Experiences from the NLC/JLC structure studies

Juwen Wang
Stanford Linear Accelerator Center
June 2007

Outline

1. **Brief review of the evolution over 15 years in the past.**

   Problems and design changes.

2. **Some Issues for meeting the design goal and tolerances.**

   Calculation, fabrication, preparation, measurement.

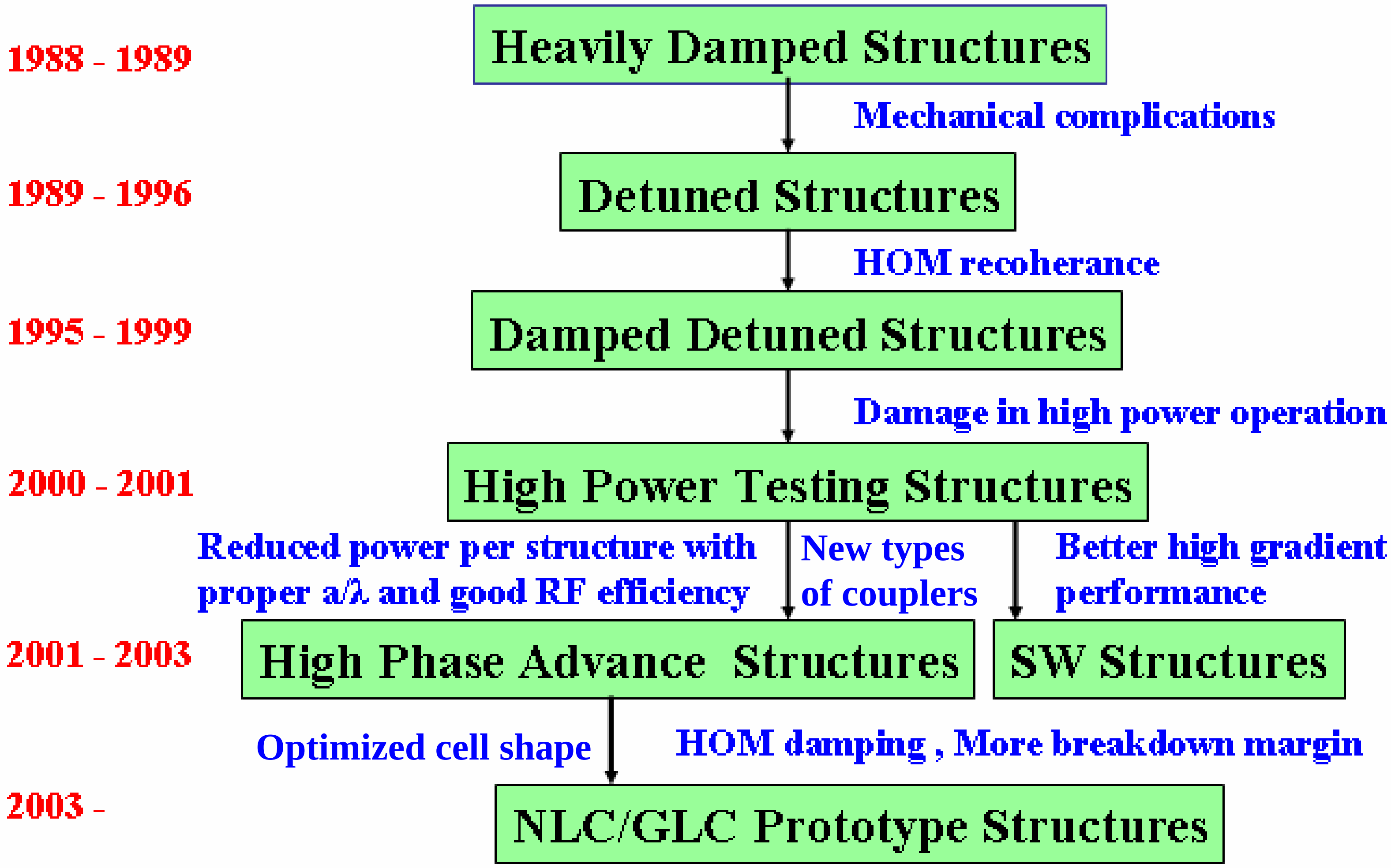
3. **Where the Next NLC/JLC Structure Design Would Have Been?**

   Planning, thinking and situation for the structures R/D just before ITRP decision.

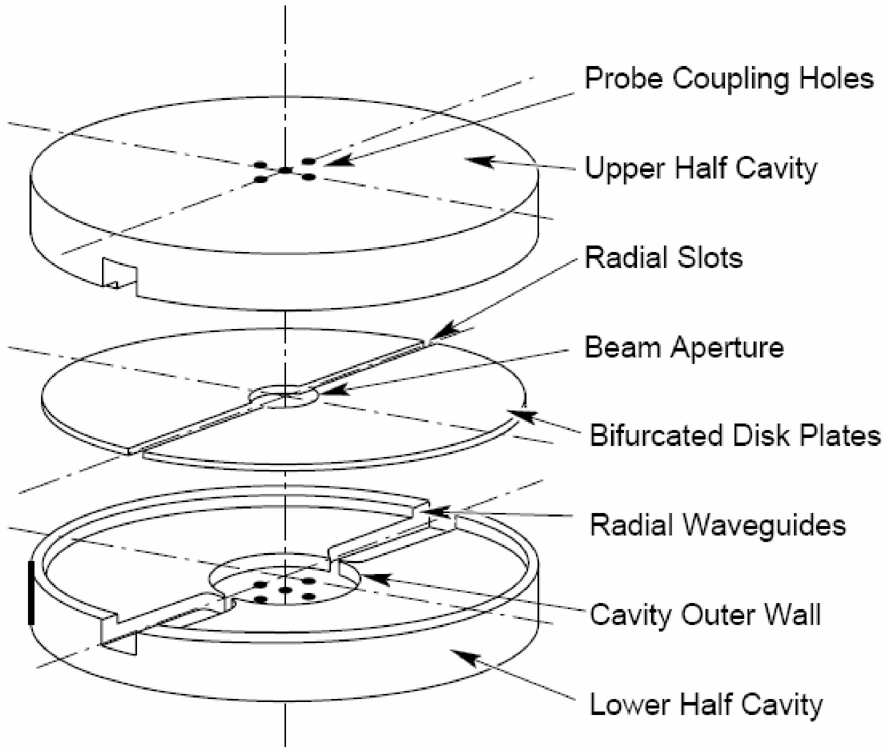
4. **T53VG3 History and Design of T26.**

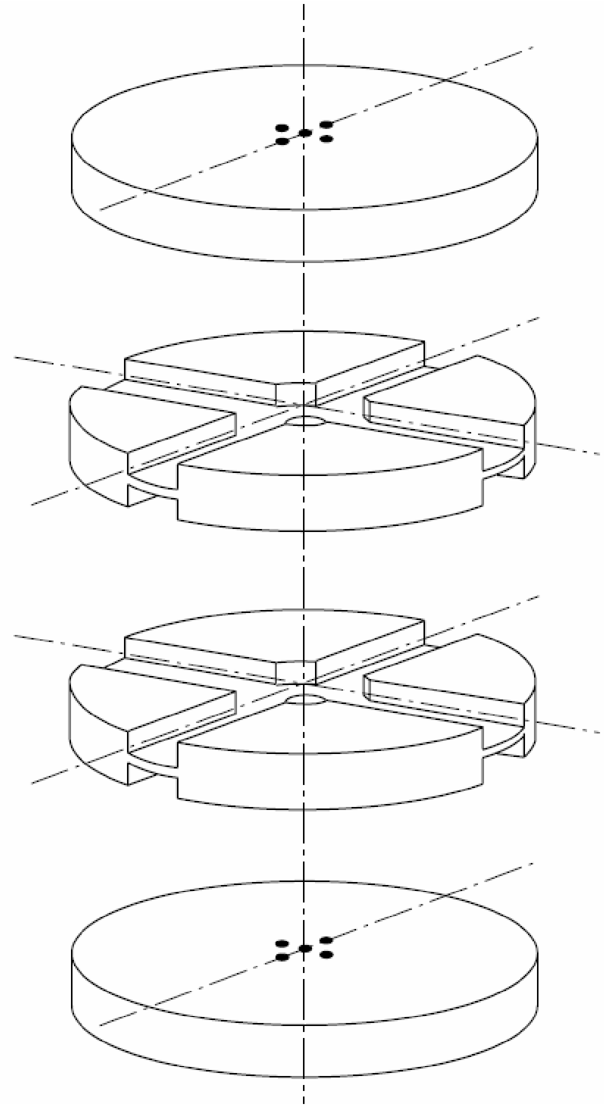
1. Brief review of the evolution over 15 years in the past

Evolution of Structures



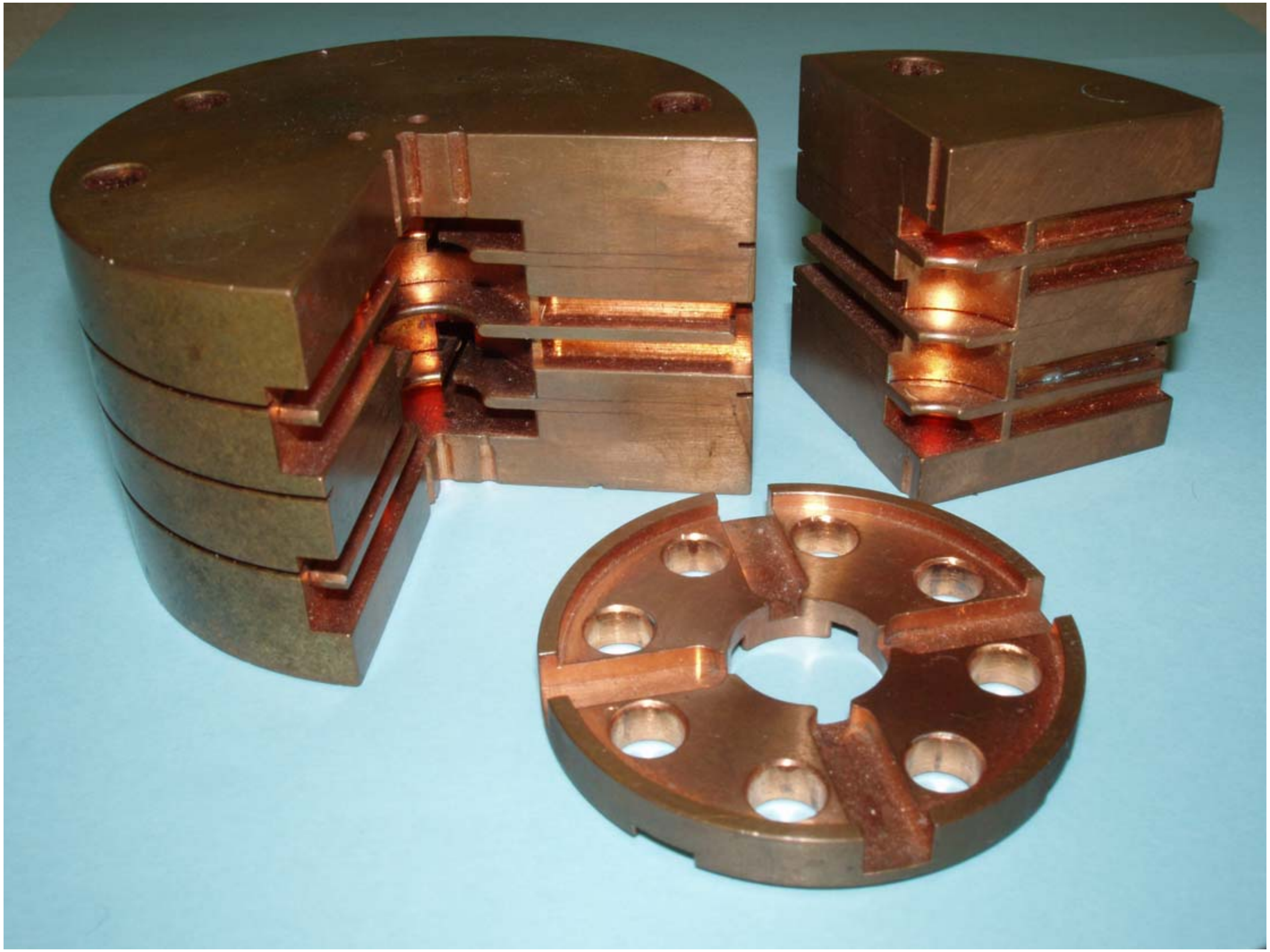
Early Studies on Two Types of Heavily Damped Structures





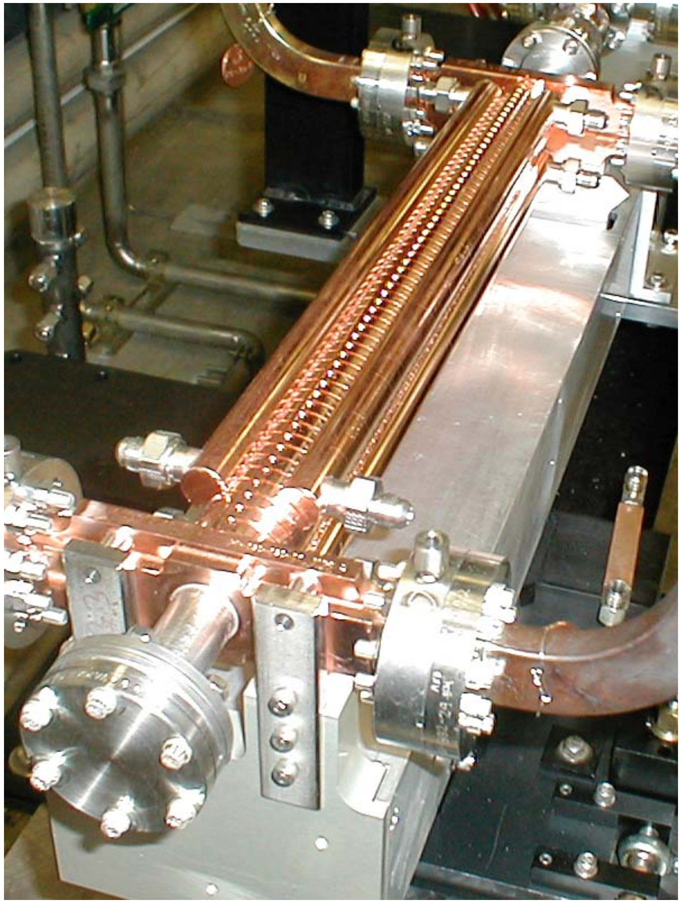
Example of structure with radial slots in iris.
Example of structure with circumferential-slot coupling: crossed-waveguide
structure, with two half-cells and one full cell.

