Project X Cavity RF and mechanical design

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TTC meeting on CW-SRF, 2013

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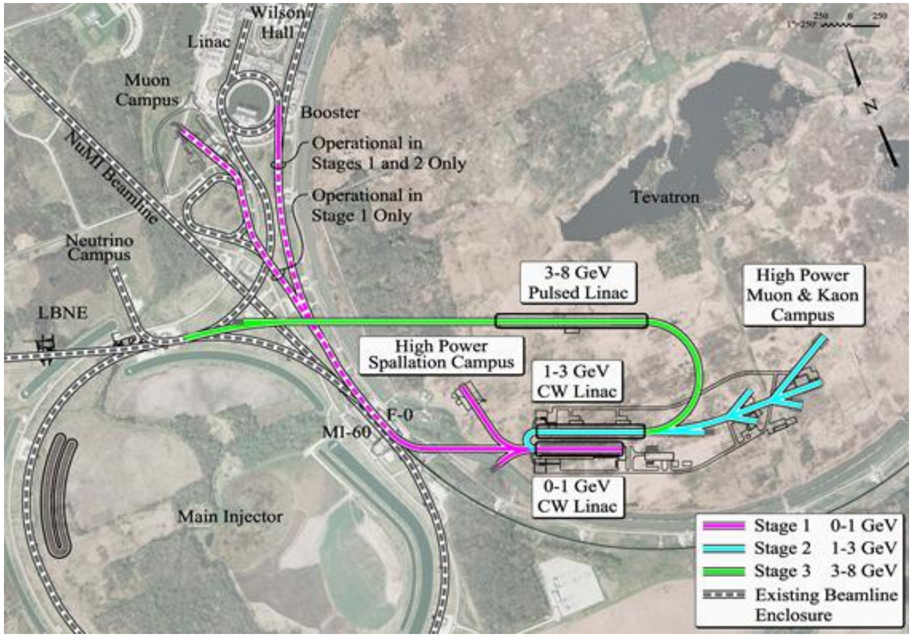
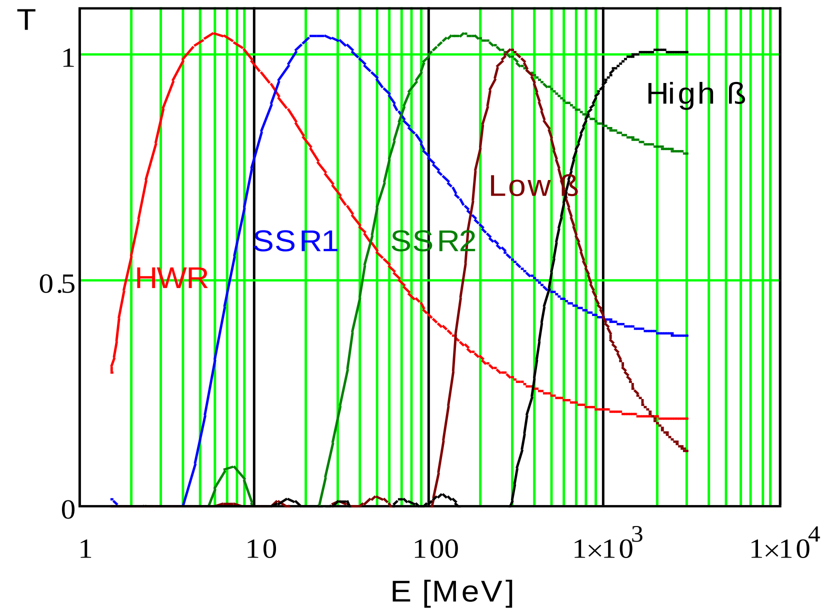
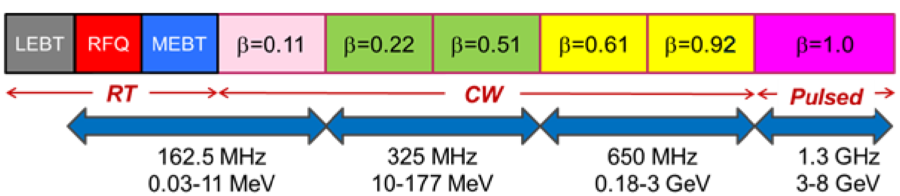


Project X layout



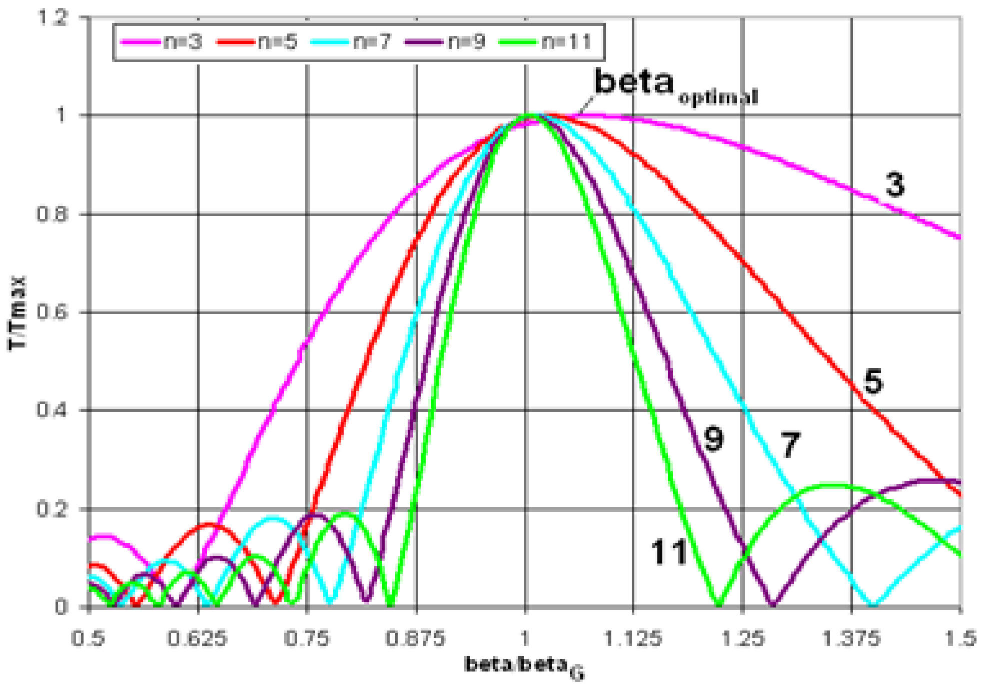


The Project X Linac consist of several types of cavities with different beta

	Stage-I					Stage-II	III
	HWR	SSR1	SSR2	β_G=0.61	β_G=0.90	β_G=0.90	ILC
Solenoids	8	8	21	0	0	0	0
Quads	0	0	0	6*- 6**	7**	15*	28**
Cavities	8	16	35	36	42	120	224
Freq. MHz	162.5	325	325	650	650	650	1300
Max. gain MV	1.7	2.4	5.0	11.5	17.5	17.5	23.3
Q_0 (10^{10})	0.5	0.8	1	2	2	2	1
Cryomodules	1	2	7	6	7	15	28
Energy MeV	10.	32.4.	159	488	1000	3000	8000

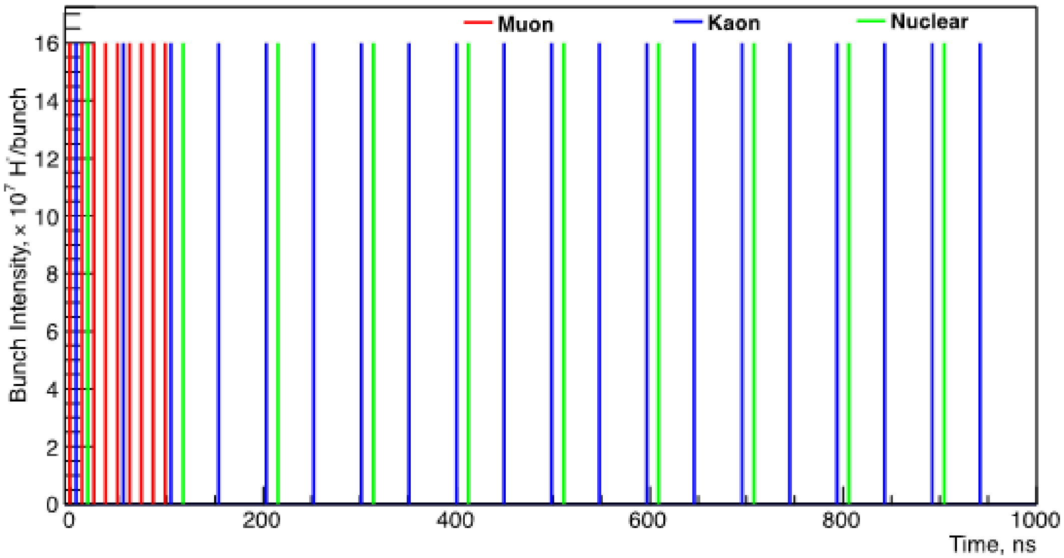
ProjectX Cavity RF and mechanical design

