Relativistic Electron Transport in a Laser-induced Plasma

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Outline

- Introduction to high intensity lasers and electron acceleration.
- Motivation and goals of this research
- Conditions for this experiment and description of TRECS diagnostic
- Time-resolved data
- Analysis of data (time-integrated also)
- Summary

Questions shown in red.
High Intensity Lasers and their Characteristics

- A high intensity laser ($>10^{18}$ W/cm$^2$) is usually preceded by a 2-3ns long ASE prepulse, called a pedestal.
- The intensity contrast of the main pulse to pedestal is generally $<10^6$ which is sufficient to ionize material on the front surface. This ionized material creates a pre-formed plasma expanding off of the front surface of the target material.
- The main pulse then interacts with the preformed plasma and NOT a solid density material.
Transfer of energy from laser to electrons - Electron acceleration

- As the main laser pulse propagates through the steepening electron density, electrons begin to gain energy through absorption mechanisms.
- Electrons are accelerated into the propagation direction of the laser.
- The laser will continue to propagate until it reaches the critical density where $\omega_p = \omega_L$.

How does the critical surface affect the intensity?
Accelerated electron distribution

- Electron distributions resulting high intensity (>10^{18} W/cm^2) interactions heating obey an exponential energy distribution with an effective temperature which scales as: \[ \theta \propto \sqrt{I \lambda^2} \]

Exponential energy distribution
(\(\theta=1.5\) MeV, \(N_0=10^{14}\))

\[
\frac{dN}{dE} = \frac{2N_0}{\sqrt{\pi}} \sqrt{\frac{E}{\theta^3}} e^{-E/\theta}
\]

Why not call this a Maxwellian?
Goal and motivations for current experiment.

- **Goal**: Understand the time history of the hot electron distribution generated by ultra-intense short pulse lasers.

- **Why do we care?** Fusion energy research and schemes such as fast ignition (shown below) require understanding of electron transport.

Typically a highly non-linear, relativistic interaction of the electrons with the bulk material and electric and magnetic fields.
Laser/target conditions for this experiment and the Time-Resolved Electron Čerenkov (TRECS) diagnostic

- Energy=10 J, \( \Delta t=100 \) fs, spot size=6 µm; \( \text{Intensity} \approx 5 \times 10^{19} \, \text{W/cm}^2 \)
- Target = 380 µm Si with 10 µm Al coated on rear surface
- **Diagnostic**: Electrons entering the spectrometer are deflected according to their energy onto a slide of glass. The glass acts as a Čerenkov radiator and electrons passing through the glass emit radiation. The radiation is collected and imaged onto an optical streak camera.

Why disperse electrons? Why not measure electrons directly?
Once the time is deconvolved, the electron duration is determined to be ~2-4.5 ps.

To the best of our knowledge, this is the only method to ever succeed in measuring the time history of hot electrons.
Understanding our results: To start, how do the electrons propagate through bulk material?

- First approximation: Using Stopping-Power and Range Tables for Electrons (ESTAR*), the CSDA range is plotted versus energy (assumes cold.)

What is CSDA range?
Why is this a first approximation?

*National Institute of Standards and Technology database*
Imaging Plate data from magnetic spectrometer

- Imaging plate is a time-integrated method of collecting electron spectra.
- The plot shows the electron spectra obtained and two “effective” temperatures fitted to the results.

What is imaging plate?
Why are there 2 temperatures?
Simulation showing electrons escaping from the surface of a target

- Left plot shows the number density of electrons (energy color coded) as a function of position for a given time
- Right plot shows the electrostatic field present at the same time as the left plot

How are the fields generated?

Why do we care about the fields?
Putting it all together and painting a picture of the interaction

- (a) Electrons accelerated by the laser propagate through the target material
- (b) Electrons with enough energy to escape the rear surface begin to charge up the target
- (c) Once a sufficient number of electrons have escaped, an electrostatic field is established which is capable of trapping nearly all remaining electrons.
Summary

- A new diagnostic for energy and time-resolving relativistic electrons was fielded and data was shown for a high intensity laser-matter interaction.
- Surprisingly, hot electrons seem to be emitted for durations longer than the laser pulse duration.
- Preliminary simulation results suggest similar behavior.
- Next step: reproduce experiment with higher laser energy for better SNR.
THE END