Summary of the WP4 breakout session

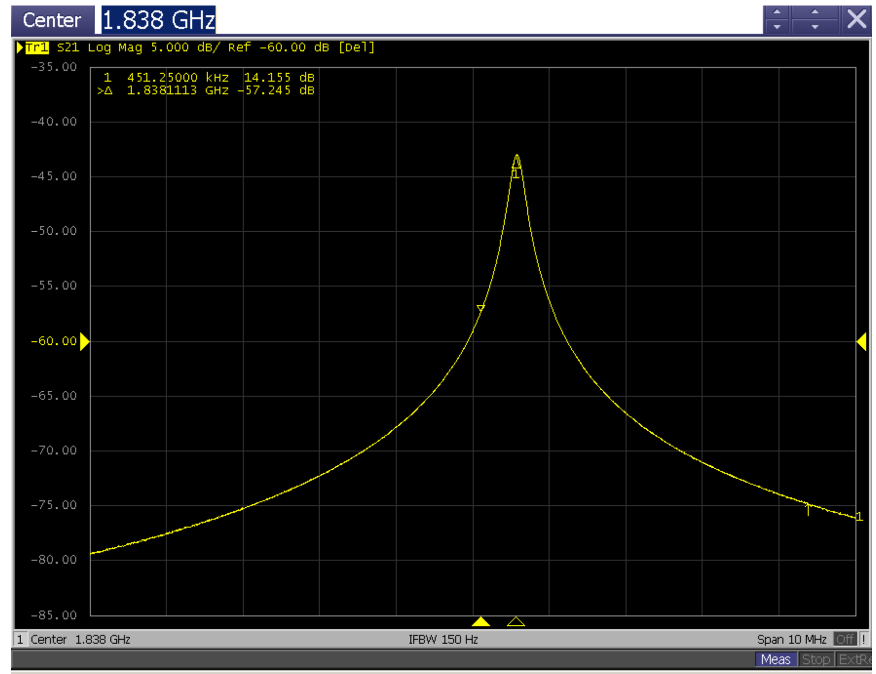
Alessandro Ratti – SLAC
for the global crab cavity team

Outline

- Details of test results and lessons learned from DQW and RFD processing and testing
- HOM damper studies and updates
- CM integration of RFDs in the UK
- Documentation and planning for AUP
  - CDR, ESD, other documents

Cold Test Frame Assembly @ CERN

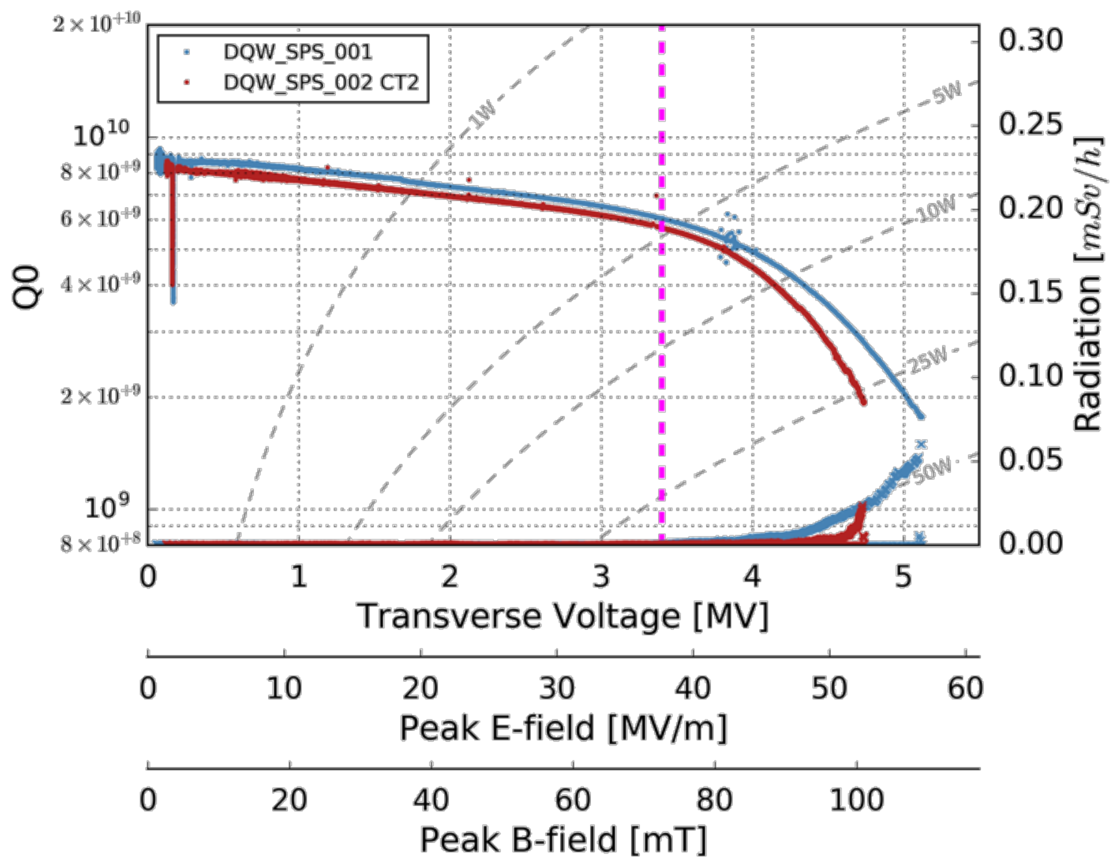
1.8 GHz mode followed to minimise Δf while mounting frame



K. Turaj, CERN-BE-RF-SRF

A. Castilla

DQW Final Results @ CERN



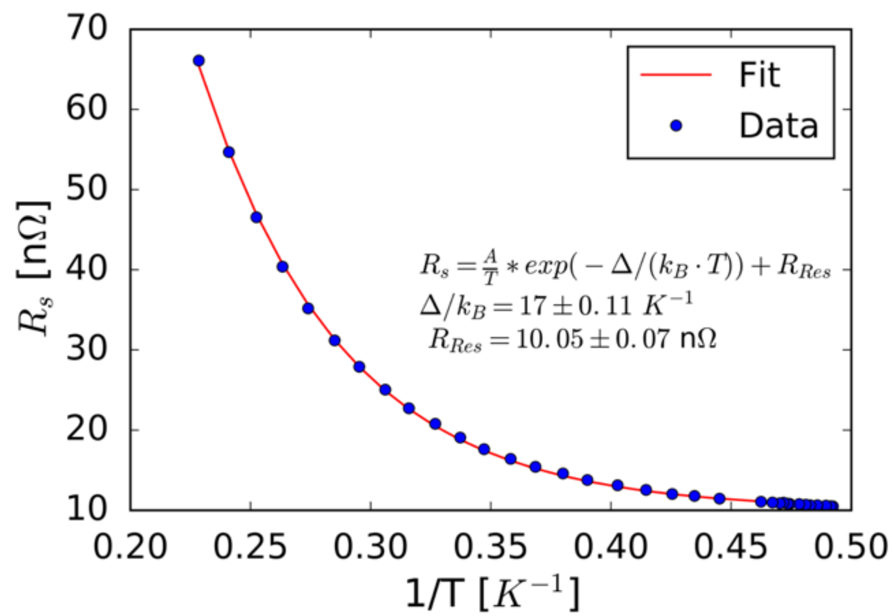
- R_{res} ~ 10 nΩ
- < 5 W/cavity at 3.4 MV
- FE onset ~4 MV
- Quench:
  - V_T > 4.5 MV
  - $B_{peak} \geq$ 100 mT
  - E_{peak} > 50 MV/m

A. Castilla

Other Results DQW_SPS_001

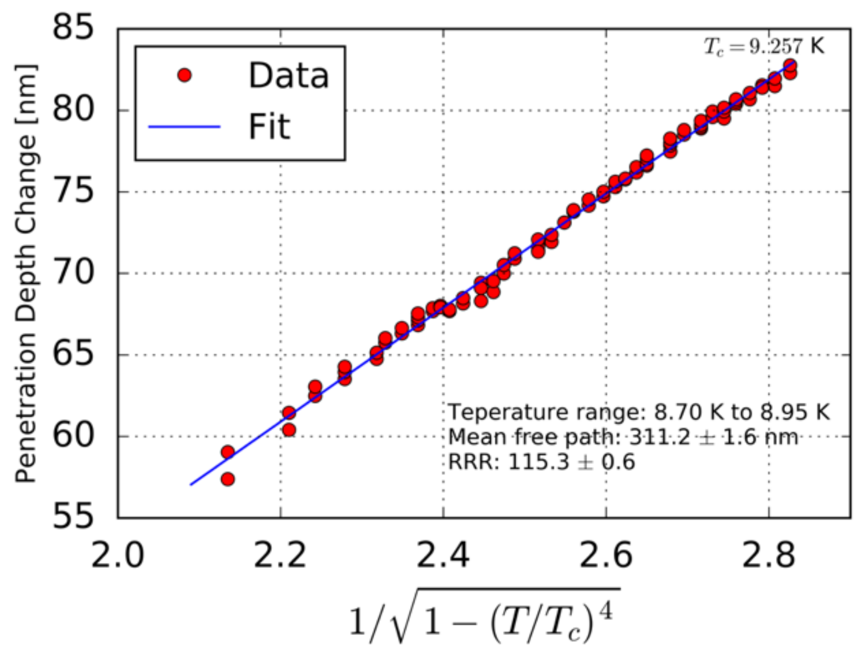
Surface Resistance

R_{res} = 10.05 ± 0.07 nΩ



Surface RRR

115.3 ± 0.6



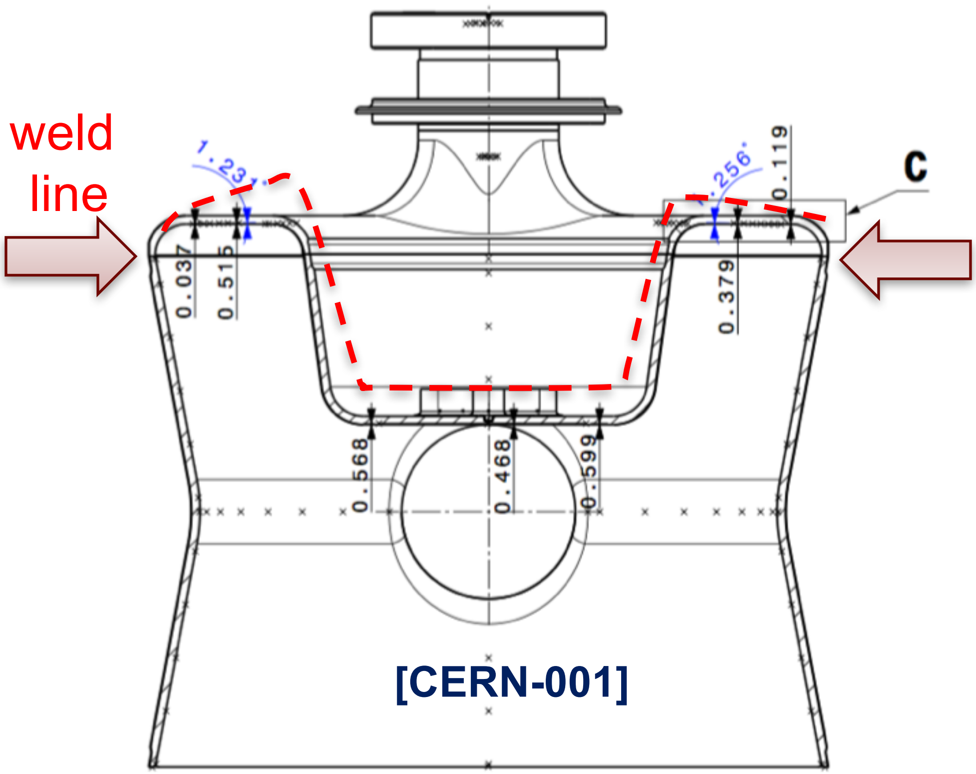
K. Hernandez-Chahin, UGto/CERN-BE-RF-SRF

