For this project we designed and manufactured helical mirrors for laser-plasma acceleration of particles. In experiments we also used the laser deformable mirror to improve the shape of the helical focused beam, as shown below. We investigated the effects of different helical topological orders with linear and circular polarized hundreds of TW - PW class laser pulses at ELI-NP and OSU (USA). The obtained results are now under evaluation.

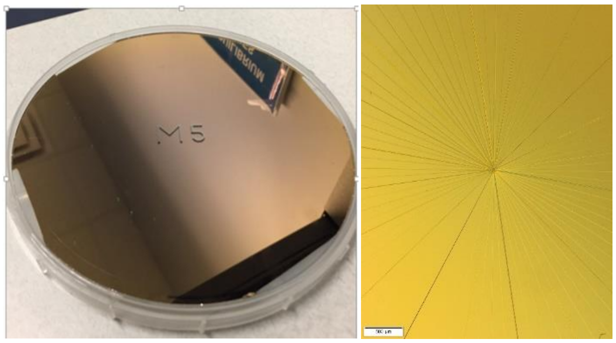


Figure 1. Helical mirror and the central part for the topological order l=5

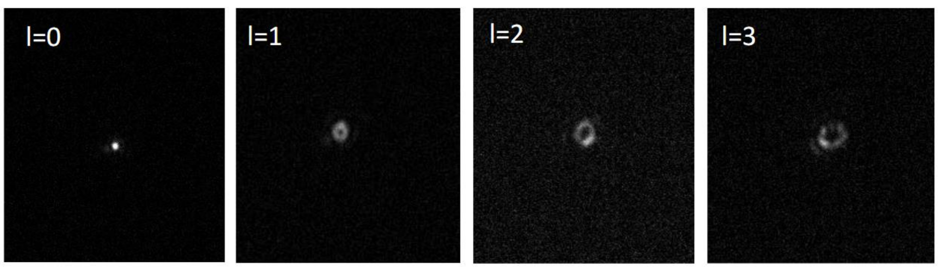


Figure 2 Examples of focal spots corresponding to Gaussian and Helical l=1.2 and 3 laser beams

The experimental campaigns were backed by extensive optical, hydrodynamic, ray-tracing and PIC simulations. The PIC simulations of the gaseous and solid targets required important computational and personnel resources. We relied on our collaborations with the groups Prof. Arefiev (USA) and Prof. Schumacher (USA).

LSD

GDED

Key Publications

1. Generation of ultrarelativistic monoenergetic electron bunches via a synergistic interaction of longitudinal electric and magnetic fields of a twisted laser, Y Shi, D Blackman, D Stutman, A Arefiev, Physical Review Letters 126 (23), 234801 (2021)
2. Electron acceleration from transparent targets irradiated by ultra-intense helical laser beams, DR Blackman, Y Shi, SR Klein, M Cernaianu, D Doria, P Ghenuche, A Arefiev, Communications Physics 5 (1), 1-13 (2022)

Contribution Scientific Report Helical Project

Conference contributions:

Title: Qualification and optimization of helical phase pulses in PW-class laser systems

Authors: V. Iancu, M. Talposi, S. Popa, P. Ghenuche, M. Cernaianu, D. Doria, G. Cojocaru, I. Dancus, R. Ungureanu, O. Chalus and D. Ursescu

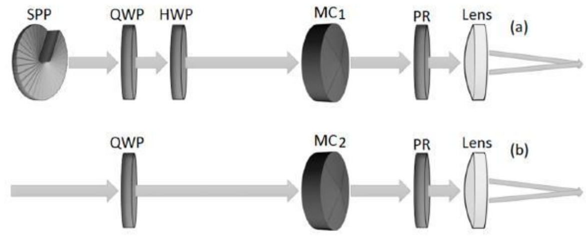
Conference: ICLPR-ST, Bucharest, Romania, June 2022

Presentation Type: poster

Articles:

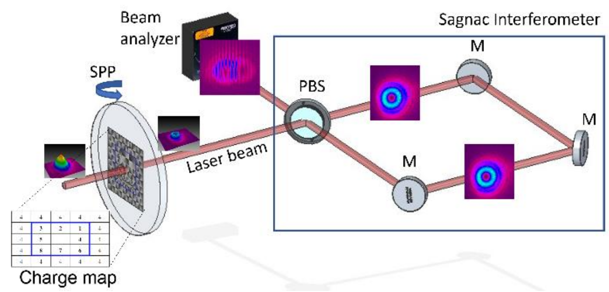
Talposi, Anda-Maria, Vicentiu Iancu, and Daniel Ursescu: "Influence of Spatio-Temporal Couplings on Focused Optical Vortices" *Photonics* **9**, no. 6: 389, 2022. https://doi.org/10.3390/photonics9060389

An optical system, capable of producing cylindrical vector beams with adjustable characteristics in the focal plane, has been designed and analysed. The focal spot can be changed from a typical doughnut spot with azimuthal polarization to an extended doughnut spot or a bi-lobed focal spot without circular symmetry, via simple rotation of certain optical elements around the optical axis. In addition, if the focal spot is circularly non-symmetric, then it could be rotated around the optical axis by rotation of certain components.



