Stabilisation et qualification des impulsions laser pour le projet PALLAS

M. Pittman, S. Kazamias, B. Lucas, K. Cassou, E. Baynard, J. Demailly, O. Neveu, O. Guilbaud, V. Kubytskyi, P. Drobniak, E. Legay, J.-L. Coacolo, D. Douillet, G. Iaquanello, Y. Peinaud

PALLAS overview

Build a laser-plasma accelerator prototype competiting with RF accelerator (@ equivalent perfs except Rep. Rate)
→ seeder for multi-staging
Potential use for laser-plasma cell designs
Cf. K. Cassou (12/05 @ 14h20)

- Demonstration of stable and controlable 150 MeV → 200 MeV @ 10Hz
- Optimization of charge / dispersion /… by:
  - → laser control
  - → target design (plasma control)
- Electron beam transport and manipulation for seeding a 2nd ALP stage

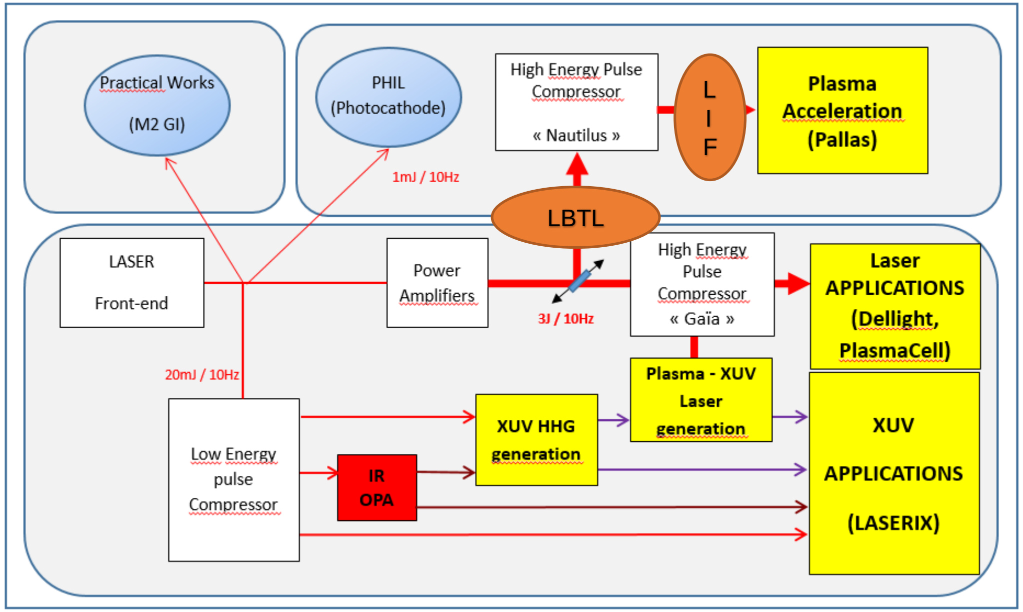
Parameters	phase 1	phase 2	phase 3	unit
energy	150	**200**	200	MeV
charge	15-30	**30**	30	pC
frep	10	10	10	Hz
energy spread	<10%	**< 5%**	< 5%	peak (FWHM)
$\varepsilon_{T,n}$	1	**<1**	<1	mm.mrad
stability	5%	**3%**	**1%**	-
reproductibility	5%	**3%**	3%	-

Technical design based on ionization seeding
Laser Driver: LASERIX → Intensity limitation: ~10^{18} W/cm^2

LASERIX Overview

<u>High Intensity laser facility</u> (2J / 40fs @ 10Hz)

- Customized system (base Amplitude PULSAR)
- Flexibility for exotic use (controled prepulses, spectrum, additionnal beams… as examples)
- CCM (ElliOOs) from Amplitude/Scarell with online controls
- Active control devices (Dazzler, Mazzler)

