This work has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.
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European Roadmap Reports for Advanced Accelerators

Ralph Assmann, DESY and INFN, & **Edda Gschwendtner**, CERN

thanks to European expert panel members, co-conveners Snowmass, Eric Esarey (LBNL), Massimo Ferrario (INFN), Carsten Welsch (Liverpool), Vladimir Shiltsev (FNAL), Andrei Seryi (JLAB), Frank Zimmermann (CERN), Rasmus Ischebeck (PSI), …

AAC 2022, Hauppauge, New York, USA

8 Nov 2022

iFAST

Innovation Fostering in Accelerator Science and Technology (I.FAST)

*I.FAST is coordinated by CERN and aims to **enhance innovation in the particle accelerator community**, mapping out and facilitating the development of breakthrough technologies common to multiple accelerator platforms. The project involves **49 partners, including 17 companies** as co-innovation partners, to explore new alternative accelerator concepts and advanced prototyping of key technologies.*

WP6 – Novel Particle Accelerators Concepts and Technologies

Includes **EAAC** organization & **strategic** discussions

WP coord: R. Assmann

- Task 1 (RA + M. Ferrario): **Novel Particle Accelerators Concepts and Technologies** (NPACT – EuroNNAc4)

  *Sub-task leaders: **B. Holzer** (CERN), **P. Nghie** (CEA), **A. Specka** (CNRS), **R. Walczak** (Oxford)*
- Task 2 (Leo Gizzi): **Lasers for Plasma Acceleration** (LASPLA)
- Task 3 (Cedric Thaury): **Multi-scale Innovative targets for laser-plasma accelerators** (MILPAT)
- Task 4 (Francois Mathieu): **Laser focal Spot Stabilization Systems**

New Eur. Roadmap Reports

Yellow Report CERN-2022-001

"**European Strategy for Particle Physics – Accelerator R&D Roadmap**"

270 pages total, considering “High field magents“, " High-gradient RF structures and systems“, "Bright muon beams and muon colliders“, “Energy-recovery linacs“

AND

“**High-gradient plasma and laser accelerators**“, which have 54 pages

ESFRI European Strategy Forum on Research Infrastructures

First accelerator project since 2016 (then Hi-Lumi-LHC):

EuPRAXIA plasma accelerator project

ESFRI projects are selected on European importance and shall be constructed wthin 10 years

iFAST

New Eur. Roadmap Reports

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ESFRI projects are selected on European importance and shall be constructed wthin 10 years

European Strategy for Particle Physics

- The **<u>European Strategy for Particle Physics</u>** is updated **<u>every 5 years</u>** in a procedure based on wide community input.
- Many of us provided input to this process:
  - Written statements from European Network for Novel Accelerators (EuroNNAc), AWAKE, ALEGRO and EuPRAXIA.
- Strategy defines future directions and priorities for particle physics in Europe and for CERN. Last update: **<u>2020</u>**.
- Outcome a great success for advanced accelerators:
  - Importance of accelerator R&D in general.
  - **Explicit mentioning of plasma and laser high gradient acceleration**.
  - **Request for accelerator R&D roadmap**, adequate resources, priorities, deliverables for next decade, synergy with other science fields, …

→ Expert Panel: European Particle Physics Roadmap for High-Gradient Novel Accelerators

Expert Panel – Panel chairs:
Chair: Ralph Assmann (DESY/INFN)
Deputy Chair: Edda Gschwendtner (CERN)

Panel members:
Kevin Cassou (IN2P3/IJCLab), Sebastien Corde (IP Paris), Laura Corner (Liverpool), Brigitte Cros (CNRS UPSay), Massimo Ferarrio (INFN), Simon Hooker (Oxford), Rasmus Ischebeck (PSI), Andrea Latina (CERN), Olle Lundh (Lund), Patric Muggli (MPI Munich), Phi Nghiem (CEA/IRFU), Jens Osterhoff (DESY), Tor Raubenheimer (SLAC), Arnd Specka (IN2PR/LLR), Jorge Vieira (IST), Matthew Wing (UCL).

Panel associated members:
Cameron Geddes (LBNL), Mark Hogan (SLAC), Wei Lu (Tsinghua U.) , Pietro Musumeci (UCLA)

Work performed: **Jan 2021 – Feb 2022**
Final report: Yellow Report CERN-2022-001

iFAST

Can we Shrink the Linear Collider?

Provide e- and e+ beams in the TeV energy regime and produce > 10^{34} cm^{-2} s^{-1} luminosity

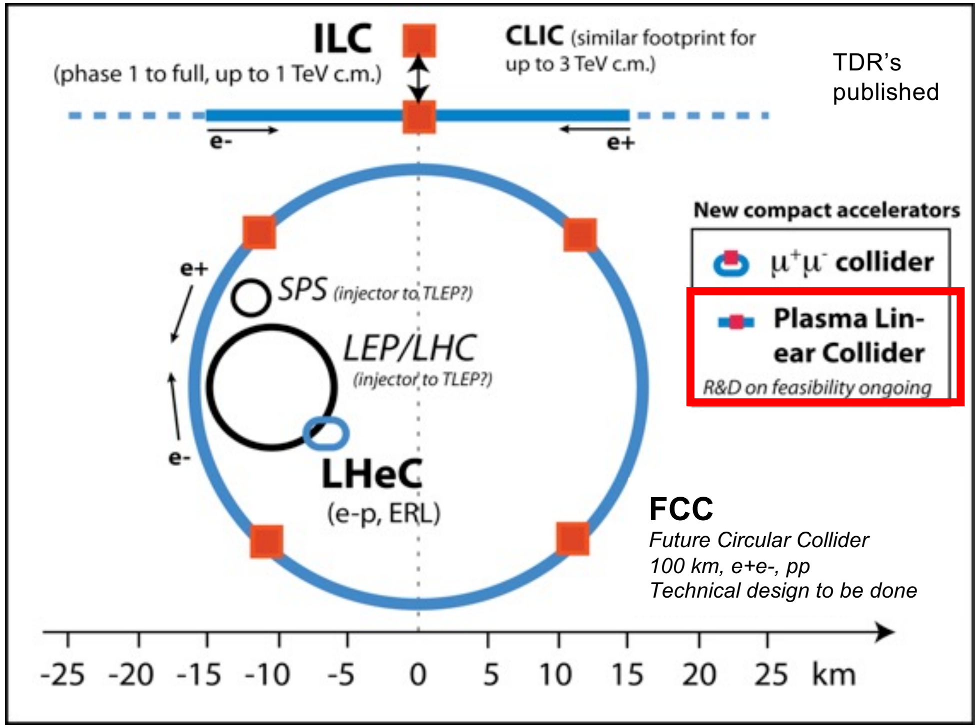


Table 1.3: Required parameters for a linear collider with advanced high gradient acceleration. Three published parameter cases are listed. Case 1 (PWFA) is a plasma-based scheme based on SRF electron beam drivers [88]. Case 2 (LWFA) is a plasma-based scheme based on laser drivers [89]. Case 3 (DLA) is a dielectric-based scheme [34].

Parameter	Unit	PWFA	LWFA	DLA
Bunch charge	nC	1.6	0.64	4.8×10^{-6}
Number of bunches per train	-	1	1	159
Repetition rate of train	kHz	15	15	20,000
Convoluted normalized emittance ($\gamma\sqrt{\epsilon_h\epsilon_v}$)	nm-rad	592	100	0.1
Beam power at 5 GeV	kW	120	48	76
Beam power at 190 GeV	kW	4,560	1,824	2,900
Beam power at 1 TeV	kW	24,000	9,600	15,264
Relative energy spread	%		$\leq$0.35	
Polarization	%		80 (for e^-)	
Efficiency wall-plug to beam (includes drivers)	%		$\geq$10	
Luminosity regime (simple scaled calculation)	$10^{34}cm^{-2}s^{-1}$	1.1	1.0	1.9

- **No fundamental show-stopper but a lot of R&D still required.**
- There can be very interesting and useful interim steps (non-linear QED, fixed target, dark matter, …)
- **Devil is in the details!** Answer requires detailed simulation, calculations, R&D, designs and tests!

Required Target Parameters

Provide e- and e+ beams in the TeV energy regime and produce > 10^{34} cm^{-2} s^{-1} luminosity

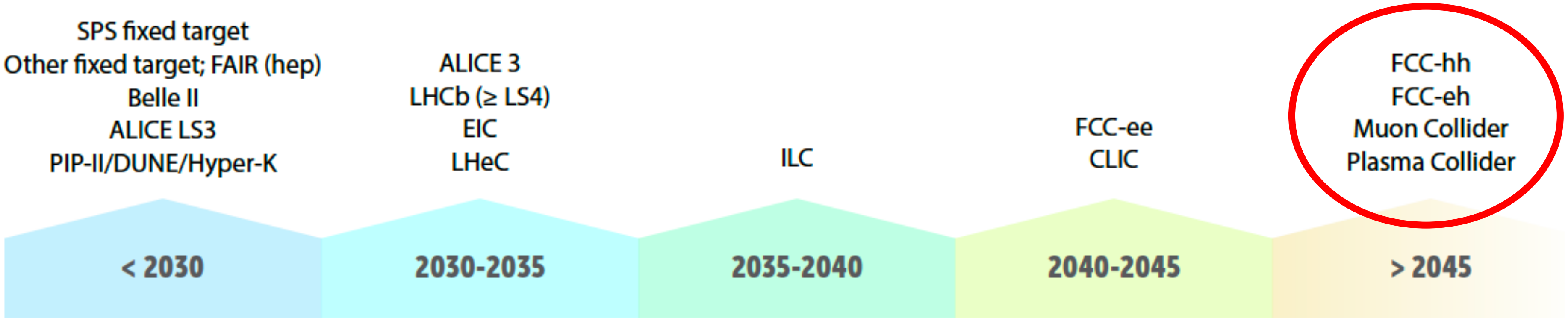
Parameter	Unit	PWFA	LWFA	DLA
Bunch charge	nC	1.6	0.64	4.8×10^{-6}
Number of bunches per train	-	1	1	159
Repetition rate of train	kHz	15	15	20,000
Convoluted normalized emittance ($\gamma\sqrt{\epsilon_h\epsilon_v}$)	nm-rad	592	100	0.1
Beam power at 5 GeV	kW	120	48	76
Beam power at 190 GeV	kW	4,560	1,824	2,900
Beam power at 1 TeV	kW	24,000	9,600	15,264
Relative energy spread	%		$\leq$0.35	
Polarization	%		80 (for e^-)	
Efficiency wall-plug to beam (includes drivers)	%		>10	
Luminosity regime (simple scaled calculation)	$10^{34}cm^{-2}s^{-1}$	1.1	1.0	1.9

