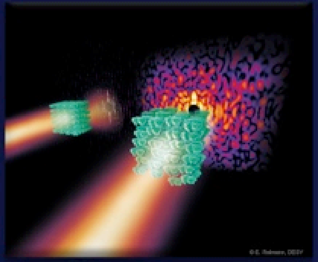
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

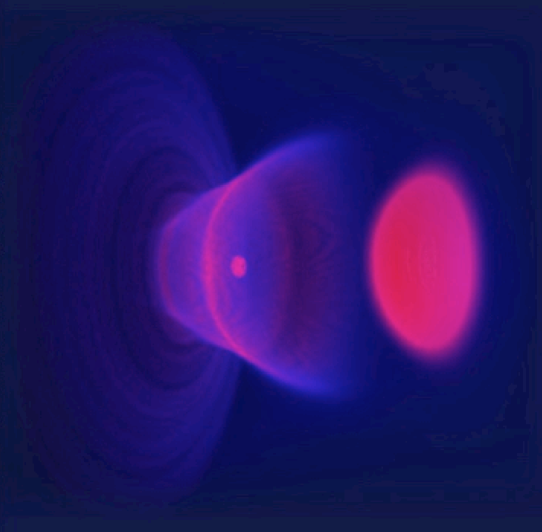
The EuPRAXIA Project: Status and Perspectives

Ralph Assmann (DESY & INFN)

EuPRAXIA@SPARC_LAB TDR I Review Committee, Frascati (Virtual)

22.02.2021





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

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.
- **Judged as eligible** and has entered the ESFRI review.

600+ page CDR, 240 scientists contributed

Targeted User Communities

Horizon 2020

EuPRAXIA provides **particle and photon beams with exceptionally short duration and small size** – ideal for the study of complex systems and ultrafast processes:

• **Biology**	structural biology, research on understanding molecular structures and biochemical processes
• **Chemistry**	crystallography, research on understanding molecular structures and chemical processes
• **Medicine**	pharmacological developments, research on understanding underlying mechanisms of drug operating modes and delivery, diseases, etc.
• **Material science**	crystallography, research on understanding molecular structures and processes, e-beam machining, material analysis
• **Physics**	crystallography, research on understanding structures and processes
• **Archaeology & history**	non-destructive testing, material analysis

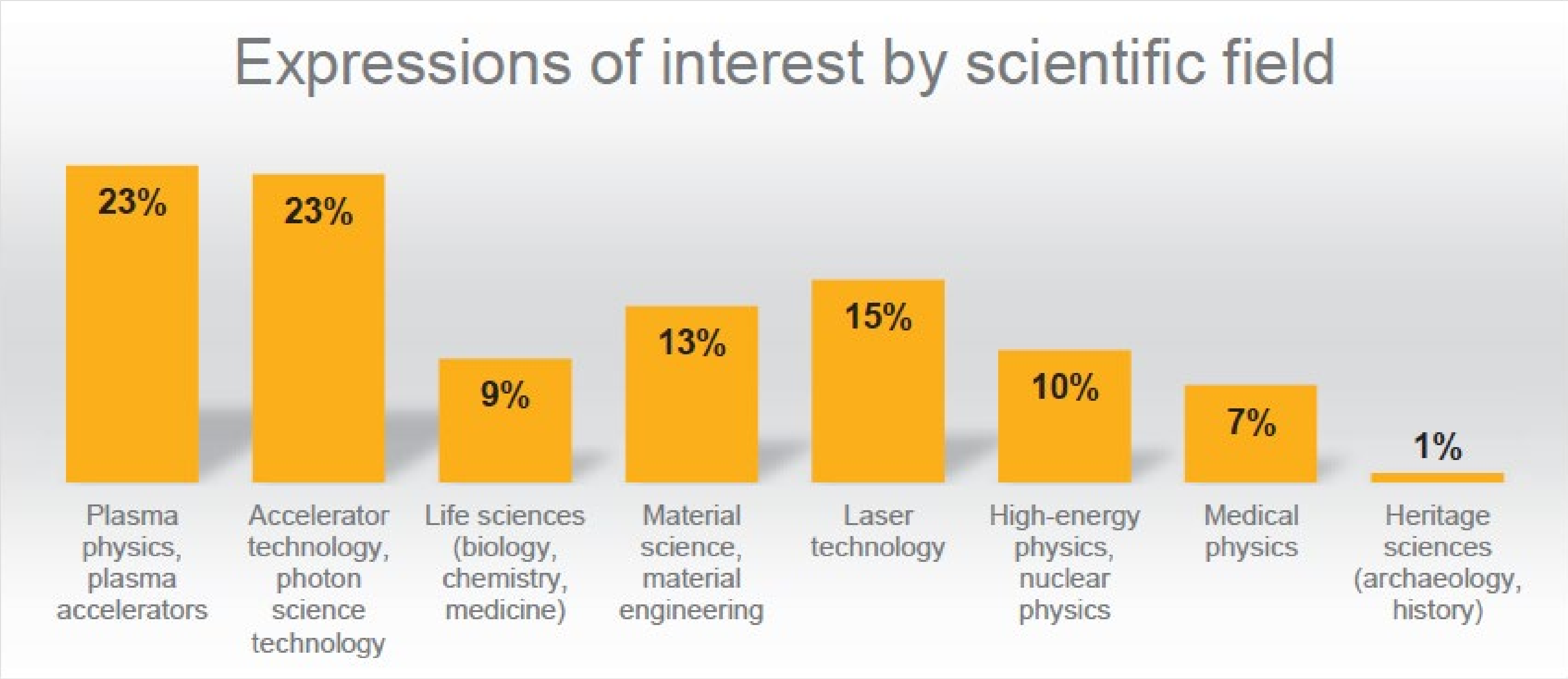
Beyond those applications various **use cases of co-development** including **accelerator R&D**, **photon science** technologies, **compact and industrial** applications, plasma-based acceleration and secondary sources for **high-energy physics**.

EuPRAXIA Deliverables and User Interests

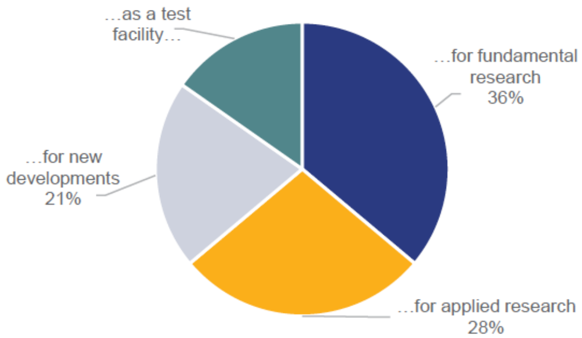
Horizon 2020

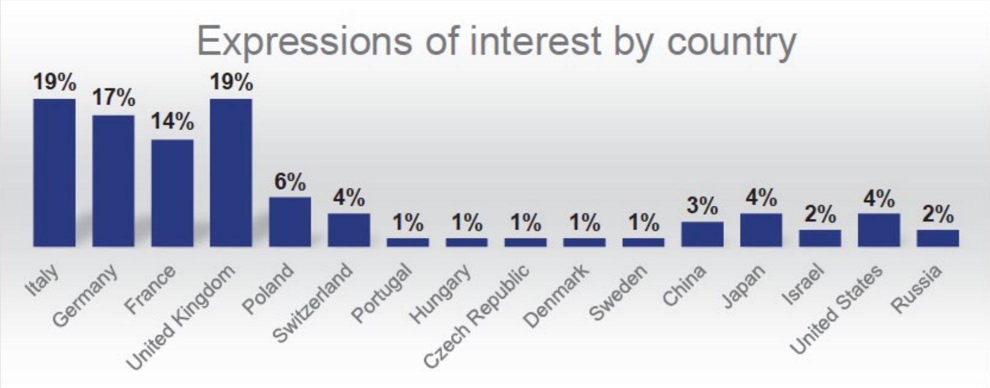
EuPRAXIA is designed to deliver at 10-100 Hz ultra-short pulses of

- Electrons (0.1-5 GeV, 30 pC)
- Positrons (0.5-10 MeV, 10^6)
- Positrons (GeV source)
- Lasers (100 J, 50 fs, 10-100 Hz)
- Betatron X rays (5-18 keV, 10^{10})
- FEL light (0.2-36 nm, 10^9-10^{13})



Expressions of interest from **95 research groups** representing several thousand scientists in total.





IMPORTANT: EuPRAXIA design includes RF injectors, transfer lines, undulator lines, shielding, ...

Realistic intermediate goals at established labs:

- 150 MeV → 1 GeV → **5 GeV** (FEL + other applications)
- 1 plasma stage → **2 plasma stages** → multiple
- factor 3 facility size reduction → **factor 10** → ...
- Low charge, 10 Hz apps of e- (+ **positron** generation)
  → high charge, 10 Hz applications (**FEL**) → 100 Hz

Some of EuPRAXIA's Ideas and Innovation

Horizon 2020

PHYSICAL REVIEW ACCELERATORS AND BEAMS **23**, 031301 (2020)

Toward a plasma-based accelerator at high beam energy with high beam charge and high beam quality

P. A. P. Nghiem,[1,*] R. Assmann,[2a] A. Beck,[3] A. Chancé,[1] E. Chiadroni,[4] B. Cros,[5] M. Ferrario,[4] A. Ferran Pousa,[2a,2b] A. Giribono,[4] L. A. Gizzi,[6] B. Hidding,[7] P. Lee,[5] X. Li,[8] A. Marocchino,[9] A. Martinez de la Ossa,[2a] F. Massimo,[3] G. Maynard,[5] A. Mosnier,[1] S. Romeo,[4] A. R. Rossi,[10] T. Silva ... P. Tomassini,[6] C. Vaccarezza,[4] J. Vieira,[11] and J. Zhu[2a]
[1]CEA, IR...

PHYSICAL REVIEW LETTERS **123**, 054801 (2019)

Compact Multistage Plasma-Based Accelerator Design for Correlated Energy Spread Compensation

A. Ferran Pousa,[1,2,*] A. Martinez de la Ossa,[1] R. Brinkmann,[1] and R. W. Assmann[1]
[1]*Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany*
[2]*Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germany*

(Received 20 November 2018; revised ...

instruments

Article

Wavelength Scaling of Laser Wakefield Accelerat... for the EuPRAXIA Design Point

Craig W. Siders, Thomas Galvin *, Alvin Erlandson, Andrew Bayramian, Brendan Reag... Emily Sistrunk, Thomas Spinka and Constantin Haefner

Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94551, USA
* Correspondence: galvin7@llnl.gov

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22**, 111302 (2019)

High quality electron bunches for a multistage GeV accelerator with resonant multipulse ionization injection

Paolo Tomassini,[1,*] Davide Terzani,[1] Luca Labate,[1,2] Guido Toci,[3] Antoine Chance,[4] Phu Anh Phi Nghiem,[4] and Leonida A. Gizzi[1,2]
[1]*Intense Laser Irradiation Laboratory, INO-CNR, Via Moruzzi 1, 56124 Pisa, Italy*

PHYSICAL REVI...

