EUROPEAN UNION

Structural Instruments 2014-2020

Competitiveness Operational Programme (COP)

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) – Phase II

Ultra-intense laser pulses and the High Power Laser System at Extreme Light Infrastructure - Nuclear Physics

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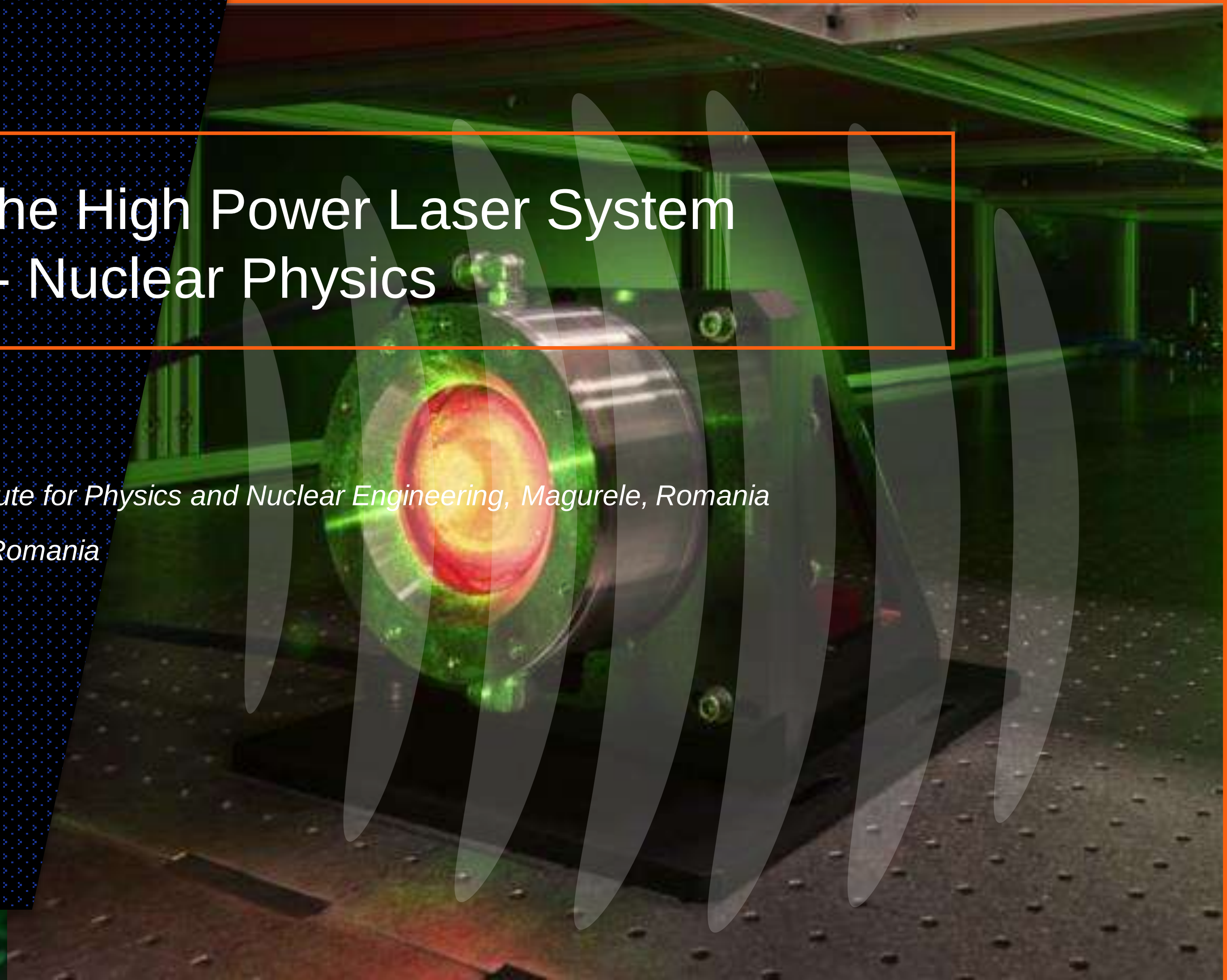
15.3.2021

FemtoUp! School, via Zoom

nuclear physics

IFIN-HH



Contents

- Why intensity matters
- Extreme Light Infrastructure facilities
- Architecture of the 2x10PW laser system (HPLS)
- Laser pulse characterization at HPLS
- Experimental areas for laser experiments

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Gaussian beam

The mathematical function that describes the Gaussian beam is a solution to the paraxial form of the Helmholtz equation.

For a Gaussian beam, the complex electric field amplitude is given by

$$E(r,z) = E_0 \frac{w_0}{w(z)} \exp\left(\frac{-r^2}{w^2(z)}\right) \exp\left(-ikz - ik\frac{r^2}{2R(z)} + i\zeta(z)\right) ,$$

where

r is the radial distance from the center axis of the beam,
z is the axial distance from the beam's narrowest point (the "waist"),
i is the imaginary unit (for which $i^2 = -1$),
$k = \frac{2\pi}{\lambda}$ is the wave number (in radians per meter),
$E_0 = |E(0,0)|$,
w(z) is the radius at which the field amplitude and intensity drop to 1/e and $1/e^2$ of their axial values, respectively,
$w_0 = w(0)$ is the waist size,
R(z) is the radius of curvature of the beam's wavefronts, and
$\zeta(z)$ is the Gouy phase shift, an extra contribution to the phase that is seen in Gaussian beams.

Wikipedia

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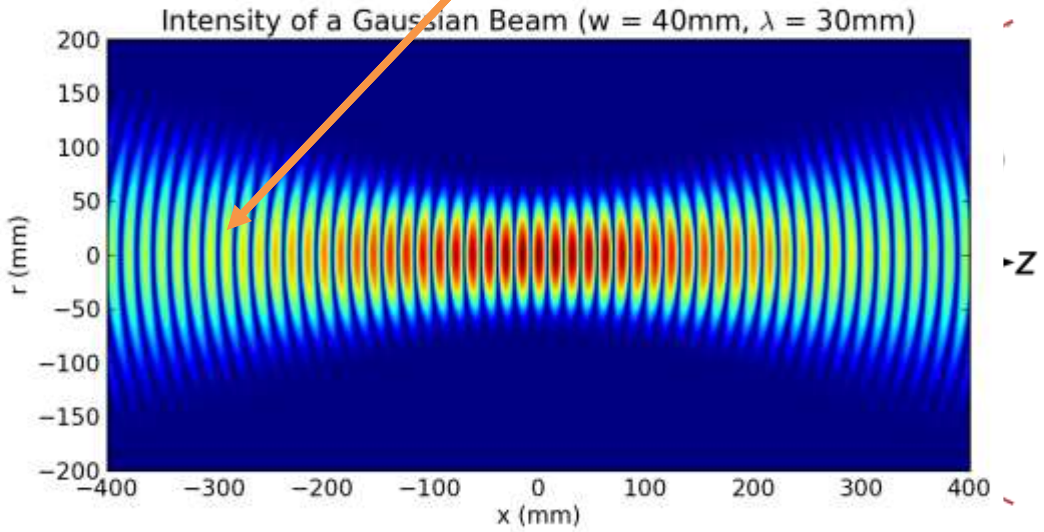
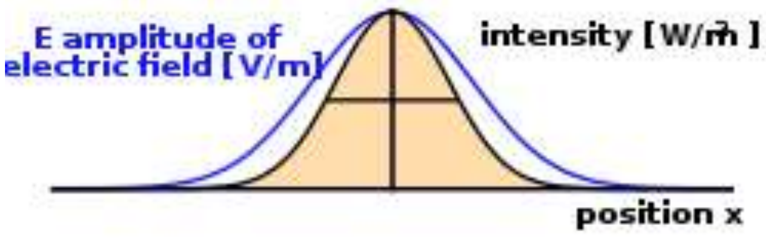




Laser beam = "simplest" electromagnetic field distribution

Wikipedia

Gaussian pulse

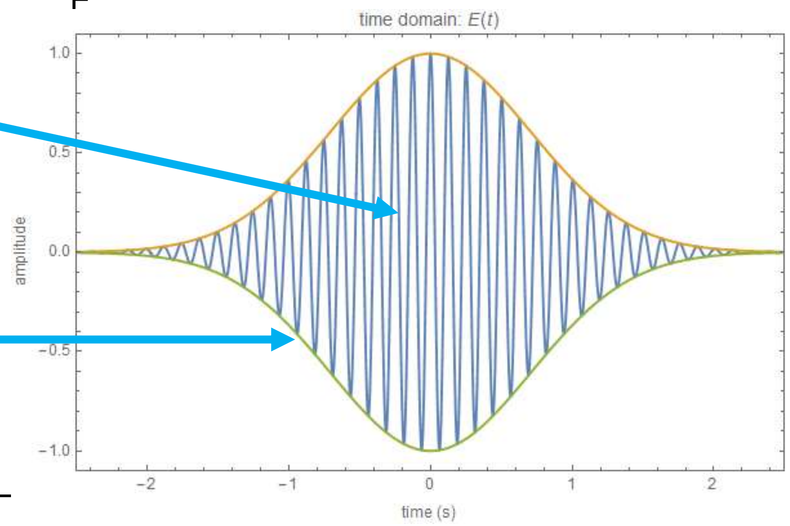
$$E(r,z) = E_0 \frac{w_0}{w(z)} \exp\left(\frac{-r^2}{w^2(z)}\right) \exp\left(-ikz - ik\frac{r^2}{2R(z)} + i\zeta(z)\right) ,$$

We go from cylindrical coordinates to cartesian coordinates:

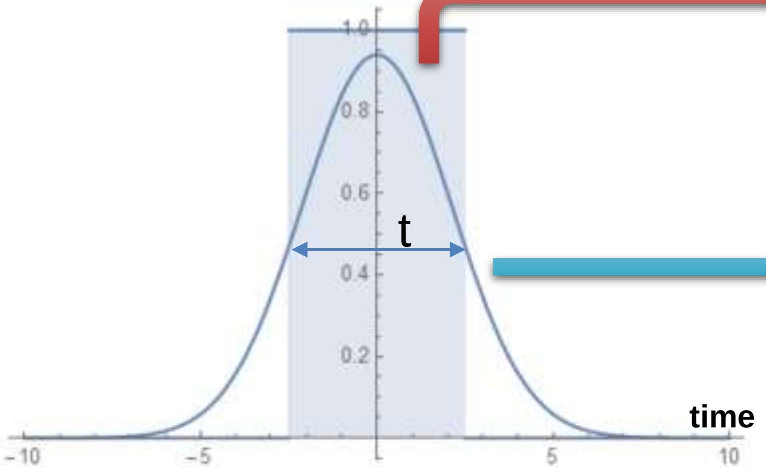
$$u(x,y,z) = u(z) \cdot \exp\left[-\frac{(x-X_0)^2+(y-Y_0)^2}{w^2(z)}\right] \exp\left[i\frac{k}{2}\frac{(x-X0)^2+(y-Y0)^2}{R(z)}\right] \cdot \exp[-i\varphi(z)] \exp(ikz).$$

We add the temporal part in the form of a Gaussian shape with duration τ_F:

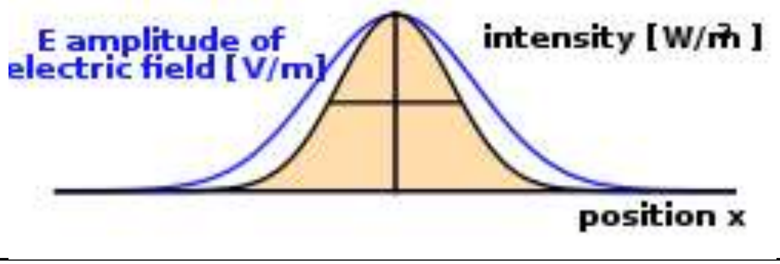
$$u(x,y,z,t) = u(x,y,z) \cdot \exp\left[-\left(\frac{z-c_0 t}{c_0 \tau_F}\right)^2\right] \cdot \exp\left[-i\frac{2\pi c_0}{\lambda}t\right]$$



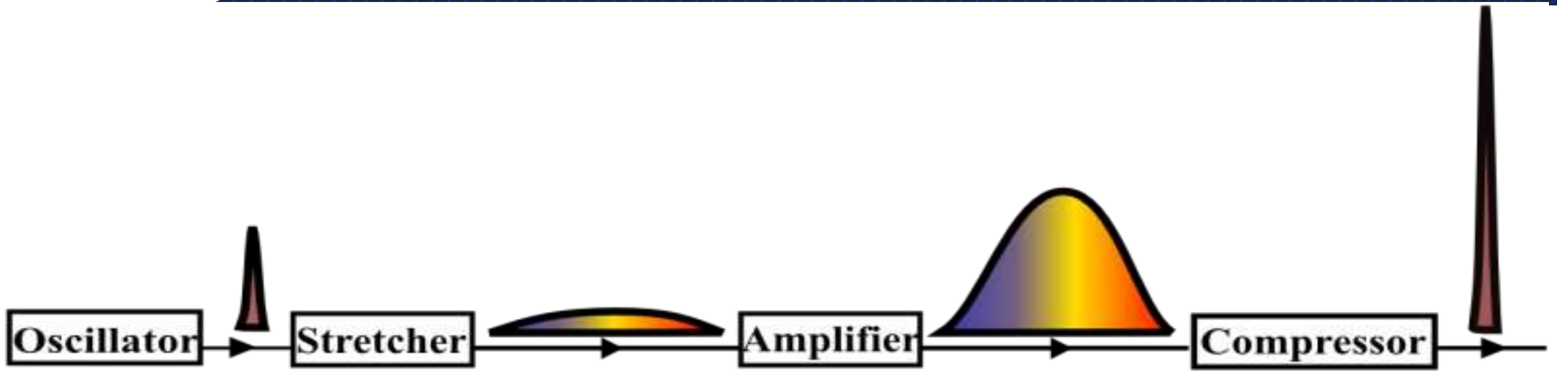
Intensity

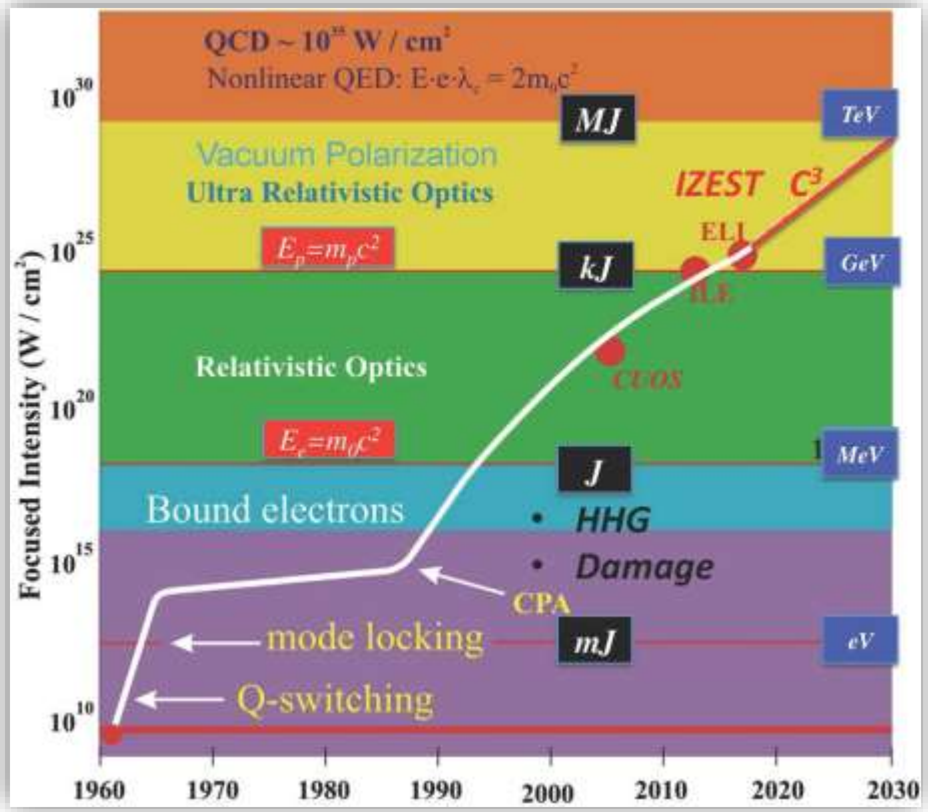


$$\frac{Energy}{t \cdot S} = I$$



Nobel 2018: Chirped Pulse Amplification





GERARD MOUROU
& DONA STRICKLAND
(Nobel 2018)

Towards higher intensity: ideal Gaussian pulses

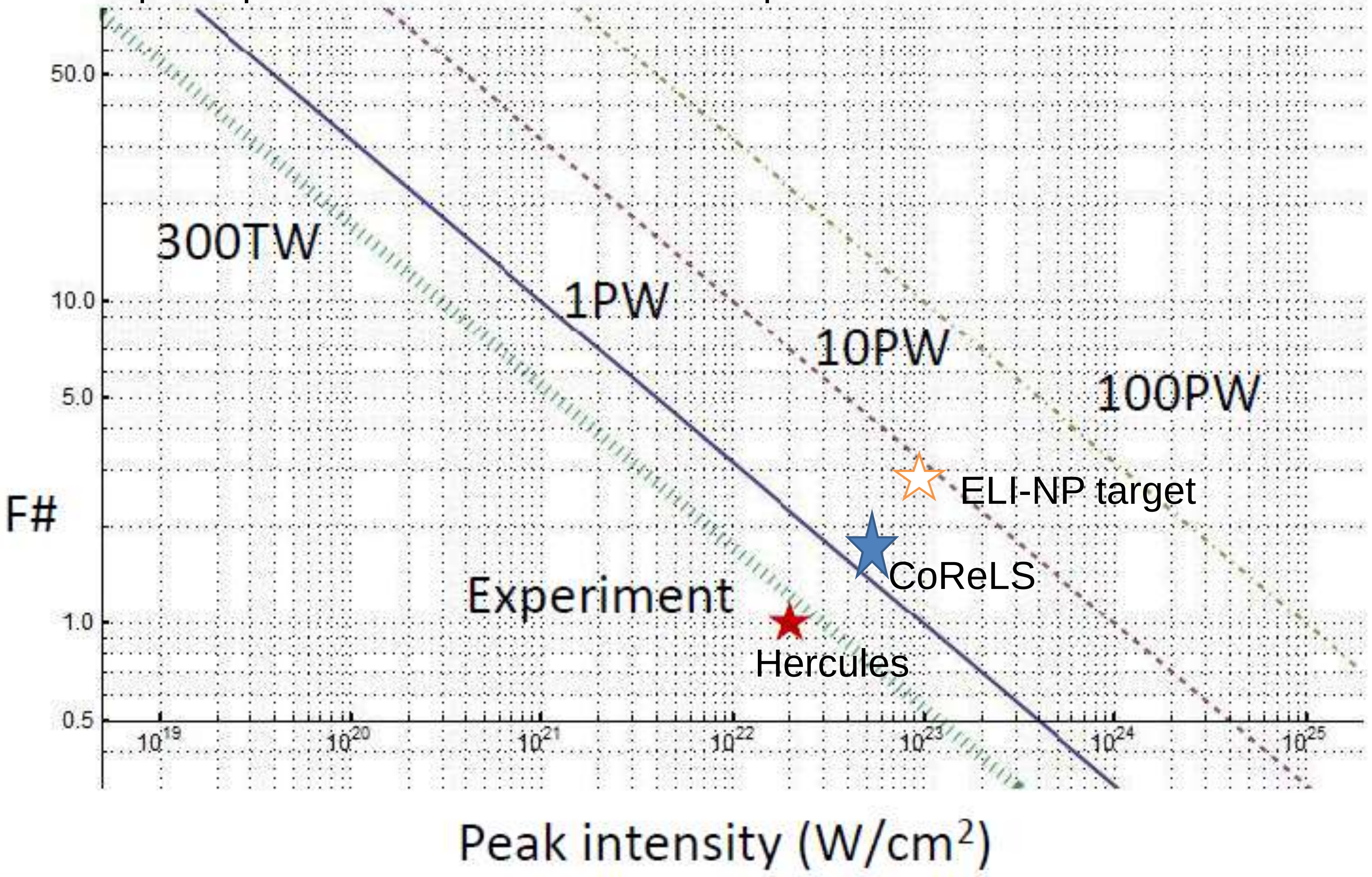
Peak intensity:

$$I = 2P/\pi w_0^2$$

Waist of the pulse:

$$w_0 \sim F\#\ \lambda$$

Laser pulse parameters in ideal vs. real experiments



Ionel L., Ursescu D., "*Spatial extension of the electromagnetic field from tightly focused ultra-short laser pulses***"** Laser and Particle Beams, 2014

Motivation: Laser pulses parameters

- Electric field

$$E_L\,(\mathrm{V/cm}) = 2.75 \times 10^9 \left(\frac{I_L}{10^{16}\ \mathrm{W/cm^2}}\right)^{1/2}$$

- Magnetic field

$$B_L\,(\mathrm{Gauss}) = 9.2 \times 10^6 \left(\frac{I_L}{10^{16}\ \mathrm{W/cm^2}}\right)^{1/2}$$

- Pressure

$$P_L = \frac{I_L}{c}(1+R) \approx 3.3\,\mathrm{Mbar}\left(\frac{I_L}{10^{16}\ \mathrm{W/cm^2}}\right)(1+R)$$

Shalom ELIEZER,
The Interaction of High-Power Lasers with Plasmas (2002)

Comparison

- Magnetic field

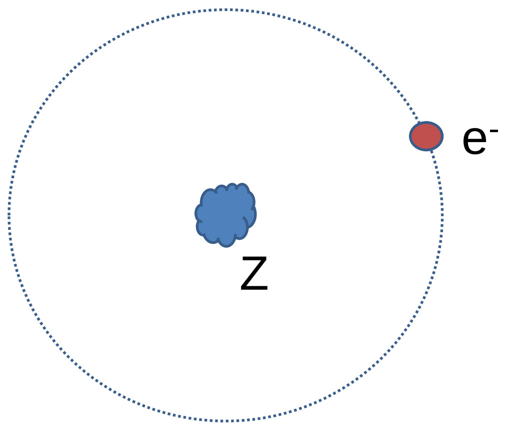
- 1 MG Strongest pulsed non-destructive magnetic field produced in a laboratory, Pulsed Field Facility at National High Magnetic Field Laboratory's, Los Alamos National Laboratory, Los Alamos, NM, USA).[18]
- 12 MG Record for indoor pulsed magnetic field, (University of Tokyo, 2018) [19]
- 28 MG Record for human produced, pulsed magnetic field, (VNIIEF, 2001)[20]
- 10 GG - 1 TG Strength of a non-magnetar neutron star.[21]
- >9.2 GG in reach at ELI-NP

- Pressure

- >600 GPa = 6 x 10^6 bar: Pressure attainable with a diamond anvil cell[84]
- 5TPa = 5 x 10^7 bar: Pressure generated by the National Ignition Facility fusion reactor
- 2.5 x10^{11} bar Pressure inside Sun's core [88]
- >3.3 x10^{12} bar in reach at ELI-NP

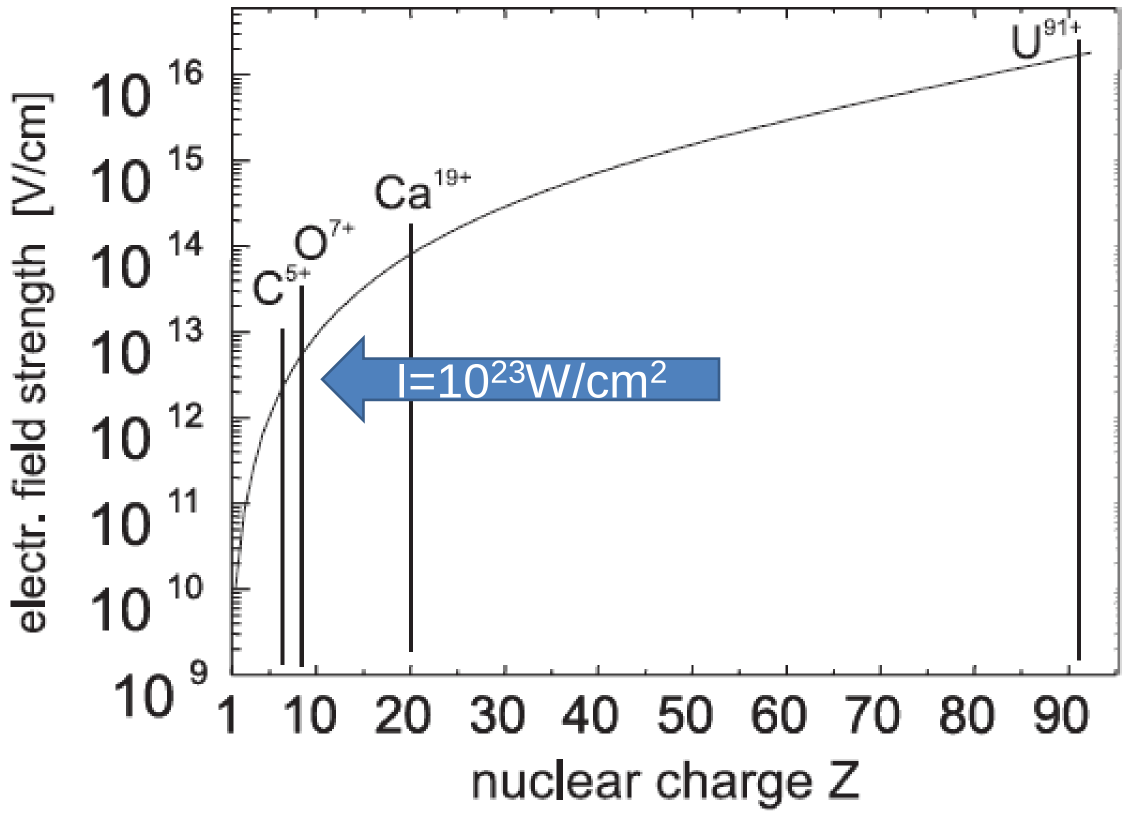
Wikipedia

Electric field *and ionization of atoms*



Bohr radius = 0.529 Angstrom · n^2/Z

$$E_L\ (\mathrm{V/cm}) = 2.75 \times 10^9 \left(\frac{I_L}{10^{16}\ \mathrm{W/cm^2}} \right)^{1/2}$$



Electric field strength at the position of the ground state electron in H-like ions as a function of the nuclear charge number Z.

Eur. Phys. J. Special Topics 163, 113–126 (2008)

Electric field *and relativistic movements*

When the electric field is expressed in terms of electromagnetic potentials, one can get:

$$\mathbf{E} = -\frac{\partial \mathbf{A}}{c\partial t}, \quad \mathbf{B} = \nabla \times \mathbf{A}$$

Define the normalized vector potential as $\mathbf{a} = \frac{e\mathbf{A}}{m_e c^2}$

This is non-dimensional factor. It can be connected to the intensity of the laser through:

$$a_0 = \left(\frac{2e^2 \lambda_0^2 I}{\pi m_e^2 c^5}\right)^{1/2} \cong 0.855 \times 10^{-9} I^{1/2}\left[\mathrm{W/cm^2}\right]\lambda_0[\mu\mathrm{m}]$$

For intensities of >$2 \cdot 10^{18}$W/cm^2 and wavelength of ~800nm => a_0~1.
=> The electron dynamics needs relativistic description.