A. Castilla

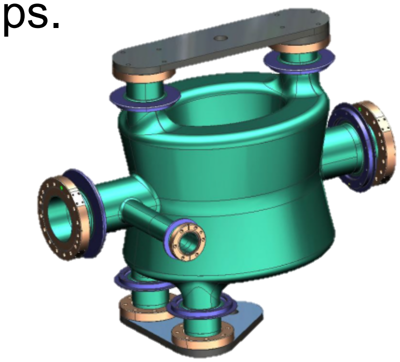
DQW - Improvements to SPS design

④ Cavity detuning after welding reveals precise tuning method

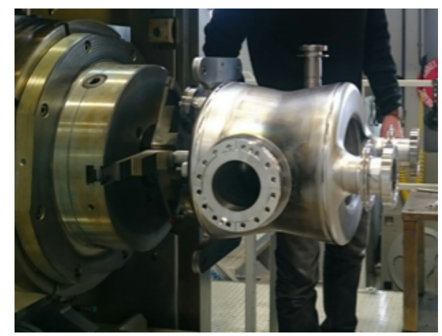
- Large frequency change after EB weld for the final welding steps.



[CERN-001]



[Weld setup: NWV-001]



[CERN-001]

- Possible explanation:
  combination of “pinching” + radial shrinkage effects influenced by clamping technique
- Next: Estimate the field distribution change due to change in cavity shape and looking into firm fixing of the ports at welding or restore frequency by tuning after weld.

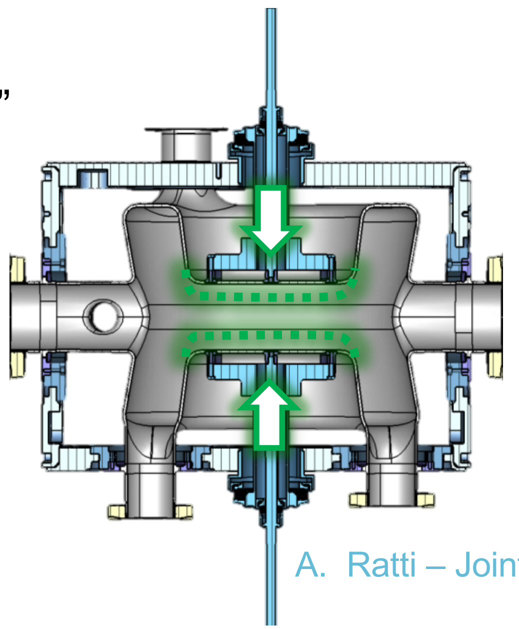
Q. Wu

DQW Improvements to SPS design

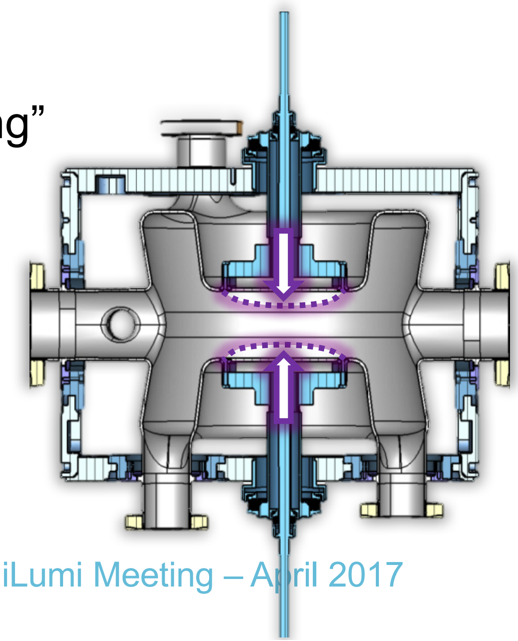
⑤ Beam aperture requirement

- The **Functional Drawing** defined manufactured cavity at 300K before BCP so that cavity at 2K after BCP [2 x (0.15 + 0.03 +0.03) mm] had 84 mm aperture.
- Also, the **Fabrication Drawing** for main subassemblies accounted for the weld shrinkage, so that aperture requirement would be satisfied by the fully welded cavity.
- However,
  1) some **processes** (weld, BCP) can lead to **unknown shifts in cavity aperture;**
  2) most of the **tuning methods** for the DQW **change cavity aperture** (highest E-field region)
- According to CERN ABP, there is **some margin from required 84 mm** to the actual aperture limitation, so there is **no need to change the DQW capacitive plate distance**.

“Pre-tuning”



“Tuning”

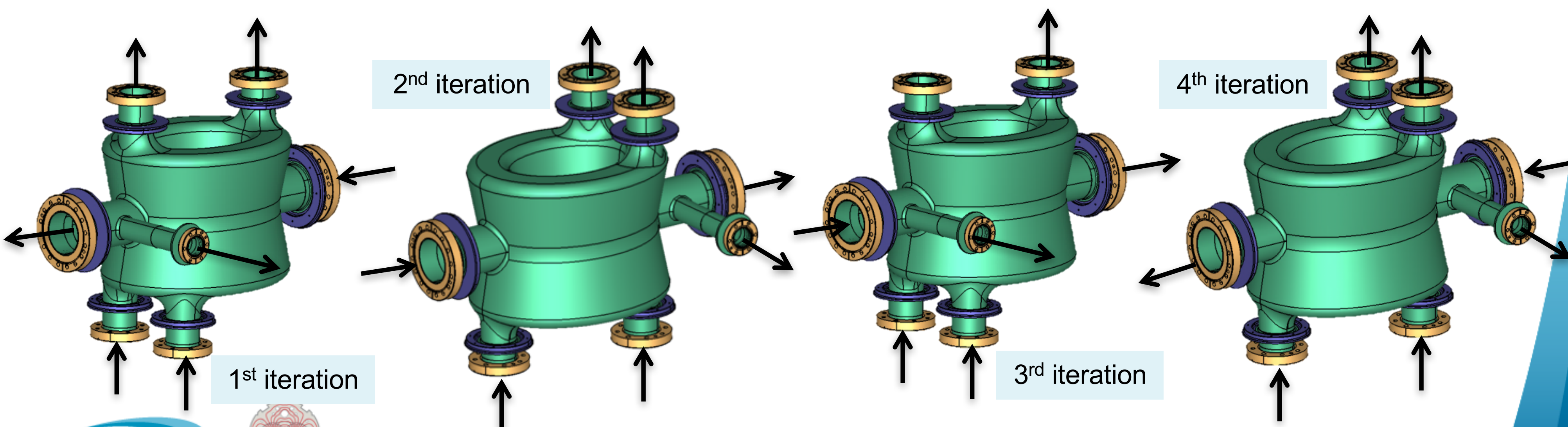


Q. Wu

DQW Improvements to SPS design

⑥ Perform **BCP in several iterations** for more **uniform removal**

- **Expected non-uniform removal** from BCP in **DQW complex shape**.
- BCP performed in **fixed bench**
- *Strategy:* **Bulk BCP** done **in several iterations** to **minimize non-uniformity** (2 at Jlab, 4 at CERN) for different **cavity orientations and inlet-outlet port configurations**
- **Complemented** with Fluent **simulations** to understand impact of acid flow and cavity orientation; **and benchmark measurements** for acid flow relation to removal rate.



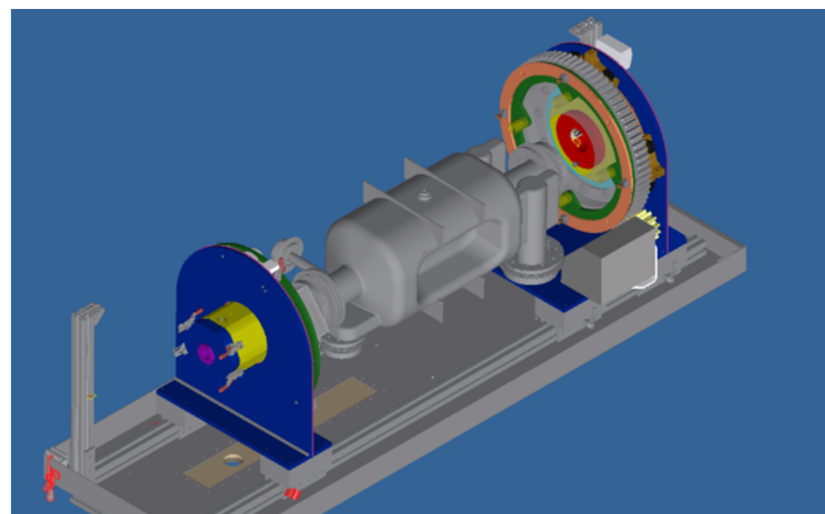
Q. Wu

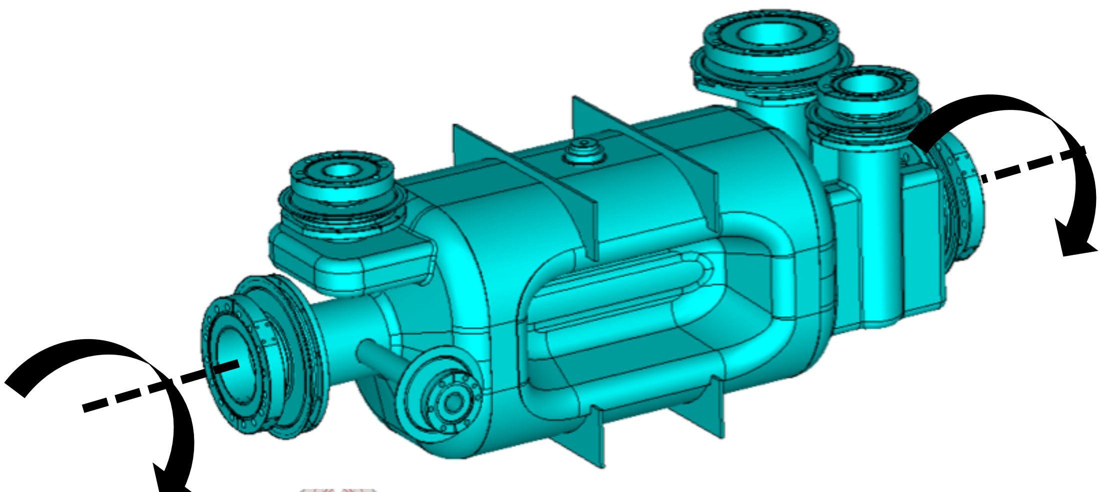
RFD Lessons Learned: Cavity Processing (2)

