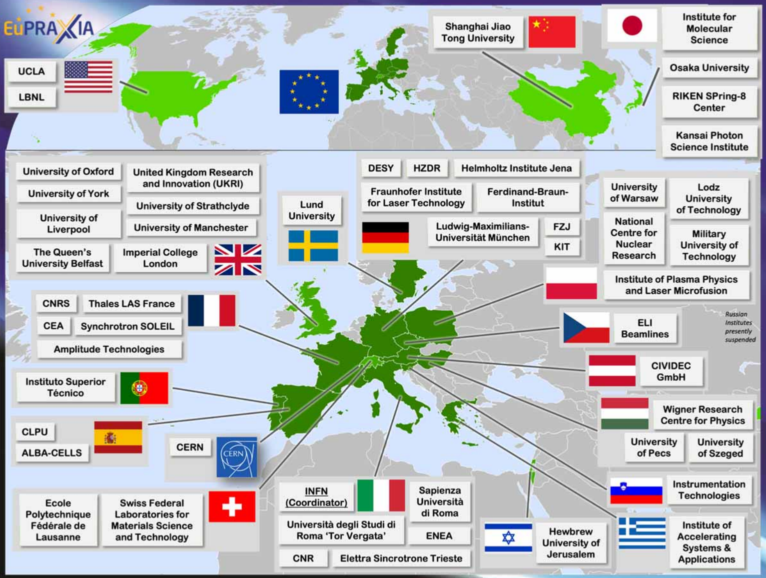
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

http://www.eupraxia-facility.org/



EuPRAXIA: The First FEL User Facility Driven by a Plasma Accelerator

R. Assmann, INFN

Future Light Sources (FLS) Workshop

Luzern, Switzerland, 28 Aug 2023

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

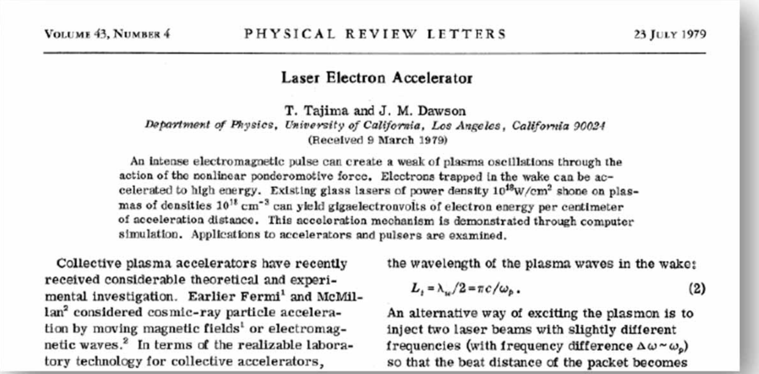
New Technology: Plasma Accelerators I

Overcome high-field limitations of metallic walls with dynamic plasma structures (undestructible)

New **idea in 1979 by Tajima and Dawson**: Wakefields inside a homogenous plasma can convert

transverse forces into **longitudinal accelerating fields**

Ponderomotive force of a laser pulse and restoring force of ion channel	or	Space charge force of a charged particle bunch (e-, p+) and restoring force of ion channel		Accelerating gradients of 10 GeV/m to 1,000 GeV/m


VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

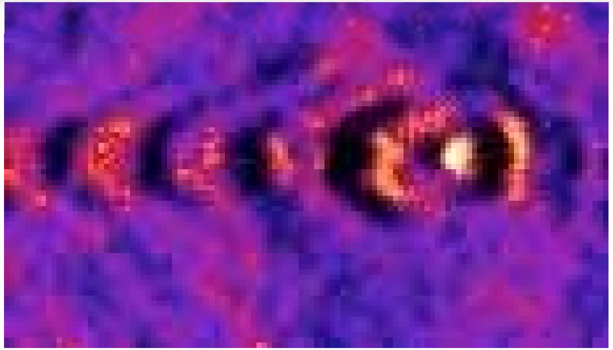
An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

Collective plasma accelerators have recently received considerable theoretical and experimental investigation. Earlier Fermi[1] and McMillan[2] considered cosmic-ray particle acceleration by moving magnetic fields[1] or electromagnetic waves.[2] In terms of the realizable laboratory technology for collective accelerators,

the wavelength of the plasma waves in the wake:

$$L_t = \lambda_w/2 = \pi c/\omega_p. \quad (2)$$

An alternative way of exciting the plasmon is to inject two laser beams with slightly different frequencies (with frequency difference $\Delta\omega \sim \omega_p$) so that the beat distance of the packet becomes



Courtesy M. Kaluza

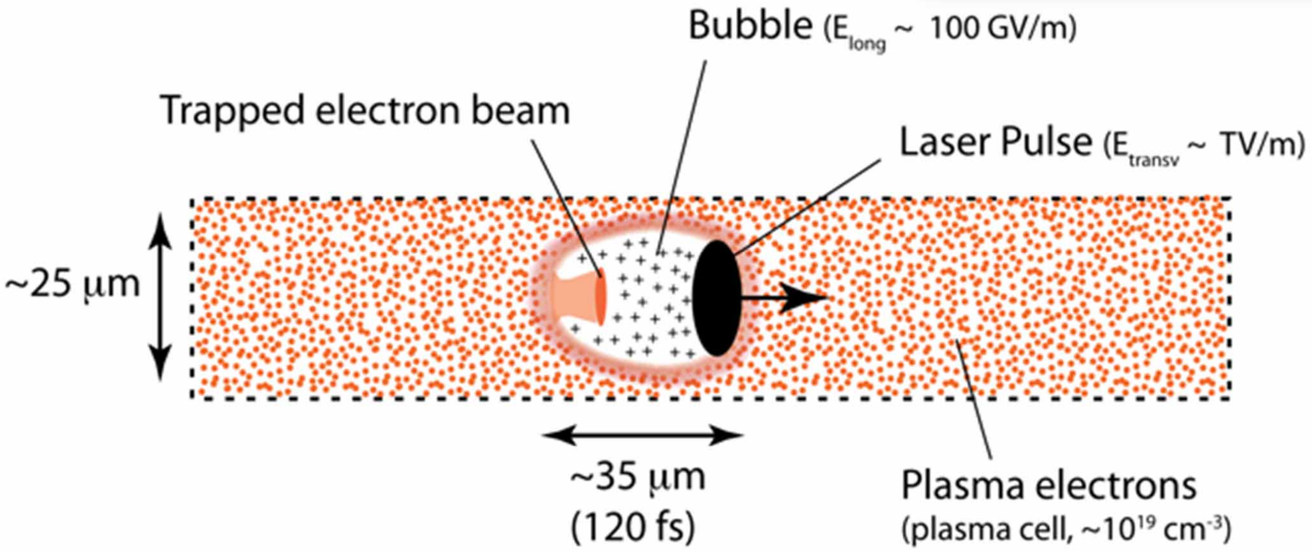
Options for driving wakefields:

- **Lasers**: Industrially available, steep progress, path to low cost
  Limited energy per drive pulse (up to **50 J**)
- **Electron bunch**: Short bunches (need μm) available, need long RF accelerator
  More energy per drive pulse (up to **500 J**)
- **Proton bunch**: Only long (inefficient) bunches, need very long RF accelerator
  Maximum energy per drive pulse (up to **100,000 J**)

New Technology: Plasma Accelerators II

Funded by the European Union

This accelerator fits into a human hair



Like wakes left behind by a boat in water

Plasma Accelerator: Natural Photon Source

Funded by the European Union

Wiggling electrons emit X rays → a plasma accelerator as accelerator and undulator at once

Electrons travel in the ion channel of the plasma accelerator:

→ experience ultra-strong transverse focusing forces, they oscillate and **emit photons**

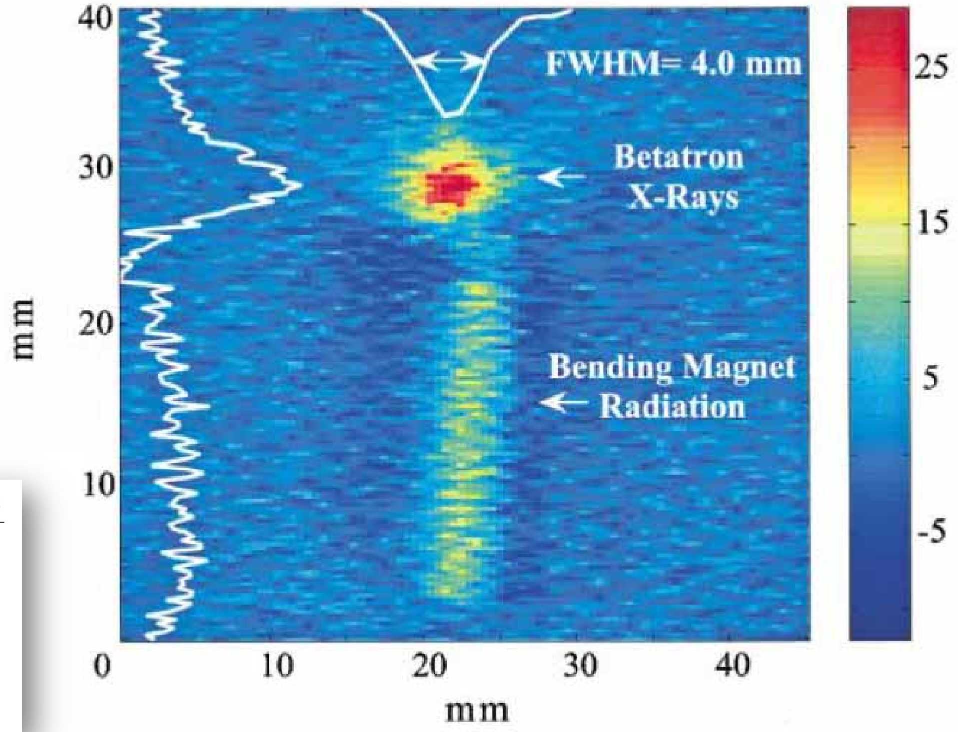
Can enhance with beta mismatch oscillations of the beam size or offsets.

We studied this in 2002 at SLAC.

VOLUME 88, NUMBER 13 PHYSICAL REVIEW LETTERS 1 APRIL 2002

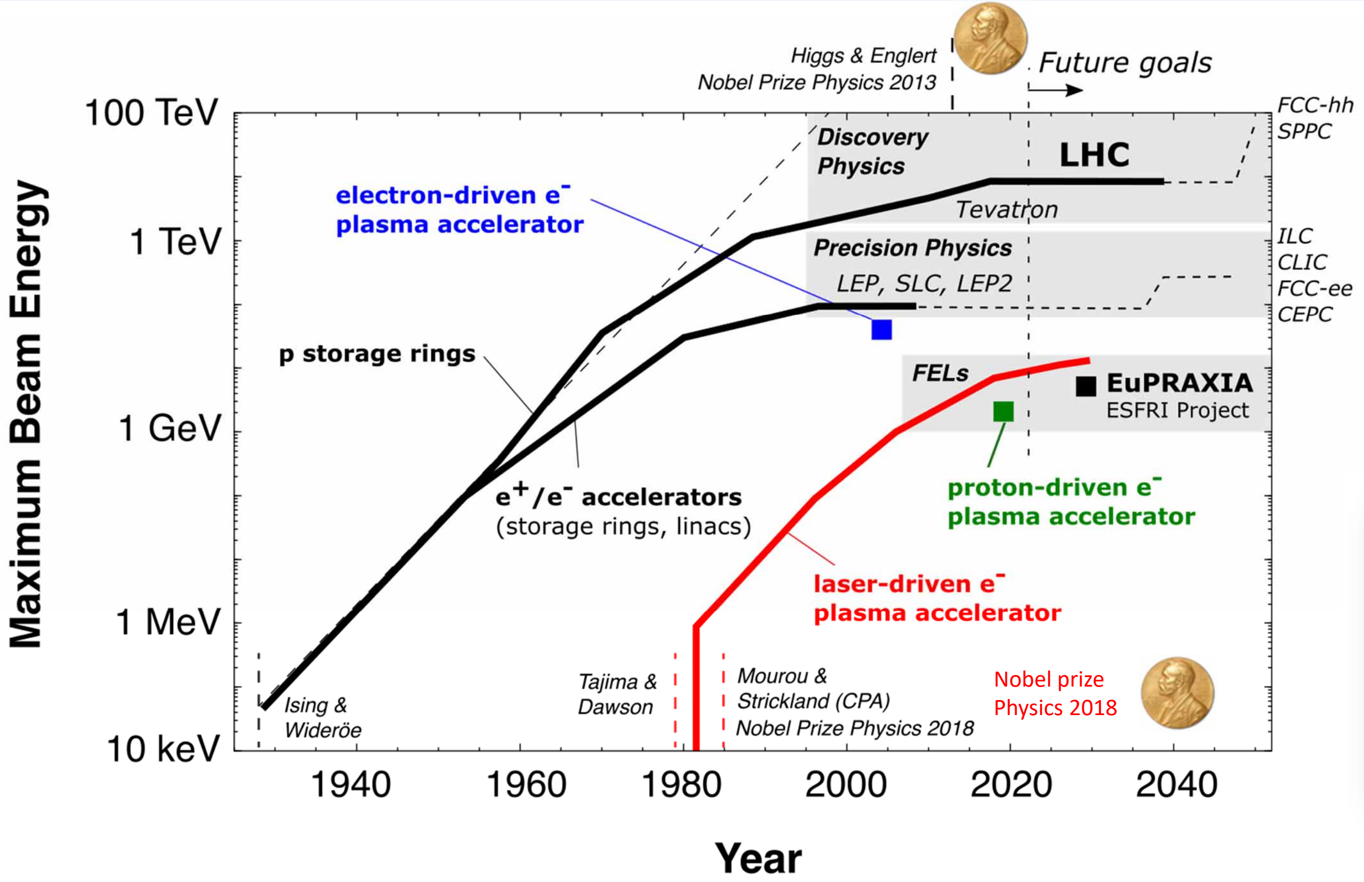
X-Ray Emission from Betatron Motion in a Plasma Wiggler

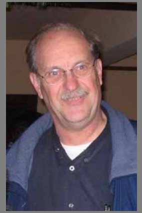
Shuoqin Wang,[1] C. E. Clayton,[1] B. E. Blue,[1] E. S. Dodd,[1] K. A. Marsh,[1] W. B. Mori,[1] C. Joshi,[1] S. Lee,[2] P. Muggli,[2] T. Katsouleas,[2] F. J. Decker,[3] M. J. Hogan,[3] R. H. Iverson,[3] P. Raimondi,[3] D. Walz,[3] R. Siemann,[3] and R. Assmann[4]
[1]*University of California, Los Angeles, California 90095*
[2]*University of Southern California, Los Angeles, California 90089*
[3]*Stanford Linear Accelerator Center, Stanford, California 94309*
[4]*CERN, Switzerland*
(Received 8 October 2001; published 19 March 2002)



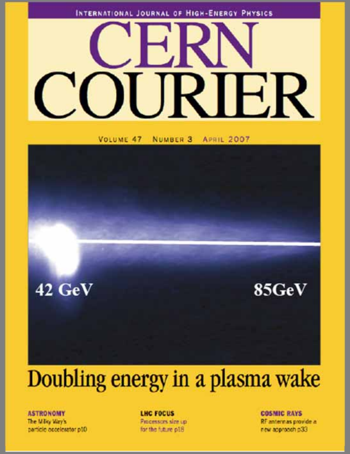
Progress in Particle Accelerators: New Technology

