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Megahertz-rate Ultrafast X-ray Scattering and Holographic Imaging at the European XFEL

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During 2019, the novel DSSC 2D imaging detector [1] was commissioned at the Spectroscopy and Coherent Scattering (SCS) instrument of the European X-ray Free-Electron Laser (EuXFEL) [2]. To fully exploit the high repetition rate provided at EuXFEL (up to 2.25 MHz), the DSSC detector was designed to be the fastest one-megapixel camera available worldwide, providing single-photon sensitivity in the soft X-ray regime. As a test-bed for operation at megahertz rates, time-resolved magnetic X-ray scattering and holographic imaging experiments in solid state samples were chosen as representative [3]. Indeed, these two types of measurements allow to assess fundamental features of a 2D detector for X-ray science. For example, a high dynamic range is needed for recording the tiny variations in magnetic scattering induced by a laser pump, and holography requires measurements characterized by a high signal-to-noise ratio in order to provide well-defined image reconstructions. During this talk, we will present the obtained results, which were validated by measurements performed at other facilities (BESSY II, SOLEIL, MBI).
As potential future application for high-repetition rate scattering and imaging experiments at free-electron lasers, we propose the use of light beams possessing orbital angular momentum (OAM), which are rapidly becoming a way for probing condensed-matter systems, even in the X-ray regime [4]. The wavefronts of such beams are characterized by an azimuthal angular dependence of the electric field phase, associated with an OAM topological charge $l \neq 0$.
In this framework, OAM beams allow for novel kinds of dichroism experiments, paving the way for new spectroscopic tools in the fields of orbital physics and magnetism [5]. In particular, it has been demonstrated that, after the scattering of an OAM beam from magnetic structures featuring a non-uniform magnetization (like magnetic vortices), the far field intensity profile encodes the vortex symmetries in a way that depends on the sign and value of l, giving rise to magnetic helicoidal dichroism [6].
On the other hand, for imaging purposes, the use of OAM beams can help in overcoming the Rayleigh criterion limit, so enhancing the theoretical resolution with respect to gaussian illumination ($l = 0$) [7]. This feature has been recently tested at the DiProI beamline of the FERMI free-electron laser [8] by performing ptychographic experiments with a standard sample. As predicted, the ptychographic reconstructions with OAM beams showed a higher image resolution, and the retrieved illumination functions proved to be very sensitive to optical aberrations, providing the basis for new characterization and diagnostic tools.

- on behalf of the collaboration supporting the beamtime "X-ray holography of ultrafast magnetism: femtosecond movies at the nanoscale" (EuXFEL proposal ID 2222)

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