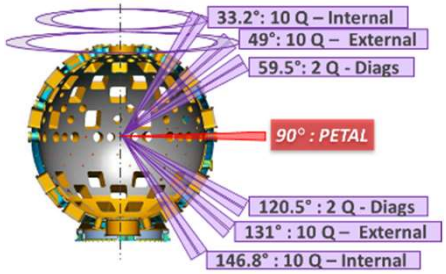
PETAL laser performance

N. BLANCHOT and PETAL team
CEA-CESTA

08/06/2023

PETAL: a PW beam coupled with LMJ



PETAL is a part of the opening policy of CEA

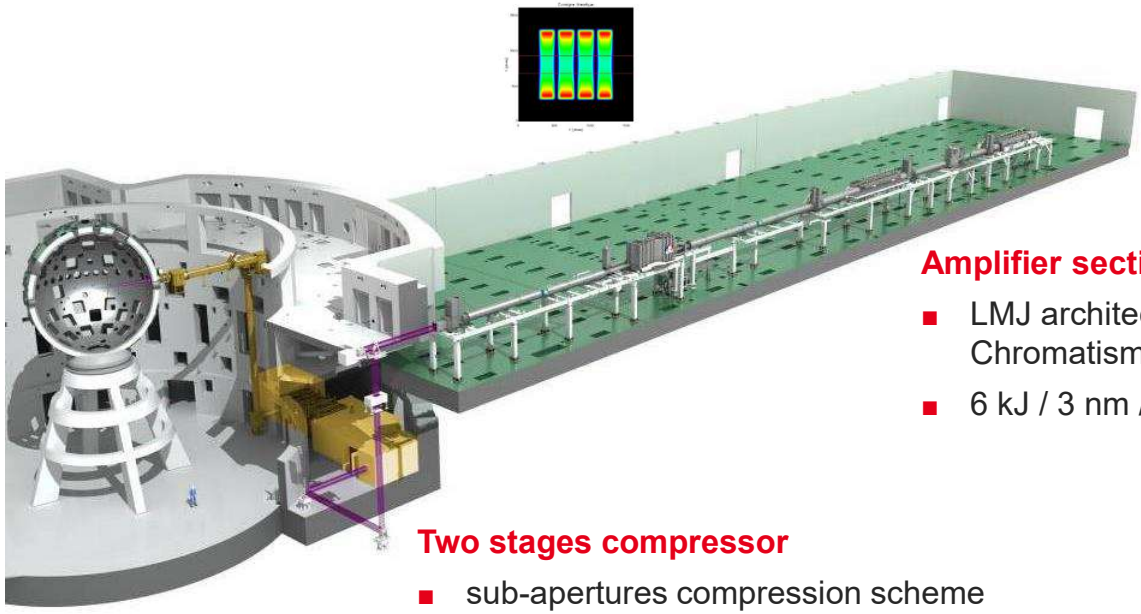
- It is dedicated to the scientific community

PETAL goals

- Energy: up to 3 kJ *
- Wavelength: 1053 nm
- Pulse duration: from 0.5 to 10 ps
- Intensity on target: ~ 10^{20} W/cm²
- Power contrast: 10^{-7} at -7 ps
- Energy contrast: 10^{-3}

Front end

- 40 mJ / 8 nm / 4.5 ns @ 1053 nm



Amplifier section

- LMJ architecture with a Chromatism Corrector
- 6 kJ / 3 nm / 1.7 ns

Focusing by off-axis parabola

- 7.8 m focal length, 90° deviation
- Focal spot ~ 50 µm

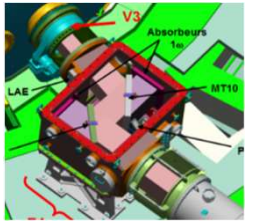
Two stages compressor

- sub-apertures compression scheme with beam phasing

* limited at the beginning to < 1 kJ due to the damage threshold of the transport mirrors

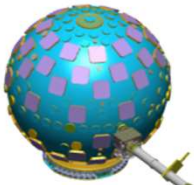
* **A. LE CAMUS** *al.*, Impact of compression grating phase modulations on beam over-intensities and downstream optics on PETAL facility,Optics Express **30**, 7425 (2022)

