RFD Crab Cavity Contribution from the U.S.
Status, Needs and Plans

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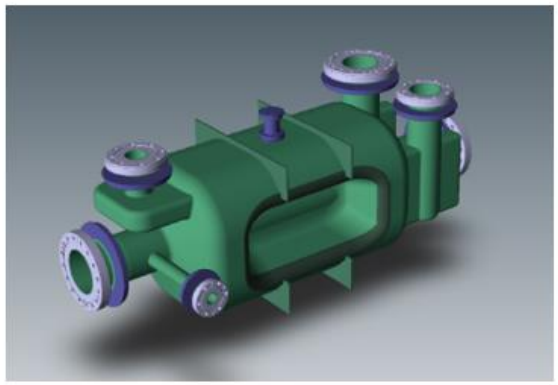
With input from: ANL, BNL, JLAB, ODU, SLAC

7th HL-LHC Collaboration Meeting – Madrid, Nov 13-16 2017

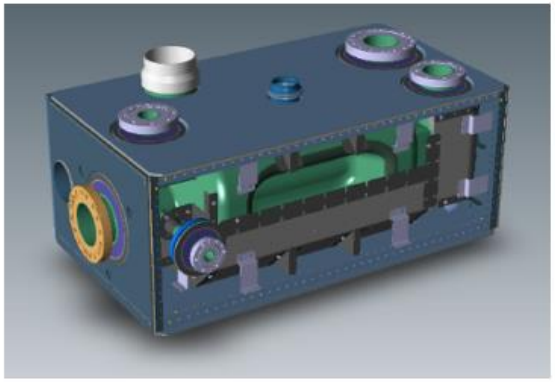
Outline

- Scope and Deliverables
- Schedule and deliveries to CERN
- Upcoming Reviews in 2018
- 2018 Effort Distribution across the AUP teams
- Cavity Design Issues and proposed solutions
- Procurement of AUP Prototypes
- RRR Niobium purchase and QC results

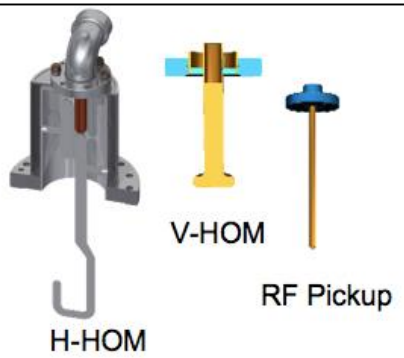
Scope and Deliverables



Bare RFD Cavity



Dressed RFD Cavity
(front wall removed to show internal components)



RF Ancillaries

- **Dressed RFD Crab Cavity**
  - Assembly: Bare Cavity + Magnetic Shields + Helium Tank + RF Ancillaries
  - Qualification at 2 K + Shipment to CERN
- **10 Dressed RFD Crab Cavities**
  - Qualified at FNAL (in VTS at 2K)
  - Ready for integration in cryomodule (at CERN)
  - (8) for tunnel installation (threshold KPP) – Need by: Summer-Fall 2023
  - (2) additional at later time (objective KPP)

Scope and Deliverables

US-HiLumi-doc-39

WBS Code	WBS Name	Control Account
302.3	RFD Dressed Crab Cavities Fabrication	No

WBS Description

Scope of Work

Design, fabricate, process, test and document Dressed Radio Frequency Dipole (RFD) cavities.

The total number of cavities produced will be 2 Prototypes + 12 Productions. Dressed cavities include the bare cavity, magnetic shields, helium containment vessel, tuner interface components and RF ancillaries (HOM couplers, RF pickup).

Scope Assumptions/Exclusions

Hardware will be fabricated almost exclusively through procurements with industry. On the other hand, inspections, preparations and qualification tests will be managed at Fermilab and performed primarily at Fermilab and ANL.

Fundamental power couplers for RFD cavities are excluded from the scope.

String assembly and Cryomodule integration of RFD cavities are excluded from the scope.

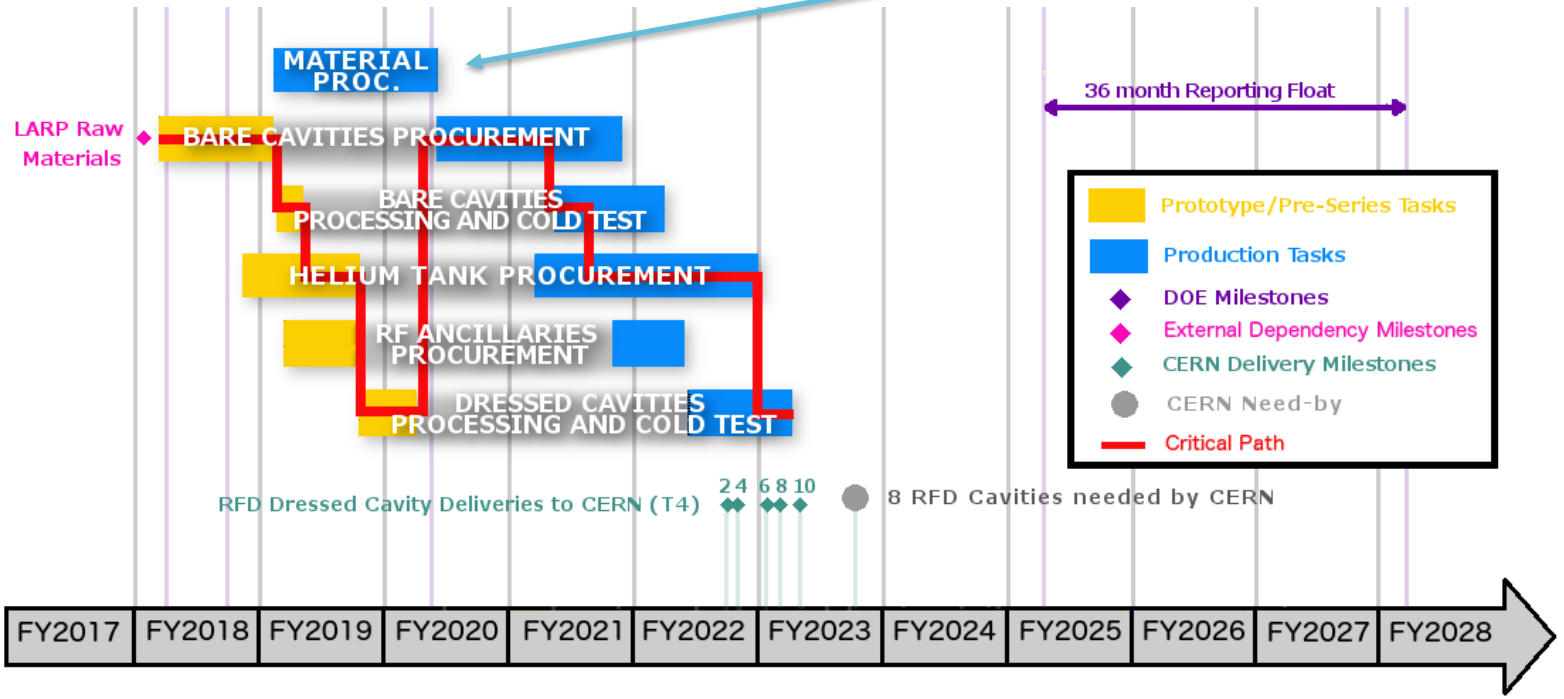
WBS Deliverables

10 Dressed and qualified RFD cavities fully documented and shipped to CERN (8 for tunnel installation + 2 spares).

Schedule

- CY 2018-2019: RFD prototype cavities, dressed and tested (yellow)
- CY 2020-2022: RFD production cavities, dressed and tested (blue)
  - PO for Bare Cavities - March 2020
  - PO for Helium Tanks - June 2021
  - Qualification of dressed cavities - May-Dec 2022
  - Deliveries to CERN - July-Dec 2022

Note: Niobium Procurement in FY2019 (next slide)



Reviews in 2018

- CD-2/CD-3b Reviews (under US Responsibility):
  - Specific Magnets:

Design Criteria	Apr ’18	Called by Project, external review Team
Magnet FDR	May ‘18	Called by Project, external review Team
Cold Mass/CA PDR	Jun ‘18	Called by Project, external review Team

  - Specific Cavities

FDR for Nb Material	May ‘18	Called by Project, external review Team
Sys. Int. Review	Jun ‘18	Called by Project, external review Team
PDR for Cavities	Jun ‘18	Called by Project, external review Team