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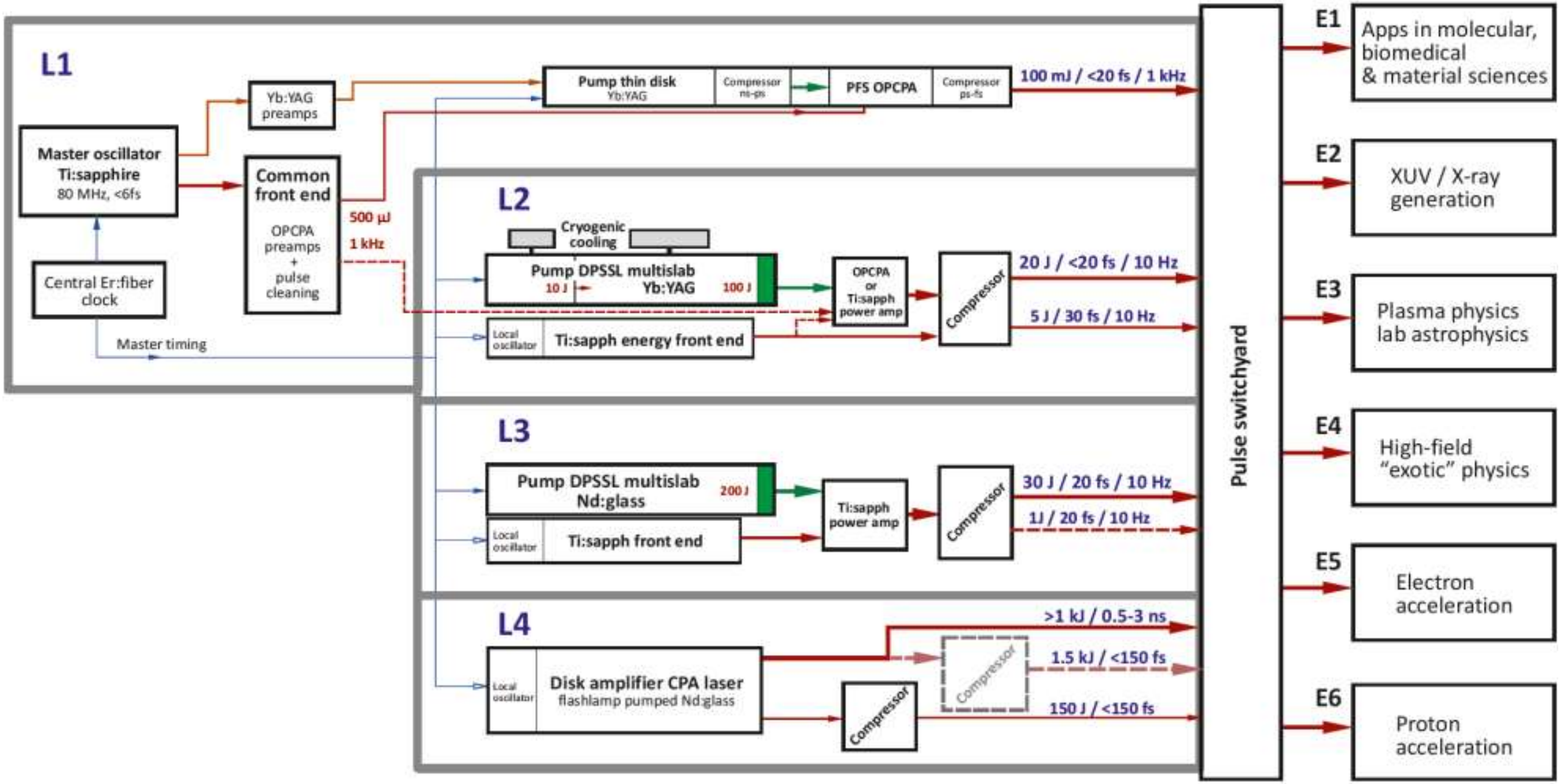
The Extreme Light Infrastructure: Laser systems

Optics and Photonics News, January 2020

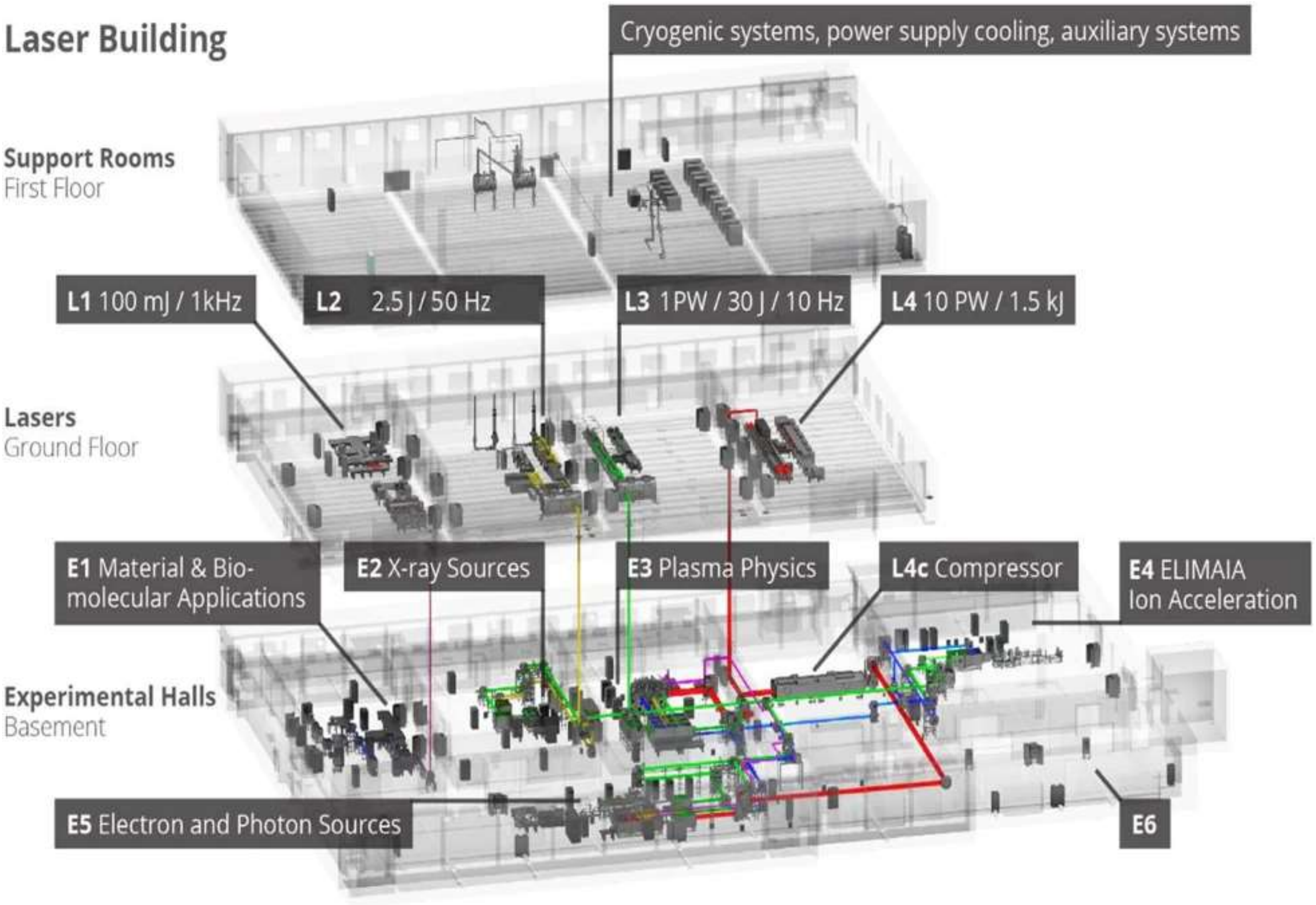
ELI-Beamlines



Bruno LeGARREC, **Extreme Light Infrastucture (ELI) Science and Technology at the ultra-intense Frontier,** spie PHOTONICS West 2014

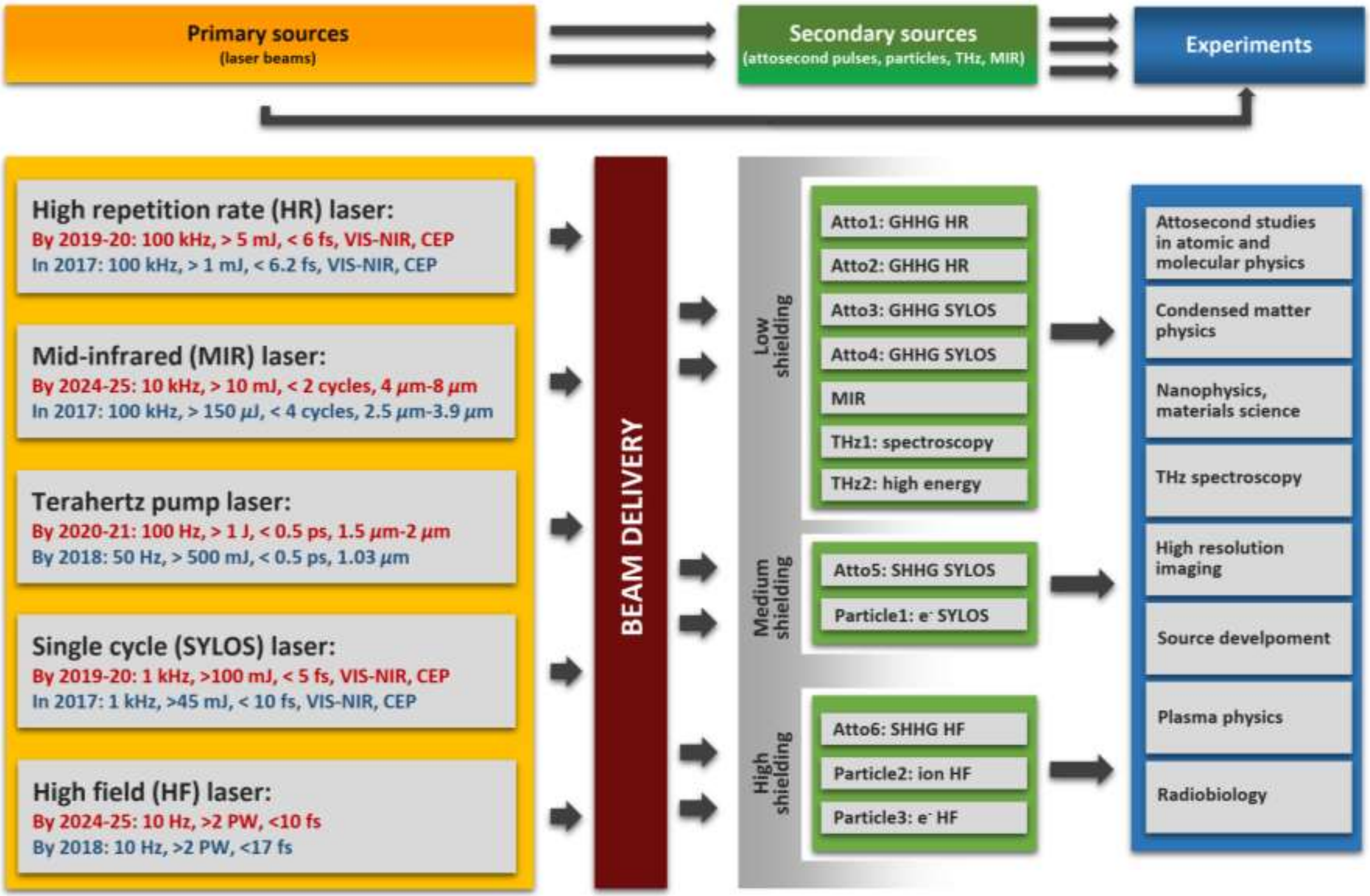
ELI Beamlines

nuclear physics

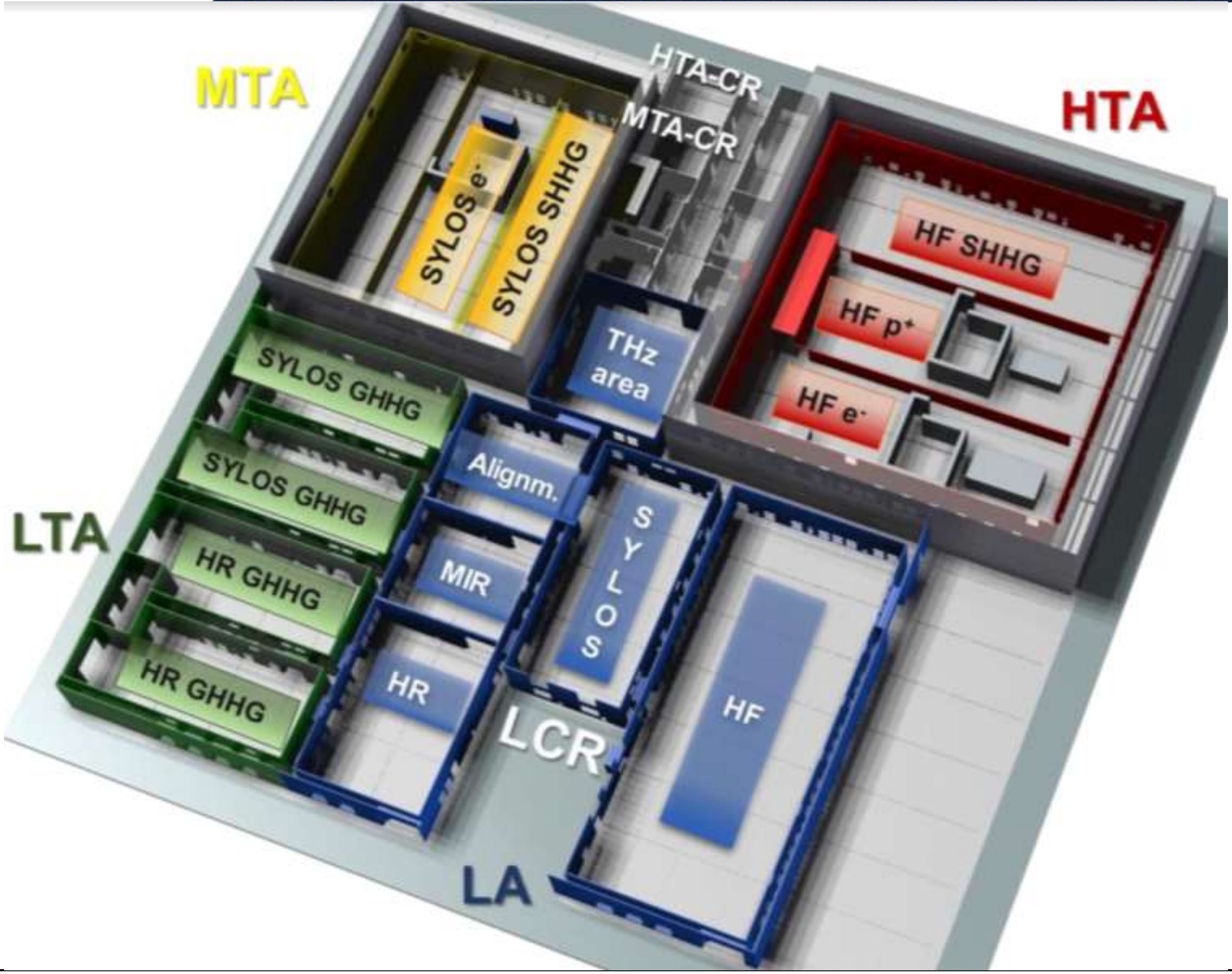


Laser Focus World, 9 June 2019

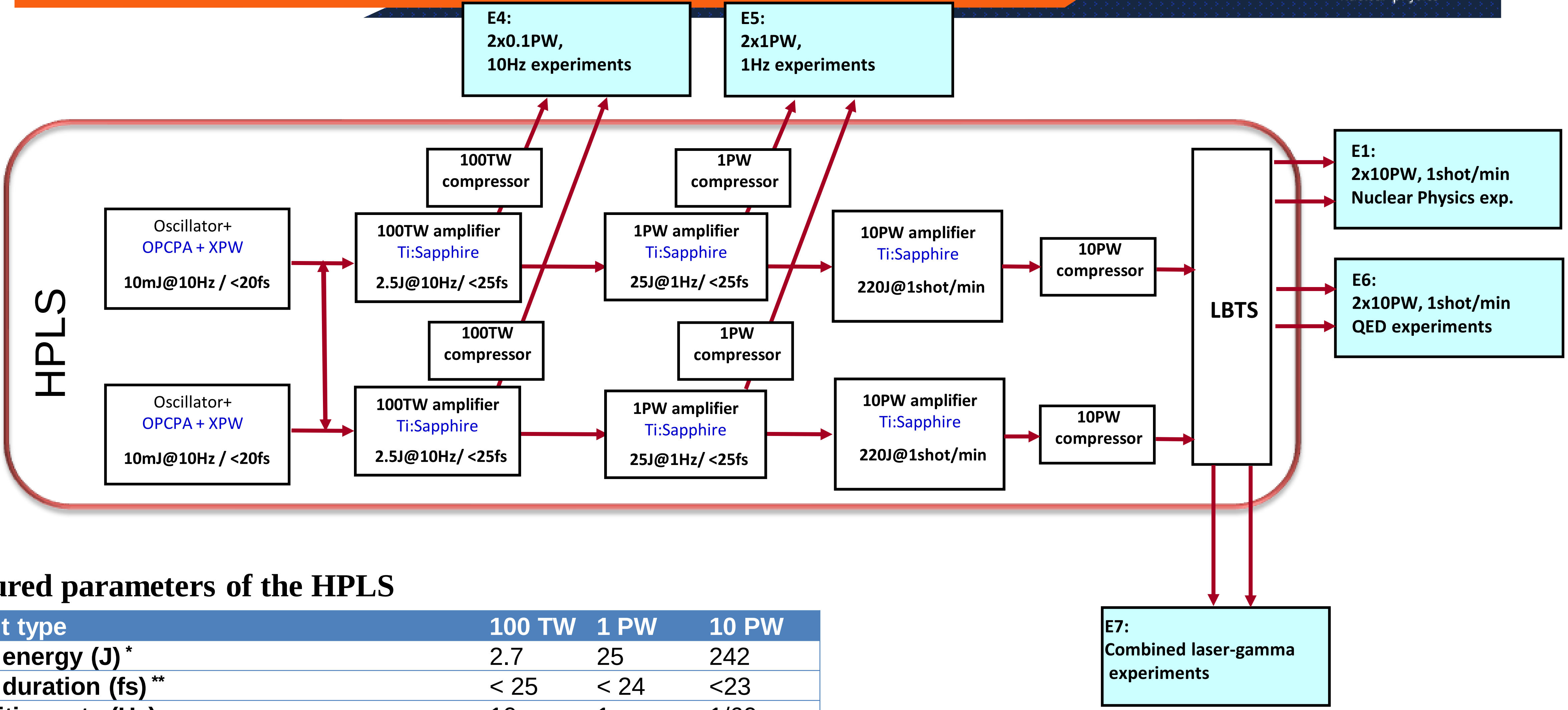
ELI-ALPS


Primary sources
(laser beams)
Secondary sources
(attosecond pulses, particles, THz, MIR)
Experiments
High repetition rate (HR) laser:
By 2019-20: 100 kHz, > 5 mJ, < 6 fs, VIS-NIR, CEP
In 2017: 100 kHz, > 1 mJ, < 6.2 fs, VIS-NIR, CEP
Mid-infrared (MIR) laser:
By 2024-25: 10 kHz, > 10 mJ, < 2 cycles, 4 μm-8 μm
In 2017: 100 kHz, > 150 μJ, < 4 cycles, 2.5 μm-3.9 μm
Terahertz pump laser:
By 2020-21: 100 Hz, > 1 J, < 0.5 ps, 1.5 μm-2 μm
By 2018: 50 Hz, > 500 mJ, < 0.5 ps, 1.03 μm
Single cycle (SYLOS) laser:
By 2019-20: 1 kHz, >100 mJ, < 5 fs, VIS-NIR, CEP
In 2017: 1 kHz, >45 mJ, < 10 fs, VIS-NIR, CEP
High field (HF) laser:
By 2024-25: 10 Hz, >2 PW, <10 fs
By 2018: 10 Hz, >2 PW, <17 fs
BEAM DELIVERY
Low shielding
Medium shielding
High shielding
Atto1: GHHG HR
Atto2: GHHG HR
Atto3: GHHG SYLOS
Atto4: GHHG SYLOS
MIR
THz1: spectroscopy
THz2: high energy
Atto5: SHHG SYLOS
Particle1: e- SYLOS
Atto6: SHHG HF
Particle2: ion HF
Particle3: e- HF
Attosecond studies in atomic and molecular physics
Condensed matter physics
Nanophysics, materials science
THz spectroscopy
High resolution imaging
Source develpoment
Plasma physics
Radiobiology

ELI-ALPS main building



The High Power Laser System at ELI-NP (HPLS)

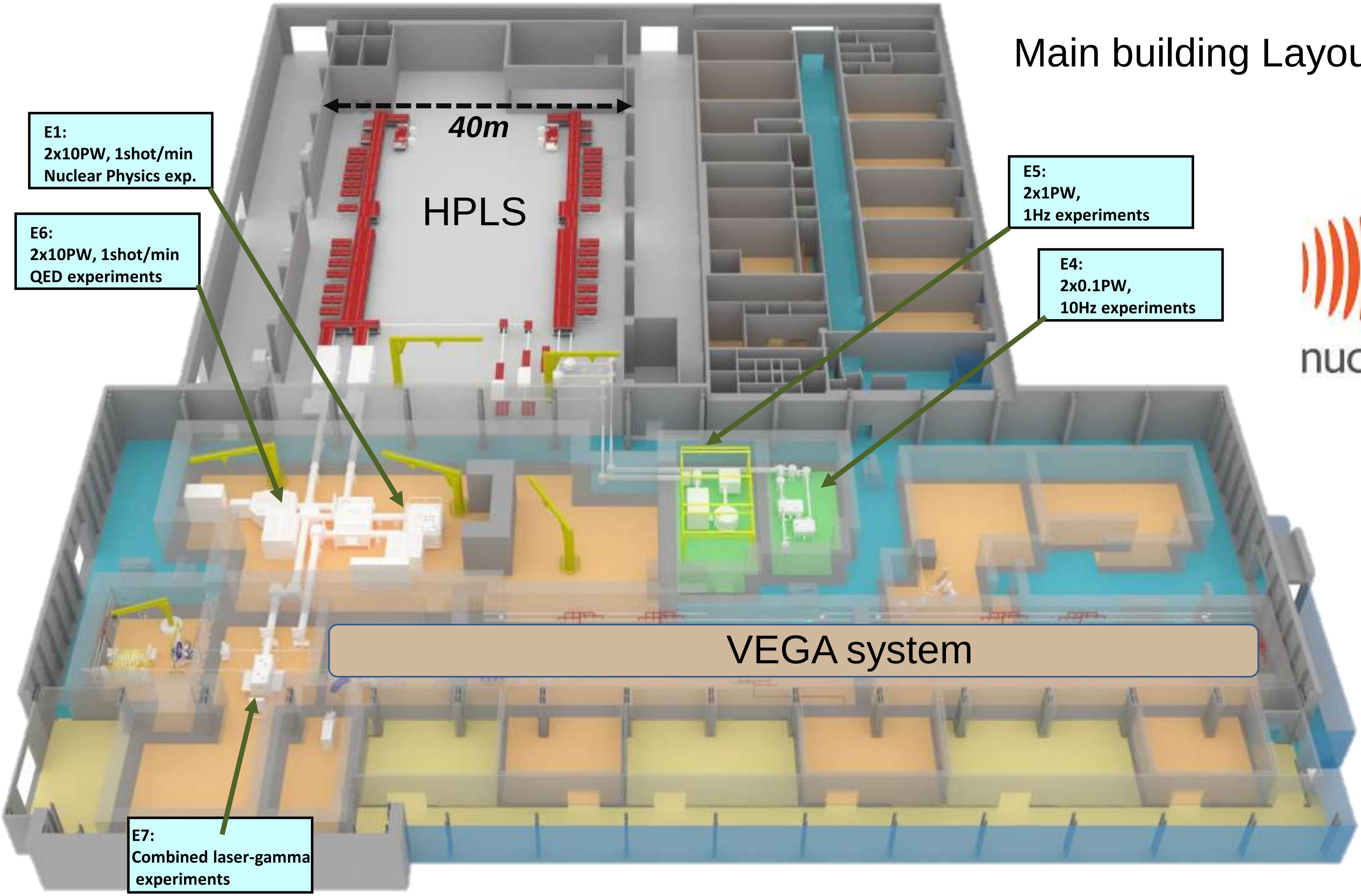


Measured parameters of the HPLS

Output type	100 TW	1 PW	10 PW
Pulse energy (J) *	2.7	25	242
Pulse duration (fs) **	< 25	< 24	<23
Repetition rate (Hz)	10	1	1/60
Calculated Strehl ratio from measured wavefront	> 0.9	> 0.9	> 0.9
Pointing stability (μrad RMS)	< 3.4	< 1.78	< 1.27
Pulse energy stability (rms)	< 2.6 %	< 1.8 %	< 1.8 %

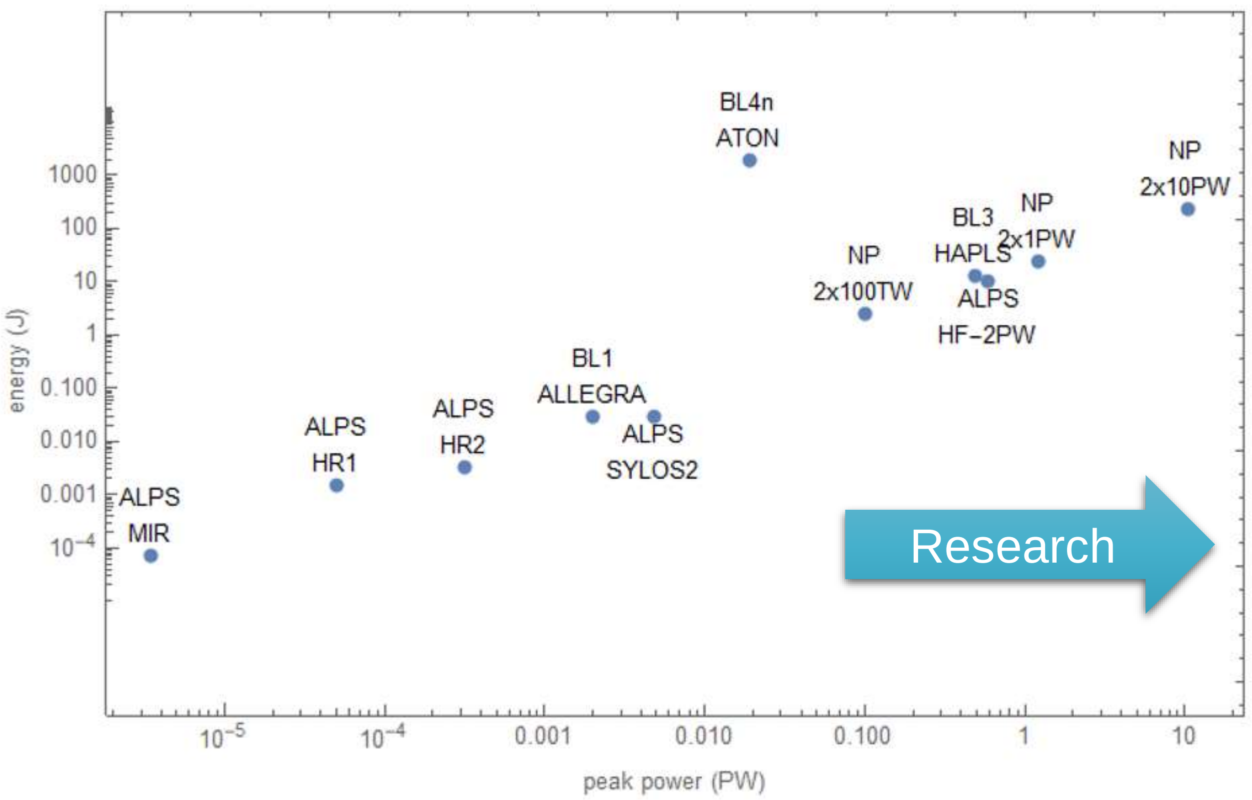
*Calculated considering the transmission efficiency of temporal compressors
**Measured with attenuated input energy in the compressors
***Front End demonstrated ps contrast - In the range of 10^{13}:1

