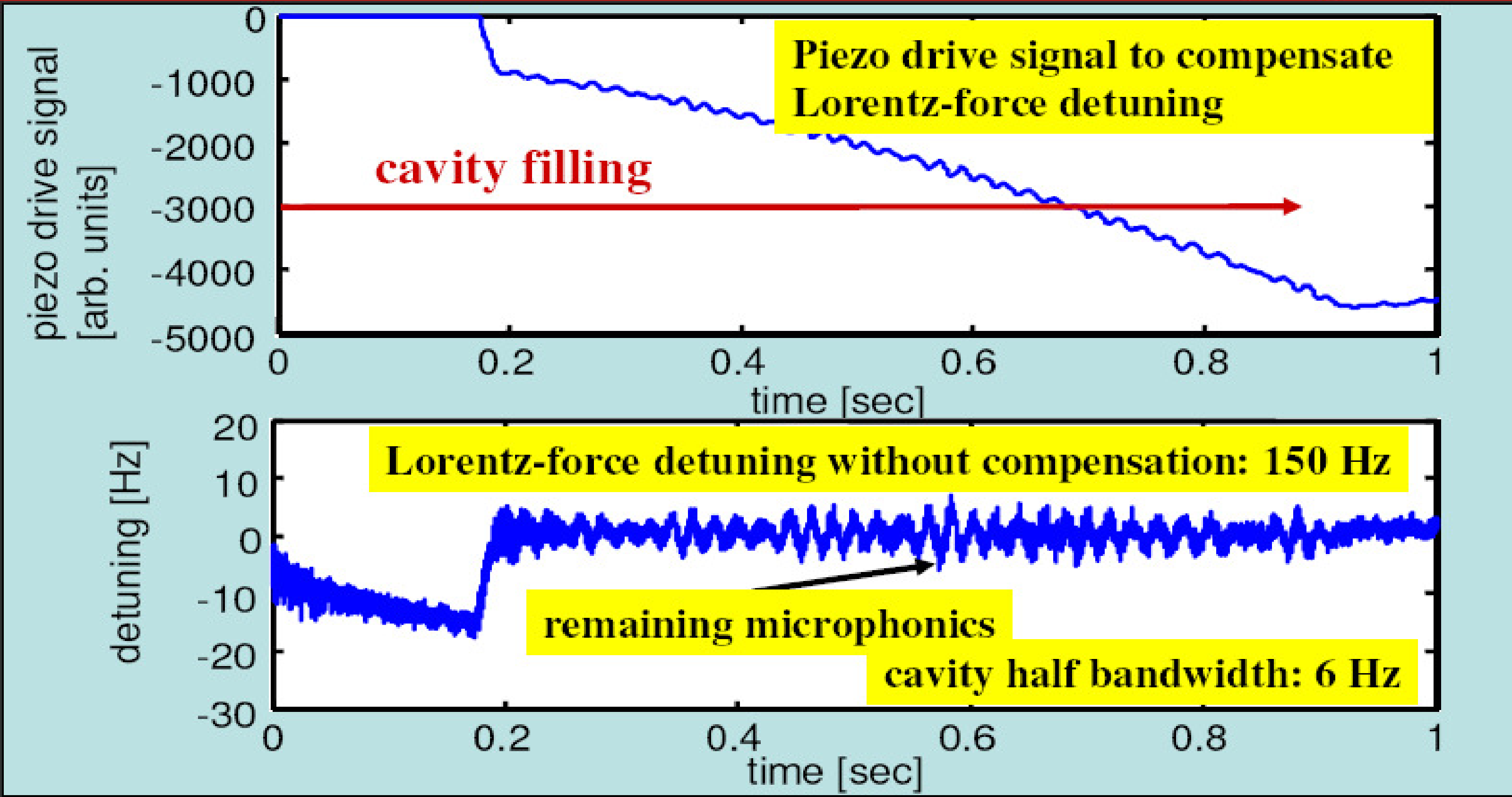
Highlights and Recommendations
RF Control

Cornell University

Where are we today?
Cornell RF control test (III)



