Pioneer in ultrafast
high energy lasers
laser solutions for scientific applications

HIGH ENERGY & HIGH AVERAGE POWER NS LASERS: THE ROUTE TO HIGH THROUGHPUT APPLICATIONS

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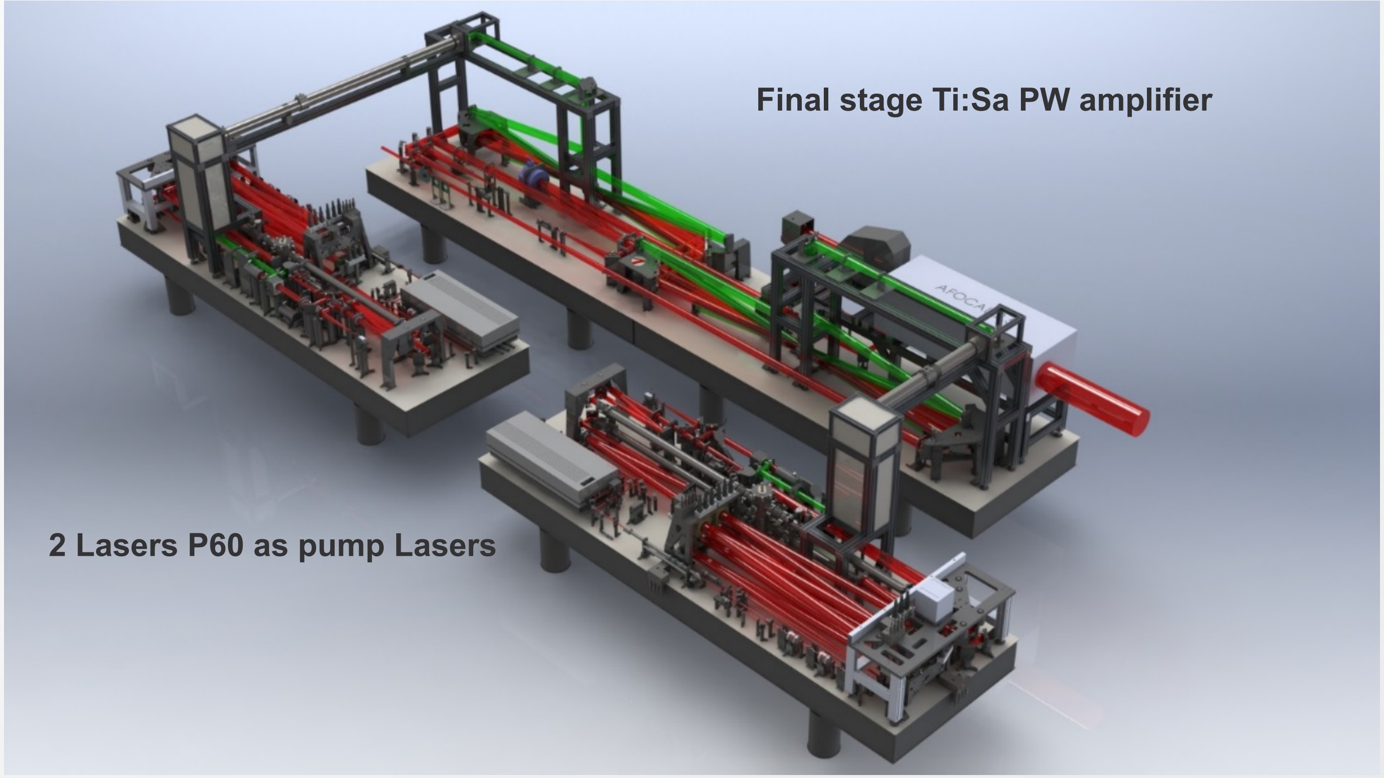
Amplitude TECHNOLOGIES

1- Goal and Opportunity of developing a High Energy & High Average Power nanosecond Laser

History of the genesis of a High Average Power nanosecond Laser named P60

- **APRIL 2014:** Call for Tender of ELI-ALPS project: development of a 2PW Laser @ 10 Hz used as a facility
- **MAY 2014:** First idea and draft for the design of a **High Energy-High Average Power pump Laser (code name: P60)**. First concept of the **PAMDAM (Pseudo Active Mirror Disk Amplifier)** for high heat load management.
- **OCTOBER 2014: Amplitude won the Call for Tender of ELI-ALPS**
- **JULY-DECEMBER 2015:** Test and Qualification of the first PAMDAM @ 10 Hz
- **MARCH-DECEMBER 2016:** Demonstration of 56J @ 532nm @ 2 Hz, 77J of IR @ 2 Hz
- **JANUARY-SEPTEMBER 2017:** partial reengineering followed by modification of the Laser for 10Hz operation.
- **OCTOBER 2017-SEPTEMBER 2018:** optimization, improvement, industrialization

Our target through ALPS project: from PW Lasers to High Average Power PW Lasers



In the framework of ELI-ALPS and as a World reference, the 2 PW (at 17fs) Laser aimed at delivering 340W average Power requires the development of **two High Average Power nanosecond Pump Lasers P60** (60J, 10Hz, 532nm)

P60: A High Energy High Average Power Laser ! What for ?

