HB650 cavity status

Grigory Eremeev

650 MHz High Beta CM Prototype FDR

29 – 30 July 2020

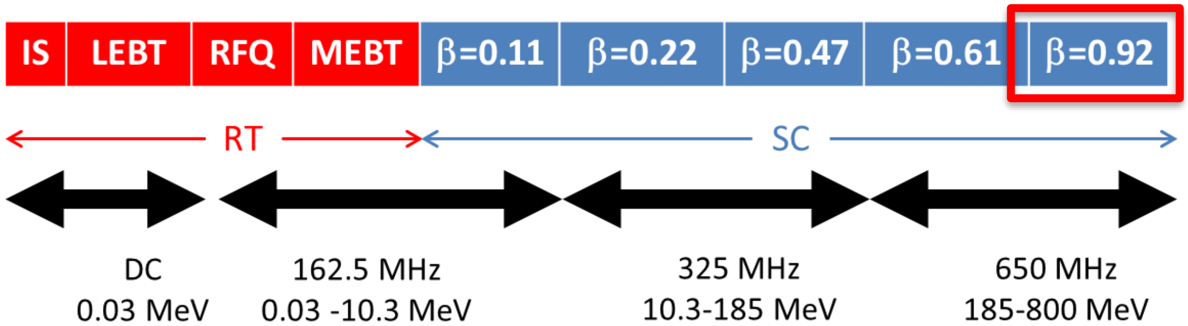
A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Outline

- Introduction
- Cavity specifications & design
- Cavity interfaces
- Cavity status
- Summary

* Based on material presented @ jacketed proto cavity FDR 2/1/2019 & proto cryomodule PDR 12/11-12/2019

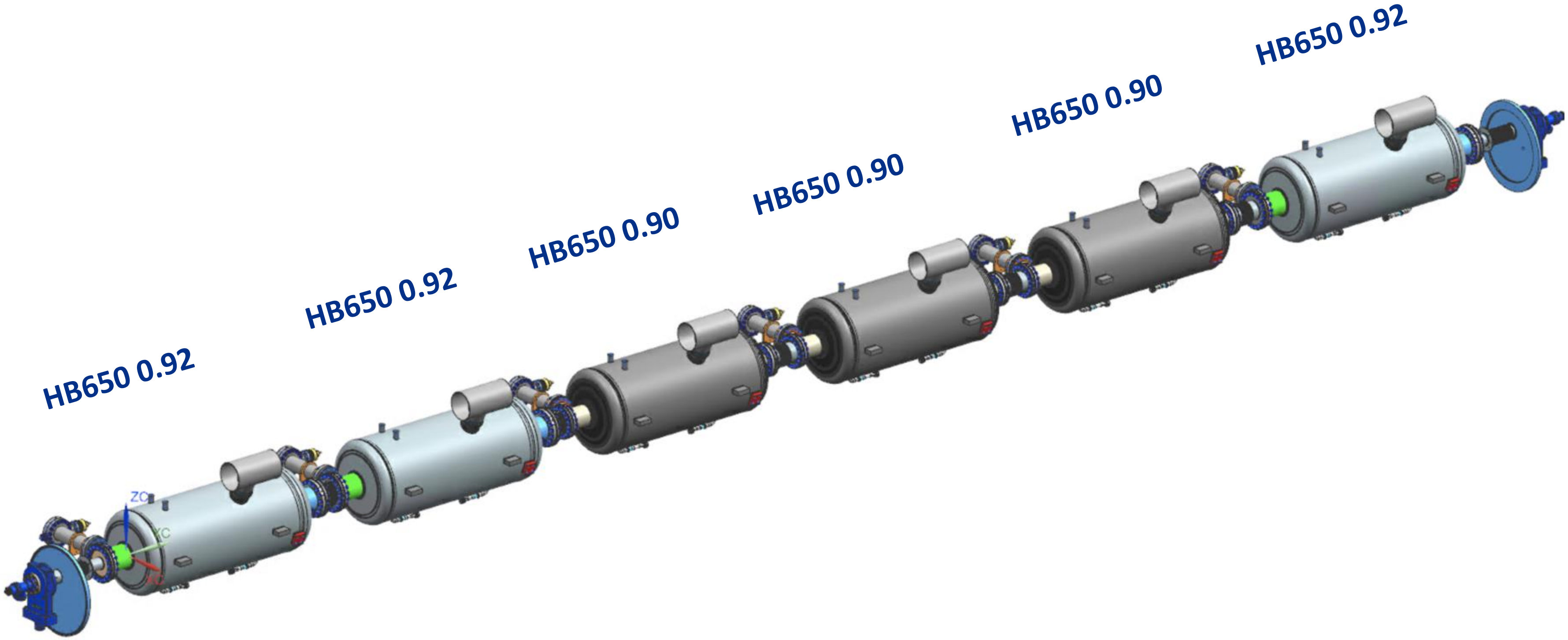
PIP-II HB650



Cryomodule	Number (Prototype + installed)	Cavity Number	Testing	Note
HB650	1+4	6	Test at FNAL	Integrated Design

- CW operation & 2 mA average beam current

PIP-II HB650 prototype cryomodule



- will comprise three 0.9 and three 0.92 cavities
- four RRCAT 0.92 cavities will be qualified at Fermilab

HB650 Cavity Requirements

- PIP-II SRF Cavity Parameters Physics Requirement Document (PRD) (ED0010221)

6.5. HB650

Table 6-5. HB650 Cavity Parameters

Parameter	Value	Units
Cavity name	HB650	-
Cavity type	Elliptical	-
Frequency	650	MHz
Optimum beta, β_{opt}	0.971	-
Effective length, L_{eff}	1060.8	mm
Energy Gain at β_{opt}	19.9	MeV
Average accelerating gradient, E_{acc}	18.8	MV/m
Peak surface electric field, E_{peak}	38.9	MV/m
Peak surface magnetic field, B_{peak}	73.1	mT
(R/Q)	610	Ohm
G	260	Ohm
Q_0 (in cryomodule at 2K)	3.2E10	-
Surface resistance	8.1	nOhm

Performance parameters for beta=0.90 cavity

Table 1. Beta 0.9 Cavity EM parameters

Parameter	Value
Frequency	650 MHz
Shape, number of cells	Elliptical, 5 cells
Geometric beta β_g	0.90
$L_{eff} = 2*(\beta_g\lambda/2)$	1037.7 mm
Iris Aperture	100 mm
Bandwidth	45 Hz
E_{peak} at operating gradient	< 35 MV/m
B_{peak} at operating gradient	< 65 mT/(MV/m)
Cavity quality factor Q_0 at 2K	$>2.0 \cdot 10^{10}$

Table 2. Beta 0.9 Cavity operational/test requirements

Operating mode	CW
Peak current	1 mA
Max Leak Rate (room temp)	$< 10^{-10}$ atm-cc/sec
Operating gain per cavity	17.7 MeV
Maximum Gain per cavity in VTS	> 21 MeV
Operating power dissipation per cavity at 2 K	< 25 W
Sensitivity to He pressure fluctuations	< 15 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	up to 100 kW (CW, operating)
Cavity longitudinal stiffness	$< 10^4$ N/mm
Tuning sensitivity	> 180 kHz/mm

dF/dP

Slide from Ivan Gonin presentation at cavity FDR

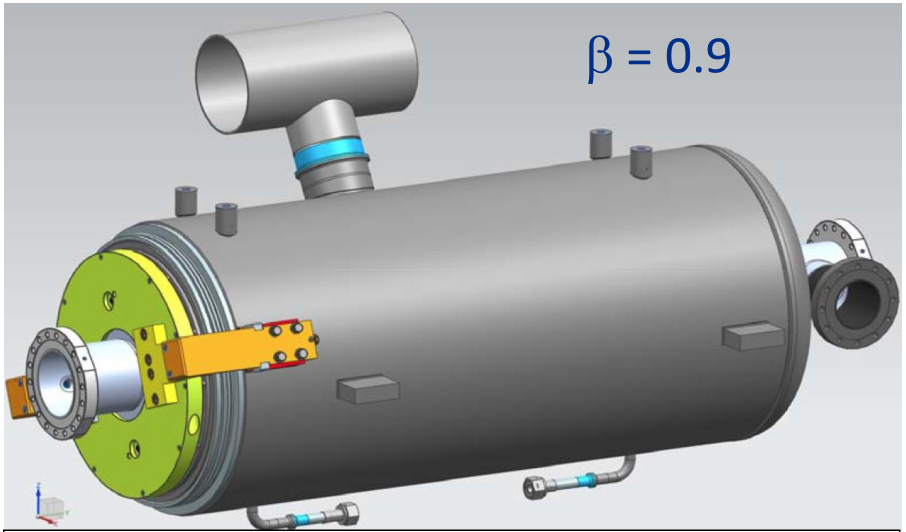
HB650 0.92 Cavity Technical Requirements (TC# ED0009659 Rev A)

