Update on status of LB650 (beta=0.61)cavity for PIP-II under IIFC

Tom Nicol, Fermilab-SPM

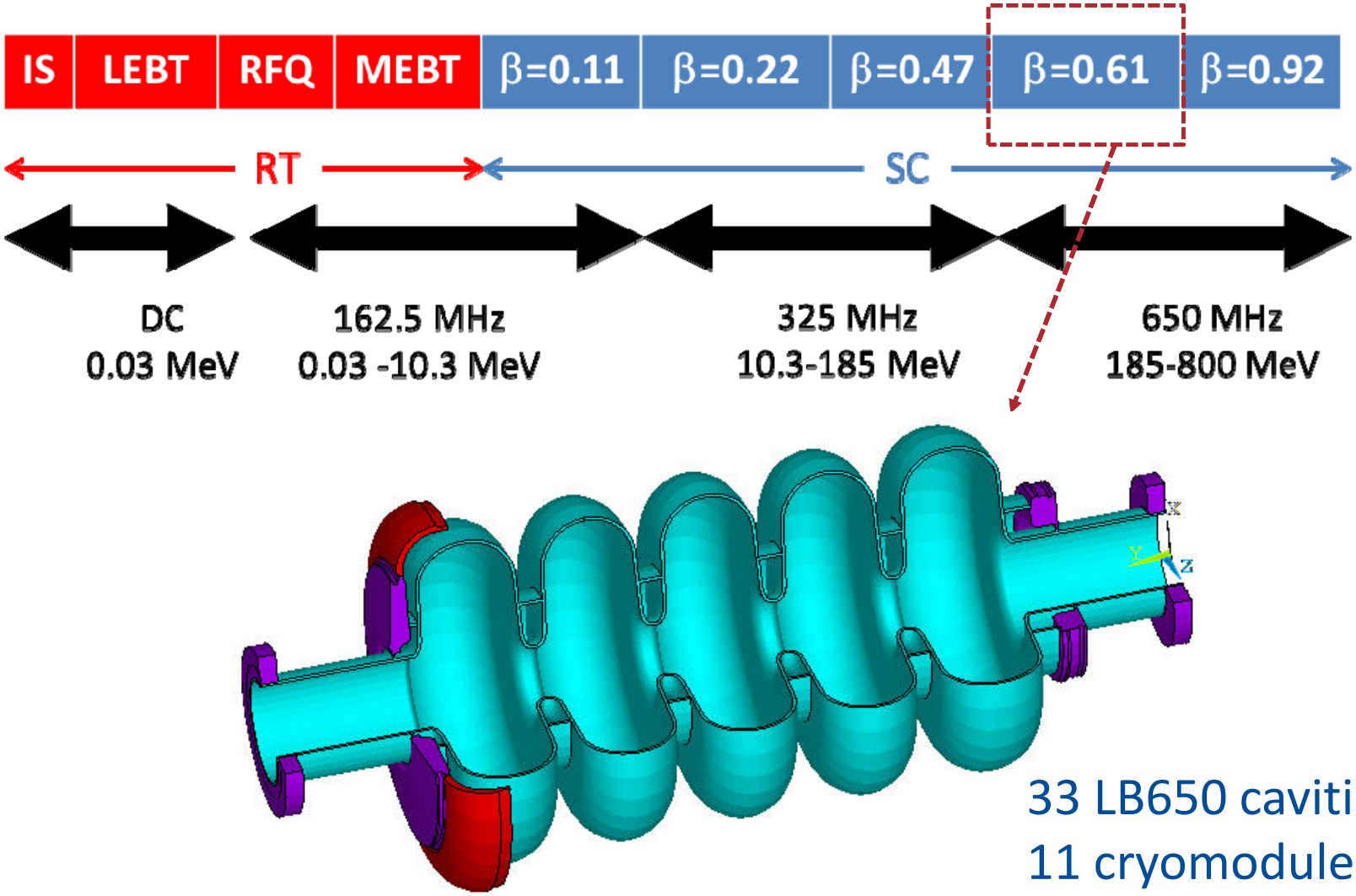
19th July 2016

In partnership with:

Content

- PIP-II
- LB650
  - 1-cell cavity status update
  - 5-cell cavity status update
    - RF Design
    - Mechanical Design
      - LFD, Pressure sensitivity, cavity stiffness
    - Helium Vessel
    - Tuner
    - Coupler
- Conclusion

PIP-II

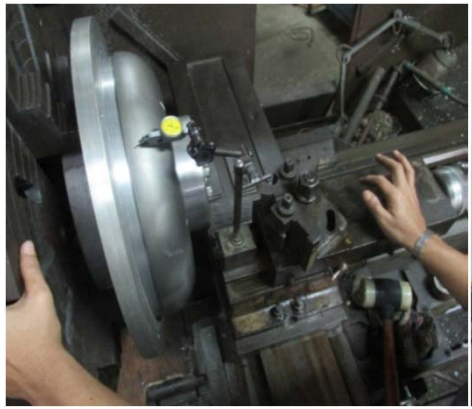


33 LB650 cavities in
11 cryomodules

Single-cell cavity status update (Development at VECC)

- Half Cells were formed at local industry in Kolkata, India
  - ❑ Die-punch were designed at VECC
- Machining at VECC Workshop
  - ❑ Iris Trimming , Equator trimming , Weld step at Equator and Iris
- CMM inspection at VECC and frequency measurement
- EB welding at IUAC, Delhi
  - ❑ Welding fixtures were manufactured at local Industry
  - ❑ Development of weld parameters for future multi-cell cavities
  - ❑ Past Experience of IUAC helped to complete successful welding

Forming set up



Half Cell machining

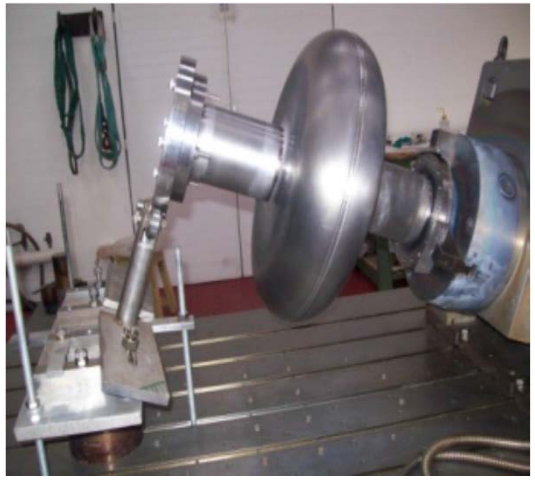
CMM inspection

EBW,IUAC

Continue…

Single-cell cavity status update (Development at VECC)

