IFAST Open Steering Committee, 15-16 November 2021, Online

WP6: TASK 6.2 “LASPLA”
LASers for PLasma Accelerators

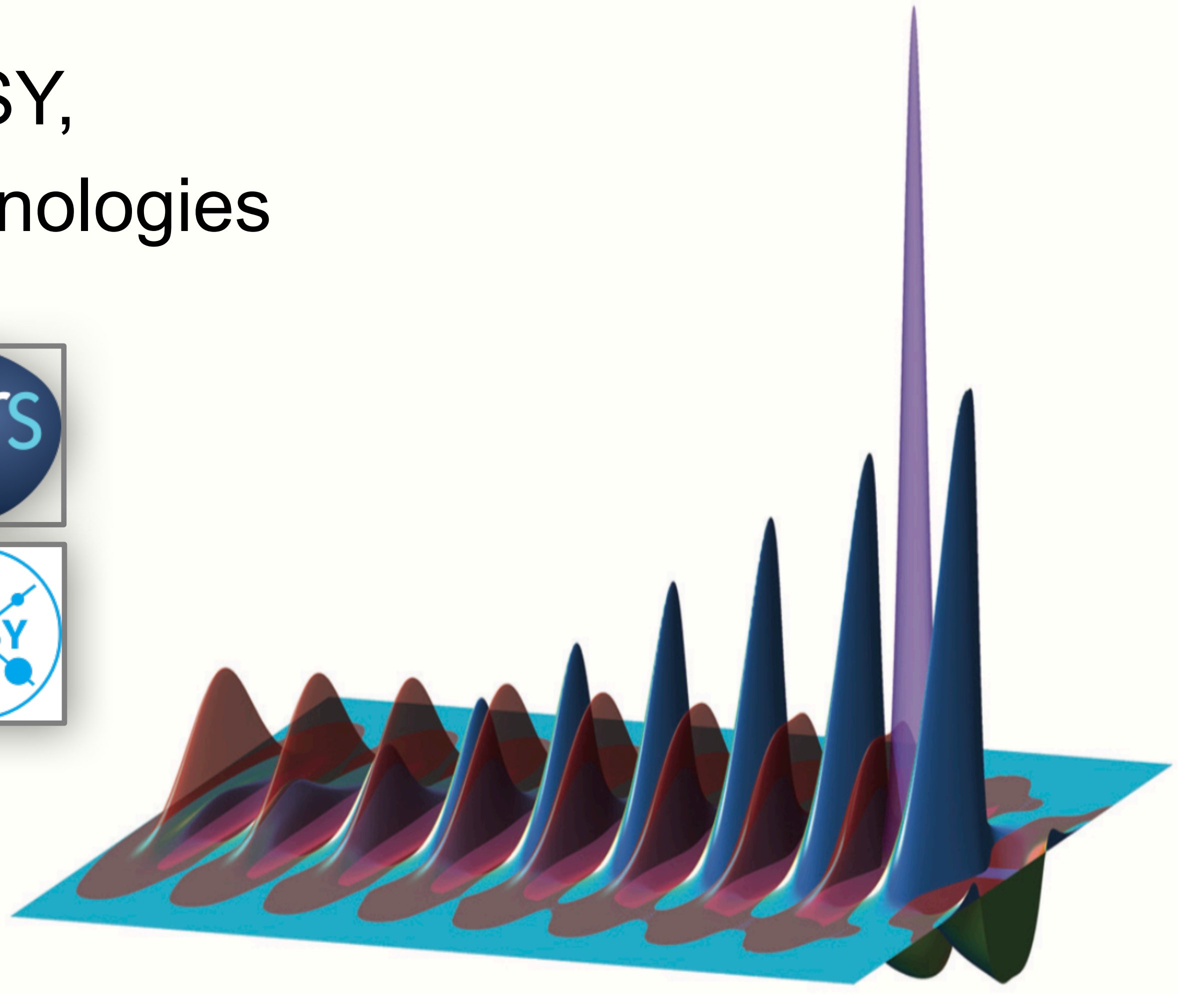
Leonida A. GIZZI, CNR, Italy

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

Task 6.2 LASers for Plasma Acceleration

- CNR, CERN, INFN, CNRS, DESY,
- THALES and AMPLITUDE Technologies

LASPLA team
L.A.Gizzi (CNR)
F. Mathieu (CNRS),
F. Falcoz (AT),
C. Simon Boisson (Thales)
D. Giove, (INFN-MI)
M.P.Anania (INFN-LNF)
…



P. Tomassini et al., Plasma Physics and Contr. Fusion, **62**, 014010 (2020); https://doi.org/10.1088/1361-6587/ab45c5
R. Assmann et al., EuPRAXIA Conceptual Design Report, EPJST, **229**, 3675–4284 (2020); https://doi.org/10.1140/epjst/e2020-000127-8

About I.FAST - Horizon 2020 (Research Innovation Action)

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)
- Develop innovative targets for laser-plasma acceleration
- Demonstrate improved beam features with the new targets
- Develop a new passive system to improve beam-pointing stability
- Define solutions to stabilize beam profile in the focal spot and ensure a shot-to-shot stability of the Strehl ratio

