# 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 pedastal.

- The intensity contrast of the main pulse to pedastal 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.
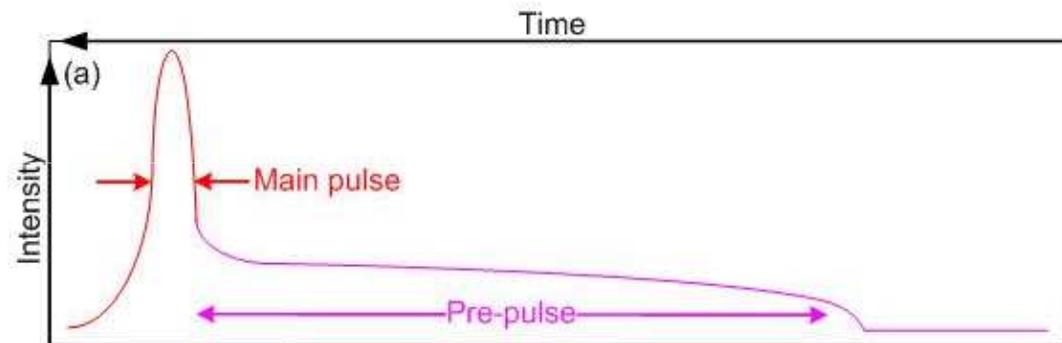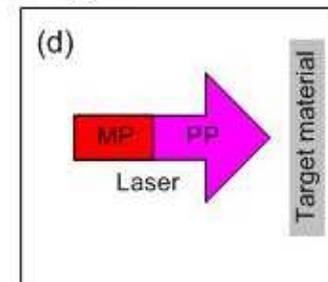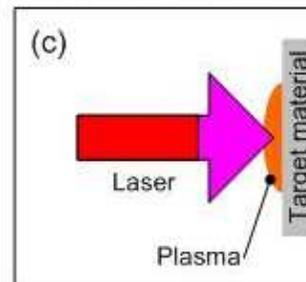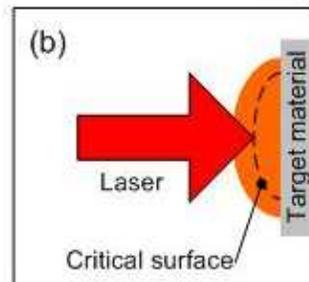
# Transfer of energy from laser to electrons - Electron acceleration

- 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 $\omega_p = \omega_L$.

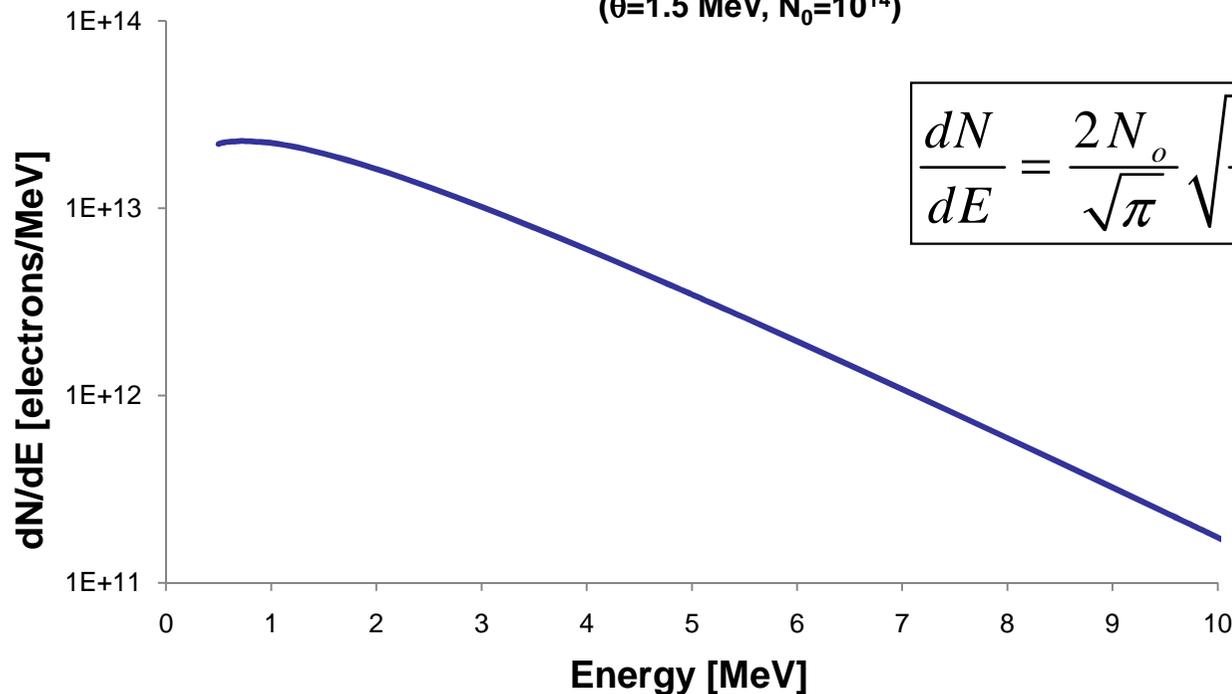**How does the critical surface affect the intensity?**

