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

Report on WP6: Novel Particle Accelerators Concepts and Technologies

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CNR, Istituto Nazionale di Ottica, Pisa, Italy

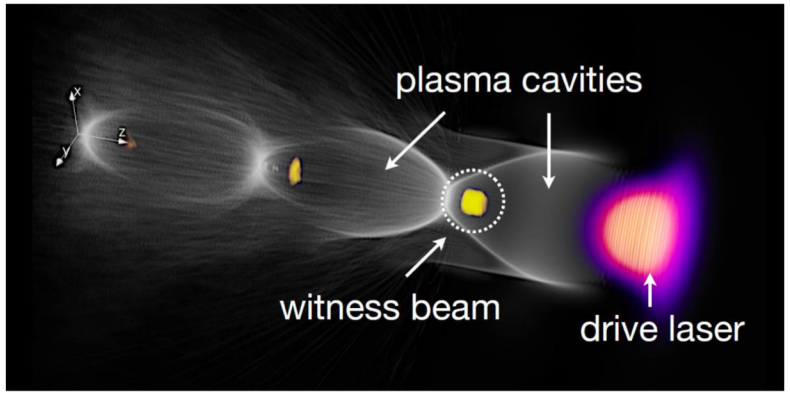
I.FAST Period 1 Review, 07.02.2023

P1: 18 months from 1 May 2021 to 31 October 2022

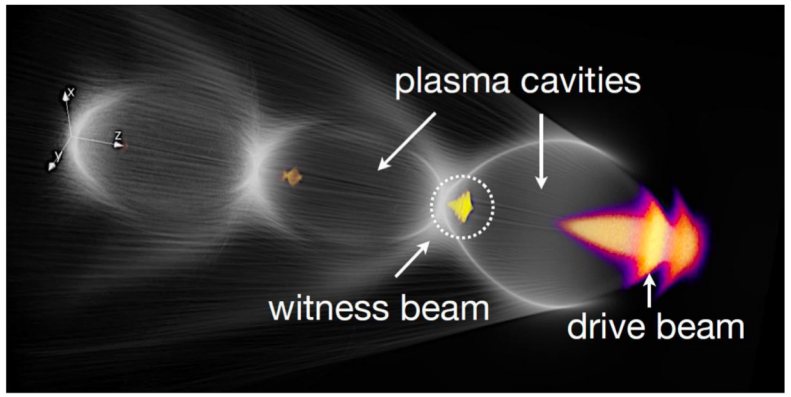
Introduction to WP6 Topics – high gradient novel accelerators

Acceleration technology

Laser-driven plasma accelerator



Beam-driven plasma accelerator



Dielectric laser accelerator

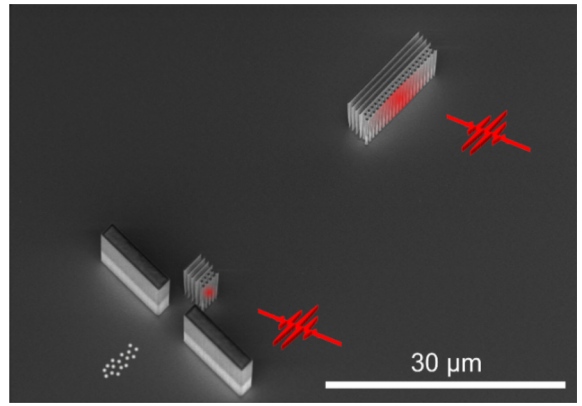
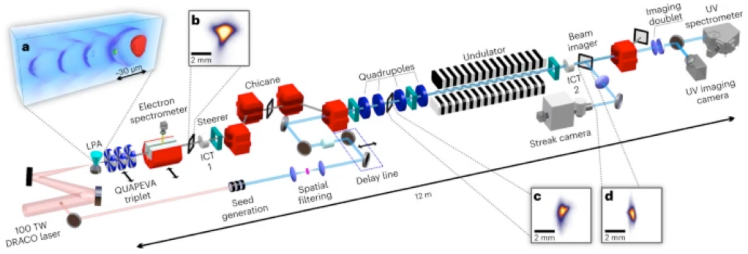


Image credit: LDG Report (2022), EuPRAXIA CDR (2020). Martinez de la Ossa

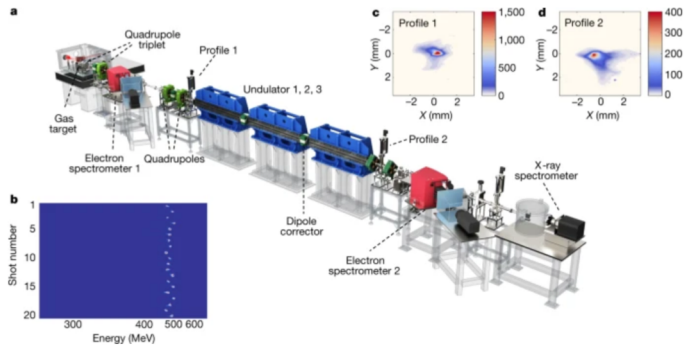
Niedermayer J. Phys. A Conf. Ser. 874 012041

Free-electron laser driven by a compact laser plasma accelerator

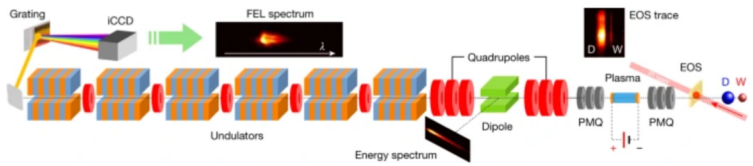
Latest achievements



M. Labat et al., *Nat. Photon.* **17**, 150–156 (2023).

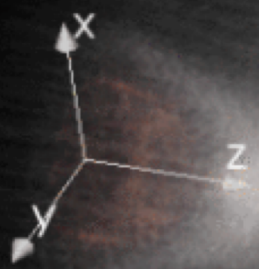


W. Wang et al., *Nature* **595**, 516–520 (2021).



R. Pompili et al., *Nature* **605**, 659–662 (2022).

WP6 Task structure and objectives



WP6: Novel particle accelerators concepts and technologies (Objectives)

