Proton Beam Characteristics Relevant to Fast Ignition

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Proton (Ion) Fast Ignition (FI)

Motivation

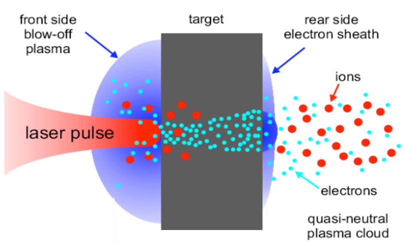
•Proton FI has potential advantages over electron FI

- •the more massive particles are less sensitive to the self-generated E and B fields
- •their energy is depositied at the Bragg Peak
- •can be focused into a highly collimated beam

•A short pulse ignition laser irradiates a hemispherical segment placed within the cone

•The protons are accelerated from the rear surface of the hemispherical segment by a process referred to as target normal sheath acceleration (TNSA)

•The proton beam (originating from a naturally occurring contaminant layer) can then deposit their energies in the compressed fuel to spark ignition

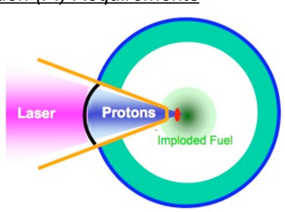


Schematic of TNSA[1]

Proton Fast Ignition (FI) Requirements[2,3]

•Ignite a uniform sphere 200μm in diameter with a density of 400g/cc

•16kJ of proton energy in a cylindrical beam with a diameter of 30μm and a Boltzmann energy spectrum with kT=3MeV propagating 1mm from the source foil to the core



Schematic of a FI target[3]

•For 100kJ of ignition laser energy (3ps, 10^{20} Wcm^{-2}) a 15% laser to proton energy conversion efficiency is required for ignition

•The generated proton jet needs to be radially uniform to achieve the smallest focal spot

•The cone protects the rear surface from the implosion of the capsule and x-rays

Important issues include: material of hemispherical segment, laser to proton conversion efficiency, and focusing.

Proton Conversion Efficiency Experiment

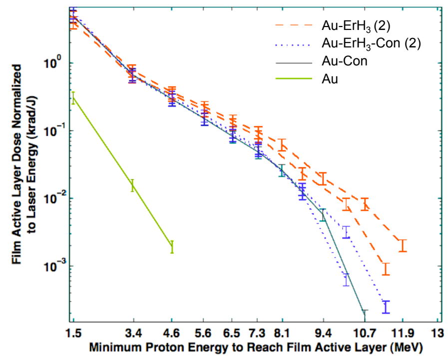
•Goal: to determine if a hydrogen rich layer added to the rear side of the target would increase the laser to proton conversion efficiency

•Experiment was conducted on the Callisto laser system at LLNL with a pulse length of 200fs, wavelength of 800nm, which delivered 7J of energy on target

•5μm thick Au foil with four different rear surface layers: ErH_3 (2000Å), ErH_3 + contaminant layer (~10Å), contaminant layer, and no rear surface layer

•An argon-ion ecther was used to remove the contaminant layer

•Main diagnostics: radiochromic film (measure energy spectrum and conversion efficiency) and the Thomson parabola (measure energy spectrum for ions with different ionization states)



Energy spectrum of four different target scenarios[4].

For protons >3MeV, the hydride targets showed a 1.24 factor increase in laser to proton conversion efficiency compared to the targets with the contaminant layer.

Simulations

•1D simulations using the hybrid PIC code LSP (large-scale plasma)

•LSP treats particles kinetically and thermally (modeled as a hybrid fluid)

•Uses the direct implicit method to solve the particle and field evolution in the plasma, which allows the simulation to run on longer time scales without numerical heating

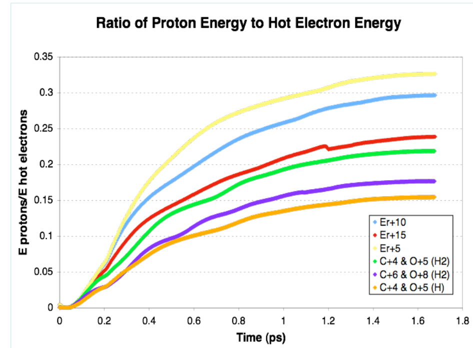
•Laser plasma interaction is not modeled. Fast electrons are excieted from the background electrons with parameters obtained from laser conditions using the scaling laws.

•Fixed ionization states were used. Ionization ranges determined from the Thomson parabola

•Ionization of the material and the composition of the contaminant and hydride layers affect the conversion efficiency

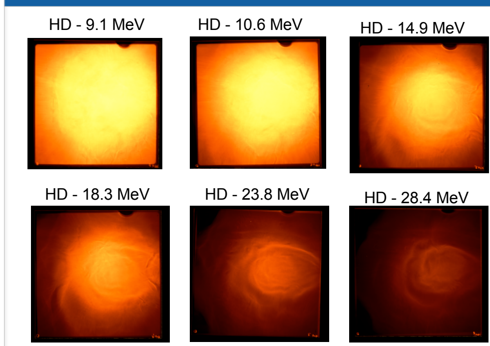
Composition	Conversion Efficiency*
Er+5	*2.85%-8.56%*
Er+10	*2.56%-7.68%*
Er+15	*2.07%-6.22%*
C+4 & O+5 (H_2)	*1.88%-5.65%*
C+6 & O+8 (H_2)	*1.53%-4.61%*
C+4 & O+5 (H)	*1.32%-3.96%*

*assuming a laser to hot electron conversion efficiency between 10%-30%.



LSP results showing the ratio of protons to hot electrons as a function of time in the simulation. The hot electrons were excited for 0.5ps.

Proton Experiment on OMEGA EP



•Target: 500μm² x 20μm Cu + 2μm CH on front and back

•Laser parameters: 965J, 10ps

•First time the proton beam was produced with laser parameters relevant to FI

•Protons were captured using stacked radiochromic film

•Proton energies up to 40MeV were observed

•First two layers (5.1MeV and 7.3MeV) were saturated (above 3*OD*)

•Data analysis is under way to obtain the proton conversion efficiency at these higher energies and pulse lengths.

References & Acknowledgements

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