Target

Critical surface

Laser
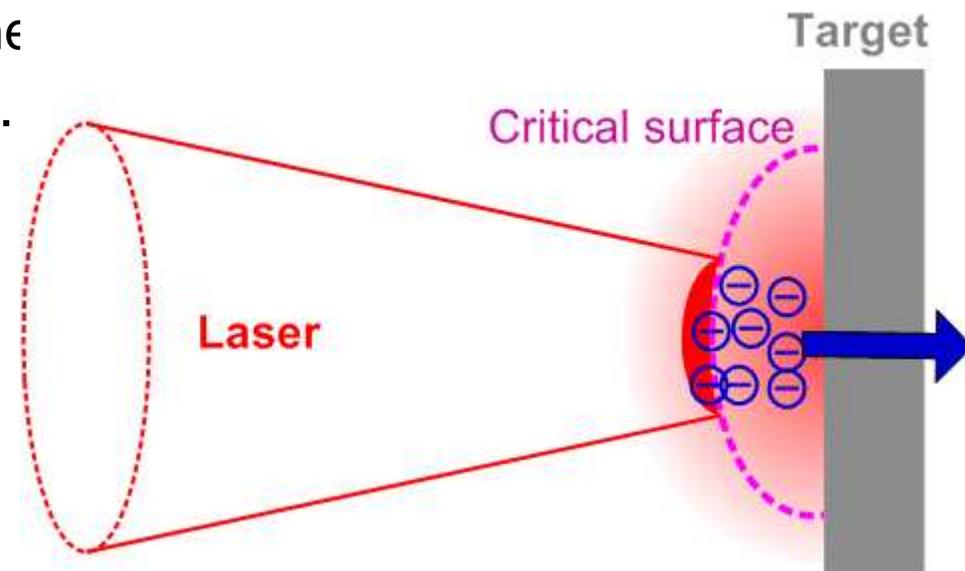
# Accelerated electron distribution

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

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

$$\frac{dN}{dE} = \frac{2N_o}{\sqrt{\pi}}\sqrt{\frac{E}{\theta^3}}e^{-E/\theta}$$
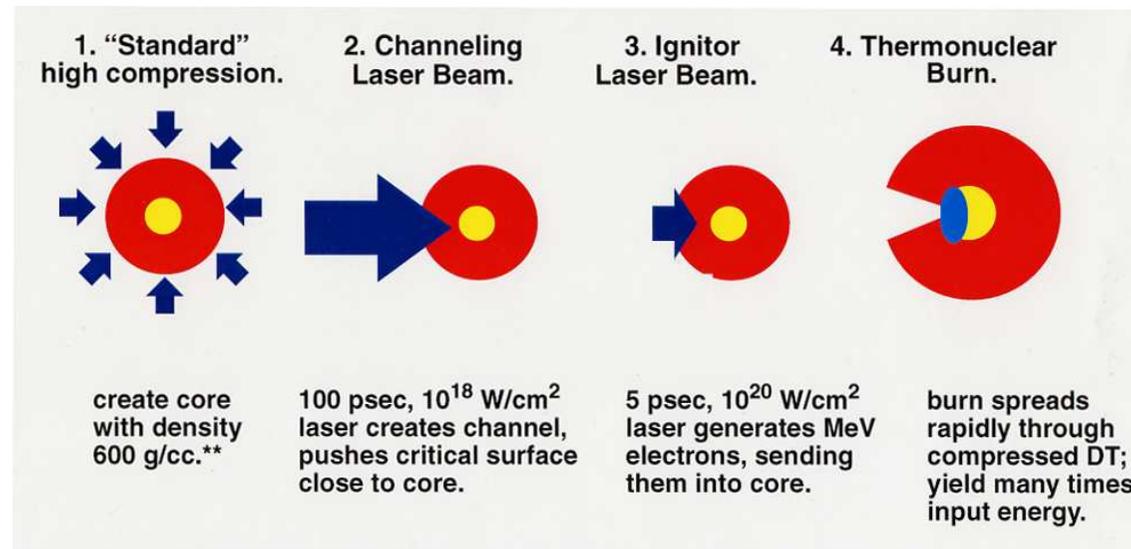
**Why not call this a Maxwellian?**