Funded by the European Union



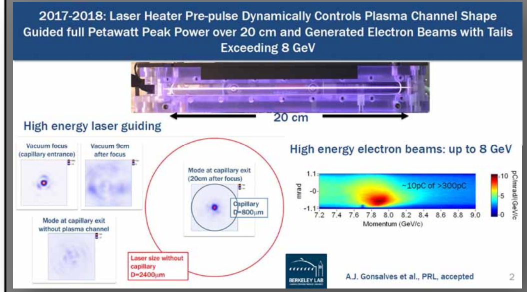


Bob Siemann, SLAC



E167 collaboration SLAC, UCLA, USC

I. Blumenfeld et al, Nature 445, p. 741 (2007)

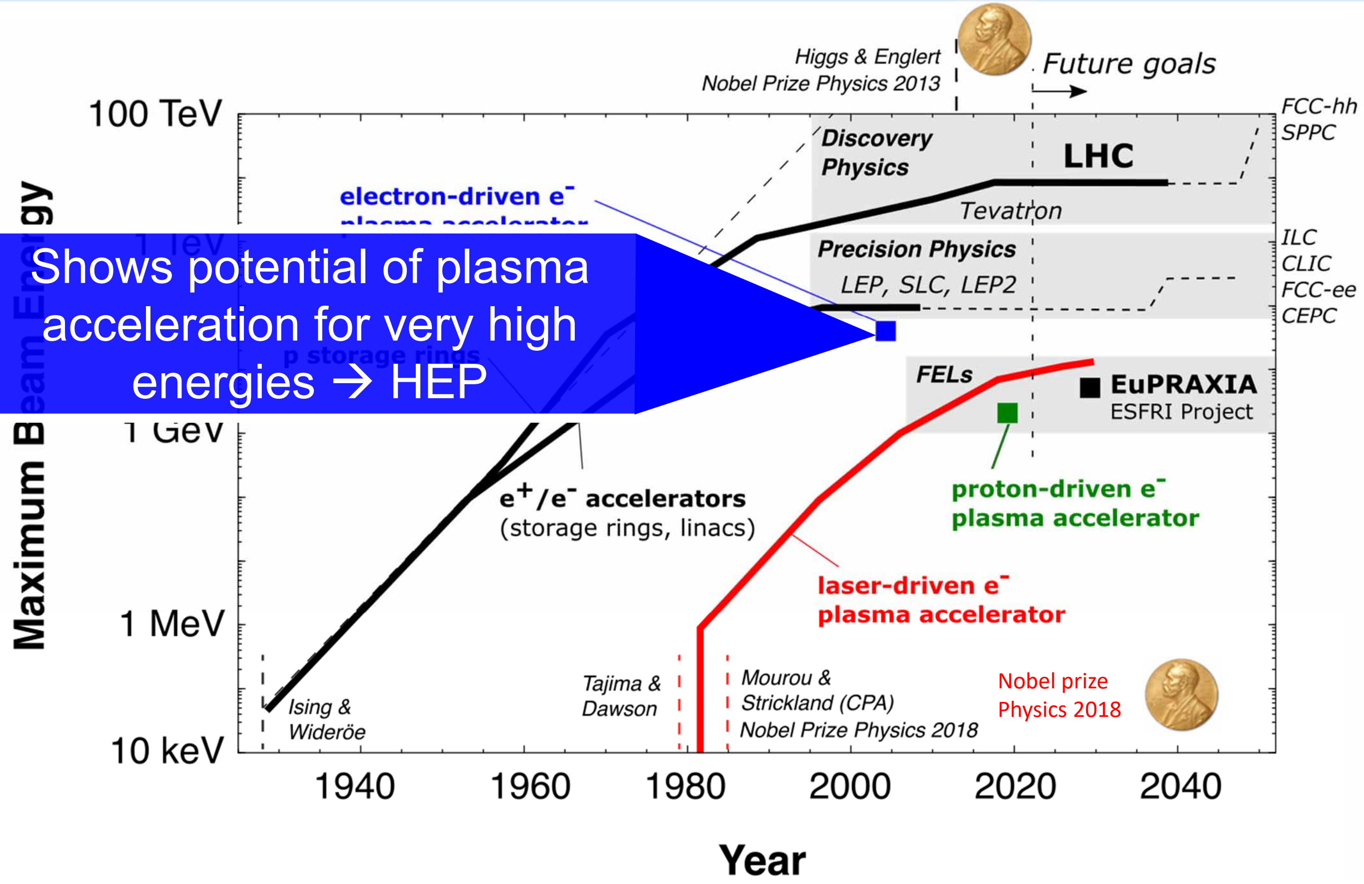


LBNL and collaborators

Gonsalves et al, PRL 122, 084801 (2019)

Progress in Particle Accelerators: New Technology

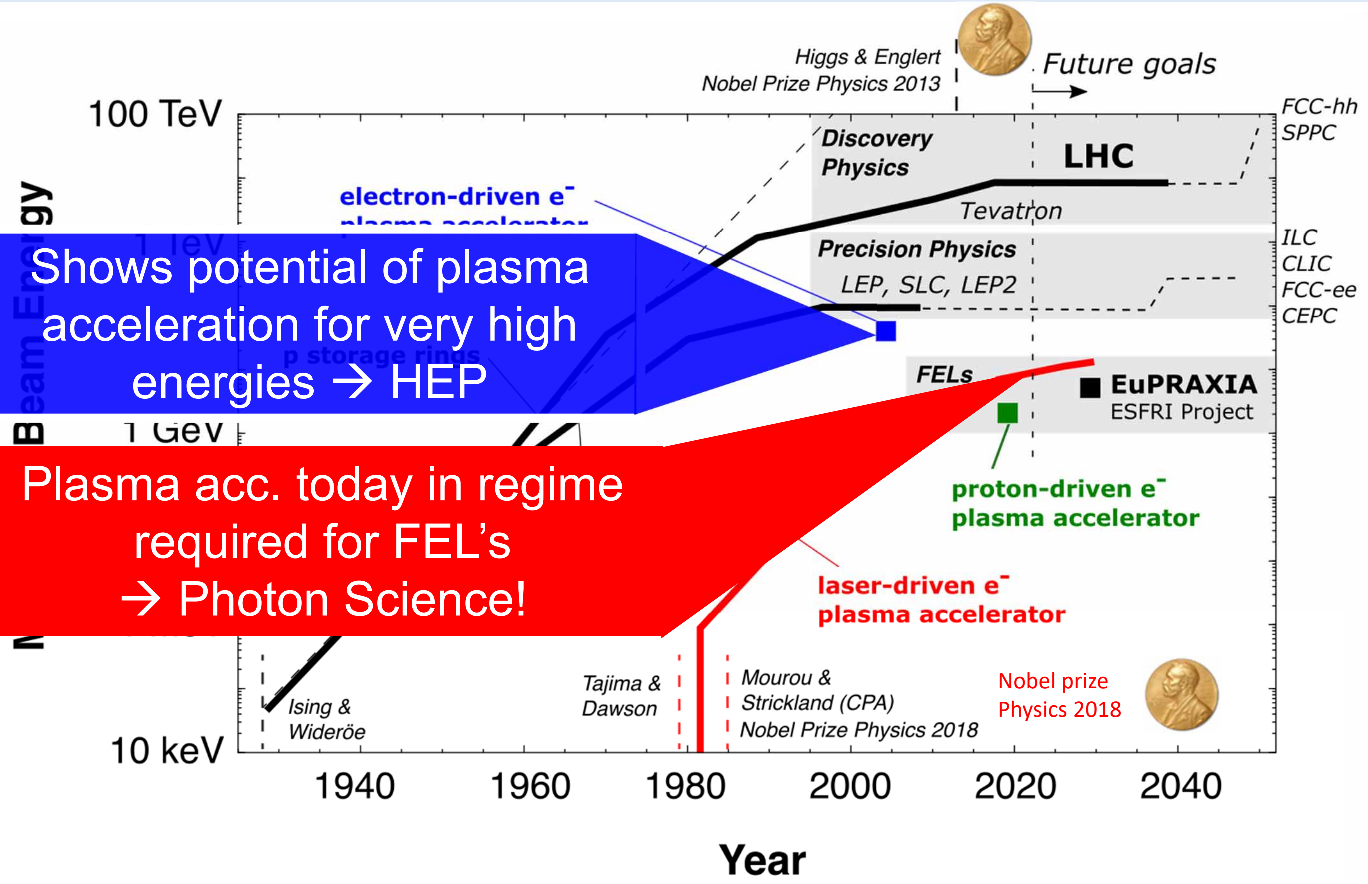
Funded by the European Union



Shows potential of plasma acceleration for very high energies → HEP

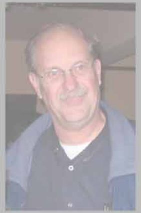
Progress in Particle Accelerators: New Technology

Funded by the European Union



Shows potential of plasma acceleration for very high energies → HEP

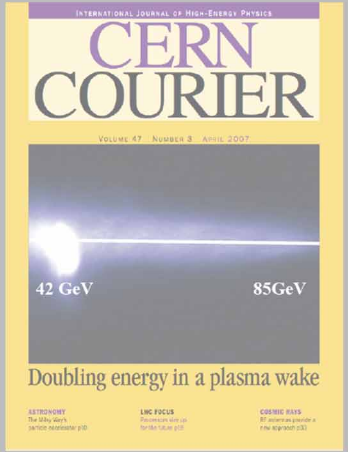
Plasma acc. today in regime required for FEL's → Photon Science!

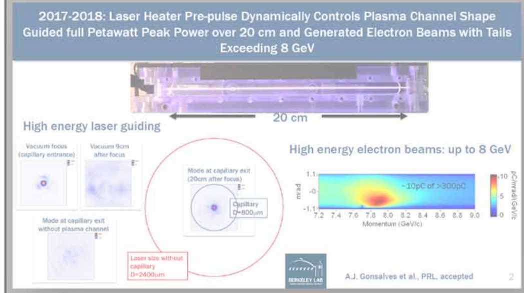


Bob Siemann, SLAC

E167 collaboration SLAC, UCLA, USC

I. Blumenfeld et al, Nature 445, p. 741 (2007)



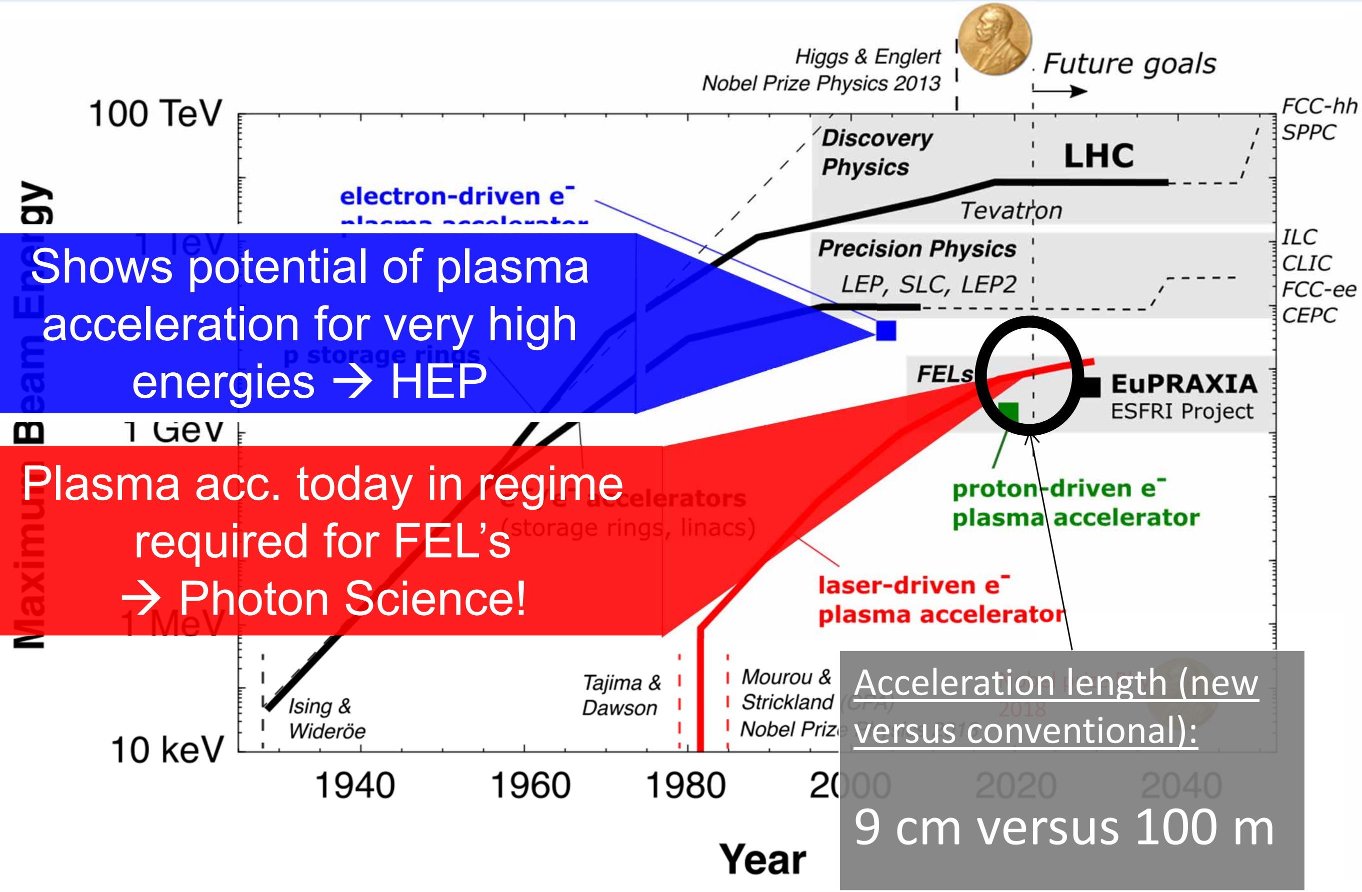


LBNL and collaborators

Gonsalves et al, PRL 122, 084801 (2019)

Progress in Particle Accelerators: New Technology

Funded by the European Union

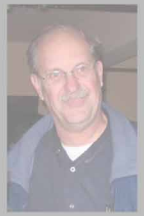


Shows potential of plasma acceleration for very high energies → HEP

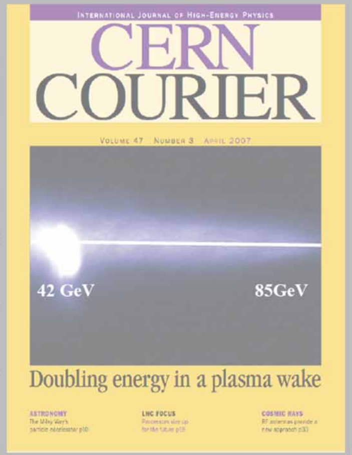
Plasma acc. today in regime required for FEL's → Photon Science!

Acceleration length (new versus conventional):

9 cm versus 100 m

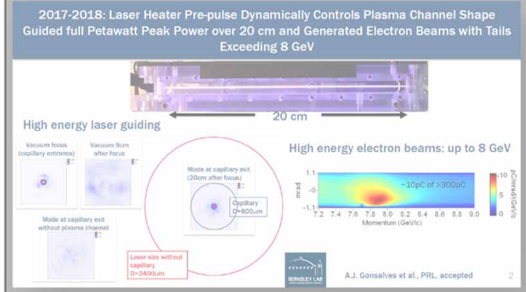


Bob Siemann, SLAC



E167 collaboration SLAC, UCLA, USC

I. Blumenfeld et al, Nature 445, p. 741 (2007)



LBNL and collaborators

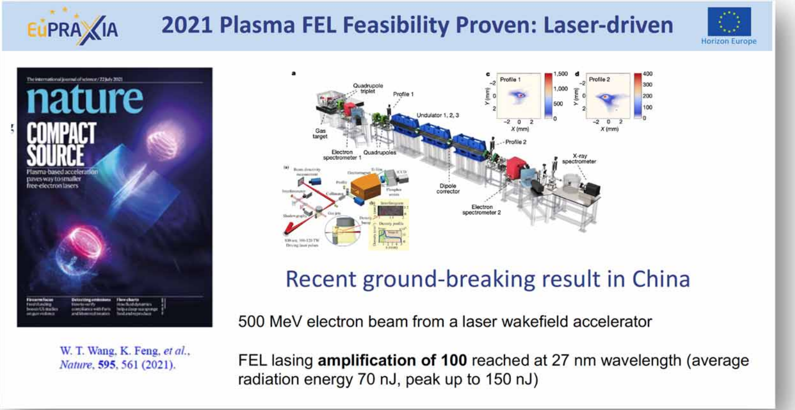
Gonsalves et al, PRL 122, 084801 (2019)

Major Experimental Demonstrations

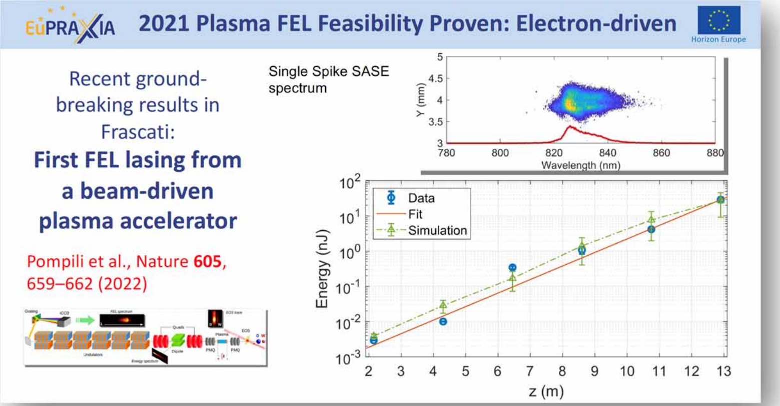
for both laser-driven (LWFA) and beam-driven (PWFA) plasma acc.

