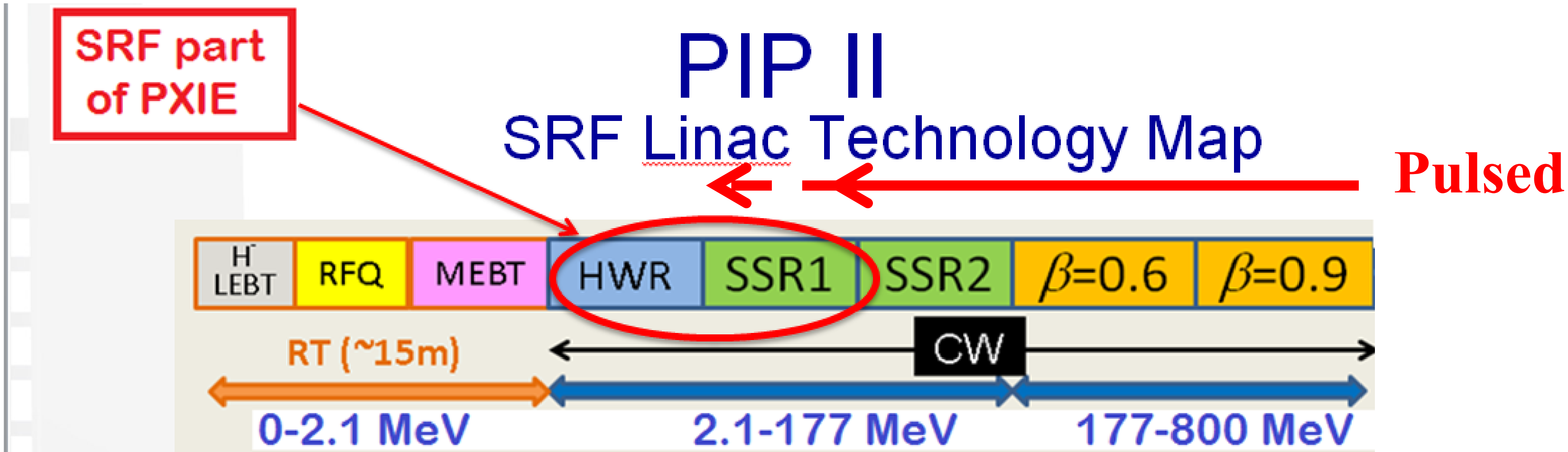
650 MHz cavity EM and mechanical design status

Ivan Gonin, Timergali Khabiboulline

PIP-II meeting, 04/21/2015

PIP-II concept



SRF Cavity Type	Freq, MHz	Energy (MeV)	Cav/mag/CM	CM type, length
HWR (β_G=0.11)	162.5	2.1-11	8 /8/1	scscscscscscscsc, 5.3m
SSR1 (β_G=0.22)	325	11-38	16 /8/ 2	csccsccsccsc, 4.8m
SSR2 (β_G=0.51)	325	38-177	35 /21/ 7	sccsccsc, 6.5m
LB 650* (β_G=0.61)	650	177-480	30 /20/5	cccfdccc, 7.1m
HB 650 (β_G=0.9)	650	480-800	24 /6/ 4	cccccc, 9.5m

*3-cavity option is under consideration; CM has no focusing elements.

5 IIFC, July 2014; Slava Yakovlev Fermilab

2 mA pulsed beam with duty factor from 0% to CW operation
Number of cavities/cryomodules changed for SSR2 and above

PIP-II cryogenics

PIP-II

Cryogenic losses in the PIP II cryo-modules

- In CW regime the total loss is 410 W;
- Pulsed operation limited by power of the cryo-plant;
- 5% duty factor for cryo, or 20.5 W.

	Energy (MeV)	CM	Cav per CM	E_{acc} (MV/m)	ΔE (MeV)	Q_0@2K (10^{10})	Static loss per CM @2 K, W	Total loss per CM @2 K in CW, W
HWR	2.1-11	1	8	8.2	1.7	0.5	14	24
SSR1	11-38	2	8	10	2.05	0.5	16	27
SSR2	38-177	7	5	11.2	5.32	1.2	8.8	52
LB 650	177-480	5	6*	16.5	11.6	1.5	8.1	153
HB 650	480-800	4	6	17.5	17.7	2.0	6.2	153

*3-cavity option is under consideration; CM has no focusing elements.

7

IIFC, July 2014; Slava Yakovlev

Fermilab

~75% of cryogenic losses take place in 650 MHz part

General Issues:

- Low beam loading → narrow cavity bandwidth → microphonics
- Lorentz Force Detuning (LFD) is an issue in a pulsed mode, and should be analyzed for each cavity type.
- Future CW operation → cryo-losses → high Q_0 is desired. Technology of the cavity processing based on N-doping is developing

Microphonics SRF cavities

Bandwidth and required power optimized for CW (2 mA)

Section	Freq MHz	Maximal detune (peak Hz)	Minimal Half Bandwidth (Hz)	Max Required Power (kW)
HWR	162.5	20	34	4.8
SSR1	325	20	45	5.3
SSR2	325	20	27	17.0
LB650	650	20	29	33.0
HB650	650	20	31	48.5

Microphonics Control Strategies:

- **Adding RF power to compensate for the expected peak frequency detuning.**
- **Minimizing Helium bath pressure peak to peak variations.**
- **Reducing df/dP , the sensitivity of the cavity resonant frequency to in the helium bath pressure.**
- **Minimizing acoustics from external sources.**
- **Active compensation using a fast tuner driven by feedback from measurements of the cavity resonant frequency.**

HB 650 FRS EM Parameters

Parameter	Value
Frequency	650 MHz
Shape, number of cells	Elliptical, 5 cells
Geometric beta β_g	0.92
$L_{eff} = 5*(\beta_g \lambda/2)$	1060.8 mm
Iris Aperture	118 mm
Bandwidth	62 Hz (2 mA)
E_{peak} at operating gradient	< 40 MV/m
B_{peak} at operating gradient	< 72 mT
Cavity quality factor Q_0 at 2K	$> 2.0_* 10^{10}$

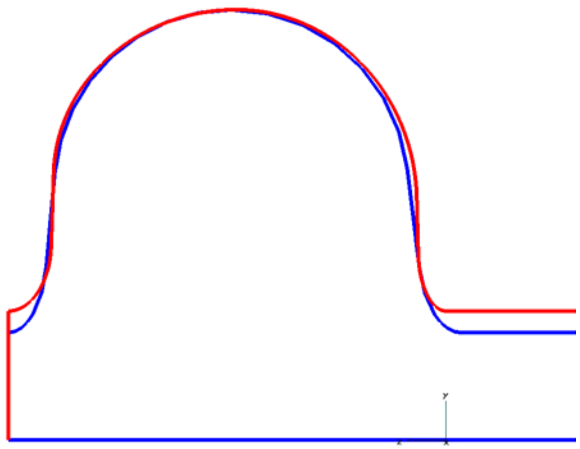
HB 650 MHz cavity

Cavity operational and test requirements

Parameter	Value
Operating node	CW
Max Leak Rate (room temp)	< 10^{-10} atm-cc/sec
Operating gain per cavity	19.9 MeV
Maximum Gain per cavity in VTS	> 24 MeV
Operating power dissipation per cavity at 2 K	< 25 W
Sensitivity to He pressure fluctuations	< 25 Hz/mbar (dressed cavity)
Field Flatness dressed cavity	> 90%
Operating temperature	2.0 K
Operating Pressure	30 mbar
MAWP	2 bar (RT), 4 bar (2K)
RF power input per cavity	50 kW (CW, 2 mA)
Cavity longitudinal stiffness	< 10^4 N/mm
Tuning sensitivity	> 150 kHz/mm

HB 650 MHz cavity

Dimensions and main parameters of β= 0.9 & 0.92 Cavities



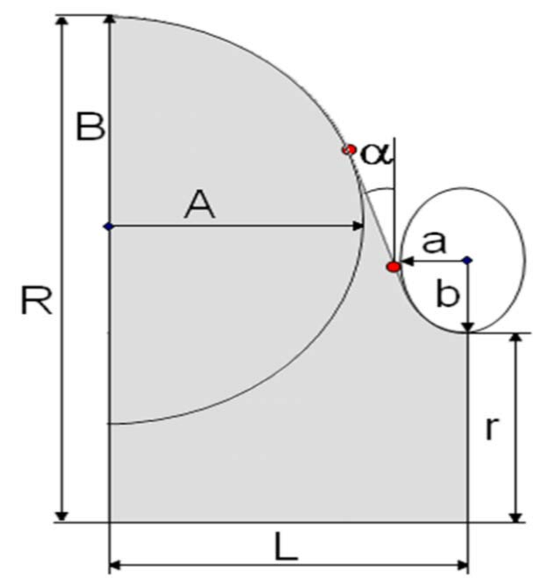
Regular half-cell

	OLD	NEW
r	**50**	**59**
R	200.3	200.052
L	103.8	106.08
A	82.5	85
B	84	78
a	18	20
b	38	33
α	**5.2°**	**1.9°**

End half-cell

	OLD	NEW
r	**50**	**59**
R	200.3	200.052
L	107	97.555
A	82.5	84
B	84.5	90
a	20	13
b	39.5	28
α	**7°**	**1.3°**

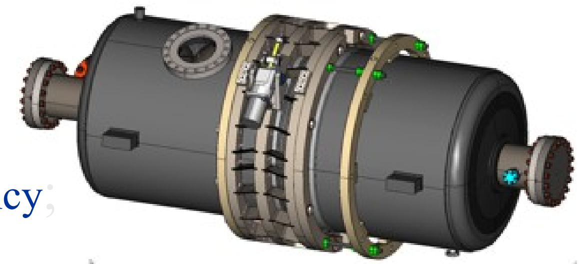
Quantity	Old	New
G, Ω	256	260
R_{sh}/Q_0 max, Ω	638	609
β_{opt}	0.95	0.97
E_{surf}/E_{acc}*	2.08	2.04
B_{surf}/E_{acc}*, mT/MV/m	3.81	3.85
K_{couple}, %	0.75	1.29
Monopole HOM Q_{ext}	10^{10}	10^{6}

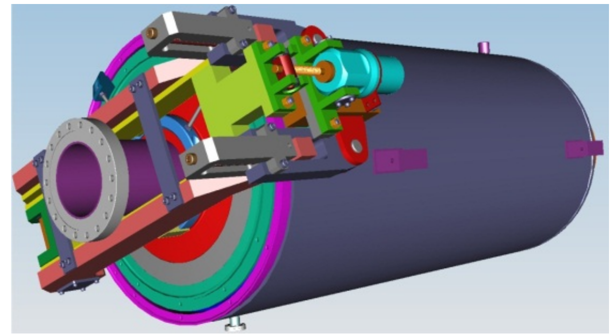


HB 650 MHz cavity

Blade Tuner – scaled ILC:

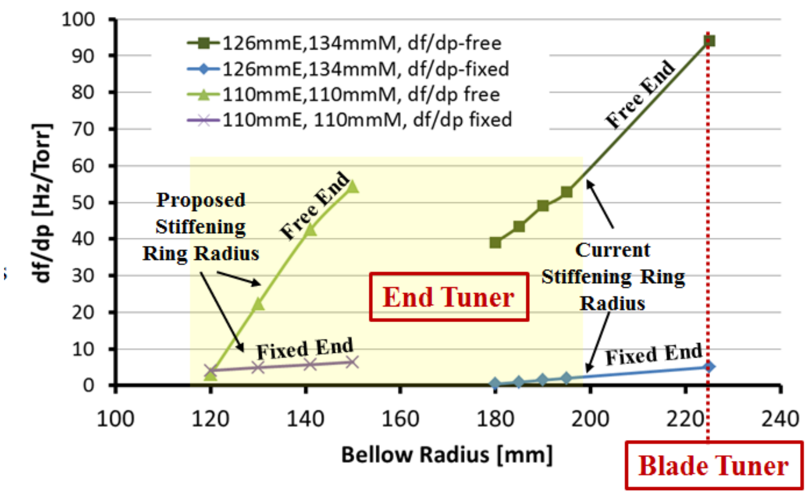
- High df/dP
- Insufficient tuning efficiency



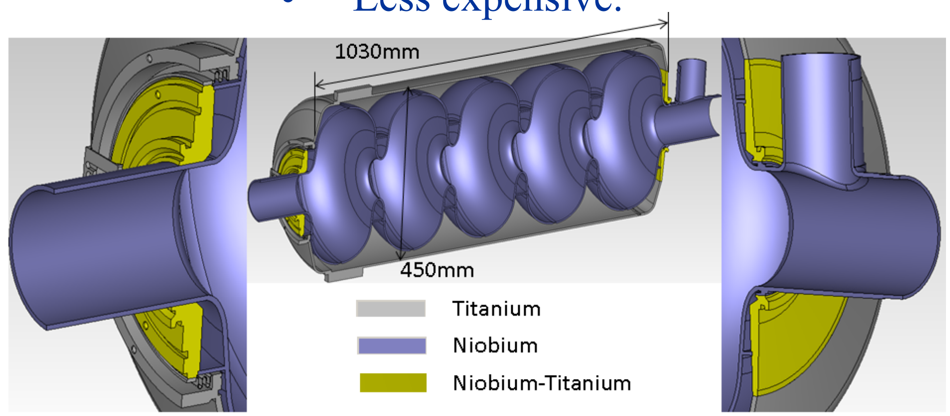


New End Lever Tuner design:

- Low df/dP,
- Mechanical resonances > 60 Hz;
- Good tunability;
- Less expensive.

