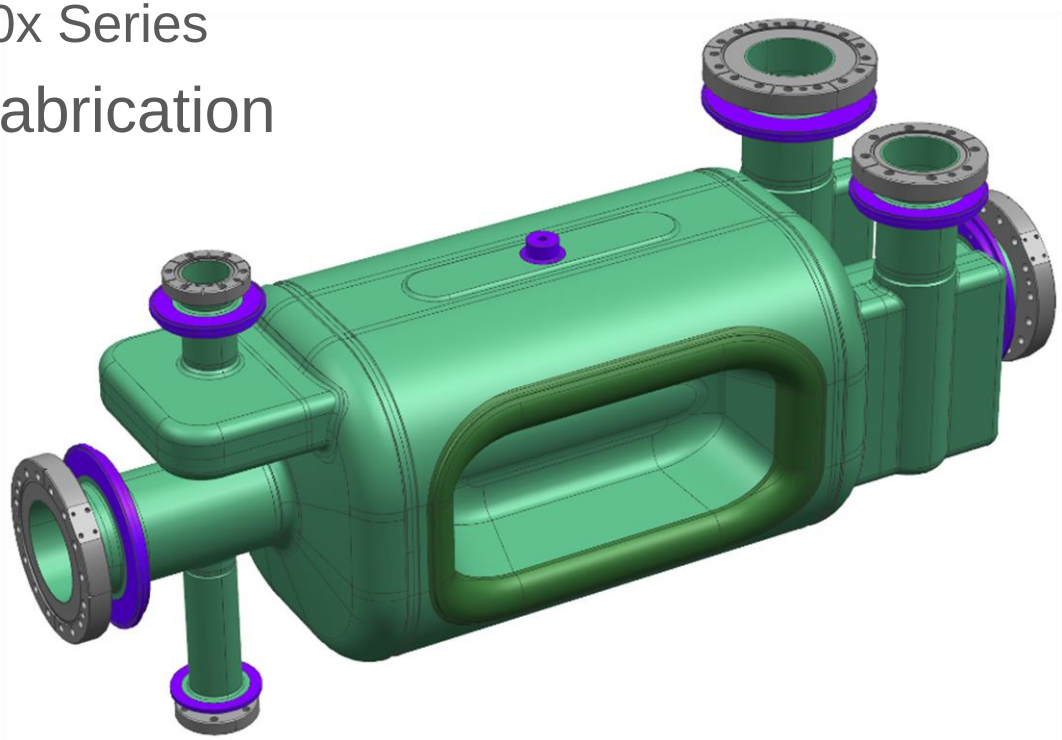
Zanon Status for Series

Manuele Narduzzi - FNAL

12th HL-LHC Collaboration Meeting – Sep 19th - 22nd, 2022

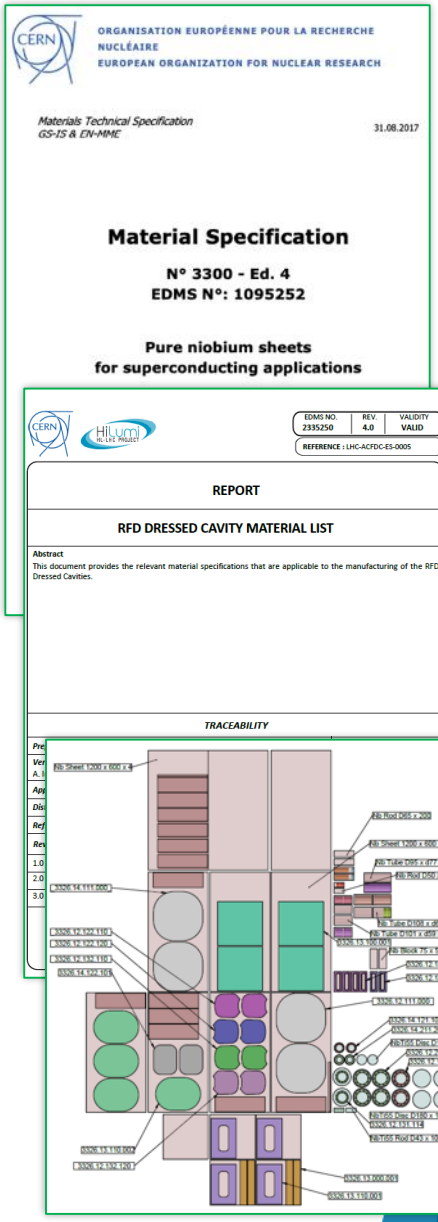
Outline

- Raw Materials Procurement
- Bare Cavities Fabrication
  - Documentation approval status
  - 2x Pre-series and 10x Series
- Jacketed Cavities Fabrication
- Upcoming plans



Raw Materials Procurement

- Dressed RFD mat. specs agreed between CERN - AUP
  - ✓ RRR300 Niobium
    - ✓ Sheets – CERN spec. 3300 ed.4 (*EDMS 1095252*)
    - ✓ Bars & Plates – CERN spec. 3301 ed.4 (*EDMS 1476934*)
    - ✓ Seamless Tubes (*EDMS 2367297*)
    - ✓ Ultrasonic Inspection Procedure (*EDMS 1971779*)
  - ✓ Nb-55Ti
    - ✓ Bars & Plates - CERN spec. 4055 ed.4 (*EDMS 1485727*)
    - ✓ Ultrasonic Inspection Procedure (*EDMS 2116737*)
  - ✓ Stainless Steel 1.4429 (316LN)
    - ✓ Forged Blanks - CERN spec. 1001 ed.5 (*EDMS 790775*)
  - ✓ Other materials for Dressed Cavity
    - ✓ (Ti, Cu, SS, Cryophy, Alumina & Gapasil)
- Sizes & quantities optimized by ZRI* after protos experience
- Purchased according to the HL-LHC requirements *(Pre-series & Series production)*
  - ✓ PO 657756 (Ningxia) Nb Sheets
  - ✓ PO 671157 (Ningxia) Nb Rods & Plates, NbTi Rods & Discs
  - ✓ PO 671490 (Ningxia) Nb Tubes
  - ✓ ZRI* PO (Ningxia) additional Nb for welding tests
  - ✓ PO 686821 (ANL) extra brazed joints for pre-series


ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Materials Technical Specification
GS-IS & EN-MME

31.08.2017

Material Specification

N° 3300 - Ed. 4
EDMS N°: 1095252

Pure niobium sheets for superconducting applications

EDMS NO. 2335250 | REV. 4.0 | VALIDITY VALID
REFERENCE : LHC-ACFDC-ES-0005

REPORT

RFD DRESSED CAVITY MATERIAL LIST

Abstract
This document provides the relevant material specifications that are applicable to the manufacturing of the RFD Dressed Cavities.