Science → Medicine:

- Ti:Sa pumping for Protontherapy application

Science:

- High energy OPCPA pumping
- Laser Driven Dynamic Compression (coupling with accelerators)
- Ti:Sa pumping for Plasma Physics (ELI-ALPS,…)

Industry:

- For Laser bond inspection of composite (LASAT, aircraft industry)
- Laser peening & forming (aircraft, automotive industry, …)
- AMOLED debonding (UV version)

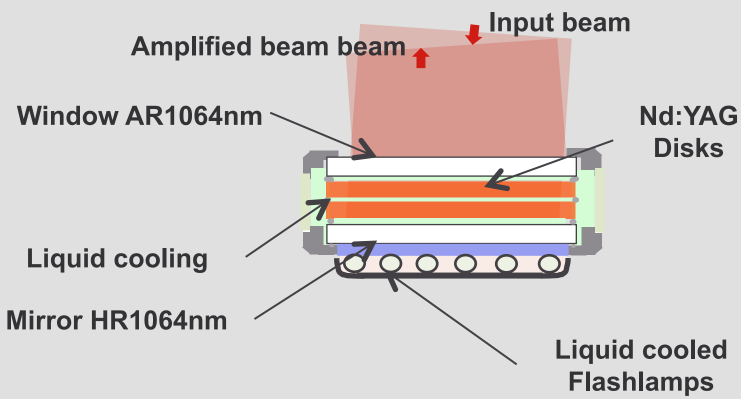
Amplitude TECHNOLOGIES

2- Core technology of amplifiers : the Pseudo Active Mirror Disk Amplifier Module (PAMDAM)

Design of Disk Amplifier Module (DAM)

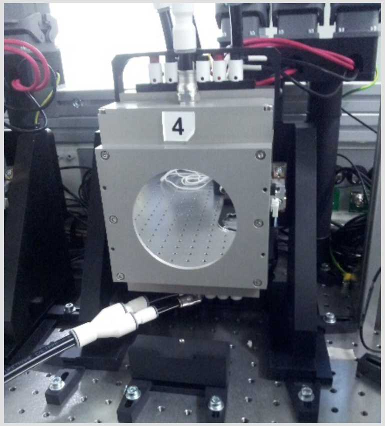
- Improved 'Active mirror' configuration
- Nd-doped materials

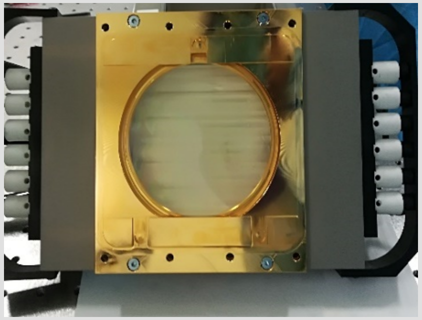
- Low cost → Flashlamps pumping instead of diodes
- High efficiency (wall plug efficiency >1%)
- High capacity of heat load extraction
- Longitudinal cooling to limit thermal effects