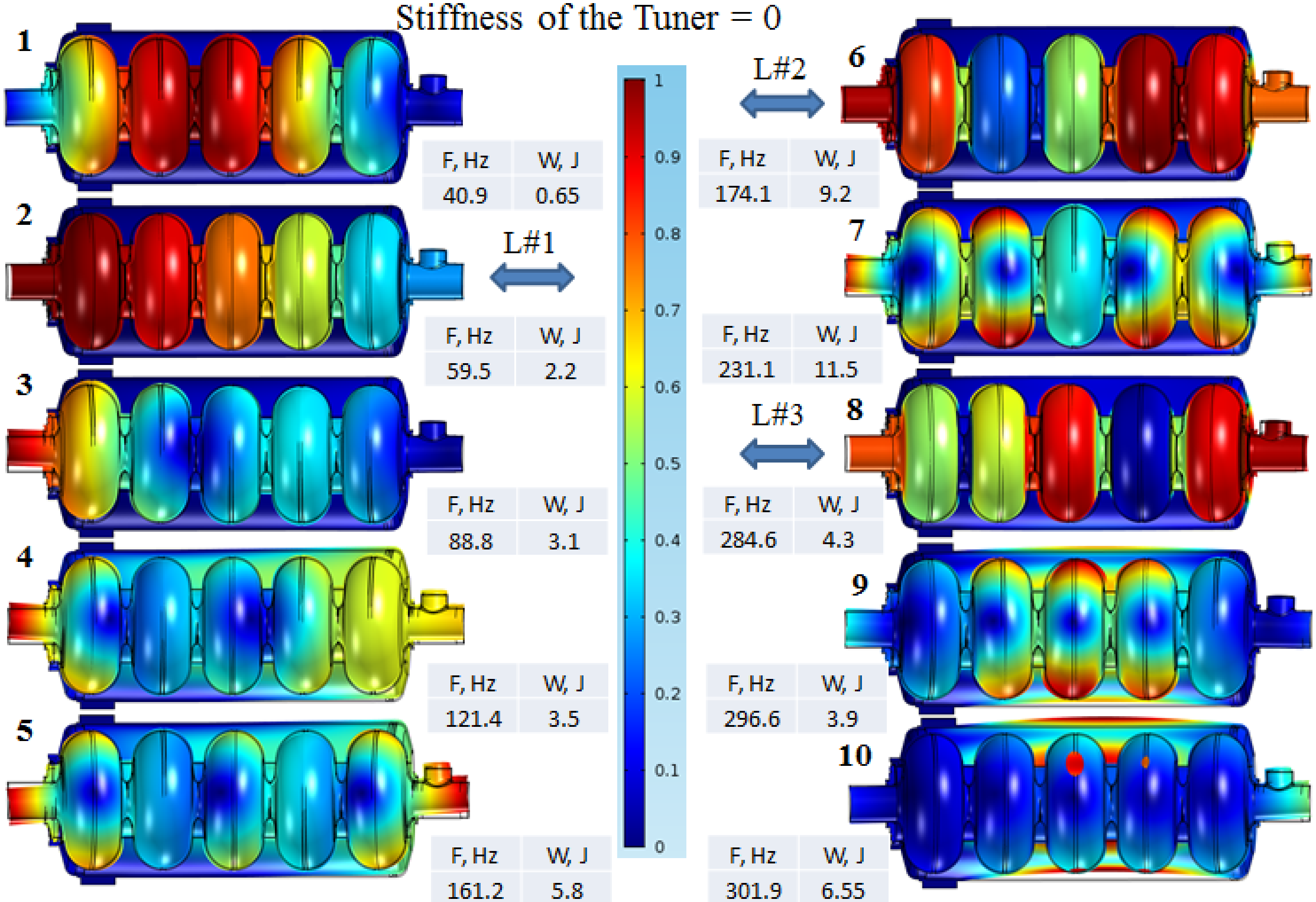


Stiffening rings located to minimize df/dP while maintaining tunability



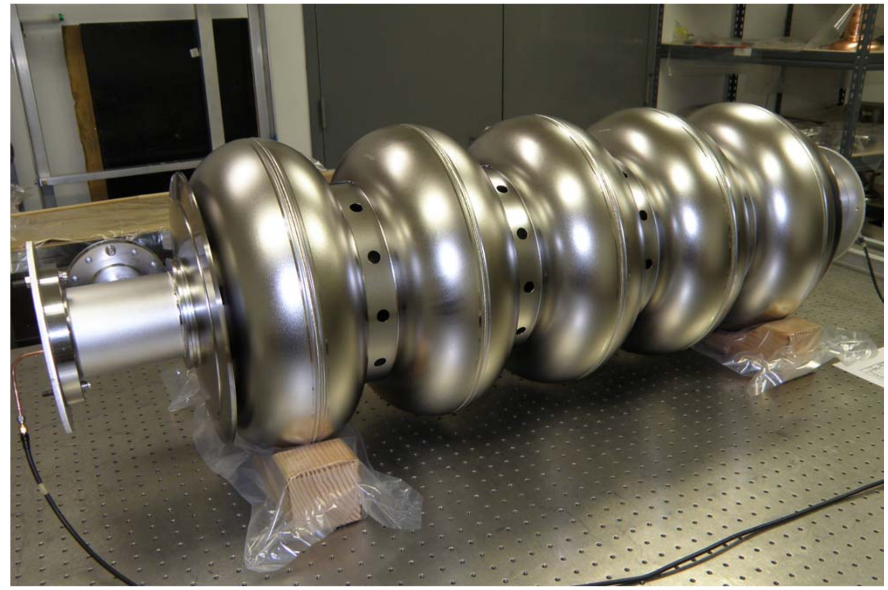
HB 650 MHz cavity

10 Lowest Mechanical Resonance
Total Energy normalized on 1mm max-displacement
Stiffness of the Tuner = 0



R_{ring}=110/115 mm

HB 650 MHz cavity production status



Currently Available Cavities:

<u>1-Cell 650 MHz</u>

1. B9AS-AES-001*
2. B9AS-AES-002*
3. B9AS-AES-003 *
4. B9AS-AES-004 *
5. B9AS-AES-005 *
6. B9AS-AES-006
7. B9AS-RRCAT-301 *

<u>5-Cell 650 MHz</u>

1. B9A-AES-007
2. B9A-AES-008
3. B9A-AES-009
4. B9A-AES-010

*VTS Tested

Expected Cavities:

<u>1-Cell 650 MHz</u>

Pavac, Inc.

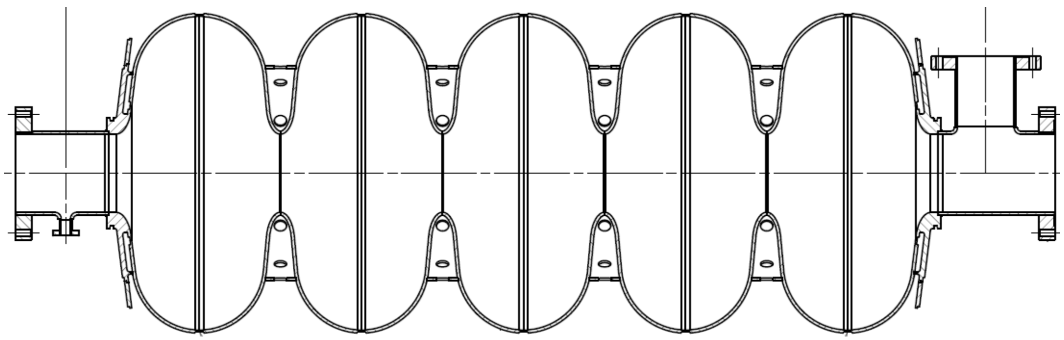
Four delivered and two to be delivered.

<u>5-Cell 650 MHz</u>

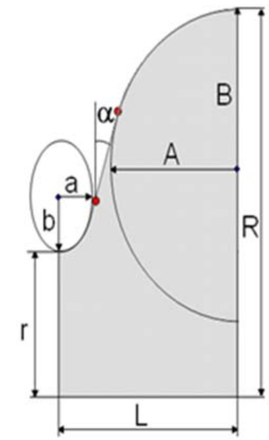
Pavac, Inc.

Five to be delivered

HB cavities under production (V1)



	Mid cell	End cell
r, mm	50	50
R, mm	200.3	200.3
L, mm	103.8	107.0
A, mm	82.5	82.5
B, mm	84	84.5
a, mm	18	20
b, mm	38	39.5
α,°	5.2	7

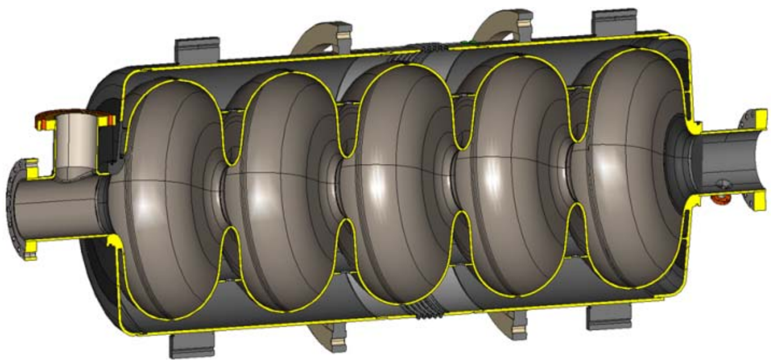


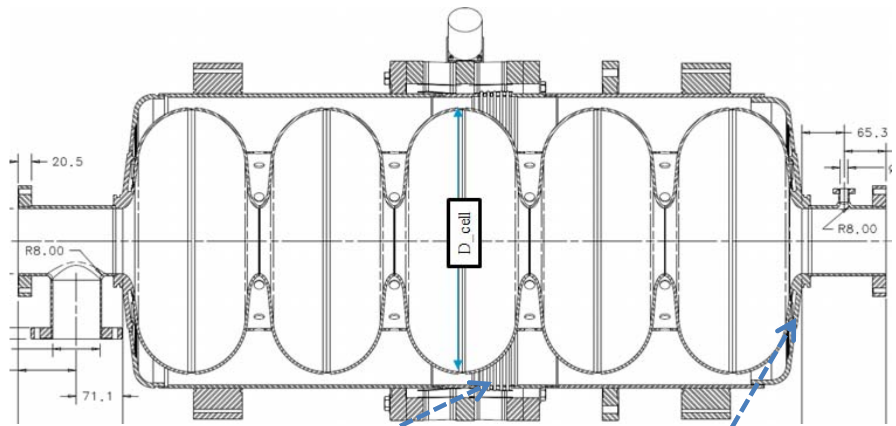
- 4 cavities manufactured in AES
  - Original RF design with 100 mm diameter iris and beam pipe
  - Stiffening rings: 126 mm radius inter-cells, 134 mm end cell to vessel
  - Delivery beginning of June
- 5 cavities under production in PAVAC
  - Original RF design with 100 mm diameter iris and beam pipe
  - Stiffening rings: 126 mm radius inter-cells, 134 mm end cell to vessel
  - Cell forming not started yet
- 2 cavities scheduled under IIFC
  - Mid-cell shape single cell will be delivered in July. Original RF design with 100 mm diameter iris and beam pipe
  - Original RF design with 100 mm diameter iris and beam pipe dies exist
  - Niobium in hand

Option I. Dressing of the cavities currently under production (V1 & BT)

Original Helium Vessel with Blade Tuner in the middle

- Mechanical design and drawings of Helium Vessel are ready
- Mechanical design and drawings of Blade Tuner are ready
- Tuner under development in India is plug compatible with Blade Tuner
- Nothing purchased yet





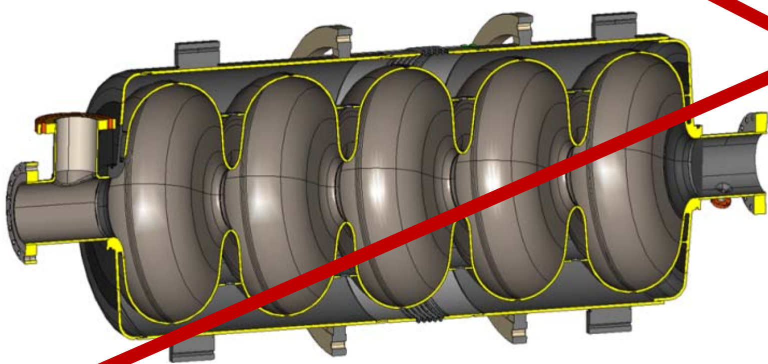
1. The design is too stiff, which may be a problem for freq. tuning
2. The Blade Tuner has a hysteresis (freq. fine tuning issue)
3. Expensive bellows (extra large diameter) and transition spools

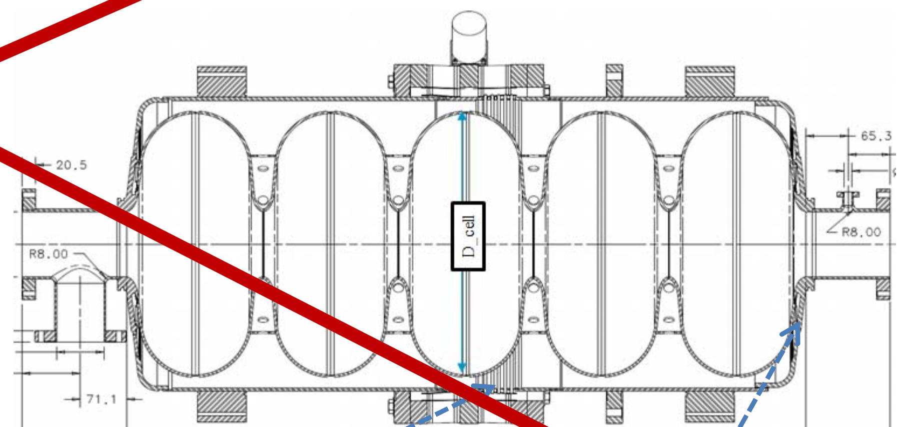
Prepared for PX Technical Board meeting on 05/31/2013

Option I. Dressing of the cavities currently under production (V1 & BT)

Original Helium Vessel with Blade Tuner in the middle

- Mechanical design and drawings of Helium Vessel are ready
- Mechanical design and drawings of Blade Tuner are ready
- Tuner under development in India is plug compatible with Blade Tuner
- Nothing purchased yet





1. The design is too stiff, which may be a problem for freq. tuning
2. The Blade Tuner has a hysteresis (freq. fine tuning issue)
3. Expensive bellows (extra large diameter) and transition spools

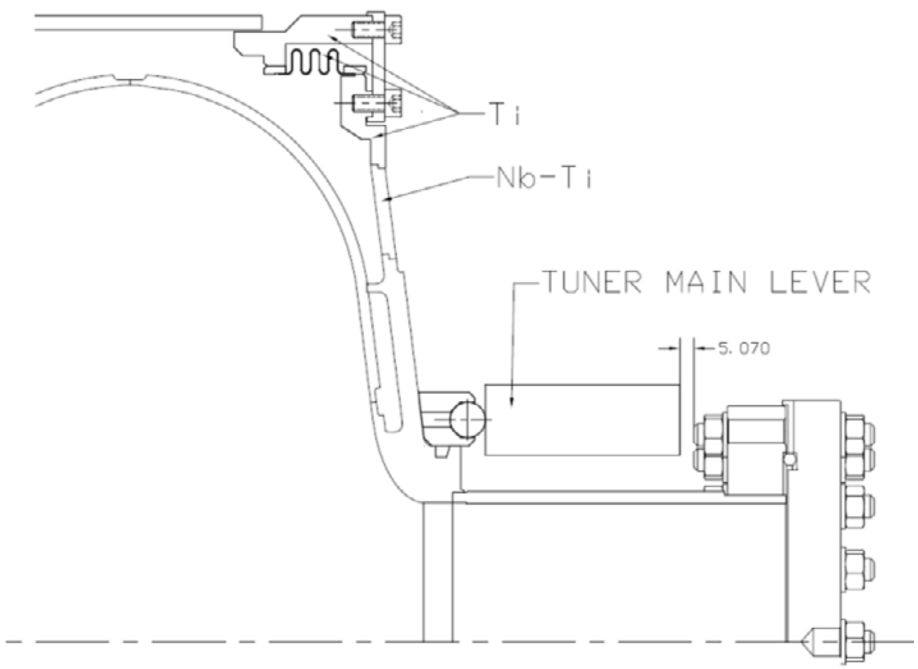
Prepared for PX Technical Board meeting on 05/31/2013

