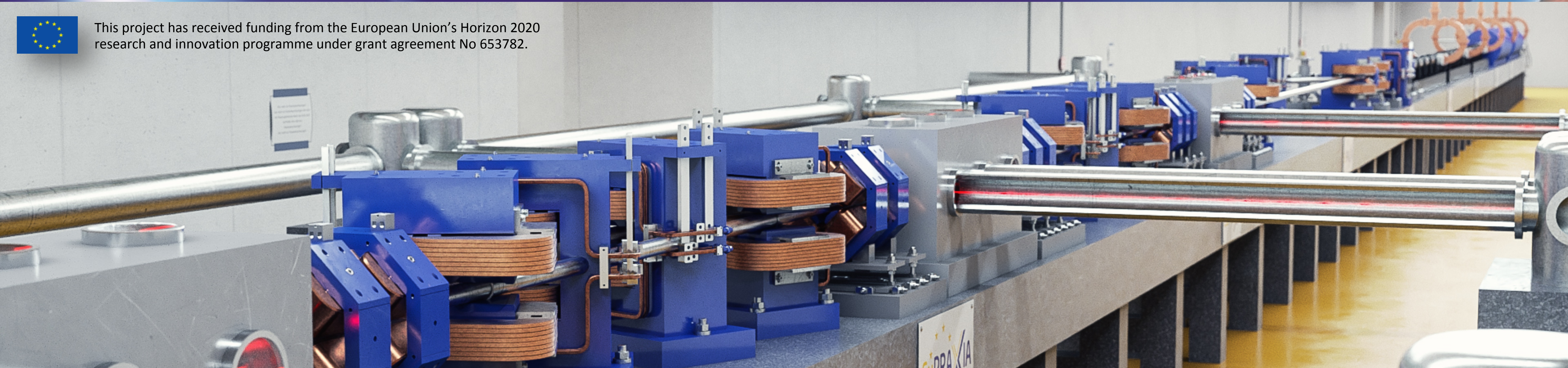
Towards a Plasma-Based Accelerator Facility

Ralph Assmann (DESY, Coordinator) for the EuPRAXIA Consortium
105th Plenary ECFA Meeting, 14 – 15 Nov 2019, CERN

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

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



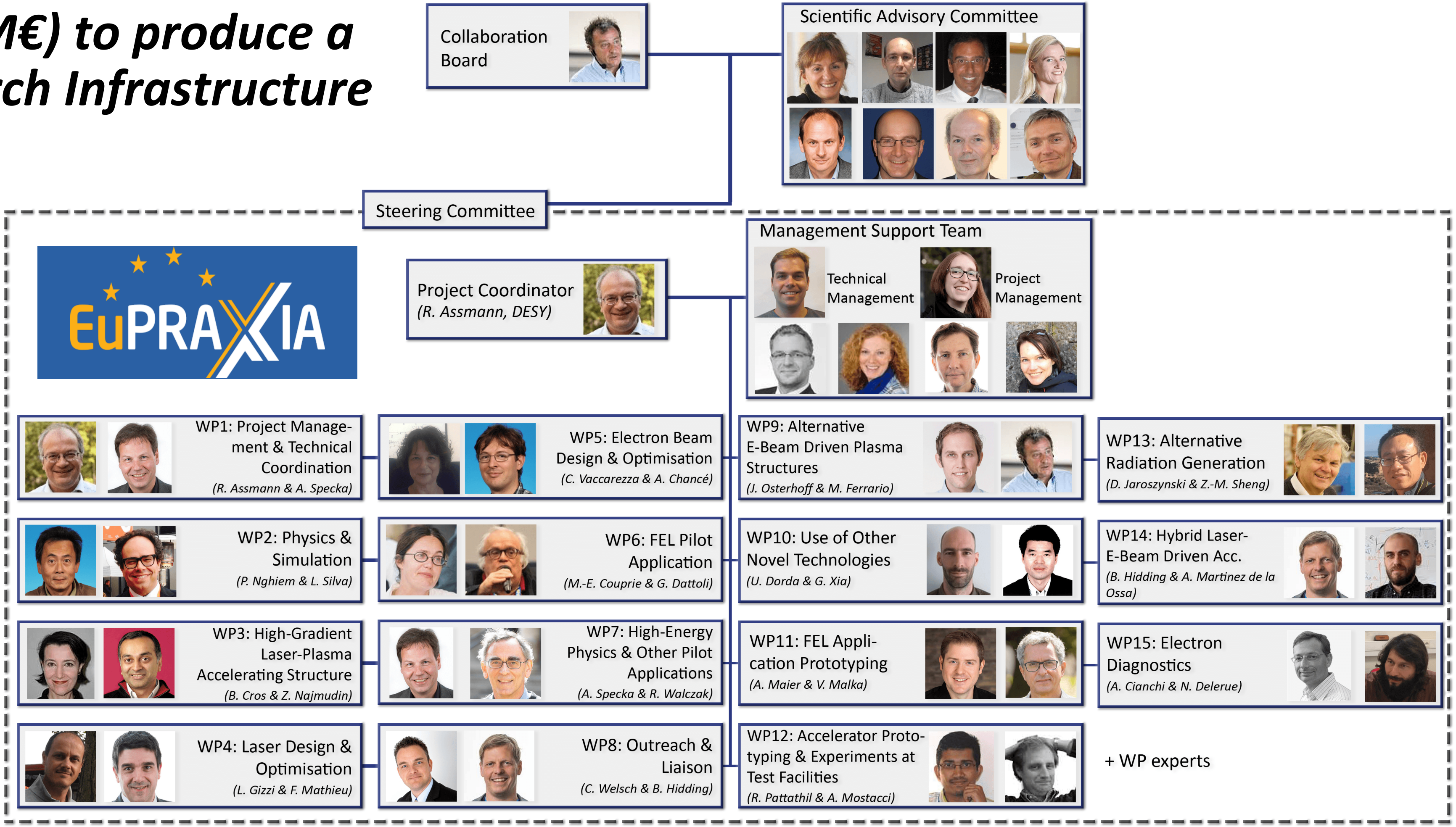
EuPRAXIA facility rendering picture

The EuPRAXIA Project

Horizon 2020

EU funded Consortium (3 M€) to produce a CDR for a European Research Infrastructure

- EU design study just completed end of October:
  - **15 Work Packages**
  - **30 WP Leaders**
- Rather big consortium. Coordinating lab: DESY
- One of four DS's in physical science approved in H2020 by EU. Others:
  - EuroCirCol (FCC)
  - CompactLight (X band)
  - Neutrino (ESS)



Collaboration Board

Scientific Advisory Committee

Steering Committee

Project Coordinator
(R. Assmann, DESY)

Management Support Team
Technical Management
Project Management

WP1: Project Management & Technical Coordination
(R. Assmann & A. Specka)

WP2: Physics & Simulation
(P. Nghiem & L. Silva)

WP3: High-Gradient Laser-Plasma Accelerating Structure
(B. Cros & Z. Najmudin)

WP4: Laser Design & Optimisation
(L. Gizzi & F. Mathieu)

WP5: Electron Beam Design & Optimisation
(C. Vaccarezza & A. Chancé)

WP6: FEL Pilot Application
(M.-E. Couprie & G. Dattoli)

WP7: High-Energy Physics & Other Pilot Applications
(A. Specka & R. Walczak)

WP8: Outreach & Liaison
(C. Welsch & B. Hidding)

WP9: Alternative E-Beam Driven Plasma Structures
(J. Osterhoff & M. Ferrario)

WP10: Use of Other Novel Technologies
(U. Dorda & G. Xia)

WP11: FEL Application Prototyping
(A. Maier & V. Malka)

WP12: Accelerator Prototyping & Experiments at Test Facilities
(R. Pattathil & A. Mostacci)

WP13: Alternative Radiation Generation
(D. Jaroszynski & Z.-M. Sheng)

WP14: Hybrid Laser-E-Beam Driven Acc.
(B. Hidding & A. Martinez de la Ossa)

WP15: Electron Diagnostics
(A. Cianchi & N. Delerue)

+ WP experts

#EuPRAXIA #plasma #accelerator

The Consortium

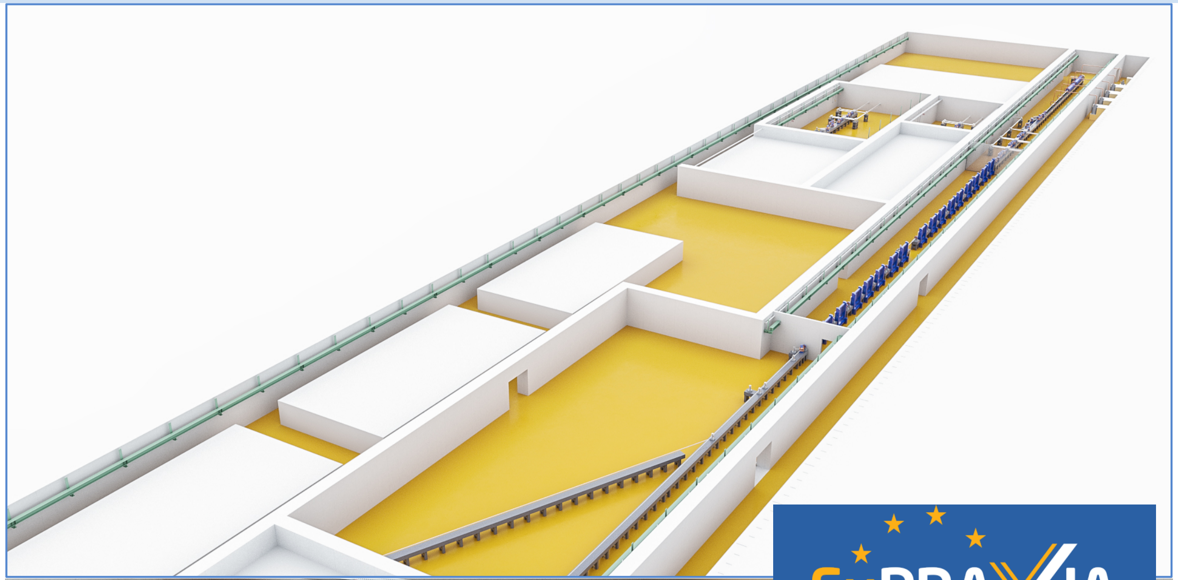
ASSOCIATED PARTNERS
(November 2018)

① Shanghai Jiao Tong University, China
② Tsinghua University Beijing, China
③ ELI – Extreme Light Infrastructure – Beamlines, International
④ PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, Université de Lille 1, France
⑤ Helmholtz-Institut Jena, Germany
⑥ Helmholtz-Zentrum Dresden-Rossendorf, Germany
⑦ Ludwig-Maximilians-Universität München, Germany
⑧ Wigner Fizikai Kutatóközpont, Hungary
⑨ CERN – European Organization for Nuclear Research, International
⑩ Kansai Photon Science Institute/Japan Atomic Energy Agency, Japan
⑪ Osaka University, Japan
⑫ RIKEN SPring-8 Center, Japan
⑬ Lunds Universitet, Sweden
⑭ CASE – Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory, USA
⑮ LBNL – Lawrence Berkeley National Laboratory, USA
⑯ UCLA – University of California Los Angeles, USA
⑰ KIT – Karlsruher Institut für Technologie, Germany
⑱ Forschungszentrum Jülich, Germany
⑲ Hebrew University of Jerusalem, Israel
⑳ Institute of Applied Physics of the Russian Academy of Sciences, Russia
㉑ Joint Institute for High Temperatures of the Russian Academy of Sciences, Russia
㉒ Università degli Studi di Roma "Tor Vergata", Italy
㉓ Queen's University Belfast, UK
㉔ Ferdinand-Braun-Institut, Germany
㉕ University of York, UK

EuPRAXIA Questions

Horizon 2020

- Could we build in the next 10 – 15 years an **accelerator facility based on plasma accelerators, lasers or beam drivers**?
- How would such a plasma-based large accelerator facility look like and would it have **advantages**?
- Could such a facility produce **high quality beams with some applications** and is there promise and interest for such a facility?
- **What would be needed** to build such a facility within the next 10 – 15 years, if it seems interesting?



EuPRAXIA Conceptual Design: Complete

Horizon 2020

- **First ever international design of a plasma accelerator facility**
- **CDR completed on time and submitted to EU on Oct 30th, 2019**
- CDR includes several **new ideas and concepts, published at high level** (e.g. Physical Review Letters)
- **Industry support in Advisory Board**: Thales (France), Amplitude (France), Trumpf Scientific (Germany)

CONCEPTUAL
DESIGN
REPORT

EuPRAXIA
European Plasma Research
Accelerator with eXcellence
In Applications

PARTNERS

FRANCE
cea
cnrs
SOLEIL SYNCHROTRON

GERMANY
DESY
Universität Hamburg

PORTUGAL
IST-ID

ITALY
INFN
ENEA
Consiglio Nazionale delle Ricerche
SAPIENZA Università di Roma

UK
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University of Strathclyde Glasgow
University of Oxford
Science and Technology Facilities Council
University of Liverpool
Manchester 1824 The University of Manchester

ASSOCIATED PARTNERS

CHINA
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Tsinghua University Beijing

FRANCE
PhLAM Université de Lille

GERMANY
HZDR
Helmholtz-Institut Jena
LMU München
Karlsruher Institut für Technologie
Forschungszentrum Jülich
Ferdinand-Braun-Institut

HUNGARY
Wigner Fizikai Kutatóközpont

INTERNATIONAL
CERN
ELI Beamlines

ISRAEL
Hebrew University of Jerusalem

ITALY
Università di Roma "Tor Vergata"

JAPAN
Kansai Photon Science Institute
Osaka University
RIKEN SPring-8

RUSSIA
Institute of Applied Physics
Joint Institute for High Temperatures

SWEDEN
Lunds Universitet

UK
Queen's University Belfast
University of York

USA
CASE at Stony Brook University and BNL
LBNL
UCLA

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653 page CDR, 240 scientists contributed

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

EuPRAXIA Open Innovation Facility on 1 Slide

Horizon 2020

- Step beyond present national projects in EU (*typically up to 1 GeV e-*).
- New European RI, delivering high quality **beams of electrons** (up to 5 GeV), **positrons** and **photons to pilot users**
  - i. High quality 5 GeV plasma accelerator stage (towards high energy)
  - ii. Point-like emission X ray sources for life science & materials
  - iii. Deeply penetrating positron annihilation spectroscopy
  - iv. Compactified Free Electron Laser facility
  - v. Table-top e-/e+/γ test beams for science, industry
- Includes further development of **compact base technologies**:
  - i. Compact X band linear accelerator for electrons that drive plasma wakefields (with CERN)
  - ii. Laser technology with Peta-Watt peak power and 100 Hz repetition rate (with European laser institutes and industry)
- Demonstration of total **facility shrinkage** by factor 7 (accelerator) to factor 3 (facility with conventional undulators).

