RFD design update

P. Berrutti for the US HL-LHC AUP team

17/11/2017

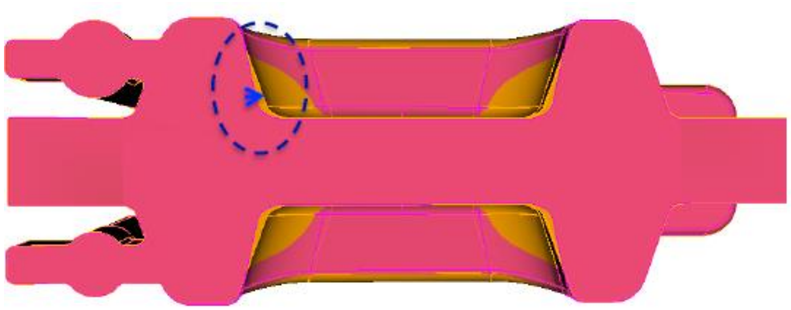
Outline

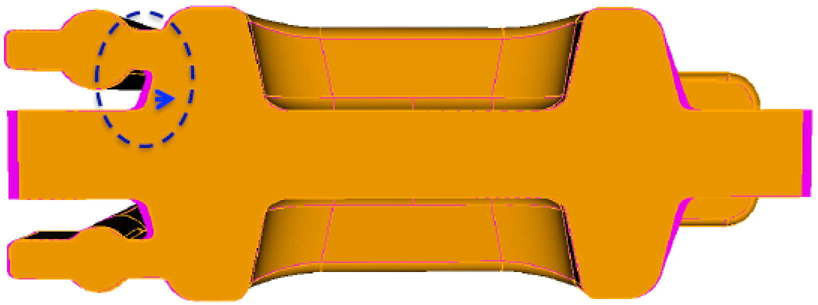
- RFD EM design change driven by 760 MHz HOM
- RFD mechanical design update:
  - Tuner interface
  - pressure sensitivity dF/dP
  - Lorentz Force Detuning
  - Tuning range
- Summary

RF Design update: shift the 760 MHz HOM

Option 1: pole shrinkage, higher 760 MHz frequency

Option 2: wall to pole shrinkage, lower 760 MHz frequency





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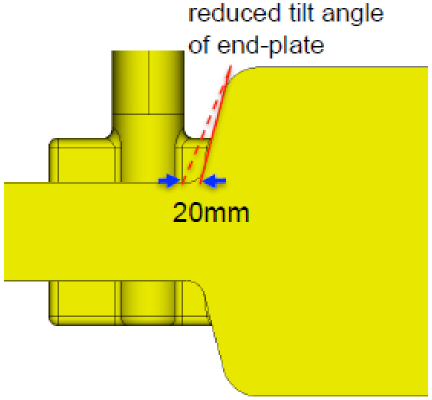
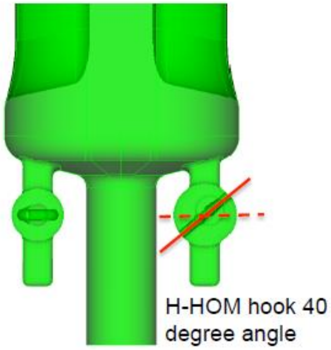
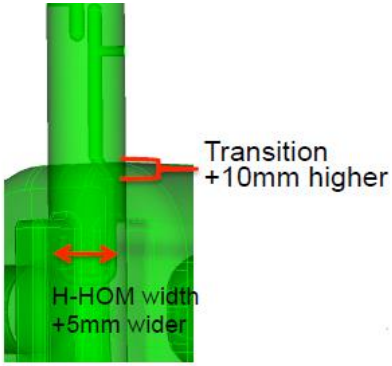
Option 2 preferable:
No changes for the pole length and tips → no changes on field components







RF Design update: MP and Multipoles

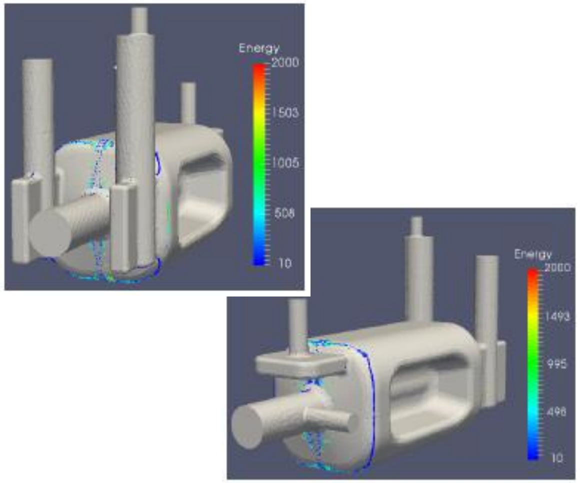
Multipoles amplitude table: roughly unchanged

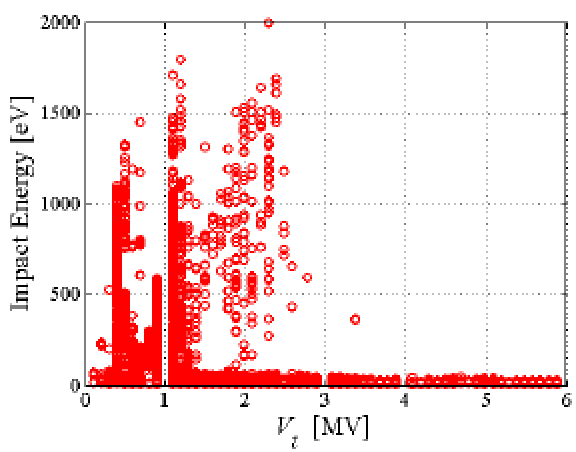
$$E_{acc}(r,\varphi) = \sum_n E^n_{acc} r^n \cos(n\varphi) \qquad (e^{j\omega z.c} \text{ included in } E^n_{acc})$$

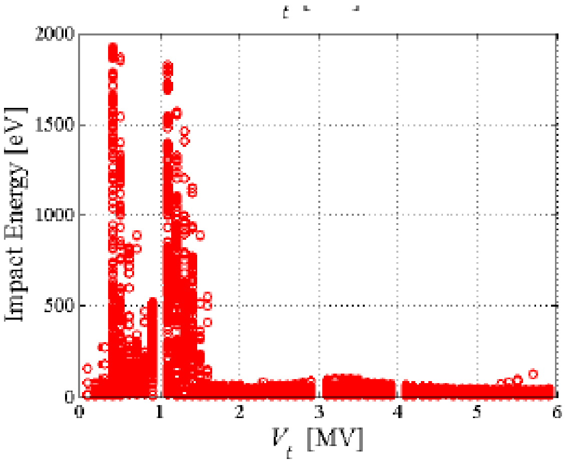
Component	Value
Vt (total)	10 MV
b3	429 mT/m^2
b5	-1.8e6 mT/m^4
b7	-4.9E+08 mT/m^6

Subashini De Silva

MP simulations show no indication of worsening in MP barriers

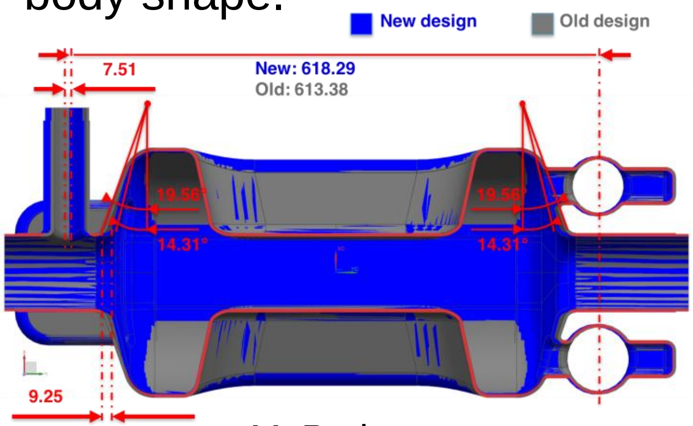


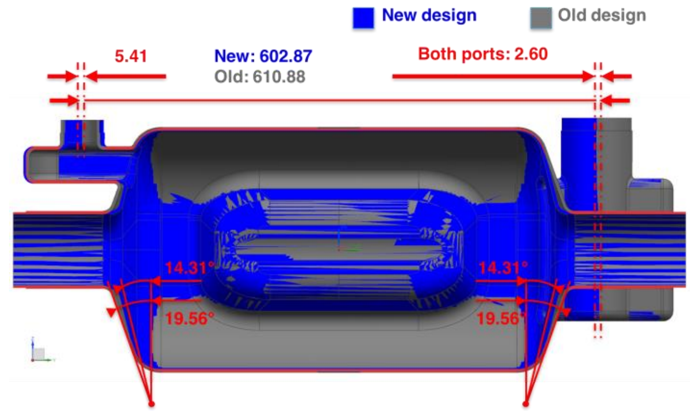




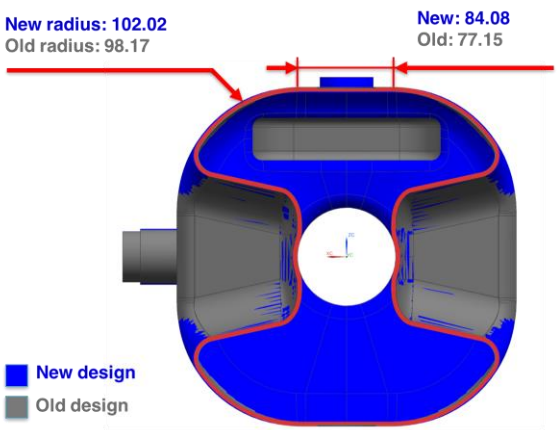
RF Design update: changes summary

Shrinking the gap implies reducing the overall cavity length.
Matching the frequency for the TE11 mode requires tweaking the outer body shape.





M. Parise



RFD Crab Cavity		
	Current Prototype	New Design
Frequency (MHz)	400	400
Lowest dipole HOM (MHz)	633	635
Lowest acc HOM	715	717
High R/Q acc HOM	760.9	755.3
Transverse dimension (mm)	281	280
Vertical dimension (mm)	281	280
R_T (ohm/cavity)	427	427
V_T (MV/cavity)	3.34	3.34
Bs (mT)	55.5	55.4
Es (MV/m)	32.6	32.7

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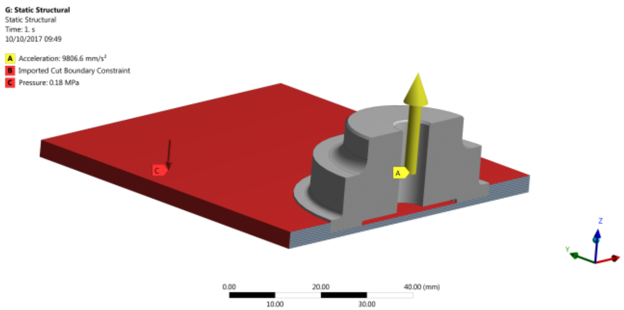
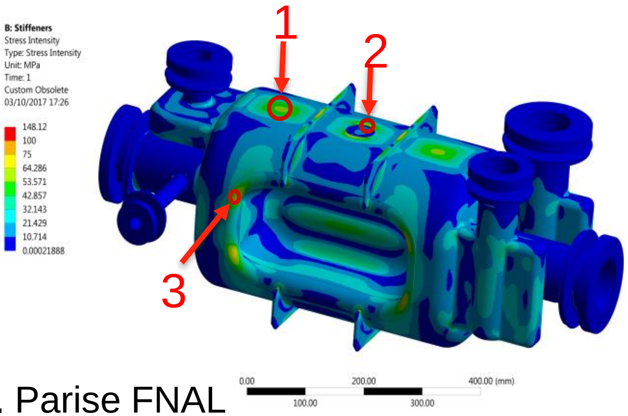
RF Mechanical design: Tuner interface

Tuner interface has been identified as a possible critical area, both from US and CERN team, stiffeners are required (1.8 bar tuner free)



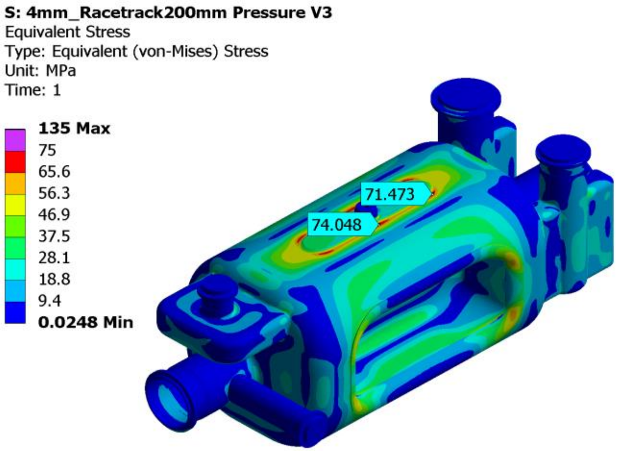
C. Zanoni CERN

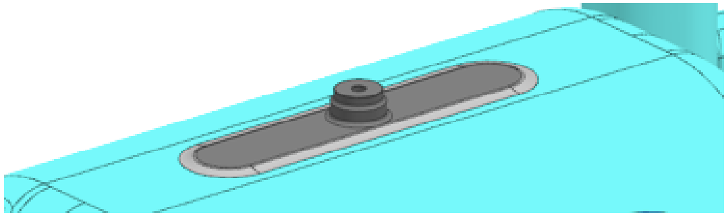
	Linearized stress	
	Pm (MPa)	Pm+Pb (MPa)
1	10.2	55.7
2	16	69.6
3	38.3	70.9
Limit	50	75