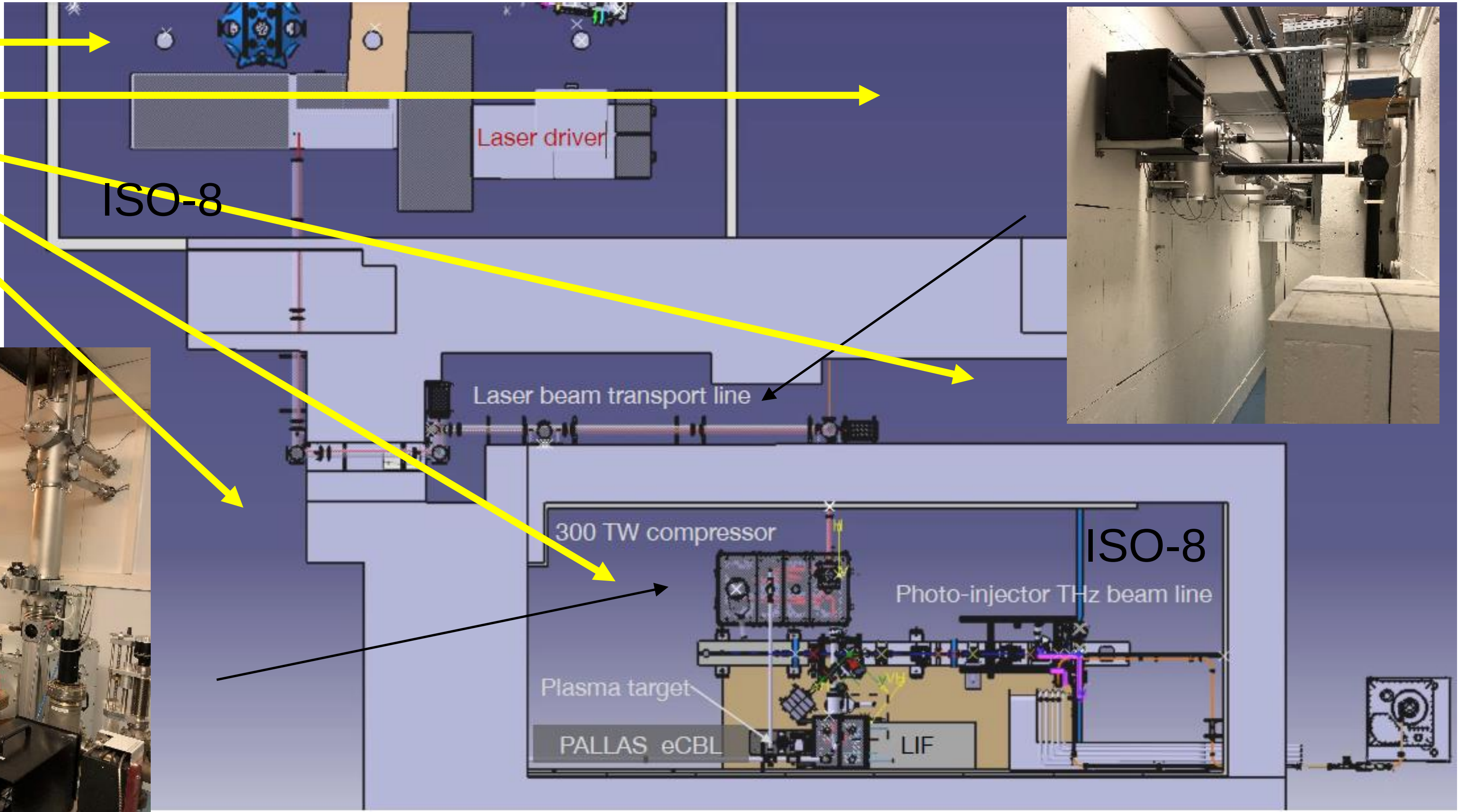


<u>Multibeam Platform</u>

- X-UV sources (HHG et SXRL) for R&D and applications
- PlasmaCell : Characterization bench for plasma cells (→ PALLAS)
- Femtosecond photo-excitation @ 3ω of PHIL photoinjector
- Practical bench for high graduate students
- **ALP (PALLAS) in progress:**
  - **Beam transport (LBTL): env. 20m**
  - **Compression**
  - **Focusing and on-line metrology (LIF)**

PALLAS: General setup

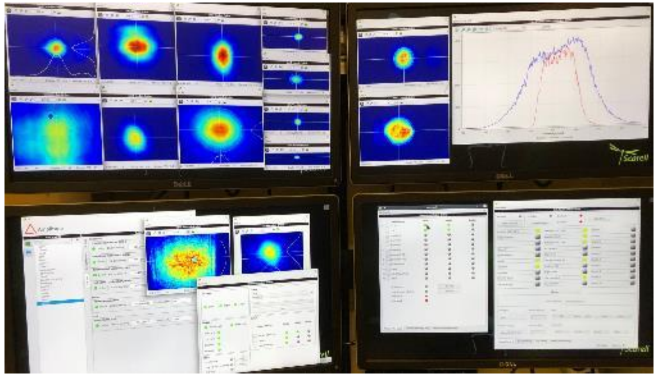
Common cooling groups for air conditionning & instrumentation



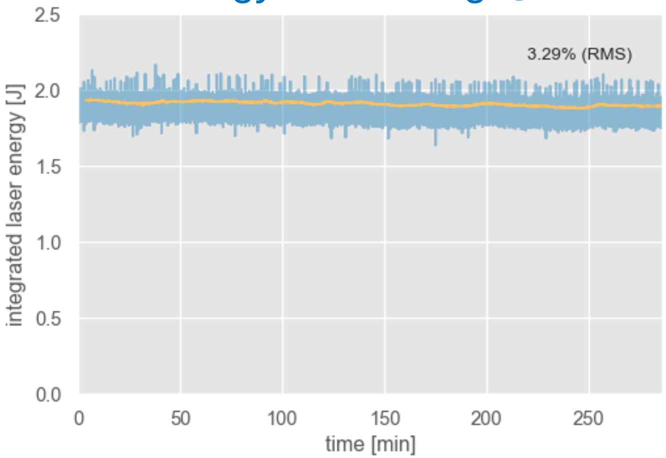
Beam monitoring controled by Amplitude/Scarell CCM (ElliOOs)