  - Overall Reviews

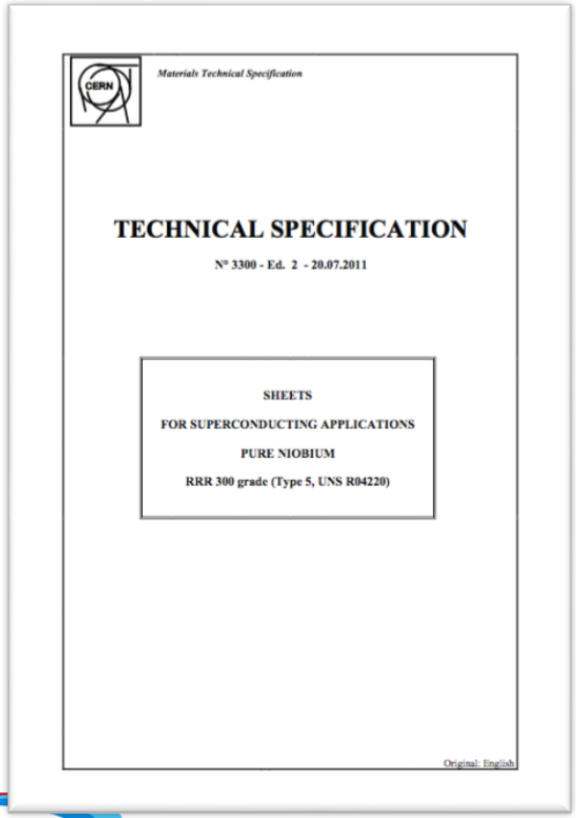
Director’s Review	Aug-Sep ‘18	Called by FNAL Director
DOE IPR	Oct-Nov. ‘18	Called by DOE
ESAAB	Dec ‘18 or Jan ’19	

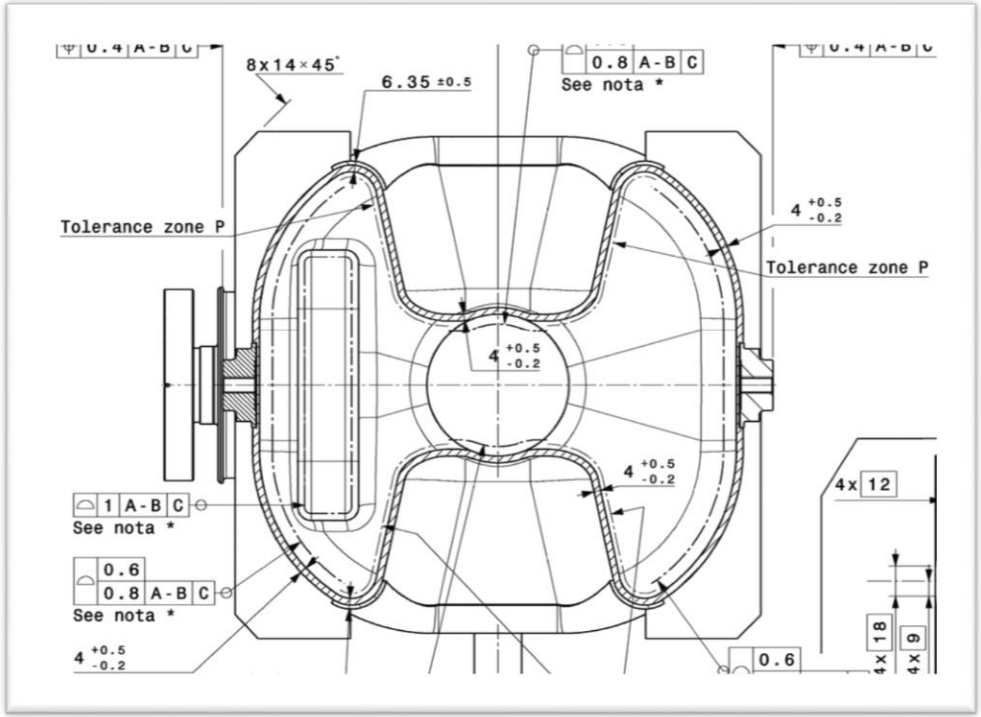
- CD-3 in FY20
  - Full approval for CryoAssemblies and RFD Production

- For production cavities we need approval for Niobium BEFORE CD-3. We will seek early approval at the time of CD-2

Final Design Review for Niobium – May 2018

- Need to formalize agreement with CERN for LHC on:
  - Material Tech. Specification (exists in EDMS, ok for LHC?)
  - Material Thickness (functional DWG exists in EDMS, converge on revision for LHC)





Preliminary Design Review in June 2018

- AUP Effort of next 6mo will feed into the Preliminary Design Report document.
  - New RF design of cavity to address 760MHz HOM by SLAC
  - New Mechanical design to satisfy functional requirements by Fermilab
  - Broad set of warm RF measurements on LARP cavity to demonstrate understanding of tolerances, multipoles, and response to elastic + plastic tuning by ODU
  - Construction of HOM dampers at JLab
  - Rotational BCP at ANL
  - Cold tests of cavity + HOM dampers at Fermilab
  - And much more…….
- First agreement on:
  - Interfaces of dressed cavity (first draft of functional drawing would be sufficient)
  - Acceptance Criteria for dressed cavity
  - MIP, weld qualification, MTF strategy

FY18 Effort from other Labs

(SOWs being finalized)

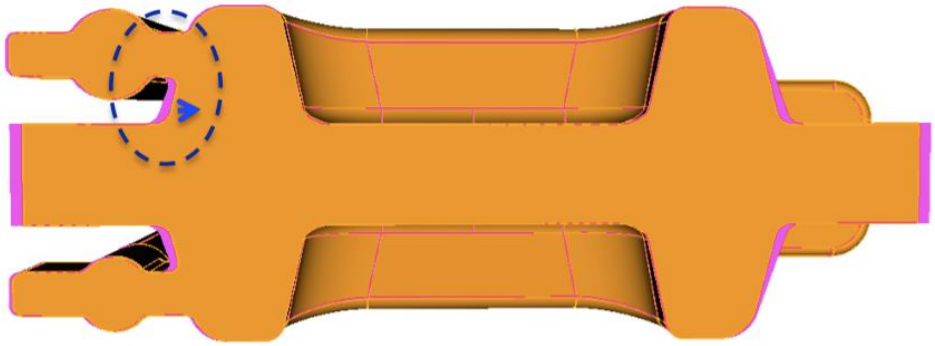
BNL	ODU	SLAC
Interfaces in SM18, SPS and LHC	Warm measurements of electromagnetic and mechanical properties of the RFD cavity	Produce a RFD cavity design addressing the 760 MHz HOM issue
Lessons learned from DQW production	Elastic and plastic tuning sensitivity, including behavior of fundamental and higher-order modes	Calculate the full HOM impedance spectrum up to 2 GHz
Preliminary MIP for RFD pre-series production	Warm measurement of the electromagnetic properties of the HOM couplers	Design HOM coupler RF windows (feed through)
	Oversee Design of dressed cavity (bare cavity, magnetic shields and helium tank)	Analyze cavity and coupler tolerance for engineering design;
Contribute the relevant sections of the Preliminary Design Report	Contribute the relevant sections of the Preliminary Design Report	Contribute the relevant sections of the Preliminary Design Report

