International Workshop on Higher-Order-Mode Damping in Superconducting RF Cavities

Cornell University, October 11-13, 2010

Experience with 3.9 GHz cavity HOM couplers

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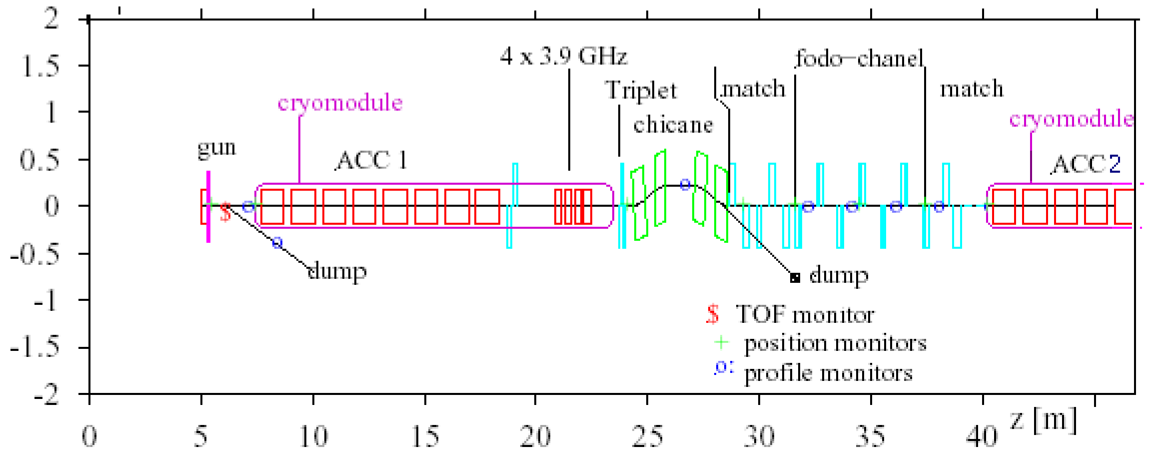
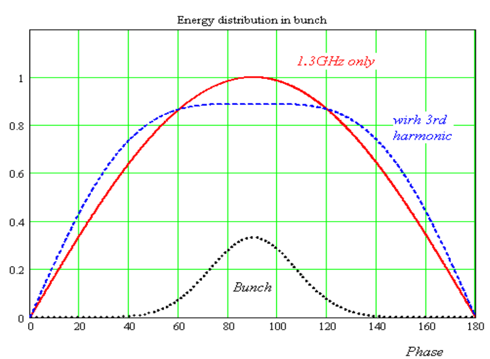
3.9 GHz cavity general parameters

Third harmonic cavity (3.9GHz) was proposed to compensate nonlinear distortion of the longitudinal phase space due to cosine-like voltage curvature of 1.3 GHz cavities.

Parameter List for 3.9 GHz cavity:

Number of cavities	4
Active Length	0.346 m
Gradient	14 MV/m
Phase	-179 deg
R/Q	750 Ω
E_{peak}/E_{acc}	2.26
B_{peak} (E_{acc}=15 MV/m)	0.0727 T
Qext	1.5e+6
BBU limit for HOM, Q	<1.e+5
Total energy	20 MeV
Beam current	9 mA

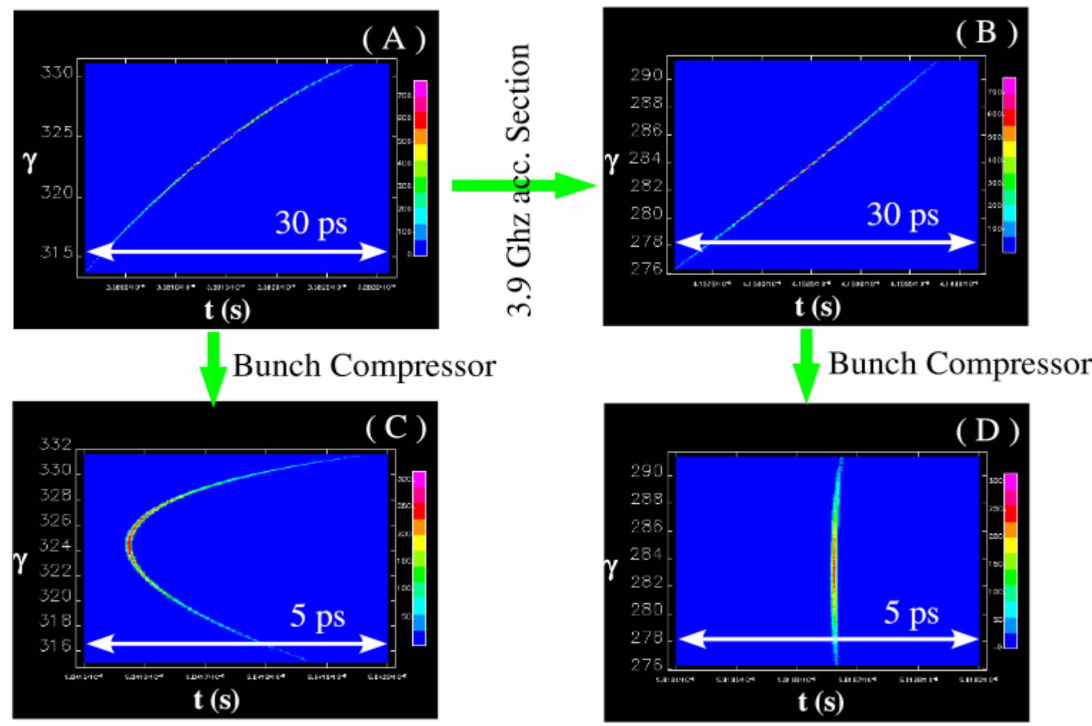




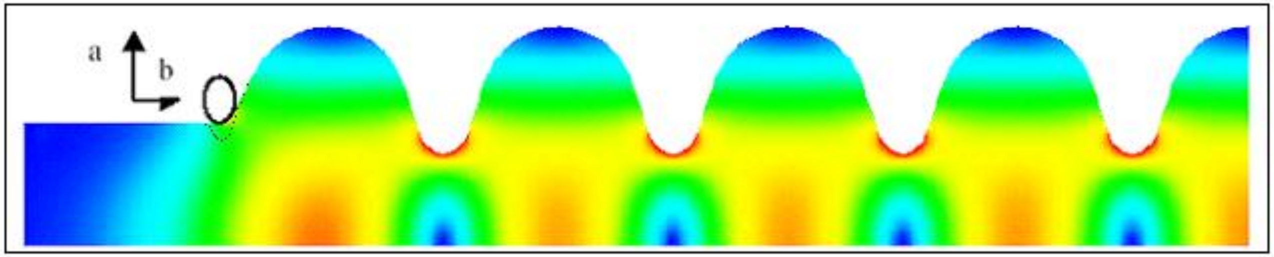
$$U_{3.9} = \frac{1}{9} U_{1.3}$$

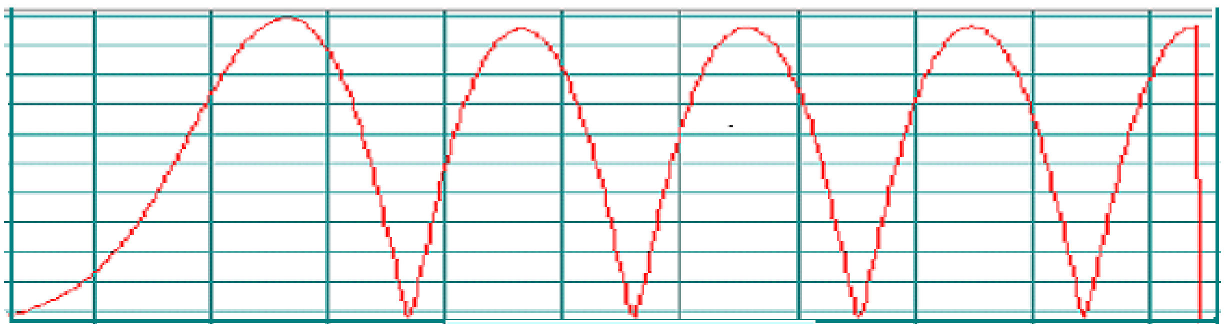
$U_{1.3}$=180 MeV

$U_{3.9}$=20 MeV

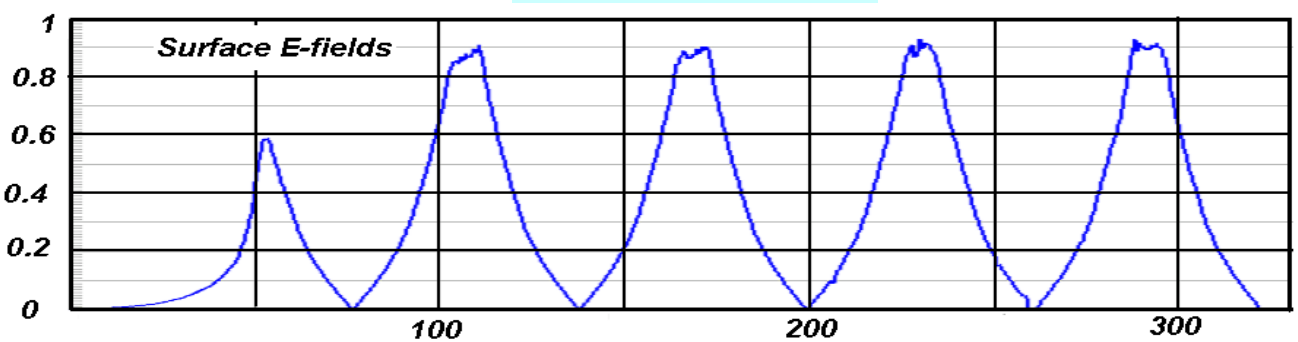


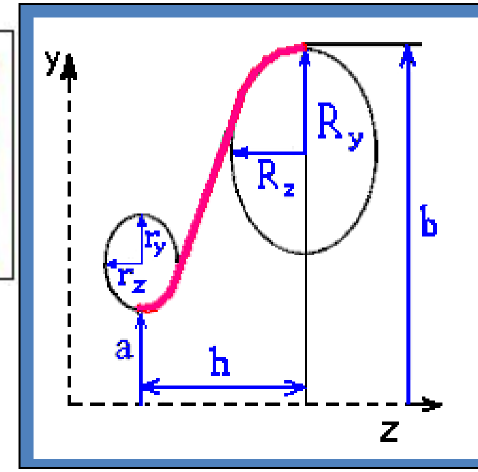
Original 3rd Harmonic Cavity design was developed in DESY.
In order to reach project Qext of the coaxial power coupler end-cell iris was increased (30→40mm). HOM coupler design finalized.