PETAL laser system



Off-axis Parabola

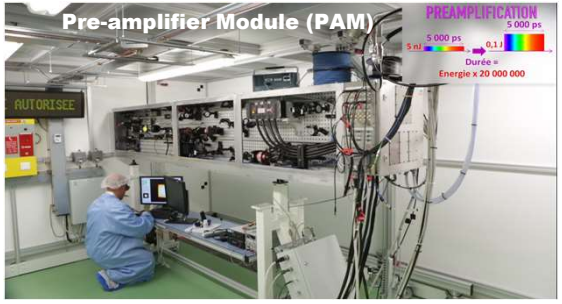
Pointing mirror



Focusing

Air Transport

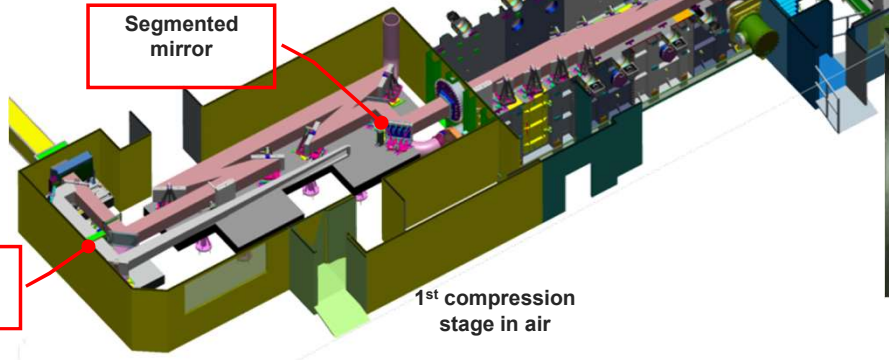
Vacuum Transport



2nd compression stage in vacuum

Diagnostics room

Segmented mirror

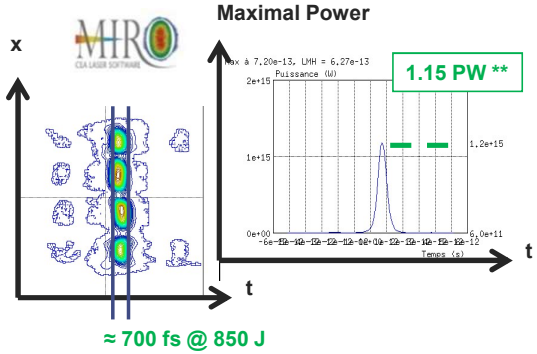


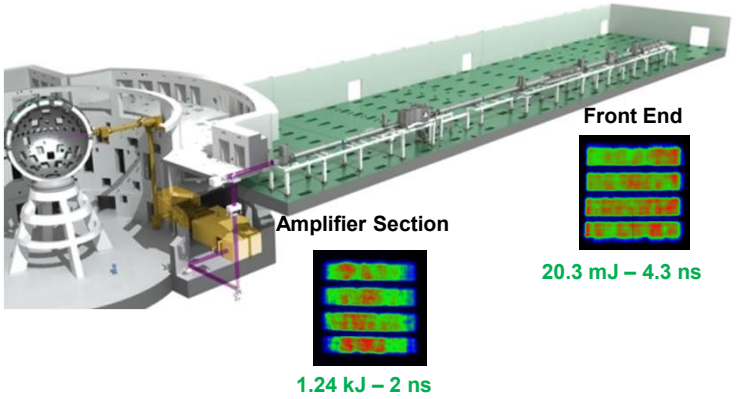
Toroidal mirror

1st compression stage in air

Current PETAL Performance

→ 2015: 1.15 PW @ 700 fs @ 850 J*
→ 2015: shots at 1 kJ @ 1 ps in the compressor





→ 2016: optimization of the pulse compression → 570 fs @ 219 J

→ 2017/2018: commissioning of the facility on target and 1st campaigns → 7.9 10^{18} W/cm² (409 J @ 660 fs)

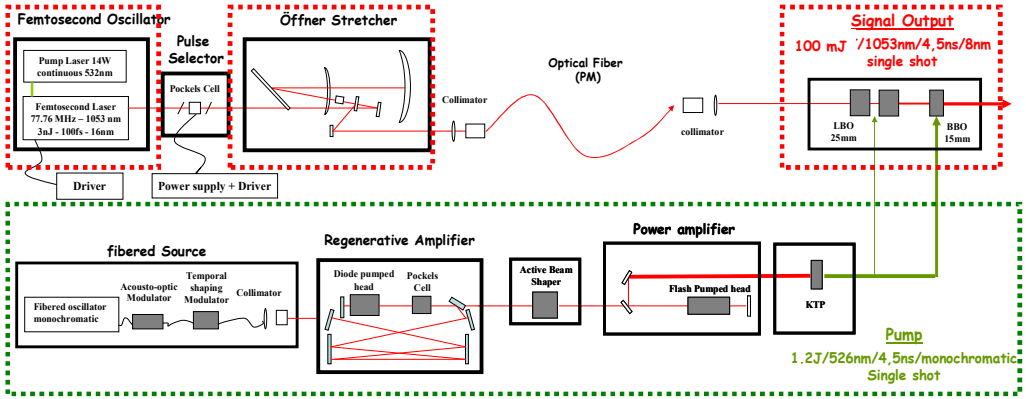
→ 2019 / 2023: 6 international campaigns (400 J)
- → Improvement of the focal spot: 0.9 10^{19} W/cm² (358 J @ 690 fs)
- → Shot on a 25 µm wire with an elliptic focal spot of 10^{18} W/cm²
- → Large focal spot
- → Different pulse durations (3 ps, 5 ps, 7 ps, 10 ps, 18 ps)

* **N. BLANCHOT** *et al.*, "1.15 PW–850 J compressed beam demonstration using the PETAL facility", *opt*. Express, **25**, 16957 (2017).
** **H. COIC** *et al.*, "Modeling of the petawatt PETAL laser chain using Miró code", *Applied Optics*, **56**, No. 34, 9491 (2017).

