

Laser-Driven Accelerators



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High energy lasers

2018 Nobel prize

“for groundbreaking inventions
in the field of laser physics”

Method of generating high
intensity, ultrashort optical pulses

1985 common work at
University in Rochester

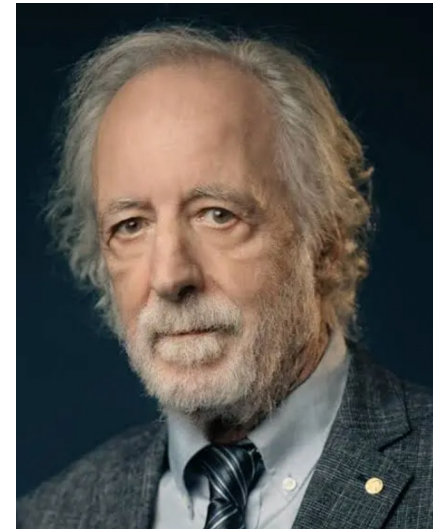


Chirped pulse amplification

- Stretch laser pulses in time
to reduce their peak power
 - Amplify the pulse
 - Compress the pulses
- > The intensity of the pulse increases dramatically!

Gérard **Mourou** (*1944, France]
Donna **Strickland** (*1959, Canada)

2023 Nobel prize



“for experimental methods
that generate attosecond
pulses of light for the study of
electron dynamics in matter”

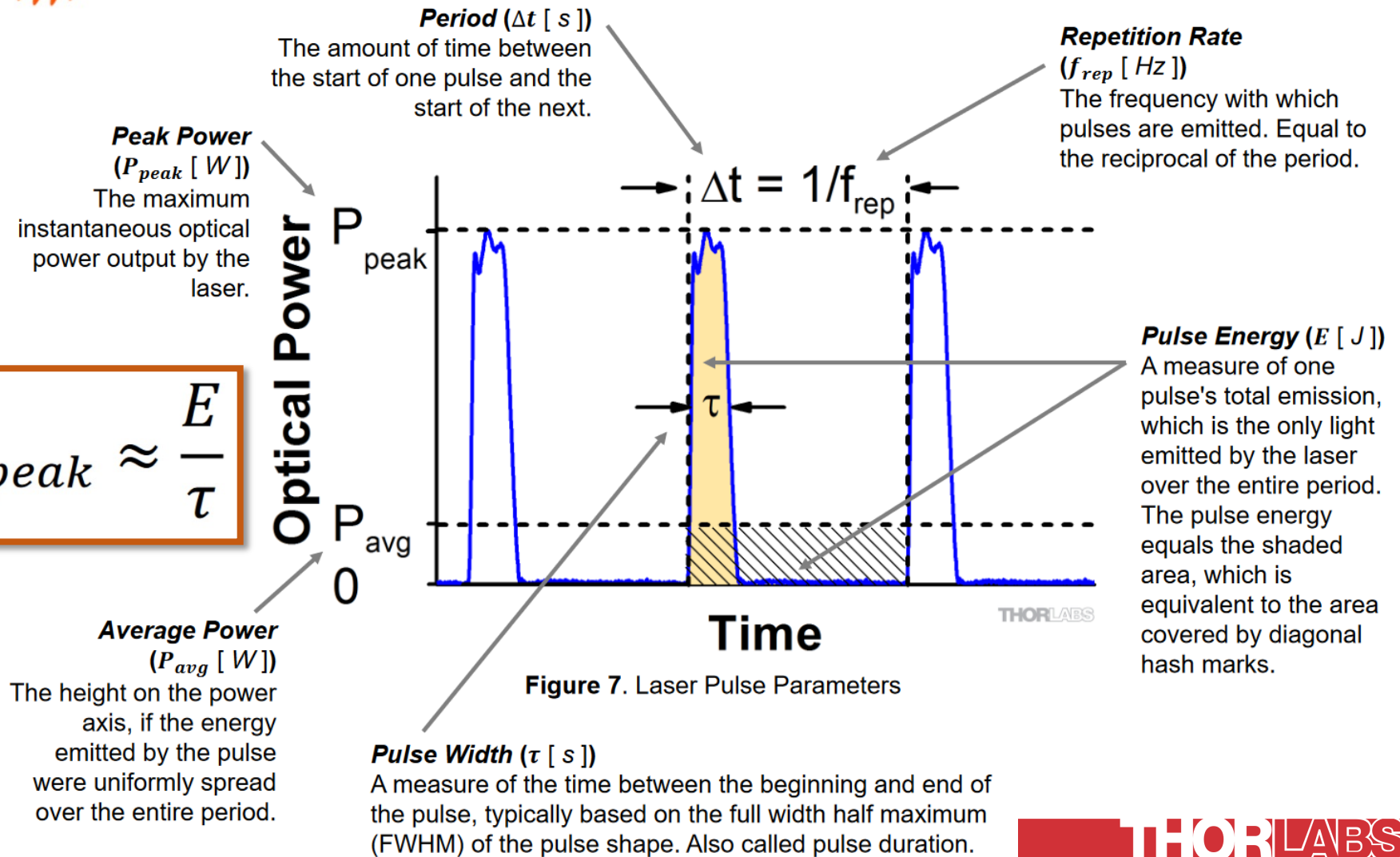
Anne **L'Huillier** (*1958, France)
Ferenc **Krausz** (*1962, Hungary)
Pierre **Agostini** (*1941, French Tunisia)