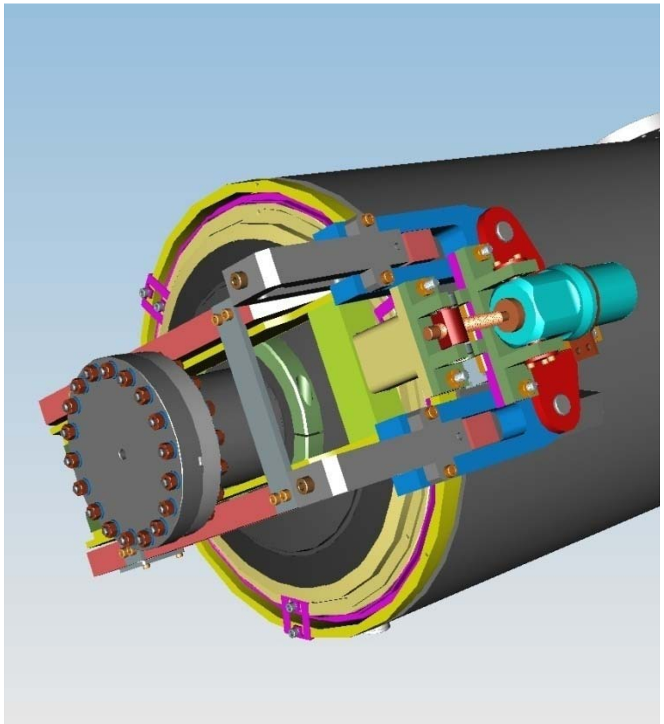
Option II. Dressing of the cavities currently under production (V1 & LT)

Modified Helium Vessel Lever Tuner in the end for the cavity V1

- Mechanical design of Modified Helium Vessel is proposed
- Mechanical design of the Lever Tuner is proposed
- Nothing purchased yet
- First V1 cavities will be ready in few months

Lever tuner for the cavity V1



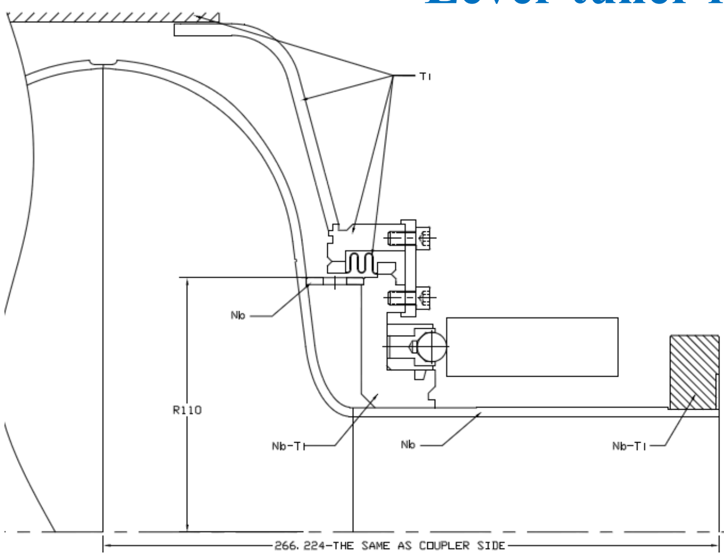


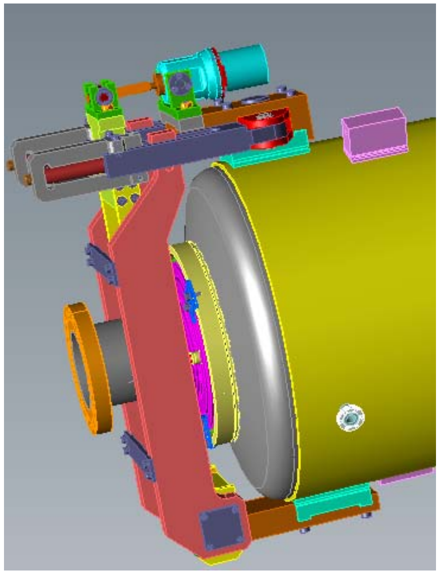
Prepared for PX Technical Board meeting on 05/31/2013

Option III. Modification of the cavity (V1a) with existing RF design

- Original RF design with 100 mm diameter iris and beam pipe
- Stiffening ring diameter reduced to improve tune-ability of the cavity
- Stiffening rings: 115 mm radius inter-cells, 110 mm end cell to vessel
- Helium Vessel bellows diameter reduced in order to reduce df/dP
- Reduced diameter bellows can be installed only at the cavity end
- Modified Helium Vessel Lever Tuner in the end
- Reduced cost of bellows (~$18k) and cavity (no transition spools, ~2 x $20k)

Lever tuner for the cavity V1a



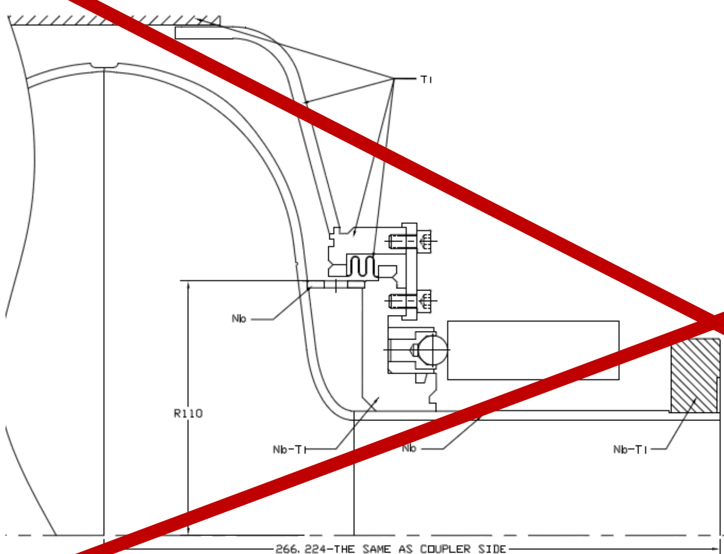


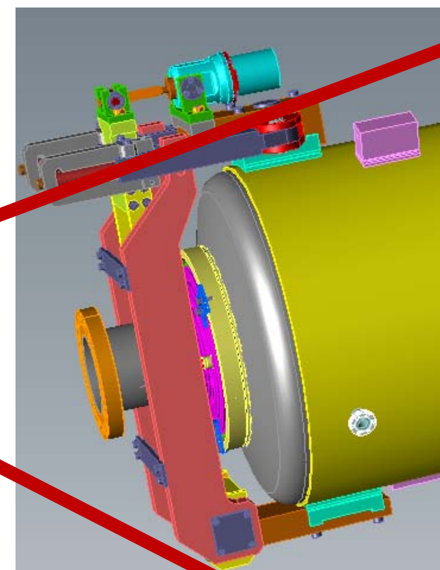
Prepared for PX Technical Board meeting on 05/31/2013

Option III. Modification of the cavity (V1a) with existing RF design

- Original RF design with 100 mm diameter iris and beam pipe
- Stiffening ring diameter reduced to improve tune-ability of the cavity
- Stiffening rings: 115 mm radius inter-cells, 110 mm end cell to vessel
- Helium Vessel bellows diameter reduced in order to reduce df/dP
- Reduced diameter bellows can be installed only at the cavity end
- Modified Helium Vessel Lever Tuner in the end
- Reduced cost of bellows (~$18k) and cavity (no transition spools, ~2 x $20k)

Lever tuner for the cavity V1a

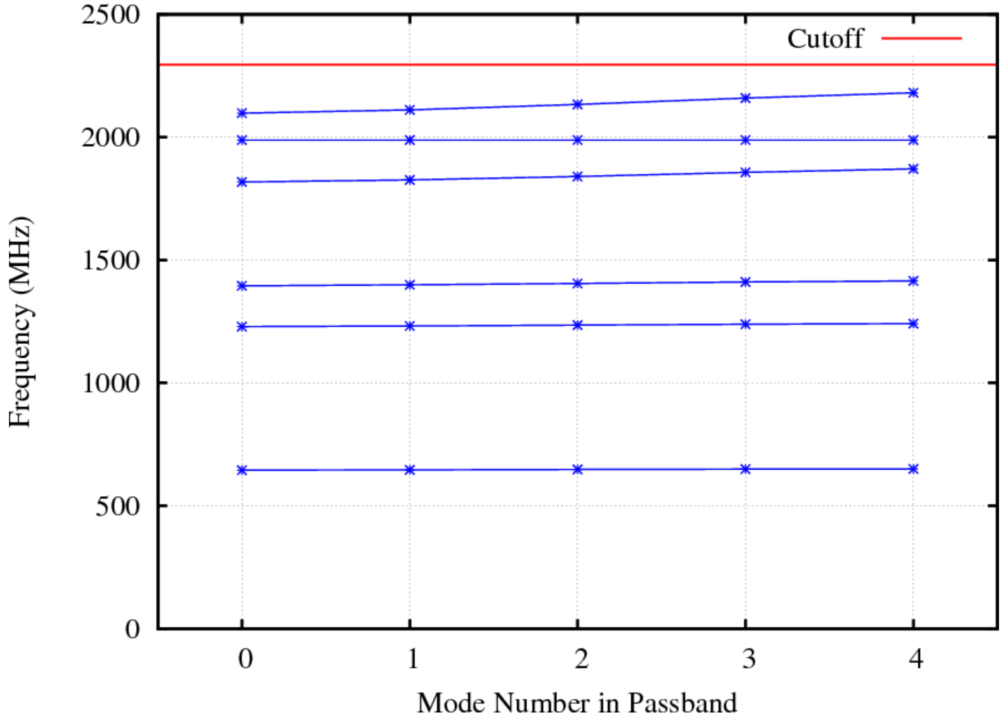




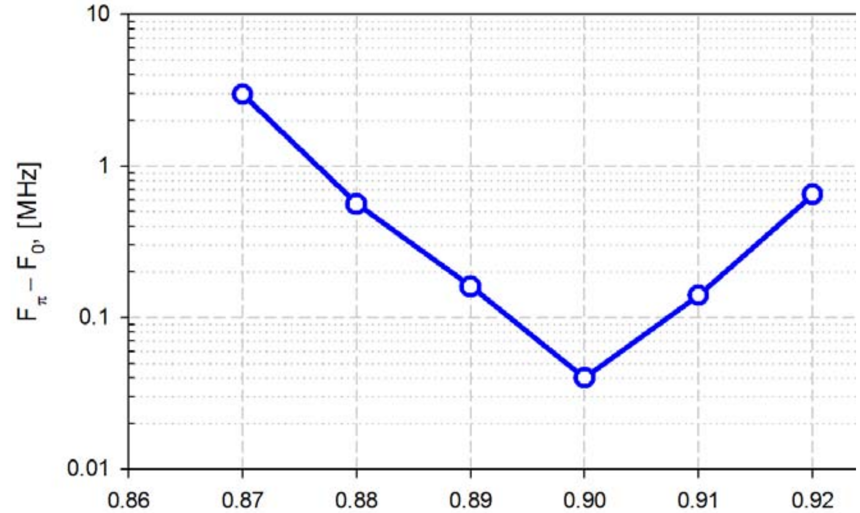
Motivation: move to the cavity with large aperture directly

Prepared for PX Technical Board meeting on 05/31/2013

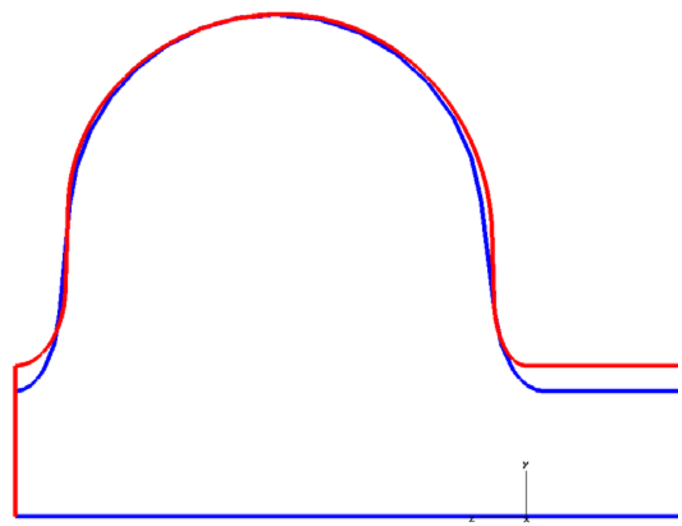
Option IV. Alternative β=0.92 cavity (V2)



The width of the 5th monopole band vs beta



	Beta = 0.90	Beta = 0.92
D_pipe, [mm]	100	118
D_cell, [mm]	400.5	400.2
L_struct, [mm]	1043.9	1043.8
L_max, [mm]	> 1335	> 1335



OLD & NEW End cell shapes

Prepared for PX Technical Board meeting on 05/31/2013

Considered combination of undressed cavities and frequency tuners

Options	Undressed Cavity	Frequency Tuner
~~I*~~	~~V1~~	~~Blade Tuner~~
II**	V1	Lever Tuner
~~III***~~	~~V1a~~	~~Lever Tuner~~
IV****	V2	Lever Tuner

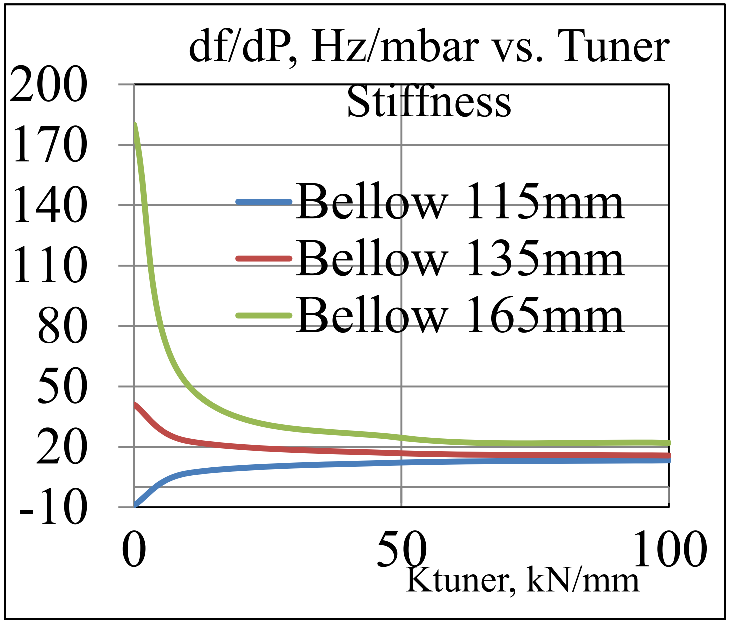
* V1 & BT is very stiff mechanically and may cause a cavity break
** V1&LT is suitable for first HB650 CM
** V1a & LT has optimized stiffening ring and bellows
*** V2 & LT is a preferred solution for future cavity production

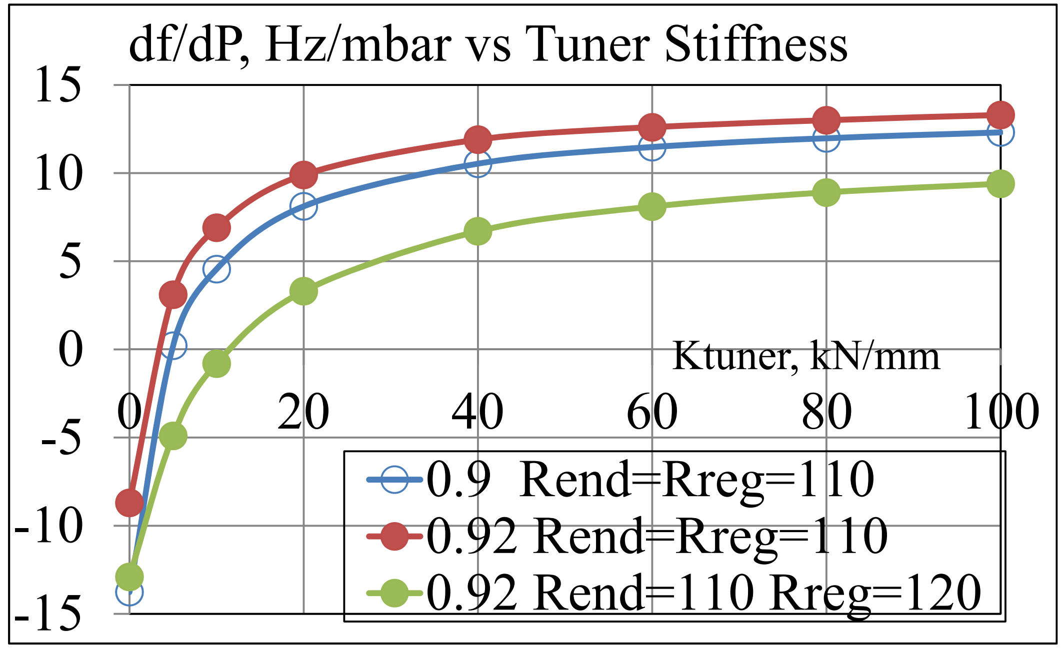
We will proceed with options II and IV !