Funded by the European Union

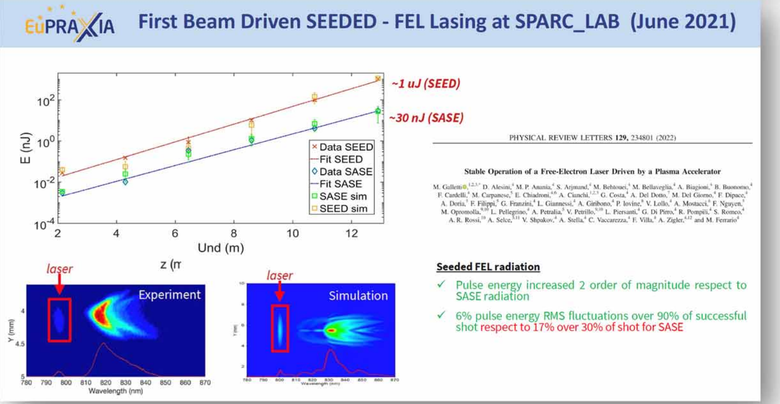
2021:
LWFA
FEL
Shanghai, China
Nature



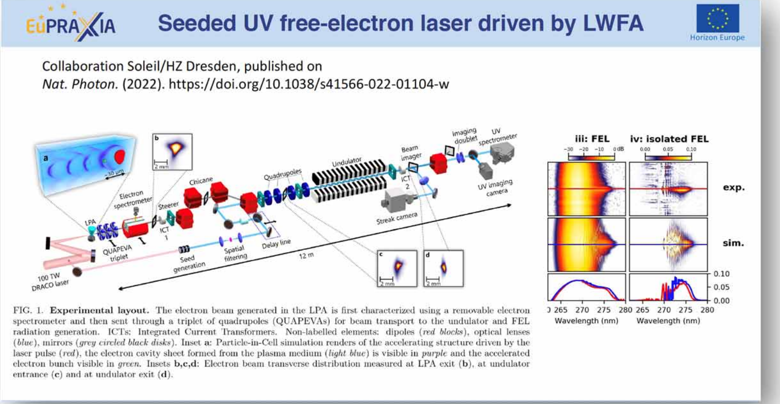
2021:
PWFA
FEL
LNF/INFN
Italy
Nature



2021:
PWFA
seeded
FEL
LNF/INFN
Italy
PRL



2022:
LWFA
seeded
FEL
HZDR,
Soleil, …
Germany
France
Nat. Phot.



The EuPRAXIA Project

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

Funded by the European Union

- 1st ever design of a **plasma accelerator facility**. 1st **ESFRI** plasma acc. project. 1st ESFRI acc. project since 2016.
- **Conceptual Design Report for a distributed research infrastructure** funded by EU Horizon2020 program. Completed by 16+25 institutes.
- Challenges addressed by EuPRAXIA since 2015:
  - **Can plasma accelerators produce usable electron beams**?
  - **For what can we use those beams**
- Next phase consortium: **> 50 institutes**
- Preparatory Phase project: **2022 – 2026** (ongoing)
- Start of 1st operation: **2028**

600+ page CDR, 240 scientists contributed

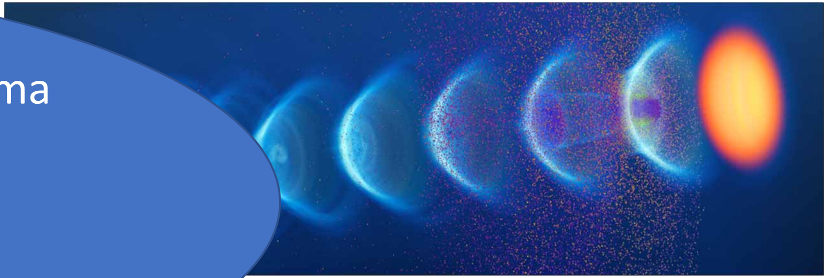
A New European High-Tech Research Facility Delivering Frontier Science

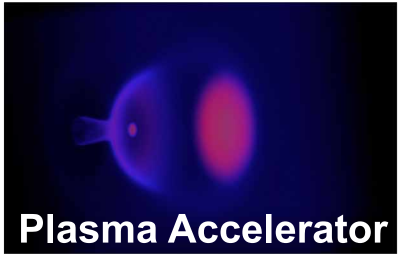
Funded by the European Union

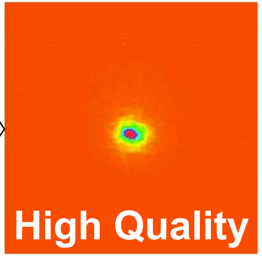
1

Building a facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

Shrink down the facility size





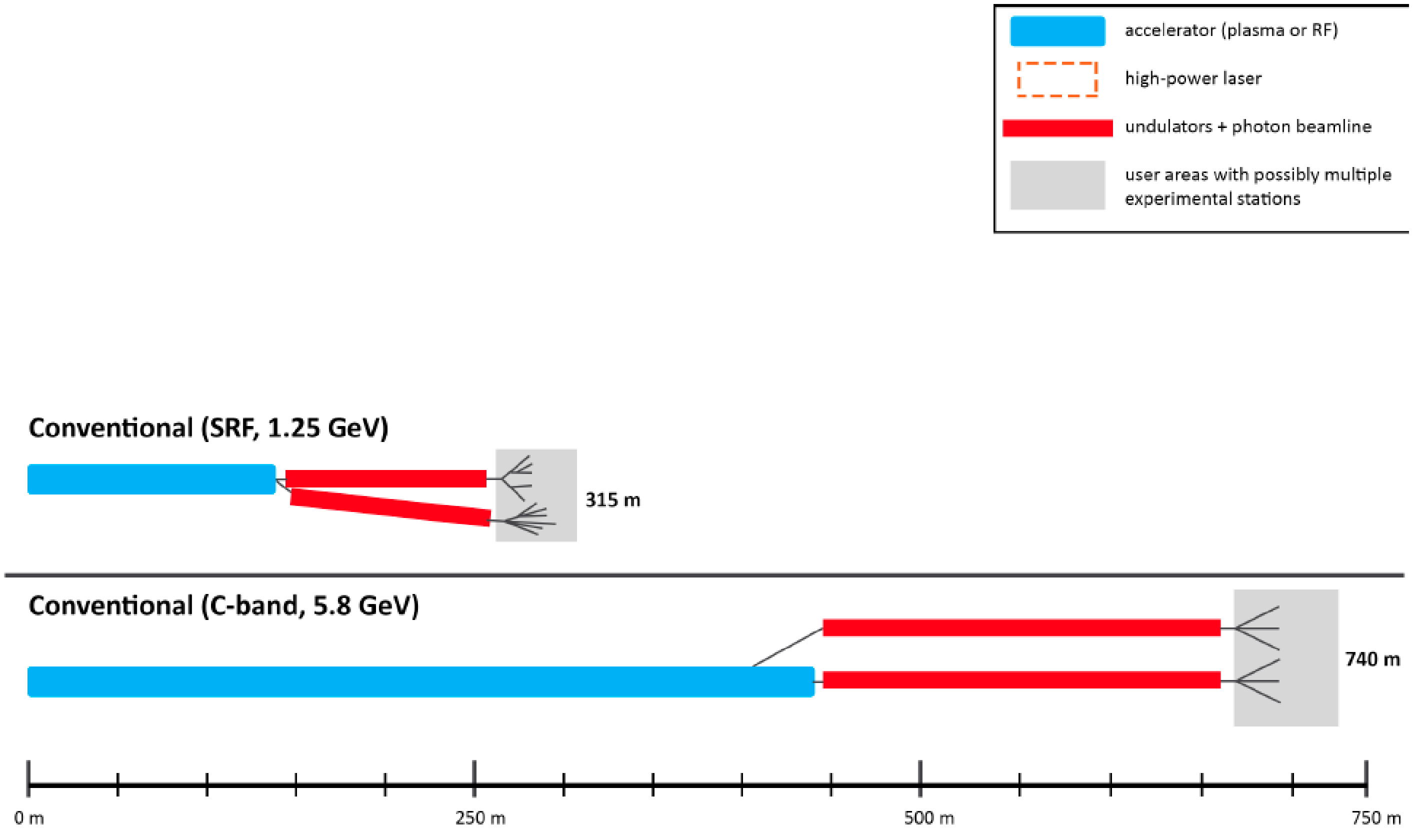


EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

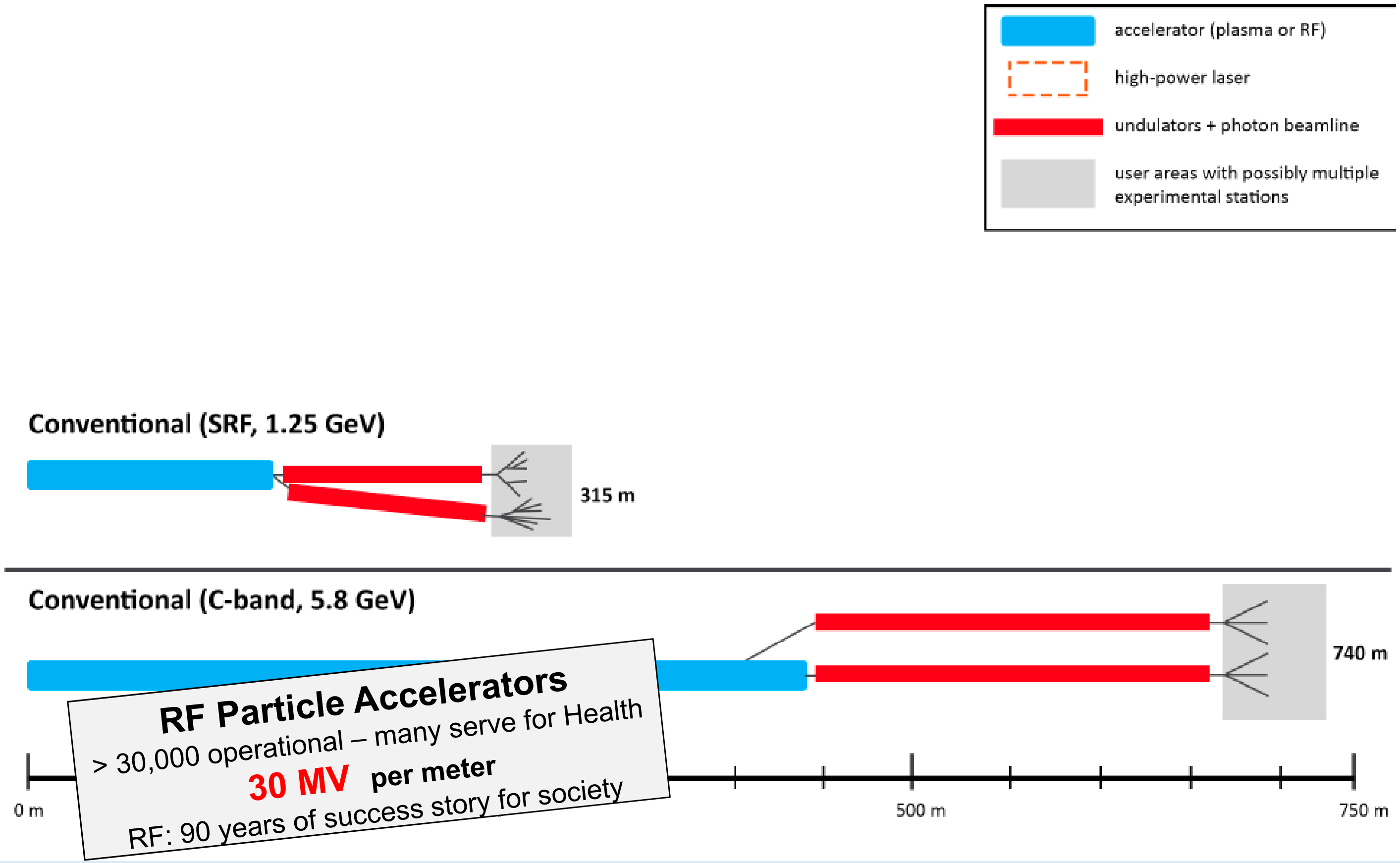
http://www.eupraxia-project.eu/

EuPRAXIA Facility Size: C O M P A C T

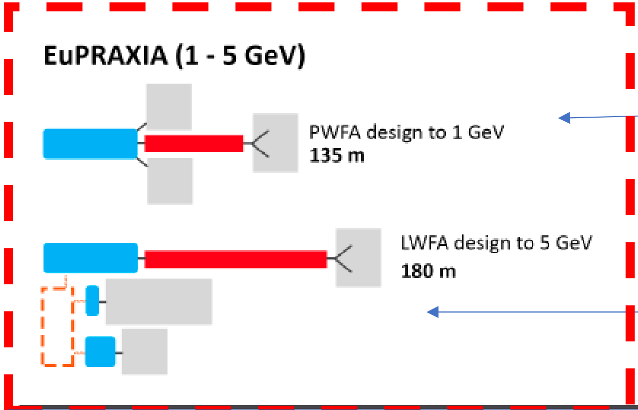
Funded by the European Union



EuPRAXIA Facility Size: C O M P A C T

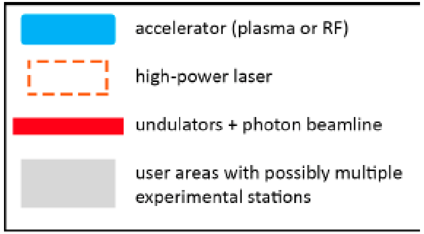


EuPRAXIA Facility Size: C O M P A C T



EuPRAXIA at Frascati

EuPRAXIA at *ELI-Beamlines or EPAC or Pisa or Salamanca or ?*



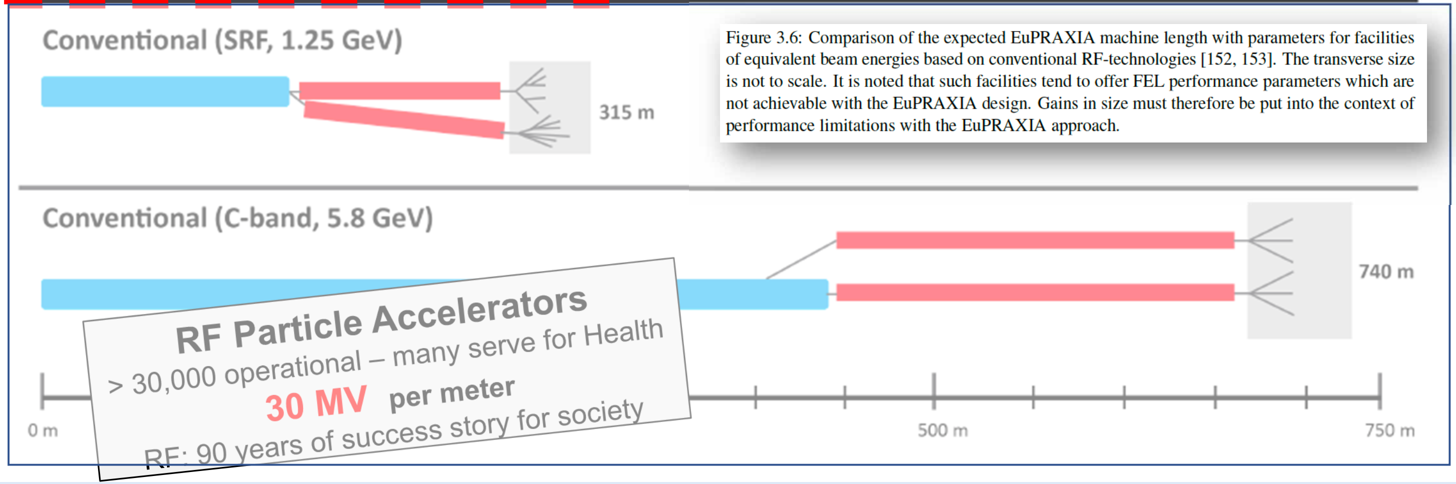


Figure 3.6: Comparison of the expected EuPRAXIA machine length with parameters for facilities of equivalent beam energies based on conventional RF-technologies [152, 153]. The transverse size is not to scale. It is noted that such facilities tend to offer FEL performance parameters which are not achievable with the EuPRAXIA design. Gains in size must therefore be put into the context of performance limitations with the EuPRAXIA approach.

- Distributed
- **2 Construction Sites**
- Several Excellence Centers

IMPORTANT:
EuPRAXIA design includes **innovative concepts & solutions** but also lab space, RF injectors, transfer lines, undulator lines, shielding, ... (the **real space** needed)

EuPRAXIA Facility Size: C O M P A C T

Funded by the European Union

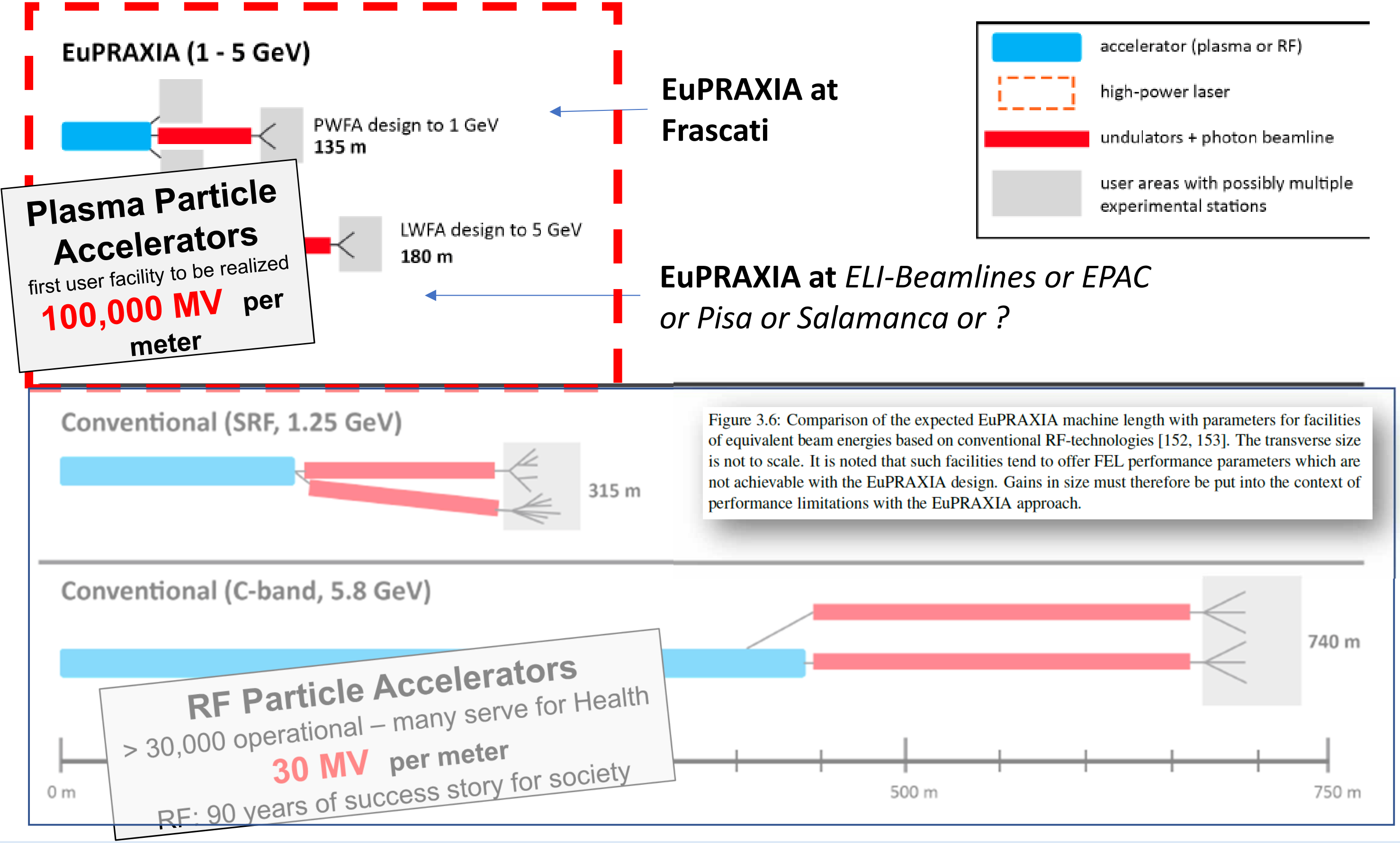


Figure 3.6: Comparison of the expected EuPRAXIA machine length with parameters for facilities of equivalent beam energies based on conventional RF-technologies [152, 153]. The transverse size is not to scale. It is noted that such facilities tend to offer FEL performance parameters which are not achievable with the EuPRAXIA design. Gains in size must therefore be put into the context of performance limitations with the EuPRAXIA approach.

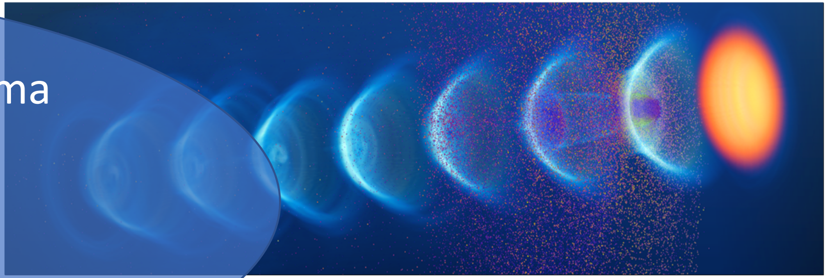
- Distributed
- **2 Construction Sites**
- Several Excellence Centers

IMPORTANT:
EuPRAXIA design includes **innovative concepts & solutions** but also lab space, RF injectors, transfer lines, undulator lines, shielding, ... (the **real space** needed)


EuPRAXIA
135 – 175 m
~35 m

A New European High-Tech Research Facility Delivering Frontier Science

Funded by the European Union



1

Building a facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

Shrink down the facility size

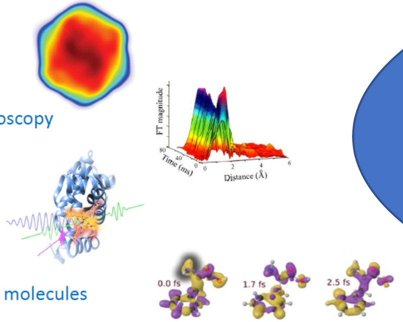
Experimental techniques and typology of samples

Coherent imaging

X-ray absorption spectroscopy

Raman spectroscopy

Photo-fragmentation of molecules

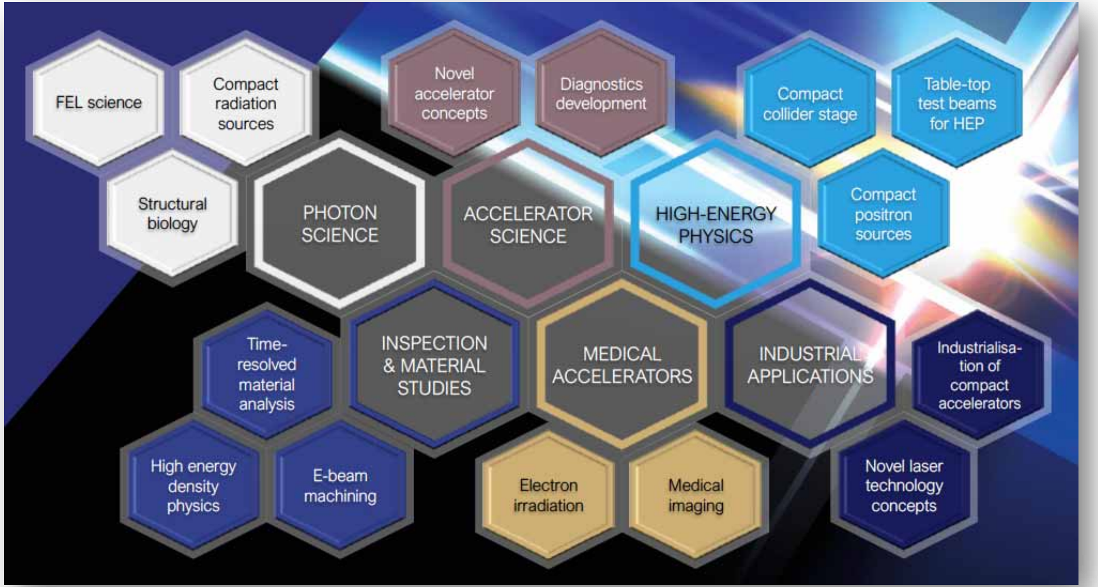


2

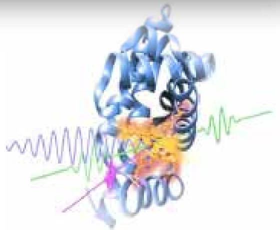
Producing particle and photon pulses to support several urgent and timely science cases

Enable frontier science in new regions and parameter regimes

Versatile – Designed for Users in Multiple Science Fields



Topics of research: proteins, viruses, bacteria, cells, metals, semiconductors, superconductors, magnetic materials, organic molecules



*Delivers 10-100 Hz **ultra-short** pulses*

- **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** (1-110 keV, 10^{10})
- **FEL light** (0.2-36 nm, 10^9-10^{13})

Achieved with Technical Innovations

Funded by the European Union

European Plasma Research Accelerator with eXcellence In Applications

Solve external timing for laser-driven plasma acc.

External injection into a laser-driven plasma accelerator with sub-femtosecond timing jitter

A Ferran Pousa[1,2], R Assmann[1], R Brinkmann[1] and A Martinez de la Ossa[1,2]

[1] DESY, 22607 Hamburg, Germany

[2] Universität Hamburg, 22761 Hamburg, Germany

E-mail: angel.ferran.pousa@desy.de

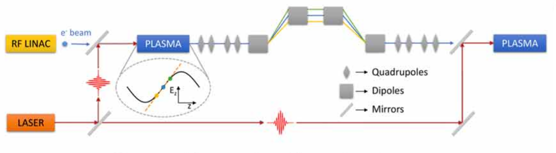


Figure 1. Schematic view of the synchronizing stage.

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

European Plasma Research Accelerator with eXcellence In Applications

Try to finally realize low energy spread…

Old proposal from Simon van der Meer

CERN/PS/85-65 (AA)
CLIC Note No. 3

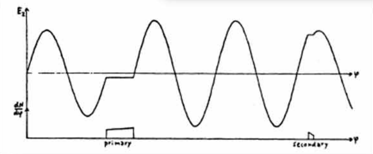
1985 van der Meer

Beam loading, energy spread and efficiency

IMPROVING THE POWER EFFICIENCY OF THE PLASMA WAKEFIELD ACCELERATOR

S. van der Meer

van der Meer: Nobel Prize Physics for invention of stochastic cooling → SppS collider at CERN



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

European Plasma Research Accelerator with eXcellence In Applications

Compact Multi-Stage Plasma-Based Accelerator

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 manuscript received 10 June 2019; published 31 July 2019)

The extreme electromagnetic fields sustained by plasma-based accelerators could drastically reduce the size and cost of future accelerator facilities. However, they are also an inherent source of correlated energy spread in the produced beams, which severely limits the usability of these devices. We propose here to split the acceleration process into two plasma stages joined by a magnetic chicane in which the energy correlation induced in the first stage is inverted such that it can be naturally compensated in the second. Simulations of a particular 1.5-m-long setup show that 5.5 GeV beams with relative energy spreads of 1.2×10^{-3} (total) and 2.8×10^{-4} (slice) could be achieved while preserving a submicron emittance. This is at least one order of magnitude below the current state of the art and would enable applications such as compact free-electron lasers.

DOI: 10.1103/PhysRevLett.123.054801

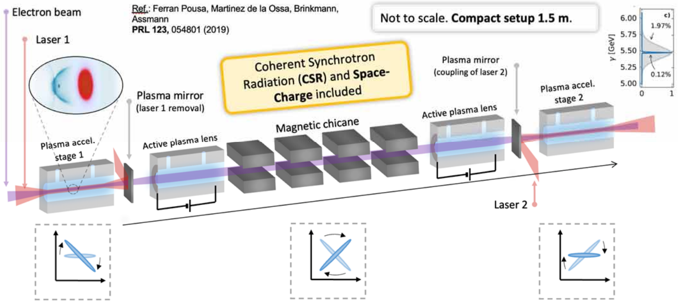
Combined RF plus optical scheme

- 1.5 m long
- 5.5 GeV
- **0.03%** slice energy spread
- **0.12 %** total energy spread
- sub-micron emittance

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

European Plasma Research Accelerator with eXcellence In Applications

Compact Multi-Stage Plasma-Based Accelerator



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

and many others…

Why Another Photon Science Facility? (smaller size, lower power, less performance intially)

→ Make it Fit!

→ **Enable Additional Science!**

EuPRAXIA

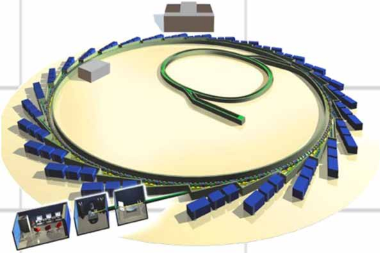
EuPRAXIA: Enabling Additional Science

Funded by the European Union

Visible light

Ultraviolet light

Soft X Rays



FELs OF EUROPE

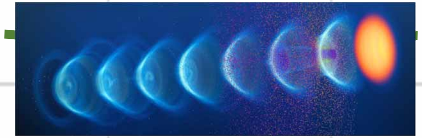
Hard X Rays

Gamma Rays

- Beautiful and highly optimized **masterpieces of science**.
- Go here for **best possible performance**.
- Issue: Only few FEL´s can be built due to their size and cost. **Access to beam time is strongly limited**.

In **addition**: Compact plasma-based FEL´s

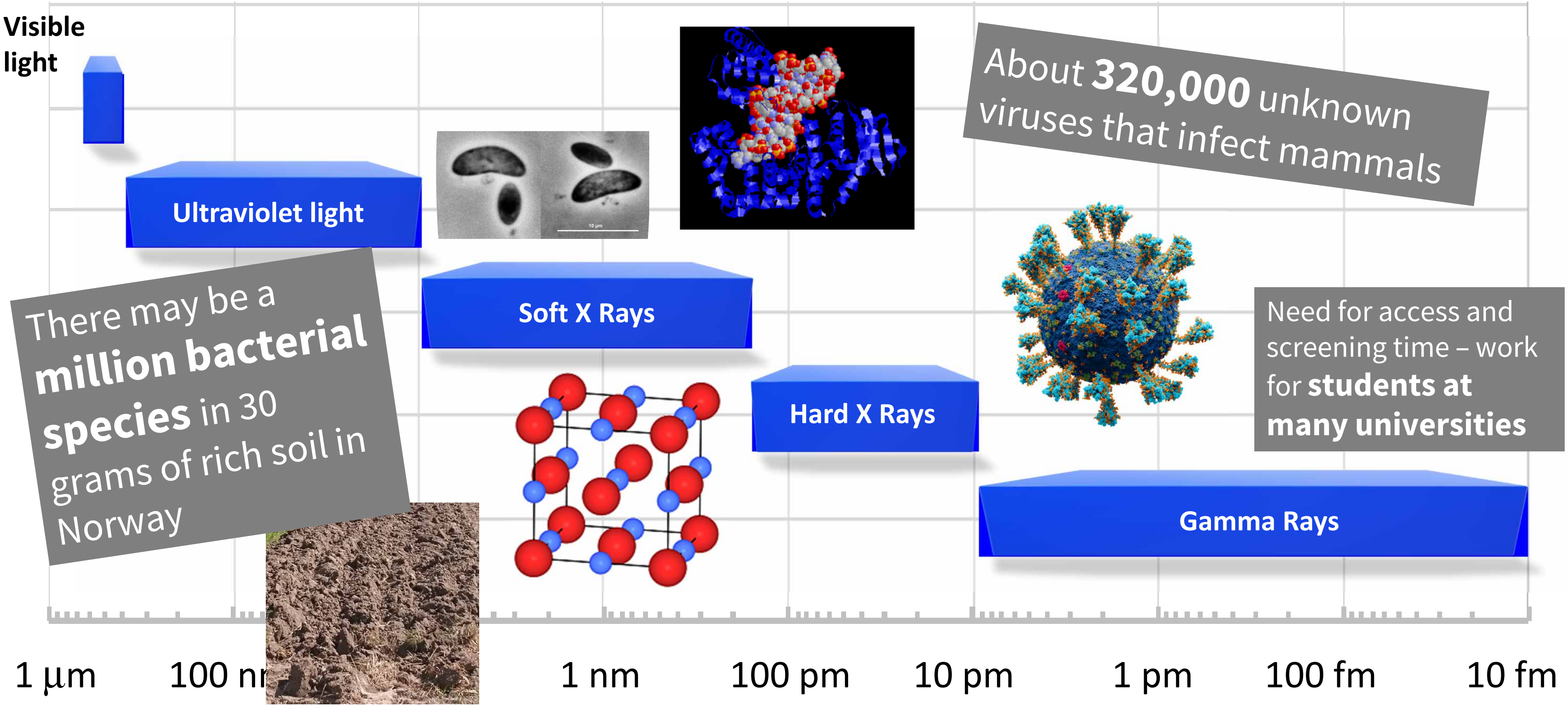
EuPRAXIA



1 µm | 100 nm | 10 nm | 1 nm | 100 pm | 10 pm | 1 pm | 100 fm | 10 fm

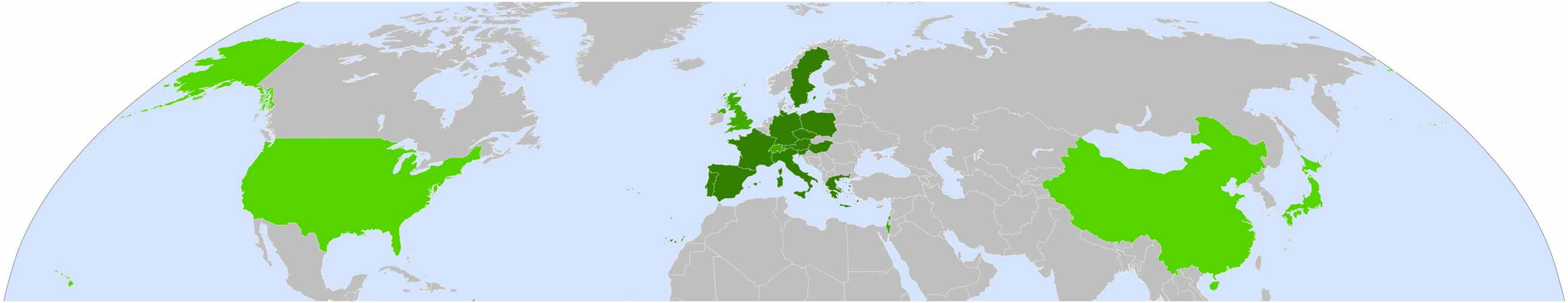
“Unlimited“ Number of Study Objects with Strong Impacts on Our Lives

