Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
Consiglio Nazionale delle Ricerche
Università degli Studi di Padova
Università degli Studi di Napoli Federico II

Nefertari

NEFERTARI project: a network of Research Infrastructures for Magnetic Confinement Fusion Research

Simone Peruzzo
Research Infrastructure Manager
CNR-ISTP & Consorzio RFX

on behalf of the NEFERTARI project Team

Nefertari Meritmut
13th century BC Egyptian queen
"The one for whom the sun shines"

Nefertari

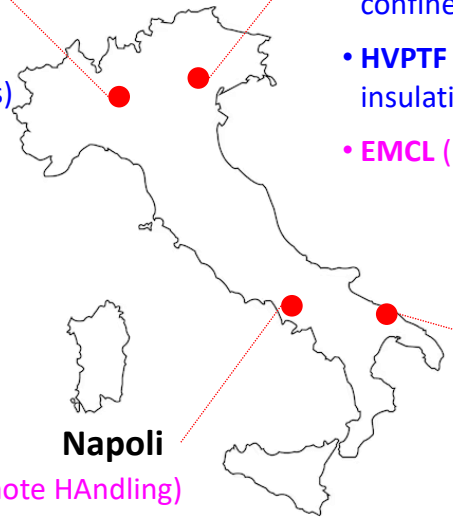
New **E**quipment for **F**usion **E**xperimental **R**esearch and **T**echnological **A**dvancement with **R**fx **I**nfrastructure

- Funding institution: Italian Ministry of University and Research
- Framework program: National Recovery and Resilience Plan
- Objective: Strengthening of high priority Research Infrastructures
- Project aim: Innovation of **experimental equipment** and **diagnostic systems** for **RFX-mod2** and **linked laboratories**, in support of **DTT**, **ITER**, **DEMO**
- Allocated funds: **18 M€** (**70%** dedicated to **hardware investment**) (**27 new positions**: 19 researchers, 8 PhD)
- Duration: 30 months (**2022 – 2025**)
- Partnership: Consiglio Nazionale delle Ricerche; Università degli Studi di Napoli Federico II; Università degli Studi di Padova

MUR

Funded by the European Union

Distribution of **experimental facilities enhanced** or **newly realized** with NEFERTARI



Milano

- **BiGym** (Linear device for plasma wall interaction study)
- **NeutronLab** (development of X-ray and neutron diagnostics)

Padova

- **RFX-mod2** (toroidal machine for RFP & TOKAMAK confinement study)
- **HVPTF** (High Voltage Padova Test Facility – vacuum and gas insulation study)
- **EMCL** (Electro-Magnetic Compatibility Laboratory)

Bari

- **LaserDiLab** (development of optical diagnostics)

Napoli

- **FARHA-ONE** (FAcility for Remote HAndling)

RFX experiment at a glance:

- 1992 - 99: **RFX**
- 2004 - 16: **RFX-mod**

} experimental phases

- 2018 - 23: modification of the vessel complex
- 2023 - 25: new experimental plants & diagnostics

- 2026 - … : **RFX-mod2**

✓High Priority Research Infrastructure included in the Italian «Research Infrastructure National Plan 2021-27» - ENERGY sector (ESFRI)

- **PNRR-NEFERTARI investment**: **10 M€**
- pre-existing investment: **110 M€**

iter china eu india japan korea russia usa

Neutral **B**eam **T**est **F**acility

Funded in the framework of international agreements ITER – F4E – MUR up to 2030
(in prospect up to 2040)