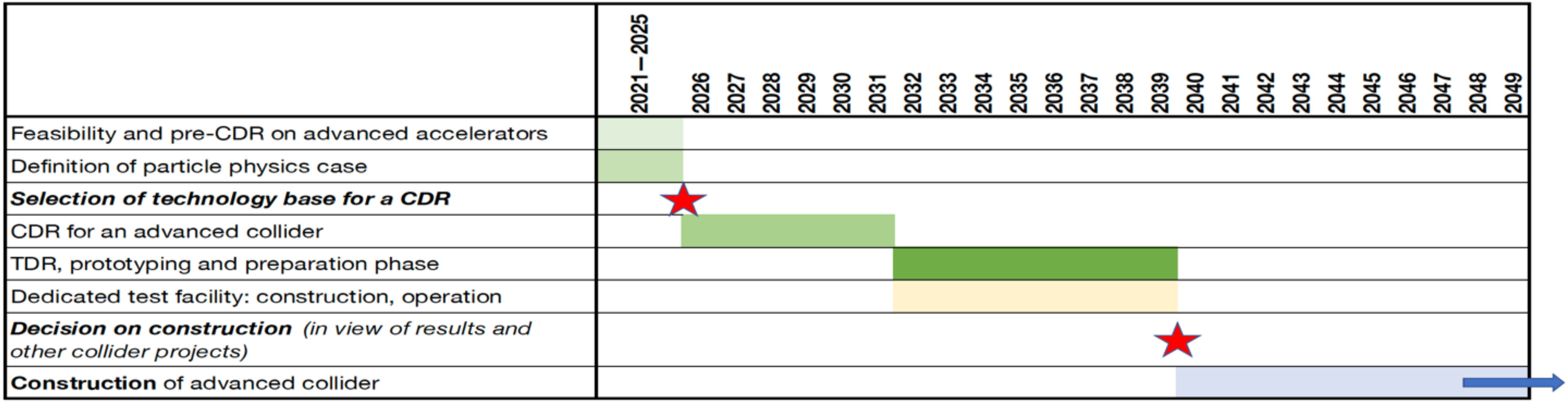
from expert panel report

iFAST

The Steps Towards an Advanced Collider

See expert panel report on European Accelerator R&D for Particle Physics





Three Pillars of Plasma R&D Roadmap

See expert panel report on European Accelerator R&D for Particle Physics

FEASIBILITY, PRE-CDR STUDY

Scope: 1st international, coordinated study for self-consistent analysis of novel technologies and their particle physics reach, intermediate HEP steps, collider feasibility, performance, quantitative cost-size-benefit analysis

Concept: Comparative paper study (main concepts included)

Milestones: Report high energy e^- and e^+ linac module case studies, report physics case(s)

Deliverable: Feasibility and pre-CDR report in 2025 for European, national decision makers

TECHNICAL DEMONSTRATION

Scope: Demonstration of critical feasibility parameters for e^+e^- collider and 1st HEP applications

Concept: Prioritised list of R&D that can be performed at existing, planned R&D infrastructures in national, European, international landscape

Milestones: High-rep rate plasma module, high-efficiency module with high beam quality, scaling of DLA/THz accelerators

Deliverable: Technical readiness level (TRL) report in 2025 for European, national decision makers

INTEGRATION & OUTREACH

Synergy and Integration: Benefits for and synergy with other science fields (e.g. structural biology, materials, lasers, health) and projects (e.g. EuPRAXIA, …)

Access: Establishing framework for well-defined access to distributed accelerator R&D landscape

Innovation: Compact accelerator and laser technology spin-offs and synergies with industry

Training: Involvement and education of next generation engineers and scientists

Case Study: High Energy Accelerator Module e⁻ & e⁺

Table 4.2: Specification for an advanced high energy accelerator module, compatible with CLIC [87]. Additional CLIC design values are listed for reference in the second part of the table.

Parameter	Unit	Specification
Beam energy (entry into module)	GeV	**175**
Beam energy (exit from module)	GeV	**190**
Number of accelerating structures in module	-	≥ 2
Efficiency wall-plug to beam (includes drivers)	%	≥ 10
Bunch charge	pC	833
Relative energy spread (entry/exit)	%	≤ 0.35
Bunch length (entry/exit)	µm	≤ 70
Convoluted normalised emittance ($\gamma\sqrt{\epsilon_h \epsilon_v}$)	nm	≤ 135
Emittance growth budget	nm	$\leq$ **3.5**
Polarisation	%	80 (for e^-)
Normalised emittance h/v (exit)	nm	900/20
Bunch separation	ns	0.5
Number of bunches per train	-	352
Repetition rate of train	Hz	50
Beamline length (175 to 190 GeV)	m	**250**
Efficiency: wall-plug to drive beam	%	58
Efficiency: drive beam to main beam	%	22
Luminosity	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.5

Acceleration module:

1. Take high quality beam at 175 GeV from the upstream accelerator
2. Accelerator by 15 GeV electrons or positrons
3. Deliver high quality beam at 190 GeV to next module

Should be demonstrated in simulation – guides selection of technology

Low Energy Particle Physics Cases Specified

Table 4.3: Specification for an electron beam for fixed-target (FT) experiments, generated by a dielectric laser accelerator (inspired by the eSPS specifications [88]) as well as for electron bunches from plasma accelerators for PEPIC [91–93], a low-luminosity LHeC-like collider [89] and for the LUXE experiment [90]. Such bunches (for PEPIC and LUXE) can also be used for a beam-dump experiment to search for dark photons. Note that the number of bunches per train in the European XFEL is 2700, but for LUXE only one is used.

Parameter	**Unit**	**single e FT**	**PEPIC**	**LUXE**
Bunch charge	pC	few e	800	250
Final energy	GeV	20	70	16.5
Relative energy spread	%	<1	2–3	0.1
Bunch length	µm	-	30	30–50
Normalised emittance	µm	100	10	1.4
Number of bunches per train	-	1	320	1
Repetition rate	-	1 GHz	0.025 Hz	10 Hz
Luminosity	10^{27} cm^{-2} s^{-1}	-	1.5	-

from expert panel report

The Advanced Accelerator R&D Project Plan

See expert panel report on European Accelerator R&D for Particle Physics

Table 4.4: Work packages and tasks in the minimal plan.

WP	Task	Short description	Invest Personnel
COOR		Coordination Plasma and Laser Accelerators for Particle Physics	—
FEAS		Feasibility and pre-CDR Study on Plasma and Laser Accelerators for Particle Physics	300 kCHF 75 FTEy
	FEAS.1	Coordination	
	FEAS.2	Plasma Theory and Numerical Tools	
	FEAS.3	Accelerator Design, Layout and Costing	
	FEAS.4	Electron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)	
	FEAS.5	Positron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)	
	FEAS.6	Spin Polarisation Reach with Advanced Accelerators	
	FEAS.7	Collider Interaction Point Issues and Opportunities with Advanced Accelerators	
	FEAS.8	Reach in Yearly Integrated Luminosity with Advanced Accelerators	
	FEAS.9	Intermediate steps, early particle physics experiments and test facilities	
	FEAS.10	Study WG: Particle Physics with Advanced Accelerators	
HRRP		Experimental demonstration: High-Repetition Rate Plasma Accelerator Module	1200 kCHF 30 FTEy
HEFP		Experimental demonstration: High-Efficiency, Electron-Driven Plasma Accelerator Module with High beam Quality	800 kCHF 10 FTEy
DLTA		Experimental demonstration: Scaling of DLA/THz Accelerators	500 kCHF 16 FTEy
SPIN		Experimental demonstration: Spin-Polarised Beams in Plasma Accelerators	350 kCHF 16 FTEy
LIAI		Liaison to Ongoing Advanced Accelerator Projects, Facilities, Other Science Fields	—

DEL3.1	12/25	High-Repetition Rate Plasma Accelerator Module	Demonstrates: at least 1 kHz characterised; robust lifetime ($> 10^9$ shots); only the plasma cell; without full repetition rate beam test but including cooling and power handling assessment. Long-term goal: 15 kHz repetition rate.
DEL4.1	12/25	High-Efficiency, Electron-Driven Plasma Accelerator Module with High Beam Quality	Beam demonstration of high efficiency PWFA module. 40% transfer efficiency from driver beam stored energy to witness beam stored energy
DEL5.1	12/25	Scaling of DLA/THz Accelerators	Staged dielectric laser or THz accelerator with 10 MeV energy gain, transverse and longitudinal focusing and at least two stages. Long-term goal: Massively scale-able design printed on a chip.
DEL6.1	12/25	Spin-Polarised Beams in Plasma Accelerators	Demonstration of polarised electron beams from plasma with 10–20% polarisation fraction. Long-term goal: Polarisation 85%.

Technical deliverables (above) point to high priority activities: high repetition rate, efficiency (power), scaling to high energy, spin polarization, …

Next step: Implementation & secure some funding for the particle physics R&D project

Resources Minimal Plan Advanced Acc. R&D

Table 4.6: Integrated resources for the minimal plan. Committed funds in the LIAI work package relate to funding in relevant ongoing projects and facilities (see Tables 4.9, 4.10 and 4.11)

WP	Task integrated resources			In-kind contributions	Committed funds
	FTEy	MCHF	G-core-h	FTEy	MCHF
COOR	0	0	0	2.5	0
FEAS	75	0.3	1.6	75	0
HRRP	30	1.2	0	3	0
HEFP	10	0.8	0	1	0
DLTA	16	0.5	0	2	0
SPIN	16	0.35	0	2	0
LIAI	0	0	0	2.5	$\sim$280
Sum	*147*	*3.15*	*1.6*	*88*	*$\sim$280*

Minimal plan would be around 25 MCHF project, mainly focused on the feasibility study FEAS. Note: High European funding in liaison projects LIAI → about 280 MCHF

Next : Implementation of Accelerator R&D Roadmap for Particle Physics

- Process again guided by Lab Director`s Group (LDG) in Europe
- Previous panels had completed their work and mandates. Partially new structures being set up.
- Advanced accelerator implementation effort led by **Wim Leemans** (DESY) with Rajeev Pattahil (STFC) as deputy. Wim Leeman`s message on update slides: “Regarding the European Roadmap strategy effort for plasma accelerators that I am chairing: **too early as we are still forming the team and exploring ways to secure funding**. Hopefully in the months to come.”
- However, parts of our strategy being implemented through approved projects (see **AWAKE** slides next) and roadmaps in fields mainly outside of Particle Physics (see **ESFRI/EuPRAXIA** slides later) → see committed resources in proposed WP LIAI listed before…

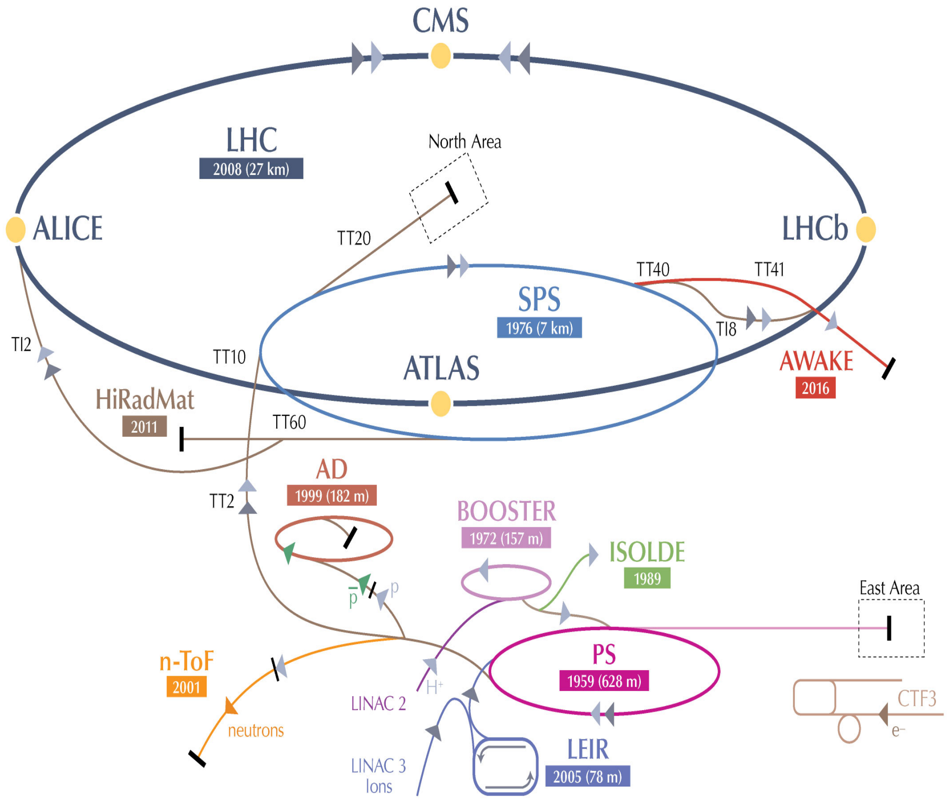
AWAKE

➔Has developed a clear scientific roadmap towards first particle physics applications within the next decade !

