Qualification Status of US-AUP

RFD Prototype Cavities Fabrication at E. Zanon

Manuele Narduzzi - FNAL

9th Collaboration Meeting, Fermilab, USA - October 14th-16th 2019

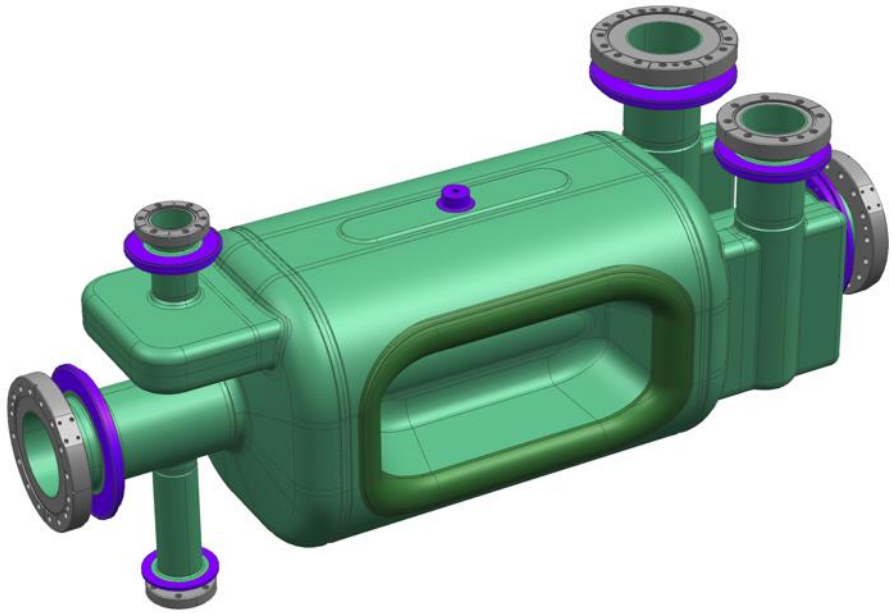
RFD Prototype Cavities Fabrication at Zanon: *Outline*

- **Design for fabrication**
  - AUP RFD Prototypes Cut-Out
  - Assembly Strategy
  - Drawing Status (back-up)

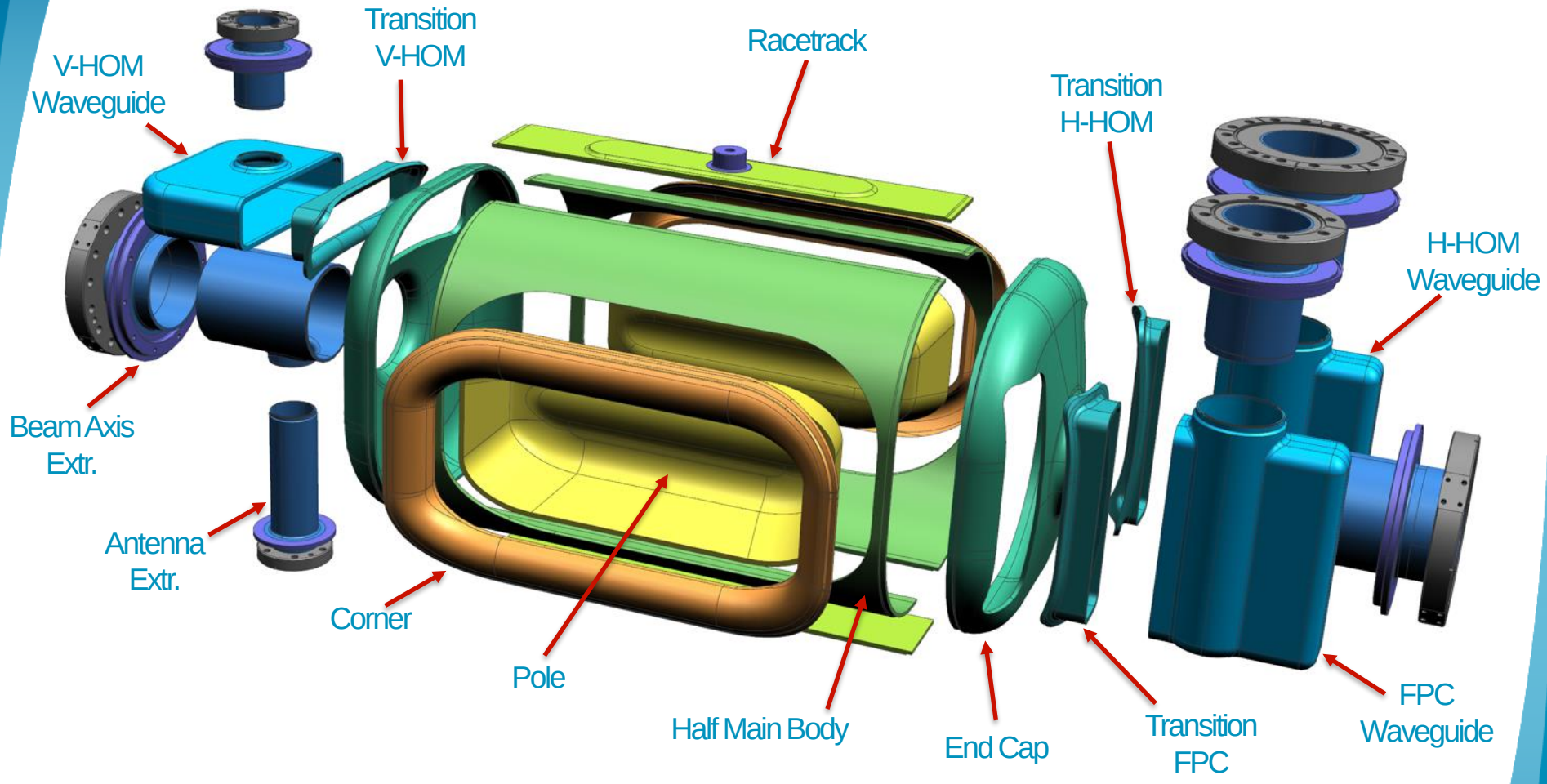
- **Fabrication Status**
  - Forming, Machining & EBW Tools
  - Manufacturing Results Summary
  - Waveguide Boxes Example
  - V-HOM Extrusion
  - Beam Axis extrusion test
  - Deep Drawing
  - Insert Machining Test
  - Next steps & Pics