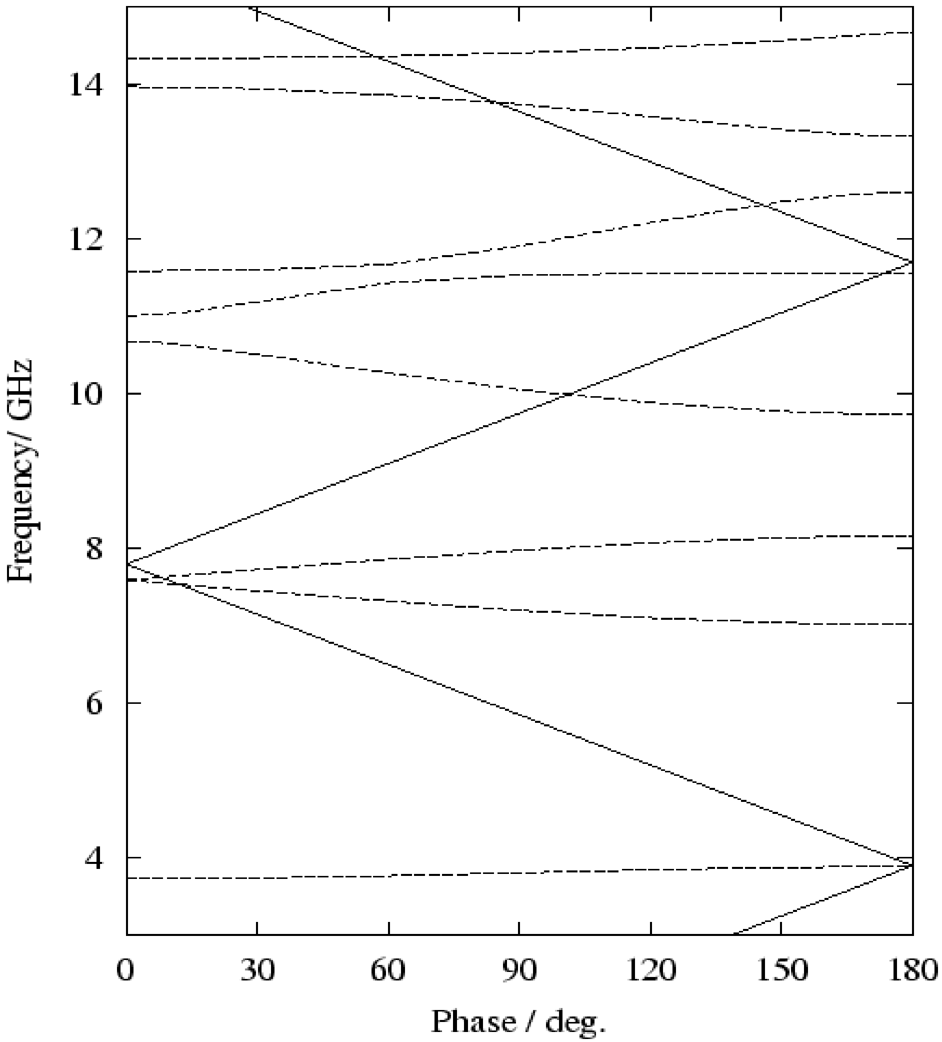
E-field along the z-axis



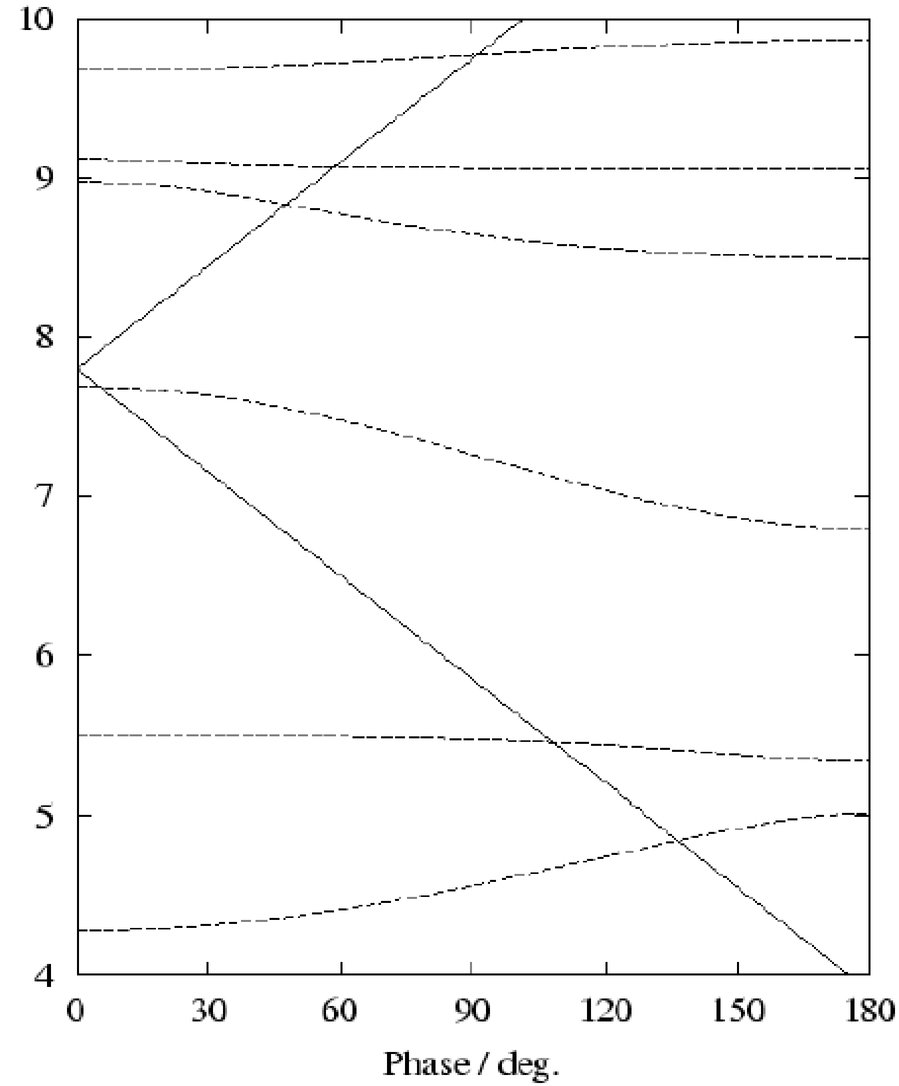


mm	Mid cell	DESY end	FNAL end
h	**19.217**	**same**	**same**
a	**15**	**15**	**20**
b	**35.787**	**same**	**same**
ry	**6**	**same**	**same**
rz	**4.5**	**same**	**same**
Ry	**15**	**same**	**same**
Rz	**13.6**	**12.081**	**14.4**

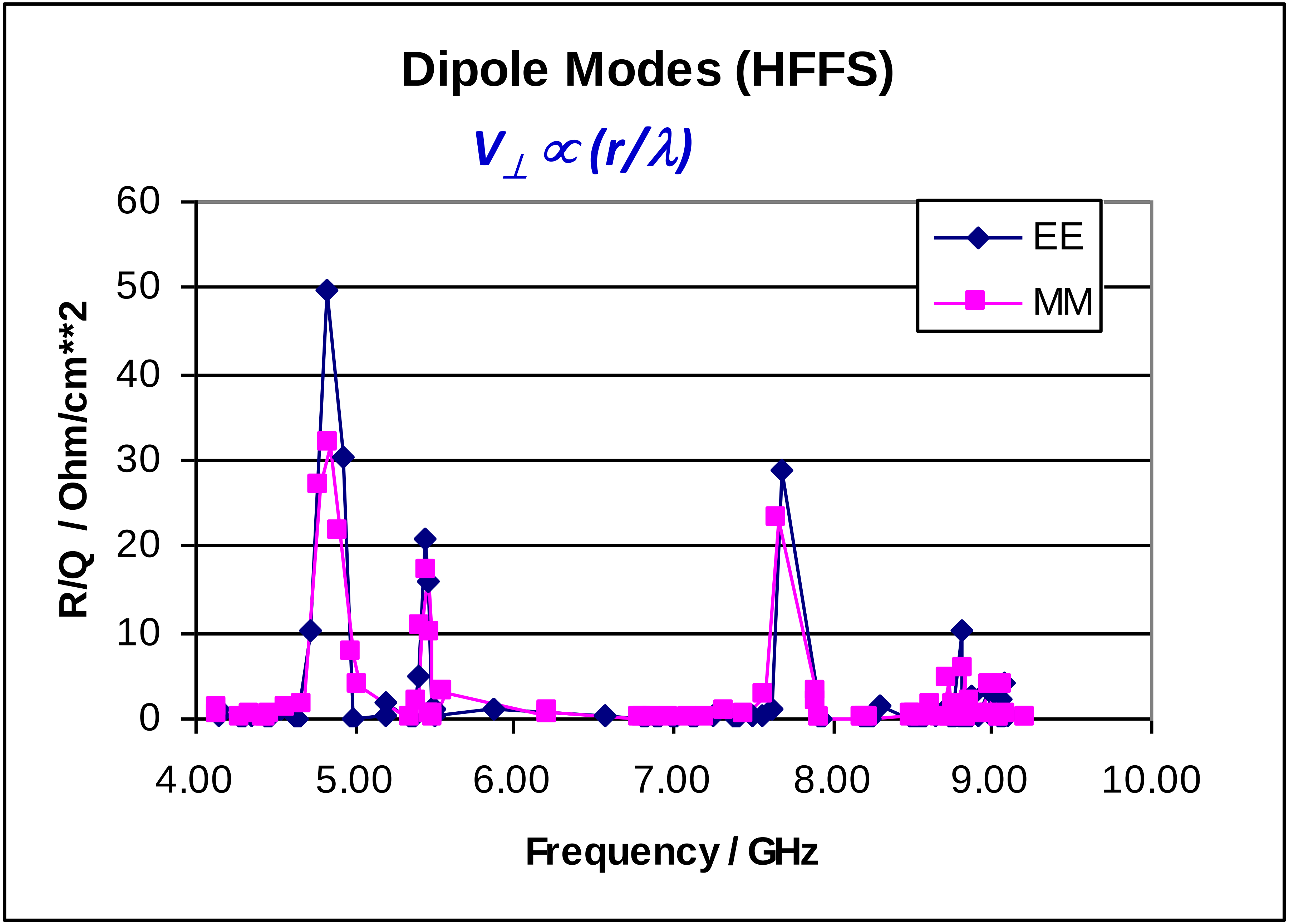
Brillouin diagrams for Monopole and Dipole modes in periodic 3.9 GHz cavity with regular mid-cells



Monopole modes

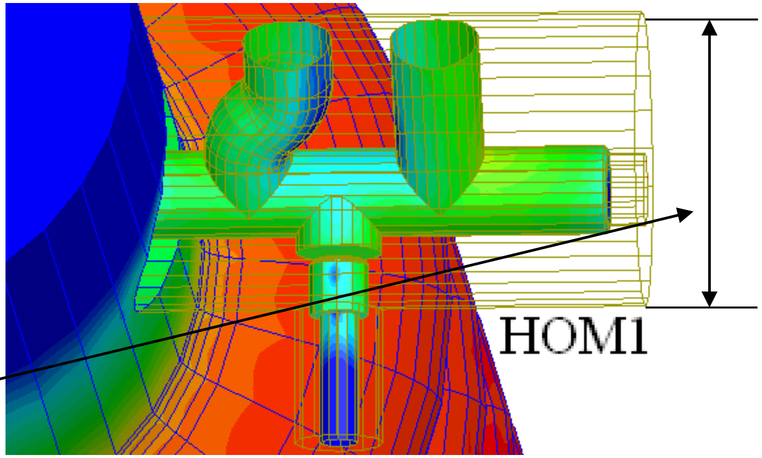


Dipole modes


Dipole Modes (HFFS)
$V_\perp \propto (r/\lambda)$
R/Q / Ohm/cm**2
0
10
20
30
40
50
60
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Frequency / GHz
EE
MM

