Additive Manufacturing for Crabs

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Outline

I. Metal Additive Manufacturing at CERN

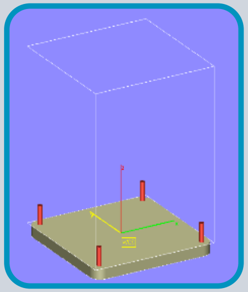
II. AM of DQW HOM coupler in niobium

- Advances in purification by Ti-gettering

III. AM of Al_2O_3 ceramic windows with cooling

IV. Future perspectives and conclusions

MME’s AM workshop at CERN

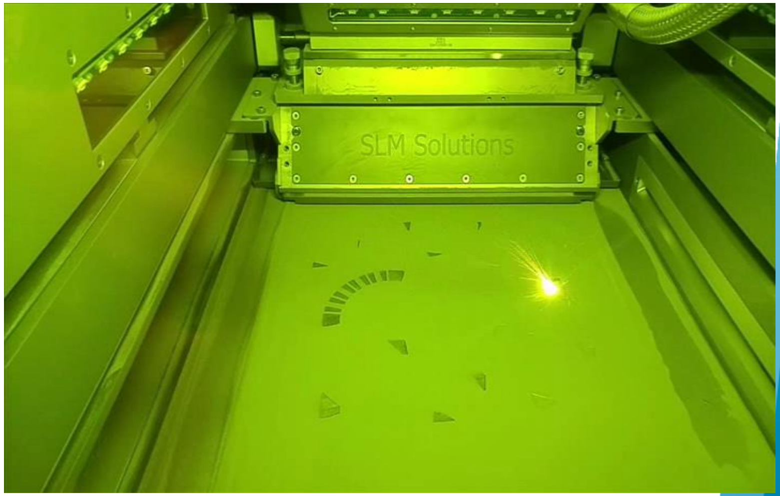


Machine:
- SLM 280HL (SLM Solutions)
- 400 W laser (1070 nm)
- Tri-axis scanning system

Build volume:
- 280 x 280 x 360 mm^3

Materials
- Ti6Al4V
- SS 316 L
- Niobium (R&D)
- Potential:
  - Copper
  - Mo

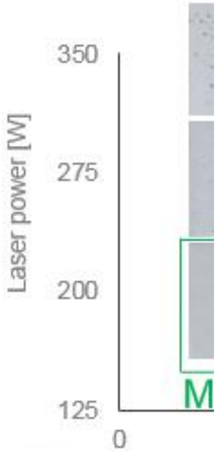
Location
- CERN-Meyrin
- bldg 156



Niobium development

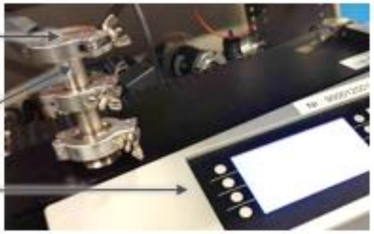
Niobium powder for SLM

Density of SLM niobium

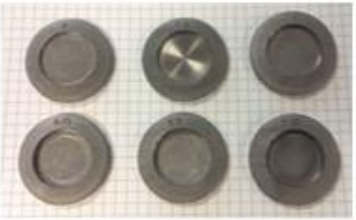


Leak Tightness to helium

vertical wall >0.5mm thickness
are **Helium Leak tight**



Material	Thickness (mm)	Vacuum (mbar)	He leak (mbar.l/s)	Leak tight
Nb	**2**	4.0 10^{-3}	<10^{-10}	YES
	1.5	5.3$10^{-3}$	<10^{-10}	YES
	1	5.0 10^{-3}	<10^{-10}	YES
	0.75	5.6 10^{-3}	<10^{-10}	YES
	0.5	5.6 10^{-3}	<10^{-10}	YES
	0.25	5	--	NO



9-13 April 2018 FCC Week 2018 11

More info: https://indico.cern.ch/event/656491/contributions/2915671/

HOM coupler for crab cavity DQW

Why 3D printing an HOM ?

