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

Daniel URSESCU
Daniel.ursescu@eli-np.ro

Extreme Light Infrastructure – Nuclear Physics, National Institute for Physics and Nuclear Engineering, Magurele, Romania

Physics Doctoral School, University of Bucharest, Magurele, Romania

15.3.2021
FemtoUp! School, via Zoom
• Why intensity matters
• Extreme Light Infrastructure facilities
• Architecture of the 2x10PW laser system (HPLS)
• Laser pulse characterization at HPLS
• Experimental areas for laser experiments
• Why intensity matters
• Extreme Light Infrastructure facilities
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• Experimental areas for laser experiments
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),
- \( E_0 = |\hat{E}(0,0)| \),
- \( w(z) \) 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.
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 $E_0$ is the peak amplitude, $w(z)$ is the beam waist, $w_0$ is the beam waist radius, $k$ is the wave number, $R(z)$ is the Rayleigh range, and $\zeta(z)$ is a phase term.

Laser beam = “simplest” electromagnetic field distribution
We go from cylindrical coordinates to cartesian coordinates:

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

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

We add the temporal part in the form of a Gaussian shape with duration \( \tau_F \):

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

\[ \text{Energy} = \frac{t \cdot S}{I} \]
Spectral coherent combination method

CPA multiple pulses generation method


Nobel 2018: Chirped Pulse Amplification
Towards higher intensity: ideal Gaussian pulses

Peak intensity:
\[ I = \frac{2P}{\pi w_0^2} \]

Waist of the pulse:
\[ w_0 \sim F\# \lambda \]
Motivation: Laser pulses parameters

- Electric field
  \[ E_L \text{ (V/cm)} = 2.75 \times 10^9 \left( \frac{I_L}{10^{16} \text{ W/cm}^2} \right)^{1/2} \]

- Magnetic field
  \[ B_L \text{ (Gauss)} = 9.2 \times 10^6 \left( \frac{I_L}{10^{16} \text{ W/cm}^2} \right)^{1/2} \]

- Pressure
  \[ P_L = \frac{I_L}{c} (1 + R) \approx 3.3 \text{ Mbar} \left( \frac{I_L}{10^{16} \text{ W/cm}^2} \right)(1 + R) \]

Shalom ELIEZER,
• 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
Electric field and ionization of atoms

Bohr radius = 0.529 Angstrom · n²/Z

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

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

Electric field *and relativistic movements*

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

\[
E = -\frac{\partial A}{\partial t}, \quad B = \nabla \times A
\]

Define the normalized vector potential as

\[
a = \frac{eA}{m_\text{e}c^2}
\]

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

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

For intensities of \(>2 \cdot 10^{18}\) W/cm\(^2\) and wavelength of \(~800\) nm \(\Rightarrow a_0 \sim 1\).

\(\Rightarrow\) The electron dynamics needs relativistic description.
• Why intensity matters

• **Extreme Light Infrastructure facilities**

• Architecture of the 2x10PW laser system (HPLS)

• Laser pulse characterization at HPLS

• Experimental areas for laser experiments
The Extreme Light Infrastructure: Laser systems

The ELI vision

Though each of the three Extreme Light Infrastructure (ELI) sites in Europe remain under development, all plan to ramp up operations for scientific users this year. Here’s a look what the sites hope to offer when fully equipped.

**ELI-Beamlines**

**LIGHT SOURCES:** Four lasers, ranging from 1 TW at 1 kHz repetition rate to 10 PW at one pulse per minute

**EXPERIMENTAL STATIONS:** Five experimental halls with multiple stations supporting work in materials science and biomedicine. X-ray sources, plasma physics, ion acceleration and electron acceleration for X-ray experiments

**ELI-ALPS**

**LIGHT SOURCES:** Five primary laser sources, including two 100-kHz repetition rate lasers, a single-cycle TW-class laser with a 1 kHz repetition rate, a 1-PW, 10-Hz high-field laser and a THz-band pump laser

**EXPERIMENTAL STATIONS:** Three large experimental suites with eight stations providing access to attosecond pulse trains, particles and other secondary sources for ultrafast experiments in atomic and molecular physics

**ELI-NP**

**LIGHT SOURCES:** Two laser arms that can deliver 100-TW pulses at 10 Hz, 1-PW pulses at 1 Hz, and 1-PW pulses at one pulse per minute; high-flux gamma-ray source (expected in 2023)

**EXPERIMENTAL STATIONS:** Eight experimental areas for work in materials science, high-energy nuclear physics, and nonlinear QED

