

# Development of X-band RF load using additive manufacturing

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CLIC17 workshop

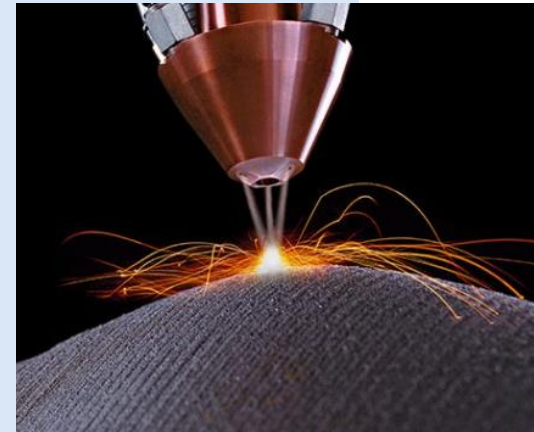
# Acknowledgements

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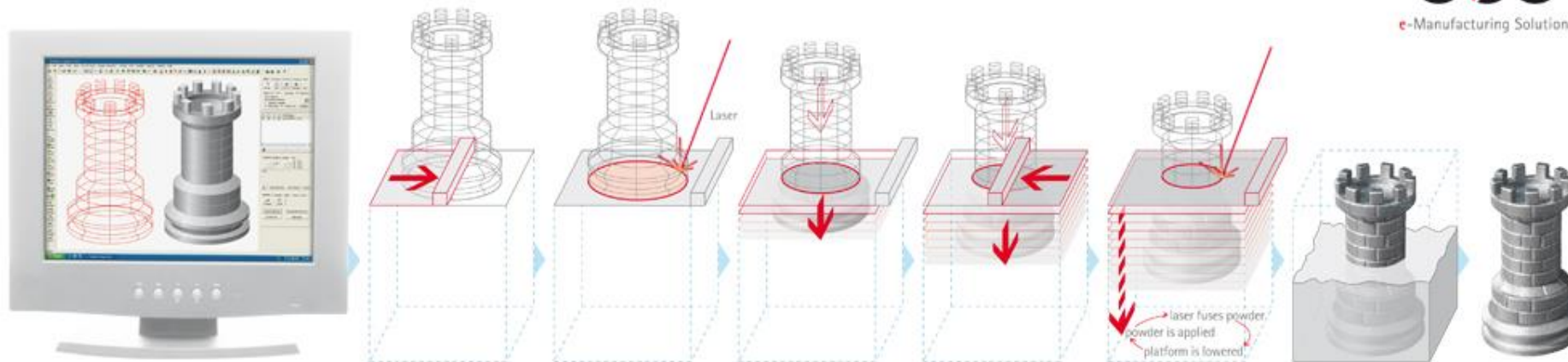
# Additive manufacturing

## Process

1. Model designed in CAD
2. CAD file sent to additive manufacturing system
3. Model divided into slices
4. 3D product sculpted from powdered material layer by layer using the specified technique



General functional principle of laser-sintering

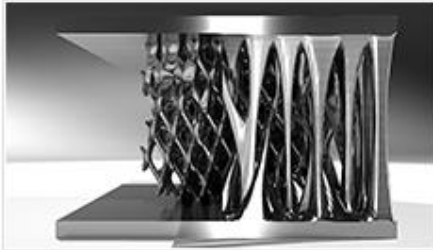


# Number of good reasons to try

Additive Manufacturing » For Your Individual Design

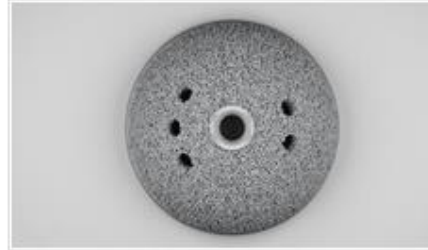
## For Your Individual Design

### The Challenge of Freedom of Design



The innovative EOS technology ensures maximum freedom of design. >

### The Challenge of Complex Geometries



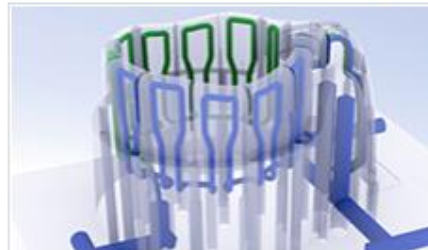
Additive Manufacturing makes design-driven production a reality. Innovative EOS technology offers the greatest possible freedom and enables complex structures. >

### The Challenge of Customised Products



Tool-less production with Additive Manufacturing technology permits customised, batch-size-appropriate serial production. >

### The Challenge of Reducing Manufacturing Costs



Additive Manufacturing permits cost-effective production for individual items as well as batch items. >

# Typical materials

EOS Aluminium AlSi10Mg - Light Metal for Motorsports and Aerospace Interior Applications



EOS CobaltChrome MP1 - CoCrMo Super Alloy for High-Temperature Engineering and Biomedical Applications



EOS CobaltChrome SP2 - CE-Certified CoCrMo Super Alloy for Dental Applications



EOS MaragingSteel MS1 - High-Performance Steel for Tooling and Mechanical Engineering



EOS NickelAlloy HX - Nickel-Alloy for Aerospace and Industry



EOS NickelAlloy IN625 – Nickel-Chromium Alloy for Aerospace, Motorsports and Industry



EOS NickelAlloy IN718 - Nickel Alloy for Aerospace and Industry



EOS StainlessSteel GP1 - Stainless Steel for Mechanical Engineering and Medical



EOS StainlessSteel PH1 - Hardenable Stainless Steel for Mechanical Engineering and Medical Technology



EOS Titanium Ti64 - Ti6Al4V Light Metal for Aerospace, Motorsports and Biomedical Applications



# Technical data Ti64

## General process and geometric data

Typical achievable part accuracy [1]	$\pm 50 \mu\text{m}$
Min. wall thickness [2]	approx. 0.3 – 0.4 mm approx. 0.012 – 0.016 inch
Surface roughness, as built [3]	
Ti64_30_030_default.job Ti64 Performance (30 $\mu\text{m}$ )	$R_a$ 9 – 12 $\mu\text{m}$ , $R_z$ 40 – 80 $\mu\text{m}$ $R_a$ 0.36 – 0.47 $\times 10^{-3}$ inch, $R_z$ 1.6 – 3.2 $\times 10^{-3}$ inch
Ti64 Speed 1.0 (60 $\mu\text{m}$ )	$R_a$ 6 – 10 $\mu\text{m}$ , $R_z$ 35 – 40 $\mu\text{m}$ $R_a$ 0.23 – 0.39 $\times 10^{-3}$ inch, $R_z$ 1.37 – 1.57 $\times 10^{-3}$ inch

Ti64 DC electrical conductivity: 600000 S/m, two times lower than stainless steel

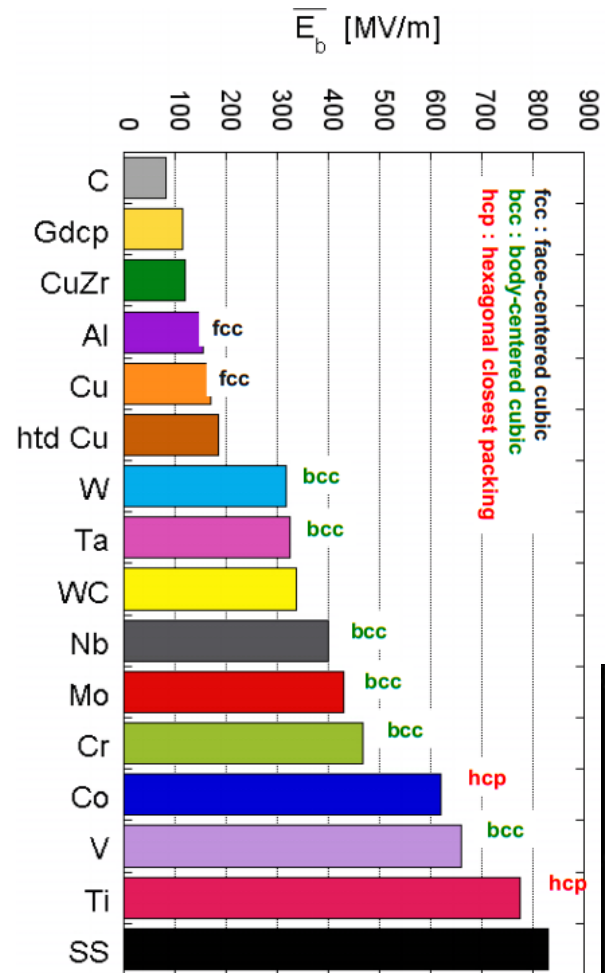
- Relatively low accuracy
- Big roughness (much larger than skin depth)
- Low DC conductivity



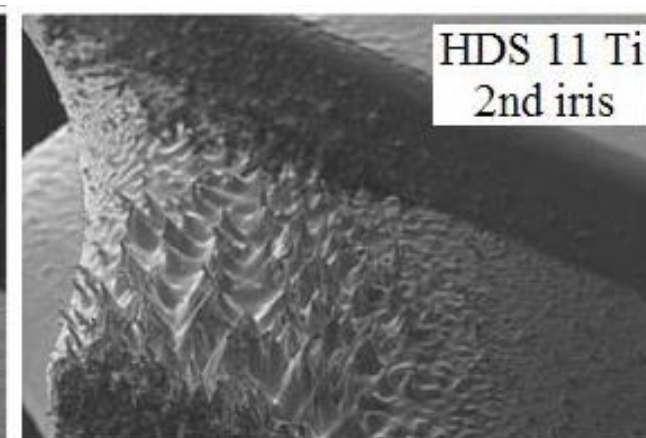
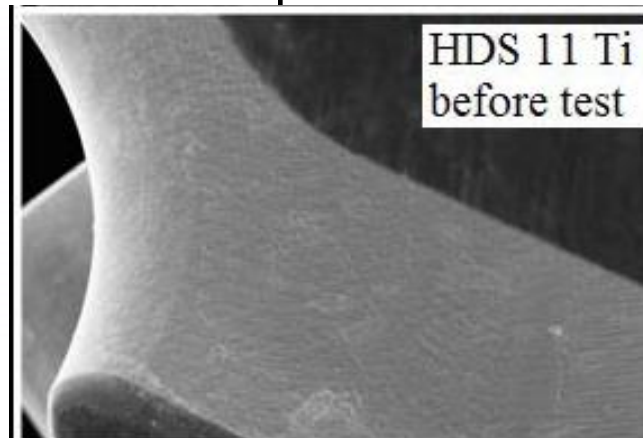
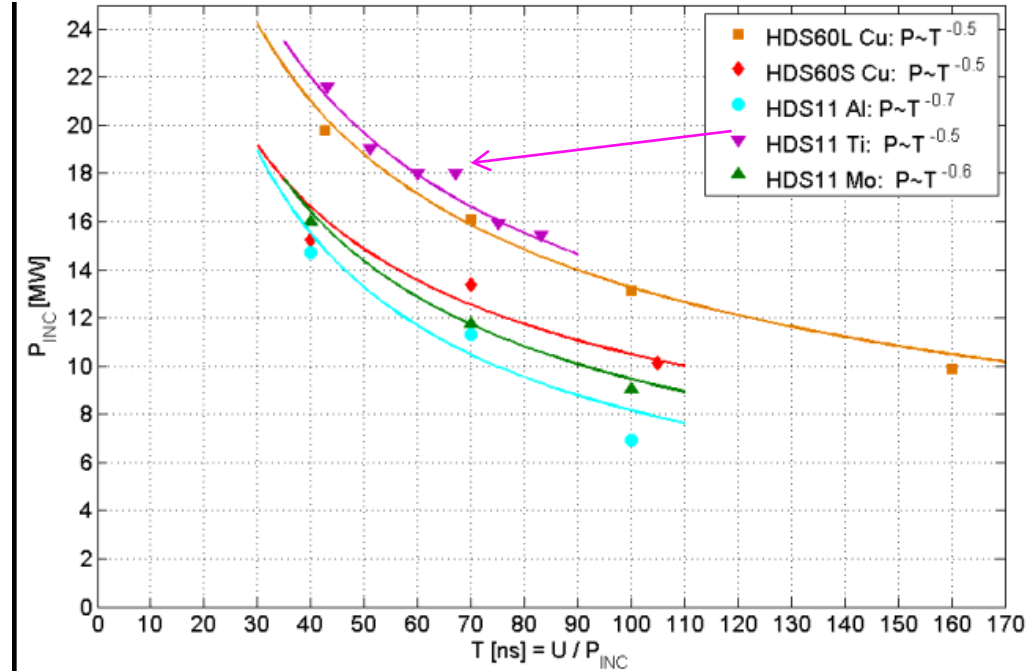
**Obvious RF application  
is a broad-band all-  
metal dry RF load**

