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650 MHz ELLIPTICAL SUPERCONDUCTING RF CAVITIES FOR PIP-II PROJECT

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In partnership with:

पऊवि DAE | IIFC | PIP-II

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Outline

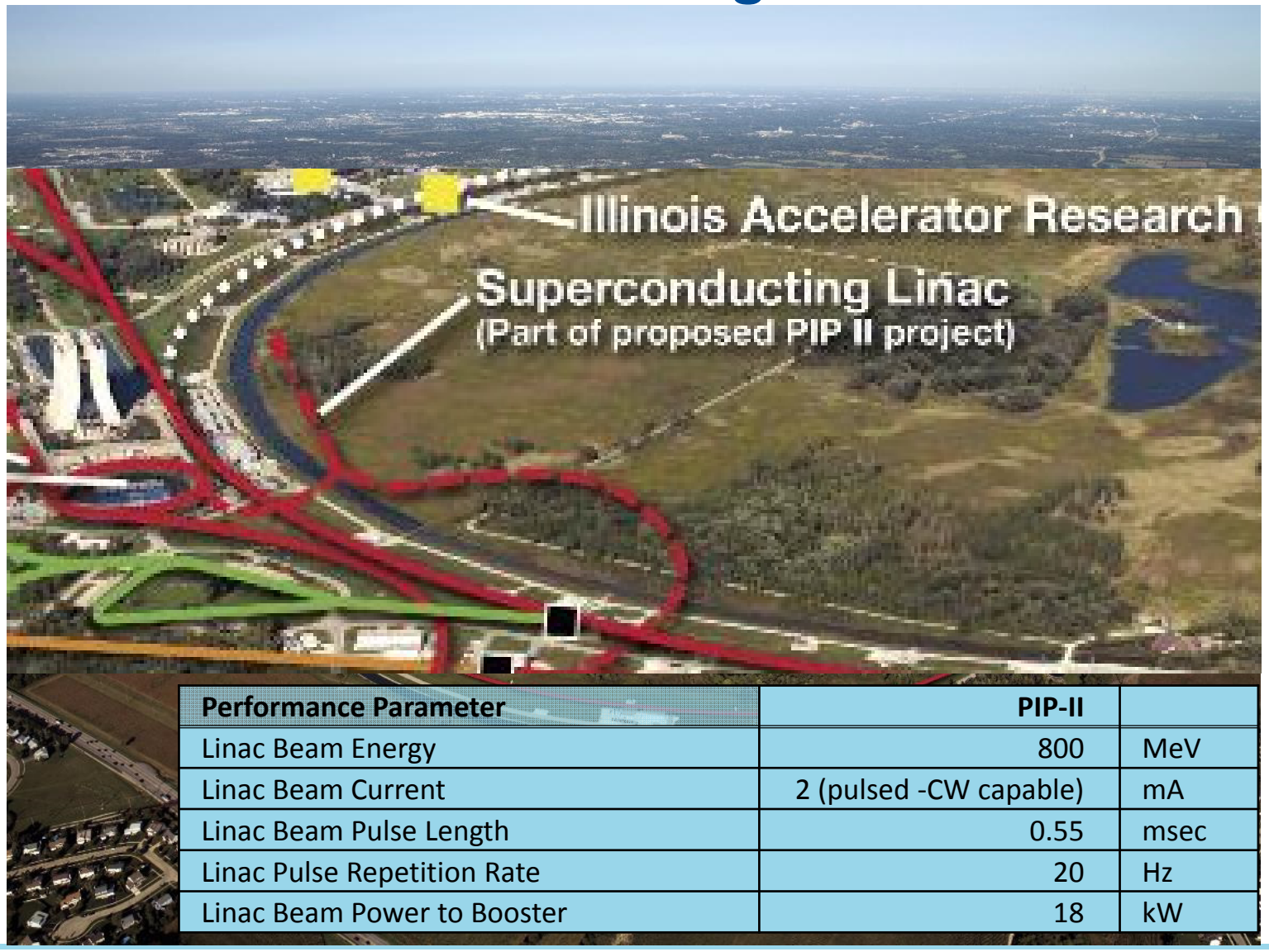
- SRF program for PIP-II
- Design methodology for SRF cavities
- LB650 & HB650 elliptical cavities
  - RF Simulations
  - Coupled Simulations
    - LFD dependence of cavity & tuner stiffness
    - Pressure sensitivity dependence of cavity & tuner stiffness
  - Mechanical Simulations
- Tuner Design
- Coupler design
- Fabrication methodology of the SRF cavity
- Conclusion

Fermilab Site PIP-II Planning

Fermilab Site PIP-II Planning

Performance Parameter	PIP-II	
Linac Beam Energy	800	MeV
Linac Beam Current	2 (pulsed -CW capable)	mA
Linac Beam Pulse Length	0.55	msec
Linac Pulse Repetition Rate	20	Hz
Linac Beam Power to Booster	18	kW

Fermilab Site PIP-II Planning



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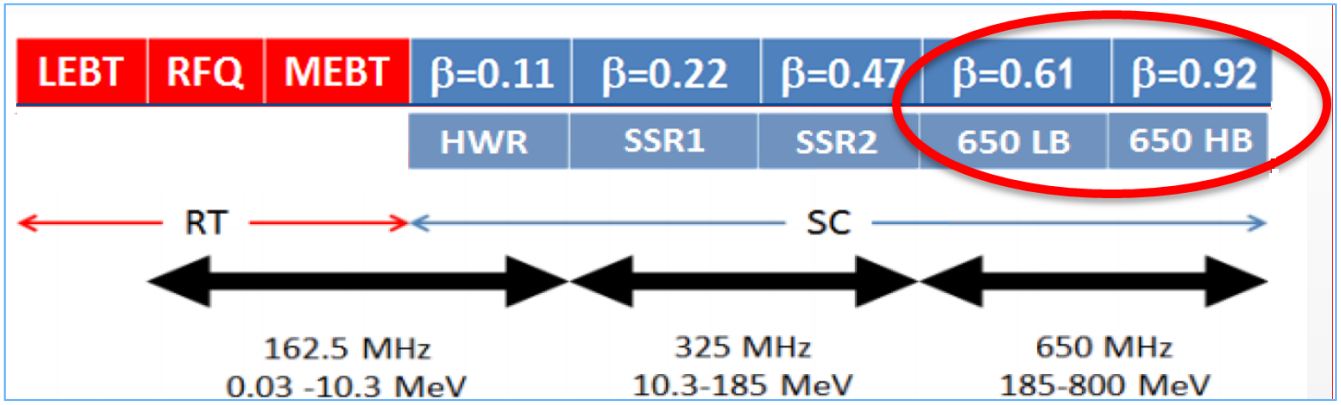
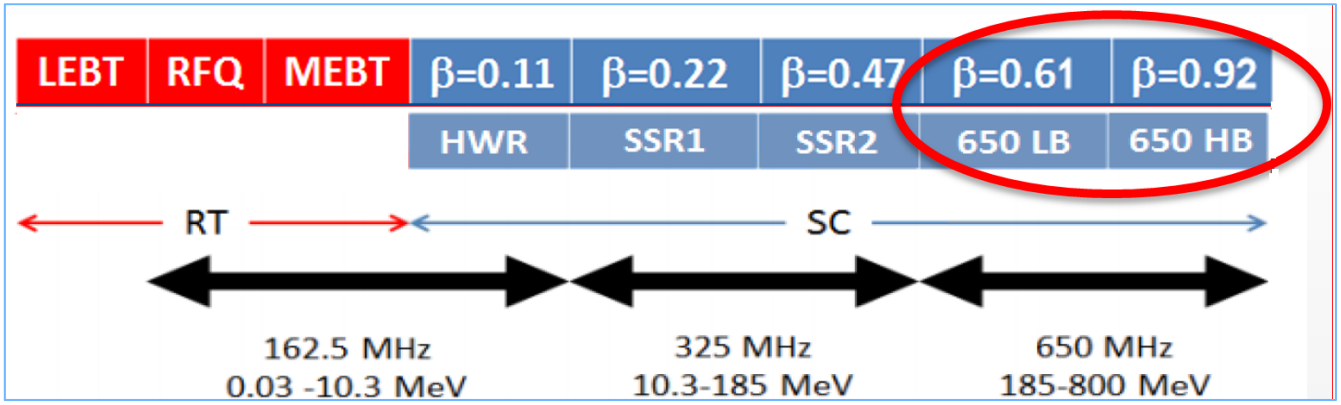
SRF cavities in PIP-II



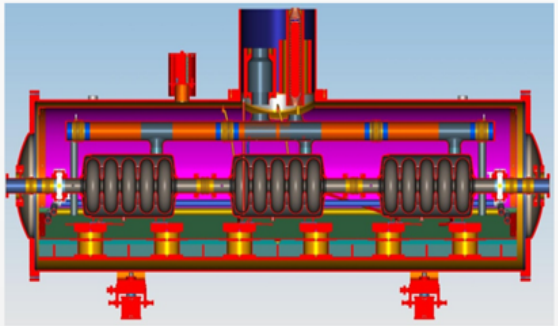
SRF cavities in PIP-II



Elliptical Cavities Cryomodule

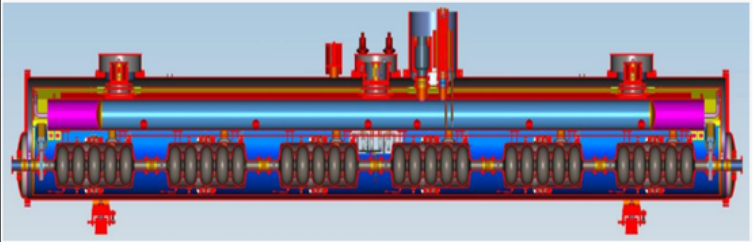
Low-β cryomodule configuration

- 11 total cryomodules
- 3 cavities each (650 MHz, 5-cell)
- 33 total cavities
- No magnets internal to the cryomodule
- Approximate length = 3.9 m

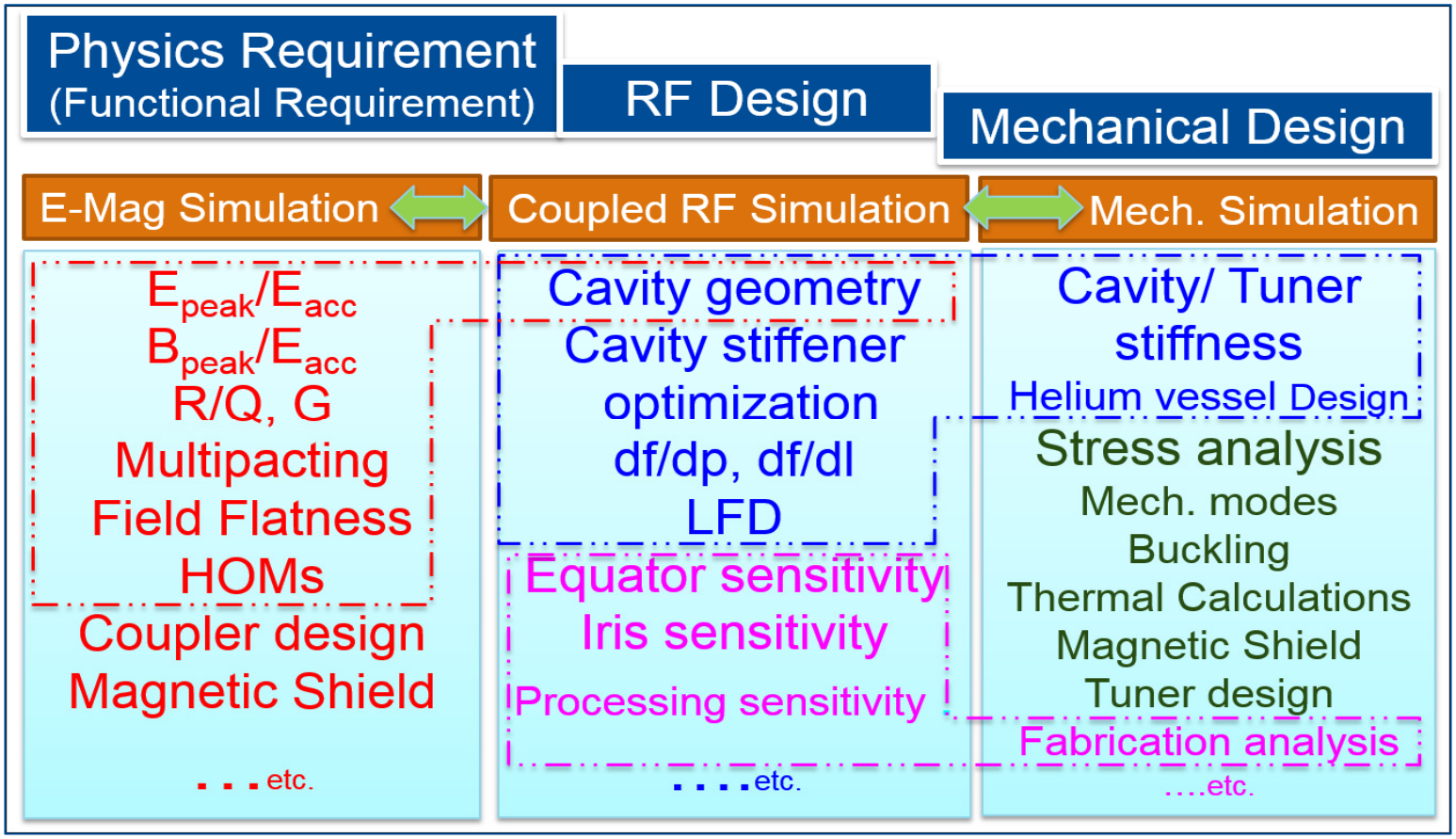


High-β cryomodule configuration

- 4 total cryomodules
- 6 cavities each (650 MHz, 5-cell)
- 24 total cavities
- No magnets internal to the cryomodule
- Approximate length = 9.5 m



Design methodology for SRF cavities



LB650 & HB650 elliptical cavities

LB650 ➔ 180 MeV to 500 MeV
HB650 ➔ 500 MeV to 800 MeV

Cavity Parameters	LB650	HB650
β_G	0.61	0.92
β_{opt}	0.65	0.97
$R/Q(\beta_G)$, Ohms	327.4	576
$E_{surf}/E(\beta_G)$	2.43	2.1
$B_{surf}/E(\beta_G)$, mT/MV/m	4.6	3.94
G, Ohms	187	260
Energy gain per cavity MeV	11.7	19.9

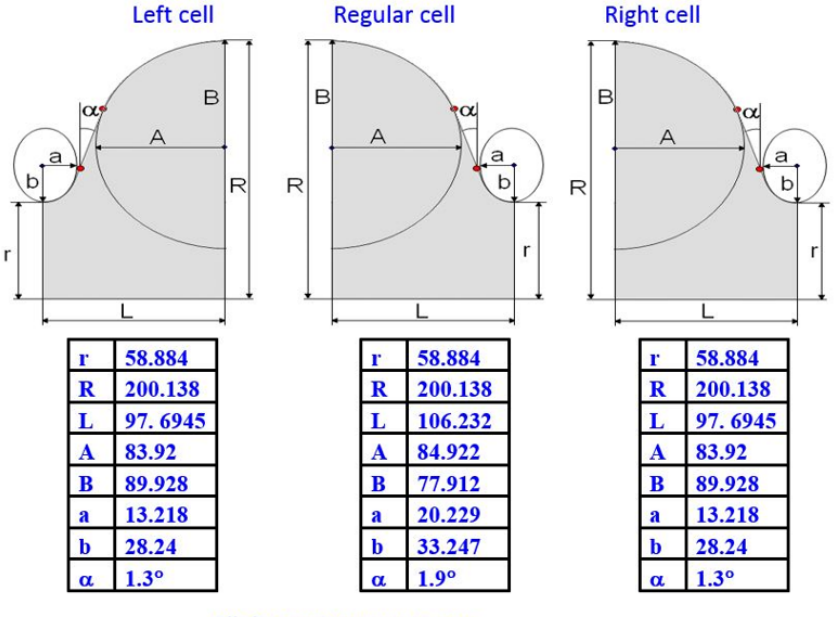
Cavity RF design for HB650

- RF design of 5 cell cavity

RF optimization

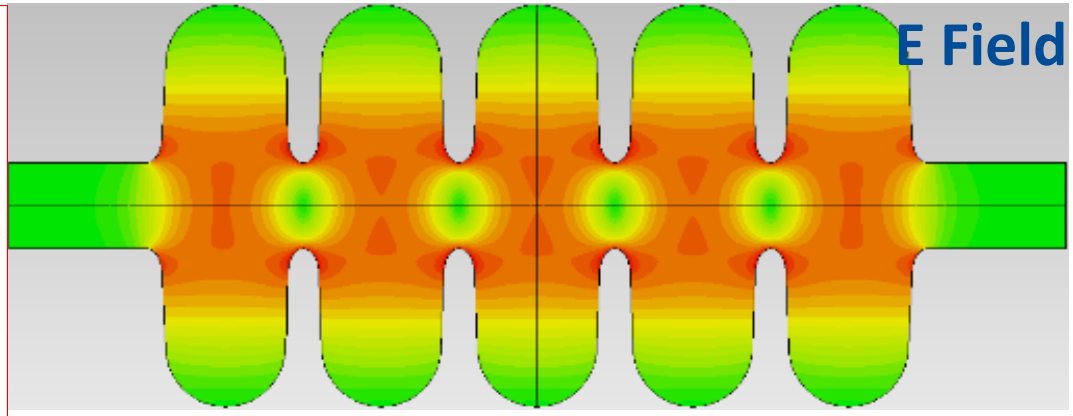
➔Multipacting simulations

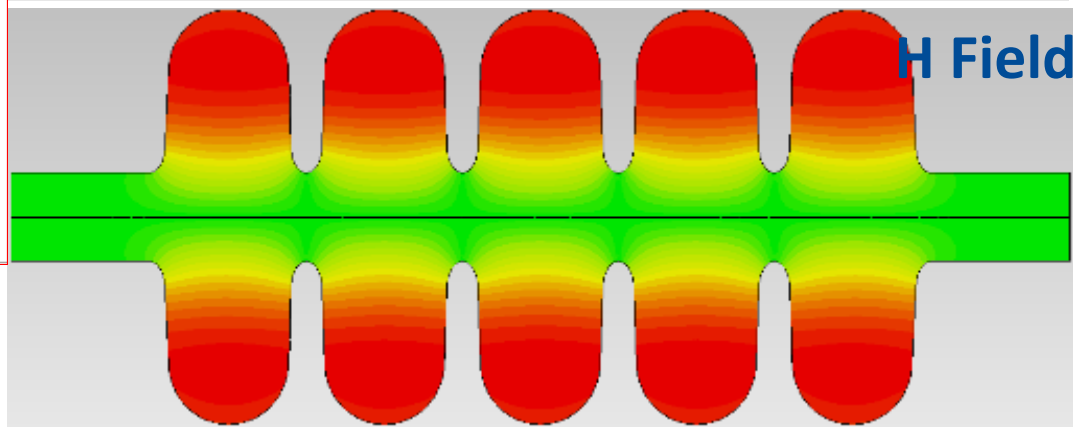
➔ RF geometry freezing



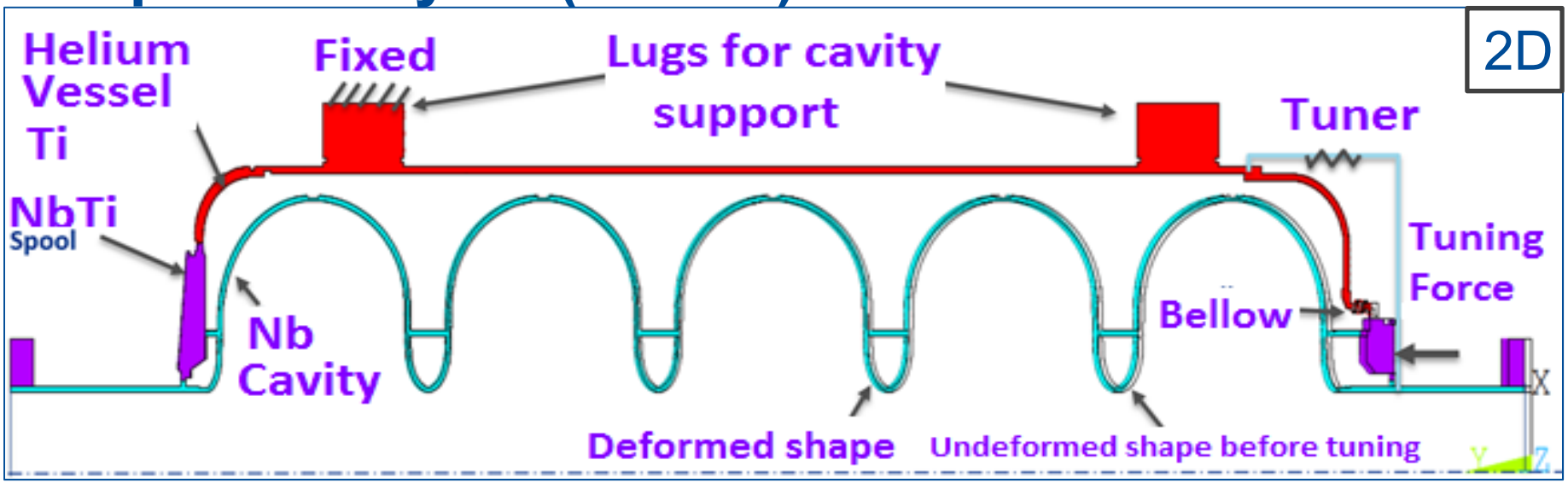
	Left cell	Regular cell	Right cell
r	58.884	58.884	58.884
R	200.138	200.138	200.138
L	97. 6945	106.232	97. 6945
A	83.92	84.922	83.92
B	89.928	77.912	89.928
a	13.218	20.229	13.218
b	28.24	33.247	28.24
α	1.3°	1.9°	1.3°

