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Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Status of SSR1 and SSR2

Leonardo Ristori

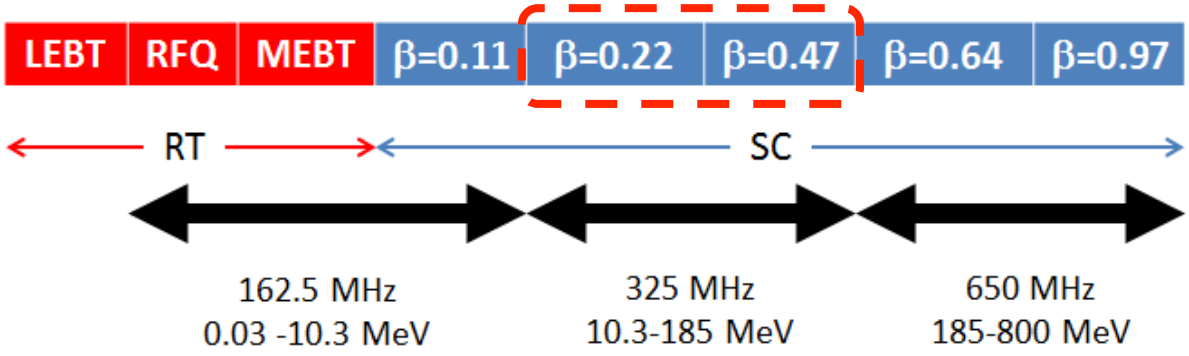
P2MAC Meeting

9-10 March 2015

Overview

- 325 MHz section of PIP-II Linac
- SSR1 & SSR2 Cryomodules
- SSR1 development
  - Focusing elements
  - SRF cavities
  - Tuners
  - Couplers
- SSR1 schedule
- SSR1 collaboration with IUAC
- SSR2 design status

PIP-II Superconducting Linac (RDR 2.1.3)



CM type	Cavities per CM	Number of CMs	CM configuration*	CM length (m)	Q_0 at 2K (10^{10})	Surface resistance, (nΩ)	Loaded Q (10^6)
HWR	8	1	8 × (sc)	5.93	0.5	9.6	2.7
SSR1	8	2	4 × (csc)	5.2	0.6	14 ($10^{\#}$)	3.7
SSR2	5	7	sccsccsc	6.5♦	0.8	14.4	5.8
LB650	3	11	ccc	3.9♦	1.5	12.7	11.3
HB650	6	4	cccccc	9.5♦	2	13	11.5

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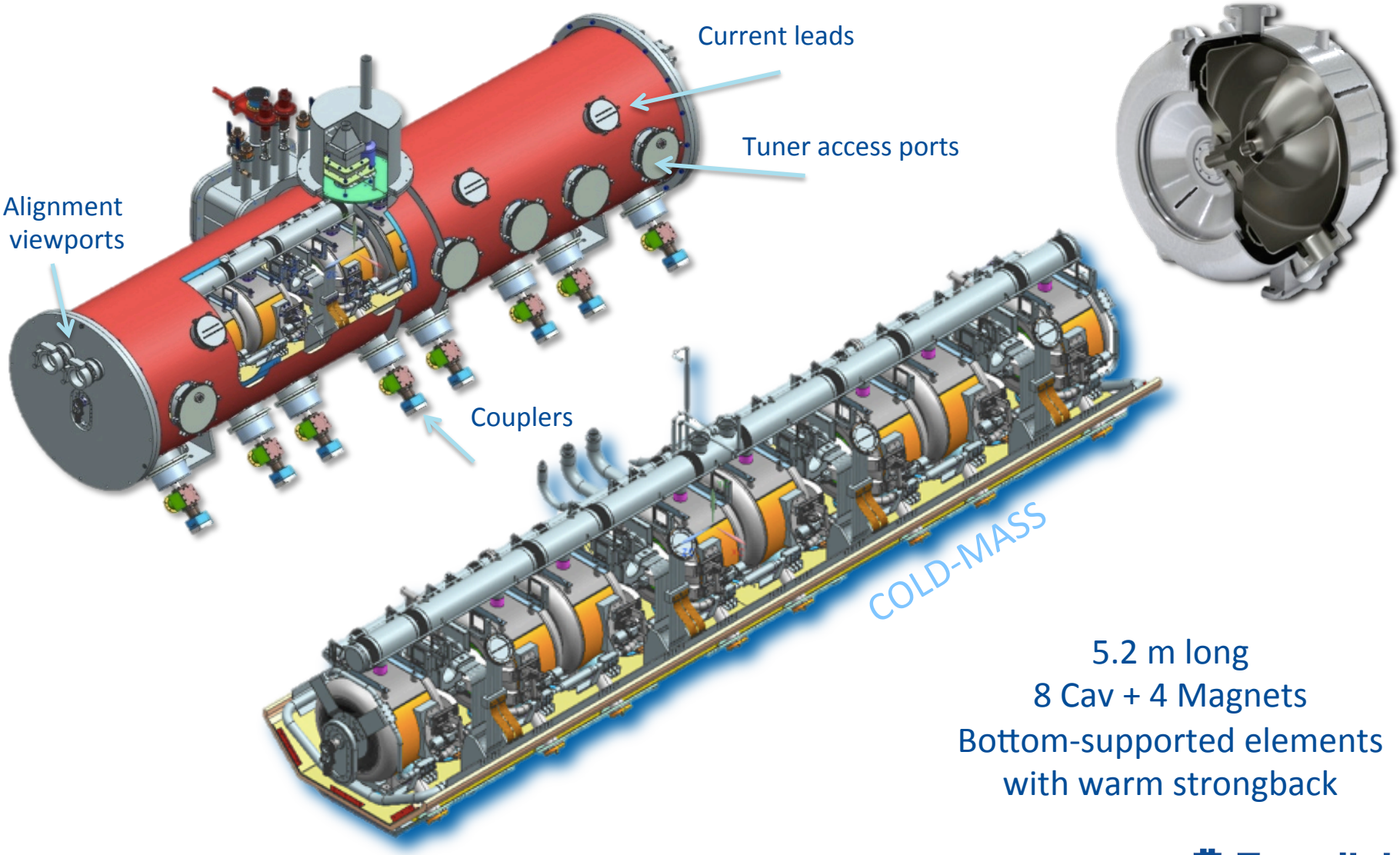
SSR1 Cryomodule

T. Nicol, Y. Orlov



5.2 m long
8 Cav + 4 Magnets
Bottom-supported elements with warm strongback

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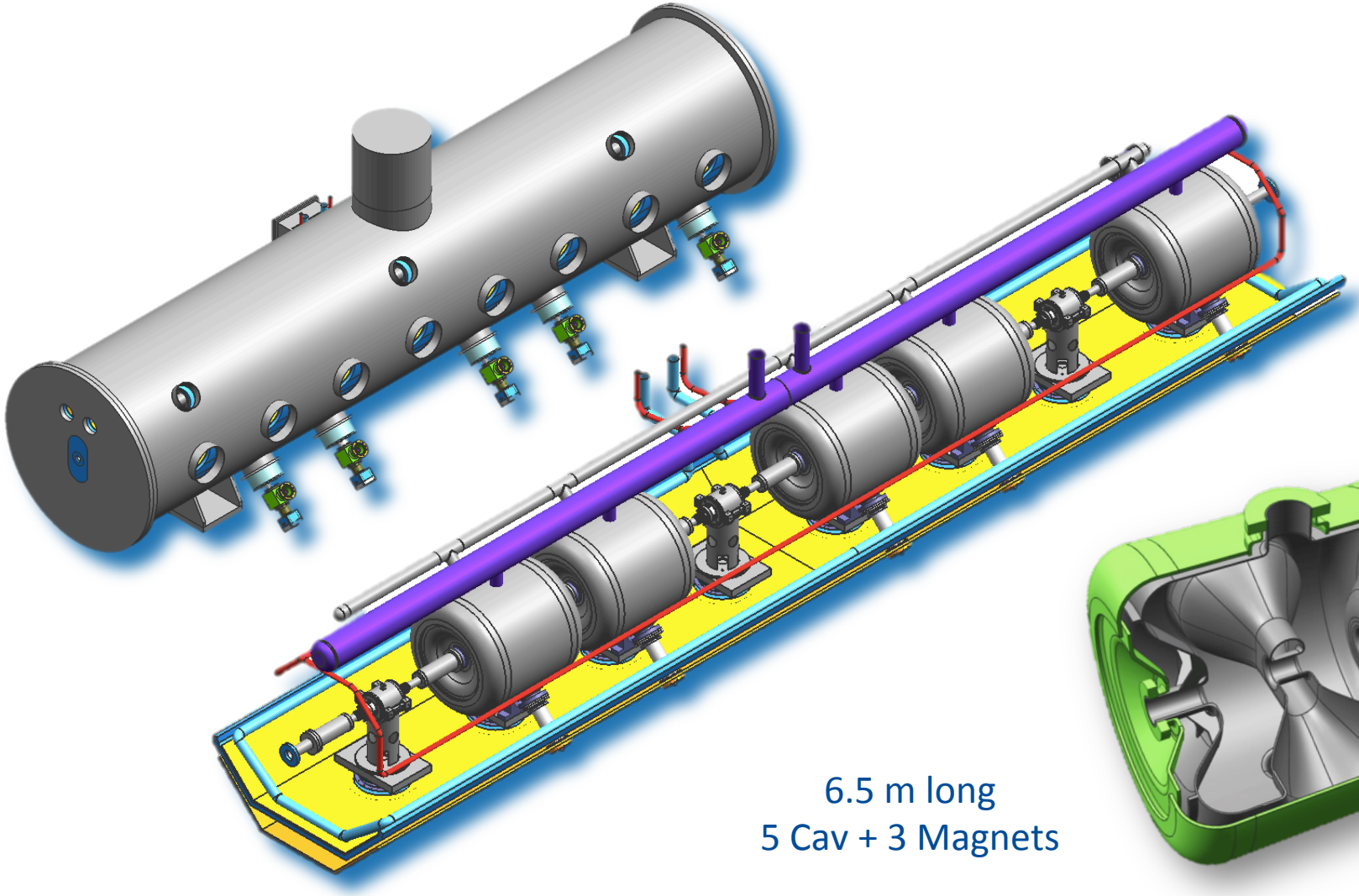
SSR2 cryomodule



6.5 m long
5 Cav + 3 Magnets

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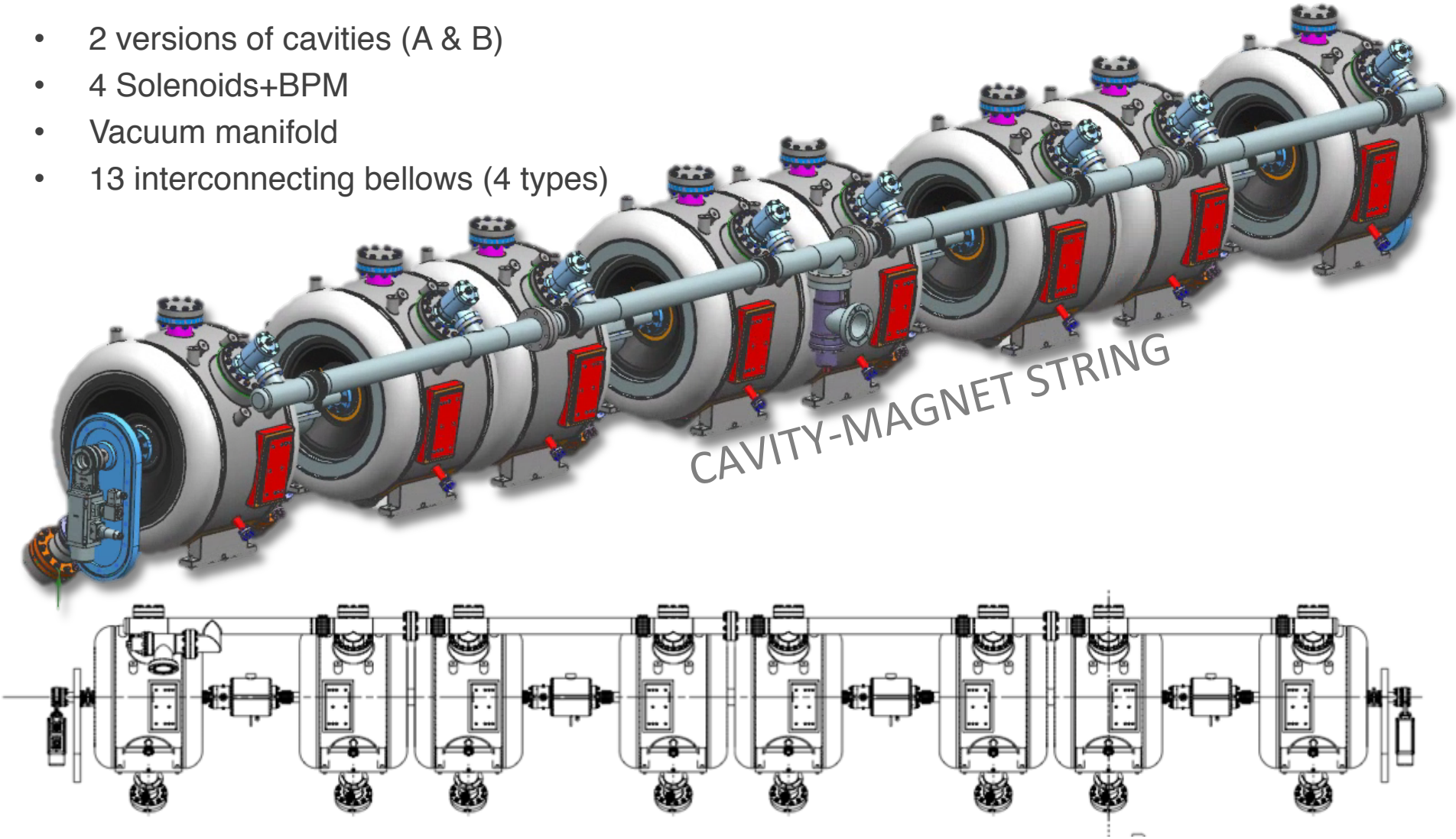
SSR1 CAVITY-MAGNET STRING