➔In AWAKE many general issues are studied, which are relevant for concepts that are based on plasma wakefield acceleration.

Paradigm change:
➔ Move from ‘acceleration R&D’ to an ‘accelerator’

AWAKE at CERN



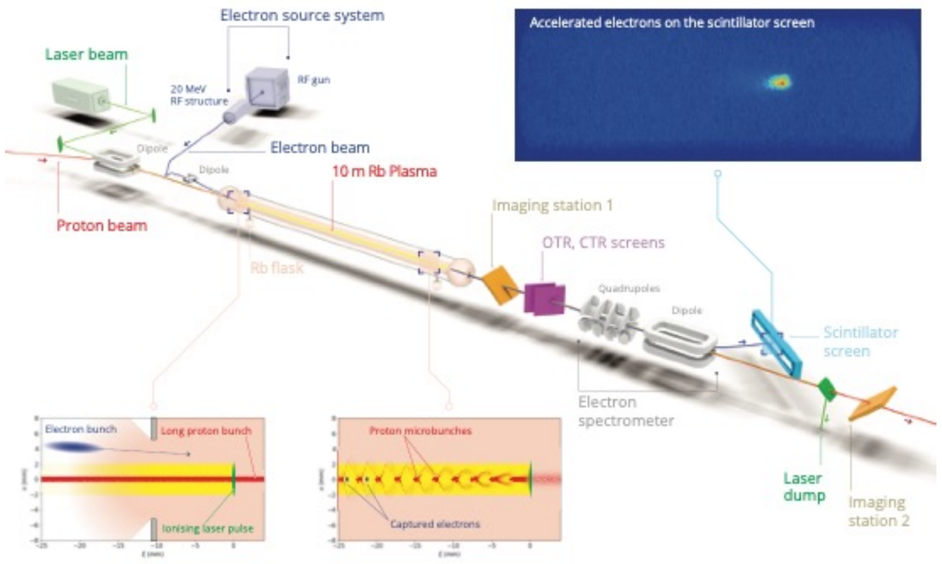
Advanced WAKEfield Experiment: Proof-of-Principle Accelerator R&D experiment at CERN to study proton driven plasma wakefield acceleration.
Collaboration of 23 institutes world-wide.

AWAKE Run 1 (2016-2018):
- ✓ 1st milestone: Demonstrated seeded self-modulation of the proton bunch in plasma (2016/17)
- ✓ 2nd milestone: Demonstrated electron acceleration in plasma wakefield driven by a self-modulated proton bunch. (2018)

AWAKE Run 2 (2021 – ~2030):
Accelerate an electron beam to high energies (gradient of 0.5-1GV/m) while preserving the electron beam quality and demonstrate scalable plasma source technology.

Once AWAKE Run 2 demonstrated: **First application of the AWAKE-like technology:** Particle physics experiments for e.g. dark photon search.

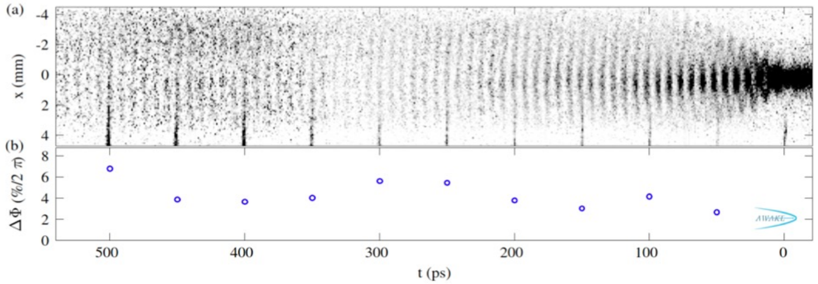
AWAKE Run 1 (2016 – 2018): Proof-of-Concept Demonstrated



→ 1st AWAKE Run 1 Milestone

- Phase stable and reproducible self-modulation of the proton bunches.

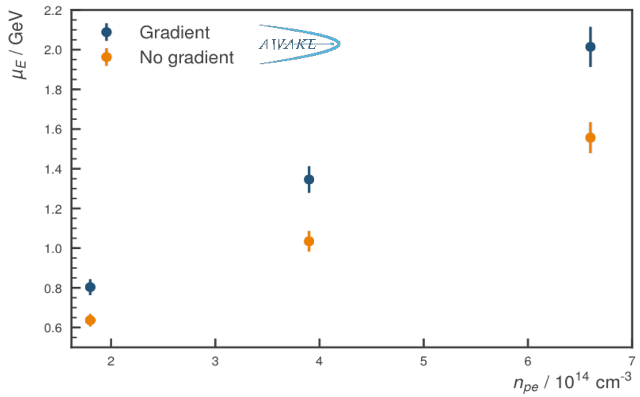
→ necessary for deterministic injection of an electron bunch into the accelerating and focusing phase of the wakefields



M. Turner et al. (AWAKE Collaboration), 'Phys. Rev. Lett. 122, 054801 (2019).
M. Turner, P. Muggli et al. (AWAKE Collaboration), Phys. Rev. Accel. Beams 23, 081302 (2020)
F. Braunmueller, T. Nechaeva et al. (AWAKE Collaboration), Phys. Rev. Lett. July 30 (2020).
A.A. Gorn, M. Turner et al. (AWAKE Collaboration), Plasma Phys. Control Fusion, Vol. 62, Nr 12 (2020).
F. Batsch, P. Muggli et al. (AWAKE Collaboration), Phys. Rev. Lett. 126, 164802 (2021).

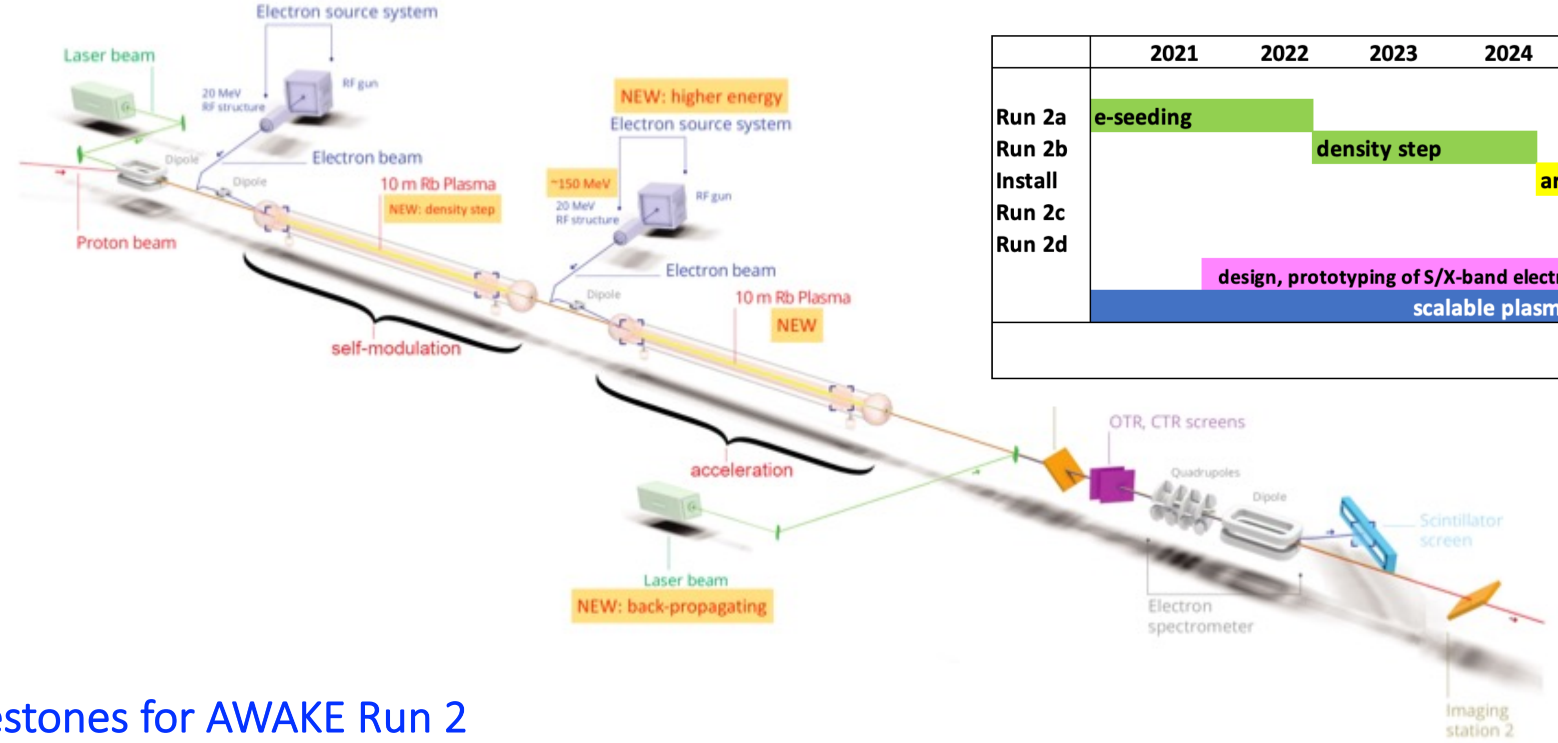
→ 2nd AWAKE Run 1 Milestone

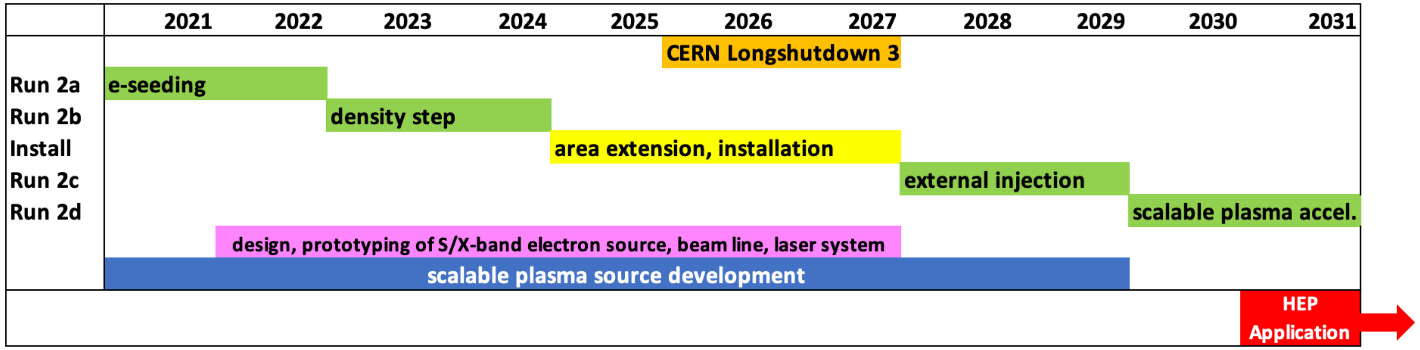
- Acceleration from 18 MeV to 2 GeV.
- Charge capture up to 100pC (~20%).



AWAKE Collaboration, Nature 561, 363 (2018)

AWAKE Run 2 (2021 – 2030): Towards an Accelerator





L. Verra et al. (AWAKE Collaboration), Phys. Rev. Lett. 129, 024802 (2022)

Milestones for AWAKE Run 2

✓ Run 2a: demonstrate the seeding of the self-modulation of the entire proton bunch with an electron bunch

- Run 2b: maintain large wakefield amplitudes over long plasma distances by introducing a step in the plasma density
- Run 2c: demonstrate electron acceleration and emittance preservation of externally injected electrons.
- Run 2d: development of scalable plasma sources to 100s meters length with sub-% level plasma density uniformity.