# 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.



| 1. "Standard" high compression. | 2. Channeling Laser Beam. | 3. Ignitor Laser Beam. | 4. Thermonuclear Burn. |
|---|---|---|---|
| create core with density 600 g/cc.** | 100 psec, $10^{18}$ W/cm² laser creates channel, pushes critical surface close to core. | 5 psec, $10^{20}$ W/cm² laser generates MeV electrons, sending them into core. | burn spreads rapidly through compressed DT; yield many times input energy. |

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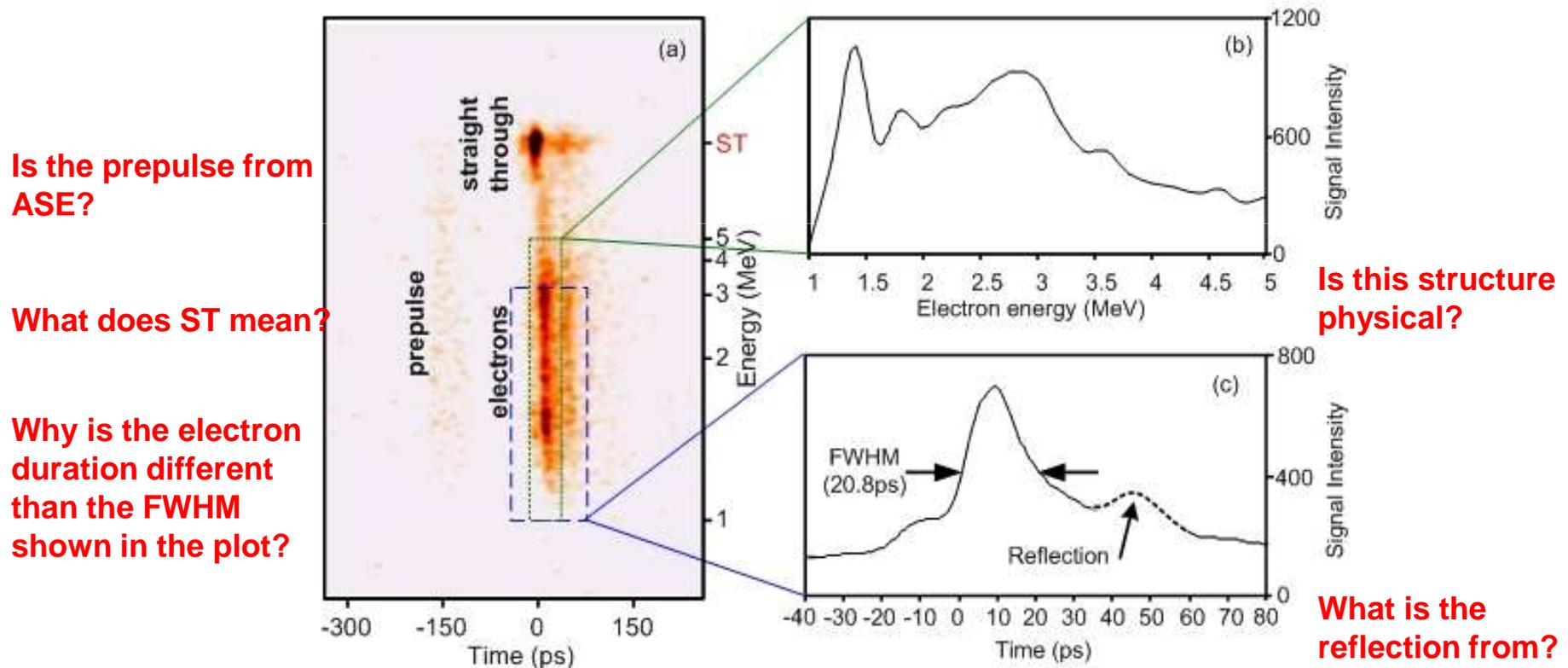
# Laser/target conditions for this experiment and the Time-Resolved Electron Čerenkov (TRECS) diagnostic