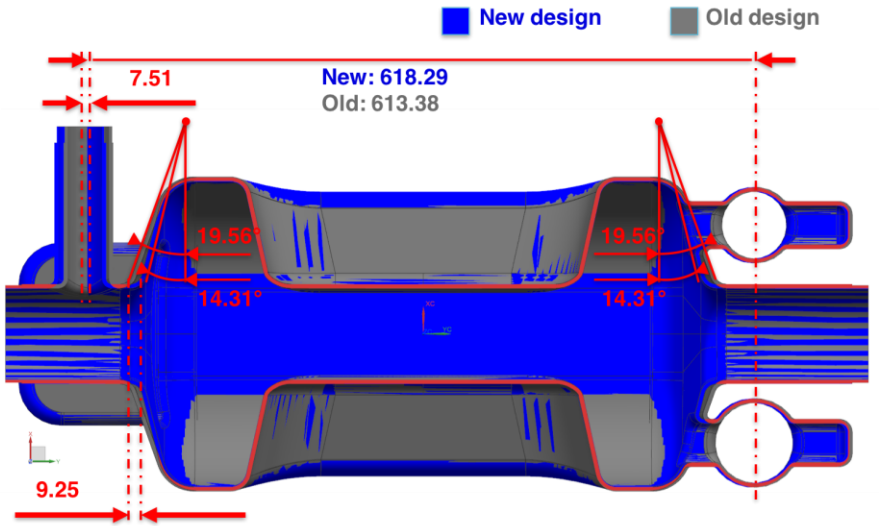
Cavity Design – Open Issues

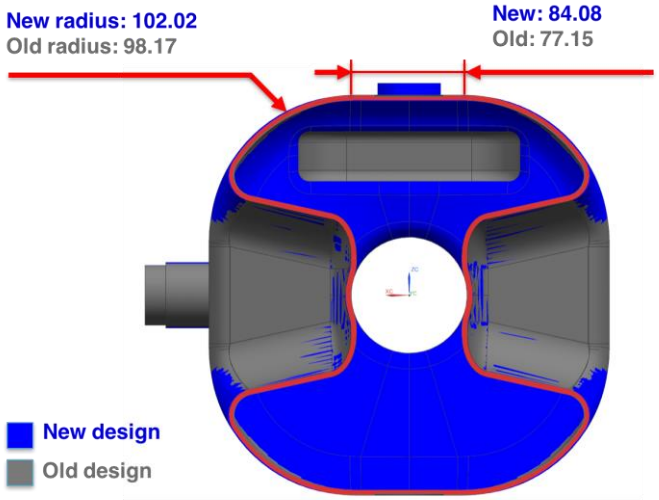
- Shift of ~760MHz Higher Order Mode
  - Solution presented by Zenghai Li (this collab. Meeting) also available at US-HiLumi-doc-722-v2
- Concerns on soundness of tuner interface
  - Solution presented by Mattia Parise
- Ensure key functional parameters meet FRS with some margin
  - Sensitivity to Lhe pressure variations
  - Amplitude of detuning due to Lorenz forces
  - Elastic tuning range at 2K

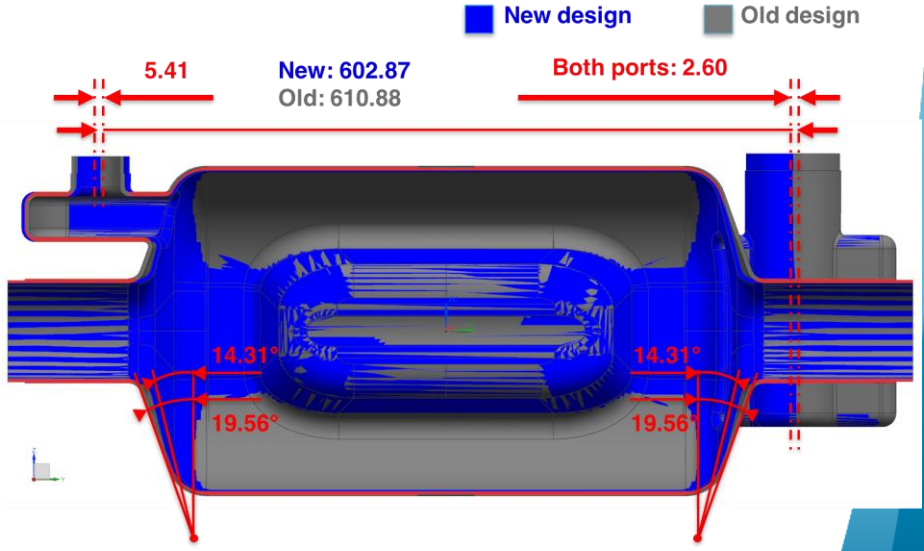
- The good news:
  - Same scheme of 4mm material thickness for the cavity
  - The deflecting poles can be left untouched

Lowering 760 MHz HOM









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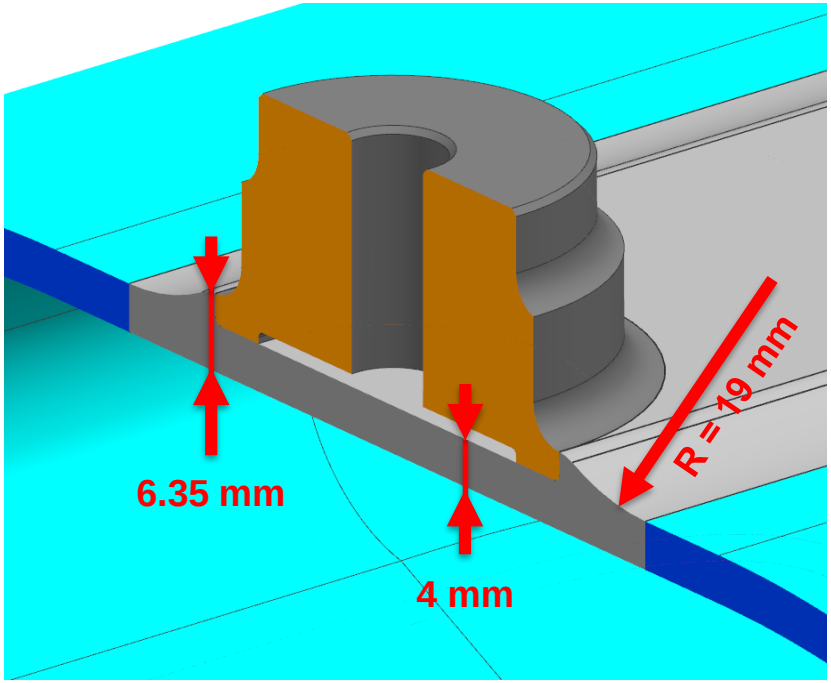
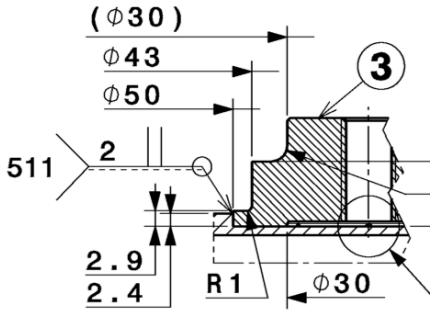
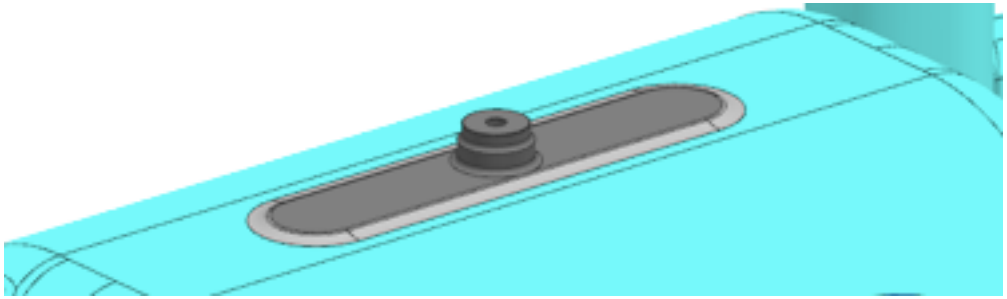
Updates on the tuner flange interface

