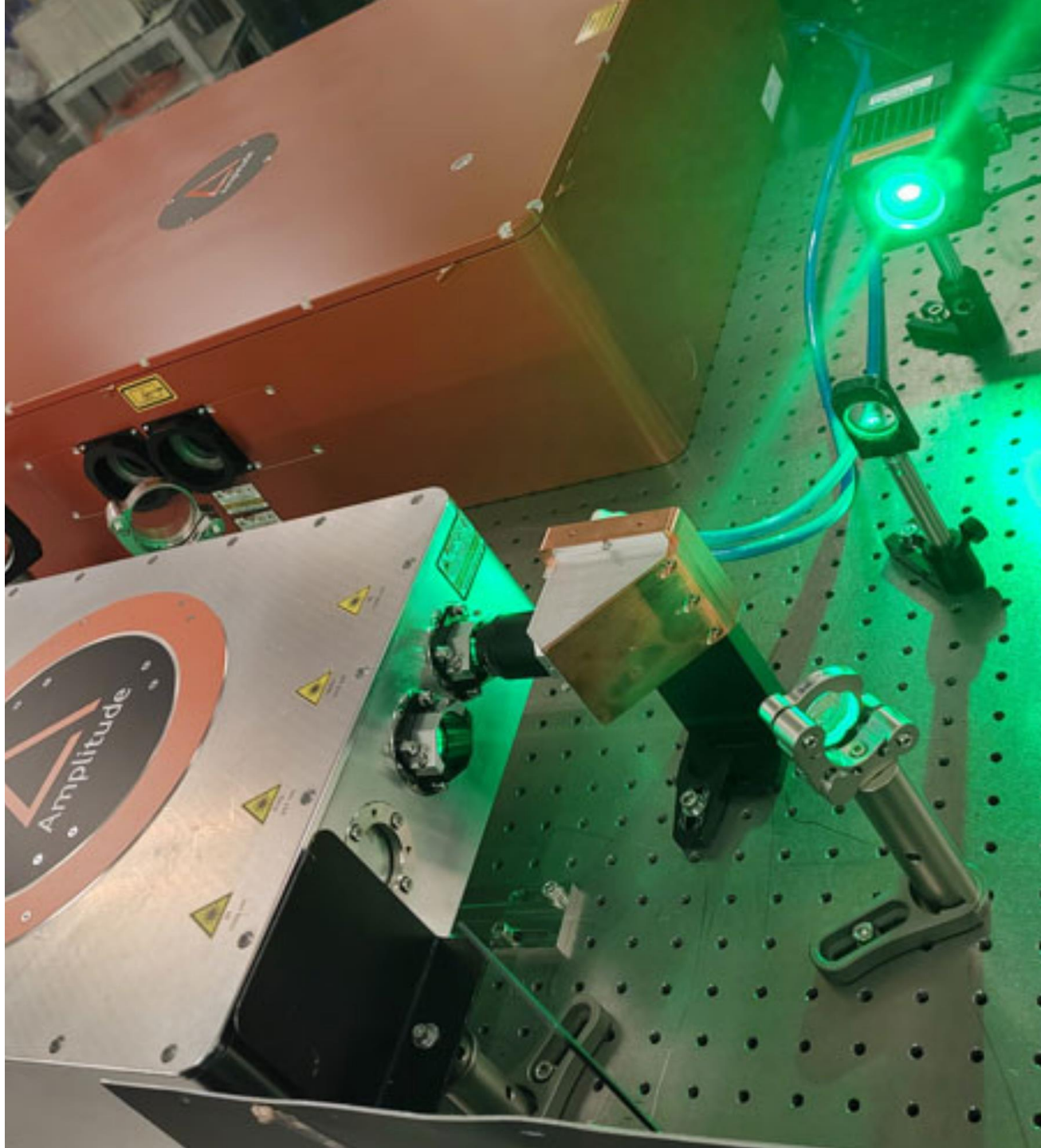
Increasing repetition rate of PW laser drivers for modern secondary sources

23th of July 2024

Antoine COURJAUD

A Laser Bright Future



01

Amplitude Laser Group

Amplitude at a glance

Innovative & visionary company, created in 2001

Expert manufacturer in ultrafast laser technology

10+ offices and production plants around the world.

450 + employees worldwide

3 000 M² of production area

5 000 + lasers in the field

Amplitude Laser Group Headquarters, near Bordeaux, France

Amplitude

Global company with a global reach

The most complete and advanced Femtosecond & Nanosecond laser portfolio

High peak power: from TW to multi-PW

Ti:Sa-based solutions
> fs to ps, up to 10s J

High repetition rate

Yb-based solutions
> Hz to kHz, up to J, ps
> MHz, mJ, 100s fs

High Energy

Nd-based solutions
> ns, up to 100s J

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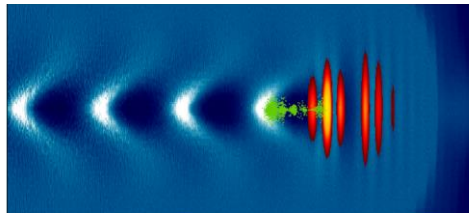
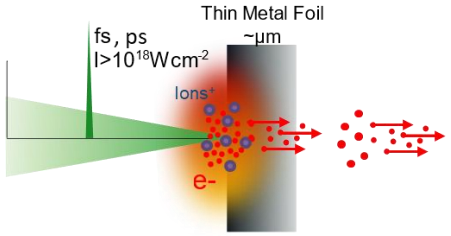
Ultrafast laser-driven secondary sources

Petawatt(Ti:Sa)

GeV electron sources

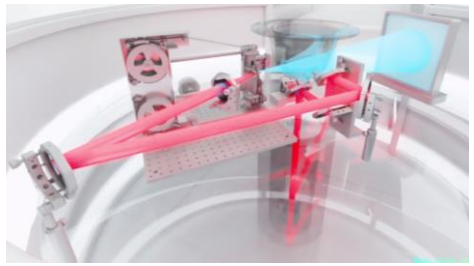


MeV proton sources

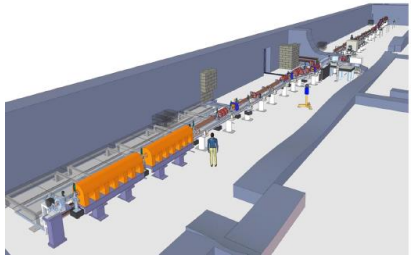


Terawatt (Ti:Sa/Yb)

LPP X-ray sources

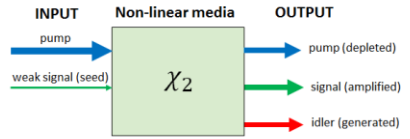


ICS X/γ-ray sources

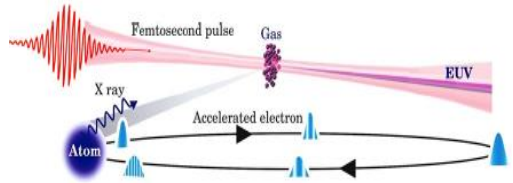


Gigawatt (Yb)

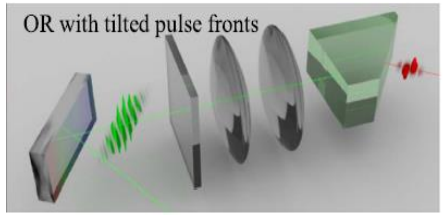
UV-VIS-MIR sources



XUV sources



THz sources



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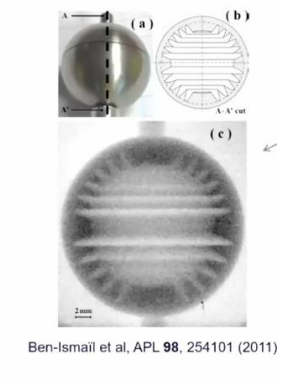
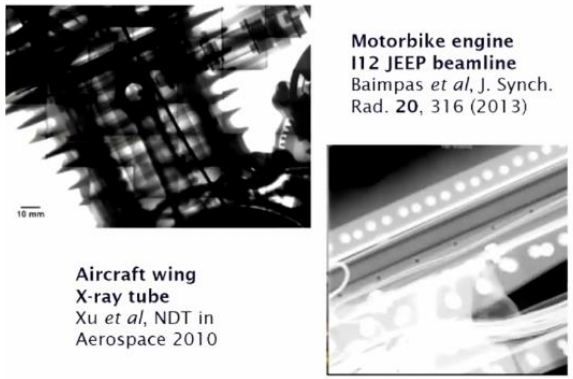
Motivation

