2010 IHEDS Workshop

Fast particle production in laser-irradiated targets

presented by Alex Arefiev

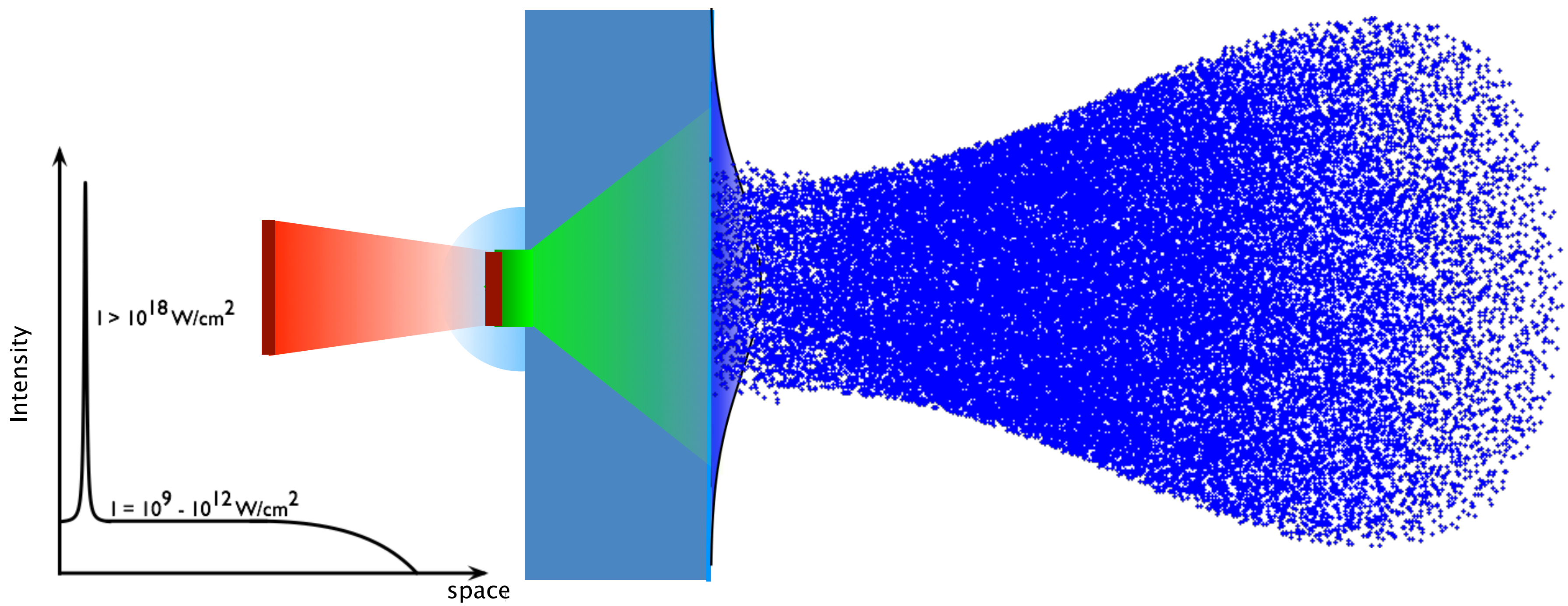
in collaboration with

Boris Breizman, Vladimir Khudik
Institute for Fusion Studies,
The University of Texas at Austin

Marius Schollmeier, Adam Sefkow
Sandia National Laboratories

Introduction

- Laser pre-pulse creates an extended pre-plasma.
- The main pulse generates a relatively small hot collisionless electron population.
- The hot electrons travel to the rear side where they set up a sheath whose field confines them in the target.
- The field accelerates protons off the surface of the target.



Role of hot electrons

- In order to achieve higher proton energies, we need a better understanding of the mechanism of electron acceleration and heating by the laser.
- The potential drop in the sheath is limited by a cut-off in electron energy.
- Therefore, the electron energy cut-off limits the maximum proton energy gain.
- Since the hot electrons are collisionless, they are unable to redistribute their energy and generate an energetic tail.

Electron acceleration and heating

- The electron energy cut-off is determined by individual interactions of electrons with the laser and self-consistent fields.

