EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Le projet EuPRAXIA: Un accélérateur plasma pour la recherche et les application pilotes

Journées Accélérateurs 2019 de la SFP

Roscoff, 02-04 octobre 2019

Arnd Specka (LLR, Ecole Polytechnique/IN2P3) pour la collaboration EuPRAXIA

Diapositives courtesy of :
Ralph Assmann (DESY)
coordinateur design study EuPRAXIA

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

The Consortium : D, F, GB, I, P + ass. partners

Horizon 2020

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

The EuPRAXIA Project

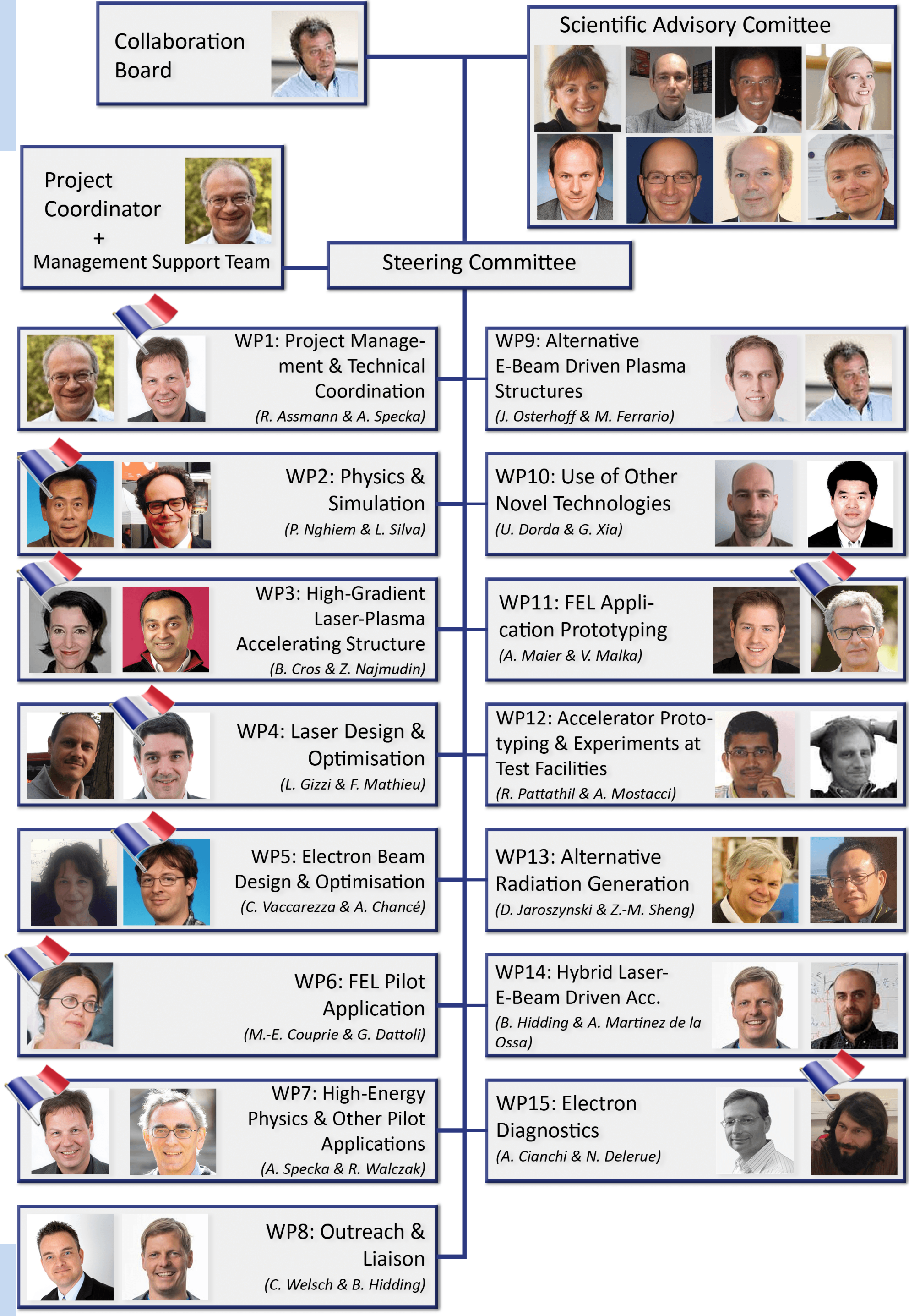
EU funded Consortium (3 M€) to produce a CDR for a European Research Infrastructure

- EU design study in 4th and final year:
  16 beneficiaries, 25 associated partners,
  15 Work Packages, 30 WP Leaders,
  more than 200 scientists contributed

- One of four DS's in physical science approved in H2020. Others: EuroCirCol (FCC), CompactLight (X band), Neutrino (ESS)

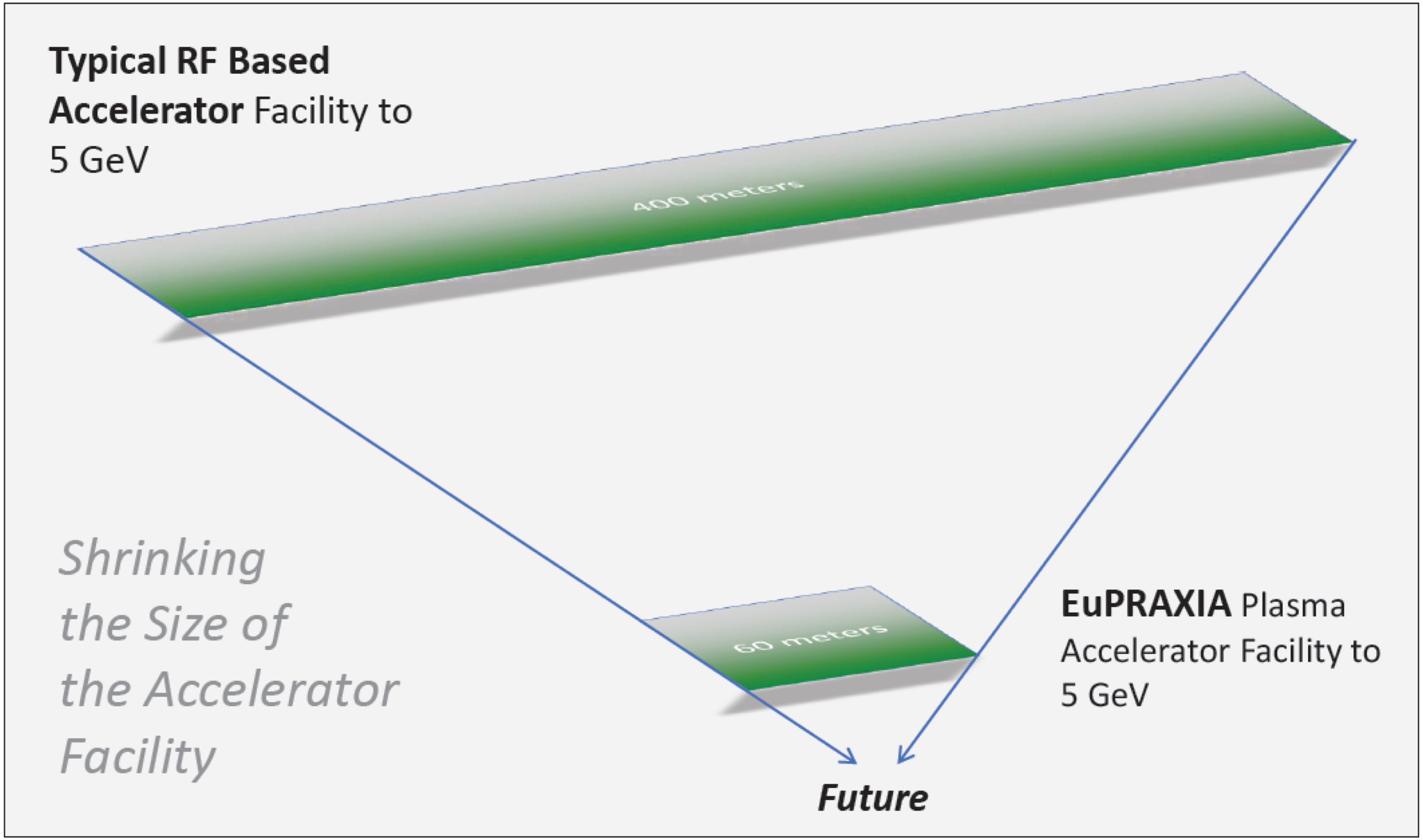
- **French WP (co) leaders for all central WP**

#EuPRAXIA
#plasma
#accelerator



EuPRAXIA Design: Shrink the Facility

Horizon 2020



Facility:

- Shielding
- RF galleries
- Klystron
- Beam transport
- Focusing
- Plasma accelerator
- ...

Factor 6-7 reduction in accelerator facility length (**factor 3** in total facility length)

EuPRAXIA Questions

- 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?

Deliverable: CDR (end of October)

- Work on **technical solutions**, but also on **facility concept**
- Present status:
  - **555 pages** strong draft
  - Some contributions still coming, changes to be included
- Cannot be reported completely here.
- Selection of results and concepts → apologies
- For more details: read the CDR once it is published...

Some Initial Design Goals (not complete)

up to 5 GeV electron beam energy

≤ 1 mm-mrad normalized emittance

30 pC charge in electron beam

10 femto-s electron bunch duration

≤ 250 m facility length

To be evaluated

Basically proven in the field

≤ 1 % total energy spread

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Horizon 2020

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To be evaluated

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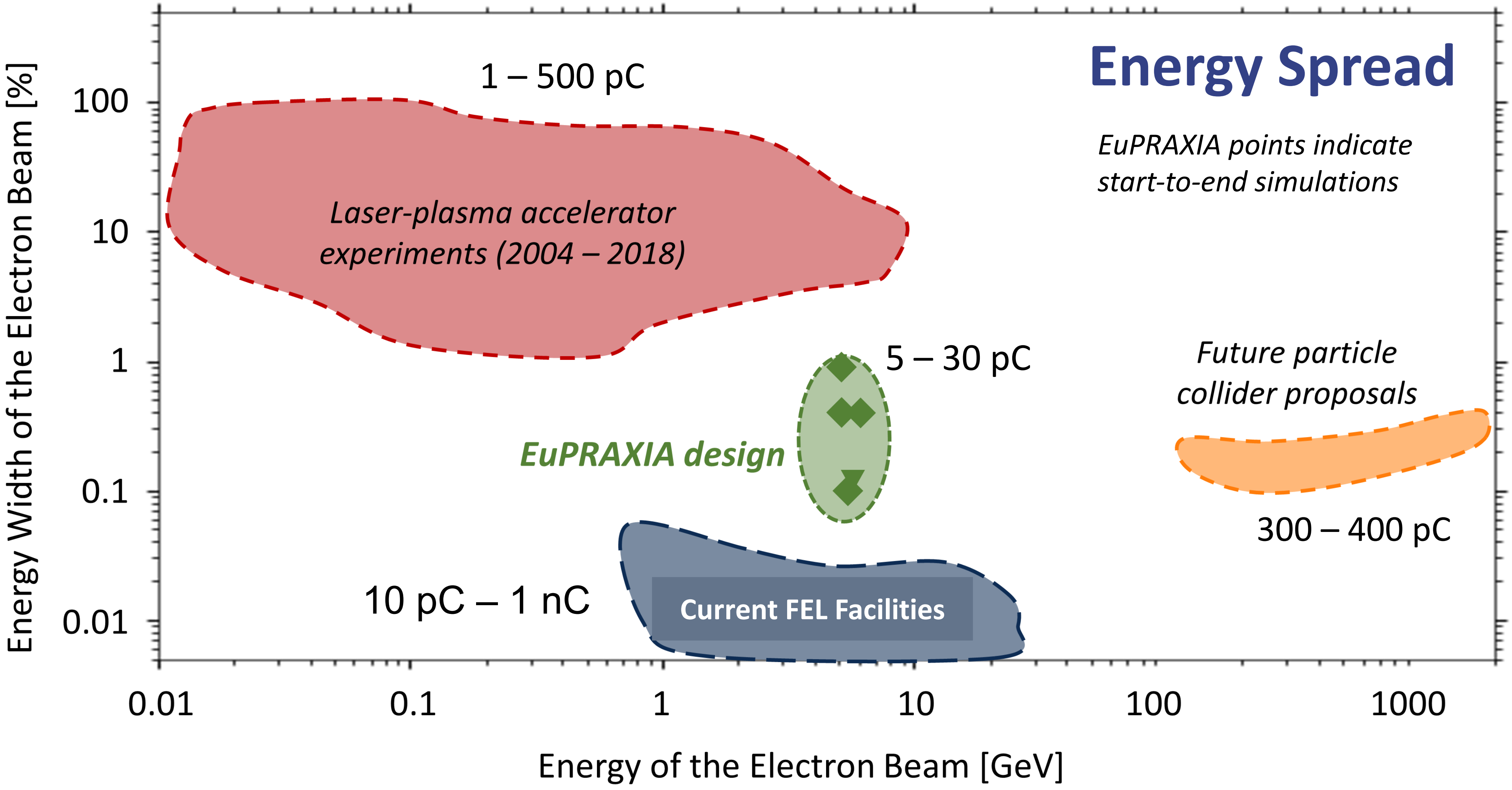
Major critical issue

And (of course)

- **stable**
- **reproducible**
- **controllable**

EuPRAXIA Design: High Quality Single Bunch



High Quality Beam

Simulations: Variety of Codes Used

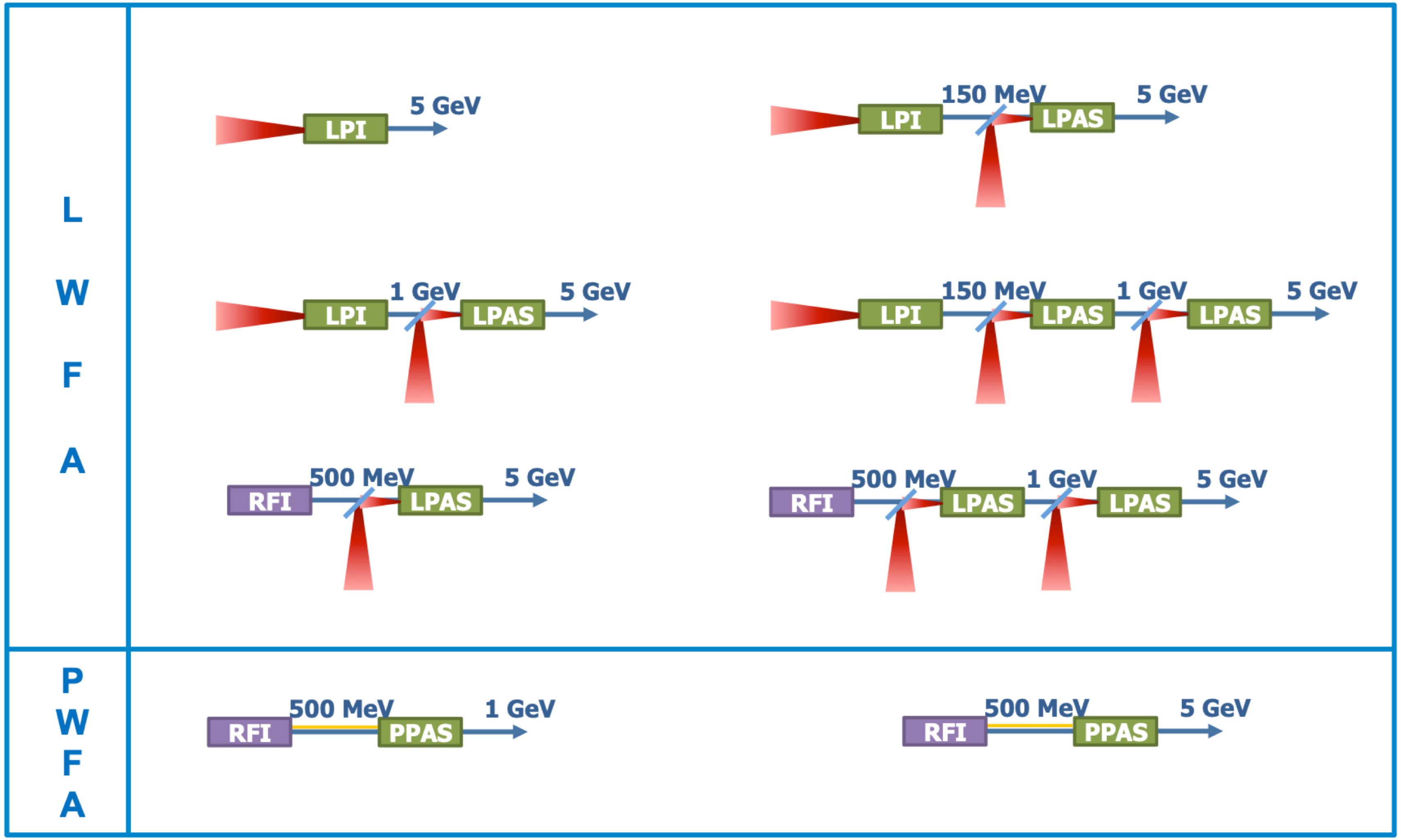
ASTRA, Tstep, Elegant,
SMILEI, CALDER-C, Warp,
OSIRIS, ALaDYN, Qfluid,
FBPIC, CSRtrack, TraceWin,
Architect, VSim

