The EuPRAXIA@SPARC_LAB Project
and related R&D activities at LNF

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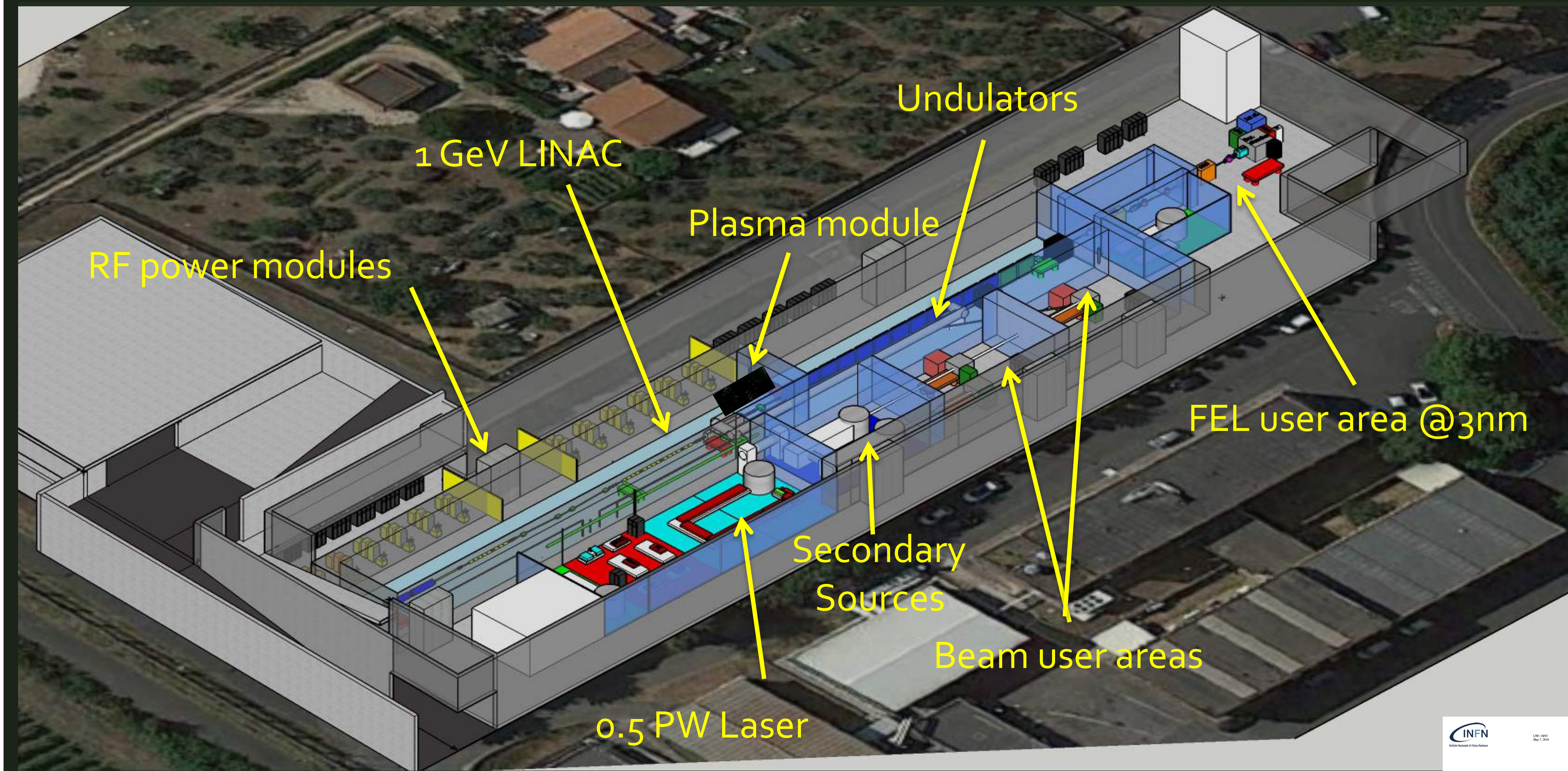
HPXM Workshop, Zoom, June 8, 2021

Istituto Nazionale di Fisica Nucleare

EuPRAXIA@SPARC_LAB



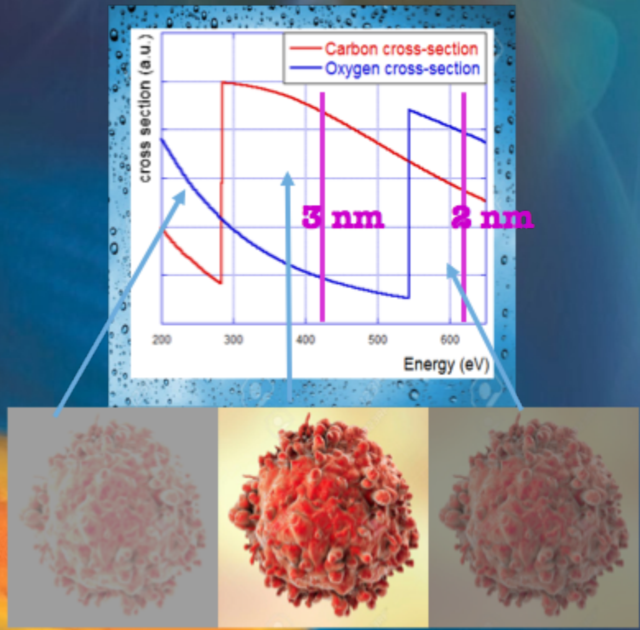
http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

Expected SASE FEL performances

	Units	Full RF case	Plasma case
Electron Energy	GeV	1	1
Bunch Charge	pC	200	30
Peak Current	kA	2	3
RMS Energy Spread	%	0.1	1
RMS Bunch Length	fs	40	4
RMS matched Bunch Spot	μm	34	34
RMS norm. Emittance	μm	1	1
Slice length	μm	0.5	0.45
Slice Energy Spread	%	0.01	0.1
Slice norm. Emittance	μm	0.5	0.5
Undulator Period	mm	15	15
Undulator Strength K		1.03	1.03
Undulator Length	m	12	14
Gain Length	m	0.46	0.5
Pierce Parameter ρ	x 10^{-3}	1.5	1.4
Radiation Wavelength	nm	3	3
Undulator matching β_u	m	4.5	4.5
Saturation Active Length	m	10	11
Saturation Power	GW	4	5.89
Energy per pulse	μJ	83.8	11.7
Photons per pulse	x 10^{11}	11	1.5

Table 2.1: Beam parameters for the EuPRAXIA@SPARC_LAB FEL driven by X-band linac or Plasma acceleration

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)

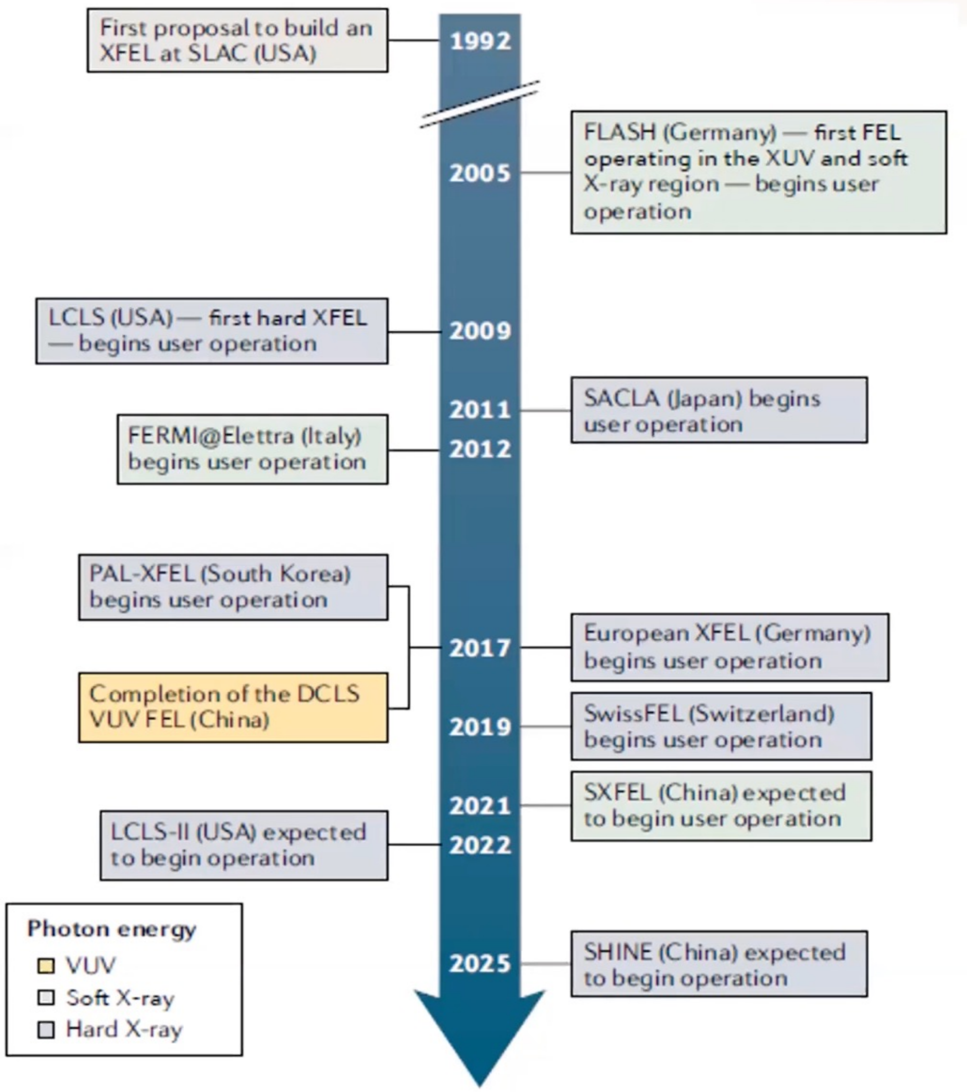


Coherent Imaging of biological samples
protein clusters, VIRUSES and cells
living in their native state
Possibility to study dynamics
~10^{11} photons/pulse needed