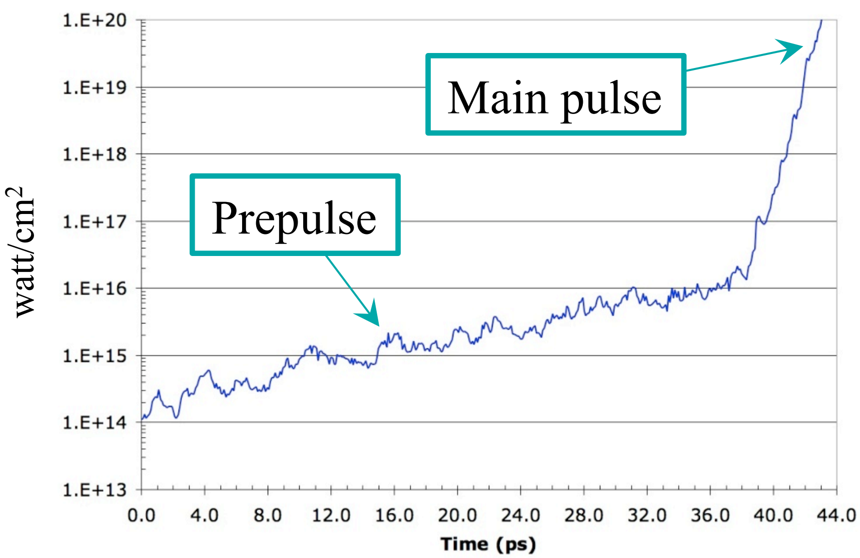
- This aspect raises two questions:
  - Can electrons accelerate to energies significantly exceeding the ponderomotive potential in a **single** interaction with the laser?
  - Can electrons undergo stochastic heating by interacting with the laser **multiple** times?

- There are two distinct areas of electron interaction:
  - extended area of transparent preplasma in front of the target,
  - steep boundary with a critical layer that absorbs and reflects the laser.

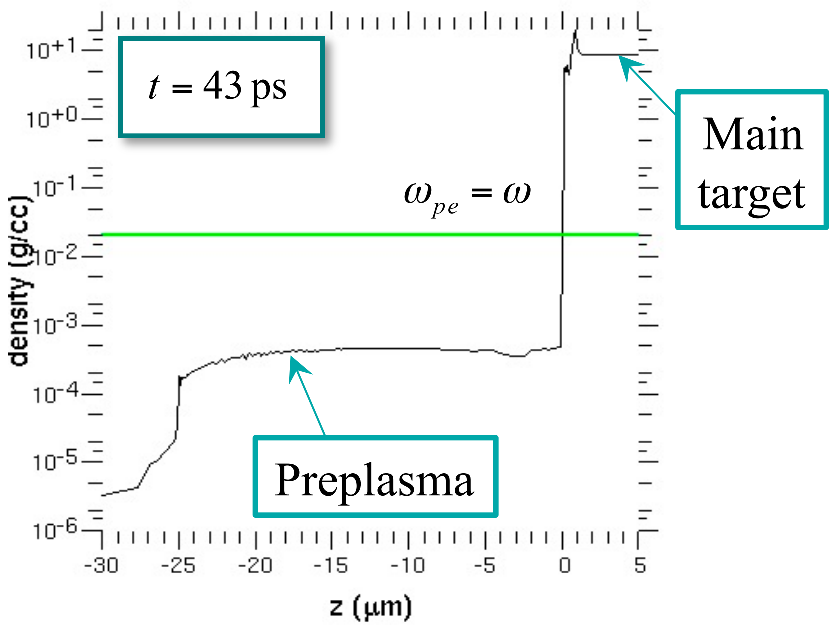
Preplasma

- There is a prepulse of almost 40 ps in duration that heats the target.
- The front surface expands forming an extended region of transparent plasma.