- Cavity Inspection after EM welding
  - ❑ Cryo-shocking with LN_2 : 3 cycles
  - ❑ Subsequent MSLD : leak rate ~ 1.3E-9 mbar-lit/sec
  - ❑ RF measurement
    - Room Temperature Q_0 ~9500
    - Higher order mode separation measurements



EBW,IUAC

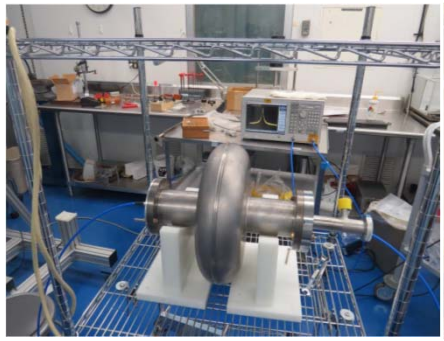
Cryo-shocking

MSLD

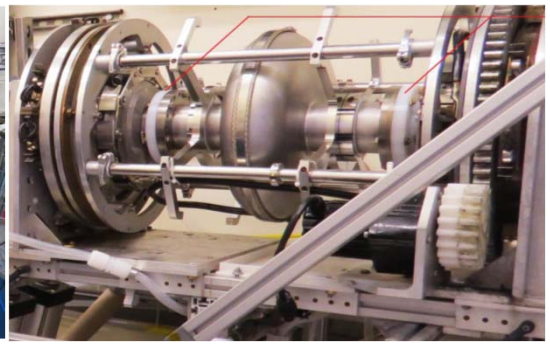
RF measurement

Single-cell cavity Processing and Testing at FNAL/ANL

- Inner conductor of VTS couplers were trimmed to required Qext
  - ❑ External Quality factor $Q_{ext\text{-}FPC}$:1E+10 and $Q_{ext\text{-}FP}$: 1E+12
- RF Measurement with VTS couplers
- Electro polishing at Argonne on 25th May 2016
  - ❑ 120 μm bulk EP (Total process time : 560 minutes)
  - ❑ Ultrasonic thickness measurement after EP
  - ❑ Process parameters were strictly controlled during the process

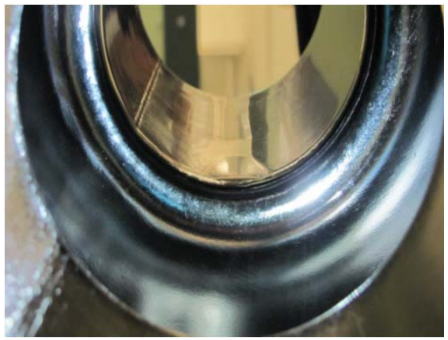


RF measurement



EP at ANL

Before EP



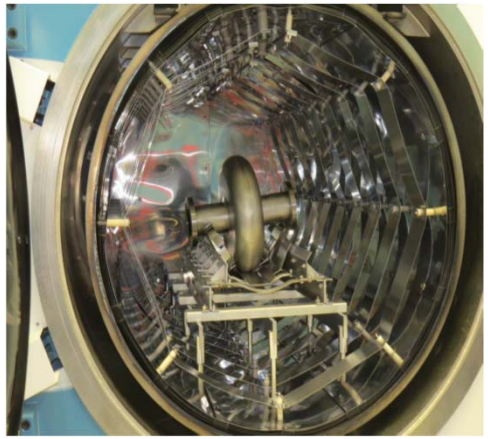
After EP

Continue…

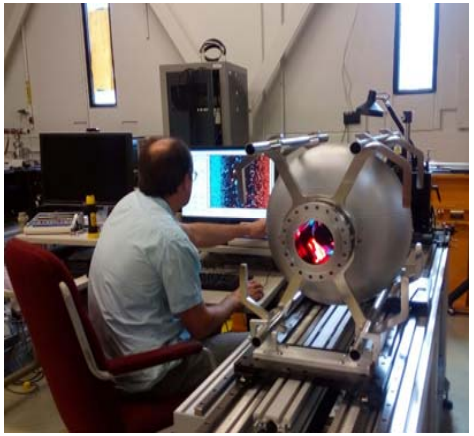
Single-cell cavity Processing and Testing at FNAL/ANL

- High pressure rinsing at ANL
- 800°C baking at FNAL for 3 hours at FNAL 6th June 2016
  - ❑ No unwanted species were found during degassing
  - ❑ Typical vacuum furnace pressure : ~1E-8 torr
- Optical Inspection of cavity RF surface at FNAL
  - ❑ No defects were found
- Final HPR at ANL
- VTS Assembly at FNAL on 30th June 2016

