Scaling relativistic laser-solid interaction using 30fs laser pulses

Jinpu Lin, Thomas Batson, John Nees, Alec Thomas, Karl Krushelnick
Center for Ultrafast Optical Science, University of Michigan, Ann Arbor, MI 48105, USA

BACKGROUND & THEORY

- Incident and reflected laser pulses form a standing wave region to accelerate electrons [1, 2]. Direct laser acceleration further boost their energy [3].
- Relativistic electrons from solid targets have superior properties in beam charge and divergence than those from underdense plasmas.
- Relativistic electron bunches of attosecond duration can be generated [4].
- Potential applications: Warm dense matter creation, Electron radiography, Seed of wakefield accelerators, Fast ignition researches.
- In this work, we present:
  - Angular dependence
  - Prepulse and target material effect
  - Attosecond electron bunches

EXPERIMENTAL

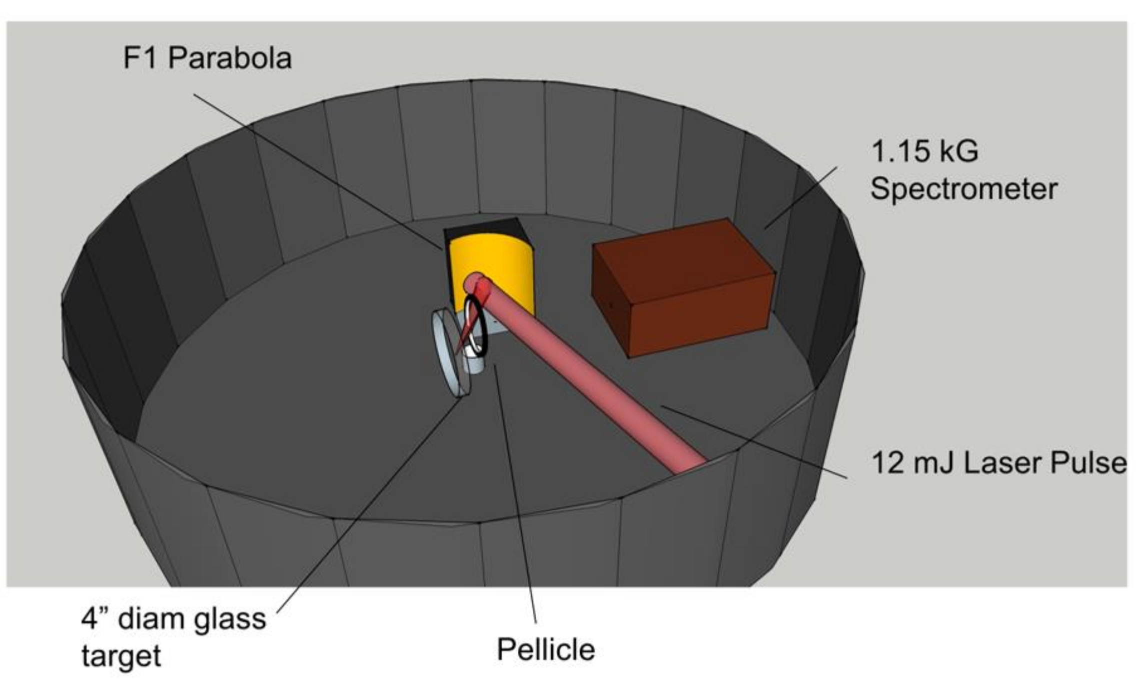
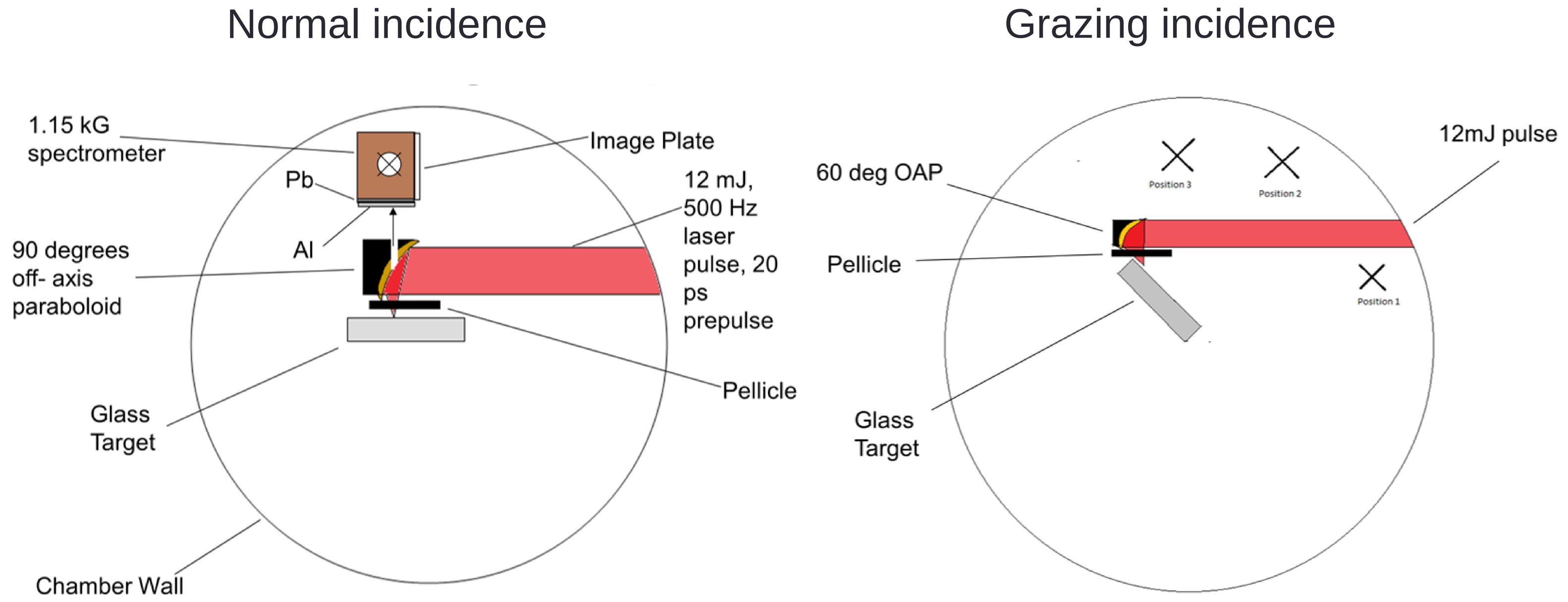


