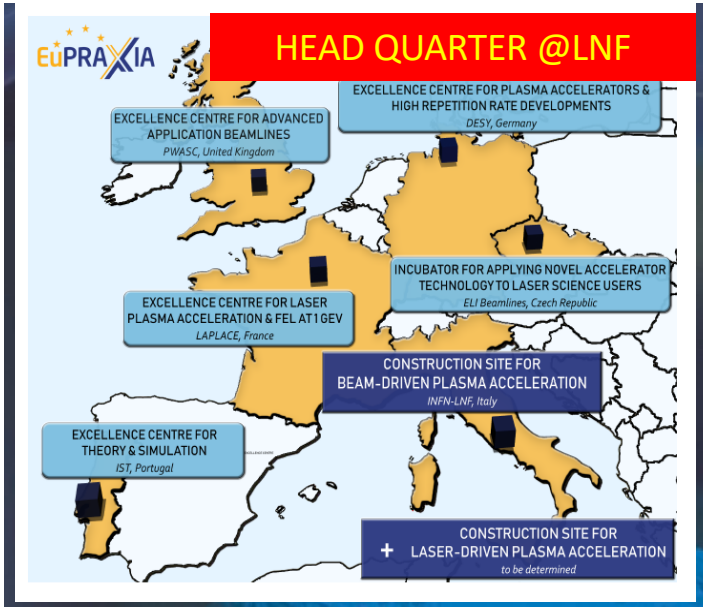
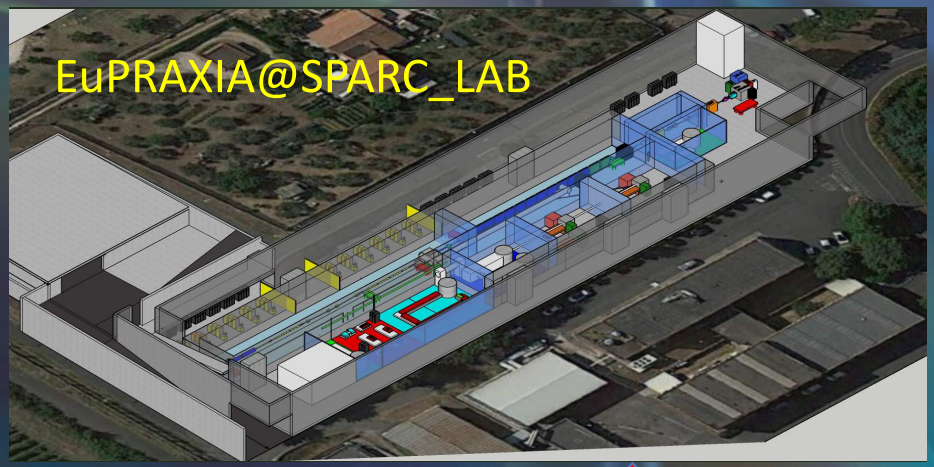
EuPRAXIA: stato e sviluppi

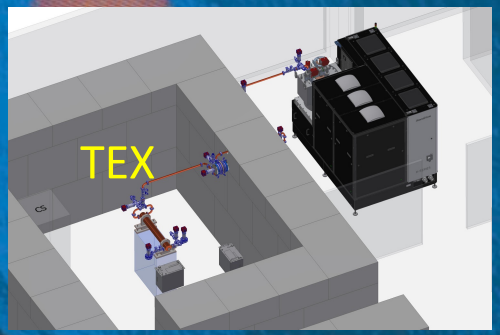
Massimo.Ferrario@LNF.INFN.IT

Giornata Nazionale Acceleratori, Milano 7 Aprile 2022

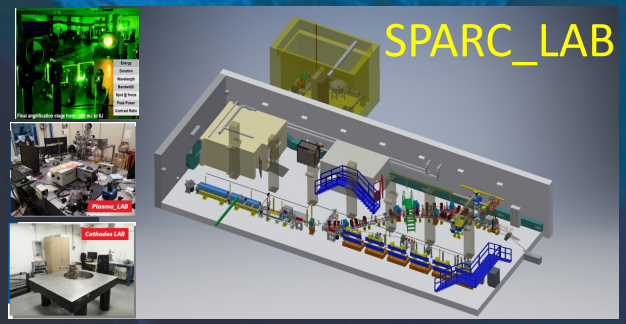
Istituto Nazionale di Fisica Nucleare







- PLASMAR
- SPARC_LAB
- EUROFEL
- SABINA



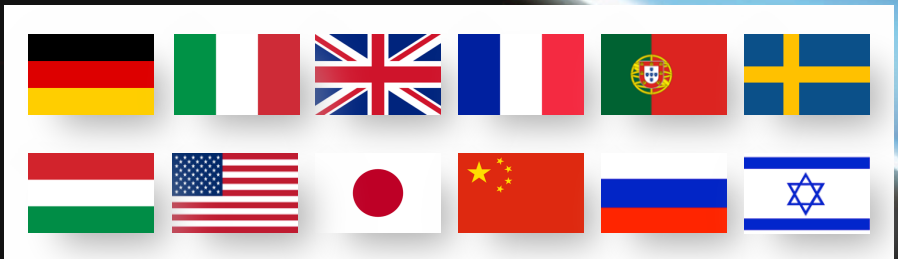
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on Novemebr 2015

Approved as HORIZON 2020 INFRADEV, 4 years, 3 M€

Coordinator: Ralph Assmann (DESY)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

http://eupraxia-project.eu

The EuPRAXIA Project

http://www.eupraxia-project.eu/

Horizon 2020

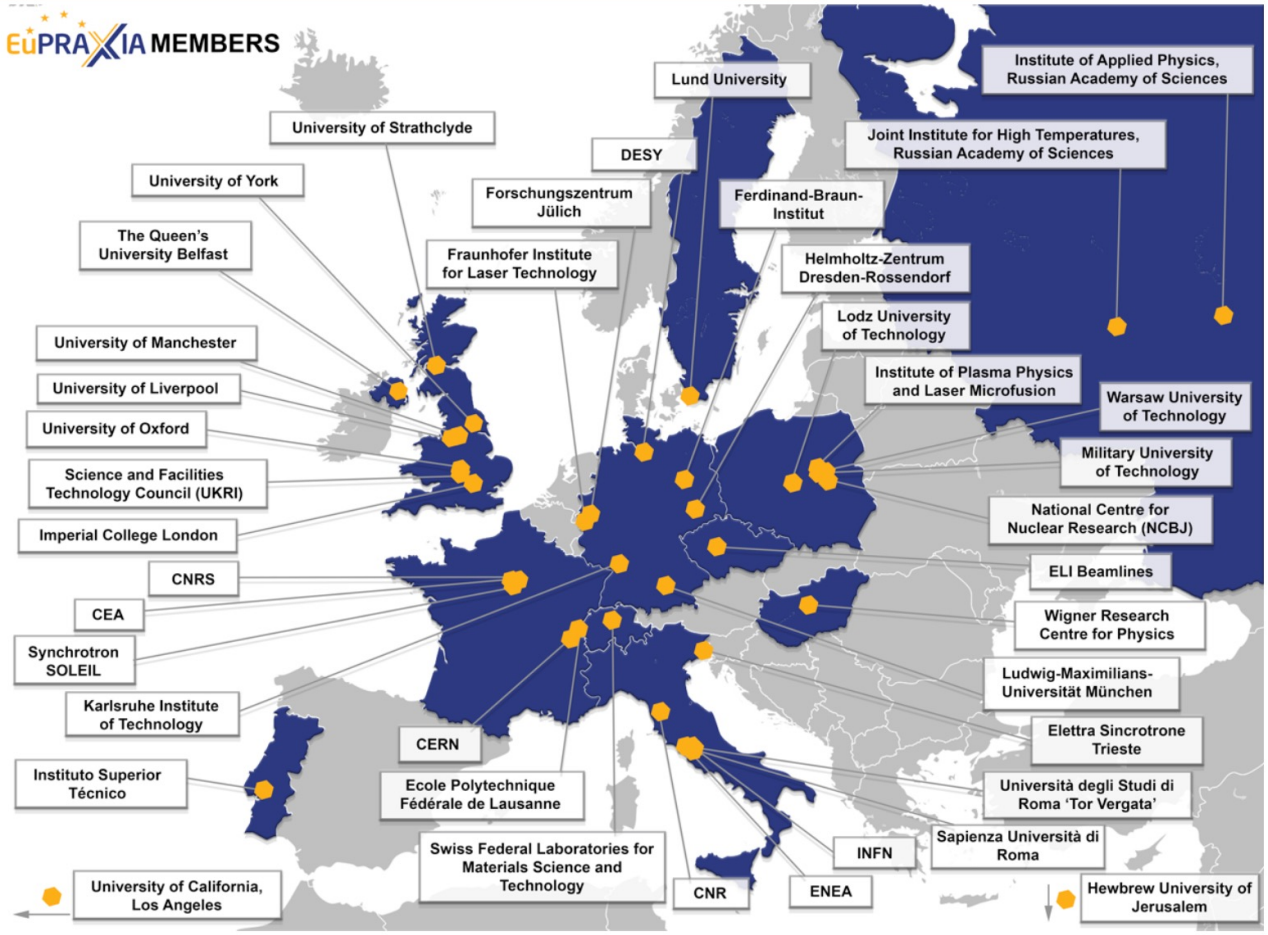
- First ever international design of a **plasma accelerator facility**.
- Challenges addressed by EuPRAXIA since 2015:
  - How **can plasma accelerators produce usable electron beams**?
  - **For what can we use those beams** while we increase the beam energy towards HEP and collider usages?
- **CDR for a distributed research infrastructure** funded by EU Horizon2020 program. Completed by 16+25 institutes.
- **Next phase consortium** with 40 partners, 10 observers.
- **Applied to ESFRI roadmap update 2021** with government support in Sep 2020.
- **Successful** and and placed on ESFRI roadma.

