Latest developments of high repetition rate TiSa lasers for Laser Plasma Accelerators

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EURONNAC SPECIAL TOPICS WORKSHOP 2022
SESSION SST-3-B

LA BIODOLA, ISOLA D'ELBA (18-24 SEPTEMBER 2022)

THALES

CONTENT

THALES HAS BUILT ULTRA HIGH PEAK POWER LASERS UP TO 10 PETAWATTS

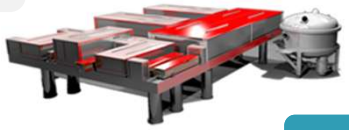
IPMA International Project Excellence Award GOLD WINNER 2013

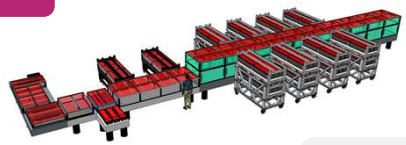
CALA (3PW)
90J / 1Hz

ELI NP
2x 100TW / 10Hz
2x 1PW / 1Hz
2x 10PW / 1sh/min

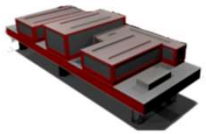
LBNL BELLA
1,3PW / 1Hz

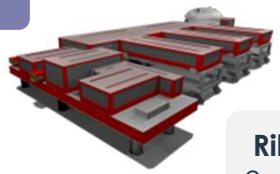
SCAPA
350TW / 5Hz



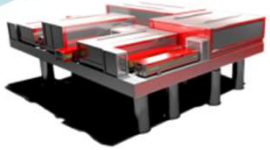


Peking Univ
2PW / 1Hz





Riken Harima
2x 500TW / 1Hz



USC
45TW / 10Hz

DESY 200TW/5Hz
Peking Univ 200TW/5Hz
Weizmann 2x100TW/1Hz

3 PW
10 PW
1 PW
2 PW
350 TW
500 TW
45 TW
200 TW

CIVIL
DEFENCE & SECURITY

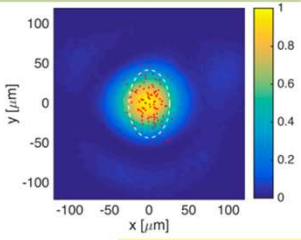
THALES

ELANCOURT

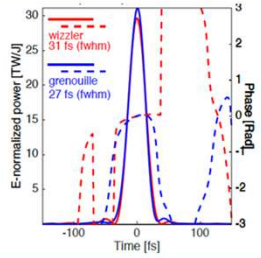
HIGHEST ELECTRON ENERGY FROM LASER PLASMA ACCELERATOR WITH BELLA PETAWATT

Final amplifier: Stable 62J, >10 hours operation

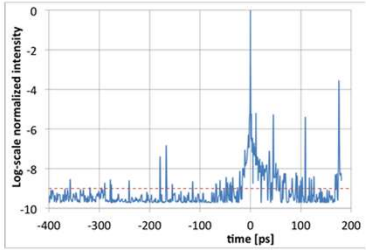
High quality spatial profile
Low pointing jitter



High quality temporal profile

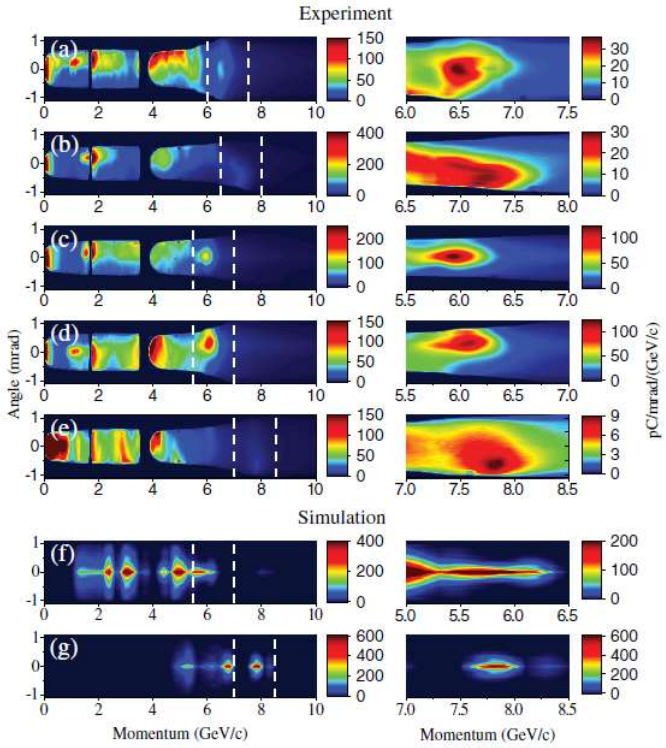


High temporal contrast



49 [J on target] x 25 [TW/J] = 1.2 PW

* K. Nakamura et al., IEEE QE **53** (2017).



LPA: Electron energy > 8 GeV

(A. Gonsalves, Phys. Rev. Lett. **122**, 084801, 2019)

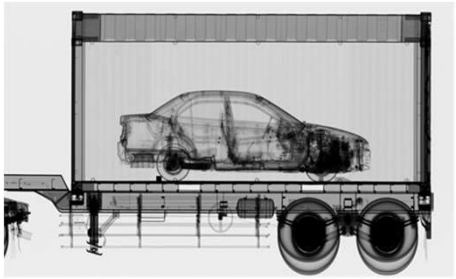
WHAT'S NEXT (1/2)

New large projects based on high average power lasers

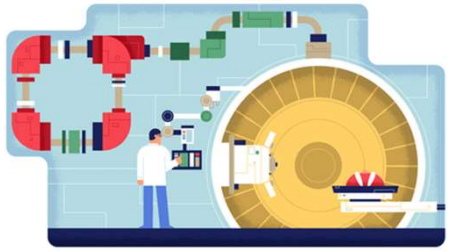
- EUPRAXIA: up to 100 J @ 20-100 Hz → Preparatory phase 2022-2026
- KALDERA @ DESY: 3 J – 30 fs @ 1 kHz (ongoing → *see Andi Maier talk, this session*)
- DoE roadmap for future colliders: 1st step is k-BELLA: 3 J – 30 fs @ 1 kHz

