# I.FAST

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730

# MILESTONE REPORT

# LASPLA WORKSHOP/SCHOOL

## MILESTONE: MS22

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| **Document identifier:** | IFAST-MS22 |
| **Due date of deliverable:** | End of Month 30 (October 2023) |
| **Report release date:** | 25/10/2023 |
| **Work package:** | WP6: |
| **Lead beneficiary:** | CNR |
| **Document status:** | Final |


## ABSTRACT

This report describes the activity related to the **MS22 – LASPLA Workshop/School** that was carried out so far that culminated in a workshop held in the framework of the European Advanced Accelerator Concept Event held in Elba, Italy from the 17 to the 23 of September 2023. The meeting and the preceding activity were organized to instruct the preparation of the roadmap for the development of laser drivers for plasma acceleration, gathering contributions from research labs and key industrial partners. The contributions covered the most advanced areas of intense laser development, with special attention to high average power, ultrashort pulse systems pumped by diode laser systems.

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730. IFAST began in May 2021 and will run for 4 years.

## Delivery Slip

| | Name | Partner | Date |
|---|---|---|---|
| **Authored by** | Leonida Antonio GIZZI | CNR | |
| **Reviewed by** | M. Vretenar [on behalf of Steering Committee] | CERN | 25/10/2023 |
| **Approved by** | Steering Committee | | 25/10/2023 |

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## *Executive summary*

Lasers as power drivers for plasma accelerators have been emerging dramatically in the past decades due to the major scientific progress in several fundamental and applied field. The available solid-state high-energy laser pulse amplification technologies currently most advanced include Ti:Sapphire-based (Ti:Sa) and Optical Parametric Chirped Pulse Amplification, (OPCPA). A number of different approaches, based on entirely new concepts, materials and architectures, are being developed to overcome fundamental limitations of these systems in terms of wall-plug efficiency, compactness and, ultimately, scalability. Scope of the workshop activity of the LASPLA Task was to gather experts from different key labs working on the most promising solutions and discuss status and perspectives towards prototyping and scaling to PW/multi kW operation.

A first preparation session on "Special Topic S-ST3: Laser Technology and LPA Results (e-, p+, ion)" was held during the EURONNAC Special Topics meeting held from the 18$^{th}$ to the 24$^{th}$ of Sep 2022 at Isola d'Elba, Italy. A number of highlights emerged concerning rapid evolution of industrial scientific lasers and the development of platforms based on either diode pumped solid state systems or fiber coherent combining to mentions a few.

Based on these emerging advances, a full workshop on Laser technology was organized in the context of the recent European Advanced Accelerator Concept 18-24 Sept. 2023. The workshop was again focused on the roadmap for laser driver and high average power technologies for plasma accelerators. The workshop offered an overview on the above issues, showing major advances and demonstrating the high interest of the community in these specific topics. Based on the outcome of this intense discussions, the knowledge base for the preparation of the full roadmap foreseen as the main outcome of Task 6.2 is progressing rapidly and effectively.

# 1 Introduction

***Background on high power laser technology.*** The use of lasers as power drivers for plasma accelerators has been emerging dramatically in the past decades, not only for the well-known effectiveness in exciting and driving plasma waves, but also for the fast-developing technologies that drive the continuous improvement in performances. Beyond that, entirely new technologies are also maturing, laying the foundations for the migration of laser drivers from the context of pioneering laser-driven acceleration R&D to the realm of viable drivers for **industrial grade plasma accelerators**. In fact, while currently available off-the-shelf technology is limited to a few tens of Watts in average power and Hz scale repetition rate, new pump power approaches based on robust solid-state diode technologies are already emerging as powerful alternative solutions to overcome such limitations. Laser-based plasma accelerator infrastructures, like the laser-driven pillar of the EuPRAXIA infrastructure relies on petawatt peak power, ultra-short pulse laser systems to drive plasma acceleration in a range of different configurations with ultra-short pulse duration, down to 30 fs or less, combined with an energy per pulse up to 100 J at a repetition rate for user applications up to 100 Hz and beyond. As shown in the plot below, these specifications are beyond the current state of the art and require dedicated effort to overcome existing technological bottlenecks.