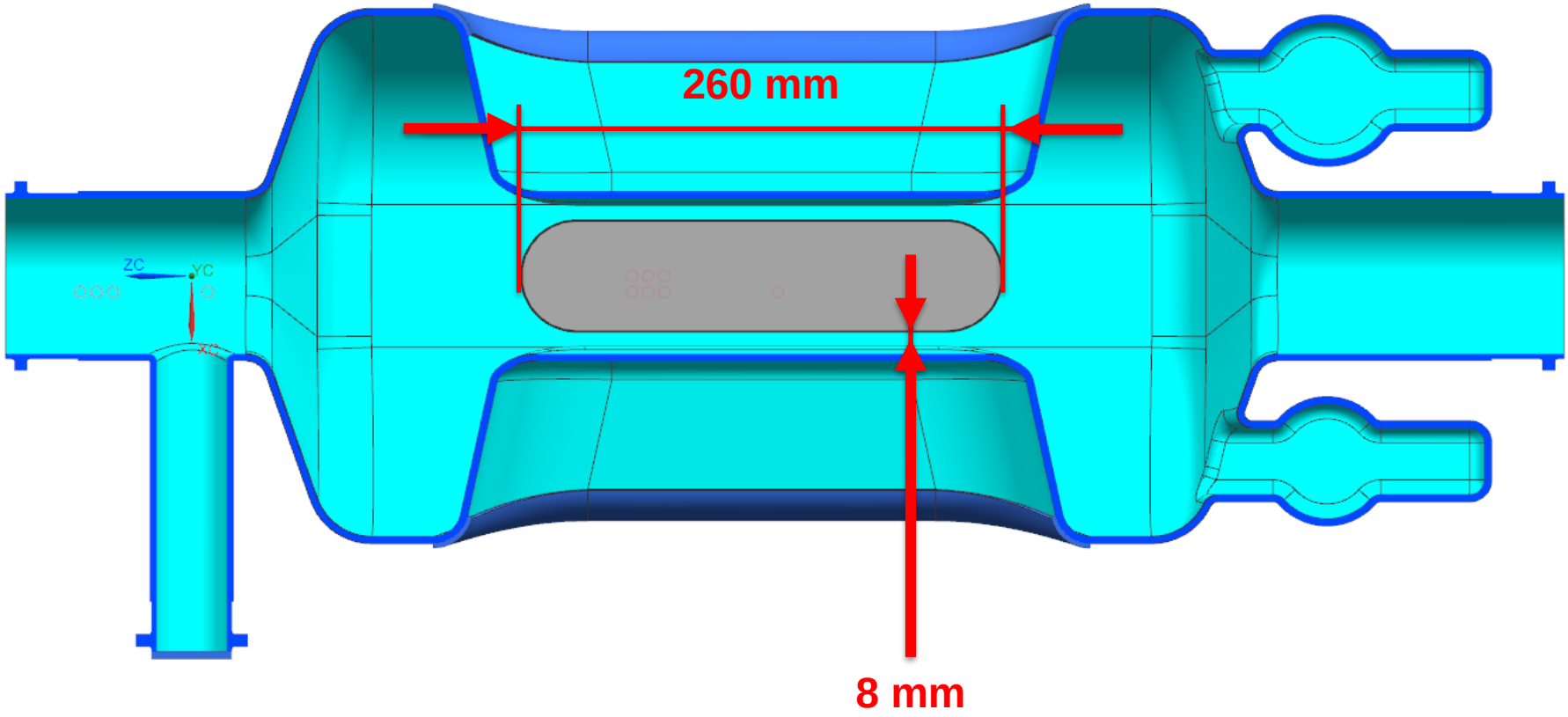




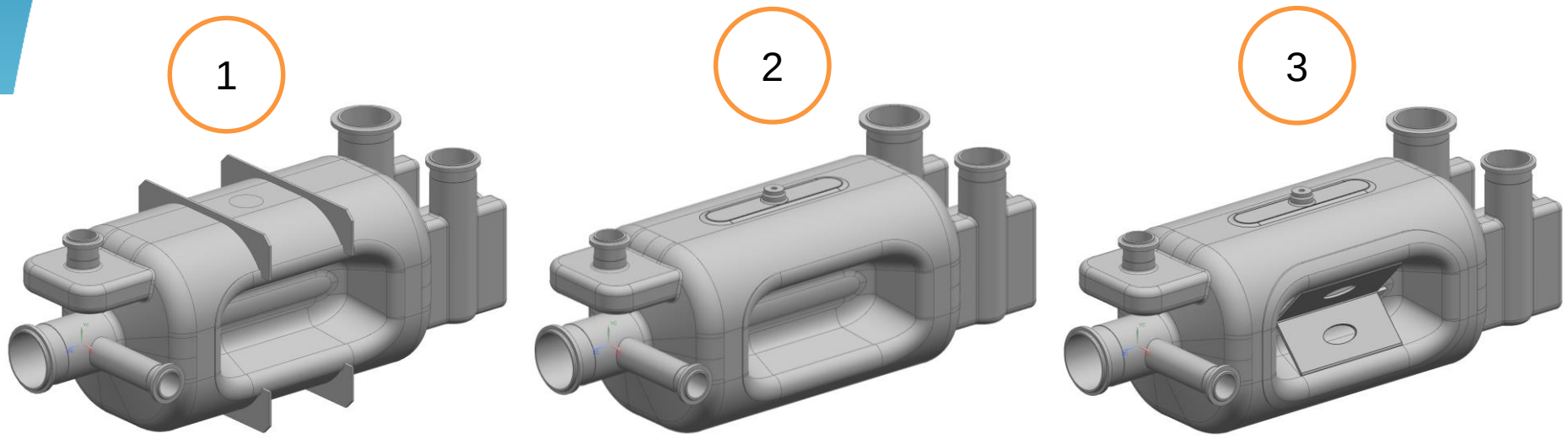


- Use of thicker material to distribute stresses and tuning forces.
- Large radius (19 mm) reduces stress concentration
- More material under the interface (original design was 1.6 mm)
- Shape optimized to allow EBW from both sides for a 4mm thick weld

Proposed design of tuning interface



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

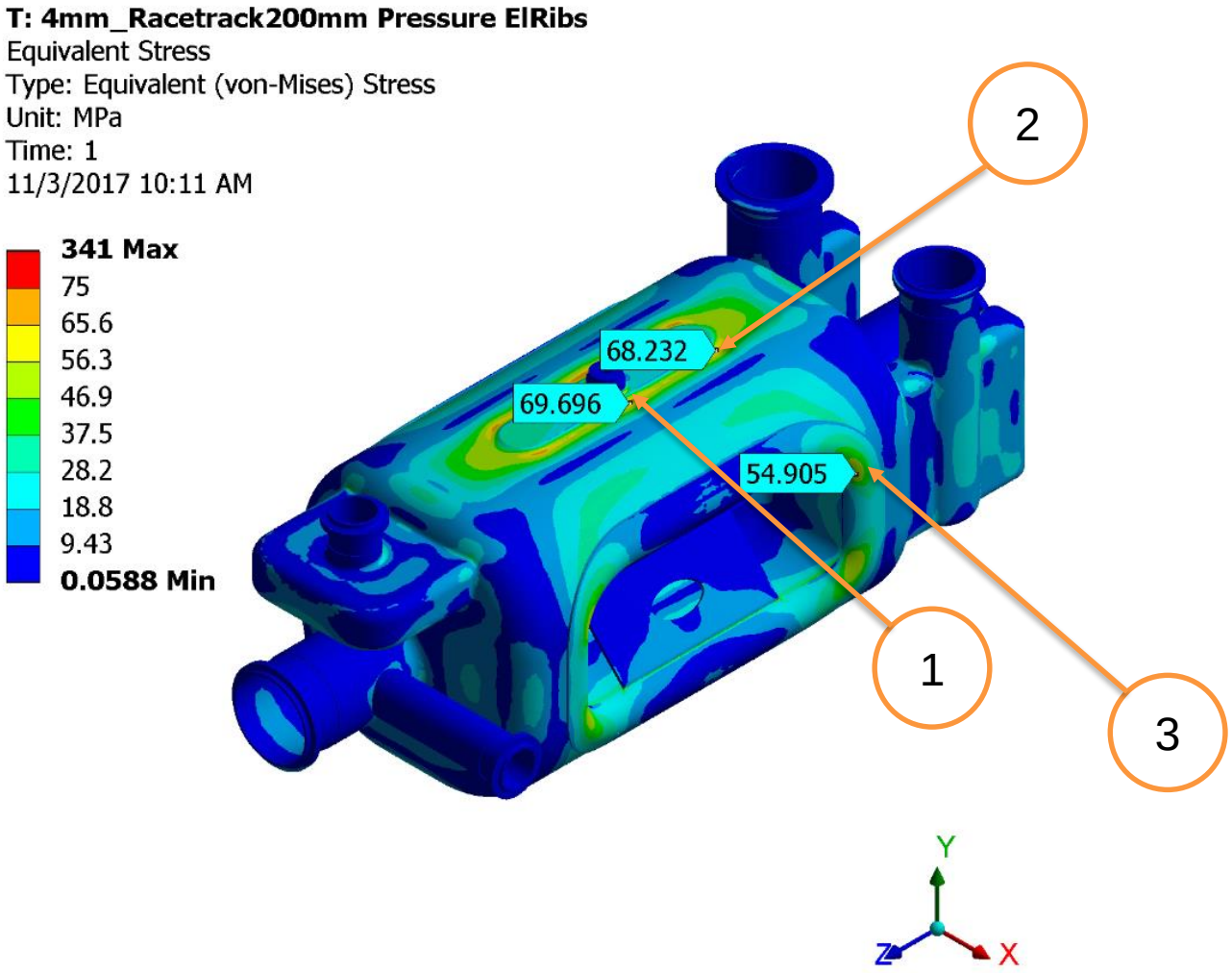
Linearized Stresses for 1.8bar – Free Tuner