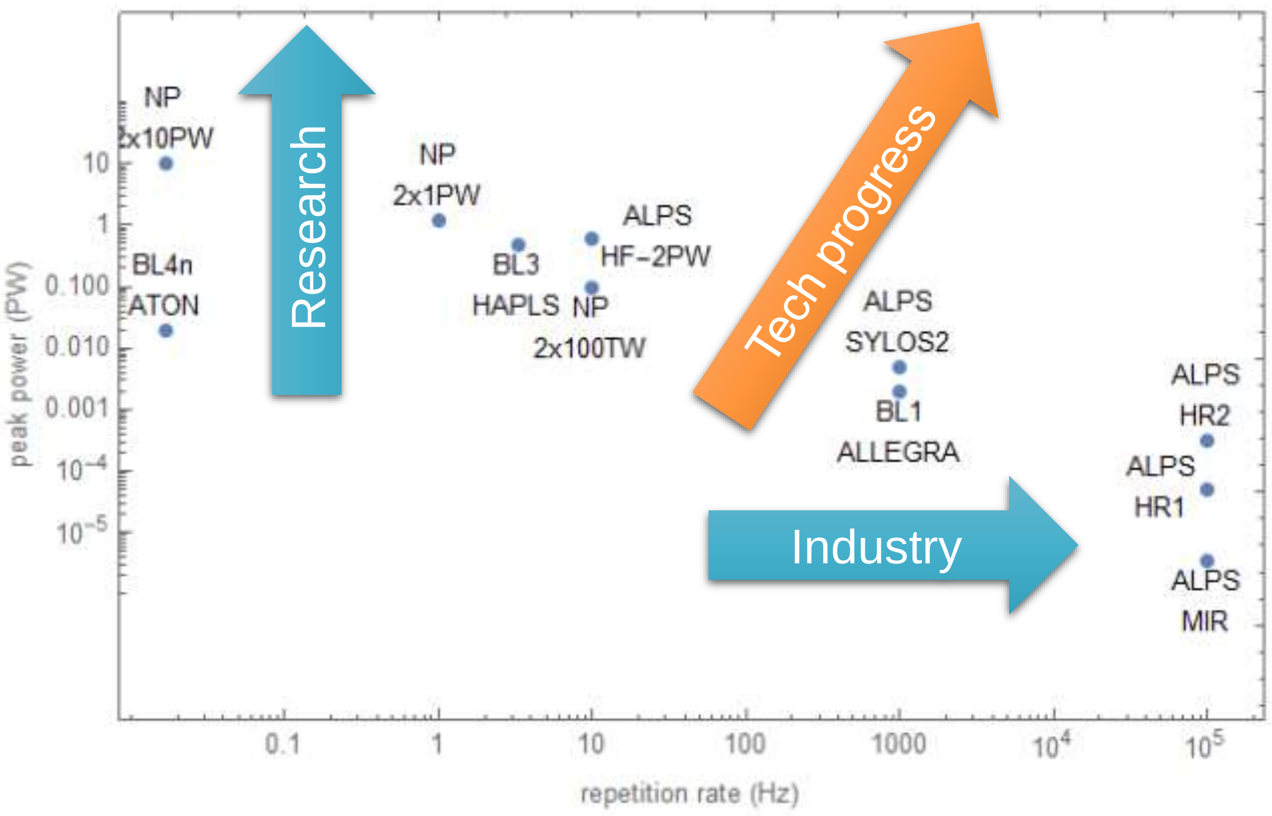
Main building Layout



eli nuclear physics

ELI performance @ end of 2020





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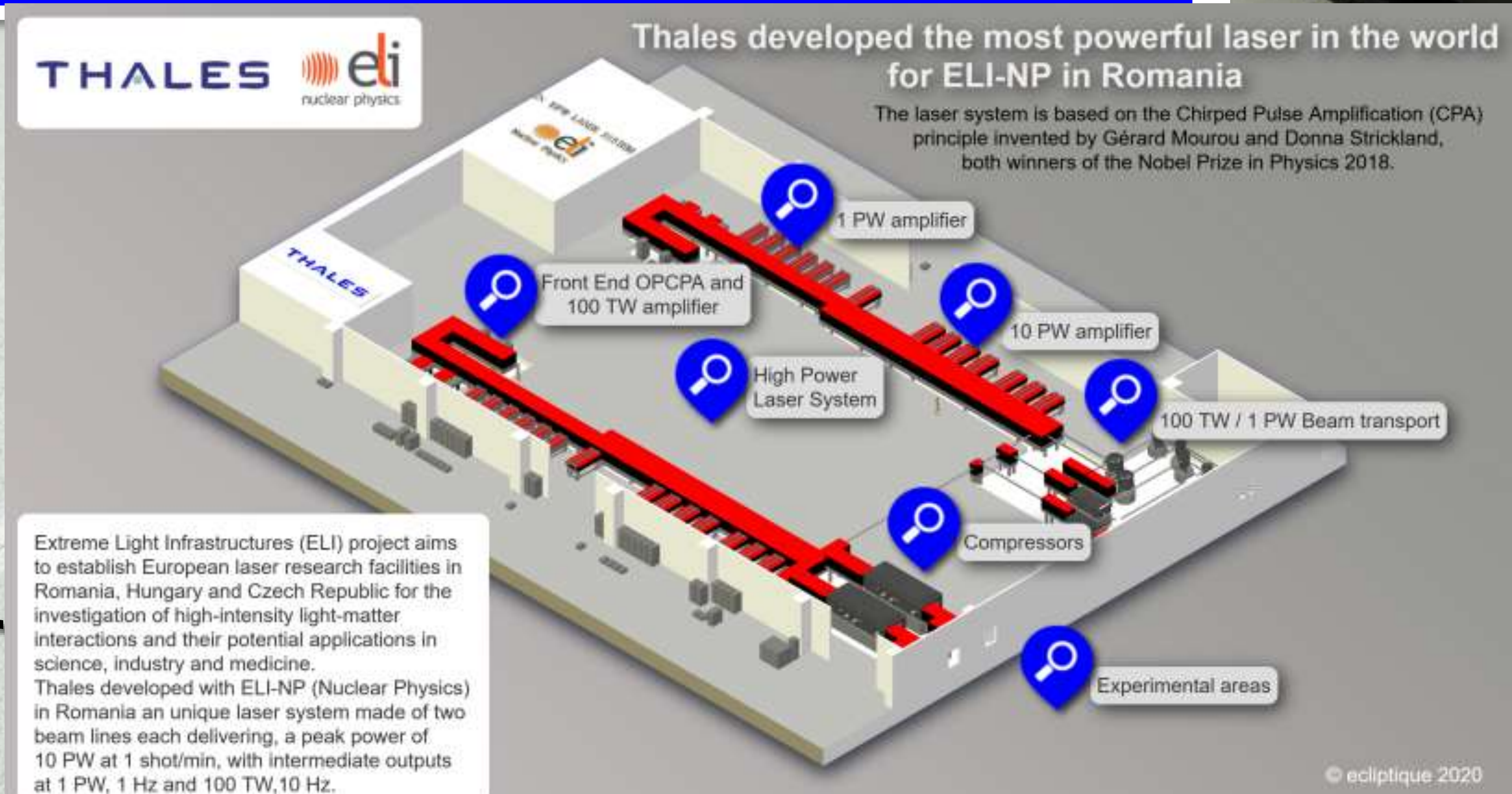
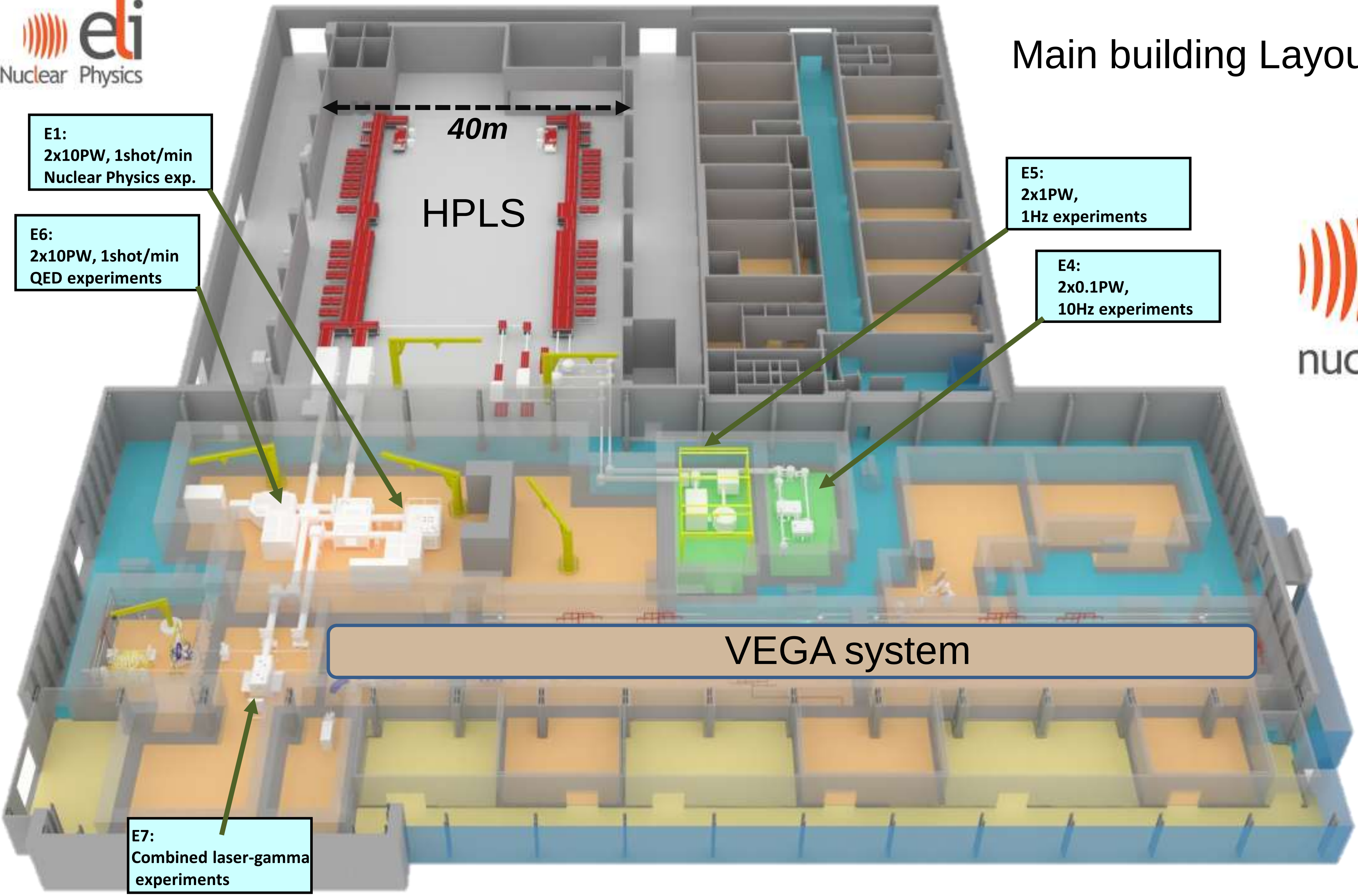
Virtual tour of the ELI-NP laser system

https://www.eli-np.ro/thales_eli-np.php



High power laser

Main building Layout



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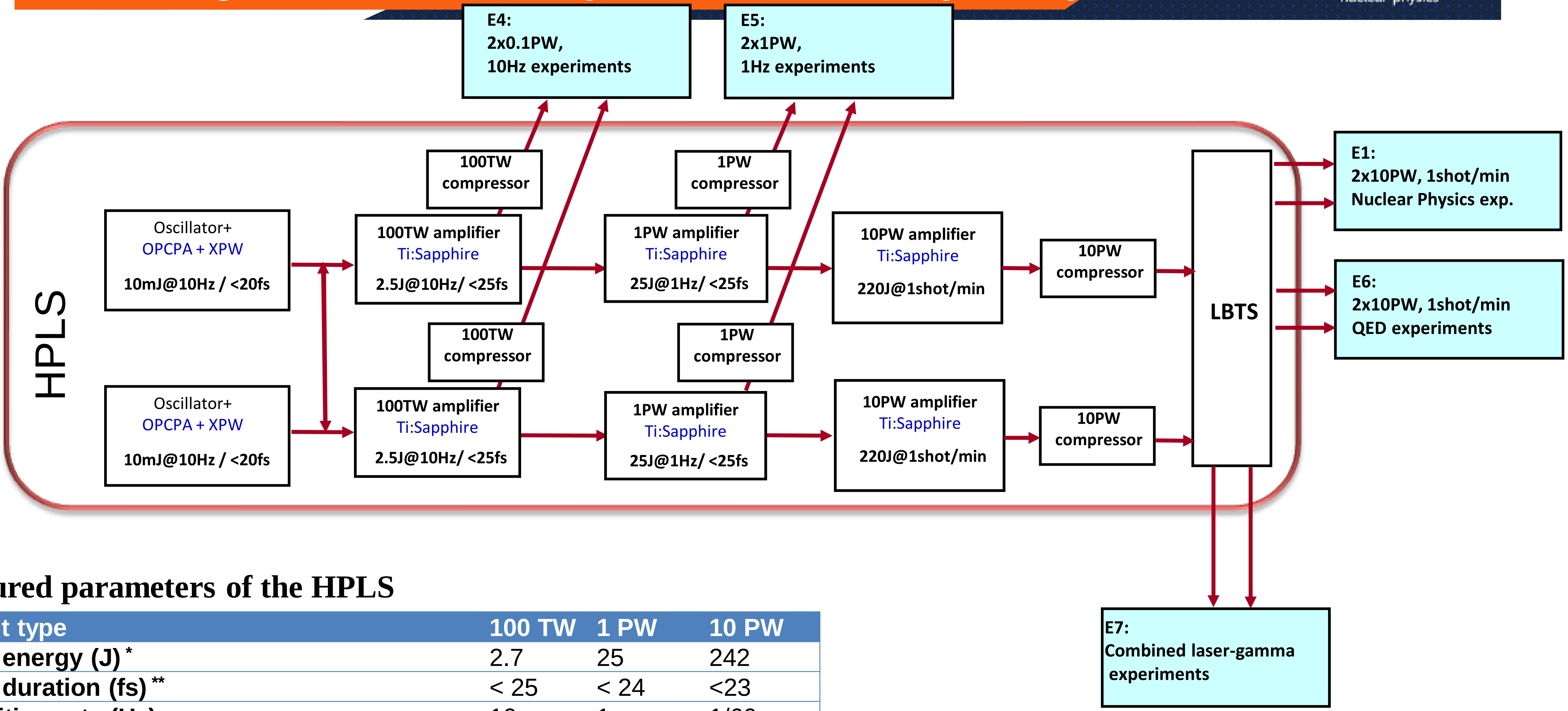

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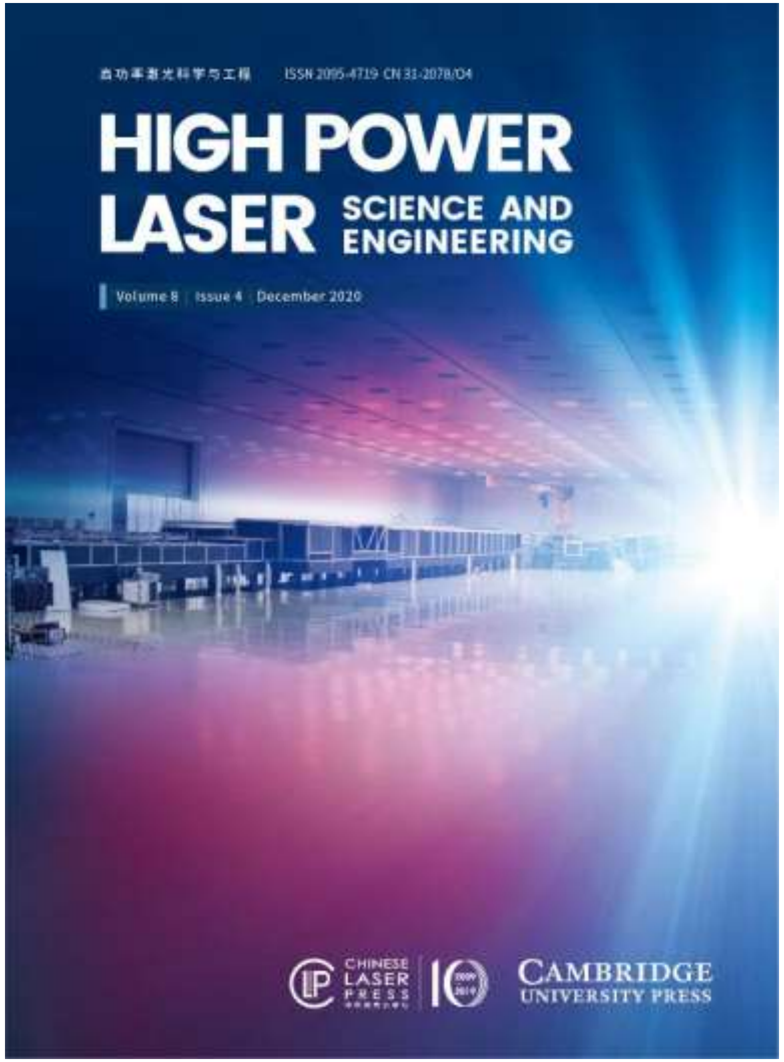

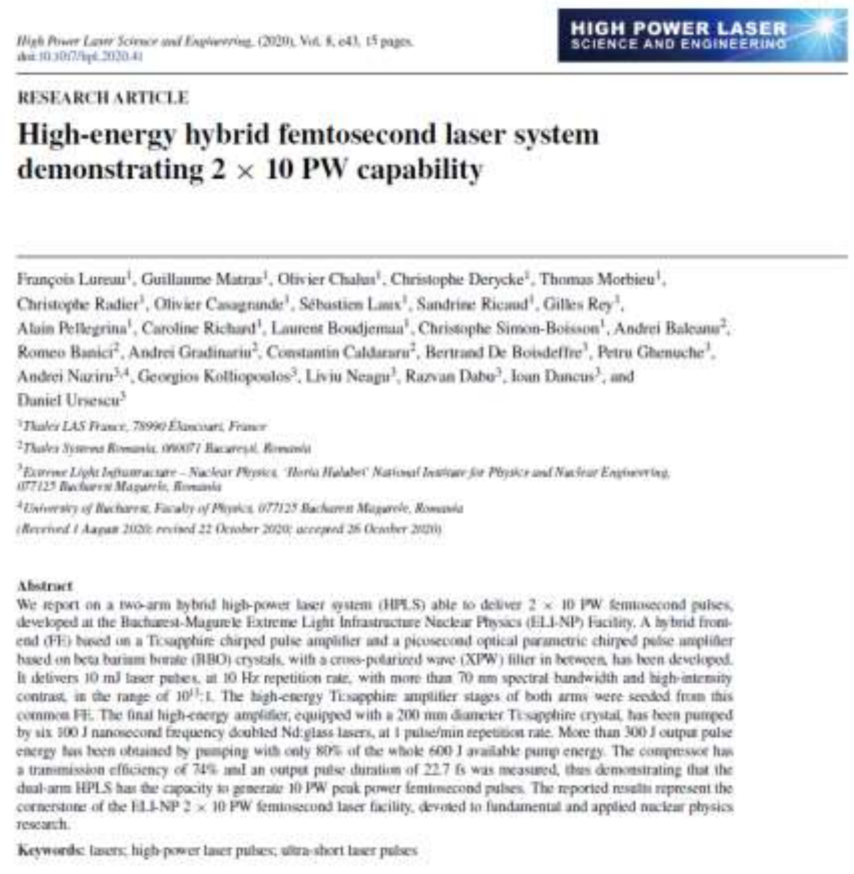

High Power Laser Science and Engineering, (2020), Vol. 8, e43, 15 pages.
doi:10.1017/hpl.2020.41

HIGH POWER LASER SCIENCE AND ENGINEERING

RESEARCH ARTICLE

High-energy hybrid femtosecond laser system demonstrating 2 × 10 PW capability

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[2]*Thales Systems Romania, 060071 Bucureşti, Romania*
[3]*Extreme Light Infrastructure – Nuclear Physics, 'Horia Hulubei' National Institute for Physics and Nuclear Engineering, 077125 Bucharest Magurele, Romania*
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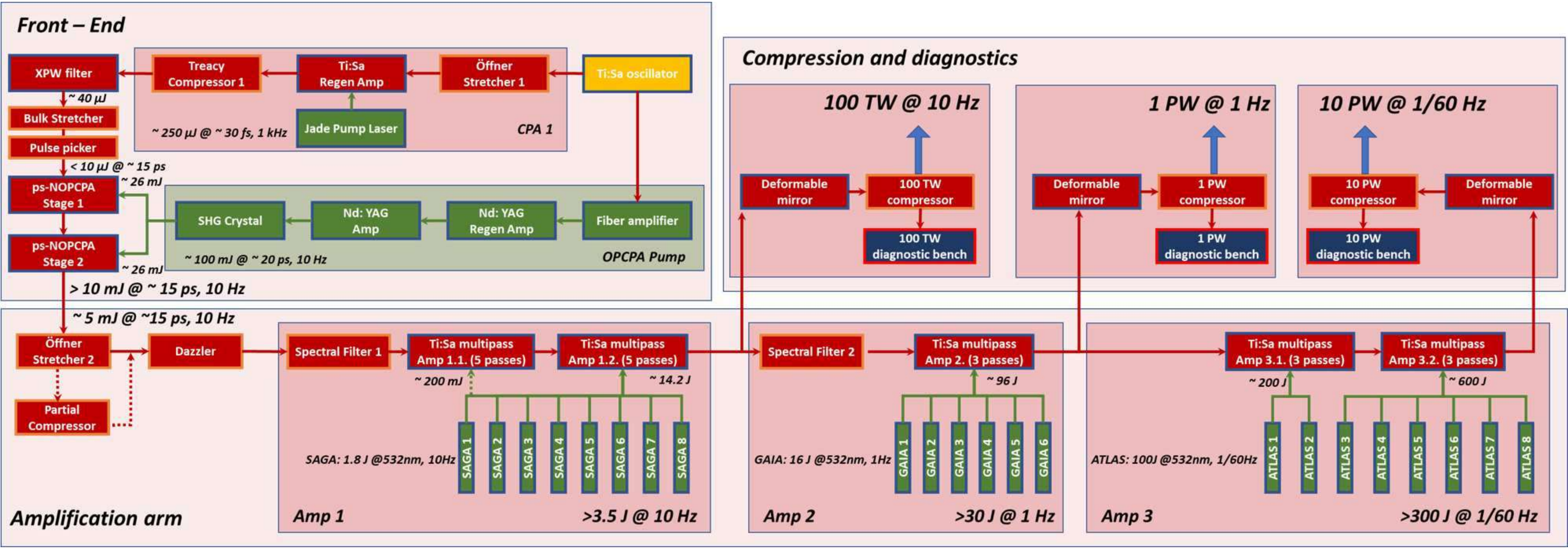
(Received 1 August 2020; revised 22 October 2020; accepted 26 October 2020)

Abstract
We report on a two-arm hybrid high-power laser system (HPLS) able to deliver 2 × 10 PW femtosecond pulses, developed at the Bucharest-Magurele Extreme Light Infrastructure Nuclear Physics (ELI-NP) Facility. A hybrid front-end (FE) based on a Ti:sapphire chirped pulse amplifier and a picosecond optical parametric chirped pulse amplifier based on beta barium borate (BBO) crystals, with a cross-polarized wave (XPW) filter in between, has been developed. It delivers 10 mJ laser pulses, at 10 Hz repetition rate, with more than 70 nm spectral bandwidth and high-intensity contrast, in the range of 10^{13}:1. The high-energy Ti:sapphire amplifier stages of both arms were seeded from this common FE. The final high-energy amplifier, equipped with a 200 mm diameter Ti:sapphire crystal, has been pumped by six 100 J nanosecond frequency doubled Nd:glass lasers, at 1 pulse/min repetition rate. More than 300 J output pulse energy has been obtained by pumping with only 80% of the whole 600 J available pump energy. The compressor has a transmission efficiency of 74% and an output pulse duration of 22.7 fs was measured, thus demonstrating that the dual-arm HPLS has the capacity to generate 10 PW peak power femtosecond pulses. The reported results represent the cornerstone of the ELI-NP 2 × 10 PW femtosecond laser facility, devoted to fundamental and applied nuclear physics research.

Keywords: lasers; high-power laser pulses; ultra-short laser pulses

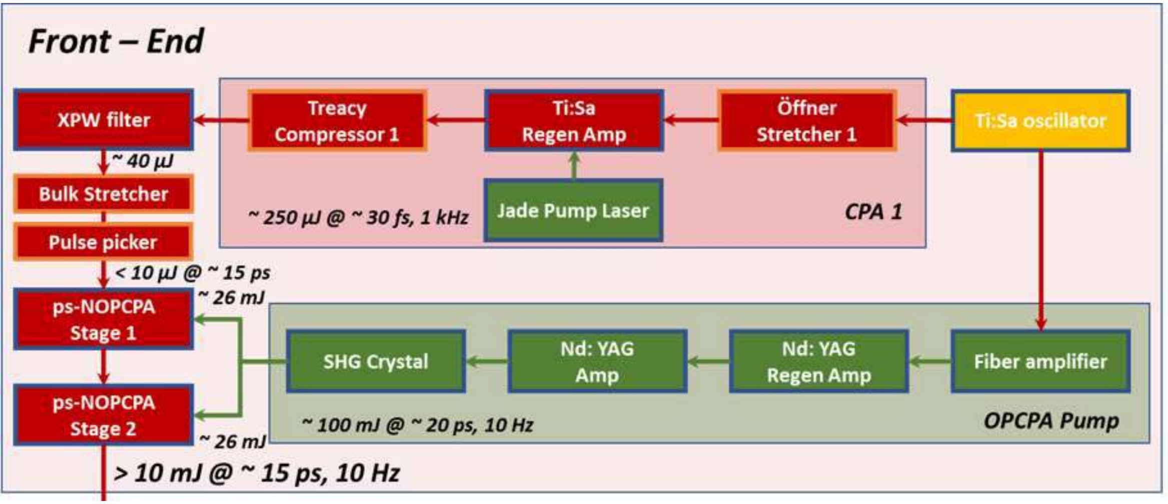
Open access Milestone article on HPLS

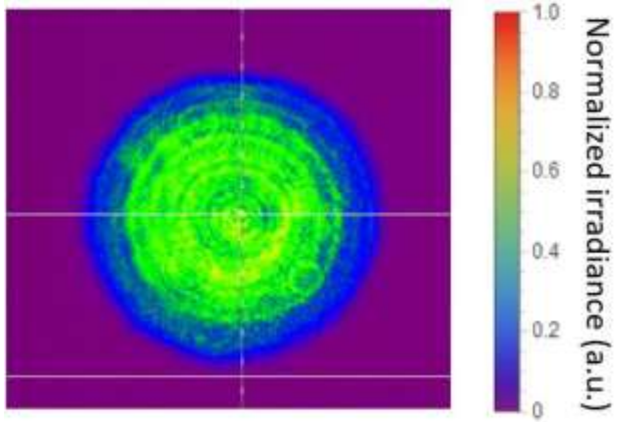
HPLS layout



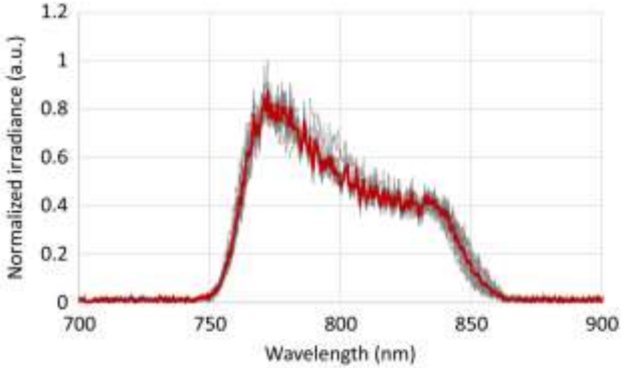
Front – End
XPW filter
Treacy Compressor 1
Ti:Sa Regen Amp
Öffner Stretcher 1
Ti:Sa oscillator
~ 40 μJ
Bulk Stretcher
Pulse picker
~ 250 μJ @ ~ 30 fs, 1 kHz
Jade Pump Laser
CPA 1
< 10 μJ @ ~ 15 ps
~ 26 mJ
ps-NOPCPA Stage 1
SHG Crystal
Nd: YAG Amp
Nd: YAG Regen Amp
Fiber amplifier
ps-NOPCPA Stage 2
~ 100 mJ @ ~ 20 ps, 10 Hz
OPCPA Pump
~ 26 mJ
> 10 mJ @ ~ 15 ps, 10 Hz
Compression and diagnostics
100 TW @ 10 Hz
Deformable mirror
100 TW compressor
100 TW diagnostic bench
1 PW @ 1 Hz
Deformable mirror
1 PW compressor
1 PW diagnostic bench
10 PW @ 1/60 Hz
10 PW compressor
Deformable mirror
10 PW diagnostic bench
~ 5 mJ @ ~15 ps, 10 Hz
Öffner Stretcher 2
Dazzler
Spectral Filter 1
Ti:Sa multipass Amp 1.1. (5 passes)
Ti:Sa multipass Amp 1.2. (5 passes)
Partial Compressor
~ 200 mJ
~ 14.2 J
SAGA: 1.8 J @532nm, 10Hz
SAGA 1
SAGA 2
SAGA 3
SAGA 4
SAGA 5
SAGA 6
SAGA 7
SAGA 8
Amplification arm
Amp 1
>3.5 J @ 10 Hz
Spectral Filter 2
Ti:Sa multipass Amp 2. (3 passes)
~ 96 J
GAIA: 16 J @532nm, 1Hz
GAIA 1
GAIA 2
GAIA 3
GAIA 4
GAIA 5
GAIA 6
Amp 2
>30 J @ 1 Hz
Ti:Sa multipass Amp 3.1. (3 passes)
Ti:Sa multipass Amp 3.2. (3 passes)
~ 200 J
~ 600 J
ATLAS: 100J @532nm, 1/60Hz
ATLAS 1
ATLAS 2
ATLAS 3
ATLAS 4
ATLAS 5
ATLAS 6
ATLAS 7
ATLAS 8
Amp 3
>300 J @ 1/60 Hz