HPR,ANL



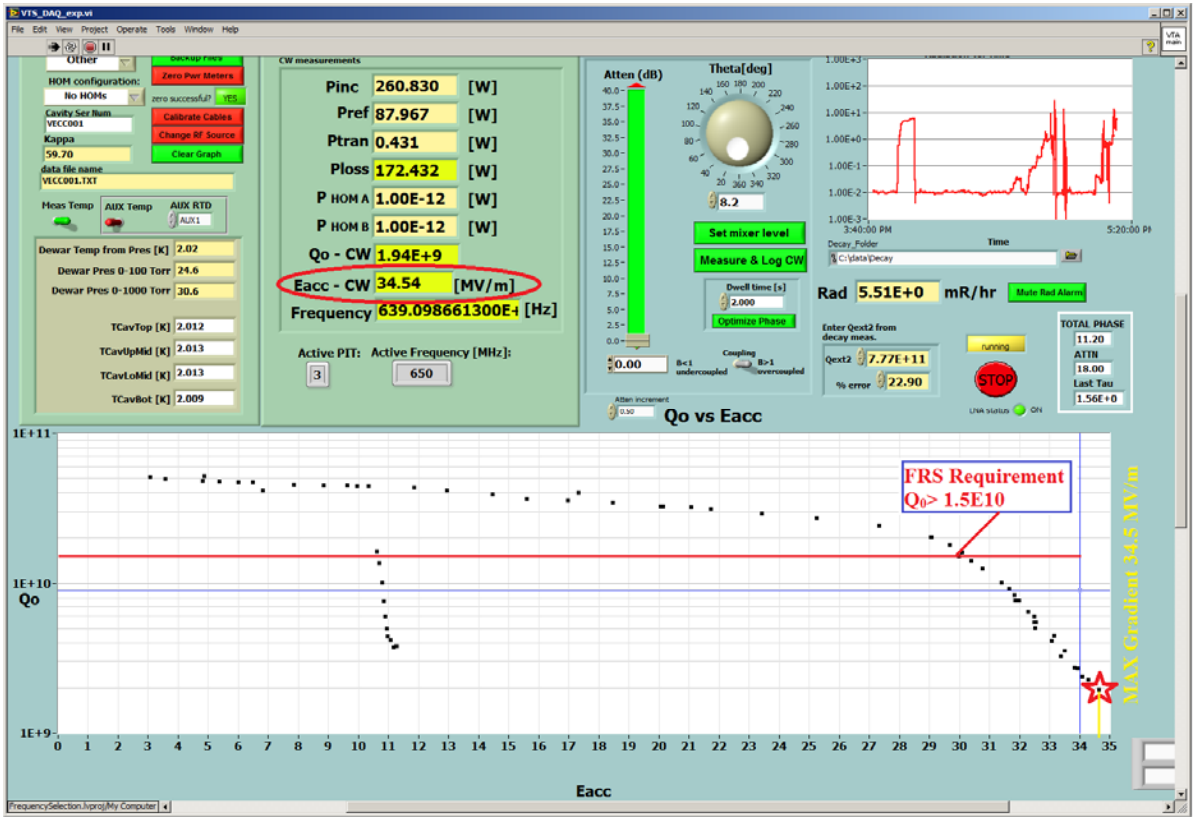
Baking, FNAL



Optical Inspection, FNAL

VTS Insert Assembly

VTS Results : VECC Single Cell (B6AS-VECC-001)



Maximum Gradient:34.5MV/m @2K

No Quench at full RF power ~ 200 W

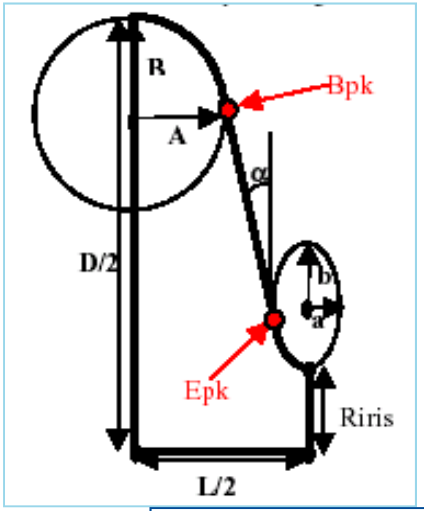
30 MV/m E_{acc} (Accelerating Gradient) at unloaded cavity quality factor
➔ Q_0=1.5E+10

E_{acc} & Q_0 Greater than required in FRS for 5-cell 650 MHz cavity

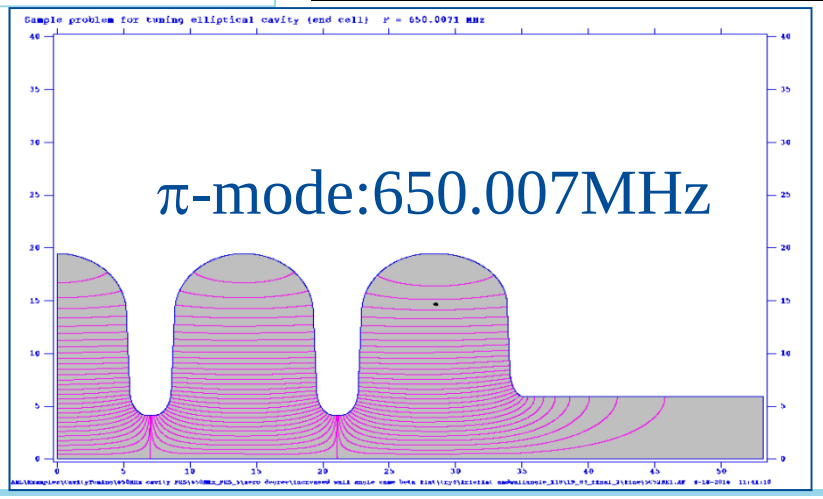
VTS Test Results on 5th July 2016

Five-Cell LB650:EM Design with 118mm dia Beam Pipe , 83 mm Mid-cell Iris Dia and 2 degree Wall Angle

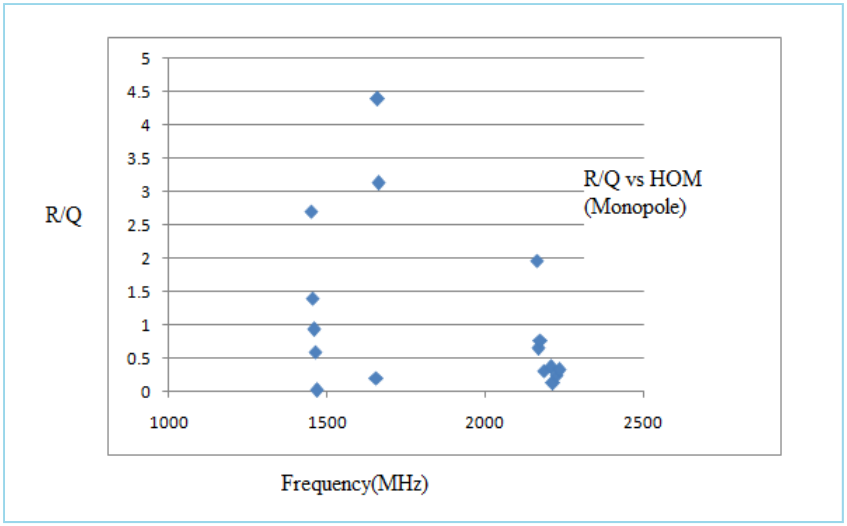
RF Parameters	Superfish simulation Result
E_p/E_a (at optimal β)	2.307 (39.04MV/m at specified energy gain at optimal β) FNAL FRS: ≤ 40 MV/m (at optimal β)
B_p/E_a (at optimal β)	4.383 (74.157 mT at specified energy gain at optimal β) FNAL FRS: ≤ 75 mT (at optimal β)
R/Q (at optimal β)	346Ω
E_p/E_a (at Geometric β)	2.43
B_p/E_a (at Geometric β)	4.61
R/Q (at Geometric β)	329.3
G	164.3
Field flatness	99.95%