Area	Pm [MPa]	Pm+Pb [MPa]	Allowable (Pm+Pb) [MPa]
1	8.4	46	75
2	30.4	56.7	75

Area	Pm [MPa]	Pm+Pb [MPa]	Allowable (Pm+Pb) [MPa]
1/2	9.8	67	75

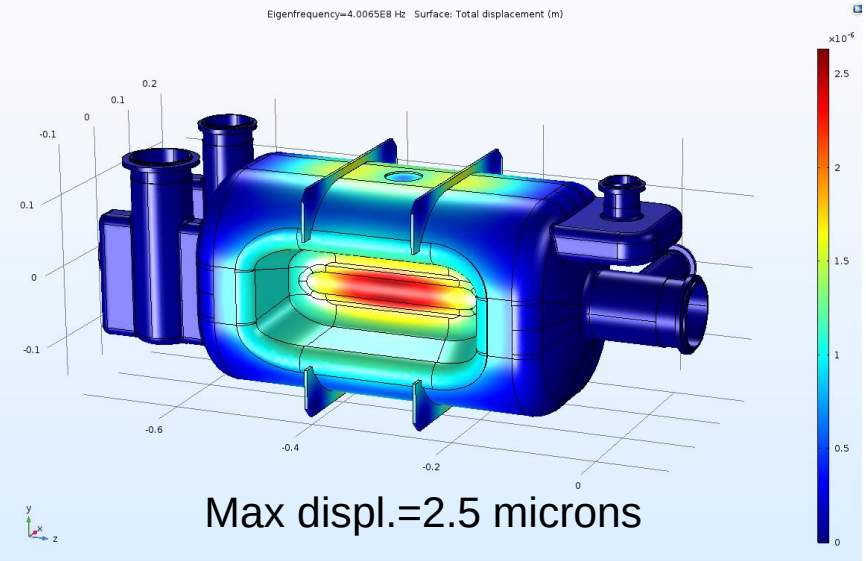
Area	Pm [MPa]	Pm+Pb [MPa]	Allowable (Pm+Pb) [MPa]
1/2	10.2	68	75
3	28	56	75

Racetrack + Electric ribs: Tuner flange free



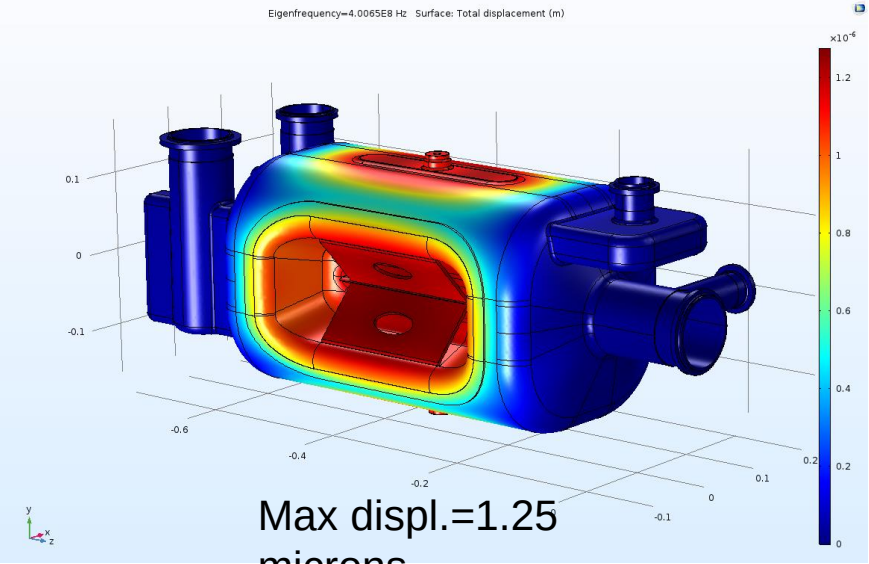
LFD study

Previous design



Max displ.=2.5 microns

Updated design

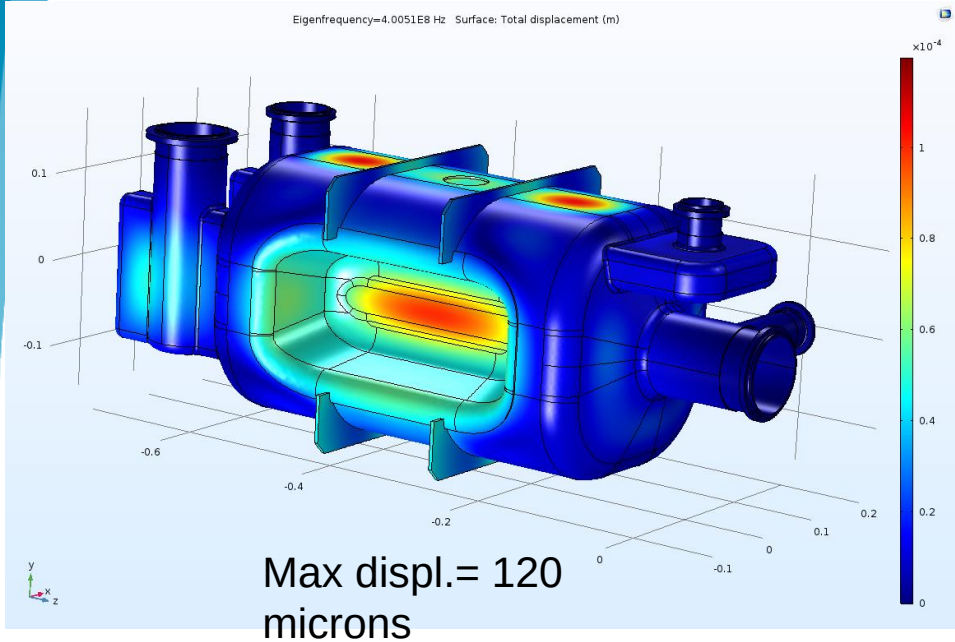


Max displ.=1.25 microns

Lorentz force Detuning WITH TUNER 6.8 kN/mm				
Case	F0 @ 0 MV	F1 @3.4 MV	dF=F1-F0 [kHz]	LFD @ 3.4 MV [Hz/MV^2]
Updated Mechanical Design	4.01E+08	4.01E+08	-5.31E+00	-4.47E+02
Previous Mechanical design	4.01E+08	4.01E+08	-7.17E+00	-6.02E+02