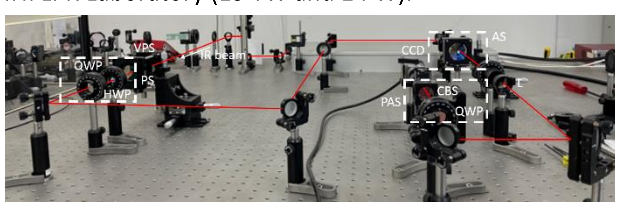
a) The set-up used to produce a beam with azimuthal or nearly azimuthal polarization in the focal plane. **b)**. The layout designed to deliver an intensity profile that is nearly uniform in the focal plane.

A study was conducted on the interaction between a Gaussian beam and a multi-sectional diffractive optical element (spiral phase plate - SPP) made of glass deposited with a polymeric material. This optical element is a matrix of SPPs, each element with an aperture of 10 mm × 10 mm, having a topological charge (TC) between 1 and 8. Measurements of the beam distribution were made for each TC, in order to establish that the laser beam generated by SPP illumination, at a different wavelength than the one for which it was made, remains of the vortex type. The system was implemented to CETAL-INFLPR Laboratory (15 TW and 1 PW) and amplification and compression of pulses with "donut" type transverse distribution were done.



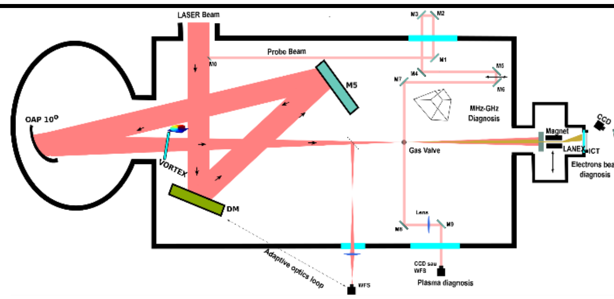
The experimental set-up used to study the influence of λ on the laser beam produced by the SPP designed for the wavelength λ_0= 633 nm.

An optical system comprising a *c*-cut uniaxial crystal placed between two axicons and illuminated by a Gaussian or a Laguerre-Gauss beam was used to demonstrate the generation of various vector vortex beams. The system was implemented to CETAL-INFLPR Laboratory (15 TW and 1 PW).

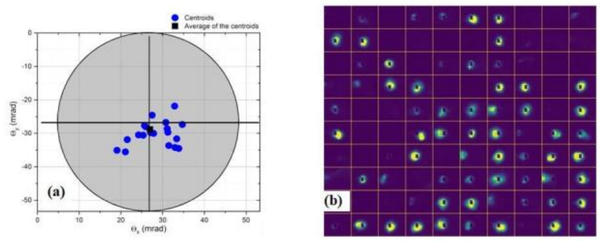


The experimental setup comprises four main parts: an SPP equivalent system (VPS) consisting of two quarter-wave plates (QWP) and a vortex half-wave plate; a polarization control system (PS) composed of a quarter-wave plate (QWP) and a half-wave plate (HWP); a vector vortex beam generation system (AS) that contains two fused silica ultra-quality axicon lenses and an uniaxial crystal, and a polarization analyser system (PAS) made up of a quarter-wave plate (QWP) and a cube polarizer.

In order to obtain helical laser beams with peak power of the order of hundreds of TW, an optical element in transmission has been configured to modulate the spatial phase of large laser beams. This optical element was used for performing experiments to obtain accelerated electron beams produced with high-power helical beams in jets of noble gases. Accelerated electron beams with maximum energies up to ~500 MeV were obtained by laser wakefield acceleration (LWFA) in the supersonic gas jet target.

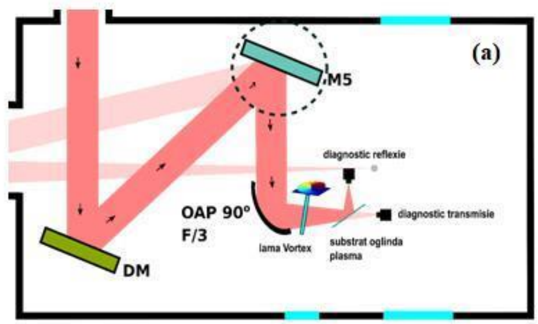


Experimental setup for CETAL-PW laser-gas jet interaction.