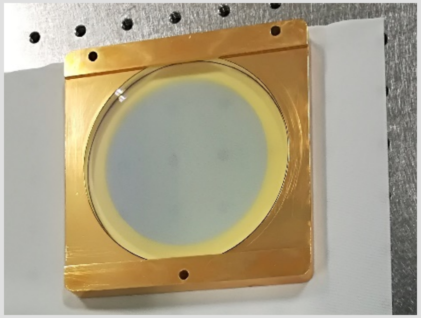
Principle of PAMDAM

PAMDAM





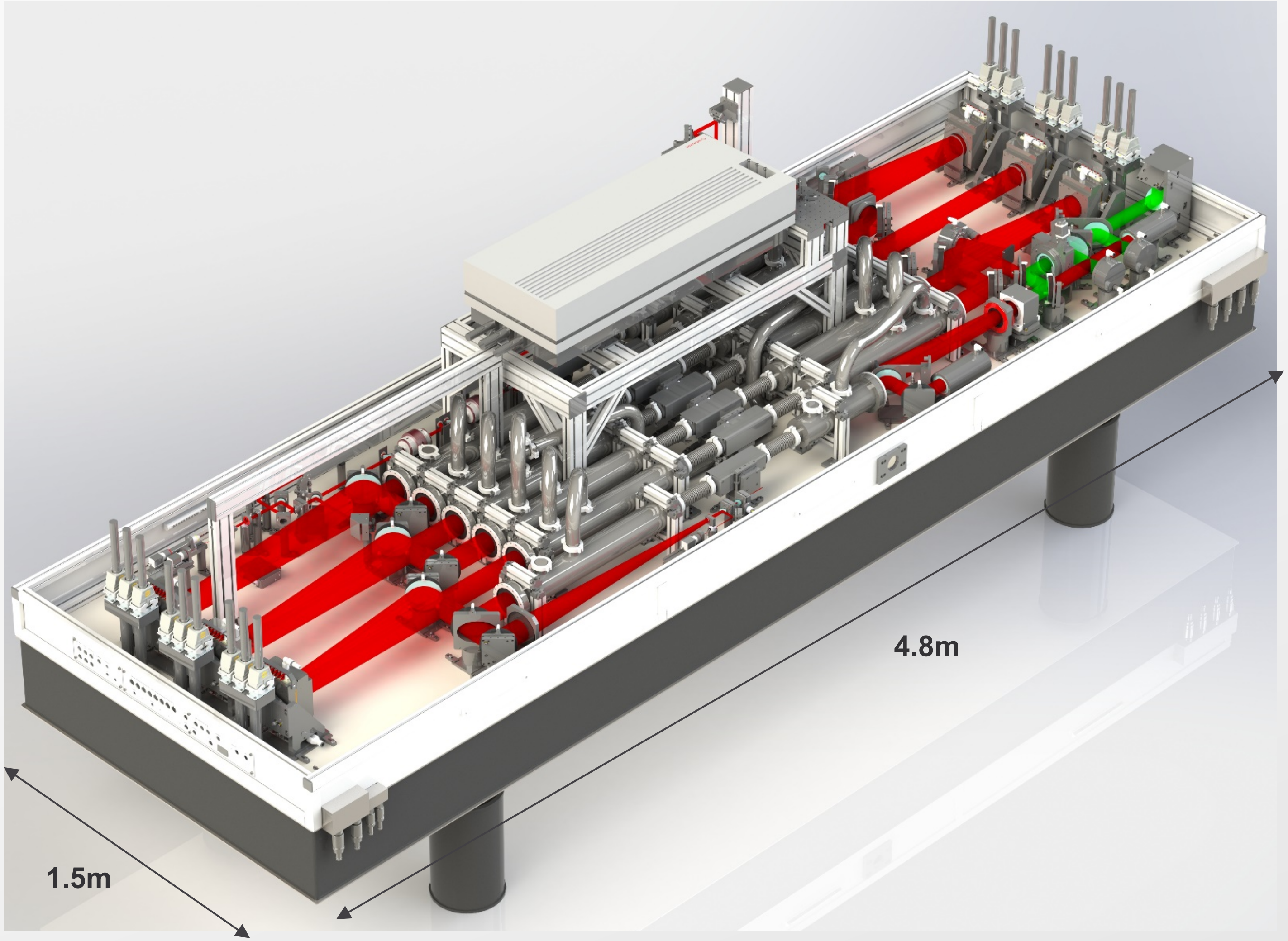
Flashlamps cassette



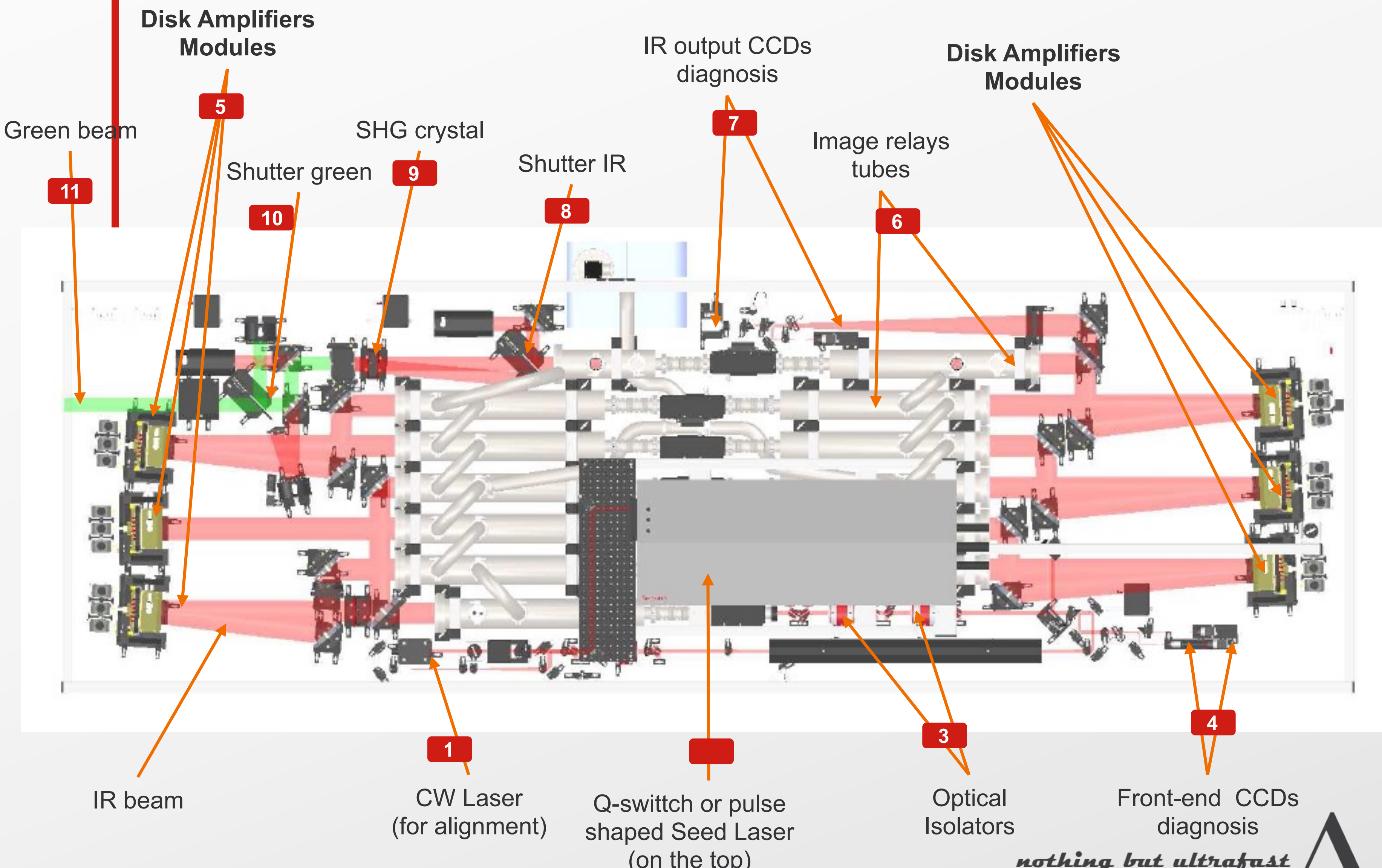
Nd:YAG disk

3- The concept of the P60 Laser

3D Lay-out of P60: a compact footprint



2D Lay-out of P60