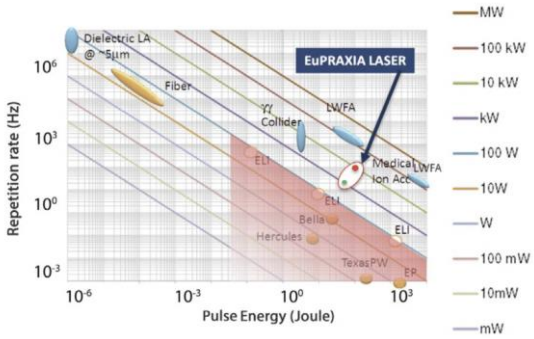



*Figure 1: Repetition rate and pulse energy of laser systems. The average power of current laser systems is limited to ≈100 Watts.*

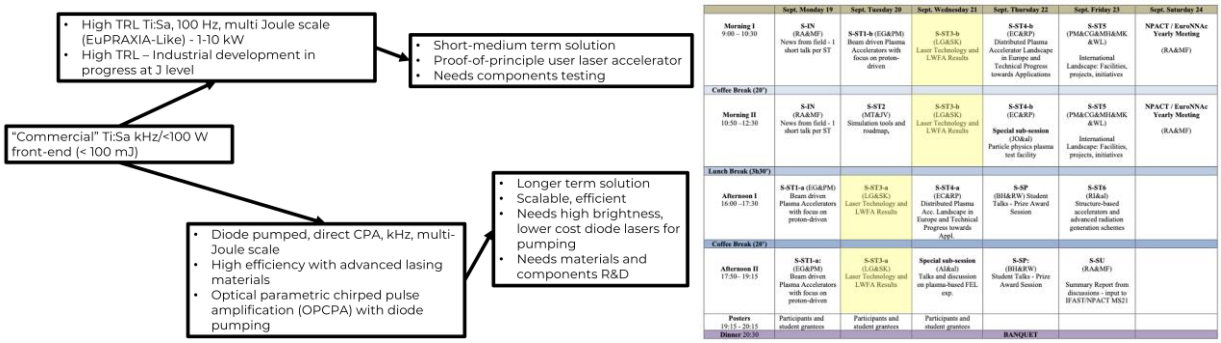
The available solid-state high-energy laser pulse amplification technologies currently most advanced include Ti:Sapphire-based (Ti:Sa) and Optical Parametric Chirped Pulse Amplification, (OPCPA). These approaches to high-average-power amplification are developing fast and hold the promise to deliver revolutionary performances to drive plasma accelerators and other major applications of such high-intensity lasers. In the perspective of a short-term approach, a driver for a plasma accelerator capable of outstanding parameters should be based on components with a high technology readiness level (TRL), ideally sourcing from a lab environment where specific technologies have been explored in depth. Ti:Sa technology is currently used in the HAPLS system (ELI Beamlines) to deliver today's highest available average power (300 W) and is certainly a valuable solution that can lead to advanced specifications by scaling existing systems. On the other hand, a number of different approaches, based on entirely new concepts, materials and architectures, are being developed to overcome fundamental limitations of these systems in terms of wall-plug efficiency, compactness and, ultimately, scalability.

Scope of the workshop activity was to gather experts from different key labs working on the most promising solutions and discuss status and perspectives towards prototyping and scaling to PW/multi kW operation.

# 2 Description of Workshop activity

## 2.1 PREPARATION ACTIVITY

A first preparation session on "Special Topic S-ST3: Laser Technology and LPA Results (e-, p+, ion)" was held during the EURONNAC Special Topics meeting held from the 18th to the 24th of Sep 2022 at Isola d'Elba, Italy. The session, coordinated by L.A.Gizzi (CNR) and S. Karsch (LMU) was conceived to contribute to the objectives of the Task 6.2 towards this Milestone 6.2, contributing to the preparation of the **roadmap to foster delivery of advanced industrial laser drivers** (see Figure 2) with high-repetition rate and higher efficiency, for the first user laser-plasma based accelerators. He agenda of the meeting included one full afternoon session and one full morning session to discuss laser technology and related laser-plasma acceleration issues.




| | 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 roadmaps, | S-ST3-b (LG&SK) Laser Technology and LWFA Results | **S-ST4-b** (EC&RP) **Special sub-session** (JOkal) 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** (RJ&aJ) 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** (AiJkal) 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** | | |