….But also LPA & light sources for industrial/medical/security applications

- X-Ray radiography for non destructive testing
- Security inspection
- Cancer therapy (Very High Energy Electrons [VHEE] / FLASH therapy)



THALES

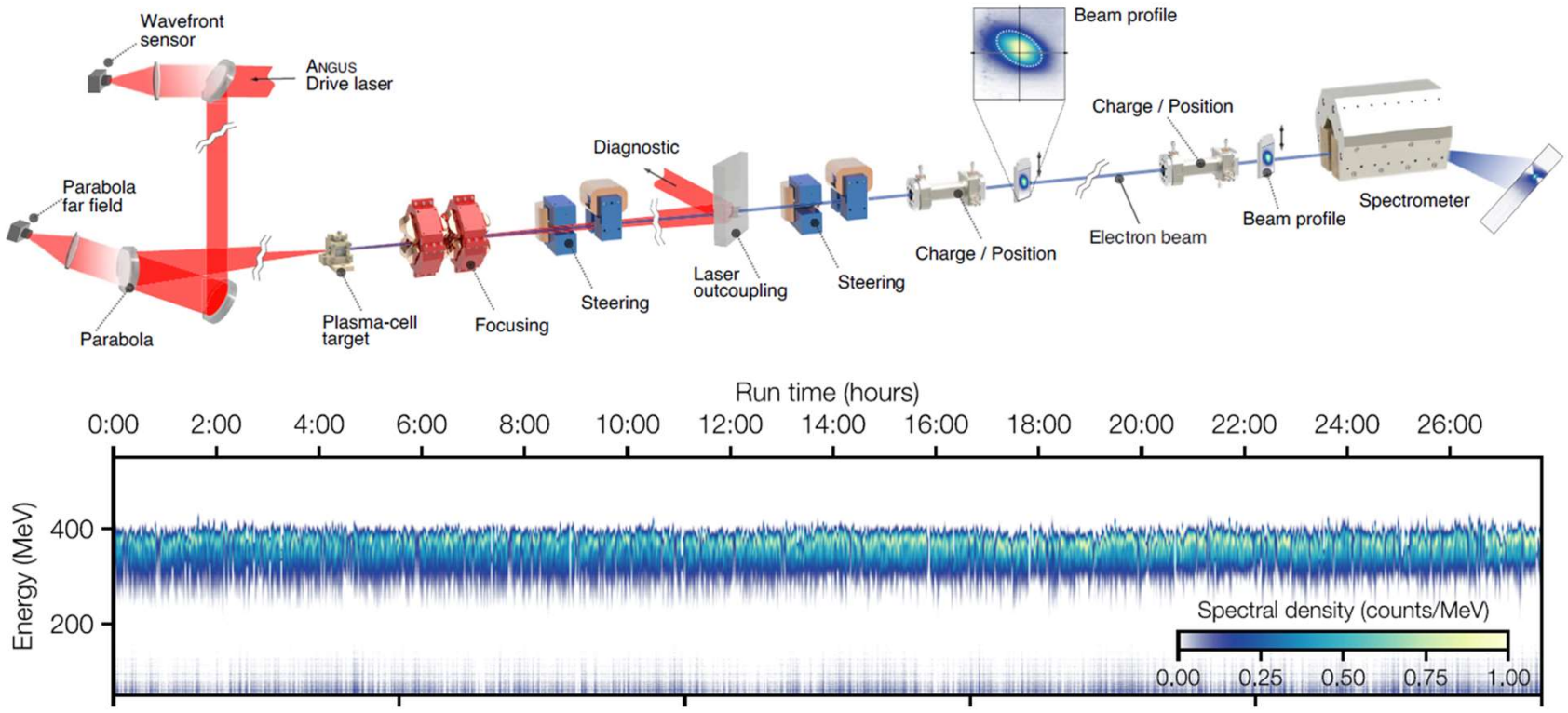


WHAT'S NEXT (2/2)

NEW PARADIGM: MOVE FROM « ACCELERATION WITH LASERS » TO « LASER ACCELERATORS »

- **Work on both lasers & acceleration stages**
- **For lasers, increase average power & reliability**
- **For acceleration stages, work on improving performance and stability**
  - Ongoing work by several groups successfully exploiting machine learning techniques (DESY, Imperial College, SLAC, …)

TOWARDS A NEW GENERATION OF LASER PLASMA ACCELERATORS



Physical Review X 10, 031039 (2020), Decoding Sources of Energy Variability in a Laser Plasma Accelerator, Maier & al

HERACLES3 JOINT LAB

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- **THALES LAS** : Bulk laser expert at Elancourt
- **THALES SA :** Thales Research Center at Palaiseau, fiber laser experts
- **THALES AVS :** Microwave and Imaging Sub-systems at Velizy – Experts in RF accelerators

ACADEMIC PARTNERS

- **Ecole Polytechnique**
- **ENSTA** → **LULI and LOA**
- **CNRS**

INSTITUT POLYTECHNIQUE DE PARIS

ENSTA

ÉCOLE POLYTECHNIQUE

cnrs

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← THALES →

RESEARCH ACTIVITIES AT HERACLES3

Very high peak power > 1PW with LULI (APOLLON)

- Improvement of ps contrast
- Intensity stabilization on target

100Hz laser-plasma accelerator with LOA

- Development of 1J, 100Hz, 25fs TiSa laser (intermediate step at 200 mJ)
- Full LPA platform with radioprotected experimental area operational from 2023
- Also light sources (X-R, Gamma) through Bremstrahlung, ICS