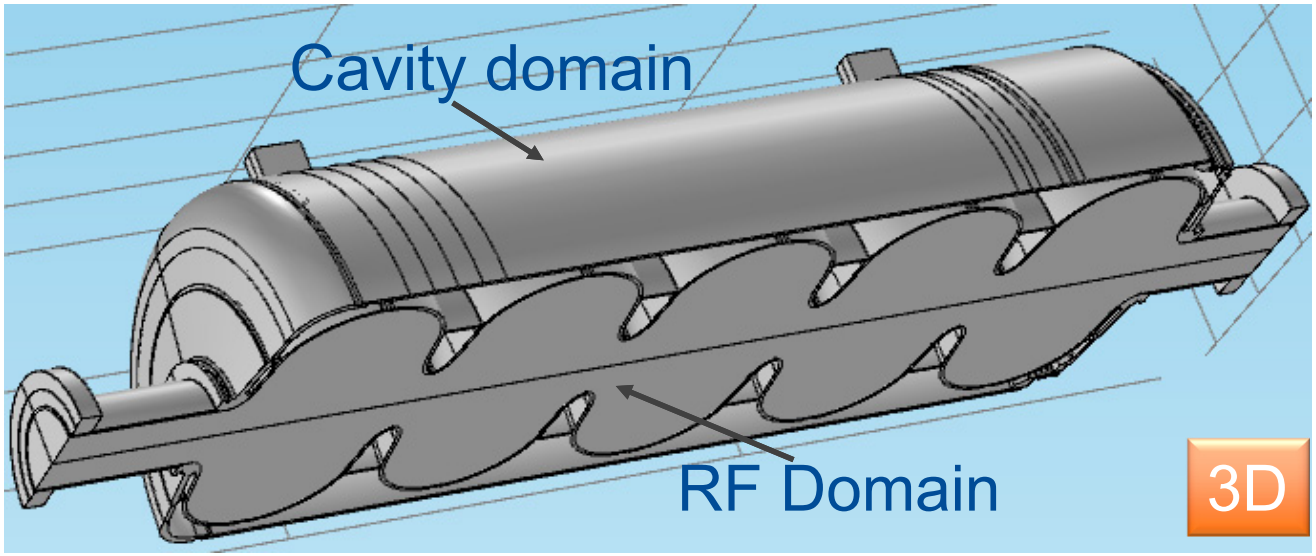
All dimensions are in mm.





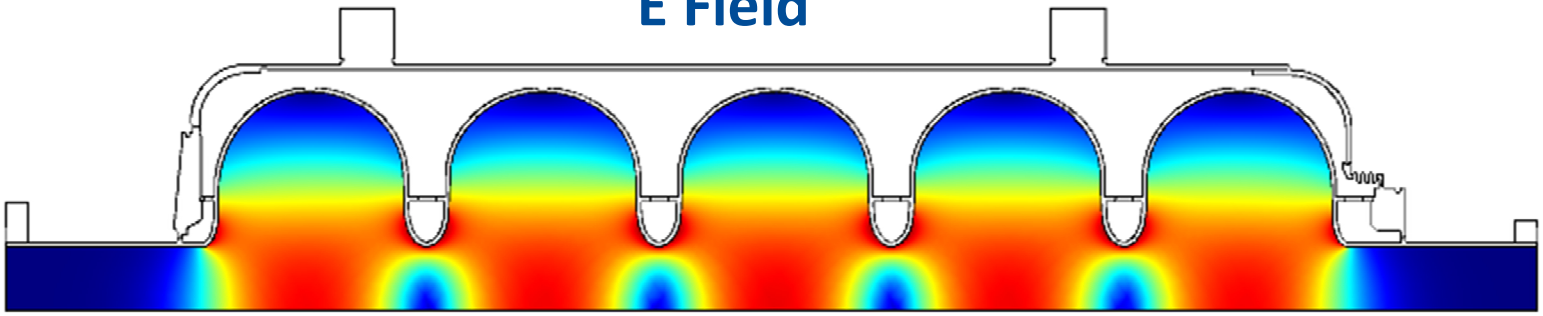
Coupled Analysis (HB650)