Sec-tion	Freq. (MHz)	Energy (MeV)	Cav/mag/CM	Gradient (MV/m)	Energy Gain (MeV)	Q_0@2K (10^{10})	CM Config.	CM length (m)
HWR	162.5	2.1-11	8 /8/1	8.2	1.7	0.5	8 x (sc)	5.8
SSR1	325	11-38	16 /8/ 2	10	2.05	0.2	4 x (csc)	5.2
SSR2	325	38-177	35 /21/ 7	11.2	5.32	1.2	sccsccsc	6.5
LB650	650	177-480	30 /20*/ 5	16.5	11.6	1.5	ccc-fd-ccc	7.1
HB650	650	480-1000	42 / 16†/ 7	17	17.6	2.0	cccccc	9.5
HB650	650	1000-3000	120 / 30†/ 15	17	17.6	2.0	cccccccc	11.2

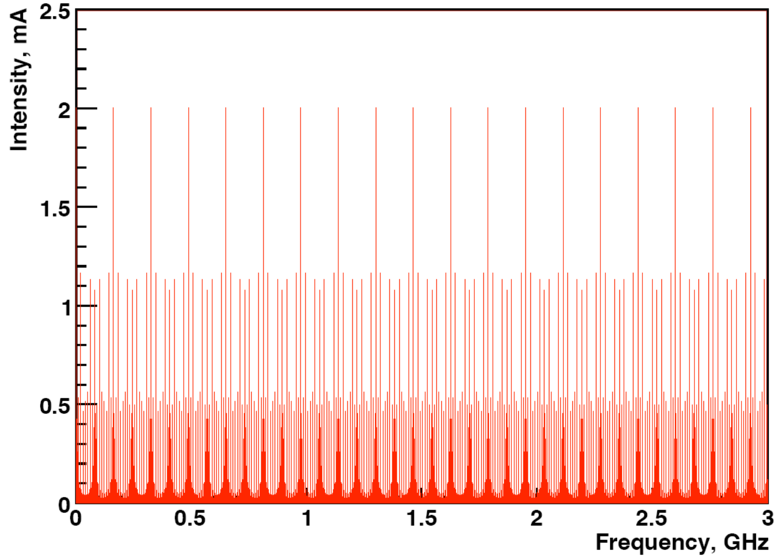


Transit time factor versus the ratio of the beta to the geometric beta, b/b_G, for different number of cells in a cavity, *n*

Complicated beam structure in ProjectX

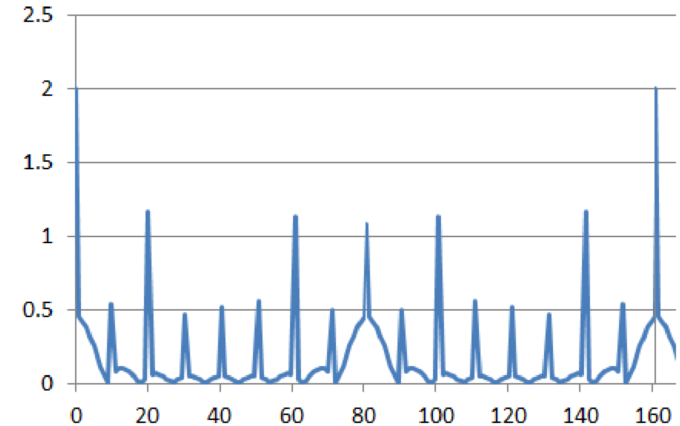


A typical bunch structure required for muon, kaon, and nuclear experiments running in parallel at 3 GeV



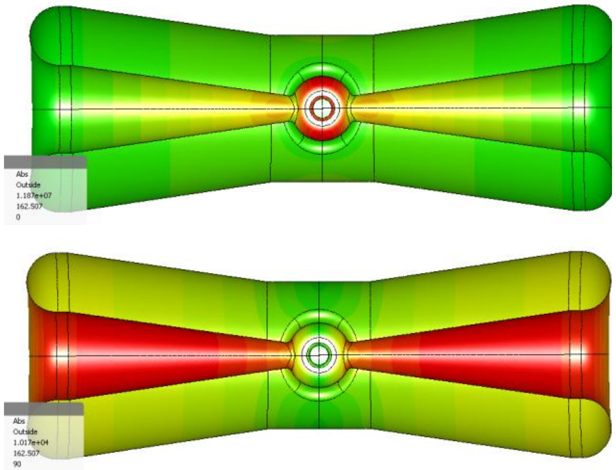
The beam current spectrum contains

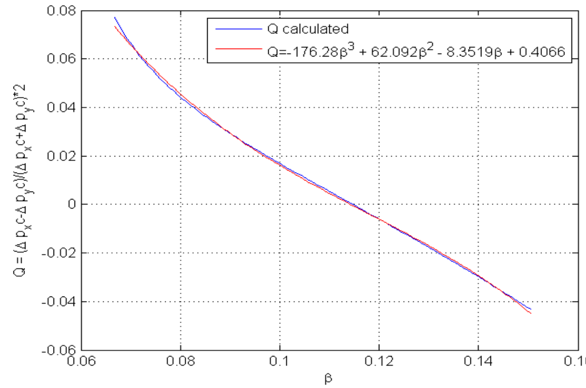
- Harmonics of the bunch sequence frequency of 10.15 MHz
- Sidebands of the harmonics of 81.25 MHz separated by 1 MHz.



162.5 MHz beam sequence frequency.

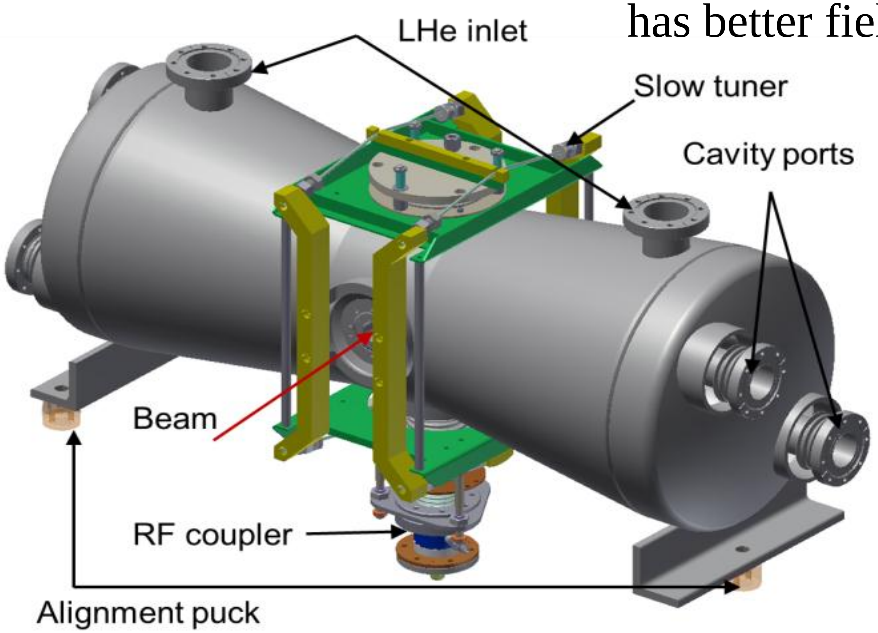
Half-Wave Resonator(HWR)

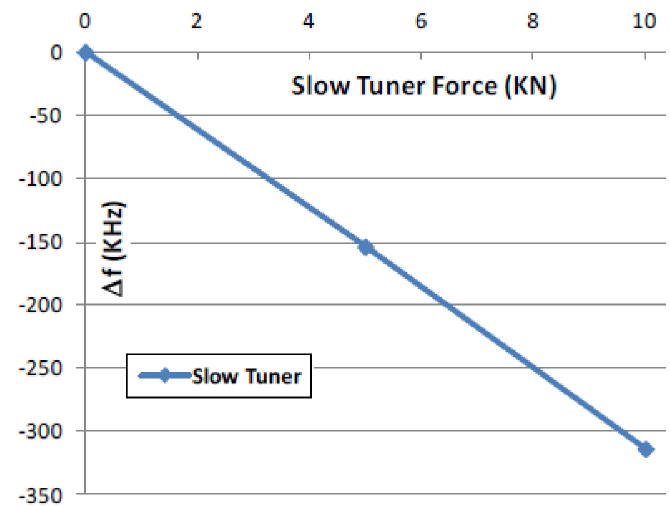




HWR Cavity	Design Value	
Frequency	162.5	MHz
Optimum Beta (b_{OPT})	0.112	
Aperture (diameter)	33	mm
$L_{EFF}= b_{OPT}\lambda$	20.7	cm
R/Q_0	275	Ω
$G = Q_0 R_S$	48	Ω
E_{max}/E_{acc}	4.65	
B_{max}/E_{acc}	5.0	mT/(MV/m)
Q_0	0.5	10^{10}
Operating Temperature	2	K

New donut shape drift tube has better field symmetry.