T. Nicol, Y. Orlov

- 2 versions of cavities (A & B)
- 4 Solenoids+BPM
- Vacuum manifold
- 13 interconnecting bellows (4 types)



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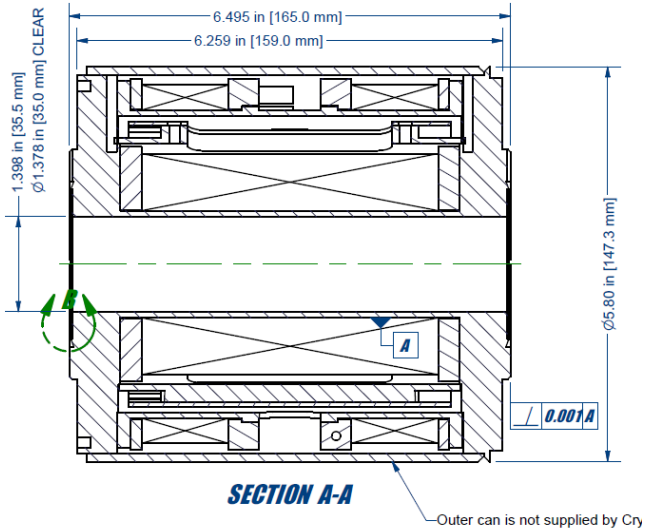
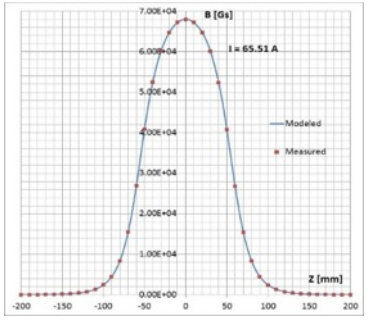
Focusing Elements

I. Terechkine

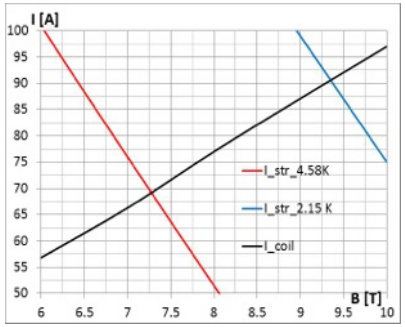
Lens strength ($T_2 \cdot m$)	4
Steering dipole strength ($T \cdot m$)	$2.5 \cdot 10^{-3}$
Insertion length, max. (mm)	160
Ferromagnetic shielding	NO
Magnetic field on Cavity, max. (μT)	$0.5 \cdot Q_0$ criterion
Transverse misalignment (mm)	0.5 RMS
Angular misalignment (mrad)	1 RMS





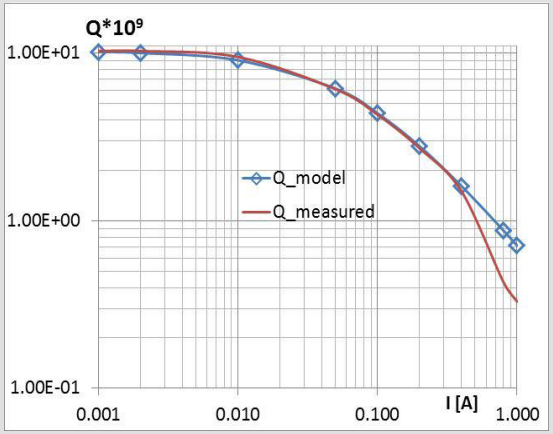
Axial Field: Measured vs Predicted

Excellent agreement between predicted and measured performances

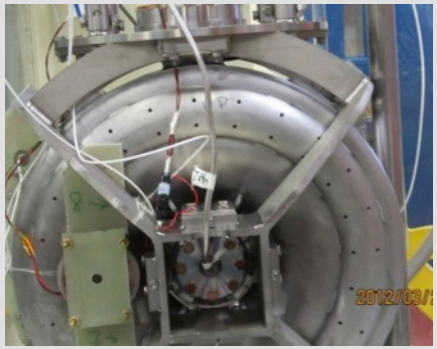


Quench Performance at 4 K and 2 K

Effects of magnetic field trapping during quenching



Cavity Q degradation predicted vs measured



Solenoid installed on SSR1 during VTS tests

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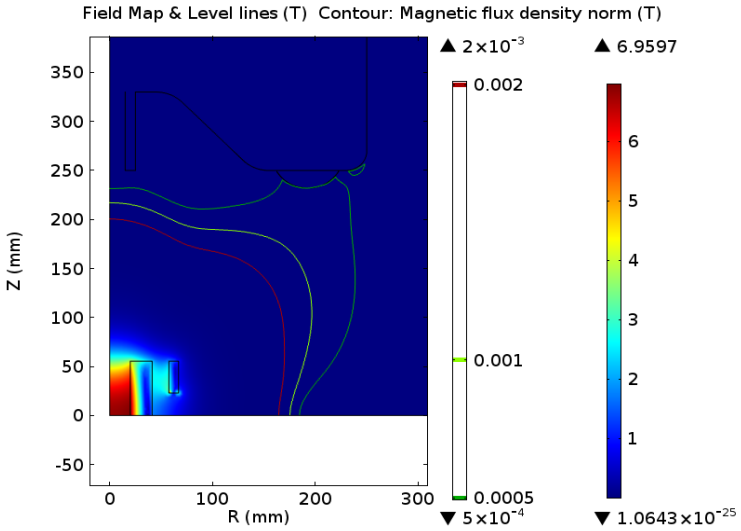
Focusing Elements

I. Terechkine

Production completed, cold tests next month

Prototype FL

1. Prototype lens' cold mass procured and tested at 2 K
2. The lens assembled and re-tested
3. Position of magnetic axis was measured by the vendor and at Fermilab: $\Delta R < 0.2$ mm; $\Delta\alpha < 0.7$ mrad



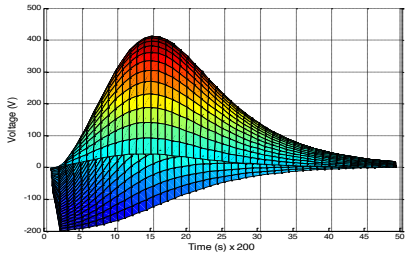
Maximum field on the surface of the cavity is below 5 G.

Production FL

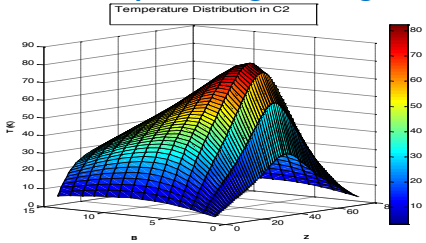
1. Four production lenses' cold masses procured and tested at 4 K by the vendor.
2. The lenses have been prepared for the final performance test in the VTS at 2 K.

Quench protection studies

Voltage to the ground in the main coil



Temperature in quenching bucking coil



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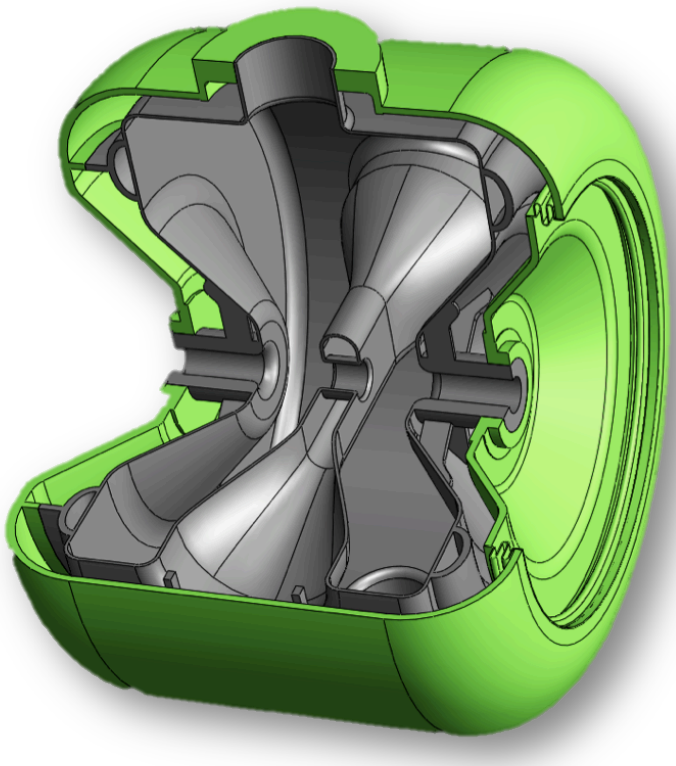
SSR1, SSR2 – Main Requirements

	SSR1	SSR2
Frequency	325 MHz	
Operation	Pulsed / CW	
β_{OPT}	0.222	0.475
Gain/cav	2 MeV	5 MeV
Q_0 at 2K	> 0.6 10^{10}	> 0.8 10^{10}
B_{peak}	58.1 mT	64.5 mT
E_{peak}	38.4 MV/m	40 MV/m
Surface Res	14 nΩ	14 nΩ
L_{EFF} (βλ)	205 mm	438 mm
G	84 Ω	115 Ω
R/Q	242 Ω	296 Ω
LFD sensitivity	< 5 Hz/(MV/m)^2	
Tuning constant	40 N/kHz	90 N/kHz
LHe Sensitivity	< 25 Hz/torr	



SSR1

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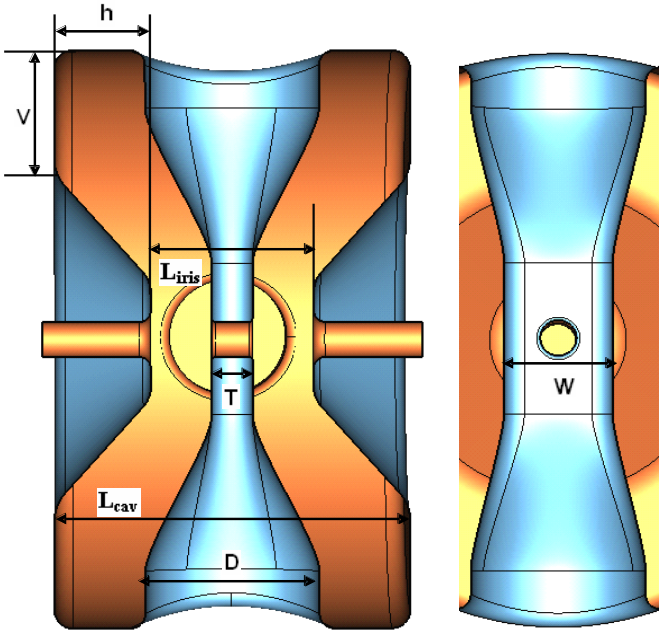
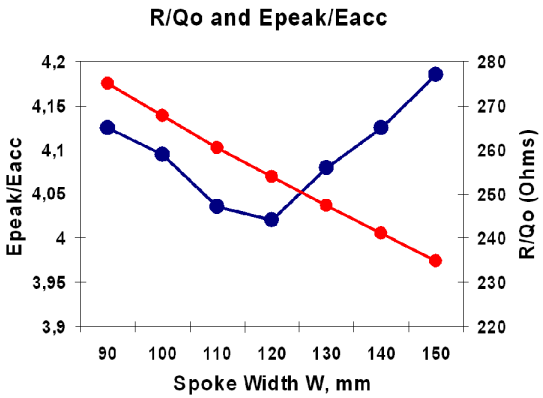
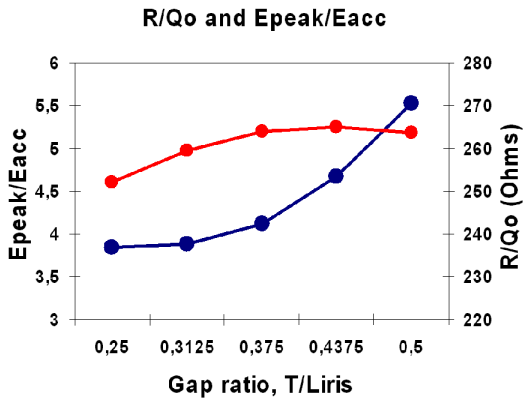
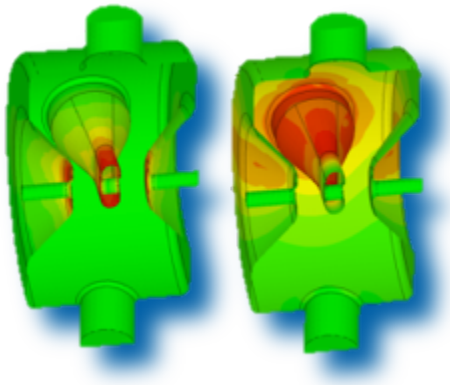
RF design of SSR1