	Inner cells (mm)	End half cell (mm)
D	389.292	389.292
R_{iris}	41.5	59
L/2	70.335	70.335
A	52.14	53.52
B	56	48
a	12.95	10.8
b	23.55	25.7
α	2^o	2^o
Equator flat	0	3.79
Iris Flat	2.61	0

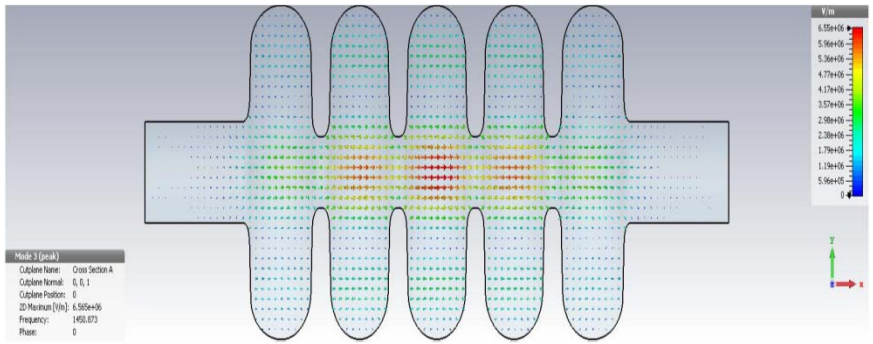


FIVE CELLLB650-HOM analysis



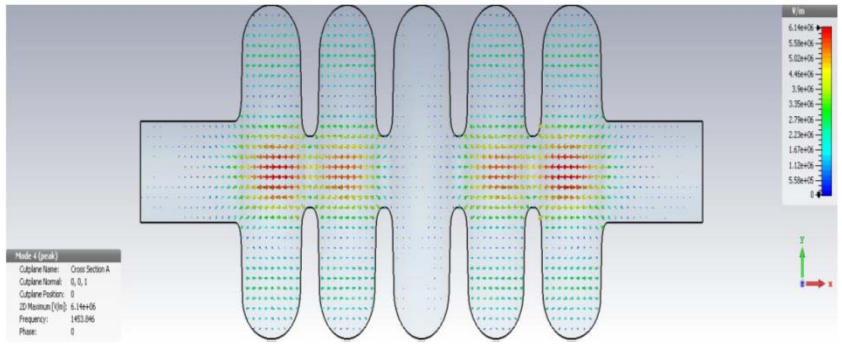
Monopole HOM

1st pass band-1450.87 to 1467.82MHz
2nd pass band-1656.6 to 1662.98 MHz
3rd pass band-2162.9 to 2185.999 MHz
4th pass band-2207.9 to 2234.5 MHz



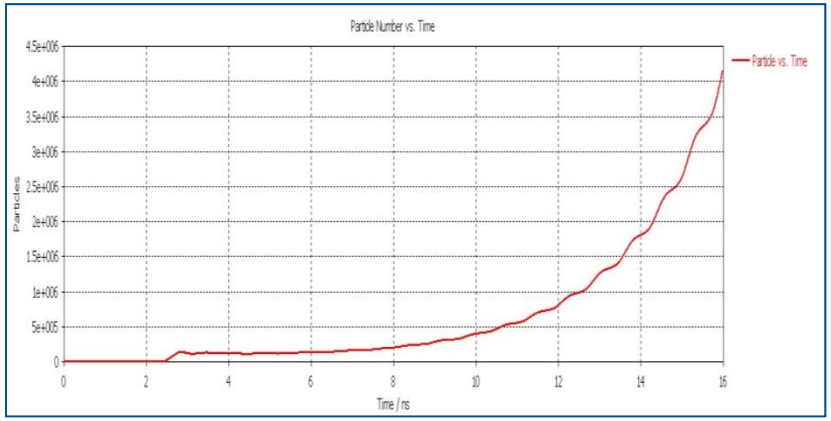
1450.87MHz(monopole)

1453.8MHz
(monopole)

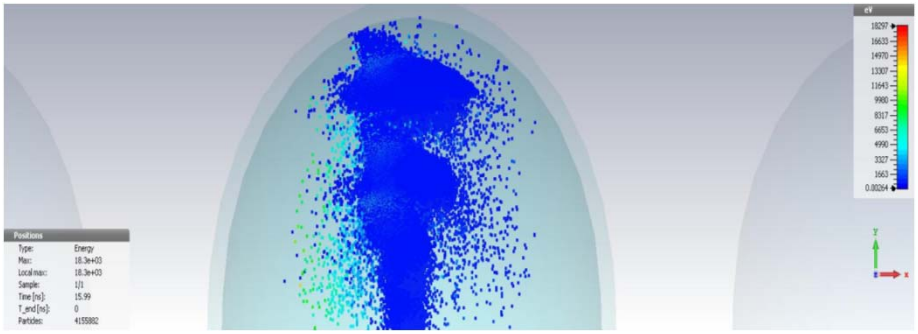


Five – Cell LB650: Multipacting simulation results for LB650 with 118mm Beam Pipe and 2◦ wall angle using 3D CST Particle Studio

- 60 mm. of equator region has been simulated.
- Multipacting Analysis has been carried out for both mid-cell and end-cell.
- Multipacting has been found up to 4.8 MV/m.
- Multipacting rate is very high in the region of 2.5MV/m.
- At 4.8MV/m, increase in particles due to multipacting is very low.



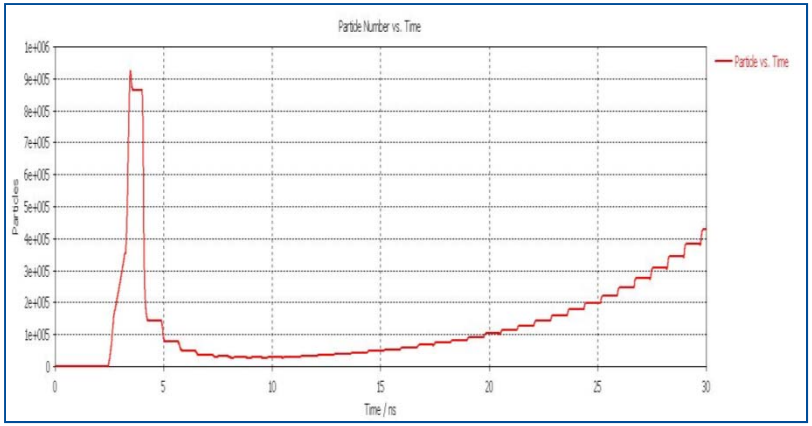
Particle vs. time (ns) at 2.6 MV/m (mid cell)



