Development of the X-band structure at Fermilab

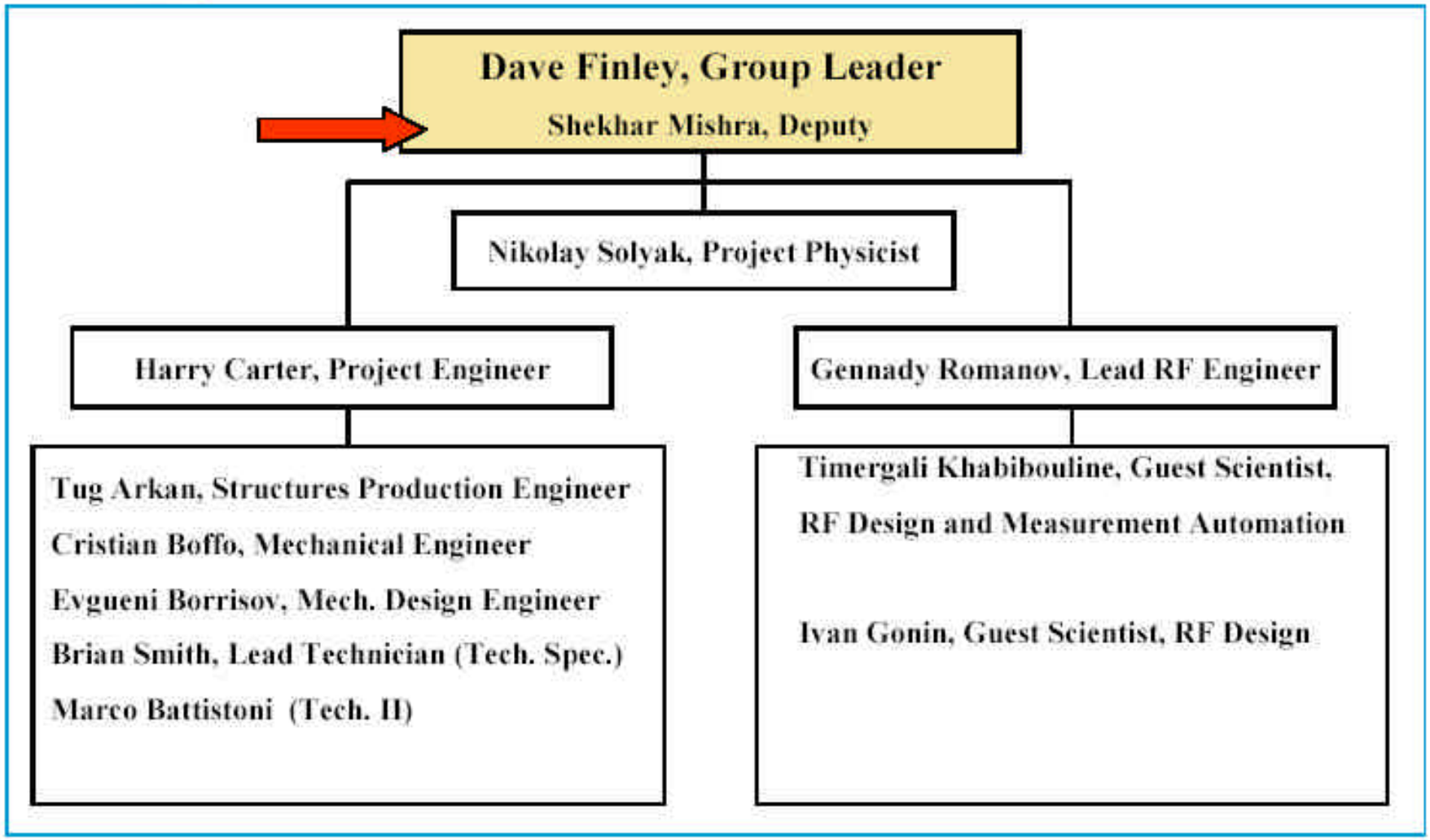
N. Solyak

Outline:

- Infrastructure and History
- Production & FY04 schedule
- Calculations
- RF QC
- Girder studies

(Slides from MAC, AAC and meeting presentations. Contributors:
D.Finley, H.Carter, T. Arkan, T.Khabiboulline, I.Gonin, G.Romanov, C.Boffo + SLAC)

RF Technology Development (Conventional) Group Personnel & Responsibilities



RF Structure Factory

- **FNAL RF Technology and Development Group goals for the RF Structure R&D Factory:**
  - RF Design
  - RF Disk Fabrication & Quality Assurance
  - RF Structure Fabrication & Quality Assurance
  - Infrastructure Setup for all above
- **Major Infrastructure of the Factory are:**
  - Two Clean Rooms (Class 1000 & 3000)
  - Two Vacuum Furnaces inside a soft sided Clean Room (Class 1000), Closed-loop Chiller System
  - Clean Room Leak Detector, Clean Room compatible Vacuum Pumps, RGA, Anaerobic Chambers, DI water system, 2 Network Analyzers, Bead-Pull Fixture, Single Disk RF QC Fixture, etc.

Infrastructure

Structure Assembly
Clean Room

(Class 1000)

Proper Clean Room Attire

Infrastructure

RF Quality Control
Clean Room

(Class 3000)

A Structure during Bead-Pull Measurements & Tuning

Infrastructure

New Hot Zone

Old Hot Zone

Small Vacuum Furnace:

- Installed in FY01
- All molybdenum hot zone
- 12 inch x 12 inch x 15 inch
- Dry Roughing Pump & CRYO Pump
- 1200 degree C max temperature

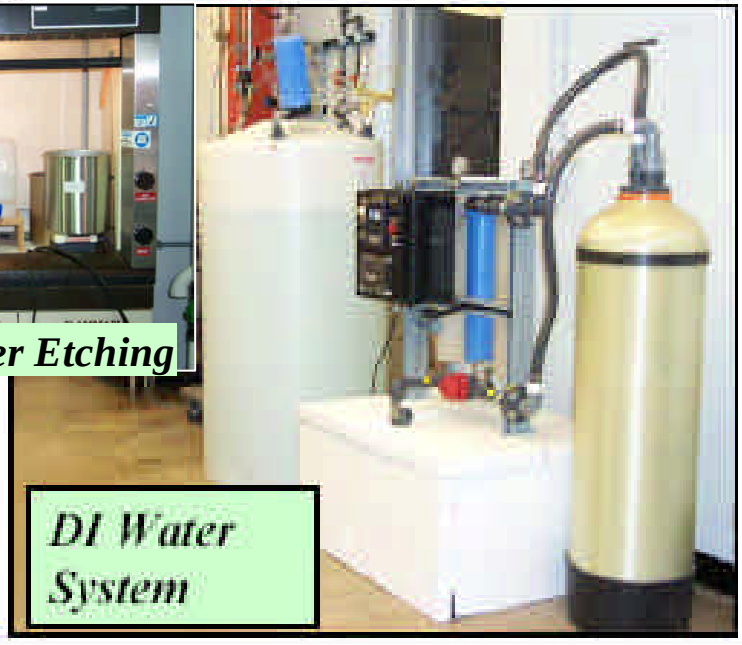
Vacuum Bake

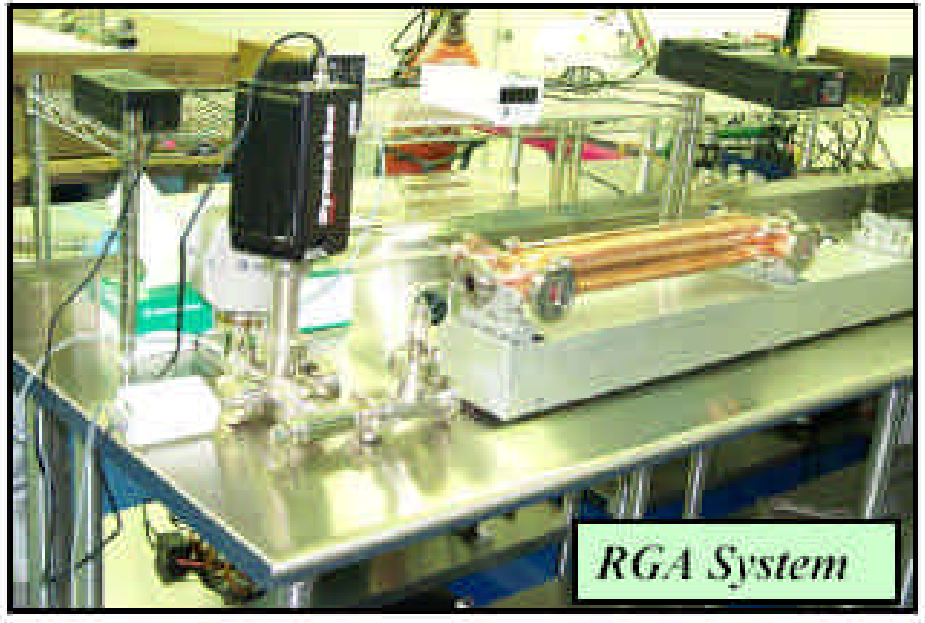
Large Vacuum Furnace:

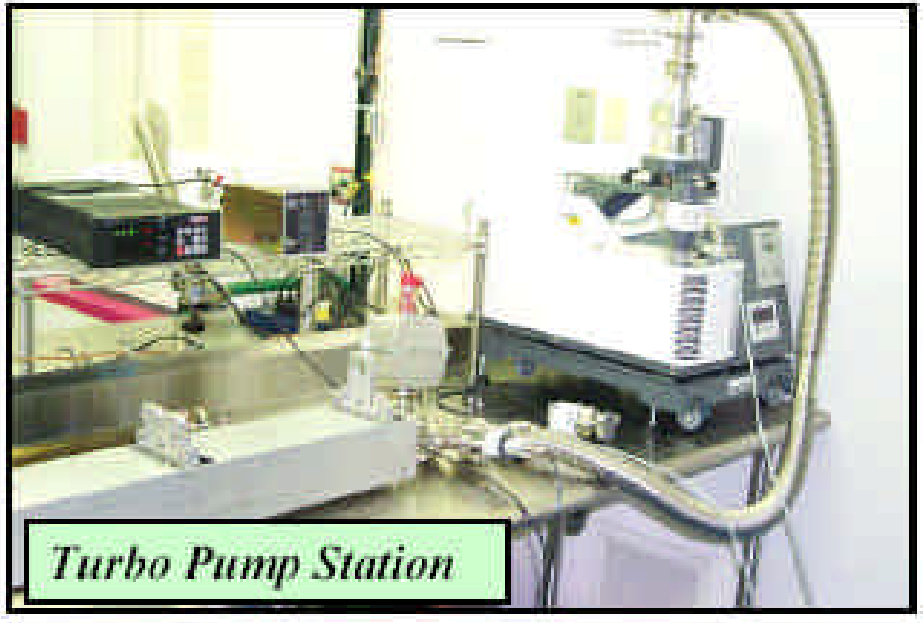
- Installed in FY02
- All molybdenum hot zone (Recently purchased from Schwarzkopf Technologies)
- 20 inch x 100 inch
- Dry Roughing Pump & CRYO Pump
- 1200 degree C max temperature


New Chiller

RF disk and coupler Etching


DI Water System


RGA System


Turbo Pump Station

History of Accelerating structures at FNAL

The first FXA structure was built Oct.2001. Now we have designed, built or ordered FXB, FXC, FXD series.

- **FXA – 20cm long, 2p/3, no damping. Built 3 structures.**
- **FXB – (H60VG3S18) 60 cm long, 150° phase advance, no damping. Couplers of 2 types: fat-lip (#2-#3) and WG (#4-#7). Built 6 structures, 3 already tested at SLAC, 2-under test.**
- **FXC-75 (H75VG4S18), 75cm, j =150°, Damped. FWG coupler. Ordered and tested few cells.**
- **FXC (H60VG3S17), 60cm. j =150°, Damped. FWG coupler. No HOM coupler. 4 structures will built in FY2004.**
- **FXD A/B (H60VG4SL17). 60cm. j =150°, Damped. FWG coupler. HOM coupler. A/B interleaved structures for ASSET tests.**

NLC Prototype Structure Evolution

Parameter Space of High Power Test Structures

Damped Detuned Structures R&D

H60VG3N-6C
H60VG3S18

a/λ=0.18, in-line taper input, 6 slotted cups.

a/λ=0.18, all slotted cups with elliptical irises.

Reduce a/λ in order to gain more breakdown margin.
Increase RF efficiency by 10%

H60VG3S17(FXC)

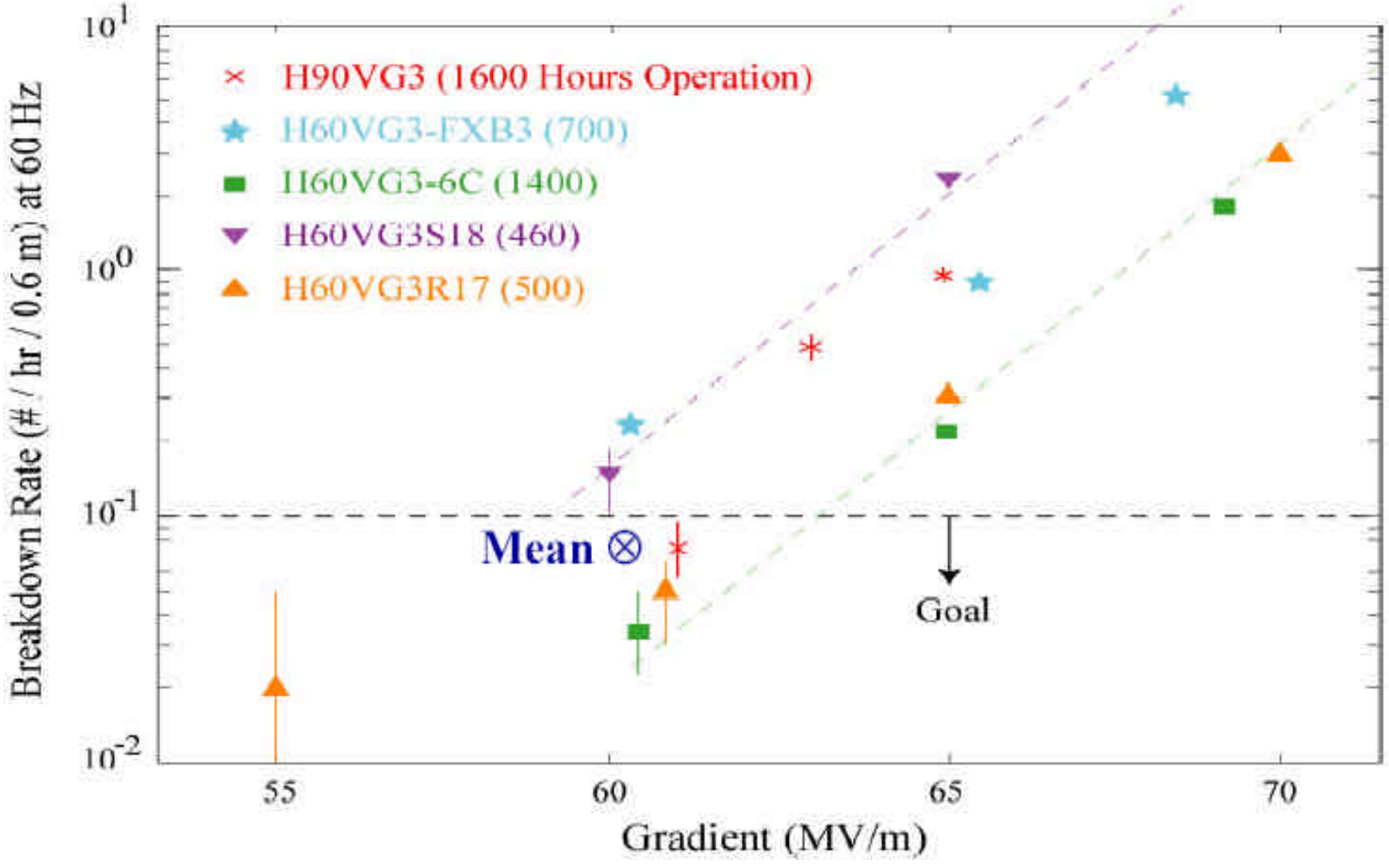
a/λ=0.17, all slotted cups with elliptical irises.
kdn/df Gaussian dipole distribution.