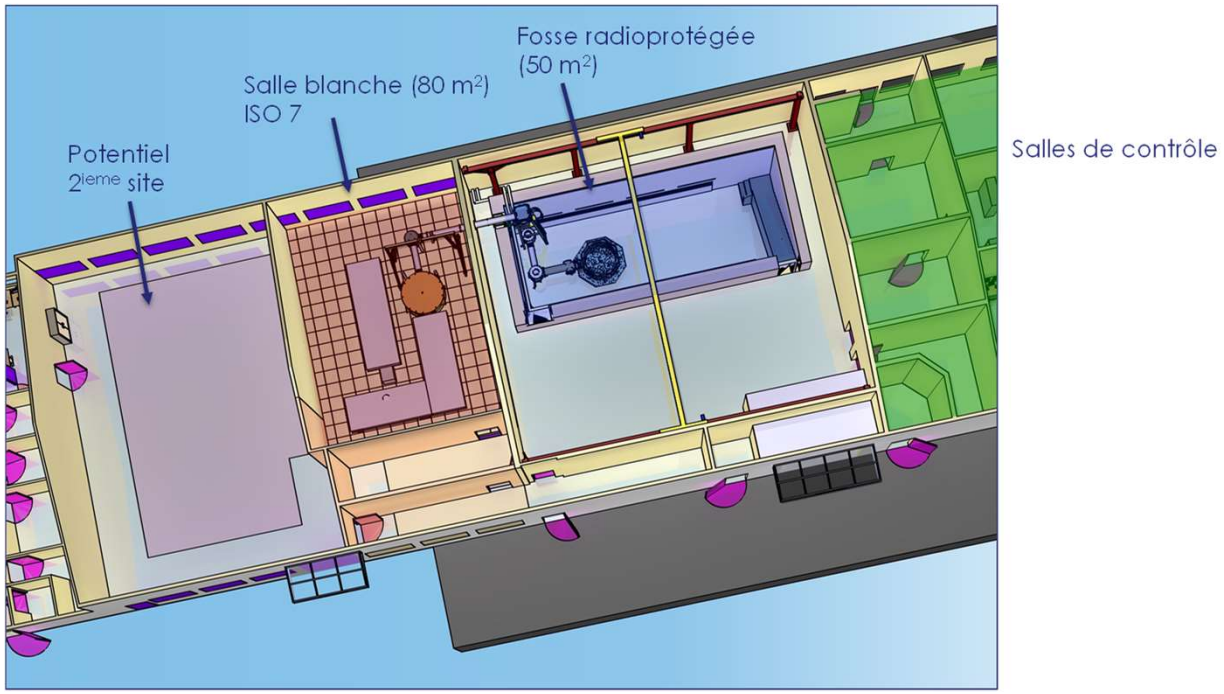
Very high average power system with LULI (XCAN)

- >500 W through coherent combination of fiber amplifiers @ MHz repetition rate
- Post compression of mJ class combined fiber laser down to < 40fs à 200 kHz repetition rate

LASER PLASMA ACCELERATOR AT LOA

LAPLACE PROJECT : LAPLACE-HC PLATFORM HOSTED AT LOA PALAISEAU

- Funding by French Government and Paris region (Ile de France) confirmed in July 2022
- Building/Laboratory preparation ongoing, completed during first semester 2023



GLOBAL VISION FOR HIGH PEAK POWER & HIGH AVERAGE POWER LASERS

Actual work in progress

- Pump laser development completed : THEIA (100-200Hz)
- TiSa disk amplifier development
- New OPCPA FE

TiSa is still identified as the right technology

- Reach 100W and beyond
- Skills and maturity to generate very short pulses with high energy

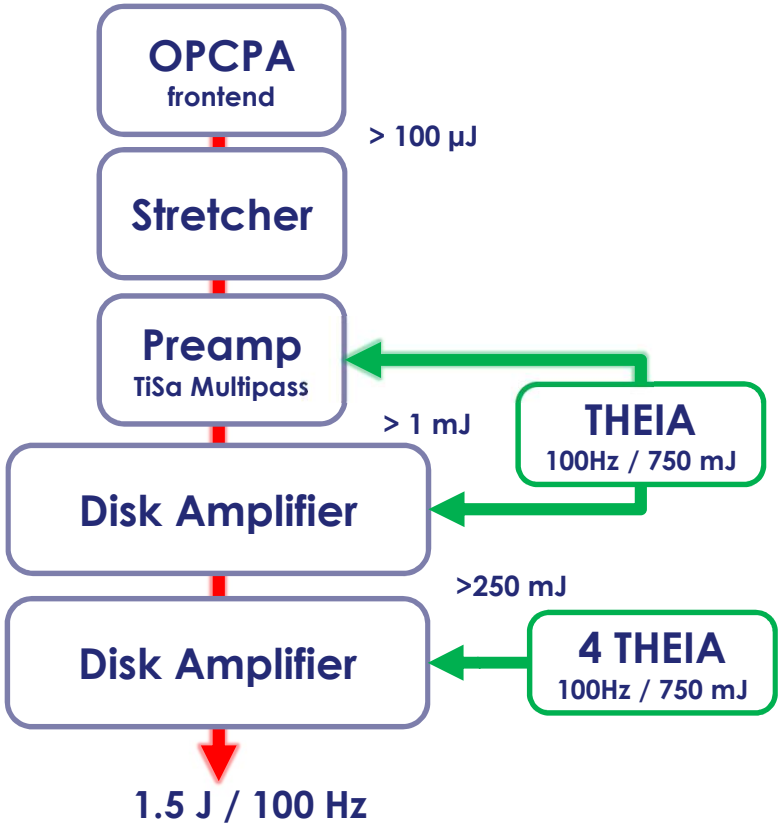
Our short term objectives 2021-2024

- R&T actions on technologic components (compression)
- Demonstration : 1J 100Hz sub 25fs

