Development of a focusing system for the AXSIS project

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1. Introduction

AXSIS (Attosecond X-ray Science: Imaging and Spectroscopy) schematic layout

AXSIS [1] aims at producing fully coherent few keV attosecond X-ray pulses for ultrafast spectroscopy and imaging applications. They will be produced via the Inverse Compton Scattering (ICS) between an IR laser pulse and a 15 MeV sub-fs electron bunch accelerated by a dielectric-loaded waveguide [2] driven by THz pulses (linac).

One of the key parts of AXSIS will be the focusing system between the linac exit and the ICS point. It has to focus the bunch at a focal point, located between 30 cm and 1 m away from the linac exit, down to a transverse size around or below 5 µm rms. The performances achievable with various focusing devices (solenoid magnet, quadrupole doublet and active plasma lens) are presented here. The design is challenging in the context of AXSIS due to the following three reasons: high energy spread (≥0.5% rms); asymmetry (size and emittance) between the two transverse planes by a factor of approximately 2 at the linac exit; necessity to keep a short bunch length after the linac exit up to the ICS point.

2. Input beam properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge</td>
<td>1 µC</td>
</tr>
<tr>
<td>Mean kinetic energy</td>
<td>14.05 MeV</td>
</tr>
<tr>
<td>RMS energy spread</td>
<td>82.70 keV</td>
</tr>
<tr>
<td>RMS length</td>
<td>1.25 µm (≈4.27 fs)</td>
</tr>
<tr>
<td>RMS horizontal size</td>
<td>213 µm</td>
</tr>
<tr>
<td>RMS vertical size</td>
<td>133 µm</td>
</tr>
<tr>
<td>RMS horizontal emittance</td>
<td>0.195 n.m.rad/min</td>
</tr>
<tr>
<td>RMS vertical emittance</td>
<td>0.090 n.m.rad/min</td>
</tr>
</tbody>
</table>

Bunch properties considered at the linac exit.

Assumption: Maximum peak magnetic field achievable with a resistive electro-magnet is 0.5 T and 1.5 T with a permanent magnet.

3. Case of a solenoid magnet (resistive electro-magnet and permanent magnet)

On-axis field profile of the solenoid magnet used for simulations.

On-axis profile of the solenoid magnet. Green area: Requirement on the magnetic field. Yellow area: Both requirements fulfilled. Bunch properties considered at the linac exit.

4. Case of a quadrupole doublet

Results for a symmetric doublet (10 cm long quadrupoles with 3 cm radii) for several distances ALQ between the linac exit and the first quadrupole.

Results for 5 cm long quadrupoles with 1.5 cm radii. Magnets location: 12 cm and 20 cm after the linac exit. Transverse gradients of -14 T/m and +18.5 T/m.

5. Case of an active plasma lens [3]

Results for a perfect active plasma lens (2 cm length and 1 mm radius) placed 5 cm after the linac exit and having 200 T/m transverse gradient.

Results for a perfect active plasma lens (2 cm length and 1 mm radius) placed 50.5 cm after the linac exit and having 200 T/m transverse gradient. A solenoid magnet with 0.5 T peak field has been placed 34 cm after the linac.

Active plasma lens alone suffers from astigmatism, due to the input bunch transverse asymmetry. This could lead to a significant bunch transverse size asymmetry at the ICS point, but can be removed by adding a solenoid magnet before the active plasma lens.

An active plasma lens would fulfill the AXSIS requirements, but several points must be carefully studied before considering implementation.

6. Conclusions & Prospects

The AXSIS requirements (position of the focal point and bunch transverse size) cannot be fulfilled by a solenoid resistive electromagnet, but possibly with a permanent magnet. A quadrupole doublet allows fulfilling the requirement on the position of the focal point and approaching the one on the transverse size, but with an asymmetry of the transverse size. The use of an active plasma lens looks promising to fulfill both requirements, but several points still have to be carefully studied.

Next steps of the study, already ongoing, are to look how each device deteriorates the bunch transverse emittance and perform simulations in combination with the linac [2] (to make coinciding the transverse and longitudinal focal points).

Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union’s Seventh Framework Programme (FP7/2007-2013)/ERC Grant Agreement n. 609920.

References: