EUROPEAN
PLASMA RESEARCH
ACCELERATOR
WITH
EXCELLENCE IN
APPLICATIONS

The EuPRAXIA project

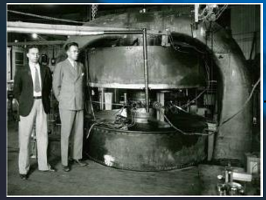
a plasma-based accelerator user facility for the next decade

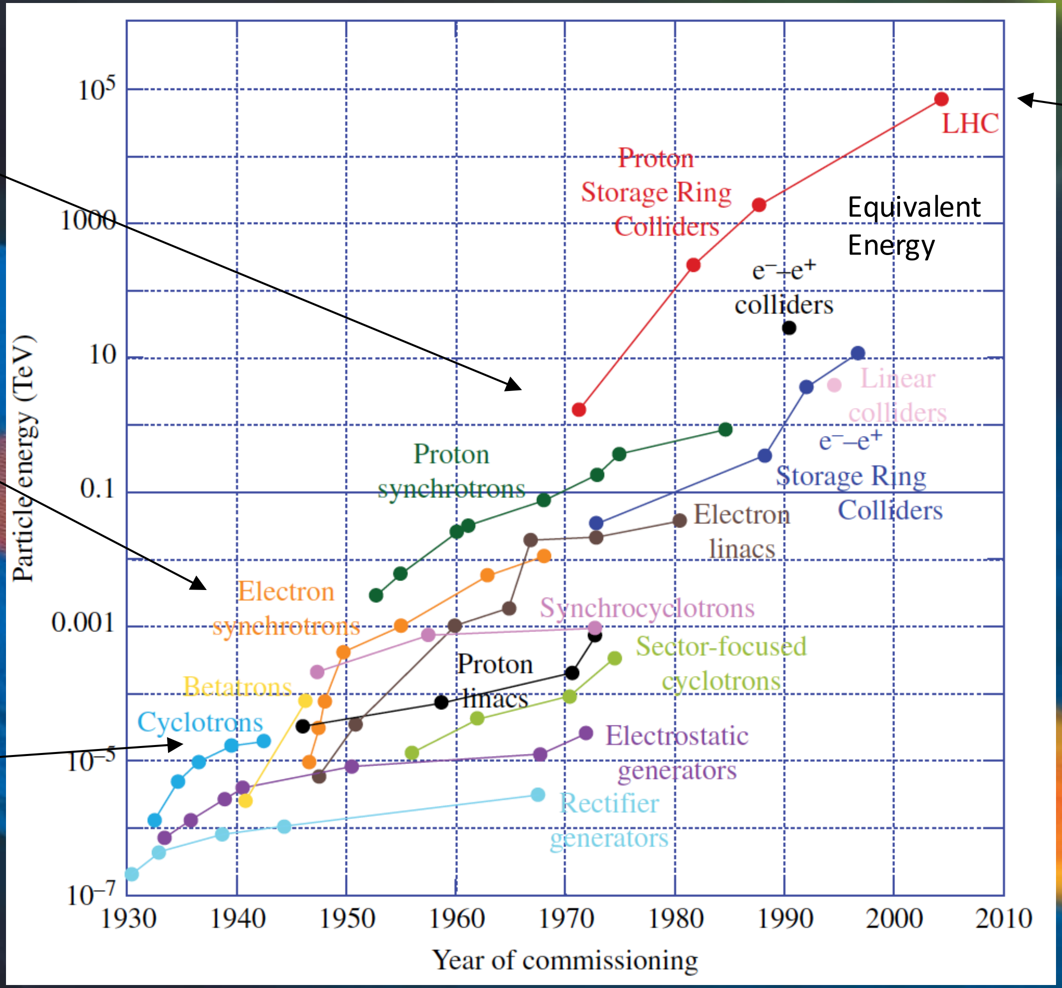
Massimo Ferrario (INFN-LNF)

On behalf of the EuPRAXIA collaboration

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

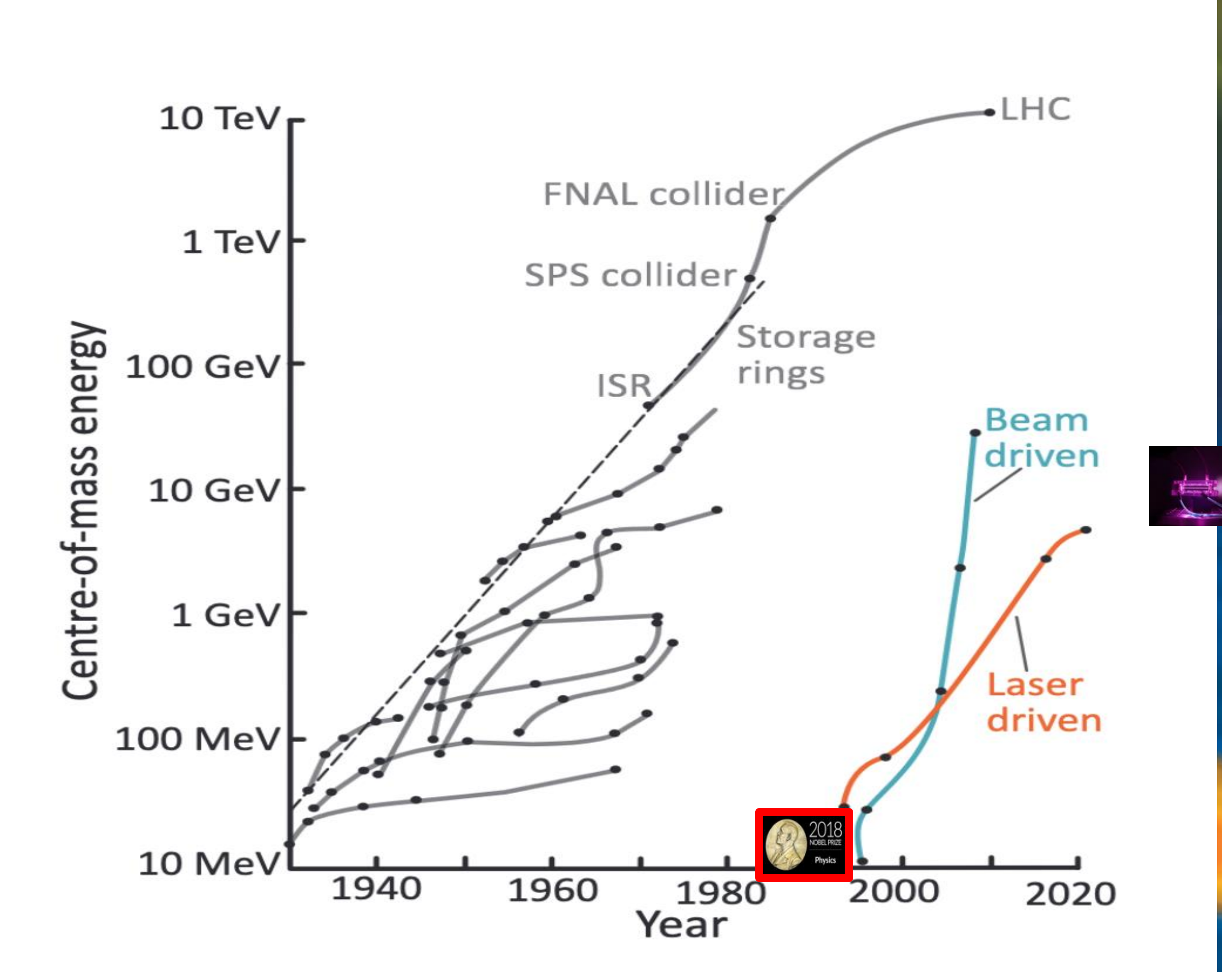
Livingstone Diagram



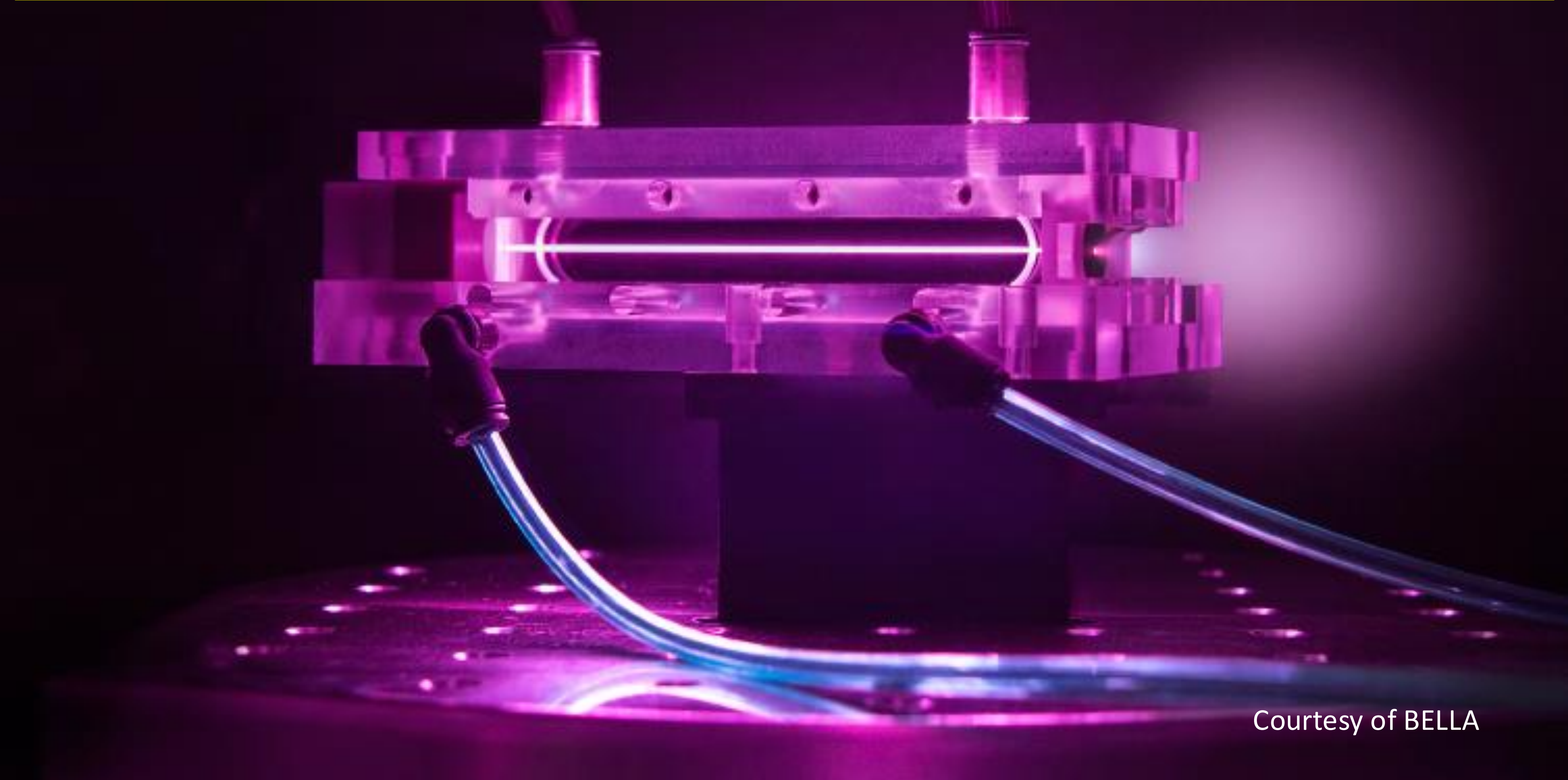


Energy of colliders is plotted in terms of the laboratory energy of particles colliding with a proton at rest to reach the same center of mass energy.

Livingstone Diagram with PWFA



Principle of plasma acceleration

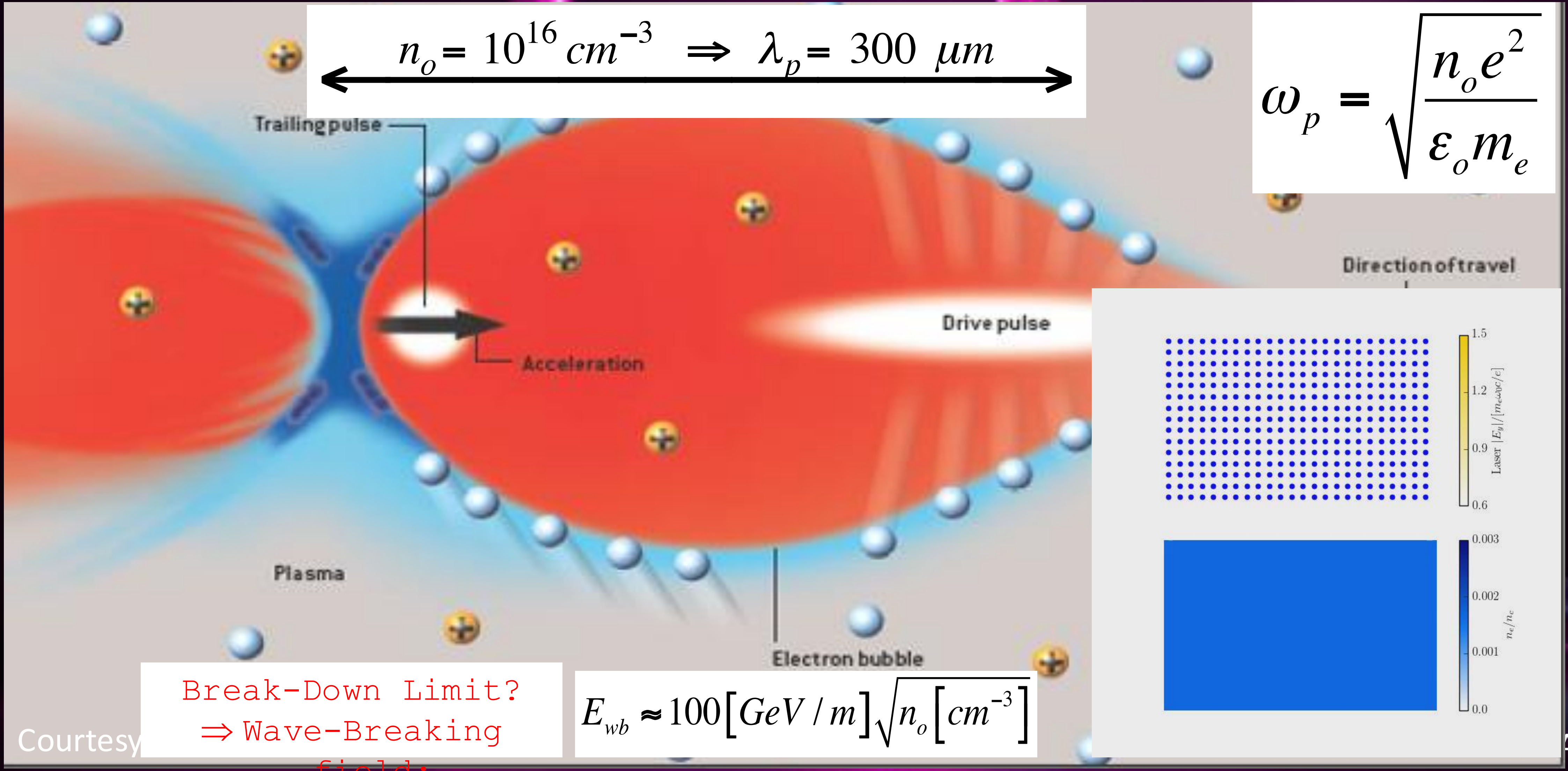


Courtesy of BELLA

Principle of plasma acceleration

$$n_o = 10^{16}\, cm^{-3} \;\Rightarrow\; \lambda_p = 300\ \mu m$$

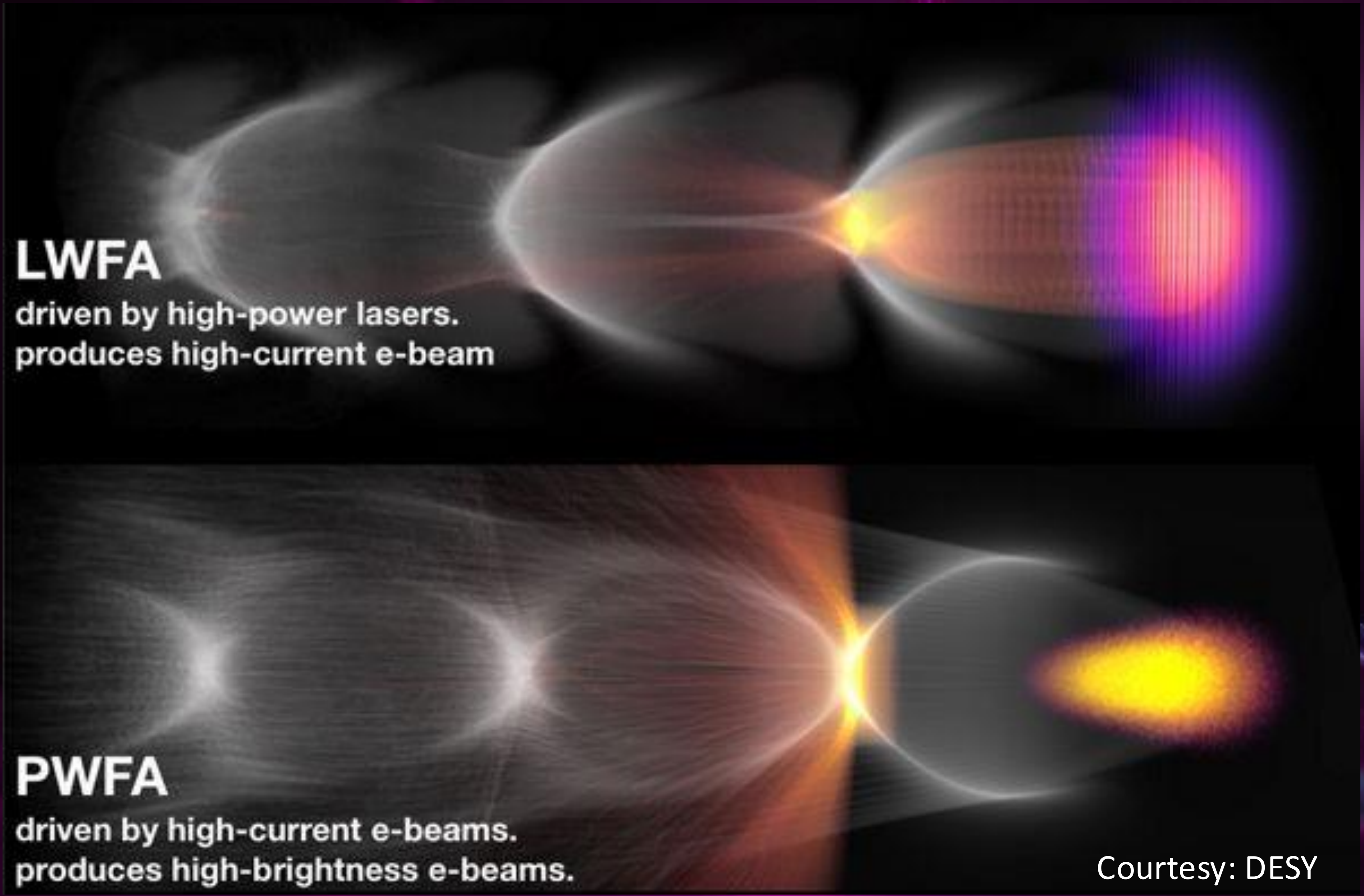
$$\omega_p = \sqrt{\frac{n_o e^2}{\varepsilon_o m_e}}$$



Break-Down Limit?
⇒ Wave-Breaking field:

$$E_{wb} \approx 100\,[GeV/m]\sqrt{n_o\,[cm^{-3}]}$$

Principle of plasma acceleration



Courtesy: DESY

A New European High-Tech User Facility

Funded by the European Union

EuPRAXIA is the first European project that develops a dedicated particle accelerator research infrastructure **based on novel plasma acceleration** concepts **driven by innovative laser and linac technologies**.

