Current Status of ELI-Beamlines

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Laser Leptonics with High-intensity Facilities, FNSPE-CTU Prague, 7-8 October, 2013
Outlines

✓ ELI pillars and ELI-Beamlines
✓ Facility layouts
✓ Lasers (RP1)
✓ Beam transport and switchyard
✓ Experiments (RP2-RP6)
Site selection decision on 1.10.2009
Structure of implementation of the ELI project

- **Beamlines facility**
  - Prague

- **Attosecond facility, ALPS**
  - Szeged

- **Photonuclear facility, NP**
  - Magurele

- **High-brightness sources of X-ray radiation & particles**
  - Attosecond XUV/X-ray physics

- **Laser-induced nuclear physics**

- **Frontier physics by exawatt lasers**

- **200 PW facility (?)**
ELI-Beamlines project mission: fundamental & applied research

- High-repetition rate and high average power lasers using diode-pumping
- Ultra-high peak power of 10 PW, focused intensities up to $10^{24}$ Wcm$^{-2}$

1. Generation of rep-rated femtosecond secondary sources of radiation and particles
   - XUV and X-ray sources (monochromatic and broadband)
   - Accelerated electrons (2 GeV 10 Hz rep-rate, 100 GeV low rep-rate), protons (200-400 MeV 10 Hz rep-rate, >3 GeV low-rep-rate)
   - Gamma-ray sources (broadband)

2. Programmatic applications of rep-rated femtosecond secondary sources
   - Medical research including proton therapy
   - Molecular, biomedical and material sciences
   - Physics of dense plasmas, laser fusion, laboratory astrophysics

3. High-field physics experiments with focused intensities $10^{23}$-$10^{24}$ Wcm$^{-2}$
   - “Exotic” physics, non-linear QED: sophisticated pump-probe capabilities

4. Development & testing new technologies for multi-PW laser systems
   - Generation and compression of 10-PW ultrashort pulses, coherent superposition, etc.
Science Case at ELI-Beamlines

ELI-Beamlines bid: balance between fundamental science and applications
ELI-Beamlines will be international user facility, partnership experiments & projects

Research Program 1
Lasers generating rep-rate ultrashort pulses & multi-petawatt peak powers

Research Program 2
X-ray sources driven by rep-rate ultrashort laser pulses

Research Program 3
Particle acceleration by lasers

Research Program 4
Applications in molecular, biomedical, and material sciences

Research Program 5
Laser plasma and high-energy-density physics

Research Program 6
High-field physics and theory (steps to $10^{23}$ W/cm$^2$, radiation reaction plays role)
ELI-Beamlines Milestones

Apr 2011  ELI-Beamlines funding approved by EC
Aug 2011  Funding (278 mil. Euro) signed by the CZ’s Ministry of Education
Dec 2011  Technical Design Report completed
July 2012  Building documentation completed
Sept 2012  Site excavations start
May 2013  Construction start
Sept 2015  Start of installation of laser systems
Dec 2015  Phase I completed: two laser units + support installed
2016-2017  Phase II: lasers & experiments installed: facility commissioned!
• Proximity of international airport (15 min drive), enjoyable surroundings, behind the border of Prague (funding issues)
• Synergy with planned large biotechnology center BIOCEV (2 km distance)
• Direct connection to Prague outer ring and the European motorway network
Ground breaking ceremony
9th of October 2012

Prime Minister Necas, Minister of Education Fiala, President of Academy, Representative of Church praying for good photons!
ELI-Beamlines facility aerial view
Ground floor (80 x 40 m)
4 laser halls (L1 to L4)

First floor (80 x 40 m)
kJ laser for L4
Support technologies, cooling systems, cryogenic systems

Basement (110 x 60 m)
Compressor(s) of L4 10-PW laser(s)
Vacuum pulse distribution
6 specialized experimental halls (E1 to E6)
✓ ELI pillars and ELI-Beamlines
✓ Facility layouts
✓ Lasers (RP1)
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ELI-Beamlines laser baseline

4 laser beamlines: L1, L2, L3 and L4

- **L1**: 10TW-class @ kHz
- **L2** and **L3**: PW @ 10 Hz
- **L4**: 10 PW (1shot/min) and high energy “kJ” beam

**Beamlines based either on existing or newly developed technologies**

- DPSSL and flashlamp pumped
- OPCPA, Ti: Sapphire and mixed glass technologies
- Thin disk (MPQ, MBI and Trumpf Scientific)
- Multi slabs (Dipole – STFC, Mercury- LIFE- LLNL)
- Mixed glass (Texas PW laser, Apollon pump laser)
- Czech program for High Power Laser development “HILASE”
L1 beamline layout

