Bunching Beam Dynamics in Final Stage of Heavy Ion Fusion Driver

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Background & Purpose

- **Heavy Ion Inertial Fusion (HIF)**
  - Intense Heavy Ion Beam (~10GeV ~10ns ~100kA)
  - Generation & Transport are required for effective implosion.

Accelerated Heavy Ion Beam ➤ Final Beam Bunching

~100ns ➤ ~10ns

Beam

Bunching

Focusing

Induction Linear Accelerator

Beam Irradiation for Implosion
Heavy Ion Beam Bunching by Induction LINAC

Apply Bunching Voltage at each Gap

Induction buncher consists of periodic lattice, acceleration gaps & FODO quadrupole.

Beam head is decelerated by

Beam tail is accelerated

Head & tail velocities are modulated. \( \Delta \beta / \beta \) indicates Velocity Tilt.

Beam bunch becomes short during transport.
### Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Species</td>
<td>Pb$^{1+}$ (207.2 amu)</td>
</tr>
<tr>
<td>Ion Number</td>
<td>$2.5 \times 10^{15}$</td>
</tr>
<tr>
<td>Total Charge</td>
<td>0.4 mC</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>250 ns ⇒ 10 ns</td>
</tr>
<tr>
<td>Total Beam Current</td>
<td>1.6 kA ⇒ 40 kA</td>
</tr>
<tr>
<td>Beam Number</td>
<td>4</td>
</tr>
<tr>
<td>Current per Beam</td>
<td>400 A ⇒ 10 kA</td>
</tr>
<tr>
<td>Particle Energy</td>
<td>10 GeV ( $\beta \sim 0.31$ )</td>
</tr>
<tr>
<td>Longitudinal Beam Length</td>
<td>23 m ⇒ 0.9 m</td>
</tr>
</tbody>
</table>

Parameters in final stage of HIF driver system

Bunch Compression Ratio = 25

Beam Transport by PIC Simulation

x-y Real Map

x-x’ Phase Map

Beam Transport in FODO Lattice

without compression
Beam Transport by PIC Simulation

Particle Maps

- 0m
- x [cm]
- y [cm]
- dx/ds [mrad]
- 444m
- 148 lattice
- KV envelope

Charge Distribution

- 0m
- 444m
- 148 lattice
We calculate about 3 compression schedules
Estimation for Beam Compression Effect

Beam Transport in FODO Lattice

*with linear compression schedule*
Estimation for Beam Compression Effect

Charge Distribution Change in x-y space

\[ \rho [\text{C/m}^2] \]

with linear compression schedule
at stagnation point
444m, 148 lattice

Emittance dilution
due to Resonance effect ($\sigma = 60\text{deg}$)
Slow Compression Schedule

at stagnation point
573m, 191 lattice

Emittance dilution
smaller than linear case

Real map
Phase map
Rapid Compression Schedule

at stagnation point
444m, 148 lattice

Phase maps and Emittance
Dilutions are changed by
Compression schedules
Intense ion beams, *non-neutral plasmas*, will show collective phenomena.

\[ H / \lambda_D = 0.23^* \]

*H* : Spatial Mesh Size (*H*\(=\Delta x=\Delta y\))

\( \lambda_D \) : Debye Length

We try to calculate with changes of PIC mesh size *H*.

Calculations with $H/\lambda_D$ Changes

at 444m, 148 lattice, just x25 compression

<table>
<thead>
<tr>
<th>$H/\lambda_D$</th>
<th>Real Map</th>
<th>Phase Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>0.4</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>0.227</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>0.2</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Calculation results are quite different in $H/\lambda_D < 0.23$ or not
Negative Feedback of Particle Loss

$$\frac{H}{\lambda_D} = 0.4$$

Real Map

$$\frac{H}{\lambda_D} = 0.2$$

Phase Map

$$N_f / N_i = 1$$

$$N_f / N_i = 0.7$$

Particle Loss causes mismatch increase

Large mismatch increases beam radius

Large beam radius causes beam loss

Seed of particle loss is Resonance & Plasma Oscillation

$N_f$ : Final super particle number

$N_i$ : Initial super particle number
Calculations with $H / \lambda_D$ Changes

in case of slow compression schedule

Phase Map

No particle loss, but phase map is clearly different at $H/\lambda_D < 0.23$. 
Emittance dilution depends on compression schedules in intense ion beam bunching.

In high-current beams, collective behavior is important.

Resonance effects induced plasma oscillations are an important issue for emittance dilution in Final Beam Bunching.