> Industry & National Security – NDT with X-ray sources



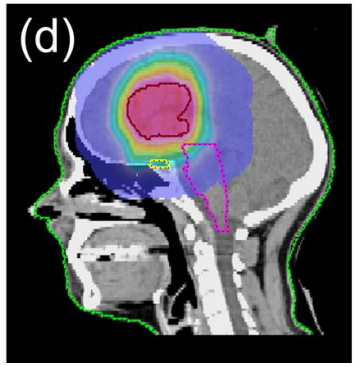
Ben-Ismaïl et al, APL **98**, 254101 (2011)



Motorbike engine
I12 JEEP beamline
Baimpas *et al*, J. Synch. Rad. **20**, 316 (2013)

Aircraft wing
X-ray tube
Xu *et al*, NDT in Aerospace 2010

> Medical – VHEE / protontherapy



> Improvements needed :

- Stability = better control on laser parameters
- Flux = higher rep rate

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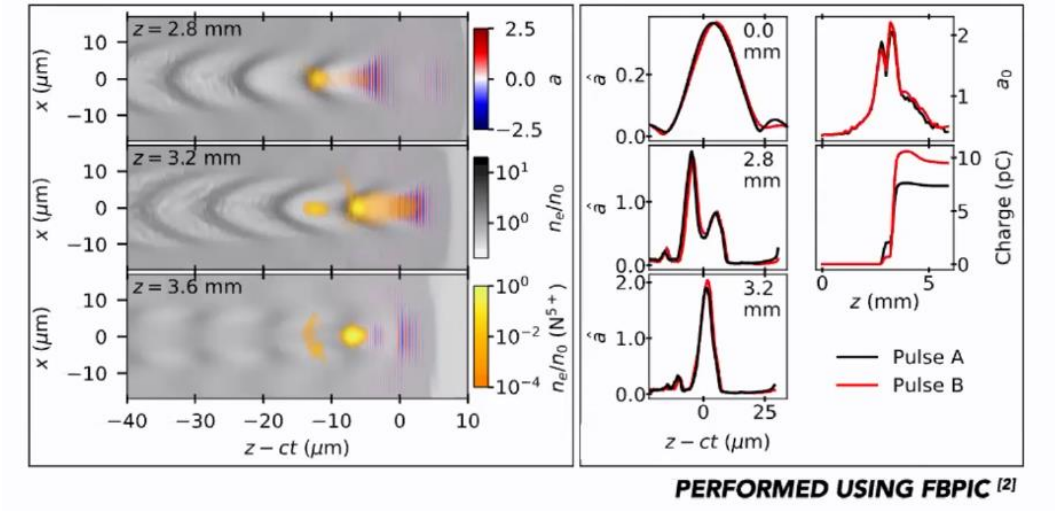
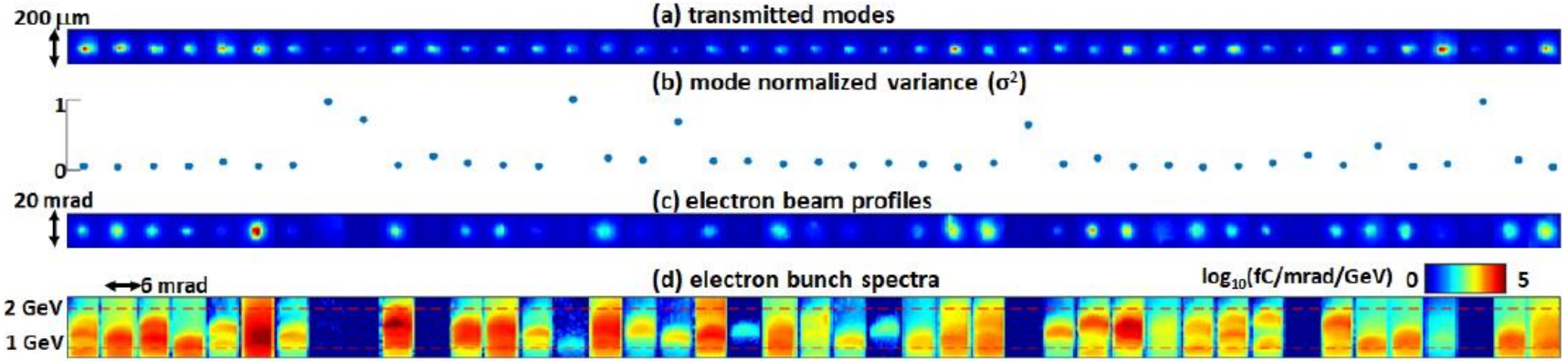
02

Controlling the laser

Stability issues

LPA example : Highly nonlinear process





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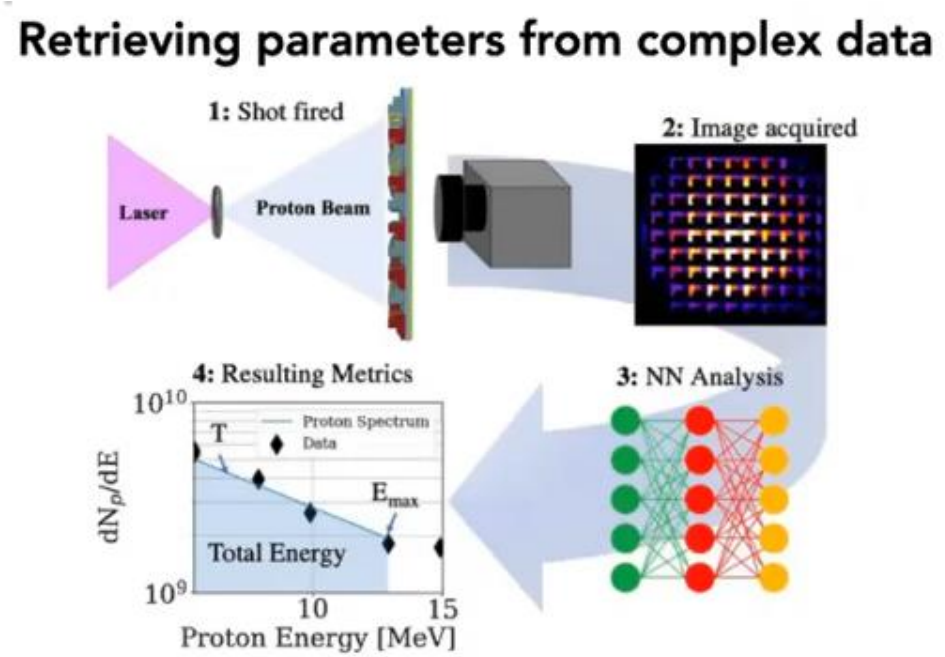
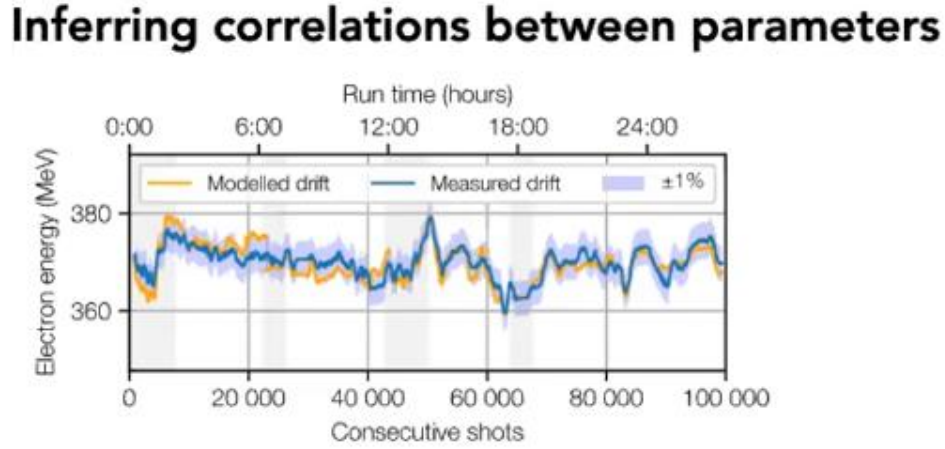
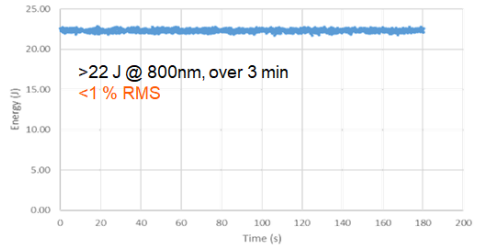
Need relevant diagnostics

