Development of a focusing system for the AXSIS project

Thomas Vinatier, Ralph Assmann, Ulrich Dorda, Barbara Marchetti
DESY, Hamburg, Germany

1. Introduction

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

★ 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. Bunch properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge</td>
<td>1.5 µC</td>
</tr>
<tr>
<td>Mean energy spread</td>
<td>1.5 keV</td>
</tr>
<tr>
<td>RMS length</td>
<td>1.2 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>
</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 solenoid magnet (resistive electro-magnet and permanent magnet)

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

★ Under our assumptions, both the requirements on the position of the focal point and on the bunch transverse size at this point cannot be achieved with a solenoid resistive electromagnet (at best 18 µm rms at 1.2 m from the linac exit). It could be possible to fulfill both requirements with a permanent solenoid magnet. However, due to their very small tunability they will not be considered as a stand-alone focusing device for AXSIS, but only in combination with other tunable focusing devices.

4. Case of a quadrupole doublet

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

★ Protocol: Fix \( \Delta L_Q \) and then find for each field gradient the position of the second quadrupole giving equal focal distances along the 2 transverse directions.

★ Range of useable gradients is limited by mechanic.

★ Requirement on the focal point position can be fulfilled if \( \Delta L_Q < 40 \) cm, but not the one on the transverse size.

★ A strong asymmetry of the transverse size remains at the focal point.

★ The transverse size asymmetry can be reduced by using smaller magnets (5 cm length and 1.5 cm radius).

★ Removing the constraint of using a symmetric doublet allows approaching the transverse size requirement (6.0*8.8 µm² rms simulated), but not removing asymmetry.

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.

★ 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.
- The 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).

★ References:


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