Fast Ignition crucial issues that could be investigated on OMEGA

A. Schiavi§ and S. Atzeni for HiPER WP9
D. Batani for HiPER WP10

§ CNISM and University of Rome “La Sapienza”
angelo.schiavi@uniroma1.it

First OMEGA Users Group Workshop
Rochester, Apr 2009
Summary

- Baseline target for the HiPER project
- crucial issues for particular design and for F.I.
- previous experiments addressing those issues
- new experimental opportunities at OMEGA
- framework for future collaborations
DUED
2D lagrangian hydrocode with real matter EOS, laser raytracing, nuclear burn, radiative transport, alpha particle diffusion, ebeam MC energy deposition

FleX
3D Eulerian hydrocode with modular design

PTRACE
3D charged particle tracer user-prescribed e.m. fields energy deposition in stack detectors
Baseline target

Compression laser pulse
- wavelength = 0.35 µm
- focusing optics f/18
- energy = 130-250 kJ
- absorbed energy = 90 kJ

1.a) Ignition at minimal energy (the initial HiPER goal)
1.b) Ignition at low risk
2) High-rep. rate test facility (burst mode)
3) Prototype of a preliminary demo reactor (?!?)

what is crucial and mission critical really depends on the final goal of the proposed facility
this will be clear at the end of the preparatory phase only
maximize energy gain while keeping risks “small” (?)

==> 

• minimize compression energy (keep entropy low)
• ignite at “minimum energy”
  at the same time
• make sure RTI growth is small
• keep LPI small
• try to leave safety margins
Compression pulse

with adiabat shaping

\[ \lambda_c = 0.35 \, \mu m \]

- 180 kJ pulse
- 2.8 kJ picket
- foot

without adiabat shaping

\[ \lambda_c = 0.35 \, \mu m \]

- 180 kJ pulse
- 4 ns foot

shock ignition

SI pulse

180 kJ pulse

4 ns foot

time (ns)
assuming good energy coupling (25%), using UV light and limiting ignition energy to 100kJ
Irradiation geometry

<table>
<thead>
<tr>
<th>l-mode</th>
<th>Perfect beam</th>
<th>12, 8, 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance (10%)</td>
<td>1, 2, 12, 3</td>
<td></td>
</tr>
<tr>
<td>Pointing (5 mrad)</td>
<td>2, 3, 1, 4</td>
<td></td>
</tr>
<tr>
<td>centring (2%)</td>
<td>12, 2, 3, 1</td>
<td></td>
</tr>
</tbody>
</table>

Energy balance 94%,

Illumination asymmetry $\sigma_{\text{rms}} = 0.15\%$

Main low l-modes: 12, 8 and 10 (< 0.004)

On the cone: 26% of max intensity
Inside the cone: 2% of max intensity

J.-L. Feugeas and CELIA
Electron beam ignition energy

uniform sphere calculations

point-like ignition

1.5 MeV electrons

n(E) ∝ \exp(-E/<E>); <E> = 1.5 MeV
Monochromatic vs Maxwellian

Maps at the end of the optimal beam pulse for ignition

**Monochromatic**, $E_e = 1.5$ MeV
cylindrical beam, source at $z = + \infty$
box profiles, $r_b = 20 \, \mu m$, $t_p = 16 \, $ ps
no scattering,

beam energy $E_{ig} = 18$ kJ

**1-D Maxwellian**, $<E_e> = 1.5$ MeV
cylindrical beam, source at $z = + \infty$
box profiles, $r_b = 20 \, \mu m$, $t_p = 16 \, $ ps
no scattering

beam energy $E_{ig} = 32$ kJ

(analogous to Solodov et al., PoP 2007)
Adding electron scattering

Maps at the end of the optimal beam pulse for ignition

1-D Maxwellian, $<E_e> = 1.5$ MeV
cylindrical beam, source at $z = 70 \ \mu m$
Gaussian pulse, $r_{HM} = 14 \ \mu m$, $t_{FWHM} = 15 \ \text{ps}$
with scattering

beam energy $E_{ig} = 38 \ \text{kJ}$

1-D Maxwellian, $<E_e> = 1.5$ MeV
cylindrical beam, source at $z = 150 \ \mu m$
Gaussian pulse, $r_{HM} = 13 \ \mu m$, $t_{FWHM} = 16.7 \ \text{ps}$
with scattering

beam energy $E_{ig} = 47 \ \text{kJ}$
For marginal ignition

deposit in the compressed fuel

18 kJ
in 15 ps
in a cylinder of diameter of 30 \(\mu\)m and depth \(\leq 1.2\) g/cm\(^2\)

\[ \text{energy: 100 kJ (\?)}\]
\[ \text{power: 6 - 7 PW} \]

wavelength: so far, 530 nm (2 \(\omega\)), \textit{but}

\textit{recent experimental results [1] and theoretical work [2] indicate that 1 \(\omega\) may be OK}

Some crucial issues for F.I.

- Energy conversion efficiency into igniting beam
- Temperature scaling of fast electrons
- Transport of fast electron beam in hot dense plasma
- Range and penetration of electrons in plasmas (collective effects; self-generated e.m. fields)
- Accurate diagnostic tools for compression and ignition
- Cone effects on compression and fuel contamination
Fast-electron transport in cylindrically compressed matter

RAL-TAW Experiment: October - December 2008

LULI  M. Koenig, S. Baton, F. Perez
Milano-Bicocca  D. Batani, R. Jafer, L. Volpe
CELIA  F. Dorchies, J. Santos, C. Fourment, S. Hulin, P. Nicolai, B. Vauzour
RAL  K. Lancaster, M. Galimberti, R. Heathcote, Ch. Spindloe, H. Lowe
Pisa  P. Koester, L. Labate, L. Gizzi
Bologna  C. Benedetti, A. Sgattoni
Roma  M. Richetta
York  J. Pasley
UCSD  F. Beg, S. Chawla, D. Higginson
LLNL  A. MacKinnon, A. McPhee
Univ. Madrid  J. Honrubia

Very large European collaboration !!
Good interaction theory / experiment !!
Good collaboration with the US !!
WP 10: Fusion Experimental Programme

Cross section

- CH covered Au cylinder
- Ni foil, ≈ 16 μm thick
- CH covered Cu foil
- Polyimide cylinder
- Cu doped CH foams:
  - 1 g/cc, 10% Cu
  - 0.1 g/cc, 20% Cu
  - 0.3 g/cc, 20% Cu
- 180 - 200 μm
- 200 μm
- 200 μm
- 20 μm
- 250 μm

Actual Target

- CH covered Au cylinder
- Polyimide cylinder
- CH covered Cu foil
- Ni foil
Proton and X-ray radiography used to follow target implosion

0 ns, ref target, 220 µm

1.56 ns, shot 5, 177 µm

2.5 ns, shot 3, 147 µm

Implosion plot for 0.1 g/cc foam filled cylinder
Results from 2D crystal imager (Cu K-α)

Images at different times:
- 1.5 ns
- 2 ns
- 2.5 ns
- 3 ns

Graph showing integrated Cu Kα signal over time.

Maximum compression indicated at 3 ns.
OMEGA laser facility offers the opportunity to perform experimental investigations that are HiPER-relevant and that are fundamental for addressing the most important uncertainties of present theoretical and numerical modelling.

OMEGA presentations and discussions in WGs will give shape to possible ways of collaboration, both on numerical modelling and experimental activities.