# High power/E-field performance of Ti

DC breakdown thresholds

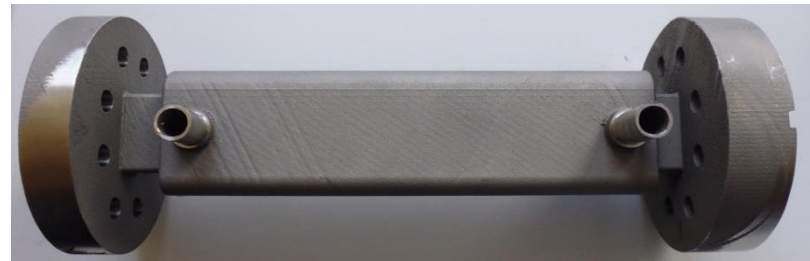
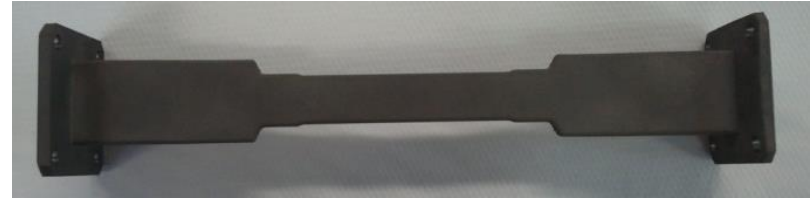


30 GHz high power performance, PAC2007



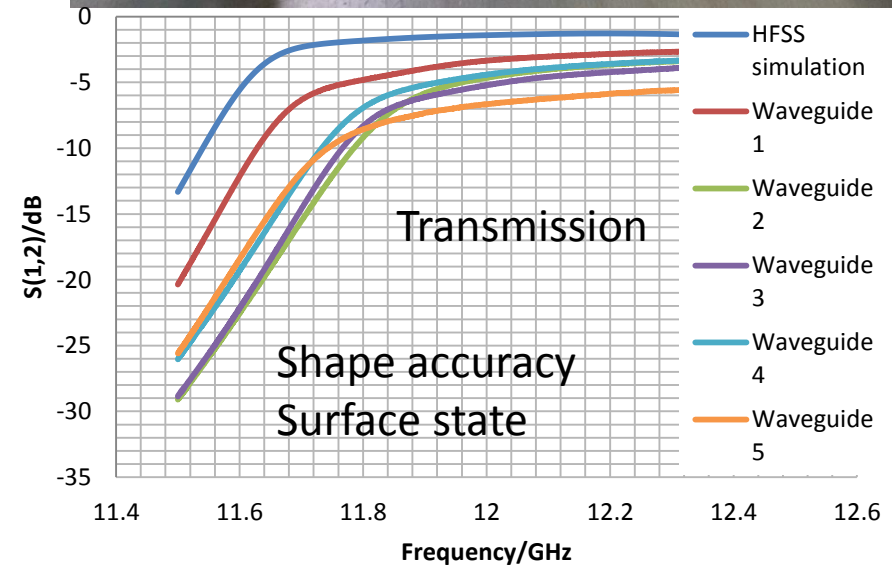
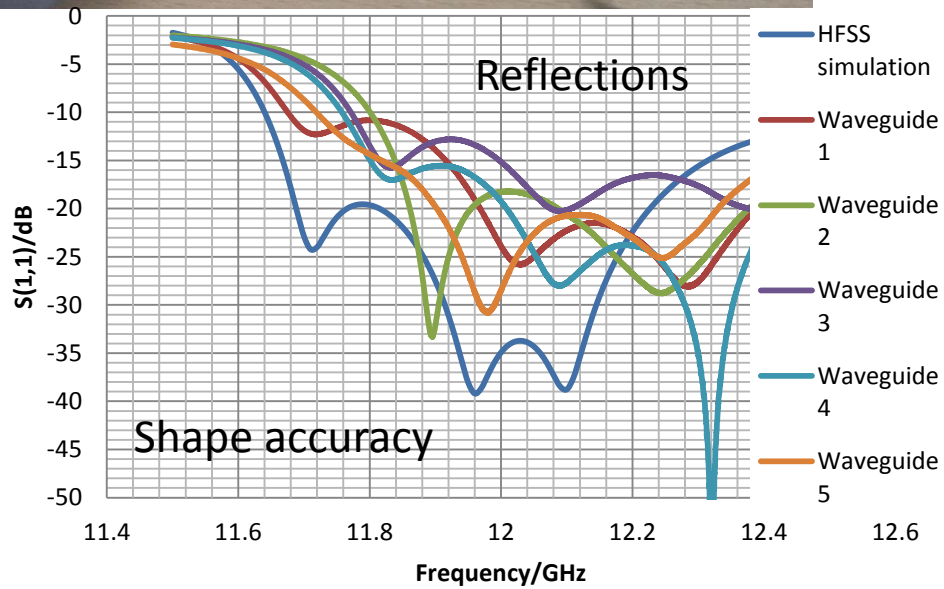
# X-band RF load development overview

1. Low power prototype for material and fabrication characterization
  1. DC conductivity and RF losses
  2. UHV compatibility: leak tightness
  3. Shape accuracy and Roughness
  4. Mechanical strength and Metallurgy
2. Prototypes for high power tests
  1. Integration of cooling
  2. UHV compatibility: outgassing
  3. High power performance
3. Design of the RF load
4. RF load prototype manufacturing and testing



← We are here

# RF measurements using VNA

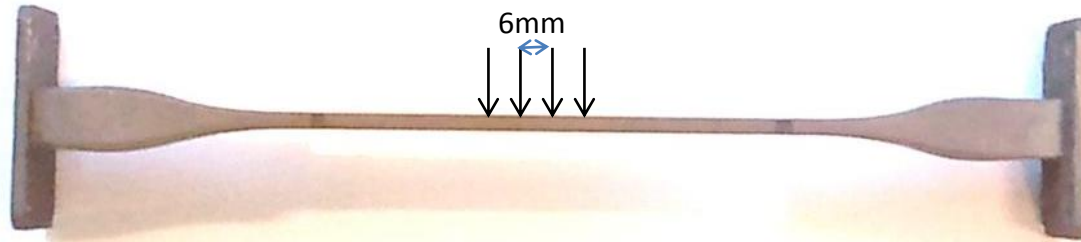


# DC conductivity measurements

Two types of DC measurements:

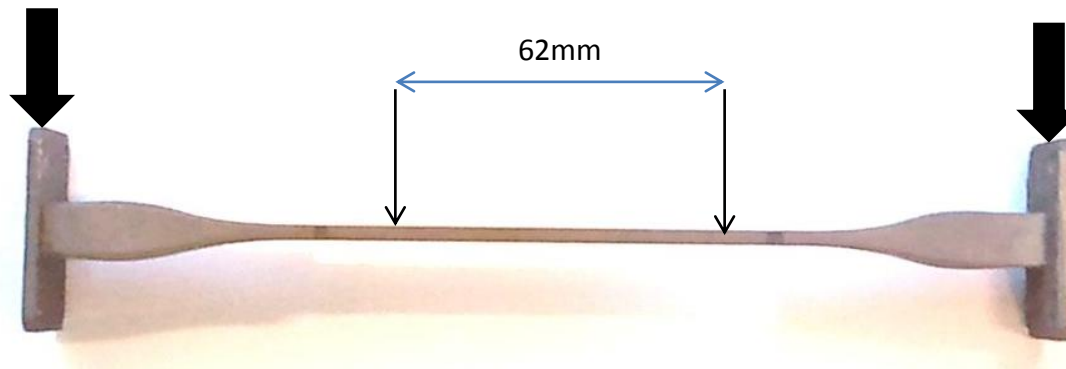
Titanium alloy conductivity:  $6E+5$  S/m

1. Four probes in contact with middle section



Waveguide No.	Conductivity/ S/m
1 -	641025
2 -	368595
3 -	496771
4 -	500000
5 -	522739

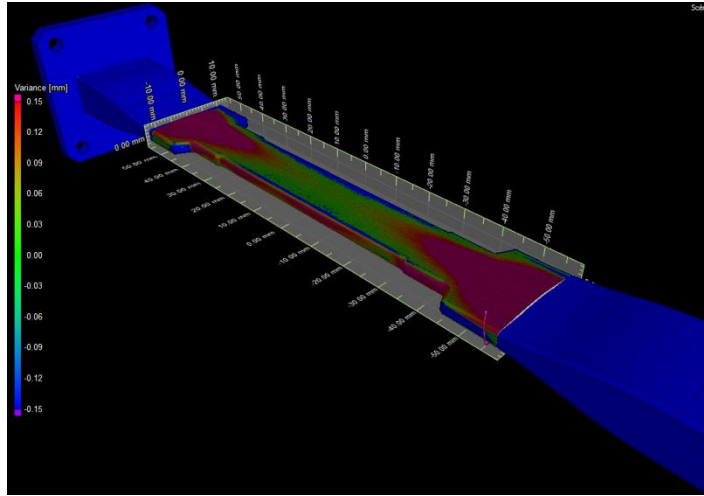
2. Two probes in contact with middle while clamps on flange provide voltage difference



