Metal Additive Manufacturing applications at CERN

Romain Gerard (EN/MME)
Mechanical and Material Engineering group

CERN

ENGINEERING DEPARTMENT

Outline

I. CERN EN-MME metal AM Workshop

II. Requirements for Additive Manufacturing in accelerator environment

III. Radio Frequency application

    I. CLIC RF load

    II. CLIC waveguide filters manufactured by different technologies

IV. Application for accelerator and detectors

    I. Titanium Wire scanner fork

    II. Lattice structure for beam interaction/future collimators

    III. Heat exchanger (Baby Demo, INFN Genova)

Additive Manufacturing Workshop EN-MME

Selective Laser Melting system

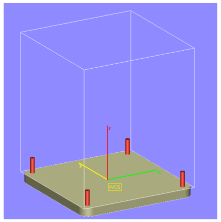
- Started September 2016
- 10 month titanium gr.5 (Ti6Al4V) campaign

Machine:

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

Build volume:

- 280 x 280 x 360 mm^3

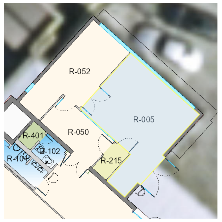


Materials:

- Currently: niobium (R&D)
- Next: SS 316 L / titanium

Location

- CERN Meyrin building 156

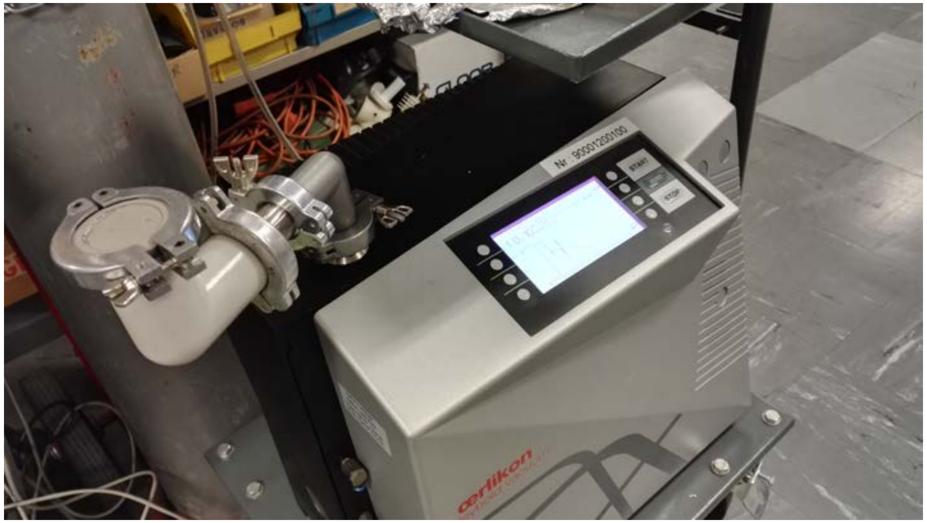


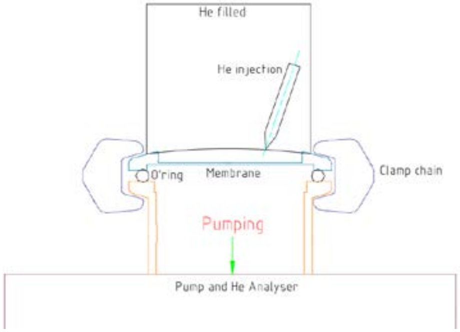
Specific requirements for accelerator environment

- **In vacuum to Ultra High vacuum 10^{-12} mbar ?**
  - Outgassing rate
  - Leak tightness
- **Cryogenic ?**
  - Liquid and supercritical He leak tightness
- **Radio-Frequency ?**
  - Cleanliness
  - Control material contamination
  - High shape accuracy ($10^{-3} - 10^{-4}$ relative for narrow band)
  - Low roughness (Ra below 100nm)
- **Radiation ?**
  - Radiation damage (Typ. $10^{2} - 10^{7}$ Gray)
  - Activation minimized