- Currently bulk BCP, light BCP and HPR are done in vertical orientation
- Recommendation → Perform chemical processing in horizontal orientation with rotation and tilting
  - Allows more uniform removal
  - Better acid circulation and drainage
- Use of a high pressure rinse set-up using multiple ports e.g. MSU (Rinsing through FPC and HHOM ports)
  - Allows minimizing field emission

Stains left from BCP

Horizontal BCP/EP tool – (ANL)

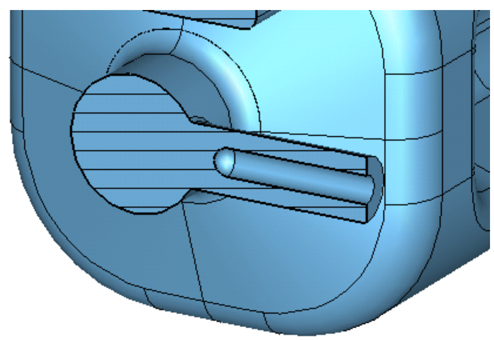


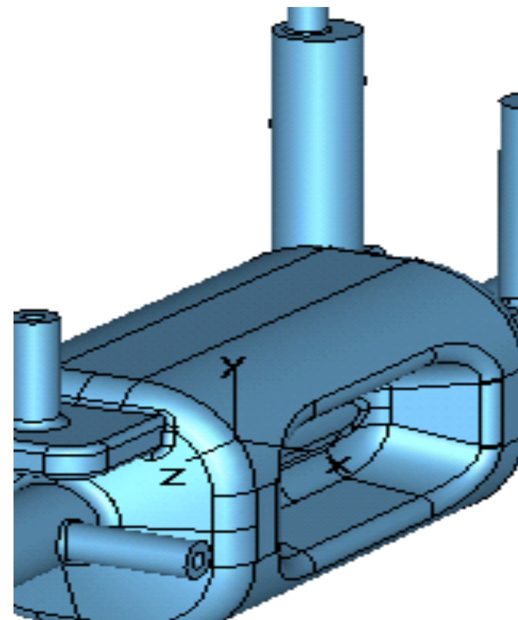


S. De Silva

Next Steps: EM Design Modifications (1)

- No major modifications are required for LHC-RFD cavity design
- Proposed changes are based on effective cavity processing, assembly, and integration of the cavity to He vessel
- Change 1: Modify pick up port diameter
  - Pickup port radius increased to 40 mm from 20 mm for easier cavity cleaning
  - Pickup probe coupling: 2.7×10^{10} to extract 1 W at operating field
  - No changes seen on cavity properties or on HOM spectrum and damping from simulations

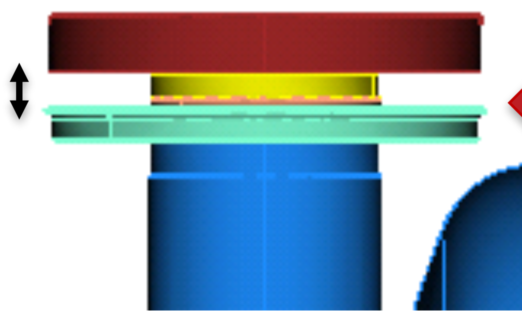




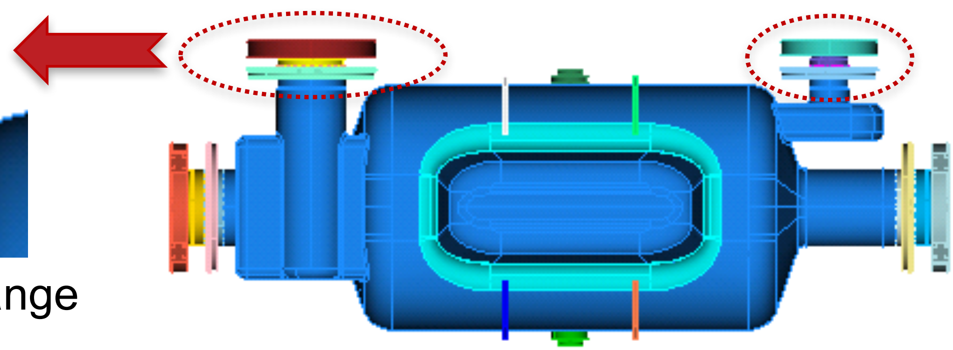
S. De Silva

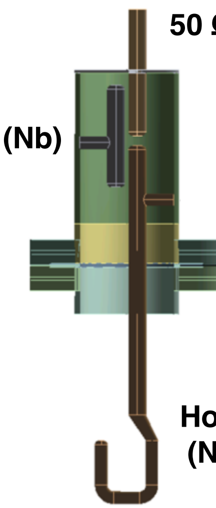
Next Steps: Eng. Design Modifications (2)

- Change 2: Increase FPC, HHOM and VHOM ports flange locations and NbTi adapter ring position
  - Present design gap between flange and NbTi adapter ring is tight
  - Also gap between NbTi adapter ring is tight
  - Would ease and speed assembly in cleanroom
  - There will be no change in damping of HOMs
  - Need to verify the heating at the flange location for