- Define a roadmap towards low-energy and high-energy physics applications
- Organise the biannual European Advanced Accelerator Concepts workshop (EAAC)
- Build a roadmap for new, efficient laser drivers for laser-plasma accelerators
- Develop innovative targets for laser-plasma acceleration
- Develop a new passive system to improve laser-driver control and quality

Task	Name	Task Leader
6.1	Novel Particle Accelerators Concepts and Technologies (NPACT)	**R. Assmann** (DESY) - WP Leader
6.2	Lasers for Plasma Acceleration (LASPLA)	**L. A. Gizzi** (CNR)
6.3	Multi-scale Innovative targets for laser-plasma accelerators	**C. Thaury** (CNRS)
6.4	Laser focal Spot Stabilization Systems (L3S)	**F. Mathieu** (CNRS)

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. *Report on the EAAC workshops as strategic forums for international accelerator R&D and resulting strategies*	M42
D6.2: LASPLA Strategy. *Report on a strategy for laser drivers for plasma accelerators.*	M46
D6.2: 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.*	M24
D6.4: Improvement of the laser intensity stability on target. *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)

MS22: LASPLA Workshop/School. Lead – CNR, **M30**, Report (task 6.2)

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)

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

WP6 - Task 6.1:

Novel Particle Accelerators Concepts and Technologies (NPACT)

Task Leader: Ralph ASSMANN, DESY & LNF/INFN

iFAST

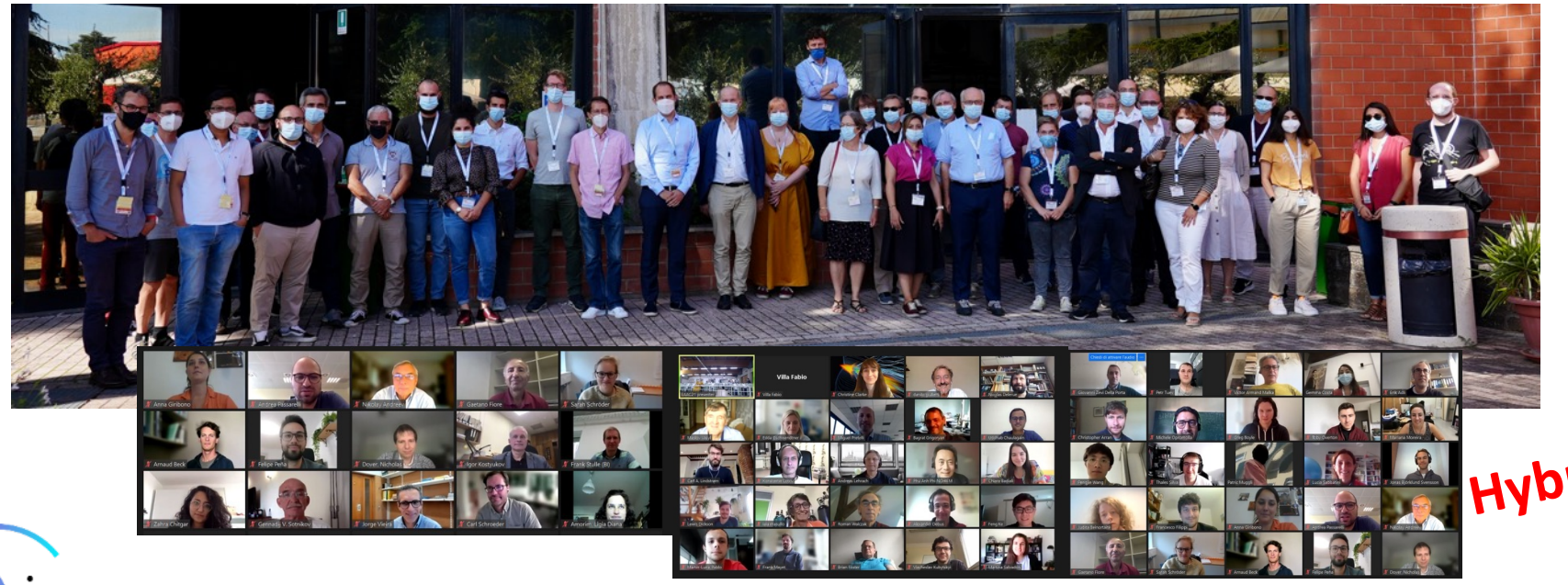
TASK WP6.1 (NPACT) – Strategy and driver

- Synergy and coordination for EuPRAXIA Infrastructure project (ESFRI):
  - World-wide 1st **conceptual design report** of the accelerator facility based on plasma accelerators
  - Consortium grown since 2015 to > 50 institutes, 17 countries
  - Only new accelerator project on ESFRI roadmap since 2016 and 1st preparatory phase project since Hi-Lumi LHC.
- Plasma accelerators for particle physics:
  - Follow-up to European and international strategy for particle physics
  - Part of European accelerator R&D program

Task 6.1 (NPACT) Summary of activities in P1

a) Organization of the EAAC2021 workshop

- The **5th European Advanced Accelerator Concepts (EAAC)** workshop was held from 20 to **23 September 2021** at the LNF-INFN laboratory at Frascati, Rome, Italy. **In total 255 experts registered from 20 countries**. Yearly meeting of the Task 6.1 was held. **EAAC2021 website**: https://agenda.infn.it/event/24374/ .
- **27 plenary presentations** showing recent highlights in the field of advanced accelerators, **in particular, successful FEL lasing** in Italy and in China.



Hybrid

Task 6.1 (NPACT) Summary of activities in P1

b) Leading contributions to the Report on the European Accelerator R&D, prepared in the context of the European strategy for particle physics

- Several coordinators of the I.FAST WP6.1 were invited to lead and **contribute to the expert panel for "High Gradient Laser and Plasma Accelerators"**, set up as part of the European Strategy for Particle Physics.
- The work culminated by the **publication of the European strategy** for accelerator R&D with a dedicated chapter on advanced accelerators. Implementation in next years followed up by Wim Leemans (Desy).