FROM HIGH PEAK POWER TO HIGH REPETITION RATE

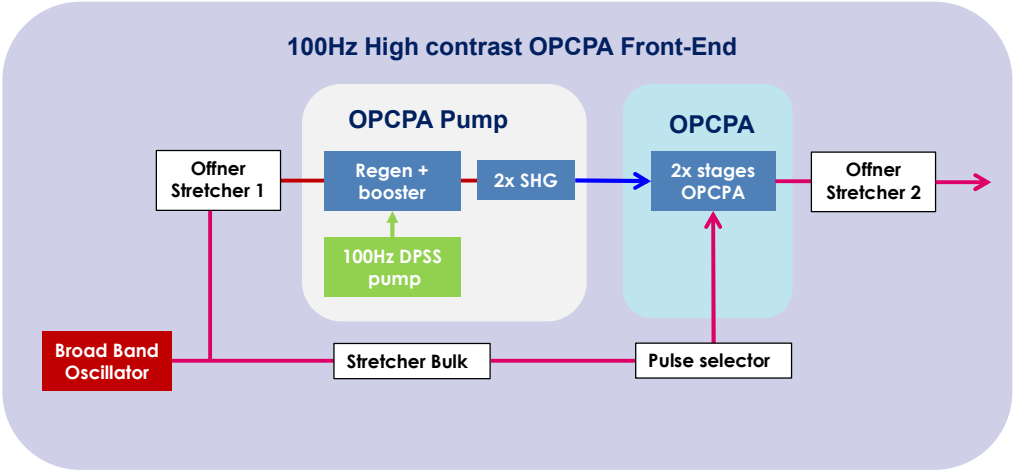
New TiSa laser architecture – In development

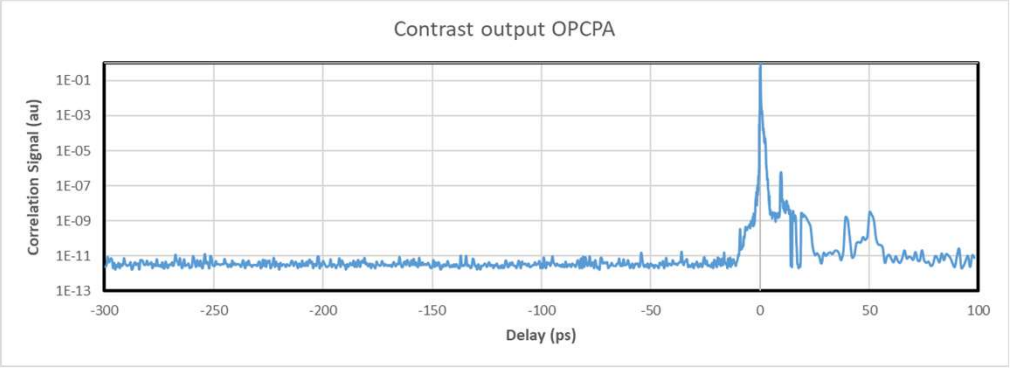
- **Robust OPCPA FE** : 100Hz / 300µJ demonstrated
- New ns diode-pumped laser : **THEIA family qualified**
- 2020-2021 / New TiSa amplifier architecture : **Qualification @ 300mJ 100Hz**
- 2022-2023 / Design and qualification of **1.5J amplifier 100Hz**



OPCPA FE

100Hz high contrast OPCPA
- Energy > 100 µJ
- Pulse duration ~ 20 ps
- Bandwidth from 730 to 870 nm (FT ~ 20 fs)
- Short term stability < 1 % rms over 500 shots





THEIA : A 200HZ MULTI-WAVELENGTH PLATFORM FOR MULTIPLE APPLICATIONS

Specifications

Version	IR	Green	UV
Wavelength (nm)	1064	532	355
Repetition rate (Hz)	Up to 200		
Energy per pulse (mJ)	1000	700	500
Pulse to pulse energy stability (% rms)	< 1.0		
Typical pulse width (ns)	10		

Compact Laser Head (160x30x20cm³) for mechanical stability, small footprint and easy integration of multiple lasers in systems

200 W / 1 Joule in the IR

140 W / 0.7 J in the green

100 W / 0.5 J in the UV

Laser Shot Peening

Adherence testing

Pumping of high repetition rate fs Ti-Sa lasers

Silicon Annealing FPD and semi-conductor

Lift-off for OLED

CIVIL DEFENCE & SECURITY

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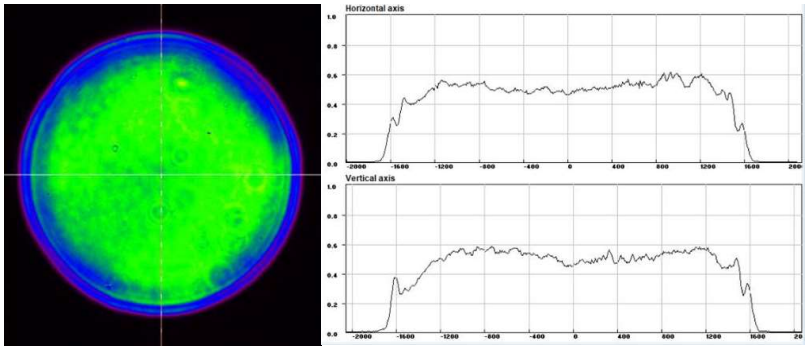
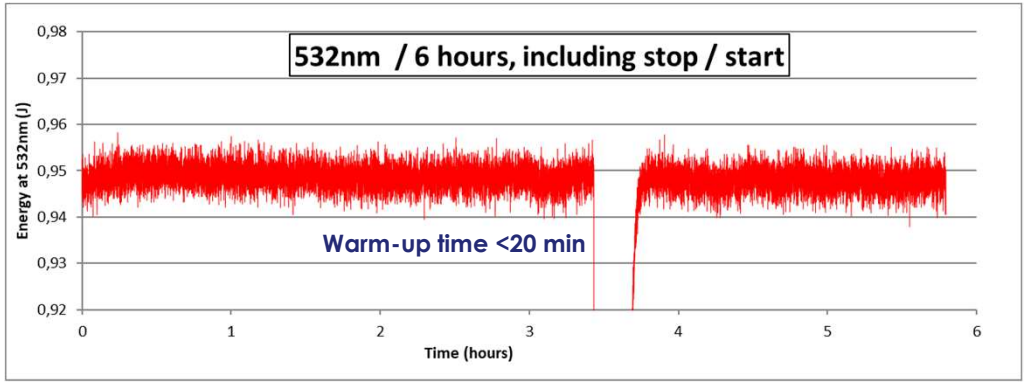
THEIA CHARACTERISATION AT 532 NM