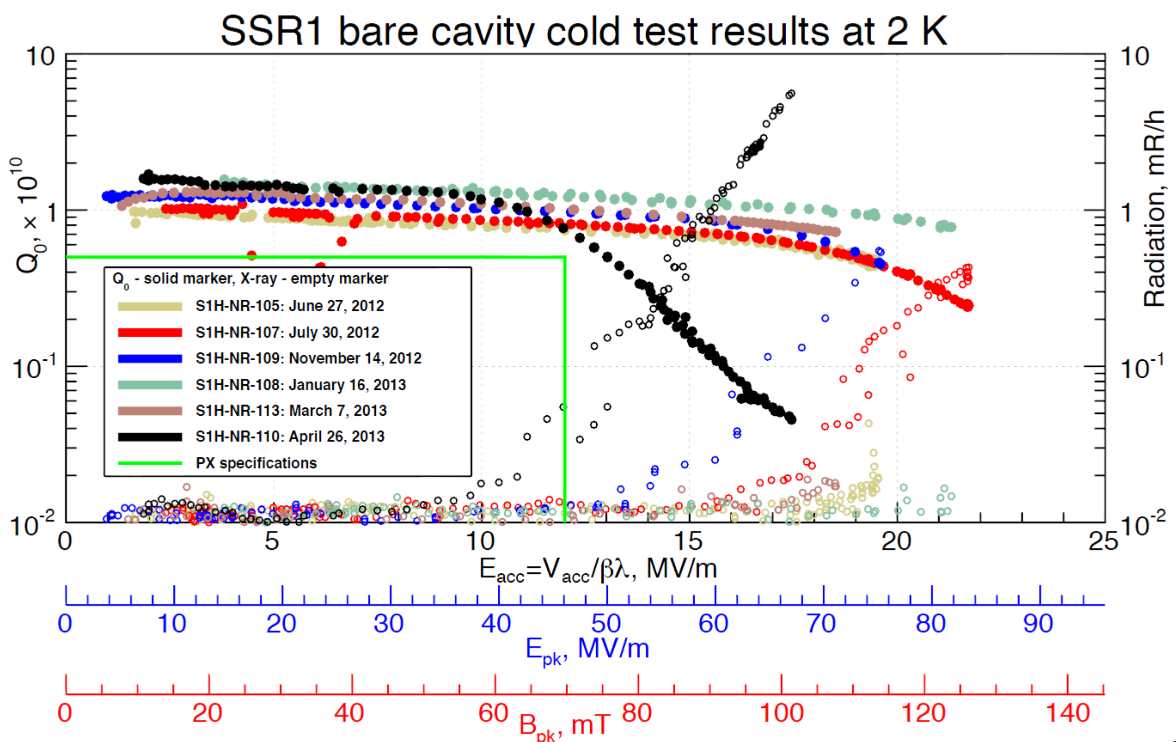


- RF and mechanical design of dressed cavity complete
- Cavity and power coupler under production.

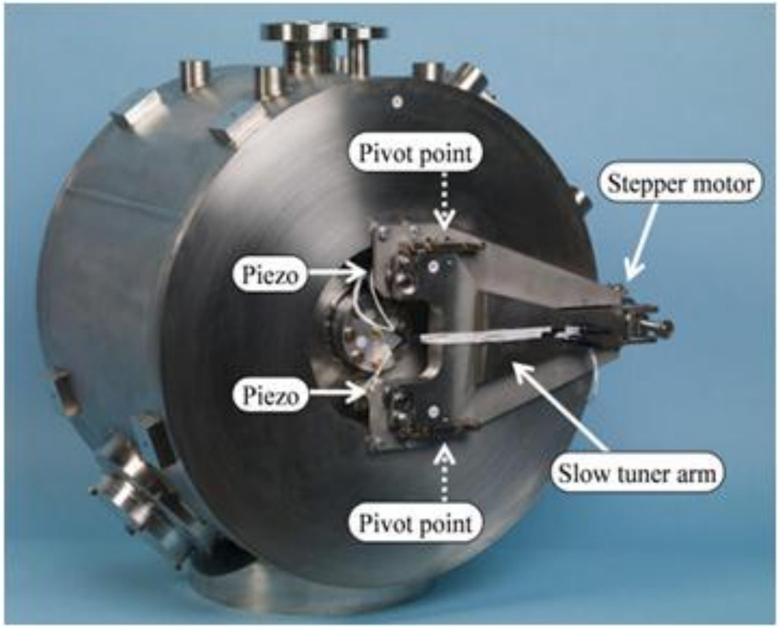
Single Spoke Resonator1(SSR1)

SSR1 Cavity	Design Value	
Frequency	325	MHz
Optimum Beta (b_{OPT})	0.222	
Aperture (diameter)	30	mm
$L_{EFF}= b_{OPT}\lambda$	20.5	cm
R/Q_0	242	Ω
$G = Q_0R_S$	84	Ω
E_{max}/E_{acc}	3.84	
B_{max}/E_{acc}	5.81	mT/(MV/m)
Q_0	0.5	10^{10}
Operating temperature	2	K

- 12 (2old and 10 new) cavities manufactured
- 10 (2 old and 8 new) cavities tested in VTS. Main issue is long time for multipactor processing
- 6 new cavities qualified for dressing
- 1 old cavity dressed, df/dP not optimized
- 1 old cavity tested in HTS (STC) with high Qext coupler (CW) and high power coupler (pulsed)

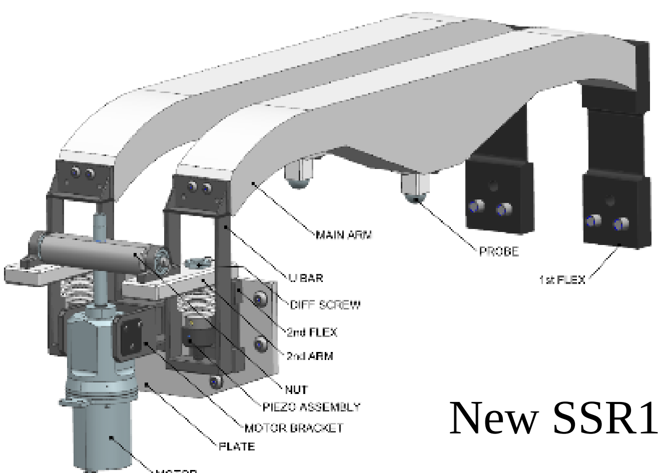


Dressing of SSR1



1st dressed SSR1 cavity

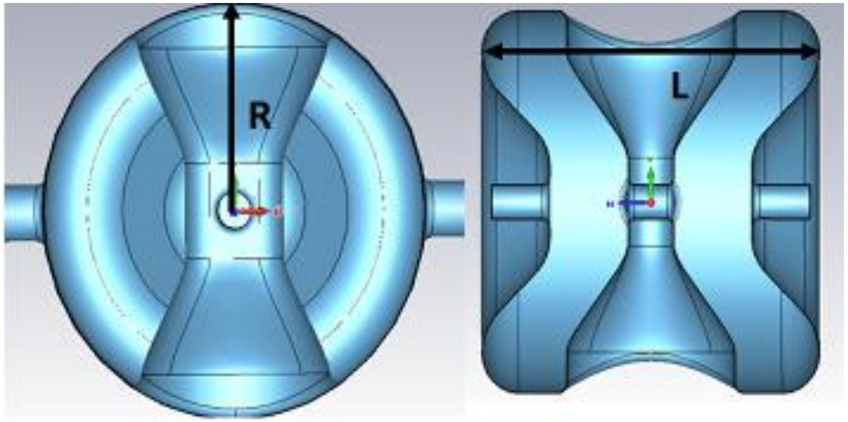
New design of Helium vessel
design goal was reducing df/dP.
|df/dP|<10 Hz/mbar is expected



New SSR1 tuner

- Transition ring welded to the 1st cavity.
- Frequency shifted by -500 kHz

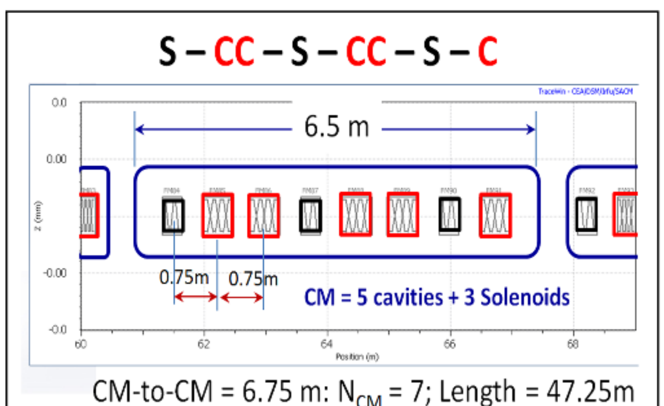
Single Spoke Resonator2 (SSR2)

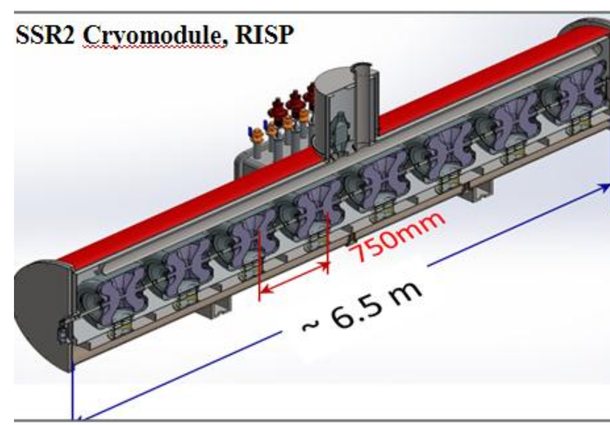


X-Y cavity view   Z-Y cavity view

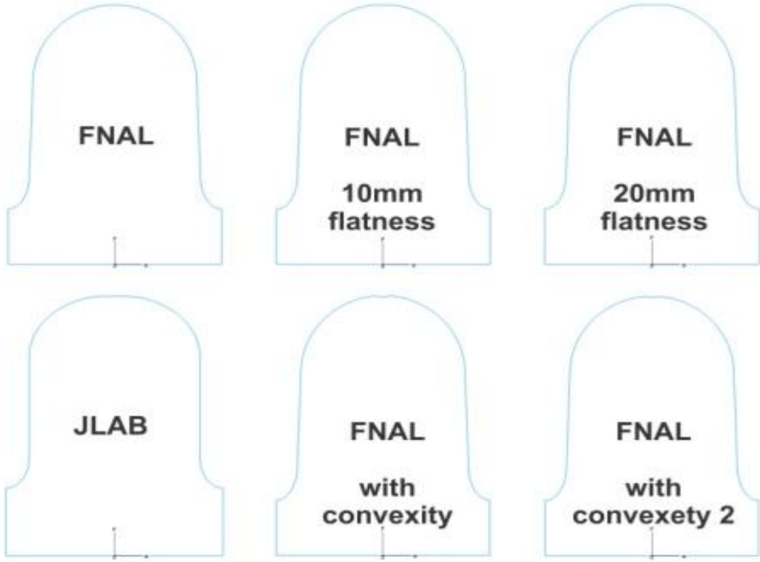
- New design is result of compromise for ProjectX and RISP applications
- RF and mechanical design complete
- Multipactor simulations in progress