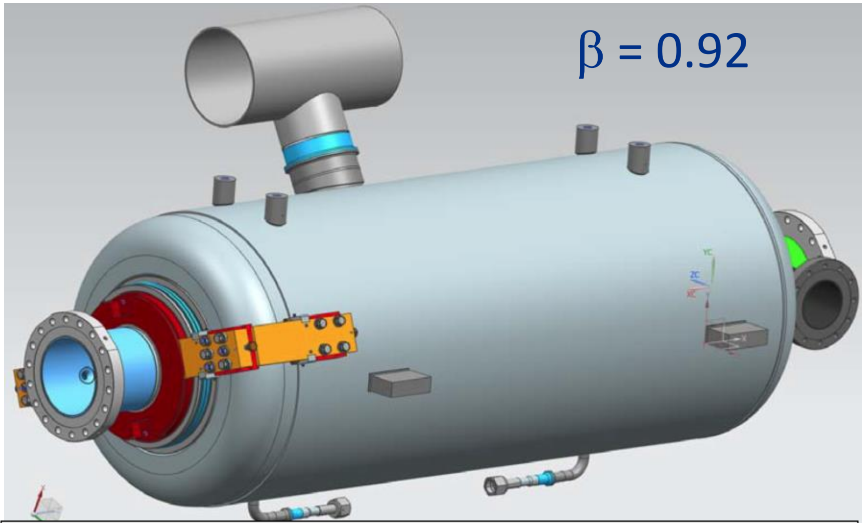
EM Design	Parameter	Value
	Frequency, MHz	650
	Iris aperture, mm	118
	Effective length $L_{eff} = 5\cdot(\beta_g \lambda/2)$, mm	1060.8
	Geometrical/Optimal beta β_{gt}	0.92/0.971
	Optimal shunt impedance $(R/Q)_{opt}$, Ω	610 Ω
	Energy gain at optimal beta V_{opt}, MeV	19.9
	Surface RF electric field E_{peak}, MV/m	38.9
	Surface RF magnetic field B_{peak}, mT	73.1
Mechanical		
	Sensitivity to LHe pressure fluctuations of dressed cavity, Hz/mbar	< 25
	Lorentz Force Detuning coefficient, $Hz/(MV/m)^2$	< 1
	Longitudinal stiffness, kN/mm	< 5
	Operating frequency tuning sensitivity, kHz/mm	> 150
	MAWP RT/2K, bar	2.05 / 4.1
	Cavity Length (flange to flange), mm	1400.2
Operational		
	Operating Field Flatness in dressed cavity, %	> 90
	Average operating cavity gradient $E_{acc} = V_{opt}/L_{eff}$, MV/m	18.8
	Maximum gradient in VTS, MV/m	≤ 24
	Operating temperature range, K	1.8 - 2.1
	Unloaded quality factor Q_0	$> 3.3\cdot10^{10}$
	Unloaded quality factor Q_0 in VTS at 19 MV/m	$>4.0\cdot10^{10}$
	Dynamic RF power dissipation, W	< 22.5
	Max Leak Rate (room temp), mbar·L/sec	$< 2\cdot10^{-10}$
	Operating cavity Q-loaded/bandwidth, Hz	$9.9\cdot10^6$ / 66
	Operating input RF power CW, kW	≤ 43
	Operating field probe RF Power CW, mW	100 – 500
	Multipacting free zone at operating gradient, %	± 10

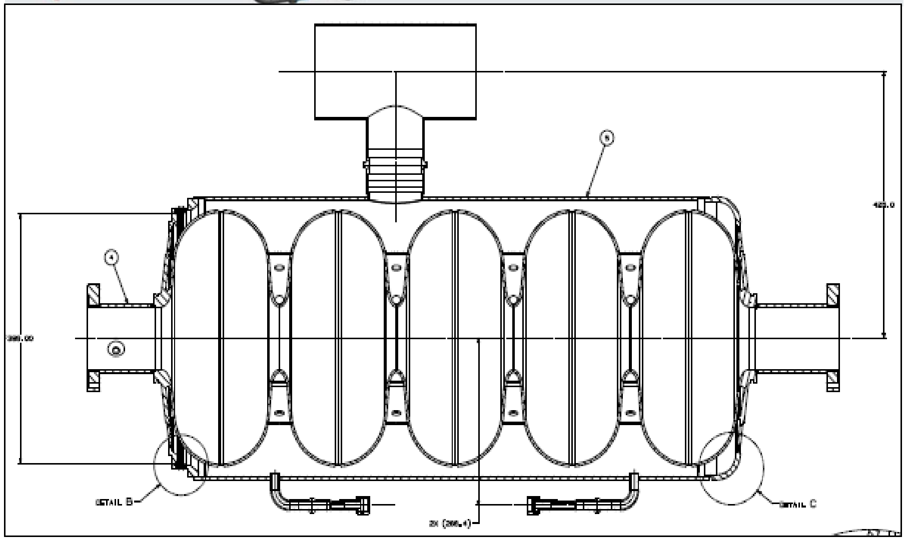
Similarities and differences in β = 0.90 & β = 0.92 Helium Vessel and Cavity

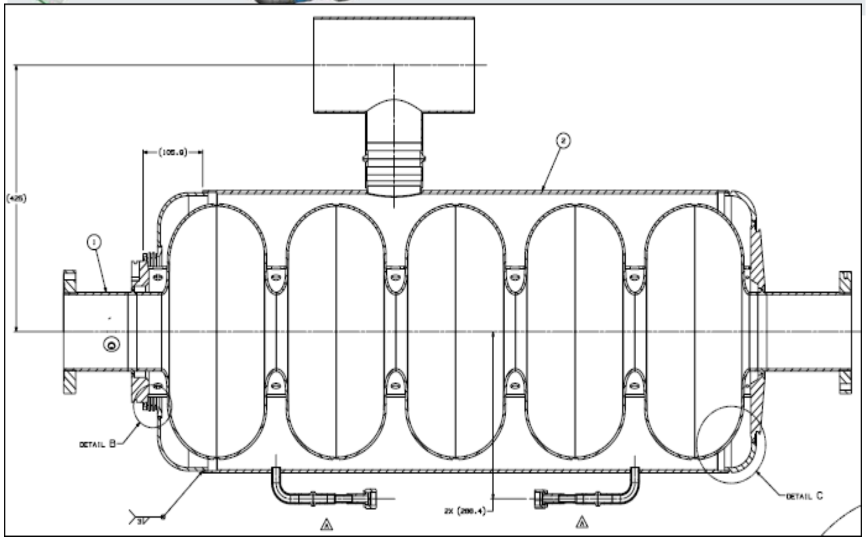
Charge 1a, 3a

From the slide by Vikas Kumar Jain presentation at cavity FDR





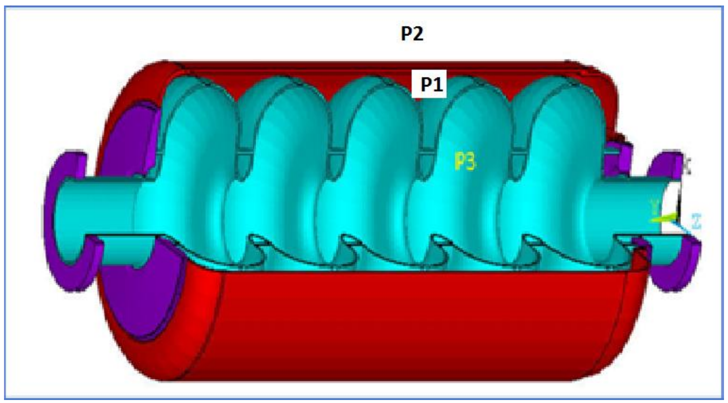




FEM Simulations
Loadings

The cavity is subjected to following loads:

1. Gravity
2. LHe liquid head
3. Thermal contraction due to 2K
4. Tuner extension (cavity compression)
5. Pressure (internal and external)



Load Case	Loads	Condition Simulated	Applicable Temperature	Applicable Stress Categories
1	Gravity $P_1 = 2.05$ bar $P_2 = P_3 = 0$	Warm Pressurization	293 K	Pm, P_L, Q, Pm + P_b , P_L + Q
2	Gravity Liquid Helium head $P_1 = 4.1$ bar $P_2 = P_3 = 0$	Cold operation, full LHe, maximum pressure – no thermal contraction	2 K	Pm, P_L, Q, Pm + P_b , P_L + Q
3	Cool down to 2 K Tuner extension of 1.5 mm * (Cavity compressed by 1.5 mm)	Cool down and tuner extension, no primary loads	2 K	Q
4	Gravity Liquid Helium head Cool down to 1.88 K Tuner extension of 1.5 mm $P_1 = 4.1$ bar $P_2 = P_3 = 0$	Cold operation, full LHe inventory, maximum pressure – primary and secondary loads	2 K	Q
5	Gravity $P_1 = 0$ $P_2 = P_3 = 1$ bar	Helium vessel leak check	293 K	Pm, P_L, Q, Pm + P_b , P_L + Q

From the slide by Vikas Kumar Jain presentation at cavity FDR

Charge 1a, 3a

HB650 cavity reviews

Charge 1a, 3a

- ED0004939 : helium vessel preliminary design review
- ED0009553 : PIP-II 650 MHz β=0.90 & 0.92 Jacketed Cavity Prototype Final Design Review

Friday, 1 February 2019

08:30 - 08:40 Introduction *10'*

a. *Team introduction and Organization*
b. *PIP-II & HB650 Context*
c. *Review Charge*

Speaker: Dr. Saravan Chandrasekaran (FNAL/TD)
Material: **Slides**

08:40 - 08:55 Design Overview *15'*

a. *Past cavity reviews recap*
b. *Cavity design & performance requirements*

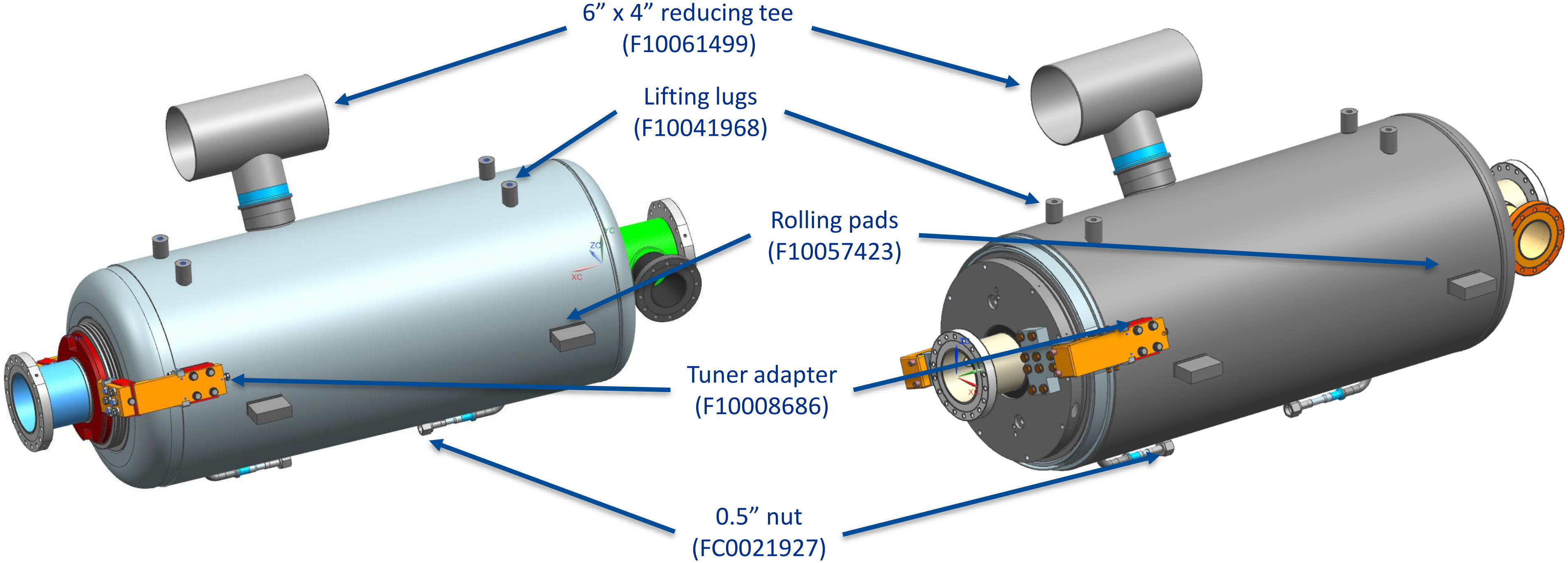
Speaker: Dr. Saravan Chandrasekaran (FNAL/TD)
Material: **Slides**

- ED0009629 : PIP-II 650 MHz beta=0.90 & 0.92 Jacketed Cavity Prototype FDR Report