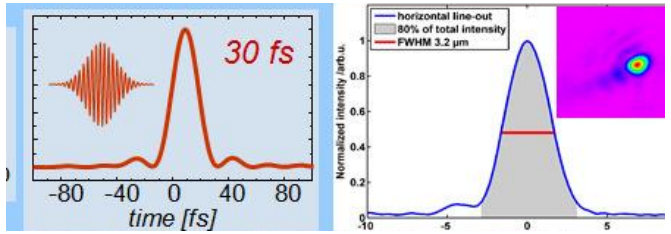
Mariscal et al., PPCF (2021)

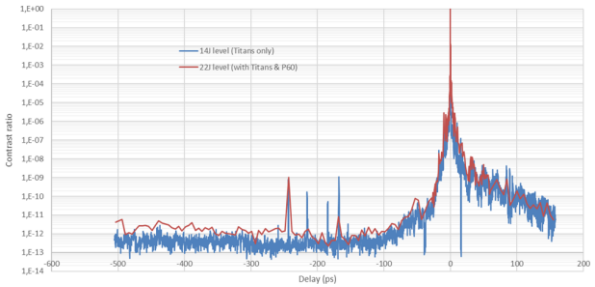


Maier et al, PRX (2020)









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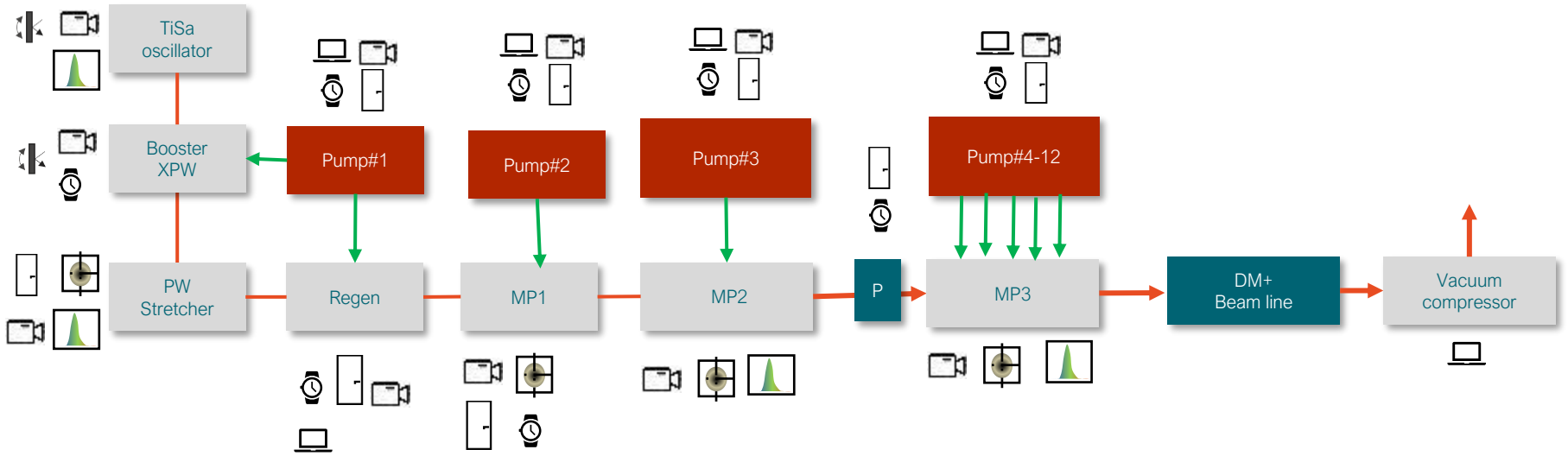
Control command on a PW laser



Camera near field (x19)

Camera far field (x5)

Spectrometer (x4)

Motorized mount (x2-8)

Laser control (x11)

Timing control (x26)

Shutter – Beam blocker (x14)

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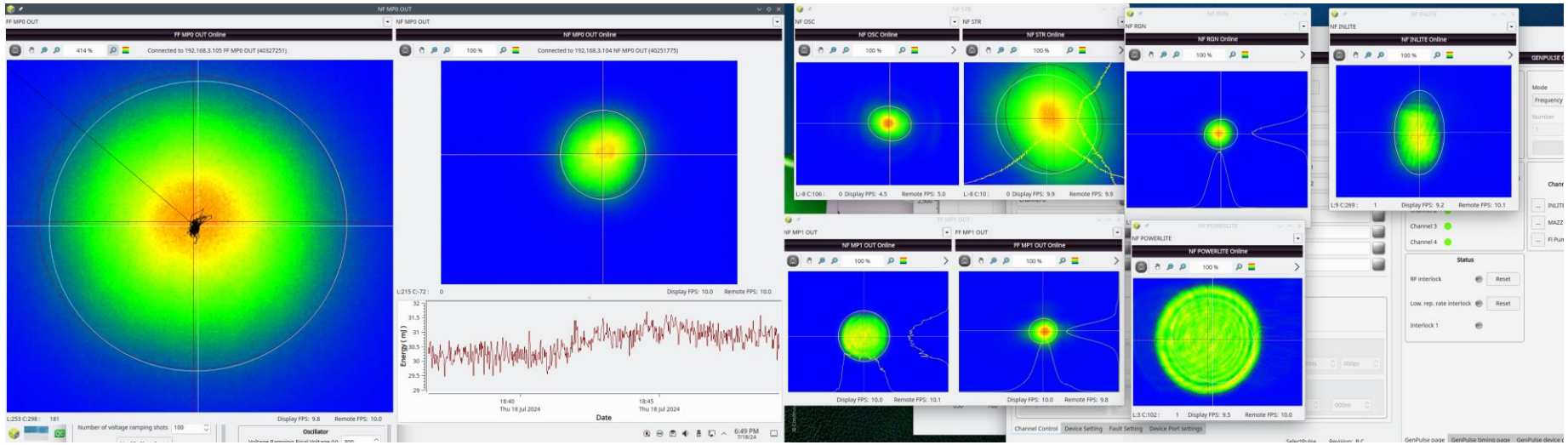
User Interface

- Display and control parameters
- Active stabilization on relevant parts
- Logging functionality



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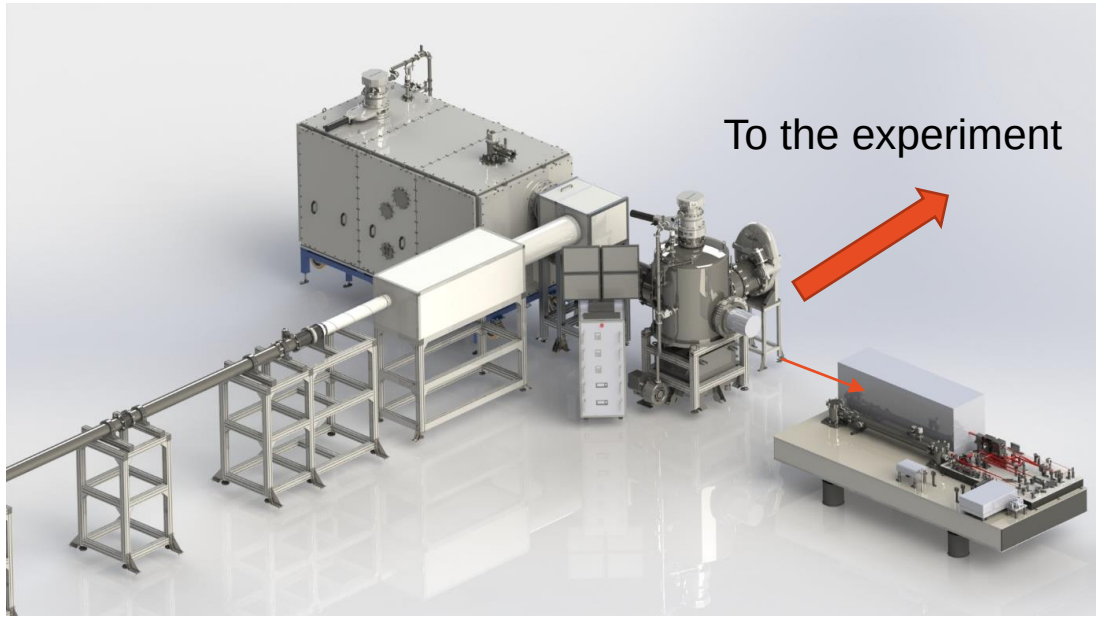
Metrology bench

> Metrology bench installed after compressor, 2 modes : leak / beam through

- Energy short-term & long-term
- Beam profile – pointing – wavefront
- Spectrum - pulse duration – angular chirp
- Picosecond & nanosecond contrast



