

MCP-BASED PHOTON DETECTOR WITH EXTENDED WAVELENGTH RANGE FOR FLASH

L. Bittner, J. Feldhaus, U. Hahn, M. Hesse, U. Jastrow, V. Kocharyan, P. Radcliffe, E.L. Saldin, E.A. Schneidmiller, K. Tiedtke, B. Timmann, R. Treusch, N. von Bargaen, M.V. Yurkov
Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

O.I. Brovko, D. Kharlamov, V.I. Lokhmatov, E.A. Matyushevskiy, A.V. Shabunov, E.M. Syresin
Joint Institute for Nuclear Research (JINR), Dubna, Moscow Region, Russia

Abstract

Experimental experience gained at the extreme ultraviolet SASE FEL FLASH (DESY, Hamburg) has shown that successful operation of the facility strongly depends on the quality of the radiation detectors. Here key issues are: wide wavelength range (6 to 100 nm for FLASH), wide dynamic range (from the level of spontaneous emission to the saturation level), and high relative accuracy of measurements which is crucial for detection of a signature of amplification and characterization of statistical properties of the radiation. In this report we describe MCP-based radiation detector for FLASH which meets these requirements. Key element of the detector is wide dynamic range micro-channel plate (MCP) which detects scattered radiation from a target. With four different targets and MCPs in combination with optical attenuators present detector covers operating wavelength range from 6 to 100 nm, and dynamic range of the radiation intensities, from the level of spontaneous emission up to the saturation level of SASE FEL.

INTRODUCTION

The free electron laser FLASH is in operation at DESY since the year 2000 [1–5]. Several upgrades of the facility have been performed, and after an upgrade of 2007 FLASH will cover a wavelength range from 6 to 100 nm. Instrumentation for photon beam characterization has been developed as well [6–11]. An important piece of the photon diagnostics are detectors for measurements of the pulse energy. Originally FLASH has been equipped with PtSi-photodiodes and thermopiles based on YBCO High-Tc-superconductors (HTSCs) [6, 7]. These detectors helped to fix the first signature of light amplification at FLASH [1], but it has been realized soon that they have rather limited possibilities. The first one refers to limited dynamic range, and the other one relates to the physics of interaction of powerful, ultrashort VUV radiation pulses with the detector. In fact, nonlinearities and saturation effects started to occur in PtSi-photodiodes much earlier with respect to calibrations performed with conventional lasers. To solve the problem of limited dynamic range and saturation effects we launched development of MCP-based radiation detector [8], and pretty soon succeeded to tune FLASH to saturation in 2001 [2,3]. An important feature of MCP-detector is high relative accuracy of intensity measurements. This is crucial for detecting the first signature of light amplifi-

cation and further fine tuning of the machine parameters for increasing the gain. MCP detector is used for measurement of statistical properties of the radiation allowing to determine the pulse length and mode contents of the radiation [12]. In 2004 the energy of FLASH accelerator has been increased to 700 MeV, and a new MCP detector optimized for wavelength down to 10 nm has been installed, and became the primary tool for searching amplification, tuning the gain, and for statistical measurements [4, 5, 9].

In this paper we describe 3rd generation MCP detector at FLASH optimized for the measurement of SASE radiation with the wavelength down to 6 nm.

CURRENT EXPERIENCE WITH MCP-BASED DETECTOR AT FLASH

Photon detectors at FLASH are installed in a beamline downstream the undulator. The most critical step of tuning lasing process is to find the signature of light amplification. The problem relates to a strong background of incoherent radiation produced by the whole bunch (charge 0.5-1 nC)

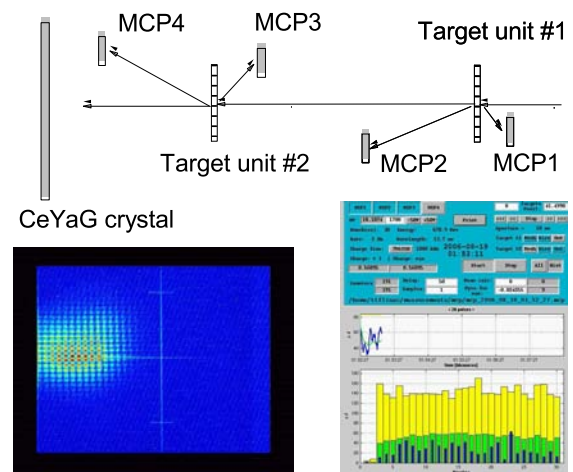


Figure 1: Top: layout of MCP-detector operated at FLASH in 2004-2007 [9]. Detector consists of two identical units for detection of radiation at fixed angles. The targets are semi-transparent gold mesh and gold wire. On-line tuning with this detector allows to have simultaneously quantitative data and visual observation of the photon beam on CeYAG crystal.

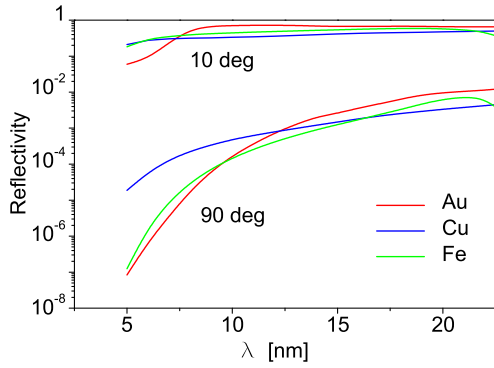


Figure 2: Reflectivities of Au, Cu and Fe versus wavelength for angles of 10 and 90 degrees. Surface roughness is 1 nm [13].