Funded by the European Union

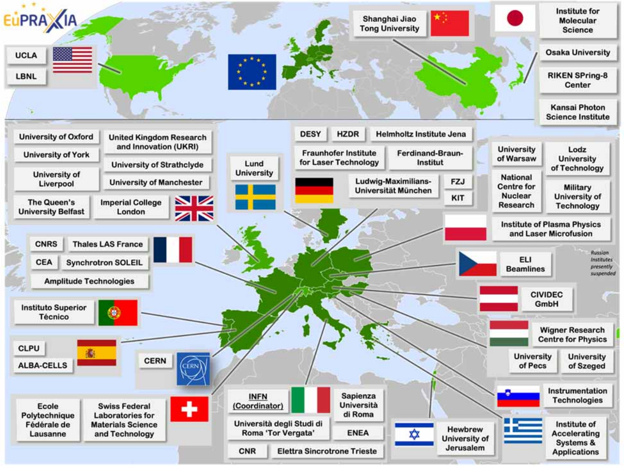


The EuPRAXIA Consortium Today

Funded by the European Union

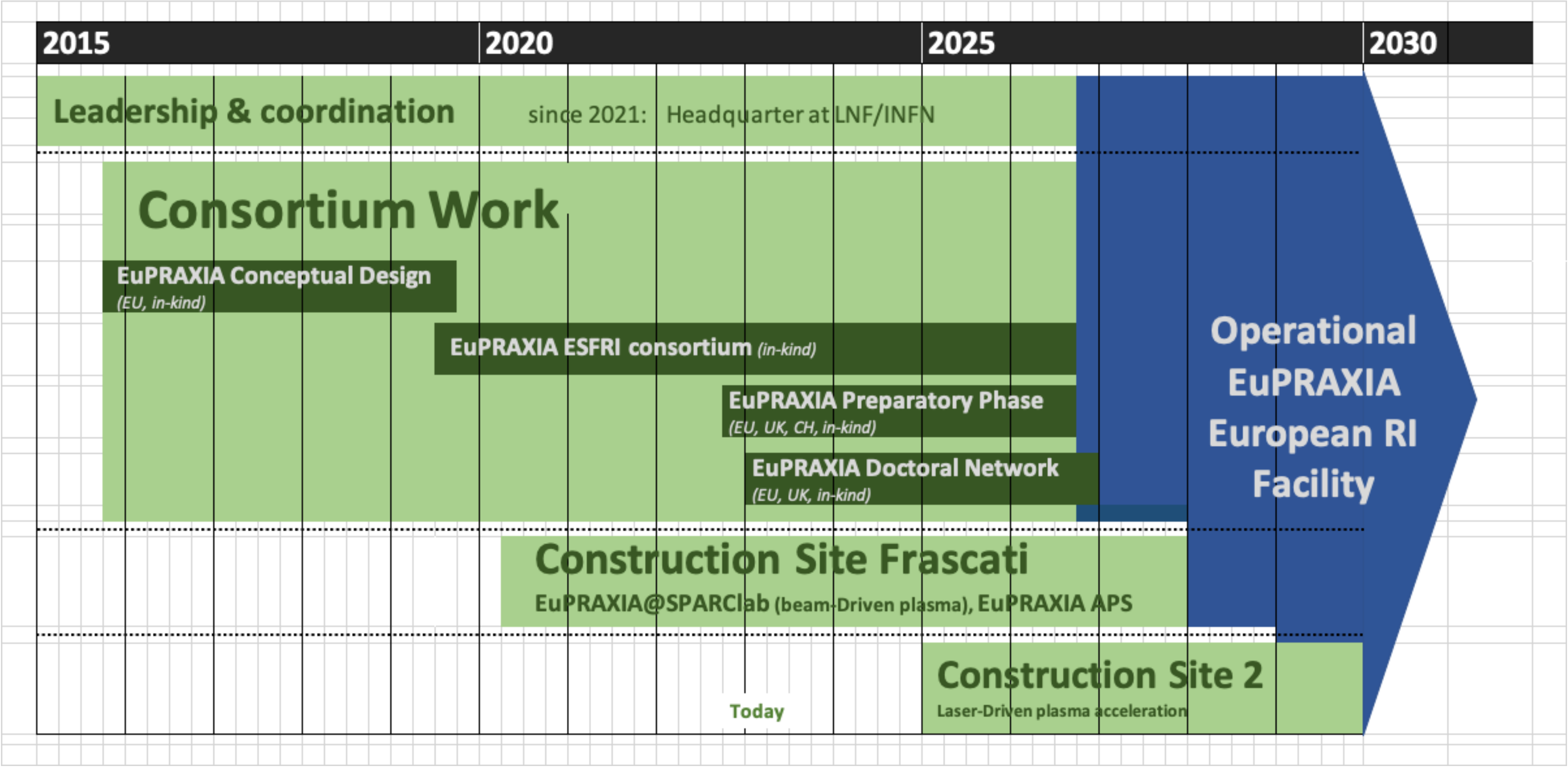


- **54 institutes** *(in addition > 3 asked to join us presently)*
- from **18 countries** plus CERN
- signed on one or several presently **active EuPRAXIA consortia**:
  - **ESFRI** consortium (funding in-kind)
  - **Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
  - **Doctoral Network** (funding EU, UK, in-kind)



EuPRAXIA Project Timeline

Funded by the European Union



EuPRAXIA: Cost/Budget Status Aug 2023

Funded by the European Union

Cost item	Invest (M€)	Personnel (M€)	Total cost (M€)	Obtained (M€)	Coverage (%)	Missing (§) (M€)
Site 1 (*), Frascati	151,0	23,0	174,0	**138,8**	**80%**	35,2
Site 2 (**), tbd	149,0	29,0	178,0	0,0	0%	**178,0**
Termination	*1,0*	*2,0*	*3,0*	*0,0*	*0%*	*3,0*
CDR	*0,2*	*2,8*	*3,0*	*3,0*	***100%***	*0,0*
Preparation, incl. excellence centers	137,0	74,0	211,0	34,6	16%	**176,4**
Total	438,2	130,8	**569,0**	**176,4**	**31%**	392,6

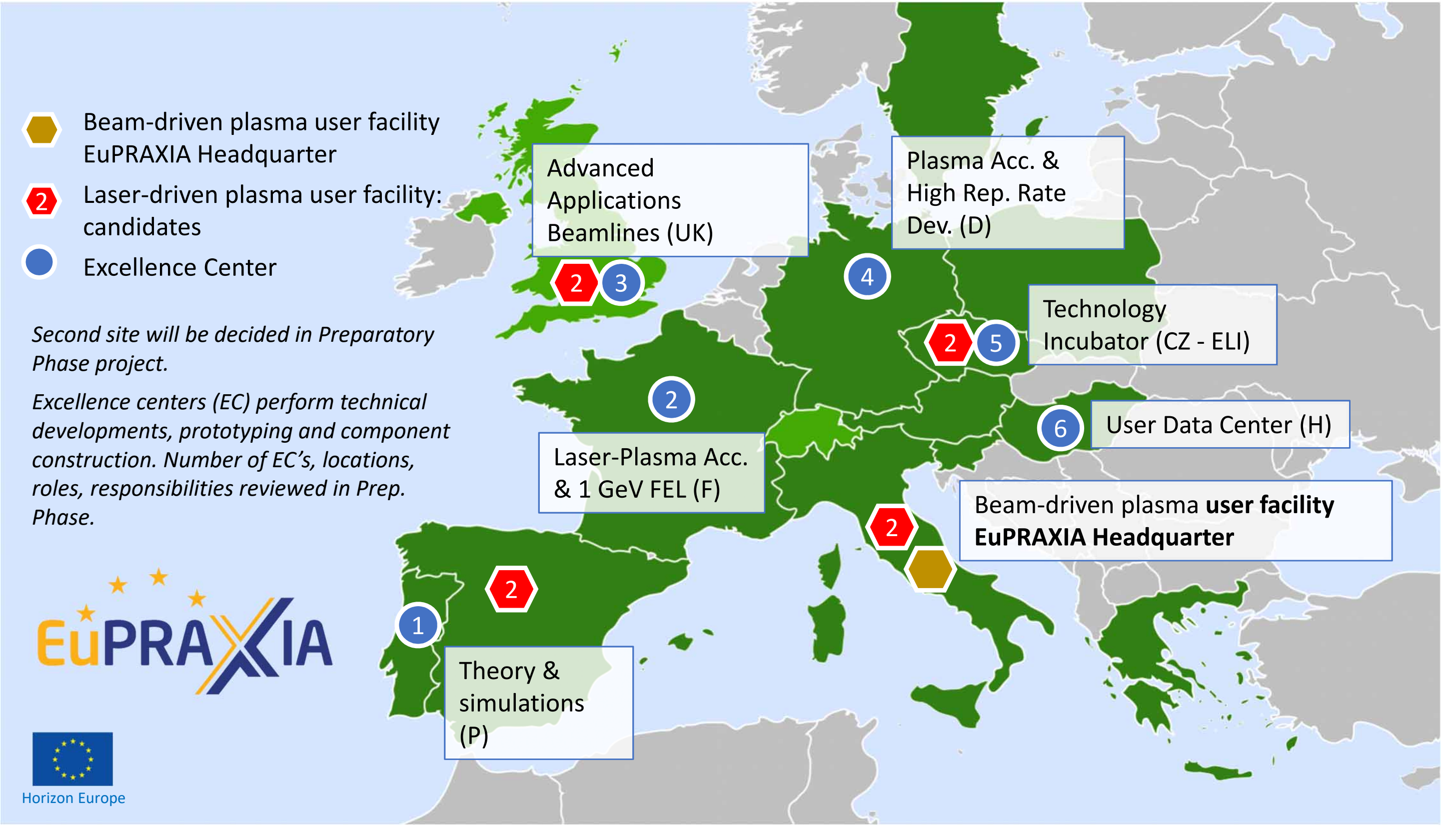
(*) includes estimate of 240 FTE-y of personpower from LNF-INFN

(**) cost will be reduced in case of relevant pre-invests (exisiting infrastructure, equipment)

(§) for full implementation, phased EuRAXIA approach allows ***user operation without full funding***

Distributed Research Infrastructure *(June 23)*

Funded by the European Union



Second site will be decided in Preparatory Phase project.

Excellence centers (EC) perform technical developments, prototyping and component construction. Number of EC's, locations, roles, responsibilities reviewed in Prep. Phase.

Today`s status

Excellence centers: **several** (6 – 10) assumed to be realized

Second site: **one** to be selected

Connect with WP´s to Horizon Europe and national funding lines

Headquarter and Site 1: EuPRAXIA@SPARC_LAB

Funded by the European Union

- Frascati`s future facility
- > 130 M€ invest funding
- Beam-driven plasma accelerator
- **Europe`s most compact and most southern FEL**
- The world`s most compact RF accelerator (X band with CERN)

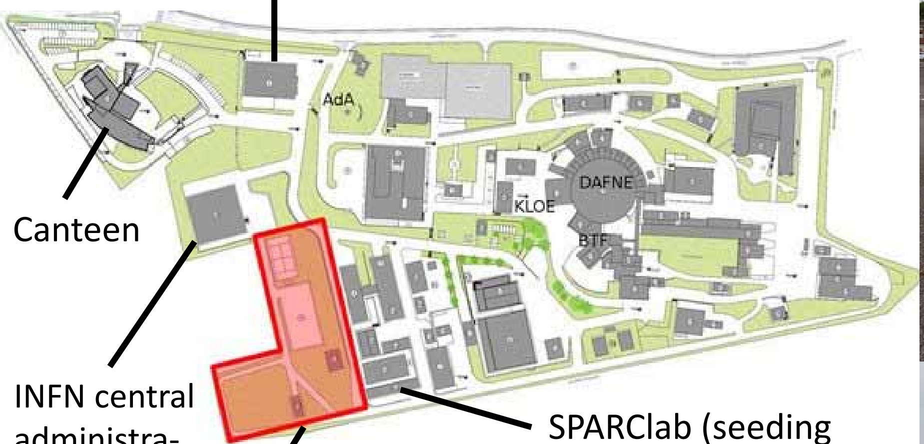
http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

It Fits the Frascati Site

(also fits sites at a large university, hospital, company, …)

Funded by the European Union

Directorate building



Canteen

INFN central administra-tion

SPARClab (seeding with plasma acc.)

EuPRAXIA **@ SPARClab**

(European site 1)

Vladimir Shiltsev

viva Eupraxia!

An: Tor Raubenheimer, Ralph Assmann

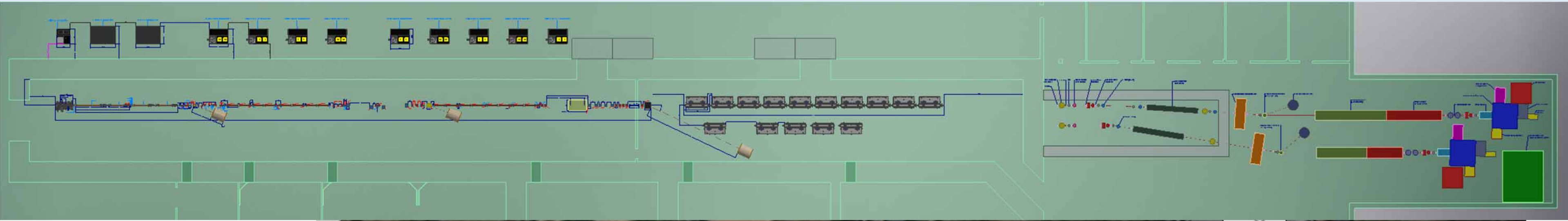
15. September 2022 um 12:07

Tor Raubenheimer SLAC, Stanford University, USA

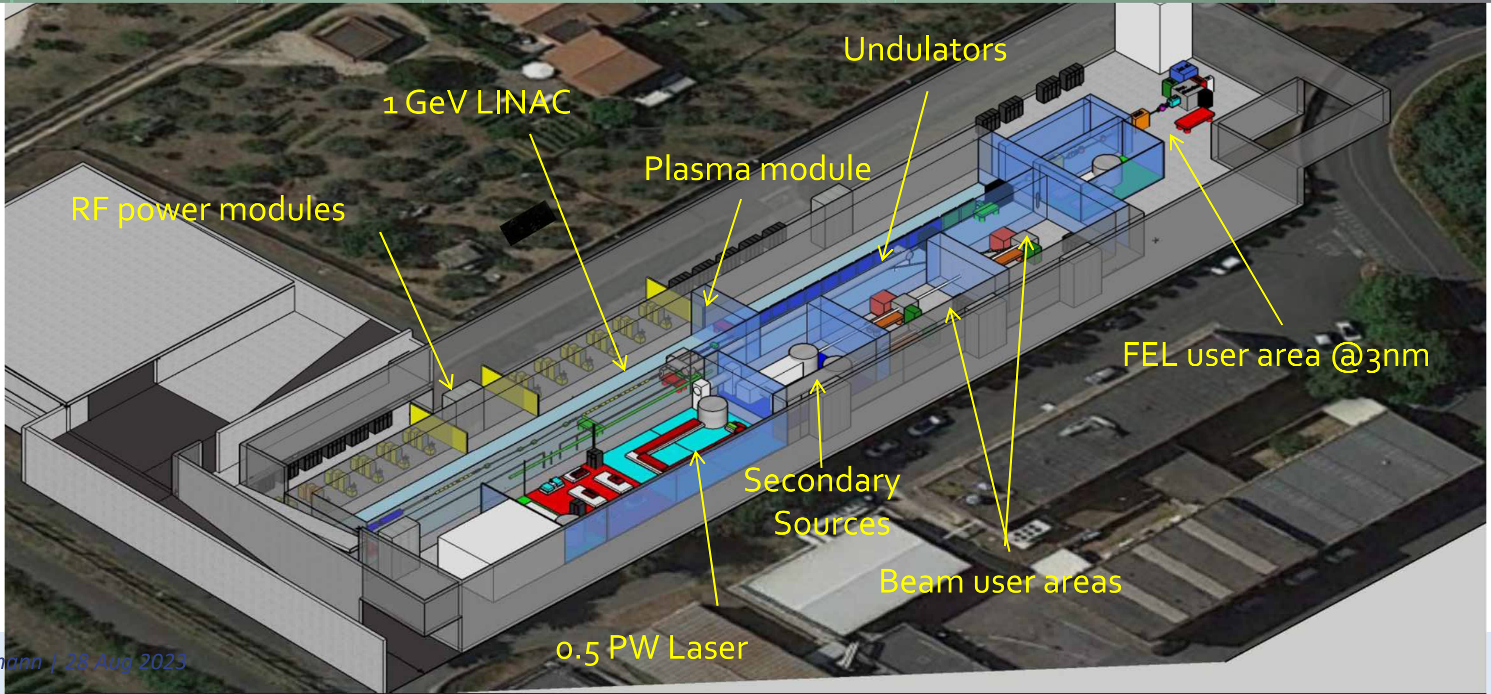
Vladimir Shiltsev, Fermilab National Laboratory, USA