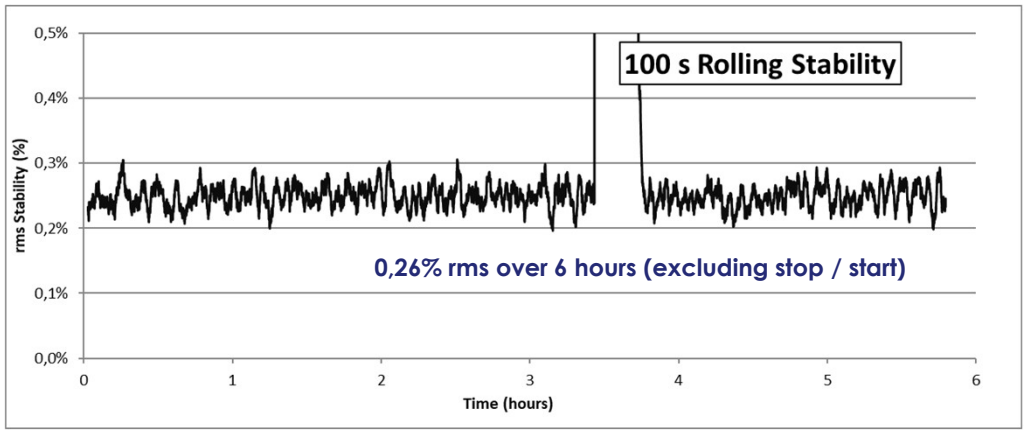


Near-field beam profile @532nm

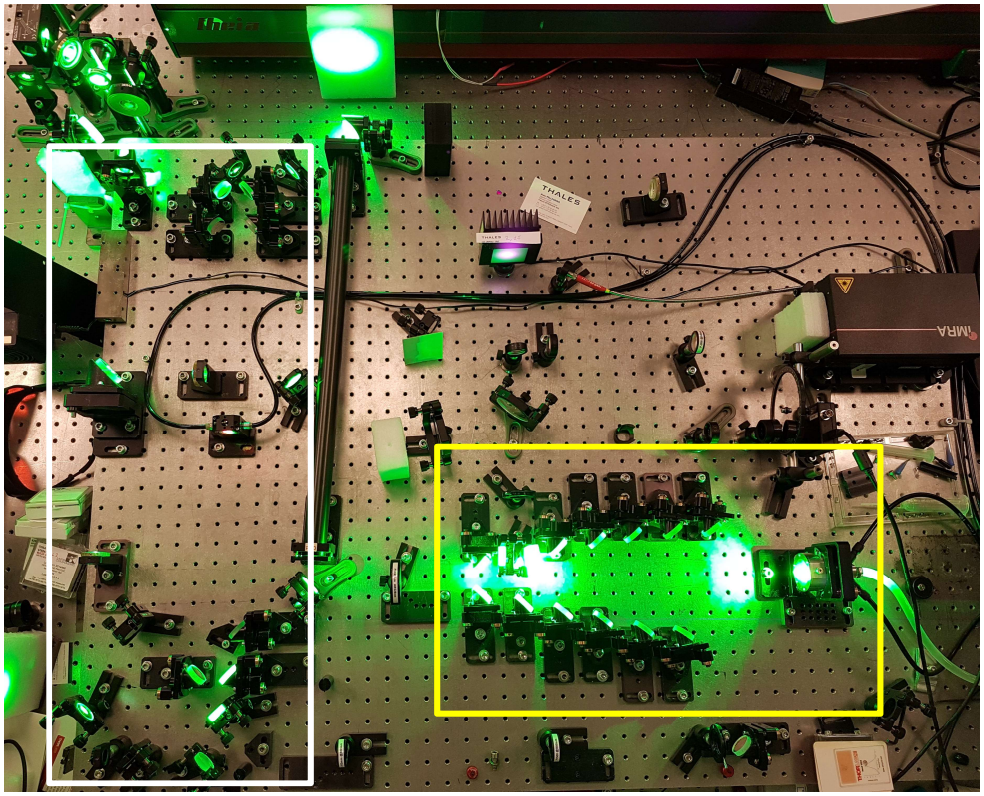
- Top-Hat near field beam profile
- More than 0,9 Joule @532nm
- < 0,3% short term stability
- 0,26% stability over 8 hours



THEIA Energy stability @532nm (no active control)