Measured laser pulse intensity



Snapshot of plasma density [simulation]



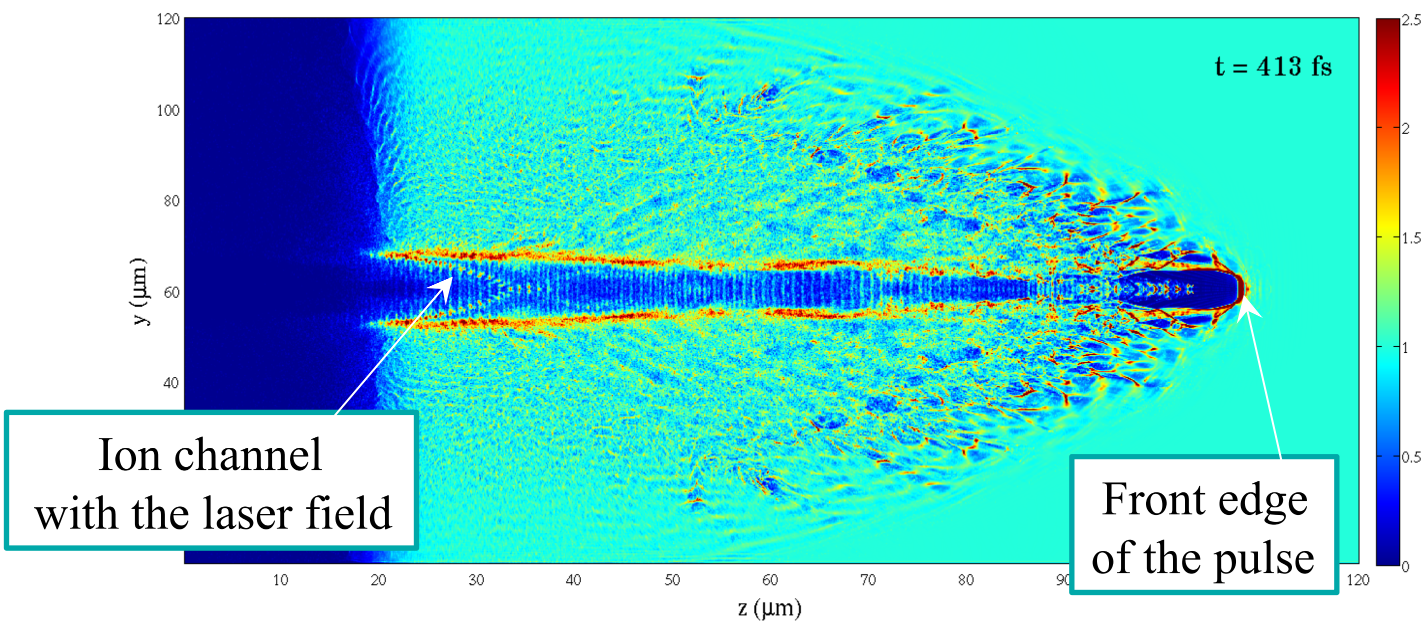
Courtesy of M. Schollmeier at SNL

Courtesy of A. Sefkow at SNL

Electron acceleration in preplasma

- The laser creates a positively charged ion channel, sweeping electrons to the side.
- Some electrons are then pulled into the channel by the ion charge.
- Electrons are accelerated along the channel by the laser field.

<u>Normalized electron density</u>



$n_0 = 10^{20}\ \mathrm{cm}^{-3}$

$n_{cr} = 1.1 \cdot 10^{21}\ \mathrm{cm}^{-3}$

The beam is Gaussian, with

$I = 1.5 \cdot 10^{20}\ \mathrm{W/cm}^2$

$\lambda = 1\mu\mathrm{m}$

$\Delta y_{FWHM} = 8.3\mu\mathrm{m}$

simulated using PSC provided by Hartmut Ruhl

Electron acceleration in preplasma

- A single electron irradiated by a plane wave accelerates to energy

$$\varepsilon \approx \frac{a_0^2}{2} m_e c^2 \quad \text{and} \quad \gamma \approx \frac{a_0^2}{2} \qquad \text{where } a_0 \equiv \frac{|e| E}{m_e \omega c} \gg 1$$

- It moves predominantly in the direction of the beam, with $p_\perp / p_\parallel \approx 1/a_0 \ll 1$
- The required interaction length is $\gamma\lambda$, where λ is the laser wavelength.
- For an electron with axial momentum $p_0 / m_e c \gg 1$ that is pulled into the channel, the energy gain is enhanced by $p_0 / m_e c$.
- Can the number of the accelerated electrons be optimized by changing preplasma parameters?