Layout

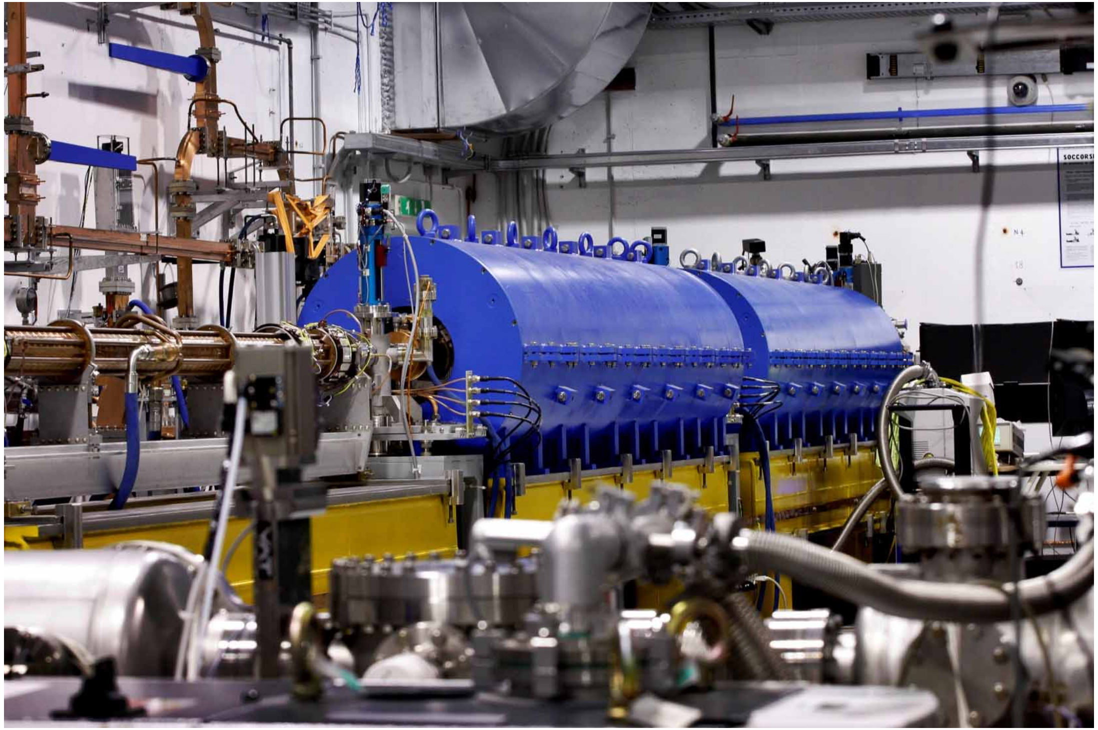
Funded by the European Union



Courtesy F.Cioeta & E.Di Pasquale

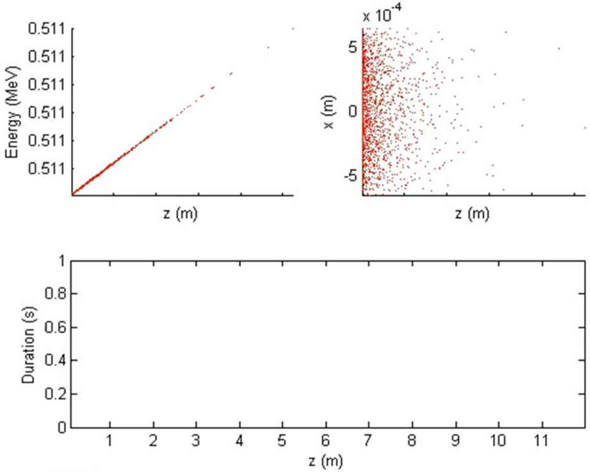


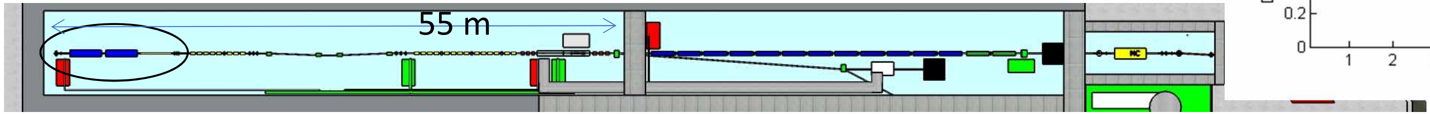
High Quality Electron Beams



Parameter	Unit	Witness	Driver
Charge	pC	30	200
Energy	MeV	101.5	103.2
RMS energy spread	%	0.15	0.67
RMS bunch length	fs	12	20
RMS norm. emittance	mm mrad	0.69	1.95
Rep. rate	Hz	10	10

Table 7.2: Driver and witness beam parameters at the end of photo-injector.

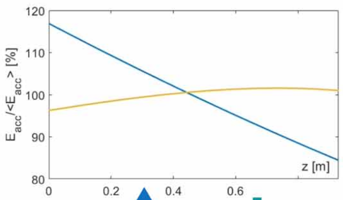


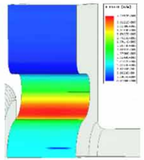


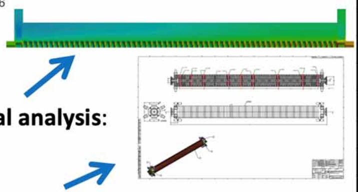
Courtesy E. Chiadroni

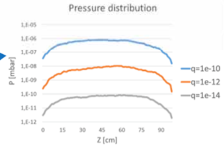
World`s Most Compact RF Linac: X Band

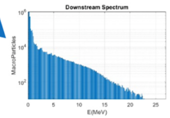
Funded by the European Union





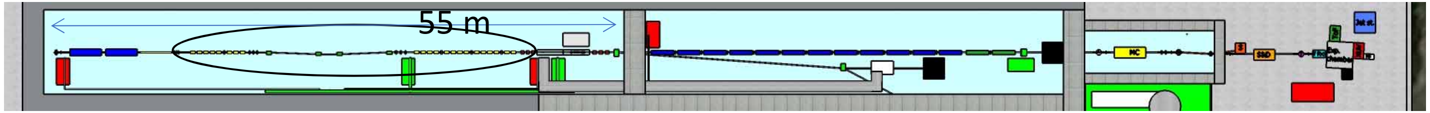






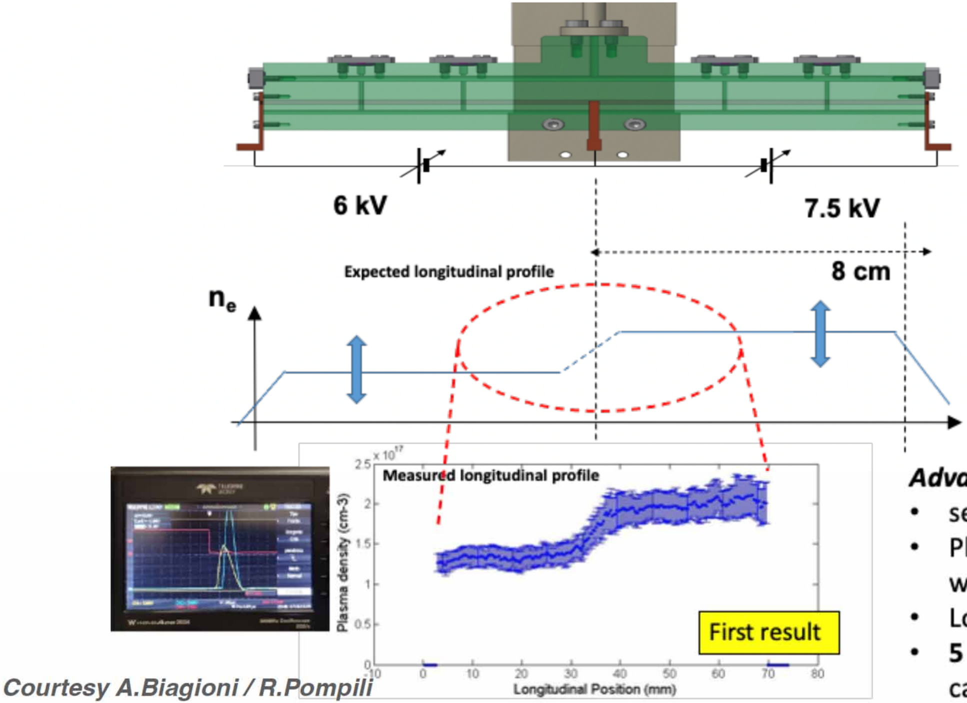
1. **E.m. design**: *done*
2. **Thermo-mechanical analysis**: *done*
3. **Mechanical design**: *done*
4. **Vacuum calculations**: *done*
5. **Dark current simulations**: *done*
6. **Waveguide distribution simulation with attenuation calculations**: *done*

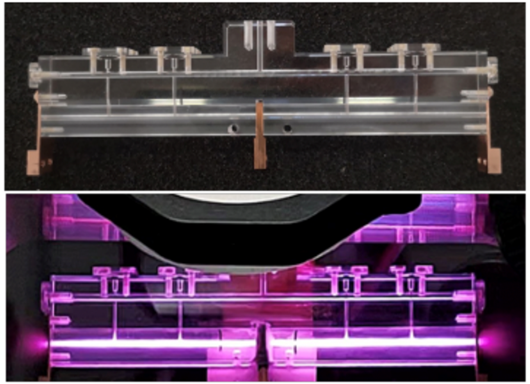
PARAMETER	Value	
	with linear tapering	w/o tapering
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85-3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length (flange-to-flange) [m]	**0.94 (1.05)**	
No. of cells	112	
Shunt impedance R [MΩ/m]	93-107	100
Effective shunt Imp. $R_{sh\ eff}$ [MΩ/m]	350	347
Peak input power per structure [MW]	70	
Input power averaged over the pulse [MW]	51	
Average dissipated power [kW]	1	
P_{out}/P_{in} [%]	25	
Filling time [ns]	130	
Peak Modified Poynting Vector [W/μm²]	3.6	4.3
Peak surface electric field [MV/m]	160	190
Unloaded SLED/BOC Q-factor Q_0	150000	
External SLED/BOC Q-factor Q_E	21300	20700
Required Kly power per module [MW]	**20**	
RF pulse [μs]	**1.5**	
Rep. Rate [Hz]	**100**	



Courtesy D. Alesini

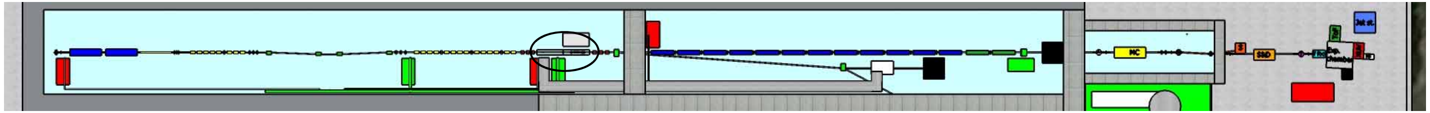
Plasma Module





Advantages:

- several independently controllable sections
- Plasma sources larger than 40 cm (m-scale) with HV pulses less than 10 kV
- Longitudinal density modulation
- **5 GeV** case for EuPRAXIA (1.5 GV/m m-scale capillary - density 10^{16} cm-3)



Courtesy A. Biagioni, R. Pompili

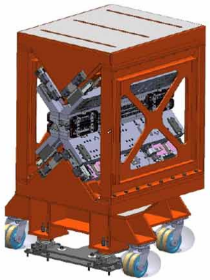
Radiation Generation: FEL

Funded by the European Union

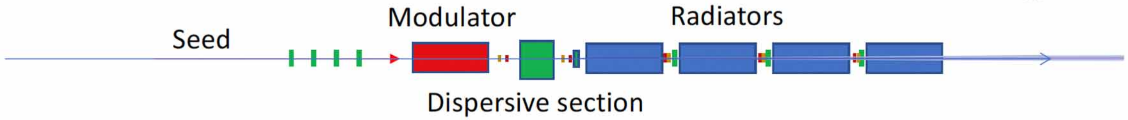
Two FEL lines:

1) *AQUA*: Soft-X ray SASE FEL – Water window optimized for 4 nm (baseline)

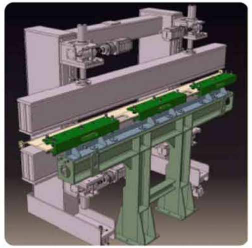
SASE FEL: 10 UM Modules, 2 m each – 60 cm intraundulator sections.
Two technologies under study: Apple-X PMU (baseline) and planar SCU.
Prototyping in progress



2) *ARIA*: VUV seeded HGHG FEL beamline for gas phase

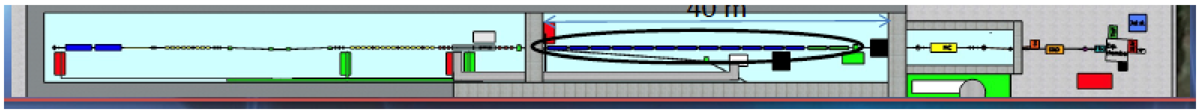


FERMI FEL-1 Radiator



SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 290 – 430 nm (see former presentation to the committee and *Villa et al. ARIA—A VUV Beamline for EuPRAXIA@SPARC_LAB. Condens. Matter 2022, 7, 11.*) – Undulator based on consolidated technology.