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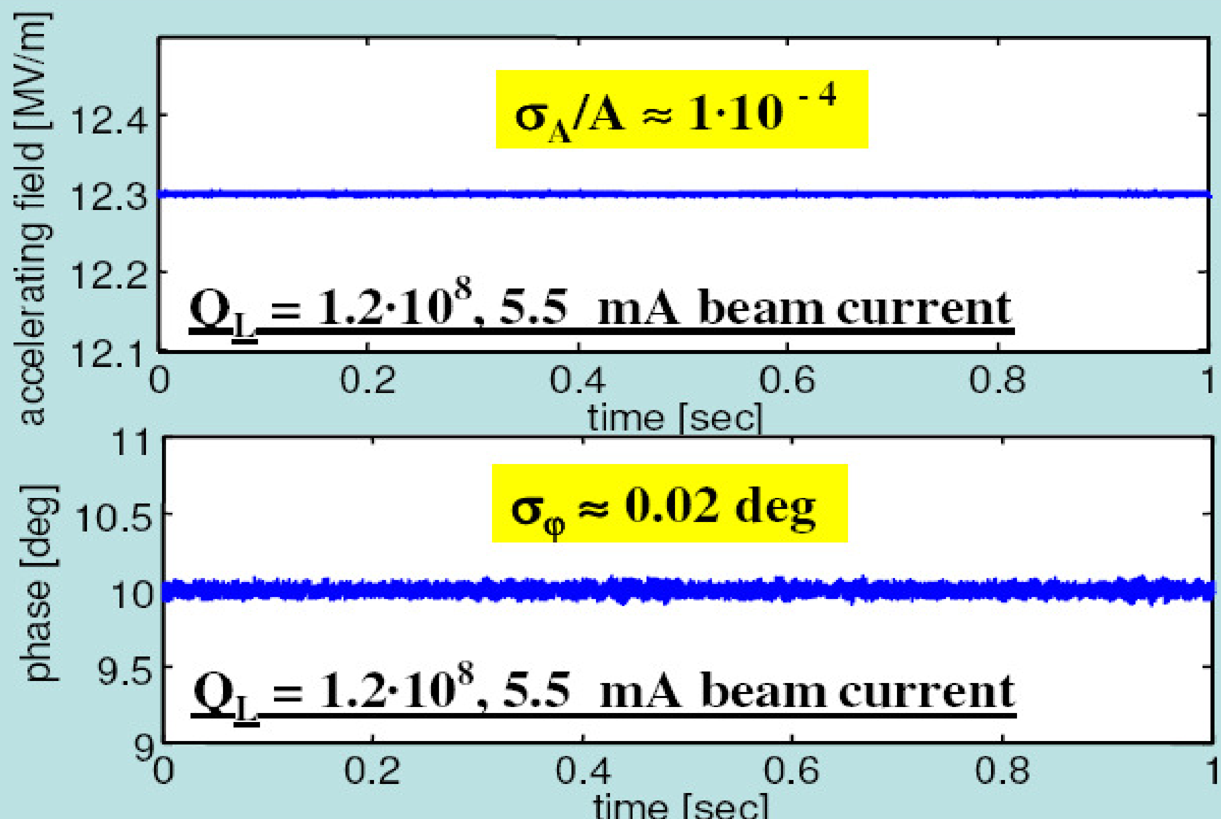
Highlights and Recommendations
RF Control

Cornell University

Where are we today?
Cornell RF control test (IV)



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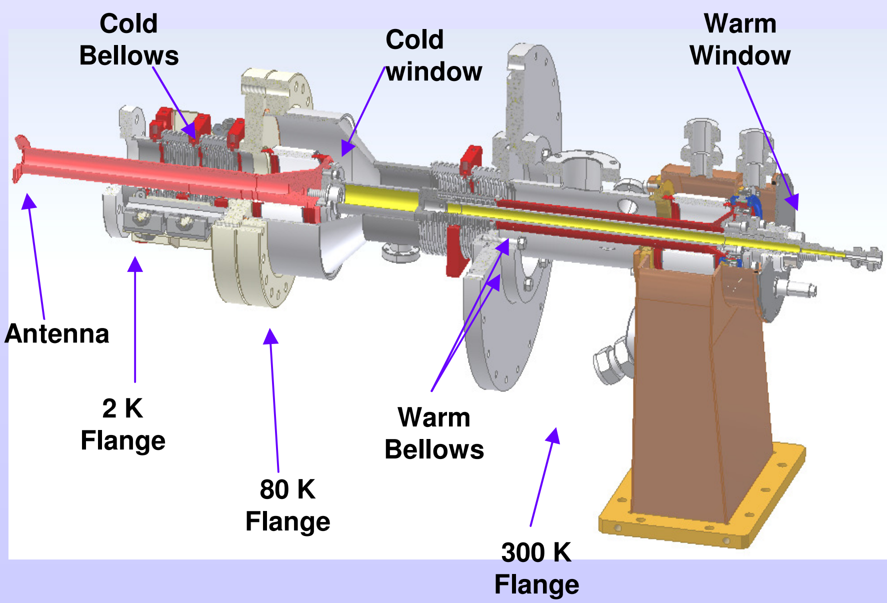
Highlights and Recommendations
RF Control