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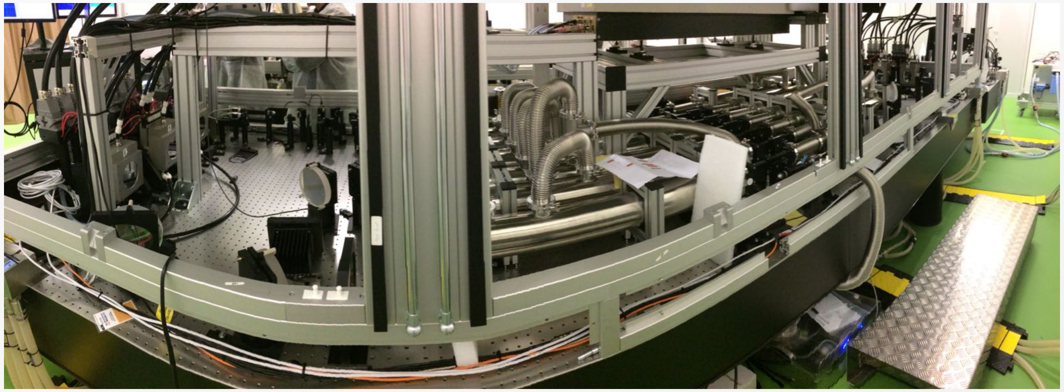
Pictures of P60



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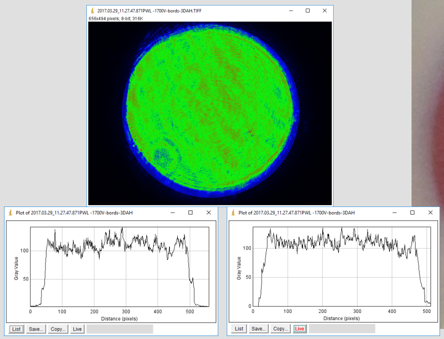
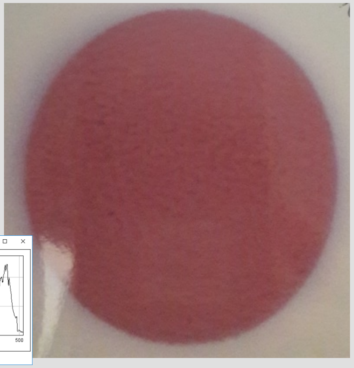
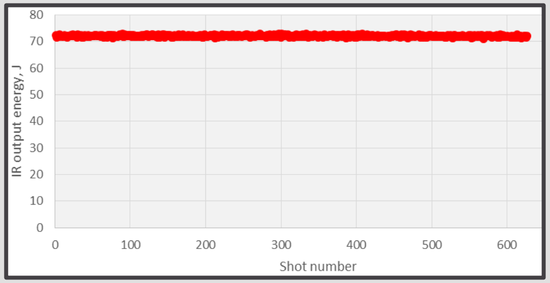
4- Demonstrated performances of the P60 up to 5Hz