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

c) Participation in the leadership and meetings of the Snowmass Accelerator Frontier AF6

- **Community effort that takes place in the US every 5-7** years. **Accelerator R&D community to** discuss a future strategy and prepar a report to implementation committees (see https://arxiv.org/abs/2209.14136).
- **The I.FAST WP6.1 leadership and members helped in the coordination of the Accelerator Frontier 6**, concerned with advanced accelerators. WP6.1 participated to meetings, presented the European perspective and joined in report writing.
- The invested effort will support a **coordinated approach between EU and US** activities, of course, subject to decisions by the involved funding agencies.

Task 6.1 (NPACT) Summary of activities in P1

d) Approval of the Advanced accelerator project EuPRAXIA for the 2021 ESFRI roadmap

- The NPACT community and its European network for Novel Accelerators (EuroNNAc) has been **driving for several years the preparation of a European Research Infrastructure** based on the plasma accelerator technology, namely the EuPRAXIA project (www.eupraxia-project.eu).
- **It is a success of the continuing WP6.1 work** that the EuPRAXIA, after the publication of its CDR, has received sufficient government support and readiness **to be placed on the 2021 update of the ESFRI roadmap**.

European Plasma Research Accelerator with eXcellence In Applications

European High-Tech Project on Accelerator Innovation

New kind of **C O M P A C T** Distributed Research Infrastructure Involving 50 Institutes from **15 Countries** – see full CDR published in 2020

Selected for 2021 Update **ESFRI Roadmap** *as first ever plasma acc. project, first accelerator project since HiLumi LHC*

569 M€ total cost: ~150 M€ already financed

EU Preparatory Phase project 11/2022 – 2026 to define full implementation: financial, legal, technical

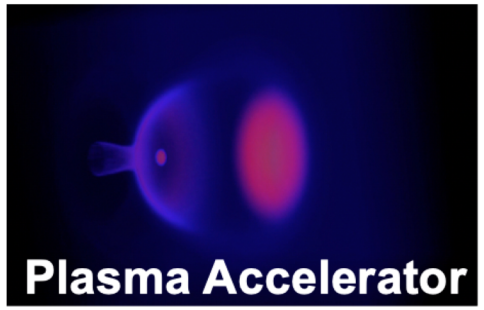
Will serve users (FEL, e+, e-) in biology, health, physics, materials, … at end of decade

EuPRAXIA delivers:
Ultra-short pulses of X rays, up to 5 GeV electrons, high energy positrons

LNF-INFN Frascati, Rome, Italy:

1st construction site & Headquarter in progress

2nd construction site in Europe for a laser-driven plasma accelerator facility to be decided in June 2024



600+ page CDR, 240 scientists contributed

ESFRI

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

New EuPRAXIA projects approved by EU

EuPRAXIA Preparatory Phase Project

(Nov 2022 – Nov 2026)

Europa / Funding & Tenders Portal notification

12 April 2022, 16:13

Dear Madam/Sir,

Congratulations. Your proposal has reached the stage of Grant Agreement preparation.
To view the evaluation results and the instructions on how to provide additional information and data required for the preparation of your Grant Agreement, log on to the Funding & Tenders Portal > My Proposal(s) (https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/myarea/proposals) and click on Action > Follow-up.

Regards,
Grant Management Services

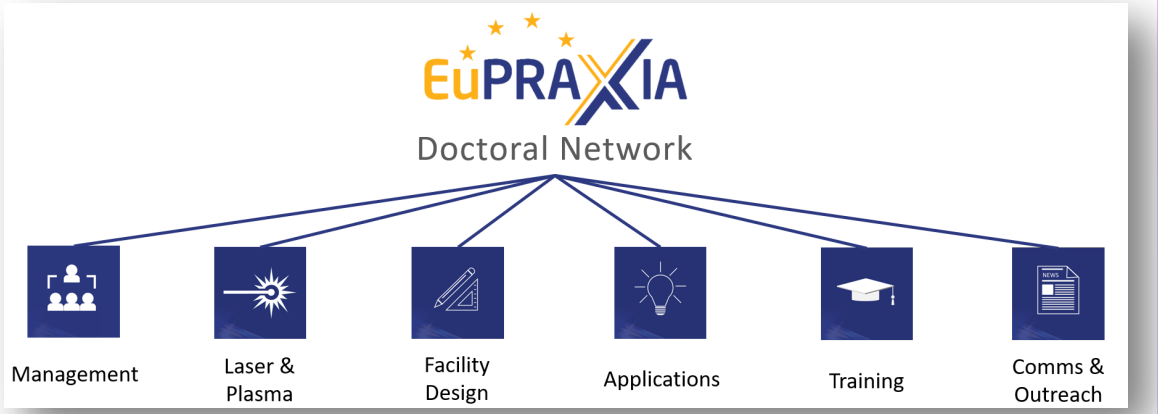
3 M€ EU funding, total value: 8.3 M€

Coordinated by INFN (R. Assmann, M. Ferrario)

Will formally establish a "**Board of Financial Sponsors**" with representatives of funding agencies. So far ~ 25% of total (569 M€) M&P funding secured.

EuPRAXIA Doctoral Network

(2023 – 2027)



2.6 M€ EU funding, 10 MSCA Fellows

Coordinated by University Liverpool (C. Welsch)

Start date: 1 Jan 2023

22.4 M€ additional funding from Next Generation EU (Italy) for the **EuPRAXIA Advanced Photon Sources**

Task 6.1 (NPACT) Summary of activities in P1

e) Organisation of the special topics EuroNNAc-NPACT-IFAST workshop (towards MS21)

- **Specialised topics (EuroNNAc-NPACT-IFAST) as an in-presence meeting**. The meeting took place 18 - 24 September on the island of Elba in Italy, bringing together **148 registered participants** from 17 countries. **42 students** from 10 countries attended, supported by WP6.1. Plenary talks were complemented by poster sessions. Meeting website https://agenda.infn.it/event/28376/.

EuroNNAc Special Topics Workshop
Hotel Hermitage, La Biodola Bay, Isola d'Elba, Italy from 18th to 24th September 2022.