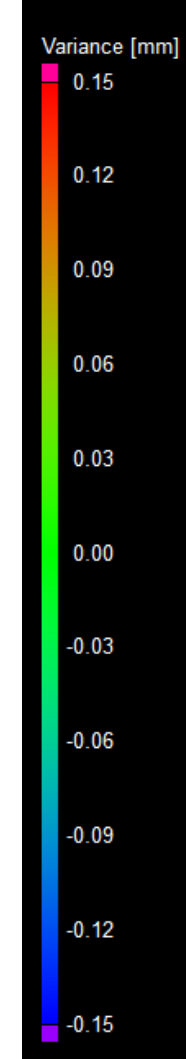
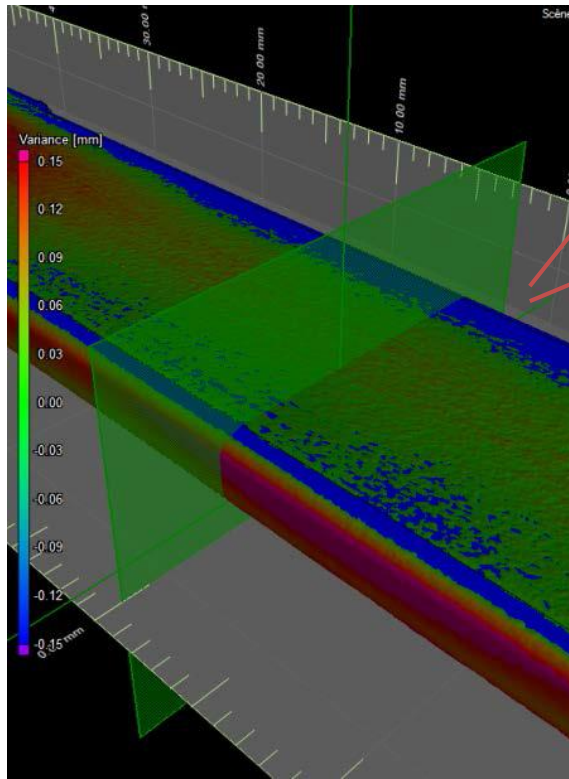
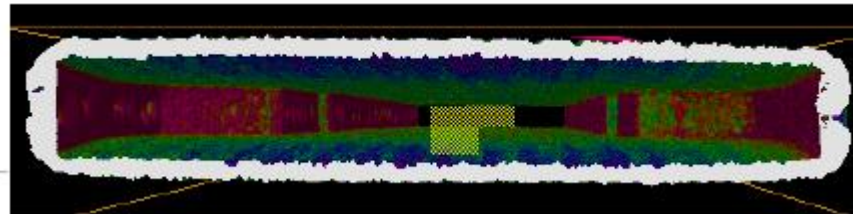
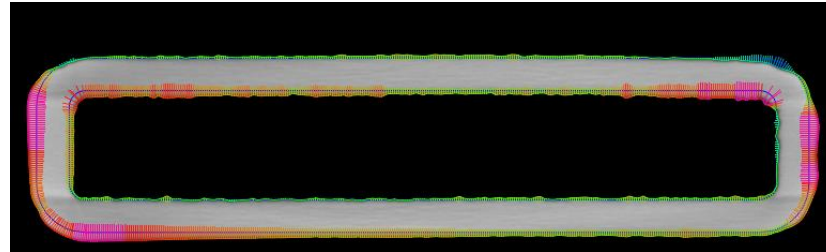
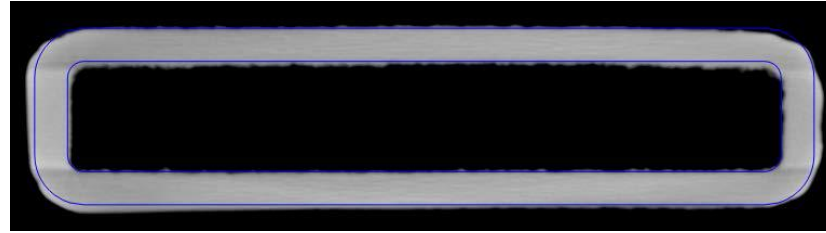
Waveguide No.	Conductivity [S/m]
1	716093
2 -	480179
3	571880
4 -	557176
5 -	580343

# Metrology Results

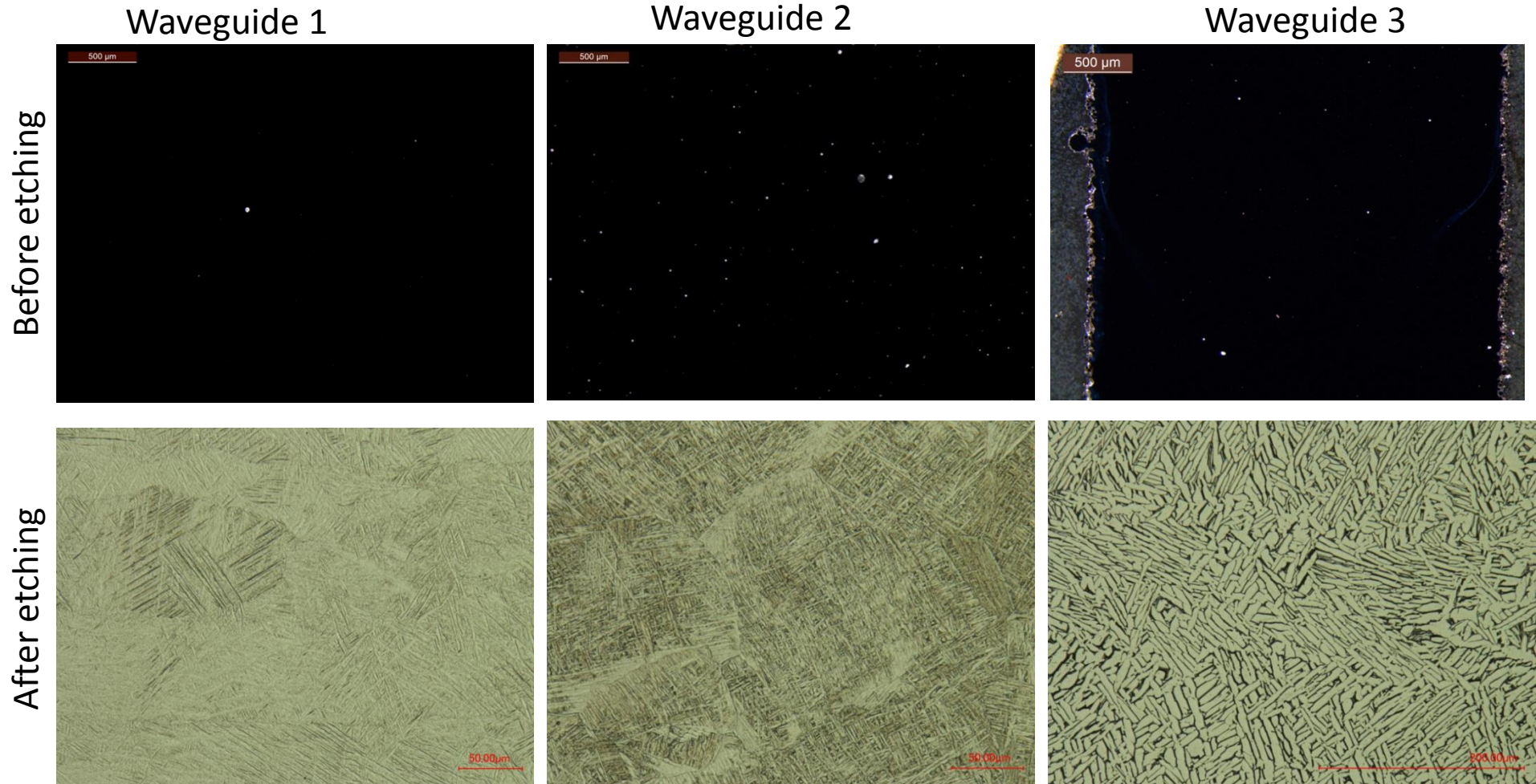
## Microtomography – X-ray non destructive testing



- Blue lines show lack of material
- Red lines show excess material



# *Mechanical testing and metallographic observations*



W1 shows least porosity

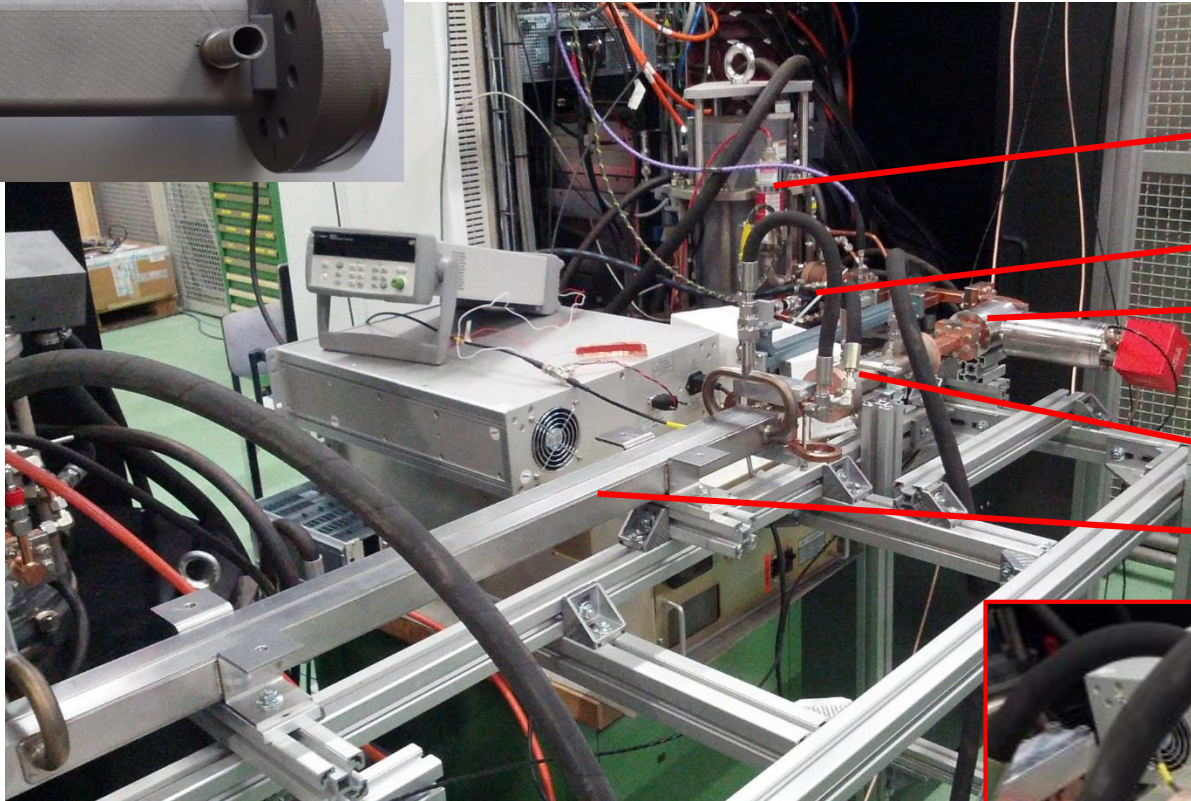
W2 shows large porosity

W3 shows different microstructure

# Summary of the results obtained after tensile tests of the samples

WG #	Company	$E_{\text{mod}}$ (GPa)	$R_{p0.2}$ (MPa)	A %	UTS (MPa)	
1	3T	$112 \pm 1$	$1097 \pm 8$	$2 \pm 0$	$1139.8 \pm 3.0$	OK
2	IPN	$51 \pm 0$	$830 \pm 36$	$11 \pm 2$	$904.8 \pm 20.4$	
3	Concept Laser	$108 \pm 1$	$825 \pm 11$	$12 \pm 3$	$893.4 \pm 10.7$	OK
Table value for standard material (www.matweb.com)		120	910 - 958	12-16	972 - 1030	