Keep same a/λ=0.17 and RF efficiency.
More input tapering to give more breakdown margin.
Shift dipole mode detuning range to avoid high field in the end.
Asymmetric dipole spectrum – deteriorate wakefield suppression.
Redesign dipole distribution as $Sech^{1.5}$

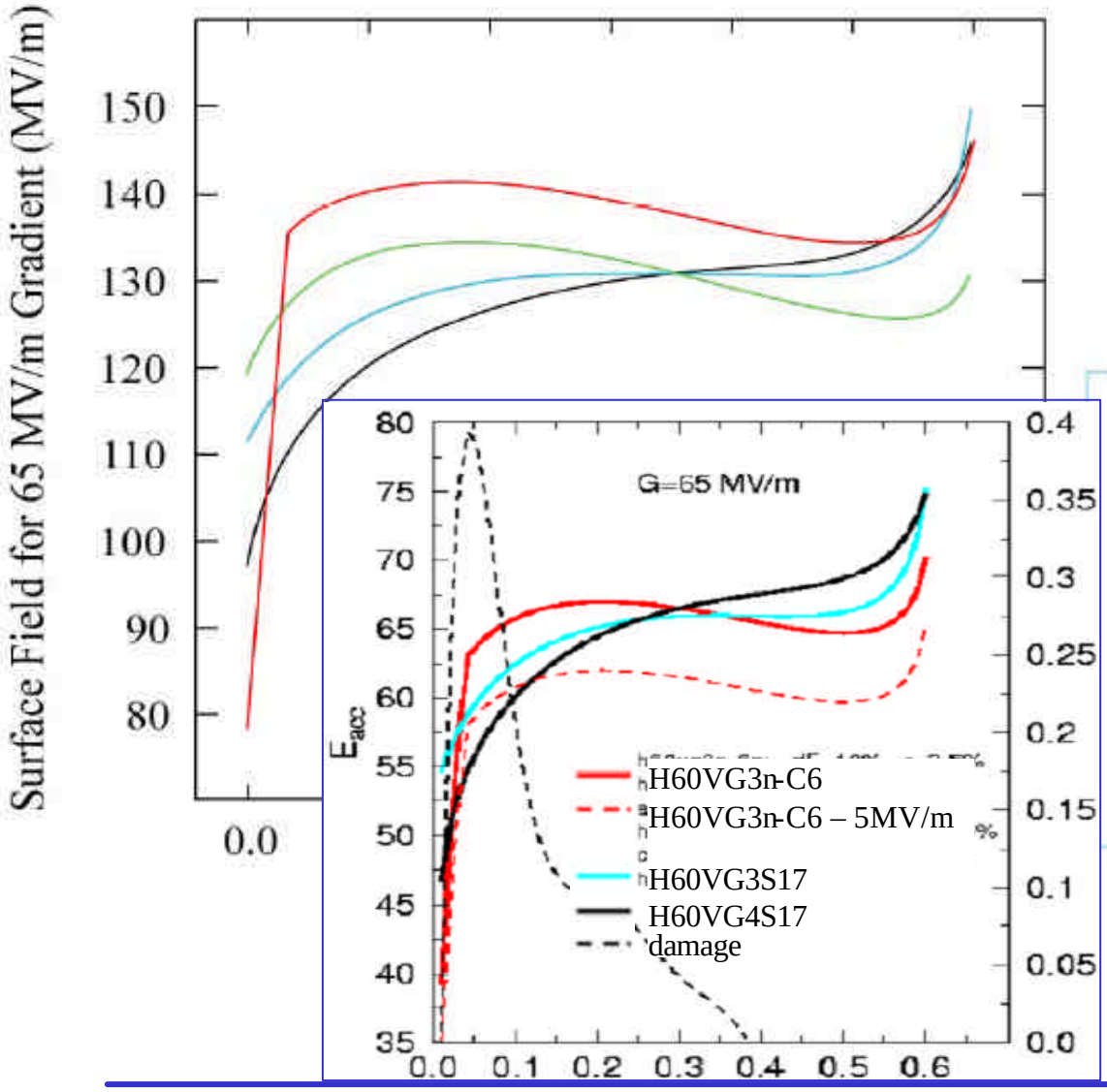
H60VG4S17(FXD)

a/λ=0.17, Starting Vg/c = 4%.
kdn/df $Sech^{1.5}$ dipole mode distribution HOM ports.

Breakdown Rate with 400ns pulses



Peak Surface Field Profile -vs- Structure Type



H60VG3 ($a/\lambda = 0.18$, Rounded Irises, Inline Taper, Already Tested)

H60VG3S18 (Elliptical Irises - Reduces Peak Fields by 5% but Requires + 5% Power, Currently Under Test)

NLC/JLC Candidates:

H60VG3S17 (Elliptical Irises, Lower a/λ, Different v_g and Thickness Profile, Requires 10% Less Input Power Than H60VG3)

H60VG4S17 (Same as Above but Wider, Asymmetric Dipole Spectrum)

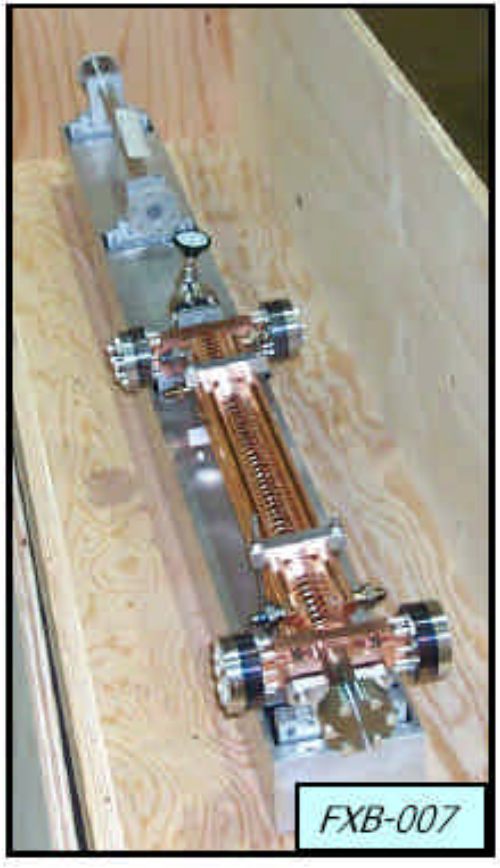
FXA type RF Structures

- We have produced three 20-cm long (short length) traveling wave, detuned, constant gradient structures: FXA-001, FXA-002 and FXA-003:
  - These structures were not high power tested. They were produced to evaluate the feasibility of the Factory Infrastructure and to learn & gain experience in RF structure fabrication
- Design is identical to SLAC T20VG5 structure (except brazing grooves in the disks)
- All brazed structures, no diffusion bonding
- Disks are precision machined, no diamond turning [industrial vendors]
- Couplers are precision machined with some diamond turned RF surfaces (iris area) [industrial vendors]

FXB Type RF Structures

- Design is identical to SLAC H60VG3 structure (except brazing grooves in the disks)
- All brazed structures, no diffusion bonding
- Disks are precision machined, no diamond turning
- Couplers are precision machined. Fat-lipped design has some diamond turned RF surfaces (iris area). FWG design is all high precision machined
- Fat-lipped design couplers to reduce the pulse heating (FXB-002 and FXB-003)
- Fermilab design waveguide (FWG) couplers (FXB-004 to FXB-007)
- Disk & Coupler Etching with SLAC C01 procedure
- Strict Clean Room Working Procedures
- Traveler Development (it is currently fully implemented & controlled)
- FXB-006 & FXB-007, disks were heat treated under full vacuum at 1000 degree C before disk stack assembly. Completed structures were vacuum baked under full vacuum at 500 degree C for 72 hours

Some FXB Structure Photos



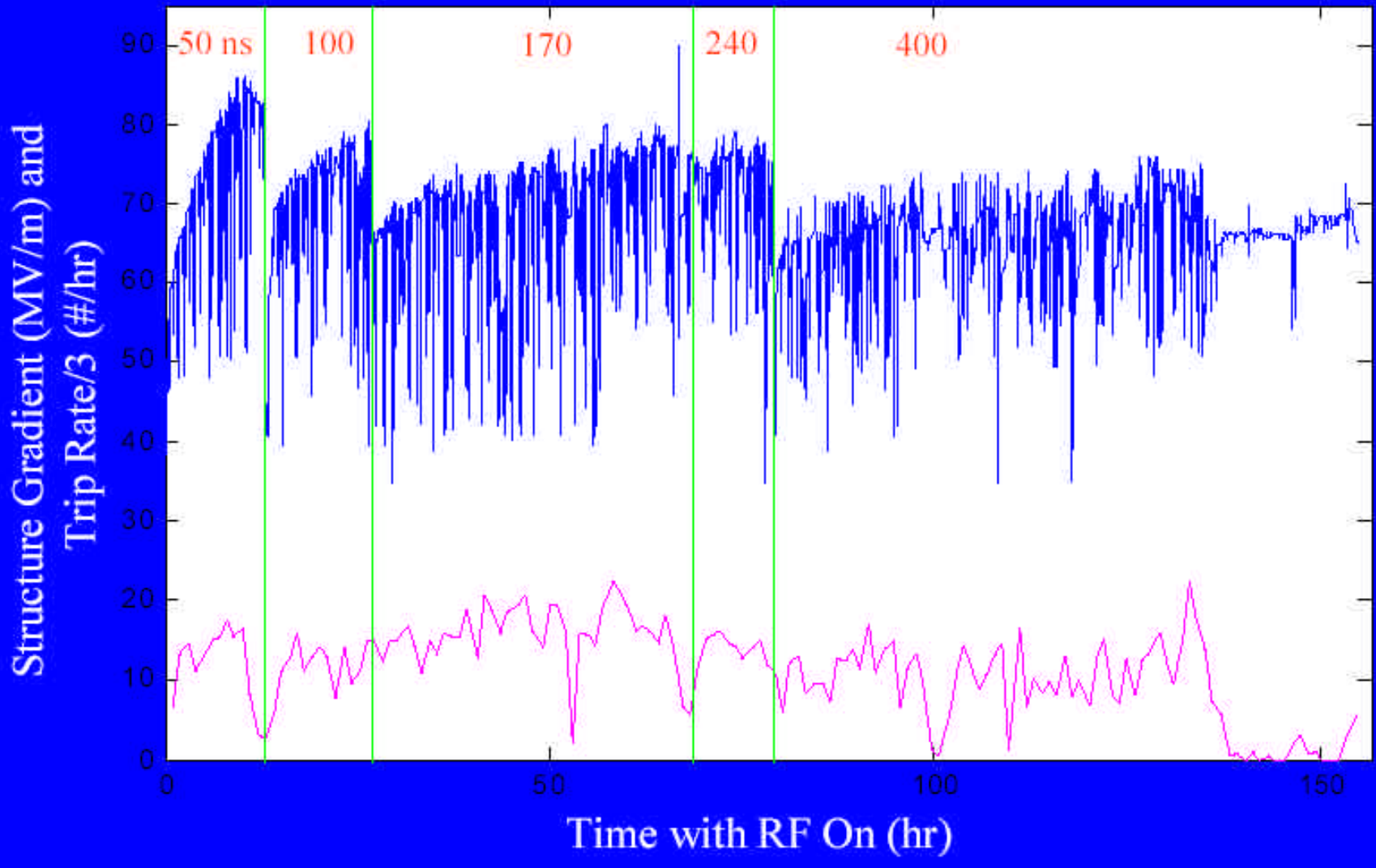
FXB Type RF Structures

- We have produced six 60-cm long traveling wave structures in FY03: FXB-002 thru FXB-007
- FXB-002, FXB-003 & FXB-004 were high power tested at NLCTA
- FXB-006 & FXB-007 were recently shipped to SLAC for high power testing. They are scheduled to be installed together to NLCTA Station I on October 2003
- The completion of the FXB-006 & FXB-007 ended the production of the FXB type structures

FXB-002 and some of us from Fermilab RF Structures Group @ NLCTA

NLCTA
Next Linear Collider
Test Accelerator

Processing history - FXB003



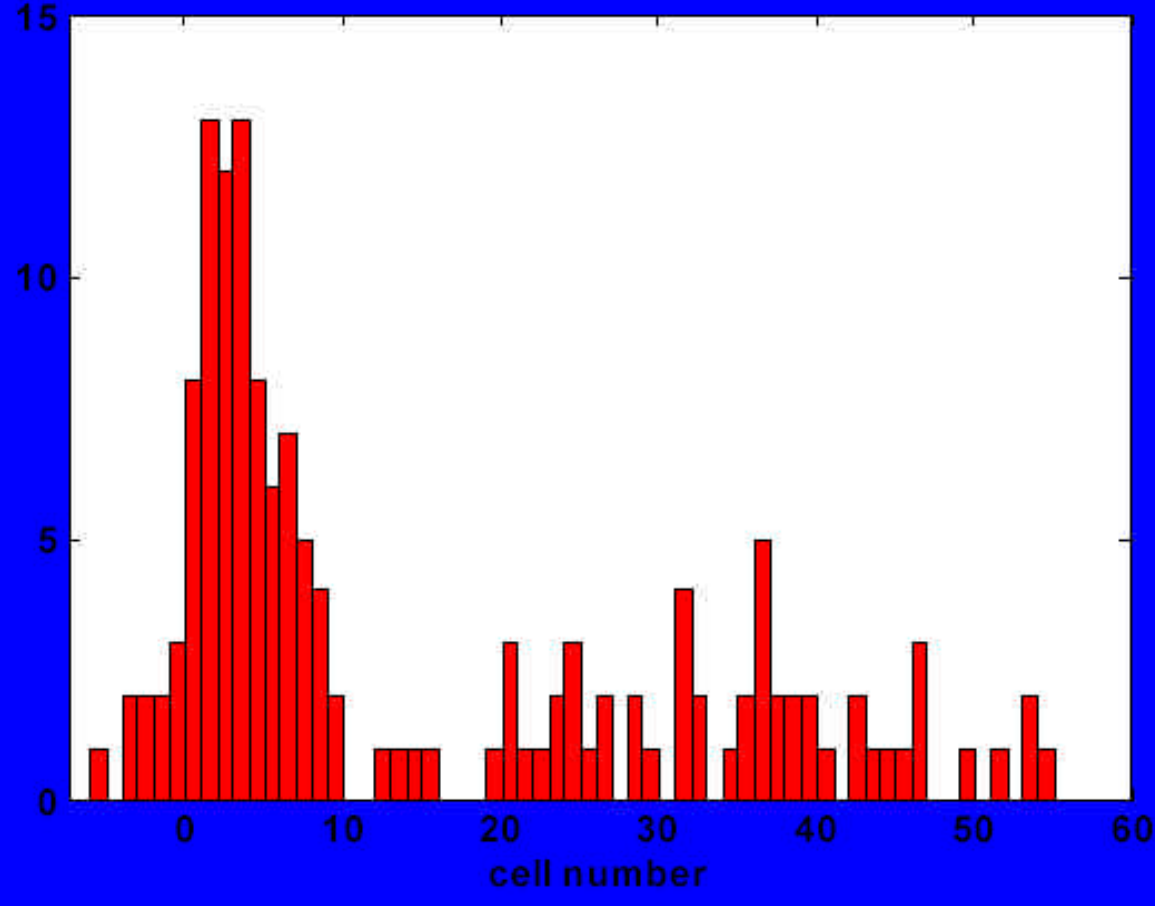
NLCTA
Next Linear Collider
Test Accelerator

Breakdown locations - FXB003

65 MV/m run

No clear hot spots

But typical front bias



FXC type RF Structures

- Design is identical to SLAC H60VG3S17 structure (except brazing grooves in the disks)
- All brazed structures, no diffusion bonding. New brazing features were added to the disks
- Disks & Couplers are precision machined, no diamond turning
- We will produce **four** 60-cm long traveling wave FXC RF structures: FXC-001 thru FXC-004 in FY04
- Fermilab design FWG couplers and matching disks will be used
- These structures will be used for Eight-Pack test at SLAC

From FXB to FXC structures:

- HOM holes and keyhole slots were introduced to the RF disks
- Fermilab design waveguide (FWG) couplers and matching disks
- Tuning holes were increased from 2 to 4
- Rotational alignment feature on the RF disks and the V-Block Fixture
- Rosette shape dam instead instead of circular dam to stop the braze material flow into the RF volume

Vendors & Machinability Tests

- **LaVezzi FXC Test Disks**: 10 identical disks were received. 8 were measured with Single Disk RF QC. 2 were measured with Mechanical QC
- **Medco FXC Test Disks:** 15 identical disks were received. 13 were measured with Single Disk RF QC. 2 were measured with Mechanical QC. Another 15 disks were ordered to re-evaluate after discussions with the vendor

FXC Test Disks Stress Relieving

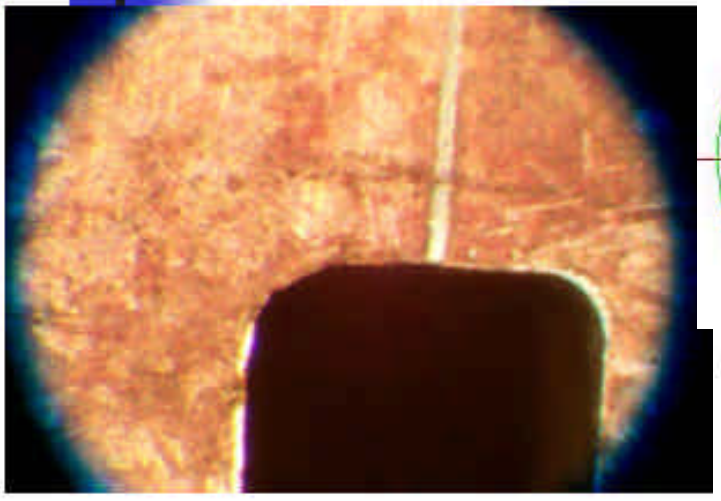
•After the evaluation of our vendors for slotted disk machining capabilities, it was decided to order 5 sets of FXC disks from LaVezzi to build 4 FXC RF Structures

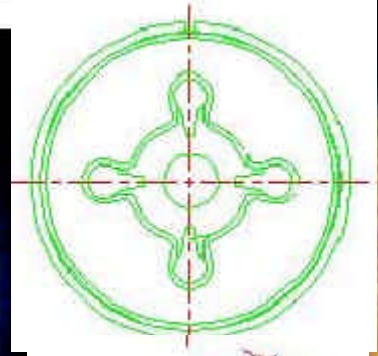
•The funds were allocated in FY03 to purchase the FXC disks

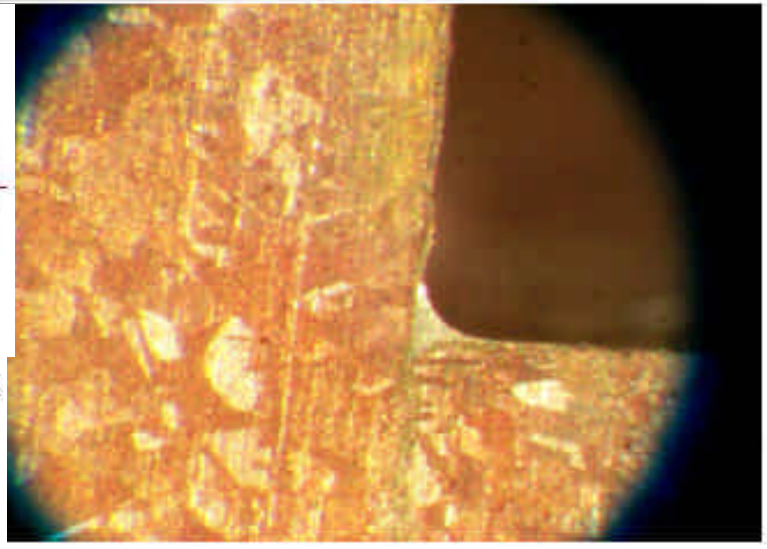
•We received a partial delivery this week, the order will be completed by the end of October 2003

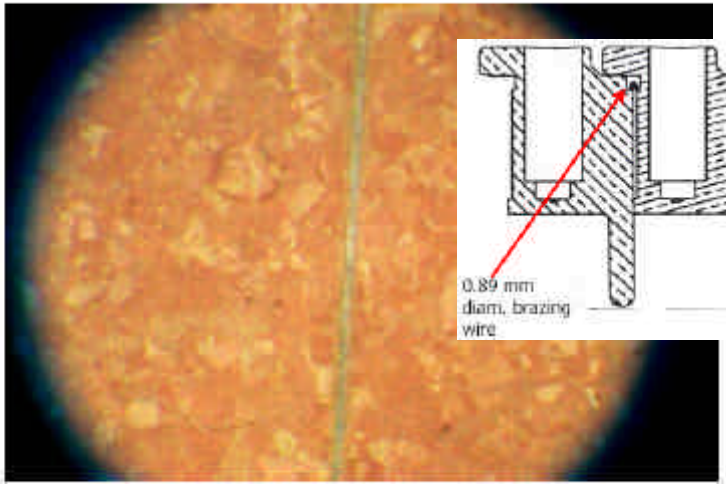
From T. Arkan AAC presentation

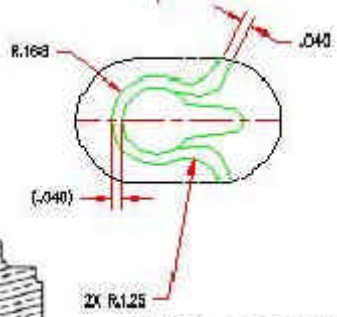
Brazing Tests











iam. CUSIL braze wire flows very good
lled braze groove. This is good to prevent any virtual leaks and also for the RF Structure quality factor

There is a slight leakage of braze material into the RF volume.

NLC Collaboration Meeting
June 17-20, 2003

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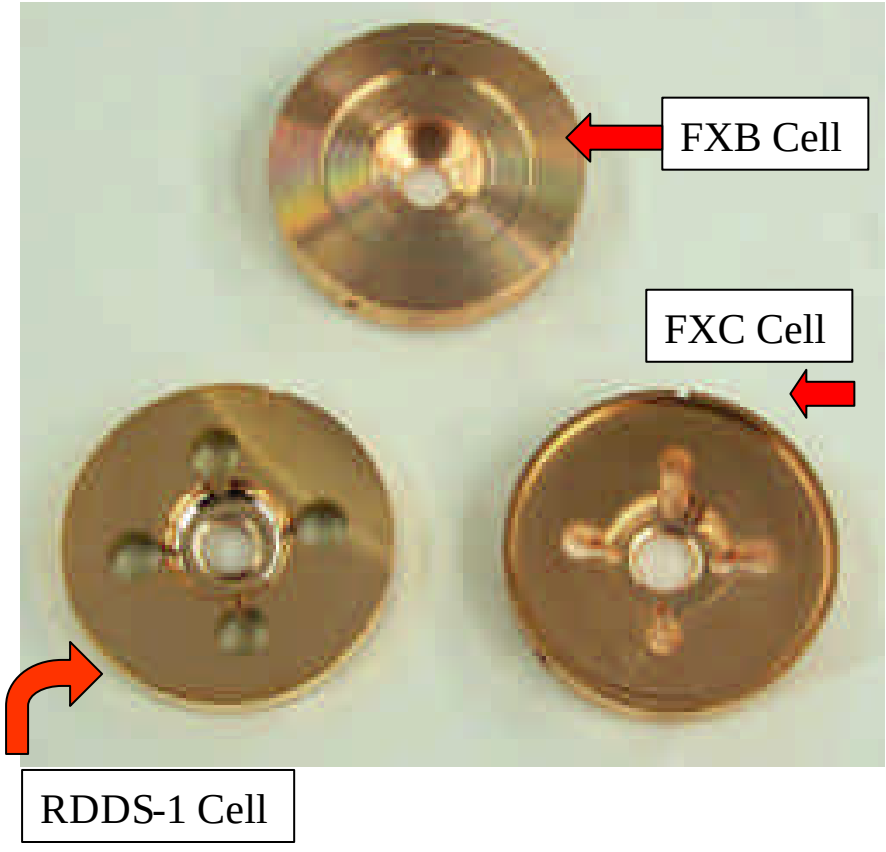
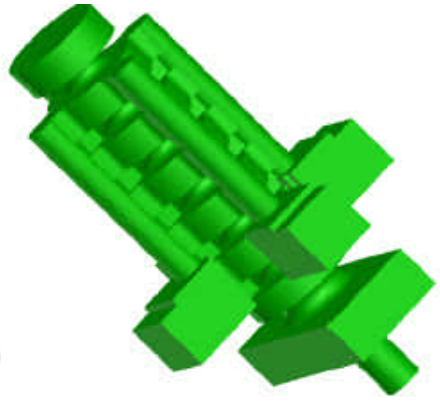
Structures for Phase II of the 8-Pack

We have begun FXC series structure production

- aka H60VG3S17, 150° , no HOM extraction
- Parts for 5 structures on hand
- RF and mechanical QC of parts completed
- First stack is brazed and measured
- Couplers are brazed and measured
- Plan to produce 4 (or 5) structures by Feb. 1, 2004



FXD type RF Structures

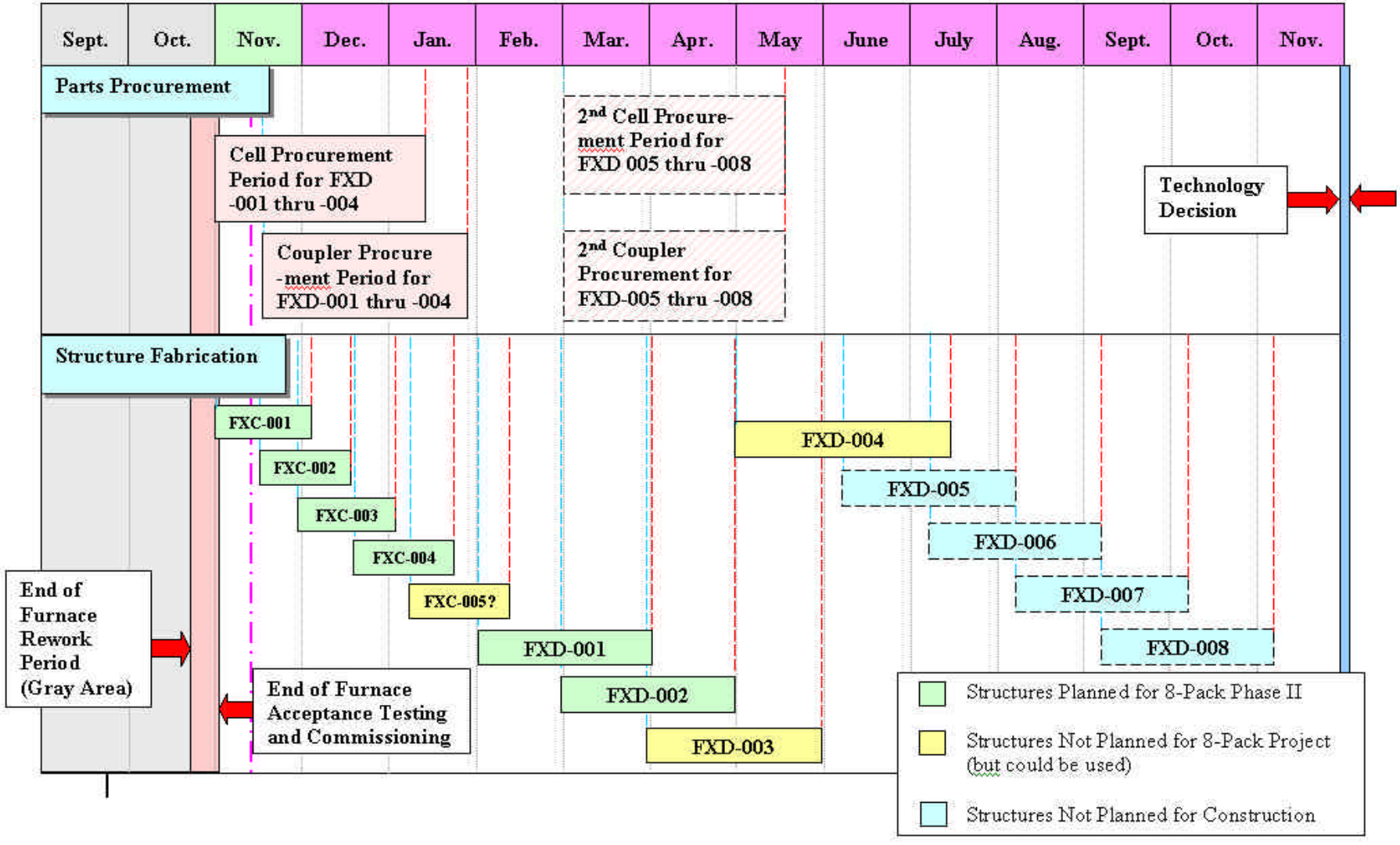


- Design is identical to SLAC H60VG4S17 structure (except brazing grooves in the disks)
- All brazed structures, no diffusion bonding. New brazing features were added to the disks
- Disks & Couplers are precision machined, no diamond turning
- We will produce 2 pairs of 60-cm long traveling wave FXD type RF structures in FY04
- Only 2 of the 4 FXD structures will be sent to SLAC for Eight-Pack test
- Fermilab design FWG couplers and matching disks will be used

From FXC to FXD structures:

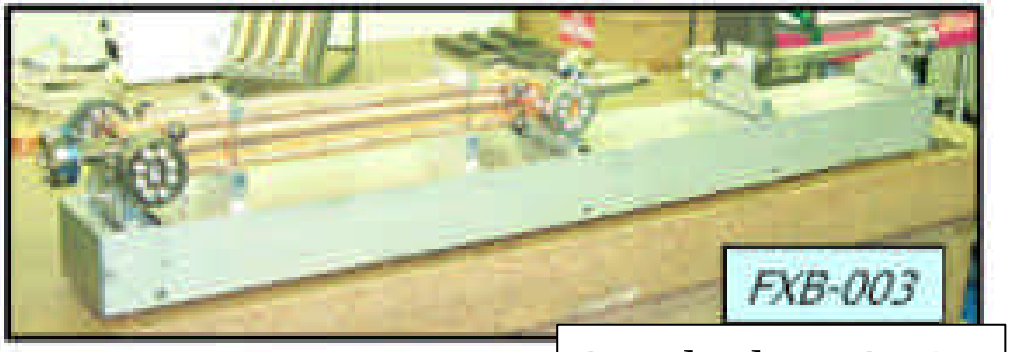
- RF Design Improvements
- HOM Extraction

Structure Fabrication Schedule

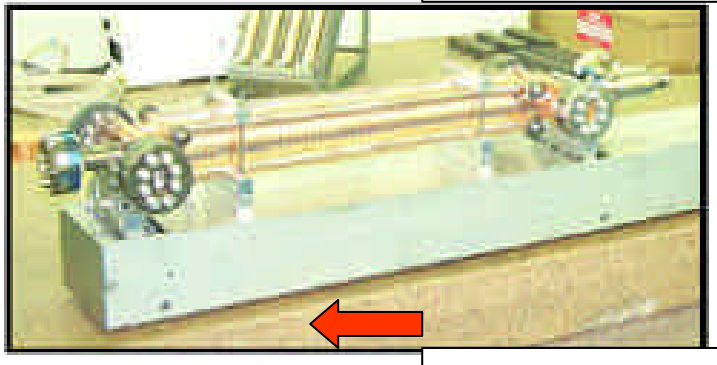


FNAL Deliverables for the 8-Pack

- For 8-Pack Phase IIa
  - –Provide two FXC structures mounted on standard NLCTA-style strongbacks
  - –Provide two FXC structures, each mounted on an “8-Pack Ready” strongback
- For 8-Pack Phase IIb
  - –Provide one FXD-a and one FXD-b structure
  - –Provide six more “8-Pack Ready” strongbacks

