US Report
Activities at

- Cornell
- JLAB
- Fermilab
- SLAC

New Funding from NSF

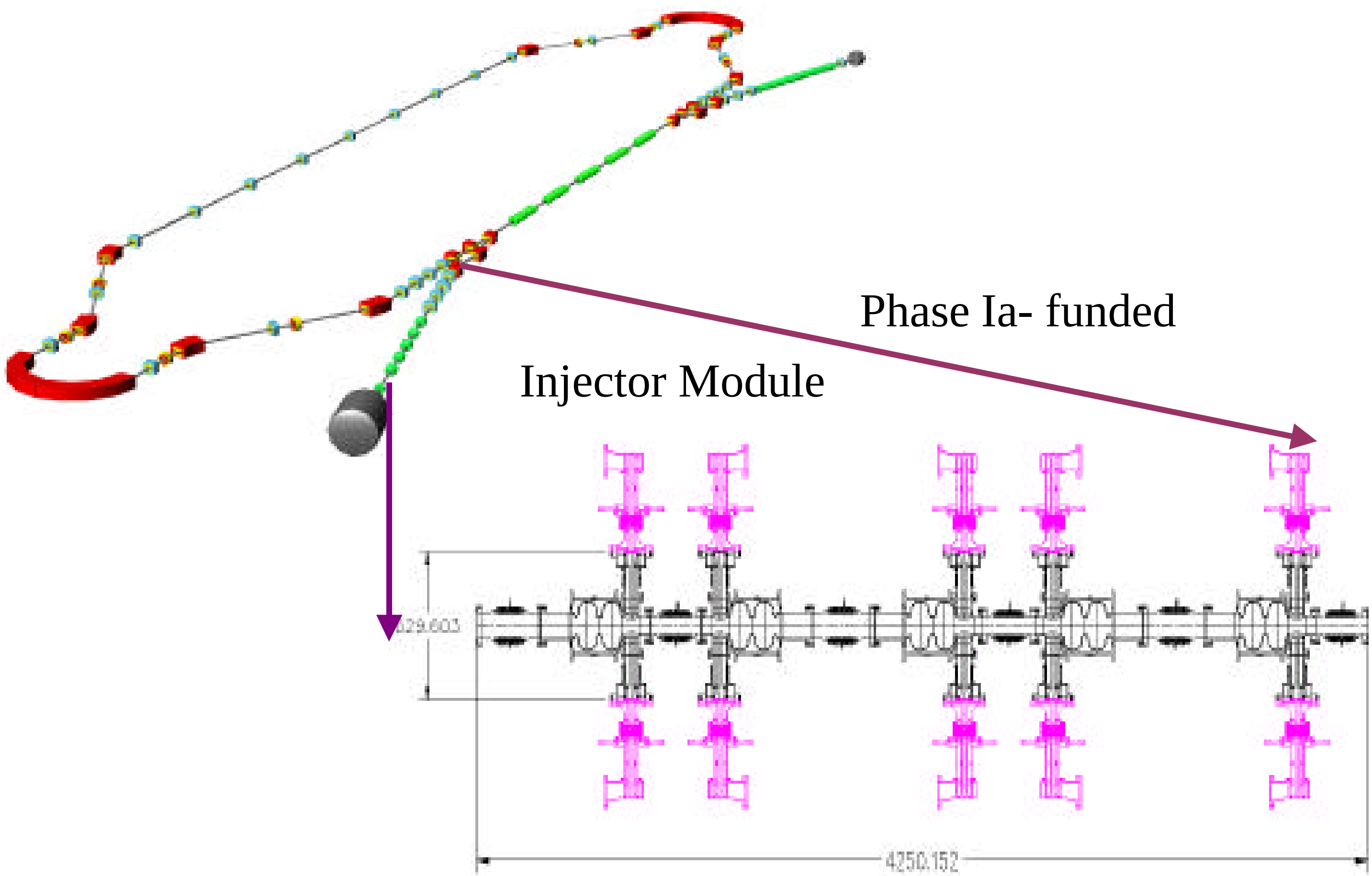
Phase Ia Energy Recovery Linac (ERL)
Synchrotron Light Source at Cornell University

Based on TESLA type SRF linac technology

Total 18 M$: FY 05 - FY 08

FY 05 Award: 5.15 M$

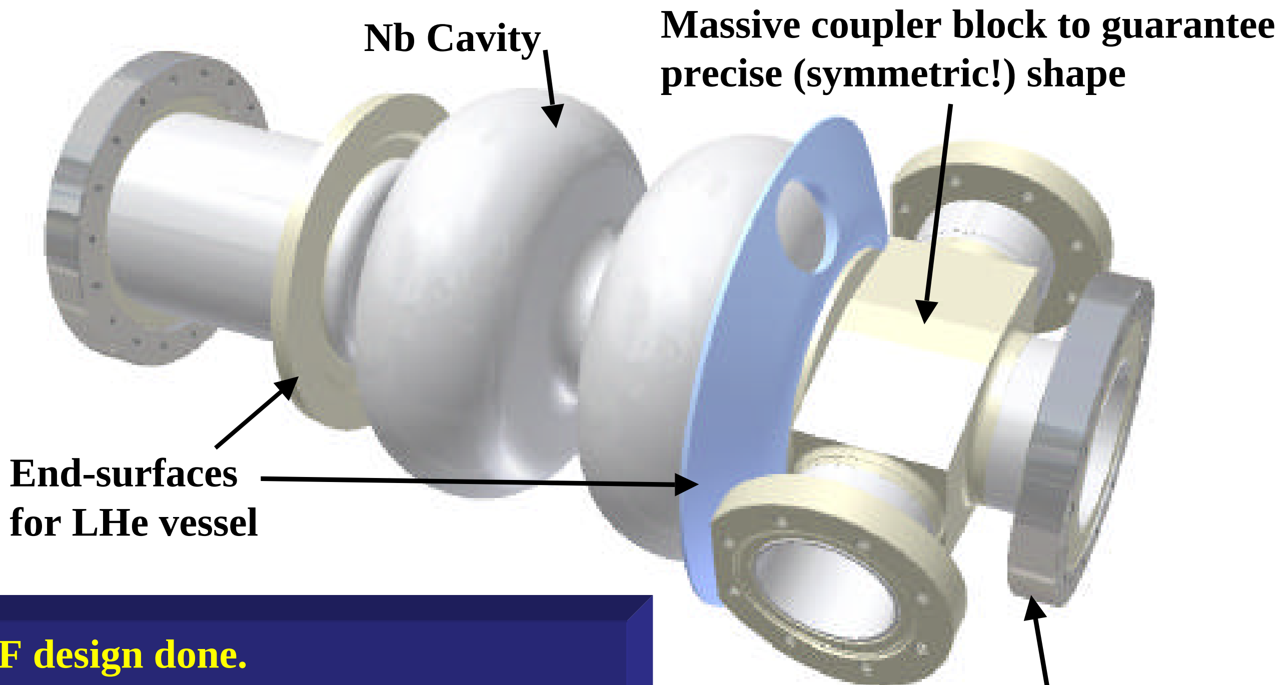
ERL Prototype (Phase I a & b)



Requirements of ERL Injector Cryomodule

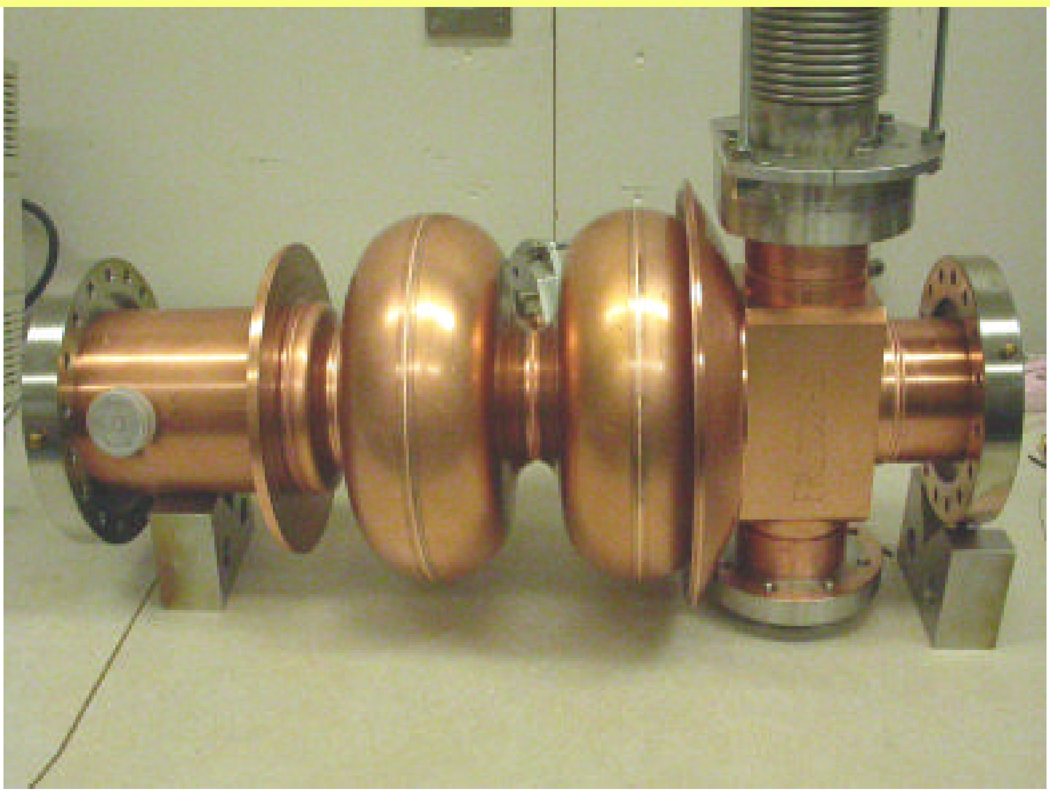
- Max gradient 14 MV/m
- Max beam current 100 mA.
- Input coupler to deliver beam power 100 kW average !
- CW operation, Q_{ext}~ 4. 10^4-> 4. 10^5.
- All HOMs propagate out of large beam tubes to HOM absorbers, 80K ferrite lined beam pipe
- Conflat end flanges
- Special requirements: cavities should impose minimum disturbance to beam emittance ≈1 μrad
- No HOM ports, symmetric input couplers

2-Cell Cavity: Design

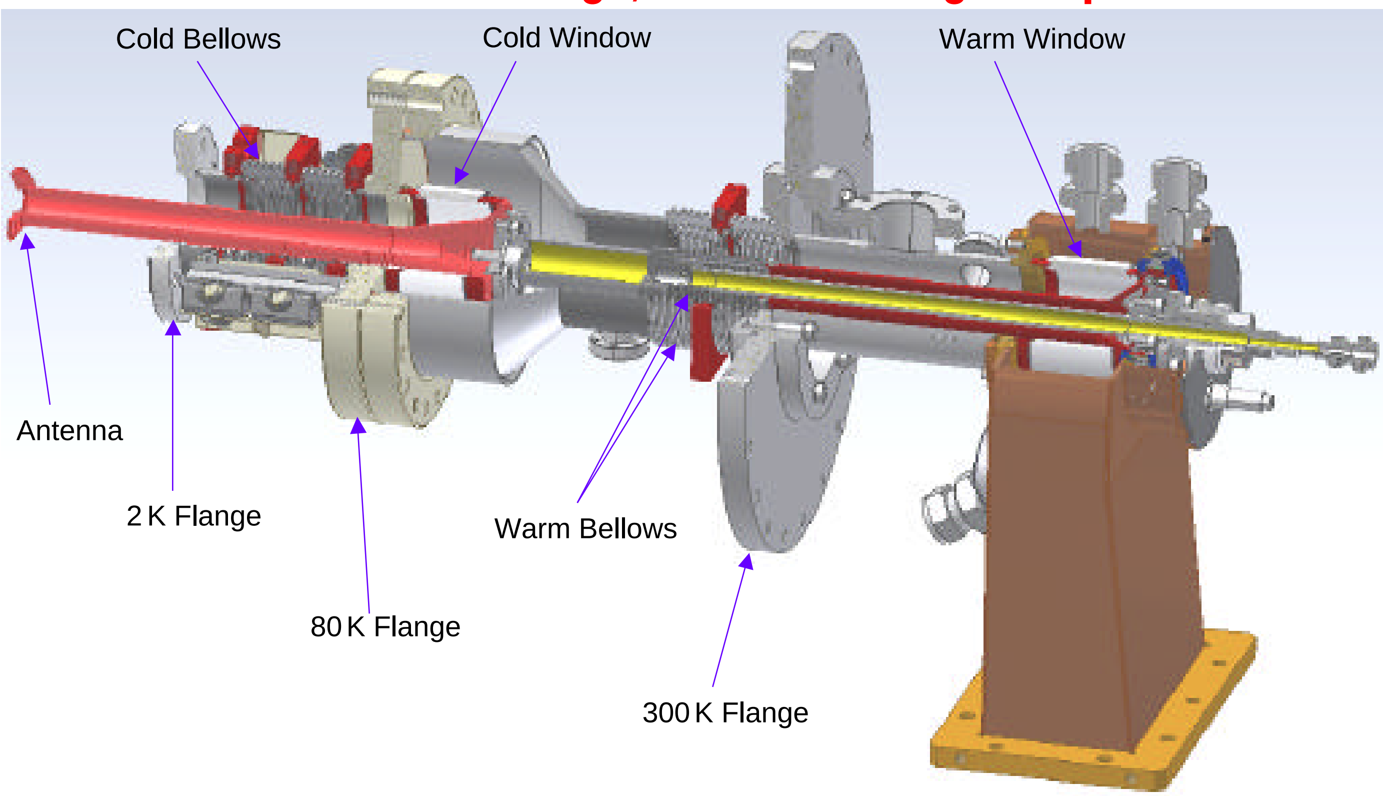


- RF design done.
- Mechanical design done.
- Fist copper prototype has been built.

