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

I.FAST Period 2 Review, 15.07.2024

Report on WP6

Novel particle accelerators concepts and technologies

Leonida A. GIZZI

CNR, Istituto Nazionale di Ottica, Pisa, Italy

Task 2 Leader

Also on behalf of:
M. Ferrario, INFN, Italy (WP6 and Task 1 Leader)
C. Thaury, CNRS, France (Task 3 Leader)
F. Mathieu, CNRS, France (Task 4 Leader)

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WP6 -Novel Particle Accelerators Concepts and Technologies

Objectives

- Define a roadmap towards development and applications of novel accelerators (Networking)
- Organise the biannual European Advanced Accelerator Concepts workshop (EAAC Workshops)
- Build a roadmap for new, efficient laser drivers for laser-plasma accelerators (Strategy)
- Develop innovative targets for laser-plasma acceleration (Technical)
- Develop a new passive system to improve laser-driver control and quality (Technical)

- **Ralph Assmann (former WP Leader) left DESY end of August 23**, now at GSI, staying connected through Frankfurt Goethe University research group.
- **Massimo Ferrario** new WP6 Leader
- Task 1 (R.A. + M. Ferrario): **Novel Particle Accelerators Concepts and Technologies** (NPACT – **EuroNNAc4**) M1 – M48
  *Sub-task leaders: **B. Holzer** (CERN), **D. Minenna** (CEA), **A. Specka** (CNRS), **R. Walczak** (Oxford)*
- Task 2 (Leo Gizzi): **Lasers for Plasma Acceleration** (LASPLA) M1 – M48
- Task 3 (Cedric Thaury): **Multi-scale Innovative targets for laser-plasma accelerators** (MILPAT) M1 – M32
- Task 4 (Francois Mathieu): **Laser focal Spot Stabilization Systems** (L3S) M1 – M36

Participants: CEA, CERN, CNR, CNRS, DESY, INFN, U. OXFORD, THALES, AMPLITUDE Technologies

WP6 Deliverables and Milestones

Deliverables related to WP6		
D6.1: EAAC workshops and strategies. **ACTIVITY IN PROGRESS** *Report on the EAAC workshops as strategic forums for international accelerator R&D and resulting strategies*	M42	Nov. 2024
D6.2: LASPLA Strategy. **ACTIVITY IN PROGRESS** *Report on a strategy for laser drivers for plasma accelerators.*	M46	Mar. 2025
D6.3: Electron acceleration experiments with new targets. *Report on electron acceleration with micro-scale target at a kHz repetition rate, and with long targets at the multi-Joule level.* **REPORT DELIVERED**	M24	
D6.4: Improvement of the laser intensity stability on target. **REPORT DELIVERED** *Report showing the stability on two laser facilities before and after improvement.*	M36	

MS21: Report on the novel accelerator landscape in Europe, facilities, projects and capabilities at the beginning of the 2020's. Lead – DESY, **M24**, Publication, website (Task 6.1) **REPORT DELIVERED**

MS22: LASPLA Workshop/School. Lead – CNR, M30, Report (Task 6.2) REPORT DELIVERED

MS23: Target manufacturing and characterization. Lead – CNRS, **M12** Report (Task 6.3) - **REPORT DELIVERED**

MS24: Hypothesis on the causes of the instabilities of the focal spot profile. Lead – CNRS, **M24** Publication (Task 6.4)- **REPORT DELIVERED**

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WP6.1 Novel particle accelerators, EuroNNAc and EuPRAXIA

Task Leader: M. Ferrario, INFN-LNF

EAAC 2023

Ralph Assmann (GSI)
Massimo Ferrario (INFN)

198 Participants

163 Delegates

35 Student Grants

We provide funding to the EAAC workshop, in particular rooms, proceedings, student grants, van der Meer prize award, (about **350,000 € since 2013**, the first EAAC)

17–22 Sept. 2023 Hotel Hermitage, La Biodola Bay, Isola d'Elba, Italy

Task 6.1 6th European Advanced Accelerator Concepts workshop

YEAR 3 - Held on 18-22 September 2023 at Elba, Italy

Workshop supported by EU via IFAST

EUROPEAN NETWORK FOR NOVEL ACCELERATORS EuroNNAc4 NPACT supported by EU via I-FAST

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

Workshop hosted by:

INFN Istituto Nazionale di Fisica Nucleare

	Monday 18th		Tuesday 19th		Wednesday 20th		Thursday 21st		Friday 22nd
09:00	*Opening remarks*	09:00	2023 AWAKE Run results (E. Gschwendtner)	09:00	Status and recent results of FLASHForward (F. Peña)	09:00	Probing strong-field QED in beam-plasma collisions (A. Matheron)		
09:20	Free electron lasers driven by plasma accelerators: status and near-term perspectives (M. Litos)	09:30	The EuPRAXIA ESFRI Preparatory Phase (R. Assmann)	09:35	High-quality 1 GeV electron beam with a 50 TW laser (C. Thaury)	09:35	Coherence and superradiance from a plasma-based quasiparticle accelerator (B. Malaca)	09:20	High average power, high rep rate lasers: Technological challenges towards multi-disciplinary applications (J. Collier)
10:00	New ideas for high beam quality from plasmas for FELs (B. Hidding)	10:00	EuPRAXIA@SPARC_LAB (A. Del Dotto)	10:10	Experimental Demonstration of Laser Guiding and Wakefield Acceleration in a Curved Plasma Channel (M. Chen)	10:10	Accelerator on a chip: Recent results and perspectives for applications (R. Shiloh)	10:00	Toward an Inertial Fusion Energy Future: Challenges and Opportunities in Science & Technology (Tammy Ma)
10:40	Coffee Break	10:30	Coffee Break	10:40	Coffee Break	10:40	Coffee Break	10:40	Coffee Break
11:00	Advancement in plasma sources towards high repetition rate operation (A. Alejo)	10:50	EuPRAXIA Second Site Options (A. Specka)	11:00	3D structure of microbunched plasma-wakefield-accelerated electron beams inferred by coherent optical transition radiation (M. Laberge)	11:00	Acceleration of polarized protons from laser-plasmas (L. Reichwein)	11:00	A hybrid, asymmetric, linear Higgs factory (HALHF) (C. A. Lindstrøm)
11:30	Modeling a novel laser-driven acceleration scheme using particle-in-cell simulations on exascale-class supercomputers (H. Vincenti)	11:15 11:25 11:35 11:45 11:55	View from ELI-Beamlines (A. Molodozhentsev) View on EPAC (R. Pattathil) View from CNR (L. A. Gizzi) View on CLPU (M. Rodriguez Frias) View on Excellence Centers (M. Ferrario)	11:30	Temperature effects in plasma-based positron acceleration (S. Diederichs)	11:30	Ion acceleration activities at ELI NP with the acceleration of more than 100 MeV protons (D. Doria)	11:30	The plans to prepare the next European Strategy (R. Pattathil)
12:00	On the Confluence of Data-Driven Techniques and Laser-Plasma Acceleration (A. Döpp)	12:10	EuPRAXIA Full Implementation: Round Table	12:00	FACET-II: Status of the first experiments and the road ahead (M. Hogan)	12:00	High energy proton acceleration at DRACO-PW and radiobiological applications (Josefine Metzkes-Ng)	12:00	Advanced Accelerator Concept activities at Snowmass (C. Geddes)
12:30	Lunch Break	12:30	Lunch Break	12:30	Lunch Break	12:30	Lunch Break	12:30	Lunch Break
16:00	Coffee Break	16:00	Coffee Break	16:00	Coffee Break	16:00	Coffee Break	16:00	Coffee Break
	Parallel Session		**Parallel Session**		**Parallel Session**		**Parallel Session**		**Plenary Session**
16:20 - 18:45	**WG1**:Plasma-based accelerators and ancillary components **WG2**: Laser technology (WP6 - Task2) **WG3**: Theory and simulations **WG5**: Applications	16:20 - 18:45	**WG1**:Plasma-based accelerators and ancillary components **WG2**: Laser technology (WP6 - Task2) **WG4**: High gradient vacuum structures **WG6**: Ion acceleration and developments towards fusion **WG7**: Beam diagnostics, instrumentation, Machine Learning	16:20 - 18:45	**WG1**:Plasma-based accelerators and ancillary components **WG3**: Theory and simulations **WG5**: Applications **WG6**: Ion acceleration and developments towards fusion **WG8**: Plasma sources and related diagnostics	16:20 - 18:45	**WG1**:Plasma-based accelerators and ancillary components **WG2**: Laser technology (WP6 - Task2) **WG4**: High gradient vacuum structures **WG7**: Beam diagnostics, instrumentation, Machine Learning **WG10**: ALEGRO towards colliders	16:20 17:00 17:45 18:30	**Laser plasma accelerators: then and now through cutting-edge experiments** (V. Malka) **Simon Van der Meer Award** **Poster Prizes Ceremony and talks** *Closing remarks*
19:00	**Poster Session**	19:00	**Poster Session**	19:00	**Poster Session**				
20:30	Dinner	20:30	Dinner	20:30	Dinner	20:30	**Social Dinner**	20:30	Dinner

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Dedicated IFAST LASPLA Workshop @ EAAC2023

EUPRAXIA: A New European High-Tech User Facility

A project stemming from the EURONNAC > EAAC plasma accelerator community building supported by I.FAST

1

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

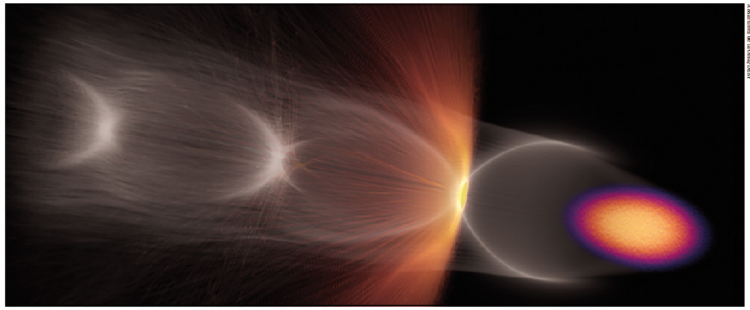
Shrink down the facility size
Improve Sustainability

