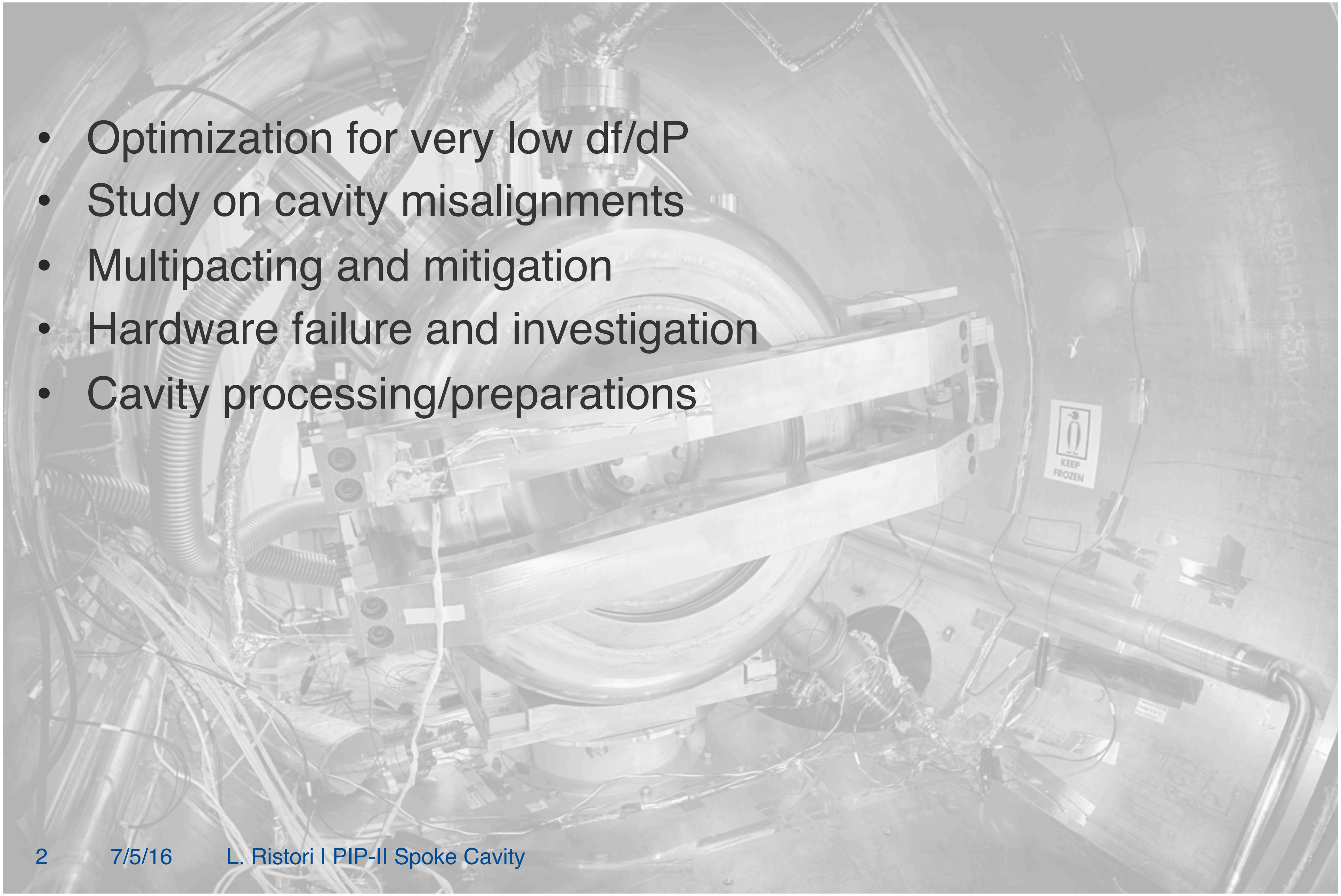
PIP-II Spoke Cavity Technical Issues

Leonardo Ristori

Meeting Title

Day Month Year

Outline



- Optimization for very low df/dP
- Study on cavity misalignments
- Multipacting and mitigation
- Hardware failure and investigation
- Cavity processing/preparations

Achieving Very Low df/dp

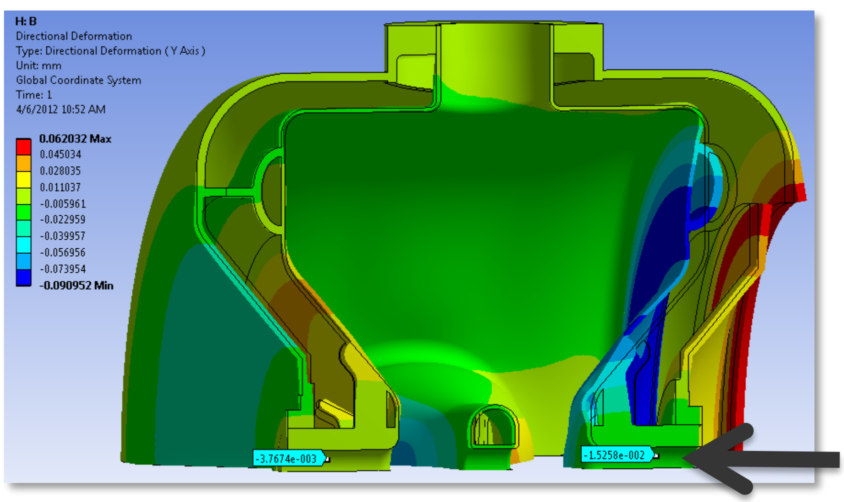
A self-compensating design was developed allowing low sensitivity

- Sensitivity of spoke resonators is typically large, large+weak end-wall with high electric fields → SSR1= 540 Hz/μm
- When shooting for 5 Hz we are dealing with 1 nm !

Despite non-negligible deformations (30-90 μm), net shift is very low thanks to Slater's Theorem

- Bare cavity ~ -650 Hz/Torr,
- Prediction with He vessel **-2 Hz/Torr** (no tuner), with infinitely rigid tuner **6 Hz/Torr**

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



Tuning Side

Work by Donato Passarelli

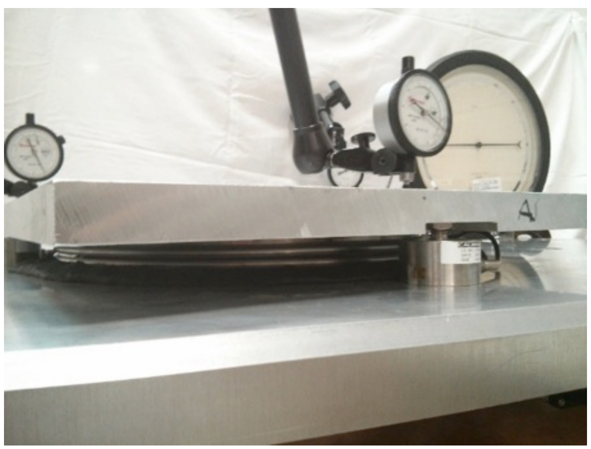
Methods used to balance deformations:

1. Diameter of bellows optimized to counteract Helium pressure on cavity end-wall.
2. Opposite end-wall coupled with vessel

Fermilab PIP-II

Bellows characterization and pairing

- SSR1 designed with large bellows D ~350mm
  - Just 1 mm error on diameter of bellows causes a pressure change on cavity which accounts for ~ 4 Hz/Torr
  - Formed bellows do not have high precision on convolutions
  - All bellows were characterized to make the best pairing with cavities



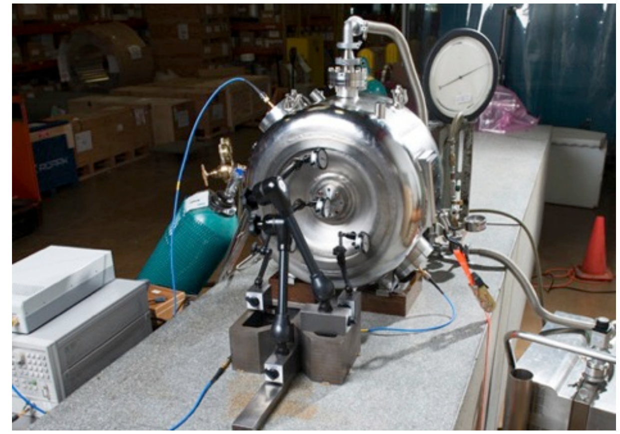
Work by Donato Passarelli

SSR1 Cavities: pressure sensitivity

Room temperature measurements on bare and jacketed SSR1 resonators showing the influence of manufacturing variations on the value of df/dP.

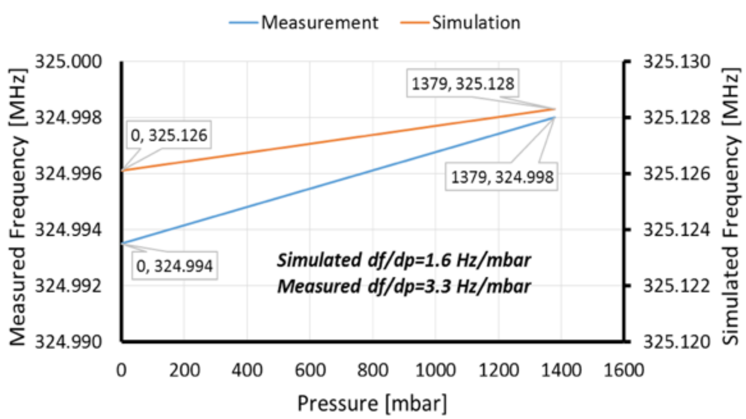
Bare cavities df/dp = 550 ± 20 Hz/Torr

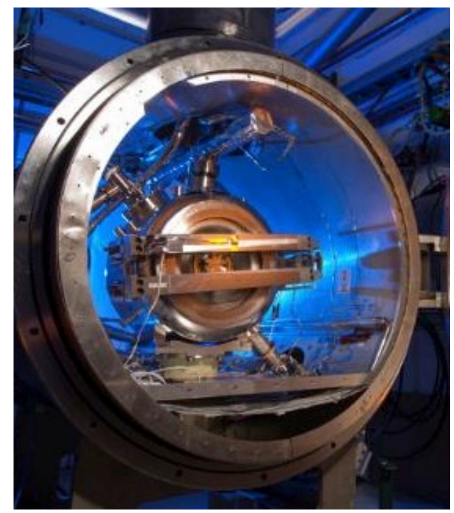
Jacketed cavities df/dp = 4 ± 5 Hz/Torr



	df/dp [Hz/Torr]	S106	S107	S108	S109	S110	S111	S112	S113	S114
Measured	Bare cavity (with transition ring)	-564	**-561**	-553.5	-555.1	-568.8	-525.8	-524.6	-544.7	-557.2
Measured	With He Vessel (without Tuner)	8	**8**	-1.2	5.4	7.9	2.7	9.0	6.3	10
	Fully integrated	4*	**4**	0*	2*	4*	2*	5*	3*	5*

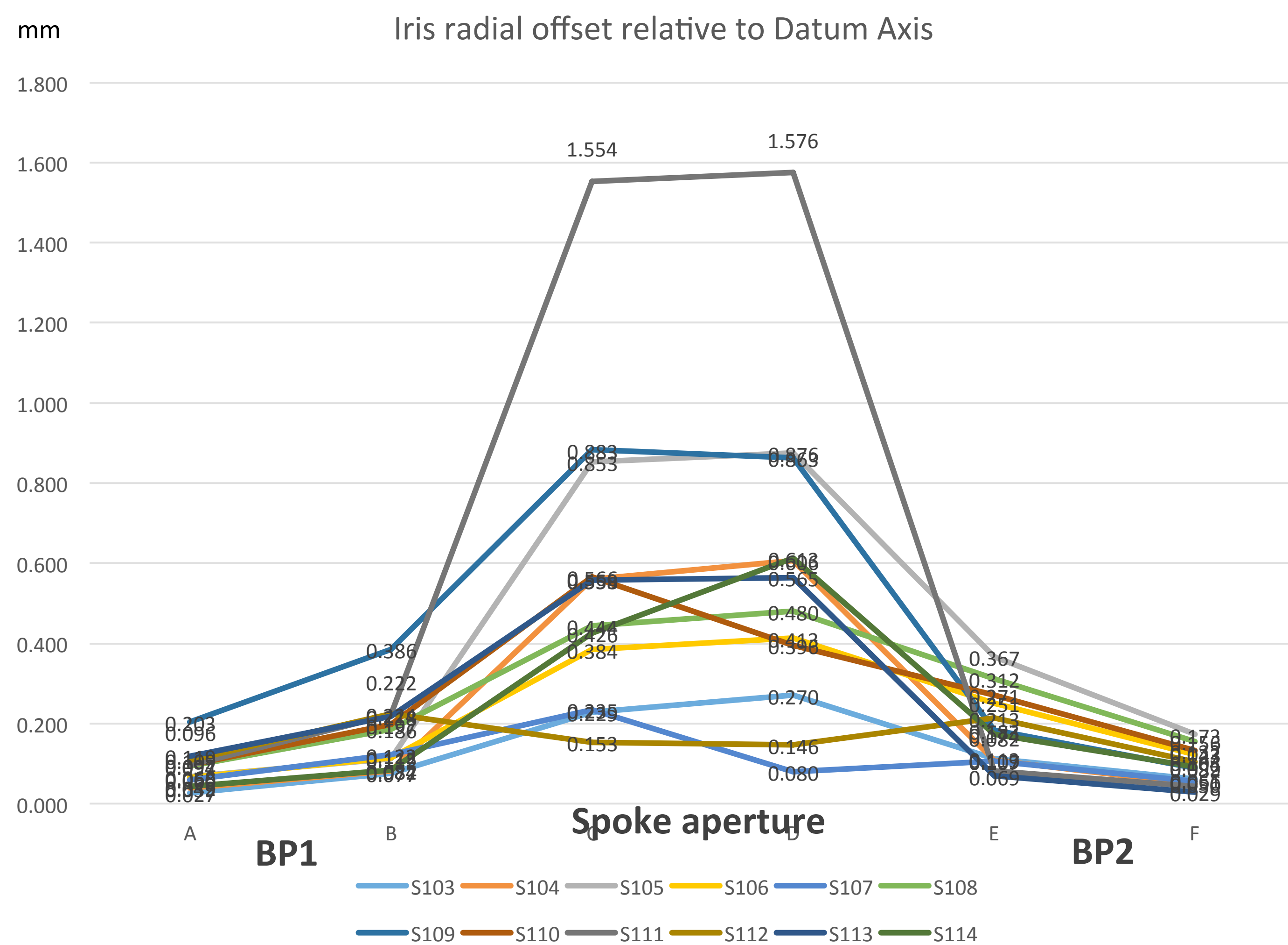
* Not measured yet (best guess)