1

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

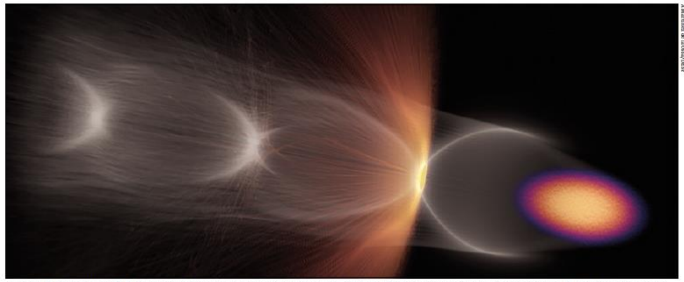
Shrink down the facility size
Improve Sustainability

2

Producing particles and photons to support several urgent and timely science cases

Drive short wavelength FEL
Pave the way for future Linear Colliders

FEATURE EuPRAXIA



Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

Energetic beams of particles are used to explore the fundamental forces of nature, produce known and unknown particles such as the Higgs boson at the LHC, and generate new forms of matter, for example at the future FAIR facility. Photon science also relies on particle beams: electron beams that emit pulses of intense synchrotron light, including soft and hard X-rays, in either circular or linear machines. Such light sources enable time-resolved measurements of biological, chemical and physical structures on the molecular down to the atomic scale, allowing a diverse global community of users to investigate systems ranging from viruses and bacteria to materials science, planetary science, environmental science, nanotechnology and archaeology. Last but not least, particle beams for industry and health support many societal applications ranging from the X-ray inspection of cargo containers to food sterilisation, and from chip manufacturing to cancer therapy.

This scientific success story has been made possible through a continuous cycle of innovation in the physics and technology of particle accelerators, driven for many decades by exploratory research in nuclear and particle physics. The invention of radio-frequency (RF) technology in the 1920s opened the path to an energy gain of several tens of MeV per metre. Very-high-energy accelerators were constructed with RF technology, entering the GeV and finally the TeV energy scales at the Tevatron and the LHC. New collision schemes were developed, for example the mini "beta squeeze" in the 1970s, advancing luminosity and collision rates by orders of magnitudes. The invention of stochastic cooling at CERN enabled the discovery of the W and Z bosons 40 years ago.

However, intrinsic technological and conceptual limits mean that the size and cost of RF-based particle accelerators are increasing as researchers seek higher beam energies. Colliders for particle physics have reached a

THE AUTHORS
Ralph Assmann *DESY and INFN,* **Massimo Ferrario** *INFN,* **Carsten Welsch** *University of Liverpool/INFN.*

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

EuPRAXIA Scientific Goals

Funded by the European Union

- Free Electron Laser

Flagship Science Goal 1: EuPRAXIA will deliver free-electron laser (FEL) X rays with 10^9-10^13 photons per pulse to user areas, covering wavelengths of 0.2 nm to 36 nm. The EuPRAXIA FEL pulses are naturally short (down to 0.4 fs) and will therefore provide users with tools for investigating processes and structures in ultra-fast photon science at a reduced facility foot print.

- Betatron Radiation Source

Flagship Science Goal 2: EuPRAXIA will deliver betatron X rays with about 10^10 photons per pulse, up to 100 Hz repetition rate and an energy of 5-18 keV to users from the medical area. The much reduced longitudinal length of the X ray emission area (point-like emission) leads to an important improvement in image resolution compared to other techniques.

- Positron Beams

Flagship Science Goal 3: EuPRAXIA will deliver positron beams at energies from 0.5 MeV to 10 MeV and a repetition rate of 100 Hz for material science studies. Per pulse about 10^6 positrons will be produced in a time duration of 20-90 picoseconds on the sample, allowing time-resolved studies. EuPRAXIA will here advance the capabilities of existing positron sources in flux and time resolution.

- e+ / e- beams

Flagship Science Goal 4: EuPRAXIA will deliver electron and positron beams at energies from a few 100 MeV up to 5 GeV for high energy physics related R&D (detectors, linear collider topics). R&D goals include the demonstration of a linear collider stage, a "table top" HEP test beam and studies on positron transport and acceleration towards a linear collider.

600+ page CDR, 240 scientists contributed

- ICS Photon Beams

Flagship Science Goal 5: EuPRAXIA will deliver photons from an inverse Compton scattering (ICS) source. The photons of up to 600 MeV and with narrow-band spectrum will enable precision nuclear physics and highly penetrative radiography for users.

- High Rep. Rate Laser

Flagship Science Goal 6: EuPRAXIA will provide access to a multi-stage, high-repetition rate plasma accelerator in the GeV range to users from accelerator science. This R&D platform will allow the testing of novel ideas and concepts, full optimisation of a plasma collider stage, certain fixed target experiments (also in combination with lasers) and performance studies of conventional versus novel accelerator technology.

- Laser Technology

Flagship Science Goal 7: EuPRAXIA will provide access to cutting edge laser technology with short pulse length in combination with high energy photon pulses and short electron/positron bunches. Novel schemes of pump probe configurations and ultra-precise timing will be researched, feeding back into laser science.

Plasma driven gamma ray source - EuGamma

Funded by the European Union

Fascio di elettroni: da 500 MeV a 2 GeV, 100 pC single bunch a 400 Hz, energy spread 0.5%, emittanza rms norm. 0.5 mm.mrad, lunghezza bunch inferiore al psec, focalizzato a sigmax=15 micron al punto di interazione con il laser

Laser: 1.2 eV Yb:Yag (lambda=1030), 0.5 Joule di energia nell'impulso a 400 Hz, M2=1.2, bandwith=0.001, sigma-t=1.5 psec, focalizzato a W0=25 micron al punto di collisione

E-elettroni = 750 MeV, energia fotoni gamma 10. MeV
E-elettroni = 1000 MeV, energia fotoni gamma 18. MeV
E-elettroni = 2000 MeV, energia fotoni gamma 73. MeV

Numero fotoni gamma a 10 MeV al secondo compresi in una bandwidth di 0.5% = 1.7 * 10^8

Densità spettrale del fascio di fotoni gamma a 10 MeV = 3320. fotoni / (sec.eV)

Le prestazioni di ELI-NP come da TDR erano: densità spettrale a 10 MeV 5000.
Quindi siamo nel range, diciamo forse inferiori solo di un fattore 2, ma con la possibilità di arrivare a 2 GeV quindi con energia di fotoni molto maggiore di ELI-NP, la cui energia massima era 19.5 MeV.

Plasma driven gamma ray source - EuGamma

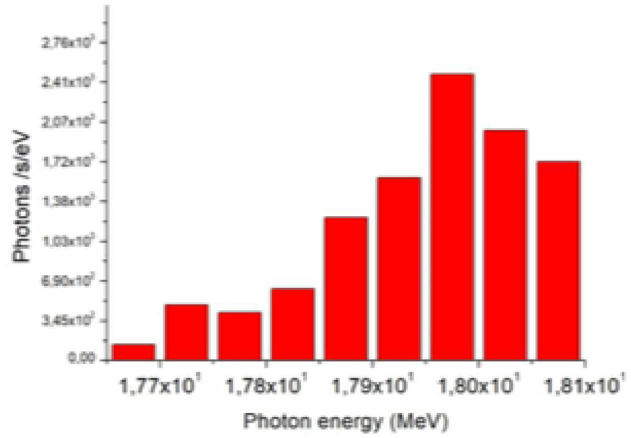
Funded by the European Union

CAIN simulations for a Gamma source at EupraXia

Laser		
wavelength	micron	1.03
sigma	micron	20
Energy	J	0.5

Electrons	@EupraXia	
Charge	pC	100
Electron energy	GeV	1
Emittance	mm mrad	0.6
Energy spread	Per mill	0.4
igma_rms	micron	20

Radiation		
Photon energy	MeV	18
Photon number per shot	X 10^8	1.38
Rep rate		400
Bandwidth	Per mill	5
Collimation angle	microrad	450
Number of collimated photons per shot	X 10^6	1.34
Collimated photons/s	Number/s	5.33x 10^8
Spectral density in 1 eV	Number/s/ eV	2500

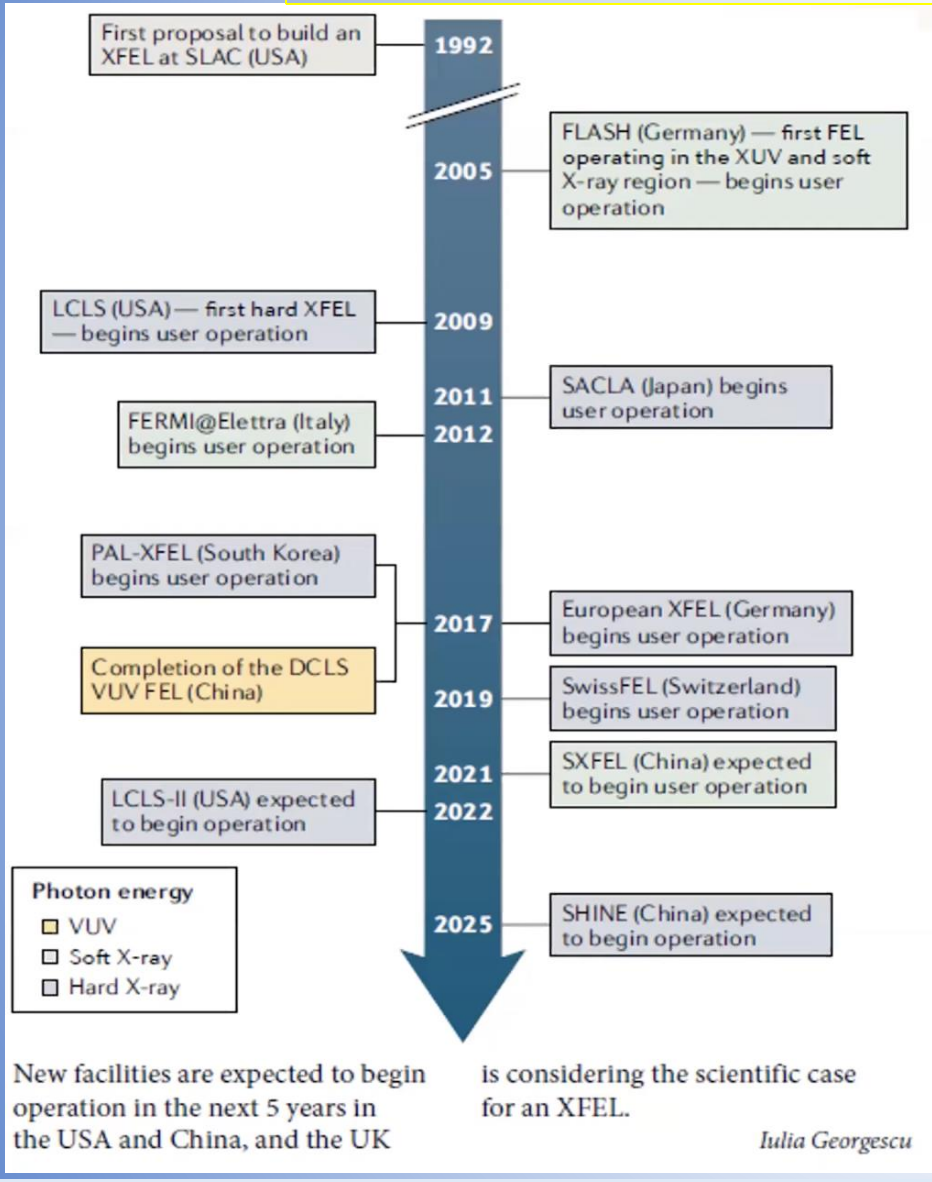


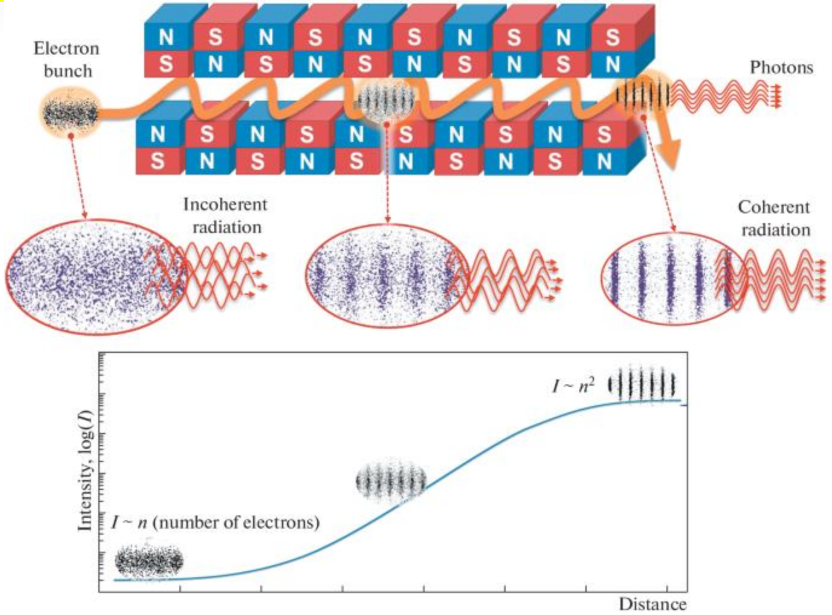
Courtsey V. Petrillo & L. Serafini

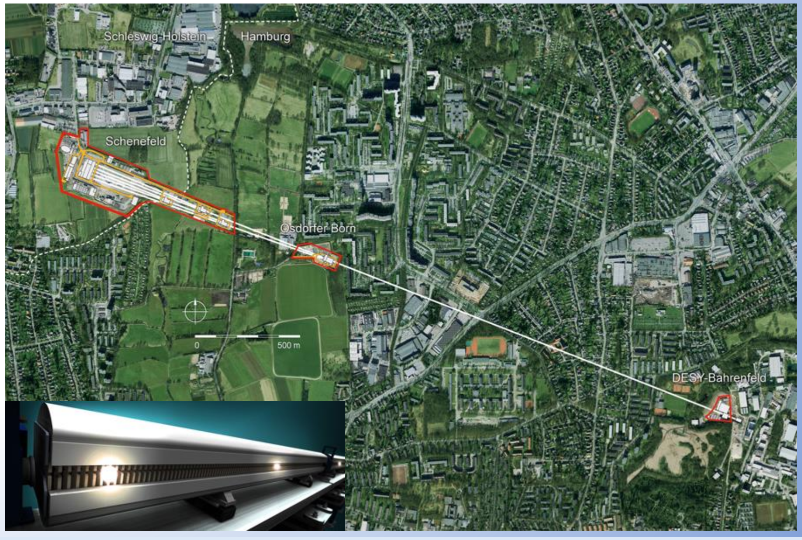
Funded by the
European Union

FEL is a well established technology

(But a widespread use of FEL is partially limited by its size and costs)