Preserving emittance by matching out and matching in plasma wakefield acceleration stage

Xiangkun Li, Antoine Chancé, and Phu Anh Phi Nghiem*
CEA-Irfu, Centre de Saclay, Université Paris-Saclay, 91191 Gif sur Yvette, France

(Received 28 August 2018; published 21 February 2019)

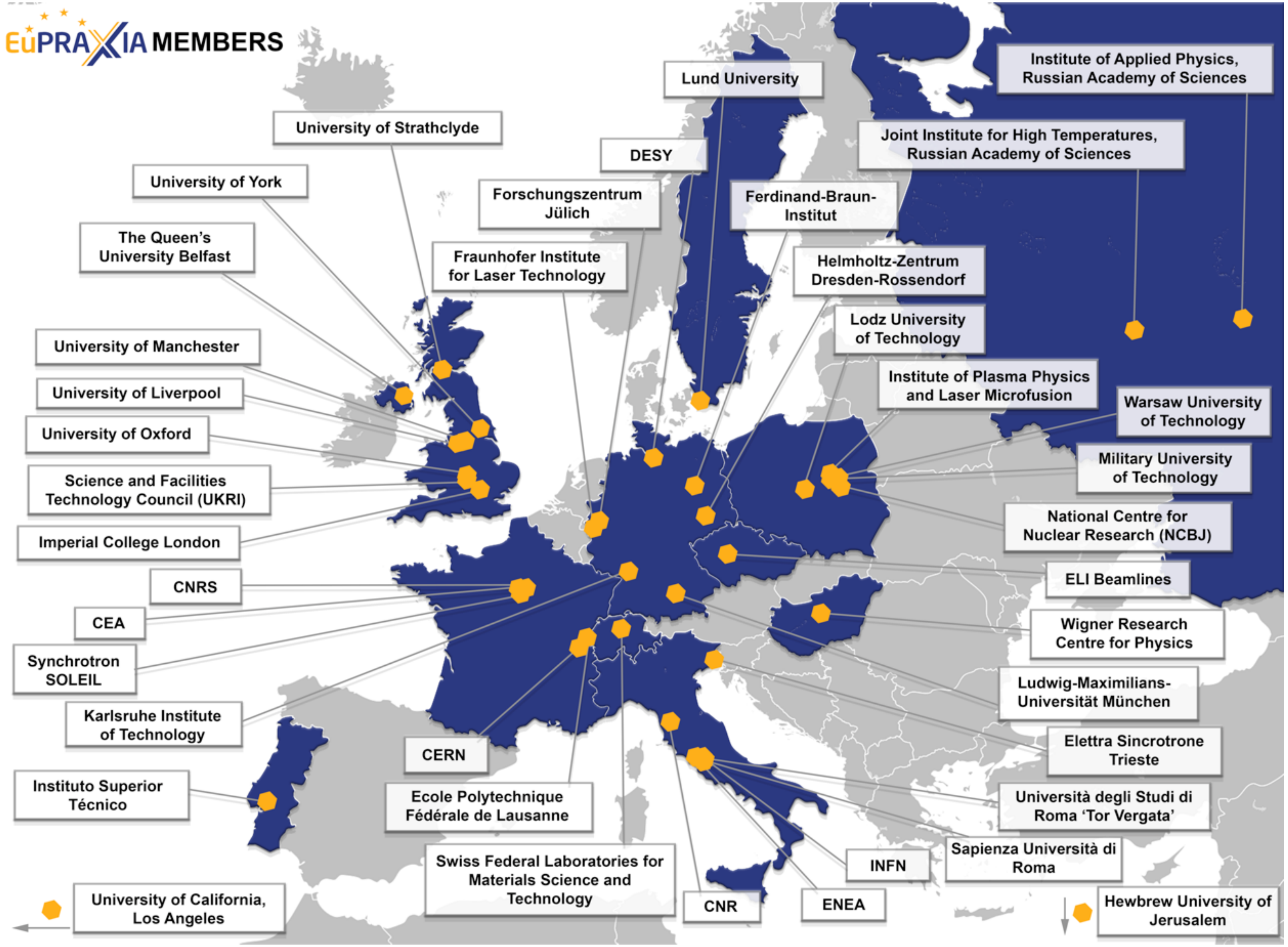
Photon beam line of the water window FEL for the EuPRAXIA@SPARC_LAB project

F Villa[1], A Balerna[1], E Chiadroni[1], A Cianchi[2,3], M Coreno[1,4], S Dabagov[1,5,6], A Di Cicco[7], R Gunnella[7], A Marcelli[1,4,8], C Masciovecchio[9], M Minicucci[7], S Morante[2], J Rezvani[1], T Scopigno[10,11], F Stellato[2,3], A Trapananti[7]
[1] Istituto Nazionale di Fisica Nucleare (INFN) Laboratori Nazionali di Frascati, via E. Fermi

New Consortium Agreement Signed in Dec 2020

(from 16 to 40 members in consortium)

Horizon 2020



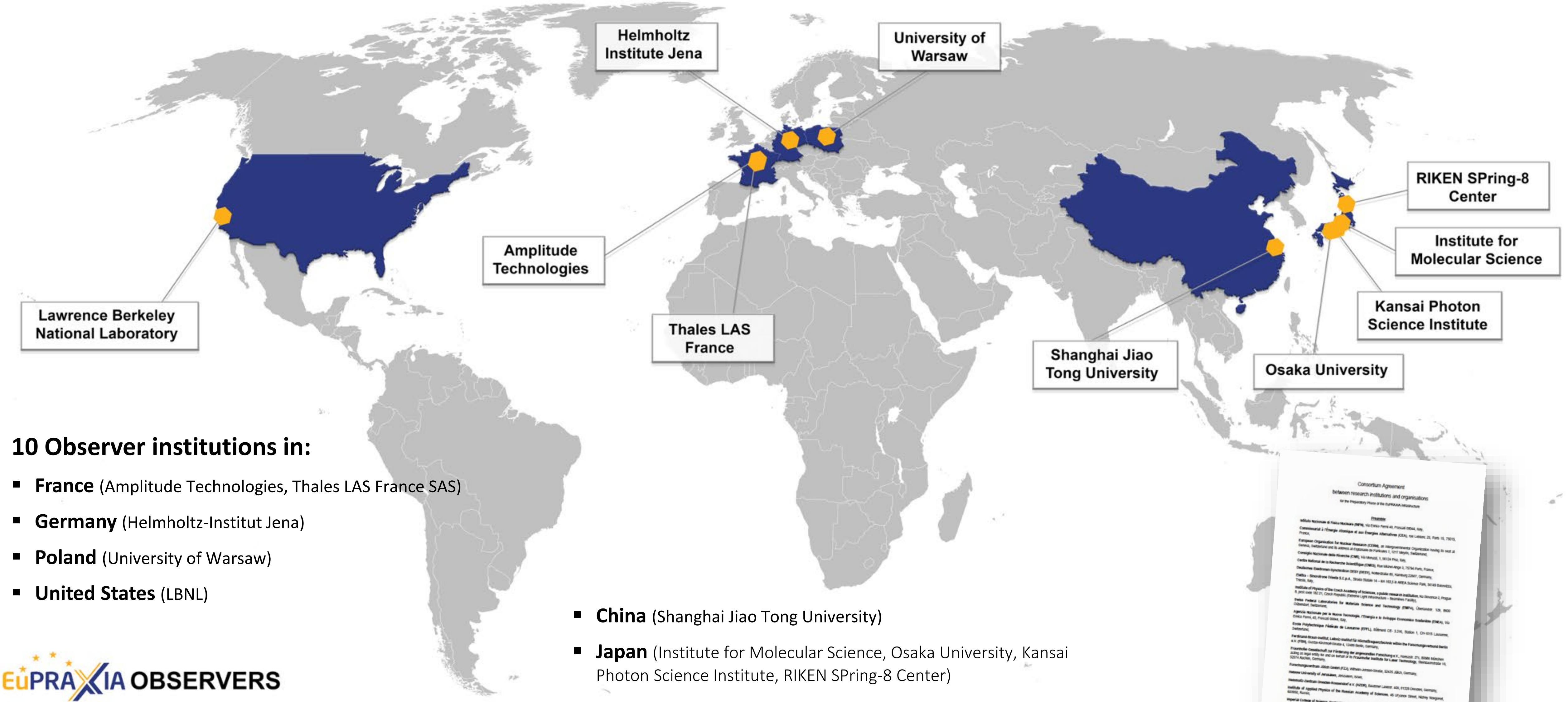
40 Member institutions in:

- **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**

New Consortium Agreement Signed in Dec 2020

(10 observer institutes)

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)

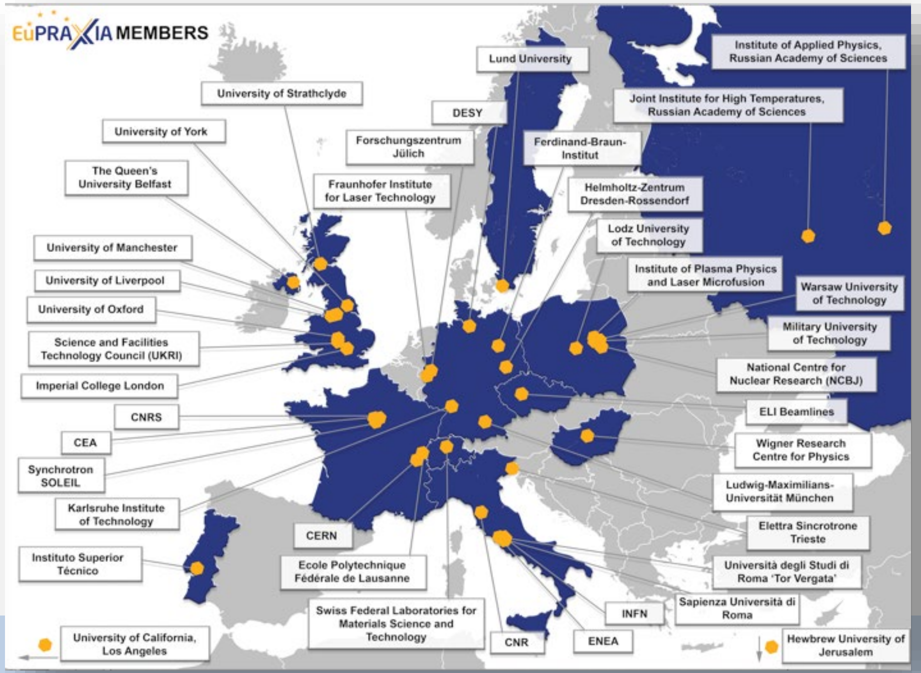
EuPRAXIA OBSERVERS

ESFRI Proposal Submitted in Sep 2020

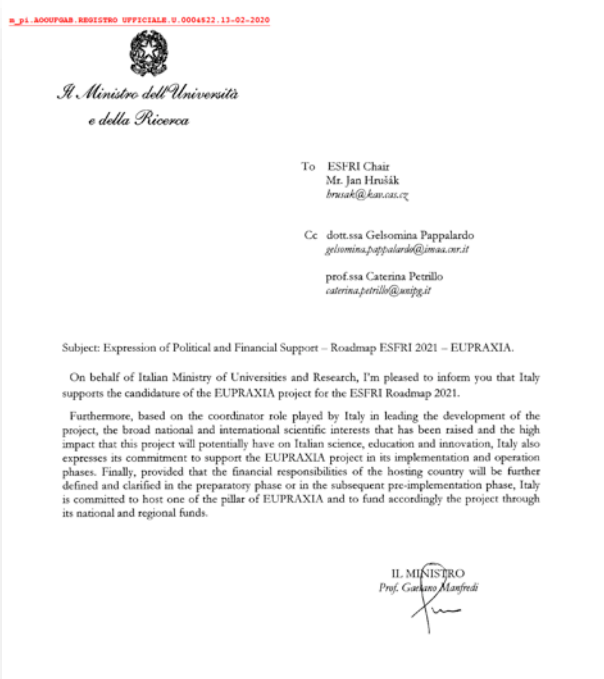
Horizon 2020

- EuPRAXIA strongly supported in European research landscape, it is **timely**, it offers **highly attractive opportunities** for innovation with industry, novel applications and pilot users.
- **Lead Country**: **Italy (LNF/INFN)**
  Political and financial support letter sent to ESFRI by Italian Ministry
- **Political support letters** (at least two needed from countries):
  - **Hungary**
  - **Portugal**
  - **Czech Republic** (ELI beamlines)
  - **UK**
- Note: All operational costs covered by host countries.

*From political + scientific landscape it is seen that **both Czech Republic and UK would be excellent sites for the second leg of EuPRAXIA,** connecting to existing facilities with laser expertise, users and few 100 million € pre-invest.*



Government Support Letters



m_pi.AOOUFGAB.REGISTRO UFFICIALE.U.0004522.13-02-2020

Il Ministro dell'Università e della Ricerca

To ESFRI Chair
Mr. Jan Hrušák
hrusak@kav.cas.cz

Cc dott.ssa Gelsomina Pappalardo
gelsomina.pappalardo@imaa.cnr.it

prof.ssa Caterina Petrillo
caterina.petrillo@unipg.it

Subject: Expression of Political and Financial Support – Roadmap ESFRI 2021 – EUPRAXIA.

On behalf of Italian Ministry of Universities and Research, I'm pleased to inform you that Italy supports the candidature of the EUPRAXIA project for the ESFRI Roadmap 2021.

Furthermore, based on the coordinator role played by Italy in leading the development of the project, the broad national and international scientific interests that has been raised and the high impact that this project will potentially have on Italian science, education and innovation, Italy also expresses its commitment to support the EUPRAXIA project in its implementation and operation phases. Finally, provided that the financial responsibilities of the hosting country will be further defined and clarified in the preparatory phase or in the subsequent pre-implementation phase, Italy is committed to host one of the pillar of EUPRAXIA and to fund accordingly the project through its national and regional funds.

IL MINISTRO
Prof. Gaetano Manfredi

Italy

PAVEL DOLEČEK
Deputy Minister for Higher Education, Science and Research
Ministry of Education, Youth and Sports

Prague, August 2020
Ref. No.: MSMT-32978/2020-1

To whom it may concern

On behalf of the Ministry of Education, Youth and Sports (hereinafter referred to as the "MEYS") – the national public authority of the Czech Republic responsible for the research infrastructures' policy making and public funding – I would like to confirm the political and financial support of the MEYS to the Czech stakeholders participating in the "EuPRAXIA" (*European Plasma Research Accelerator with eXcellence in Application*) European research infrastructure project proposal, applying for the "ESFRI Project" status on the upcoming 2021 update to the Roadmap of European Strategy Forum on Research Infrastructures (hereinafter referred to as the "ESFRI").

The "ELI Beamlines" large research infrastructure, which participates in "EuPRAXIA" from the Czech Republic, has been adopted by the Government of the Czech Republic for its public funding. Simultaneously, it has also been included in the latest 2019 update to the Roadmap of Large Research Infrastructures of the Czech Republic for the years 2016–2022.

Having said that, the presented letter shall be viewed as an official commitment of the Czech Republic to politically and financially support the "EuPRAXIA" project in the preparation and implementation phases, within the "ELI Beamlines" funding framework, which was approved by the Government of the Czech Republic in 2018.

I truly hope that the involvement of the "ELI Beamlines" large research infrastructure in the "EuPRAXIA" European research infrastructure project consortium will be beneficial, and thus contribute to a positive ESFRI's assessment outcome, resulting in inclusion of "EuPRAXIA" on the forthcoming 2021 ESFRI Roadmap update as an "ESFRI Project".

Yours sincerely

PhDr. Pavel Doleček Ph.D.

Czech Republic

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE
HUNGARY

PRESIDENT

Administrative number: NKFIH-1055-2/2020.
Subject: Expression of Political Support (EoS) for the ESFRI Roadmap 2021 application – EUPRAXIA (European Plasma Research Accelerator with eXcellence In Application)
Reference number:
Enclosure: - pcs

Budapest, " " April 2020

Expression of Political Support (EoS) for the
European Plasma Research Accelerator with eXcellence In Application (EUPRAXIA)
ESFRI Roadmap 2021 application

By signing the Expression of Political Support (EoS), we express the interest of Hungary to be involved in the process towards the construction and operation of 'European Plasma Research Accelerator with eXcellence In Application' (EUPRAXIA) as a Pan-European research infrastructure.

The National Research, Development, and Innovation Office (NRDI Office) recognizes EUPRAXIA as an important research infrastructure and provides its political support for the Hungarian participation, in case the proposal will be accepted into the new 2021 ESFRI Roadmap. The NRDI Office encourages the Wigner Research Centre for Physics to participate in the preparatory phase of the consortium, subject to further assessments and bilateral agreements.

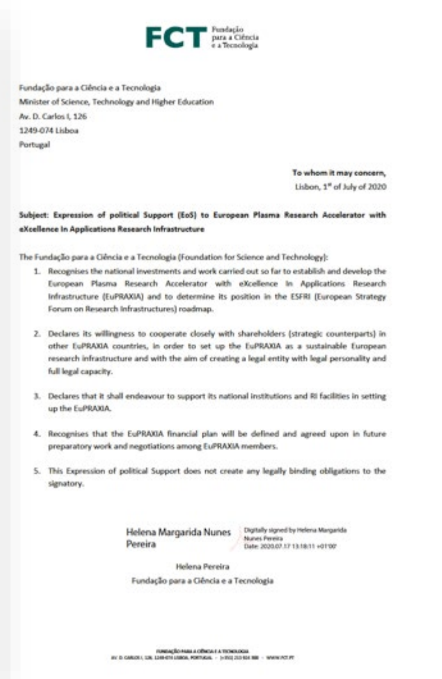
The NRDI Office recommends the Wigner Research Centre for Physics, coordinator of the Hungarian interested stakeholders, as representing organization to EUPRAXIA.

This Expression of Political Support does not entail any financial support by the National Research, Development and Innovation Office and implies that EUPRAXIA will be seeking any future funding through existing research programs at European and national level.

Sincerely yours

Dr. Birkner Zoltán
Dr. Zoltán Birkner
President of NRDI Office

Hungary



FCT Fundação para a Ciência e a Tecnologia

Fundação para a Ciência e a Tecnologia
Minister of Science, Technology and Higher Education
Av. D. Carlos I, 126
1249-074 Lisboa
Portugal

To whom it may concern,
Lisbon, 1st of July of 2020

Subject: Expression of political Support (EoS) to European Plasma Research Accelerator with eXcellence In Applications Research Infrastructure

The Fundação para a Ciência e a Tecnologia (Foundation for Science and Technology):

1. Recognises the national investments and work carried out so far to establish and develop the European Plasma Research Accelerator with eXcellence In Applications Research Infrastructure (EuPRAXIA) and to determine its position in the ESFRI (European Strategy Forum on Research Infrastructures) roadmap.
2. Declares its willingness to cooperate closely with shareholders (strategic counterparts) in other EuPRAXIA countries, in order to set up the EuPRAXIA as a sustainable European research infrastructure and with the aim of creating a legal entity with legal personality and full legal capacity.
3. Declares that it shall endeavour to support its national institutions and RI facilities in setting up the EuPRAXIA.
4. Recognises that the EuPRAXIA financial plan will be defined and agreed upon in future preparatory work and negotiations among EuPRAXIA members.
5. This Expression of political Support does not create any legally binding obligations to the signatory.

Helena Margarida Nunes Pereira
Digitally signed by Helena Margarida Nunes Pereira
Date: 2020.07.17 13:18:11 +01'00'

Helena Pereira
Fundação para a Ciência e a Tecnologia

Portugal

UKRI Science and Technology Facilities Council

Dr. Jan HRUSAK, CSc.
ESFRI Chair
J. Heyrovsky Institute of Physical Chemistry AS CR, vvi,
Dolejškova 2155/3, 182 23 Prague 8, Czech Republic

Letter of Support from the **UK Research and Innovation (UKRI) Science and Technology Facilities Council** (STFC) for
The EuPRAXIA Infrastructure
Submitted as a proposal to the ESFRI Roadmap 2021
By Dr. Ralph Assmann (DESY, Germany and INFN, Italy) and Dr. Massimo Ferrario (INFN, Italy)

Dear Dr HRUSAK,

The United Kingdom through the representing entity, the Science and Technology Facilities Council (STFC), hereby submits a Letter of Support confirming the UK's interest in EuPRAXIA Infrastructure.

EuPRAXIA will be a unique international Research Infrastructure (RI) based on next-generation plasma accelerators and as a leading country for research in this field, the UK and its academic community will have a strong interest in this area. The goals and the technologies of the EuPRAXIA project align well with STFC's future infrastructures in this area. In particular, the Extreme Photonics Application Centre (EPAC) at the Harwell Campus will be developing key technologies that have synergies with EuPRAXIA. The UK community is interested in continued collaboration in the preparatory phases for EuPRAXIA. UK participation in EuPRAXIA will ultimately be subject to scientific prioritisation and would need to be tensioned against other potential infrastructure investments.

STFC have delegated authority from the UK's Department for Business, Innovation and Skills (BEIS) for submitting this Letter of Support. Please note that this Letter of Support constitutes no legal or financial commitment for the construction and operation of the RI. The specific nature of the UK's future involvement will be subject to a decision by the Parliamentary Under Secretary of State for Science, Research and Innovation and dependent on the future legal structure of the project. In addition, negotiations on potential UK association to Horizon Europe from 2021-2027 are on-going. This letter is sent without prejudice to those negotiations and any future UK association to Horizon Europe is subject to those discussions.

Yours sincerely,

Professor Mark Thomson
Executive Chair of the Science and Technology Facilities Council

UK Research and Innovation, Polaris House, North Star Avenue, Swindon SN2 1FL
www.stfc.ukri.org

United Kingdom

plus 32 non-governmental support letters

First Feedback from EU (Nov 2020)

Horizon 2020

We are glad to inform you that, following ESFRI internal procedures, **the proposal "European Plasma Research Accelerator with Excellence in Applications - EuPRAXIA" has been considered eligible** and can now be assessed for entering the ESFRI Roadmap 2021.

The evaluation exercise has just started and below you can find the next steps with an indicative timeframe:

- Invitation for the hearing with list of critical questions: February-March 2021
- Hearing: April-May 2021

Budget Overview and Cost-Benefit Analysis

(all prepared according to ESFRI and EU rules)

Horizon 2020

Project duration	10 years
Full cost (including manpower, past CDR cost and termination cost)	**569 M€**
Cost of Phase I (including manpower and past CDR cost)	388 M€
Operational cost	30 M€/y
Internal rate of return	**9.22 %**
Start of pilot operation	2028
Funding secured (status 11/2020)	**118 M€** *(21 % of full cost)*
OP budget secured (status 11/2020)	9 M€/y *(30 %)*

Return rate found in cost-benefit analysis shows the expected gain of the sustained EuPRAXIA investment also in economical terms. Credits to our consultant F. Brottrier.

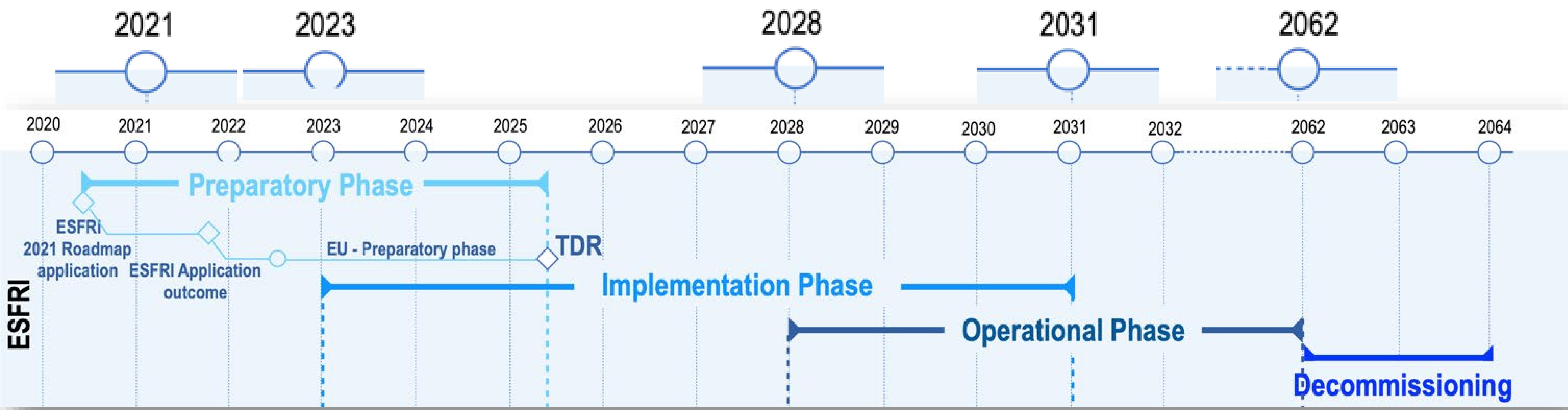
6.5 Socio-economic analysis

Net Present Value (ENPV)	80 985 945
Internal Rate of Return (ERR)	9.22%
Benefit-Cost ratio (B/C)	1.10

The chart below indicates the variations of the ENPV when changing the socio-discount rate between 0 and 20%. As per the definition of internal rate of return, EuPRAXIA's socio-economic net present value becomes negative when the socio-economic discount rate exceeds 9.22%.

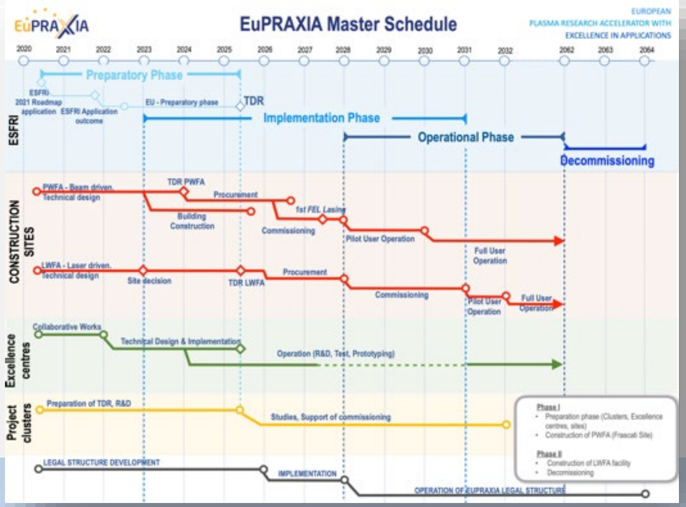
EuPRAXIA Schedule

Horizon 2020



European World-Class RI on compact accelerators for the end of the 2020's to the beginning of the 2060's

More detail in Master Schedule



Organization

Horizon 2020

Co-funded by the European Union

Advisory & Oversight Boards

- Open Innovation Forum
- Scientific & Technical Advisory Committee
- User Meetings & Program Committees
- Resource Review Board
- Quality Assurance Panel
- Ethical Advisory Board

Collaboration Board

1 representative per Member & Observer
1 Chair and 1 Deputy Chair

Project Coordinator + Management Team

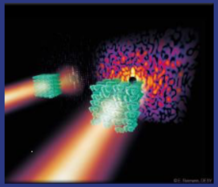
Steering Committee

Central EuPRAXIA Management

Construction Site Frascati

Local Project Team

Beam-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, particle physics, medicine, materials



Location: metropolitan area Rome, Italy

Construction Site

(tbd in 2023)

Local Project Team

Laser-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, medicine, materials

Four candidate sites described in conceptual design report

Excellence Centres

Local Project Teams

- *Plasma Simulations & Theory*
- *Laser-Plasma Acceleration & FEL Developments*
- *Plasma Acceleration & High-Rep-Rate Developments*
- *Advanced Application Beamlines*
- *Technology Incubator to Laser Science Users*
- *EuPRAXIA user e-needs infrastructure*

Technical design tests, prototyping, production

Project Clusters (WPs)

- *Theory & Simulation*
- *Laser Technology*
- *Plasma Components & Systems*
- *RF Technology*
- *Magnets & Other Beamline Components*
- *Diagnostics*
- *Applications*
- *Transfor-mative Innovation Paths*
- *Training, Outreach & Dissemi-nation*
- *Implemen-tation & Layout*

Technical Design Report

National projects and facilities

Individual groups at universities and laboratories

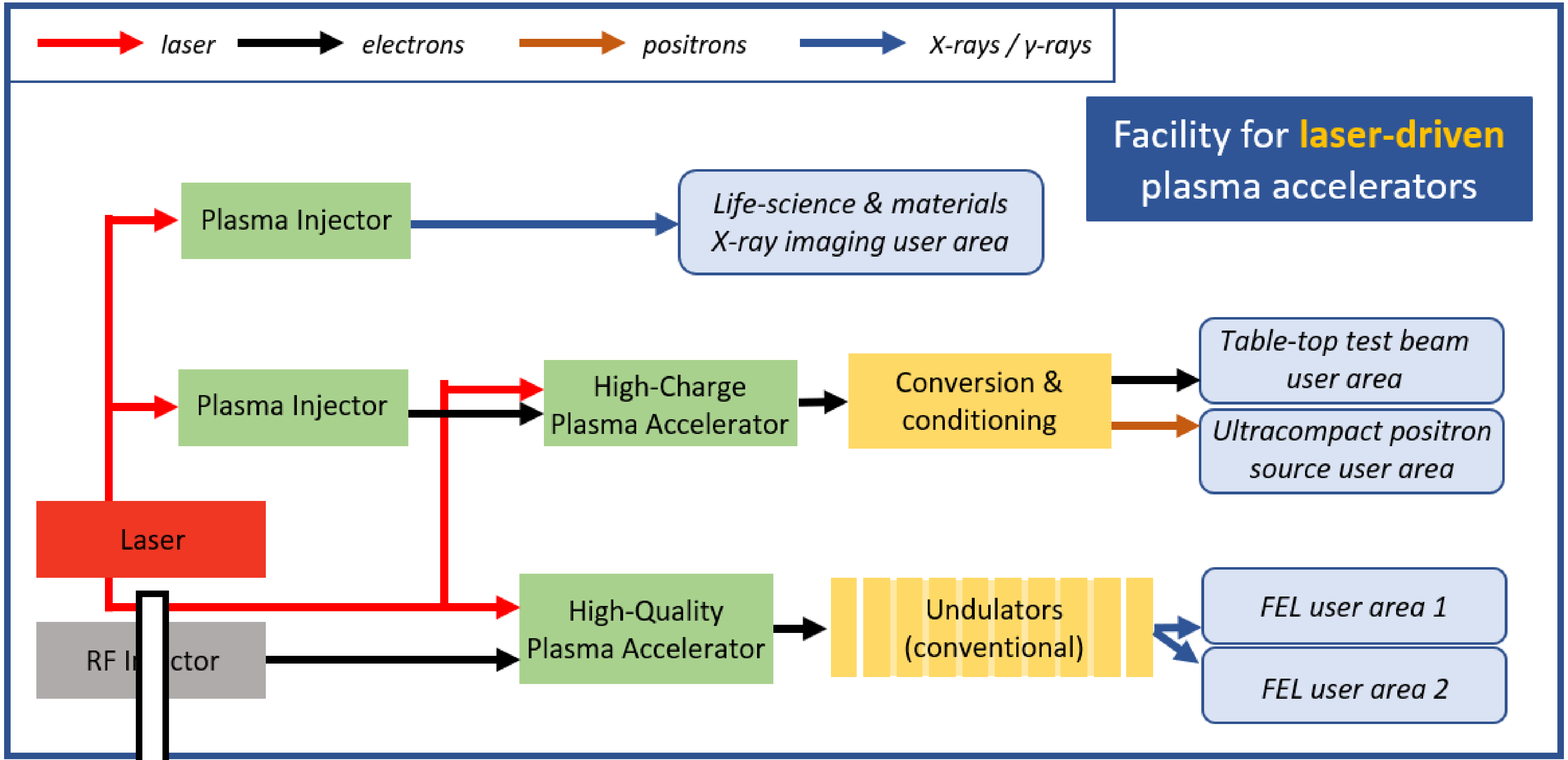
Organization for initial Preparatory Phase in dark blue

Features to be added with decision on second site or in later phases are indicated in lighter shades

The Laser-Driven EuPRAXIA Construction Site

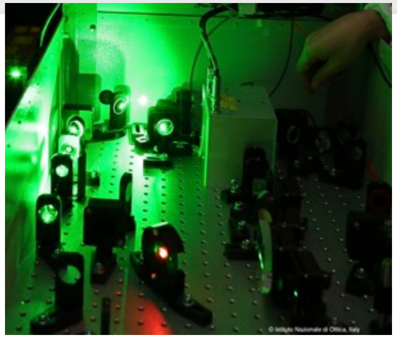
(decide in 2023, candidates alphabetic: CNR, ELI-Beamlines, EPAC, LNF)

Horizon 2020



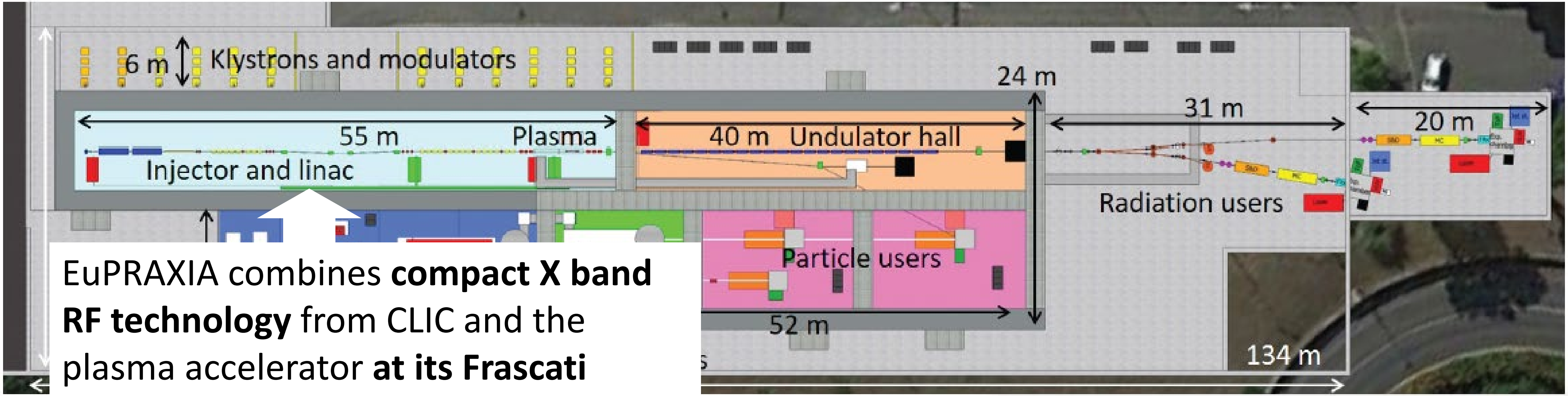
- Free-electron laser
- Life-science & materials X-ray imaging (betatron source)
- Ultracompact positron source
- Table-top test beams

THREE HIGH-POWER LASER SYSTEMS			
Wavelength	Energy on target	Pulse duration	Repetition rate
800 nm	5 – 100 J	≥ 20 – 60 fs	20 – 100 Hz



The Beam-Driven EuPRAXIA Construction Site
(EuPRAXIA@SPARC_lab)

Horizon 2020



EuPRAXIA combines **compact X band RF technology** from CLIC and the plasma accelerator **at its Frascati construction site**! Brings confidence and **excellent synergy** with international linear collider efforts!

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

UNIVERSITA' DEGLI STUDI DI SASSARI

The executive design of the building has officially started few weeks ago, the delivery of the design is expected in November 2020.

Multiple users from different fields:
studying and understanding **bacteria**, **viruses**, **materials**, ...
using intense bursts of photons, electrons, positrons resolving time-dependent processes in **ultra-fast science**
co-developing **novel technologies** for accelerators, users, ...

Cost Split Preparation and Implementation

(from ESFRI, excluding manpower cost)

Horizon 2020

Cost Breakdown for Preparation & Implementation	Investment cost (excl. contingencies, payroll)
Laser-driven plasma acceleration site	148 M€
Beam-driven plasma acceleration site	**141 M€**
Excellence Centres	41.5 M€
Laser prototyping (Clusters)	38.5 M€
Plasma prototyping (Clusters)	7.3 M€
Applications prototyping (Clusters)	25.7 M€
Other prototyping (Clusters)	26.7 M€
Central EU Project Office	0.8 M€
Total	429.5 M€

The full EuPRAXIA CDR includes, amongst others,

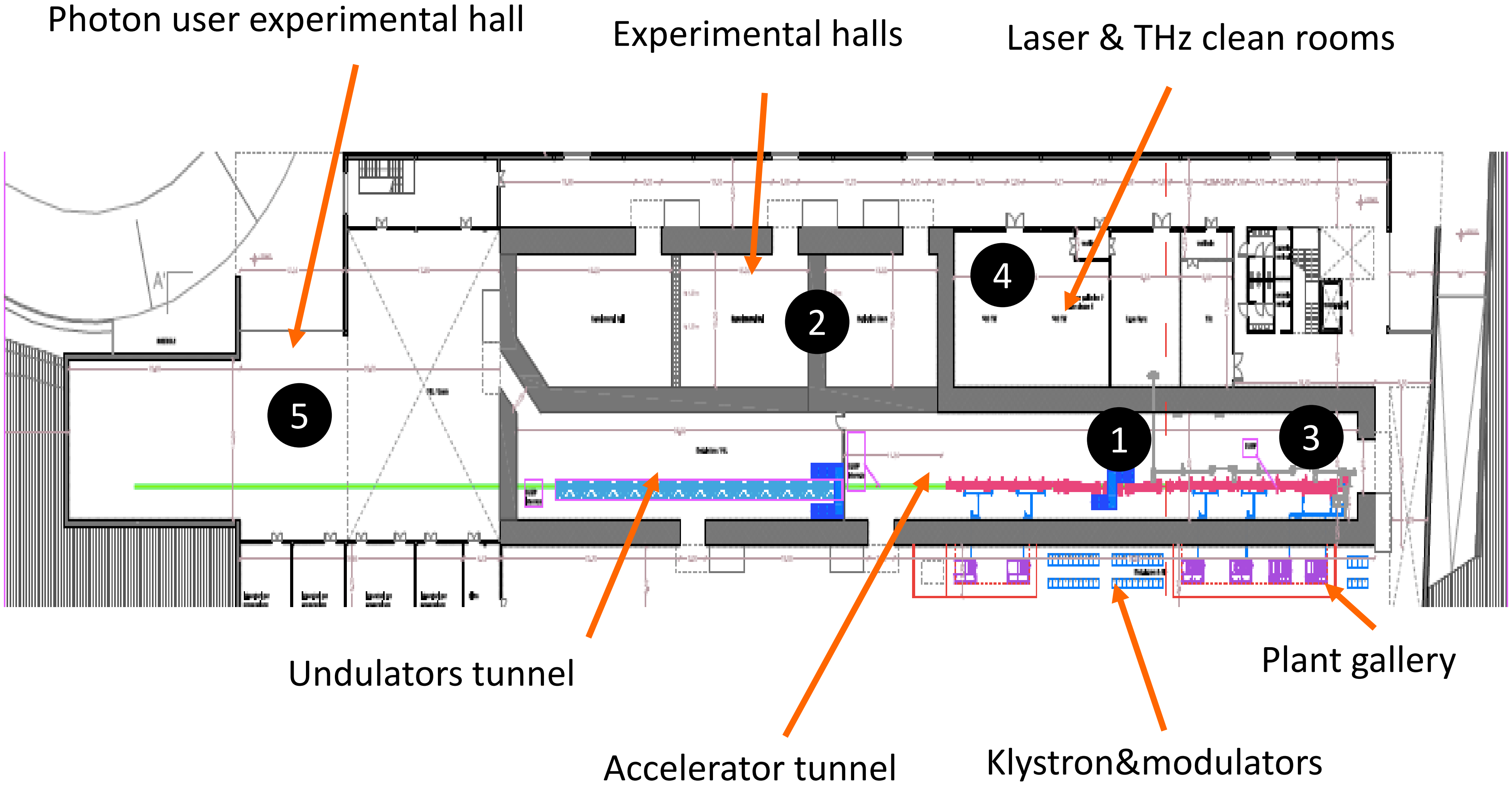
- about **12 M€** of prototyping cost for Frascati applications (done by partners)
- about **4 M€** of of prototyping for Frascati plasma structure (done by partners)
- about **40 M€** of additional component costs to be installed at Frascati (not in EuPRAXIA@SPARClab budget)
- profits from laser and other prototyping work, excellence centres, …