- Strong variety in codes used → less prone to a single source of errors
- PIC codes for plasma dynamics

Technical EuPRAXIA Solutions

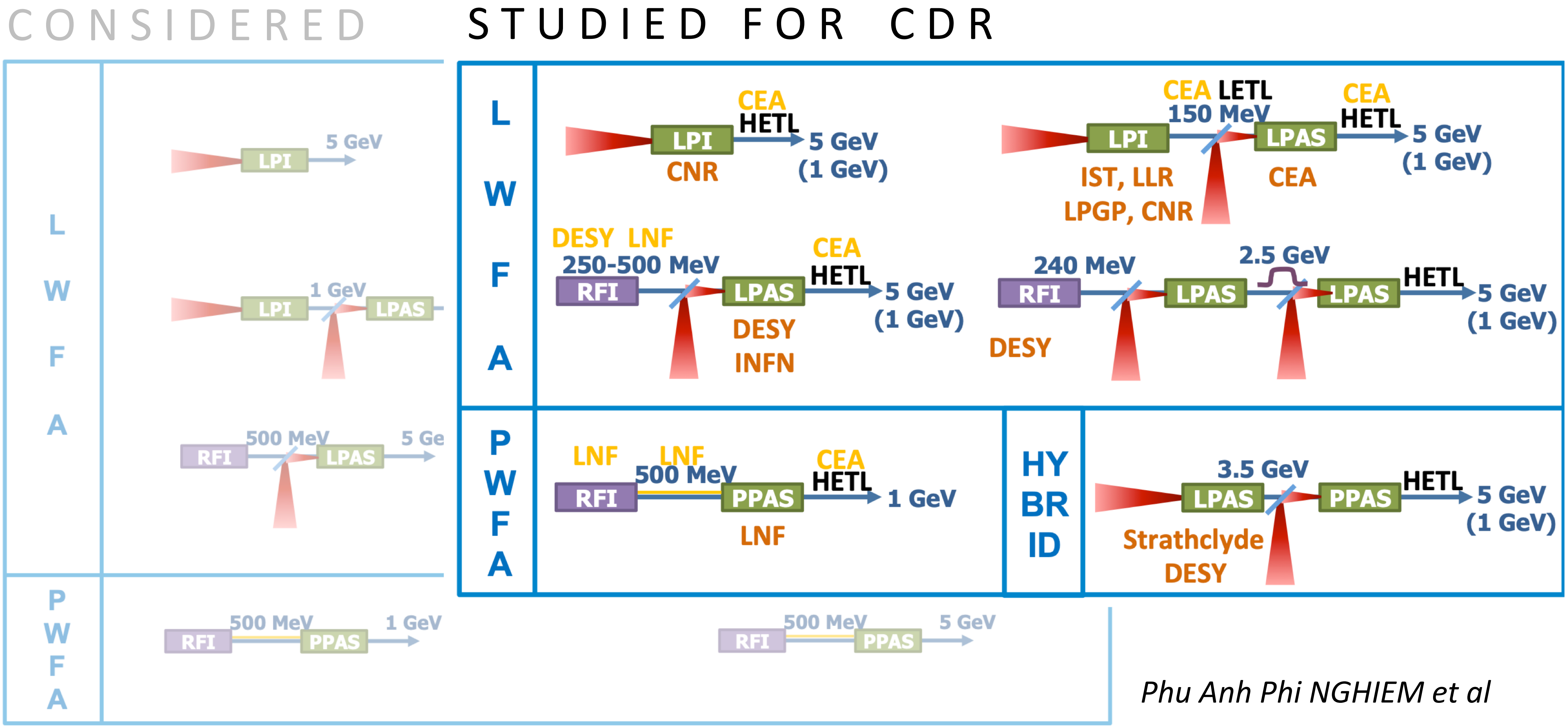
Horizon 2020

CONSIDERED



Phu Anh Phi NGHIEM et al

Technical EuPRAXIA Solutions



Phu Anh Phi NGHIEM et al

Down-Selection Process

Horizon 2020

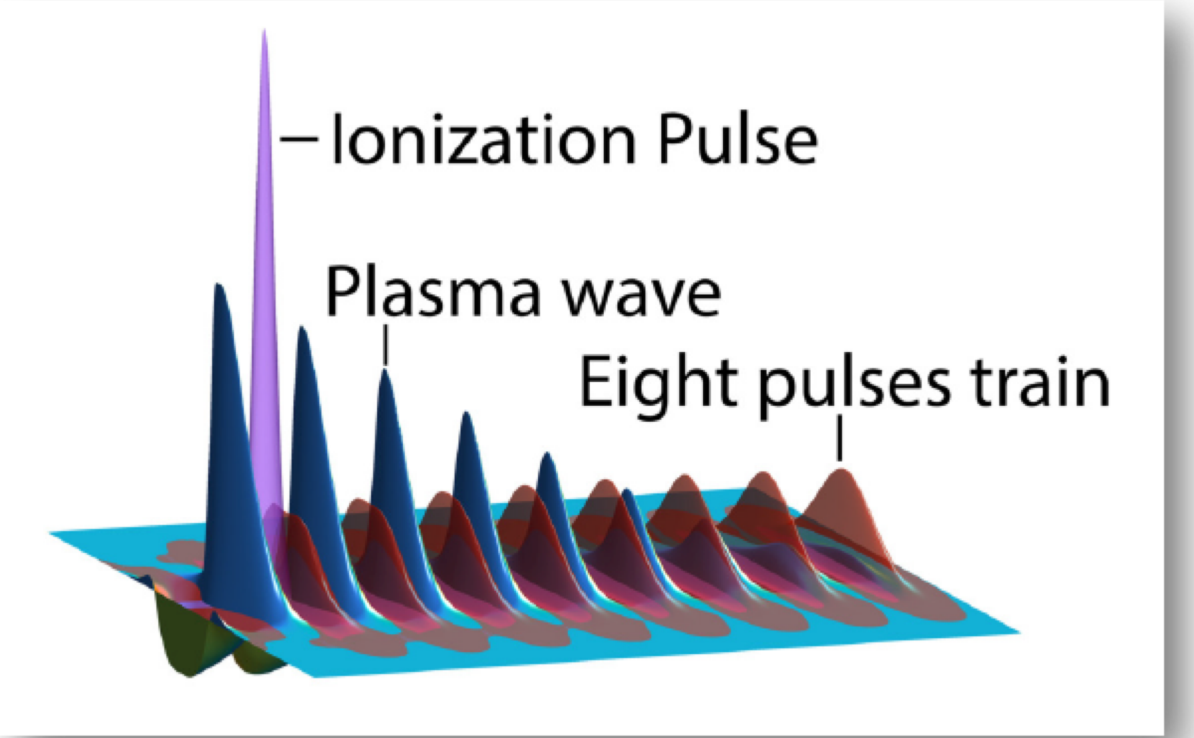
- Mild down-selection process. WHY?
- Some realizations:
  - European research infrastructure landscape is quite diverse with different boundary conditions at various places → **one technology does not suit all needs**
  - The major cost drivers are infrastructure, RF, lasers, instrumentation, ... → 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.