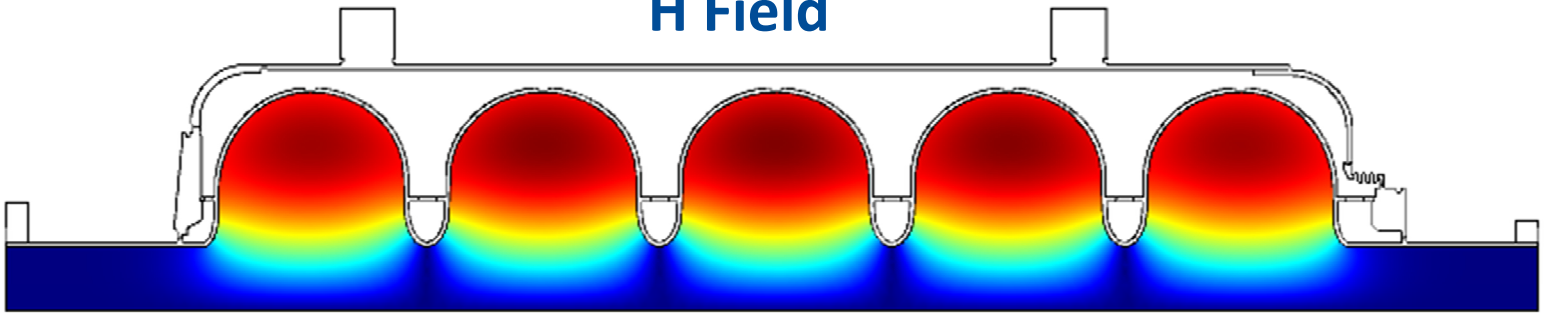


RF simulations ➔LFD

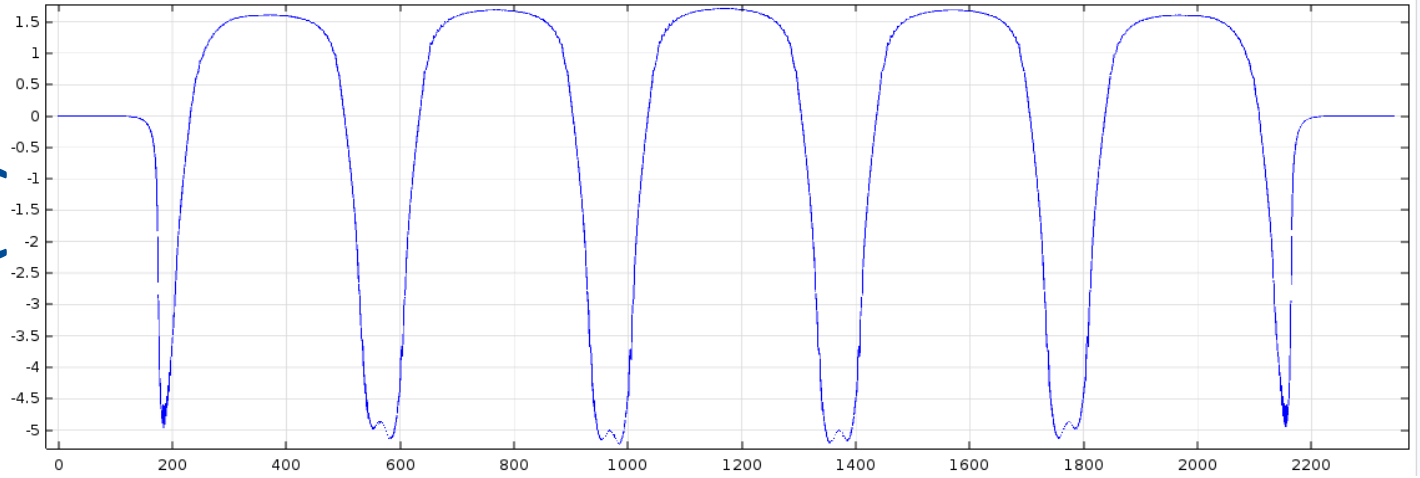
E Field



H Field

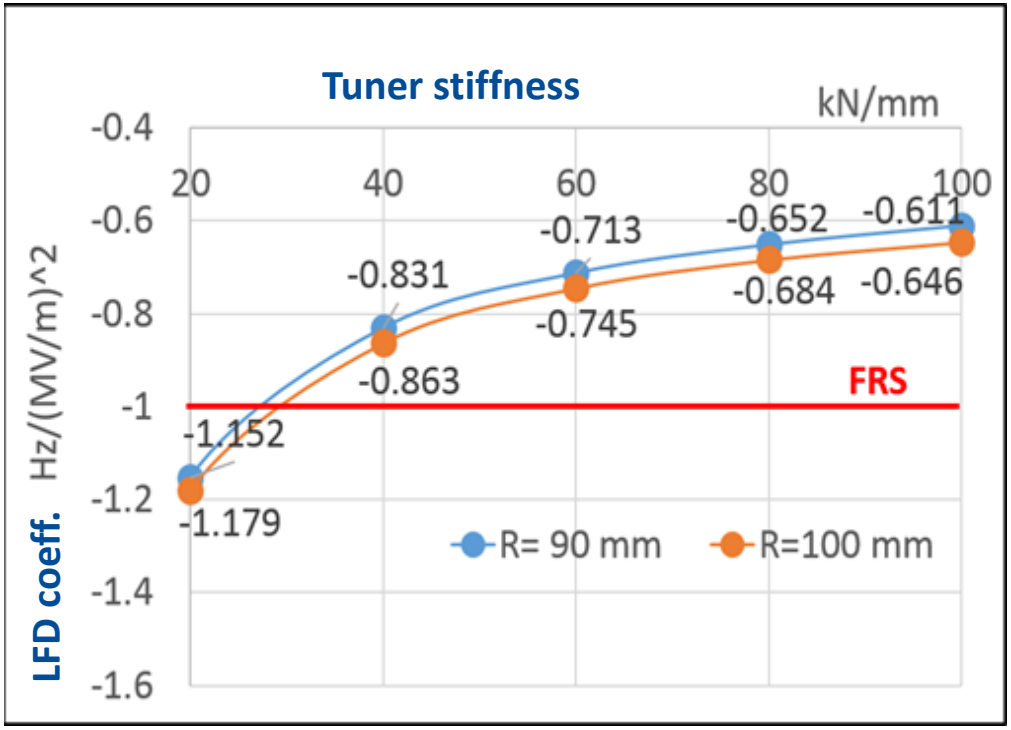


$$P_{rad} = \frac{1}{4}(\varepsilon_0 \mathbf{E}^2 - \mu_0 \mathbf{H}^2)$$

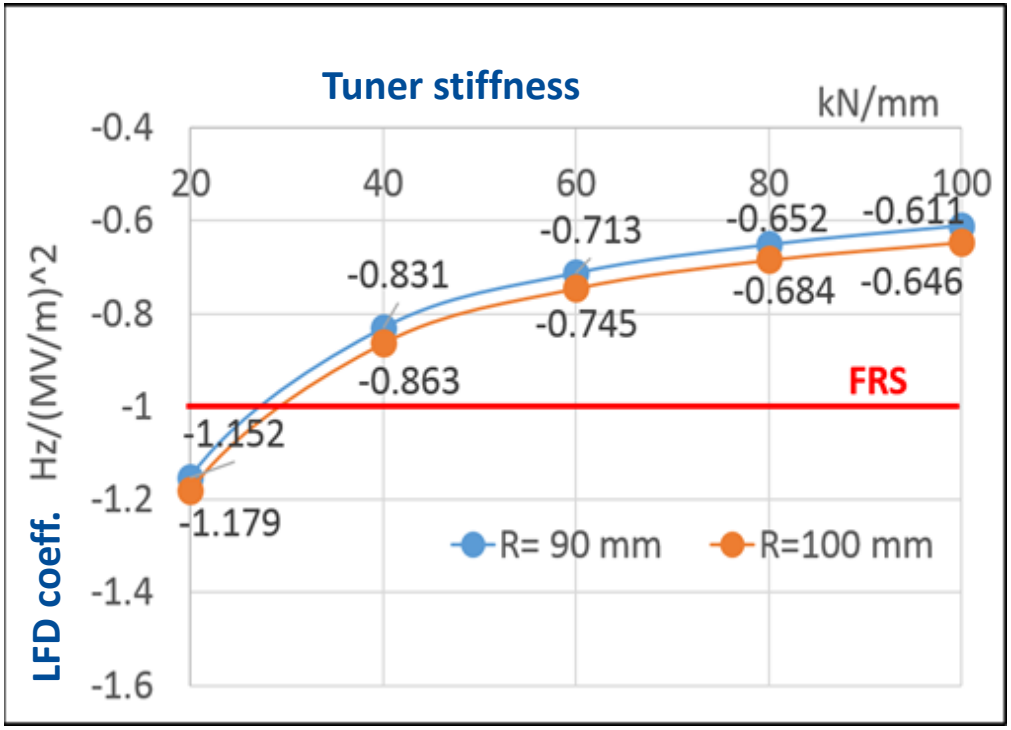


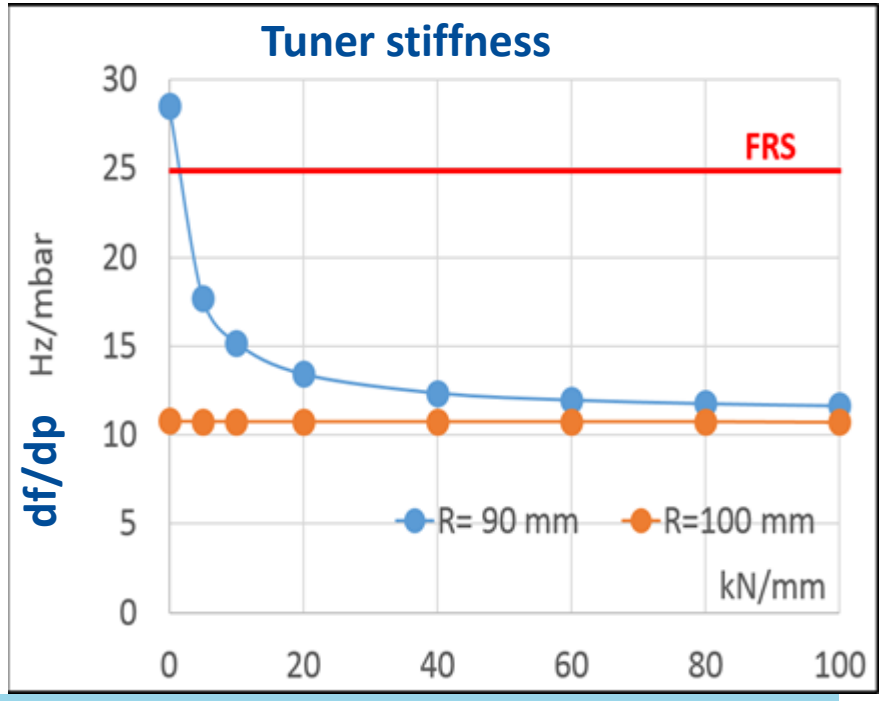
Cavity boundary (mm)

