Mechanical Design of Single Spoke Resonator Type-2 (SSR2) Superconducting Cavity for RISP

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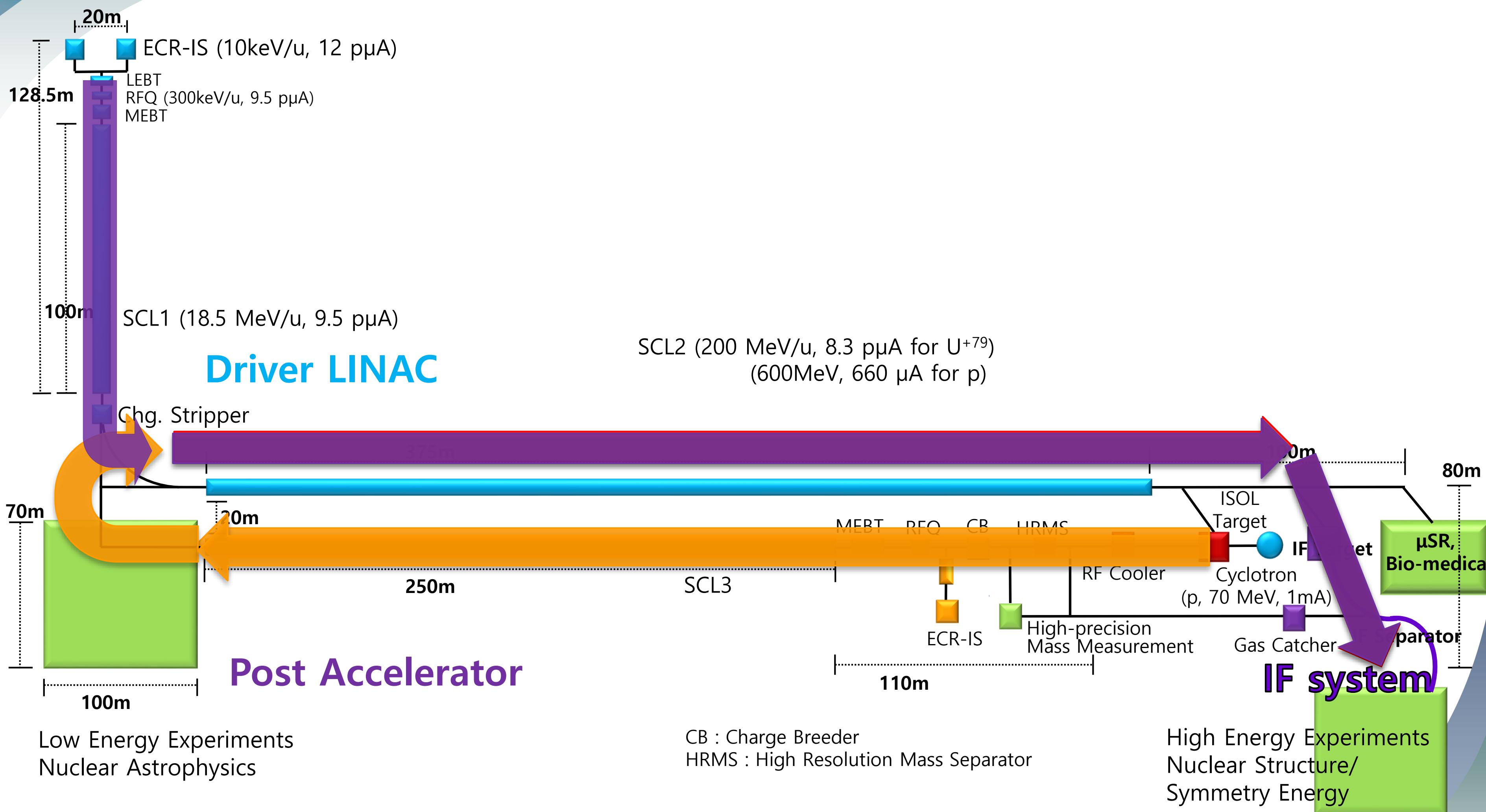
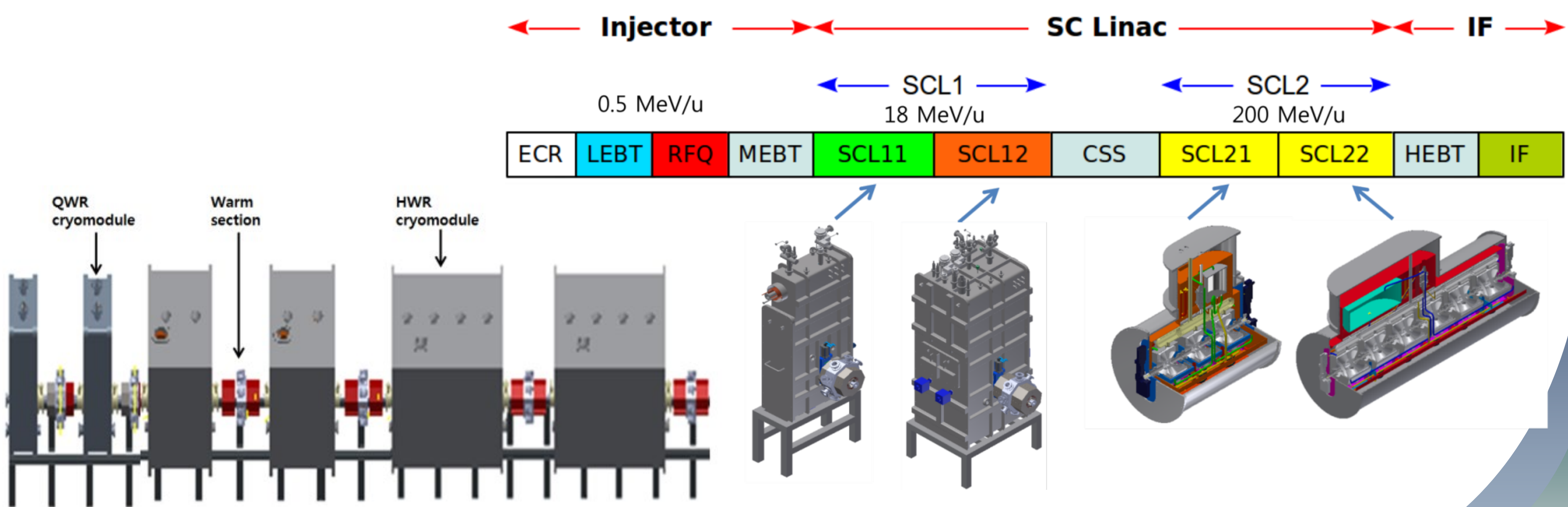
RISP / IBS / South Korea

