Beam-Target Interaction for Heavy Ion Fusion

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Background

Heavy Ion beam

Fuel pellet

Accelerator

~mm

4~6m

Problems

* Beam Accelerator (Scale, Cost, etc.)
* Physics of Intense Beam (Bunching, Emittance growth, etc.)
* Beam Final Transport (Stable transportation, Interaction with gas, etc.)
* Beam-Target Interaction
* Analysis of Target-Plasma Hydrodynamics
etc..
**Purposes**

1. Effective Implosion
   - Non-uniformity (< few %)
   - Calculation of deposition energy on a fuel target
   - Development of 3D-implosion code

**Equation:**

\[ D + T \rightarrow ^4\text{He} + ^1\text{n} + 17.6\text{MeV} \]
**Simulation Model**

Pb+Al pellet structure

**Beam parameter**

- *Heavy ion beam:* Pb⁺
- *Particle energy:* 8GeV
- *Beam temperature:* 100MeV
- *Transverse beam emittance:* 5.0 mm mard
- *Beam number density:* 1.3x10¹¹ 1/cc
- *Beam number:* 12, 20, 32, 60, 92, 120
- *Beam distribution:* Gaussian
HIB transverse emittance

Include the Emittance Effect by changing the Focal Spot
Non-uniformity

\[ \sigma_{\text{RMS}} = \sum_{i} w_i \sigma_i \]

\[ \sigma_{\text{RMS}i} = \frac{1}{\langle E_i \rangle} \sqrt{\frac{1}{n_\theta n_\phi} \sum_{j} \sum_{k} \left( \langle E \rangle_i - E_{ijk} \right)^2} \]

\[ w_i = \frac{E_i}{E} \]

\( \sigma_{\text{rms}} \): root mean square (RMS) non-uniformity

\( \sigma_i \): non-uniformity at a surface

\( \langle E_i \rangle \): mean deposition energy at a surface

\( E_{ijk} \): deposition energy at each point

\( n_r, n_\theta, n_\phi \): each mesh number

\( E \): total deposition energy

\( E_i \): total deposition energy at a surface

\( w_i \): weight function include the Bragg peak effect
Simulation Results

32-beam system

\[ \sigma_{\text{rms}} = 1.86\% \]
Effect of HIB Number

At least 32 beams are effective
Effect of Target Temperature

(a) Changes of stopping range

(b) Target temperature v.s. RMS non-uniformity

HIB illumination non-uniformity is kept low during the HIB pulse duration
**Pellet Displacement**

Pellet entrance

Reactors chamber center

Displacement $dz$

Fuel pellet

Fusion reactor

(a) $R_{ch}=2m$

(b) $R_{ch}=5m$

RMS Non-uniformity [%]

- 32-Beam
- 60-Beam
- 120-Beam

<table>
<thead>
<tr>
<th>$dz$ [mm]</th>
<th>32-Beam</th>
<th>60-Beam</th>
<th>120-Beam</th>
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<td>0.01</td>
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</table>
Reduce the Non-uniformity for the Pellet Displacement

32-HIBs

Displace the HIB illumination point for the theta-direction (2 deg.)

New scheme

Large radius

New scheme & Large radius

32-HIBs system
Background2

Problems

* Beam Accelerator (Scale, Cost, etc.)
* Physics of Intense Beam (Bunching, Emittance growth, etc.)
* Beam Final Transport (Stable transportation, Interaction with gas, etc.)
* Beam-Target Interaction

* **Analysis of Target-Plasma Hydrodynamics**

etc..
Initial Condition

Illumination Pattern

12-HIBs system

32-HIBs system

Power [TW]

320

6

Pulse [nsec]

20 24 34

3.57mm

3.54mm

3.14mm

3.04mm

Pb

Al

DT

Void

11.3g/cm³

2.69g/cm³

0.19g/cm³
Preliminary results

12-HIBs@32nsec

32-HIBs@32nsec
Initial Condition2

Illumination Pattern

12-HIBs system

32-HIBs system

Power [TW]

320

6

20 24 34

Pulse [nsec]
Preliminary results

12-HIBs@36nsec

32-HIBs@36nsec
Summary

- HIB illumination non-uniformity can be smoothed due to the beam temperature and emittance.
- HIB illumination non-uniformity is kept low during the HIB pulse duration onto a direct-driven pellet in ICF.
  - The non-uniformity is reduced by changing the illumination pattern for the pellet displacement.
  - In the case of the large non-uniformity (12-HIBs system), our implosion code works well.
- The implosion non-uniformity is suppressed by foam layer.

Future Subject

- Find optimum parameters (HIB pulse, target structure, etc.) to effective implosion.