Tasks

Task	Name	Task Leader
6.1	Novel Particle Accelerators Concepts and Technologies (NPACT)	R. Assmann (DESY)
6.2	Lasers for Plasma Acceleration (LASPLA)	L. 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)

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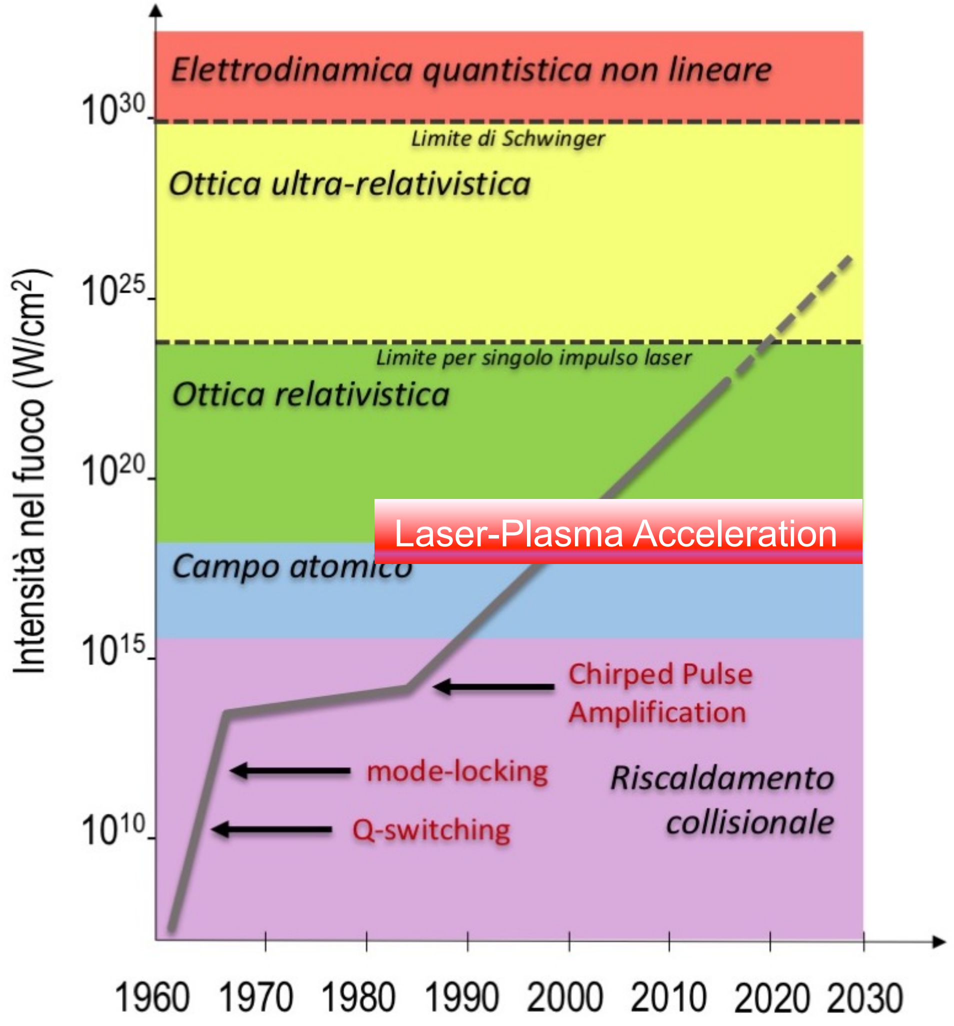
https://ifast-project.eu/

Task 6.2: 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, focused on laser-driver R&D.
- **MS22** - LASPLA Workshop/School [M30] – Report
- **D6.2** : LASPLA Strategy [M46] - Strategy for laser drivers for plasma accelerators

Scenario on intense lasers

- Current laser technology development mainly driven by **extreme intensity** applications;
- Laser-Plasma **acceleration** has developed along with progress in laser performance;
- **Recent LWFA-FEL demonstration** [*] highlights the role of **laser stability and control**;
- **LASPLA** will focus on the technology required to achieve **high-repetition** rate at **multi-joule** (≈100 TW) scale [**], with high quality and enhanced control and stability;
- **Key role of industry** to establish turn-key, high average/peak power ultrashort pulse technology;



*W. Wang, K.Feng et al., Free-electron lasing at 27 nanometres based on a laser wakefield accelerator, *Nature* **595**, 516–520 (2021)
L.A. Gizzi et al., A viable laser driver for a user plasma accelerator, NIM **A 909 , 58 (2018); https://doi.org/10.1063/1.4984906

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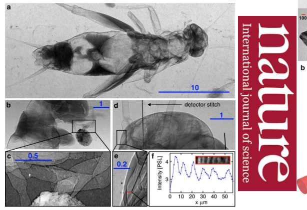
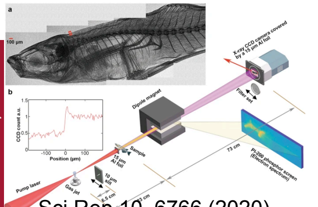
Societal applications for impact on industry