Optics and Photonics News, January 2020
The High Power Laser System at ELI-NP (HPLS)

**Measured parameters of the HPLS**

<table>
<thead>
<tr>
<th>Output type</th>
<th>100 TW</th>
<th>1 PW</th>
<th>10 PW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse energy (J)</td>
<td>2.7</td>
<td>25</td>
<td>242</td>
</tr>
<tr>
<td>Pulse duration (fs)</td>
<td>&lt; 25</td>
<td>&lt; 24</td>
<td>&lt; 23</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>10</td>
<td>1</td>
<td>1/60</td>
</tr>
<tr>
<td>Calculated Strehl ratio from measured wavefront</td>
<td>&gt; 0.9</td>
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<td>Pointing stability (µrad RMS)</td>
<td>&lt; 3.4</td>
<td>&lt; 1.78</td>
<td>&lt; 1.27</td>
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<td>&lt; 2.6%</td>
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*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
E1: 2x10PW, 1shot/min Nuclear Physics exp.

E6: 2x10PW, 1shot/min QED experiments

E5: 2x1PW, 1Hz experiments

E4: 2x0.1PW, 10Hz experiments

E7: Combined laser-gamma experiments

Main building Layout
ELI performance @ end of 2020
• Why intensity matters
• Extreme Light Infrastructure facilities
• **Architecture of the 2x10PW laser system (HPLS)**
• Laser pulse characterization at HPLS
• Experimental areas for laser experiments
Virtual tour of the ELI-NP laser system


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

**E4:**
- 2x0.1PW, 10Hz experiments
- Oscillator + OPCPA + XPW
  - HPLS 10TW compressor
  - 100TW amplifier Ti:Sapphire
    - 2.5J@10Hz/25fs
  - 1PW compressor
  - 1PW amplifier Ti:Sapphire
    - 25J@1Hz/25fs

**E5:**
- 2x1PW, 1Hz experiments
- Oscillator + OPCPA + XPW
  - HPLS 10TW compressor
  - 100TW amplifier Ti:Sapphire
    - 2.5J@10Hz/25fs
  - 1PW compressor
  - 1PW amplifier Ti:Sapphire
    - 25J@1Hz/25fs

**E6:**
- 2x10PW, 1shot/min QED experiments
- Oscillator + OPCPA + XPW
  - HPLS 100TW compressor
  - 10PW amplifier Ti:Sapphire
    - 2.5J@10Hz/25fs
  - 1PW compressor
  - 1PW amplifier Ti:Sapphire
    - 25J@1Hz/25fs

**E7:**
- Combined laser-gamma experiments
- Oscillator + OPCPA + XPW
  - HPLS 100TW compressor
  - 10PW amplifier Ti:Sapphire
    - 2.5J@10Hz/25fs
  - 1PW compressor
  - 1PW amplifier Ti:Sapphire
    - 25J@1Hz/25fs

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*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 $10^{13}:1$
High-energy hybrid femtosecond laser system demonstrating $2 \times 10$ PW capability

François Larouze, Guillaume Martin, Olivier Chada, Christophe Bercche, Thomas Morin, Christophe Kelier, Olivier Casanova, Armand Lux, Sandrine Ricard, Gilles Roy, Alain Pellegrino, Caroline Richard, Laurent Brodin, Christophe Simon-Giroux, André Bahame, Roméo Bani, André Gobbay, Constantin Calandra, Bertrand De Boestefde, Pierre Ourmazd, André Narrist, Georges Kottopoulou, Liviu Sengra, Ivan Dabou, Jean Demeur, and Daniel Ursu

Abstract

We report on a two-arm hybrid high-power laser system (HPLS) able to deliver $2 \times 10$ PW femtosecond pulses, developed at the Brazilian Nuclear Energy Laboratory (Laboratório de Energia Nuclear de Fusão, LENA). A hybrid laser system consists of a 800 nm chirped pulse amplifier and a nanosecond-scale regenerative chirped pulse amplifier based on beta-barium borate (BBO) crystals, with a cross-polarization scheme (CPA) triplet in between. It has been demonstrated to deliver 80 TW, 10 fs, 1 Hz repetition rate, with more than 70 nm spectral bandwidth and high-repetition rate, in the range of $10^3$. The high-energy Ti:sapphire amplifiers stages of both arms were seeded from the common FL. The final high-energy amplifier, equipped with a 250 mm diameter Ti:sapphire crystal, has been pumped by six, 400 mJ, nanosecond frequency-doubled Nd:glass lasers, at a pulse-to-pulse repetition rate. More than 40% output pulse energy has been obtained by pumping with only 50% of the whole 800 J available pump energy. The compressor has a transmission efficiency of 80% and an output pulse duration of 22 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 HPLS, $2 \times 10$ PW femtosecond laser facility, devoted to fundamental and applied nuclear physics research.