Nefertari

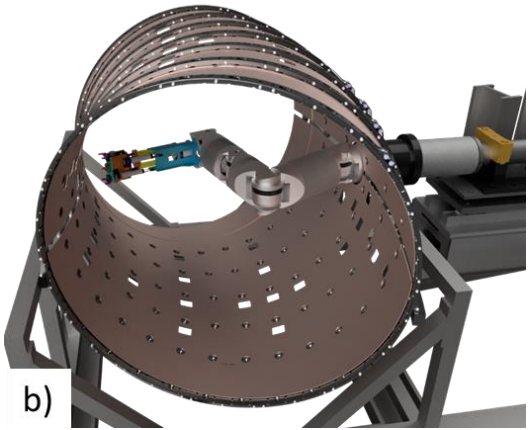
Involved Operating Units

NEFERTARI project - Work Packages	CNR-ISTP		UniPD	UniNA	
(1) RFX-mod2 Technological Plants	Pd		CRF	DII	
(2) Electromagnetic measurements and feedback control in fusion devices	Pd		CRF		DIETI
(3) Innovative diagnostics for edge fusion plasmas	Pd				
(4) Enhancement of RFX-mod2 main plasma diagnostics	Pd		CRF		
(5) Neutral beams injectors in RFX-mod2	Pd				
(6) Laboratory of High Voltage insulation in fusion devices			CRF		
(7) Laboratory for the study of fusion relevant high-density plasmas and materials interaction		Mi			
(8) Laboratory for innovative diagnostics for imaging of soft X-rays and neutrons		Mi			
(9) Research and Development of optical plasma diagnostics and modelling for fusion	Ba				

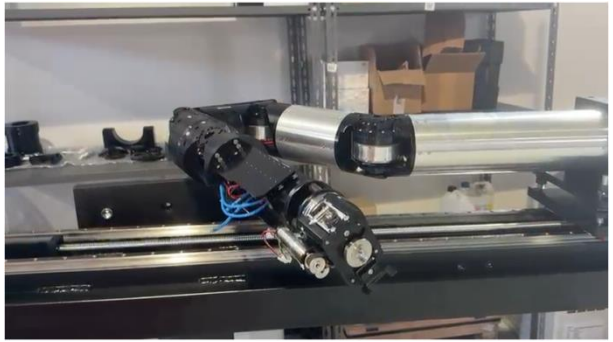
(1) RFX-mod2 Technological Plants

✓**new RH system for RFX-mod2 first wall maintenance**

- Self-consistent Training Facility @Napoli
- Main system @Padova



- Vacuum and Gas Injection System
- Glow & Pulsed Discharge Cleaning Systems
- **Remote Handling system for first wall maintenance**



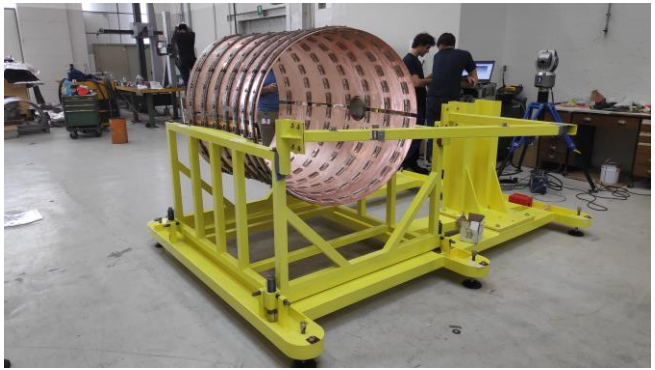
Main procurements:

- Robotic arm (serial robot with 7 DoF)
- 1:1 vessel complex mockup (30°)
- RH robot Control systems
- Server for RH Virtual Reality and accessories

SOPHIA HIGH TECH

B&R BREMBANA&ROLLE

BECKHOFF New Automation Technology



Project update:

✓ Factory Acceptance Tests in progress

➢ Commissioning by Oct 2025

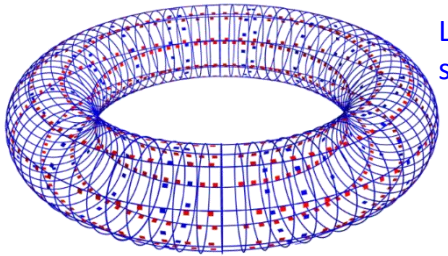
ref.: G.A. Fontanelli, et al., Fusion Engineering and Design 206 (2024) 114586
https://doi.org/10.1016/j.fusengdes.2024.114586

(2) RFX-mod2 Electromagnetic measurements

- Development and prototyping of machine protection and plasma control software
- EMC laboratory (new anechoic chamber for em compatibility tests < 18GHz)
- **EM sensors and acquisition systems for plasma control and machine protection**

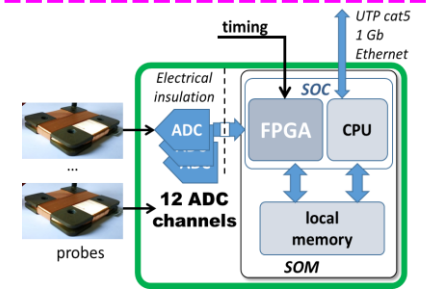
✓**Complete refurbishment of:**

- In-Vessel Electro-Magnetic sensors
- signal acquisition and preprocessing system