Courtesy F. Stellato, UniToV

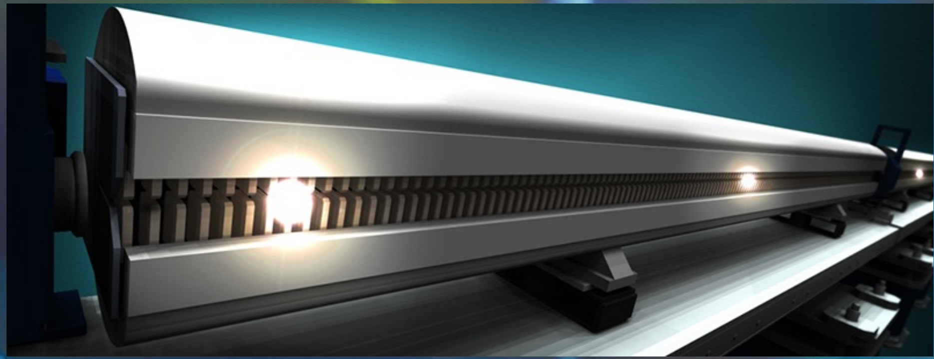
FEL is a well established technology

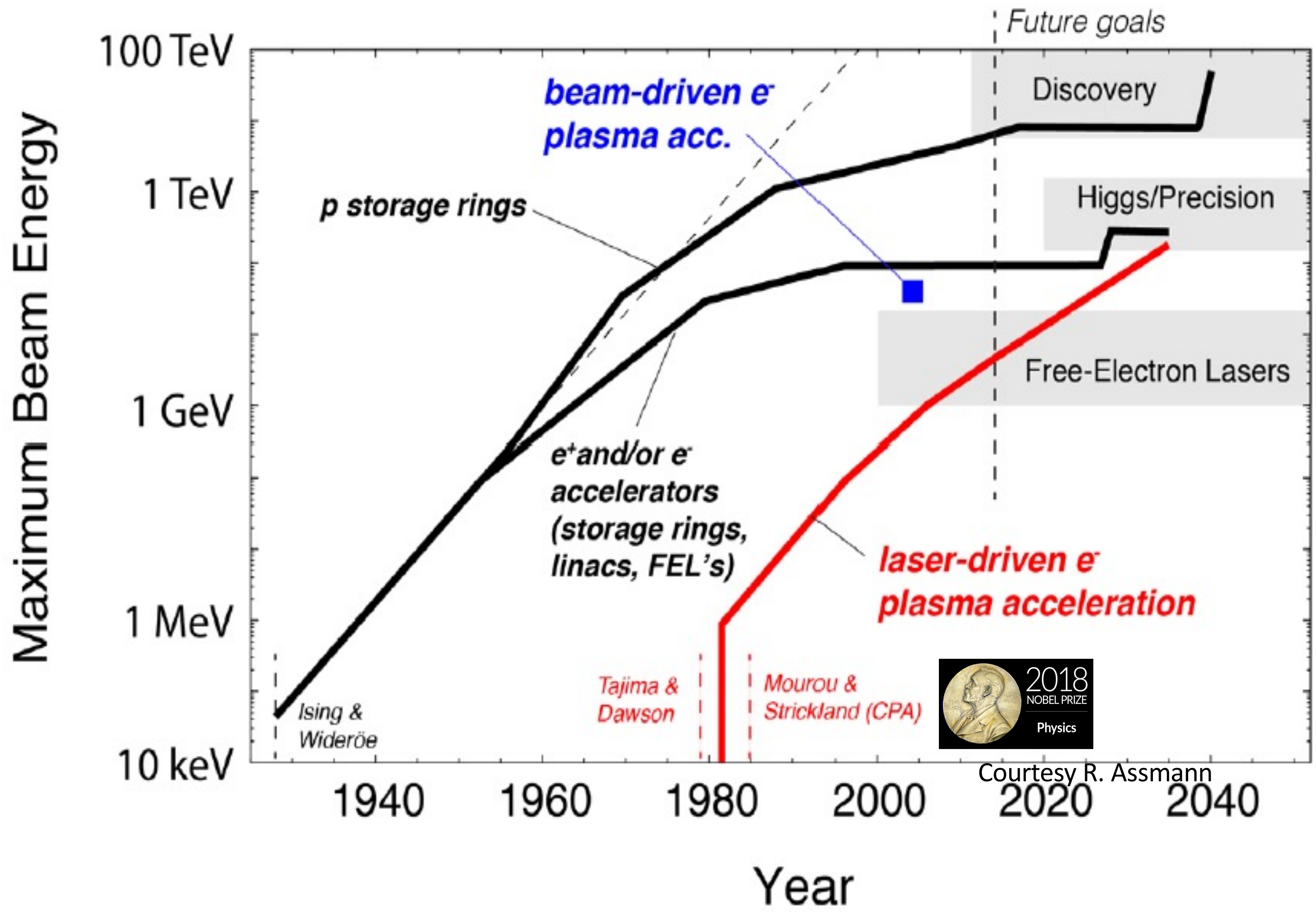
(But a widespread use of FEL is partially limited by size and costs)



New facilities are expected to begin operation in the next 5 years in the USA and China, and the UK is considering the scientific case for an XFEL.

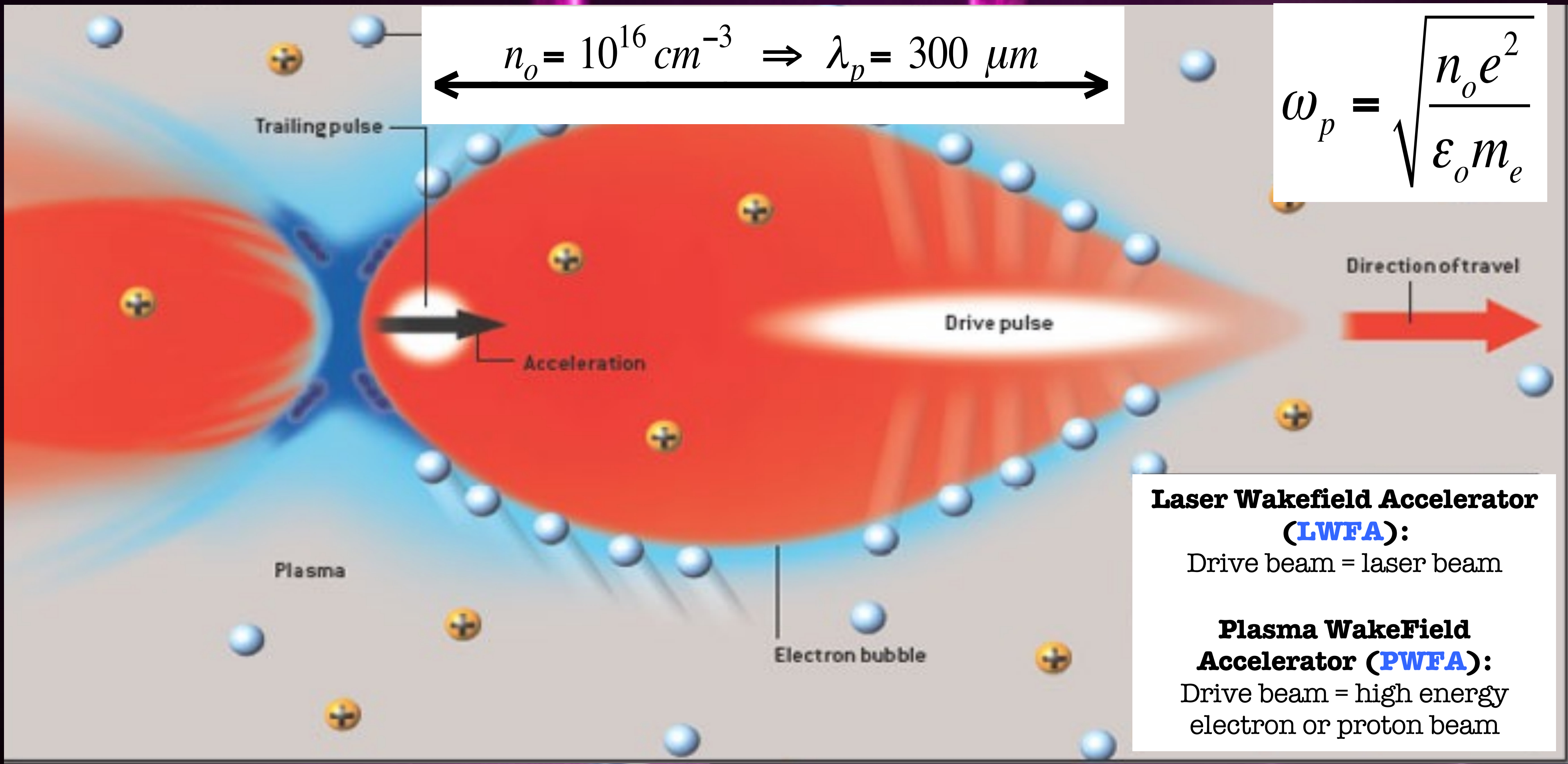
Iulia Georgescu





Courtesy R. Assmann

Principle of plasma acceleration



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

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

Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

Plasma WakeField Accelerator (PWFA):
Drive beam = high energy electron or proton beam