2

Producing particles and photons to support several urgent and timely science cases

Drive short wavelength FEL
Pave the way for future Linear Colliders

https://www.eupraxia-facility.org/



A Martinez de la Ossa/DESY

Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

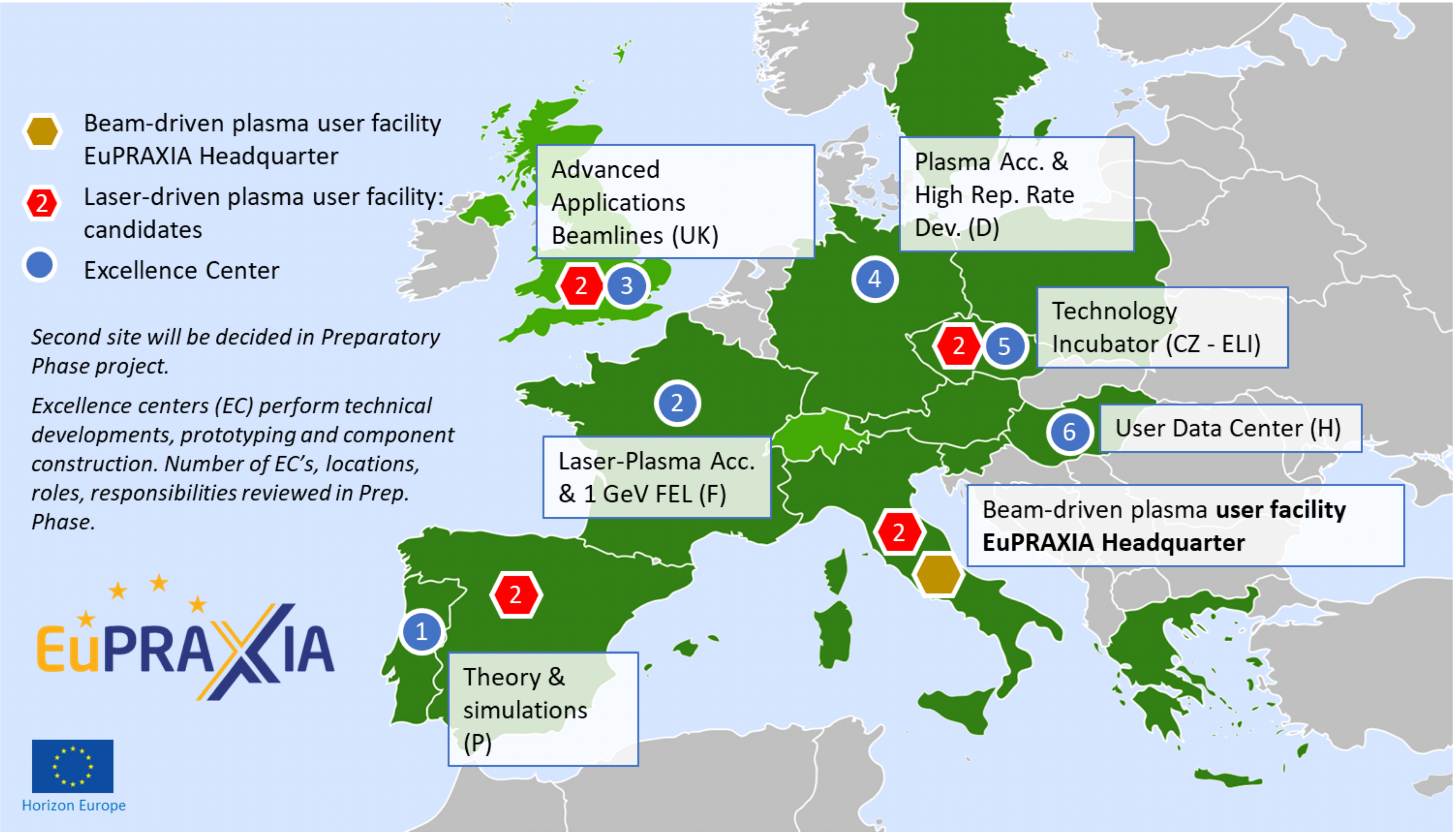
Energetic beams of particles are used to explore the fundamental forces of nature, produce known and unknown particles such as the Higgs boson at the LHC, and generate new forms of matter, for example at the future FAIR facility. Photon science also relies on particle beams: electron beams that emit pulses of intense synchrotron light, including soft and hard X-rays, in either circular or linear machines. Such light sources enable time-resolved measurements of biological, chemical and physical structures on the molecular down to the atomic scale, allowing a diverse global community of users to investigate systems ranging from viruses and bacteria to materials science, planetary science, environmental science, nanotechnology and archaeology. Last but not least, particle beams for industry and health support many societal applications ranging from the X-ray inspection of cargo containers to food sterilisation, and from chip manufacturing to cancer therapy.