Prepared for PX Technical Board meeting on 05/31/2013

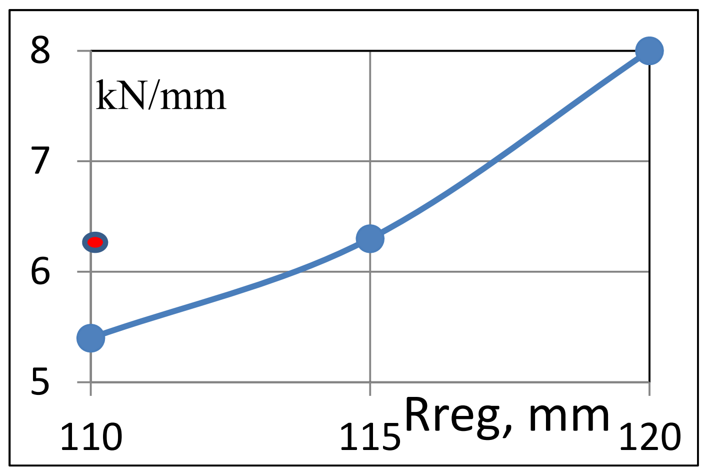
HB 650 MHz cavity

df/dP vs. Tuner Stiffness



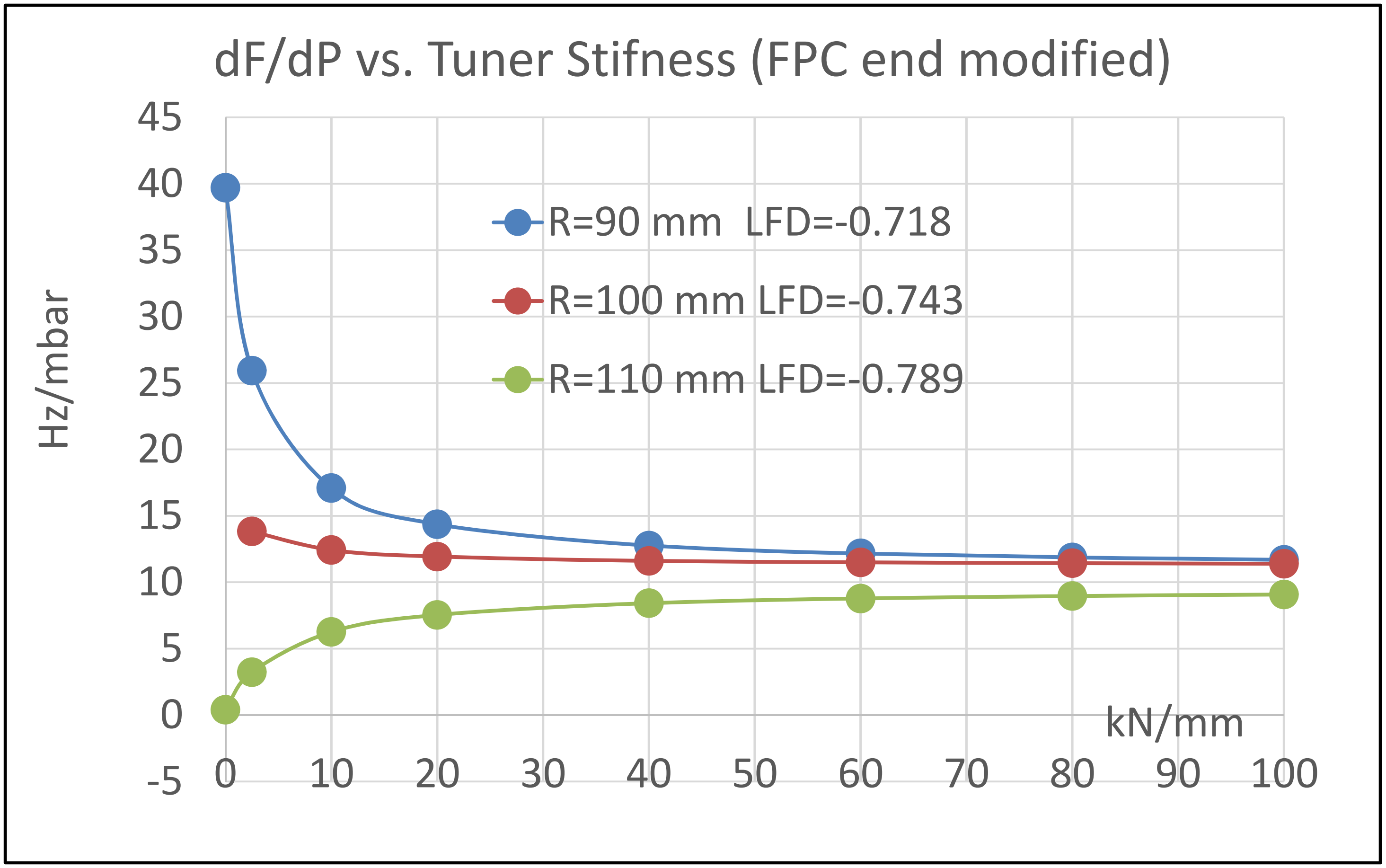


Stiffness of β=0.92 cavity kN/mm vs. Radius of the Regular stiffening ring
- Stiffness of β=0.9 cavity



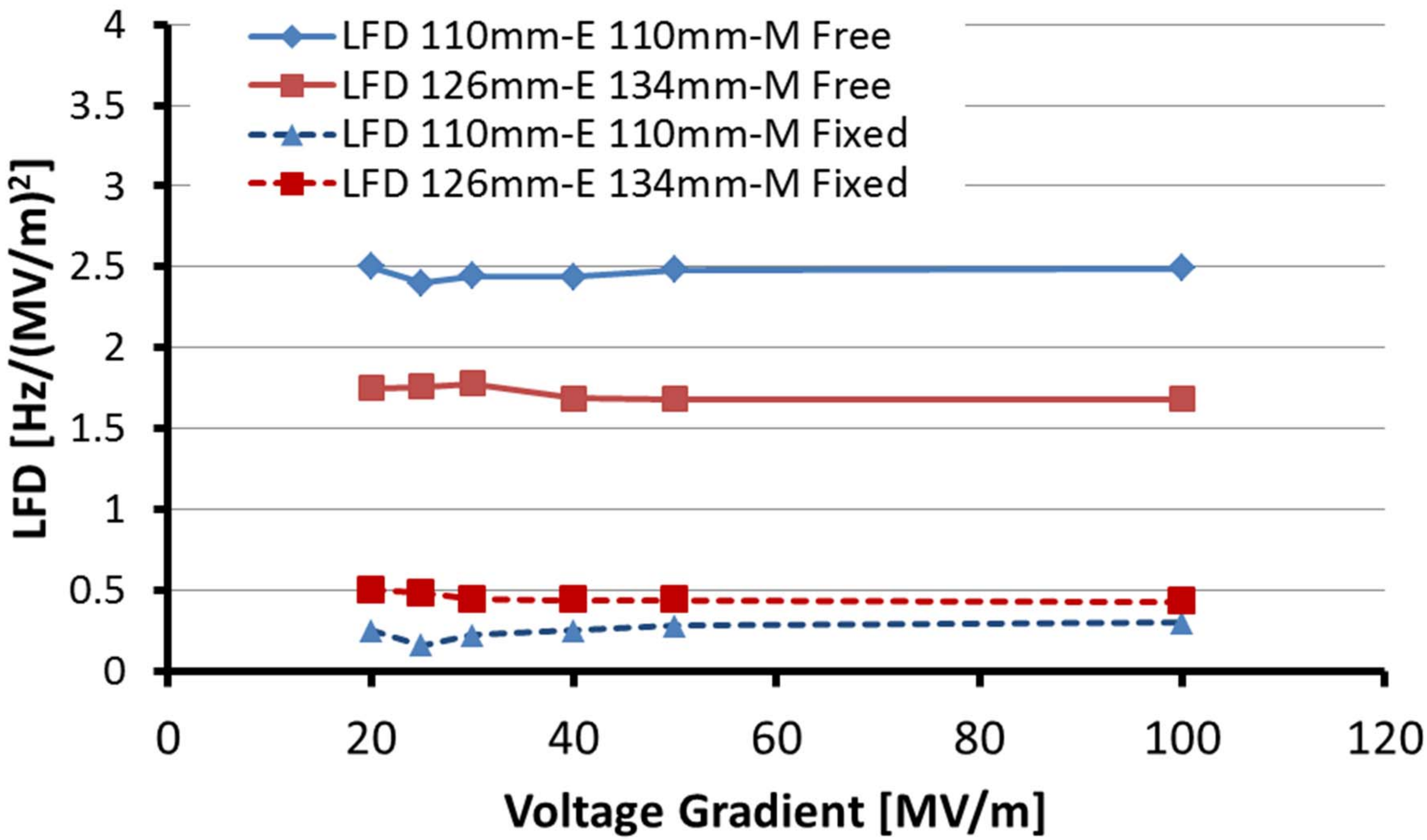
HB 650 MHz cavity

dF/dP vs. Tuner stiffness.
At different Radius of the stiffening rings



HB 650 MHz cavity

LFD Coefficient



*Leff=n*βλ/2=1.03846153846 m

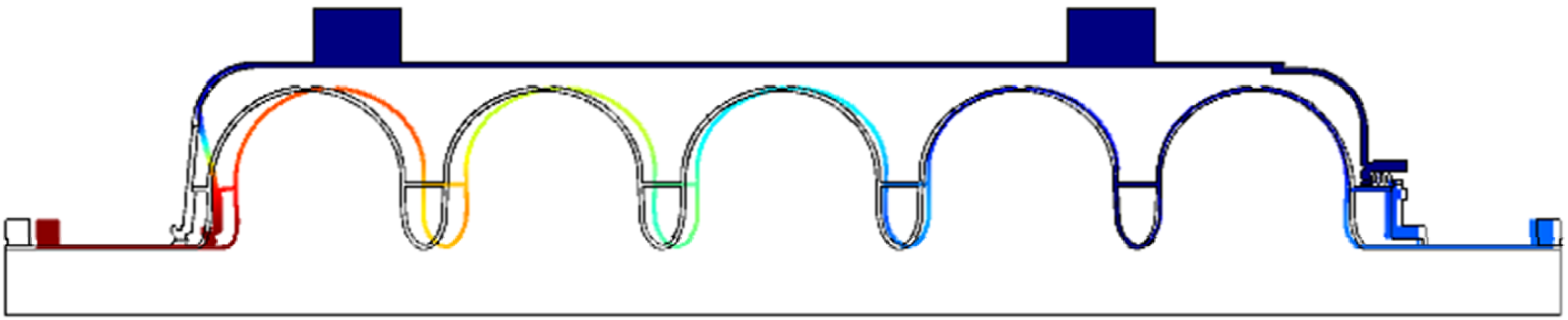
HB 650 MHz cavity

Lorentz force detuning

Original design of HB650 cavity with
deformations due to Lorentz forces
Eacc = 20 MV/m, Tuner stiffness 100 kN/mm

Fixed in transverse direction

Fixed



dL~2.01μm

LFD ~ -1.33 Hz/(MV/m)^2

dL~0.418μm

Cavity tuning sensitivity ~ 160 Hz/μm

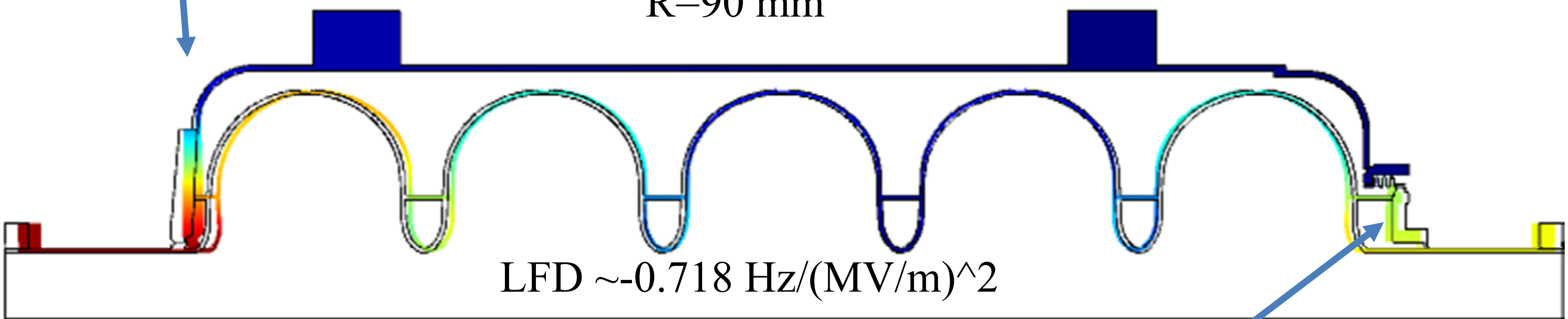
HB 650 MHz cavity

Lorentz force detuning, version V2.1

FPC end modification

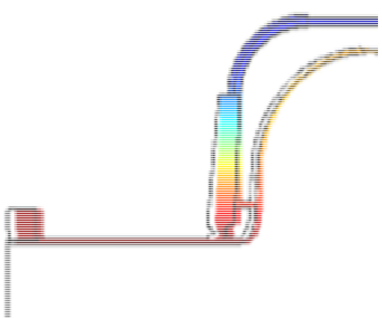
Eacc = 20 MV/m, Tuner stiffness 100 kN/mm