- Energy=10 J, $\Delta t$=100 fs, spot size=6 $\mu$m; *Intensity~5x10$^{19}$ W/cm$^2$*

- Target = 380 $\mu$m Si with 10 $\mu$m 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?**
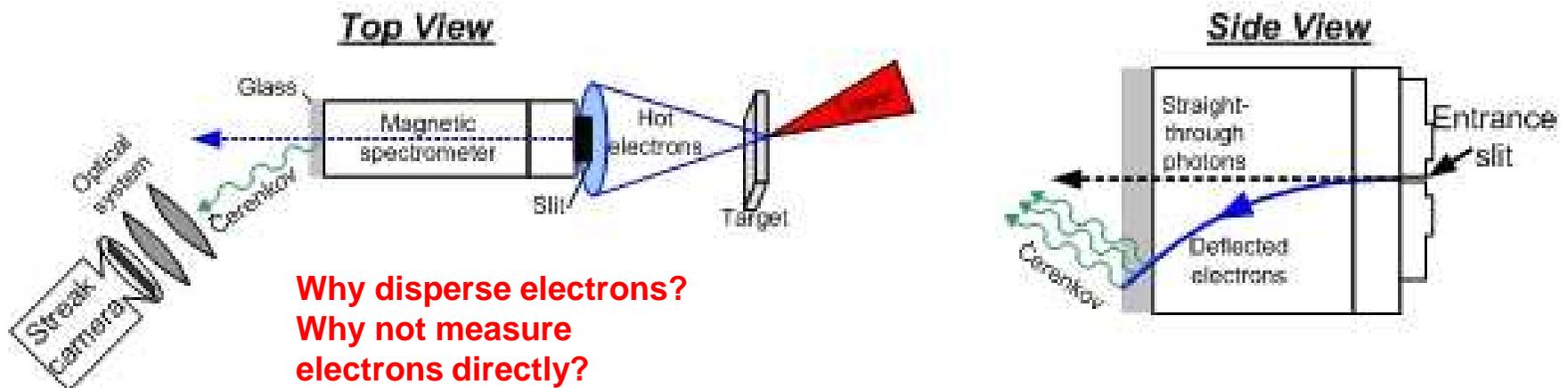
# Streaked data (TRECS)

- Once the time is deconvolved, the electron duration is determined to be ~2-4.5 ps.



