

# Amplitude Roadmap for high average power ultraintense laser for plasma acceleration

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*GDR APPEL 2023*

Presentation AG 13/11/2023



# Summary

- 01** ELI ALPS PW laser presentation
- 02** 700TW level Amplification & Compression at 10Hz
- 03** On the way to 2PW level at 10Hz...
- 04** Roadmap to 100Hz and above.

# 01

## ELI ALPS PW Laser presentation

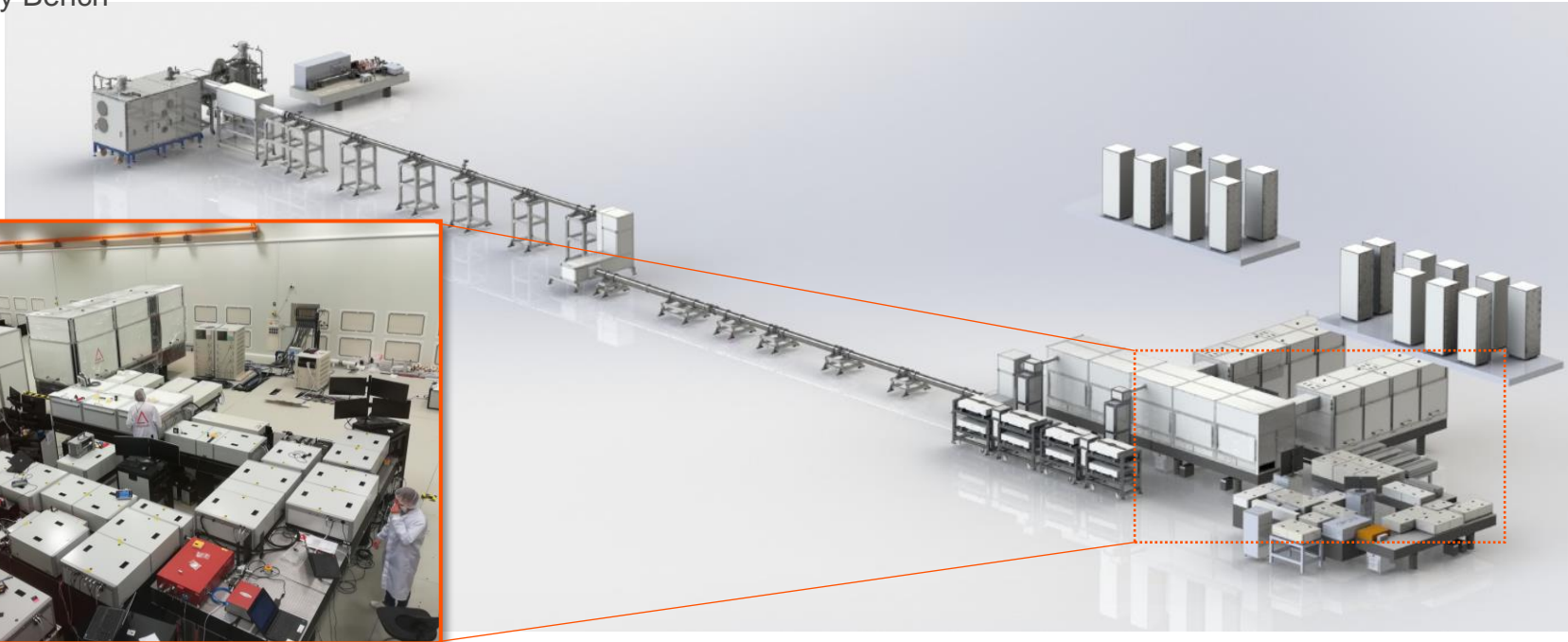
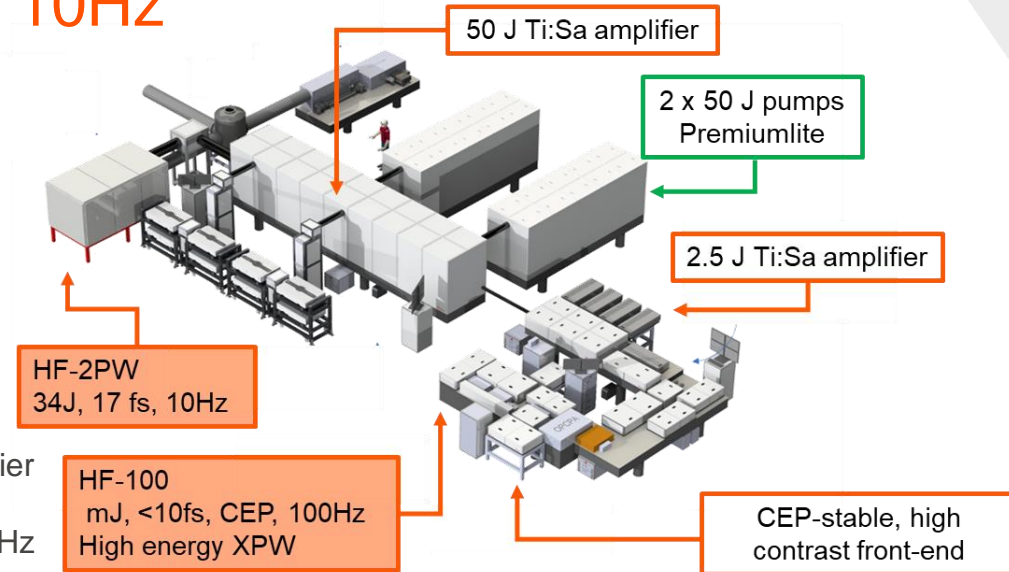
# ELI-ALPS laser 2PW @ 10Hz

## HF laser system Main Features

- > High Repetition rate, High Average Power
- > Ultra Short Pulse
- > Ultra High Contrast

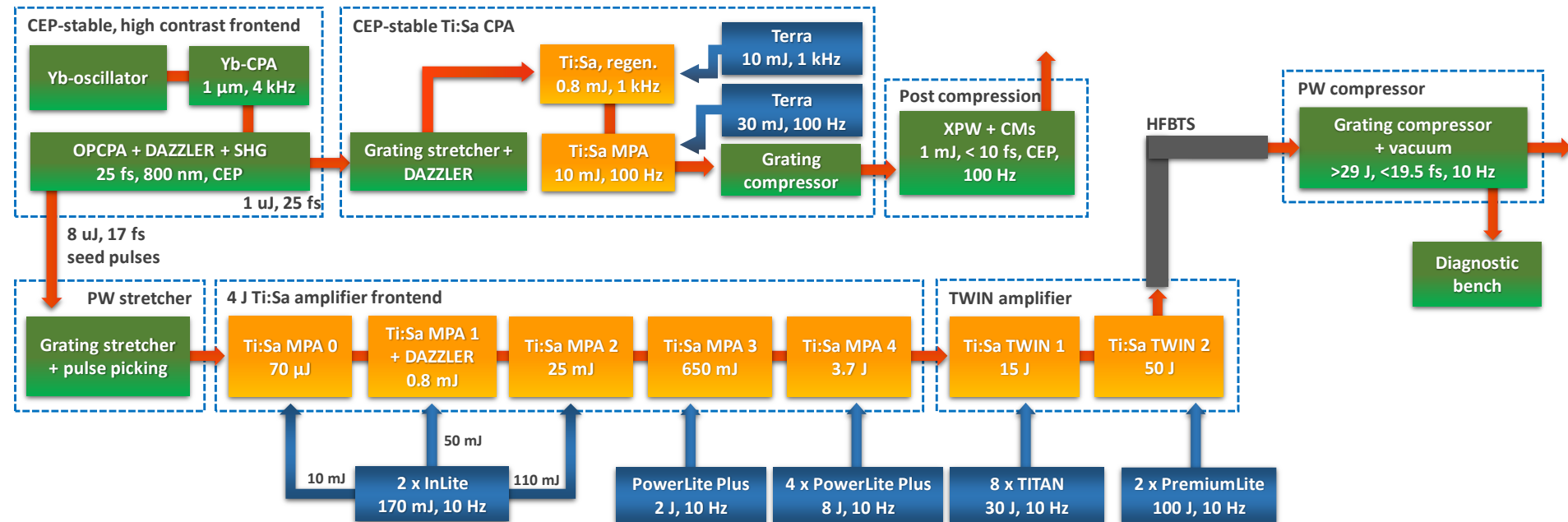
## Major developments

- > OPCPA front end
- > Aux output: High energy XPW and high contrast amplifier (ring cavity)
- > Premiumlite lasers: 50J single-beam pump laser at 10 Hz
- > Beam transport from PW lab to experiment hall
- > Metrology Bench



# ELI-ALPS PW laser project

## / General layout of the system



The High Field (HF) Laser of ELI-ALPS is a double arm system devoted to generate pulses with ultrahigh peak power.