➔ Propose first applications for particle physics experiments with 50-200 GeV electron bunches!

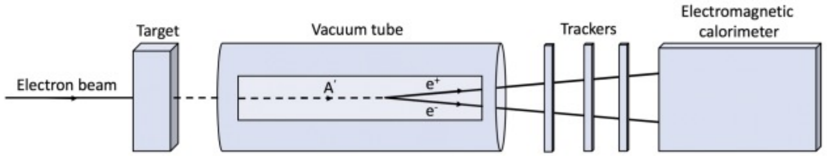
Particle Physics Applications with AWAKE-Like Technology

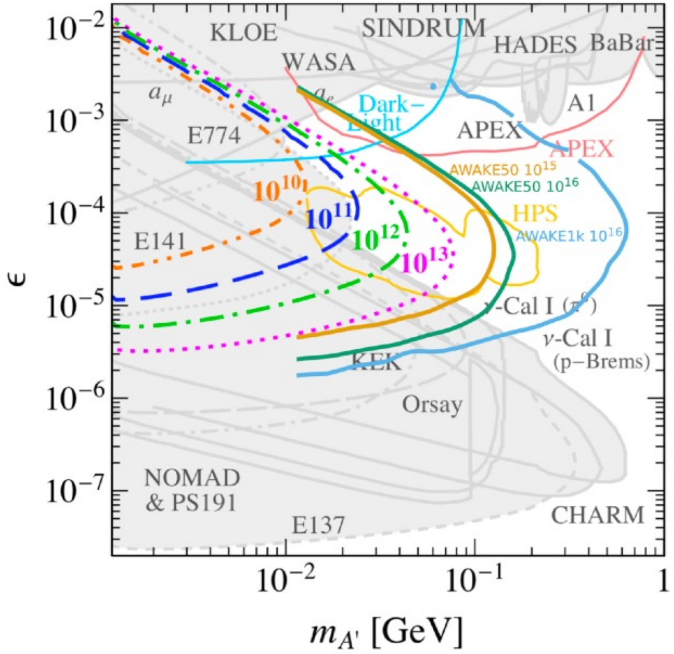
Many opportunities for first particle physics applications in the nearer future:

→ Beam quality sufficient for **fixed target experiments**
→ Currently for O(100) GeV electrons by scattering SPS protons on a target: inefficient and very low yield

➔ Beam Dump Experiment: Search for dark photons.

→ Decay of dark photon into visible particles (e.g. e+/e-)





→ Extension of mixing strength of the kinematic coverage for 50 GeV electrons and even more for 1 TeV electrons

➔ **Investigate non-linear QED** in electron- photon collisions.
➔ **Produce TeV-range electr**ons with an LHC p+ bunch: use for lower luminosity measurements in electron-proton or electron-ion collisions.

$\mathcal{L}$ Limited by proton accelerator repetition rate – look for high-cross-section processes to compensate.

New Eur. Roadmap Reports

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ESFRI Roadmap Update December 2021

Horizon Europe

E uropean
S trategy
F orum on
R esearch
I nfrastructures

https://roadmap2021.esfri.eu

Roadmap projects selected after thorough review by ESFRI committee and approved by **EU governments** every few years

2006 – 2008 – 2012 – 2016 – 2018 – **2021**

EuPRAXIA facility rendering picture

ESFRI Landmarks Roadmap 2021

(Physical Sciences & Engineering)

PHYSICAL SCIENCES & ENGINEERING

ESFRI LANDMARKS

NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	INVESTMENT COST (M€)	OPERATION COST (M€/Y)
CTA	Cherenkov Telescope Array	single-sited	gGmbH, 2014	2008	2024*	400.0	20.0
ELI ERIC	Extreme Light Infrastructure	single-sited	ERIC, 2021	2006	2018	850.0	80.0
ELT	Extremely Large Telescope	single-sited	ESO#	2006	2027*	1,309.0	48.0
EMFL	European Magnetic Field Laboratory	distributed	AISBL, 2015	2008	2014	170.0	20.0
ESRF EBS	European Synchrotron Radiation Facility Extremely Brilliant Source	single-sited	ESRF#	2016	2020	128.0	82.0
European Spallation Source ERIC	European Spallation Source	single-sited	ERIC, 2015	2006	2026*	3,009.0	140.0
European XFEL	European X-Ray Free-Electron Laser Facility	single-sited	European XFEL#	2006	2017	1,540.0	137.0
FAIR	Facility for Antiproton and Ion Research	single-sited	GmbH, 2010	2006	2025*	NA	NA
HL-LHC	High-Luminosity Large Hadron Collider	single-sited	CERN#	2016	2027*	1,408.0	136.0
ILL	Institut Max von Laue - Paul Langevin	single-sited	ILL#	2006	2012	188.0	100.0
SKAO	Square Kilometre Array Observatory	single-sited	SKAO, 2011	2006	2027*	1,986.0	77.0
SPIRAL2	Système de Production d'Ions Radioactifs en Ligne de 2e génération	single-sited	GANIL	2006	2019	307.3	5.2

https://roadmap2021.esfri.eu

ESFRI Projects Roadmap 2021

https://roadmap2021.esfri.eu

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ESFRI PROJECTS

NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	INVESTMENT COST (M€)	OPERATION COST (M€/Y)
EST	European Solar Telescope	single-sited		2016	2029*	200.0	12.0
ET	Einstein Telescope	single-sited		2021	2035*	1,912.0	37.0
EuPRAXIA	European Plasma Research Accelerator with Excellence in Applications	distributed		2021	2028*	569.0	30.0
KM3NeT 2.0	KM3 Neutrino Telescope 2.0	distributed		2016	2020	196.0	3.0

PHYSICAL SCIENCES & ENGINEERING

- Two new entries in 2021: **Einstein Telescope (ET)** and **EuPRAXIA**
- EuPRAXIA is the only accelerator facility selected in the last 6 years
- EuPRAXIA is the first plasma accelerator facility ever included

PHYSICAL SCIENCES & ENGINEERING

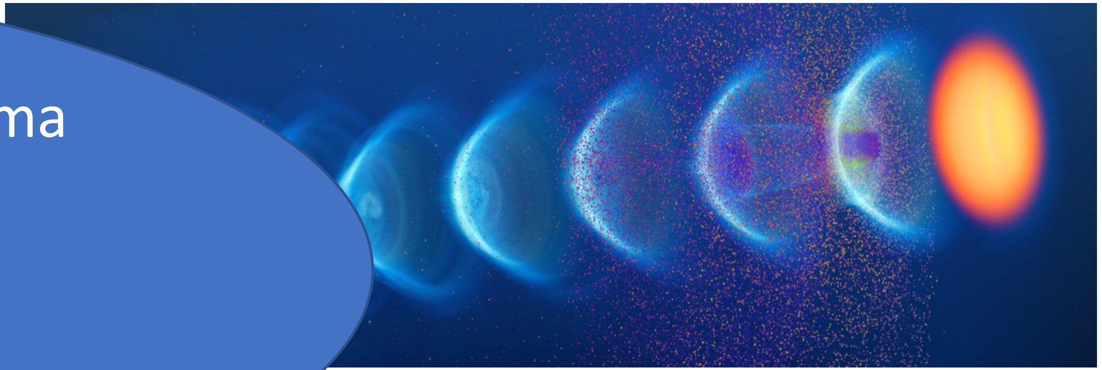
What is EuPRAXIA About?

Horizon Europe

1

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

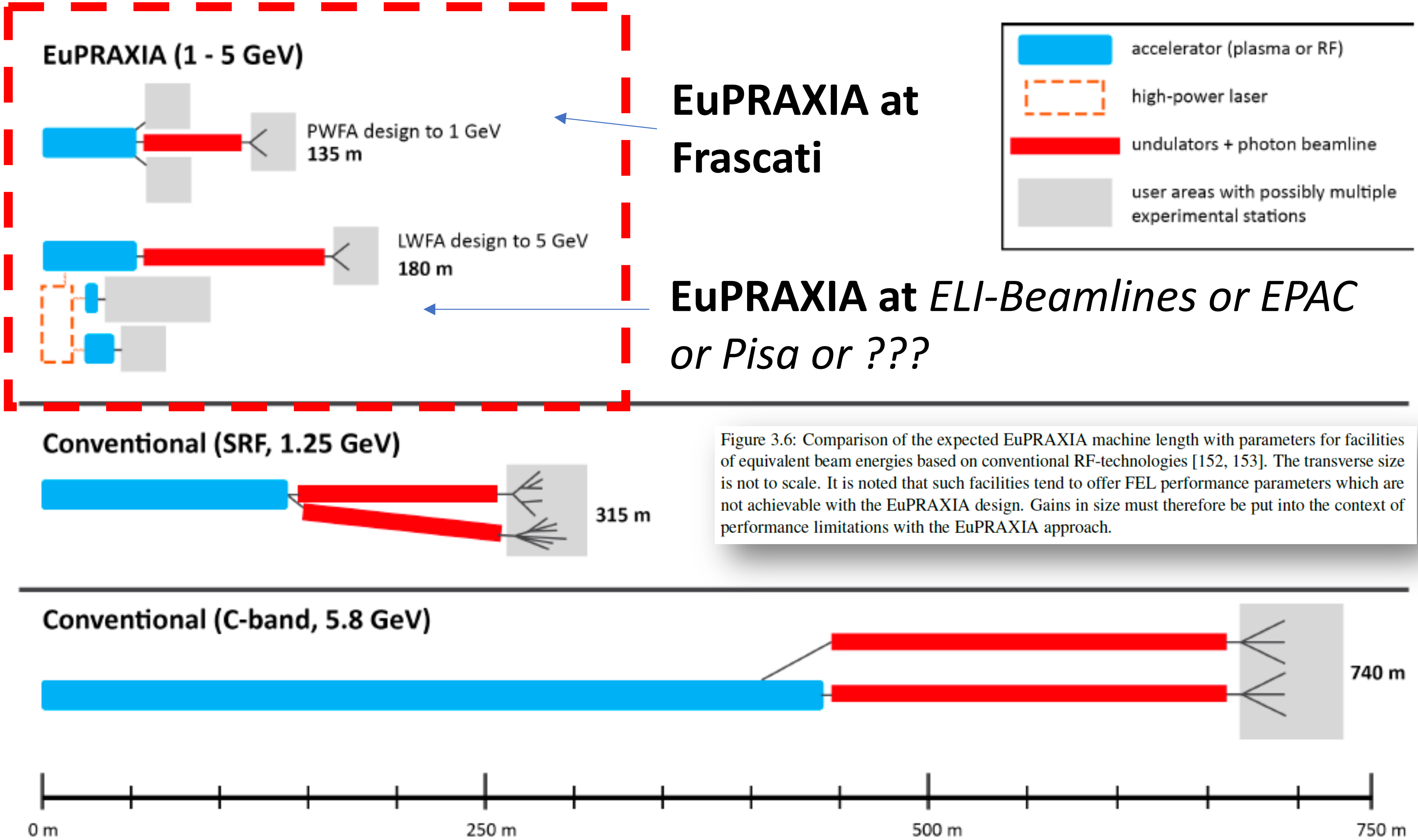
Shrink down the facility size



2020 Publication of Conceptual Design Report
600+ page CDR, 240 scientists contributed

EuPRAXIA Facility Size: C O M P A C T

Horizon Europe



EuPRAXIA at Frascati

EuPRAXIA at ***ELI-Beamlines or EPAC or Pisa or ???***

Figure 3.6: Comparison of the expected EuPRAXIA machine length with parameters for facilities of equivalent beam energies based on conventional RF-technologies [152, 153]. The transverse size is not to scale. It is noted that such facilities tend to offer FEL performance parameters which are not achievable with the EuPRAXIA design. Gains in size must therefore be put into the context of performance limitations with the EuPRAXIA approach.