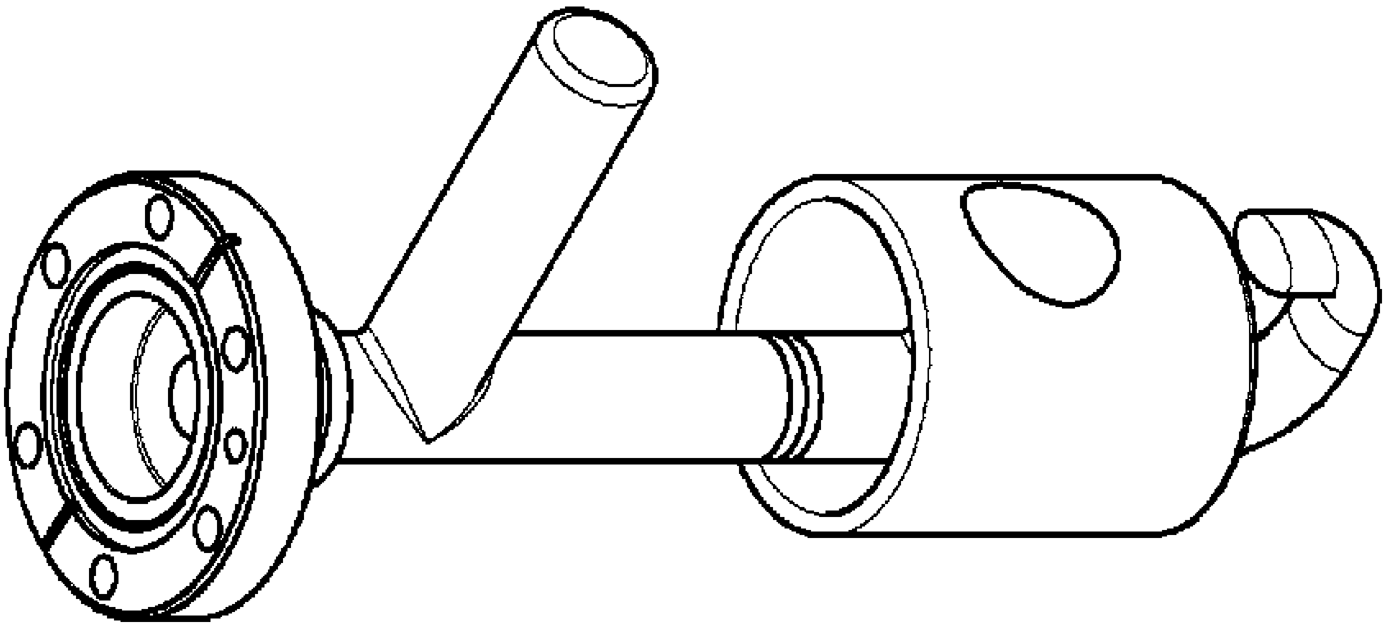
1. Bring cooling closer to high field area ex: bring He to the tip of the hook
2. Test bed for novel Nb parts designed from scratch
3. Design freedom advantages
   - Manufacture directly on a Ti Flange Hybrid AM
   - Reduce assemblies (save time and costs)
4. (Possible reduction of cost thanks to better material utilisation rate)

DQW 3D HOM :
Leak tightness to superfluid He

Next step: CF DN40 flange dressing

To be tested in cryolab:

- “reversed leak test”: Vacuum inside, SF He outside

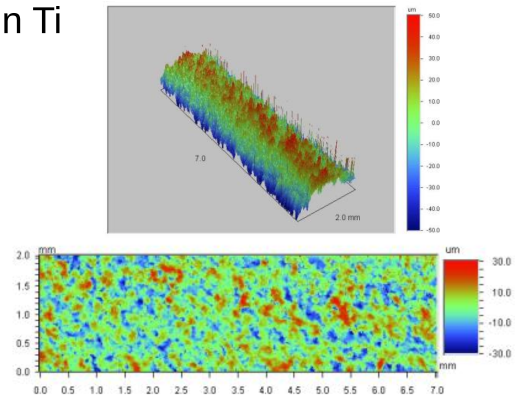


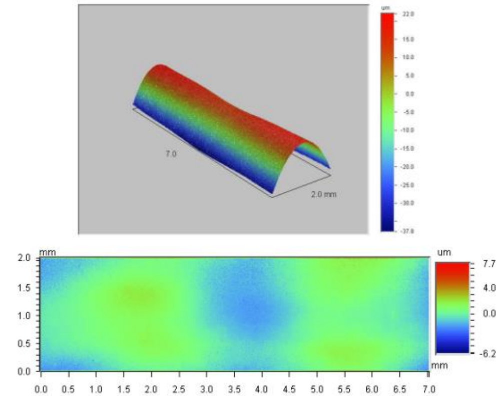
Superfinishing of the parts

	As-build	Polished with MMP TECHNOLOGY®
		MMP: Mechanical-physical-chemical surface treatment applied to items placed inside a treatment tank.