Only the full EuPRAXIA project realizes significant synergy benefits of a fully European project!

European Interests and Possible Contributions

(final decisions depend on funding and TDR solutions)

Horizon 2020



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.

Excellence Center for Laser Acceleration and FEL

Horizon 2020

3 French institutions have signed the EuPRAXIA Consortium Agreement : **CNRS, CEA** and **Soleil**

French contribution is structured around 2 main facilities and projects

LAPLACE

development of LPA and their applications

- **high repetition rate** (≥100Hz) LPA sources development
- **FEL** LPA-driven development, robust high quality beam LPA development (SOLEIL/LOA)

PALLAS

10 Hz, 150 MeV laser-plasma injector (LPI) test facility devoted to:

- **advanced online control** of LPI
- **plasma target** development for high beam beam quality
- beam transport for **staging**

Phase 1 funded as French national contribution to EuPRAXIA

In addition the following CNRS labs contribute to **EuPRAXIA clusters**

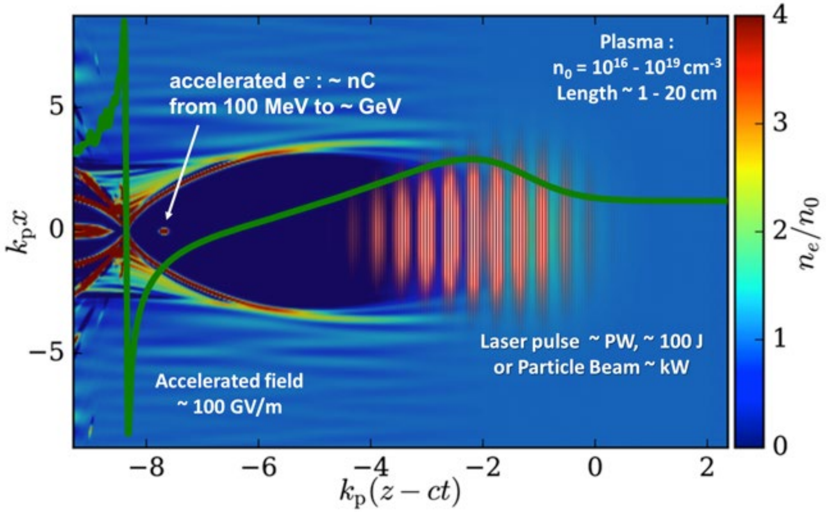
Laboratoire Leprince-Ringuet **:** **multi-PW** driven **LPA** experimental demonstration at APOLLON, applications to HEP and other field, beam diagnostics and compact beam transport, and theory **simulations** and continuous development of PIC Smilei

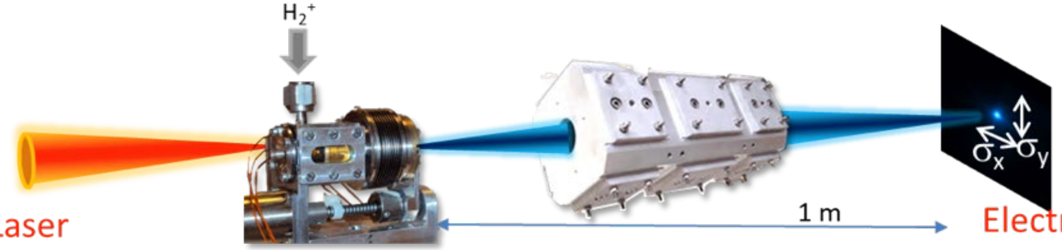
: **new advanced laser technology development** : Compressor, intensity stabilization, focal spot alignment stabilization, amplification stage, beam transport + bring benefit from its close links with the laser industrials partners to ensure the economic feasibility.

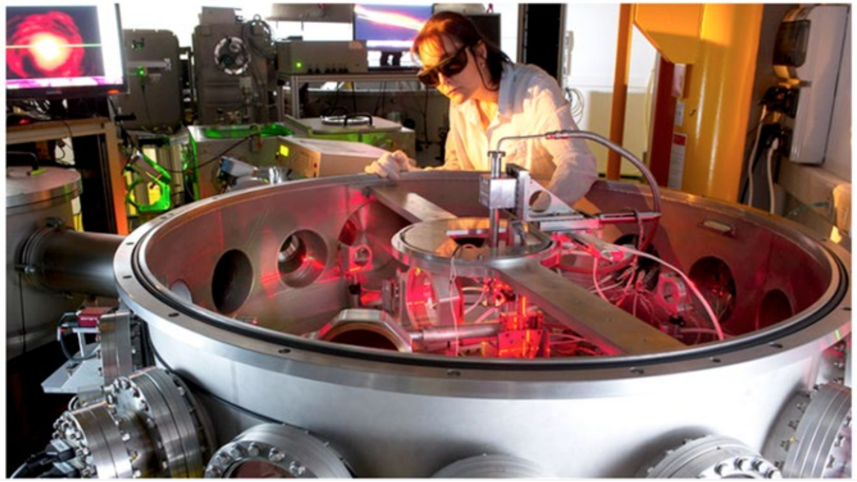
: R&D of optimised LPI in tailored plasma density profile and of specific **plasma components**, based **on novel discharge schemes** or laser ionised plasmas, suitable for **laser guiding over large propagation distances** and experimental tests

Participations to EuPRAXIA:

- Theory and simulations
- Integrated laser-plasma experiments on UHI 100
- Design and fabrication of transport lines
- Design and fabrication of laser and particle diagnostics





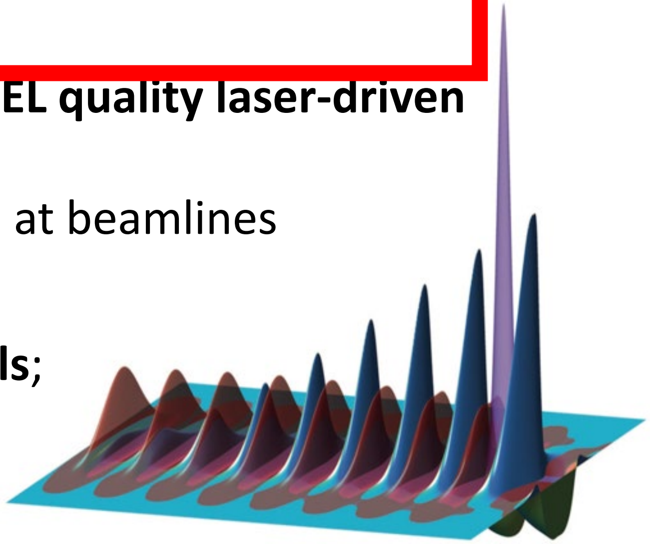


UHI100 versatile and user friendly environment for Laser Plasma Acceleration studies at LIDYL (CEA-CBRS, Université Paris Saclay (Image: Ph.Stroppa/CEA)

EuPRAXIA Laser-Driven Site Option CNR

Preparation of the EuPRAXIA laser-driven site option at the CNR Campus in Pisa

- Builds on experience running the **existing facility** including a >200 TW laser driver for electron and proton **beamlines currently active**;
- Part of the **National roadmap** for Extreme Light Infrastructure, and founding participant to ELI along with INFN and Elettra ST;
- Currently engaging R&D on key EuPRAXIA pillars:
  - High average power **laser development** as efficient and reliable drivers
  - Validation of novel schemes for **FEL quality laser-driven** acceleration
  - Multi-disciplinary **user operation** at beamlines



- Currently promoting EuPRAXIA laser-driven site option **at National and Regional levels**;
- Strong focus on **bio-medical uses of laser-driven sources** for pre-clinical and clinical studies are motivating growing collaborations.
- **ESFRI listing of EuPRAXIA** will boost all related developments and innovation.

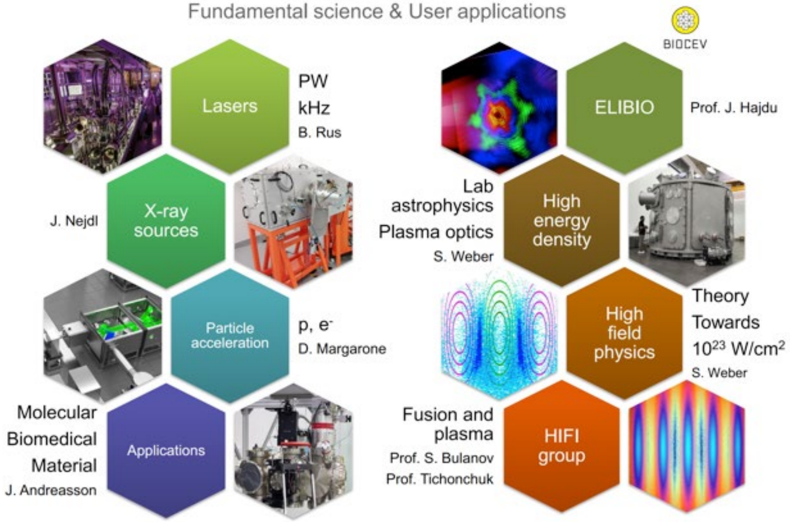
eli delivery consortium INFN CNR-INO ISTITUTO NAZIONALE DI OTTICA CONSIGLIO NAZIONALE DELLE RICERCHE