- Distributed
- **2 Construction Sites**
- Several Excellence Centers

IMPORTANT:
EuPRAXIA design includes **innovative concepts & solutions** but also lab space, RF injectors, transfer lines, undulator lines, shielding, ... (the **real space** needed)

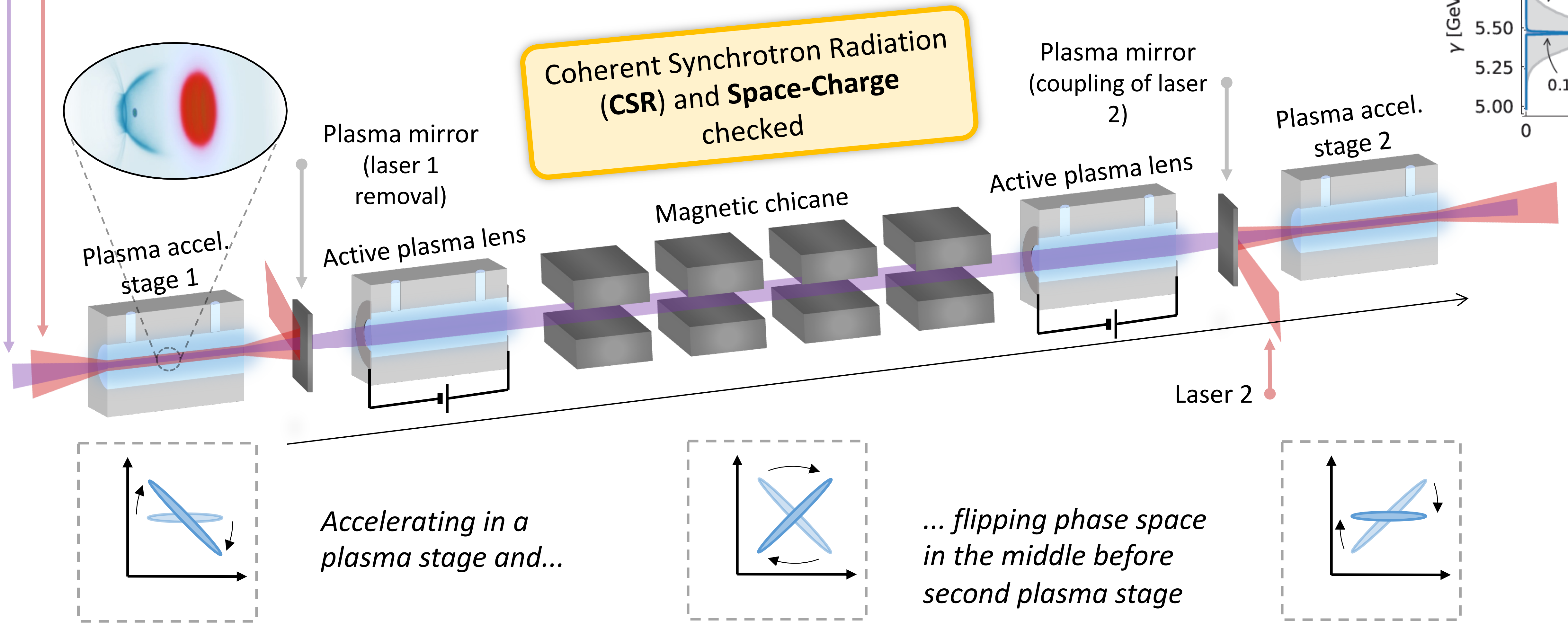
EuPRAXIA Innovation Ex.: High Quality Staging

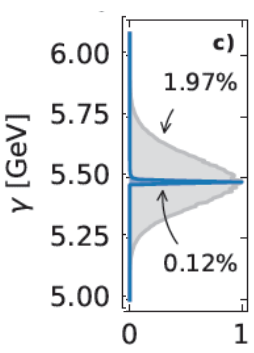
in 2 stages to 5 GeV, Touschek Prize 2020

Horizon Europe

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

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





Accelerating in a plasma stage and...

... flipping phase space in the middle before second plasma stage

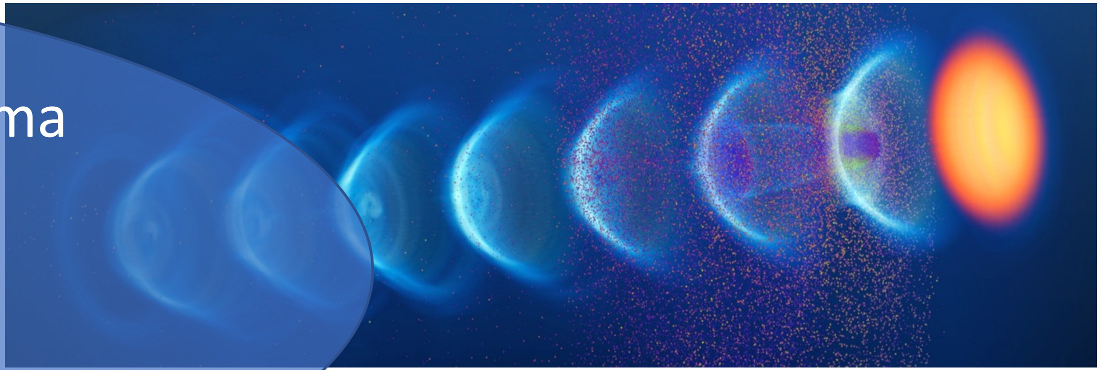
What is EuPRAXIA About?

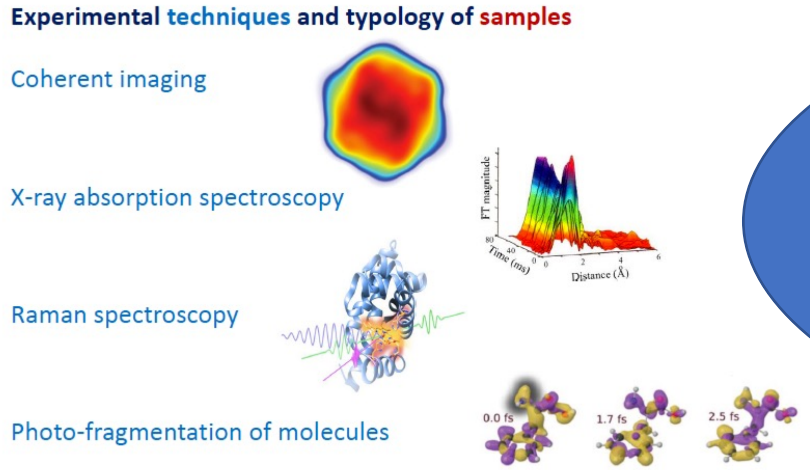
Horizon Europe

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



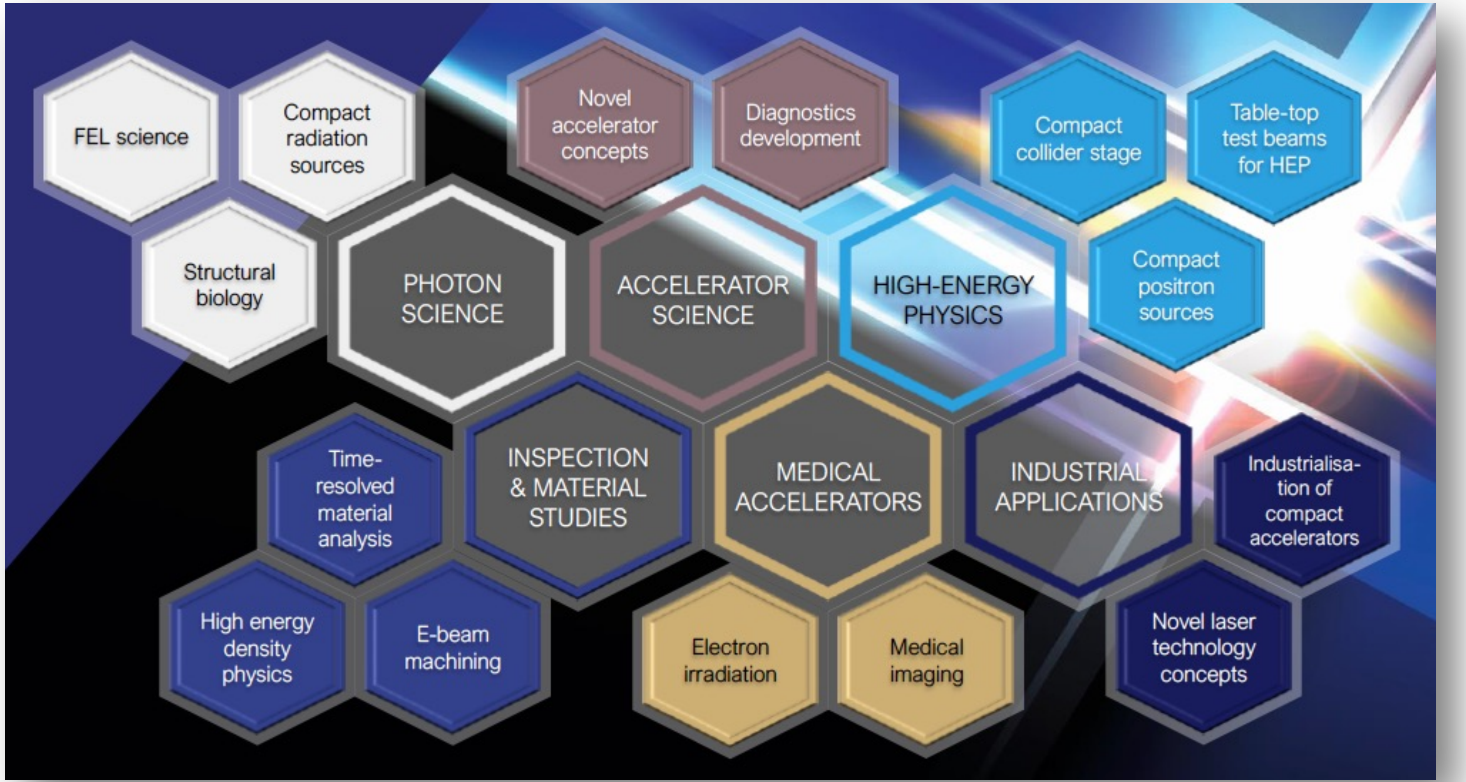


2

Producing particle and photon pulses to support several urgent and timely science cases

Enable frontier science in new regions and parameter regimes

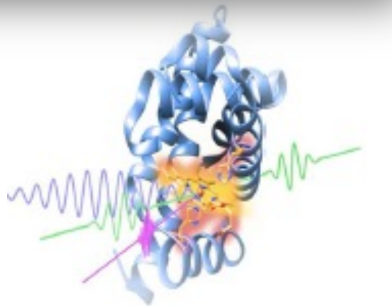
Versatile – Designed for Users in Multiple Science Fields



*Delivers 10-100 Hz **ultra-short** pulses*

- **Electrons** (0.1-5 GeV, 30 pC)
- **Positrons** (0.5-10 MeV, 10^6)
- **Positrons** (GeV source)
- **Lasers** (100 J, 50 fs, 10-100 Hz)
- **Betatron X rays** (1-110 keV, 10^{10})
- **FEL light** (0.2-36 nm, 10^9-10^{13})

Topics of research: proteins, viruses, bacteria, cells, metals, semiconductors, superconductors, magnetic materials, organic molecules



R. Assmann & E. Gschwendtner, AAC 2022

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

Distributed RI Concept

Horizon Europe

Co-funded by the European Union

Advisory & Oversight Boards

- Open Innovation Forum
- Scientific & Technical Advisory Committee
- User Meetings & Program Committees
- Resource Review Board
- Quality Assurance Panel
- Ethical Advisory Board