Copper Prototype Ready

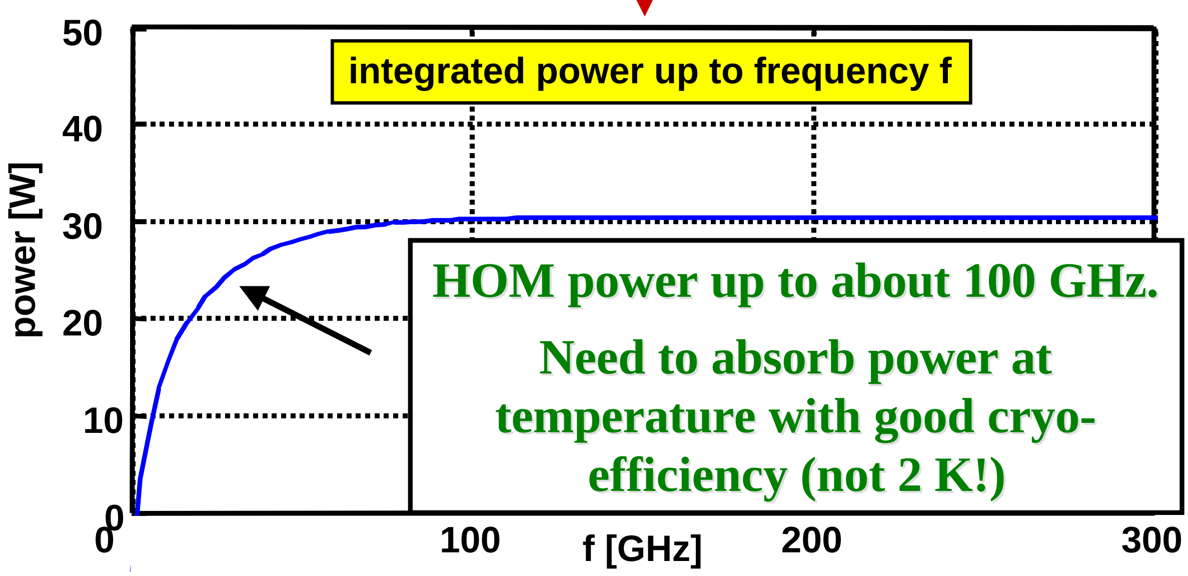


ERL Injector Cavity Coupler, 50 kW average power
Based on TTF-III design, modified for high ave power