**Is the prepulse from ASE?**

**What does ST mean?**

**Why is the electron duration different than the FWHM shown in the plot?**

**Is this structure physical?**

**What is the reflection from?**

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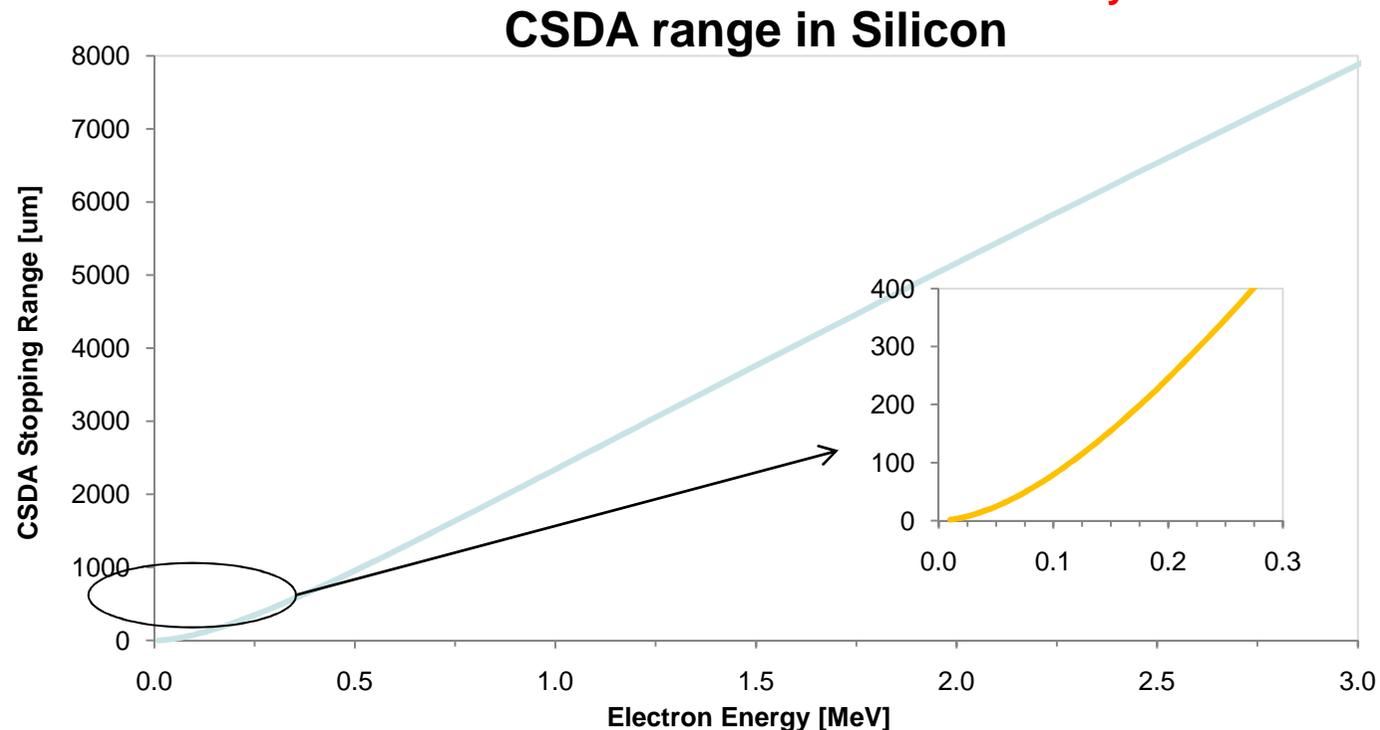
# Understanding our results: To start, how do the electrons propagate through bulk material?

- 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.

  **What is imaging plate?**

- The plot shows the electron spectra obtained and two "effective" temperatures fitted to the results

