INFN PADOVA DIAM

PhD Retreat @ LNGS (17-21 February 2025)

MECHANICAL SERVICES at INFN

Adriano Pepato
Senior Technologist (STA and DIAM)
INFN Sezione di Padova

DIAM – Development and Innovation on Additive Manufacturing

OUTLINE.

- The INFN Technologist along the years.
- INFN Laboratories and Divisions.
- Tooling and instrumentations.
- Some relevant experiences.
- Special application: DIAM (Development and Innovation on Additive Manufacturing for metals@INFN PD).

The Technologist along the years.

- Need to design experimental detector apparatuses and parts of accelerator machines necessitated specific skills of Mechanics, Electronics and Computing and Networking Services (Laboratories and Divisions);
- Over the years there has been a shift from the figure of the Team Technician to the CTP, up to the figure of the Technologist (due to the increasing complexity of commitments);
- Specific design services were instituted with some differences between Laboratories and Divisions units;
- Mechanical Design Services and Workshops are more involved with projects promoted by GR I to GRIII and with residual proposals with GR V and Outreach;
- Applied Physics and Outreach became relevant in the last 20 years (Energy, Health, etc.) and INFN R&T earn relevant funds that helps on financing cutting-edge equipment for the Technical Services.
- The PhD TECH-FPA is a natural consequence and will offer an opportunity for young engineers and science graduates to participate in frontier technological developments in an international and interdisciplinary scientific environment

The Technologist along the years.

- INFN is always proposing frontier projects in multiple fields. Its structure, network, personnel are almost unique and therefore easily attracts the interest of young graduates
- The work of the Technologist within INFN structures often consists of developing non-standard solutions for original and challenging projects adopting less developed technologies to meet untested requirements;
- Training is fundamental as teamwork and collaboration with industry.
- The international environment offers a great opportunity to enhance the skills and the shared competences
- We are often called upon to find exotic solutions with unverified experience and the prototyping and commissioning steps performed in our laboratories represent an outstanding peculiarity

INFN (Padova) Mechanical Design Service tools & know-how

- Mechanical design: Siemens NX CAD
- Finite Element Analysis: Ansys Workbench, Ansys Fluent (COMSOL, Mechanica, Nastran)
- Thermography : Flir IR camera
- Metrology: Zeiss Accura CMM measuring machine. Optical Microscope, SEM, Portable Optical roughness meter
- Metrology: Hexagon measuring arm

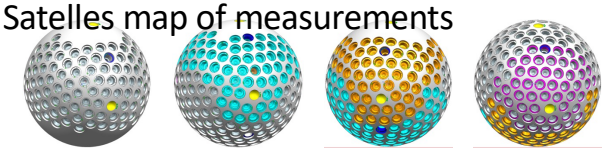
Personnel past and periodic training:

- NX and Ansys periodic training on different subjects
- Geometrical dimensioning and tolerancing GD&T courses
- Zeiss Aukom level II metrology training and certification
- Phase array ultrasound scanning of structural discontinuities (weldings, gluing, composites)
- Experiences in design of metallic and composite structures for detectors, structural glueing, detectors cooling, high vacuum applications , brazing and welding applications, …(Composite Lab: processing oven, post processing, clean room for assembly)

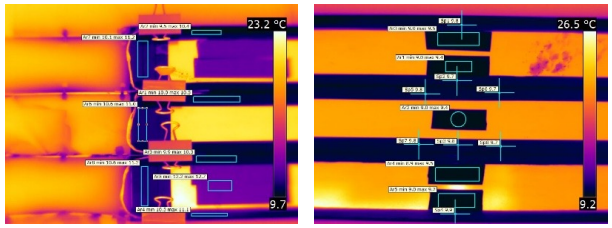
Measuring machine

Measuring arm

Satelles map of measurements



CCR Nr.	Ø37.3 [37.3-37.4]	Error [mm]	Ø26.9 [26.9-27]	Error [mm]	205.278	5.9 [5.9-5.95]	Error [mm]	True Position	Error [mm]
Nominal	37.300	0.100	26.900	0.100		5.900	0.050	0.1	
5	37.361		26.948		205.231	5.947		0.097	
6	37.372		26.947		205.203	5.975	0.025	0.158	0.058
10	37.343		26.927		205.203	5.975	0.025	0.153	0.053
11	37.328		26.954		205.150	6.028	0.078	0.161	0.061



CMS timing layer prototype IR imaging

Mechanical workshop (OM PD)

- 10 staff technicians, ~ 350 m^2 workshop
- Involved in producing samples, prototypes, parts and small productions for various experiments and projects..
- Opticam CAM software
- 3 and 5 axis CNC milling machines, up to 800 x 800x 1000 mm
- 2x wire EDM (wire electrical erosion)
- Various single and double spindle lathes
- 2x Wire and 1x SLA polymers “3d printers”
- 1 x laser welding
- And many other ancillary machines and tools

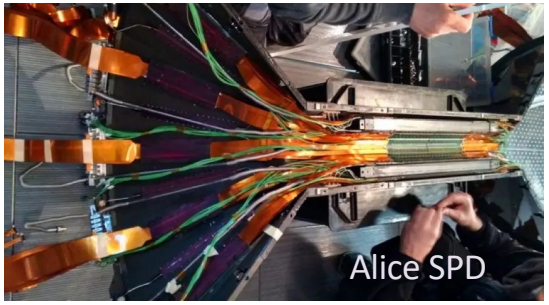
INFN Padova Mechanical Design Service: overview

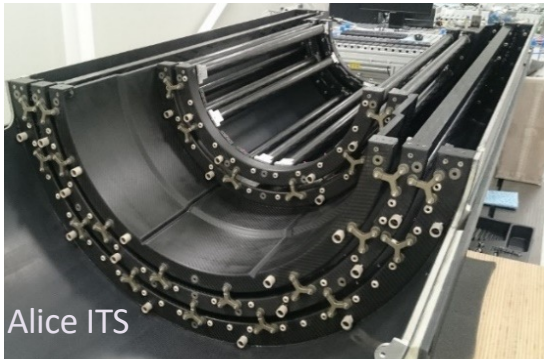
Composed by 9 staff: 4 bachelor engineers, 5 graduate mechanical designers

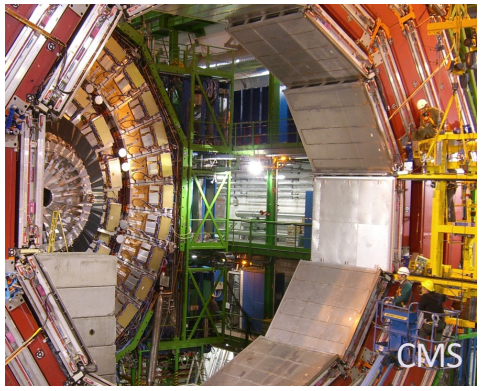
Involved in R&D, design, prototyping, qualification, production … up to delivery, installation and commissioning of detectors and accelerators components ..

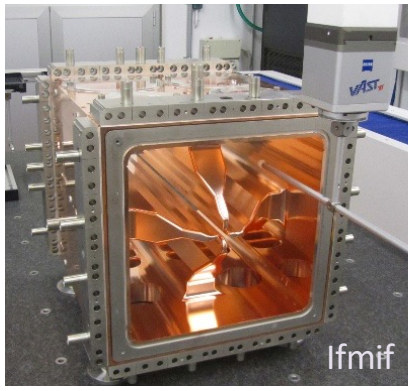
In the far and recent past we have contributed to many projects, e.g.:

- **Alice tracker (Cern)**
- **Belle II Dirc (KEK, Japan)**
- **CMS muon chambers (Cern)**
- **CTA mirrors (Canary islands)**
- **Icarus (LNGS and Fermilab)**
- **Ifmif RFQ (Rokkasho, Japan)**
- **LHCb RICH (Cern)**
- **Galileo (LNL, Italy)**
- **Zeus muon chambers (DESY)**





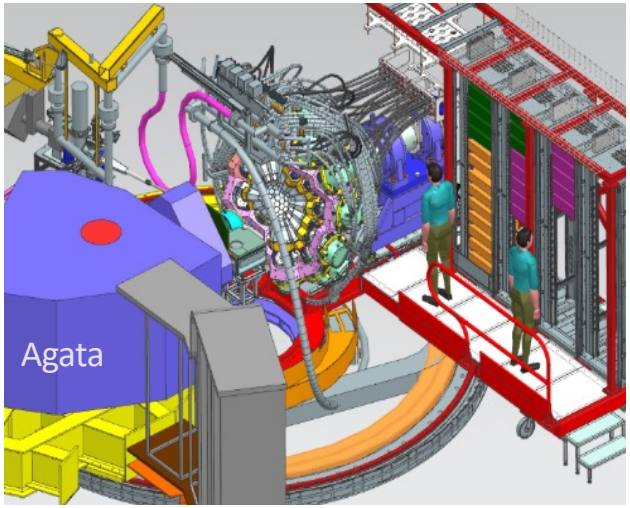


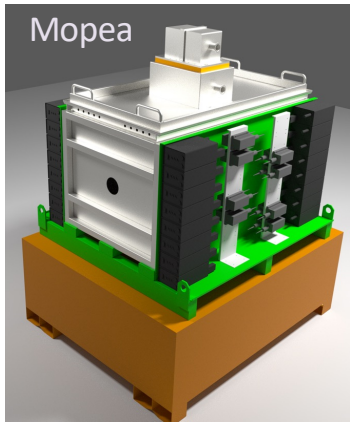


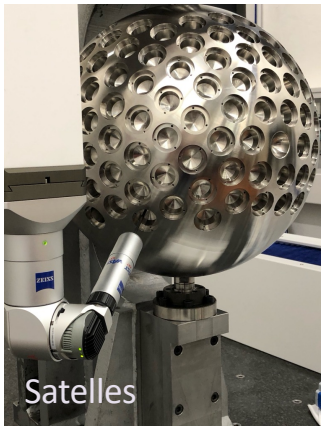
INFN Padova Mechanical Design Service: current activities