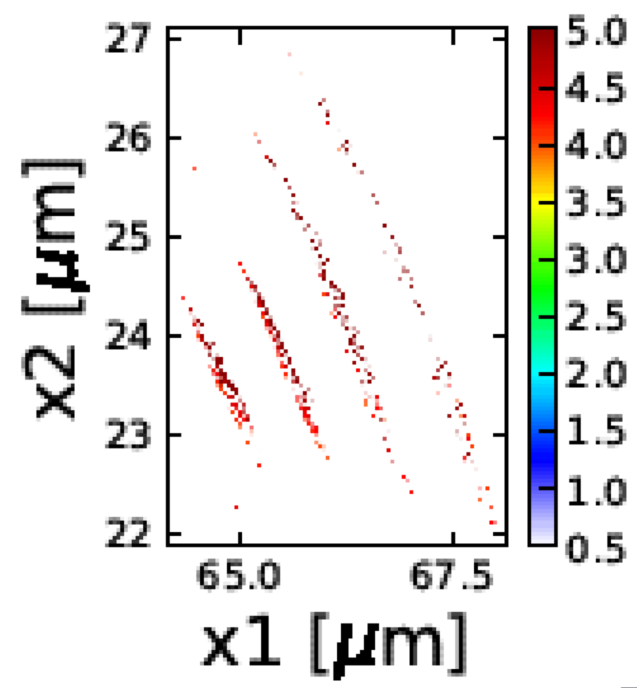
Fig.1 Experimental setup. F1 parabola: Off-axis paraboloid at 60° or 90°; Pellicle: 2 μm thick nitrocellulose pellicle; laser pulse is at 12 mJ, 30fs, 800nm, p-polarized. IP: FUJI BAS-SR 2025 image plate.