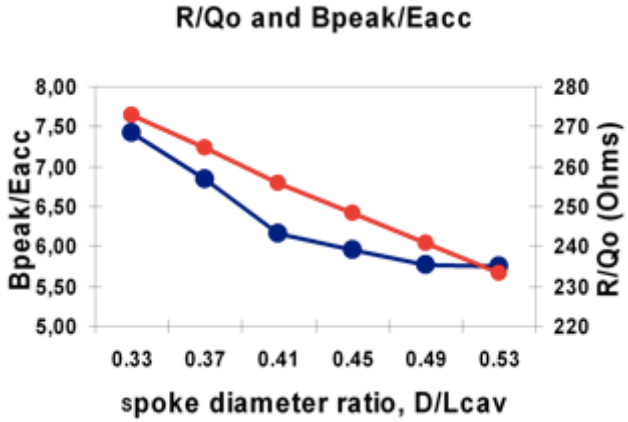
Ivan Gonin











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Multipacting studies

Gennady Romanov

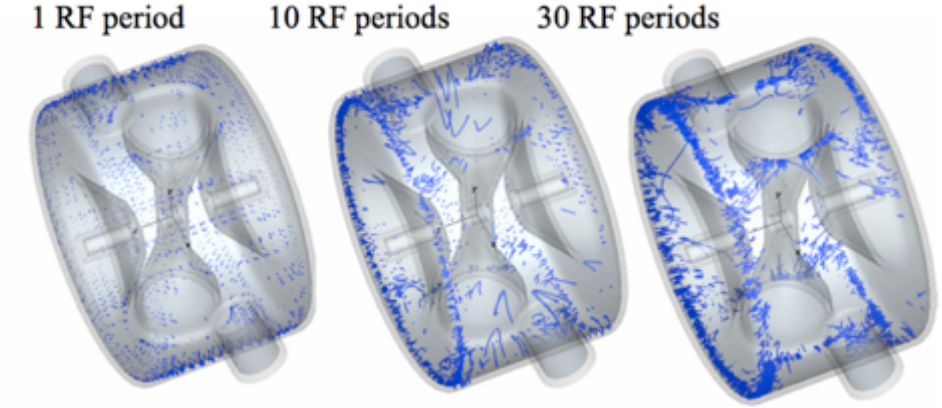
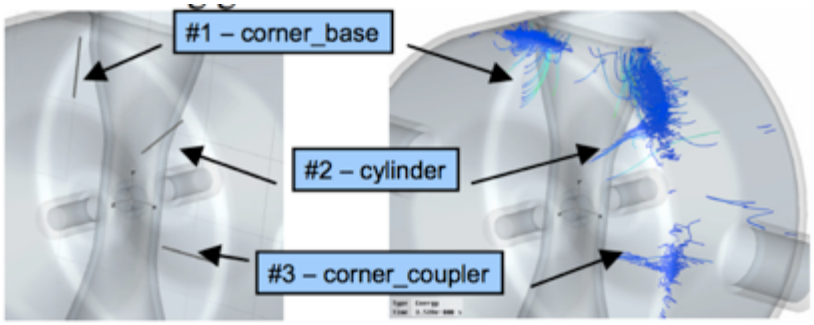
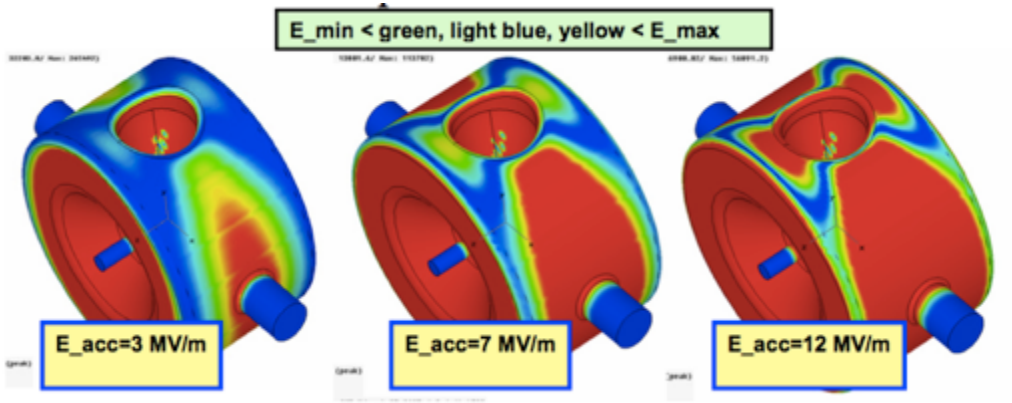
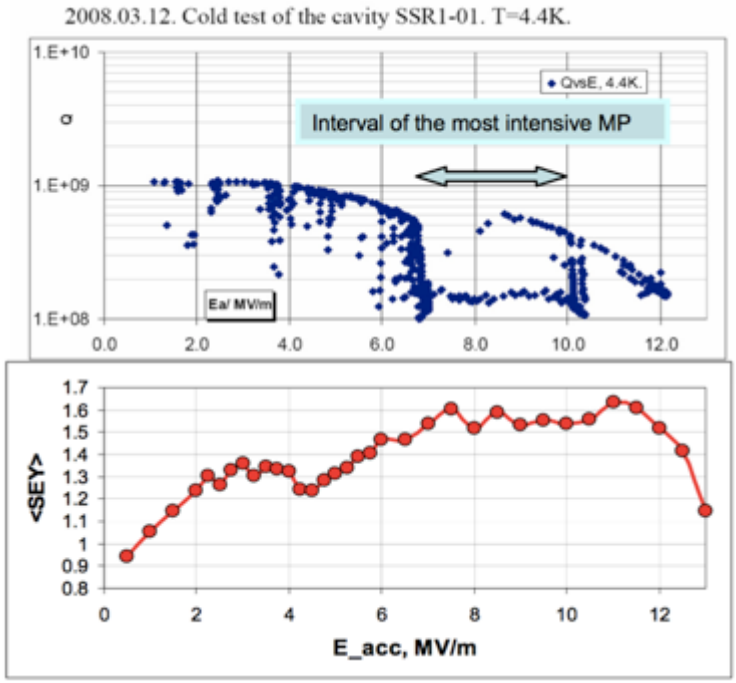


Figure 6: Development of multipacting in time at accelerating gradient of 7 MV/m.







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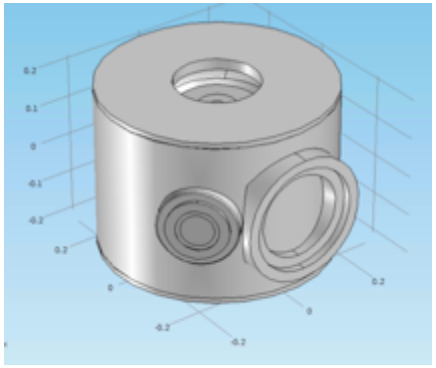
Lorenz-Force Detuning studies

M. Awida Hassan

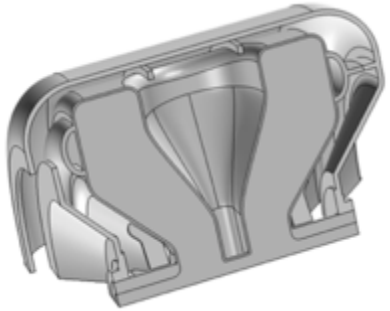
The LFD factor of SSR1 was studied with various boundary conditions.
In working conditions the predicted LFD factor is less than - 3 Hz/(MV/m)^2
The requirement is < 5 Hz/(MV/m)^2

Prototype

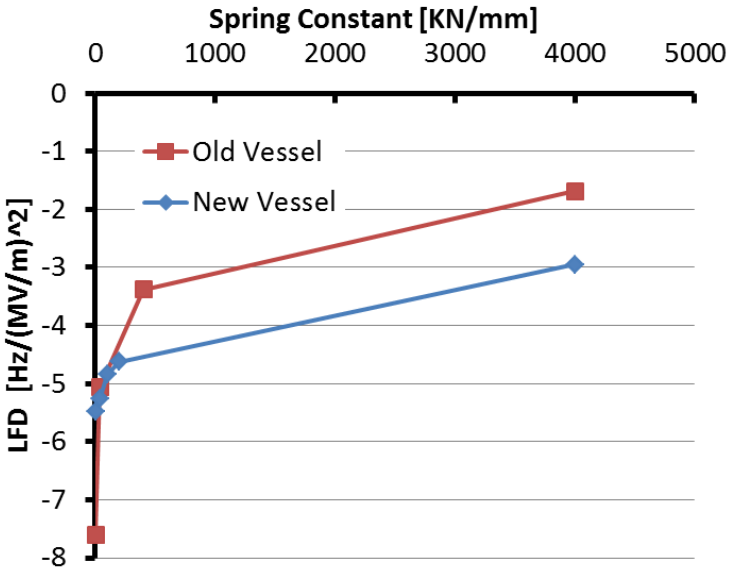


Spring Const [kN/mm]	LFD [Hz/(MV/m)^2]
∞	-1.69
4000	-1.69
400	-3.38
40	-5.07
0	-7.6

Production



Spring Const [kN/mm]	LFD [Hz/(MV/m)^2]
∞	-2.74
4000	-2.95
200	-4.63
100	-4.85
40	-5.27
0	-5.48



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SSR1- Sensitivity to He pressure variations

D. Passarelli

SSR1 must operate within a small bandwidth ± 20 Hz

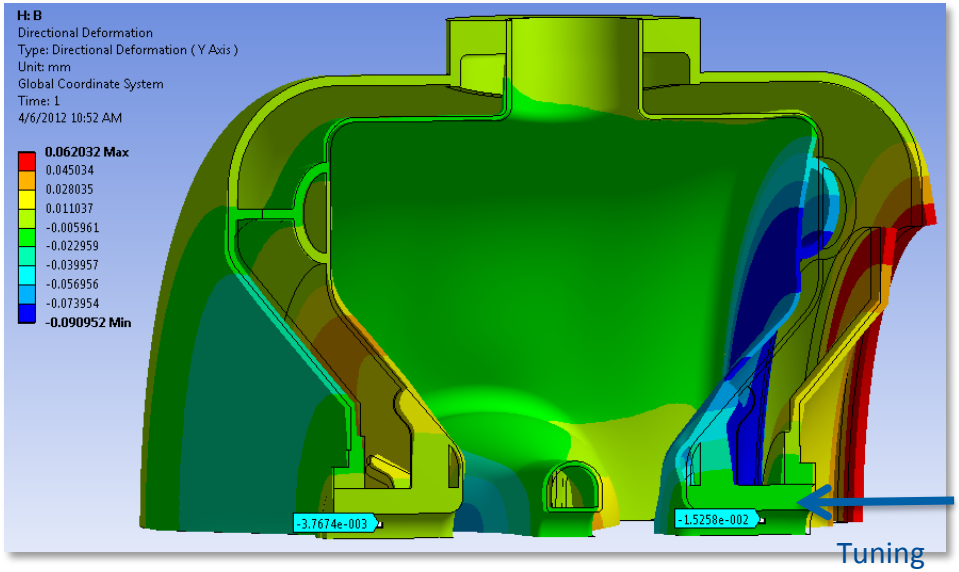
Pressure of L_{He} can vary by ± 0.5 Torr in the cryomodule

A self-compensating design was developed allowing low sensitivity

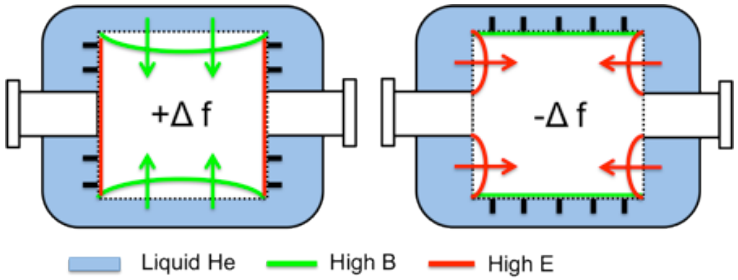
Despite non-negligible deformations (see picture), net shift is very low thanks to Slater's Theorem

Bare cavity ~ 600 Hz/Torr, with He vessel ~ 10 Hz/torr

Ease of tuning 39 N/kHz (bare), 40 N/kHz* (with He vessel)



* It is possible to reduce sensitivity without increasing rigidity



- Deformations in high E and B regions balance out resulting in a small frequency shift (Slater's Theorem)

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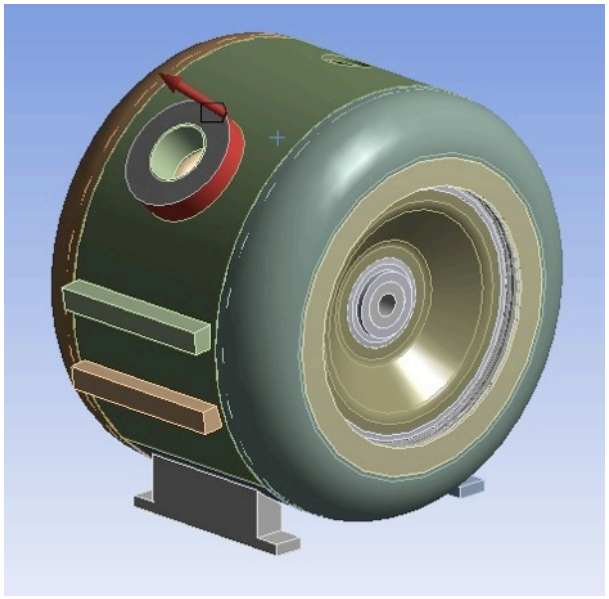
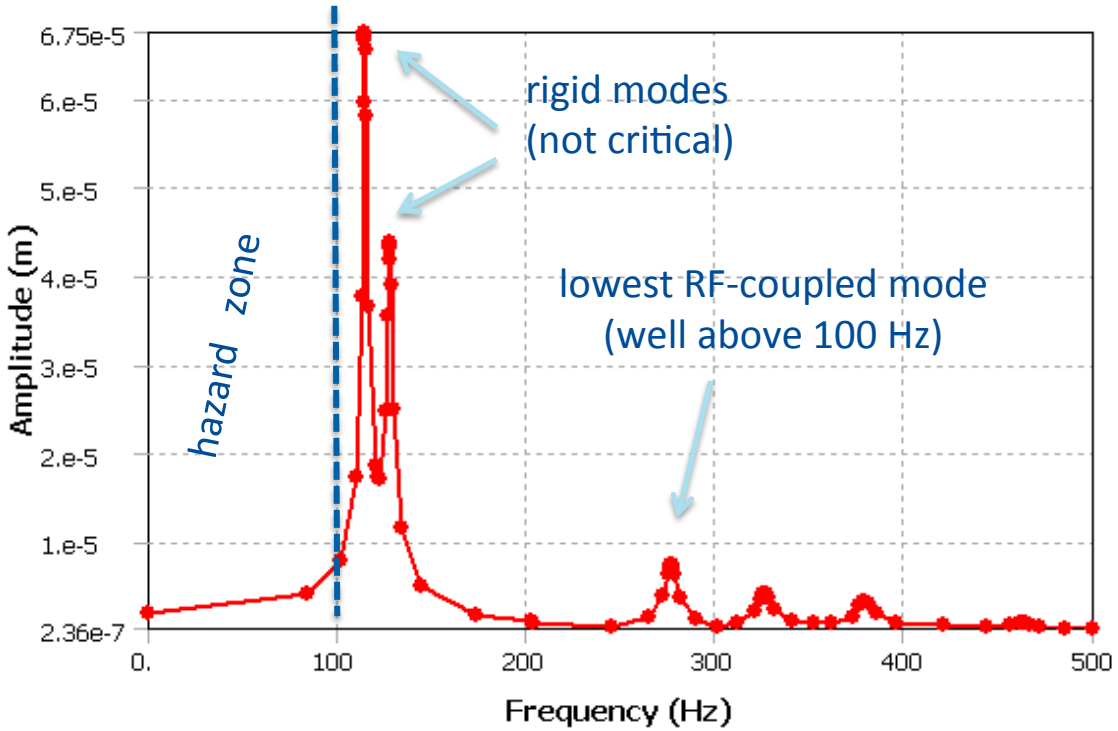
Harmonic Analysis – SSR1

