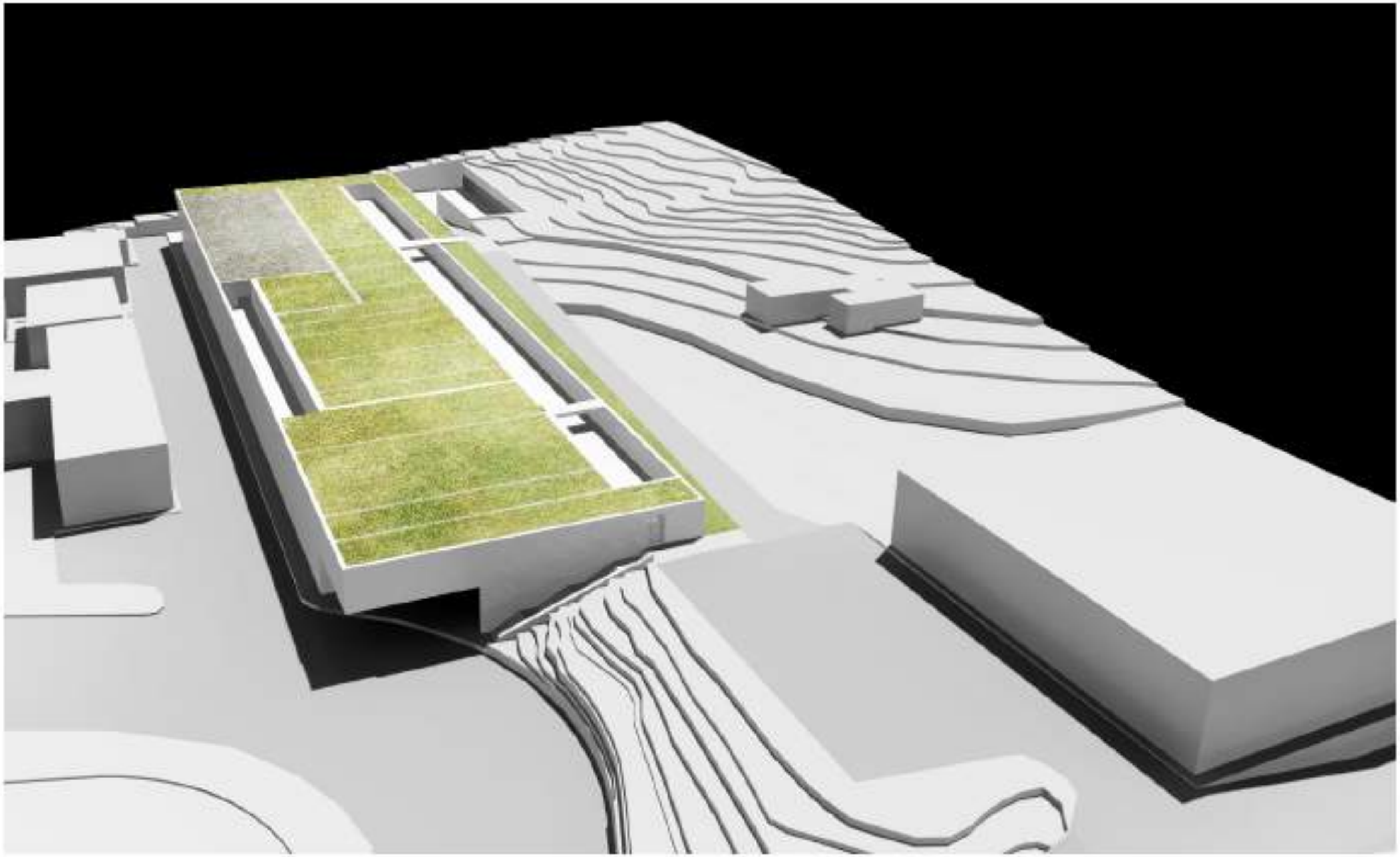
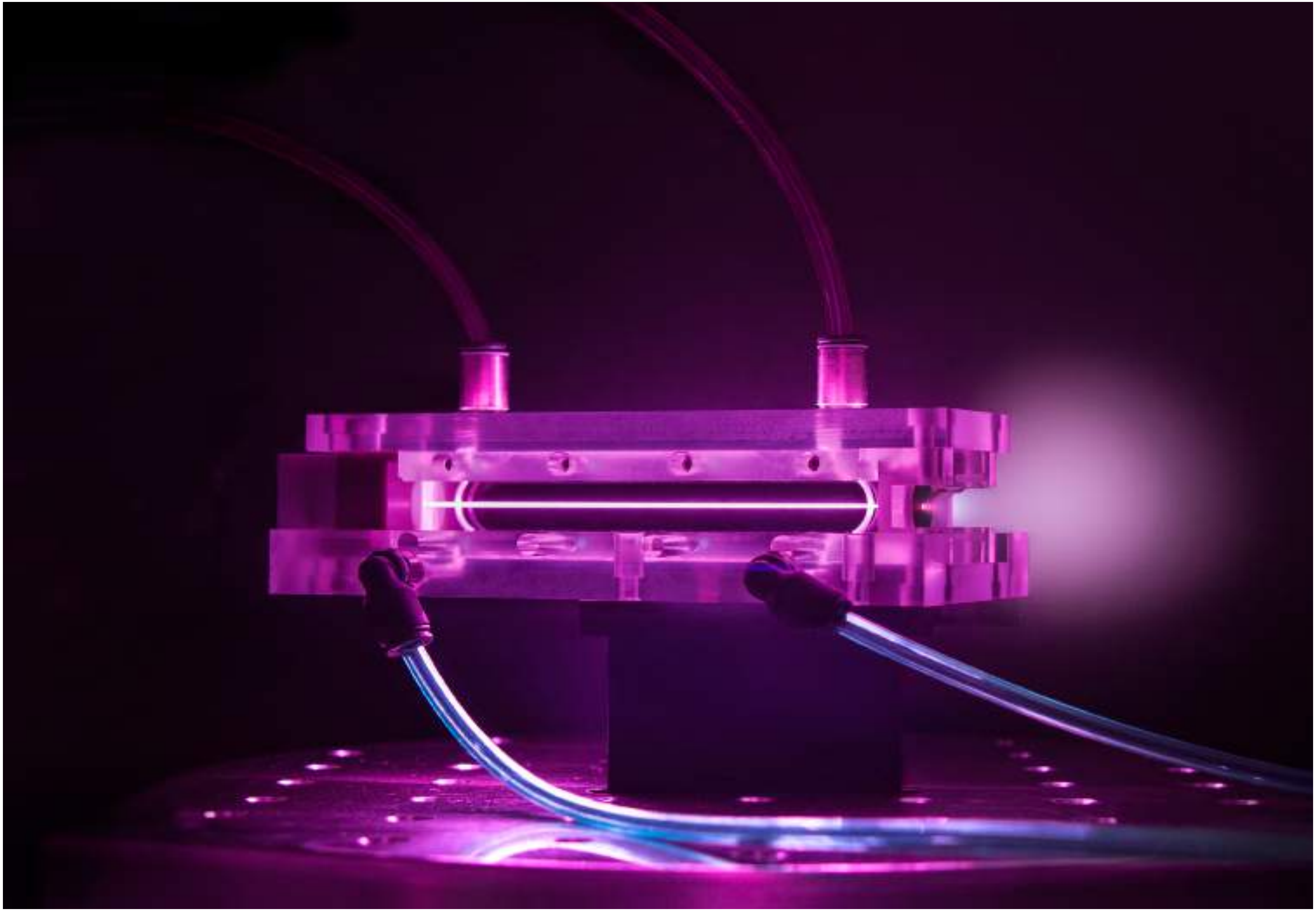
EuPRAXIA@SPARC_LAB

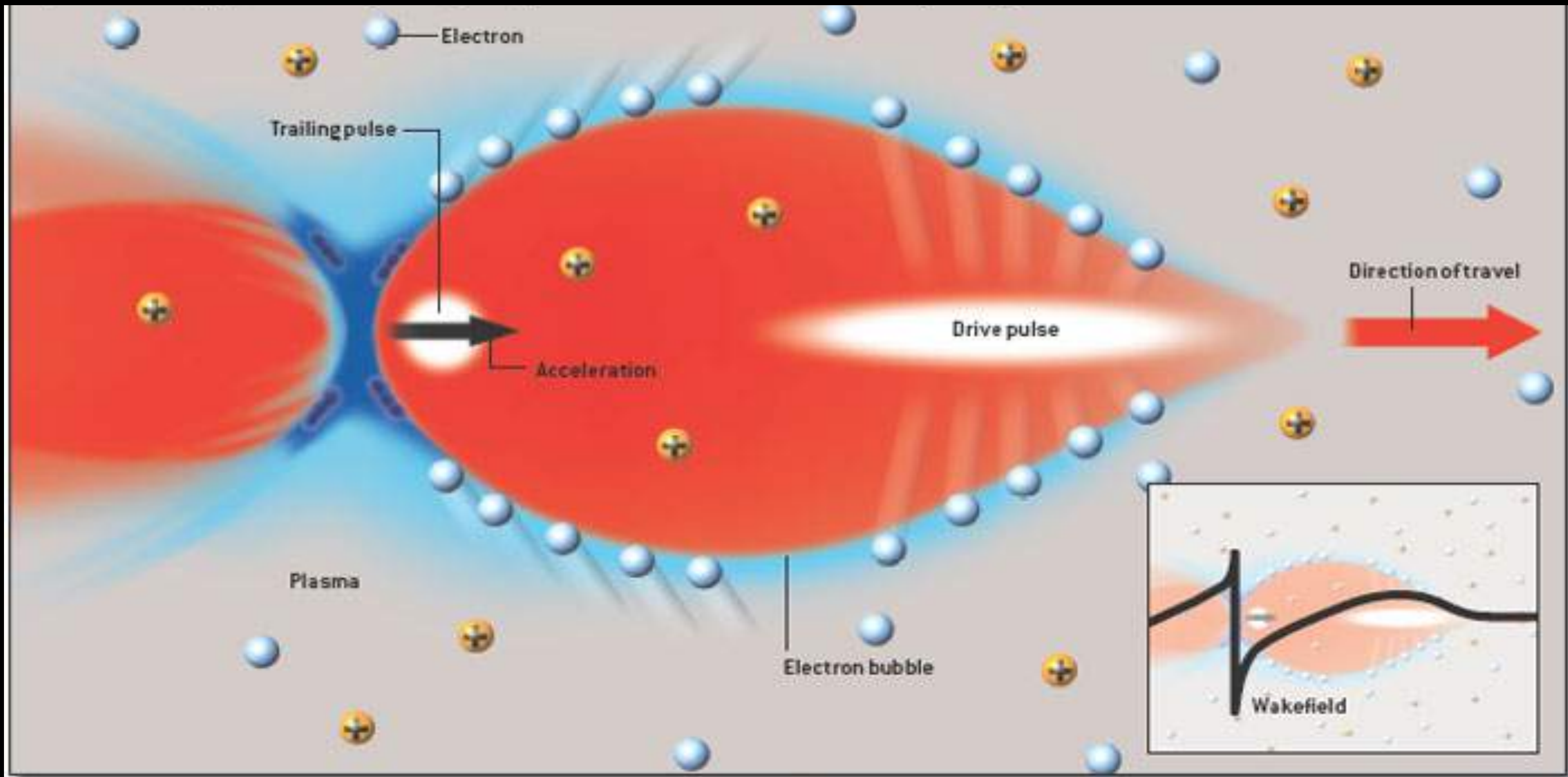
Massimo.Ferrario@lnf.infn.it
On behalf of the design study team