This scientific success story has been made possible through a continuous cycle of innovation in the physics and technology of particle accelerators, driven for many decades by exploratory research in nuclear and particle physics. The invention of radio-frequency (RF) technology in the 1920s opened the path to an energy gain of several tens of MeV per metre. Very-high-energy accelerators were constructed with RF technology, entering the GeV and finally the TeV energy scales at the Tevatron and the LHC. New collision schemes were developed, for example the mini "beta squeeze" in the 1970s, advancing luminosity and collision rates by orders of magnitudes. The invention of stochastic cooling at CERN enabled the discovery of the W and Z bosons 40 years ago.

However, intrinsic technological and conceptual limits mean that the size and cost of RF-based particle accelerators are increasing as researchers seek higher beam energies. Colliders for particle physics have reached a

THE AUTHORS
Ralph Assmann *DESY and INFN,* **Massimo Ferrario** *INFN,* **Carsten Welsch** *University of Liverpool/INFN.*

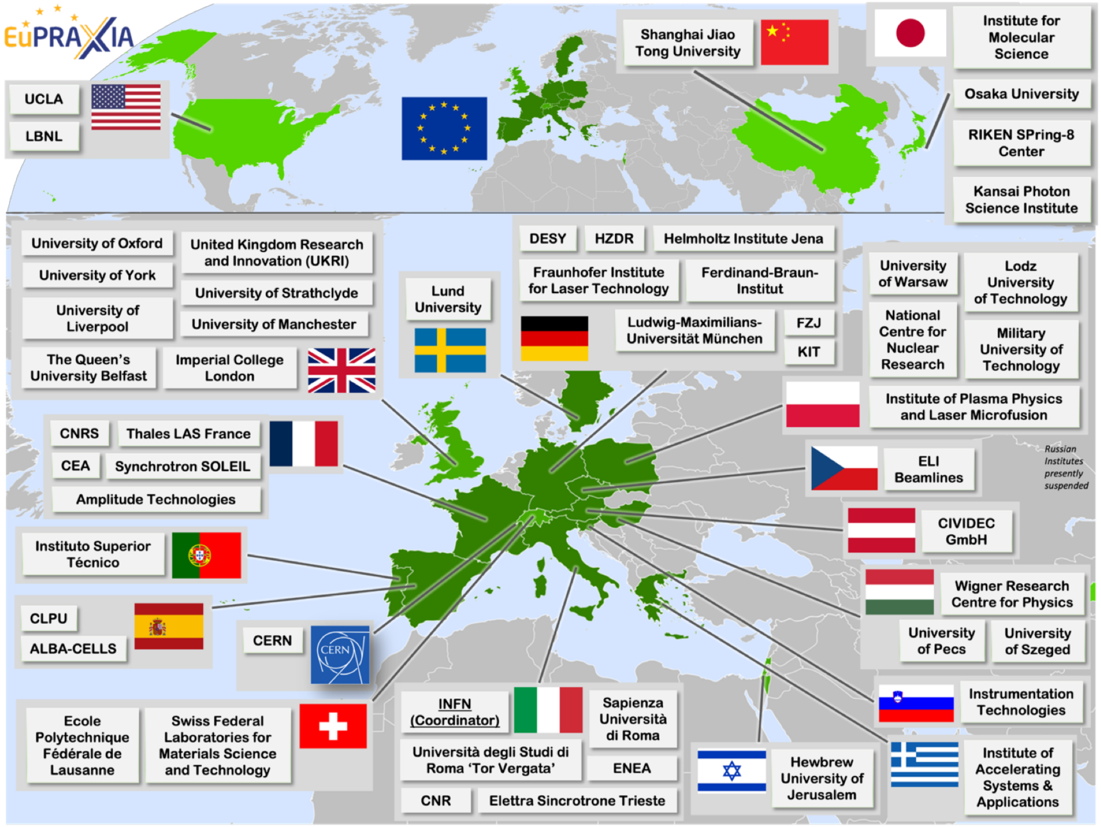
Distributed Research Infrastructure



2nd (laser-driven) SITE decision approaching (September 2024)

Wide International Collaboration

- **The EuPRAXIA Consortium today: 54 institutes** from **18 countries** plus CERN
- Included in the **ESFRI** Road Map
- **Efficient fund raising:**
  - **Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
  - **Doctoral Network** (funding EU, UK, in-kind)
  - **EuPRAXIA@SPARC_LAB** (Italy, in-kind)
  - **EuAPS Project** (Next Generation EU)
  - **What Next => PACRI** (Infratech EU funded 2025-2029)



PLASMA ACCELERATORS FOR COMPACT RESEARCH INFRASTRUCTURES (PACRI)

Innovative breakthrough technologies for sustainable electron accelerators

Participant No.	Participant organisation name	Country
1 (Coordinator)	Elettra - Sincrotrone Trieste SCpA	IT
2	European Organization for Nuclear Research	Internat.
3	Istituto Nazionale Fisica Nucleare	IT
4	University of Liverpool	UK
5	Thales-MIS	FR
6	Scandinova Systems AB	SE
7	VDL ETG Technology & Development BV	NL
8	COMEB	IT
9	United Kingdom Research and Innovation	UK
10	Consiglio Nazionale delle Ricerche	IT
11	Extreme Light Infrastructure ERIC	CZ
12	Centre National de la Recherche Scientifique CNRS	FR
13	Thales LAS France SAS	FR
14	Amplitude	FR
15	Centro de Láseres Pulsados	ES
16	Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik	DE
17	Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento	PT
18	Università degli Studi di Roma La Sapienza	IT
19	Heinrich-Heine-Universitaet Düsseldorf	DE
20	Deutsches Elektronen-Synchrotron DESY	DE
21	The Chancellor, Masters and Scholars of the Univ. of Oxford	UK
22	Ludwig-Maximilians-Universität München	DE
23	GSI Helmholtz Centre for Heavy Ion Research	DE
24	Università degli Studi di Roma Tor Vergata	IT
25	SourceLAB	FR
26	Paul Scherrer Institute	CH

