Leonida A. GIZZI
CNR, Istituto Nazionale di Ottica, Pisa, Italy

iFAST 3rd Annual Meeting

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)	**M. Ferrario (INFN)** - 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. **ACTIVITY IN PROGRESS** *Report on the EAAC workshops as strategic forums for international accelerator R&D and resulting strategies*	M42
D6.2: LASPLA Strategy. **ACTIVITY IN PROGRESS** *Report on a strategy for laser drivers for plasma accelerators.*	M46
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 BEING 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**

iFAST

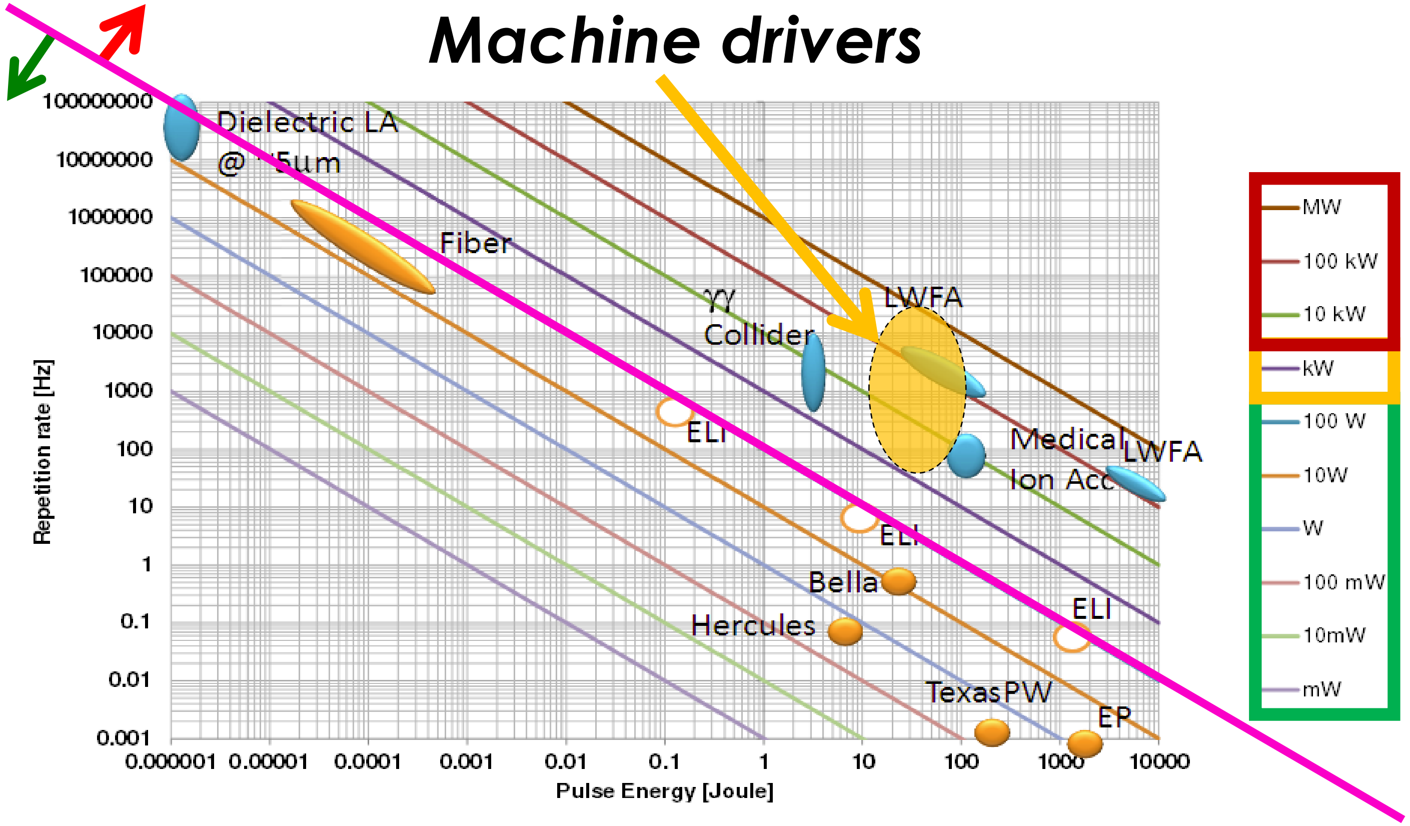
Task Leader: Leonida A. GIZZI – CNR-INO

Status of laser driver development

Current reqirement for LPA driver: PW-class system, with high repetition rate (≈kHz)

Demanding high average power

Machine drivers



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.

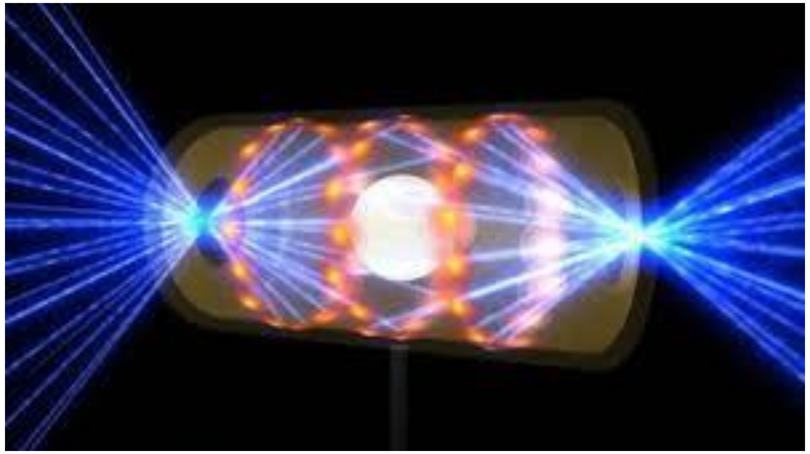
Establish a **coordination activity with networking** and training of **main laser labs and industrial partners**, focused on laser-driver R&D.

Major effort required to fill the gap between **existing** and **required** laser technology

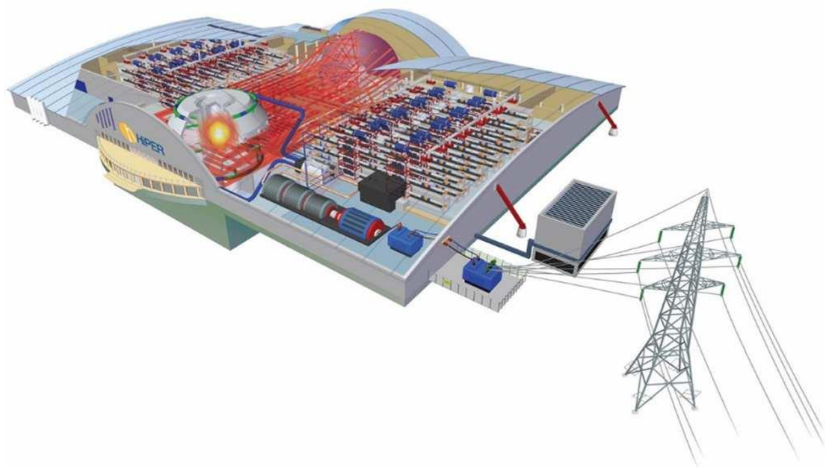
L.A. Gizzi et al., A viable laser driver for a user plasma accelerator, NIM **A 909 , 58 (2018); https://doi.org/10.1063/1.4984906