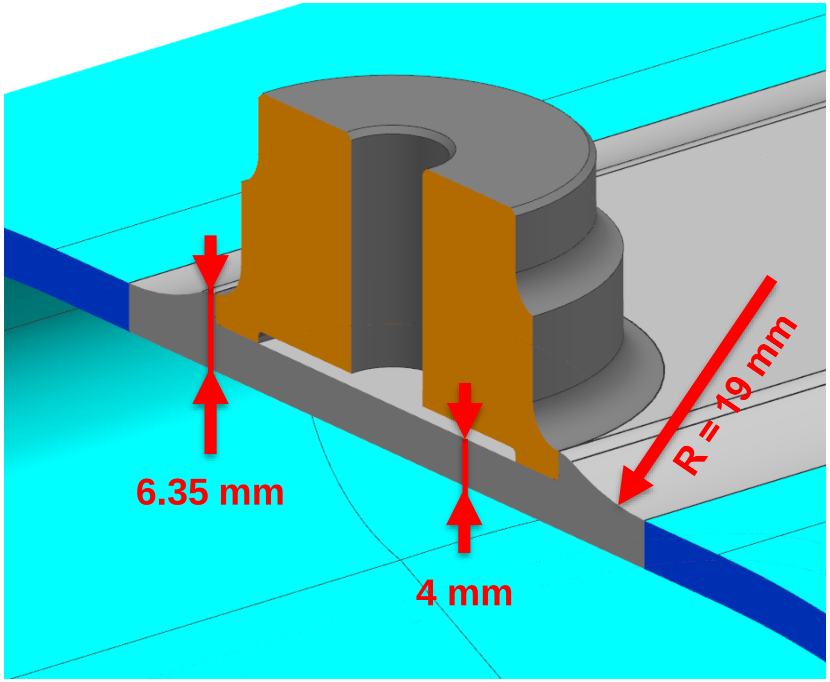
M. Parise FNAL

Updated mechanical design: racetrack shape

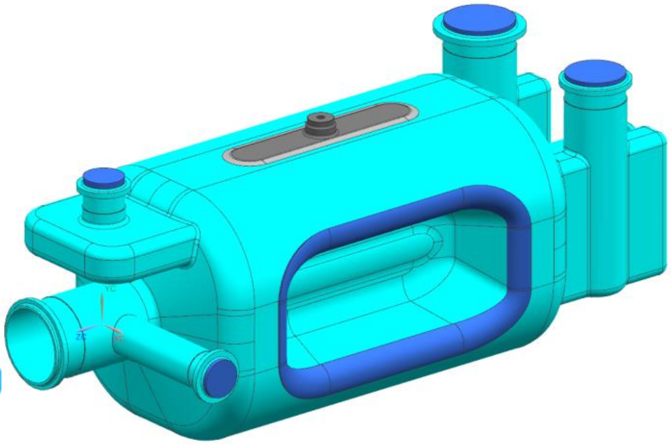


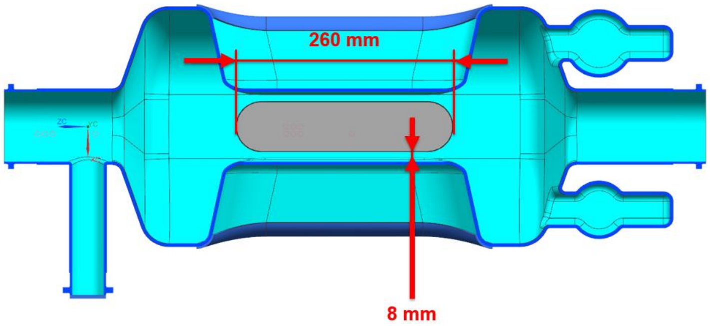


RF Mechanical design: Tuner interface

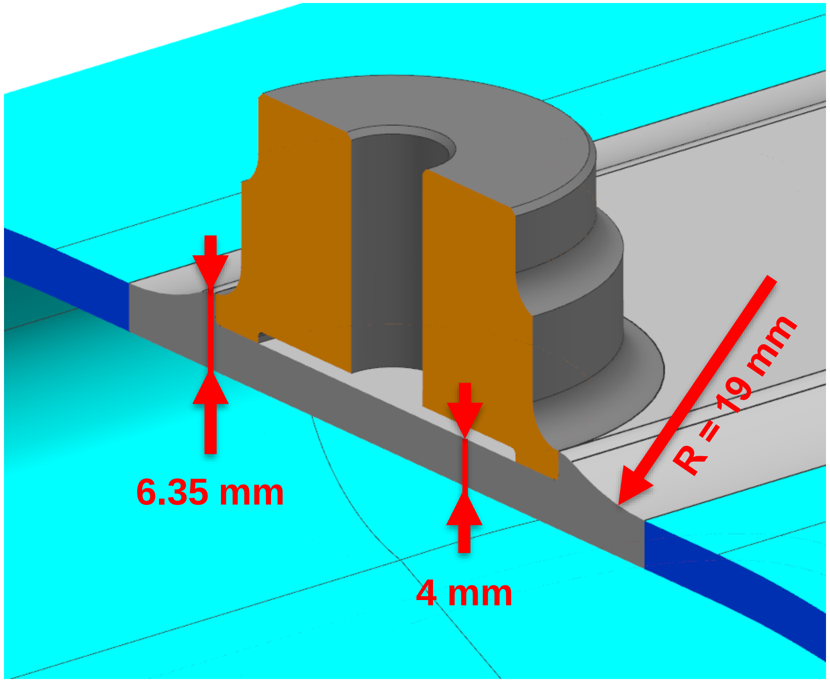


- Use of thicker material to distribute stresses and tuning forces.
- Large radius (19 mm) reduces stress concentration
- More material under the interface (original design was 1.6 mm)
- Shape optimized to allow EBW from both sides for a 4mm thick weld