Fig.1



- Focused the laser beam onto a thick glass target at normal and grazing incidence.
- Recorded the spatial profile of the emitted electron beam on a stack of image plates at grazing exit and along the beam path.
- Tuned the prepulse delay [5] and angle of incidence.
- Performed two-dimensional Particle-In-Cell (PIC) simulation using OSIRIS framework [6].

RESULTS



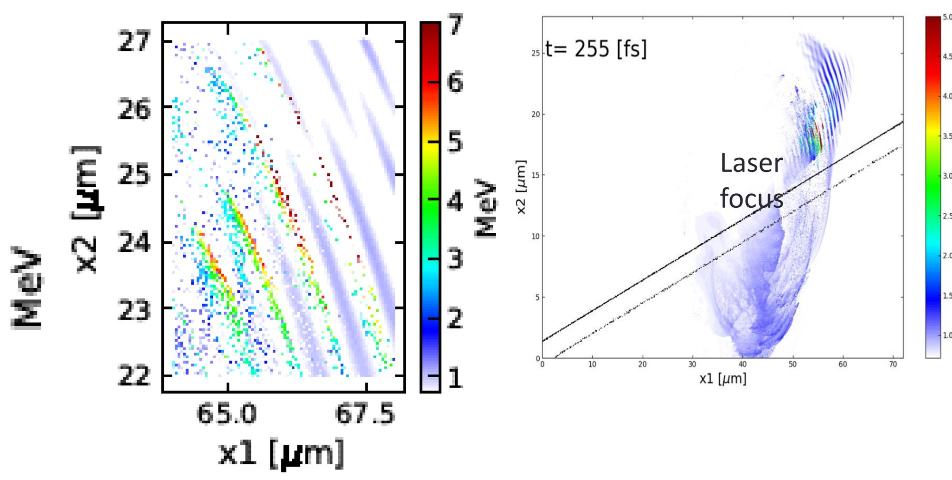
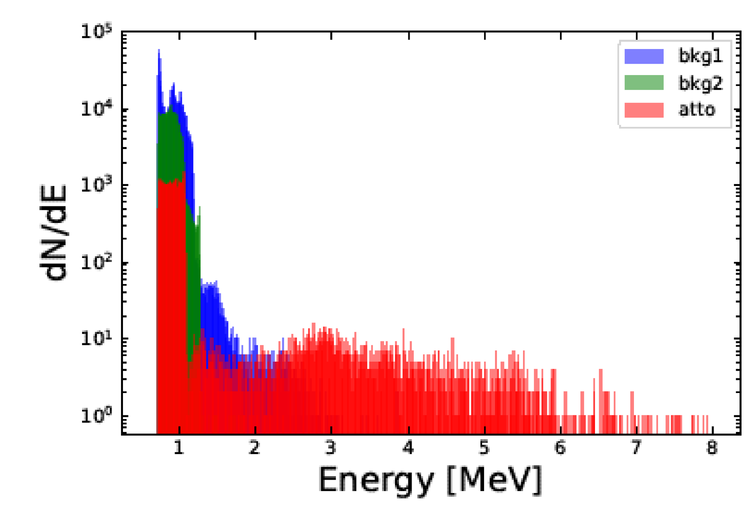


Fig.2

Fig.2 shows the attosecond electron bunches generated in the PIC simulation in a grazing incidence geometry (76°) at specular reflection direction. The bunch has an energy of ~5MeV and thickness ~$\lambda/10$. The bunches repeat every laser cycle while the electrons excited by the laser field (lower energy) repeat every half cycle.