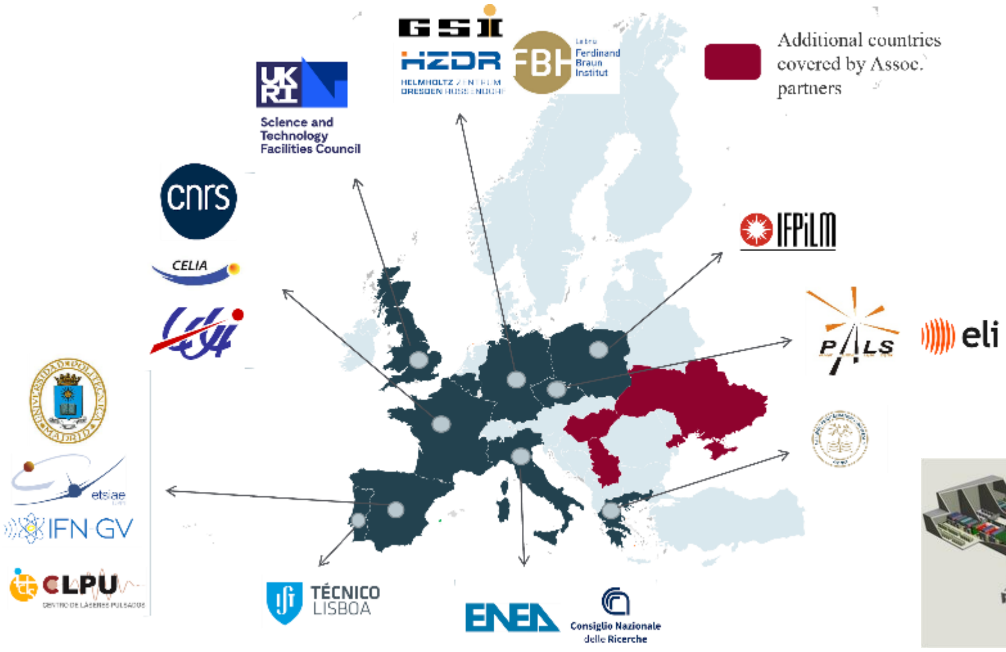
SYNERGY WITH LASERS FOR *INERTIAL FUSION ENERGY*

From ICF IGNITION@NIF ...



... to Inertial Fusion Energy





Massive investments in lasers needed, and started.

HiPER+: Single beamline specifications

REACTOR LEVEL FRONT END
Laser specifications for repetitive operation (reactor level): 10 Hz

Front end Pulse shaping → Pre-Amplifier ≈ 1-10J → Power-Amplifier up to 1kJ →

MAIN AMPLIFIERS FOR IGNITION STUDIES
Laser specifications for single shot operation (ignition level): 1 shot/10 min

Main Amplifier ≈10 kJ → Beam Transport → Final Optics →

HiPER+ user infrastructure laser operation: L1

Target Chamber
10 Hz, 100 kW /beamline

HiPER+
EUROPEAN LASER FUSION ENERGY

An InfraDEV EU proposal for Inertial Fusion Energy - 2024

Task 6.2 (LASPLA): Roadmap for laser driver development

Parto of the **WP6: Novel Particle Accelerators Concepts and Technologies of i.FAST**

Innovation Fostering in Accelerator Science and Technology

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)	M. Ferrario (INFN)
6.2	Lasers for Plasma Acceleration (LASPLA)	L. Gizzi (CNR)
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6.4	Laser focal Spot Stabilization Systems (L3S)	F. Mathieu (CNRS)

Existing "Commercial"
100 Hz,<100 W, J-SCALE front-end
&
Efficient diode laser technology

- High TRL Ti:Sa, 100 Hz, multi Joule scale (EuPRAXIA-Like) - 1-10 kW
- Coherent combination of multi-J-scale beams
- 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 (DPSSL)**
- Optical parametric **chirped pulse amplification (OPCPA)** with diode pumping
- Post-compression of thin-disk lasers
- Coherent combination of fibers

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

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

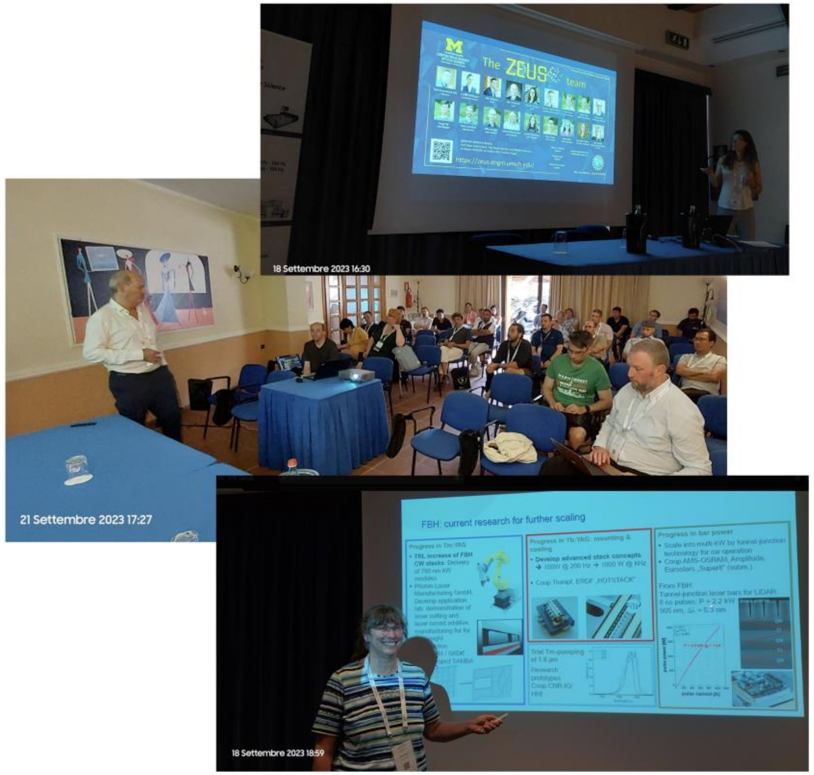
	Monday 18th		Tuesday 19th		Wednesday 20th		Thursday 21st		Friday 22nd
09:00	*Opening remarks*	09:00	2023 AWAKE Run results (E. Gschwendtner)	09:00	Status and recent results of FLASHForward (F. Peña)	09:00	Probing strong-field QED in beam-plasma collisions (A. Matheron)		
09:20	Free electron lasers driven 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