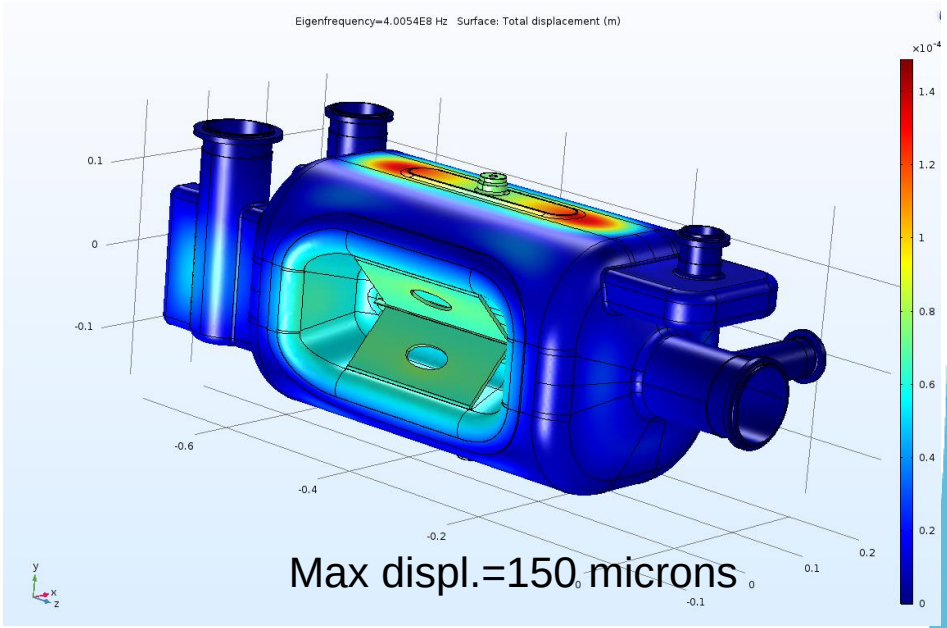
dF/dP study

Previous design



Max displ.= 120 microns

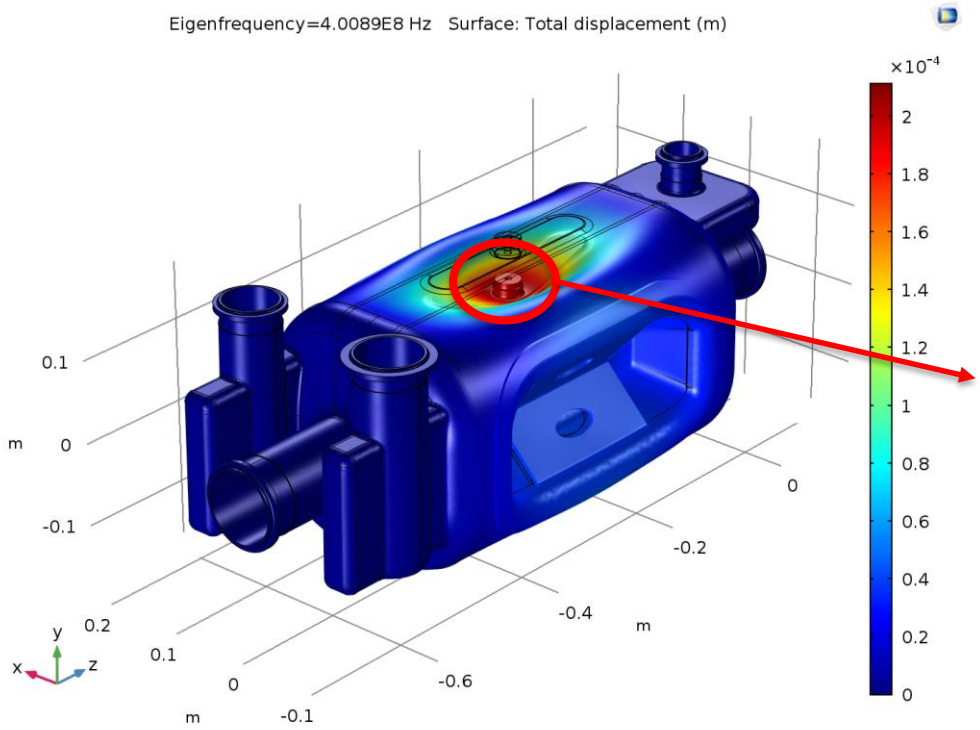
Updated design



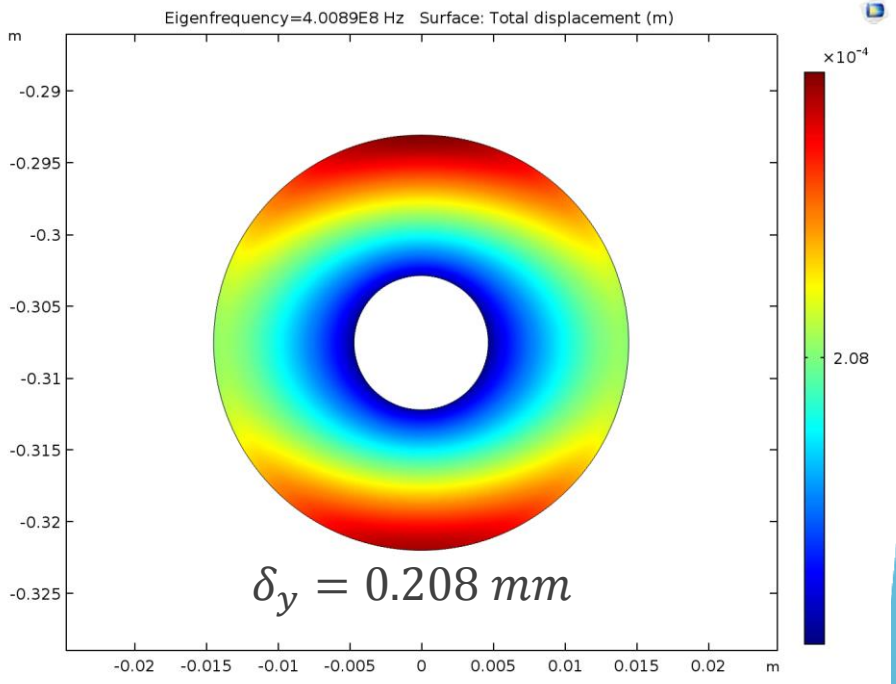
Max displ.=150 microns

dF/dP WITH TUNER 6.8 kN/mm				
Case	F0 @ 0 Bar	F1 @1 Bar	dF=F1-F0 [kHz]	dF/dP [Hz/mbar]
Updated Mechanical Design	4.01E+08	4.01E+08	-1.12E+02	-1.12E+02
Previous Mechanical design	4.01E+08	4.01E+08	-1.47E+02	-1.47E+02

Frequency shift and displacement

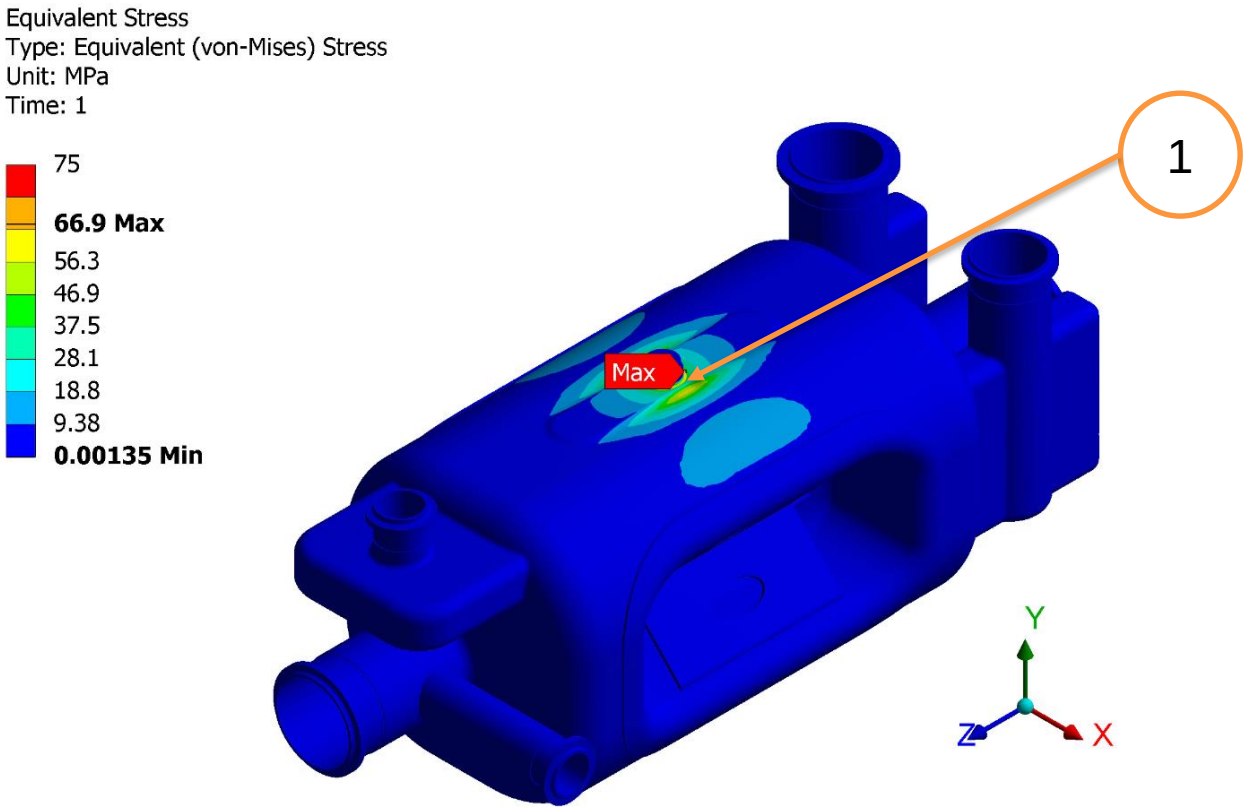


Displacement of the top flange along Y: δ_y



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

Peak stress



Area	Pm [MPa]	Pm+Pb [MPa]	Allowable (Pm+Pb) [MPa]
1	9.8	40.7	75

Procurement of AUP Prototypes

- Main goal of prototypes is to lead the path for production in 2020-2021
- Procurement will be set up as 2 + option of 12 units to ensure continuity at the same supplier
- Bare cavity and Helium Tanks not necessarily at same supplier
- Heavy Oversight of AUP representatives
- Award will be based on ”best value” to include a technical score
- Material provided to cavity supplier:
  - RRR niobium sheets
  - Nb-Ti discs
  - Nb-SST brazed joints
- Minimum set of documents necessary for launching prototypes:
  - Functional drawing of bare cavity (exists for LARP cavity, exists for CERN DQW call for tender)
  - Engineering specification (exists from CERN DQW call for tender)
  - Example of MIP (exists for CERN DQW)