Work by Donato Passarelli

Geometrical Misalignments in Spoke Cavities



Work by L. Ristori

Electrical-Geometrical Axis Offsets

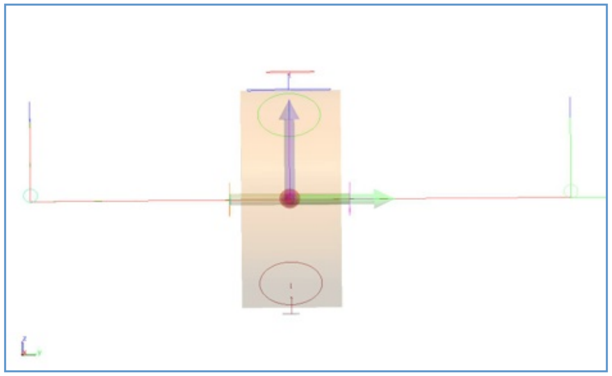
- Alignment data refer the electric center line to the mechanical center, defined as the center of the two beam ports.
- Most cavities have offsets within 0.5mm
- One cavity has offset of > 2mm (we studied this conservatively)

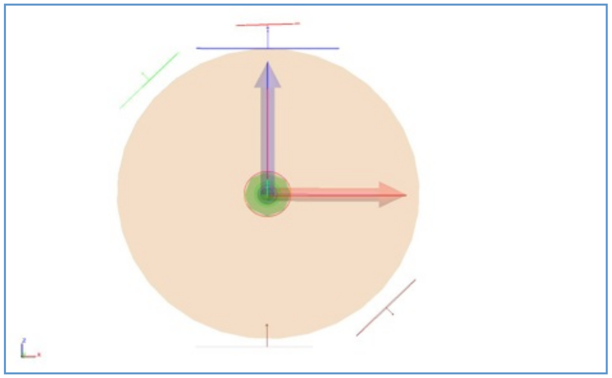
SSR1-111 alignment data

The local coordinate system has the following axes orientation:
Origin = Cavity Center (midpoint between Flanges and on Electrical Axis)
X = positive beam right when looking downstream beam line
Z (stationing) = positive downstream beam line - line built on Electrical Centers
Y = positive upward when looking downstream beam line (and orthogonal to the beam)

NAME	X [mm]	Z [mm]	Y [mm]	Comments
STAGE_B_WIRE	0.351	-627.087	0.414	UPST Wire Stage
Bead UPSTRM	0.000	-146.111	0.000	Electrical Center
UPST-Flange_Ctr	0.035	-145.703	**-2.082**	Mechanical Center
S1H-NR-111-A_LL3	-130.736	-102.919	300.685	Fiducials
S1H-NR-111-A_LL4	129.106	-101.993	300.692	Fiducials
S1H-NR-111-A_LL8	-149.073	-62.977	294.864	Fiducials
S1H-NR-111-A_LL7	-297.641	-62.306	146.304	Fiducials
S1H-NR-111-A_CT	0.000	0.000	0.000	Origin
S1H-NR-111-A_LL6	-150.053	56.931	295.932	Fiducials
S1H-NR-111-A_LL5	-298.672	57.577	147.296	Fiducials
S1H-NR-111-A_LL1	-132.327	96.717	302.449	Fiducials
S1H-NR-111-A_LL2	127.642	97.999	302.458	Fiducials
Bead DNSTRM	0.000	144.905	0.000	Electrical Center
DNST-Flange_Ctr	-2.455	145.704	**0.531**	Mechanical Center
STAGE_A_WIRE	-0.340	680.927	0.573	DNST Wire Stage

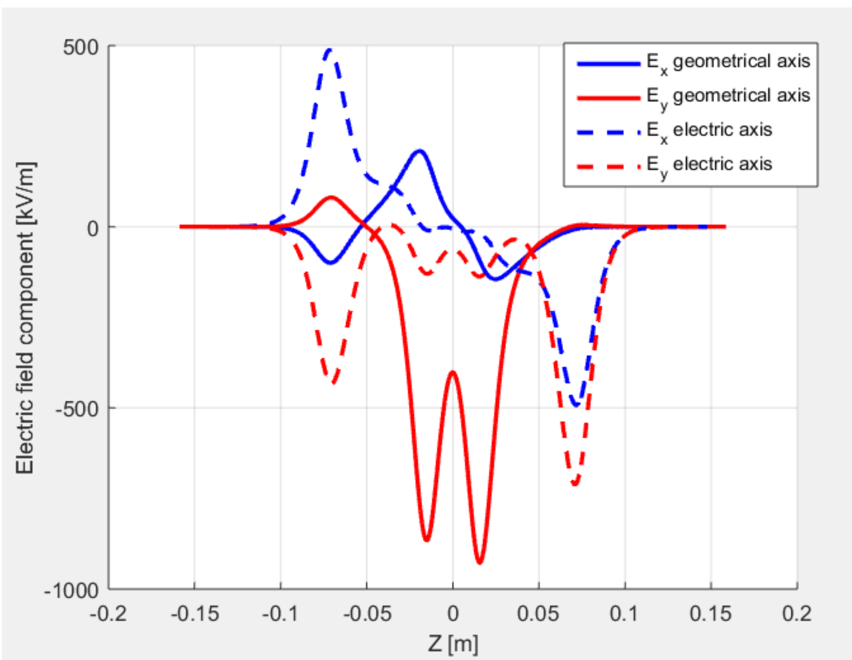
Courtesy of V. Bocean

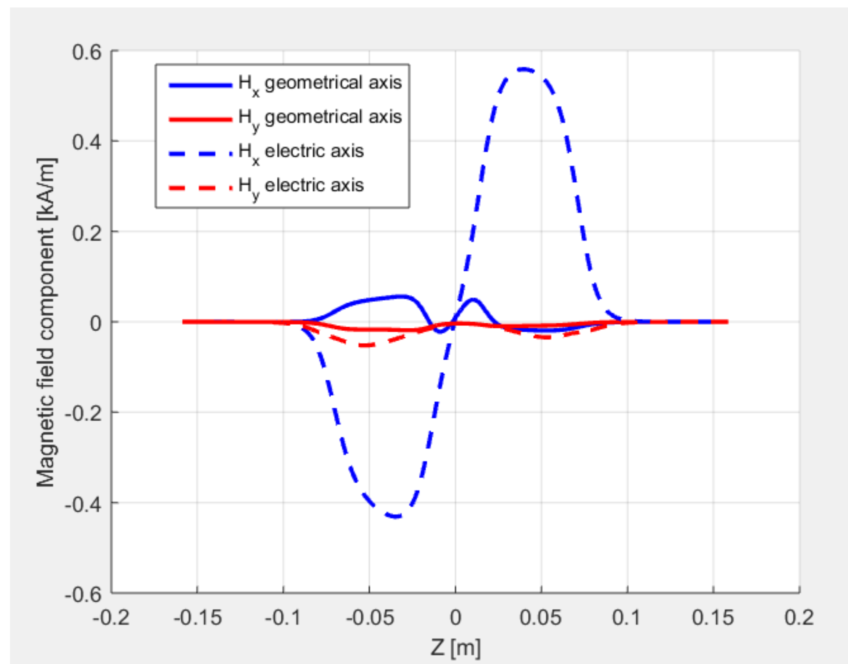




Transverse Fields on geometrical and electric center

- The transverse fields amplitude on cavity axis are zero for an ideal cavity, the misalignments introduce a field perturbation on both transverse axes.
- Transverse fields on cavity axis are shown below (for S111), the electric field is on the left, the magnetic on the right, dashed lines represent fields on the electric axis, the solid lines represent fields on geometrical axis.