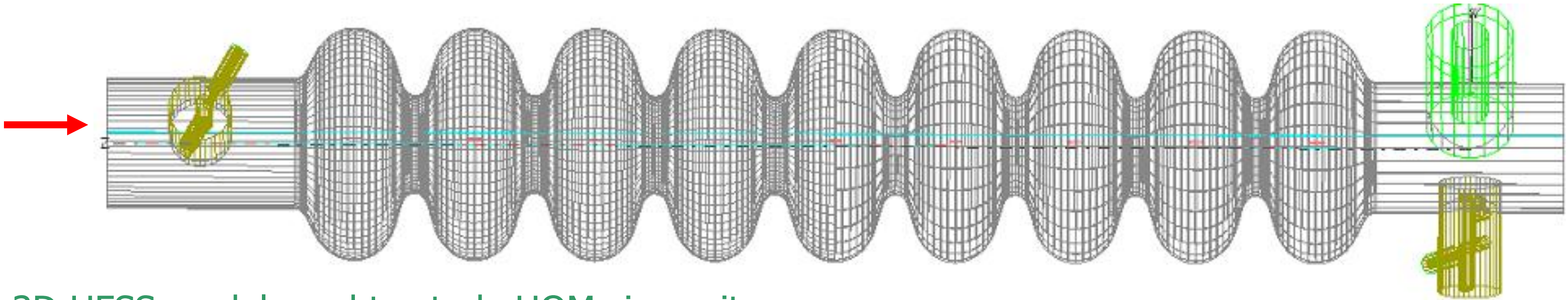
3.9 GHz HOM coupler

- 3rd harmonic HOM coupler has similar design to TESLA HOM coupler, but not in 3:1 scale:
- Beam pipe diameter:
  - TESLA cavity – 78mm
  - 3rd harmonic – 40mm
- HOM coupler diameter
  - TESLA = 40mm
  - 3rd harmonic 20mm

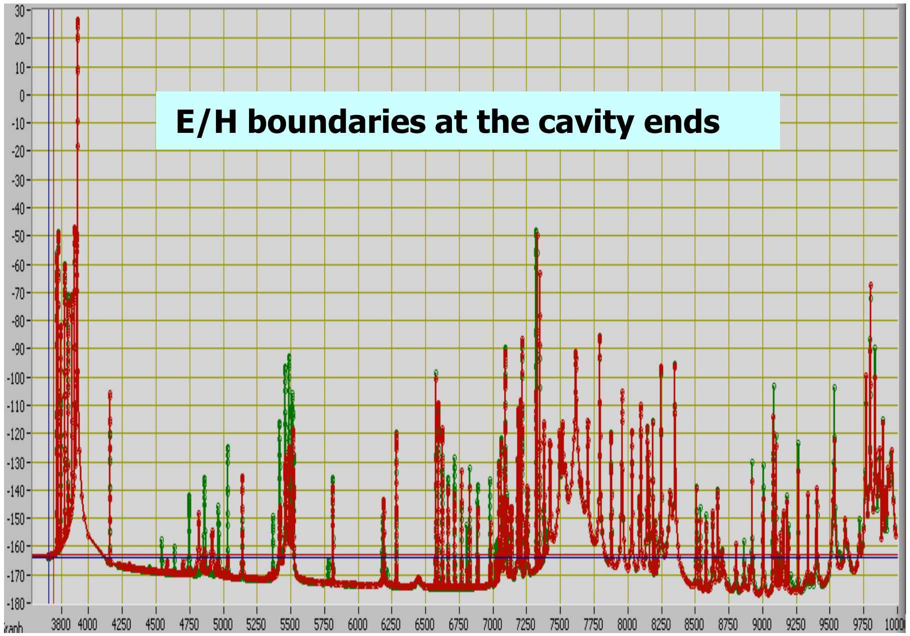


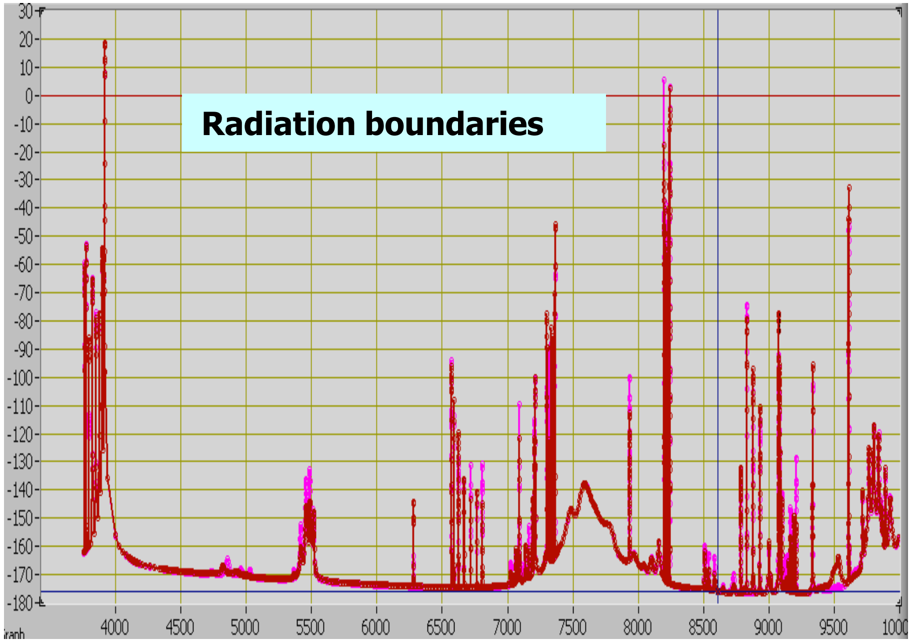
- Distance of the HOM coupler from cavity is 30mm → less attenuation for fundamental mode

HOM damping simulation (HFSS)



3D HFSS model used to study HOMs in cavity.
HOMs are excited by the beam with 2mm off-set in x/y direction

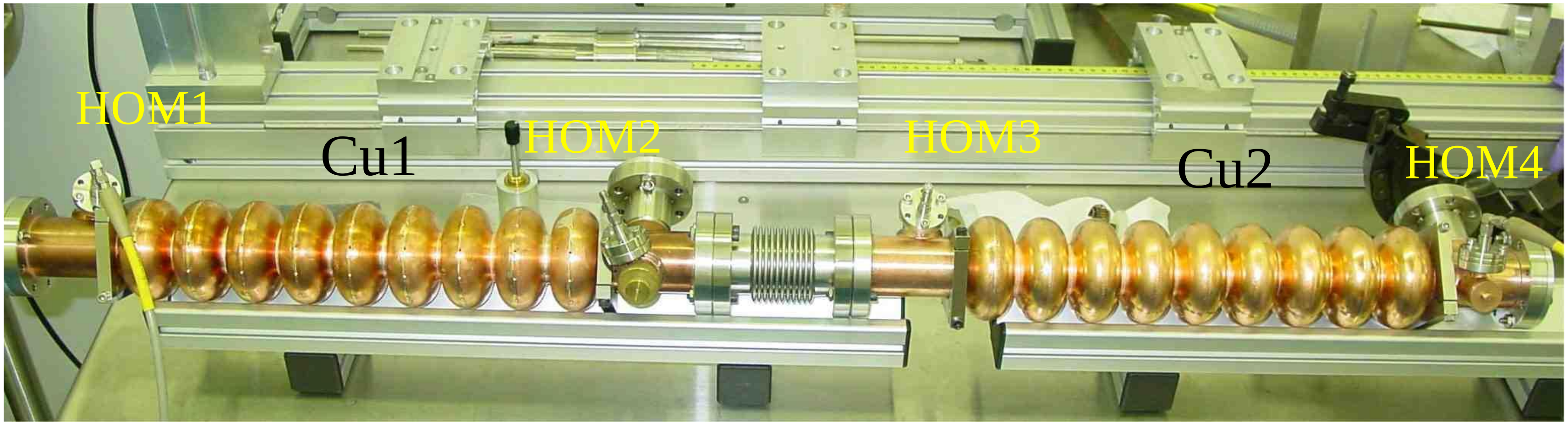


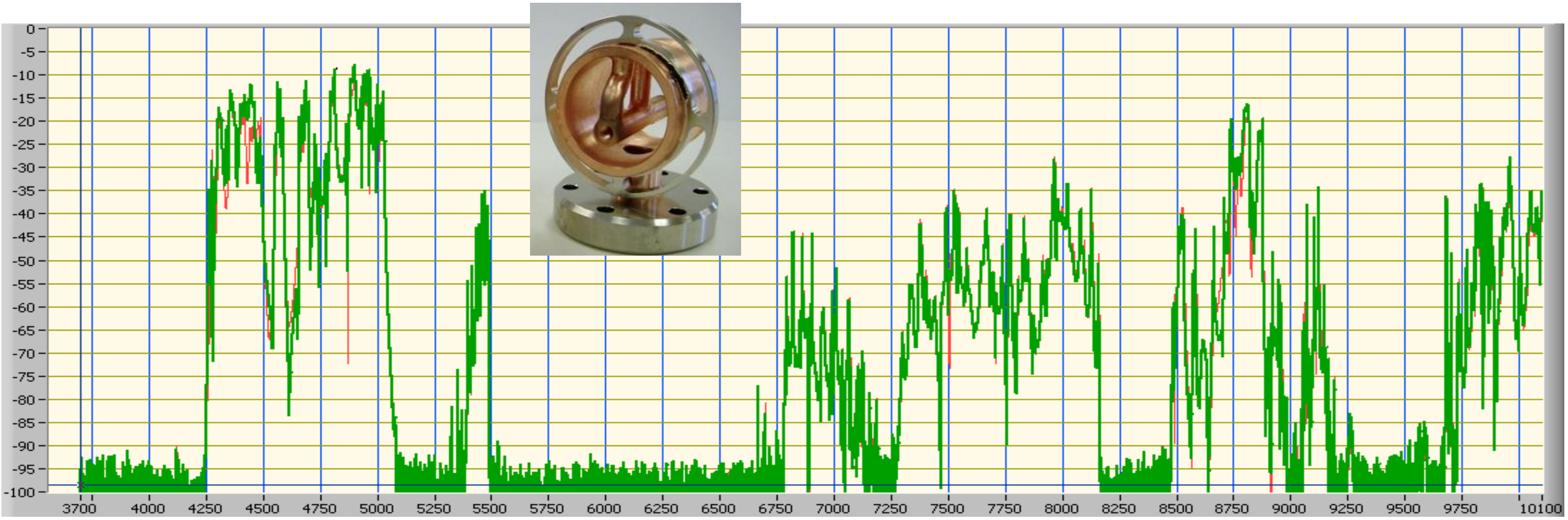


Stored energy vs. Frequency

Copper mockup cavity was designed.