EuPRAXIA

INFN
Istituto Nazionale di Fisica Nucleare

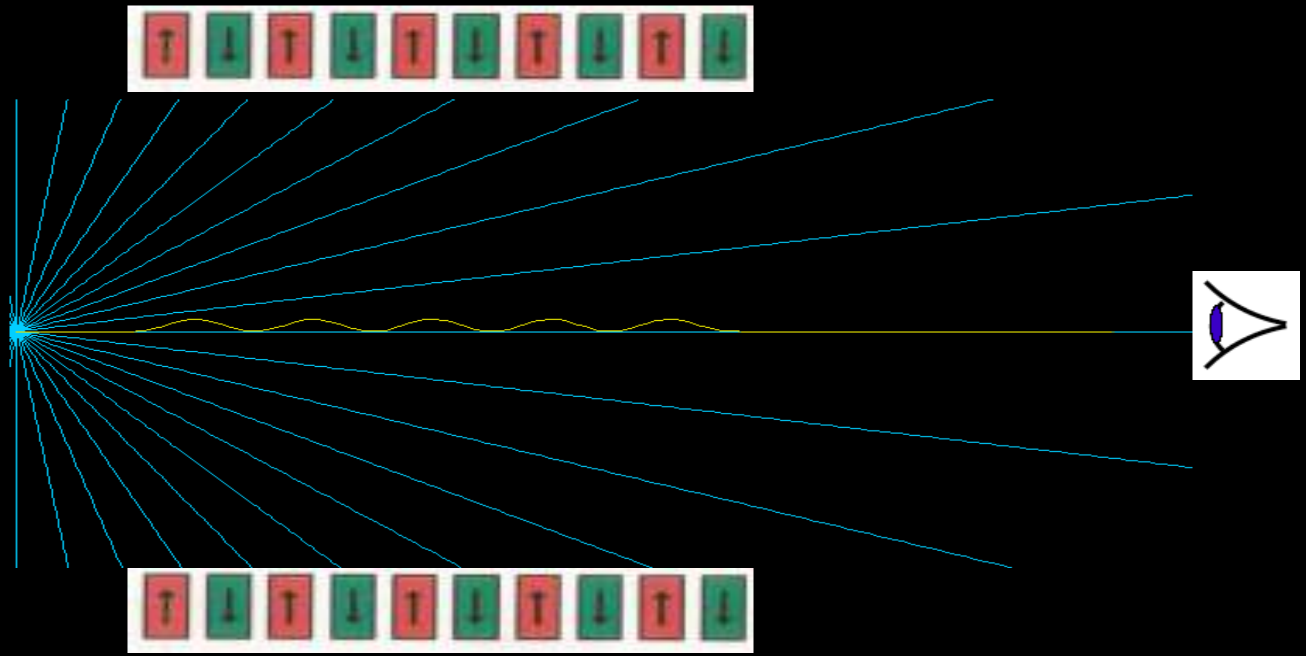






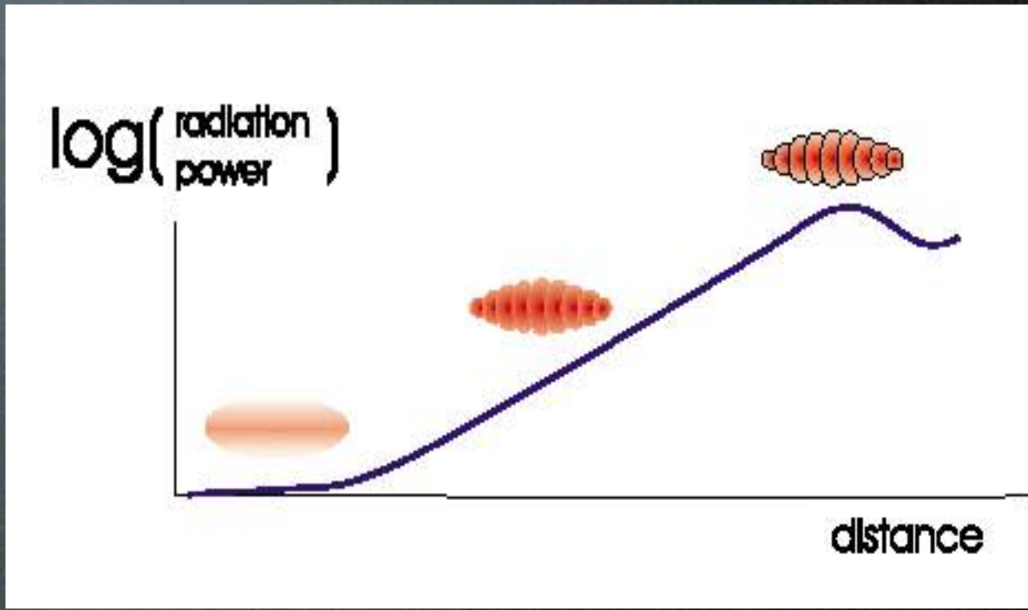
Breakdown limit?

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$



Radiation Simulator – T. Shintake, @ http://www-xfel.spring8.or.jp/Index.htm

A Free Electron Laser is a device that converts a fraction of the electron kinetic energy into coherent radiation via a collective instability in a long undulator



$$\lambda_{rad} \approx \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\vartheta^2\right)$$

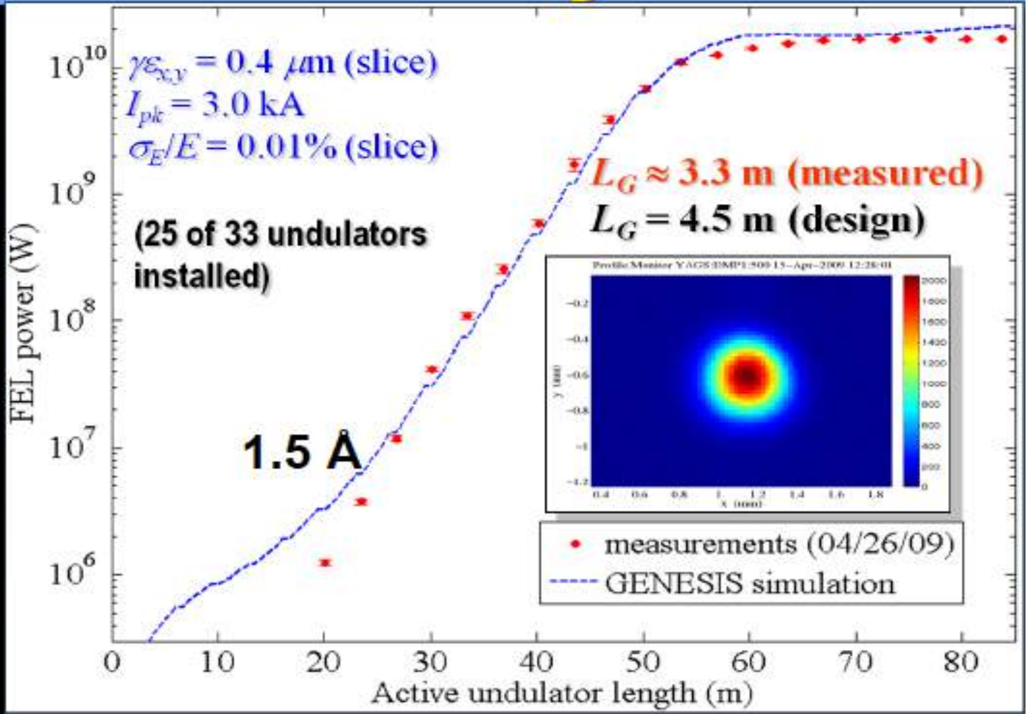
(Tunability - Harmonics)

SASE FELs at short wavelengths requirements

$$\lambda_{rad} \approx \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}+\gamma^2\vartheta^2\right)$$

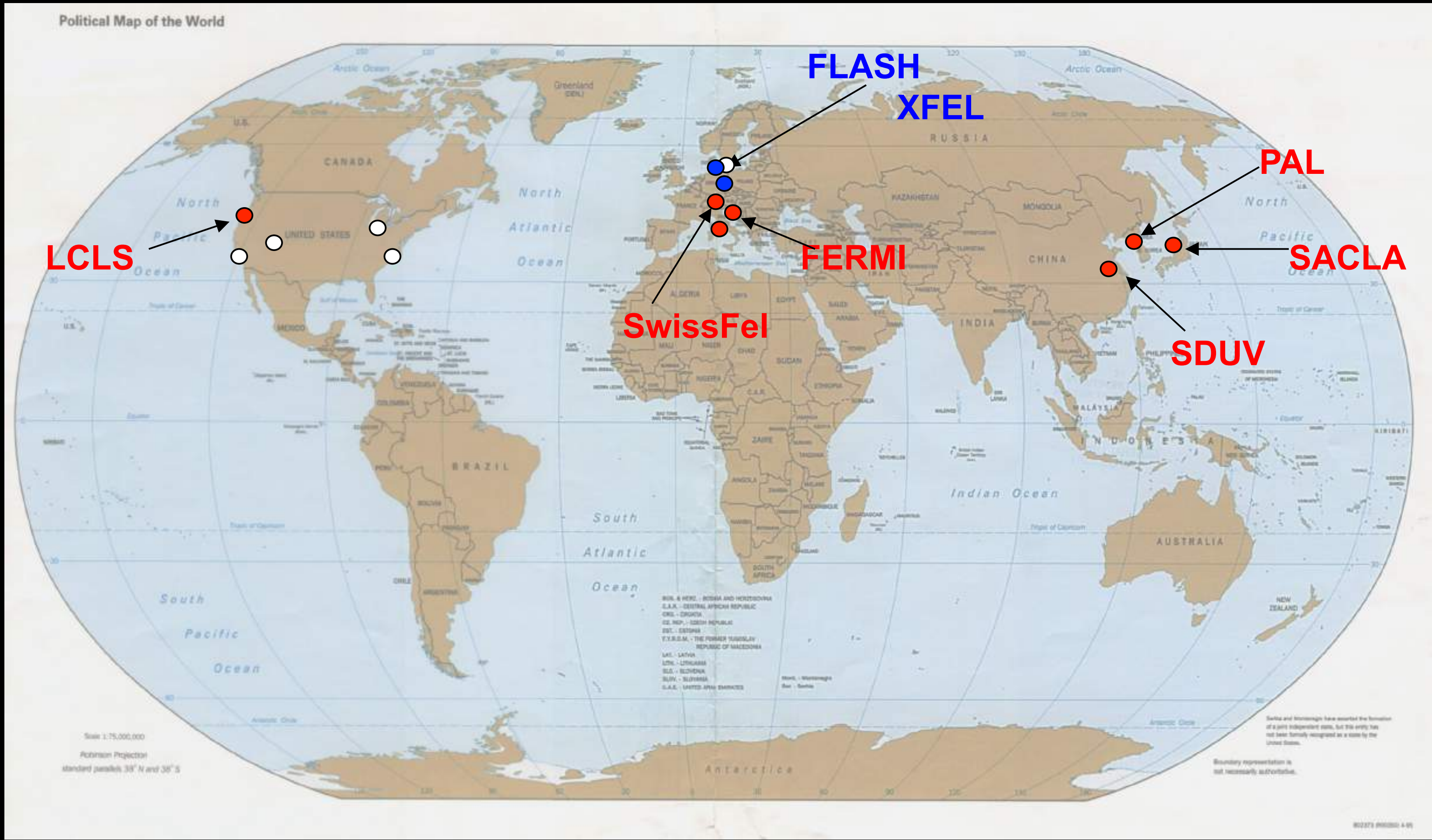
- FEL Parameter $\quad \rho = 0.136 \frac{1}{\gamma_r} J^{1/3} B_u^{2/3} \lambda_u^{4/3} \Rightarrow 10^{-3}$
- Number of Photons at saturation $\quad N_{ph} \approx 1.6 \frac{E_b}{h\nu_{ph}} \rho Q \Rightarrow >10^{11} \Rightarrow$ Q>30pC
- Gain Length $\quad L_G = \frac{\lambda_u}{4\pi\sqrt{3}\rho}$
- Slice Length $\quad L_s = \frac{\lambda_r}{2\sqrt{3}\rho} \Rightarrow \approx 1\ \mu\text{m}$
- Constraint on emittance $\quad \varepsilon_n < \frac{\gamma\lambda_r}{4\pi} \Rightarrow <1\ \mu\text{m}$
- Constraint on energy spread $\quad \Delta\gamma/\gamma < 0.5\rho \Rightarrow <10^{-3}$
- Relative bandwidth $\quad \frac{\Delta\omega}{\omega} = \sqrt{\frac{\rho}{N_u}}$