# 3D Printed Waveguide Installation # Xbox-3A



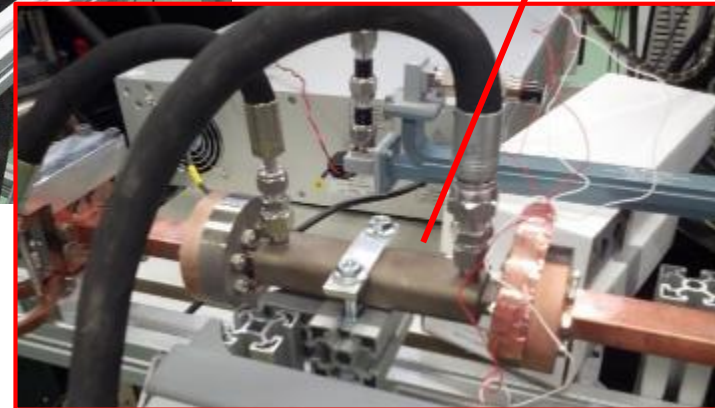
6.5-7MW Klystron

Directional Coupler

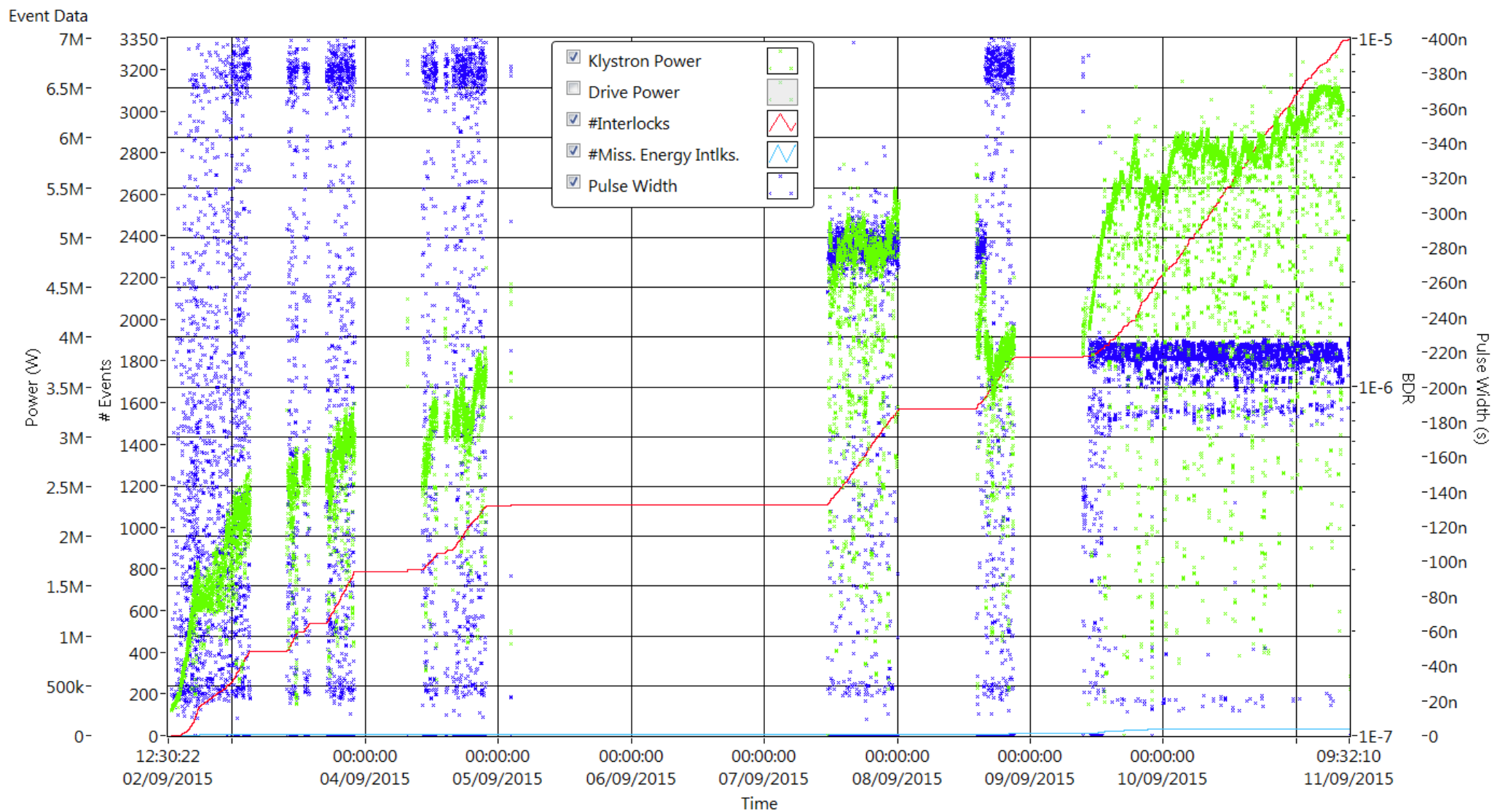
Vacuum Port

3D Printed Waveguide Ti

RF Load



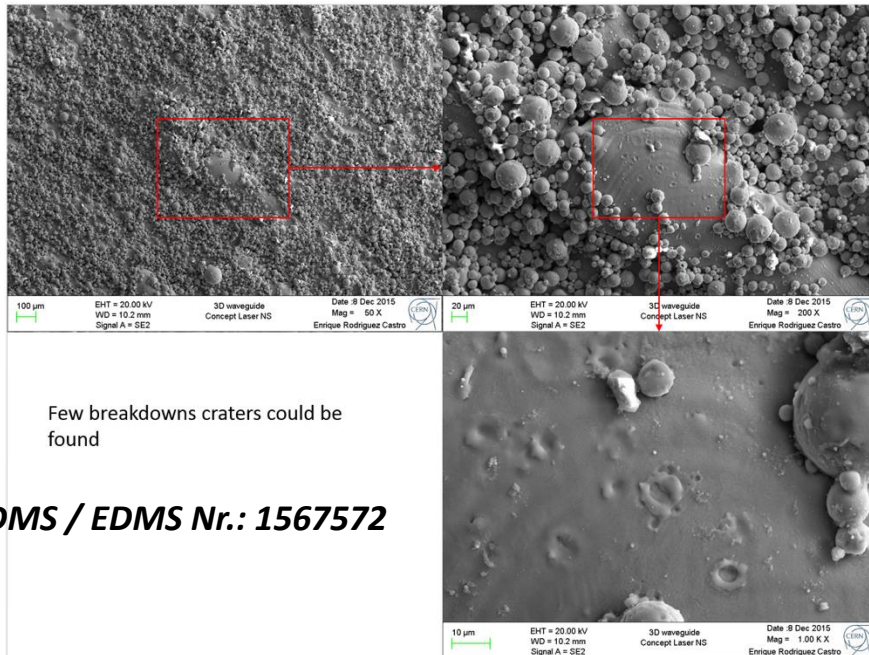
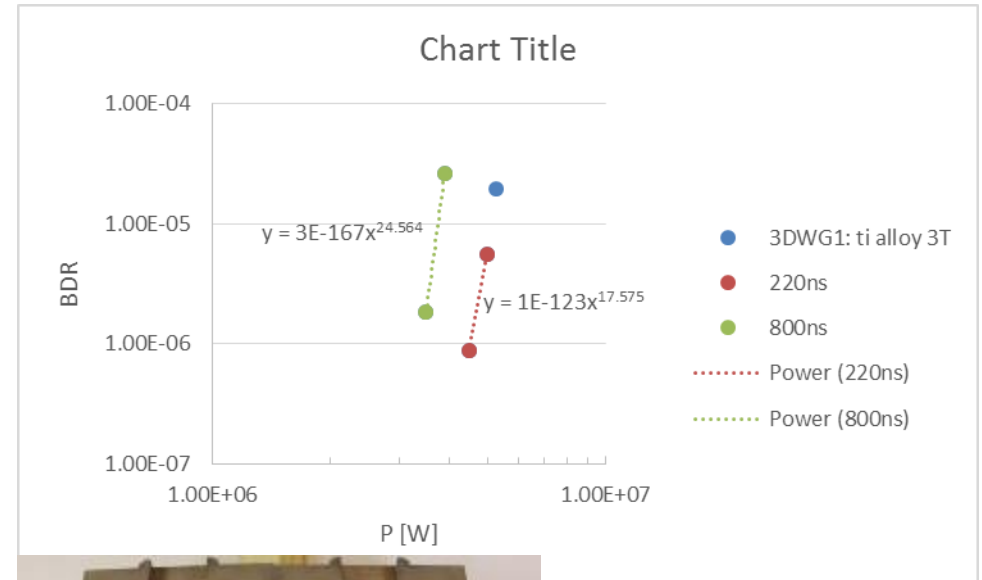
# Conditioning Strategy



Started at 400ns but struggled to get to full power ~6.5MW so pulse width was reduced

# Ti WG testing summary

Power (W)	Pulse Width (ns)	#BD	#pulses	BDR per Structure	BDR error
5.00E+06	220	281	5.08E+07	5.53E-06	3.30E-07
4.50E+06	220	15	1.73E+07	8.68E-07	2.24E-07
5.25E+06	400	28	1.44E+06	1.94E-05	3.67E-06
3.90E+06	800	38	1.44E+06	2.64E-05	4.28E-06
3.50E+06	800	21	1.14E+07	1.85E-06	4.03E-07