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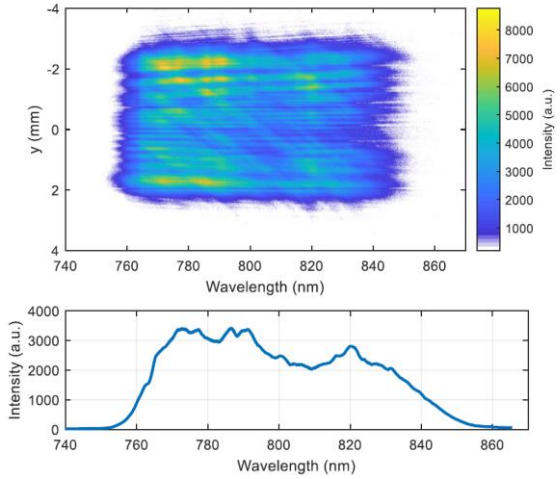
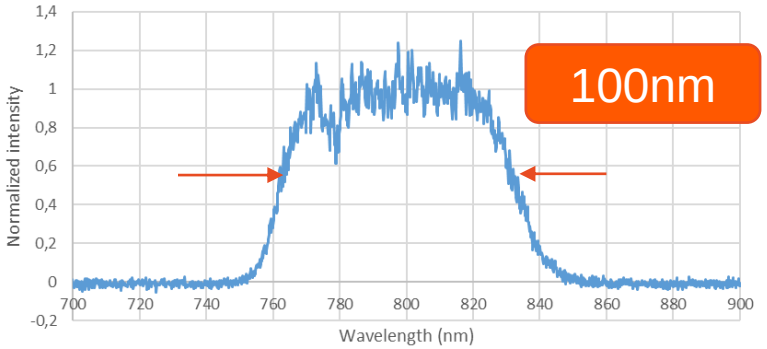
Pulse duration and chirp

Pulse duration - Wizzler

Spatial chirp – 2D spectrometer



Spectrum - spectrometer



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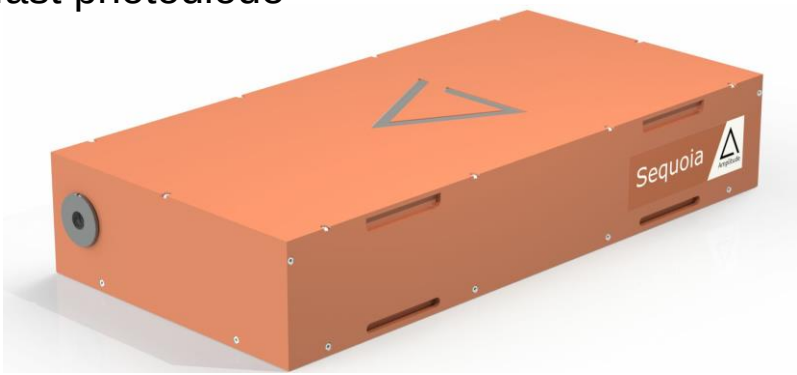
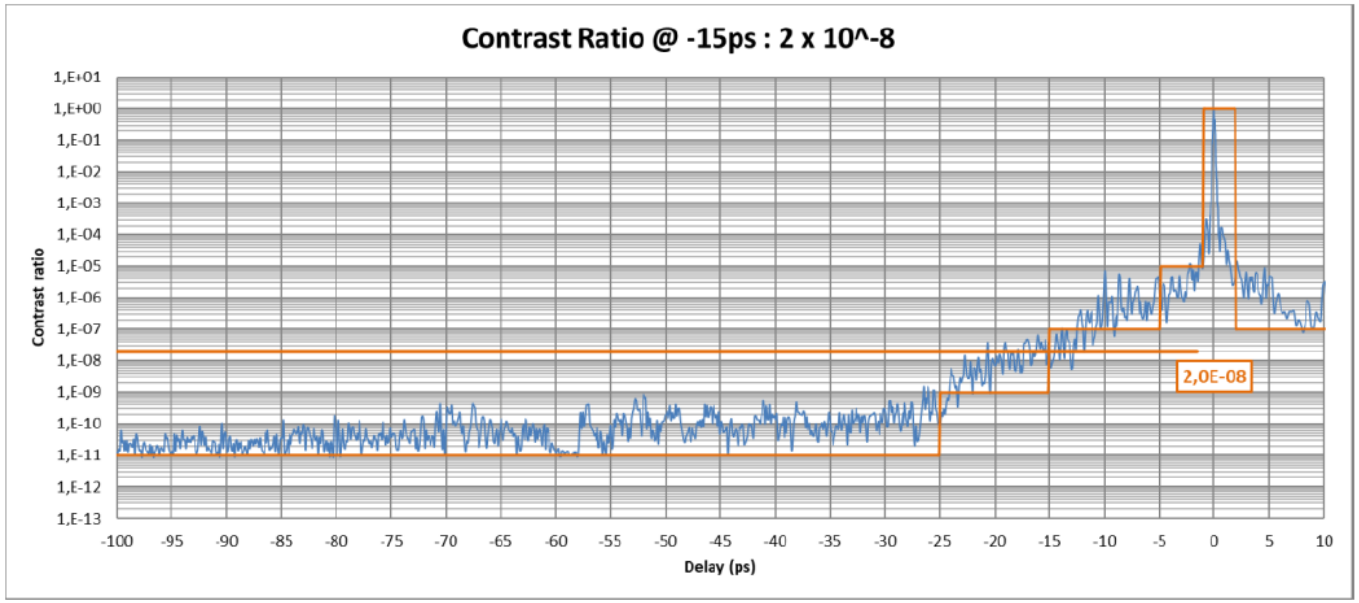
Temporal contrast

Temporal contrast – Sequoia & fast photodiode





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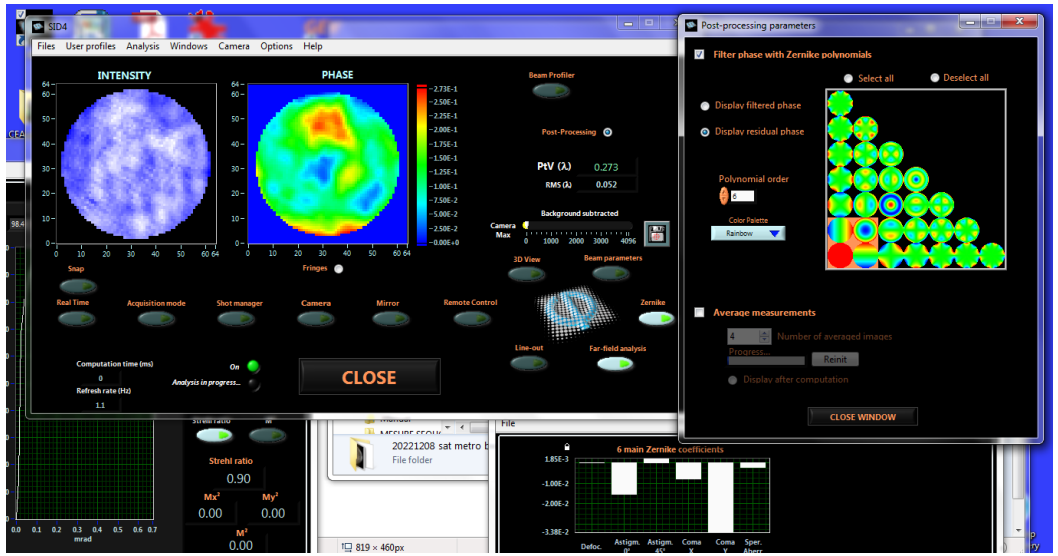
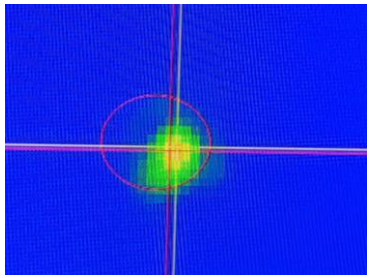
Beam quality & pointing

Wavefront measurement – SID4
Strehl ratio & defocus



Pointing stability - Far-field camera
Active stabilization available with Control Command