653 page CDR, 240 scientists contributed

The Consortium Members for the Next Phase

(from 16 to 40)

Horizon 2020



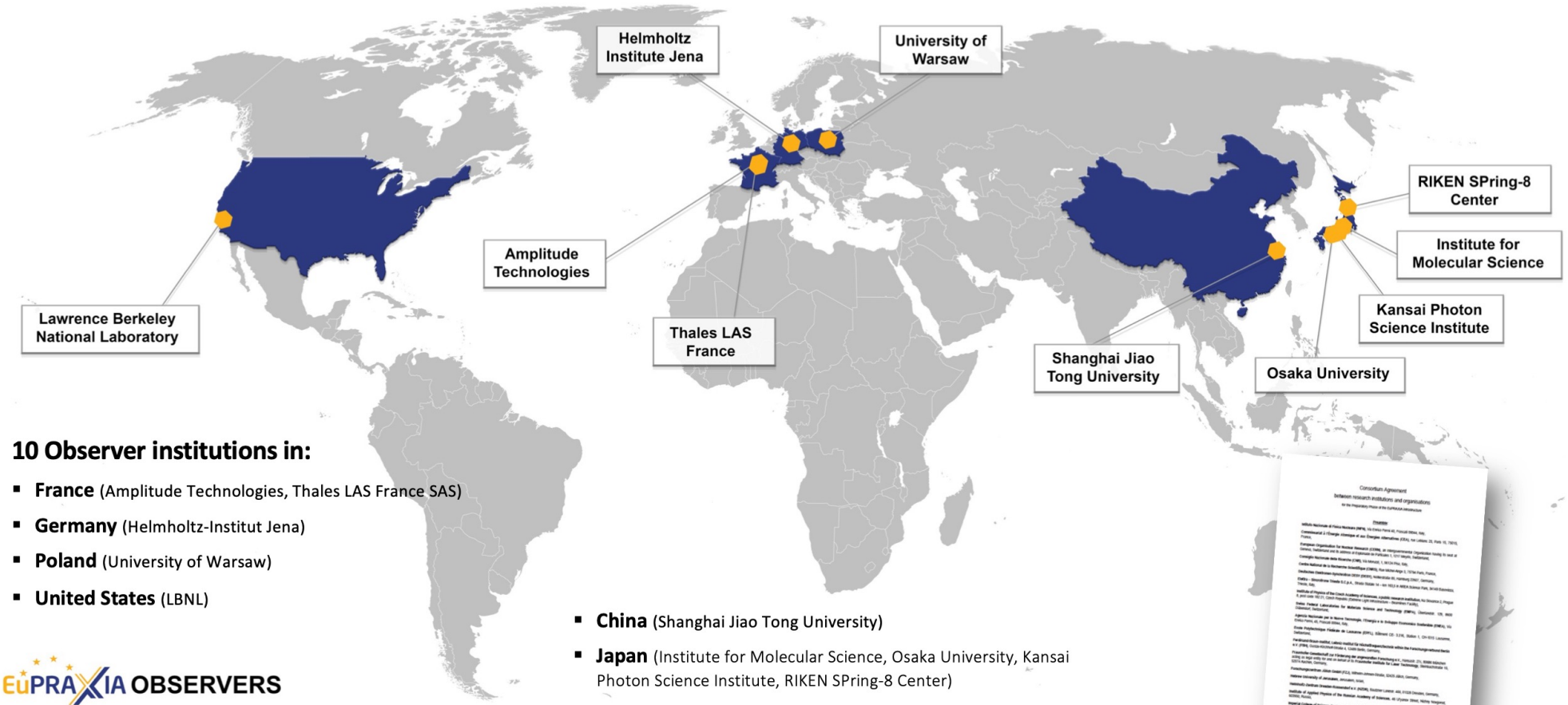
40 Member institutions in:

- **Italy** (INFN, CNR, Elettra, ENEA, Sapienza Università di Roma, Università degli Studi di Roma "Tor Vergata")
- **France** (CEA, SOLEIL, CNRS)
- **Switzerland** (EMPA, Ecole Polytechnique Fédérale de Lausanne)
- **Germany** (DESY, Ferdinand-Braun-Institut, Fraunhofer Institute for Laser Technology, Forschungszentrum Jülich, HZDR, KIT, LMU München)
- **United Kingdom** (Imperial College London, Queen's University of Belfast, STFC, University of Liverpool, University of Manchester, University of Oxford, University of Strathclyde, University of York)
- **Poland** (Institute of Plasma Physics and Laser Microfusion, Lodz University of Technology, Military University of Technology, NCBJ, Warsaw University of Technology)
- **Portugal** (IST)
- **Hungary** (Wigner Research Centre for Physics)
- **Sweden** (Lund University)
- **Israel** (Hebrew University of Jerusalem)
- **Russia** (Institute of Applied Physics, Joint Institute for High Temperatures)
- ***United States*** (UCLA)
- **CERN**
- **ELI Beamlines**

The Consortium Observers for the Next Phase

(from 25 to 10, Consortium Agreement signed)

Horizon 2020



10 Observer institutions in:

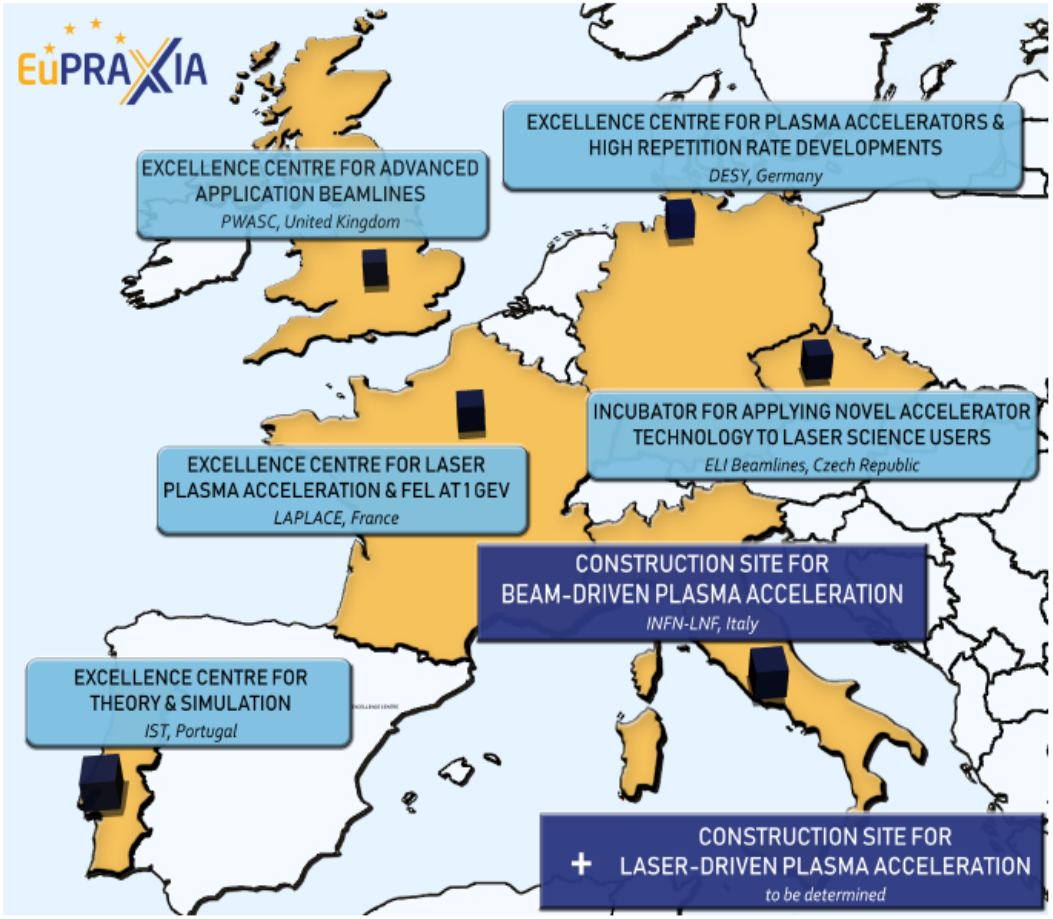
- **France** (Amplitude Technologies, Thales LAS France SAS)
- **Germany** (Helmholtz-Institut Jena)
- **Poland** (University of Warsaw)
- **United States** (LBNL)
- **China** (Shanghai Jiao Tong University)
- **Japan** (Institute for Molecular Science, Osaka University, Kansai Photon Science Institute, RIKEN SPring-8 Center)

EuPRAXIA OBSERVERS

… and Builds a European Distributed Facility

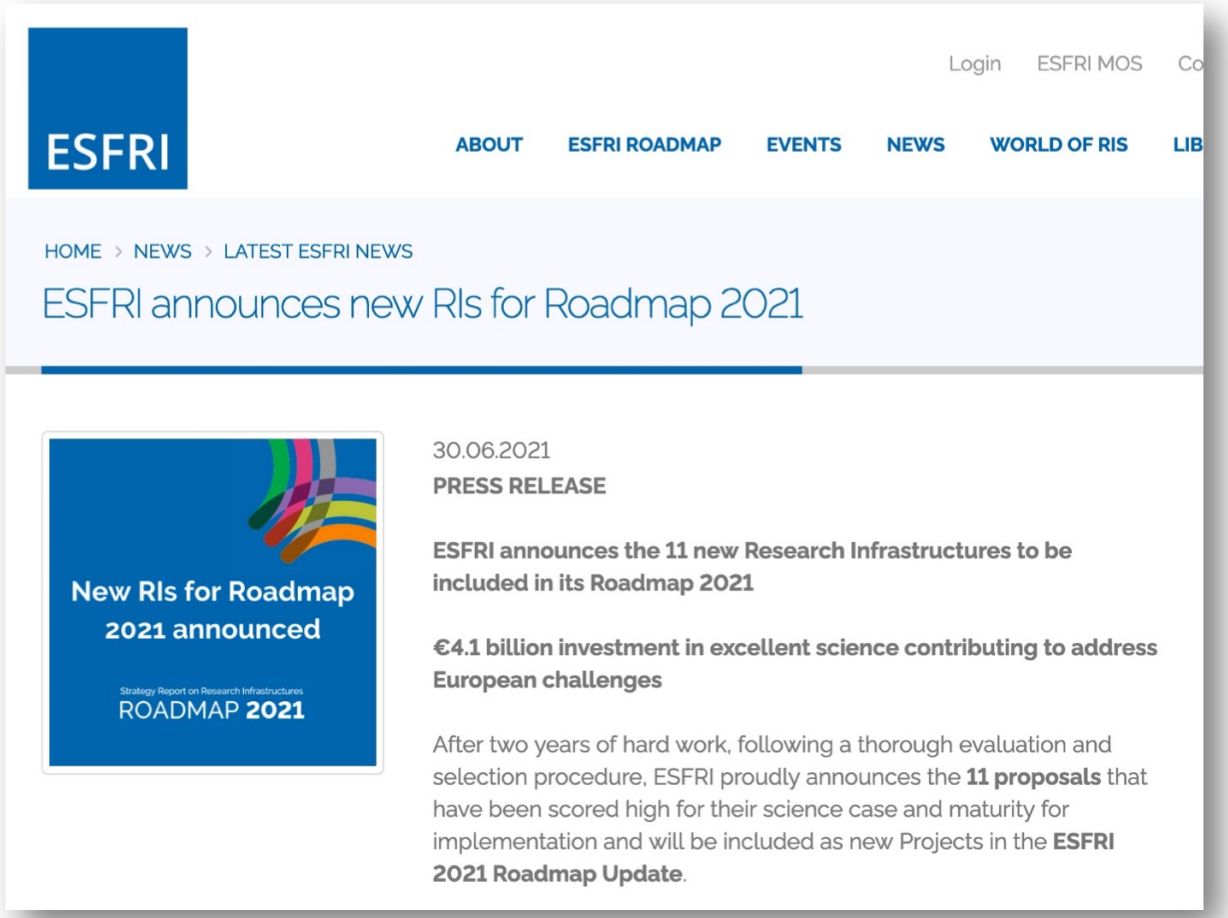
Position Europe as a Leader in the Global Context

1. Lean overall **EuPRAXIA management**
2. **Ten clusters:** Collaborations of institutes on specific problems, developing solutions, technical designs, driving developments with EuPRAXIA generated funding → **expertise of Helmholtz centers required - opportunities**
3. **Five excellence centers** at existing facilities: Using pre-investment, support tests, prototyping, production with EuPRAXIA generated funding → **DESY excellence center**
4. **One or two construction sites** at existing facilities with EuPRAXIA generated funding:
   - **Beam-driven** at Frascati (Italy).
   - **Laser-driven** at CLF/STFC (UK), CNR/ INFN (Italy) or ELI-Beamlines.



Great News 30.6.2021

Building the first plasma accelerator facility



About the ESFRI Roadmap

ESFRI has established a European Roadmap for Research Infrastructures (new and major upgrades, pan-European interest) for the next 10-20 years, stimulates the implementation of these facilities, and updates the roadmap as needed. The ESFRI Roadmap arguably contains the best European science facilities based on a thorough evaluation and selection procedure. It combines ESFRI Projects, which are new Research Infrastructures in progress towards implementation, and ESFRI Landmarks successfully implemented Research Infrastructures enabling excellent science.

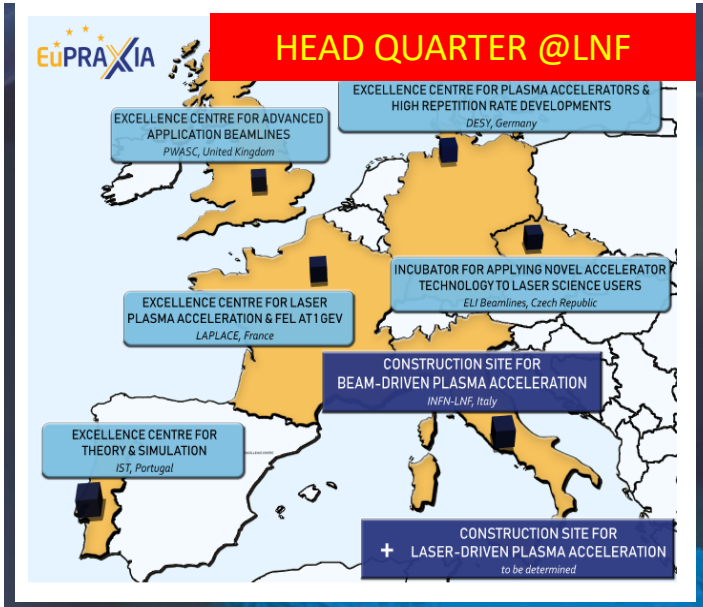
EuPRAXIA related submitted proposal

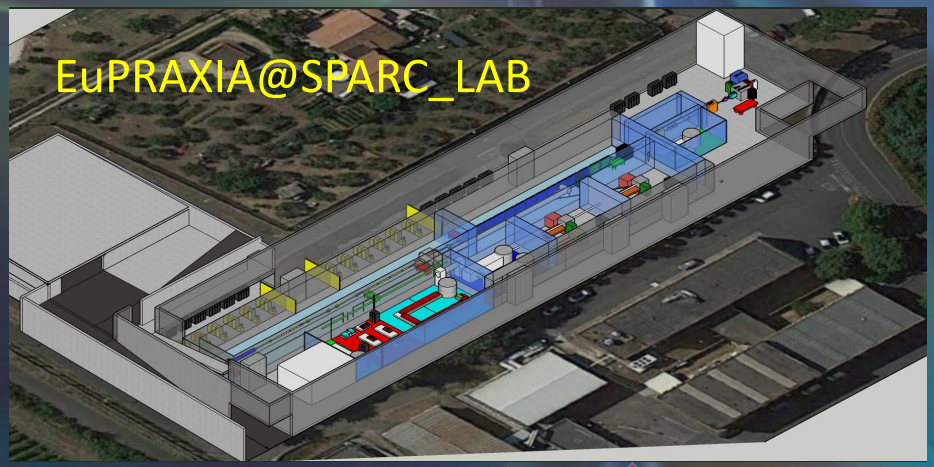
✓ MSCA Doctoral Network on EuPRAXIA

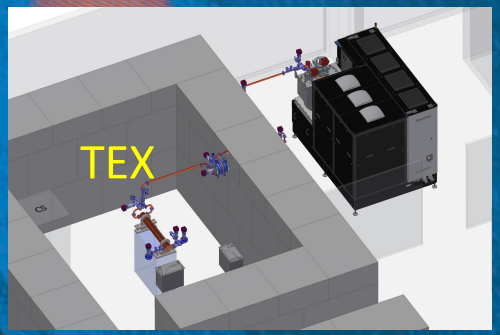
➢ EuPRAXIA Preparatory Phase

➢ EuPRAXIA Advanced Radiation Sources (PNRR)

- Compact and Resource-Efficient Accelerator TEchnologies (CREATE) (H2020)







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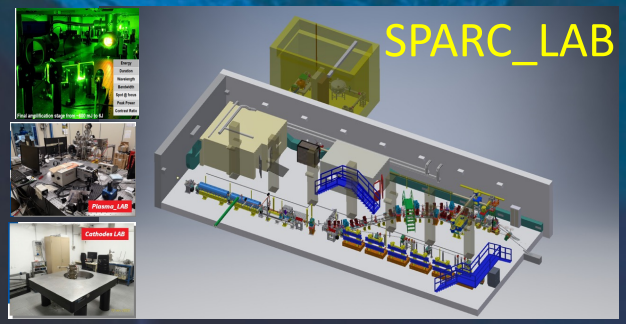
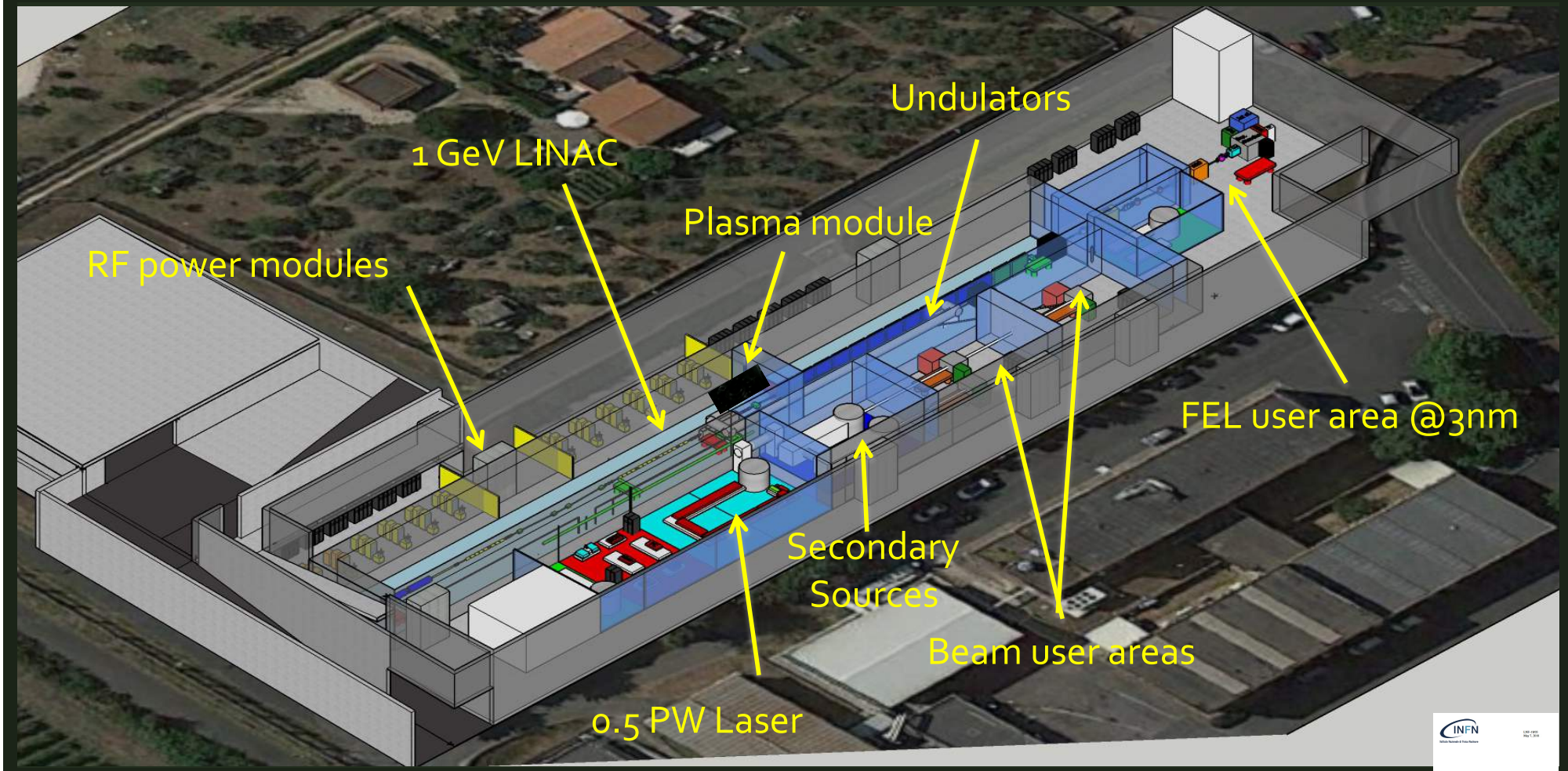
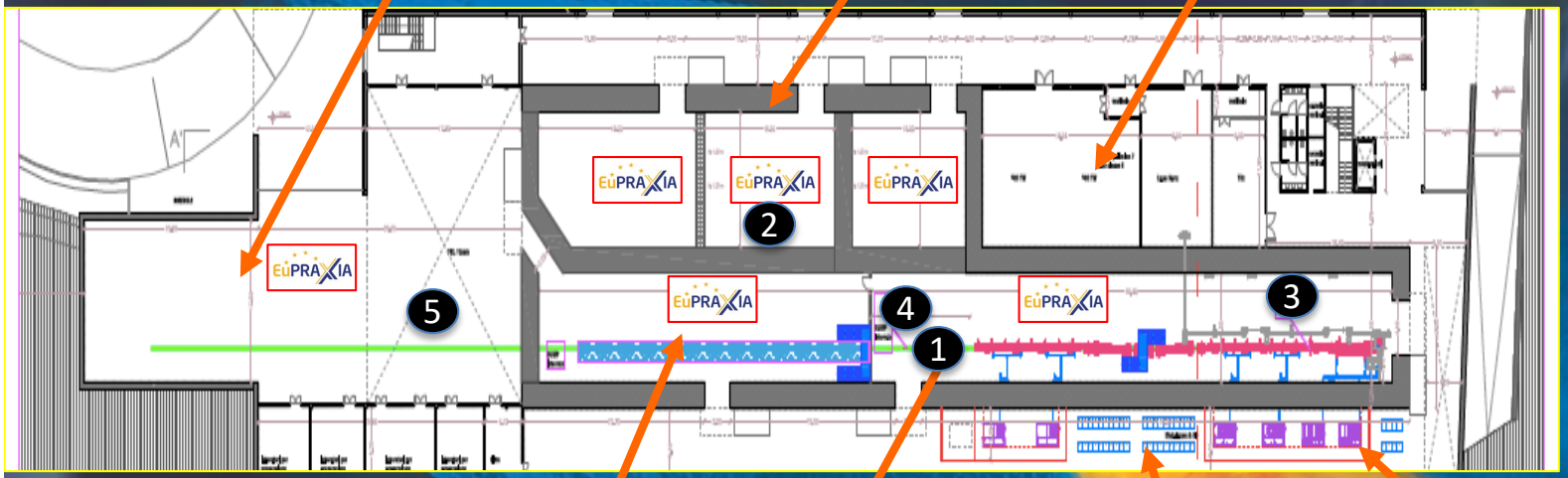


EuPRAXIA@SPARC_LAB



http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

Opportunities for Collaborations at EuPRAXIA@SPARC_LAB

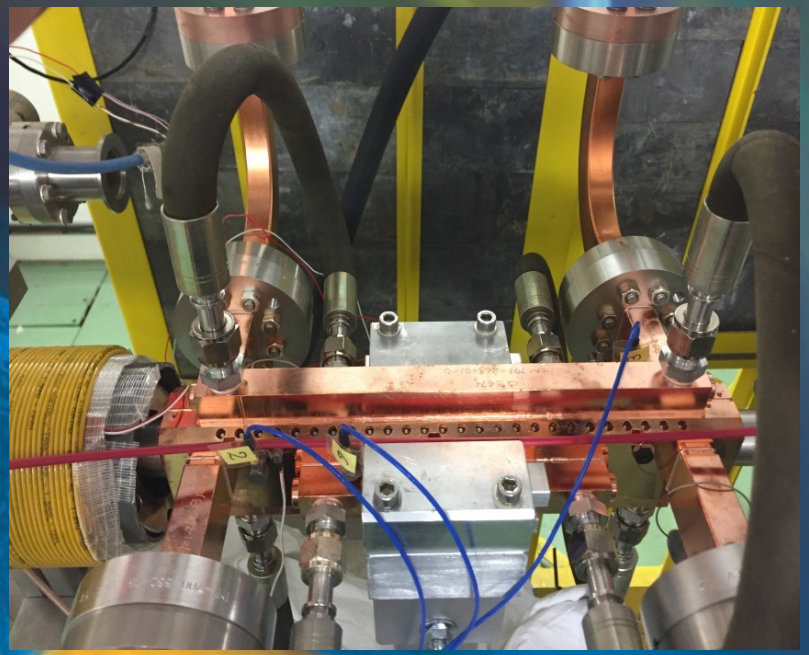


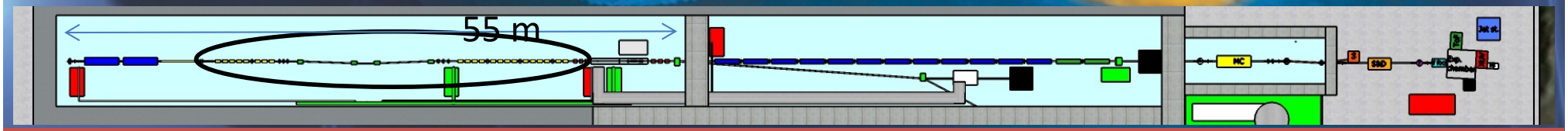
European interests & possible contributions to Frascati site:

1. Plasma structure designs, devices
2. Compact positron source
3. HQ 150 MeV laser plasma injector
4. HQ laser driver
   - Hybrid concepts
   - Simulations
5. User experiments and lines

To be detailed in TDR phase.

X-band Linac



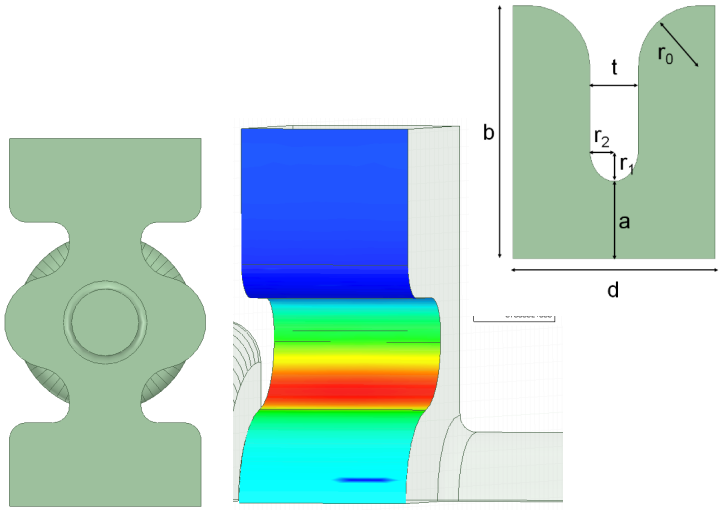


X BAND STRUCTURES: PARAMETERS

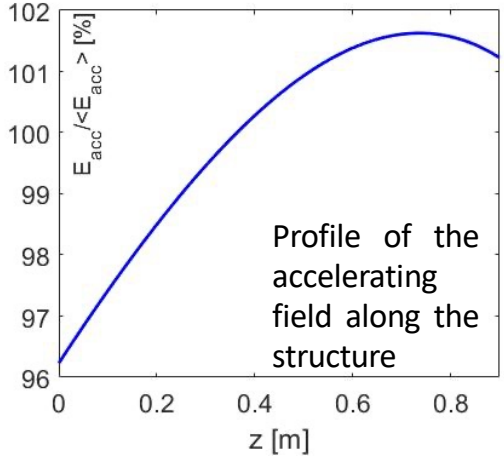
1. **e.m. design**: **linear tapering of the irises,** race track coupler to cancel the quadrupole field components (*PhD M. Diomede*);

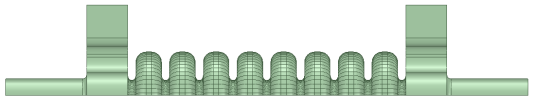
2. **0.9 m long** structures with 3.5 mm average iris radius

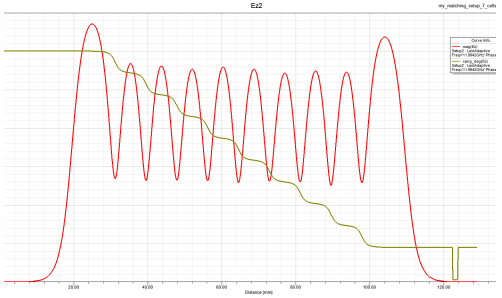
3. **60 MV/m** average accelerating field



Courtesy M. Diomede





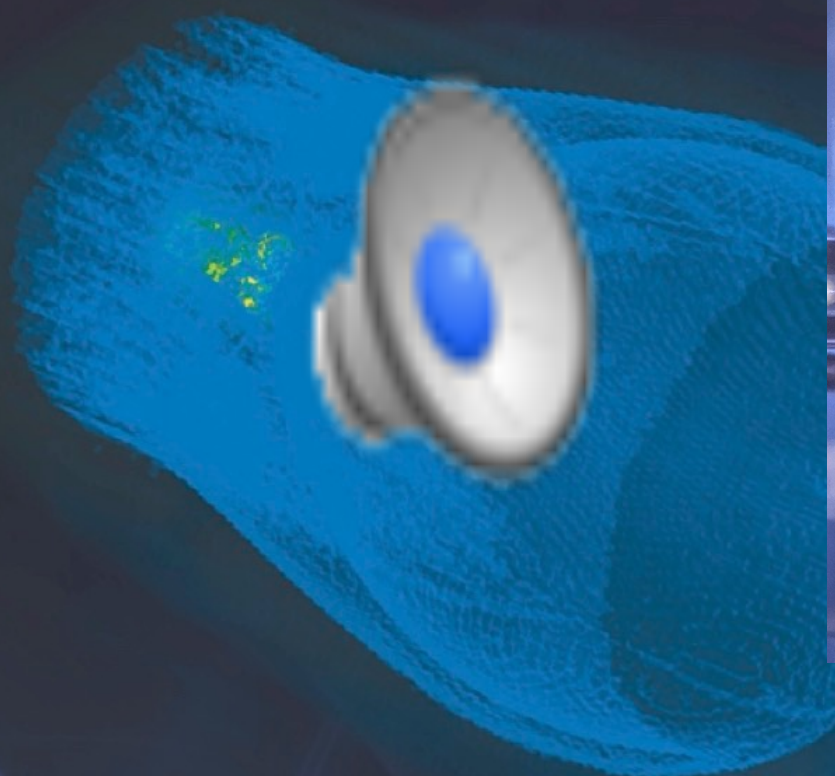


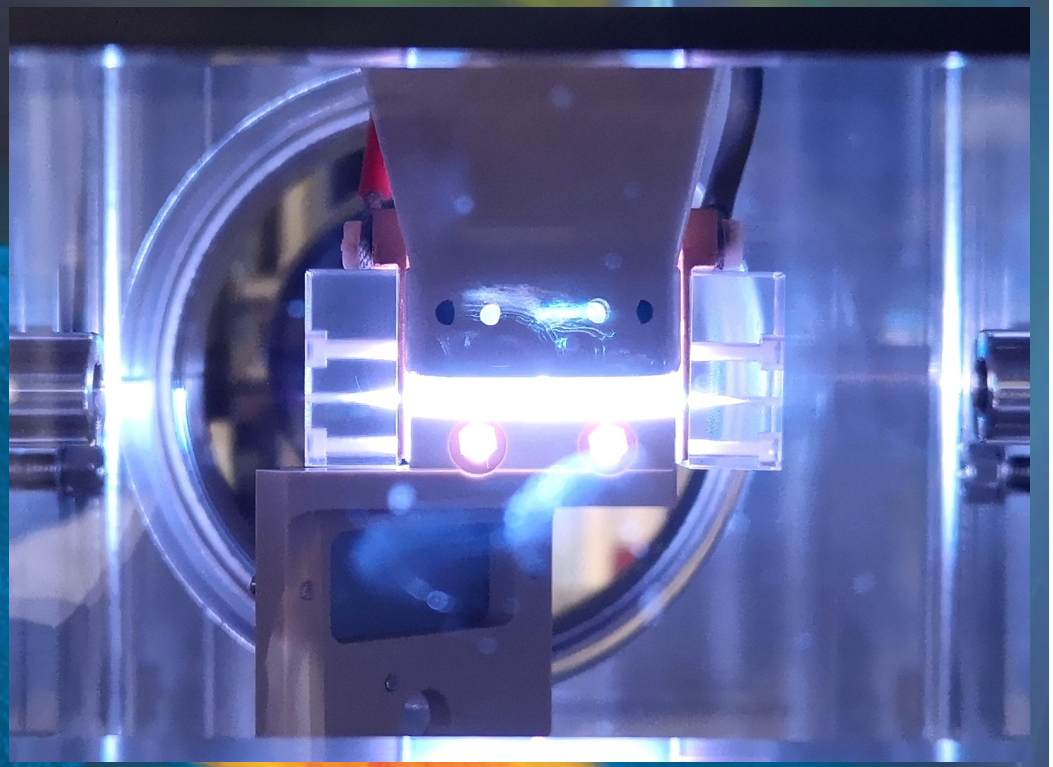
Parameter	Value
Frequency [GHz]	11.9942
Average acc. gradient [MV/m]	**60**
Structures per module	4
Iris radius a (linear tapering) [mm] <a>=3.5	3.8-3.2
Tapering angle [deg]	0.04
Structure length L_s [m]	**0.9**
No. of cells	109
Shunt impedance R [MΩ/m]	94-107
Peak input power per structure [MW]	65
Input power averaged over the pulse [MW]	45
Average dissipated power [kW]	1
Filling time [ns]	126
Effective shunt Imp. R_s [MΩ/m]	350
Peak Modified Poynting Vector [W/μm²]	3.5
Unloaded SLED/BOC Q-factor Q_0	150000
External SLED/BOC Q-factor Q_E	21000
Required Kly power per module [MW]	**37/19**
RF pulse [μs]	**1.5**
Klystron power (available) [MW]	**50/25**
Rep. Rate [Hz]	**100**

$$R_s = \frac{G^2 L}{P_{kly}}$$

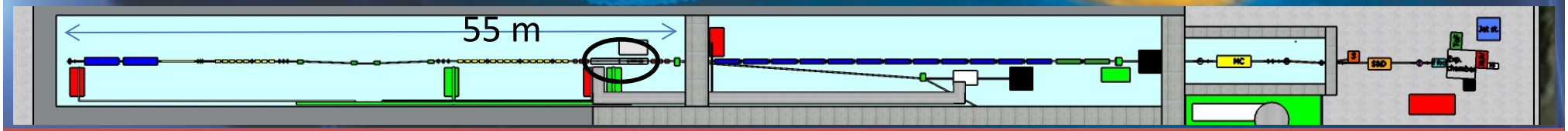
G=average accelerating gradient
L=structure length
P_{kly}=klystron power (pre-sled pulse)

Plasma WakeField Acceleration

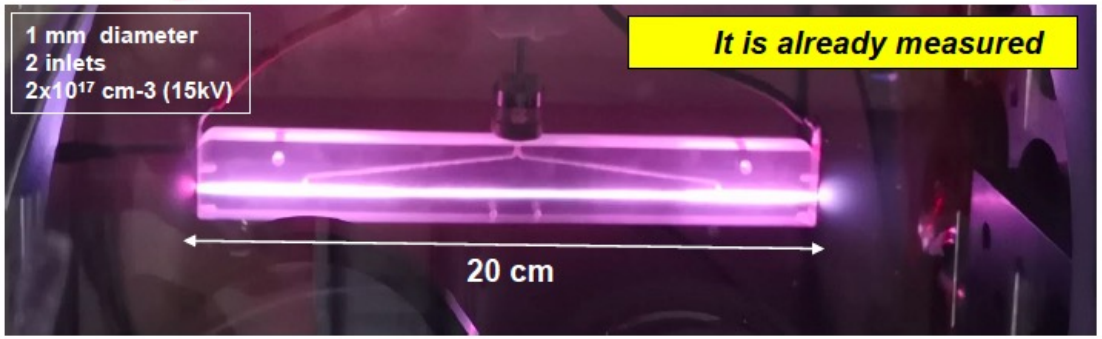




Capillary discharge at SPARC_LAB

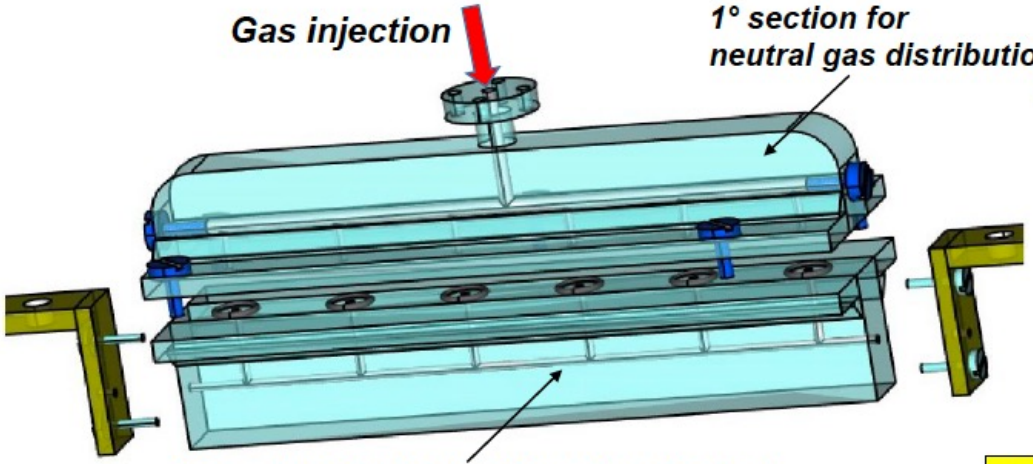


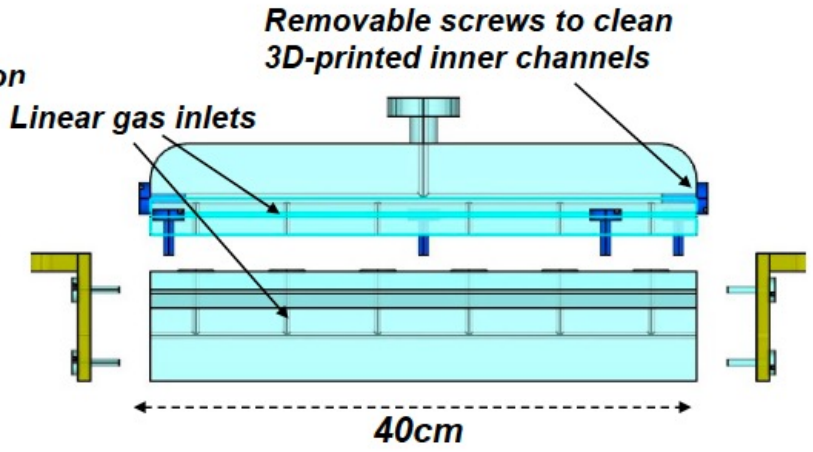
40 cm-long Gas-filled discharge-capillary



Paschen curves (50 mbar)

Length	*Density*	*Vb*
3 cm	$4x10^{16}$ cm-3	3 kV
10 cm	$4x10^{16}$ cm-3	8 kV
20 cm	$4x10^{16}$ cm-3	14 kV
40 cm	$4x10^{16}$ cm-3	23 kV





Linear channel/inlets allow us to clean them from printing residuals

Marzo 2022 - Accesa la prima scarica nel modulo di accelerazione a plasma di EuPRAXIA@SPARC_LAB