Dedicated IFAST LASPLA Workshop @ EAAC2023

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

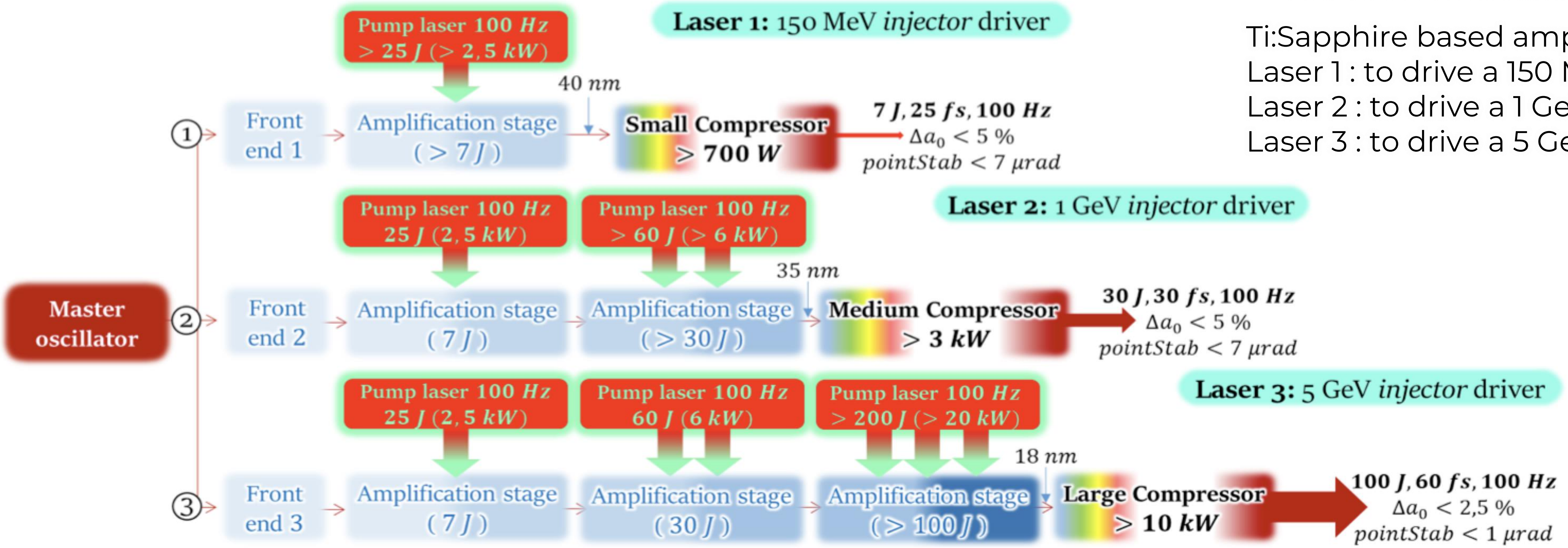
iFAST

EuPRAXIA: Baseline Laser Design

EuPRAXIA Advanced Photon Source

Funded by the European Union

The current EuPRAXIA laser design relies on Titanium Sapphire technology to address average (10 kW) and peak (PW) power as required by the project (1-5GeV LWFA).



EuPRAXIA baseline laser systems:

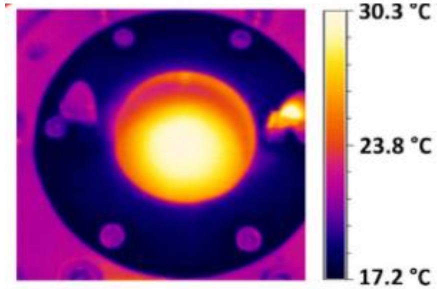
Ti:Sapphire based amplification chains
Laser 1 : to drive a 150 MeV injector
Laser 2 : to drive a 1 GeV injector
Laser 3 : to drive a 5 GeV accelerator

•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 EPJ-ST 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)

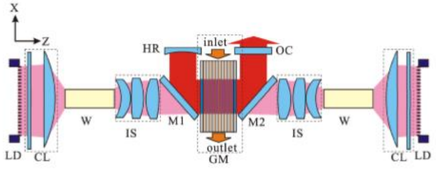
Underpinning EuPRAXIA-like Laser driver TDR

Funded by the European Union

THERMAL MANAGEMENT OF POWER AMPLIFIERS



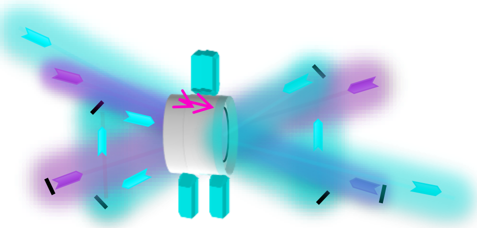
WATER/GAS COOLING



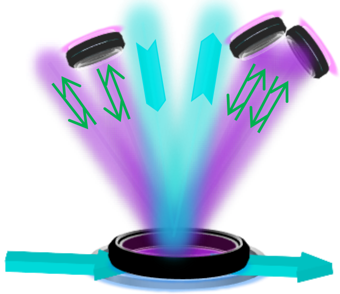
Prototyping needed

AMPLIFIER GEOMETRY TRANSMISSION VS. REFLECTION

Multipass transmission

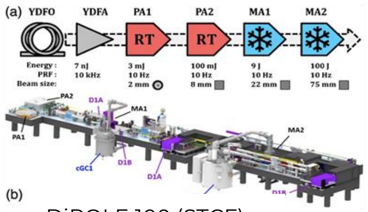


Multipass reflection

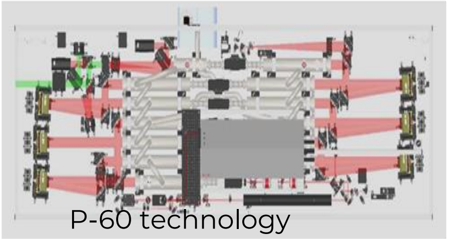


Prototyping needed

DPSSL PUMP SOURCES TECHNOLOGY



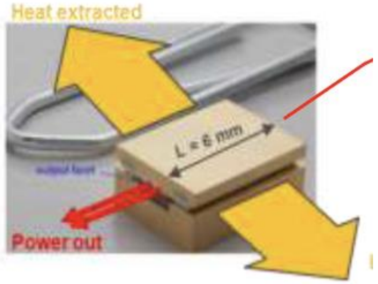
DiPOLE 100 (STCF)

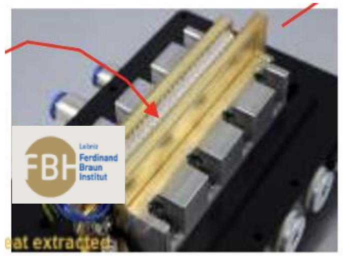


P-60 technology (Amplitude)

Currently no solution for full system specs (P1): development

DIODE LASERS EFFICIENCY, BRIGHTNESS AND LIFETIME



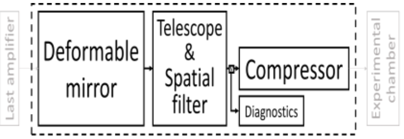


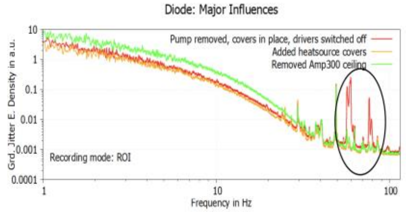
Needs development

COMPRESSOR AND TRANSPORT: THERMAL AND MECHANICAL

Gold -> MD, MLD, MMLD

reduction of the thermal load
cooling of residual heat
control of thermal effects





Main challenges: large optics, mechanical stability, beam quality control, pointing stability

Intermediate milestone in progress

Funded by the European Union

Eupraxia laser development is aimed at delivering more efficient, kW-PW laser driver for plasma acceleration at >100 Hz rate

