

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS



WP12 – Laser Technology and Liaison to Industry

Diode Laser Pumps for Advanced Accelerators

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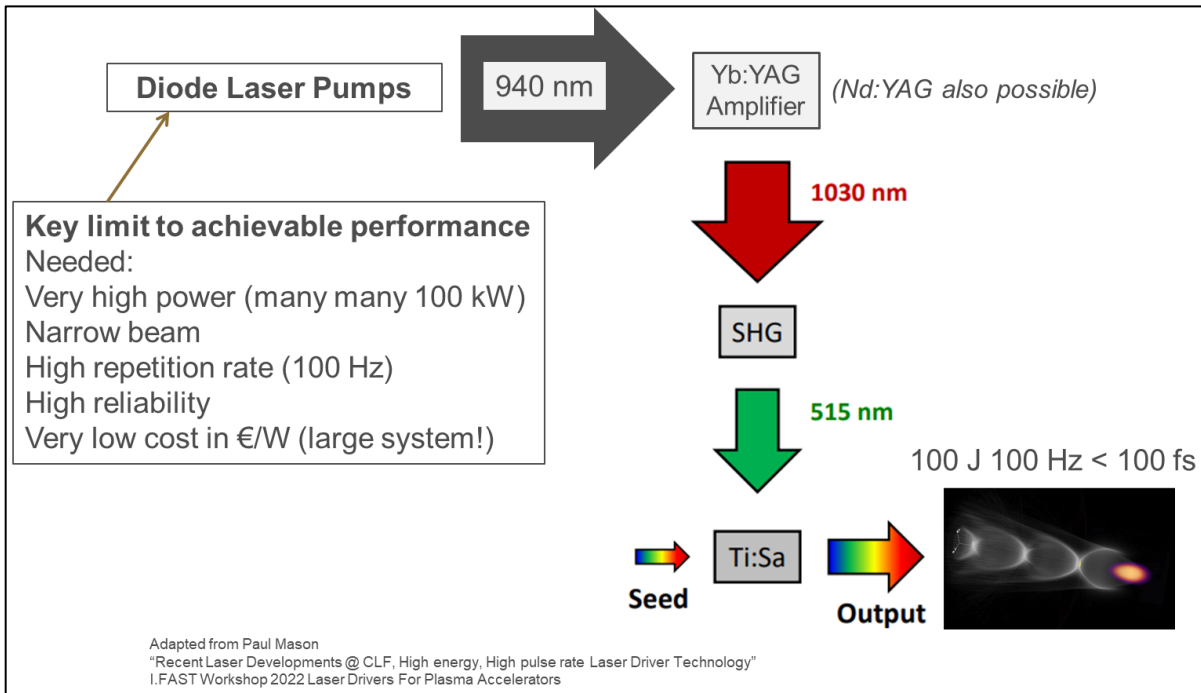
September 24, 2024,

EuPRAXIA Meeting, Island of d'Elba, Italy



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101079773

Diode lasers source of all optical power in EuPRAXIA



Primary Challenge: 100 Hz pump supply

MAIN OUTPUTS OF THE EUPRAXIA DESIGN STUDY

- Requirements on energy, pulse duration, stability etc set by the LPA working point
- Design based on CPA in Ti:Sapphire, dictated by requirements vs. time scale
- Thermal management issues addressed by means of liquid cooling
- Main developments required:
- Prototyping of Ti:Sa amplifiers: fluid cooling (choice between reflection/transmission amplifier): possibly by means of pilot devices
- **Addressing 100 Hz pump lasers developments**
- Thermal management of compressor gratings
- Stability (pointing & more) and active control
- Driver pulse temporal shaping and synchronization
- Construction
- Integration Issues

LA Gizi, IFAST Workshop "Laser drivers for plasma accelerators", Palaiseau, 20-22 April, 2022

CNR-INO

Overall Diode Pump Goals:

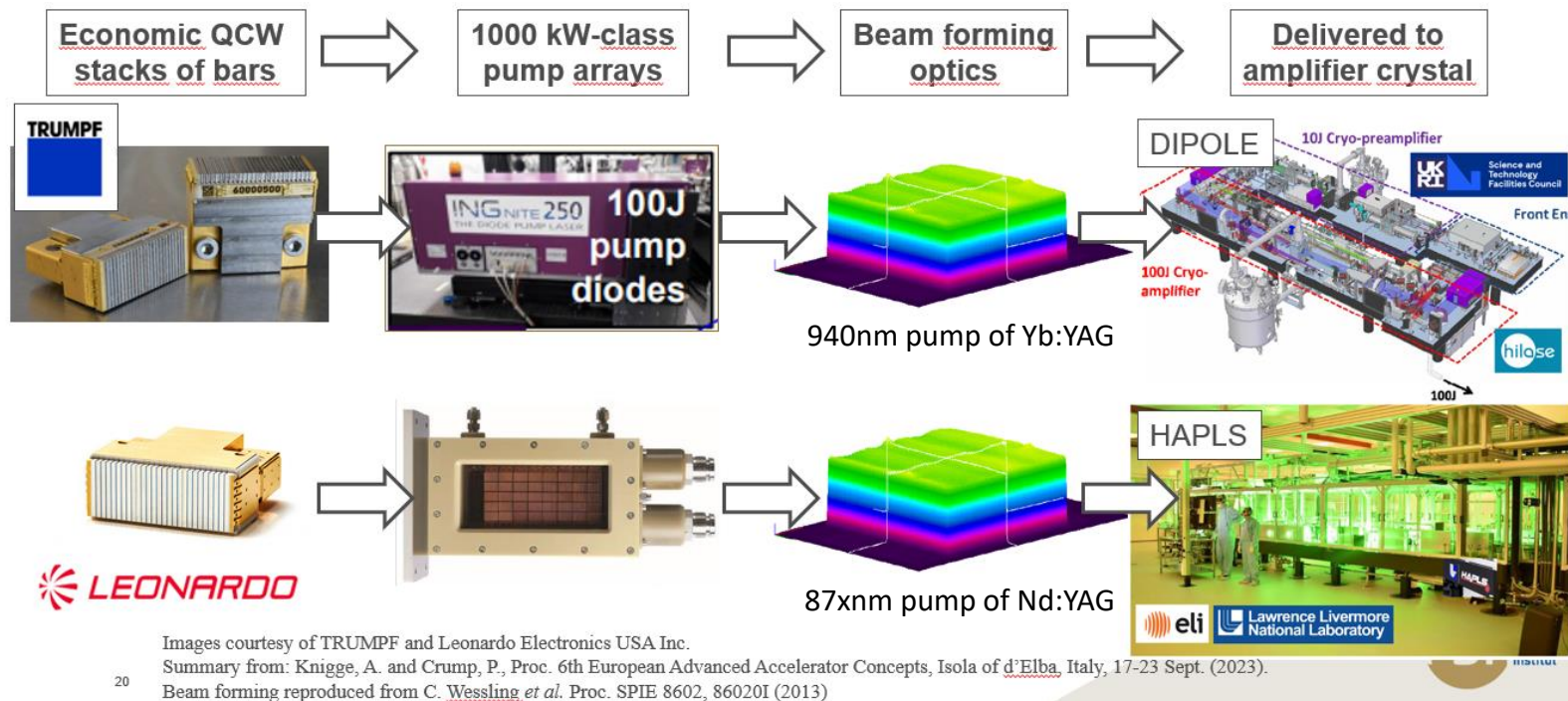
- Coordination with industry
- Fund and perform research studies
- Establish new structures (excellence centers, hubs etc.)

- best prepare for second-site commissioning
- enable highest performance diode laser pumps
- sustain ongoing performance and cost scaling

One current large scale industrial solution

Plausible vendors for EuPRAXIA 1000 kW supply: Trumpf, Leonardo, Coherent
 Others, EU: Jenoptik, Lumibird, Monocrom, Asia: Hamamatsu, Focuslight, Everbright

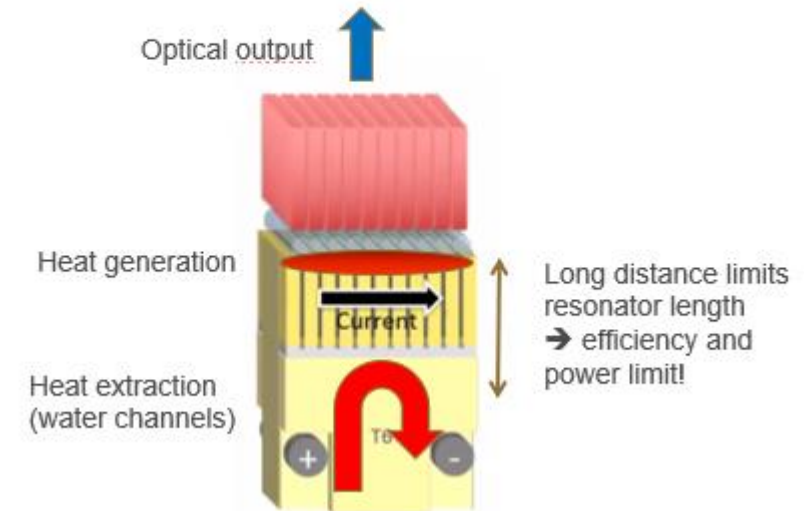
Industrial diode laser pumps for application in extreme photonics



Economical diode coolers limited to low duty cycle

~ 10 Hz

Limited by design to ~ 1% duty cycle
 One water cooler per 20...50 bars
 Highly economic solution, low €/W



Other solutions too expensive
 100 Hz from research (FBH) but €€€
 CW from industry but €€€