RF Mechanical design: Tuner interface



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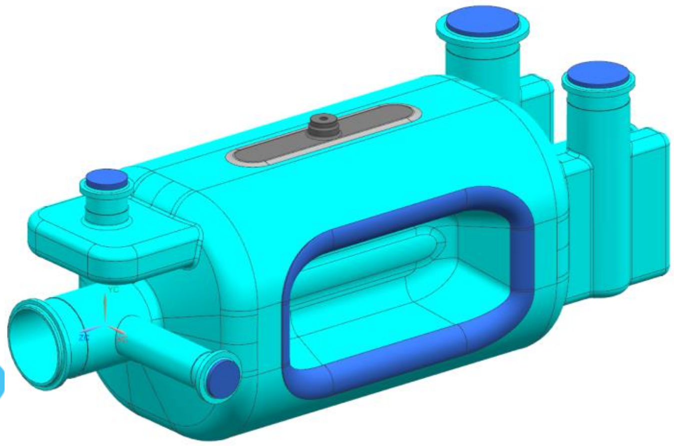
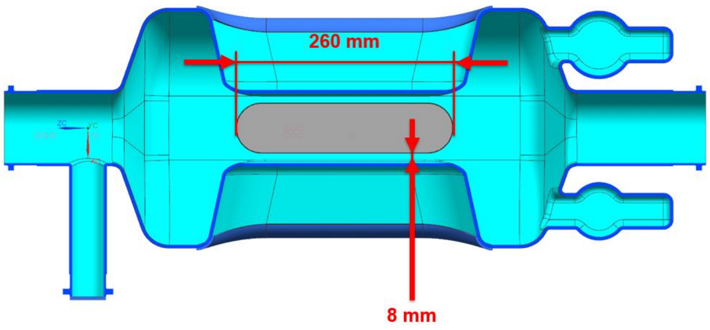
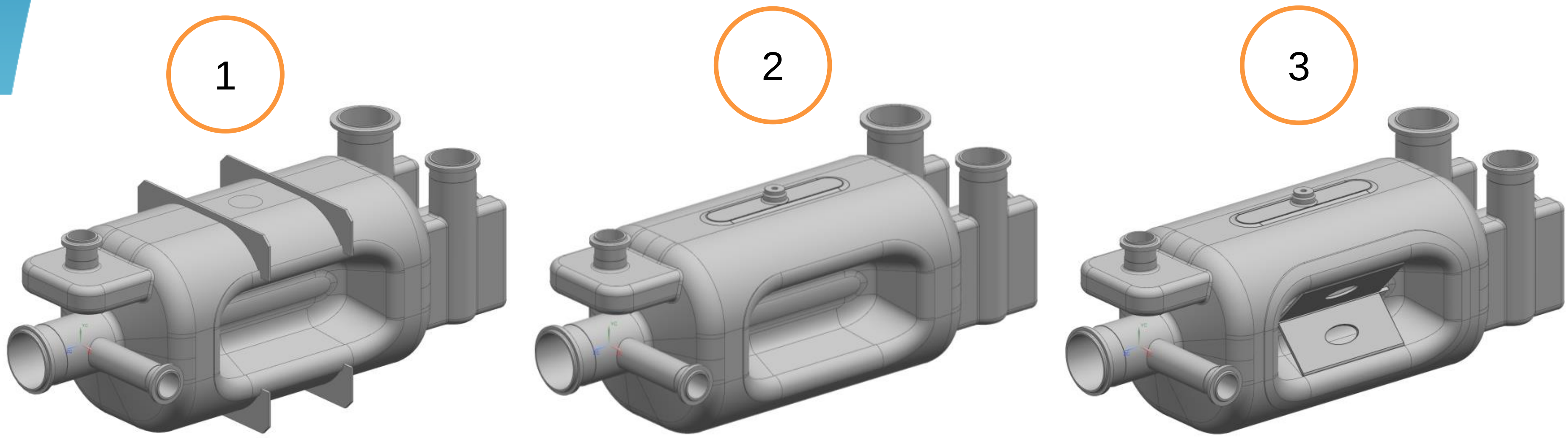




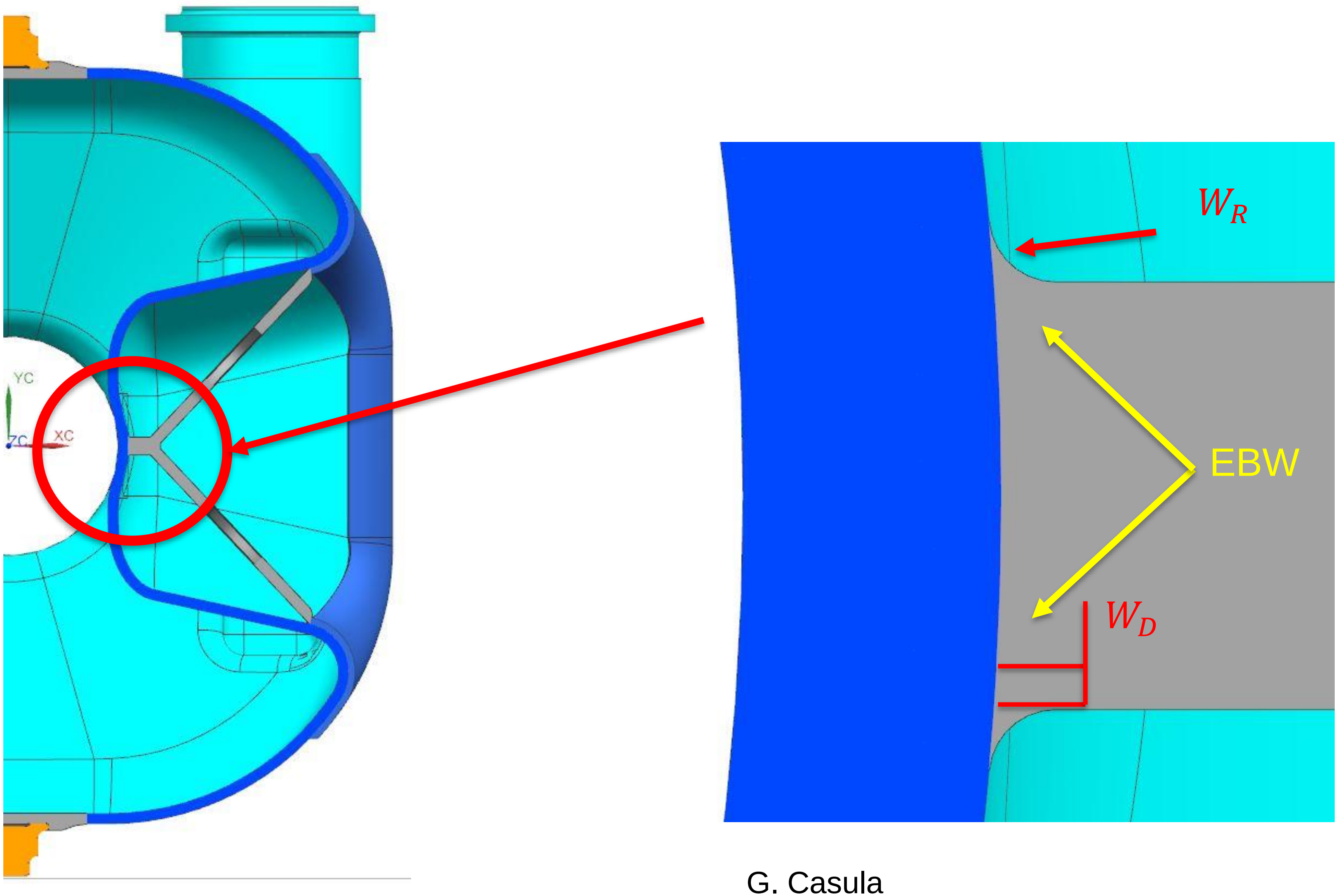
Evolution of Mechanical Design



GOAL: Guarantee satisfying functional specifications
1.8 bar pressure, df/dP, LFD