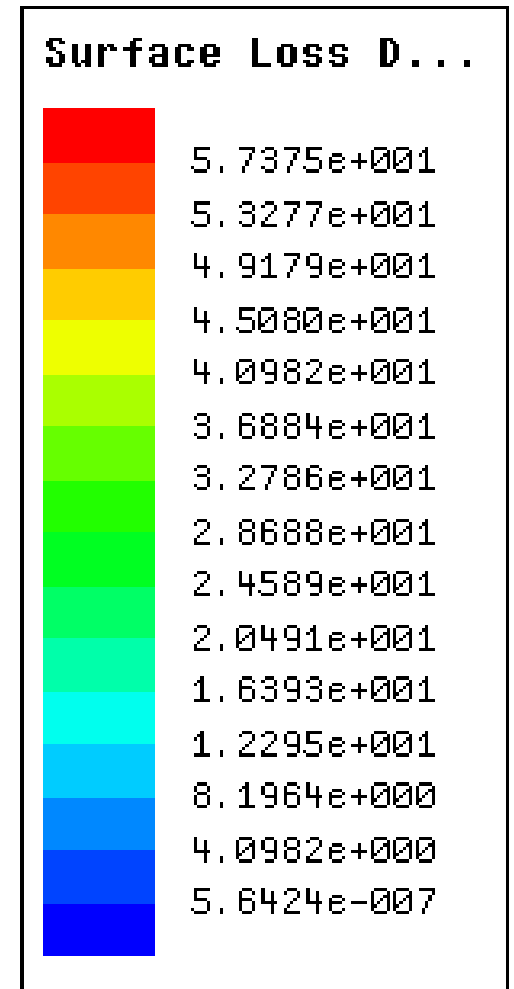
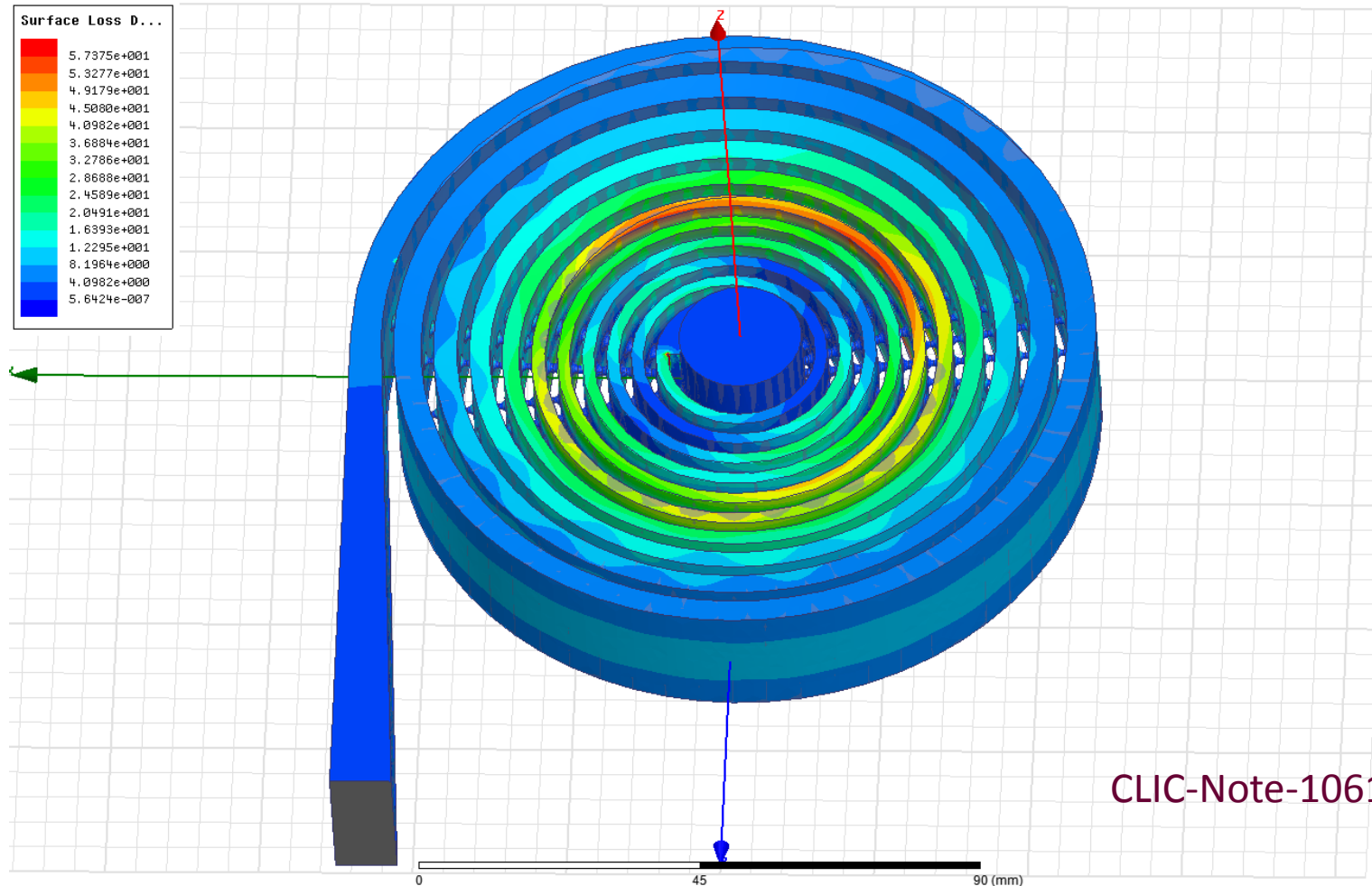


N<sup>o</sup> EDMS / EDMS Nr.: 1567572



- Reached: P = 5MW
- Es = 30MV/m
  - Sc = 0.4MW/mm<sup>2</sup>

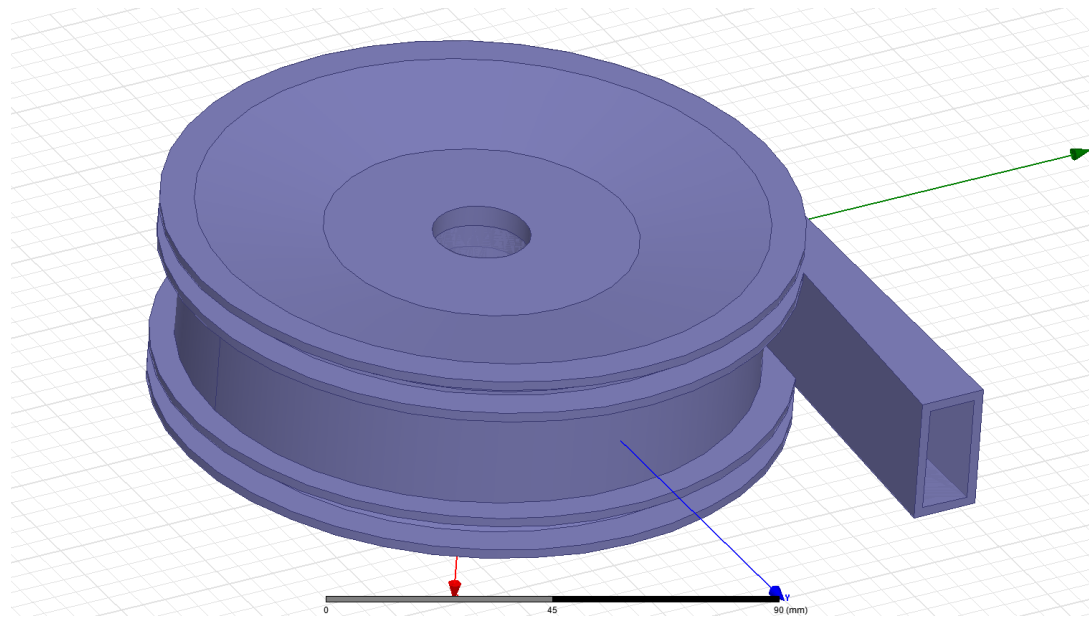
# RF load design: Power Loss density for 1 Watt Input ( $W/m^2$ )



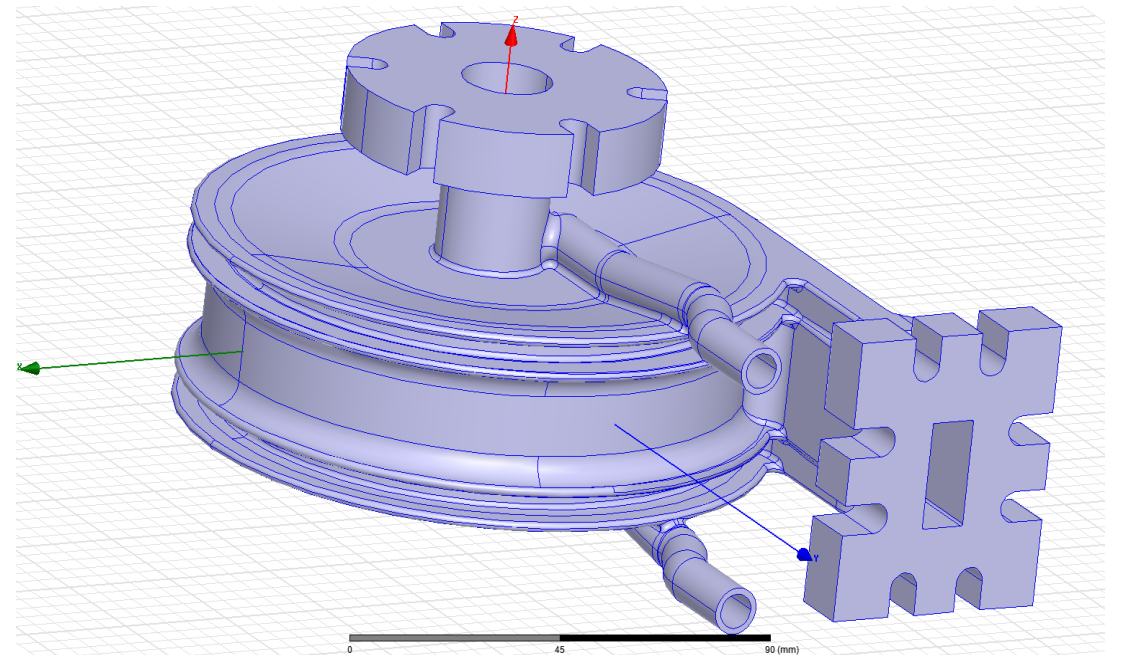
# RF Design => Mech. Design

A model has been created in CATIA based on our RF Design. Flanges, external roundings, and two pipes for the cooling system have been added externally.