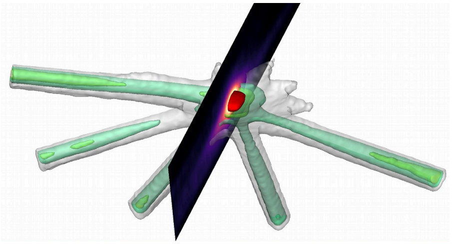
Motivating transition to industrial systems production

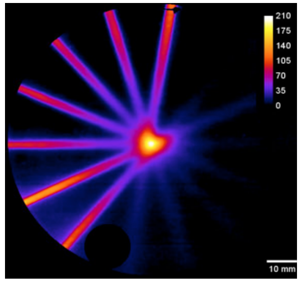
- **X-ray imaging** for compact, high resolution (phase contrast imaging[1]) bio-medical diagnostics;
  - Address some of the needs of large SR facility users
- **Laser-driven VHEE electrons[2] and hadron beams** can provide ultra-high dose-rate to meet requirements of future "FLASH[3]" radiotherapy, currently unaddressed:
  - Unique working point for beam readio-therapy
- **γ-rays or neutron sources[4]** for industry and security
  - Leading to dedicated centers (e.g EPAC)
- **Convergence with laser needs for FEL and FUSION research**
  - Broadband laser amplification
  - Unique tool for high energy density studies



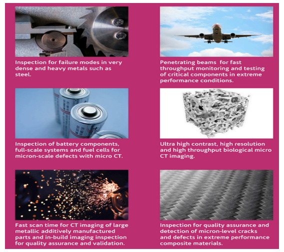
Nat Commun 11, 6174 (2020)

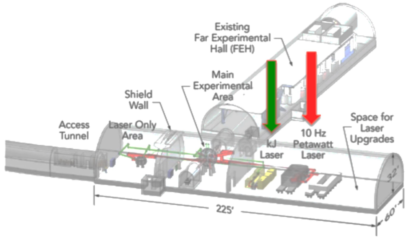

Sci Rep 10, 6766 (2020)





Sci. Rep.**10**, 17307 (2020)


The Extreme Photonics Applications Centre (EPAC), CLF, UK



SLAC 10 Hz Petawatt laser facility recently approved

Laser development Roadmap for FUSION being established.

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[1]J.M.Cole et al., Sci. Rep. **5**, 13244 (2015); [3]L. Labate et al., Scientific Reports **10**, 17307 (2020); [2]V. Favadoun et al., Sci. Transl. Med. 245ra93 (2014); [4]C. M. Brenner et al, PPCF, 58 014039, (2015)

What laser driver specs for future LPA

Rapidly evolving scenario for laser technologies relevant for plasma acceleration towards multi-stage accelerators design:

Pillars for a STRATEGY for laser drivers for plasma accelerators:

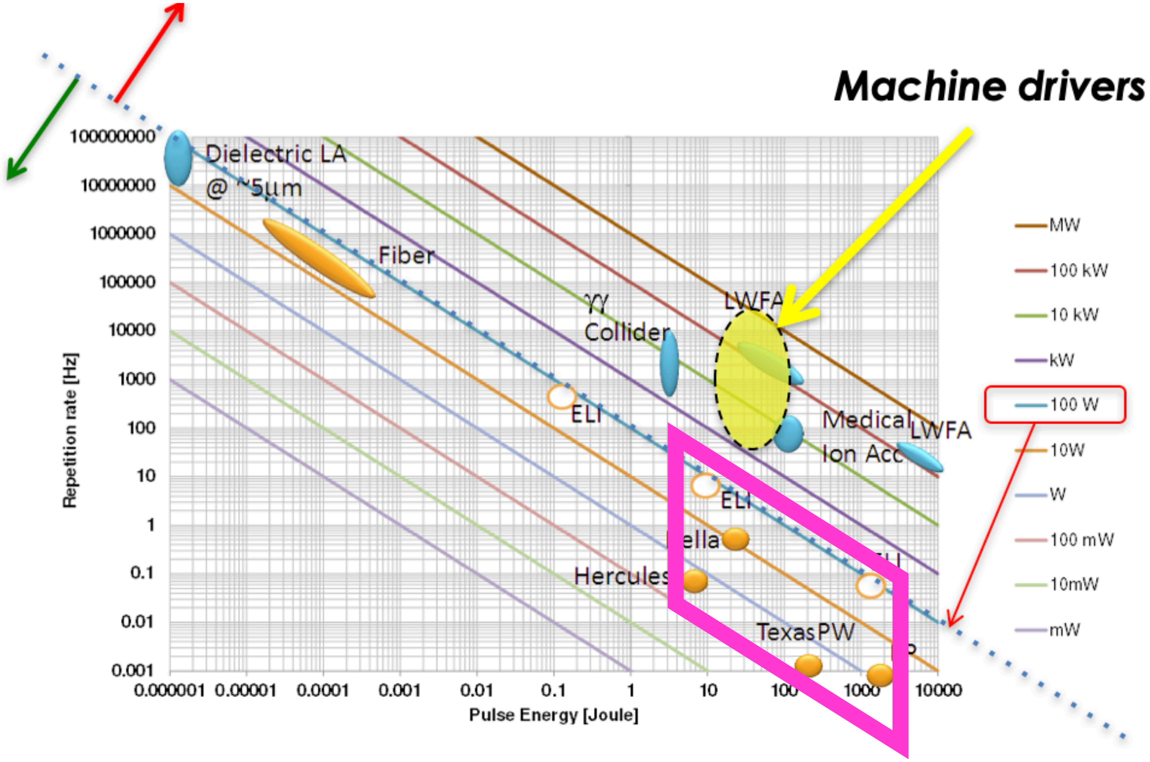
- Ultrashort pulses (large bandwidth <50 fs)
- High Repetition rate (100 Hz – 15 kHz)
- High average power (kW -10 kW)
- High wall-plug efficiency (>30%) → **Beyond TiSA**