ELI-Beamlines

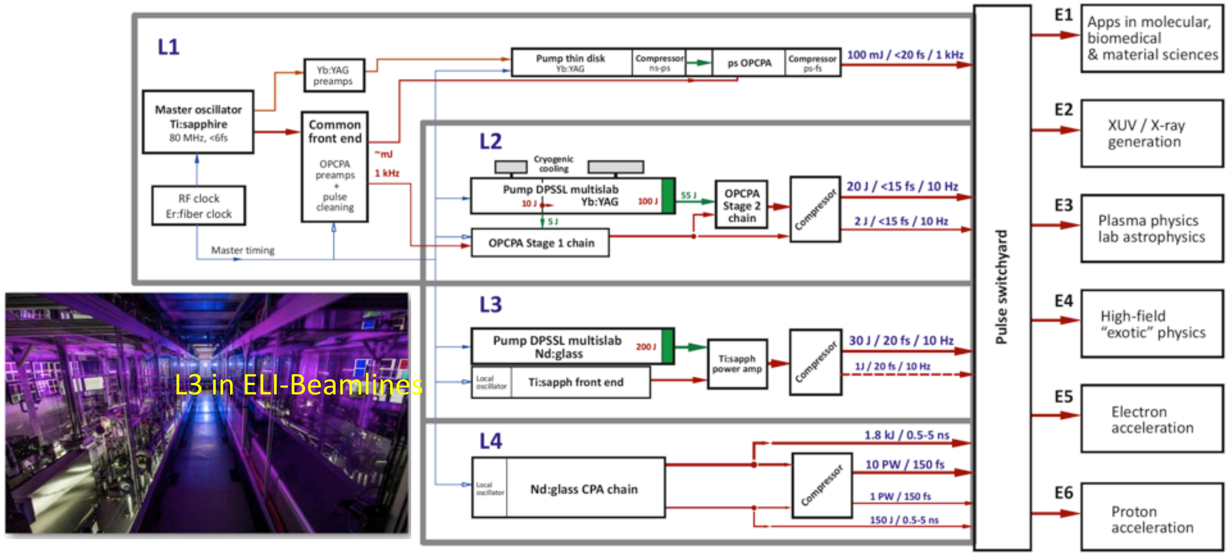
Horizon 2020

Research campus

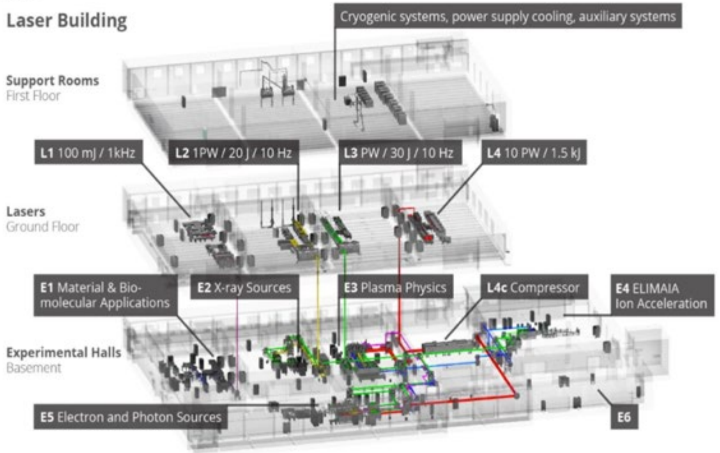
The Science Case
Fundamental science & User applications



ELI Beamlines master scheme



Lasers and experiments

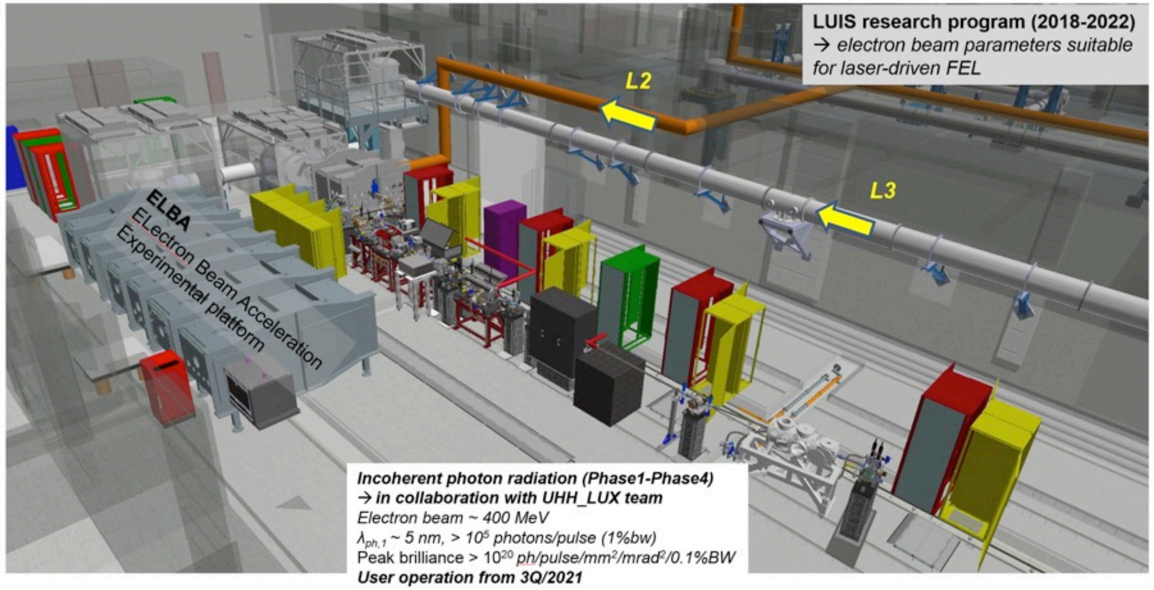


ELI-Beamlines: Compact X-FEL Development

Horizon 2020

From incoherent to coherent undulator X-ray source for users

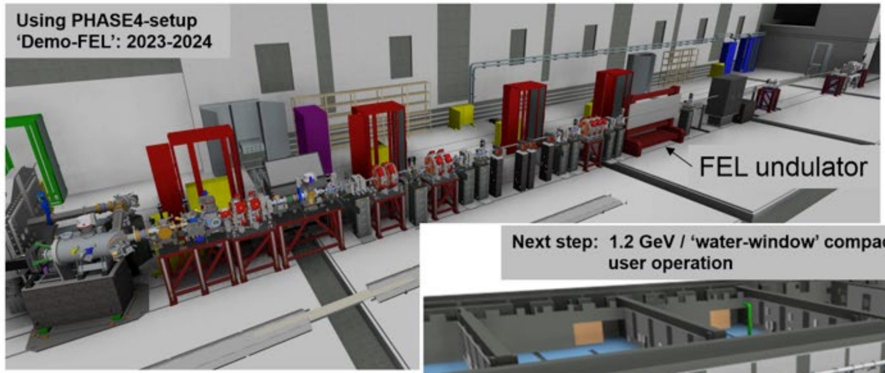
Current RESEARCH PROGRAM
Undulator photon radiation at ELI beamlines



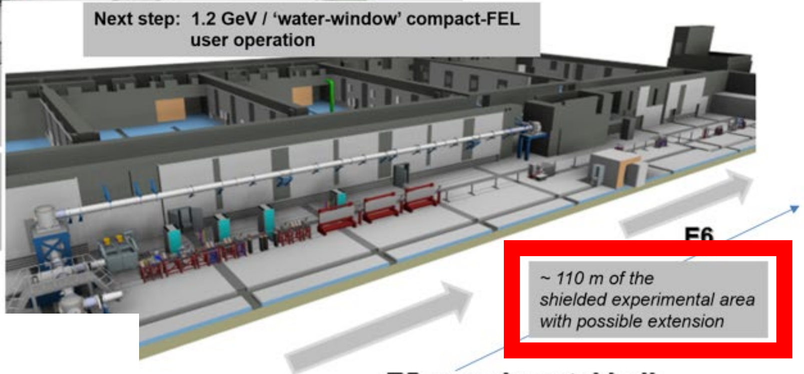
Under preparation in E5 experimental hall
'First L3-laser light' in E5-LUIS → March 2021

FUTURE RESEARCH PROGRAM
Laser-driven compact FEL at ELI beamlines

EUPRAXIA collaboration



Goal: demonstration of the SASE-FEL regime
- We ~ 350 MeV
- saturation in a single undulator (2.5m)
- 'seeded' FEL



E5 experimental hall

SASE EUV X-ray FEL

Main parameters of the 'demo'-FEL at ELI-Beamlines

Main challenges

Electron beam in Undulator (K_0=1.4)		
Beam energy	MeV	350
Bunch charge	pC	30
RMS bunch duration	fs	3
Peak current	kA	4
Matched beam size	μm	25
Normalized emittance	π mm.mrad	0.24
'Slice' energy spread	%	0.3
Photon coherent radiation at saturation		
Radiation wavelength	nm	32
Pierce parameter, ρ	$\times 10^{-2}$	0.8
Coherent normalized RMS emittance	π mm.mrad	1.7
Cooperation length (3D), L_{coop}	μm	0.26
Gain length (3D), $L_{g,3D}$	m	0.12
Saturation length (3D)	m	2.4
Radiation bandwidth	%	0.65
Photon flux per 0.1%bw	$\times 10^{12}$ #	2.2
Photon brilliance	$\times 10^{30}$ #	1
Photon pulse power	GW	8.2
Photon pulse energy	μJ	63

Expected photon beam parameters are comparable with the FLASH (Germany) and FERMI (Italy) parameters.

'Swiss-FEL' type of undulator

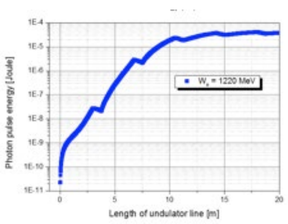
FERMI @elettra

Linac-based UV-FEL:
FERMI FEL1 (Italy)
Linac 1.2 GeV
Acc.Length ~ 200 m
Und.Length ~ 30 m
RepRate = 10-50 Hz
Peak power ~ **0.4-3 GW**
Wavelength= **80-20 nm**

CONCEPT: soft X-ray FEL

Photon beam parameters (h=1) / 1D model			
Radiation wavelength	$\lambda_{ph,1}$	nm	2.5
Radiation energy	$E_{ph,1}$	keV	~0.5
Coherence RMS normalized emittance	[illegible]	π mm.mrad	0.55
1D Pierce parameter	ρ_{1D}	--	0.0016
1D gain length	$L_{g,1D}$	m	0.40
1D coherence length	$L_{coh,1D}$	nm	450
Total number photons at saturation per pulse	N_{photon}	photons/pulse	6.4 × 10^[illegible]
Relative RMS frequency bandwidth	[illegible]	%	0.15
Photon flux per 0.1% bandwidth	[illegible]	photons/pulse/ 0.1% bw	4.2 × 10^[illegible]
Photon brilliance (50 Hz)	B_{ph}	ph/sec/mm²/mrad²/0.1%bw	7.6 × 10^[illegible]
1D Peak photon radiation power at saturation	$P_{ph,1D}$	GW	~6
Photon bean parameters (h=1) / 3D model (Xie parametrization)			
3D constrain	$L_{g,3D}$ / $L_{g,1D}$		< 2.5
3D coherence length	$L_{coh,3D}$	nm	0.16
3D Peak photon radiation power at saturation	$P_{ph,3D}$	GW	~2
3D total saturation length (**Figure 4**)	$L_{saturation}$	m	~20

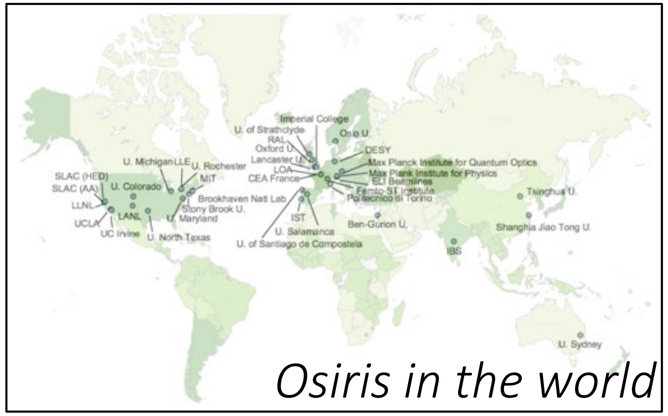
Undulator parameters / Super conducting based Nb_3Sn wires / Planar			
Undulator period	λ_u	mm	14
Undulator gap	Gap	mm	7
Peak magnetic field	B_0	T	1.1
Undulator parameters	K_0	--	1.4
Average beta function (matched, 1220 MeV)	β_{av}	m	7.5
Electron beam parameters (Soft X-ray)			
Electron beam energy	W_b	MeV	1220
Peak current	I_{peak}	kA	[illegible]
Normalized transverse RMS emittance (slice)	ε_n	π mm.mrad	0.47
Average RMS transverse beam size in undulator	$\langle\sigma_{x,y}\rangle$	μm	38
Relative RMS energy spread (slice)	$\sigma_{\Delta E/E}$	%	0.002
RMS bunch length	σ_t	fsec	3.5
Total bunch charge	Q_b	pC	26



Plasma theory and simulations excellence center

- **Long tradition in developing plasma simulation tools in Portugal**

ZPIC



Osiris in the world

- **Instituto Superior Técnico (IST) is the largest science&engineering school in Portugal**

TÉCNICO LISBOA

- **Concept collaboratorium**
  - Platform for coordination, collaboration, scientific and technical exchange.
  - Lead coordination efforts for code development and integration
  - Front end for the EU exascale initiatives in plasma accelerators
  - Hub for new and disruptive ideas, to explore future directions of facility.