## HFSS

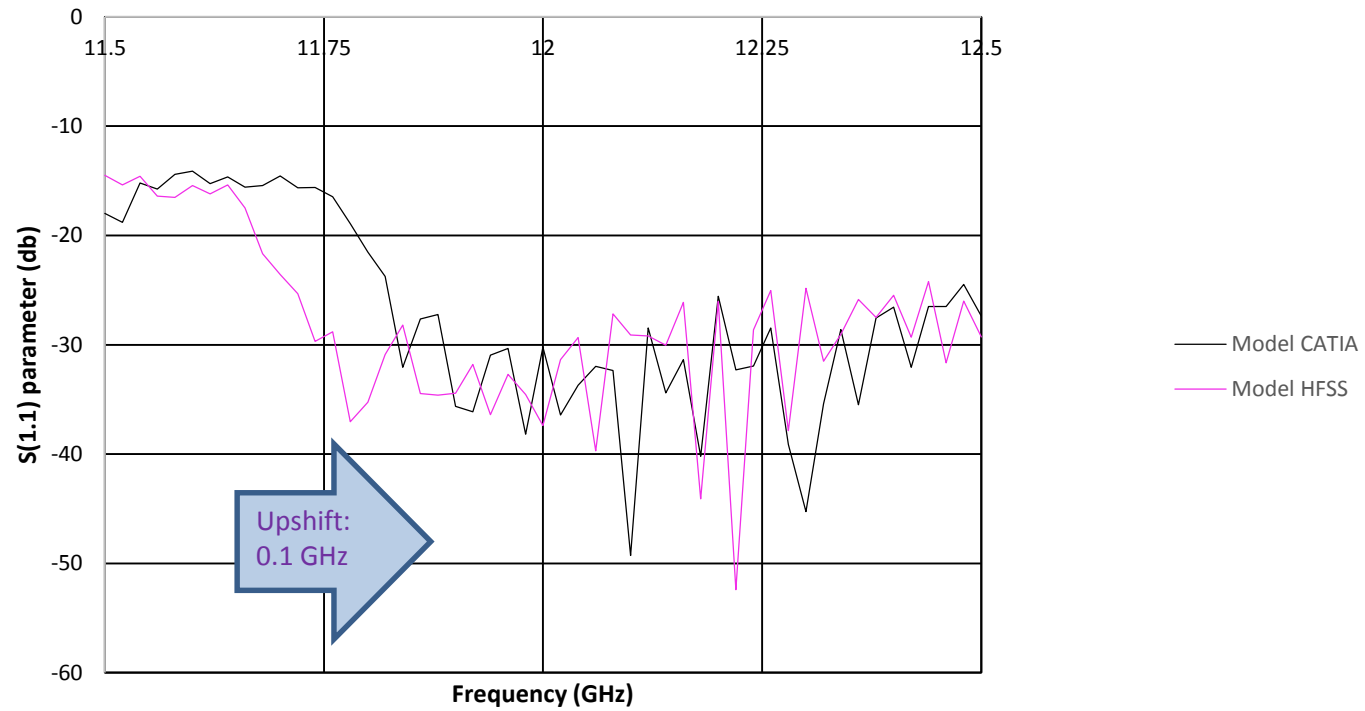


## CATIA

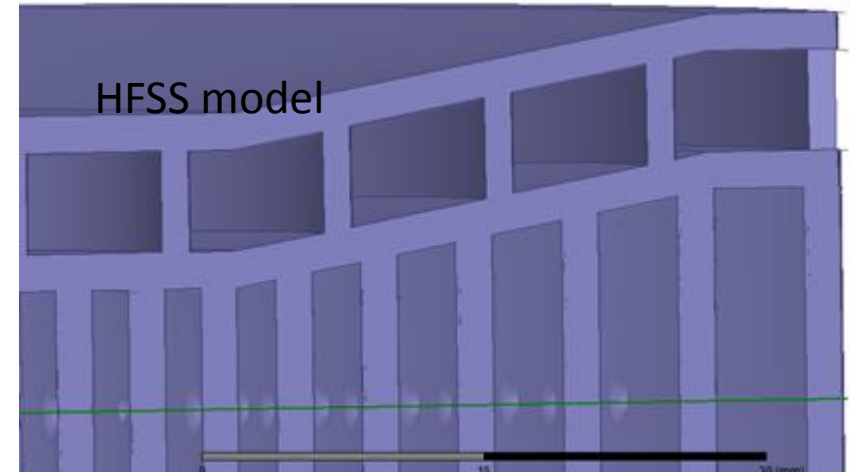


# RF CHECK

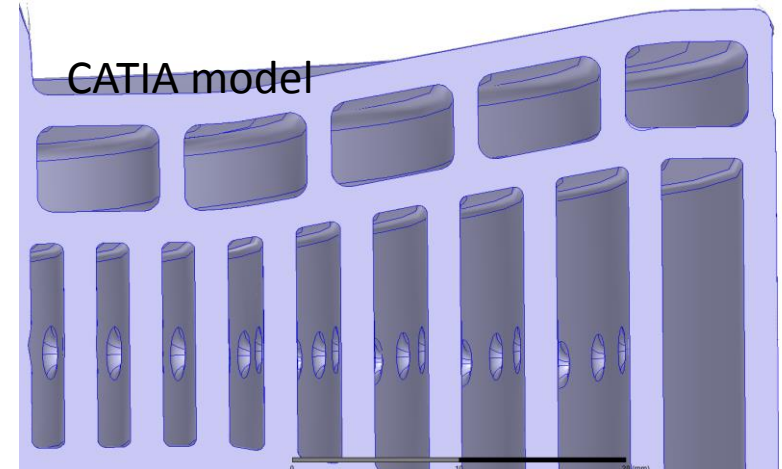
RF check



HFSS model

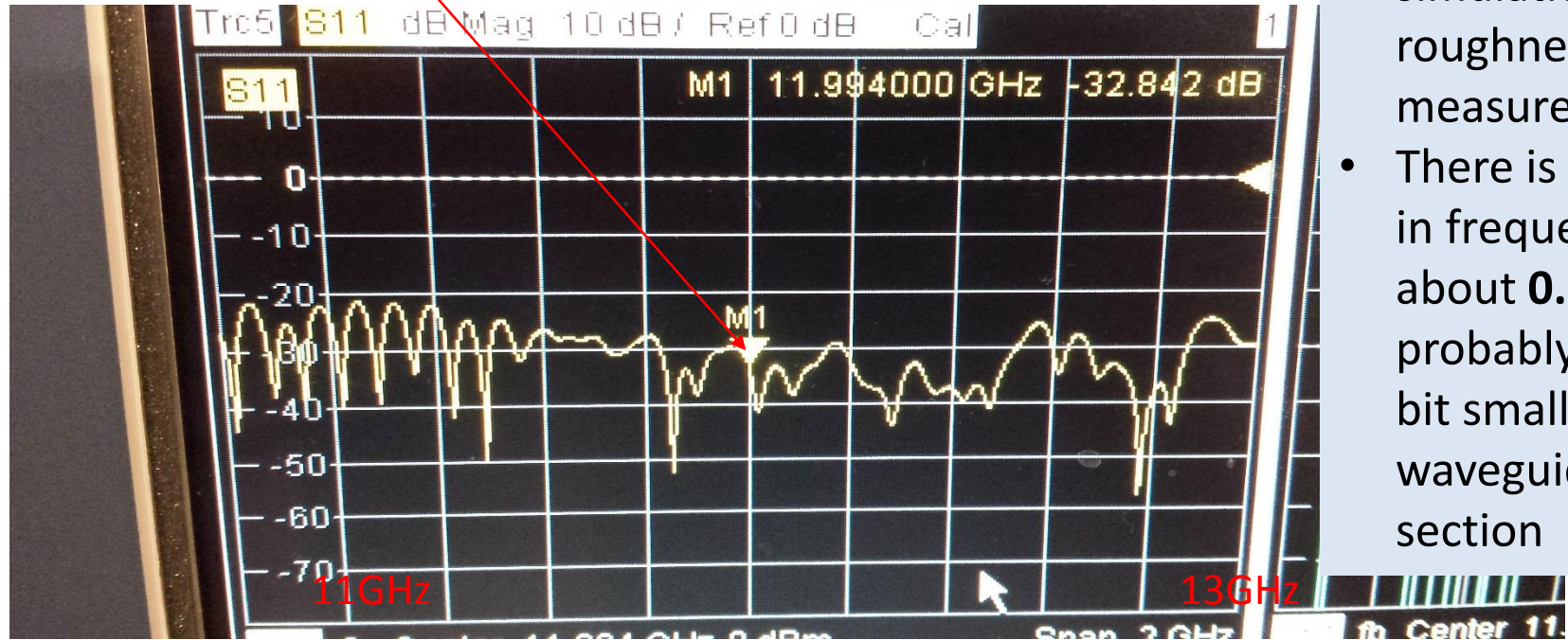
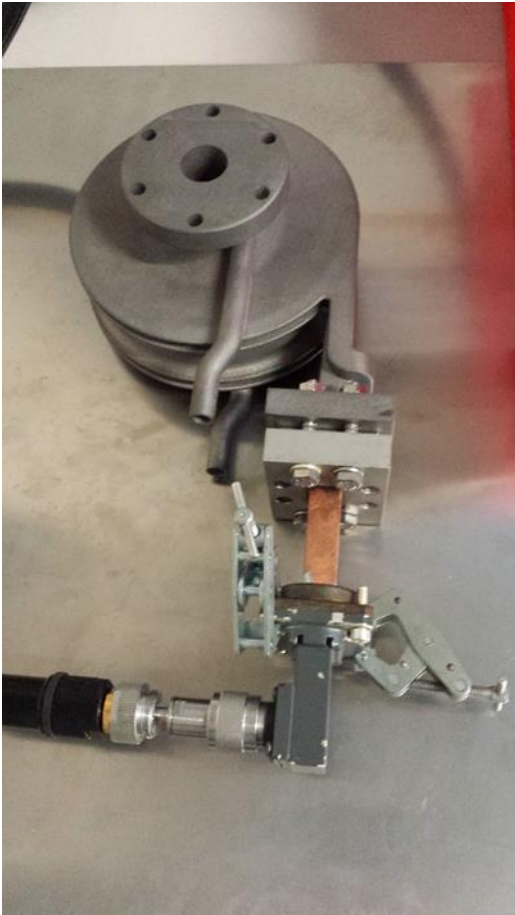
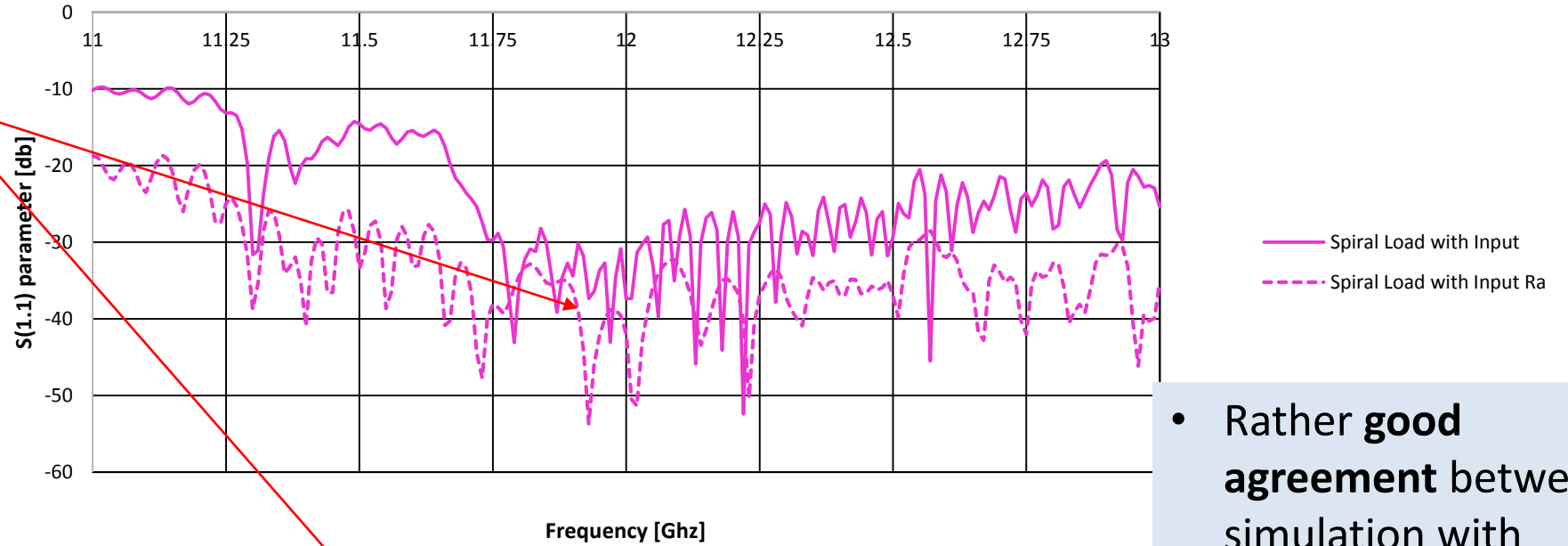