PROPOSED GOALS:

- **Developing high rep-rate plasma modules,** as required for the EuPRAXIA project, extending its scientific domain from high average brightness radiation sources up to high energy physics;
- **Developing key laser components required to upscale high-power high repetition rate Laser technology** as required by the EuPRAXIA and ELI Research Infrastructure.
- **Improving the performance of normal conducting technology for X-band linac drivers,** extending them to the kHz regime, with focus on efficiency and energy consumption;
- **Supporting development towards compact linear colliders and nuclear physics facilities;**
- **Developing compact advanced undulator modules,** in order to reduce the overall size of the future FEL facilities.
- **Supporting the availability of compact X-ray facilities (FELs, ICSs, Betatron)** to serve a larger number of users in many scientific fields, industry and society;

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WP6 - Task 6.2:

LASers for PLAsma accelerators (LASPLA)

Task Leader: Leonida A. GIZZI, CNR-INO

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Task 6.2 LASPLA *Laser Technology* Workshop

Held on 19th, 20th and 22nd of September 2023 in the framework of the 6th EAAC 2023 at Elba, Italy

- Major progress on industrial & scientific laser development;
- Robust industrial multi kW, thin disk laser technology + NL Pulse compression;
- Coherent combination of fibers aiming at few cycle, 100 Hz;
- OPCPA based on robust and high beam quality DPSSL pump lasers;
- Progress in the development of pump lasers for high average power Ti:Sa system;
- Direct diode-pumping of Thulium-doped now in robust development phase and needs coordinated effort across labs for materials and architecture;
- Strong impulse to diode laser developments for high average power, new wavelengths, high energy density, compactness.

Dissemination of IFAST 6.2 activity

L.A.Gizzi, Novel high-intensity lasers for plasma acceleration, Invited talk at the 109 th Congress of the Italian Physical Society, 11-15 Sept. 2023, Salerno, Italy

L.A.Gizzi, Laser and plasma studies at ILIL, Invited talk at the CMD30 and FISMAT 2023 Joint conference, 4-8 September 2023, Milano, Italy

L.A.Gizzi, Science and Technology of laser drivers for plasma accelerators, Invited Lecture at the INFN Erice Accelerator School, EMFCSC, 27 Jul – 2 Aug, 2023, Erice Italy

L.A. Gizzi, The EuPRAXIA Compact Plasma Accelerator Infrastructure and Perspectives for Nuclear Applications, Invited talk at the International Conference on Applications of Nuclear Technique, June 18-24, 2023, Crete, Greece.

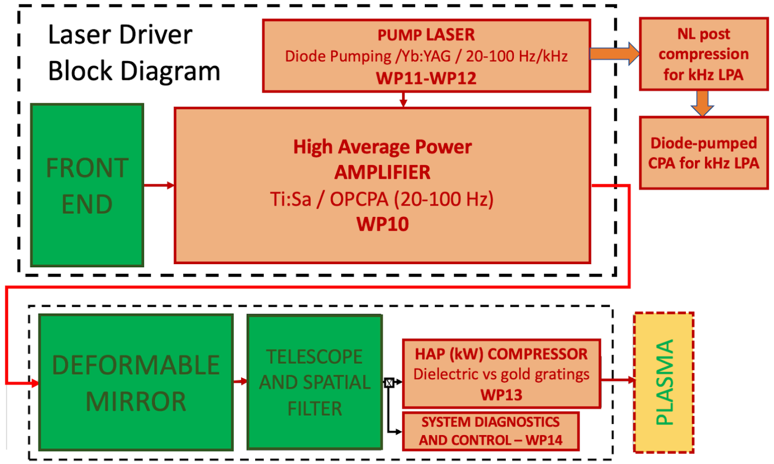
L.A.Gizzi, Lasers for Plasma accelerators, Workshop on "Lasers, from nanoscale to petaWatt" 6-9 September 2022, Université Côte d'Azur, Nice, France

Laser TDR Working plan: PACRI EU *Infratech* proposal

PLASMA ACCELERATOR SYSTEMS FOR COMPACT RESEARCH INFRASTRUCTURES

Funding for scaleup of collaborative TDR development (within InfraTECH proposal PACRI)

EuPRAXIA laser driver (100 Hz) and longer term options (1 kHz)