R=90 mm



dL~0.765μm

dL~0.481μm



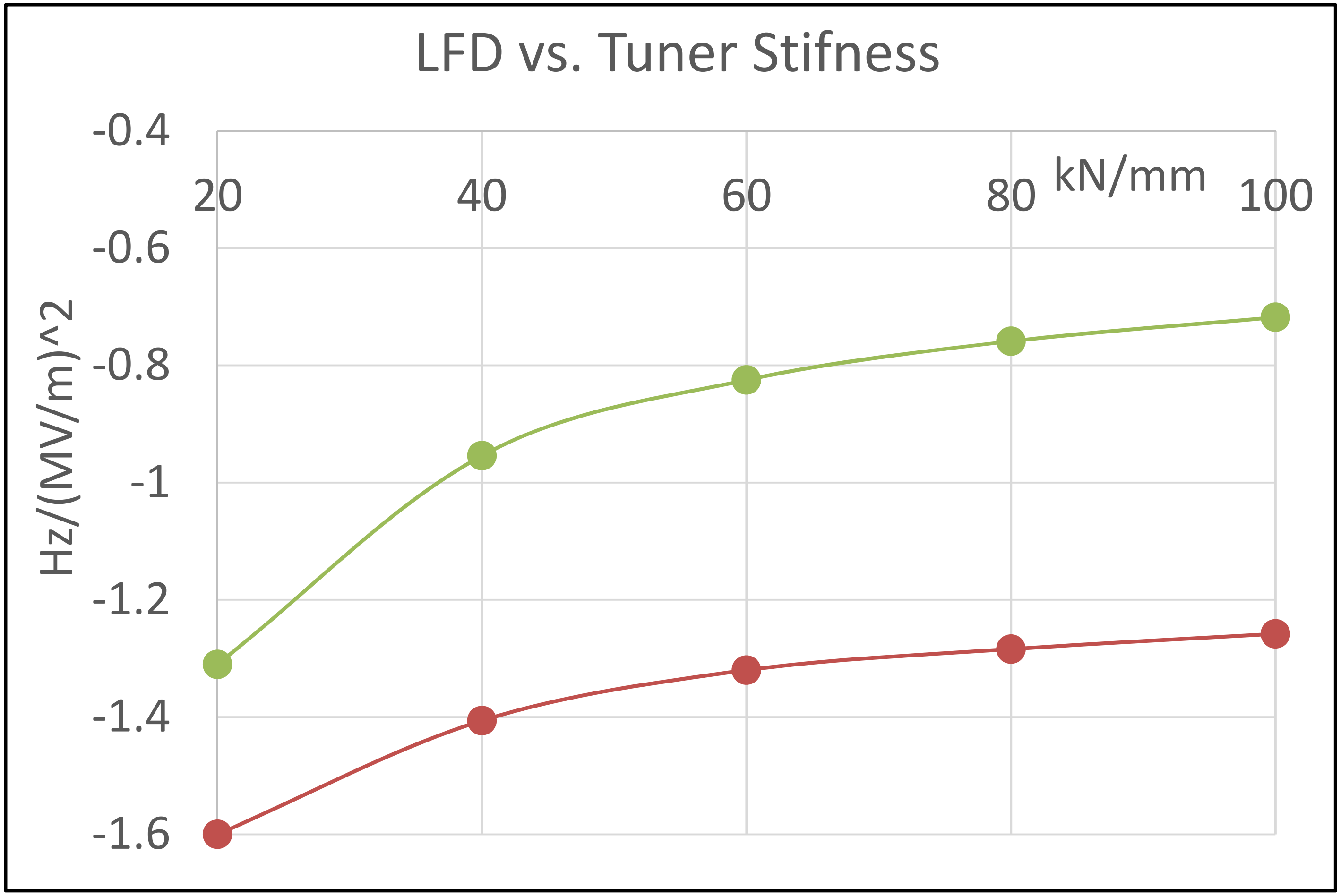
LFD~-0.654 Hz/(MV/m)^2

Tuner end modification will include better interface with the Tuner

HB 650 MHz cavity

Lorentz force detuning

Lorentz factor dependence vs. Tuner stiffness



Before (red) and after (green) FPC end modification

HB 650 MHz cavity

Lorentz force detuning

- 2D simulation has been done.
- LFD Coefficients (for 100 kN/mm tuner stiffness):
  V2 design: - 1.33 Hz / (MV/m)^2
  V2.1 design with modified ends: - 0.654 Hz / (MV/m)^2
- dF/dP is less than 15 Hz / mbar.
- Cavity stiffness is less than 3 kN/mm and tuning sensitivity is ~ 160 kHz/mm.
- Input RF power coupler is to be moved by 5 – 10 mm.
- A decision has to be taken for acceptable LFD coefficient and tuner stiffness.
- Tuner end conical flange modification will include better compatibility with the Tuner
- Design will be finalized and further works will be done.

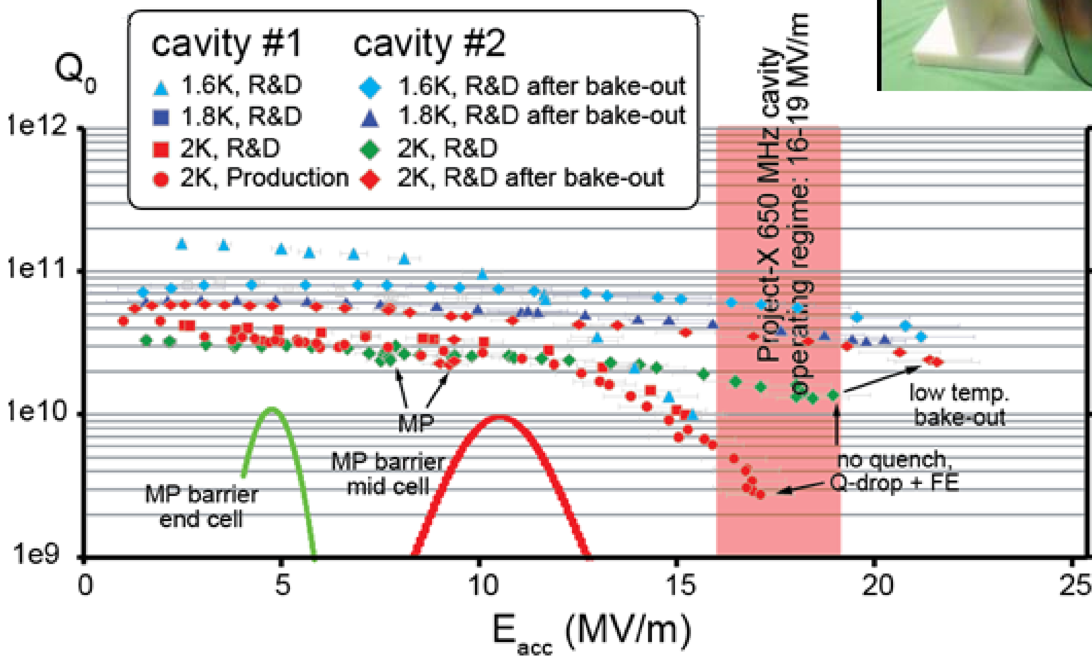
LB 650 MHz cavity

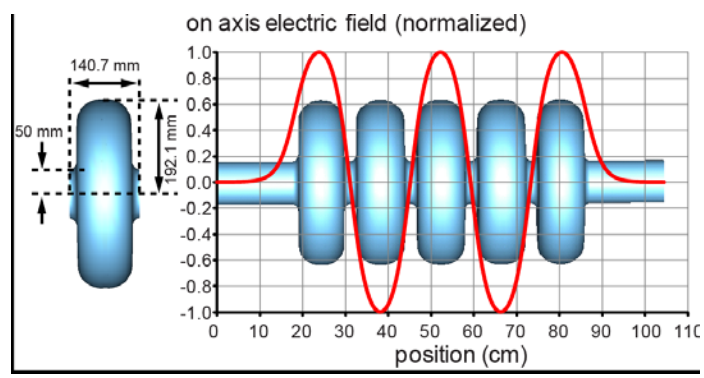
Cavity operational and test requirements

Parameter	Value
Max Leak Rate (room temp)	< 10^{-10} atm-cc/sec
Operating gradient	16.5 MeV/m
Maximum Gain per cavity	11.6 MeV
Q_0	>1.5x 10^9
Maximum power dissipation per cavity at 2 K	24 W
Sensitivity to He pressure fluctuations	< 25 Hz/Torr
Field Flatness	Within ±10%
Multipacting	none within ±10% of operating gradient
Operating temperature	1.8-2.1 K
Operating Pressure	16-41 mbar differential
MAWP	2 bar (RT), 4 bar (2K)
Max RF power input per cavity	33 kW (CW, 2 mA)

LB 650 MHz cavity

JLAB 1-cell 650 MHz, beta=0.61 cavity



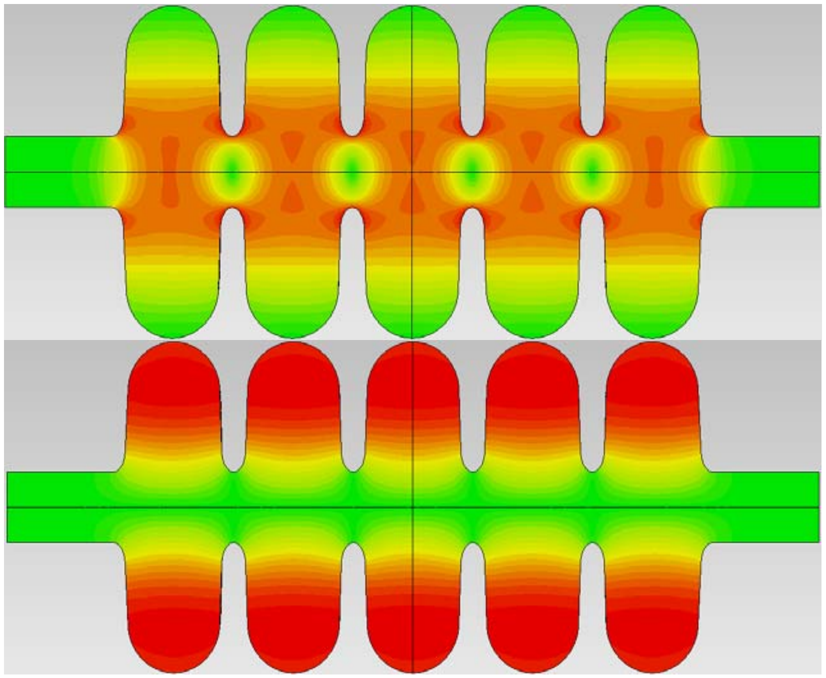


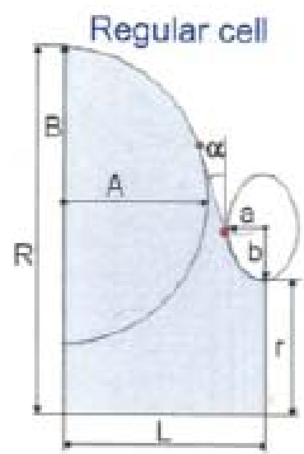
For the cavity #2

Q_0 >4e10 @17MeV/m

We have 6 more single cell cavities manufactured in RI:
3 JLAB design and 3 FNAL design

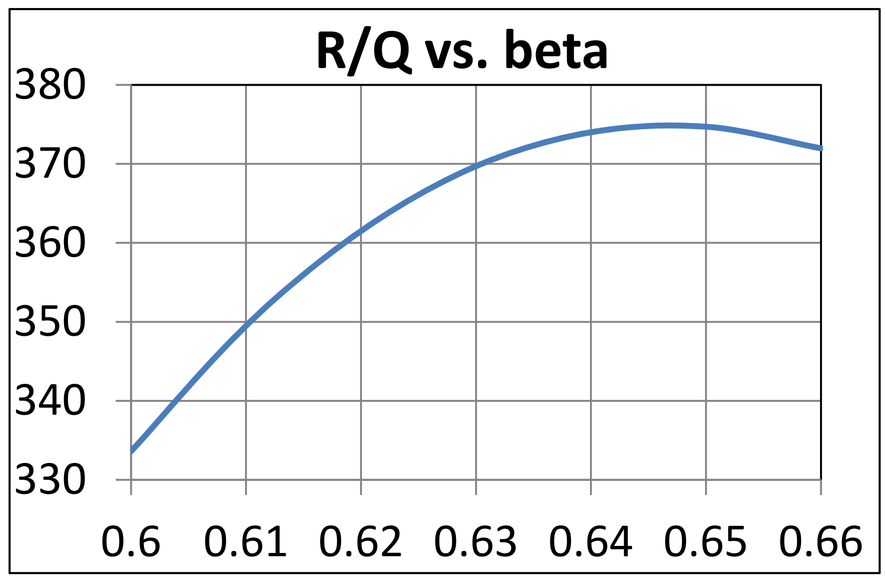
LB 650 MHz cavity





r, mm	41.5
R, mm	195
L, mm	70.3
A, mm	54
B, mm	58
a, mm	14
b, mm	25
α,°	2

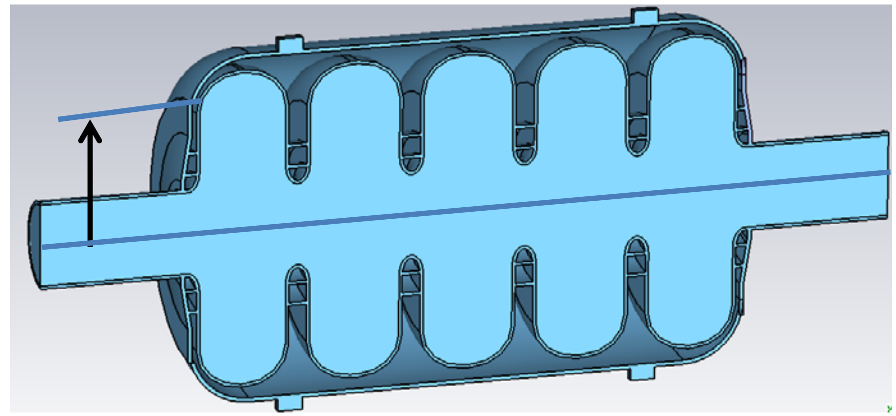
F, MHz	650.00	
Beta	0.61 (g)	0.647(o)
Leff, $5\beta_g\lambda/2$,m	0.703	
R/Q, Ohm	350.7	375.4
G, Ohm	191	
Epeak/Eacc	2.34	2.26
Bpeak/Eacc	4.36	4.21