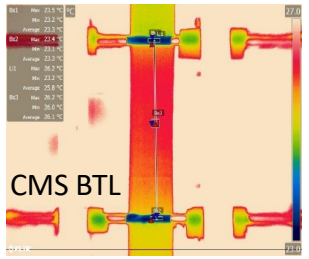
Currently involved in > 15 project of detectors, experiments, accelerators:

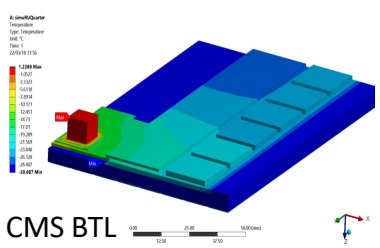
- **ALADDIN (CERN)**
- **AGATA (LNL, Italy)**
- **CMS BTL (CERN)**
- **CTA (Canary Islands, Spain)**
- **DTT-NBI (Italy)**
- **ENUBET (CERN)**
- **GERDA Legend (GSSI, Italy)**
- **HEAT (LNL, Italy)**
- **I.FAST (EU project)**
- **MOPEA (LNL, Italy)**
- **MUON-E (CERN)**
- **MUTOMCA (KKK Germany)**
- **NUCL-EX (LNL, Italy)**
- **QUAX (LNL, Italy)**
- **SATELLES (…space)**
- **SPES (LNL, Italy)**
- **VIRGO (Pisa, Italy)**
- and others ..

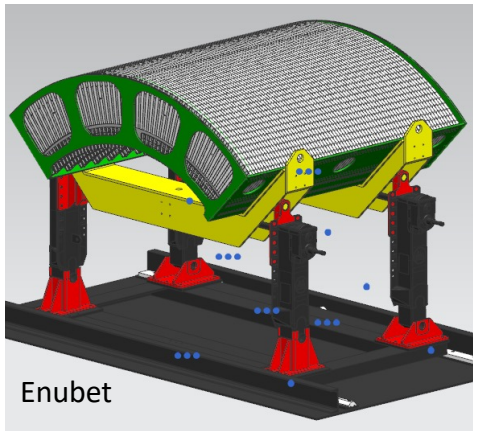


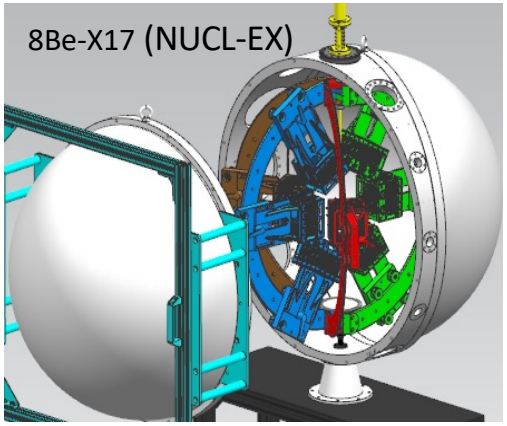




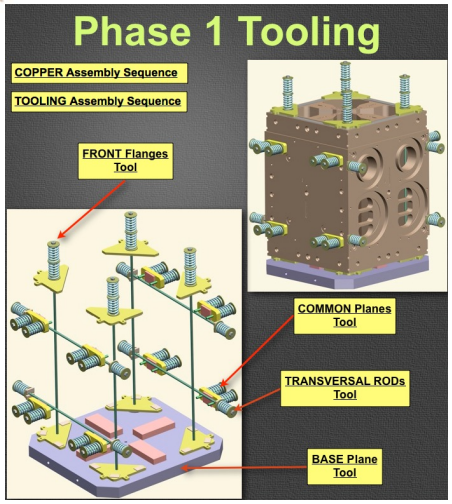


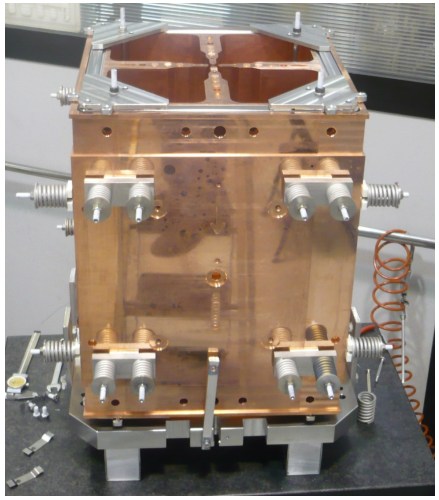




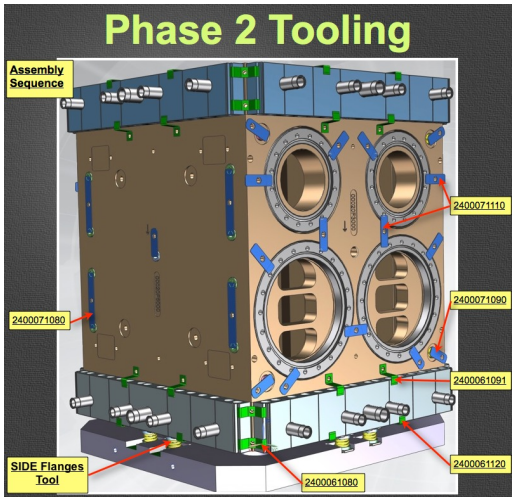


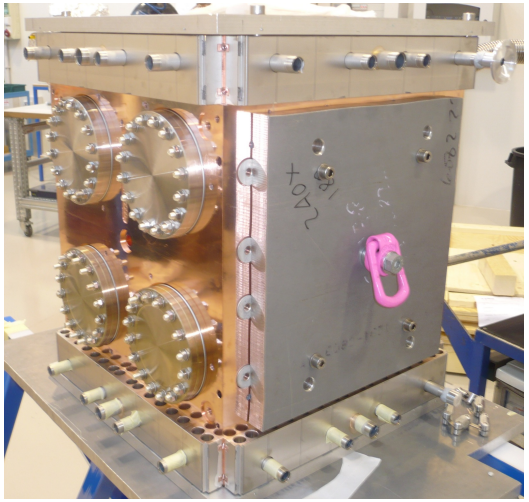
Modules produced with 2SB (M_16 and M_17).



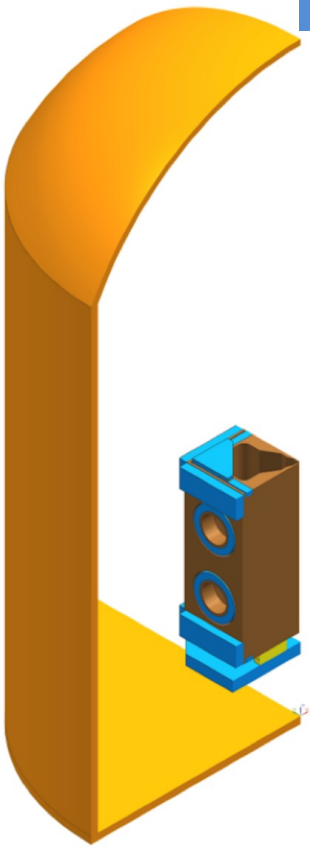


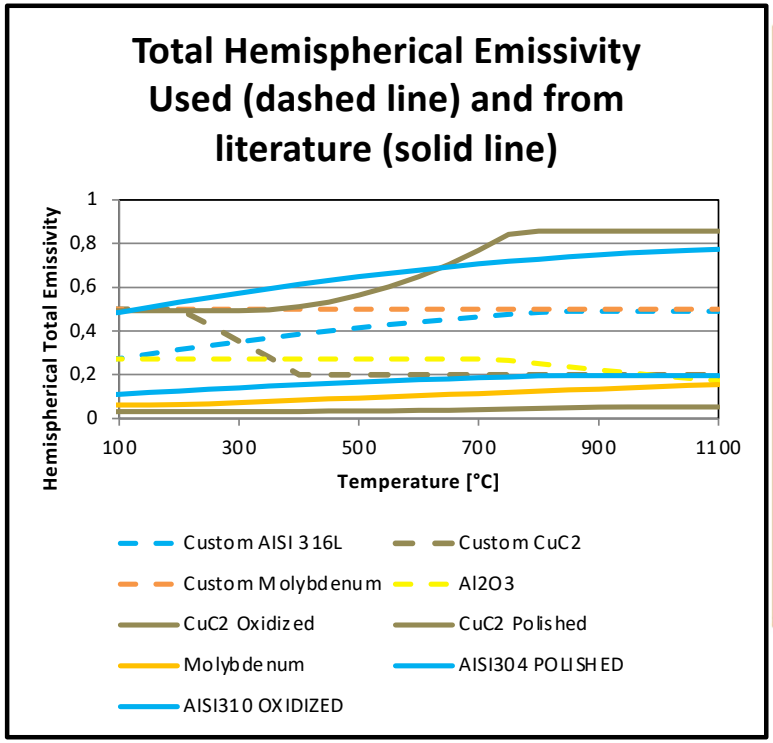
The first Module of the RFQ cavity line was brazed with 2SB due to the need to confirm the large amount of design changes introduced.
We had unpredictable problems on the 2° step brazing (thermal differential behaviour of AISI & CuC2) that induced us to a careful characterization (data from technical literature not confirmed). The report of this activity was done @5thIFMIF Workshop.
We updated the design on M_17 while maintaining the 2SB.
The results in terms of geometrical aspect and tolerances were excellent (well below the very stringent overall specification: ref. TABLE 2).