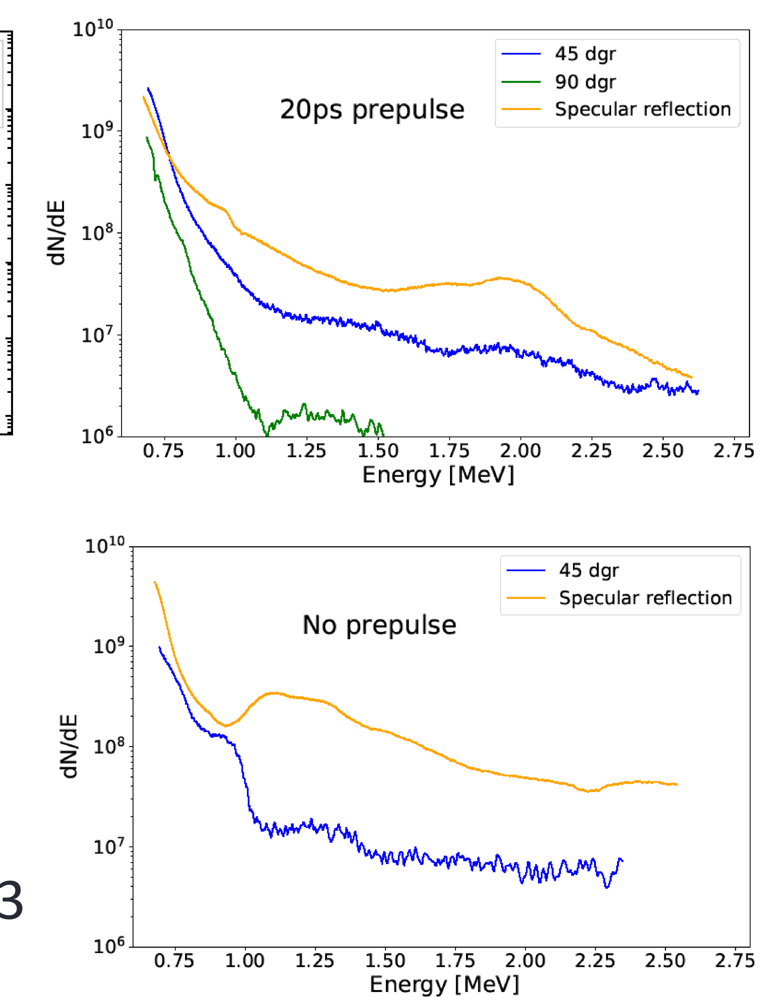
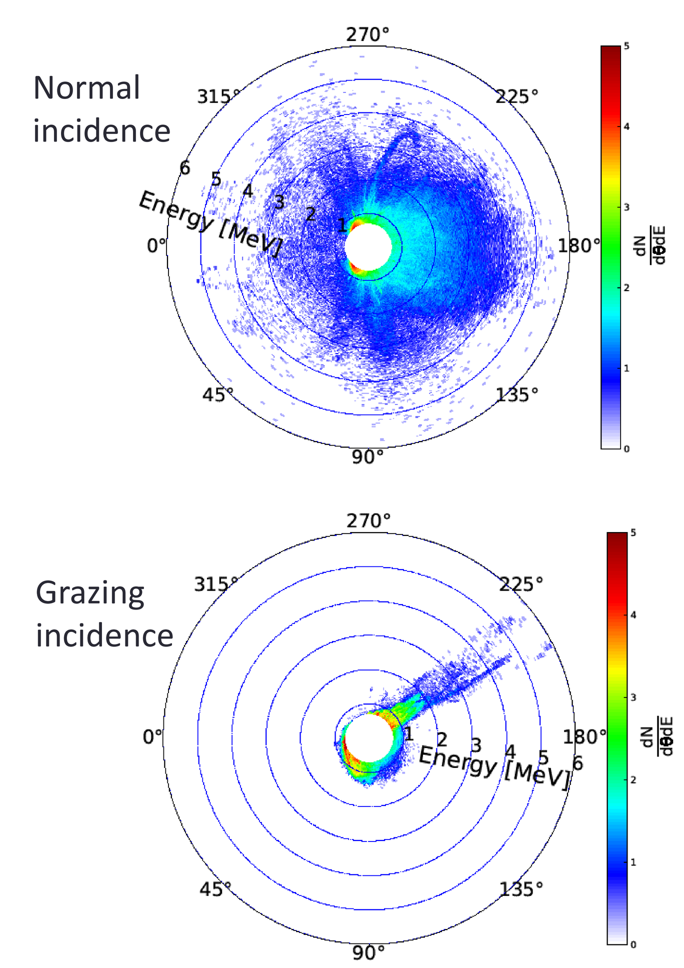


Fig.3 presents the electron energy spectra captured at different direction from simulation (left) and experiment (right), all at grazing incidence. The experiment was carried out using a 60° OAP, with and without prepulse. Spectrometer positions are labeled in the geometry drawing.