Frascati 06/05/23 – EUPRAXIA TDR



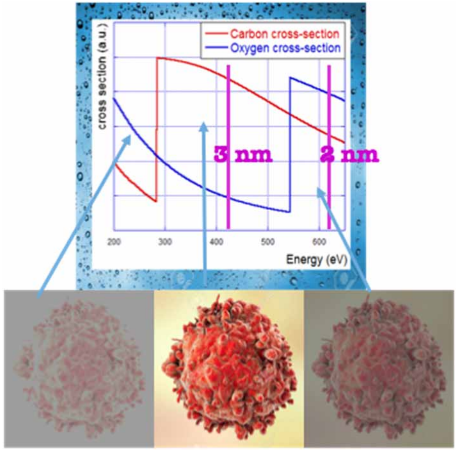
Courtesy L. Giannessi

Expected SASE FEL Performance

Parameter	Unit	PWFA	Full X-band
Electron Energy	GeV	1-1.2	1
Bunch Charge	pC	30-50	200-500
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	0.1	0.1
RMS Bunch Length	μm	6-3	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	≤0.05	≤0.05
Slice norm Emittance	mm-mrad	0.5	0.5

Parameter	Unit	PWFA	Full X-band
Radiation Wavelength	nm	3-4	4
Photons per Pulse	$\times 10^{12}$	0.1-0.25	1
Photon Bandwith	%	0.1	0.5
Undulator Area Length	m	30	
ρ(1D/3D)	$\times 10^{-3}$	2	2
Photon Brilliance per shot	$mm^2 mrad^2$ $bw(0.1\%)$	$1-2 \times 10^{28}$	1×10^{27}

In the Energy region between Oxygen and Carbon K-edge 2.34 nm – 4.4 nm (530 eV -280 eV) water is almost transparent to radiation while nitrogen and carbon are absorbing (and scattering)



Coherent Imaging of biological samples protein clusters, VIRUSES and cells living in their native state
Possibility to study dynamics
~10 11 photons/pulse needed

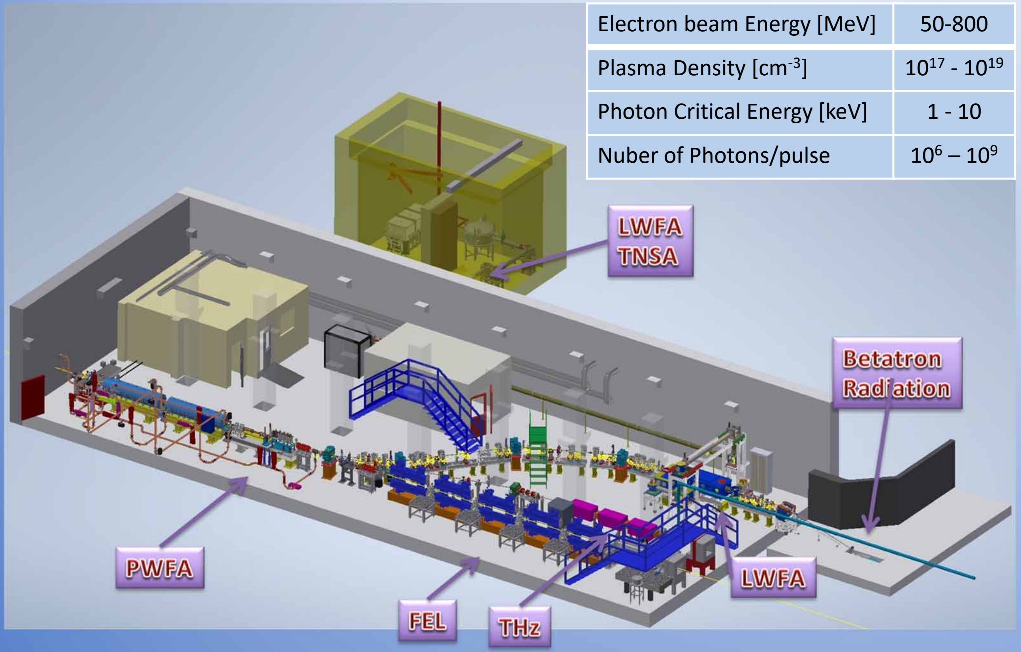
Courtesy F. Stellato, UniToV

Courtesy C. Vaccarezza

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
EuPRAXIA Advanced Photon Sources

Betatron Radiation Source at SPARC_LAB

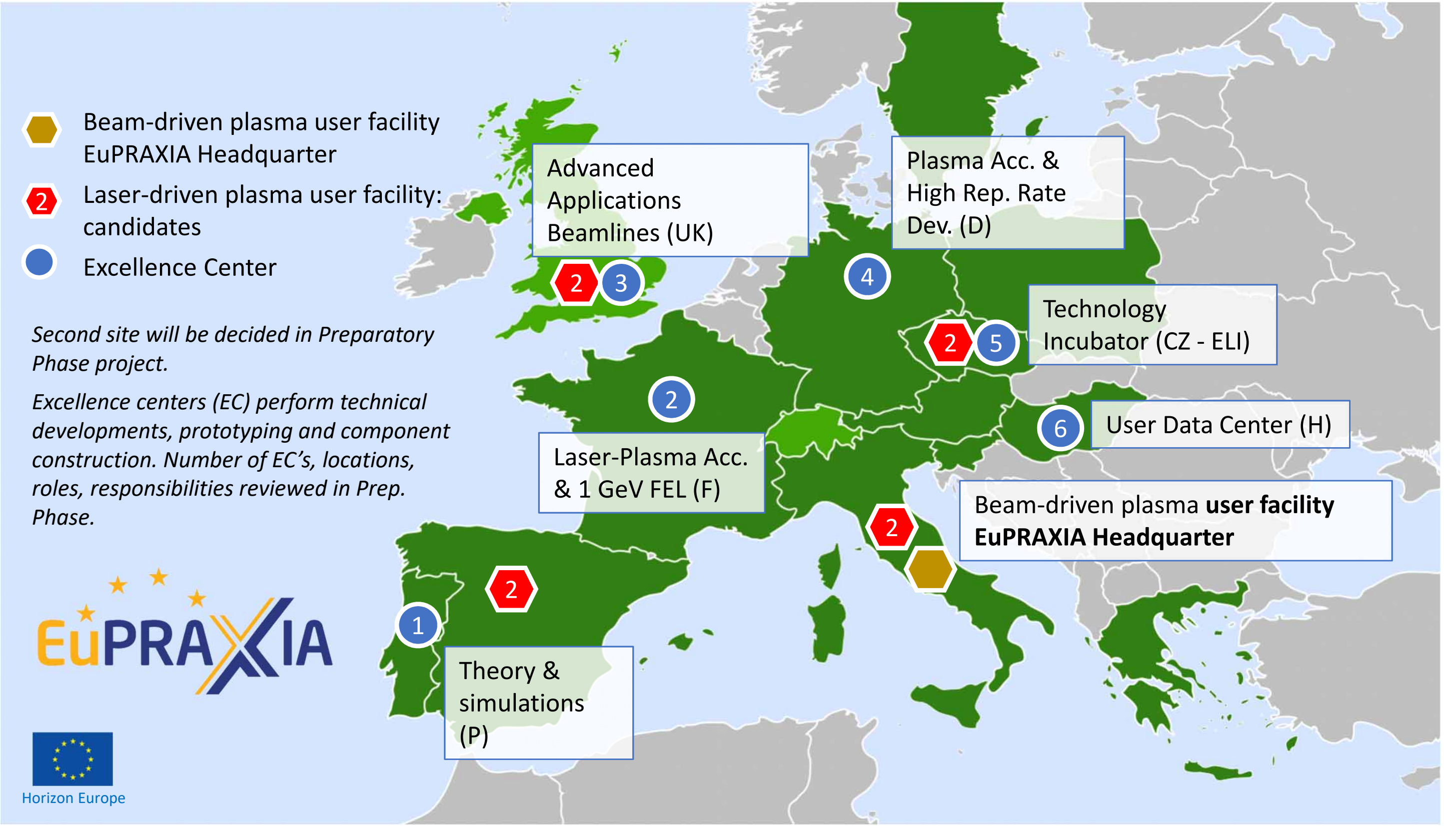
Electron beam Energy [MeV]	50-800
Plasma Density [cm^{-3}]	10^{17} - 10^{19}
Photon Critical Energy [keV]	1 - 10
Nuber of Photons/pulse	10^{6} – 10^{9}



- Supported by PNRR funding
- Collaboration among INFN, CNR, University of Tor Vergata
- Operational facility at SPAClab by end of 2025
- EuPRAXIA pre-cursor for users

Distributed Research Infrastructure *(June 23)*

Funded by the European Union



Today`s status

Excellence centers: **several** (6 – 10) assumed to be realized

Second site: **one** to be selected

Connect with WP´s to Horizon Europe and national funding lines

Main concept of the LPA-based FEL facility

Funded by the European Union

32.9 CAD Model of the Conceptual EuPRAXIA Facility Layout

Some example screenshots of the CAD model of the proposed EuPRAXIA facility layout are shown below. The current model is conceptual, but will form a basis for the detailed technical layout to be developed in the next phase of EuPRAXIA. The full CAD model is available upon request.

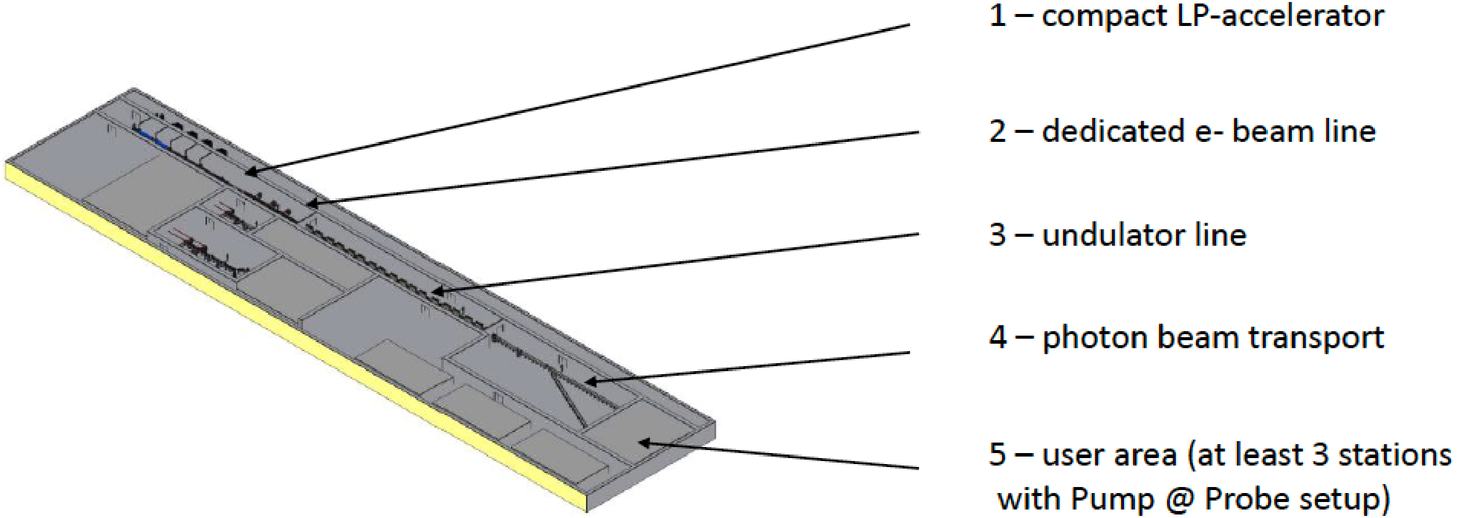


Figure 32.27: Screenshot of the CAD model of the proposed EuPRAXIA facility layout. Here, the laser-driven plasma acceleration construction site is shown in a perspective view.

eli | beamlines

ELI Beamlines explores the interaction of light with matter at intensities 10 times higher than previously achievable.

4 PW class laser systems, 4 support lasers

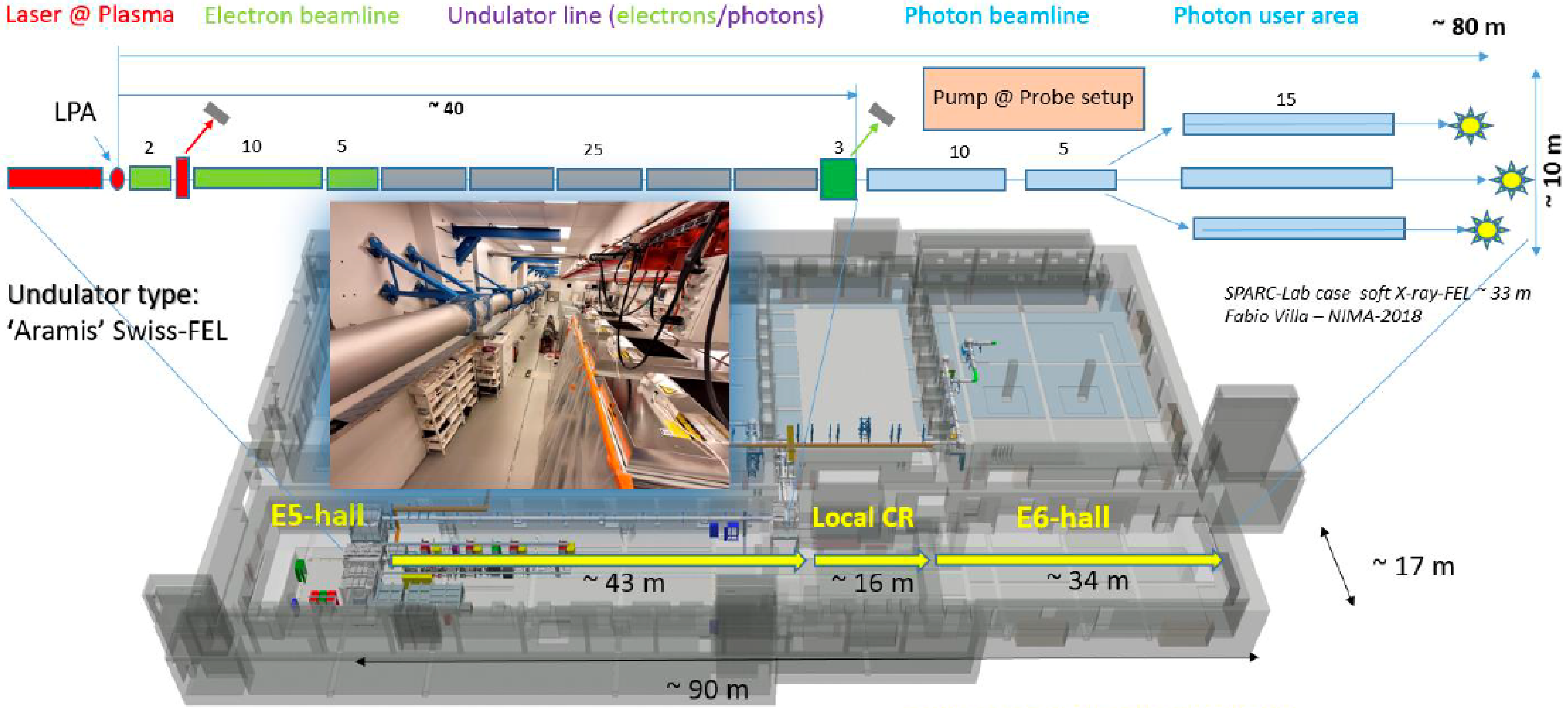
7 Secondary sources – EUV - X-rays, Electron and Ion Accelerators

10 User stations

- 350 international staff
- Area 31,000 m2

- Structural Dynamics
- Particle Acceleration and Applications
- HED Physics and ICF
- High Field Physics

1-GeV LPA-based FEL at ELI-Beamlines



EXISTING INFRASTRUCTURE at ELI-Beamlines

ELI-Beamlines: infrastructure (5 GeV case)

Option-A (using existing facility)

Extension of E6 hall → extra 60 meters length

→ **Budget estimation for E6 extension**

permission @ TDR ~ 10% (NON-inv) of total budget → 1.5 year

underground work ~ **11 MEur** (INV) → + 2 years

→ **Finalization of extended infrastructure (shielding, engineering) ~ 20 MEur**

→ **Budget for other key components → TBD**

ELI-Beamlines: infrastructure (5 GeV case)

Funded by the European Union

Option B: new facility

- Underground work (160m x 35m x 5m) → **~ 40 MEur**
- **Time:** Permission @ TRD ~ 10% (NONinv) → **~ 3 years**
- Building / Laser-Hall and Experimental-Hall finalization → **~ 20 MEur**
- **Time: + 3 years**