The HF-100 arm is planned to generate 500 mJ pulses with 10 fs duration and with carrier-envelope phase (CEP) stability.

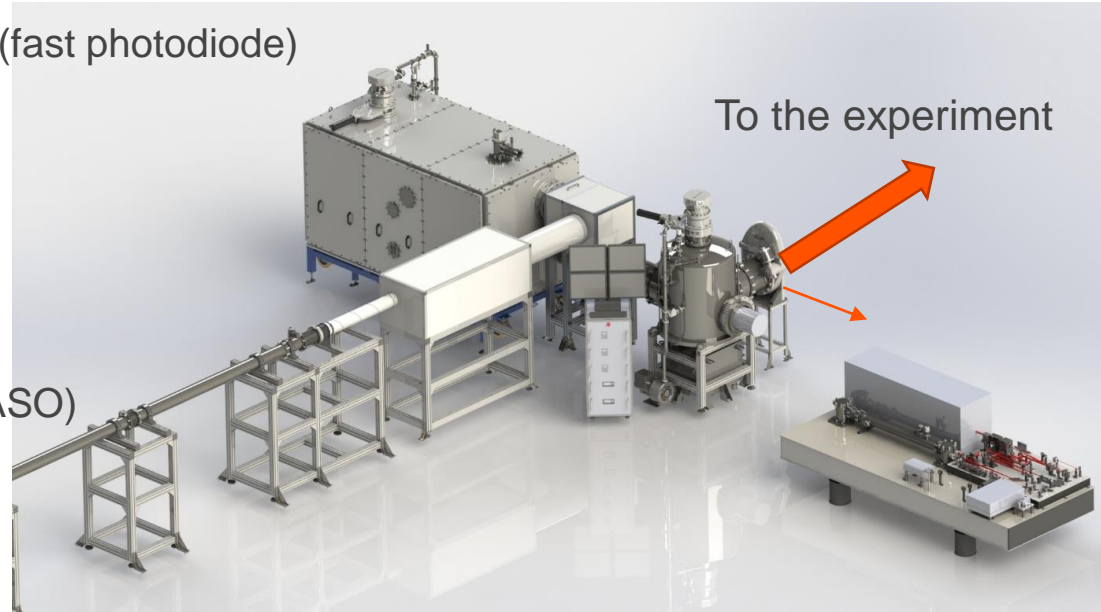
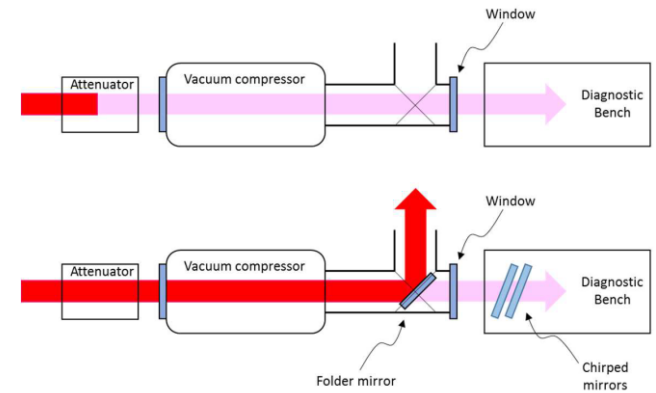
The output pulses are going to be used for surface high harmonic generation, electron and ion acceleration experiments

# Metrology Bench

/ A Metrology Bench is installed at the output of the compressor after the Turning box chamber

Two modes of operation (full energy and attenuated beam)

- > Angular chirp measurement (PhaDim)
- > Picosecond contrast measurement (Sequoia)
- > Pulse duration measurement (Wizzler)
- > Nanosecond contrast measurement (fast photodiode)
- > Beam profile (NF camera)
- > Beam pointing (FF camera)
- > Energy (energy meter)
- > Output spectrum (spectrometer)
- > Wavefront measurement (Sid4 or HASO)



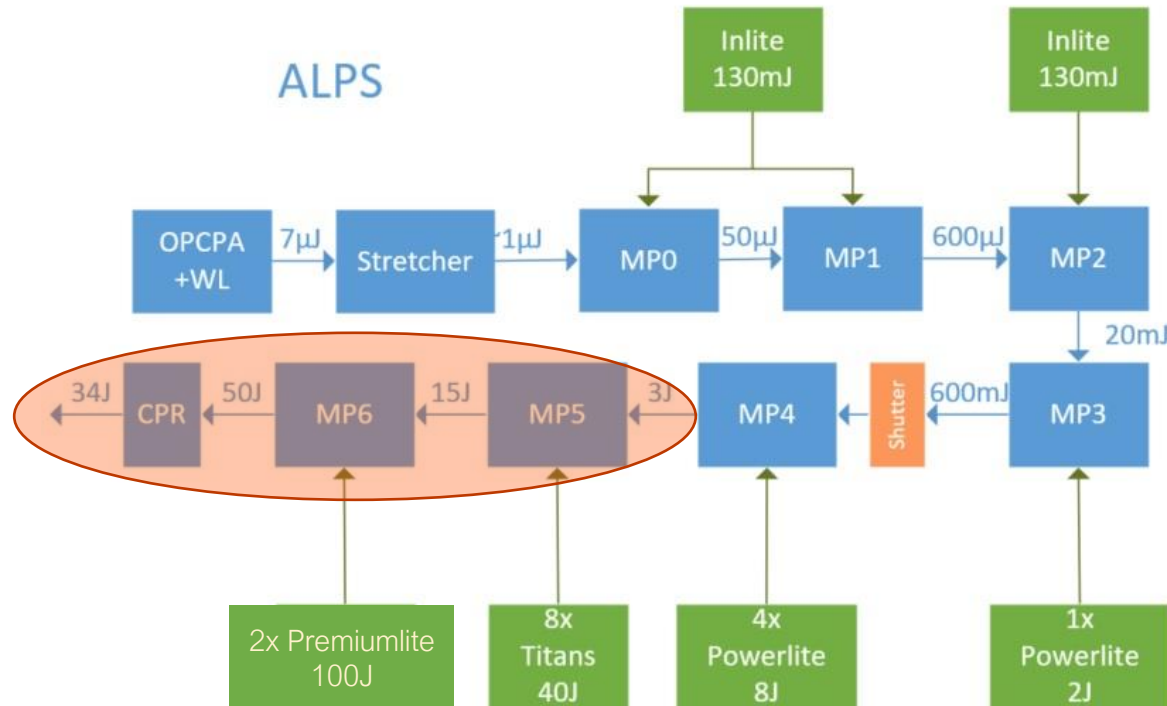
# 02

700TW level Amplification

& Compression at 10Hz

# 700TW level Amplification & Compression at 10Hz

/ The 2 last amplifiers MP5 & MP6 are pumped respectively by >30J and >90J.