Collaboration Board

1 representative per Member & Observer
1 Chair and 1 Deputy Chair

Project Coordinator + Management Team

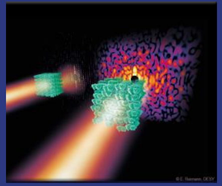
Steering Committee

Central EuPRAXIA Management

Construction Site Frascati

Local Project Team

Beam-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, particle physics, medicine, materials



Location: metropolitan area Rome, Italy

Construction Site

(tbd in 2023)

Local Project Team

Laser-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, medicine, materials

Four candidate sites described in conceptual design report

Excellence Centres

Local Project Teams

- *Plasma Simulations & Theory*
- *Laser-Plasma Acceleration & FEL Developments*
- *Plasma Acceleration & High-Rep-Rate Developments*
- *Advanced Application Beamlines*
- *Technology Incubator to Laser Science Users*
- *EuPRAXIA user e-needs infrastructure*

Technical design tests, prototyping, production

Project Clusters (WPs)

- *Theory & Simulation*
- *Laser Technology*
- *Plasma Components & Systems*
- *RF Technology*
- *Magnets & Other Beamline Components*
- *Diagnostics*
- *Applications*
- *Transfor-mative Innovation Paths*
- *Training, Outreach & Dissemi-nation*
- *Implemen-tation & Layout*

Technical Design Report

National projects and facilities

Individual groups at universities and laboratories

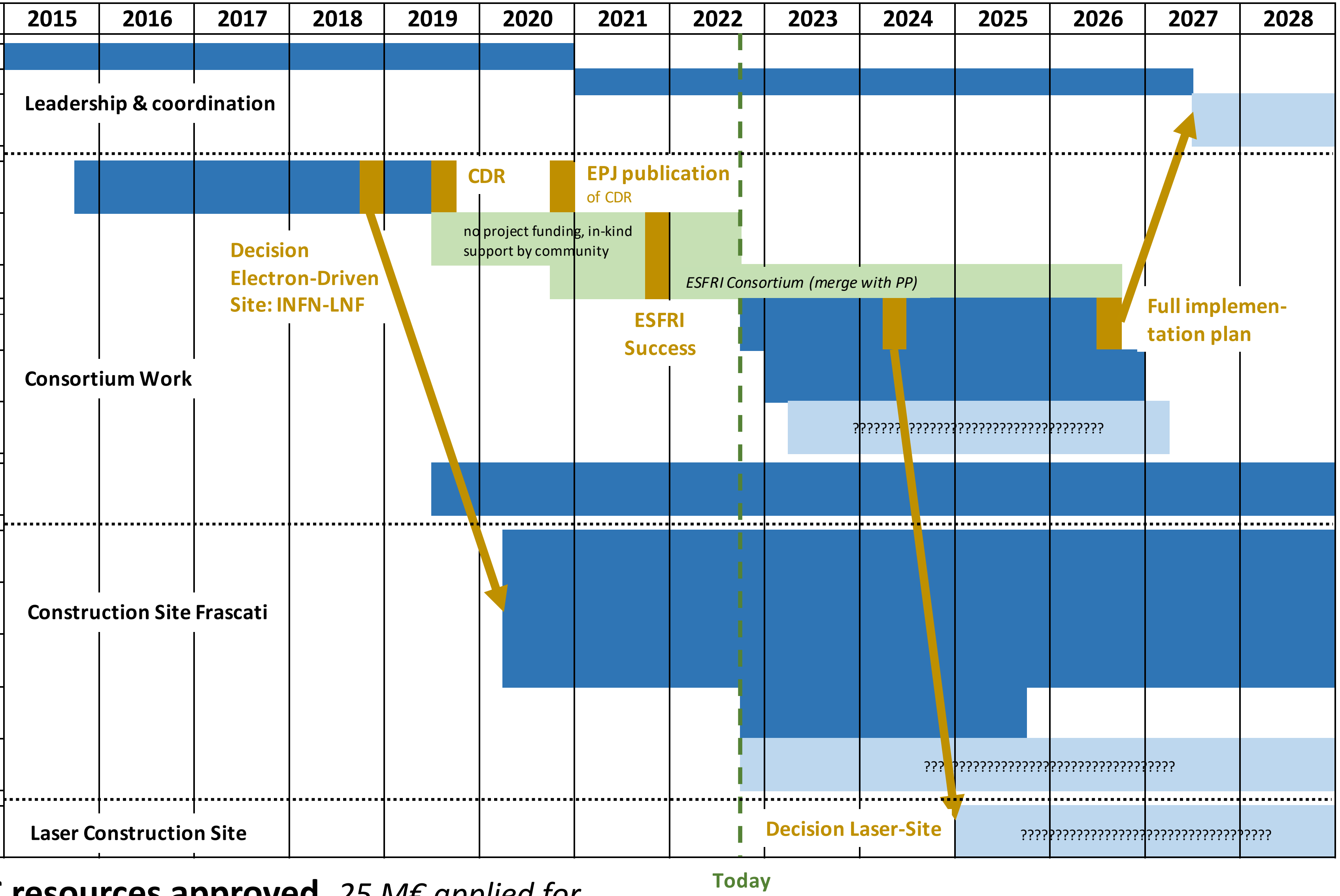
Organization for initial Preparatory Phase in dark blue

Features to be added with decision on second site or in later phases are indicated in lighter shades

EuPRAXIA Project Overview & Funding Lines

Horizon Europe

Activity	Resources	Origin
Headquarter Hamburg/DESY	0 €	In-kind DESY
Headquarter Frascati INFN-LNF	0 €	In-kind INFN and DESY
*EuPRAXIA **Legal Structure of European RI***		*Defined in Preparatory Phase*
Conceptual Design Project	6.000.000 €	EU + in-kind (included here)
Application ESFRI Roadmap, Funding applications	0 €	In-kind DESY, INFN and EuPRAXIA consortium
ESFRI Consortium		
Preparatory Phase Project	8.310.000 €	EU, UK,Switzerland + in-kind (included here)
EuPRAXIA Doctoral Network	2.600.000 €	EU
CREATE (includes EuPRAXIA R&D) - proposed - reserve list	*15.000.000 €*	EU INFRATECH
CNRS project PALLAS (letter J.L. Biarrotte 30.3.2021)	1.670.000 €	CNRS France
EuPRAXIA **Construction in Frascati LNF-INFN** (EuPRAXIA@SPARClab)	108.000.000 €	Italian government invest (plus personnel)
Local EuPRAXIA support projects	7.000.000 €	Regional Lazio funding
Confinancing Regional Funds, preparation building project	7.000.000 €	INFN direct funds
EuPRAXIA Advanced Photon Source (EuAPS)	22.000.000 €	PNRR (EU/Italian recovery funding)
EuPRAXIA beamline support - in discussion	*10.000.000 €*	Regional Lazio funding
Site 2 (laser site) implementation		Defined in Preparatory Phase
Total (available)	162.580.000 €	
Total (applied)	25.000.000 €	



162.6 M€ resources approved, *25 M€ applied for*

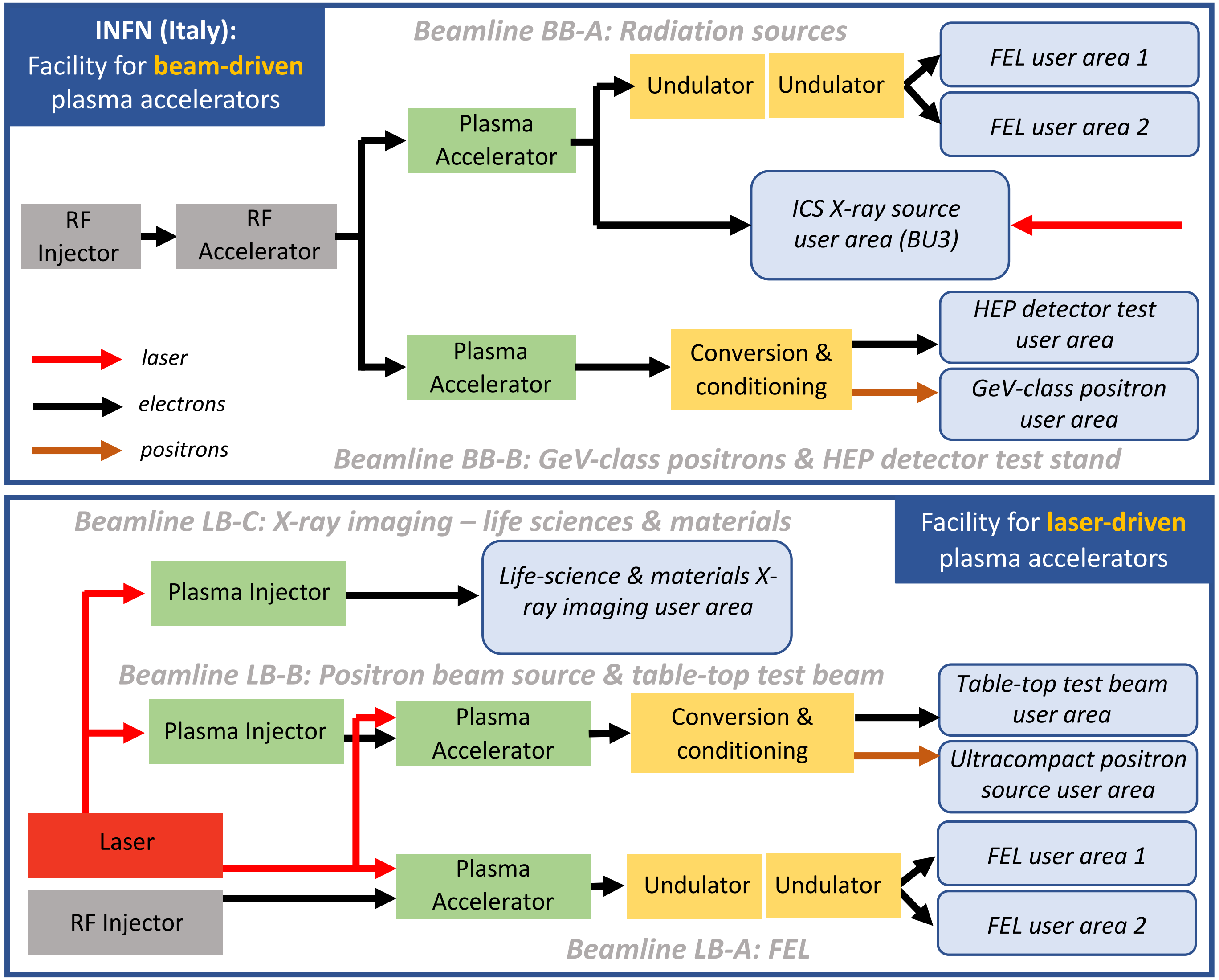
Phased Implementation of Construction Sites

Horizon Europe

	Laser-driven	Beam-driven
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 **1** ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area **2** ✓ Table-top test beams user area ✓ FEL user area 2 ✓ FEL to 5 GeV	✓ ICS source beamline + user area ✓ HEP detector tests user area ✓ FEL user area 2 ✓ FEL to 5 GeV
Phase 3	✓ High-field physics beamline / user area ✓ Other future developments	✓ Medical imaging beamline / user area ✓ Other future developments

1: INFN-LNF construction funding 108 M€

2: INFN/CNR/TorVer demo facility 22 M€ (PNRR)