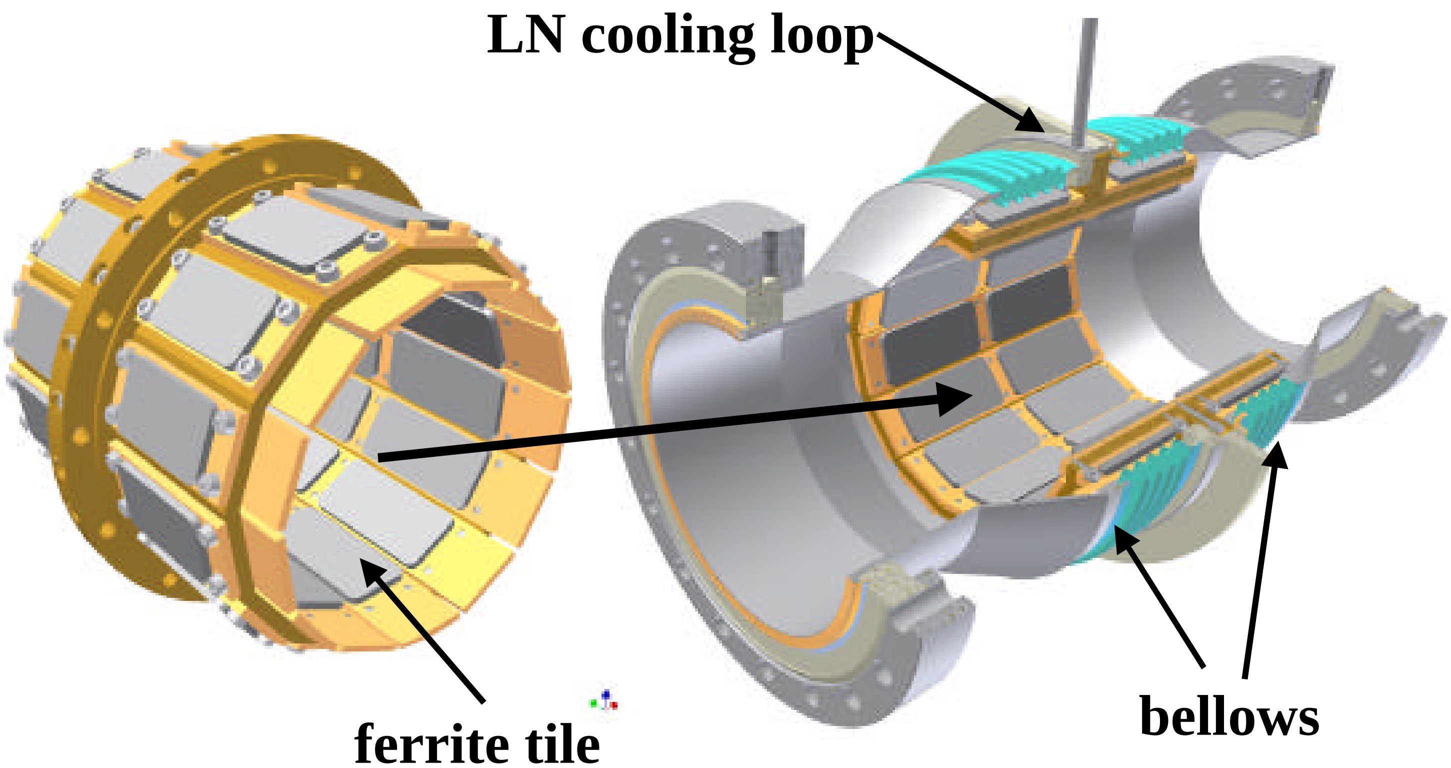


HOM Damping Challenge: HOM Monopole Power at High Frequencies

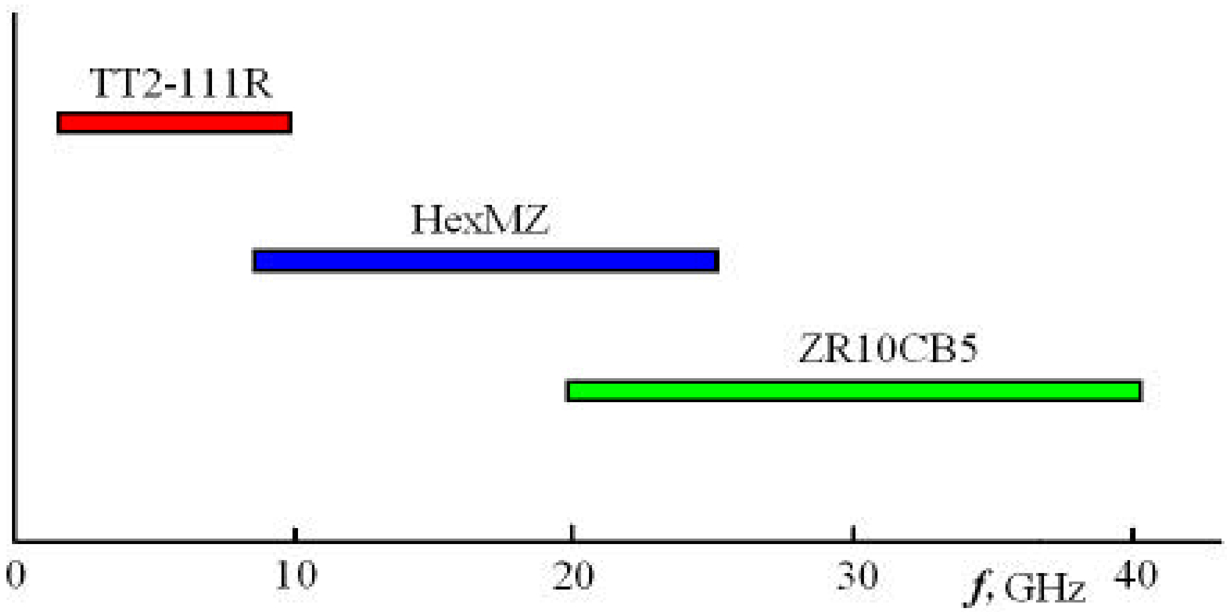
600 μm bunch length in the linac



Ferrite Shielded Bellow: Design

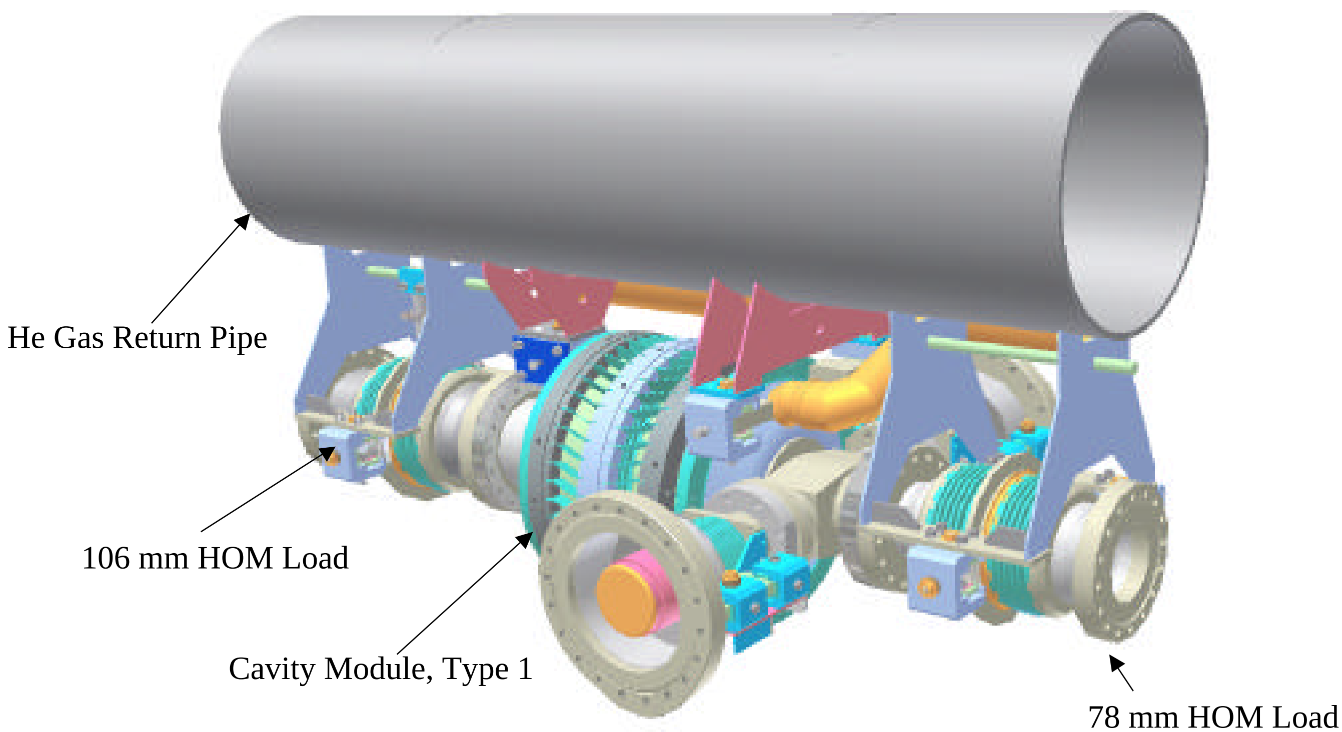


Regions of application for 3 chosen materials

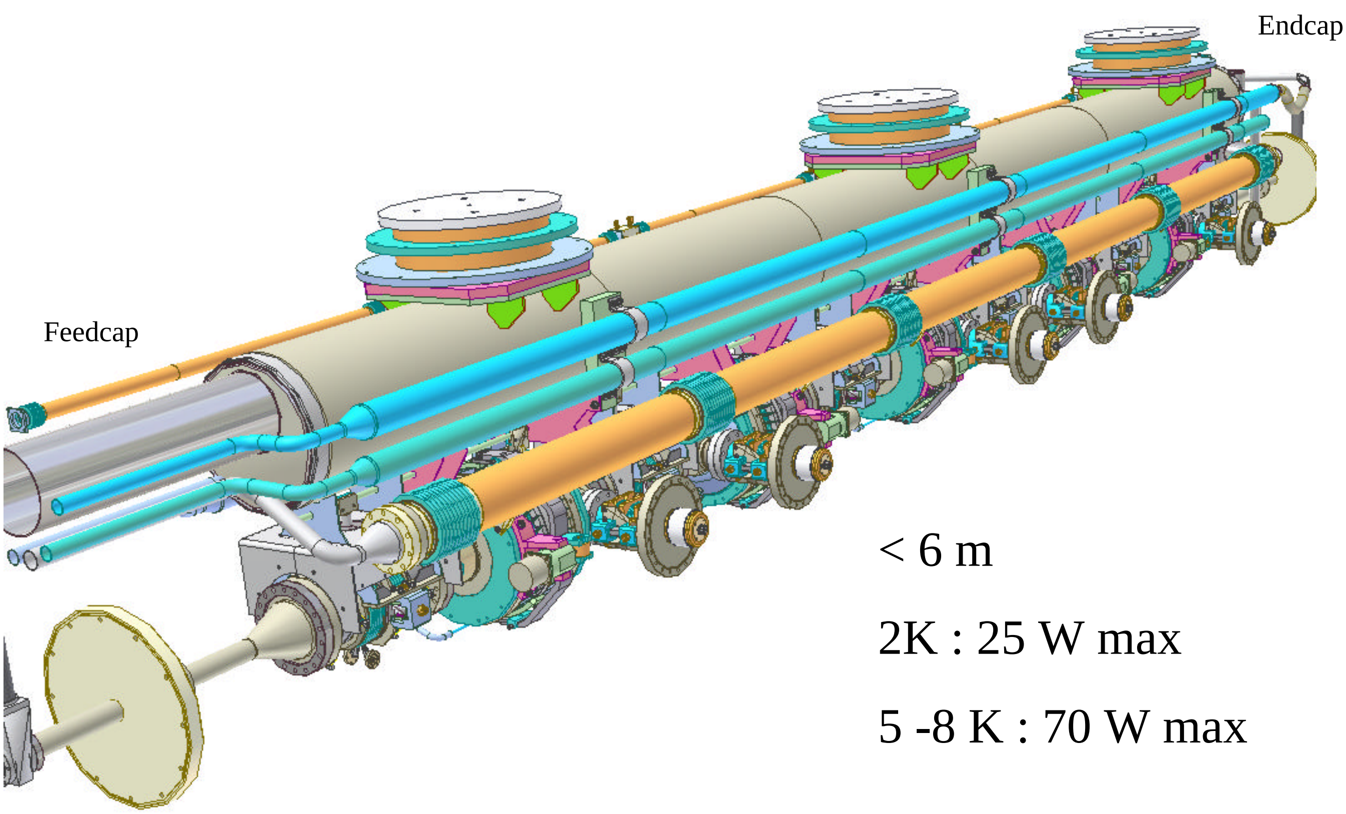


Losses measured at 100 K over full frequency range

Injector Cryomodule Section (1/5)
Based on TESLA Design
Nearly Complete



ERL INJECTOR CRYOMODULE DESIGN



< 6 m

2K : 25 W max

5 -8 K : 70 W max

Cryomodule Main Elements Assembly on HeGRP

Ultra-Fast Digital RF Field Control System for ERLs Tested at CESR, and JLAB CEBAF & FEL at Qext > 10^8

Based on DESY system of IQ detection and control (instead of traditional amplitude and phase control.)

Improved for CW operation and very low measurement noise.

Very small delay in the control loop pushes gains as high as possible to keep field stable.

Loop delay reduced by a factor of 4 compared to the original TTF system by using new hardware (so called FPGAs instead of DSPs)

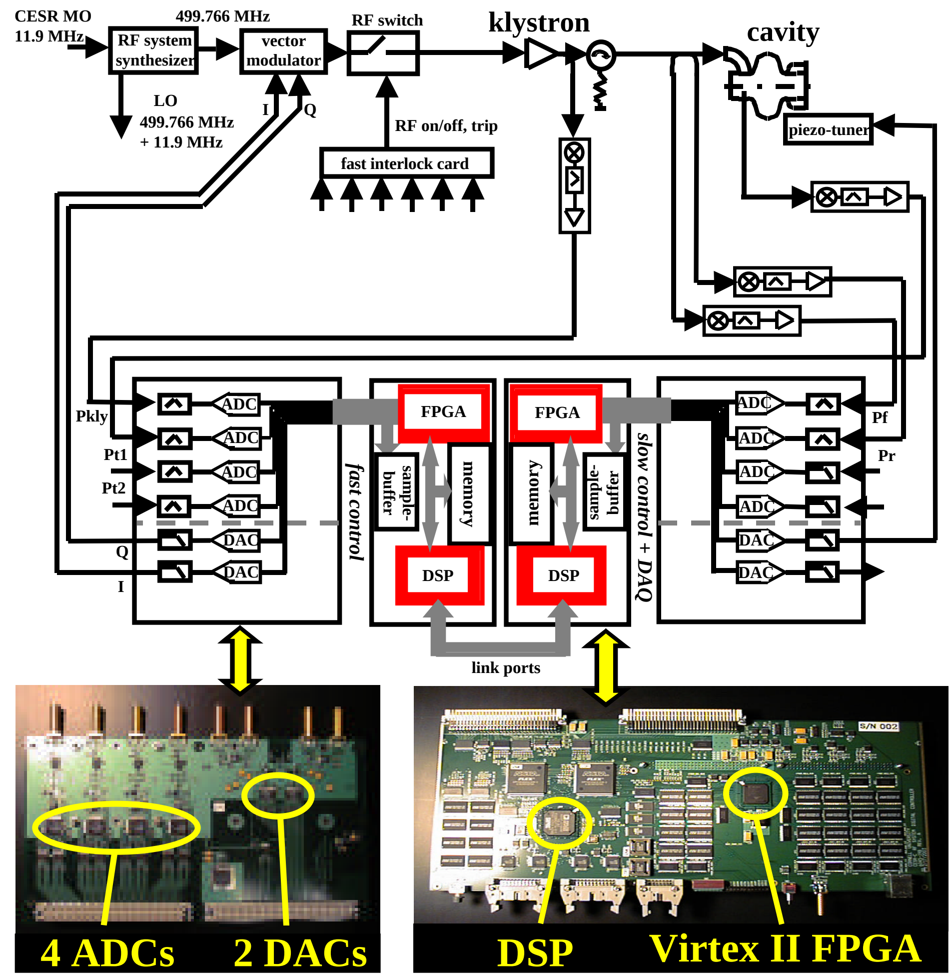
Field Programmable Gate Array (FPGA) design combines the speed of an analog system and the flexibility of a digital system

40 times faster data sampling

Piezo based frequency control to keep the cavity on resonance, and to ramp up the field.

Matthias Liepe
CORNELL
UNIVERSITY

Ultra-Fast Digital RF Field Control System for ERLs Tested at CESR, CEBAF and JLAB FEL

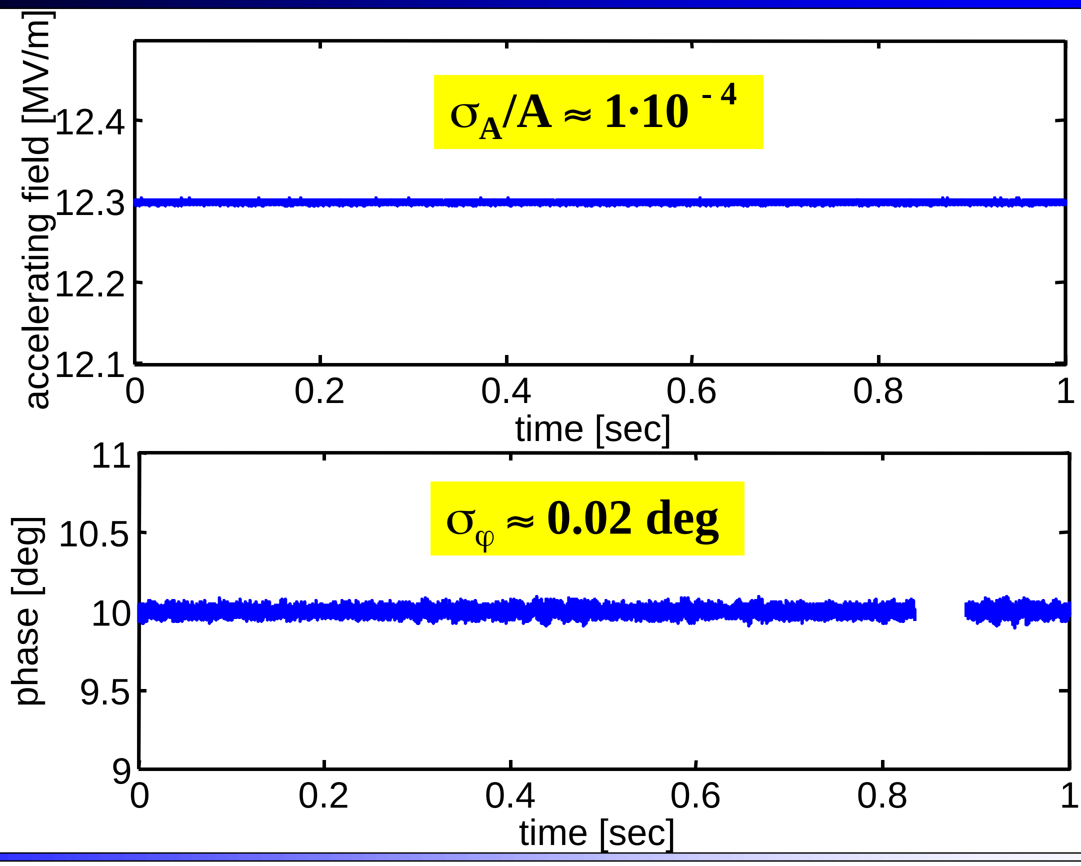


- *high computation power allows advanced control algorithms*
- *all boards designed in house*
- *generic design: digital boards can be used for a variety of control and data processing applications*