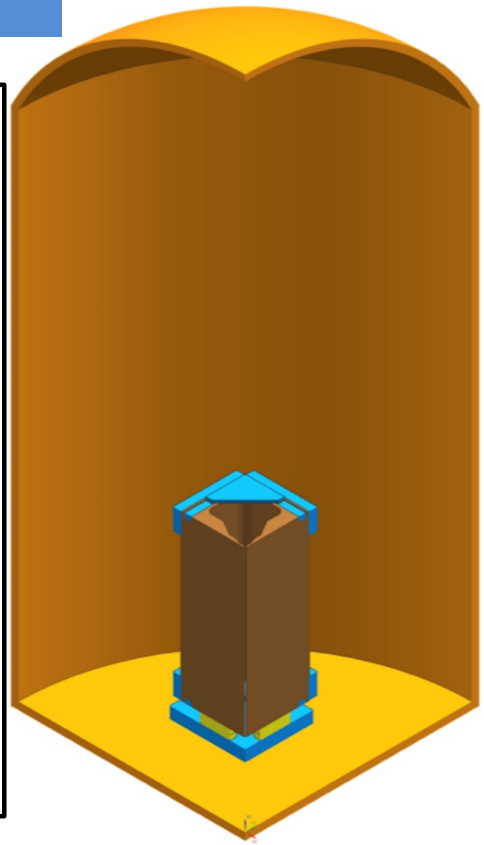


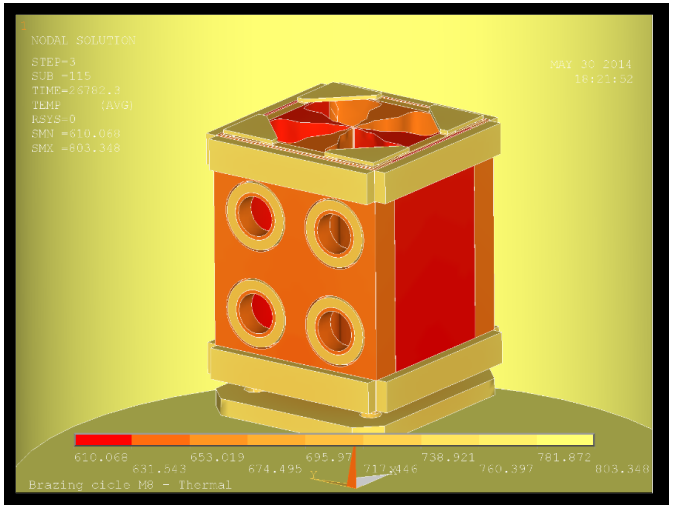


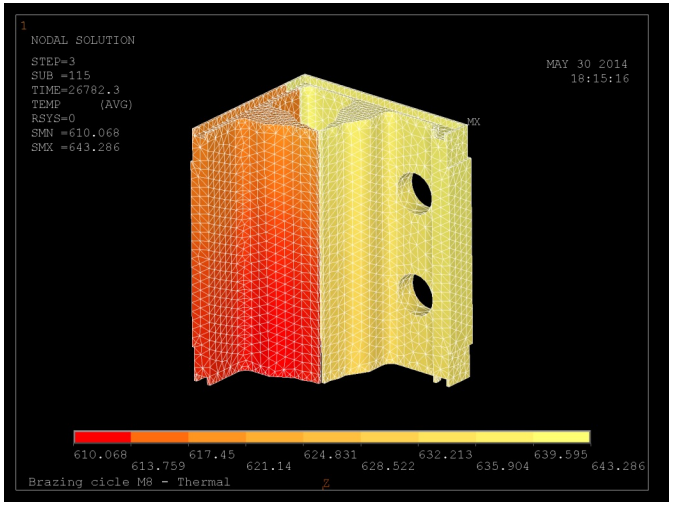
Since only difference between M_12 and M_8 is the vane thickness, we decided to develop FEM simulations of the thermal cycle to cope with the experimental data and provide a proper cycle and gauge positioning.



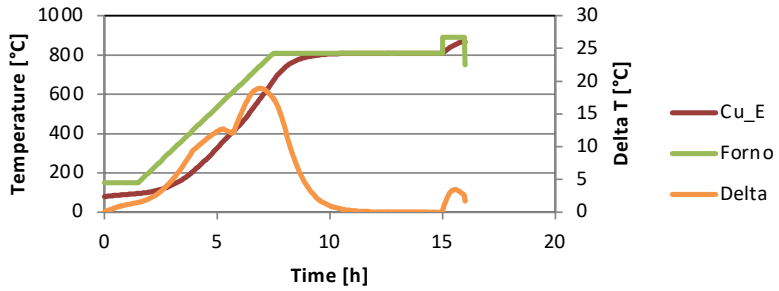




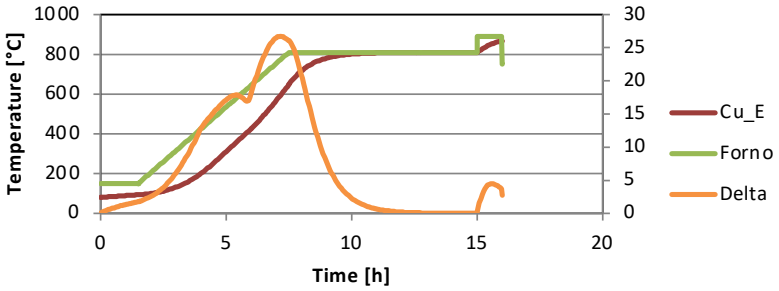




M_12 - Main temperatures simulated, expected difference temperatures between E's and T's

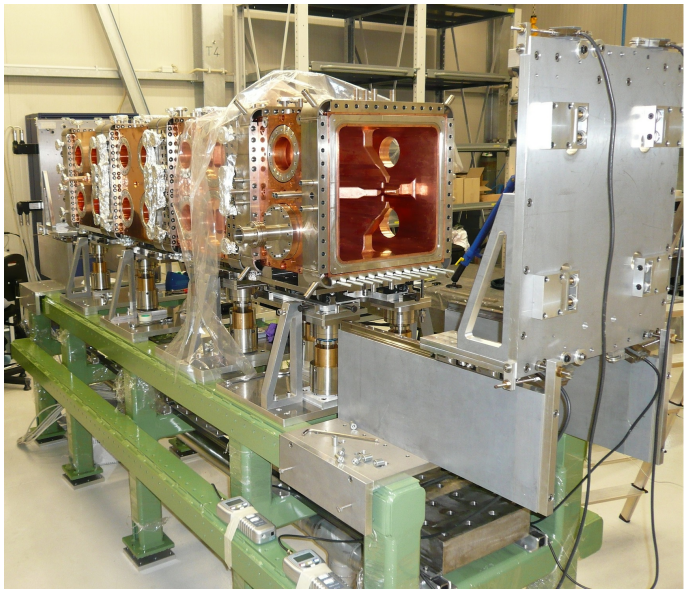


M_8 - Main temperatures simulated, expected difference temperatures between E's and T's

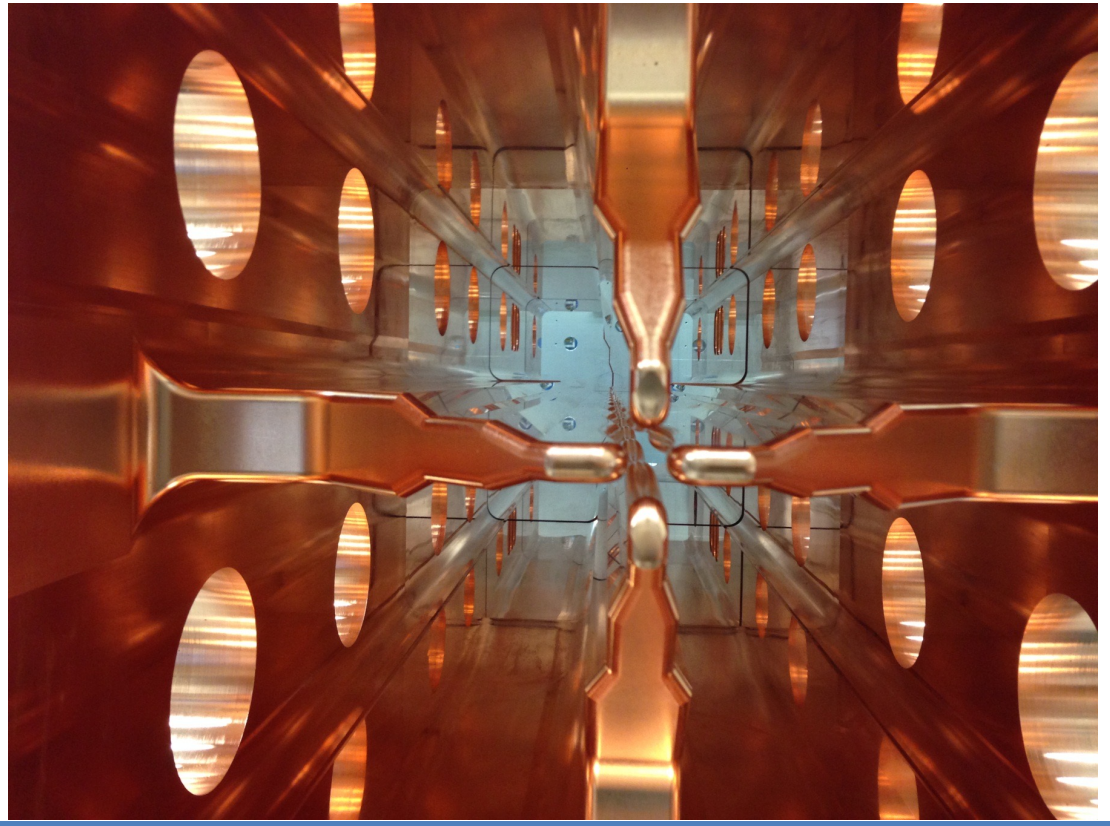


Power Test Line.