HIGH ENERGY LASERS:

Principles

Laser optical parameters

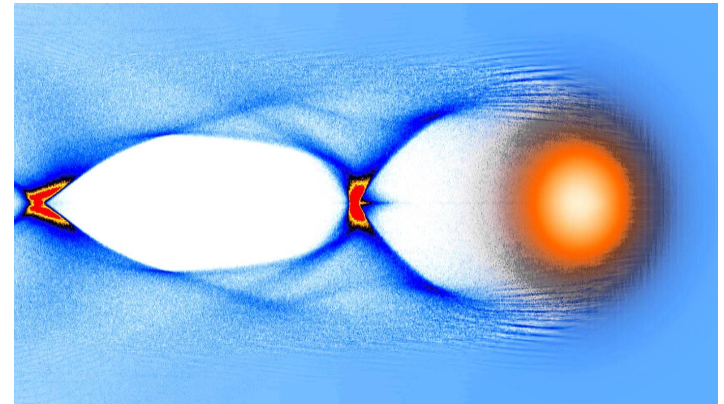


Laser acceleration: electrons

Laser pulse propagating through the plasma produces a wave behind which the electrons are accelerated. During fast acceleration or deceleration of electrons, X-ray radiation is produced.



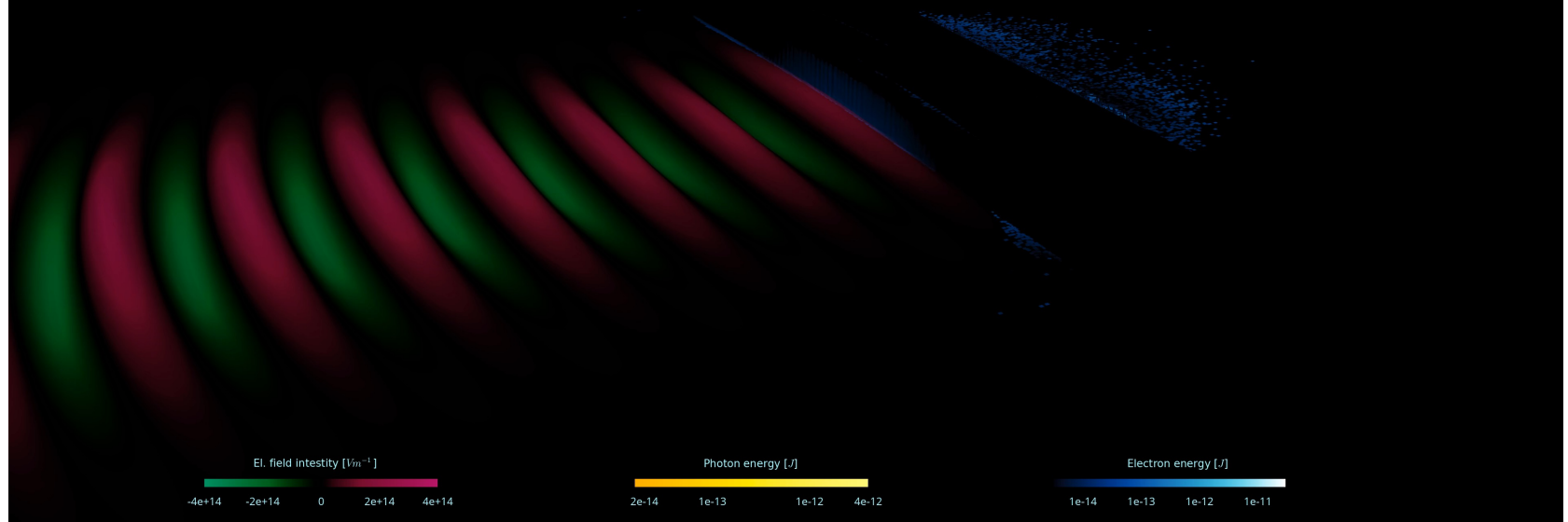
- **Laser wakefield (LWFA)**
- Plasma beat wave (PBWA)
- Multiple laser pulses
- Blow out regime



Laser produced gamma rays

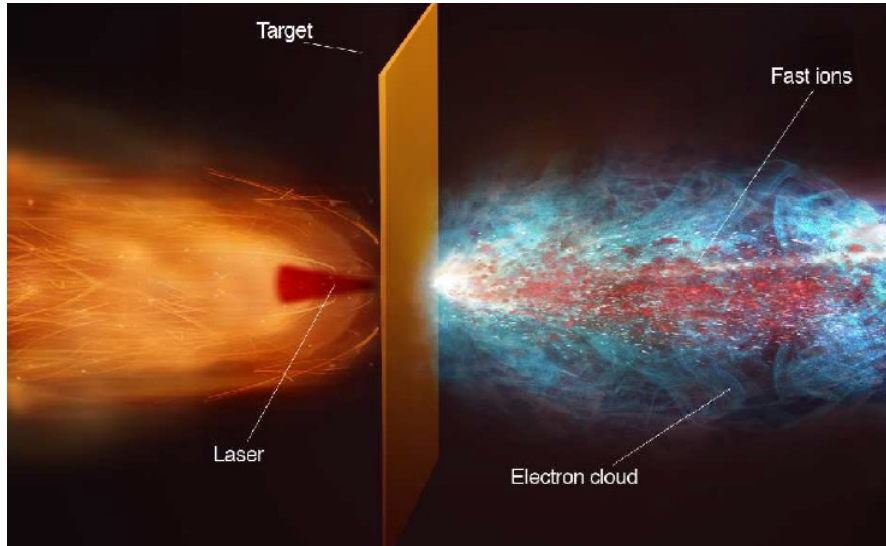
Electrons accelerated from a thin foil irradiated by an ultra-intense laser pulse emit energetic photons in the gamma region. The pulse rips electrons out of the initially solid target into the free space in front of it. While the laser pulse still burns through the target, the fast electrons interact with its strong electromagnetic field, producing energetic photons through the process of quantum radiation reaction - a peculiar kind of self-force stemming from higher-order corrections to the Lorentz force only observable in the presence of extremely strong electromagnetic fields, such as those of produced by the ELI lasers.