Parameter	Value
Frequency	325 MHz
β_o	0.514
$L_{eff} = 2*(\beta_o\lambda/2)$	475. 3 mm
Iris Aperture	50 mm
E_{pk}/E_{acc}	3.53
B_{pk}/E_{acc}	6.25 mT/(MV/m)
G	119 Ω
R/Q	276 Ω
Operating gain / cav	5 MeV
Max Gain / cav	5.32 MeV
Q_0	>8 x 10^9
df/dp	< 19 Hz/mbar
Operating temp	2 K

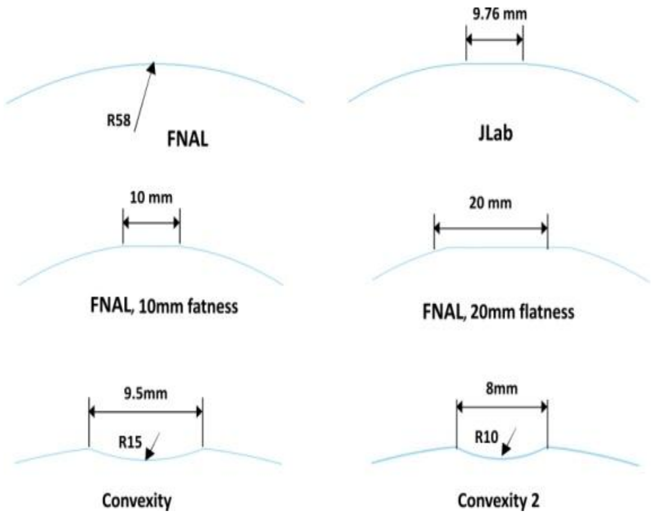




Low beta 650 MHz 1-cell cavity



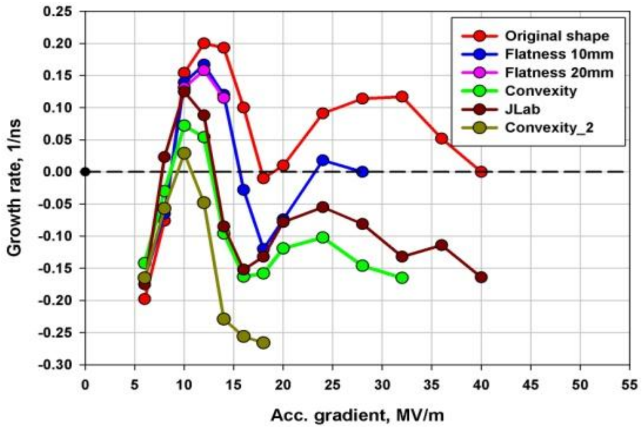
Different shape 650MHz cavities were simulated for multipactor properties

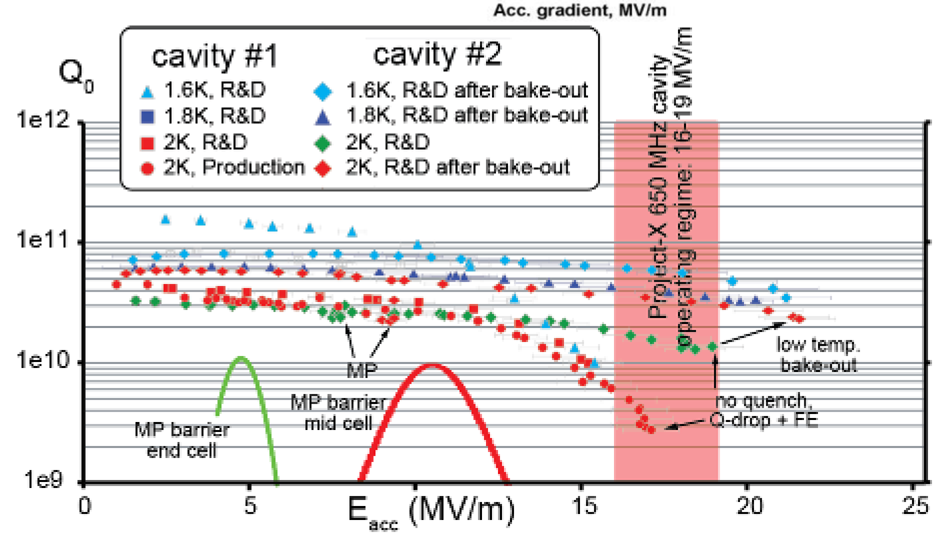


- Multipactor can be processed away

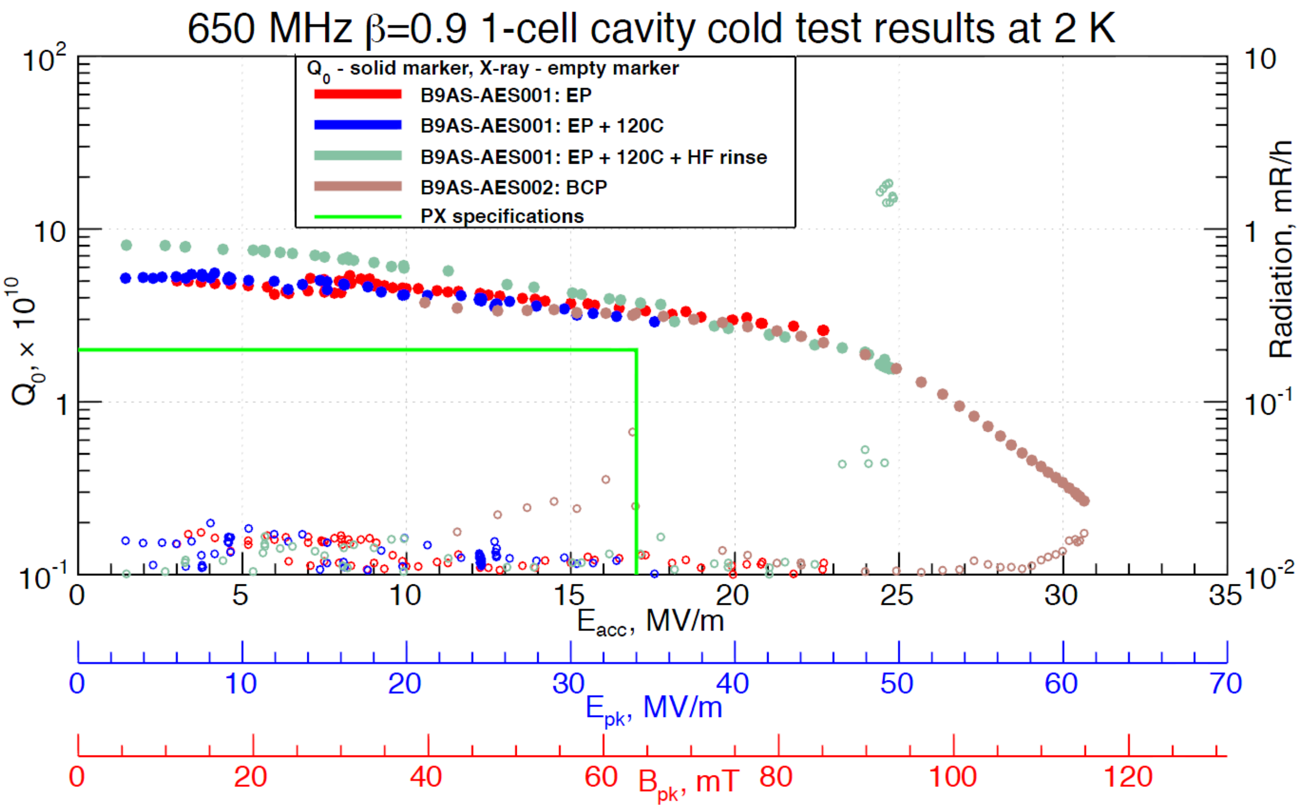
3 JLAB β=0.6 cavities, 100mm iris with, 0 degree