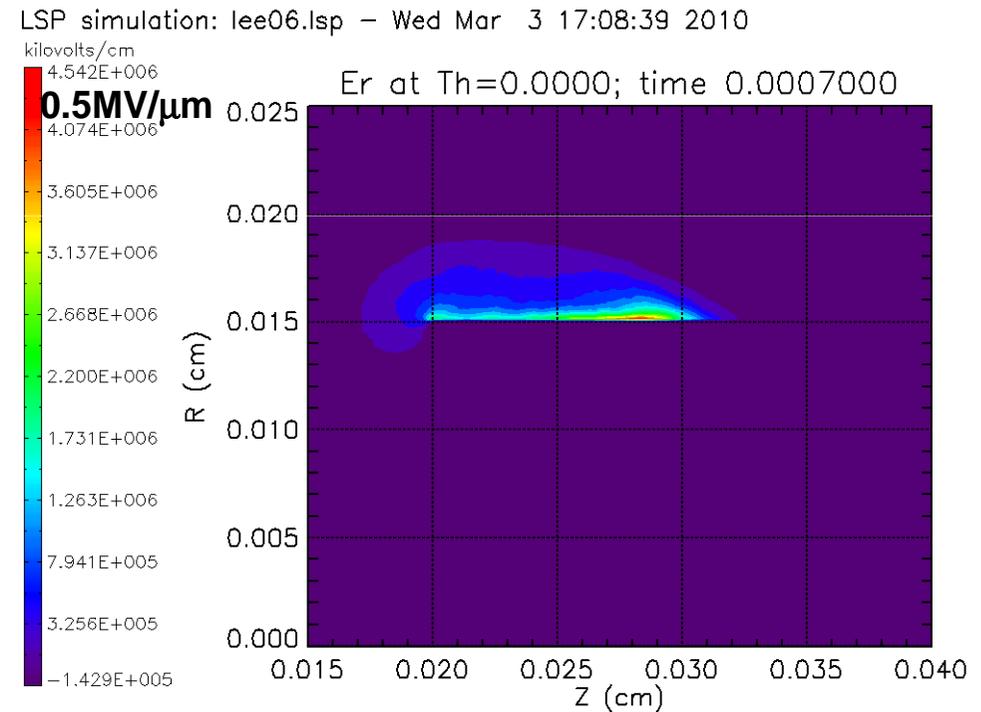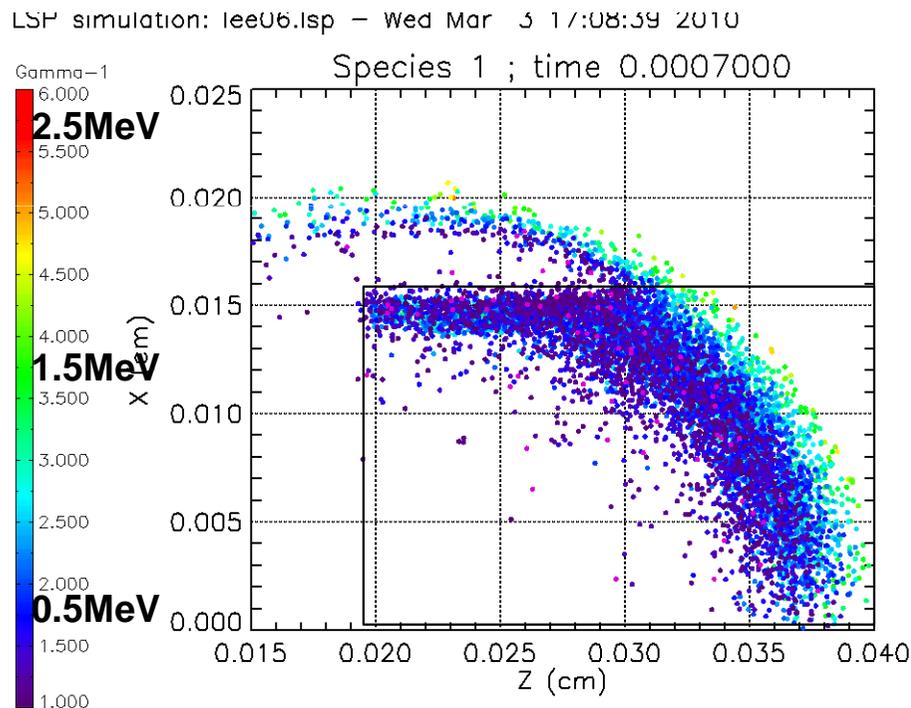  **Why are there 2 temperatures?**
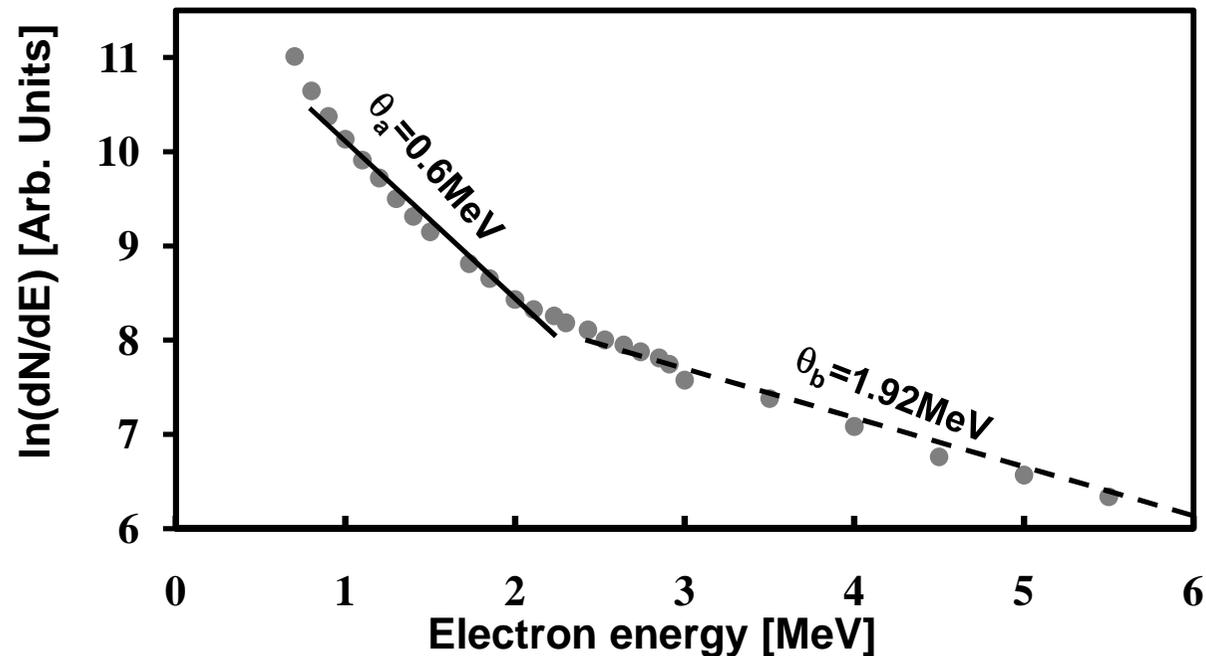
# Simulation showing electrons escaping from the surface of a target