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

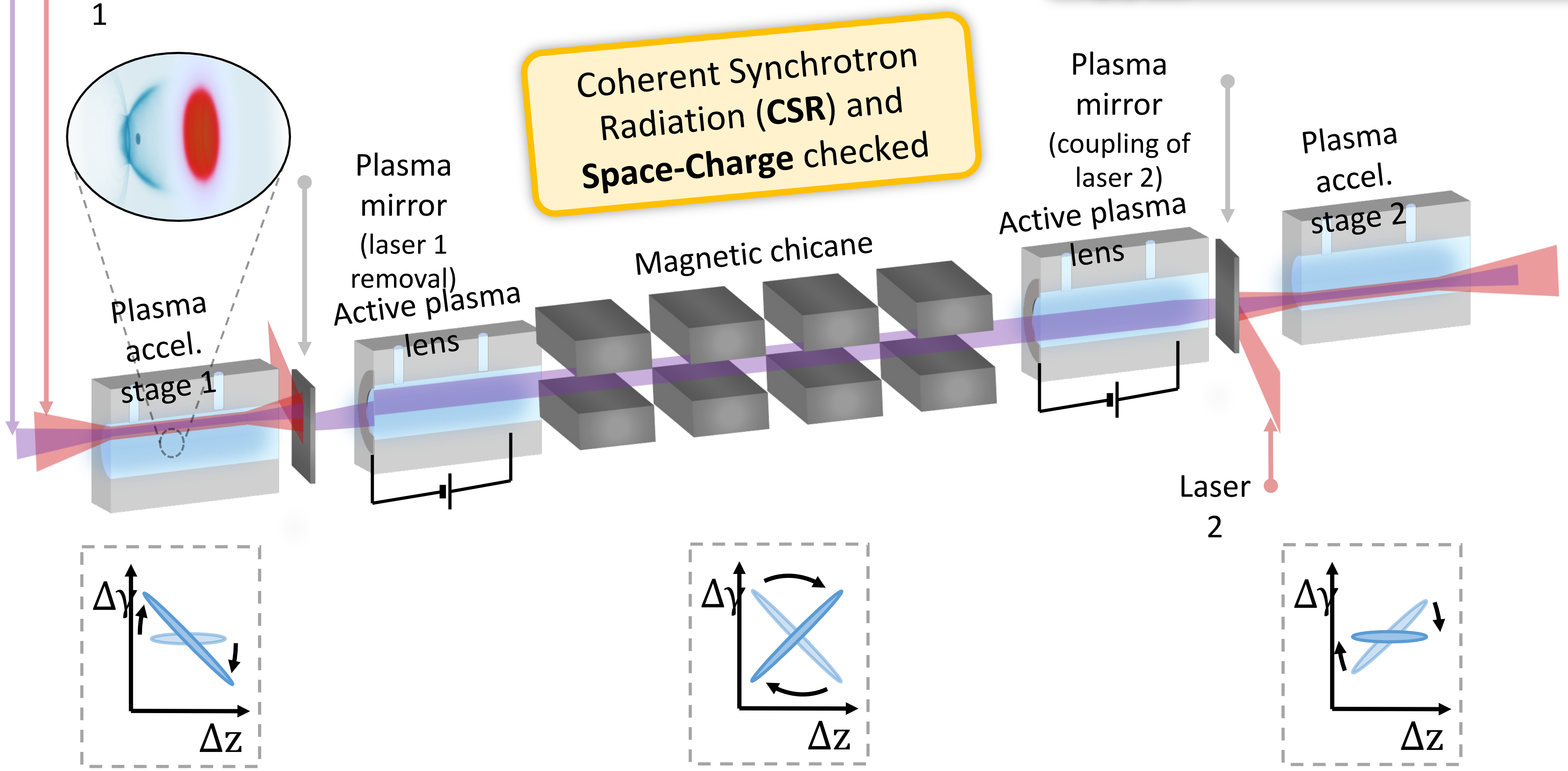
Paolo Tomassini et al

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

Horizon 2020

Ángel Ferran Pousa et al

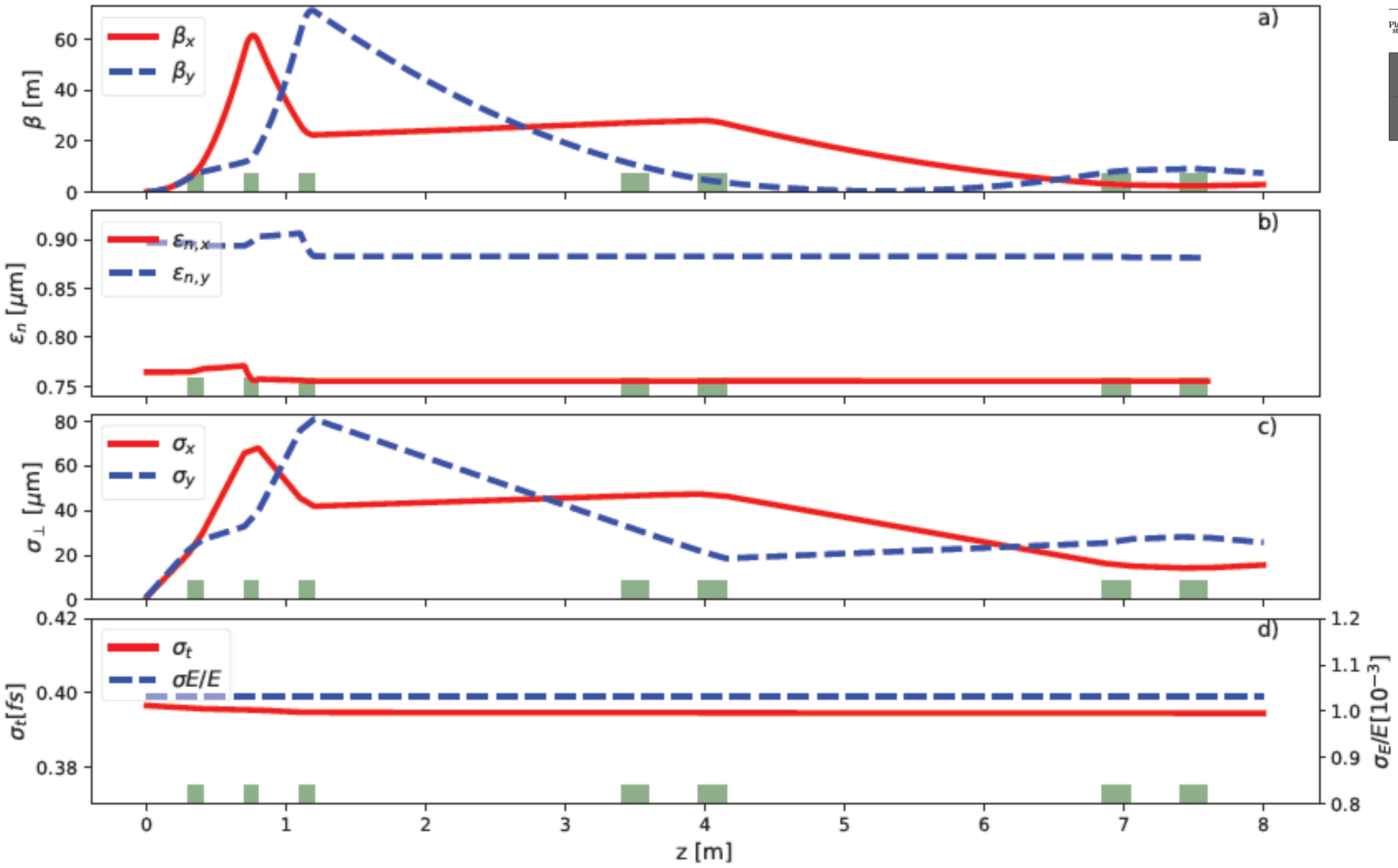


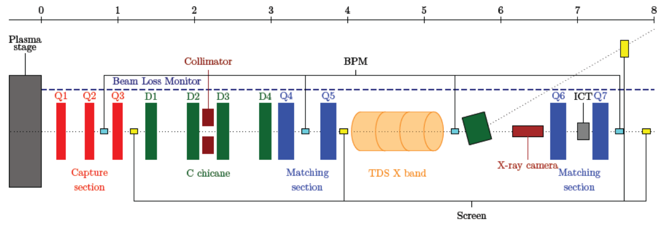
Not to scale. **Compact setup ~1.5 m.**

Combined RF plus optical scheme

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

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