LB 650 MHz cavity

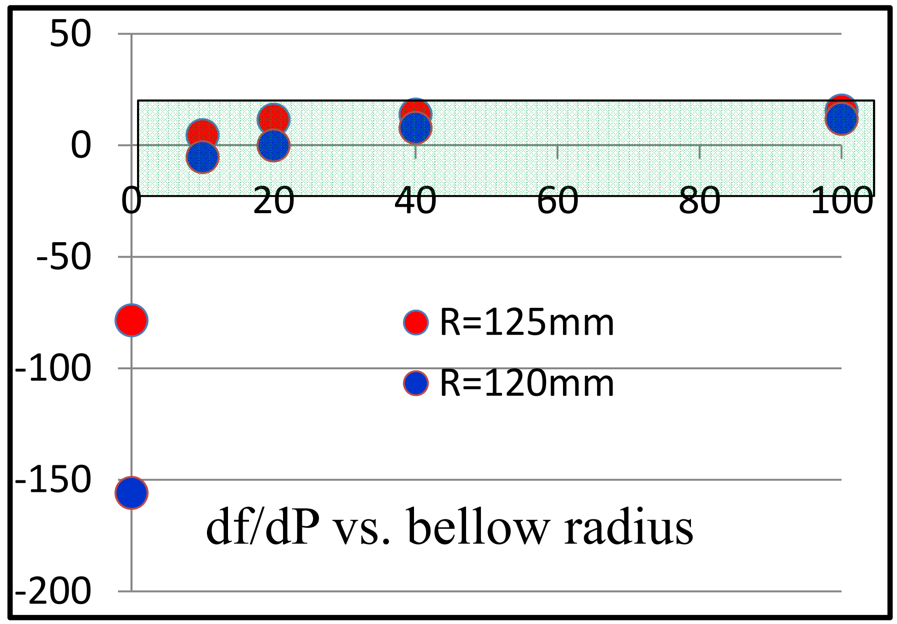
df/dP simulations

Bellows radius



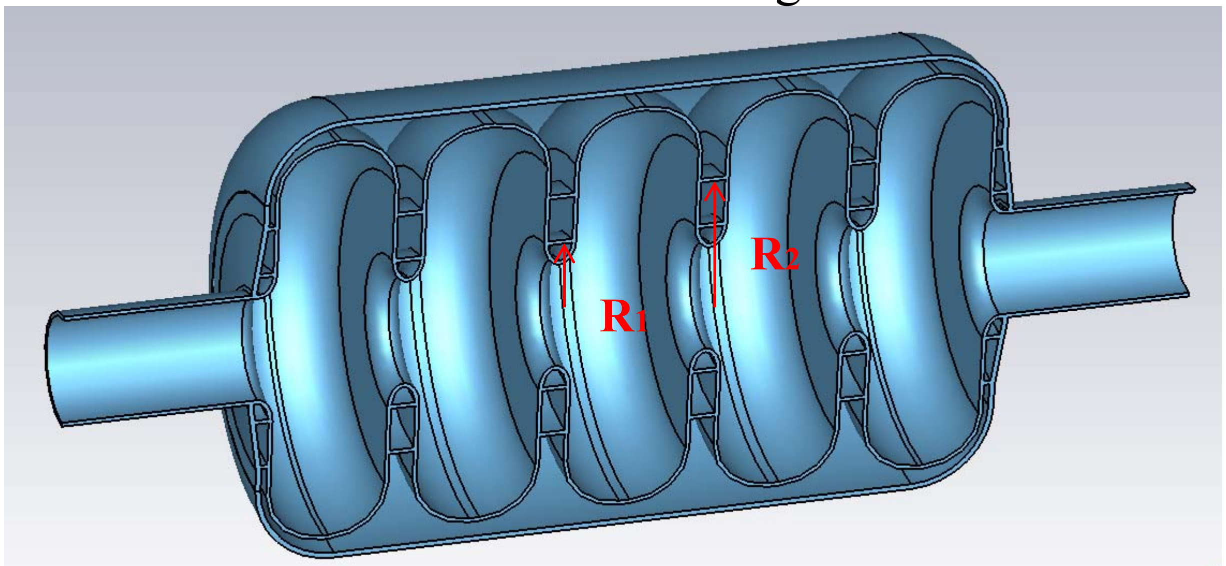
Sensitivity to He pressure fluctuations
df/dP optimization

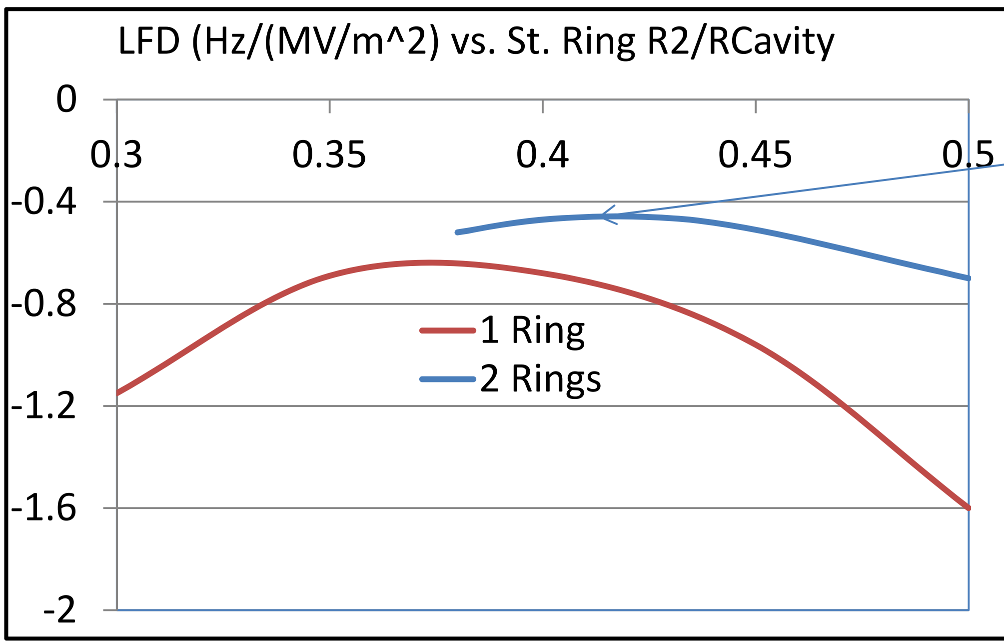
- Bellows radius was used as a parameter for optimization
- Frequency Tuner stiffness range of 10 - 100 kN/mm was considered



LB 650 MHz cavity

Lorentz force detuning





Cavity Stiffens ~2.7 kN/mm

Summary

1. HB 650 cavity design status
   - Four old design cavities manufactured and need to be tested.
   - New design of the dressed 5-cell cavity is complete.
   - LFD reduction could be necessary, simulations started
   - Version V2.1 proposed with reduced LFD

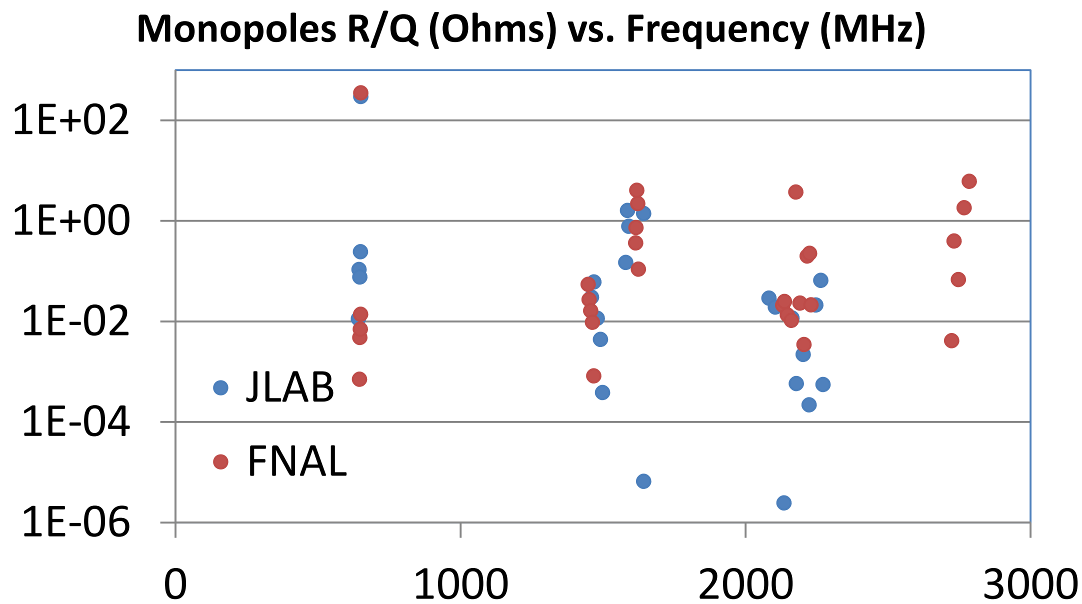
2. LB 650 cavity design is ready in two versions.

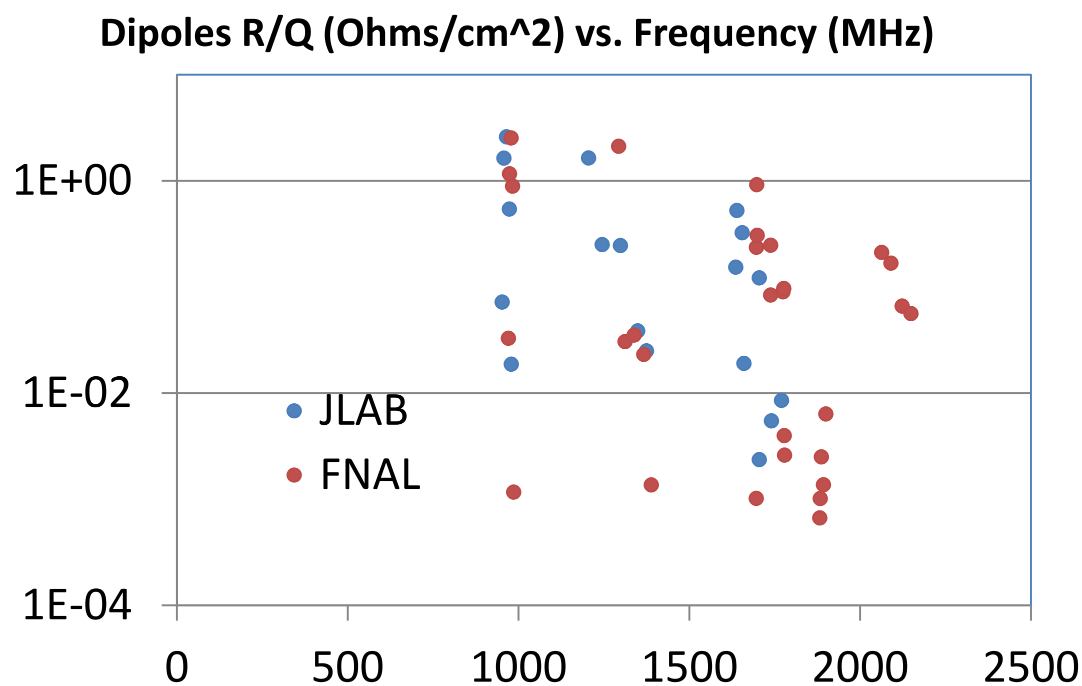
- EM design of both LB 650 versions, JLAB and FNAL, are ready
- Four single-cell cavities LB 650 JLAB and three LB 650 FNAL are manufactured
- Two LB 650 JLAB cavities are processed and tested
- We plan to test LB 650 FNAL cavities in order to make a choice between them and continue design
- Need to finish cold tests of both types of single cells
- Design of Helium Vessel with low df/dP and LFD started

Additional slides

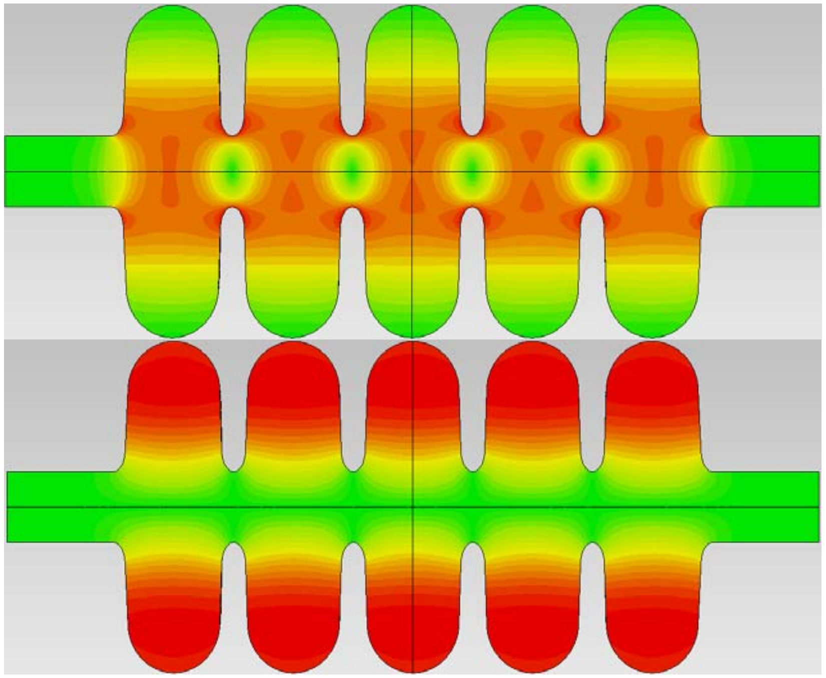
PROJECT X β=0.61 CAVITY
FNAL 83mm, JLAB 100mm , JLAB 92mm
PARAMETERS SUMMARY

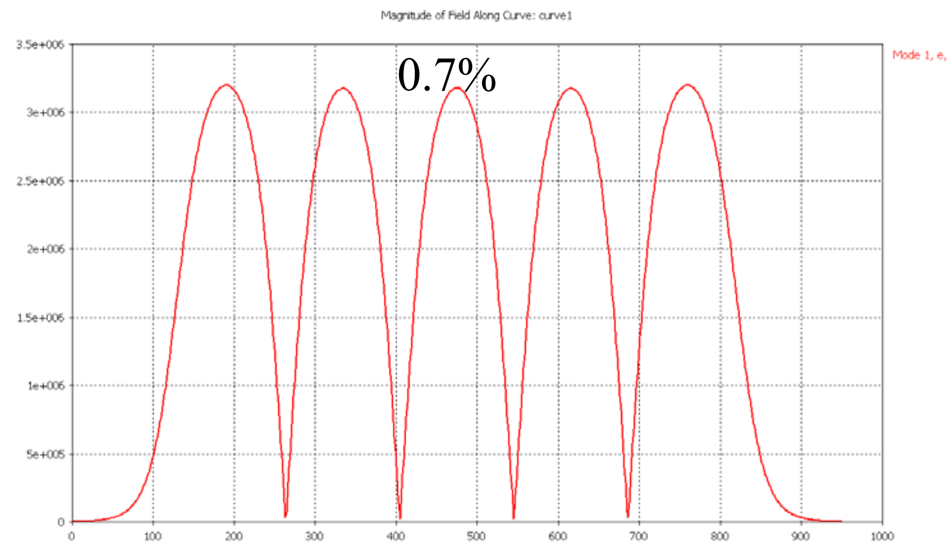
	FNAL 83 mm	JLAB 100 mm
β_G	0.61	0.61
β_{opt}	0.647	0.645
$R/Q(\beta_G)$, Ohms	351.5	297.2
$R/Q(\beta_{opt})$, Ohms	377.0	317.5
$E_{surf}/E(\beta_G)$	2.34	2.73
$E_{surf}/E(\beta_{opt})$	2.26	2.64
$B_{surf}/E(\beta_G)$, mT/MeV/m	4.36	4.80
$B_{surf}/E(\beta_{opt})$, mT/MeV/m	4.21	4.64
G, Ohms	191	191


Monopoles R/Q (Ohms) vs. Frequency (MHz)
1E+02
1E+00
1E-02
1E-04
1E-06
JLAB
FNAL
0
1000
2000
3000