Time = 0.0 [fs]



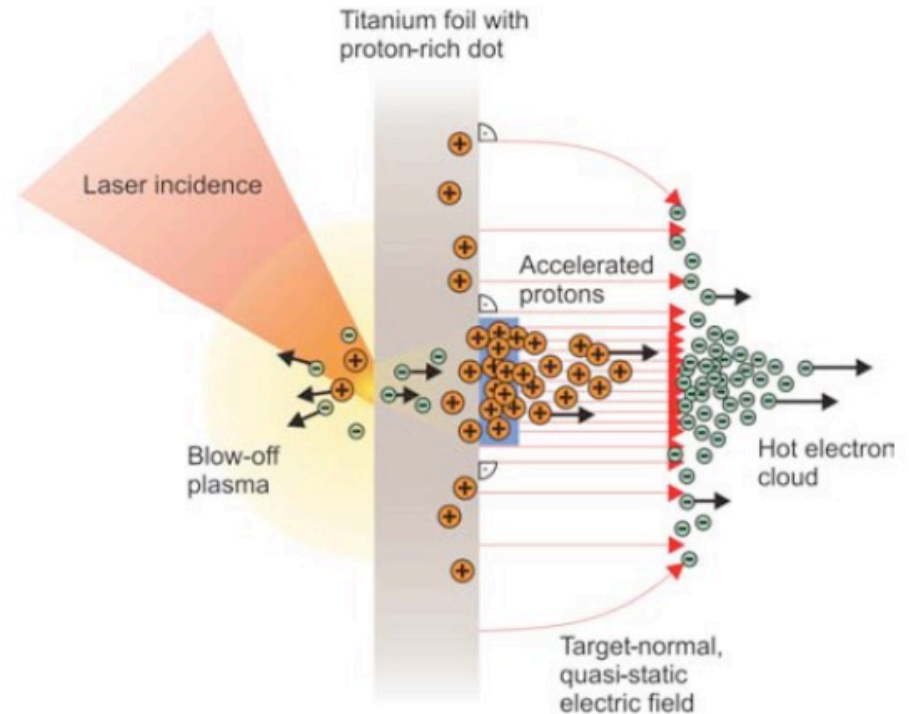
J. Vyskočil, ELI Beamlines

Laser acceleration: ions



- Magnetic vortex acceleration (MVA)
- Coulomb explosion (CE)
- Directed Coulomb explosion (DCE)
- Shock wave acceleration (SWA)
- Break-out afterburner (BOA)

- Target normal sheath acceleration (TNSA)
- Radiation pressure acceleration (RPA)



Laser-driven ion acceleration from plastic target

2D particle-in-cell simulation of the interaction of high-intensity laser pulse (parameters are relevant to L3 laser and thus ELIMAIA beamline) with a micrometer-thick flat plastic target. Acceleration of both protons (pink color) and carbon ions (green color), to maximum energy 150 MeV/nucleon and 40 MeV/nucleon, respectively, can be clearly distinguished in the visualization as well as different ion acceleration mechanisms (from the target front side and from its rear side). Such high-energy protons and ions have a great importance for various foreseen applications in Physics, Biology, Medicine, Chemistry, Materials Science, Engineering, and Archaeology.

Time: 2 [fs]



carbon energy [MeV/nucleon]

0.01 0.1 1 10



proton energy [MeV/nucleon]

0.1 1 10 100



ax []

0.5 1 2 5



ay []

-100 0 100



HIGH ENERGY LASERS:

Examples of installations:

- Large scientific installations
- Small labs (university type)
- Industry

- ## 2020 ULTRAHIGH INTENSITY LASER FACILITIES



<https://www.icuil.org/pdf/icuil-world-map-2020.pdf>

EPAC: Extreme Photonics Applications Centre



Construction started: 2020
Building finished: 2022
Expected operation: 2026



Science and
Technology
Facilities Council

Central Laser Facility

ATLAS: Advanced Technology Lasers for Applications and Science facility



**COLORADO STATE
UNIVERSITY**



ELI ERIC

The Extreme Light Infrastructure

2011: Start of parallel implementation

2018: First users

2021: ELI ERIC founded

2022: Regular open calls (2 per year)