RAON Concept in RISP/IBS



RISP Superconducting (SC) Linac

- RISP SCL is designed to accelerate high intensity beams.
- Lattice consists of the units of (cryomodule + quad doublet).
- Optimized geometric β of SC cavities (0.047, 0.12, 0.30, 0.51).
- Employs larger aperture SC cavities to reduce beam loss (40 mm and 50 mm aperture).

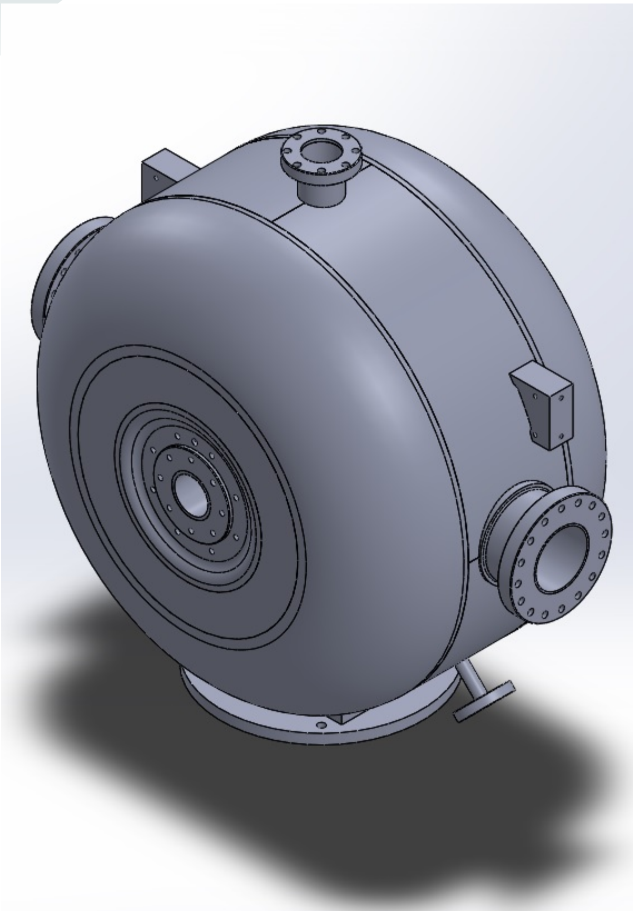


SC Cavity Specifications in RISP

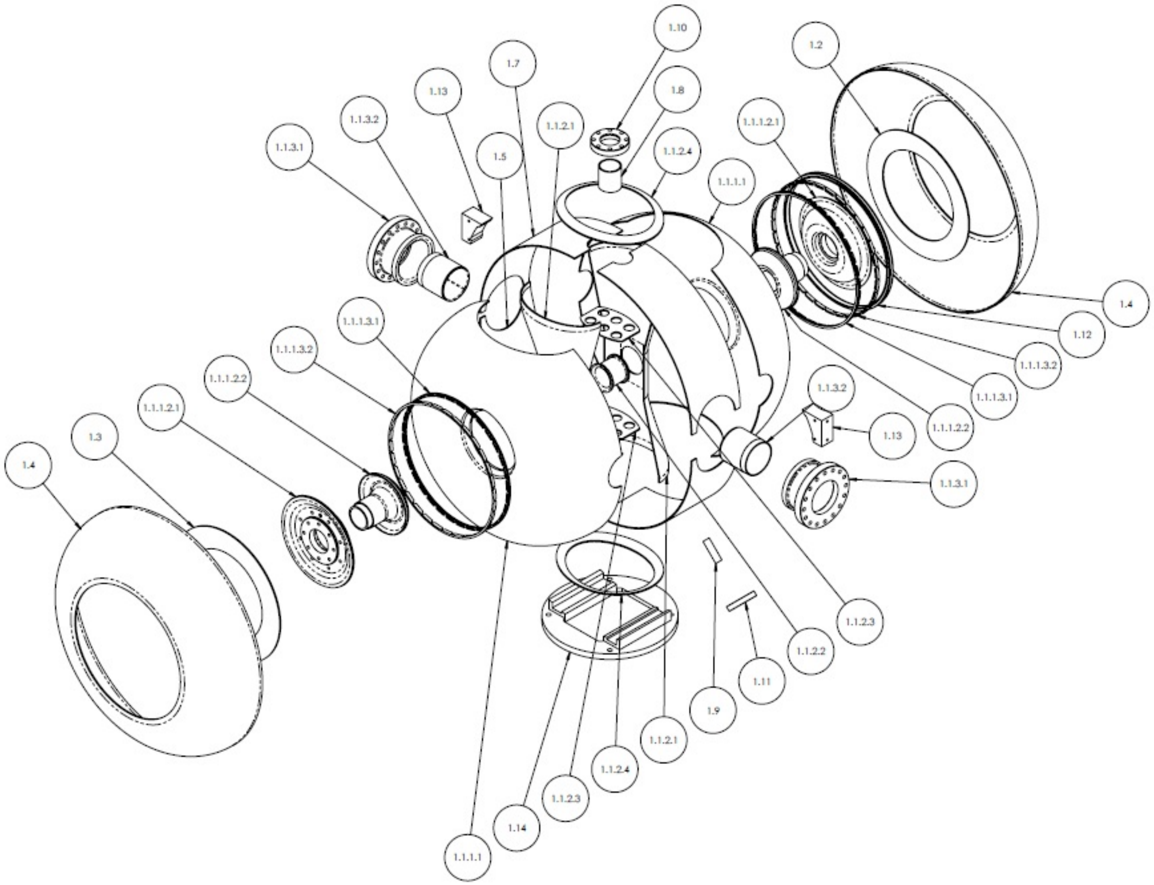
RAON

Parameters	Unit	QWR	HWR	SSR1	SSR2