/ Due to Premiulites beam propagation issues, pump energy was limited to 12J for each Premiulite in the last stage.

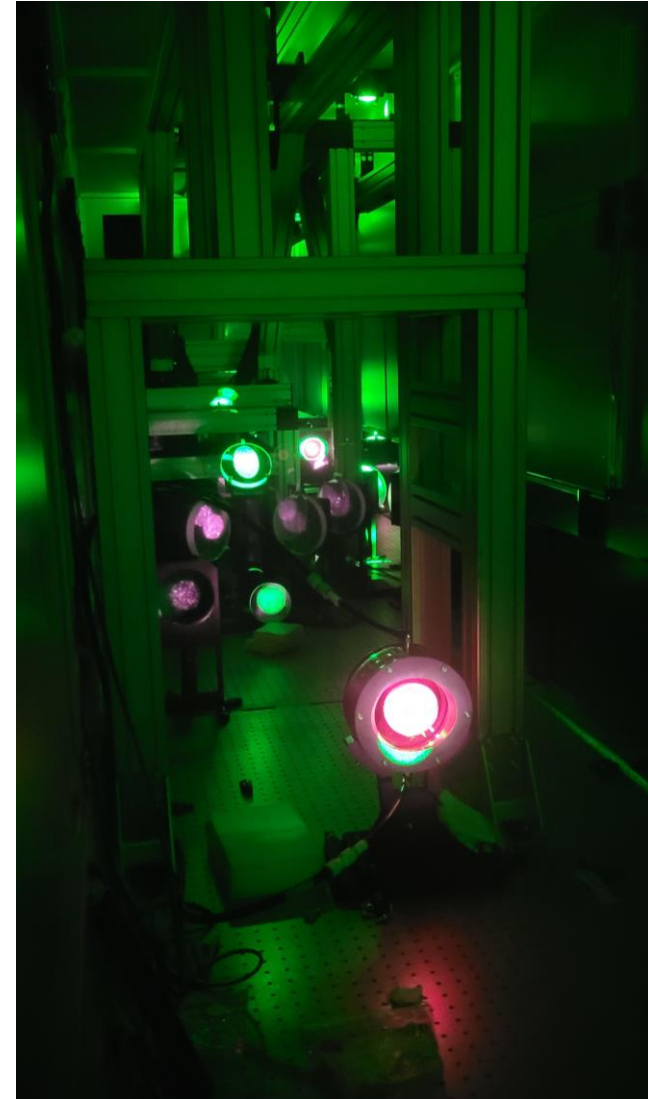
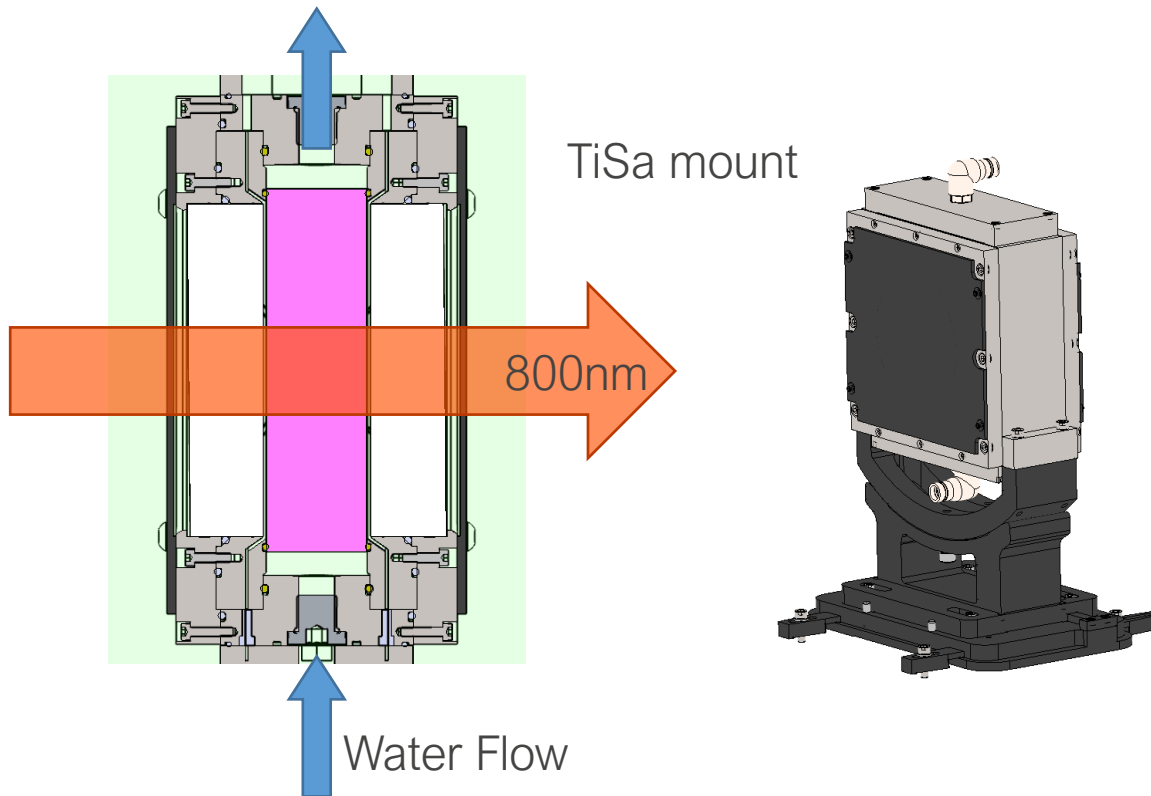
/ In the next slides we will present the result obtained when the MP6 amplifier is pumped with 24J@10Hz on the crystal (2x12J from each PremiumLite) and seeded with 15J from the previous amplifier (MP5).



# 700TW level Amplification & Compression at 10Hz

## / Longitudinal cooling Crystal mount

MP5 & MP6 Ti:Sapphire Crystals are pumped respectively by **>300W** and **>900W**. To minimize thermal lens the crystals are cooled with **water circulating directly on the TiSa surface** (Lower transverse temperature gradient). Amplified **IR beam is going through the water!**



# 700TW level Amplification & Compression at 10Hz



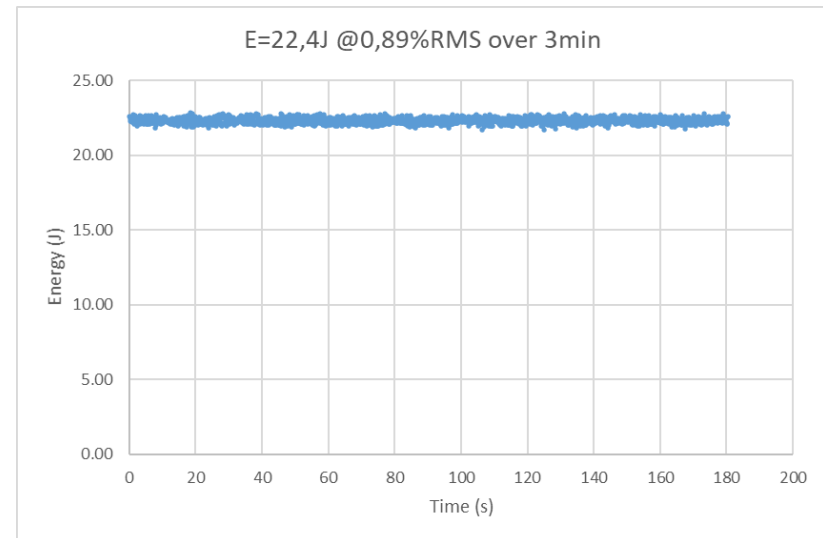
/ Energy at Amplifier output > **22 J**

/ Average Power extracted from TiSa > **220W**

/ Energy stability < **1% RMS**

/ Transmission of Optical line + Compressor is **71,4%**

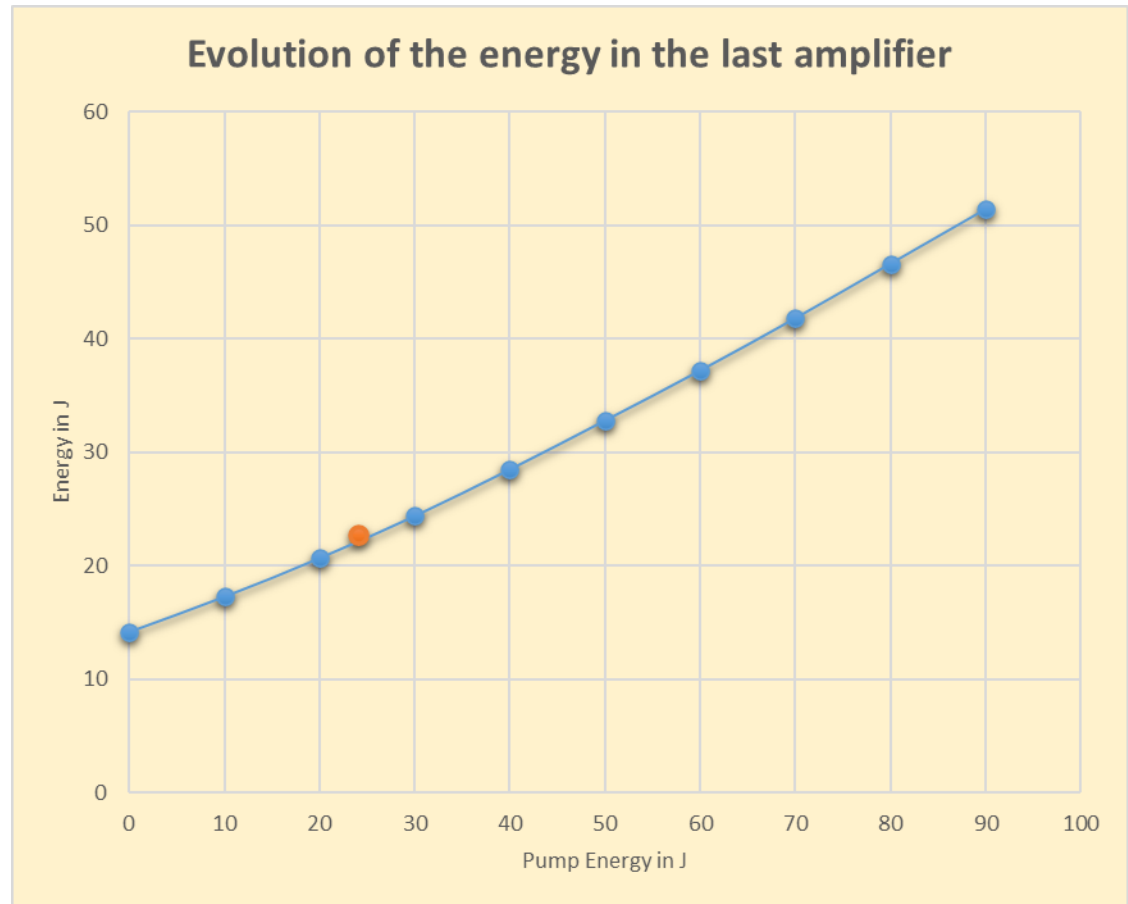
/ Compressed Energy >**16J** i.e. Power > **160W**



# 700TW level Amplification & Compression at 10Hz

Parameters			
IR	Diameter @1/e <sup>2</sup>	75 mm	75 mm
	Input Energy	15.5J	15.5J
	SG order	6	6
Pompe	Diameter @1/e <sup>2</sup>	75 mm	75 mm
	Input Energy (measured)	<b>24 J</b>	<b>78 J</b>
	SG order	8	8
	Recycling	ON	ON
Ampli	Pass number	2	2
	Ampli Transmission	92%	92%
Results	Amplifier Output Energy	22.25 J	45.95 J
	Compressor output Energy T=75%	16.7 J	34.46

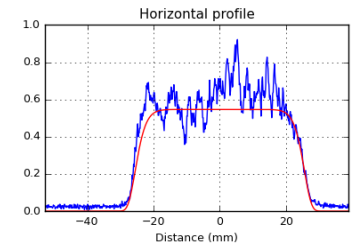
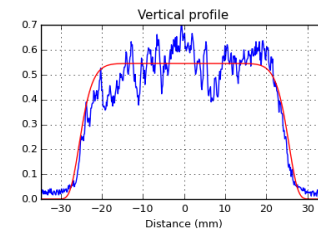
Parameters of simulation



/ The experimental point at 22,7J is matching perfectly the simulation. Extrapolated Energy is more than 50J at 90J pumping level

# 700TW level Amplification & Compression at 10Hz

/ Near Field and Far Field at the output of each amplifier (15J and 22J)



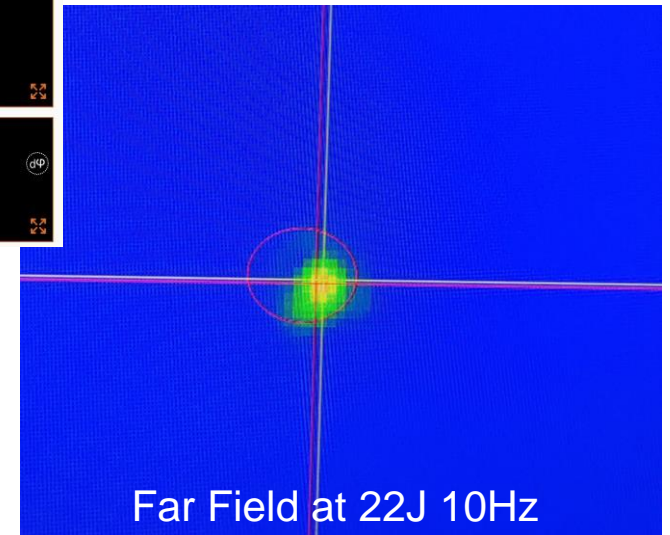
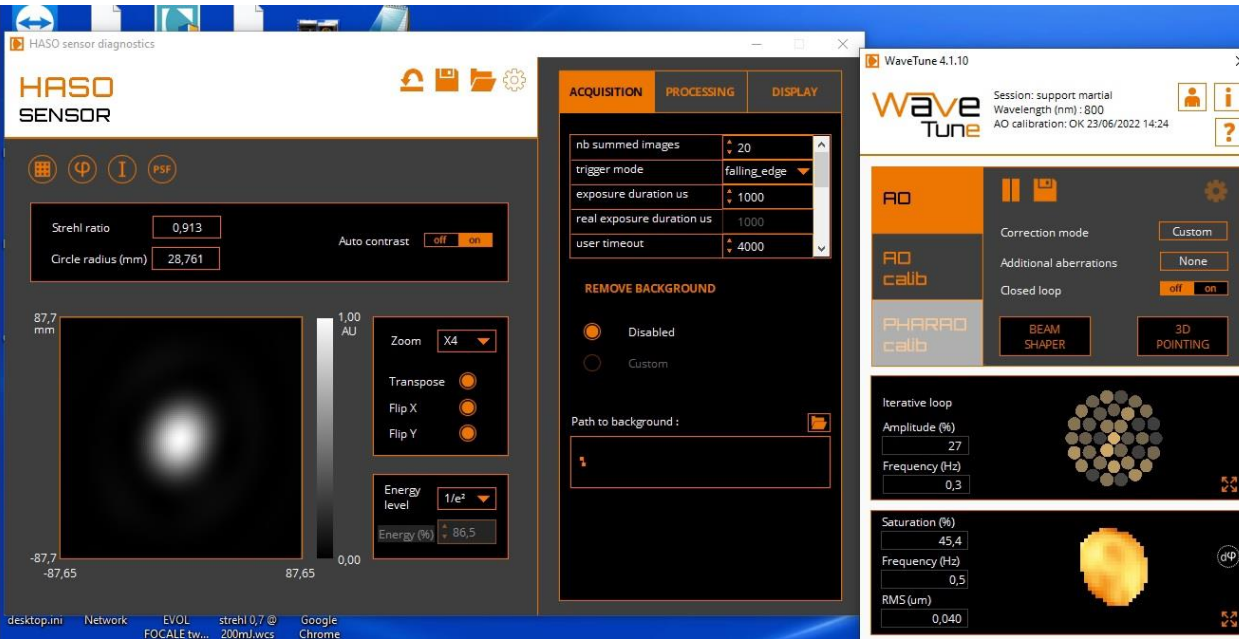
The screenshot displays four panels for Near Field (NF) and Far Field (FF) measurements of two amplifiers (TWIN 1 and TWIN 2).