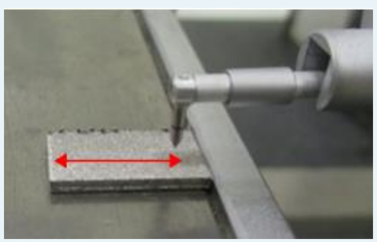
Titanium

HOM prototype in Ti





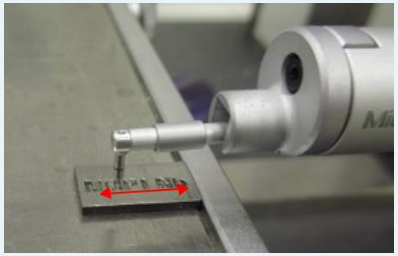
Niobium



Niobium samples

Nb SLM As built	
R_a	10.8 μm
R_z	65 μm
R_t	78.5 μm

Nb SLM after MMP	
0.070 μm	R_a
0.7 μm	R_z
1.62 μm	R_t

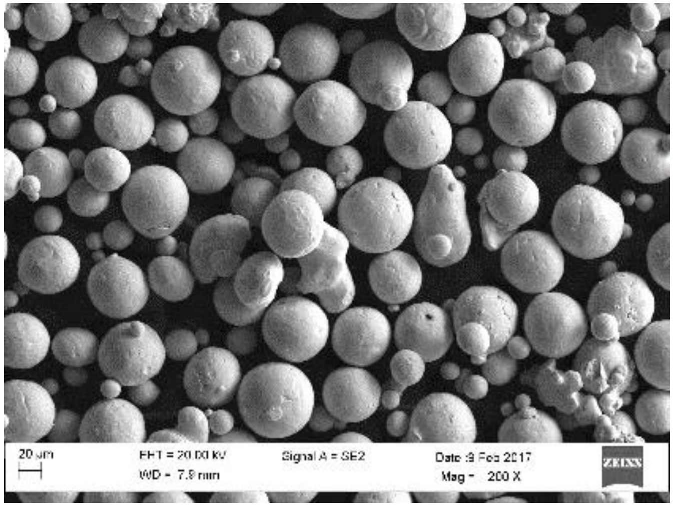


Chemical composition of SLM Nb: High quantity of light interstitial elements

Element in µg/g	Nb	O	N	C	H	Al	Ti	Ta	Mo	Si	Fe	Others
Powder	99.98%	510	99	39	60	120	66	35	31	24	16	<35 in total
Parts	99.98%	590	150	39	9.6	90	31	30	17	15	14	<35 in total
CERN RRR300		10	10	10	2	30	50	500	50	30	30	30 each

All light interstitial impurities are out of traditional RRR300 specifications

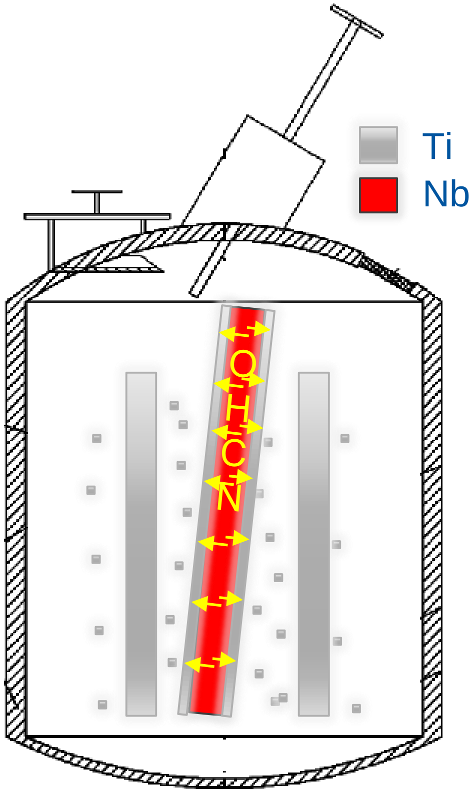
Aluminium impurities due to cross-contamination during atomisation

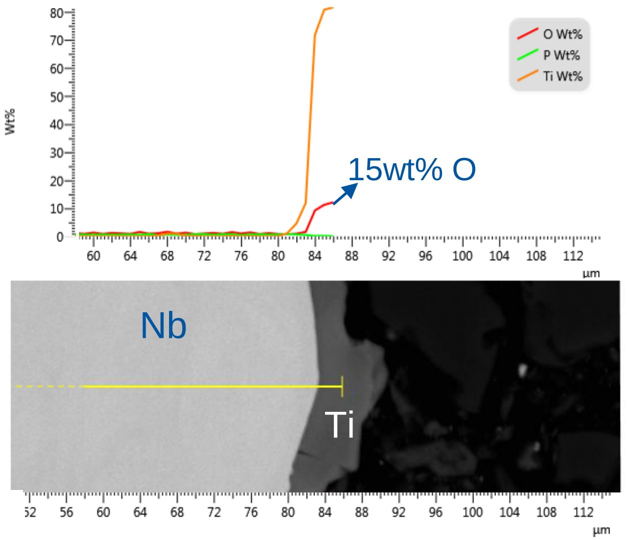


Purification of SLM Nb
Re-discovery of Ti-gettering purification

Working principle:

1. Vaporisation of Titanium at high temperature (1000-1400 °C) and high vacuum ($10^{-5} mbar$)
2. Deposition on the SLM Nb parts (1 – 10 μm thickness)
3. Diffusion of light impurities from the Nb to the Ti coating (2000 – 8000 min)
4. Removal of the outer layer with chemical etching

