Characterization of LWFA with realistic laser profiles for ESCULAP project

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Introduction

A goal of ESCULAP [1-3] experiment is the external injection of photo-injector electrons bunch with consequent LWFA acceleration in the moderate density plasma cell. In our configuration small fraction of LASERIX laser is send to the photocathode, and the rest is delivered to the plasma cell for the wake excitation.

Stability of the laser beam, its shape, “flatness”, duration, intensity etc. are crucial parameters for the reproducible shot-to-shot acceleration. We study numerically LWFA and evolution/propagation of flattened Gaussian profile of the laser approximating the experimental one. The study is performed for 10, 20 and 50 MeV externally injected electron beam.

Experimental setup scheme

Numerical Modelling

Features of FBPIX code [4]
- Cylindrical grids with azimuthal decomposition and dispersion-free field solver.
- The simulation can be performed on CPU / GPU and in cluster environment.
- Moving window with boosted frame technique (crucial when plasma cell is several centimetres length).
- Post-processing: OpenPMDDiagnostics and LPATools modules.

Benchmarking

Total calculation time for 9 cm plasma cell.

<table>
<thead>
<tr>
<th>LPAD code</th>
<th>Bunches x CGI/CP</th>
<th>Total, h</th>
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<tbody>
<tr>
<td>FBPIX CPL, OpenMP(32)</td>
<td>2456 HCPU</td>
<td>1.75</td>
</tr>
<tr>
<td>FBPIX CPL, OpenMP(256)</td>
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</tr>
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<tr>
<td>WAKE-UP</td>
<td>9 HCPU</td>
<td>9</td>
</tr>
</tbody>
</table>

Results and discussion

Modelling parameters

- Gaussian electron bunch / or one from Astra
  - Beam longitudinal rms size 5 μm
  - Beam transverse rms size 10 μm
  - Beam Gamma Mean = 19; Beam Gamma rms = 0.5%
  - Normalised emittance 1 μm

Plasma cell

- 2-4 e17 cm-3 variable density profile, total length of 9 cm (focal plane at 4 cm)
- Plasma density
  - Uniform 2e17 cm-3

Conclusions

We demonstrate that the external injection scheme, which consist in trapping electrons before laser focal plane with consequent acceleration in the focal plane is robust with respect to the laser radial profile. Acceleration in the wake from Flattened Gaussian laser is more efficient than with Gaussian beam of the same waist. This can be partly explained by increase of the effective waist, longer Rayleigh distance and consequently acceleration along longer distance. Moreover some optimisation on the laser radial profile can have some significant impact for LPAs.

Increase of energy of injected electron bunch, without optimisation of initial electron bunch distribution does not seems beneficial for the ESCULAP experiment. Shaping of high energy electron bunch with plasma wake fields after capturing becomes difficult. No additional energy gain were observed for injection at higher energies, apart from the difference in the energy of injected bunches.

References