- NF TWIN 1 Module Online:** Connected to 192.168.3.131. Shows a large circular intensity map. Calibration energy is 15.30 J. Energy estimated by camera is 0.00830515 (a.u.).
- NF TWIN 2 Module Online:** Connected to 192.168.3.150. Shows a smaller circular intensity map. Calibration energy is 22.50 J. Energy estimated by camera is 0.0184259 (a.u.).
- FF TWIN 1 Module Online:** Connected to 192.168.3.125. Shows a small, localized intensity spot. Calibration energy is 0.0. Energy estimated by camera is 0.0.
- FF TWIN 2 Module Online:** Connected to 192.168.3.151. Shows a small, localized intensity spot. Calibration energy is 0.0. Energy estimated by camera is 0.0.

Each panel includes a control panel with options for Image Properties, Centroid and User Cross, Pointing Stability, Profiles and Gabarits, Energy and Power, Disk saving, Camera trigger, and Configuration. The bottom of the screen shows system information including the time 6:28 PM.

# 700TW level Amplification & Compression at 10Hz

/ A Deformable Mirror (Imagine Optics) installed between the two amplifier allows to correct the remaining aberrations

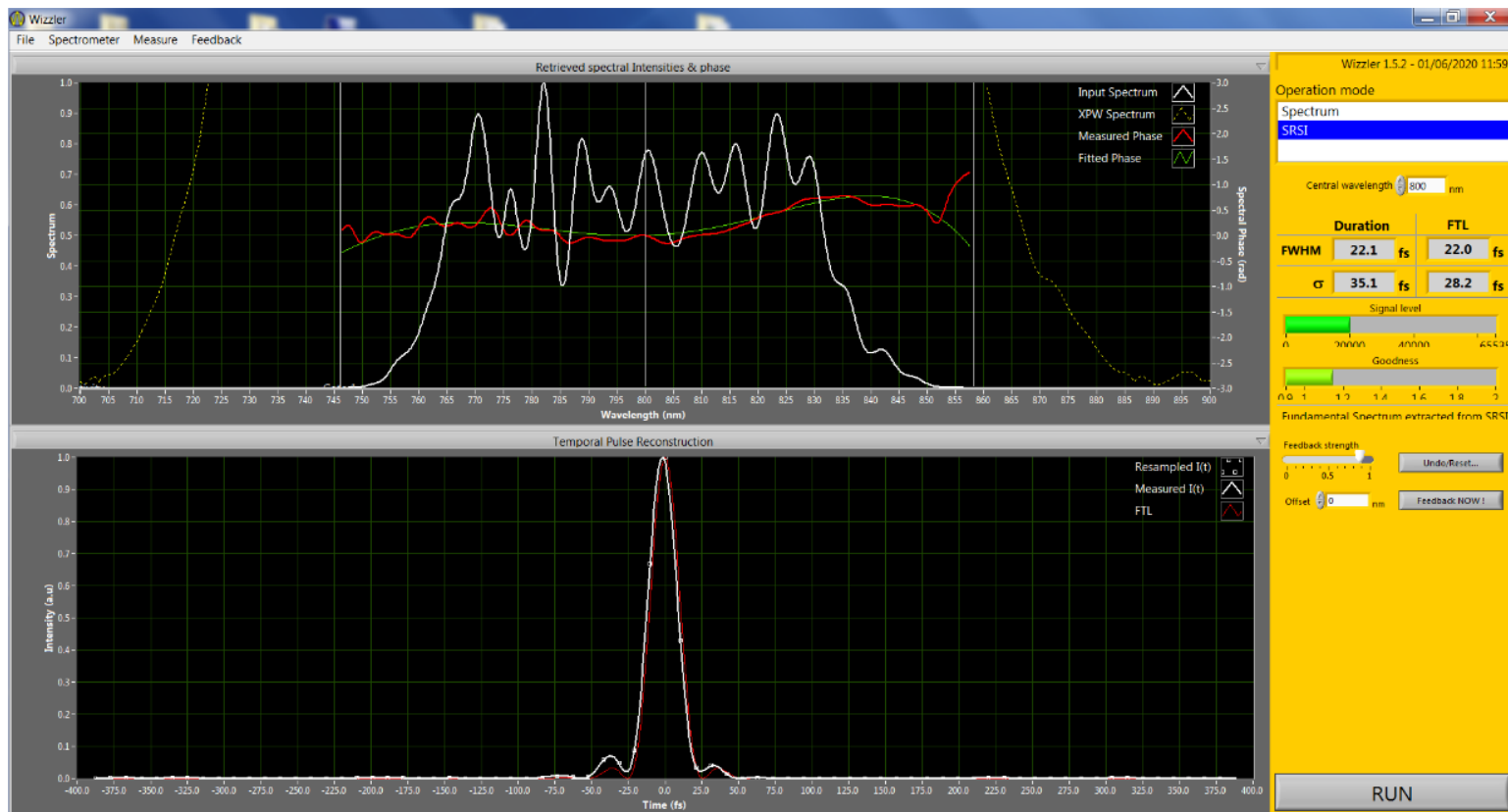


/ Strehl ratio at full energy is  $>0.90$

# 700TW level Amplification & Compression at 10Hz

/ Pulse Duration measured at full energy at **22fs**

Peak Power greater than **730TW @ 10Hz**



# 03

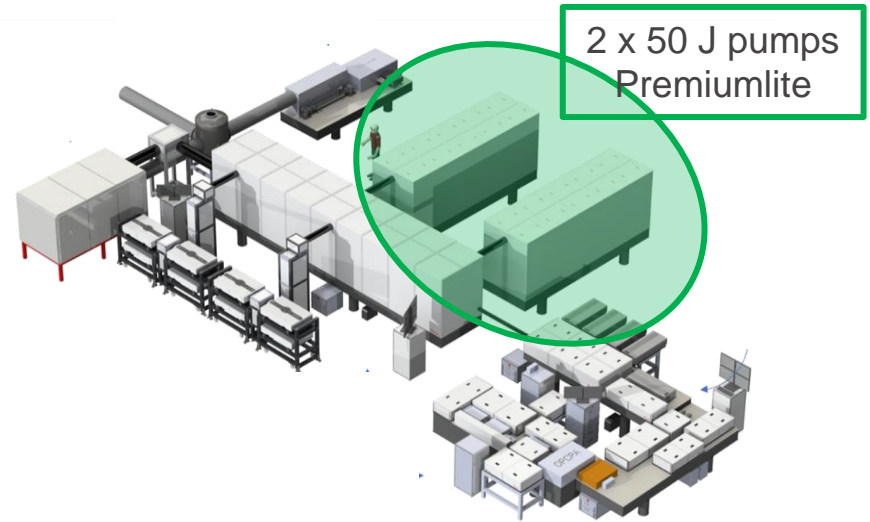
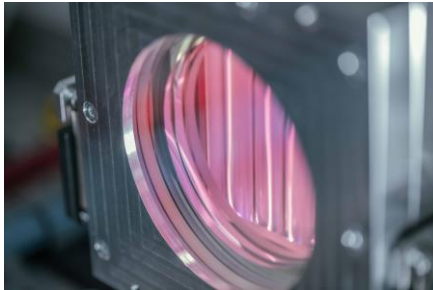
On the way to 2PW level at 10Hz...