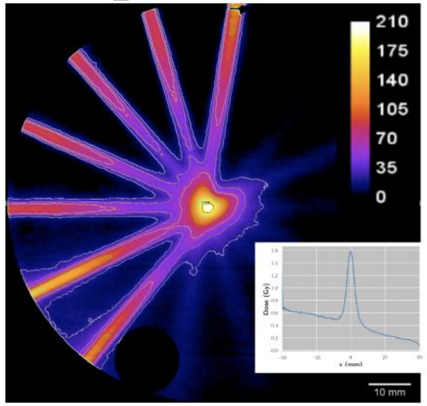
Developments ongoing at national level (NextGeneration EU)

>4 M€ investment

FUTURE SYSTEM

- **PW class,**
- **100 Hz repetition rate,**
- **multi kW average power,**
- **diode pumped,**
- **Thermal load effects.**

VHEE-RT



IN PROGRESS

- **>30 TW peak power**
- **100 Hz repetition rate**
- **100 W average power**
- **Diode pumped**
- **Thermal load effects**

THALES

Establish the platform for 100 Hz operation LPA with **twofold objective**:

- **Biomedical** developments VHEE-RT & FLASH (100 MeV – 250 MeV);
- Front-end level **test platform** for multi GeV LPA driver development.

Laser TDR Working plan: PACRI *Infratech* proposal

PLASMA ACCELERATOR SYSTEMS FOR COMPACT RESEARCH INFRASTRUCTURES

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

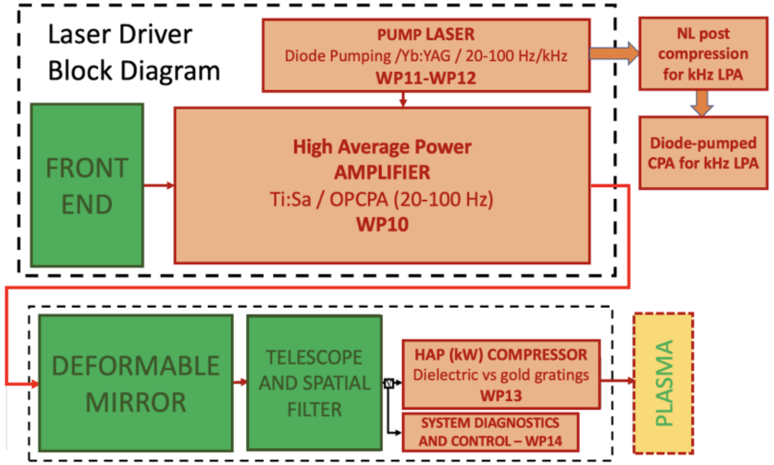
EuPRAXIA laser driver (100 Hz) and longer term options (1 kHz)

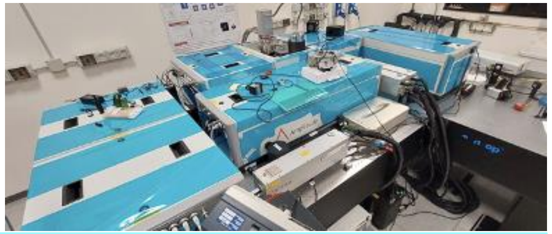
WP10: High repetition rate High power Ti:Sa amplifier module

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





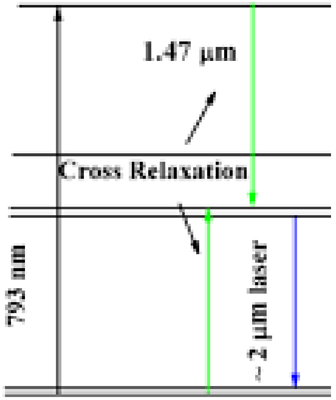
WP12: Efficient **kHz** laser driver modules for plasma acceleration: 1) NL broadening +post compression and 2) new materials (Tm:XX)

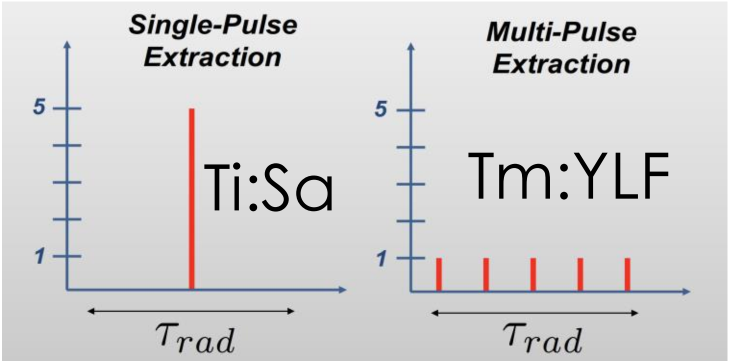
- **Laser-driven 2nd site development and (new) excellence center(s) on laser technologies will boost activities**
- **Leveraging on developments ongoing at national level (all partners)**

Thulium based gain materials

Main features

- Emission at 2 µm, eye safe;
- Ultrashort possible (<100 fs);
- High peak power ≈ PW;
- High average power(scalable from kW to 300 kW);
- Direct pumping at 800 nm, using diodes operating in CW mode (available and scalable);
- Multi-pulse extraction at high repetition rate
- 10 kHz; Ideal for accelerator technology;
- High efficiency;
- Mature material technology (crystal growth or ceramics);



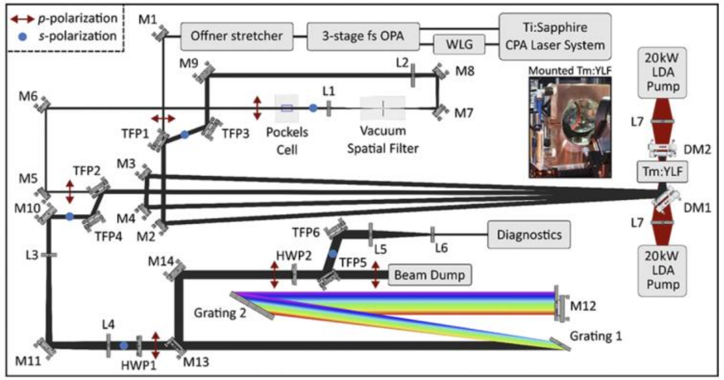


C. Haefner et al., EAAC 2017

High Efficiency enabled by multipulse extraction (energy storage)

Relatively new approach for short pulse operation: needs R&D, but promising

Demonstration of a 1 TW peak power, joule-level ultrashort Tm:YLF laser*



E=1.59 J
Pulse duration=270 fs
P=1.7 TW
Pump: 35.3 kW p.p. 40 ms

Thulium starting to show real potential for a new, efficient driver platform.