1) LARP prototype design
2) Removed Ribs + Racetrack
3) Racetrack and electric ribs + wider stiffeners at pole base

RFD electric ribs



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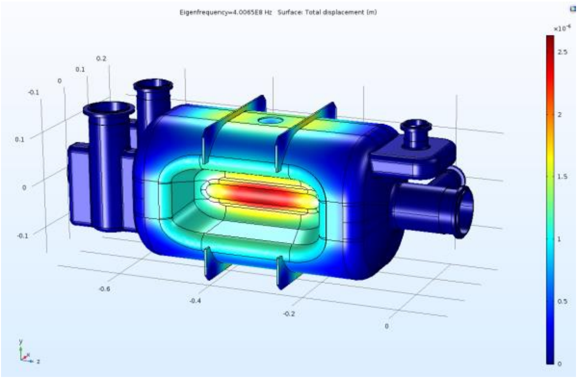
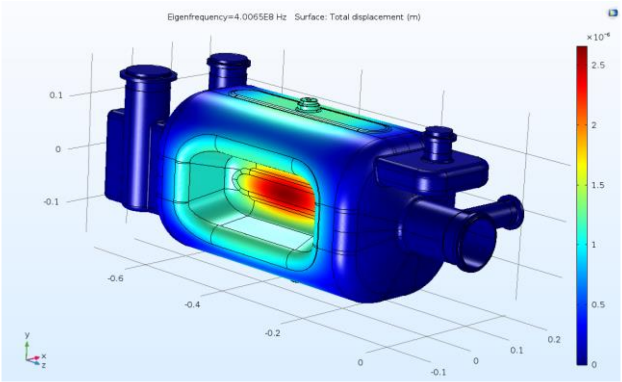
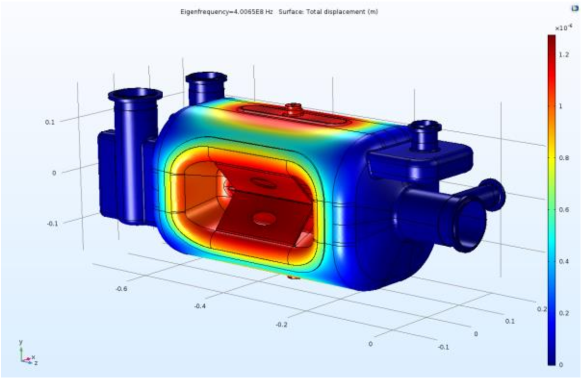
RFD mechanical design: LFD

1 2 3

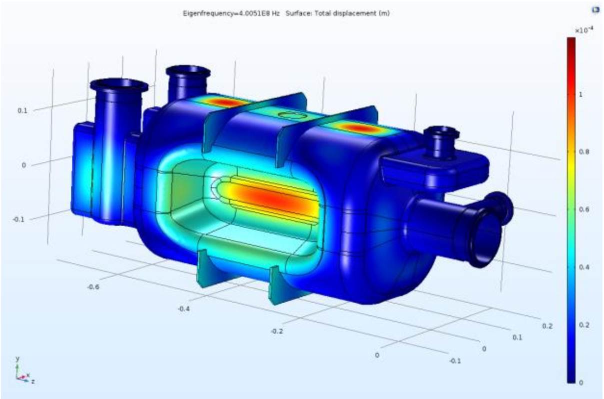
GOAL: LFD dF < |10| kHz (0 to 3.4 MV)
LFD has been simulated with tuner stiffness= 6.8 kN/mm

1) LFD dF= -7.2 kHz
2) LFD dF= -7.2 kHz
3) LFD dF= -5.3 kHz

Model	dF [kHz]	LFD [Hz/(MV)^2]
1	-7.17	-602
2	-7.16	-602
3	-5.31	-447

RFD mechanical design: pressure sensitivity

1



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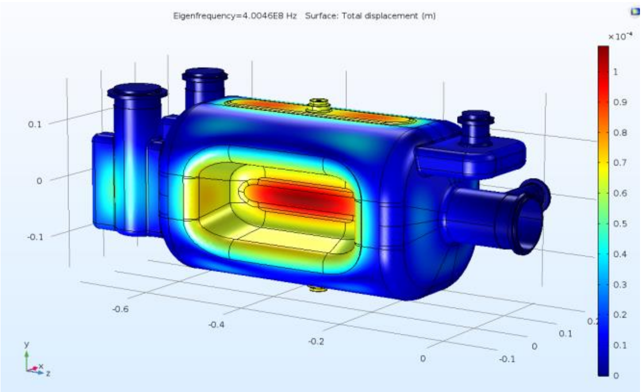