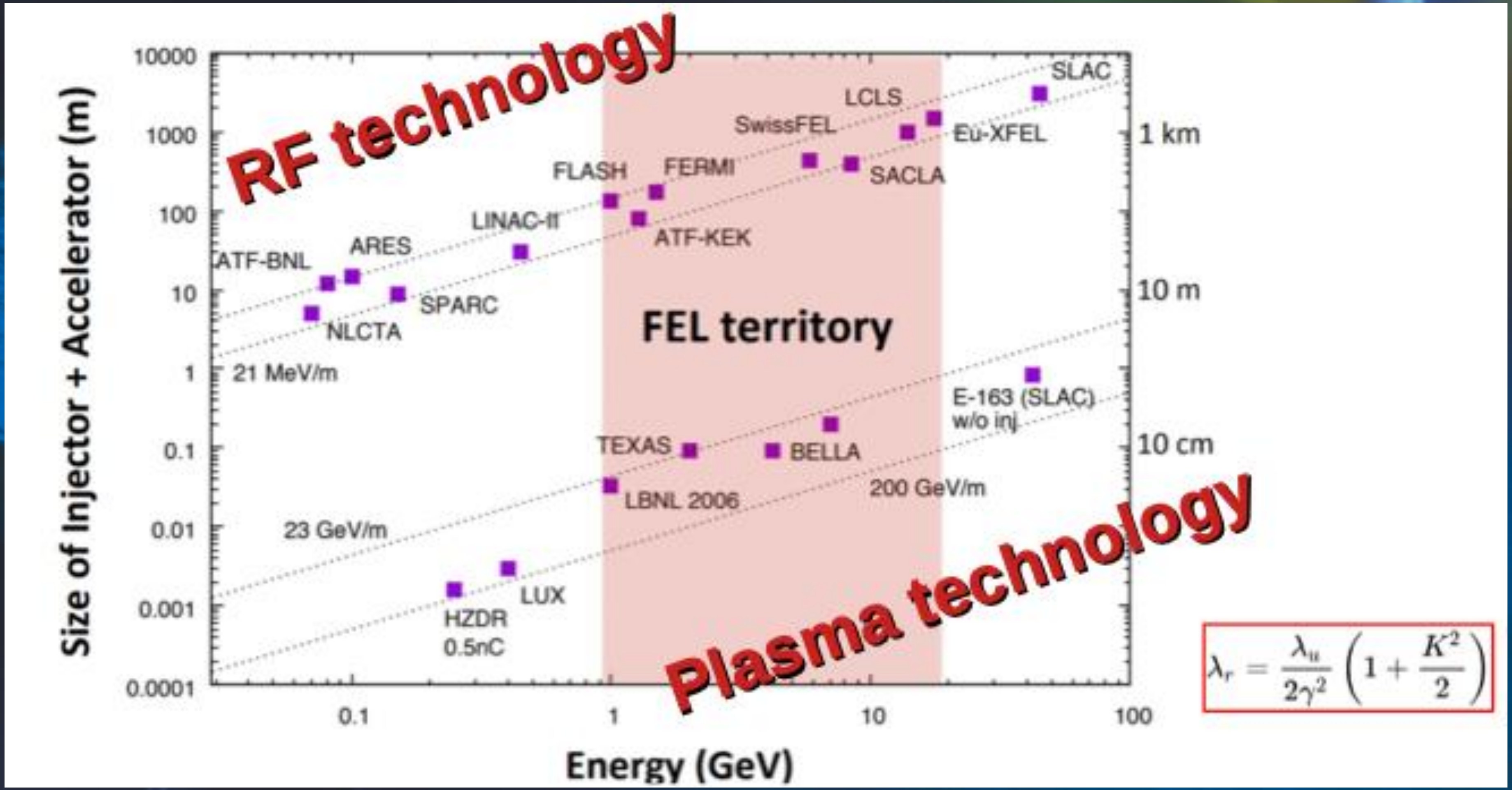




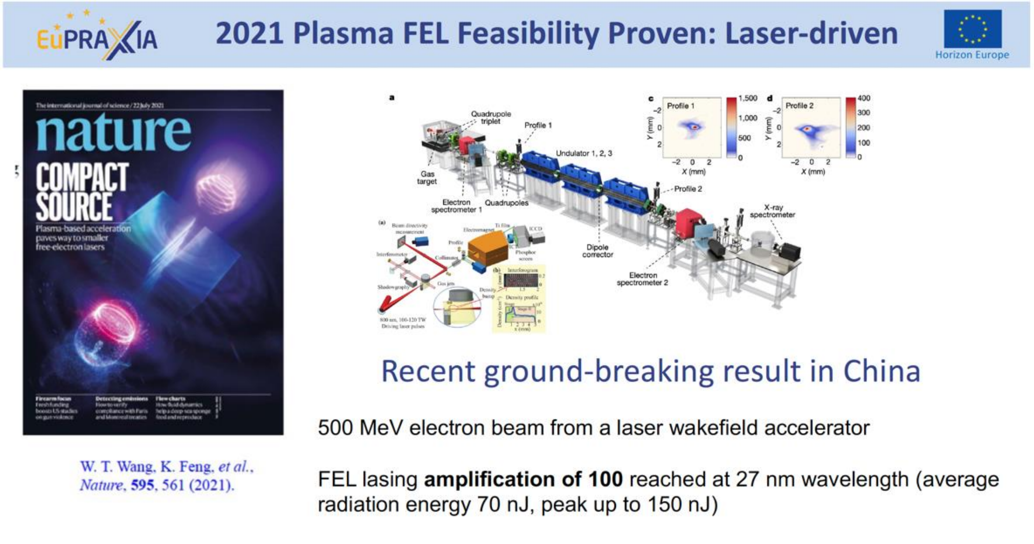


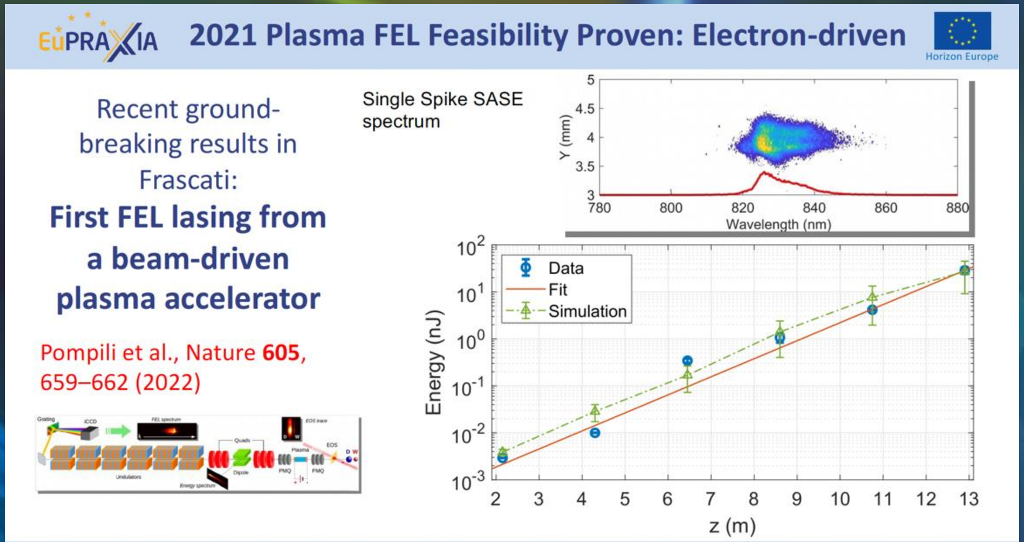
Funded by the European Union

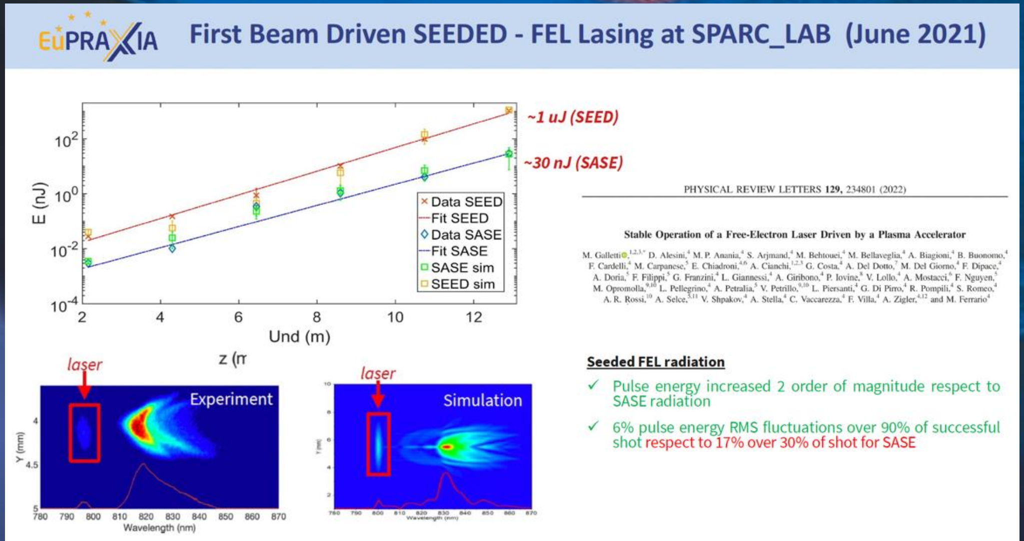
High Quality Beams Required

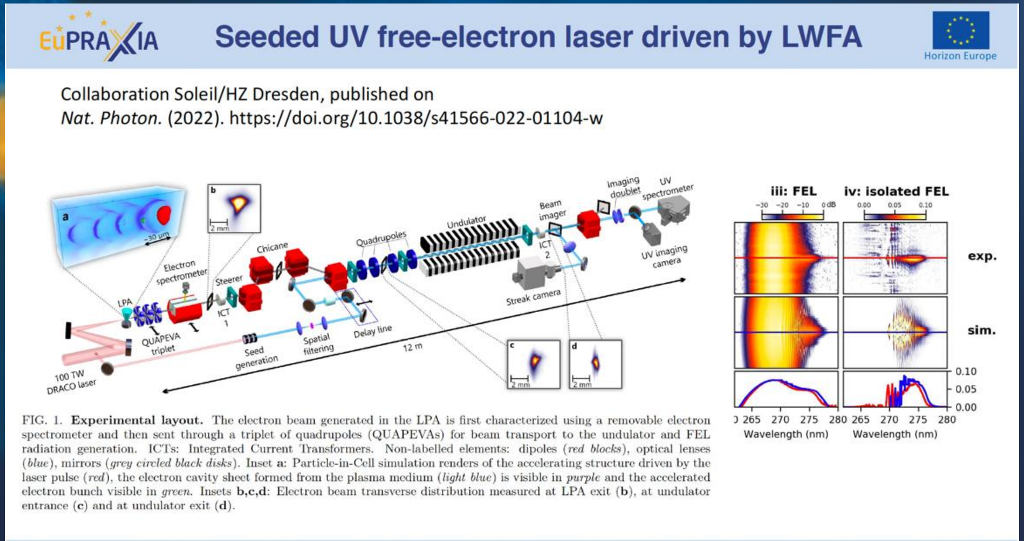


Basic beam quality achieved in pilot FEL experiments





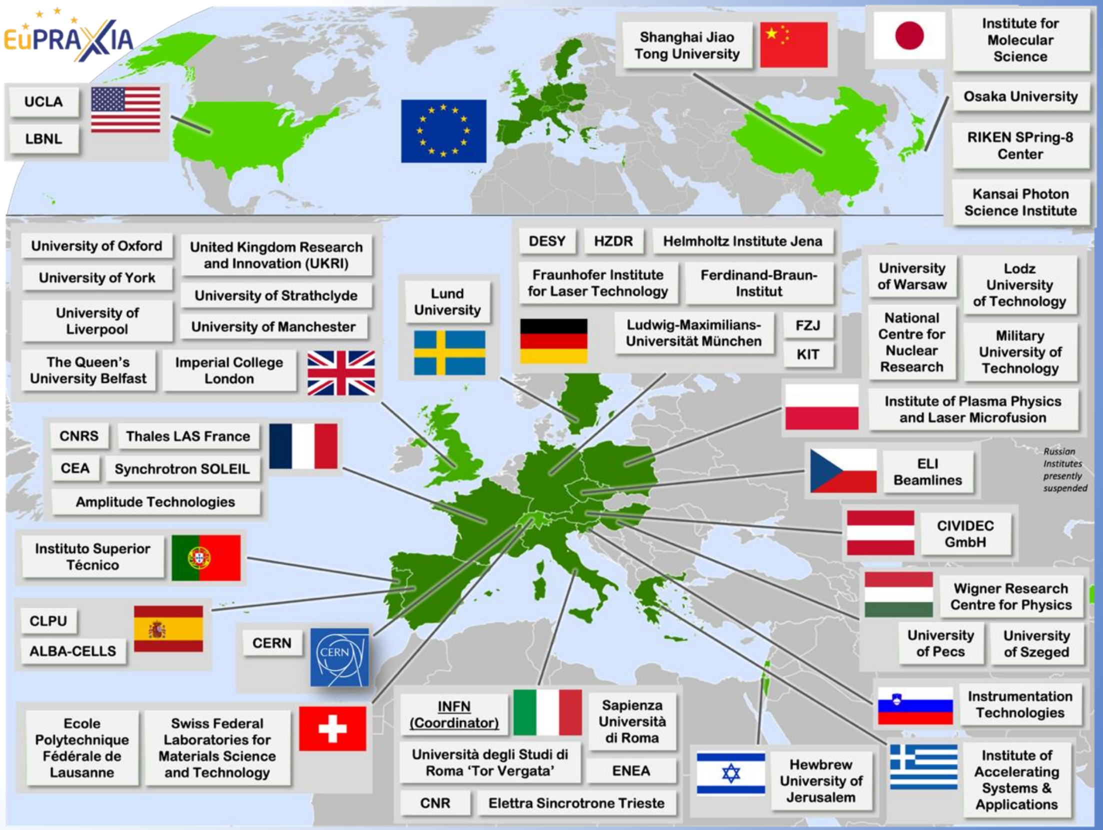




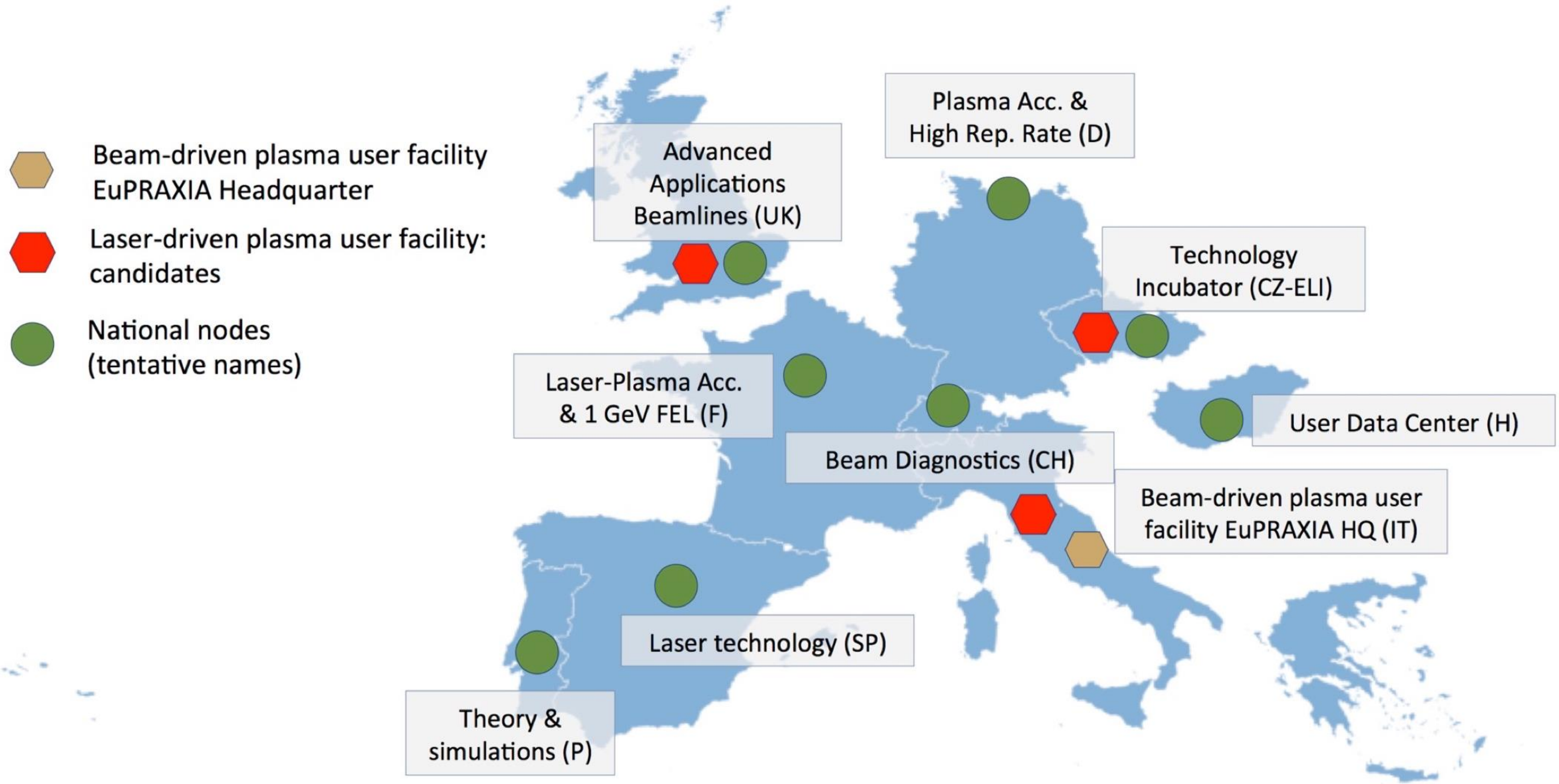
Wide International Collaboration

Funded by the European Union

- **The EuPRAXIA Consortium today: 54 institutes** from **18 countries** plus CERN
- Included in the **ESFRI** Road Map
- **Efficient fund raising:**
  - –**Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
  - –**Doctoral Network** (funding EU, UK, in-kind)
  - –**EuPRAXIA@SPARC_LAB** (Italy, in-kind)
  - –**EuAPS Project** (Next Generation EU)
  - –**What Next? => PACRI !**