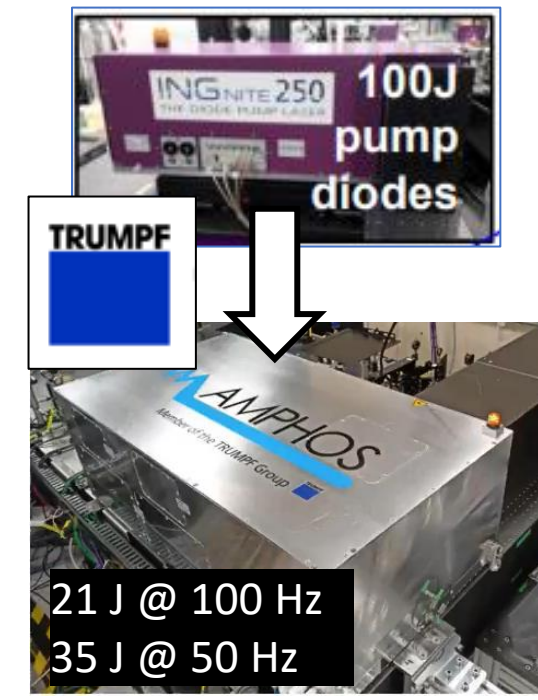
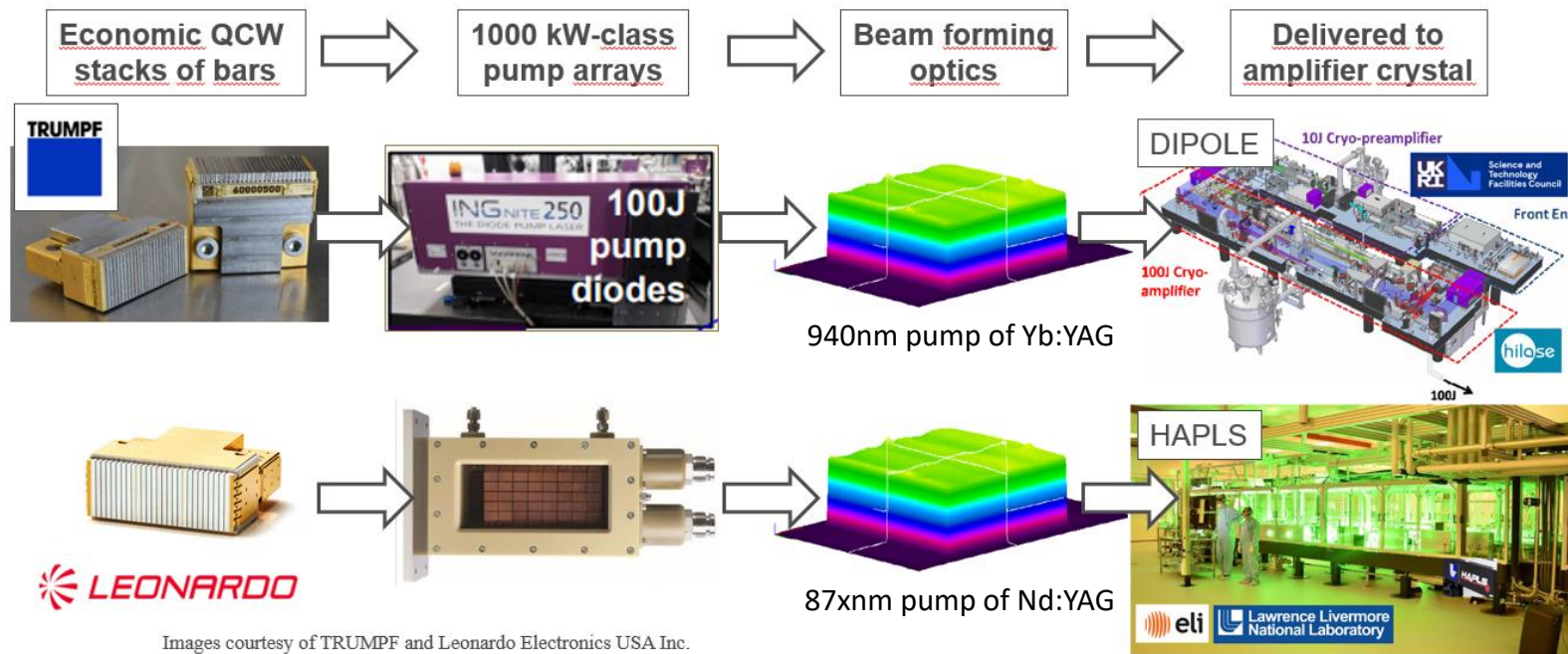
One current large scale industrial solution

Plausible vendors for EuPRAXIA 1000 kW supply: Trumpf, Leonardo, Coherent
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Current solution: Push to limit

(higher €/W or €/J at 100 Hz)
 100 J 10 Hz → 21 J 100 Hz

Industrial diode laser pumps for application in extreme photonics



De Vido M. et al., Proc SPIE PC12399, PC123990C (2023)

Images courtesy of TRUMPF and Leonardo Electronics USA Inc.
 Summary from: Knigge, A. and Crump, P., Proc. 6th European Advanced Accelerator Concepts, Isola of d'Elba, Italy, 17-23 Sept. (2023).
 Beam forming reproduced from C. Wessling et al. Proc. SPIE 8602, 86020I (2013)