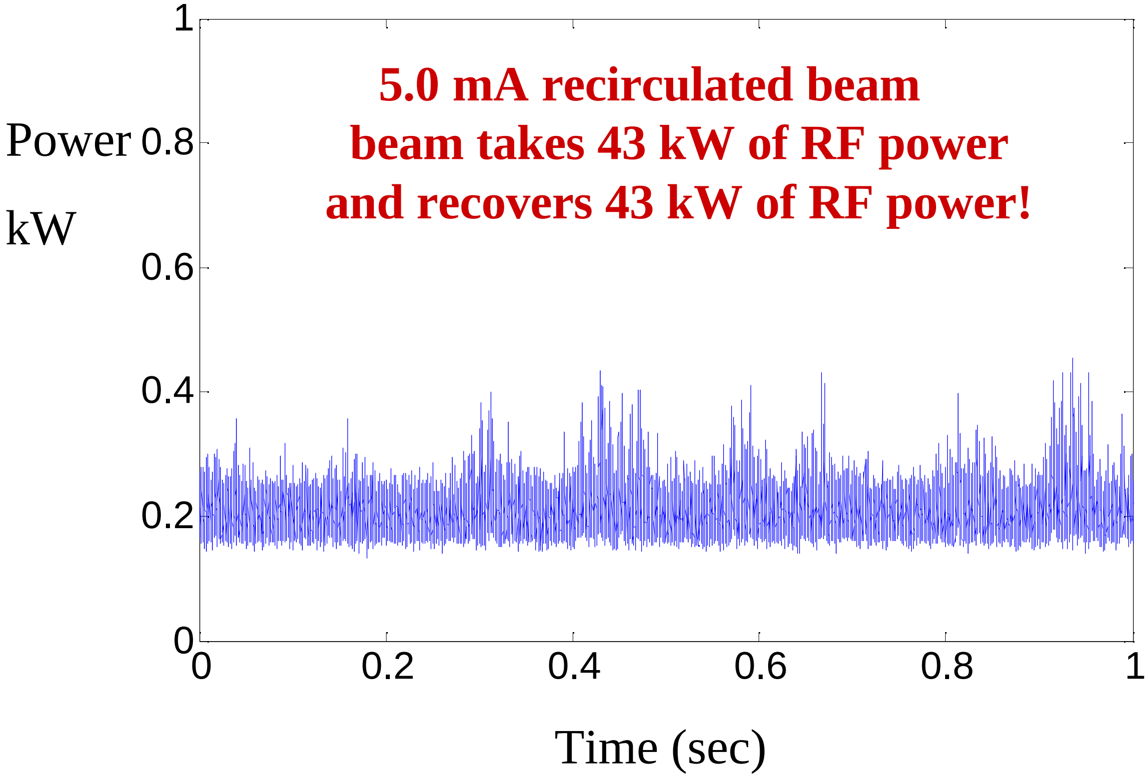
Beam Test at the JLAB FEL

- Operated cavity at Q_L=1.2·10^8 with 5 mA energy recovered beam.
- Need 200 - 500 watts for 12 MV/m operation
- Compare to 1.3 kW at Q_L=2·10^7
- Had the following control loops active:
  - PI loops for cavity field (I and Q component)
  - Stepping motor feedback for frequency control
  - Piezo tuner feedback for frequency control

Test at JLAB FEL: Q_L= 1.2·10^8, 5 mA recirculating beam, 10 deg off-crest



Test at JLAB FEL: $Q_L = 1.2 \cdot 10^8$, 5 mA recirculating beam, 10 deg off-crest



Test with CEBAF Cavity
at 200 μA beam current

- E = 10 MV/m, $Q_{ext} = 4.2x10^7$
- Microphonics peak detuning 15-20 Hz
- Amp control 10^{-4}
- Phase control 0.01 deg
- Need power 1 - 1.6 kW instead of 2.4 kW at Q = 6.6 $x10^6$

New Shapes for Higher Gradients

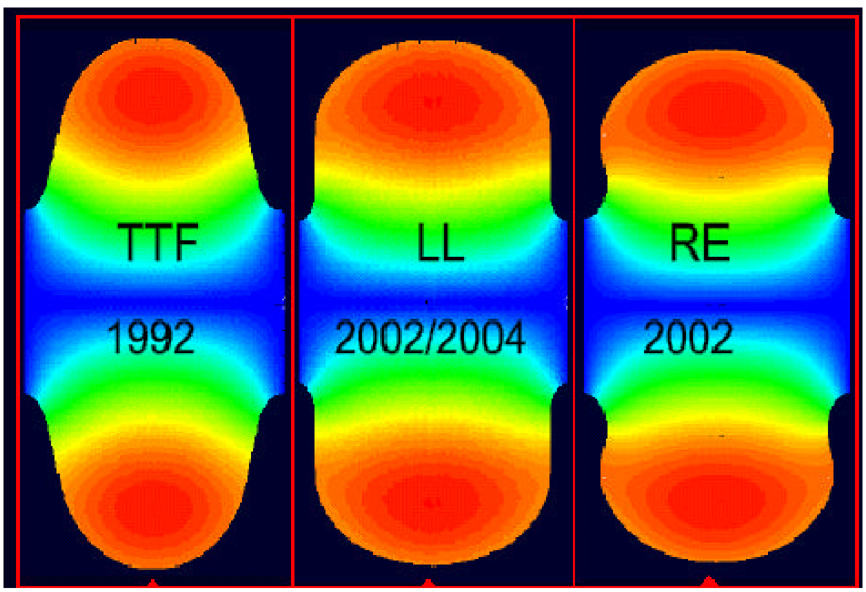
Philosophy:

• Critical magnetic field is a brick wall near 1800 Oe.

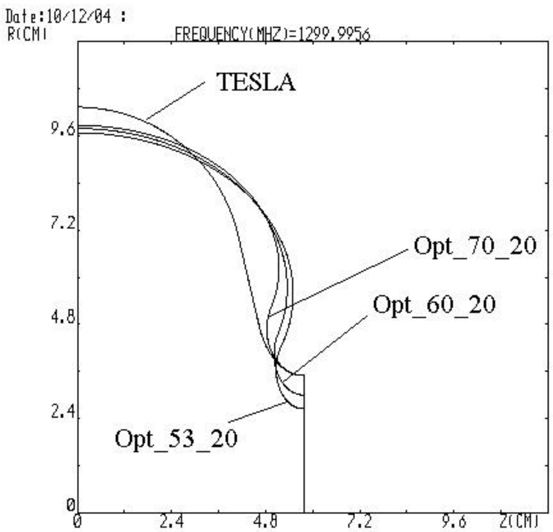
• Losses from field emission can be reduced by HPR and HPP

-> Lower Hpk

Even if we must raise Epk



+ Variations

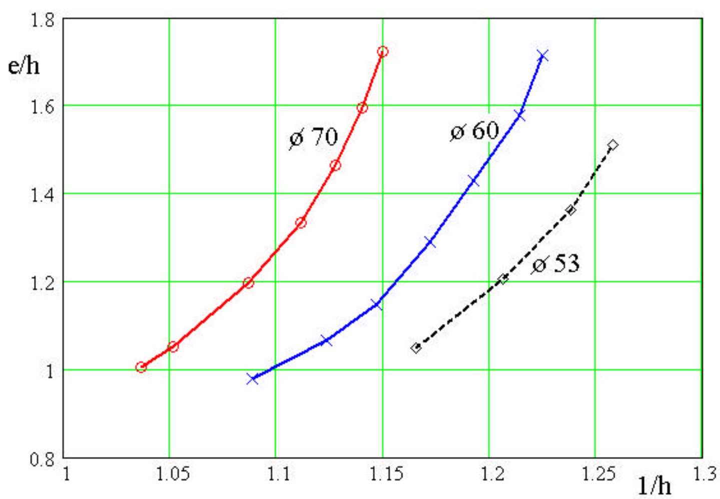


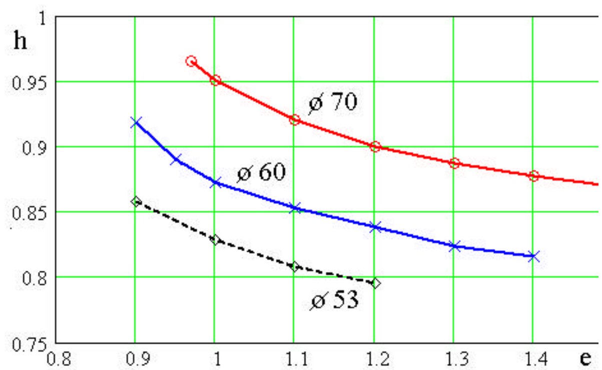
Opt_70_20 - reentrant cavity with aperture 70 mm, electric field 20 % higher than in TESLA, magnetic field 10 % less than in TESLA, at the same acceleration.

Opt_60_20 - aperture 60 mm, el. field: +20 %, mag. field: - 16.1 %.

Opt_53_20- aperture 53 mm, el. field: +20 %, mag. field: - 20 %.

e = Epk/2 Eacc	e/h = Epk/Epk(TESLA)
h = Hpk/42Eacc	
for TESLA e = 1, h = 1.	1/h = Eacc/Eacc(TESLA)



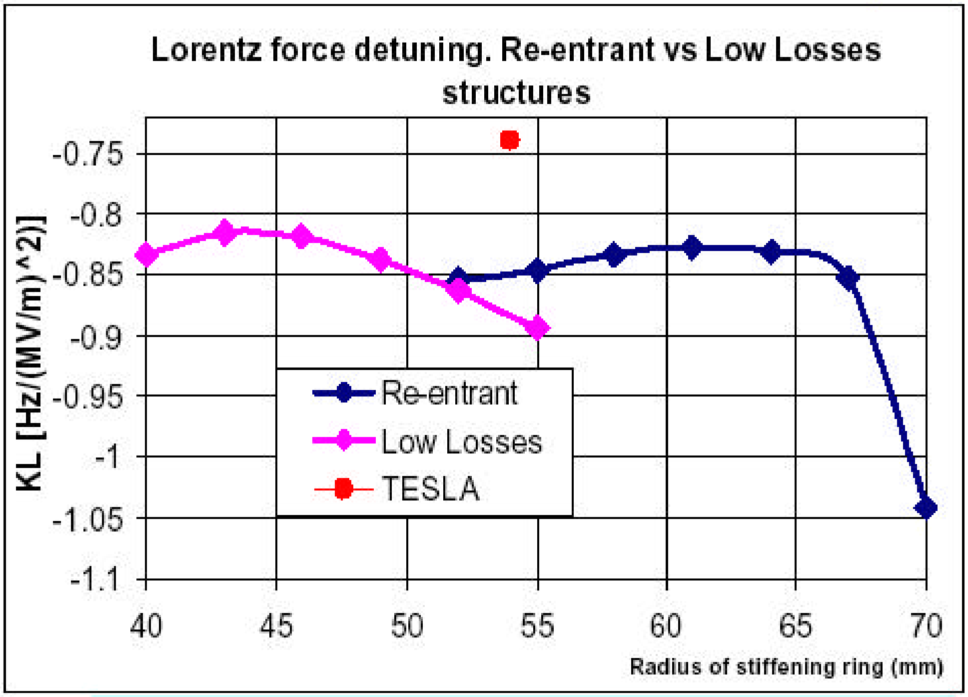


Downsides of Smaller Aperture

- Higher wakefields
  - LL shape : k_l up 20%, k_t up 70%
  - RE shape : same as TESLA shape
- Smaller cell-to-cell coupling LL shape
  - More sensitivity to mechanical tolerances
  - 1.5% instead of TTF 1.9%
- Higher R/Q
  - Lower cryogenic losses by 20%
- LL and RE
  - Slightly higher Lorentz-Force detuning