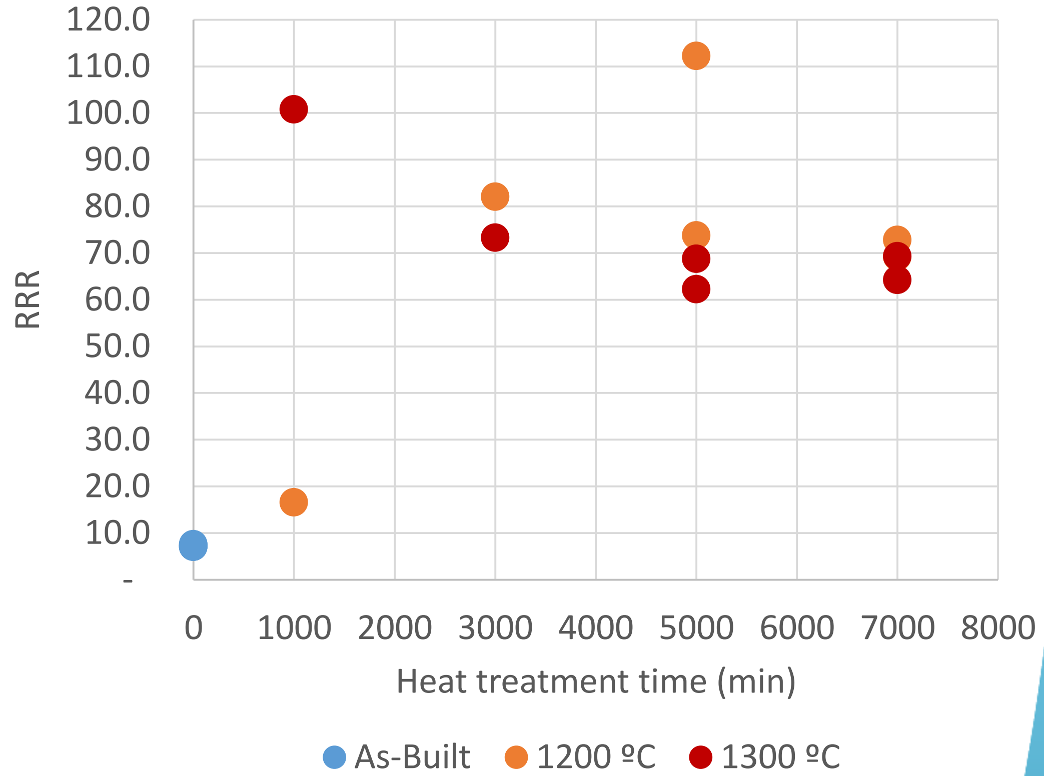




RRR after Ti-gettering treatment

Optimum to find:

- High T/ long duration
  - ➢ Ti diffuses in Nb
- Low T/ short duration
  - ➢ Not enough Ti deposition or O/N/C diffusion



Exploration of dual-Temperature Heat-treatment ?