	Sept. Monday 19	Sept. Tuesday 20	Sept. Wednesday 21	Sept. Thursday 22	Sept. Friday 23	Sept. Saturday 24
Morning I 9:00 – 10:30	**S-IN** (RA&MF) News from field - 1 short talk per ST	**S-ST1-b** (EG&PM) Beam driven Plasma Accelerators with focus on proton-driven	**S-ST3-b** (LG&SK) Laser Technology and LWFA Results	**S-ST4-b** (EC&RP) Distributed Plasma Accelerator Landscape in Europe and Technical Progress towards Applications	**S-ST5** (PM&CG&MH&MK &WL) International Landscape: Facilities, projects, initiatives	**NPACT / EuroNNAc Yearly Meeting** (RA&MF)
Coffee Break (20')						
Morning II 10:50 –12:30	**S-IN** (RA&MF) News from field - 1 short talk per ST	**S-ST2** (MT&JV) Simulation tools and roadmap,	**S-ST3-b** (LG&SK) Laser Technology and LWFA Results	**S-ST4-b** (EC&RP) **Special sub-session** (JO&al) Particle physics plasma test facility	**S-ST5** (PM&CG&MH&MK &WL) International Landscape: Facilities, projects, initiatives	**NPACT / EuroNNAc Yearly Meeting** (RA&MF)
Lunch Break (3h30')						
Afternoon I 16:00 –17:30	**S-ST1-a** (EG&PM) Beam driven Plasma Accelerators with focus on proton-driven	**S-ST3-a** (LG&SK) Laser Technology and LWFA Results	**S-ST4-a** (EC&RP) Distributed Plasma Acc. Landscape in Europe and Technical Progress towards Appl.	**S-SP** (BH&RW) Student Talks - Prize Award Session	**S-ST6** (RI&al) Structure-based accelerators and advanced radiation generation schemes	
Coffee Break (20')						
Afternoon II 17:50– 19:15	**S-ST1-a:** (EG&PM) Beam driven Plasma Accelerators with focus on proton-driven	**S-ST3-a** (LG&SK) Laser Technology and LWFA Results	**Special sub-session** (AI&al) Talks and discussion on plasma-based FEL exp.	**S-SP:** (BH&RW) Student Talks - Prize Award Session	**S-SU** (RA&MF) Summary Report from discussions - input to IFAST/NPACT MS21	
Posters 19:15 - 20:15	Participants and student grantees	Participants and student grantees	Participants and student grantees			
Dinner 20:30				**BANQUET**		

The **special topics covering all aspects of novel particle accelertors WP6** gave an excellent overview of our field and the activities of network institutes and the network itself. This Special Topics workshop will **prepare the milestone MS21 (M24)**

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

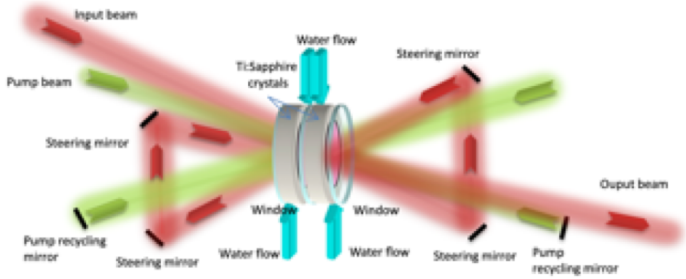
WP6 - Task 6.2:

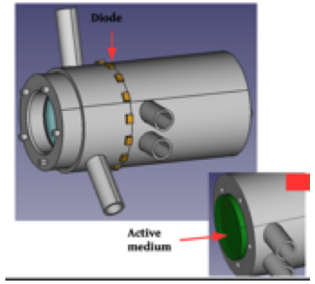
LASers for PLAsma accelerators (LASPLA)

Task Leader: Leonida A. GIZZI – CNR-INO

Task 6.2 (LASPLA): Objectives

- Establish a roadmap to foster delivery of **advanced industrial laser drivers** with high-repetition rate and higher efficiency, for the first user laser-plasma based accelerators.
- Establish a **coordination activity with networking** and training of **main laser labs and industrial partners**, focused on laser-driver R&D.





- High TRL Ti:Sa, 100 Hz, multi Joule scale (EuPRAXIA-Like) - 1-10 kW
- High TRL – Industrial development in progress at J level

→

- Short-medium term solution
- Proof-of-principle user laser accelerator
- Needs components testing

"Commercial" Ti:Sa kHz/<100 W front-end (< 100 mJ)

- Diode pumped, direct CPA, kHz, multi-Joule scale
- High efficiency with advanced lasing materials
- Optical parametric chirped pulse amplification (OPCPA) with diode pumping