Test Cells for Damped Structures

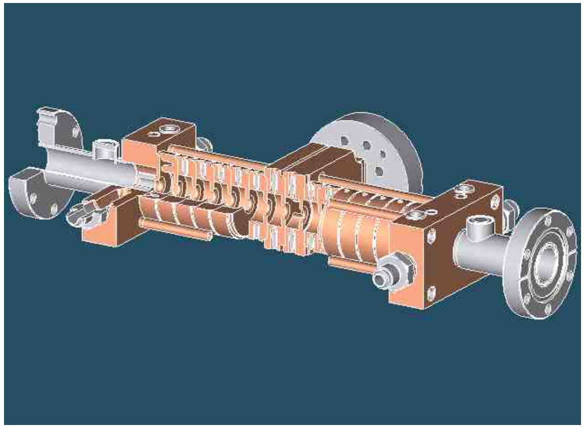


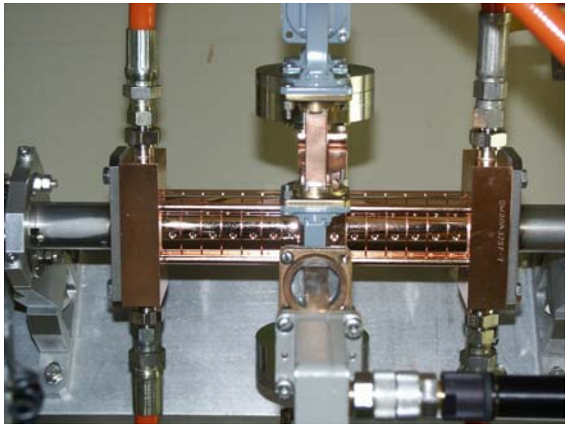
High Gradient Test Structures

One of four T-type Structures --
T53VG3, 60-Cell $2\pi/3$ Mode TW.



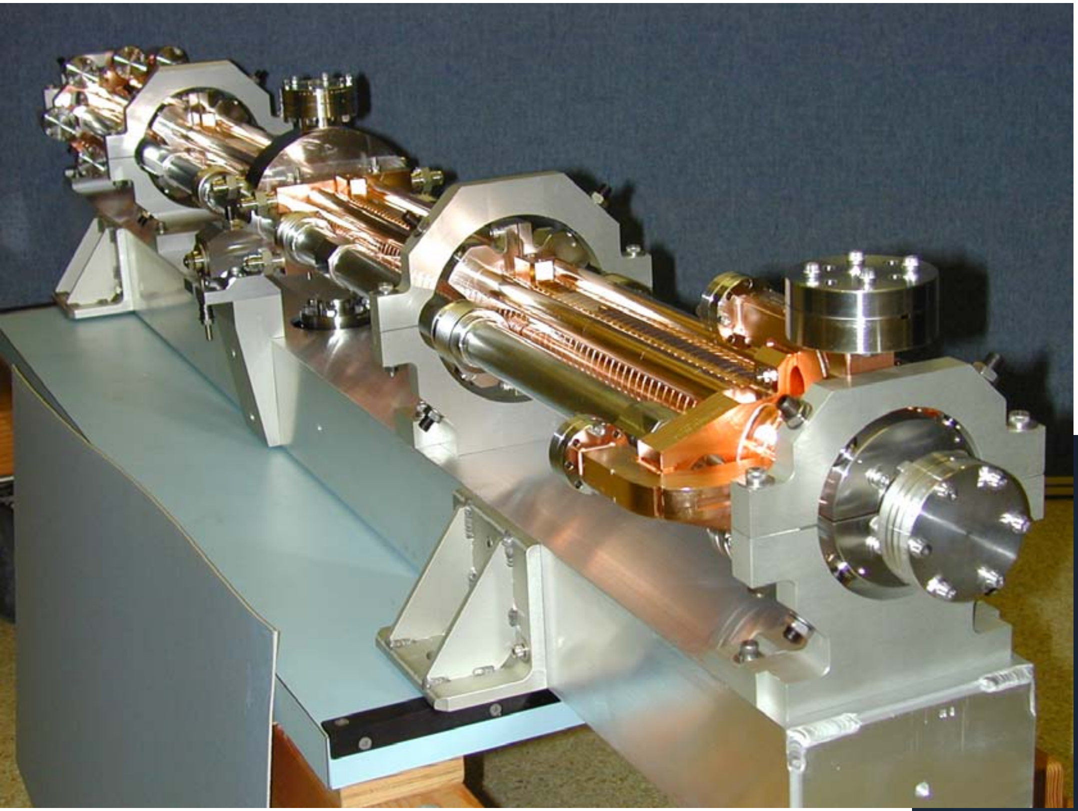
SW20PIL
15-Cell π Mode SW





One of six H-type Structures -- H60VG3S18, $5\pi/6$ Mode TW with HOM Slots and Manifolds.

Complete Damped Detuned Structures

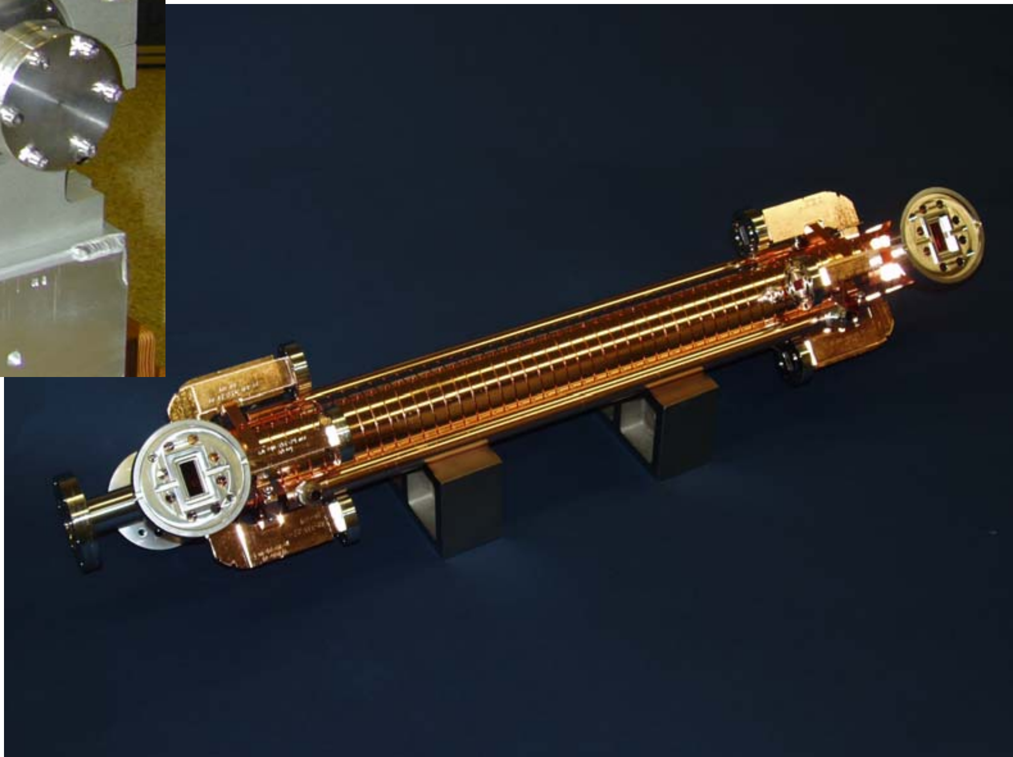


H60VG4SL17A/B

Damped Detuned 5π/6 Mode TW

Interleaving Pair of Structures

Single diamond turning cups with tuning. Final NLC/JLC structures built.



DDS1 (Round Damped Detuned)

2π/3 Mode TW

Single diamond turning discs without tuning; Micron level cell-to-cell alignment.

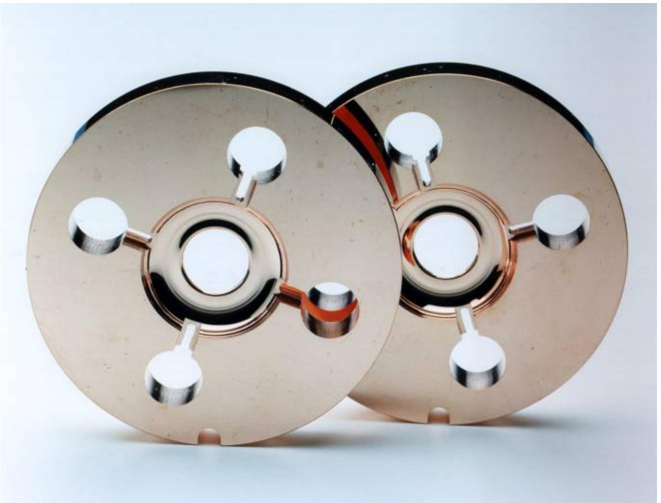
Achievements of X-Band Structures R&D

1. **Designed, fabricated and tested 50 X-Band accelerator structure sections.** (Among them, 8 were made with KEK collaboration and 12 were fabricated by FNAL).
2. **Greatly contributed to the accelerator technology:**

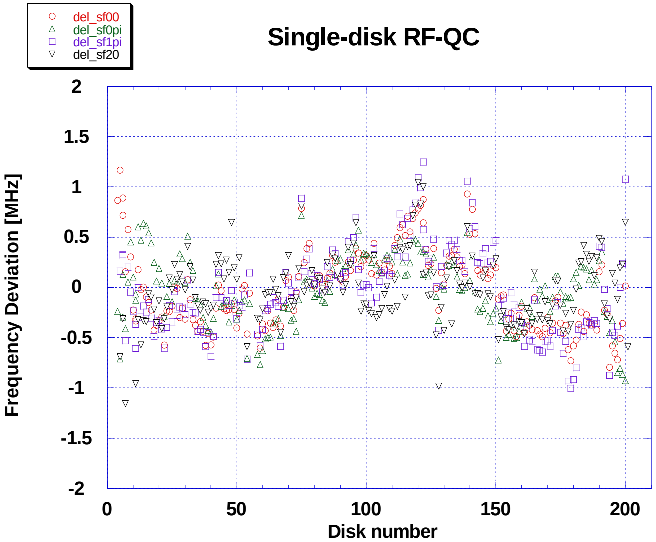
- Theoretical analysis for full understanding of **HOM suppression** in RF accelerator structures.
- **Damped and Detuned Structures** can be applied to any low emittance, high beam loading accelerators.
- **Simulation methods** for beam-structure interaction: structure wakefield, emittance growth and analysis of structure alignment and dimension tolerances.
- **Optimization of accelerator parameters** for highest RF efficiency and dimension determination with sub-micron precision.
- Manifold damping gives **structure position monitor** with micron transverse sensitivity and frequency multiplexed longitudinal resolution of the order of several cells.
- **Fabrication technologies** for normal conducting accelerator structures such as precision machining, diffusion bonding and long structure alignment.
- Extensive studies for high gradient RF operation: **extremely new types of couplers, Procedure for structure treatments.**