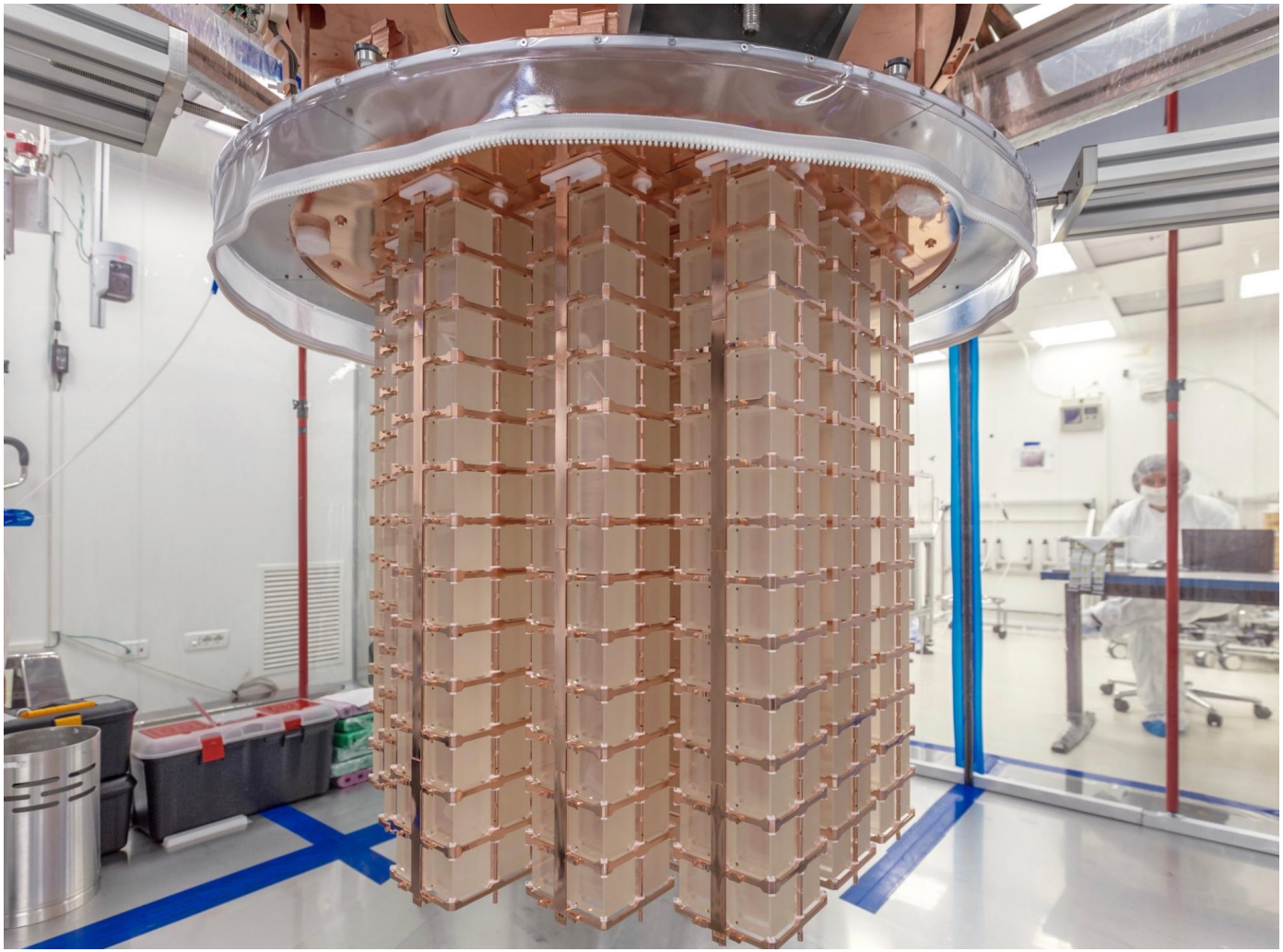
Power Test Line assembly: October 2013.

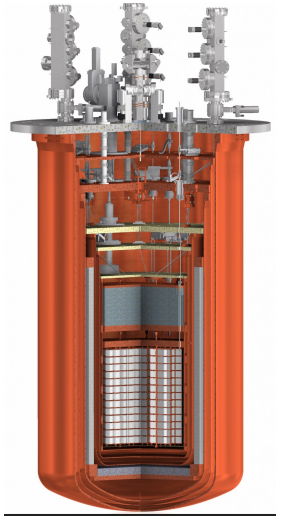


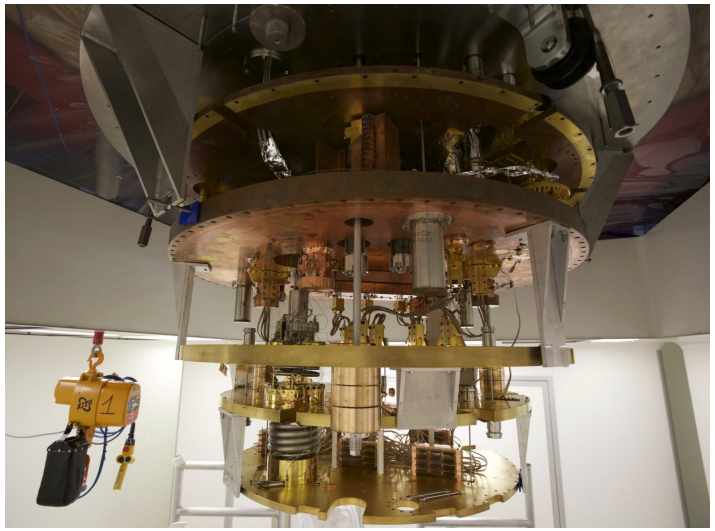
Power Test Line assembly: view from HE side.