Distributed Research Infrastructure

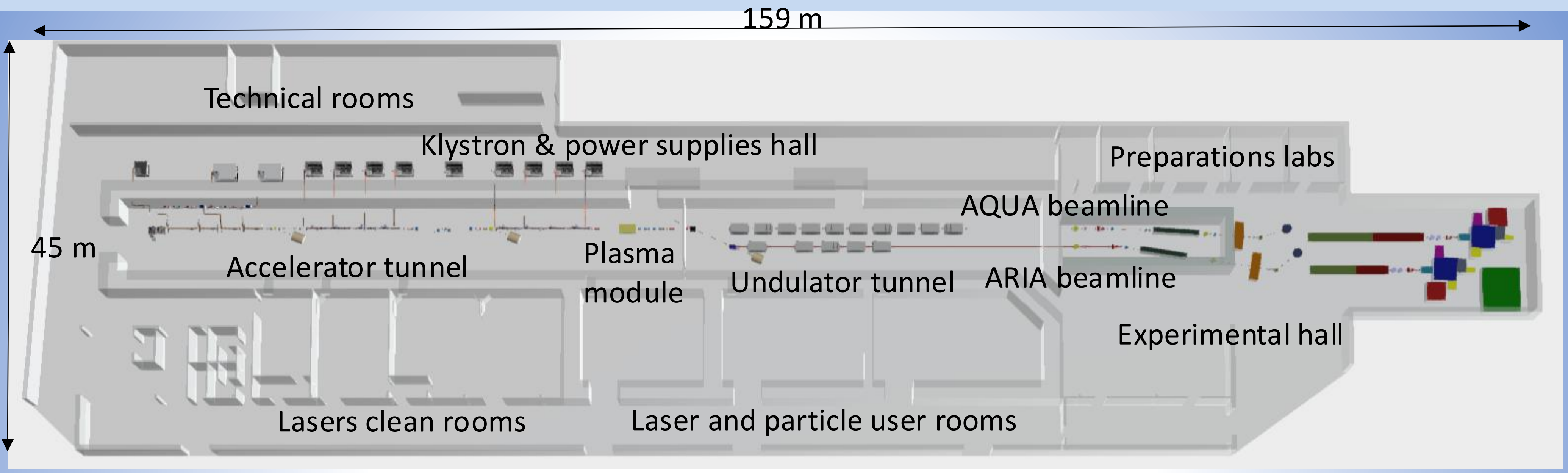


Funded by the European Union

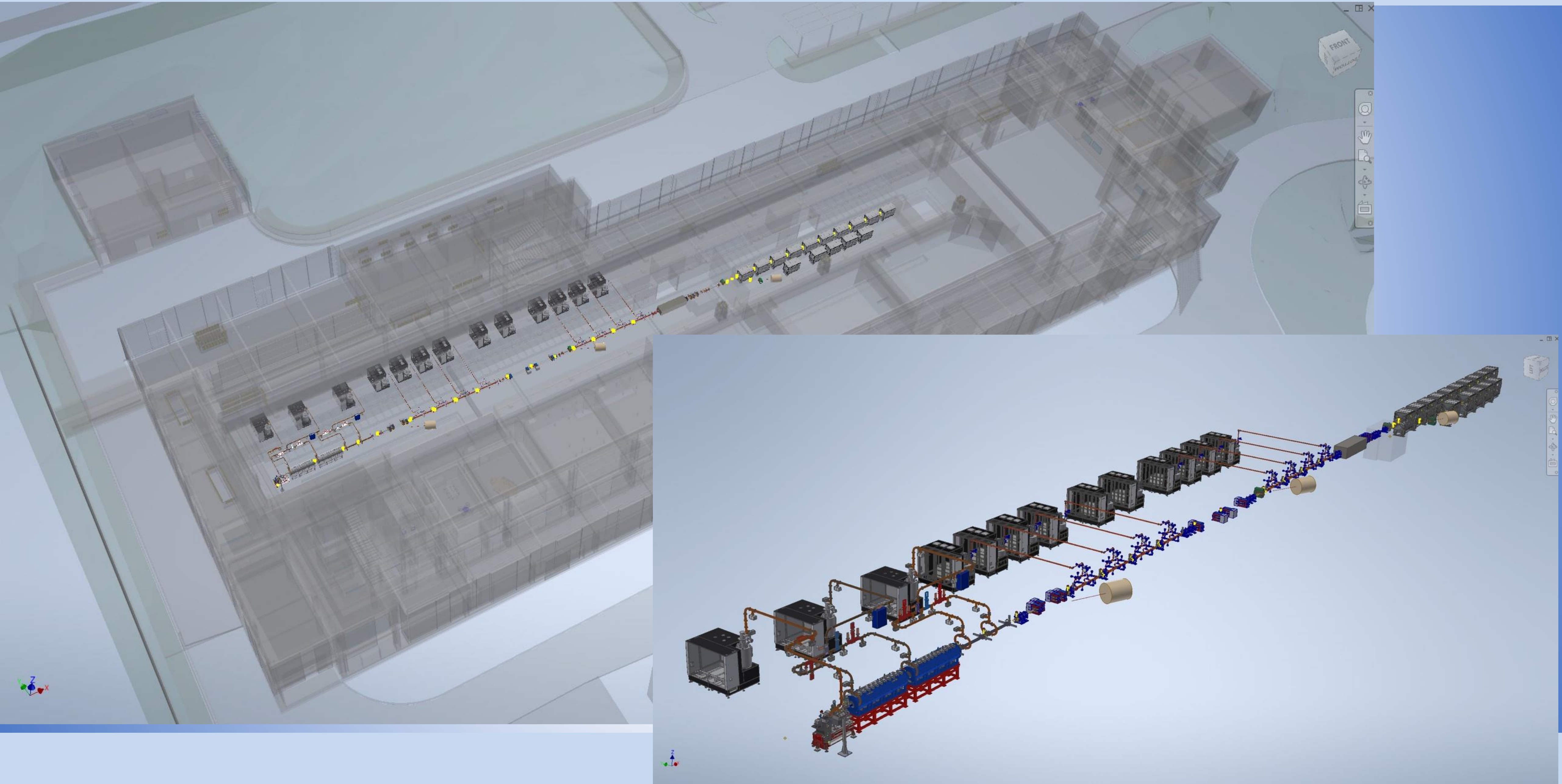
EuPRAXIA Headquarter and Site 1: EuPRAXIA@SPARC_LAB

- 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)

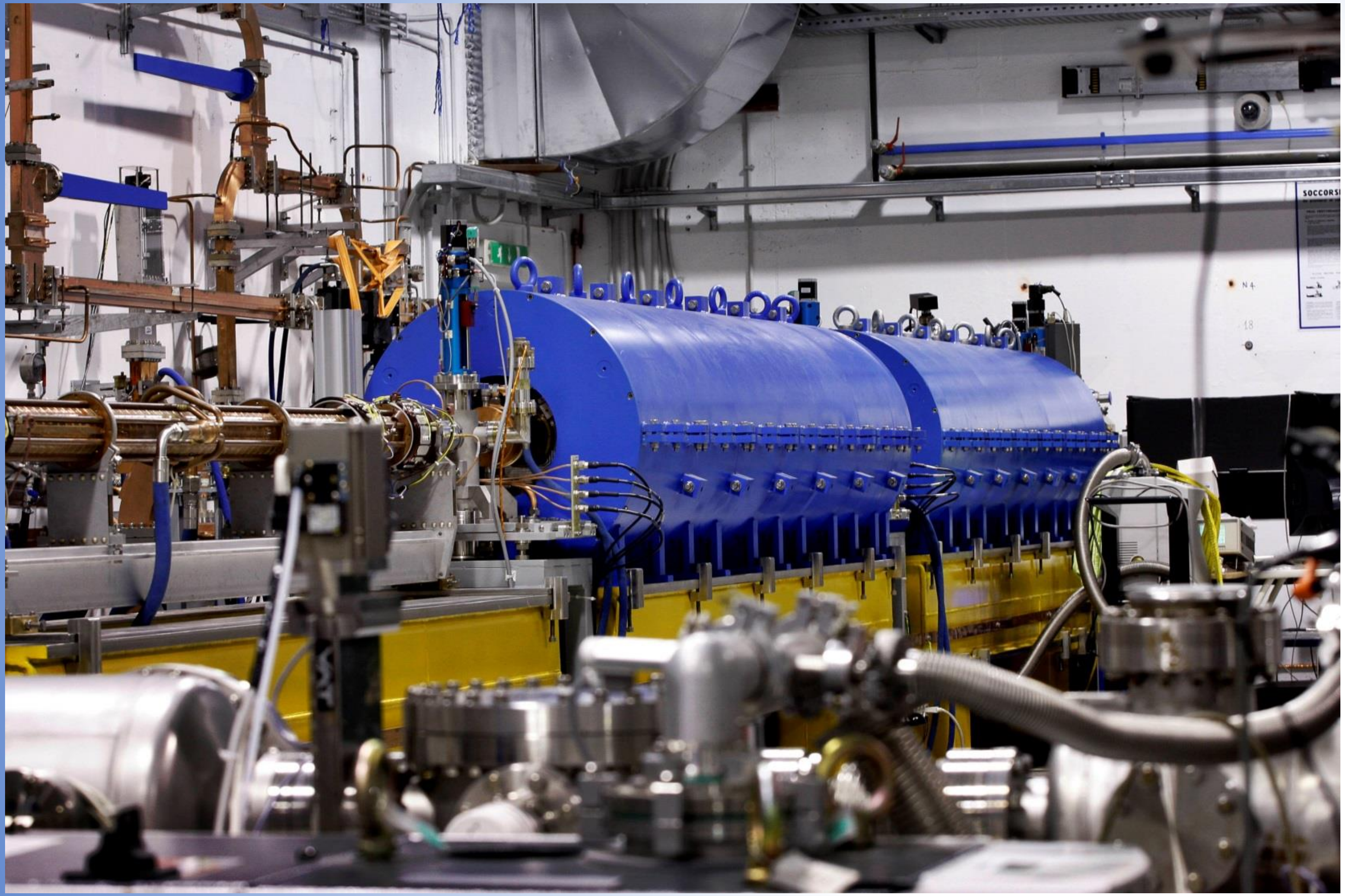
EuPRAXIA@SPARC_LAB Layout



Machine Layout with all components included

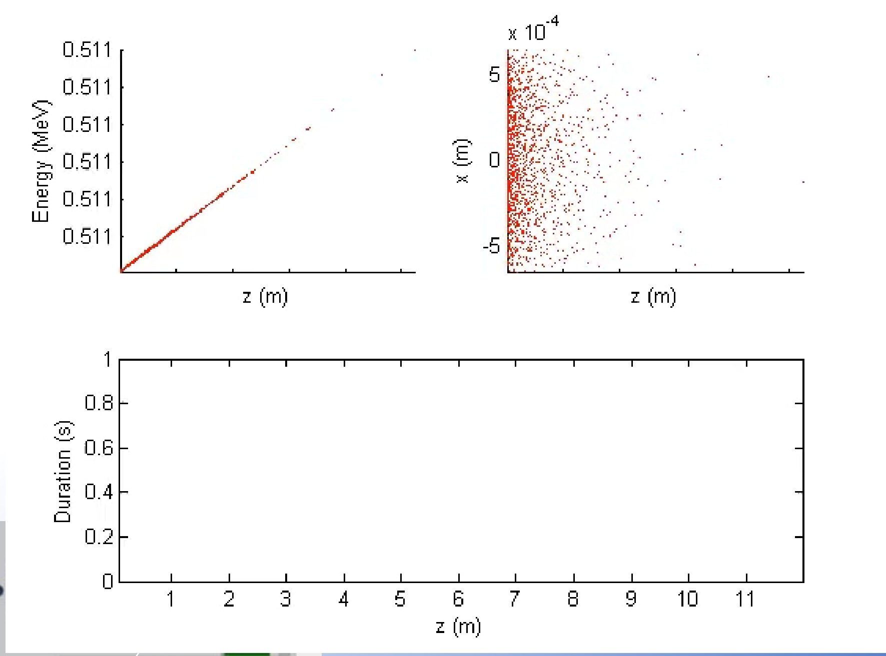


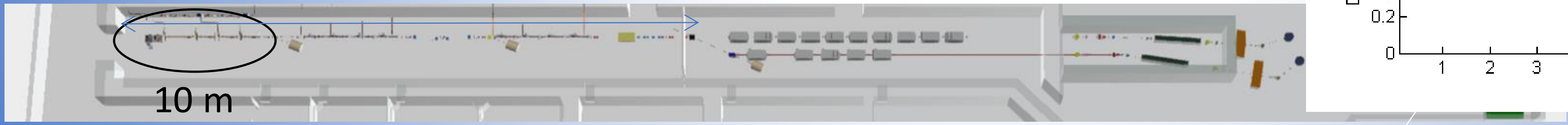
High Quality Electron Beams



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

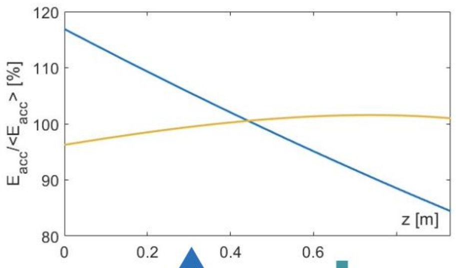
Table 7.2: Driver and witness beam parameters at the end of photo-injector.

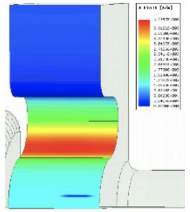




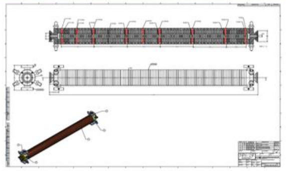
Courtesy E. Chiadroni

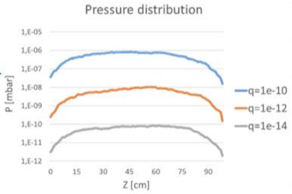
World`s Most Compact RF Linac: X Band

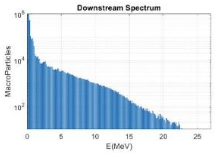




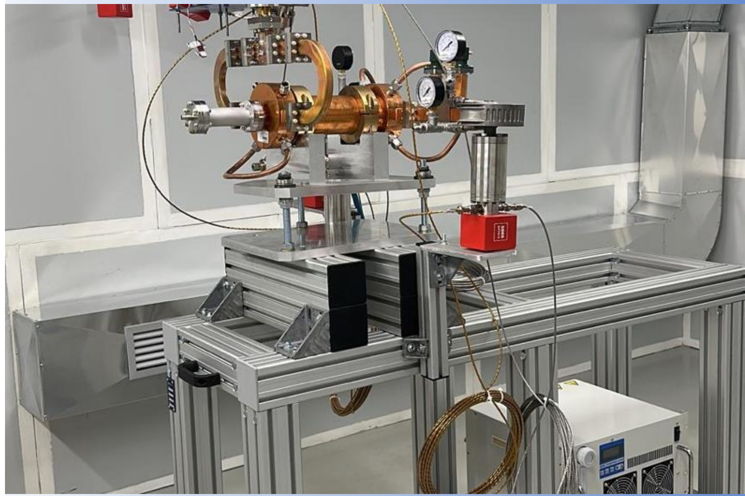
1. **E.m. design**: *done*
2. **Thermo-mechanical analysis**: *done*
3. **Mechanical design**: *done*
4. **Vacuum calculations**: *done*
5. **Dark current simulations**: *done*
6. **Waveguide distribution simulation with attenuation calculations**: *done*

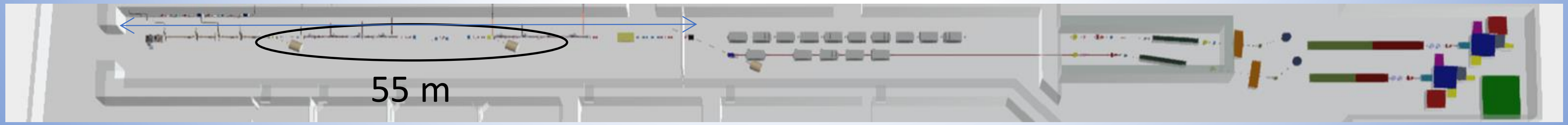






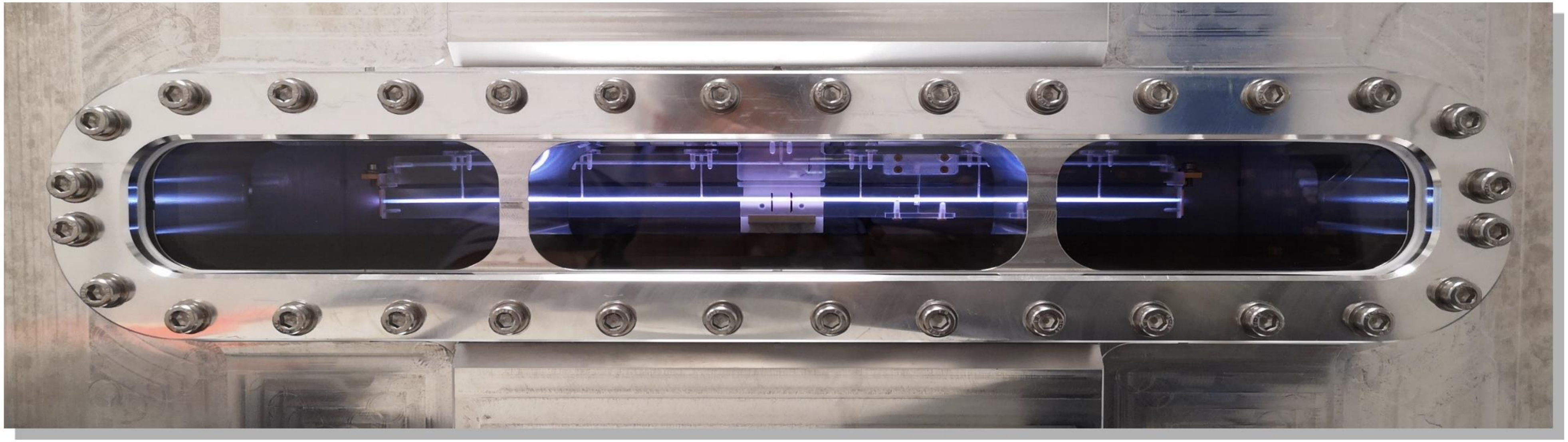
PARAMETER	Value	
	with linear tapering	w/o tapering
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85-3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length (flange-to-flange) [m]	**0.94 (1.05)**	
No. of cells	112	
Shunt 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**	