L.A Gizzi, F. Mathieu, P. Mason, P P Rajeev, *Laser drivers for Plasma Accelerators*, in Félicie Albert et al, *2020 roadmap on plasma accelerators*, 2021 New J. Phys. 23 031101, https://doi.org/10.1088/1367-2630/abcc62

Roadmap on LPA Laser Driver technology

Laser-driven plasma acceleration needs ultrashort, high power lasers with <u>high average power</u>

- **Current technology: ≈ Ti:Sa technology, pumped by flash-lamp pumped lasers**
  - Robust, reliable industrial technology
- **Mature technology: ≈ Ti:Sa technology, pumped by diode-pumped lasers**
  - Strong R&D effort in place (e.g HAPLS@ELI)
  - ≈ 3-5 years to go to first industrial LWFA demonstrator (e.g. Eupraxia) [1]



Current Systems

- **Targeting higher wall-plug efficiency and rep. rate, kHz and beyond, stability, control (space, time, spectral)**;
  - **5-10 yrs for first efficient**, multi-kW-scale demonstrator,
  - A strategy is needed to steer effort in the LPA laser driver direction: LASPLA

[1] R. Assmann et al., EuPRAXIA Conceptual Design Report, The European Physical Journal Special Topics **229**, 3675–4284 (2020)
[2] C. Danson et al., Petawatt and exawatt class lasers worldwide High Power Laser Sci. and Eng. **7**, e54 (2019)

Several options under development

- **Fiber laser technology** offers the best WPE >50% in CW mode and coherent combination is being developed (FSU Jena-Fraunhofer IOF and Ecole Polytechnique-Thales in France).
  - Suited for moderate energy per pulse/high rep-rate (10s of kHz);
  - Now 96 fibers delivering 23 mJ and 674 W in a 235 fs pulse
- **Direct Chirped Pulse Amplification** with lasing media pumped directly by diodes is ideal for higher efficiency and higher rep-rate;
  - several materials under consideration, Yb:CaF2, Tm:YLF, Tm:Lu2O3 …
  - PENELOPE (Jena) 150 J, 1 Hz, at 1030 nm
- **OPCPA** optical parametric amplification within large-aperture lithium triborate (LBO) crystals;
  - ELI-Beamlines facility, L1 ALLEGRA (100 mJ at 1 kHz) and L2 AMOS (100 TW, 2 to 5 J between 10and 50 Hz), and the Shenguang II Multi-PW beamline(SIOM, China) …

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L.A Gizzi, F. Mathieu, P. Mason, P P Rajeev, *Laser drivers for Plasma Accelerators*, in Félicie Albert et al, *2020 roadmap on plasma accelerators*, 2021 New J. Phys. 23 031101, https://doi.org/10.1088/1367-2630/abcc62

Currently explored R&D path

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

- 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

- Diode pumped, direct CPA, kHz, multi-Joule scale
- High efficiency with advanced lasing materials

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

LASPLA Technical meetings

WP6 - NPACT-Novel particle accelerators concepts and technologies

Task 6.2 - LASPLA

1st Technical Meeting – 23rd June 2021

10.00 - "Introduction about IFAST/LASPLA" - Leo GIZZI/CNR, Italy

10.20 - "Overview of Laser Technology Developments @ CLF" - Paul MASON/STFC, UK

10.40 - "First acceleration experiments on Apollon" - Francois MATHIEU/CNRSApollon, France

11.00 - "Overview of laser technology developments @ Thales" - Christophe SIMON BOISSON/THALES, France

11.20 - "New materials for pulse amplification at 1 and 2 microns" - Guido TOCI/CNR-INO, Italy

11.40 - "Tm:Lu2O3 amplifier design issues" - Luca LABATE/CNR-INO, Italy

12.00 - "Challenges for diode laser pump sources: high intensity & high repetition rate & efficient & low €/W" - Paul CRUMP/FB, Germany

12.20 - Discussion and next meeting/conference - All

12.30 - Close

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LASPLA Technical meetings

WP6 - NPACT-Novel particle accelerators concepts and technologies

Task 6.2 - LASPLA

2nd Technical Meeting – 7th October 2021

Session 1 (Convenor, L. GIZZI, CNR)

15.00 – Leonida A GIZZI, INO-CNR, Pisa, Italy, “Overview and motivation of the IFAST project”

15.15 - Georgia ADRIANAKI, HMU, Greece,“Experiencing the development of the ZEUS laser facility at IPPL for particle acceleration optimization experiments”