β_g	-	0.047	0.12	0.30	0.51
F	MHz	81.25	162.5	325	325
Aperture	mm	40	40	50	50
G	Ohm	22	42	94	112
R/Q	Ohm	468	310	233	290
V_{acc}	MV	1.1	1.4	2.5	4.1
E_{peak}	MV/m	35	35	35	35
B_{peak}	mT	57	55	55	67
$Q_{calc}/10^9$	-	0.24	1.45	>5	>5
Temp.	K	4.5	2.05	2.05	2.05

SSR1 Cavity Design (TRIUMF)



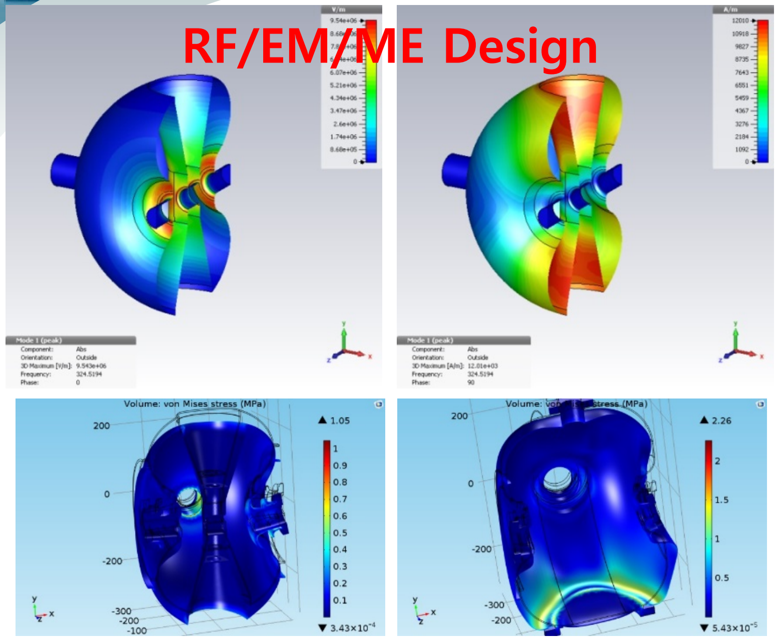
SSR1 3D Model



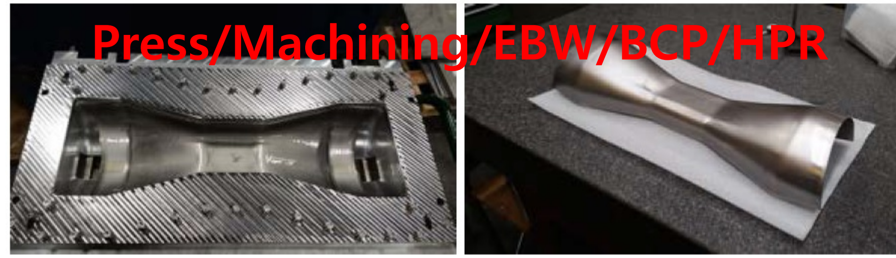
SSR1 Exploded View

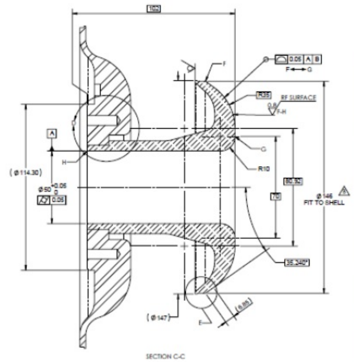
SSR1 Cavity Prototype (TRIUMF)

RF/EM/ME Design



Press/Machining/EBW/BCP/HPR



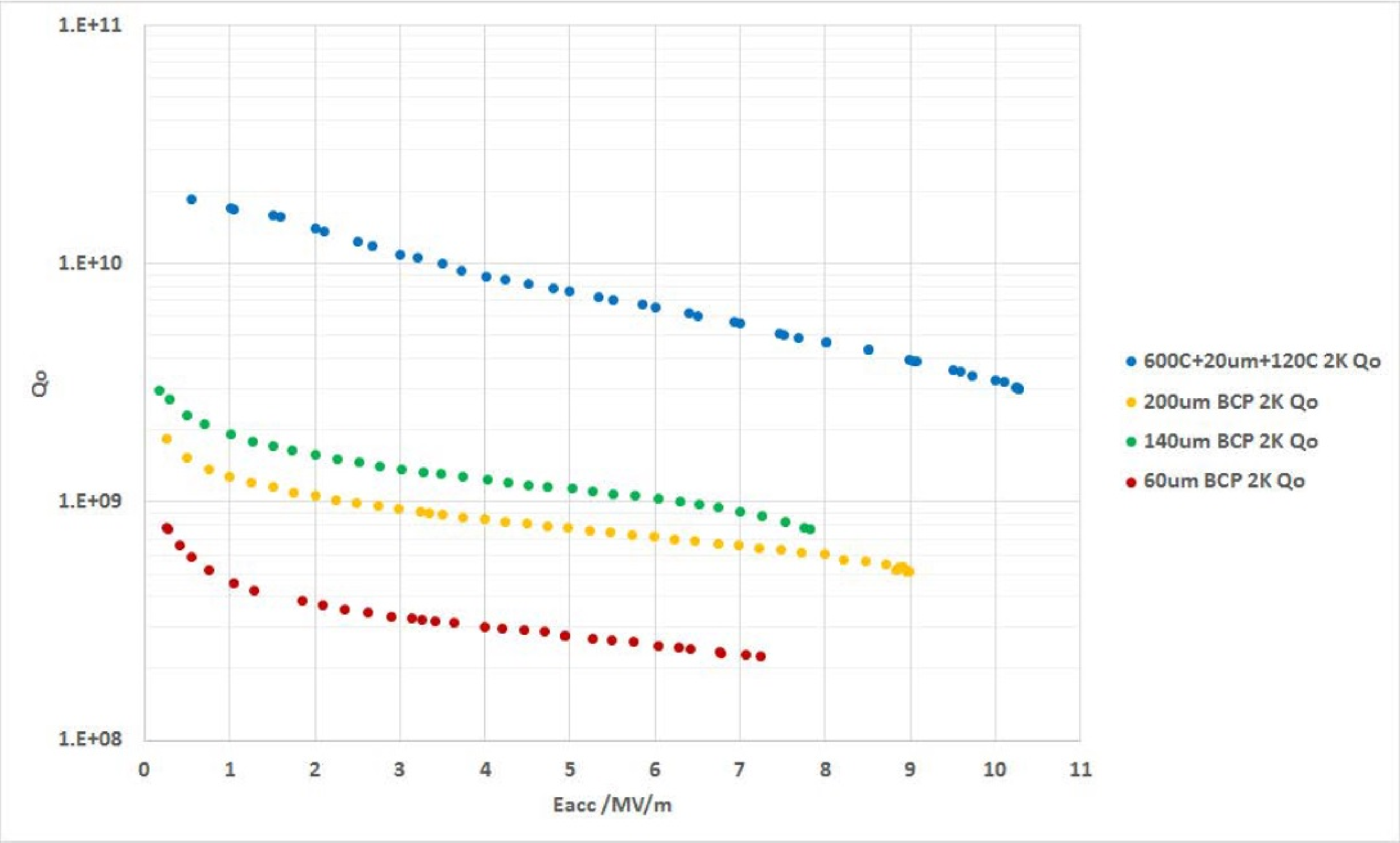


SSR1 Bare Cavity

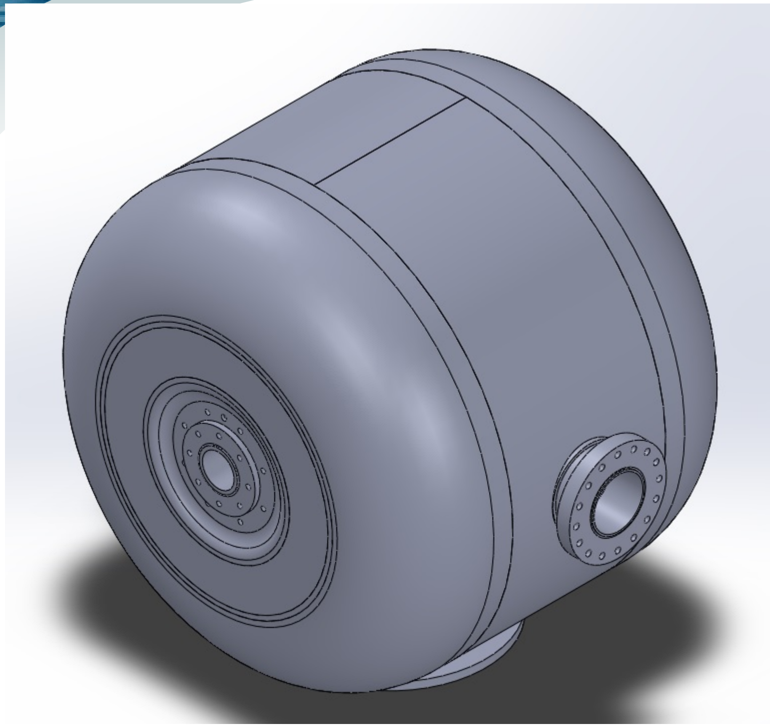
Jacketing

Proceeded By TRIUMF

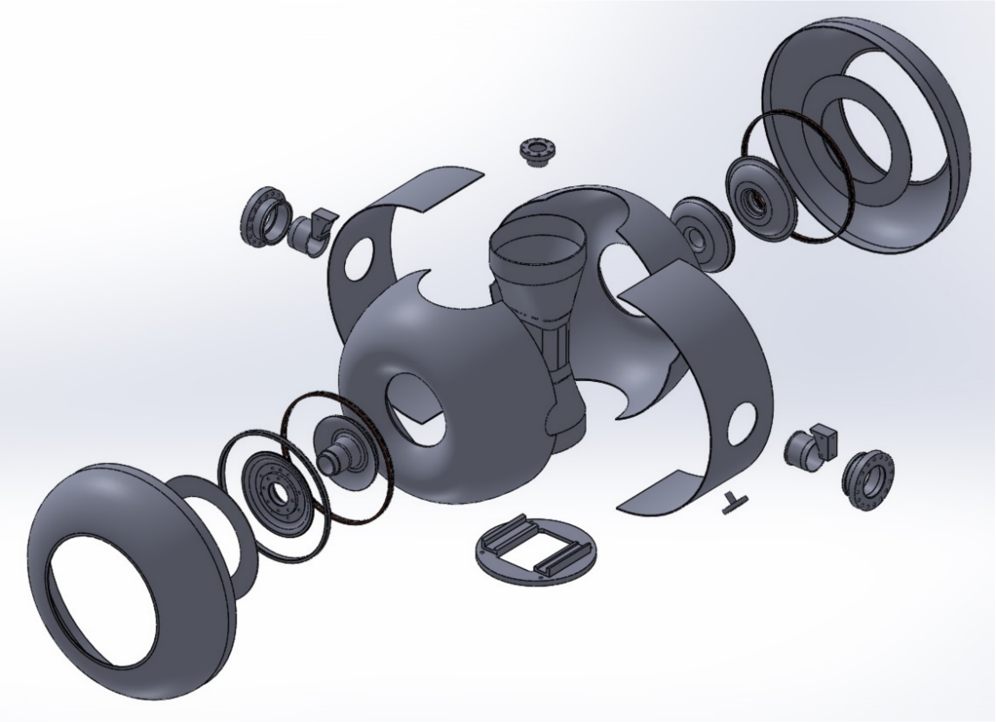
SSR1 Cavity Cold Test Results (TRIUMF)