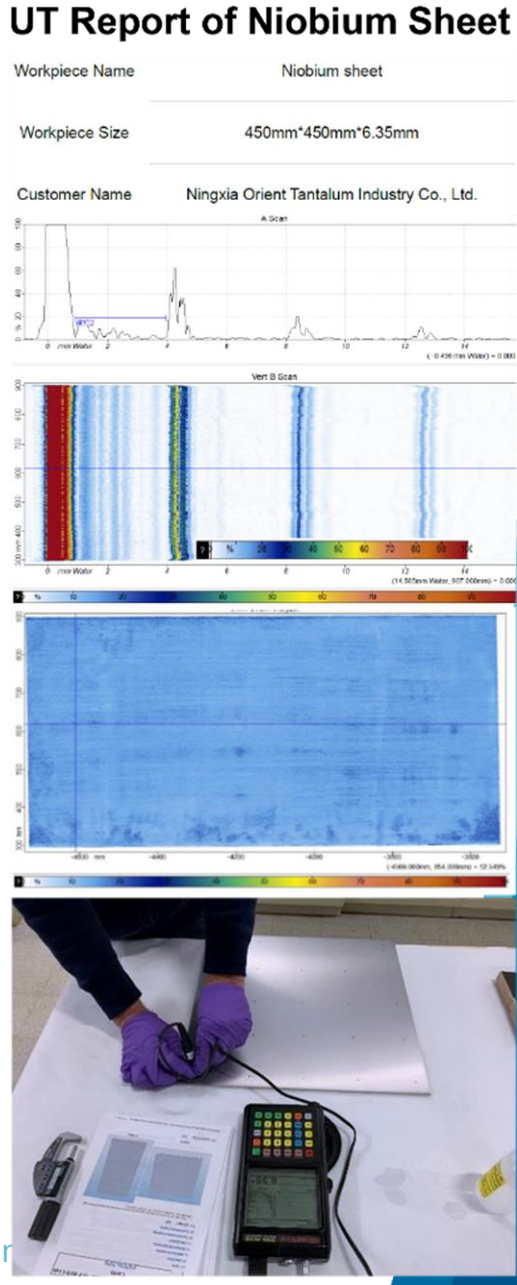
TRACEABILITY

** "Ettore Zanon spa" has changed its name in ZRI: "Zanon Research & Innovation srl"*

Raw Materials QC

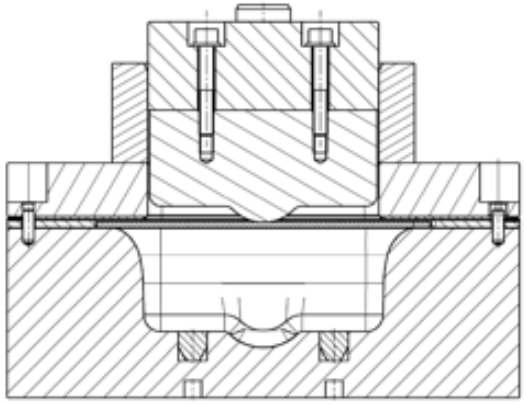
- Pre-series
  - ✓ Nb and NbTi QC approved by CERN. Available at ZRI.
  - Brazed Joints qualified to CERN specs. Ongoing QC at FNAL
- Series
  - ✓ Nb sheets QC approved by CERN. Stored at FNAL.
  - Nb & NbTi other materials: QC are being approved by CERN.
  - Nb tubes: not yet received. Shipping after CERN approval.
  - Brazed Joints and extra Nb: are being procured by ZRI
- All the materials certificates, UT and QC on EDMS

2244070 v.1.1	Material certificates and UT report, Order 657756 . Niobium RRR300. (Preseries production)
2422456 v.1.1	Material certificates and UT report, Order 657756. Niobium RRR300. (Series production)
2470058 v.1.4	Material certificates and UT report, Order 671157. Nb Rods & Plates, NbTi Rods & Disks. (Preseries production)
2476239 v.1.6	Material certificates and UT report, Order 671490. Nb Tubes. (Pre-series production)
2655931 v.1	FNAL materials qualification for Niobium Sheet (Series production)
2733735 v.1.4	Material certificates and UT report, Order 671157. Nb Rods & Plates, NbTi Rods & Disks. (Series production)
2733738 v.1.5	Material certificates and UT report, Order 671490. Nb Tubes. (Series production)
2753455 v.1	Material certificates and UT reports, ZRI procurement of Niobium tubes and rods (Pre Series production, welding qualification)



AUP RFD Prototypes (ZRI)

- ✓ 2 x RFD Prototypes manufactured at ZRI (PO 647590) to HL-LHC specs
- ✓ Exceeded functional requirements (*Frequency, Deflecting Voltage, Q_0*)
- ✓ ZRI developed all the dwgs, DFMA* & tooling
- ✓ ZRI QA documentation exercised on MTF
- ✓ FNAL established QC & VTS tests
- ✓ Paved the way for Series manufacturing



confidential

** DFMA = Design For Manufacturing & Assembly*

AUP Pre-series Fabrication Recap (ZRI)

- ✓ Adopted CERN Eng. Spec. & Dwg for pre-series
- ✓ Approved Fab. Dwgs, MIP & QA/QC Procedures
- ✓ Approved Weld Test Plan
- ▪ Partially approved Welding book
- ✓ Addressed all the PRR recommendations

Documentation prior to Manufacturing

- ✓ Adopted the HL-LHC quality system (MTF/EDMS)
- ✓ Enhanced QC, Inspections & VTS tests at FNAL

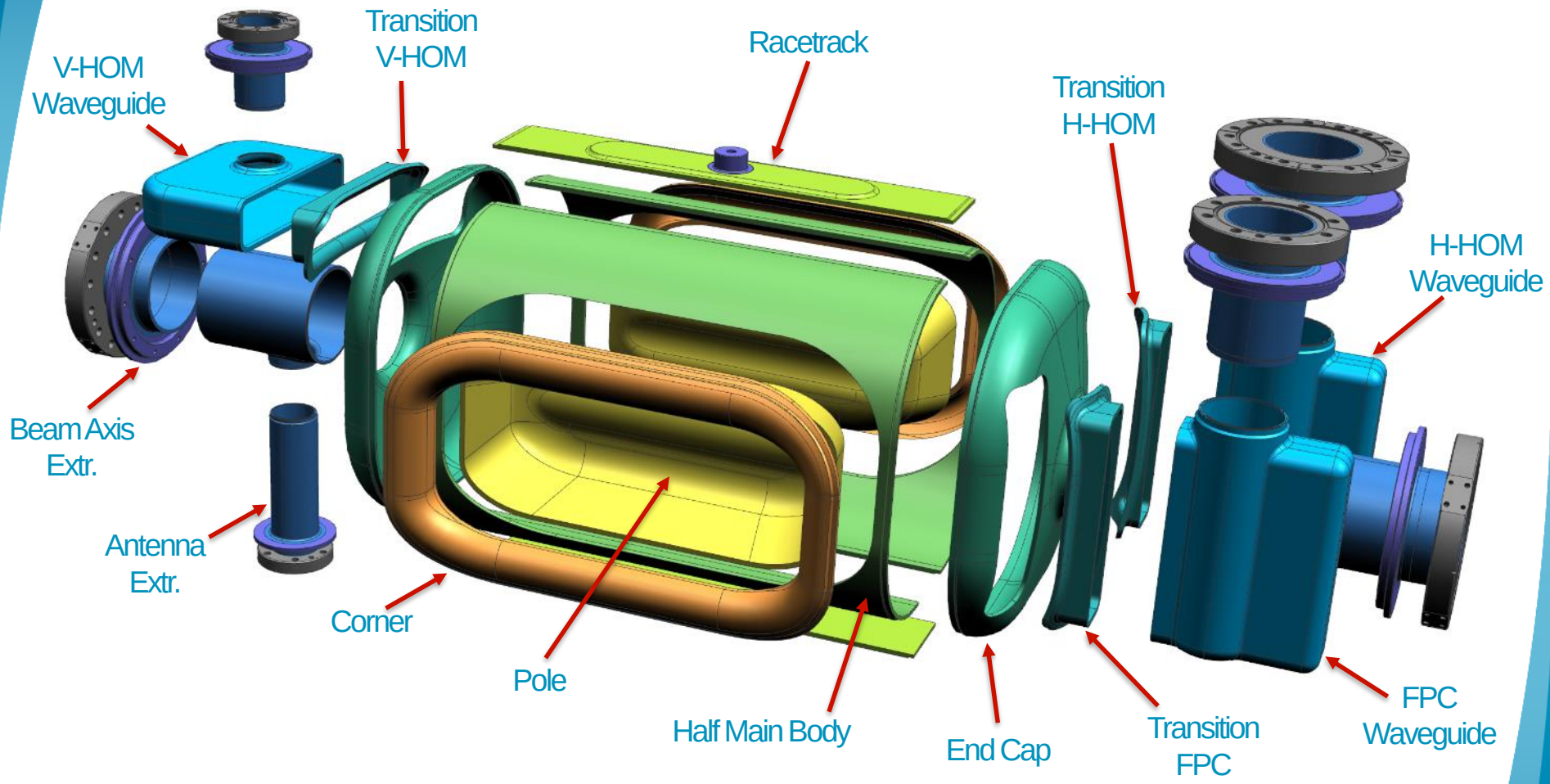
QA/QC during production

- ✓ Validated manufacturing tooling & strategy
- ✓ Solved Pole forming issues after extensive testing