- 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 <u>nearly</u> all remaining electrons.
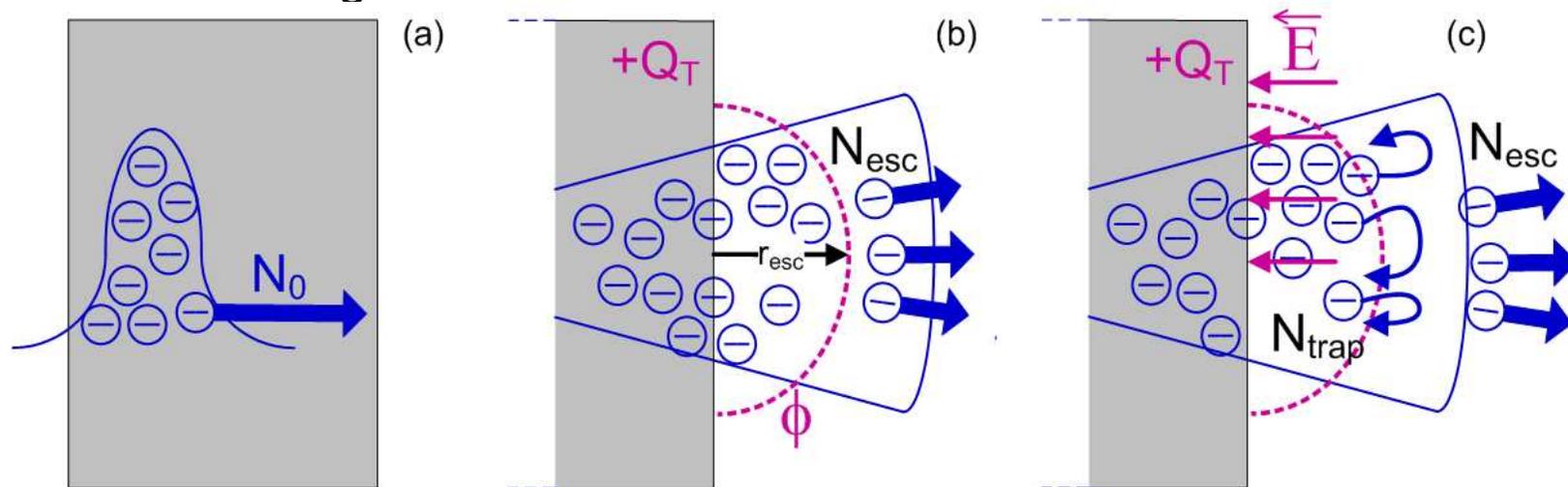
# Summary

- 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