THICK DISK TISA PUMPED BY THEIA LASER



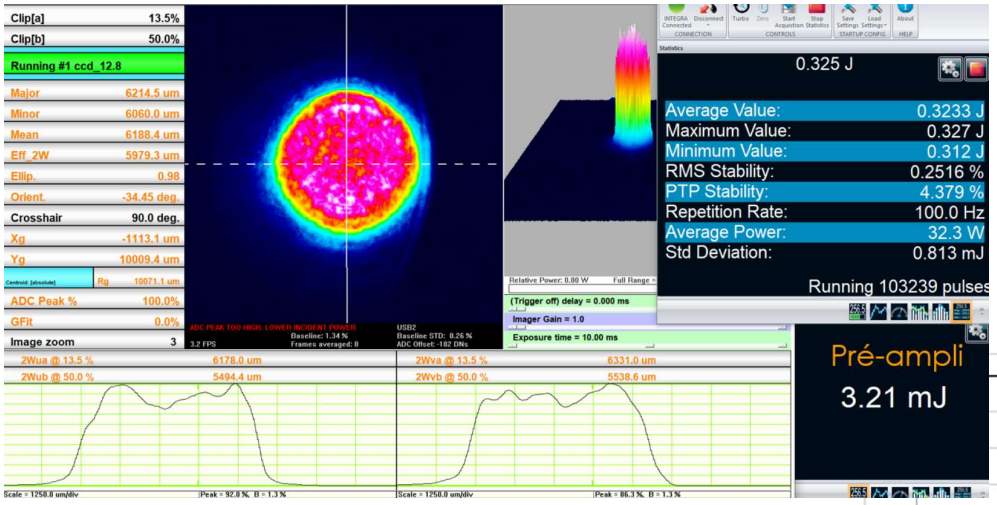
Multi-pass amplifier seed by XPW

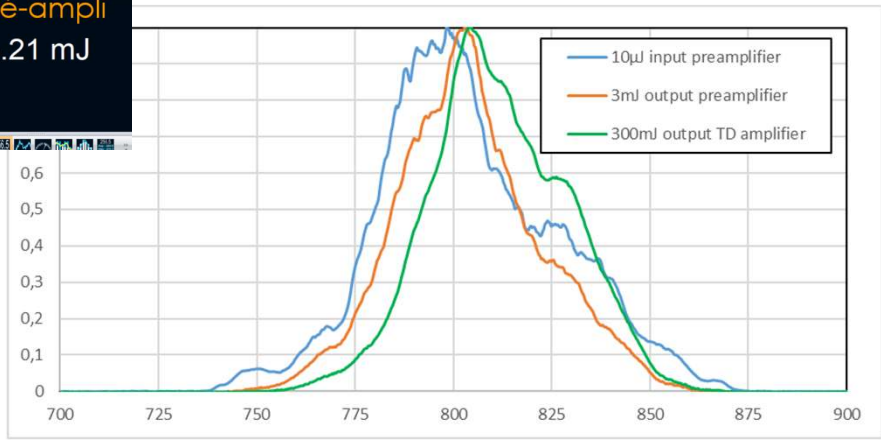
- Seed 10µJ
- Standard 4 passes preamplifier : output energy 3mJ
- Thick-disk TiSa amplifier : output energy > 300mJ, stability < 0.5%rms for an hour

New TiSa amplifier configuration

- Thick disk geometry (few mm thickness)
- Optimisation of thermal management for room temperature operation (no cryogenic device !)
- Measurements confirm moderate thermal lensing (focal lengths exceeding several meters)