MEMBERS



CZECH
REPUBLIC



HUNGARY



ITALY



BULGARIA



LITHUANIA

OBSERVERS



ROMANIA



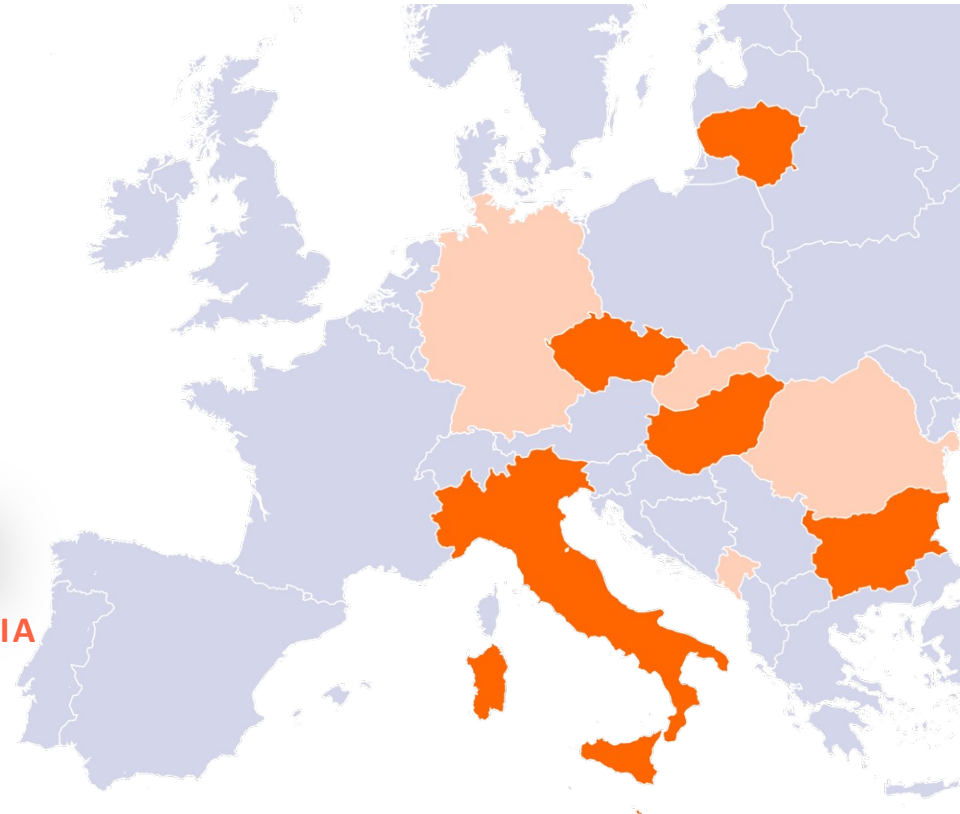
GERMANY



SLOVAKIA



MONTENEGRO





ELI ERIC

The Extreme Light Infrastructure

International, civilian, laser-driven open access user facility

ELI ALPS - Hungary

- Ultrafast physical processes
- Attosecond measurement techniques

ELI Beamlines – Czech Rep.