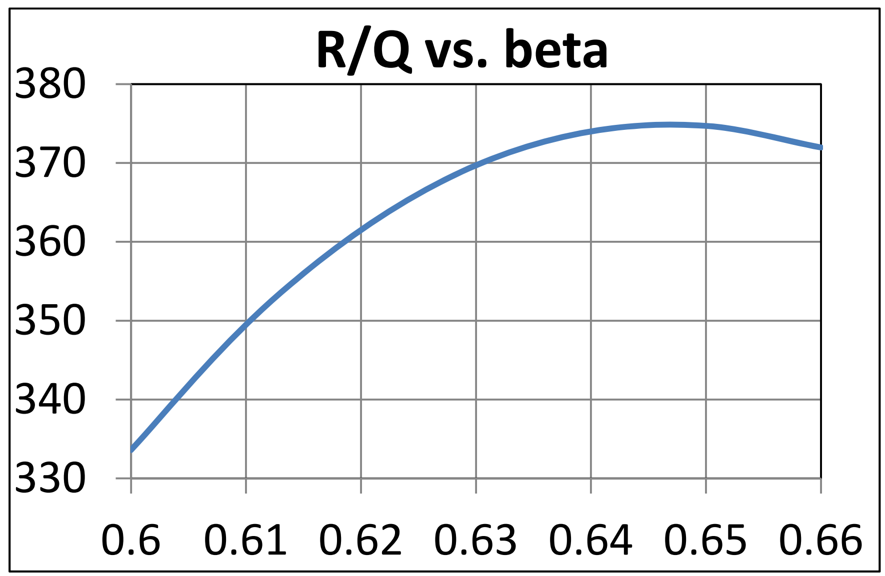

Dipoles R/Q (Ohms/cm^2) vs. Frequency (MHz)
1E+00
1E-02
1E-04
JLAB
FNAL
0
500
1000
1500
2000
2500

FNAL LB 5-cell 650 MHz

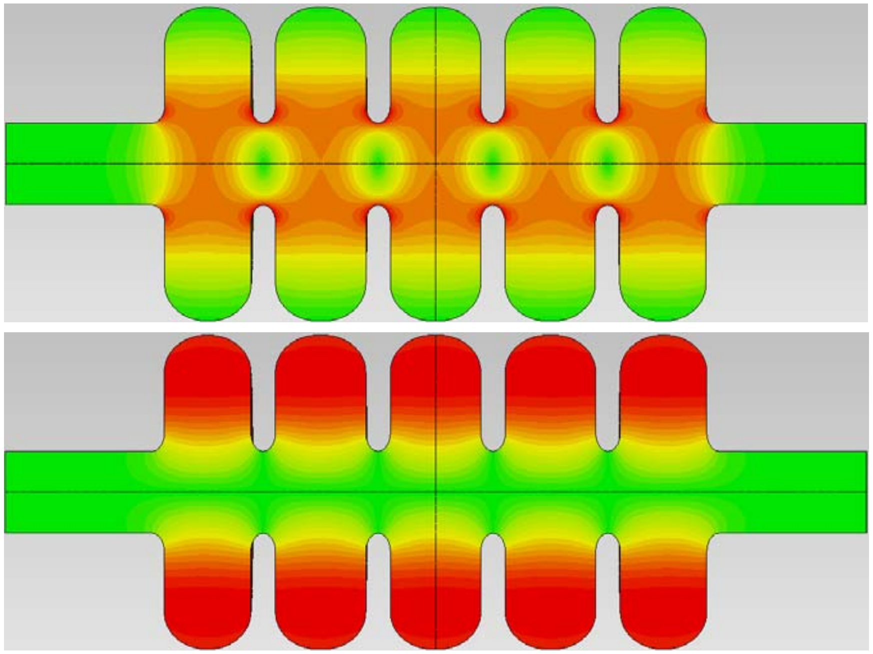


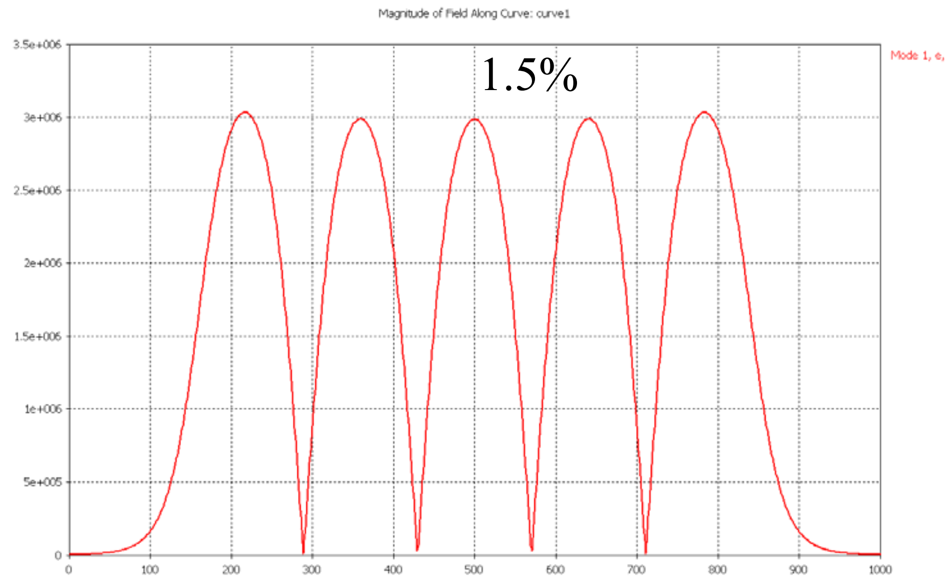


F, MHz	650.00	
Beta	0.61 (g)	0.647(o)
Leff, $5\beta_g\lambda/2$,m	0.703	
R/Q, Ohm	351.5	377.0
G, Ohm	191	
Epeak/Eacc	2.34	2.26
Bpeak/Eacc	4.36	4.21

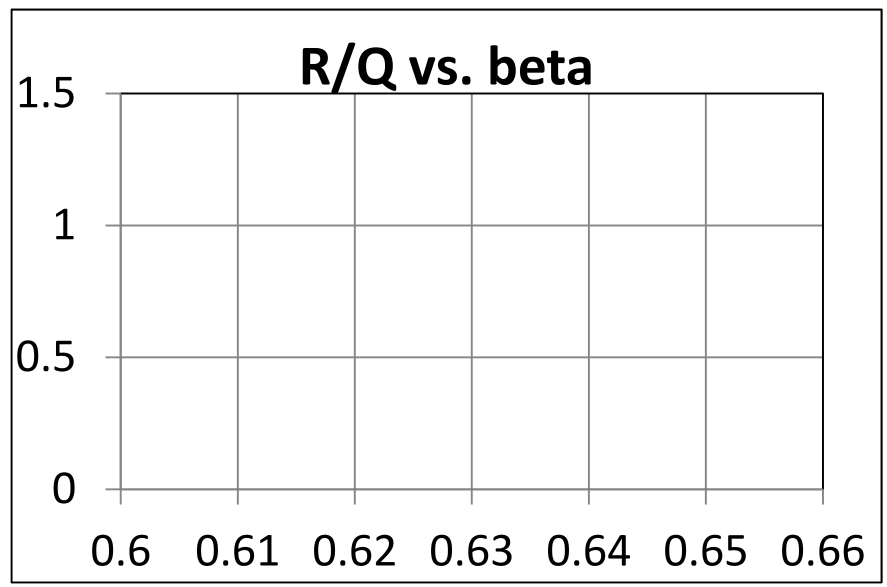


JLAB LB 5-cell 650 MHz



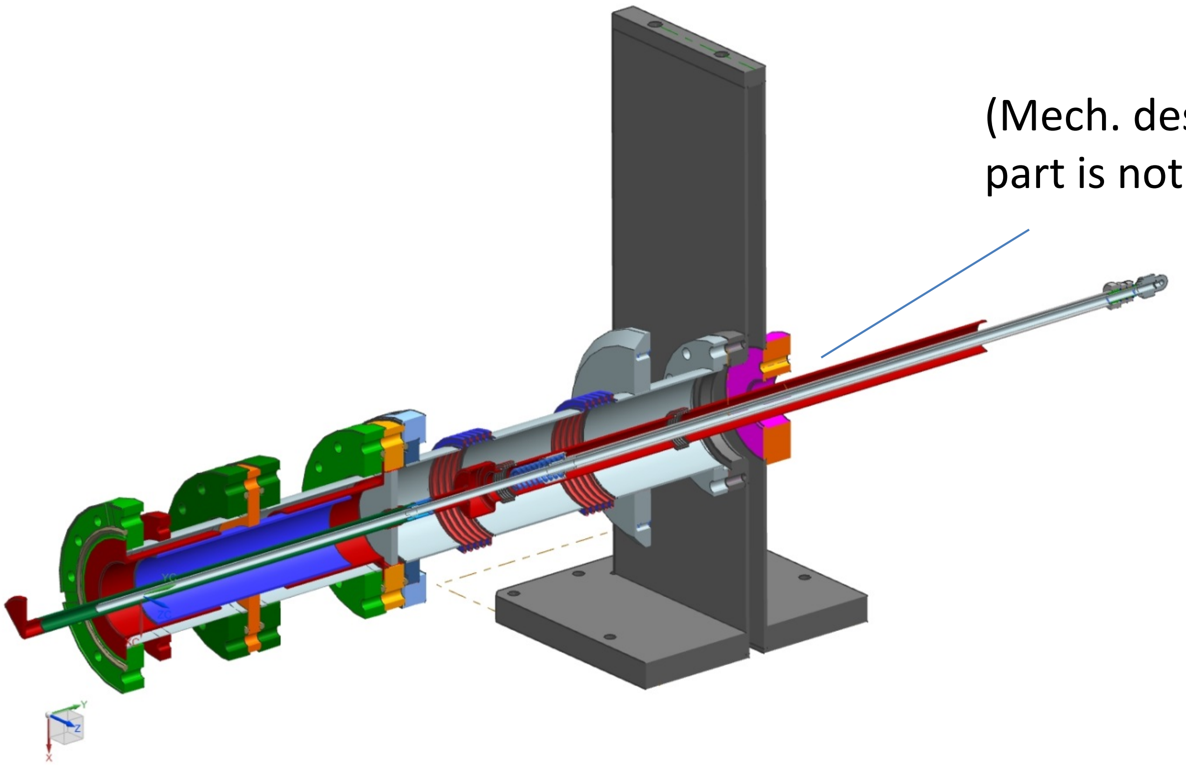


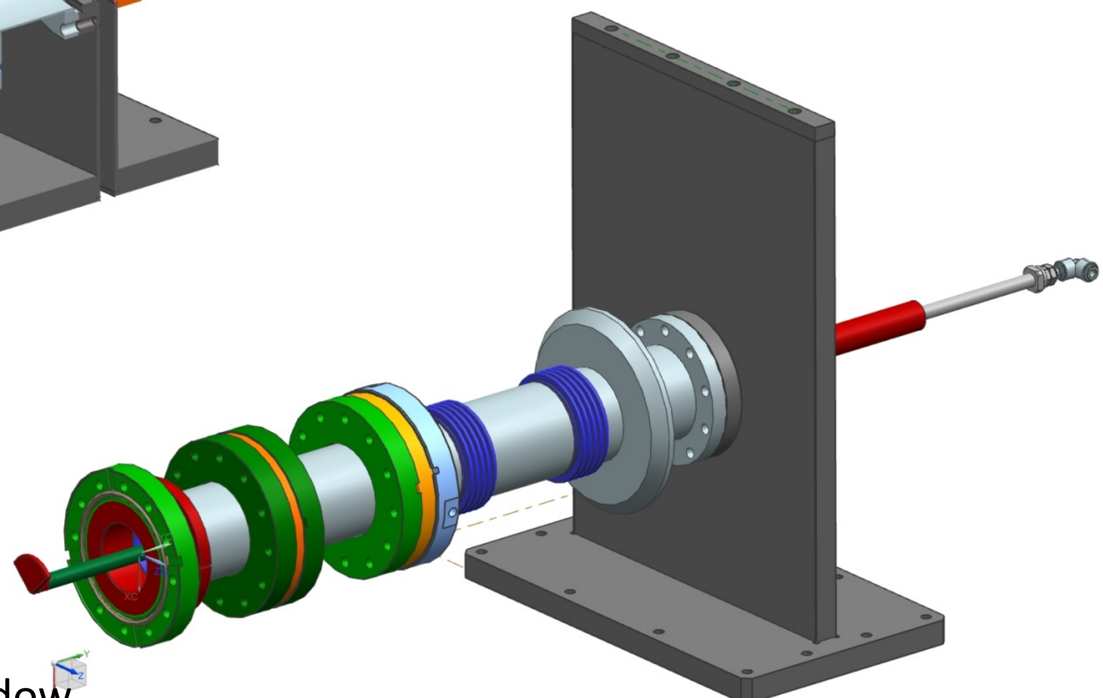
F, MHz	650.00	
Beta	0.61 (g)	0.645(o)
Leff, 5$\beta_g\lambda$/2,m	0.703	
R/Q, Ohm	297.2	317.5
G, Ohm	191	
Epeak/Eacc	2.73	2.64
Bpeak/Eacc	4.80	4.64



650 MHz couple work is resumed.

(Mech. design of this
part is not ready yet)