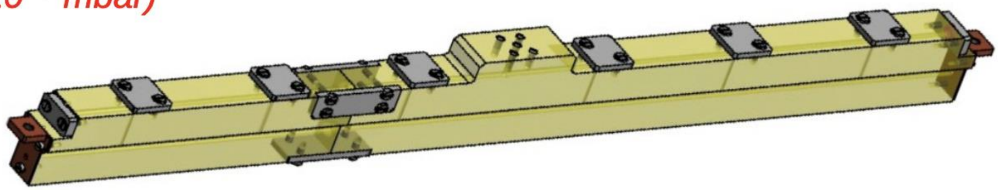
Courtesy D. Alesini

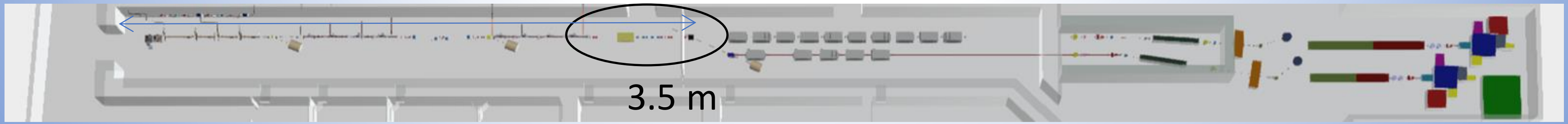
Plasma Module



- 40 cm long capillary → 1st prototype for the EuPRAXIA facility
  - *Made with special junction to allow negligible gas leaks (<10^{-10} mbar)*
- Operating conditions
  - *1 Hz repetition rate (to be increased up to 100 Hz)*
  - *10 kV – 380 A minimum values for ionization*
  - *6 inlets for gas injection. Electro-valve aperture time 8-12 ms*

A. Biagioni, V. Lollo



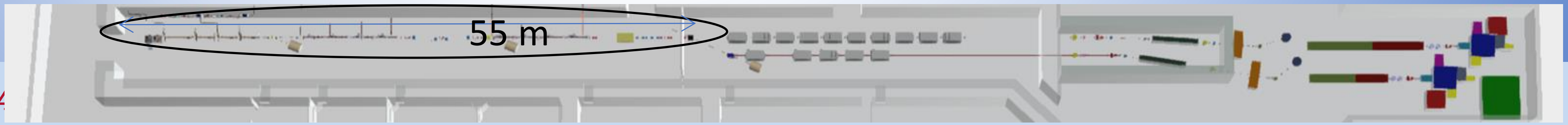


Courtesy A. Biagioni, R. Pompili

Expected electron parameters

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

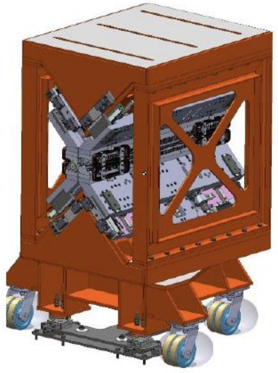
- Two different configurations:
  - Main: ~500 MeV beam from the X-band linac + 60 cm capillary **PWFA** acceleration up to **1.2 GeV**
    - Smaller accelerated charge
    - Shorter pulses
    - Final energy easily upgradable in future with similar building occupancy ($\sim m$)
  - Secondary: ~**1 GeV** beam from the **X-band** linac alone (with additional RF power)
    - Larger charge per bunch
    - Longer pulses
    - At the upper limit of RF technology (not easily upgradable without extending the occupancy)

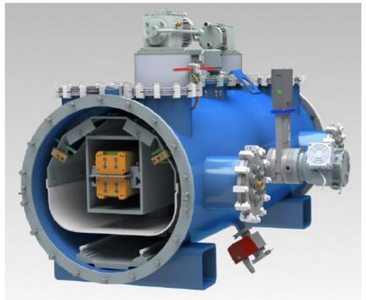


Radiation Generation: FEL

Two FEL lines:

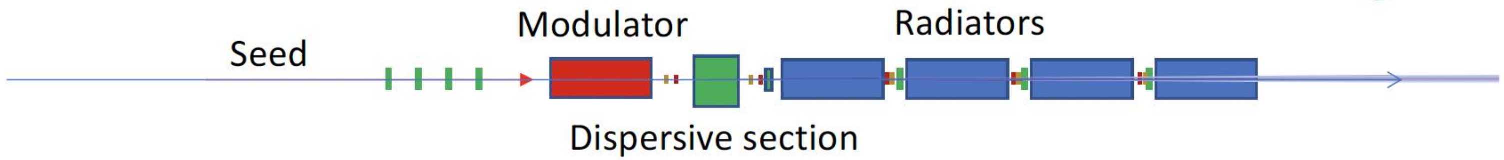
1) ***AQUA*: Soft-X ray SASE FEL – Water window optimized for 4 nm (baseline)**



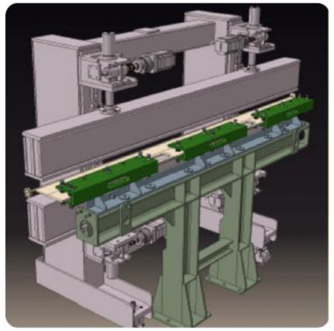


SASE FEL: 10 UM Modules, 2 m each – 60 cm intraundulator sections.
Two technologies under study: Apple-X PMU (baseline) and planar SCU.
Prototyping in progress

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

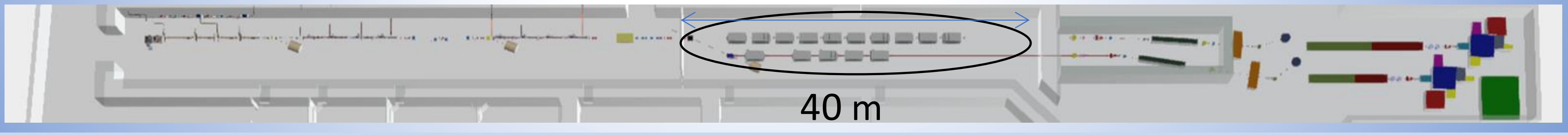


FERMI FEL-1 Radiator



SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 50-100 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.

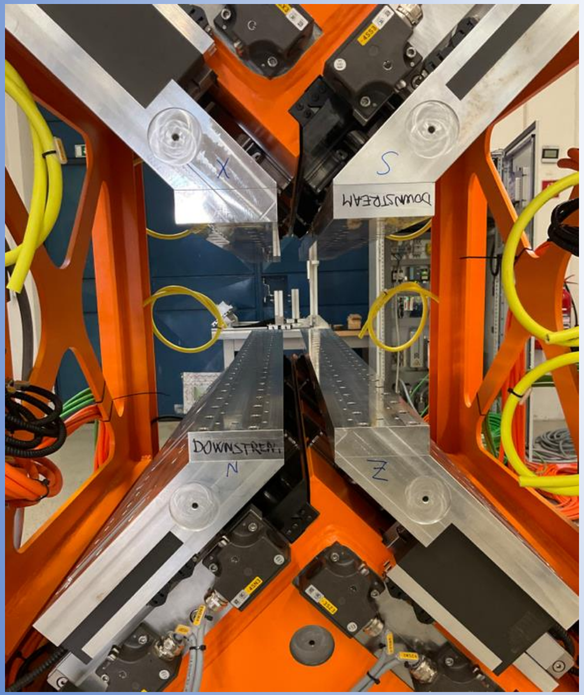
Frascati 06/05/23 – EUPRAXIA TDR



Courtesy L. Giannessi

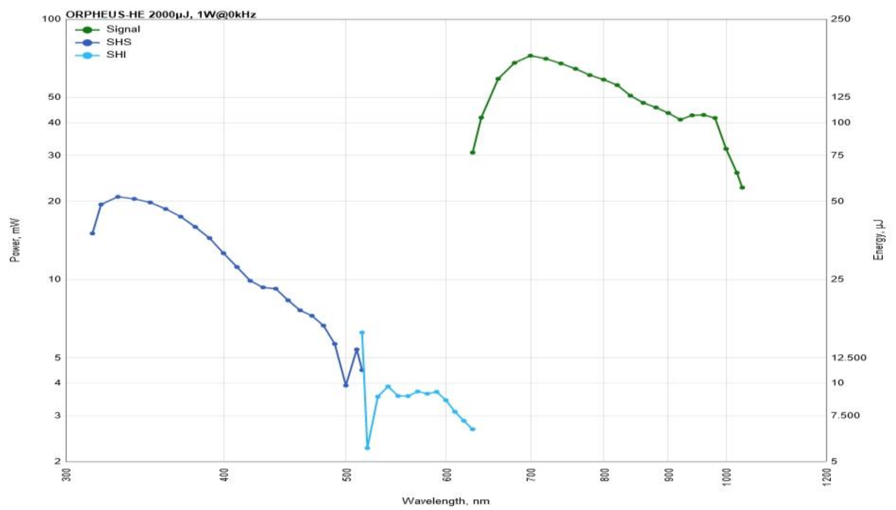
Undulators

Undulator parameters	AQUA
Period (mm)	18
Maximum strength (k)	1.47
Minimum gap (mm)	6
Active length (m)	19.8

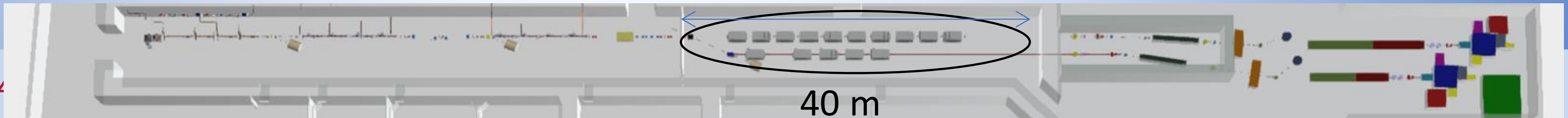


APPLE X undulator
allow for polarization tuning
(from linear to circular)

Undulator parameters	ARIA	
	Modulator	Radiator
Period (mm)	100	55
Active length (m)	3.0	8.4
Seeding laser	OPA configuration	
Seeding wavelengths (nm)	320-400 + 600-800	
Seeding energy	>20 µJ	
Seeding duration	200 fs	

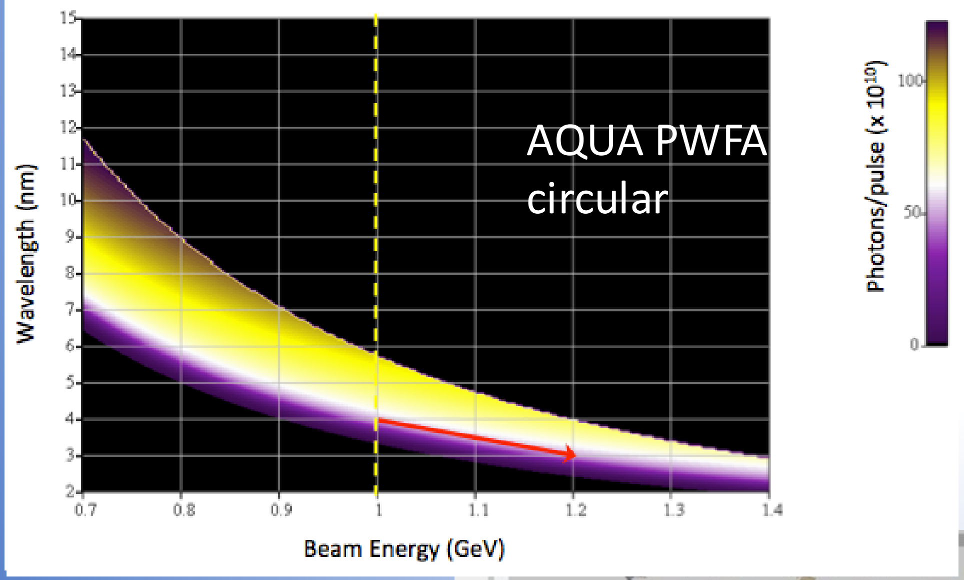


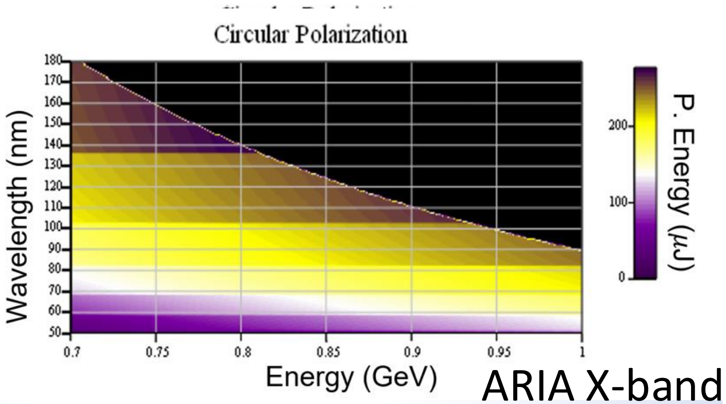
Seed laser tunability

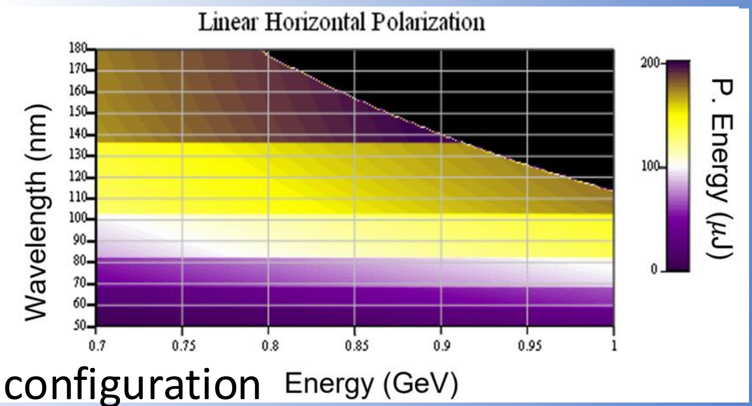


Expected FEL radiation

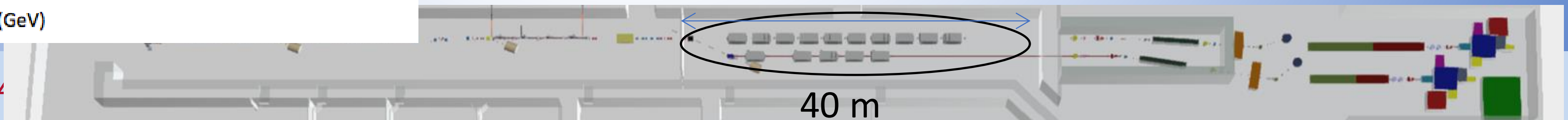
Parameter	Unit	AQUA PWFA	AQUA X-band	ARIA PWFA	ARIA X-band
Radiation Wavelength	*nm* *eV*	3-10 415-120	4-10 310-120	50-150 25-8	50-150 25-8
Photons per Pulse	$\times 10^{12}$	0.25-1	0.25-1	10-60	12-150
Photon Bandwith	*%*	0.3	0.3	0.05	3
Configuration		SASE		HGHG seeding	