15.30 - Thomas M. SPINKA, LLNL, USA, - "Demonstration of a compact, multi-joule, diode-pumped Tm:YLF laser”,

15.45 – Roman WALCZAK, Clarendon Laboratory, Oxford, UK – “High-repetition-rate, GeV-scale accelerators driven by plasma-modulated laser pulses”

16.00 - Joachim HEIN, Jena University, Germany, “Prospects of high energy Tm lasers and first tests”

Session 2 (Chair Paul CRUMP, FBH)

16.30 – Luca LABATE, CNR-INO, Pisa, Italy, “Tm laser development for the ELITE infrastructure at CNR”

16.45 - Luis ROSO, CLPU, Salamanca, Spain, “Petawatt Lasers: High Repetition Rate Challenges”

17.00 - Victor MALKA, Weizmann Institute, Israel - “What about very high energy electrons radiotherapy (VHEE-RT) with compact laser plasma accelerators?”

17.15 - Andreas R. MAIER, Hamburg University, Germany - “High Average Power Laser-Plasma Acceleration”

17.30 – Conclusions/Next meeting (All)

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LASPLA: map of active participation to technical meetings

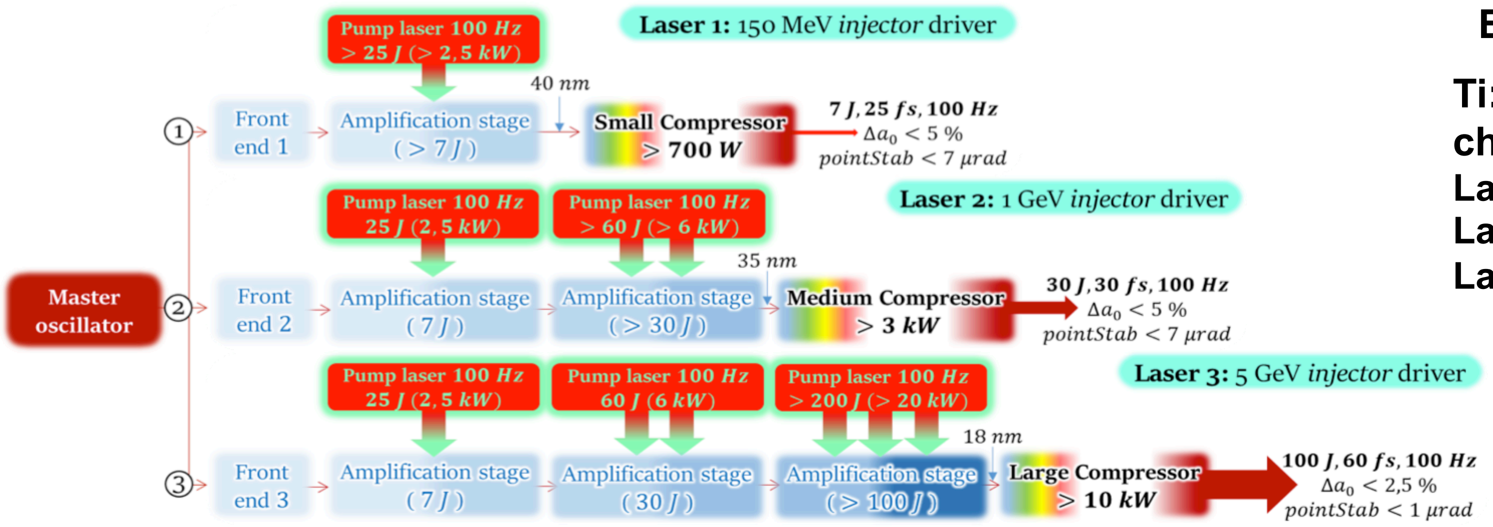
LLNL, (US)

Maximum of 50 attendees to the 2nd technical meeting

Very positive feedback from participants: informative and effective

EuPRAXIA: Overall Baseline System Design

The current EuPRAXIA laser design relies on Titanium Sapphire technology to address average and peak power as required by the project.

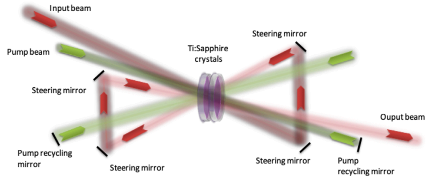


EuPRAXIA baseline laser systems:

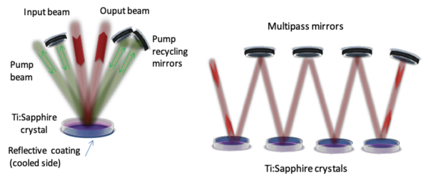
Ti:Sapphire based amplification chains
Laser 1 : to drive a 150 MeV injector
Laser 2 : to drive a 1 GeV injector
Laser 3 : to drive a 5 GeV accelerator

MAIN CHALLENGES
Pumping technology:
High rep. rate, high energy
Gain media:
Bandwidth, Size, Thermal load, Cooling
Grating technology
Size, LIDT, Thermal load, Cooling
Pointing stability
Transport

Amplifier geometries (needs TDR)