- **QA documentation**
  - Actual Status
  - MTF Status

- **Summary**



Design For Fabrication: *AUP RFD Prototypes Cut-Out*

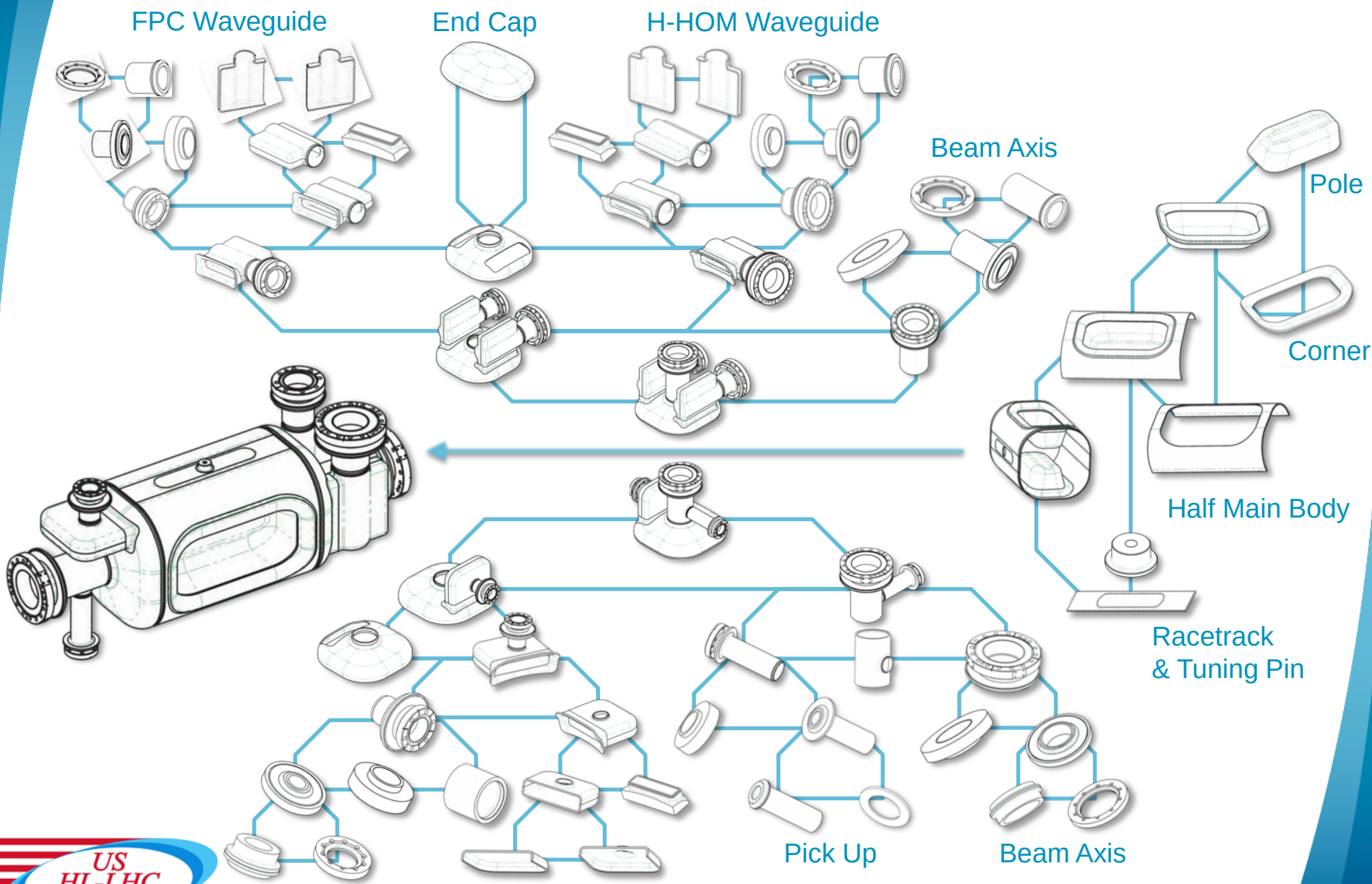


Rationale behind AUP RFD cut-out:

- Adopted CERN LHCACFCA0002vAE design also for protos
- Cut-out close to CERN prototype (baseline: **favor EBW**) but:
  - Extremities machined from thick Nb pipe (no rolled tube)
  - Adopted same transition insert between End Cap & Waveguides (different EBW strategy)

US HL-LHC AUP

Design For Fabrication: *Assembly Strategy*



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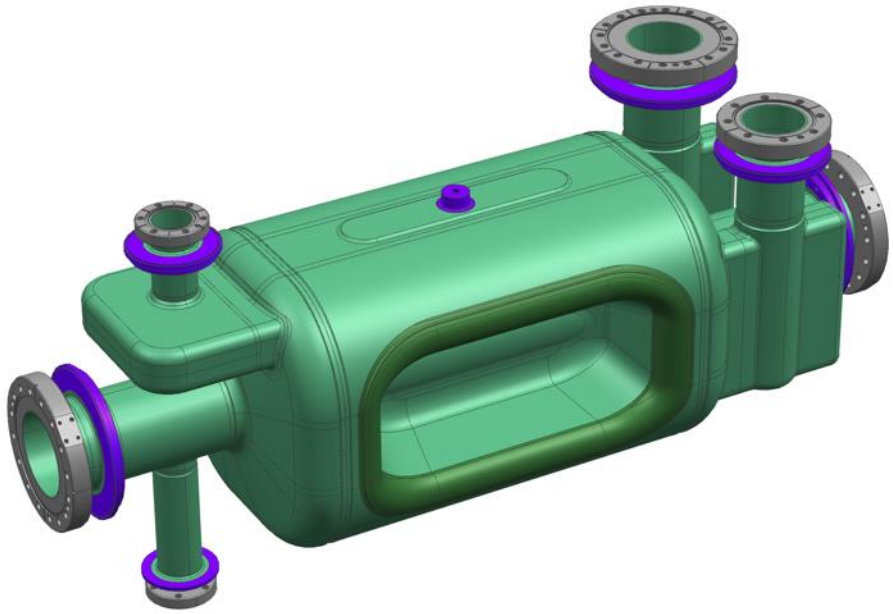
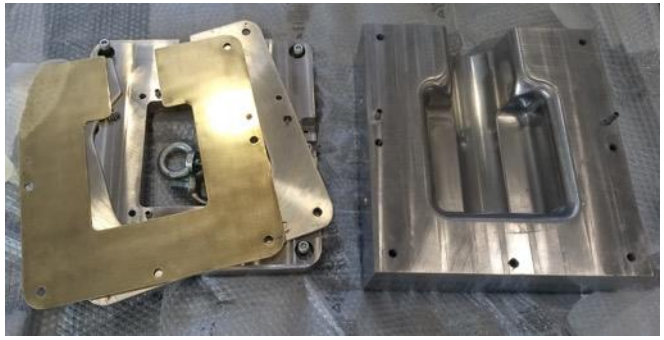


Fabrication Status: *Forming, Machining & EBW Tools*

Components	Description	Drawing Status (E. Zanon)
RFD Bare Cavity	EBW Tool	
Corner	Forming Tool	
	Machining Tool	
Pole	Deep Drawing Tool	
	Machining Tool	
Pole + Corner	Machining & EBW Tool	
Half Main Body	Forming Tool	
	Machining Tool	
Tuning Band	Machining & EBW Tool	
Main Body	Machining & EBW Tool	
End Caps	Forming Tools	
	Machining & EBW	
Beam Axis Extremities	EBW Tools	
H-HOM	Boxes Forming Tools	
	Machining & EBW Tools	
H-HOM Extremities	EBW Tools	
V-HOM	Boxes Forming Tools	
	Machining & EBW Tools	
V-HOM Extremities	EBW Tools	
FPC	Boxes Forming Tools	
	Machining & EBW Tools	
FPC Extremities	EBW Tools	