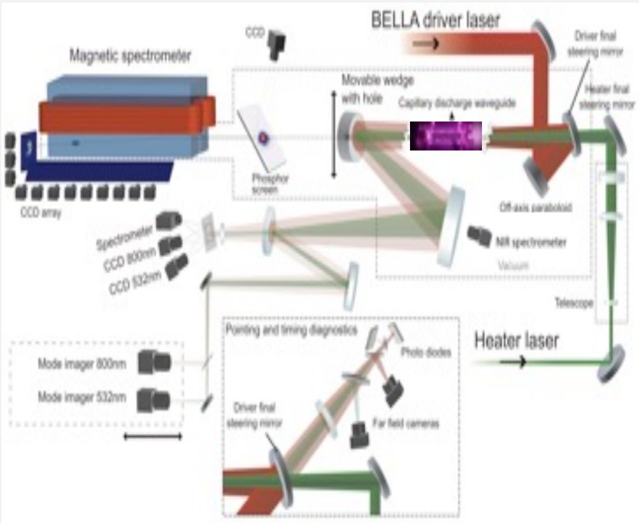
BELLA, Berkeley Lab, US

Laser Driven Plasma Wakefield Acceleration Facility: Today: PW laser!

BERKELEY LAB

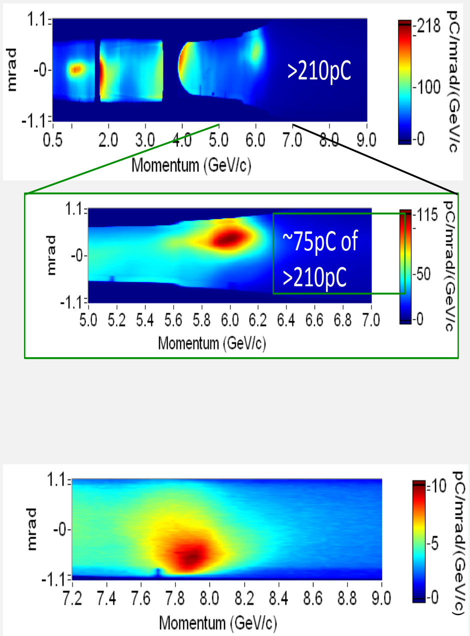
Petawatt laser guiding and electron beam **acceleration to 8 GeV** in a laser-heated capillary discharge waveguide

A.J.Gonsalves et al., Phys.Rev.Lett. ***122****, 084801 (2019)*



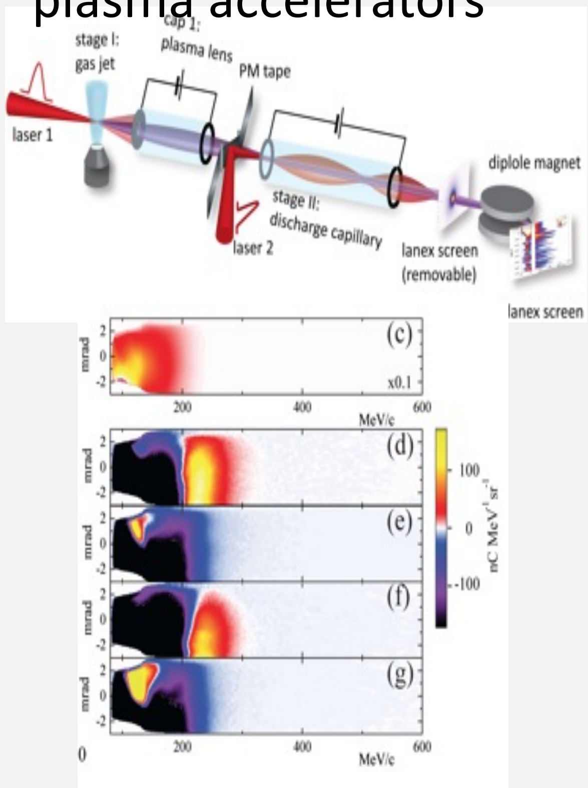
Laser heater added to capillary

Electron spectra, up to 6- 8 GeV



→ path to 10 GeV with continued improvement of guiding in progress

Multistage coupling of independent laser-plasma accelerators



Staging demonstrated at 100 MeVs

S. Steinke, Nature ***530****, 190 (2016)*

Beam Quality Requirements

Future accelerators will require also high quality beams :

==> High Luminosity & High Brightness,

==> High Energy & Low Energy Spread

$$L = \frac{N_{e+} N_{e-} f_r}{4\pi \sigma_x \sigma_y}$$

- N of particles per pulse => 10^9
- High rep. rate f_r => bunch trains

- Small spot size => low emittance

$$B_n \approx \frac{2I}{\varepsilon_n^2}$$

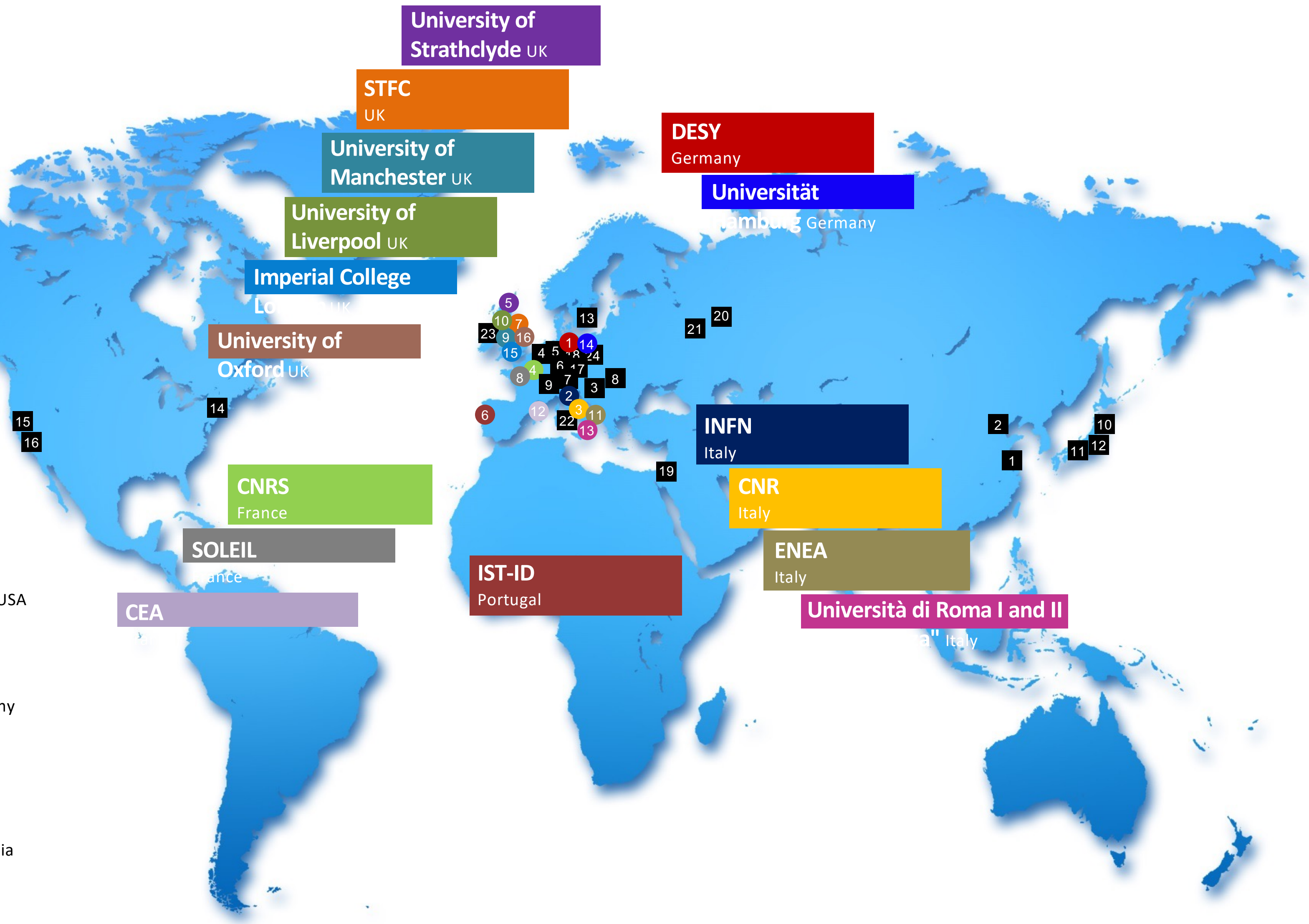
- Short pulse (ps => fs)

- Little spread in transverse momentum and angle => low emittance

Worldwide effort towards high quality plasma beams

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
19. **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



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

EuPRAXIA Conceptual Design: Complete

Conceptual design report submitted as planned to EU on November 1st

- **First ever international design of a plasma accelerator facility**
- Funded 2015-2019 by European Union (Horizon2020) with 3 Million Euro
- Coordinating lab: DESY (R. Assmann)
- Growing **consortium**: 32 → 41 labs, ELI, CERN, LBNL, Osaka, Shanghai, Russian labs
- **Industry**: Thales (France), Amplitude (France), Trumpf Scientific (Germany)

