Tunable polarization plasma channel undulator for narrow-bandwidth photon emission

S.G. Rykovanov[1,*], J.W. Wang[1], V.Yu. Kharin[1], B. Lei[1,2], C.B. Schroeder[3], C.G.R. Geddes[3], E. Esarey[3] and W.P. Leemans[3]

[1]*Helmholtz Institute Jena, Froebelstieg 3, 07743, Jena, Germany*
[2]*Friedrich-Schiller University, Helmholtzweg 4, 07743, Jena, Germany*
[3] *Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, 94720, Berkeley, CA, USA*
**E-mail: S.Rykovanov@gsi.de*

Abstracts: *An undulator based on control of the focusing forces inside a laser-plasma accelerator is proposed. Controlling the focusing force is achieved by inducing laser pulse centroid oscillations in a plasma channel. The period of such a plasma undulator is proportional to the Rayleigh length of the laser pulse and can be sub-millimeter. The electron trajectories inside the plasma undulator are examined, expressions for the undulator strength are presented, and the spontaneous radiation is calculated. Multimode and multicolor laser pulses are considered for greater tunability. Effortless polarization control of the emitted light is demonstrated.*

Synchrotron radiation produced by the electrons travelling in bending magnets or insertion devices is essential for our understanding of the microcosm. X-ray pulses produced by the synchrotron facilities are widely used in, for example, chemistry, biology and material science. The brightest X-ray pulses are generated using the free- electron lasers (FELs) - a combination of a high-quality linear accelerator (LINAC) and magnetic undulators. Presently, the lower limit to the undulator period λ_u for magnetic undulators is on the order of 1 cm. Reducing λ_u is highly beneficial as it will decrease the required electron energy for the same specified radiation wavelength and, hence, decrease the size of the light source. Undulators with periods on the order of a millimeter, often referred to as micro-undulators, are, therefore, of great interest.

In this report, we propose a novel type of the undulator for the narrowband photon emission based on the laser pulse centroid oscillations inside a plasma channel. It has been theoretically shown [1] that the electrons injected into the wakefield created by the laser pulse undergoing centroid oscillations inside a parabolic plasma channel, wiggle with the characteristic wavelength of $\lambda_u=2\pi Z_R$, where Z_R is the Rayleigh length of the laser pulse. It is theoretically possible to achieve high undulator strength $a_u\sim1$ for undulator periods of 1mm or less. This makes such a plasma undulator or plasma wiggler (PIGGLER) a promising way towards a ”table-top” bright incoherent soft X-ray source, and, theoretically a ”table-top” FEL with tunable polarization.

Using linear plasma theory and numerical simulations, the field structure of the plasma undulator is examined, electron trajectories and emitted radiation are calculated. Polarization control, achieved by the laser pulse injection into the parabolic channel off-axis and under some angle, is demonstrated. Additional control using higher-order Hermit-Gaussian laser modes is proposed. Analytical calculations are supported by the Particle-in-Cell (PIC) simulations. Beam loading and dephasing effects are discussed.