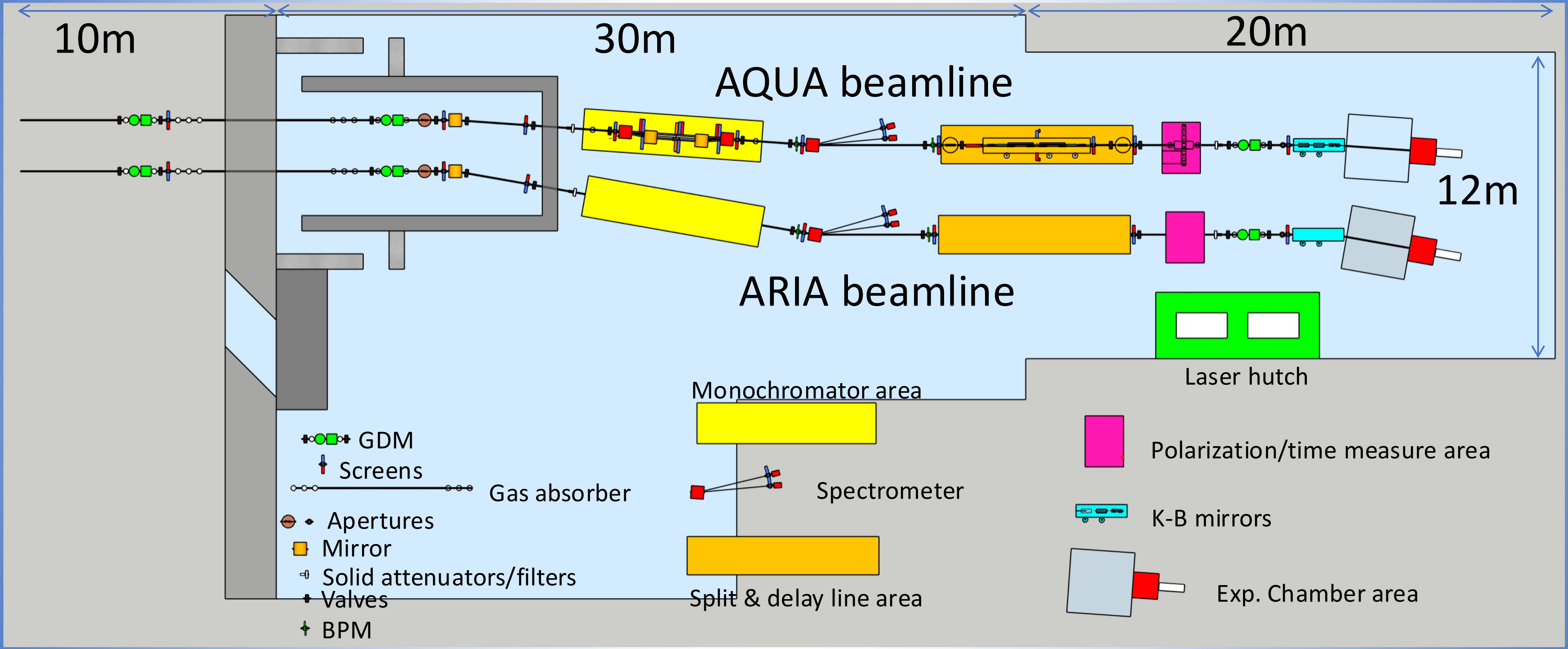


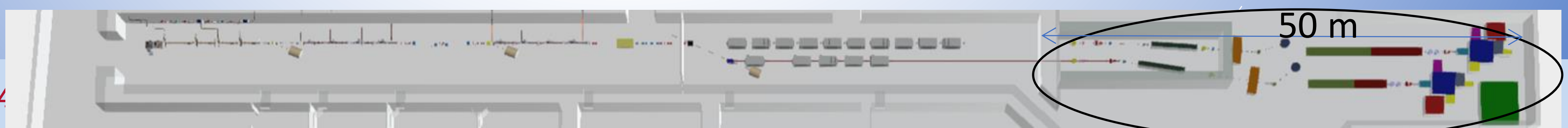


ARIA X-band configuration



FEL Beamlines

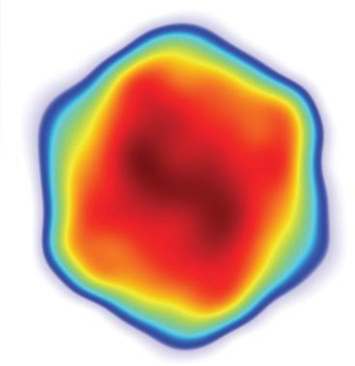




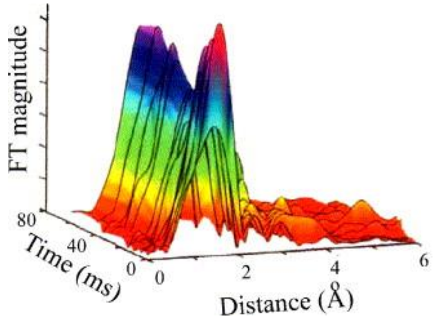
AQUA beamline scientific case

Experimental techniques and typology of samples

Coherent imaging



X-ray spectroscopy



Raman spectroscopy

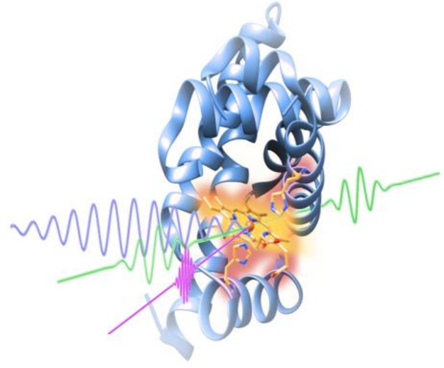
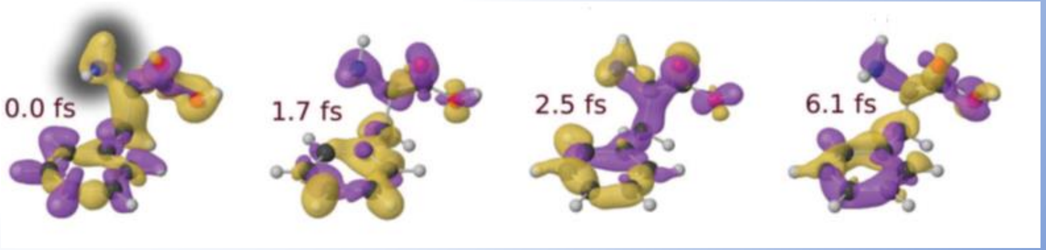
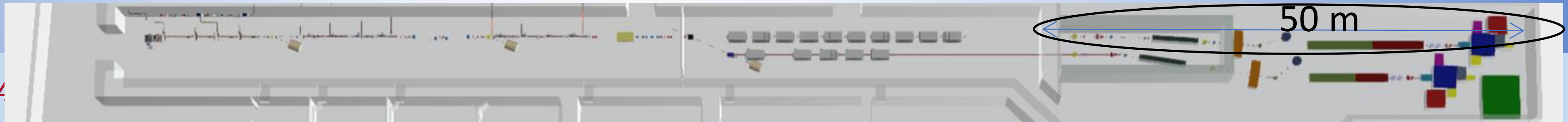


Photo-fragmentation of molecules



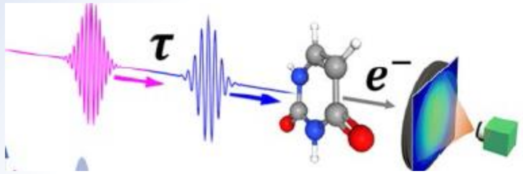
(Large) Viruses
Organelles
Bacteria/Cells
Organic molecules
Metals
Semiconductors
Superconductors
Magnetic materials



ARIA beamline scientific case

Defining experimental techniques and typology of samples (and applications)

Photoemission Spectroscopy



Photoelectron Circular Dichroism

Raman spectroscopy

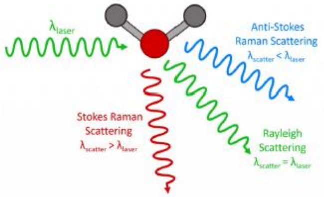
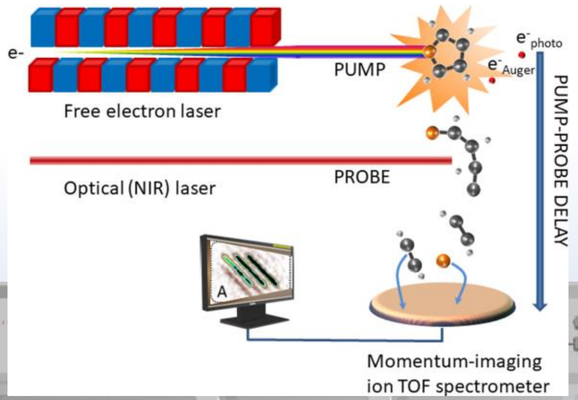
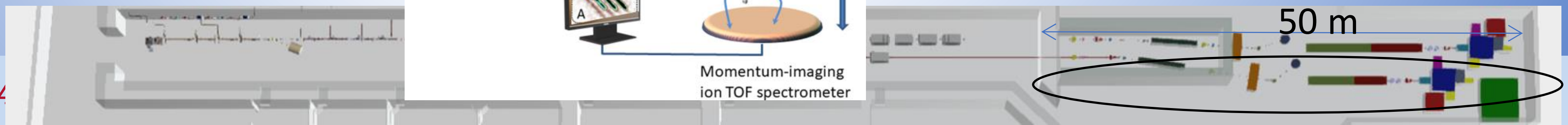


Photo-fragmentation of molecules Time of Flight Spectroscopy





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

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EuPRAXIA Advanced Photon Sources

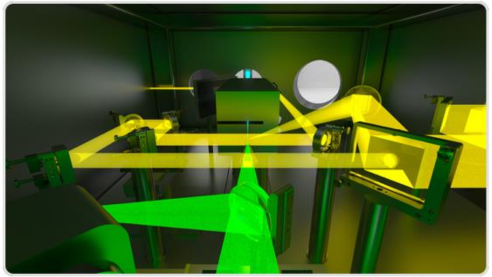
EuAPS: EuPRAXIA Advance Photon Sources

- Principal Investigator: M. Ferrario,
- Infrastructure Manager: C. Bortolin,
- Management and Dissemination: A. Falone

Research

The **EuPRAXIA Advanced Photon Sources** (**EuAPS**) project, led by INFN in collaboration with CNR and University of Tor Vergata, foresees the construction of a laser-driven “betatron” X Ray user facility at the LNF SPARC_LAB laboratory. EuAPS includes also the development of high power (up to 1 PW at LNS) and high repetition rate (up to 100 Hz at CNR Pisa) drive lasers for EuPRAXIA. EuAPS has received a financial support of 22.3 MEuro from the PNRR plan on “creation of a new RI among those listed in NPRI with medium or high priority” and has received the highest score for the action 3.1.1 of the ESFRI area “Physical Sciences and Engineering”.

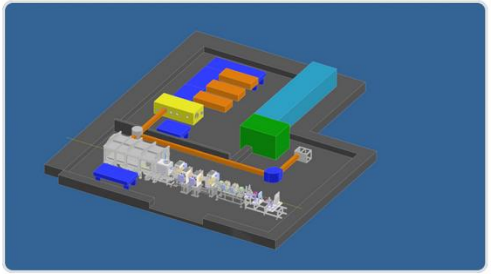
A. Cianchi (Uni ToV)



Betatron Radiation Source

READ MORE

P. Cirrone (INFN-LNS)



High Power Laser Beamline

READ MORE

L. Labate (CNR-INO)

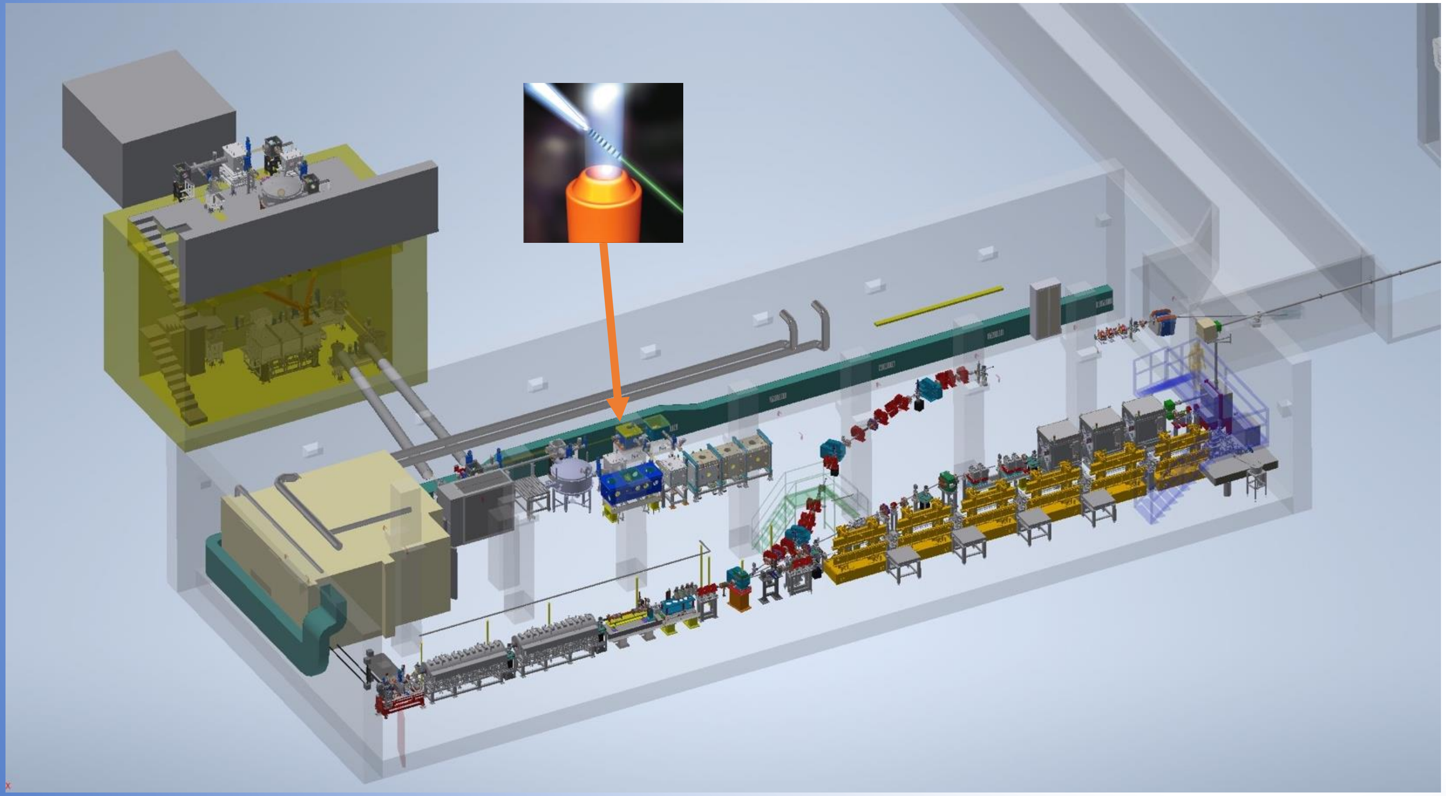
High Repetition Rate Laser Beamline

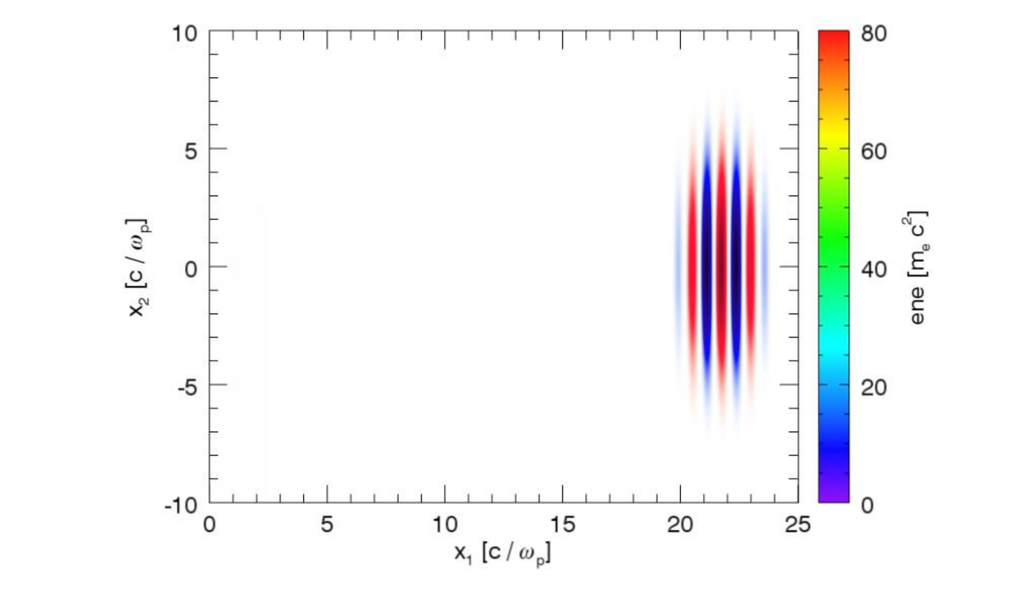
READ MORE

M. Ferrario et al. INFN-23-12-LNF (2023)

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





Courtesy J. Vieira, R. Fonseca/GoLP/IST Lisbon

$K_u<1$

$K_u>1$

$K_u>>1$

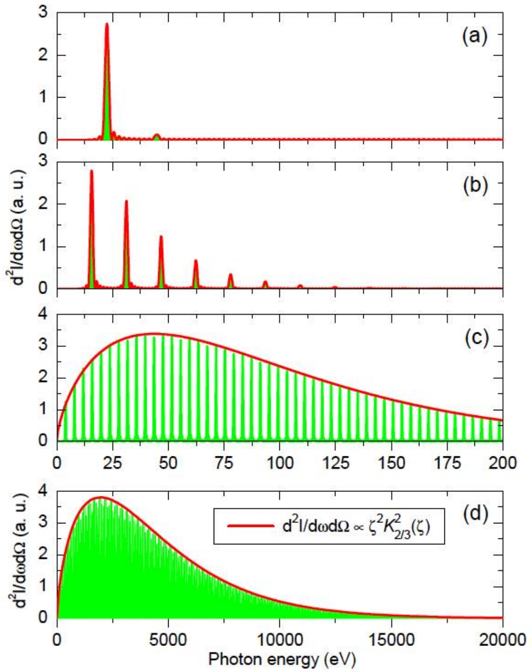
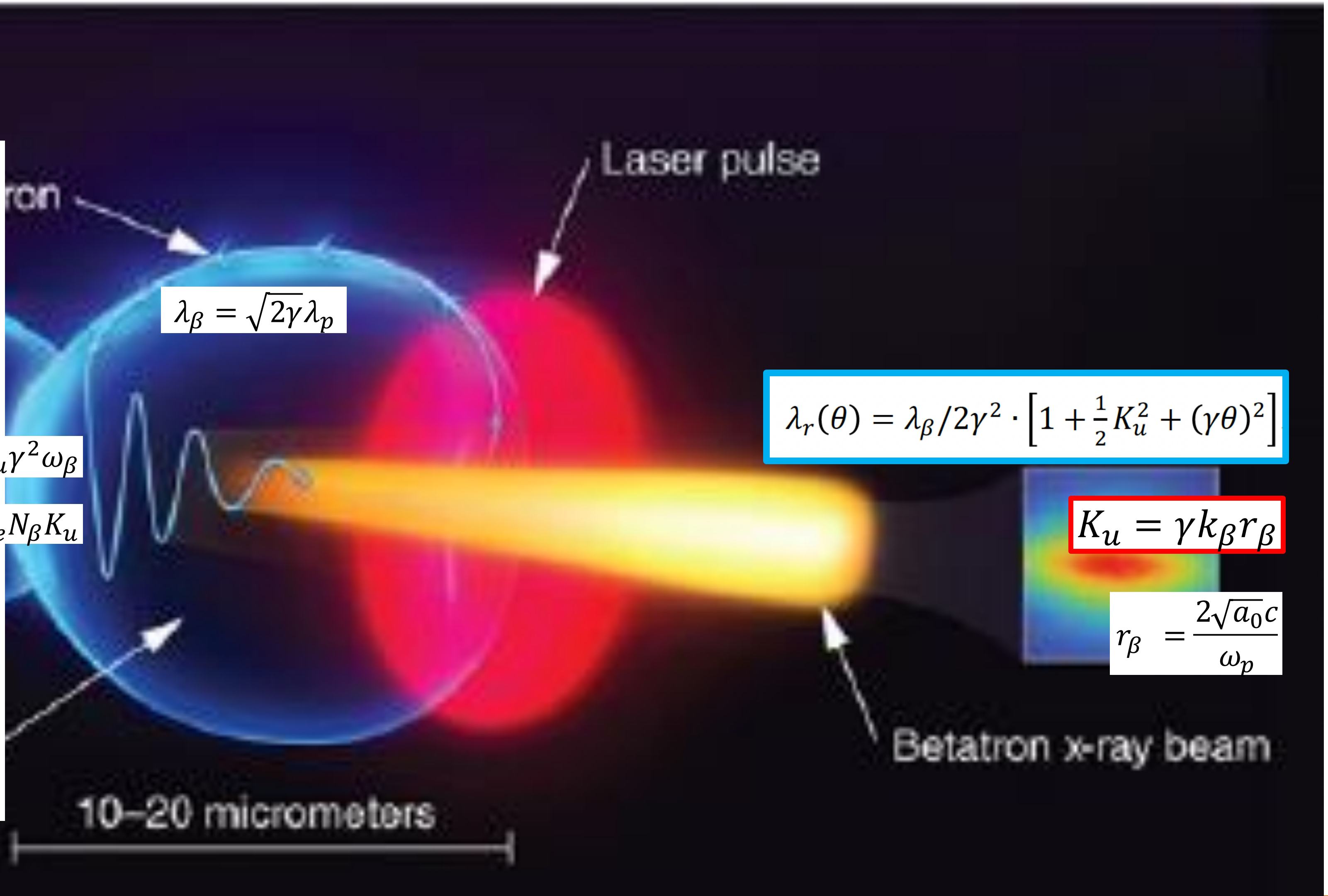