L. Ristori

Oscillating force f (x,y,z)





Results					
Minimum	0. m				
Maximum	0.14647 m	0.16846 m	0.29507 m	0.41893 m	0.41125 m
Minimum Occurs On	Part 33				
Maximum Occurs On	Part 25	Bellows	ssr1_rf	Bellows	
Information					
Frequency	114.77 Hz	127.92 Hz	276.87 Hz	326.31 Hz	378.96 Hz

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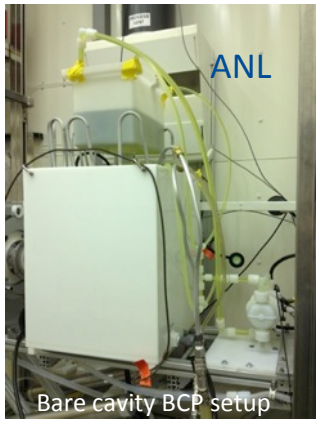
Processing/Testing steps (ANL, FNAL)

1. Inspection – RF & Optical
2. BCP 120-150 μm (flip half-way)
3. HPR
4. 600 °C, 10 h (< 5°C/min ramp rate)
5. RF Tuning
6. BCP 20-30 μm
7. HPR (horiz + vert)
8. Assemble
9. Evacuate + 120 °C, 48 h
10. Vertical Test
11. Helium Vessel Dressing
12. RF Tuning
13. BCP 20-30 μm
14. HPR
13. Assemble
14. Evacuate + 120 °C, 48 h
15. Horizontal Test
16. Ready for String



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Status of SSR1 cavities

- ED0002558						IB4	IB4	IB4	IB4	ANL	ANL	MP9	IB4	ANL	ANL	MP9	VTS (IB1)	ROARK	IB4	MEYER TOOL	IB4	IB4	IB4	IB4	IB4	ICB	ICB	ANL	ANL	MP9	STC (MDB)
OPERATION -->	Deep drawing	Sub-assy EBW	Freq. trimming	Final EBW	Delivery to FNAL	Visual QC	Dimensional QC	RF QC	Leak QC	Bulk BCP	HPR	600 C Bake	RF Tune	Light BCP	HPR + Prep for VTS	120 C Bake	VTS Tests	Ring EBW	RF Tune	Jacketing	Visual QC	Dimensional QC	RF QC	Leak QC	RF Tune	Flange Polishing	Thread Maintenance	Light BCP	HPR + prep for STC	120 C Bake	STC Tests
TRAVELER # -->	-	-	-	-	-	333990	333884	464013	464012	333862		464022			464116	464121														464121	
LINKS TO VECTOR (ONSITE ACCESS ONLY)	Leonardo	Leonardo	Leonardo	Leonardo	Leonardo	Donato	Donato	Paolo Mohamed		Brent		Margherita	Paolo Mohamed	Brent	Brent	Margherita	Anna Sukhanov Sergatskov	Leonardo	Paolo Mohamed	Donato	Donato	Donato	Paolo Mohamed		Paolo Mohamed	Damon	Damon	Brent	Brian	Margherita	Andy, Joe
S103 travelers																															
S104 travelers																															
S105 travelers					no estimate															type B											
S106 travelers					8-Jan-14												20 MV/M			type A											
S107 travelers					4-Nov-11												22 MV/m			type A						skipped	skipped				in proc
S108 travelers					4-Nov-11												21 MV/m			type A	in proc										
S109 travelers					19-Dec-11												20 MV/m			type A	in proc										
S110 travelers					19-Dec-11												17 MV/m			type A											
S111 travelers				equator repaired	31-Dec-12												19 MV/m			type B											
S112 travelers					10-Dec-12												17 MV/m			type B											
S113 travelers		spoke repaired			10-Dec-12												19 MV/m			type B											
S114 travelers		spoke repaired			31-Dec-12												21 MV/m			type B											
S1H-RK-115	in proc				no estimate																										

9 of 10
Delivery
(Bare Cavity)

9 of 10
Cold Test
(Bare Cavity)

3 of 10
Jacketing

1 of 10
Cold Test
(Jacketed
Cavity)

- Most of the 10 production cavities are in the jacketing stage
- S107 is leading the group, 2nd test in STC to qualify prototype coupler and tuner
- S106 and S105 are trailing due to repairs

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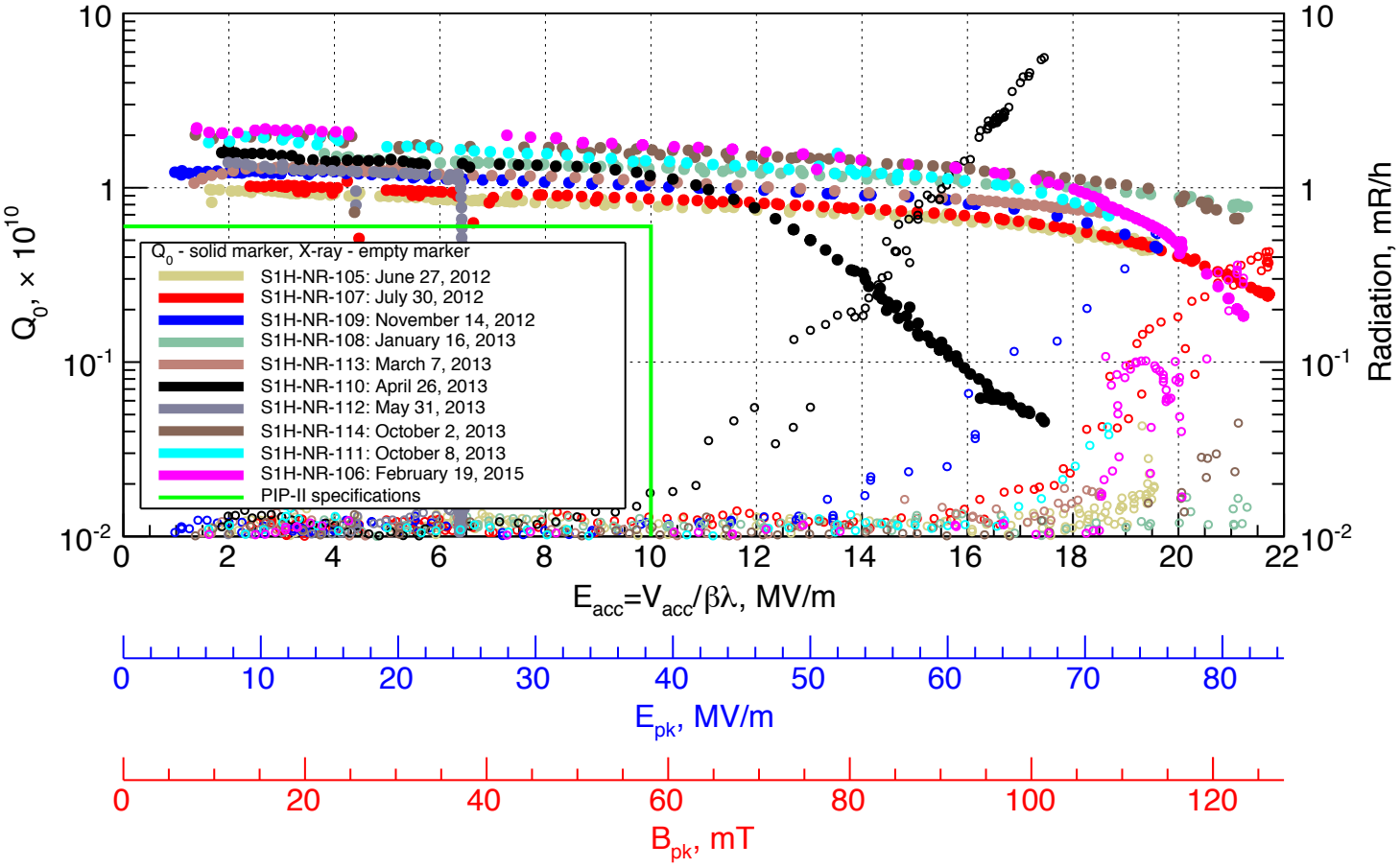
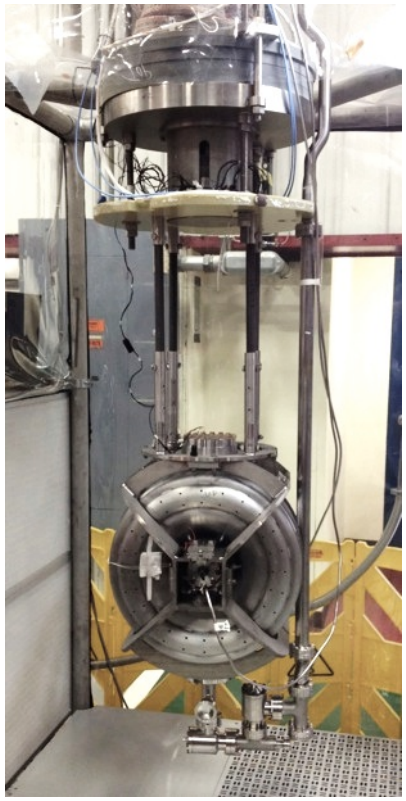
Vertical Test Stand (VTS)

A. Sukhanov

Successful qualification of production cavities for PXIE cryomodule





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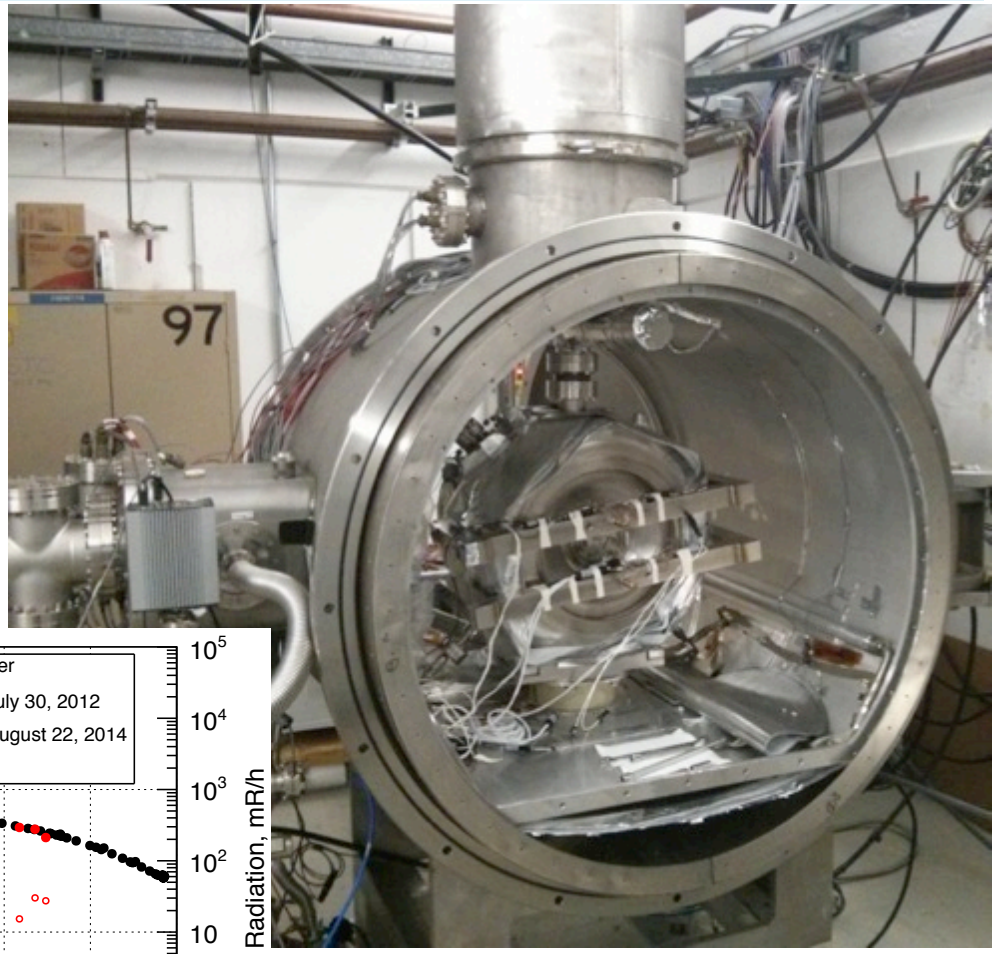
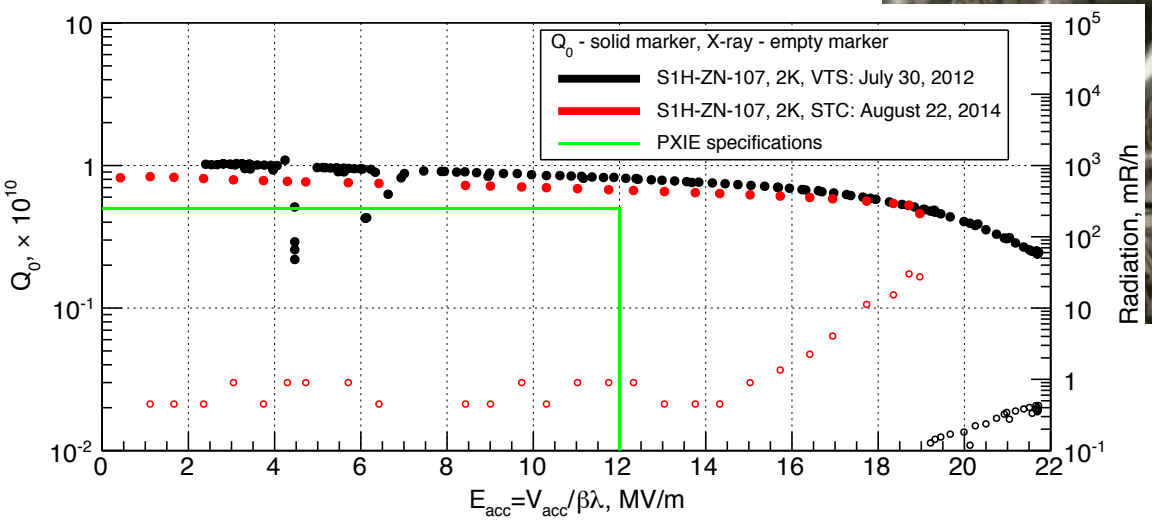
Spoke Test-Cryostat (STC) – S107 Run 1