SSR2 Cavity Design - Layout



SSR2 3D Model

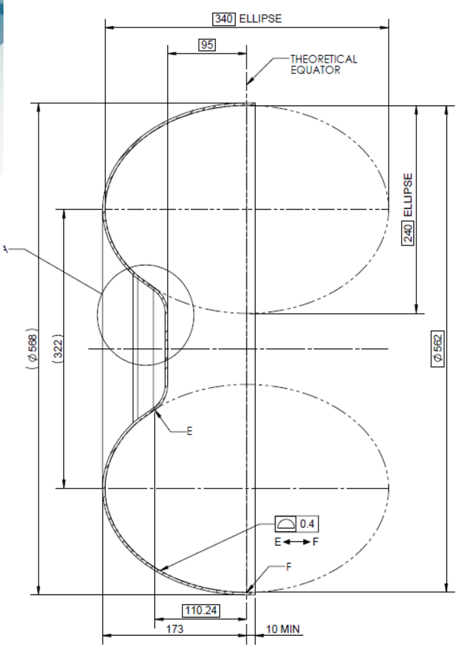


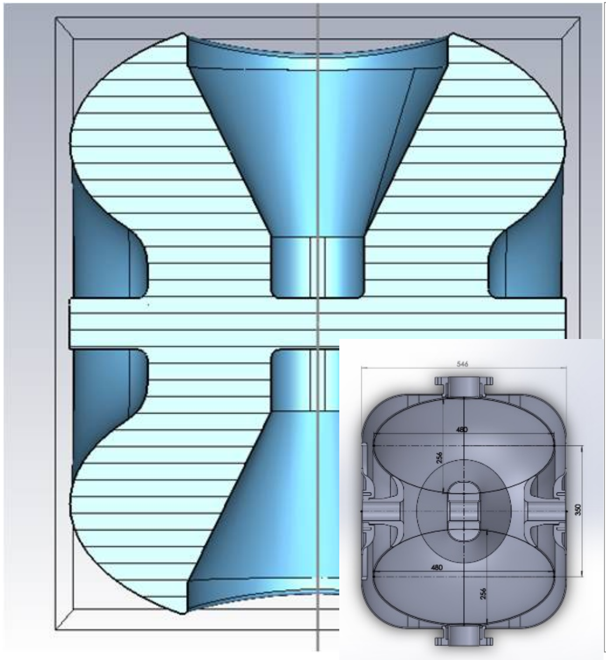
SSR2 Exploded View

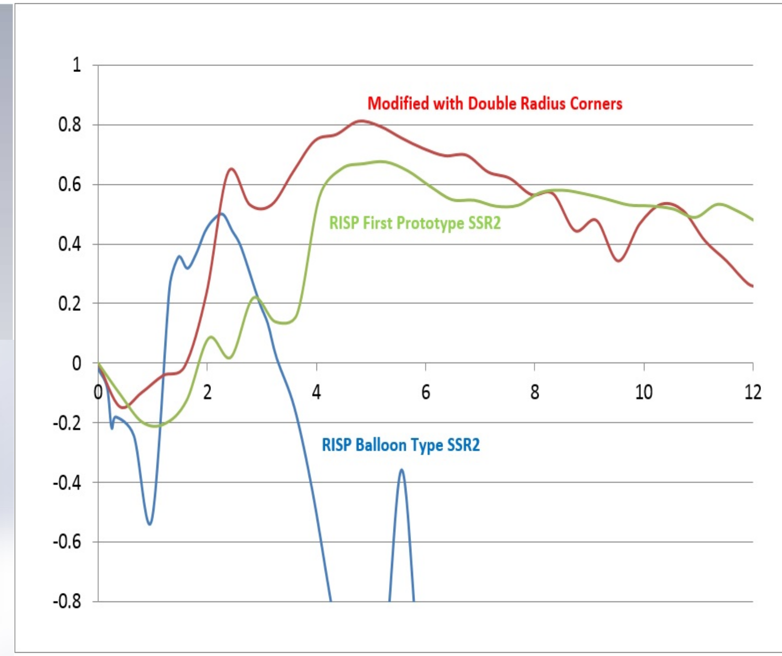
❖ SSR2 Superconducting Cavity

- Cavity : 3T pure niobium (RRR 300 grade), single spoke, 0.51 beta, 325MHz, bulk machining beam port, stiffening ring and spoke stiffener for structural reinforcement, vacuum braze at every ports and flanges, EBW for weldment attach, beam port trimming for frequency adjustment
- Jacket : 3T STS316L, 1.3 bar pressure vessel design (ASME Section-2 Part-D Subpart-1) , liquid helium volume 51.32L (33.05L for SSR1), GTAW for weldment attach, transition ring for stiffening ring interface

SSR2 Cavity Design – RF/EM







❖ SSR2 SC Cavity RF Design (run by Dr. HC Jung)

- Two elliptical shape for making shell design : For SSR1, longer axis is 340mm and shorter axis is 240mm. For SSR2, longer axis is 480mm and shorter axis is 256mm (inner surface)
- Elliptical axis-to-axis : 322mm for SSR1, 350 for SSR2