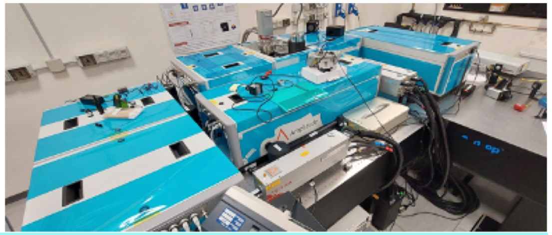
WP10: High repetition rate High power Ti:Sa amplifier module

Science and Technology Facilities Council

WP12: High repetition rate pump sources for laser drivers

WP13: Prototype of High average power optical compressor

WP14: Laser driver System Architecture, transport and engineering



WP11: Efficient **kHz** laser driver modules for plasma acceleration: 1) NL broadening +post compression and 2) new materials (Tm:XX)

FUNDED 2025-2029

- **Laser-driven 2nd site development and (new) excellence center(s) on laser technologies will boost activities**
- **Leveraging on developments ongoing at national level (all partners)**

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WP6 - Task 6.3:

Multiscale innovative targets for laser-plasma acceleration

Task Leader: Cedric THAURY, CNRS-LOA

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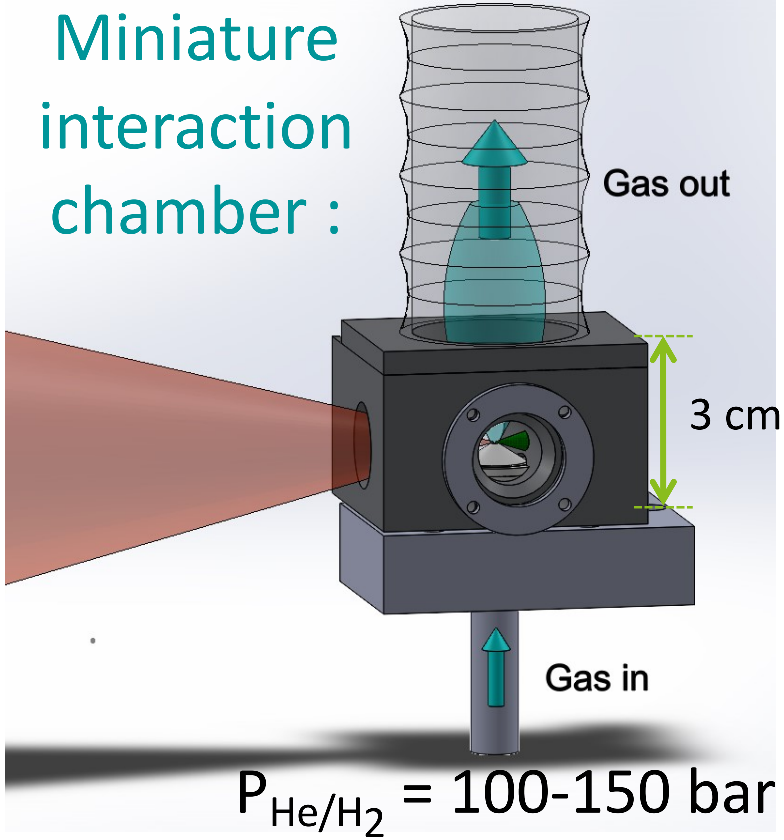
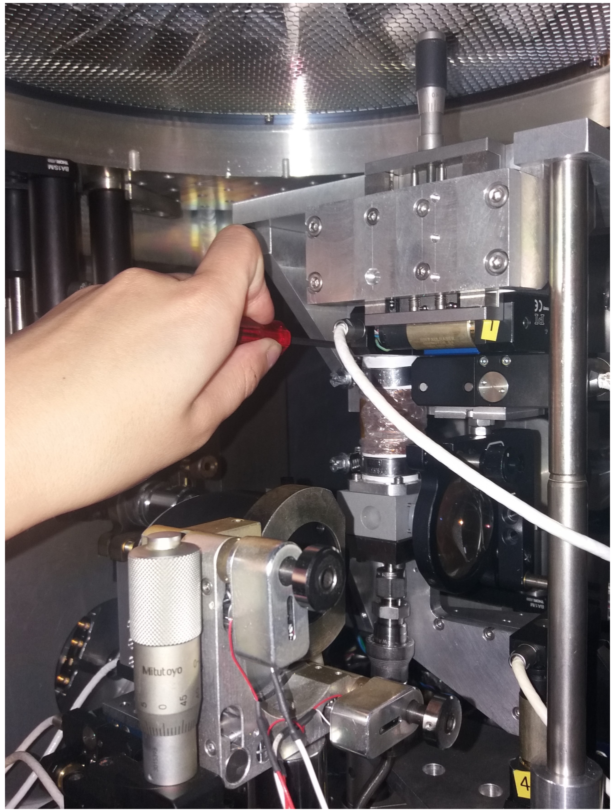
Task 6.3 multi-scale innovative targets for laser-plasma accelerators : kHz targets