653 page CDR, 240 scientists contributed

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

EuPRAXIA Brings together European Actors in this Field…

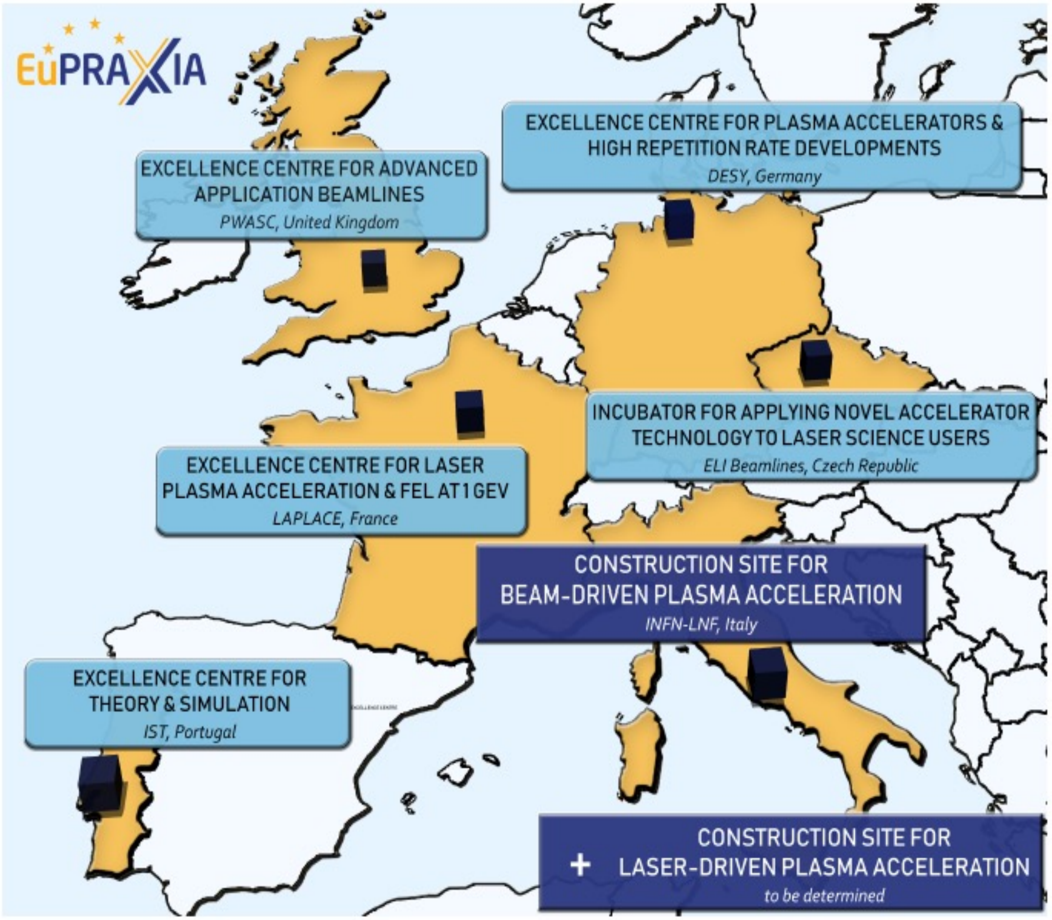
Position Europe as a Leader in the Global Context

- Avoid internal competition, **position Europe globally as lead player** in the compact accelerator "market", in innovative technology

… and Builds a European Distributed Facility

Position Europe as a Leader in the Global Context

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

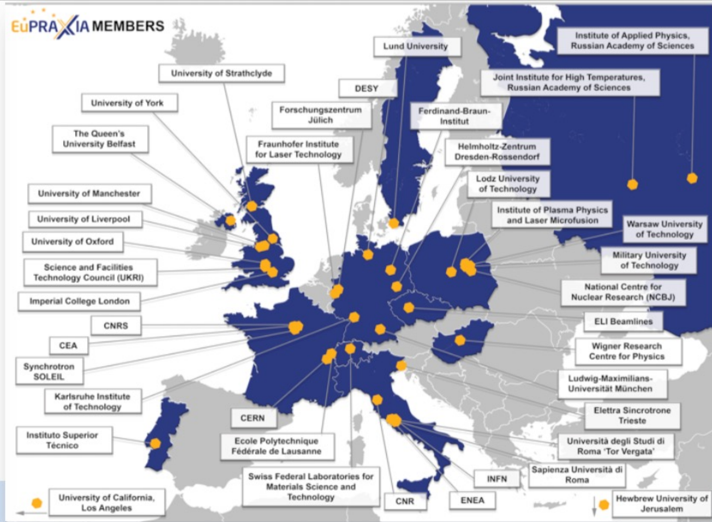


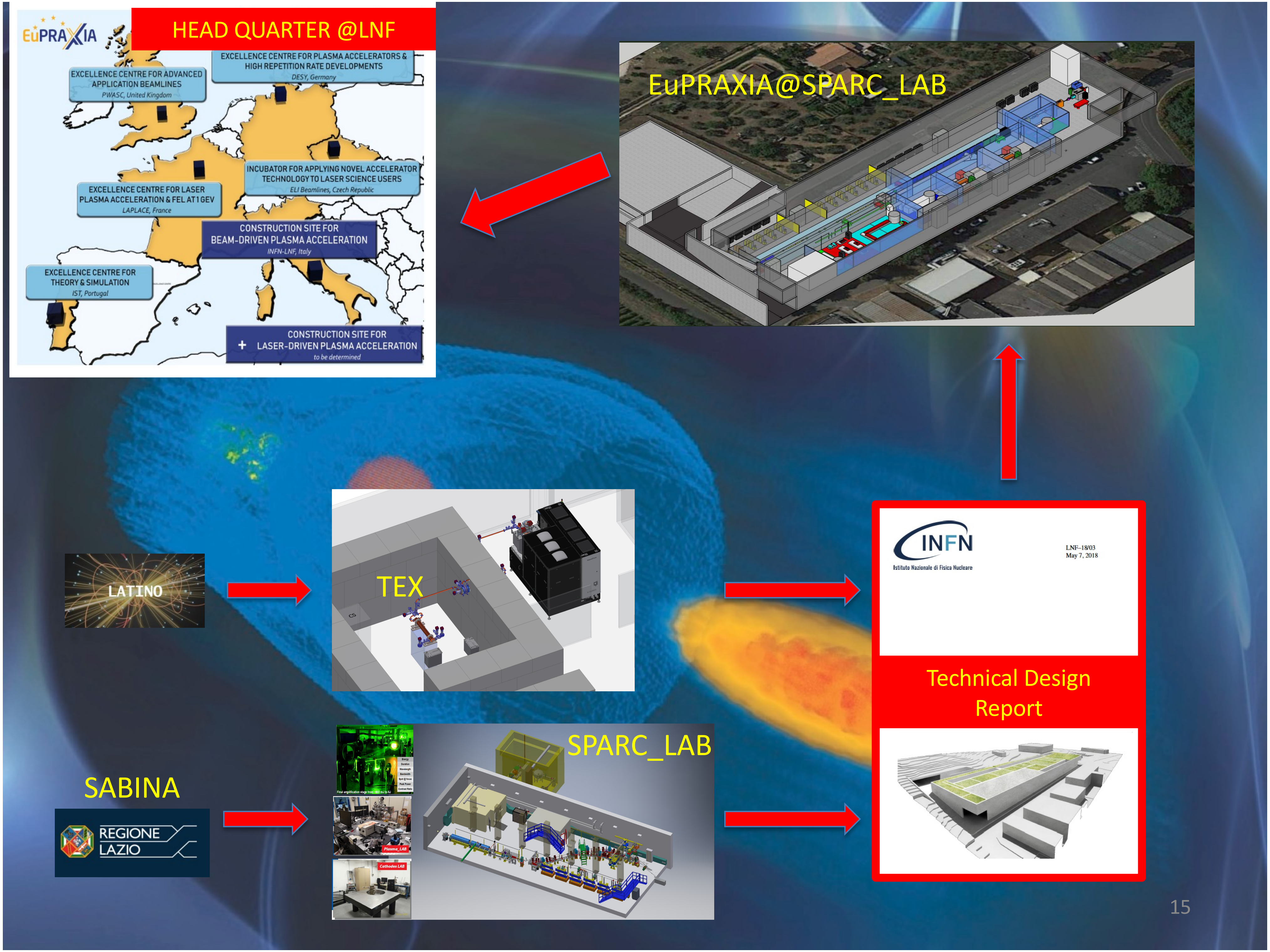
ESFRI Proposal: Submitted on September 9