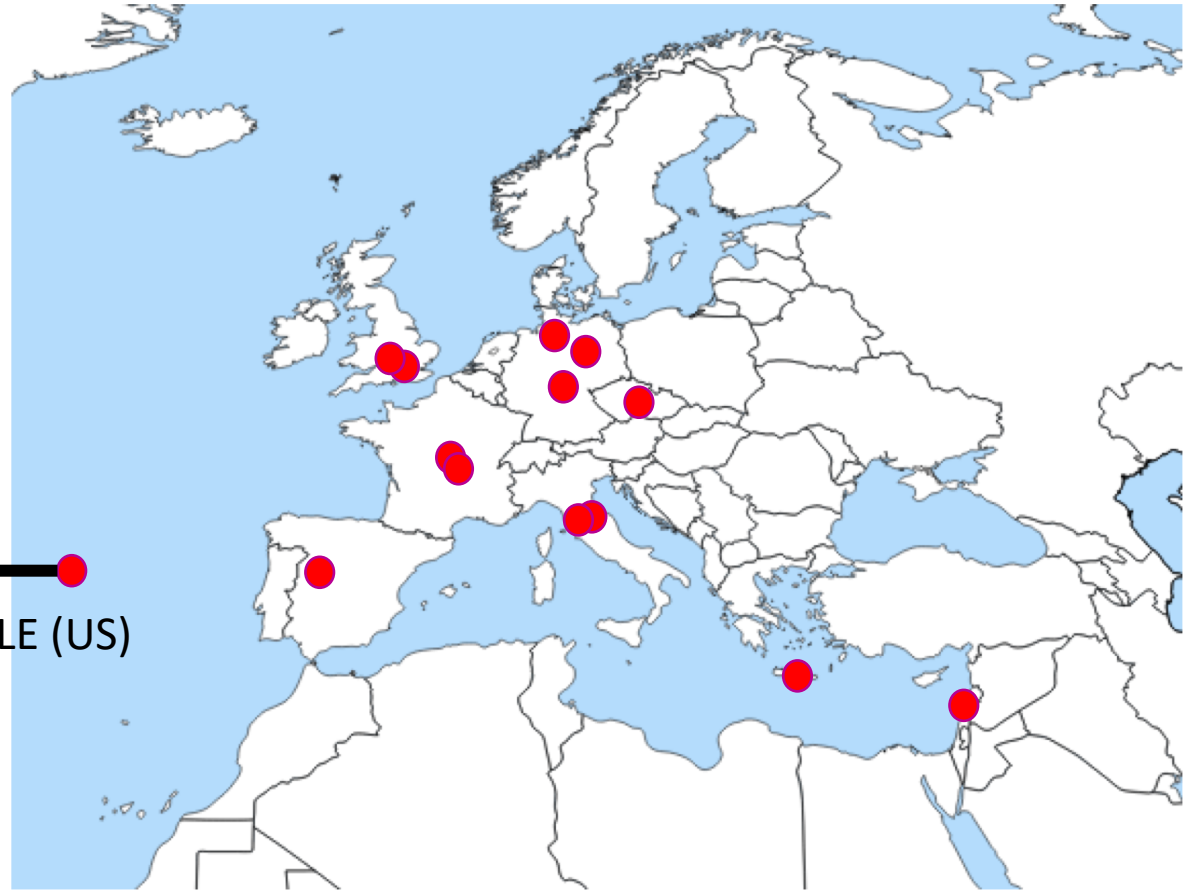
→

- Longer term solution
- Scalable, efficient
- Needs high brightness, lower cost diode lasers for pumping
- Needs materials and components R&D

TASK 6.2 (LASPLA): *warm up* technical meetings

Warm up technical meetings on Laser Development for Plasma Acceleration (online)

1st Technical Meeting – 23rd June 2021
2nd Technical Meeting – 7th October 2021



LLNL, LBNL, LLE (US)

Up to 50 attendees to the 2nd technical meeting

Strong participation from laser industrial partners

Very positive feedback from participants: informative and effective

TASK 6.2 (LASPLA): Laser Workshop (in presence), April 20-22, 2022, Palaiseau (FR)

Laser workshop is towards **milestone MS22 (M30)**

I.FAST Workshop on

"LASER DRIVERS FOR PLASMA ACCELERATORS"
April 20-23, 2022

École Polytechnique, Palaiseau, Paris (FR)

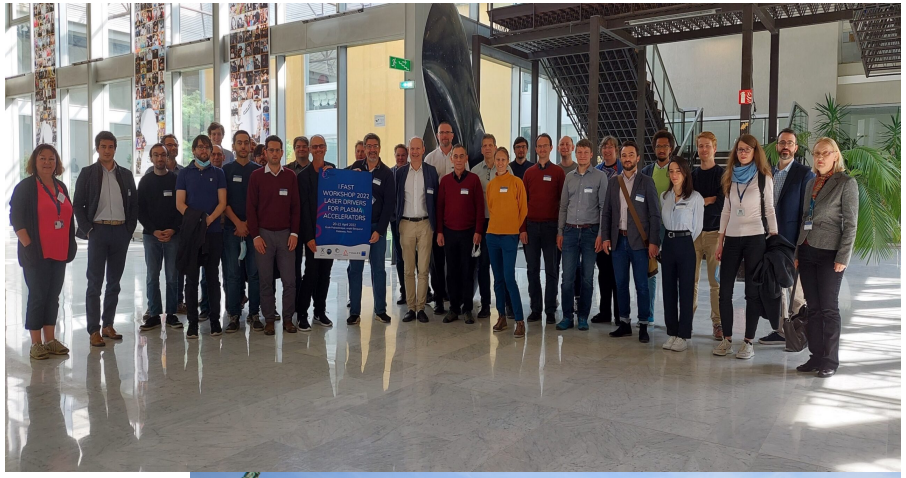
Jointly organized by CNR, CNRS, Amplitude and THALES

- **Establish a roadmap** to foster delivery of advanced industrial laser drivers with high-repetition rate and higher efficiency;
- **Highlight laser requirements** for user plasma-based accelerators and other key high power, high intensity laser applications:
- **Promote a coordination activity** with networking and training of **main laser labs and industry**, focused on laser-driver R&D.

52 registred participants in presence

- >100 participants online
- >300 connections per day

IFAST Laser Workshop (in presence), April 20-22, 2022, Palaiseau



PROGRAMME of the
I.FAST WORKSHOP 2022
"LASER DRIVERS FOR PLASMA ACCELERATORS"

Time	Wednesday 20	Thursday 21	Friday 22
09:00 – 09:30	**REGISTRATION**	**Mike CAMPBELL,** LLE, University of Rochester (*)	**Jonathan Tyler GREEN,** ELI Beamlines
09:30 – 10:00	**OPENING and IFAST overview**	**Laura CORNER*,** University of Liverpool	**Francois MATHIEU,** LULI-CNRS
10:00 – 10:30	**Gérard MOUROU – Jonathan WHEELER,** IZEST	**Bedrich RUS,** ELI Beamlines	**Sandrine RICAUD,** Thales LAS
10:30 – 11:00	**Coffee break**	**Franck FALCOZ/Stefane BRANLY,** Amplitude	**Paul MASON,** CLF-STFC
11:00 – 11:30	**Sydney GALES,** IJCLab & IFIN/ELI-NP	**Coffee break**	**Coffee break**
11:30 – 12:00	**Andreas R. MAIER,** DESY	**Ralph ASSMANN,** DESY and INFN (*)	**Federico CANOVA,** ELI-ERIC
12:00 – 12:30	**Kevin CASSOU,** CNRS/IN2P3/IJClab, U. Paris Saclay	**Andrea KNIGGE,** Ferdinand-Braun-Institut	**Luca LABATE,** INO-CNR (*)
12.30 – 13.00	**LUNCH**	**Markus LÖSER,** Helmholtz-Zentrum Dresden	**Cedric THAURY,** LOA-CNRS
13:00 – 13:30		**LUNCH**	**Closing**
13:00 – 14:00			**LUNCH**
14:00 – 14:30			
14:30 – 15:00	**Cameron G. R. GEDDES,** LBNL	**Karoly OSVAY,** NLTL, University of Szeged	
15:00 – 15:30	**Roman WALCZAK,** University of Oxford	**Leonida A. GIZZI,** INO-CNR	
15:30 – 16:00	**Tea Break**	**Tea Break**	
16:00 – 16:30	**Jérôme FAURE,** LOA-CNRS	**ROUND TABLE**	
16:30 – 17:00	**Francois SYLLA,** SourceLAB	***"High average power accelerators for nuclear and medical uses"***	
17:00 – 17:30	**Bjorn Manuel HEGELICH,** University of Texas		(*) Remote