Tight gap between SS flange and NbTi adapter ring



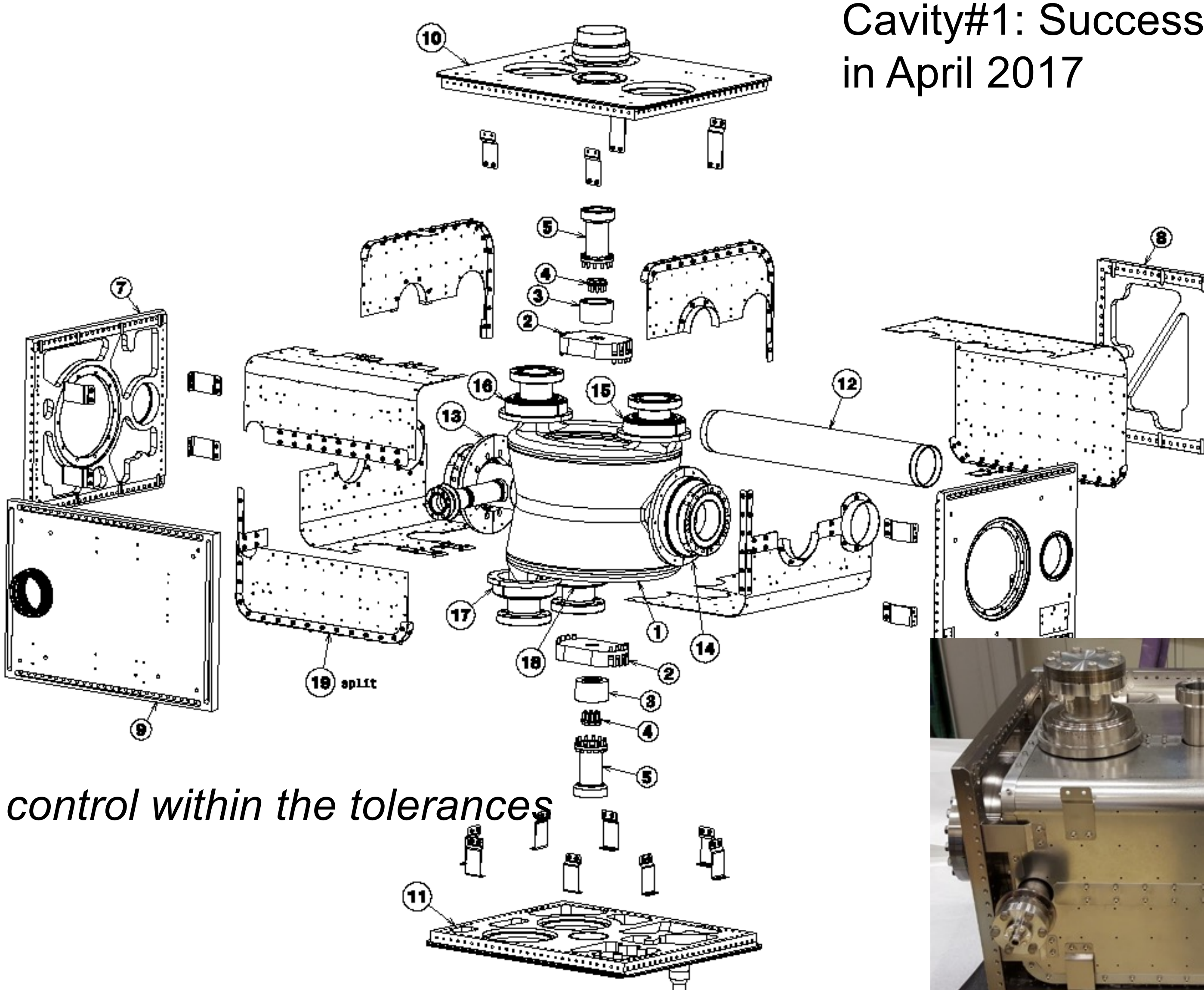


S. De Silva

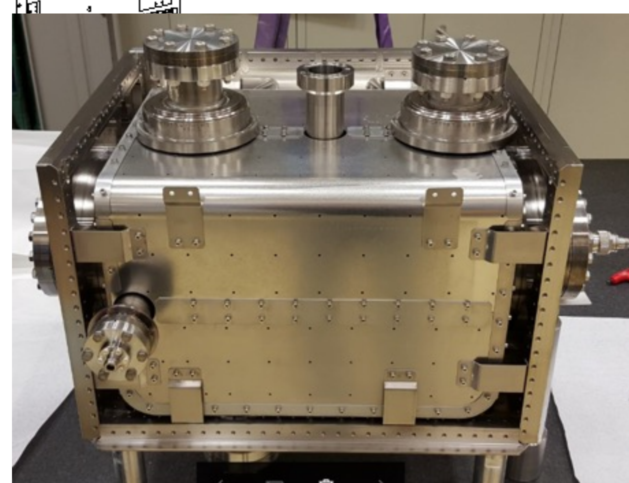
CAVITY DRESSING @ CERN

DQW CAVITY + COLD MAGNETIC SHIELD + He TANK

Cavity#1: Successfully assembled in April 2017



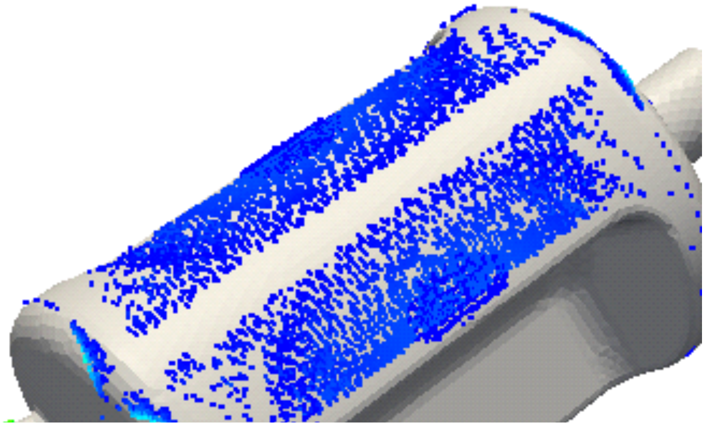
Metrology control within the tolerances

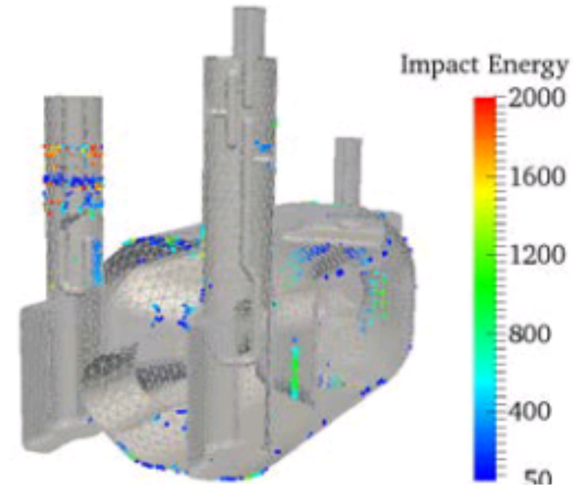


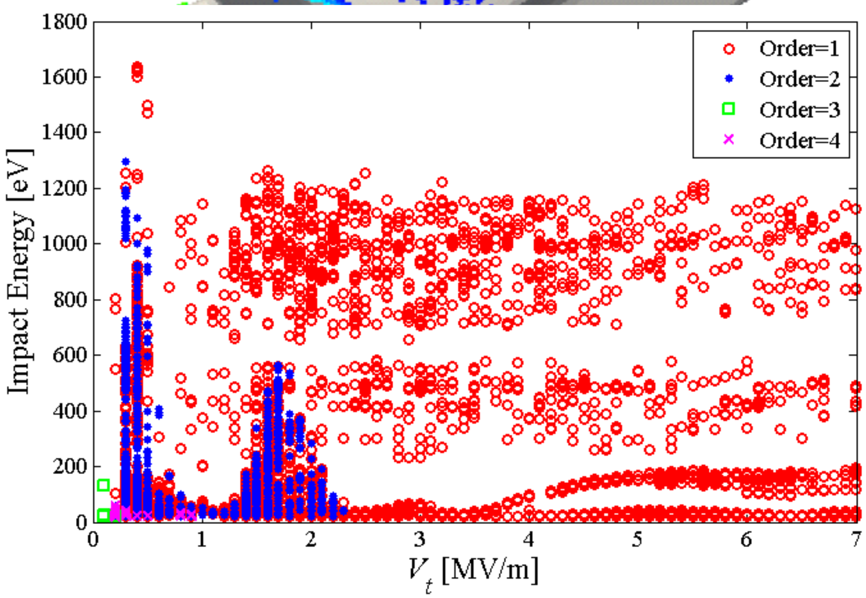
P. Freijedo Menendez

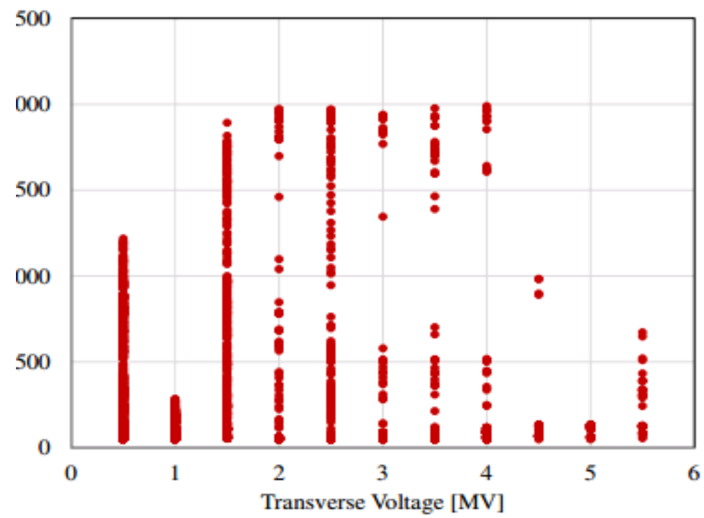
PoP and SPS RFD Cavities: Multipacting Analysis

- Improved multipacting levels on SPS-RFD cavity design
- Multipacting levels easily processed in both designs and did not reoccur









S. De Silva

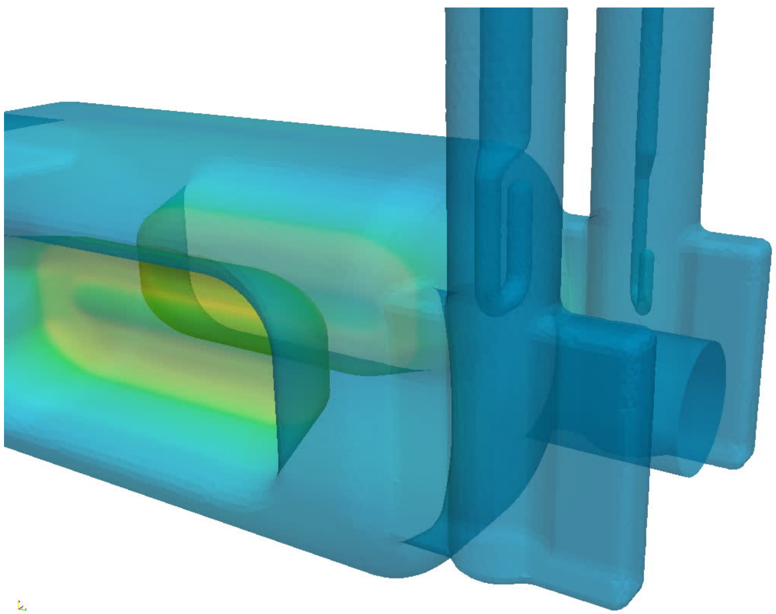
Content

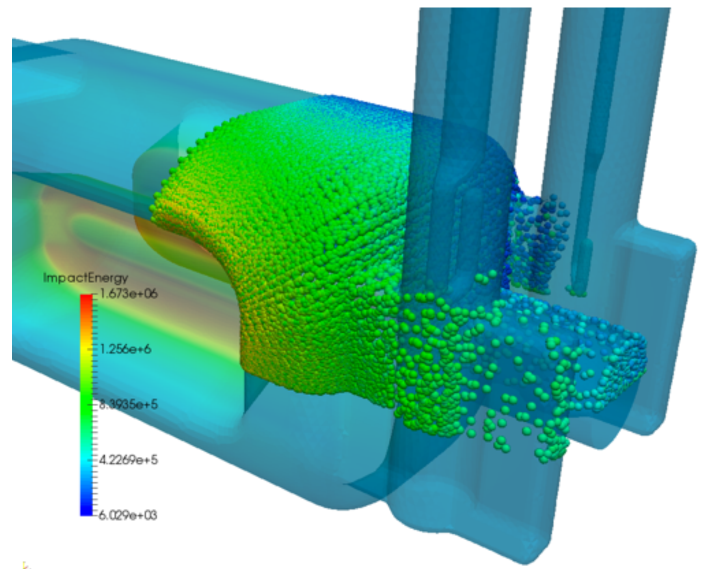
- Field emission simulation
  - Fowler-Nordheim emission in all surfaces
  - With a high emission beta (800) - emulate potential emitter in high field region
  - Record impact locations of electrons
- Simulations
  - RFD
  - DQW

Z. Li

RFD: FPC/HHOM End

- Emit in (+x, +y)



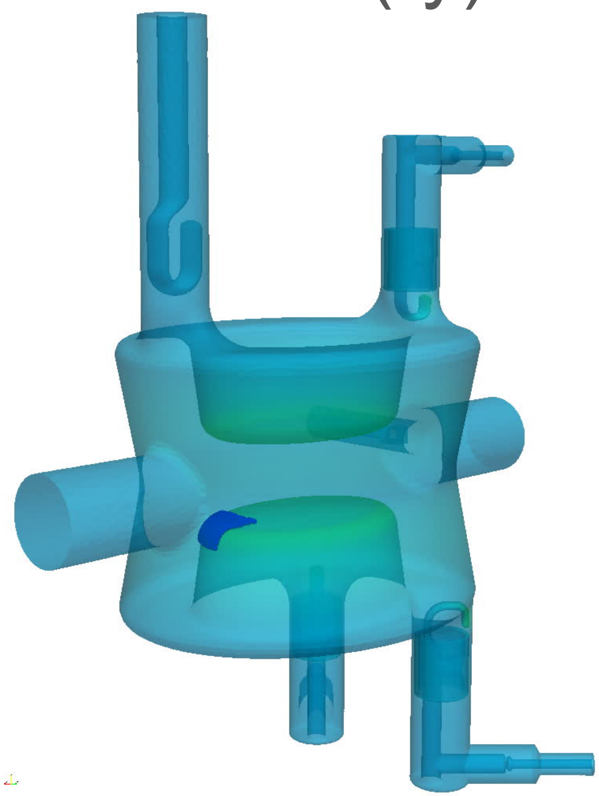


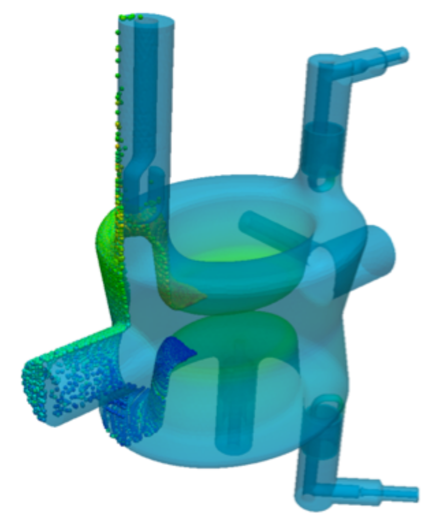
Impact location

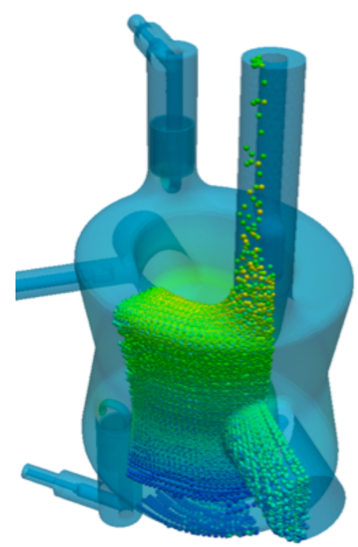
Z. Li

DQW: FPC End

- Emit in (-y)