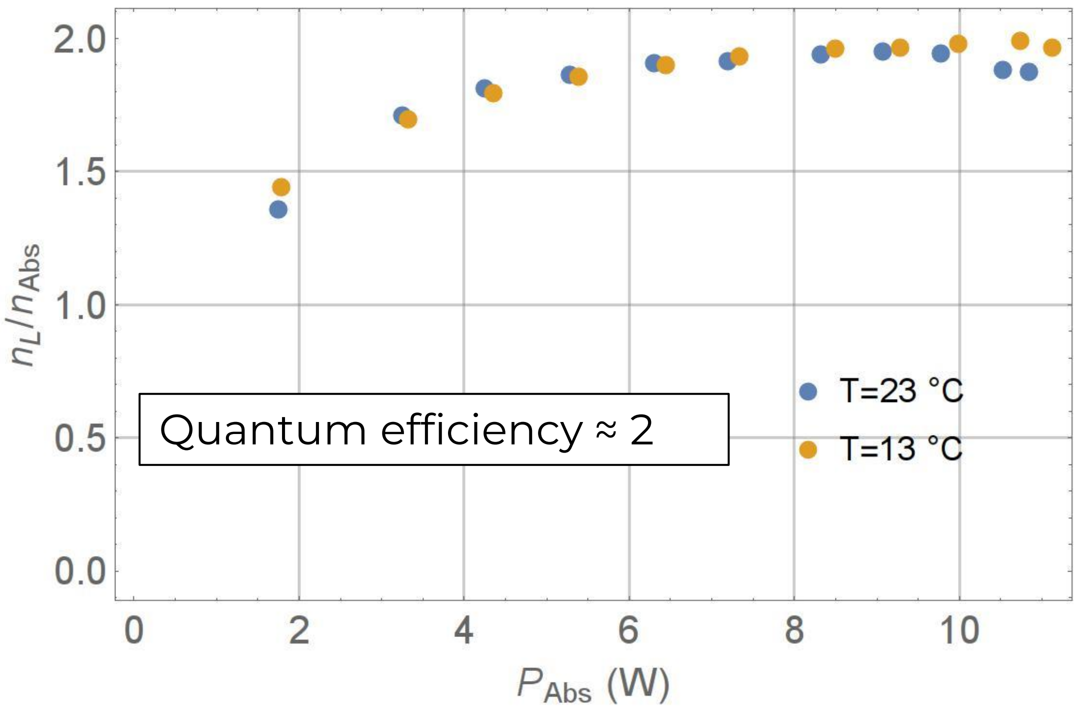
*I. Tamer et al., Optics Letters **49**, 1583 (2024)

iFAST

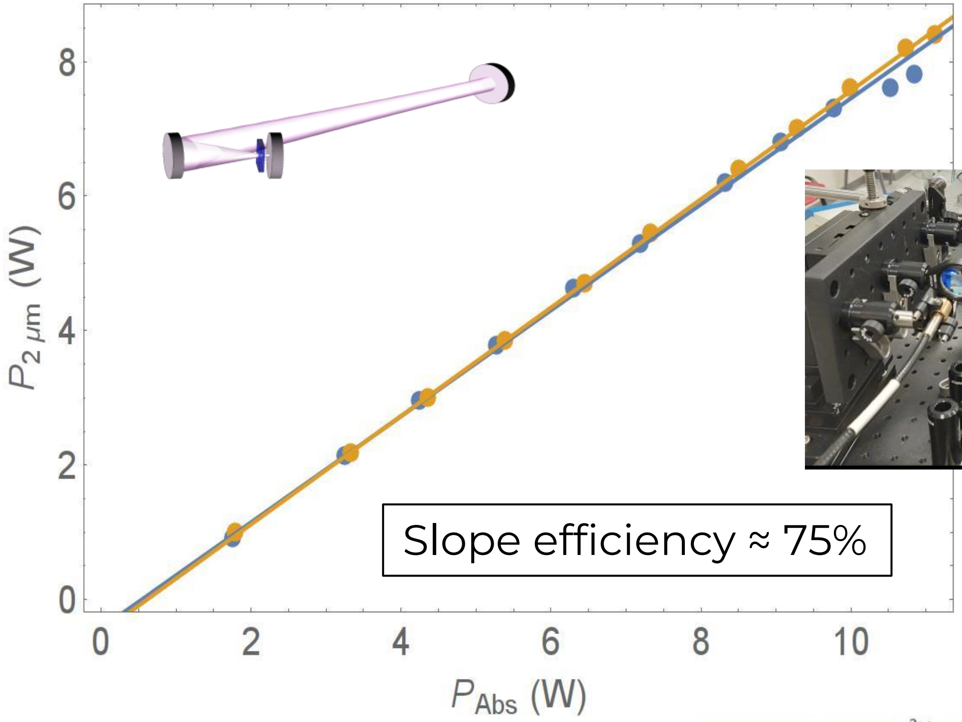
Our platform: Tm in Sesquioxide

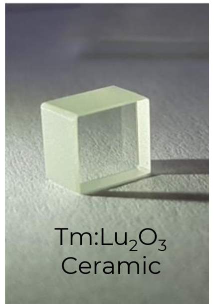
Accurate characterizaton of absorbed pump energy to measure quantum efficiency

Quantum efficiency

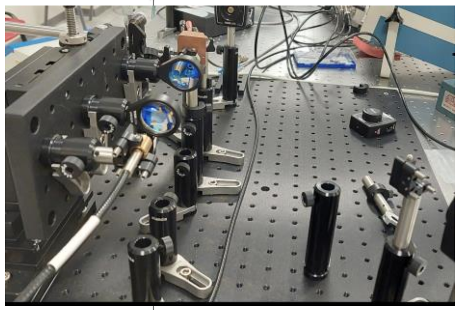


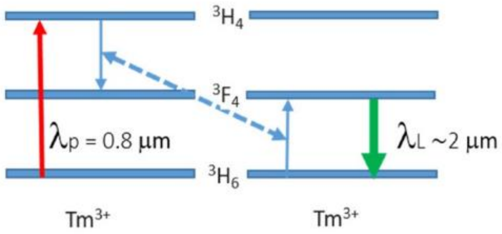
Slope efficiency





Sample from Konoshima



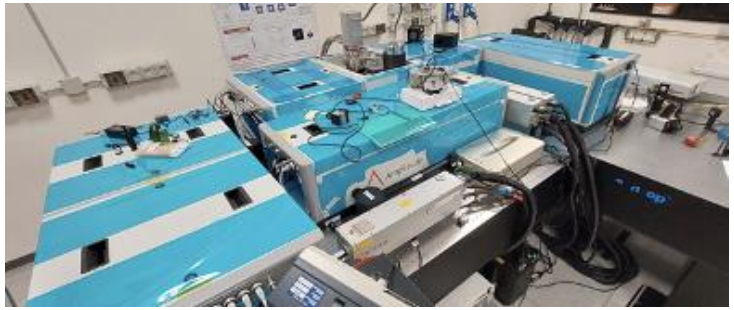


Preliminary: quantum efficiency close to 2 :
<u>Evidence of strong cross relaxation</u>