CATIA model



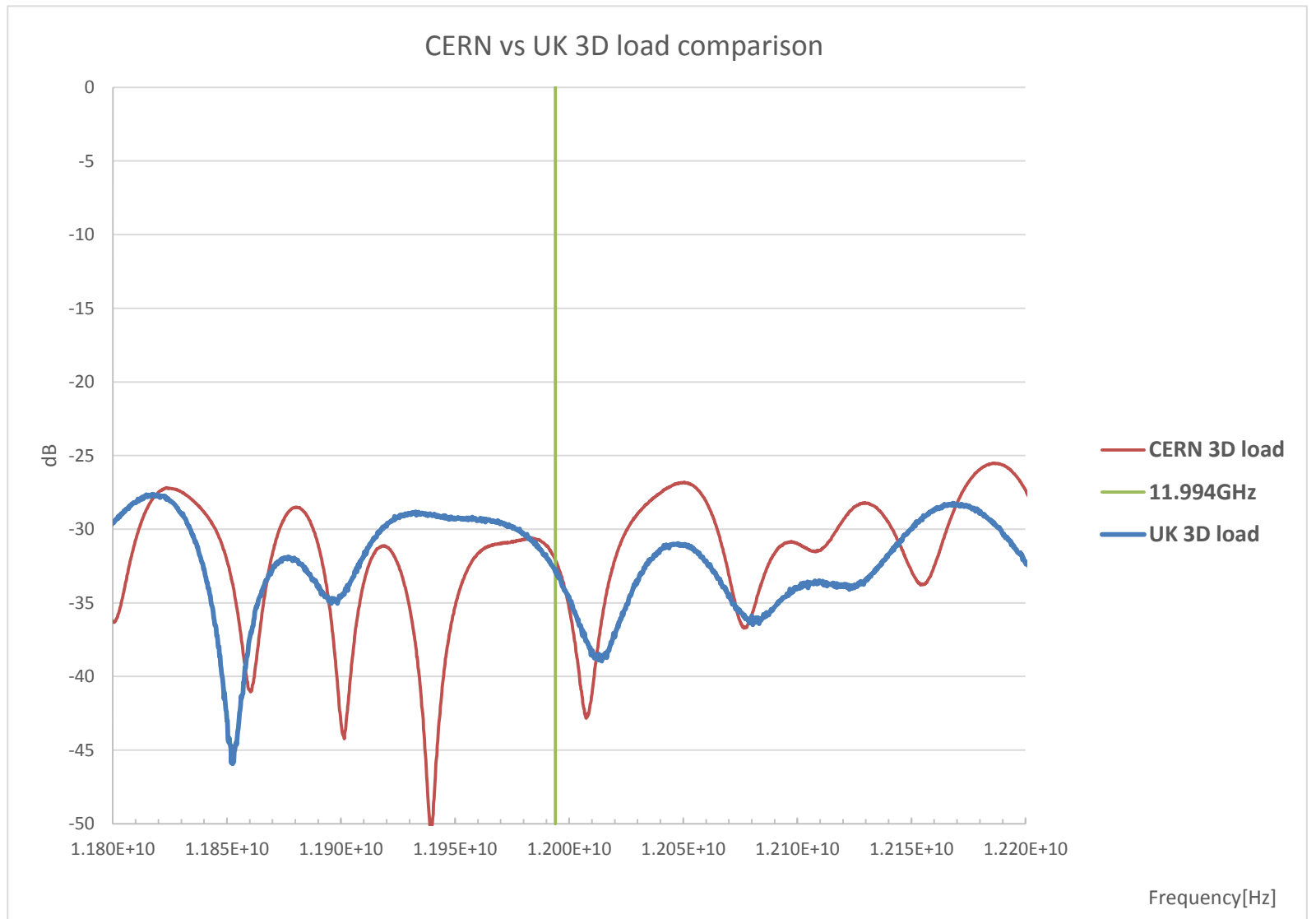
# Comparison

S(1.1) Parameter Spiral Load with input, with and without Roughness



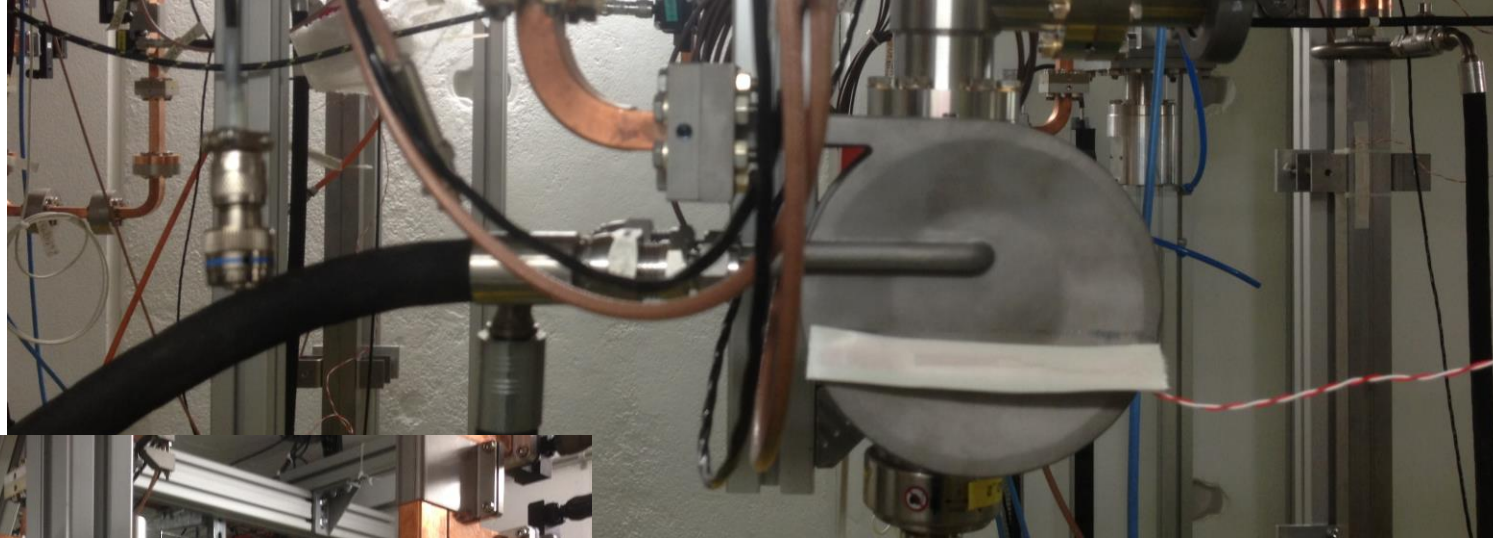
- Rather **good agreement** between simulation with roughness and RF measurements
- There is an **upshift** in frequency of about **0.1 GHz**, probably due to a bit smaller waveguide cross-section