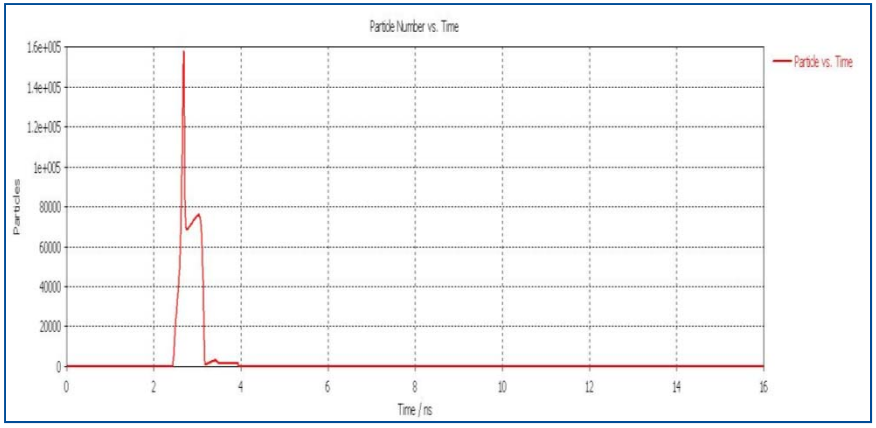
Particles after 16ns at 2.6MV/m (midcell)

Continue…

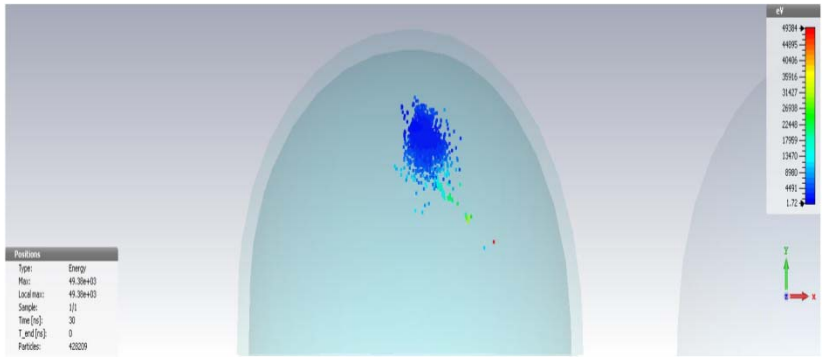
Multipacting simulation results for LB650 with 118mm Beam Pipe and 2° wall angle using 3D CST Particle Studio



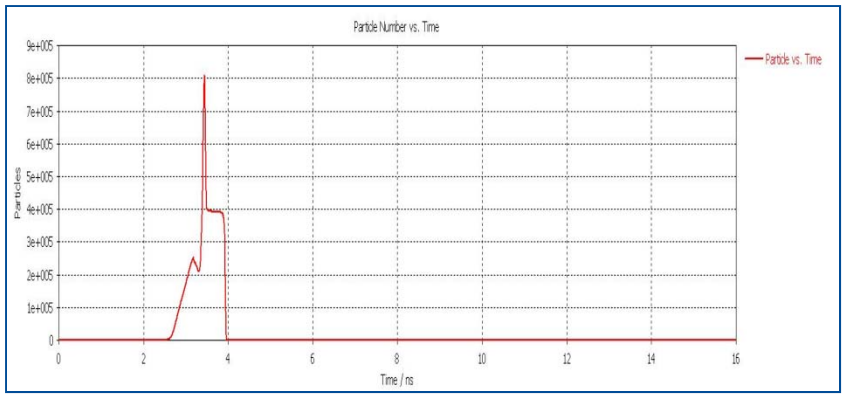
Particle vs. time (ns) at 4.7 MV/m (endcell)



Particle vs. time (ns) at 17.5MV/m (midcell)(no multipacting)



Particle after 30ns at 4.7 MV/m(endcell)



Particle vs. time (ns) at 17.5V/m(end cell)(No multipacting)

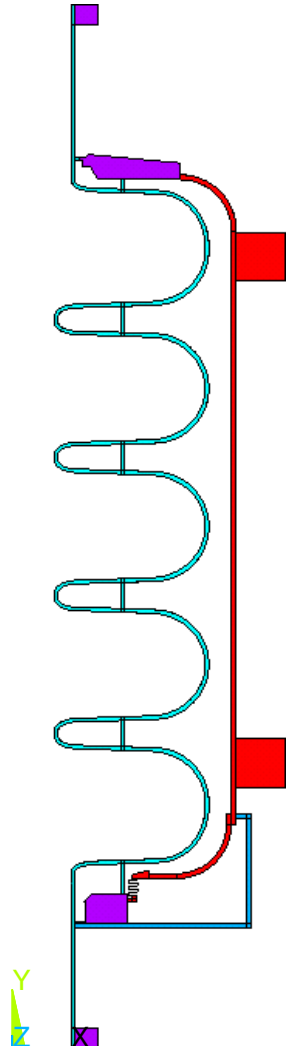
Dimensions of 650 MHz, 5-cell, β=0.61, Niobium Cavity

Dimensional Parameters	COLD Dimension (inside) (as designed) (mm.)	COLD Dimension Pre- BCP treatment of 250 μm (mm.)	WARM Dimension Inside (for fabrication) (mm.)
Equator radius	194.646	194.396	194.674
Iris radius	41.5	41.25	41.30899
A	52.14	51.89	51.9642
B	56	55.75	55.82972
a	12.95	13.2	13.21888
b	23.55	23.8	23.83403
Iris radius (for end cell)	59	58.75	58.83401
A (for end cell)	53.52	53.27	53.34618
B (for end cell)	48	47.75	47.81828
a (for end cell)	10.8	11.05	11.0658
b (for end cell)	25.7	25.95	25.98711
Equator flat (end cell)	3.79	3.79	3.79542
Iris flat (mid cell)	2.61	2.61	2.613732
Half cell length (L/2)	70.335	70.335	70.43488

Five-cell LB650 :LFD Results

Design-1: Same stiffener ring radius for mid & end cells

R-mid/end (mm)	F1 (Hz)	F2(Hz)	F2-F1 (Hz)	LFD [Hz/(Mv/m)^2]
90	649973074	649972677	-397	-1.386887155
100	649973069	649972605	-464	-1.620946197
109	649973073	649972541	-532	-1.858498656