Example of specific material characterisation UHV – Leak tightness

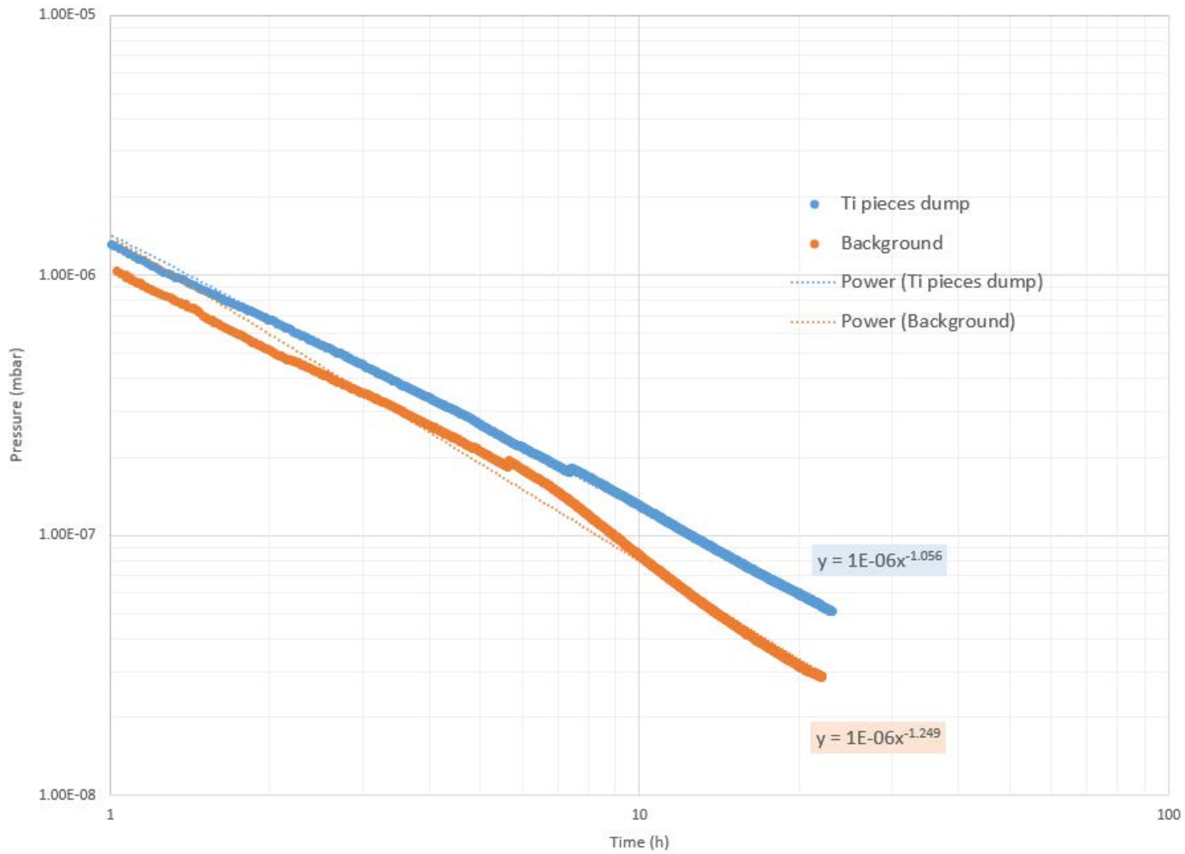
Wall thickness	**He leak tightness UHV**	
0.25 mm (membrane deformed)	Not OK 2.10^{-10} mbar.l/s (detector limit: 1.10^{-10} mbar.l/s)	OK after HIP (Hot Isostatic Pressure) Heat treatment
0.5 mm (membrane deformed)	OK	
0.75 mm	OK	
1 mm	OK	
1.5 mm	OK	
2 mm	OK	
2.5 mm	OK	