# Reflection comparison: 3T(UK) and CERN



# *RF load conditioning*

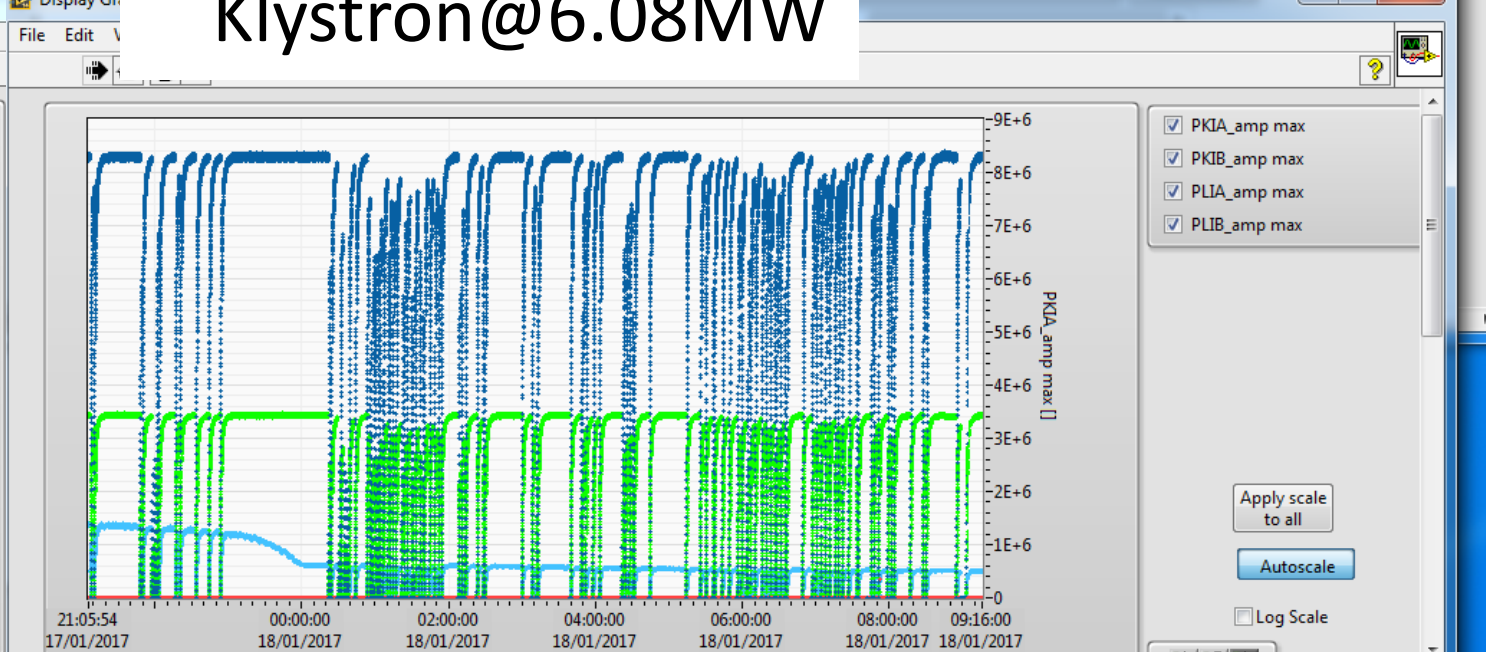
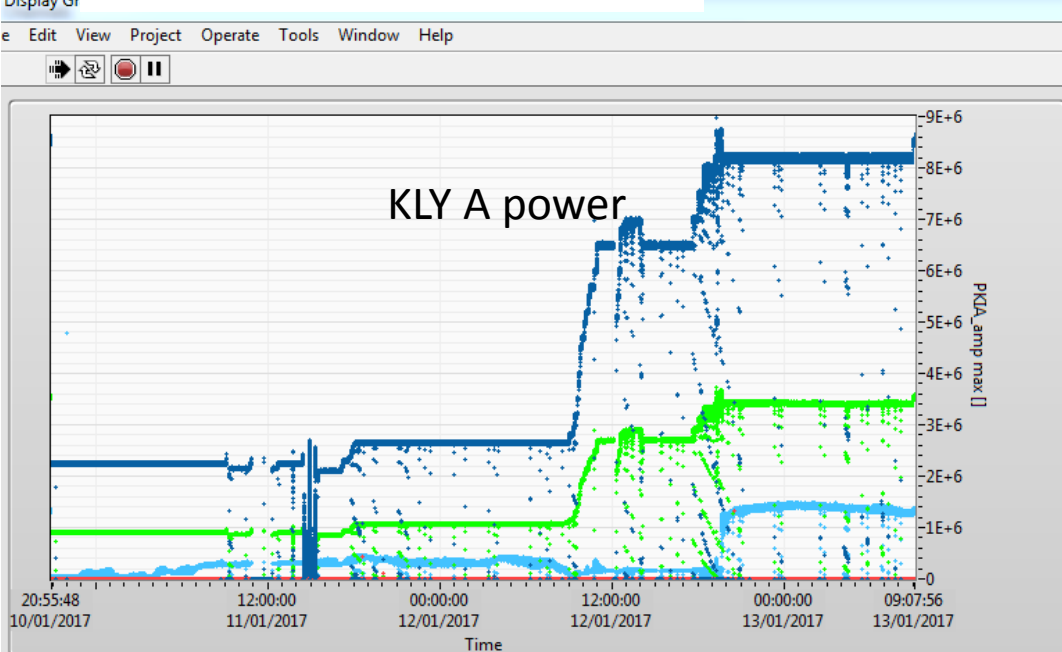
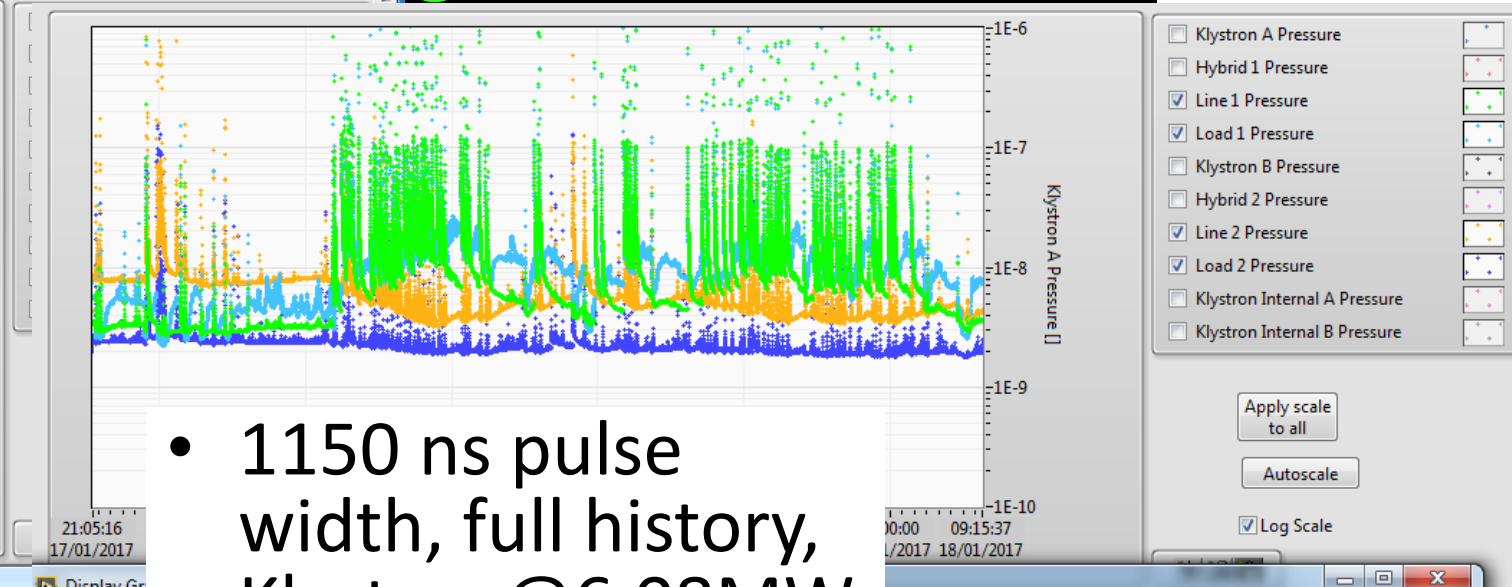
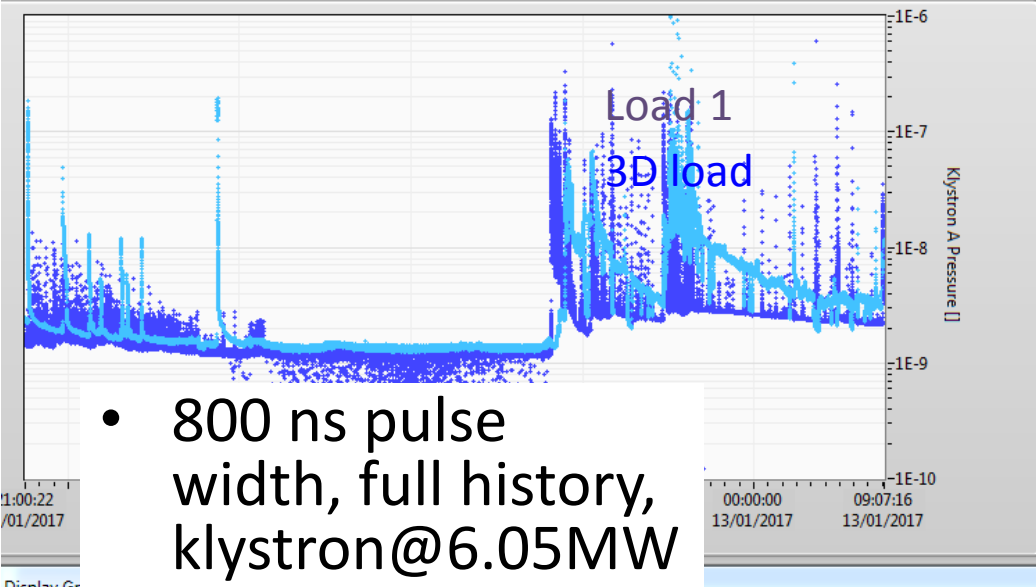
- We test 3D load (UK printing) on line 2 of Xbox3\_AB



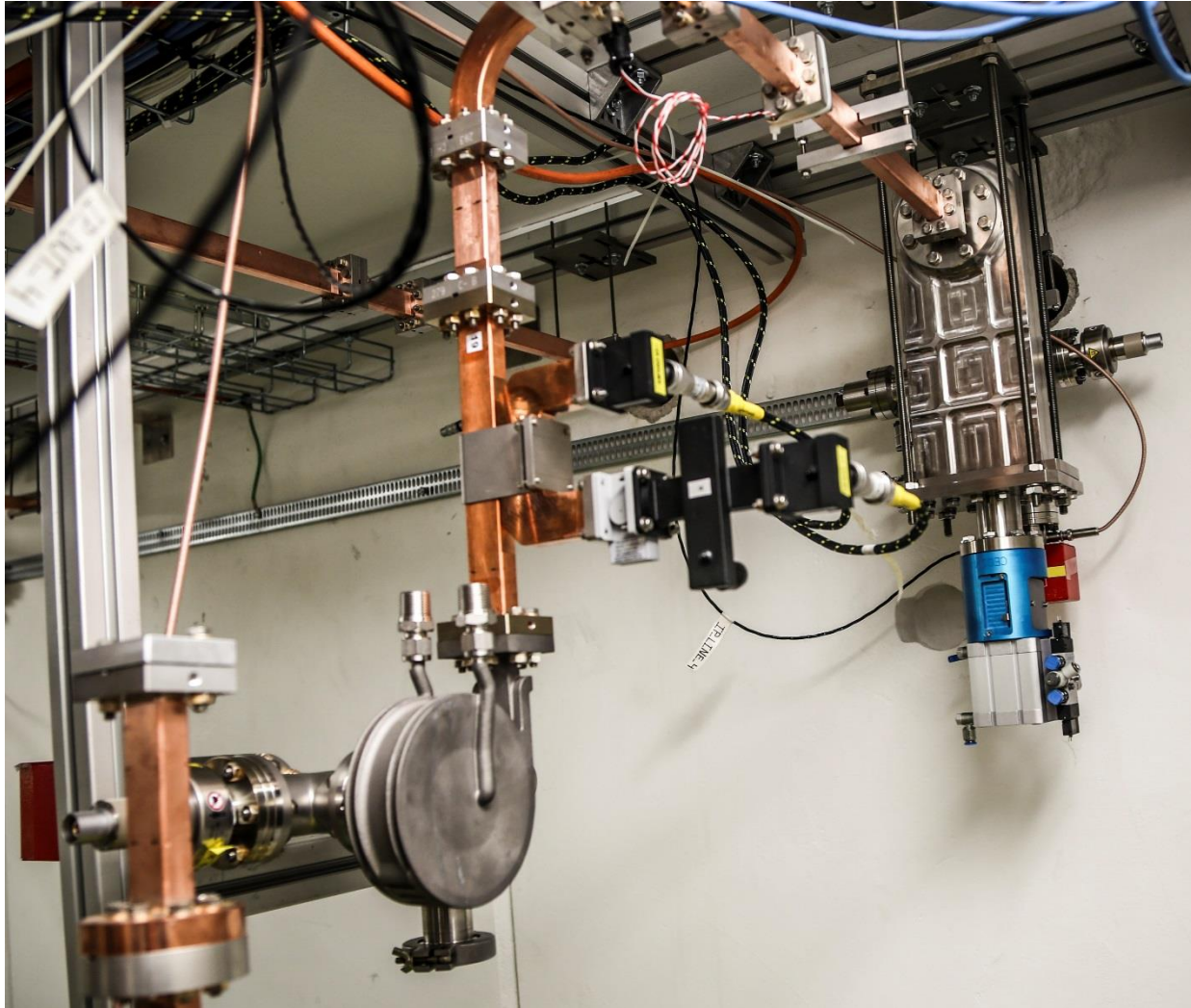
Frequency 400Hz  
Max pulse width **1000ns**  
KLY power 6.05MW  
Line power **2.5MW**  
Average power = 1KW into 3D load  
Temperature 3D load < 24C<sup>0</sup>

**Limited by available RF power**

# 3D load conditioning: vacuum



Today 3T load is connected to Xbox with pulse compressor which can go up to 40 MW



We hope to  
report you more  
results in Valencia

Thank You !!!