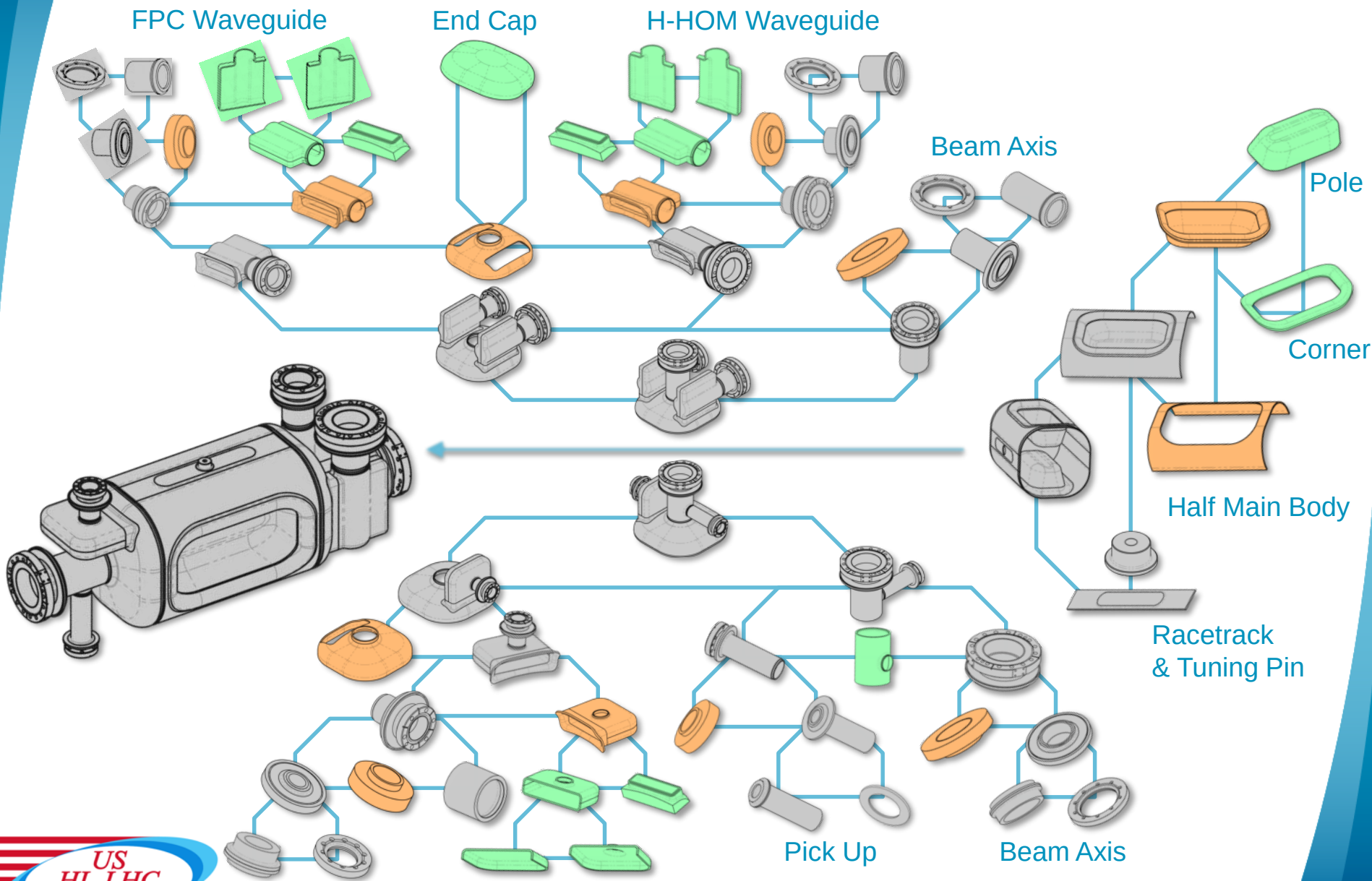
Tool validated after Niobium tests

Manufacturing ongoing

Not Machined

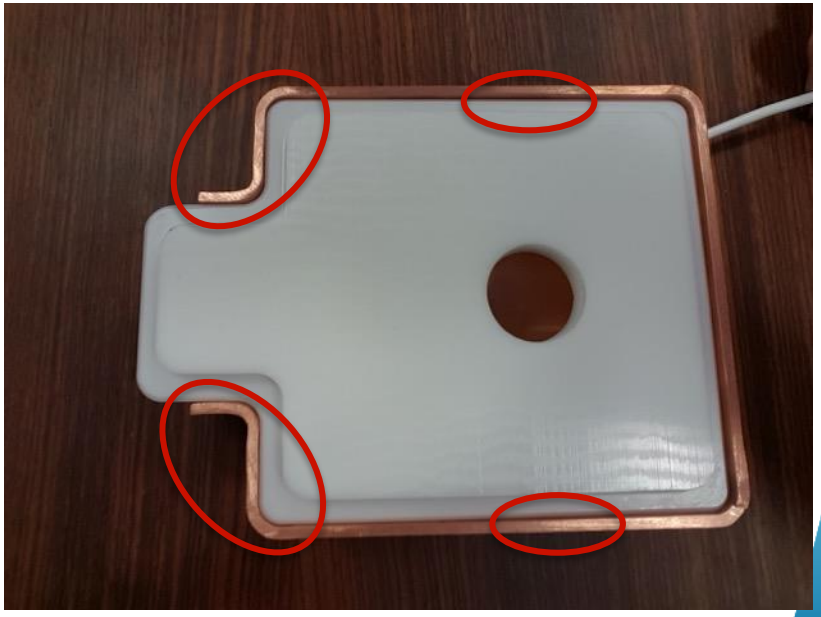
NOTA: Forming Tools based on CERN RFD prototype experience.

Fabrication Status: *Manufacturing Results Summary*



Fabrication Results: *Waveguide Boxes Example*

- **Copper H-HOM Box Shaping**
  - Upgrade forming procedure
    - Increase deep drawing pressure (>100 Ton)
    - Trimming (+3mm on theoretical shape)
    - 3 x Stamping at 300bar (120 Ton)
  - Use POM template for calibration



NOTA:
Reshaping not enough in highlighted areas.
Local Thickness 3.85mm.

Fabrication Results: *Waveguide Boxes Example*

- **Copper H-HOM Box Metrology Results**
  - Shape accuracy <u>after reshaping 300bar</u>:
    - Flat surfaces: encouraging **<0.7mm** (**±0.35mm**) shape accuracy
    - Tube interface area to be improve by calibration ~**1.3mm** (**±0.65mm**) shape accuracy
  - Minimum thickness: **3.85mm** (only local area)

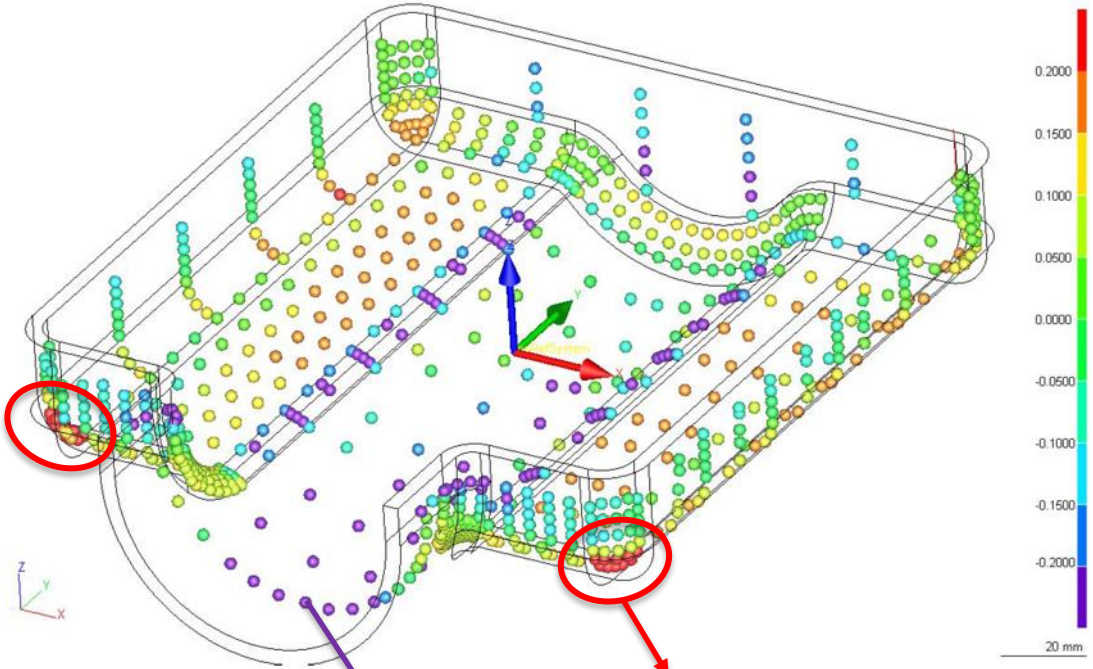
Fabrication Results: *Waveguide Boxes Example*

- **Niobium Waveguides Box Shaping (lessons learnt after Cu trials)**

  - Upgrade forming procedure
    - Using **Br** intermediate plate (less friction)
    - Increase deep drawing pressure up to 350bar (>120 Tons)
    - Trimming (+3mm on theoretical shape)
    - 3 x Stamping at 375bar (>130 Tons)
  - Use stiffer POM+SS template for comparison
  - Calibration utmost importance

Fabrication Results: *Waveguide Boxes Example*

- **Niobium H-HOM Box: *First Metrology Results***
  - Shape accuracy after forming at 350bar
    - No reshaping
    - Shape accuracy on “flat surfaces” better than **0.4mm (±0.2mm)**
    - Calibration of extremity tube interface required
    - Refine process and/or mold in Corners area
  - Thickness:
    - Some friction scratch in blue area (no RF side)
    - Minimum thickness in line with Cu trials