PETAL Front-End performance

Offner stretcher

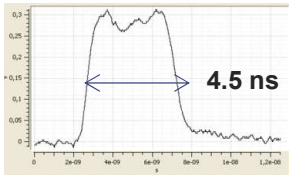
100 fs → 9ns @ 16 nm

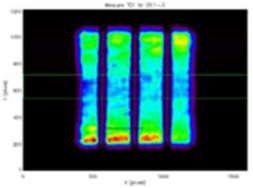


PAM

Output beam from PAM:

4.5 ns @ 8 nm - 40 mJ





Experiments required few ps pulses on the targets

Implementation of an optical fiber (OF) to increase the stretching factor

For **10 ps** : **84 m** OF

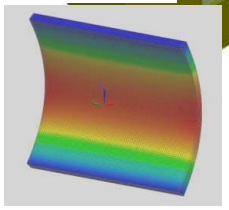
(Dispersion: **-40 ps/km/nm**)

→ **Pulse duration has to be defined in advance to purchase the OF**

→ **100' ps pulses required to adjust the PAM OPA stages**

Sub-aperture compression scheme

Segmented mirror
50 nm, 0.1 µrad



01 COMPRESSION
Annual optimization with 2nd stage of compression and the stretcher.

02 FOCAL SPOT AND BEAM PHASING
Daily alignment with the segmented mirror

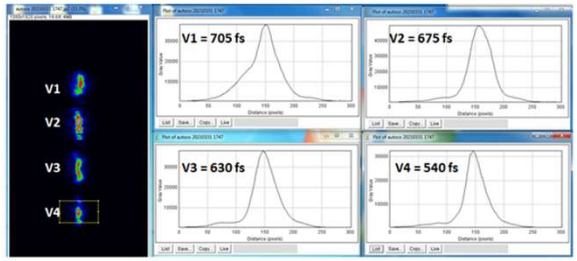
03 SPECIFIC FOCAL SPOT
Adjustment of the segmented mirror and the 2nd compression stage

Compression Performance

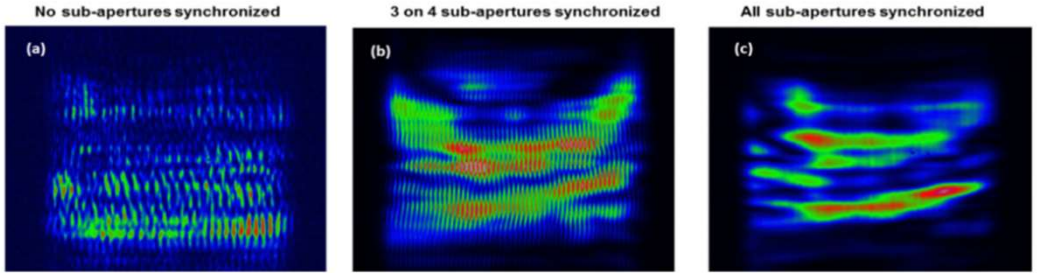
01 COMPRESSION

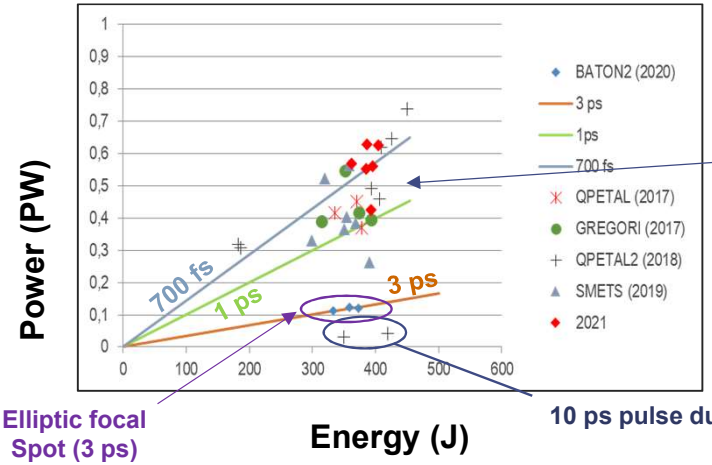
Annual optimization with 2nd stage of compression and the stretcher : compression and sub-apertures synchronization

Autocorrelator = duration



2D - Spectral Interferometer = delay





→ **Duration between 650 fs and 1 ps**

Compression duration instabilities due to front-end:

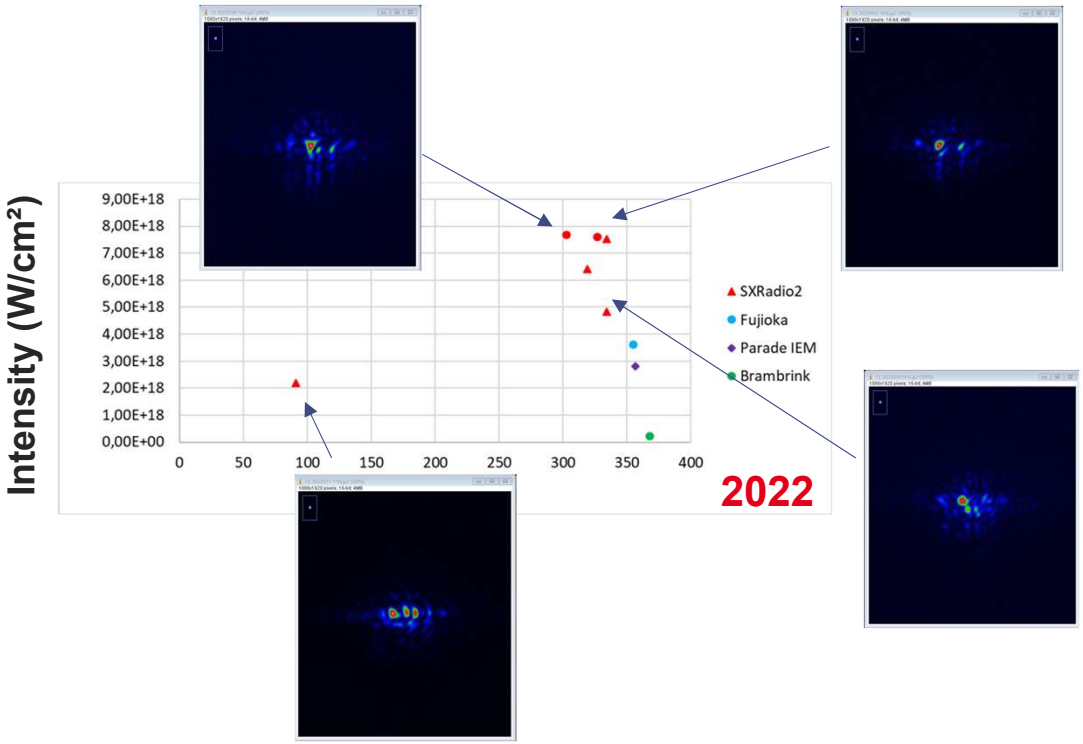
- **spectral amplitude modulation (OPA pump modulation)**
  → new pump oscillator (summer 2022)
- **front-end room air conditioning fluctuation**

→ **New short range contrast measurements (April 2023) : analysis in progress**

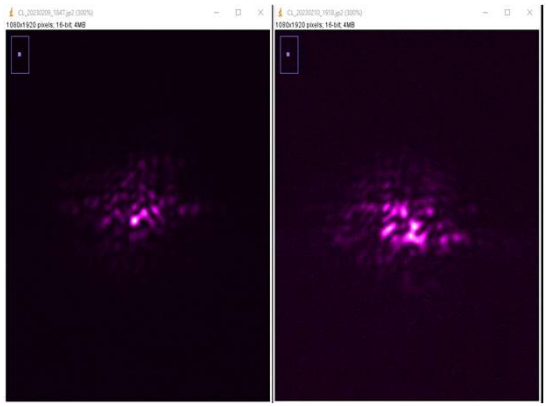
Focal spot performance

02 FOCAL SPOT AND BEAM PHASING

Daily alignment with the segmented mirror



Amplifier atmosphere (high hygrometry level) : few hours to be stable



9th February 2023 **10th February 2023**

instability related to a poor temperature set point in a bay room, the beam being however tubed !

Specific Focal Spot (1/2)

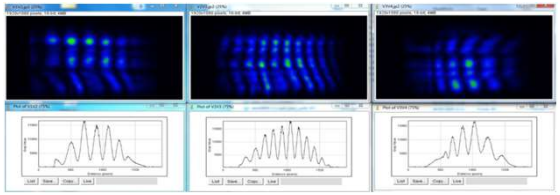
03 **SPECIFIC FOCAL SPOT**

Adjustment of the segmented mirror and the 2nd compression stage

→ **100 x 25 µm² focal Spot for shot on vertical wire**

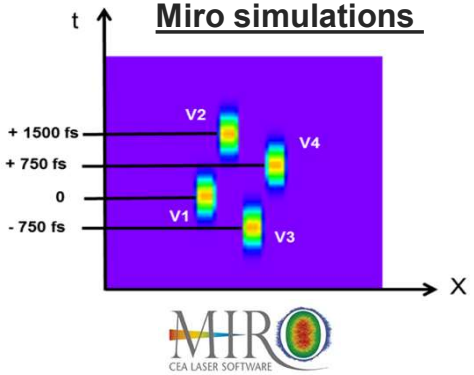
Adjustments of the 4 independent compressors to obtain a focal spot of ~ 100 x 25 µm² on the wire :

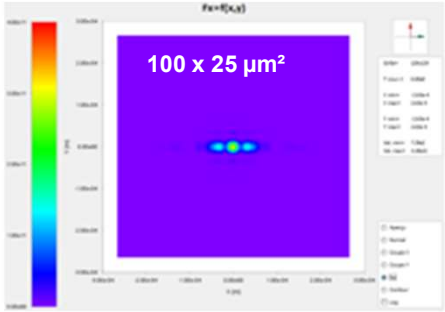
- **Each sub-aperture has 700 fs pulse duration**
- **They are delayed by 750 fs to limit beam phasing**

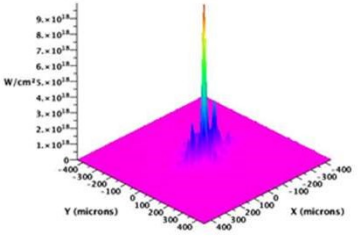


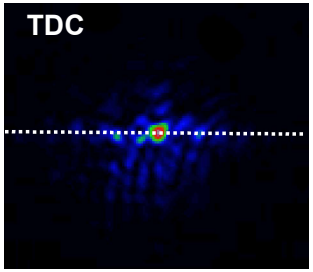
2D - Spectral Interferometer measurement

