On behalf of SPARC_LAB collaboration

Time-Resolved Measurements of Fast Electrons and Protons Emitted in Ultra-Intense Laser-Solid Matter Interactions at SPARC_LAB

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Outline

• The FLAME laser @ SPARC_LAB
  – SPARC_LAB Test Facility
  – FLAME laser system
• FLAME-solid target interaction experiment
  – Experimental setup
  – Preliminary results
• Conclusions
Sources for Plasma Accelerators and Radiation Compton with Lasers and Beams

SPARC_LAB is a multi-disciplinary TEST Facility composed by a high brightness LINAC and the high power laser FLAME: this characteristic makes it unique.

The FLAME laser system

The FLAME laser: parameters on target

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy on target</td>
<td>4 J</td>
</tr>
<tr>
<td>Central wavelength</td>
<td>800 nm</td>
</tr>
<tr>
<td>Spectral bandwidth (FWHM)</td>
<td>70 nm</td>
</tr>
<tr>
<td>Spot size at focus (1/e^2 radius)</td>
<td>15 μm</td>
</tr>
<tr>
<td>Temporal duration (FWHM)</td>
<td>25 fs</td>
</tr>
<tr>
<td>Peak Power</td>
<td>&gt; 150 TW</td>
</tr>
<tr>
<td>Intensity</td>
<td>$5 \times 10^{19}$ W/cm²</td>
</tr>
<tr>
<td>Contrast Ratio (at 100 ps)</td>
<td>$10^9$</td>
</tr>
</tbody>
</table>
FLAME experimental activities

High intensity laser - matter interaction

Gas target
- LWFA electron acceleration in self-injection scheme.
- Generation and characterization of betatron-based X-ray sources.
- Study and realization of new single shot electron beam diagnostics.
- NEW! Laser guiding in plasma channel.

Solid state target
- Electro-Optic Sampling diagnostics to characterize fast electrons.
- Study of target geometry influence on fast electron emission.
- NEW! Detection and characterization of accelerated protons via TNSA.
1) Laser interacts with pre-formed plasma.
2) Electron acceleration and positive charge left on target.
3) Only more energetic electrons escape and their electric field causes proton and ion acceleration.

FLAME-solid target interaction experiment

LASER PARAMETERS:
• Energy: 0.4 J – 4 J
• Pulse duration: 25 fs FWHM
• Spot radius $1/e^2 = 15 \, \mu m$

Vacuum chamber

Stainless steel Angle: 18°
FLAME-solid target interaction experiment

EOS crystal
500 um ZnTe

Target

Stainless steel
Angle: 18°

Vacuum chamber

LASER PARAMETERS:
• Energy: 0.4 J – 4 J
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FLAME-solid target interaction experiment

**LASER PARAMETERS:**
- **Energy:** 0.4 J – 4 J
- **Pulse duration:** 25 fs FWHM
- **Spot radius** $\frac{1}{e^2} = 15 \, \mu m$

**Target**
- Stainless steel
- Angle: 18°

**Detectors and Crystals**
- TOF detector
  - 500 um thick diamond
  - 1m downstream
- EOS crystal
  - 500 um ZnTe

**Vacuum Chamber**
- 4mm CVD Diamond
- 0.5mm HPHT diamond substrate
- 4mm 1m downstream
FLAME-solid target interaction experiment
FLAME-solid target interaction experiment

to TOF

e⁻
p⁺

Probe
to CCD

FLAME

CCD to TOF
FLAME-solid target interaction experiment

TOF detector
FLAME-solid target interaction experiment
Fast electrons diagnostics
Experimental setup: EOS diagnostics

Temporal resolution: 100 fs
Temporal window: 8 ps

Probe energy: 60 uJ
Probe duration: 30 fs

Preliminary results: EOS diagnostics
Preliminary results: EOS diagnostics

**Bunch length** $\Delta t$: 0.4 ps  
**Peak electric field**: 1.5 MV/m  
**Charge**: 1 nC  
**Energy**: $\sim$10 MeV
Protons diagnostics
Particles (photons, electrons, protons, ions)

TOF diagnostics: typical signal
TOF diagnostics: typical signal

Electron and x-ray peak
TOF diagnostics: typical signal

Electron and x-ray peak

Proton signal
TOF diagnostics: typical signal

Electron and x-ray signal

10 um thick aluminum foil energy cut-off

Proton signal
TOF diagnostics: typical energy spectrum

Energy resolution: \( \sim 30 \text{ KeV} \)

Charge over \( \Omega_{\text{detector}} \) \( \sim 0.3 \text{ nC} \)
Conclusions

• We have reported about temporal characterization of emitted charged particles from laser-solid target interactions
  – EOS diagnostics has provided the fast electrons bunch length with femtosecond resolution.
  – TOF diamond detector has been employed to measure the proton temporal structure and energy spectrum.
• Data analysis is still undergoing to study possible fast electrons-protons correlations.
Thanks for your attention!

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The emitted bunch travels normally to the crystal surface and moves below it while the probe laser crosses the crystal with a non-zero incidence angle.

**ENCODING SIGNAL**

a) the bunch Coulomb field makes the crystal birefringent.

b) while the electric field penetrates in the crystal, the local birefringence shifts downwards.

c) The probe laser crosses the crystal and its polarization is rotated; the resulting signal comes from where the local birefringence and the probe laser are temporally overlapped.