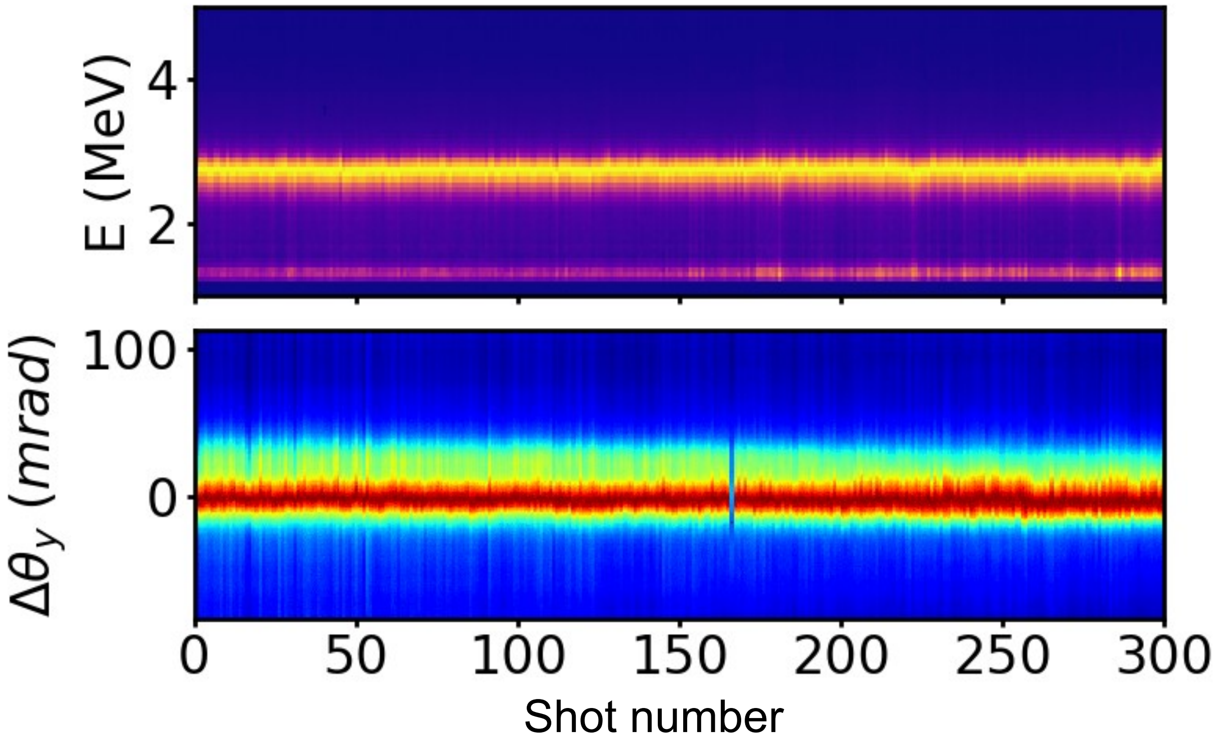
Differential pumping for using light gases at high rep. rate





Task 6.3 multi-scale innovative targets for laser-plasma accelerators : kHz targets

Stable mono-energetic beams



	Mean	rms
Energy	2.9 MeV	5 %
Energy spread	1.8 MeV	3 %
charge	2 pC	3%
divergence	17 mrad	4 %
Beam pointing		1.5 mrad

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WP6 - Task 6.4:
Laser focal Spot Stabilization Systems

Task Leader: F. MATHIEU, CNRS-LULI

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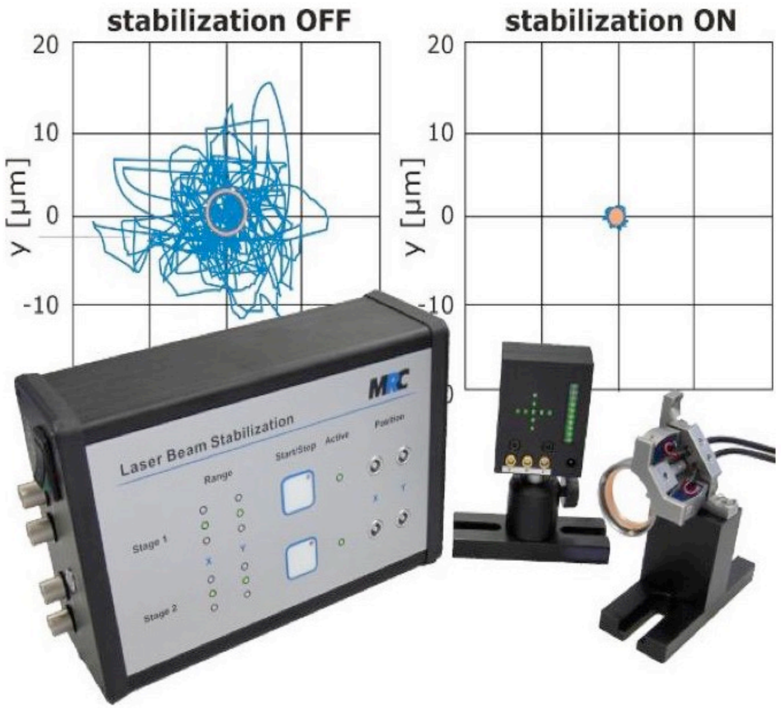
Summary of activities in P2

- *Installation of a loop to stabilize pointing @ APOLLON*



Basic spectrum for 1PW in LFA

Test done with a cw probe beam and note with the signal beam

Measurement done at the amplification stage output and not at final focal spot location