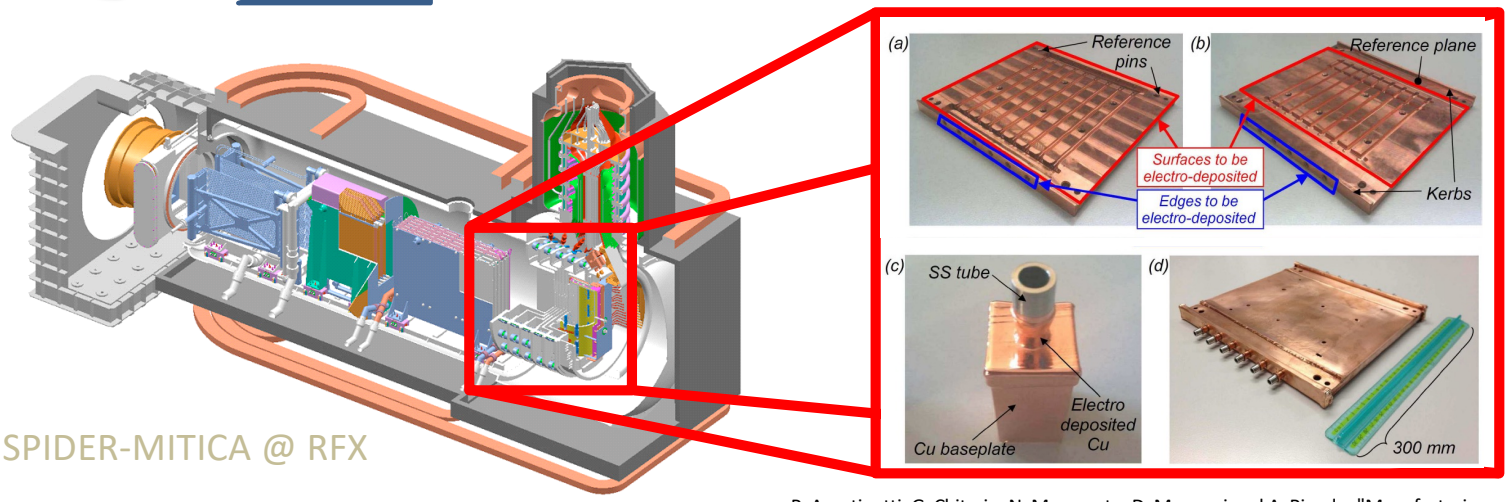
The ‘CUORE’ Experiment @ LNGS





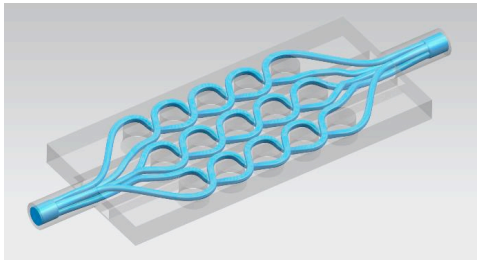


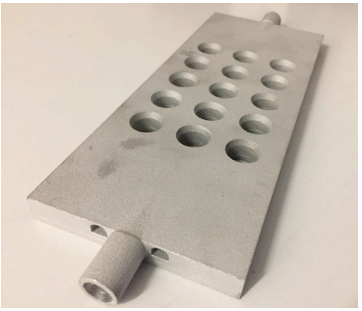
Origin of DIAM

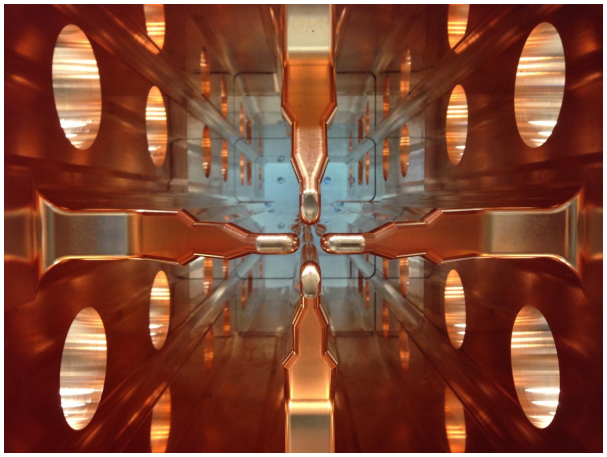


SPIDER-MITICA @ RFX

P. Agostinetti, G. Chitarin, N. Marconato, D. Marcuzzi and A. Rizzolo, "Manufacturing and Testing of Grid Prototypes for the ITER Neutral Beam Injectors," in *IEEE Transactions on Plasma Science*, vol. 42, no. 3, pp. 628-632, March 2014.





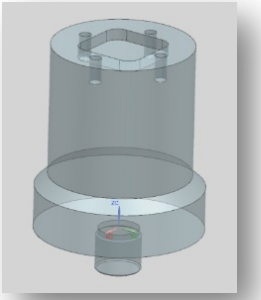


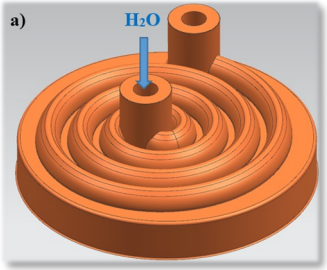
Cavità RFQ di IFMIF-EVEDA

Singer, F.,et all. (2017). Additively manufactured copper components and composite structures for thermal management applications.

POLIDORO
for excellence in combustion

OFFICINA DEI MATERIALI





DIAM 1.0: POR-FSE 2016

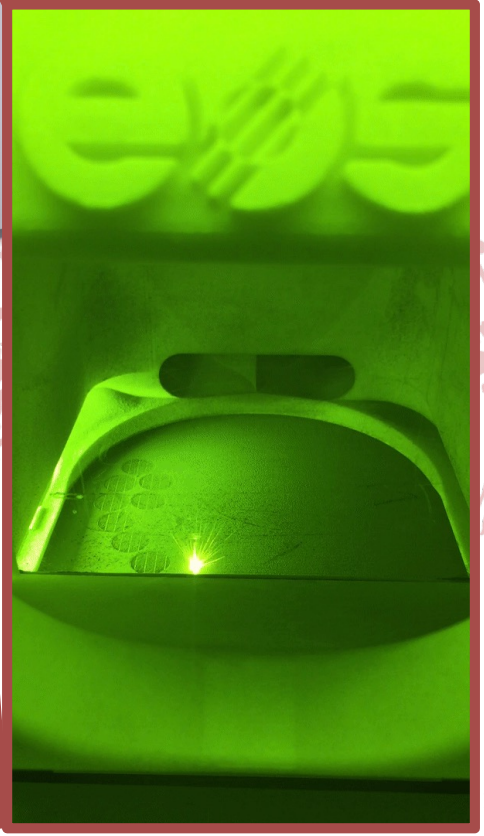
Laser Powder Bed Fusion Process

EOSint M280

Copper & Copper Alloys

EOS M100

Refractory Metals

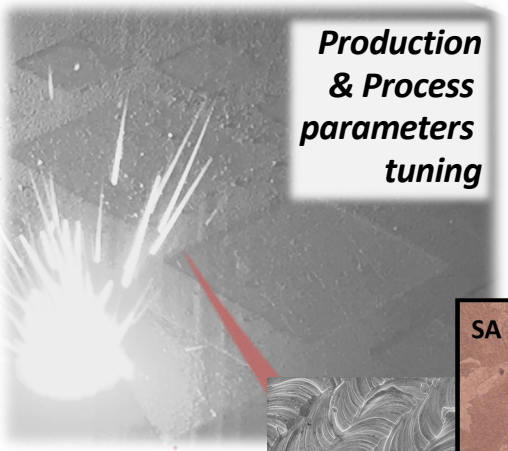


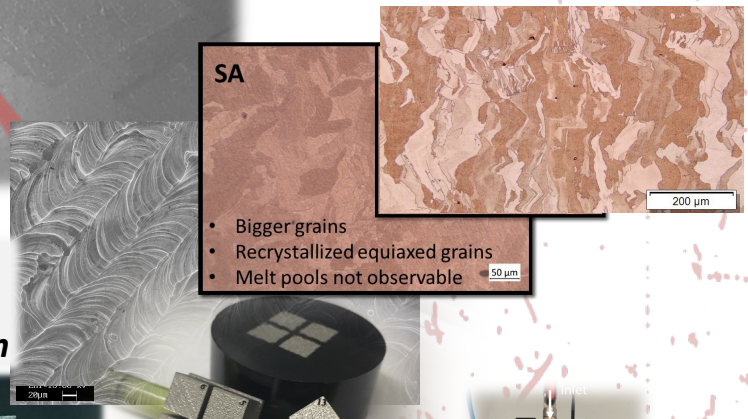
INFN DIAM
Istituto Nazionale di Fisica Nucleare

DIAM Research Core

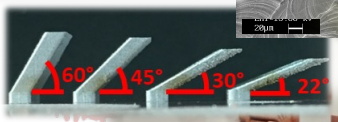
from MATERIAL to PRODUCT characterization

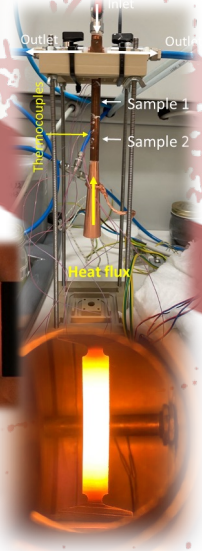
Production & Process parameters tuning





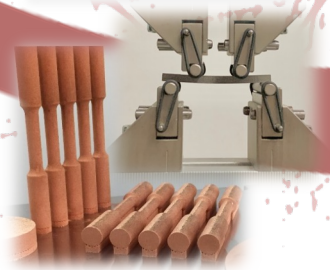
Microstructural & Geometrical Characterization

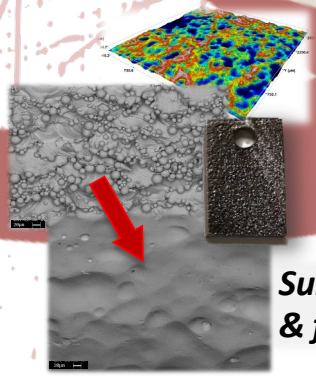




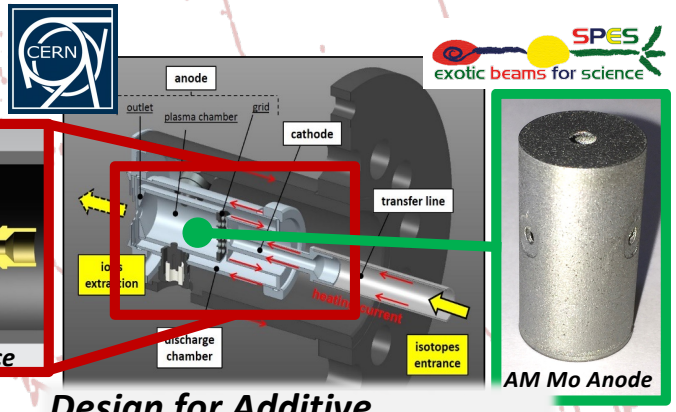
RT & HT Thermal Characterization

Mechanical Characterization





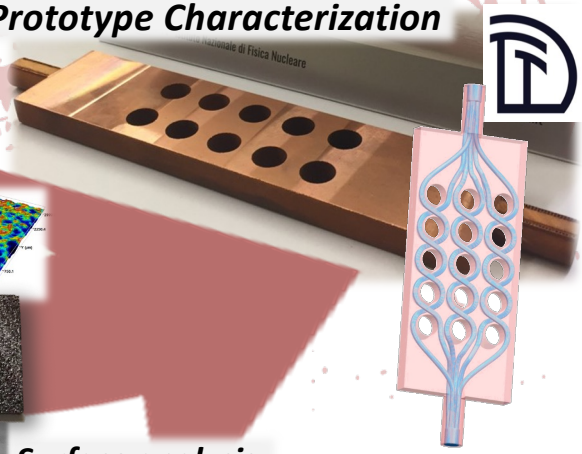
Surface analysis & finishing



AM - PIS ION Source

AM Mo Anode

Design for Additive & Prototype Characterization



INFN DIAM
Istituto Nazionale di Fisica Nucleare

COPPER & COPPER ALLOYS

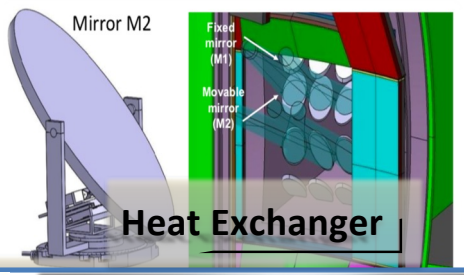
@ DIAM lab:

- ✓ Pure Copper
- ✓ CuCrZr
- ✓ GRCop-42

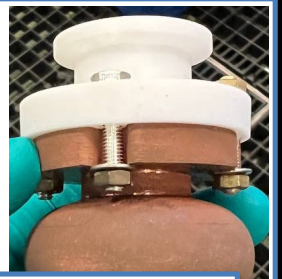
Physical and Chemical properties:

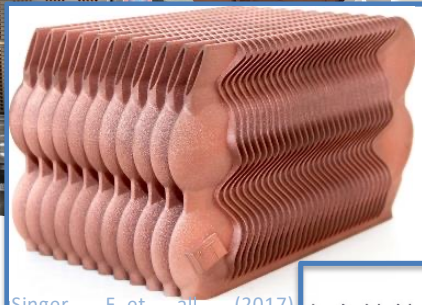
- ➢ Excellent thermal conductivity;
- ➢ Excellent electrical properties;
- ➢ Good mechanical properties (alloy);
- ➢ Good corrosion resistance;
- ➢ Anti bacterial performances.

Nuclear Fusion



Heat Exchanger





Singer, F.,et all. (2017). manufactured copper comp composite structures fo management applications.

Space and Aerospace

Fraunhofer IWS project enables green laser to melt pure copper

Corals - boiling tests

LAUNCHER **CuCrZr**

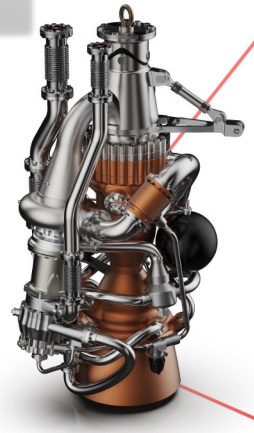
launcherspace.com

LAUNCHER E-2

THE WORLD'S **LARGEST 3D PRINTED** COMBUSTION CHAMBER ARRIVED AT LAUNCHER IN NOVEMBER 2019 FOR FULL-SCALE TESTING IN 2020.

Our partner

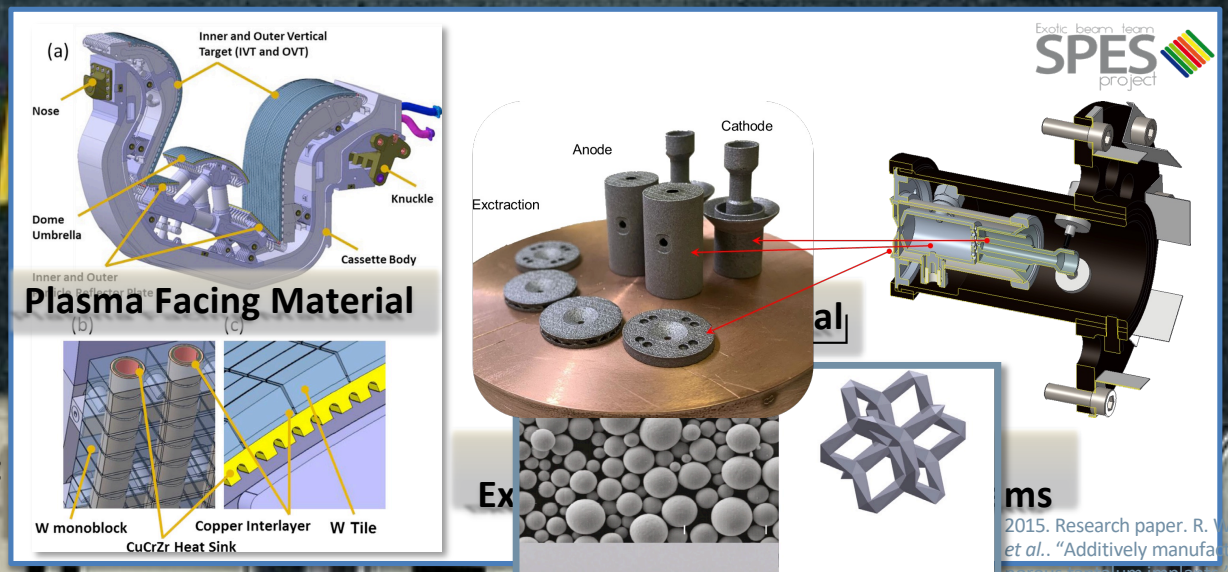
AMCM



Nuclear Fusion & Nuclear Physics

@ DIAM lab:

- ✓ Tungsten
- ✓ Molybdenum
- ✓ Tantalum
- ✓ Niobium



Plasma Facing Material

Ex…al

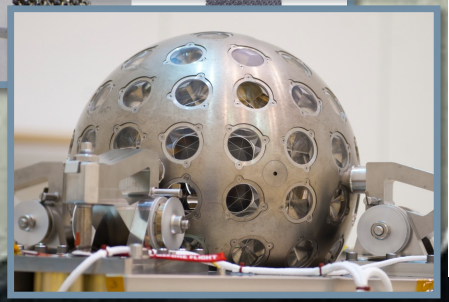
…ms

2015. Research paper. R. …
et al.. "Additively manufactured …
porous tantalum implants".

Physical and Chemical properties:

- ➢ Ultra-high melting point
- ➢ High density;
- ➢ Excellent corrosion resistance;
- ➢ Good thermal conductivity;
- ➢ Low thermal expansion;
- ➢ High strength and hardness.

Space and Aerospace



Lares Satellite. Courtesy of LARES Team. Produced in Tungsten

NASA MSFC AM C103 Green Propulsion Thruster and Stand-off

NICKEL SUPERALLOYS

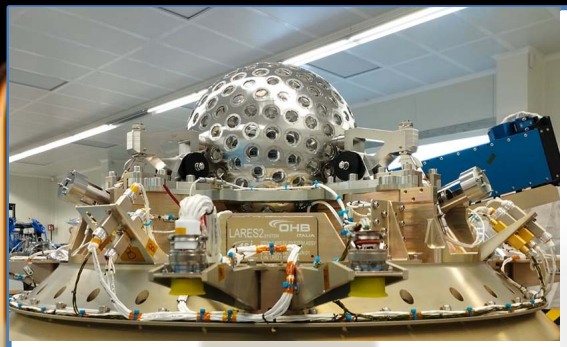
@ DIAM lab:

✓ Inconel 718

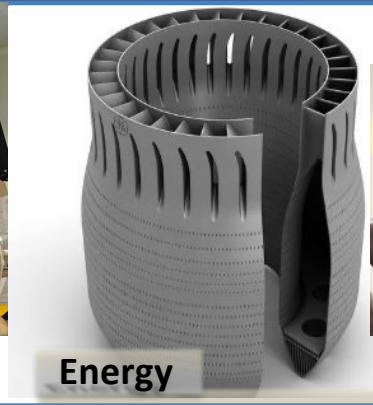
Physical and Chemical properties:

- Exceptional strength;
- High heat resistance;
- Excellent corrosion protection;
- Good oxidation resistance;
- Excellent creep resistance;

Aerospace

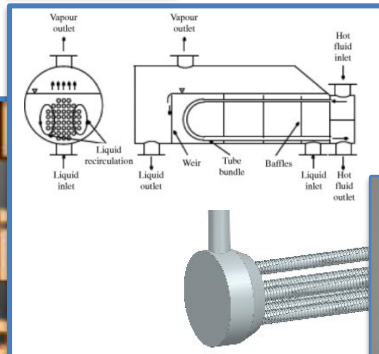


Satellite



Energy

Turbine Blades



Molten salt steam g

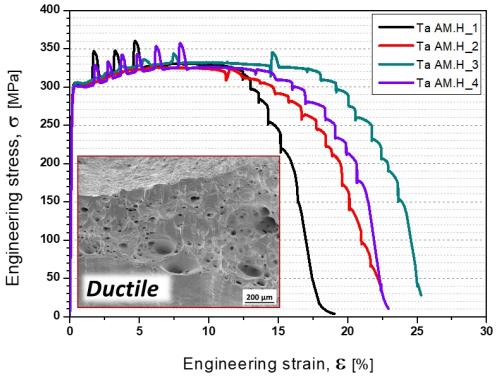
Oil and Gas

1b. AM Material Properties

Ta

TANiOBIS inspiring metal evolution

- High Density (> 99.8%)
- Mechanical properties higher than STD tantalum



Sample	E [GPa]	σ_y [MPa]	UTS [MPa]	A [%]
Ta STD	173	155	210	> 50%
Ta AM	177	300	330	~22%