HOM study in a chain of two copper TM_{01} cavities

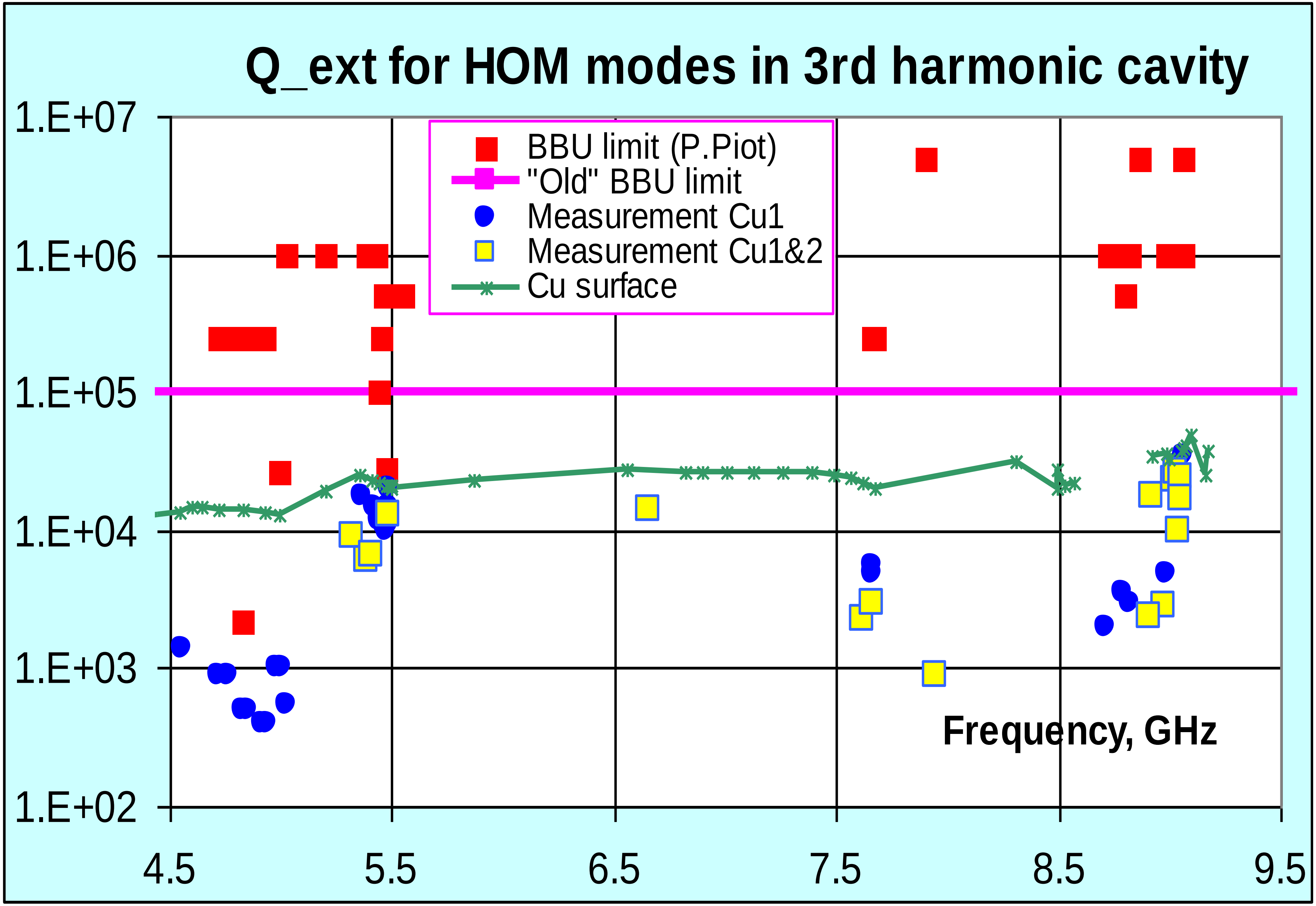




F=4813 MHz. Qmax=2180, Q2=1160, Q4=890

F=4994 MHz. Qmax=26000, Q2=4990, Q4=4320

F=5474 MHz. Qmax=28300, Q2=12500, Q4=9300



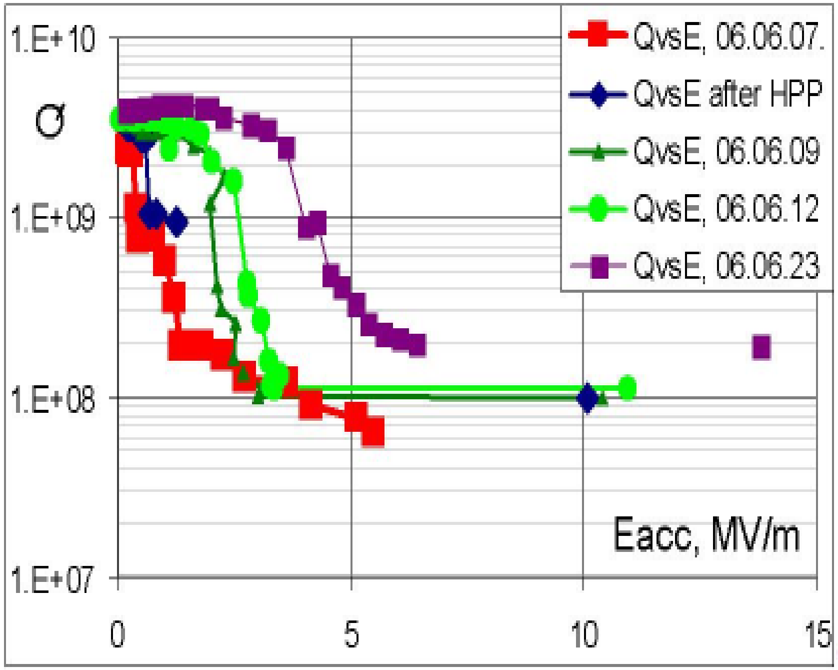
Q_ext for HOM modes in 3rd harmonic cavity
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
BBU limit (P.Piot)
"Old" BBU limit
Measurement Cu1
Measurement Cu1&2
Cu surface
Frequency, GHz
4.5
5.5
6.5
7.5
8.5
9.5

3-cell Niobium cavity without HOM couplers was built and tested.
Full scale Niobium cavity production started in 2005.

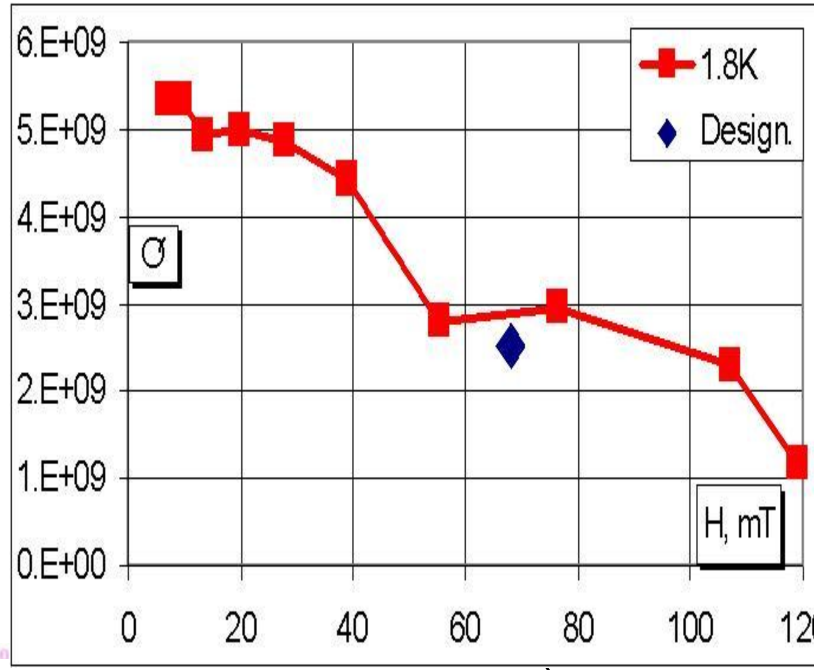
5 sets of couplers welded to beam pipe.

3.9 GHz cavity design

Performance of the 1st cold tested cavity (#2). MP in HOM coupler

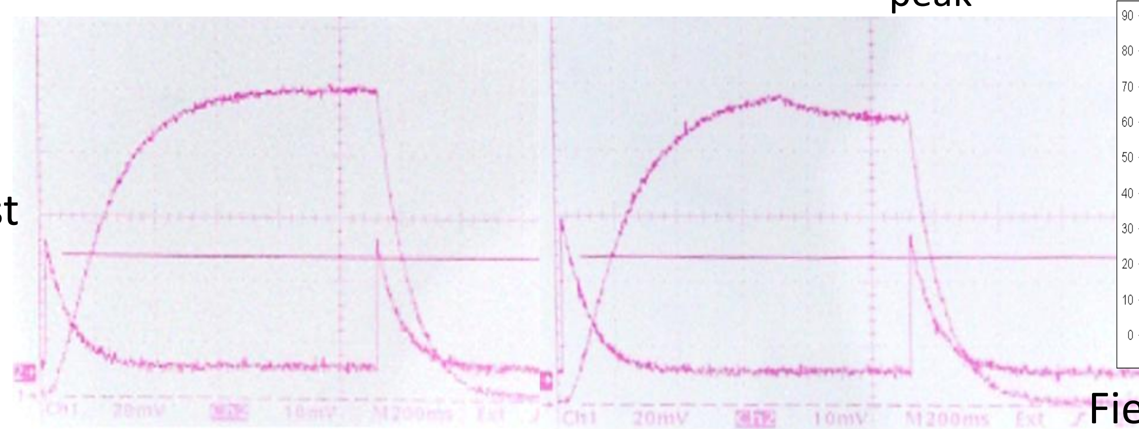


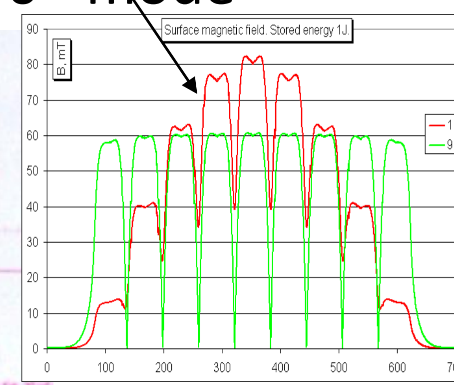
Q vs. E for π-mode



Q vs. H_{peak} for “0”-mode

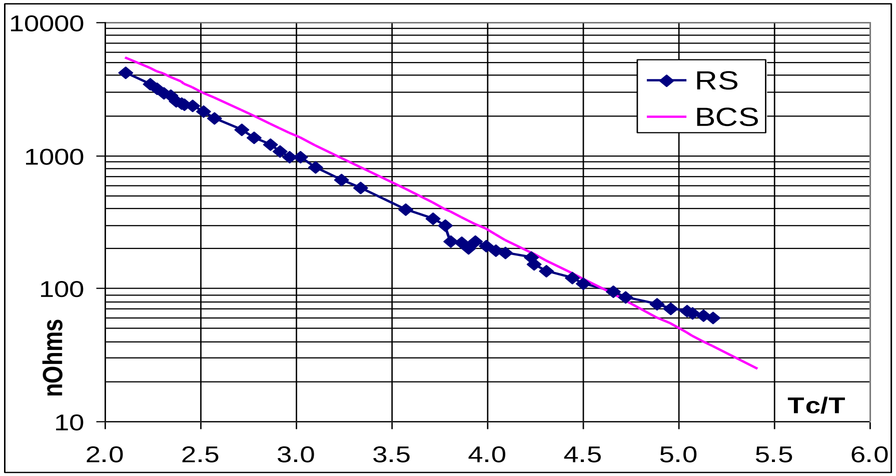
MP in vertical test



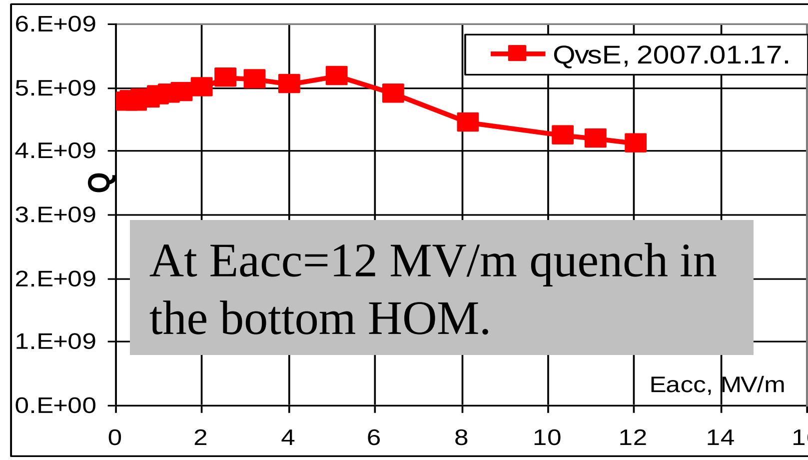


Field for 0 and pi mode

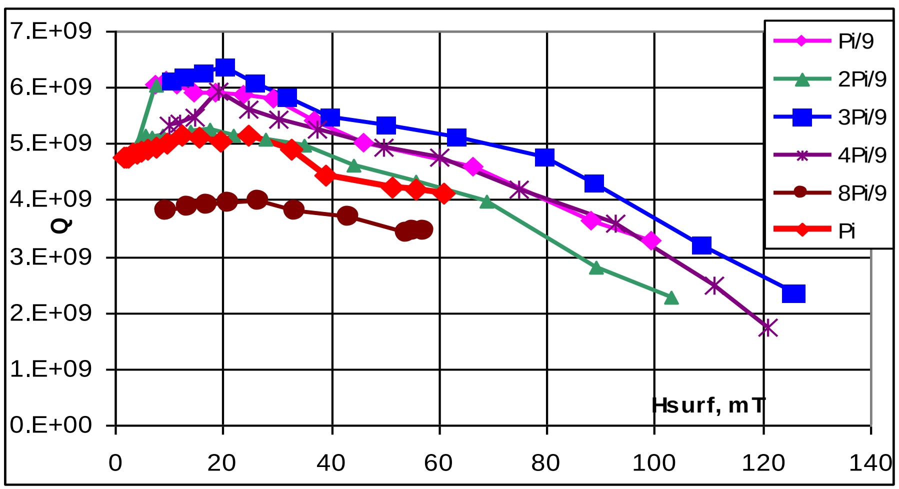
Cavity No.3: Results of the Cold Test #3 (2007.01.17)