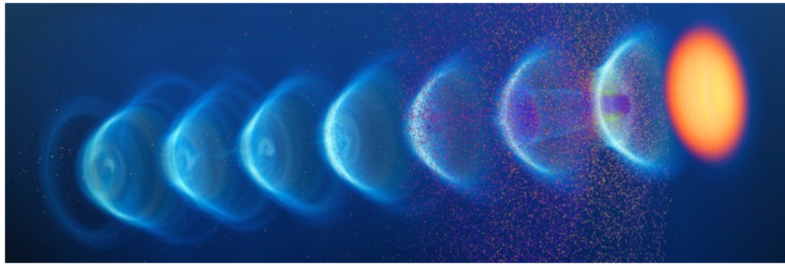


EuPRAXIA-PP (Preparatory Phase) Key Facts

Horizon Europe

Prepares the implementation of the full RI in Europe

- Total project volume (including in-kind): **8.3 M€**
    - EU funding: **2.49 M€** (EU without in-kind)
    - Outside EU **0.69 M€** (Switzerland)
      0.51 M€ (UK)
- Work organized in 16 Work Packages
- Project dates: **1 Nov 2022 – 31 Oct 2026**
- Coordinator and location of headquarters: **INFN**
- **34** participating organizations from 12 countries
- Will establish a "Board of Financial Sponsors" with representatives of funding agencies.
- So far **~ 25%** of total M&P funding (**569 M€**) secured. Site 1 is essentially financed



EuPRAXIA-Preparatory Phase Consortium

34 Institutes from 12 Countries → to be merged with ESFRI Consortium

Horizon Europe

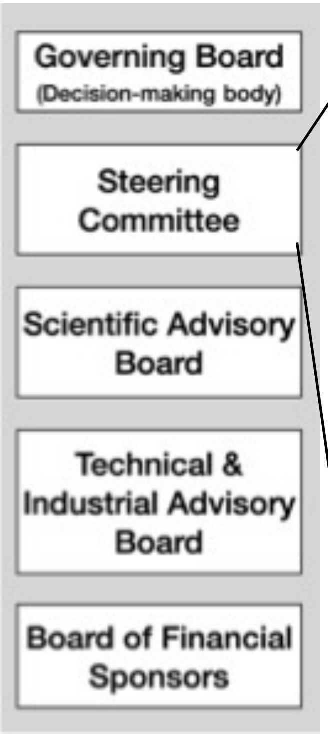
EuPRAXIA Preparatory Phase

Coordinator

Complemented by institutes in **EuPRAXIA ESFRI consortium: additional 17 institutes** from France, Germany, Poland, Sweden, United Kingdom, China, Japan, United States. Russian institutes presently suspended.

PP Steering Committee: Leaders Behind EuPRAXIA

Horizon Europe



WP1 - Coordination & Project Management
R. Assmann, INFN & DESY
M. Ferrario, INFN

WP2 - Dissemination and Public Relations
C. Welsch, U Liverpool
S. Bertellii, INFN

WP3 - Organization and Rules
A. Specka, CNRS
A. Ghigo, INFN

WP4 - Financial & Legal Model. Economic Impact
A. Falone, INFN

WP5 - User Strategy and Services
F. Stellato, U Tor Vergata
E. Principi, ELETTRA

WP6 - Membership Extension Strategy
B. Cros, CNRS
A. Mostacci, U Sapienza

WP7 - E-Needs and Data Policy
R. Fonseca, IST
S. Pioli, INFN

WP8 - Theory & Simulation
J. Vieria, IST
H. Vincenti, CEA

WP9 - RF, Magnets & Beamline Components
S. Antipov, DESY
F. Nguyen, ENEA

WP10 - Plasma Components & Systems
K. Cassou, CNRS
J. Osterhoff, DESY

WP11 - Applications
G. Sarri, U Belfast
E. Chiadroni,U Sapienza

WP12 - Laser Technology, Liaison to Industry
L. Gizzi, CNR
P. Crump, FBH

WP13 - Diagnostics
A. Cianchi, U Tor Vergata
R. Ischebeck, EPFL

WP14 - Transformative Innovation Paths
B. Hidding, U Strathclyde
S. Karsch, LMU

WP15 - TDR EuPRAXIA @SPARC-lab
C. Vaccarezza, INFN
R. Pompili, INFN

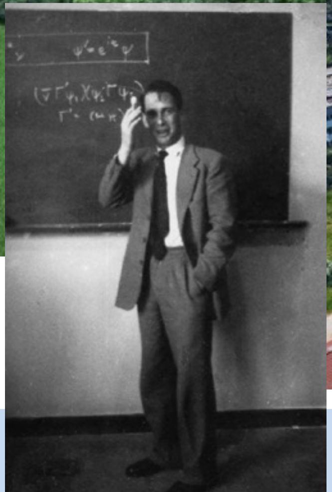
WP16 - TDR EuPRAXIA Site 2
A. Molodozhentsev, ELI-Beamlines
R. Pattahil, STFC

WP's on coordination & implementation as ESFRI RI (organization, legal model, financing, users)

WPs on technical implementation and sites

Headquarter and Site 1: EuPRAXIA@SPARClab

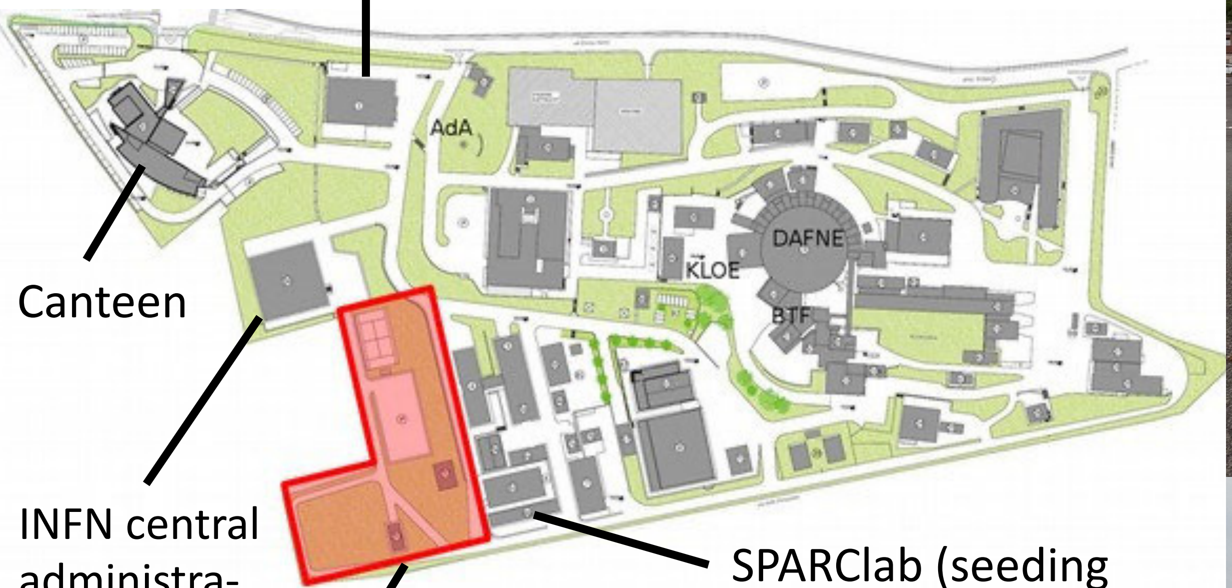
- Frascati`s future facility
- > 130 M€ invest funding
- Beam-driven plasma accelerator
- Europe`s most compact and most southern FEL
- The world`s most compact RF accelerator (X band with CERN)



It Fits the Frascati Site

(also fits sites at a large university, hospital, company, …)

Directorate building



Canteen

INFN central administra-tion

SPARClab (seeding with plasma acc.)

EuPRAXIA @ SPARClab

(European site 1)

Vladimir Shiltsev

viva Eupraxia!

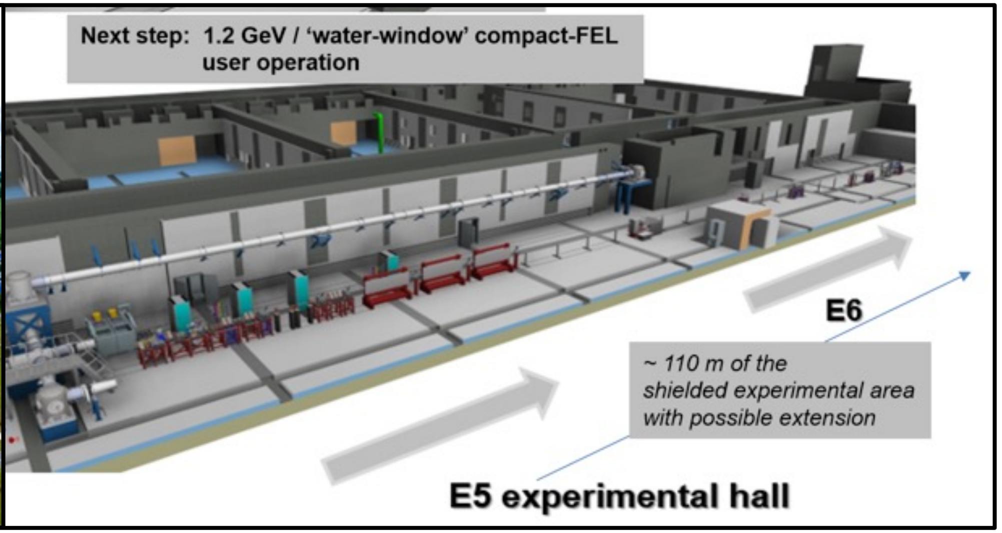
An: Tor Raubenheimer, Ralph Assmann

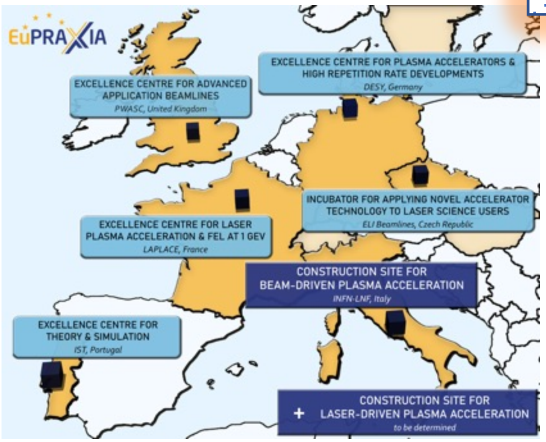
15. September 2022 um 12:07

Tor Raubenheimer SLAC, Stanford University, USA

Vladimir Shiltsev, Fermilab National Laboratory, USA

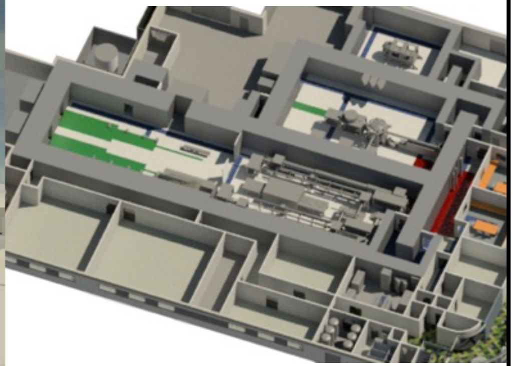
Selection Laser Site: Candidates from CDR