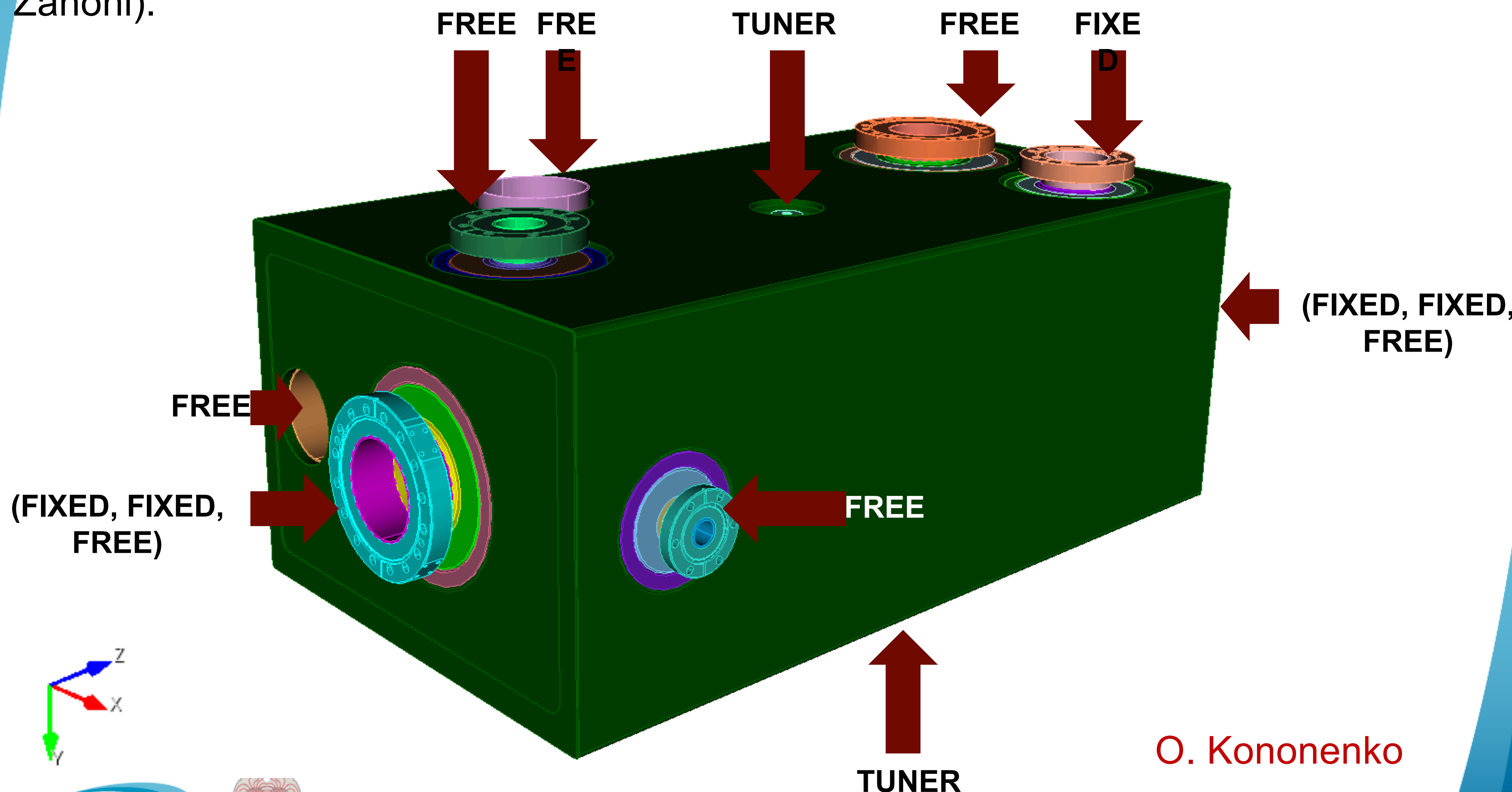


Impact location

Z. Li

RFD - Mechanical Model

Mechanical model of the RFD LHC crab cavity received from Jlab (HyeKyoung Park) with input regarding the boundary conditions and materials from CERN (Carlo Zanoni).



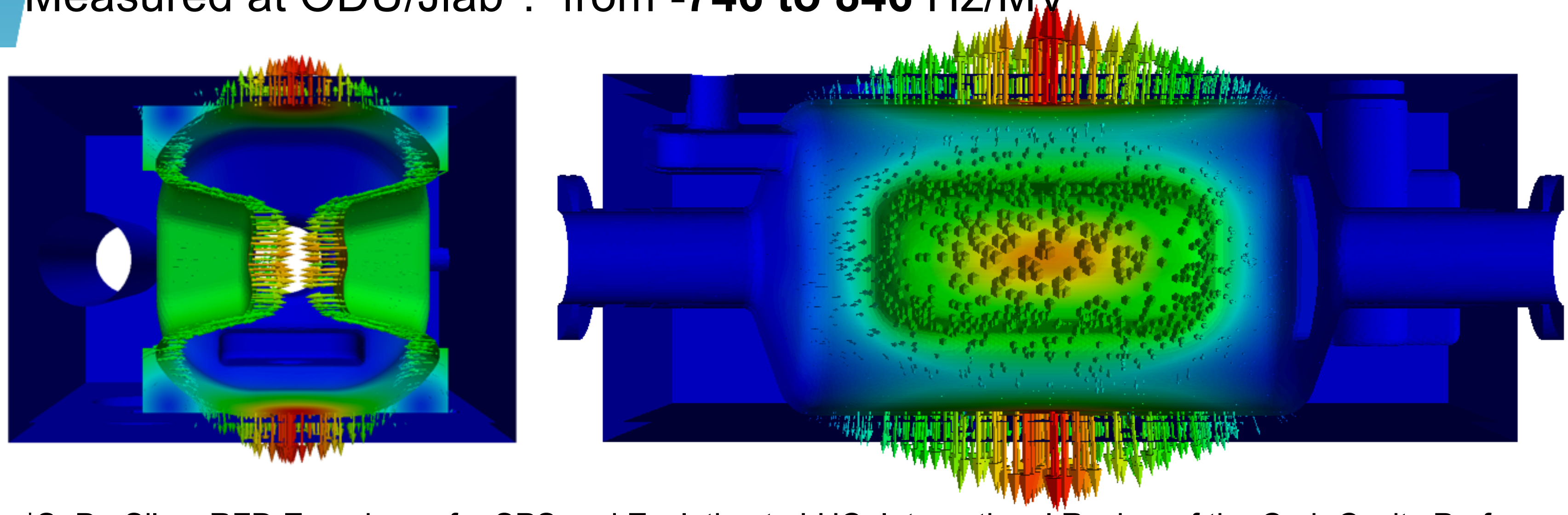
O. Kononenko

Lorentz Force Detuning

No tuner attached, simulated RF detuning : **-898** Hz/MV^2

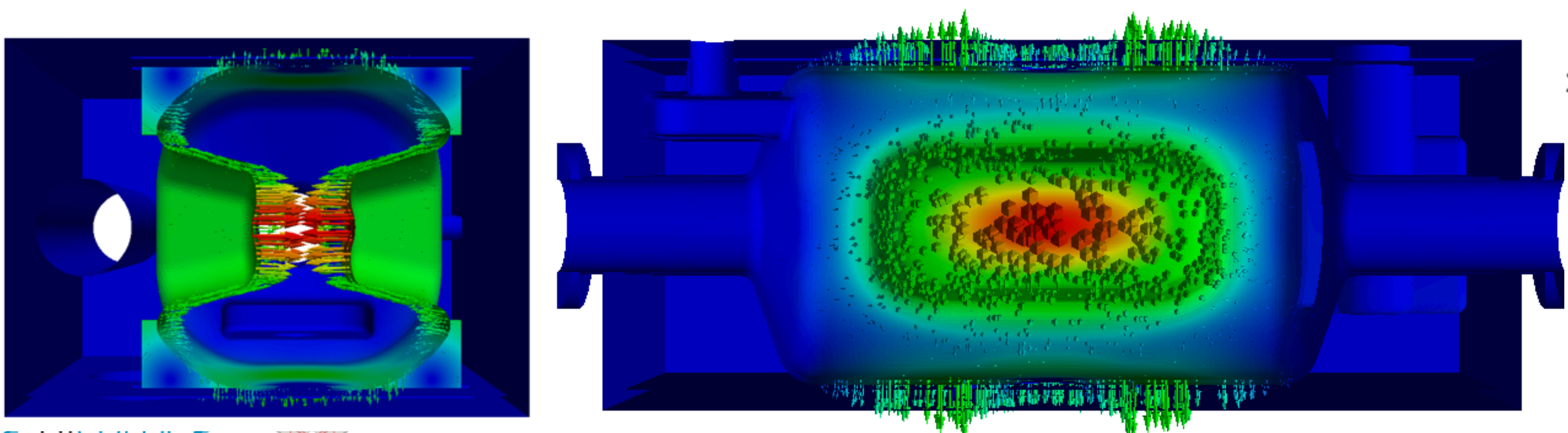
Measured at ODU/Jlab*: from **-746 to 846** Hz/MV^2

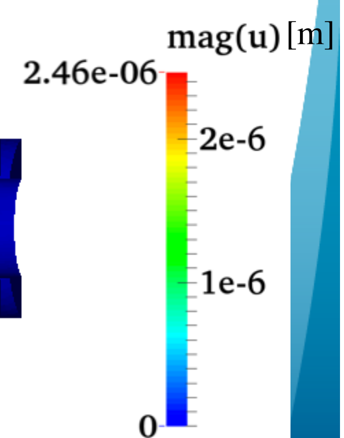
O. Kononenko



*S. De Silva, RFD Experience for SPS and Evolution to LHC, International Review of the Crab Cavity Performance for HiLumi, April 3-5, 2017