HPLS front-end

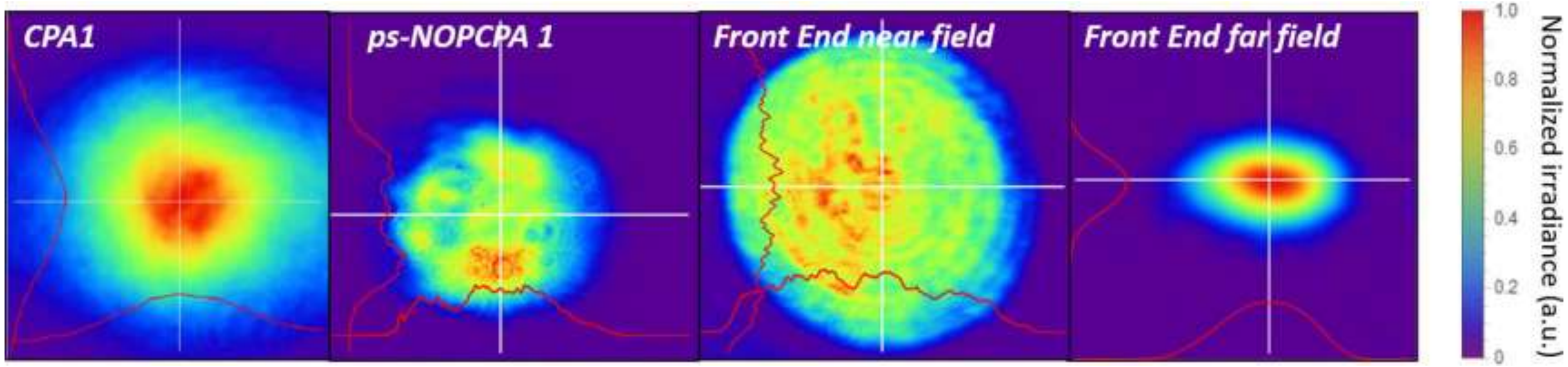


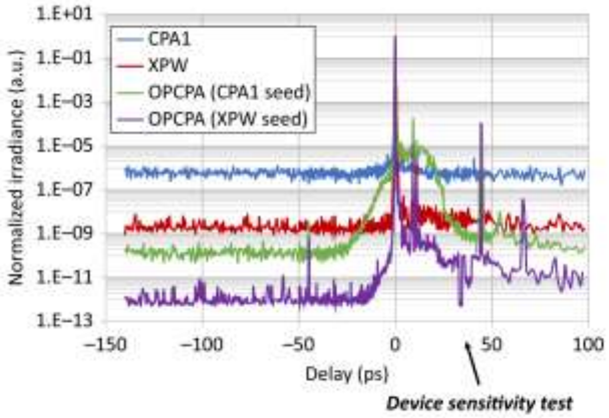


Near-field beam intensity profile of the 532 nm picosecond pump laser for OPCPA

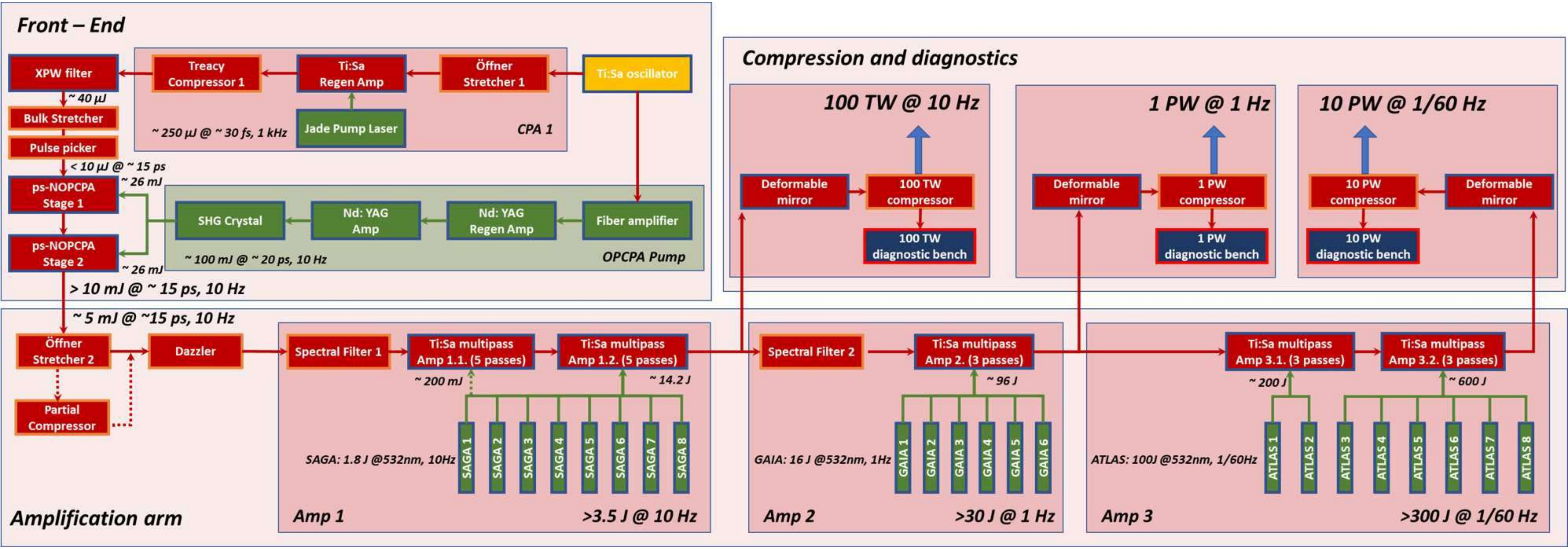


Stability of the OPCPA spectrum over 7 h continuous operation. The red curve is the average (data acquired each 10 min)





HPLS layout



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SHG Crystal
Nd: YAG Amp
Nd: YAG Regen Amp
Fiber amplifier
ps-NOPCPA Stage 2
~ 100 mJ @ ~ 20 ps, 10 Hz
OPCPA Pump
~ 26 mJ
> 10 mJ @ ~ 15 ps, 10 Hz
Compression and diagnostics
100 TW @ 10 Hz
Deformable mirror
100 TW compressor
100 TW diagnostic bench
1 PW @ 1 Hz
Deformable mirror
1 PW compressor
1 PW diagnostic bench
10 PW @ 1/60 Hz
10 PW compressor
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~ 5 mJ @ ~15 ps, 10 Hz
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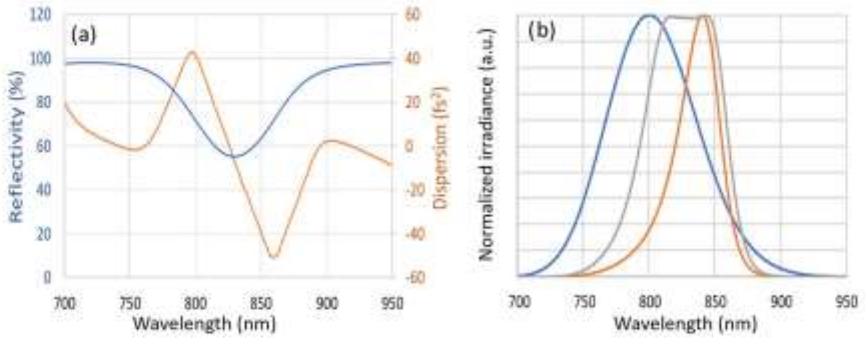
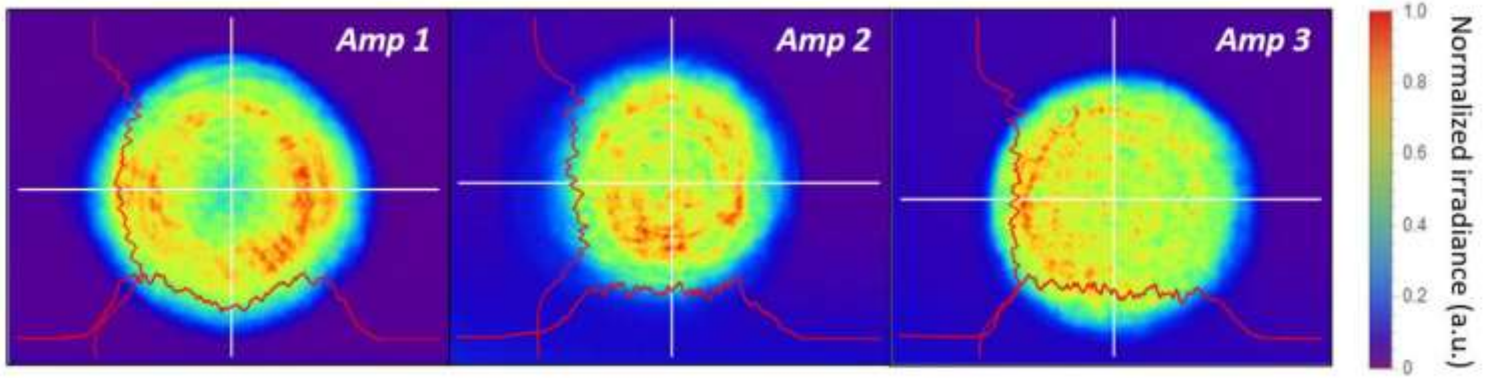
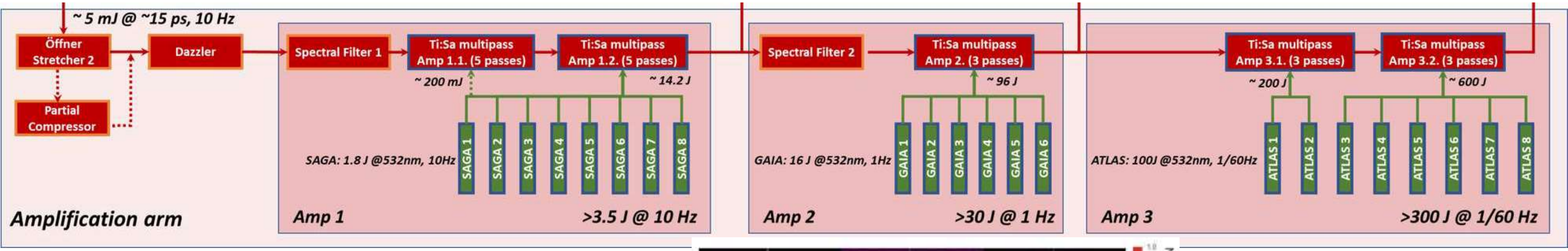
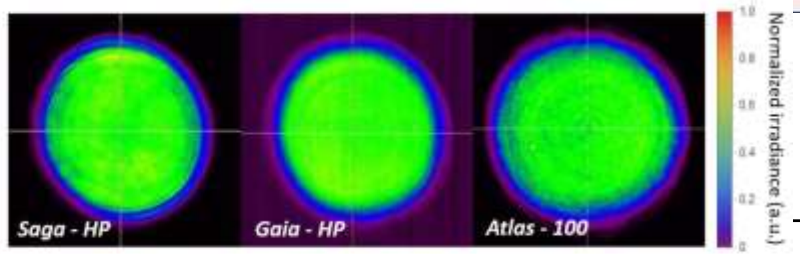
Dazzler
Spectral Filter 1
Ti:Sa multipass Amp 1.1. (5 passes)
Ti:Sa multipass Amp 1.2. (5 passes)
Spectral Filter 2
Ti:Sa multipass Amp 2. (3 passes)
Ti:Sa multipass Amp 3.1. (3 passes)
Ti:Sa multipass Amp 3.2. (3 passes)
Partial Compressor
~ 200 mJ
~ 14.2 J
~ 96 J
~ 200 J
~ 600 J
SAGA: 1.8 J @532nm, 10Hz
SAGA 1
SAGA 2
SAGA 3
SAGA 4
SAGA 5
SAGA 6
SAGA 7
SAGA 8
GAIA: 16 J @532nm, 1Hz
GAIA 1
GAIA 2
GAIA 3
GAIA 4
GAIA 5
GAIA 6
ATLAS: 100J @532nm, 1/60Hz
ATLAS 1
ATLAS 2
ATLAS 3
ATLAS 4
ATLAS 5
ATLAS 6
ATLAS 7
ATLAS 8
Amplification arm
Amp 1
>3.5 J @ 10 Hz
Amp 2
>30 J @ 1 Hz
Amp 3
>300 J @ 1/60 Hz

HPLS amplifiers

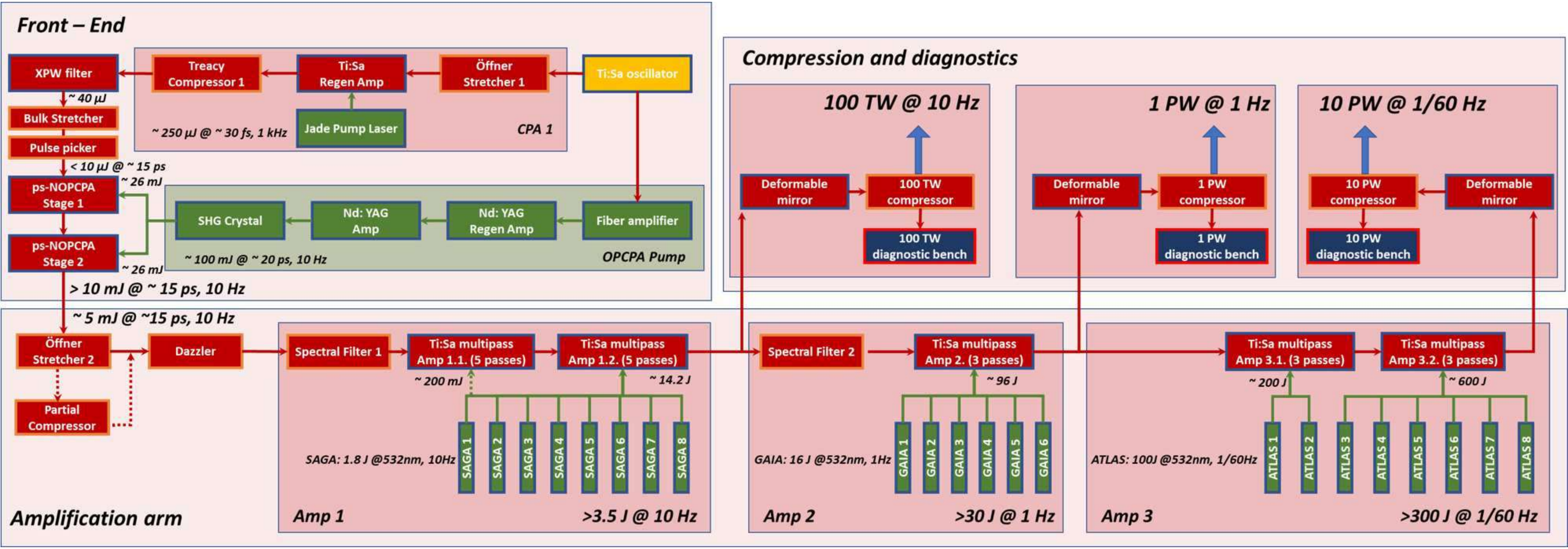








HPLS layout



Front – End
XPW filter
Treacy Compressor 1
Ti:Sa Regen Amp
Öffner Stretcher 1
Ti:Sa oscillator
~ 40 µJ
Bulk Stretcher
Pulse picker
~ 250 µJ @ ~ 30 fs, 1 kHz
Jade Pump Laser
CPA 1
< 10 µJ @ ~ 15 ps
~ 26 mJ
ps-NOPCPA Stage 1
SHG Crystal
Nd: YAG Amp
Nd: YAG Regen Amp
Fiber amplifier
ps-NOPCPA Stage 2
~ 100 mJ @ ~ 20 ps, 10 Hz
OPCPA Pump
~ 26 mJ
> 10 mJ @ ~ 15 ps, 10 Hz
Compression and diagnostics
100 TW @ 10 Hz
Deformable mirror
100 TW compressor
100 TW diagnostic bench
1 PW @ 1 Hz
Deformable mirror
1 PW compressor
1 PW diagnostic bench
10 PW @ 1/60 Hz
10 PW compressor
Deformable mirror
10 PW diagnostic bench
~ 5 mJ @ ~15 ps, 10 Hz
Öffner Stretcher 2
Dazzler
Spectral Filter 1
Ti:Sa multipass Amp 1.1. (5 passes)
Ti:Sa multipass Amp 1.2. (5 passes)
Spectral Filter 2
Ti:Sa multipass Amp 2. (3 passes)
Ti:Sa multipass Amp 3.1. (3 passes)
Ti:Sa multipass Amp 3.2. (3 passes)
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~ 200 mJ
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SAGA 6
SAGA 7
SAGA 8
GAIA: 16 J @532nm, 1Hz
GAIA 1
GAIA 2
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GAIA 4
GAIA 5
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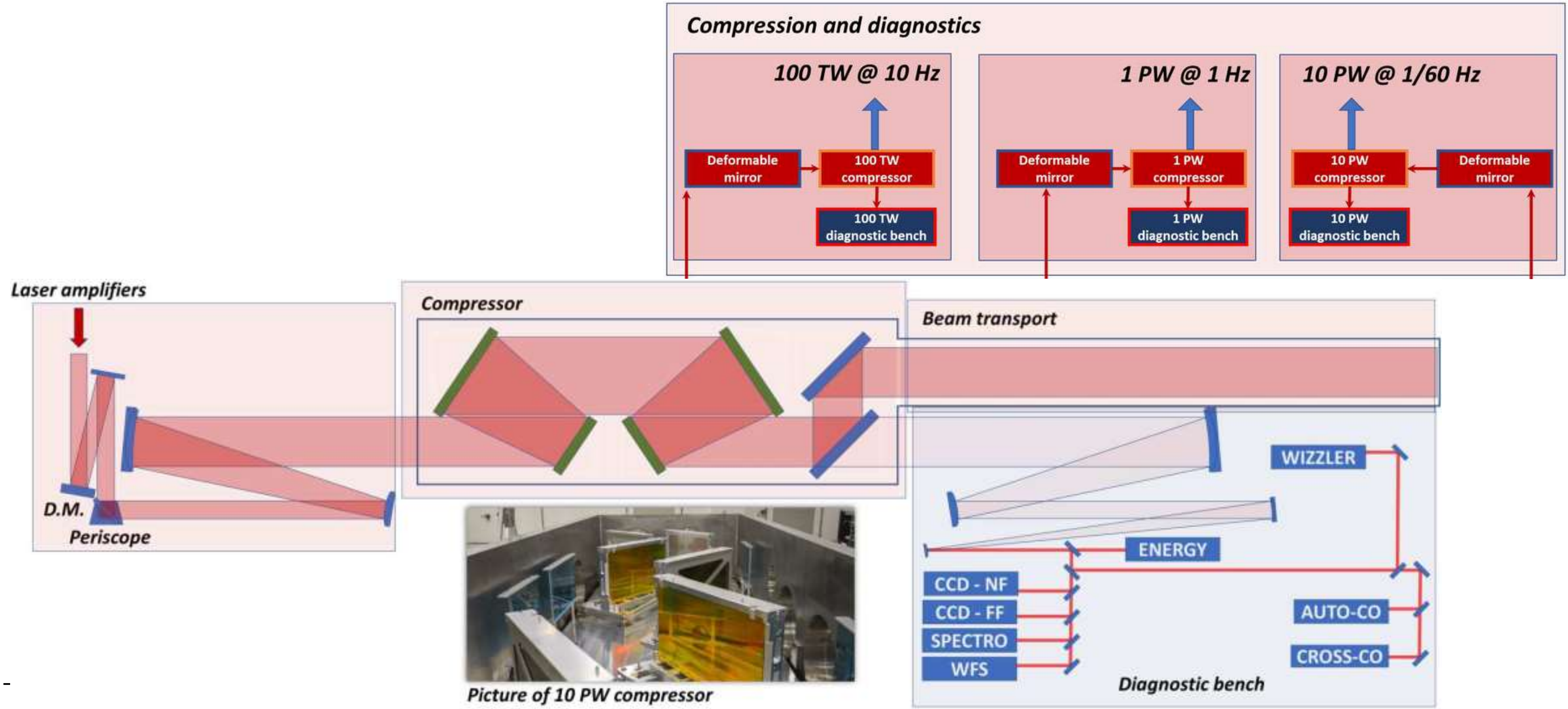
ATLAS 1
ATLAS 2
ATLAS 3
ATLAS 4
ATLAS 5
ATLAS 6
ATLAS 7
ATLAS 8
Amplification arm
Amp 1
>3.5 J @ 10 Hz
Amp 2
>30 J @ 1 Hz
Amp 3
>300 J @ 1/60 Hz

HPLS compressors and diagnostics



-

Contents

nuclear physics

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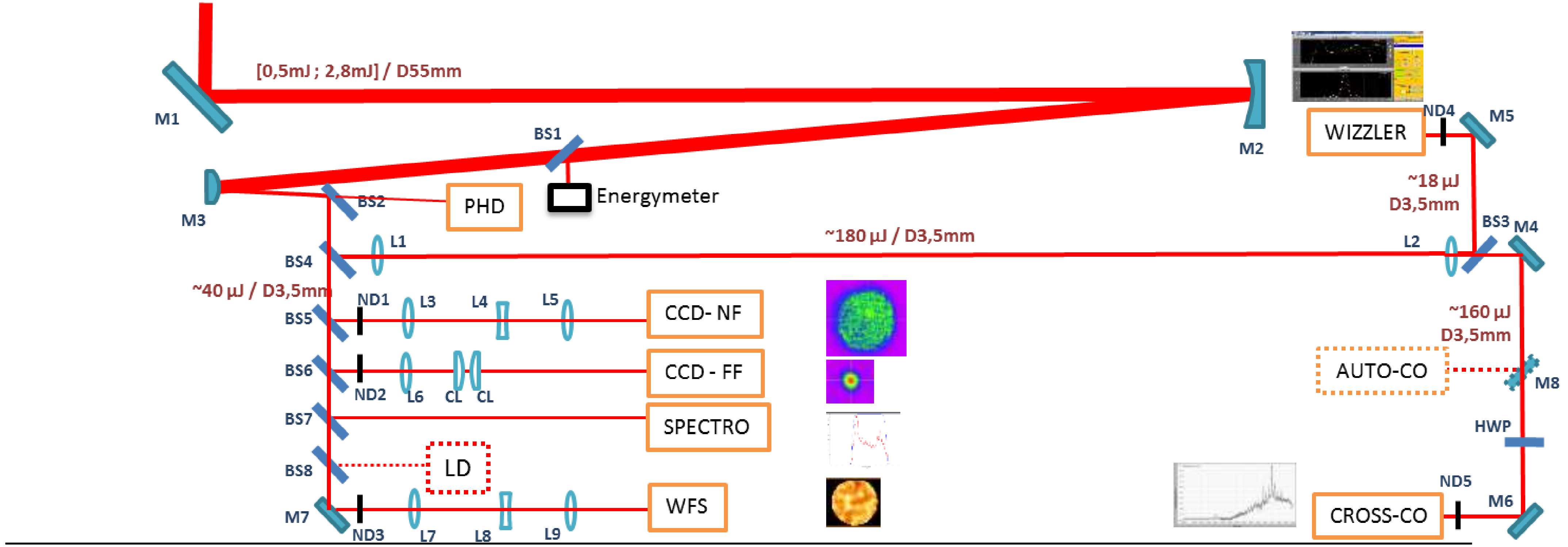
Experiment metrology

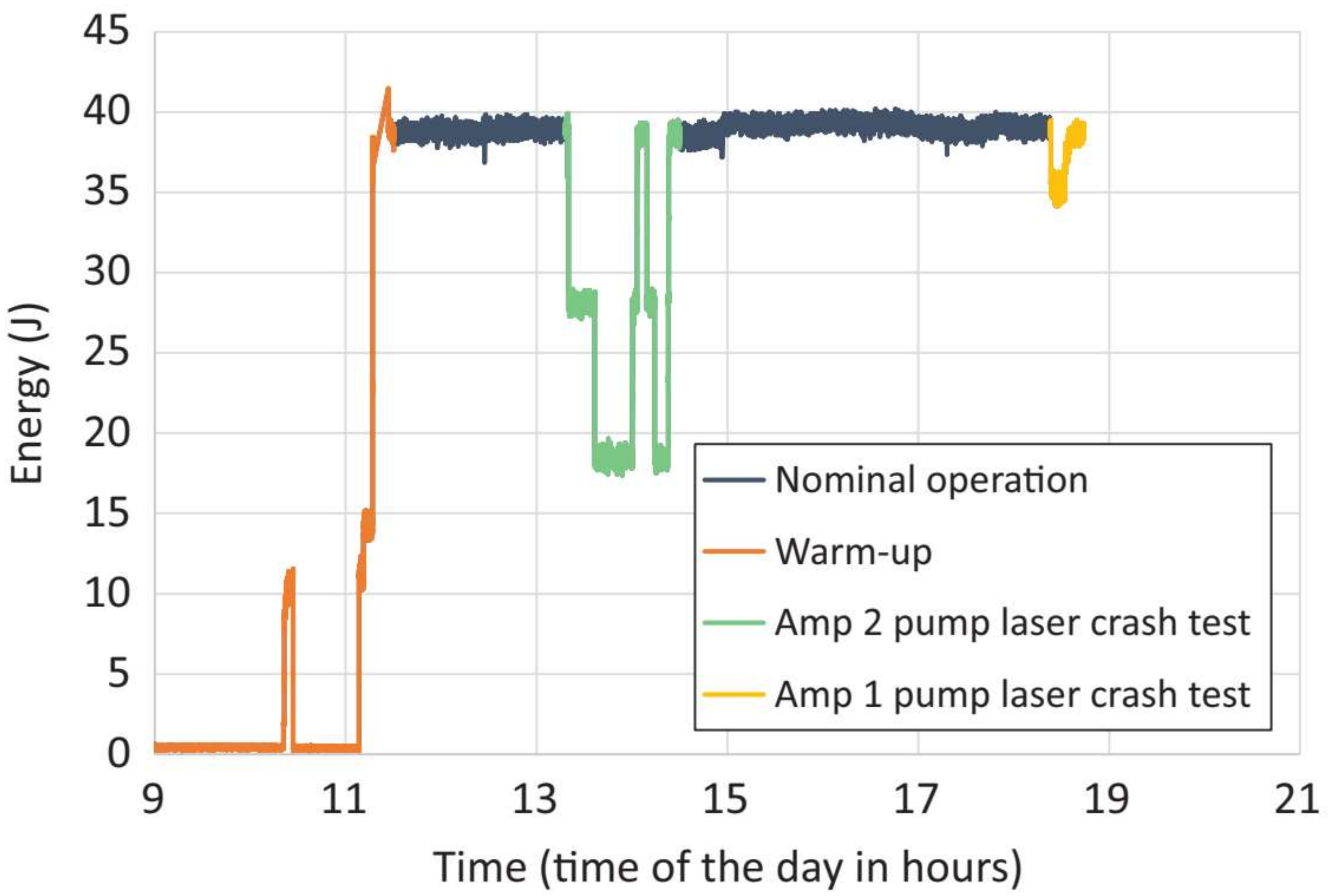
Measured parameters

- Pulse energy using energy-meter
- Spectral measurement using spectrometer
- Pulse duration using Phase retrieval device
- Near and far-field Beam profile using camera
- Strehl ratio and pointing stability using wavefront sensor
- Picosecond contrast using cross-correlator

$$\frac{E}{t\,S} = I$$



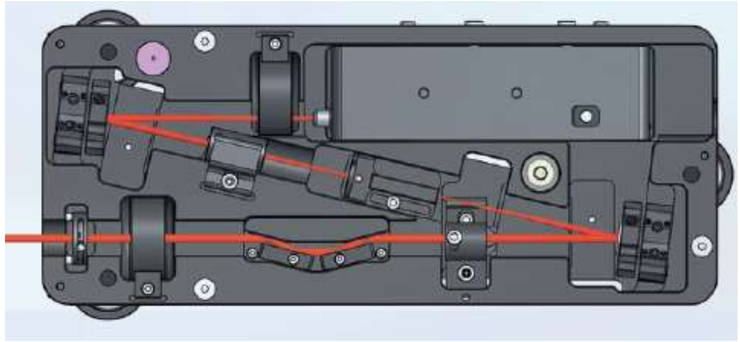
Energy stability for Amplifier 2

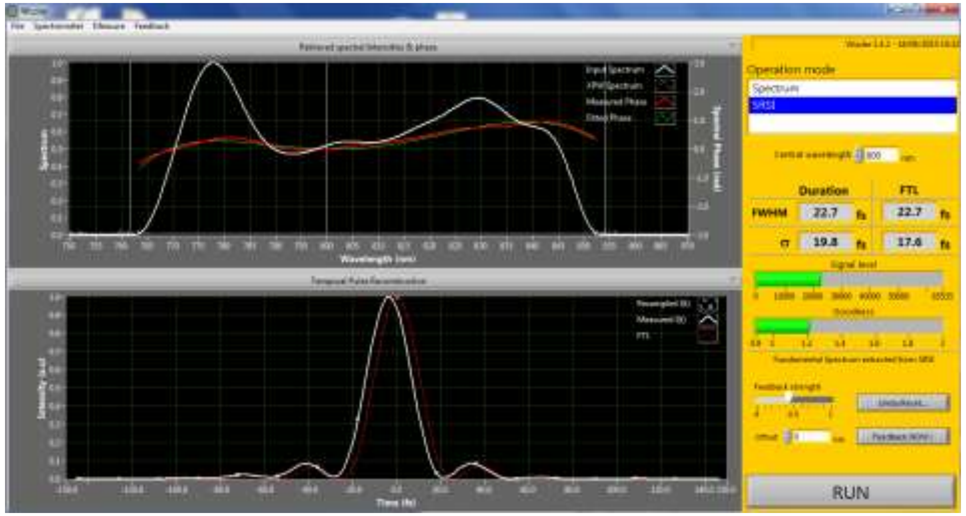


>25000 shots/day

Pulse duration measurement and control

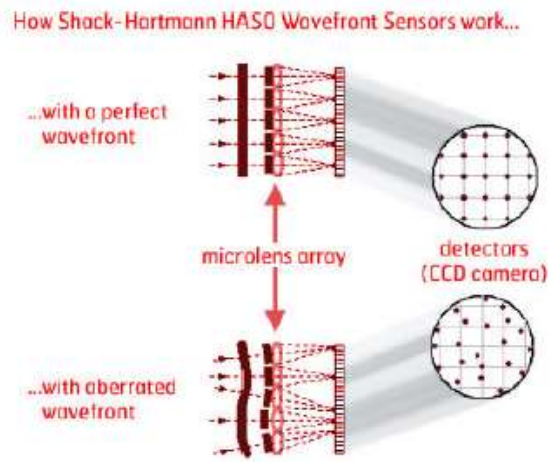
- Pulse width : Wizzler (Fastlite)
  - Pulse duration range : 20-100fs
  - Required pulse energy : 2-20 µJ
- Principle
  - XPW → reference pulse with flat spectral phase generated from the input pulse
  - spectral interference pattern resulting from the combination of the input pulse with reference pulse
  - the reference pulse allows direct retrieval of the spectral phase and intensity
- Pulse duration optimization with Dazzler
  - Wizzler calculates the phase mismatch between the current spectral phase and a flat spectral phase
  - The differences are recorded in a phase file shared with the Dazzler