- **Main goals**
  - Simulation and theory support for EuPRAXIA teams involved in computing
  - Coordinate virtual interactions in EuPRAXIA in theory and simulations
  - Visiting/workshop program on plasma accelerators (advanced trainning, convene PhD students, Post-Docs and senior researchers.

UK contributions to EuPRAXIA

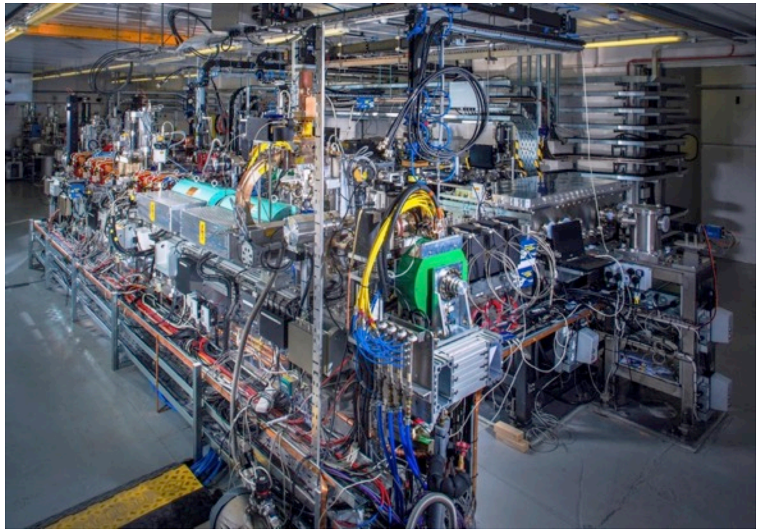
Horizon 2020

Primary contribution through Excellence Centre (in CDR)

- Prototyping & Delivery of Application Beamlines (Betatron, high-& low-energy positrons, Gamma, Compton..): 91,570 k€
- Individual contributions from institutions to different clusters
- Coordinated by UK's Plasma Wakefield Accelerator Steering Committee (PWASC)

Potential Additional Contributions from the UK (through additional funding)

- Part 1: A LWFA-based user facility in EPAC for applications in 2024
- Part 2: A EuPRAXIA-driven technology development programme towards plasma-based X-FEL-ready beams
  High-rep rate (>100Hz), high-brightness, high-quality beams for plasma-based X-FELs



Slide from R. Pattahil et al

EuPRAXIA @ EPAC

A potential flagship international research facility for propelling laser-driven plasma accelerators to transformative real-world applications

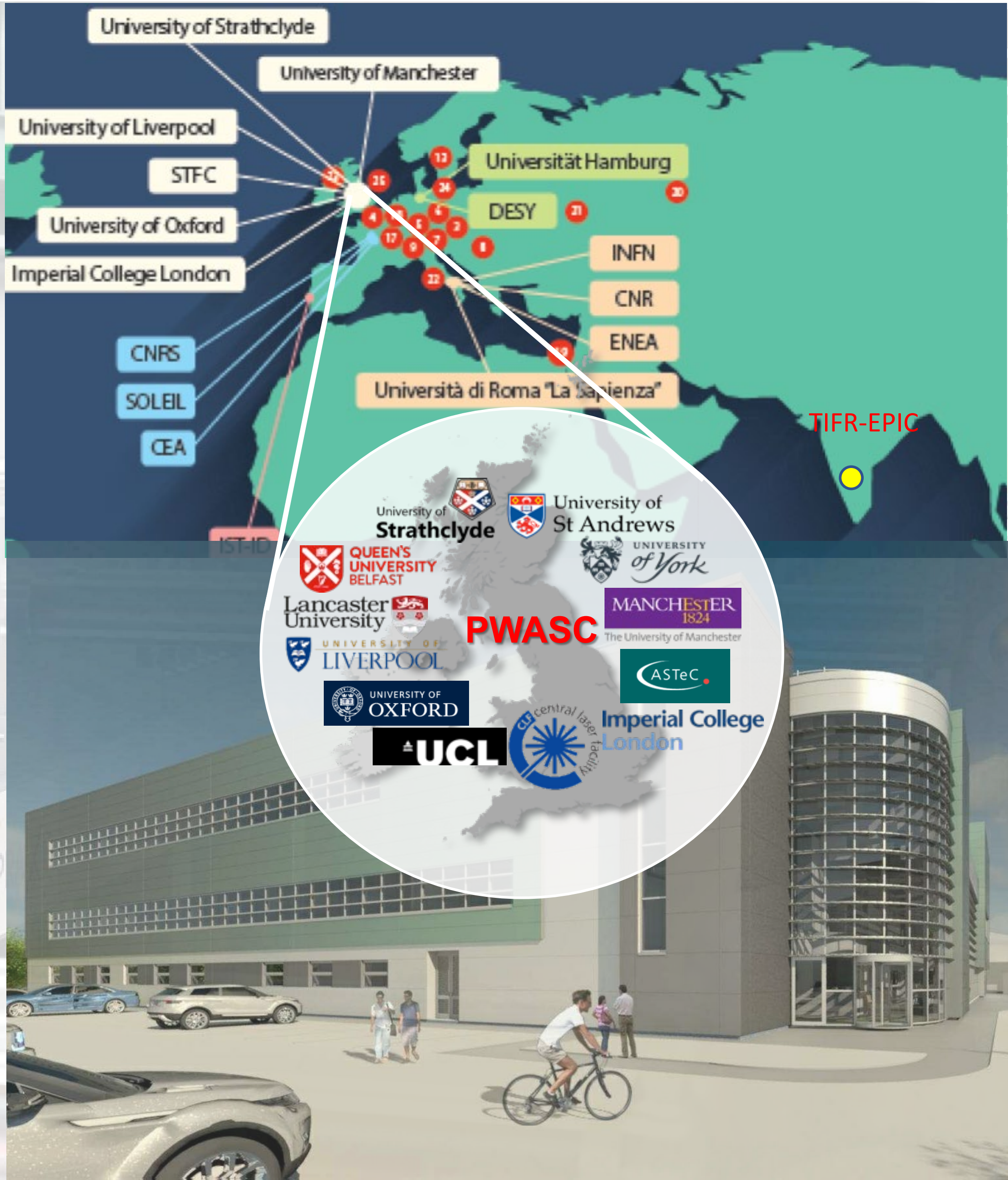
A distributed Infrastructure Proposal to combine EPAC with EuPRAXIA, for establishing the laser-driven arm of EuPRAXIA in the UK

First phase: developing EuPRAXIA-beamlines in collaboration with Universities and Accelerator institutes: £59M

Develop a 100Hz laser driver (technology development program exists already)

In the second phase (post-2024), expand the EPAC building to house the additional beamlines for EuPRAXIA

Infrastructure proposal submitted to UKRI



Science and Technology Facilities Council

Slide from R. Pattahil et al

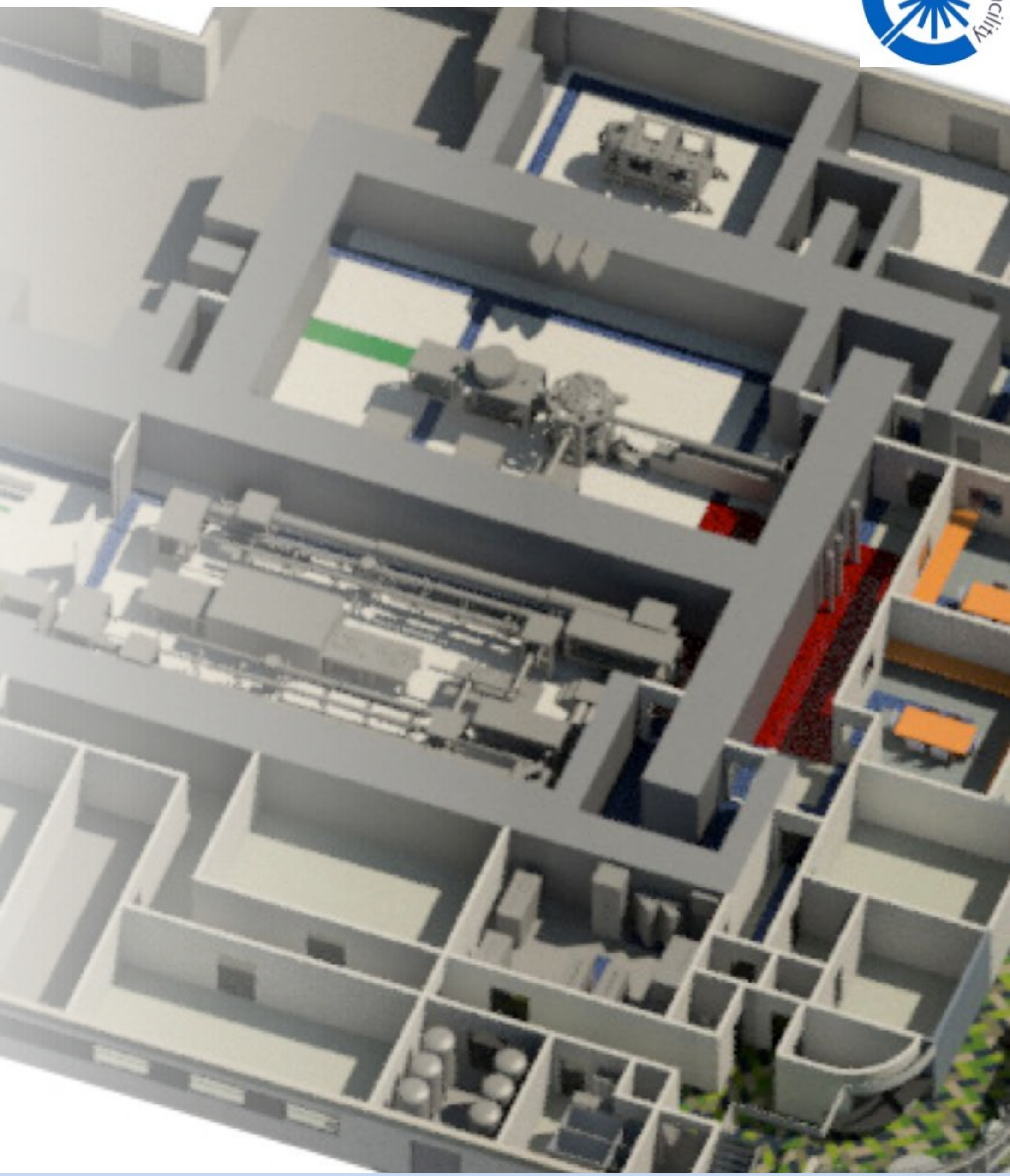
EuPRAXIA @ EPAC

- EPAC's spec (PW@10Hz) is very close to EuPRAXIA baseline (PW@20Hz)

- A dedicated facility for LWFA applications – hitting several EuPRAXIA milestones

- EPAC will be operational in 2024 – during EuPRAXIA construction period

- With EU funding, this could be a de-risking option for EuPRAXIA: technological & facility operations

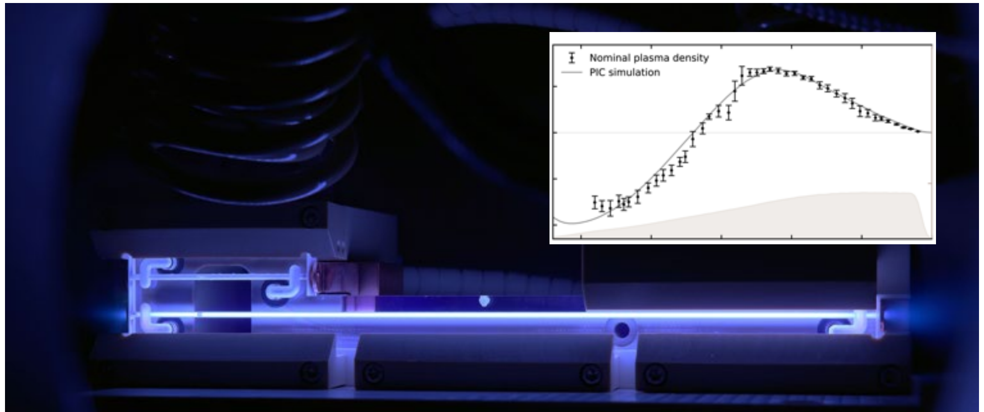


Slide from R. Pattahil et al

Excellence Centre for Plasma Accelerators and High Repetition Rate Developments at DESY