Demonstrated performances up to 5 Hz

Beam profile at 81J at 1064nm @ 5Hz: beam diameter is 76mm

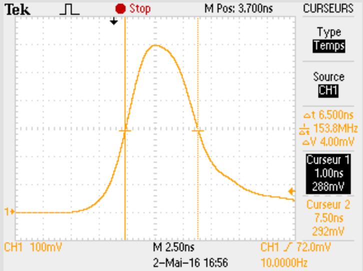


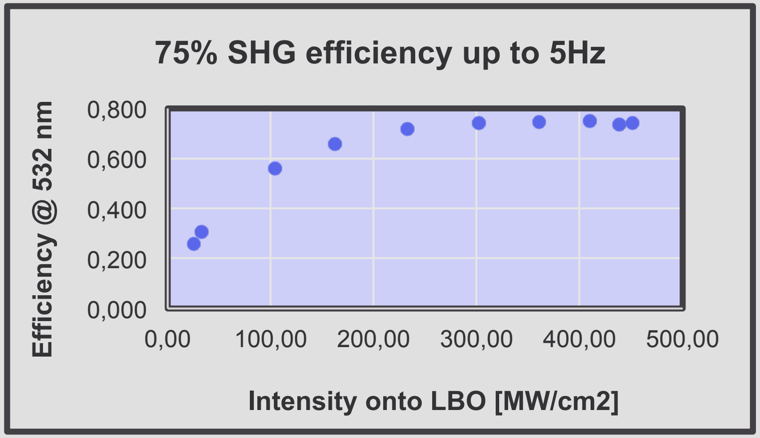


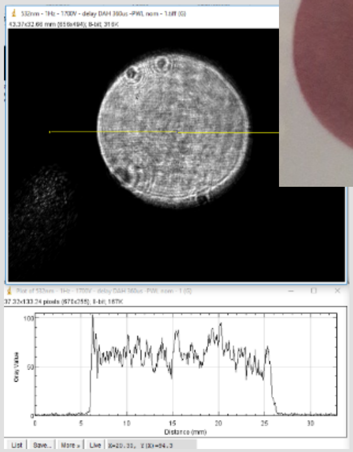


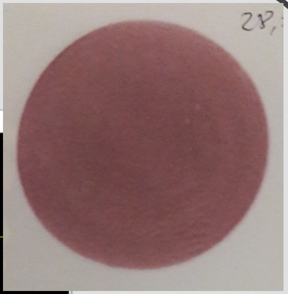
Stability at 1064nm @ 72J over 600 shots: 0.41% RMS shot-to-shot stability

Pulse duration: 6ns FWHM









Beam profile at 56J @ 532nm @ 5Hz: beam diameter is 52mm

5- But @ 10Hz, drop of some performances to overcome

Demonstrated performances @ 10 Hz

- *660W average power demonstrated @ 10Hz @ 1064nm, but:*
  - *>750W expected*
- *« Only » 40J @ 532nm ➡ 55% conversion efficiency instead of 75%*

- *Root causes of these performances drop have been identified*
- *Solutions are under implementation*

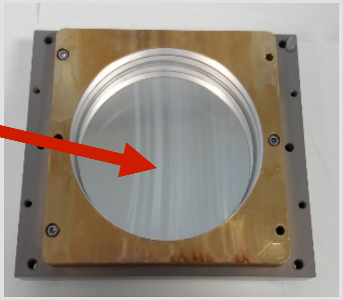
Transmission drop of the amplifiers

Forth and back Transmission in DAM	Initial	After 100's Hours
	94% (average)	86%

1- Corrosion pollution as the cause of transmission losses:

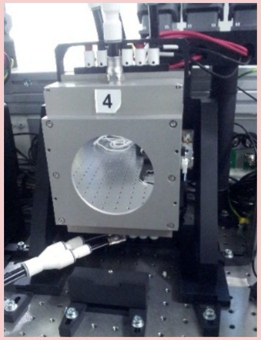
Corrosion occurs on long term. White powder deposit detected: alumina oxide.

Alumina oxide pollution onto optics of the DAM results in aborption @ 1064nm and transmission loss.



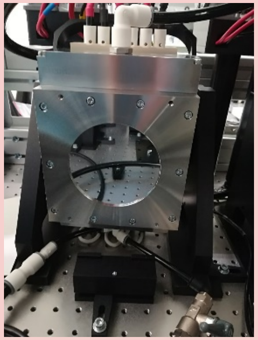
Solution implemented:

Initial PAMDAM: mix of coated metallic materials. Despite the coatings, corrosion cannot be avoided on long term.



☹ → ☺

Stainless steel version of PAMDAM:
No more aluminium used in order to suppress alumina oxide.