Figure 3.3: *Calculated betatron radiation spectra in a plasma column with density of 7×10^{18} cm^{-3}. The electron energy is 15 MeV, and oscillation amplitudes are (a) 0.1 μm, (b) 0.5 μm, and (c) 1.6 μm. (d) shows the case of a 100 MeV electron with an oscillation amplitude of 1.6 μm.*

$$\omega_c = 3K_u\gamma^2\omega_\beta$$

$$N_{ph} \propto N_e N_\beta K_u$$



$$\lambda_\beta = \sqrt{2\gamma}\lambda_p$$

$$\lambda_r(\theta) = \lambda_\beta/2\gamma^2 \cdot \left[1 + \frac{1}{2}K_u^2 + (\gamma\theta)^2\right]$$

$$K_u = \gamma k_\beta r_\beta$$

$$r_\beta = \frac{2\sqrt{a_0}c}{\omega_p}$$

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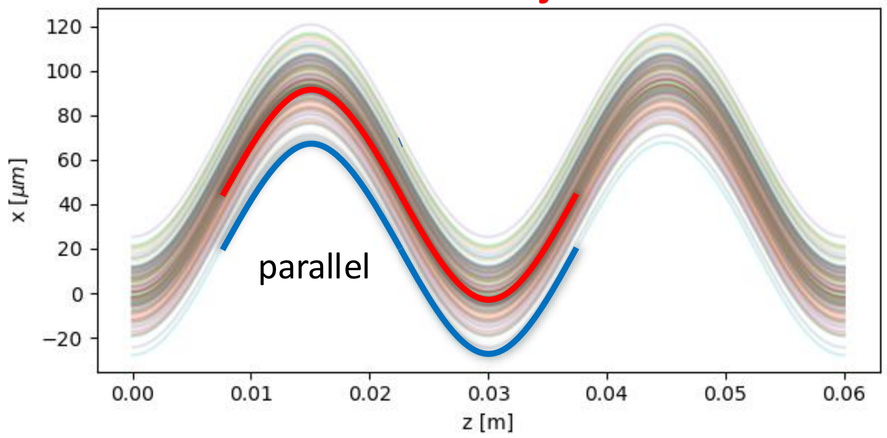
Betatron motion: trajectory crossing

- While in a magnetic undulator the oscillation amplitude is given by particle energy and **undulator strength *K***, inside the bubble it's given by the axial offset
- This gives an **intrinsic *K*-spread** due to the source size (beam spot), greater in case of on axis injection
- The **nearly continuous *K* distribution** reaches very low values, **enhancing low energy spectral intensity**

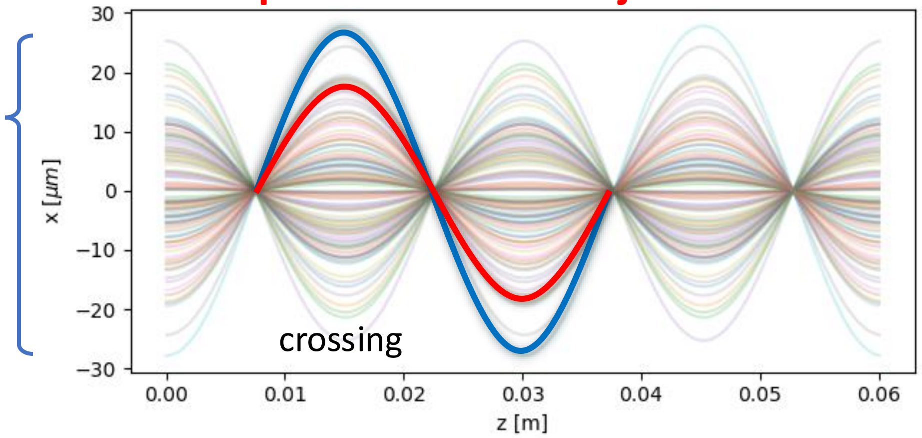
$$K = \gamma \, k_\beta \, r_\beta$$

particle energy (γ), betatron wavenumber (k_β), oscillation amplitude (r_β)

undulator trajectories



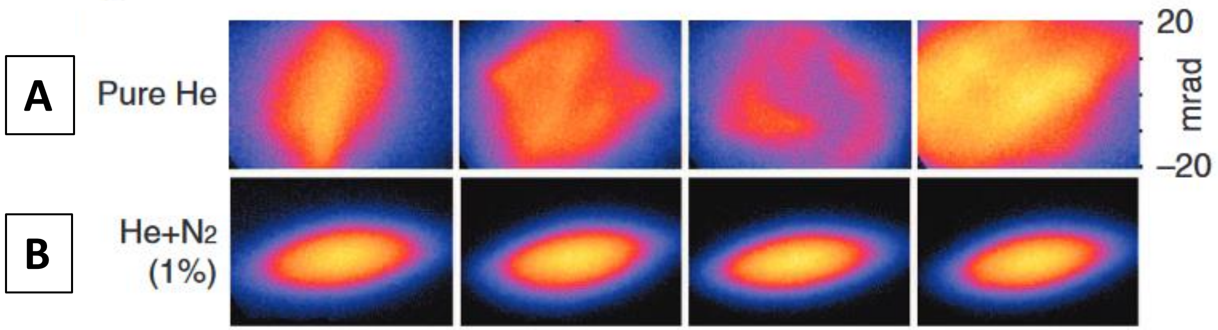
plasma bubble trajectories



Self-injection VS Ionization injection

- **A – Self-injection**: some of the main gas component ionized electrons oscillate around the bubble and get **trapped inside the** wake, with a typically **unstable *transverse injection*.**

- **B – Ionization injection:** adding a **doping gas** with higher atomic number (e.g. nitrogen) some of the dopant electrons are **ionized directly inside the bubble**. This gives an intrinsically **more stable *longitudinal injection***.



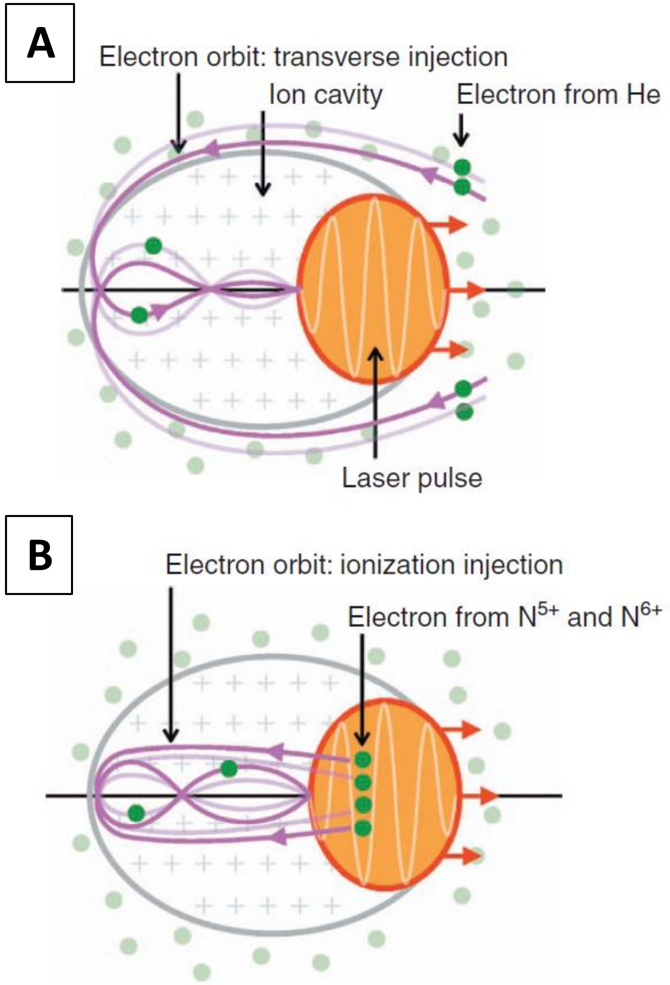
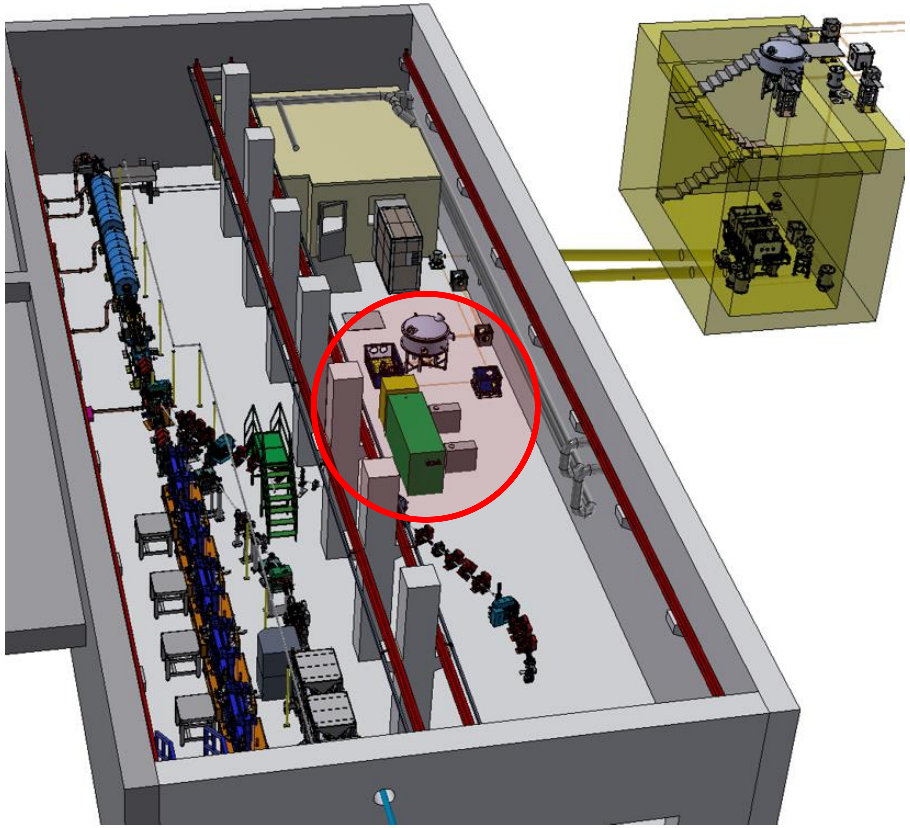
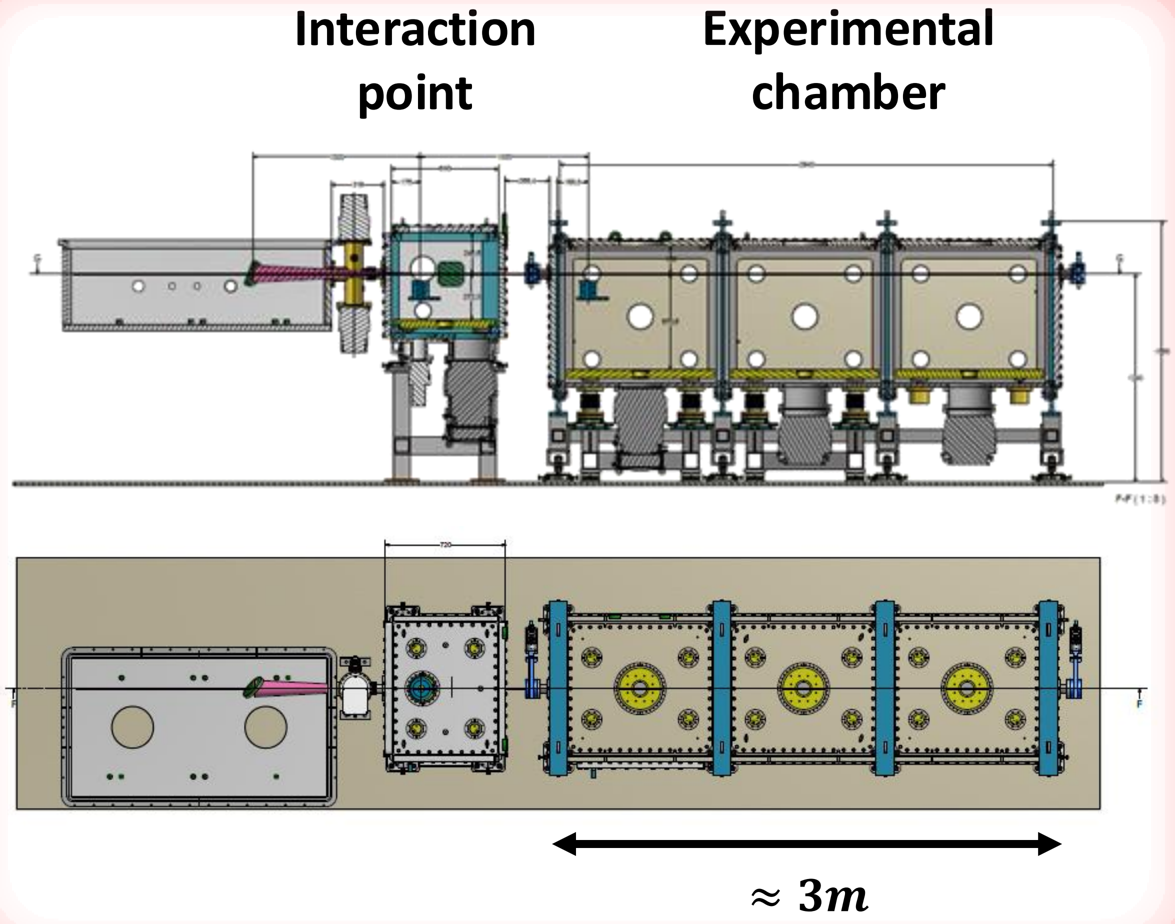


Image credits: A. Döpp et al. "Stable femtosecond X-rays with tunable polarization from a laser-driven accelerator" https://doi.org/10.1038/lsa.2017.86

The EuAPS source





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Photon Science @ EuAPS

Plasma-Generated X-ray Pulses: Betatron Radiation Opportunities at EuPRAXIA@SPARC_LAB

Francesco Stellato [1,2,*], Maria Pia Anania [3], Antonella Balerna [3], Simone Botticelli [2], Marcello Coreno [3,4], Gemma Costa [3], Mario Galletti [1,2], Massimo Ferrario [3], Augusto Marcelli [3,5,6], Velia Minicozzi [1,2], Silvia Morante [1,2], Riccardo Pompili [3], Giancarlo Rossi [1,2,7], Vladimir Shpakov [3], Fabio Villa [3] and Alessandro Cianchi [1,2]

Condensed Matter 7.1 (2022): 23.