LCLS: world's first hard x-ray FEL

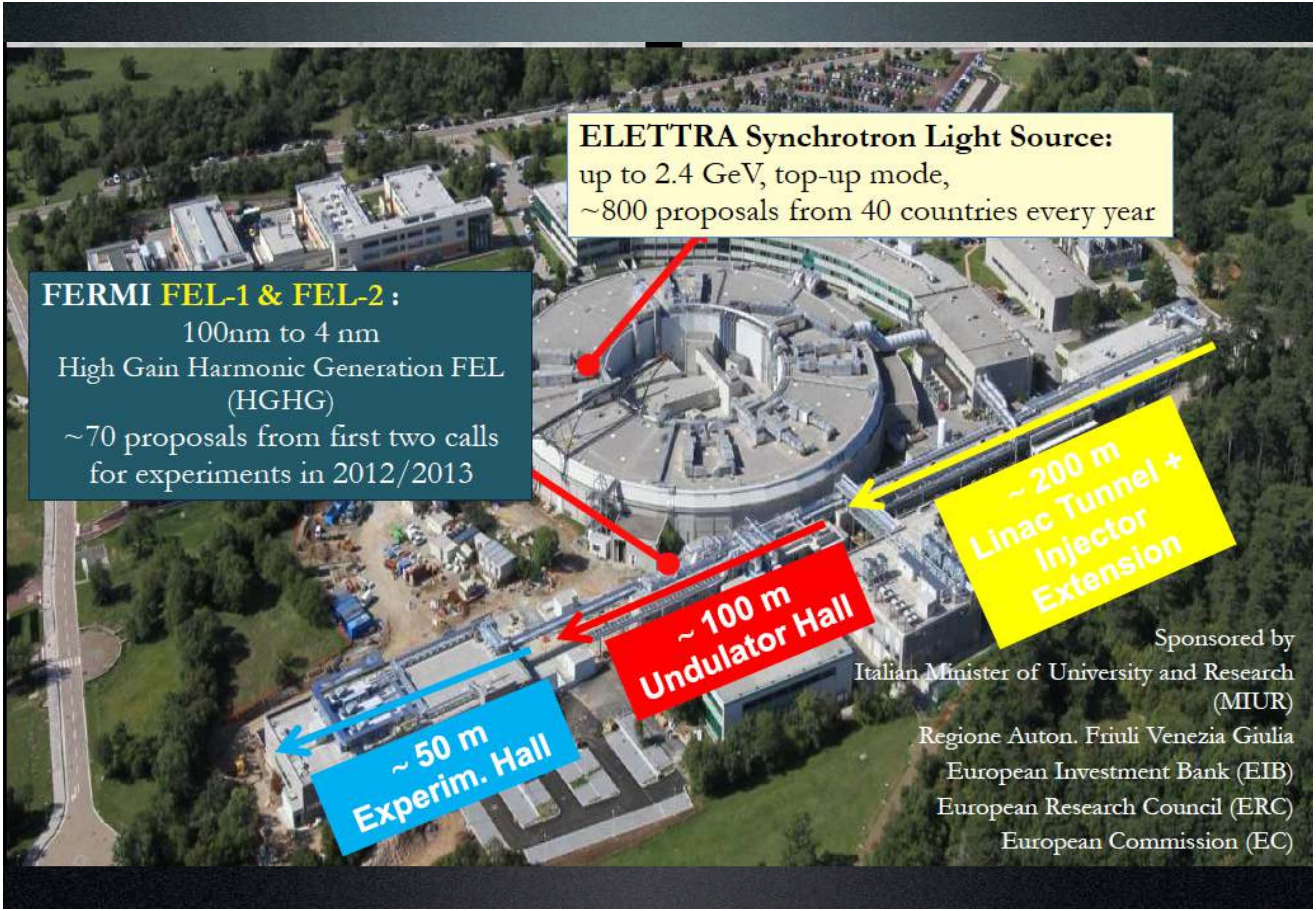


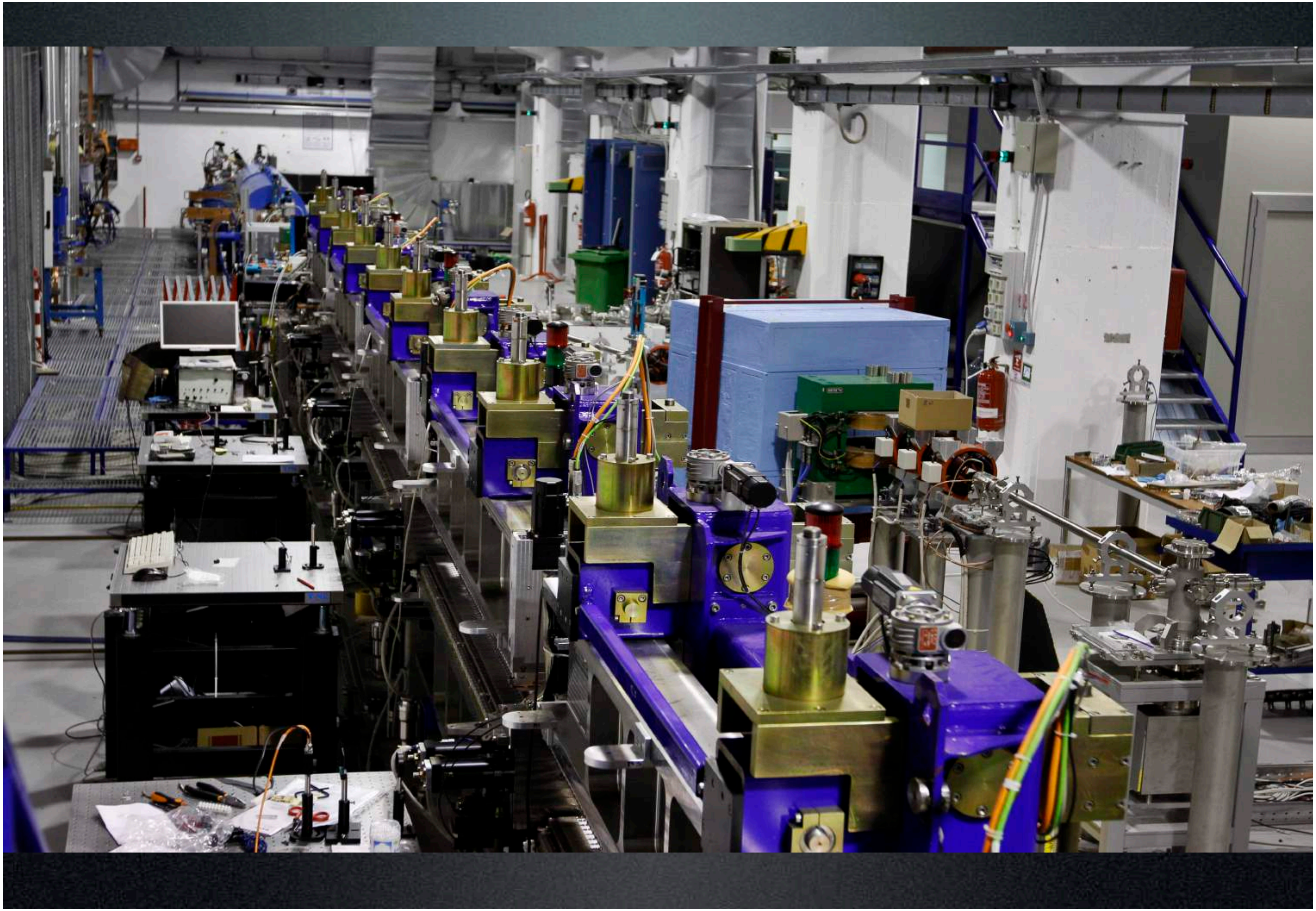
- SASE wavelength range: **25 – 1.2** Å
- Photon energy range: **0.5 - 10** keV
- Pulse length FWHM **5 - 500** fs (SXR only)
- Pulse energy up to **4** mJ

Short Wavelength SASE FEL



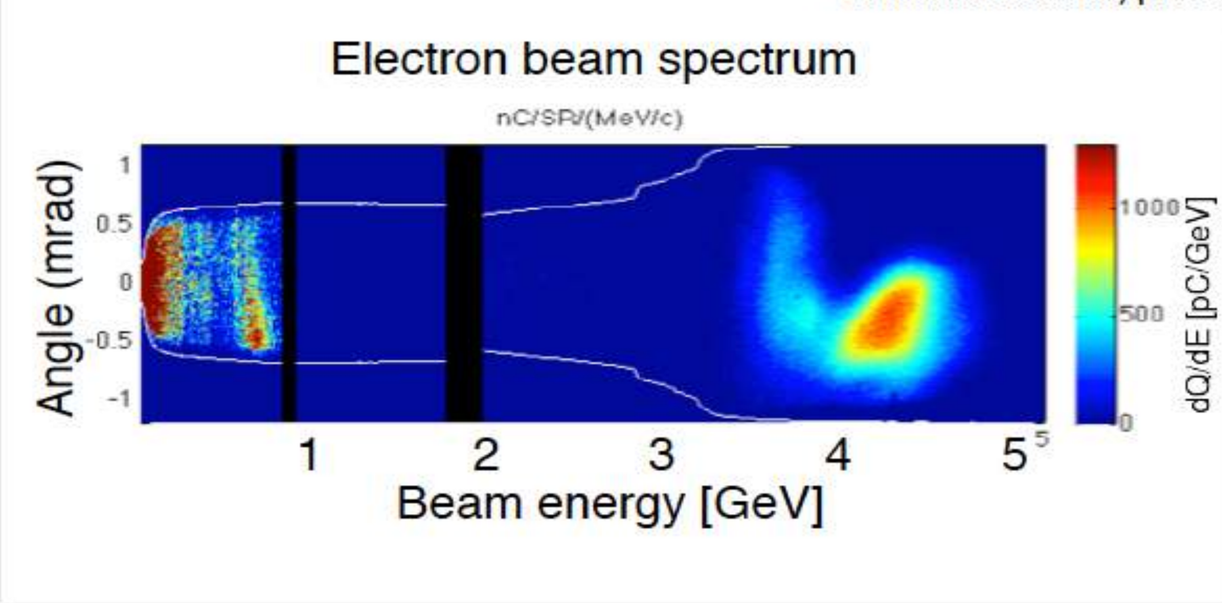
XFEL first lasing – Hamburg - May 2017

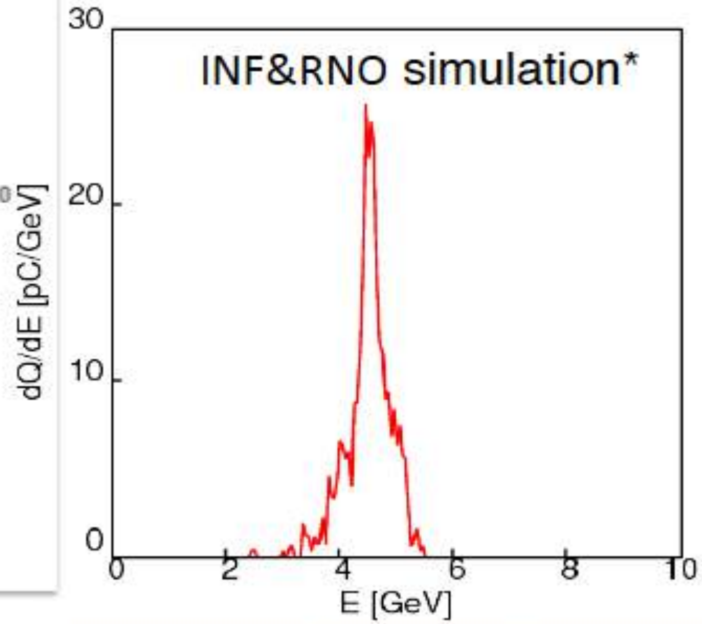

ELETTRA Synchrotron Light Source:
up to 2.4 GeV, top-up mode,
~800 proposals from 40 countries every year
FERMI FEL-1 & FEL-2 :
100nm to 4 nm
High Gain Harmonic Generation FEL
(HGHG)
~70 proposals from first two calls
for experiments in 2012/2013
~ 200 m
Linac Tunnel +
Injector
Extension
~ 100 m
Undulator Hall
~ 50 m
Experim. Hall
Sponsored by
Italian Minister of University and Research
(MIUR)
Regione Auton. Friuli Venezia Giulia
European Investment Bank (EIB)
European Research Council (ERC)
European Commission (EC)