EuPRAXIA Features

EuPRAXIA Design: 20 – 100 Hz Lasers

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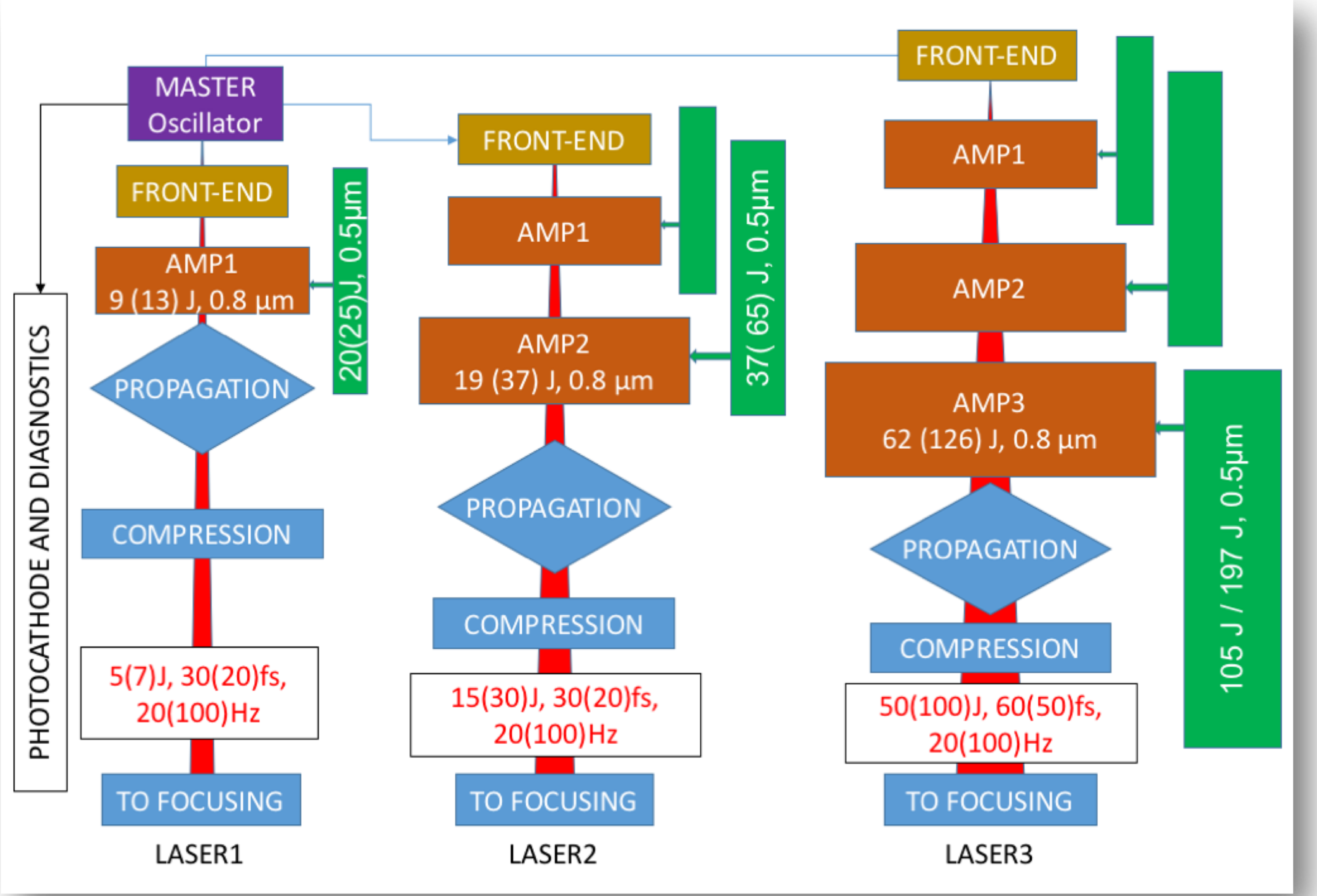
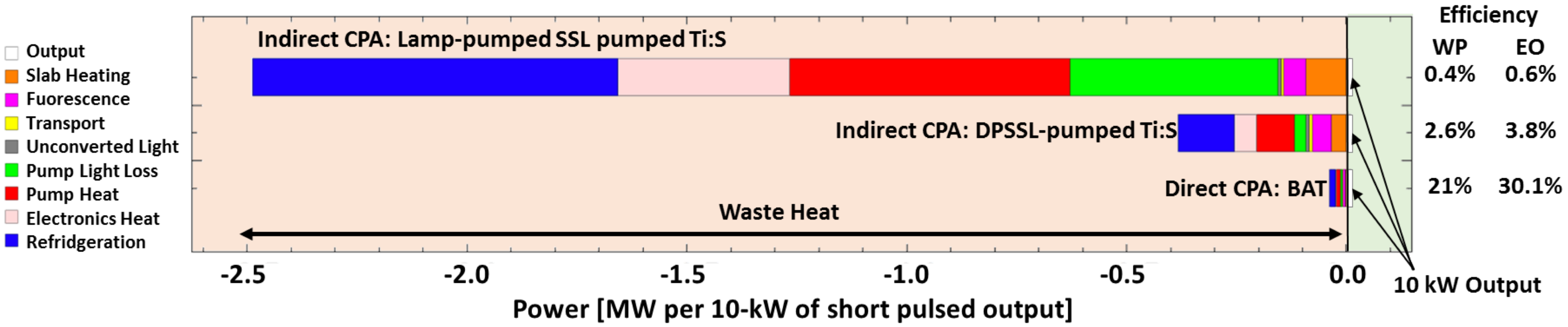


- **Three laser systems** for the laser-driven plasma accelerator facility
- Baseline: Start from lasers at present **state-of-the-art**, however, extended to 20 Hz and then to 100 Hz
- In parallel: **Development** of high efficiency, high average power lasers