A. Hocker, A. Sukhanov



Sep-Oct 2014
Successful cold tests of first production SSR1 (S107) and piezo encapsulations



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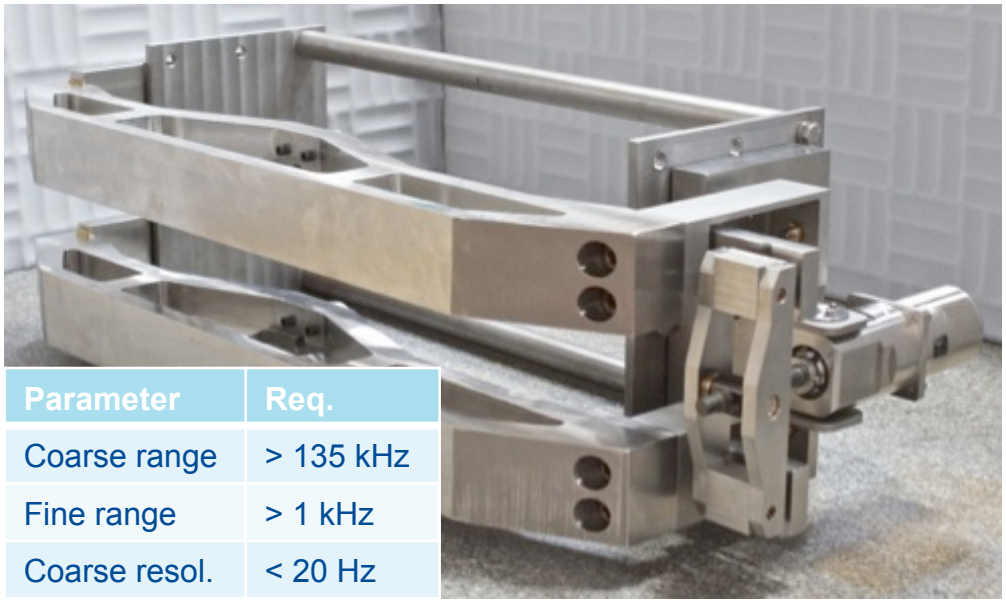
Prototype Tuner

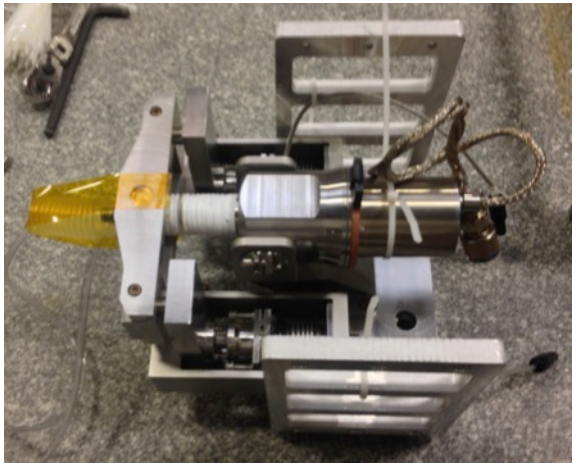
D. Passarelli



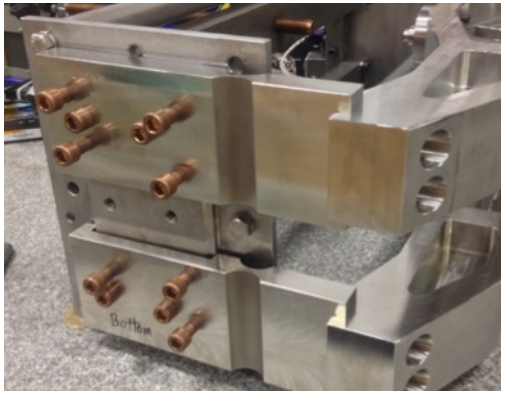
Parameter	Req.
Coarse range	> 135 kHz
Fine range	> 1 kHz
Coarse resol.	< 20 Hz

Piezo encapsulations include bellows for retainment

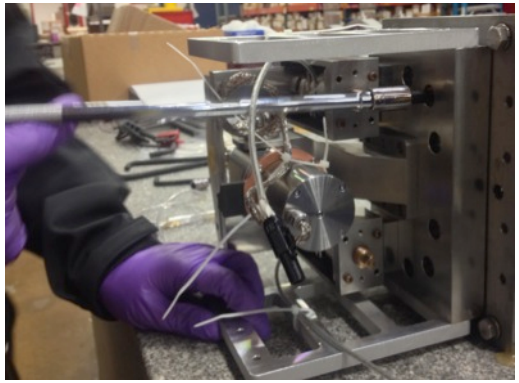
Cartridge with motor and piezos



Alignment system for main arms



Installation of cartridge



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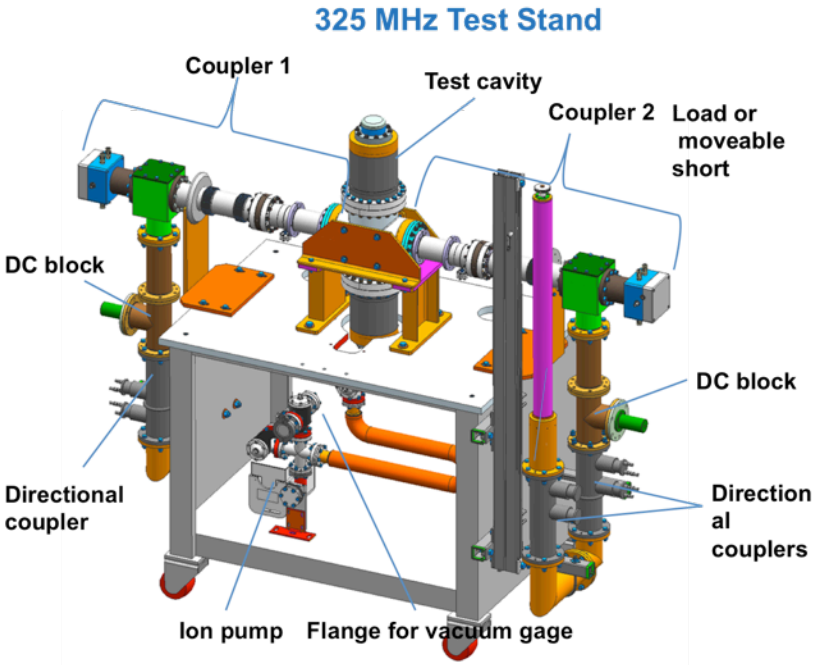
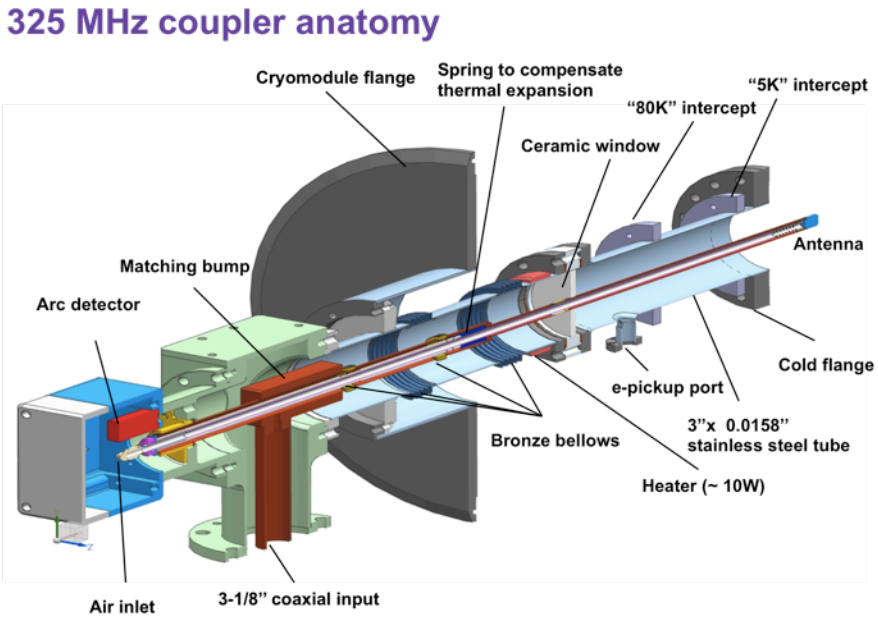
Couplers

- We have 3 prototypes
  - 2 installed on RF test stand, 1 installed on first production cavity in STC
- Design was changed to address several issues
  - upgrade to aluminum seals, increase thickness of electro-deposited bellows,...
- All components for 10 production couplers have been ordered
  - cold-ends are needed for qualification of cavities





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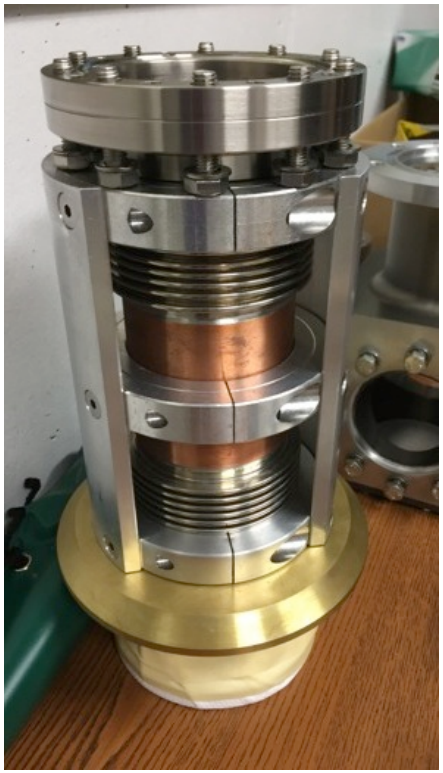
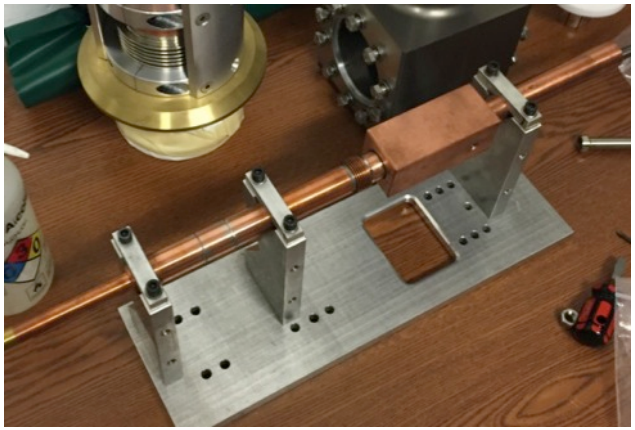
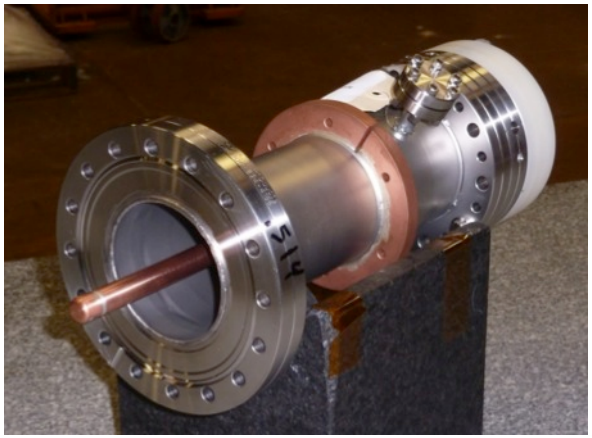
Prototype couplers



Warm Outer conductor
Electro-deposited bellows
(Cu-Ni layers)