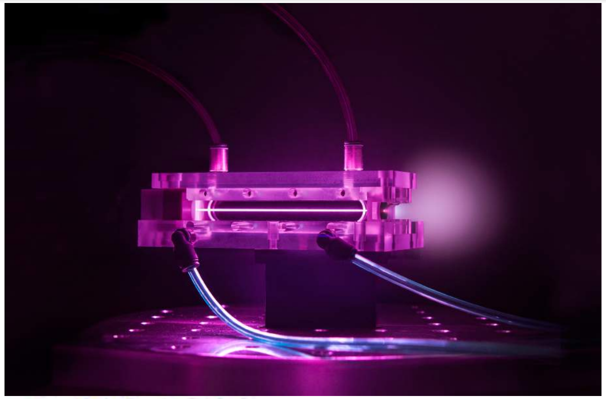


4.25 GeV beams have been obtained from 9 cm plasma channel powered by 310 TW laser pulses (15 J)

*C. Benedetti et al., proceedings of AAC2010, proceedings of ICAP2012



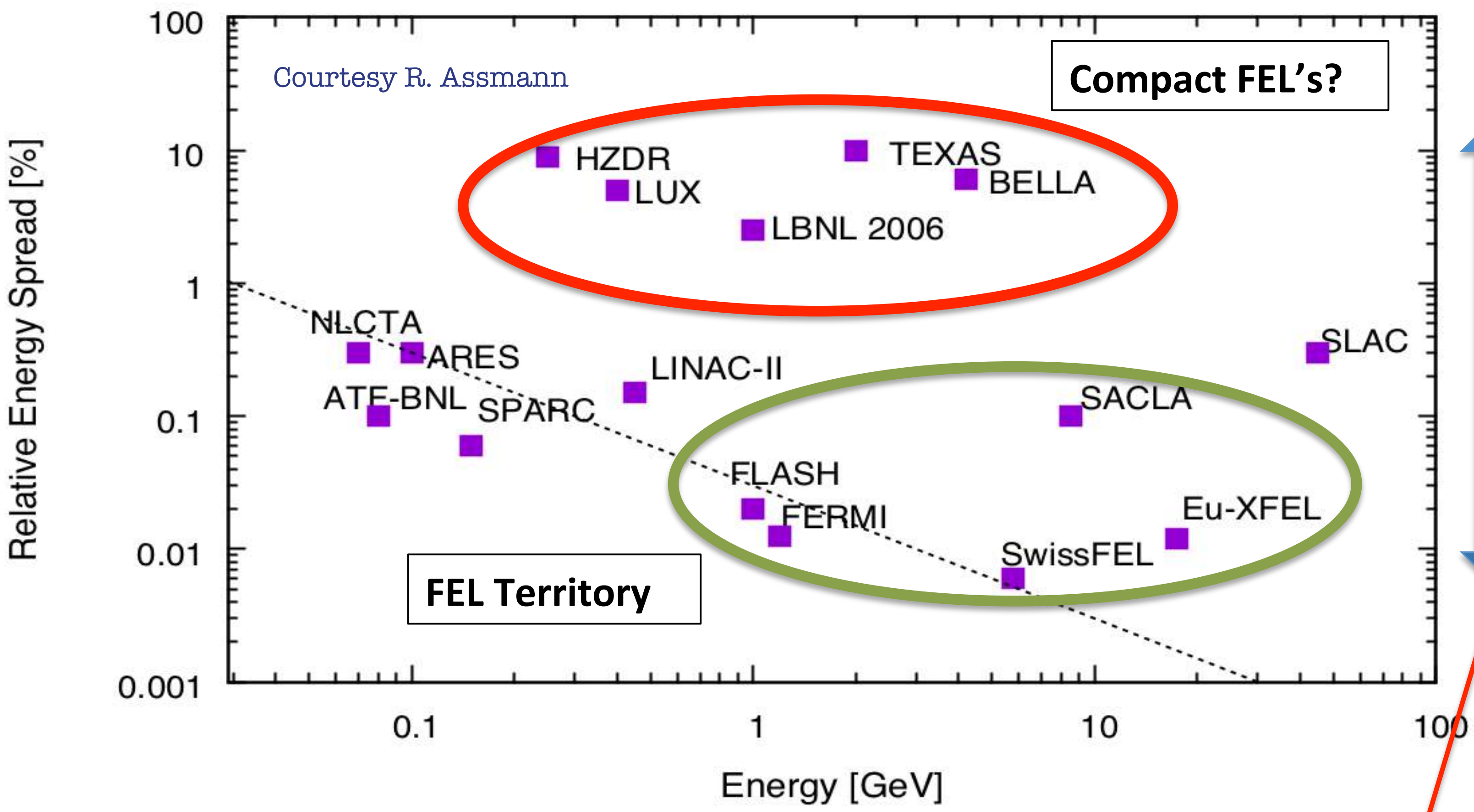




	Exp.	Sim.
Energy	4.25 GeV	4.5 GeV
ΔE/E	5%	3.2%
Charge	~20 pC	23 pC
Divergence	0.3 mrad	0.6 mrad

W.P. Leemans et al.,PRL 2014

Quality: Example Energy Spread



Lower quality

Higher quality

$$\frac{\sigma_\gamma}{\gamma} = \frac{\sqrt{3}}{2} k_p^2 \sigma_z^2$$

$$\sin\varphi_w \propto \frac{q_w}{Q_d}$$

$$\varepsilon_{n,rms} = \sqrt{\langle\gamma^2\rangle\left(\sigma_\gamma^2 \sigma_x^2 \sigma_{x'}^2 + \varepsilon_{rms}^2\right)}$$

M. Migliorati et al, Physical Review Special Topics,Accelerators and Beams 16, 011302 (2013)
K. Floettmann, PRSTAB,6, 034202 (2003)

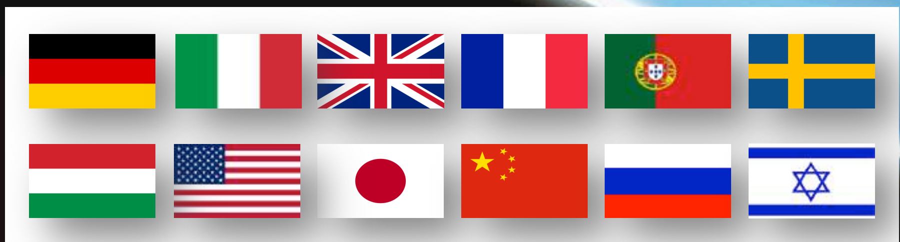
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on Novemebr 2015

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

Coordinator: Ralph Assmann (DESY)



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

http://eupraxia-project.eu

Motivations

Horizon2020

PRESENT EXPERIMENTS

Demonstrating **100 GV/m** routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

Medical, industrial applications soon





Courtesy R. Assmann

Consortium

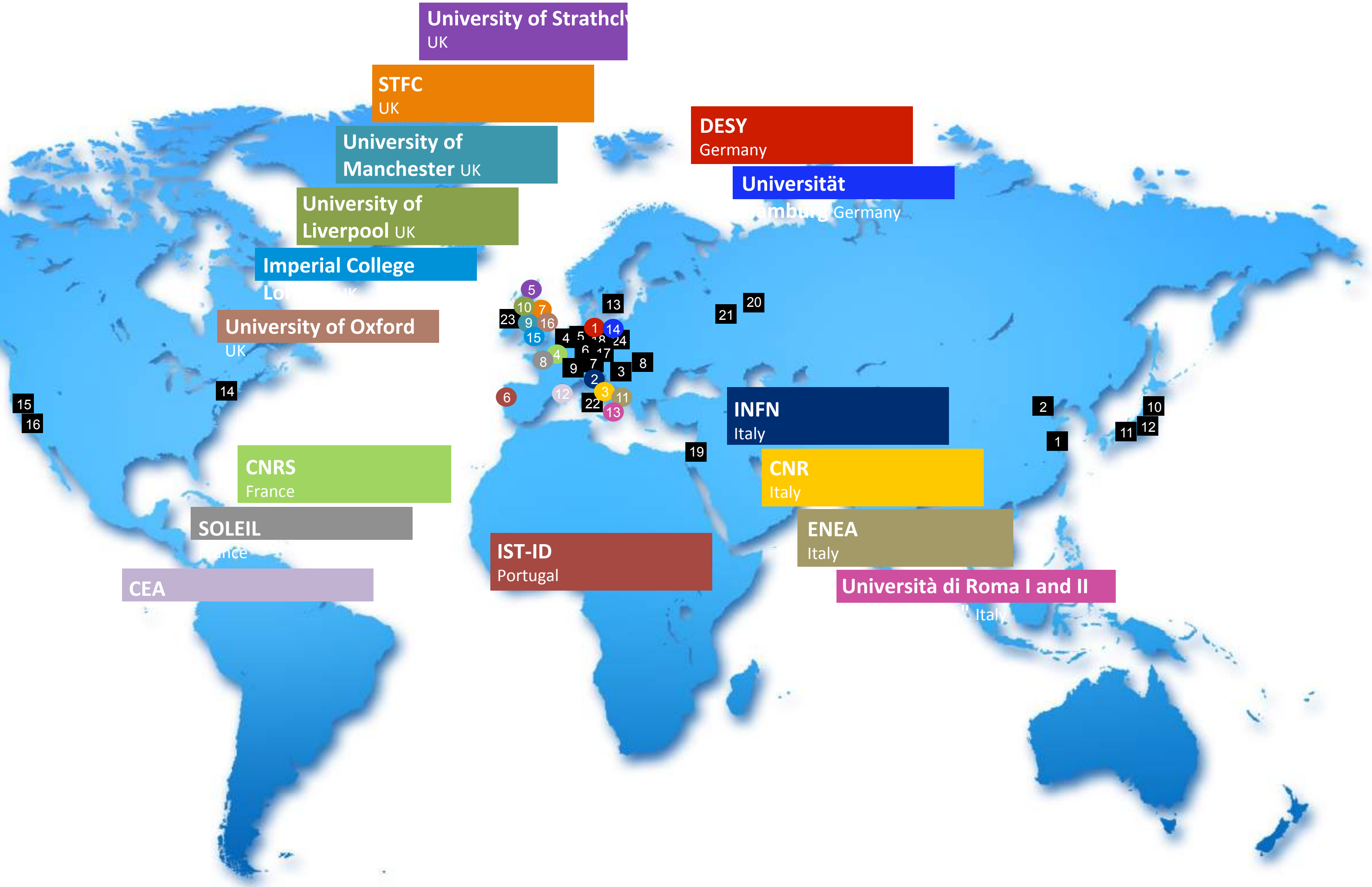
16 Participants

24 Associated Partners

(as of December 2017)

Participating Institutions

Horizon 2020



Associated Partners
(as of December 2017)

1 **Shanghai Jiao Tong-University**, China
2 **Tsinghua University Beijing**, China
3 **ELI Beamlines**, International
4 **PHLAM, Université de Lille**, France
5 **Helmholtz-Institut Jena**, Germany
6 **HZDR (Helmholtz)**, Germany
7 **LMU München**, Germany
8 **Wigner Fizikai Kutatóközpont**, Hungary
9 **CERN**, International
10 **Kansai Photon Science Institute**, Japan
11 **Osaka University**, Japan
12 **RIKEN SPring-8**, Japan
13 **Lunds Universitet**, Sweden
14 **Stony Brook University & Brookhaven NL**, USA
15 **LBNL**, USA
16 **UCLA**, USA
17 **Karlsruher Institut für Technologie**, Germany
18 **Forschungszentrum Jülich**, Germany
193 **Hebrew University of Jerusalem**, Israel
20 **Institute of Applied Physics**, Russia
21 **Joint Institute for High Temperatures**, Russia
22 **Università di Roma 'Tor Vergata'**, Italy
23 **Queen's University Belfast**, UK
24 **Ferdinand-Braun-Institut**, Germany

Industrial Participation

Horizon 2020

Industry: involved through workshops and Scientific Advisory Board

Contacts still evolving, several cooperations under discussion

Thales group (France): Number of employees: 62,194 (2015)
Sales 14.06 B€ (2015)

Amplitude (France): Number of employees: 80 (2015)
Sales 17.4 M€ (2015)

Trumpf group (Germany): Number of employees: 11,181 (2016)
Sales 2.81 B€ (2016)