Validation of DFMA

63% of 2x Pre-series RFD completed at ZRI (Delivery to FNAL Mar 2023)

Documentation Prior To Manufacturing:
Pre-series RFD Design & Fabrication Strategy



- ✓ Adopted CERN specification drawing for Pre-series RFD fabrication
- ✓ Extremities tubes machined from Nb seamless pipes (no roll-forming)
- ✓ Single design for all the Transitions (machined from a block)
- ✓ CNC interfaces and EBW joints handled as ZRI know-how

Documentation Prior To Manufacturing:
Technical Documentation Status

- ✓ Fabrication drawings (68) approved by CERN

2080712 v.6 | Released | Restricted access | Drawing Folder
Manufacturing Drawings RFD Bare Cavities by Manuele Narduzzi
Created on 2022-03-11
Last Modified on 2022-03-11

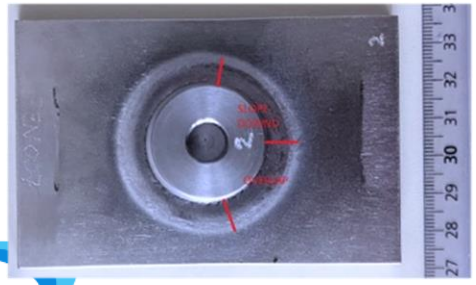
- ✓ Welding Test Plan PQR approved by CERN

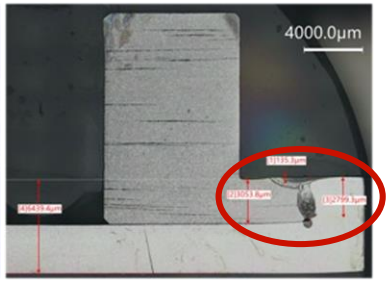
2479595 v.5 | Released | Restricted access | Procedure
Test Plan PQR by MANUELE NARDUZZI
Created on 2021-09-20
Last Modified on 2021-11-10

- ▪ Welding Book partially approved by CERN

2397280 v.2 | Draft For Discussion | Restricted access | Procedure
Welding book by Manuele Narduzzi
Created on 2022-06-28
Last Modified on 2022-07-18

  - ✓ 6 of 9 PQRs approved by CERN after internal qualification EDMS 2726311
  - ✓ 3 x missing coupons will be ready for end of Sep 2022 (ZEN01, 07, 09)





First ZEN007 PQR was rejected for under penetration (2.7 instead of 3.2mm) and angular misalignment around 2º.

ZRI will provide new sample to CERN.

Documentation Prior To Manufacturing:
QA/QC Procedures Status

- ✓ Manufacturing & Inspection Plan approved by CERN

- ✓ QA & QC Procedures approved by CERN
  - ✓ All the procedures are well established for series production
  - ✓ All the PRR recommendation have been addressed (MIP & Welding Plan approval)

2069492 v.4	Cleaning and Etching Procedure	1	Released	2021-09-20
2069496 v.1.2	Identification, Marking and Traceability Procedure	1	Released	2021-09-20
2069497 v.3	Procedure for Radiographic Examination of Welds	1	Released	2021-09-20
2080831 v.4	Leak Test procedure	1	Released	2021-09-20
2080834 v.1.1	Dimensional Control Procedure	1	Released	2021-09-15
2100569 v.2.2	Visual Testing	1	Released	2021-09-20
2630567 v.3	Grinding Procedure	1	Released	2021-09-30
2080833 v.2	RF measurements & Trimming Procedure	1	Released	2021-10-13
2642947 v.1	Packing Procedure	1	In Work	2021-10-06

QA/QC During Fabrication:
Quality Approval Process

- All QC reports are uploaded on FermiCloud by ZRI

Projects > LHC-AUP > Crab Cavities > Uploads > Zanon Uploads > **RFD Bare Cavities - PRE-SERIES (Z20008)**

Name	Modified	Modified By	File size	Sharing
Fermilab docs & tracking	May 20	Manuele Narduzzi	2 items	Shared
NCR	July 20	Manuele Narduzzi	1 item	Shared
Pictures	A few seconds ago	Manuele Narduzzi	13 items	Shared
RFD Pre-series Drawings	May 17	Manuele Narduzzi	2 items	Shared
RFD Pre-series Manufacturing Pictures	May 17	Manuele Narduzzi	5 items	Shared
RFD Pre-series QA documents	May 17	Manuele Narduzzi	12 items	Shared
RFD Pre-series QC Reports	July 20	Manuele Narduzzi	26 items	Shared
RFD Pre-series Weldings	May 17	Manuele Narduzzi	5 items	Shared

- The documentation is checked and approved by FNAL (189 QCs per RFD) before it can be uploaded on EDMS/MTF for final CERN approval.

QA/QC During Fabrication:
NC management

- ✓ Guidelines provided in AUP Quality Plan*
  - ✓ For vendors and FNAL Incoming Inspections NCs
- ✓ Agreed AUP-WP4 NCRs handling (EDMS 2384617)

- The NC Impact is assessed by AUP team:
  - Based on Technical, Schedule, Financial and Reputational impact
  - Collaborations Impact Matrix can be used for assessment or escalate to CERN

- ✓ *All NCs are communicated to CERN upon completion of sub-assy.*

- Non-critical NCs are managed internally by AUP
  - NC documents *can* use vendor's templates
  - Special attention to Welding NCs to be discuss with CERN

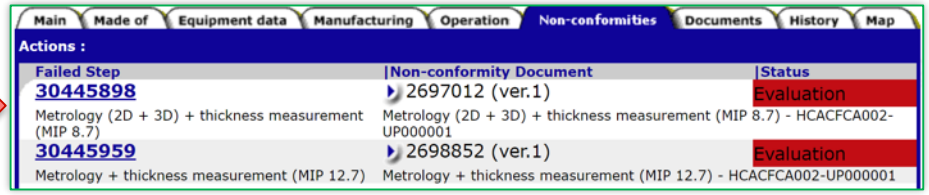
- Critical NCs will be managed according to HL-LHC NC Policy (WPL**)
  - Critical NCs will be shared within days to CERN
  - HL-LHC NC template is used
  - AUP to provide all the info (**W**hat, **W**here, **W**hen, **W**ho, **W**hy)

**Fulfills HiLumi quality plan requirements.* ***WPL= work package leader*

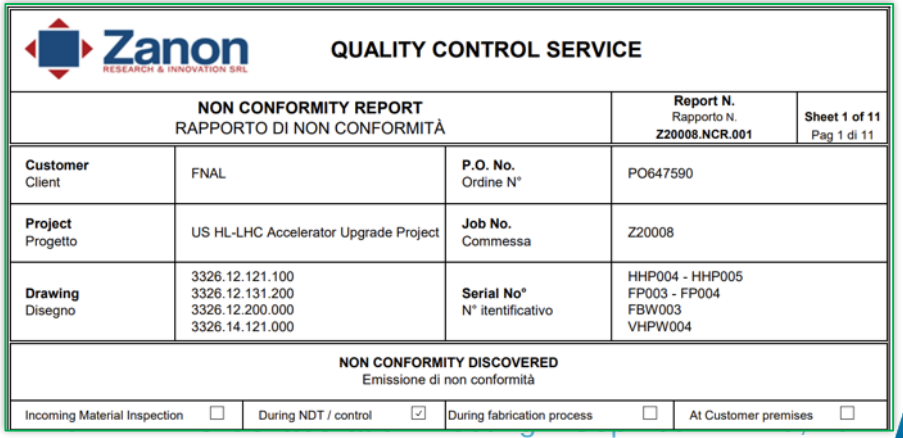
QA/QC During Fabrication:
NCR management