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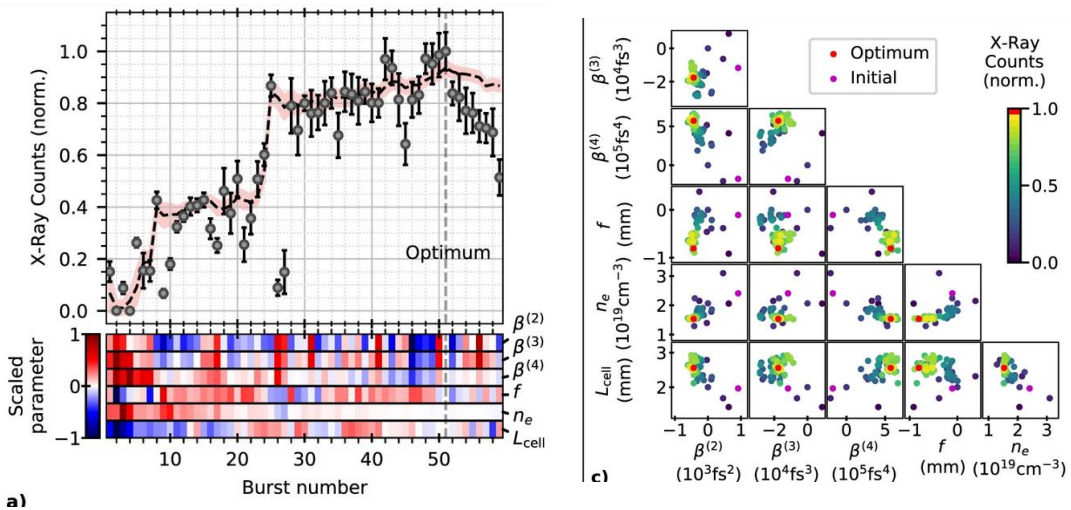
Active feedback strategy

Optimization depends on process

Example on a X-ray source :

- Pulse shape
- Focus position
- Gas density
- Jet length



Contrast will play a stronger role in proton acceleration

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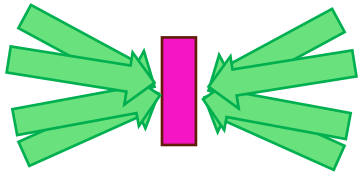
03

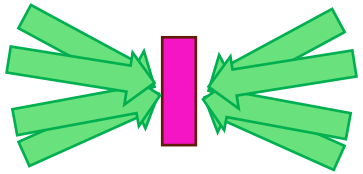
Increasing the repetition rate

Strategies for higher reprate

- Multiplexing standard pump lasers
  - Flexible designs
  - higher pump homogeneity



Spatially for higher energy



Spatially&temporally for higher rep rate

- Develop new pump lasers
  - Optimized costs per Joule
  - Compatible with OPCPA pumping

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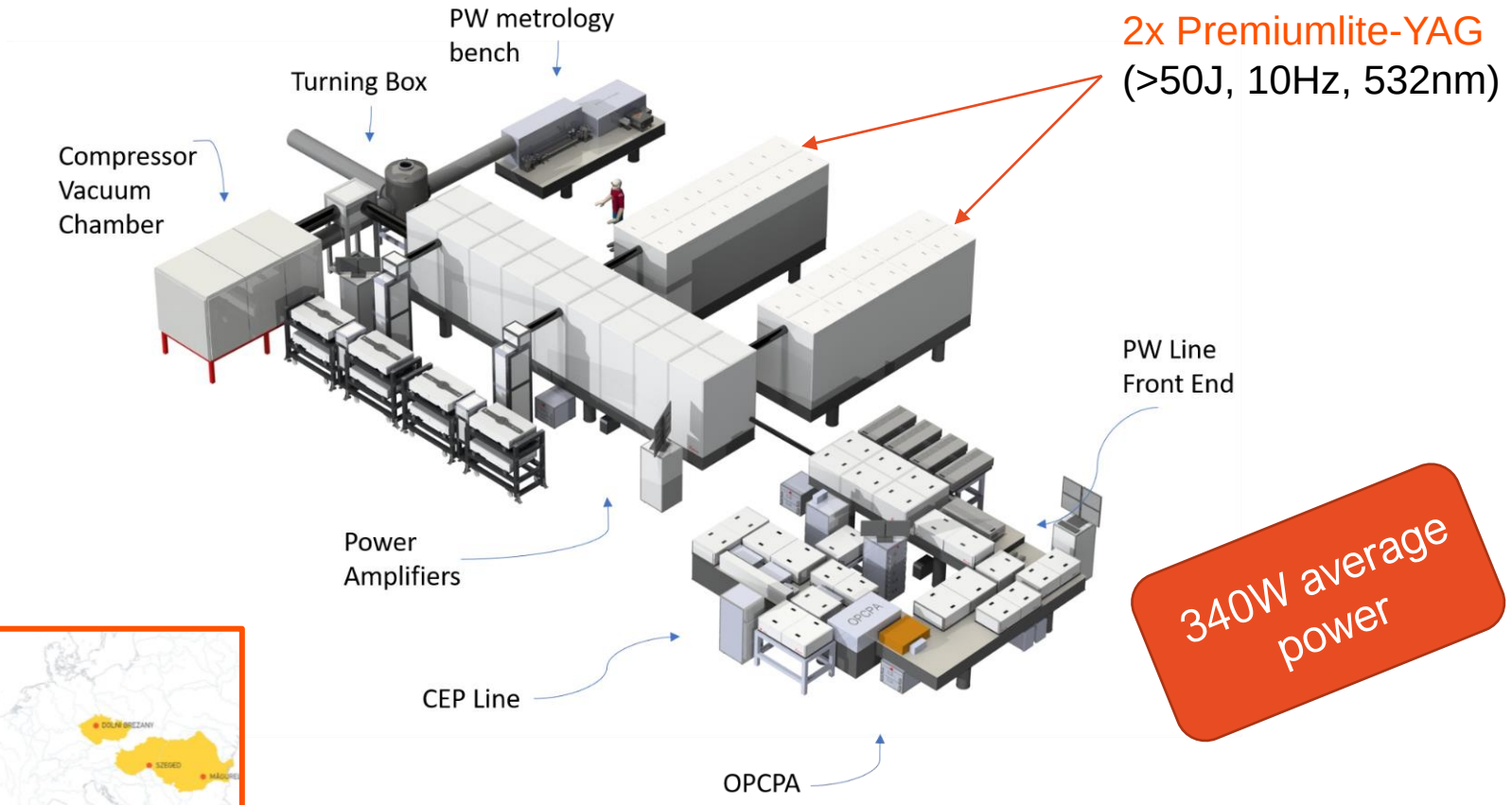
ELI-ALPS : 2PW 10Hz laser

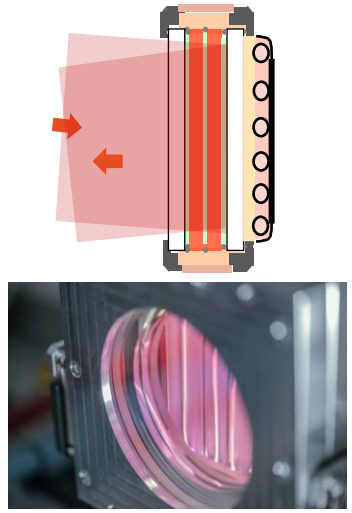


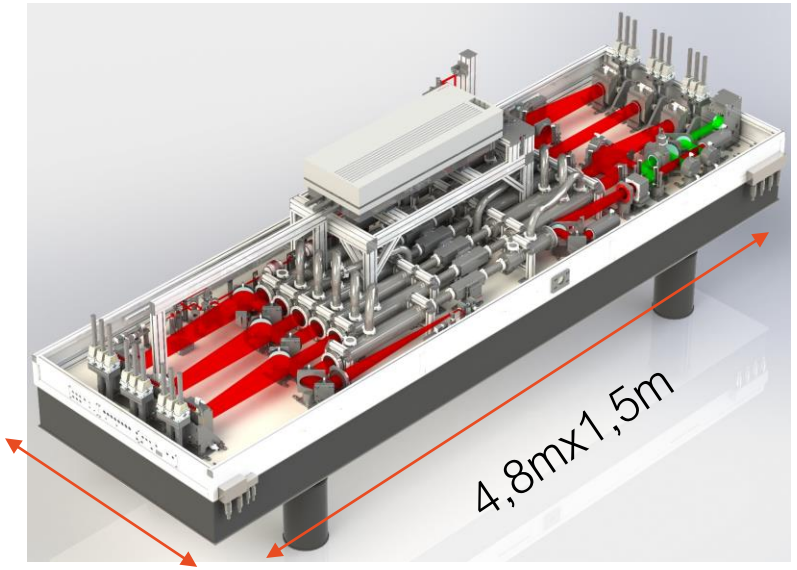
Extreme Light Infrastructure: 2PW - 10Hz - 17fs