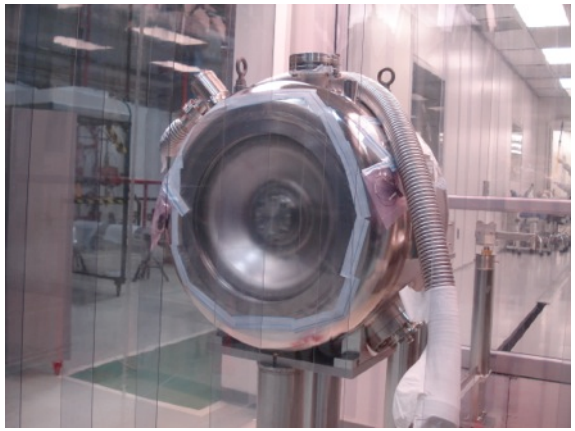
Warm Inner conductor

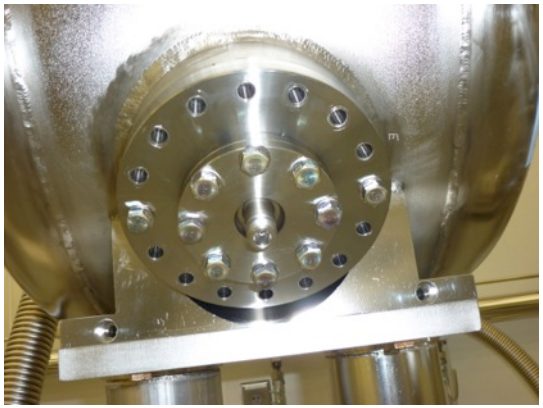


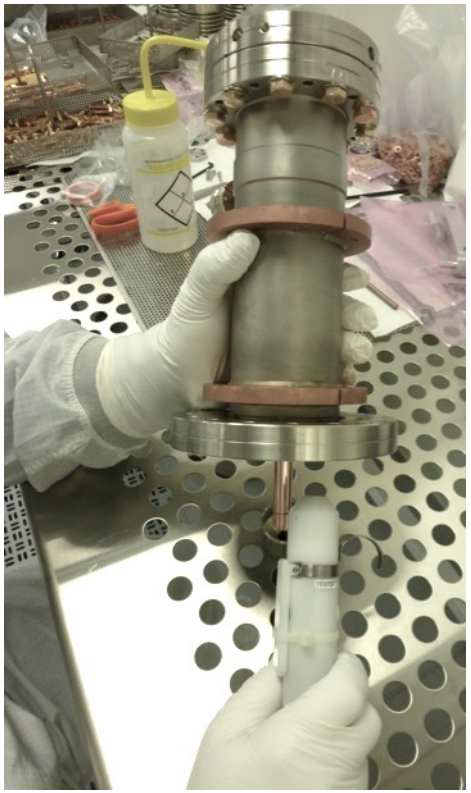
Cold-end assembly

RF test stand

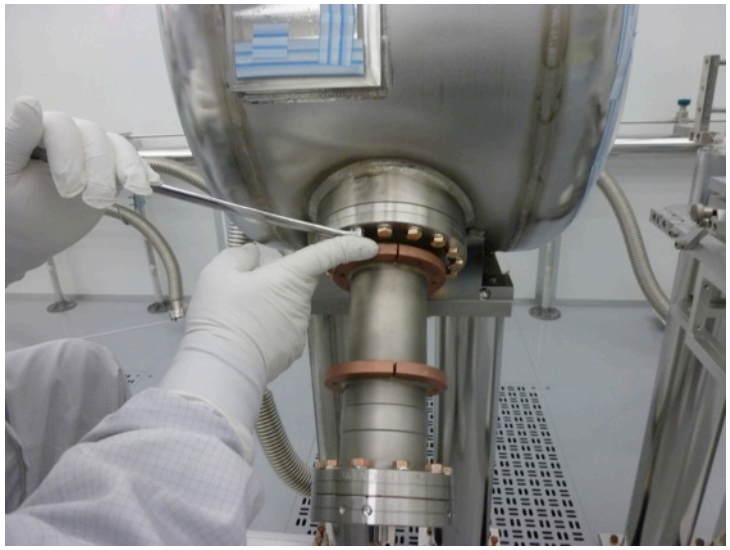
Preparations for Run 2 – Installation of prototype coupler

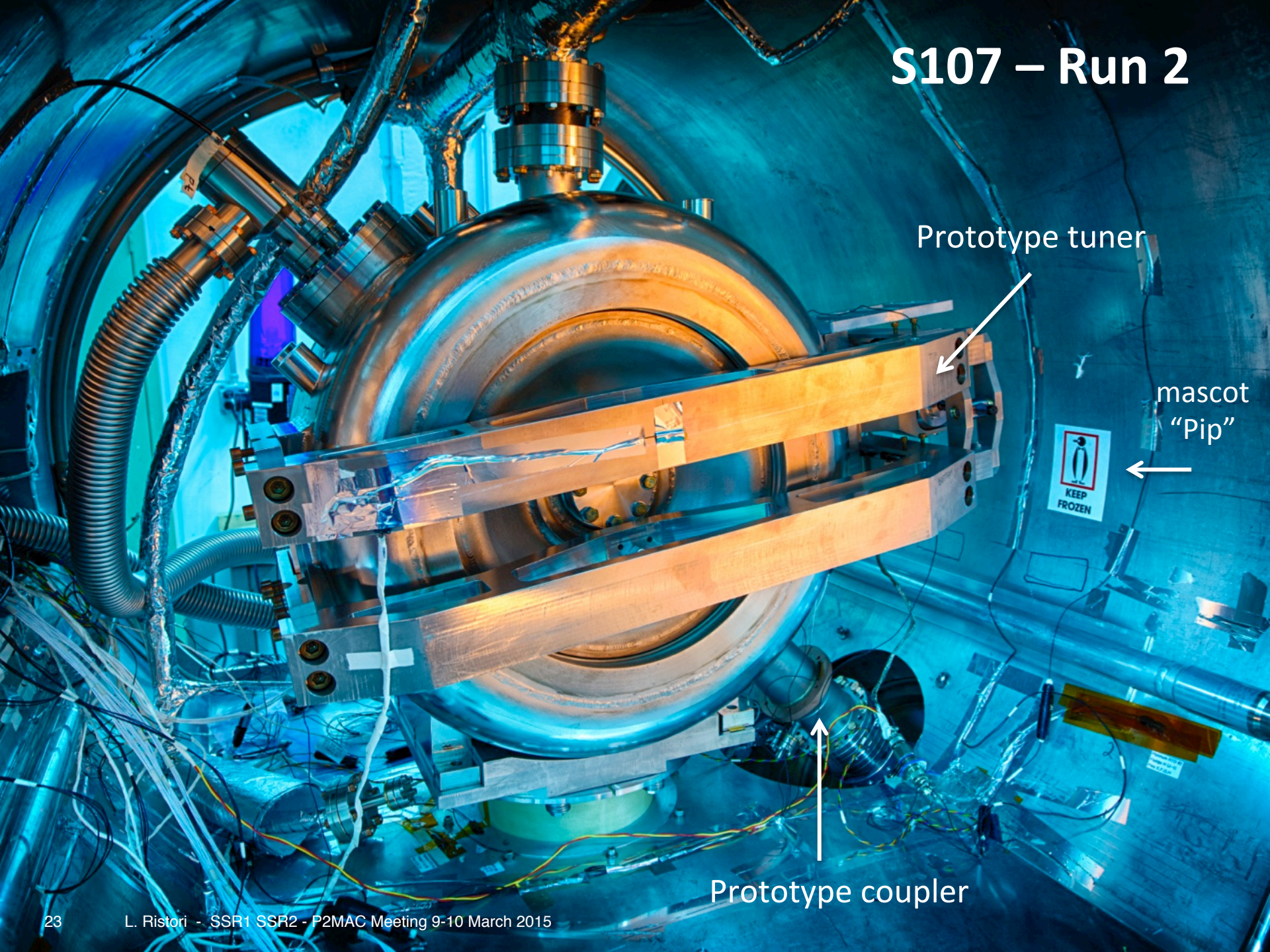




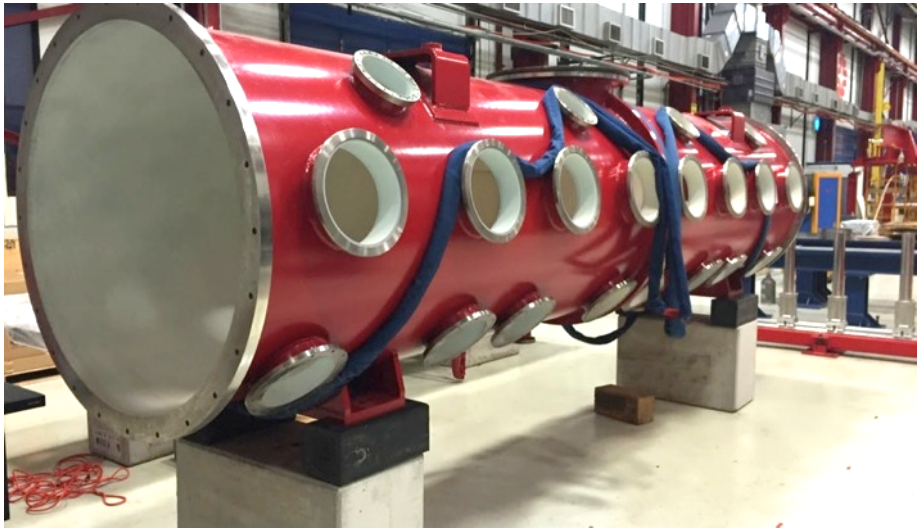


- All work done at MP9
- Unity coupler was replaced with prototype high-power coupler

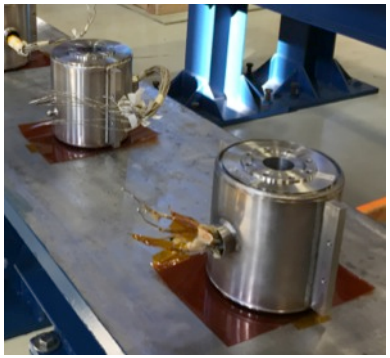



S107 – Run 2
Prototype tuner
mascot
“Pip”
KEEP
FROZEN
Prototype coupler

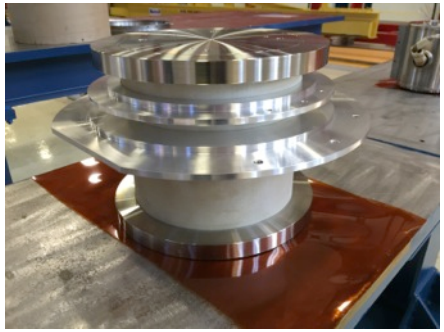
Other cryomodule components received as of today..



Vacuum vessel



Focusing Elements



Support Posts

Strong-back

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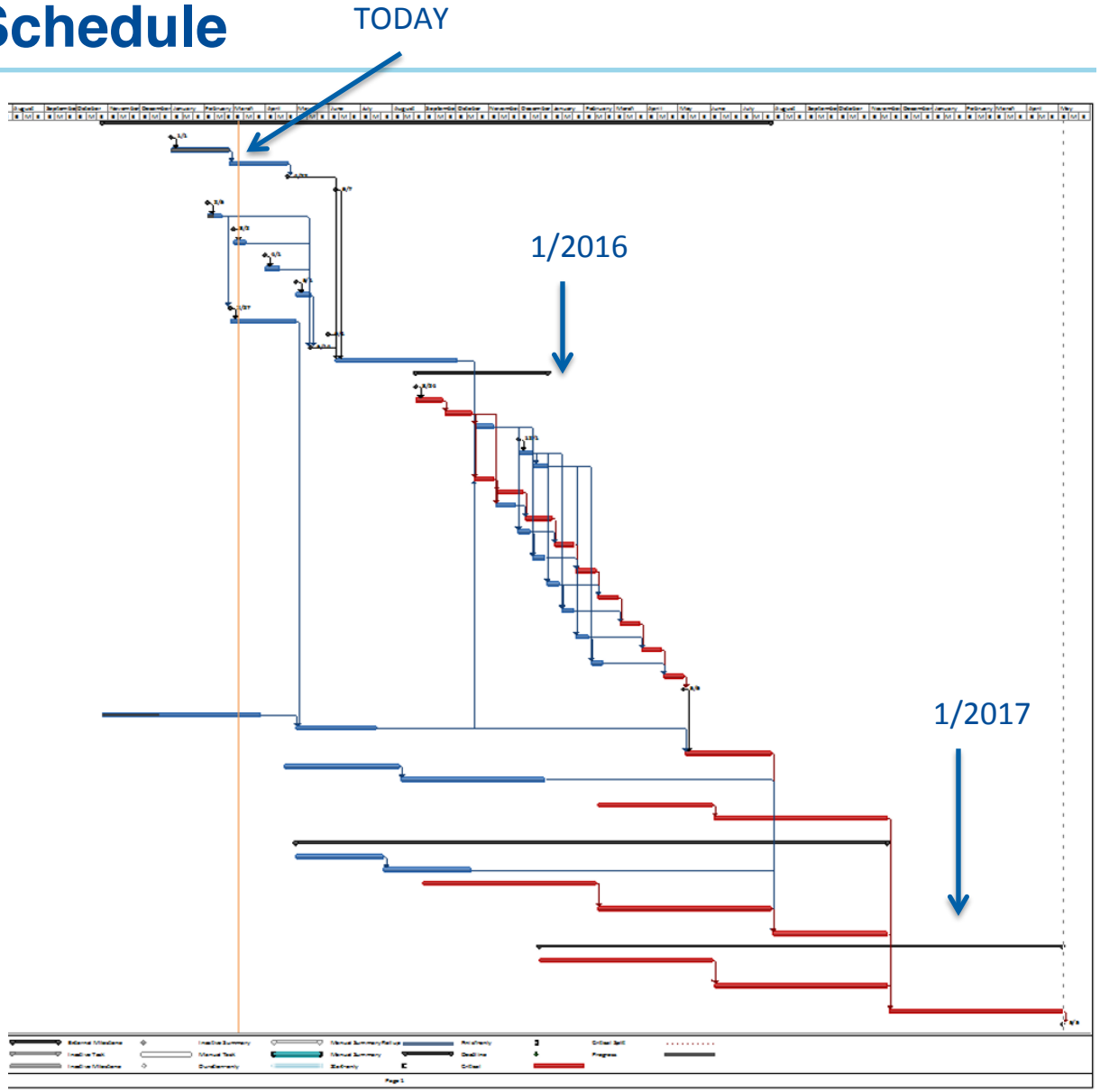
SSR1 Cryomodule Schedule