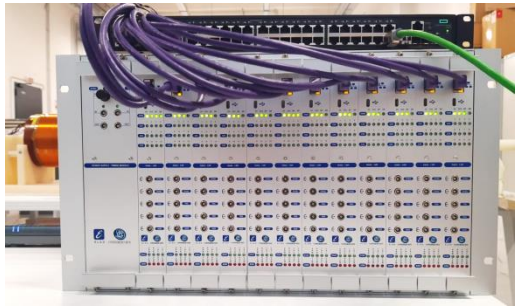
Layout of new in-vessel sensors (tot. n. 2216):

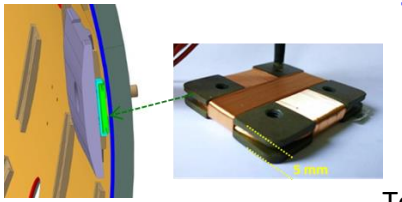
✓ 1736 magnetic
✓ 480 electrical



Modular system

- 20 bit ADC - 1 MSample/s
- 250 kHz analog bandwidth.
- Galvanic isolation < 2.5 kV AC rms
- Numerical signal integration in FPGA - 10 sec
- Based on Xilinx Zynq 7020 architecture





Triaxial pick-up coils located in the clearance between First Wall tiles and In-Vessel Shell

- **Support**: Torlon 5530
- **Winding**: enameled copper wire (∅ 0.18 mm)
  (Vessel baking temperature < 200°C)

Technical solutions:

✓ **derived from RFX-mod experience**
✓ **proposed for DTT with minor adaptations**

ELAD

Project update:

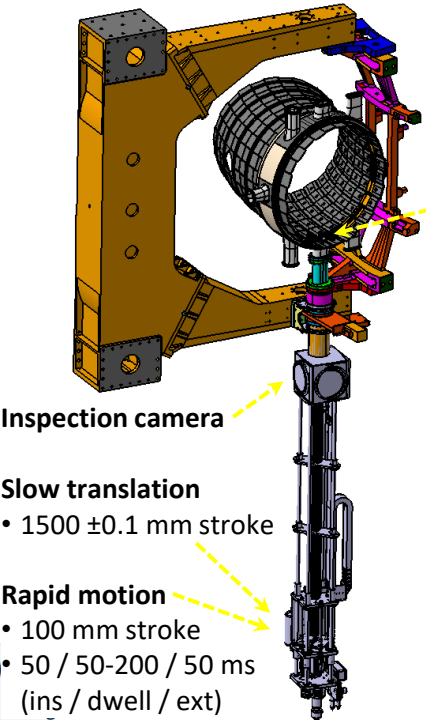
✓ Acceptance Tests completed
➢ installation on RFX-mod2 planned by Dec 2025

ref.: R. Cavazzana, et al., SOFE 2025, https://plasmafusion.eventsair.com/sofe2025, submitted to IEEE Transactions on Plasma Science

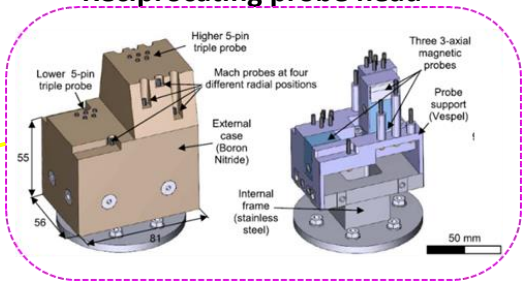
(3) plasma edge diagnostics for RFX-mod2

- reflectometric system for real time plasma position control (proposed also for DTT and DEMO)
- light impurity tomography (LIT)
- spectroscopic diagnostics system based on the use of polychromator (MANTIS)
- **movable system of probes with FAst Reciprocating Manipulator (FARM)**

✓**New manipulator** for rapid insertion in the plasma edge region of **electro-magnetic probes** for detection of plasma parameters (n, T, V, B)



Reciprocating probe head



Technical solutions:
✓ **Used also on W7X**

Main procurements:
- Manipulator
- Probe heads
- Power supply & data acquisition system

T.E.E.S.