OUTCOME

- **New and major laser-based facilities progressing fast and going online**
- **Key Labs delivering repetitive operation of LPA with quality and stability**
- **Laser developments addressing high repetition rate and high efficiency**
- **Major cases for medical and industrial applications being established**

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

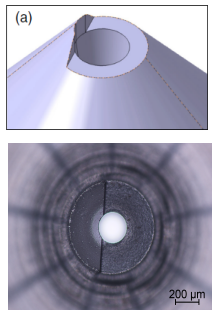
WP6 - Task 6.3:

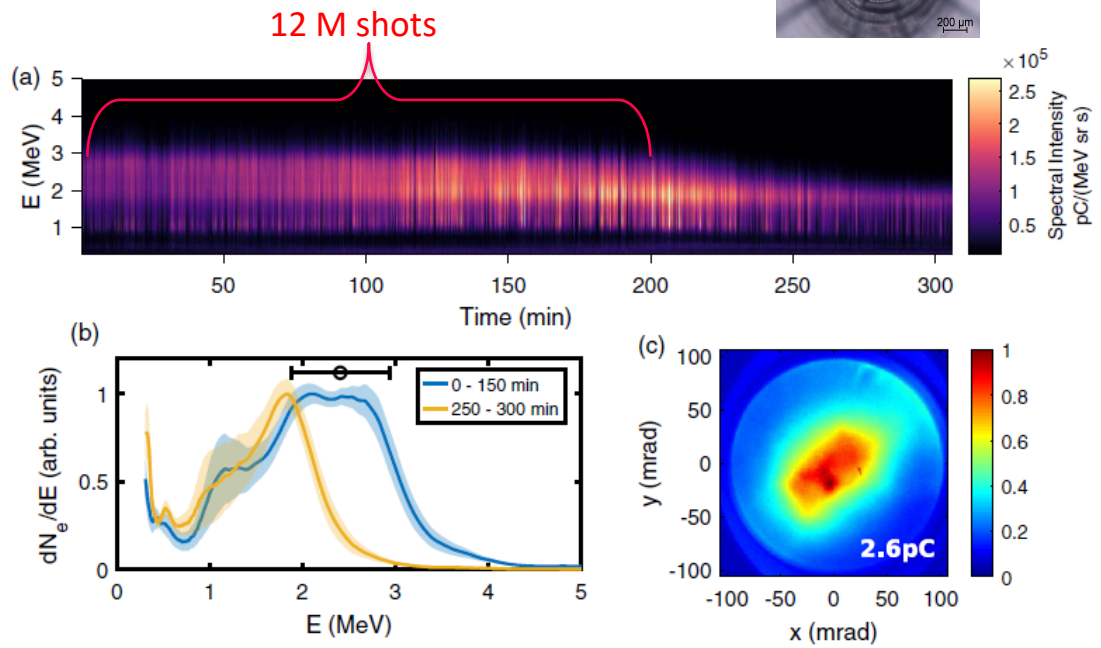
Multiscale innovative targets for laser-plasma acceleration

Task Leader: Cedric THAURY, CNRS-LOA

Task 6.3 multi-scale innovative targets for laser-plasma accelerators : *low-energy kHz accelerator*

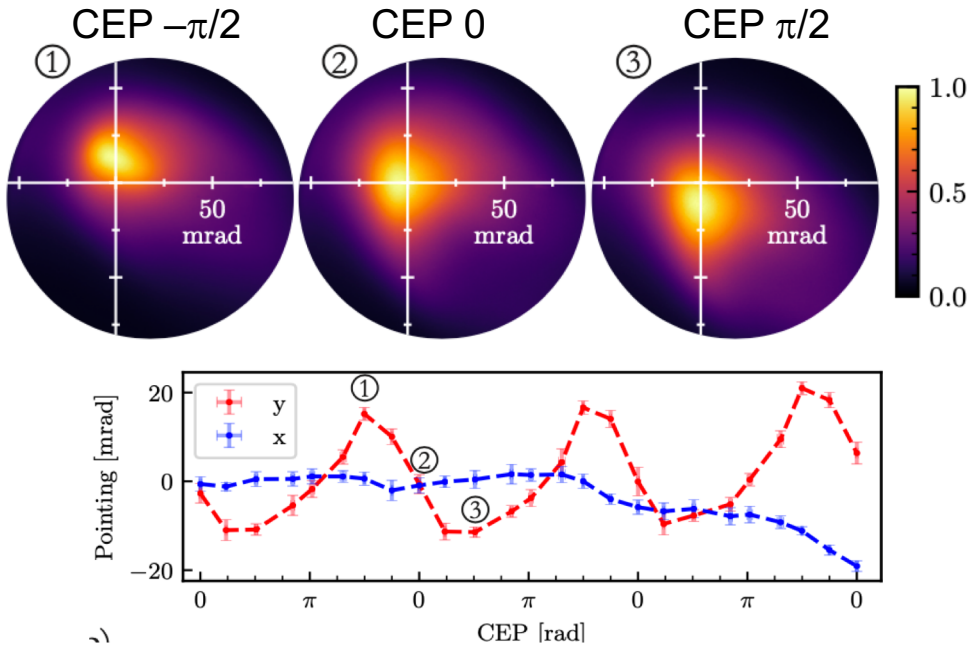
Glass nozzles with shock
→ stable acceleration at a kHz rep. rate