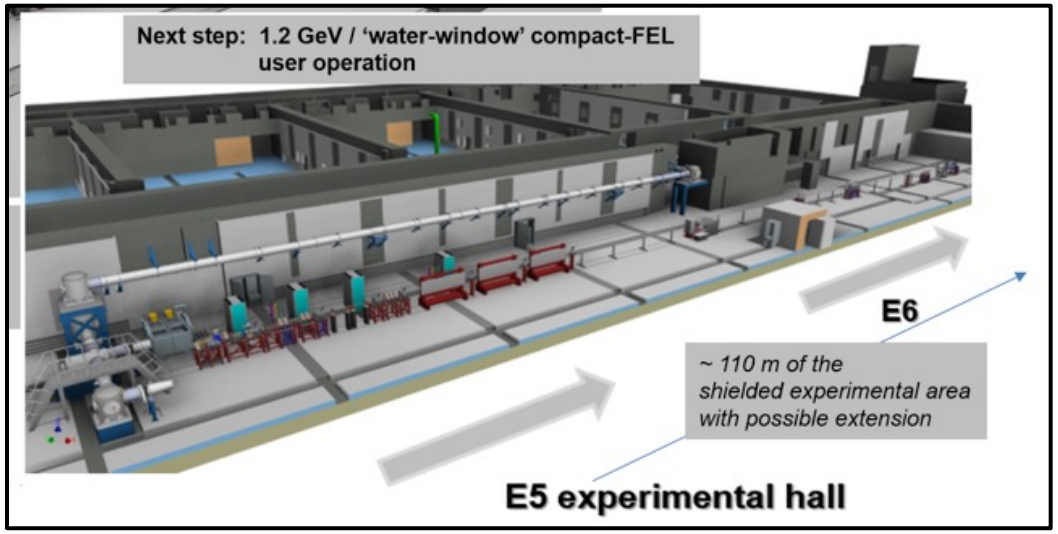
EuPRAXIA @ EPAC

Rutherford, STFC, UK



CNR Campus Pisa

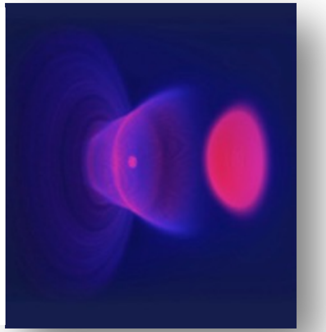
Visit to ELI-Beamlines (13 - 14 Oct 2022)



Data Rate and Networking Capacity

(numbers refer to maximum rate operation at 100 Hz)

Data Source	Data rate	Data / exp for online analysis	Reduced data / exp for long term storage	Long term storage (reduced data)	Exchange (derived data and meta data)
Modeling and simulations (3D)	300 TB / case	900 TB	1 TB	0.1 PB/y	12 TB/y
Machine monitoring	20 TB / h	2.4 PB	5 TB	0.17 PB/y (A) 0.33 PB/y (B)	20 TB/y
End user exp. (e.g. PCO Edge at 8 MB @ 100 Hz)	2.9 TB / h	207 TB	20 TB	0.66 PB /y (A) 1.32 PB/y (B)	100 TB/y
Total				**≈ 2.6 PB/y**	**≈ 132 TB/y**



- Networking capacity **10 Gbit/s** sufficient for data rates
- Exists at Frascati (LHC computing needs) and the EuPRAXIA candidate sites – benefit of existing sites
- Specified for 1 PB high performance parallel file system (online analysis) and 100 GBE → see E-Infrastructure slide)

E Infrastructure Concept and Scale

Level	Plans for Resource Use
Institutional	• **1 PByte** high performance parallel file system • **100 GBE** network connection on site • **~ 8192 cores, 32 TByte** main memory for cloud hardware with Infiniband connect • **16 GPUs** for Machine Learning / fast image analysis • **Open Source cloud infrastructure** (Open Stack + scalable data analytics via e.g. Jupyter Hub, Apache Kafka, ..)
Regional	• Tier 3 centers at **universities** for offline data analysis and small-scale simulations • Tier 2 centers at **laboratories** for data analysis and capacity simulations
National	• Tier 1 and especially Tier 0 systems such as **MARCONI→LEONARDO**, both for full-scale 3D capability simulations but also for high performance data analysis of selected data sets, especially when developing AI surrogate models of the accelerator
International	• Build on EuPRAXIA partner links to **WLCG** and the **EGI** Federation • EuPRAXIA will contribute to and exploit **EOSC** in its digital infrastructure • **PRACE** *(Partnership for Advanced Computing in Europe)* for large-scale simulations & AI learning

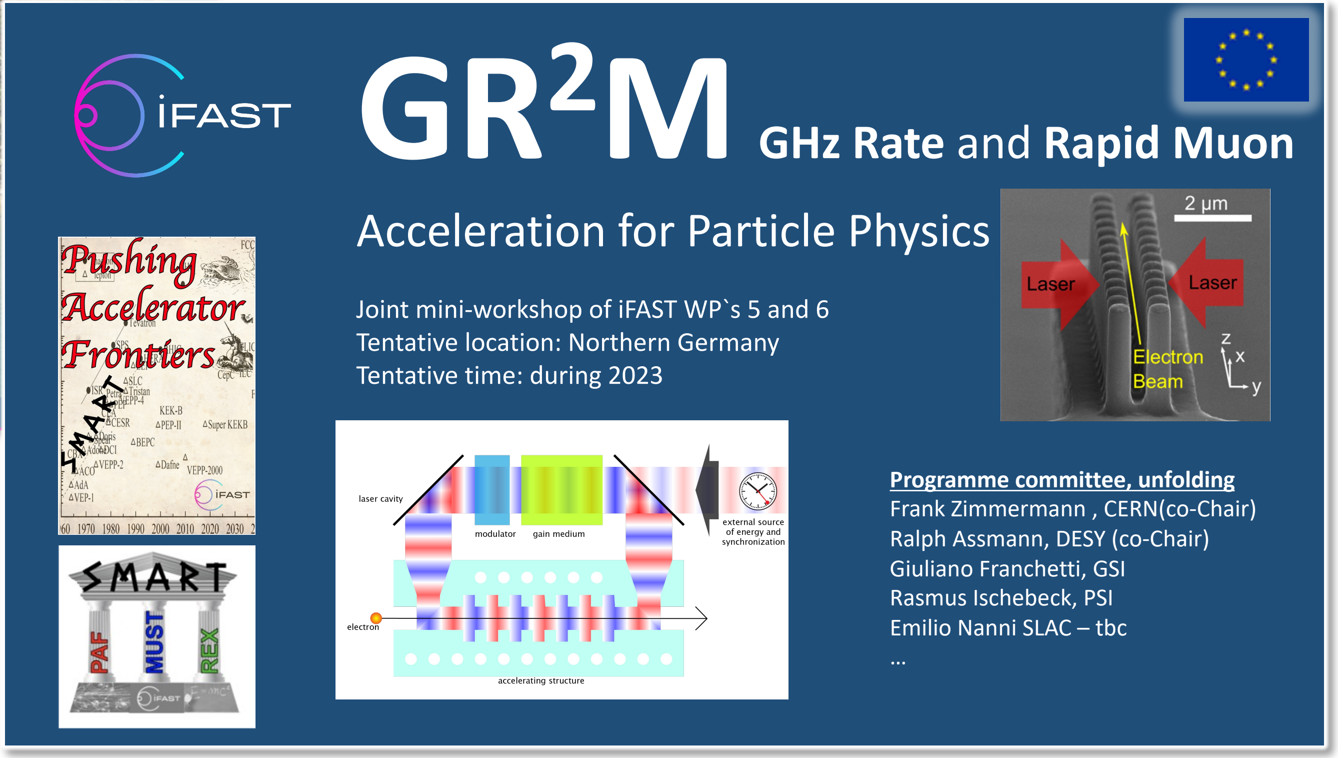
Conclusion

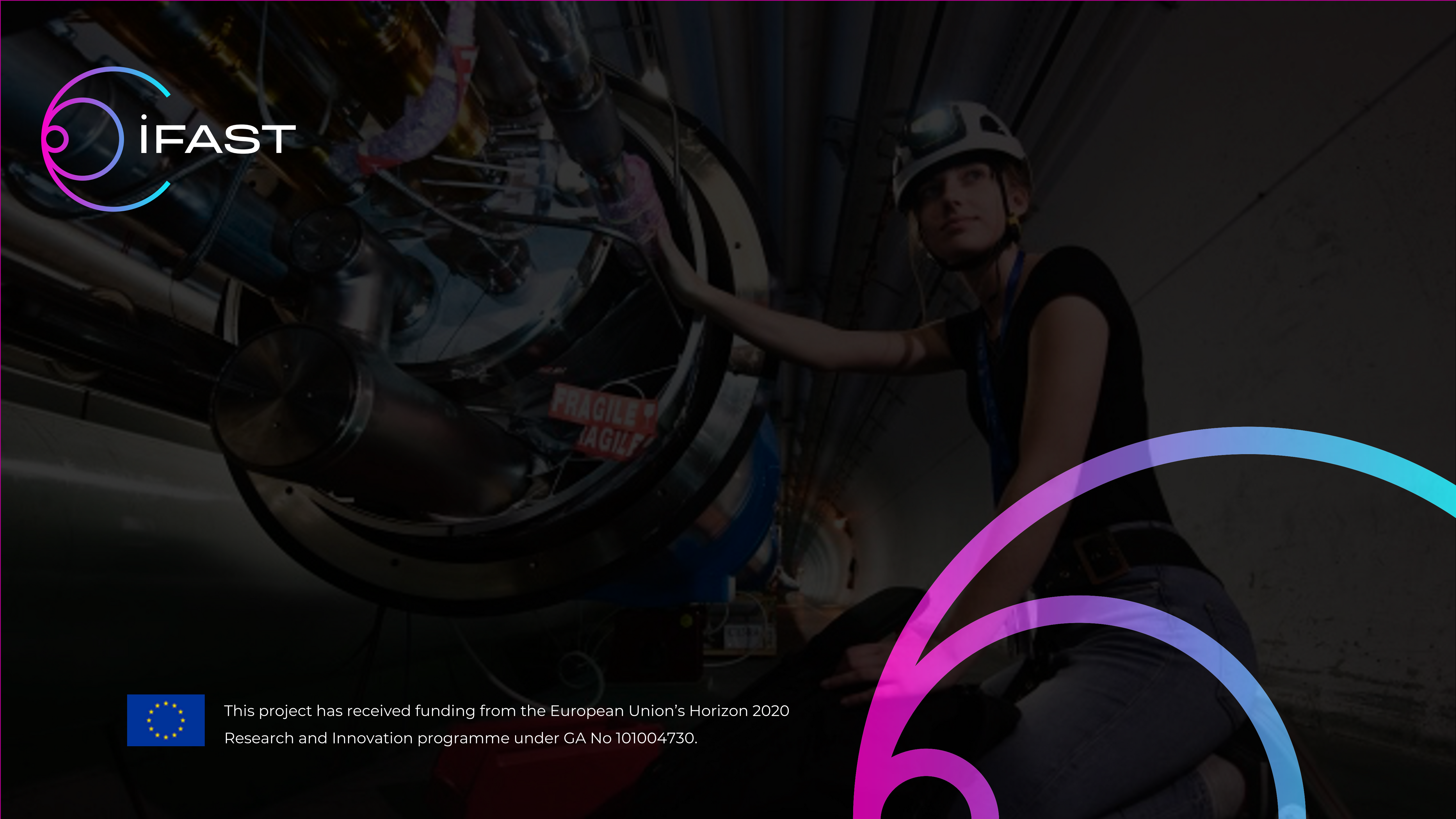
- Advanced accelerators positioned prominently in two recently published roadmaps in Europe: ESPP ARD and ESFRI.
- Roadmaps translate into major European activities ongoing
  - For applied science and accelerator R&D in EuPRAXIA (e- driven and laser driven)
  - For particle physics in AWAKE (p driven plasma acceleration)
  - For particle physics in implementation of European Particle Physics roadmap for accelerator R&D → to be reported by Wim Leemans once defined
- Particle physics is the grand goal but near-term science applications are realistic, timely & important: attracting funding on the path to the collider

Upcoming iFAST sponsored events in Europe

iFAST WP6

iFAST WP5 & WP6





This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

Outcome for Accelerator R&D

3

High-priority future initiatives

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. ***The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***