- No fundamental limit to operation $Q = 10^8$
- Proof of principle 10^{-4} is OK and 0.01 deg is OK.
- Distribution system must be able to handle this.
- The consensus was that a digital system was the way to go.

Highlights and Recommendations
Power couplers

1. The cold part was completely redesigned using a 62 mm, 60 Ohm coaxial line for stronger coupling, better power handling and avoiding multipacting.
2. Antenna tip was enlarged and shaped for stronger coupling.
3. "Cold" window was enlarged to the size of "warm" window.
4. Outer conductor bellows design was improved for better cooling.
5. Air cooling of the warm inner conductor bellows was added.



Frequency	1300 MHz
Bandwidth	+/- 10 MHz
Max. power to matched load	75 kW
Number of ceramic windows	2
Cold coax. line impedance	60 Ω
Warm coax. line impedance	46 Ω
Coaxial line OD	62 mm
Q_{ext} range	$9.2 \cdot 10^4$ to $8.2 \cdot 10^5$
Antenna position change	16 mm

Highlights and Recommendations
Power couplers

- Power couplers suitable for the main linac have been demonstrated
- Injector power coupler under development
- Adjustability is desirable, but may not be essential
- Coupler is a critical item and cost driver.

Highlights and Recommendations
Operating Temperature

Q (T) is linked to the BCS surface resistance

$$R_s = A\, f^2 \exp^{-\Delta/kT} \; (+ R_0)$$

R_s : BCS surface resistance
A : material constant
f : frequency
R_0: residual resistance

Δ : BCS energy gap
k : Boltzmann constant
T : temperature

1.5 K is taken here as a reasonable lower limit of BCS Q=Q(T) dependence

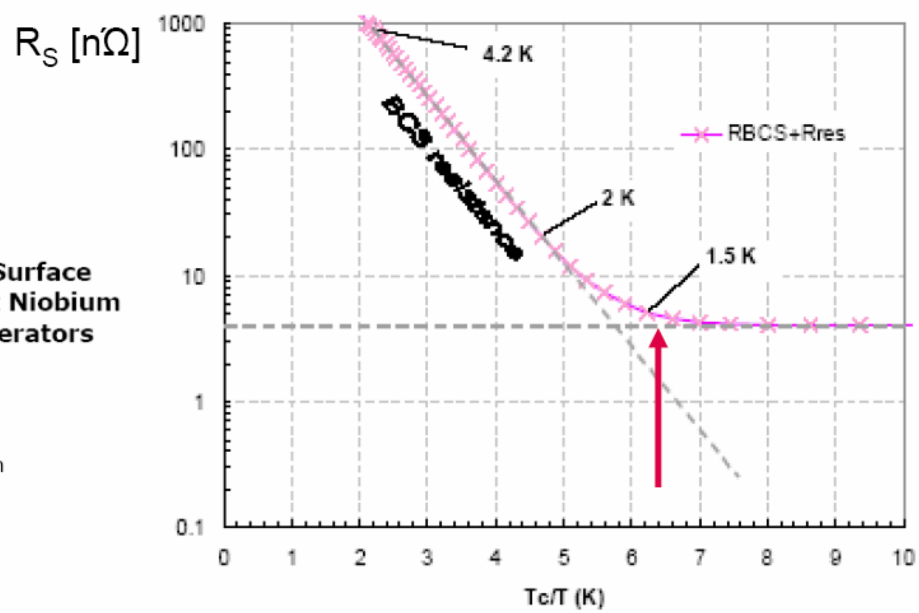
Diagramm taken from:

Review of Models of RF Surface Resistance in High Gradient Niobium Cavities for Particle Accelerators

P. Bauer

Fermilab, Technical Division

TD-04-014, June 2004



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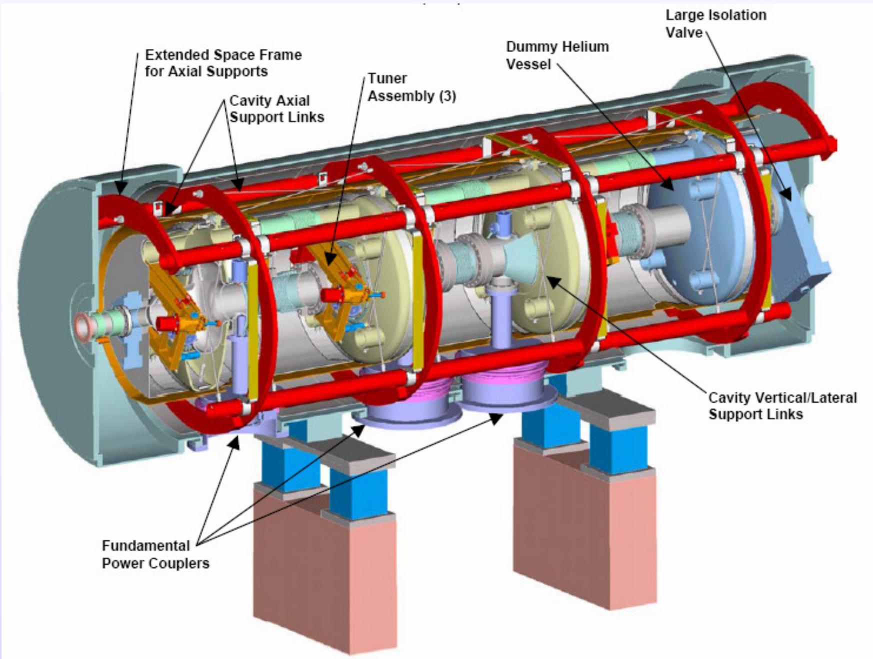
Highlights and Recommendations
Cryogenics 1

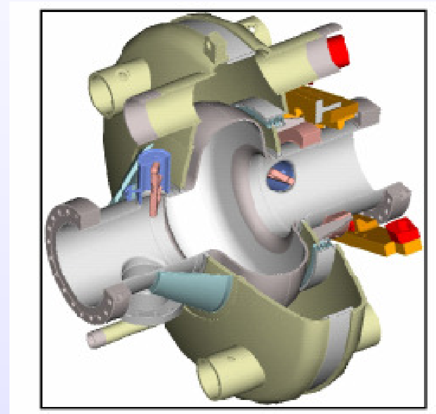
- Fight residual resistance, then go lower in temperature (down to 1.8 K looks safe), retrofit system is possible.
- Module design for 2K should work at 1.8K provided BCS losses dominate.
- Capital cost does not increase as you lower the temperature (provided BCS losses dominate.) You trade off cold compressors versus warms screw compressors.

Highlights and Recommendations
Cryogenics 2

- Design headroom used is 50% by several large institutions. (This is a minimum)
- 4 K shield comes for free (capital cost versus 10 year operating) and 4K heat intercept is useful for coupler etc. anyway. And each 2K watt takes you closer to the limit. (Based on the TESLA module)