Fully plasma-based beamline for generating betatron radiation as a ***compact X-ray source for medical imaging and material analysis****. The user area is behind the wall on the right.*

Fully plasma-based beamline for generating ***electron and positron beams****. The accelerator stages can be seen in the front. In the back the beamline splits and leads to two user areas behind the back wall.*

EuPRAXIA

Brings together European Actors* in this Field…

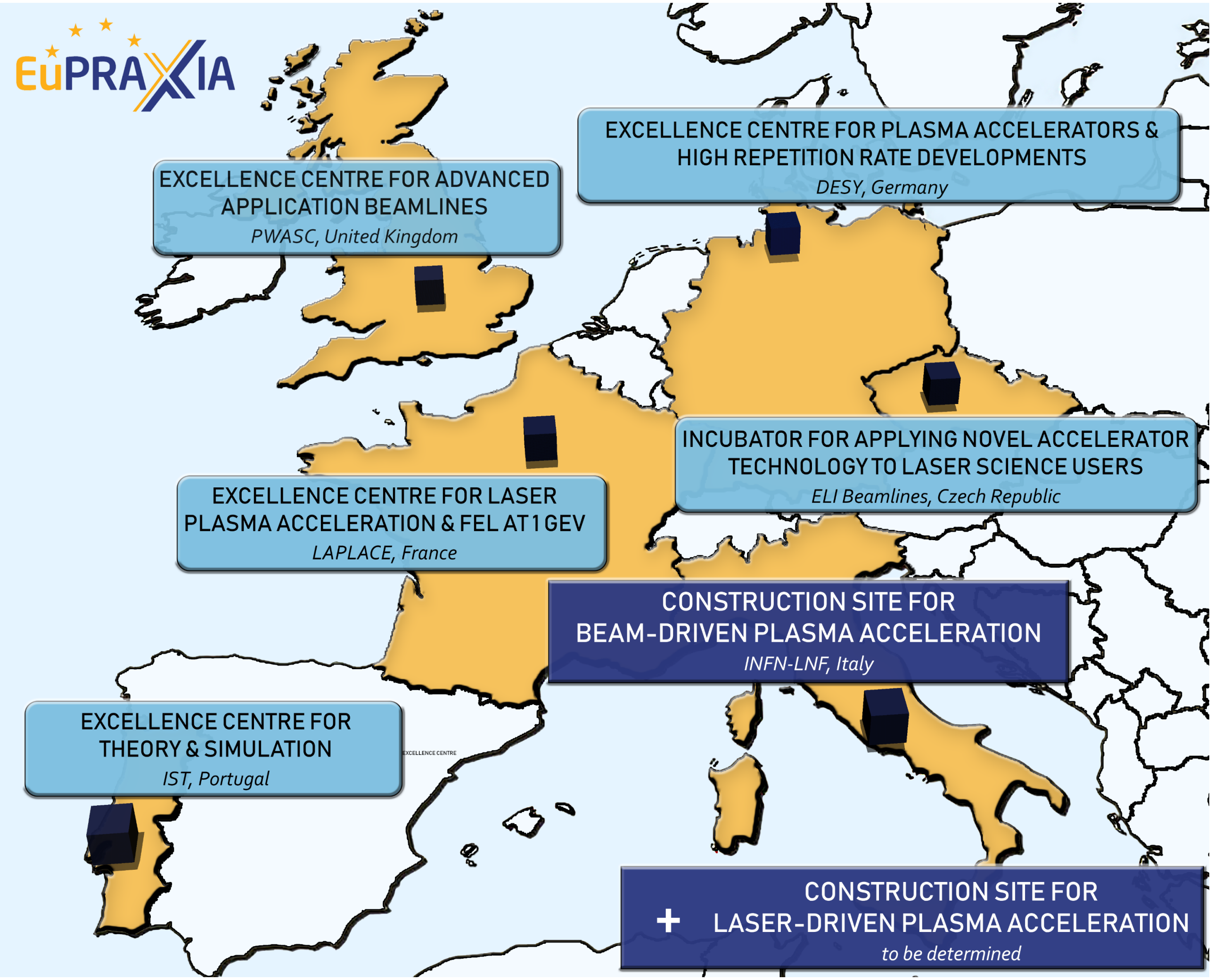
Horizon 2020

- **Embeds national projects into a European context**
- Avoid internal competition, **position Europe globally as lead player** in the compact accelerator “market”, in innovative technology

*and our international partners and friends

… and Builds a European Distributed Facility

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 all labs required - opportunities**
3. **Five excellence centers** at existing facilities: Using pre-investment, support tests, prototyping, production with EuPRAXIA generated funding (F, UK, D, P, ELI)
4. **One or two construction sites** at existing facilities with EuPRAXIA generated funding:
   - **Beam-driven** at Frascati/INFN (Italy).
   - **Laser-driven** at CLF/STFC (UK), CNR/ Frascati/INFN (Italy) or ELI-Beamlines.



EXCELLENCE CENTRE FOR ADVANCED APPLICATION BEAMLINES
PWASC, United Kingdom

EXCELLENCE CENTRE FOR PLASMA ACCELERATORS & HIGH REPETITION RATE DEVELOPMENTS
DESY, Germany

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

→ **Position Europe as a Leader in the Global Context**

EuPRAXIA Cost Estimate and Funding

Horizon 2020

Scenario	Invest
Beam-driven plasma accelerator facility	
Full EuPRAXIA proposal	119 M€
Plasma accelerator facility with FEL	68 M€
Laser-driven plasma accelerator facility	
Full EuPRAXIA proposal	204 M€
Plasma accelerator facility with FEL	110 M€
Minimal laser plasma accelerator with FEL	75 M€

Full cost: **323 M€**

(~80 M€ to laser industry)

Duration: **8 – 10 years**

Options: **from 68 M€**

See CDR for details – all preliminary – to be detailed in preparatory phase

Operating costs of facilities: Covered by host labs at existing sites & facilities.

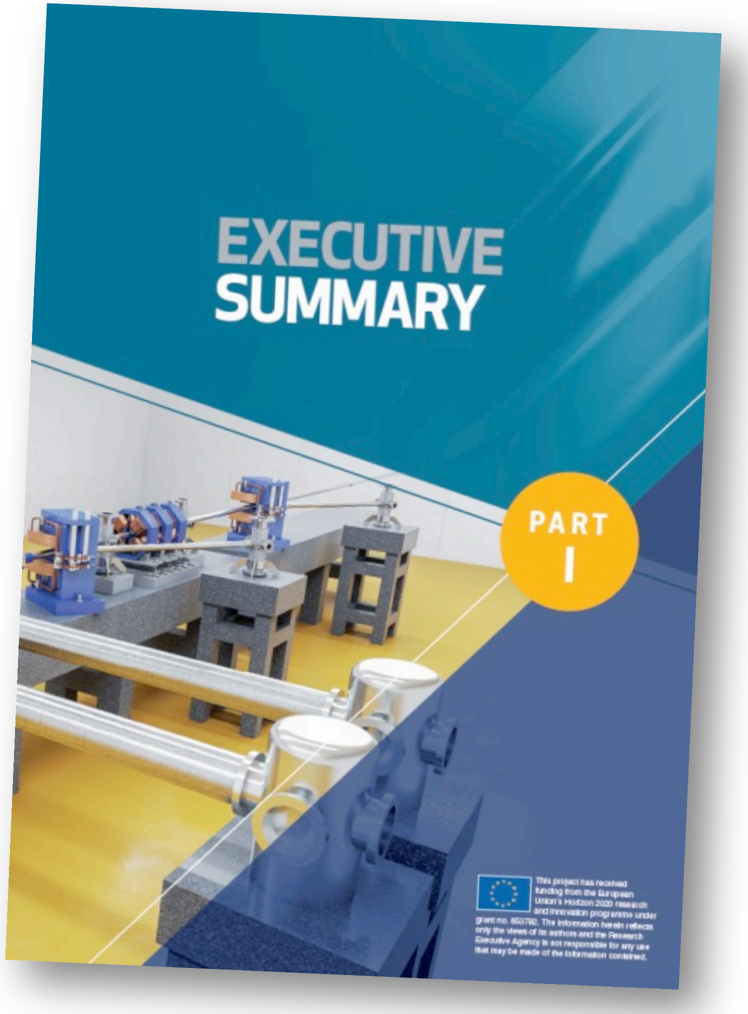
Only **full project will be fully European**, will bundle effectively capabilities

How can EuPRAXIA generate funding?

- It already helped to generate **funding (~130 M€) for national projects** in UK, Germany, Italy.
- EU funding to be discussed with new commission:
  1. Get **EU preparatory phase funding** once on **ESFRI roadmap.**
  2. Will get access to **EU structural funds (>100 M€)** and other funds once on **ESFRI roadmap.**
  3. **Will ask EU for 15 M€** funding to start technical design (old JRA type activity).

Next Step: Application of EuPRAXIA to ESFRI

- EuPRAXIA strongly supported in European research landscape, it is **timely**, it offers **highly attractive opportunities** for innovation with industry, novel applications and pilot users.
- **EuPRAXIA needs to get on the ESFRI roadmap** now to move forward: opportunities for significant funding and synergy.
- Deadline ESFRI: **May 2020**
- **Lead Institute**: LNF/INFN (Italy)
- **Political support letters** (at least two needed from other country than lead country):
  - Discussions ongoing with **UK** (STFC), **Germany** (Helmholtz), **France** (LAL, CNRS, LOA, CEA, Soleil), **Portugal** (IST), **Hungary, ELI-Beamlines (Czech)**
  - Industry supporting through advisory committee and in design work: letters of support will be asked



EXECUTIVE SUMMARY

PART I

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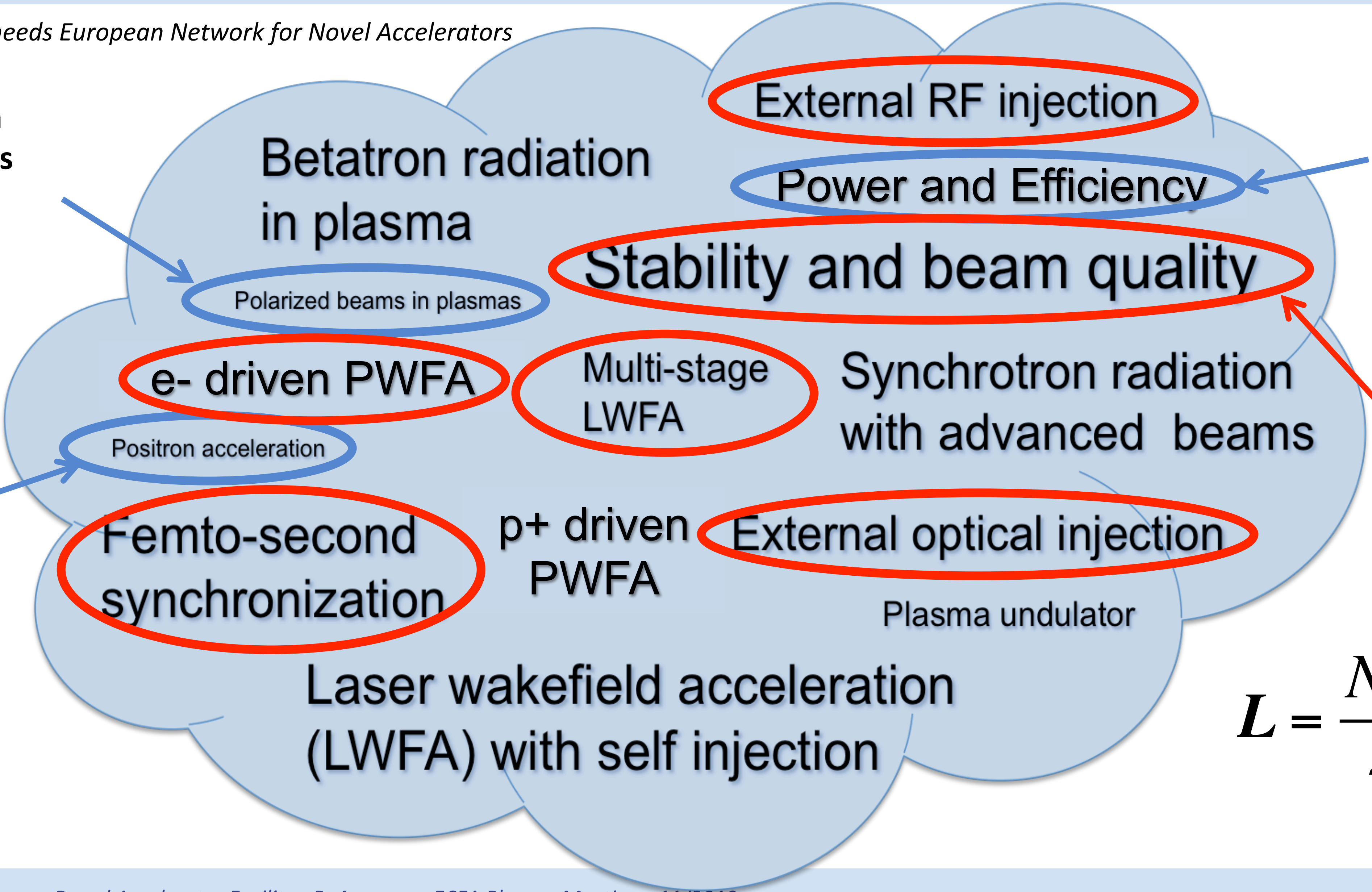
http://www.eupraxia-project.eu/

R&D Paths Plasma Accelerators: Luminosity

Horizon 2020

Evaluation R&D needs European Network for Novel Accelerators



Betatron radiation in plasma

External RF injection

Power and Efficiency

Stability and beam quality

Polarized beams in plasmas

e- driven PWFA

Multi-stage LWFA

Synchrotron radiation with advanced beams

Positron acceleration

Femto-second synchronization

p+ driven PWFA

External optical injection

Plasma undulator

Laser wakefield acceleration (LWFA) with self injection

Can plasma accelerators deliver polarized beams?

Can plasma accelerators accelerate positrons?

Can plasma accelerators deliver integrated luminosity?

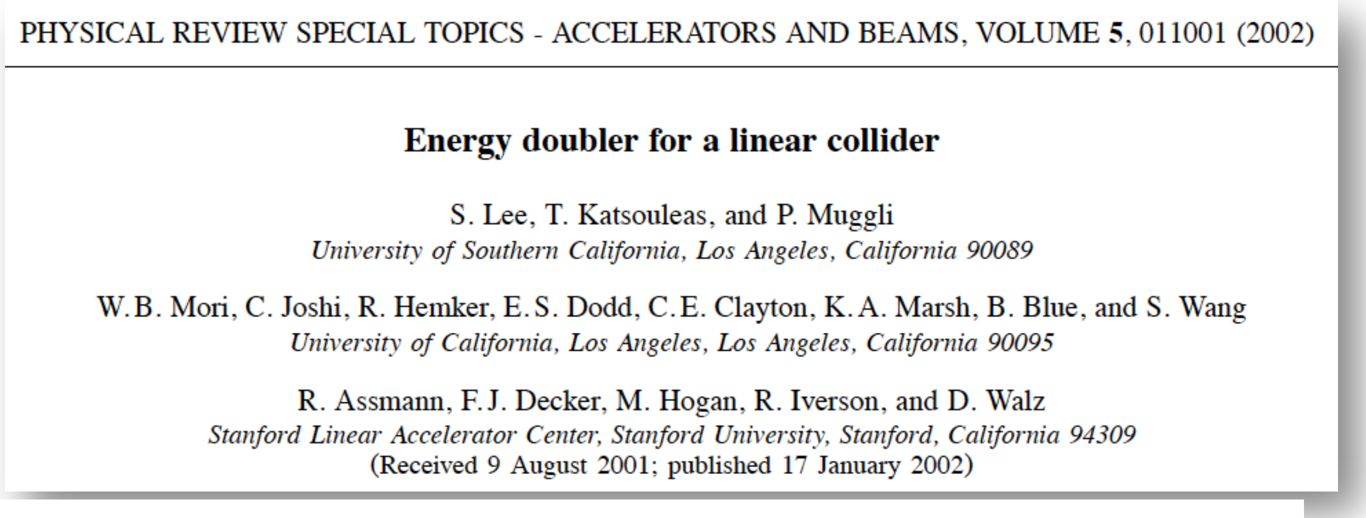
Can plasma accelerators deliver peak luminosity?