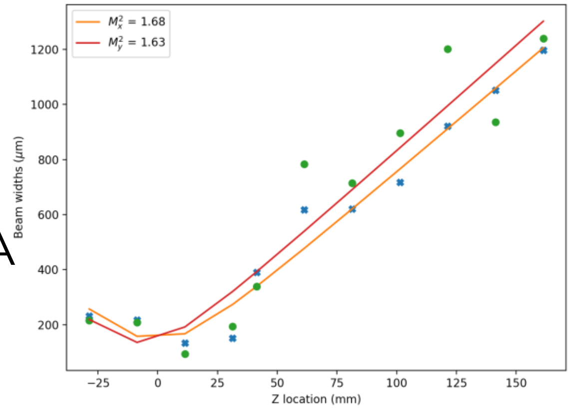
iFAST

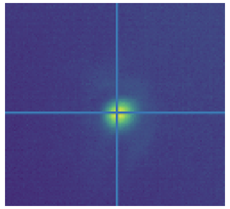
2µm, kHz, mJ front-end: operational@CNR

kHz, mJ, mid-IR, fs front-end:
Ti:Sa (20 mJ, 30 fs) pumped OPA

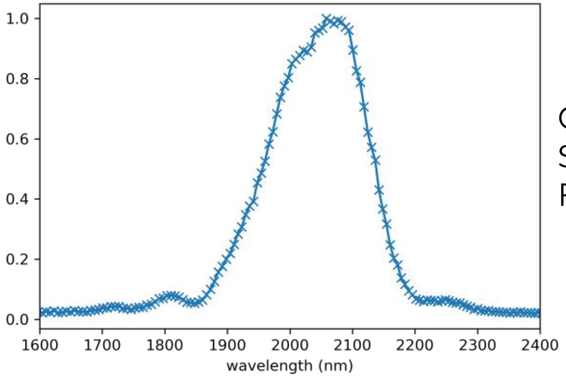


Beam Profile



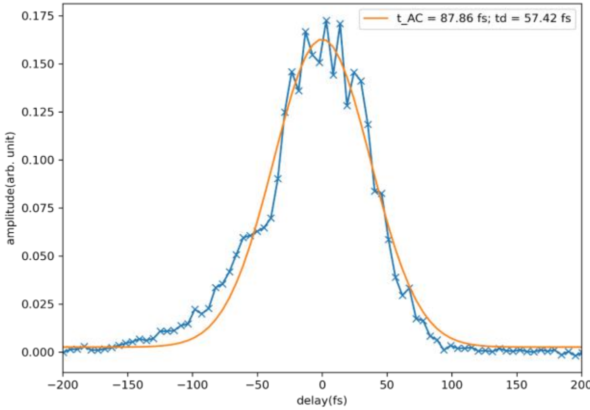


Spectrum

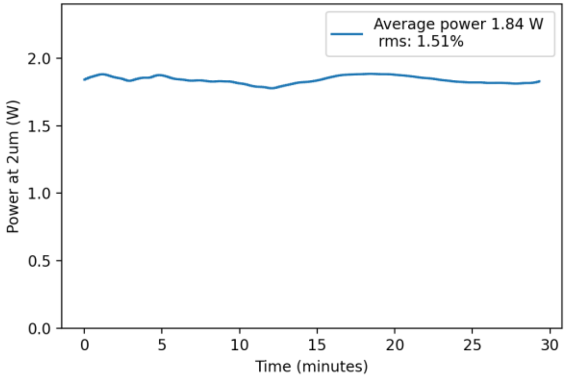


Center wavelength: 2025 nm
Spectrum FWHM: 182 nm
FTL pulse duration: 33 fs

Pulse duration: <60 fs



Pulse Energy >1.8 mJ



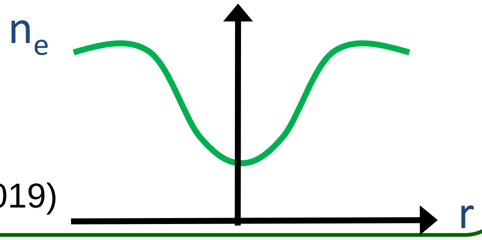
Task Leader: Cedric THAURY, CNRS-LOA

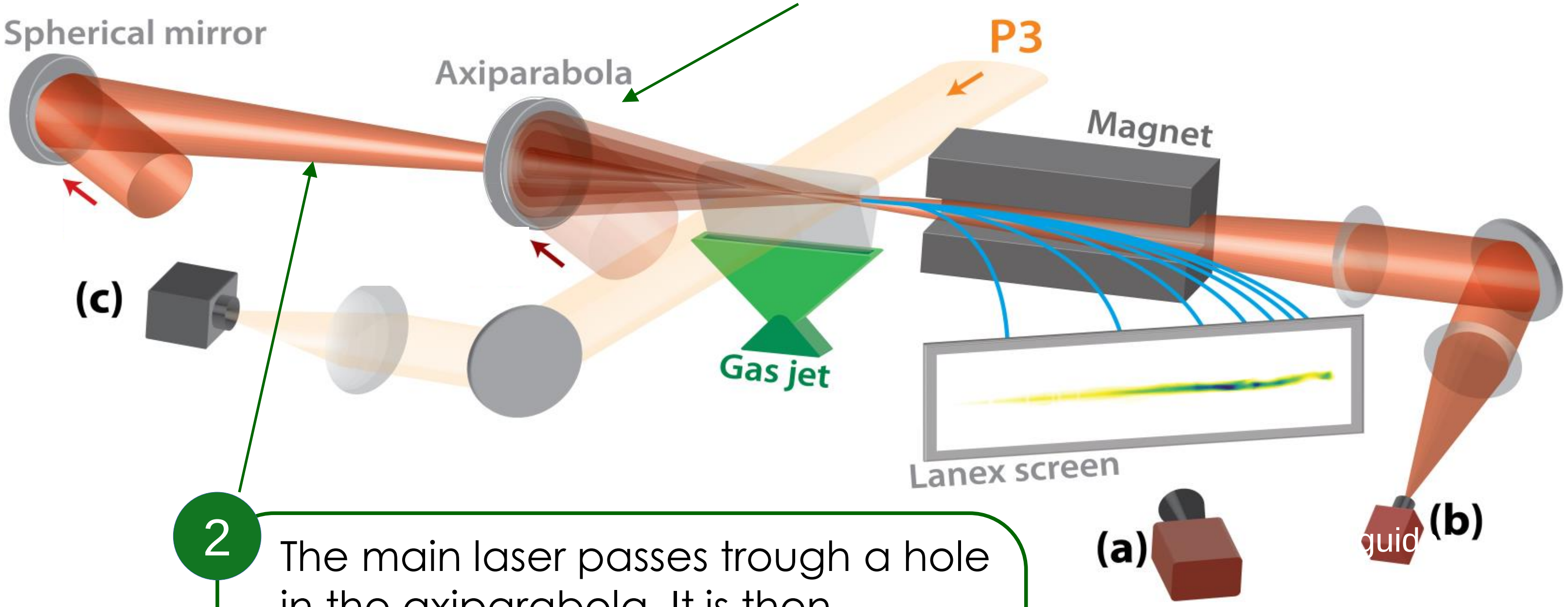
Task 6.3 multi-scale innovative targets for laser-plasma accelerators : laser-plasma waveguide

1

Axiparabola focuses inline a low energy beam to create a plasma waveguide

Optics Letters 44, 3414-3417 (2019)





2

The main laser passes trough a hole in the axiparabola. It is then coupled into the 6 cm long He plasma waveguide, where it drives a wakefield accelerator.

Light Sci Appl 11, 180 (2022)

3

A dipole deflects the beam. The spectrum is then measured on a scintillating screen.