- Example of NCRs handling

Impact assessment	Assessment scale	Financial loss	Reputation	Alignment with Business Objectives (WP Deliverables)	Who I shall inform in the project	When
Catastrophic / Extreme	5	Requiring resources outside the collaboration that can not be covered by the project	Large media (or scientific media) coverage - International coverage	Occurrence of the risk will significantly deter the achievement of all the objectives (ex, delay of the full project, not delivery of a component fully under the responsibility of the collaboration, ...)	PL, WPL, WPE	As soon as detected
Major	4	Requiring resources outside the collaboration that can be covered by the project	Host MS press coverage - Scientific media - Escalating community activism	Occurrence of the risk will significantly hamper the achievement of the of the objectives (ex, delay beyond the collaboration margin but not yet the WP margin, request of a permanent deviation permit for a component, engineering change request afecting the WP, ...)	PL, WPL, WPE	As soon as detected
Moderate	3	Requiring resources outside the collaboration but that can covered inside the WP	Local press coverage - Neighbourhood reputation (public, suppliers, etc.)	Occurrence will have some adverse effect on the achievement of the objectives (ex, delay eliminating al the margin, request of a deviation permit for a component, engineering change request, ...)	WPL, WPE	In the 3 days
Minor	2		No one has heard of the occurrence of risk outside CERN; Problem dealt with at CERN's management level.	Occurrence of the risk will have minimal impact on the achievement of the entity's business objectives (magnet, cold mass, cryoassembly)	WPE	During periodic feedback
Negligible	1		No one has heard of the occurrence of the risk outside he department who owned the risk; problem dealt at department management level	Occurrence of the risk will have very little or no impact on the achievement of the entity's business objectives (magnet, cold mass, cryoassembly)	WPE	During periodic feedback



- Non-critical NCRs upload to MTF using Vendor's template



Zanon RESEARCH & INNOVATION SRL

QUALITY CONTROL SERVICE

NON CONFORMITY REPORT
RAPPORTO DI NON CONFORMITÀ

Report N. Rapporto N. **Z20008.NCR.001**

Sheet 1 of 11 Pag 1 di 11

Customer Client	FNAL	**P.O. No.** Ordine N°	PO647590
Project Progetto	US HL-LHC Accelerator Upgrade Project	**Job No.** Commessa	Z20008
Drawing Disegno	3326.12.121.100 3326.12.131.200 3326.12.200.000 3326.14.121.000	**Serial No°** N° itentificativo	HHP004 - HHP005 FP003 - FP004 FBW003 VHPW004

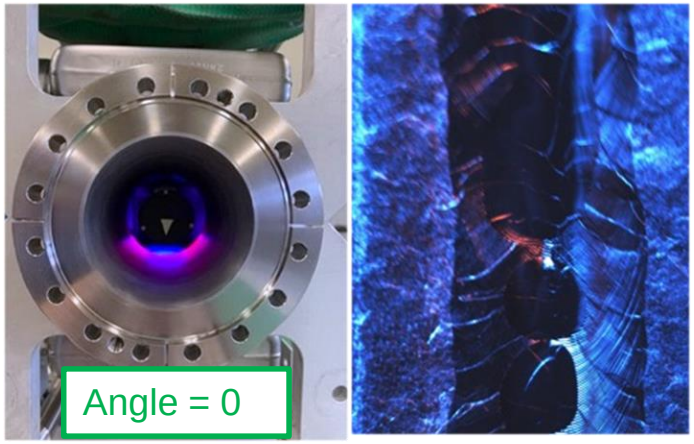
NON CONFORMITY DISCOVERED
Emissione di non conformità

Incoming Material Inspection ☐	During NDT / control ☑	During fabrication process ☐	At Customer premises ☐

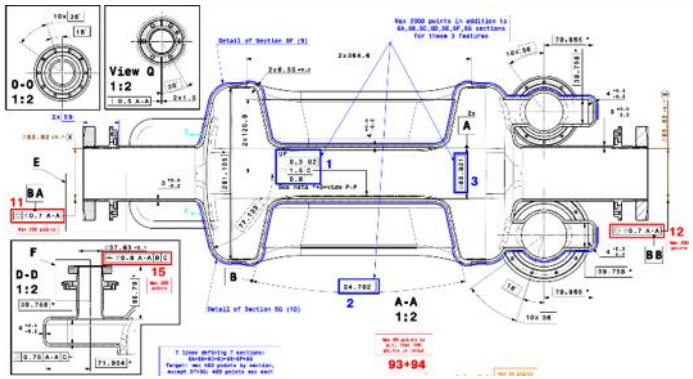
US HL-LHC AUP

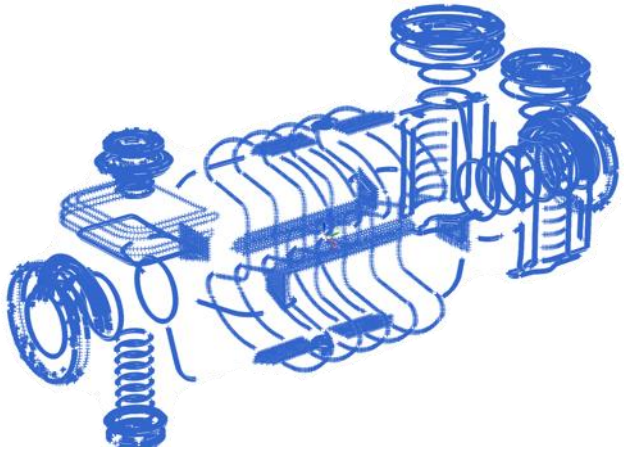
QA/QC During Fabrication:
Incoming Inspections at FNAL

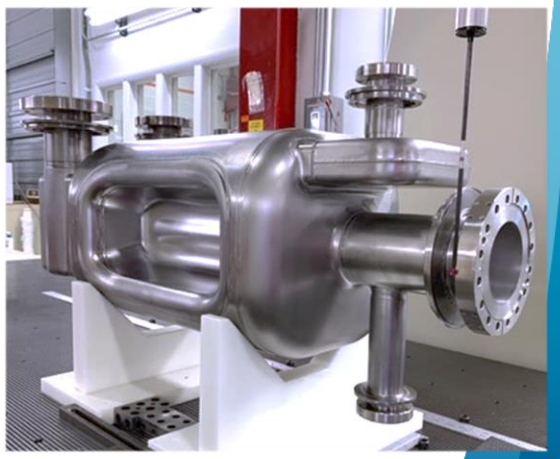
- ✓ Finalized all the incoming inspections QC:
  - ✓ Visual Inspection of external surfaces and crates
  - ▪ CMM metrology and UT thickness inspection
  - ✓ Optical Inspection of RF surfaces
  - ✓ RF QC before leak check
  - ✓ Leak Check
  - ✓ RF QC after leak check



- ▪ CMM v2: optimization ongoing
  - ✓ Inspection drawings developed with CERN collaboration (LHCACFCA0565)
  - ▪ Simplification of CMM: the data points can be used for "as-build" 3D models