THICK DISK TISA PUMPED BY THEIA LASER





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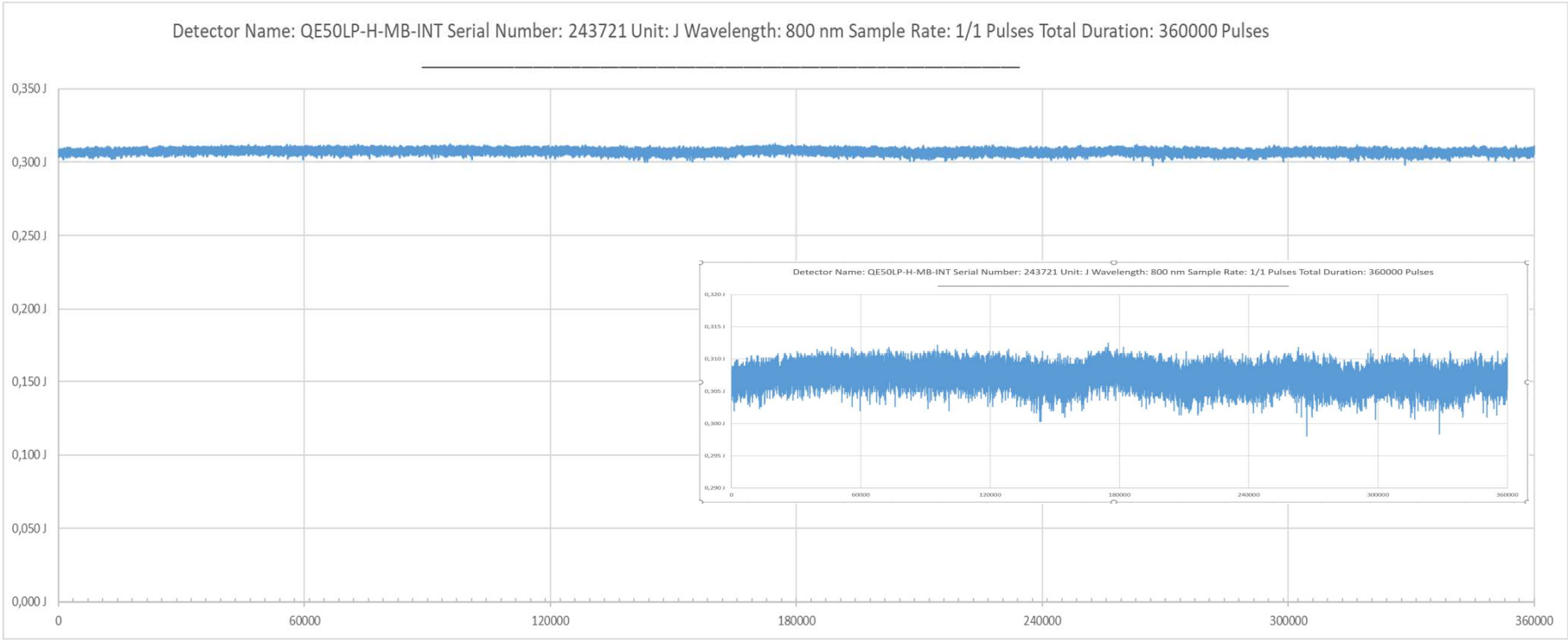
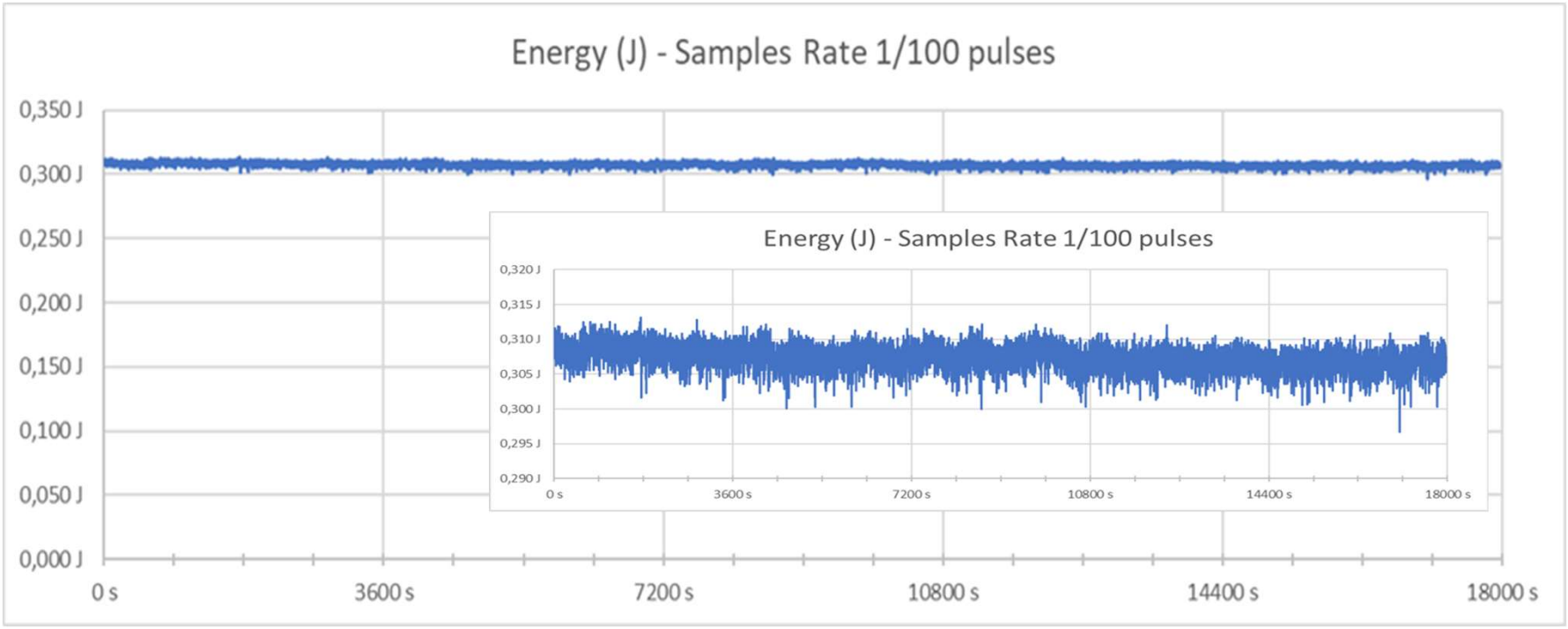
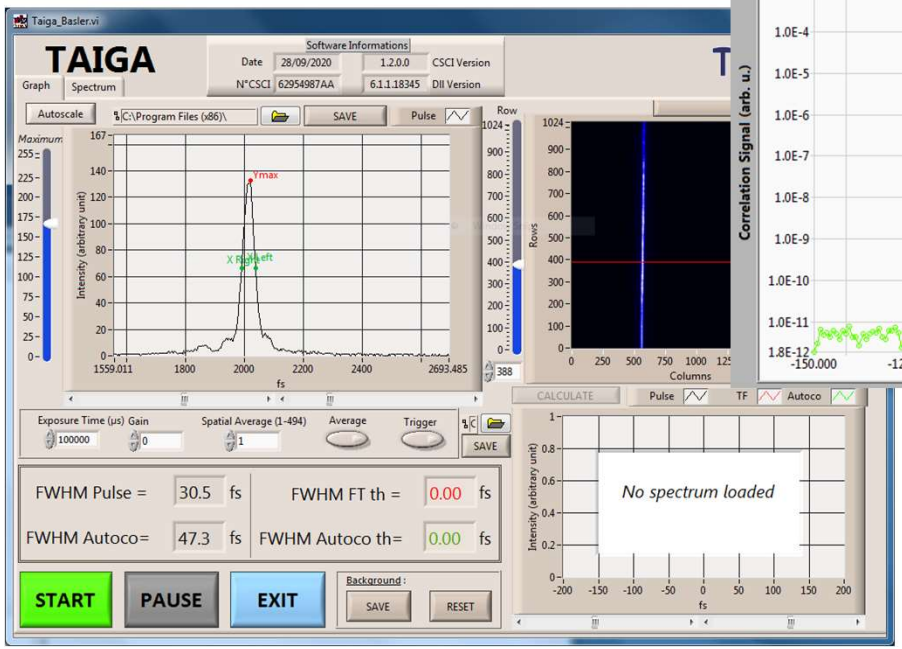
THICK DISK TISA PUMPED BY THEIA LASER : 1 HOUR OPERATION