3 FN AL β=0.6 cavities, 86mm iris with, 1.9 degree



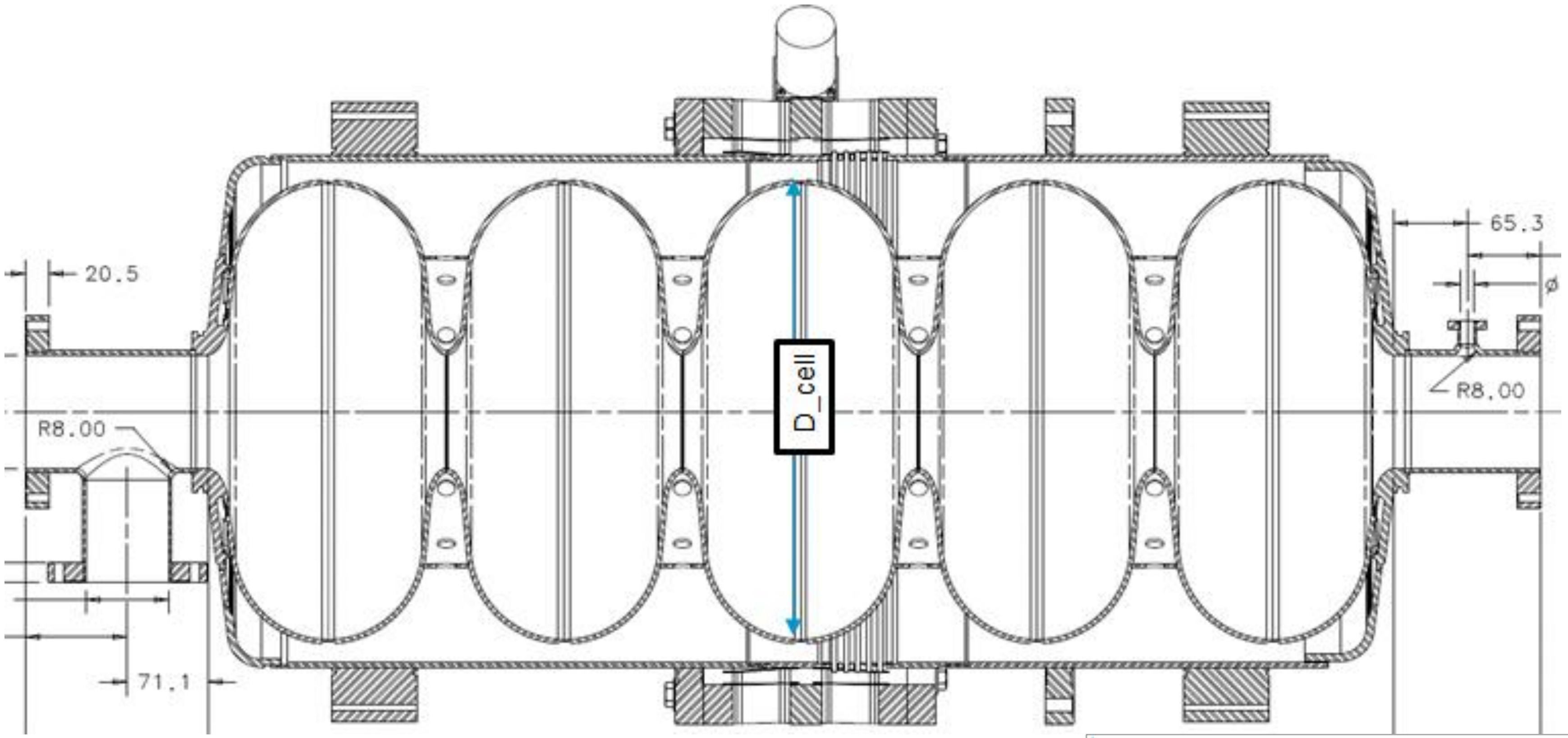


High beta 650 MHz 1-cell cavity



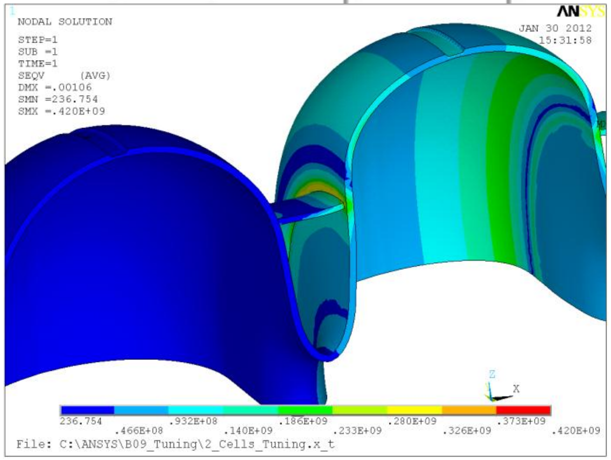
- 6 single cell cavities manufactured
- 2 cavities tested in VTS.
- Both tested cavities exceed design gradient and Q0.
- R&D ongoing to find best processing recipe for Q maximization, see A. Grassellino’s talk tomorrow

High beta 650 MHz 5-cell cavity



Original design of the dressed cavity optimized for

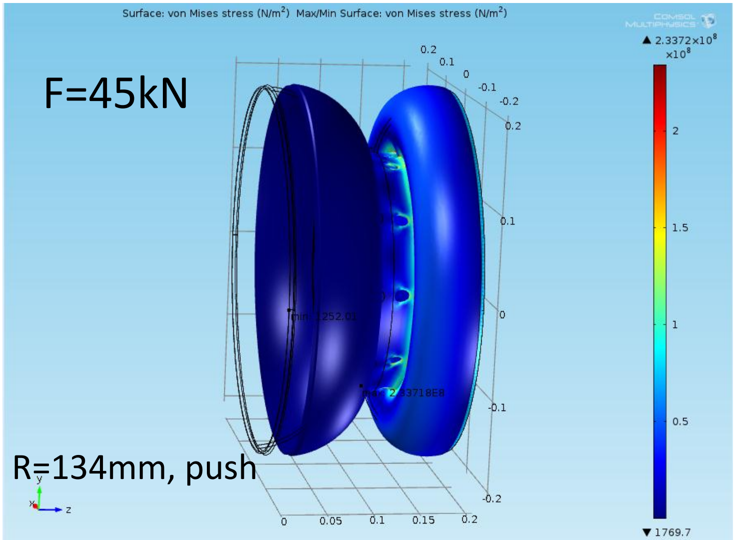
- High stiffness and mechanical resonances
- Low df/dP.

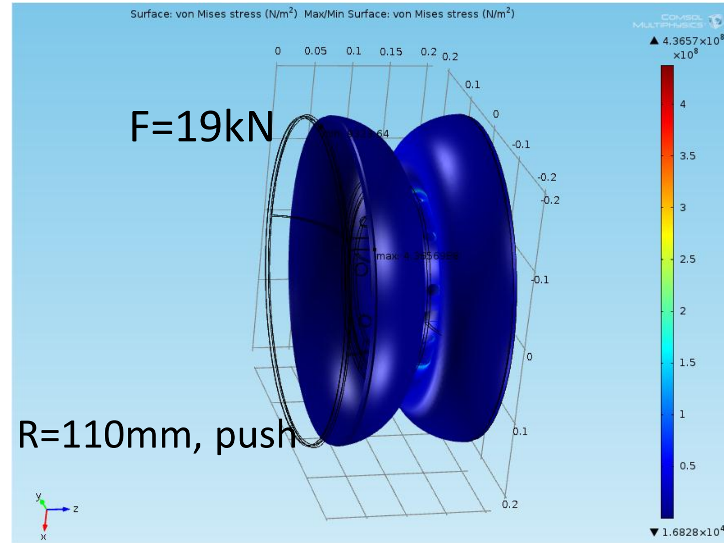


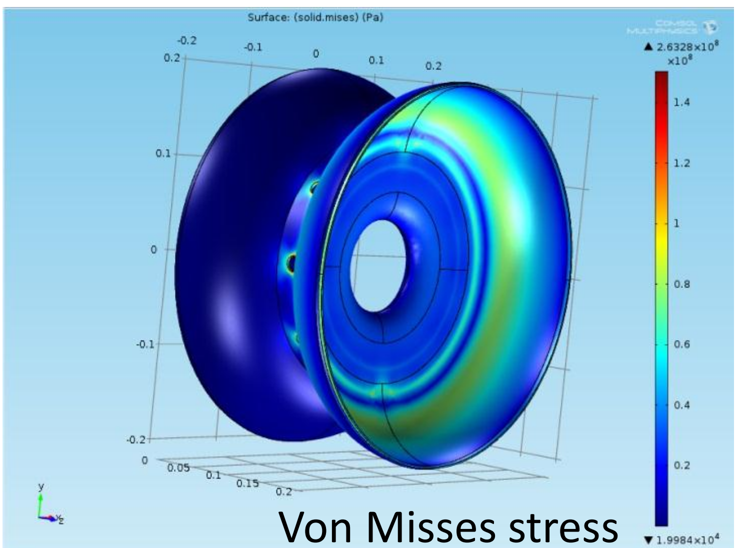
But in other hand

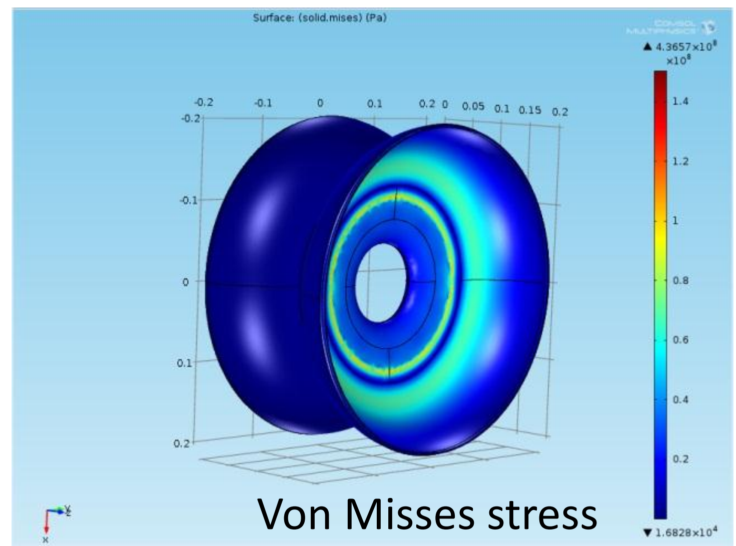
- Too stiff for room temperature frequency and FFtuning
- Large load to the tuner, cavity stiffness 18 kN/mm