L. Rovige et al., RSI **92**, 083302 (2021)

Control of the laser CEP
→ improved stability and beam stearing



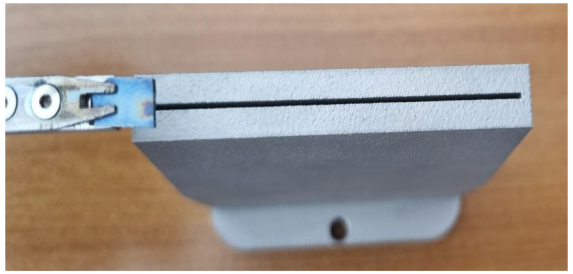
J. Huits et al. Phys. Rev. X 12, 011036 (2022)

Task 6.3 multi-scale innovative targets for laser-plasma accelerators : ***high-energy accelerator (awaiting laser drivers)***

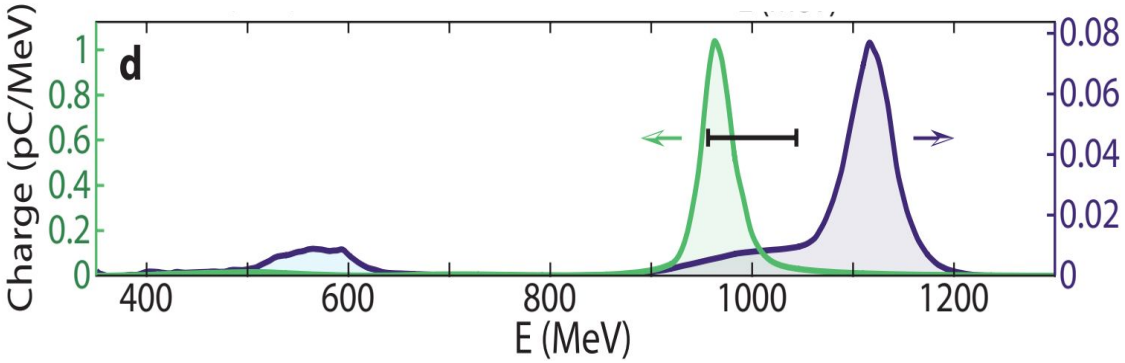
First demonstration of **controlled injection** and acceleration in a **laser-plasma waveguide**

→ High quality GeV beam with a J-class laser (LOA)
→ High quality 2.5 GeV beam with a 10 J laser (Apollon)

6cm long target



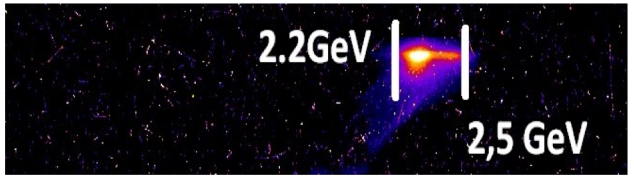
LOA results (1.5 J)



Apollon results (10 J)

Best electron spectrum without guiding

Best electron spectrum with guiding



Oubrerie et al. Light Sci Appl 11, 180 (2022), Oubrerie et al J. Opt. 24 045503 (2022)

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

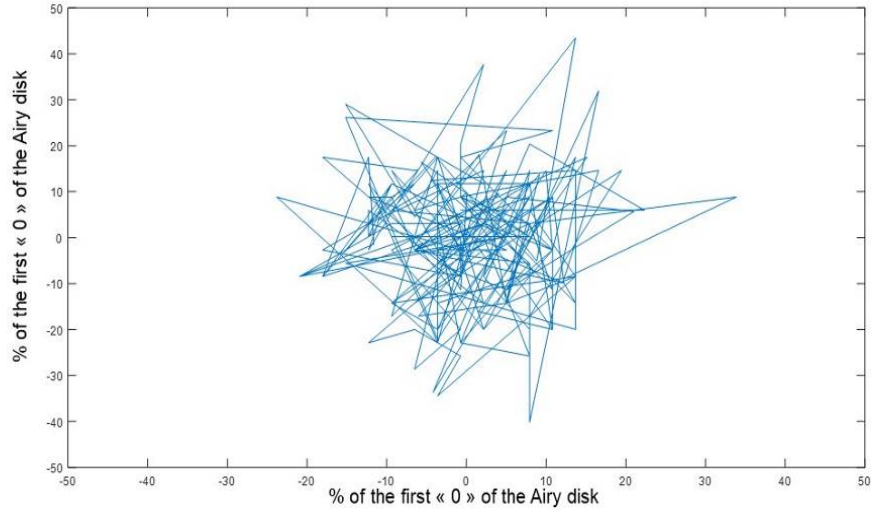
WP6 - Task 6.4:

Laser focal Spot Stabilization Systems (L3S)

Task Leader: Francois MATHIEU, CNRS-LULI

Task 6.4 - Summary of activities in P1

- ***Characterization of beam pointing stability with high sensitivity for accelerator-level performace***



Measurement done over 1 hour in the target chamber

The beam stability is ± 3 µrad PTV

Objective is ± 0,1 µrad PTV

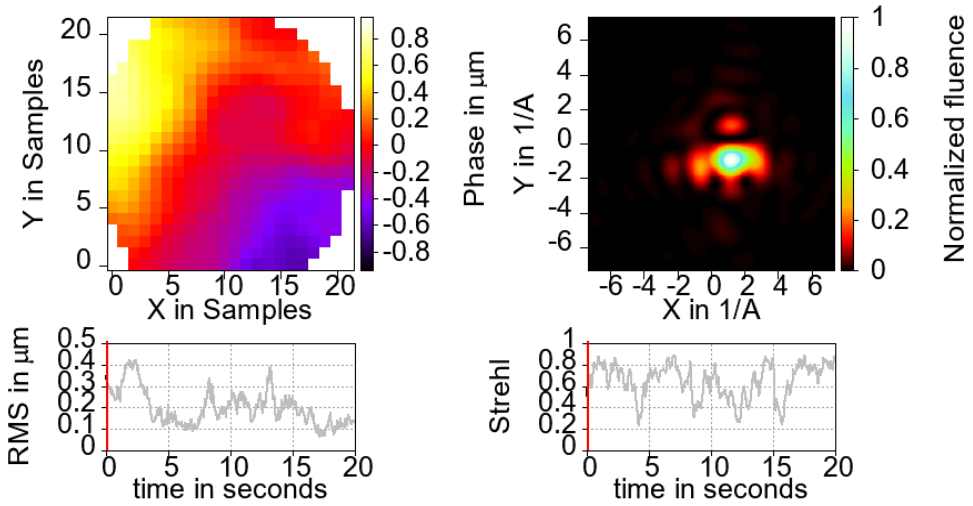
- ***Installation of an active stabilization loop in the amplification stages***