EuPRAXIA

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

EuPRAXIA: Intermediate Step to a LC Booster

Plasma booster idea for a LC published
in 2002 for SLAC Linear Collider parameters



PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **5**, 011001 (2002)

Energy doubler for a linear collider

S. Lee, T. Katsouleas, and P. Muggli
University of Southern California, Los Angeles, California 90089

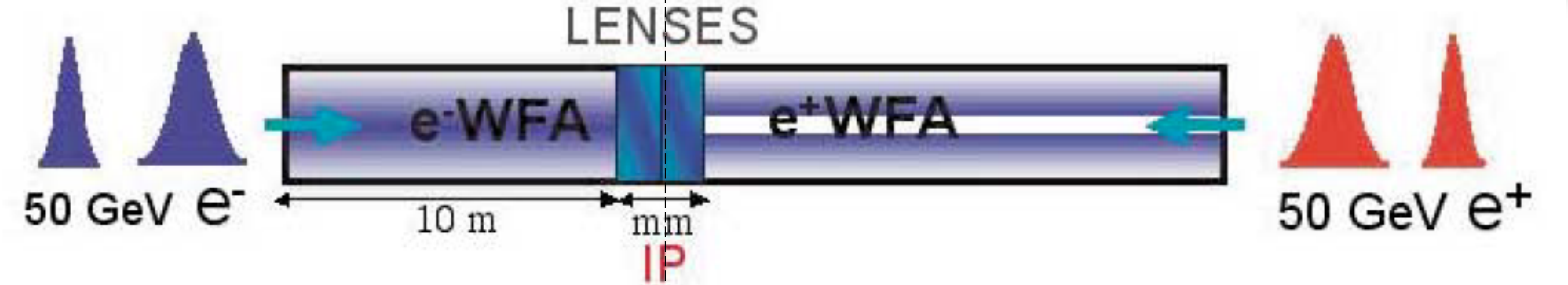
W.B. Mori, C. Joshi, R. Hemker, E.S. Dodd, C.E. Clayton, K.A. Marsh, B. Blue, and S. Wang
University of California, Los Angeles, Los Angeles, California 90095

R. Assmann, F.J. Decker, M. Hogan, R. Iverson, and D. Walz
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

(Received 9 August 2001; published 17 January 2002)

Linear Collider bunch (single bunch ILC/CLIC)
e- bunch to be injected into plasma

Driver pulse
Laser, e- or p+ bunch



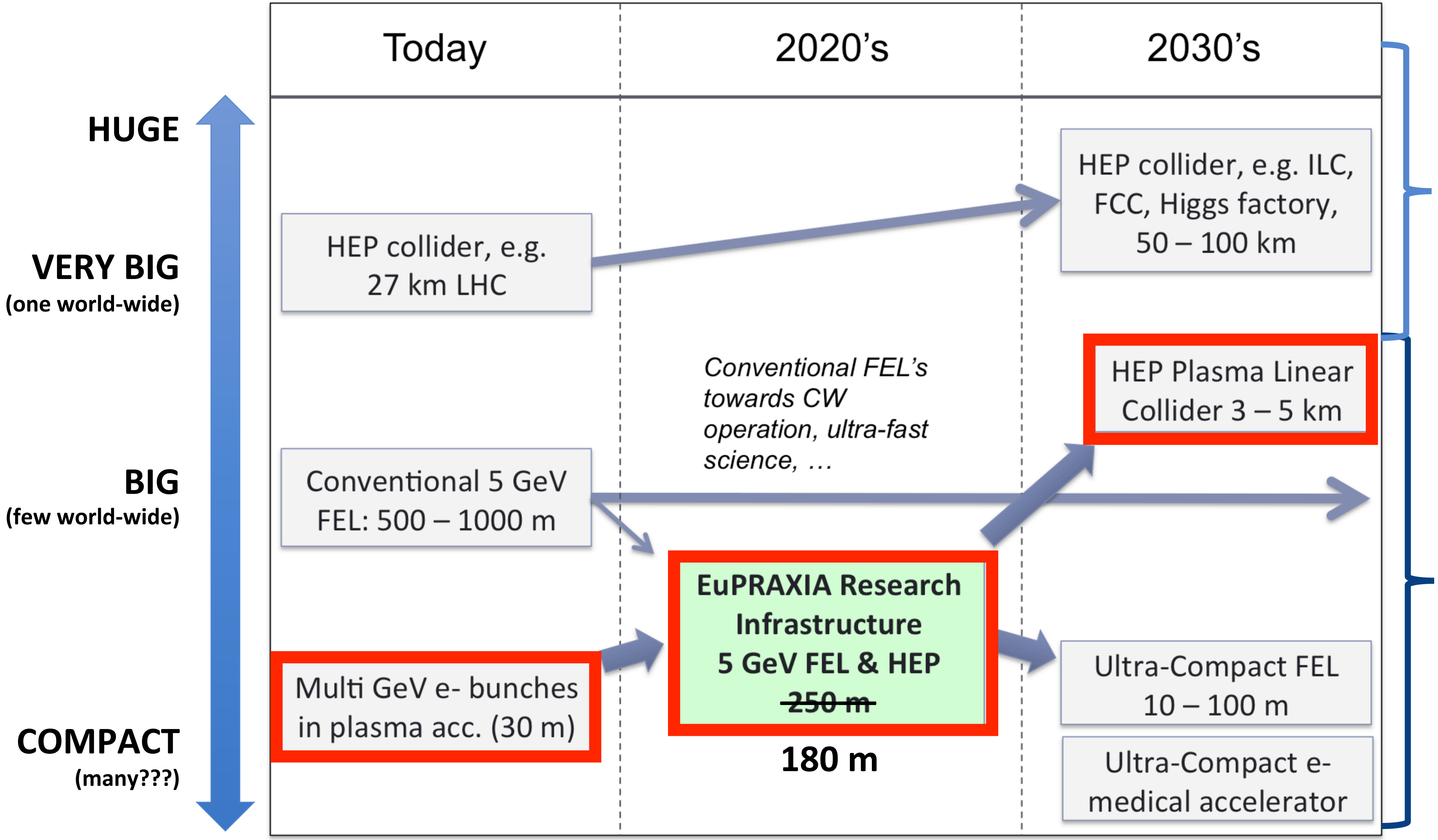
Plasma wakefield accelerator

Plasma lenses

We have much of this in hand

→ EuPRAXIA booster system test 0.2 GeV → 5 GeV

EuPRAXIA: Intermediate Step to Plasma LC



Today

2020's

2030's

HUGE

VERY BIG
(one world-wide)

BIG
(few world-wide)

COMPACT
(many???)

HEP collider, e.g.
27 km LHC

Conventional 5 GeV
FEL: 500 – 1000 m

Multi GeV e- bunches
in plasma acc. (30 m)

Conventional FEL's towards CW operation, ultra-fast science, …

EuPRAXIA Research Infrastructure
5 GeV FEL & HEP
~~250 m~~

180 m

HEP collider, e.g. ILC,
FCC, Higgs factory,
50 – 100 km

HEP Plasma Linear
Collider 3 – 5 km

Ultra-Compact FEL
10 – 100 m

Ultra-Compact e-
medical accelerator

~ 10's billion Euro, high power consumption, technology pushed to limits, 20-30 years to make, fewer/one facilities

Lower cost, new technology, 10 years to make one, many facilities

?

Selection of Some Details

→ See CDR for complete picture

Versatile – Facility with Parallel Paths

- Some realizations:
  - European research infrastructure landscape is quite diverse with different boundary conditions at various places → **one technology does not suit all needs**
  - The major cost drivers are infrastructure, RF, lasers, instrumentation, ... → very **little cost overhead to include several solutions** at one facility
  - Our solutions are innovative but paper solutions → **unavoidable risk can be mitigated by parallel approach**.
- **Multiple site, multiple solution approach**.

Beam-Driven Plasma Accelerator Site

Laser-Driven Plasma Accelerator Site

Laser-Plasma Injector

RF Injector

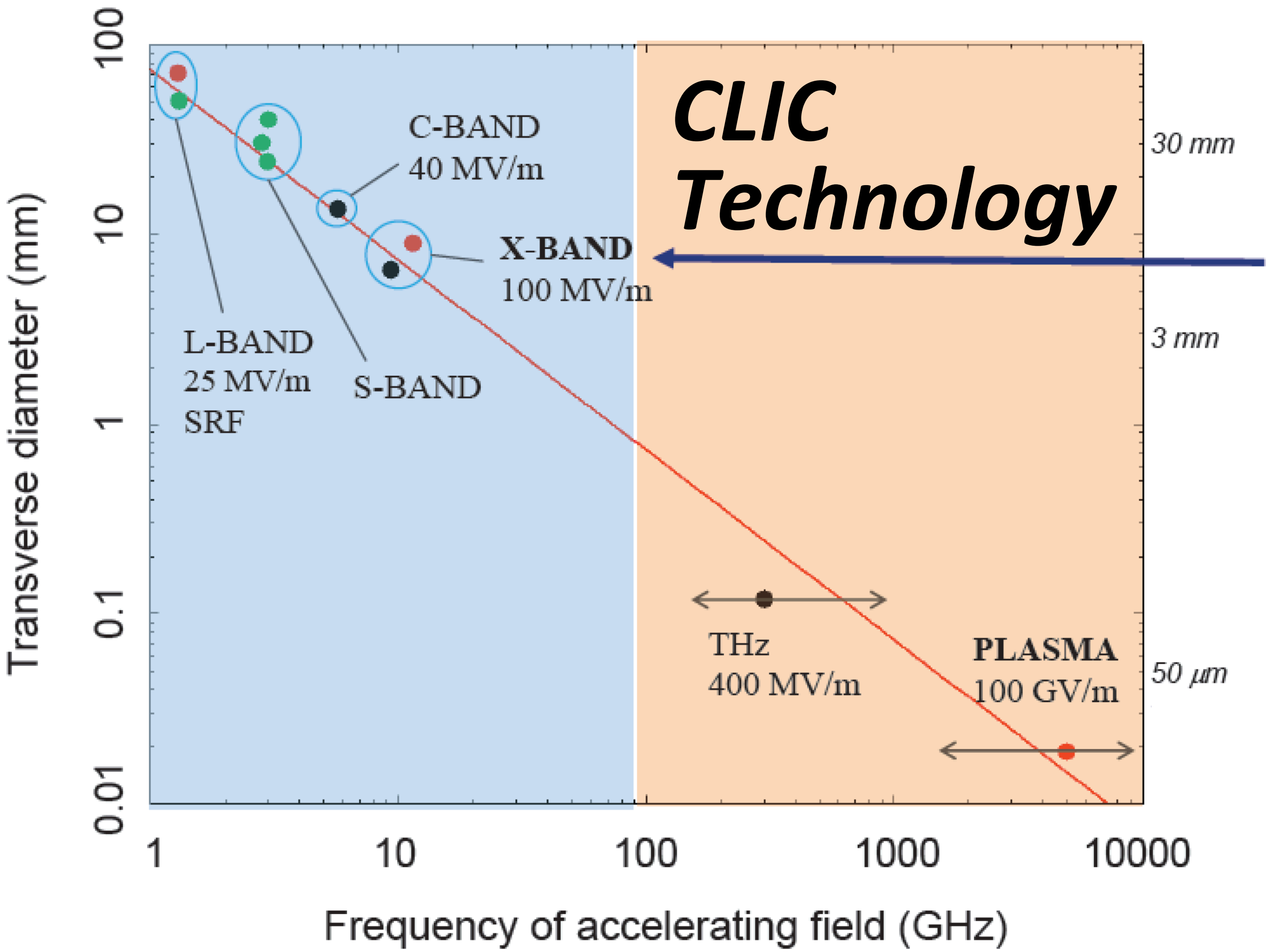
Multiple Acceleration Schemes

Excellence Sites

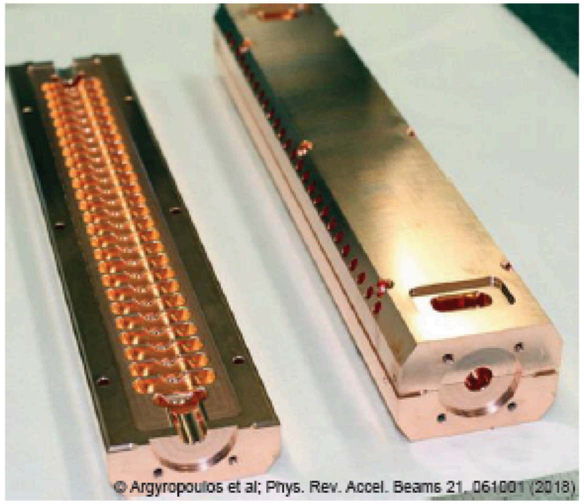
Complementary Applications

EuPRAXIA Design: Most Compact 1 GeV RF Linac

Horizon 2020



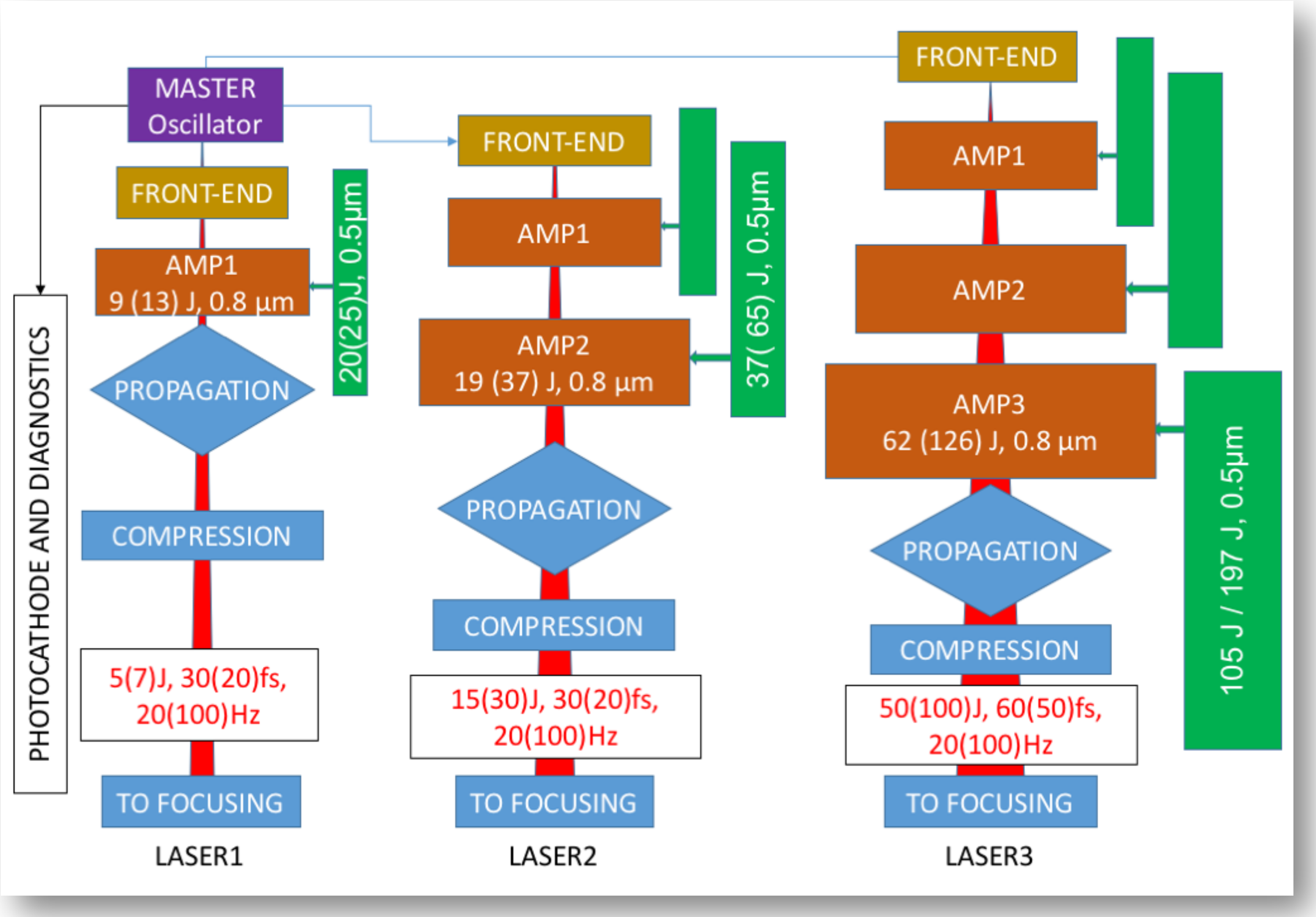
CLIC Technology


© Argyropoulos et al; Phys. Rev. Accel. Beams 21, 061001 (2018)