NO pre-investment from ELI-beamlines

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

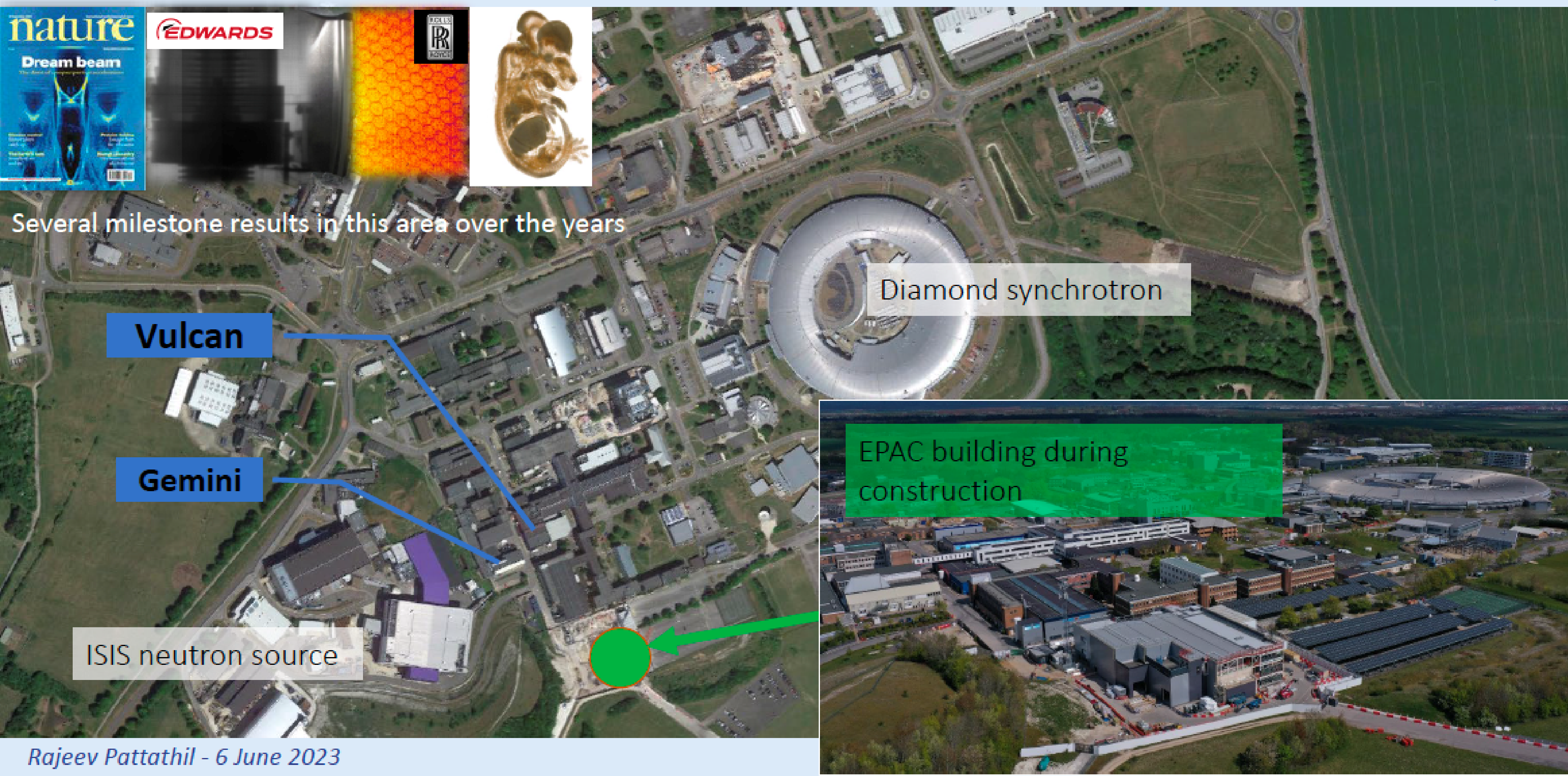
Option for Second Site: Extreme Photonics Applications Centre

Rajeev Pattathil

Rome, Italy, 5 – 7 June 2023

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

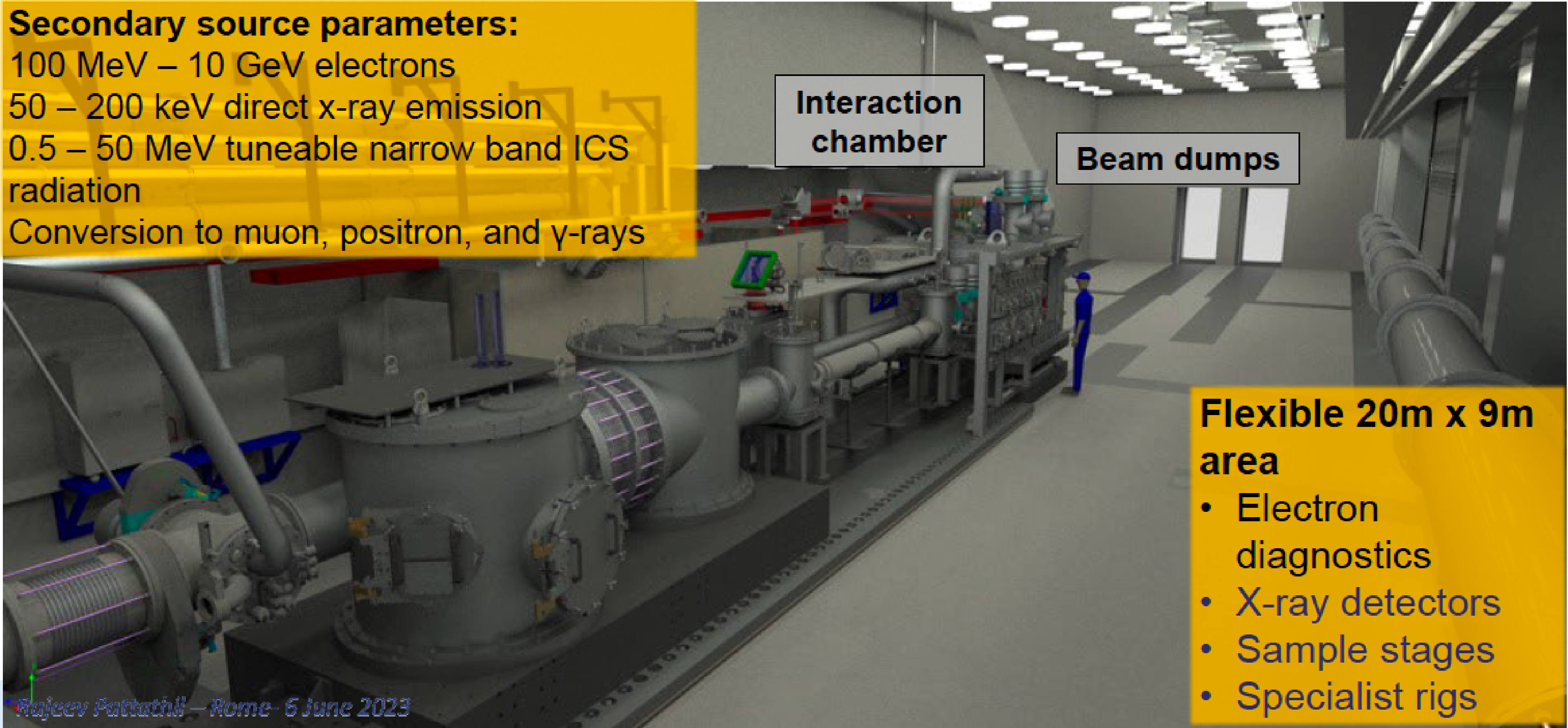
Builds on the success of Gemini and Vulcan



EuPRAXIA EA1 Applications area

Funded by the European Union

Secondary source parameters:
100 MeV – 10 GeV electrons
50 – 200 keV direct x-ray emission
0.5 – 50 MeV tuneable narrow band ICS radiation
Conversion to muon, positron, and γ-rays

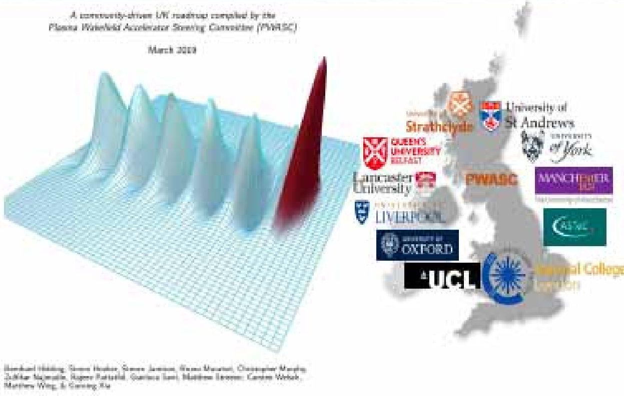


Flexible 20m x 9m area
- Electron diagnostics
- X-ray detectors
- Sample stages
- Specialist rigs

EuPRAXIA @ EPAC?

- EPAC's operations would start 2025/26 – can de-risk a lot of EuPRAXIA concepts
- Additional space for future laser and experimental areas (eg. a 100Hz system under development)
- Has the capacity to expand the EPAC building to house the additional beamlines – EuPRAXIA @ EPAC
- EPAC's strategy, applications-oriented program and industry links would help EuPRAXIA
- STFC has all the infrastructures required to run a successful user programme
- Infrastructure proposal to UKRI was identified as "future potential funding"
- STFC's Accelerator Strategy now includes development of plasma accelerators
- STFC Executive is in full support – Mark Thomson was instrumental in getting support for EuPRAXIA

- Political questions remain, however



EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA 2nd SITE @CNR

Status of preparation

Leonida A. GIZZI, CNR-INO and INFN, Pisa, Italy

EuPRAXIA-PP and ESFRI Workshop on Excellence Centers and 2nd site (Laser-driven)
6th June, 2023, Museo Ninfeo, Roma, Italy

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

CNR, Area della Ricerca del CNR, Pisa

Funded by the European Union

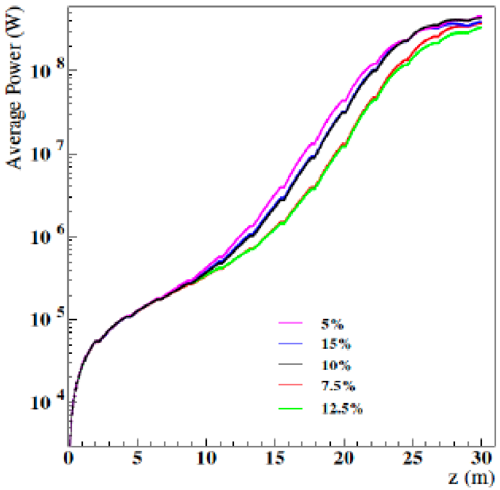
FEL MODELLING of REMPI BEAM

Funded by the European Union

Laser-plasma REMPI SCHEME → TRANSPORT to undulator → FEL emission

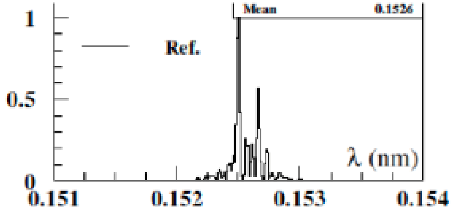
Up to 39 m planar undulator line with period λ_u = 14 mm, with $E_{beam} \approx$ 4.5 GeV, the resonant wavelength of 1.5 Å.

The Self-Amplified Stimulated Emission (SASE) vs. pulse energy, gain length and resonant wavelength



e-beam	L_G [m]	$E_p(z_{exit})$ [μJ]	λ_{exit} [nm]
7.5%	1.753	9.28	0.152619
15%	1.781	9.60	0.152533
5%	1.912	11.15	0.152546
12.5%	1.756	8.22	0.152574
10%	1.791	10.78	0.152568
RMS	0.065	1.6	0.000033

Emission stable against plasma density variations (10%)



SIS 1.3 simulations by Federico NGUYEN (ENEA, Frascati)

P. Tomassini, L. Giannessi, A. Giribono, F. Nguyen, and L. A. Gizzi, "Brilliant X-Ray Free Electron Laser Driven by Resonant Multi-Pulse Ionization Injection Accelerator", presented at the FEL2022, Triest, Italy, Aug. 2022, paper TUP17.

Now working on the proof of principle implementation

INTERMEDIATE MILESTONE

Eupraxia laser development is aimed at delivering more efficient, kW-PW laser driver for plasma acceleration at >100 Hz rate

- **EuPRAXIA**
- PW class,
- 100 Hz repetition rate,
- multi kW average power,
- diode pumped
- Full therma load transport

EuPRAXIA Advanced Photon Sources

I-PHOQS INTEGRATED INFRASTRUCTURE INITIATIVE IN PHOTONIC AND QUANTUM SCIENCES

- **EuAPS@CNR-Pisa**
- 30 TW peak power
- 100 Hz repetition rate
- 100 W average power
- Diode pumped
- Thermal load effects

- **CURRENT**
- **PW class,**
- **Hz repetition rate,**
- **≈10 W average power**
- **flashlamp pumped**
- **No thermal load transport**

CLPU as ***EUPRAXIA*** *LASER SITE*

G. Gatti

Scientific Division Head

- ***CLPU: Location & Governance***
- ***Infrastructure***
- ***International Framework***
- ***Glimpses on User Access***
- ***Upgrade***
- ***Activities***
- ***Strong Points***

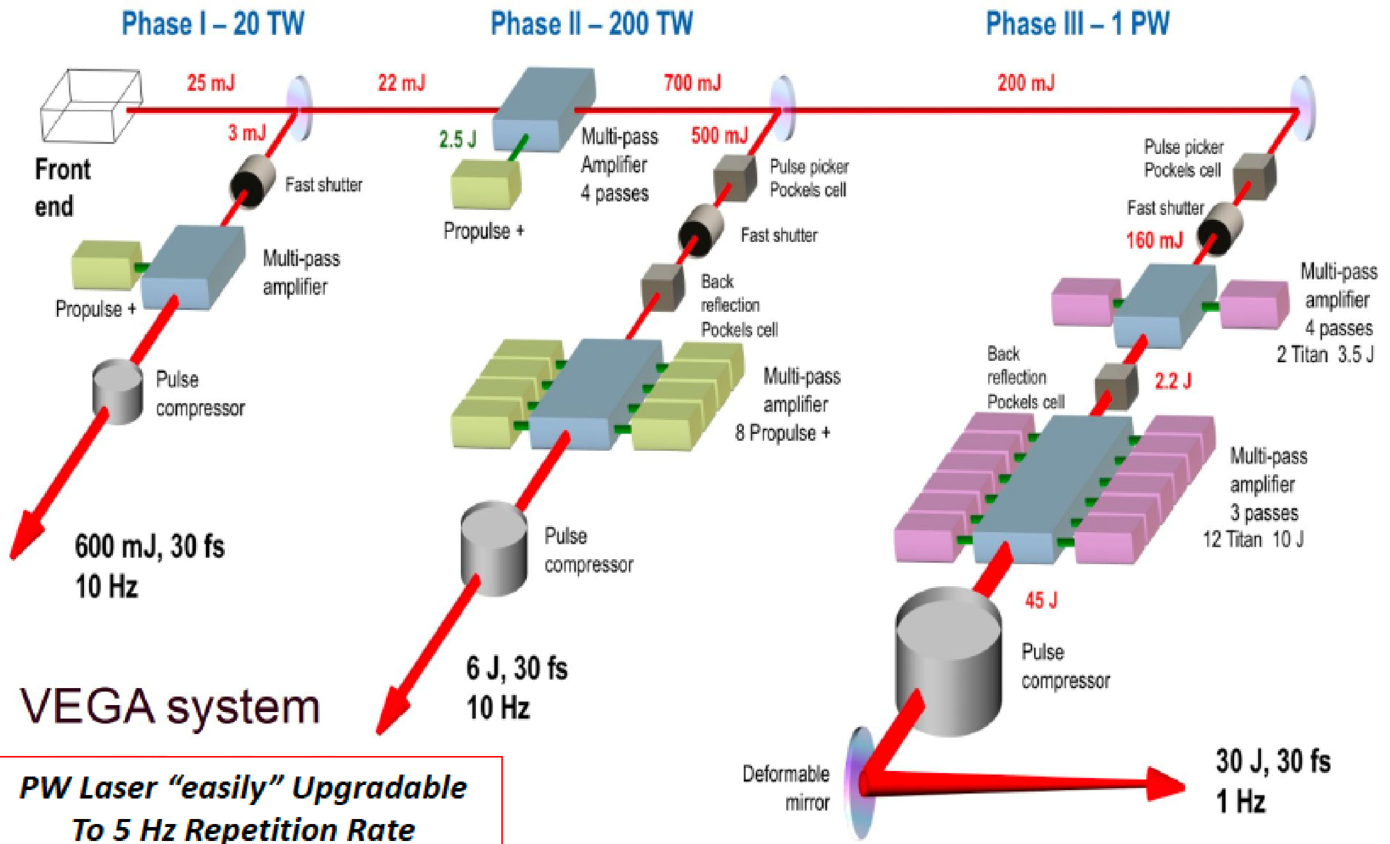
ggatti@clpu.es

Funded by the European Union

Location

ggatti@clpu.es

Infrastructure



VEGA system

PW Laser "easily" Upgradable To 5 Hz Repetition Rate

Building Upgrade

Financiado por la Unión Europea
NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

Funded by the European Union

- Multiple Users & Set-ups
- Get Advantage of Laser Independence
- 3 M€ Funding

Conclusion

Funded by the European Union

- Plasma accelerators have advanced considerably in beam quality, **achieving FEL lasing**.
- EuPRAXIA is a design and an ESFRI project for a distributed European Research Infrastructure, **building two plasma-driven FEL´s in Europe**.
- EuPRAXIA FEL site in Frascati LNF-INFN is sufficiently funded for **first FEL user operation in 2028**.
- Second EuPRAXIA FEL site will be selected in next 18 months, among **4 excellent candidate sites**.
- Concept today **works in design and in reality**. Expect (solvable) problems in stability for **24/7 user operation**. Facility needed to demonstrate!
- *Many thanks to all my EuPRAXIA colleagues and close friends, especially Massimo Ferrario from INFN.*

Thank You

Funded by the European Union