Target with a steep density gradient

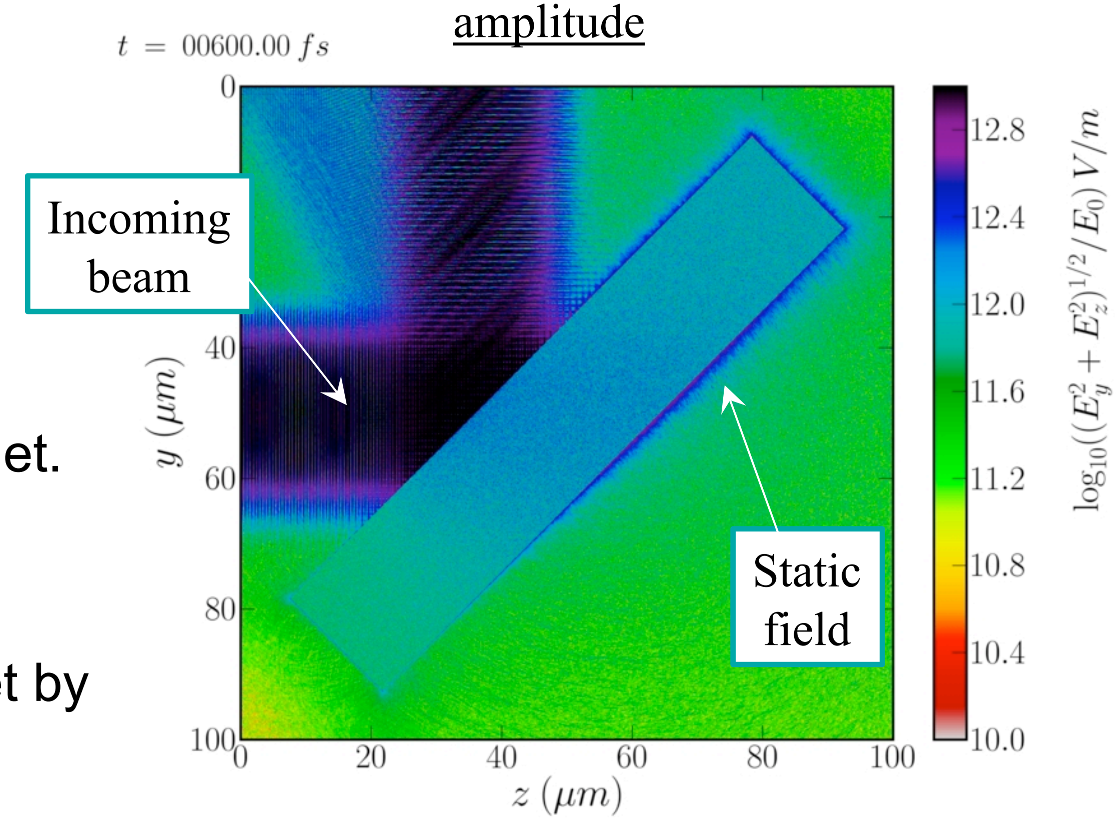
- We study the stochastic heating for a target without preplasma that consists of immobile ions and cold electrons.

- The target is irradiated by a pulse of constant amplitude.

- The laser creates a hot electron minority that spreads through the target.

- The hot electrons are confined inside the target by a surface electric field.

<u>Snapshot of electric field amplitude</u>



Courtesy of M. Schollmeier at SNL [simulated using PSC provided by Hartmut Ruhl]

The need for stochastic heating

- The pulse is absorbed and partially reflected by hot electrons at critical density n_H determined by the condition $\omega_{pe} = \sqrt{\gamma}\,\omega$
- Assuming that roughly half of the incident power flux I is absorbed and that it is carried away by injected electrons, we find that

$$I \approx \gamma m_e c^2 n_H c$$

- The scaling for the energy of injected electrons is

$$\gamma m_e c^2 \approx \frac{e}{\omega}\sqrt{4\pi c}\sqrt{I} \longrightarrow \gamma \approx a_0$$

- This energy is relatively low and it increases slowly with I.
- By how much can the electron energy increase due to multiple interactions with the laser field?

Summary and conclusions

- The laser pulse can accelerate preplasma electrons to energies significantly exceeding the ponderomotive energy.
- Can the number of these electrons be optimized by changing preplasma parameters?
- The energies of electrons accelerated at the critical surface are comparable to the ponderomotive energy.
- Can these electrons get heated stochastically by interacting with the laser multiple times?
- **What is the key mechanism behind electron heating?**