High beta 650 MHz 5-cell cavity tune-ability study



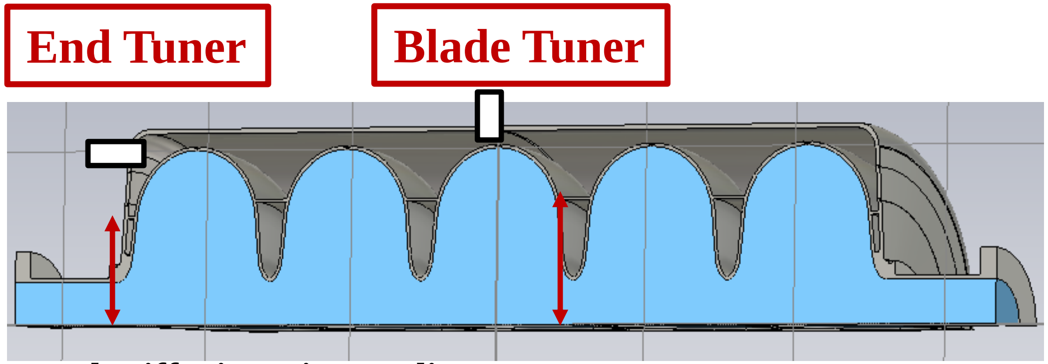






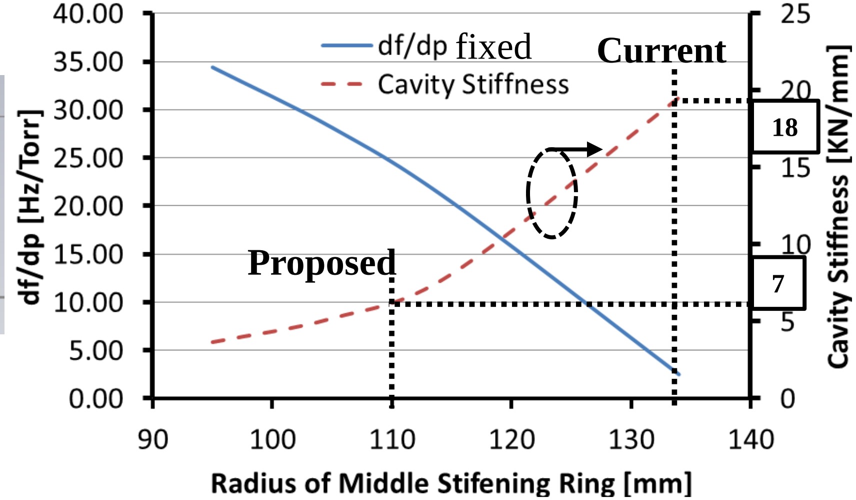
- Stiffening ring radius reduced from 134 mm to 110 mm
- Stresses in stiffening ring during FF tuning reduces 2 times
- Cavity stiffness reduced from 18 kN/mm to 7 kN/mm.

Dressed high beta 650 MHz 5-cell cavity optimization

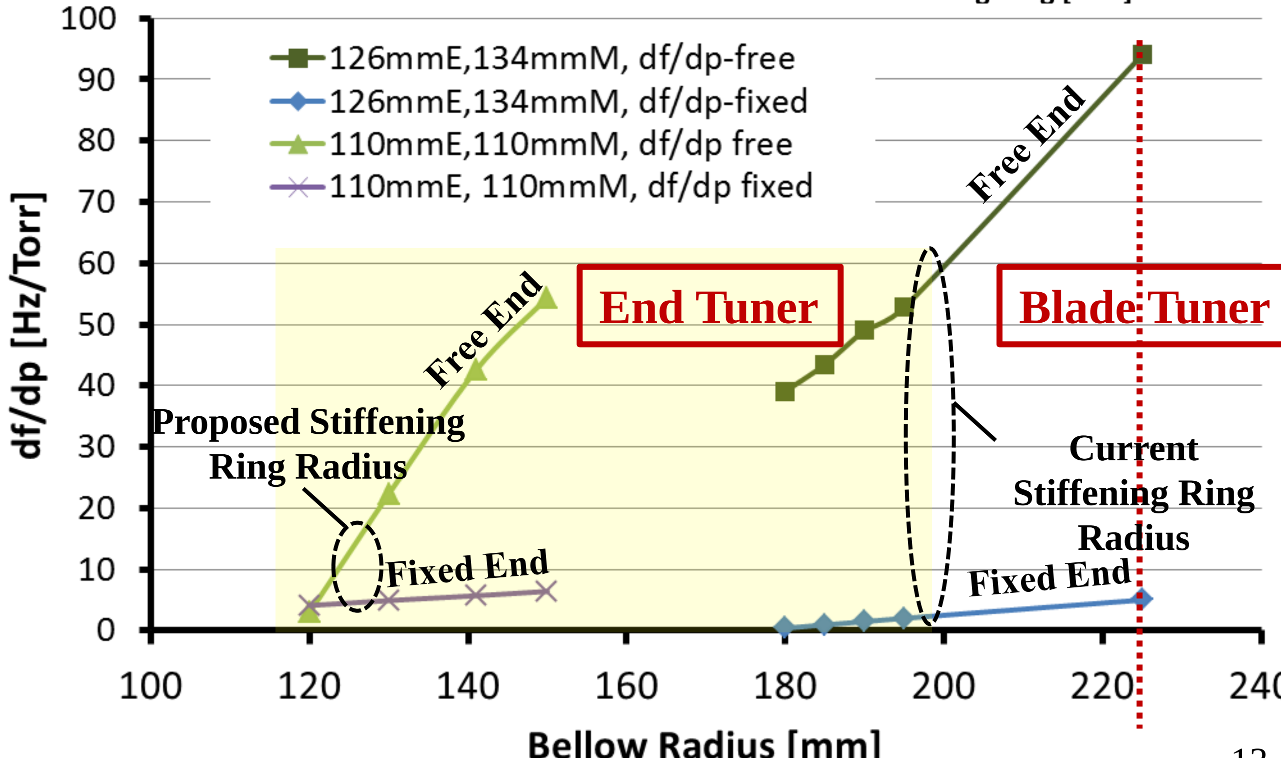


End Stiffening Ring Radius
Current: 126 mm
Proposed: 110 mm

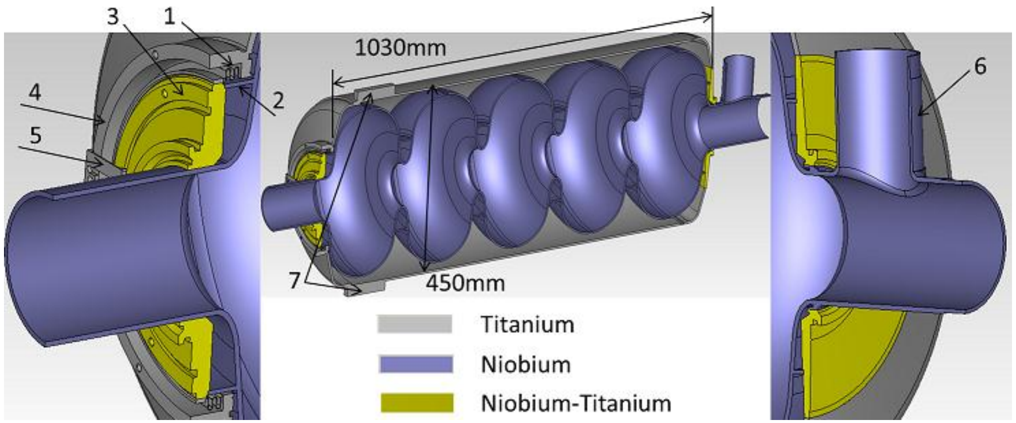
Middle Stiffening Ring Radius
Current: 134 mm
Proposed: 110 mm