Mech. simulations ➔RF simulations

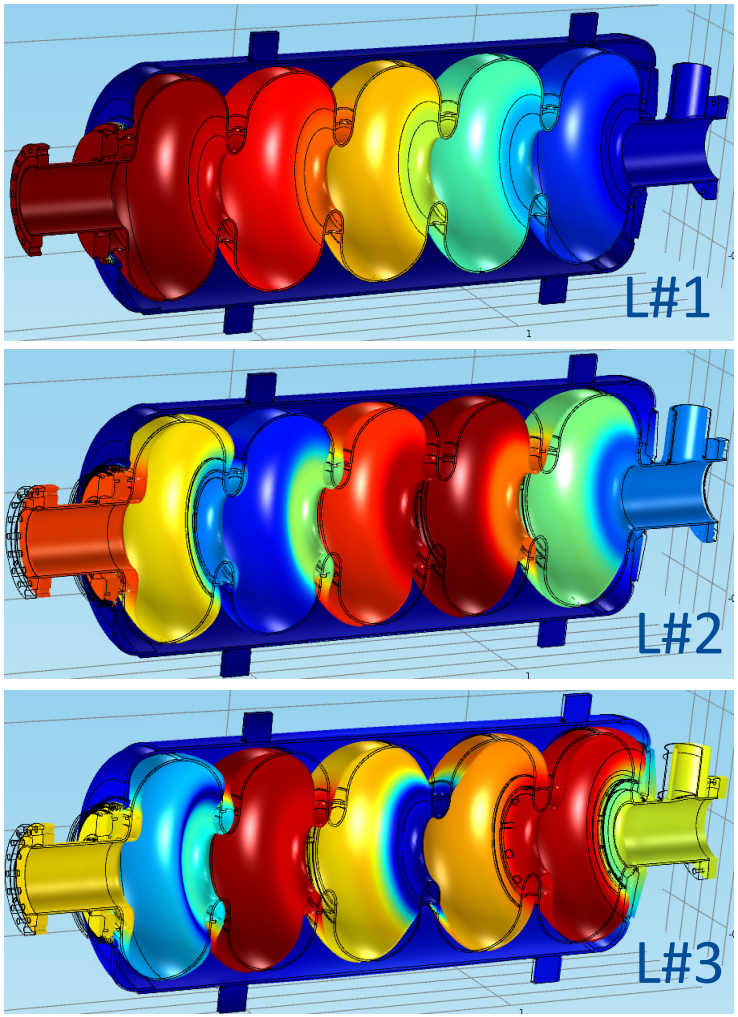


Mech. simulations ➔RF simulations

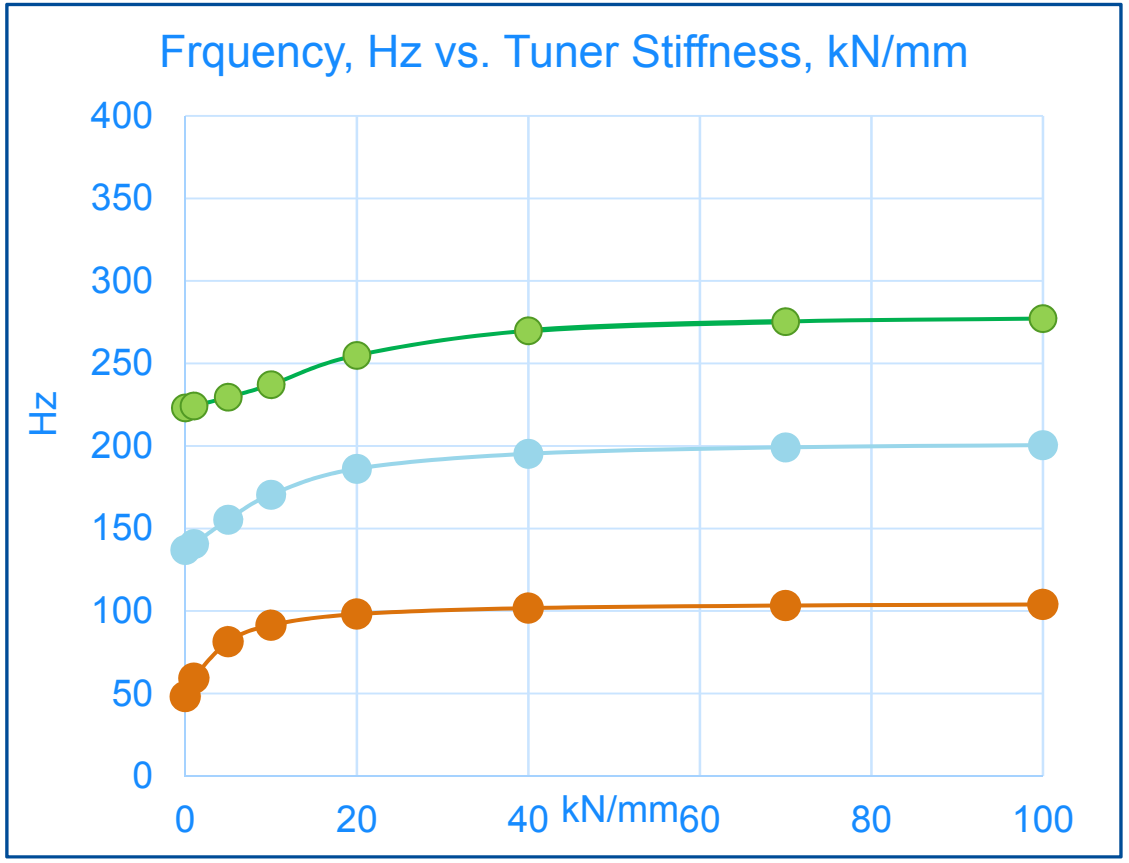




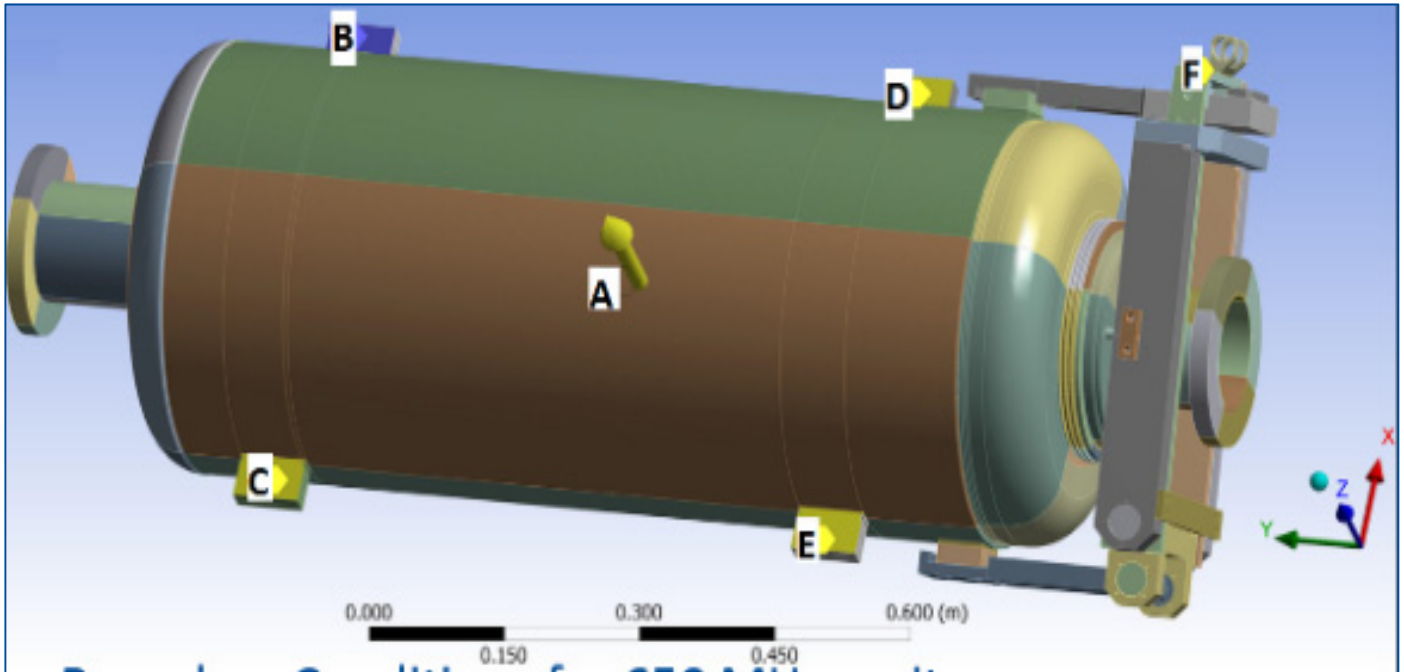
Beta=0.92, Frequencies of Longitudinal Modes L#1-#3 vs. Stiffness of the Tuner, thickness =3.75 mm



Modal Analysis



Stress Analysis

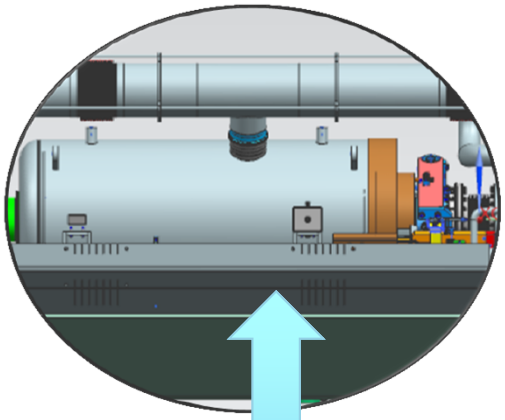


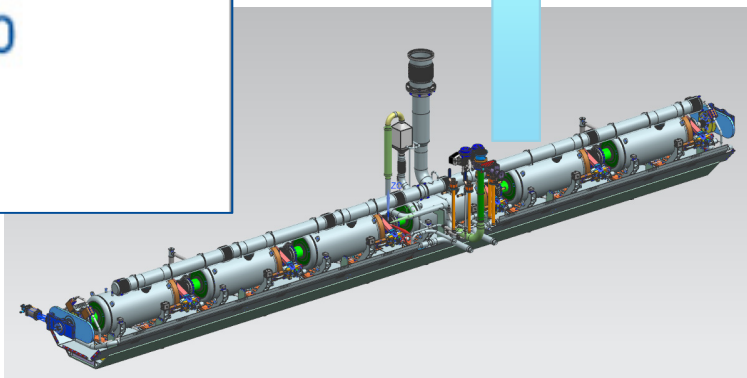
Boundary Conditions for 650 MHz cavity

B; x=0, y=0, z=0 / C; y=0, z=0 / D; x=0, z=0 / E; z=0

Loads:- A; g = 9.81 (Vertical)

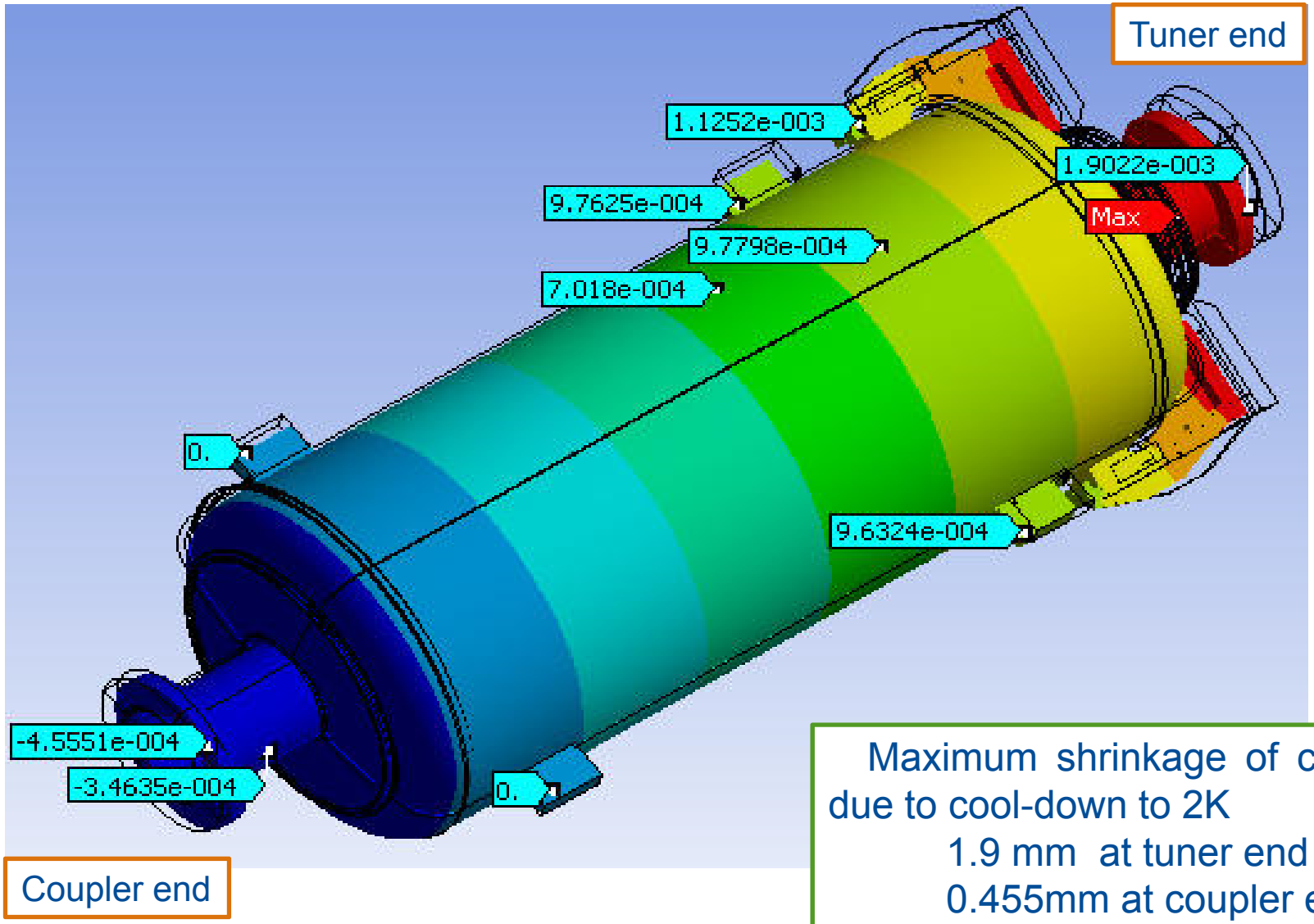
F; y = displacement at tuner motor Location.





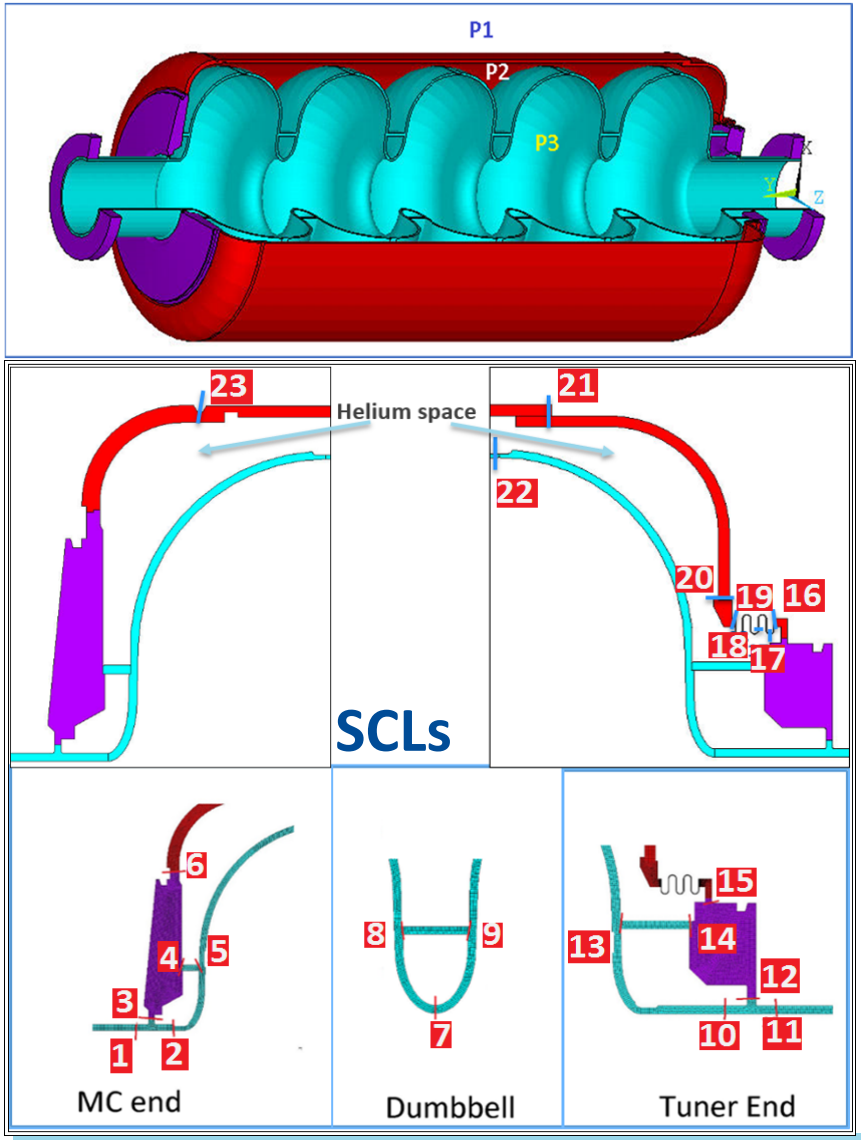
Different BC as compared to ILC cavity due to Bottom supported cavity in CM

Cavity Cool-down to 2K



Maximum shrinkage of cavity due to cool-down to 2K
1.9 mm at tuner end and
0.455mm at coupler end.