Horizon 2020

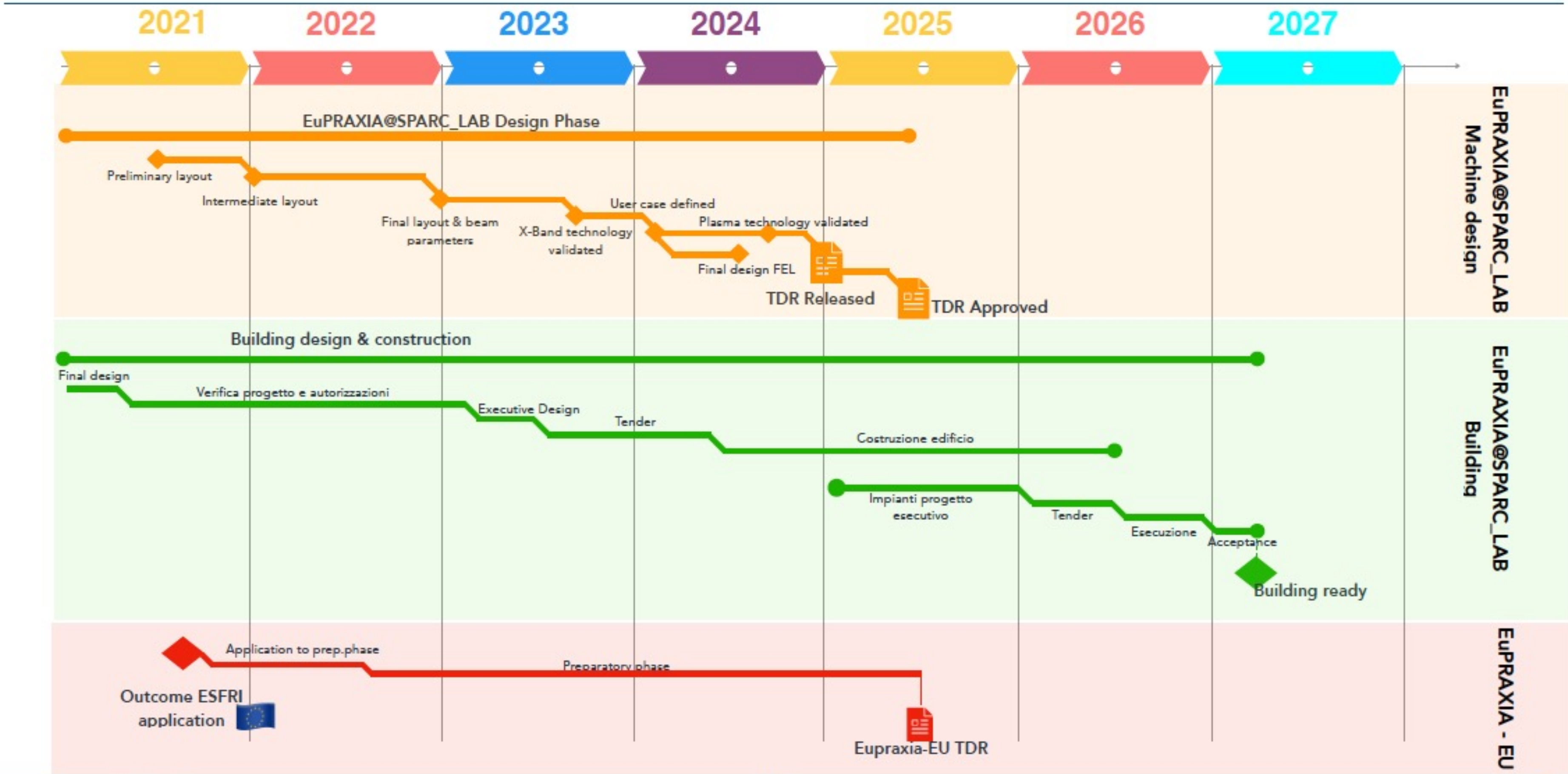
- EuPRAXIA strongly supported in European research landscape, it is **timely**, it offers **highly attractive opportunities** for innovation with industry, novel applications and pilot users.
- **Lead Country**: **Italy (LNF/INFN)**
  Political and financial support letter sent to ESFRI by Italian Ministry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

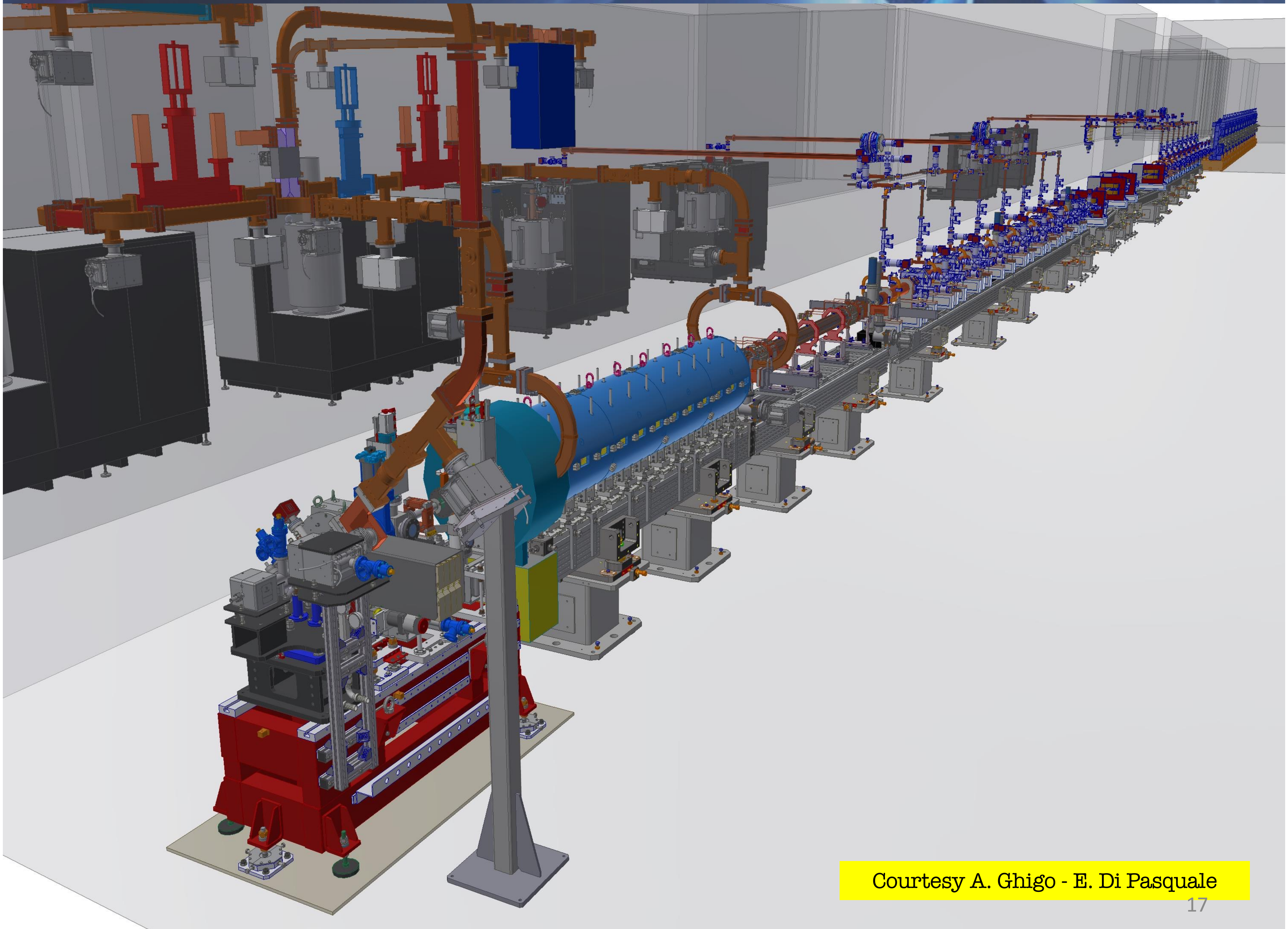
From political landscape it is seen that both Czech Republic and UK would be excellent sites for the second leg of EuPRAXIA, connecting to existing facilities with laser expertise and few 100 million € pre-invest.




HEAD QUARTER @LNF
EuPRAXIA
EXCELLENCE CENTRE FOR PLASMA ACCELERATORS & HIGH REPETITION RATE DEVELOPMENTS
DESY, Germany
EXCELLENCE CENTRE FOR ADVANCED APPLICATION BEAMLINES
PWASC, United Kingdom
INCUBATOR FOR APPLYING NOVEL ACCELERATOR TECHNOLOGY TO LASER SCIENCE USERS
ELI Beamlines, Czech Republic
EXCELLENCE CENTRE FOR LASER PLASMA ACCELERATION & FEL AT 1 GEV
LAPLACE, France
CONSTRUCTION SITE FOR BEAM-DRIVEN PLASMA ACCELERATION
INFN-LNF, Italy
EXCELLENCE CENTRE FOR THEORY & SIMULATION
IST, Portugal
+ CONSTRUCTION SITE FOR LASER-DRIVEN PLASMA ACCELERATION
to be determined
EuPRAXIA@SPARC_LAB
LATINO
TEX
SABINA
REGIONE LAZIO
SPARC_LAB
INFN
Istituto Nazionale di Fisica Nucleare
LNF–18/03
May 7, 2018
Technical Design Report