Fig.3



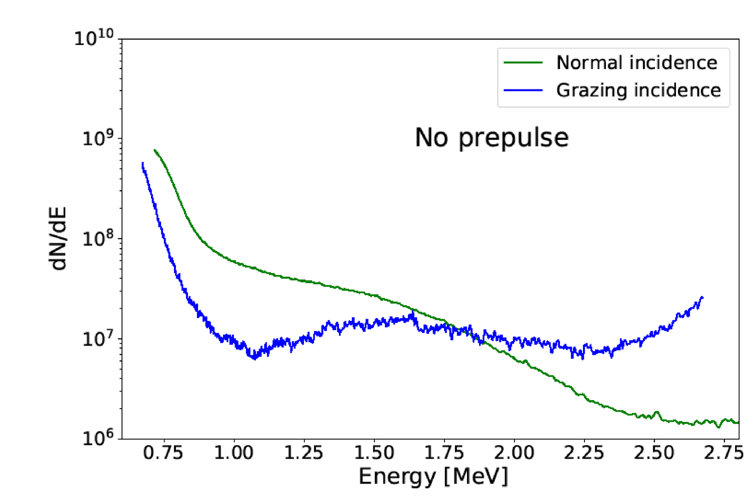


Fig.4 compares different angle of incidence from both experiment (right) and simulation (left).The experiment was taken by 60° OAP without prepulse. Angular distribution of electron energy spectra is simulated in normal incidence, grazing incidence(Fig. 4a) and 45° incidence (Fig. 4b).