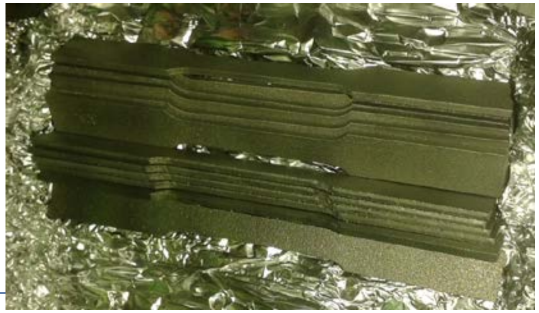
TE-VSC – C. Garion and J.Garguilo

Example of specific material characterisation Outgassing in Ultra High Vacuum



34 Ti6Al4V Samples with total area of 696.7 cm^2

Total outgassing:
2.2 10^{-7} mbar.l/s
Specific outgassing:
3.2 10^{-10} $mbar.l.s^{-1}.cm^{-2}$
(after 24 hours of pump-down).
Conclusion: 2.5x standard stainless steel outgassing



Applications in Radio Frequency

- CLIC RF load
- CLIC waveguide filters

RF Load Development

First targeted application for RF: Broad-band all-metal RF load (Profiting also from roughness for attenuation)

Aim: Develop a compact design achieving a reduction of

-30dB for 12GHz frequency

Current load configuration
1m long

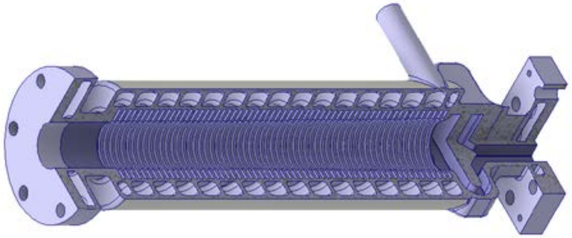
I. Low power material characterisation (Waveguides)

- DC conductivity, UHV compatibility, shape accuracy and roughness, mechanical strength and Metallurgy

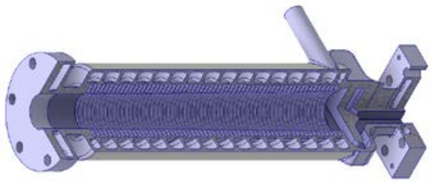
II. High power tests

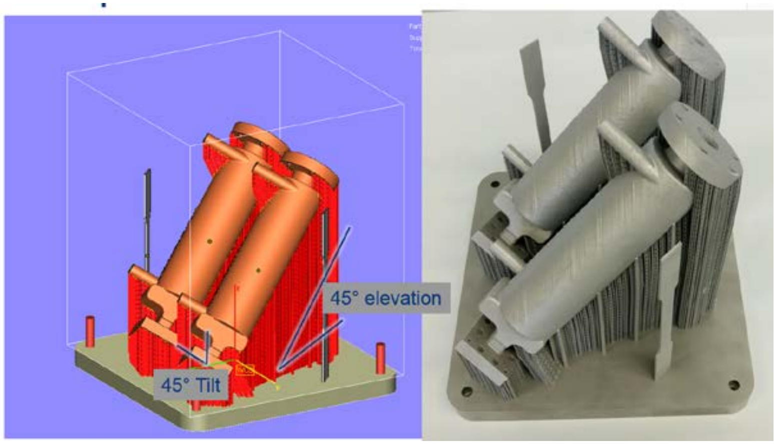
- Cooling integration, UHV compatibility, High power performances

III. RF Load prototype manufacturing and testing

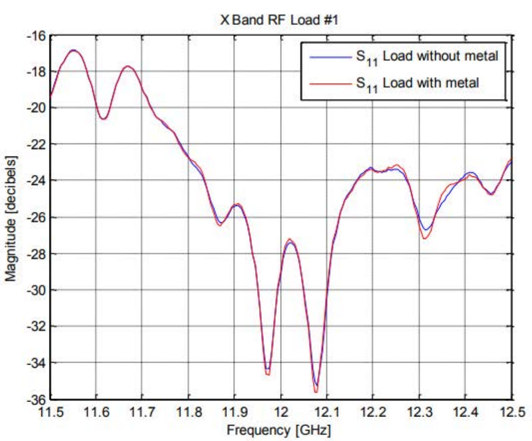


RF Load manufacturing





VNA Measurements and Setup of X Band RF Load #1(CERN print)