2. Some Issues for meeting the design goal and tolerances.

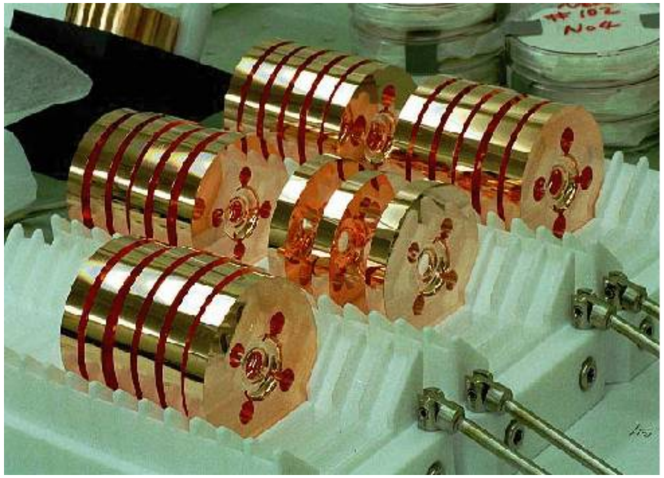
Precision Calculation, Fabrication and Measurement for Accelerator Discs



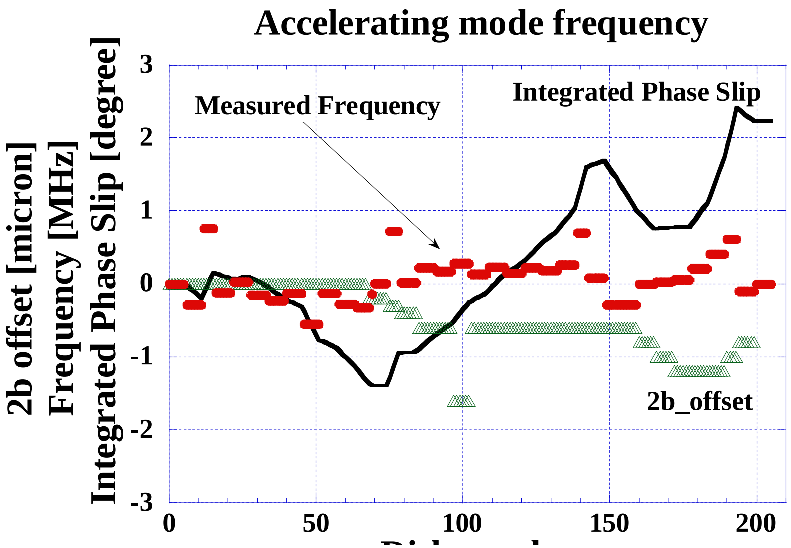
Discs made by Single-Crystal Diamond Turning



Deviations of Cell fundamental Mode Frequencies



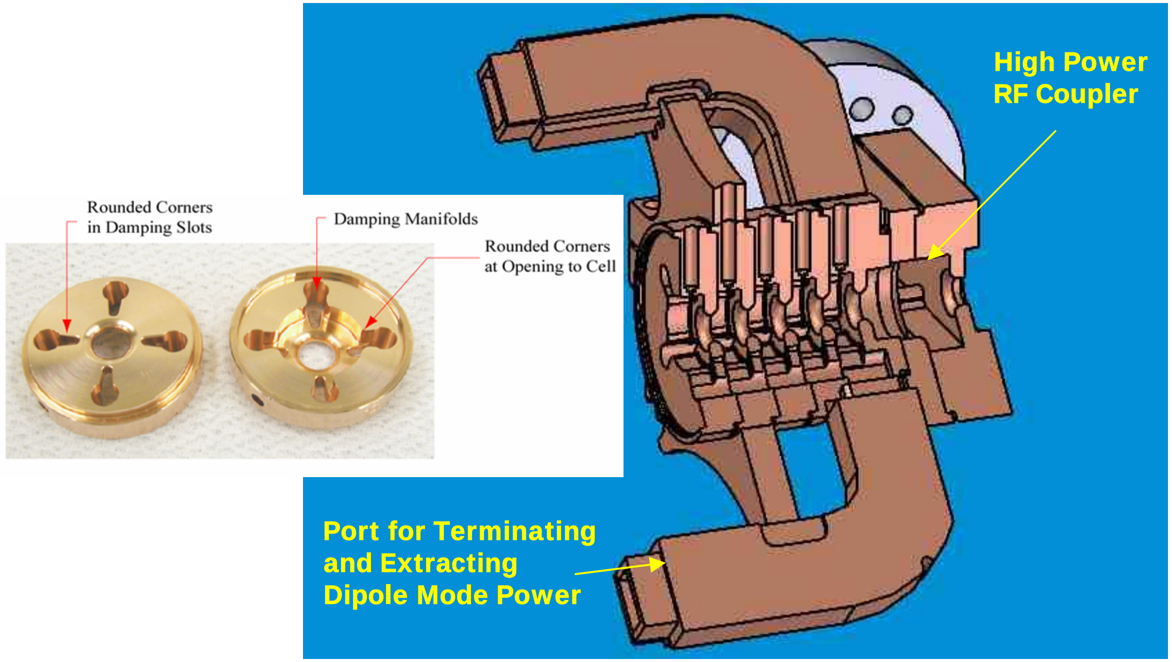
Discs ready for diffusion bounding



Summary of RDDS1 Dimensional Properties

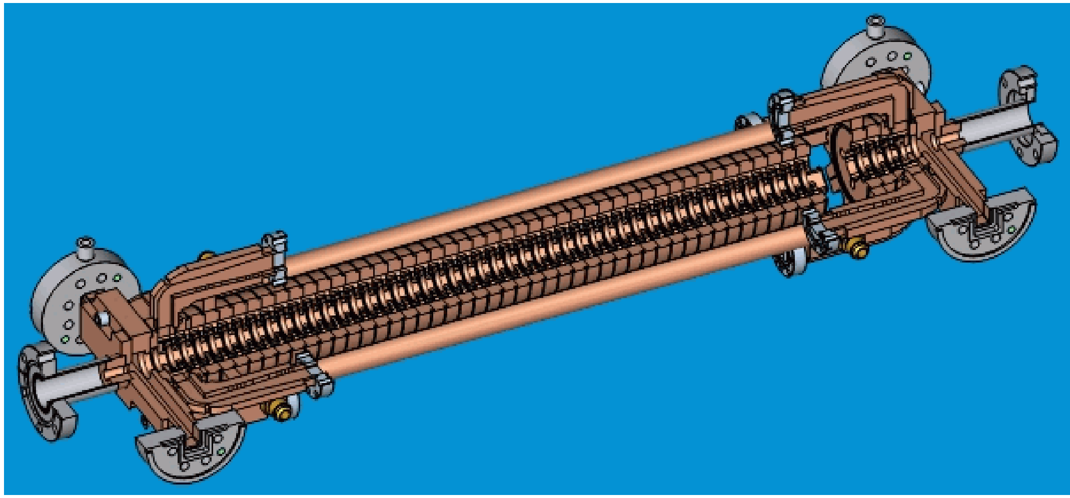
Item	Design	Typical	Worst
Flatness	0.5 μm	<0.5	0.6
Thickness	±1 μm	< ±1	1.5
Parallelism	17 μrad	<10	25
OD	±1 μm	< ±1	1.5
2D Contour	±1 μm	< ±1	
2a	±2 μm	< ±0.7	0.7
2b	±2 μm	< ±1	1.3
Gap	±1 μm	< ±0.5	0.5
Concentricity	±0.5 μm	< ±0.5	2.0
Slit Width	±15 μm	< ±5	10
Slit Depth	±30 μm	< ±10	15
Rotational Angle	±0.05°	<0.05°	0.06°
Bookshelf	50 μrad	<100	
Misalignment	±3 μm	±1	

Prototype Accelerator Structure for the NLC Structure Main Linac

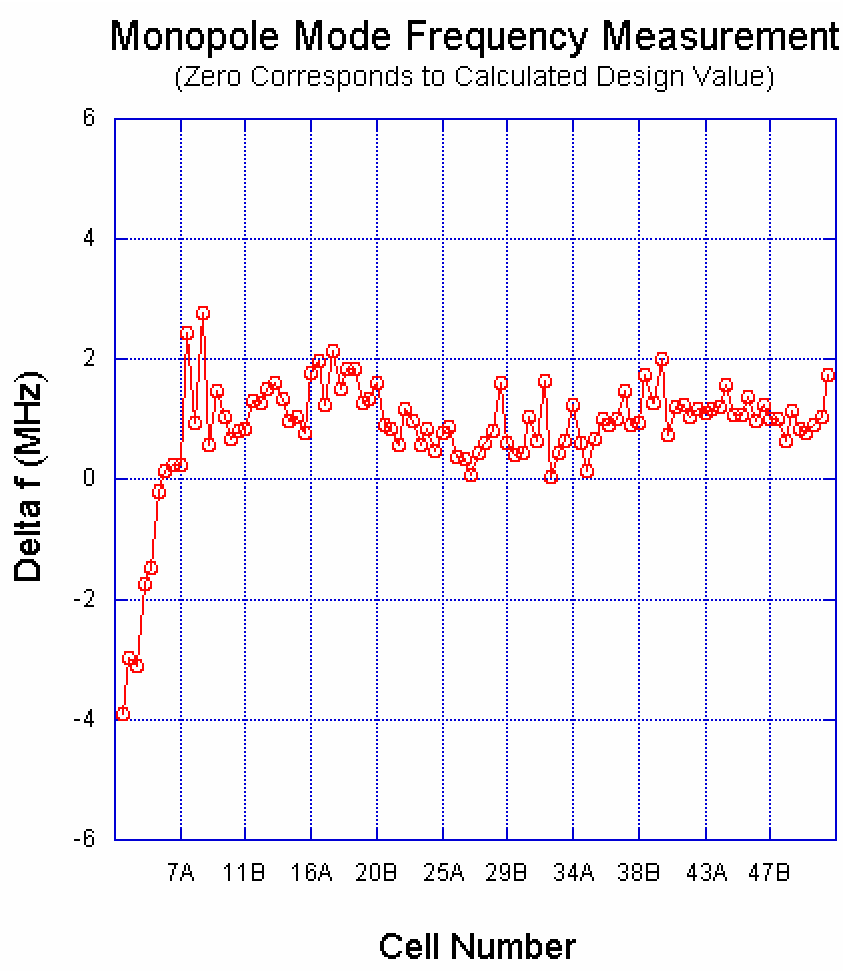


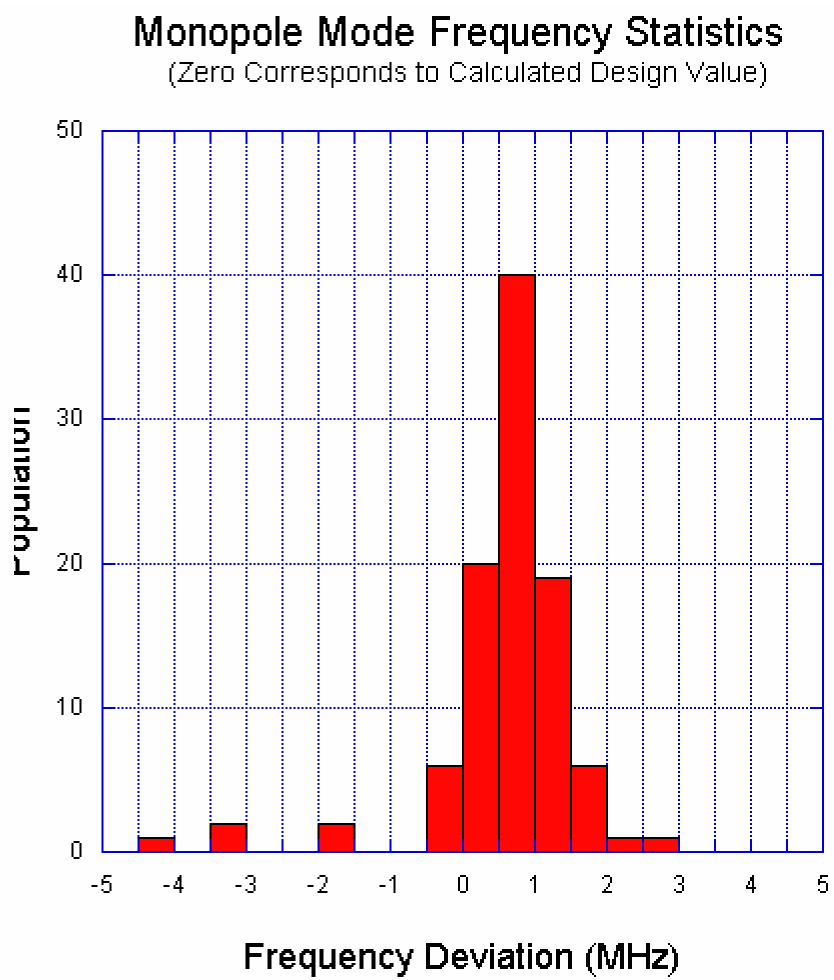
H60VG4SL17A/B structure with most of final design features

Fabricated and tested more than thirty structures with over 20,000 hrs of high power operation at NLCTA. The RF breakdown rate was less than 1 per 10 hours at 65 MV/m average gradient and 60 Hz, 400 ns RF pulses.