Leo Gizzi, Francois Mathieu et al

Development Paths Required: Example Lasers

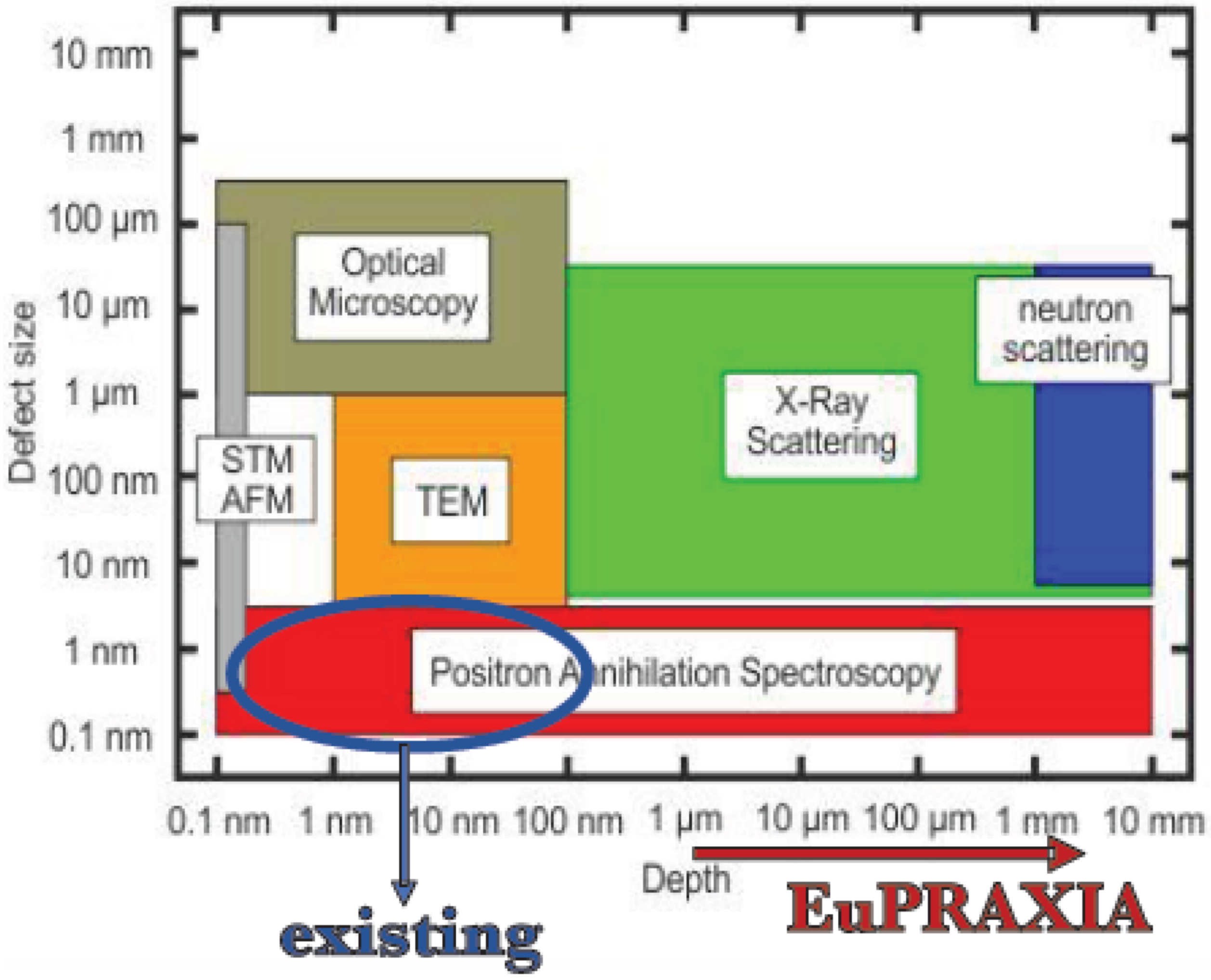
Laser efficiency at present is a problem → towards high efficiency solutions, enabling high average power



Courtesy C. Siders, EAAC 2017

Application: Positron Annihilation Spectroscopy

Horizon 2020



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

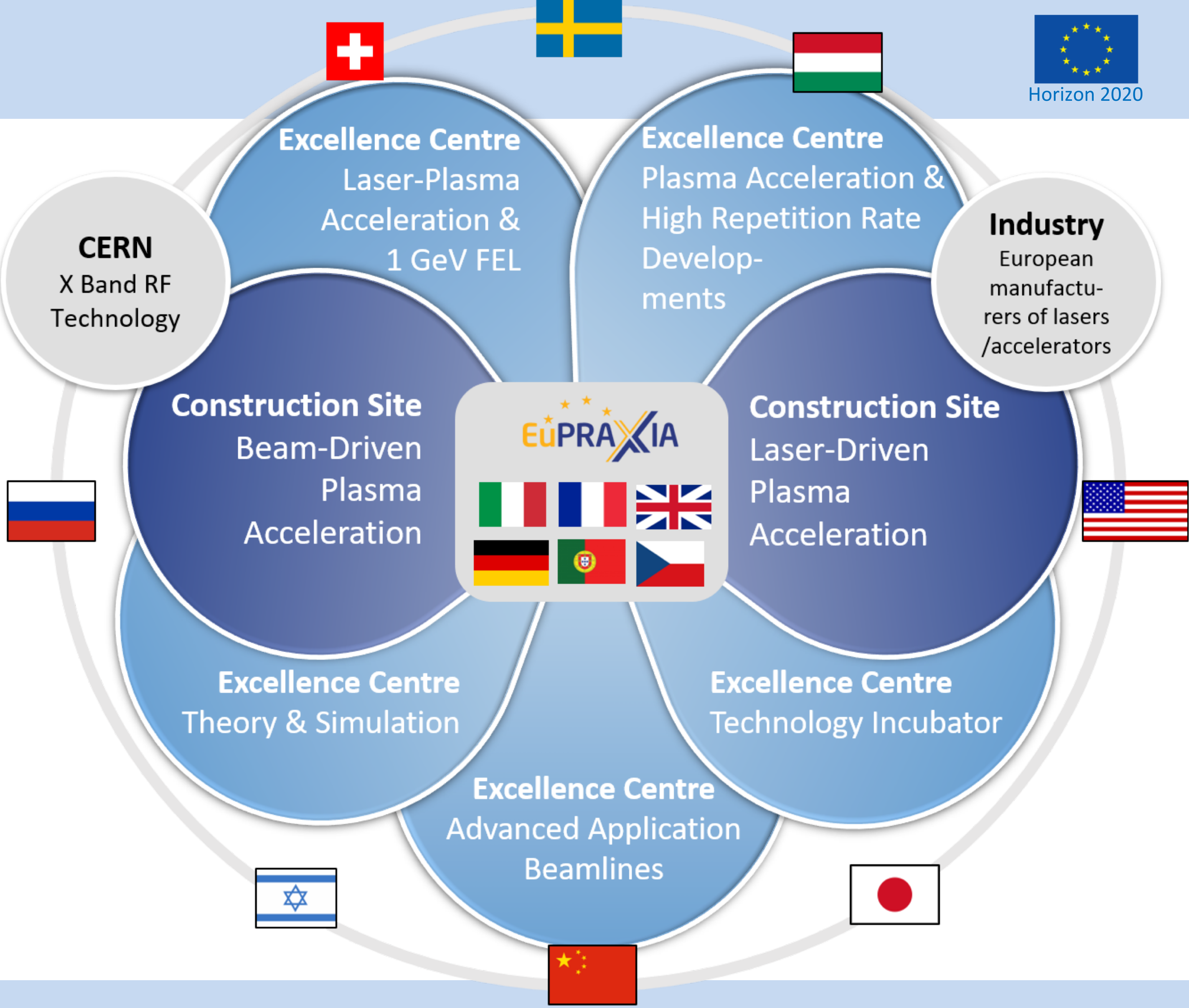
Gianluca Sarri et al

EuPRAXIA Model and Sites

Excellence Sites

Located at existing major facilities in Europe, profiting from ongoing investments

- demonstration of major **critical principles**
- construction of **prototypes**
- testing and qualification of prototypes
- construction/testing of **components for construction site(s)**



Horizon 2020

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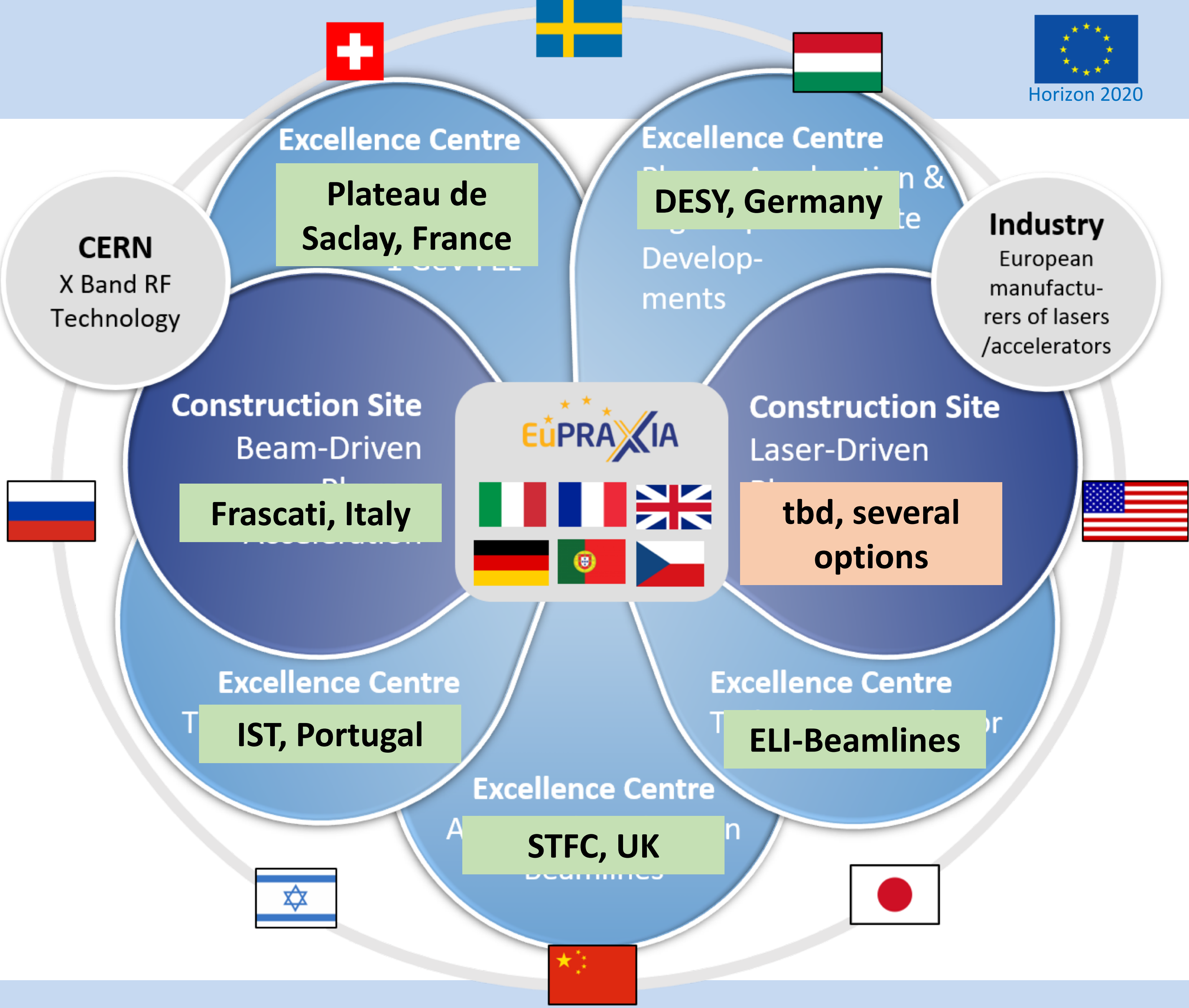
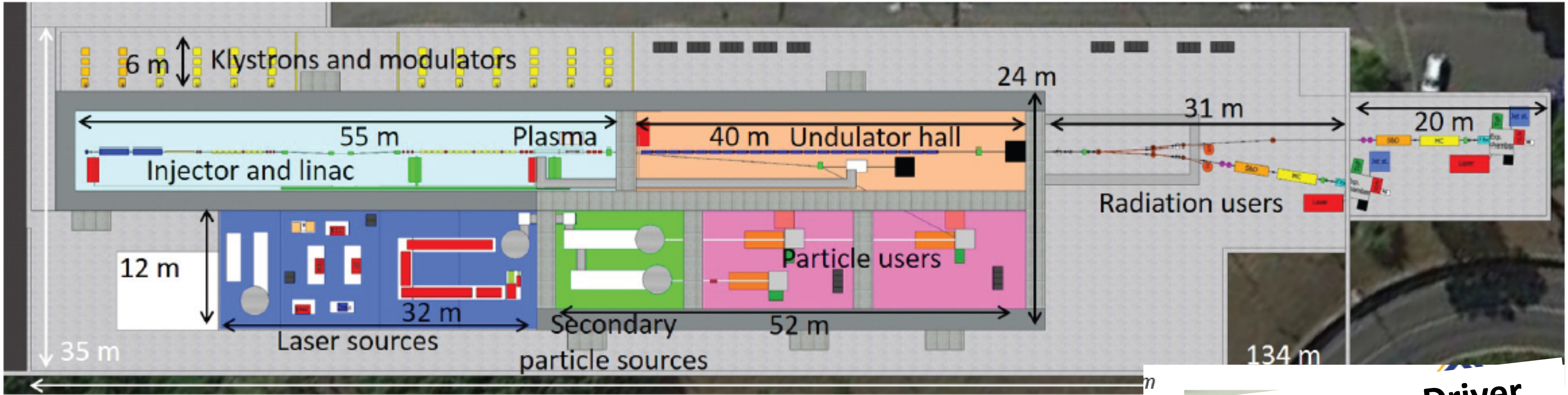
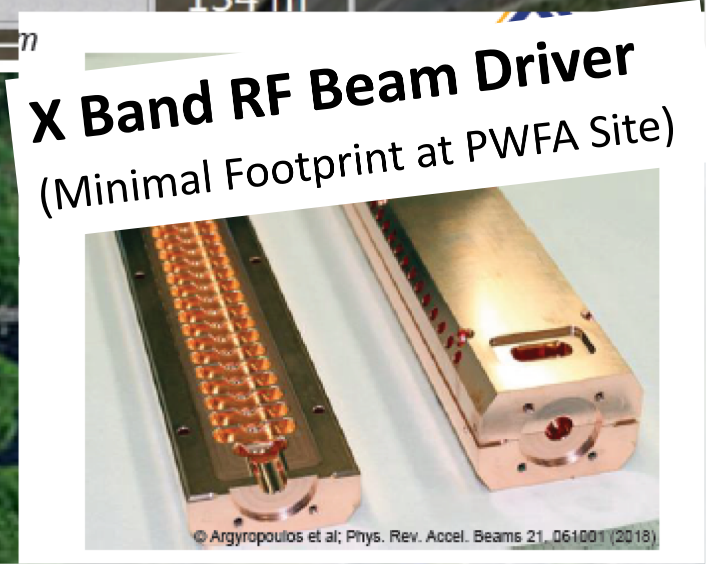


Beam-Driven EuPRAXIA Site at Frascati

Horizon 2020





Concept du projet LAPLACE: 2 directions

Slide: J.Faure (LOA,ENSTA)

- Pousser la R&D vers l'accélération laser-plasma à haute énergie: LAPLACE-HE
  - Débloquer les verrous sci&tech pour la production d'une source ~GeV, robuste et stable
  - Développement des applications d'une telle source
    → multiples lignes de lumières (5 ou plus)

- Pousser la R&D vers l'accélération laser-plasma à haute cadence: LAPLACE-HC
  - Débloquer les verrous sci&tech liés à la haute cadence
  - Utiliser les électrons dans la gamme 10-50 MeV: aspect source femtoseconde

LAPLACE: porteurs de projet LOA + LAL

Slide: J.Faure (LOA,ENSTA)