HB 650 MHz Cavity & Helium Vessel

Charge 1a,3a

0.92 - F10127563   0.90 - F10129206



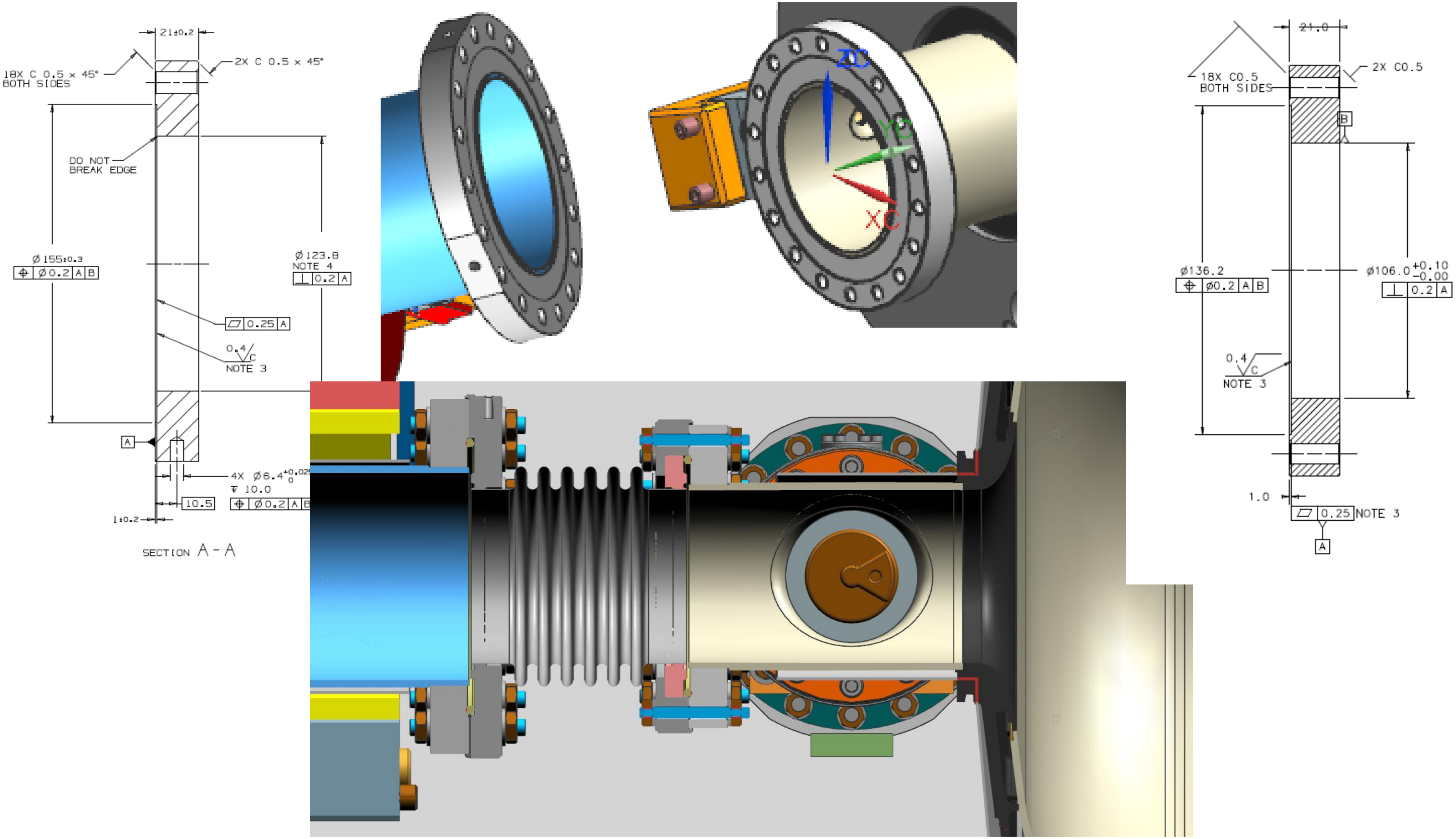
- Beamline flanges are different, e.g., no alignment markers on 0.90 flanges (F10046673 & F00481600)
- Main coupler flanges are different (F10007345 & F00482496)
- Field probe flanges are different (F10007350 & F00482728)
- NbTi transition rings are different (F10089369 & F00482495)