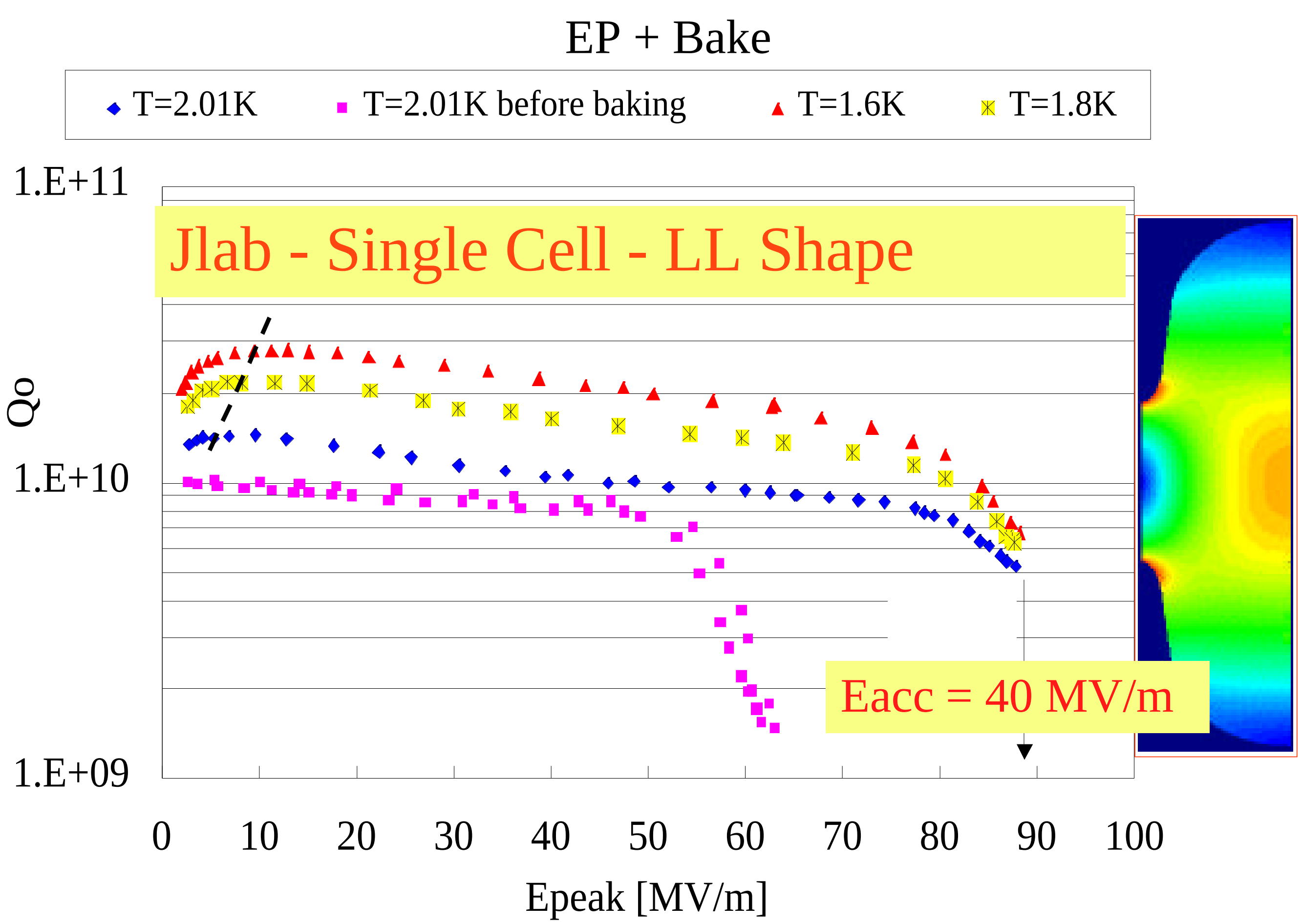
Mechanical properties. Lorentz forces (2)

Fermilab



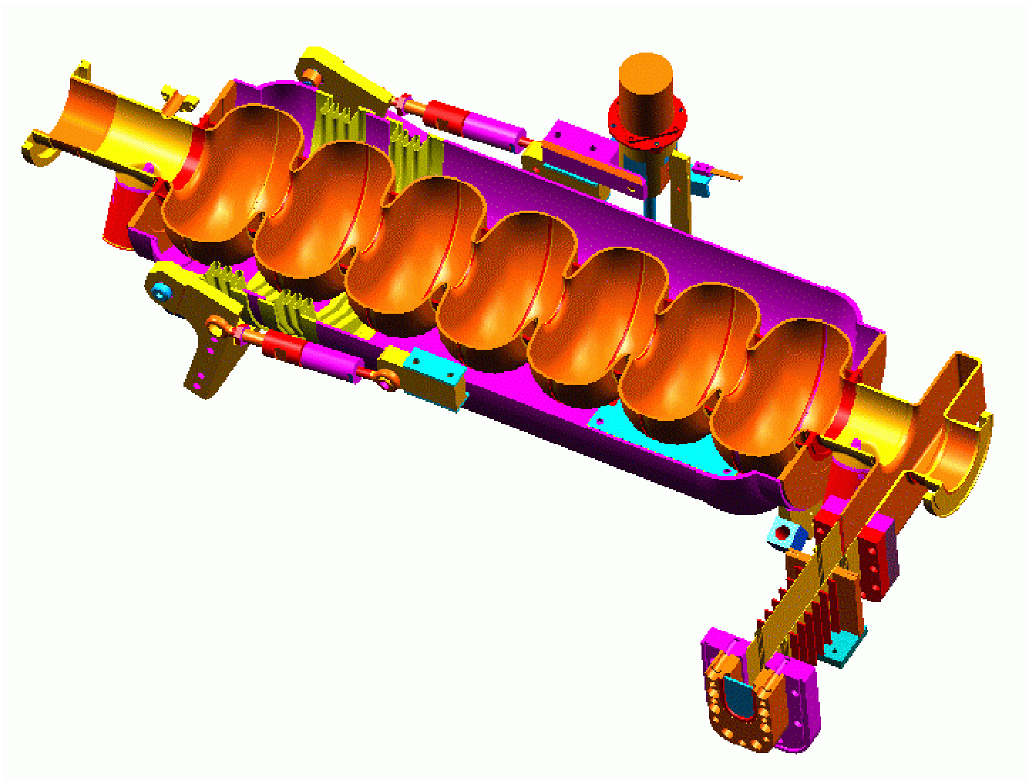
TESLA(wall=2.8mm)	ΔF(wo/w ring) = - 801/-463 Hz for 25 MV/m
Low Losses(2.8mm)	ΔF(wo/w ring) = - 871/-509 Hz for 25 MV/m
Re-entrant(2.8mm)	ΔF(wo/w ring) = - 860/-517 Hz for 25 MV/m

Cavity Test Results

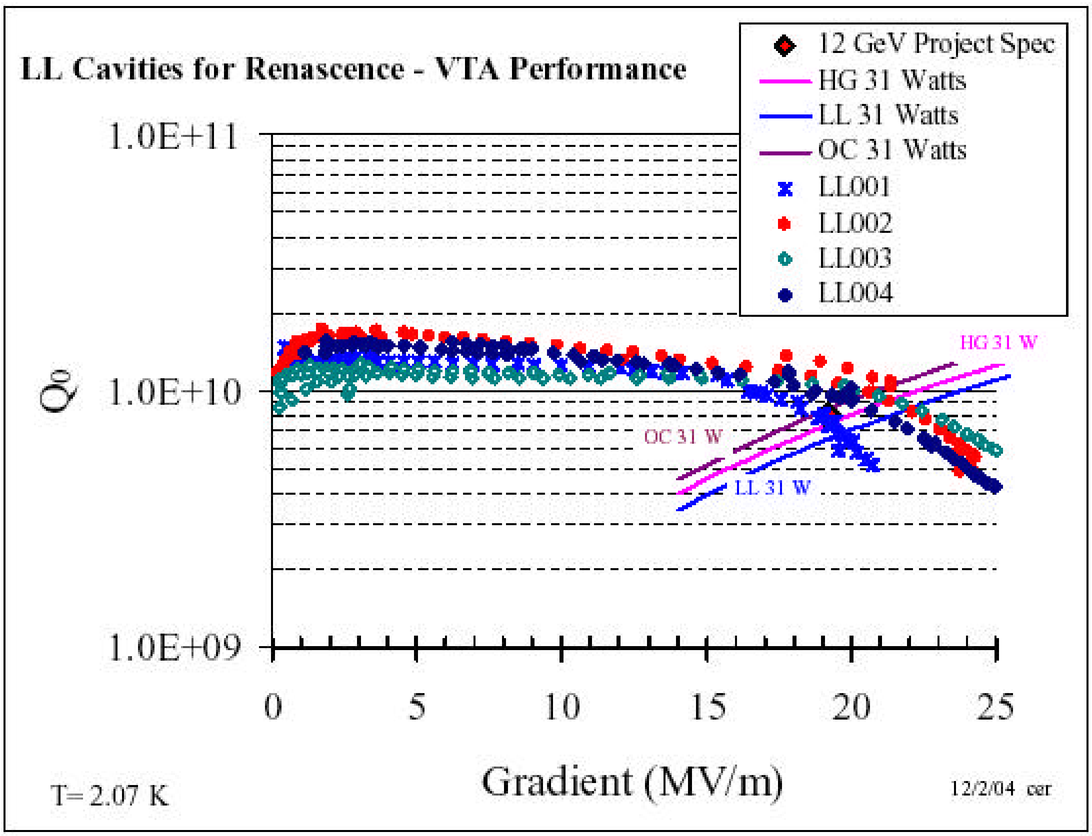


EP + Bake
T=2.01K
T=2.01K before baking
T=1.6K
T=1.8K
1.E+11
1.E+10
1.E+09
Qo
Jlab - Single Cell - LL Shape
Eacc = 40 MV/m
0
10
20
30
40
50
60
70
80
90
100
Epeak [MV/m]

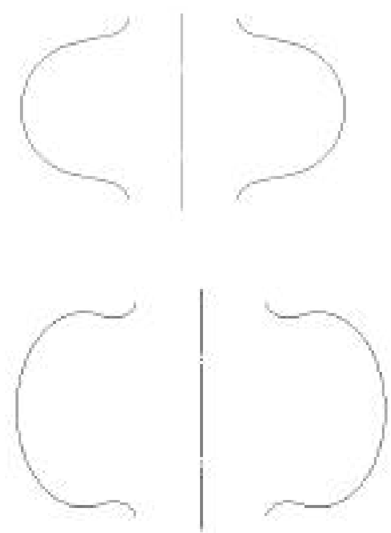
Jlab - LL Cavity Shape, 7-cell Cavity



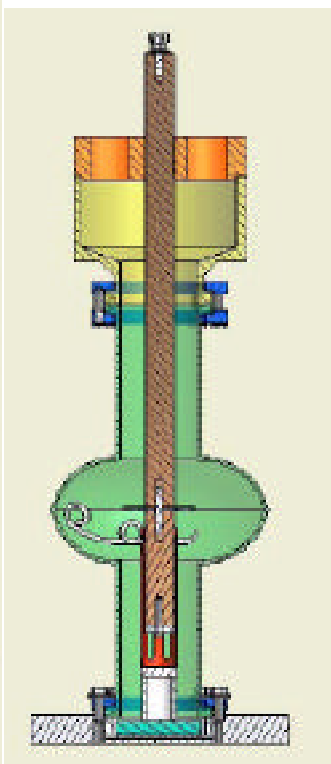
Jlab - 7-cells BCP, no bake



Cornell Single Cell :
Comparison of TESLA and RE Shape



Electropolish in Vertical Orientation



- Technically less complex than horizontal orientation
- Previous attempts failed due to improper stirring
- Special stirrer geometry developed

