Plasma Physics Platform at ELI-Beamlines

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The Extreme Light Infrastructure (ELI) Beamlines will be a multi laser beam user facility and is being constructed southwest of Prague in Czech Republic. The facility will provide for the first time both high rep rate (upto 10 Hz) PW laser pulses and also ultra high power (∼10 PW at 0.02 Hz). The unique combination of such synchronized laser beams will be used for generation of secondary beamlines (X-rays, protons, electrons) and also for direct applications in molecular, biomedical and material science, as well as in fundamental studies of laser-plasma interaction and high energy density physics[1]. The plasma physics platform (P3) at ELI Beamlines will be the target area for performing experiments in diverse fields like ultraintense laser-matter interaction, warm dense matter (WDM), high energy density physics (HEDP), laboratory astrophysics and other fundamental disciplines. This paper describes the P3 platform including the layout, preliminary beam geometry and a brief description of the planned detectors/diagnostics.

Figure 1 shows the basement of the experimental building of the ELI facility and highlights the locations of individual secondary beamlines. P3 platform is located in experimental hall 3 which has overall dimension 25 m × 18 m × 5 m. Bulk radiation shielding is provided by the 1.2 m thick concrete walls of the room[2]. Electro-magnetic pulse (EMP) shielding is provided by the target chamber and grounded rebars within the concrete walls of the experimental room.

A total of five beams will be available simultaneously to P3 and their parameters are summarized in Table 1. A total energy of upto 1.5 kJ can be split into the three L4 beams (represented as L4n, L4p or L4f) depending on the experimental requirements. The last character in the beam name is indicative of the pulse width i.e., n=nano, p=pico and f=femto seconds (see Table 1). The L4n beam will also have the ability for temporal shaping, which will be useful in shock and
Table 1: Parameters of laser beams planned for P3.

<table>
<thead>
<tr>
<th>Laser beam</th>
<th>Uncompressed (Energy; Pulse Width)</th>
<th>Compressed (Energy; Pulse Width)</th>
<th>Cross section (cm × cm)</th>
<th>Max rep rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4f</td>
<td>-</td>
<td>&lt;1.5 kJ; ~150 fs</td>
<td>40 × 40</td>
<td>0.02</td>
</tr>
<tr>
<td>L4p</td>
<td>-</td>
<td>Energy depends on pulse length; 150 fs-100ps for e.g., &lt;150 J; ~150 fs</td>
<td>20 × 20</td>
<td>0.02</td>
</tr>
<tr>
<td>L4n</td>
<td>&lt; 1.5 kJ; 5 – 10 ns</td>
<td>-</td>
<td>20 × 20</td>
<td>0.02</td>
</tr>
<tr>
<td>L3</td>
<td>30J; ns</td>
<td>30J; 20 fs</td>
<td>20 × 20</td>
<td>10</td>
</tr>
<tr>
<td>L2</td>
<td>10 – 20J; ns</td>
<td>10 – 20J; 30 fs</td>
<td>20 × 20</td>
<td>10</td>
</tr>
</tbody>
</table>

WDM experiments. The synchronized delivery with an accuracy of 20 ps (to be upgraded later to within 20 fs) of all the laser beams provides three unique advantages to P3:

1. **High Intensity**: The 10 PW L4f beam will provide intensities of $\geq 10^{23}$ W/cm$^2$, thereby leading to laser-matter interaction in the ultra-relativistic regime. Such high intensities provide an access to many experimentally unexplored phenomena, e.g., ion acceleration through radiation pressure[3], dense electron-positron plasma generation[4], directed $\gamma$ ray flash from solid target interaction[5] and other such extreme field experiments[6] which can be studied in P3.

2. **High repetition rate**: The high repetition rate ($\sim$ 10 Hz) of the two PW laser pulses available to P3 will be beneficial for improving the signal strength by repetitive experiments for e.g., while using single photon counting detection in fast electron transport experiments, or in hitherto unattempted experiments like those for measuring vacuum birefringence[7].