- **M1 (10.22): Industry Workshop, confirmation: Must currently choose 10 Hz or higher €/W**
 - 5 October 2022 „Berlin Laser Tech Symposium“, Research: CNR (Gizzi). Chair: FBH Berlin (Crump)
 - Large industry: Coherent, Leonardo, Lumibird, Jenoptik, Hamamatsu, High-tech SMU: Lastronics
- **M11 (09.23): Summary of Industry & Research Status of Diodes at EAAC 2023: main vendors confirmed**
- **M15 (01.24): Invited talk Photonics West, share status and needs of EuPRAXIA with diode community**
 - Gizzi / Crump: Diode pumps for future laser plasma accelerators: <https://doi.org/10.1117/12.3010830>
- **M24 (10.24): Big Science Business Forum – Panel discussion → pull in further industrial partners**
- **M25 (11.24): Special Symposium on Diode Pumps - Status at IEEE Photonics Conf, Rome → D12.2**
 - “Technology Roadmap for Diodes for Large Facilities” (FBH / LLNL) See: <https://ieee-ipc.org/special-symposia/>
 - Strong industry (TRUMPF, Coherent, Hamamatsu, Lumibird, Laytec) & research (Livermore/FBH as chairs, STFC, ELI ERIC, ILT Aachen) participation
- **M29 (03.25): iFAST, Diode technology update – in planning**
- **Overview of grant applications for improved diode pumps for EuPRAXIA & high energy community (two approved, one started)**
 - **M12: October 2023: Project HOTSTACK** TRUMPF + FBH (ERDF / Regional Berlin funding) – **started!**
 - M17 March 2024: Project SUPER8 → low €/W, via high power 808nm for Nd:YAG (Eurostars, FBH/Amplitude) – **rejected** (plan B?)
 - **M17 March 2024: Project PACRI** → ensure supply for EuPRAXIA & prepare for future – **approved!**
 - M19...22 May-August 2024: German BMBF fusion technology applications – applied for, updates soon (looking positive)
 - M26 December 2024: DIRECTA (w/Amplitude) in preparation
 - M31 May 2025: HIGHDRA (w/CNR) in preparation

Progress in Industry (e.g. TRUMPF)

Internal studies*

Power / cost scaling for fusion 10 Hz

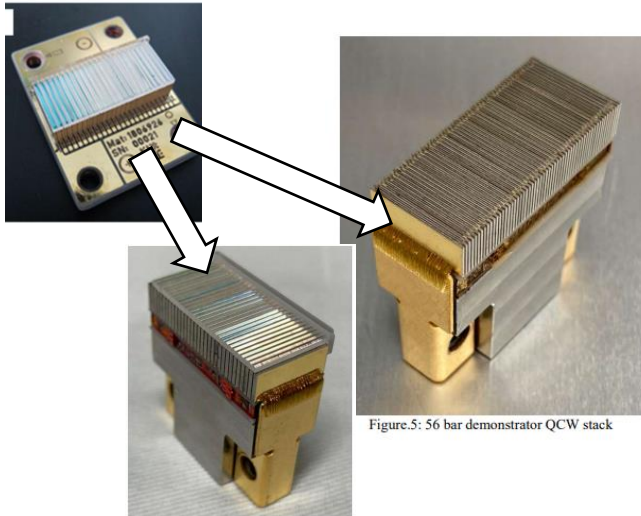


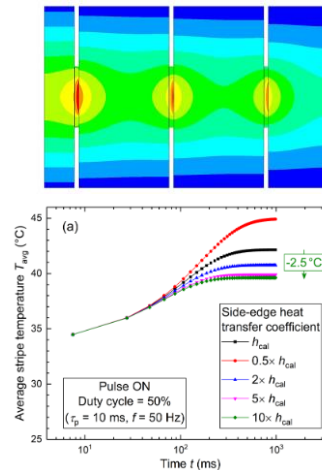
Figure.5: 56 bar demonstrator QCW stack

Funded efforts for $f > 10$ Hz
Duty cycle scaling (HOTSTACK)

* T Barnowski *et al.*
Proc SPIE 12867 1286713 (2024)

Progress at Research Institutes (e.g. FBH)