Load #1 without metal

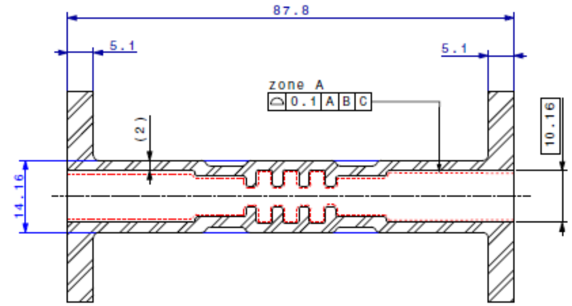
Load #1 with metal

No differences in the return signal with and without metal

The load correctly dissipate the RF power

Additive Manufacturing of an RF filter by different technologies

- Goal: filter out the 24 GHz frequency
- Electroless copper deposition (SWISS12)

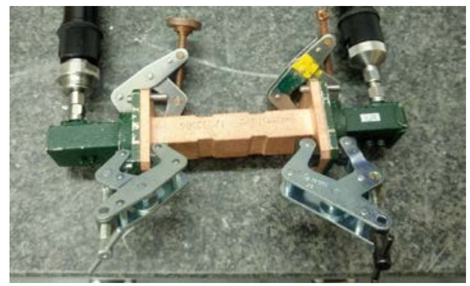


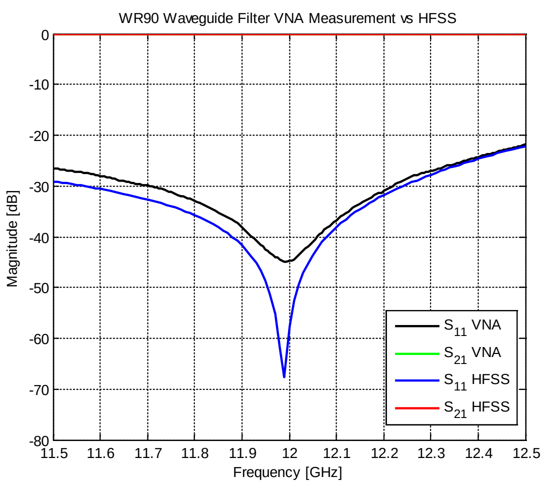
A-A
2:1

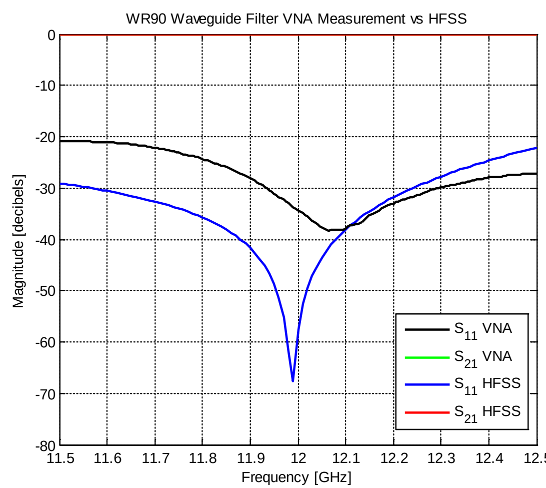
Aluminium	Copper plated Aluminium	Copper plated polymer SLA
		

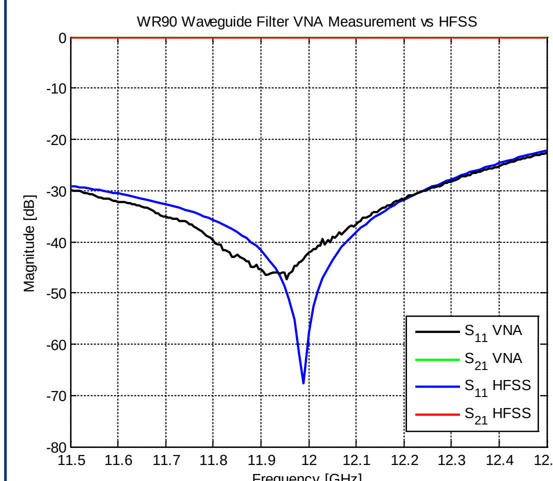
All filters are according to specification