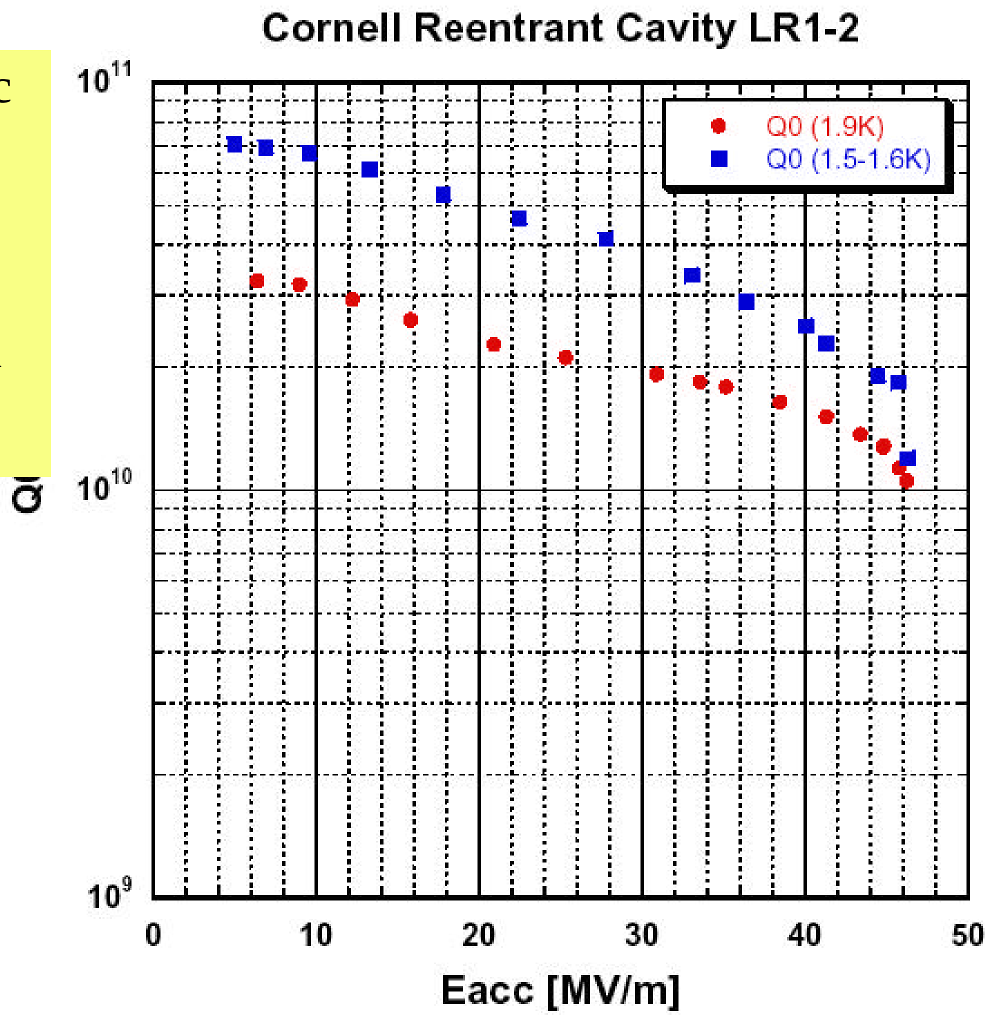
Extending to multicells

World Record Eacc

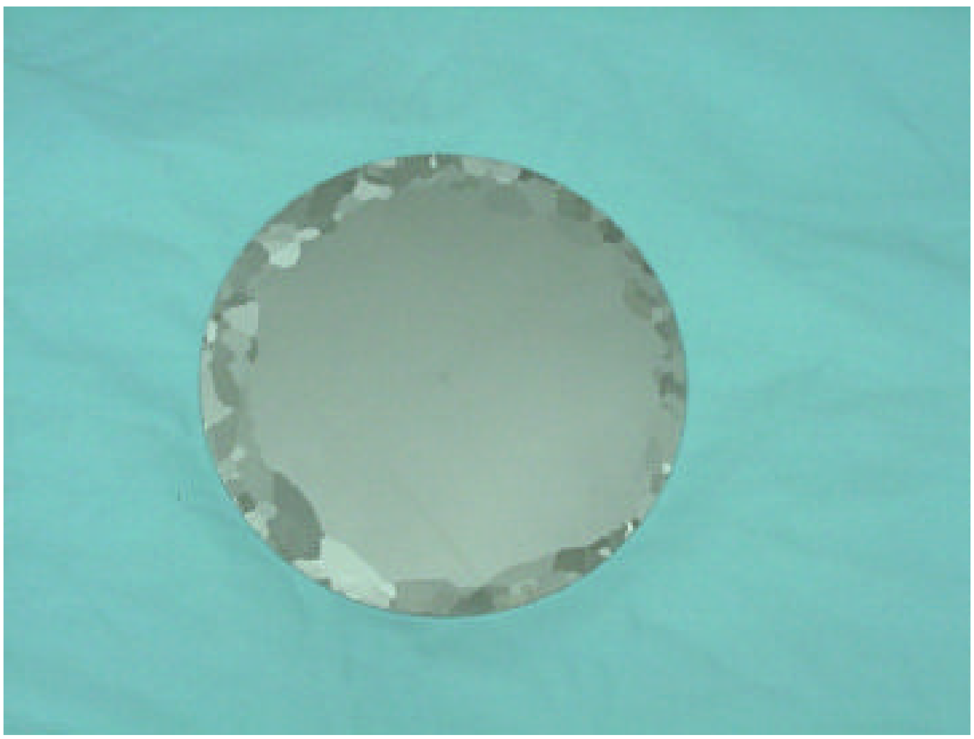
= 46.4 MV/m, CW

Pulsed = 47 MV/m

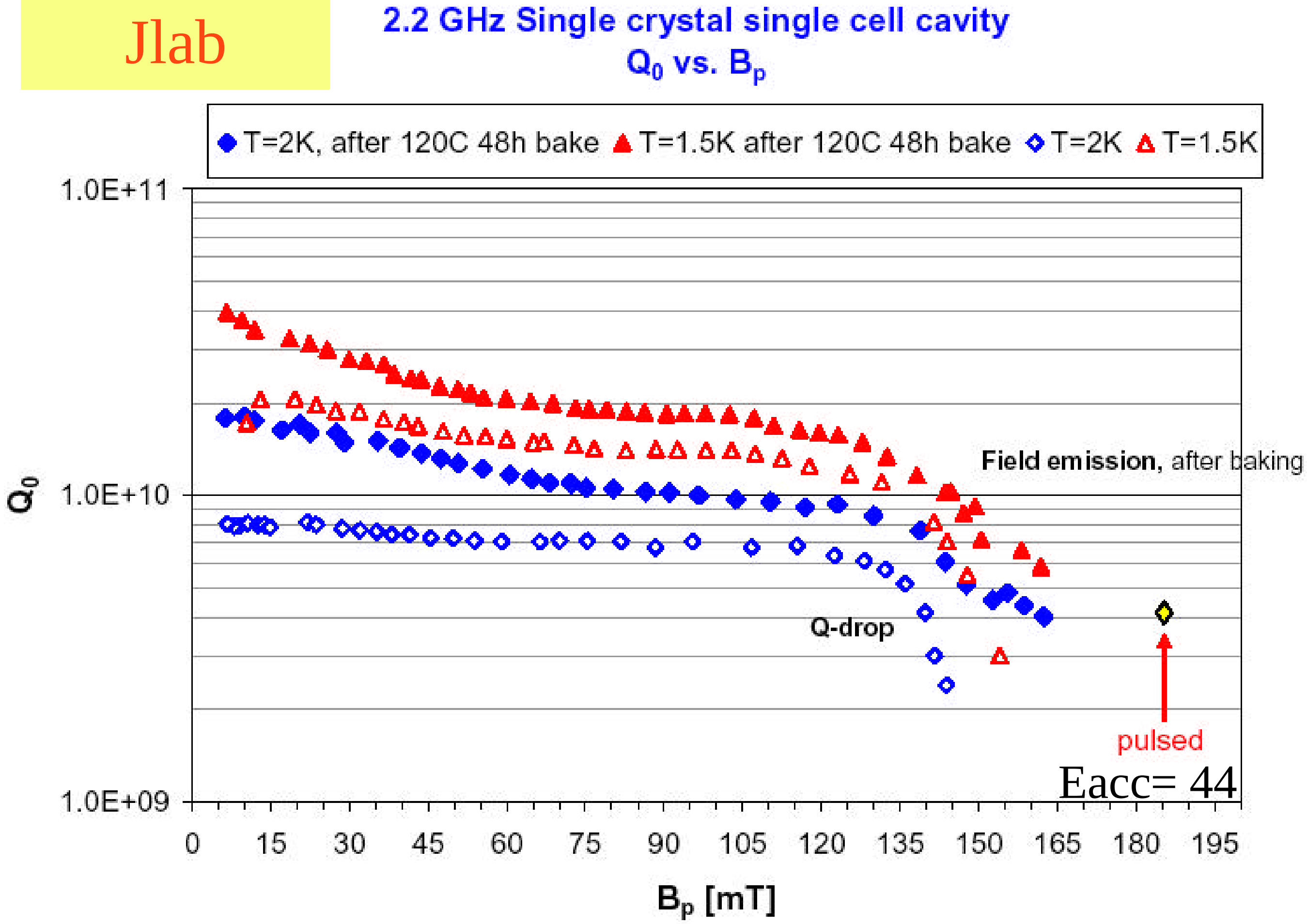
= 1800 Oersted



Jlab Large Crystal RRR Niobium



Jlab



2.2 GHz Single crystal single cell cavity
Q0 vs. Bp
T=2K, after 120C 48h bake
T=1.5K after 120C 48h bake
T=2K
T=1.5K
1.0E+11
1.0E+10
1.0E+09
Q0
Field emission, after baking
Q-drop
pulsed
Eacc= 44
0
15
30
45
60
75
90
105
120
135
150
165
180
195
Bp [mT]

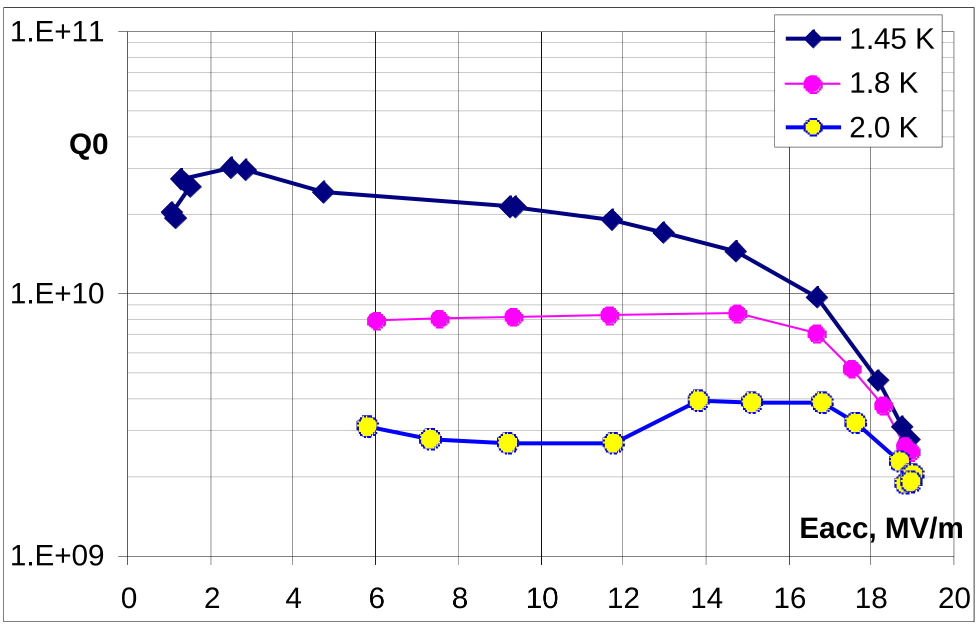
Fundamental Properties

- Q-slope still present in single crystal
- => Q-slope is not purely due to grain boundaries
- Baking improves Q-slope

Fermilab

- 3rd Harmonic for TTF-II injector
- SMTF preparations

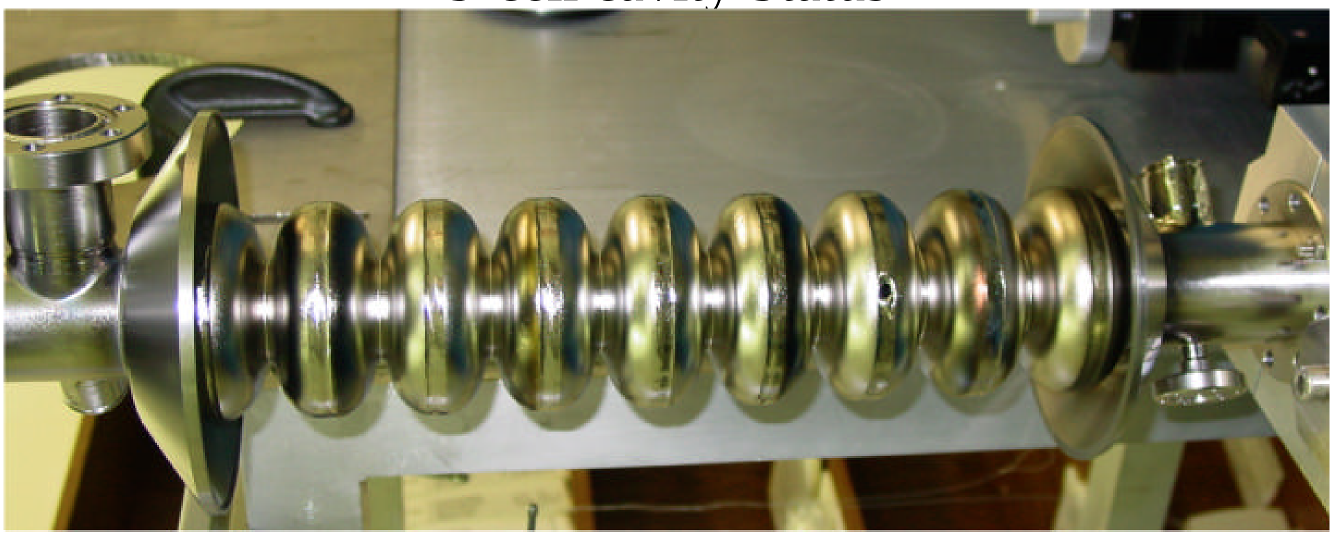
3-cell, 3rd Harmonic Cavity for TTF Injector-II
Q vs. E.   Quench limit vs.Temperature