Loads Cases and Results



Different loads applicable to cavity

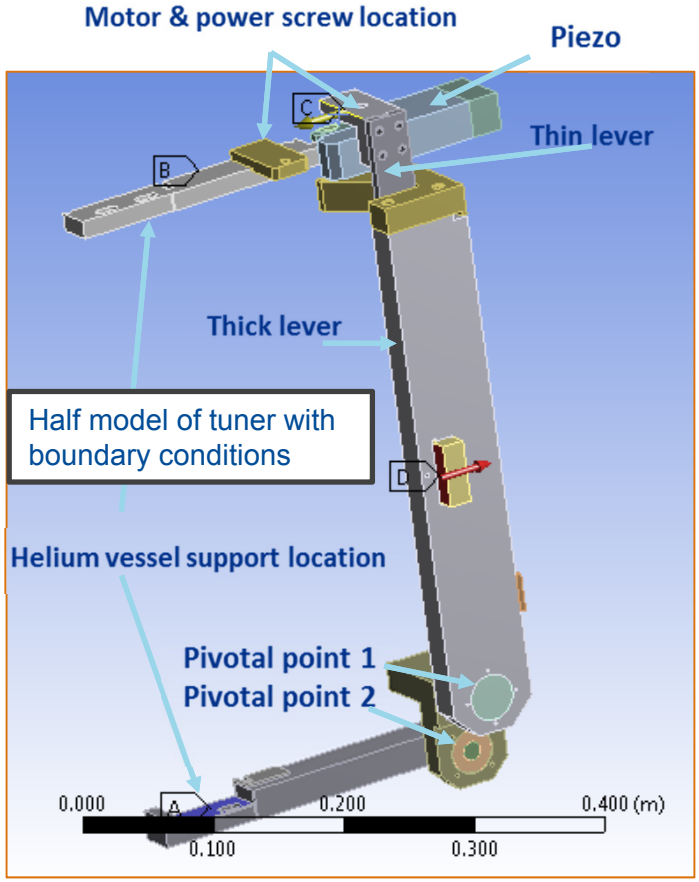
- Gravity
- Liquid helium pressure head
- P2 = 2 bar at room temp. p1=p3=0
- Cool-down shrinkage to 2K
- P2 = 4 bar at room temp. p1=p3=0
- Tuner extension and
- Cavity vacuum failure loads p3=1bar

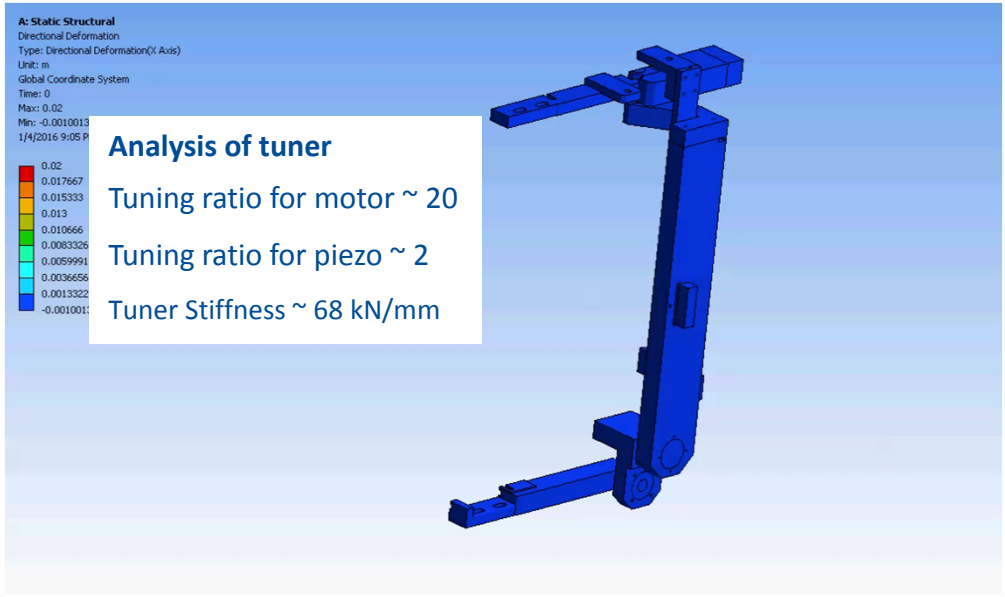
- 5 load cases with different combination were qualified.
- All applicable stress categories have been evaluated at the stress classification lines.
- It was found that in all cases the stresses are below the allowable values.

Lever Tuner for 650MHz SCRF cavity

Fermilab

Common tuner for LB & HB cavities



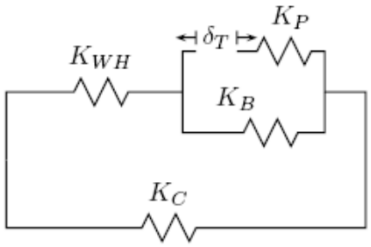


Analysis of tuner

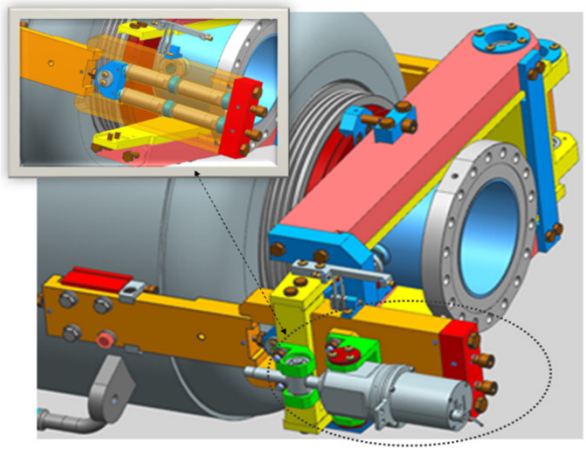
Tuning ratio for motor ~ 20

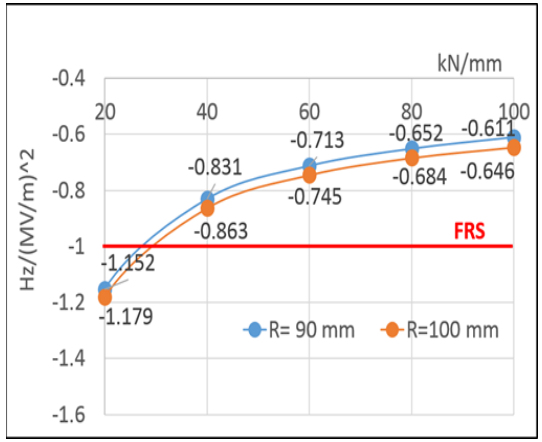
Tuning ratio for piezo ~ 2

Tuner Stiffness ~ 68 kN/mm



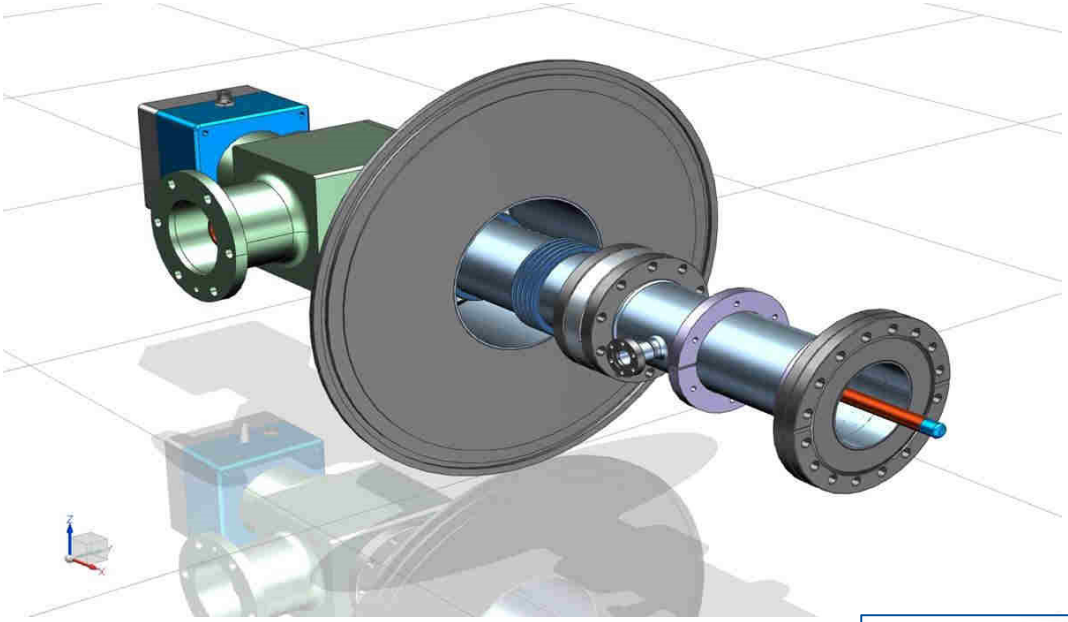
Equivalent spring model





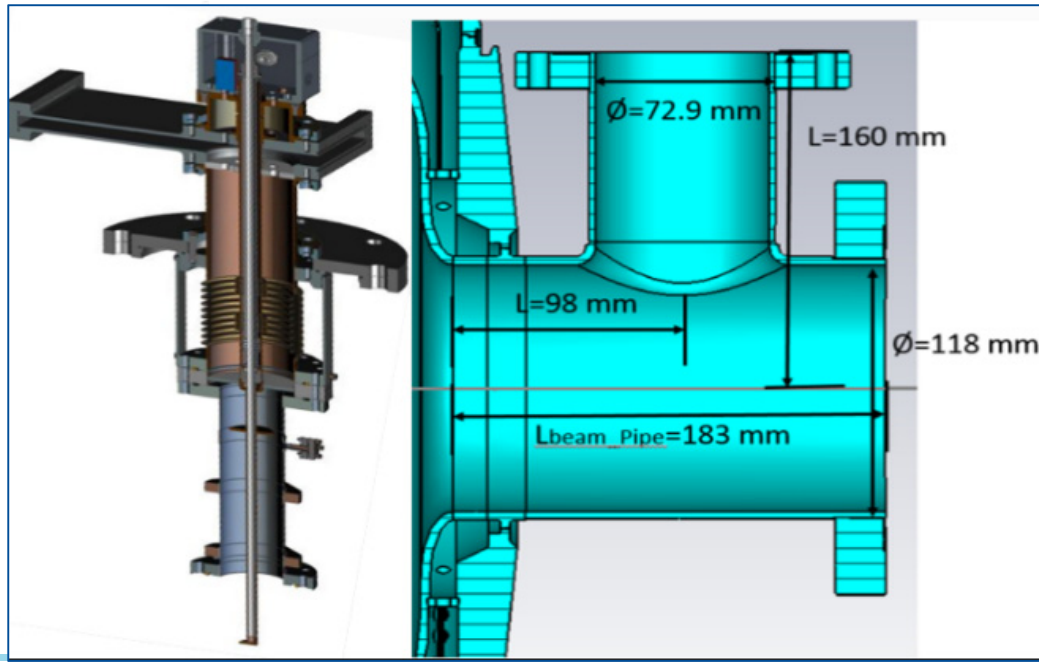
*Y.M. Pischalnikov, et al,"Testing of the Prototype Tuner for 650MHz SRF Cavities for PIP II Project", 28th International Linear Accelerator Conference, 25-30 September 2016, East Lansing, MI, USA

DAE IIFC PIP-II



Coupler for 650 MHz design (low and high-β)

- The RF coupler for LB650 and HB650 cavities is same.
- Coupler has a single room temperature coaxial ceramic window.
- The window diameter is 4''. Central conductor of the coupler is cooled by air.