X Band RF Beam Driver

(Minimal Footprint at PWFA Site)

EuPRAXIA Design: 20 – 100 Hz PW Class Lasers

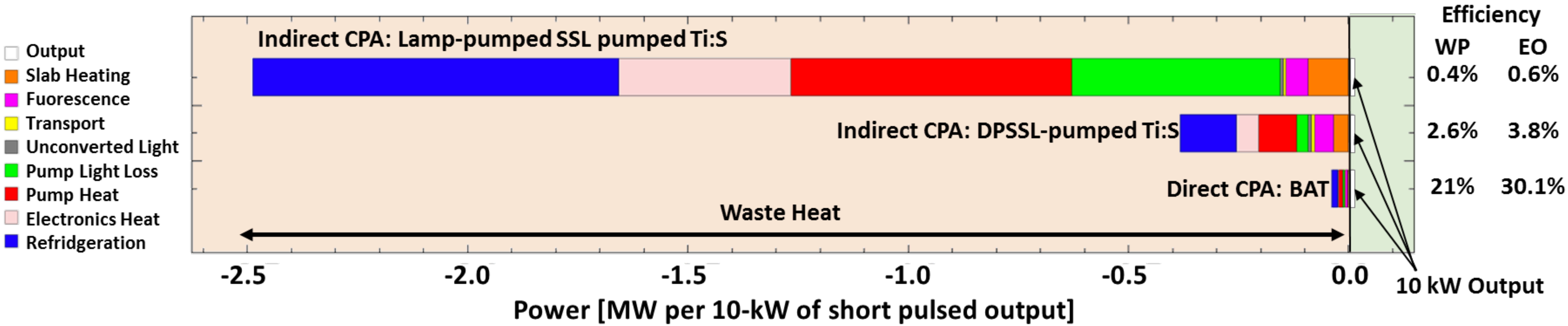


- **Three laser systems** for the laser-driven plasma accelerator facility
- Baseline: Start from lasers at present **state-of-the-art**, however, extended to 20 Hz and then to 100 Hz
- In parallel: **Development** of high efficiency, high average power lasers

Leo Gizzi, Francois Mathieu et al

Development Paths: Example Lasers

Laser efficiency at present is a problem → towards high efficiency solutions, enabling high average power



Courtesy C. Siders, EAAC 2017

kHz laser developments ongoing in various places

W. Leemans (DESY), S. Hooker (Oxford - STFC), J. Faure (France), ...

Design Parameters (not complete)

Up to 5 GeV electron beam energy

≤ 1 mm-mrad transverse emittance

30 pC charge in electron beam

10 femto-s electron bunch duration


EuPRAXIA facility render

≤ 180 m facility length

Basically proven in the field

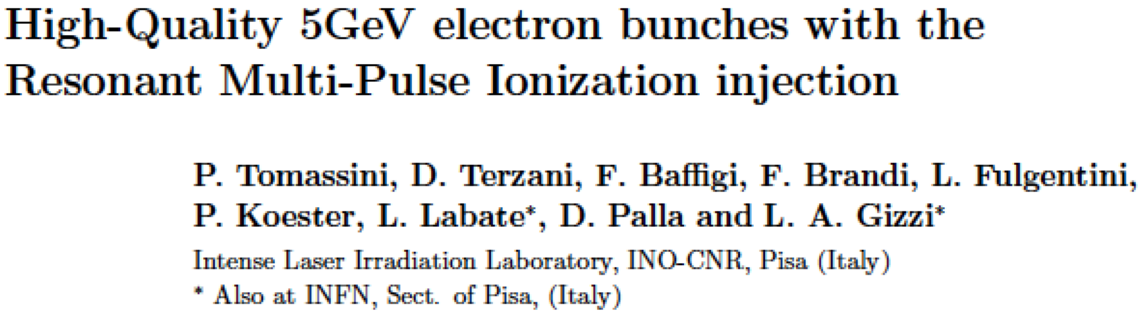
≤ 1 % total energy spread

Major critical issue


EuPRAXIA facility render


EuPRAXIA facility render

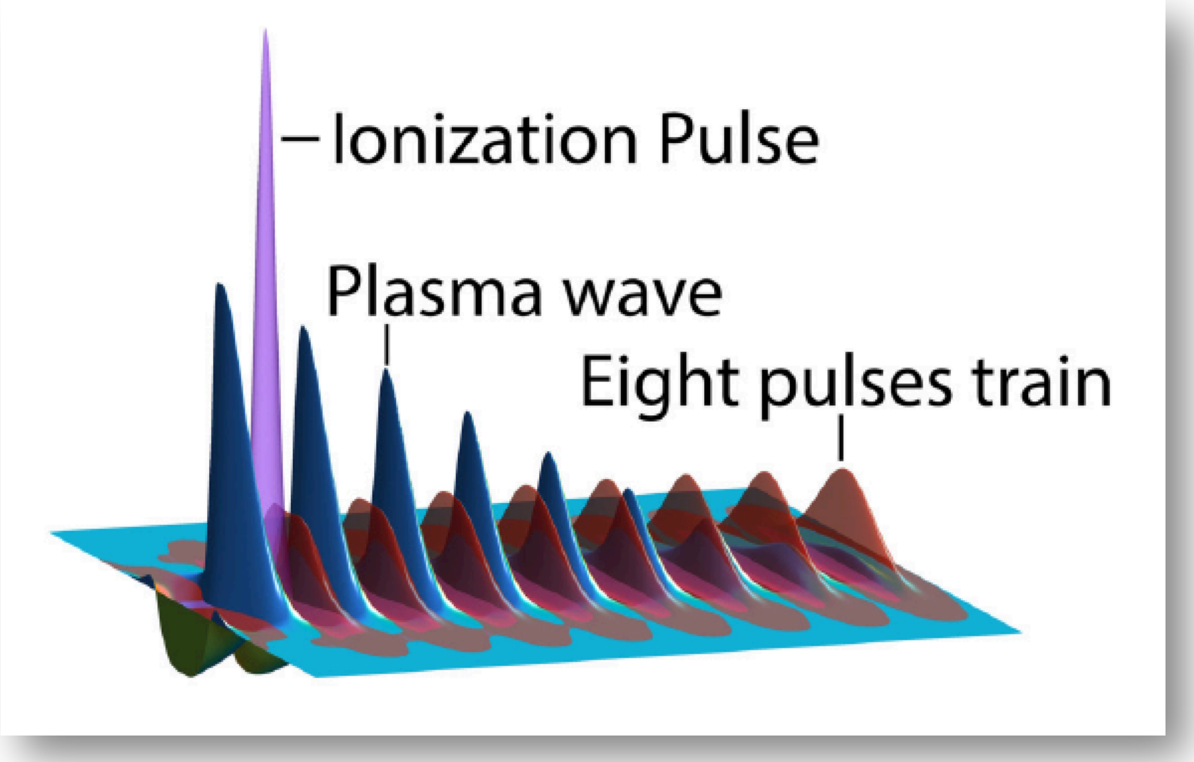
Resonant Multi-Pulse Ionization Injection



High-Quality 5GeV electron bunches with the Resonant Multi-Pulse Ionization injection

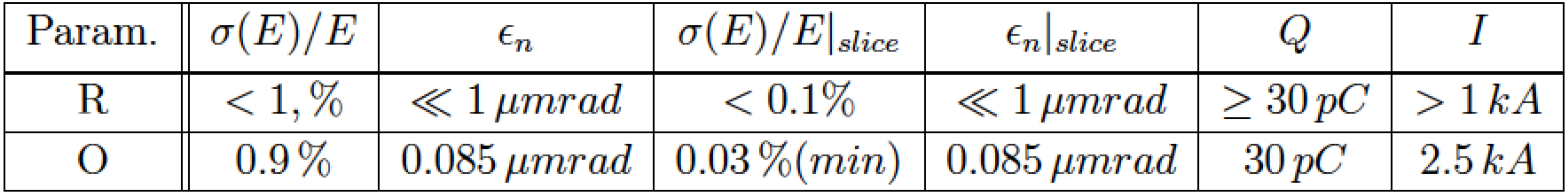
P. Tomassini, D. Terzani, F. Baffigi, F. Brandi, L. Fulgentini,
P. Koester, L. Labate*, D. Palla and L. A. Gizzi*
Intense Laser Irradiation Laboratory, INO-CNR, Pisa (Italy)
* Also at INFN, Sect. of Pisa, (Italy)

Accepted by Physics of Plasmas



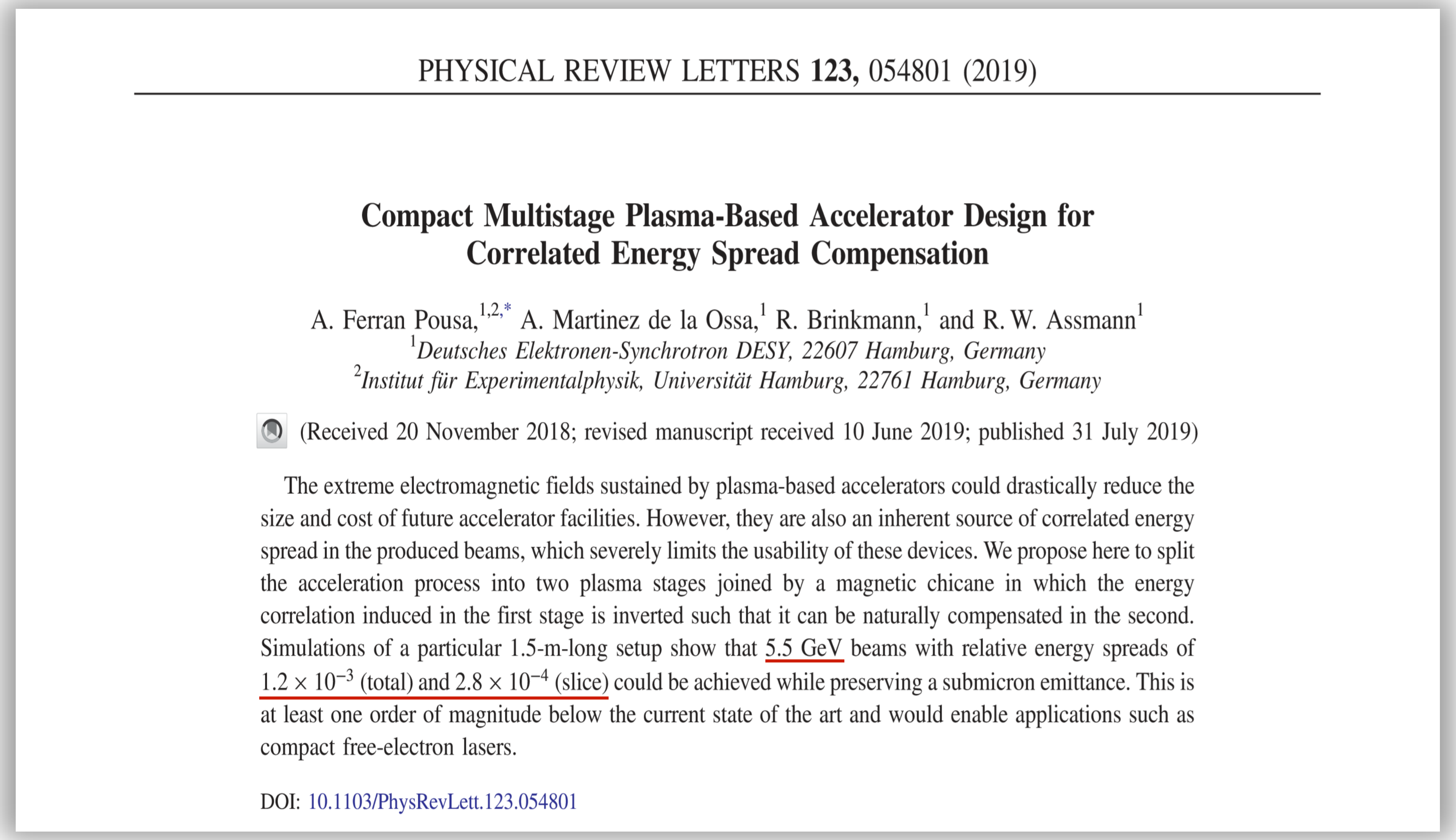
All optical scheme

Paolo Tomassini et al



Param.	$\sigma(E)/E$	ϵ_n	$\sigma(E)/E\|_{slice}$	$\epsilon_n\|_{slice}$	Q	I
R	$< 1,\%$	$\ll 1\,\mu mrad$	$< 0.1\%$	$\ll 1\,\mu mrad$	$\geq 30\,pC$	$> 1\,kA$
O	$0.9\,\%$	$0.085\,\mu mrad$	$0.03\,\%(min)$	$0.085\,\mu mrad$	$30\,pC$	$2.5\,kA$