- String assembly rehearsal
  - July - Aug 2015
- Cav. qualifications
  - Nov 2015 - Apr 2016
- String assembly
  - May - July 2016
- Cold mass assembly
  - Aug - Nov 2016
- Cryomodule assembly
  - Oct 2016 - May 2017



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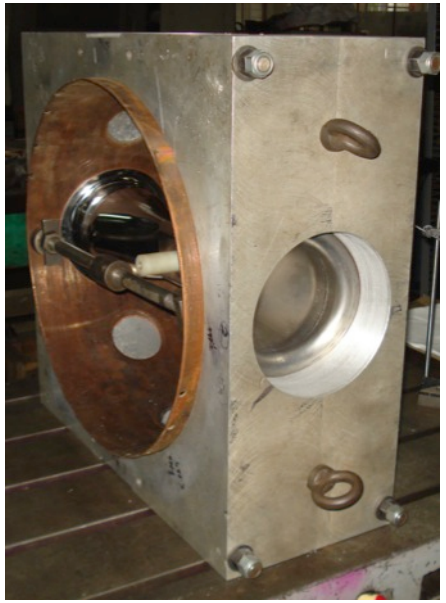
SSR1 - Collaboration with IUAC (New Delhi) – P.N. Prakash

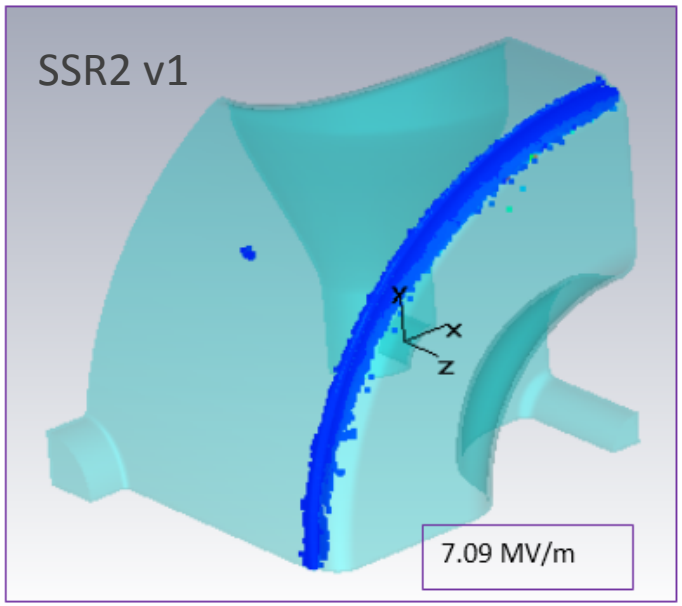
- IUAC is developing 2 SSR1 cavities
- Slightly different process with EP components (intead of BCP)
- Interesting to compare results
- Delivery this year

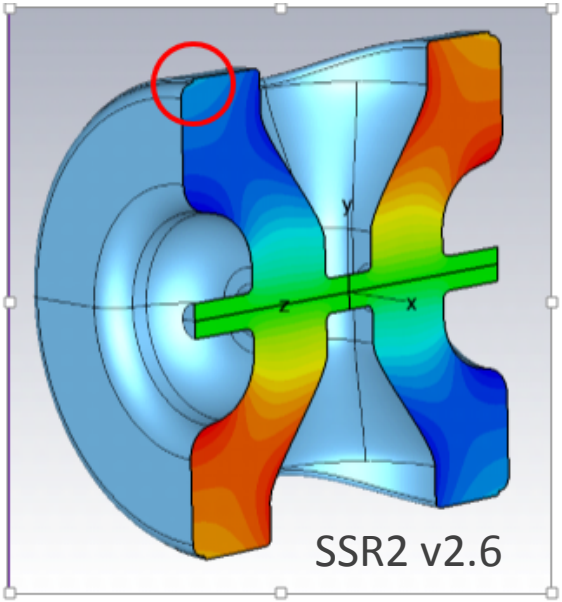


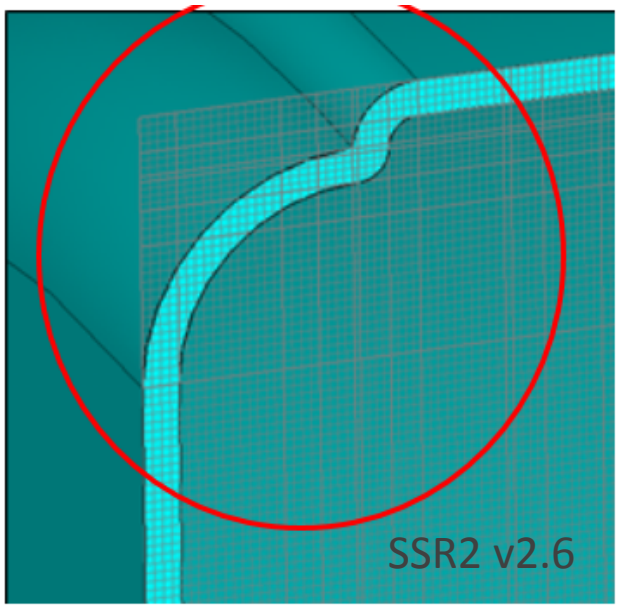
RF Design of SSR2 - Multipacting

P. Berrutti

Most severe multipacting take place near transition of cylindrical part to end walls. Several design options of this transition was considered. Most significant improvement was achieved after introducing additional step in the transition are.







Modification of this transition reduce multipacting in operating range of cavity fields.

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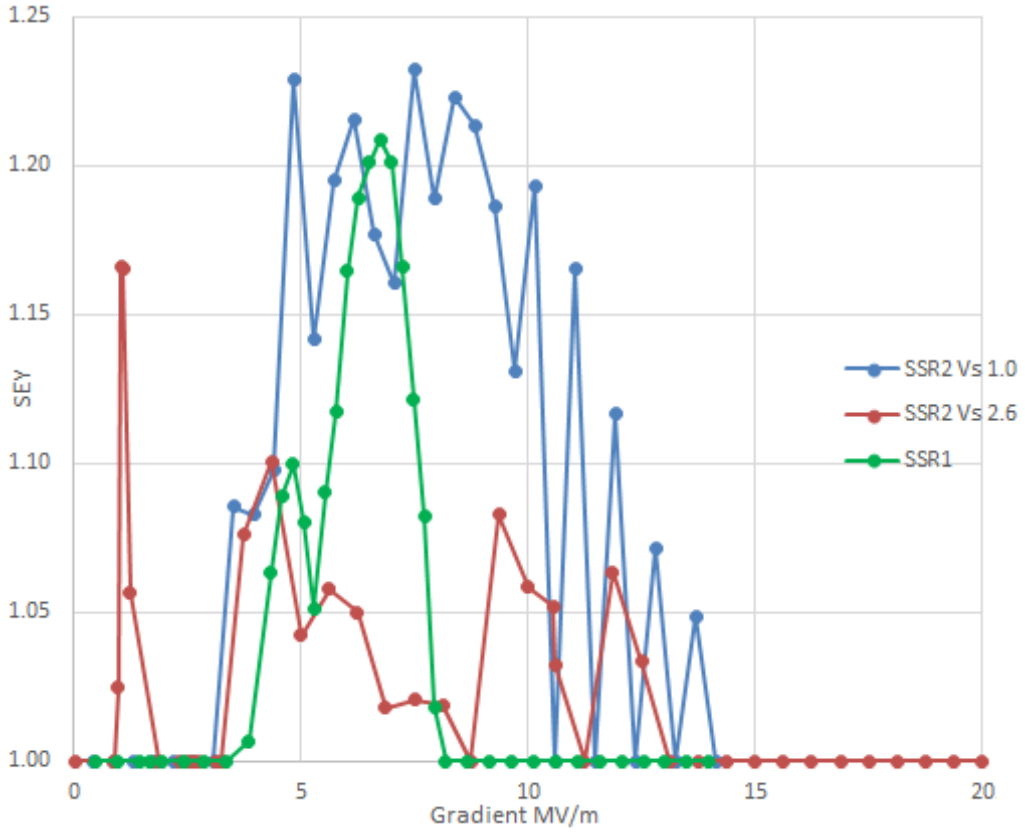
SSR2 - Multipacting SEY comparison

P. Berrutti



Parameters	SSR2 v1	SSR2 v2.6
Optimal beta	0.471	0.475
Epeak/Eacc	3.45	3.69
Bpeak/Eacc [mT/(MV/m)]	6.107	5.95
G [Ohm]	112.98	114.9
R/Q [Ohm]	289.94	295.6

Secondary Emission Yield (SEY)significantly reduced in the operating gradient range of 5-12 MV/m. Comparison with SSR1 cavity demonstrates that multipacting in the modified SSR2 cavity version 2.6 can be processed away easier than in SSR1 cavity.

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Summary

- Production of SSR1 cryomodule has begun
  - All bare cavities tested successfully
  - 1st Jacketed cavity tested successfully
  - Prototype coupler and prototype tuner under testing
  - All bare solenoids tested successfully
  - Large components received
- SSR1 cryomodule estimated to be completed in May 2017
- IUAC will deliver (2) SSR1 cavities to FNAL
- Design of SSR2 recently changed to address MP

Thank you ...

Backup Slides

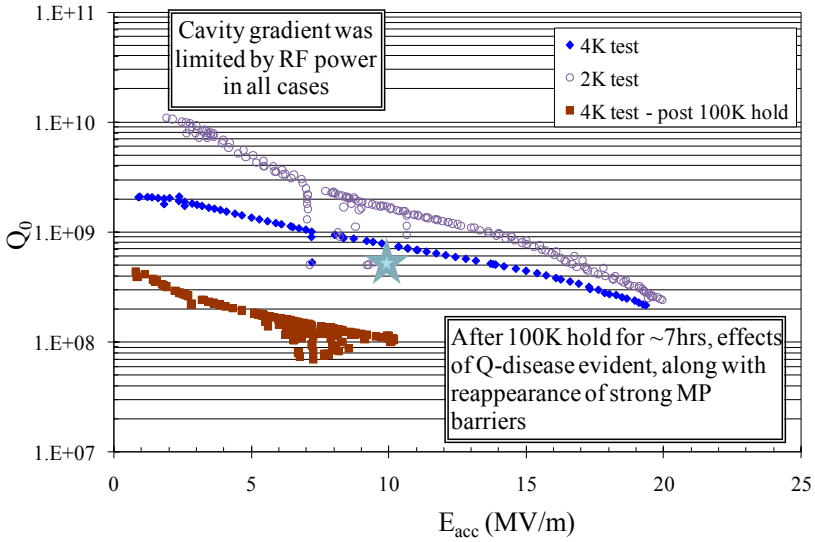
SSR1 Prototypes – VTS tests

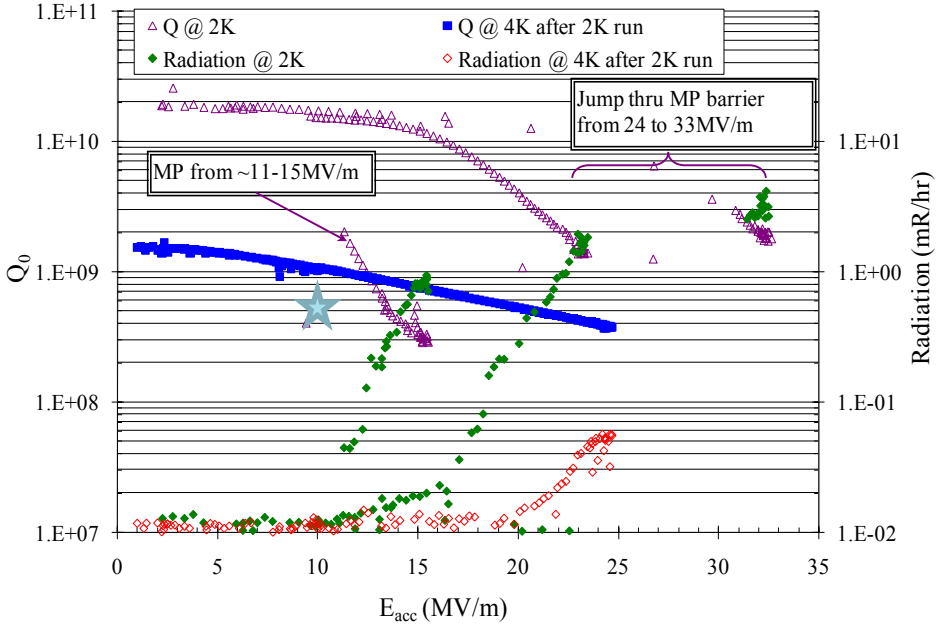
S101 – 4th test

- During cool down, a 7 hr hold at 100 K produced a large Q0 drop, confirming **Q disease.**
- Subsequently baked SSR1-01 at 600 C for 10 hours at Jlab.

S102 – 1st test

- Effects of Q disease should not appear on first cooldown.
- X-rays increase at MP barriers, then disappear after punch through.