HB 650 MHz 0.90 & 0.92 beamline flanges

Charge 1a,3a

0.92 - F10046673

0.90 - F00481600



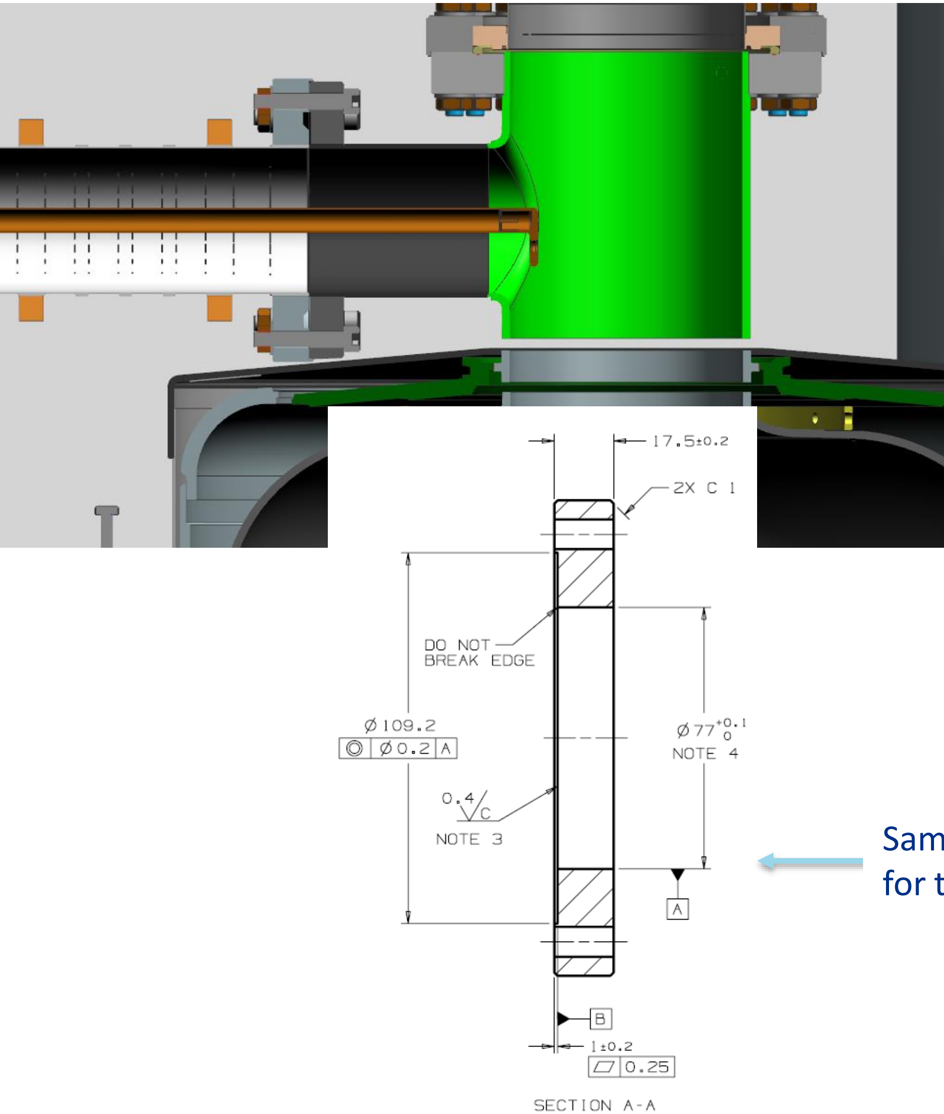
PIP-II

HB 650 MHz 0.9 & 0.92 main coupler

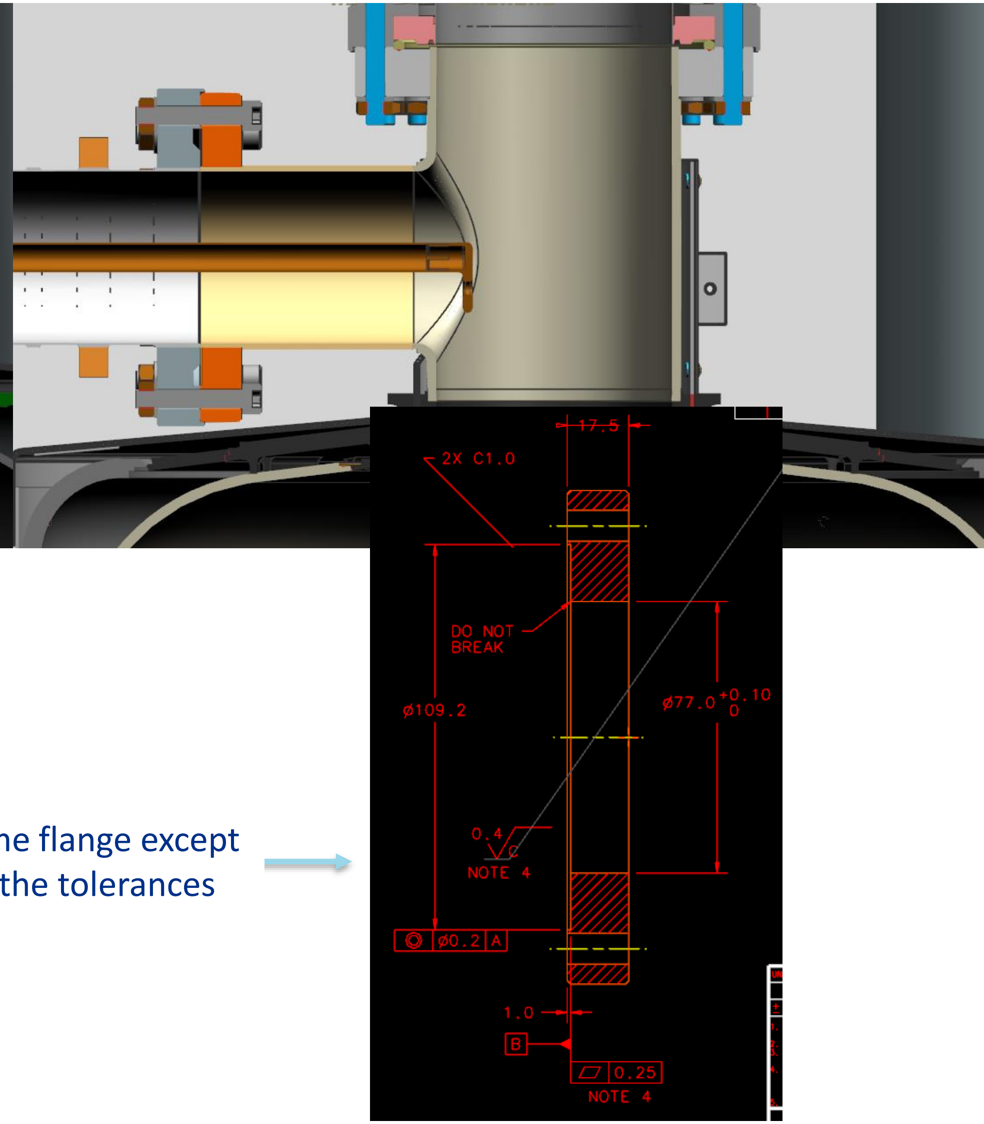
Charge 1a,3a

0.92 - F10007345

0.90 - F00482496

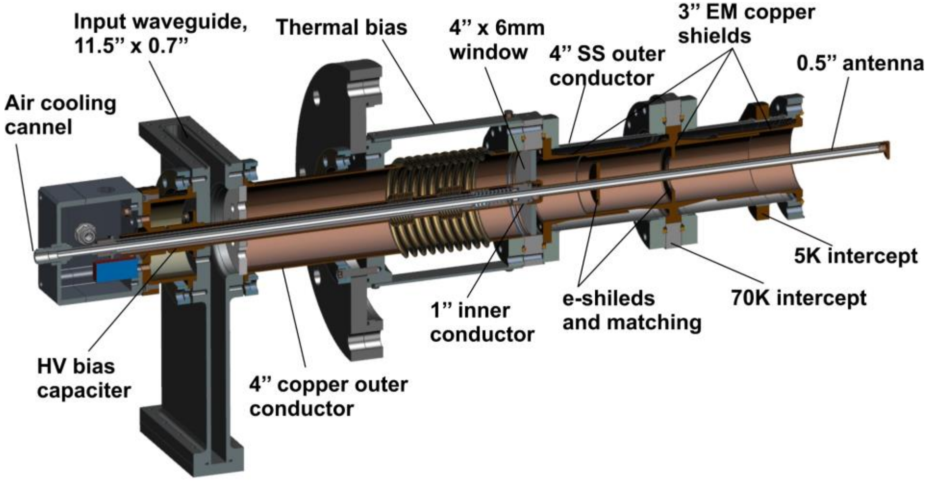


Same flange except for the tolerances



Coupler design for HB 650 MHz cavities

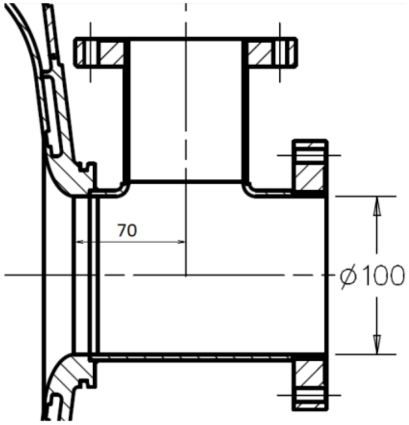
Charge 1a, 3a



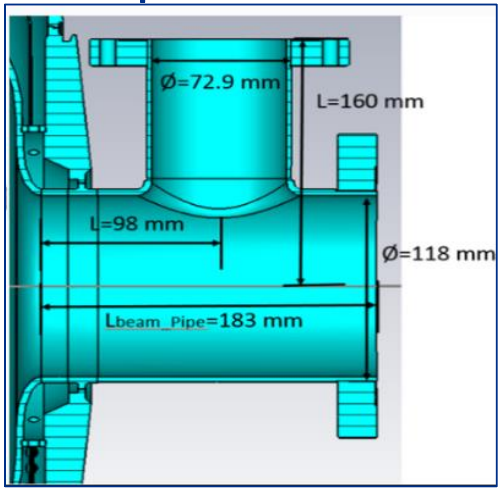
Current status:

Electrical, thermal designs are done.
Mechanical design is done.
Test stand has been designed and currently under assembly

β=0.90



β=0.92



Main Coupler Port

- The RF coupler for β=0.90, β=0.92 cavities is same.
- Coupler has a single ceramic window operating at room temperature.
- Central conductor of the coupler is cooled by air.

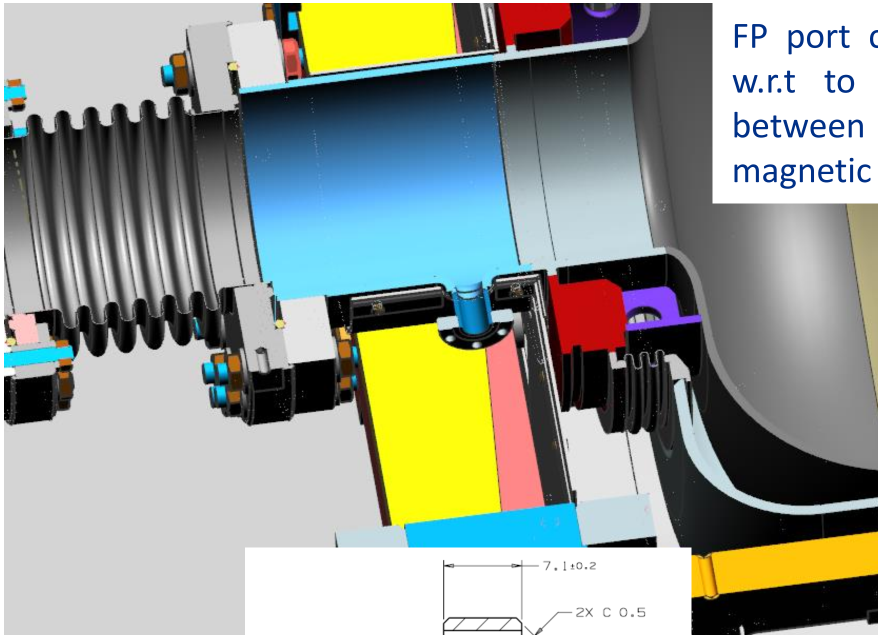
Slide from Ivan Gonin presentation at cavity FDR