- Cam NF-FF for each multipass amplifier stage
- Spectrometers : oscillator / output front-end / HE and LE Outputs
- Energy measured with precalibrated output NF

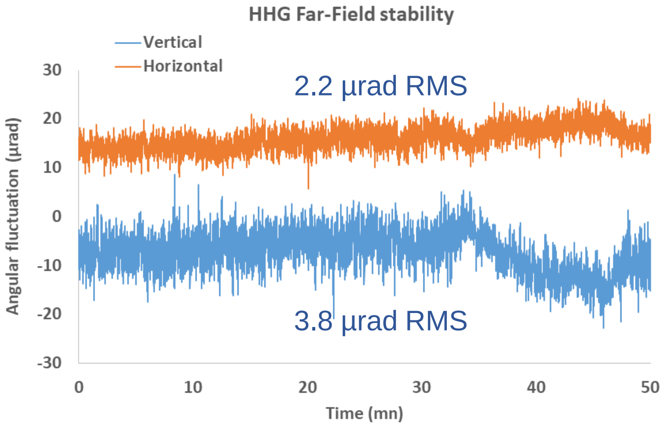
Laser monitoring with ElliOOs



Energy monitoring @ 2J



Pointing stability on HHG beamline



Alignments with piezo-mirrors controled by home-made software

- NF-FF tunings from oscillator up to experiments
- Polarization rotation for Beam attenuation

Ongoing Improvements

Beam monitoring AND piezzo-mirrors integrated into ElliOOs

→ **Beam alignments**

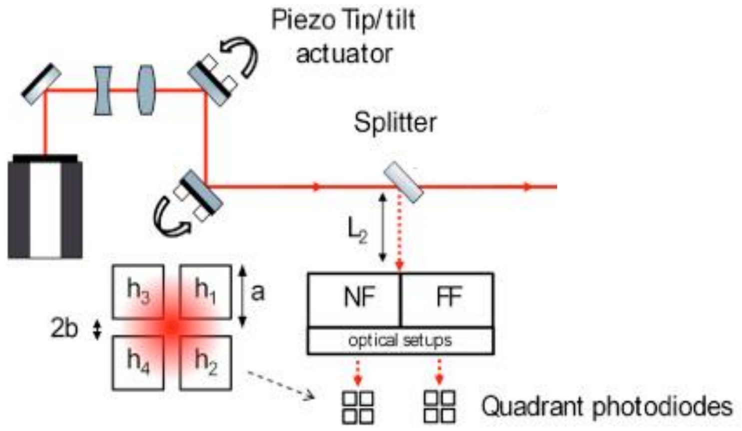
→ **Thermal drift compensation (Slow time loop < Hz)**

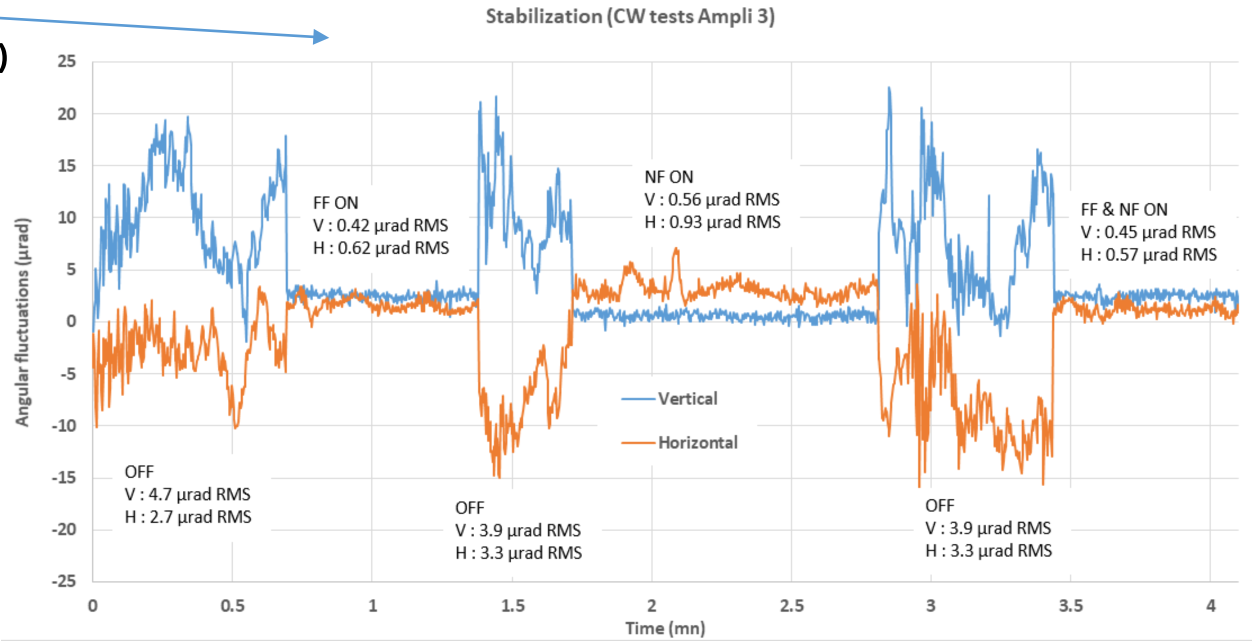
Fast pointing stabilization (Up to 500Hz for mechanical vibrations, air flows…)