Keywords: lasers, high power laser pulses, ultra-short laser pulses
Front – End

XPW filter
- 40 μl
Bulk stretcher
Pulse picker
< 10 μl @ ~15 ps
> 26 μJ
ps-NOPCPA
Stage 1
< 10 μl @ ~15 ps
> 26 μJ
ps-NOPCPA
Stage 2
> 10 mJ @ ~15 ps, 10 Hz
~ 5 mJ @ ~15 ps, 10 Hz

Amplification arm

Amp 1
>3.5 J @ 10 Hz

Amp 2
>30 J @ 1 Hz

Amp 3
>300 J @ 1/60 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
- Deformable mirror
- 10 PW compressor
- 10 PW diagnostic bench
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 amplifiers

Amplification arm

~ 5 mJ @ 15 ps, 10 Hz

Offner Stretcher 2

Dazzler

Partial Compressor

Spectral Filter 1

Ti:Sapphire multipass Amp 1.1 (3 passes)

Ti:Sapphire multipass Amp 1.2 (5 passes)

~ 200 mJ

SAGA 1
SAGA 2
SAGA 3
SAGA 4
SAGA 5
SAGA 6
SAGA 7
SAGA 8

GAIAs: 16 J @ 532 nm, 1 Hz

~ 14.2 J

~ 96 J

SAGA - HP
GAIAs - HP
ATLAS - 100

~ 200 J

~ 600 J
HPLS compressors and diagnostics

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
- Deformable mirror
- 10 PW compressor
- 10 PW diagnostic bench

Laser amplifiers
- D.M.
- Periscope

Compressor
- Picture of 10 PW compressor

Beam transport
- WIZZLER
- ENERGY
- AUTO-CO
- CROSS-CO

Diagnostic bench
- CCD - NF
- CCD - FF
- SPECTRO
- WFS
• Why intensity matters
• Extreme Light Infrastructure facilities
• Architecture of the 2x10PW laser system (HPLS)
• Laser pulse characterization at HPLS
• Experimental areas for laser experiments

Compressor metrology
Beam transport
Experiment metrology
Diagnostics bench

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

\[ \frac{E}{tS} = I \]
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): λ/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

Normalized irradiance (a.u.)

Delay [ps]

1 PW
100 TW
10 PW

Normalized irradiance (a.u.)

Delay [ps]
• Why intensity matters
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We select the highlighted route for our modeling
2 flat mirrors
1 OAP f=1500mm @ 45°

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

Wavefront Function

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/15/2020</td>
<td>0.8100 µm at 0.0000 (deg) Peak to valley = 0.6014 waves, RMS = 0.0916 waves.</td>
</tr>
<tr>
<td>Surface: 22</td>
<td>Exit Pupil Diameter: 2.0003E+02 Millimeters Tilt Removed: X = -0.8413, Y = 0.7017 waves</td>
</tr>
</tbody>
</table>

Zemax
Zemax OpticStudio 19.4 SP1

Total Irradiance surface 22

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<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/15/2020</td>
<td>Beam wavelength is 0.81000 µm in the media with index 1.00000 at 0.0000 (deg)</td>
</tr>
<tr>
<td>Display X Width = 8.1360E-02, Y Height = 1.2621E-01 Millimeters &amp; Peak Irradiance = 1.024E+21 Watts/Millimeters², Total Power = 1.0000E+16 Watts</td>
<td></td>
</tr>
<tr>
<td>X Pilot: Sizes: 4.5100E-02, Waist= 1.4064E-03, Pos= +2.4589E-01, Rayleigh= 7.6717E-03</td>
<td></td>
</tr>
<tr>
<td>Beam Width X = 1.26402E-02, Y = 1.39835E-02 Millimeters</td>
<td></td>
</tr>
</tbody>
</table>

Ioan Dancus et al. FiO+LS 2020
Encircled energy

Fraction of Enclosed Energy

Radius from centroid (µm)

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Diffraction limited
Real beam + perfect OAP
Real beam + (50 nm RMS) OAP
Real beam + (50 nm RMS) OAP + 4-8 Zernike correction