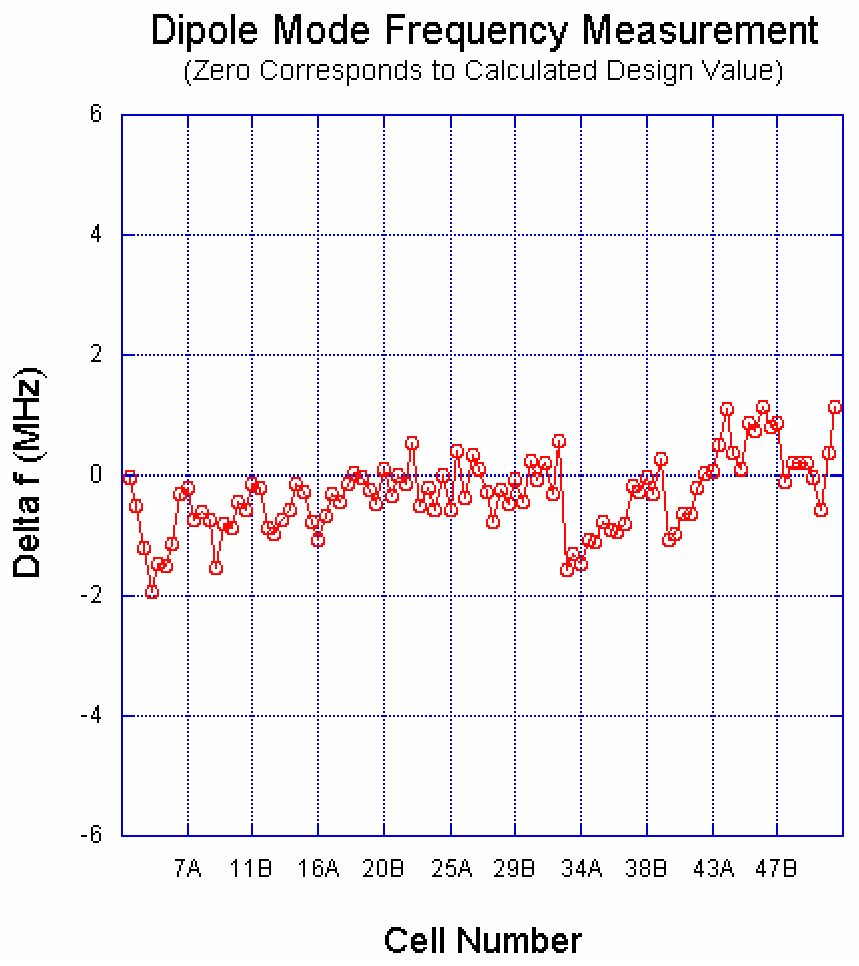
Microwave QC of Fundamental Mode for H60VG4SL17A/B Regular Cups

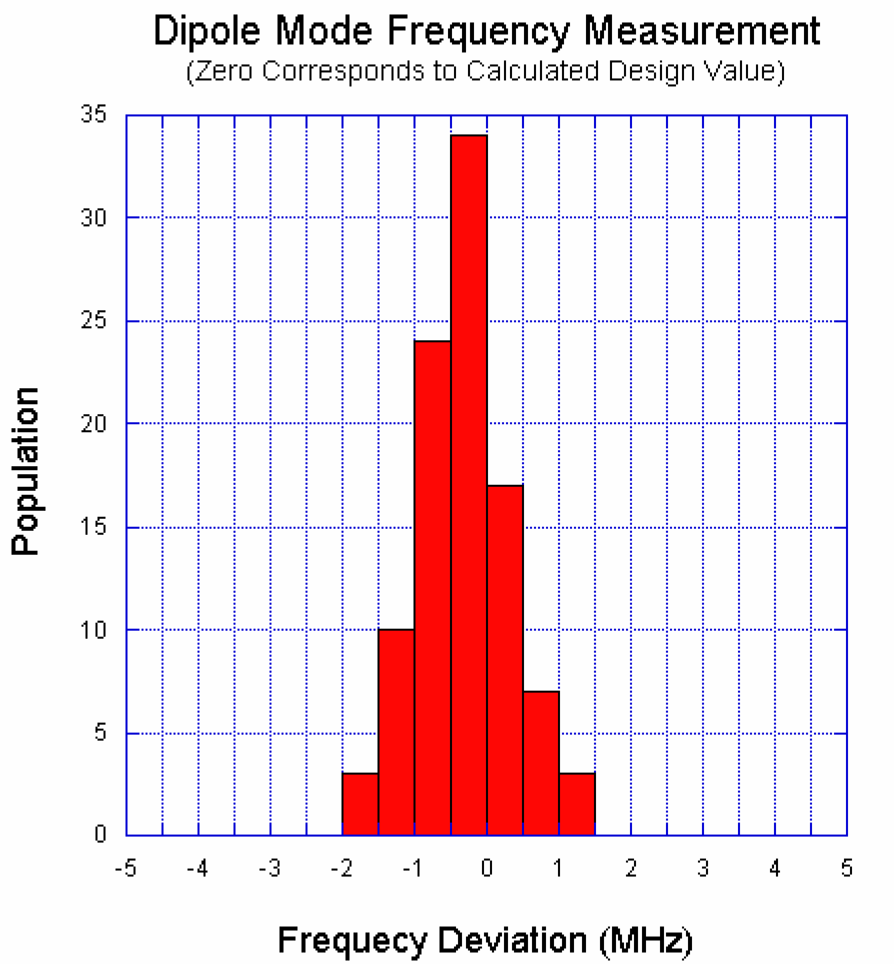




Temperature and humidity corrected

Microwave QC of Dipole Modes for H60VG4SL17A/B Regular Cups

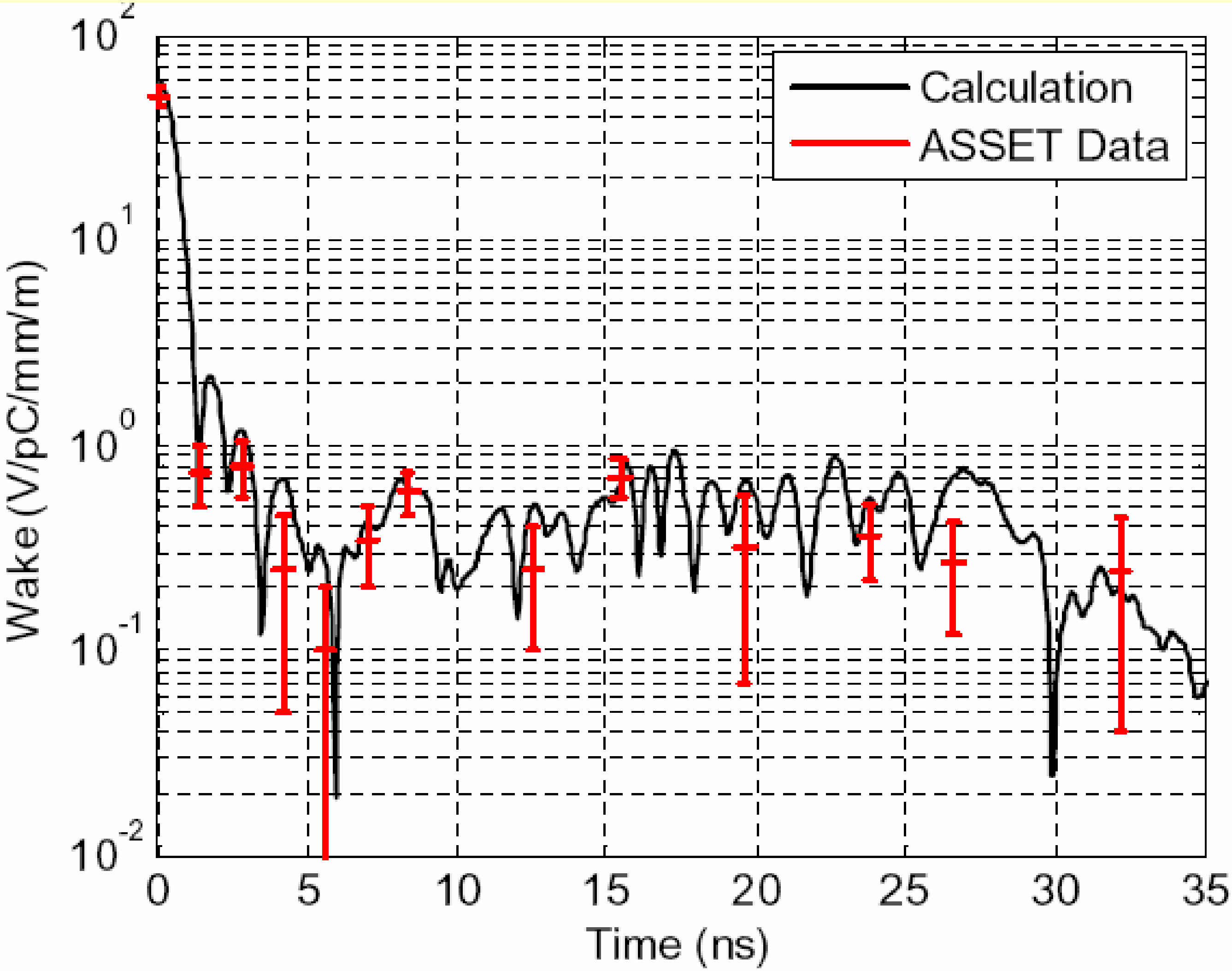




Temperature and humidity corrected

Theoretical and Experimental Proof of Transverse Wakefield Suppression

A Pair of Interleaving DDS Structures: H60VG4SL17A and H60VG4SL17B



3. Where the Next NLC/JLC Structure Design Would Have Been?

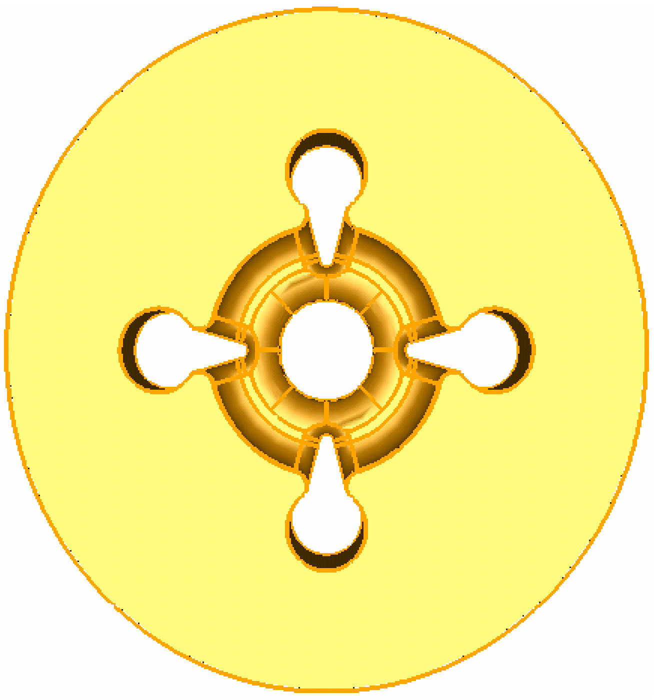
Status and Planning for the structures R/D before ITRP decision

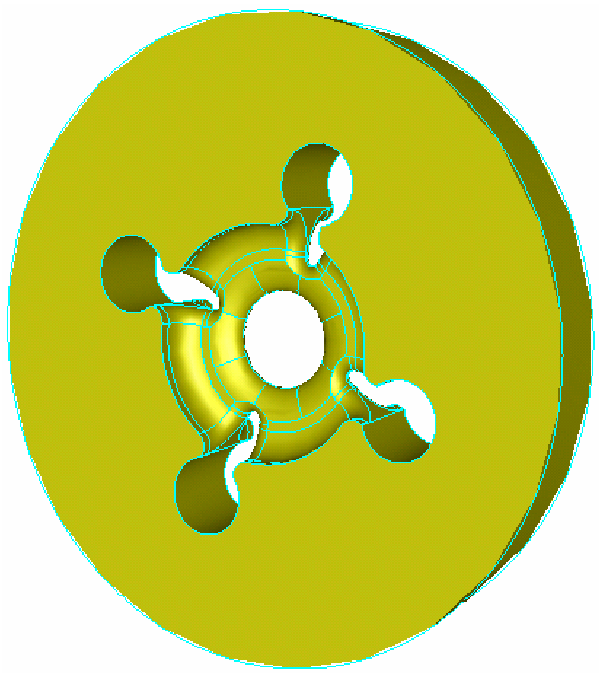
- ASSET Test for a Pair of H60VG4SL17A/B.
- Design issues for Finalized Accelerator Structures.