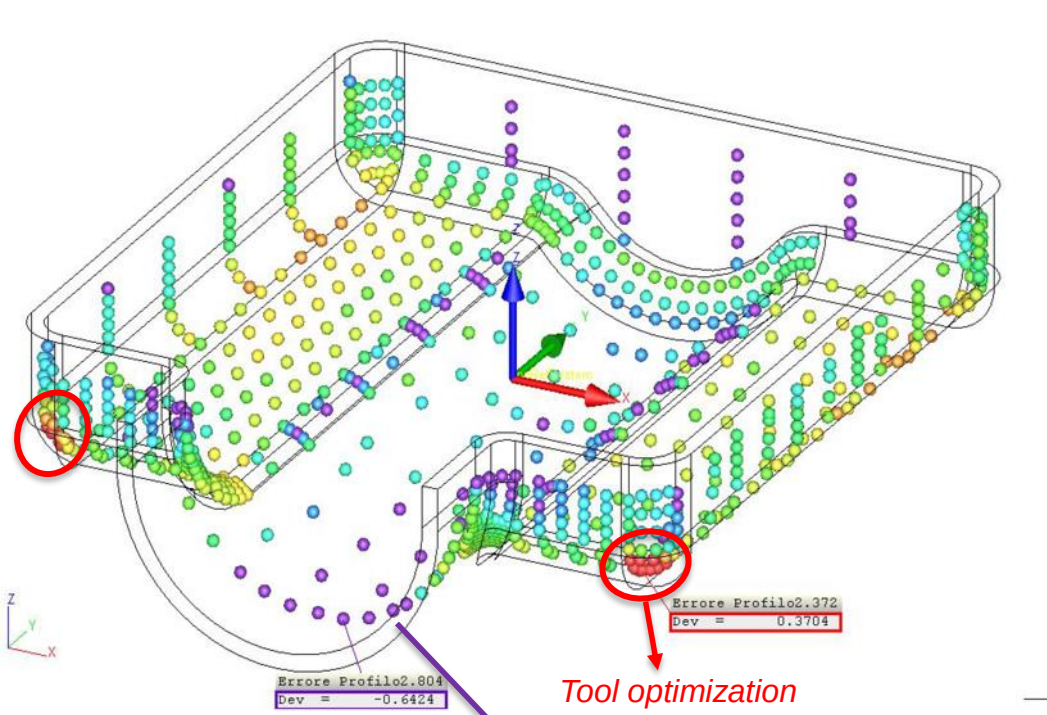
Refine process and/or mold

To be improved by manual calibration

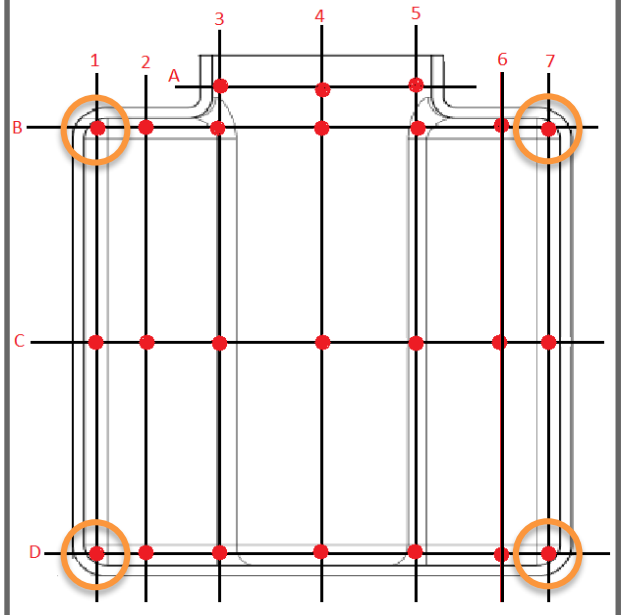
Fabrication Results: *Waveguide Boxes Example*

- **Niobium H-HOM Box 1-4: *Metrology Results***
  - Shape accuracy <u>after trimming & reshaping</u>
    - Improved surfaces accuracy **<0.3mm (±0.15mm)**
    - Calibration of extremity tube interface <u>still required</u>
    - Refine process and/or mold in Corners area <u>confirmed</u>
  - Thickness:
    - Minimum thickness > 3.5mm (on worst sample)

    <u>NOTA</u>: Only in local corners area!



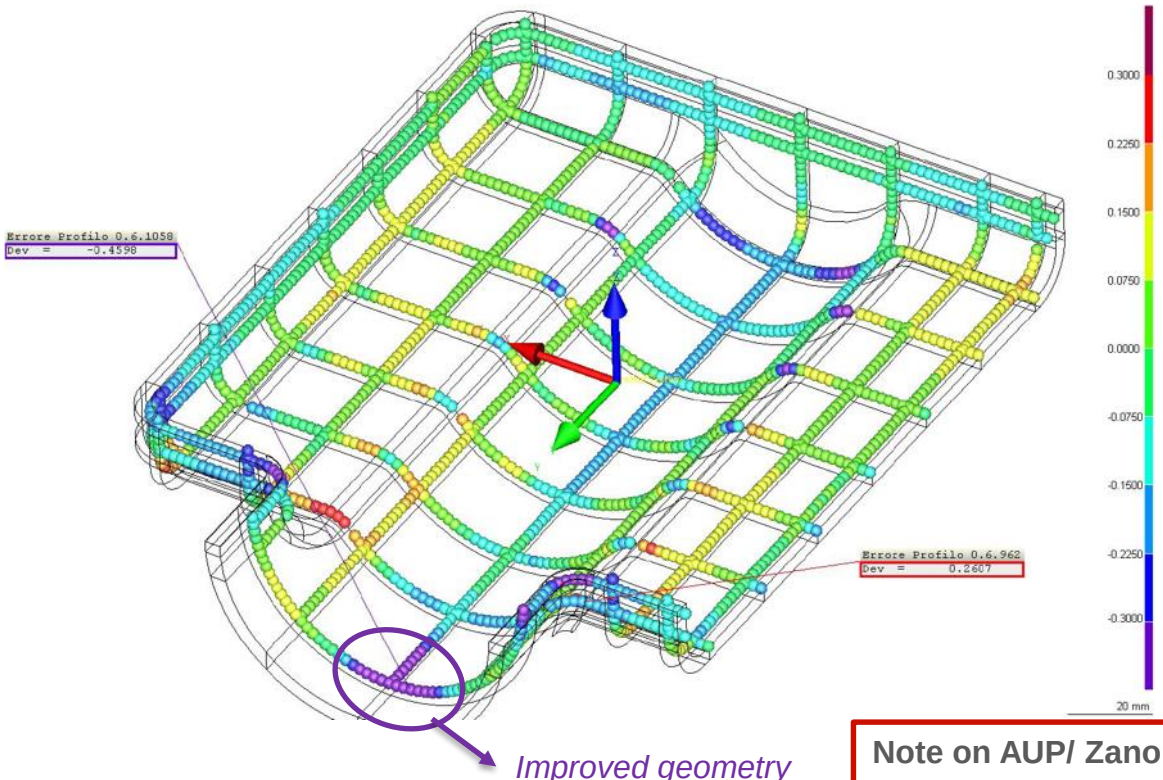
Thickness report



	1	2	3	4	5	6	7
A			4.10	4.10	4.40		
B	3.50	4.20	4.50	4.20	4.40	4.30	3.50
C	4.10	4.10	4.00	4.10	4.00	4.10	4.00
D	3.70	4.10	4.10	3.75	4.00	4.15	3.65

Fabrication Results: *Waveguide Boxes Example*

- **H-HOM Box 2-3: *Final Metrology***
  - Shape accuracy boxes ready to weld
    - Good overall shape accuracy achieved
    - Effective calibration of extremity tube interface
    - Effective forming even in Corners area
  - ***NOTA:*** Improve machining fixture!