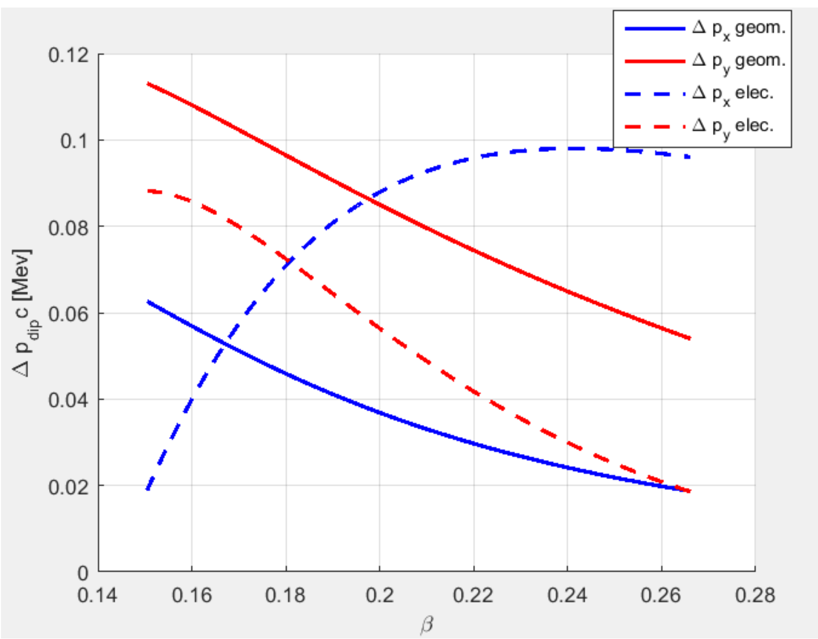


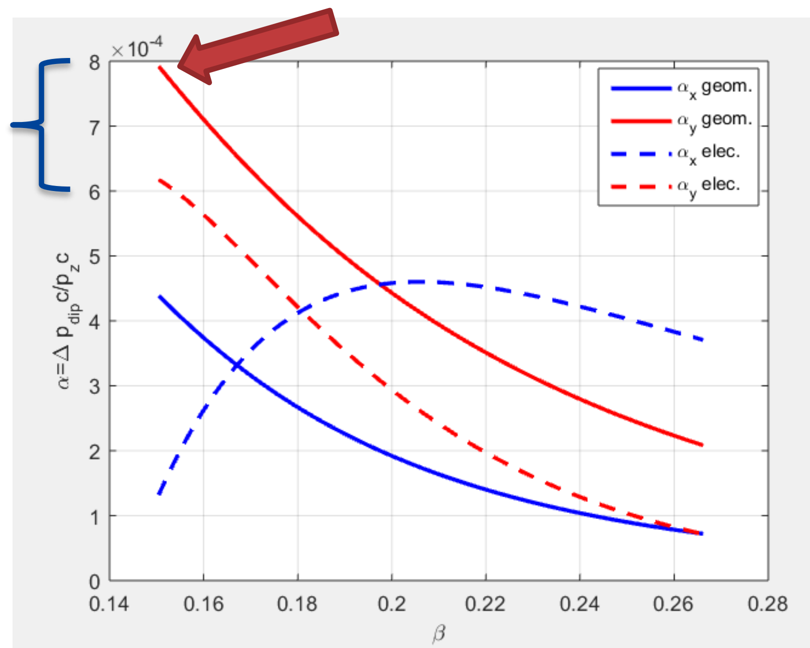


Work by Paolo Berrutti

Kick and Momentum Gain

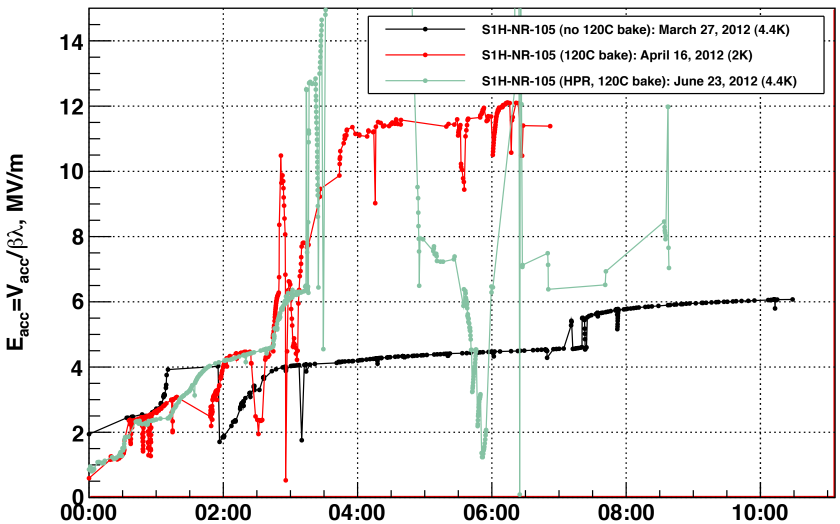
- Transverse kick (left) and $\Delta p_{\perp}/p_z$ (right) have been plotted for the SSR1 section of PIP-II using particle beta and synchronous phase from the lattice design. The energy gain per cavity is kept at its maximum.
- The maximum Transverse Momentum Gain $\Delta p_{\perp}/p_z$ (≈ 0.8 mrad) occurs at the beginning of the SSR1 section, it should not be a problem since the dipole corrector can manage easily ≈ 10 mrad (10 times more).
- Alignment of cavities on the electric axis creates a reduction in aperture, <u>alignment to the geometric axis was the chosen option.</u>