Highlights and Recommendations
Injectors – JLab 750MHz



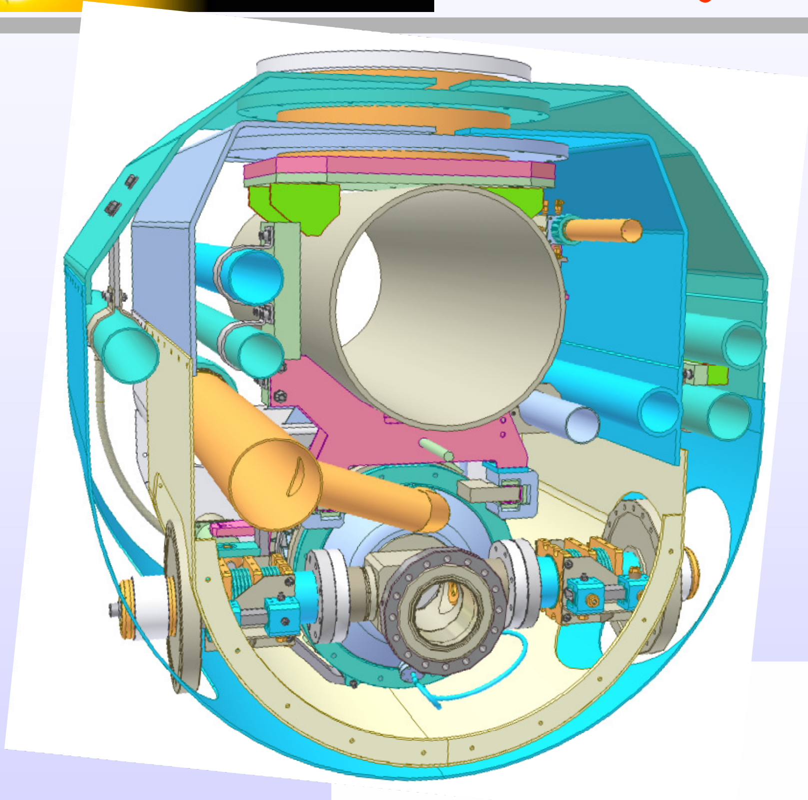


Three single-cell 750-MHz cavities will accelerate beam consisting of 133 pC, 6.3 ps long bunches to 7 MeV. The fourth upstream vessel is presently used for helium inventory and does not contain an accelerating cell. The cavity Q factor is > 10^{10}.

The cryomodule is "100-mA-compatible" with the exception of the three SNS-style couplers. 500 kW replacement couplers are under development. *a la* TTF HOM couplers are used in this design.

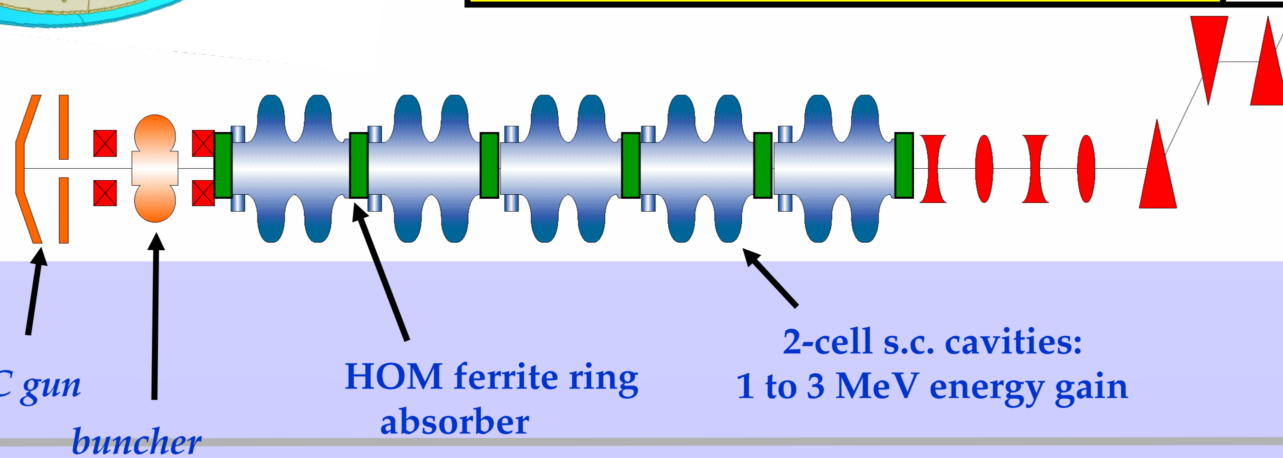
Four cavities have been delivered from AES and are being prepared for chemistry and an eventual vertical test.