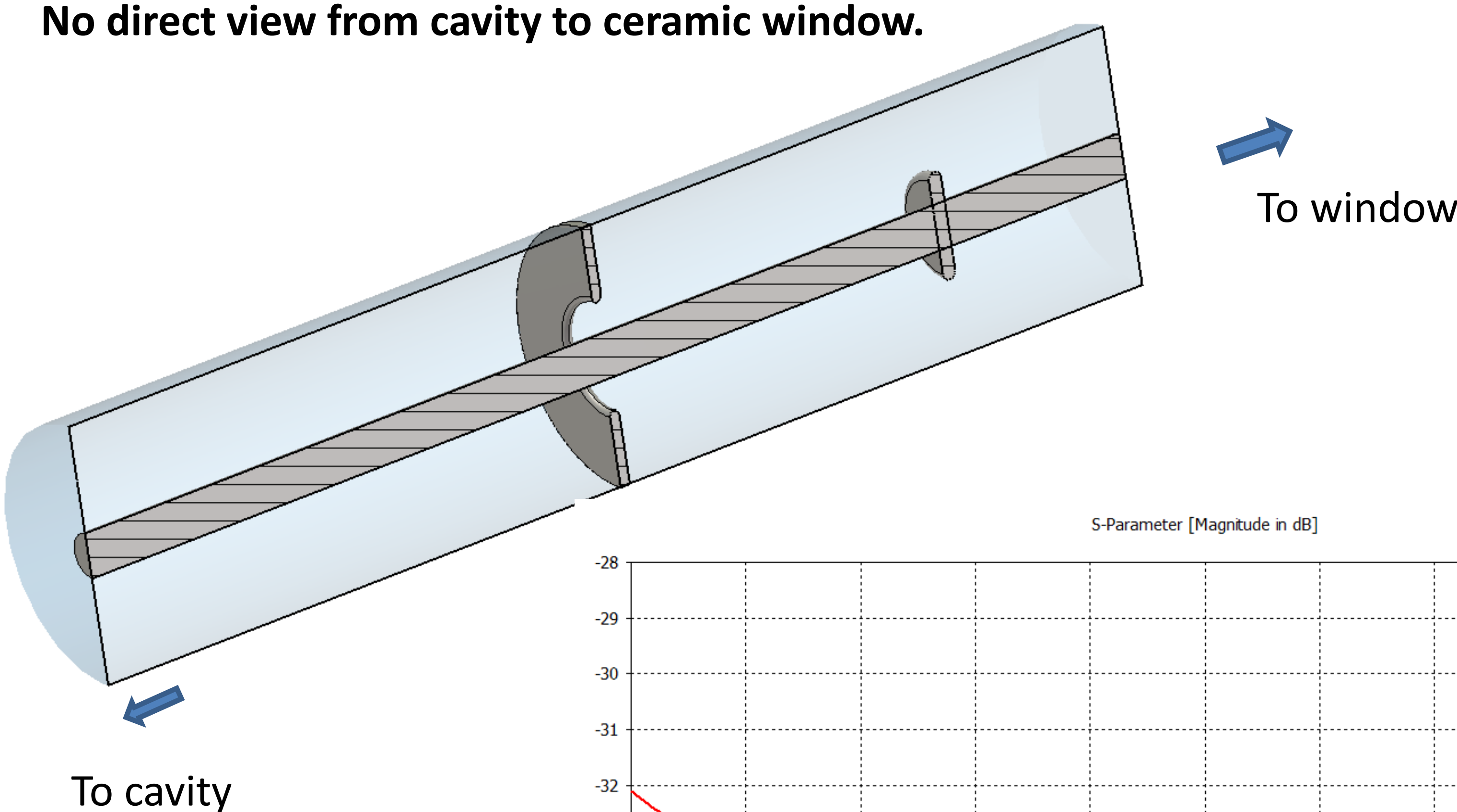


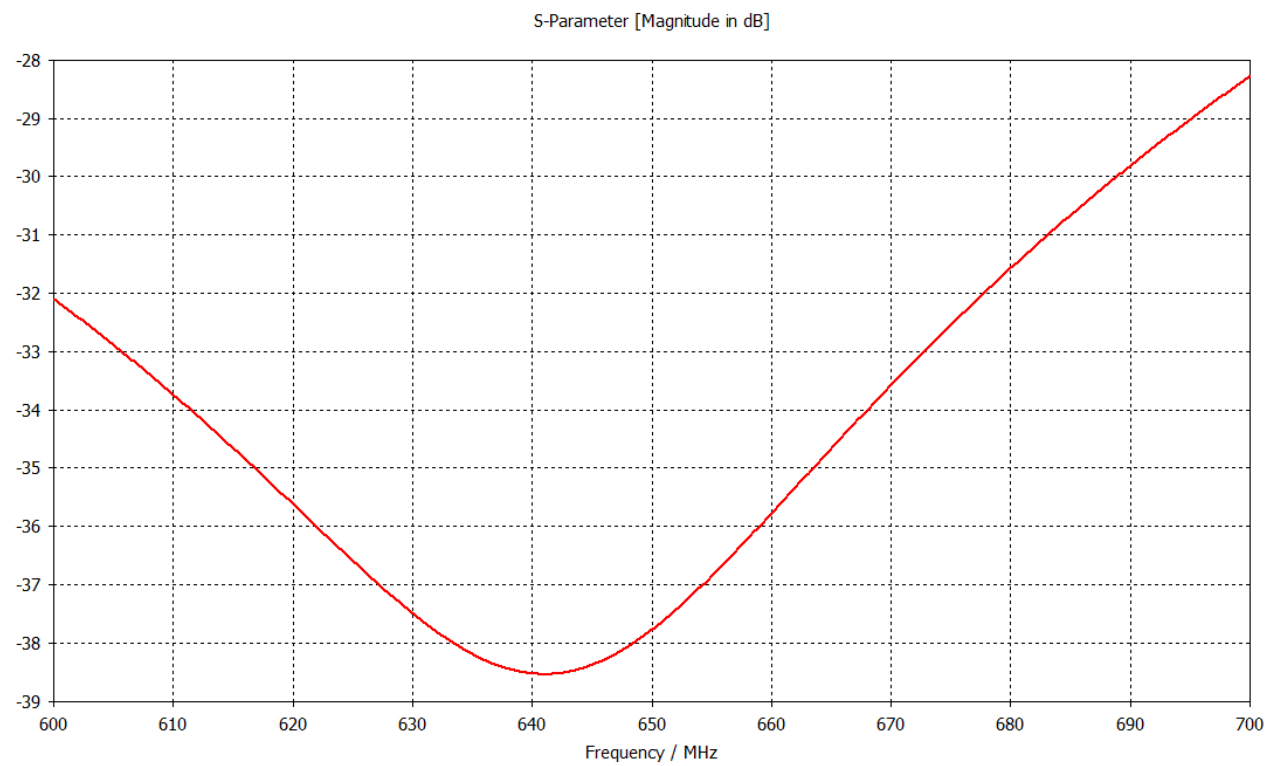


Possible features:

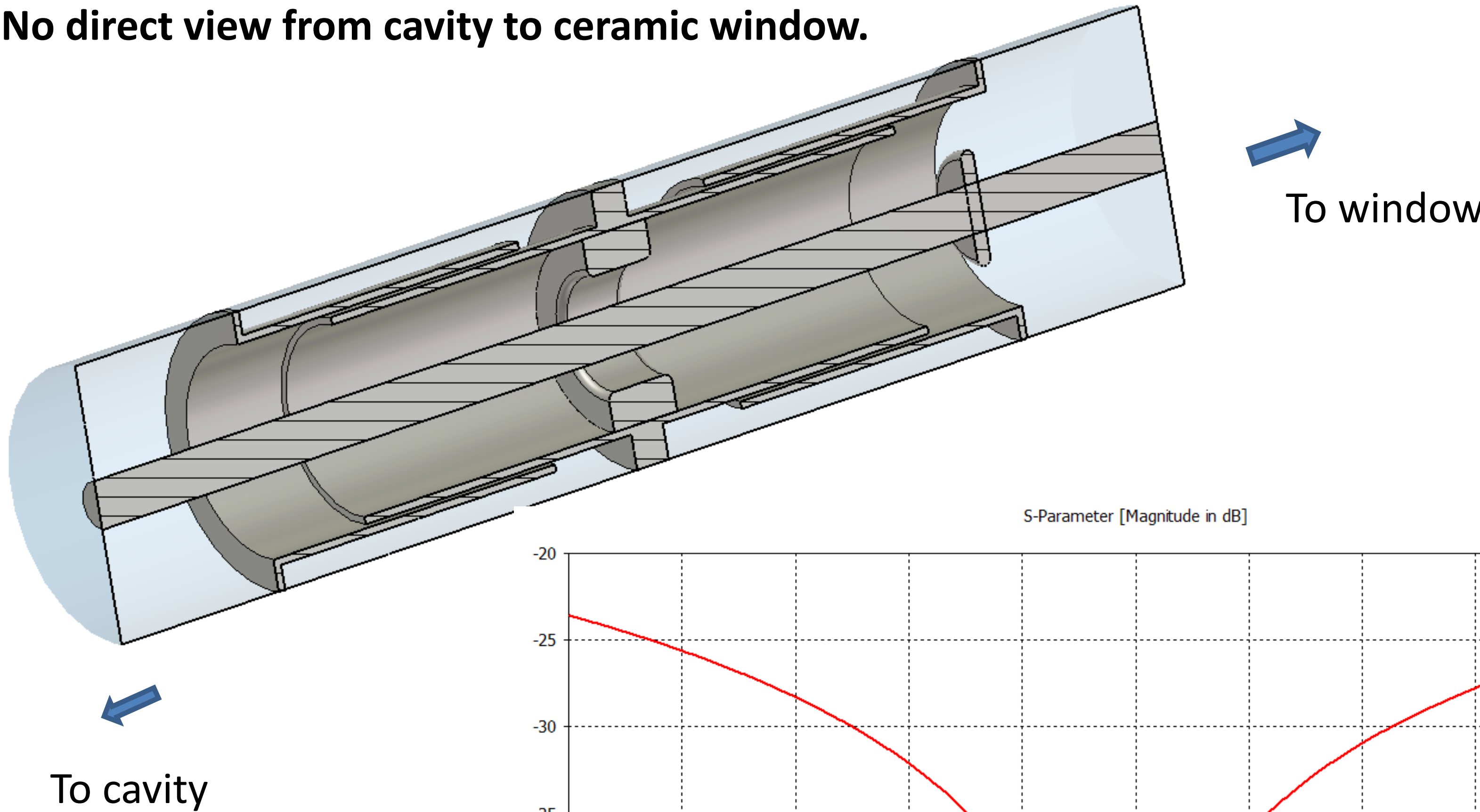
- No copper coating.
- No direct view from cavity to window.
- Double window.

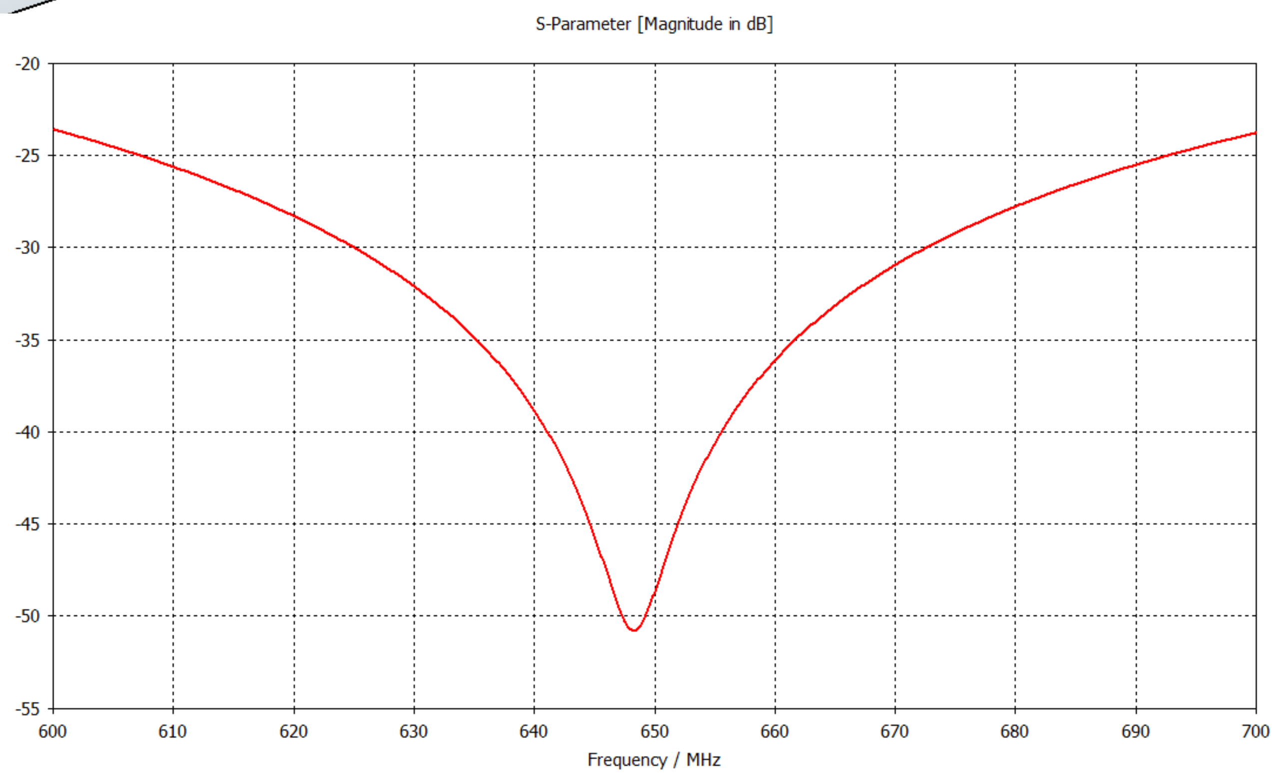
Possible configuration of vacuum part with copper coating.
No direct view from cavity to ceramic window.



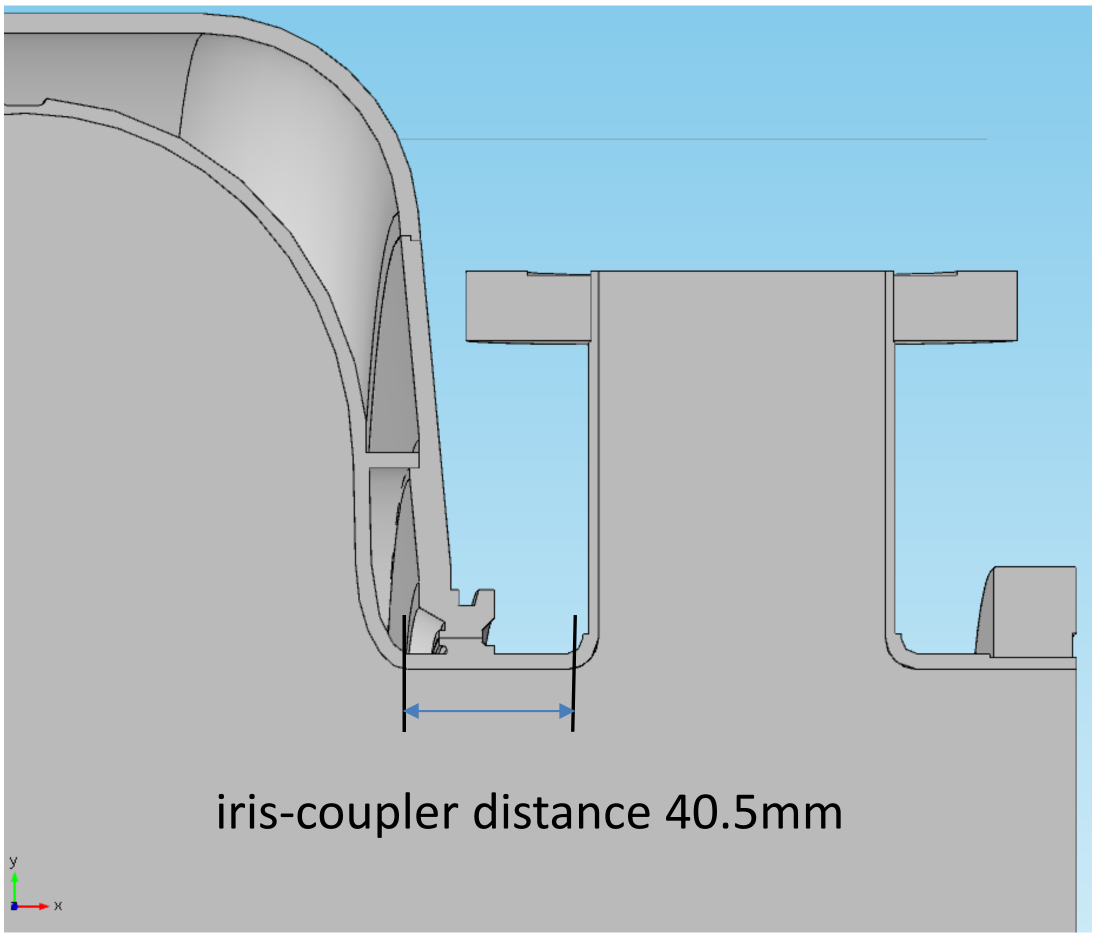


Possible configuration of vacuum part without copper coating.
No direct view from cavity to ceramic window.





V2 design of FPC end



LFD ~ - 1.33 Hz/(MV/m)^2
bandwidth ~ 60 Hz
operating gradient ~ 18 MV/m
f detuning ~ 430 Hz (7 bw)