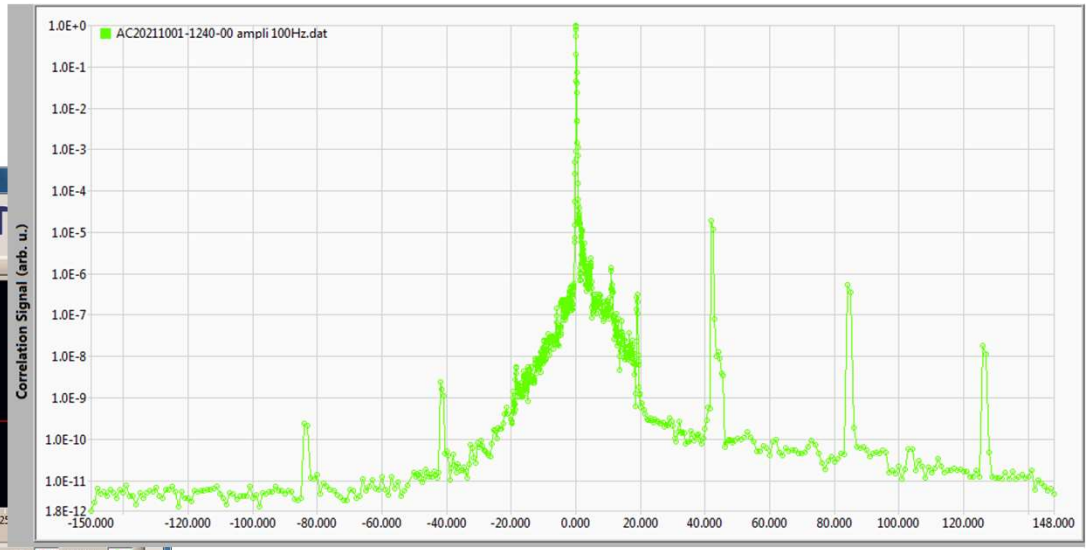


THICK DISK TISA PUMPED BY THEIA LASER : 5 HOURS OPERATION 1/100 PULSES



THICK DISK TISA PUMPED BY THEIA LASER





- No dazzler in the laser

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THALES - HORIBA COLLABORATION ON COMPRESSION GRATINGS

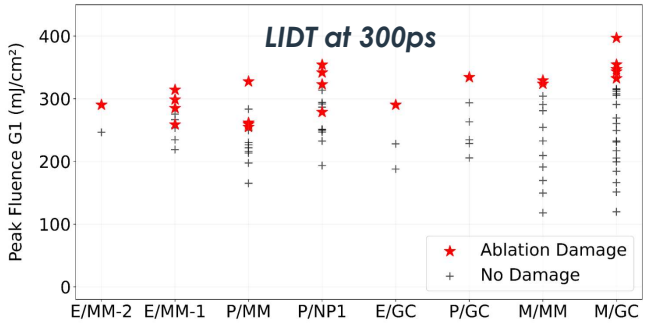
Work on ps and fs LIDT for gold gratings

- Different kind of samples

  - Tested samples are photoresist (P) or fused silica etched (E) gratings or mirrors (M). Evaporated coatings can be gold coating (GC), NP1 coatings, or mixture of metal coating (MM, different samples 1 or 2)

- LIDT tests at THALES under air :
  - 10 Hz Ti:Sapphire laser with a 800 nm central wavelength and 300 ps pulse duration and a 52° incidence angle
  - The beam surface is as large as 1.3cm².
  - Maximum fluence has been characterized at the test sample level.
  - N on 1 test with N=6000 has been selected to increase repeatability of the tests
- Fine characterization of damage at TRT and Horiba
- New design based on optimized gold coatings on photoresist grating proved to withstand up to 130 mJ/cm² average fluence for hundreds of kshots (Horiba France NP1 gratings) at 30fs
- LIDT characterization in picosecond regime :

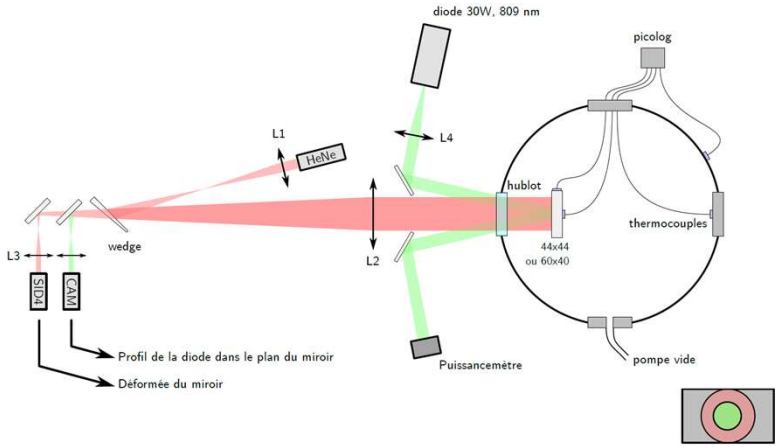
New results will be presented at ICUIL conference in Korea this week by Horiba with Thales co-authors



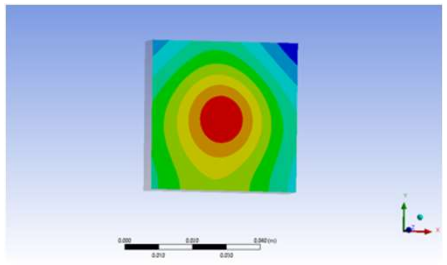
THERMAL MANAGEMENT IN HIGH-REPETITION SYSTEMS

Joule-class laser compression @100Hz requires attention:

- **Experimental characterization** under progress in Thales laboratories.
  - Measure thermal deformations in experimental conditions using a test-bench under vacuum.
  - Understand the impact on wavefront, and criticity for end-user applications.
  - Develop thermal management systems for high repetition rate lasers.



- Extrapolate our observations using **thermal system engineering and finite-elements simulations**



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CONCLUSIONS

- The new paradigm in laser plasma acceleration is to move from « acceleration with lasers » to « laser accelerators » to open the way to many applications (industry, medicine)
- To do this Thales in engaged in a long term scientific and technical collaborative effort with lead researchers in LPA field (HERACLES3)
- Purpose is to run from 2023 a full LPA platform, operating first with a 200 mJ – 100 Hz TiSa laser, then 1 J – 100 Hz
- As a first significant milestone, a room temperature 300 mJ – 100 Hz TiSa amplifier has been demonstrated


Thank You !