S. Kazakov et al., "Design of Main Coupler for 650 MHz SC Cavities of PIP-II Project", **MOPOB24,** this conference

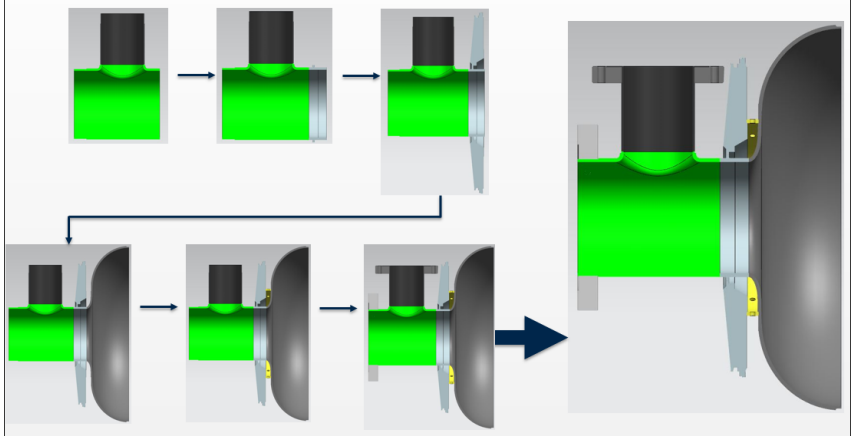
Dressed cavity fabrication

- Bare Cavity Fabrication & qualification
  - The development of bare cavity
  - Qualifications consists of leak tests, inspection, and RF QC tests.
  - Processing BCP, EP, HPR ➔ VTS testing
- Cavity Dressing
  - Fabrication of helium vessel, bellow and end transition ring.
  - The following tools/fixtures are used for cavity dressing:-
    - a. Insertion device (medium bertha) for preparing cavity for dressing.
    - b. Rotating fixture to revolve cavity during welding.
    - c. Globe box for welding 5-cell 650 cavities in inert atm.

  During the entire fabrication process the dressed cavity RF frequency is monitored and kept within the specified limit.

Step 1

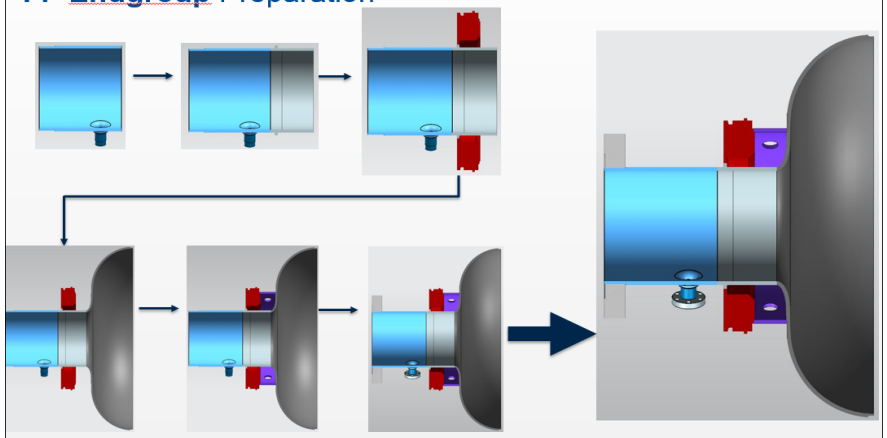
MC Endgroup Preparation



Endgroup Electron-Beam Welding Sequence

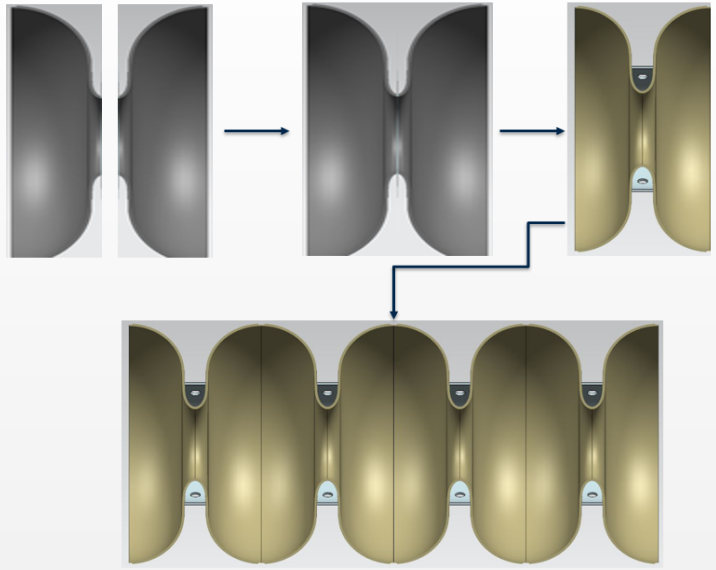
Step-2

FP Endgroup Preparation



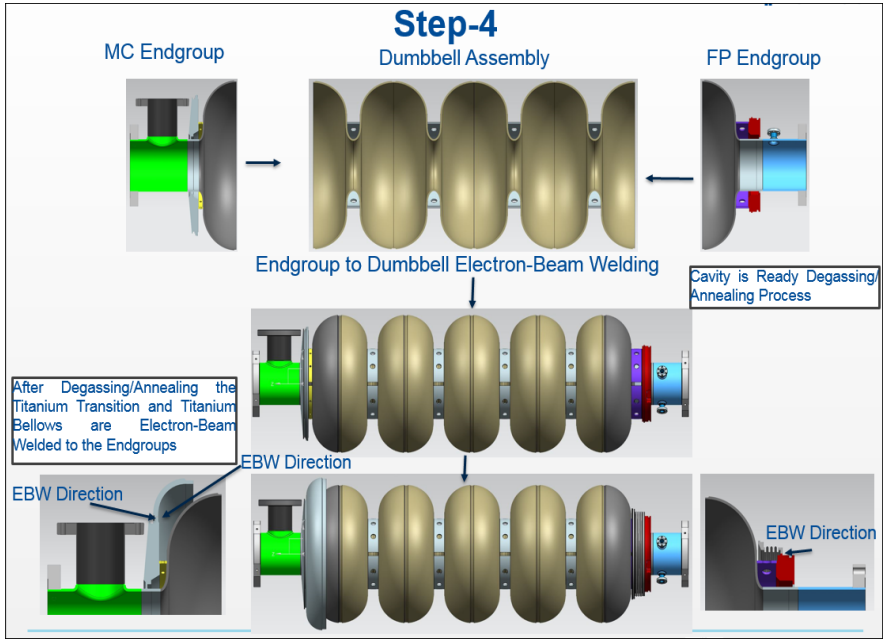
Endgroup Electron-Beam Welding Sequence

Step-3



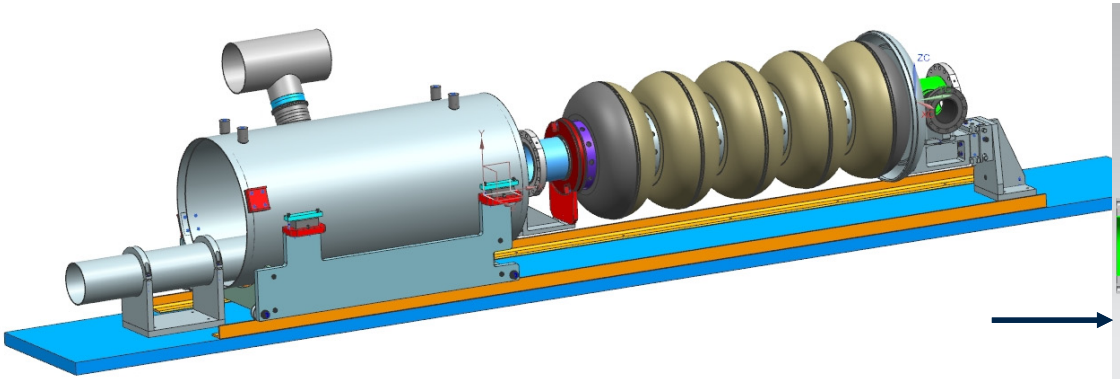
Dumbbell Assembly Electron-Beam Welding Sequence