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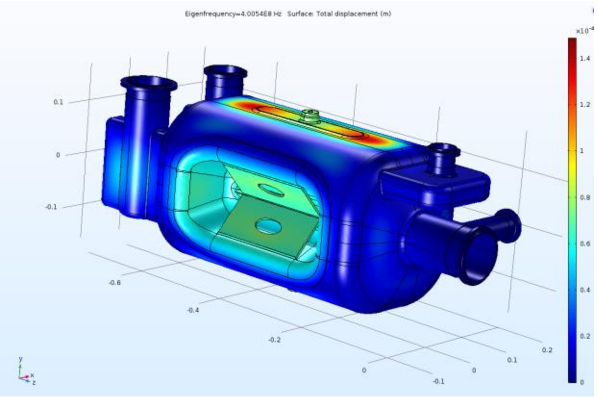
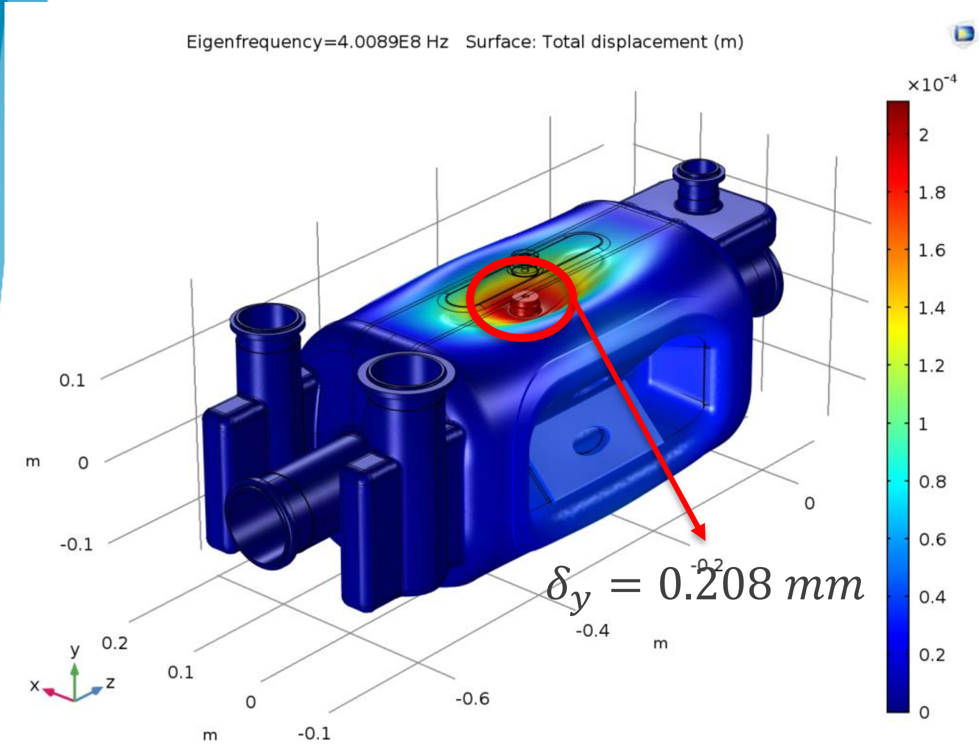
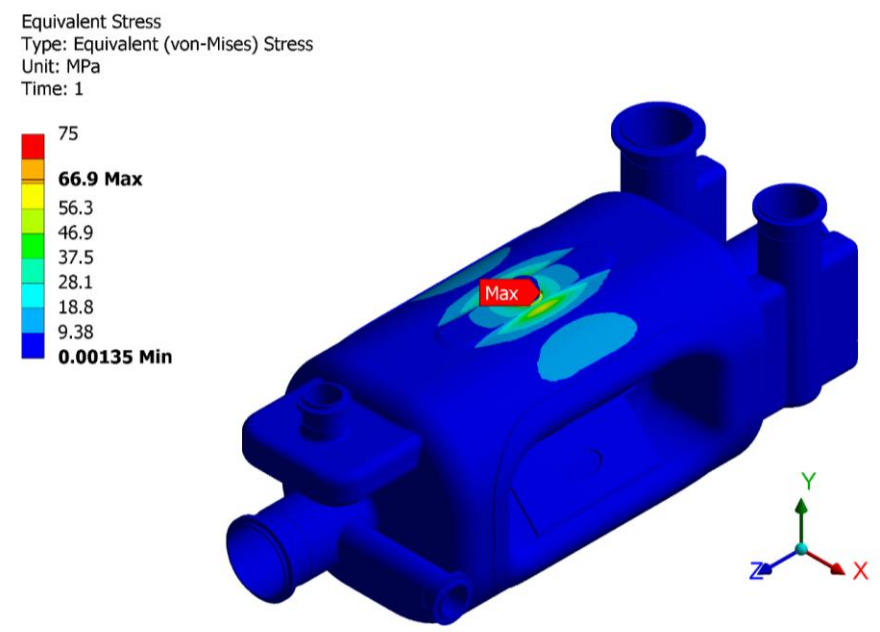


GOAL: pressure sensitivity < |150| Hz/mbar
dF/dP has been simulated with tuner stiffness= 6.8 kN/mm

1) dF/dP= -147 Hz/mbar → exactly in spec
2) dF/dP= -194 Hz/mbar → out
3) dF/dP= -112 Hz/mbar → well within spec

RFD mechanical design: tuning range I





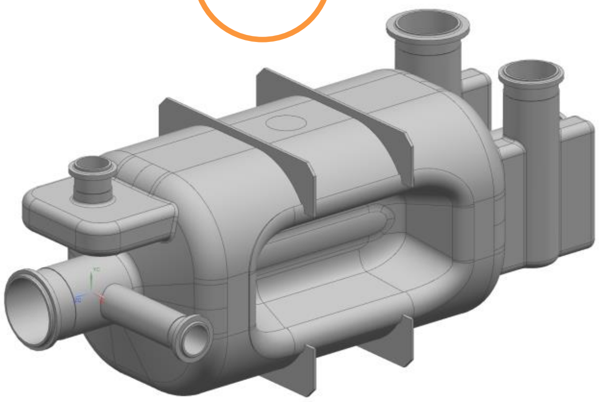
Mattia Parise

Force at each side applied along Y on each tuner flange:	$F = 1500\ N$
Frequency shift due to tuning force:	$\Delta f\ = 2.33 \cdot\ 10^2\ kHz$

RFD mechanical design: tuning range II

The new tuner interface design improves the tuning range since the stresses are lowered by approx. 50%

1



3

Parameter	1	3
Force at each side	$1500\ N$	$1500\ N$
Total frequency shift	$240\ kHz$	$233\ kHz$
Displacement at each side	$0.357\ mm$	$0.208\ mm$
Peak stress	$124\ MPa$	$66.9\ MPa$
Calculated sensitivity per side	$\frac{120}{0.357} = 340\ kHz/mm$	$\frac{116}{0.208} = 560\ kHz/mm$
Spring constant of cavity wall	$\frac{1500}{0.357} = 4202\ N/mm$	$\frac{1500}{0.208} = 7212\ N/mm$
Calculated tunability (Total)	$\frac{4202}{2 \cdot 340} = 6.2 \frac{N}{kHz}$	$\frac{7212}{2 \cdot 560} = 6.44 \frac{N}{kHz}$
Allowable stress at 2K	$333\ MPa$	$333\ MPa$
Maximum elastic range at 2K	$240 \cdot \frac{333}{124} = 644\ kHz$	$233 \cdot \frac{333}{66.9} = 1160\ kHz$