HB 650 MHz 0.9 & 0.92 field probe

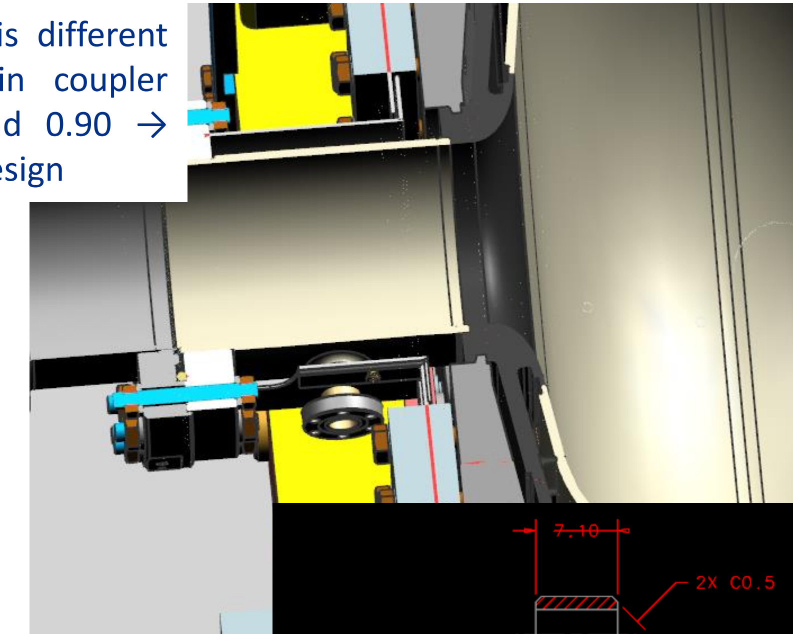
Charge 1a,3a

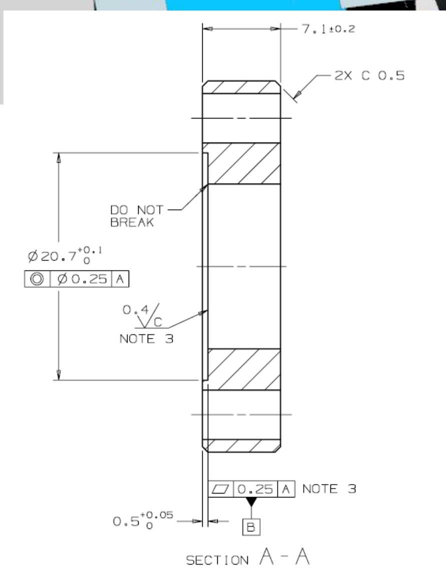
0.92 - F10007350

0.90 - F00482728

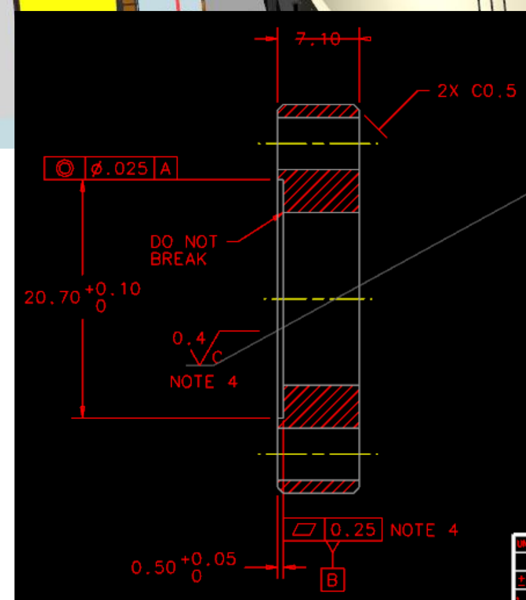


FP port clocking is different w.r.t to the main coupler between 0.92 and 0.90 → magnetic shield design