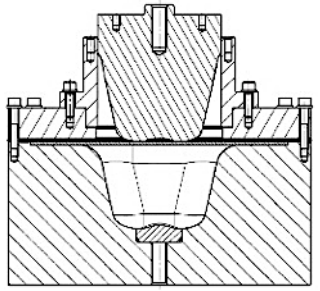




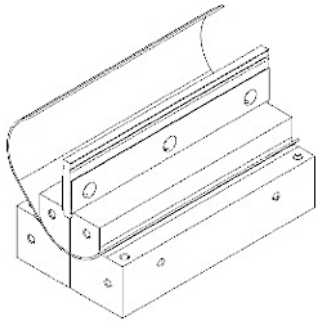


Validation of DFMA:
Design and Manufacturing Tooling at ZRI

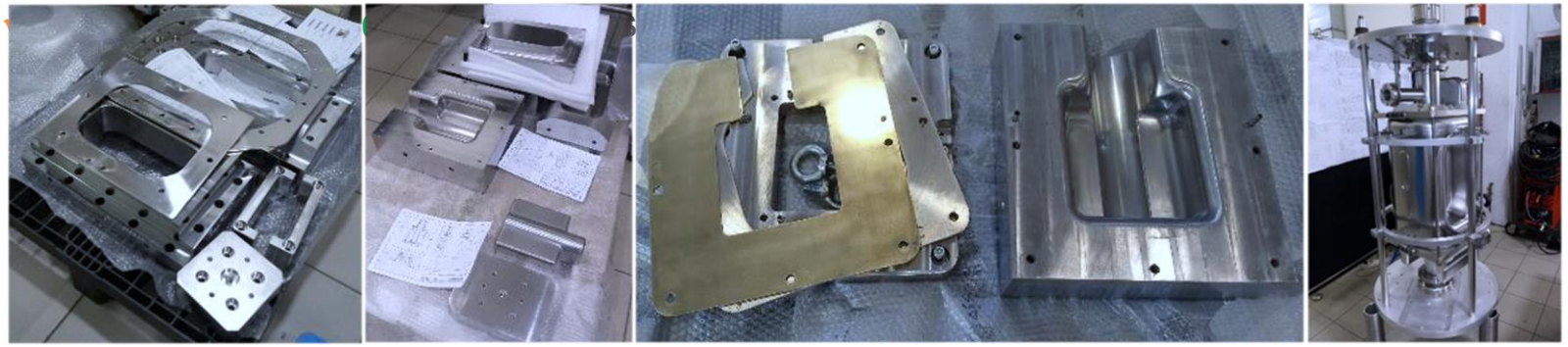
- Forming & Calibration Tooling
  - ✓ Formerly based on CERN prototypes' experience
  - ✓ Enhanced from lessons learned after protos fabrication at ZRI
  - ✓ Case study of Pole forming issues (see next slides)



- CNC Machining & EBW Tooling
  - ✓ Developed from ZRI expertise on SRF Cavity fabrication
  - ✓ Refined according to ZRI know-how and lessons learned



- Trim Tuning, Leak Test and final EBW Tooling
  - ✓ Developed according to ZRI expertise



Validation of DFMA:
Pole Forming Case Study

- Poles formed from pre-series Nb showed "orange peel" appearance and serious thickness reductions
- Held the production for weeks!

- Further tests with different materials provided much better results (shape, thickness, appearance)

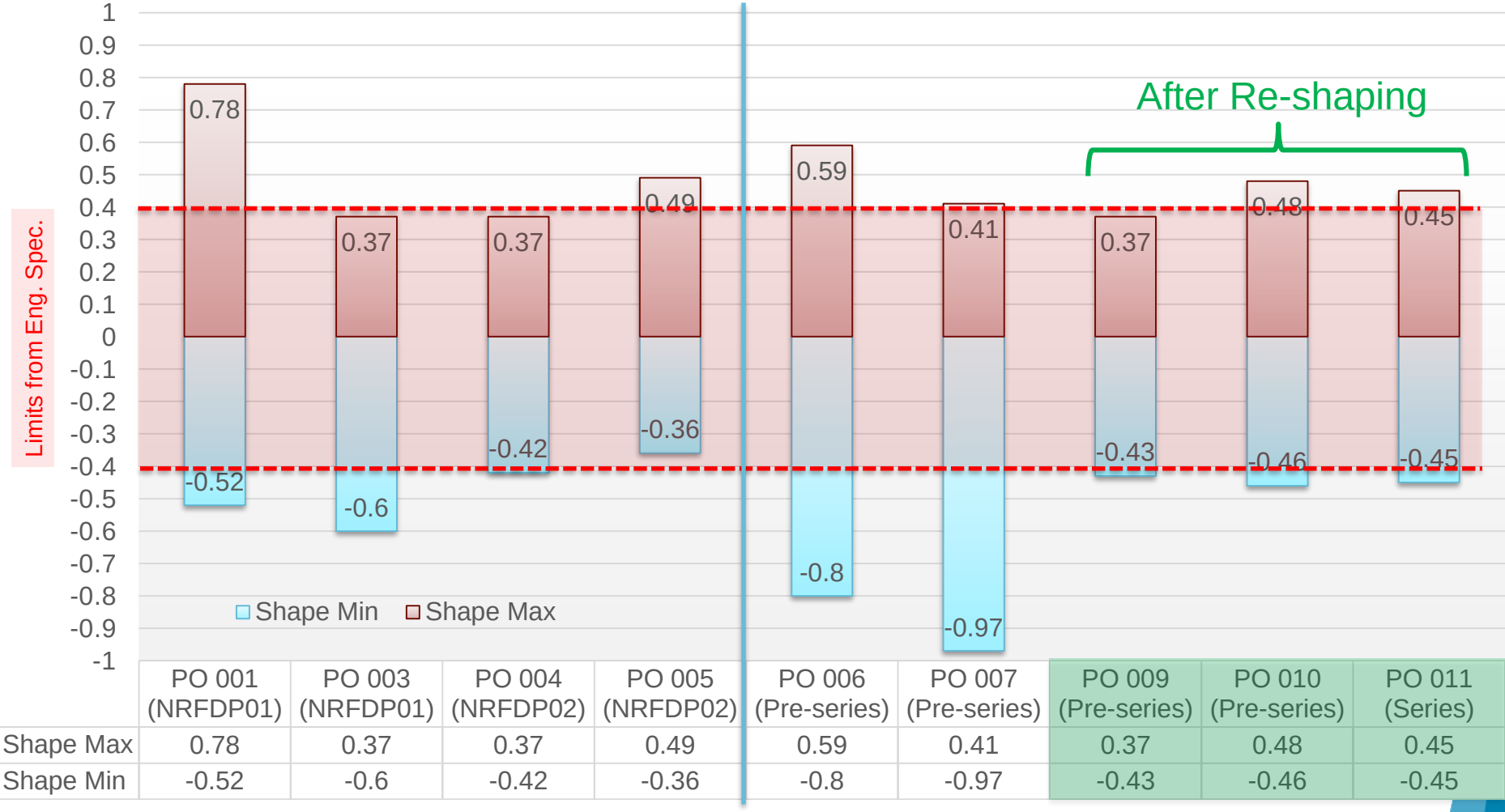
Validation of DFMA:
Pole Forming: Raw Materials or Procedure Issue?

- Raw Materials checks:
  - Mechanical tests on three different materials: results within specs (up to 15% variation!)
  - Series Nb showed results more suitable for deep drawing
- Forming tooling and procedure:
  - CERN & ZRI formed a Pole from the same Nb sheet
  - ZRI's Pole showed better results: thickness and shape accuracy acceptable
- **Conclusion:**
  - Pre-series materials showed results less suitable for forming
  - Series production showed better formability (lower $Rp_{0.2}$/Rm)
  - ZRI forming procedures effective even for non-ideal materials
  - ZRI adopted CERN CMM and thickness templates for metrology

$Rp_{0.2}$= Yield Strength
Rm= Ultimate Tensile Strength

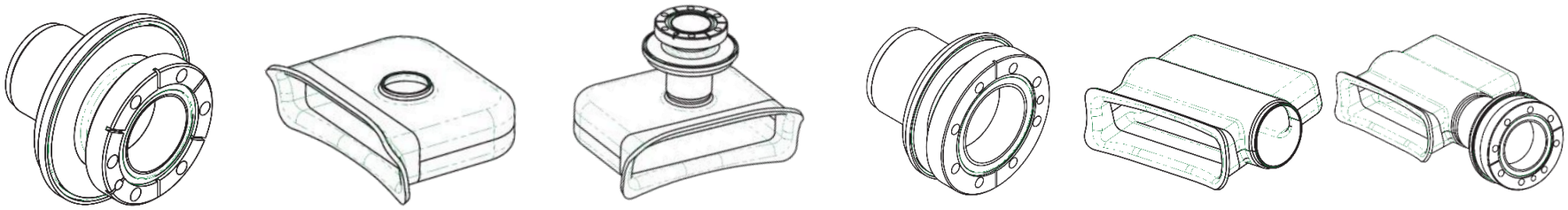
Validation of DFMA:

ZRI Poles: Shape Accuracy history



	PO 001 (NRFDP01)	PO 003 (NRFDP01)	PO 004 (NRFDP02)	PO 005 (NRFDP02)	PO 006 (Pre-series)	PO 007 (Pre-series)	PO 009 (Pre-series)	PO 010 (Pre-series)	PO 011 (Series)
Shape Max	0.78	0.37	0.37	0.49	0.59	0.41	0.37	0.48	0.45
Shape Min	-0.52	-0.6	-0.42	-0.36	-0.8	-0.97	-0.43	-0.46	-0.45

AUP RFD Pre-Series Advancement

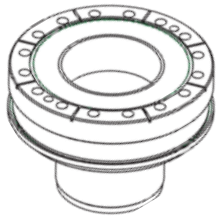
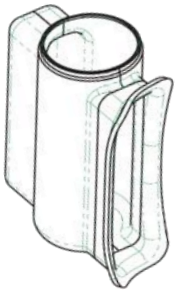
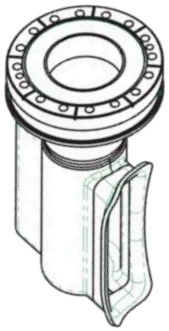
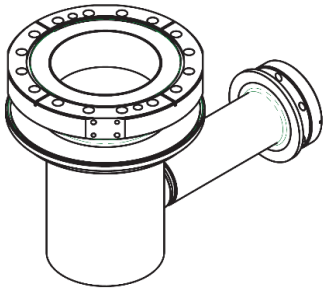
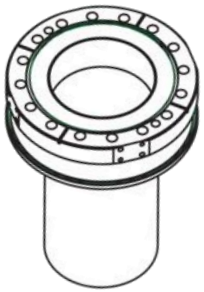


V-HOM Port Weldment	V-HOM WG with Insert	V-HOM WG Weldment	FPC Port Weldment	FPC WG with Insert	FPC WG Weldment
87%	88%	0%	87%	88%	0%

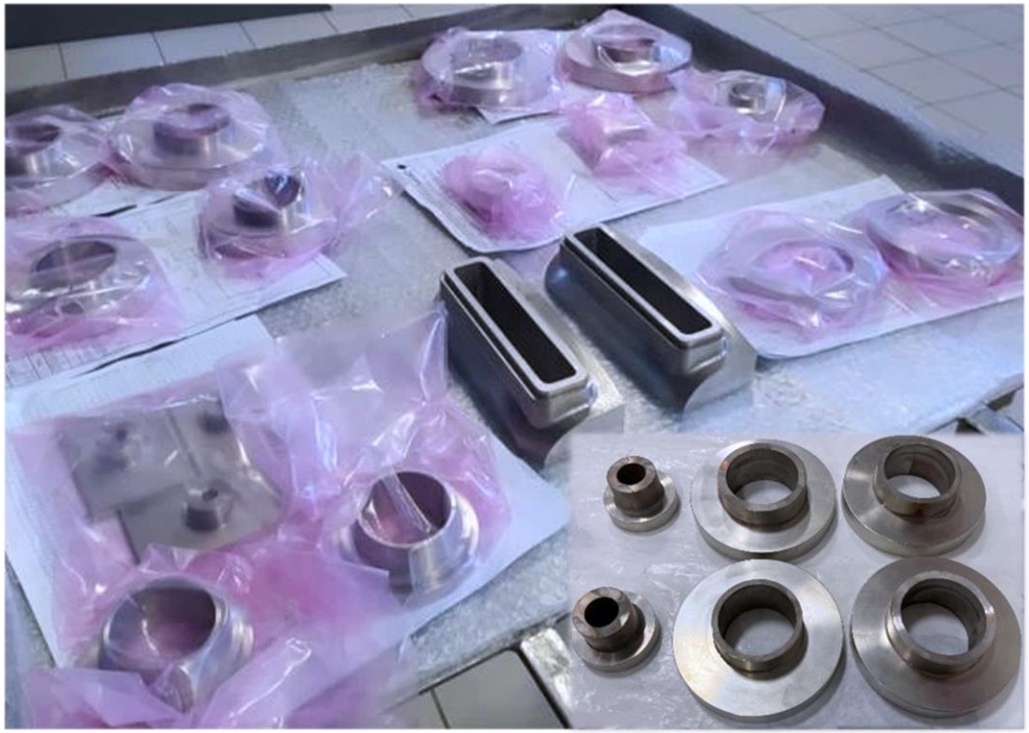
H-HOM & V-HOM waveguides

FPC waveguides

AUP RFD Pre-Series Advancement

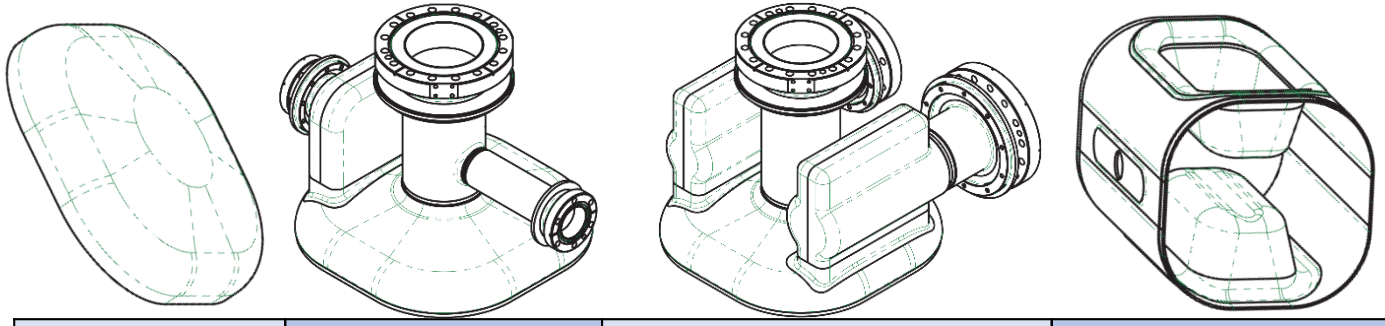






H-HOM Port Weldment	H-HOM WG with Insert	H-HOM WG Weldment	V-HOM Beam Line Weldment	FPC End Group Beam Line Weldment
87%	88%	0%	57%	83%

Sub-components & Brazed Joints ready for weld

AUP RFD Pre-Series Advancement



End Cap	V-HOM End Group	FPC End Group	Main Body Weldment
100%	25%	25%	42%

End Caps, Bowls and Half Main bodies

AUP RFD Series Contract (ZRI)

- ✓ PO 685322 placed for 10 x RFD fabrication at ZRI (CERN specifications)
- Fabrication will benefit from previous manufacturing experience
  - ✓ All the QA/QC/ Manufacturing procedures have been already validated
- ✓ Kick-off meeting held on Jul 2022
- FNAL will provide most of the materials.
- Brazed Joints and testing materials will be procured by ZRI

CERN HiLumi HL-LHC PROJECT

EDMS NO.	REV.	VALIDITY
1389669	2.6	VALID

REFERENCE : LHC-ACFDC-ES-0002

ENGINEERING SPECIFICATION

DRESSED BULK NIOBIUM RADIO-FREQUENCY CRAB CAVITIES

Abstract

The present document concerns a general description of the engineering specifications of superconducting niobium radio-frequency crab cavities of two types (DQW and RFD) to be installed in HL-LHC.