Project update:
✓ Ready for installation

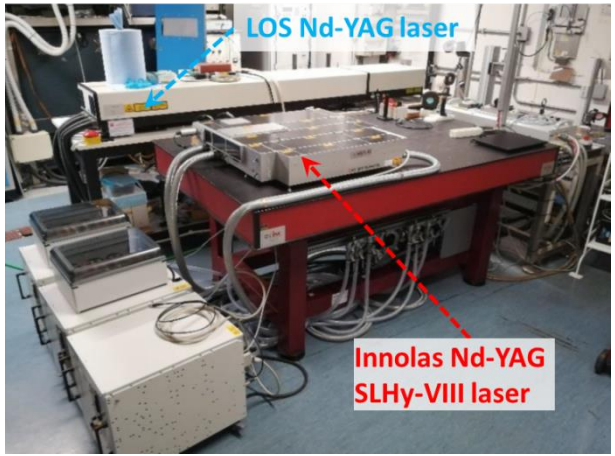
ref.: P. Agostinetti , et al., SOFE 2025, https://plasmafusion.eventsair.com/sofe2025, submitted to IEEE Transactions on Plasma Science

(4) Enhancement of RFX-mod2 main plasma diagnostics:

- Soft X Rays and bolometry tomography
- Compact Neutral Particle Analyzer
- **Thomson Scattering for radial Te and ne profiles measurement**

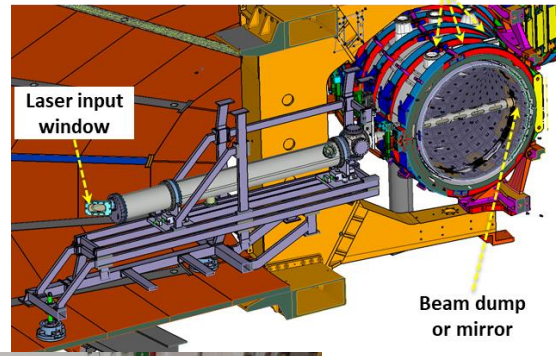
Requirement	Specification
Wavelength	1064 nm
Pulse Energy	4 J per pulse
Operation mode	Single shot, 0.3, 1, 2, 3 kHz
Pulse Duration (FWHM)	10 ns
Max pulse-to-pulse jitter	< 100 ns
1st pulse-trigger jitter	10 µs
Trigger delay	10 µs
Beam Divergence	≤ 0.5 µrad (full angle)
Pointing Stability	≤ 50 µrad
Burst Operation	≥ 10 pulses per burst

✓**new Nd:Yag laser 0.3 ÷ 3 Khz** coupled to existing **4Joule 100 Hz LOS Nd:Yag laser**



Main procurements:

- Laser
- Manipulator and support structure
- Acquisition system
- Optical components



Manipulator for dump/mirror installation without breaking vacuum

Project update:

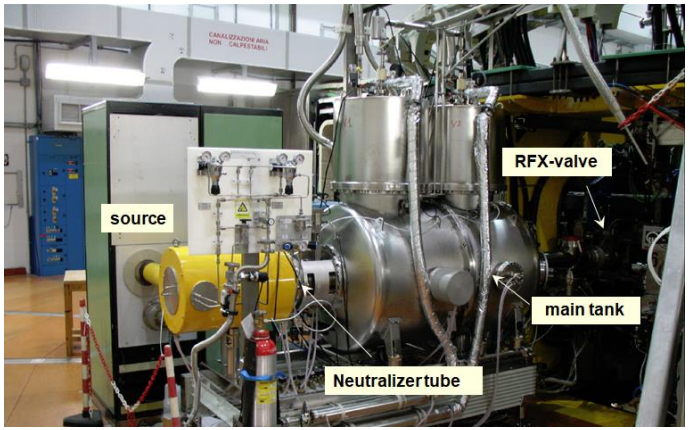
✓ Site Acceptance Tests of laser accomplished 2025

➢ installation on RFX-mod2 planned for 2026

ref.: L. Carraro, et al., Nucl. Fusion 64 (2024) 076032
https://doi.org/10.1088/1741-4326/ad490a

(5) Neutral beams injectors in RFX-mod2:

✓ **Complete refurbishment** of the **50 keV, 100 kW** Diagnostic Neutral Beam Injector (**DNBI**) for core measurements of **Ti**, **ion flow**, **impurity content**, $\vec{B}$



in collaboration with:

EPFL Tokamak Energy

Main activities and procurements:

- Redesign of **High Voltage Deck** and related **power units** and **control system** — ESSEGI SYSTEM
- Replacement of open-cycle **cryopumps** with closed-cycle ones — Leybold
- Redesign of DNBI-RFX-mod2 **duct** to reduce beam losses
- New **spectrometer** and **EMCCD cameras** for
  - CHarge Exchange Recombination Spectroscopy (**CHERS**)
  - Motional Stark Effect (**MSE**) polarimetry — iMAGES

Project update:

✓ Acceptance Tests of spectrometer and cameras accomplished 2025

➢ Completion of electrical and vacuum components planned by Dec 2025

ref.: M. Barbisan, et al., Fusion Engineering and Design 220 (2025) 115320
https://doi.org/10.1016/j.fusengdes.2025.115320

(6) Laboratory of High Voltage insulation in fusion devices

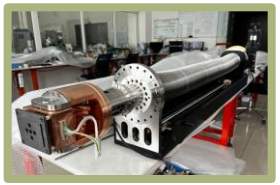
- Refurbishment and upgrade of the facilities of the High Voltage Padova Test Facility (HVPTF)
- Facility of the HVPTF for the study of pressurized gas insulation in high voltage systems

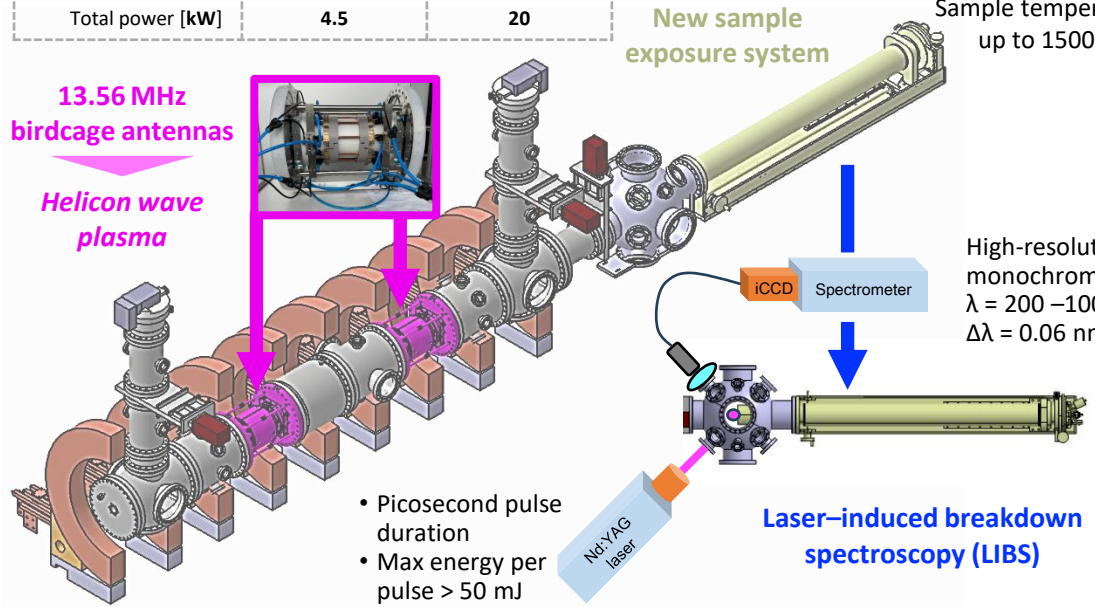
This conference:

- **Study of in-vacuum discharges with X-rays at the High Voltage Padova Test Facility**
  Speaker: **Federico Caruggi**
  3 Sept 2025, **16:15**

(7) Laboratory for the study of fusion relevant high-density plasmas and materials interaction

	GyM	BiGyM
Plasma density [m^{-3}]	$10^{15} – 10^{17}$	$10^{18} – 10^{19}$
Ion flux [$m^{-2}s^{-1}$]	10^{21} ITER first-wall relevant	$10^{22} – 10^{23}$ ITER divertor relevant
Source type	2 Magnetrons	2 RF birdcage antennas
Total power [kW]	4.5	20





✓ **Upgrading linear plasma device GyM to BiGyM:**
- BiGyM helicon wave plasma sources
- BiGyM sample exposure system
- Upgrade of BiGyM diagnostic system

OCEM POWER ELECTRONICS
PraMa.
acal bfi
IMAGES
FLIR A TELEDYNE COMPANY

Project update:
✓ procurements almost completed
➢ Commissioning planned by end 2025

ref.: A. Uccello, et al., Front. Phys. 11, 1108175 (2023)
https://doi.org/10.3389/fphy.2023.1108175