- kHz repetition rate laser-diode pumped using thin-disk pump technology
- Oscillator and common front end producing mutually synchronized seed pulses
- Capable to generate several seeds with central wavelengths from 800 to 900 nm
- Picosecond OPCPA system for L1 broadband amplification
L1 beamline conceptual design

- L1 Laser hall
- Oscillator room
- Front end
- OPCPA & mirror compressor
- Diagnostics
- Pump laser(s)
- Compressor chamber

Fyzikální ústav
Akademie věd ČR, v. v. i.

projekt podporovaný: EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI
Cryogenic Yb:YAG laser-diode pumped multislab technology
First stage (10J/10Hz) of the pump system being built (completion end 2013)
Strong support from HiLASE project!
OPCPA short-pulse amplifiers
Optional 200-TW-class Ti:sapphire commercial system
10J/10Hz Yb:YAG subsystem of the L2 pump laser

Yb:YAG amp head & pump diode lasers: STFC (DiPOLE)
Front end, beam transport & cryo unit: ELI-Beamlines
- Nd:glass laser-diode pumped multislab technology
- Planned to become PW workhorse of the ELI-Beamlines facility
- Pump engine based on diode pumped technology
- Nd:glass active medium
- Operation at near room temperature
L3 & L2, 10 Hz, PW beamlines conc. design
**L4 beamline layout**

- **Disk amplifier CPA laser**
  - flashlamp pumped Nd:glass

- Nanosecond kJ pulses required for laser plasma experiments
- Spectral bandwidth for direct compression down to 120-150 fs
- Auxiliary beam for generation of “long” PW probe pulses (e- and ion acc.)
- Prospects for future OPCPA upgrade

**Outputs:**
- >1 kJ / 0.5-3 ns (non-compressed)
- 10 PW / <150 fs
- 1 PW / <150 fs
- 150 J / 0.5-3 ns
- 400 J / <20 fs
✓ ELI pillars and ELI-Beamlines
✓ Facility layouts
✓ Lasers (RP1)
✓ Beam transport and switchyards
✓ Experiments (RP2-RP6)
Facility general layout
ELI-Beamlines will provide synchronized beams of short pulse optical photons, x-rays, electrons, ions to be used by users (including pump-probe experiments).
Beam transport and switchyards

All laser beamlines can be delivered to any of the experimental rooms!
Beam transport and switchyard 1
✓ ELI pillars and ELI-Beamlines
✓ Facility layouts
✓ Lasers (RP1)
✓ Beam transport and switchyards
✓ Experiments (RP2-RP6)
Experimental Area (underground floor)
RP2: Laser-driven X-ray sources

Plasma sources

Laser

Harmonics (gas)

Laser

X-rays from relativistic e-beams

Laser

RP2: Laser-driven X-ray sources

LUX/XFEL

X-Rays

Plasma sources

Harmonics (gas)

LUX/XFEL

X-Rays

Laser

X-Rays

Laser

Betatron radiation

Gas jet
X-ray beamlines in E1
Betatron & Compton sources in E2

Using 30J/30fs PW laser @ ELI-Beamlines

LUX (Laser Undulator X-ray) beamline

- Development in collaboration with Hamburg University (F. Gruner) and DESY
- Water window wavelength range with sub-5fs pulse duration
- Future extension to laser driven X-FEL with more undulators (5 keV, short and tunable x-ray pulses)
**RP3: Electron Acceleration (Scaling Laws)**

**Electron Beam Parameters**

- **PW-class** beamline (30J/30fs, 0.01-10 Hz): L3
  - **Bubble regime**
    - Energy: **few GeV**
    - Charge: **several nC**
    - Divergence: **>>1 degree**
  - **Blow-out regime/self-guided**
    - Energy: **several GeV**
    - Charge: **~1 nC**
    - Divergence: **<1 degree**
  - **Blow-out regime/external-guided**
    - Energy: **>10 GeV**
    - Charge: **<1 nC**
    - Divergence: **<1 degree**

- **10 PW-class** beamline (1.3kJ/130fs, <0.01 Hz): L4
  - **Phase 3**
    - Energy: **100 GeV**
    - Charge: **>1 nC**
    - Divergence: **<1 degree**

**Scaling laws:**

\[ E_e = k m_e c^2 \frac{P}{P_{cr}} \]


**OSIRIS PIC simulations:**

RP3: Ion Acceleration (Scaling Laws)

- **Vertical Axis:** Maximum Proton Energy [MeV]
- **Horizontal Axis:** Elongation [W.µm²/cm²]