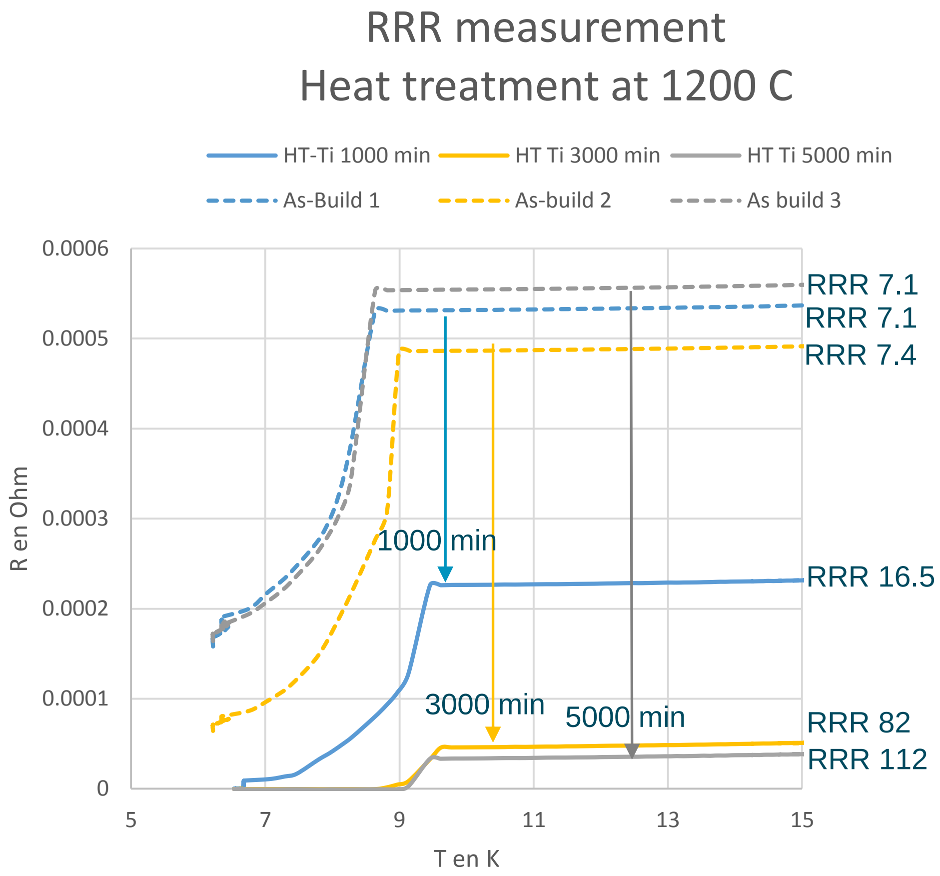
Purification heat treatment

As-build

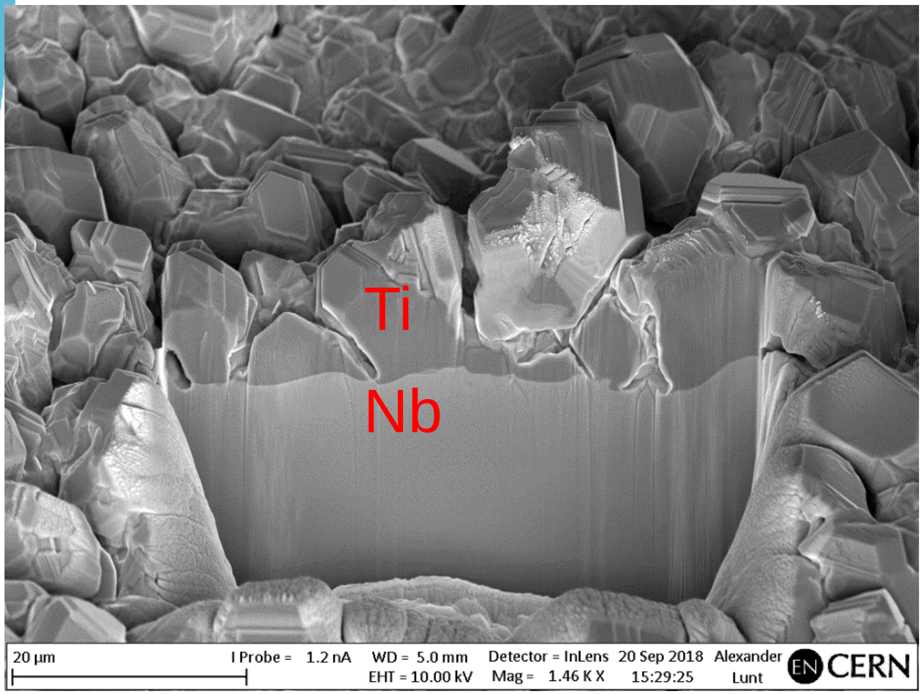
Chemical composition	As-build
O	590
N	150
C	39
H	9.6
Al	90
Ti	31

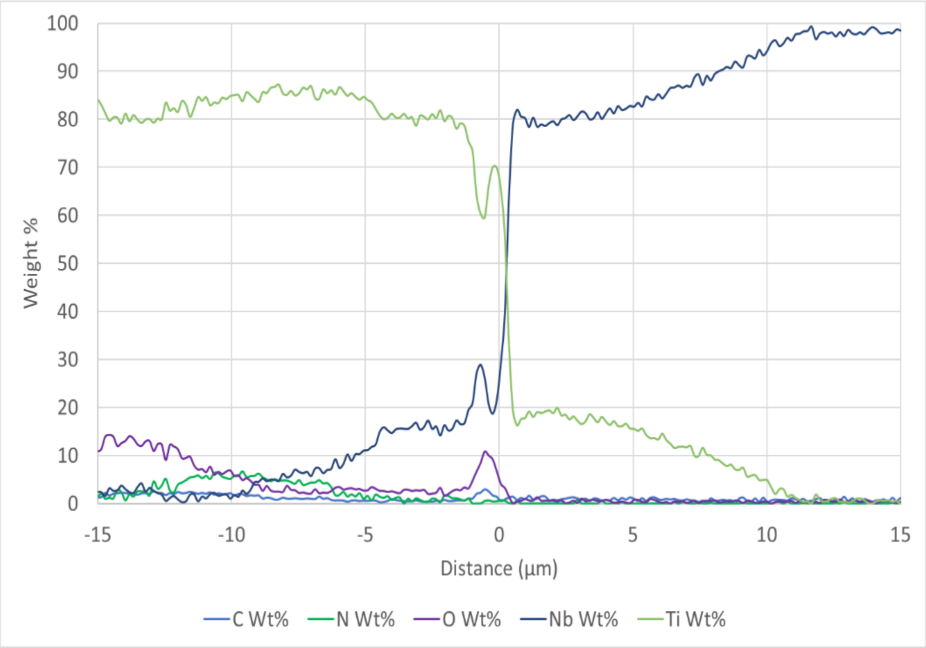
After Ti-gettering

Chemical composition	
After Ti-get	unit
17	ppm wt.
<5	ppm wt.
<5	ppm wt.
1.1	ppm wt.
90	ppm wt.
100	ppm wt.



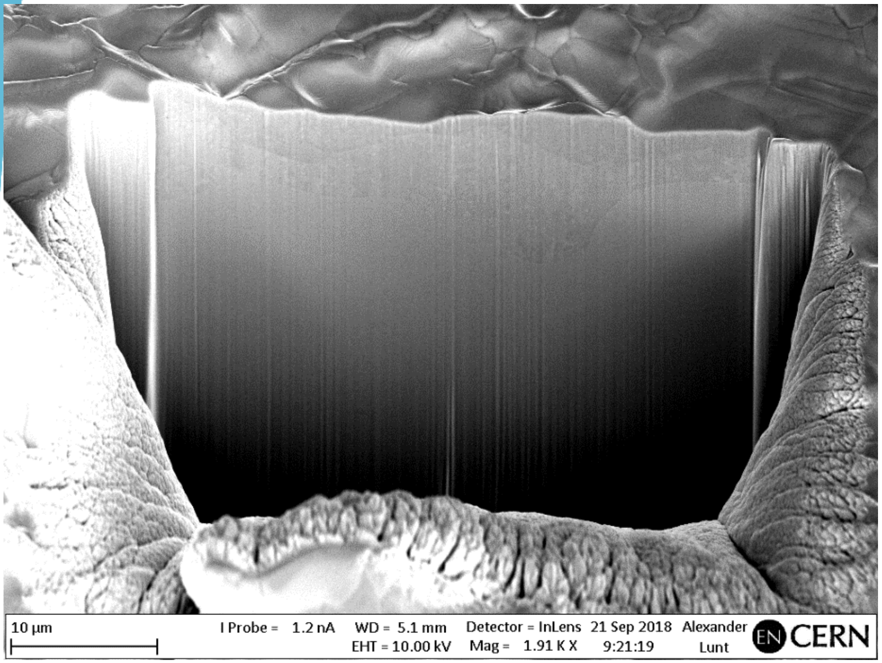
Layer inspection with Focused Ion Beam
Short treatment 1000min @ 1300 ºC