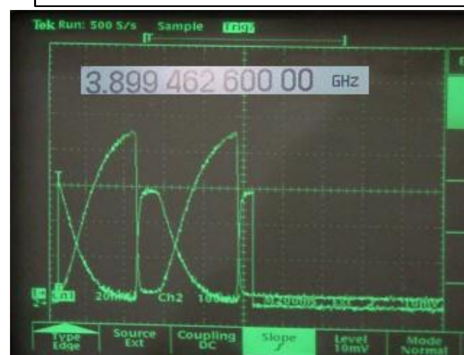
QvsT at Pi-mode. F=3899.46 MHz. Cavity baked 150C 48 h. **Rres=25 nOhms.**

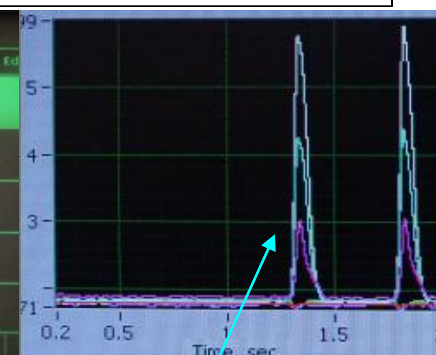


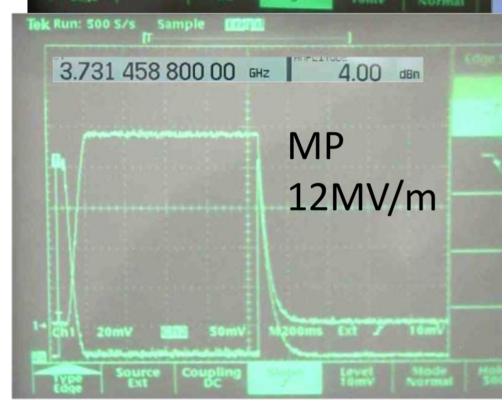
At Eacc=12 MV/m quench in the bottom HOM.



Q vs. max. surface H-field for some modes. Quench in HOM for Pi and 8/9Pi modes and in the cavity cells for lower modes.

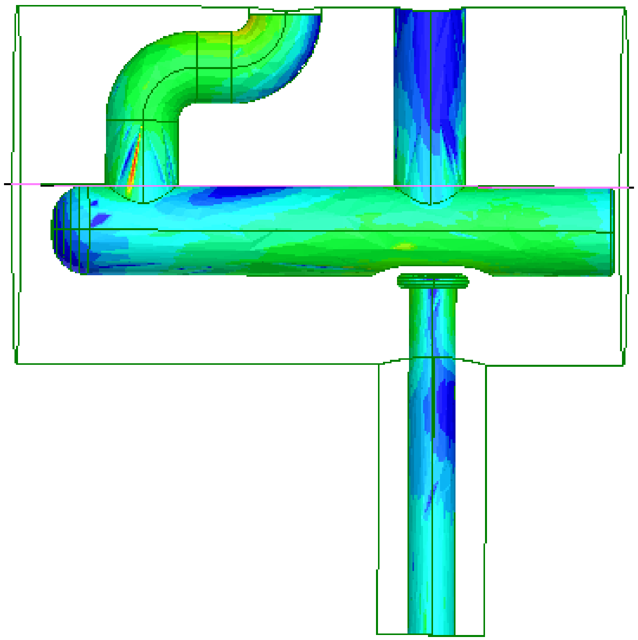


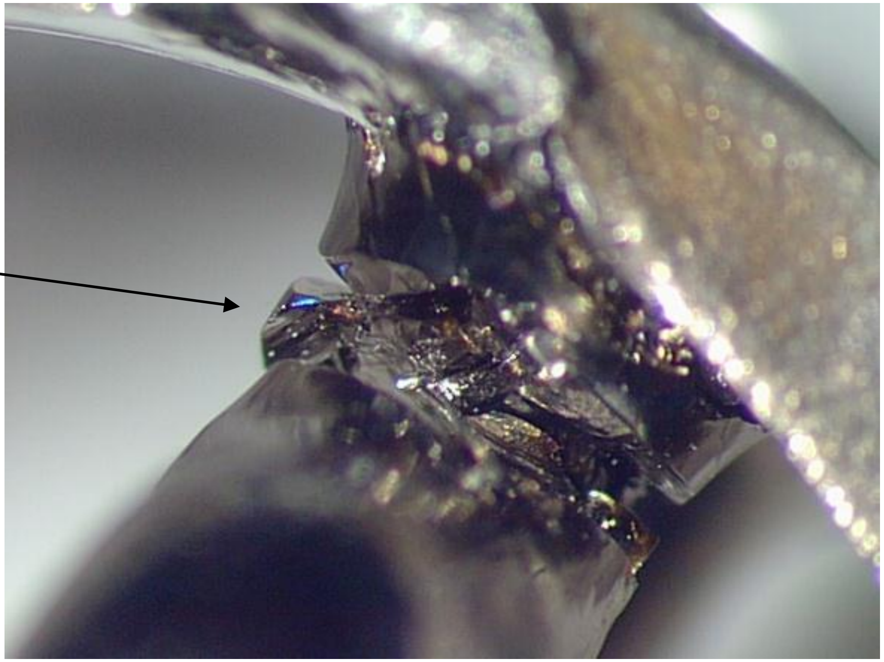


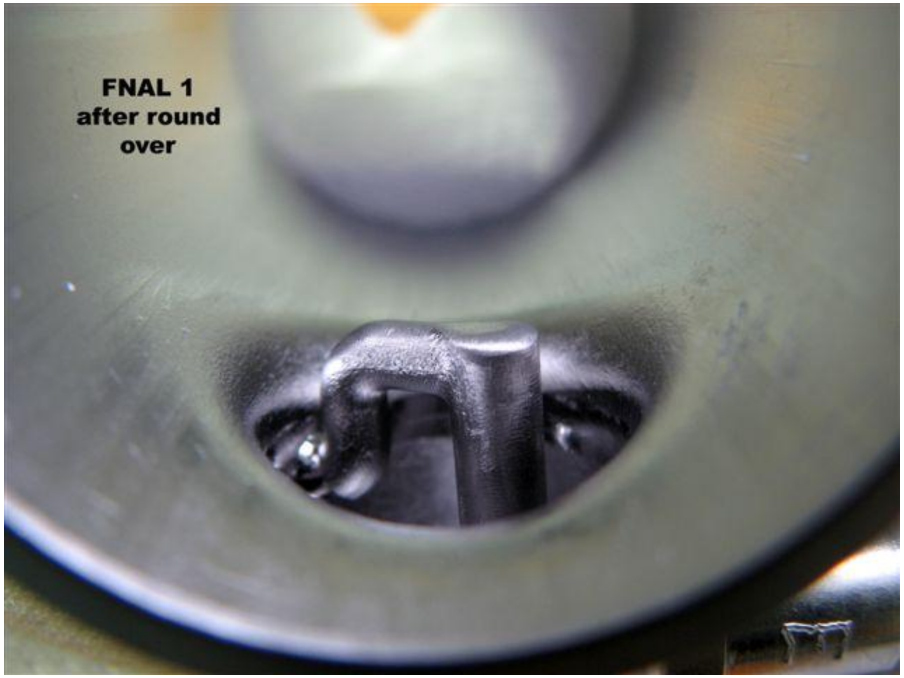


T-sensor between welds of the bottom HOM go up to maximum 6 K. RF fall time 20 msec.

Problems with the HOM coupler in cavity No. 2 (MP→overheating→ fracture)

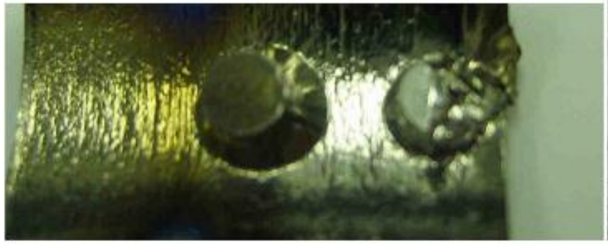


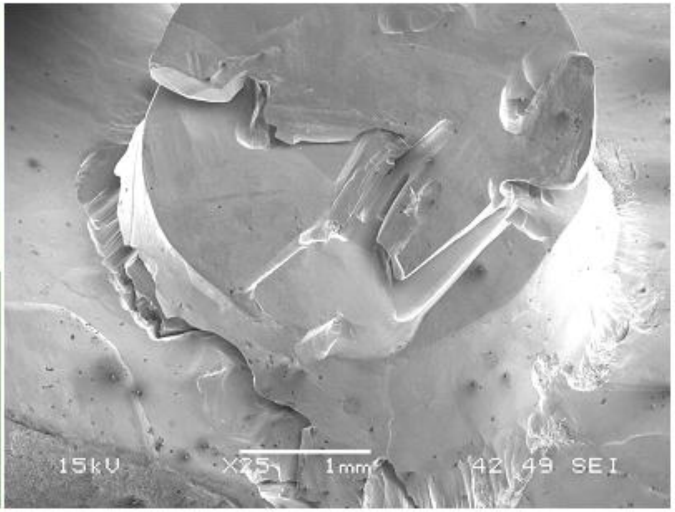




Cavity No.4 HOM coupler were modified.

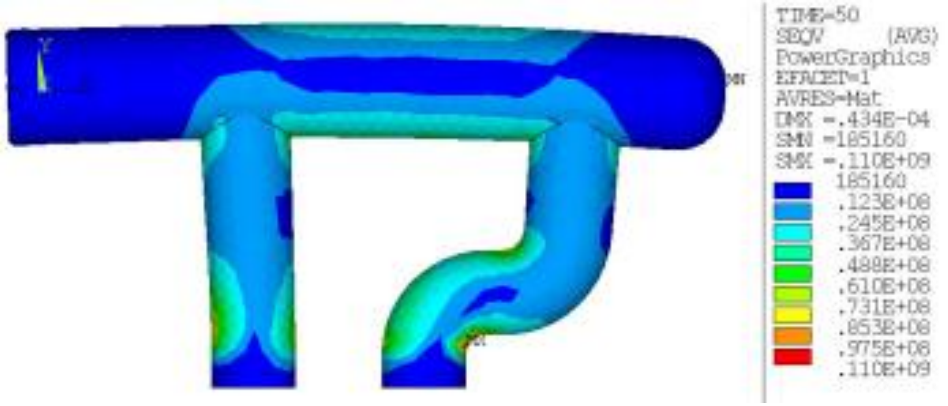
Cavity #2 both HOM couplers were fractured. SEM analysis also shows cracking at the base of the weld.