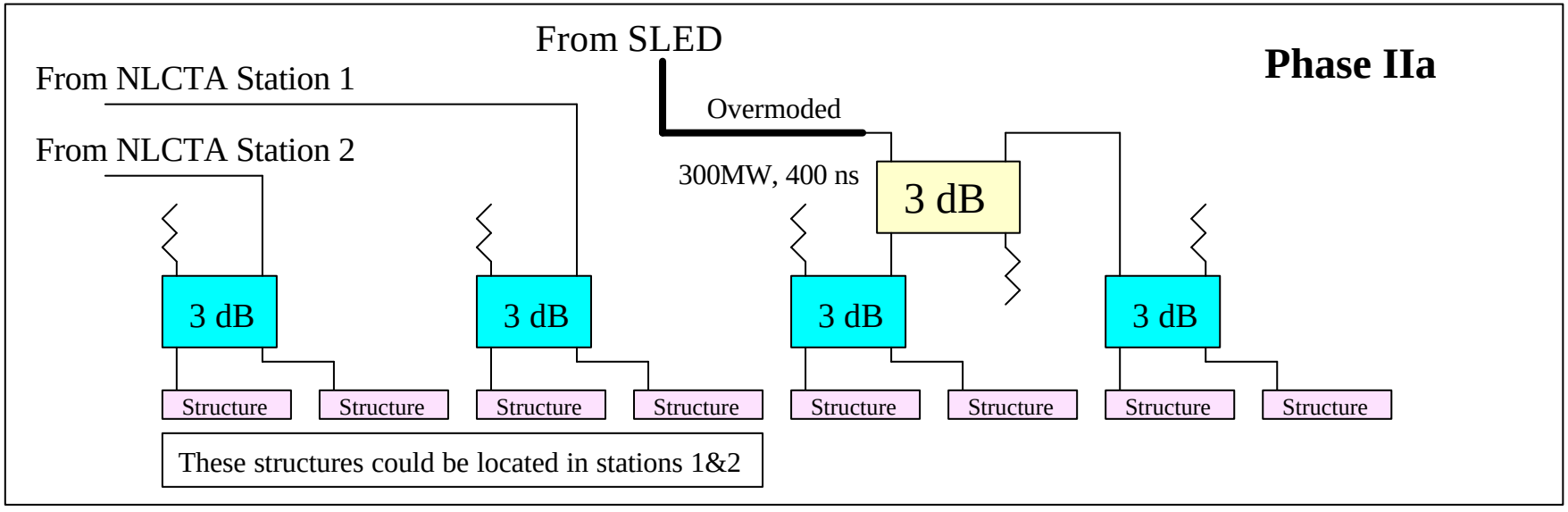


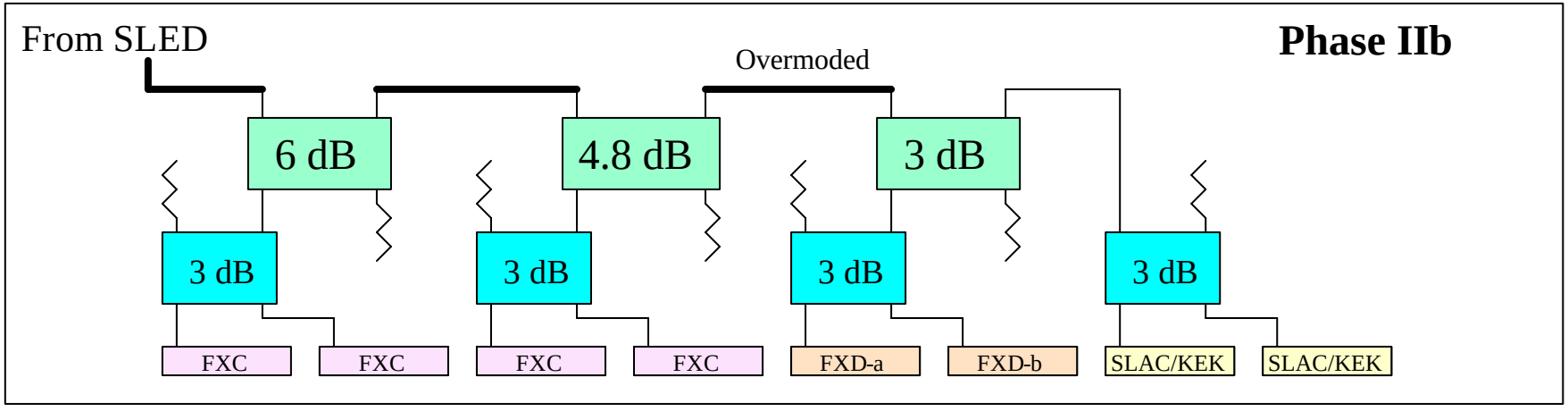
Standard NLCTA-style Strongback



Shorter “8-Pack Ready” Strongback

8-Pack Project Overview: Power Handling Schematic





Structure Goals for FY04

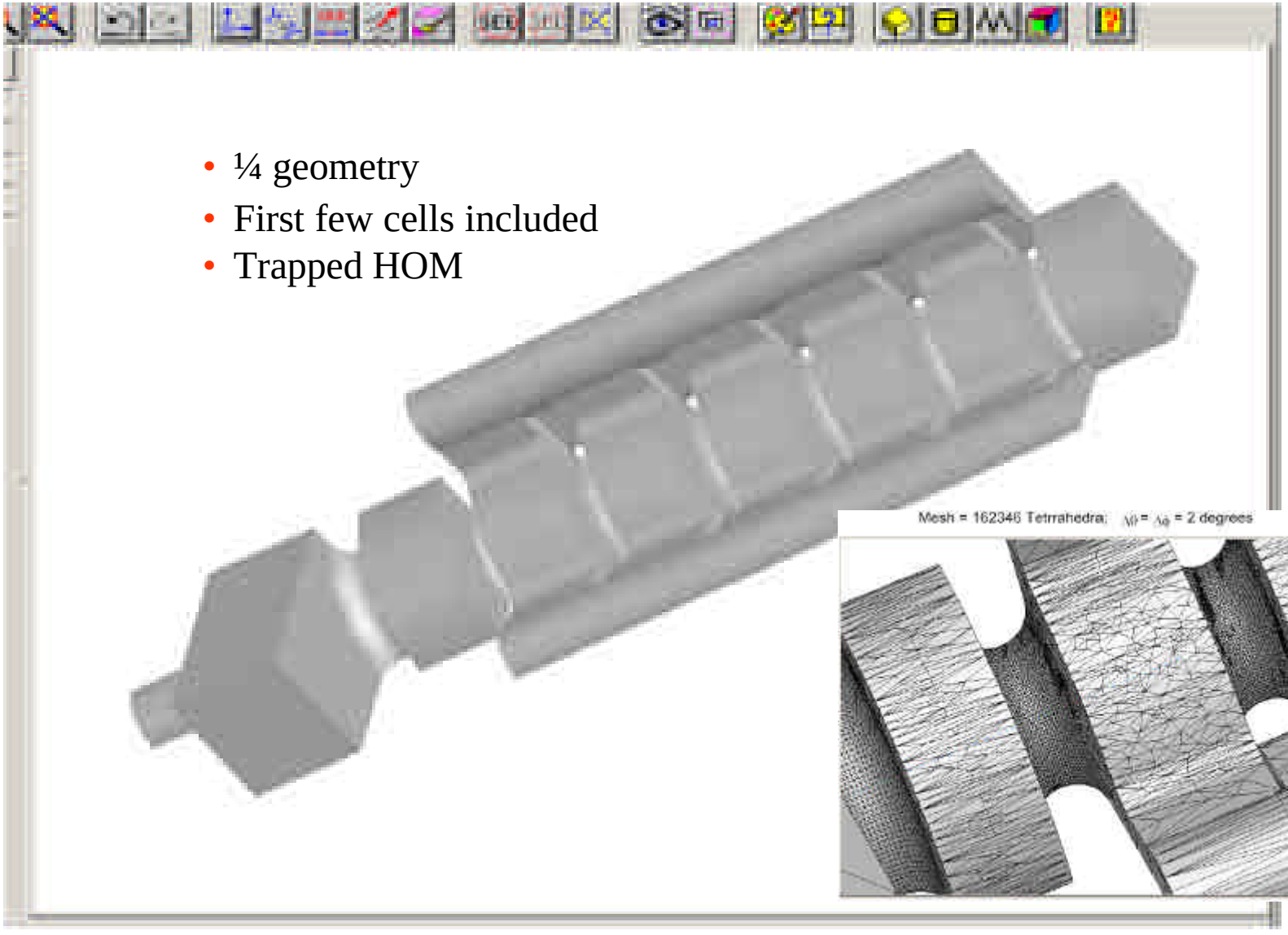
- Satisfy Structure R1 Requirement
  - Operate at least one $a/\lambda = 17\%$ or 18% structure with detuning and damping (i.e., with slots but not necessarily HOM outputs) at 65 MV/m with 400 ns pulses for a few hundred hours at 60 Hz with a breakdown rate < 0.1.
- As Part of Satisfying R2 Requirement,
  - Run eight $a/\lambda = 17\%$ or 18% structures simultaneously for a few months (goal is 2000 hours at 60 Hz) at 65 MV/m with 400 ns pulses.
- Demonstrate Wakefield Suppression
  - Measure a pair of detuned (two-fold interleaving), damped, $a/\lambda = 17\%$ structures in ASSET to show an acceptable long-range wakefield can be achieved.

Menu of Structures for Test in FY04

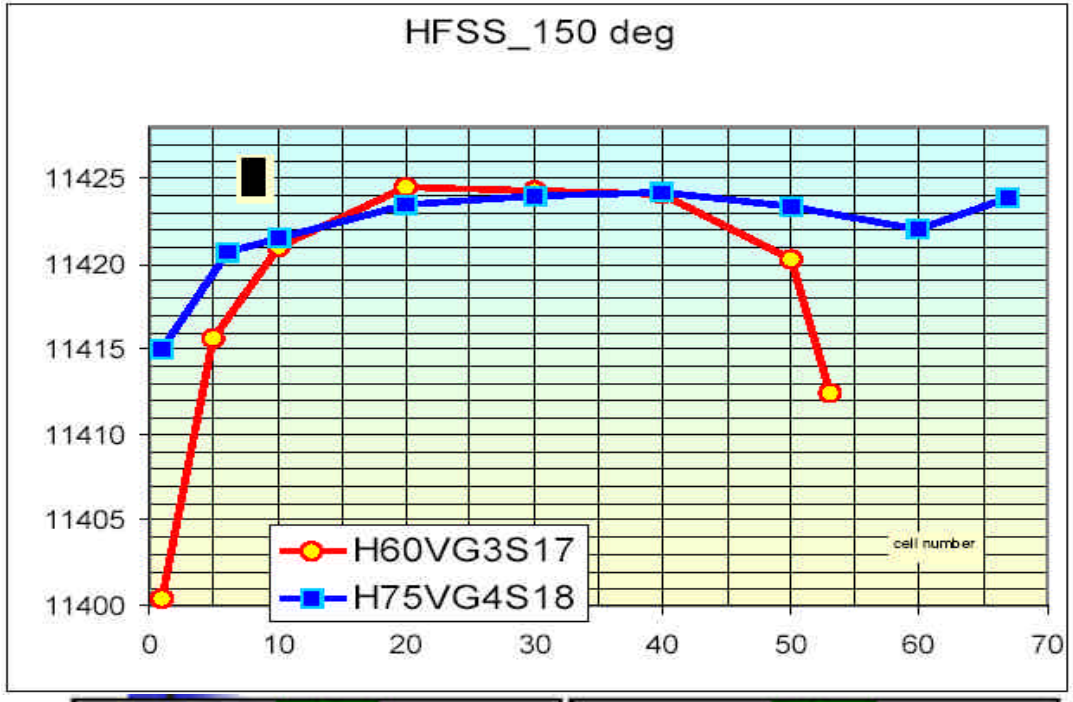
Appetizers		a/λ (%)	Slots	HOM	Coupler
1	H60VG3R17	17	no	no	mc
2	H60VG3 (FXB 6 & 7)	18	no	no	wg_fnal
1	H60VG3S18 (Retest with matched arms)	18	yes	no	mc
Main Course Cuisine (R1/R2 Candidates)					
	'Taste of Chicago'				
4/5	H60VG3S17 (FXC)	17	yes	no	wg_fnal
2/4	H60VG4SL17 (FXD)	17	yes	yes	wg_fnal
	Japanese-American				
2	H60VG4S17	17	yes	no	mc
2	H60VG4SL17	17	yes	yes	wg_slac
	Californian				
-	Robertson/SLAC (Temporarily Discontinued)				