FEL Electron Beam Requirements

Horizon 2020

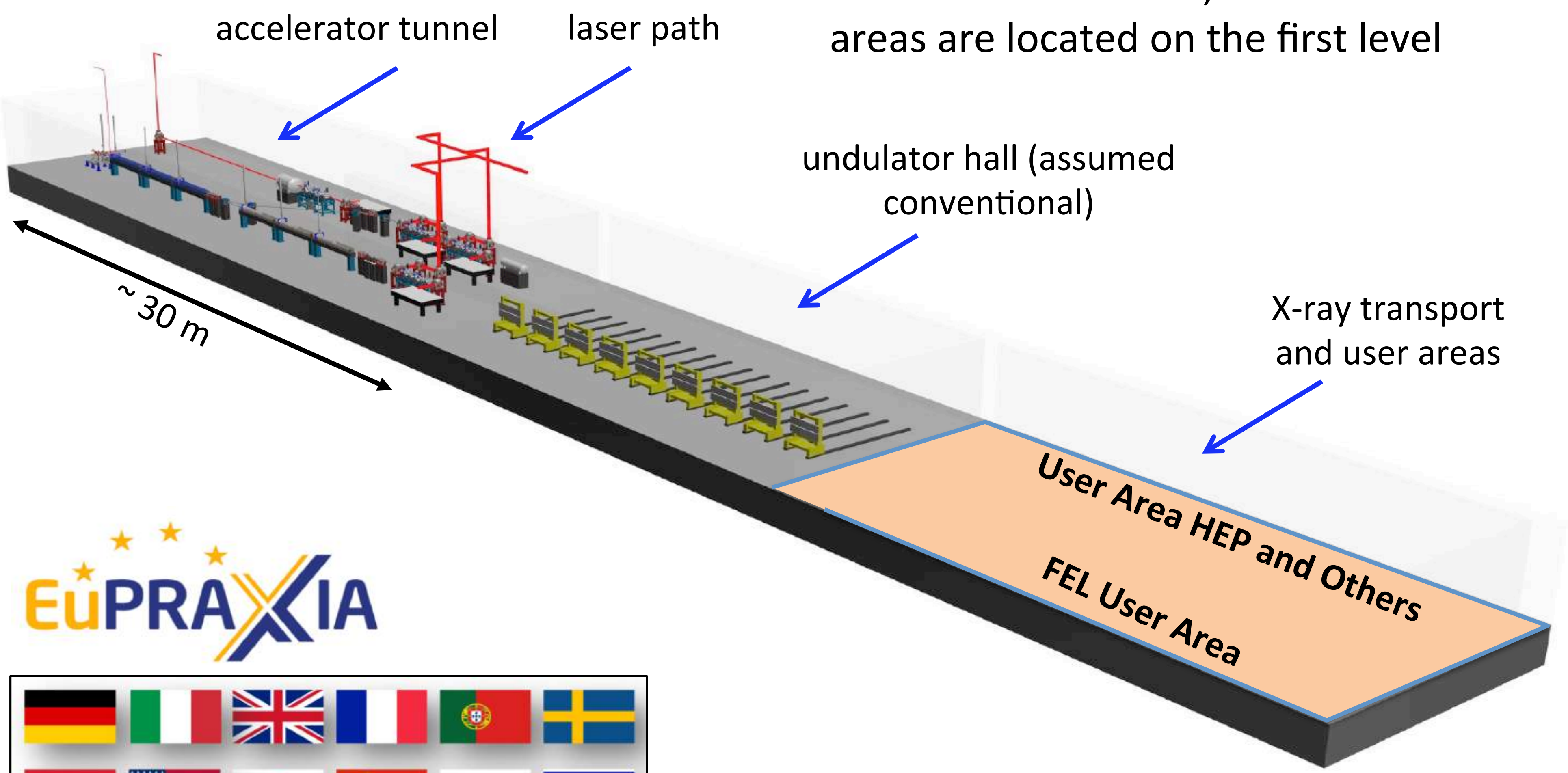
Electron beam parameters at the undulator

Quantity	Symbol [Unit of Meas.]	Target parameters
Energy	E [GeV]	1 - 5
Charge	Q [pC]	30
Bunch length (FWHM)	t_{FWHM} [fs]	10
Peak current	I [kA]	3
Repetition rate	f [Hz]	10
# of bunches	N	1
Transverse Norm. emittance	$\varepsilon_{n,x}, \varepsilon_{n,y}$ [mm mrad]	<1
Total energy spread	σ_E/E [%]	1
Slice Norm. emittance	$\varepsilon_{n,x}, \varepsilon_{n,y}$ [mm mrad]	<<1
Slice energy spread	$\sigma_{E,s}/E$ [%]	~0.1
Slice length	L_{Slice} [μm]	0.75 - 0.12

Overall layout status (ongoing)

Horizon 2020

Accelerator research, undulators and user areas are located on the first level



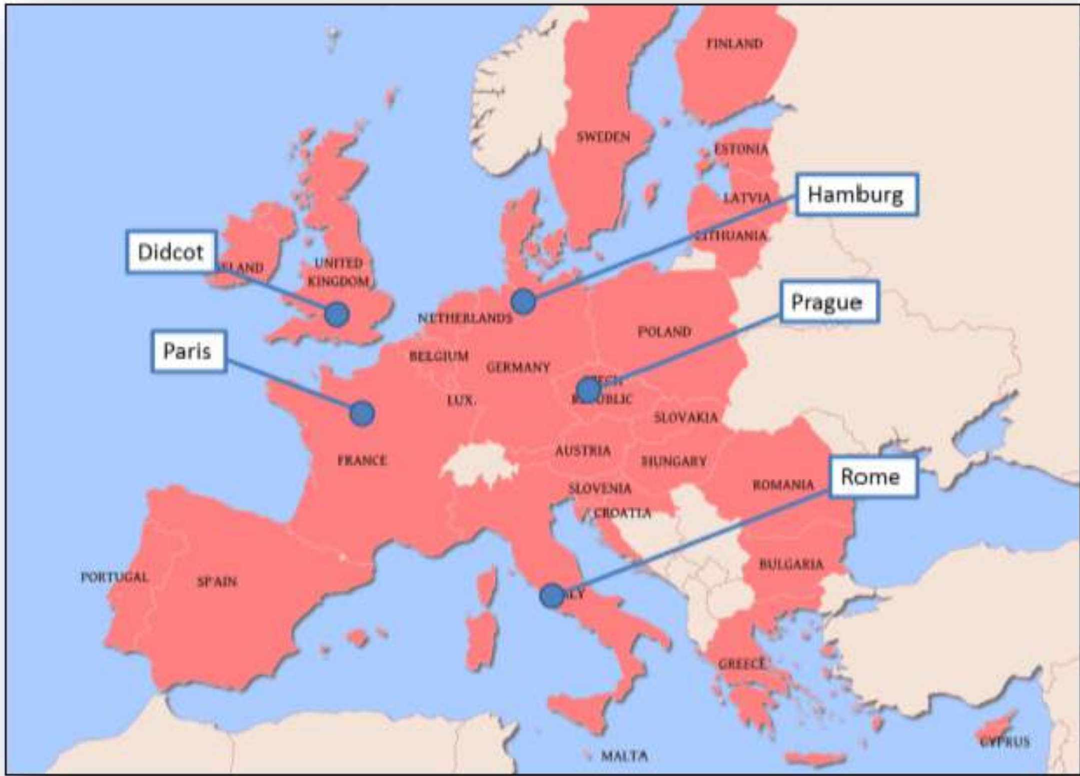
Design by A. Walker (DESY) and Dariusz Kocoń (ELI-Beams)

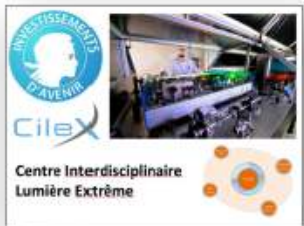
Location of possible sites within EU

Horizon 2020

EuPRAXIA site studies:

- Design study is site independent
- Five possible sites have been discussed so far
- We invite the suggestions of additional sites





Central Laser Facility
Didcot, United Kingdom

Eli Beamlines
Prague, Czech Republic

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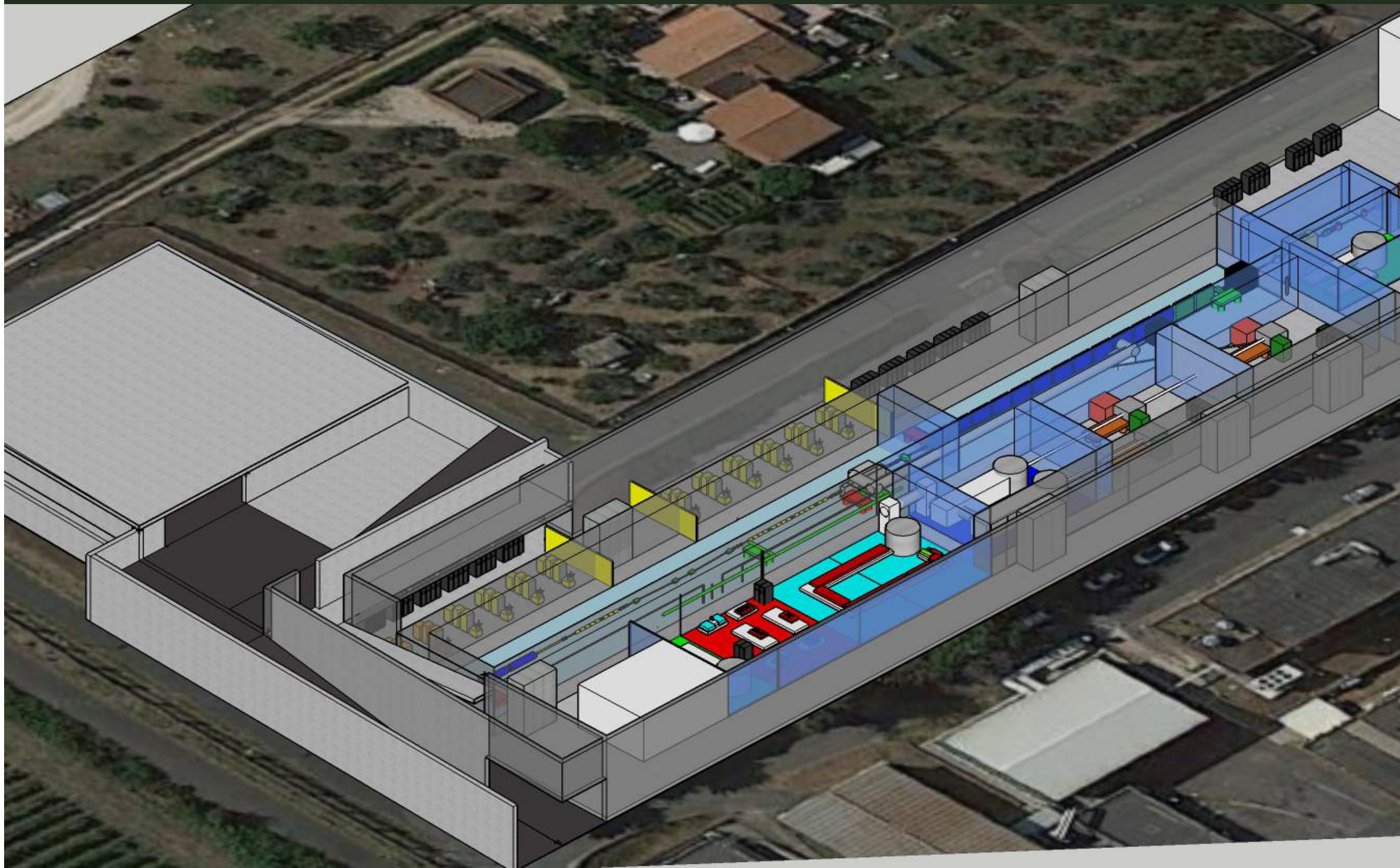