➢Achieved Gradient: ***Eacc = 19 MV/m Hpeak = 103 mT (50% beyond goal)***

(Goal: Eacc=14 MV/m Hpeak = 68 mT)

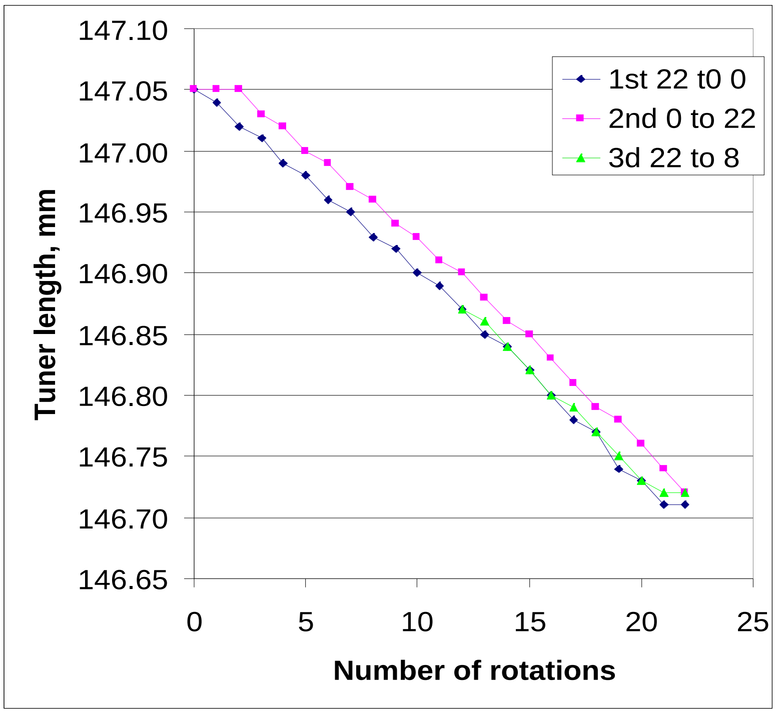
9-cell cavity Status

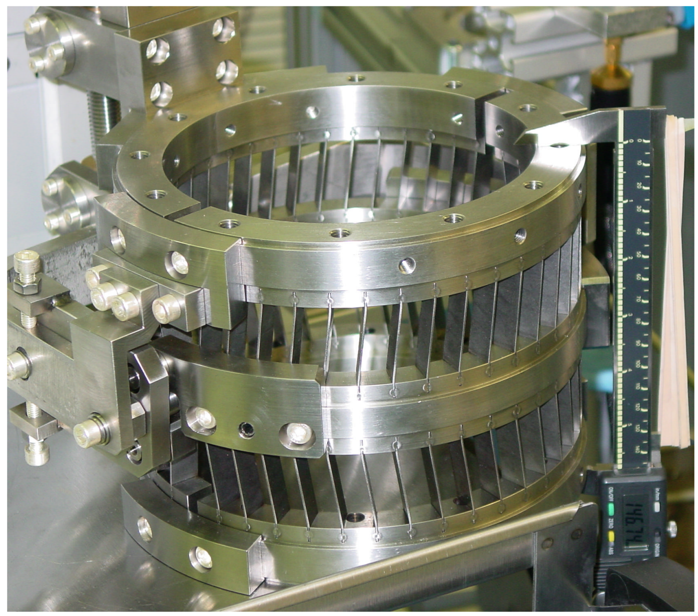


First cavity was finished but last EB welds was failed (see hole at equator). Will be repaired at JLAB. Second cavity under building now. Next 4+1 3rd harm cavities is planning to build this year with help of JLAB.

Ready: 2 blade-tuners (incl stepper motors with controllers) and Helium vessel.

Frequency Blade-Tuner test.





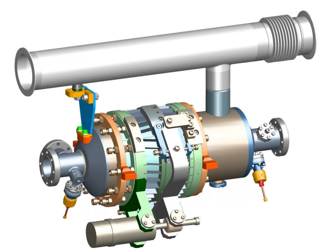
Blade Tuner range 0.3 mm without load.

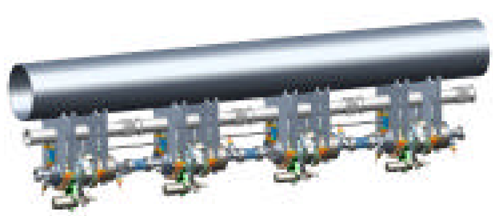
22 full rotations, 1 rotations 1e6 steps of motor.

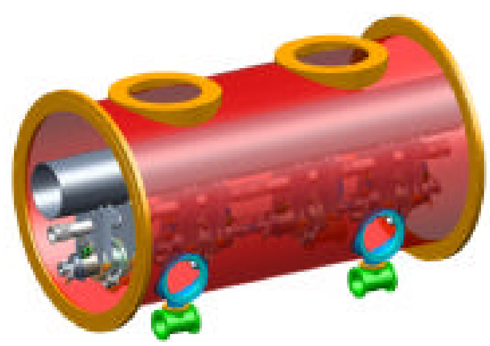
Next test with symmetrical and asymmetrical loading in horizontal position.

3.9 GHz Cavities & Cryostat(s): Work in Progress

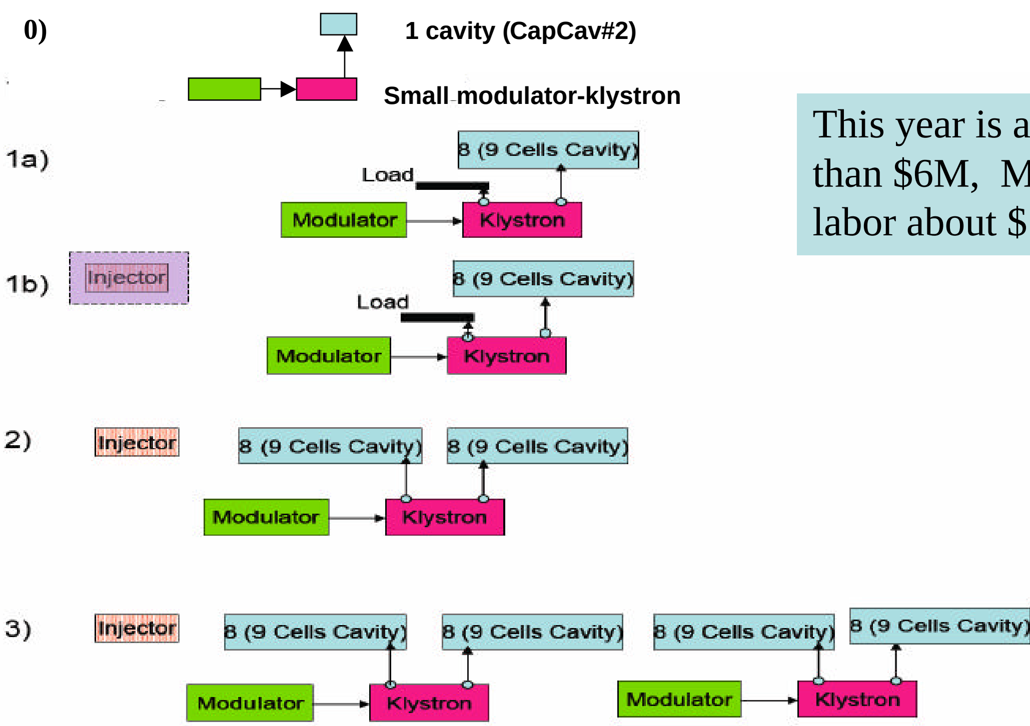
- Finalize 3.9 GHz cavity design
- Design cold-mass supports, both sliding and fixed
- Design Cold-mass and Cryostat
- Main Coupler design
- Helium Vessel design complete but may need revision
- Helium supply pipe redesign (spacing & material)
- Heat Loads and cool-down analysis







Phases of SMTF Beta=1 Modules



FY05

This year is a little more than $6M, M&S. With labor about $12M.

FY06-08

FY08-09

FY09-….

Plans- SMTF Modules (1)

- Step Zero- CryoCap#2 test in Meson by Oct-Challenging
  - Single cavity test with 4K helium and RF
  - Cavity prepared at DESY
- DESY/FNAL module
  - DESY offered to provide a module TTF3+ in the mid 06, early 07 time scale
  - This depends to some extent on FNALs preparedness to deal with module assembly and readiness for test
  - Most likely implementation-
    - DESY to send tested cavities ready for string assembly.
    - String assembled in cleanroom at FNAL
    - Module then assembled from parts provided by DESY
- US International ILC Module
  - Module assembled from cavities discussed above and components (eg cold mass) with possible contributions from collaborators.
- Schedule - Plan to assemble these 2 modules starting late 06 continuing in 07 and cryo-RF test at least one in 07

Capture Cavity #2 Status

- Required for A0 Photoinjector upgrade
- Cryostat with low gradient 1.3GHz 9-cell cavity was received from DESY and is currently being disassembled
- DESY to supply new high gradient replacement cavity and peripheral components which will be installed when they are received

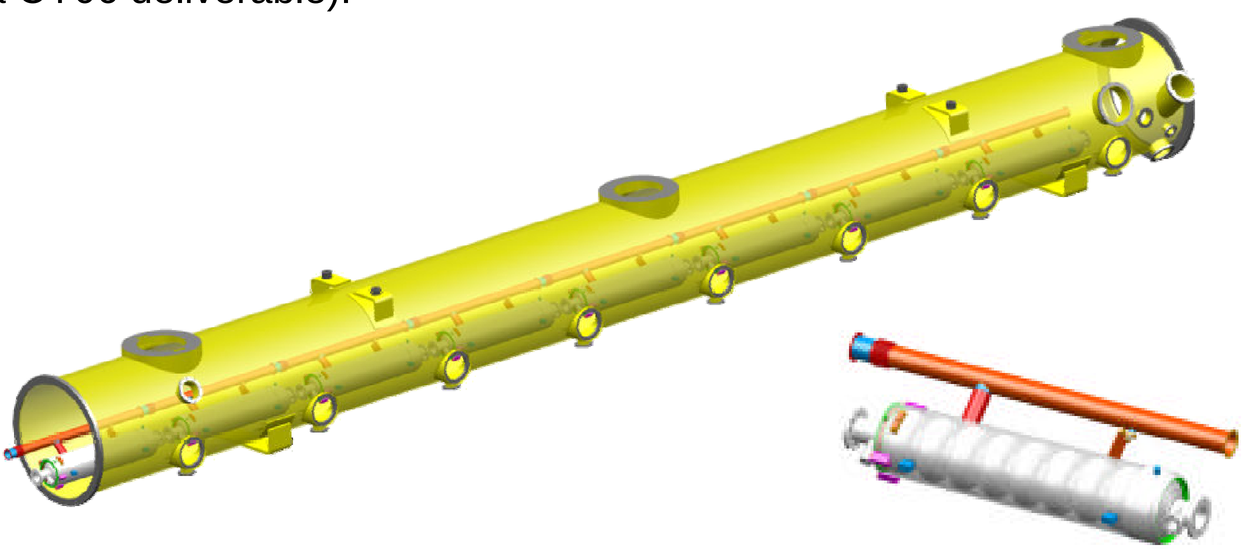
SMTF plans for Cavities (in process)

- Cavities - Parallel paths -starting this year
  - JLab adapt and commission their electropolish system(EP) for TESLA cavities
  - JLab to commission EP system with two cavities supplied from DESY
  - Cornell & AES to team on producing, BCP processing, and vertical dewar testing (VDT) 4 - 8 cavities
  - JLab to tool up to build model, prototype, and 4 Tesla cavities
  - KEK plans to provide 4 low loss (LL) cavities - higher gradient design to be processed and VDT at Cornell or JLab
  - Consideration being given to buying 4 Tesla cavities from Accel
- Total cavities :16-18 Probably take at least 6 months to start seeing some cavities tested and at least 12-18 months to see sizable number tested
- Nb Material order for 12

Support Infrastructure for 1st U.S. Built Cryomodule

• A 3-D model of the TTF 1.3 GHZ Cryo3 Vessel has been created.