Same flange except for the tolerances

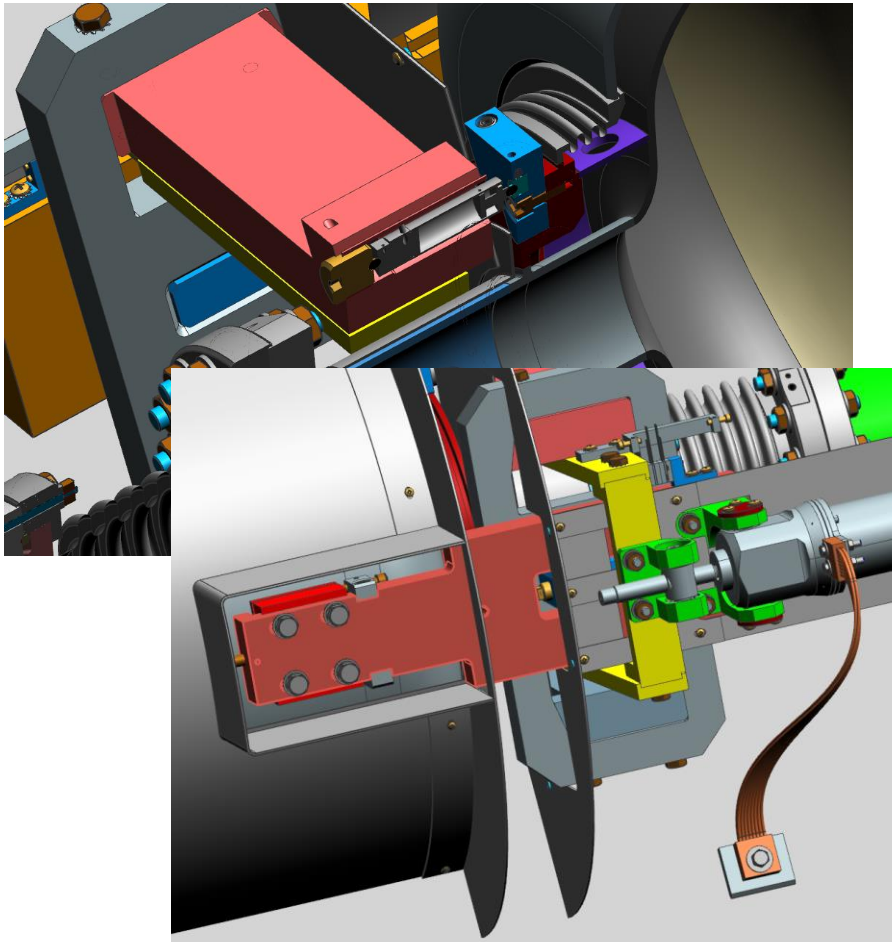


PIP-II

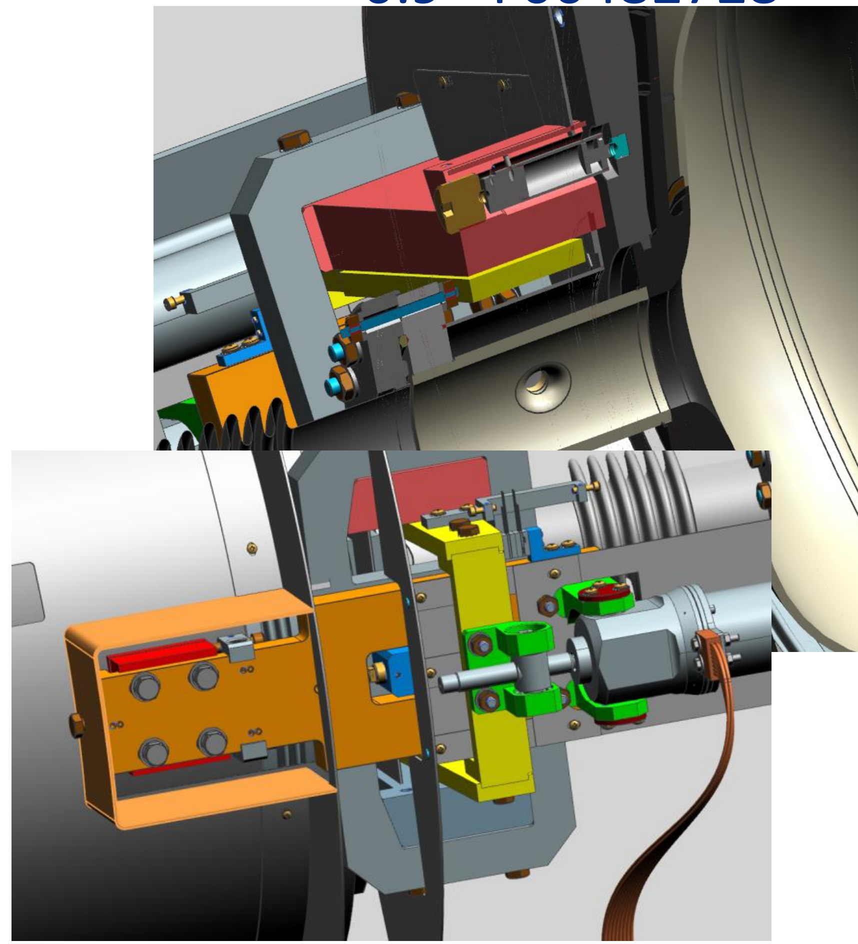
HB 650 MHz 0.9 & 0.92 tuner interface

Charge 1a,3a

0.92 - F10007350

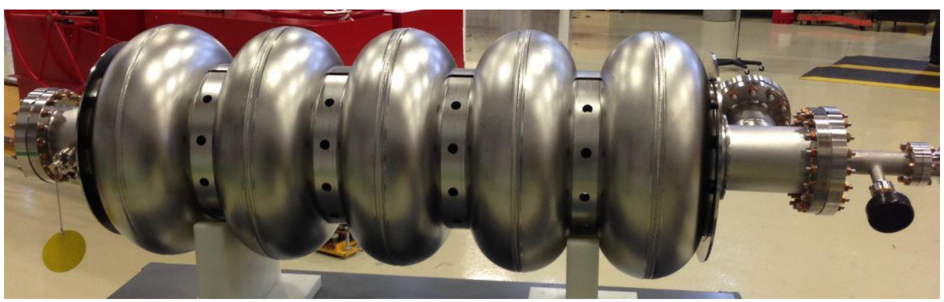


0.9 - F00482728

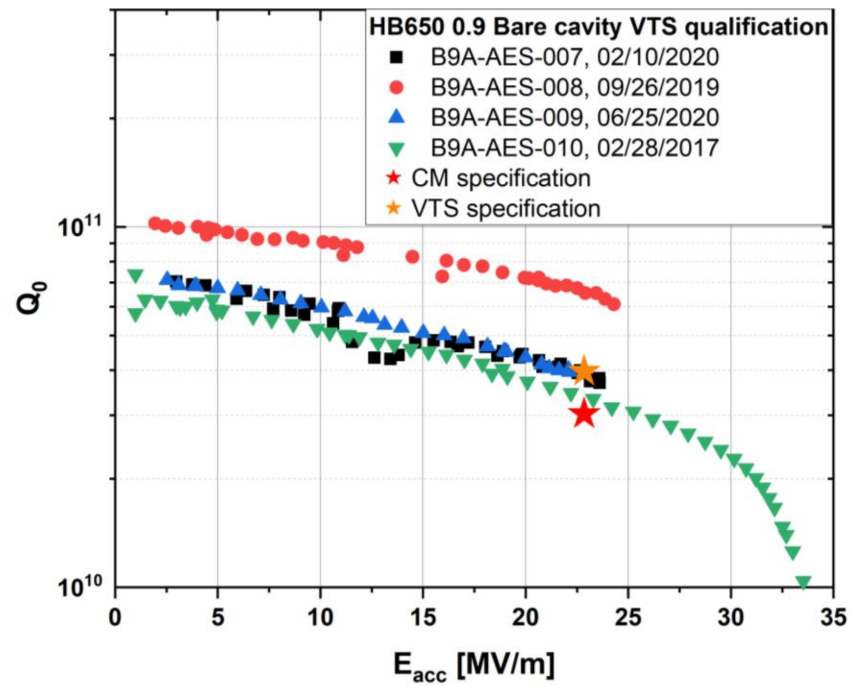


HB650 MHz β=0.90 Cavity status

Charge 1b



- B9A-AES-010 is qualified and was tested in the horizonal cryostat
- B9A-AES-008 has been dressed
- B9A-AES-007 and B9A-AES-009 are qualified in VTS and are being prepared for dressing



PIP-II

Charge 1b

HB650 MHz cavity magnetic field sensitivity

- 650 MHz cavities will require low remnant field and efficient flux expulsion in order to achieve PIP-II specifications in operation
- About 3 mG is the maximum field that cavities can trap and still reach above $3.2 \cdot 10^{10}$

	R_0 (nΩ)	R_{BCS} (nΩ)	S (nΩ/mG)	B_{ext} (mG)	% flux exp	Q_0
N-doping	1.2	2.4	1.46	Any	100	7.2e10
				5	50	3.6e10
					0	**2.4e10**
				3	50	4.5e10
					0	3.3e10
EP	2	4.7	0.44	Any	100	3.9e10
				5	50	3.3e10
					0	**2.9e10**
				3	50	3.5e10
					0	3.2e10

Slide from Martina Martinello

Summary

- Prototype HB650 cryomodule will comprise three 0.90 and three 0.92 650 MHz cavities
- Cryomodule design needs to accommodate the differences in cavity interfaces between 0.90 and 0.92 cavities
- Four HB650 0.92 cavities from RRCAT and four HB650 0.90 cavity at Fermilab are being qualified
- Four bare HB650 0.90 cavities were qualified in VTS at Fermilab
- Three HB650 0.92 cavities are being procured by Fermilab, but have been delayed
- The status of HB650 0.92 from RRCAT will be summarized in the next slides

HB-650 (β=0.92) Cavity activities at RRCAT

Avinash Puntambekar
SPC-HB650 Dressed Cavity RRCAT

on behalf of RRCAT HB650 cavity Team

FDR_29-30 July 2020

Outline : HB650 β=0.92 Five cell SCRF cavity

- Cavity fabrication
- Cavity processing and VTS testing
- Cavity dressing
- Tuner qualification
- Summary

Cavity fabrication status

Cavity Fabrication and qualification infrastructure

120 T Press for forming

Formed Half cells

CNC machining Centre

15 kW EBW machine

RRR measurement facility

SIMS

Cavity Fabrication progress

- Four HB650 Five-cell SCRF Cavities have been fabricated at RRCAT under IIFC

- These cavities have undergone pre-processing qualification which include vacuum leak check, mechanical inspection (CMM), optical inspection and RF qualification with first stage of FF tuning

Cavity processing and VTS testing status

Processing & Testing Facilities

Optical Inspection

Electropolishing

Annealing and N_2 doping

Room Temperature Tuning of cavity

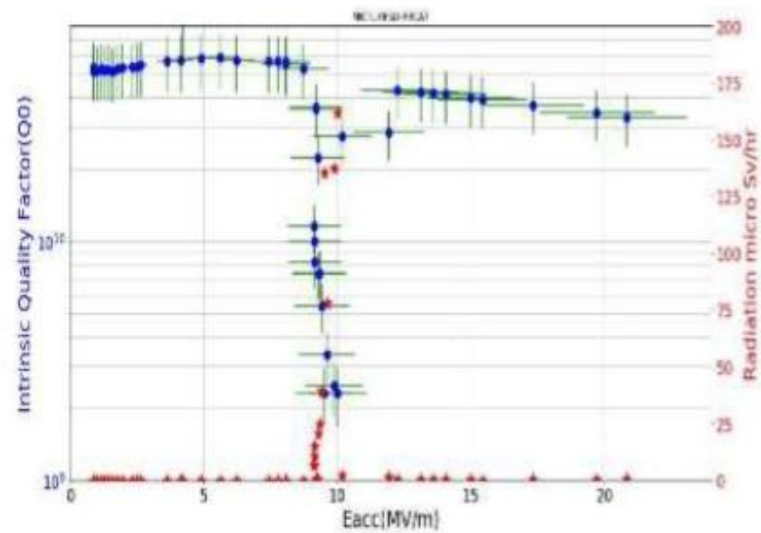
HPR and Cleanroom Assembly

Preparation for VTS test

Cavity processing and VTS testing progress

- All the cavities were processed with standard processing recipes steps
  - Bulk EP (~ 150- 200 μm)
  - Hydrogen degassing (@ 800^{0}C for 3 hours) - 2/6 N doping recipe. Light EP (5 ~ 7 μm)
  - HPR (@100 bar, 3 x1 passes)
  - Low temp bake @120^{0}C for 48 hrs (for non nitrogen doped cavities)