- Spoke is also lofted to the elliptical shape : For SSR1, longer axis is 221mm and shorter axis is 170mm. For SSR2, longer axis is 276mm and shorter axis is 252mm.
- Multi-pacting simulation is run by CST PIC solver. Comparing with previous SSR2 model and curvature modification model, RISP SSR2 (balloon type) is highly improved at the multi-pacting phenomenon.

SSR2 Cavity Design – Mechanical Analysis

	Unit	RRR300 Niobium	STS 316L
Young's Modulus	GPa	107	193
Poisson's Ratio	-	0.36	0.25
Density	g/cm^3	8.56	7.99
Tensile Strength	MPa	134	483
Yield Strength	MPa	51	170
Allowable Stress	MPa	34	113

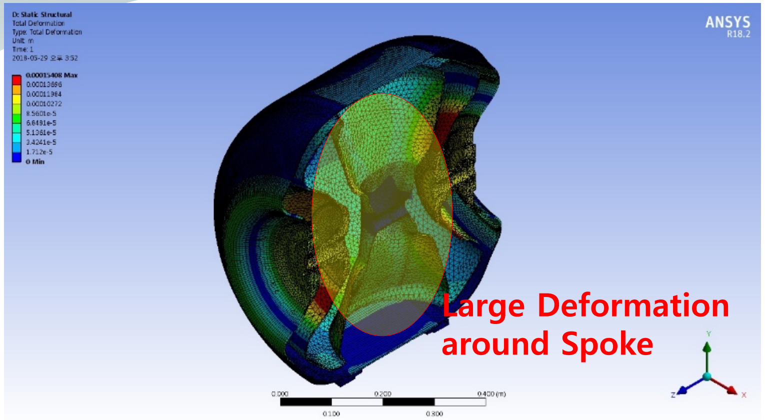
❖ SSR2 SC Cavity Material Properties

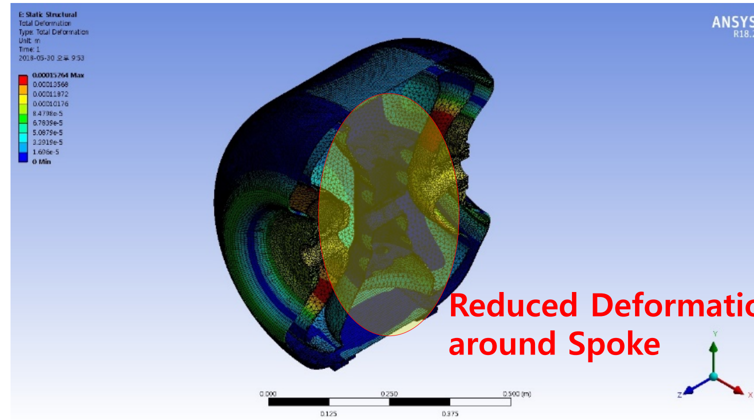
- RRR300 Pure Niobium : 3T sheet for shell/spoke/RF ports, 200mm pi Bulk cylindrical ingot for beam ports (considering 4T sheet for shell due to thickness change during pressing/forming)
- Reactor Grade (RRR 50) Niobium : 5T sheet for spoke stiffeners/ring stiffeners
- STS316L : 3T sheet for jacket walls, Bulk materials for beam/RF port flanges and support