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Conceptual Design Report

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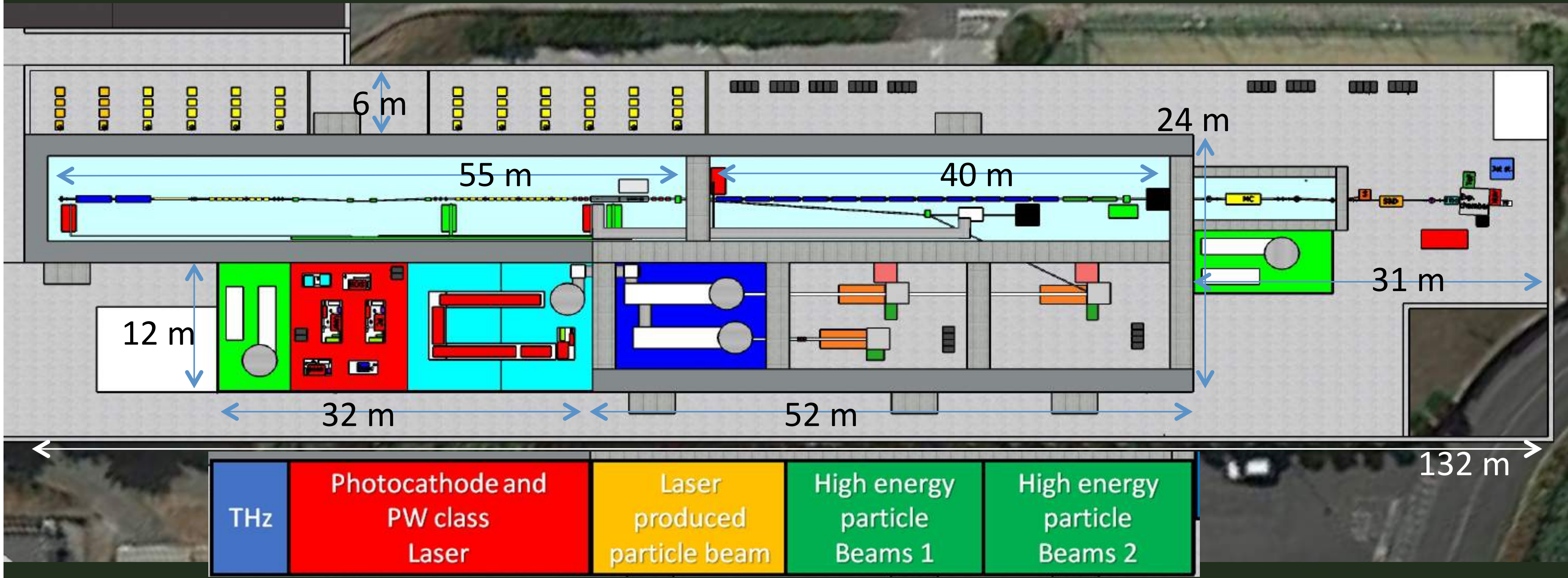
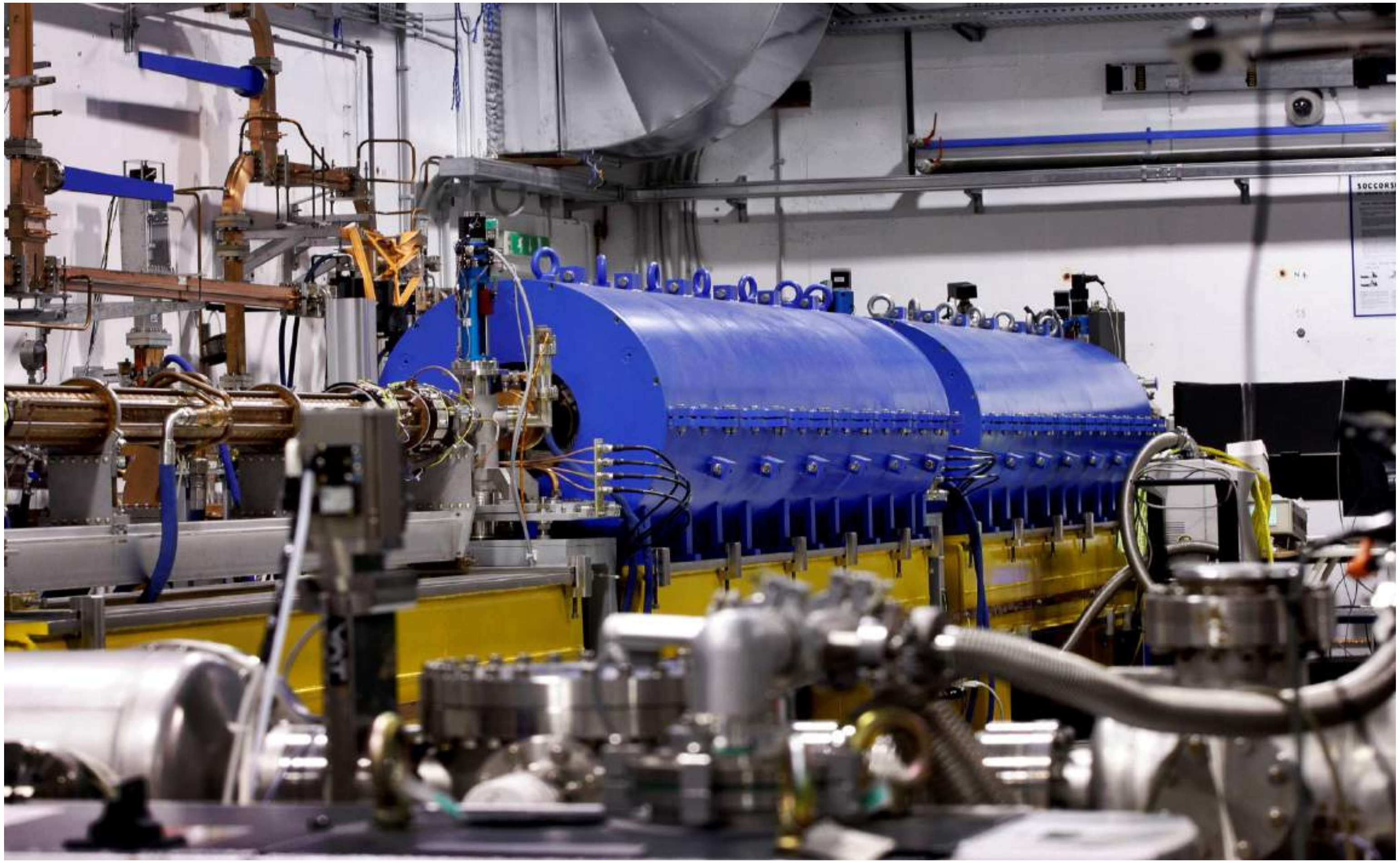
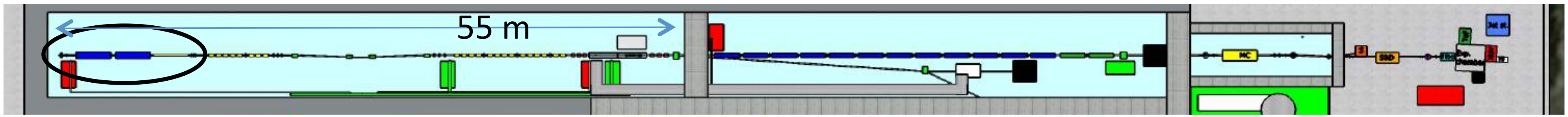
- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3nm)
- Advanced Accelerator Test facility (LC) + CERN



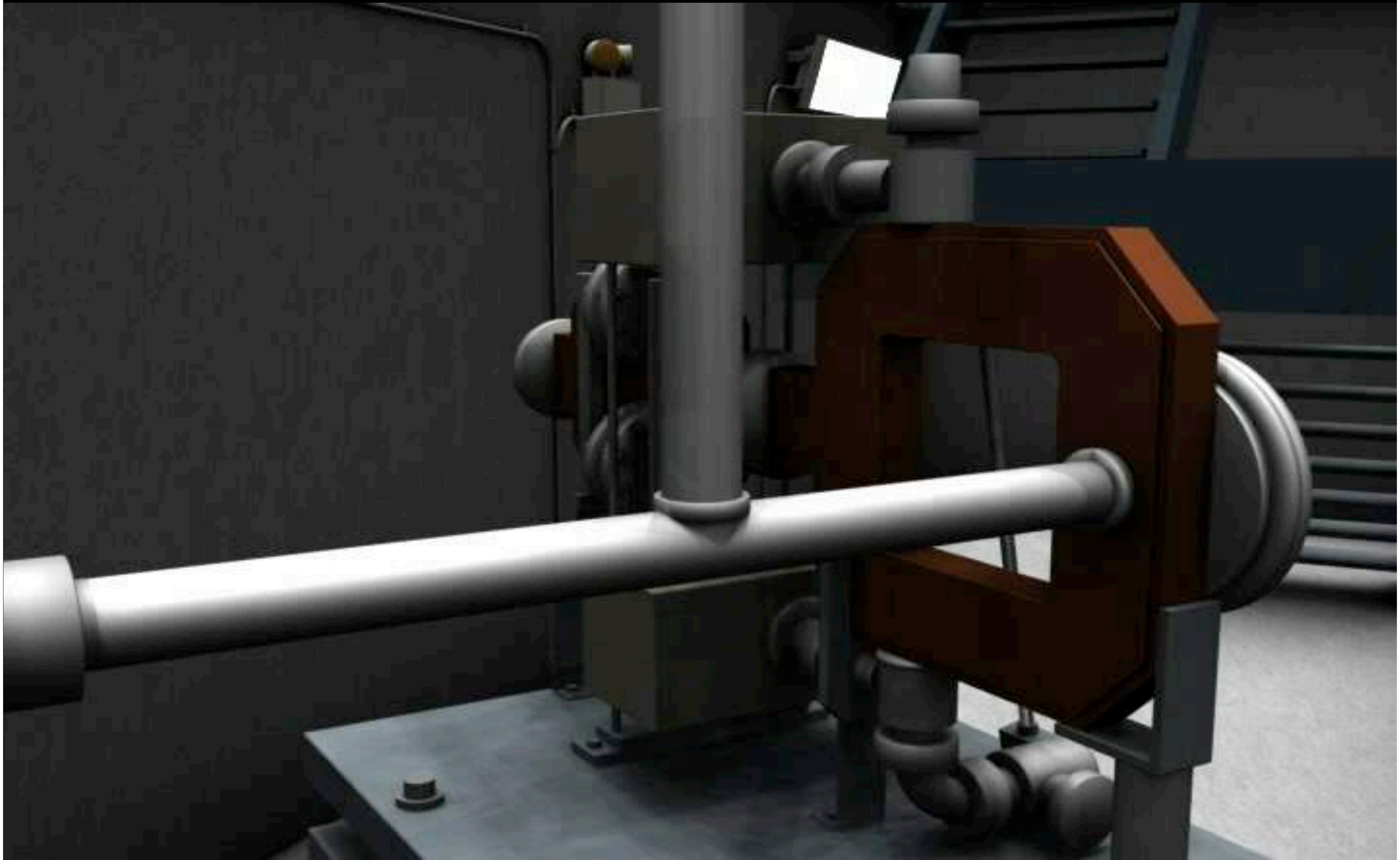
- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator

SPARC_LAB HB photo- injector

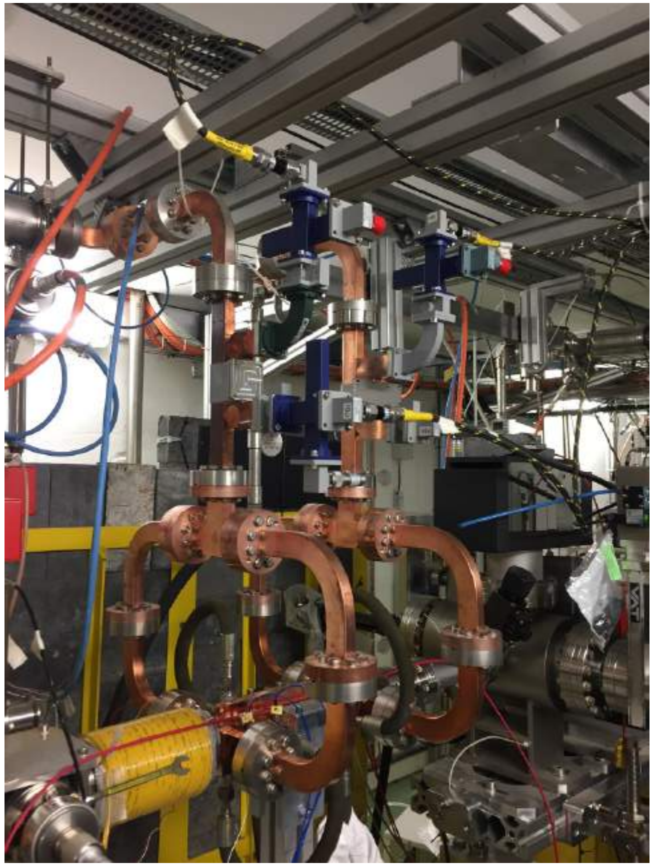




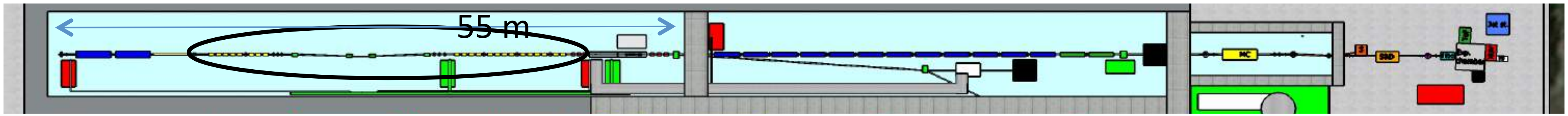
Electron source and acceleration



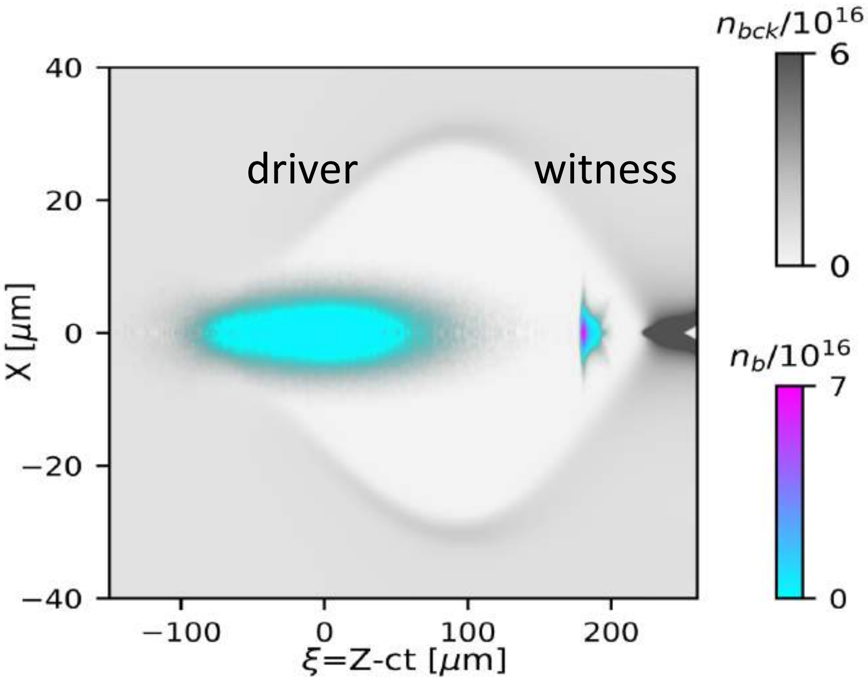
X-band Linac and High Power Laser

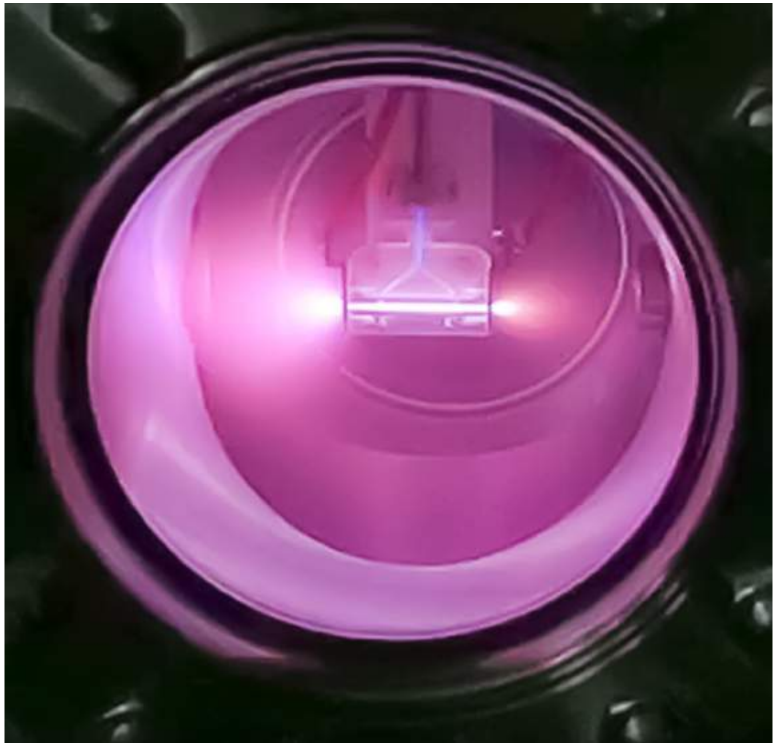


Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 µm
Peak Power	300 TW
Contrast Ratio	10^{10}

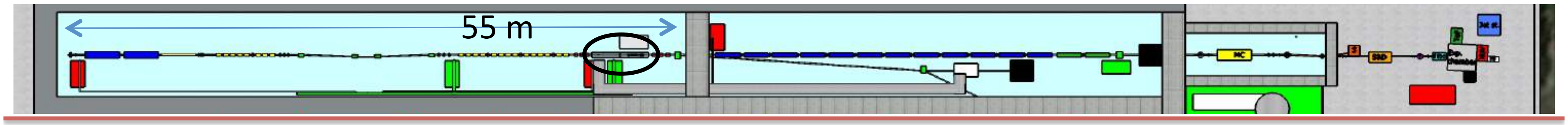


Plasma WakeField Acceleration – External Injection

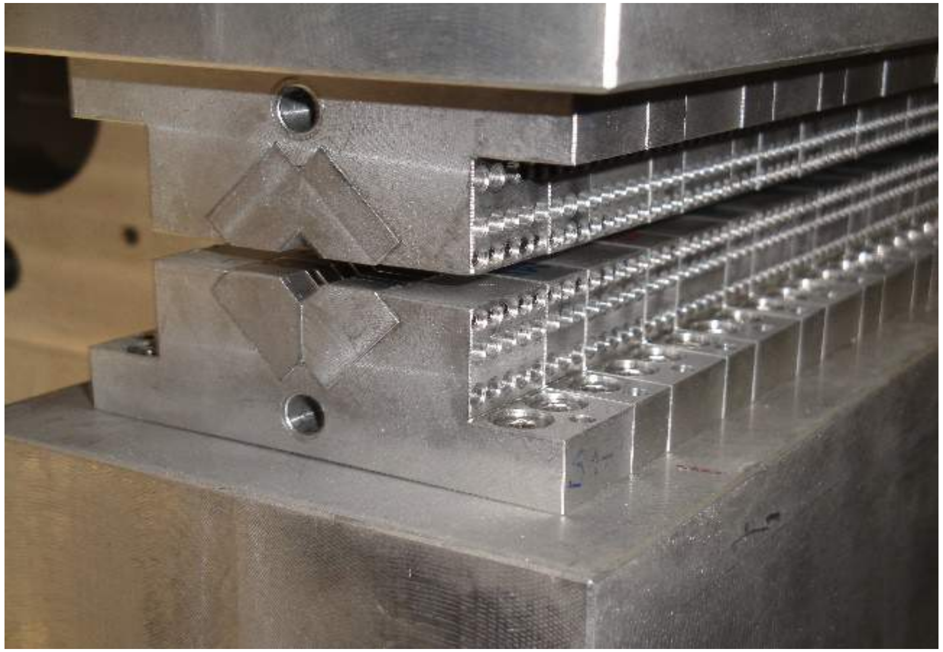




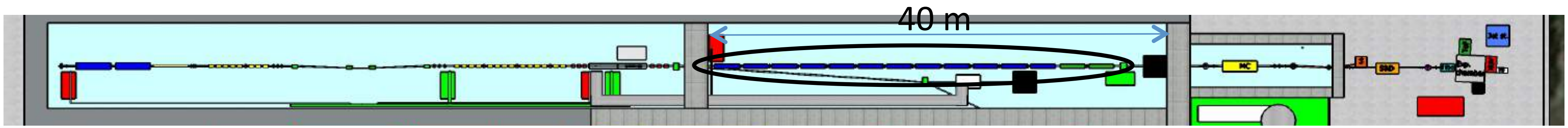
Capillary discharge at SPARC_LAB



Undulators



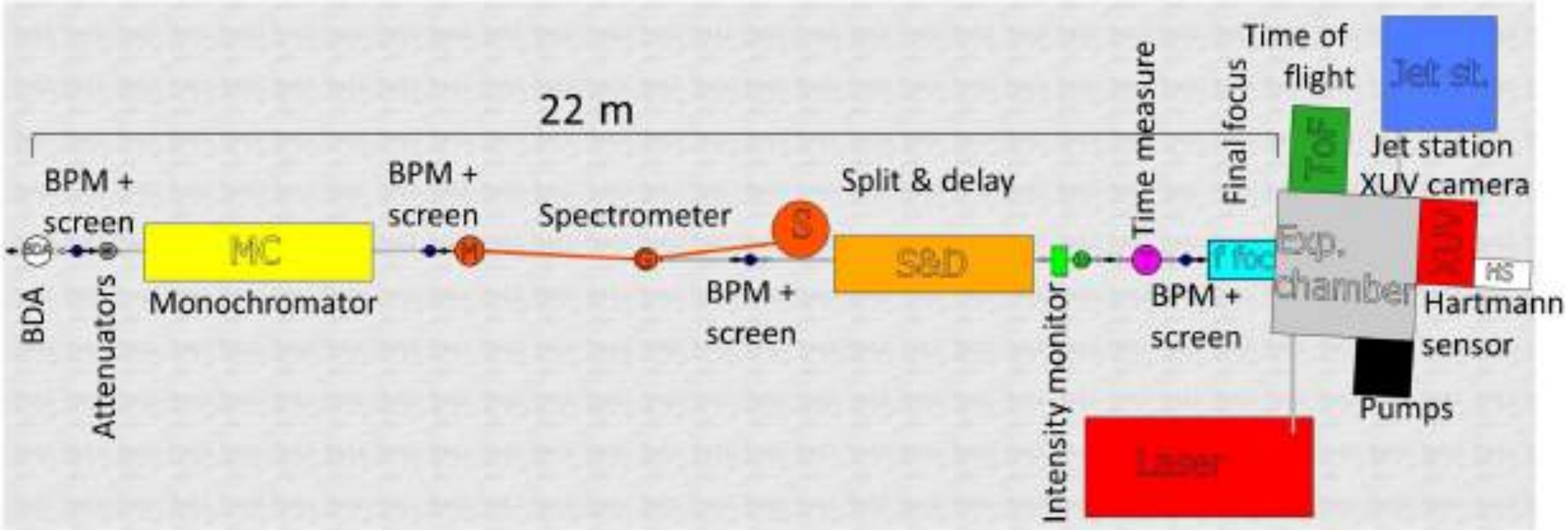
KYMA Δ udulator at SPARC_LAB: λ=1.4 cm, K1