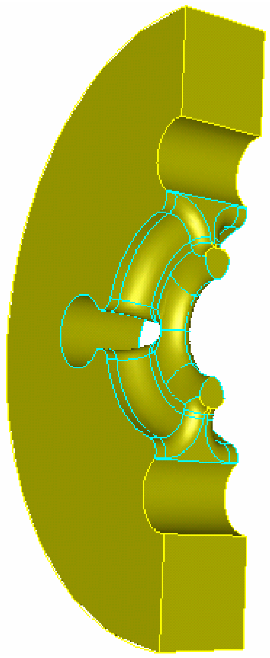
1. Studies on trapped modes in waveguide coupler region.
2. Optimized structure design for high RF efficiency with shunt impedance more than 10% increase.
3. Simulation and machining practice of round cavities.
4. Internal HOM loads and signal pick-ups for output end.
5. Studies on eliminating HOM loads for input end.
6. Design studies of compact output fundamental couplers for keeping waveguide coupler for input end).
7. Integration studies – design for Super-structures.

Design for Rounded Discs

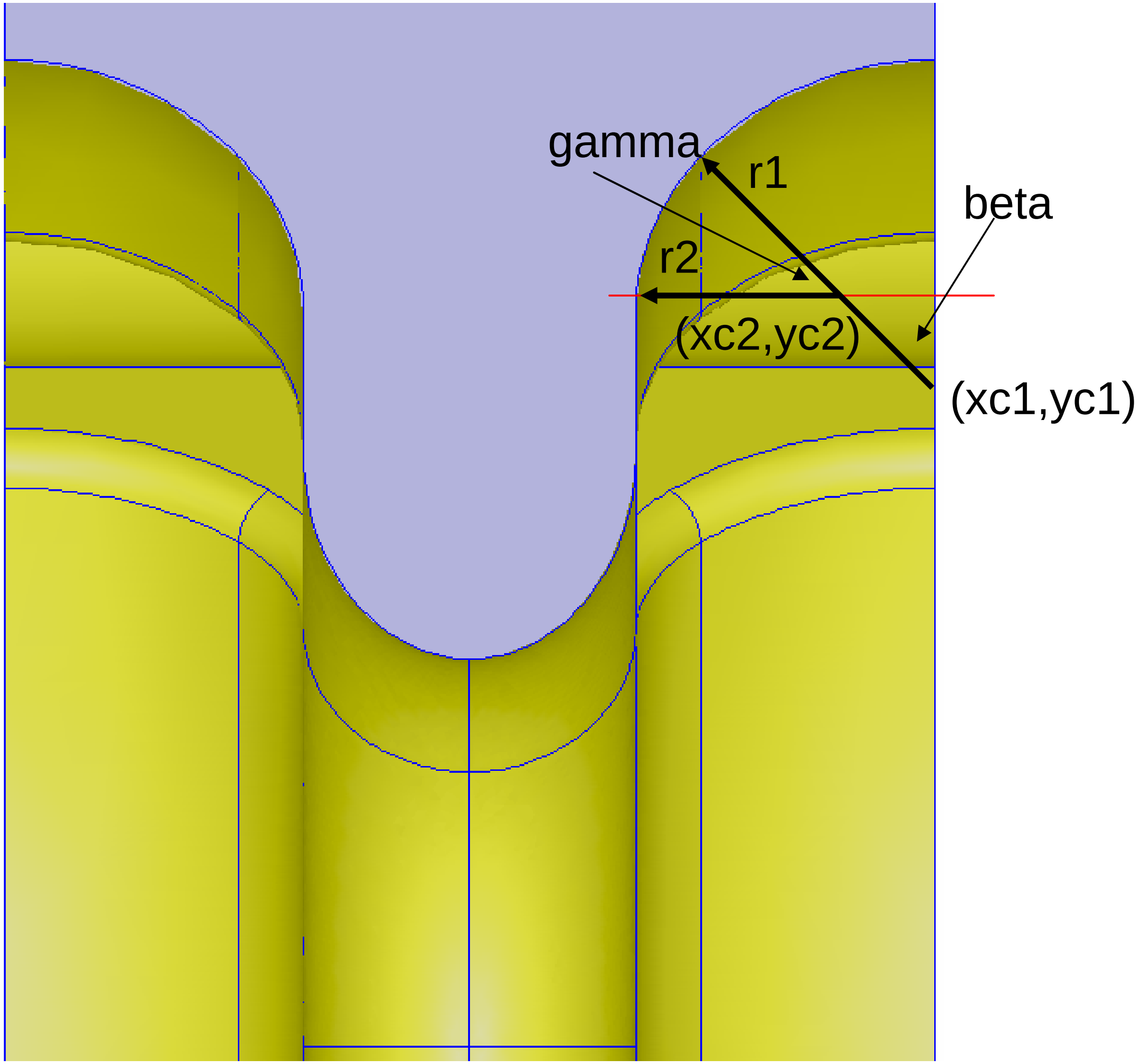
Challenges in Machining Curved Rounded HOM Slots





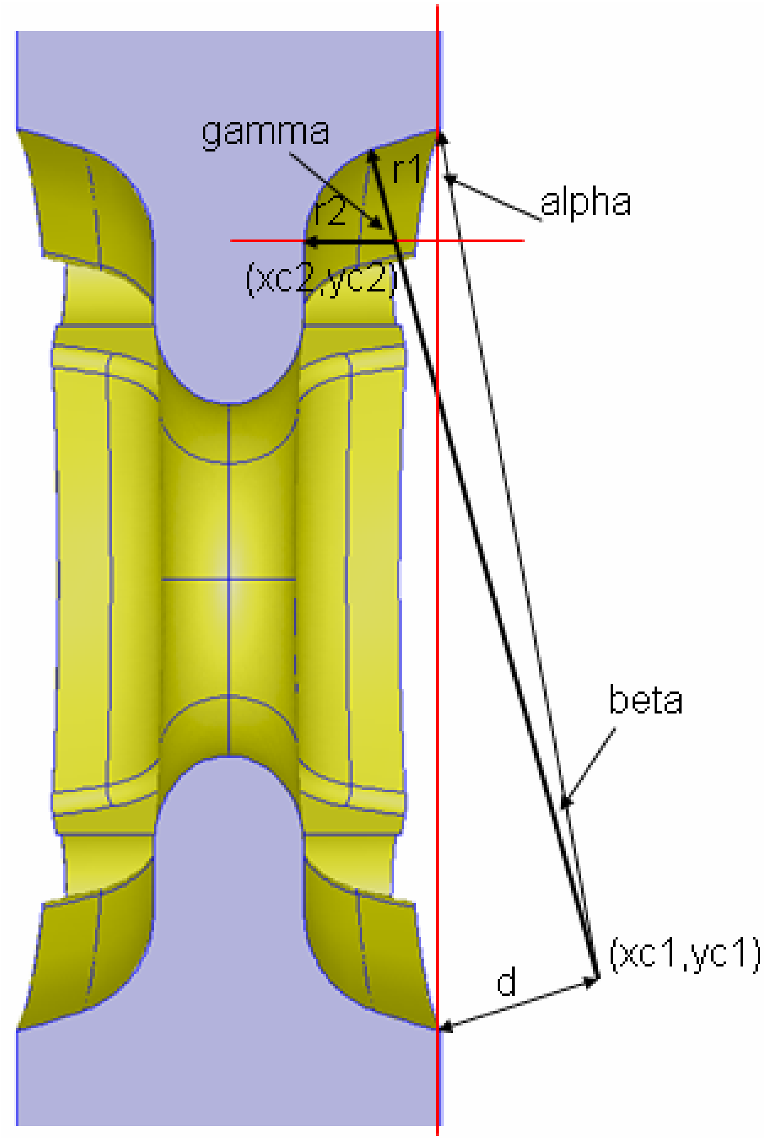


PIE-Rounded With Two Arcs



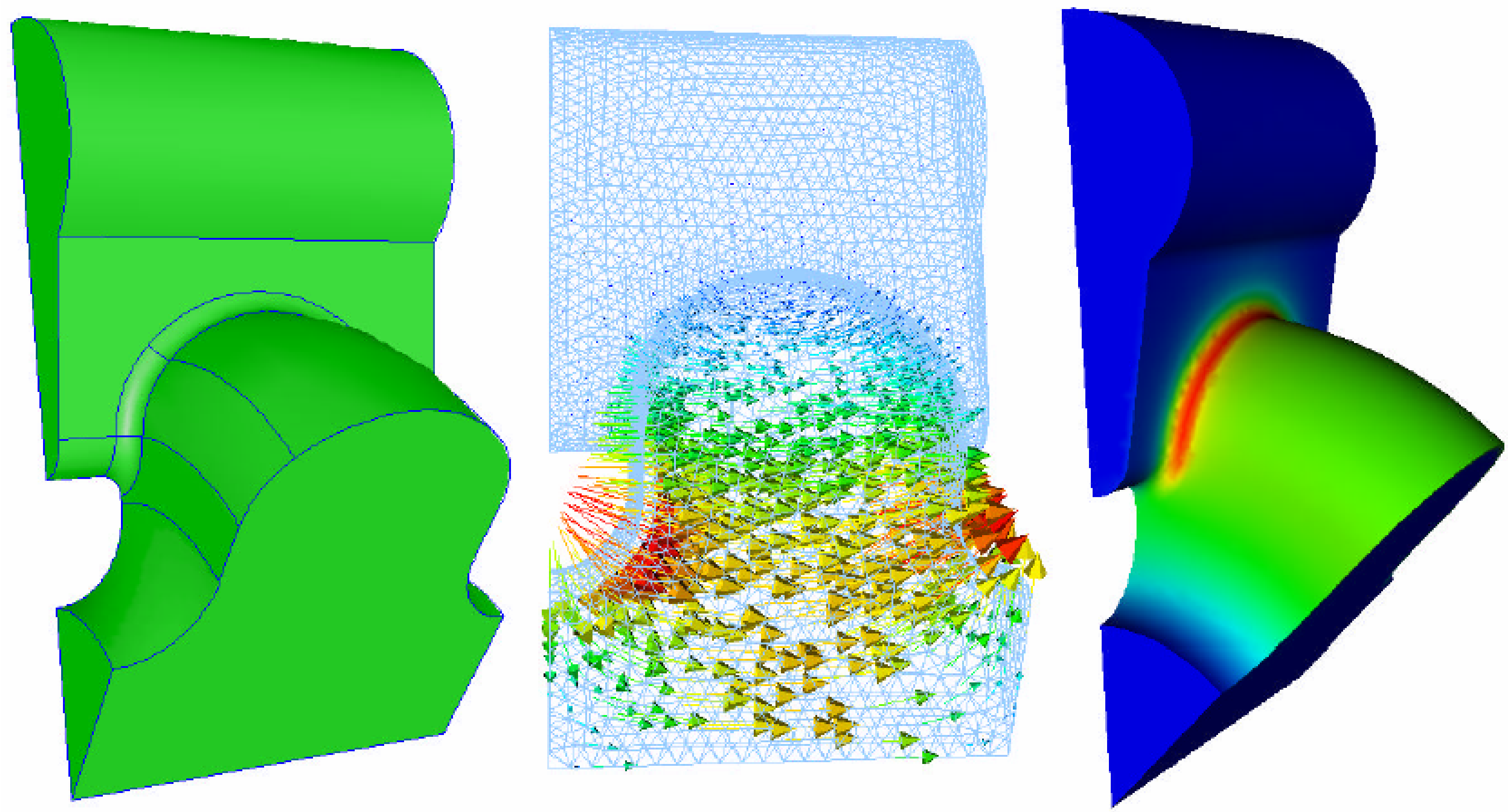
A	4.547
B	11.59051
T	3.90124
Anose	2.39936
Sdepth	3.93881
S_b_manif	1.000
Rmanif	3.250
r1	3.89146
xc1,yc1	(0.0,7.69905)
r2	2.61138
xc2,yc2	(-0.90515,8.60420)
Alpha	0.0
beta	45 degree
gamma	45 degree