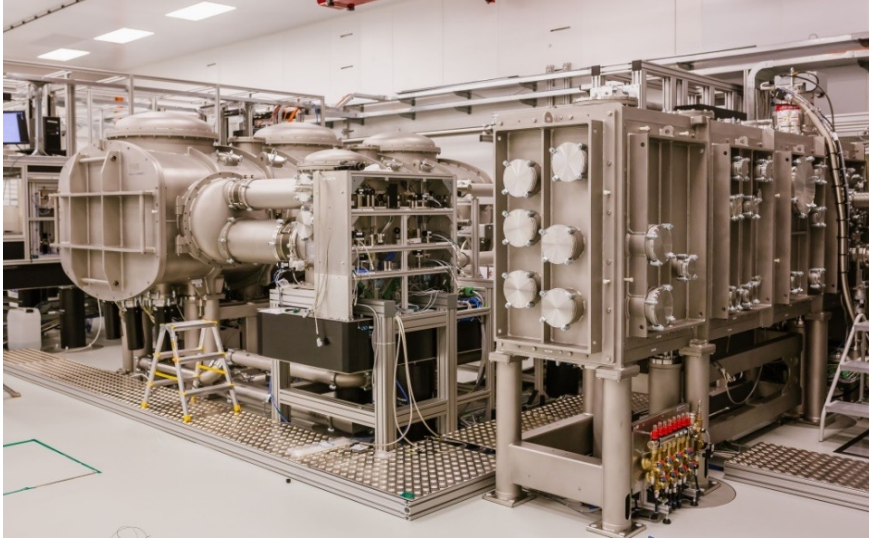
- Secondary sources (p, e, X)
- Medical imaging and diagnostics, radiotherapy

ELI NP – Romania

- Photonuclear Physics
- Nuclear spectroscopy



L1-Allegro: 10 TW, 100 mJ, 1 kHz



L2-Duha: 100 TW, 2 J, 50 Hz



L3-HAPLS: 1 PW, 30 J, 10 Hz



L4-Aton: 10 PW, 1,5 kJ, 0,016 Hz



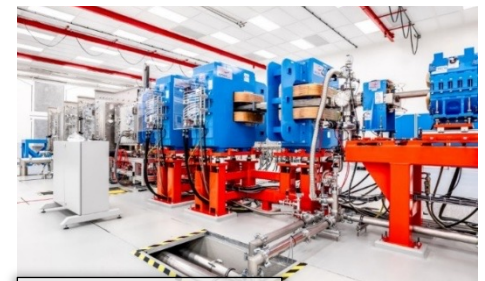
Parameters achieved

World record	DRACO, HZDR	BELLA (Berkley) TPW (Texas uni)
particle	protons	electrons
E max	~110 MeV	~10 GeV
frequency [Hz]	Single shot	Single shot
DOI	10.1038/s41467-025-56667-3	10.1103/PhysRevLett.133.255001 10.1063/5.0161687



ELBA

ELI Beamlines	Current		Target	
particle	protons	electrons	protons	electrons
E max	~40 MeV	~5 GeV	250 MeV	50 GeV
frequency [Hz]	3.3	3.3	10	10



ELIMAIA

Small labs (university type)



Number of systems & labs
capable to create ionizing radiation
is increasing

Compact commercial systems can

- Produce X-rays
- Accelerate e- to **tens of MeV**

Issue:

typically missing radioprotection awareness due to move from
pure laser science to wake field acceleration

- Low plasma intensity: 10^{13-14} W/cm²
- High rep rate: 10^2 MHz
- Low energy X-rays: ~ 30 keV
- Results in high cumulative dose rates: 10 mSv/h
- First implementation to legislation – Germany (PTB)
- <https://www.light-pulse.de/en-gb/xray>
- Newest work: Radiation safety considerations for ultrafast lasers beyond laser machining (doi: 10.48550/arXiv.2603.25585)

Radiation Protection Dosimetry (2019), Vol. 183, No. 3, pp. 361–374
Advance Access publication 5 September 2018

doi:10.1093/rpd/ncy126

X-RAY EMISSION FROM MATERIALS PROCESSING LASERS

R. Behrens*, B. Pullner and M. Reginatto

Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

Applied Physics A (2018) 124:407
<https://doi.org/10.1007/s00339-018-1828-6>

INVITED PAPER

Applied Physics A
Materials Science & Processing



X-ray emission as a potential hazard during ultrashort pulse laser material processing