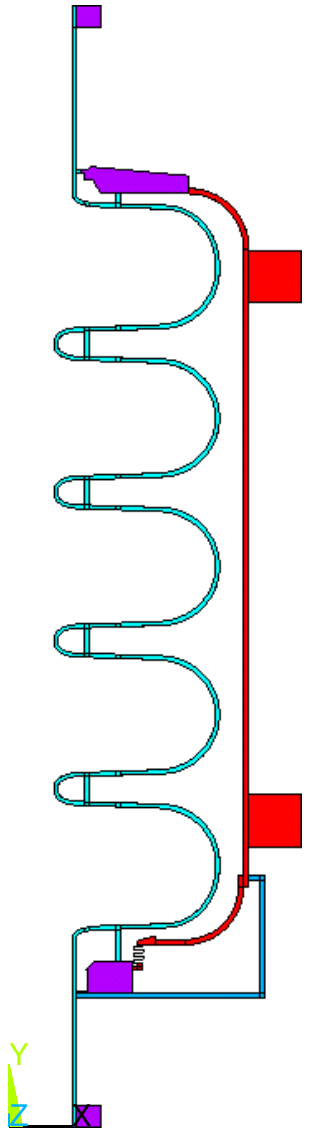


Comments:

1. The above table is generated taking tuner stiffness = 100 kN/mm
2. LFD decreases with reducing stiffener ring radius.
3. Reduction of radius below 90 mm is not possible since it will come out of MC spool.

Design-2: Different stiffener ring radius for mid & end cells

R-mid (mm)	R-end (mm)	F1 (Hz)	F2(Hz)	F2-F1 (Hz)	LFD [Hz/(Mv/m)^2]
60	100	6.5E+08	6.5E+08	-336	-1.173788625
60	109	6.5E+08	6.5E+08	-345	-1.205229392
70	100	6.5E+08	6.5E+08	-314	-1.096933417
70	109	6.5E+08	6.5E+08	-323	-1.128374184
80	100	6.5E+08	6.5E+08	-345	-1.205229392
80	109	6.5E+08	6.5E+08	-354	-1.236670159
90	100	6.5E+08	6.5E+08	-401	-1.400860829
90	109	6.5E+08	6.5E+08	-411	-1.435795015

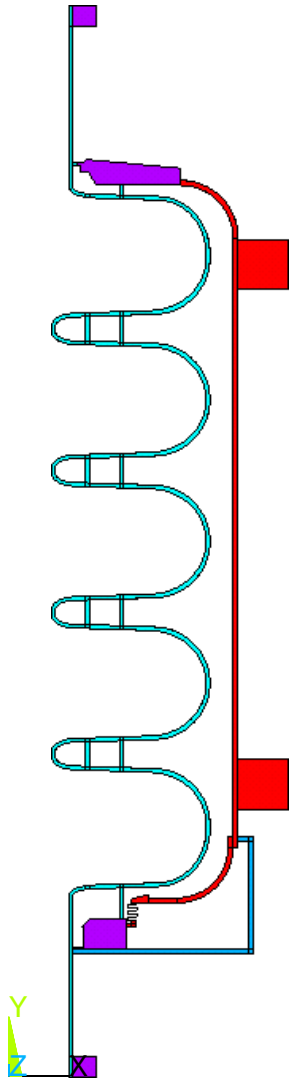


Comments:

1. Keeping stiffener radius fixed for end cells, minimum LFD is found at 70 mm.
2. As stiffener radius for end cell is increased, LFD also increases.
3. The above table is generated taking tuner stiffness = 100 kN/mm
4. For tuner stiffness = 70 kN/mm, LFD for combination of 70 & 100 mm radius = 1.096 Hz/(Mv/m)^2

Design-3: Two stiffener rings for mid cells & one for end cells

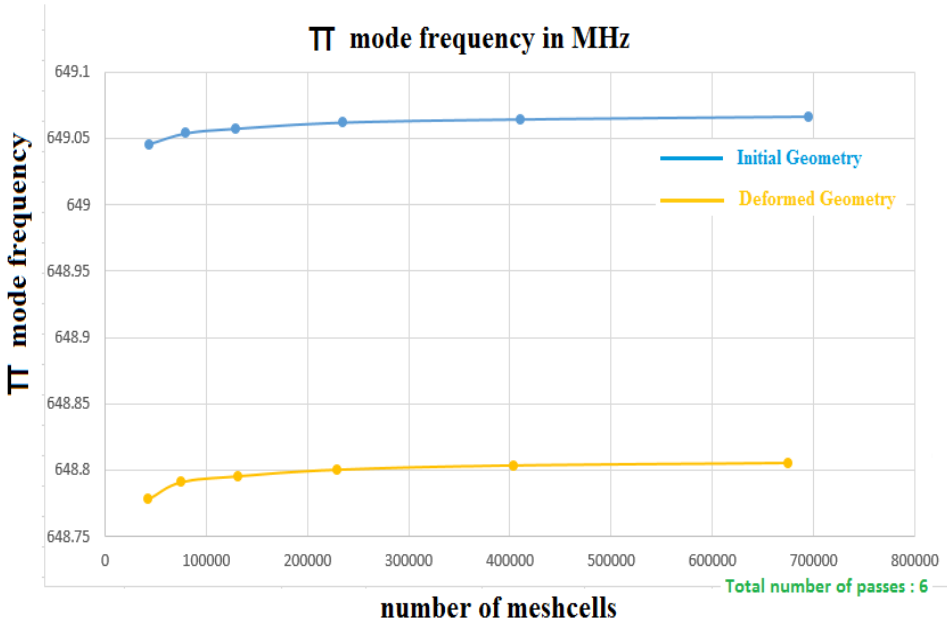
R-mid (mm)	R-mid/end (mm)	F1 (Hz)	F2(Hz)	F2-F1 (Hz)	LFD [Hz/(Mv/m)^2]
60	100	649973031	649972718	-313	-1.093439999
60	109	649973032	649972716	-316	-1.103920255
70	100	649973028	649972734	-294	-1.027065047
70	109	649973027	649972743	-284	-0.992130862
75	109	649973073	649972789	-284	-0.992130862
80	100	649973031	649972729	-302	-1.055012395
80	109	649973030	649972741	-289	-1.009597954