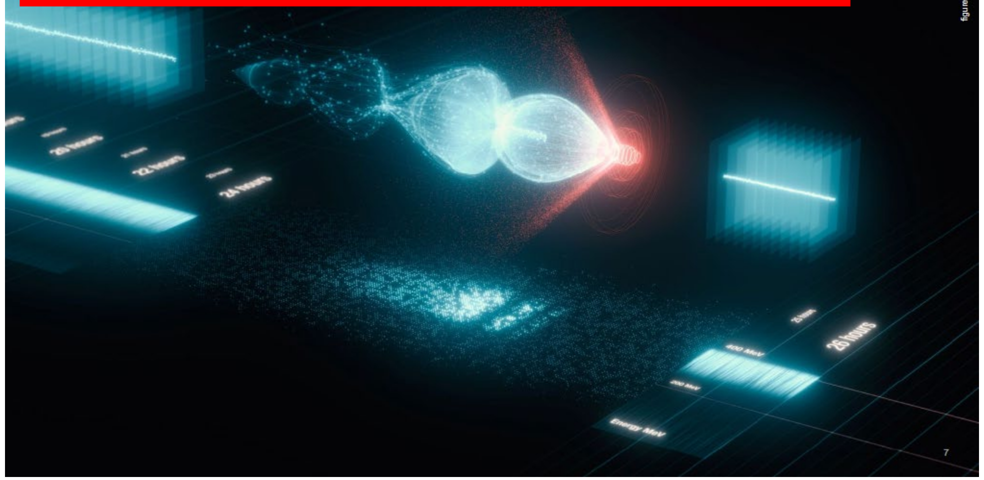
Horizon 2020

- **Plasma accelerators at DESY are progressing toward high beam quality, high average power, and applications**
- **Ongoing technology R&D will be important for integration at EuPRAXIA**
- **Key DESY facilities involved**
  - **FLASHForward►►: 10 kW, 1.2 GeV FEL-quality electron drive beam, user-facility-grade feedbacks, and advanced diagnostics**
  - **KALDERA: kHz, kW drive laser and laser-plasma accelerator, accelerator-grade control-system integration, and stability systems**
- **Research targeted at beam-quality conservation, high efficiency, high avg. power, stability, intelligent controls, and applicability**
- **10-year development roadmap in place**



Wakefield Sampling
S.Schröder *et al.*, accepted, Nat. Commun. (2020)

24-hour Operation
A.R.Maier *et al.*, Phys. Rev. X 10, 031039 (2020)



For further information, please contact jens.osterhoff@desy.de

Hungarian user's interests

PÉCSI TUDOMÁNYEGYETEM
UNIVERSITY OF PECS

Institute of Physics:

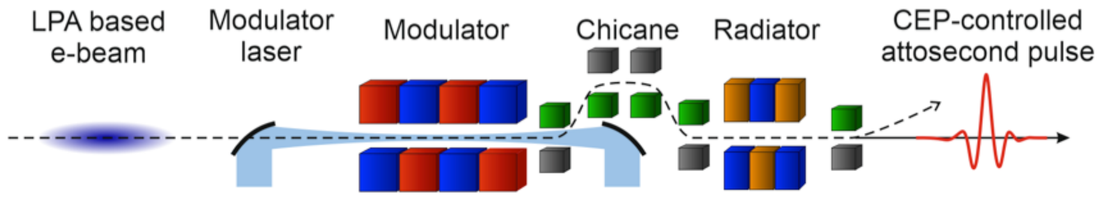
The group has leading role in the high-field THz generation by optical rectification. Near single cycle THz pulses with well controlled waveform can be generated at the 0.3-0.7 THz frequency range. The pulses have excellent focusability and around 0.5 MV/cm field strength is available. Using the setups newly proposed by the group, even higher ~10 MV/cm electric field will be available in the near future. These pulses could be used for streaking and other dynamic manipulation of electrons. The group owns US patents for manipulating charged particles with terahertz radiation.

J. Hebling et al., Opt. Express 10(21), 1161–1166 (2002), L. Pálfalvi et al., Opt. Express 25(24), 29560–29573 (2017), Gy. Tóth et al., Opt. Express 27(21), 30681-30691 (2019)

Interest: Carrier-envelope-phase (CEP) stable attosecond pulse generation:

Generation of extreme ultraviolet pulses with attosecond duration is nowadays routinely possible by high-order harmonic generation. However, a precise waveform control is difficult with this technique. Therefore, we proposed a device for producing CEP controlled single-cycle attosecond pulses in the EUV–VUV spectral range, which utilizes a LINAC or laser-plasma-based electron accelerator (the optimum electron energy is 1-2 GeV), a modulator undulator, and a radiator undulator. The waveform of the attosecond pulses can be engineered by the choice of the magnetic field distribution in the radiator undulator. Generation of both linearly and circularly polarized single-cycle attosecond pulses with up to 60 nJ energy and 90–400 attosecond duration in the 30–120 nm wavelength range are predicted by numerical simulation. We would like to perform proof-of-principle experiment in the EuPraxia project.

Z. Tibai et al., Phys. Rev. Lett. **113**, 104801 (2014) (basic consideration)
Z. Tibai et al., Frontiers in Phys., 6, 140, (2018) (detailed numerical investigation)
Gy Tóth et al., JOSA B, 35(5), A103 (2018) (extension of the technique for producing circularly polarized pulses)
Z. Tibai et al., Applied Physics B, **124,** 113 (2018) (laser plasma accelerator based electron source)



Slide from I. Barna et al

Albert Szent-Györgyi HEALTH CENTER

UNIVERSITY OF SZEGED
FACULTY OF MEDICINE
DEPARTMENT OF ONCOTHERAPY

Veritas Virtus Libertas

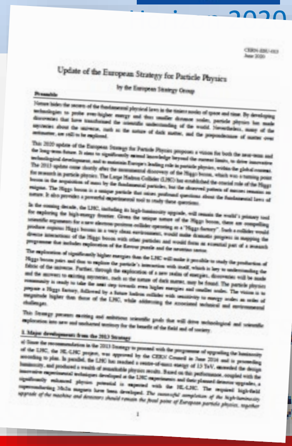
University of Szeged, Department of Oncotherapy:
The department has gained expertise in cancer treatment based on different types of radiation therapies, including novel approaches under clinical evaluations, e.g. hadron therapy, mixed energy radiotherapy or immuno-radiotherapy. It is also committed in testing and developing novel approaches under preclinical evaluations, like FLASH-Radiotherapy (FLASH-RT), Microbeam Radiation Therapy (MRT) for example, shows promising results in minimizing the side effects of radiotherapy, i. e. it lets the applied dose to be increased drastically without the patient having post-treatment complications. A 17 Gy conventional irradiation induced pulmonary fibrosis in 100% of the animals 24-36 weeks post-treatment, whereas no animal developed complications below 23 Gy flash RT. The FAST-01 (FeAsibility Study of FLASH Radiotherapy for the Treatment of Symptomatic Bone Metastases) clinical study was launched 12. Oct 2020.
Synchrotron-based MRT composed of spatially fractionated, planar x-ray (50-600keV) 25-75 micron-wide beams, with a very sharp penumbra, separated by a distance several times of their beam width. These microbeams create unique dose profiles of alternating peaks and valleys with high peak-to-valley-dose-ratios (PVDR). They can be produced in highly brilliant synchrotron sources and are characterised with very small beam divergence and extremely high dose rate, >100 Gy/s.

Favaudon V, Fouillade C, Vozenin MC ***Ultrahigh dose-rate, "flash" irradiation minimizes the side-effects of radiotherapy]*** *Cancer Radiother. 2015 Oct;19(6-7):526-31*
M.-C. Vozenin, P. De Fornel, K. Petersson, V. Favaudon, et al ***The advantage of FLASH radiotherapy confirmed in mini-pig and cat-cancer patients*** *Clin Cancer Res 2018*
Bourhis J, Sozzi WJ, Jorge PG, Gaide O, Bailat C, Duclos F, et al. Treatment of a first patient with FLASH-radiotherapy. Radiother Oncol 2019; 139: 18–22.
Zhang et al. Expert Rev Anticancer Ther. 2015 December

Interests:
Laser driven VHEE (Very High Energy Electron beams) can produce compton and betatron photons that are feasible for MRT. Ultraintense beam and ultrashort dose delivery results in short treatment time, and in general, in a treatment without increased entrance (skin) dose. There is no need for internal organ motion management. Since the EuPRAXIA electron beams make accessible high temporal and spatial resolution, the instrument would be ideal to perform immuno-RT, FLASH-RT and MRT treatments. In vivo an in vitro proof-of-principle experiments in MRT therapy.

Slide from I. Barna et al

2020 Update of European Strategy for Particle Physics



Update had input from the European Network for Novel Accelerators (EuroNNAc), EuPRAXIA, ALEGRO, AWAKE, ... on novel accelerators.

b) Innovative accelerator technology underpins the physics reach of high-energy and high-inter . It is also a powerful driver for many accelerator-based fields of science and industry. The techn r consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. *The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.*

Success for our community, including EuPRAXIA → An expert panel has been formed for proposing an HEP-oriented R&D roadmap for plasma accelerators (chairs: R. Assmann & E. Gschwendtner)

In Discussion: Structure EuPRAXIA HQ at LNF/INFN

to be set up in 2021 – fully operational in mid-2022 for PP EU Project

Horizon 2020

Local EuPRAXIA@SPARClab

PL: Massimo Ferrario
TC: Antonio Falone
…

See organization chart by Massimo and Antonio

EuPRAXIA HQ	Tasks
Coordinator: R. Assmann	• Project coordination + management
Co-Coord: Massimo Ferrario	• Represent local LNF/INFN pillar
TC: Antonio Falone	• Planning
HQ Office Manager: G. Vinicola	• eurpraxia-admin@infn.it, calendar, events, contact point, coordinate technical EU reporting, central documentation
Financial Officer: xxx	• Financial planning, coordinate financial EU reporting, EU funding programs
Outreach/PR Officer: xxx	• Communications, web page, newsletter, publications followup, local outreach (also politics, embassies)
Implementation Officer: xxx	• Governance model EuPRAXIA RI
Lead Science Officer: xxx	• EuPRAXIA science and user outreach
HQ scientists: xxx, xxx	• Work on EuPRAXIA solutions with WP's

Structure and all names tentative. Need to be agreed and approved at LNF and EuPRAXIA collaboration board.

→ 40+10 institute consortium, governing board, steering committe

Conclusion

- Collaboration of **41 institutes** produced a conceptual design report, now also published as peer-reviewed book in **EPJ**.
- EuPRAXIA is a **unique chance for Europe** in new technology.
- During course of project > 200 M€ funding approved in national projects of EuPRAXIA partners.
- New consortium agreement with **50 institutes** signed. **EuPRAXIA headquarters** moved to Frascati.
- **ESFRI proposal** submitted and found eligible! Now in review.
- Next: *2021 decision for ESFRI, preparatory phase project, decision laser-driven site in 2023, TDR in 2025. In parallel: Legal and financial model*.

600+ page CDR, 240 scientists contributed

Some Quotes from Support Letters

(from 32 non-governmental support letters)

Horizon 2020

“...a fantastic opportunity for the **regional scientific development** as it would provide state-of-the-art facilities for education and training of the **young community**...” (TIARA)

“...truly European project that realizes a **major competitive advantage, strong scientific impact, and important societal benefits**.” (LEAPS)

“...is timely and has an extremely high potential for **strengthening the European position in a world-wide highly competitive landscape**.” (Thales)

“...**tackles the need for compact and cost-effective particle and radiation sources** for research and industry, as not yet addressed elsewhere at a European level.” (AVS)

Many thanks to all our supporters from local government, interest organizations, industry, universities and research organizations! This is extremely encouraging and valuable support!

It supports our view that there can be a very strong societal impact of such a European infrastructure on compact plasma accelerators!

Thank you

Many thanks to I. Barna, P. Campana, K. Cassou, B. Cros, A. Falone, A. Ferran Pousa, M. Ferrario, L. Gizzi, A.Molodozhentsev, P. Nghie, J. Osterhoff, R. Pattahil, A. Specka, J. Viera for help with the preparation of this talk, provision of slides and material..

Many apologies to my colleagues and the many outstanding results, contributions and infrastructures I could not mention today!

Many thanks to our consortium members and involved management for their untiring support to EuPRAXIA and help to form the new consortium!

Special thanks to P. Campana, A. Zoccoli, L. Silva, J. Viera, G. Korn, R. Hvezda, P. Levai, R. Pattahil, M. Thomson for help on obtaining the governmental support letters .

Special thanks to Maria Weikum, Massimo Ferrario, Pierluigi Campana, Antonio Falone and Franck Brottier for the ESFRI roadmap application support.