Improved geometry

QUALITY CONTROL SERVICE — E. ZANON

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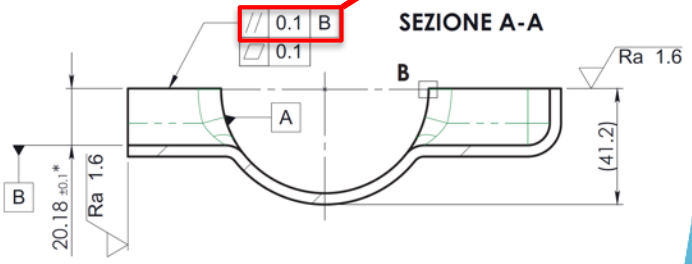
Cliente: / Customer:	FNAL			
Disegno di riferimento: / Reference drawing:	3326.12.122.120	Rev.: / Rev.: 0	Commessa N.: / Job No.:	3326
Identificazione: / Identification:	Left Half H-HOM Wave Guide			

Cod. Part.: / Item code:	0	Operatore: / Operator:	0
Data: / Date:	27/08/2019	Firma: / Sign:	

	Quota nominale / Nominal dimension		Tolleranza / Tolerance		Quota rilevata / Dim. found	
A		154.00	-0.50	0.50	154.28	OK
B	height	20.38	-0.10	0.10	20.32	OK
C	Thickness	4.00	-0.20	0.50	4.28	OK
D	Parallelism B	0.10	-0.10	0.00	0.25	0.15
E	Planarity	0.10	-0.10	0.00	0.10	OK

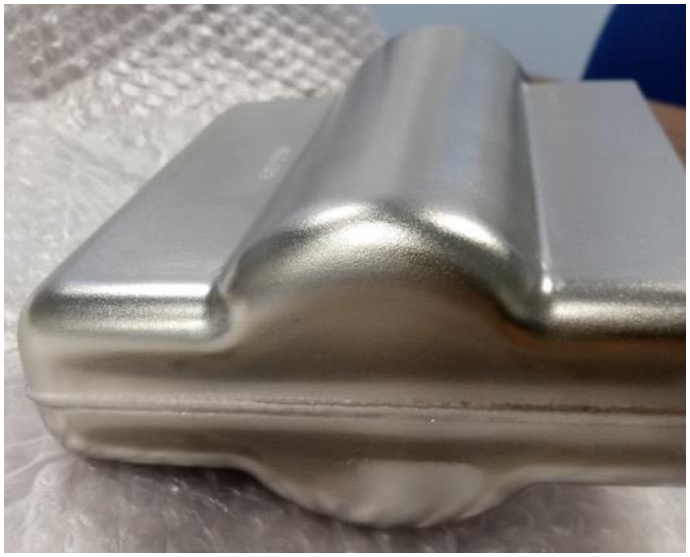
P = passa - pass; n/a = non applicabile - not applicable

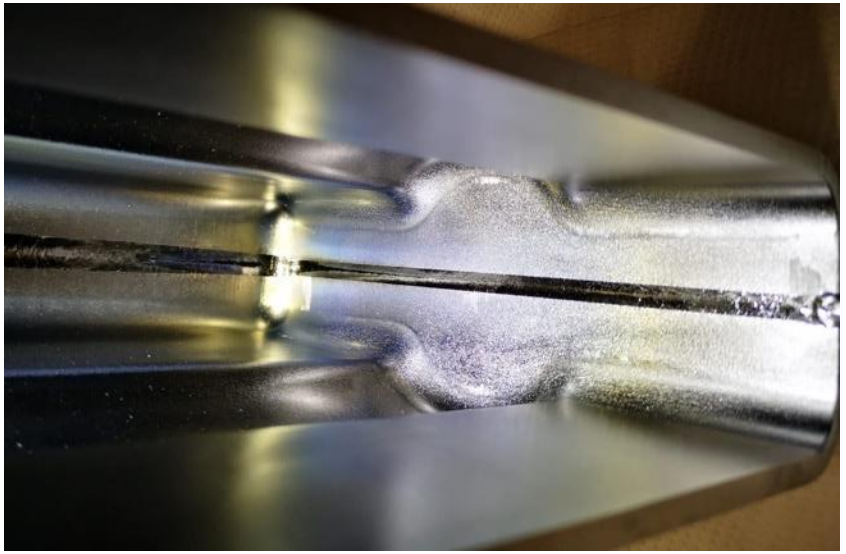


Note on AUP/ Zanon fabrication strategy:
- The worst manufactured components → Used for RFD proto #1
- Leave room for improvement on second RFD Cavity #2

Fabrication Results: *Waveguide Boxes Example*

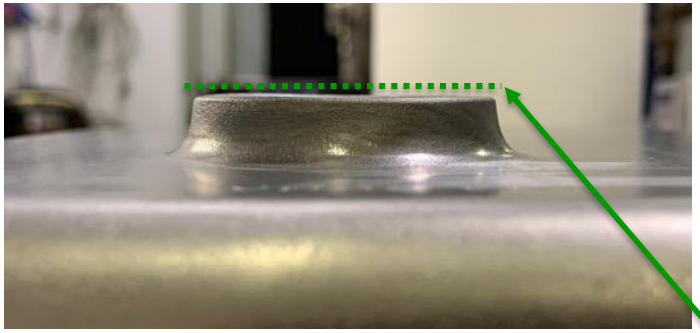
- **H-HOM Boxes: EBW highlight**
  - No official fixture used
    - **Tight schedule & lack of funding = Creativity!**
  - Metrology of welded boxes ongoing
  - RX test ongoing
  - Consideration about results
    - ✓ External weld bead is homogeneous and clean
    - ✓ RF side: smooth and constant welding width
    - ✓ No undercut
    - ✓ No excessive penetration
    - ✓ No misalignments
    - ✓ No sagging

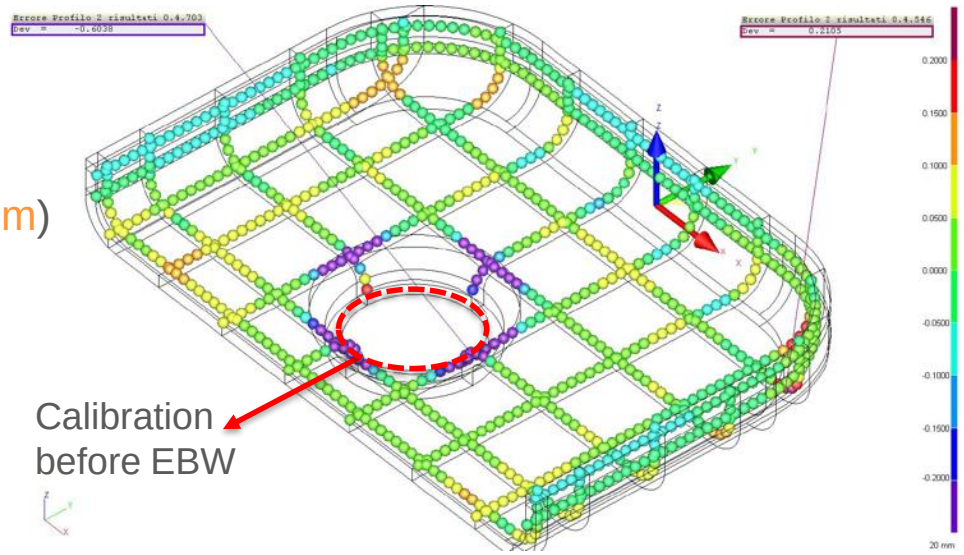




Fabrication Results: *V-HOM Extrusion*

- **Niobium V-HOM Box: extrusion**
  - First test: shape tolerance ±0.17mm
  - Extrusion: very good results
  - Improve machining for EBW (// 0.25mm)





Very flat extrusion even w/o trimming!