2 closed loop systems (from MRC) each with NF & FF correction

→ **Before transport beamline (output AMPLI 3J)**

→ **Before target Focussing (Output pulse compressor)**





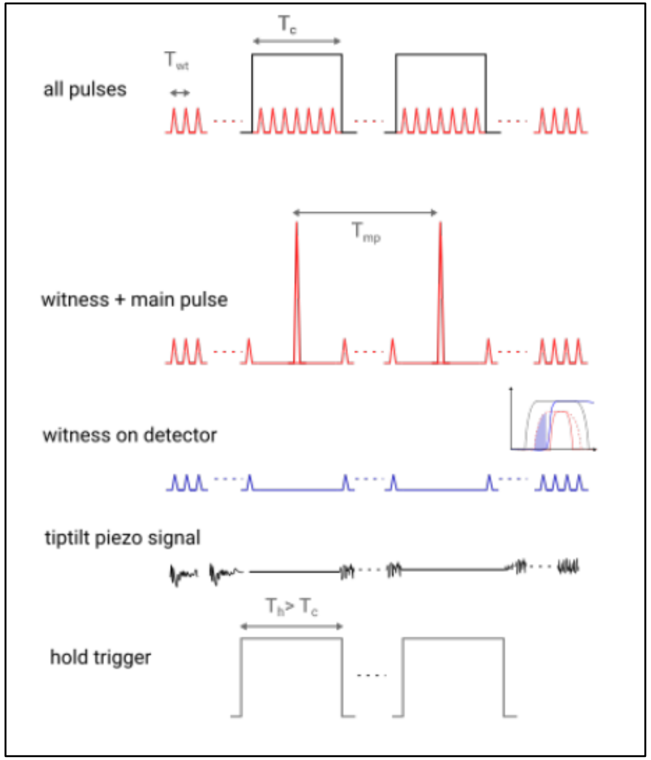
Preliminary results on Ampli-3 exit (Laser diode)

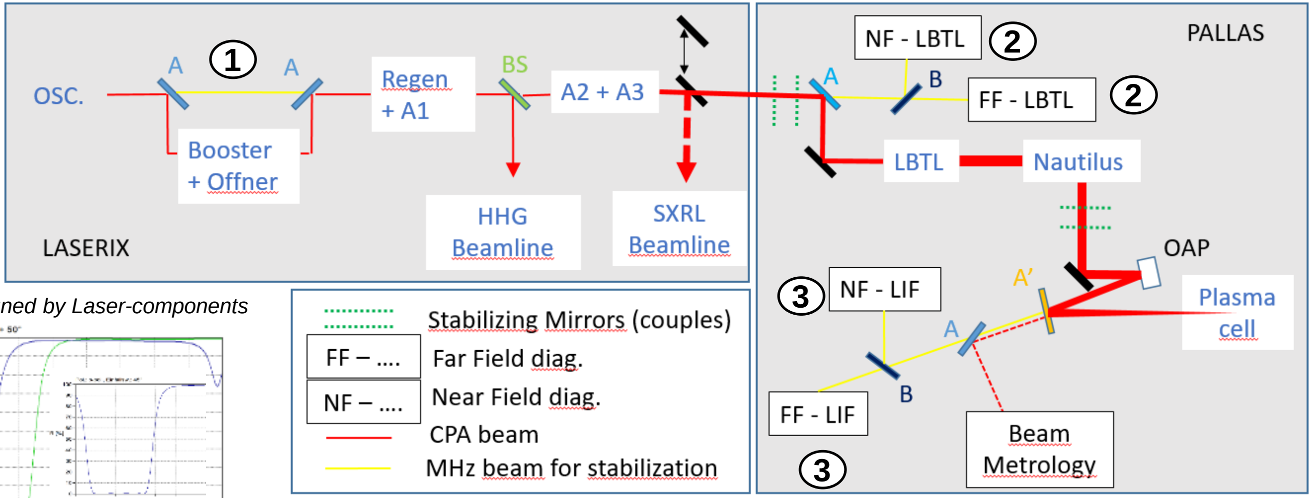
Strategy for laser stabilization -1

Special beam-samplers

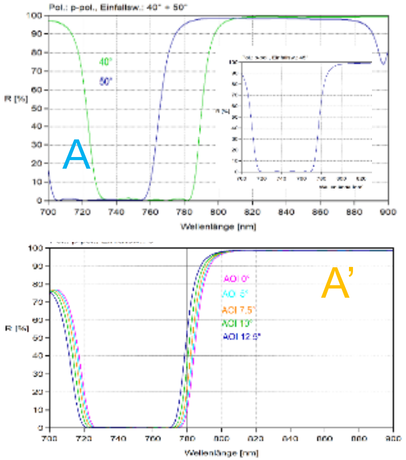
→Beam stabilization with MHz probe (coming from oscillator spectrum @ 780nm) + temporal selection