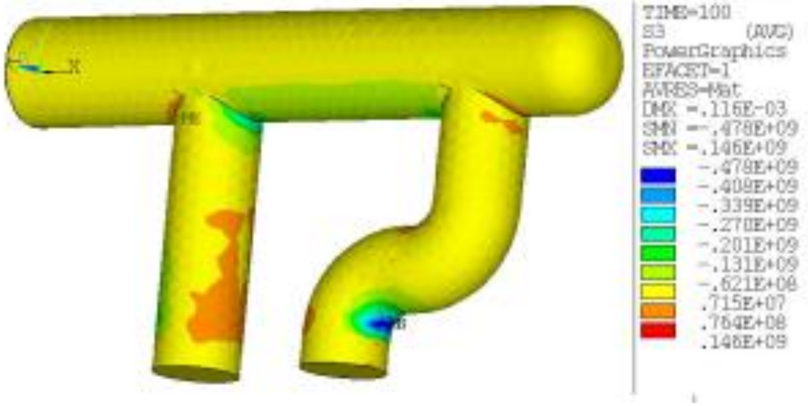


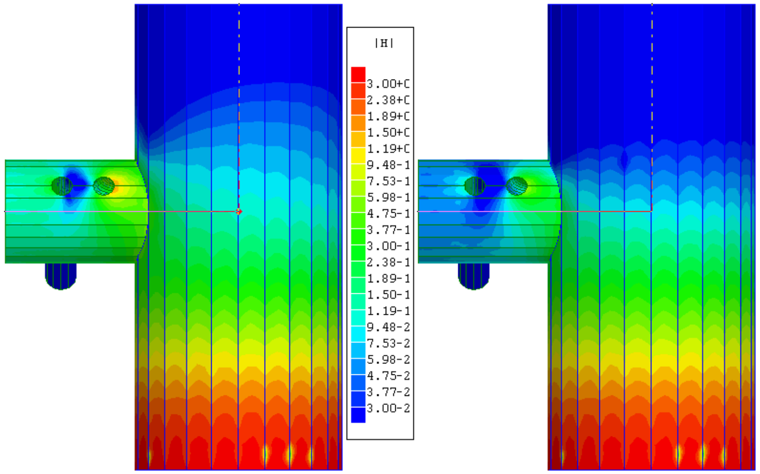


Thermal stress analysis.

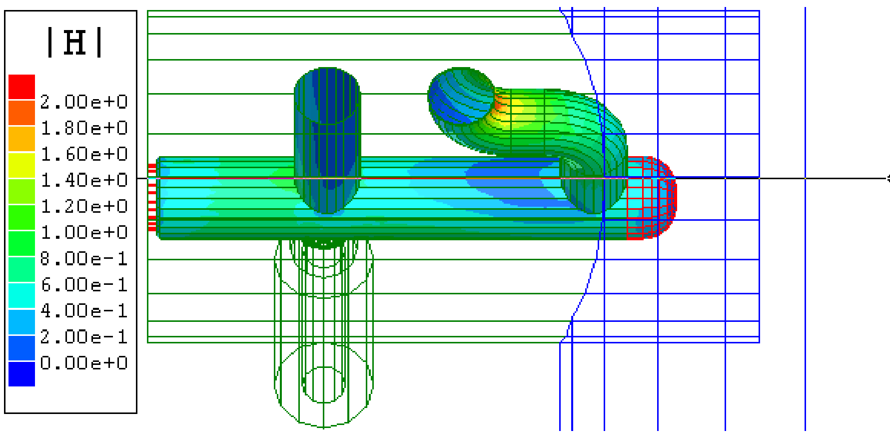
- Initial heating starts as a result of MP. When the formteile surface reaches normal-conducting temperature, the surface resistance increases dramatically and it results in additional power loss in the formteile. The outside surface of the HOM can stays cold, cooled by the surrounding superfluid helium. Significant temperature difference and associated thermal extension could result in enough stress to cause damage.
- Finite element analysis (FEA) indicates high local thermal stresses at the exact same location where the fractures occurred. The maximum principal and shear stress are always compressive at this location, and the 3rd principal stress at 100W was found to exceed the tensile strength of Nb at 100K.

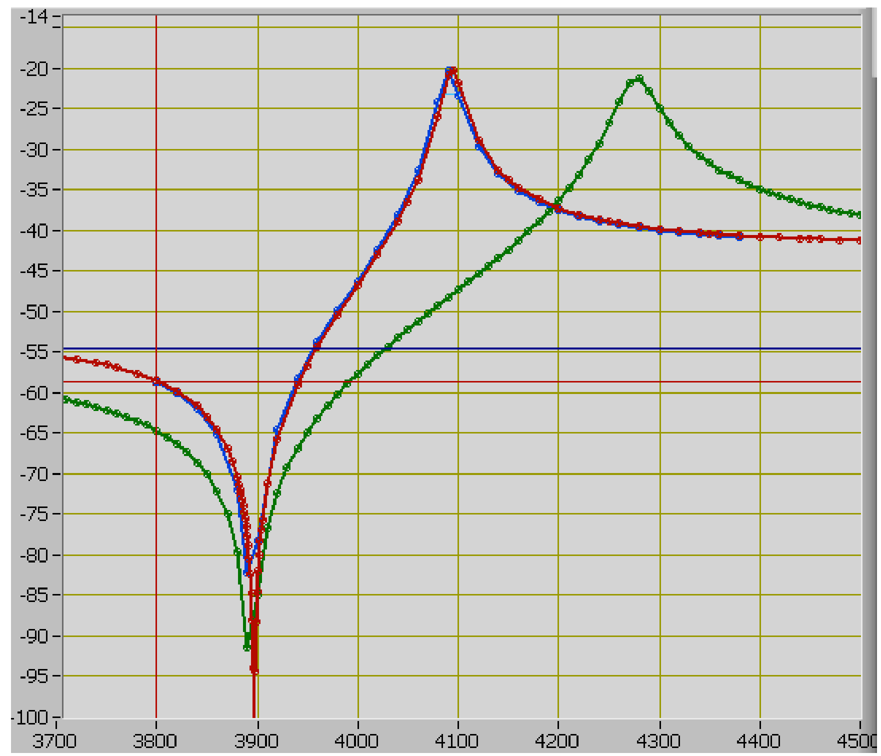


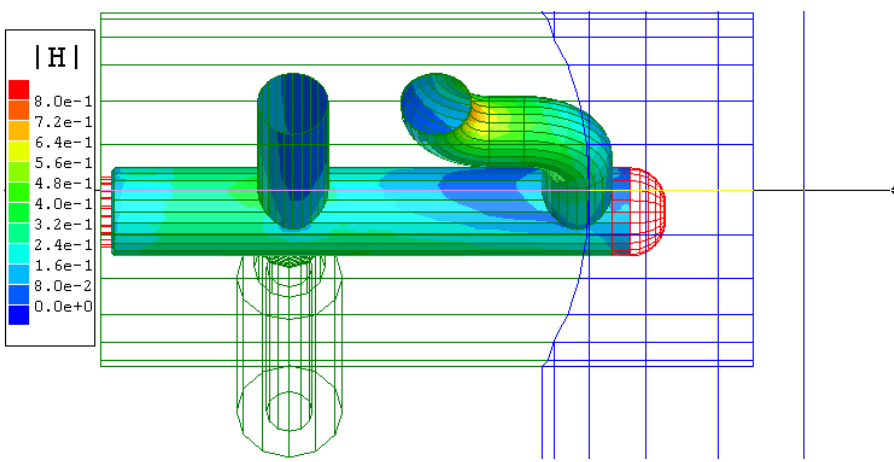




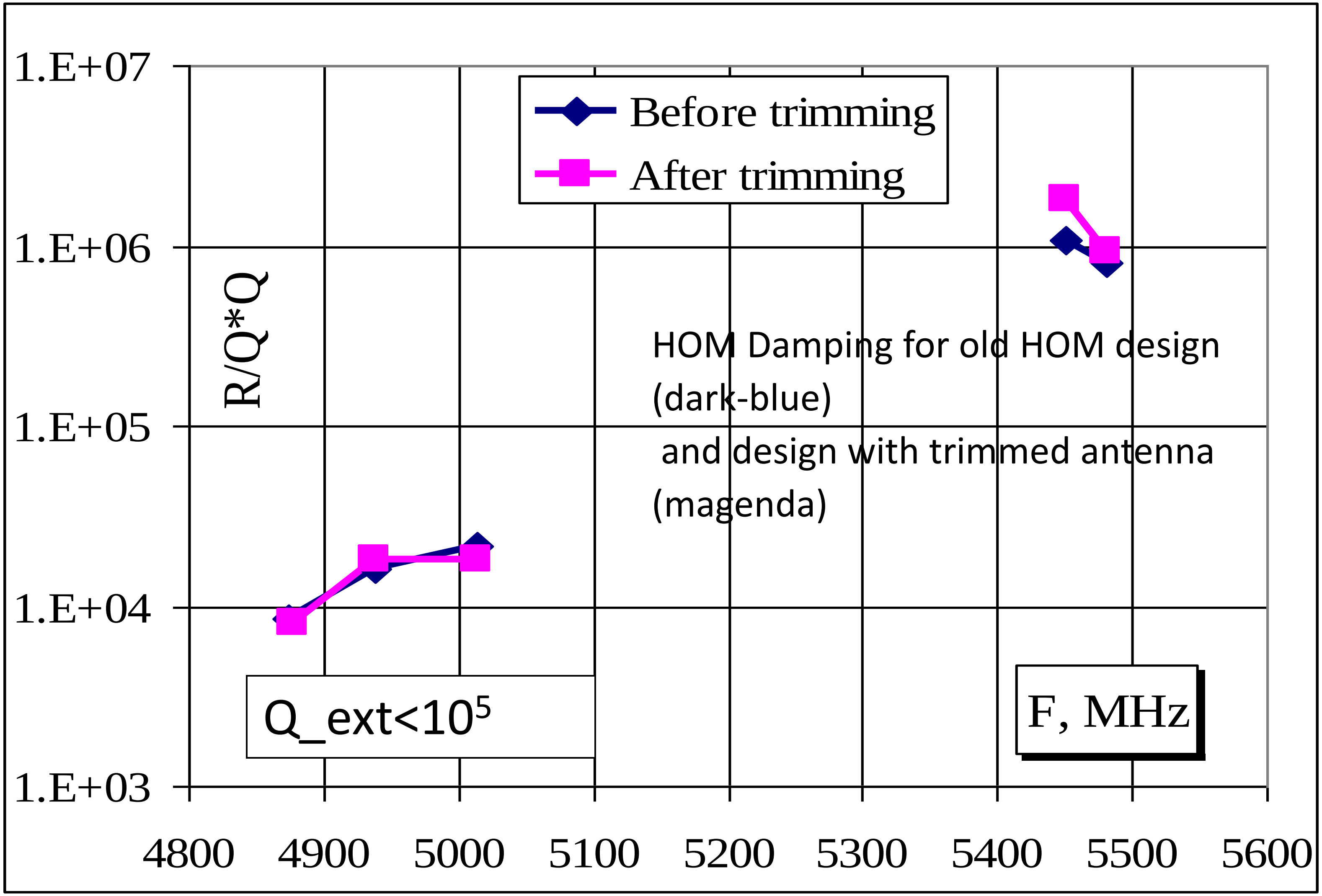
Simulations of the HOM form-tile tip cutting. Red and blue with 3 mm tip, green without. Resonance shifted by 190 MHz. Peak surface field lower 2.5 times.







HOM Damping properties for modified coupler design.