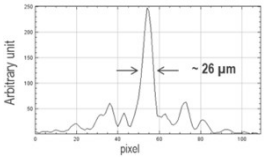
Miro simulations



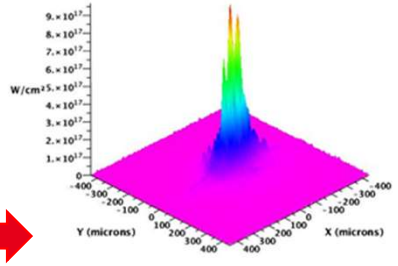


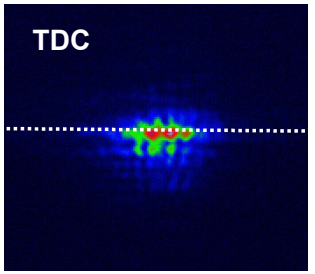


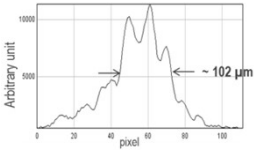




SMETS campaign - 6th may 2019
0.75 10^{19} W/cm² < I < 1.25 10^{19} W/cm²
(358 J @ 637 fs)







BATON campaign - 9th may 2019
0.77 10^{18} W/cm² < I < 1.18 10^{18} W/cm²
(396 J @ 3 ps)

Specific Focal Spot (2/2)

03 **SPECIFIC FOCAL SPOT**

Adjustment of the segmented mirror and the 2nd compression stage

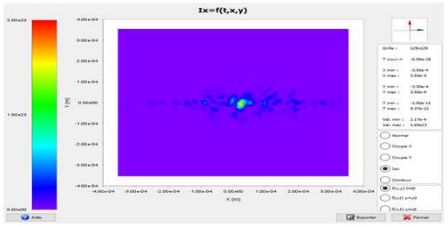
→ **Large focal spot for BRAMBRINK campaign**

Miro simulations :

- Vertical tilt of 2 sub-apertures of 6.2 µrad
- Focal spot size: 20 x 60 µm²
- Pulse stretched at 20 ps
- Intensity divided by a factor 57

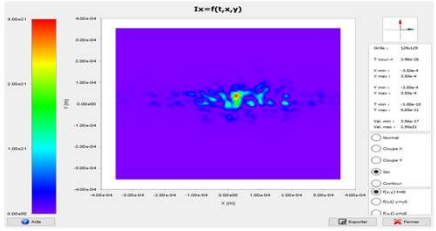
Aberrant beam, 700 fs
Perfect beam phasing

I_{max} = 1.69 10^{19} W/m²
(I_{max})



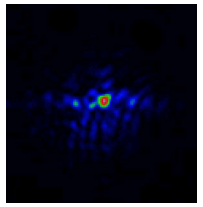
Aberrant beam, 20 ps
Tilt = 6.2 µrad on 2 sup-apertures

I_{max} = 2.95 10^{17} W/cm²

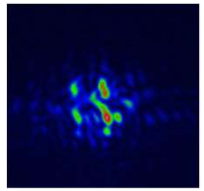


Experimental intensities:

- **SMETS** : 700 fs
  - I_{max} = 10^{19} W/m²



- **BRAMBRINK** : 18 ps, tilt 6.2 µrad
  - I_{max} = 2 10^{17} W/m²



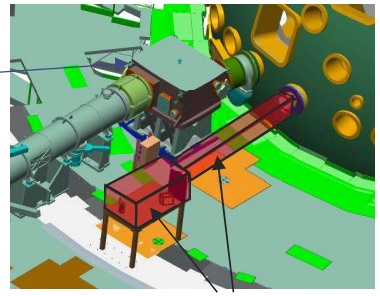
→ **Large focal spot but with modulations**

Fine alignement on target with TωIST 1ω

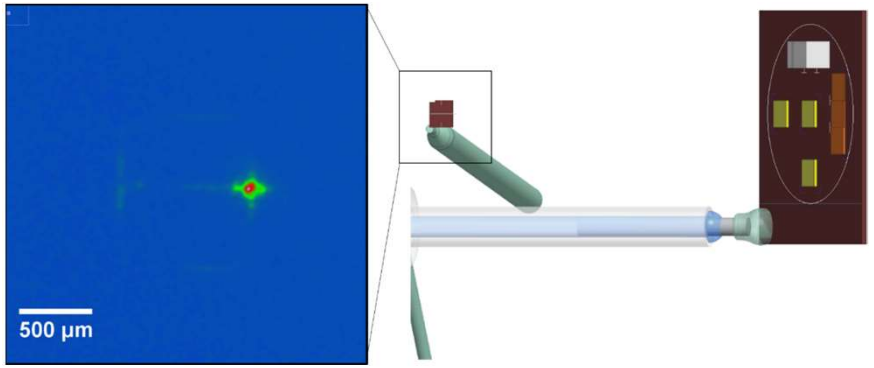
For fine alignments, 2 steps are used:

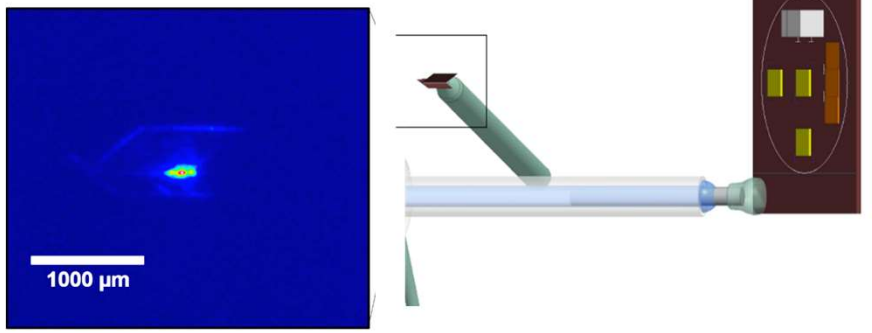
- Alignment with the camera of the LMJ « Reference Commune »: 50 µm
- Fine alignment on the wire with TwIST after the target positioning

Parabola +
Pointing mirror



TwIST





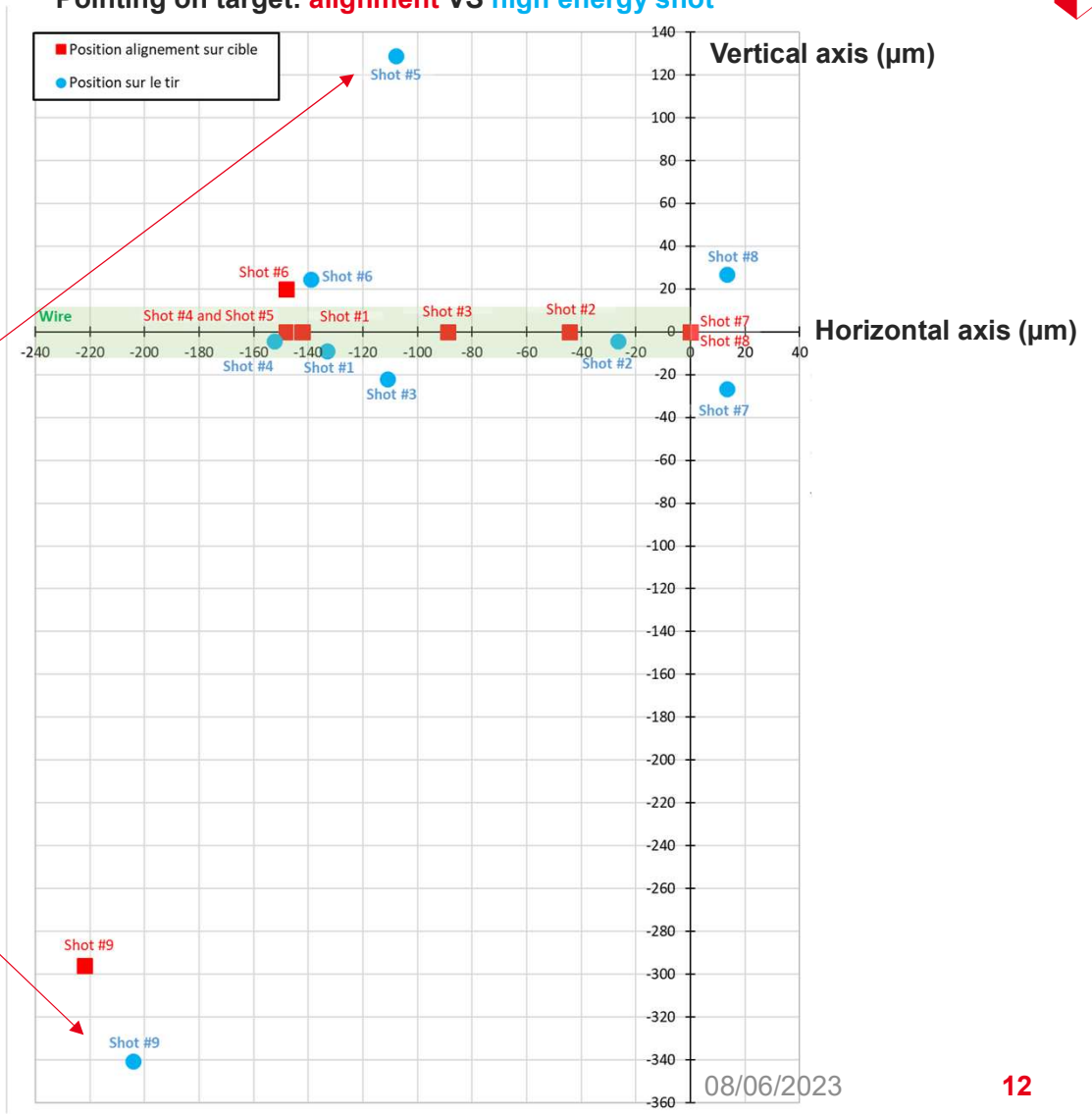
TωIST (Two/three ω Imaging System)*:
focal spot imaging = imaging of the interaction region at 2nd (2ω) or 3rd (3ω) harmonics of the laser frequency

* D. RAFFESTIN *et al.*, "Application of harmonics imaging to focal spot measurements of the "PETAL" laser", J. Appl. Phys. 126, 245902 (2019)

Pointing on target

The performance obtained are:

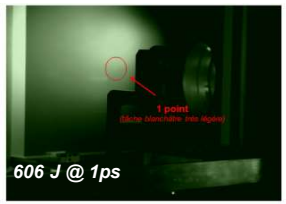
- Around than 20 µm in X and 30 µm in Y
- Amplifier Section vibrations: +/- 2.5 µrad → +/- 20 µm
- (40 µm, 130 µm) on Shot #5:
  Air conditioning in the 1st stage compressor room stopped after the alignment on target and 1h before the shot (increase of temperature)
- (20 µm, 40 µm) on Shot #9:
  Air conditioning in the 1st stage compressor room not well controlled during all the day (decrease of temperature)

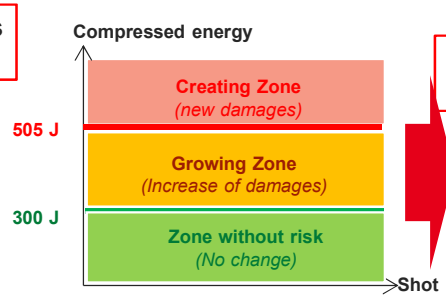


Energy performances (1/2)

→ Energy limited to 400 J to avoid damage growth* on old coating design of final optics under vacuum

2nd semester of 2015: damages on the MT6bis allowing to define the energy limitations

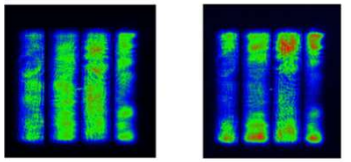




2017: front end beam shaping for gain compensation

Maximum fluence outside the damage area: 400 J

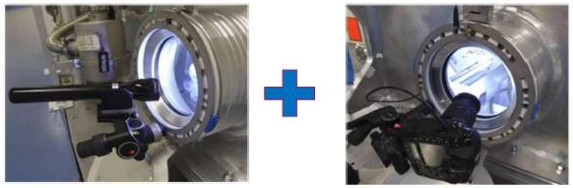
→ 2 different apodizations in the front end depending on output energy in the amplifier section