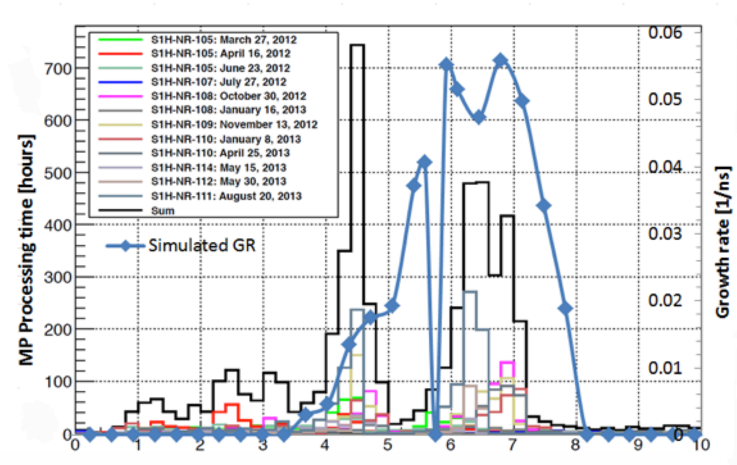




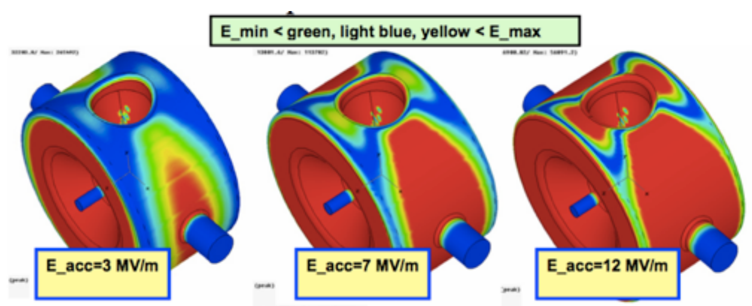
Work by Paolo Berrutti

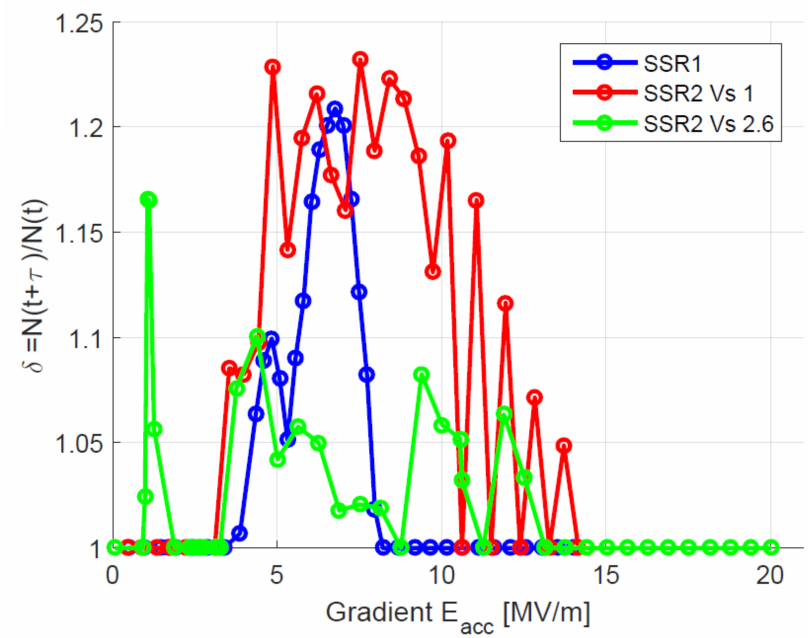
Multipacting in Spoke Resonators





Multipacting was simulated in SSR1 cavities for PIP-II, the results of SSR1 simulations have been compared with experimental data and the agreement seems very good.

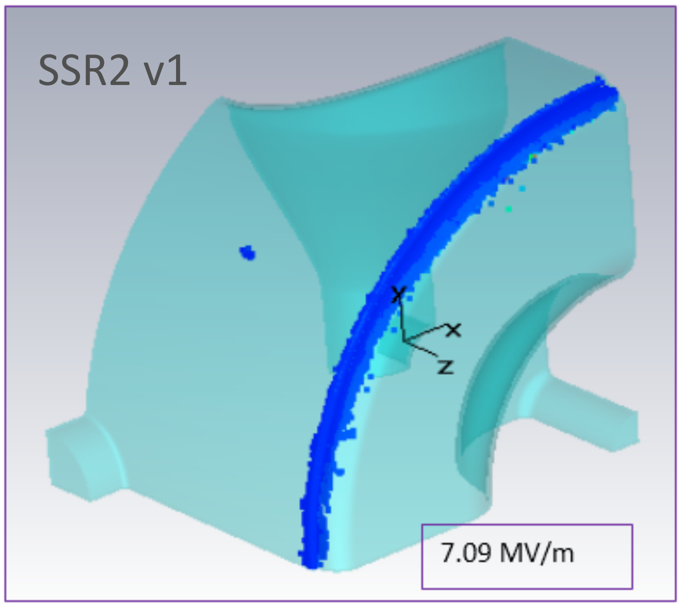


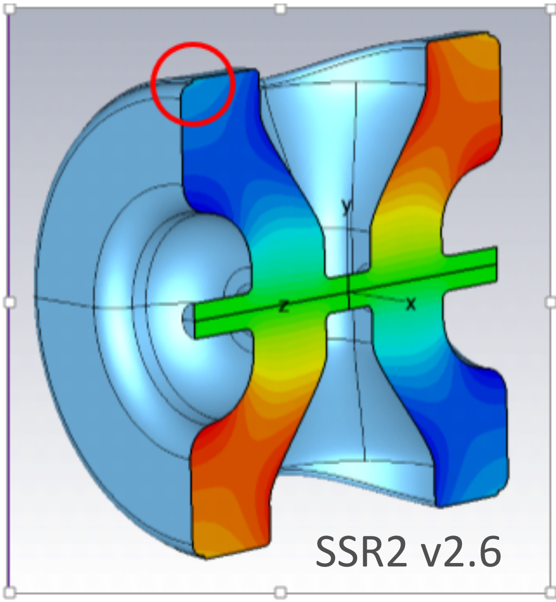


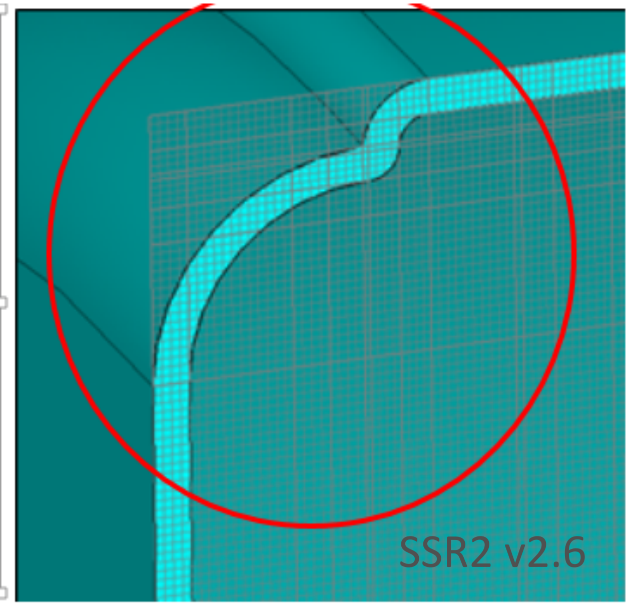
Simulation of Multipacting in SC Low Beta Cavities at FNAL, G. Romanov et al., Proceedings of IPAC 2014, Richmond, VA, USA
Multipacting Simulations of SSR2 Cavity at FNAL, P. Berrutti et al., Proceedings of NA-PAC 2013, Pasadena, CA, USA