Pro: More efficient (double-side) cooling and reduced complexity;
Con: propagation through flowing cooling liquid



Pro: Well established concept with no propagation through cooling fluid
Con: limited cooling (single face), to be modelled

Strong synergy

Ti:Sa amplifier (EPAC 30J, 30fs @ 10H
Science and Technology Facilities Council
Gas cooled Ti:Sa amplifier
50J @ 10Hz with 100+nm bandwidth – installation commences Q3 2022
Full 3D Ti:Sa amplification model developed
Spatial, temporal, polarization & spectral dependencies
ASE mitigation strategies, delayed pulse pumping etc.
Developing solid-state Ti:Sa cladding solution for ASE suppression
central laser facility

Pump lasers options:
- P60 (Amplitude)
- Dipole (STFC)

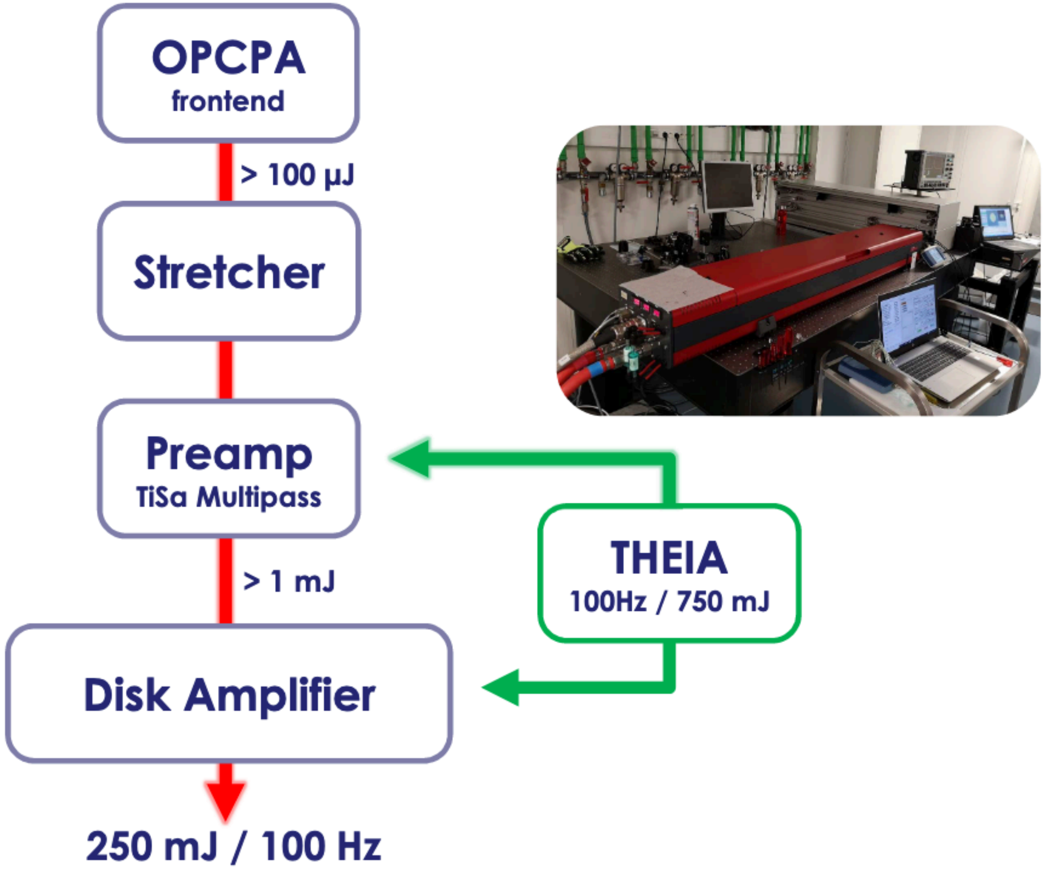
- L.A. Gizzi, et al., A viable laser driver for a user plasma accelerator, NIMA **909** , 58 (2018); https://doi.org/10.1063/1.4984906
- R. Assmann et al., EuPRAXIA Conceptual Design Report, The European Physical Journal Special Topics **229**, 3675–4284 (2020); https://doi.org/10.1140/epjst/e2020-000127-8
- Water cooled Ti:Sa amplifier under development at ELI-HU (After V. Cvhykov *et al.* , Opt. Lett, **41,** 3017, 2016)
- Fluid (D_2O) cooled Nd:YAG laser, 20 kW CW pump power, D_2O (After X. Fu *et al.* , Opt. Express, **22**, 18421 (2014)
- Fluid (Siloxane) cooled Nd:YLF laser, 5 kW CW pump power (After Z. Ye *et al.* , Opt. Express, **24**, 1758 (2016)

Ongoing Ti:Sa high rep rate industrial developments

FROM HIGH PEAK POWER TO HIGH REPETITION RATE

New TiSa laser architecture – In development

- **Robust OPCPA FE** : 100Hz / 300µJ demonstrated
- New ns diode-pumped laser : **THEIA family qualified**
- New TiSa amplifier architecture : **Proof of Concept demonstrated** @ 10 Hz and ready for 100 Hz operation