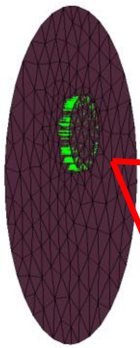


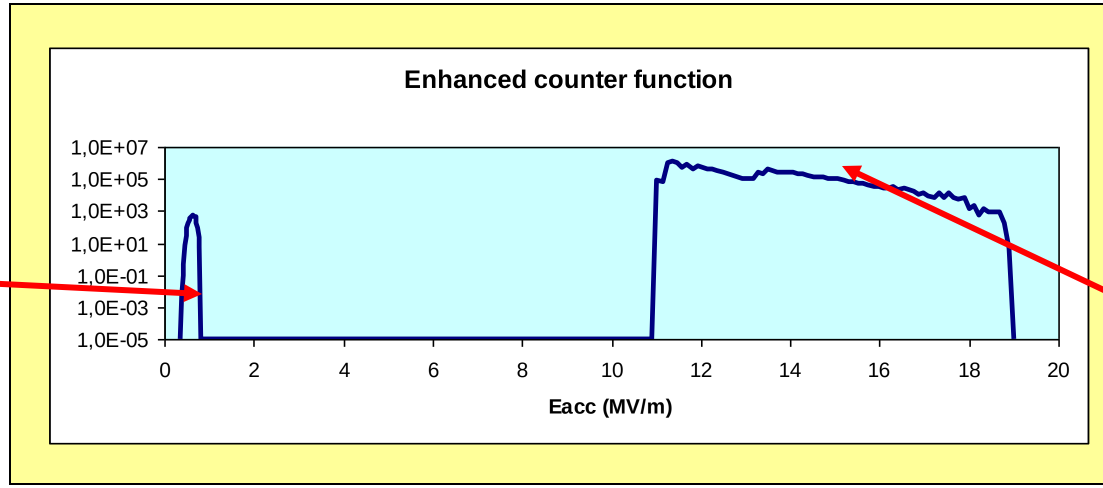
HOM damping for the 1st Dipole band remains same and slightly worth for a 2nd dipole band.

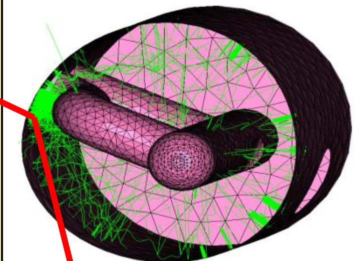
MP in initial HOM coupler design at F=3.9GHz

3D simulation

Analyst

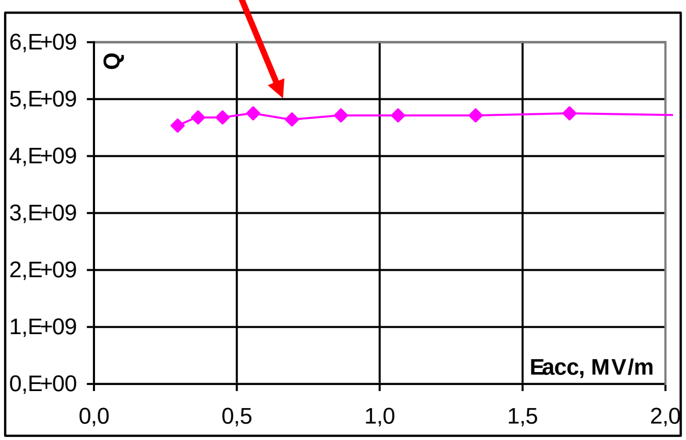


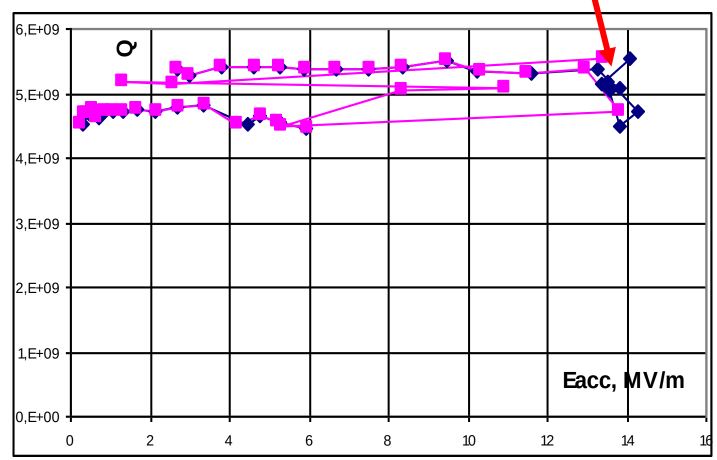




MP in notch gap 0.6 mm

MP in 2 mm Leg-wall gap

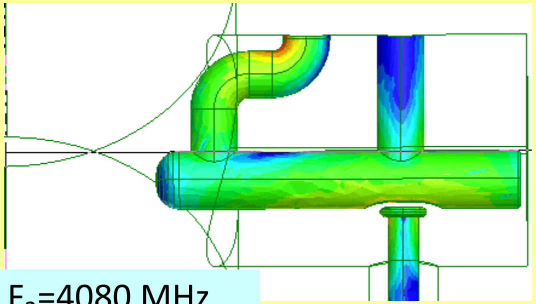




Results of vertical test MP observed at Eacc~0.7MV/m (Q drop). Quench at Eacc~14MV/m. Second resonance frequency of HOM was tuned higher than designed value.

Fields in HOM coupler for the nominal parameters: E_{acc}=14 MV/m; Hp=70mT

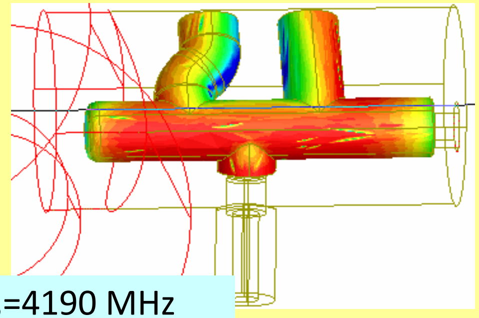
Current design



F_2=4080 MHz

Surface	$\int H^2 dS$	S, m^2	Hp, A/m	Ep, V/m
Cavity	2.4E+08	0.11	5.61E+04	3.3E+07
Form1	2.3E+04	0.00077	7.60E+03	9.5E+06
Form2	2.0E+04	0.00077	7.03E+03	8.6E+06

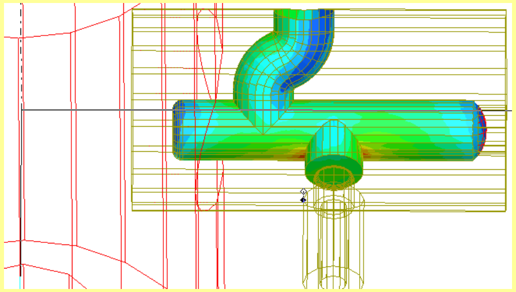
Modified 2-post design



F_2=4190 MHz

Surface	$\int H^2 dS$	S, m^2	Hp, A/m	Ep, V/m
Cavity	2.4E+08	0.116	55165.5	3.3E+07
Form1	2.6E+04	0.0011	5683.718	4.0E+06
Form2	2.8E+04	0.0011	5850.886	4.3E+06
Ant1	1357	0.00014	4012.036	

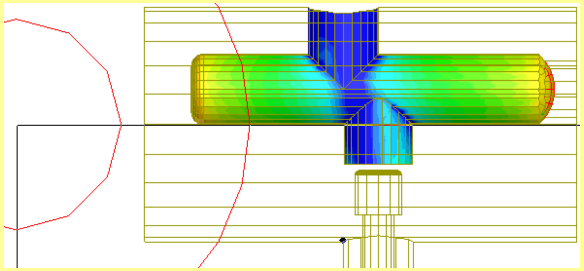
1-post design #1



F_2=4350 MHz

Surface	∫ H2dS	S, m2	Hp, A/m	Ep, V/m
Formtile	1.2E+04	0.0008	5910.1	4.6E+06

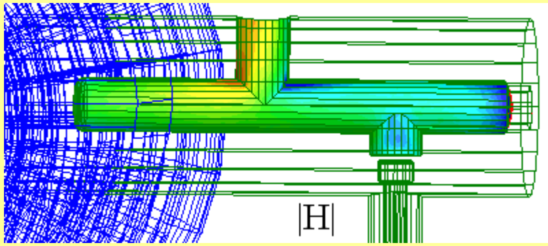
1-post design #2



F_2=4400 MHz

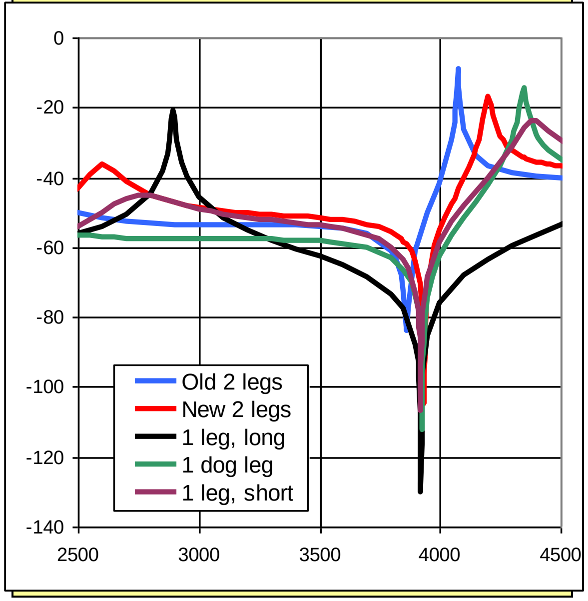
Surface	∫ H2dS	S, m2	Hp, A/m	Ep, V/m
Formtile	7.3E+03	0.0007	5076.9	3.0E+06

1-post Long design



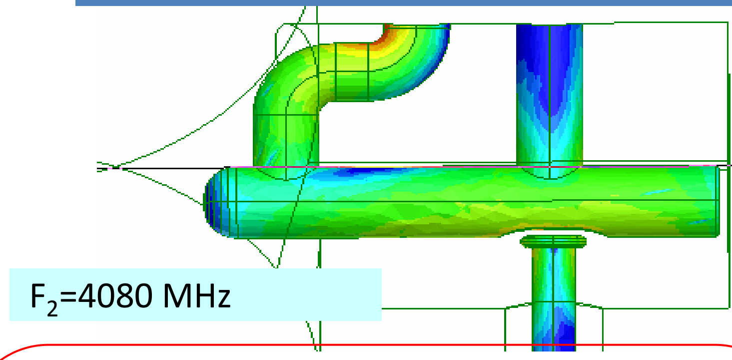
F_2=2900 MHz

Surface	∫ H2dS	S, m2	Hp, A/m	Ep, V/m
cavit	2.4E+08	0.11	54890.22	3.3E+07
Form1	2.4E+03	0.0011	3659.348	8.3E+05
Form2	2.6E+03	0.0011	4324.684	9.3E+05

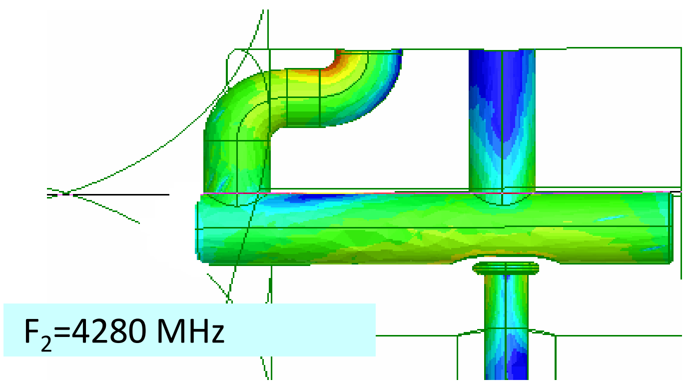


Final Designs of the HOM couplers.