# On the way to 2PW at 10Hz ...

... Premiulite Pump lasers ...

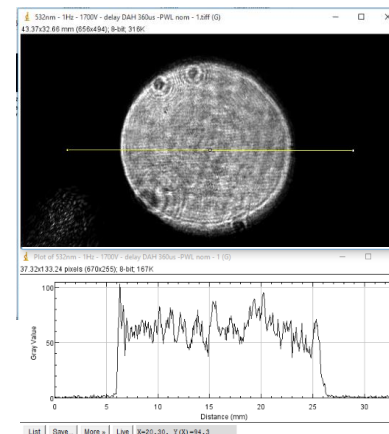
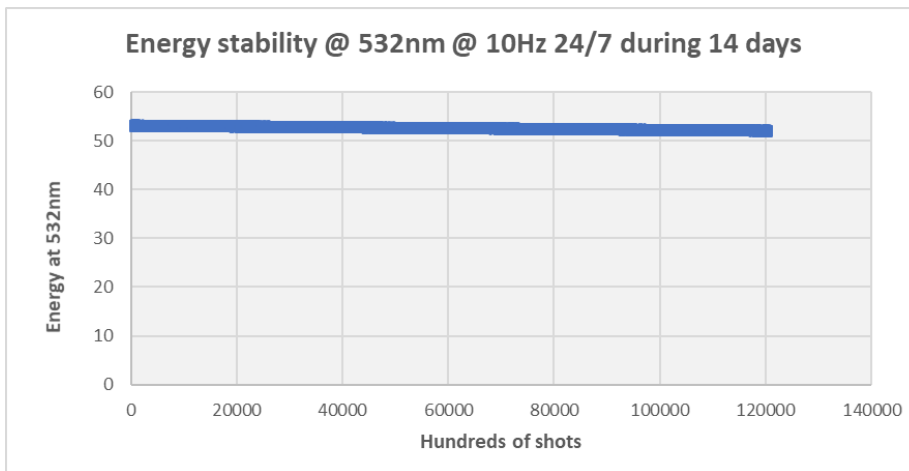
## / State-of-the-art technology

- > Multidisk amplifier
- > Longitudinal heat extraction



## / Excellent performance & reliability @ 10 Hz

- > 2 x 72J , 10Hz, 1.440 kW, IR average power
- > 2 x 50J, 10Hz, 1kW SHG average power

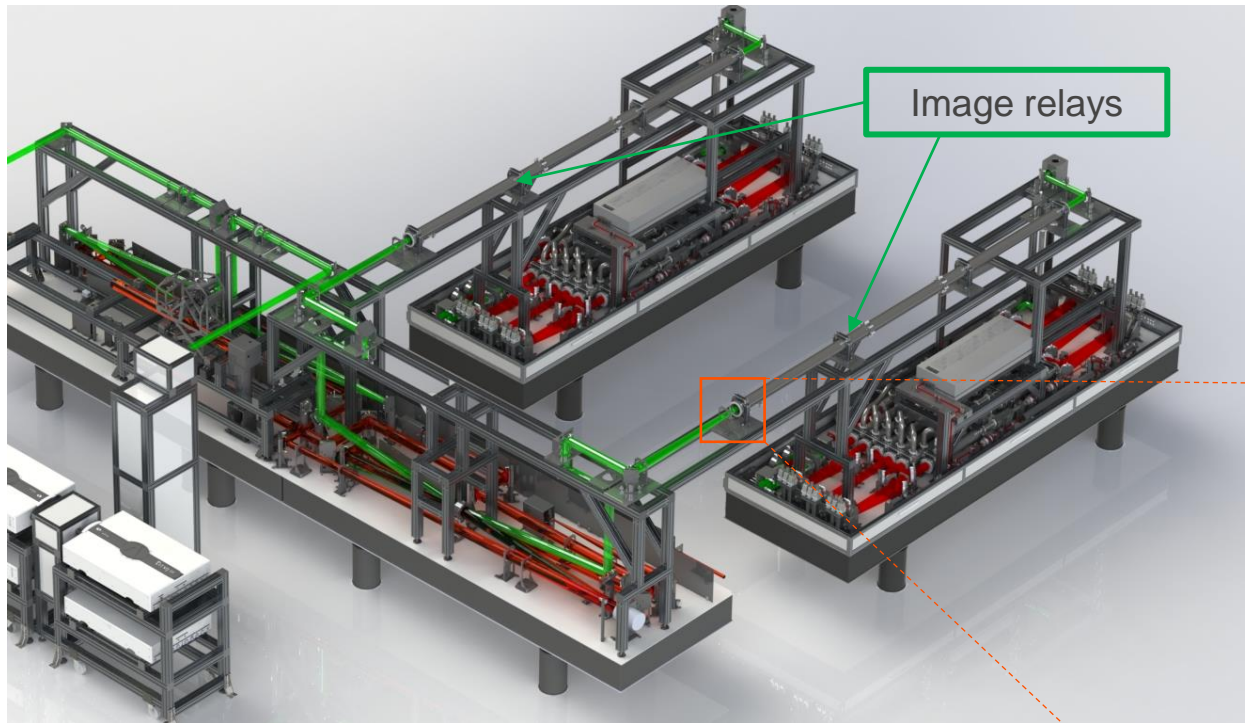




# On the way to 2PW at 10Hz ...

... Premiulite Pump lasers propagating to the crystal

- / Premiulite beam are fully designed with **imaging relays scheme** to preserve a perfect beam profile during amplification in DAM and SHG generation
- / Premiulite beam are also **image relayed on the Ti:Sapphire** crystal for similar purpose

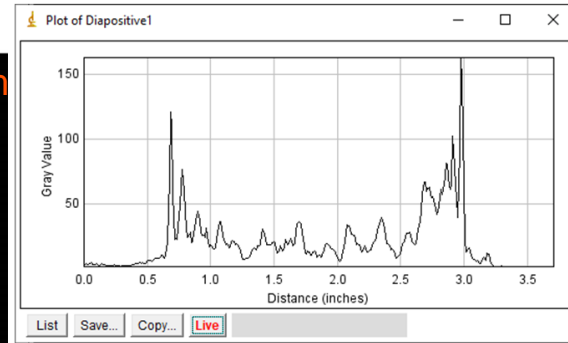
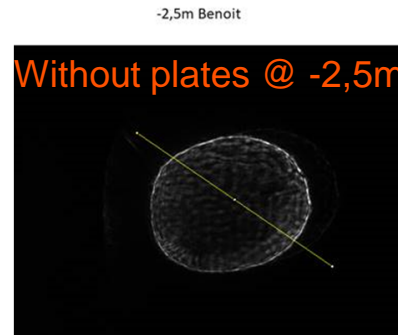


- / But when we have increased the energy... **Damages!**

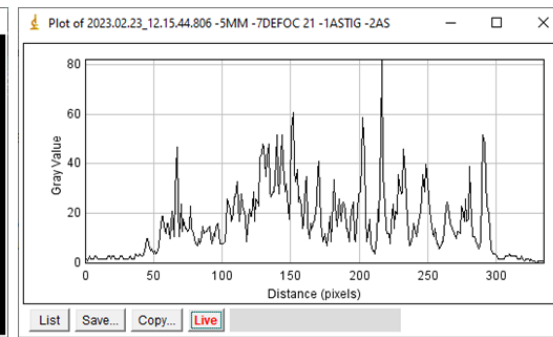
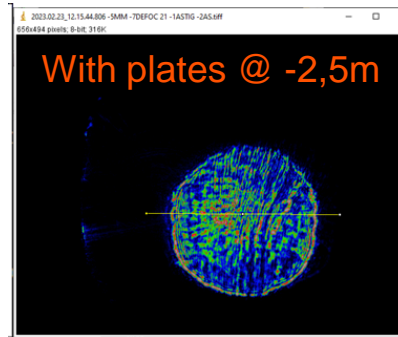
# On the way to 2PW at 10Hz ...