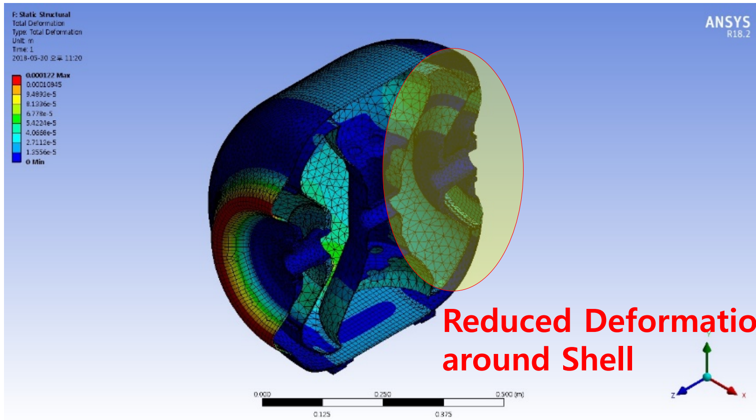
❖ SSR2 SC Cavity Boundary Conditions

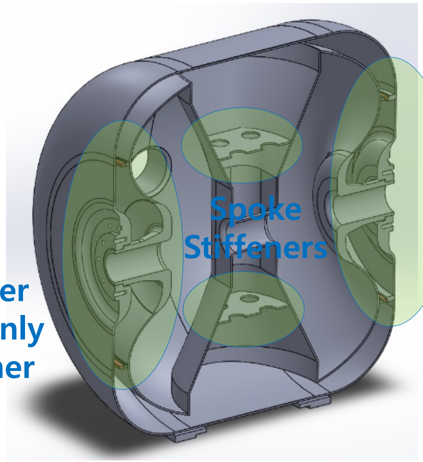
- Fixed conditions at spoke beam tube
- Applied 1.3 bar helium pressure at the outside surface of SC cavity and inside surface of helium jacket

SSR2 Cavity Design – Mechanical Analysis





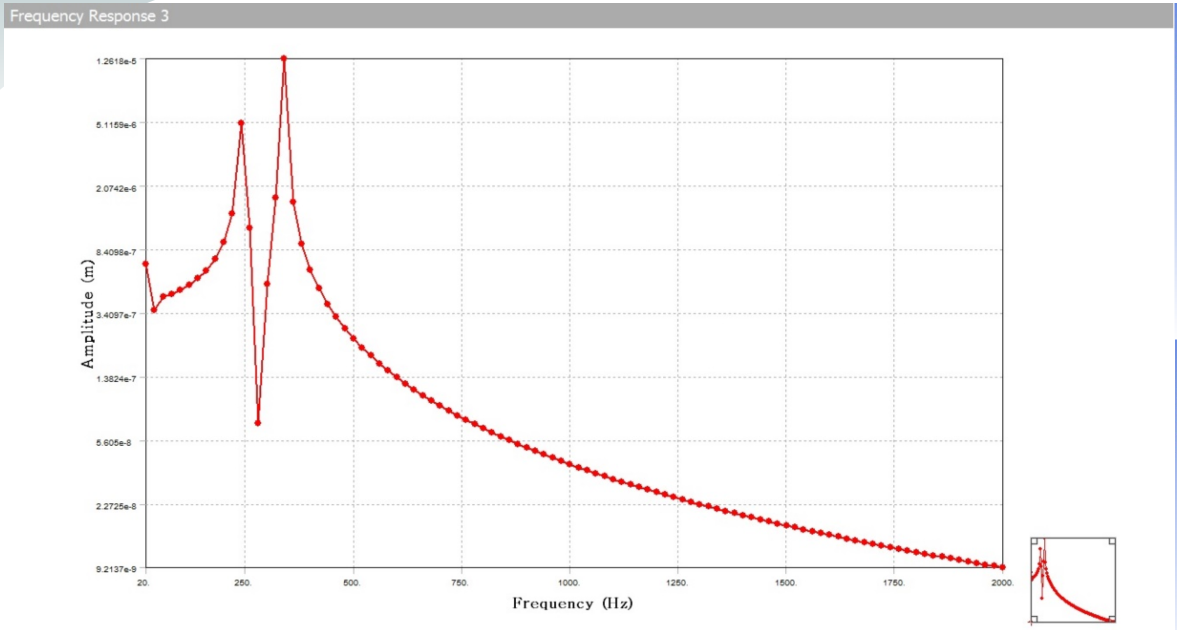


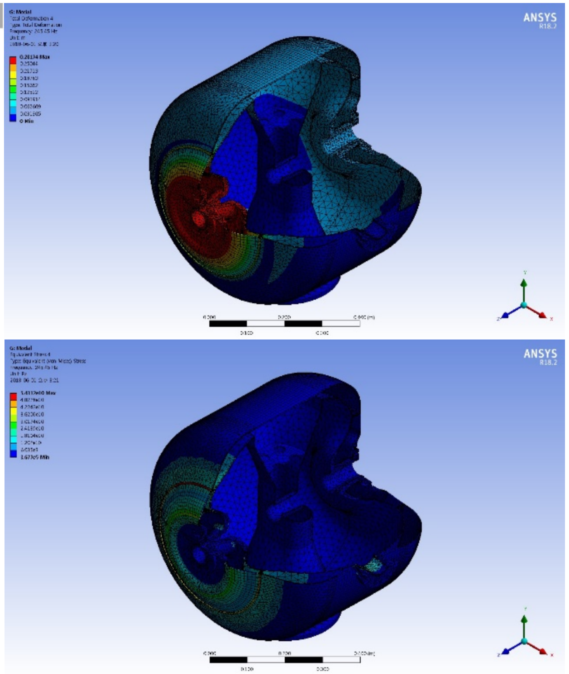


❖ SSR2 SC Cavity Mechanical Design

- Before applying spoke stiffeners, spoke deformation/stress is quite large due to helium pressure. After applying spoke stiffeners at the upper and lower side of spoke, deformation/stress is reduced.
- Still shell deformation/stress is over yield strength so that we applied stiffener rings at the front/rear side of shell surface. After applying stiffener rings, deformation/stress of shell is reduced.