*Figure 2: Block diagram of the Roadmap conceived to move from existing commercial technology to advanced solutions meeting laser-driver needs of plasma accelerators. On the right the agenda of the preparatory session on Laser technology held in September 2022.*

Among the key results presented, a number of highlights emerged:

- Development emerged clearly on **industrial scientific laser** development towards the kW regime of Ti:Sa systems.
- Marked progress on **the use of** robust, efficient industrial multi kW, thin disk laser technology with nonlinear was also presented:
    - plasma-modulation resonant wakefield
    - **non-linear spectral broadening** for multi-TW, kW, kHz femtosecond pulse generation with high efficiency (up to 80%)
- **Fiber coherent combination** aiming at few cycle, 100 Hz, with self-phase modulation and J-scale pulses with multi-core fibers.
    - Demonstrated wp efficiency of 30% is an extremely valuable result.
- Direct **diode-pumping of Thulium doped** new materials (sesquioxides) is expanding, entering development phase

## 2.2 LASPLA WORKSHOP 2023

Based on these emerging advances, a full workshop on Laser technology was organized in the context of the recent European Advanced Accelerator Concept 2023. The workshop was again focused on the roadmap for laser driver and high average power technologies for plasma accelerators. Highlights include new ideas for diode-pumped CPA lasers, networking of intense laser labs and major industrial advances for upcoming plasma accelerators (EuPRAXIA). Below a detailed description.

**Workshop Title: WG2- Laser technology (IFAST WP6 - Task2- LASPLA)**

*Topics addressed*:

- Recent achievements and future challenges in laser drivers for LPA
- Needs for laser driven accelerators (laser-plasma ion source, LWFA, IFEL, dielectric laser, ...)
- State-of-the-art of high peak and average power and perspectives
- Laser beam quality, contrast, stability
- High repetition rate issues
- TRL Studies

**Co-Leader**: Leonida A. Gizzi, INO-CNR
**Co-Leader**: Mariastefania De Vido, STFC
**Co-Leader**: Paul Crump, FBH – Berlin
**Co-Leader**: Gilles Cheriaux, CNRS
**Co-Leader**: Christophe Simon-Boisson,
The programme of the workshop is reported below with the list of the presentations including titles and speaker.

| | | |
|---|---|---|
| 16:20 | [413] Introduction to WG2 | CHERIAUX, Gilles<br>GIZZI, Leonida Antonio |
| 16:25 | [185] The ZEUS laser user facility | WILLINGALE, Louise |
| 16:45 | [272] ELI Beamlines L1 ALLEGRA laser: experience with operation of high energy, 1 kHz, 15 fs OPCPA based system for user experiments | BAKULE, Pavel |
| 17:05 | [275] Amplitude Roadmap for high average power ultraintense laser for plasma acceleration | FALCOZ, Franck |
| 17:25 | [280] "Bivoj / DiPOLE" as a pump source for high repetition rate laser particle accelerators | PILAR, Jan |
| 17:45 | [301] Design of direct diode pumped amplification stages based on Tm ceramics for kHz rep-rate, kW average power lasers: Design issues and material characterization | LABATE, Luca |
| 18:05 | [356] Diode Laser Pumps for Advanced Accelerators | KNIGGE, Andrea |
| 18:25 | [427] discussion | |

| | | |
|---|---|---|
| 16:20 | [414] Introduction to WG2 | |
| 16:25 | [310] Pulse characterisation technique for multi-pulse laser plasma wakefield accelerators | WANG, Wei-Ting |
| 16:45 | [367] EuPRAXIA laser requirements and current conceptual design issues | GIZZI, Leonida Antonio |
| 17:05 | [331] High-power laser development in Jena | KALUZA, Malte |
| 17:25 | [342] Diode-pumped Laser-drivers for plasma accelerators | DE VIDO, Mariastefania<br>PATTATHIL, Rajeev |
| 17:45 | [349] Joule-class Yb:YAG lasers for driving plasma-modulated plasma accelerators | KRÜGER, Mathias |
| 18:05 | [372] Robust high-average-power lasers and scaling to high pulse energy | WEITENBERG, Johannes |

| | | |
|---|---|---|
| 16:20 | [415] Introduction to WG2 | |
| 16:25 | [365] Laser development for LWFA and future plans | CORNER, Laura |
| 16:45 | [383] Precision high average power ultrashort pulse lasers | GEDDES, Cameron |
| 17:05 | [305] High peak power and high average power Ti :Sa lasers for high performance particle acceleration | CHALUS, Olivier |
| 17:25 | [361] A 100 Hz laser system with with few-cycle and TW Pulses | OSVAY, Karoly |
| 17:45 | [325] Industrial Compact Free Electron Lasers and Laser-driven Accelerators | HEGELICH, B.M. |
| 18:05 | [212] The X-lites Network | WILLINGALE, Louise |
| 18:25 | [401] The HORIZON project : towards face-cooled kiloWatt-class Yb:YAG laser systems | BALCOU, Philippe |
| 18:45 | [431] discussion | |