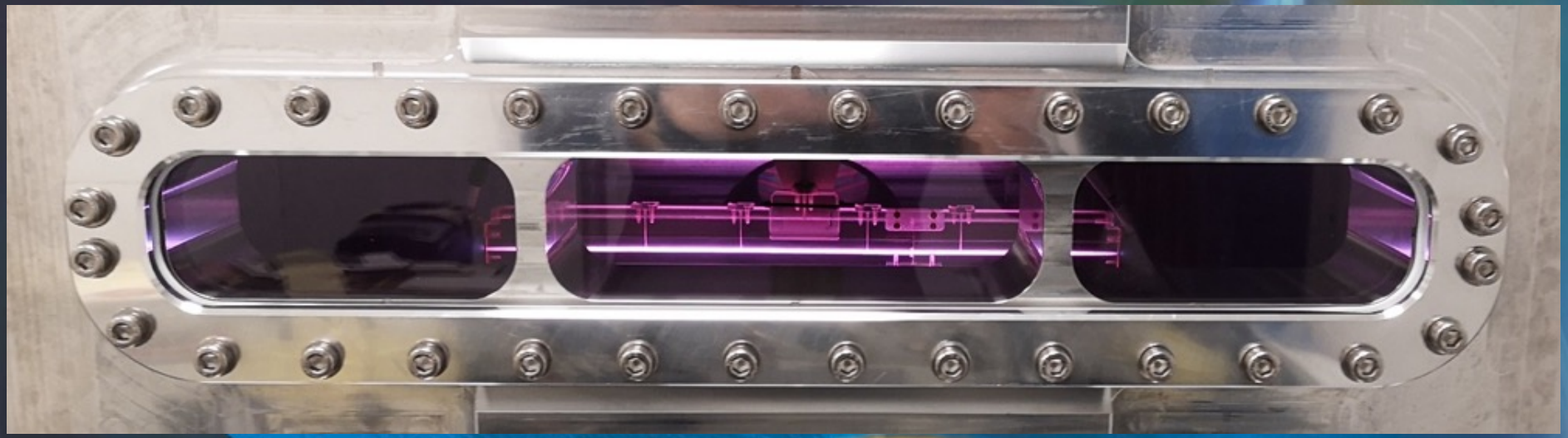
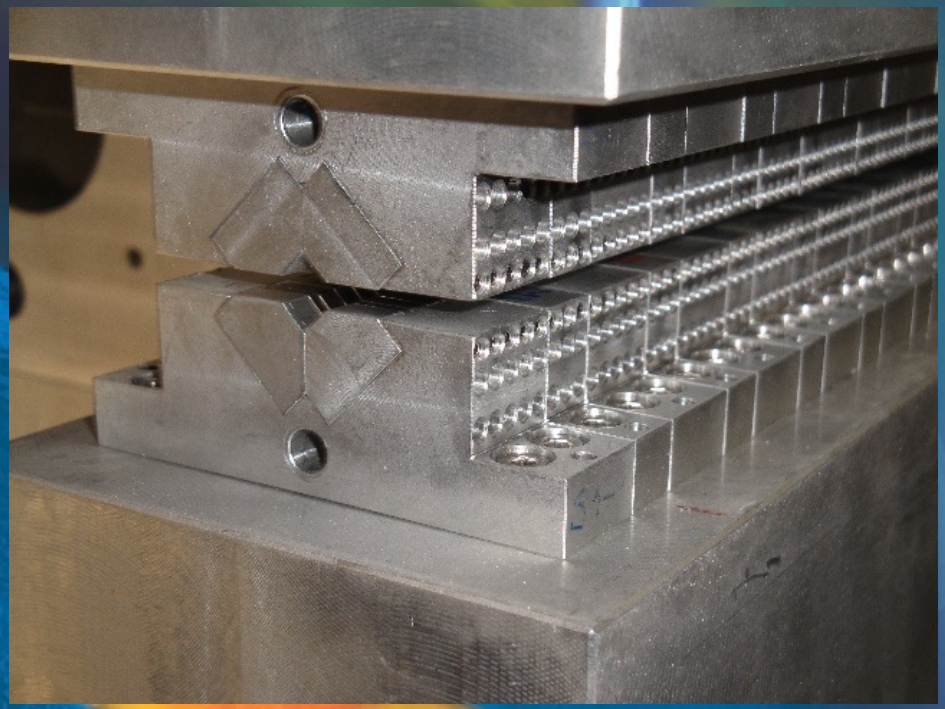


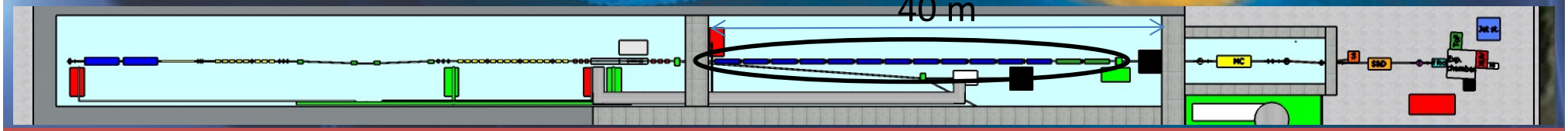
Immagine catturata durante la formazione del plasma nel **capillare di lunghezza 40 cm** e diametro 2 mm, installato all'interno di una camera da vuoto appositamente creata per ospitare sorgenti di plasma di grandi dimensioni. L'impulso di tensione applicato è di 9 kV e la corrente di picco raggiunge circa 500 A.

Courtesy Angelo Biagioni

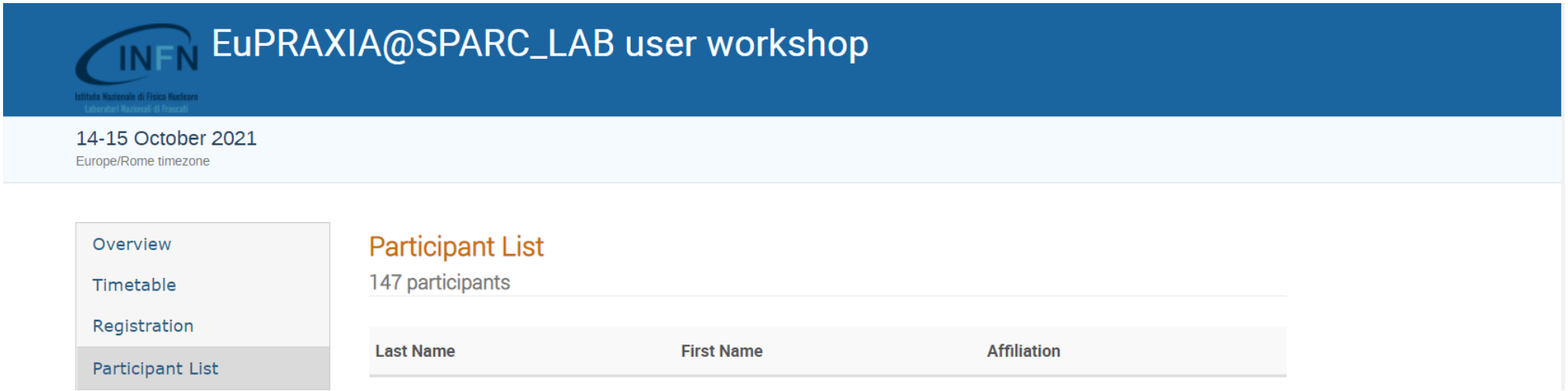
Undulators



KYMA Δ udulator at SPARC_LAB: λ=1.4 cm, K1



AQUA/ARIA - A growing community



The first EuPRAXIA@○SPARC_LAB user workshop

More than 140 registrants from 9 countries and ~30 institutions

https://agenda.infn.it/event/27926/overview

AQUA - Techniques & Samples @ 3 nm

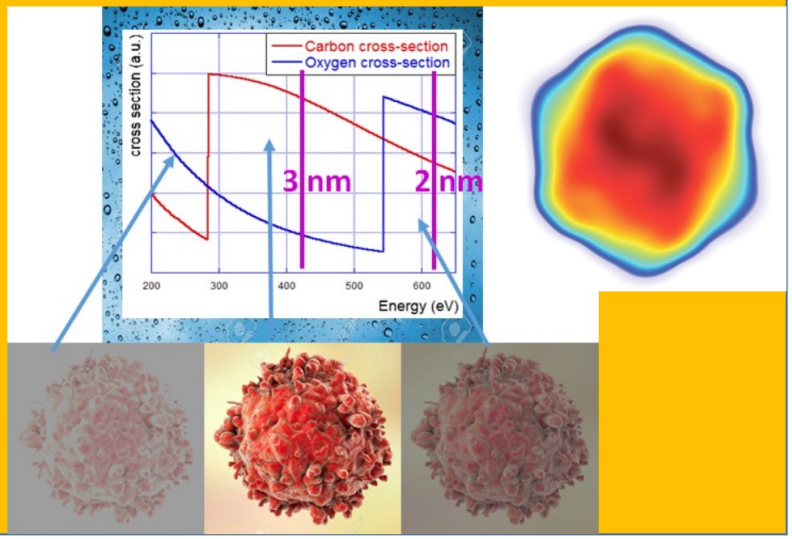
Scientific case assembled and published.
Contributions from >15 different institutions

Balerna *et al.* Condensed Matter 4, 30 (2019)

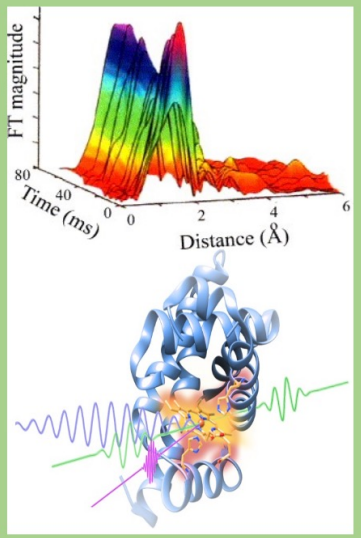
Bio & Inorganic Samples

Proteins - Viruses
Bacteria- Cells
Metals – Magnetic materials
Superconductors -Semiconductors

Coherent imaging



X-ray absorption spectroscopy



Raman spectroscopy

ARIA - Techniques & Samples @ 50-180 nm

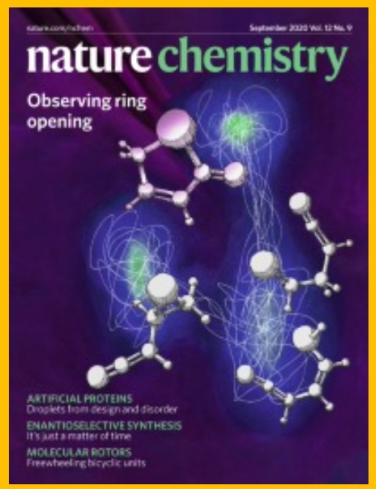
Scientific case in the DUV (DeepUV) and VUV (VacuumUV) is being assembled
Wavelength interval **complementary** with FEL1 @ Fermi

Samples & (techniques)

Gas phase & Atmosphere (Earth & Planets)
Aerosols (Pollution, nanoparticles)
Molecules & gases (spectroscopies, time-of-flight)
Proteins (spectroscopies)
Surfaces (ablation e deposition)

Photoemission Spectroscopy

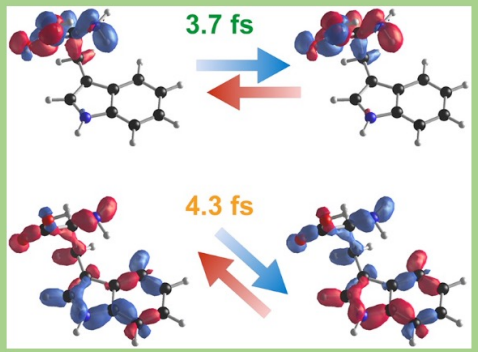
Ring opening in organic molecules
Pathak *et al. Nature Chemistry* 2020