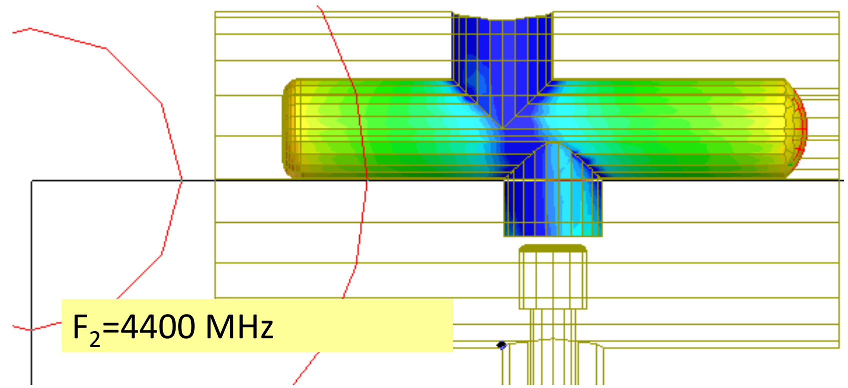
Initial design No.1



Trimmed Initial design -1a



1-post design

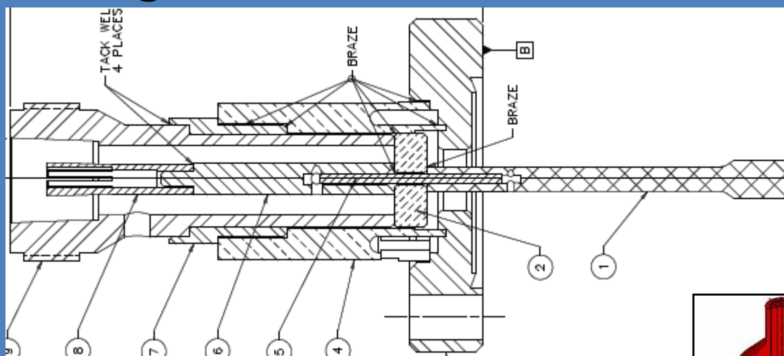


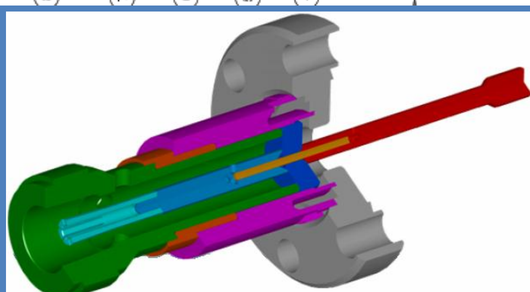
HOM field - Comparison

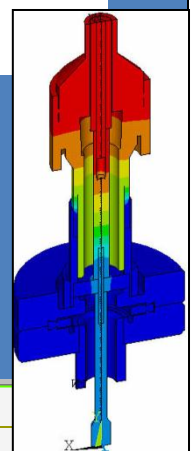
	Hpk/H	Epk/E
cavity	**7.4**	**3.5**
HOM1-original	1	1
HOM1-modif	**0.4**	**0.4**
HOM-1post	**0.67**	**0.31**

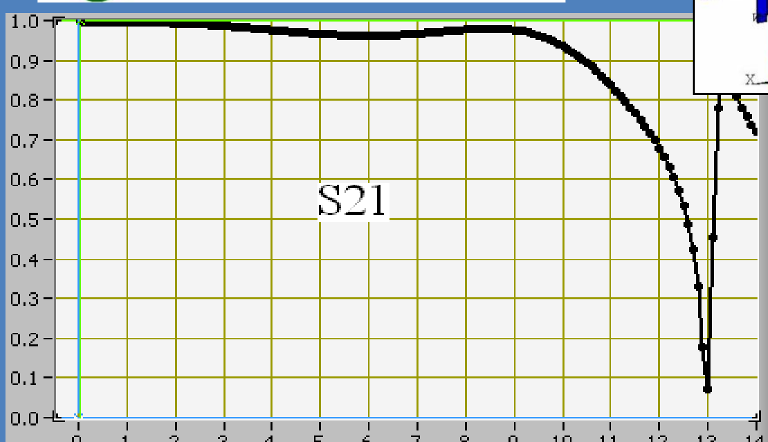
HOM coupler feed through development.

1st design manufactured in Ceramtec.

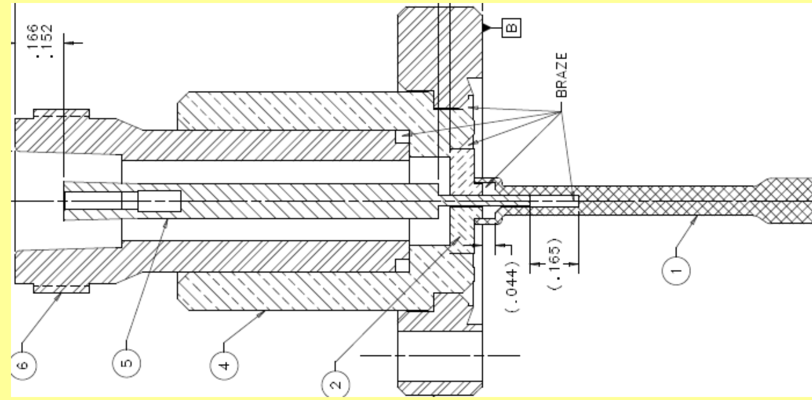




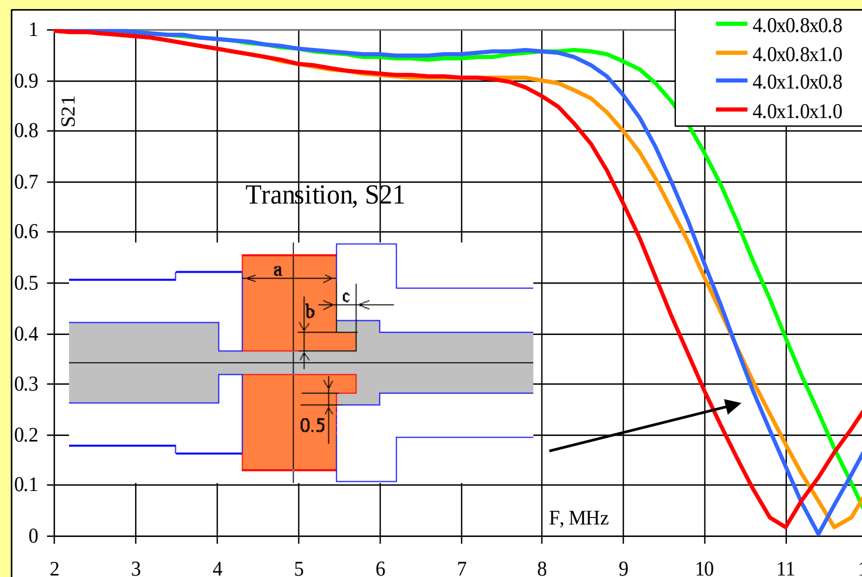




2nd design with sapphire.

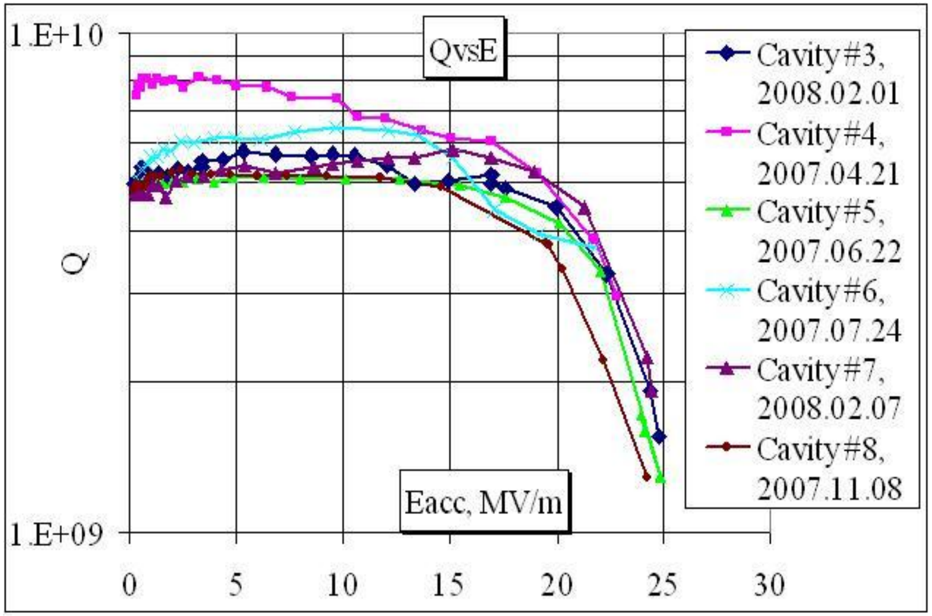


Better thermal properties

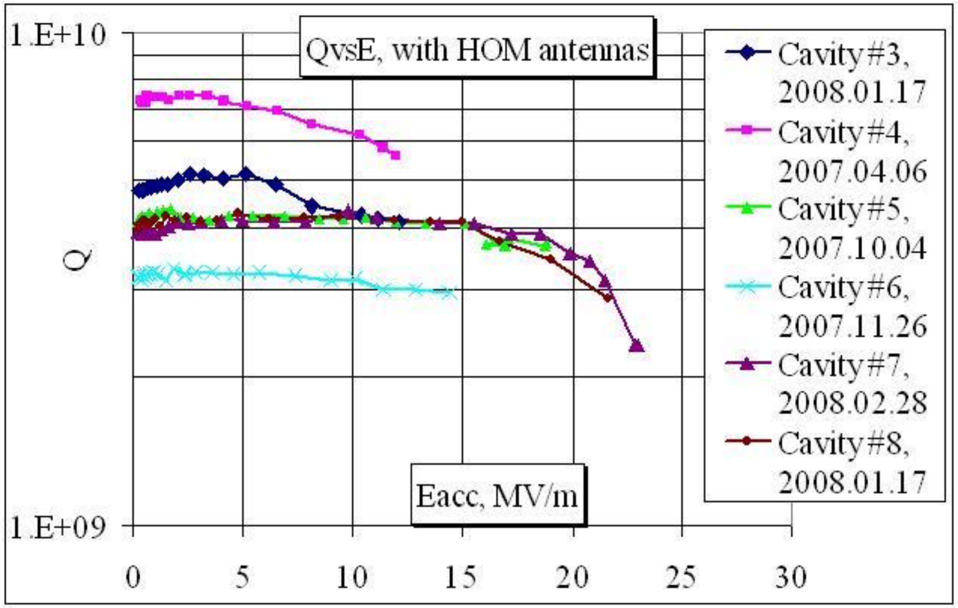


Six cavities successfully tested in VTS, CW regime.

Cavities #3-6 with modified HOM coupler and cavity #7 and#8 with 1post design.



CW Vertical test results of the cavities #3-8. Cavity #4 was 120C 48hours baked.



CW Vertical test results of the cavities #3-8 with HOM antennas installed. In cavities 3-6 gradient limited by quench in HOM antenna tip.

SUMMARY of 3.9 GHz cavity HOM studies

- Initial design HOM coupler shows strong MP at level of accelerating field Eacc=12 MV/m.
- Few new designs (one or two legs) were proposed to reduce MP, field level in coupler and improve thermal properties. In a new designs we have increased the notch gap 0.6→2.5mm and formteil thickness 4→6mm.
- Simulations shows, that new designs have good HOM damping and much less MP.
- Old HOM couplers with trimmed (~3mm) antenna was tested on Cavities #3-6, accelerating gradient reached 22-25 MV/m.
- 1-leg design #4 after testing of copper prototypes was approved for cavities #7-8. Cavity accelerating gradient reached 23-25 MV/m.
- Four cavities successfully tested in HTS and installed in cryomodule.
- Cryomodule was shipped to DESY and installed in FLASH. High power tests results same as in FNAL.
- Cryomodule tested with the beam. Design parameters are reached.