*Table 1: Scientific programme of the IFAST LASPLA Laser Technology Workshop held on 19th, 20th and 22nd of September 2023 in the framework of the EAAC 2023 at Elba, Italy*


***Figure 3:*** *Images from the IFAST LASPLA Laser Technology Workshop held on 19th, 20th and 22nd of September 2023 in the framework of the EAAC 2023 at Elba, Italy.*

## 2.3 WORKSHOP HIGHLIGHTS

Highlights of the workshop include

- Major progress on industrial scientific laser development towards very high peak power ≈10 PW operation on one side and ≈ kW regime at 100 Hz of Ti:Sa systems that are now becoming established tools in view of the prototype development and EuPRAXIA baseline (AMPLITUDE, THALES)
- Robust industrial multi kW, thin disk laser technology entering rapidly the contest for LPA laser-driver, via NL compression or plasma-modulation resonant wakefield (LMU, OXFORD)
- Coherent combination of fibers aiming at few cycle, 100 Hz, with self-phase modulation and J-scale pulses with multi-core fibers (LBNL)
- High energy multi J scale, OPCPA based on robust and high beam quality DPSSL pump lasers. 100 TW scale in progress ( ELI-Beamlines)

- Significant progress in the development of pump lasers for high average power Ti:Sa system, along with other major blocks (compressor gratings, kW amplifiers) for Ti:Sa systems for user LPA (STFC)
- Direct diode-pumping of new materials (sesquioxides) now in development phase and needs coordinated effort across labs for materials and architecture (CNR)
- Strong impulse to diode laser developments for high average power, new wavelengths, high energy density, compactness (FBH, Leonardo …)

# 3 Future plans / Conclusion / relation to other IFAST work

The workshop provided an invaluable forum for the discussion on the prospect of laser driver development for plasma acceleration. It emerged clearly from the presentations and the discussions, that a number of initiatives are in progress world-wide aiming at a major development of laser-plasma acceleration for a number of cases, from medical accelerators for radiobiology, radiotherapy and diagnostics, to future colliders schemes for high energy physics studies. Indeed, the pressing demand for high repetition rate accelerators for radiotherapy is providing a short term motivation for industrial development of novel systems capable of ≈100 W average power that are now emerging on the market, based on further improvement of existing robust technology, like Ti:Sa. On the other hand the scaling to collider level requires a tremendous upscaling of the technology, calling for more fundamental developments to overcome limitations of the Ti:Sa platform, that are well beyond the current industrial capabilities.

Here the activity of several labs is rapidly providing a number of potential solutions, with entirely new approaches. The types of solutions presented at the workshop range from coherently combined fiber lasers to diode pumped solid state systems based upon new gain materials, like Thulium doped sesquioxide ceramic or Thulium doped YLF crystals, and unique cooling configurations capable of handling high average power. These are just examples of the many currently ongoing developments. Interestingly, all these systems have in common the use of laser diodes as efficient, reliable and robust pumping sources in place of flashlamp pumping. It is quite clear that the cost per unit power of such laser diodes is currently one of the limiting factor that is preventing the massive upscaling of DPSSL to high average power.

Other important limiting factors are the finite heat dissipation of pumped gain media and beam transport components for values of the average power above a few hundred Watts. The workshop offered an overview on the above issues, showing major advances and demonstrating the high interest of the community in these specific topics. Based on the outcome of this intense discussions, the knowledge base for the preparation of the full roadmap foreseen as the main outcome of Task 6.2 is progressing rapidly and effectively.

# 4 References

RELEVANT CONFERENCE CONTRIBUTIONS

L.A.Gizzi, Novel high-intensity lasers for plasma acceleration, *Invited talk at the* 109th 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