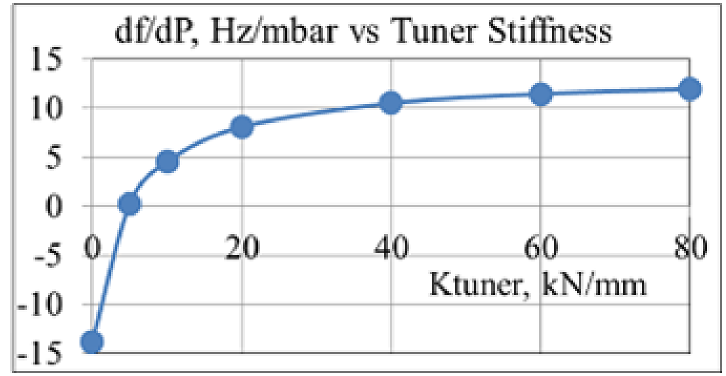


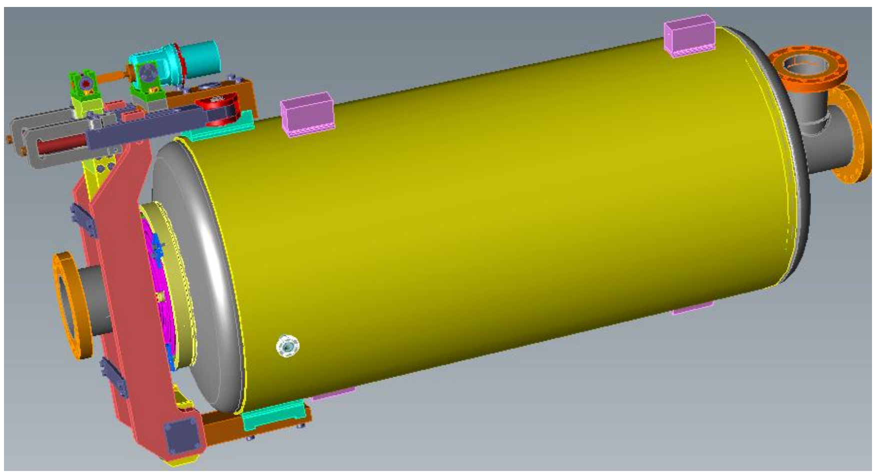
- Current cavity design was too stiff ~18 kN/mm
- Stiffening ring radius needs to get smaller to soften the cavity
- To keep df/dP within acceptable limits bellows radius needs to get smaller
- End tuner is proposed to replace the blade tuner



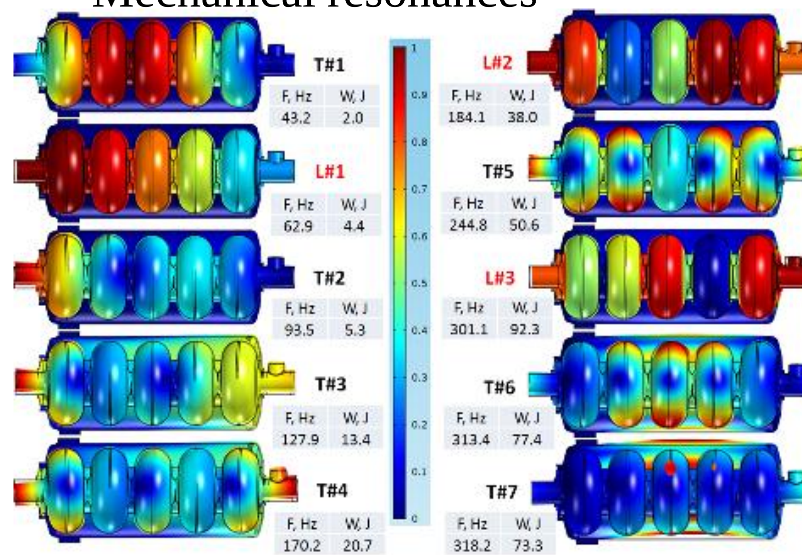
Dressed high beta 650 MHz 5-cell cavity, new design



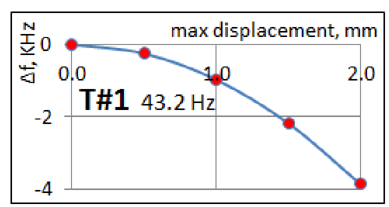


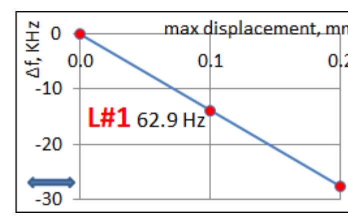


Mechanical resonances

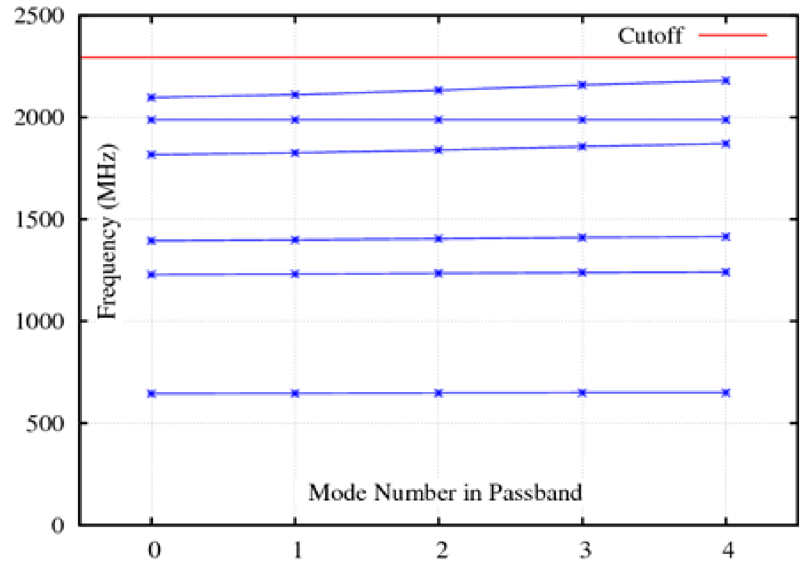


- New design of helium vessel developed
- df/dP ~ 10 Hz/mbar (in FRS <15 Hs/mBar)
- Lever tuner 3D design complete