Most powerful femtosecond Laser in the world

50J 10Hz pumps

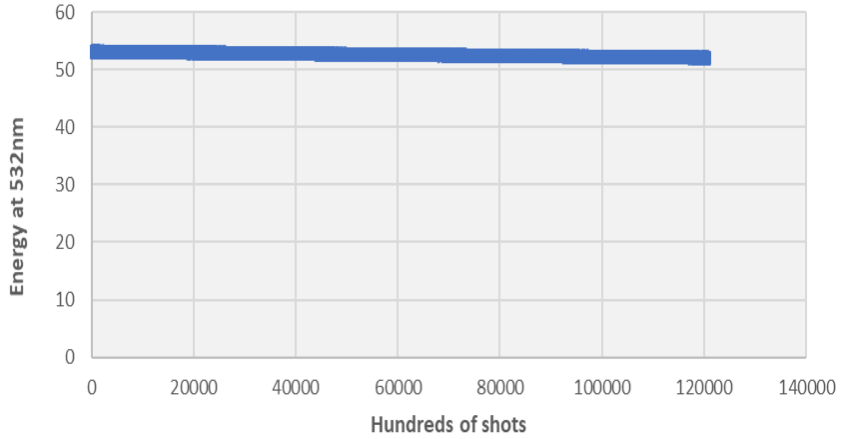
- PAMDAM amplifier technology
  - Nd:YAG multidisk amplifier
  - Flashlamp pumped
  - Water cooling - Longitudinal heat extraction
- Compact system



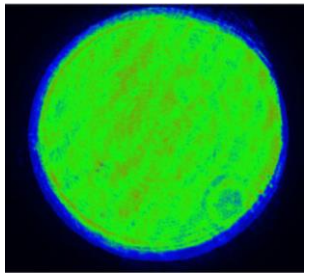


2 systems installed since 2019 at ELI-ALPS

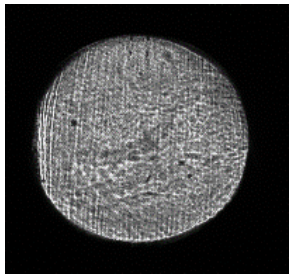
- 2 x 50J @10Hz 532nm (72J IR)
- For acceptance : dry-run 8h/day during 4 months in 2018



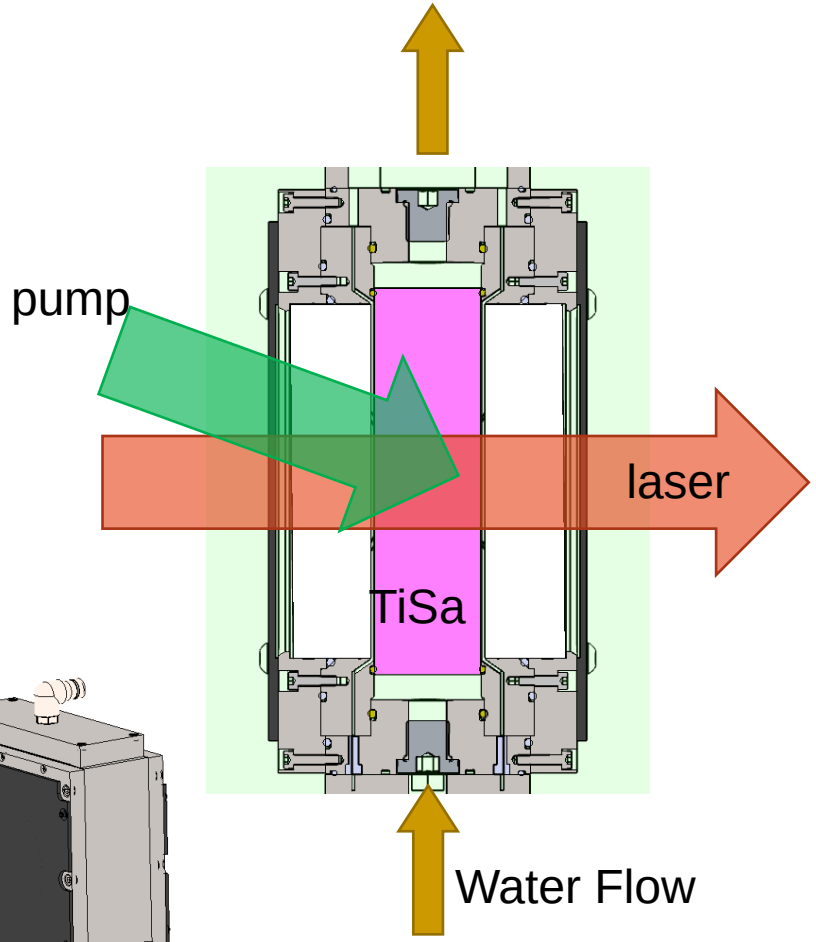
72J IR



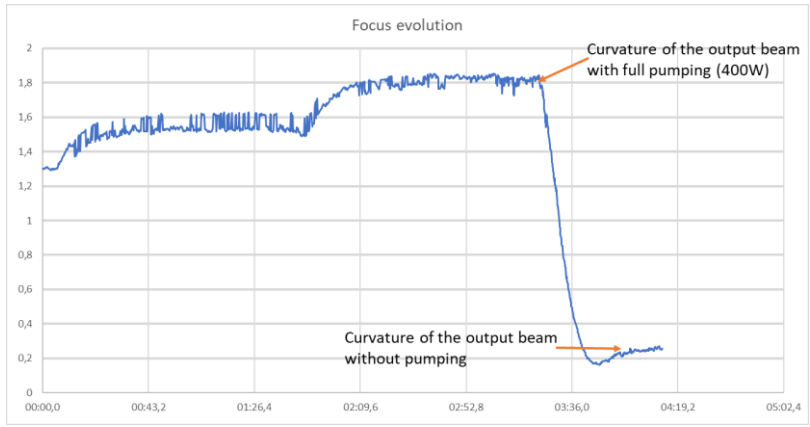
50J Green



Ti:Sa crystal cooling



Deformable mirror for defocus compensation



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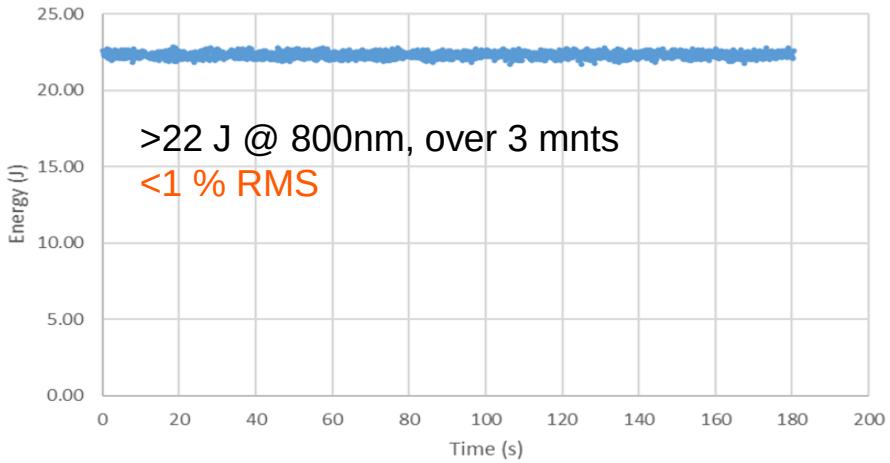
Energy and beam stability

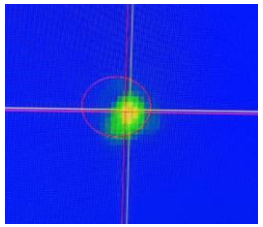
Pulse energy

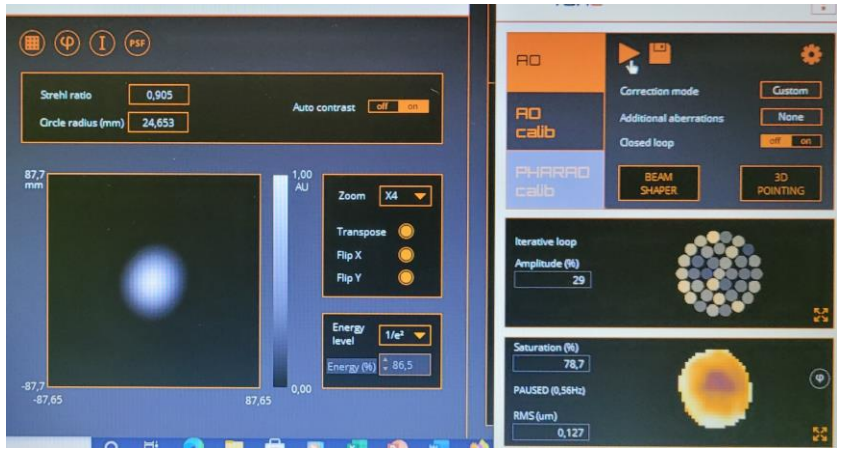
- >22J @ 10Hz, before compression
- 220W average power
- Pump energy 2x15J



