Overview of Recent CIFS-Relevant Research

Imperial College London
Problem of measuring fast electron energy
Energy at the spectrometer

Two opinions:

(a) Only higher energy electrons reach the spectrometer, so it measures an energy that’s *too high*.

(b) The average electron loses energy when it moves through the sheath, so it measures an energy that’s *too low*. 
Assumptions

- Planar geometry is OK at small distances
- Divergent (e.g. spherical) geometry applies at large distances

L=30um
Simple particle simulation

![Graph showing particle simulation at t=20fs]
Why is the vacuum energy lower?
Why is the vacuum energy lower?
Electric field
Continuous electron model

\[ p(\tau, t) = p_0 - j_0 \tau (t - \tau) \]

\[ x(\tau, t) = \frac{\sqrt{1 + p_0^2} - \sqrt{1 + p_0^2 + j_0^2 \tau^2 (t - \tau)^2 + 2p_0j_0 \tau (t - \tau)}}{j_0 \tau} \]
Continuous electron model

\[ p(\tau,t) = p_0 - j_0 \tau(t - \tau) \]

Expand around \( \tau = 0 \) for small \( \tau \) and large \( t \)

\[ p \approx p_0 + \text{const} \times \tau \]

\[ f(p) \approx \text{const} \quad p < p_0 \]

\[ f(p) \approx 0 \quad p > p_0 \]

near the front of the electron stream

\[ \Rightarrow \langle E \rangle = mc^2 \int_0^{p_0} (\gamma(p) - 1) f(p) dp = \frac{1}{2} \left( \sqrt{1 + p_0^2} - 1 \right) + \frac{\arcsinh(p_0)}{p_0} \]

\[ \frac{\langle E \rangle}{E_{\text{injected}}} = \frac{\langle E \rangle}{\sqrt{1 + p_0^2} - 1} \approx \frac{1}{2} \quad \text{(ultra-relativistic limit)} \]
Continuous electron model

$$\langle E \rangle_{\text{vac}} \approx \frac{1}{2} E_{\text{injected}}$$

![Graph showing energy reduction factor against intensity]
“Realistic” distributions?

(Vlasov simulation)
Transport in target

\[
\langle E \rangle \approx 0.6 \left\{ \sqrt{1 + \frac{I\lambda^2}{1.3 \times 10^{18} \text{Wcm}^{-2}}} - 1 \right\} mc^2
\]

\[
E_{\text{vac}} \approx \frac{1}{2} \left( \frac{1}{2} E_{\text{target}} \right)
\]
Some results

Full Vlasov simulation (including transport through target).
Best to use short pulses and thick targets.
Energy at the spectrometer

Two opinions:

(a) Only higher-energy electrons reach the spectrometer, so it measures an energy that’s too high.

(b) The average electron loses energy when it moves through the sheath, so it measures an energy that's too low.

(c) The first electrons to reach the rear surface are the only ones able to escape so the measured energy is lower. Furthermore these electrons lose more energy as they generate the “escape sheath”.
DT ice ball with gaseous hotspot, 2\(\mu\)m spatial resolution – initiated during the coast phase with velocity 4\(\times\)10\(^5\) m/s

Unperturbed 1D test problem – local alpha deposition model “clean yield” \(\sim\) 10MJ
DT ice ball with gaseous hotspot, 2μm spatial resolution – initiated during the coast phase with velocity $4 \times 10^5$ m/s

Temperature of Hotspot

Density of main fuel

4,2 mode Legendre polynomial – local alpha deposition model “yield over clean” ~ 1%
3D Gorgon - Capsule Calculations (J. Chittenden & S. Taylor)

DT ice ball with gaseous hotspot, 2μm spatial resolution – initiated during the coast phase with velocity $4 \times 10^5$ m/s

Next we will try noise perturbation to generate a more realistically asymmetric hotspot.

The main purpose of these calculations is to provide a target for studies of non-local alpha transport in inhomogenous burning plasma.

8,16 mode Legendre polynomial – local alpha deposition model “yield over clean” $\sim 10\%$
Zeus 2D (C. Davie & R.G. Evans)

- Zeus maintains spherical symmetry very well for an ideal converging shock.
- Converging spherical shock with small perturbation in driving pressure. Single T Eulerian.

Although the shock wave distorts markedly near the bounce it rapidly recovers its sphericity in the outgoing phase. This contributes to the robustness of shock ignition since the burn is initiated by the return shock in the DT shell rather than in a central hot spot.
PIC Simulations (EPOCH) of Dense Targets Collisions

\[ T = 1 \times 10^5 \text{ K} \]
\[ E = 1 \times 10^7 \]
\[ n_e = 1 \times 10^{26} \]
\[ dt = 1 \times 10^{-16} \]
\[ \tau \approx 1 \times 10^{-14} \]

\~1\text{million particles (per cell)}
PIC Simulations (EPOCH) of Dense Targets

- 3072 × 3072 cells
- $20 \mu m \times 20 \mu m$
- density = 1g/cc
- $T = 100$eV
- $dt \approx 7.66 \times 10^{-18}$s
- $dx = 6 \times 10^{-9}$m
- $2 \times 10^9$ particles
- 5$\mu$m laser spotsize
- $I = 5 \times 10^{19}$W/cm$^2$
Magnetic Field (time-av) at 200fs

Monte-Carlo collisions give a resistive magnetic field.
Fast Electron Divergence

100fs

200fs

All electrons

Fast electrons (1-2MeV)
Experimentally, we probe the target rear surface. Can we infer the correct divergence angle from rear surface measurements?

- Density and temperature give conflicting evidence
- A better estimate of divergence is gained from targets that suppress refluxing.
Summary

• Fast electron energy measured at spectrometer is too low.
• Need to suppress refluxing to get a better understanding of fast electron divergence.
• Collisions in PIC codes do not significantly modify the beam divergence.
• 3D implosion simulations are underway to investigate the effect of non-local alpha-energy deposition in non-uniform hotspots.
• 2D implosion simulations show shock waves that are initially distorted can recover their symmetry after the bounce.