PIE-Leek – Two Arcs With Max R1



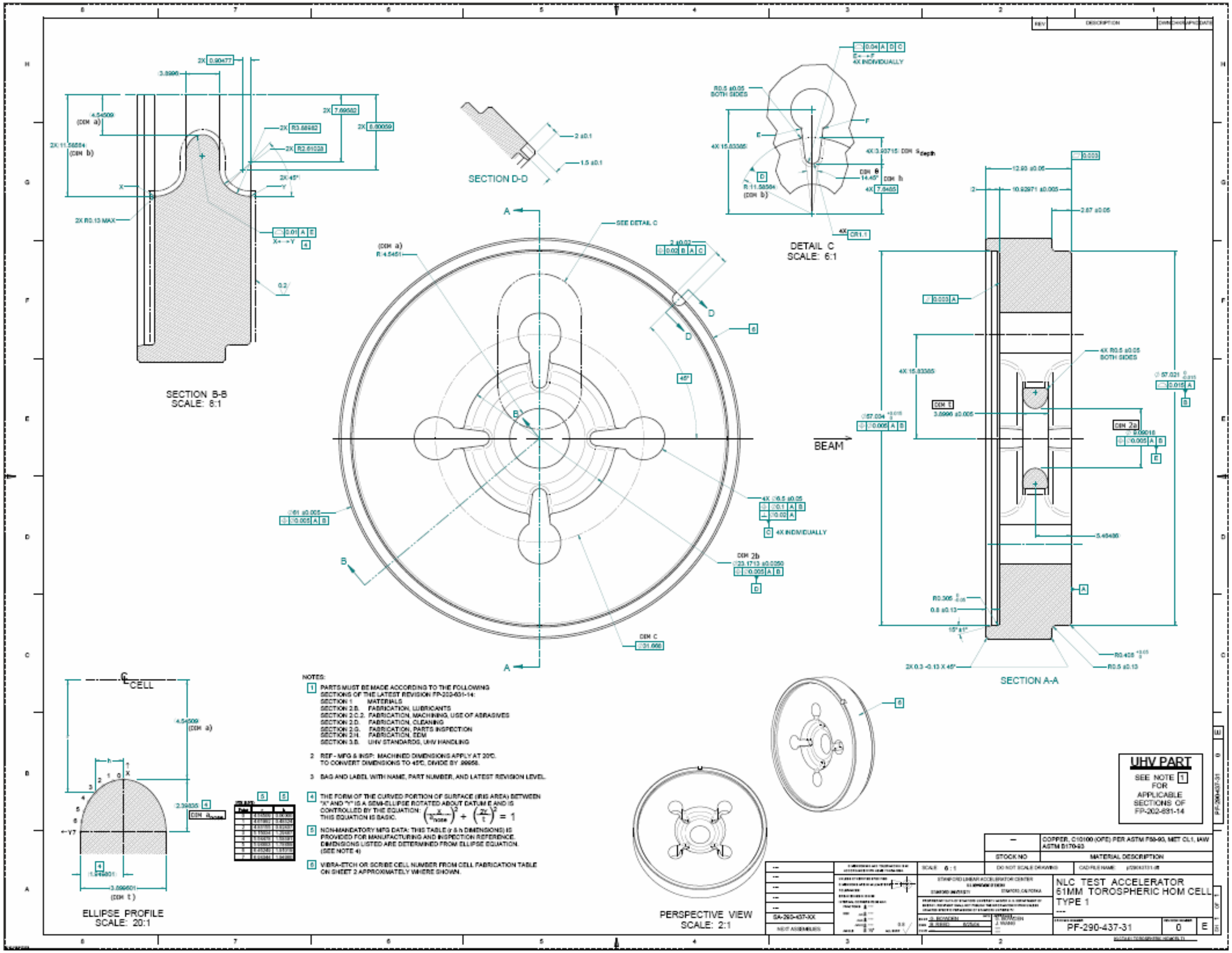
A	4.547
B	11.67551
T	3.90124
Anose	2.39936
Sdepth	4.02381
S_b_manif	1.000
Rmanif	3.250
d	6.000
r1	22.56701
xc1,yc1	(5.79855,-10.13382)
r2	2.69341
xc2,yc2	(-0.82312,8.60420)
alpha	14.8891 degree
beta	4.57342 degree
gamma	70.5375 degree

RF Pulse Heating Simulation

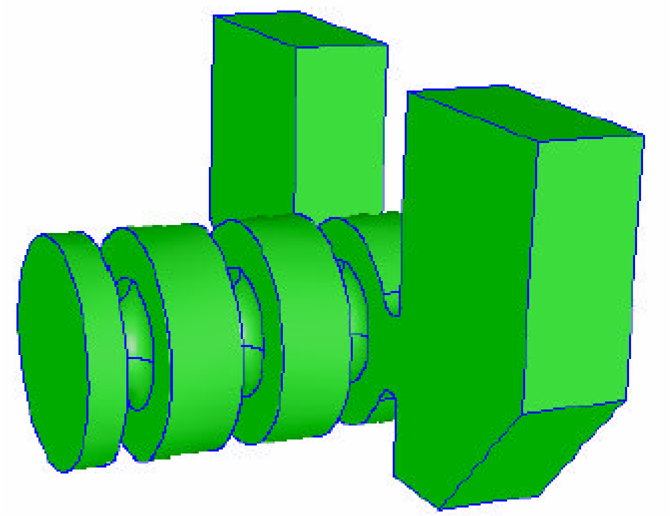


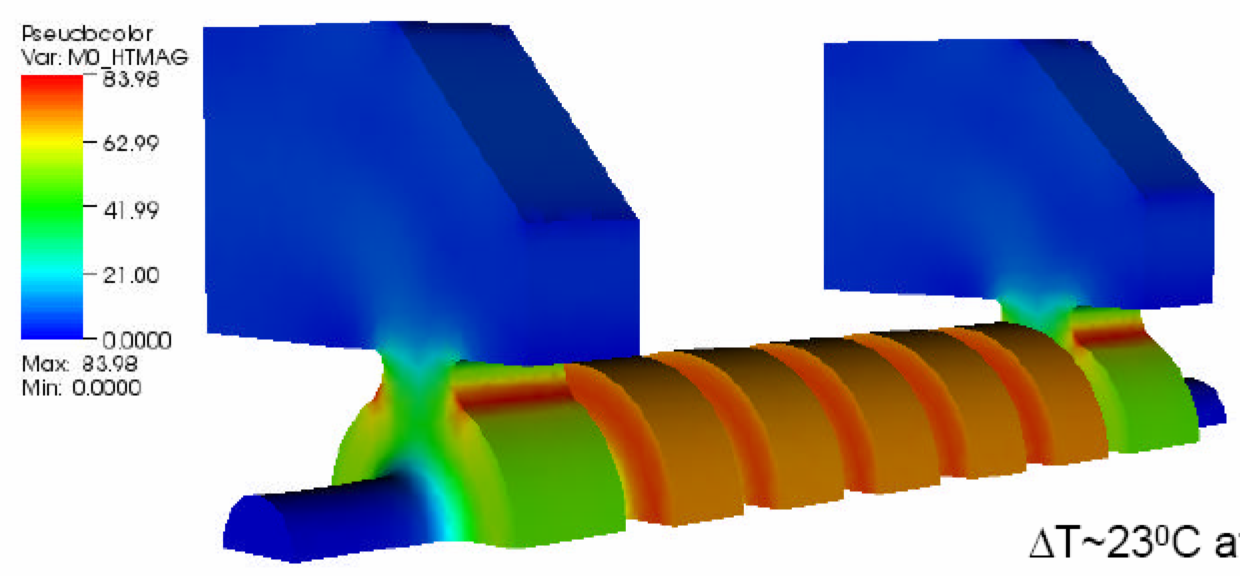
$\Delta T < 30°C$ at 65 MV/m

Mechanical Drawing for One Type of Rounded Disc



Compact Fat-lip Output Coupler

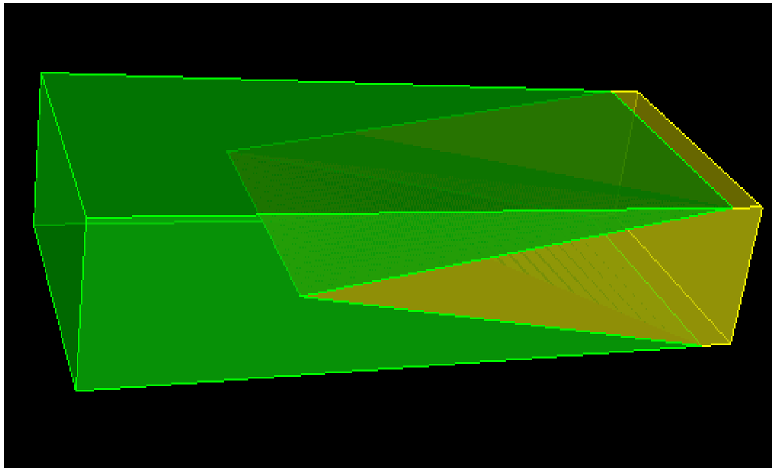


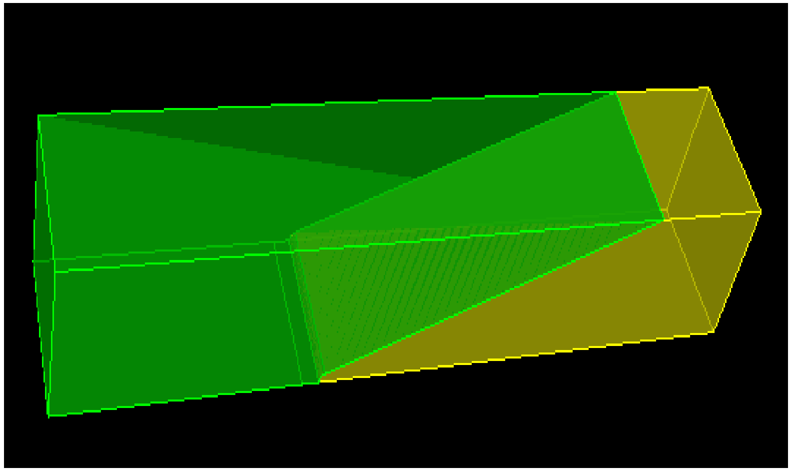


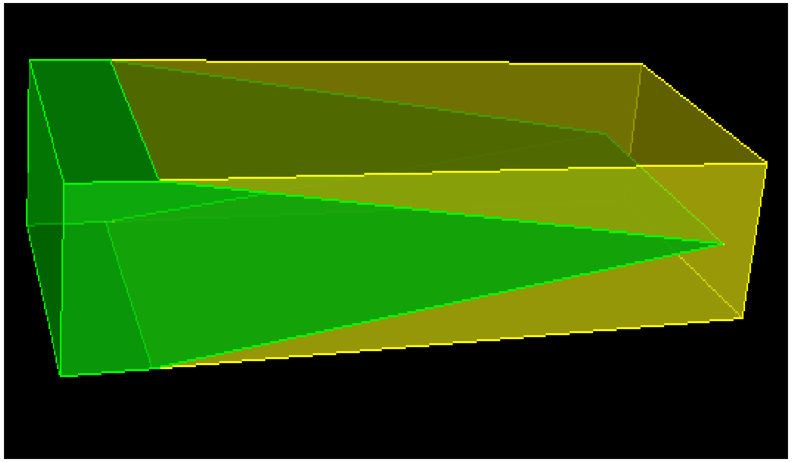
ΔT~23^{0}C at 65 MV/m

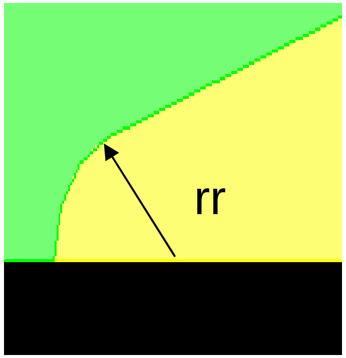
Inner HOM Loads

(Ceradyne- Ceralloy)