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

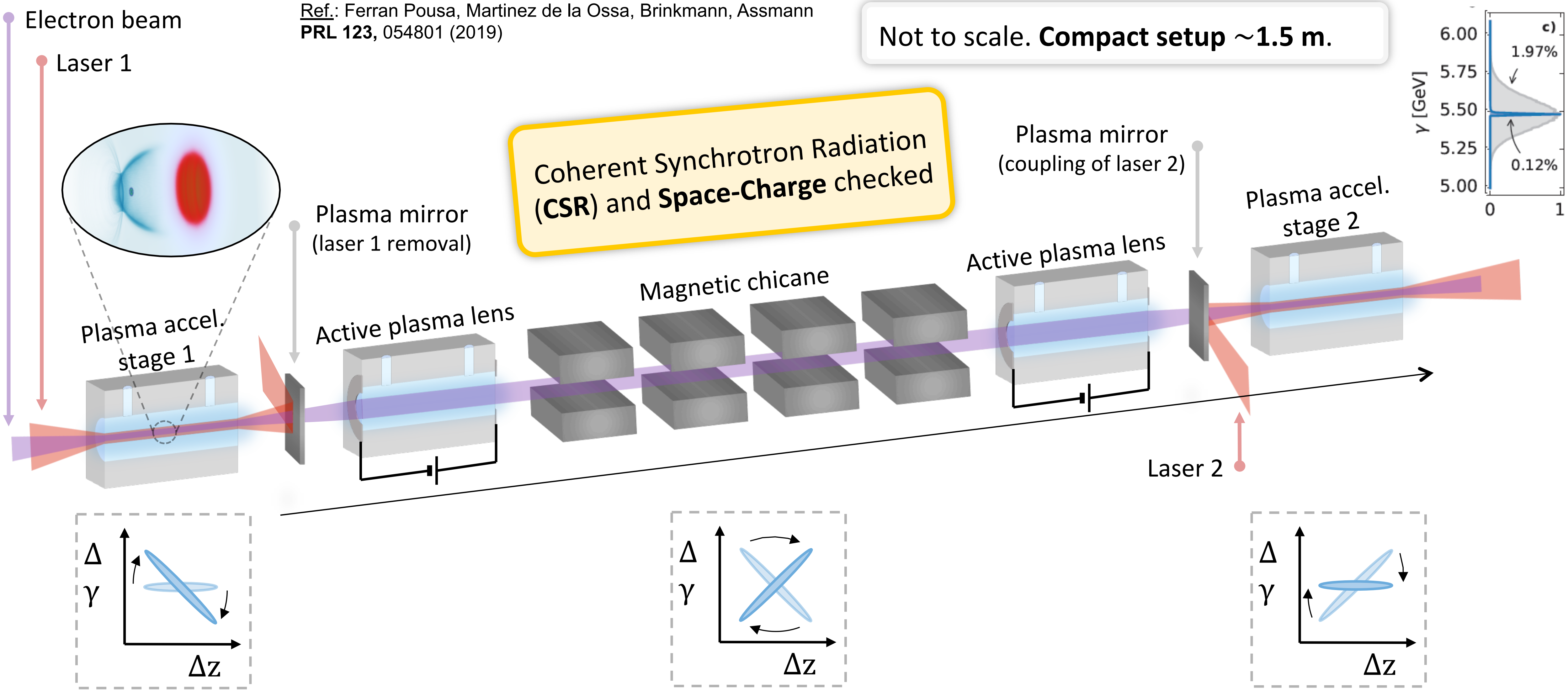
- 1.5 m long
- 5.5 GeV
- **0.03%** slice energy spread
- **0.12 %** total energy spread
- sub-micron emittance

Compact Multi-Stage Plasma-Based Accelerator

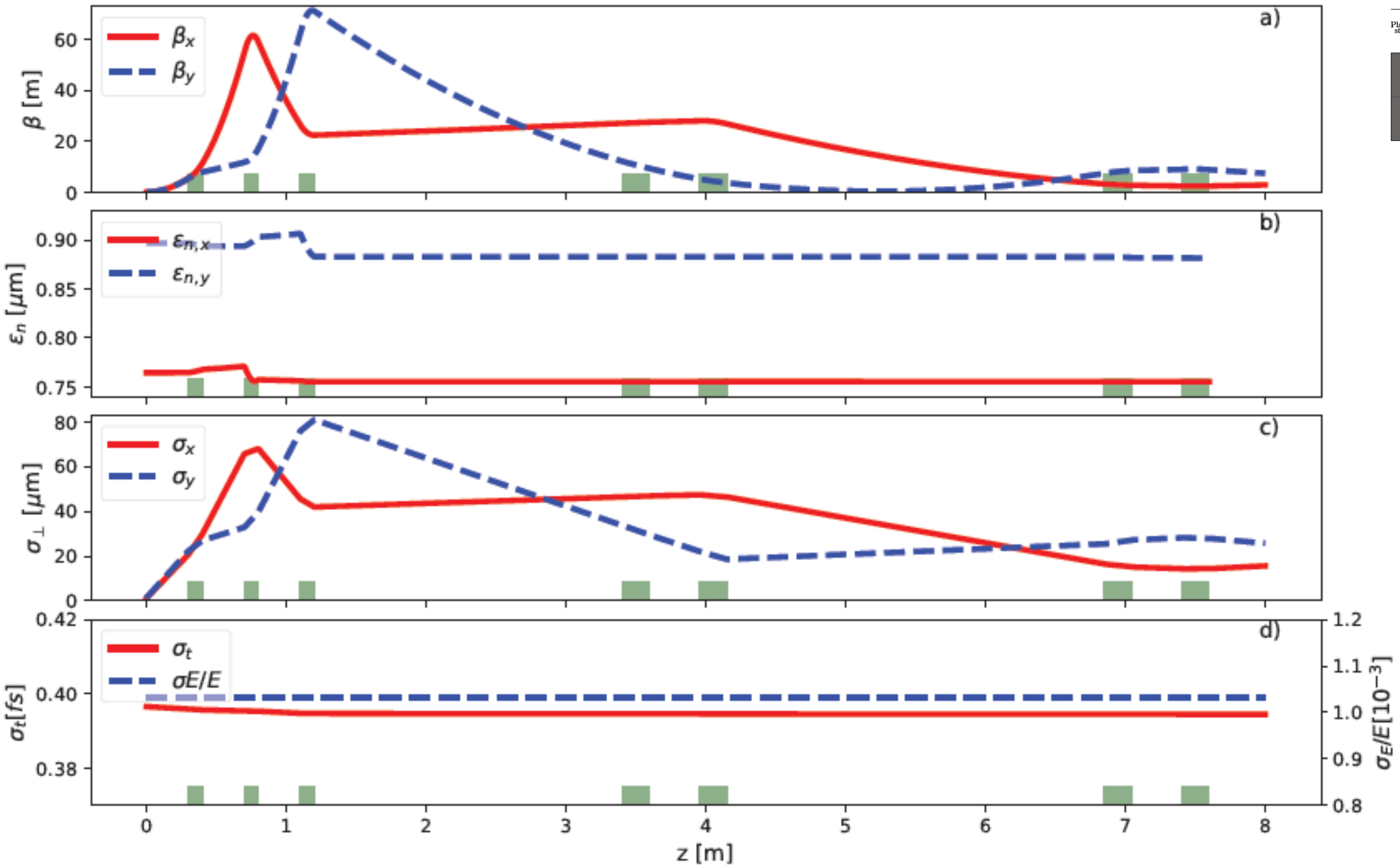
Ref.: Ferran Pousa, Martinez de la Ossa, Brinkmann, Assmann
PRL 123, 054801 (2019)

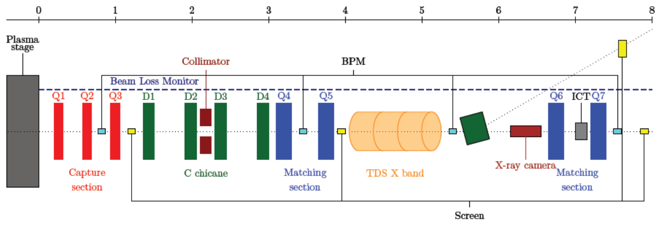
Not to scale. **Compact setup ∼1.5 m.**

Coherent Synchrotron Radiation (**CSR**) and **Space-Charge** checked


Electron beam
Laser 1
Plasma accel. stage 1
Plasma mirror (laser 1 removal)
Active plasma lens
Magnetic chicane
Active plasma lens
Plasma mirror (coupling of laser 2)
Plasma accel. stage 2
Laser 2

Beam Transport Design

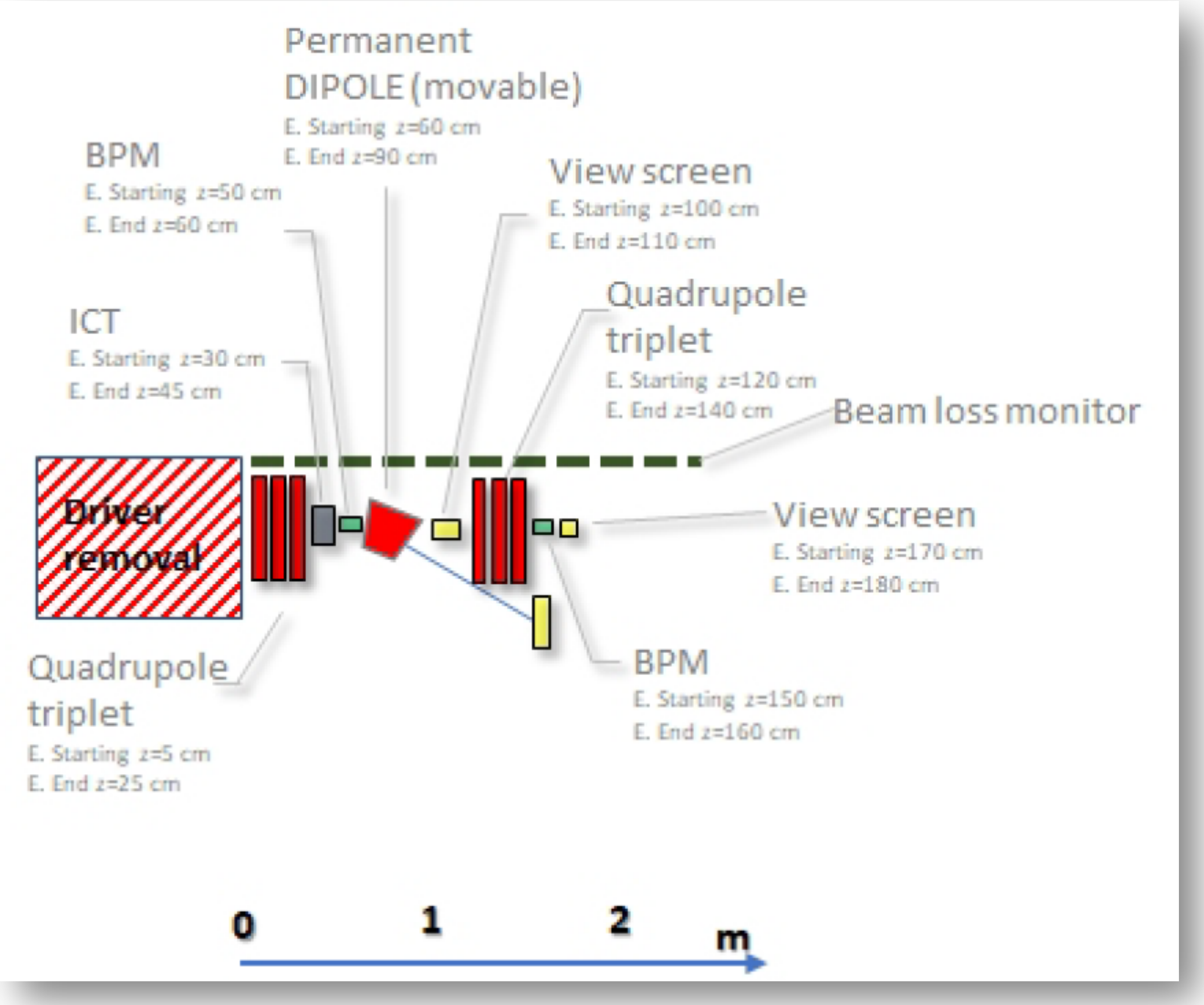




- Here: high energy **beam transport over 8 meters**
- Preserved beam quality is achieved in the design
- Space has important benefits

A. Chance et al

Diagnostics: Electron Beam



Example:

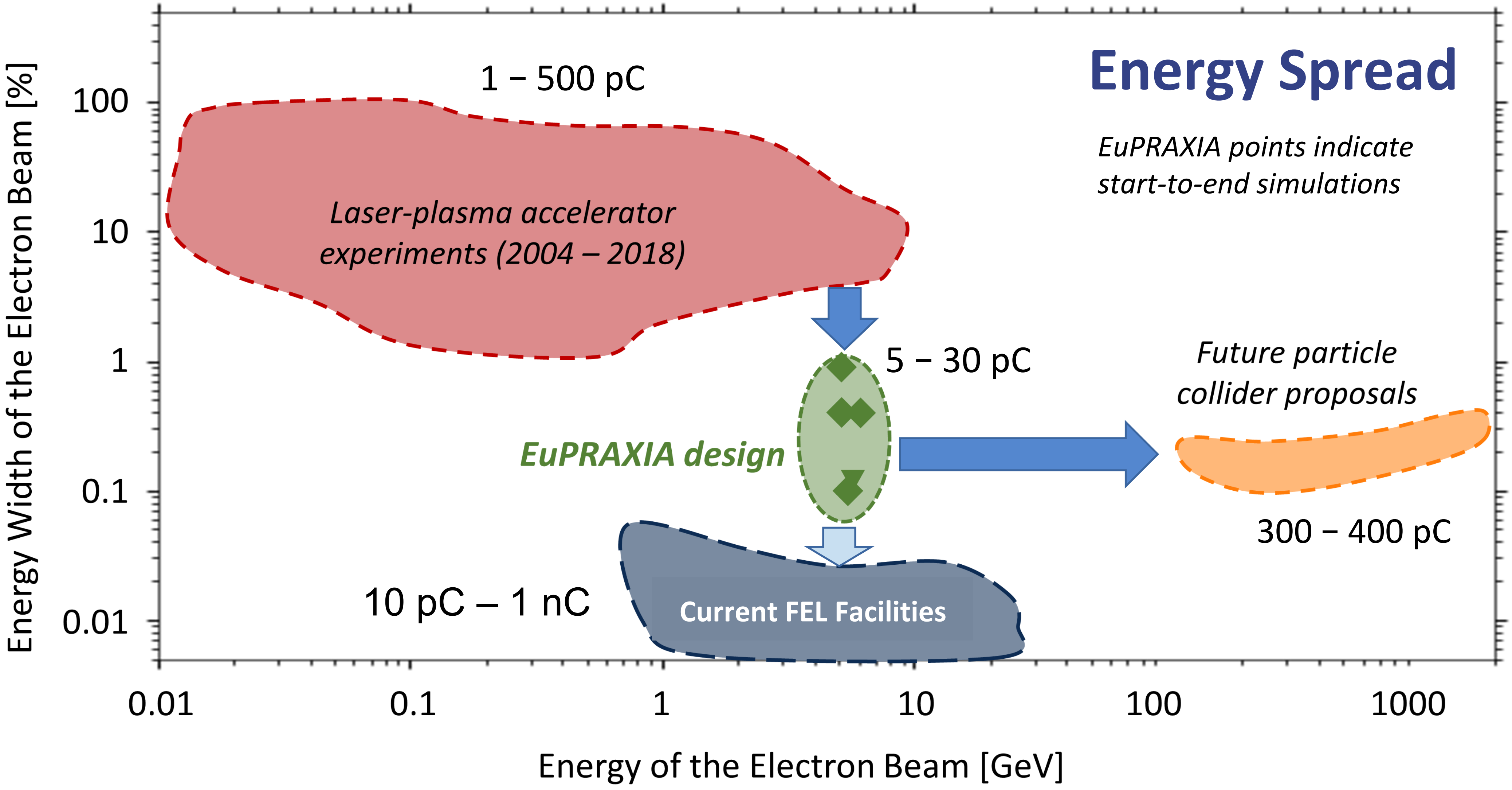
Permanent beam line from **laser-plasma injector to laser plasma accelerator**