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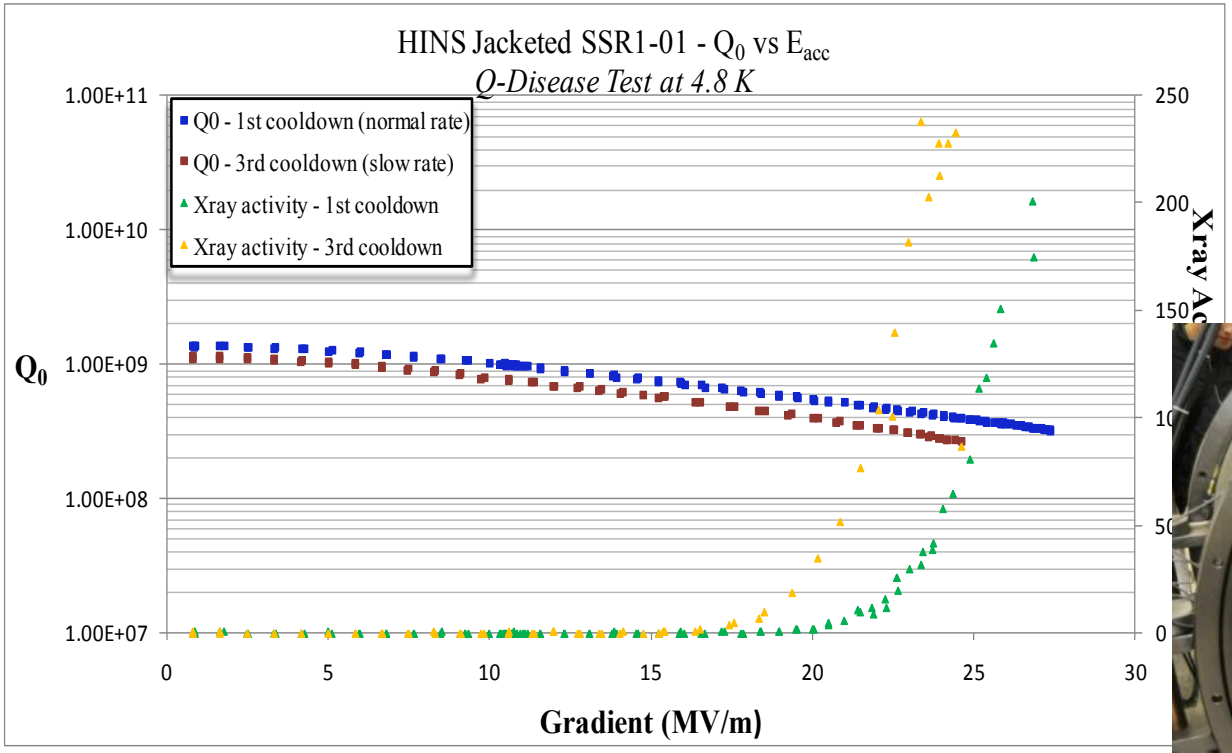
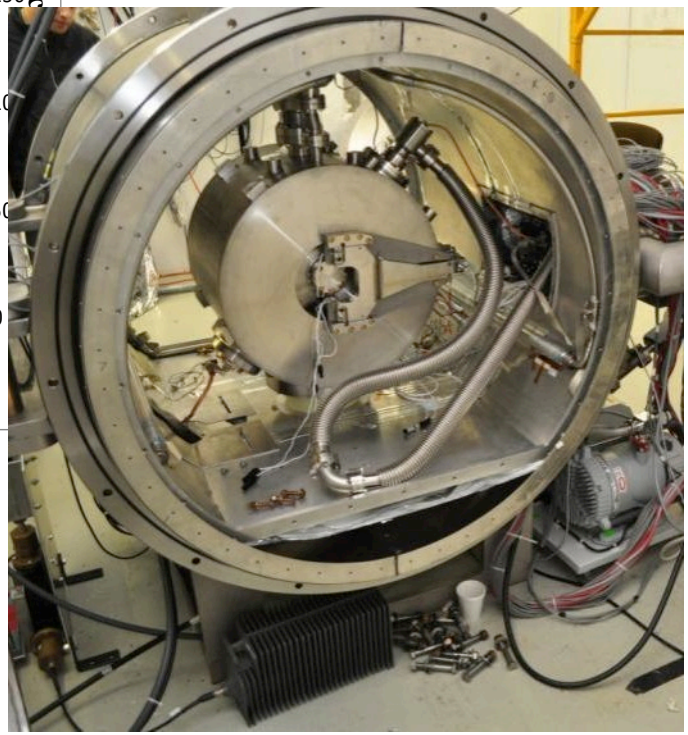
SSR1 Prototype – STC Tests





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- Assembly procedure
- Meeting the technical specification
- Feature of interest

SSR1 Tuner: Requirements and data

Parameter	*Value*	*Notes*
Total Frequency Range	> 135 kHz	From FRS
Frequency Resolution of stepper motor	< 20 Hz	From FRS
Piezo Frequency Range	> 1 kHz	From FRS
Tuner Passive spring constant	30 kN/mm	Derives from df/dP requirement
Sensitivity of end-wall	540 kHz/mm	Simulation/Experimental
Cavity wall spring constant (K_{cav})	30 kN/mm	Simulation/Experimental

Parameter	*Value*	*Notes*
Stepper motor max force	± 1300 N	Symmetrical
Stepper motor resolution*	0.1 μm (100 nm)	At interface with 2nd lever
Piezo stroke @ RT	64 μm ± 2%	Measured
Piezo stroke @ operating T	15μm (25% of RT)	
Piezo max rated force	3360-5040 N	4200 N ± 20% (blocking force)
Piezo max operating force	2688 N	3360 · 80%

Parameter	*Value*	*Notes*
Motor Travel at beam pipe	> 0.25 mm	135/540 kHz
Piezo Travel at beam pipe	> 1.85 μm	1/540 kHz
Maximum Force at beam pipe	7500 N	0.25 mm · 30000 N/mm
Motor Resolution at beam pipe	< 37 nm	20/540000 mm
Motor Tuning Efficiency (Te)	< 37 %	37/100 nm
Motor Mechanical Advantage (M)	> 5.8	7500/1300 N, **picked 6**
Piezo Tuning Efficiency (Te)	> 12 %	1.85/15 μm
Piezo Mechanical Advantage (M)	> 1.4	0.5* · 7500/2688 N, **picked 2**
Piezo Elastic Efficiency (E)	> 24 %	2 · 12 % (Te · M)

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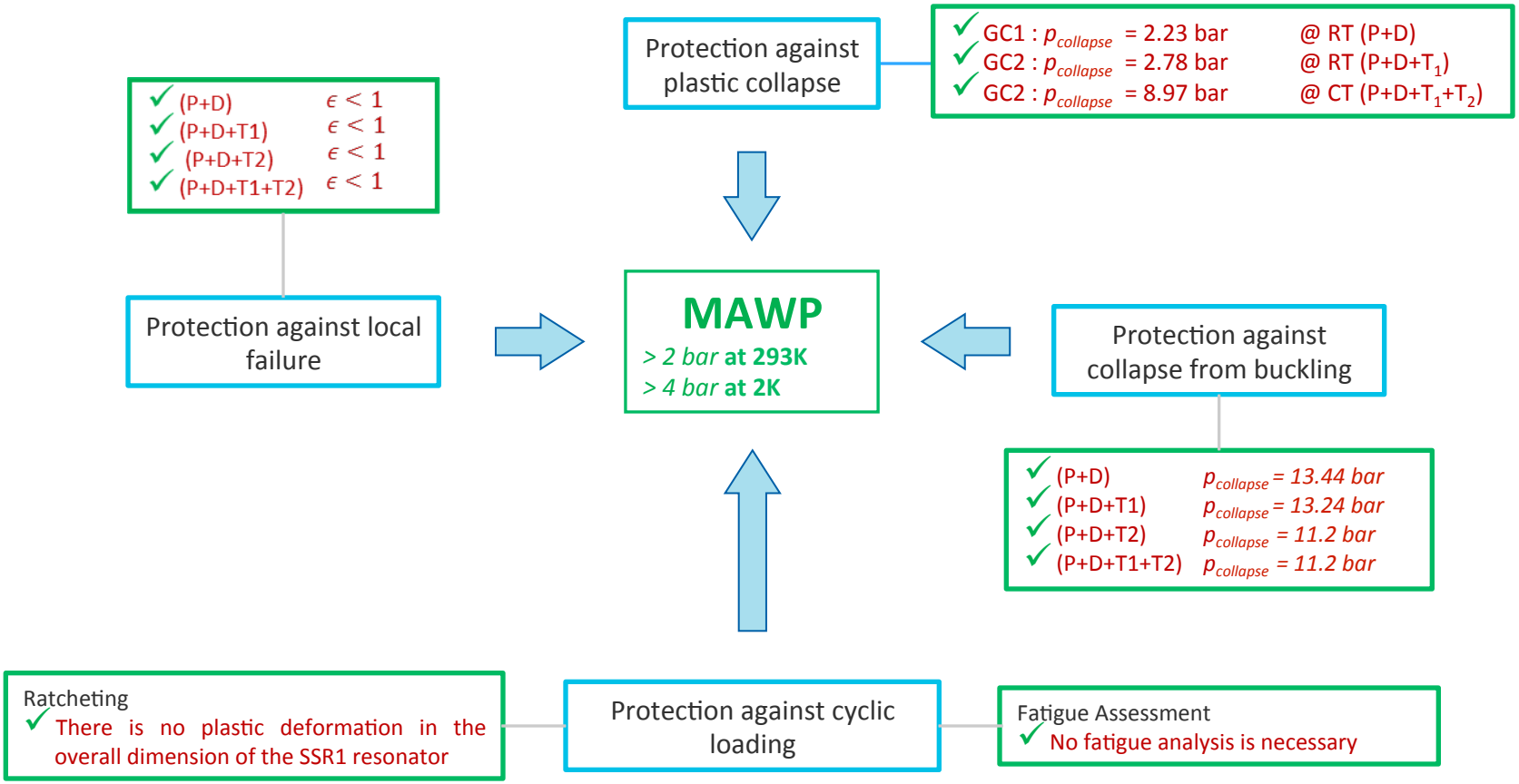
ASME Pressure Rating

D. Passarelli

The table summarizes the results obtained by simulations performed following the Div 2, Part 5 directions. It **shows** that the desired MAWP is achieved both at RT and CT.



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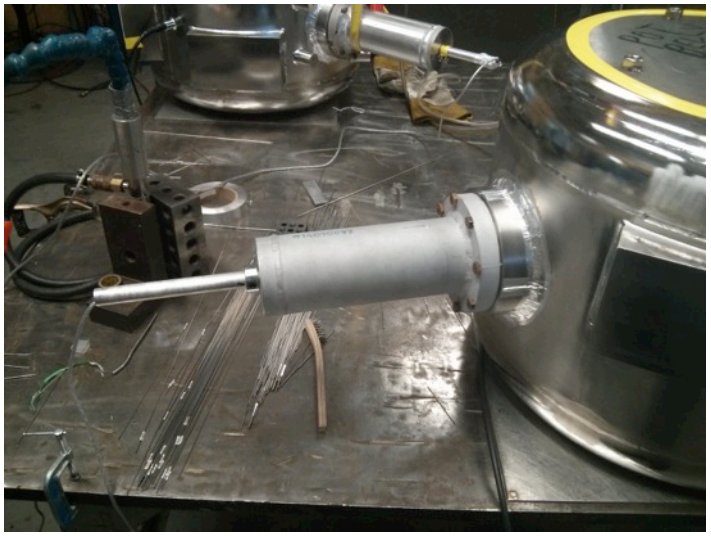
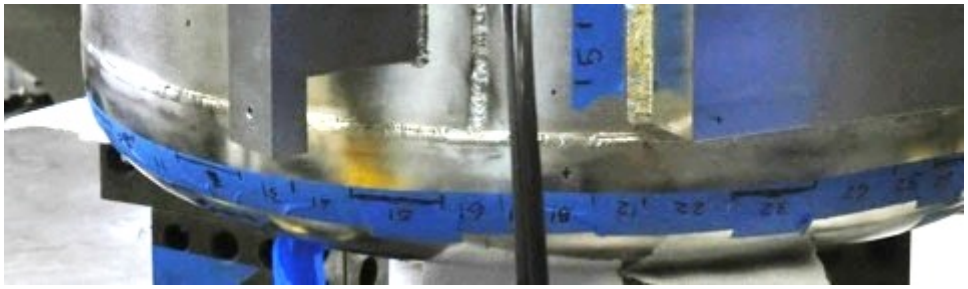
Jacketing operations

D. Passarelli, M. Hassan, P. Berrutti



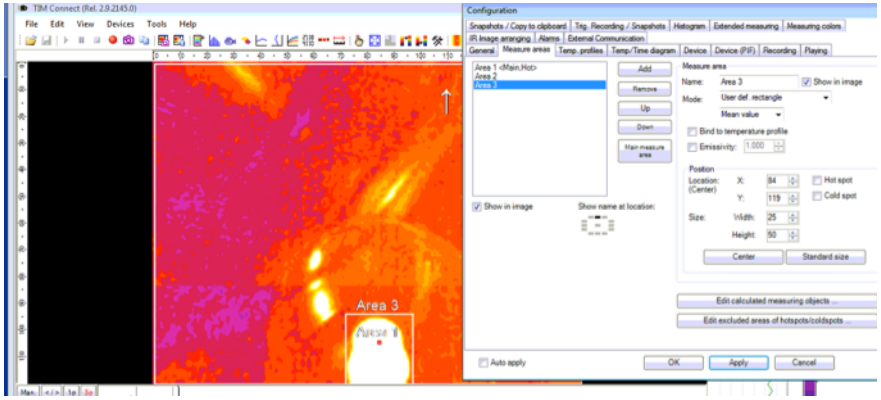
Thermal cameras insertion tubes (above)



Welding inch-by-inch on 6 mm thick steel

Large fixtures needed to control warping

Screenshot of remote connection from FNAL



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