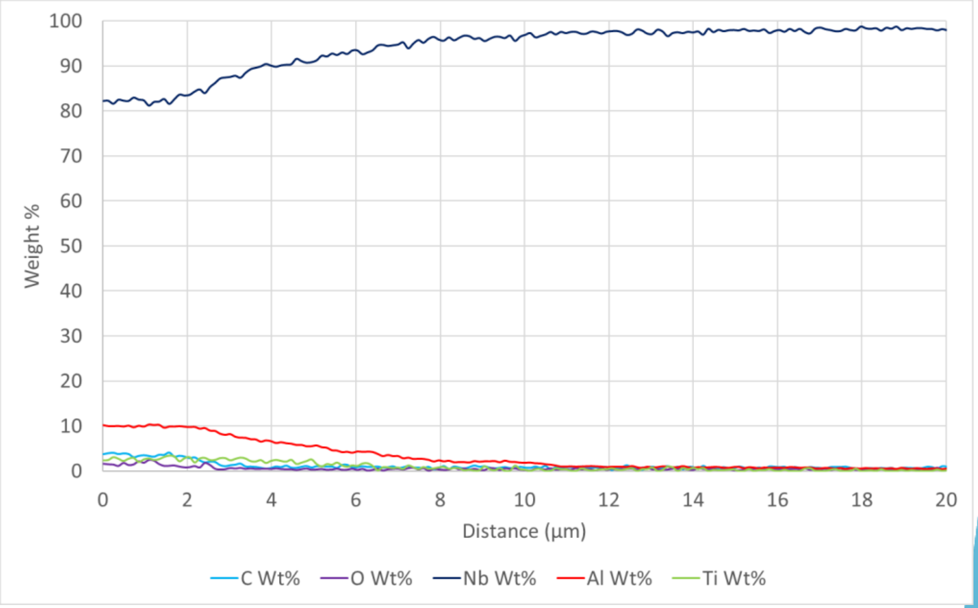




Results: A. J. G. Lunt EN-MME-MM
EDMS 2024699

Layer inspection with Focused Ion Beam
Long treatment 7000min @ 1300 ºC





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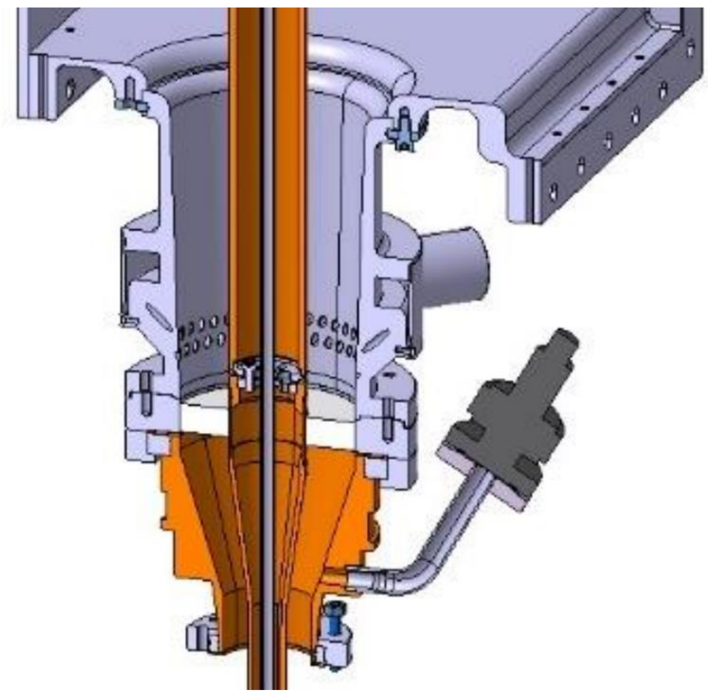
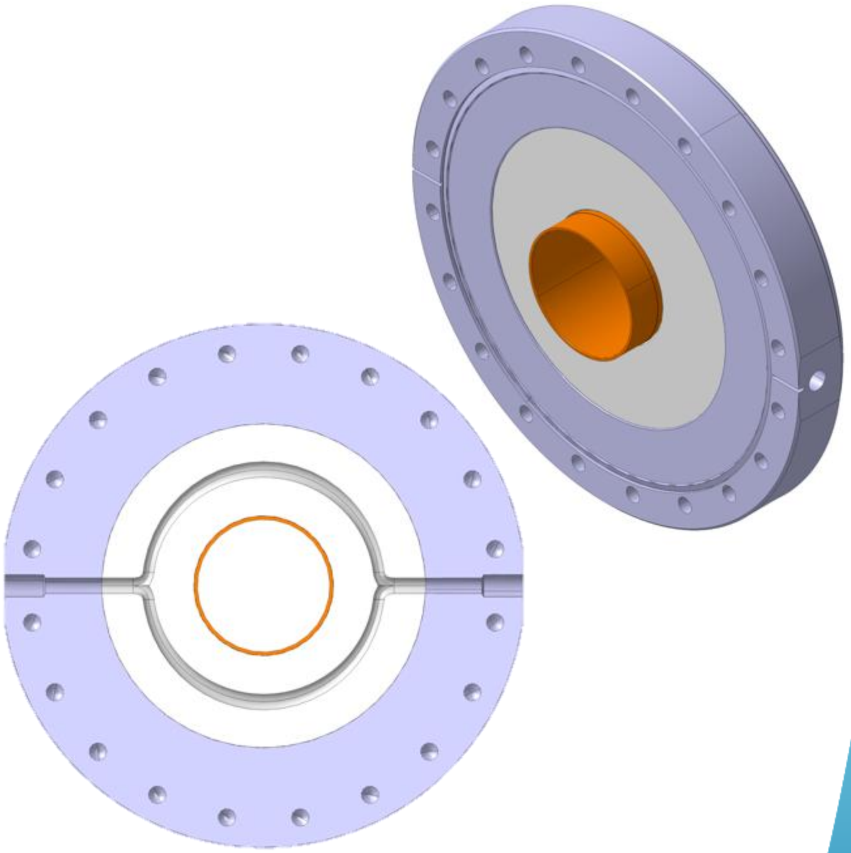
Crab cavity FPC