Use space in beam transport for beam diagnosis

A. Cianchi, N. Delerue et al

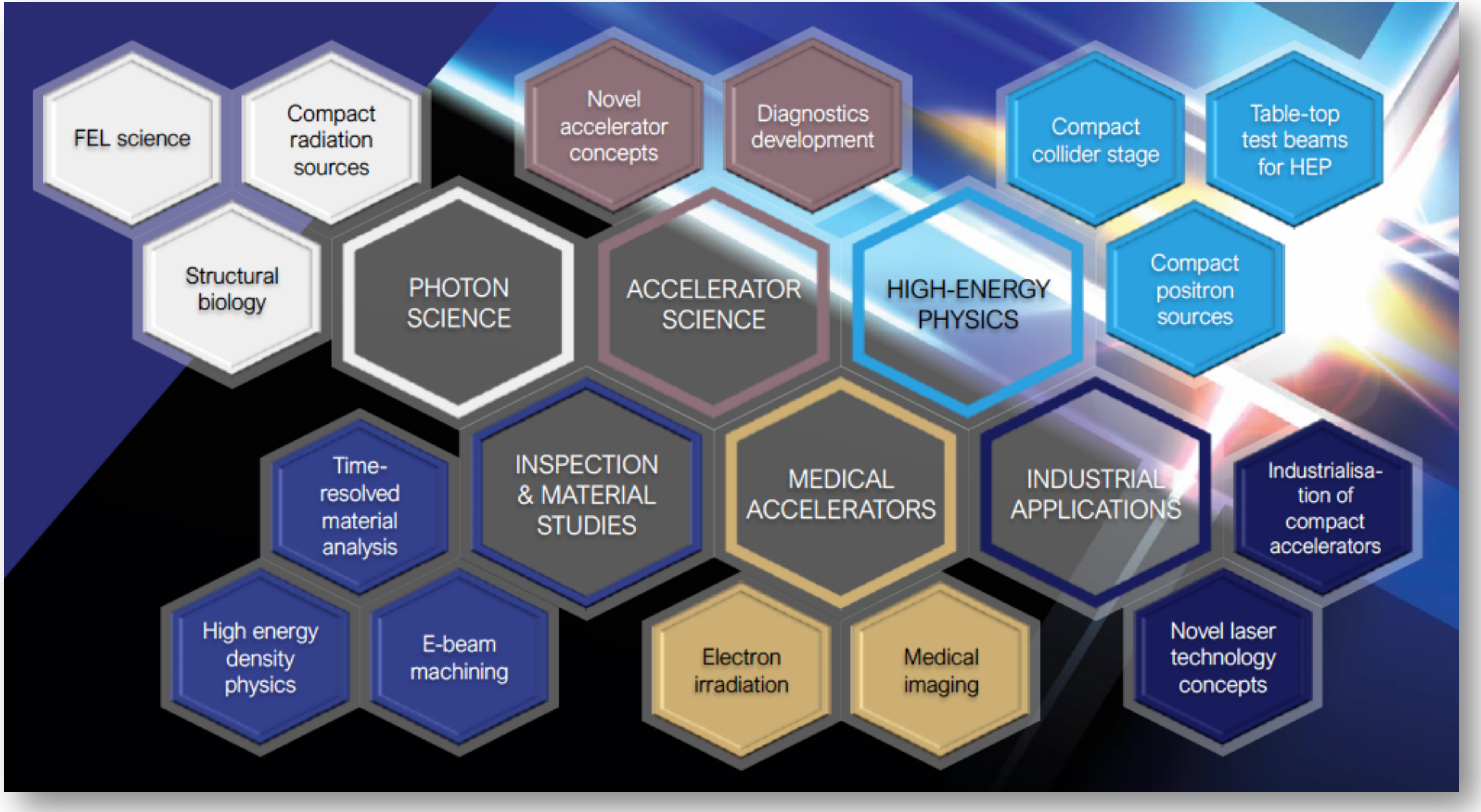
EuPRAXIA: Progressing on the Quality Problem

Horizon 2020



EuPRAXIA points indicate start-to-end simulations

Versatile – Designed for Multiple Applications



High Energy

Accelerator R&D

Photon Science

Material

Medical

Industrial

Design: Medical Imaging X Rays

Horizon 2020

Has Unique Advantages – Already Working Today – Too Slow at the Moment

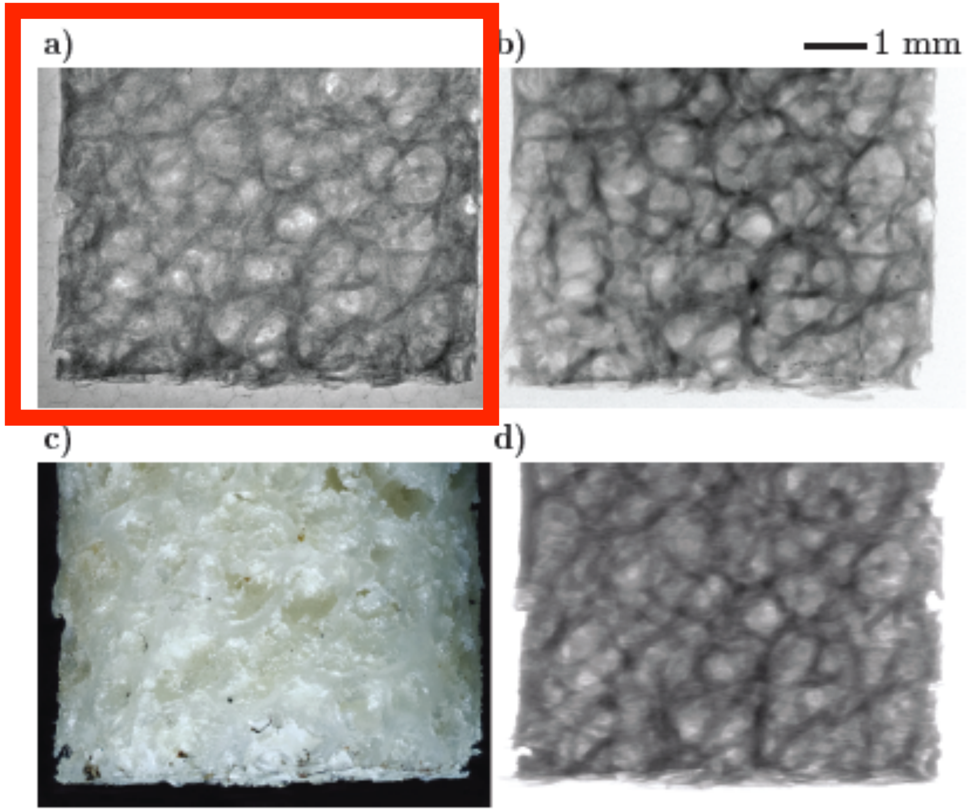
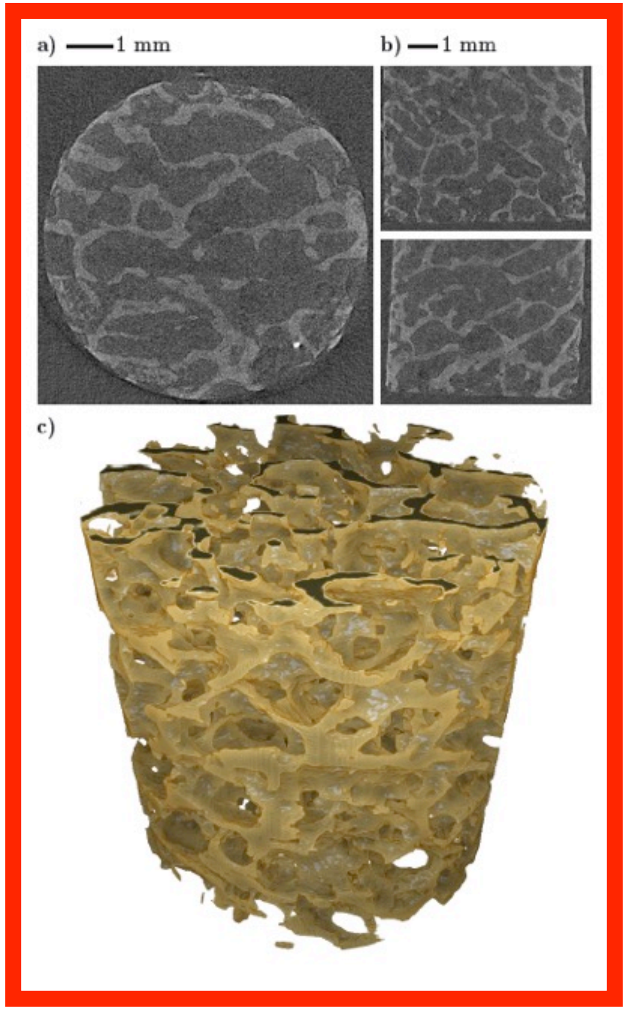
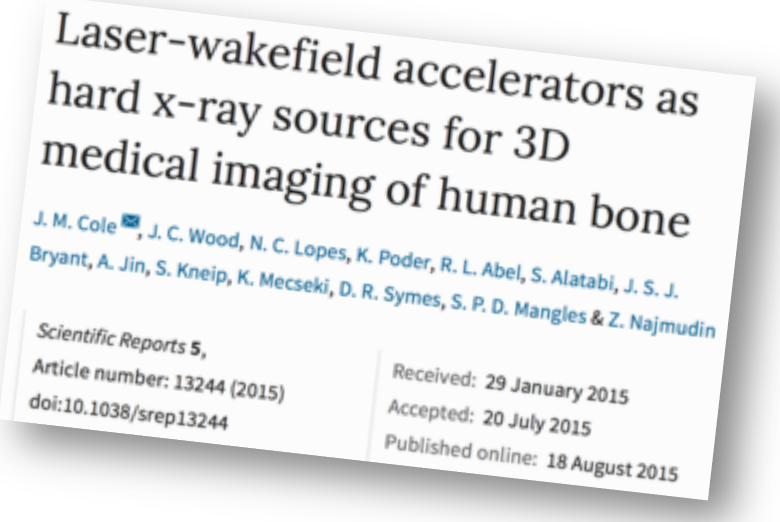


Figure 3. Images of the bone sample recorded with a) the betatron x-ray source b) conventional μCT scanning c) composite macro photography d) virtual illumination of the 3D reconstruction by a source of $E_{crit} = 33\,\text{keV}$.



2015 publication from J.M. Cole et al., John-Adams-Institute, UK: "Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone". Nature Scientific Reports 5, 13244 (2015)



Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone

J. M. Cole, J. C. Wood, N. C. Lopes, K. Poder, R. L. Abel, S. Alatabi, J. S. J. Bryant, A. Jin, S. Kneip, K. Mecseki, D. R. Symes, S. P. D. Mangles & Z. Najmudin

Scientific Reports 5,
Article number: 13244 (2015)
doi:10.1038/srep13244

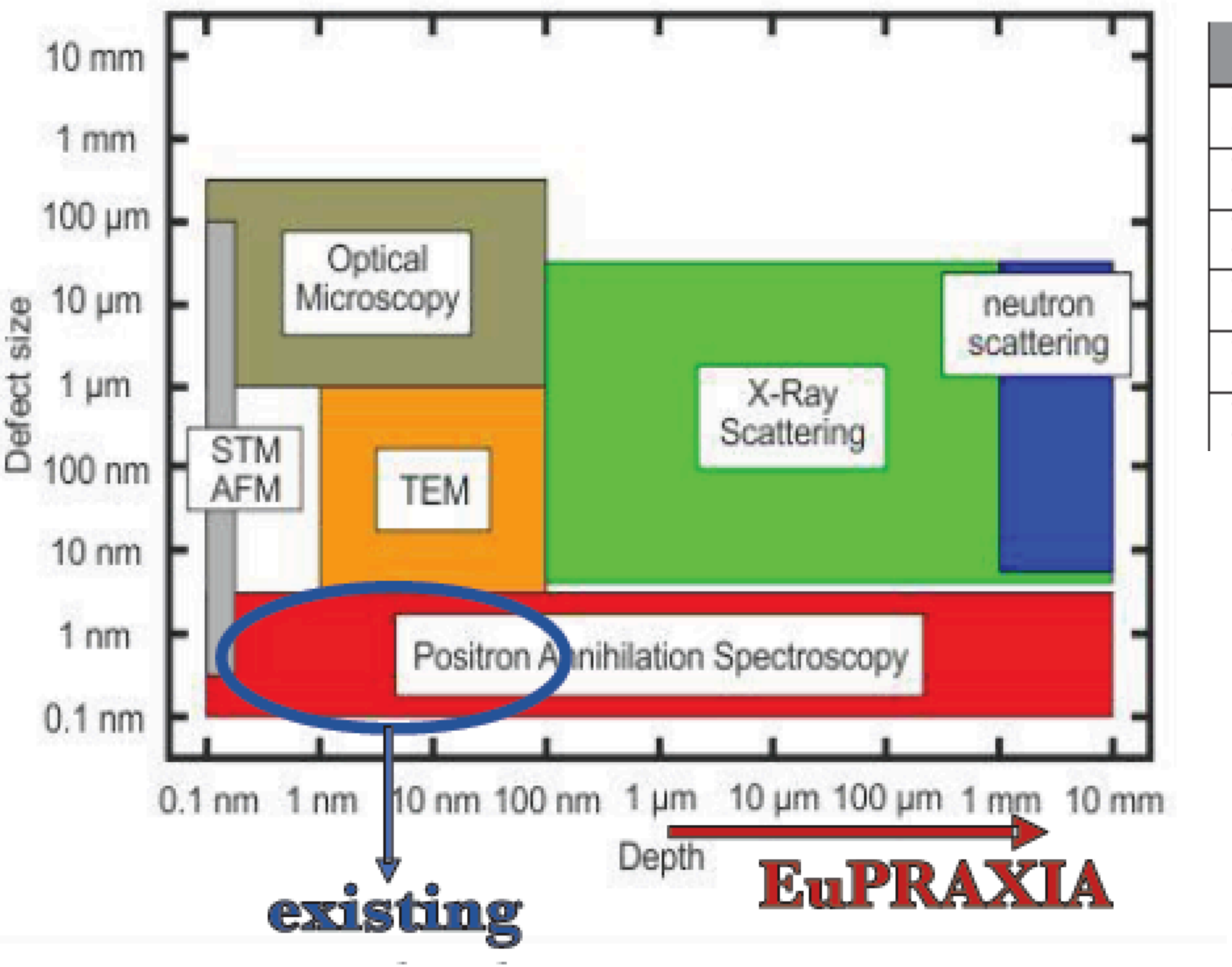
Received: 29 January 2015
Accepted: 20 July 2015
Published online: 18 August 2015

Laser plasma based betatron X ray source

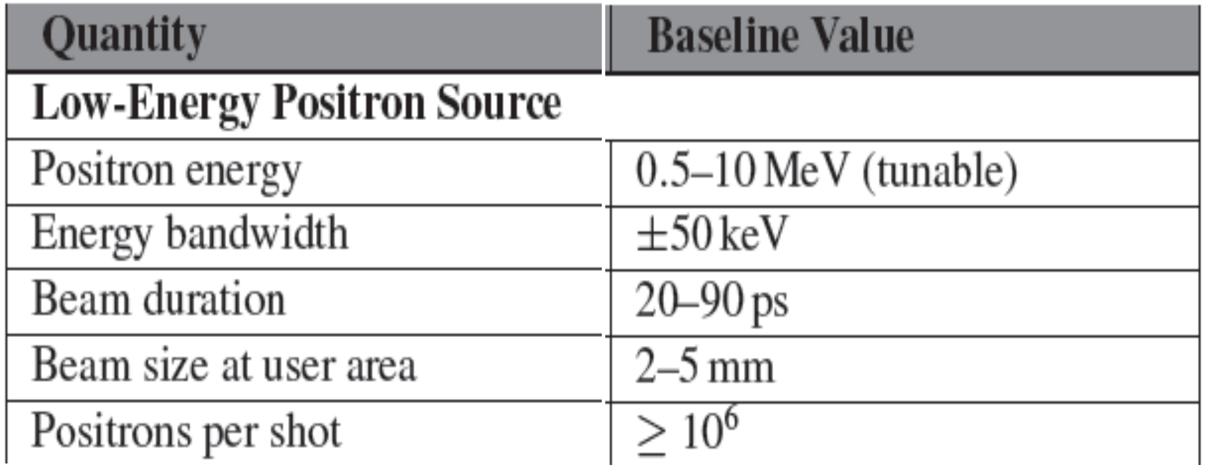
*Fully plasma-based beamline for generating betatron radiation as a **compact X-ray source for medical imaging and material analysis**. The user area is behind the wall on the right.*