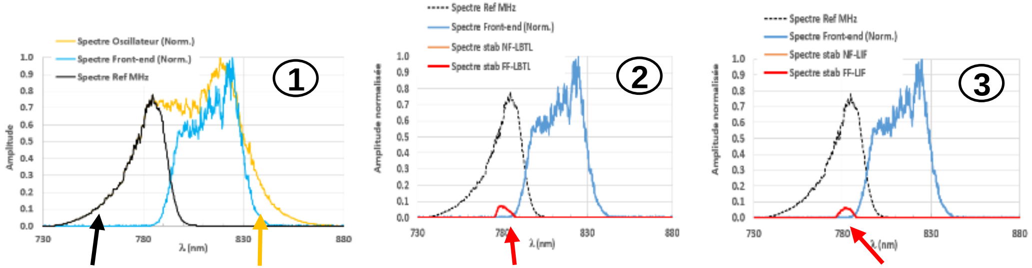
→Beam online metrology: low spectro-temporal and spatial distorsions (flat transmission)





Courtesy designed by Laser-components





A coat : 99% vs 0 → 90% @ 780nm

A' coat : 98% vs 15 → 40% @ 780nm

250mW 800mW NF/FF LBTL : 1.2mW NF/FF LIF : 0.4mW

Strategy for laser stabilization -2

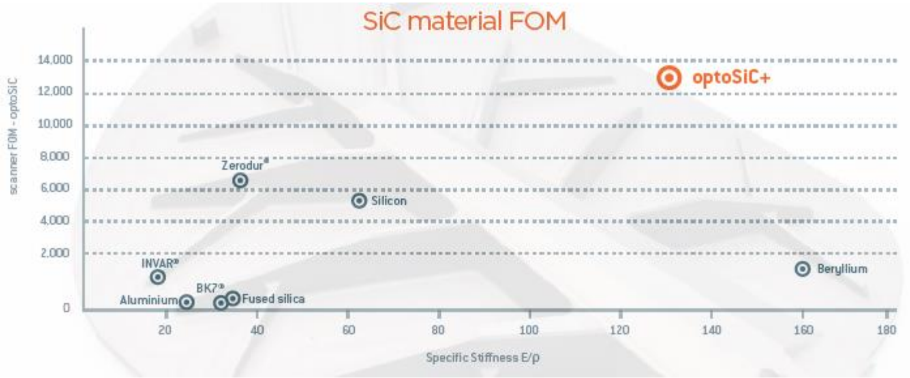
“High-speed” mirrors for pointing stabilization on target

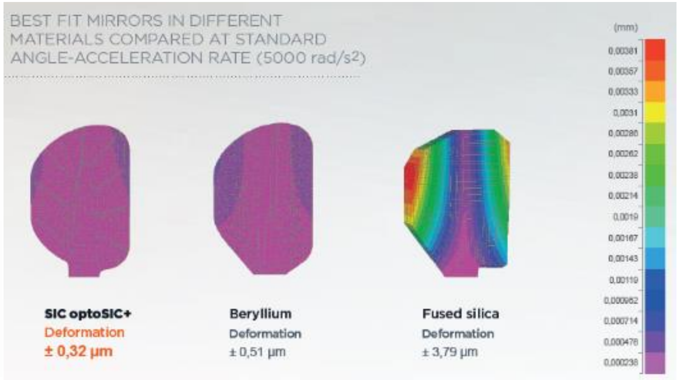
Lightweight mirrors for high speed stabilization @ 50 TW (90 x 130 mm²) : SiC ceramic material (Mersen « OptoSIC™ »)

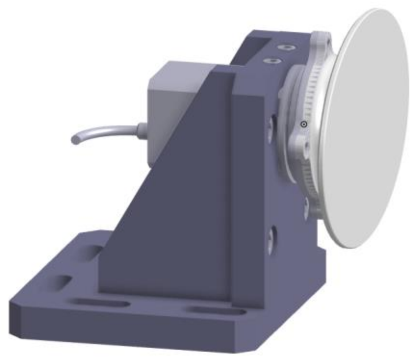
Mounted on specially designed Piezzo mount (MRC)

→ Tests on piezo tip-tilt for optimal bandwidth [~400Hz] validated [1]

→ Ongoing qualification of femtosecond broadband coating on SiC, LDIT under vacuum [2] (expected > 0.2J/cm²)







Src: https://www.mersen.com/products/graphite-specialties/boostecr-silicon-carbide-sic/laser-processes-galvo-scanning-and-fast-steering-mirrors-optosic

