ELI Flagship Experiment Proposal

BRIEF INFORMATION

Title: Probing dense laser-plasma with ultrafast X-rays and accelerated particles in the context of inertial confinement fusion and laboratory astrophysics.

Short Title/ ID of Project: Multi-LPI-P3

PIs: External users (To be determined)

Contact persons in ELI: S. Bulanov, V.T. Tikhonchuk & S. Weber

Affiliation of PIs: ELI-Beamlines

ELI Facility: ELI-BL

Experimental Area: E3 experimental hall of ELI-BL

Experimental chamber / station: P3 infrastructure

Phase: Flagship Experiments

Estimated Duration (days of beamtime & preparation): 3 x 20

Risk estimation & quantification: Availability & reproducibility of laser pulses

LASER SYSTEM PARAMETERS

Pulse duration (fs, ns): 30 fs & 3-5 ns

Wavelength (nm): 820 & 526

Pulse energy (J): 10-30 & 1500

Repetition rate (Hz): 0.02

Others: n/a

Diagnostics: ion TOF & Thomson parabola, gamma-ray detector, interferometry, soft X-ray spectrometer, hard X-ray spectrometer, X-ray area detector, electron spectrometer, VISAR/SOP

Special Technical Requirements for the beams: Synchronization on 10 ps-level between L4n and L3.

OTHER TECHNICAL INFORMATION

EMP expected: (Y/N) Y

Compatibility with vacuum: Y

Vacuum contamination risks: N

Special technical works requested on-site: N

SCIENTIFIC PROPOSAL

Aims / Objectives:

The objectives of this flagship experiment are to characterize shocked material with a variety of diagnostic tools using synchronized multi-beam configurations. The pulse-shaping capabilities of the L4n driver beam allow to access EOS off the Hugoniot, thereby providing new insight into complex, dynamic states of matter under extreme conditions.

Brief description of the scientific background and rationale of the project:

Scientific background: High-energy density physics is of relevance to a wide range of problems in nuclear fusion, astrophysics, and geophysics. High-power lasers allow to reproduce extreme states of matter in the laboratory under controlled conditions and study the temporal evolution on the micro- and meso-scale. They are also essential to benchmark numerical tools for predictive simulations.
Rationale: The rationale for this project is the uniqueness of the P3 infrastructure [6] which provides synchronized multi-beam environment with pulse-shaping capabilities (for the driver beam) for experiments in a high repetition-rate configuration.

Proposed experimental method and working plan:

The experimental campaign is expected to take place in three distinct stages:

- Use of the L4n driver with passive diagnostics such as e.g. VISAR/SOP for creating a compressed matter
- Use of the short focal length backlighter based on L3 separately and together with L4n (see details below) for diagnosing the compressed target with energetic x-rays and/or protons
- Use of the long focal length backlighter (betatron) based on L3 separately and together with L4n (see details below) for diagnosing a compressed material with hard x-rays

The experimental campaign increases in complexity and the various diagnostic tools mean to provide complementary information. The necessary diagnostic development will be mostly in-house whereas the sophisticated targetry required for high repetition rate experiments will be provided by existing collaborations (Germany & USA).

Description of the experimental arrangement including main optics, targetry, and diagnostics

The P3 [7] chamber allows the combination of the L4n [3] and L3 laser beams for sophisticated pump-probe experiments. The ~0.5 PW, ~30 fs HAPLS beam can be focused with an f/3 OAP (SFL-configuration for solid interaction, 0.75 m focal length) or with an f/20 spherical mirror (LFL-configuration for interaction with gas, 5 m focal length).
The driver beam L4n, 1.5 kJ, few ns at 527 nm, will interact either with multi-layer solid targets or foam targets. Both kinds of targets are set in a raster for multi-shot operation (up to ~100 shots) without breaking the vacuum.
The L3 beam is used as a diagnostic tool. In the SFL-configuration it would interact with solid targets for the generation of hard X-rays (K-alpha X-ray narrowband emission) or energetic protons (radiography for characterizing electric and magnetic fields). In the LFL-configuration it is used as a driver for a plasma betatron [1,5,6] to generate electrons and broadband X-rays for femtosecond time-scale radiography and phase contrast imaging. Standard detectors will be employed to characterize the sources of protons (TOF, Thomson parabola), electrons (magnetic spectrometer, CTR, ICT), X-rays (soft X-rays for background and