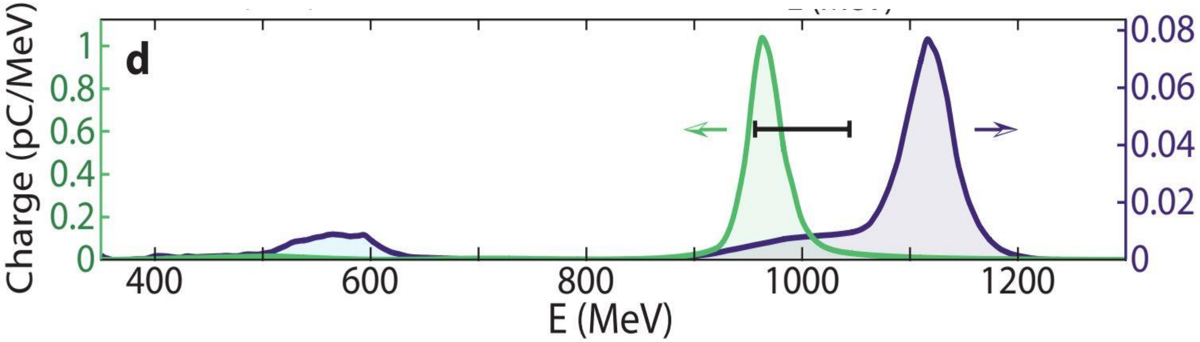
Task 6.3 multi-scale innovative targets for laser-plasma accelerators : laser-plasma waveguide

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

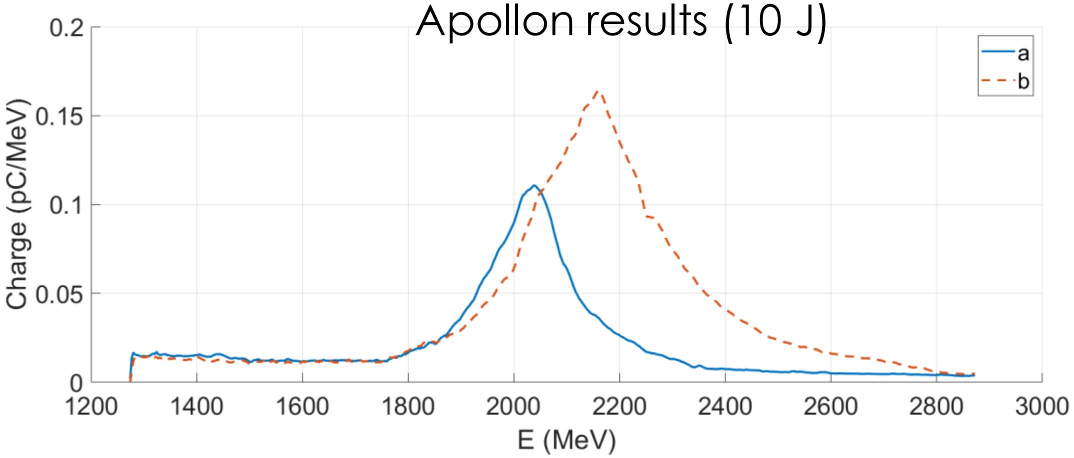
→ High-quality ~1 GeV beams with a J-class laser (LOA)
→ High-quality >2 GeV beams with a 10 J laser (Apollon)

6 cm long target

LOA results (1.5 J)



Apollon results (10 J)



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

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

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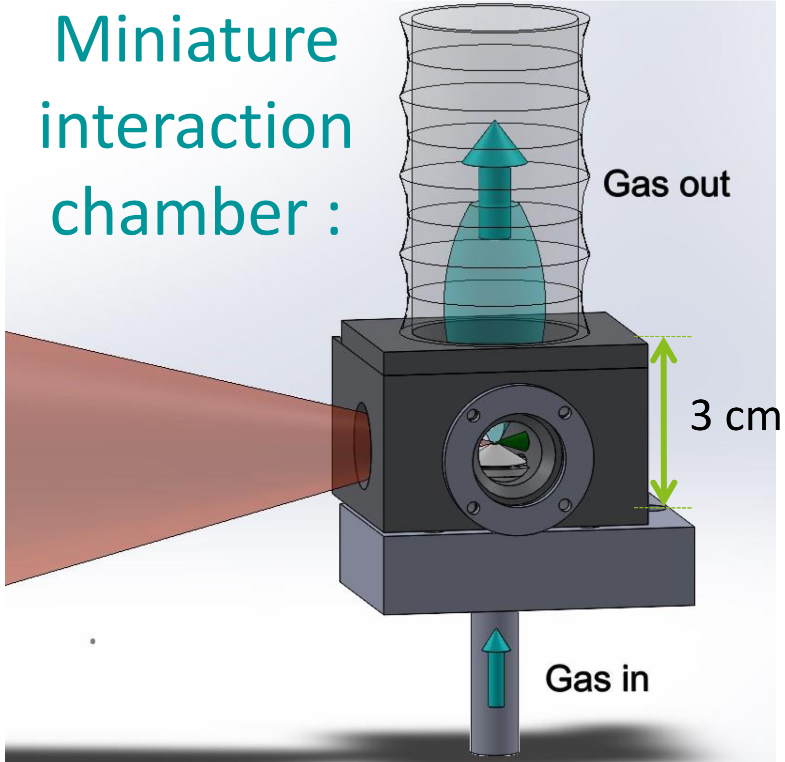
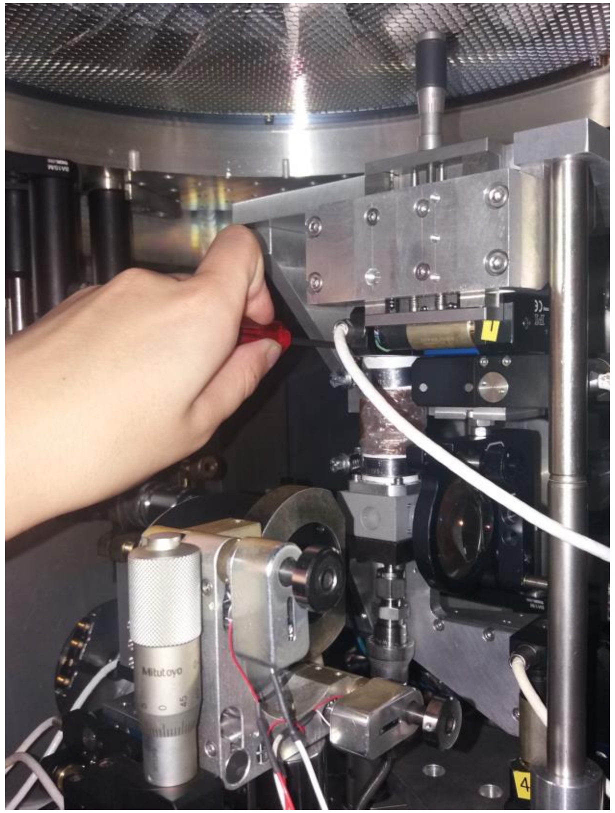
Differential pumping for using light gases at high rep. rate