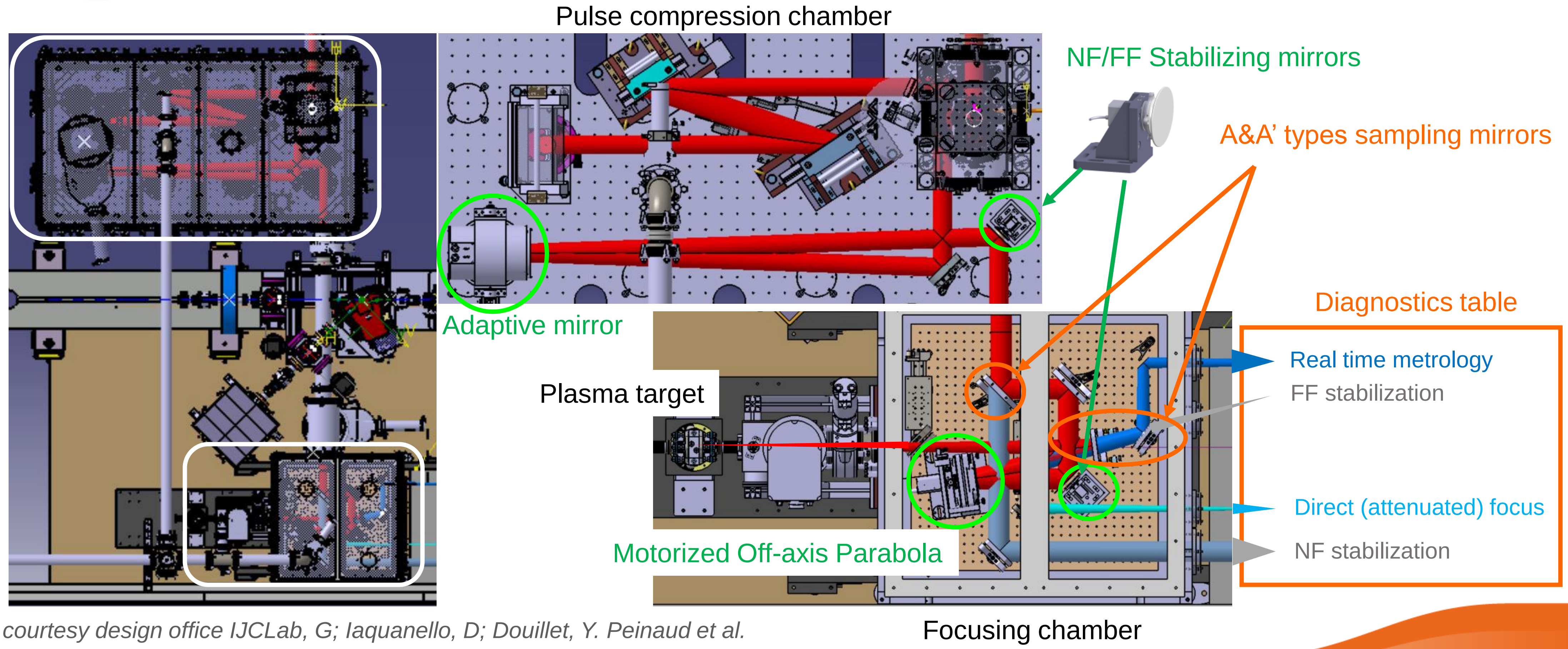
courtesy of MRC / MERSEN

[1] MRC gmbh
[2] MERSEN/ARDOP/LIDARIS

Strategy for laser metrology

Laser delivery setup : compression → Control → Focusing → | Target

Laser metrology



courtesy design office IJCLab, G; Iaquanello, D; Douillet, Y. Peinaud et al.

Final metrology setup

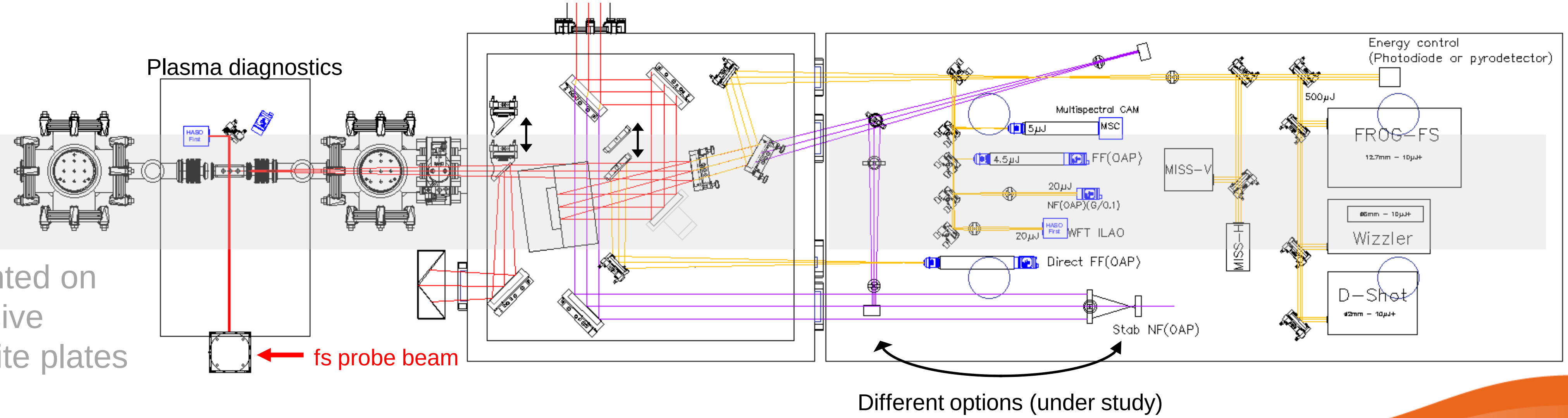
Beam sampling on the last optic before target