I_{peak} 1.6 \times 10^{23} \text{ W/cm}^2
0.96 \times 10^{23} \text{ W/cm}^2
0.9 \times 10^{23} \text{ W/cm}^2
1 \times 10^{23} \text{ W/cm}^2
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

- Wavefront map, Strehl ratio > 0.7

- NF LBTS output

- Pulse duration LBTS output
• Calculated peak power $= \frac{243 \text{ J}}{23.4 \text{ fs}} = 10.4 \text{ PW}$
• Verification of transmission efficiency
• Visual inspection of optical components within HPLS compressor and LBTS

• No losses of efficiency and no damages observed
17 November 2020
Moving into Uncharted Territories
Energy in the main peak (J)

Time of the day

Energy in main peak = 90.4905%

\[ \Delta t = 2.1125 \times 10^{-14} \]
• Why intensity matters
• Extreme Light Infrastructure facilities
• Architecture of the 2x10PW laser system (HPLS)
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Beam sampling for diagnostics

- HPLS → Compressor
- Compressor → Experimental area
- Experimental area → Sampling
- Sampling → Window + Leakage Mirror
  - Large dispersion (30-120 mm of glass)
  - Positive chirp: $22\text{fs} \rightarrow 491\text{fs} @ 1\text{PW}$
- Sampling → Diagnostics bench
- Diagnostics bench → Wizzler
- Wizzler
- $\tau_{\text{exp}} \neq \tau_{\text{Diag.}}$
## ELI-NP diagnostics scenario

### HPLS
- Control system
- Front End
- amplifiers
- 6x Compressors
- 6x diagnostics benches

### LBTS
- Vacuum system
- optics
- Alignment control

### Experiments E1, E4-E7
- Interaction chamber
- target
- Laser diagnostics
- Experiment diagnostics

### Parameters and Devices

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Device</th>
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<tbody>
<tr>
<td>Near field</td>
<td>CCD</td>
</tr>
<tr>
<td>Far field</td>
<td>CCD</td>
</tr>
<tr>
<td>Wavefront</td>
<td>ImaginOptics Wavefront sensor</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>Wizzler</td>
</tr>
<tr>
<td>Spectral phase</td>
<td></td>
</tr>
<tr>
<td>Spectrum</td>
<td></td>
</tr>
<tr>
<td>ns-contrast</td>
<td>Fast photodiodes and oscilloscope</td>
</tr>
<tr>
<td>ps-contrast</td>
<td>Tundra</td>
</tr>
<tr>
<td>Energy</td>
<td>Gentec energy-meter</td>
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<tr>
<td>Far field</td>
<td>CCD (high resolution)</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>Frog or D-Scan or Spider</td>
</tr>
<tr>
<td>Spectral phase</td>
<td></td>
</tr>
<tr>
<td>Spectrum</td>
<td>Ocean optics</td>
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**Calibration**

**ELI-NP diagnostics scenario**

**On shot**

**+ focal spot size**
• Why intensity matters
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• 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
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
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\(^2\) \(\Rightarrow\) +/-70mm of BK7 \(\Rightarrow\) 400fs chirped pulse
Dispersion variation between -3000fs$^2$ and 3000fs$^2$, in steps of minimum 100fs$^2$
Target position at 250mm from focus. Energy per pulse ~45mJ

Glass: BK7 1mm

Plastic: OKP 0.1mm
LWFA Experimental setup of E4

PI: Domenico Doria / Petru Gheneche

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
Magnet length: 160 mm
Magnetic field: 0.7 T
Nozzle: 2 mm diameter nominal
Gas target: He, He + 2% N₂
Gas density best data: $\sim 4 \times 10^{18}$ atom/cm$^3$ @ the plateau

Typical electron spectra obtained

Typical quasi-monoenergetic spectrum with pure He gas

Typical broadband spectrum with He + 2% N₂ gas

Electron spectrum
Laser power $\sim$ 80 TW

Electron spectrum
Laser power $\sim$ 90 TW
• 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+/-y Spectrometer: up to 100 MeV, 5% @ 100 MeV, optically coupled optional (online)
  - e- Spectrometer (permanent /electromagnet, 2GeV)
  - Optical Plasma Probe: 1&2omega +shadowgraphy +interferometry

2 x 1PW Laser Input
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**

- Radiographic 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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https://www.youtube.com/watch?v=qBse2Uw2WTQ
Overview of 10PW Experimental Area
Overview of 10PW Experimental Area
• **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
Thank you!