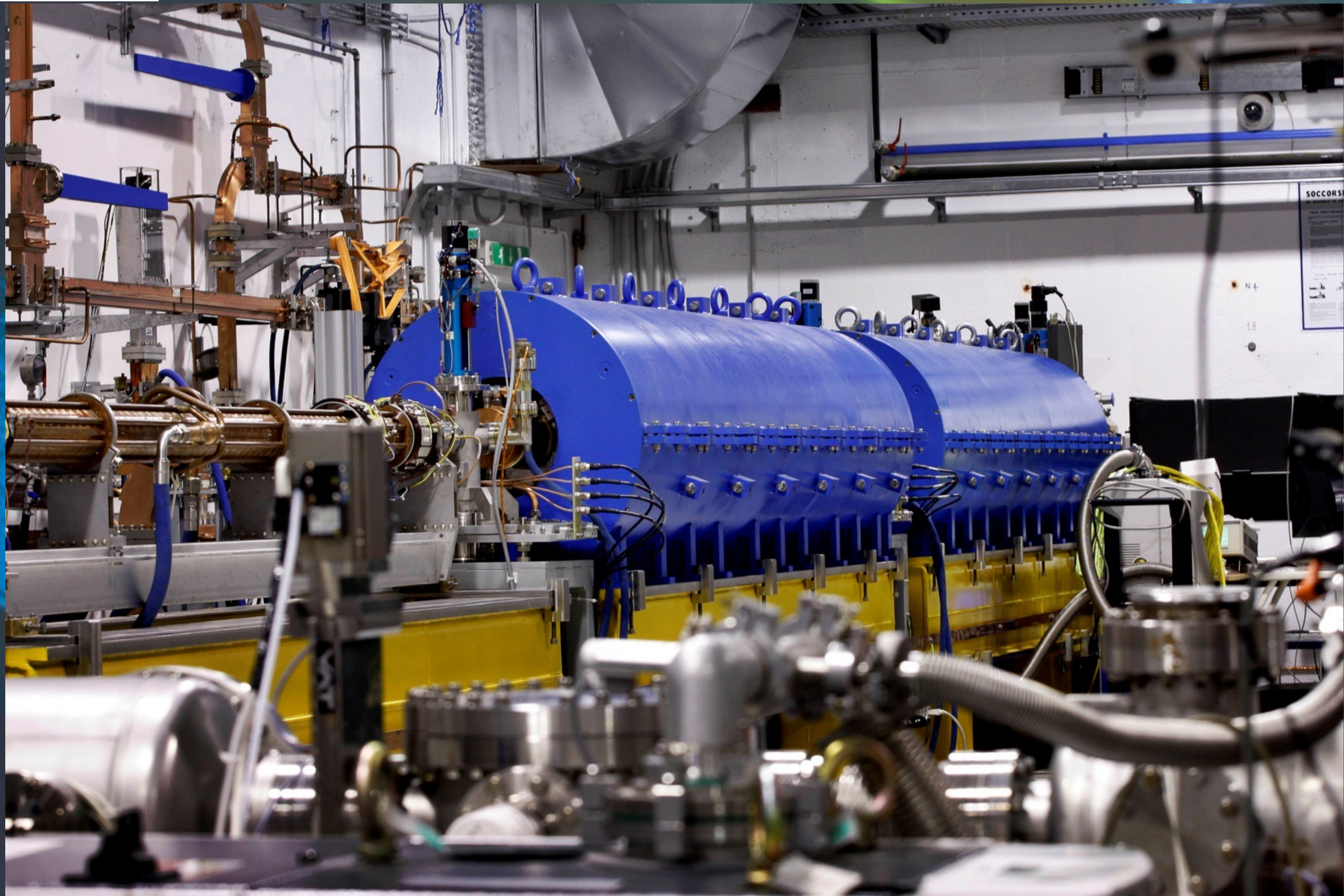
Road map

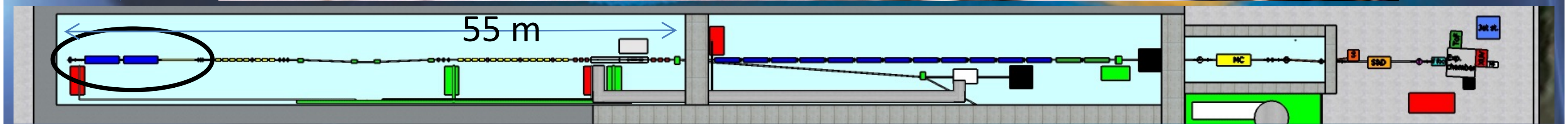

2021
2022
2023
2024
2025
2026
2027
EuPRAXIA@SPARC_LAB Design Phase
Preliminary layout
Intermediate layout
Final layout & beam parameters
X-Band technology validated
User case defined
Plasma technology validated
Final design FEL
TDR Released
TDR Approved
EuPRAXIA@SPARC_LAB Machine design
Building design & construction
Final design
Verifica progetto e autorizzazioni
Executive Design
Tender
Costruzione edificio
Impianti progetto esecutivo
Tender
Esecuzione
Acceptance
Building ready
EuPRAXIA@SPARC_LAB Building
Application to prep.phase
Preparatory phase
Outcome ESFRI application
Eupraxia-EU TDR
EuPRAXIA - EU