Highlights and Recommendations
Injectors – Cornell 1.3GHz



Beam Parameters:

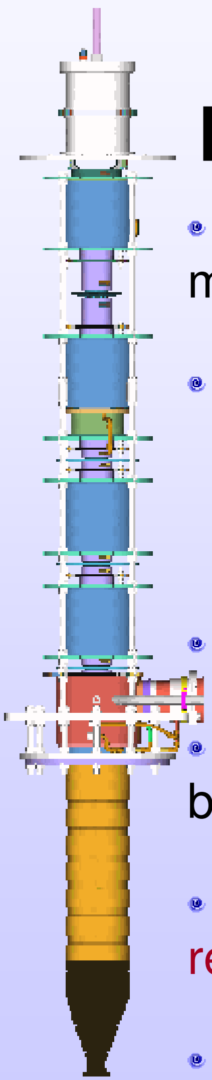
max beam current at q = 77 pC	100 mA
max beam current at q= 1 nC	1 mA
bunch repetition rate	1.3 GHz
transverse emittance	< 0.5 μm rad
max. emittance growth	< 0.1 μm rad
bunch length	0.6 mm
beam energy gain	5 MeV



Highlights and Recommendations
Injectors

- Active field, three projects (Cornell injector, JLab 100 mA injector)

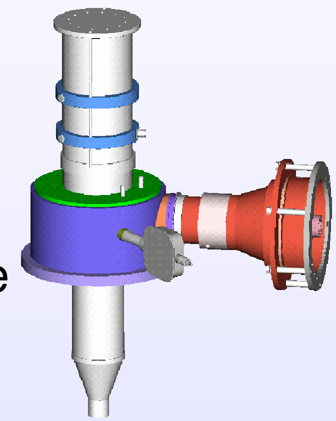
Highlights and Recommendations
Power Sources



Klystron

- Electron Bunches formed by density modulation from the cavities.
- Several bunching cavities
  - High Gain
  - Long Device
  - Expensive
- Considerable velocity spread
- Maximum gap voltage determined by the slower electrons
- Rapid reduction in efficiency for reduced output power
- High Gain

IOT

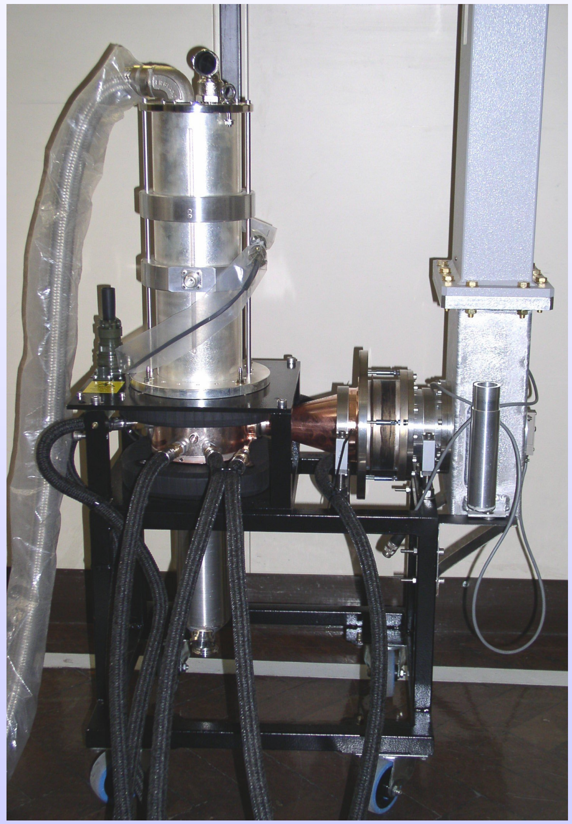


- Velocity modulation direct from the cathode
- Little velocity spread
- Higher gap voltage
  - Increased output power
  - Higher efficiency
- Efficiency is approximately constant for reduced output power
- Low Gain
- Grid geometry will not permit IOTs to operate at high frequencies like Klystrons.

Highlights and Recommendations
Power Sources

1.3GHz IOTs

CPI



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Thales TH713

Highlights and Recommendations
Power Sources

- IOTs look like the way to go for main linac, development nearly complete.
- Efficiency must still be demonstrated with the gain at the same time.
- Drive amplifier becomes a cost driver.