Aluminium	Copper plated Aluminium	Copper plated polymer SLA





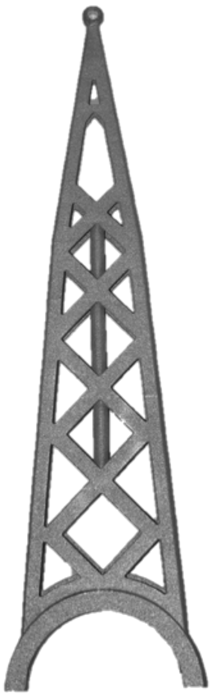




Applications for accelerator and detectors

- Titanium Wire scanner fork
- Lattice structure for future collimators
- Heat exchanger (Baby Demo, INFN Genova)

Wire Scanner for accurate measurement of beam position



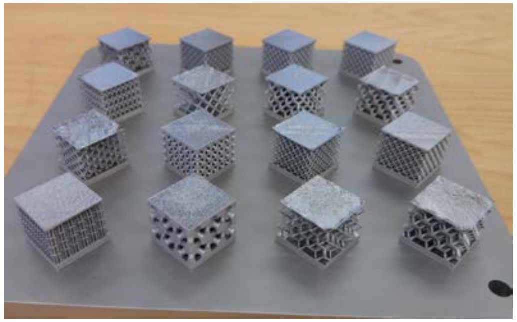
Ti6Al4V
Topology optimised
Lightweight: 50g
High Stiffness

Fast wire scanner with speed up to 20m/s

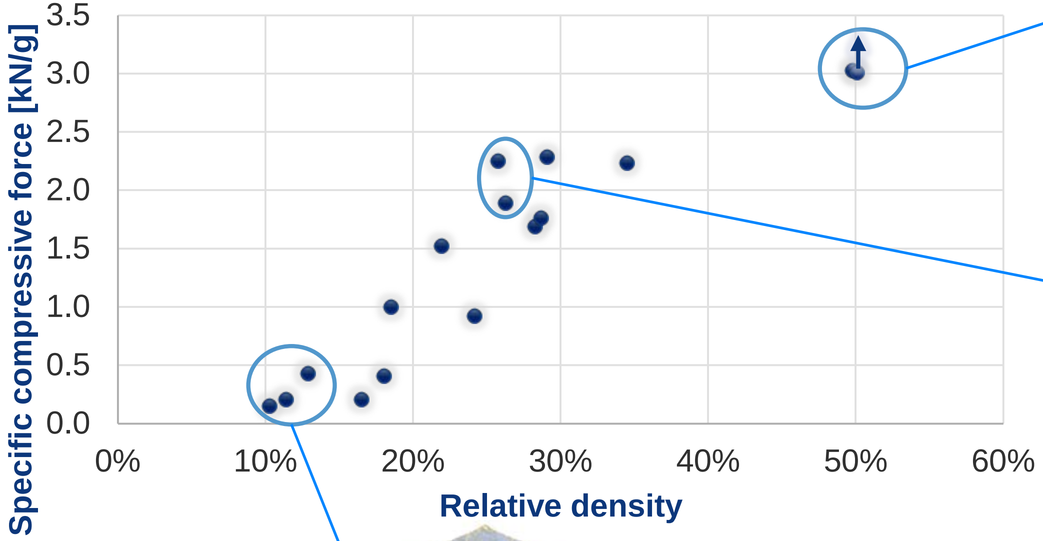
Lattice structure for MultiMat

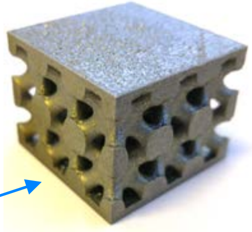
MultiMat experiment:

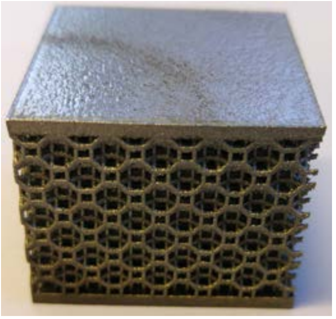
Advanced testing of materials for HL-LHC collimators

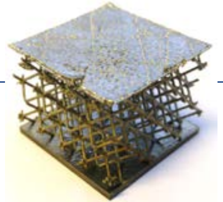


Specific compressive force vs structure density



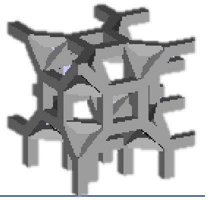






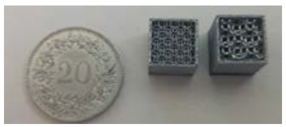
Choice:
Rhombic 2.5 and 5mm cell

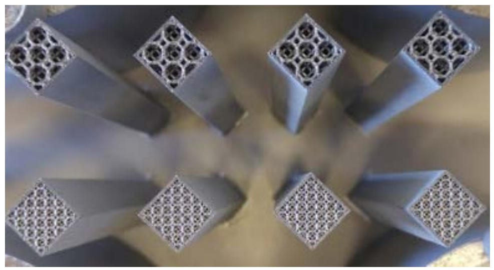
- target density
- good structure integrity



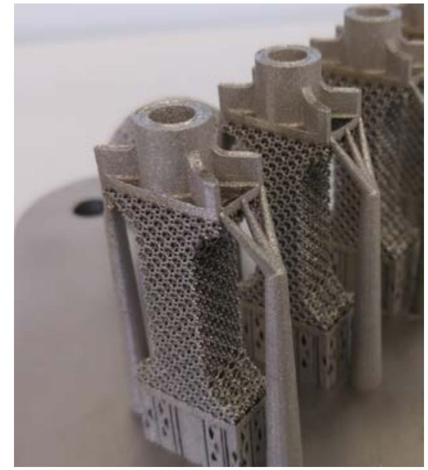
Lattice thermophysical characterisation On-going

Lattice blocks To be instrumented and integrated to MultiMat





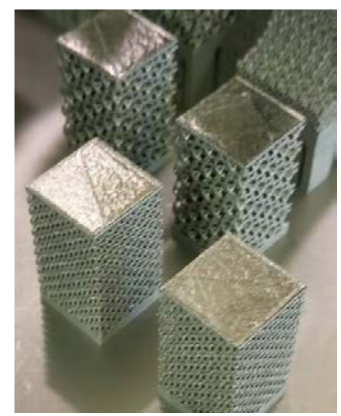
Mechanical properties
Tensile test for elastic/plastic behaviour



Thermal diffusivity
Laser flash analysis

Specific heat
Differential scanning calorimetry

Coefficient of thermal expansion CTE



Capillaries for Warm nose heat exchanger (INFN Genova)

- For ATLAS ITk (Inner tracker) Baby Demo splitter box.
- 500 W heat exchanger in a restricted 100x100 mm² space
- Design by INFN Genova (Rosanna Puppo, Cecilia Rossi) and the first prototype will be printed by Tech4Sea, spin-off of UniCal Cosenza (Alessandro Gallo)
- Preliminary tests on Ti samples (Giuseppe Gariano, Alessandro Rovani, Cecilia Rossi)

Pressure drop measurements with compressed air (INFN Genova)

Results:
The pressure drop in the different pipes is comparable
The measured diameter is smaller by a factor of 1.5-2
(approximation due to air leaks and instruments precision)

<u>Samples in Ti6Al4V</u>
Manufactured @ CERN
D_{int} from 0.25 to 1mm

Conclusion

- Additive Manufacturing is a disruptive technology for High Energy Physics with high potential
- It particularly shines at manufacturing parts with:
  - Integrated and efficient cooling
  - Novel and Complex geometries
  - Light weight and compact shapes
- But also features restrictions:
  - Part size
  - Dimensional accuracy
  - Surface roughness
  - Availability of materials (especially good- and super- electrical conductors)

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