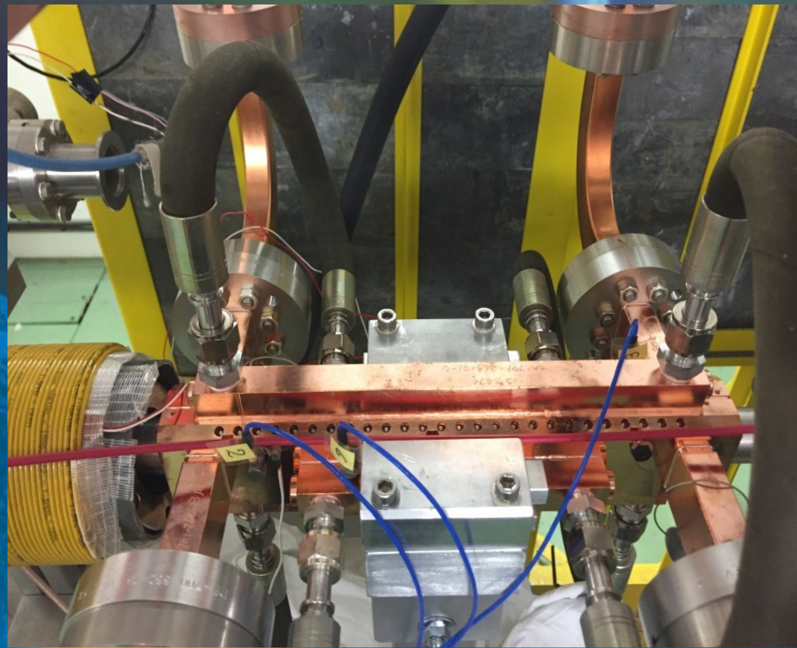
Courtesy A. Ghigo - E. Di Pasquale

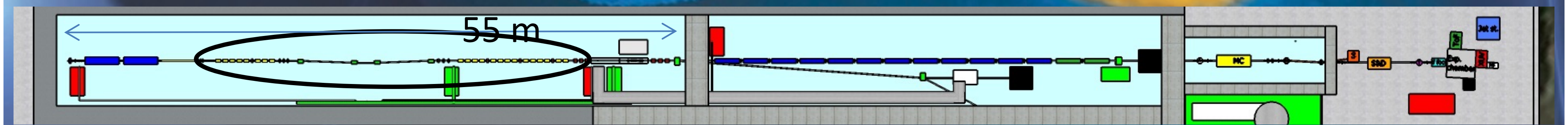
SPARC_LAB HB photo- injector



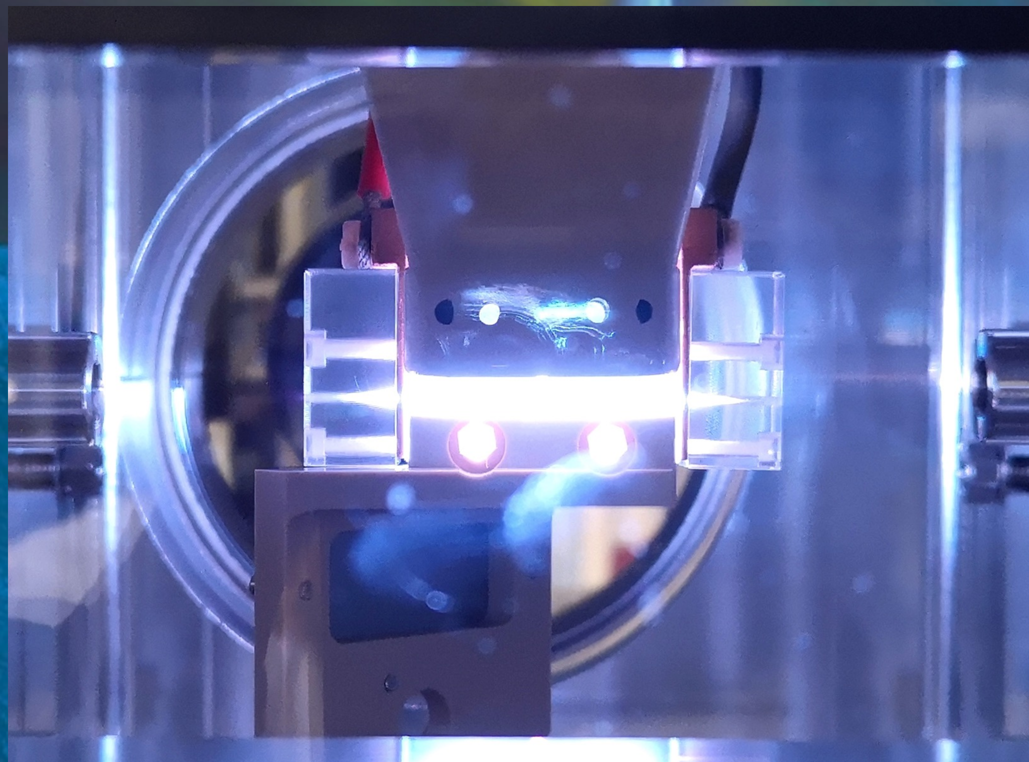


X-band Linac

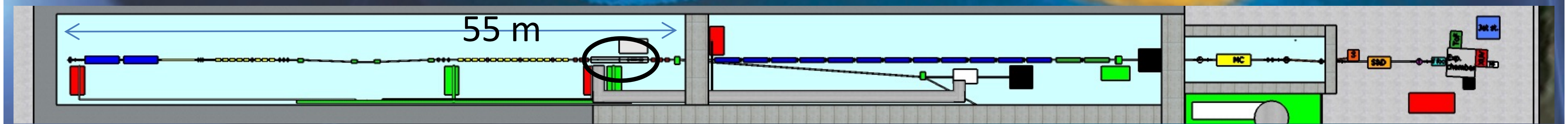




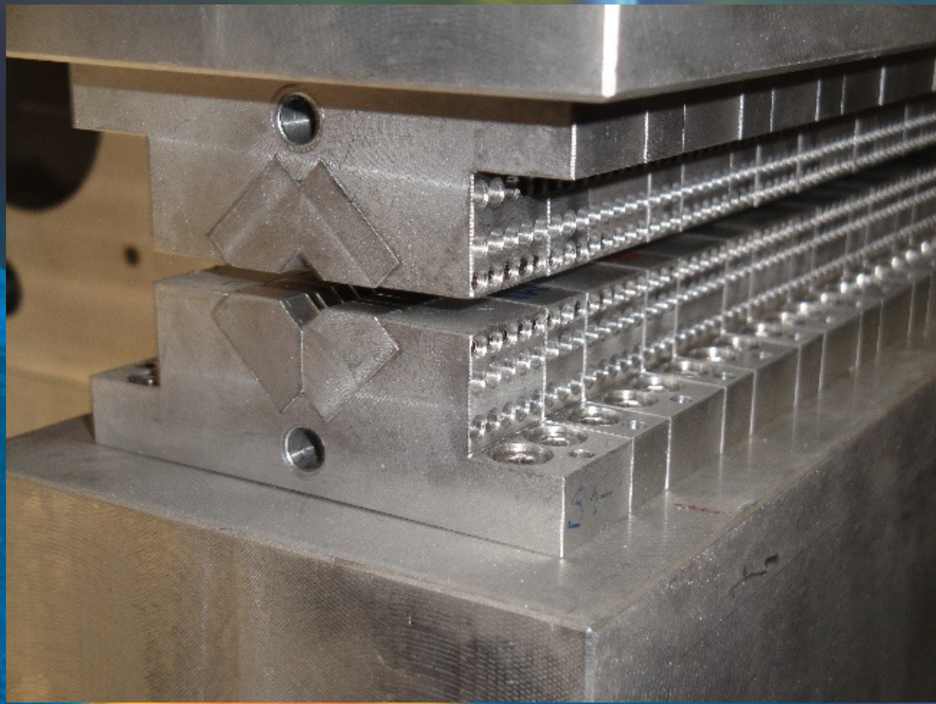
Plasma WakeField Acceleration



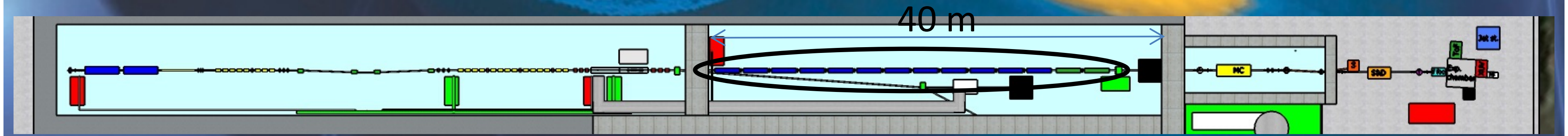
Capillary discharge at SPARC_LAB



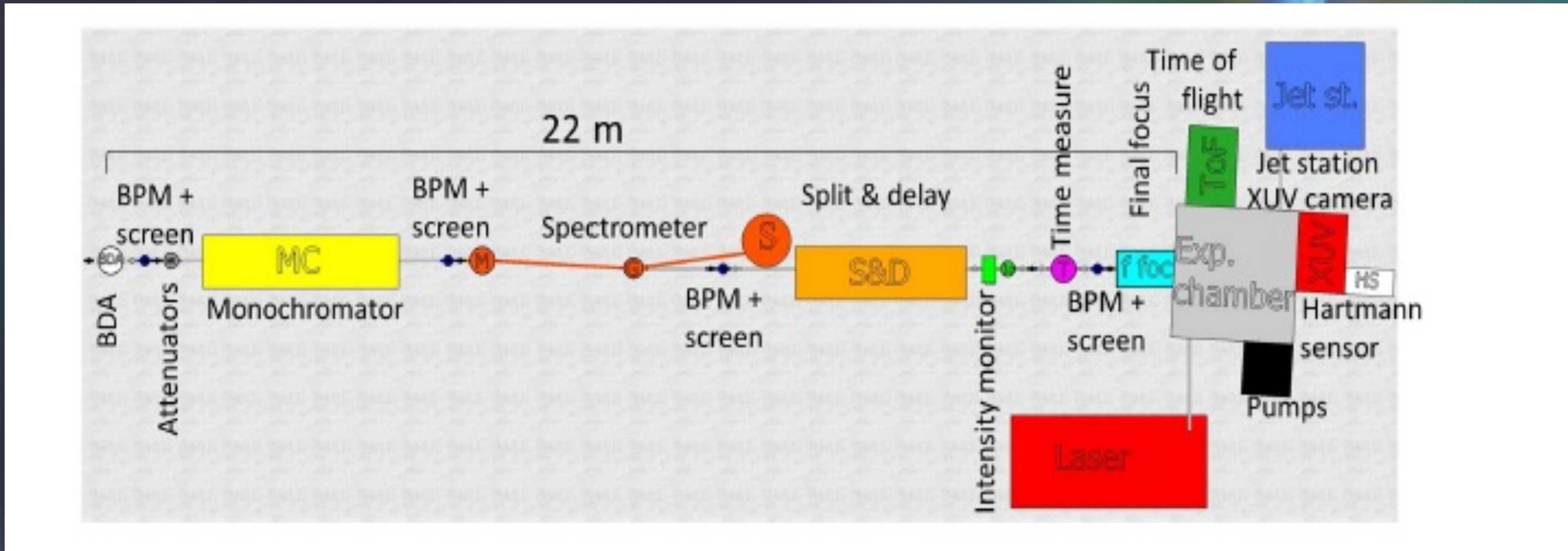
Undulators

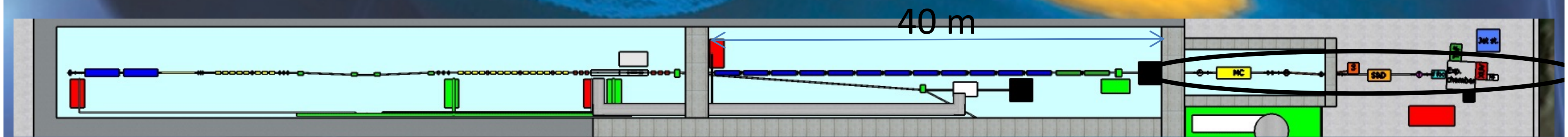


KYMA Δ udulator at SPARC_LAB: λ=1.4 cm, K1



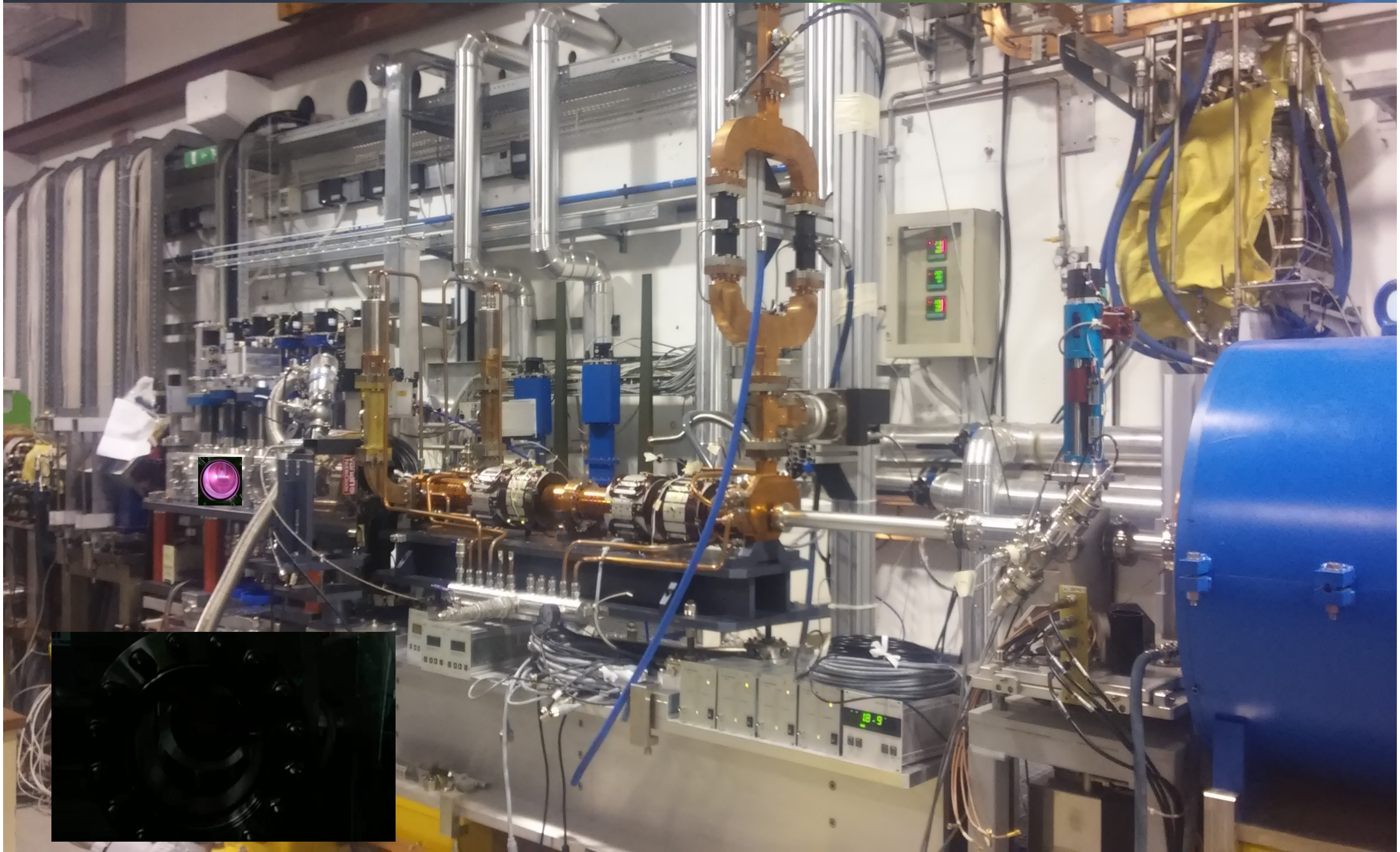
Photon beam line



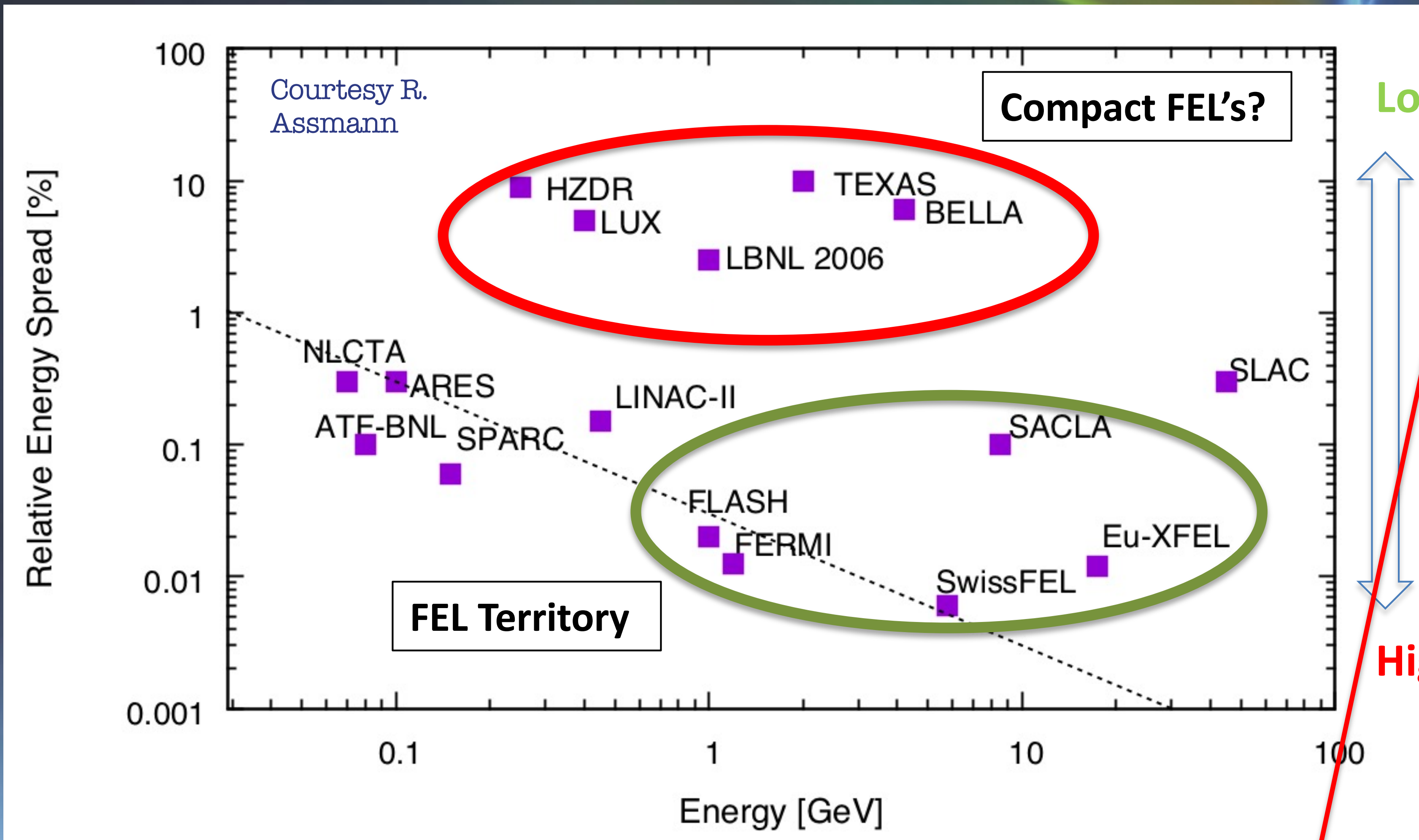


SPARC_LAB is the test and training facility at LNF for Advanced Accelerator Developments (since 2005)

PWFA vacuum chamber at SPARC_LAB



High Quality Beam



Lower quality