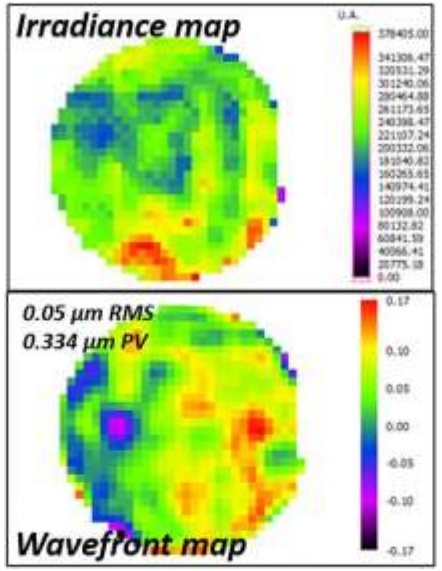


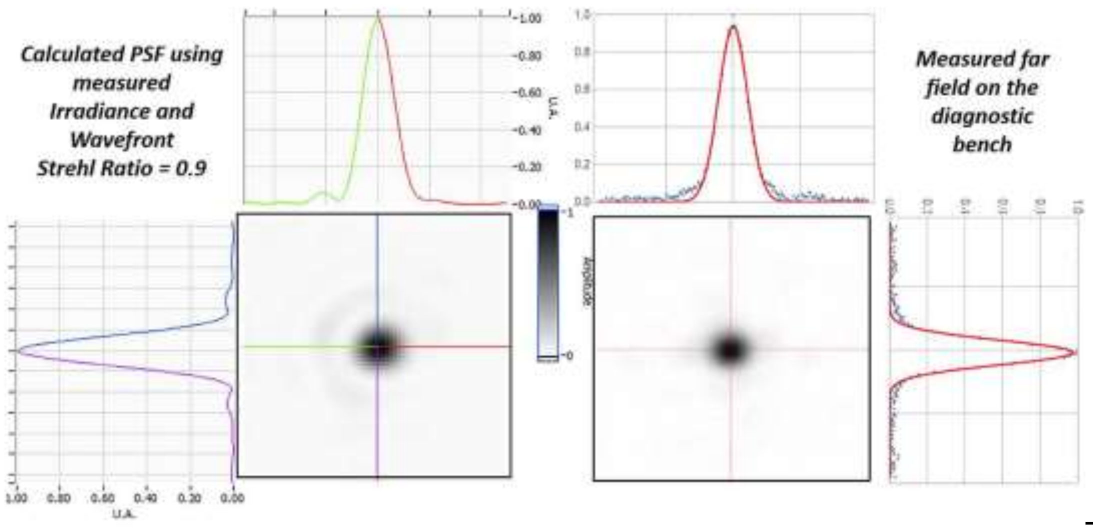
Wavefront measurement and control

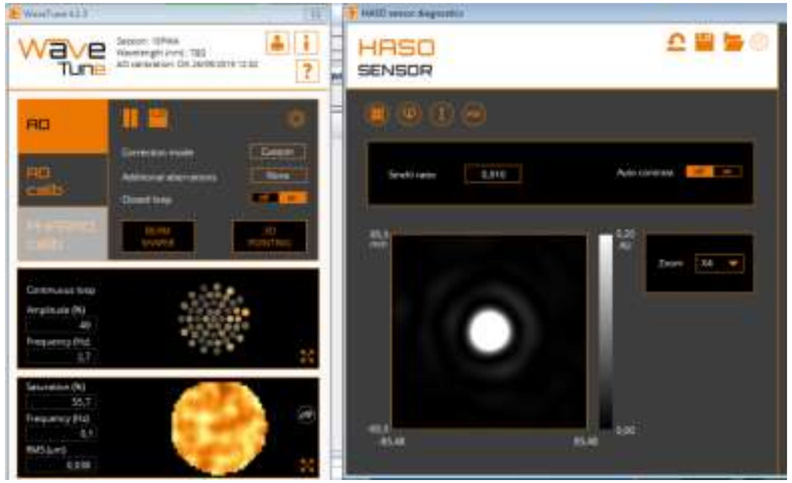
- Wavefront sensor : HASO (Imagine Optics)
  - Shack-Hartmann technology
  - Number of µ-lenses : 32x40
  - Wavefront measurement accuracy (rms) : $\lambda/150$
  - Working wavelength : 400-1100 nm



- Wavefront correction
  - Works in open or closed-loop with deformable mirror placed before each compressor input

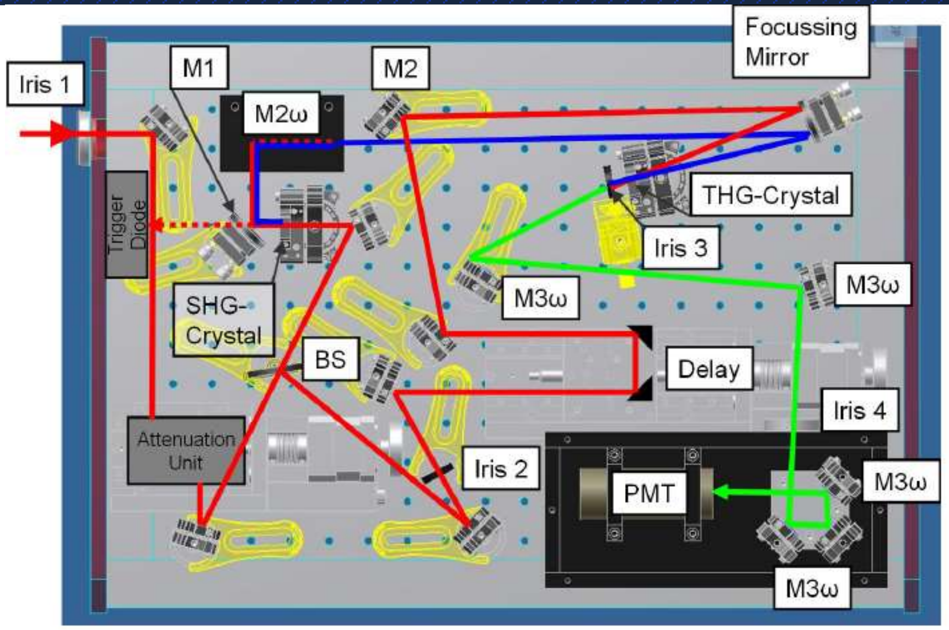


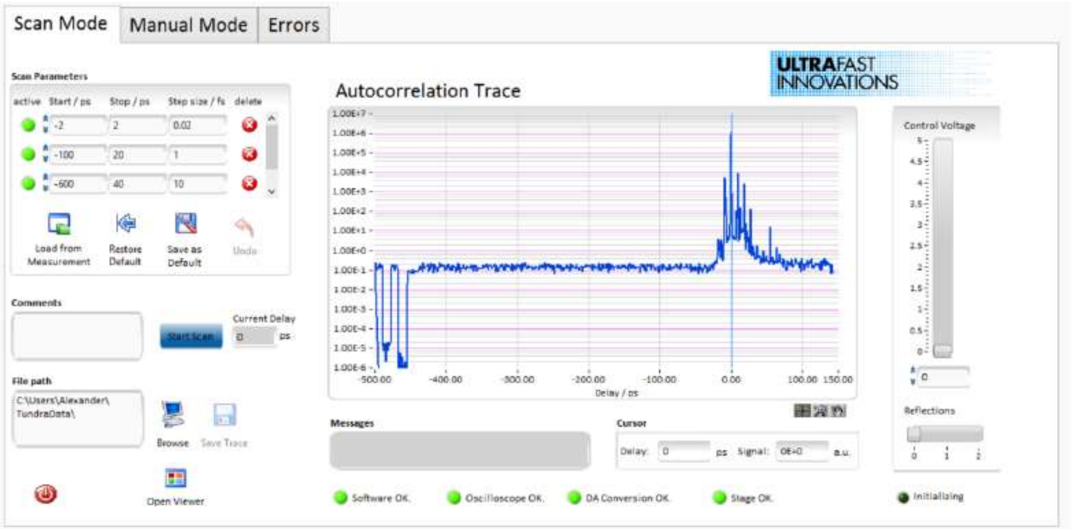




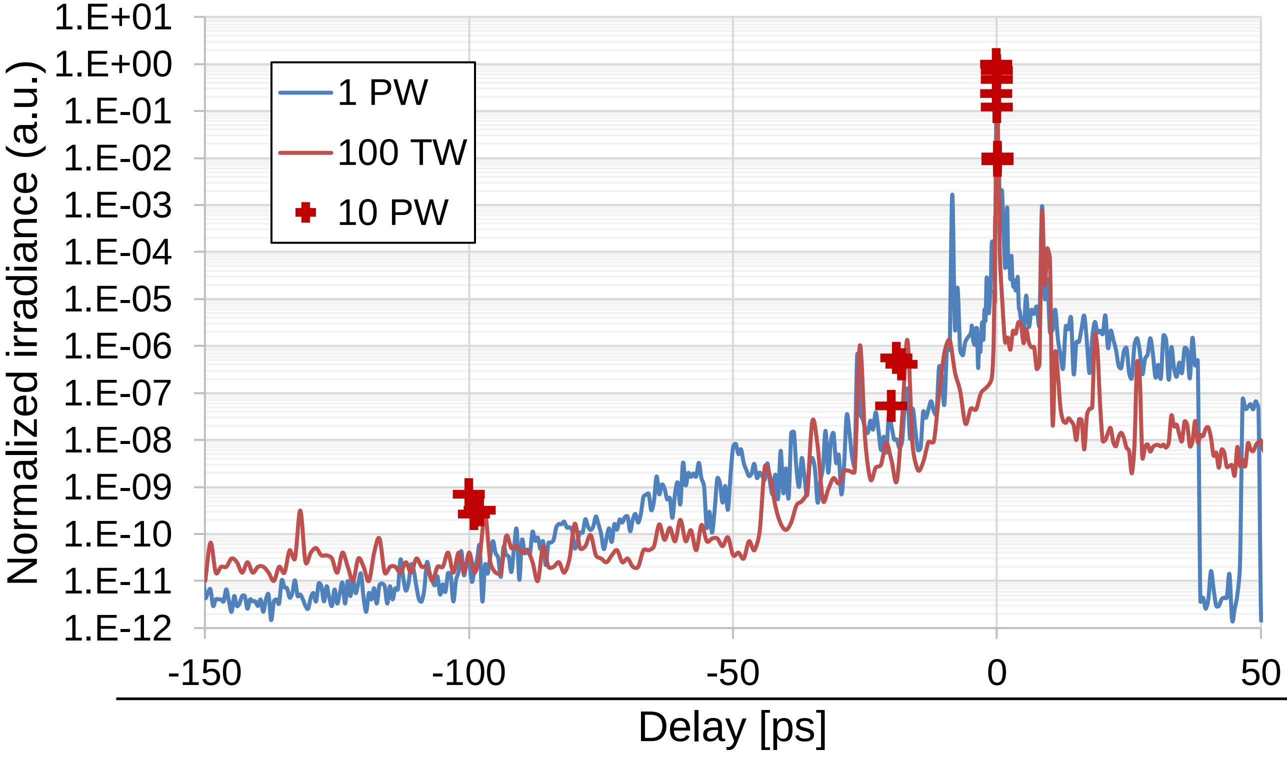
Temporal contrast measurement

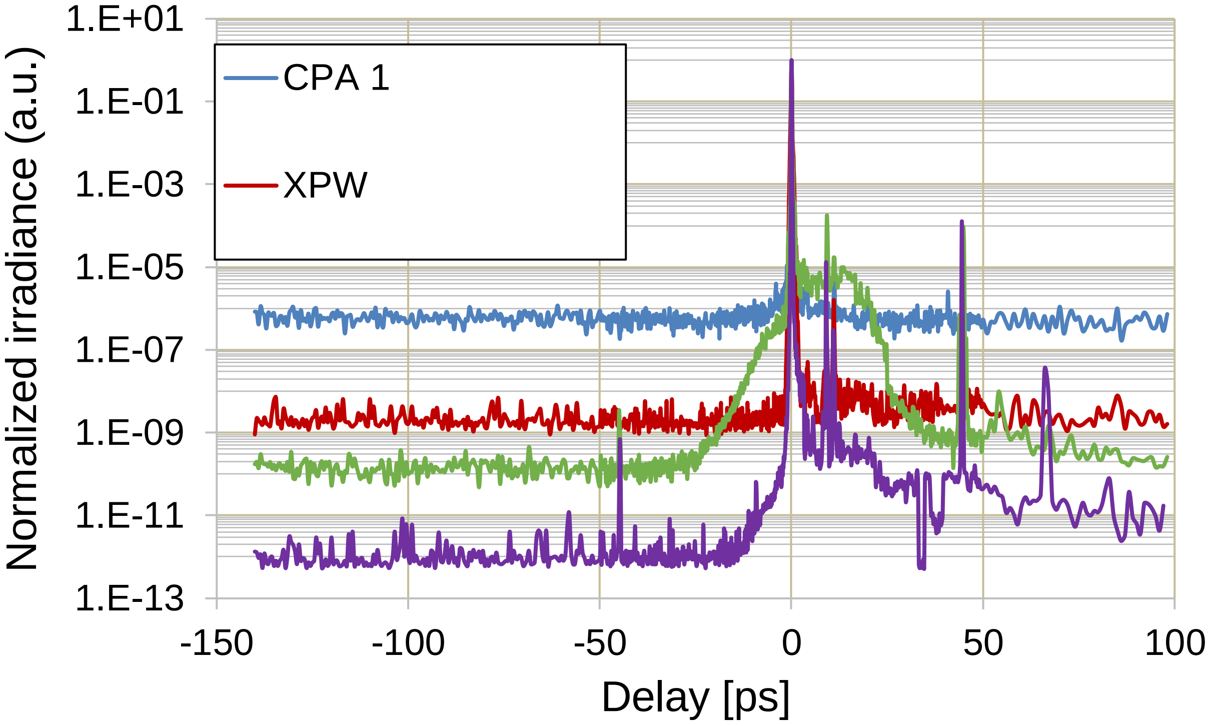
- Picosecond contrast : Tundra (Ultrafast Innovations)
  - Signal dynamic range : up to 11 orders of magnitude
  - Pulse energy range : 50-100µJ
  - Delay range : 633 ps
  - Scan resolution : down to 1 fs





Contrast measurements





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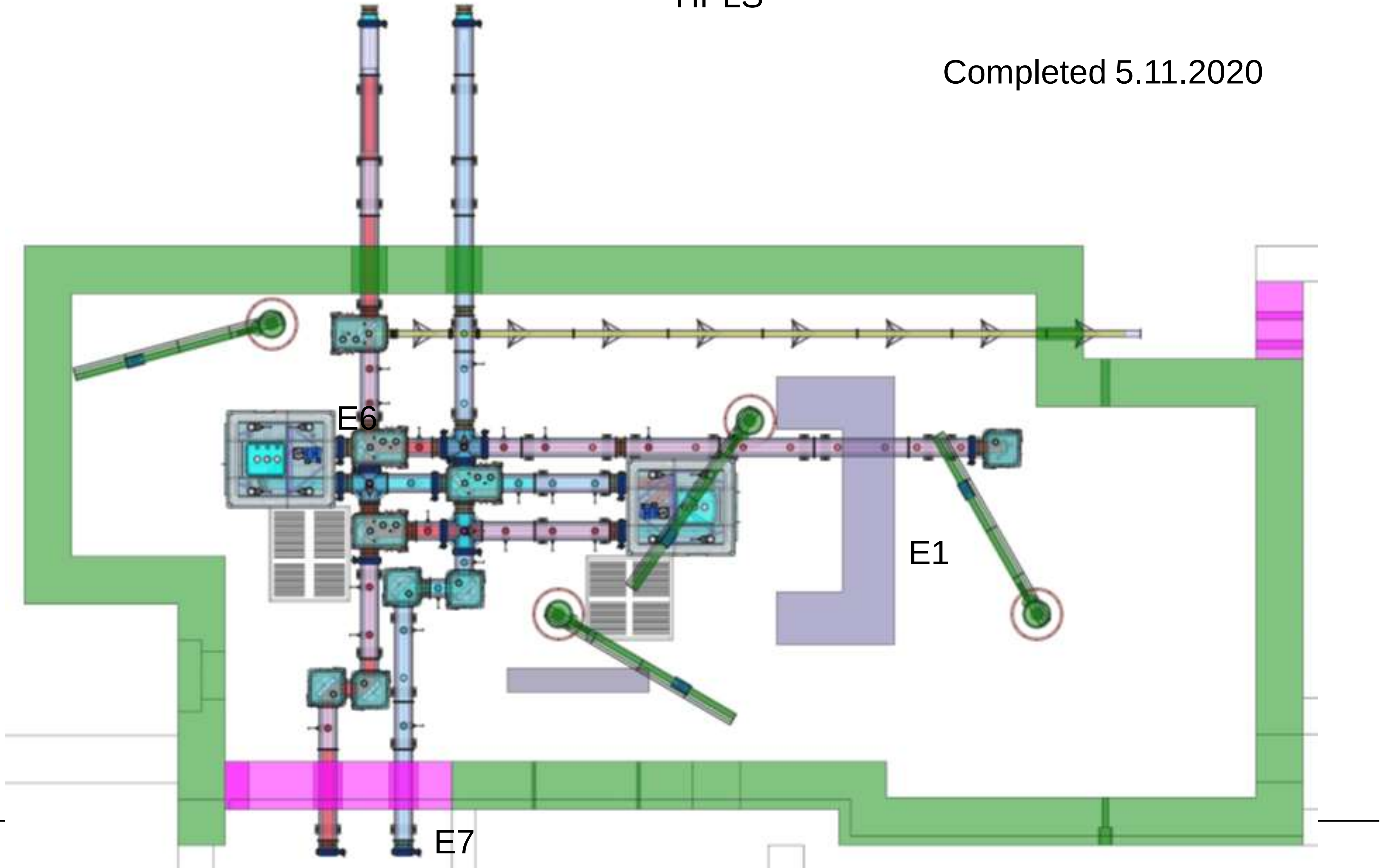
ELI-NP Laser Beam Transport System

HPLS

Completed 5.11.2020



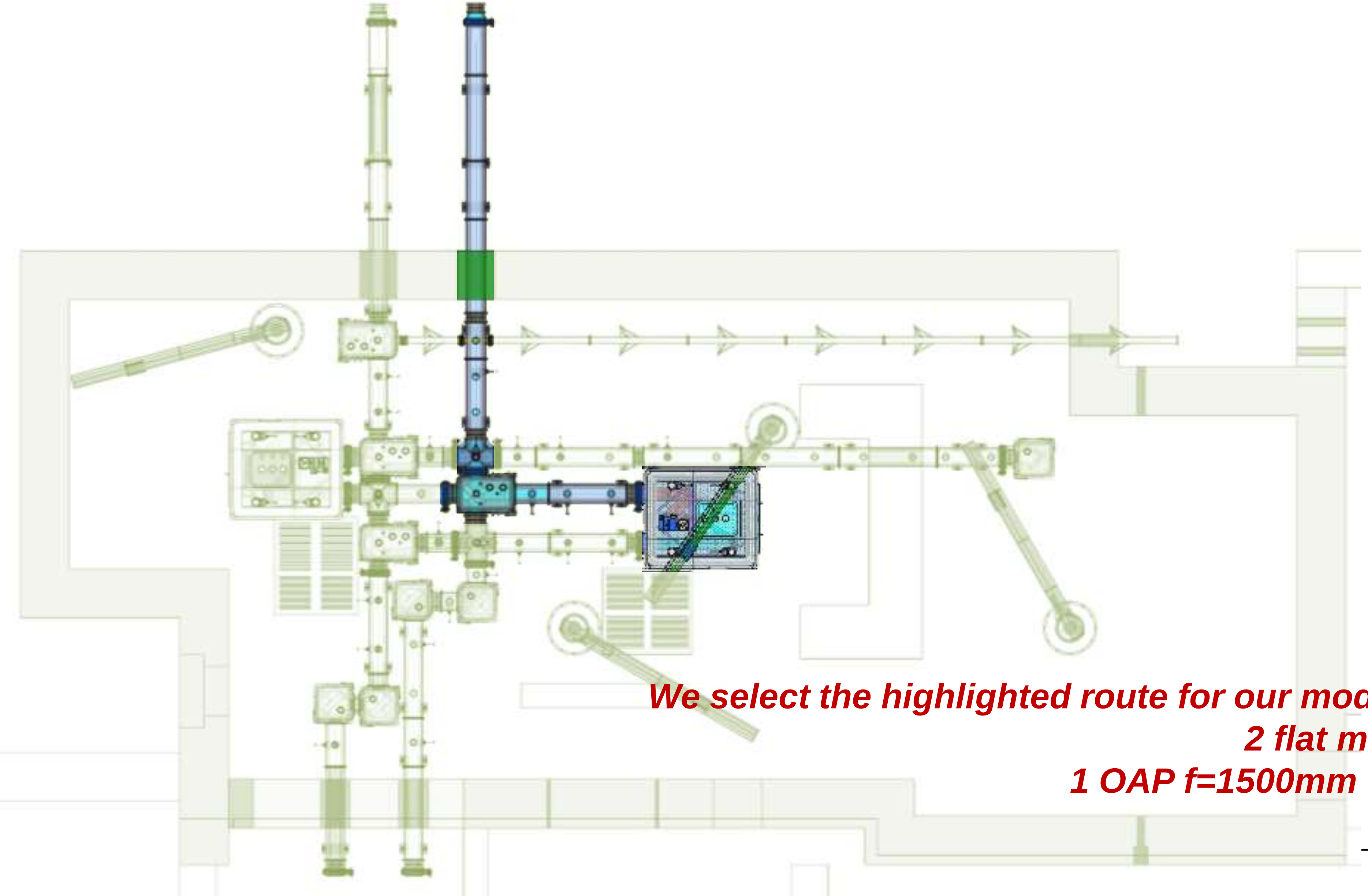
eli Nuclear Physics

THALES

ALSYOM
ALCEN

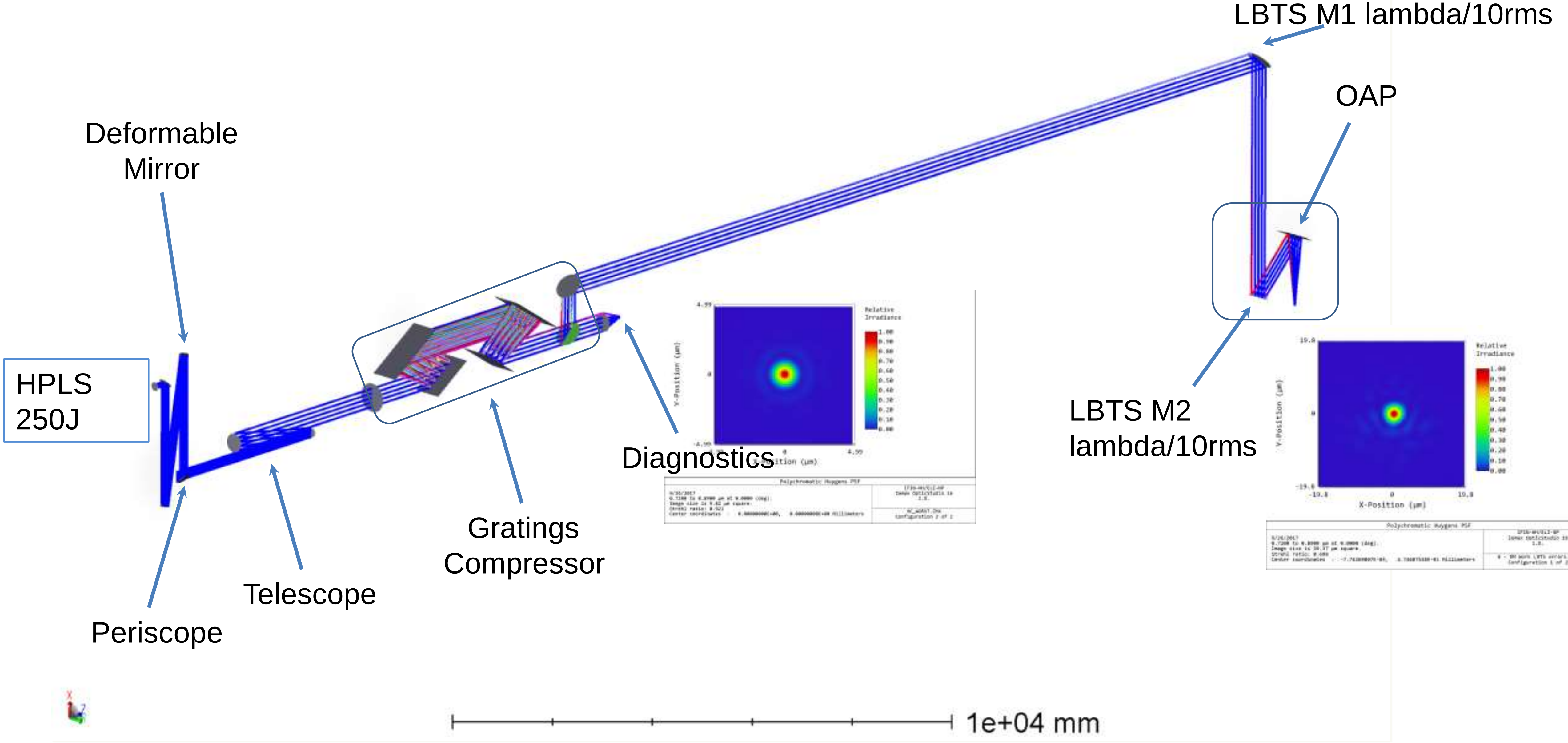
September 2019

LBTS beam quality preservation



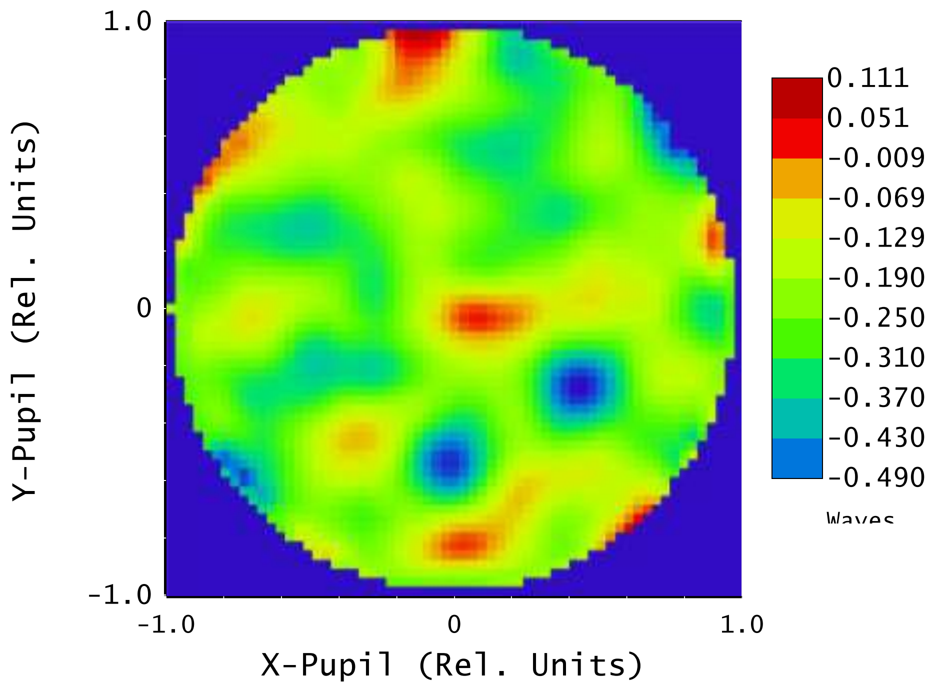
We select the highlighted route for our modeling
2 flat mirrors
1 OAP f=1500mm @ 45º

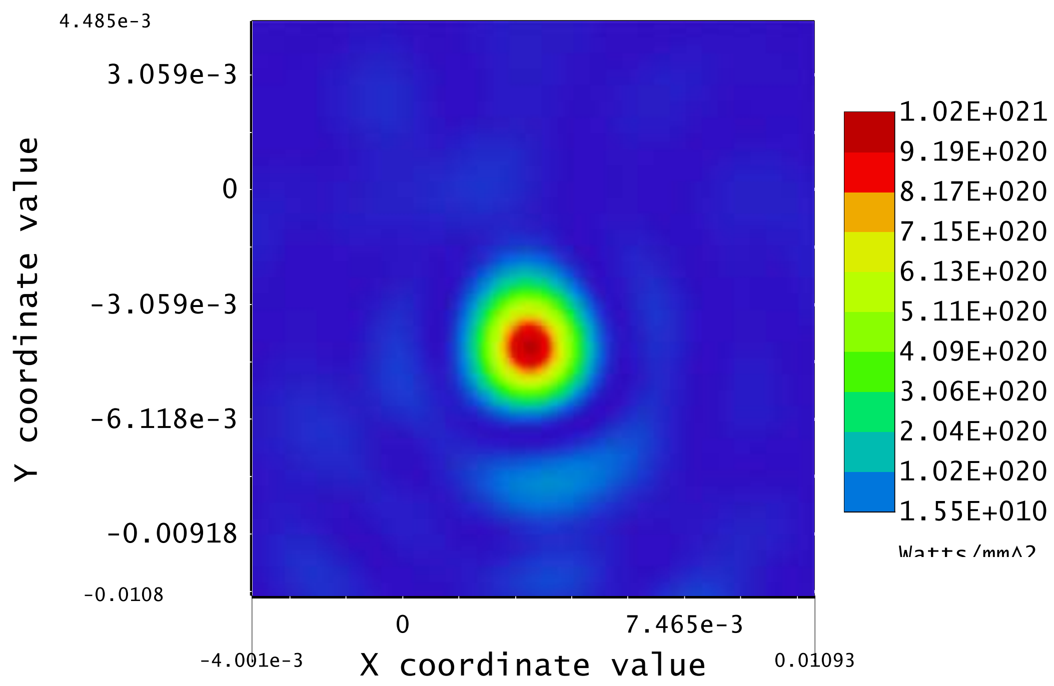
Zemax study



Simulations by Ioan Dancus

Measured beam + OAP with 50 nm RMS wavefront error + 4-8 orders Zernike polynomials correction