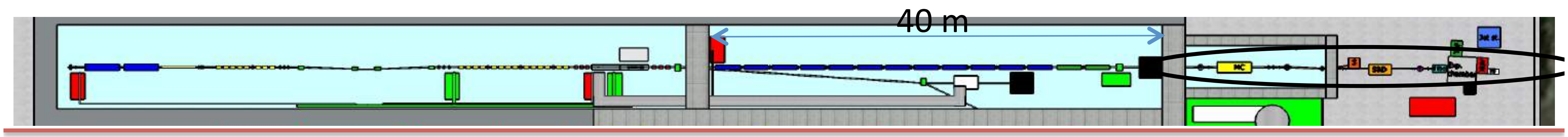


Long undulators chain

Beam separation

Photon beam line

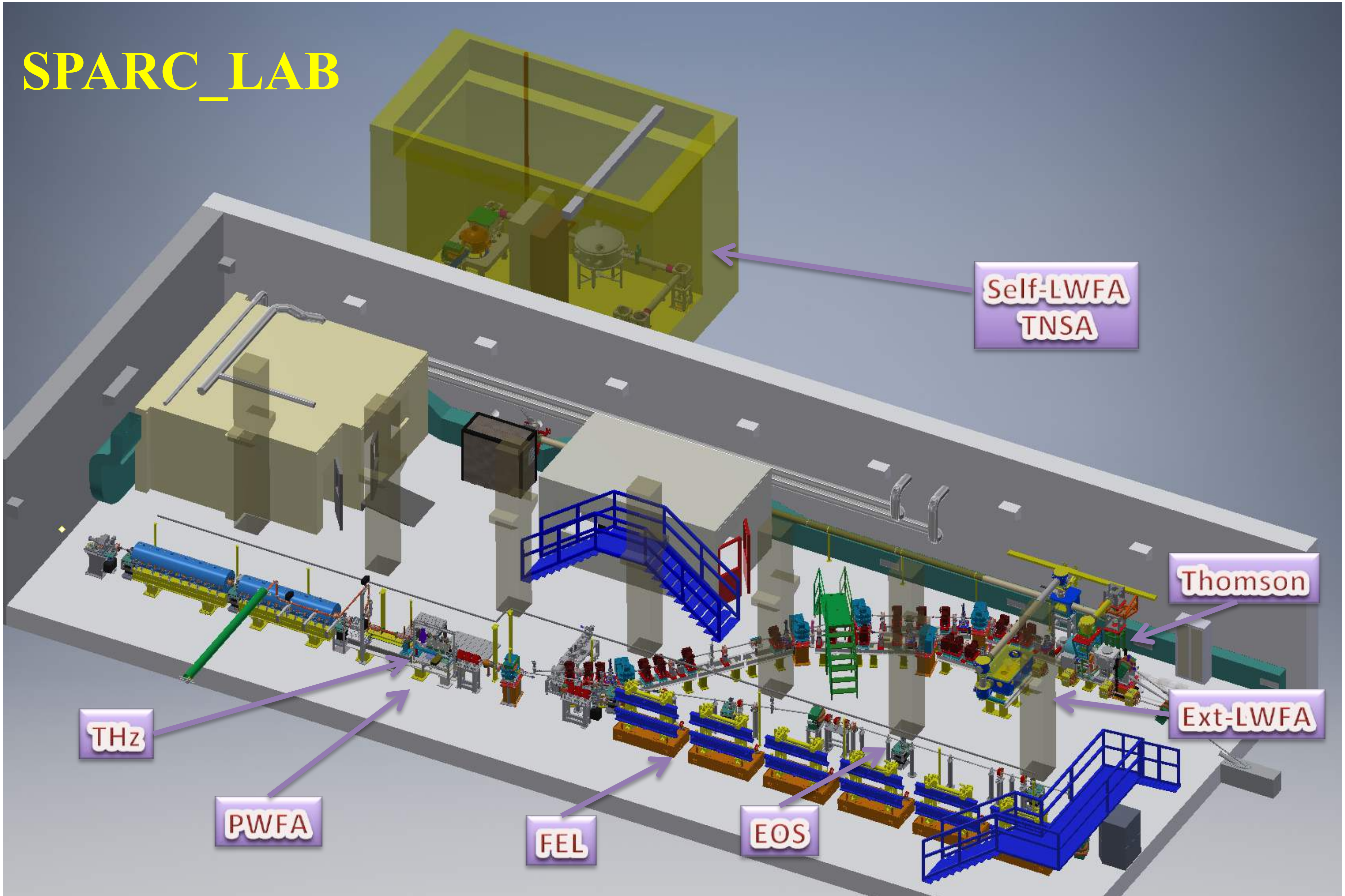




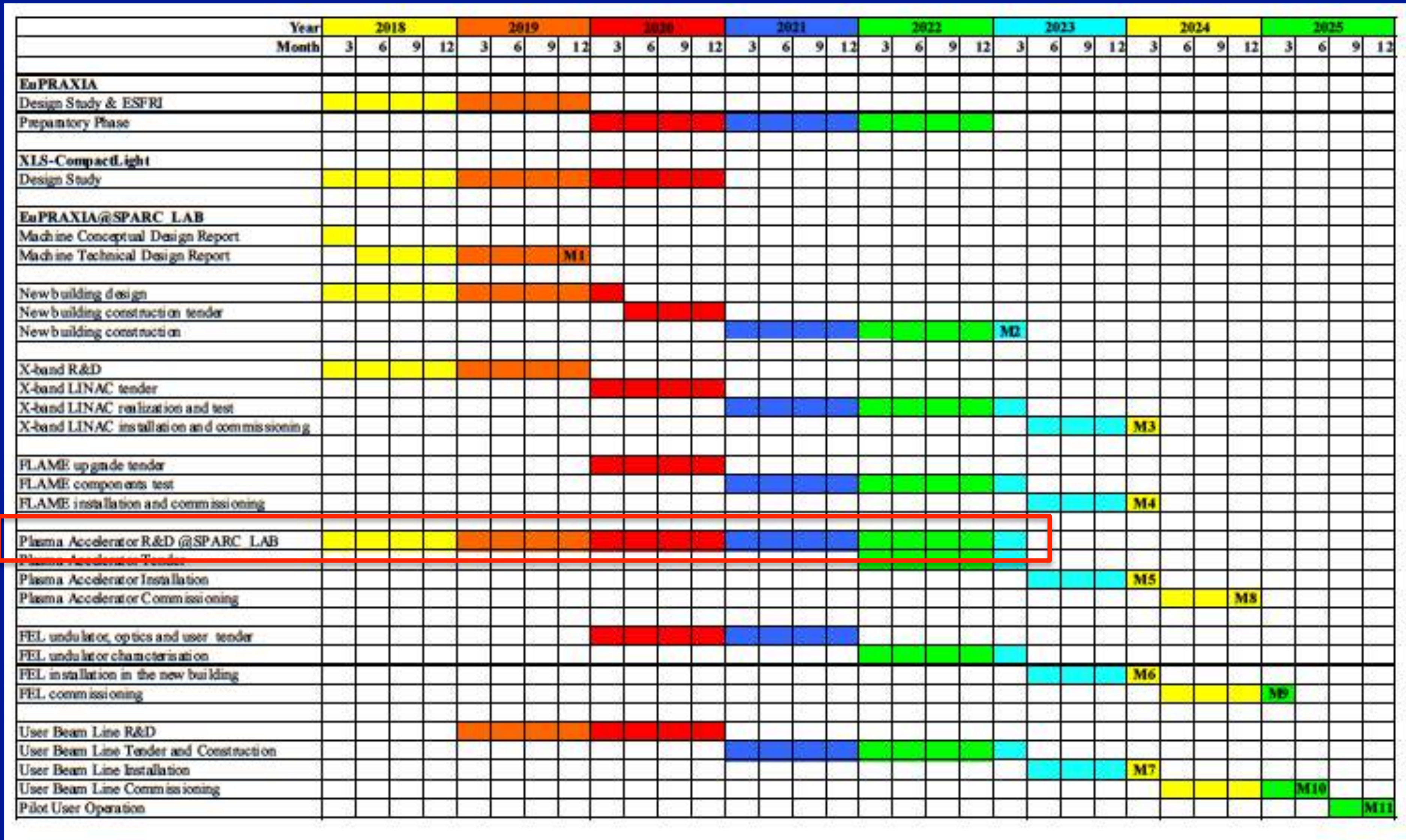
	Units	Full RF case	LWFA case	PWFA case
Electron Energy	GeV	1	1	1
RMS Energy Spread	%	0.05	2.3	1.1
Peak Current	kA	1.79	2.26	2.0
Bunch Charge	pC	200	30	30
RMS Bunch Length	µm (fs)	16.7 (55.6)	2.14 (7.1)	3.82 (12.7)
RMS normalized Emittance	mm mrad	0.5	0.47	1.1
Slice Length	µm	1.66	0.5	1.2
Slice Charge	pC	6.67	18.7	8
Slice Energy Spread	%	0.02	0.03	0.034
Slice normalized Emittance (x/y)	mm mrad	0.35/0.24	0.45/0.465	0.57/0.615
Undulator Period	mm	15	15	15
Undulator Strength $K(a_w)$		0.978 (0.7)	1.13 (0.8)	1.13 (0.8)
Undulator Length	m	30	30	30
Pierce parameter ρ **(1D/3D)**	$\times 10^{-3}$	1.55/1.38	2/1.68	2.5/1.8
Radiation Wavelength	nm (keV)	2.87 (0.43)	2.8 (0.44)	2.98 (0.42)
Photon Energy	µJ	177	40	6.5
Photon per pulse	$\times 10^{10}$	255	43	10
Photon Bandwidth	%	0.46	0.4	0.9
Photon RMS Transverse Size	µm	200	145	10
Photon Brilliance per shot	$(\text{s mm}^2\ \text{mrad}^2\ \text{bw}(0.1\%))^{-1}$	1.4×10^{27}	1.7×10^{27}	0.8×10^{27}

Table 4.1: Beam parameters from start-to-end simulations for full RF and for plasma wakefield acceleration cases with electron (PWFA) or laser (LWFA) driver beam

SPARC_LAB



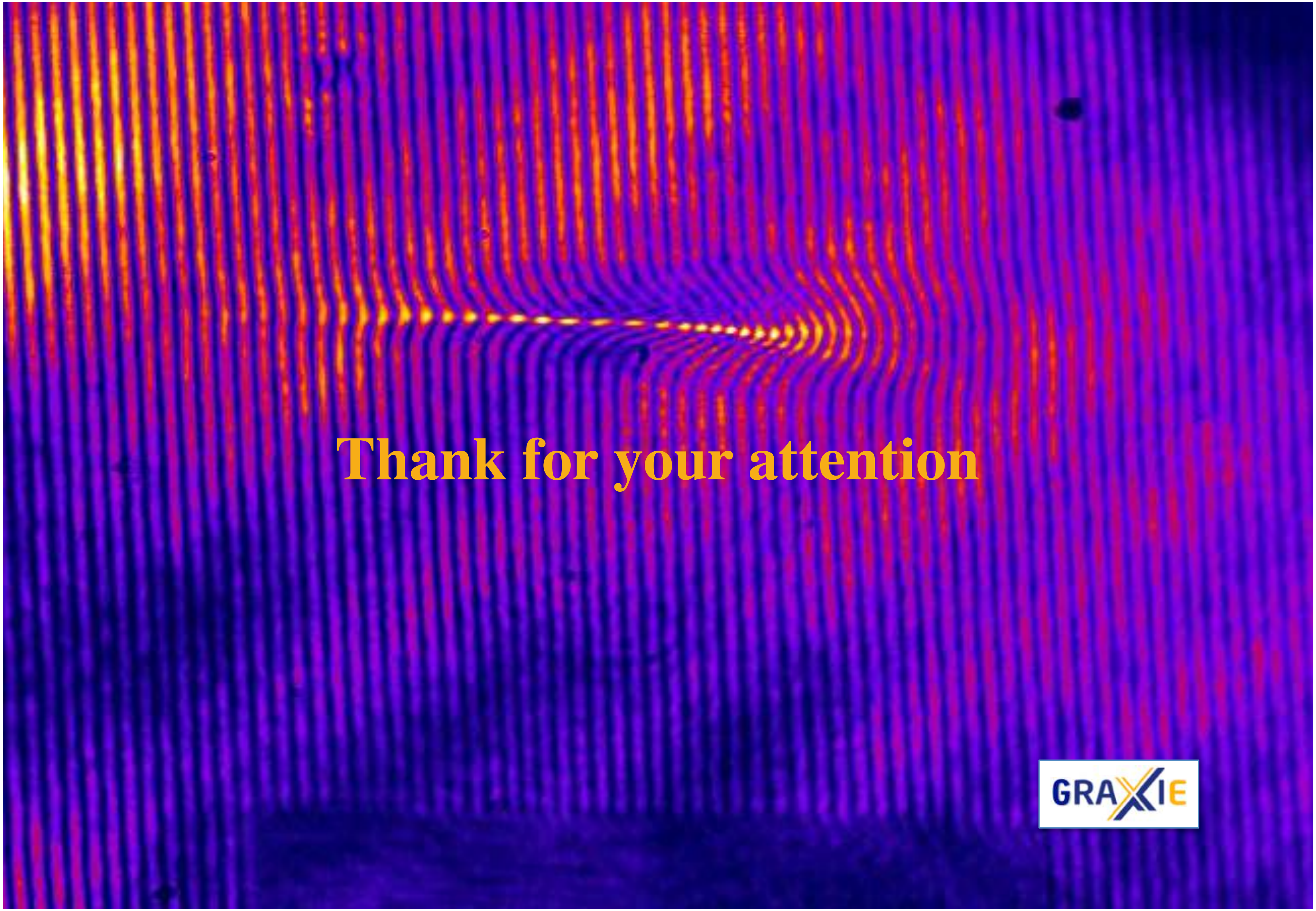
Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.



Year
2018
2019
2020
2021
2022
2023
2024
2025
Month
3 6 9 12
EuPRAXIA
Design Study & ESFRI
Preparatory Phase
XLS-CompactLight
Design Study
EuPRAXIA@SPARC_LAB
Machine Conceptual Design Report
Machine Technical Design Report
M1
New building design
New building construction tender
New building construction
M2
X-band R&D
X-band LINAC tender
X-band LINAC realization and test
X-band LINAC installation and commissioning
M3
FLAME upgrade tender
FLAME components test
FLAME installation and commissioning
M4
Plasma Accelerator R&D @SPARC_LAB
Plasma Accelerator Tender
Plasma Accelerator Installation
M5
Plasma Accelerator Commissioning
M8
FEL undulator, optics and user tender
FEL undulator characterisation
FEL installation in the new building
M6
FEL commissioning
M9
User Beam Line R&D
User Beam Line Tender and Construction
User Beam Line Installation
M7
User Beam Line Commissioning
M10
Pilot User Operation
M11

EuPRAXIA@SPARC_LAB

- X-band RF technology implementation,➔ CompactLight
- Science with short wavelength Free Electron Laser (FEL)
- Physics with high power lasers and secondary particle source
- Compact Neutron Source
- R&D on compact radiation sources for medical applications
- Detector development and test for X-ray FEL and HEP
- Science with THz radiation sources
- Nuclear photonics with γ-rays Compton sources
- R&D on polarized positron sources
- R&D in accelerator physics and industrial spin – off


Thank for your attention
GRAXIE