Challenges of Prototype Fabrication

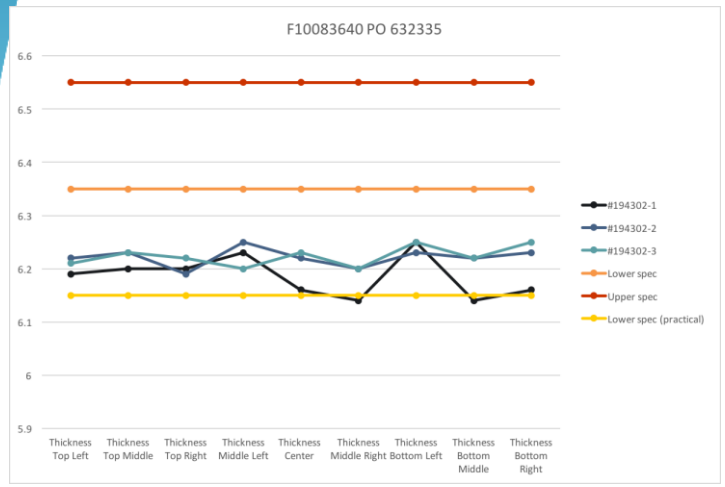
- Interactions AUP-Industry and AUP-CERN to compile all necessary QA/QC documentation
- Qualification of all weld joints according to CERN requirements
- Definition of best plan for Radiographic inspection of welds in Industry
  - Likely to be outsourced to independent body
  - Favorable to minimize number of setups and shipments
  - Possible to explore digital imaging, allowing inspection of multiple welds with same setup

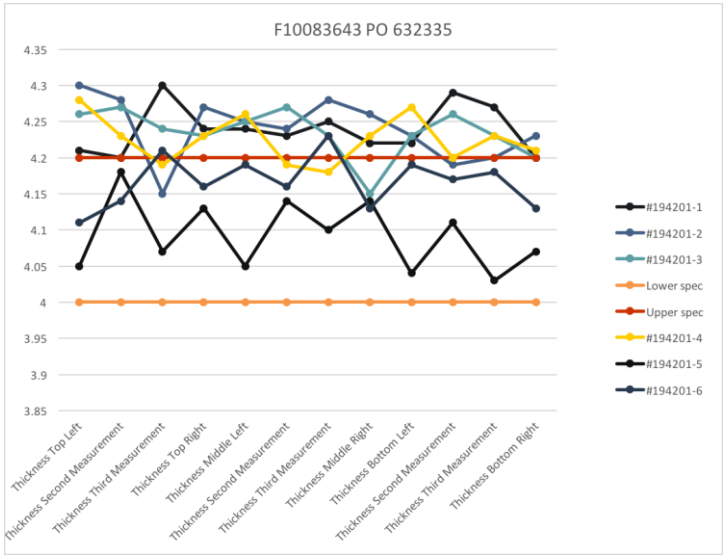
RRR Nb for AUP Prototypes

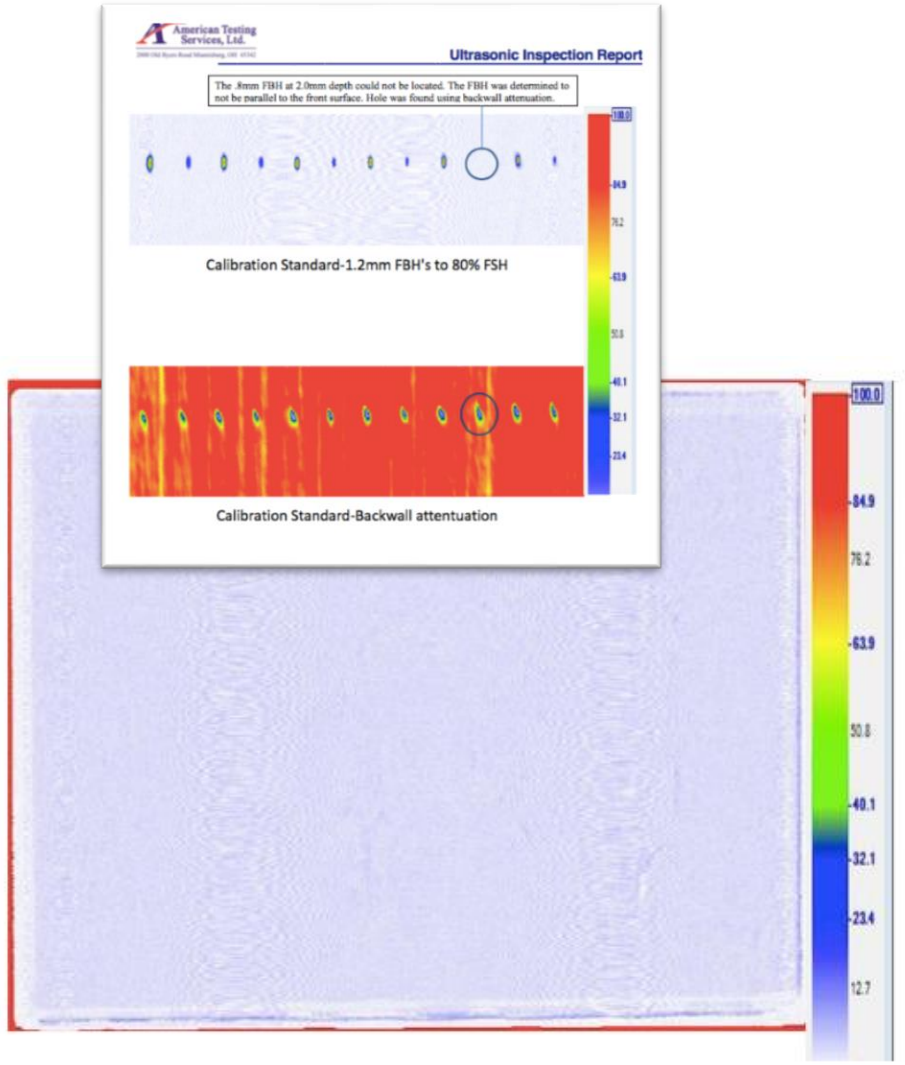
- Received RRR Nb for 2x RFD prototypes
  - 3.15mm Sheets
  - 6.35mm Sheets
  - Rods
  - Tubes
  - (+ NbTi Discs)
- Visual & Dimensional Inspections, Including water-soak completed and documented: OK
- Ultrasonic Inspection for sheets completed: OK
  - do we need UT on rods/tubes?
- Traceability is given highest importance
- First opportunity to use CERN MTF system

US HL-LHC AUP

RRR Nb Sheets Inspections (in progress)