Flat phase plate *Deep phase plate*

→ No evolution with energy < 400J, evolution with energy up to 450J

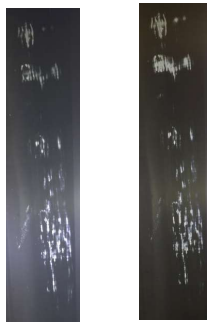
Optics inspection after each shot



Mechanical systems to hold maglite-LED

camera in the same position after each shot

Parabola



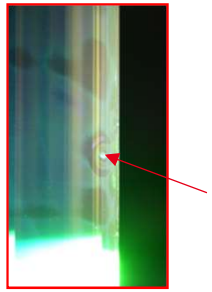
3 march 25 April

Pointing Mirror

3 march 25 April

2022

Vacuum Grating



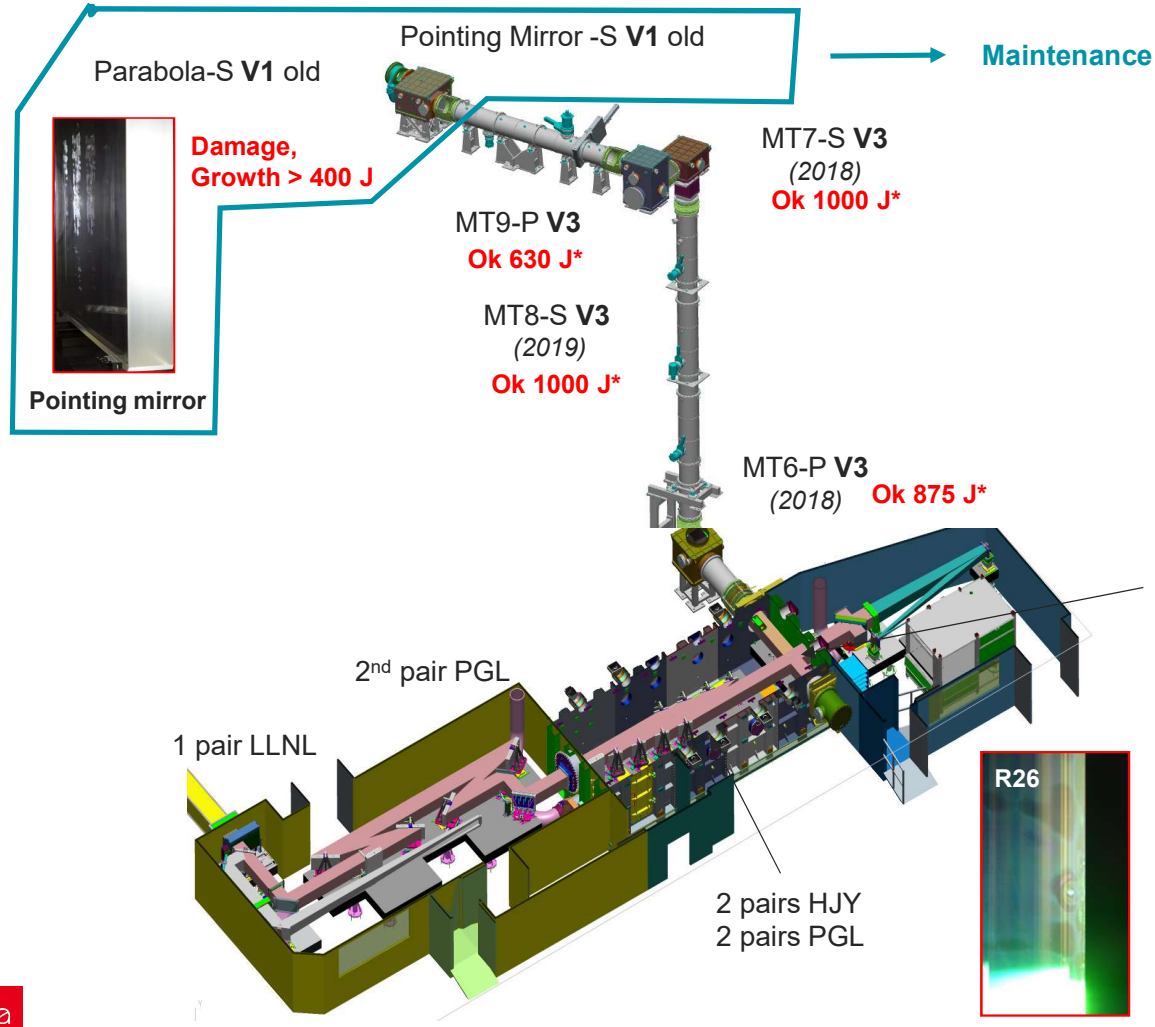
Damage unchanged at 400 J

Observation inside the compressor

=> Small decrease of the vacuum transport transmission: 94 % => 88 %

* **M. SOZET** *et al.*, "Sub-picosecond laser damage growth on high reflective coatings for high power applications", *opt*. Express, **21**, 25768 (2017).

Increase of Energy performances in 2024 (2/2)



Maintenance in june/2023 with Parabola V2 and pointing mirror V3 : Ok 900 J

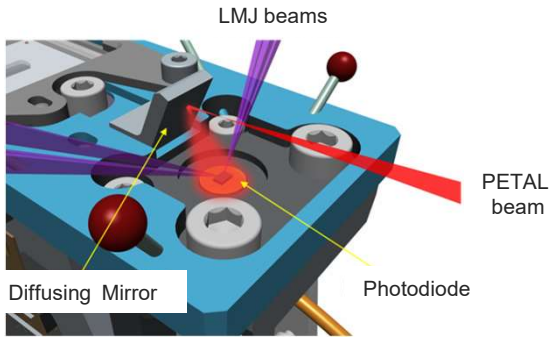
Increase of energy in 1st semester 2024 :
→ Energy: 650 J @ 700 fs
→ Observation System of the grating has to be developed this year !

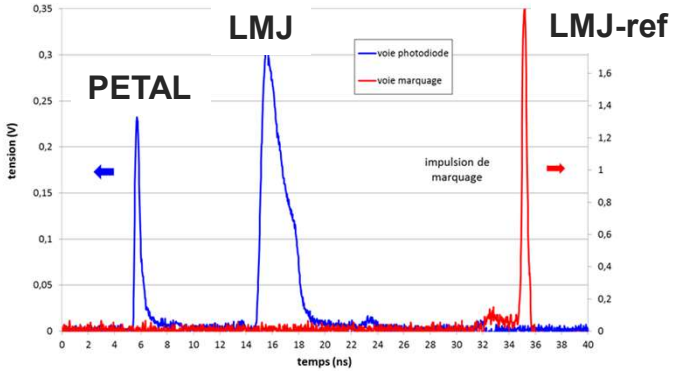
Damage,
Initiation > 900 J
No growth < 450 J

* V3 Estimation from V1 and DERIC test

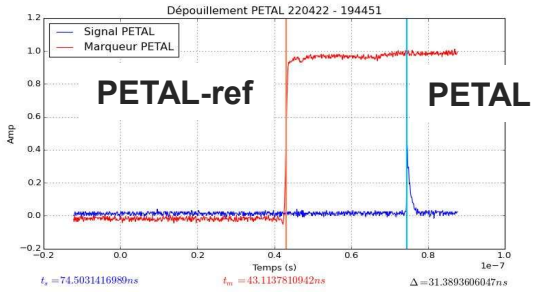
Synchronization PETAL/LMJ on target

- **Measurements at the LMJ target chamber center with (PETAL & LMJ) PAM shots**





- **Measurement on high energy shot: photodiode with reference on TDC (Compression Diagnostic Table)**



T0 + 5.9 ns / LMJ: +31 ps obtained

→ **Shot to shot synchronization well controlled and measured: +/- 50 ps obtained**
→ **High resolution (15 ps) installed but not fully implemented on TDC (new photodiode required)**

Conclusion

- Up to 2023 experimental campaigns
  - Vibrations and instabilities of the focal spot
    - → Vibrations corrected: due to vacuum pump vibration
    - → Instabilities corrected but after the campaign: due to air conditioning → action plan under progress

- 2023 maintenance of equipment's
  - New oscillator to replace the Mira oscillator (20 years old !)
  - New final optics : parabola and pointing mirror with recent coating design (not the last one, see next talk)

- 2024: first step of PETAL energy increase
  - 650 J @ 650 fs = 1 PW on target in April
    - → Go/NoGo after each shot with observation of the components and particularly the grating under vacuum

→ **Evolution of the performances in the future will be presented by E. Hugonnot in the next talk with the PETAL-UPgrade project**

Petal-UPgrade

Thanks for your attention

and

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