Highlights and Recommendations
Technology Transfer to Industry

- Lab must demonstrate in more module than 1 that the desired guarantees can be achieved.
- Small labs cannot do this and must therefore do "research" together with the bigger Labs and industry.

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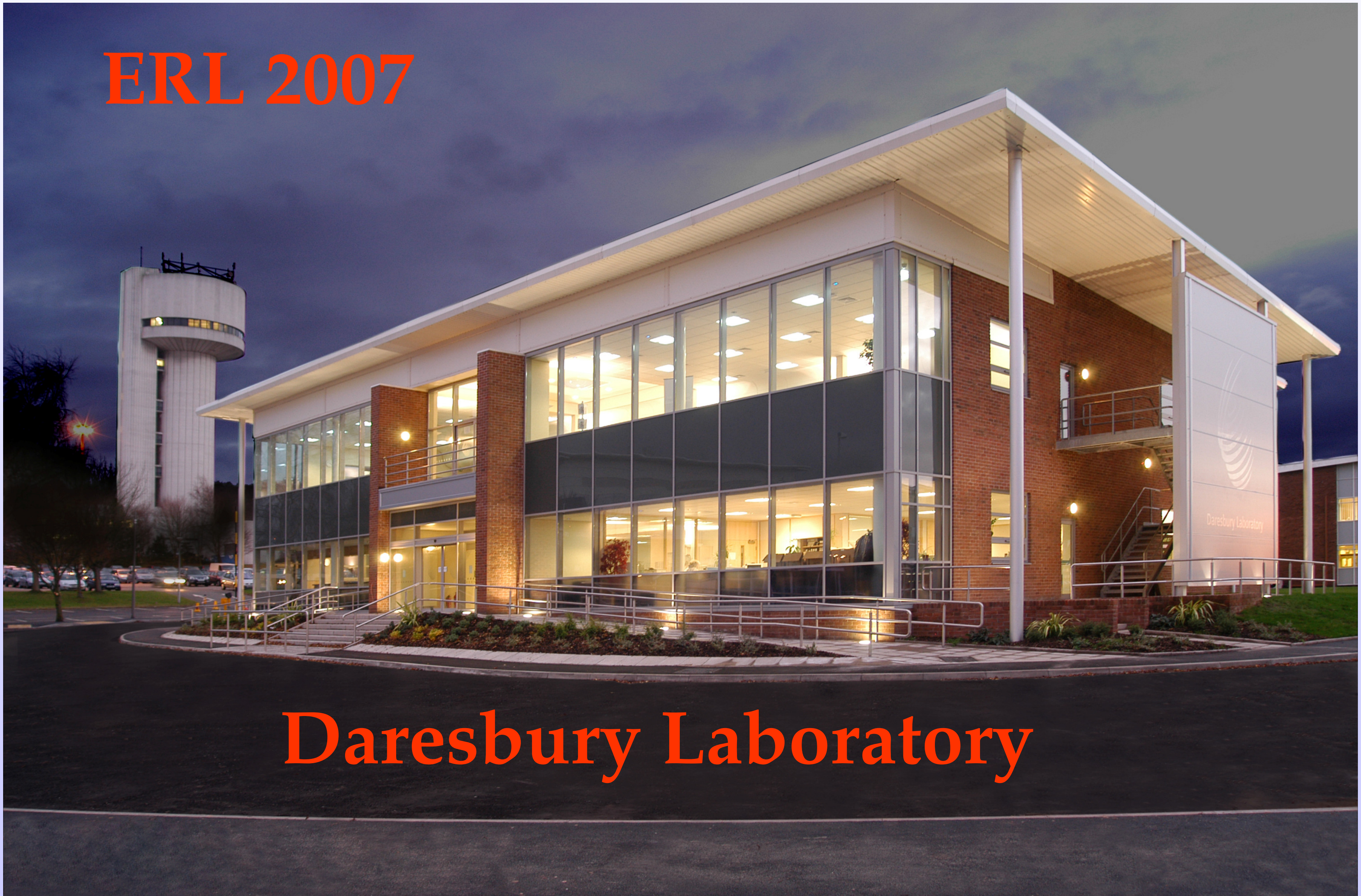


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