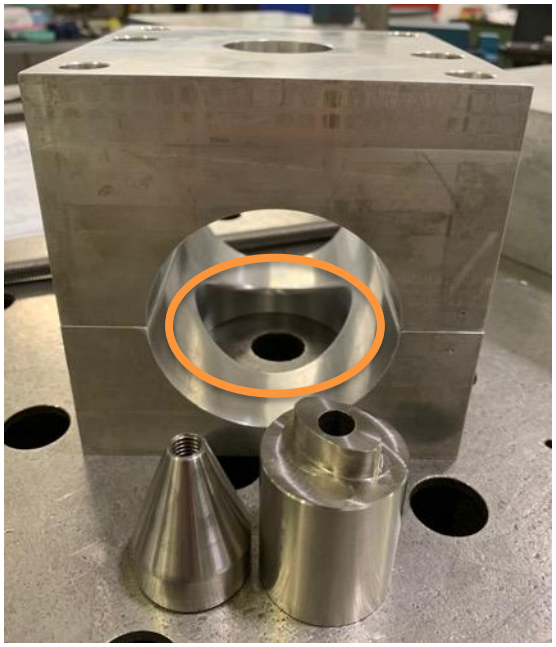
From Left: Extrusion Tool. V-HOM Results. Results: nominal Ø37.63mm, nominal thickness 2.2mm!

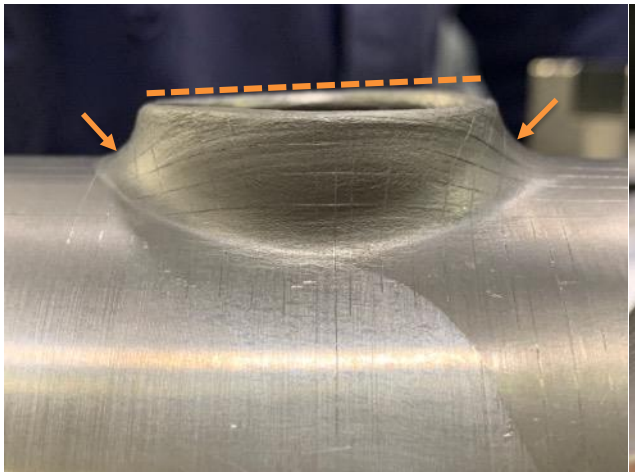
Fabrication Results: *Beam Axis extrusion test*

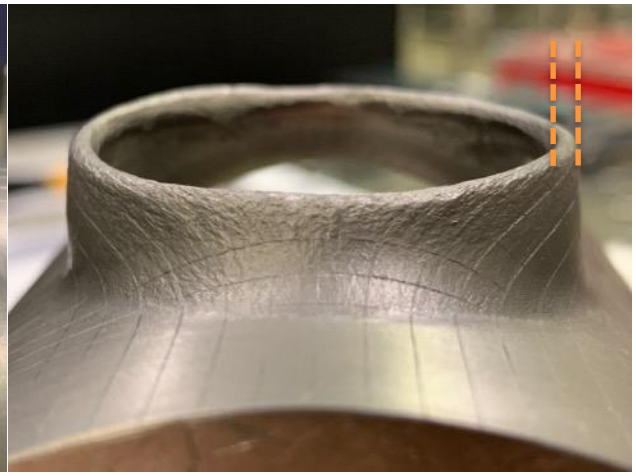
Niobium Beam Tube Extrusion Test

- First extrusion test: from a high thickness pre-machined tube
- Some issue due to inaccurate machining of extrusion tool
  - Excessive clearance between coupling elements
    - Uneven extrusion
    - Not constant thickness
    - Low circularity
  - Internal radius not well machined
    - Different external radius on extruded component

❖ Ongoing test with new extrusion tool



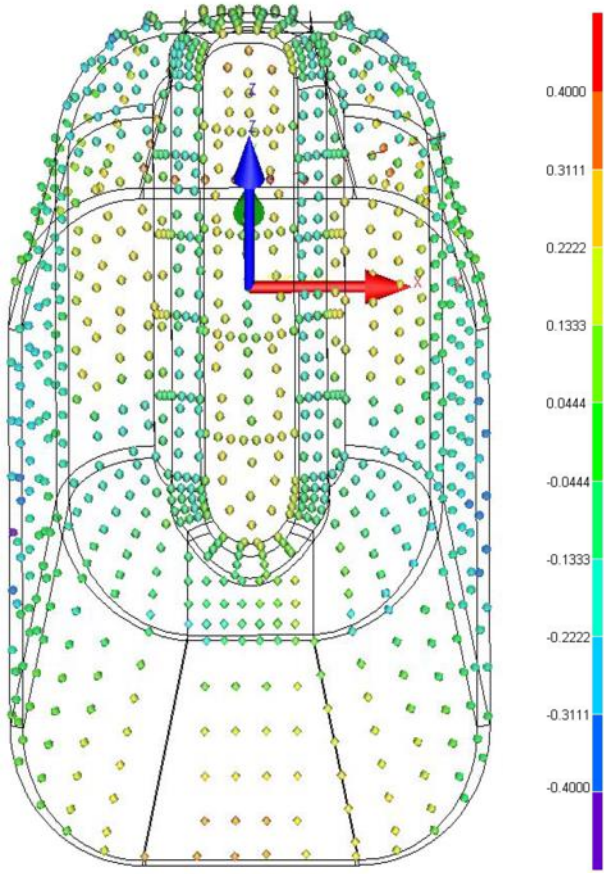




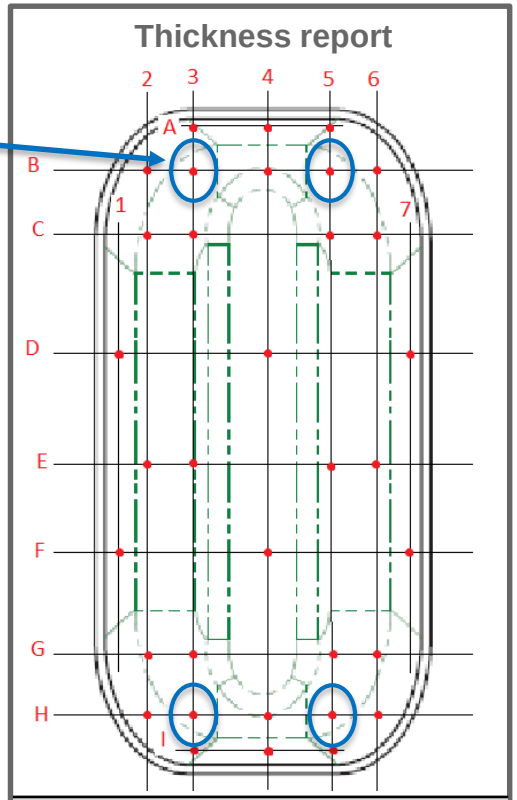
Uneven extrusion w/o trimming & different external radius. Not constant and low thickness. Low circularity.

Fabrication Results: Deep Drawing

- **Niobium Pole 1-4: Metrology Results**
  - Shape accuracy after reshaping 400bar: ~0.6mm
    - **NOTA**: shape defects due to initial sheet thicker than requirements (>4.15mm)
  - Minimum thickness: >3.6mm (only local area)



Pole n. 2: Metrology after trimming



	1	2	3	4	5	6	7
A			4.25	4.20	4.27		
B		3.81	**3.61**	3.88	**3.6**	3.92	
C		4.02	3.96		3.98	4.12	
D	4.19			4.09			4.15
E		4.22	4.07		4.1	4.25	
F	4.22			4.1			4.21
G		4.07	4.05		4.08	4.13	
H		3.92	**3.71**	3.89	**3.65**	3.89	
I			4.25	4.15	4.25		

Fabrication Results: *Insert Machining Test*

- **Copper Waveguides/ End Cap transition insert**
  - ✓ Good overall results
  - ✓ Satisfying quality of machined welding edges (shape accuracy <0.2mm)
  - ❖ Need better fixture for machining centering (see rectangles)

QUALITY CONTROL SERVICE

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Cliente: / Customer:	FNAL		
Disegno di riferimento: / Reference drawing:	3326.12.130.001 — Rev.: / Rev.: 0	Commessa N.: / Job No.:	3326
Identificazione: / Identification:	FPC/V-Hom Insert		

Cod. Part.: / Item code:	Copper Test	Operatore: / Operator:	Negro Dario	
Data: / Date:	9/25/19	Firma: / Sign:		