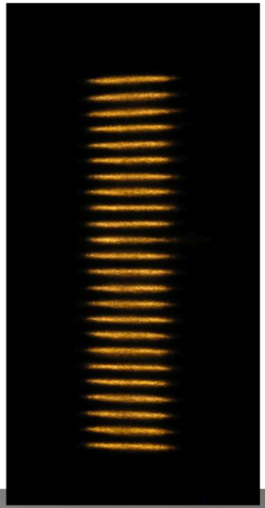
C.Simon-Boisson@1st LASPLA meeting

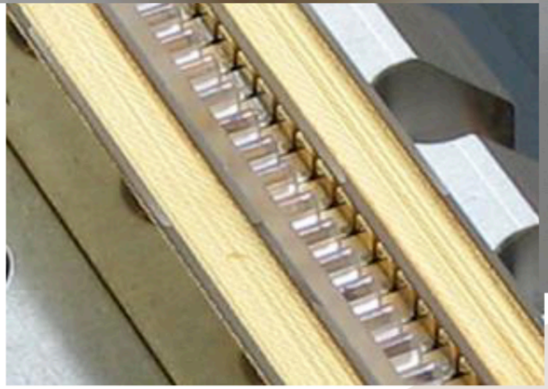
Diode lasers pump source development

High intensity & repetition rate & efficient & low €/W

Fully assembled stack module made with FBH infrastructure

- Stack on Base plate
- Base plate connectors (water, electronic, power)
- Stack interchangeable
- 3 x PT100 for early warning monitoring
- Each equipped with FACs (share a common side tab)
- One SAC for a stack module
- 24 StEl near 780nm
- Interchangeable with 28StEl version



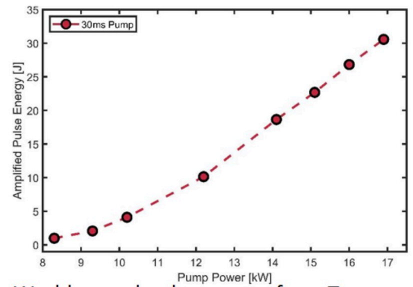


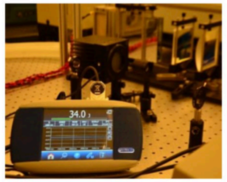
P. Crump@1st LASPLA Technical meeting

Leibniz Ferdinand Braun Institut

Latest developments on high efficiency Tm doped lasers

Single Shot Demonstration: >30 J Pulse Energy Extracted in Long Pulse Mode



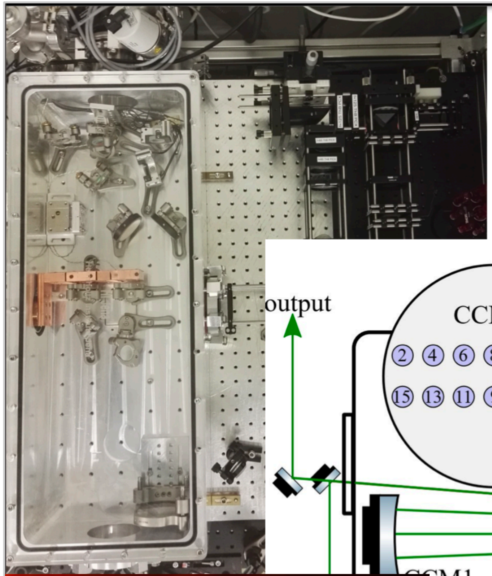


- World record pulse energy from Tm materials.
- Demonstrated high energy storage and extraction confirms gain physics and models.

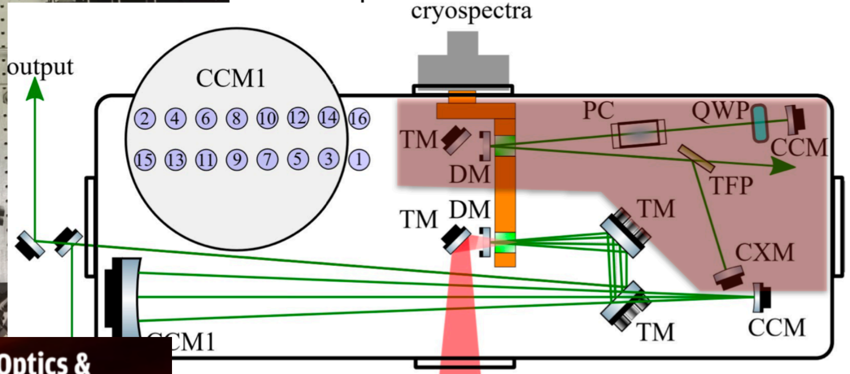
Lawrence Livermore National Laboratory

LLNL-PRES-827720

T. Spinka@2nd IFAST-LASPLA meeting



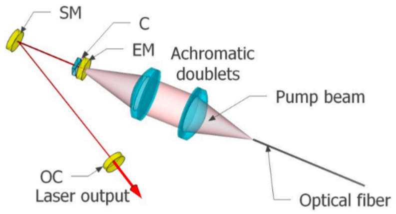
- Tm:YAG 3at.% @ 150K
- 4 material passes per round-trip
- 15mm RTP Q-switch
- 3.5kW homogenized pump (same as amp)
- magnification of 1.25
- setup in vacuum