Wavefront Function

9/15/2020
0.8100 µm at 0.0000 (deg)
Peak to valley = 0.6014 waves, RMS = 0.0916 waves.
Surface: 22
Exit Pupil Diameter: 2.0003E+02 Millimeters
Tilt Removed: X = -0.8413, Y = 0.7017 waves

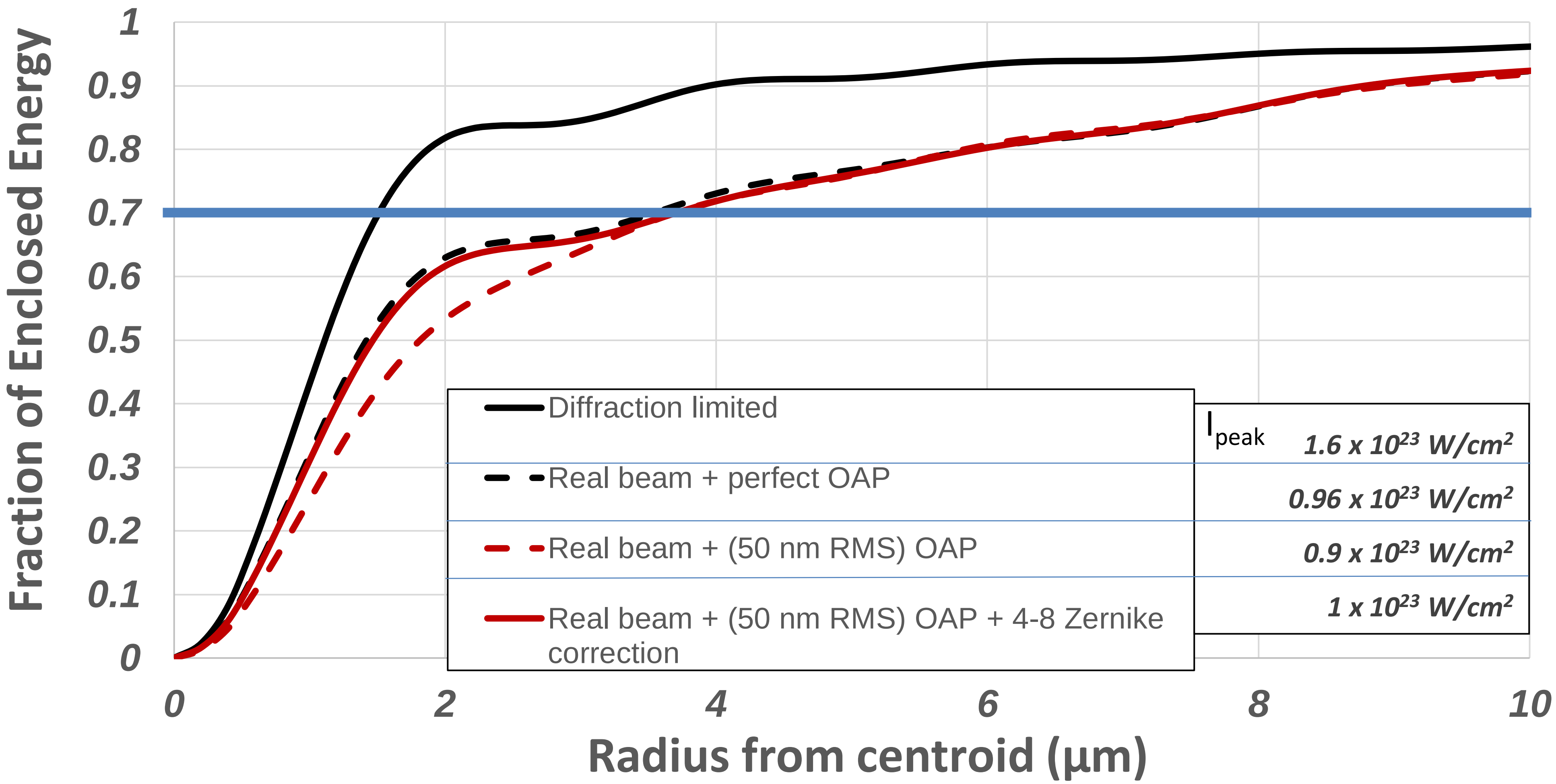
Zemax
Zemax OpticStudio 19.4 SP1

Short OAP aberations + DM correction 1 optimised 50
Configuration 3 of 6

Total Irradiance surface 22

9/15/2020
Beam wavelength is 0.81000 µm in the media with index 1.00000 at 0.0000 (deg)
Display X Width = 8.1960E-02, Y Height = 1.2621E-01 Millimeters
Peak Irradiance = 1.0214E+21 Watts/Millimeters^2, Total Power = 1.0000E+16 Watts
X Pilot: Size= 4.5100E-02, Waist= 1.4064E-03, Pos= +2.4589E-01, Rayleigh= 7.6717E-03
Y Pilot: Size= 6.9428E-02, Waist= 1.4065E-03, Pos= +3.7865E-01, Rayleigh= 7.6721E-03
Beam Width X = 1.26402E-02, Y = 1.59835E-02 Millimeters

Encircled energy

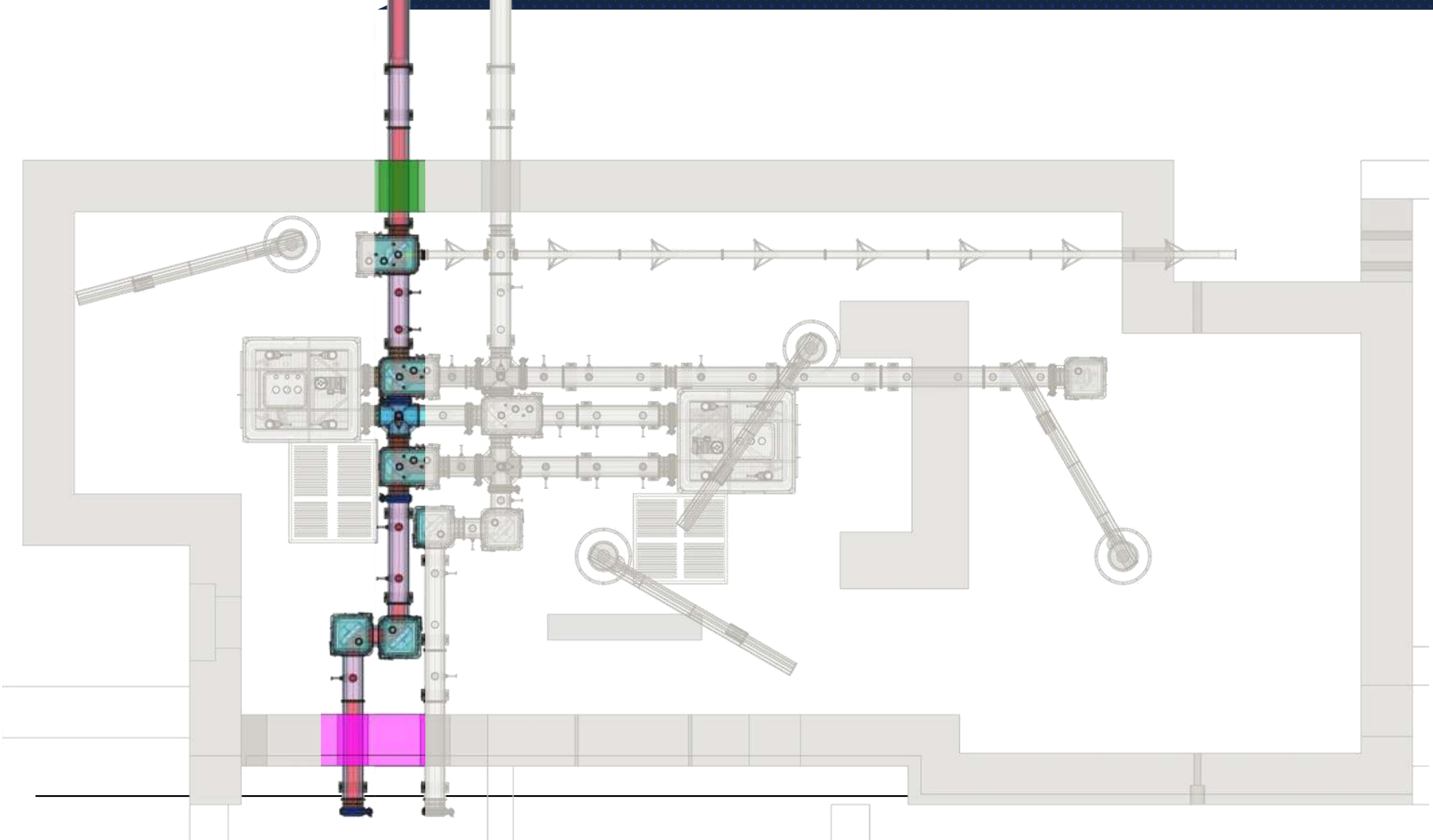


Ioan Dancus et al. FiO+LS 2020

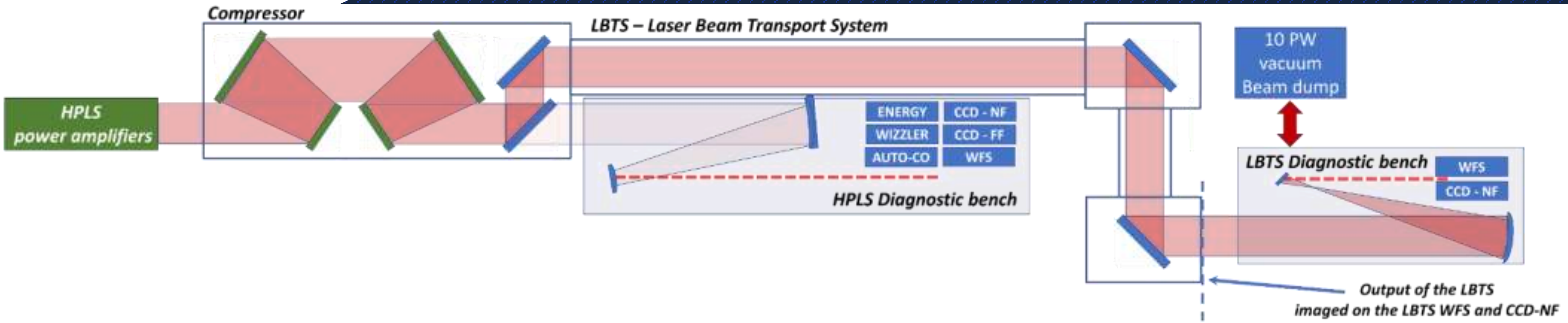
19 August 2020
First 10 PW propagated pulses

Part of the LBTS endurance test

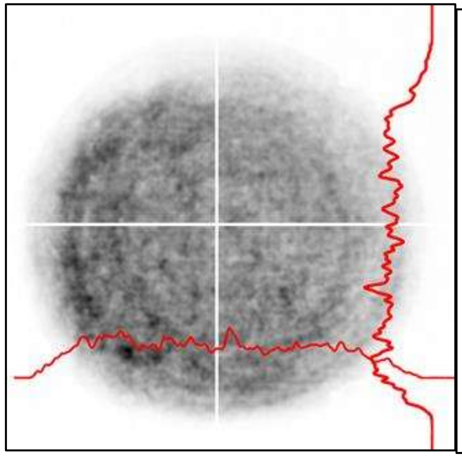
10 PW Laser beam transport system



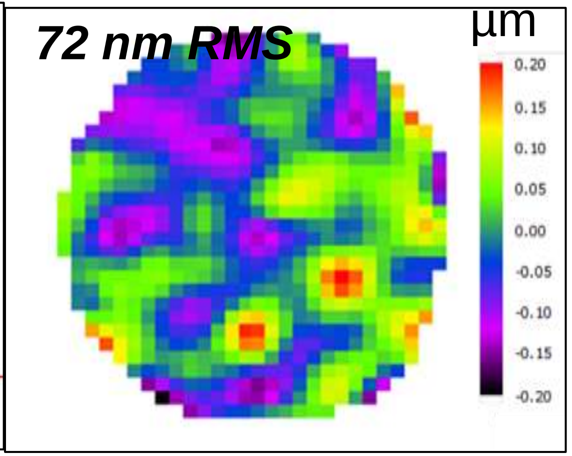
LBTS test configuration – step 1



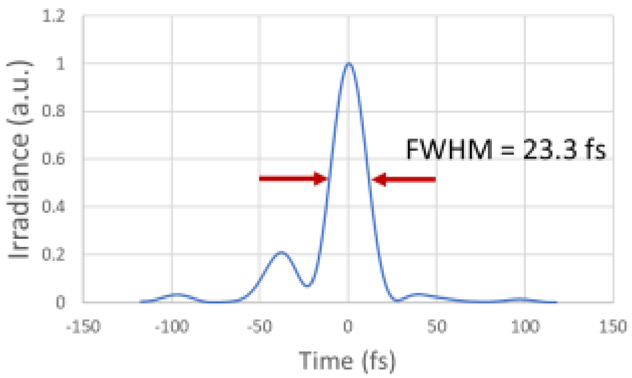
- HPLS laser running at full energy attenuated before compressor for beam profile analysis after propagation through the LBTS and transmission efficiency



NF LBTS output



Wavefront map, Strehl ratio > 0,7



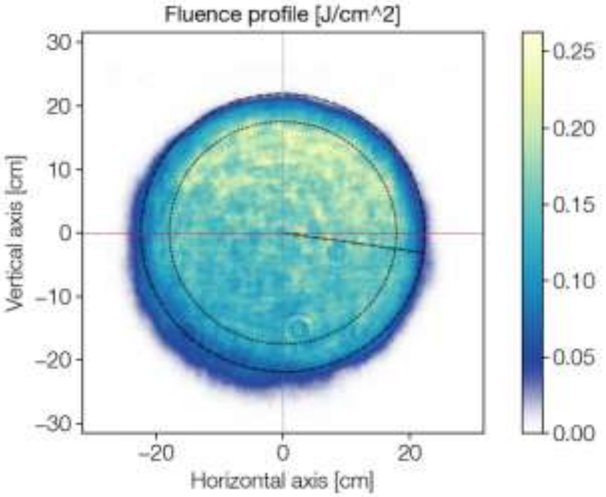
Pulse duration LBTS output

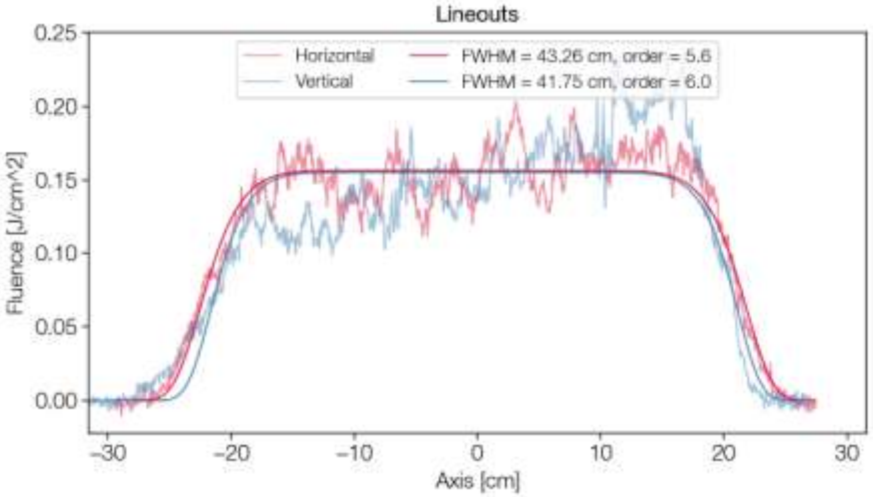
Compressor output - beam line 2

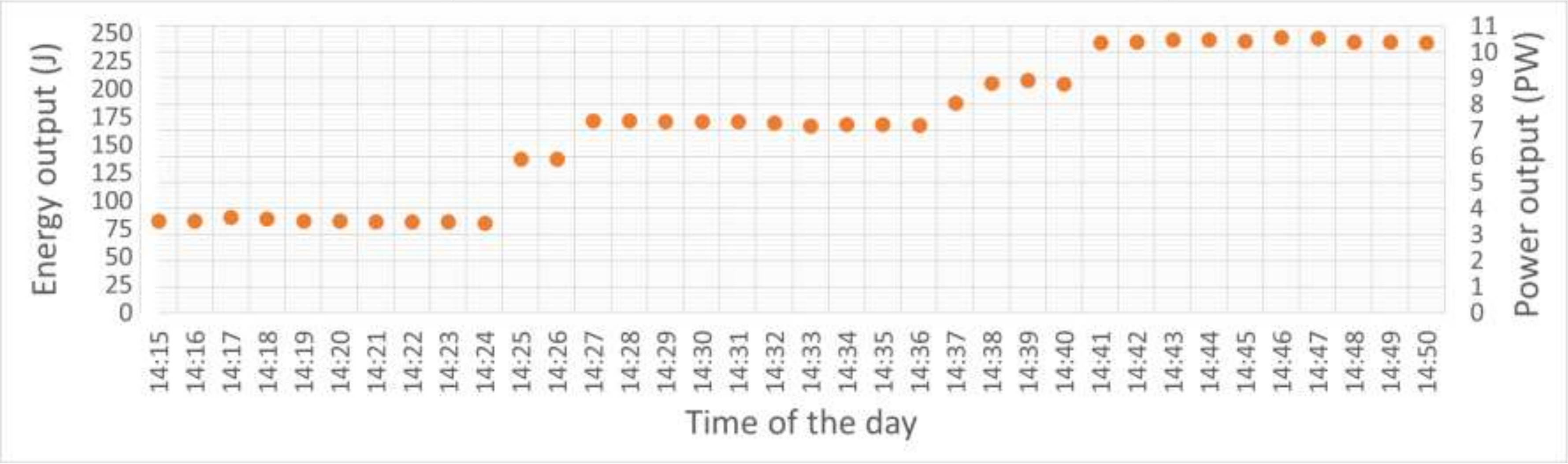
(measurements at full aperture with full energy after compressor)

eli nuclear physics

- Calculated peak power = 243 J / 23,4 fs = 10,4 PW

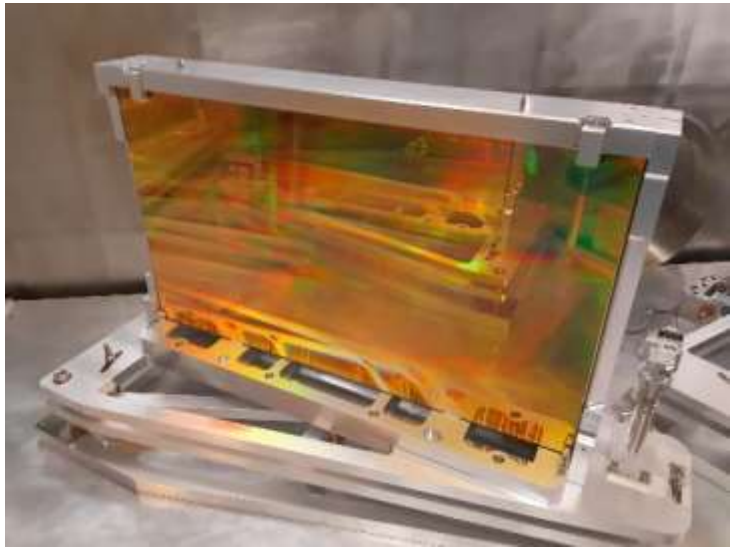




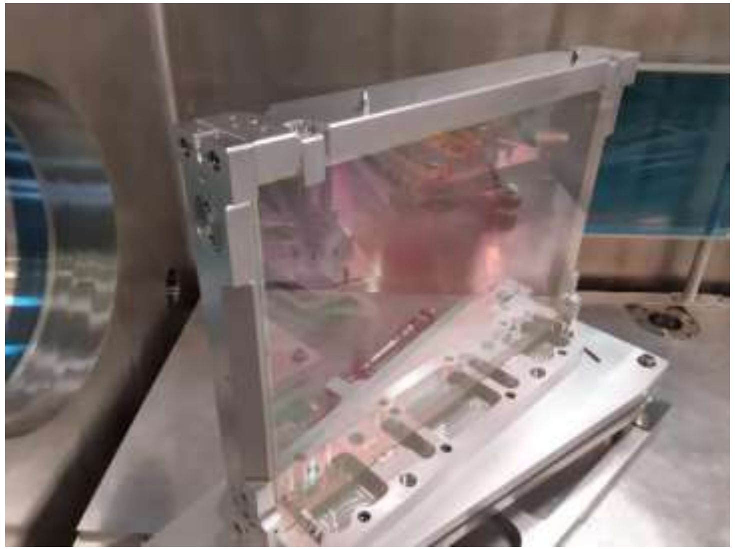


LBTS test configuration – step 3

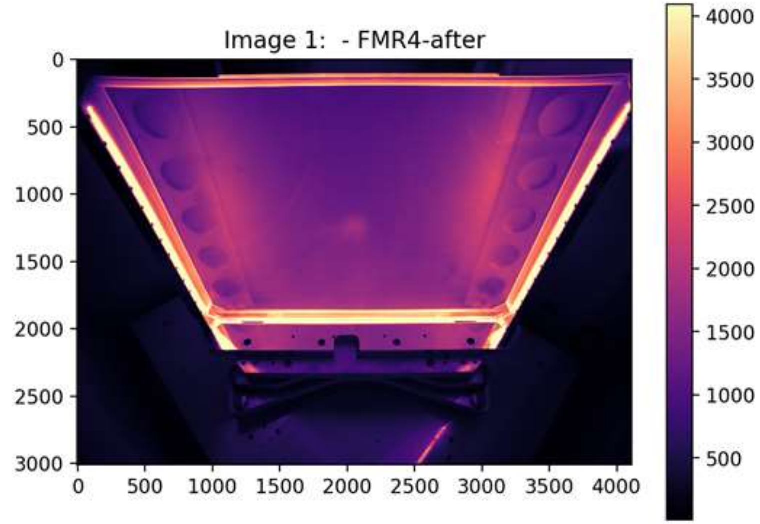
- Verification of transmission efficiency
- Visual inspection of optical components within HPLS compressor and LBTS



Grating



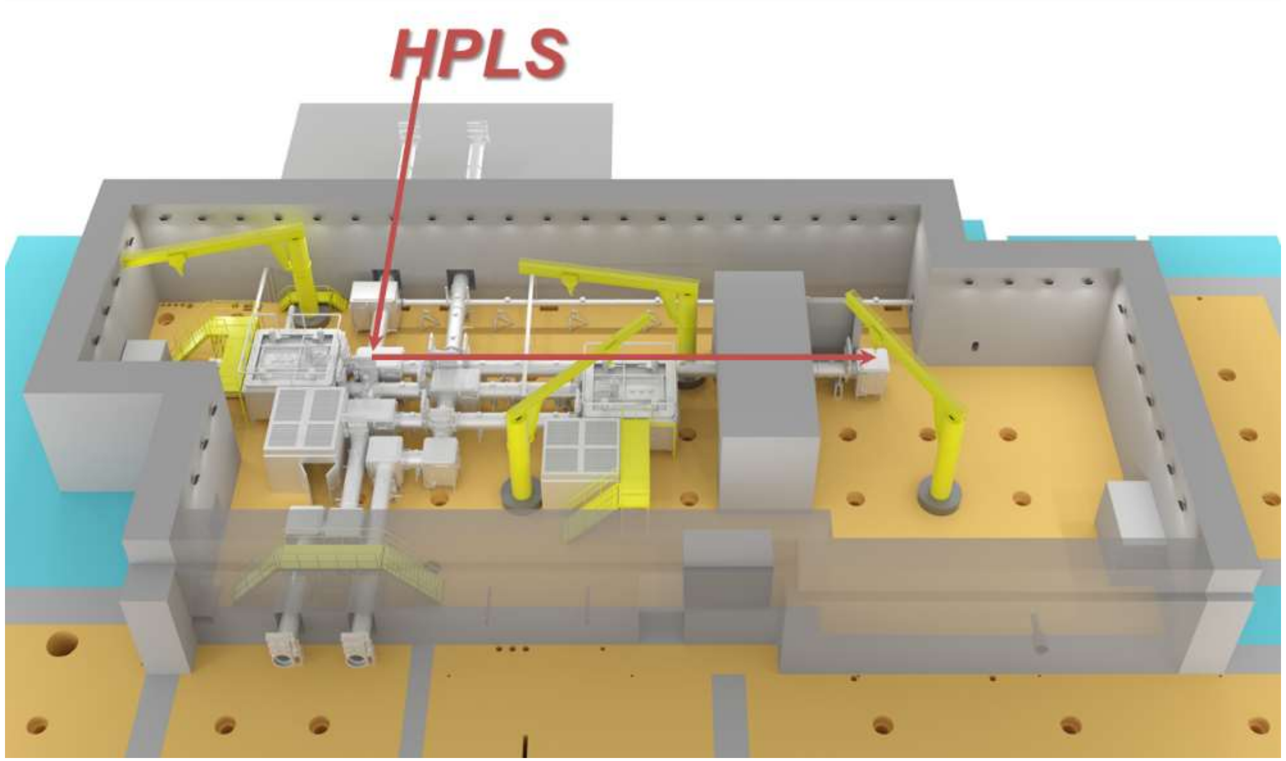
Compressor mirror



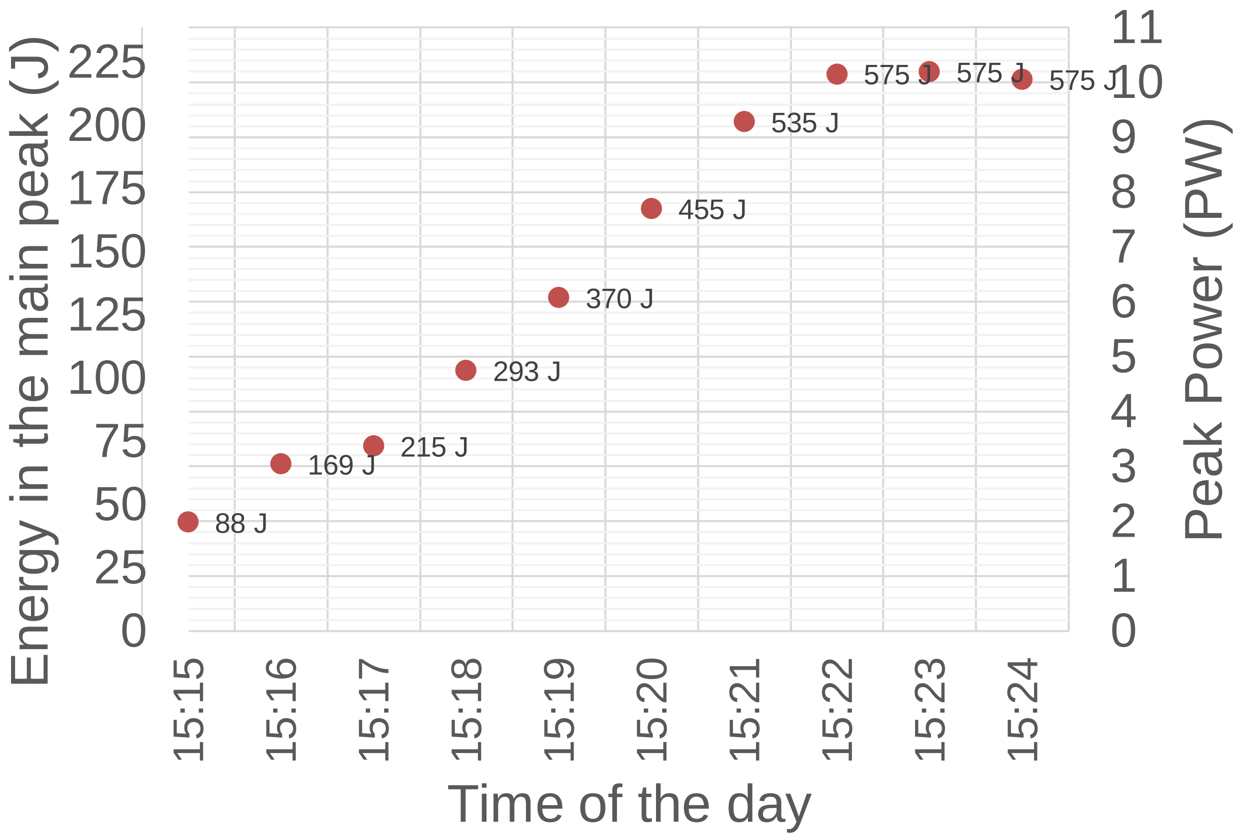
LBTS mirror

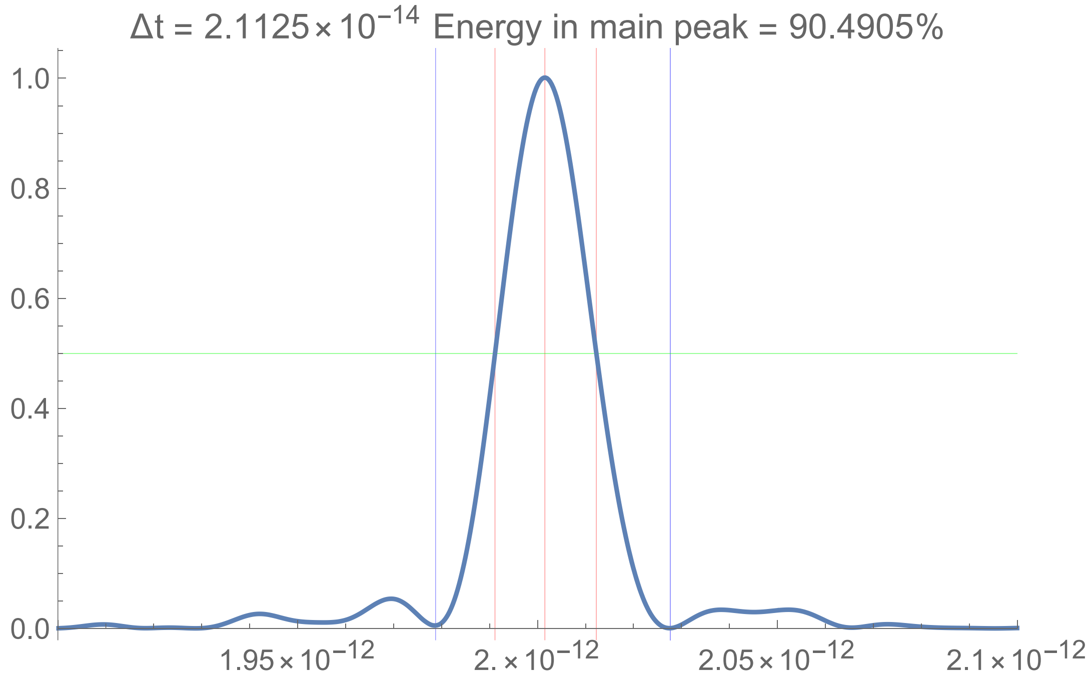
- No losses of efficiency and no damages observed