Multipacting mitigation

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





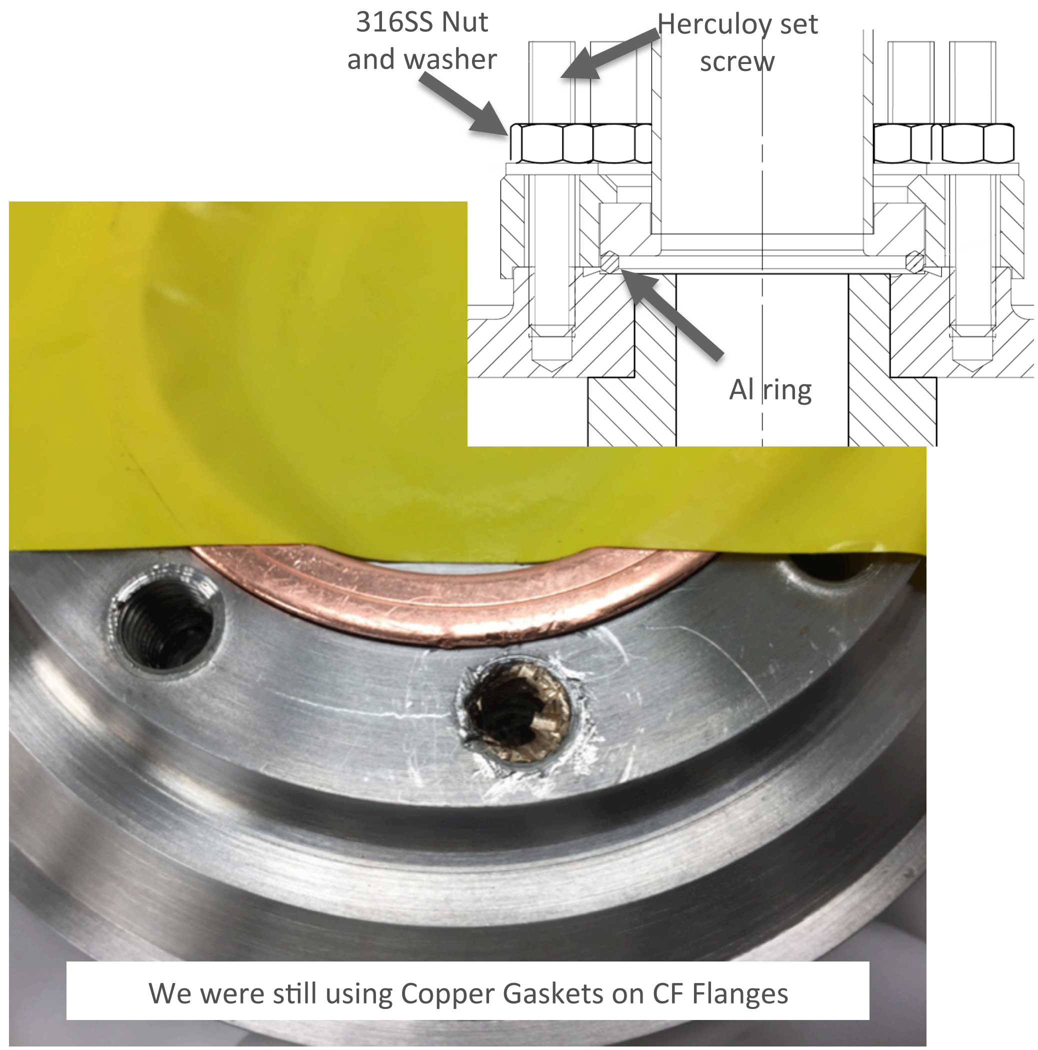


Modification of this transition reduces multipacting in operating range of cavity fields.

Work by Paolo Berrutti

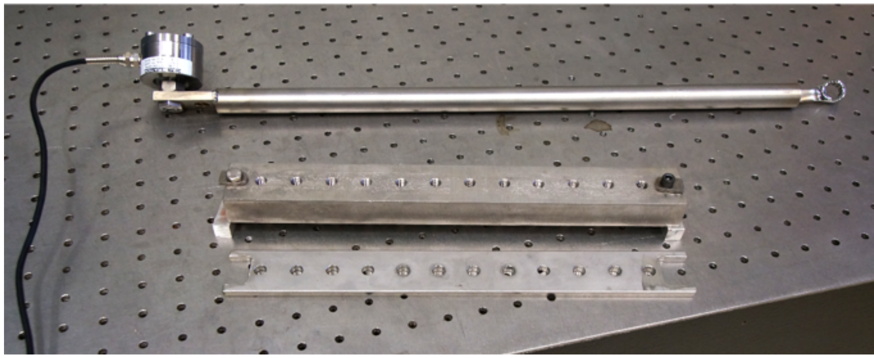
Failure modes of Herculoy studs in blind tapped holes

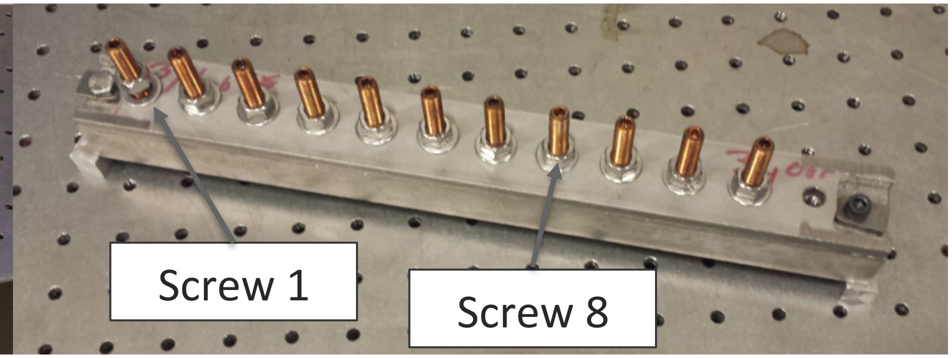
- One cavity had sealing issues on CF knife edge due to poor machining flange area
- The torque on studs was increased to the breaking point
- The stud was trapped & completely bonded inside the threads
- Repair involved drilling larger hole to install thread insert
- Now we use Aluminum Diamond Seals.
- Nevertheless a study was necessary...