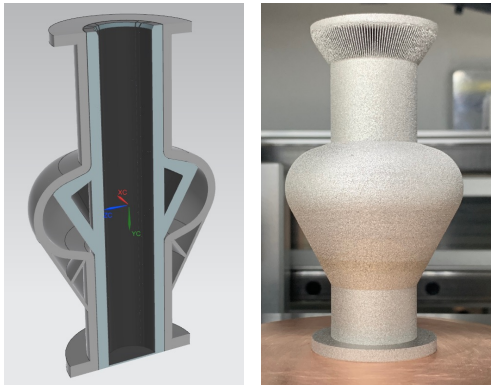
- Suitable for STRUCTURAL components (ex. Cathode)

AM Cathode - Ta

Nb

TANiOBIS inspiring metal evolution

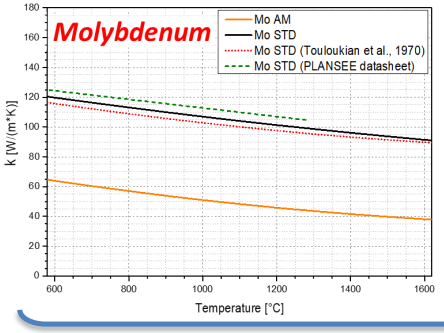
- High Density (> 99.8%)
- Extreme geometrical integrity during the production process



AM SRF 6GHz cavity - Nb

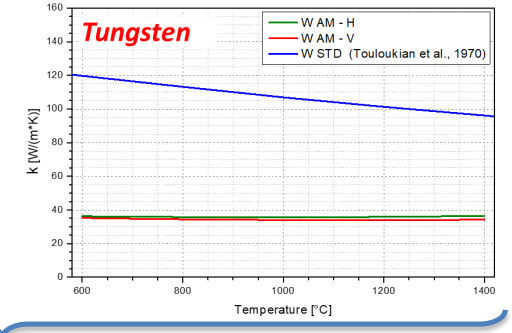
Mo

- High Density (> 99.9%)
- Thermal and mechanical properties lower than STD



W

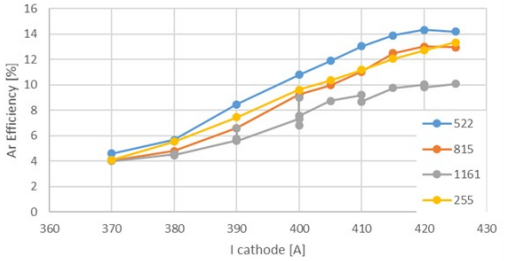
- High Density (> 99.6%)
- Thermal and mechanical properties lower than STD



- Suitable for NON-STRUCTURAL components (i.e. Anode)

AM Anode - Mo

Ionization efficiency using AM Mo Anode comparable to STD Ta Anode



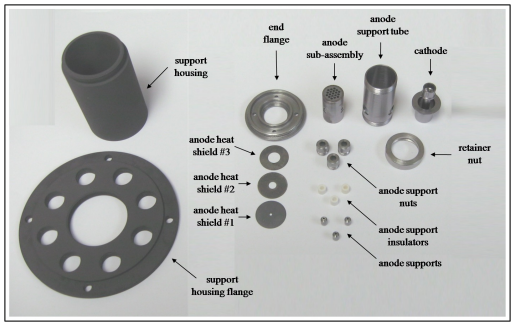
Eng. Adriano Pepato – I.FAST IIF –

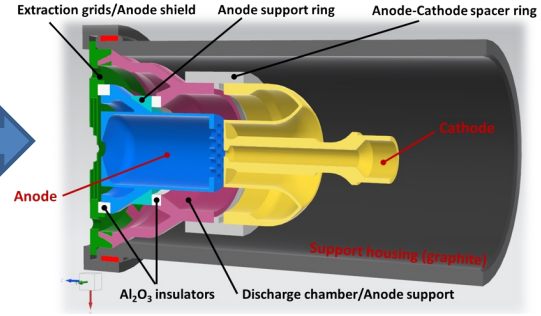
Nov. 16th 2022

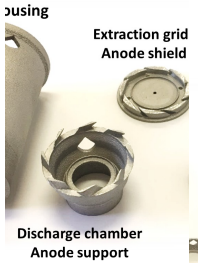
2. Project Objectives

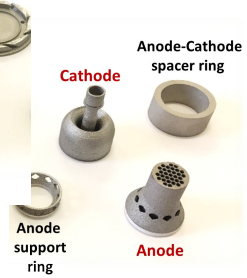
2. Development and Off-line/On-line test of a New ION source designed for Additive Manufacturing production in order to:

→ Improve the Assembly phase: components n° reduction (from n° components > 20 → to max 8 components)





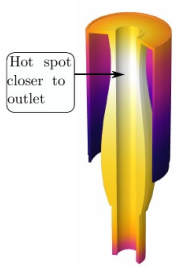




→ Develop a topological optimized design for the ION source physical performance improvement

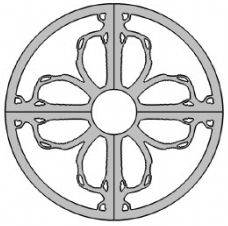
→ Optimized Cathode shape

(a) Nominal geometry



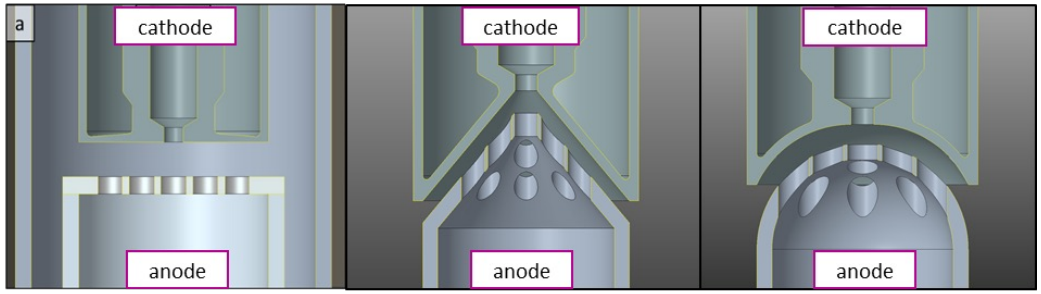
(b) Optimized geometry

→ Anode Grid generative design



(c) Optimized geometry

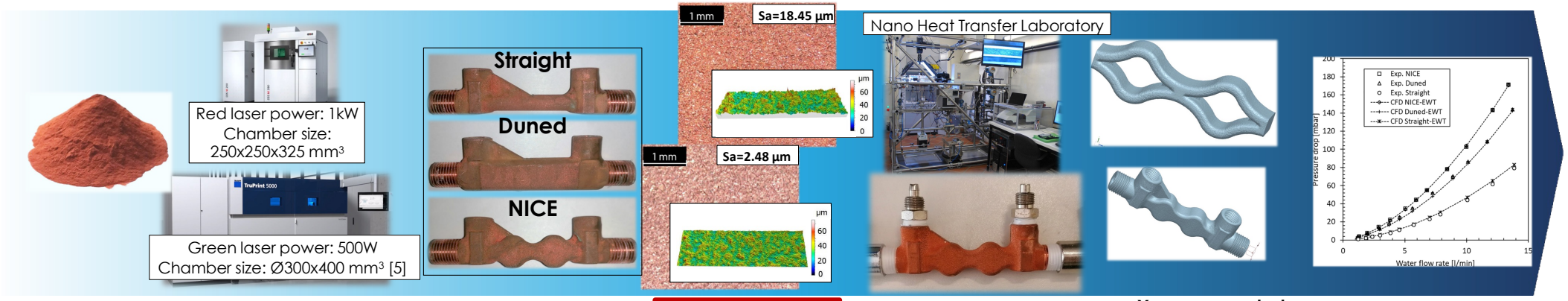
→ Optimized Cathode-Anode interface



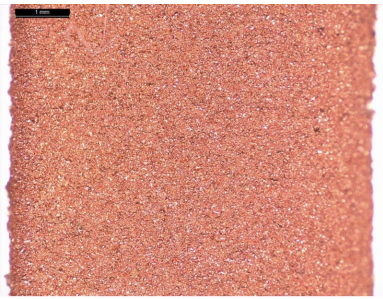
***State of the Art*: Old traditional design of the FEBIAD Ion Source**
DOI: https://doi.org/10.1063/1.4933081

Quantitative and verifiable output:
AM ION Source → New DfAM Ionization efficiency estimation

The integrated cooling system: performance optimization and pressure drop minimization

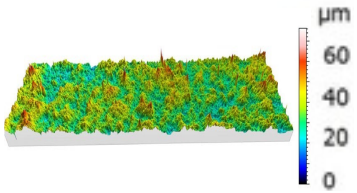


Pure Cu metal powder | **LPBF machines** | **6 channels samples** | **Chemical finishing treatment** | **Pressure drop tests before and after finishing** | **X-ray computed Tomography verification** | **CFD calibration-smooth channel**