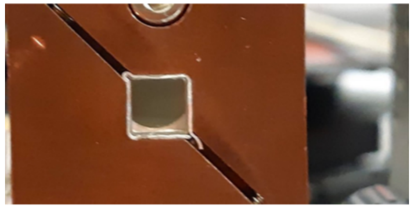


Institute of Optics & Quantum Electronics JENA

Friedrich Schiller University

J. Hein et al @2nd IFAST-LASPLA meeting





Lasing with Tm:Lu2O3 ceramic

CNR-INO

ISTITUTO NAZIONALE DI OTTICA

CONSIGLIO NAZIONALE DELLE RICERCHE

L.Labate et al @2nd IFAST-LASPLA meeting

- Among the most exciting results presented at the 2nd IFAST-LASPLA Technical meeting on Lasers for Plasma Acceleration
- Collaborations are spinning off

Forthcoming actions:

- **Towards D6.2 : LASPLA Strategy [M46] - Strategy for laser drivers for plasma accelerators:**
  - Update survey of existing/developing laser technologies, including next-in-line industrial products;
    - List against TRL of components and architectures;
    - Identify key needed collaborative developments;
    - R&D funding opportunities for labs/facilities;

- **Towards MS22 - LASPLA Workshop/School [M30]:**
  - Start preparation of the first LASPLA related workshop (18-22 April, 2022, tbc);
  - Secure participation and scientific contribution to EAAC 2022/2023
  - Training programme for LPA laser-driver development (Capri Summer School (Spring 2022, tbc);

Collaborative space

Collaboration Workspaces

BROWSE PAGE

WP6 **Task 6.2** EDIT LINKS

Task 6.2

- **Home**
- Notebook
- Documents
- Site Contents

EDIT LINKS

Lasers for Plasma Acceleration (LASPLA)

Task Leader: L. Gizzi (CNR)

SUMMARY

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, focused on laser-drivers R&D

MS22 - LASPLA Workshop/School [M30] - Report

D6.2 - LASPLA Strategy [M46] - Strategy for laser drivers for plasma accelerators

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All files of the 1st Technical Meeting of Task 6.2 (LASPLA) have been uploaded. See Readme file for info and agenda of the meeting.
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LASPLA_1sr_Tech_meeting_L.Labate	...
LASPLA_1sr_Tech_meeting_P.Mason	...

1 - 15

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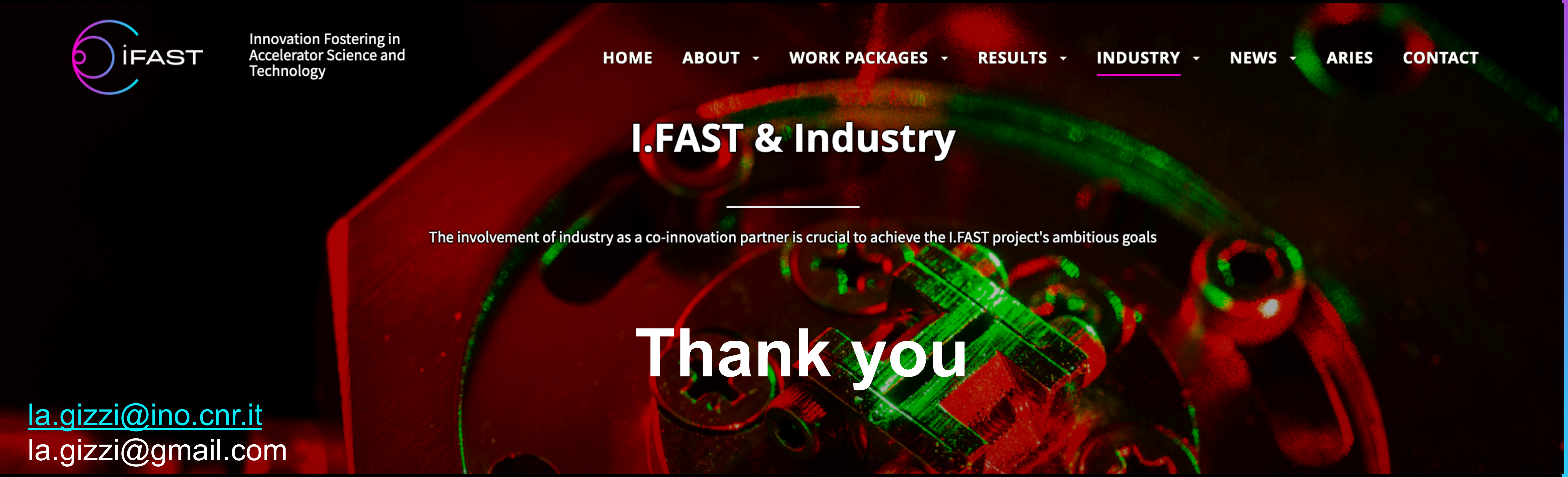
Summary

- IFAST Lasers for Plasma Acceleration Task 6.2 on track
- Network established and further growing
- Technical discussion focusing on needed solutions for plasma accelerators



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