17 November 2020
Moving into Uncharted Territories



Pulse sequence





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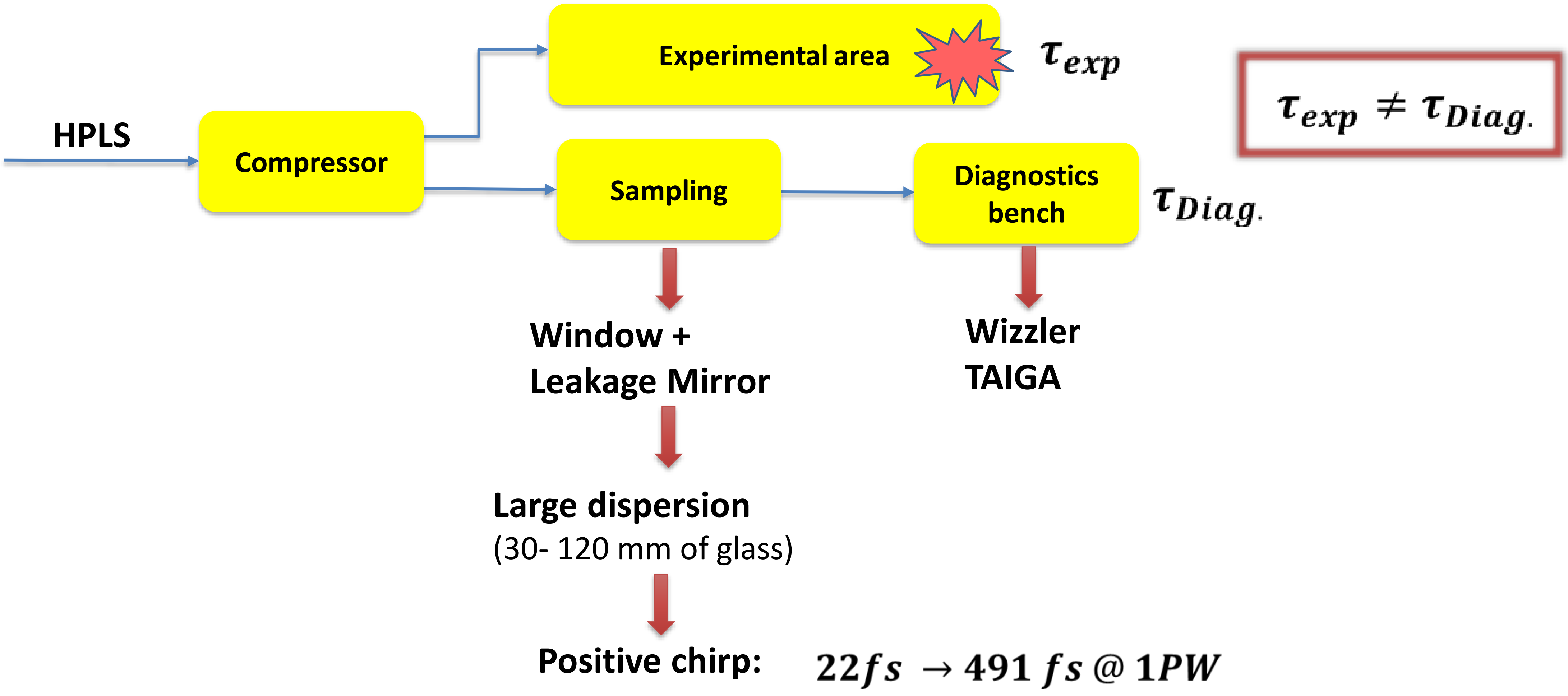
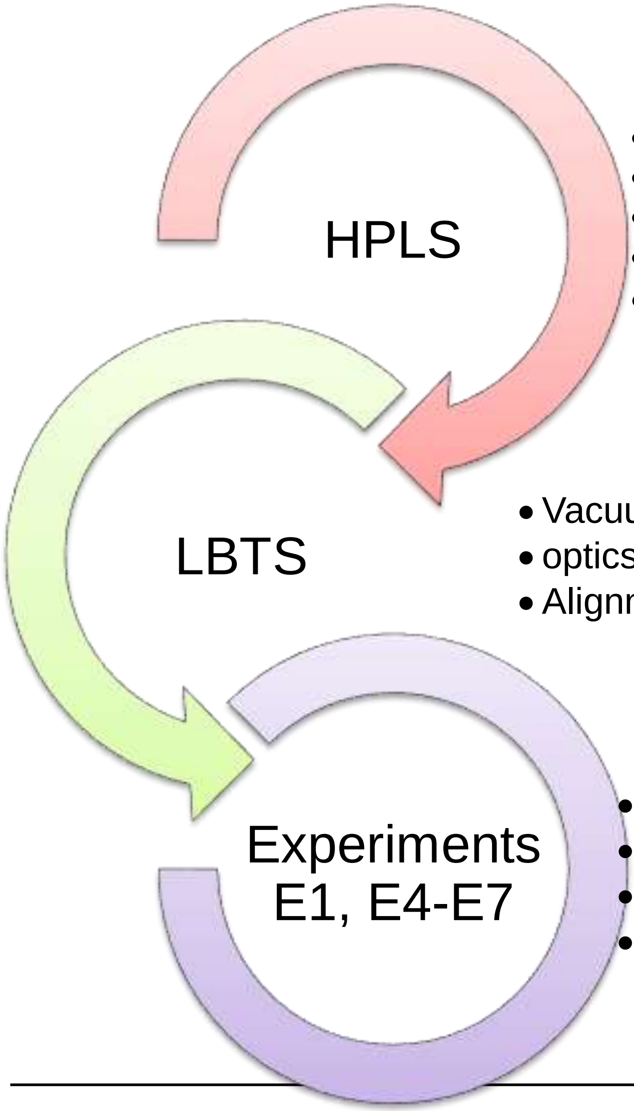
Beam sampling for diagnostics



ELI-NP diagnostics scenario



- Control system
- Front End
- amplifiers
- 6x Compressors
- **6x diagnostics benches**

- Vacuum system
- optics
- Alignment control

- Interaction chamber
- target
- **Laser diagnostics**
- Experiment diagnostics

On shot

Parameter	Device
Near field	CCD
Far field	CCD
Wavefront	ImaginOptics Wavefront sensor
Pulse duration	Wizzler
Spectral phase	
Spectrum	
ns-contrast	Fast photodiodes and oscilloscope
ps-contrast	Tundra
Energy	Gentec energy-meter

Calibration

Parameter	Device
Far field	CCD (high resolution)
Pulse duration	Frog or D-Scan or Spider
Spectral phase	
Spectrum	Ocean optics
ns-contrast	Fast photodiodes and oscilloscope
Energy	Gentec energy-meter (Q12)

+ focal spot size

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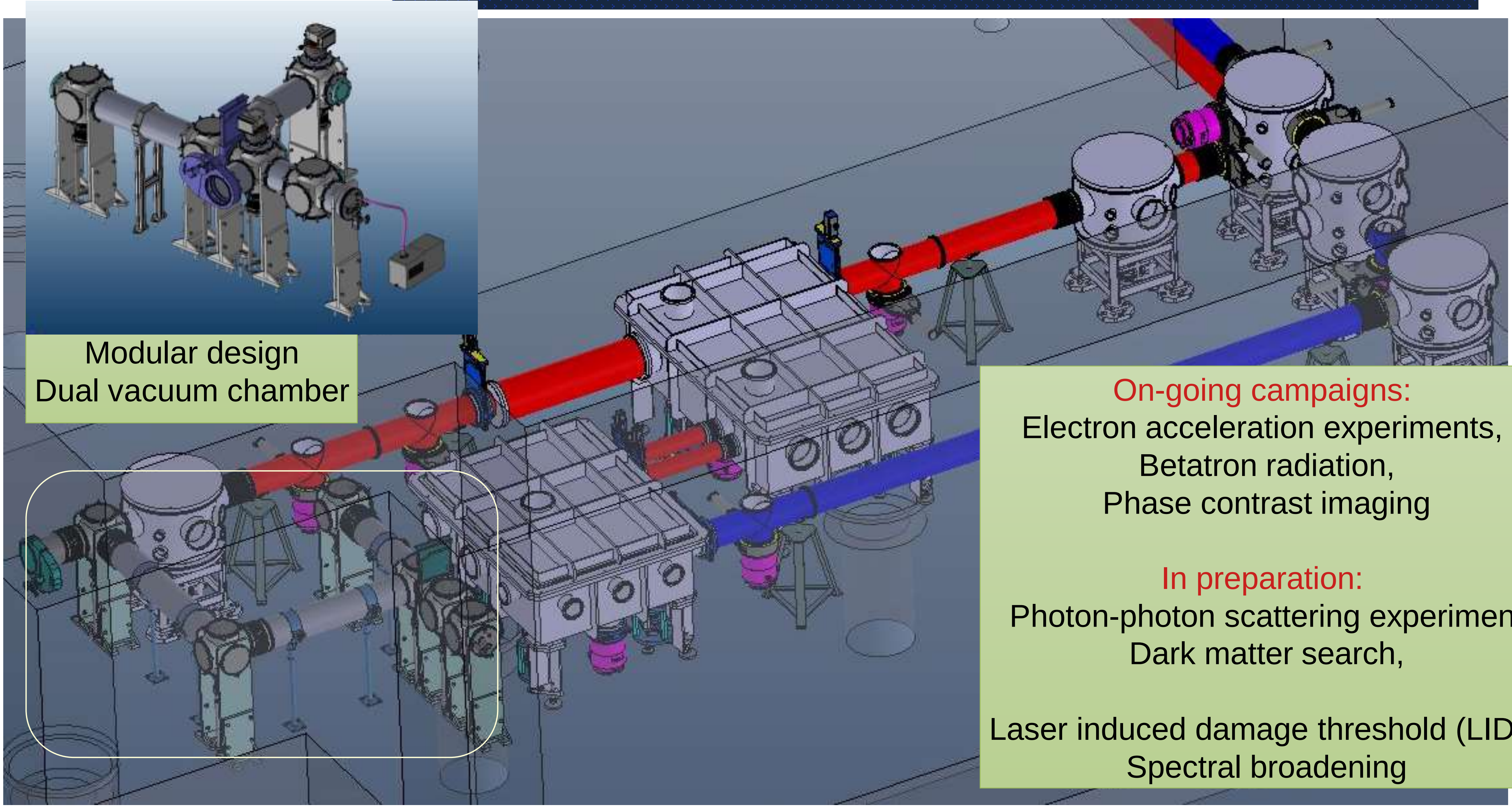
E4: 2x100TW@10Hz

E5: 2x1PW@1Hz

E1/E6: 2x10PW@1 shot/min

https://www.youtube.com/watch?v=qBse2Uw2WTQ

E4 2x100TW experimental area



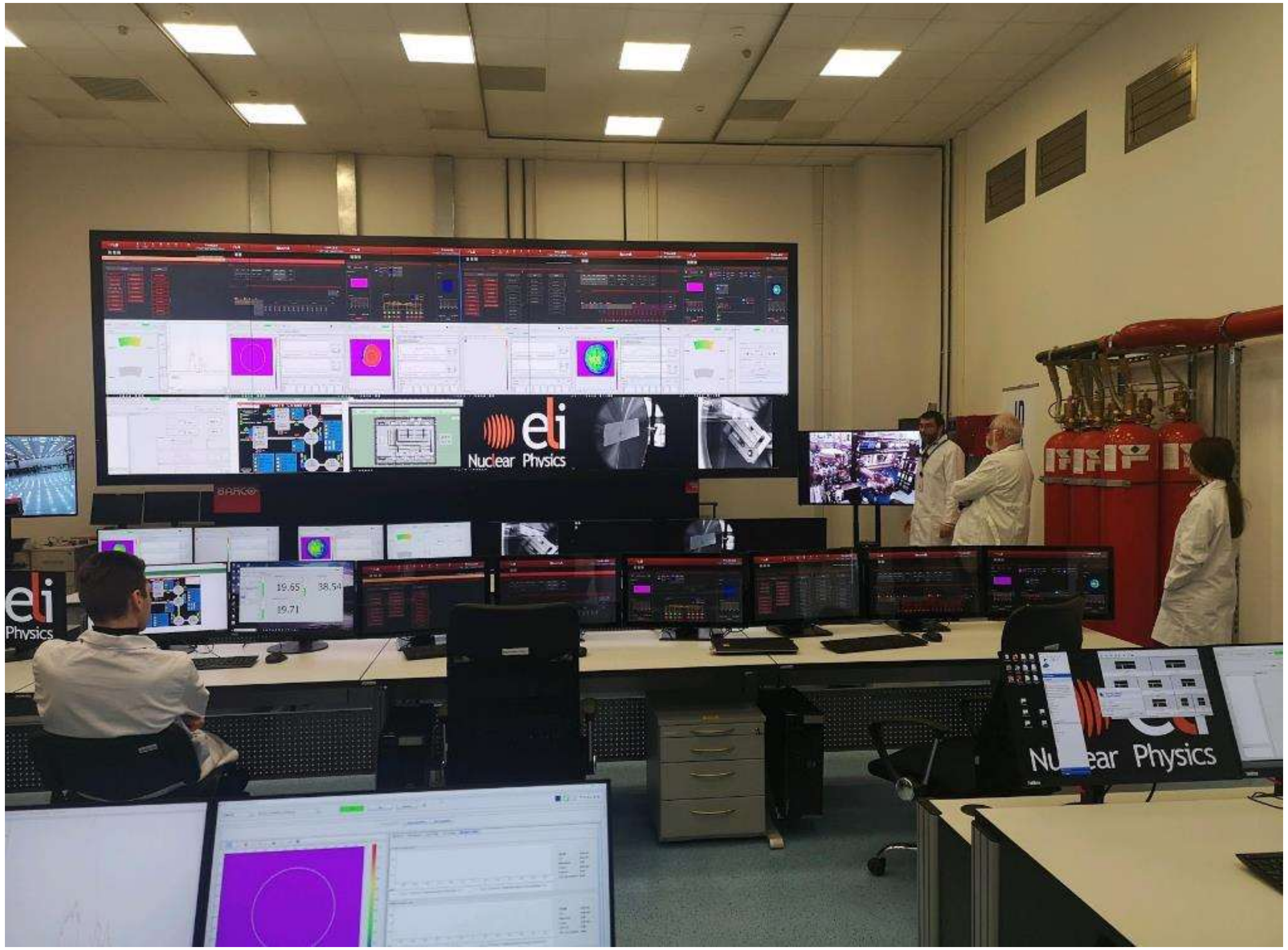
Modular design
Dual vacuum chamber

On-going campaigns:
Electron acceleration experiments,
Betatron radiation,
Phase contrast imaging

In preparation:
Photon-photon scattering experiment
Dark matter search,

Laser induced damage threshold (LIDT)
Spectral broadening

18 March 2020
First HPLS beam on a target



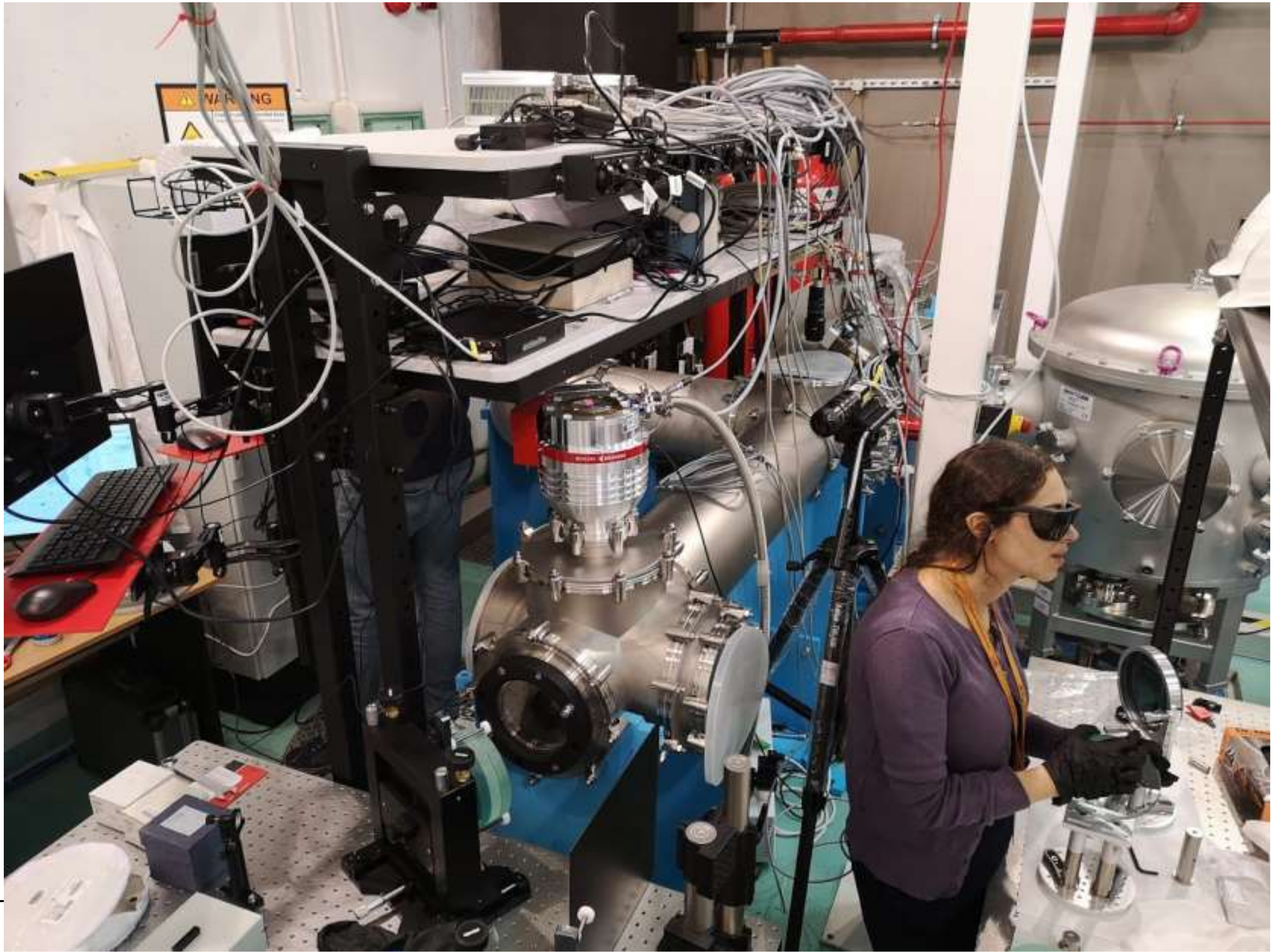
Experiment: Spectral broadening

P.I.: Dr. Daniel Ursescu

Collaboration: Gerard Mourou (IZEST)

Preliminary results presented at:
FiO+LS – OSA - 14 – 17 September 2020

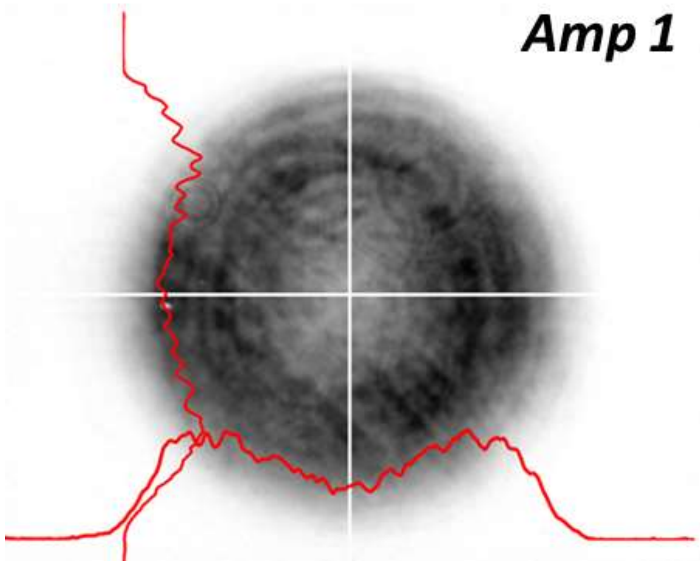
Integration of the experiment



Input beam characterization

eli nuclear physics

Near Field after amplification

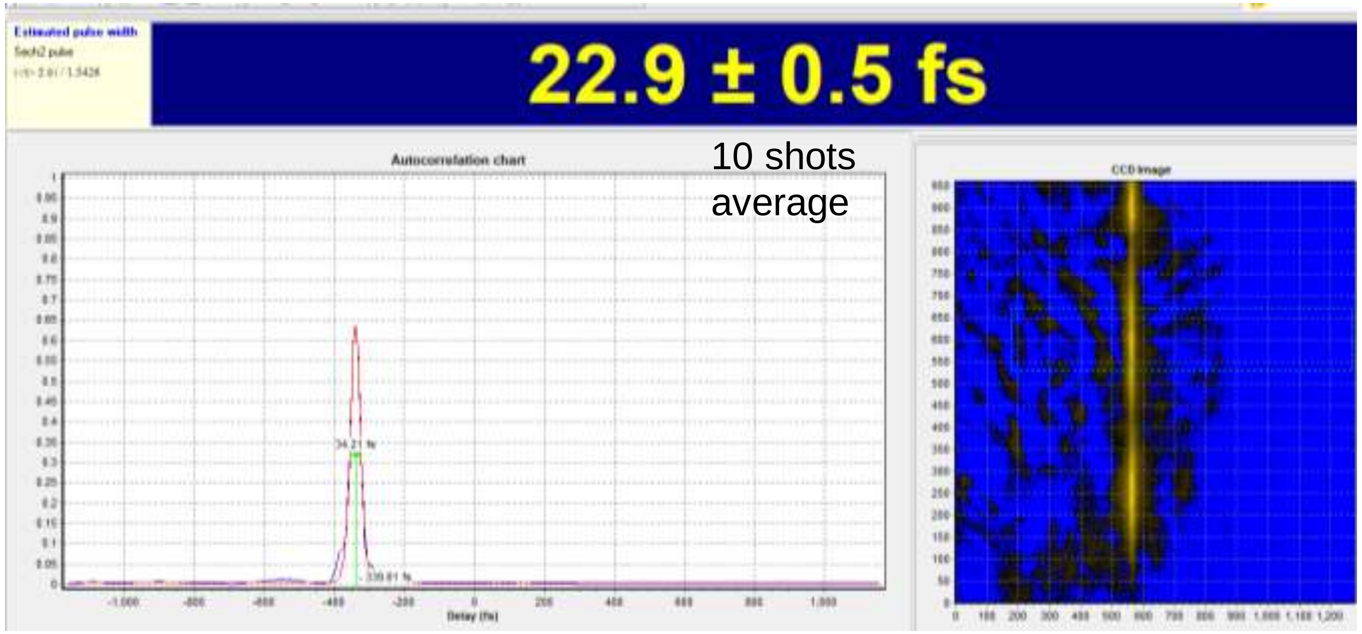


Input energy: up to 3.1J
Compressor efficiency: 73%
Compressed pulse energy: up to 2.3J
Energy stability (full amplified pulses): 1.2% rms

7.5% PV

Pulse duration in E4 LIDT station (through 4mm fused silica AR coated):

- second order single shot autocorrelator (AVESTA)

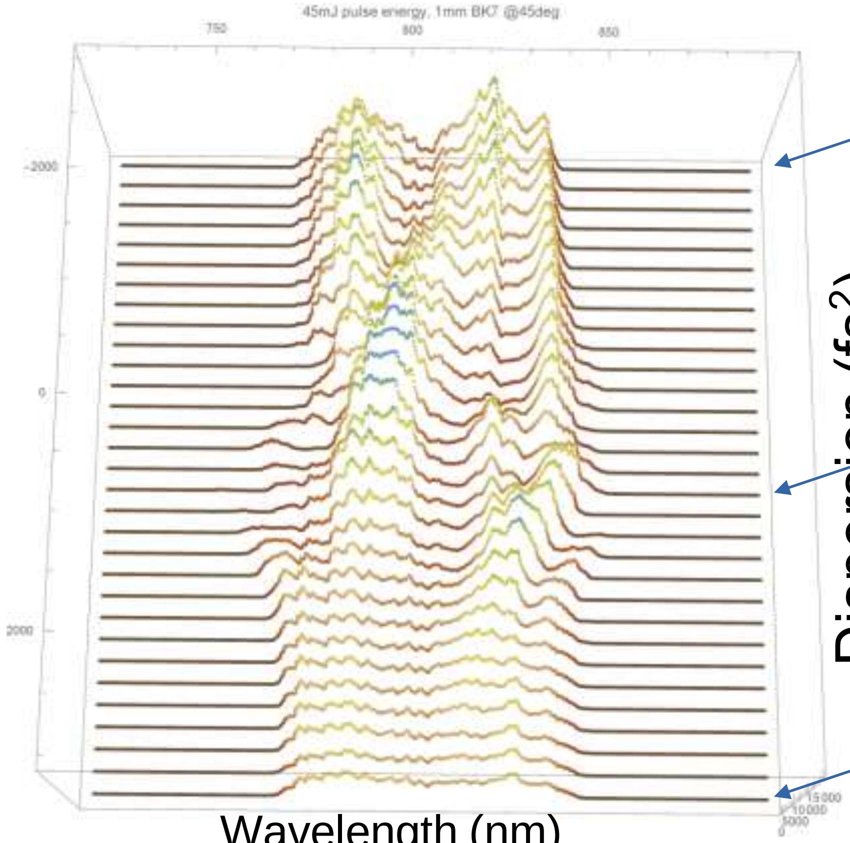


DAZZLER - acusto-optic programmable dispersion filter: +/-3000fs^2 ==> +/-70mm of BK7 <==> 400fs chirped pulse