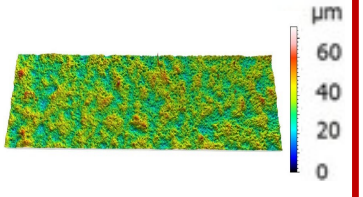
As built
Straight channel

Sa max=18.45 µm



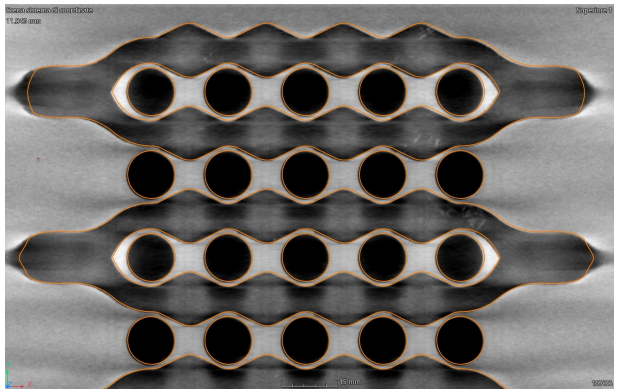
Straight channel
after chemical milling

Sa max=3.08 µm

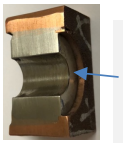


DTT AM applications for the NBI: Acceleration Grids

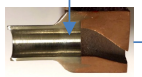
- First full-size prototypes
- Manufactured with AMCM M4K (Gmbh, EOS)
- Height 880mm; Width 450 mm
- Material CuCrZr
- Conformal cooling channels
- Spherical shape
- Heat treated with TAV S.p.A. furnace
- Quenched with GAr (argon gas)

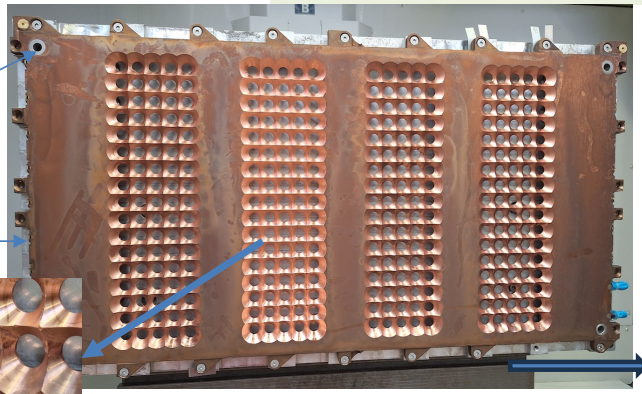


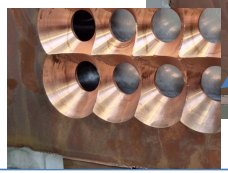
Tomographic scan of an EG portion

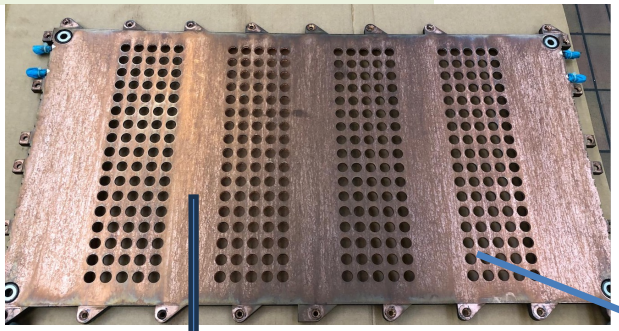


EBW connections:
- AISI 316l inserts
- AISI 316l cooling connection

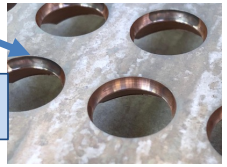








Plasma Grid finished and tested



Full-size printed Raw blanks:
- Plasma Grid
- Extraction Grid
- Samples for fatigue lifetime study

Process optimization of copper alloys

PhD stage at EOS Electro Optical System Finland Oy

Machine: M290 1kW red-laser
Materials: CuCrZr and pure copper

PhD student

Valentina Candela
Materials Engineer

valentina.candela@pd.infn.it

Activity:

- Printing parameters optimization
- Heat treatments
- Geometrical precision assessment
- Surface finishing optimization of as-built parts

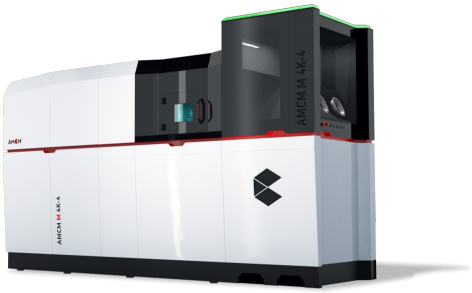
INFN DIAM
Istituto Nazionale di Fisica Nucleare

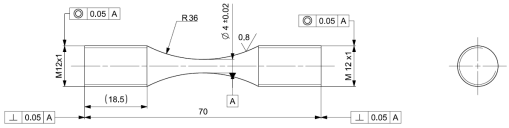
Characterization of **AMCM 4K CuCrZr 80 um**

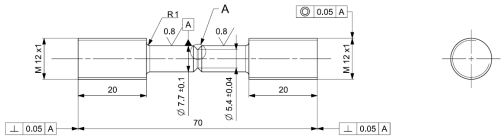
- Relative density
- Microstructural characterization
- Tensile tests
- **Fatigue life (hourglass and notched)**

Low and **high cycle fatigue life** at RT and 300 °C of the following materials:

- EOS CuCP EOS M290 1KW
- EOS CUCRZR 60 um EOS M290 1KW
- EOS CUCRZR 80 um AMCM 4K (optimized parameters)
- CuCrZr EOS M280







PhD project - Corrosion of components made by additive manufacturing for extreme applications

Corrosion/erosion performance with the same water chemistry condition found in ITER NBTF systems and at same high velocity required (up to 12 m/s) and temperature (150 ˚C)

- CuCrZr
- Inconel 718

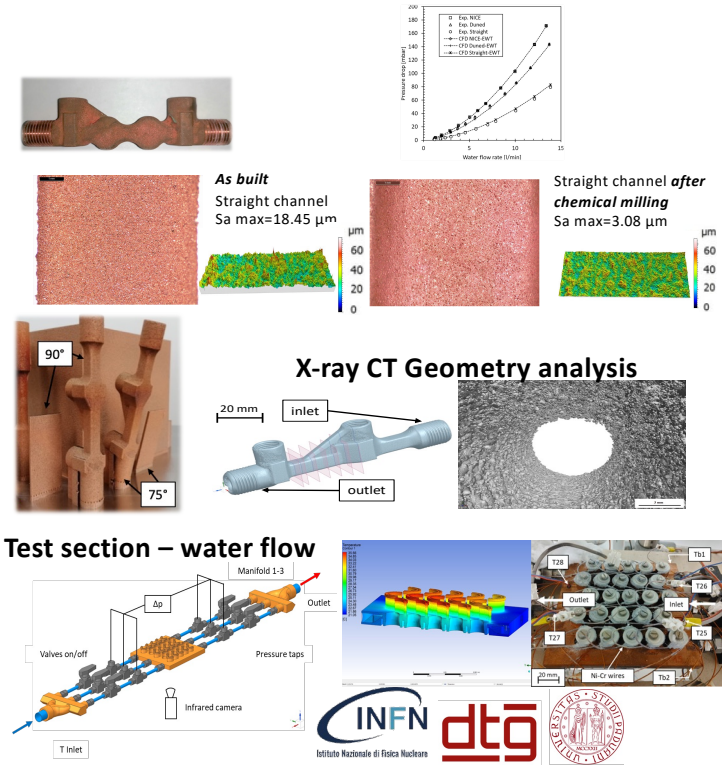
Corrosion behavior in molten salts at the high temperature (550 ˚C)

AM for thermal management application: numerical modelling and experimental tests.

Fluid flow inside additively manufactured and smoothed cooling channels.

Influence of the building orientation on the hydraulic performance of additively manufactured cooling channels.

Experimental tests and CFD simulations of additively manufactured extraction grid prototypes for the DTT neutral beam injector.



PhD Program of National Interest in Technologies for fundamental research in Physics and Astrophysics

SCHOLARSHIP N.2 Materials - Metallurgy
HOSTING UNIVERSITY/RESEARCH CENTRE: Università degli Studi di Padova
CURRICULUM: Mechanics
TOPIC: Development and Characterization of Innovative Additively Manufactured Metal Alloys for High and Ultra-High Temperature Applications

SCHOLARSHIP N.3 Design for Additive Manufacturing - Mechanical
HOSTING UNIVERSITY/RESEARCH CENTRE: Università degli Studi di Padova
CURRICULUM: Mechanics
TOPIC: Advanced Design for Additive Manufacturing (DfAM) approaches for cutting-edge applications in Physics and Engineering

DM 629 P.A.

Periods abroad	Periods in companies/institutions
Mandatory	Mandatory in companies, research centres or public administrations

SCHOLARSHIP N.8 Chemistry
HOSTING UNIVERSITY/RESEARCH CENTRE: Università degli Studi di Padova
CURRICULUM: Mechanics
TOPIC: Sustainable Surface Finishing of Additively Manufactured Metal Components for High-Precision Applications

DM 630

Periods abroad	Periods in companies/institutions
Mandatory	Mandatory in the company

INFN-LNL & Weal3T System

SCHOLARSHIP N.29 Mechanical - SPES
HOSTING UNIVERSITY/RESEARCH CENTRE: INFN - Laboratori Nazionali di Legnaro
CURRICULUM: Mechanics
TOPIC: Development, design and testing of metallic components for high-temperature nuclear physics applications produced using additive manufacturing technologies

INFN