MHz witness sampling → NF/FF laser stabilization

Complete online "real-time" laser characterization:

- → Far-Field with x40 magnification
- → Near-Field imaging
- → Energy monitoring
- → Wavefront with potential feedback on AM
- → Temporal pulse measurement (various devices)
- → Spatio-spectral coupling: crossed 2D spectrometers (NF) + multispectral camera (FF) (ML-COLA project)

Direct beam extraction for metrology benchmark & calibration



Mounted on massive Granite plates

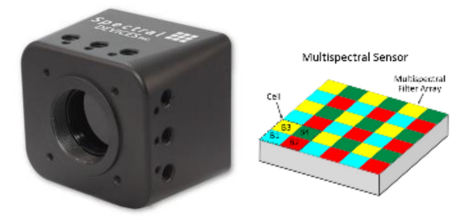
Strategy for laser metrology

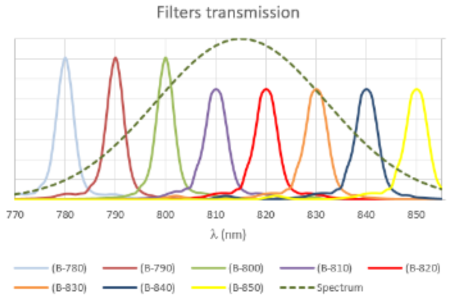
ML COLA (V. Kubytsky), coll. APOLLON

Machine Learning based online Characterization and Optimization of a high intensity LAser pulse

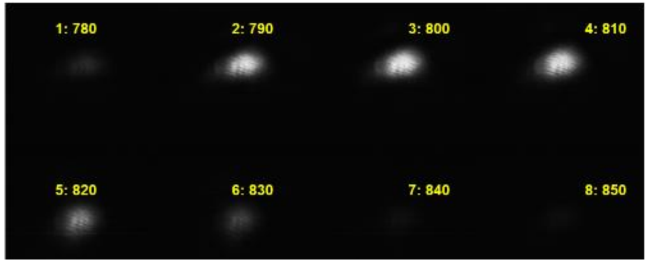
Spatio-spectral coupling I(x,y,λ) in one shot / real-time (10Hz) → Customized **Multispectral camera**

Precalibration with high sensitivity scanning devices: TERMITES Amplitude, INSIGHT SourceLAB

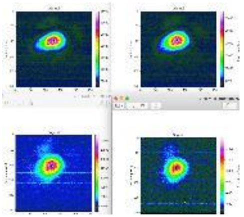




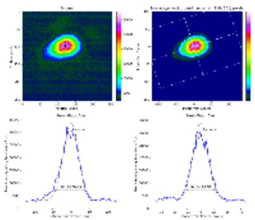
Courtesy Spectral Devices
Multispectral camera filters designed for a 40nm laser bandwidth



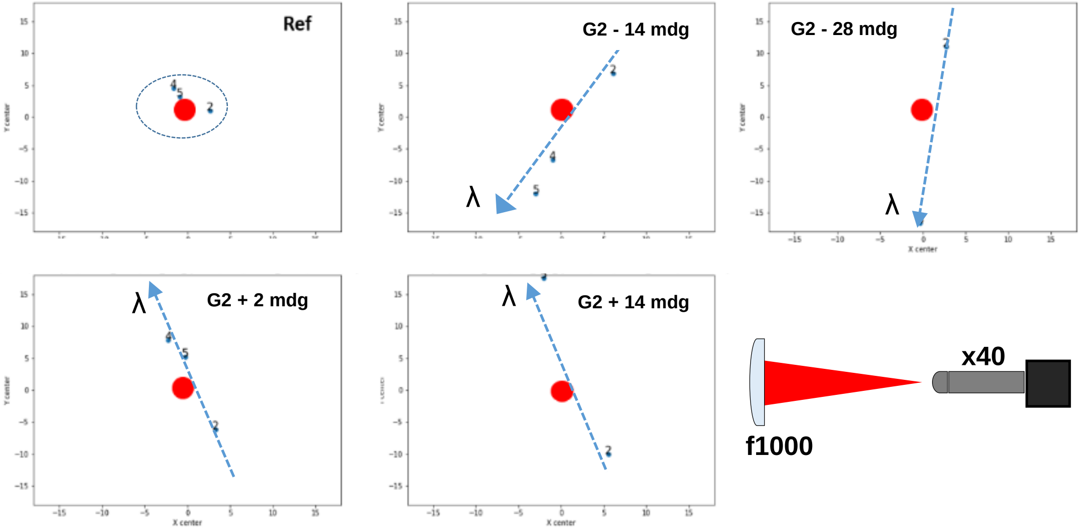
Raw single shot images on 8 channels (for 30nm FWHM spectrum)