Structure design

- ¼ geometry
- First few cells included
- Trapped HOM

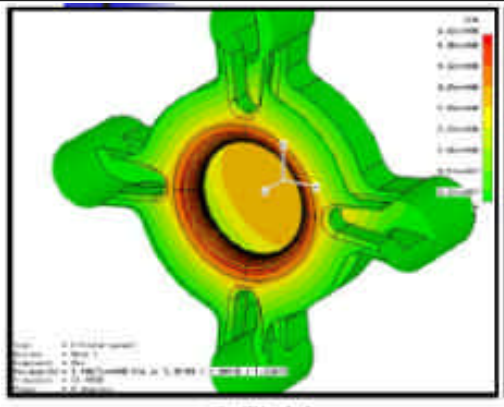


FXC RF Disk Simulation

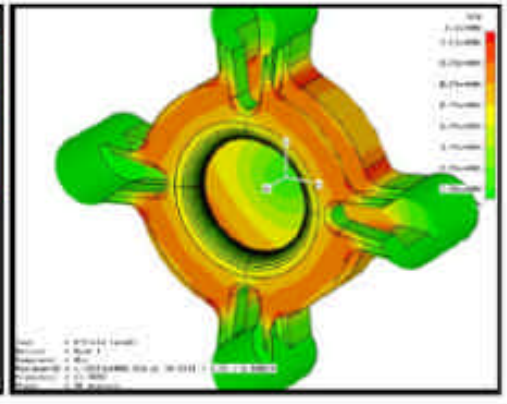


HFSS

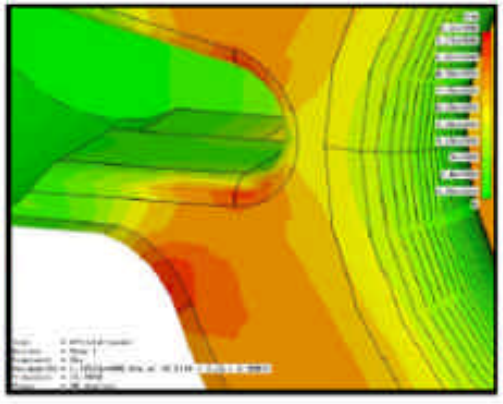
MWS



E-Field

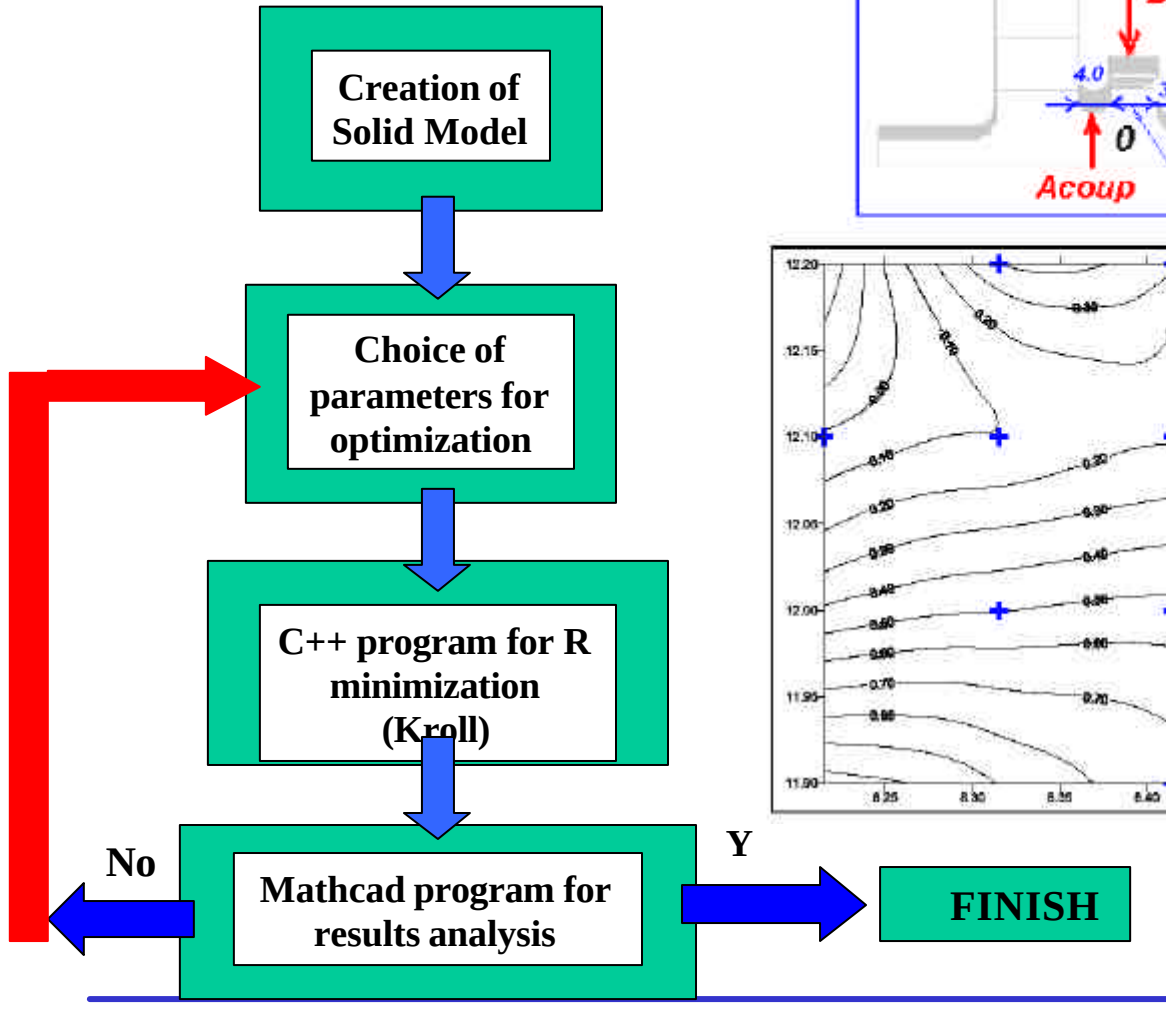


H-Field

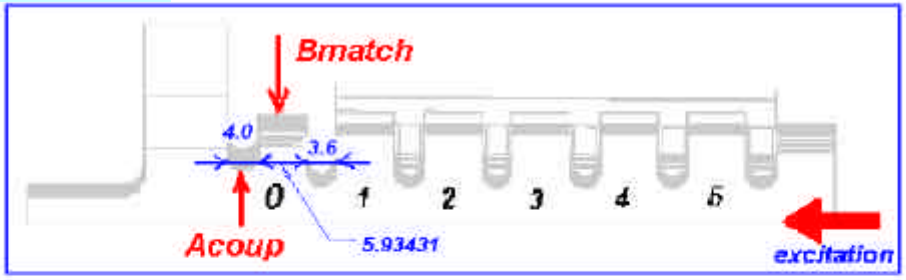


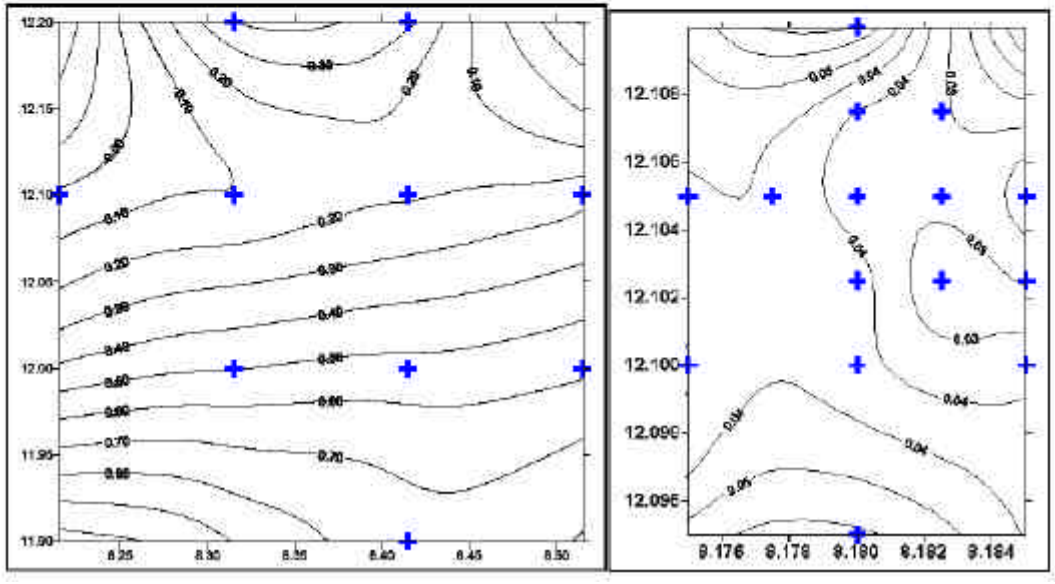
H-Field zoom

Procedure of couplers optimization



H60VG3S17 input coupler optimization

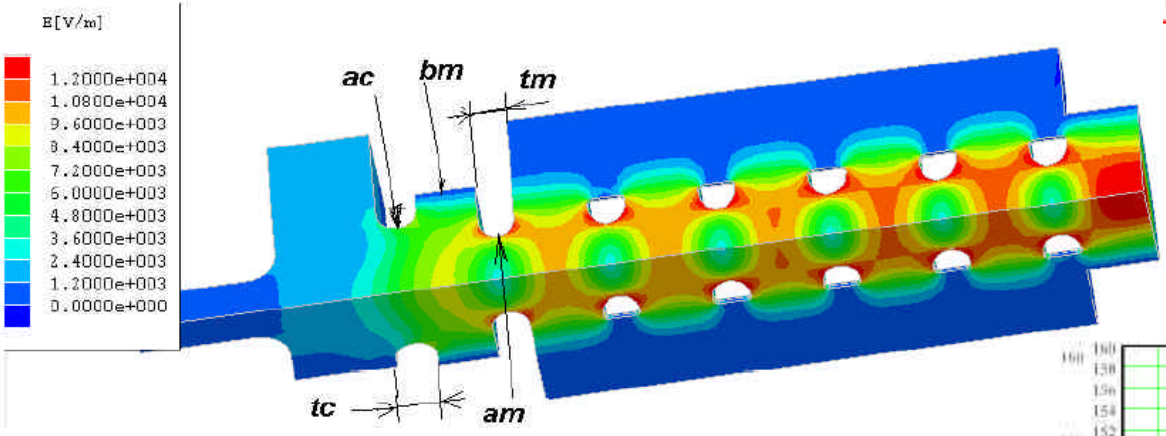


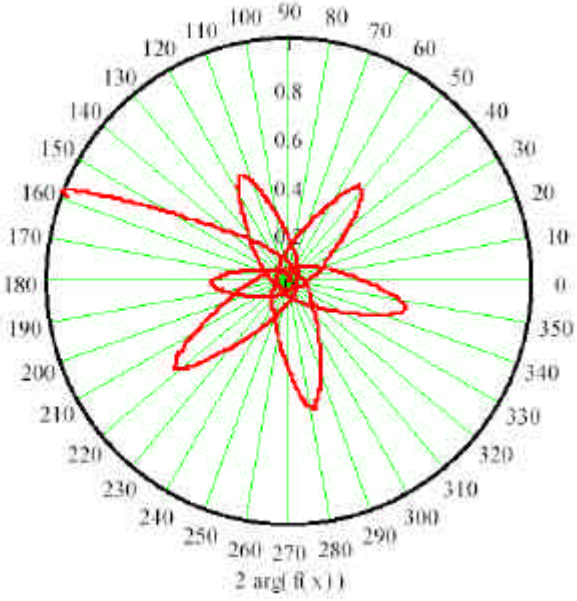


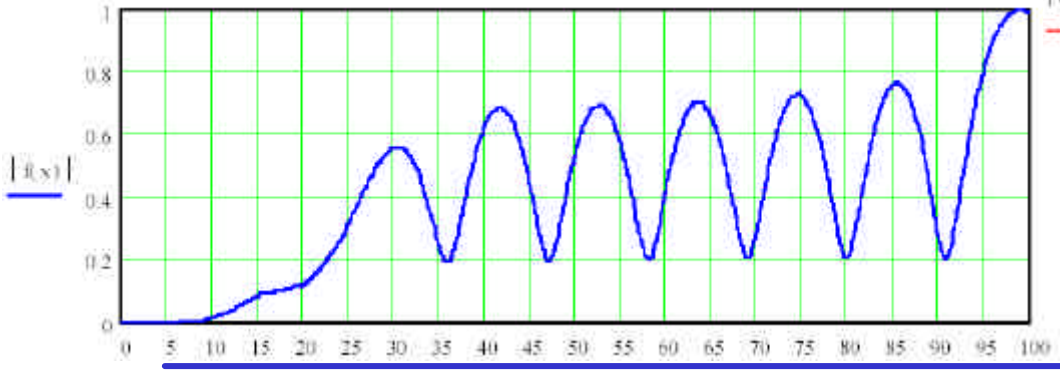
FXC input coupler FWG

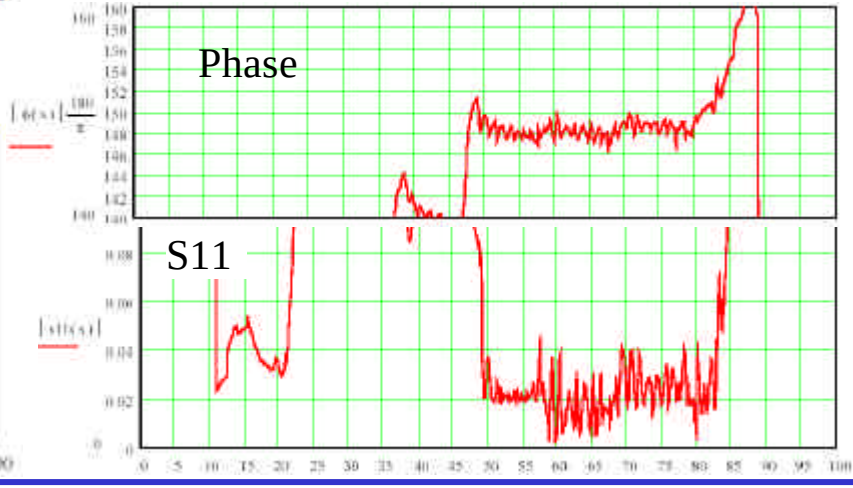
H60VG3S17 WG Input Coupler with short(L-1.4mm) matching cell

coupler diaphragm: ac=8.1825mm; tc=4mm
matching cell: bm=12.1025mm, am=5.4mm, tm=3.6mm with elliptical iris (1.8*2.1)





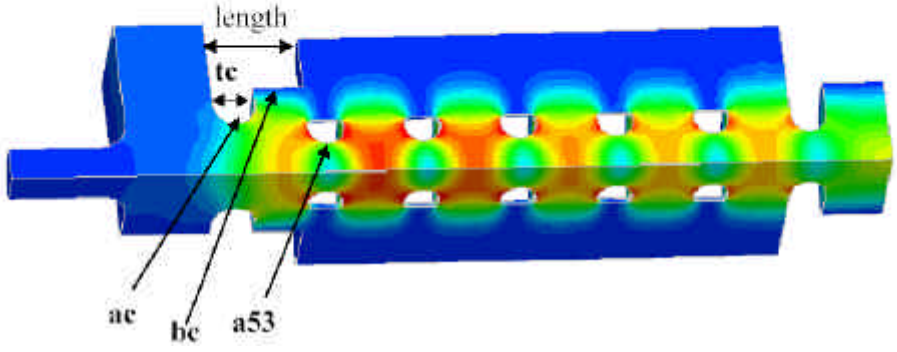


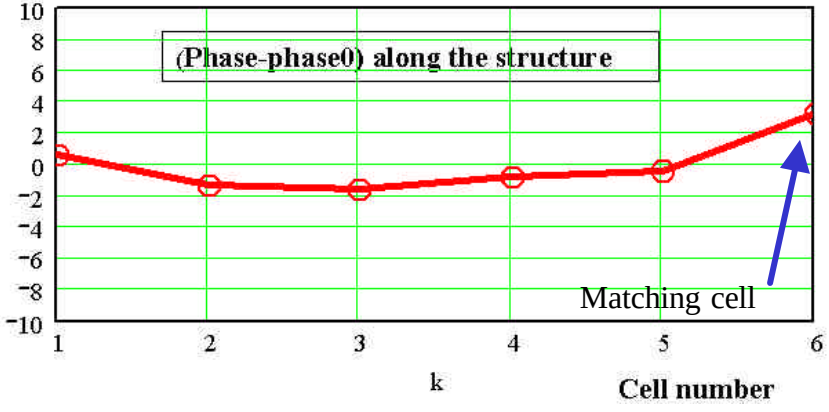


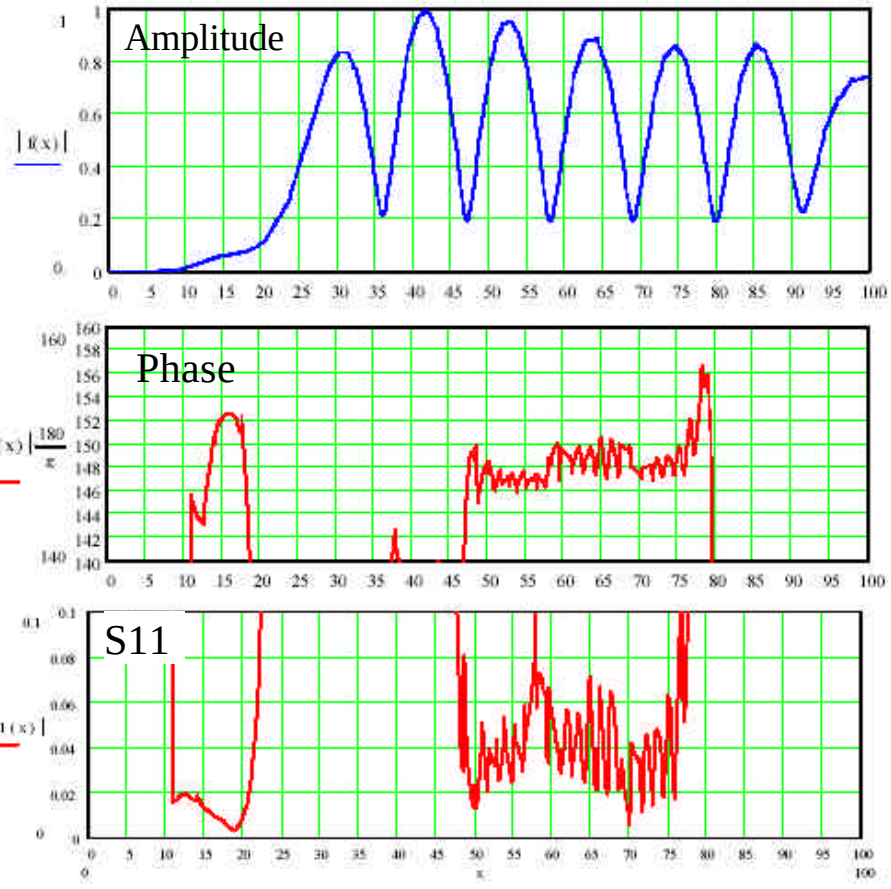
Output coupler

H60VG3S17 WG output Coupler with short(L-0.5mm) coupler cel

coupler diaphragm: ac=6.84125mm; tc=4.8mm, length=L0-0.5
matching cell: bc=11.5mm, a53=3.88mm, no_fillet



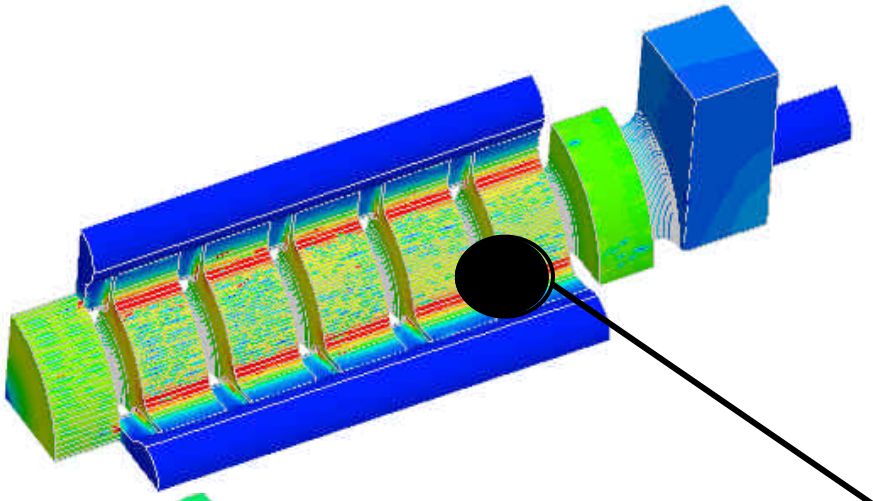


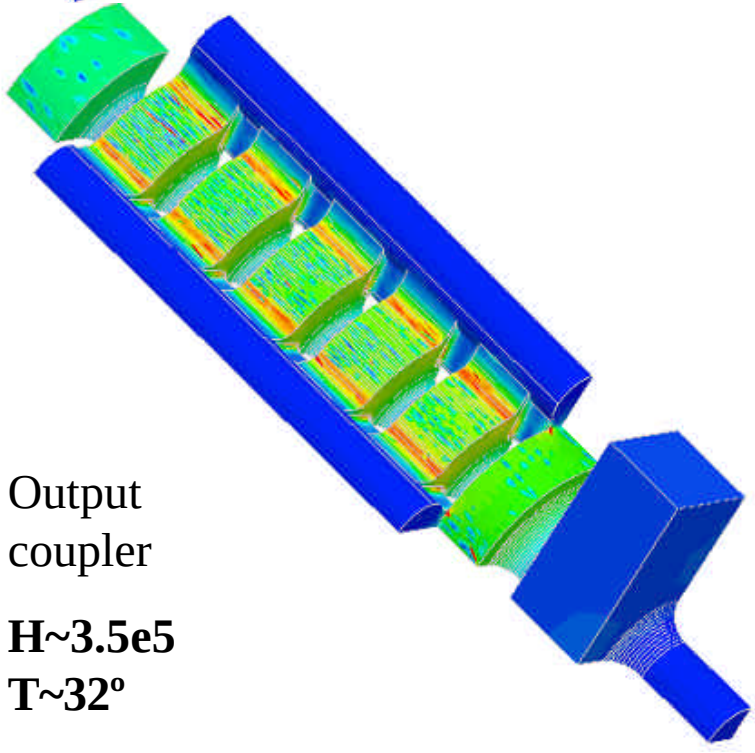


Calculated Phase and S11 (N.Kroll)