  Beam stability improved by a factor 2

- ***Characterization of the mechanical frame under progress***
- ***Aiming at +/- 0,15 µrad PTV stability requisite for particle beam stability in a laser driven accelerator***

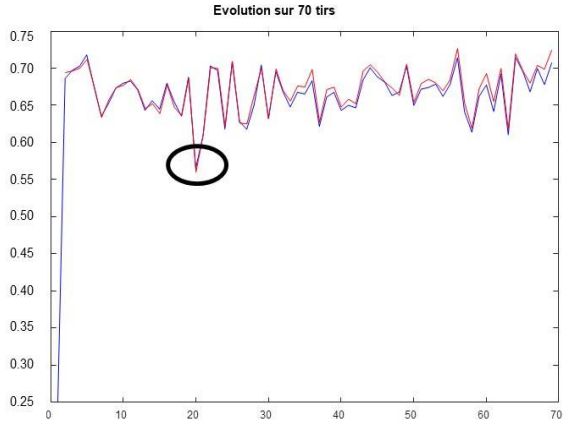
Task 6.4 - Summary of activities in P1

- *Characterization of focal spot stability with most **advanced metrology framework***



Measurement done with a **wavefront sensor** running at 200Hz and a cw laser

Strehl ratio varies from 0.25 to 0.85



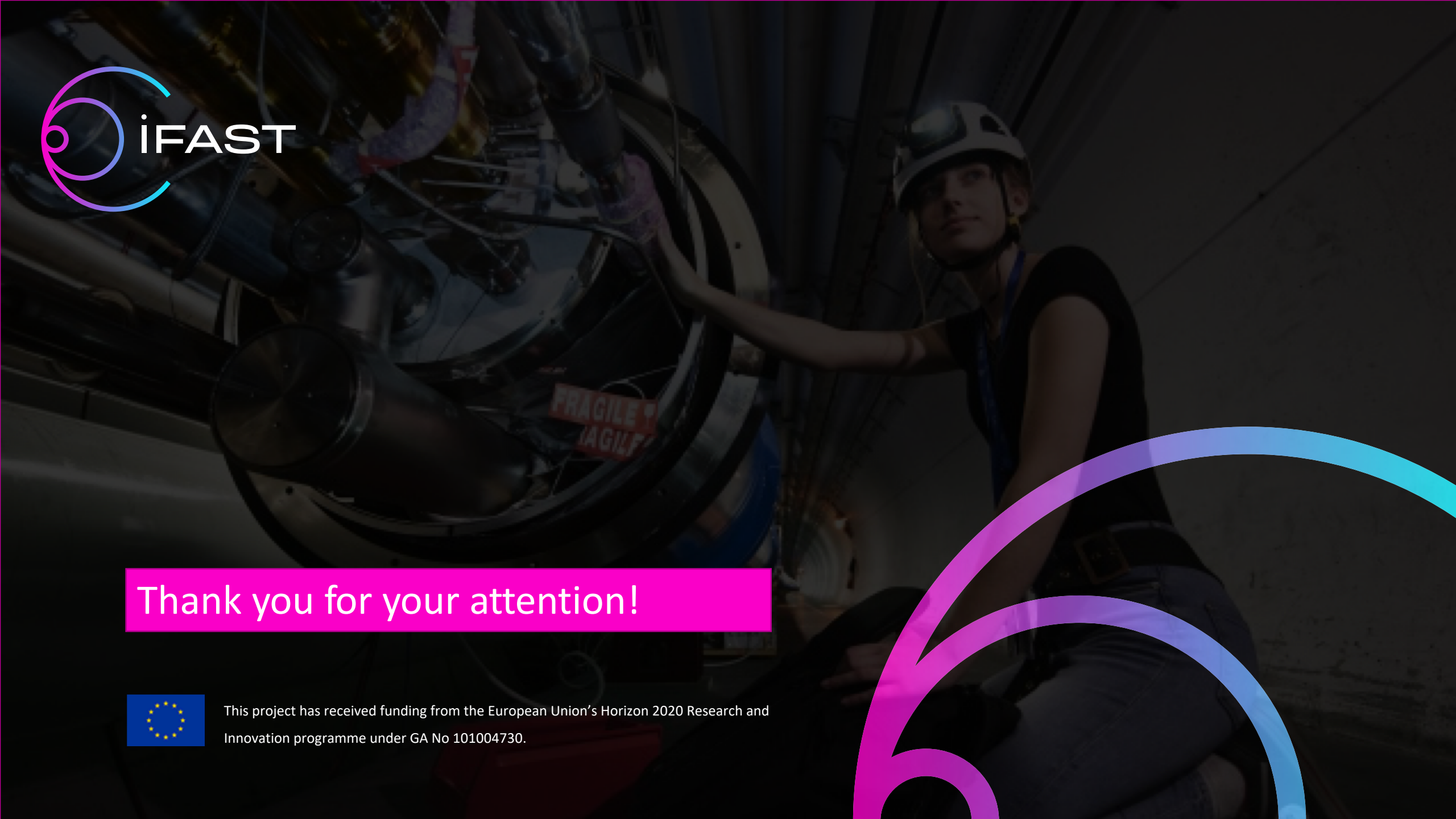
- *Installation of new system to **minimize airflow***

  Strehl stability improved up to ± 7.8%.

- *Procurement of an 1kHz active loop under progress*
- ***Aiming at +/- 2% PT>V stability on the Strehl ratio, since this impacts beam pointing stability***

Relevance of objectives and impact of WP6

- Objectives of WP6 at the core of novel **plasma accelerators development**
  - Providing major thrust for the development of the **first ever plasma accelerator** infrastructure (ESFRI) for users: **EuPRAXIA**
  - **Key contributions to networking** for accelerator R&D for particle accelerators
- Key scientific and technological **inputs for industry innovation on the next generation of laser-drivers** and high performance **plasma targetry**;
- Effective dissemination events with **large and growing participation** motivated by the **socio-economical impact** of novel compact accelerators for fundamental and multidisciplinary applications.



Thank you for your attention!

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