Herbert Legall¹  · Christoph Schwanke¹ · Simone Pentzien¹ · Günter Dittmar² · Jörn Bonse¹ · Jörg Krüger¹



HIGH ENERGY LASERS:

Challenges

Upgrade of existing laser facilities

- Existing sites not designed for sources of ionizing radiation
- Civil structure typically does not shield adequately

Penetrations

- Many large openings for services (vacuum, HVAC, laser beam)
- Laser beam distribution needs straight openings, without juggling (each elbow affects beam quality & is expensive)

Beam dump

- Beam stoppers have to be variable
- Source term is a matter of research
the real beam may significantly differ
from expectations

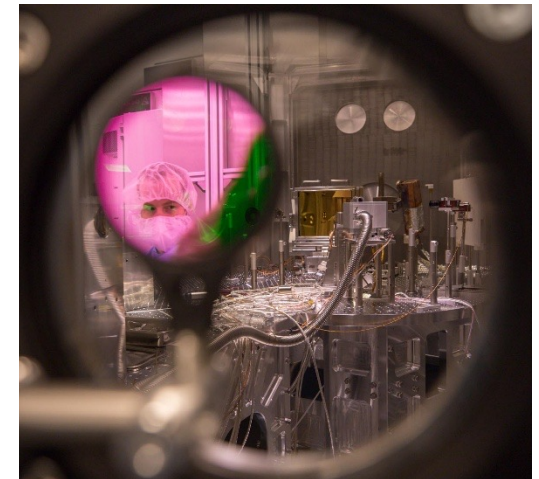


Character of generated fields

- Pulsed – length of primary pulse $\sim 10^{-14}$ s
- Low repetition rate: 0.1 Hz – 1 kHz - 1 MHz
- Mixed – e⁻, p⁺, n, μ
- Wide spread of energies (10^0 eV to 10^9 eV)
- Extremely high dose rate in a single pulse
- Strong magnetic field (10^2 kV/m)

Source term not well known

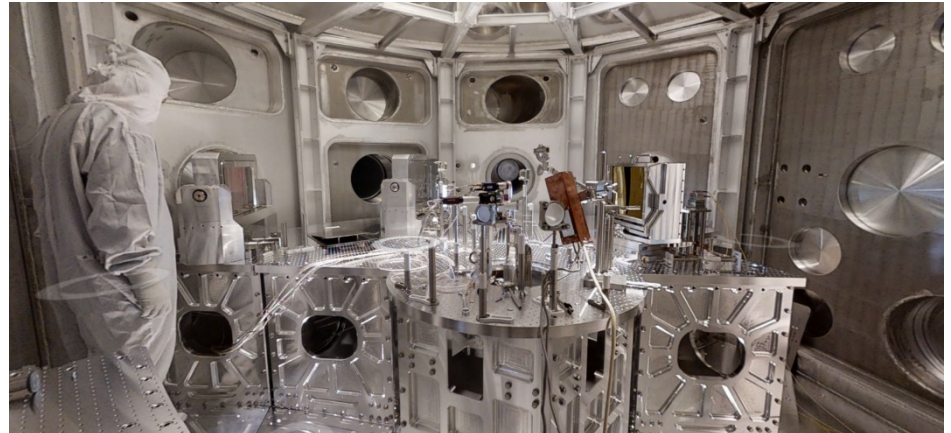
- Subject of research
- Strongly dependent on the experiment



View to P3 through a port

What detectors are needed?

- Reliable response in pulsed mixed fields for **wide range of energies**
- Ability to reliably detect **pulses as short as ~ 20 fs length**
- Not susceptible to **saturation** in high dose rate environment
- Resistance to **electromagnetic** pulses (few hundreds of kV)
- Sensitivity to detect small fractions of legal limits
- Availability to provide online data
- Standardization – traceability



31.10.2025

Thank you
for your
attention



EXTREME LIGHT
INFRASTRUCTURE



A EUROPEAN RESEARCH INFRASTRUCTURE
CONSORTIUM