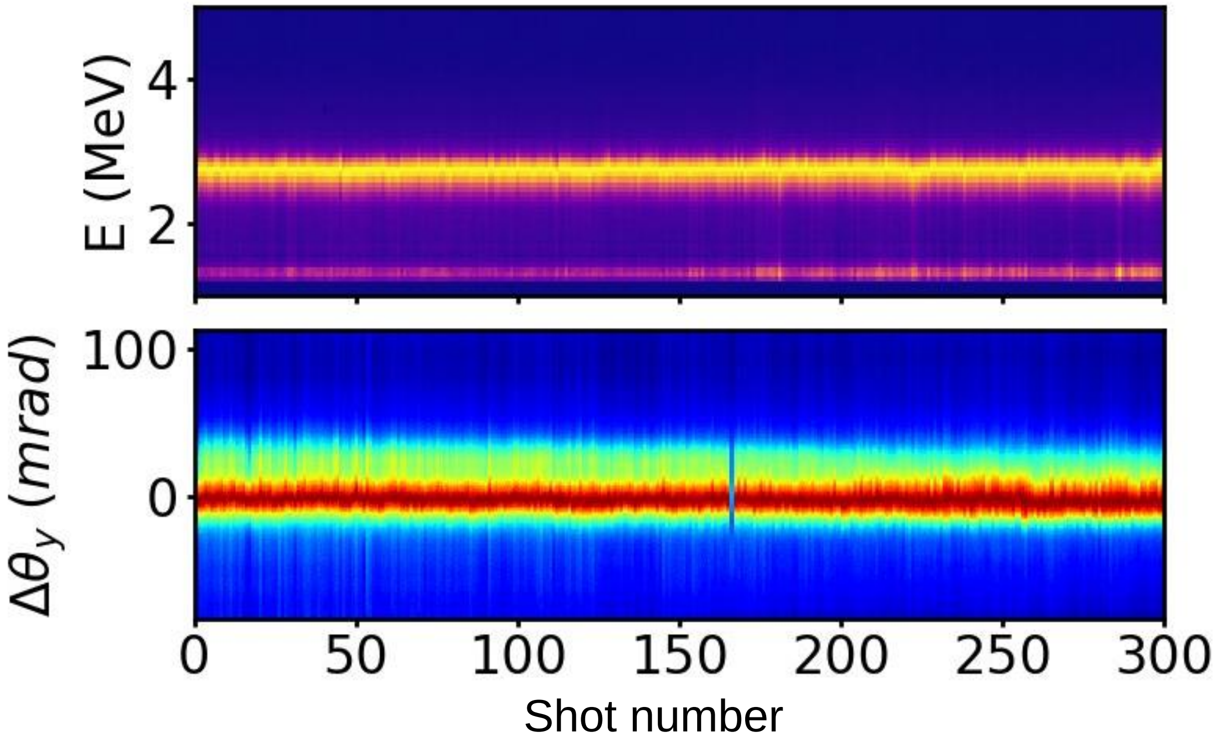


P_{He/H_2} = 100-150 bar



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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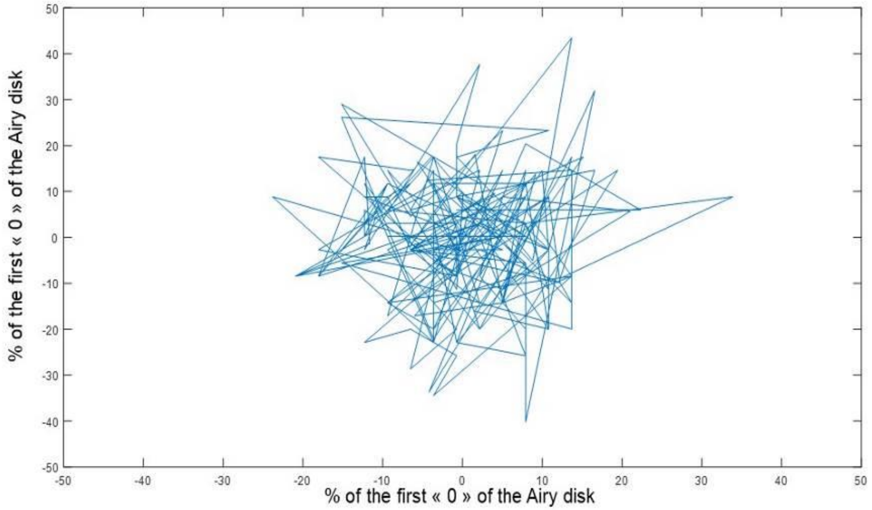
Task Leader: Francois MATHIEU, CNRS-LULI

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 active stabilization loop in the amplification stages <u>completed</u>***

  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***

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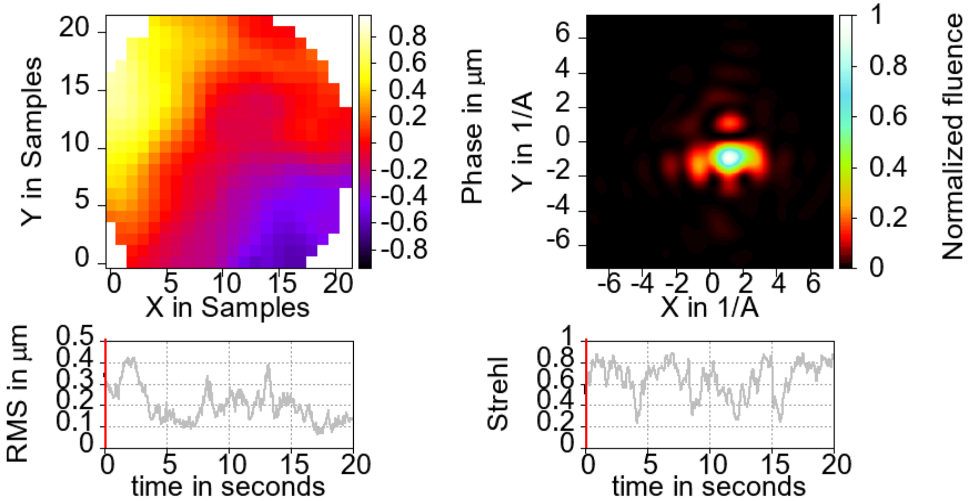
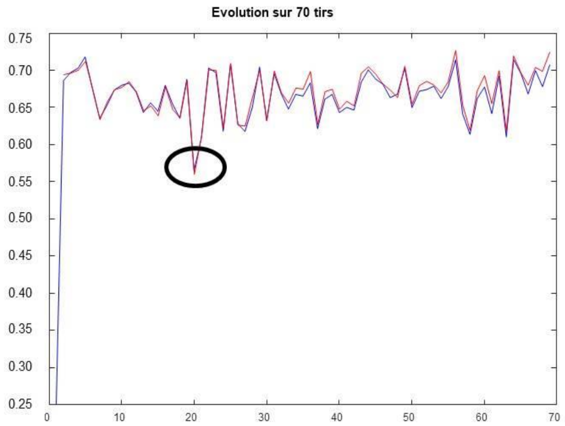
Task 6.4 - Summary of activities in P1

- *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 tl I stability***

Summary

- Strong progress on laser driver developments for plasma acceleration:
  - Increasingly involving industrial partners
  - Industrial femtosecond Ti:Sa laser technology with diode-pumped pump lasers being established at 100 W
  - Tm:based CPA DPSSL architecture aiming at high efficiency and demonstrating fs operation
  - Major advances in gas targets for LPA
  - Significant achievements in active beam stability
- Milestones and Deliverables on track
- Activity towards preparation of the LASPLA Strategy document D6.2 is ongoing

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Thank you for your attention!

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