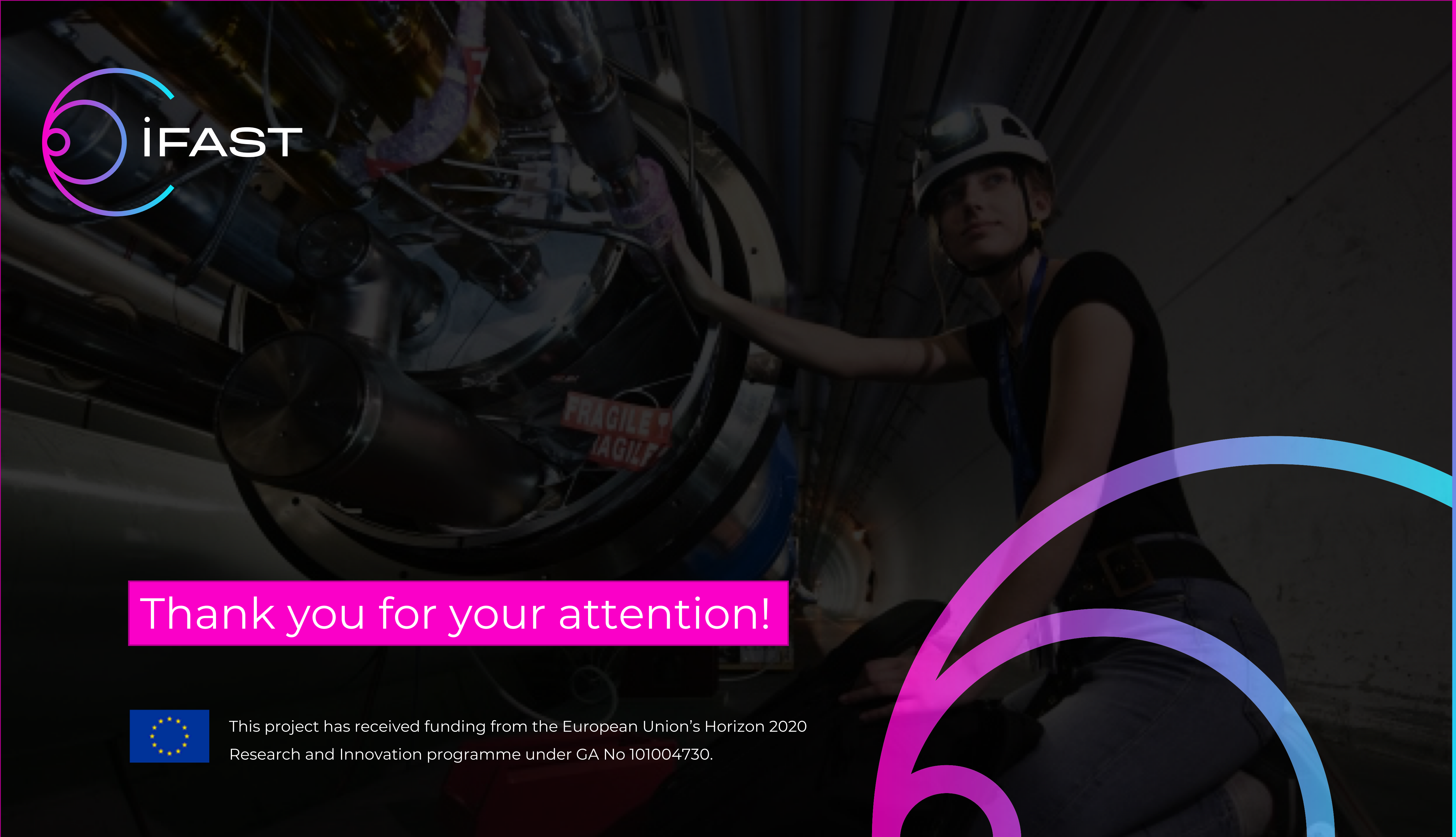
Improvement of the stability by a factor of over 3

BUT focal spot was too small on the 4 quadrants and we should be able to get better results.

Conclusions and Acknowledgements

- Novel Plasma accelerators have advanced considerably in beam quality, **achieving FEL lasing**. WP6 fully engaged with EAAC (**T6.1**) to strengthen the community
- EuPRAXIA is a design and an ESFRI project for a distributed European Research Infrastructure, **building two plasma-driven FEL´s in Europe (T6.1)**
- **Laser Driver strategy (T6.2)** showing impact on industrial developments (100 Hz) and further R&D towards 1kHz (PACRI) and repetitive (kHz) accelerator operation stability and control **(T6.3 and T6.4)**.
- **WP6 Milestones and Deliverables on track**
- **Activity towards preparation of the EAAC strategy (D6.1) and LASPLA Strategy (D6.2) is ongoing**

- **Acknowledgment to the IFAST (T6.1) project for supporting the EuRONNAC > EAAC activities that allowed the consoldation of the Plasma Accelerator Community in EuROPE that is now engaged in delivering EuPRAXIA.**



Thank you for your attention!

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