Strehl ratio

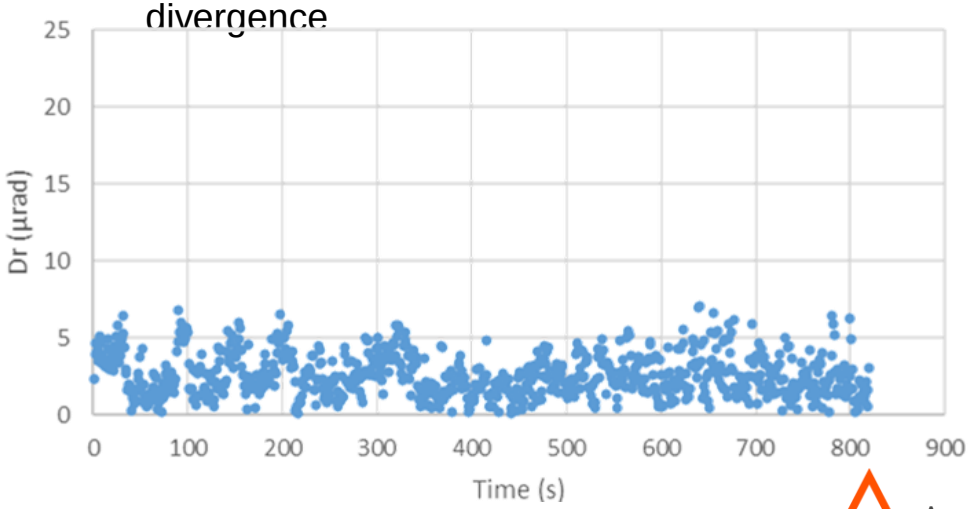
- SR 0.9 at full energy (22J)





Pointing stability

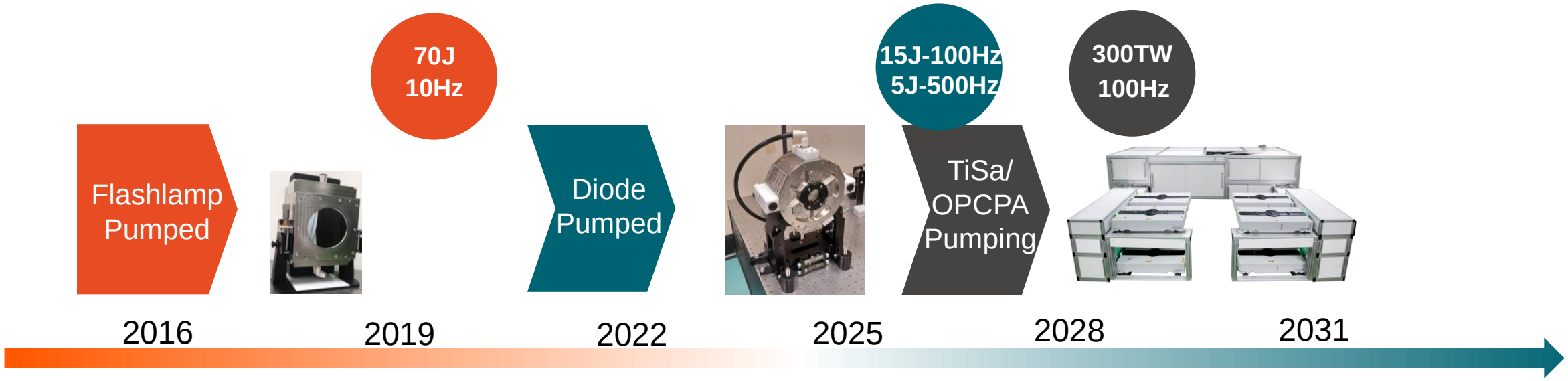
- Pointing Stability is <5% of the beam divergence



Amplitude

Increasing rep rate: Amplitude roadmap

Liquid cooling of multidisks is a key enabling technology for high rep rate PW lasers



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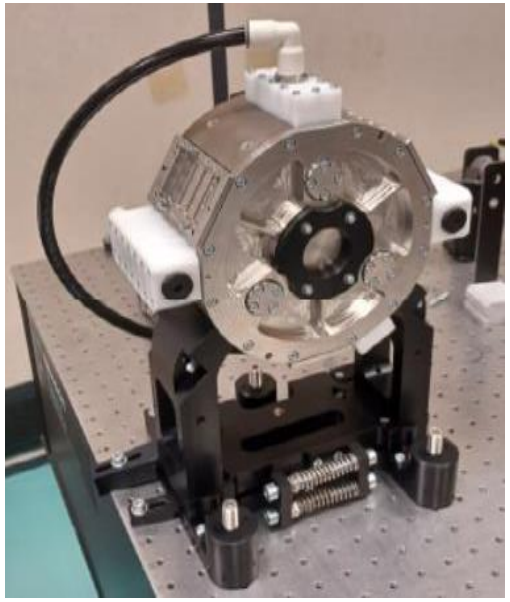
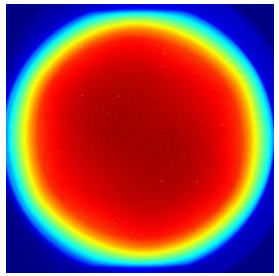
Pump development at 100Hz

- Use diode-pumping technology
- Liquid cooling technology (capitalize on PAMDAM experience)
- Design compatible with 100 to 500Hz operation



Preliminary results
Gain homogeneity



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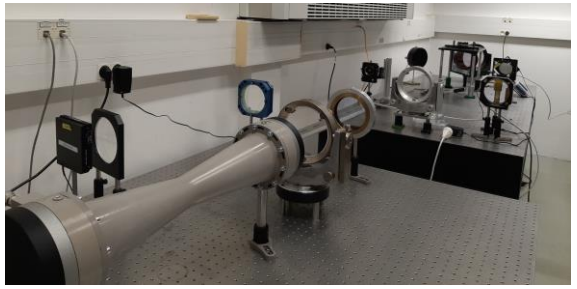
Rep rate tunability

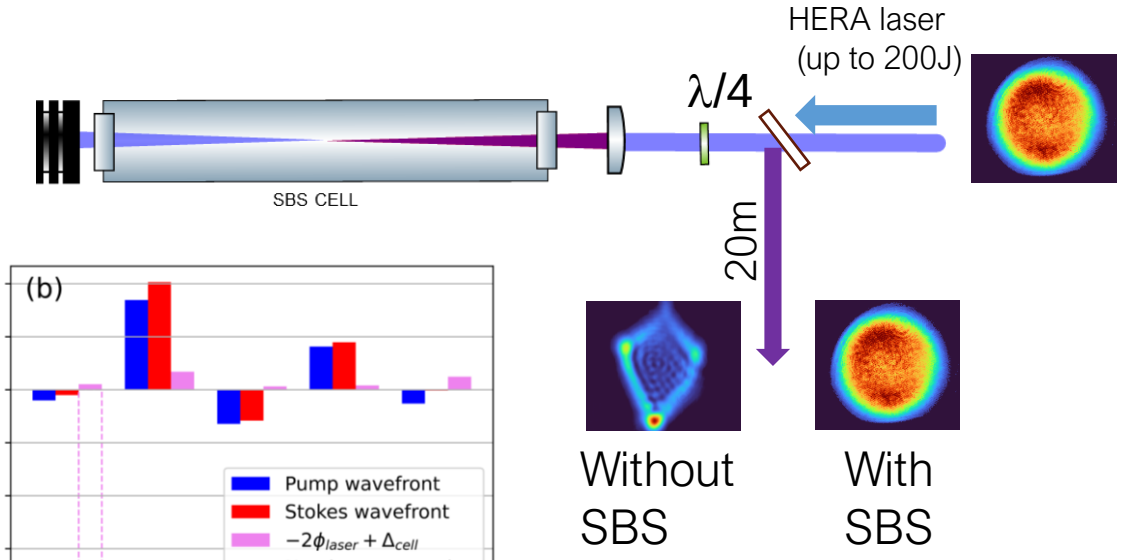
Collaboration with

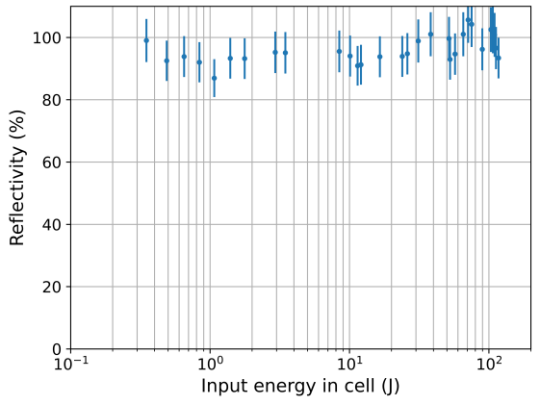
> Passive wavefront compensation using SBS mirror