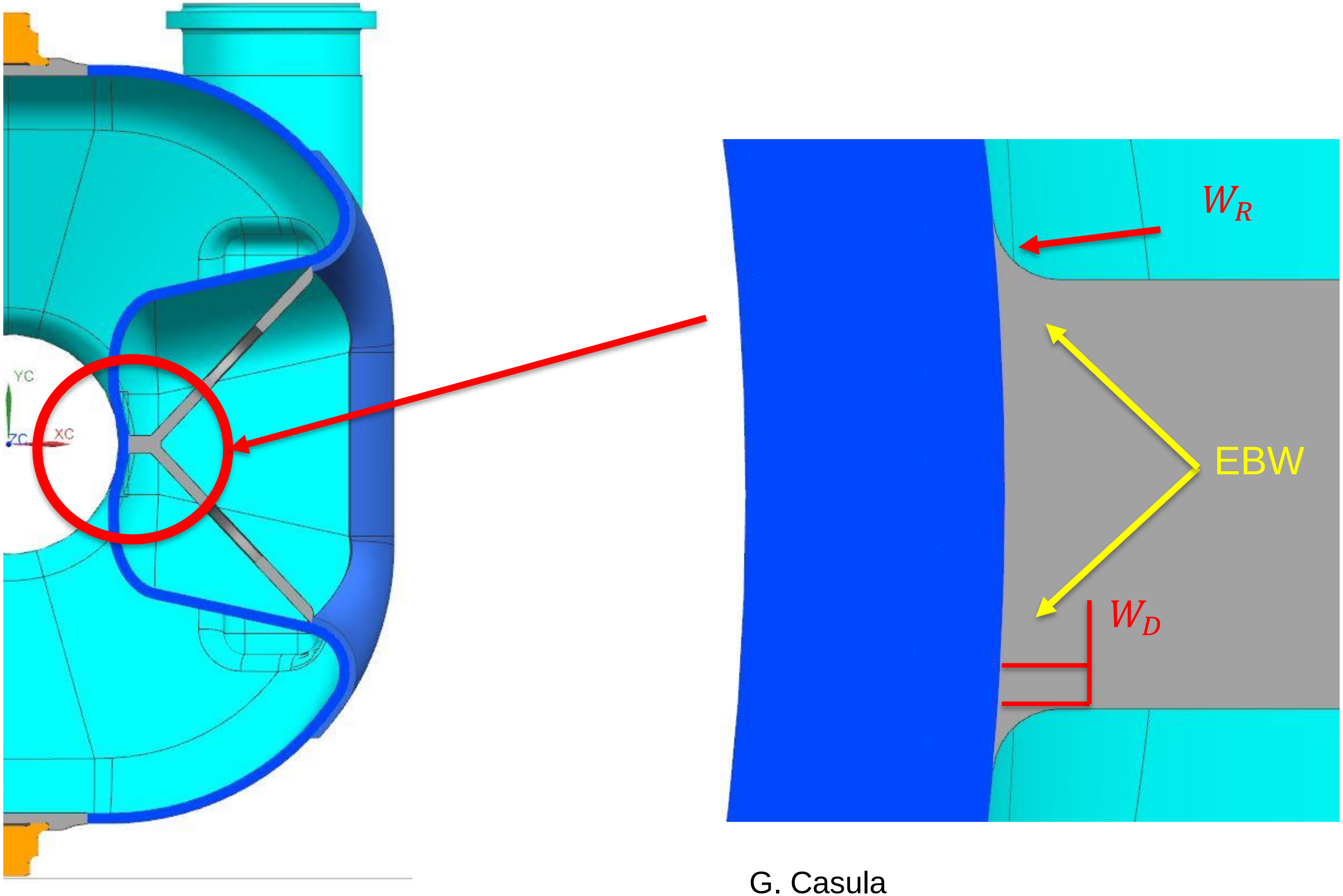
Mattia Parise

Summary

- The updated RFD EM design detunes the 760 MHz HOM preserving the cavity performance, field components and MP characteristics.
- Few dimensions need to be adjusted as a consequence of the new EM design.
- The proposed new tuner interface improves the e-beam welding procedure (NbTi parts) keeping stresses below allowable values (1.8 bar pressure).
- Electric ribs (pole area) improve dF/dP and LFD parameters, both well within specs.
- Tuning range results improved by the usage of racetrack shape on the cavity side.