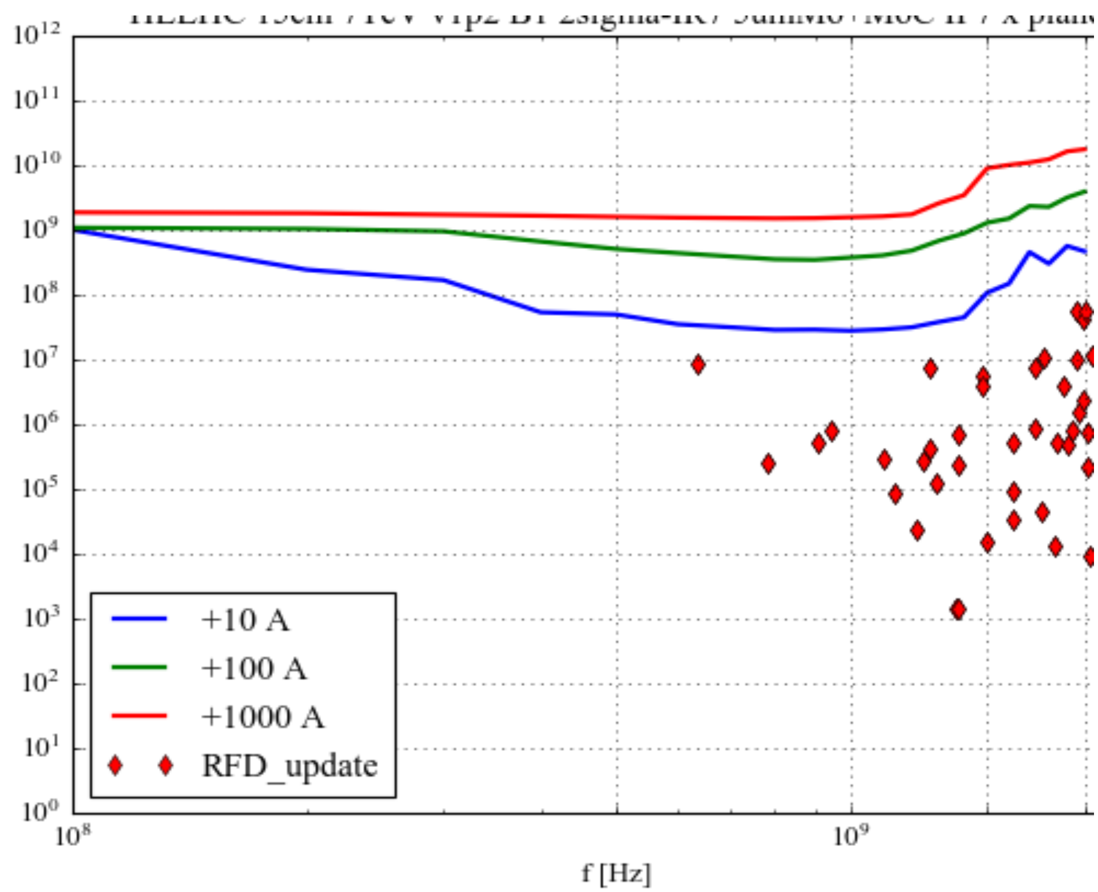
Tuner fixes the cavity vertically, simulated RF detuning: **-595.1** Hz/MV^2





Beam Stability (Courtesy: Elias Metral)

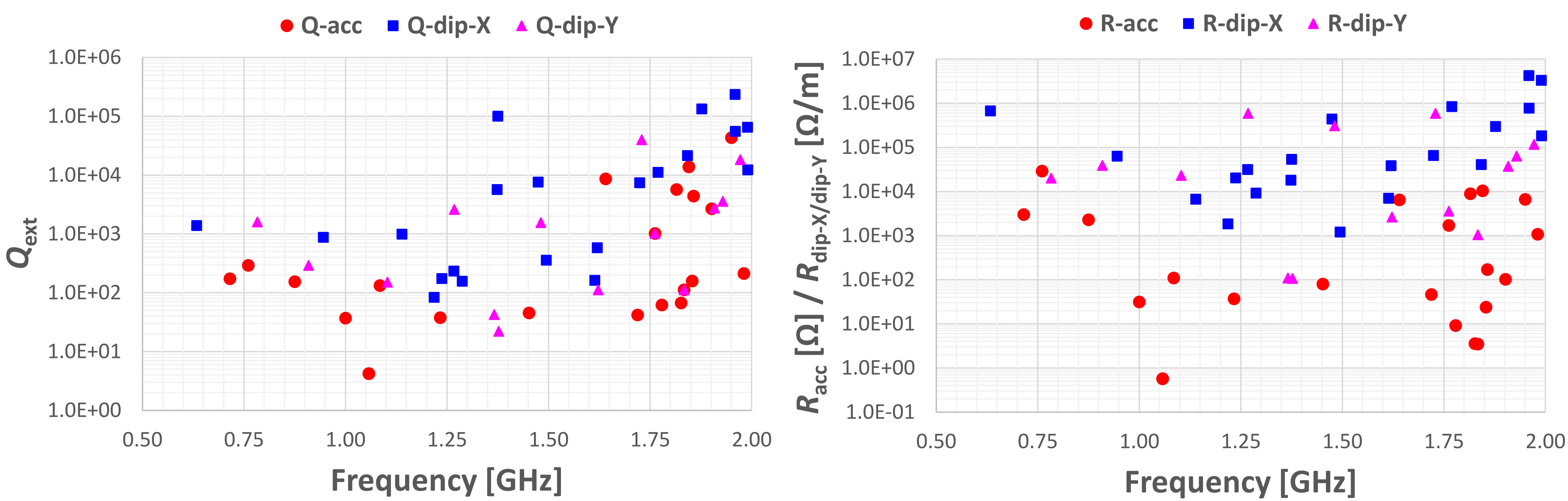
- Ref: Impedance Update – Elias Metral – HiLumi Meeting – SLAC 2016
- *Coupled bunch thresholds for the increase of octupole current over the machine baseline*



RFD HOM Damping: Stage 2

- Modes damped well up to 2 GHz
- $Z_z < 50\ k\Omega$
- $Z_t < 1\ M\Omega/m$ (except for two modes near 2 GHz)

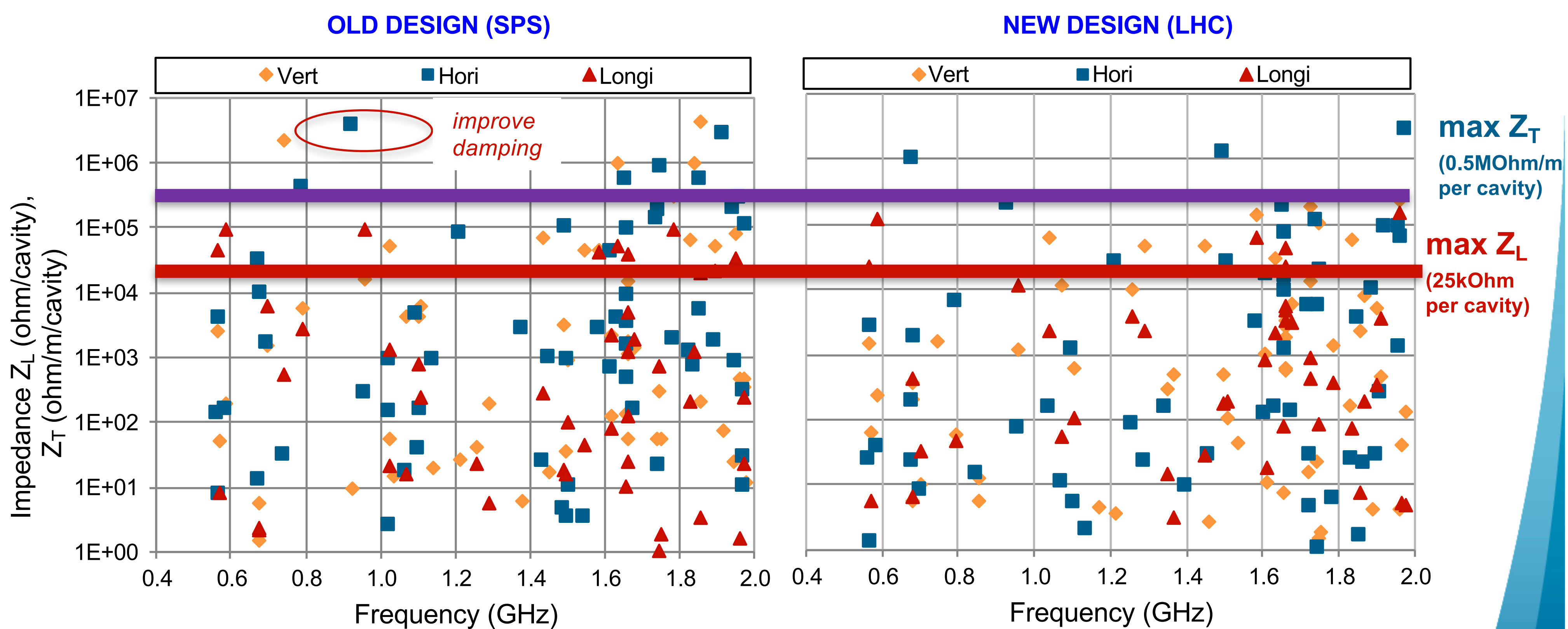
Scaled by ½ to be consistent with beam dynamics definition



DQW – HOM Damping

HOM dampers for LHC:

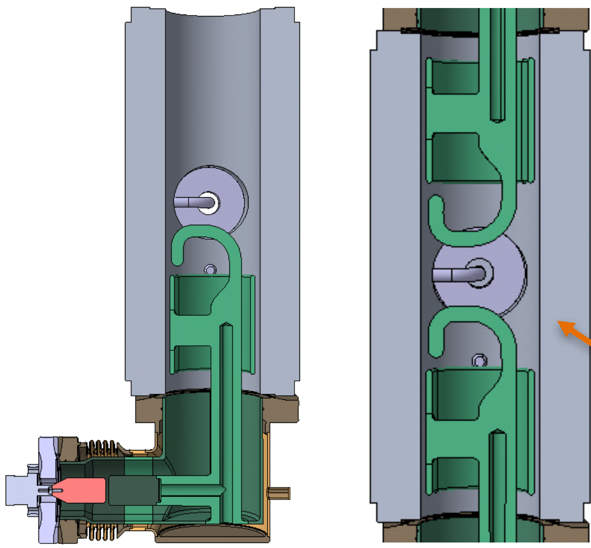
- **Z_L< 100 kOhm/cavity** for old and new design
- New design pushes **Z_T< 1 MOhm/m** per cavity except for HOM at high frequency
- Both old and new design **need pickup** to extract **1.75 GHz** mode

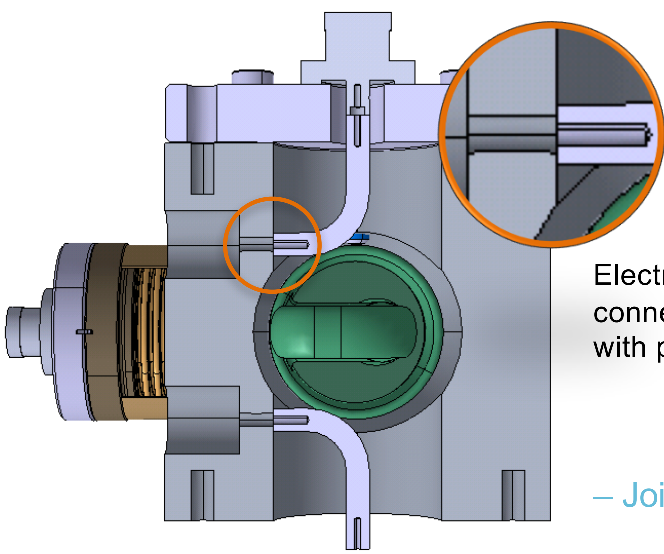


Q. Wu

L-Bend Test Box: Measurements

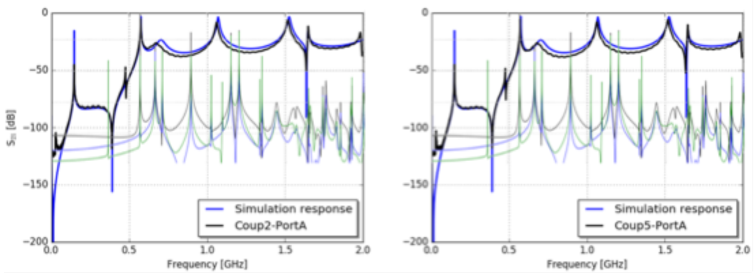
- The L-bend test box uses a **pick-up probe**, with an **electrical connection** to the wall, measure the **transmission response of the coupler**.
- Single coupler measurements can be done on one port, with a blank fixed to the other side.
- Two pick-ups are available for comparison and hence evaluation of alignment/rotational errors.