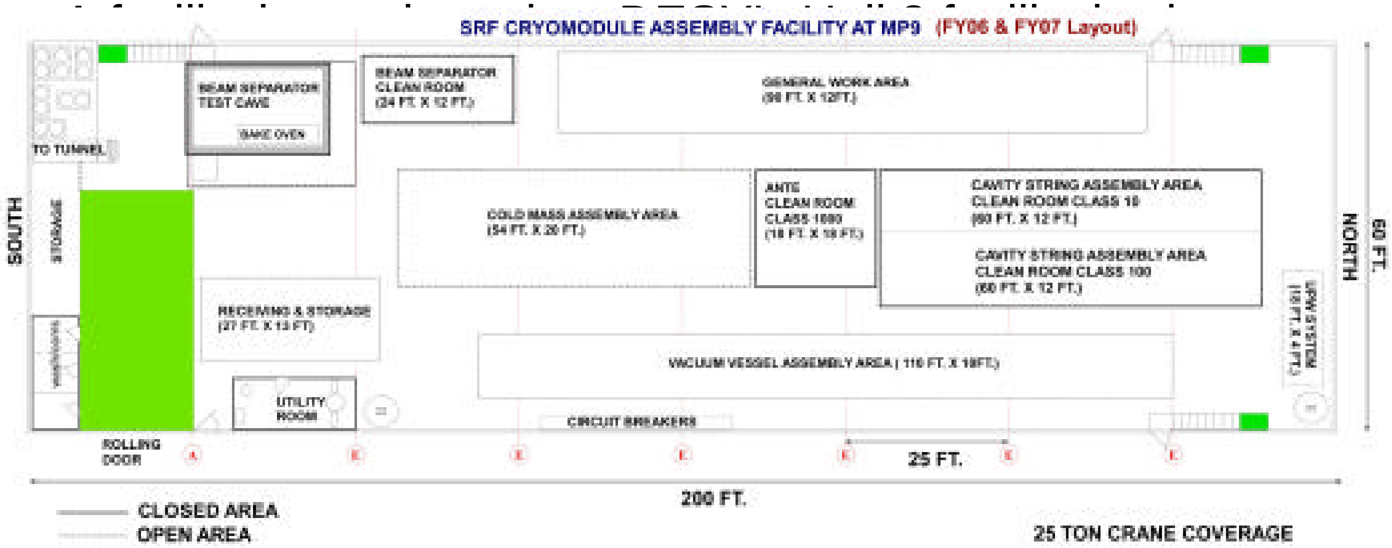
• Preparation of americanized drawings is in progress (consistent with a CY06 deliverable).



Support Infrastructure for 1st U.S. Built Cryomodule: MP9 Cryomodule Assembly Facility Development

• Separator Work at MP9 ends this Fall

•Building is sufficiently sized for R&D production quantities (1 per month)



BCP Facility Support

- Design and construction of 3.9 GHz etching jackets almost complete. 1.3GHz etching jacket design will commence once the 3.9GHz work is complete.
- Infrastructure tooling and fixturing development to support 3.9GHz and 1.3GHz cavity etching underway.
- Facility is scheduled for completion and initial operations by end of FY05

Planned Procurements and Agreements in Support of Infrastructure Development and Cryomodule Production

- Infrastructure Procurement Plans:
  - FY05: - Purchase Class 10, 100, and 1000 clean rooms for MP9 facility
  - FY06: - Complete infrastructure with the purchase of major fixturing and tooling with the goal of a functioning facility by Summer 2006

SLAC
Solid State Modulator Development

Existing 10MW TTF Modulator

Developed in the early 90's at FermiLab for use with the TTF.

Currently in use at FNAL and on the XFEL at DESY.

Uses a passive 'bouncer' circuit to compensate for capacitor droop.

Advantages:

- Simple circuit topology
- Proven design; 10+ years of operation

Disadvantages:

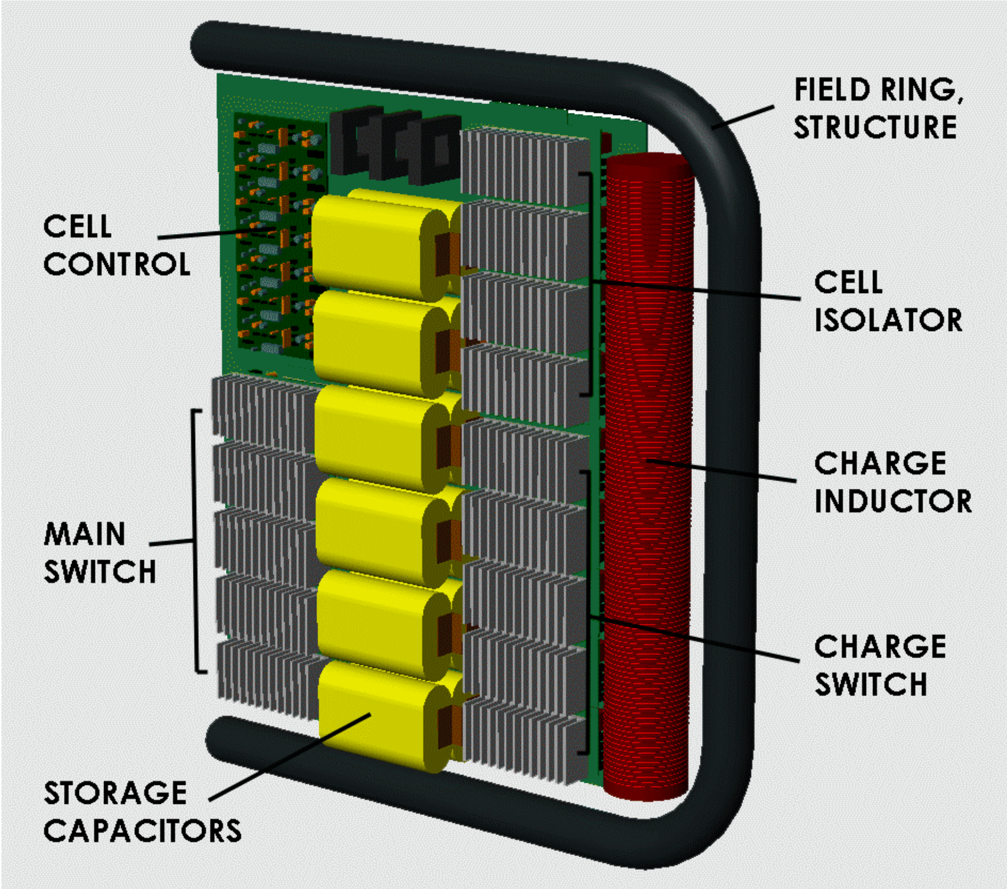
- High stored energy – 270kJ
- Massive pulse transformer – 6.5 tons
- Single-point failures can damage klystron
- Requires large floor area
- Insulating oil – 100's of gallons

Solid State Marx Modulator Pros and Cons

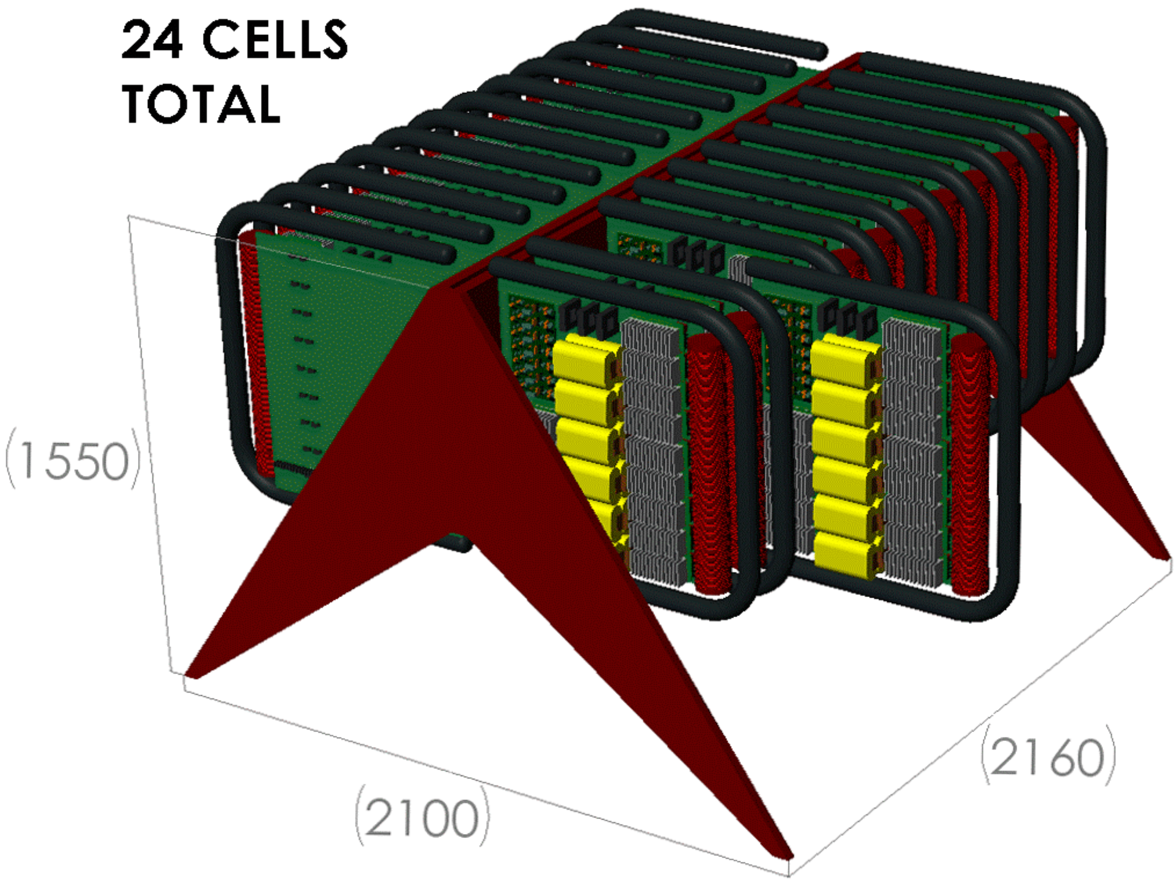
- Lower IGBT currents
- No magnetic core issues
  - losses
  - core reset
  - acoustic noise
  - core saturation
  - leakage inductance
  - magnetizing currents
- PC board integration
- Mechanically simple, more compact
- Finer waveform control

- IGBT controls float at high voltage during pulse
- DC power flow to cells must be isolated
- Timing signals must cross high voltage gradients

ILC Marx Cell Module Layout



ILC Marx Modulator Core Layout



Prototype Development Approach

- Start with the highest technical risk items – 12kV switch, energy storage capacitors.
- Assemble, test, debug a complete cell.
- Work towards developing a ‘short stack.’
- Explore stack-level fault scenarios.
- Design, test the active regulation control loop.
- Develop complete modulator, control system, RF station. Integrate with L-Band klystron.

Marx Prototype – Schedule

Test 12kV switch module performance	May 05
Evaluate cell components	May 05
Integrate, test completed Marx cell	Aug 05
Start active control system design	Sep 05
Marx ‘short stack’ ready for evaluation	Nov 05
Integrate short stack, control system	Dec 06
Short stack fault scenario testing complete	Feb 06
Start construction of full modulator stack	Mar 06
Marx modulator ready for klystron connection	Oct 06

Current Status – 24 Mar 05

12kV Switch v1.0

- Design – 60% complete
- Assembly – 20% complete

Capacitors

- First engineering samples have arrived
- Lifetime testing to start in a few weeks

ILC Marx Test Area

- Design – 80% complete
- Assembly – 10% complete

Damping Ring Designs
BDS World Studies
Overviews

Kwang-Je Kim

Andrei Seryi

2005 International Linear Collider Workshop March 18-22, 2005

Stanford Linear Accelerator Center, Stanford, CA

& SLAC Collaboration meetings

Conclusion: SRF Technology Rocks !