Microcoulomb-Class Laser-Plasma Accelerator on OMEGA EP


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Summary

A microcoulomb-class, high-conversion-efficiency laser-plasma accelerator (LPA) was demonstrated on OMEGA EP

- Produced electron beams have:
  - Maximum energies >200 MeV
  - Divergences as low as 32 mrad
  - Charges that exceed 700 nC
  - Laser-to-electron conversion efficiencies up to 11%

- Total charge in the electron beam scales with both $a_0$ and plasma density
Collaborators

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LPAs driven by kJ-class lasers can provide compact sources of high-energy electrons for conversion to photons and positrons.

Motivation

Hard, Bright X Ray Sources

Positron Sources

\[ N_{\text{photons}} \propto N_e \]

Calculations for proof-of-principle experiments using electron beam from OMEGA EP predict up to \(10^9\) e\(^+\)/MeV/sr\(^+\).

\(^*\)Calculation courtesy G. J. Williams
LPA experiments based on self-modulated laser wakefield acceleration (SMLWFA) and direct laser acceleration (DLA) were performed on OMEGA EP.

1054 nm, ~700 fs, 10 to 95 J, $a_0 \sim 1.3$ to 6.7

M5 gas jet

$\Phi_{\text{nozzle}} = 2$ to 10 mm

f/2 OAP apodized to f/5 to f/10

EPPS: electron–positron–proton spectrometer

OAP: off-axis parabola

$\text{EPPS}$

$\text{OMEGA EP}$
Electron beams with divergences as low as 32 x 39 mrad were measured

**Lowest-Divergence**
- $a_0 = 4.4$
- $\Phi_{\text{nozzle}} = 10 \text{ mm}$
- $n_e = 1.1 \times 10^{19} \text{ cm}^{-3}$
- Pointed 8 mrad

**Highest-Charge**
- $a_0 = 6.6$
- $\Phi_{\text{nozzle}} = 6 \text{ mm}$
- $n_e = 7.5 \times 10^{18} \text{ cm}^{-3}$
Total charge in the electron beams scales approximately linearly with $a_0$

Same trend was observed for:
- 6-mm-dia. nozzle at $n_e = 1, 2, \text{ and } 3 \times 10^{19} \text{ cm}^{-3}$
- 4-mm-dia. nozzle at $n_e = 1 \times 10^{19} \text{ cm}^{-3}$
- 10-mm-dia. nozzle at $n_e = 0.2, 0.5, 1, \text{ and } 3.5 \times 10^{19} \text{ cm}^{-3}$
The ideal regime for producing high-charge electron beams for this SMLWFA-based LPA is for $n_e \sim 1 \times 10^{19} \text{ cm}^{-3}$ or less.

Electron beams with charges up to $707 \pm 429/224 \text{ nC}$ were measured.
Laser-to-electron conversion efficiencies up to 11% were observed

- The weighted average electron energy of the representative electron spectrum from this experiment is 17.9 MeV

- Using this energy, the 707 nC electron beam corresponds to a conversion efficiency from laser energy to electron energy of 11%
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Charge Measurement Technique

- Image plates (IPs) have a known response per electron given the electron energy *,**, it is therefore straightforward to scan the IPs and retrieve the charge of the incident electron beam.

- The photostimulated luminescence (PSL) measured by the second front image plate was integrated and a constant conversion factor was used (0.026 PSL/electron).

- Total measured charge reported was determined within the solid angle of the front image plates:
  - For the highest-charge shot only, the EPPS detector was located at a distance of 47.63 cm from target chamber center (solid angle of 26 msr).
  - For the remainder of the shots, the EPPS sat at 56.52 cm (solid angle of 18 msr).
  - The charge in the highest-charge shot contained in the 18 msr aperture is 600 ± 185/162 nC.

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Charge Measurement Technique, Continued.
• Decay of the PSL signal takes the form of a power distribution \( PSL = \alpha N^\beta \)
  – \( PSL \) = signal
  – \( N \) = number of scans of the image plate.

• Decay of the PSL signal was fit with the power distribution to recover the fit parameters \( \alpha \) and \( \beta \)

• Fit parameters from the seven points are averaged to produce an average decay of the signal on the image plate for each scan

• Total signal can then be recovered via the ratio
\[
\frac{PSL_{\text{scan1}}}{PSL_{\text{scanN}}} = \frac{\alpha(1)^\beta}{\alpha N_{\text{unsat}}^\beta} = \frac{1}{N_{\text{unsat}}}^\beta
\]

• \( N_{\text{unsat}} \) = # of scans required to unsaturate IP