... Premiulite Pump lasers propagating to the crystal

/ Phase plates with **static Spherical Aberration compensation** added to the Premiulite design



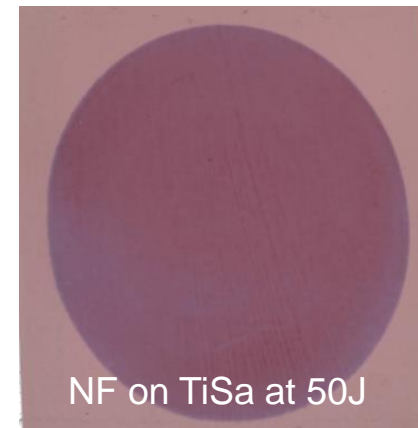
/ New beam profile has a **strongly reduced** ring pattern, coupled with perfect NF profile.  
→ Additional filtering should remove last structure if needed



/ New design in the imaging relay to use the optics in **less sensitive** propagation plans

/ Thanks to all these improvements, propagation from Premiulites to the Ti:Sapphire is possible in a safe way

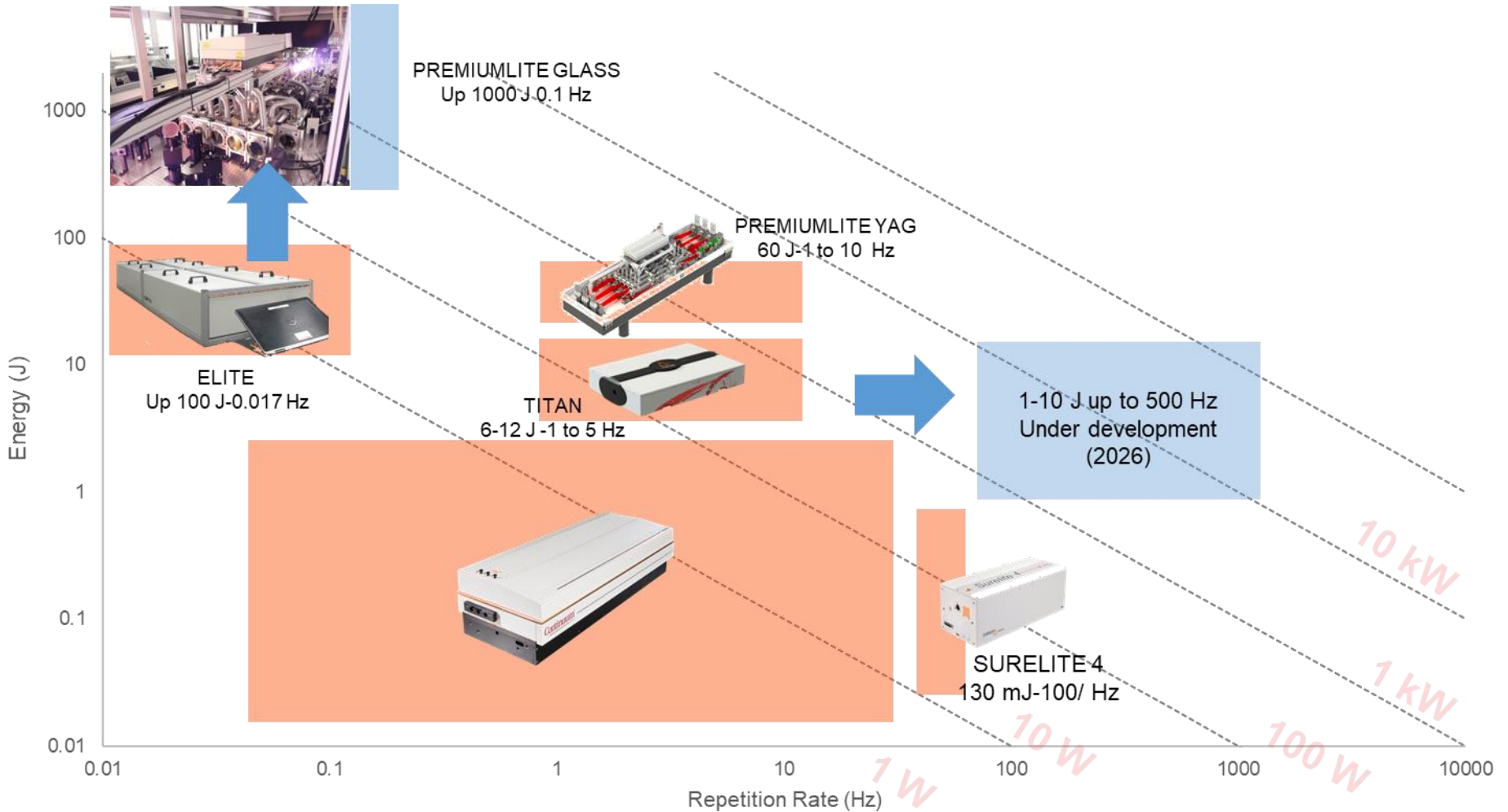
**Our next Challenge → full energy amplification: 50J at 10Hz !!**



# 04

Roadmap to 100Hz and above.

# Mapping of Amplitude Ns Advanced Lasers & expected roadmap to higher average power



# Roadmap for >100Hz operation

The roadmap for increasing the repetition rate of the pump laser contains three steps :

**Step #1** :Development of a SBS conjugate mirror compatible of High Energy High Average power (2022-2024)

Step #1 done

**Step #2** :Development of a 1 to 2kW diode-pumped pump laser @ 100Hz-200Hz (2022-2026..)

**Step #3** : Development of a ~10kW diode-pumped pump laser @ 100Hz

# Control of wavefront and beam quality

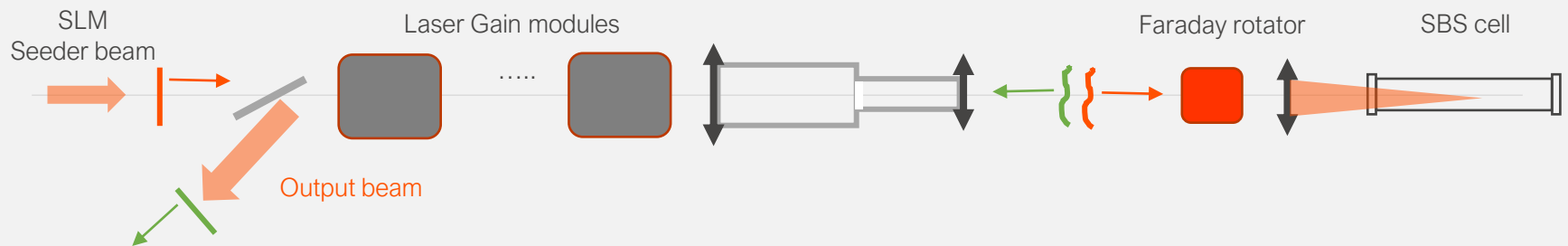
Use of Stimulated Brillouin Scattering (SBS) for Phase Conjugate Mirror application (SBS-PCM)

Step 1: Wavefront aberration occurs during the first pass in the High Average Power amplifiers.

Step 2: The beam is reflected with >95% efficiency and is phase-reversed by the High Energy SBS mirror.

Step 3: The wavefront is perfectly self-compensated during the second pass in the High Average Power amplifiers.

*Typical amplification scheme for SBS-PCM*



# Automatic beam quality optimization with SBS Mirror

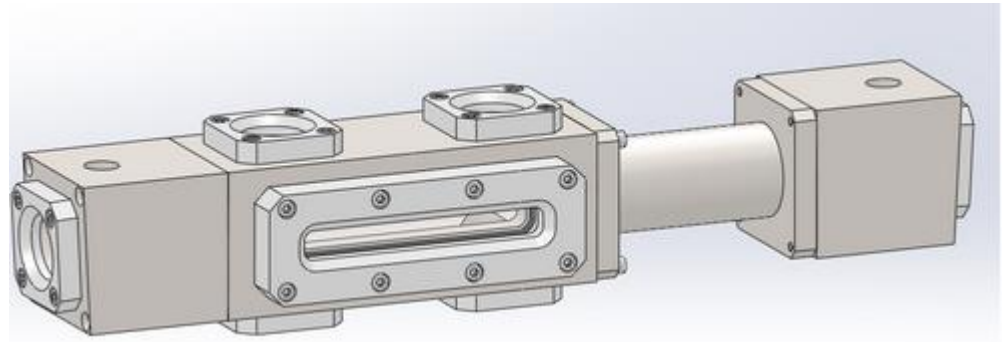


Brillouin fluid is ultra-filtered to ensure 100% successful aberration compensation:

Our new ultra-filtration station.

Step #1 done

Our prototype Brillouin mirror cell for operation @ up to 100J and  $\gg 100$ s Watt of average power





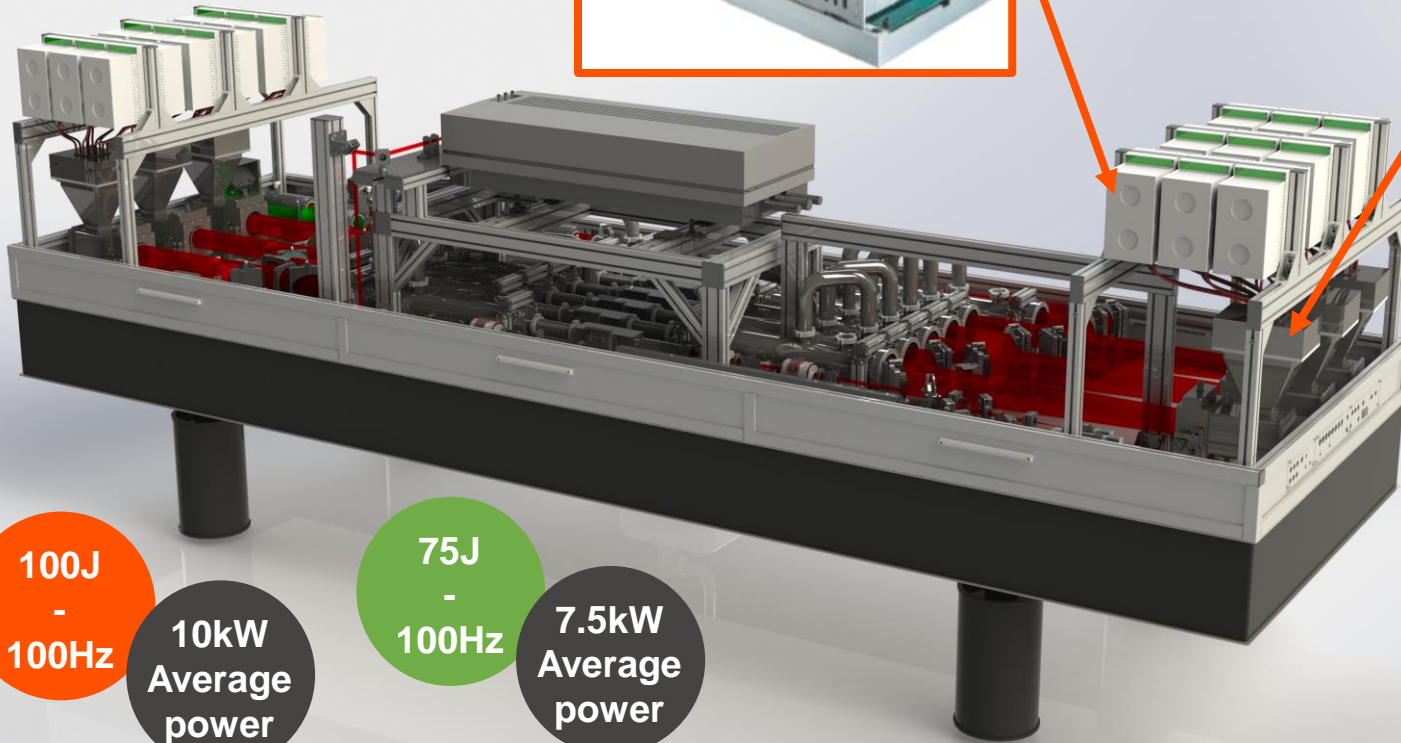
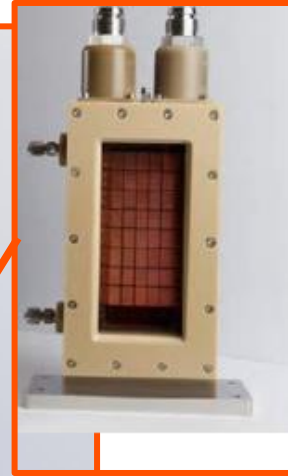


# Design of a diode-pumped 100J -1064nm - 100Hz version

QCW Diodes Power supplies



QCW Diodes



100J  
-  
100Hz

10kW  
Average  
power

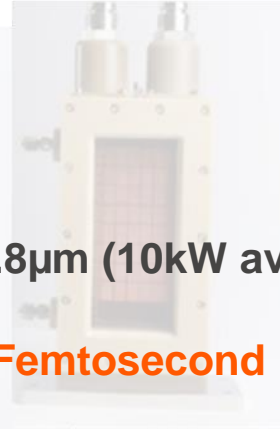
75J  
-  
100Hz

7.5kW  
Average  
power

Large investment → development driven by EUPRAXIA ?

# Design of a diode-pumped 100J -1064nm - 100Hz version

Our roadmap is driven by  
Particle Acceleration and secondary sources applications:  
Amplitude as the reference industrial partner



Diodes  
Pumping

>>10kW  
Average  
power

> 100Hz

- Up to 30J @ 0.8 $\mu$ m (10kW av.)
- Ti: Sa based
- Nanosecond /Femtosecond

> 100Hz

- Up to 1J @1  $\mu$ m
- Ytterbium based
- Femtosecond

Work performed in Szeged and Lisses by  
Amplitude team :



Benoît Bussiere  
Muriel Senkans  
Olivier Roy  
Steven Calvez  
Emilien Gontier  
Florian Mollica  
Raphael Humblot  
Stéphane Branly  
Franck Falcoz



Great thanks to ELI team :

Roland, Victor, Janos, Levente, Nikita, Abdollah, Huabao, ...

**Thank you for your attention**