TRACEABILITY

Prepared by: L. Alberty, S. Atieh, L. Dassa, G. Favre, P. Freijedo Menendez, M. Garlaschè, C. Parente, N. Valverde, C. Zanoni	***Date:*** 2021-11-19
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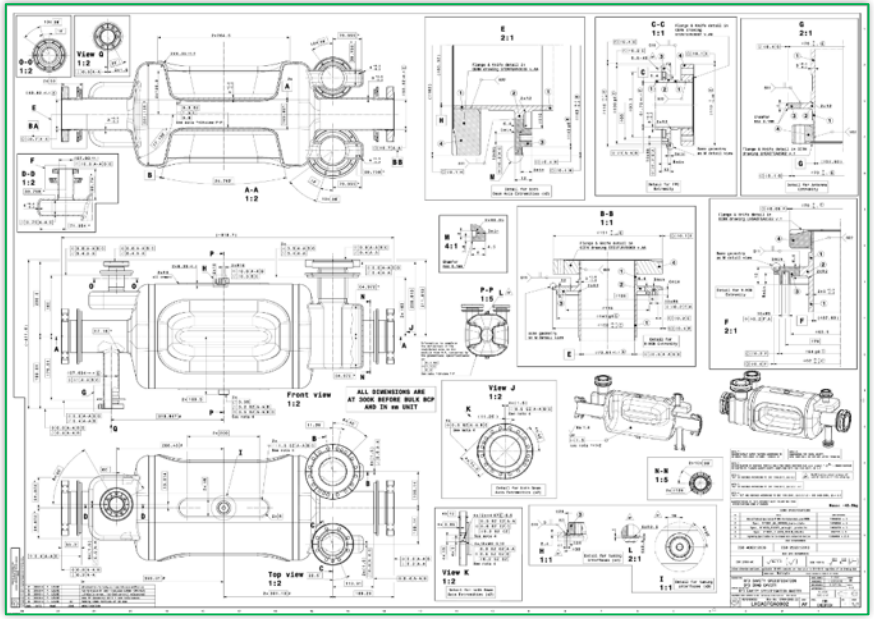
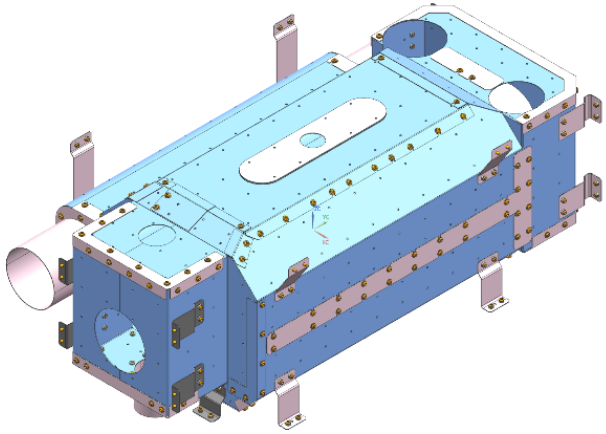
Distribution: *HI-LUMI-LHC-WP4-MEMBERS*	

2.6	22/03/2022	Rev. 2.6 set to Valid



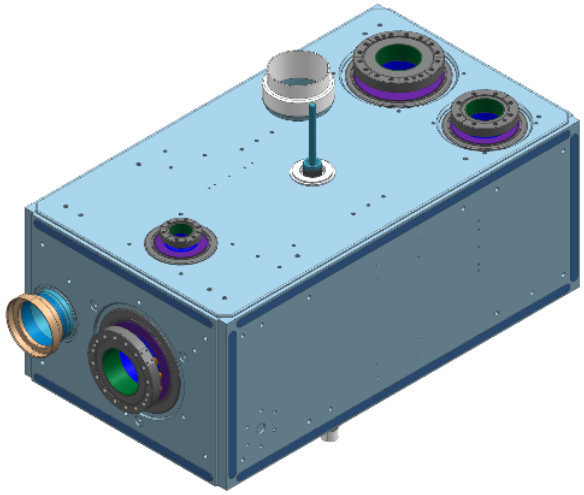
RFD Magnetic Shields Prototypes (Ad-Vance)

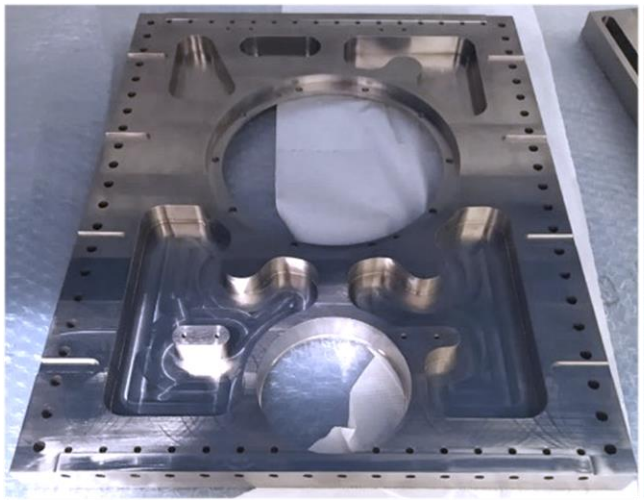
- ✓ 3D/ 2D Fabrication Drawing made at FNAL (F10129735)
  - ✓ based on STFC 253-10570-G approved by CERN
  - ✓ Subcomponents Fabrication Drawings by FNAL (50+ dwgs)
  - CERN approval for Series
- ✓ PO 667755 placed with *Ad-Vance Magnetics*
  - ✓ 3x prototypes available at ZRI for Jacketed Cavities integration
  - ✓ 11x shields on option for series

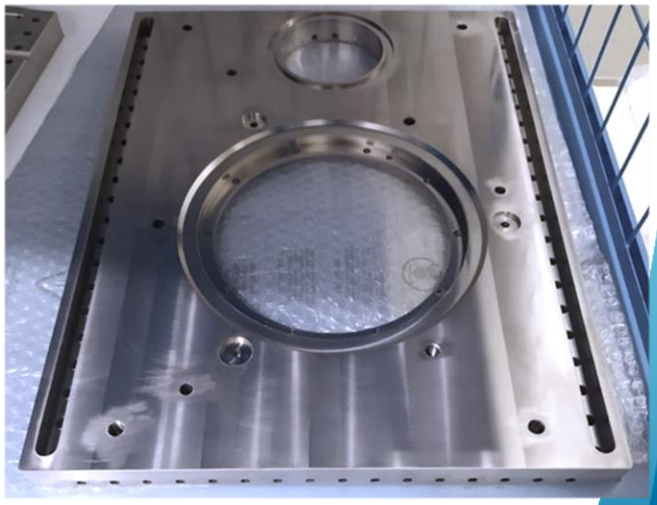


RFD He Tank Prototypes Fabrication (ZRI)

- ✓ PO 681514 placed for 2x He Tanks prototypes fabrication at ZRI
  - PO for 11x Series He Tanks imminent
- ✓ ZRI fab. dwgs, MIP, Weld Test and LT checked by FNAL for prototypes
  - CERN approval (for all QA/QC procedures) before Series fabrication.
- ✓ Majority of materials available at ZRI.
- ✓ Most of the Sub-components have been manufactured
- ✓ Welding tests will start shortly
- ✓ RFD proto#1 and Magnetic Shields available at ZRI for integration
- Processing will start Nov up to Jan 2023. Integration will follow.







Summary & Plans

Raw materials:

All materials were purchased to approved documentation.

Pre-series materials are available at ZRI, except the extra Brazed Joints.

Most of the Series materials are at FNAL; ZRI will provide Brazed Joints.

RFD Bare Cavities:

2x Prototypes qualified at FNAL. Exceeded functional requirements.

2x Pre-series RFD are being manufactured to CERN's requirements. QA/QC procedures approved. Welding book close to full approval.

PO placed for 10 x Series RFD at ZRI.