Crab Ceramic RF window



Water cooled concept



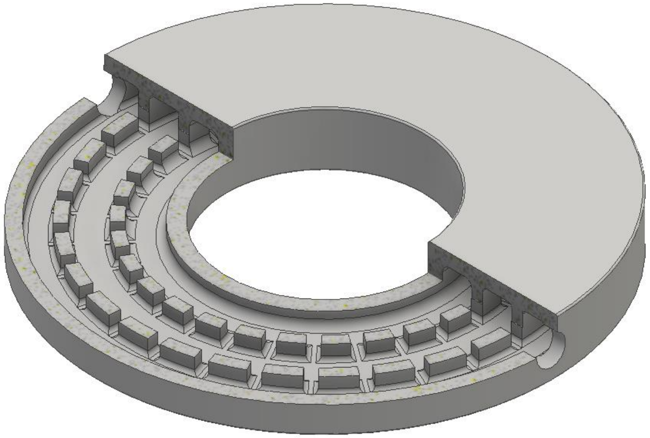
courtesy: E. Montesinos

Ceramic 3D printing

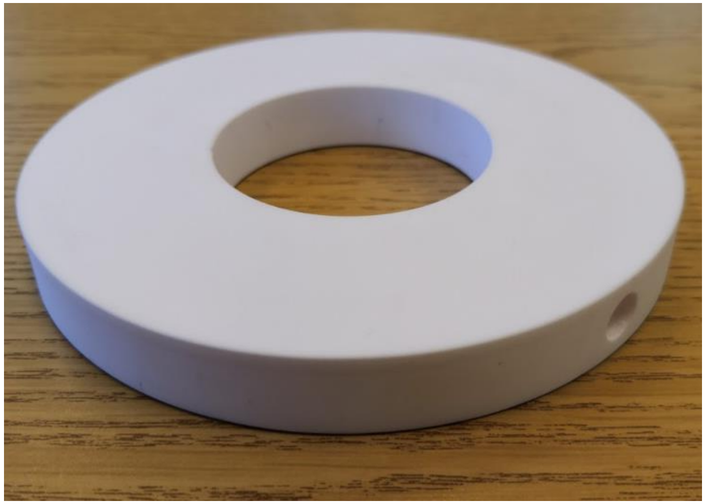
Video courtesy of 3D CERAM (FR)