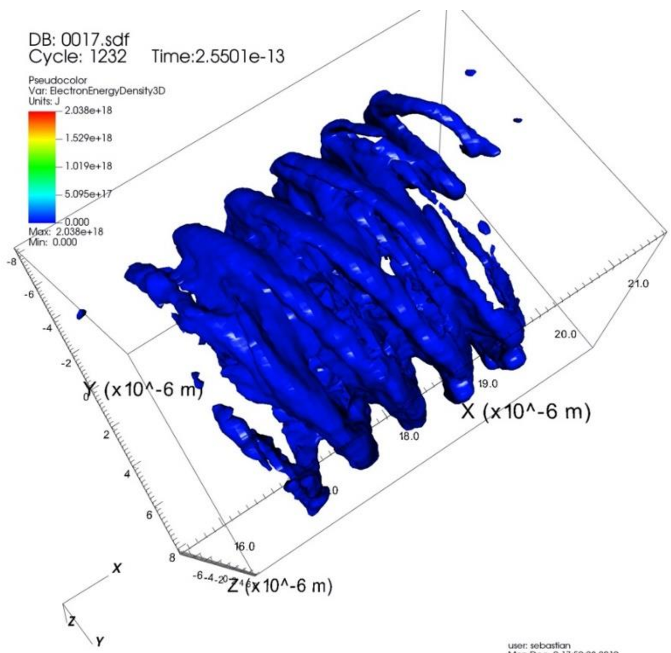
a) Electron spot centroids distribution on LANEX. **b**) Map of the pointing stability illustrated by an images matrix of the scintillating screen (LANEX) exposed to accelerated electrons during a 100-pulse irradiation campaign.

An optical assembly has been designed to be implemented in the interaction chamber to allow i) the production of plasma beams with standard laser beams (Gaussian) and helical beams, and ii) the characterization of emissions produced by interacting with specific targets.



Setup design for TNSA proton beam acceleration using gaussian and helical beam prepared to be implemented in CETAL-PW interaction chamber.

In this project the team of University of Bucharest coordinated by Prof. Virgil BARAN investigated by analytical and computational means the interaction of helical beams within a series of complementary formalisms. Following an exploratory investigation into fluid turbulence of 2D quantum plasma, see Ref. [1], highly relevant for properties of plasma targets, the team focused on the dynamics of free electrons in twisted field and the scattering of an intense laser beam by atomic systems , see Refs. [2, 3], the self-consistent Particle-in-Cell simulations (PIC) of the interaction of twisted laser pulses with matter, a topic on which the results on the transfer of orbital angular momentum from the laser field to the electrons of the target have been partly published (see Ref. [4]), and beyond-PIC effects on higher-order nonlinear QED processes with first-order building blocks, see Refs. [5, 6]. The rationale behind the beyond-PIC investigations is that PIC results have a somewhat limited validity because the locally-constant-field (LCF) approximation on which all PIC codes rely is not valid at moderately high field intensities, which is a regime that is experimentally relevant. To go beyond this limitation of all available PIC codes, we have investigated higher-order three-level processes using a sequence of first-order processes to estimate higher orders at moderate intensities provided the field is sufficiently long, see Ref. [5] for details. Moreover, we have studied helical beams in the context of collective modes of atomic nuclei, see Refs. [7, 8], and have studied the decomposition of twisted photons in spherical ones, the results being currently prepared for publication. We have also developed a series of data processing and visualization tools for the large-volume of simulated data outputted by the PIC and PIC-like codes.



Screw-like energy density isosurface of electrons generated through the interaction of a Laguerre-Gauss laser pulse with a gaseous target.

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2. M. Dondera, *Electrons in twisted fields and ponderomotive effects*, Journal of Physics B – Atomic Molecular and Optical Physics **53**, 064003 (2020)
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4. P.-V. Toma, S. Micluta-Campeanu, M. Boca, A. Nicolin, V. Baran*, Scaling properties of angular momentum transfer for charged particles under Laguerre-Gauss laser pulse*, AIP Proceedings 2022, *in press*
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7. T. Isdraila, V. Baran, M. Colonna, A.I. Nicolin, M.C. Raportaru, E. Boicu, *An extended Brown-Bolsterli model for pygmy dipole resonance*, Romanian Journal of Physics **66**, 304 (2021)
8. C. Parascandolo *et al.*, *Dynamical dipole excitation in the fission of a ^{40}Ca + ^{152}Sm composite system*, Physical Review C **105**, 064611 (2022)