- **Data Points and Labels:**
  - **1PW(L3):** 1-10 Hz
  - **10PW(L4):** > 0.01 Hz
  - **10 PW (L3) - 1-10 Hz**
  - **10 PW (L4) - > 1 GeV**
  - **ELI intensity regime**

- **Legend:**
  - Black square: 30-60 fs
  - Blue circle: 100-150 fs
  - Red triangle: 0.3-1 ps
  - Purple triangle: Simulations

- **Notes:**
  - **K. Ogura et al., Optics Letters 37 (2012) 2868**
  - 0.8 µm Al target; 200 TW (8J/40fs) laser

- **References:**
  - J. Fuchs et al., C. R. Physique 10 (2009) 176 and references therein
The ELIMIAA beamline: ELI-beamlines
Multidisciplinary Ion Acceleration Applications

Experimental Hall 4
Plasma mirror and target chambers design
The ELIMIAA Beamline

Laser-target interaction

Beam diagnostics, transport & selection

Beam delivery, dosimetry & radiobiology
The ELIMED international cooperation

2nd ELIMED Workshop and Panel, 18-19 October 2012 @ INFN-LNS, Catania
2nd ELIMED Workshop and Panel

Catania, Italy
18-19 October 2012

Editors
Daniele Margarone, Pablo Cirrone, Giacomo Cuttone and Georg Korn
HELL (High-energy ELeCtron-acceleration by Lasers)

Flexible platform for laser-plasma accelerators with PW-class and 10PW-class lasers (L3 & L4)

Synergy with RP6 (gas target)
- stable acceleration with 1-2PW laser
- inverse Compton scattering (counter-propagating setup) with 1-2PW laser
- Flying mirror type experiments with 1-2PW
- similar experimental setups for 10PW

S.V. Bulanov, ... G.Korn, Nuclear Instruments and Methods in Physics Research A 660 (2011) 31–42
RP4: applications in molecular, biomedical, and material sciences

- User end-stations
- “flexible” end-stations will be available @ ELI-Beamlines
- Few examples are identified

Layout of the X-diffraction “pump-probe” end-station

Layout of the pulse radiolysis end station using plasma X-ray pulse and laser probe transient absorption
RP5: Laser plasma and high-energy-density physics

- X-ray diagnostics for E3
- Target chamber design
- Radiation protection in a PW-laser environment
- The ELI Virtual Beamline
- Laser-plasma interaction for shock-ignition approach to ICF
- Amplification of short light pulses
- WDM investigations
- Laboratory Astrophysics
- Proton and X-ray plasma radiography
Summary of Laser-Plasma Interaction in “Radiation-Dominant” Regimes

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Intensity</th>
<th>Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0 = \frac{eE_0}{m_\omega}$</td>
<td>2.4 × 10^{28}</td>
<td>$e^+, e^-$ in vacuum</td>
</tr>
<tr>
<td>$a_{QED} = \frac{e^2 m_c}{\hbar \omega}$</td>
<td>5.6 × 10^{24}</td>
<td>quantum effects</td>
</tr>
<tr>
<td>$a_p = \frac{m_p}{m_e}$</td>
<td>1.3 × 10^{24}</td>
<td>ultra-relativistic p</td>
</tr>
<tr>
<td>$a_{rad} = \left(\frac{3 \lambda_{\text{rad}}}{4\pi r_e}\right)^{1/3}$</td>
<td>1 × 10^{23}</td>
<td>radiation damping</td>
</tr>
<tr>
<td>$a_{rd} = 1$</td>
<td>1.3 × 10^{18}</td>
<td>relativistic $e^-$</td>
</tr>
</tbody>
</table>

Ultrarelativistic ELI

$a_0 > 2000$, $E = 4$ PV/m
High-Power $\gamma$-Ray Flash Generation in Ultraintense Laser-Plasma Interactions

Tatsufumi Nakamura,\textsuperscript{1} James K. Koga,\textsuperscript{1} Timur Zh. Esirkepov,\textsuperscript{1} Masaki Kando,\textsuperscript{1} Georg Korn,\textsuperscript{2,3} and Sergei V. Bulanov\textsuperscript{1,4}

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(Received 23 November 2011; revised manuscript received 10 February 2012; published 9 May 2012)
Quantum description is necessary when the recoil due to photon emission is of the order of the electron energy $\rightarrow 10^{21} \text{ Wcm}^{-2}$ for 10 GeV electrons

*Stepan Bulanov et al, AAC 2012*
Thank you for your kind attention!

For more info about the ELI Beamlines facility see http://www.eli-beams.eu