3D printed Ceramic with cooling channels

Redesigned watercooled concept



3D printed

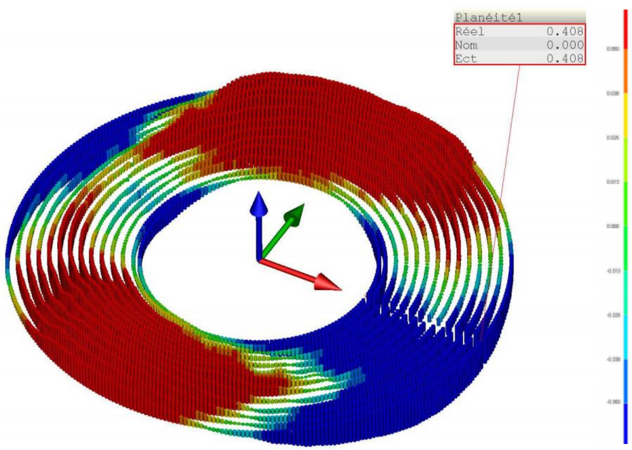


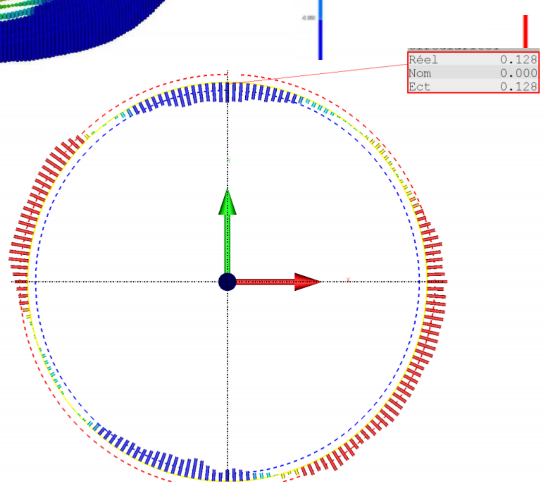
Metrology and inspection with X-Ray CT

Planarity: **400 µm**
Cylindricity: **126 µm**

Requirements: **20µm**

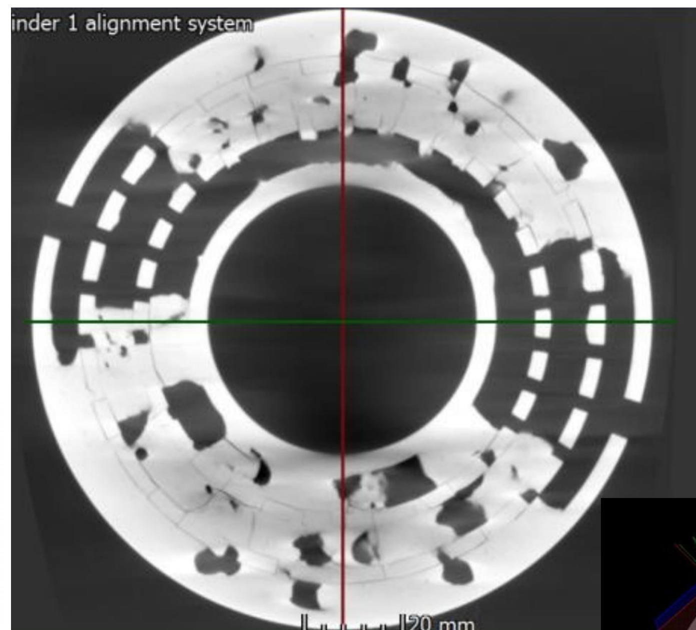
Machining to be performed

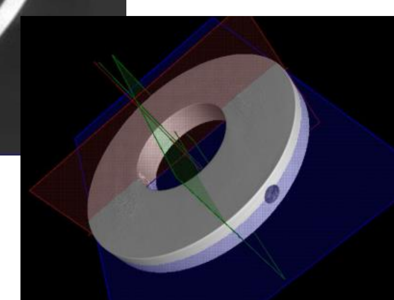




X-ray CT unvealed clogged channels
- Due to poor removal of binder (subsequently sintered)

To be corrected with design adjustment





Conclusions and future perspectives

I. Niobium Additive Manufacturing was demonstrated in 2018

- ➢ Further characterisation is moving forward
  - Superfluid He leak test of the complete HOM part
  - QPR RF characterisation

II. Titanium gettering purification is further understood

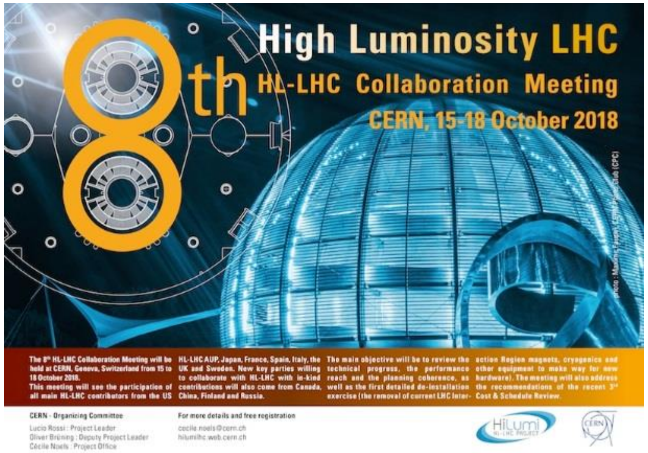
- ➢ Different diffusion regimes are revealed with FIB (dep. time and T)
- ➢ Yields to at least a factor 10 improvement in RRR to ~70

III. Currently preparing a Nb run on the AM machine

- ➢ Innovative modification of the machine to produce long parts with minimal powder investment
- ➢ Ongoing discussions for narrower chemical comp. of Nb powder

IV. AM of Al2O3 ceramic with cooling channel feasible

- ➢ However heavy post-processing required before brazing (rectification and metallisation)
- ➢ Removal of the binder in the channels to be solved



Thank you for your attention !