RFD Jacketed Cavities

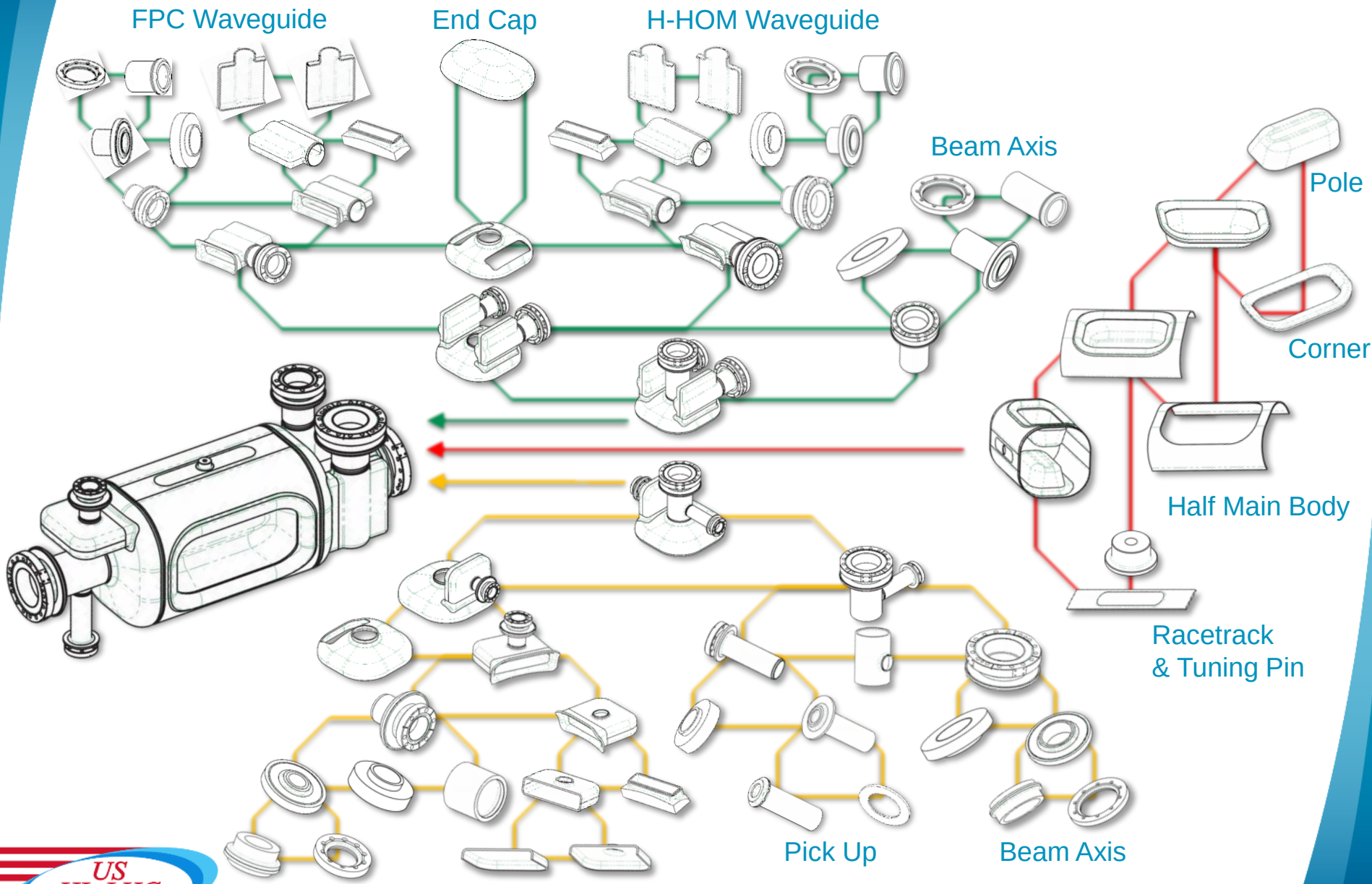
PO Placed for 2x Protos at ZRI. Majority of He Tanks components ready.

CERN approval required for series production.

PO for 11 x Series He Tanks estimated in spring 2023.

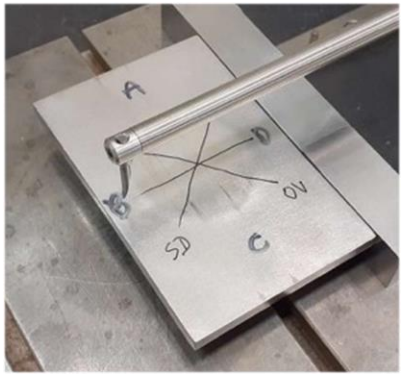
Thanks for the attention!

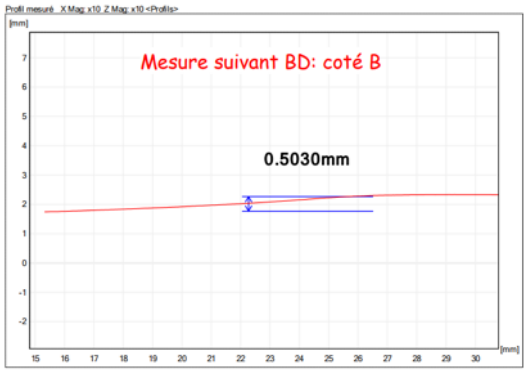
ZRI Fabrication Strategy

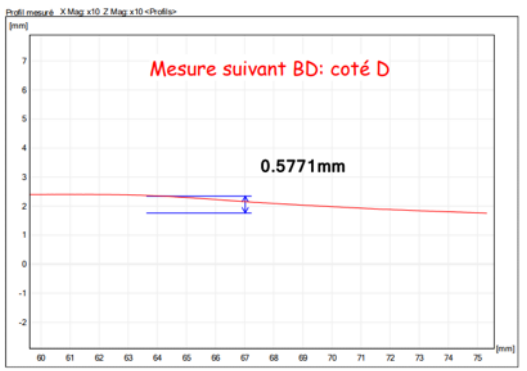


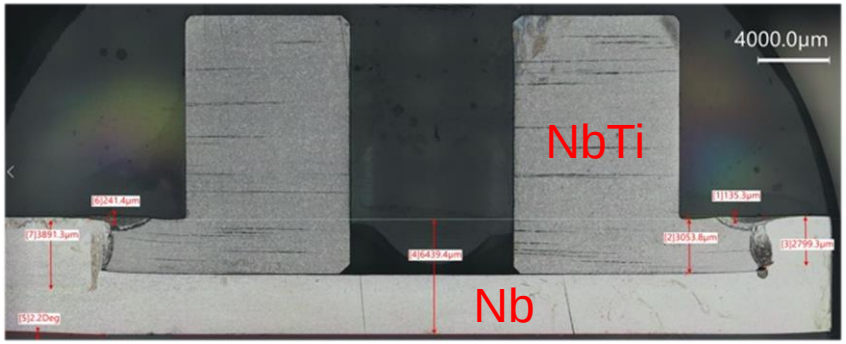
ZRI welding coupon tested at CERN

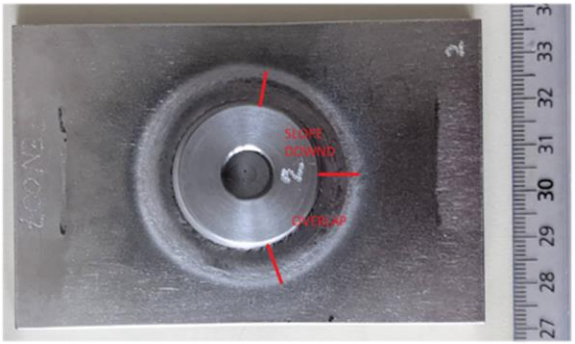
- ✓ The ZEN02 and ZEN05 coupons showed acceptable results
- The Tuning Pin weld ZEN07 showed some issues











RF surface

- FNAL provided ZRI with CERN qualification results (EDMS 2726311)
- ZRI will provide a new coupon for CERN evaluation ETA Oct 2022