Input coupler
H ~ 3.05E+5 A/m
T ~ 25º

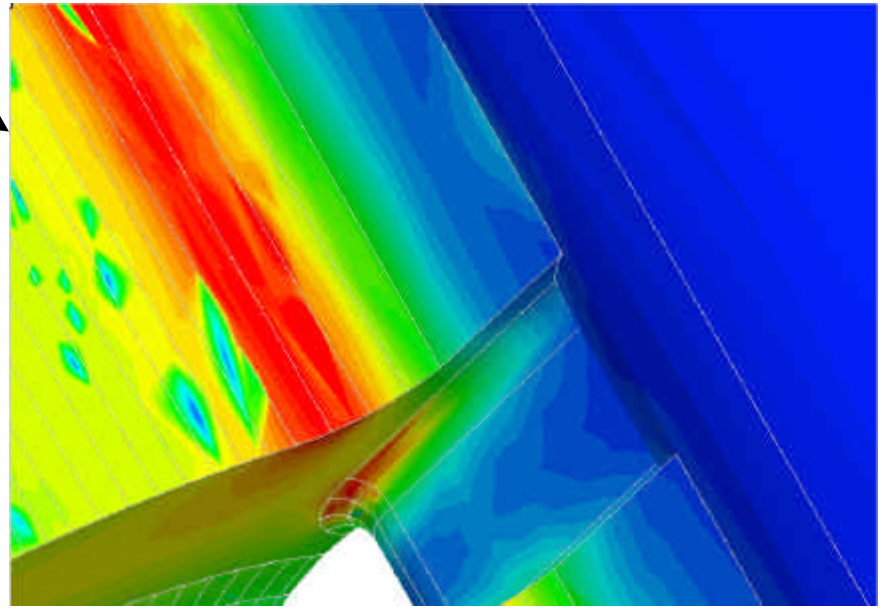
Pulse heating at 400ns
Eacc=65 MV/m





Output coupler

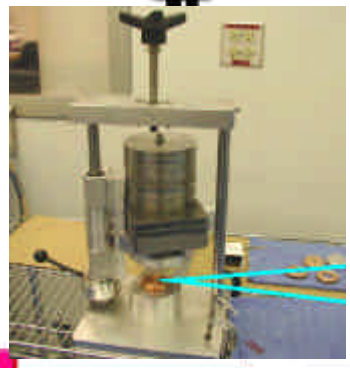
H~3.5e5
T~32º

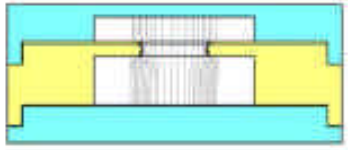


Magnetic field in area of rounding at slot and b

ANSYS: Cu annealed **T~ 44º**
Cu hard T~**130º**

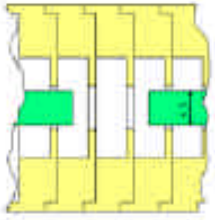
Structure testing



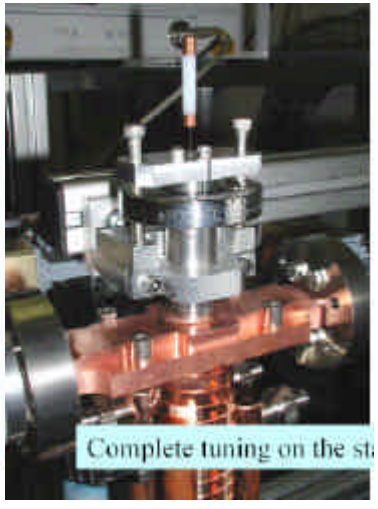


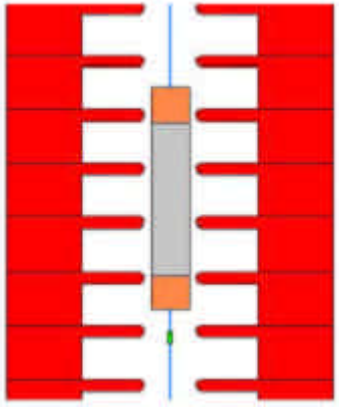
Accuracy=±2MHz
Automated, 4 modes
Record 35 sec/cell

Input disk sets QC. Short stacks.
Fundamental modes, HOM, Q



Stacks, brazed stacks
Fundamental modes, HOM,
Nodal measurements

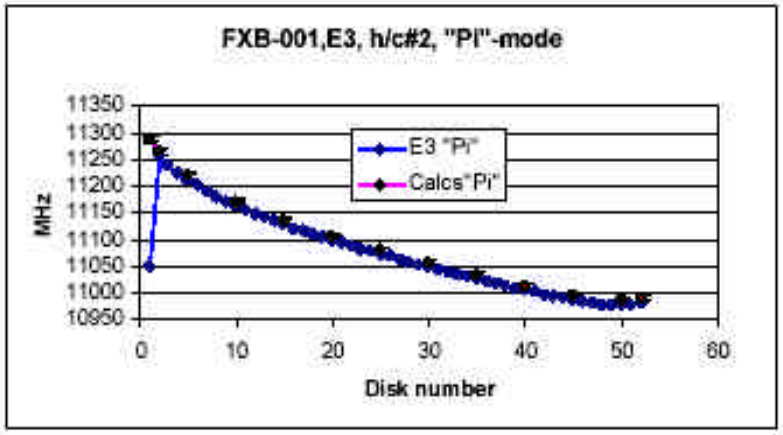


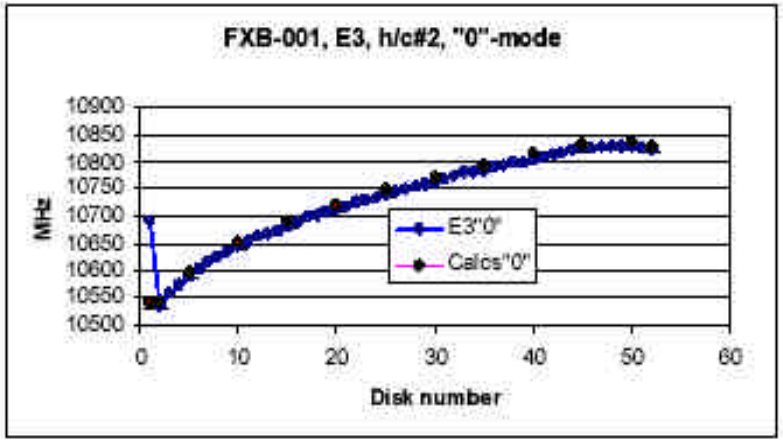


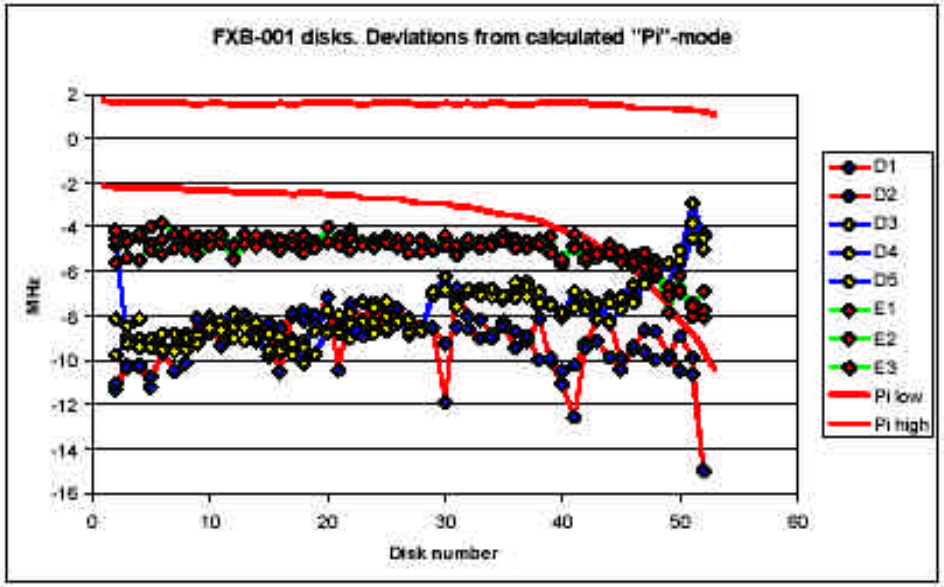
Couplers, brazed structures.
Complete tuning and matching.

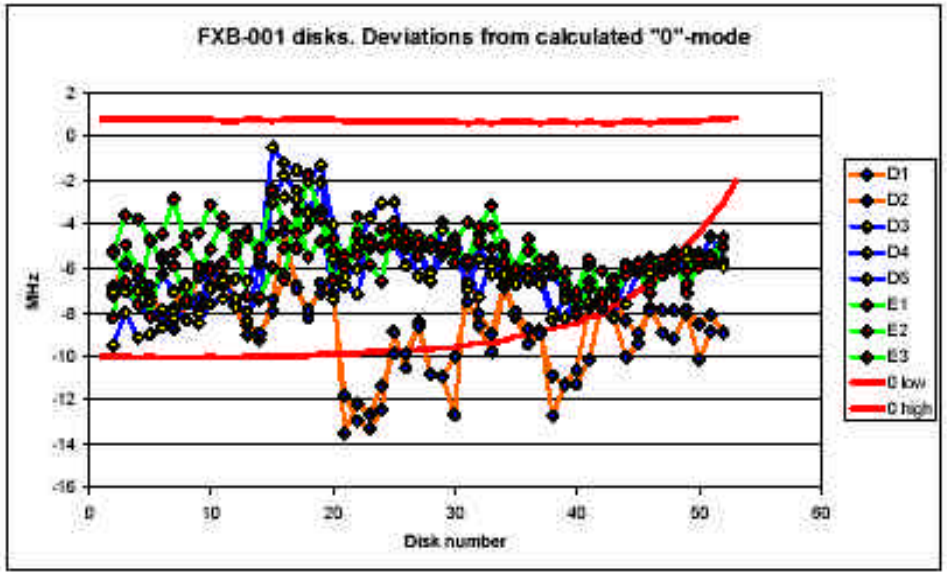
Structure testing

Single disk QC. Summary. FXB.







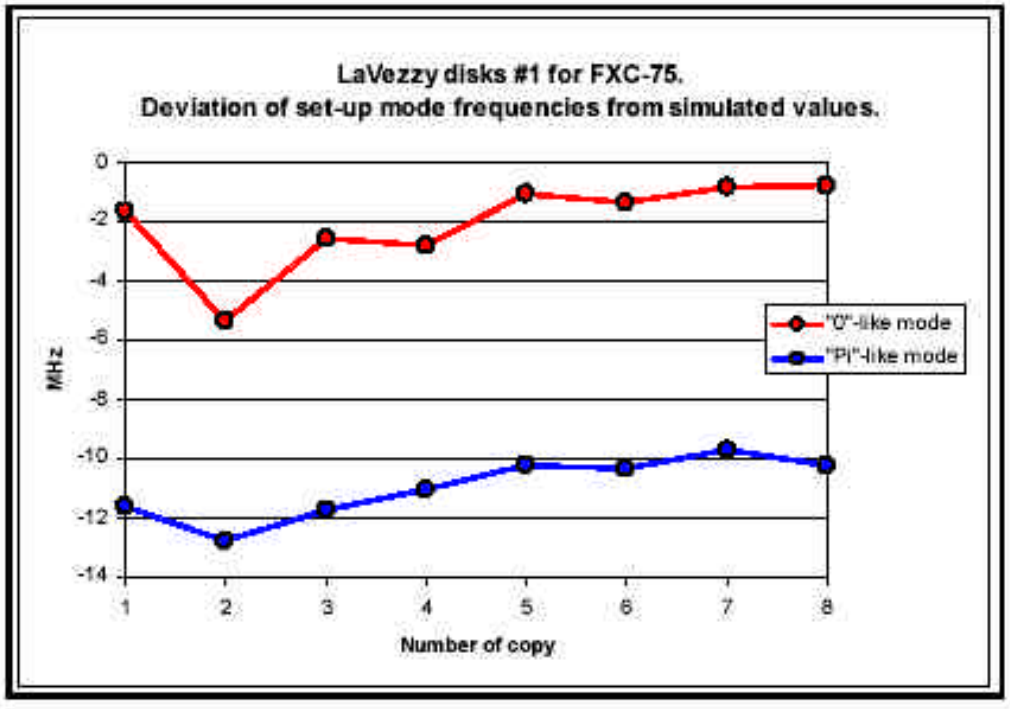


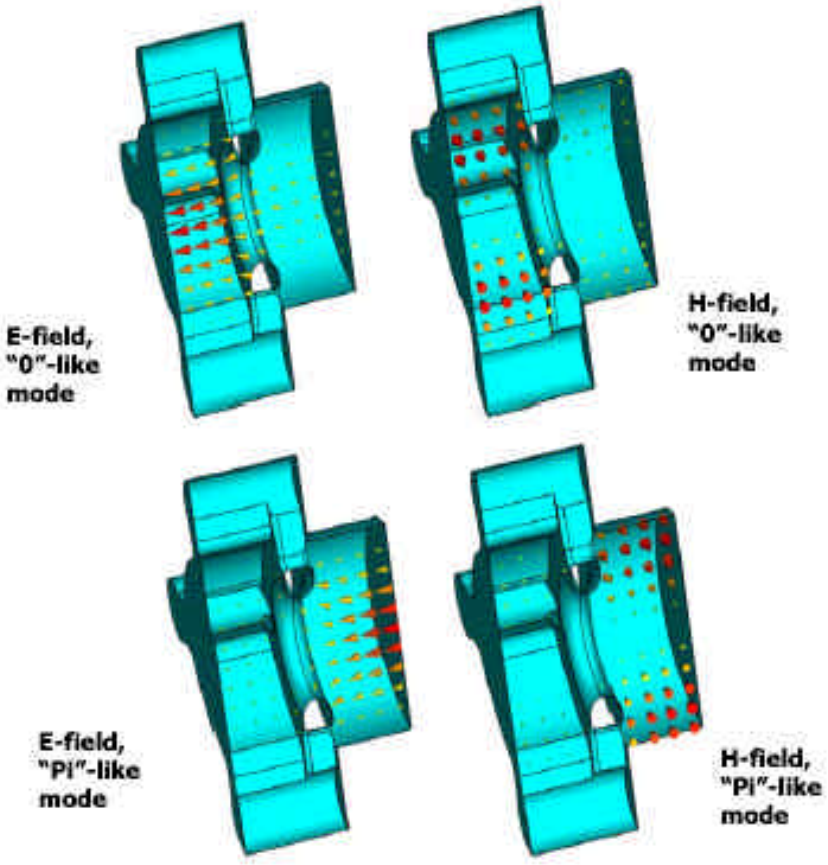
LaVezzi Disks RF QC

LaVezzi disks are good:

absolute deviation is about: – 3 MHz

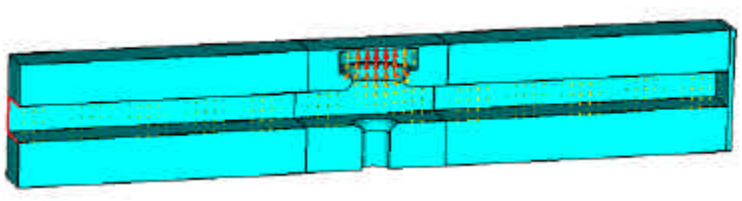
random errors: +-3 MHz





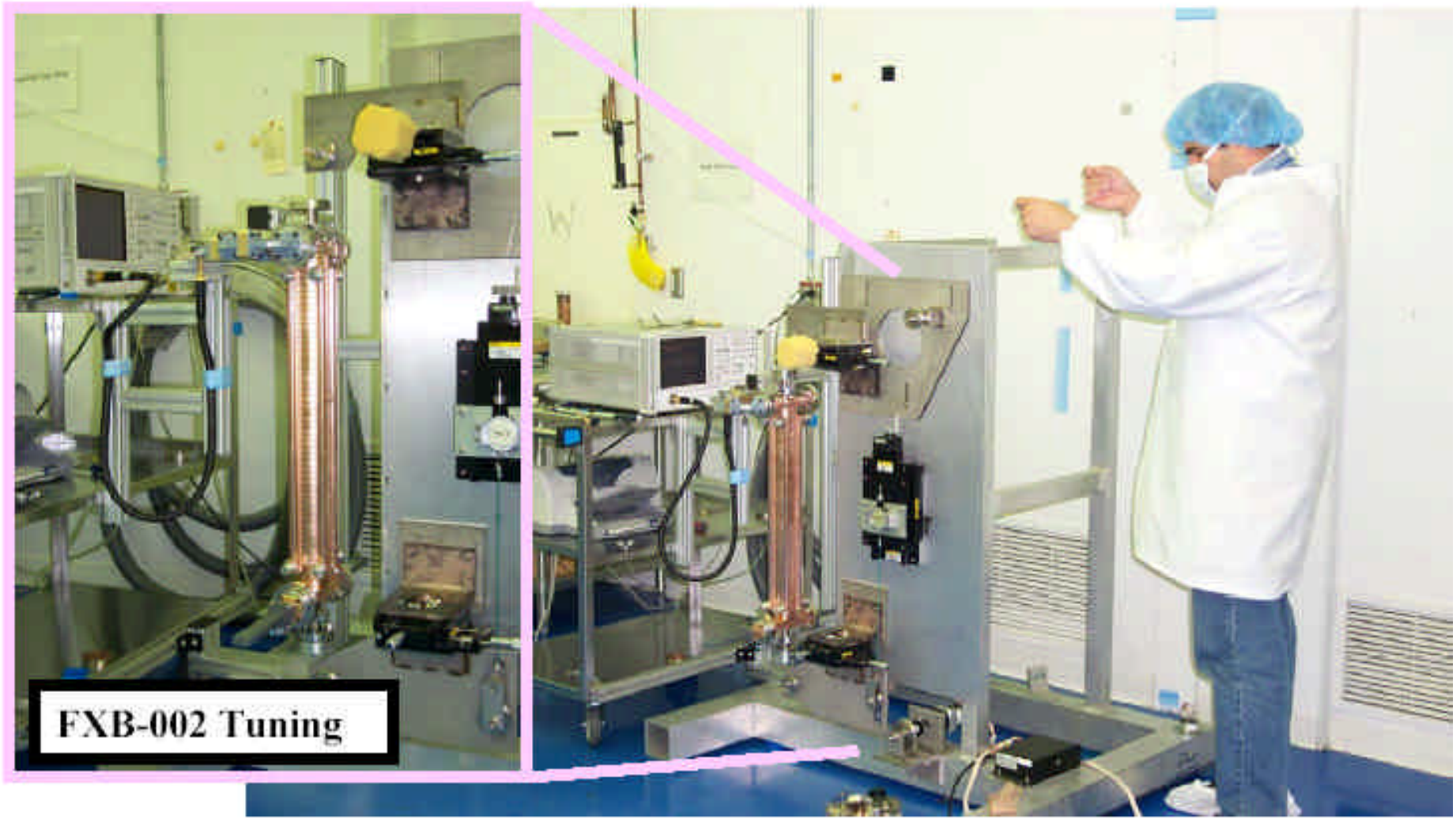
Structure testing

Measurements of couplers before brazing

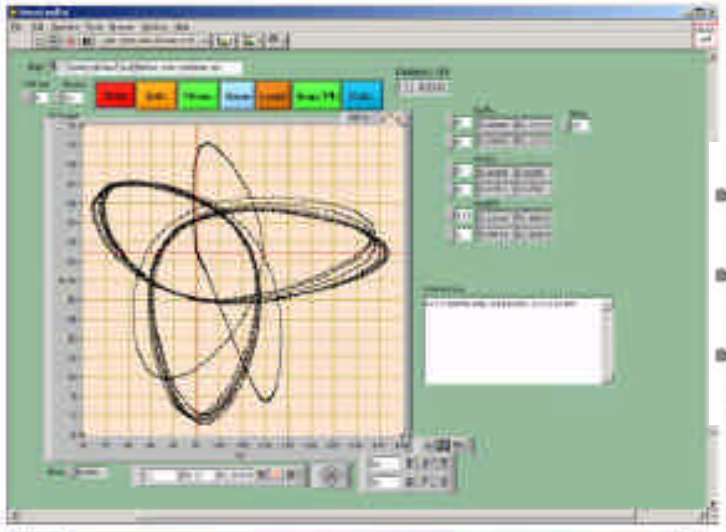


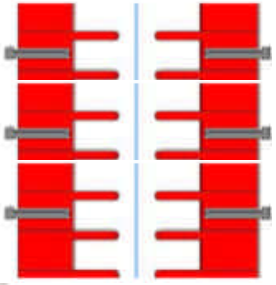
New technique: shorted matching cell

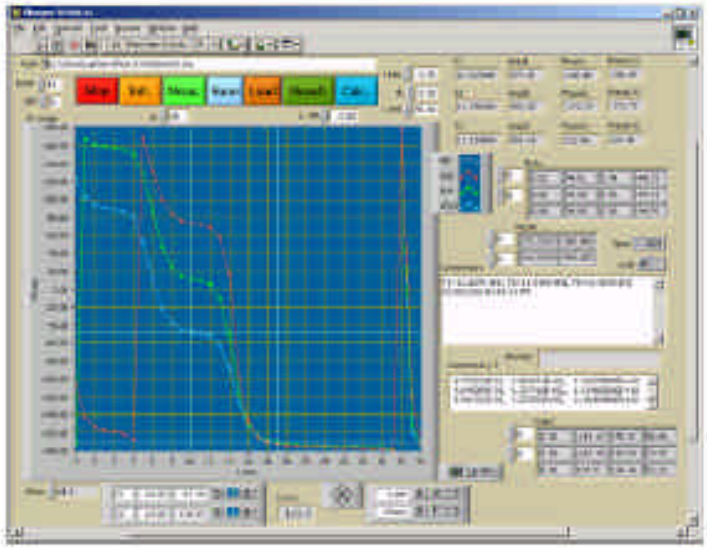
RF tests / Bead-pull measurements

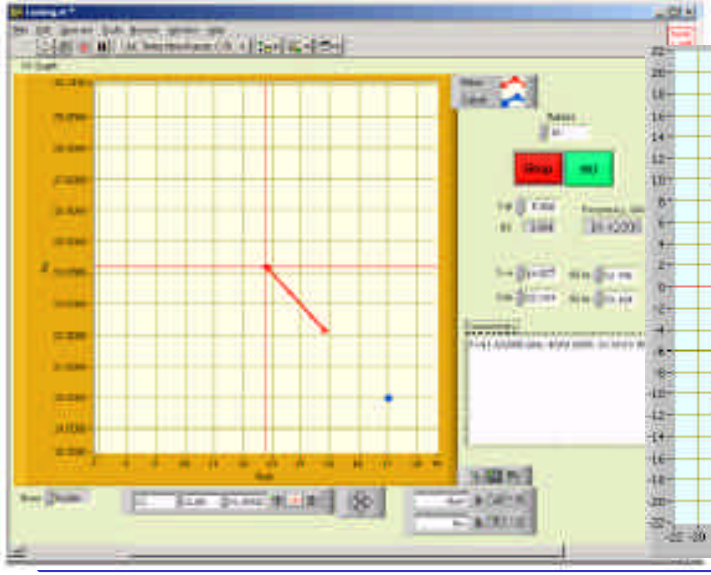


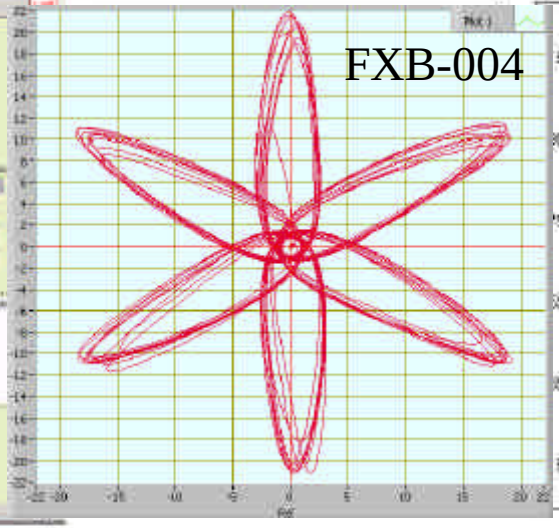
Work Accomplished: RF Testing/Bead-pull Measurements

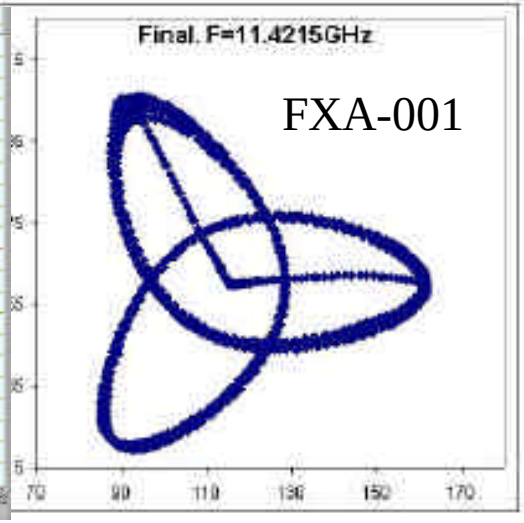




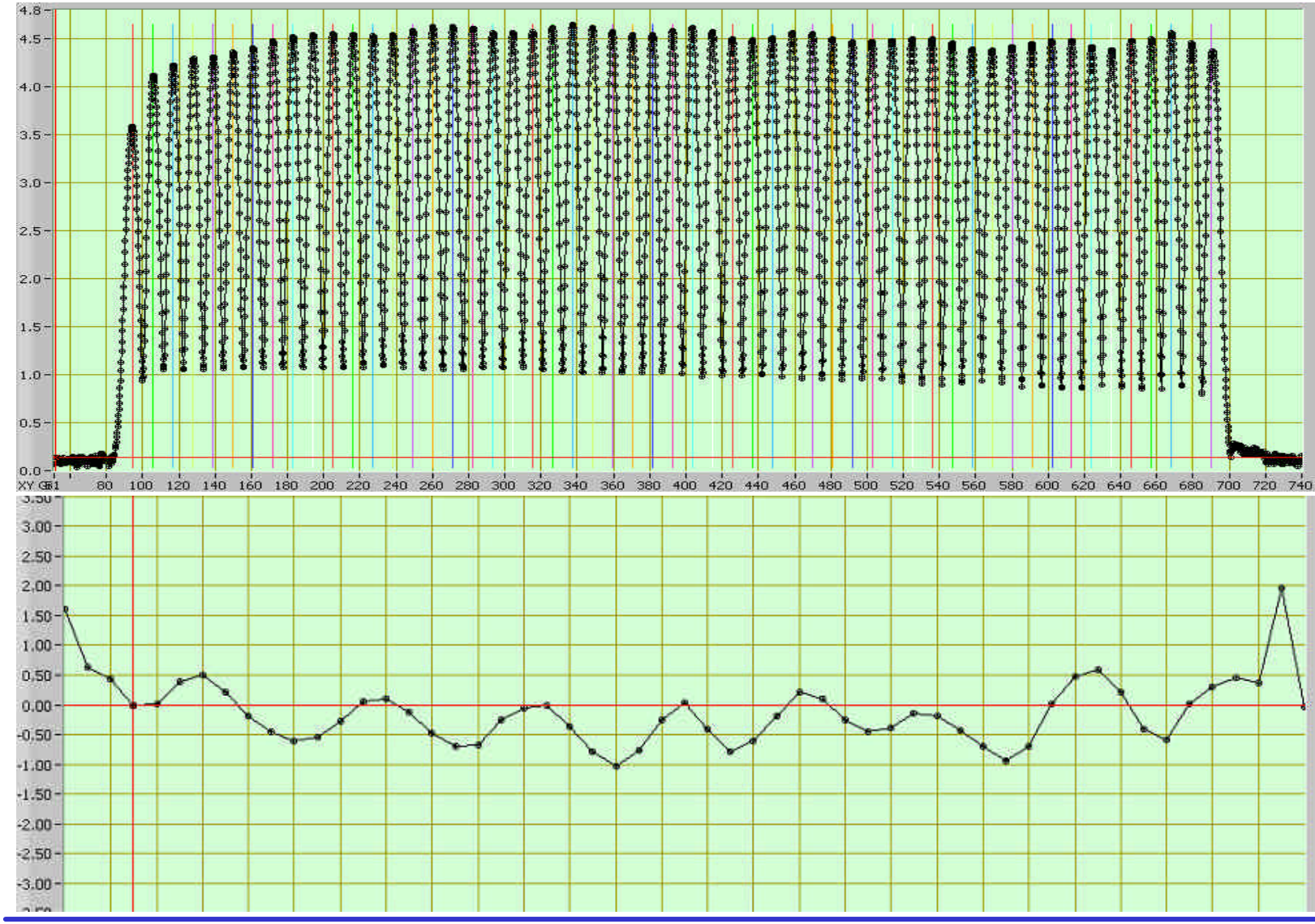






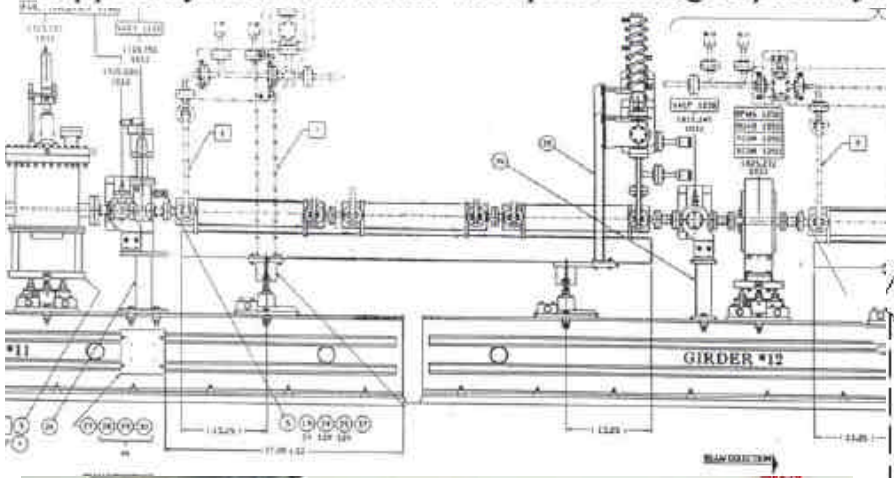


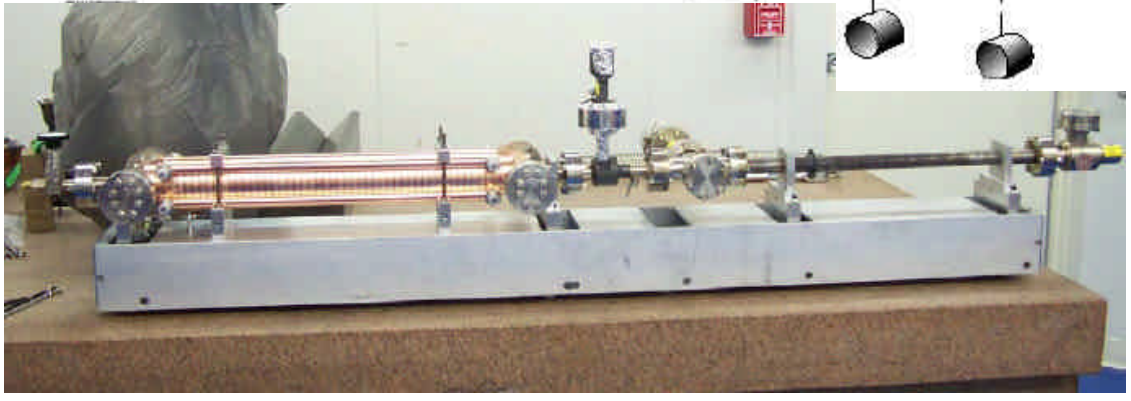
Amplitude and phase FXB-003

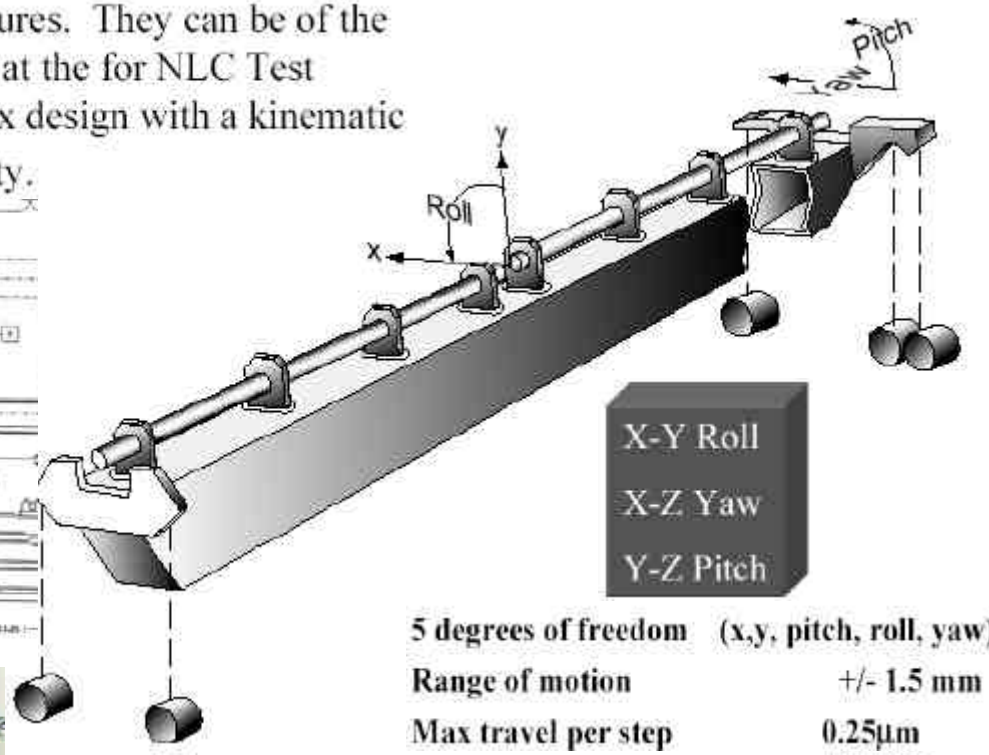


Girders studies

Girders serve as the supporting bases for RF structures. They can be of the more simple box beam "strongback" design in use at the for NLC Test Accelerator (NLCTA) at SLAC, or a more complex design with a kinematic support system and multi-axis positioning capability.