		Quota nominale / Nominal dimension	Tolleranza / Tolerance		Quota rilevata / Dim. found	
A		169.94	0.05	0.15	170.05	
B	Centering	0.00	-0.20	0.20	0.54	0.34
C		39.73	0.05	0.15	39.88	OK
D		20.05	-0.10	0.10	20.07	OK
E		15.20	-0.10	0.10	14.85	-0.25
F		7.86	0.025	0.075	7.91	
G		47.97	-0.50	0.50	48.33	OK
H		4.00	-0.10	0.10	4.07	OK
I		4.00	-0.10	0.10	4.08	OK
J		3.00	-0.10	0.10	3.01	
K	Shape A-B-C	0.20	-0.10	0.10	1.70	1.40

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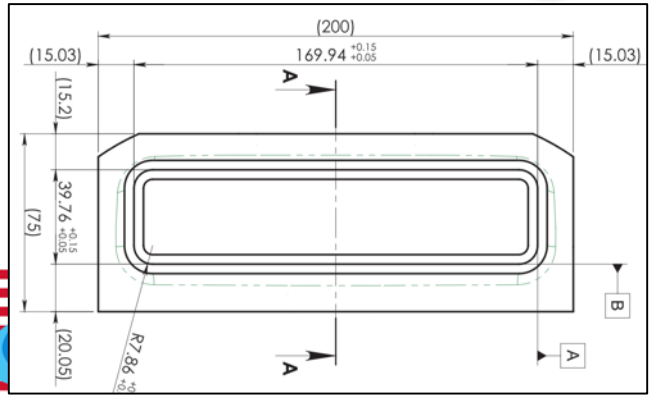
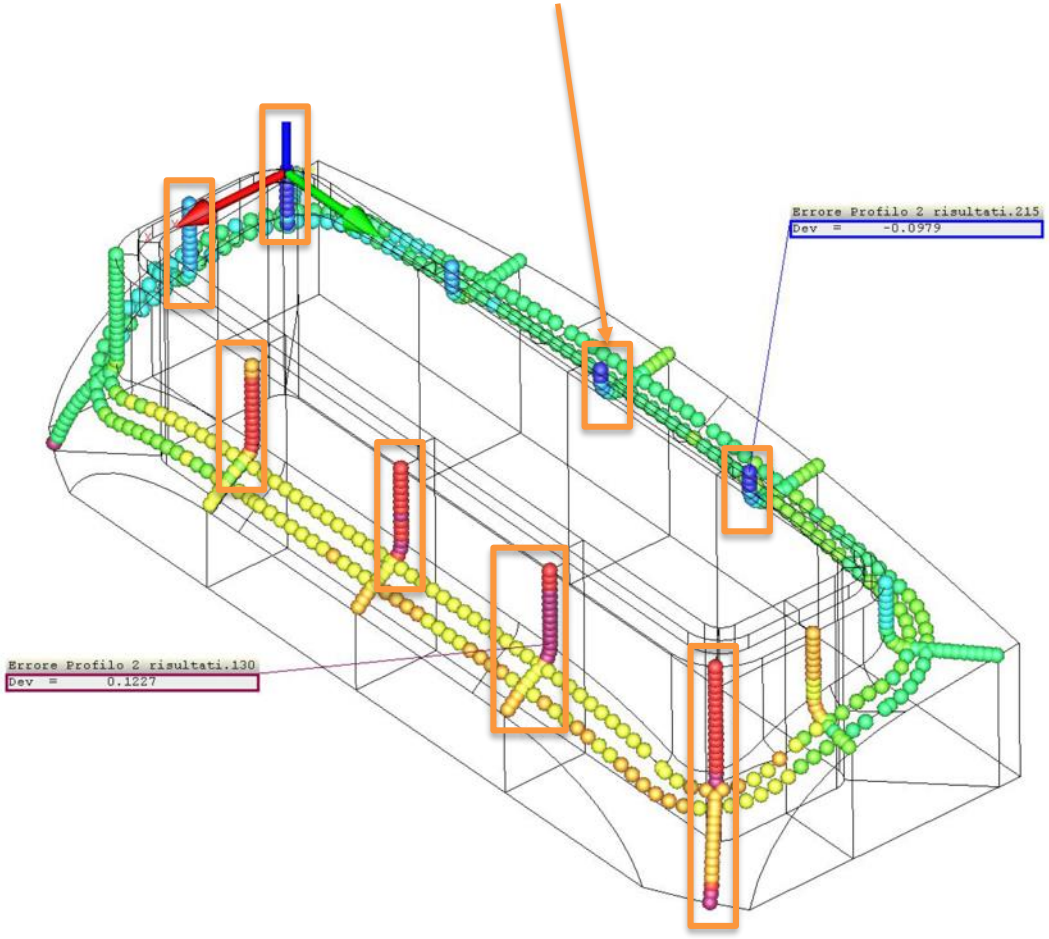




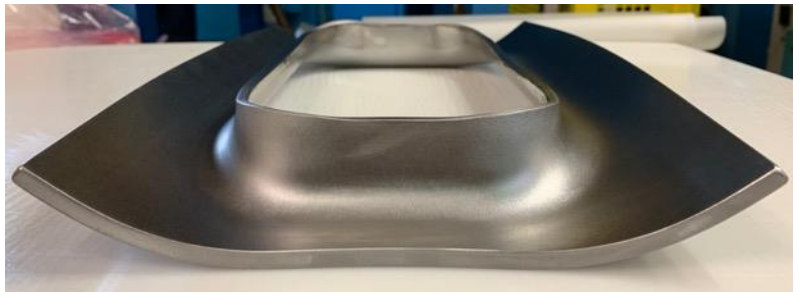
Fabrication Status: *Next steps & Pics*

Imminent activities:

- Forming of Half Main Body (full scale)
- EBW test between *copper* Pole & Corner
- RX EBW of waveguides (MTF upload)
- Metrology check of Nb transition insert
- Machining of Nb End Caps
- Machining of Nb extremities
- Finalization of Machining & EBW Tools
- …

End Cap

Half Main Body “short Test”



Corner

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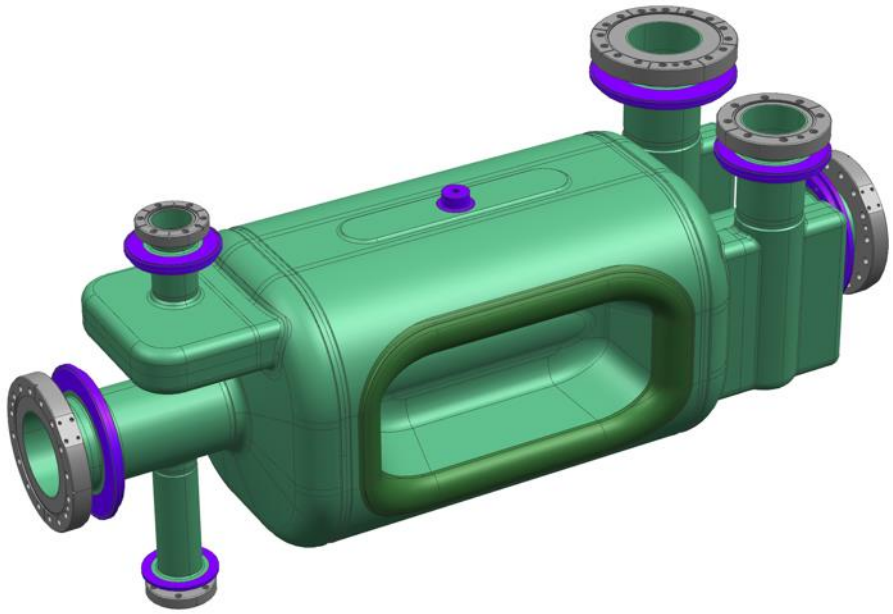