HB650-501
15.5 MV/m @ Q 1.5 E10 (N doping)



HB650-504
21.5 MV/m @ Q 2.2 E10 (w/o N doping)

HB650-502

- Cavity # B92A-RRCAT-502 : Bare cavity has arrived Fermilab (Jan 2020)
- Processing in progress : After HPR due for VTS test- end early Aug.
- One full set of dressing components-HV, Tuner, Bellows, Adopter ring under shipment for HB650-502

On CMM inspection @ FNAL

Cavity dressing

Cavity dressing of HB650-RRCAT-501

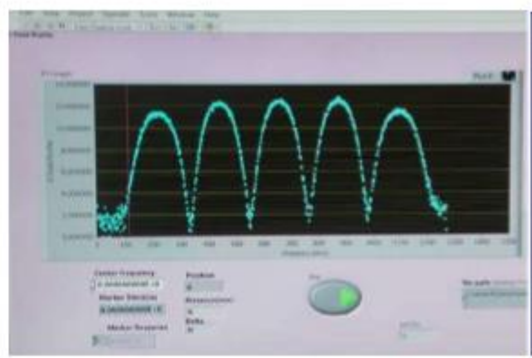
- Dressing of first HB650 (β=0.92) cavity completed successfully in presence of Chuck Grimm
- FF post dressing > 90%, dF -82 kHz (tuner range 200 kHz), Pressure test successfully done with negligible (~ 0.5 KHz) change in frequency.

Cavity Assembly on Insertion Bench

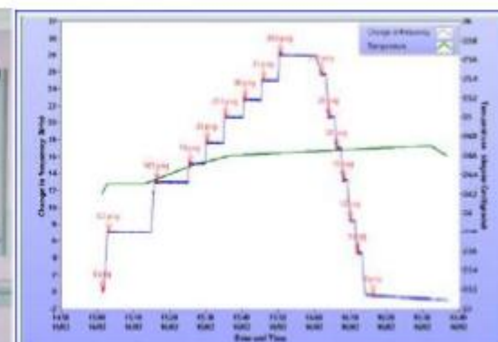
Controlled environment Glove Box

Cavity dressing in progress

Dressed cavity coming out of GB



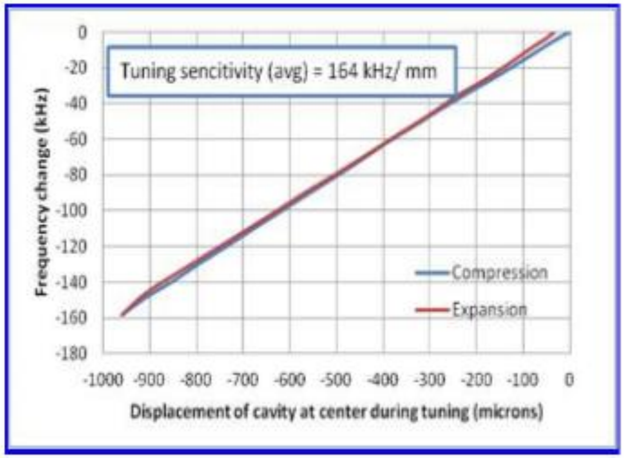
Cavity Field Flatness after Dressing ~92%



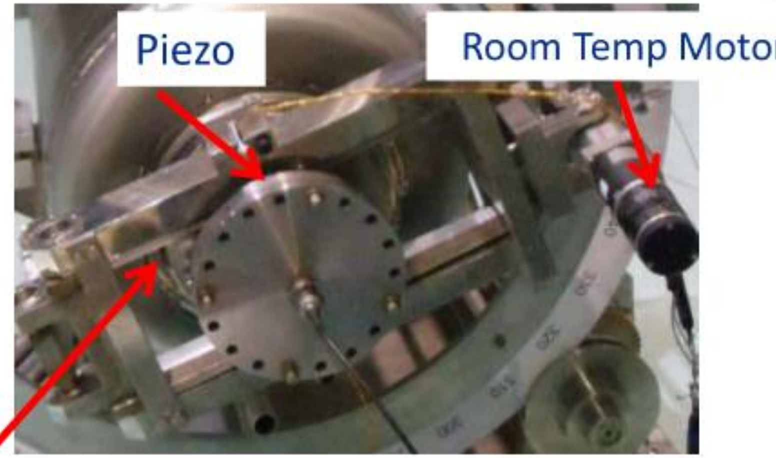
Pressure testing result of dressed cavity

Tuner qualification

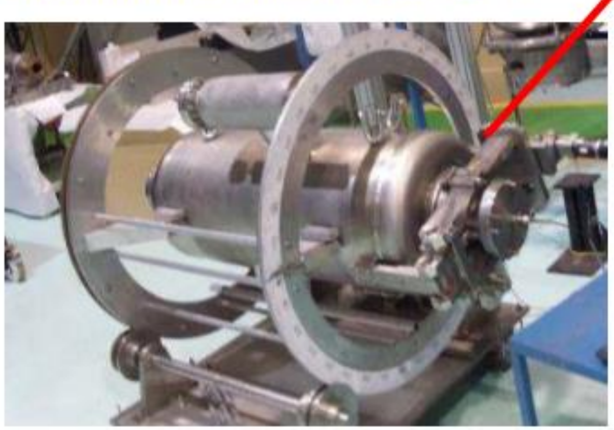
Tuner Testing at 300 K on β=0.92 Five cell SCRF cavity



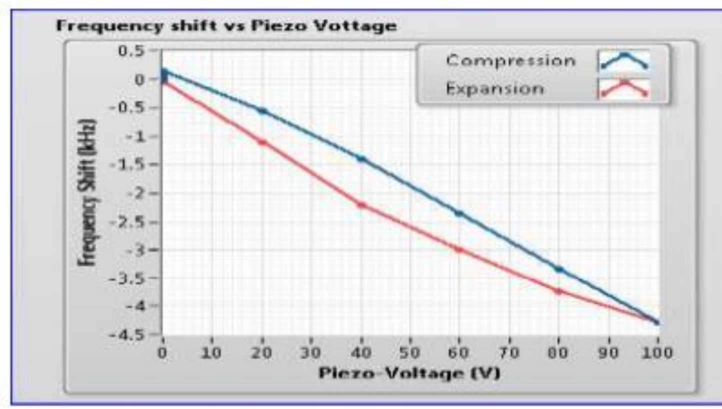
Slow tuner characteristic curve



Tuner Assembly on HB650-501



Dressed HB650-501



Piezo DC excitation Curve

SUMMARY

Summary

- Four + 1 HB650 (β=0.92) bare cavity fabrication completed.
- Processing and VTS testing of four cavities competed.
  - Max Eacc 21.5 MV/m, Q 2.2E10 (W/o Nitrogen Doped)
  - One bare Cavity (RRCAT-502) shipped to FNAL for reprocessing, Re-testing
  - Further processing R&D ongoing in collaborative mode.
- Dressing of first HB650 (β=0.92) RRCAT-501 successfully completed.
- Four + 1 HB650 tuner manufacturing completed.
- Tuner integrated on HB650 B92 dressed cavity and qualification done at 300 K.