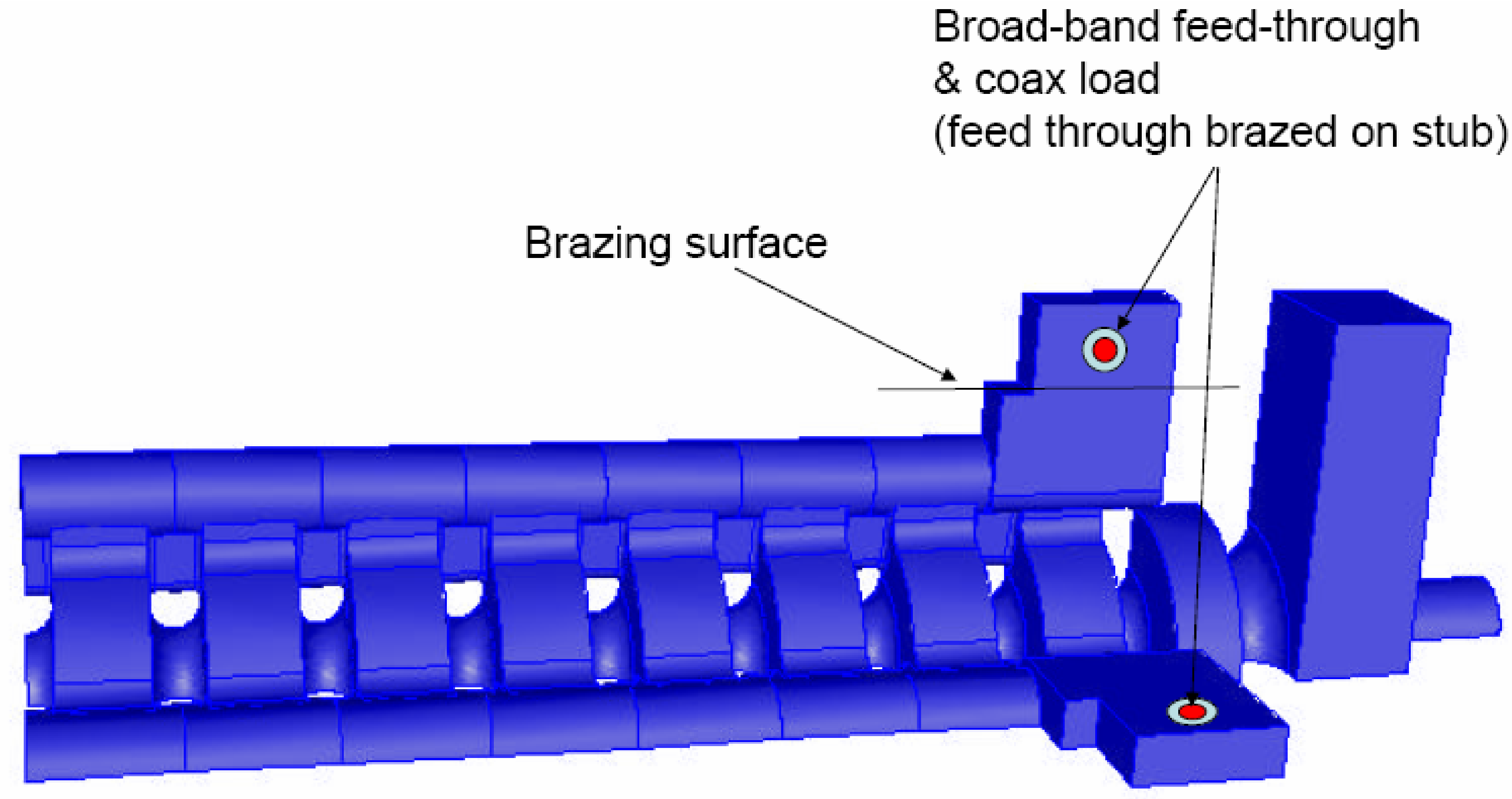






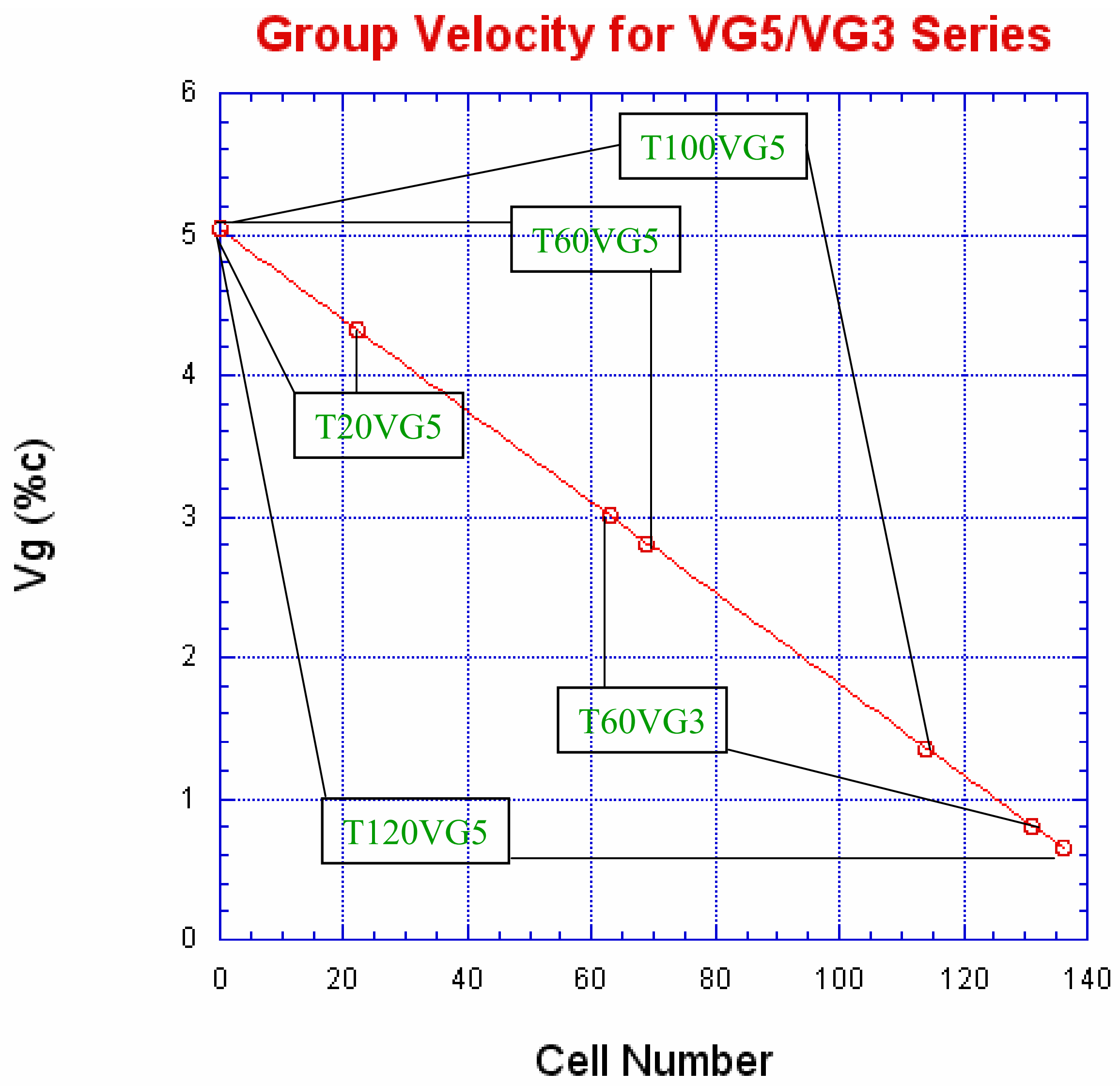


Coaxial HOM Loads



4. T53VG3 History and Design of T26 for the CLIC

2001 Planning for High Gradient Test Structures

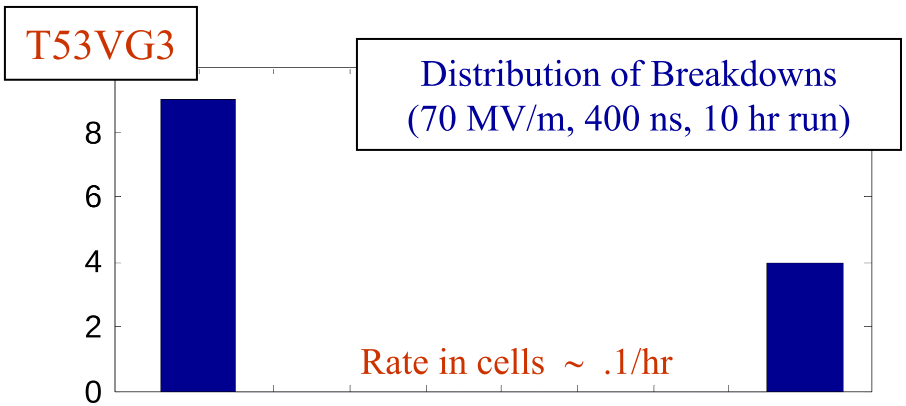


Test Structures Specifications

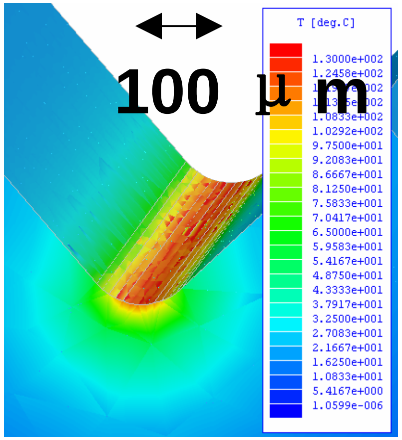
Constant Gradient TW Structures
for Mapping of RF Parameters Space

Name	L (cm)	Total Cells	v_g % c	2a mm	r MΩ/m	τ	Q_{ave}	T_f ns	E_p/E_a	P_{in} for E_a 50MV/m
T20VG12	20	23	12–11.3	11.4-11.3	67.5	.028	7300	5.7	3.0	132.6
T20VG5	20	23	5–4.4	8.9–8.5	82-86	0.071	6857	14.2	2.22–2.18	43.4
T53VG5	53	60	5–3.3	8.9–7.8	82-92	0.22	6843	42.3	2.22–2.13	42.1
T105VG5	105	120	5–1.6	8.9–6.3	82-107	0.61	6820	116.6	2.22–1.99	40.0
T53VG3	53	60	3.3–1.6	7.8–6.3	92-107	0.39	6797	74.3	2.13-1.99	24.5

Performance Limited by RF Breakdowns at Input and Output Couplers

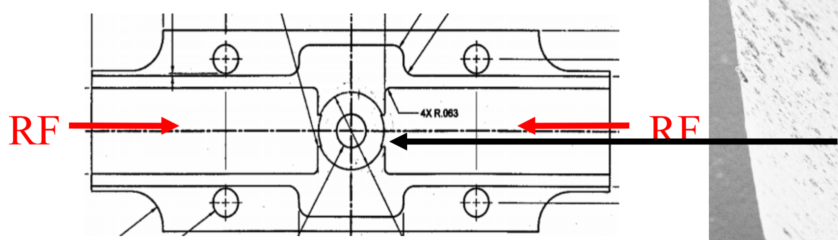


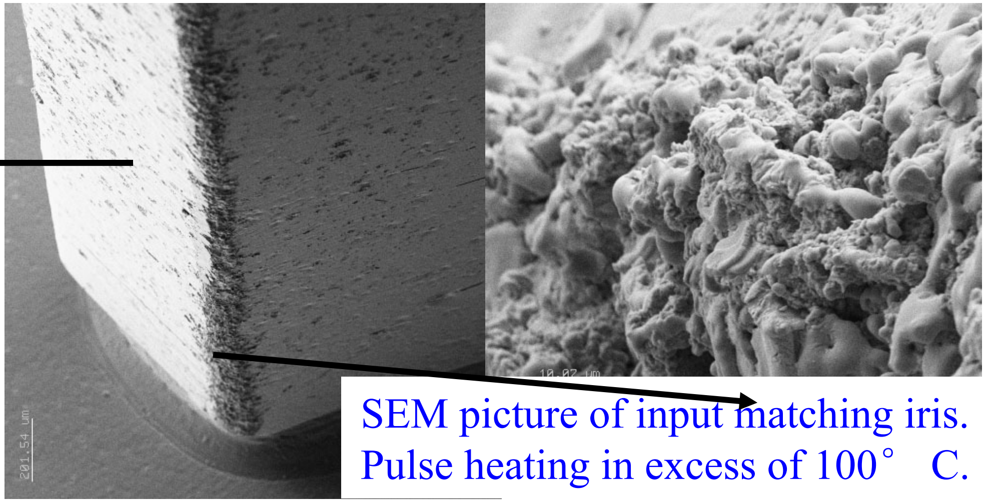
Input coupler ← 58 Cells → Output coupler



Surface **temperature** distribution, 400 ns pulse, 48 MW, maximum temperature **127 deg. C.**

Beam's eye view of input coupler.

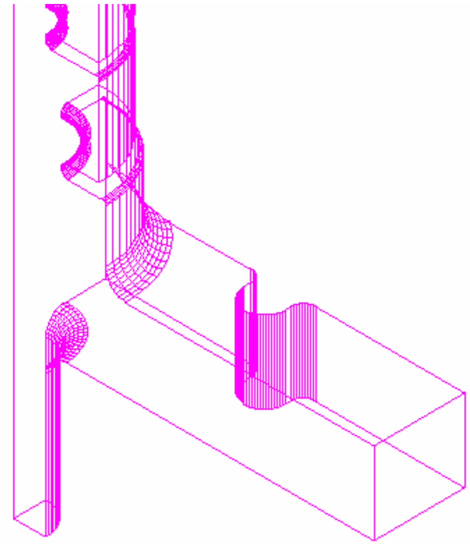




SEM picture of input matching iris.
Pulse heating in excess of 100° C.