Higher quality

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

$$\sigma_{x,eq} = \sqrt[4]{\frac{2}{\gamma}} \sqrt{\frac{\varepsilon_n}{k_p}}$$

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

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

Assisted Beam Loading Energy Spread Compensation

Achieved 4 MeV acceleration in 3 cm plasma with 200 pC driver

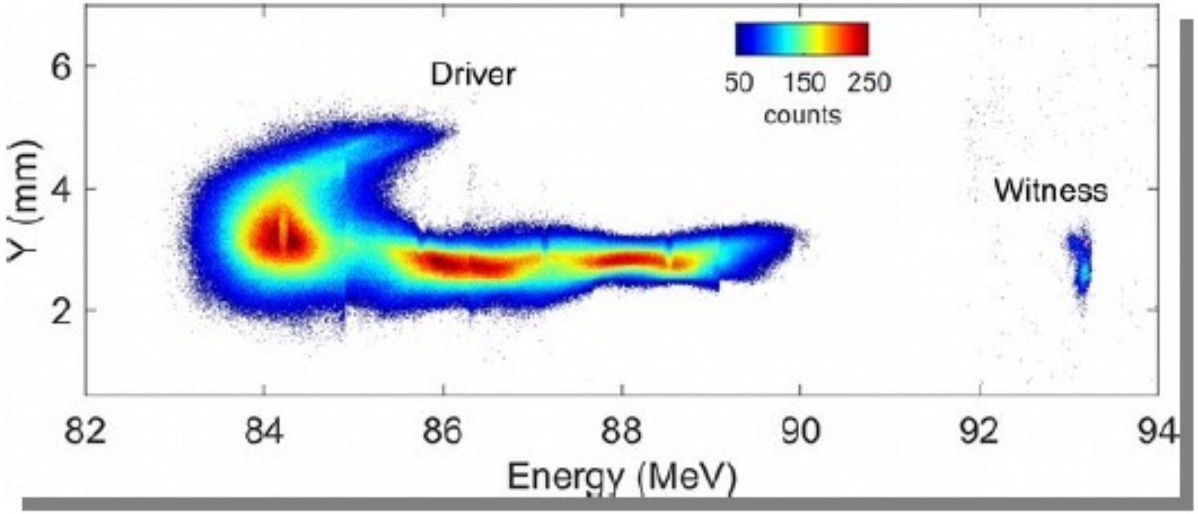
~133 MV/m accelerating gradient

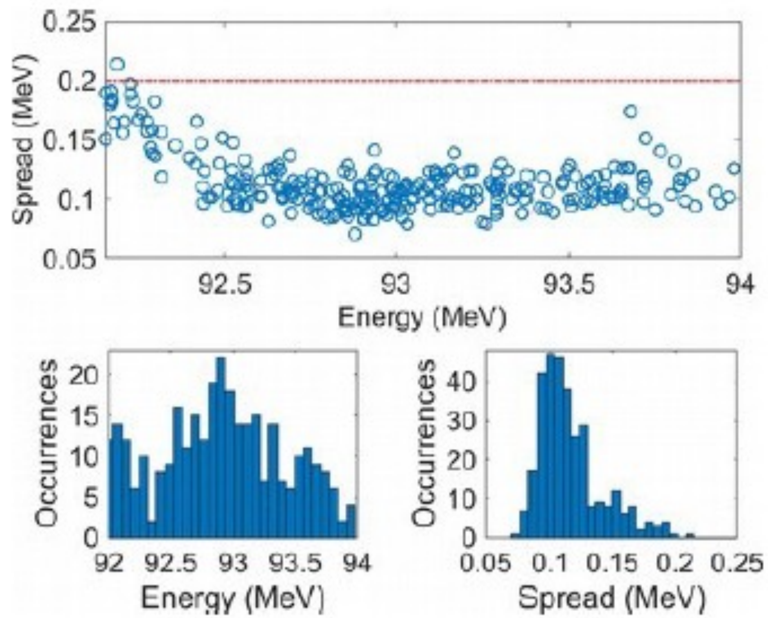
2x10^{15} cm^{-3} plasma density

→ demonstration of energy spread compensation during acceleration

Energy spread reduced from 0.2% to 0.12%

99.5% energy stability





Pompili, R., et al. "Energy spread minimization in a beam-driven plasma wakefield accelerator." Nature Physics (2020): 1-5.


Thank for your attention