HOTSTACK: progress at $\lambda = 940$ nm
scaling power, duty cycle, frequency



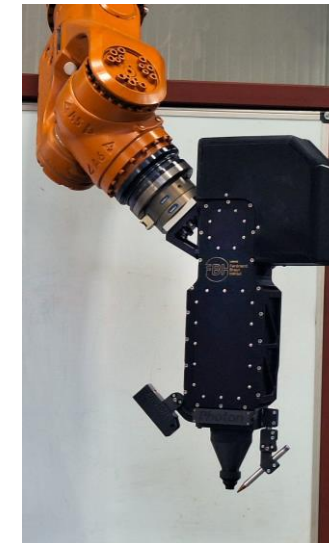
Targeted re-design for highest duty cycles at $\lambda = 940$ nm**

** M. Elattar *et al.*
IEEE J. Sel. Top. Qu. Electr. 31(2), 1500407 (2025)
*** FBH Annual report 2023 / 2024

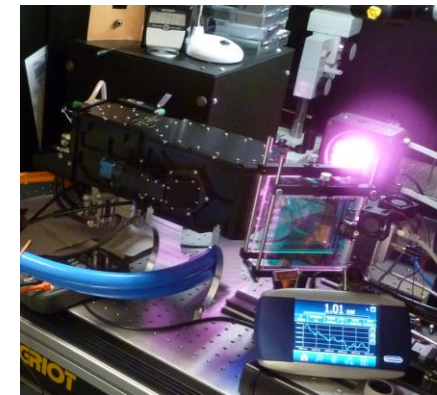


Commissioning world's first 1000 Hz 500 μs 1300 A drivers***

SAMBA: progress at $\lambda = 780...800$ nm
Compact kW-CW industrial modules****



Demo module In factory



Commissioning In lab

**** H. Alder *et al.* Proc. 42nd International Congress on Applications of Lasers & Electro-Optics, Chicago, USA, Oct. 16-19 (2023).

Progress in Industry (e.g. TRUMPF)

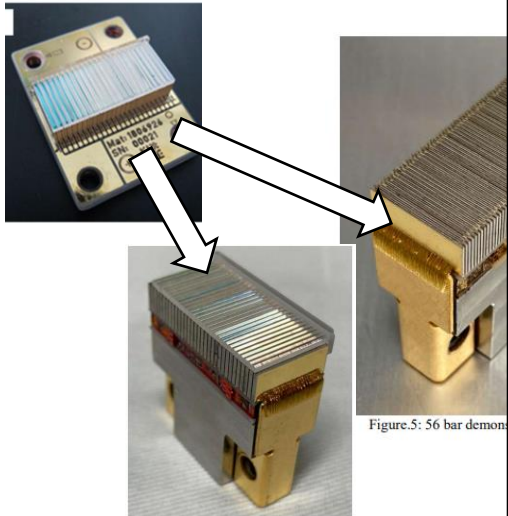
Progress at Research Institutes (e.g. FBH)

Internal studies*

HOTSTACK: progress at $\lambda = 940$ nm

SAMBA: progress at $\lambda = 780...800$ nm

Power / cost scaling for fu



PACRI: Prepare diodes for EuPRAXIA facility

Clarify requirements with second site
Design study to enable best achievable performance with industry
Consistent with €/W and reliability goals