Fig.4a

RESULTS

Fig.4b

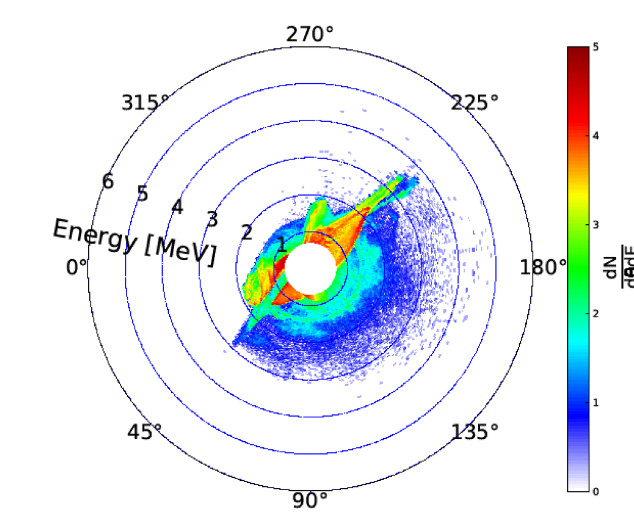


Fig.5

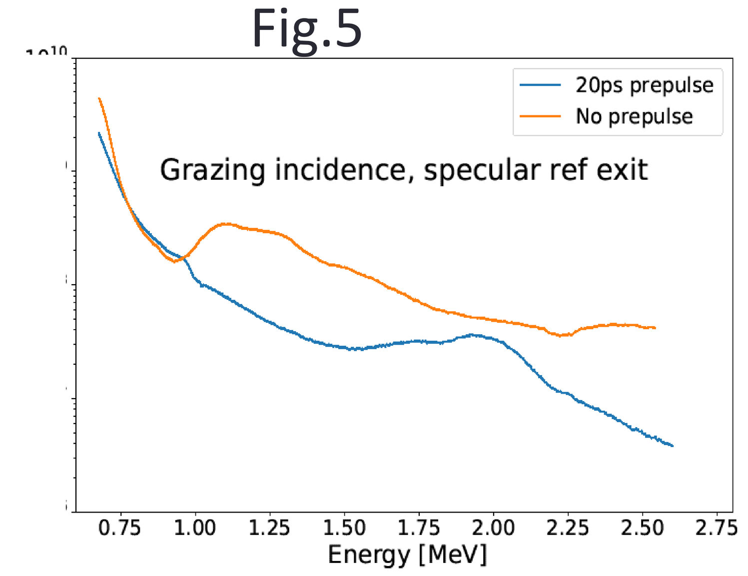


Fig.5 shows the electron energy spectra with and without including a 20ps prepulse. The laser pulses were focused by a 60° OAP at grazing incidence, and the spectra were also taken at grazing incidence. With the prepulse, the “bump” moves towards high energy on the spectrum.

Fig.6

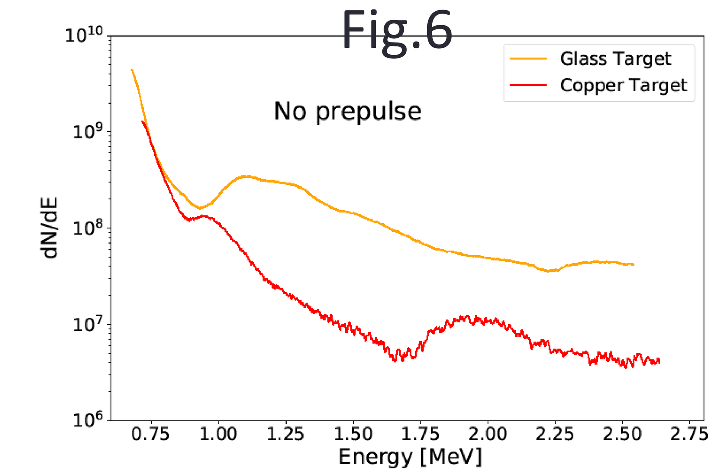


Fig.6 presents the electron energy spectra obtained using different targets. The laser pulses were focused by a 60° OAP at grazing incidence without prepulse, and the spectra were also taken at grazing incidence.

CONCLUSIONS

- Short-pulse laser solid interaction produces attosecond electron bunches. It’s angle of exit is close to the specular reflection direction. It is observed in 76° and 45° incidence but not normal incidence in simulations and is observed in grazing incidence but not normal incidence in experiments.
- Attosecond electron bunch generation favors larger angle of incidence.
- Angle of incidence is tuned for the angular distribution of electron energy spectra.
- Prepulse delay is included to find higher energy bump at 20ps from experiments. Simulations need to be done.

FUNDING ACKNOWLEDGEMENT

ASFOR FA9550-16-1-0121

REFERENCE

[1] Kemp, A. J., Yasuhiko Sentoku, and Max Tabak. "Hot-electron energy coupling in ultraintense laser-matter interaction." Physical review letters 101.7 (2008): 075004.

[2] Orban, Chris, et al. "Backward-propagating mev electrons in ultra-intense laser interactions: Standing wave acceleration and coupling to the reflected laser pulse." Physics of Plasmas 22.2 (2015): 023110.

[3] Arefiev, A. V., A. P. L. Robinson, and V. N. Khudik. "Novel aspects of direct laser acceleration of relativistic electrons." Journal of Plasma Physics 81.4 (2015).

[4] Naumova, N., Sokolov, I., Nees, J., Maksimchuk, A., Yanovsky, V., & Mourou, G. (2004). “Attosecond electron bunches.” Physical review letters, 93(19), 195003.

[5] Mordovanakis, Aghapi G., et al. "Quasimonoenergetic electron beams with relativistic energies and ultrashort duration from laser-solid interactions at 0.5 kHz." Physical review letters 103.23 (2009): 235001.

[6] Fonseca, Ricardo A., et al. "OSIRIS: A three-dimensional, fully relativistic particle in cell code for modeling plasma based accelerators." International Conference on Computational Science. Springer, Berlin, Heidelberg, 2002.