

Comprehensive 3+1D numerical simulation tool for thin plate post-compression of high energy ultrashort pulses

Levente Lehotai,¹ Szabolcs Tóth,¹ Imre Seres,¹ János Csontos,¹ Viktor Pajer,¹ Ádám Börzsönyi,¹ Károly Osvay,² and Roland S. Nagymihály,¹

¹ELI ALPS, ELI-HU Non-Profit Ltd., Wolfgang Sandner u. 3, H-6728 Szeged, Hungary

²National Laser-initiated Transmutation Laboratory, University of Szeged, Dugonics tér 13, 6720 Szeged, Hungary

Numerical analysis of the post-compression of ultrashort laser pulses has been already demonstrated and experimentally validated for the multiple thin plate compression (MPC) technique both in 1+1D [1] and 2+1D [2], although they are limited by the number of physical effects included and the possible optical geometries. Simulations for the multipass cell scheme have been even performed in 3+1D, although with limitations on the number of implemented nonlinear effects [3]. Comprehensive 3+1D numerical simulation of high energy post-compression, on the other hand, has been prohibited due to the unreasonable computational costs and time, especially for large aperture beams.

Here we present a 3+1D simulation combined with a 1+1D code to effectively predict the spectral broadening in any MPC arrangement. Our strategy is, first to find a proper peak intensity for significant spectral broadening, where the generated electron plasma does not absorb significant energy and distort the spectral phase of the pulse. Second, the beam propagation is simulated with the 3+1D component of the code, taking into account the focusing geometry, plate position, linear and nonlinear effects in the thin plate. The same process is repeated for the next plates. Dispersion compensation is achieved by utilizing dispersion curves of real chirped mirror designs. This method lets us sweep large space of parameters with variety of impulse parameters in relatively short time compared to other implementations, and it can also give information about the spatio-temporal distribution of energy. We found good agreement with experimental results on the post-compression of 13 mJ pulses with 12 fs input pulse duration to the single-cycle regime obtained with the SEA laser of ELI ALPS. This simulation method enables the optimization of post-compressed pulses for secondary sources, such as high harmonic generation or ion acceleration.

References:

- [1] O. Melchert et al, arXiv:2104.11649 (2021)
- [2] Y-C. Cheng et al, Optics Express 24, 7224-7231 (2016)
- [3] M. Hanna et al, JOSAB 34, 1340-1347 (2017)

Short summary

Simulation strategy on efficiently combining 3+1D and 1+1D numerical simulations of high energy pulse post-compression in multiple thin plate compressor. While the main part of the optimization takes place in the 1D space, the final result describes the electric field of the pulse in the spatio-temporal space, and effected by third order nonlinearity, Raman-scattering, ionization and linear dispersion. The technique is compared to an experimental result where single cycle regime was reached, and the validation showed high accuracy. This method enables further optimization of post-compression for secondary sources, such as high harmonic generation and ion acceleration.