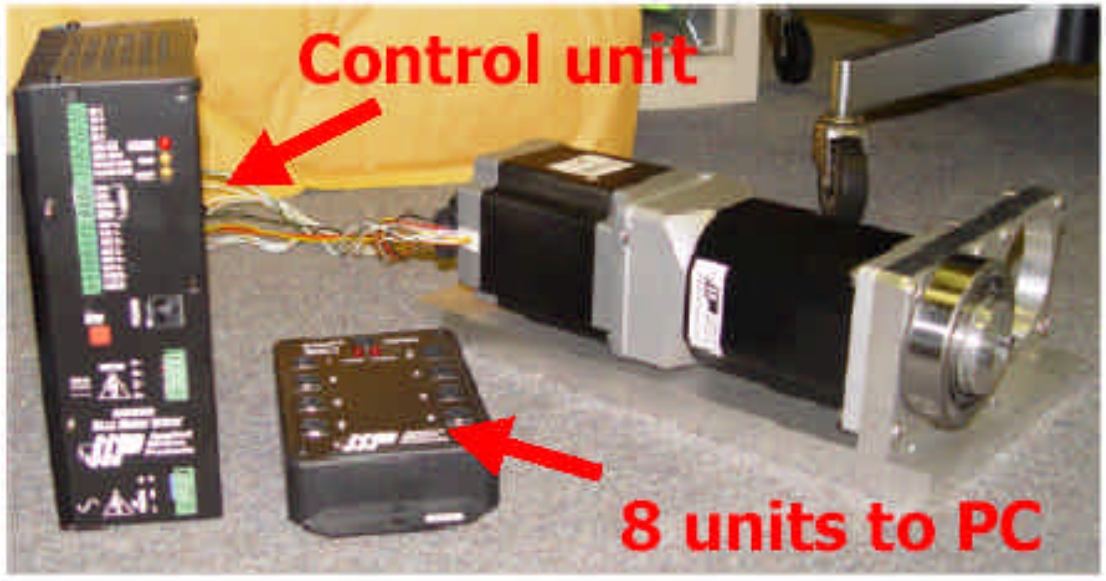


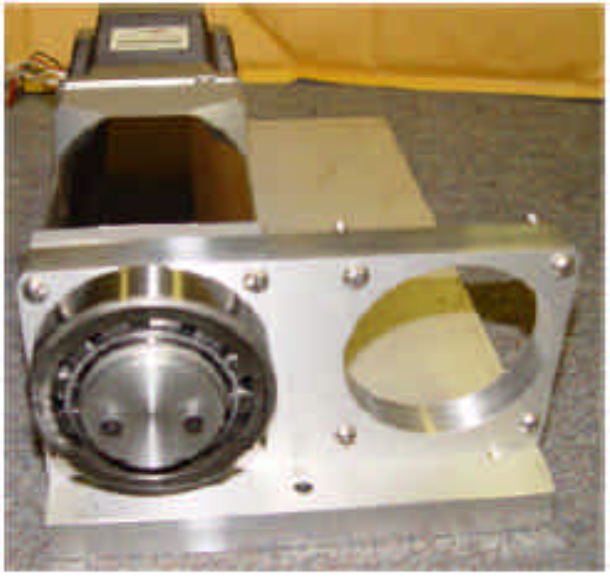


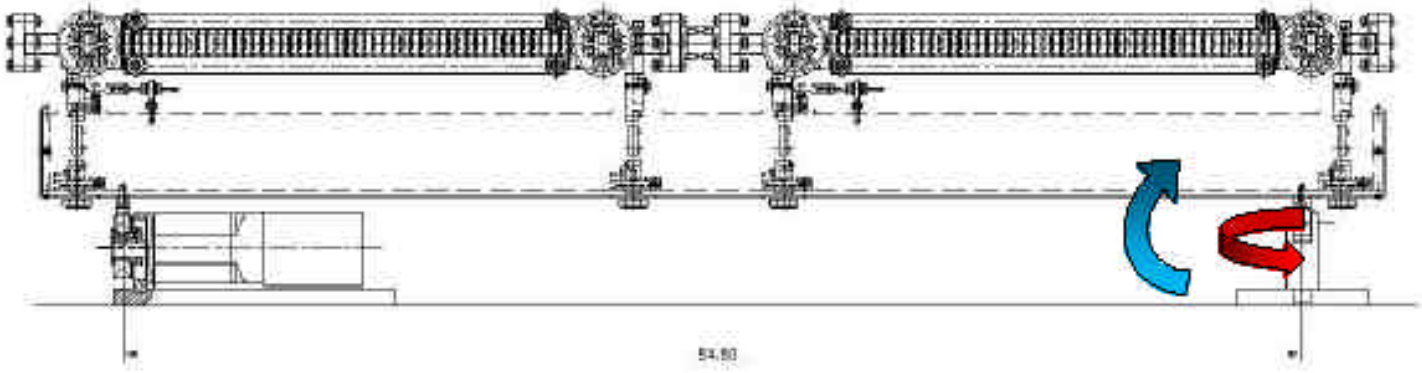


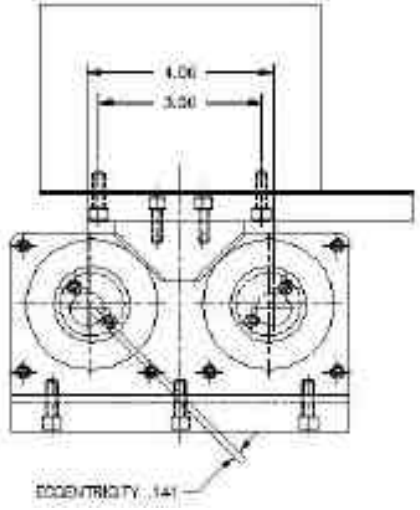
5 degrees of freedom	(x,y, pitch, roll, yaw)
Range of motion	+/- 1.5 mm
Max travel per step	0.25μm

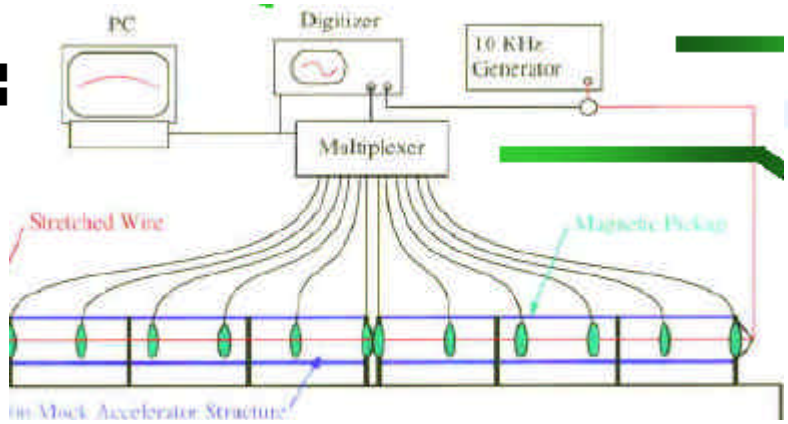
Motors and movers



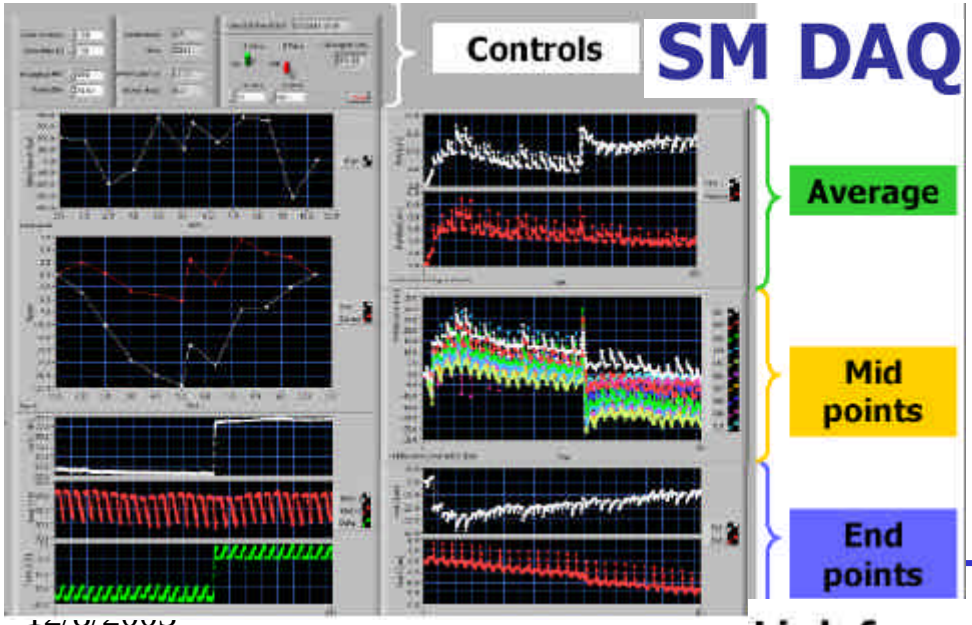


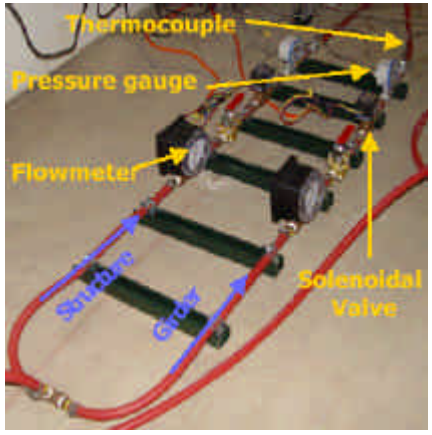






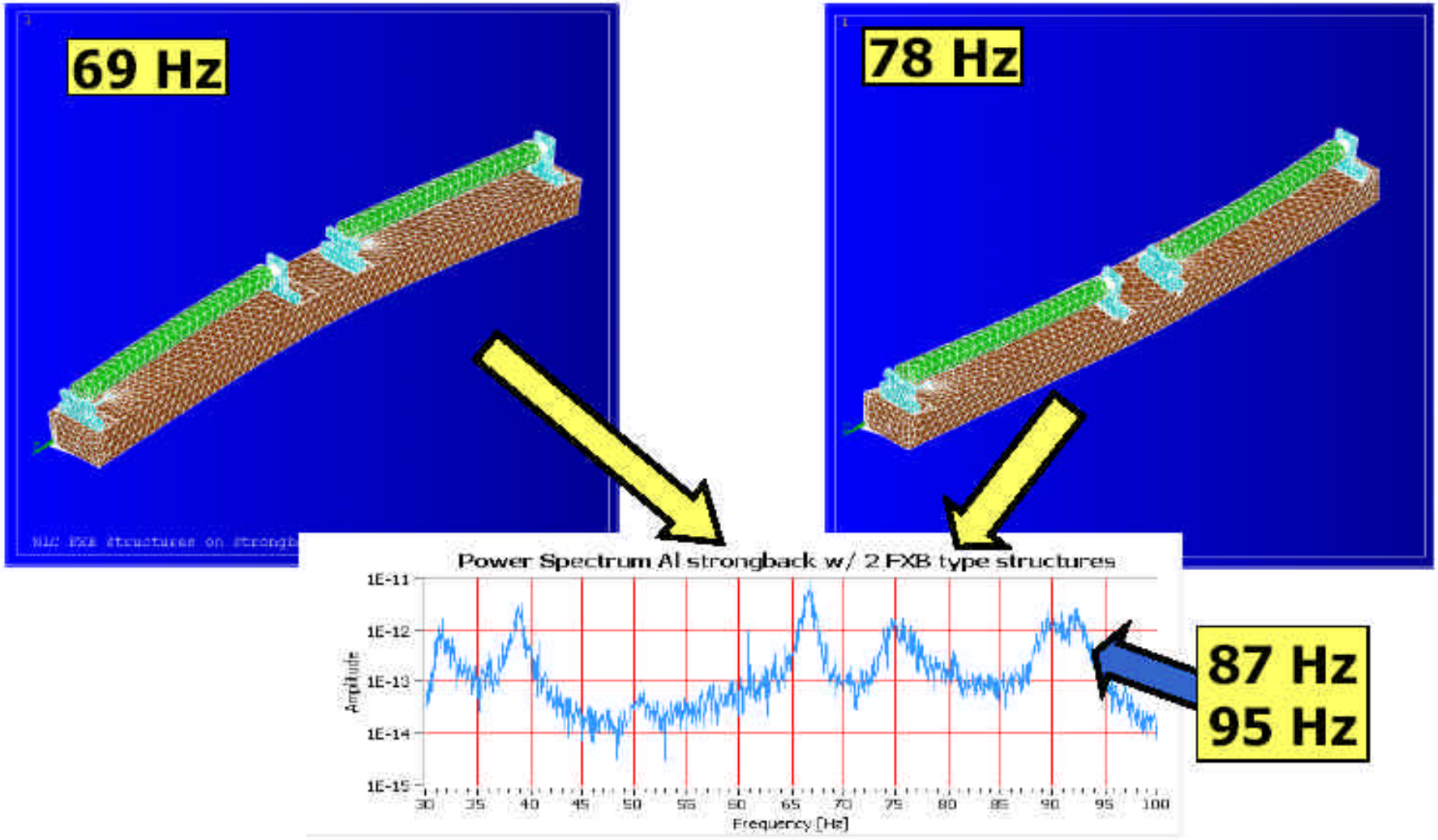
- Linac Girders development
  - Stability Measurements
  - Vibrations FEM/FEA
  - Movers





Link for remote monitor: TDPC157.fnal.gov

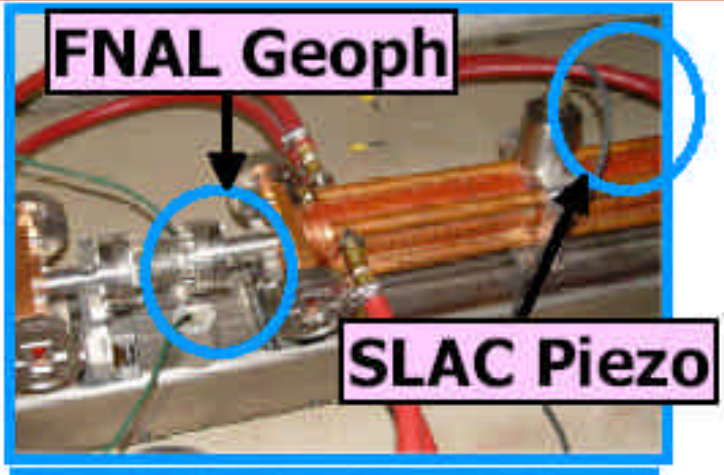
Girder R&D: Structure/Strongback Modeling and Analysis (C. Boffo)

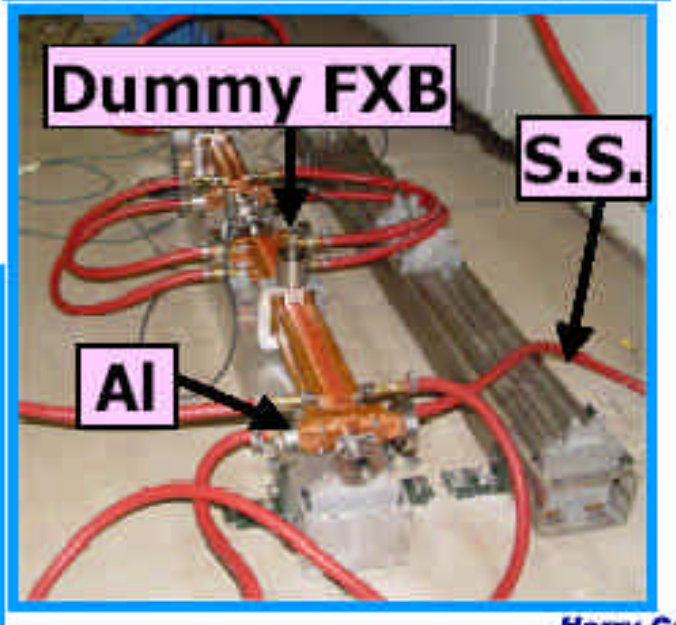


Girder R&D: Vibration Studies (C. Boffo)

Studies:

- Effect of cooling water on structures stability
- Comparison of Al and Stn.Stl. strongbacks
- Effect of vacuum on vibration transmission
- Transmission of vibration to quads (PM EM)
- Study on more realistic supports
- Effect of movers on structure stability
- Adding more constrains: waveguides





Summary

- FXB structure production was completed in FY03. FXC structures cell fabrication and brazing tests were also completed in FY03.
- FXC production is underway and on schedule to deliver 4 structures by February 2004.
- FXD parts (cells and couplers) for four structures have been ordered. Design work for FXD HOM extraction is ongoing.
- Strongback construction is in progress, and will continue in support of the NLCTA and Eight-Pack Programs. We will build eight "8-Pack" strongbacks.
- We continue to improve our RF testing and measurement capabilities in support of structure production.
- We continue to improve our RF design and analysis capabilities.
- R&D work (modeling and analysis, vibration studies, and stability studies) leading to a prototype NLC girder has increased in FY04.