Gain drop of the amplifiers

Gain in DAM	@ 1-5Hz	@ 10Hz
	0.68 (average)	0.59 (average)

1- Cathode electrode of lamps as a cause of gain drop:

Slow degradation of the flashlamps cathode electrode

Increase of the discharge circuitry resistivity resulting in a drop by 10's of Amps of the current flowing through the flashlamps: ~1% gain drop

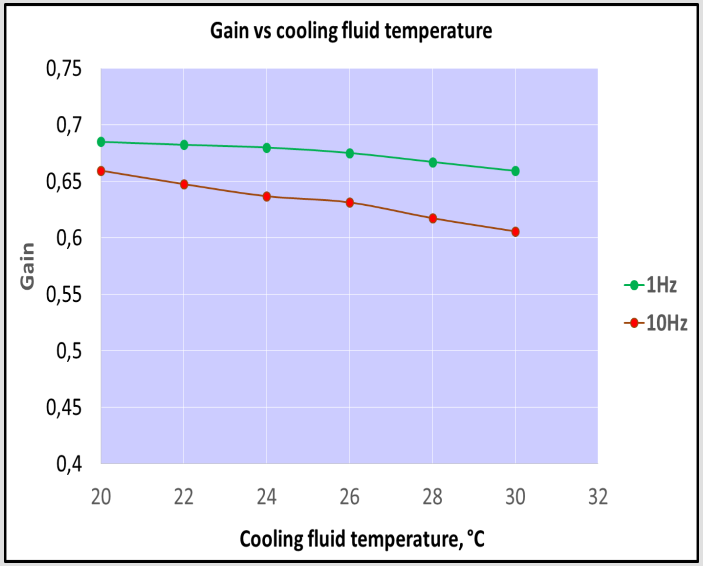
Solution implemented:

- Modification of the material of our connector at the HV cable end.
- Modification of the shape of our connector at the HV cable end:
  - Contact pressure has been increased
  - Contact area has also been increased to improve the conductance

As a results of these 2 actions the current has been increased by 1.7% resulting in a better gain

Gain drop of the amplifiers

2- Shift of the properties of a specific optic as a cause of gain drop:



- At 1Hz the gain is quite insensitive to the cooling fluid temperature under 26°C. Above this temperature, the gain slightly drops due to thermal population of the lower state of the Laser transition and slight mismatch between the seeder wavelength and the Nd:YAG disks of the PAMDAM.
- At 10Hz the temperature rise of a specific optical component results in 10% gain drop as the cooling fluid temperature is increased from 20 to 30°C.

Solution implemented:

- The cooling fluid temperature must be shifted from 25°C @ 1Hz down to 18-20°C @ 10Hz.
- In order to keep the heat extraction capacity, the tap water of the primary circuitry must be downset from 18°C to less than 10°C.

Drop of the SHG efficiency @ 10Hz

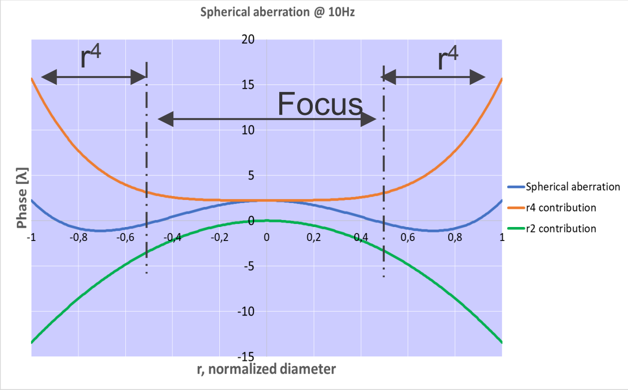
SHG Efficiency	Up to 5Hz	@ 10Hz
	75%	63%

1- Increase of spherical aberration as a cause of SHG efficiency drop:

- @ 10Hz spherical aberration increases a lot. Total contribution reaches ~3.3λ PtV.

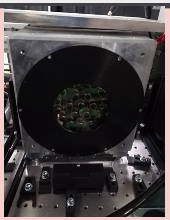
Sph. Aberr. comes from heat load @ 10Hz in the outer Sm-doped YAG ring dedicated to anti-transverse Lasing. The high filling factor (95%) of the beam in the Nd-doped part of the disks makes the beam very sensitive to this aberration.

- Spherical aberration is the sum of: ‘focus’ + ‘r^4 polynom’
- The 50% central part of the beam diameter can be efficiently converted to 532nm (68.7%) if the ‘focus’ contribution is compensated by the telescope before the LBO.
- The outer part of the beam contributes to 15λ e.g ~1.5 mrad angle mismatch (half angle) before the LBO.



Solution under implementation:

- Deformable mirror
- Or/and MRF compensation plates



Drop of the SHG efficiency @ 10Hz

2- Increase of depolarization as a cause of SHG efficiency drop:

- Depolarization: 10% @ 10Hz vs 2% @ 5Hz
  - Despite the quartz rotators implemented in the system, depolarization increases at 10Hz.
- Depolarization reduces the Second Harmonic Generation efficiency.

Solution to be implemented in a near future:

- we suspect the r^4 contribution of the spherical aberration to be responsible for a bad collimation of the edge of the beam in the quartz rotator. This could result in depolarization induced by the quartz rotators themselves.