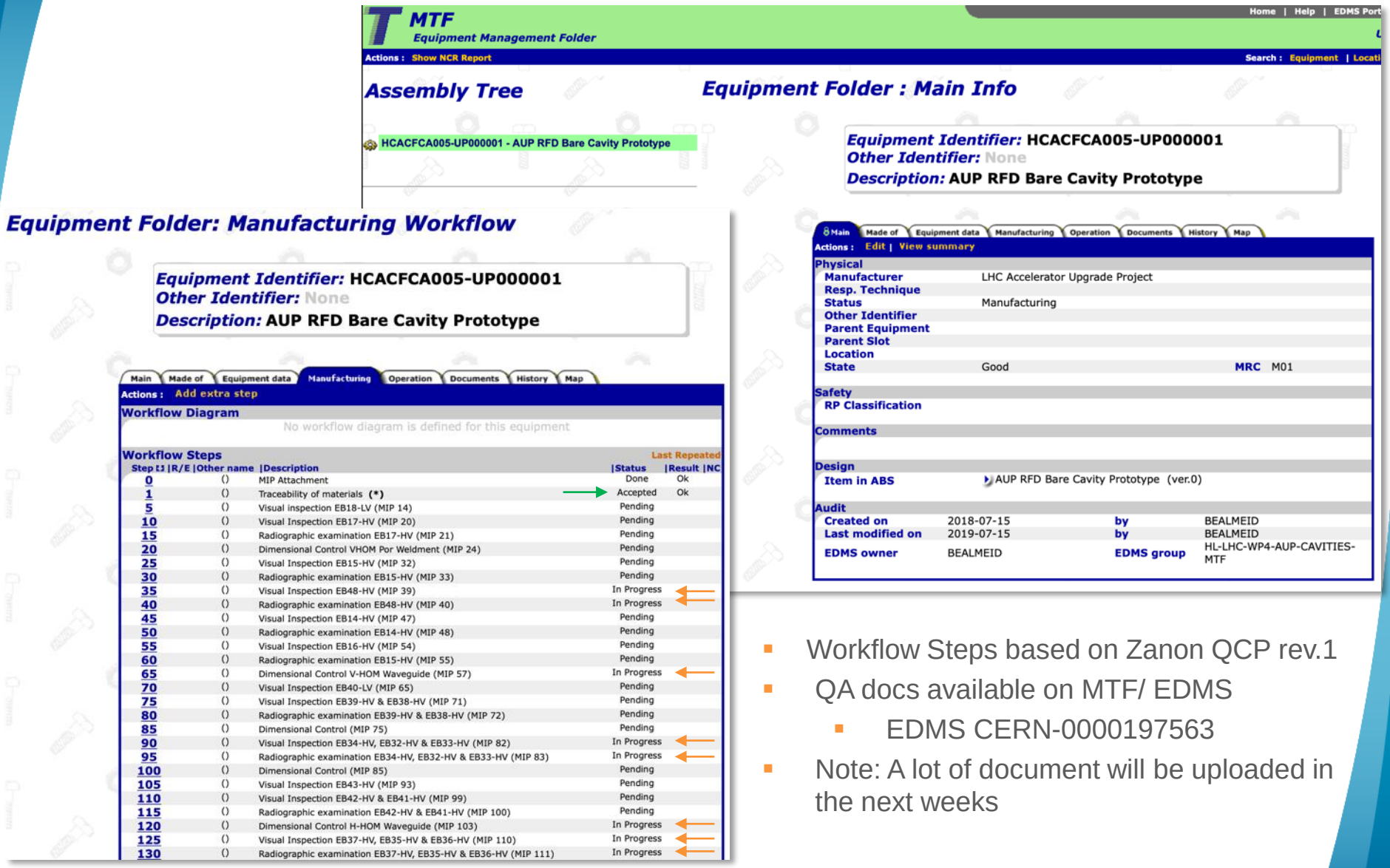
QA Documentation: *Actual Status*

Description Procedure	Procedure N.	Revision	Status
RFD Crab Cavity Drawing Package	3326.1.000.000	0	Check ongoing (FNAL)
Manufacturing Drawing Tooling	Not Available	0	Update ongoing (Zanon)
Welding Book – section 1 Welding Map	3326.W.001	0	Update ongoing (Zanon)
Welding Book - section 3 Test Coupon (WPQR)	3326.W.001	0	Update ongoing (Zanon)
Welding Book - section 2 (WPS)	3326.W.001	0	Update ongoing (Zanon)
Welding Book - section 4 Welding Operators (WOPQ)	3326.W.001	0	Update ongoing (Zanon)
Welding Book – section 1-4	3326.W.001	0	Update ongoing (Zanon)
Quality Control Plan – RFD Prototypes (MIP)	3326.F.001	2	Update ongoing (Zanon)
Quality Control Plan – Deep Drawing of Cu Test	3326.F.002	0	Approved (for Prototype)
Cleaning & Chemical Etching	3326.S.004	1	Approved
Identification, Marking, Traceability	3326.S.001	1	Approved
Radiographic Examination (RT)	3326.S.005	1	Approved
Radiographic Test Extent	Radiographic Tests Extent	1	Update ongoing (Zanon)
Manufacturing Sequence	3326.S.008	0	Update ongoing (Zanon)
Helium Leak (LT)	3326.S.006	0	Waiting for comments (CERN)
Dimensional Control	3326.S.002	0	Waiting for comments (CERN)
Visual Inspection	3326.S.003	1	Approved
Packing Procedure	3326.P.001	0	Ongoing (Zanon)

QA documents provides by Zanon are available on EDMS

NOTA: *The Eng. Spec. (EDMS 1389669) requires CERN approval for all procedures concerning Pre-series and Series production*

QA Documentation: *MTF Status*



- Workflow Steps based on Zanon QCP rev.1
- QA docs available on MTF/ EDMS
  - EDMS CERN-0000197563
- Note: A lot of document will be uploaded in the next weeks

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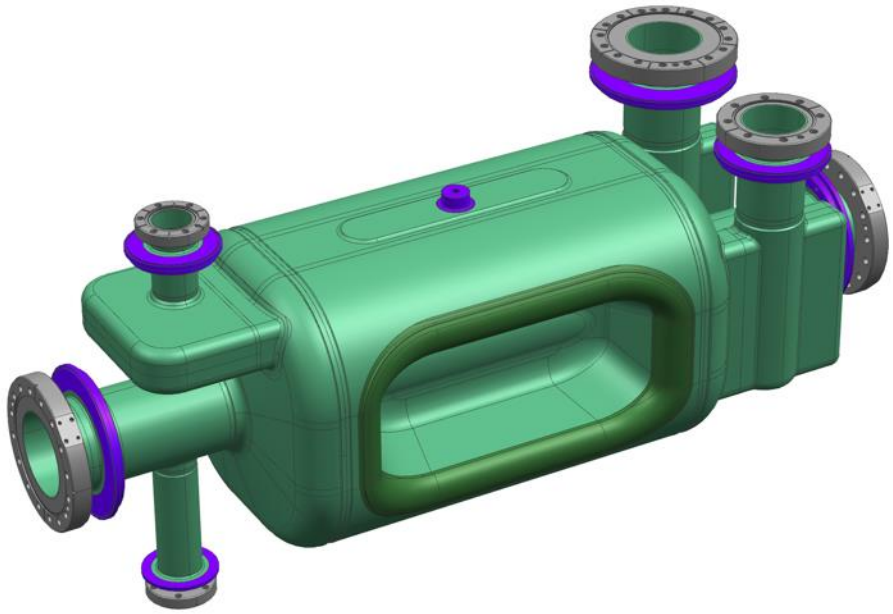

Summary

- Fabrication drawings
  - Fixing minor details to achieve ISO GPS standard requirements
- Fabrication Tools:
  - Forming Tools almost validated
  - Machining and EBW manufacturing ongoing
- Subcomponents Manufacturing:
  - 4x Pole: ready for EBW
  - 2x H-HOM: boxes welded (RX ongoing)
  - 2x V-HOM: boxes welded (RX ongoing)
  - 2x FPC: boxes welded (RX ongoing)
  - 2 x End Cap: formed
- Machining agenda for next weeks
  - Half Main Body: first forming on Niobium ongoing
  - End Cap: preparation for EBW ongoing
  - Waveguides bulk transition insert: machining ongoing
  - Pole & Corner preparation for EBW: machining ongoing
  - Copper Pole & Corner EBW test ongoing
  - Extremities machining ongoing
- Updating QA documents according to CERN/FNAL feedbacks
- Tight schedule for prototype!

Thank for the attention!