Side 1

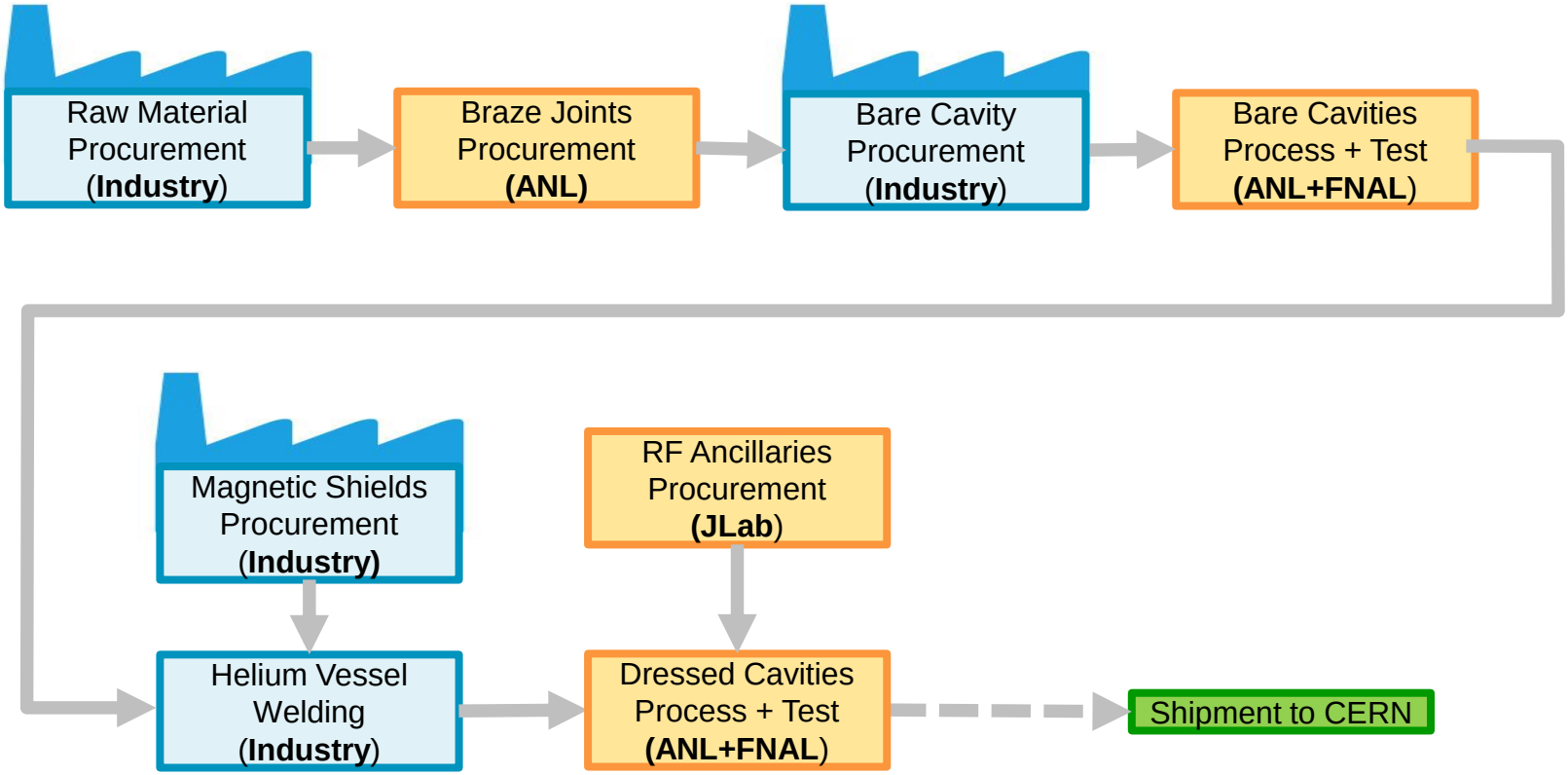
Summary

- Final Design Review for Nb procurement is May 2018
  - Need agreement on Niobium documents
- Preliminary Design Review for Dressed Cavity is June 2018
  - Need “first-pass” agreement on interfaces, functional drawing, acceptance criteria (including MIP, weld qualification,..)
- RF Design of RFD modified, need agreement
- New Mechanical Design proposed, need to evaluate best strategy, considering impact on CERN fast-track in-house plan
- Niobium inspections are first opportunity for using CERN MTF system, let’s start
- Procurement of 2x RFD Prototypes imminent by AUP. Need to converge on functional drawing of bare cavity

Additional Slides

Fabrication and Qualification Flow Plan

- Large procurements in industry
- Processing/Testing in laboratories
- Centralized management at Fermilab (Issue PO's, Perform QC)



Charge 2.a

Processing & Testing Plan (2)

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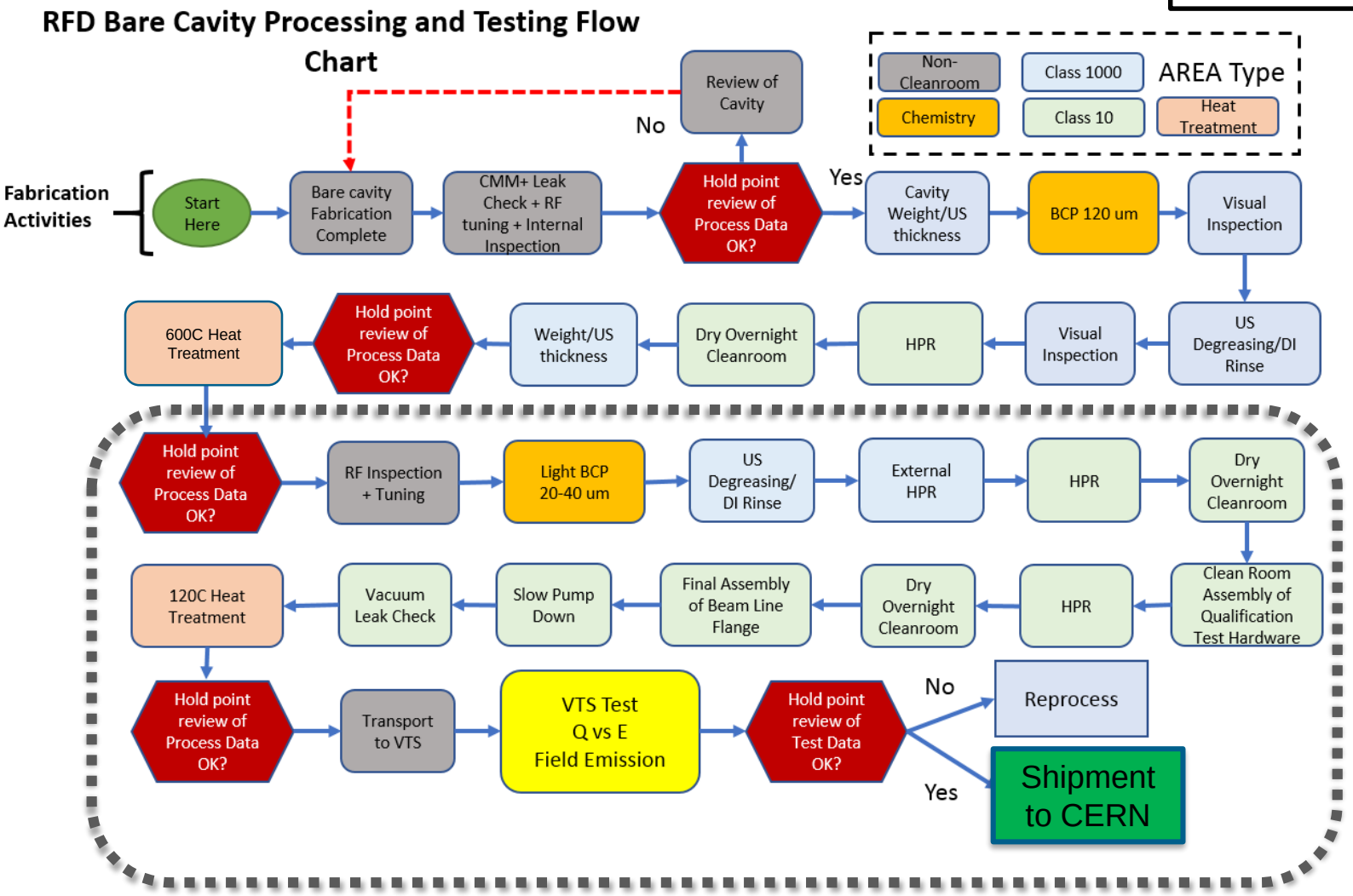
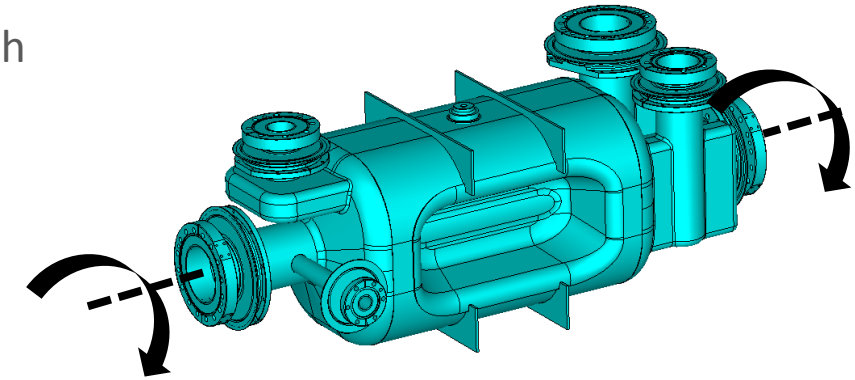
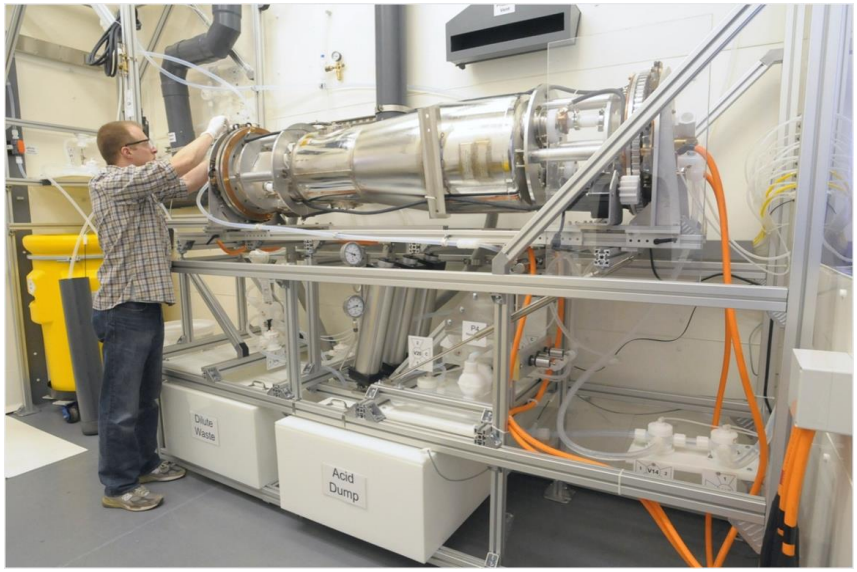


For Dressed Cavity: Only second half of operations

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