3. **Multiple synchronized beams**: One of the most exciting features of P3 for plasma physics experiments is the simultaneous and synchronized availability of five beams. The various beams can be used in pump/interaction/probe geometries. An example is shown in figure 2, where the L4n (pink) beam is used to generate a plasma by ionizing a gas jet, while counter propagating L4f (red) and L4p (blue) beams are used to study the plasma amplification by stimulated Brillouin scattering[8]. The two beams L2 (green) and L3 (yellow) provide probe beams for two-dimensional proton radiography in horizontal and vertical direction, respectively.

Figure 2: Setup of plasma amplification experiment in P3. Inset shows the detailed image of the gas jet, with the ionizing beam (pink), the seed (red) and the pump beam (blue) with orthogonal proton probing.
Providing a flexible environment to the user community for accommodating various experimental geometries along with access to beams and diagnostics is a challenging task. One of the most versatile beam distribution geometry being considered transports the L4f (10 PW) beam horizontally and uses a static $f/3$ $15^\circ$ off axis parabola (OAP) to focus it to Target Chamber Centre (TCC). The nano second beam is also transported in a horizontal plane (under air) and can be brought in through various ports on the chamber. The remaining three beams are brought in from the top of the vacuum chamber and are steered to TCC using mirrors and OAPs (either vertical or horizontal) as required. A cartoon of the vacuum chamber with this beam geometry is illustrated in figure 3.

Extensive work has been done for identifying the diagnostics covering different spectral ranges that may be needed for various kind of experiments in P3[9]. Procurement of detectors is currently underway and some of the detectors and their uses are described in Table 2. A set of commissioning and enabling experiments are being identified for P3 and the development of diagnostics useful for such experiments will be prioritized.

P3 will also offer additional experimental hardware, e.g., pulsed $\vec{B}$ field ($\lesssim 100$ T) and fast gas valve for reaching neutral pressure up to $10^3$ bar. In addition, a betatron source as an X-ray backlighter with small source and short pulse width is also being considered. One of the critical issues for improving the user experience at P3 consists in minimizing the turn over time between individual shots. To this end, efforts are being made to minimize the pump down time and also options for replenishing targets without breaking vacuum are being considered.

In conclusion, P3 will have multiple synchronized beams ranging from low rep rate 10 PW beam to high rep rate (10 Hz) 1 PW beams. The design of such a unique platform is very challenging, and this paper describes the progress achieved - sample experimental geometries and beam transport as well as some of the diagnostics and detectors.

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Detector Characteristics | Used in diagnostics | Used in experiments
--- | --- | ---
Optical Streak Camera | Time resolution \( \sim 10\) ps, spatial resolution \( \sim 5\) \(\mu\)m | VISAR, SOP, ASBO | Shocks, WDM, Inertial Fusion studies, HEDP
Optical CCD | cooled, \( \sim 16\) bit, \( \sim 6\) \(\mu\)m px | Interferometer (including TASRI) | Multiple applications including plasma characterization and hot electron dynamics
XUV CCD (direct detection) | cooled, Energy band \( \sim 10\) eV - 12 keV, \( \sim 12\) \(\mu\)m px | XUV spectrometers (transmission grating or grazing incidence) | Opacity measurements, radiative shocks, \(n_e\) and \(T_e\) modeling
X-ray CCD (direct detection) | cooled, Energy band \( \sim 1\) keV - 12 keV, \( \sim 12\) \(\mu\)m px | Pin hole cameras, crystal spectrometers | \(T_e\) measurements, fast electron transport
X-ray CCD (indirect detection) | cooled, Energy band \( \sim 10\) eV - 100 keV | spectrometers, radiography, phase contrast imaging | \(T_e, n_e\) in shocks
X-ray streak Camera | Energy band \( \sim 100\) eV - 10 keV, time resolution \( \sim 1\) ps, space resolution \( \sim 40\) \(\mu\)m | 1-D imaging, XANES, spectrometers | WDM experiments, \(n_e, T_e\) evolution
High Purity Ge detector | Energy band \( \sim 40\) keV > 10 MeV | post shot \(\gamma\) spectroscopy | Estimating yield of neutrons and fast ions

Table 2: Some of the detectors and diagnostics planned for P3. Acronyms used: VISAR=Velocity Interferometry System for Any Reflector, SOP=Streaked Optical Pyrometry, ASBO=Active Shock Break-Out system, TASRI=Time And Space Resolved Interferometry, XANES=X-ray absorption near edge structure.

References