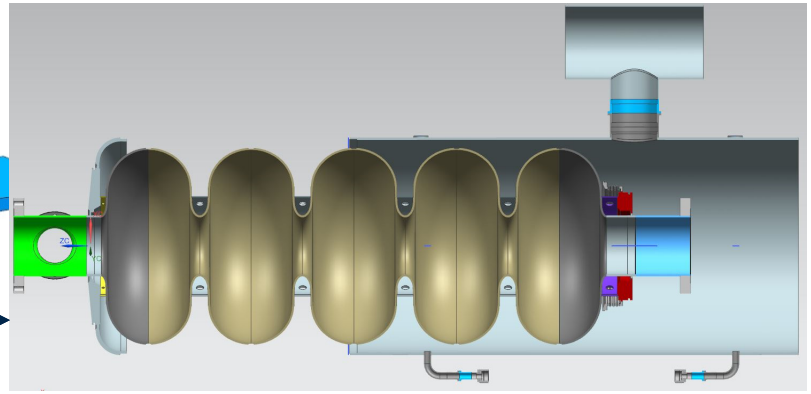
Step-4



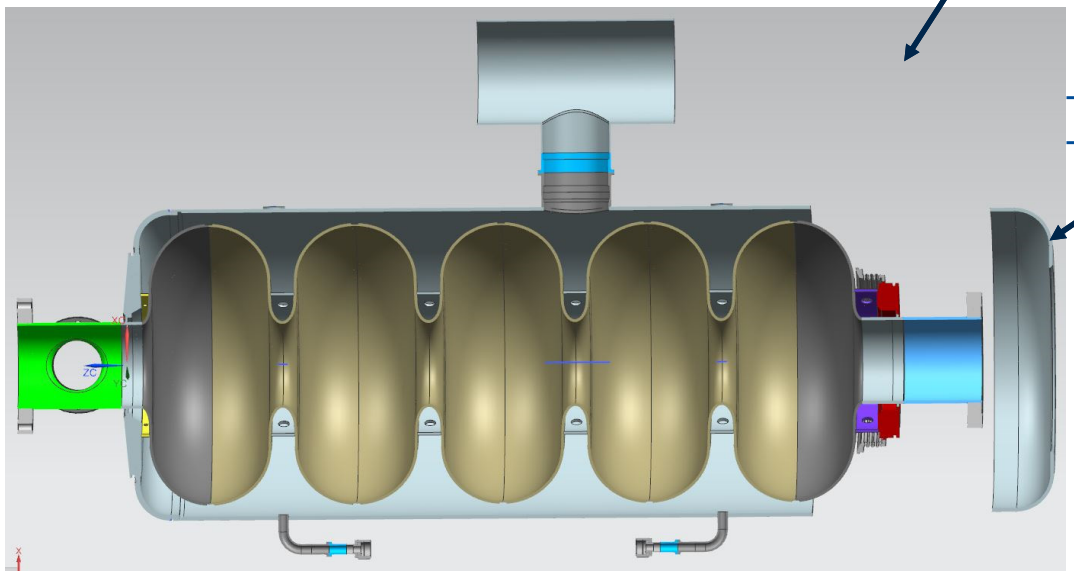
BARE CAVITY FABRICATION STEPS

Dressed cavity preparation by tack welding





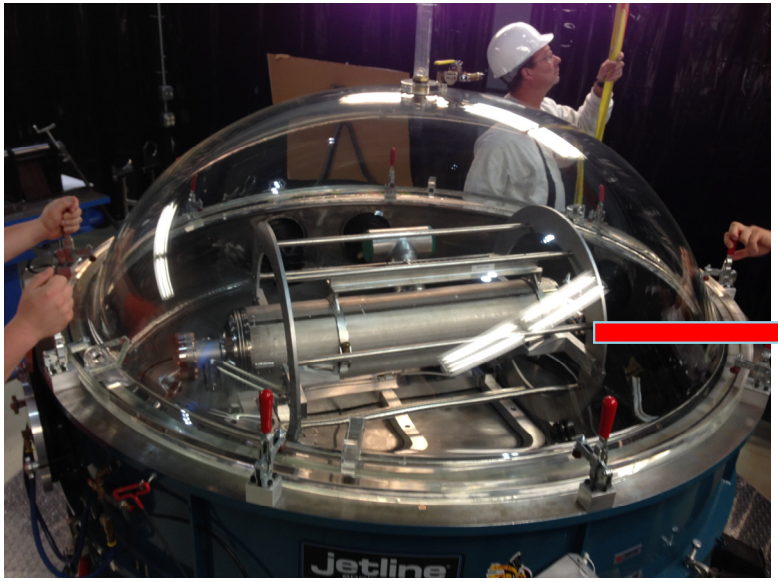
Insertion device (medium bertha) for cavity dressing

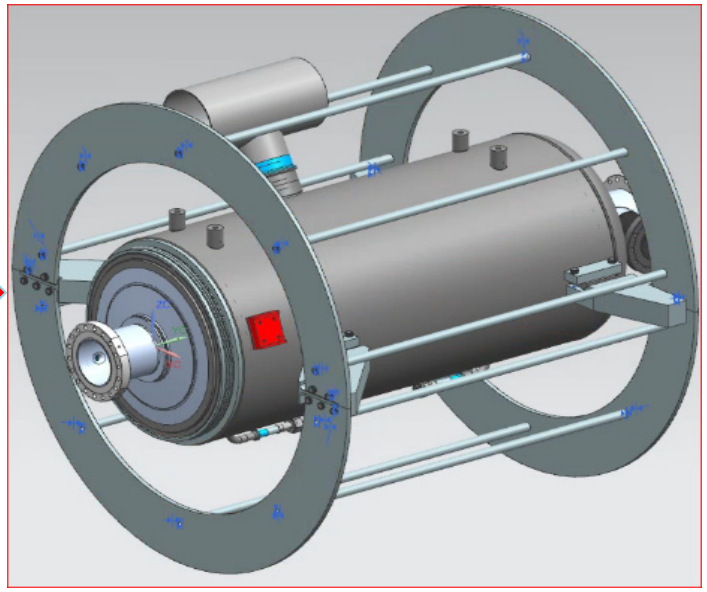


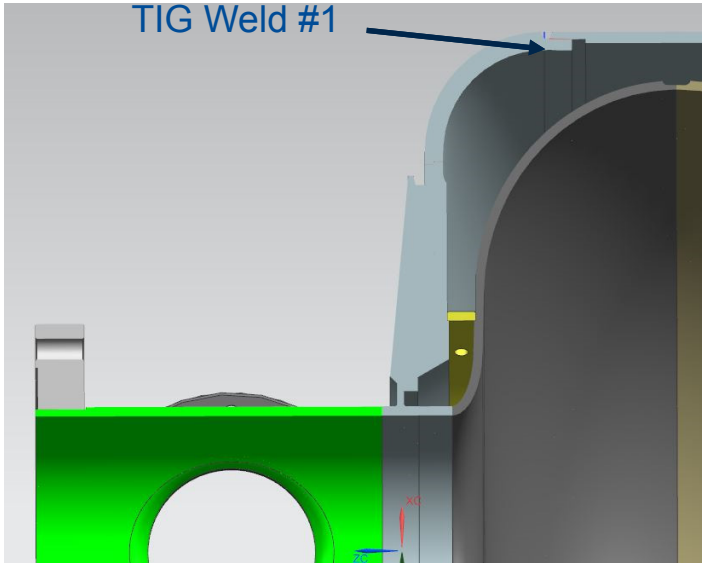
Titanium
Transition Ring

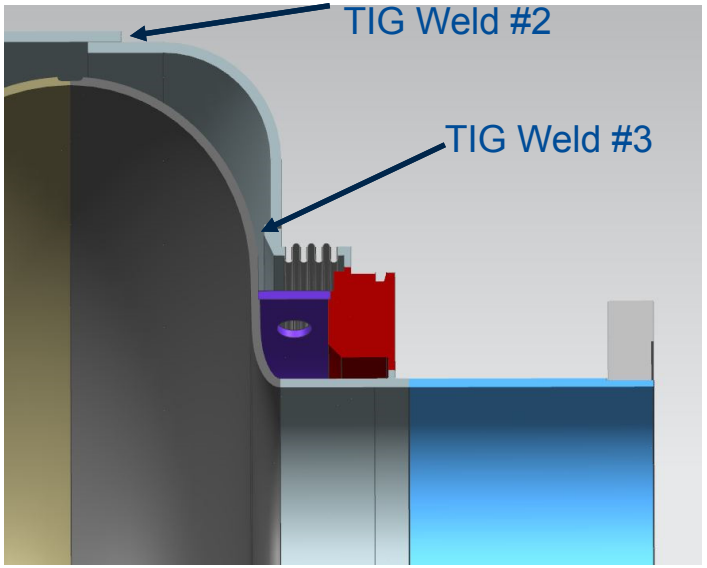
Dressing the Bare Cavity

CAVITY DRESSING STEPS







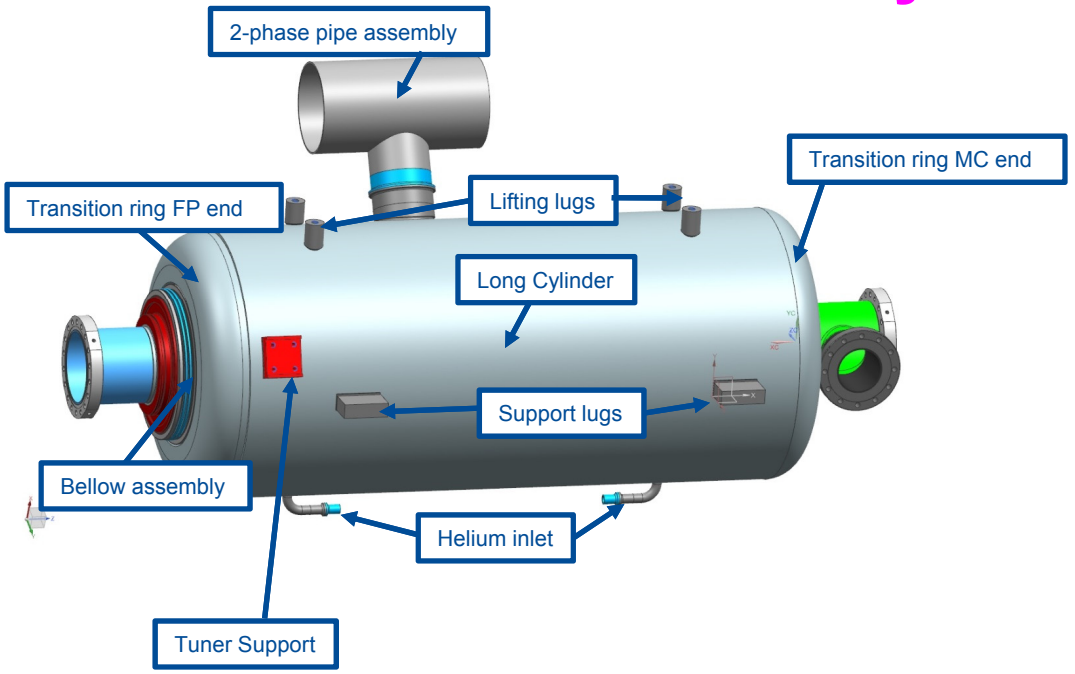


Glovebox TIG Welding

HB 650 MHz Dressed Cavity

Component of LB 650 MHz Dressed Cavity same/ similar are

1. MC & FP End groups
2. Helium vessel (item 1 to 10)
3. Tuner
4. Coupler
5. Magnetic shield



Cavity schedule for HB650

- Bare cavity ➔ March 2017
- VTS Testing ➔ April 2017
- Dressing ➔ July 2017
- STC/HTS Testing ➔ Dec 2017

Conclusion

- Development of 650 MHz elliptical cavities has been initiated for PIP-II project.
- For these cavities, it was decided to have similar mechanical structures for the end groups, helium vessel, and tuner.
- The common design of these components allows us to reduce complexity and risk, as well as the cost of development and production.
- Design and drawings of HB650 cavities are released by FNAL.
- RRCAT and FNAL are working for the development of β=0.92 650 MHz cavity.
- VECC and FNAL have also initiated work on LB650 dressed cavity.

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THANKS FOR YOUR KIND ATTENTION