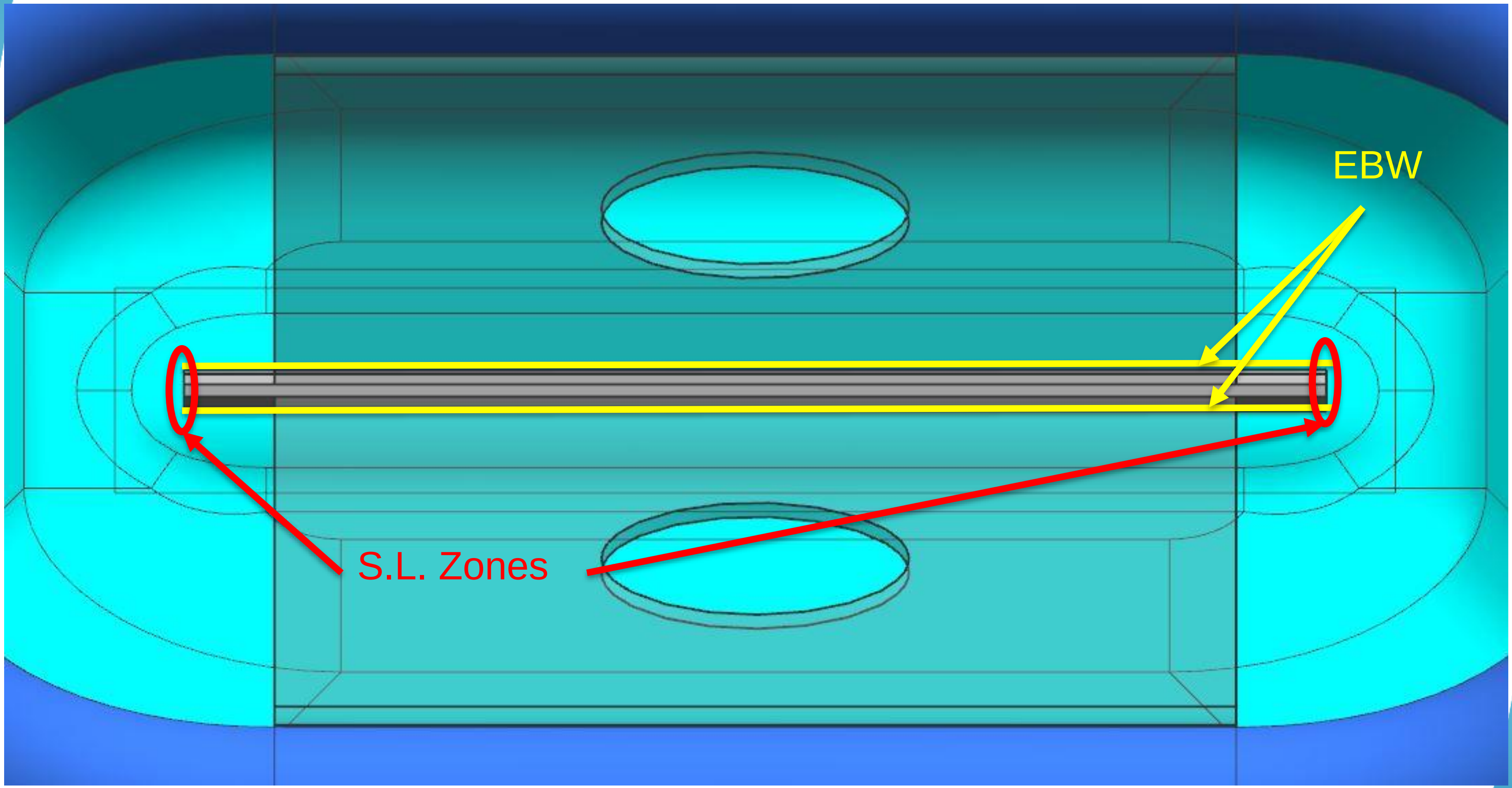
Backup Slides

RFD electric ribs



G. Casula

RFD electric ribs weld detail I



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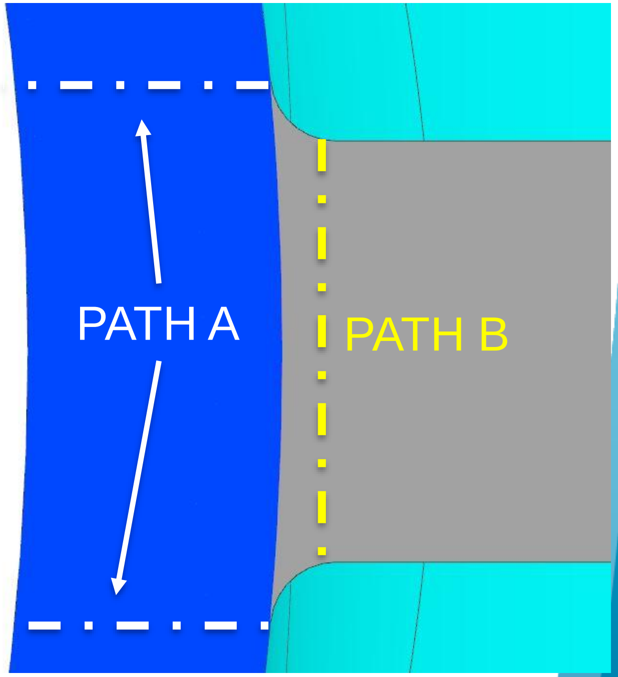
RFD electric ribs weld detail II

- Negligible impact: maximum displacement along X under LFD load varies less than 1‰
- Max. equivalent linearized stress values (ASME BPVC) along Paths A group and Paths B group are under the allowable values in every considered situation. Results of FEM analysis:

Fillet Radius \ Weld Depth		$0.5\ mm$	$1\ mm$	$1.5\ mm$	All. values
PATH A	$0.5\ mm$	$10.1\ MPa$	$8.2\ MPa$	$8.3\ MPa$	$50\ MPa$
		$27.3\ MPa$	$22.2\ MPa$	$22.6 MPa$	$75\ MPa$
	$1\ mm$	$8.4\ MPa$	$8.3\ MPa$	$8.4\ MPa$	$50\ MPa$
		$21.3\ MPa$	$20.7\ MPa$	$21.1\ MPa$	$75\ MPa$
PATH B	$0.5\ mm$	$13.2\ MPa$	$26.7\ MPa$	$26.8 MPa$	$50\ MPa$
		$35.0\ MPa$	$37.3\ MPa$	$37.5\ MPa$	$75\ MPa$
	$1\ mm$	$24.7\ MPa$	$25.7\ MPa$	$25.8\ MPa$	$50\ MPa$
		$34.8\ MPa$	$35.2\ MPa$	$35.2\ MPa$	$75\ MPa$

▪ Membrane ▪ Membrane + Bending



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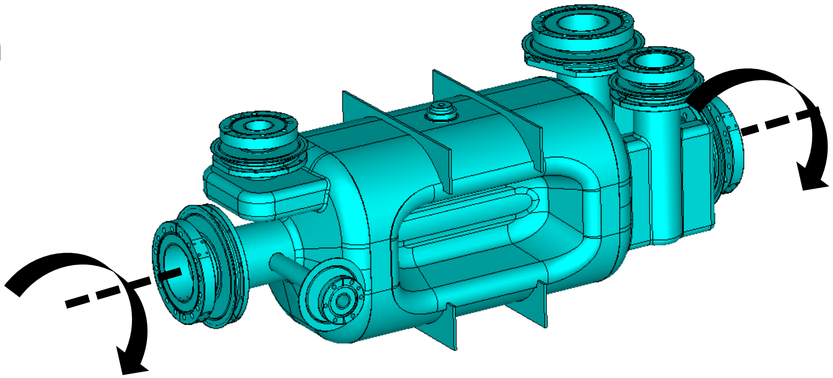
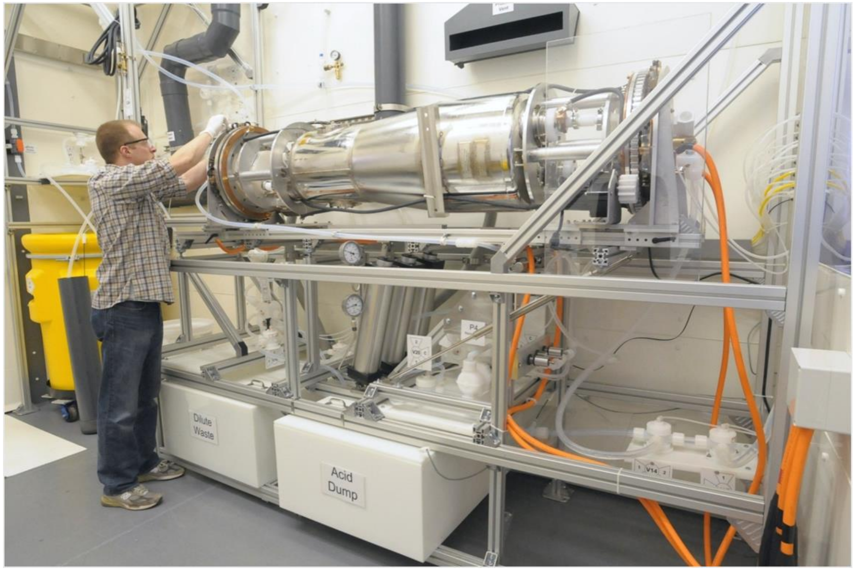
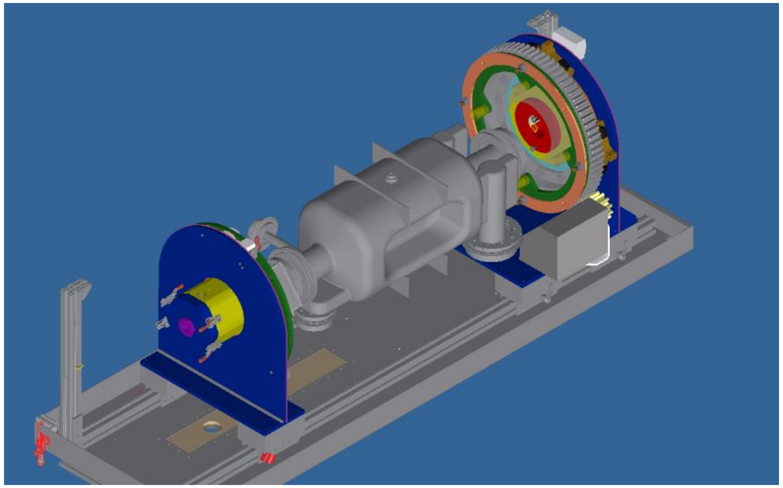
Cavity Processing

- BCP Processing in horizontal orientation with rotation and possibly also tilting
  - Allows more uniform removal
  - Better acid circulation and drainage







ANL rotational processing tool