Indeed, because of bad collimation, the edge of the beam would not propagate parallel to the quartz optical axis: the quartz acts as a birefringent material for the edge of the beam

⇒ **Spherical aberration should be compensated before passing through quartz rotator (to get good low depolarization) and before LBO (to maintain angle mismatch well below the LBO angle acceptance)**

Synthesis on SHG efficiency

		Up to 5Hz	10Hz	
	SHG eff. over >95% CA	75%	63%	**No Spherical Aberration compensation and with 8% depolarization in IR**
	SHG eff. with polarization filtering before LBO over >95% CA	75%	68%	**No Spherical Aberration compensation but suppression of depolarization before LBO**
	SHG eff. over 50% CA		68.6%	**Reduced Spherical Aberration and with 8% depolarization in IR**
	SHG eff. over 50% CA with polarization filtering before LBO		74%	**Reduced Spherical Aberration & after suppression of depolarization before LBO**
	SHG eff. over >95% CA		75%	**After compensation of Spherical Aberration before LBO and with 8% depolarization in IR**
Obtained	**SHG eff. over >95% CA**		**85%**	**After compensation of Spherical Aberration and filtering of depolarization**

Next step: full performance @ 10 Hz

- *SHG efficiency issues have been identified and solved*
- *Improvement on the overall design of the laser*

↓

- *New stainless steel heads have been implemented and we are ramping up the energy at 10Hz*
- *Final performances should be reached in the summer*

From P60 to a new product line: the Premiumlite-YAG serie

Amplitude TECHNOLOGIES

Premiumlite-YAG datasheet

Specifications

	Premiumlite 30		Premiumlite 40		Premiumlite 50		Premiumlite 60	
Performances	1064 nm	532 nm	1064 nm	532 nm	1064 nm	532 nm	1064 nm	532 nm
Beam profile	Round, Supergaussian order ≥ 20							
Beam diameter (mm)	44 ± 2.5				55 ± 2.5			
Disk Amplifier Modules (DAM)	3		4		5		6	
Divergence (μrad)	≤ 500							
Energy (J)	38	28	50	38	65	48	78	55
Energy drift over 8 h	≤ 3 % after warm-up time							
Pulse to pulse energy stability, % RMS	≤ 1	≤ 1.5	≤ 1	≤ 1.5	≤ 1	≤ 1.5	≤ 1	≤ 1.5
Pulse duration FWHM (ns)	4 - 7							
Jitter RMS (ns)	≤ 1							
Polarisation	Linear or circular							
Beam pointing stability (μrad)	≤ 50 (at fixed rep-rate)							
Repetition rate (Hz)	Up to 10							

System dimensions

Optical table LxW	4.8 x 1.5 m / 15.8 x 4.9 ft
Table Thickness	30.5 cm / 1 ft
Table weight	2500 kg / 5512 lb
Cabinet for each DAM HxLxW	200 x 62 x 71 cm / 6.6 x 2.1 x 2.4 ft
Cabinet for front-end HxLxW	67 x 62 x 71 cm / 2.2 x 2.1 x 2.3 ft

Utilities

Frequency	Up to 10 Hz
Water Flow	2 x 10l/min + 20l/min per pair of DAM
Pressure	4 bars max
Temperature	15 - 18 °C
Electrical plugs	1 (Three phases + neutral + ground, 25 Amp) for each DAM, 1 (Single phase + ground + neutral, 32 A) and 2 (Single phase + ground, 16 A)

From our expertise acquired with P60, Amplitude has built a product line named **_Premiumlite-YAG_**: *''Delivering Laser light with Premium performances''.*

6- New perspectives

A versatile concept: from YAG to Glass, the Premiumlite-Glass serie

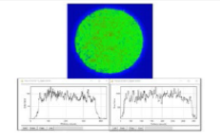
Replacing Nd:YAG by Nd:Glass and changing the power supplies allow higher energy Lasers.

Our 200J-class at 0.1 Hz set a new reference compare to 1 shot/minute previous standard.

Premiumlite-Glass datasheet

Specifications

	Premiumlite 75	Premiumlite 120	Premiumlite 150	Premiumlite 200
Beam profile	Round, Supergaussian order ≥ 20			
Beam diameter @ 1/e²	80 mm ± 3.0			
Disk Amplifier Modules (DAM)	3	4	5	6
Divergence	≤ 500 µrad			
Energy per pulse at 1053 nm	> 100 J	> 150 J	> 200 J	> 260 J
Energy per pulse at 527 nm	> 75 J	> 120 J	> 150 J	> 200 J
Long term mean energy stability	≤ 5 % P-V over 8H (after warm-up time)			
Pulse to pulse energy stability	≤ 1.5 % RMS at 1053 nm and ≤ 2.0 % RMS at 527 nm			
Pulsewidth FWHM	20 ns ± 5			
Jitter RMS	≤ 1 ns RMS			
Polarization	Linear or circular			
Pointing stability	≤ 50 µrad (at fixed rep-rate)			
Repetition rate	Up to 0.1 Hz			



Horizontal and vertical beam profiles at 1053 nm

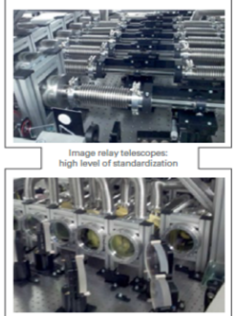


Image relay telescopes: high level of standardization

Specifications are subject to change without prior notice | © 03-2018 | CM18-0026-A