We were still using Copper Gaskets on CF Flanges

Failure modes: breaking test



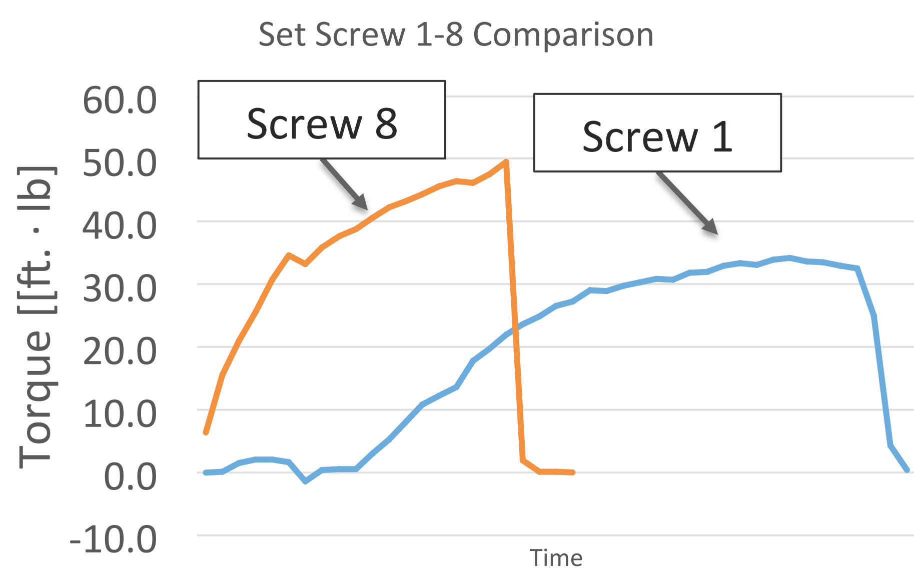


Two cases:

- The set screw is touching the bottom of the blind hole. (Screw 1)
- The set screw is unscrewed for 2 turns out. (Screw 8)

→ Screw 8 can be removed easily by hand after breaking.

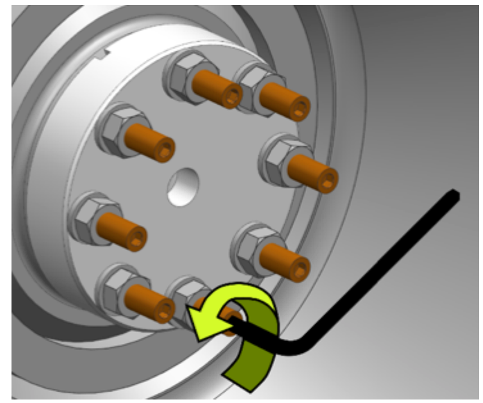
→ Screw 1 stuck inside the hole.

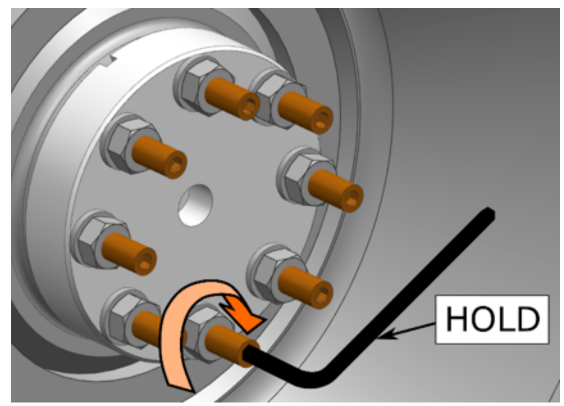


Work by Mattia Parise

6. Flange installations

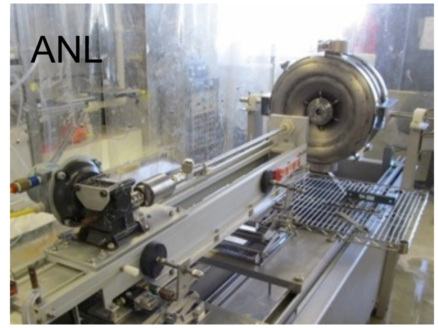
- Hand tighten all nuts
- Unscrew studs by 2 turns
- Tighten nuts, <u>Holding studs</u>
- Add 4 ft*lbs (5 Nm) per round
- Reach 16 ft*lbs (22 Nm)
- If leaks, increase to max 24 ft*lbs (32 Nm)

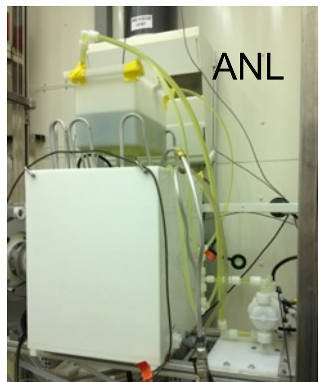




Processing/Preparations of SSR1 Cavities

1	Bare Cavity Inspection – Visual, Dimensional, Vacuum, RF
2	US cleaning and rinse
3	BCP 120-150 µm (flip half-way)
4	High-Pressure Rinse
5	Hydrogen Degassing 600 °C, 10 h
6	RF Tuning
7	BCP 20-30 µm
8	HPR (horiz + vert)
9	Clean Room Assembly
10	Low Tem Bake 120 °C, 48 h
11	Vertical Test @ 2K
12	Helium Vessel Welding + Maintenance
13	US cleaning
14	BCP 20-30 µm
15	HPR (horiz + vert)
16	Clean Room Assembly
17	Low Temp Bake 120 °C, 48 h
18	Horizontal Test @ 2K
19	Ready for String Assembly



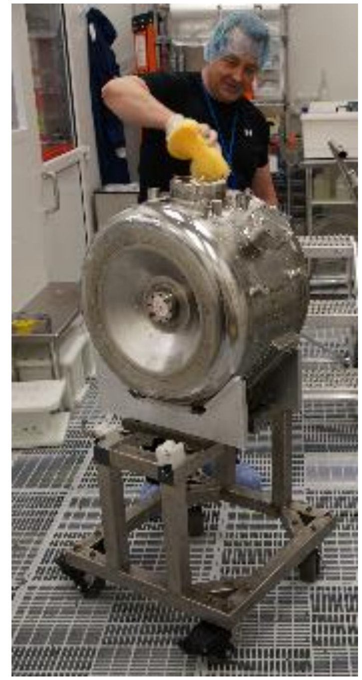


Bare cavity BCP setup

Low-Temp Ovens (<300'C)

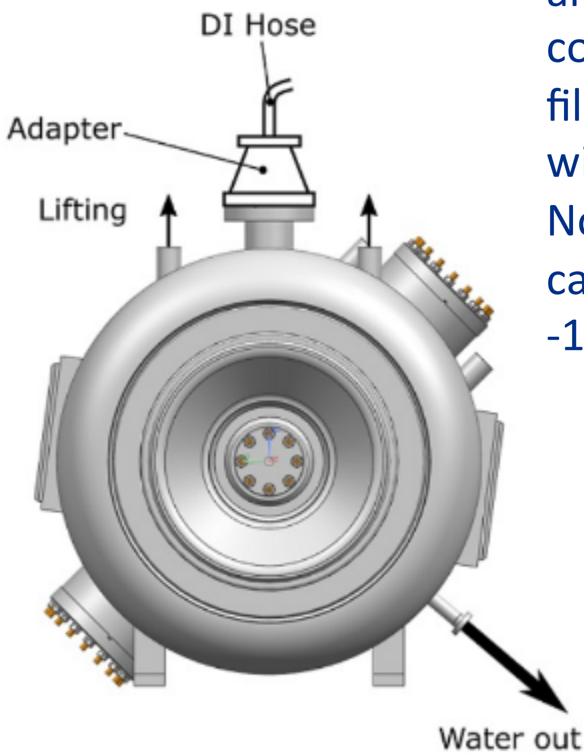
High-Temp Oven (<1000'C)