EuPRAXIA facility rendering picture

Design: Positron Annihilation Spectroscopy



Courtesy M. Butterling, HZDR



Quantity	Baseline Value
Low-Energy Positron Source	
Positron energy	0.5–10 MeV (tunable)
Energy bandwidth	±50 keV
Beam duration	20–90 ps
Beam size at user area	2–5 mm
Positrons per shot	$\geq 10^6$

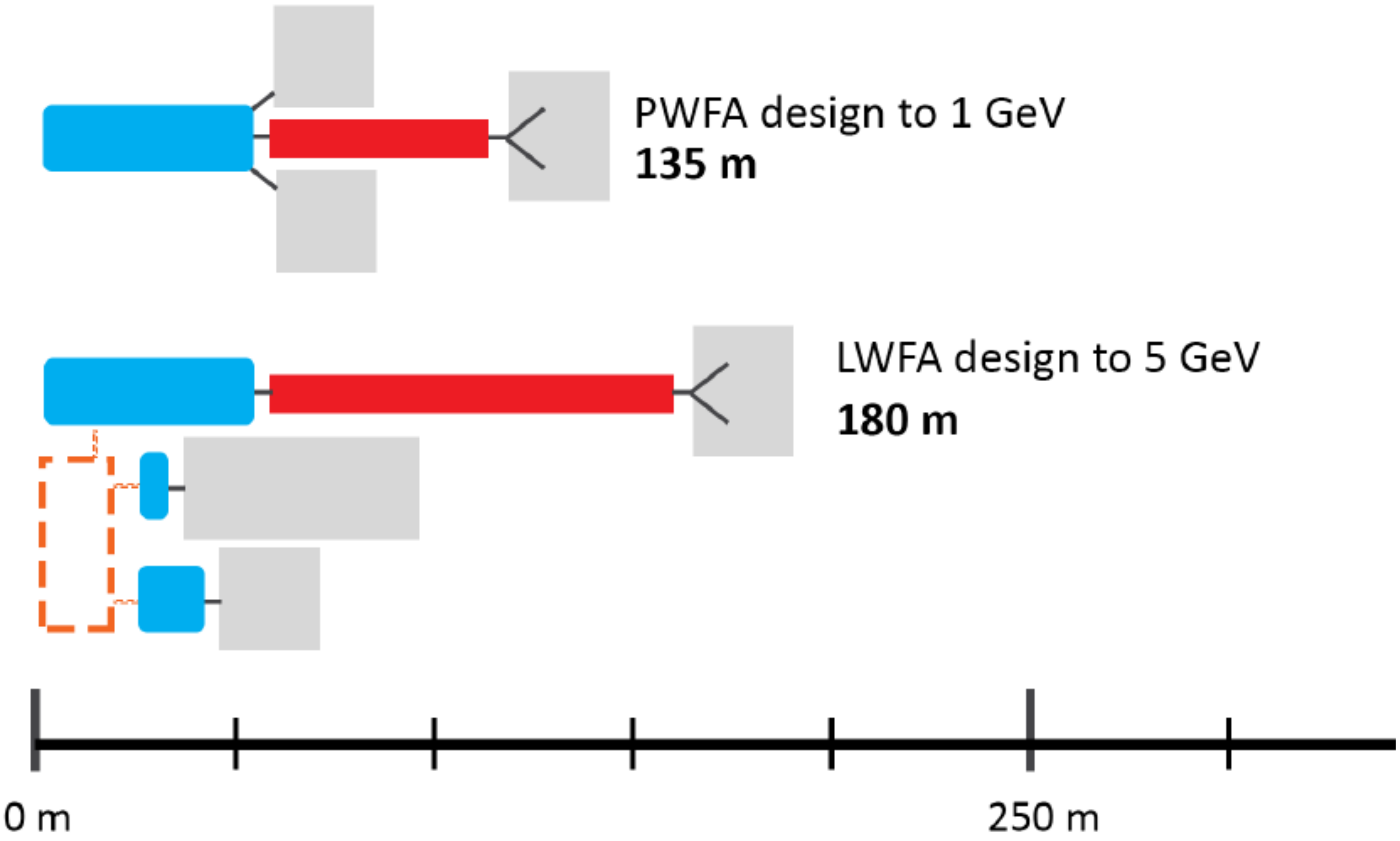
- EuPRAXIA would provide access to unique regime of detecting small defects at large penetration depths
- Does not require highest quality of electron beam

Gianluca Sarri et al

*Fully plasma-based beamline for generating **electron and positron beams**. The accelerator stages can be seen in the front. In the back the beamline splits and leads to two user areas behind the back wall.*

EuPRAXIA facility rendering picture

Footprint EuPRAXIA Facility(ies)



🟦 accelerator (plasma or RF)

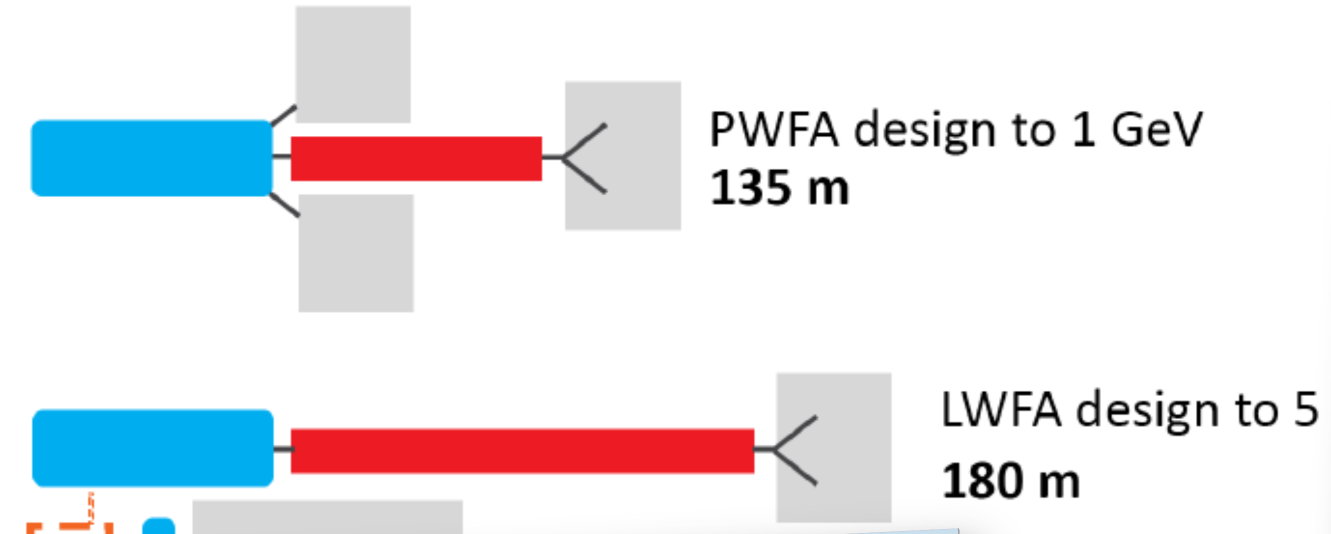
⬚ high-power laser

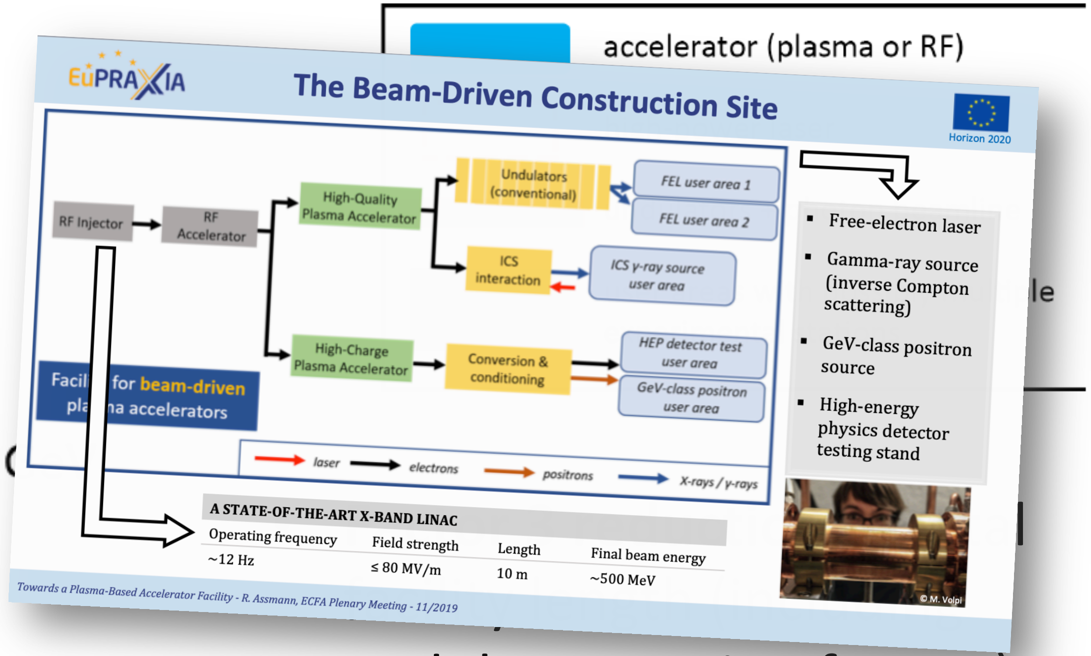
🟥 undulators + photon beamline

⬜ user areas with possibly multiple experimental stations

- **Factor 3 reduction** in total facility length (including undulator section for FEL).
- **Factor 6-7 reduction** in accelerator facility length
- Includes all required facility infrastructure.

Footprint EuPRAXIA Facility(ies)





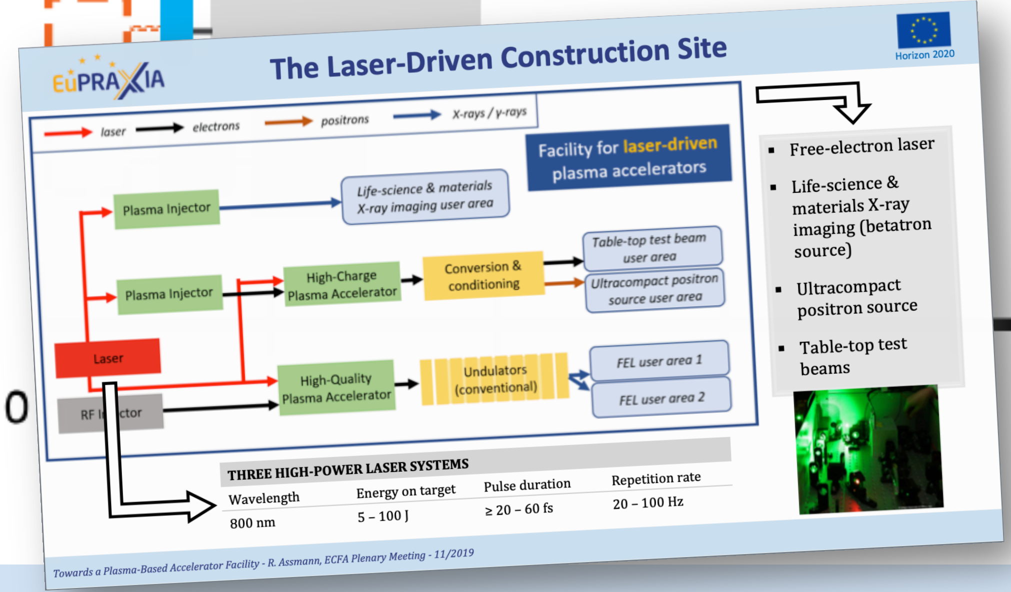
The Beam-Driven Construction Site

- Free-electron laser
- Gamma-ray source (inverse Compton scattering)
- GeV-class positron source
- High-energy physics detector testing stand

A STATE-OF-THE-ART X-BAND LINAC

Operating frequency	Field strength	Length	Final beam energy
~12 Hz	≤ 80 MV/m	10 m	~500 MeV

Towards a Plasma-Based Accelerator Facility - R. Assmann, ECFA Plenary Meeting - 11/2019



The Laser-Driven Construction Site

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

THREE HIGH-POWER LASER SYSTEMS

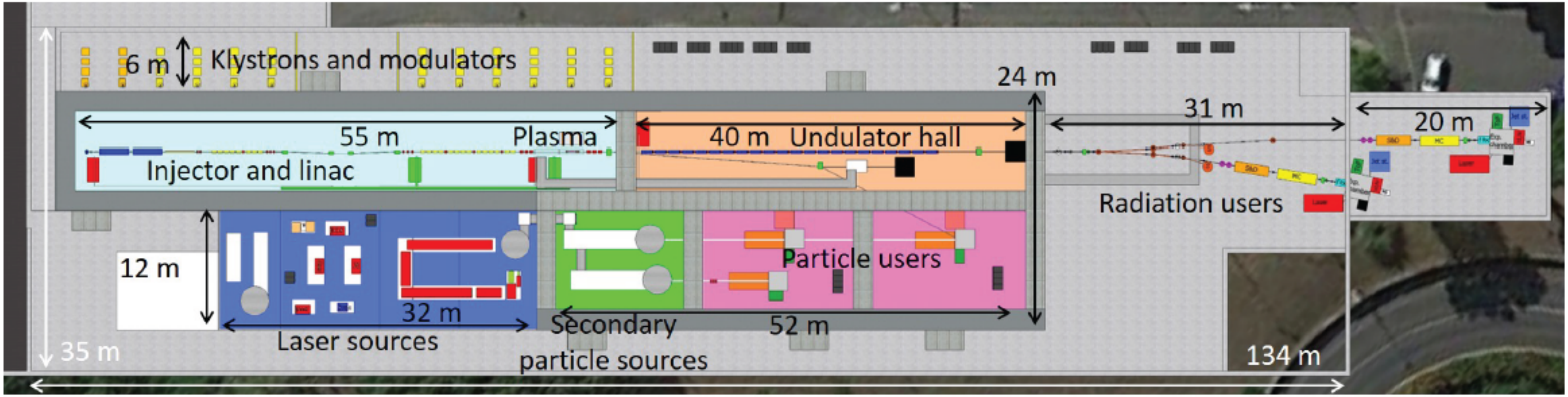
Wavelength	Energy on target	Pulse duration	Repetition rate
800 nm	5 – 100 J	≥ 20 – 60 fs	20 – 100 Hz

Towards a Plasma-Based Accelerator Facility - R. Assmann, ECFA Plenary Meeting - 11/2019

undulator section for FEL).

- **Factor 6-7 reduction** in accelerator facility length
- Includes all required facility infrastructure.

Beam-Driven EuPRAXIA Site at Frascati



Building construction process launched – planning contract awarded!

Conclusion

- The CDR for EuPRAXIA, a **European accelerator facility based on plasma**, lasers and beam drivers, has been worked out with contributions from 240 scientists.
  - **Technical clusters, five excellence centers and 1-2 construction sites** at existing laboratories
  - **Hosts of excellence centers and one construction site (Frascati/INFN) have been identified**.
  - Strong links to CERN and laser industry have been defined.
- EuPRAXIA will establish high **quality beams for various applications.** Some **innovative new ideas.** Several parameters have advantages (short pulse length, short emission length, ...).
- Addresses many important LC challenges and opens several low energy applications. In a survey we found strong interest for the facility.
- About **320 M€ invest needed over next 8-10 years** to prepare the implementation, refine resource plans, perform the technical design, define implementation and to construct the full facility.