(8) Laboratory for innovative diagnostics for imaging of soft X-rays and neutrons:

- Realization of a Detector Assembly Unit (DAU)
- Test Irradiation Area
- Realization of an advanced X-ray imaging diagnostic for high time and space resolution of RFX-mod2
- Realization of a multiple lines of sight system with spectroscopic information for imaging of neutron

This conference:

- **Neutron diagnostics for RFX-mod2**
  Speaker: **Andrea Dal Molin**
  3 Sept 2025, **15:45**

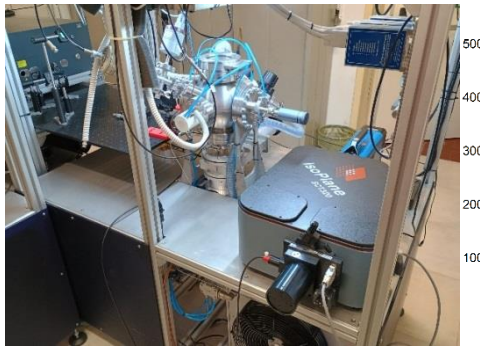
- **The GEM soft x-ray diagnostics on RFX-mod2**
  Speaker: **Oscar Putignano**
  3 Sept 2025, **16:00**

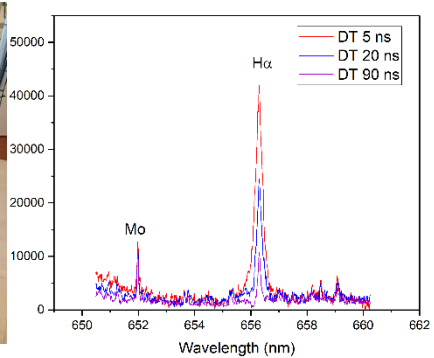
(9) Research and Development of optical plasma diagnostics:

Laser Induced Breakdown Spectroscopy (LIBS)

Main procurements:

- 400 fs-10 ps laser for LIBS
- Spectrograph for high-speed LIBS spectroscopy
- Vacuum chamber with 2-cathode reflex discharge
- Optical microscope and profilometer





Optical Spectroscopy: emission (OES) and laser (LIF)

Main procurements:

- 4 ns tunable OPO laser for LIF spectroscopy
- 30 ps tunable OPO laser for kinetic studies by laser spectroscopy
- Spectrograph with, 500 ps minimum gate for optical spectroscopy
- 8-cathode reflex discharge systems

SPascal HIGH VACUUM & Cryogenic System

OPTOPRIM

Project update:

✓ Acceptance Tests of instrumentation accomplished 2025

➢ Set up of a new laboratory space (civil works and technical systems) almost completed

Crisel Instruments 30 YEARS

ref.: S.F. Cipelli, et al., 2025, submitted to Journal of Nuclear Materials

Time schedule for RFXmod2 restart and forthcoming experimental phase

>10 years of operation
(obligation due to NRRP funding)

	2025	2026	2027-2036
NEFERTARI project (RFX-mod2 new plant & diagnostics)			
Re-installation of RFX-mod2			
Commissioning			
Experimental Phase			
Further investments (*)			

(*)
Italian Nuclear Research Plan
Research and Development of technologies for innovative and sustainable nuclear power

MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA
MISSION INNOVATION accelerating the clean energy revolution

Take-home message:

- ✓ **NEFERTARI = great opportunity of investment in** { **equipment** ; **human resources** }
- ➢ **Ready for scientific exploitation with present or prospective stakeholders**

International Institutions

EUROfusion · iter · Fusion for Energy

National Institutions

MUR · Ministero dell'Ambiente e della Sicurezza Energetica · Mission Innovation Italy · Fondazione Puglia · Regione Puglia · Fondazione Cassa di Risparmio di Padova e Rovigo · Regione del Veneto

Private initiatives

Politecnica cetal · Siemens · eni · IMAGES · acal bfi · Innolas Laser · Sophia · Beckhoff New Automation Technology · Brembana&Rolle · T.E.E.S. · ELAD · Leybold · Optoprim · Essegi System · Tokamak Energy · CAEN · Spascal High Vacuum & Cryogenic System · OCEM Power Electronics · Crisel Instruments 30 years · PraMa · ACS · FLIR