hard X-rays for hot electrons), and gamma-rays (gamma-ray spectrometer). The laser harmonics emission from the solid target will be measured for understanding the interaction conditions. The properties of those sources (particles and photons) have high scientific merit too. Gamma-photons of a few MeVs can be generated with the present L3-SFL configuration employing (relativistically) transparent foam targets and used as a probe for compressed matter as well.

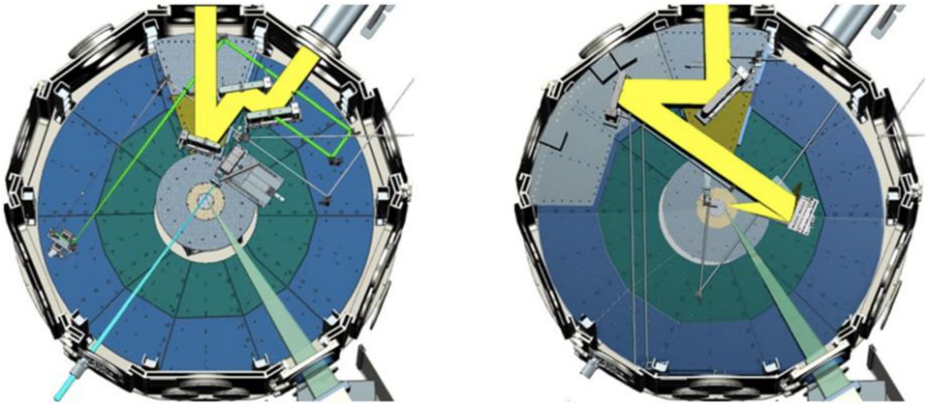

Fig. 1: The two multi-beam configurations in P3. Left: L4n-L3/LFL and right: L4n-L3/SFL, from [3].

Expected outcome / yield:

The generation of shock waves in a compressed matter or hypersonic radiative shocks in low-density targets by the L4n laser are of foremost relevance to equation-of-state measurements in inertial confinement fusion [3,4], planetary physics, and astrophysical objects [2,8]. The proposed probing allows high-temporal resolution and high-contrast images of fast-moving shock waves and provide key information about the structural evolution of materials under extreme pressure and temperatures on the Hugoniot adiabat as well as far-from-Hugoniot states.

Relevant publications in the field by participating scientists, in reverse chronological order

No.		Year
1	M. Lamac et al., *Two-color nonlinear resonances in betatron oscillations of laser accelerated relativistic electrons*, Phys. Rev. Research **3**, 033088 (2021)	2021
2	A. Gintrand et al., *Collision between radiative and adiabatic supersonic flows,* Astrophys. J. **920,** 113 (2021)	2021
3	N. Jourdain et al., *The L4n laser beamline of the P3-installation: towards high-repetition rate high-energy density physics at ELI-Beamlines*, Matter Radiat. Extremes **6**, 015401 (2021)	2021
4	V.T. Tikhonchuk et al., *Studies of laser-plasma interaction physics with low-density targets for direct-drive inertial confinement fusion on Shenguang III prototype*, Matter Radiat. Extremes **6**, 025902 (2021)	2021
5	S. Fourmaux et al., *Laser-based synchrotron X-ray radiation experimental scaling*, Opt. Express **28**, 3147 (2020)	2020
6	M. Kozlova et al., *Hard X Rays from laser-wakefield accelerators in density tailored plasmas,* Phys. Rev. X **10**, 011061 (2020)	2020
7	S. Weber et al., *P3: An installation for high-energy density plasma physics and ultra-high intensity laser-matter interaction at ELI-Beamlines*, Matter Radiat. Extremes **2**, 149 (2017)	2017
8	S.V. Bulanov et al., *On the problems of relativistic laboratory astrophysics and fundamental physics with super powerful lasers,* Plasma Phys. Rep. **41**, 1 (2015)	2015