Our Long-Term Vision: EuPRAXIA Plasma Accelerator Stages as Building Blocks or Upgrade Stages for a Linear Collider in the 2030's

Thank You for Your Attention!

EuPRAXIA facility rendering picture

EuPRAXIA

Consortium

Horizon 2020

16 Participants

DESY
INFN
Consiglio Nazionale delle Ricerche
cnrs
University of Strathclyde Glasgow
IST-ID Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento
Science & Technology Facilities Council
SOLEIL SYNCHROTRON
MANCHESTER 1824 The University of Manchester
UNIVERSITY OF LIVERPOOL
ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development
cea
SAPIENZA UNIVERSITÀ DI ROMA
UH Universität Hamburg
Imperial College London
UNIVERSITY OF OXFORD

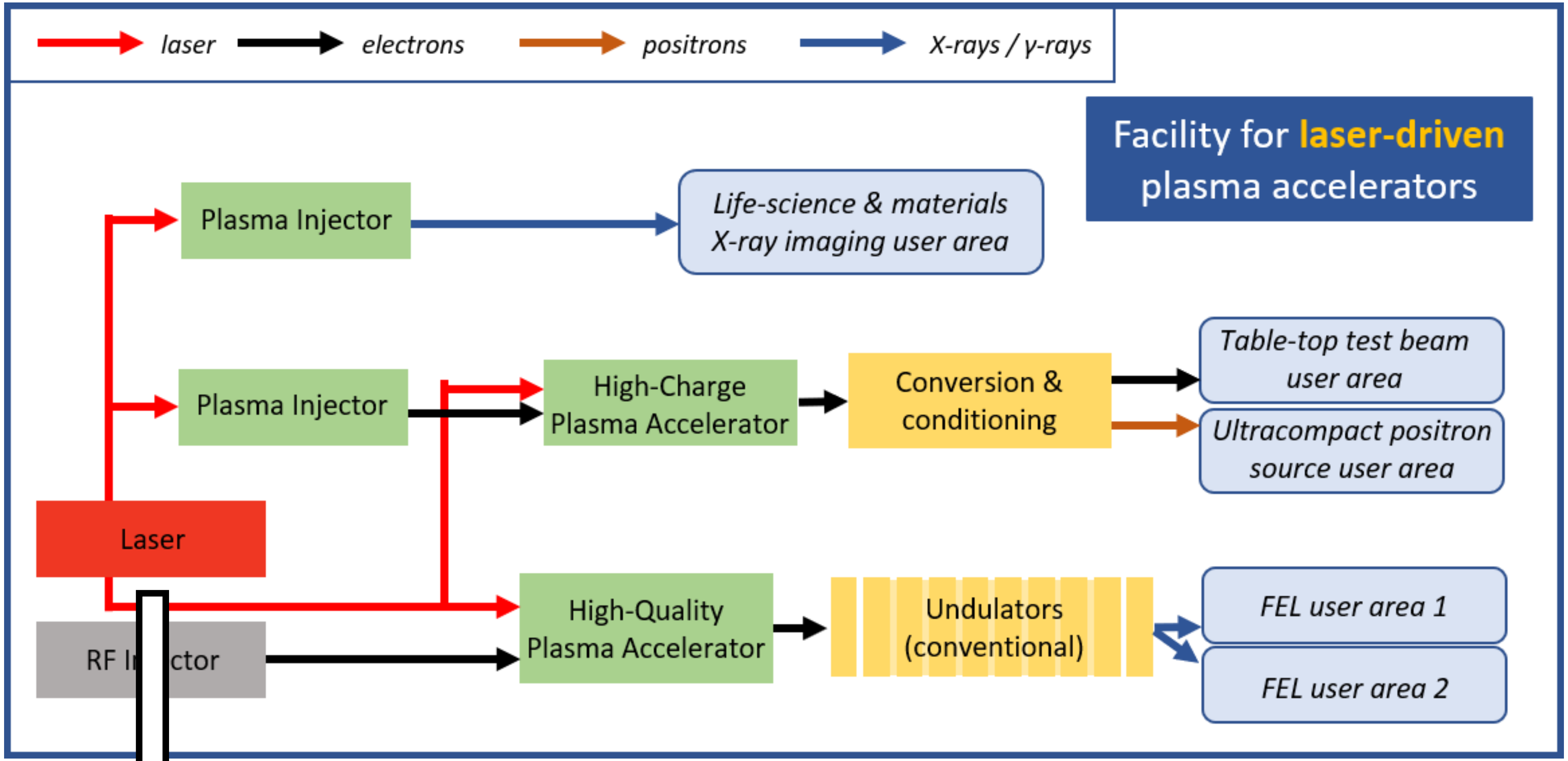
25 Associated Partners

(as of December 2018)

上海交通大学 SHANGHAI JIAO TONG UNIVERSITY
Université de Lille 1 SCIENCES ET TECHNOLOGIES
eli beamlines
HI Jena Helmholtz Institute Jena
清華大學 Tsinghua University
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN
wigner
KPSI Kansai Photon Science Institute
JAEA
大阪大学 OSAKA UNIVERSITY
RIKEN
Stony Brook University
CASE
CERN
LUND UNIVERSITY
BERKELEY LAB
UCLA
KIT Karlsruhe Institute of Technology
Università di Roma Tor Vergata
האוניברסיטה העברית בירושלים THE HEBREW UNIVERSITY OF JERUSALEM
ОБЪЕДИНЕННЫЙ ИЯИ
ИПФ РАН
JÜLICH FORSCHUNGSZENTRUM
QUEEN'S UNIVERSITY BELFAST
FBH Ferdinand Braun Institut
UNIVERSITY of York

Backup Slides

The Laser-Driven Construction Site


laser *electrons* *positrons* *X-rays / γ-rays*

Facility for **laser-driven** plasma accelerators

Plasma Injector

Life-science & materials X-ray imaging user area

Plasma Injector

High-Charge Plasma Accelerator

Conversion & conditioning

Table-top test beam user area

Ultracompact positron source user area

Laser

RF I ctor

High-Quality Plasma Accelerator

Undulators (conventional)

FEL user area 1

FEL user area 2

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

THREE HIGH-POWER LASER SYSTEMS			
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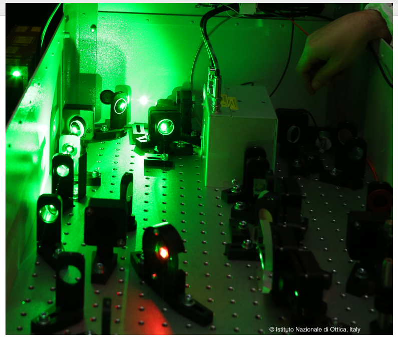
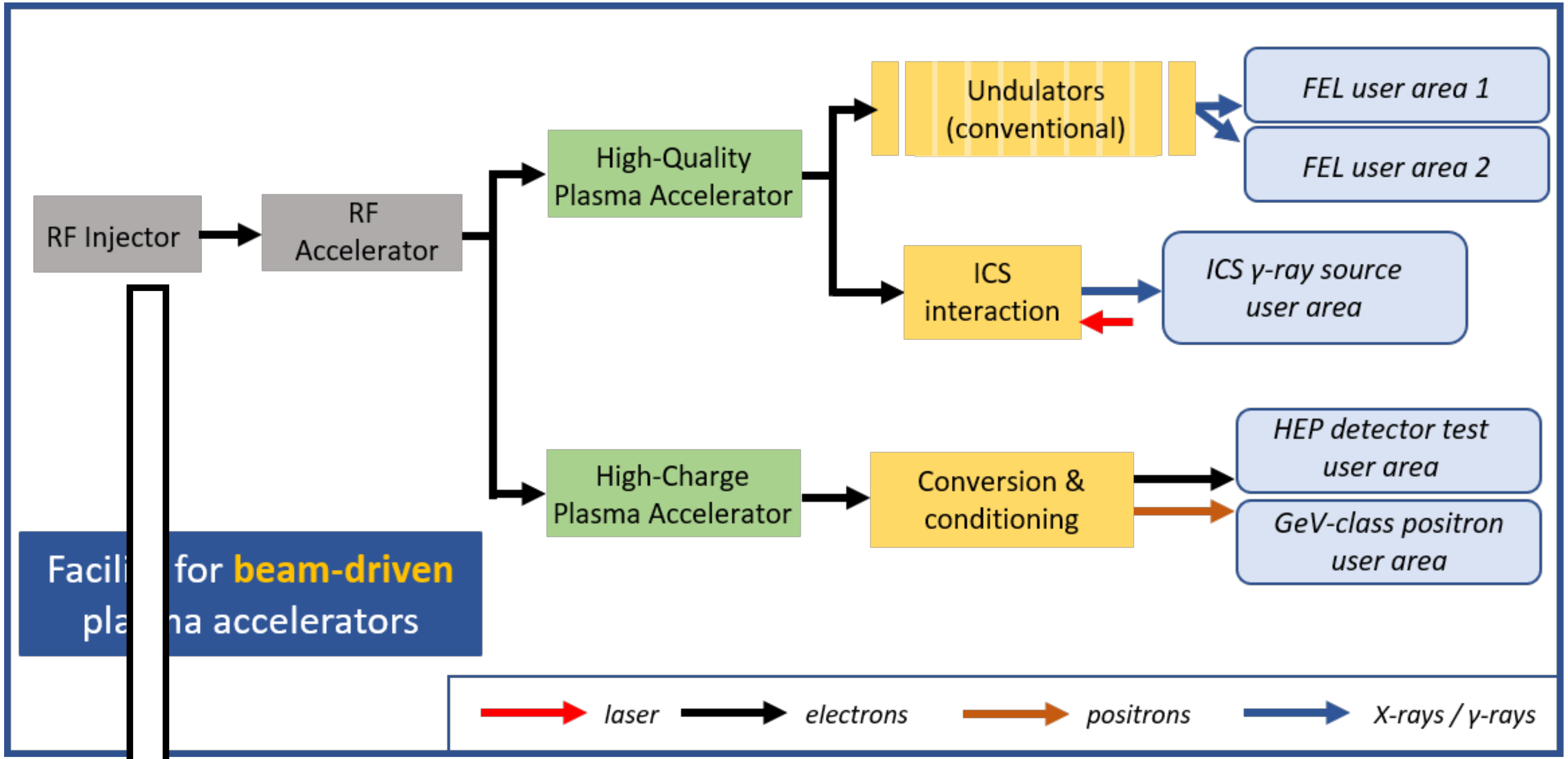


The Beam-Driven Construction Site



RF Injector

RF Accelerator

High-Quality Plasma Accelerator

Undulators (conventional)

FEL user area 1

FEL user area 2

ICS interaction

ICS γ-ray source user area

High-Charge Plasma Accelerator

Conversion & conditioning

HEP detector test user area

GeV-class positron user area

Facili for **beam-driven** pla na accelerators

laser *electrons* *positrons* *X-rays / γ-rays*

- Free-electron laser
- Gamma-ray source (inverse Compton scattering)
- GeV-class positron source
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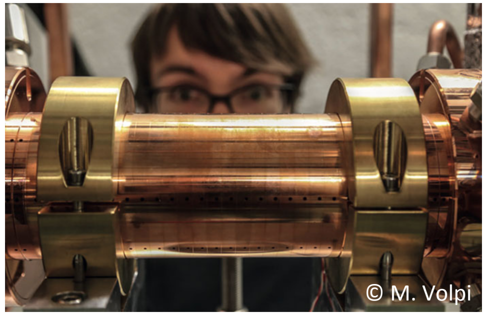

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Main Project Milestones & Deliverables

Horizon 2020

<table>
<tr><th></th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>...</th><th>2065</th><th>2066</th></tr>
<tr><td><i>Project Phases</i></td><td colspan="2">Conceptual Design Phase</td><td colspan="6">Technical Design Phase (Jan 2020 – Dec 2025)</td><td colspan="4">Implementation & Construction (Jan 2026 – Dec 2029)</td><td colspan="4">Operation (Jan 2030 – Dec 2065)</td><td>Decommissioning</td></tr>
</table>

- **Submission of CDR**

Step 2

- Development of future user and stakeholder support
- Calculation of detailed, realistic budget & cost-benefit analysis
- **Submission of ESFRI Roadmap Application**

Step 3

- **Technical design of excellence centre sites**
- Prototyping of essential machine components
- ESFRI Review 1

…

- **Technical design of construction site(s)**
- Decision on legal structure & governance model for implementation and operation
- Procurement of funding for implementation & operation

- Development of long-term science programme

- ESFRI Review 2
- **Procurement and delivery of each essential component**
- **Installment of each essential component**
- **Commissioning of each essential component**

- **Start of operation**

Next steps:

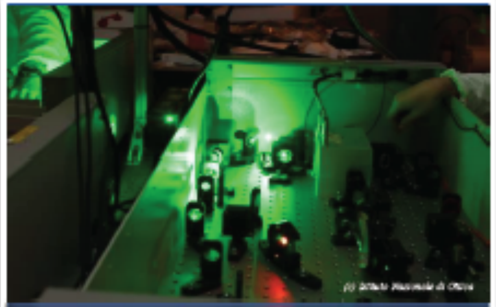
Publish CDR
Agree collaboration
Discuss with EU
Apply to ESFRI roadmap

Long-Term Scientific Program

Horizon 2020

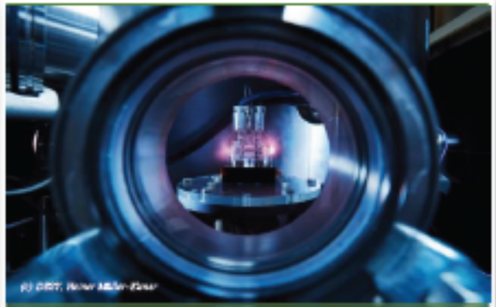
1. Reduced facility footprint

- ☐ *compact beamline components (undulators, magnets, etc.)*
- ☐ *compact diagnostics*
- ☐ *development of simplified, ultracompact prototype systems*



2. High power laser technology

- ☐ *high repetition rate*
- ☐ *high average power*
- ☐ *increased efficiency*
- ☐ *reduced footprint / cost*
- ☐ *robustness*

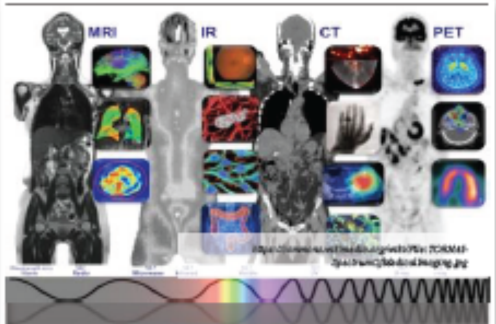


3. Accelerator technology

- ☐ *staging towards high energies*
- ☐ *advanced diagnostics*
- ☐ *hybrid plasma acceleration & other novel injection concepts*
- ☐ *beam control & quality*
- ☐ *ultrashort beams*

4. Plasma-based FEL

- ☐ *higher photon flux*
- ☐ *lower wavelength*
- ☐ *advanced undulator technologies*
- ☐ *ultrashort beams*
- ☐ *seeded FEL*



5. Method improvement for applications

- ☐ *medical imaging*
- ☐ *high-energy physics detectors*
- ☐ *material analysis (cargo scanning, structural analysis)*
- ☐ *positron generation and acceleration (plasma collider studies)*