SSR2 Cavity Design – Modal Analysis

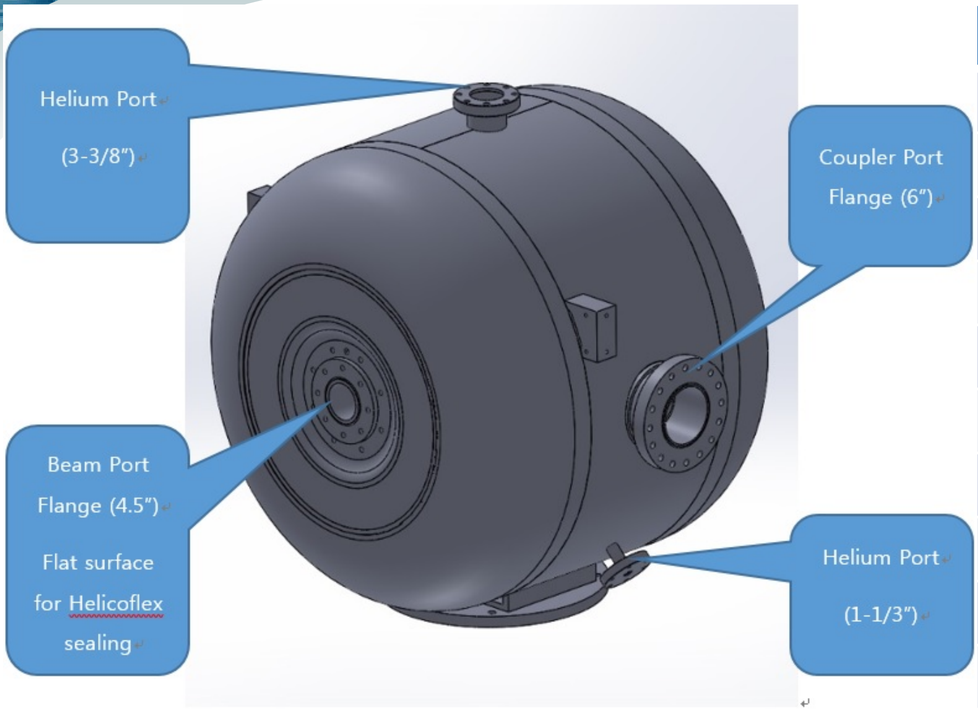




❖ SSR2 SC Cavity Modal Analysis

- Boundary Conditions : Fixed at spoke beam tube, applied Front-cover pressure as 1.3 bar
- Mesh Conditions : 5mm free mesh (program controlled)
- Resonance frequency is calculated at 245.45Hz and 342.4Hz, and we should consider more severely at 245.45Hz frequency because normal motor or generator has 50Hz or 60Hz frequency (rotating speed or electrical transmission frequency) and it can make resonance with multiplication of this frequency, 4X or 5X.
- Mode shape at 245.45Hz is also severe due to its direction can make beam tube iris-to-iris length longer which can affect to the tuning mechanism, so that we should consider it more.

SSR2 Cavity Design – Interfaces & Dimensions



	Unit	SSR1	SSR2
Outer Diameter	mm	568	612
Iris-to-Iris Length	mm	190	320
Beam Flange Length	mm	400	538
Stiffener Diameter	mm	327	345
Spoke Stiffener Length	mm	376	200
Coupler Ports Width	mm	718	716
Stiffener Thickness	mm	5	5
Jacket Diameter	mm	590	626
Jacket Length	mm	400	546
Jacket Thickness	mm	3	3

SSR2 SC Cavity Interfaces & Dimensions

- RISP SSR2 SC cavity interface is exactly same as SSR1 SC cavity. Beam ports is 4.5" HF, RF ports is 6" HF, liquid helium inlet is 1.33" HF, and helium outlet is 3.375" HF. (CF is also considerable but we chose HF for avoiding cryogenic temperature leakage during cool-down.)
- Dimensions of RISP SSR2 SC cavity is increased comparing with RISP SSR1 SC cavity because of its high geometry factor and accelerating voltage gradient.

Conclusions & Future Works

- RISP SSR2 design starts from the "Balloon Variant" concept of RISP SSR1 which is invented and developed with the collaboration between TRIUMF and RISP.
  - Z.Yao, R.E.Laxdal, V.Zvyagintsev, "Balloon variant of Single Spoke Resonator", in Proceedings of SRF2015, Whistler, Canada, 2015, paper THPB021, pp.1100-1114.
  - Z.Yao, R.E.Laxdal, B.Waraich, V.Zvyagintsev, R.Edinger, "Design and Fabrication of Beta=0.3 SSR1 for RISP",in Proceedings of LINAC2016, East Lansing, MI, USA,2016, paper MOPLR041, pp.226-228.

- With RF surface design run by RISP RF engineer, RISP ME engineer proceeded mechanical design including structural and modal analysis. For removing larger deformation of spoke, we applied spoke stiffeners at the upper and lower side of spoke and deformation/stress of spoke is reduced effectively. Also, we applied stiffener rings at the front/rear half shell sides so that deformation of half shell is reduced.

- Next, we will proceed our mechanical design of RISP SSR2 for satisfying the pressure vessel code (ASME/KSME) and other cavity performances like df/dp or target frequency. With our objectives, we will setup design parameters of RISP SSR2 and find the optimal value of design parameters.

Thank you!