LOA (20 year experience in the field):
- **18 perm. staff** (13 research, 5 support)
- 2x60 TW laser (Salle Jaune), 1kHz 1 TW laser (Salle Noire)

SOLEIL (since ~ 2012):
- **18 perm. staff**
- Users of electron beams from Salle Jaune for producing FEL radiation. Transport beamline, undulators

LAL
- **Potentially 35 perm staff** (60 % research, 40 % support)
- 100 TW laser, RF accelerators

Other actors disseminated in other institutions:
- LPGP: B. Cros (exp.) + G. Maynard (theory / simulations)
- LLR: A. Specka (exp.) + A. Beck (theory / simulations)
- CEA: S. Dobosz (exp.), X. Davoine (theory / simulations), A. Chancé, Phi Nghiem…

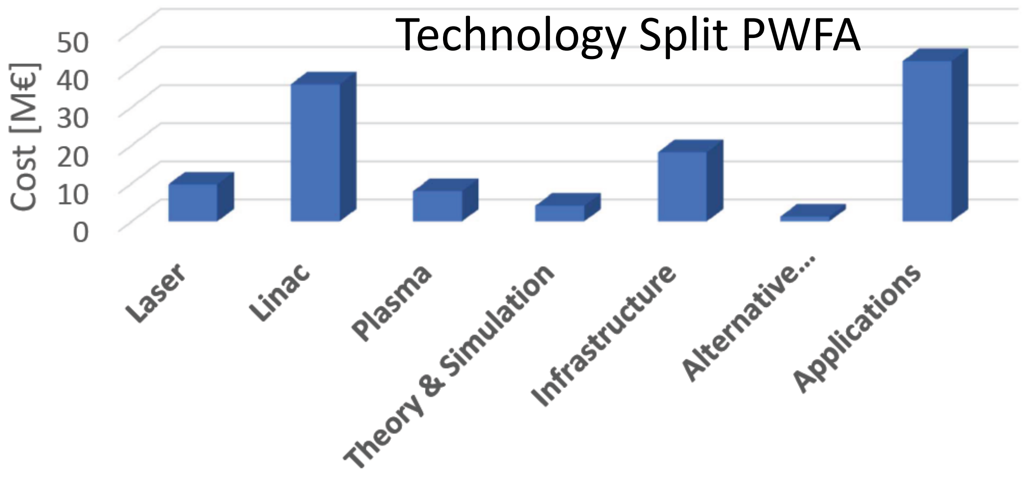
Cost Estimate in CDR (to be detailed and reviewed in technical design phase)

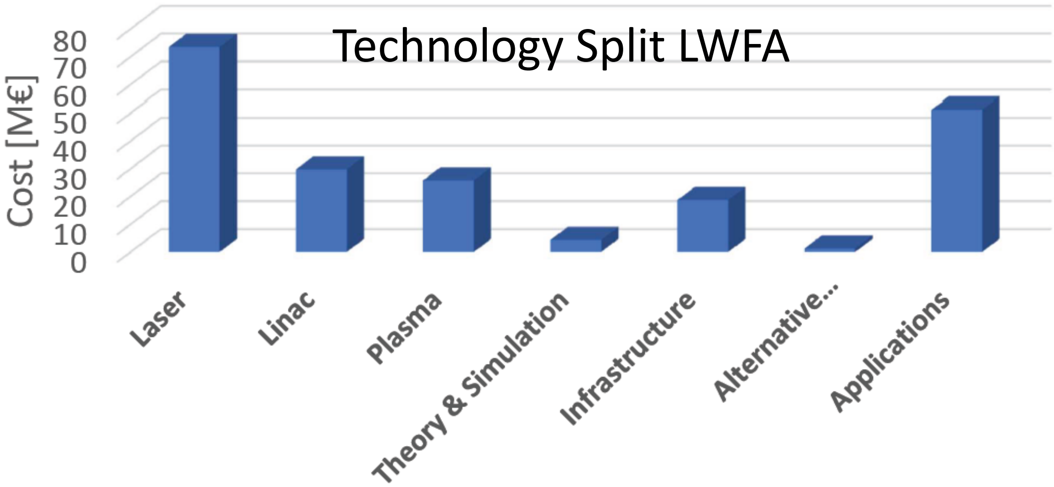
Scenario	Invest
Beam-driven plasma accelerator facility	
Full EuPRAXIA proposal	119 M€
Plasma accelerator facility with FEL	68 M€
Laser-driven plasma accelerator facility	
Full EuPRAXIA proposal	204 M€
Plasma accelerator facility with FEL	110 M€
Minimal laser plasma accelerator with FEL	75 M€

Full cost: 323 M€

Duration: 8 – 10 years

Reduced cost systems possible, e.g. 1 construction site only, pre-existing invest, ... Full project will be fully European and will bundle capabilities!





Main Project Milestones & Deliverables

Horizon 2020

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	...	2065	2066
Project Phases	Conceptual Design Phase		Technical Design Phase (Jan 2020 – Dec 2025)						Implementation & Construction (Jan 2026 – Dec 2029)				Operation (Jan 2030 – Dec 2065)				Decommissioning

- **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:

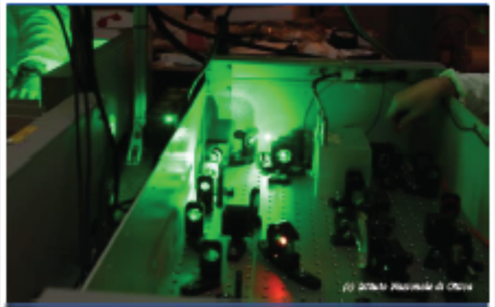
Publish CDR
Agree collaboration
Discuss with EU
Apply to ESFRI roadmap

Long-Term Scientific Program

Horizon 2020

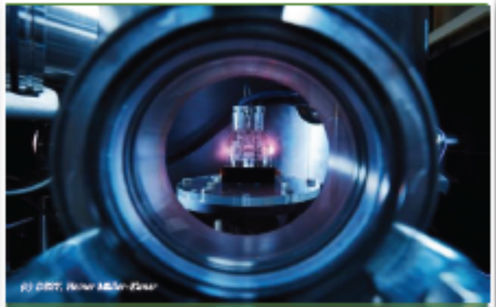
1. Reduced facility footprint

- ❑ *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*

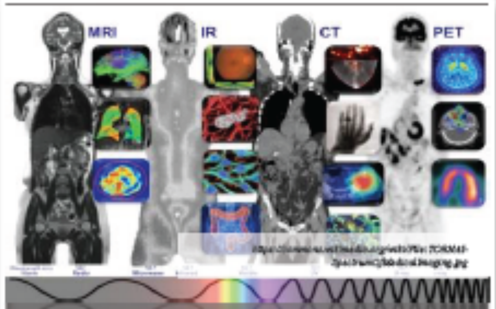


3. Accelerator technology

- ❑ *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)*

Conclusion

Horizon 2020

- The CDR for EuPRAXIA, a **European accelerator facility based on plasma**, lasers and beam drivers, has been worked out with contributions from about 200 scientists.
  - **Technical clusters, five excellence centers and 1-2 construction sites** at existing laboratories could realize EuPRAXIA in the next 8-10 years.
  - **Hosts of excellence centers and one construction site have been identified**. Frascati would host the beam-driven plasma accelerato construction site.
  - Strong links to CERN and laser industry have been defined.
- EuPRAXIA can produce higher **quality beams for various applications.** Several parameters have advantages (short pulse length, short emission length, ...). In a survey we found strong interest for the facility.
- About **323 M€ invest would be needed over the next 8-10 years** to prepare the implementation, refine resource plans, perform the technical design, define implementation and to construct the facility.
- EuPRAXIA is a **new high-tech option for the European research infrastructure landscape**, connecting to cutting-edge science, innovation, European industry and international partners!

Consortium

16 Participants

25 Associated Partners

(as of December 2018)