PACRI: Prepare diodes for the future

100 Hz kW 7xx nm Pumps for Tm:YAG

Deliver to CNR
Based on SAMBA technology

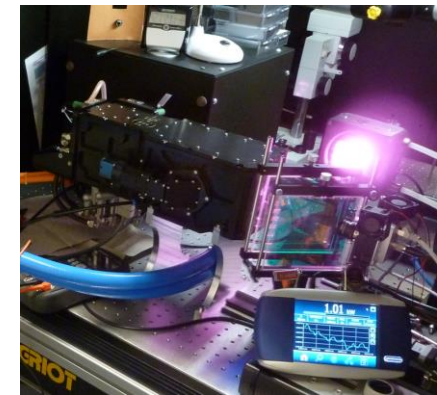
1000 Hz 940 nm pumps for Yb:YAG

Full beam-formed multi-kW Demo with ELI ERIC / LMU
Based on HOTSTACK technology

Direct-diode TiSa pumps

Design path to realize them, as seed for future demonstration

ct kW-CW industrial modules****



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tory

Commissioning
In lab

Funded efforts for f >
Duty cycle scaling (HOT

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Reminder from June 2023

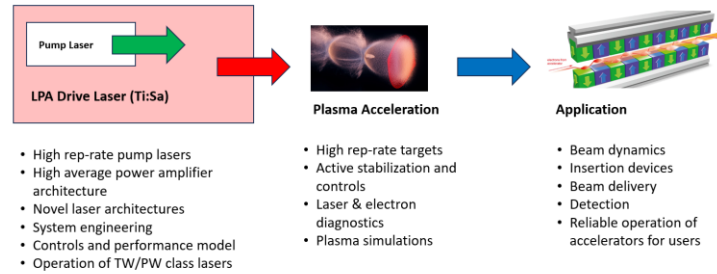
ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

The German Excellence Center for Plasma Acceleration and High-Rep-Rate Developments

J. Osterhoff on behalf of all partners
Rome, June 5th, 2023



All key positions in value chain addressed



Experience in laser R&D and plasma accelerators

- DESY** (WP9 co-lead, WP10 co-lead): High average power & rep-rate development: kHz drive laser and plasma accelerator; Know-how, operating large infrastructure, including TW laser systems; Theory and simulations, beam dynamics, control system, active stabilization.
- hhu** (WP14 co-lead): Operation of a TW-class laser; Laser-plasma acceleration, diagnostics, applications, and theory; Beam-driven plasma acceleration, hybrid schemes.
- Fraunhofer ILT**: Laser core technologies and novel concepts as building blocks for future LPA drive lasers; Laser packaging.
- JÜLICH** (Forschungszentrum): Operation of a kHz laser to drive a high rep-rate LPA.
- KIT** (Karlsruhe Institute of Technology): TW-laser operation, Laser-plasma acceleration & applications; Accelerator R&D and technologies, phase-space diagnostic and control; Light source development (X-ray, THz); Energy-efficiency optimization.
- LMU CALA** (WP14 co-lead): TW/PW-class laser development and operation, including laser core technologies and novel architectures at kHz rep rate; Laser-plasma acceleration, diagnostics & pioneering applications; Multi-pulse wakefields.
- FBH** (Ferdinand Braun Institut): High repetition-rate diode laser pumps; Local hot-spot, high-power diode laser industry.
- hizdr**: TW/PW-class laser development, including laser core technologies and novel architectures; Experience in operating TW/PW-class lasers; Laser-plasma acceleration, diagnostics & applications, FEL.
- HI JENA** (Helmholtz-Institut Jena): TW-class laser operation and development, including laser core technologies and novel architectures; Laser-plasma acceleration & diagnostics and applications.

P. Crump, A. Maier et al. – EuPRAXIA Meeting, Rome, 2023-06-05

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Maier et al. – EuPRAXIA Meeting, Rome, 2023-06-05

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Our role in EuPRAXIA

- The German Excellence Center for Plasma Acceleration and High-Rep-Rate Developments will integrate the partner competences under a common roof to benefit EUPRAXIA and the whole plasma accelerator community.
- It will combine the programmatic strength and experience of the Helmholtz Centers and the excellence of the Ferdinand Braun and Fraunhofer ILT institutes in the development, application and transfer of enabling technology with the innovative freedom of research Universities.
- Its leadership will consist of representatives of all partners and will act as a **coordinating link** to EUPRAXIA governance.
- The Center will **amplify innovation and collaboration** in the field in Germany and Europe by promoting EUPRAXIA-relevant topics within the (complex) German funding landscape.
- We perform the R&D to enable high user-facility standards at the EuPRAXIA sites.

Opportunity: German national funding for new research infrastructures for fusion --> backbone for excellence center?

Careful coordination with EuPRAXIA Board of Financial Sponsors needed!

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Thank you for your attention

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Nº 101079773

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