Raw Data for most intense channels 2, 3, 4, 5



Postprocessing for each channel: Beam center, and beam size retrieval



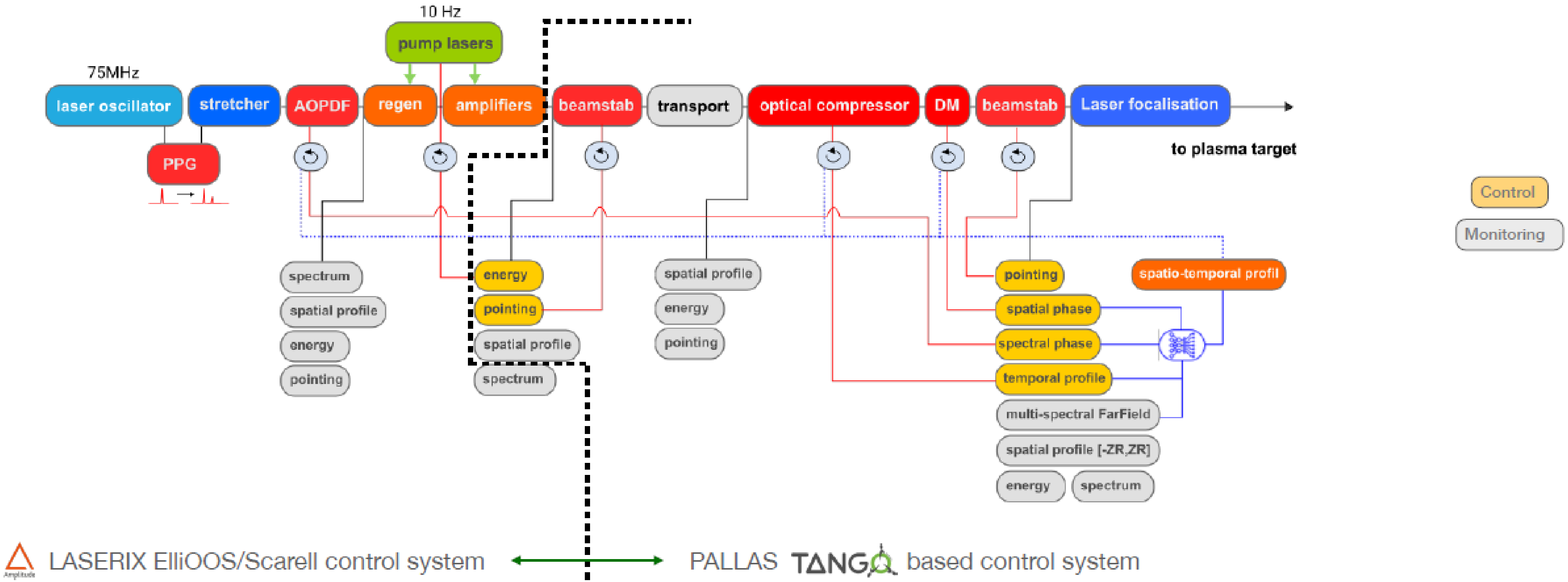
Preliminary results: centroid position @ focus for each channel relative to Ch3 (800nm) for different angular tuning of G2 vs G1. The beam is rotated with a crossed mirrors periscope (Horiz. → Vert.)

Ongoing work

- Real-time monitoring during compressor gratings alignment
- Need of spectral filter for normalization of spectral intensities (8 usable channels)
- Robust and automatized algorithm for image processing
- Future inputs for ML

General strategy for laser control

Active feedback Diags → online laser controls (Dazzler, Adaptive Mirror, Compressor…)



Summary & conclusion…

PALLAS is based on the 40 TW LASERIX laser driver which has to be improved
General infrastructure is almost ready for homogeneous and stable environment / beam transport is pre-installed

Main efforts for

- Beam pointing stabilization @ low (thermal drift) and high (air flows, vibrations) frequencies
- Beam sampling for:
  - stabilization with MHz witness beam from oscillator with spectral & temporal selection
  - High quality & real-time beam characterization: spatial (NF/FF/WFT), spectro-temporal and coupling

Development yet under process

- Special coating designs for beam sampling: beam stabilization & online metrology
- Ultra-light large aperture mirrors for high frequency stabilization
- Development of real-time FF-STC measurement based on multispectral camera

Supplementary laser upgrades

- New oscillator for increased RF & spectral stability and higher Power (stabilization seeding)
- Improvement of last amplifier (larger -available- Ti:Sa crystal in new cryogenic chamber, potential increase of pumping energy)

Driving idea: Machine Learning approach

Data-collection (laser/plasma/e-) → automatic configurations / optimizations (feedback from plasma, then e-beam diagnostics)