Raman spectroscopy

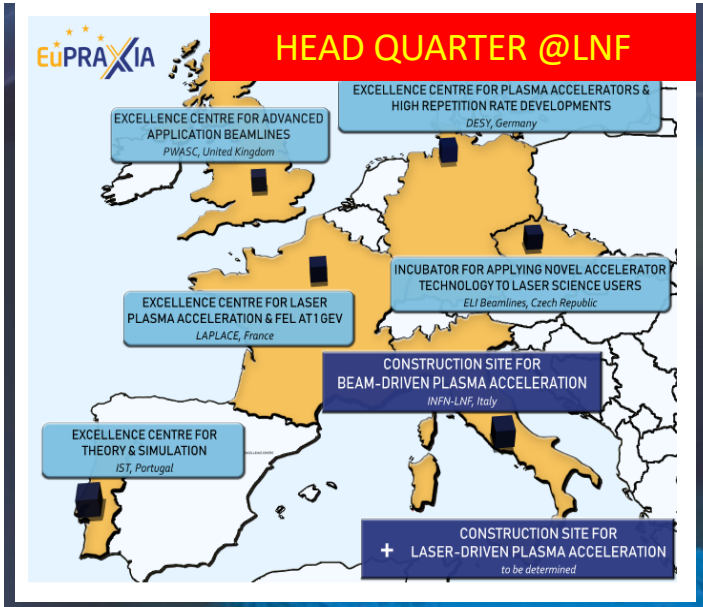
Photo-fragmentation of molecules

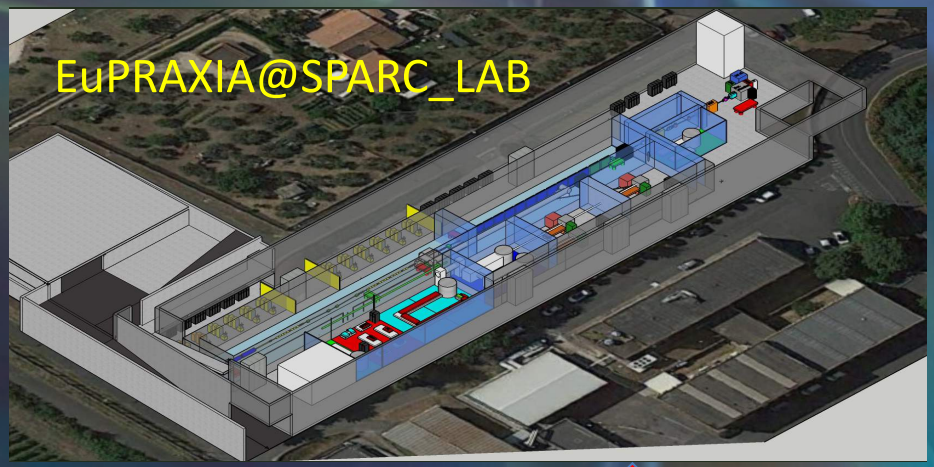
Ultrafast Quantum Interference in the Charge Migration of Tryptophan.
J Phys Chem Lett 2020

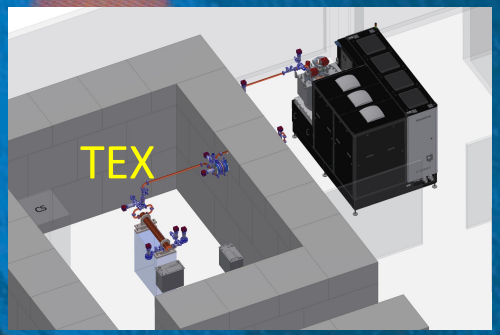


Time of Flight Spectroscopy

Not yet funded







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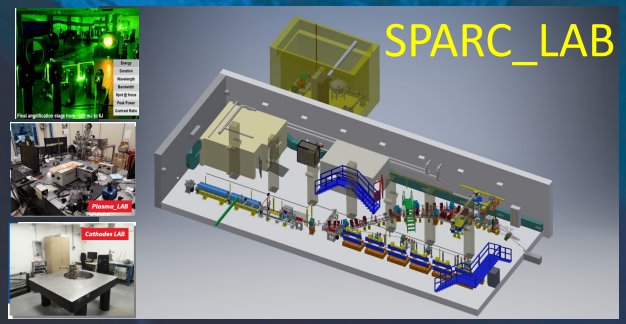


TEX facility – TEst stand for X-band at Frascati

- The *TEst-stand for X-band* (**TEX**) is a facility conceived for R&D on high gradient X-band accelerating structures and waveguide components in view of Eupraxia@SPARC_LAB project.
- It has been co-funded by Lazio regional government in the framework of **the LATINO project** (*Laboratory in Advanced Technologies for INnOvation*). The setup has been done in **collaboration with CERN** and it will be also used to test CLIC structures.
- TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded to host the high gradient facility and other labs.

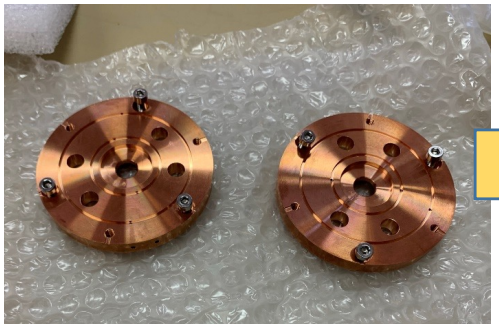
Concrete shielded Bunker and Modulator Cage