1. Cavity washing and rinsing

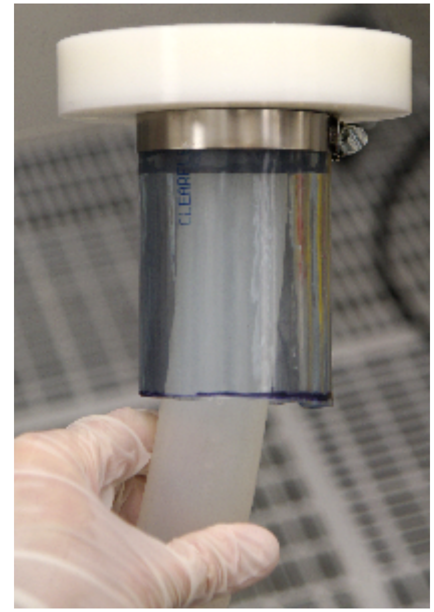


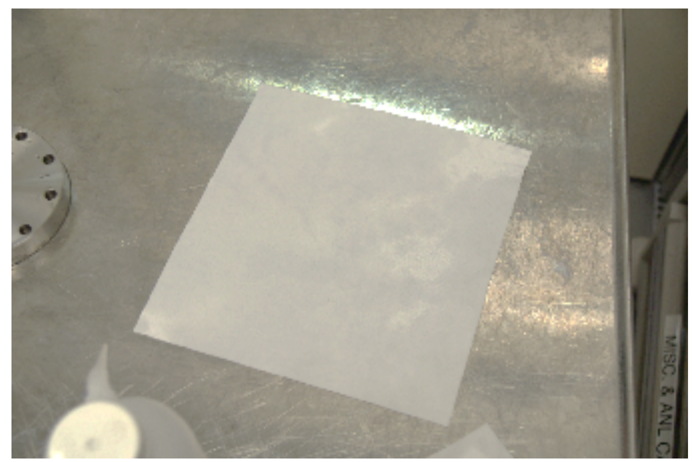
The exterior of the cavity is washed using DI water and soap, the port's holes are cleaned deeply to remove the dirt from the inside. The cavity is then rinsed with DI water.

1. Cavity washing and rinsing



The Helium space is washed using DI water and soap, the water coming out from the He filling line is intercepted with a white cloth.
No visible impurities came out for S1H – NR -112.





2. Light BCP

- Helium volume contains chilled water
- Acid inputs: 2 at beam-pipes + 2 through overflow bucket
- Acid pre-chilled overnight < 5C
- Water chilled during processing at = 10C

3. Ultrasonic cleaning/Horizontal HPR

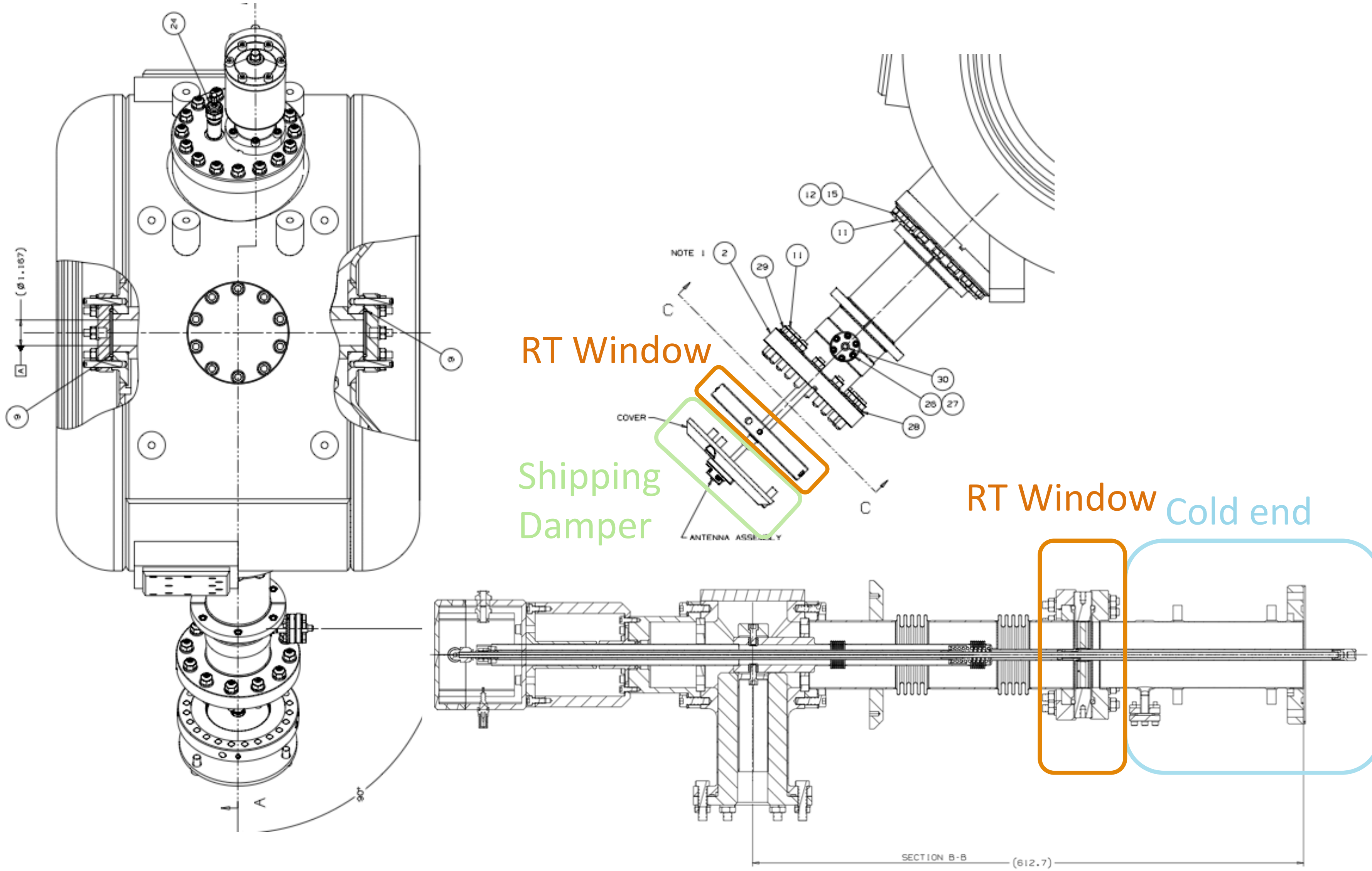
- Cavity is ultrasonically cleaned in a bath of DI water and Liquinox
- Horizontal HPR is then carried out.
- Cavity dry over night. With all 4 ports open
- All four cavity ports (2 beam pipes, coupler port, vacuum port) are used to perform the washing.

4. Vertical HPR




- The cavity is mounted on the backtech cart and the vertical HPR is performed in class 10 clean room conditions.
- All four cavity ports (2 beam pipes, coupler port, vacuum port) are used to perform the washing.
- The cavity is then left to dry in the clean room with all the 4 ports open.
- Vertical HPR is 100% manned due to small cavity aperture of 30 mm.

SSR1 Cavity Preparation for STC



5. Cavity assembly for STC

- The hardware is ultrasonically cleaned and blown using a particle counter
- The assembly is done on the backtech cart rotating each flange downwards

Thank YOU - See Talk Tomorrow for:

- Couplers
- Tuners
- String Assembly Plans