- Imaging of biological (and cultural heritage) samples
  - Exploits the brilliance and coherence of betatron radiation, requires small divergence and good focusing
- Static X-ray Spectroscopy
  - Relatively easy, but does not exploit the radiation time structure
- Ultra-fast X-ray spectroscopies exploiting ultra-short betatron pulses
  - More complicated, requires timing between pump and probe pulses, but fully exploits the fs pulse duration
- Time-resolved imaging (ultrafast dynamics)
- Wide angle scattering, diffraction
  - Depending on the samples, requires monochromatic beams with high flux

Courtesy F. Stellato

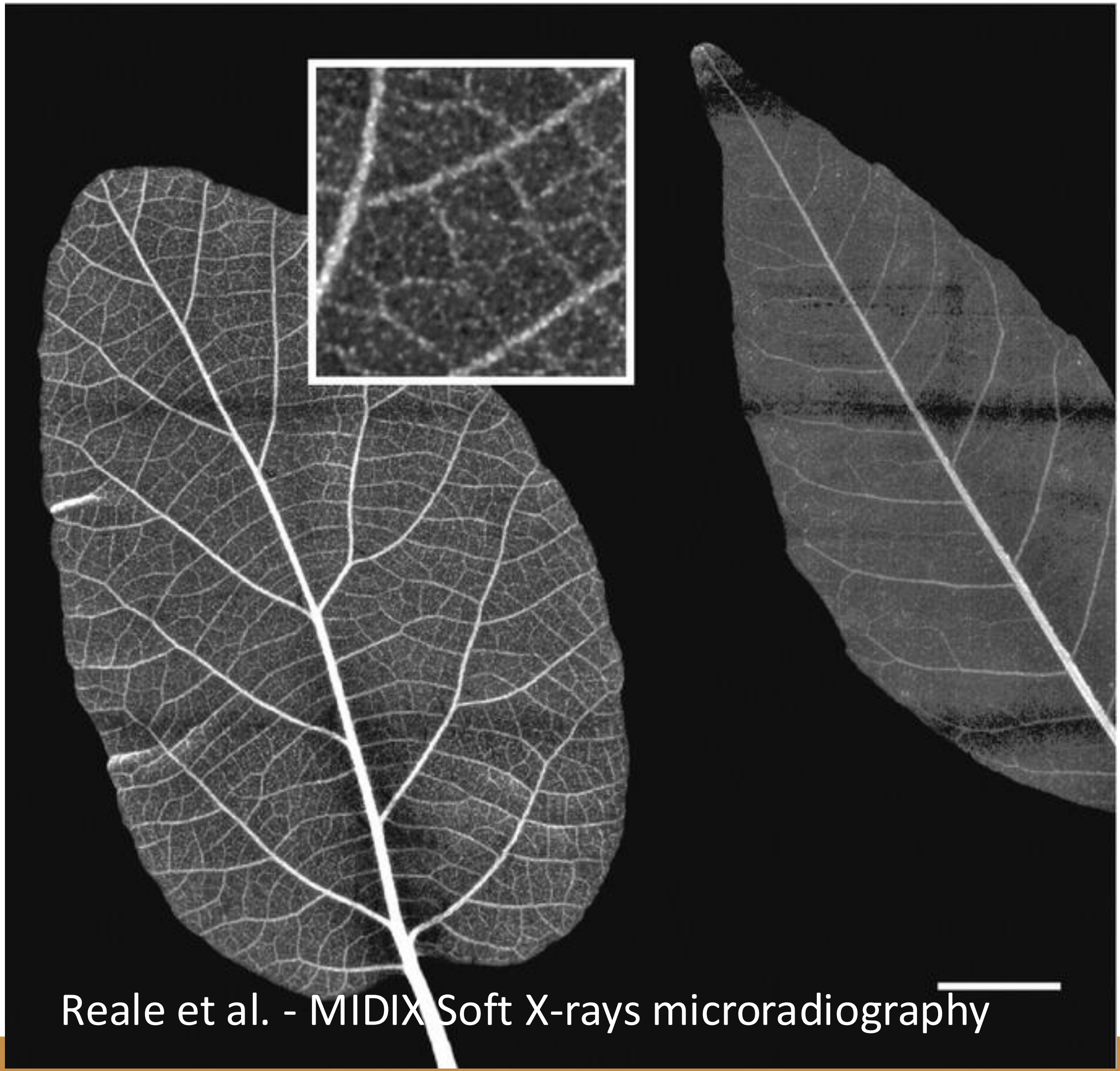
Imaging – The pilot experiment

Green science

X-ray imaging of leaves (and wood)

aiming at the (tens of) microns resolution

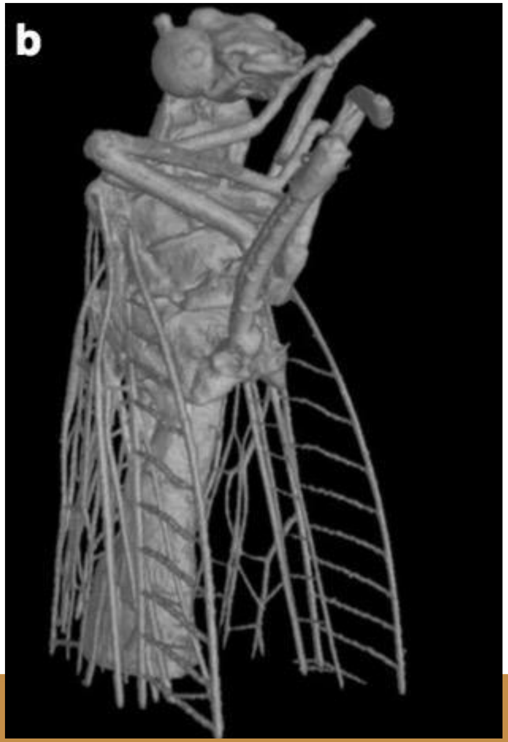
Experiments performed with the broad radiation spectrum **filtered** by different materials to obtain **difference maps** emphasizing the presence of heavy metal contaminants → **pollution control**


Reale et al. - MIDIX Soft X-rays microradiography

Imaging – CT and Phase Contrast

Betatron sources can fill the gap between synchrotrons and X-ray tubes and **Computer Tomography** (CT)

Guo *et al.* Scientific Reports 2019
Cole *et al.* PNAS 2018



Betatron sources have a **spatial coherence** that allows performing **Phase Contrast Imaging** (PCI). In PCI, one measures the difference in wavefront, while in “traditional” imaging one measures the difference in the **X-ray absorption coefficient** between different “objects”

PCI provides better **contrast** than radiography, especially when dealing with biological samples. Wenz *et al.* Nature communications 2015

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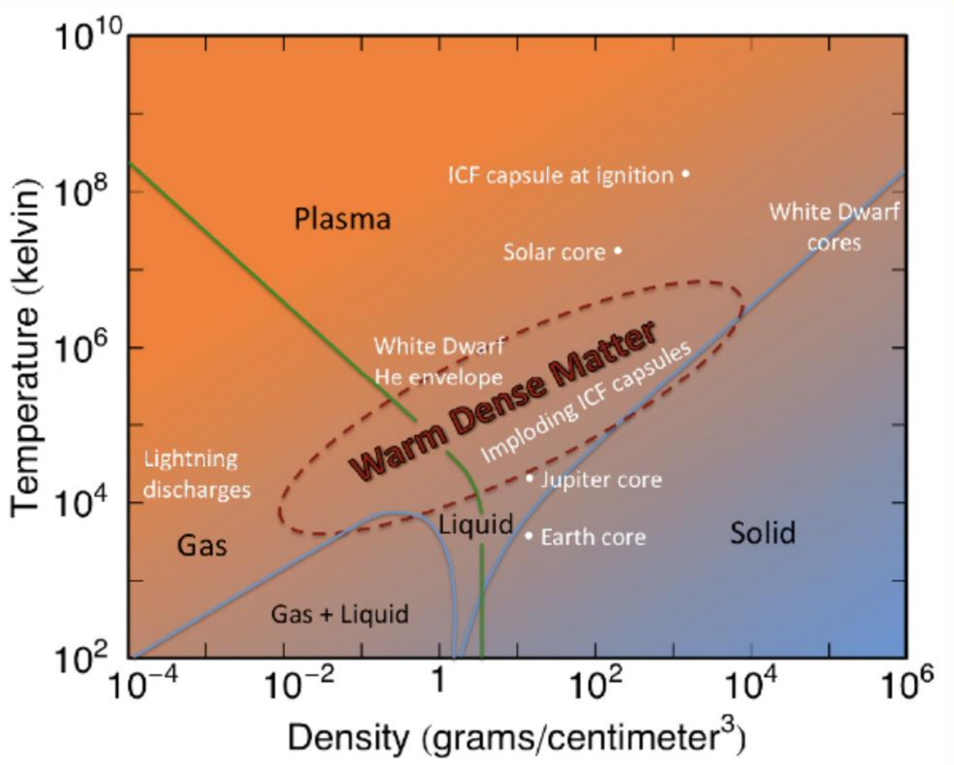
Material Science Applications: Warm Dense Matter (WDM)



Mahieu, B., et al. "Probing warm dense matter using femtosecond X-ray absorption spectroscopy with a laser-produced betatron source." *Nature Communications* 9.1 (2018): 3276.

WDM occurs in:

- **Cores of large planets;**
- **Systems that start solid and end as a plasma;**
- **X-ray driven inertial fusion implosion (aspects of indirect-drive inertial fusion).**

The **investigation of such warm dense matter (WDM) is one of the great challenges of contemporary physics**.

Femtosecond lasers can rapidly heat matter, leading to ultrafast solid-liquid-WDM transitions, followed by a more complex **multiphase expansion at a picosecond time scale**. Highly nonequilibrium states of matter are expected, due to the finite rate of energy transfer from the excited electrons to the lattice.

As the atomic structure modification is supposed to be driven by the photoexcited electrons, it is of primary importance to determine the respective time scales of the evolution of both electron and atomic structures.

Towards a Plasma Undulator for FEL

Ultrahigh brightness beams from plasma photoguns

A. F. Habib,[1,2,*] T. Heinemann,[1,2,3,†] G. G. Manahan,[1,2] L. Rutherford,[1,2] D. Ullmann,[1,2,4] P. Scherkl,[1,2] A. Knetsch,[3] A. Sutherland,[1,2,5] A. Beaton,[1,2] D. Campbell,[1,2,6] L. Boulton,[1,2,3] A. Nutter,[1,2,7] O. S. Karger,[8] M. D. Litos,[9] B. D. O'Shea,[5] G. Andonian,[10,11] D. L. Bruhwiler,[12] J. R. Cary,[9,13] M. J. Hogan,[5] V. Yakimenko,[5] J. B. Rosenzweig,[10] and B. Hidding[1,2]

5

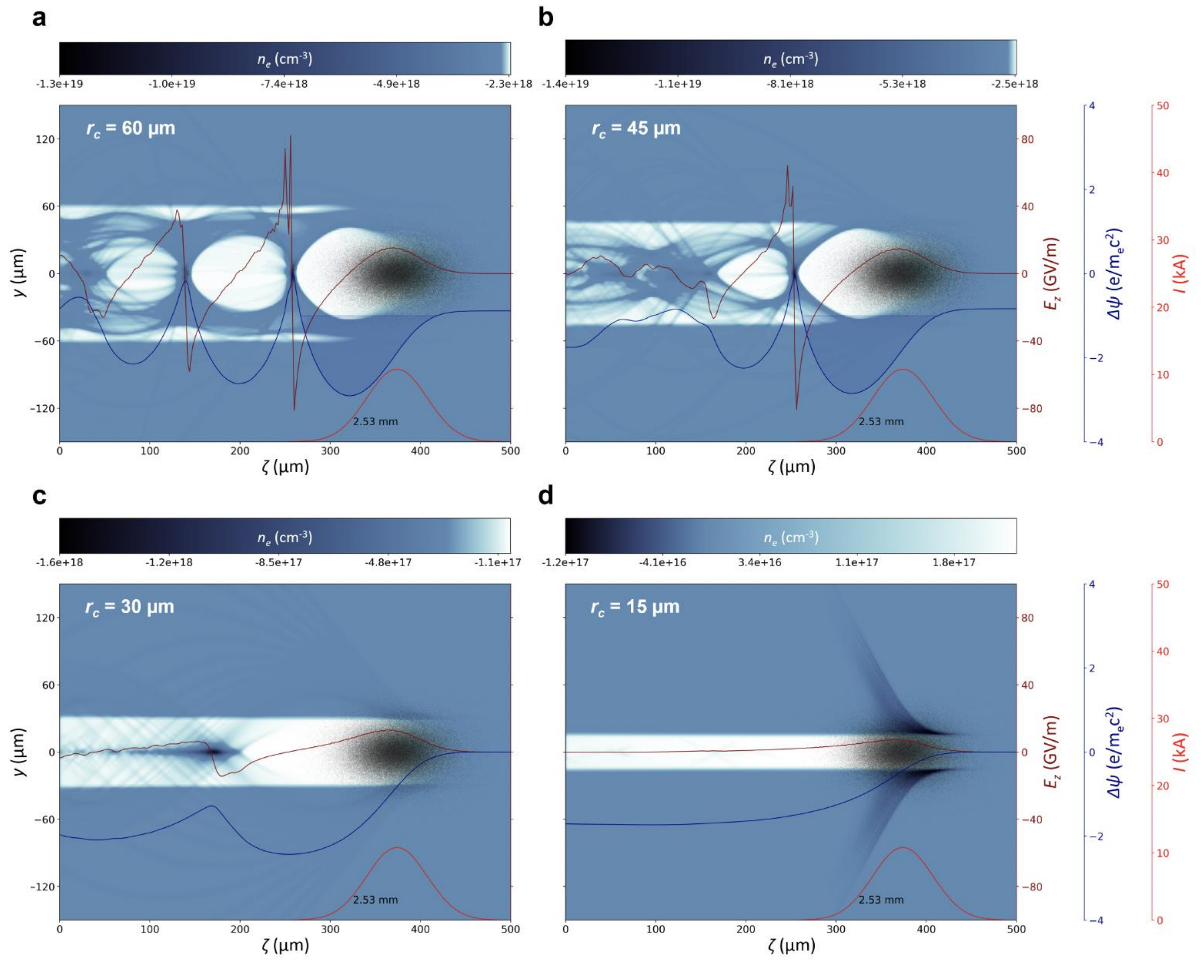


FIG. 3. 3D PIC-simulations (VSim) of intense electron beam interaction with a preionized plasma channel of different radii r_c. The FACET electron driver beam (black) propagates to the right, expels plasma electrons and sets up a nonlinear PWFA blowout as in a) and b), or for a thinner channel generates a wakeless ion channel as in c) and d) that could be used e.g. for light source applications.

➔ Neutral plasma creation through ionization laser

➔ Blowout of the plasma electrons through the driver beam

◆ **plasma electrons are expelled from the plasma region toward the neutral gas region**

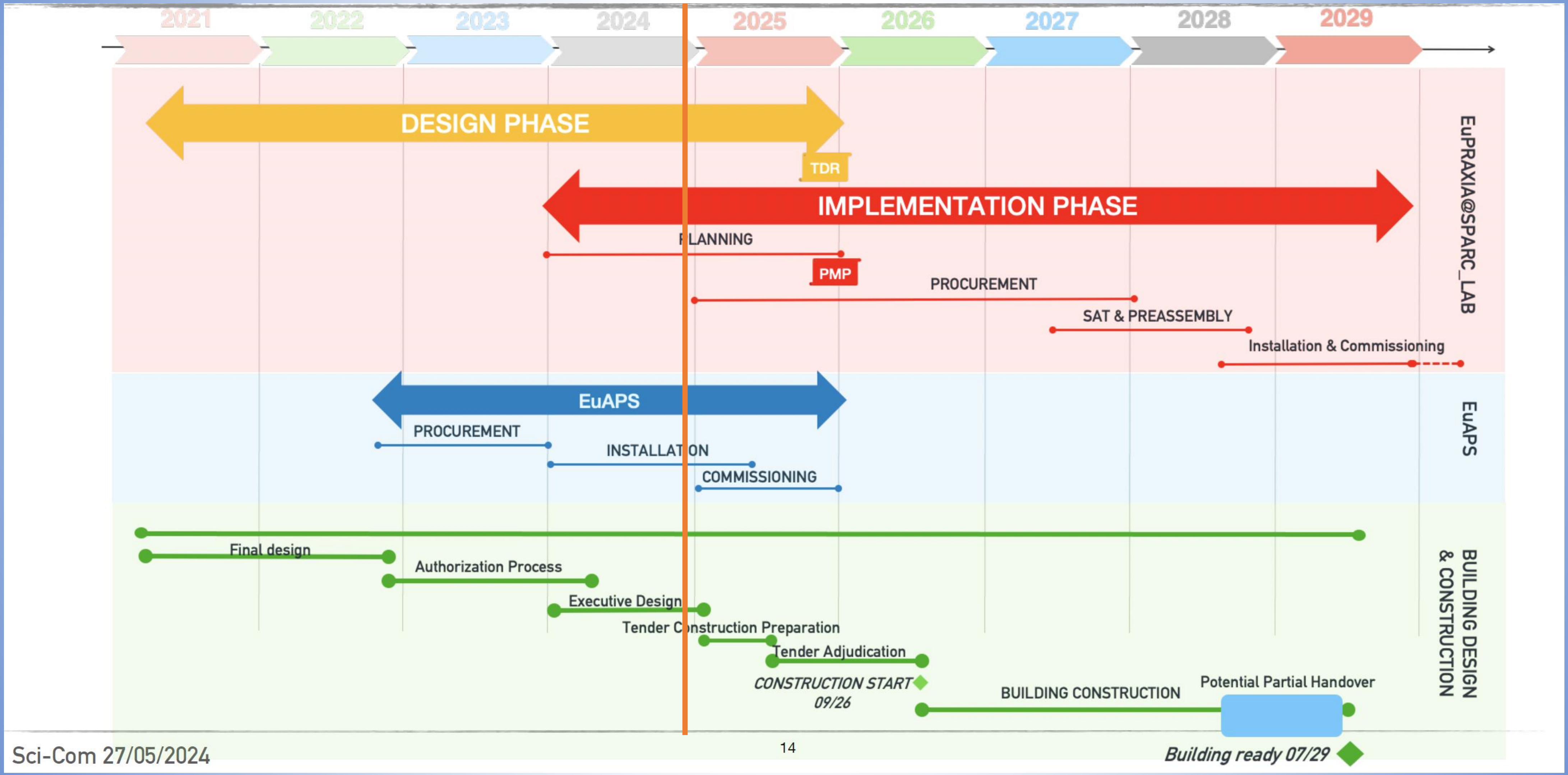
● **negligible restoring force** outside column

● **negligible accelerating force** inside column

● **linear restoring force** inside column

E. Chiadroni et al., INFN-CSN5 project “Beta-test” at SPARC_LAB

EuPRAXIA@SPARC_LAB baseline updating




Thank for your attention

LPAW 2025 – Ischia Island

EuPRAXIA

Funded by the European Union

LPAW 2025
Laser and Plasma Accelerators Workshop 2025
14-18 April 2025, Ischia Island, Italy

https://agenda.infn.it/event/42311/

The **Laser and Plasma Accelerators Workshop 2025 (LPAW 2025) will be held at Hotel Continental Ischia, in the Ischia Island (Campania, Italy), from Monday 14 to Friday 18 April 2025.**

The Laser and Plasma Accelerators Workshop (LPAW) series is one of the leading workshops in the field of plasma-based acceleration and radiation generation.

The following scientific topics will be the main focus of the conference:
•Plasma-based lepton acceleration (experiments, simulations, theory, diagnostics…).
•Plasma-based ion acceleration (experiments, simulations, theory, diagnostics…).
•Secondary radiation generation and applications (experiments, simulations, theory, diagnostics…).

John Dawson Thesis Prize
"John Dawson Thesis Prize" is awarded on a biannual basis to the best PhD thesis in the area of plasma accelerators driven by laser or particle beams. The prize will be awarded for fundamental (theoretical or experimental) or applied aspects.
Each prize winner will receive a certificate of merit, up to 500 Euros, and financial support to attend the "Laser and Plasma Accelerators Workshop," where the prize will be awarded.

Conclusions

- 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 2029**.
- Second EuPRAXIA FEL site will be selected in next months, among **3 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!
- Additional fund raising is continuosly going on