SB coarse adjusting: pulse duration variation

Dispersion variation between -3000fs^2 and 3000fs^2, in steps of minimum 100fs^2

Target position at 250mm from focus. Energy per pulse ~45mJ



~400 fs

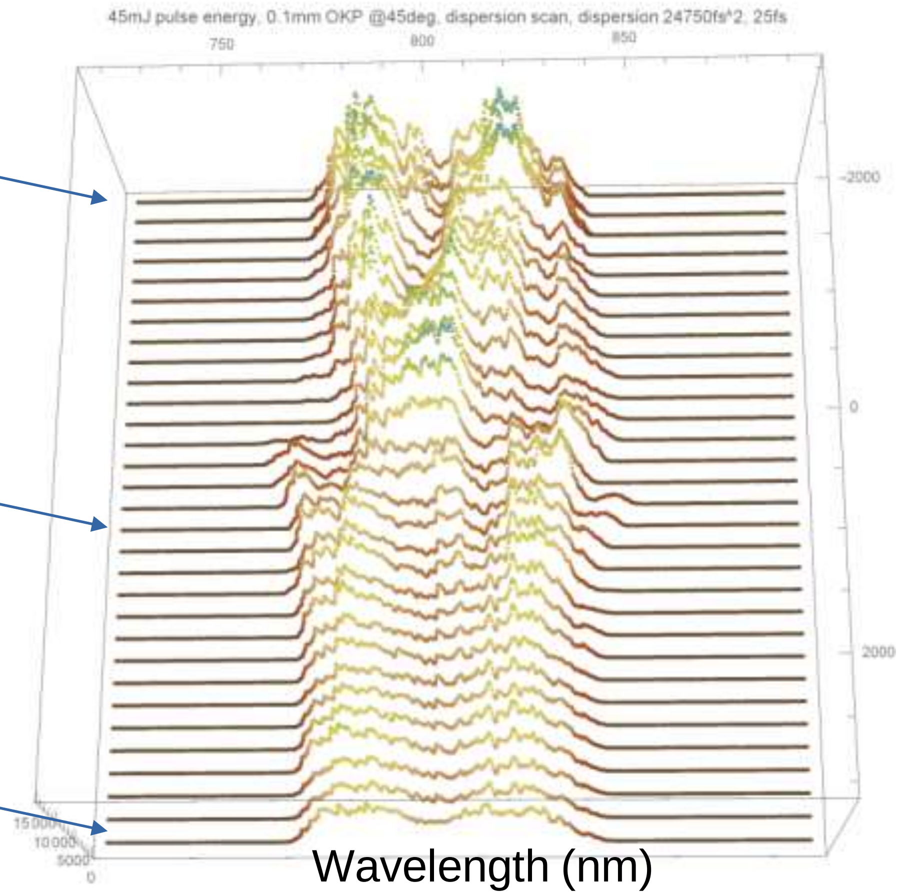
23 fs

~400 fs

Dispersion (fs^2)

Wavelength (nm)

Glass: BK7 1mm



Dispersion (fs^2)

Wavelength (nm)

Plastic: OKP 0.1mm

LWFA Experimental setup of E4

PI: Domenico Doria / Petru Ghenuche

Max Energy: ~ 2.5 J

Pulse duration: ~ 25 fs

Beam diameter: ~ 56 mm

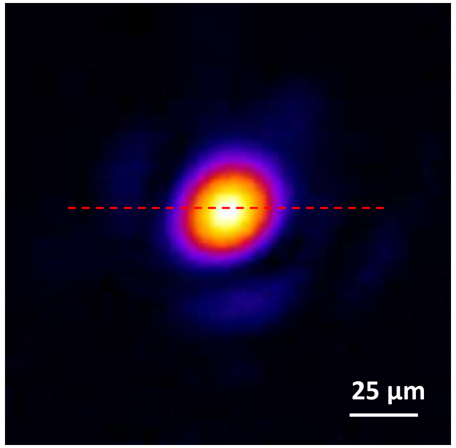
Laser pointing fluctuation: ~ 30 µrad

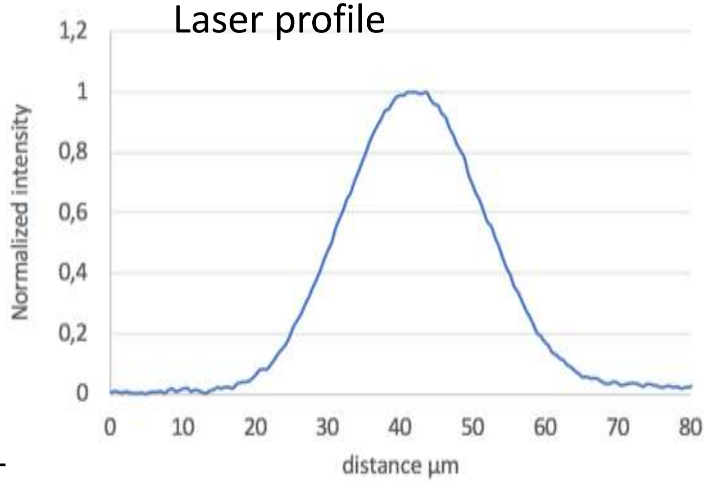
Parabolic mirror: 1.5 m focal length (F# ~27)

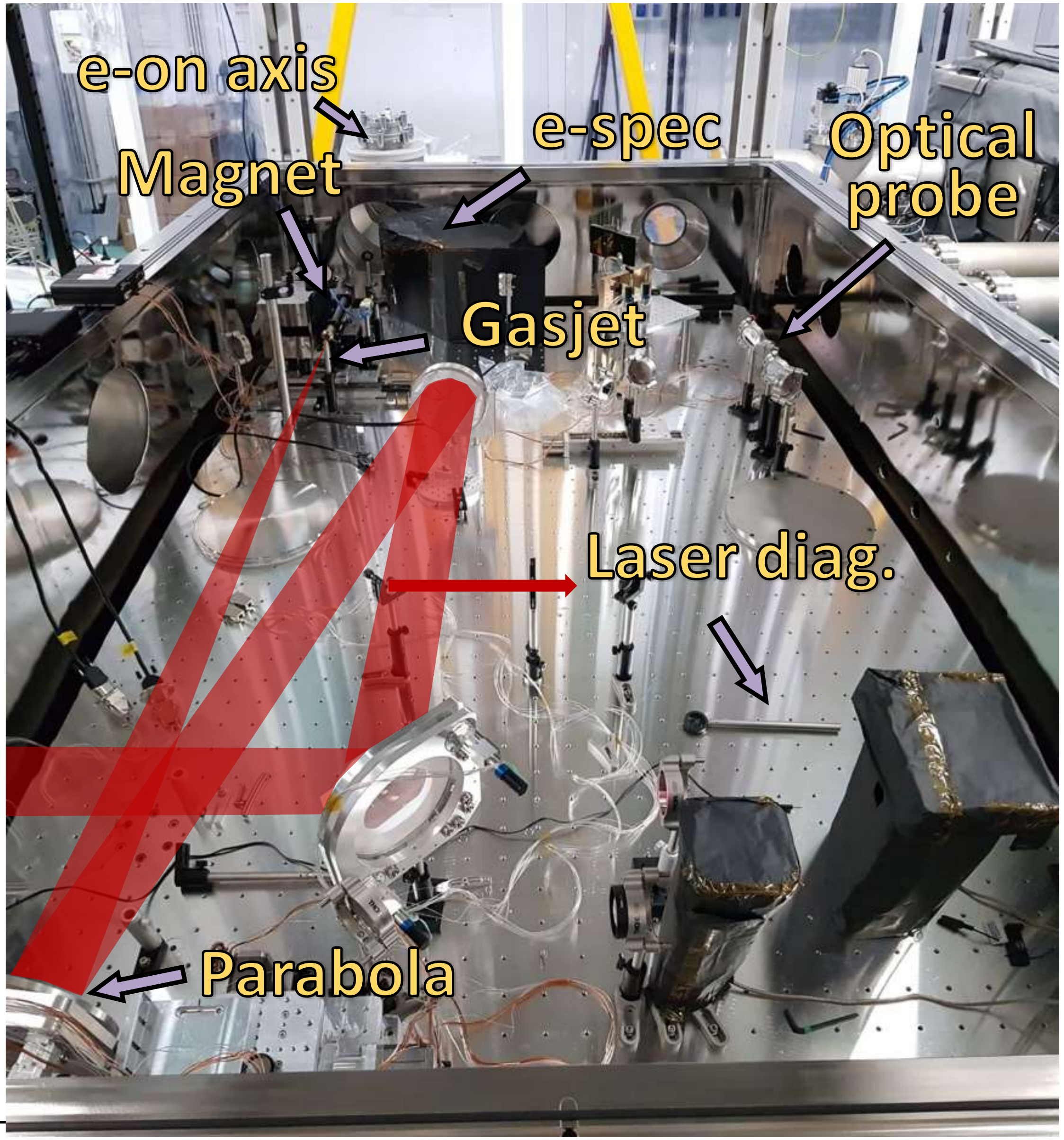
Spot size diameter: ~ 26 µm at FWHM

Encircled energy ~ 67% @ $1/e^2$

The laser spot is measured at full power, with attenuation







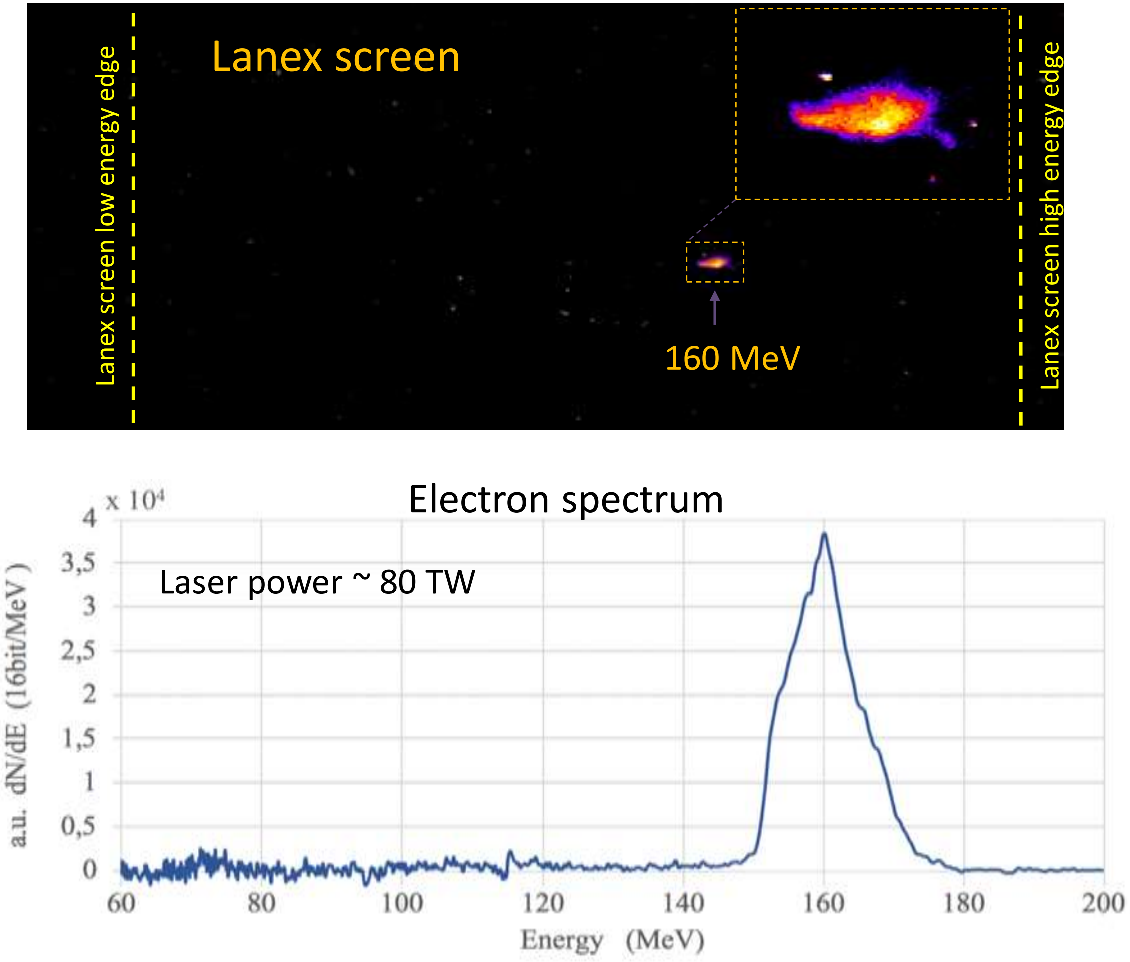
Experimental data

Magnet length: 160 mm
Magnetic field 0.7 T

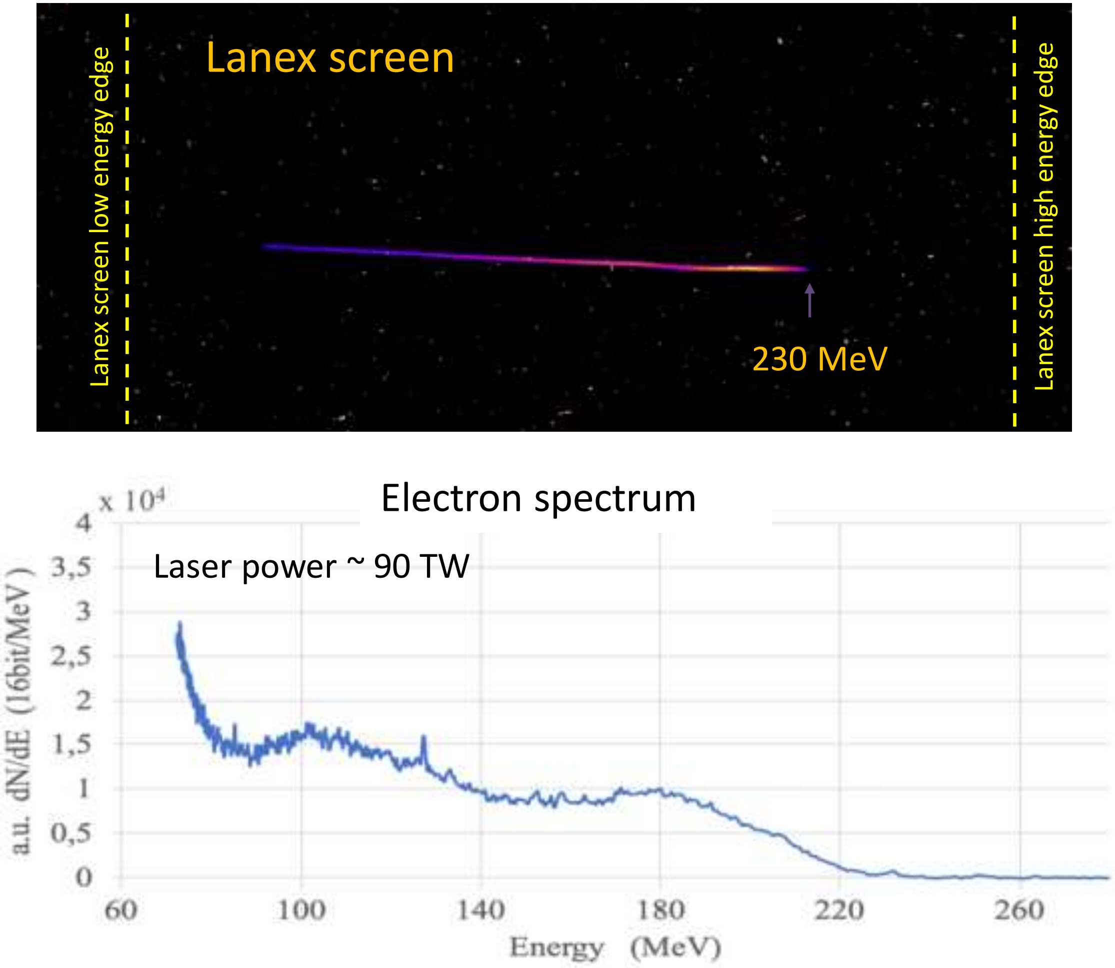
Nozzle: 2 mm diameter nominal
Gas target: He, He + 2% N_2
Gas density best data ~ $4x10^{18}$ atom/cm^3 @ the plateau

Typical electron spectra obtained

Typical quasi-monoenergetic spectrum with pure **He** gas



Typical broadband spectrum with **He + 2% N_2** gas



Contents

- Why intensity matters
- Extreme Light Infrastructure facilities
- Architecture of the 2x10PW laser system (HPLS)
- Laser pulse characterization at HPLS
- **Experimental areas for laser experiments**

E4: 2x100TW@10Hz

E5: 2x1PW@1Hz

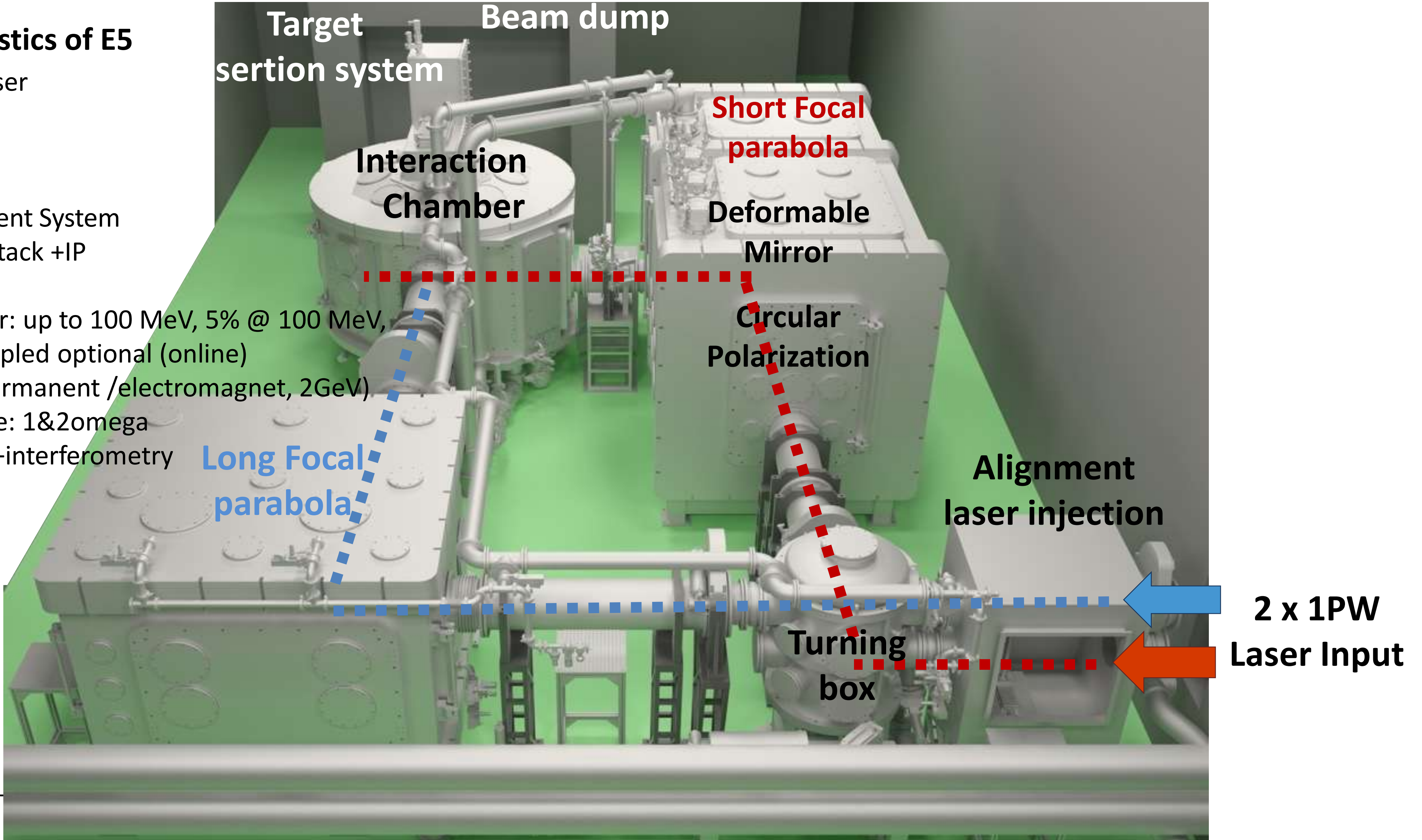
E1/E6: 2x10PW@1 shot/min

https://www.youtube.com/watch?v=qBse2Uw2WTQ

Overview E5 chamber

List of main diagnostics of E5

- Internal Injection Laser
- Laser Diagnostics
- Deformable Mirror
- Circular Polarization
- Targetry and Alignment System
- Radiochromic Film Stack +IP
- Thomson Parabola
- e−e+/γ Spectrometer: up to 100 MeV, 5% @ 100 MeV, optically coupled optional (online)
- e− Spectrometer (permanent /electromagnet, 2GeV)
- Optical Plasma Probe: 1&2omega +shadowgraphy +interferometry



E5 on-going proton acceleration experiments preparations

Laser, alignment and target manipulation

Internal Injection Laser: CW 632-800nm, 150mm dia.

Laser Diagnostics: (FF, NF, laser energy at full power, FROG, Stokes Parameters, back-reflection)

Circular Polarization System: Mica waveplates (permanent system upgrade to come)

5X – 20X objectives alignment system, 1µm spatial resolution motion

Deformable Mirror: 52 actuators, 400mm dia. membrane

Shack-Hartmann wavefront sensor λ/100 r.m.s. 32x40 px

Particle detection

Radiochromic Film Stack: 1’’x 1’’, 2’’x 2’’up to 100 MeV proton

Thomson Parabola: up to 60 MeV, 8% res. @ 60 MeV , optically coupled optional (online)

Optical plasma probe: up to 200 mJ, 2w,1’’ dia., ~ µm res., Interferometry, shadowgraphy.

e−p+, Spectrometer: up to 100 MeV, 5% res. @ 100 MeV , optically coupled optional (online)

Streak camera: VIS, 1 ps res.

Optical spectrometer: ANDOR Shamrock (VIS)

Pin-hole cameras: UV-X-ray, ~ 10 - ~ 100 µm res.

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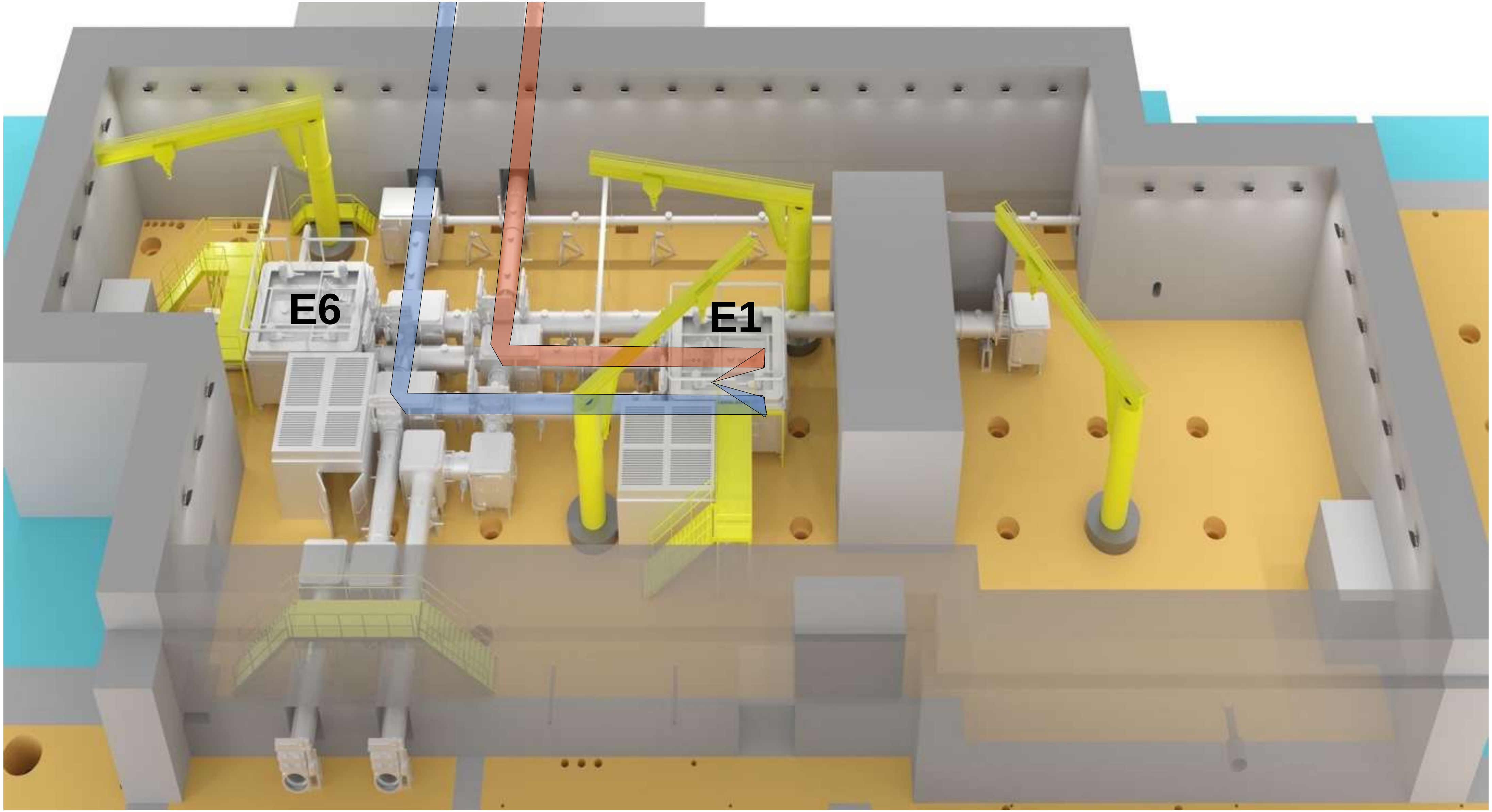
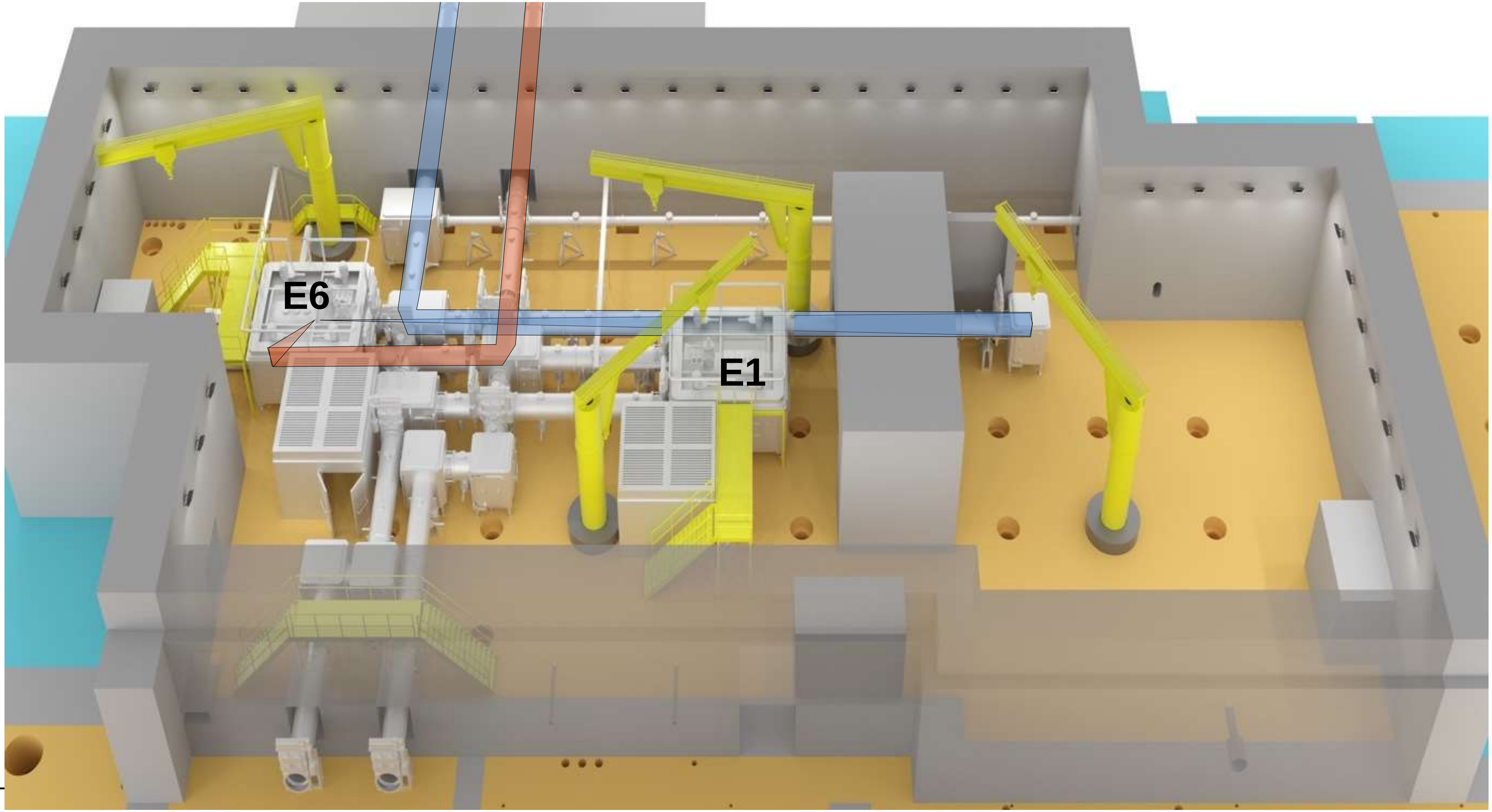
Overview of 10PW Experimental Area



Overview of 10PW Experimental Area



Summary

- **Peak intensity** is central parameter for ultrafast lasers
- ELI pillars will provide **state-of-the-art laser systems for users**
- The most powerful laser worldwide, HPLS at ELI-NP, operates **reliably at nominal parameters**
- Complete diagnostics bench for laser qualification in place for all 6 outputs
- Laser pulse characterization in experimental areas for **users is essential**
  - ✓ LBTS for 10PW pulses was successfully operated up to experimental areas
  - ✓ 2x100TW@10Hz and 2x1PW@1Hz **experimental areas are operational**
  - 2x10PW@1/min E1 and E6 experimental areas get the focusing optics in 2021

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Sectoral Operational Programme "Increase of Economic Competitiveness"

"Investments for Your Future!"

IFIN-HH

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase II

eli Nuclear Physics

www.eli-np.ro

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Thank you!