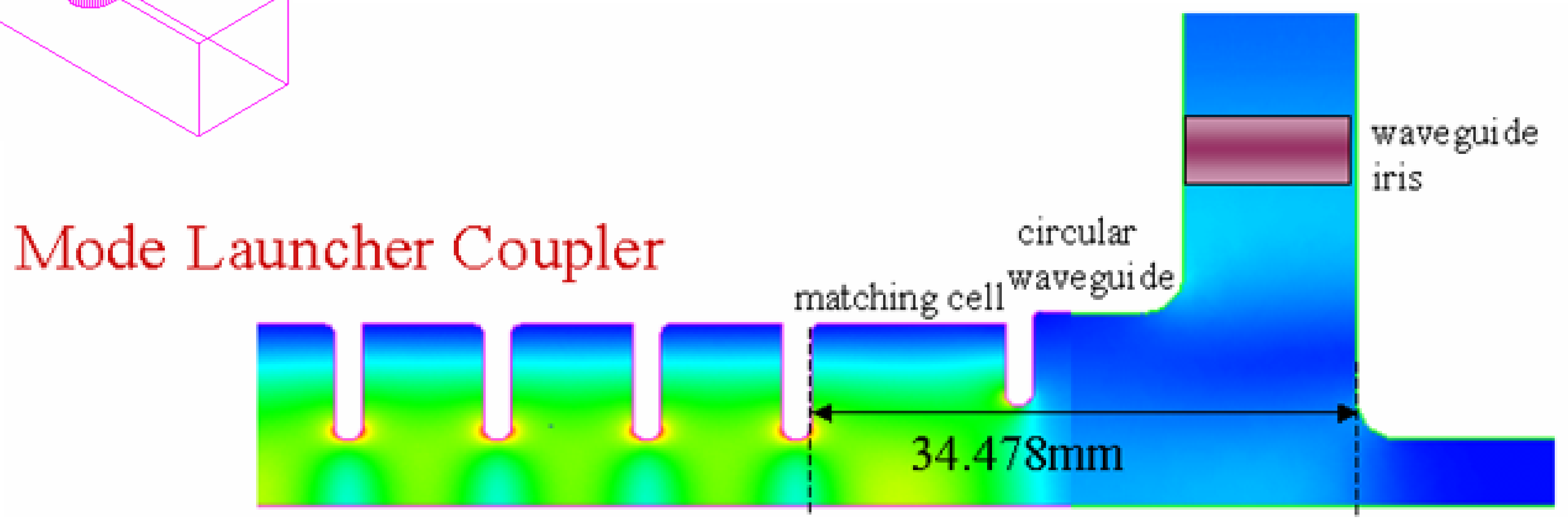
Autopsy performed after high-gradient testing.

Modification of Input Coupler for T53VG3MC in 2002



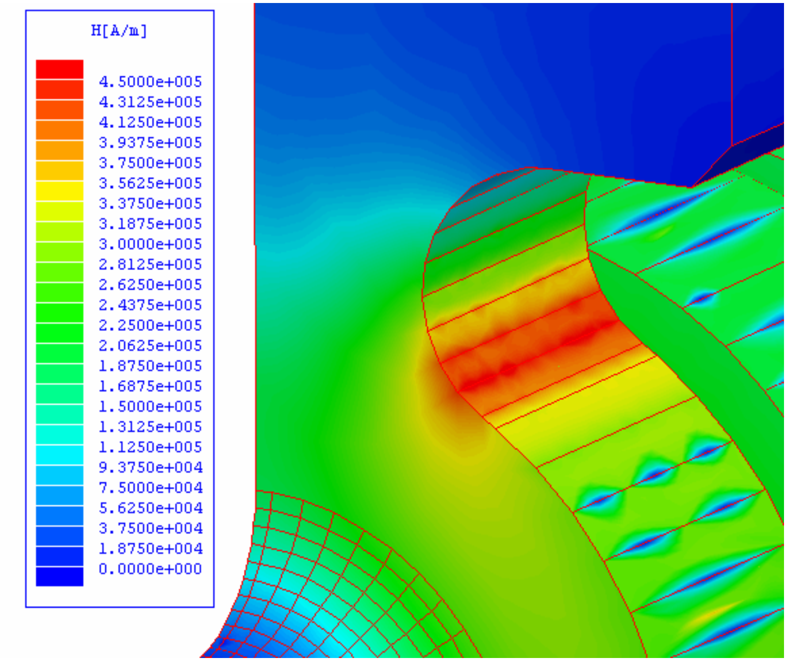
$|E^s|_{max}$= ~34 MV/m @ 48 MW

$|H^s|_{max}$= ~98.4 kA/m @ 48 MW → **Pulse Heating ~ 3° C**



Modification of Output Coupler for T53VG3MC in 2002

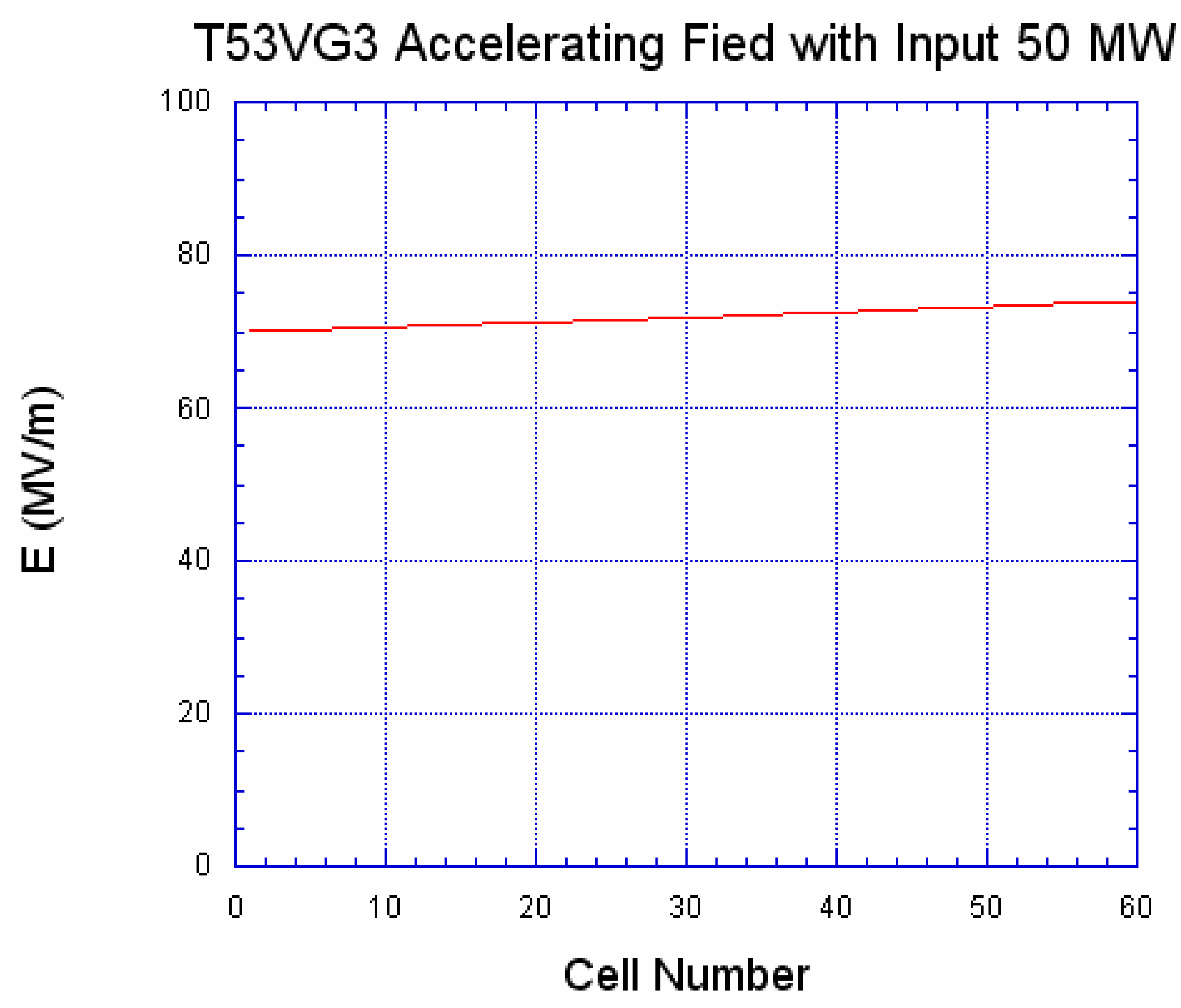
Rounded coupling iris with 6 mm thickness



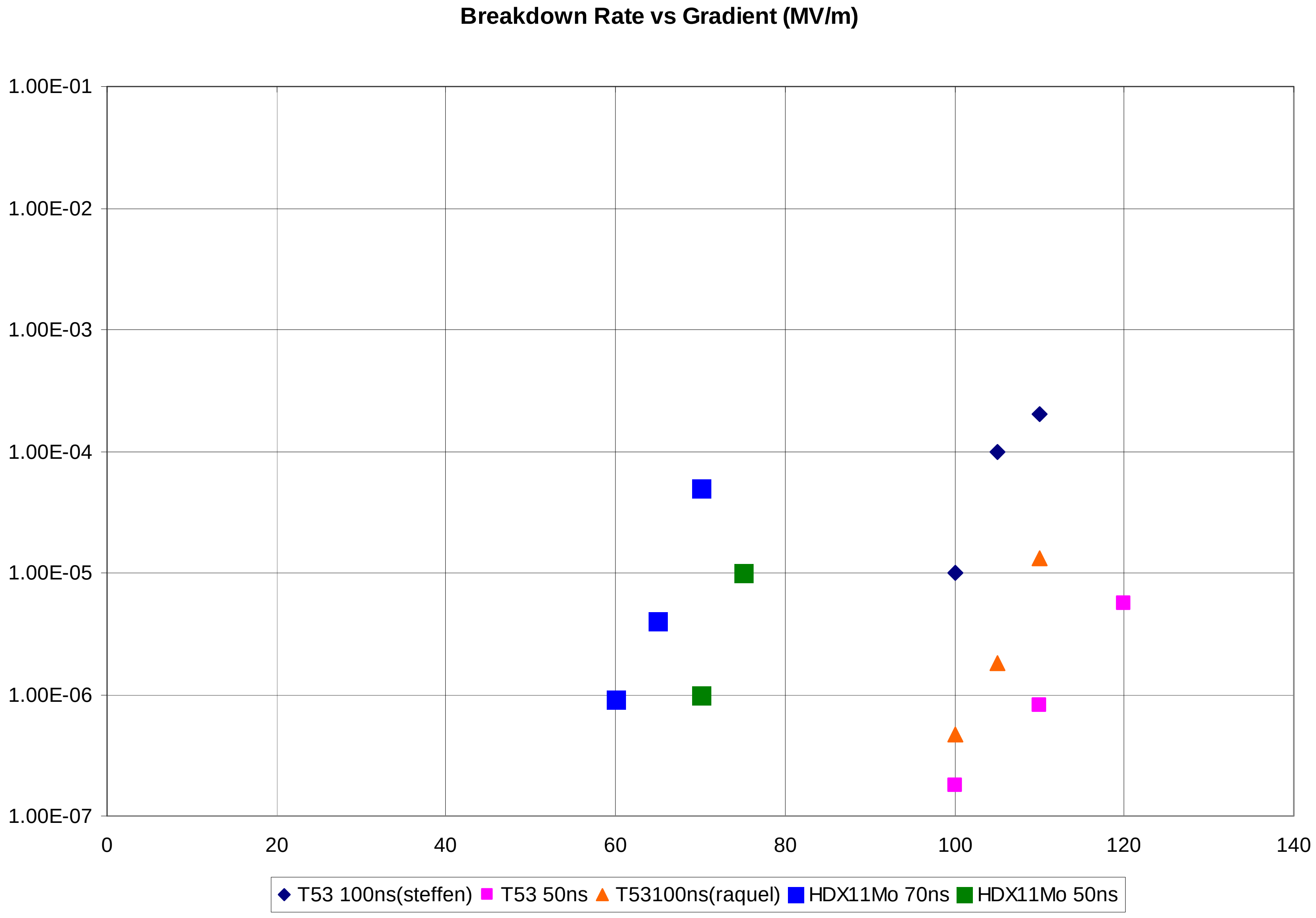
Surface **electric** field distribution, max. field ~190 MV/m, power 30 MW

Surface **magnetic** field distribution, max. field on coupler iris ~0.42 MA/m, 44 deg. C pulse heating during 400 ns pulse.

Field Distribution for T53VG3 Structure



T53VG3MC
Built in December 2002



RF Parameters for Three Types of T26 Structures Design

Structure Type	L (cm)	Total Cells	v_g % c	2a mm	r MΩ/m	τ	Q_{ave}	T_f ns
Type – I 1st Half	27	30	3.30-2.46	7.8-7.1	92-99	0.16	7300	29.6
Type – II 2nd Half	27	30	2.43-1.62	7.1-6.3	99-107	0.23	6857	42.7
Type – III Odd/Even	27	30	3.30-1.62	7.8-6.3	92-107	0.19	6843	35.8

Field Distribution for Three Types of T26 Structures