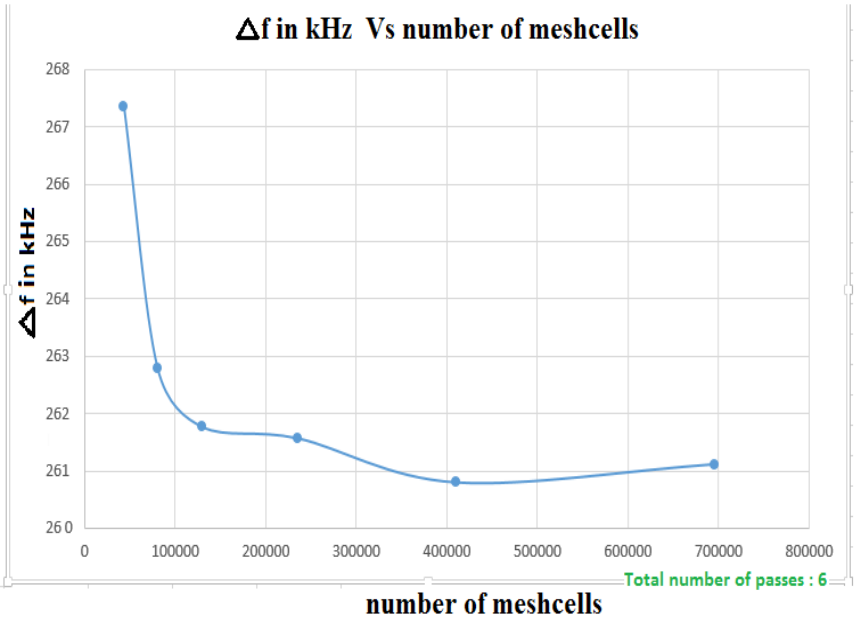


Comments:

1. Minimum LFD is found for a combination of stiffener radius of 75 mm & 109 mm.
2. The above table is generated taking tuner stiffness = 100 kN/mm
3. For tuner stiffness = 70 kN/mm, LFD for combination of 75 & 109 mm radius = 1.02 Hz/(Mv/m)^2

Five Cell LB650:Tuning Sensitivity Analysis





Tuning Sensitivity (df/dl) = 261 kHz/ mm

FRS requirement : >180 kHz/mm
Ref: ED0001834

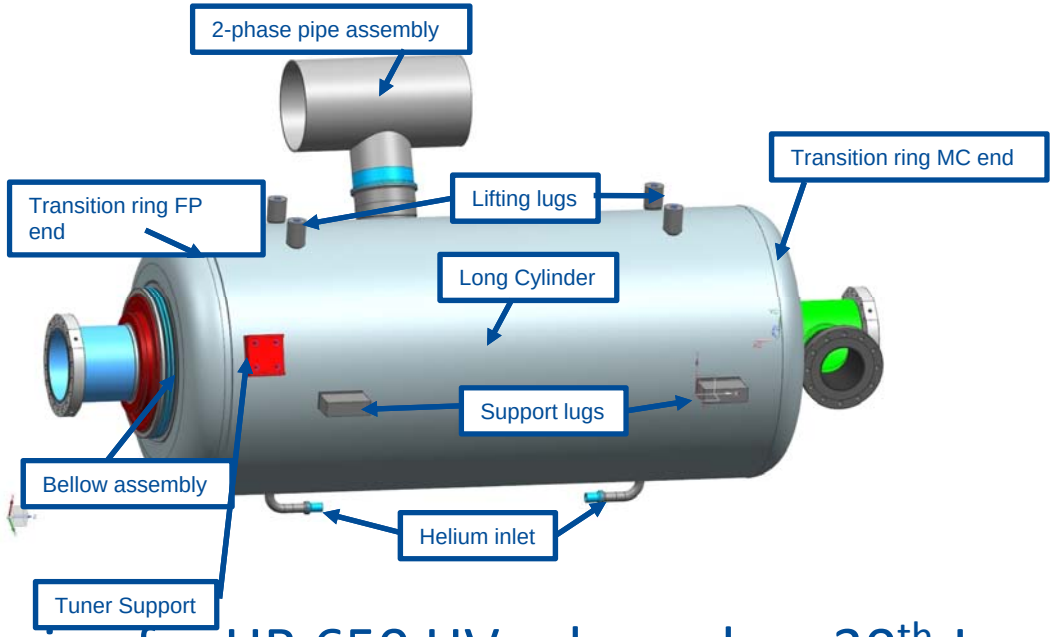
Satisfies FRS Criterion :
Yes ✓

Review of LB650 Bare Cavity

- FRS was released in Sep, 2015 by Fermilab.
- VECC presented preliminary RF and Mechanical design of the LB650 5-Cell cavity with End Groups on June 28th 2016.
- Fermilab is reviewing the LB650 5-Cell bare cavity design and about to give primary approval soon.
- After Stiffener ring optimization, Structural analysis and modal analysis will be carried out to meet other criteria in the FRS.
- Final Review of LB650 Cavity tentatively in August 2016.
- Accordingly, fabrication of 1st 5-cell LB650 bare cavity is expected to be completed by August 2018.

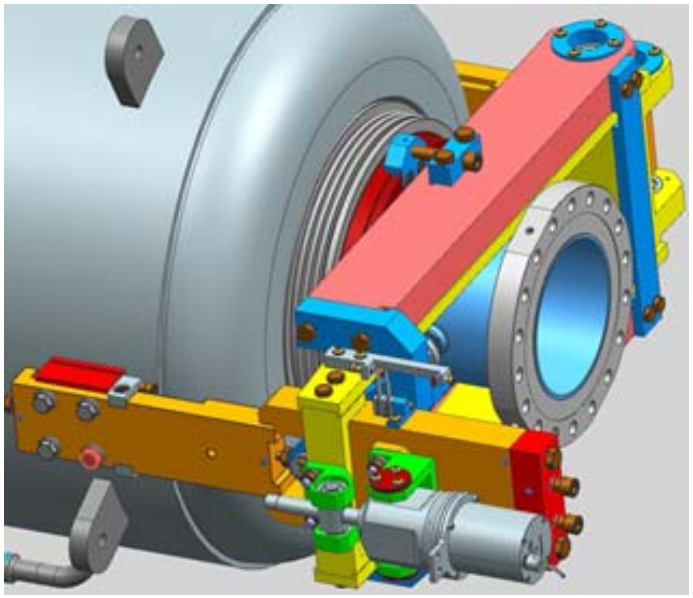
Five-cell LB650: Helium vessel (F10042401)

1. Long Cylinder
2. Transition ring MC end
3. Transition ring FP end
4. Bellow assembly
5. Support lugs
6. Lifting lugs
7. Helium inlet
8. 2-phase pipe assembly
9. Tuner mounting lugs
10. Bellow restrains
11. Magnetic shielding (external)



