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Foreword to the special virtual issue dedicated to the proceedings of the PhotonDiag2018 workshop on FEL Photon Diagnostics, Instrumentation, and Beamlines Design

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From the pioneering early days of synchrotron radiation, with rings like Tantalus, SURF, ADONE and DESY among others, to the third-generation storage rings, the quest for better photon transport systems has been stimulated by inventive users and by competition for users and funding. This quest drove major breakthroughs in optics, coating and optical design (McKinney & Howells, 1980; Padmore, 1989; Johnson, 1986; Howells, 1980; Harada & Kita, 1980; Reininger & Saile, 1990; Chen & Sette, 1989; Petersen, 1982; Reininger & de Castro, 2005; Cocco *et al.*, 1999; Follath, 2001; Naletto & Tondello, 1992), metrology (von Bieren, 1982; Takacs & Qian, 1989; Irick & McKinney, 1997; Cocco *et al.*, 2003; Siewert *et al.*, 2004; Vivo & Barrett, 2017) and simulation codes (Lai & Cerrina, 1986; Raimondi & Spiga, 2015; Sanchez del Rio & Rebuffi, 2019; Rebuffi & Sanchez del Rio, 2017; Shi *et al.*, 2014). New optical designs have been proposed to meet the request for new experiments, challenging the optical manufacturers to improve their polishing capabilities or coating quality and the metrologists to improve their ability in measuring the optics. The result has been that better beamlines have been put into operation and more sophisticated experiments have been performed. This virtuous loop generated a constant and steady progress in all the photon transport system related instrumentation and techniques. However, a novel approach to optics and optical design, and, somehow, a revolutionary way of thinking, did not happen until a new kind of facility – the free-electron laser (FEL) – became operational. Pioneering work carried out at FLASH (the first VUV FEL) (Ackermann *et al.*, 2007; Ayvazyan *et al.*, 2006; Tiedtke *et al.*, 2009), LCLS (the first X-ray FEL) (Emma *et al.*, 2010; White *et al.*, 2015) and FERMI (the first seeded FEL) (Allaria *et al.*, 2010, 2012) paved the way to a new boost in optics development. The development became a clear priority for all facilities with the advent of the European XFEL (Abela *et al.*, 2006; Tschentscher *et al.*, 2017), SACLA (Ishikawa *et al.*, 2012), SwissFEL (Ko *et al.*, 2017) and PAL-XFEL (Milne *et al.*, 2017). New challenges came along, related to the high peak photon pulse energy, short pulse duration, and increasing repetition rates. In the meantime, thanks to the development made at Osaka University (Yamauchi *et al.*, 2002), diffraction-limited optics became available. Thanks to these mirrors, diffraction-limited nano-scale spots, or almost perfect beam out of focus, were made possible (Matsuyama *et al.*, 2016; Cocco *et al.*, 2018). New sources, not only FELs but also the diffraction-limited storage rings (DLSRs) under construction all around the world, will strongly benefit from the work done so far.

A uniquely distinguishing feature that highly differentiates the photon transport system of a FEL from that of a synchrotron radiation source is the need for completely new photon diagnostics (Tiedtke *et al.*, 2009; Moeller *et al.*, 2011; Grünert, 2012), with the ability and necessity to measure the properties of the light pulses with high precision, sometimes even shot by shot. Intensity, for sure, but also spectrum, wavefront, polarization, beam position and pointing and temporal jitter among others are often required to be continuously monitored, ideally in a non-invasive way, to provide real-time information to the experimentalists and to the operators for machine performance optimization.

To face these challenges, in 2010, under the auspices of the EuroFEL consortium, a first workshop was held in Hamburg, Germany[1]. It was focused on optimized concepts for the photon beam transport of femtosecond laser-like radiation of short wavelength, including the metrology of optical components and centered on advanced diagnostics for the determination of photon beam properties. Following the first workshop, with the increasing demand in highly performing diagnostics and better optical systems, a second workshop was held in Trieste, Italy, hosted by FERMI in 2015[2] and a third, hosted by the Linac Coherent Light Source at SLAC, in 2017[3]. The fourth workshop of this successful series, presented in this proceedings volume, took place, as the original one, in Hamburg in September 2018, co-hosted by DESY, the site of FLASH, and the European XFEL facility. The workshop has been organized under the auspices of the FELs of Europe consortium and has seen the participation of almost 100 scientists and engineers from all over the world (see Fig. 1).


Group photo from the PhotonDiag2018 workshop.

The participants had the chance to attend 40 technical talks, including 7 invited presentations, and 28 posters. The oral presentations spanned from the status and update of the existing (in operation or in advanced state of construction) FEL facilities, to some specific scientific applications of the FEL radiation. But, of course, the central topics covered during the workshop were related to advances in X-ray optics and diagnostics. Among the various novel diagnostic concepts presented, the wavefront sensors played a central role in the workshop, as they became central to the operation of most advanced facilities worldwide. Similarly to the workshop presentations, the 17 articles that are part of these proceedings are describing innovative X-ray optics and novel or improved diagnostics. This is the first virtual issue published in the *Journal of Synchrotron Radiation* and is intended to give the largest possible access to the researchers and engineers around the world to one of the most dynamically evolving topics in the X-ray science world, *e.g.* the development of better, ideally non-invasive and shot to shot, photon diagnostics.

This virtual proceeding (https://journals.iucr.org/special_issues/2020/photondiag2018/index.html) starts with the articles focused on diagnostics to study the spectral distribution, the wavefront, the intensity, the profile, the polarization and the temporal distribution. The combined use of photon diagnostics and electron diagnostics to study machine performance follows after the initial section. The third part deals with more conventional X-ray optics, from metrology over adaptive focusing mirrors to crystal monochromators. The proceedings close with one crucial component to most experiments and diagnostics, *e.g.* the X-ray detectors.

We hope these high-level articles will seed in you, the reader, new ideas to further advance the demanding field of optics and diagnostics for diffraction-limited sources and inspire you to attend future events of this workshop series and be part of this community.

[1] https://photondiag2010.eurofel.eu.
[2] http://www.elettra.trieste.it/events/2015/PhotonDiag/Main.HomePage.html.
[3] https://portal.slac.stanford.edu/sites/conf_public/photondiag2017.

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