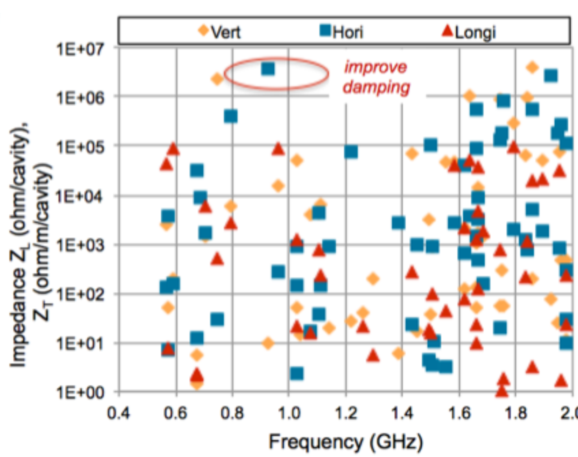


- The test box can also be used as a means to test the transmission between couplers.
  - This acts as a feasibility study for pre-installation conditioning.
- <u>**Initially two HOM couplers were available for test: coupler_2 and coupler_5.**</u>

Comparison with Impedance Spectrum



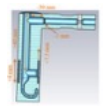
- The on-axis impedance spectrums superimposed for visualisation.
- For both HOM couplers, the 0.6 – 0.7 GHz peak and interaction regions are higher in frequency.
- Reduced damping is observed in the three high impedance modes highlighted.

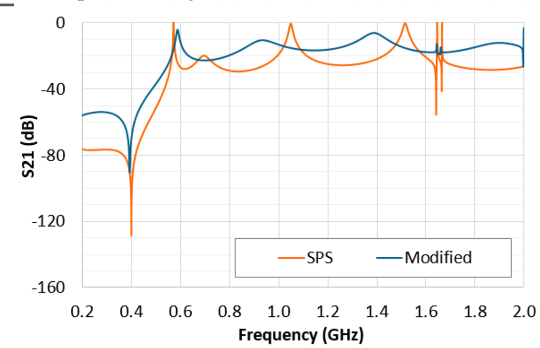


- Although the damping is only slightly reduced. The 980 MHz mode is high and damping of this mode should be maximised.
- Graph on left is courtesy of B. Xiao and BNL. **See talk by Qiong Wu.**
- This is also discussed later in this presentation.

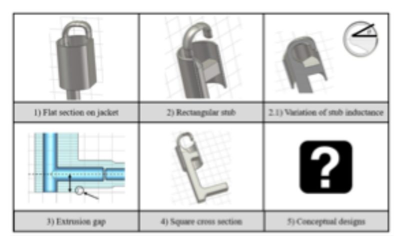
HOM Coupler – LHC considerations

- For LHC it was decided that the HOM coupler design should be re-visited.
- Two main aims:
  - **Increase damping of HOMs.**
  - **Improve ease of manufacture in terms of machining time, tolerances and cost.**





- Initial RF improvements investigated by B. Xiao et al, see talk by Q. Wu.

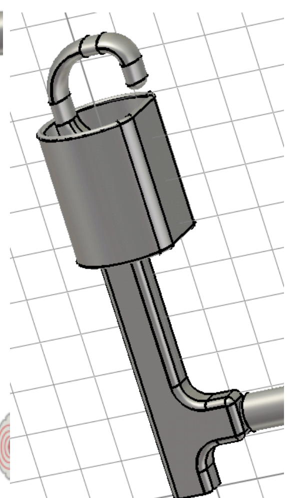


- Manufacturing improvements investigated at CERN.
  - A few examples are shown on the right.

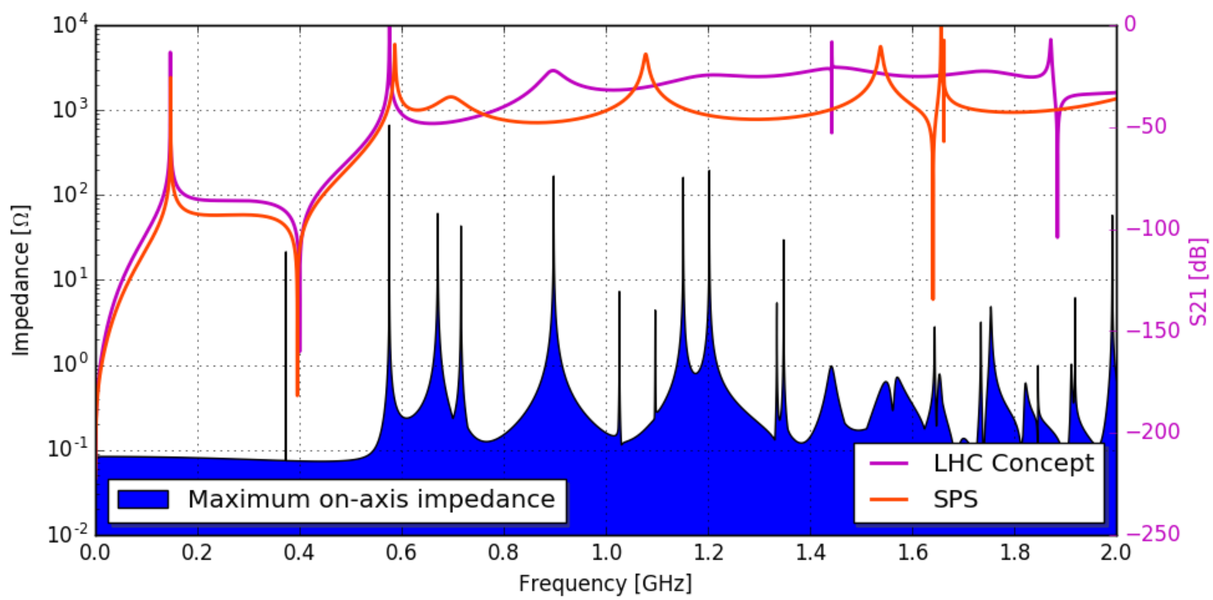
HOM Coupler
Manufacturing Improvements

- The S21 transmission characteristics of the new design are shown below.
- It is plotted alongside the SPS design for comparison.
- **The RF optimisation was done by putting higher weighting factors at the places where the on axis impedance was higher.**
  - It was also done using results found from research done by B. Xiao et al.
- Therefore, for visualisation, the on-axis impedance spectrum is plotted alongside.

SPS



LHC concept



J. Mitchell

Plans for CM integration of pre-series RFDs in the UK

- A 4 year project has been launched to build SPS/PS CM for RFD cavities at Daresbury Laboratory. We are already 1 year into the project.
- CERN and STFC will continue to work together sharing resources, expertise and facilities.
- Daresbury Lab already has a basic infrastructure to undertake the assembly work. Some of the facilties will be modified to meet the new requirements and to be compatible with CERN's facilities.
- Baseline design requirements have been drawn and detail plan and schedule have been prepared
- Next key date : Design Review in May-June 2018 (at STFC-DL)

Shrikant Pattalwar

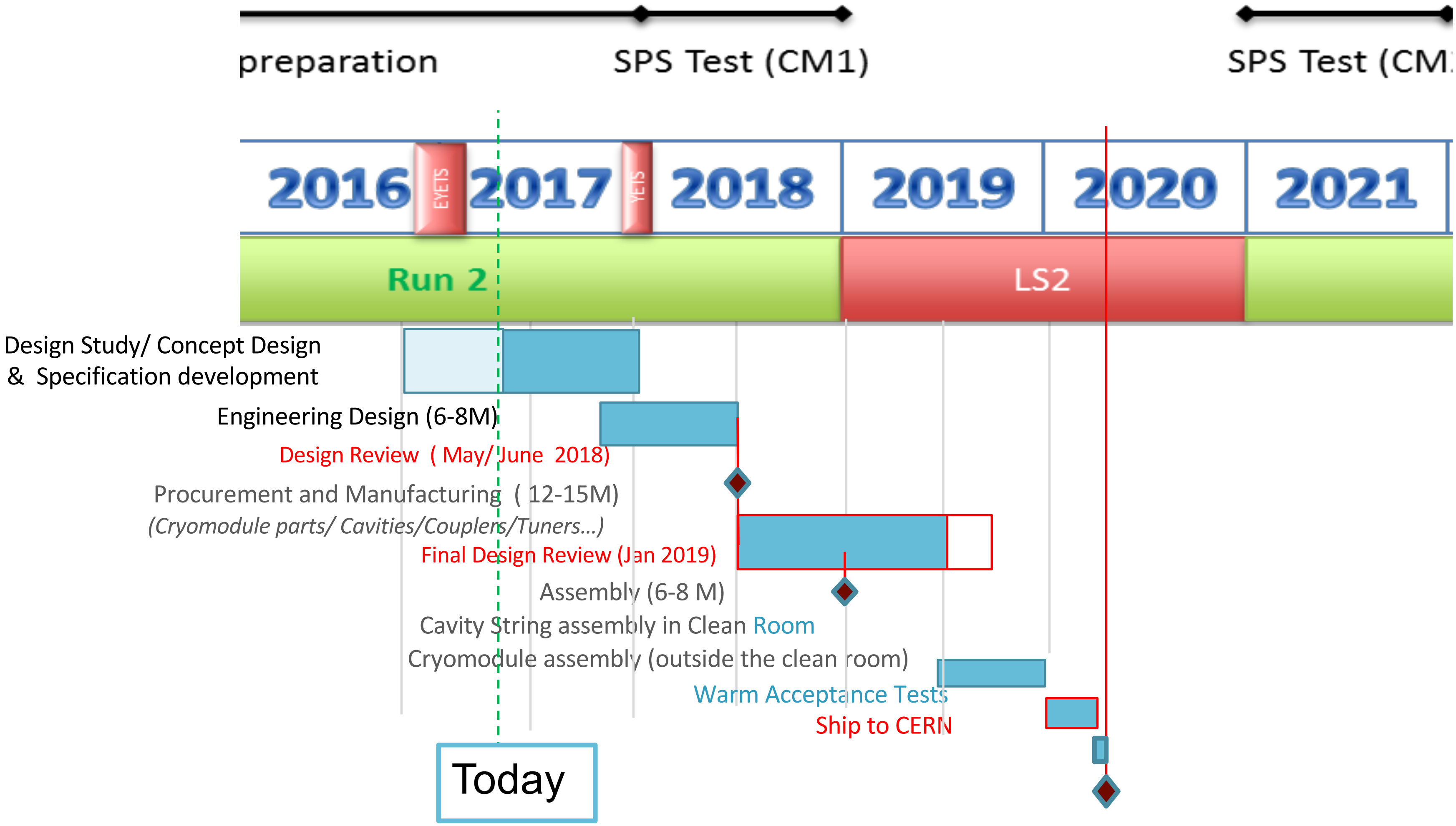
RFD CM - Design studies required

- Interchangeable helium level probes? On all equipment in LHC they are interchangeable.
- Cooling capacity in LHC to be determined but limiting factor will be helium vessel design. For SPS this is 35W at 2K. The helium vessel is designed with a factor of safety of 2, to be confirmed.
- Effect of -1.23% tunnel slope on the cryomodule.
- Support structure analysis for RFD cavity.
- Cold to warm transitions need more detailed studies for electron-cloud and finalize the ac-Coating zones.