Control room and Rack room

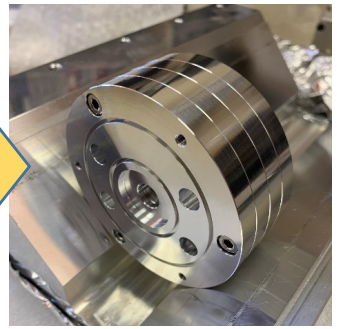
Courtesy S. Pioli

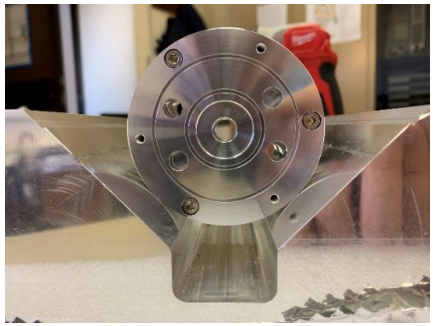
X-BAND STRUCTURE PROTOTYPING ACTIVITIES: REALIZATIONS

Realization



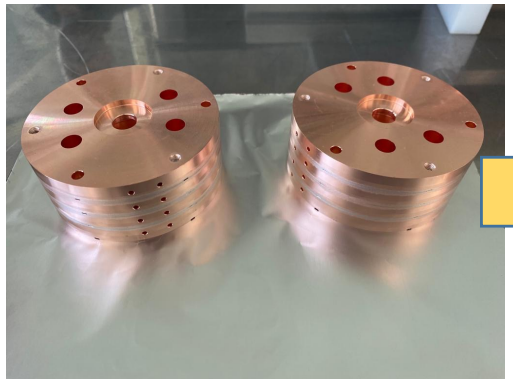
Assembly



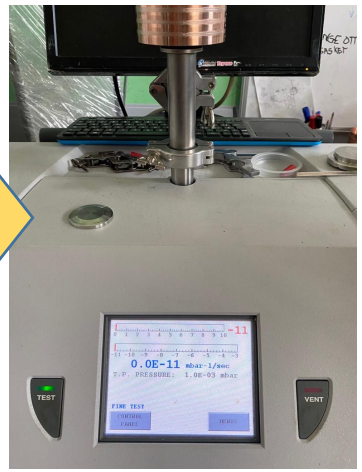


Characterization CMC

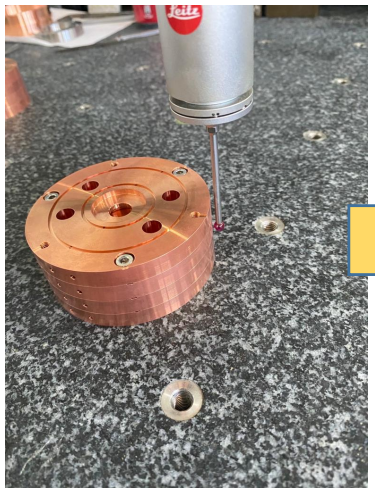
Brazing



Vacuum test



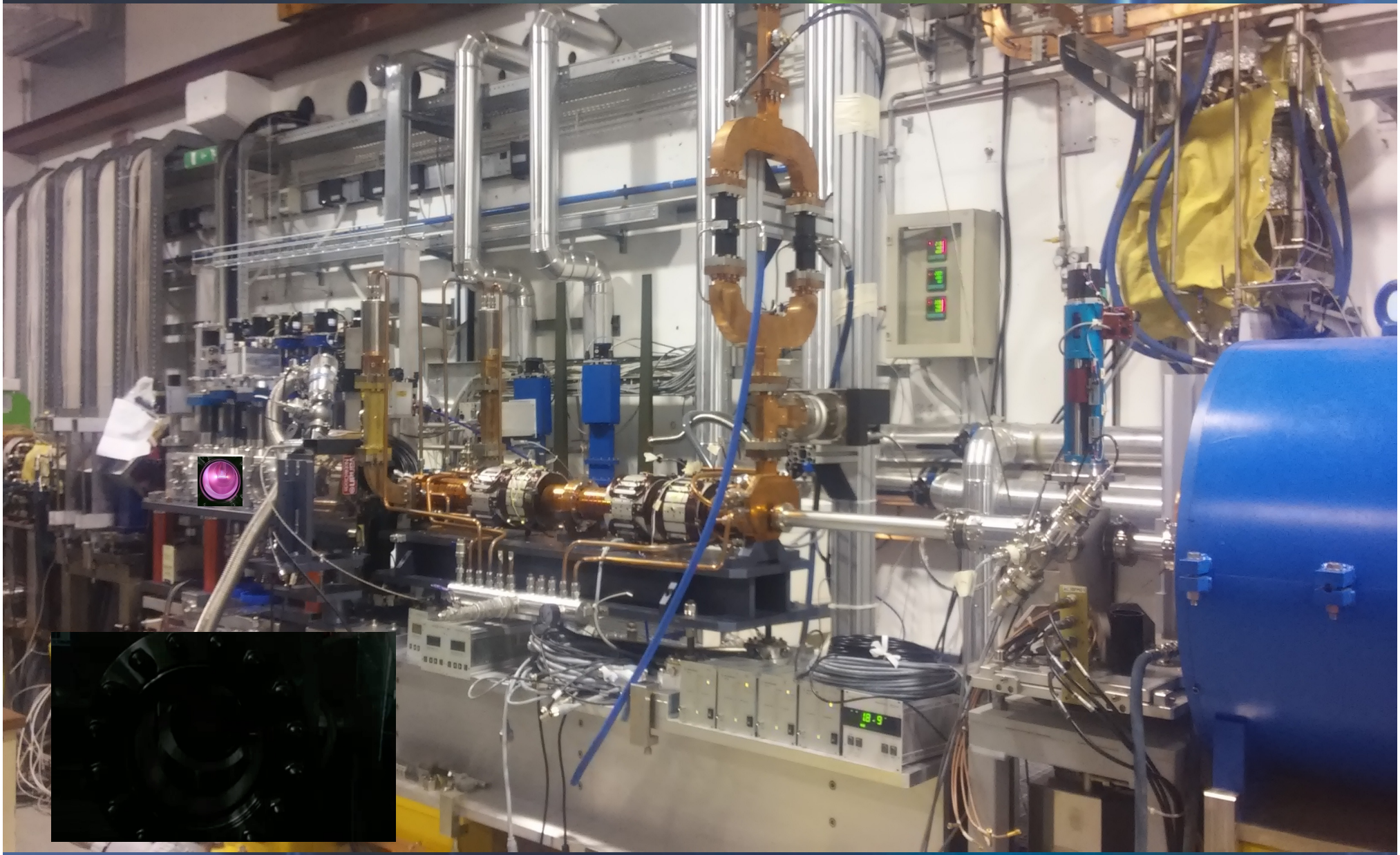
Characterization CMC



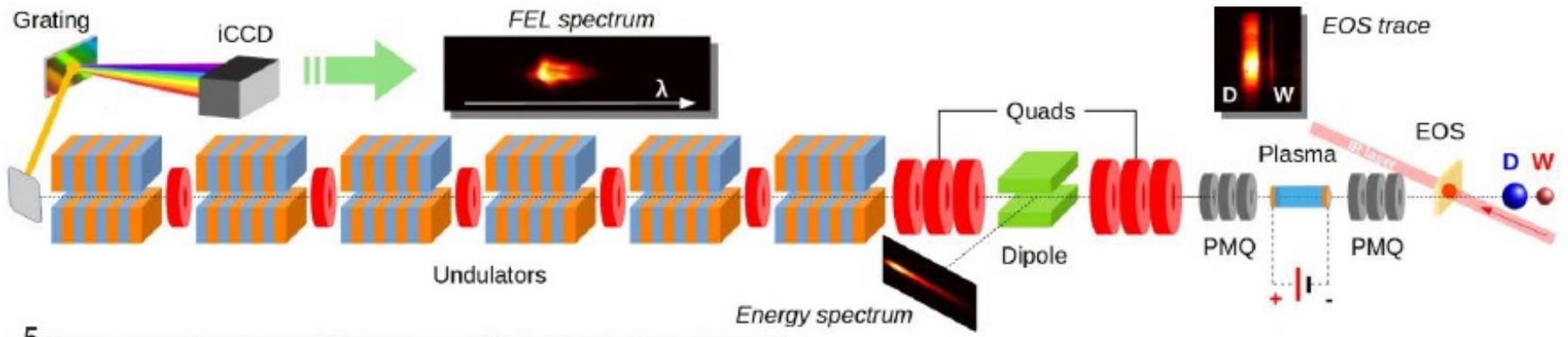
<+/-5 µm alignment
(before/after brazing)

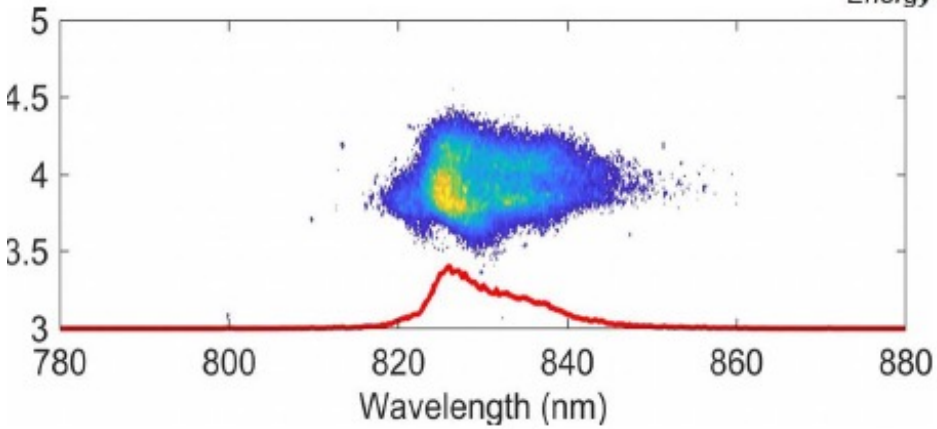
Realizations in parallel to all LNF activities…

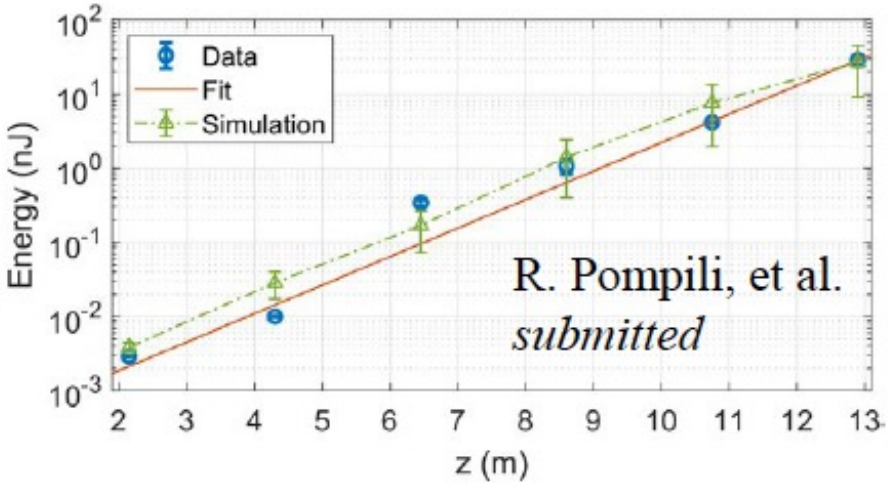
PWFA vacuum chamber at SPARC_LAB



First Beam Driven SASE-FEL Lasing at SPARC_LAB (May 2021)







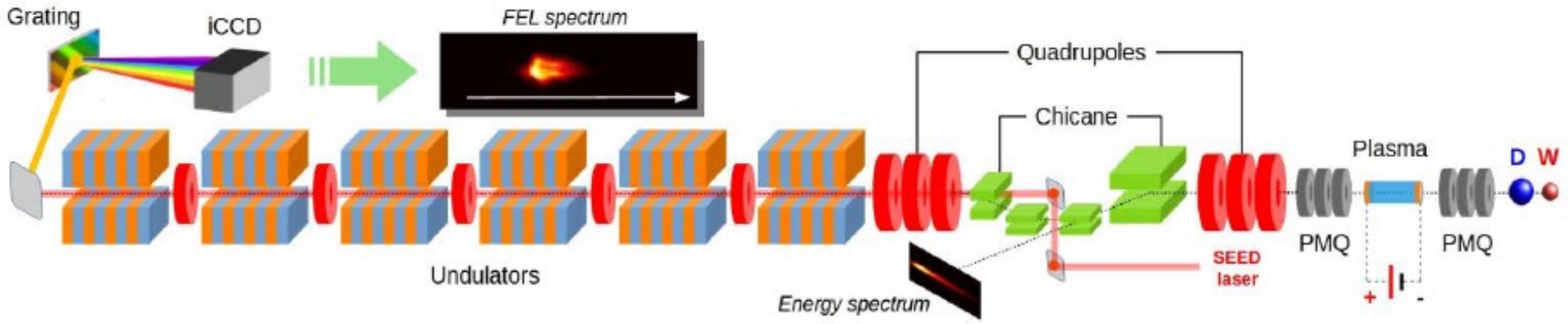
SASE FEL radiation:

- peak at 830 nm;
- 6 undulators, ~ 15 m;
- data taken with 6 (Si) photo-diodes, after each undulator.

Exponential gain of FEL radiation energy

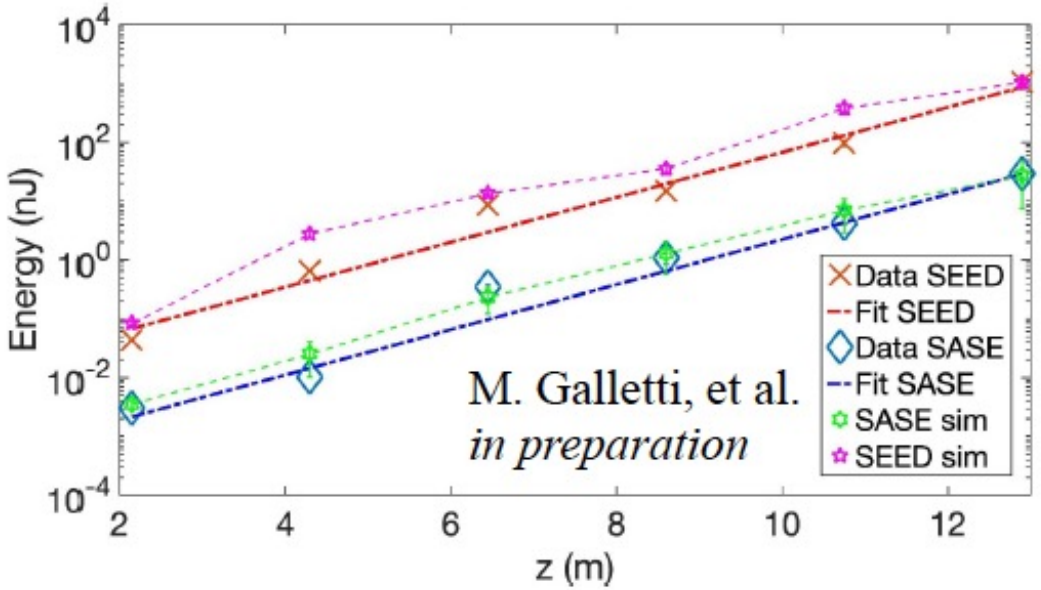
Accepted by Nature

First Beam Driven SEEDED - FEL Lasing at SPARC_LAB (June 2021)



Seeded FEL radiation:

- part of the EOS laser was used as a seed;
- seed laser 795 nm, FEL peak still at 827 nm;
- pulse energy increase from ~30 nJ up to ~ 1 μJ;
- increased stability of radiation.




Thank for your attention