- Drawing for HB 650 HV released on 30th June,2016. LB650 HV drawing will be derived from it.
- LB650 HV :
  - Radial dimension is same
  - Length will be less
  - Position & dimensions of support lugs will change

Five-cell cavity : Tuner (F10006928)



Requirement for Tuning

Cavity Parameters	Cavity Beta		
	0.92	0.9	0.61
Stiffness, (N/um)	4	20	3-4
Cavity tuning sensitivity, [Hz/um]	160	180	240
bandwidth (F1/2), [Hz]	29	29	29
Lorentz Force Detuning coefficient (Hz/MV/m)2	<1	<1	<1
Cavity sensitivy to pressure, dF/dp	<20	<20	<25

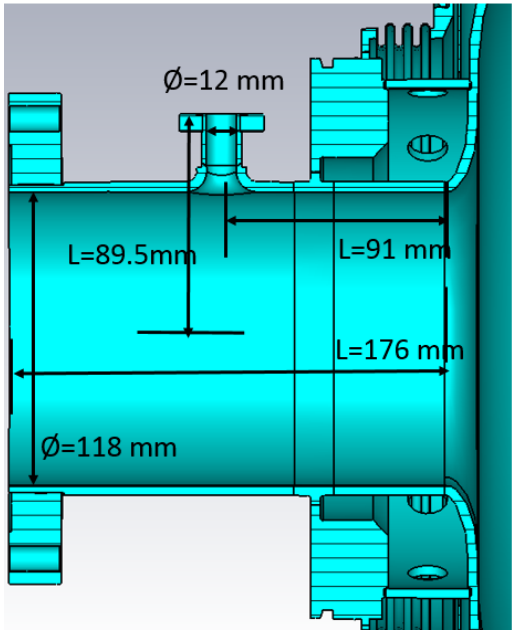
- Tuner Design (synergy of the LCLS II & PIP II Project)- during design of 650 tuner we(FNAL) applied many ideas and "lessons learned" from 1.3GHz tuner.
- The final drawing of tuner has been released on 30th June,2016.

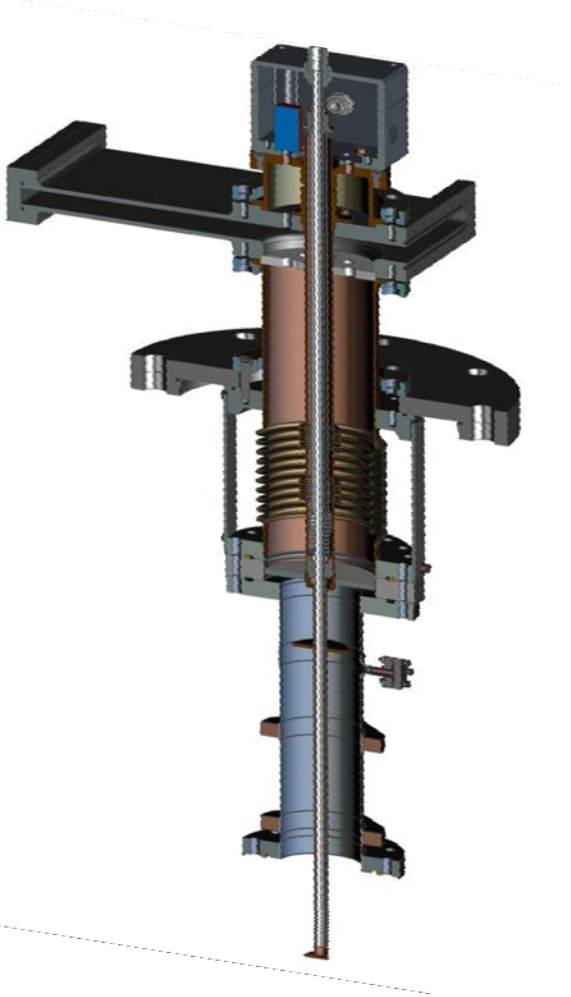
Five-cell cavity : Coupler

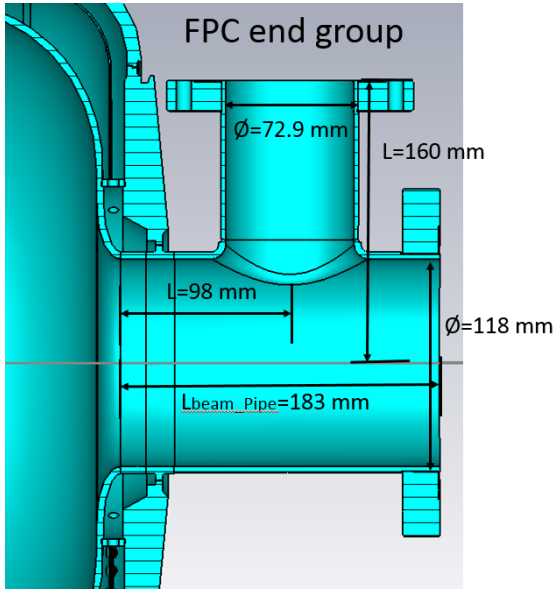
Proposed design with D=118 mm beam pipe coupler:

- Same end assemblies as in HB650 cavity
- Same coupler position as in HB650 cavity

Field probe end group







S. KAZAKOV

T. Khabiboulline

Works Status

Item	Status	Remarks
1-Cell Cavity	Tested successfully	-
5-Cell cavity RF design	VECC presented RF design which satisfies FRS criteria	Under review at FNAL
5-Cell Cavity Mechanical Design	Preliminary results presented by VECC	Detail analysis to be presented by VECC by Aug,2016
5-Cell Cavity Helium vessel	Drawing for HB650 Helium vessel has been released by FNAL	LB650 Helium vessel drawing will be derived from it
5-Cell cavity Tuner	Drawing has been released by FNAL	Tuner for HB and LB are same
5-Cell cavity Coupler	Design is under progress at FNAL	Approximately same coupler to be used for HB and LB

Conclusion

- Single cell cavity is tested successfully at VTS with a record voltage gradient of 34.5 MV/m for LB 650 cavity.
- RF design of LB650(beta=0.61) 5-cell cavity is finalized.
- Mechanical design of LB650 (beta=0.61) 5-cell bare cavity is under progress.
- Fermilab is carrying forward the Helium Vessel, Tuner & Coupler Design in line with HB 650 design.

Thanks