- More presented at the meeting

Shrikant Pattalwar

Schedule Compatible with HL-LHC



Shrikant Pattalwar

(Real) Goals of HiLumi/LARP CM28 !

1. **Design and Scope.** Have performance requirements been appropriately and sufficiently defined for this stage of the project? Is the conceptual design sound and likely to meet the performance requirements? Is the U.S. project scope well defined within the CERN HL-LHC project? Does the conceptual design support the stated cost range and duration? Is the need, technical justification and schedule justification sufficient to approve early materials procurement?

- Functional Requirement Specifications for all US deliverables is a must !
  - Failure to leave this CM without at least WP agreement on the basic FRS would be a bad omen for a successful approval of HL-LHC AUP
- Conceptual Design (including, where possible, Integration) must be discussed
- US Project within CERN HL-LHC Endeavor
- Cost and Duration

G. Apollinari

US HL-LHC AUP

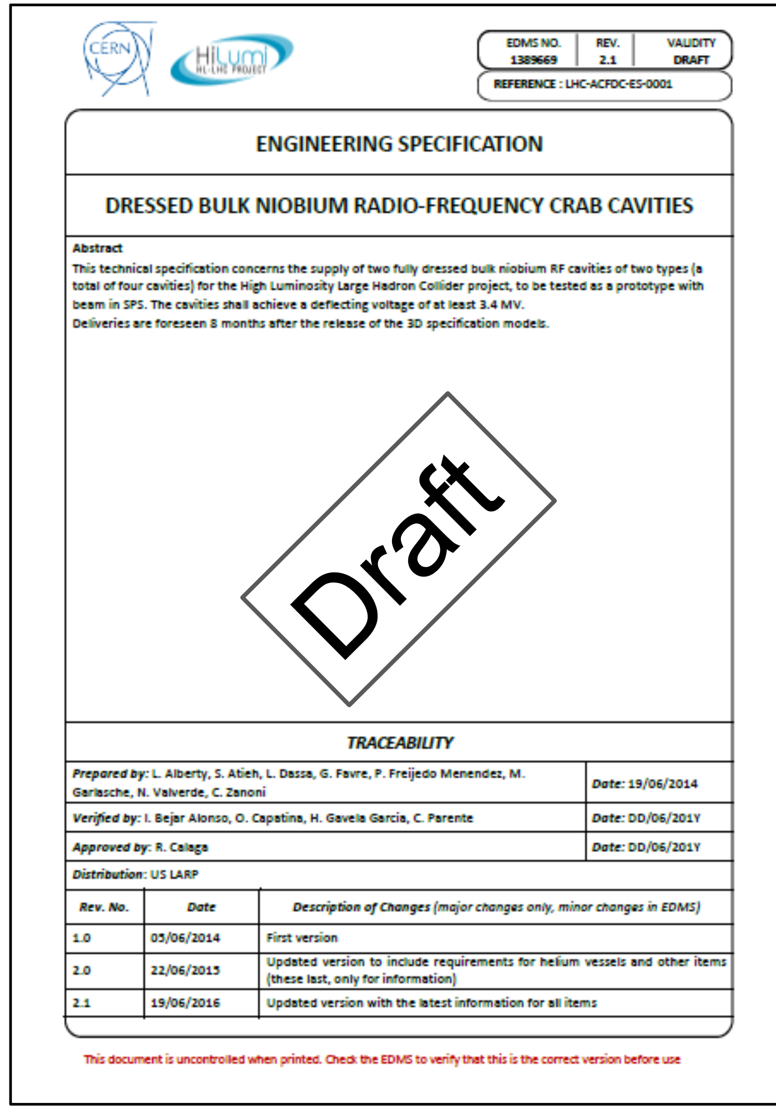
Engineering Specification (E.S.) for series

- Need compliance with the Cryogenic & Pressure standards (PED)
- CERN will make available all the info learned from the SPS prototypes

<u>Team Work</u>

- Develop an E.S. for series production based on the experience with the prototypes
  Draft in EDMS 1389669

- Reviewing the technical specifications



EDMS NO.	REV.	VALIDITY
1389669	2.1	DRAFT

REFERENCE : LHC-ACFDC-ES-0001

ENGINEERING SPECIFICATION

DRESSED BULK NIOBIUM RADIO-FREQUENCY CRAB CAVITIES

Abstract

This technical specification concerns the supply of two fully dressed bulk niobium RF cavities of two types (a total of four cavities) for the High Luminosity Large Hadron Collider project, to be tested as a prototype with beam in SPS. The cavities shall achieve a deflecting voltage of at least 3.4 MV.
Deliveries are foreseen 8 months after the release of the 3D specification models.

Draft

TRACEABILITY

Prepared by: L. Alberty, S. Atieh, L. Dassa, G. Favre, P. Freijedo Menendez, M. Garlasche, N. Valverde, C. Zanoni	***Date:*** 19/06/2014
Verified by: I. Bejar Alonso, O. Capatina, H. Gavela Garcia, C. Parente	***Date:*** DD/06/201Y
Approved by: R. Calaga	***Date:*** DD/06/201Y
Distribution: US LARP	

Rev. No.	*Date*	*Description of Changes (major changes only, minor changes in EDMS)*
1.0	05/06/2014	First version
2.0	22/06/2015	Updated version to include requirements for helium vessels and other items (these last, only for information)
2.1	19/06/2016	Updated version with the latest information for all items

This document is uncontrolled when printed. Check the EDMS to verify that this is the correct version before use

P. Freijedo Menendez

Conceptual Design Report

- **Contents of CDR:**
  - Motivation
  - Requirements
  - RF Cavity Design
  - Proof-of-Principle Cavity
  - SBIR Prototypes for SPS
  - Cavity Auxiliary Components
  - Mechanical/RF Design
  - Bare Cavity Fabrication

- **Purpose of CDR:**
  - Convince that the design of the RFD, and the plans for fabrication and qualification are likely to meet the requirements (at a conceptual level)

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U.S. HL-LHC Accelerator Upgrade Project

DRESSED RFD CAVITIES
CONCEPTUAL DESIGN REPORT

DRAFT

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(Proposed) Functional Requirement Specification

- Rationale behind the numbers
- Frequency
  - Ideally, in operating conditions, the tuning system will sit at around its mid-range position with the cavity locked at the nominal frequency. This requires the cavity to reach a frequency of 400.790 + 0.150 MHz = 400.940 MHz after cool down and before the tuner is engaged.
- Gradient
  - In order to provide a safety margin for the operation of RFD cavities in the LHC, the threshold requirement for the deflecting voltage is set to 4.1 MV which is 20% above nominal.
- Quality Factor
  - A $Q_0 = 2.7\ 10^9$ corresponds to a dynamic load of 10W and a surface resistance of $R_s = 40\ n\Omega$.
- Df/dP
  - With an expected variation of +/- 1 mbar in the liquid helium and a bandwidth of 800 Hz, the RFD cavity must be designed in order to have a sensitivity of dF/dP < 800 Hz/mbar with a certain margin, considering that other perturbations (such as LFD) will contribute to the overall budget of 800 Hz.
  - A value of dF/dP < 300 Hz/mbar was chosen as a design requirement.

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U.S. HL-LHC Accelerator Upgrade Project

DRESSED RFD CAVITIES

FUNCTIONAL REQUIREMENTS SPECIFICATION

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DRAFT

(Proposed) Functional Requirement Specification

Item	Threshold Requirement
Resonant Frequency (During qualification tests at 2K without tuner)	400.940 MHz +/- 150 kHz
Deflecting Voltage	≥ 4.1 MV
Lorentz Force Detuning Coefficient	≤ Hz / Mv^2
dF/dp (Sensitivity to LHe pressure fluctuations)	≤ 300 Hz/mbar < 100 Hz/mbar
~~Q_{ext} (fixed coupling range)~~	~~5 × 10^5 (+/- ?)~~
Q_0 at Nominal Voltage (3.4 MV)	≥ 2.7 × 10^9 ← Probably not needed if dynamic load is specified
Dynamic Load at 2K	≤ 10 W
HOM Filters	? < + 20% of simulated values; F_0 rejection < -100dB @ 2K

Item	Threshold Requirement
Beam Aperture	D = 84 mm
Maximum Envelope	R < 145 mm
Fundamental Power Coupler Port	D = 62 mm
~~Maximum Cavity Length~~	~~1000 mm~~ Add dim. spec of FPC port
Maximum Weight (Dressed)	< 200 kg

To be discussed at the upcoming satellite meeting

L. Ristori

AUP Important Dates + Next Steps

- Cost estimate (~ 40 spreadsheets aka BOEs)
  - Finalize asap to be scrubbed and defended in June
  - Held Cost-Schedule-Risk Internal Review in Dec 2016: numbers are in the right ball-park
- Conceptual Design Report
  - This is the main technical document to be finalized for CD-1
  - RFD team working hard on this for the last weeks
- Functional Requirements Document
  - Discussion started between AUP and WP4 towards a first draft consistent with CDR

- FNAL Director's review scheduled June 13-15, 2017
- DOE CD-1 Review scheduled August 8-10, 2017

- Important dates:
  - 2x dressed prototypes tested at FNAL: Nov 2019
  - 8x dressed production RFDs qualified: Dec 2022
    - (~ 6 month float compared to CERN need-by-date)
  - Design for prototypes finalized ASAP no later than Dec 2017
  - Design for HL-LHC reviewed, approval of documentation (FRS, A.C, Drawings, Fabrication Spec) by: Feb 2020

Conclusions

- Making progress on all fronts
  - From processing and testing…
  - ...to AUP project planning
- Successes from testing are feeding back into design improvements
- Some requirements are still being defined
- One day satellite meeting will continue addressing open issues

Questions