System dimensions

Optical table LxW	6.4 x 1.5 m / 21.0 x 4.9 ft
Table thickness	30.5 cm / 1 ft
Table weight	2 x 1700 kg / 2 x 3748 lb
Cabinet for each DAM HxLxW	200 x 62 x 71 cm / 6.6 x 2.1 x 2.4 ft
Cabinet for front-end HxLxW	200 x 62 x 71 cm / 6.6 x 2.1 x 2.4 ft

Utilities

Frequency	Up to 0.1 Hz
Water flow	2 x 10l/min + 10l/min per pair of DAM
Pressure	4 bars max
Temperature	15 - 20 °C
Electrical plugs	1 (single phase + neutral + ground, 20 Amp) for each DAM, 2 (single phases + neutral + ground, 20 Amp), 1 (single phase + neutral + ground, 30 Amp) for front-end

www.amplitude-laser.com

First Premiumlite-Glass Laser dedicated to Dynamic Pulse Compression has been sold to a European accelerator.

Future: from flashlamps to diode pumping, a 50J green YAG Laser at 50-100Hz operation

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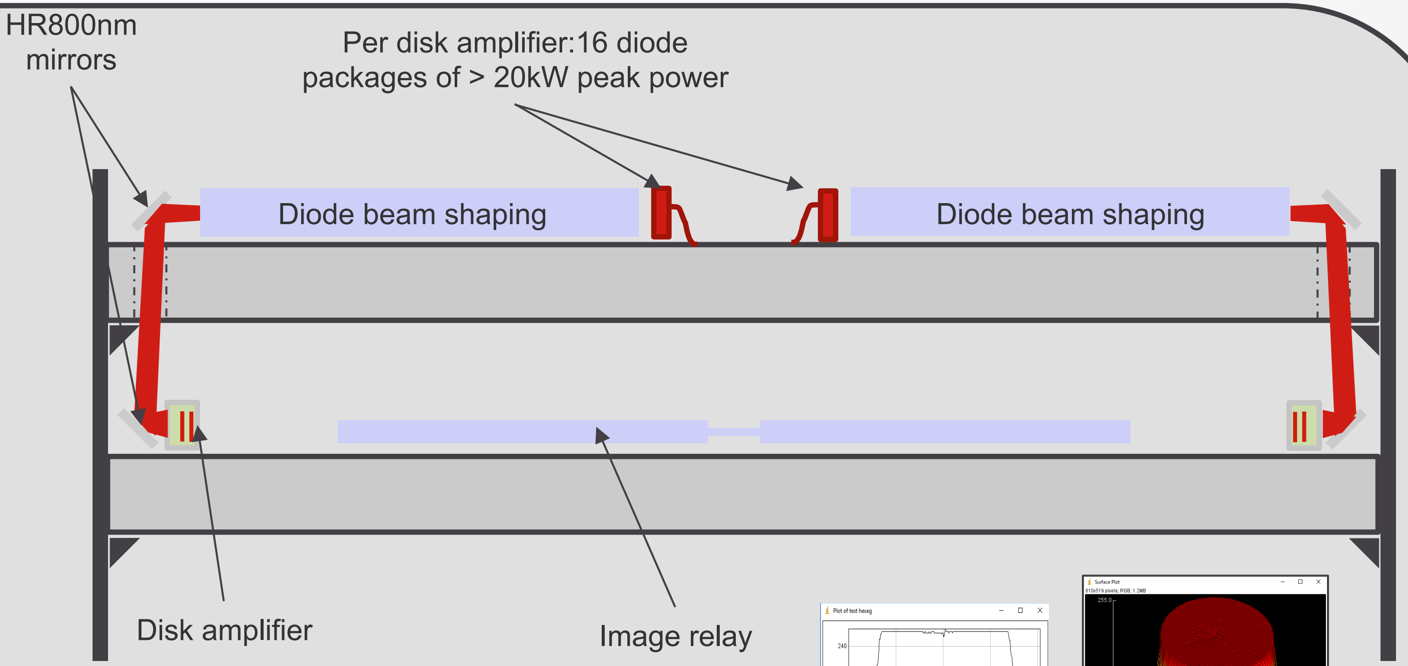

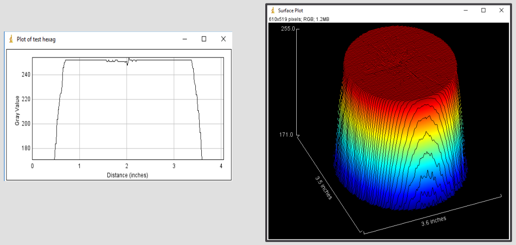

Simulation of diode pump distribution onto Nd:YAG disks

- ✓ Diodes are identified and concept is validated.
- ✓ Diode Power supplies designed.
- ✓ Diodes and associated beam shaping on upper level of the Laser. Principle of beam shaping is existing.
- ✓ **At 50-100Hz with diode pumping, similar heat management as with flashlamps at 10Hz.**

Amplitude TECHNOLOGIES

Thank you for your attention …