> 95% reflection measured up to 120J input energy

> Ideal solution to be integrated in 100Hz pump laser



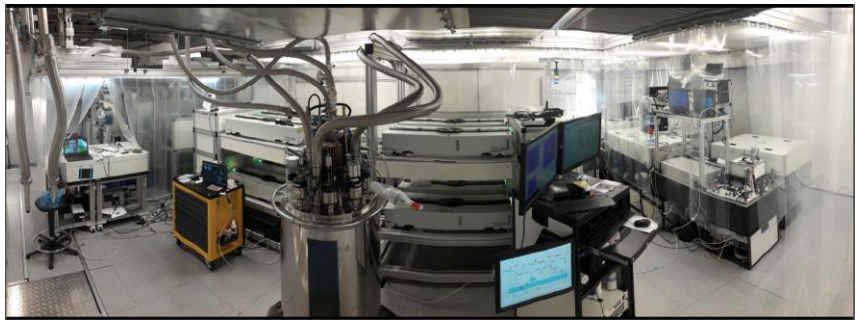


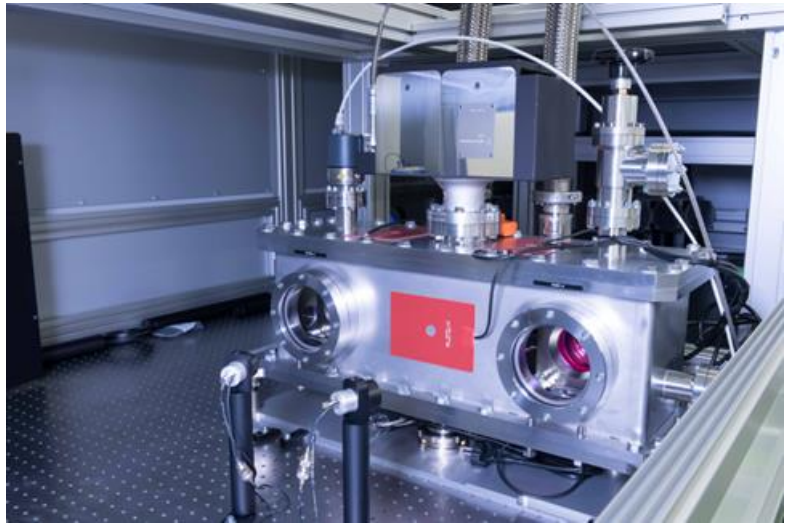


Amplitude

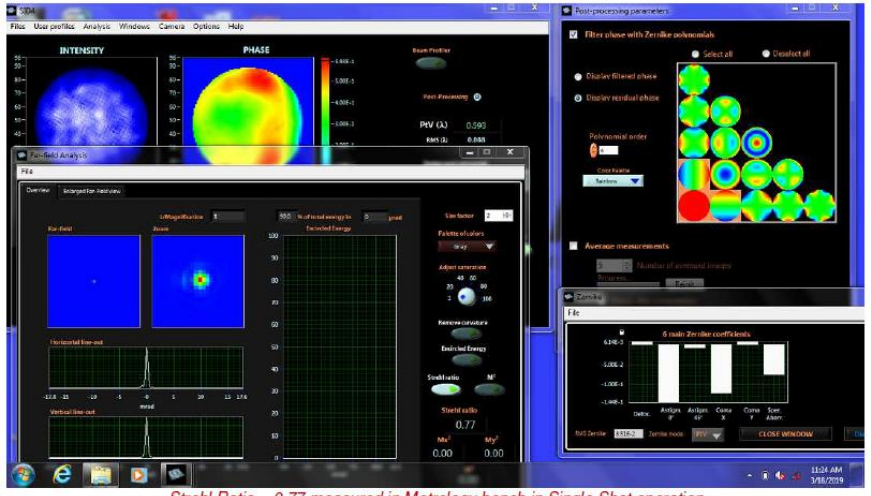
Ti:Sa cryo cooling

- Cryo temperatures : better conductivity, i.e. lower thermal lensing
- Use twin architecture (patented solution)
- High beam quality and focus stability
- Already validated on HiBEF Relax laser @ XFEL (400TW@5Hz)





TWIN CryoCooler with the two TiSa crystals



Strehl Ratio = 0.77 measured in Metrology bench in Single Shot operation

Data	Operation mode:	Measured Strehl Ratio:
Reference Measure	5Hz	0.81
Measure 1	Single Shot	0.77
Measure 2	Single Shot	0.77
Measure 3	Single Shot	0.82
Measure 4	Single Shot	0.67
Measure 5	Single Shot	0.84

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Conclusion & perspectives

> Control-command and metrology are key for stability of secondary sources

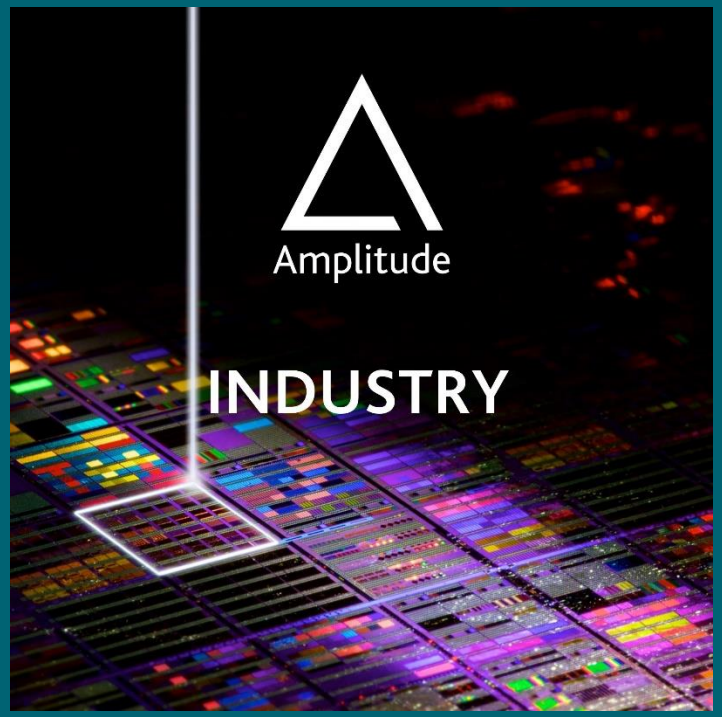
> Need to implement active feedback on relevant parameters

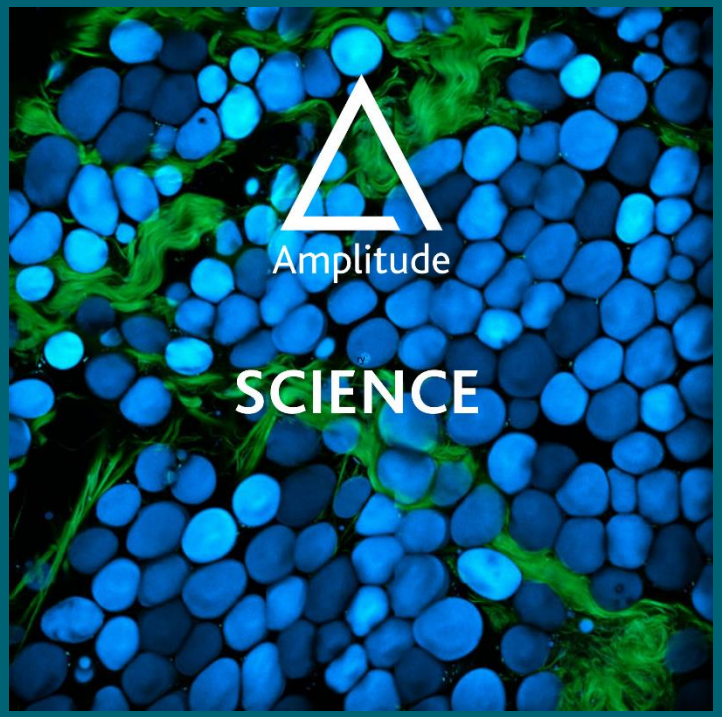
> Thermal management is well advanced for Petawatt lasers at 10Hz

> Current challenge is 100Hz to kHz drivers for industrial applications

Amplitude

A Laser Bright Future





*Sparking a **brighter future** with our laser **solutions**: excellence, **innovation**, **purpose***

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