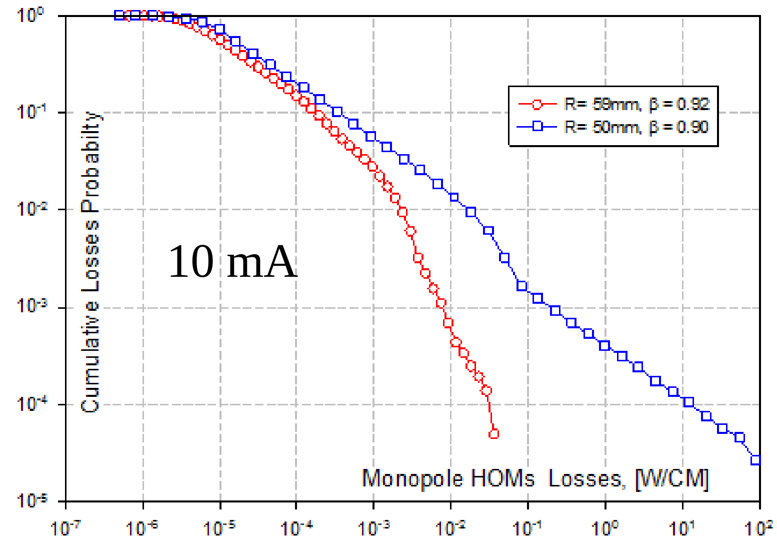


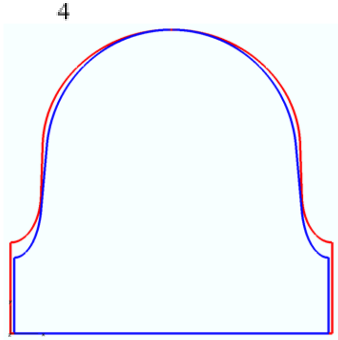


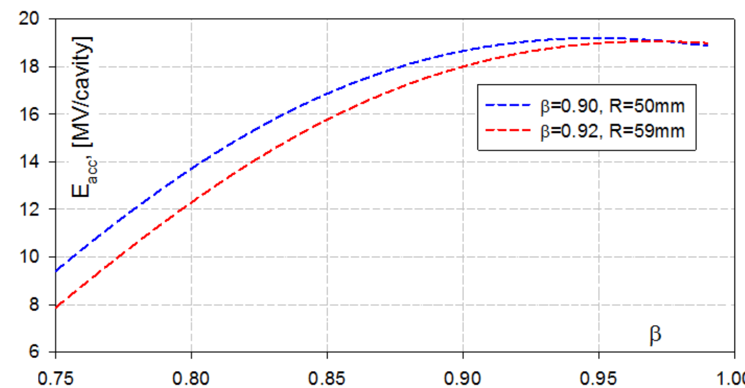
New high beta 650 MHz 5-cell cavity

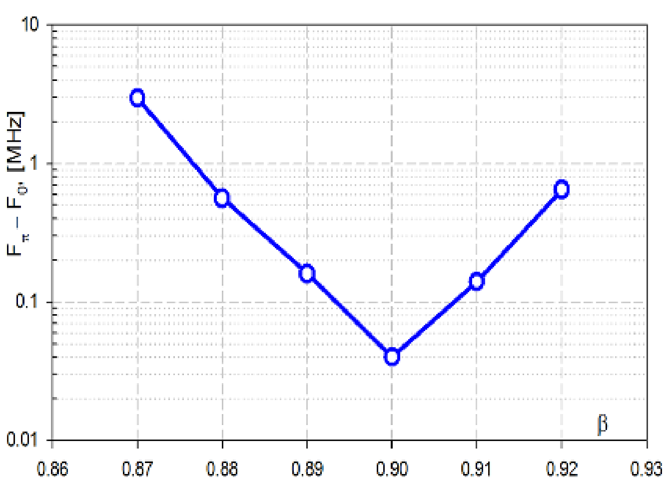


Flat 5-th monopole pass band







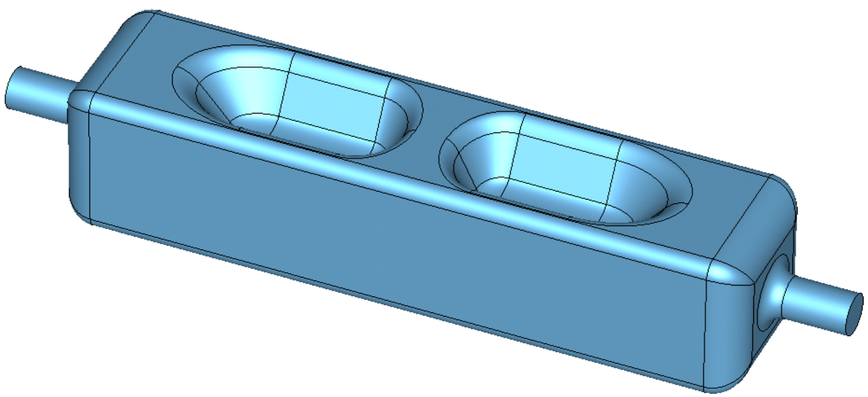


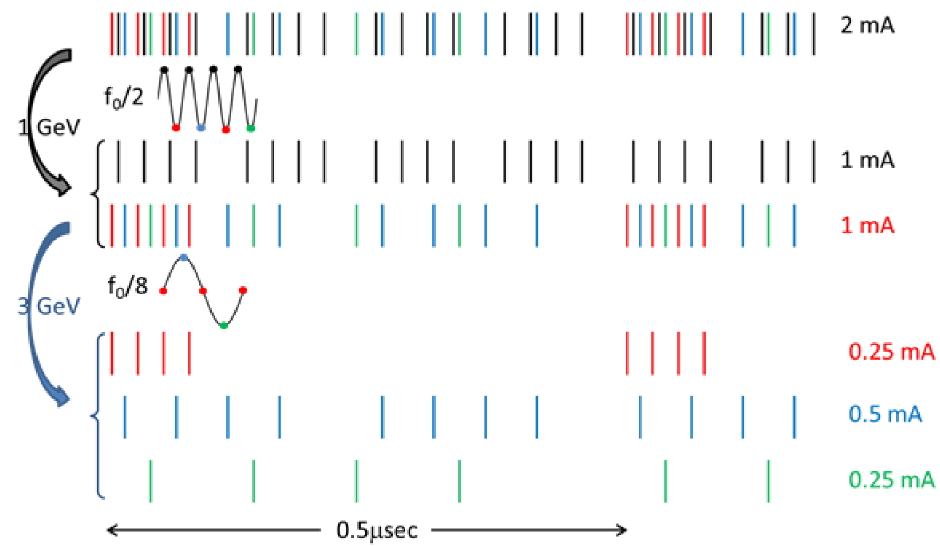
- Larger aperture, 118 mm (was 100 mm)
- Wider HOM pass bands, good for higher beam current
- More cell to cell coupling, better field stability
- Increased coupling with the power coupler

- Process single and 5-cell bare cavities
  - Test in VTS
  - Best high Q recipe found on single cell will be implemented
  - HPR, EP, BCP, Centrifugal Barrel Polishing (Tumbling), heat treatments….etc.
- Continue fabrication of prototypes
  - Lever Tuner
  - Helium vessels
  - Assembly and welding fixtures
- Dress 5-cell cavity
  - VTS tests
  - Room temperature tests
  - Mechanical test of tuner(s)
  - HTS tests
  - Assembly of 6 best cavities in 1st HB cryostat

RF Splitters

Two-cell deflecting mode cavity





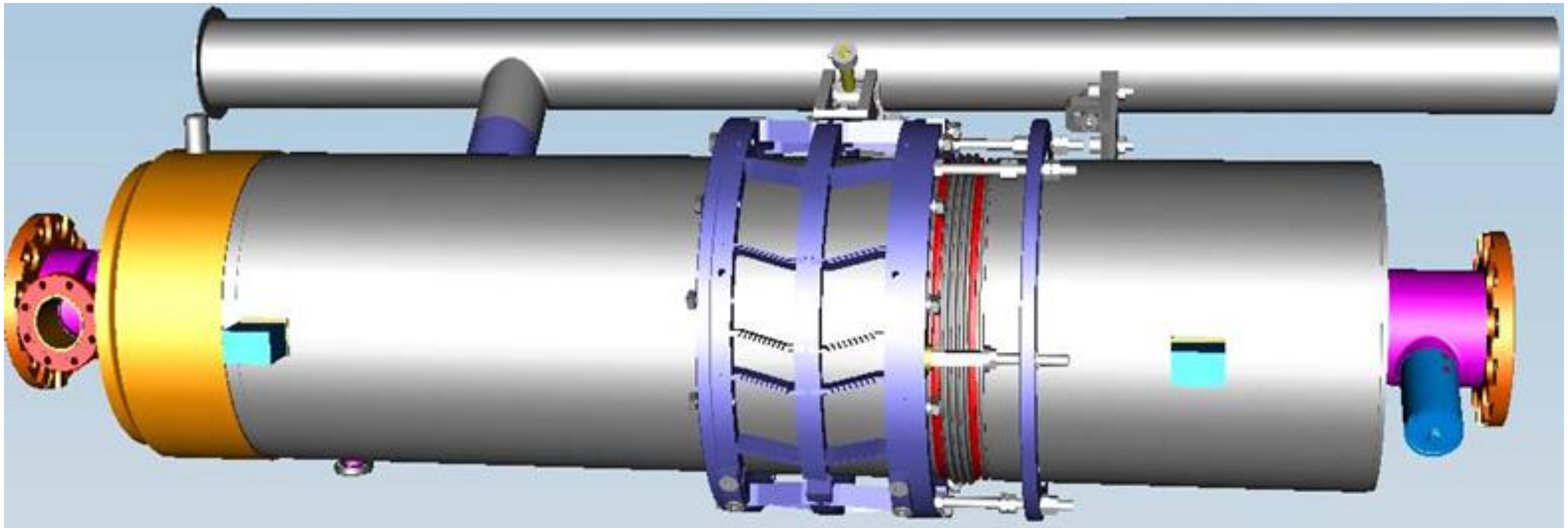
The first will split the beam buckets into two equal parts for bunch frequencies of 162.5 MHz. This requires operations at frequencies equal to $(n+1/2)\cdot 162.5$ MHz

The splitter in Stage 2 splits the beam with 81.25 MHz bunch into 3 parts, the frequency of this RF splitter has to be $(n+1/4)\cdot 81.25$ MHz

Stage	I	II
Operating frequency, MHz	406.25	426.5625
Number of cells	2	2
Optimal beta	0.87	0.92
Transverse kick, MeV	7	7
Maximal surface electric field, MV/m	36	37
Maximal surface magnetic field, mT	50.5	52
R/Q*, Ohm	485	510
G-factor, Ohm	115	115
Dimensions, mm^3	270×270×1200	260×260×1150
Aperture, mm	70	65

- Preliminary RF design is proposed
- Helium vessel and frequency tuner development is planned

3-8 GeV Pulsed Linac cavity



Parameter	Recycler/MI	Direct Injection to MI	Units
Frequency	1.3	1.3	GHz
Loaded Q	1.e7	1.e7	
RF pulse width	7.4	30	ms
Cavity Gradient	25	25	MV/m
Beam current	1	1	mA
Repetition rate	10	10	Hz
Cavity RF power	32	32	kW
Cavity power +losses+regulation +EOL	50	50	kW
Power per Cryomodule	400	400	kW

- Existing ILC cavity
- Needs new Power Coupler design with higher average power

Summary

- HWR production in ANL in progress
- SSR1 cavities fro 1st cryomodule are manufactured and VTS tests almost complete
- Dressing (new design) of 1st SSR1 cavity in progress
- SSR2 design modified to fit both Project X and RISP
- 2 designs of low beta 650 MHz single cell cavities are manufactured. JLAB design successfully tested in VTS at JLAB and FNAL.
- High beta 650 MHz single cell cavities are manufactured. 2 cavities tested in VTS
- High beta 650 MHz 5-cell (original design) 9 cavities under production. 4 of them will be delivered in June. 6 best will be used for installation in 1st cryomodule. Mechanical design of dressed cavity with lever tuner complete
- New RF design of high beta 650 MHz 5-cell complete and approved for Project X

1. What are the design criteria for frequency, #cells, and geometric-beta choices, cell shapes?
    - Bunch repetition frequency choice depend available technology: amplifiers, developed RF system. Accelerating cavity frequency is a harmonic of injector frequency. Odd harmonics used for acceleration of both positively and negatively charged particles.
    - Number of cells defined by available space, field distribution stability, required β range, technology limits.
    - Geometric beta by beam dynamics, power losses, available technology
    - Cell shape by surface field optimization, power loss surface processing technology
2. What are the design criteria driven by beam current, emittance, LOM's, HOM's?
    - All modes resulting to additional cryo-loading, emittance grow, beam stability should be damped
3. How predictive are HOM calculations?
    - Manufacturing accuracy, difference on (chemical) treatment, tuning requirements
4. How predictive are 3D multipacting calculations?
    - Current simulation tools allow to predict with good accuracy multipacting.
    - Quantity is depend on surface preparation
5. What determines production tolerances?
    - Forming accuracy 0.1-0.3 mm, weld shrinkage accuracy 0.1-0.2 mm
6. What level of mechanical stability (stiffness) is required to operate reliably and to maintain tune-ability?
    - Mechanical stability is compromise between desire of higher mechanical resonances and acceptable tune-ability
    - Sensitivity to helium pressure fluctuations df/dP is not necessarily require highest stiffness