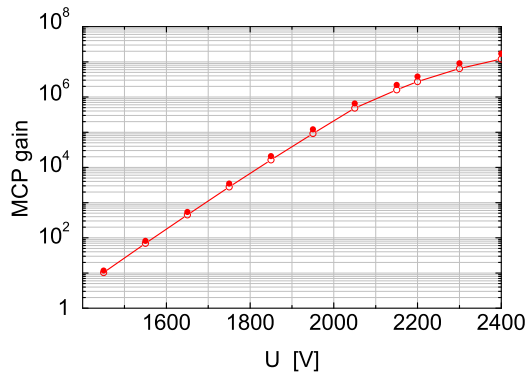


Figure 3: MCP gain versus applied voltage.

passing through the whole undulator length (27 m). In the present experimental conditions, at the energy of electrons of 700 MeV and bunch charge of 0.7 nC the pulse energy of the spontaneous emission is about 40 nJ within the 10 mm aperture of the detector located 18.5 m downstream of the undulator. Thus, it becomes crucial to have high-precision photon detectors permitting the detection of small increases in the radiation intensity. For this purpose a radiation detector equipped with a microchannel plate (MCP) is used [9]. Schematic layout of the detector is shown in Fig. 1. It consists of two identical units, each of them contains removable targets (gold wire of 250 μm diameter and gold mesh with wire of 60 μm diameter, open area 65%) and two MCPs detecting photons at large and small reflection angles. Figure 2 shows reflectivity of the gold for large and small reflection angles. Geometrical positions of MCPs have been chosen such that acceptances of photons (given by convolution of the reflectivity with geometrical factors: reflecting area and angular acceptance) differ by a factor about 300, but overlap at some intermediate light intensity. MCPs detecting backward scattered radiation are

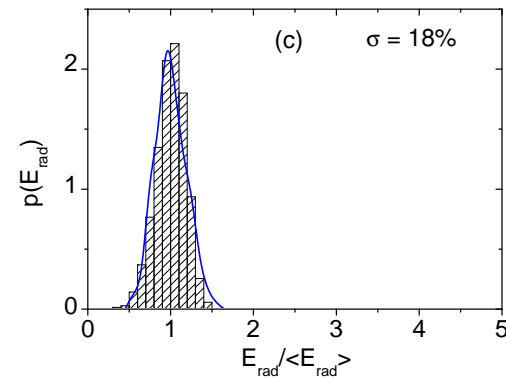
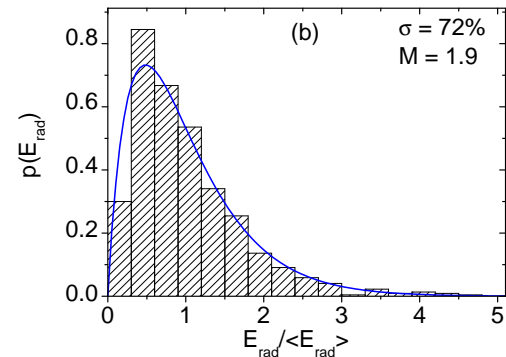
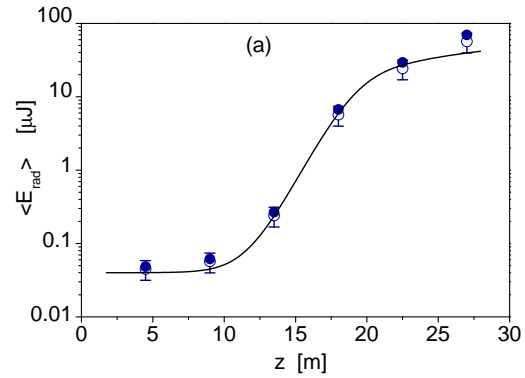


Figure 4: Measured average energy in the radiation pulse versus undulator length (up) showing exponential growth and saturation [5]. Center and lowest panels, probability distributions for the energy in the radiation pulses. Center plot: end of the regime of exponential growth where the average pulse energy is equal to 1 μJ . Lowest plot: saturation regime where the average pulse energy is equal to 40 μJ . Radiation wavelength is 13.7 nm. Solid line on the center plot represents a gamma distribution with the parameter $M = 1.9$. The solid line on the right plot represents simulations with the code FAST [14].

placed very close to the target and accept more photons despite less reflection coefficient. Inspecting the amplification curve of MCP (see Fig. 3) one can wonder why we complicated setup with two different MCPs: one MCP has

very large dynamic range of six orders of magnitude. The choice of such a geometry has been mainly dictated by the following reasons. In the real experimental conditions there is always gamma background originated from the accelerator beamline. In the case of FLASH this background becomes to be significant when high voltage applied to MCP exceeds 1900 V. When light intensity is high, applied voltage needs to be reduced, and below 1400 V space charge effects in MCP channels start to play significant role. Thus, practical operating range of the MCP gain is about three orders of magnitude only, less than the dynamic range of SASE intensity.

The electronics of the MCP-detector itself has low noise, about 1 mV at a level of signal of 100 mV (1% relative measurement accuracy). Another source of disturbances of measurements were fluctuations of the bunch charge. To exclude the influence of bunch charge fluctuations we perform on-line normalization of the radiation energy to the bunch charge. This technique gave us the possibility to detect reliably SASE gain at a 2% level above spontaneous emission. Once amplification is detected, output energy can be easily increased to the level of about ten μJ , the onset of the saturation regime. This occurs due to the exponential dependence of the output signal on a change in any important parameter of the electron beam. Tuning of the radiation energy in the saturation regime above 10 μJ is a delicate procedure, and requires perfect alignment of the orbit in the undulator (on a scale of ten micrometers), and the rf phases of the gun and the first three accelerating modules with relative accuracy of about 0.1 degree.

Absolute calibration of MCP has been performed with spontaneous emission at one operating boundary (nanjoule range of pulse energies), and with gas monitor detector [11] at another operating boundary (from a few to 70 microjoules pulse energies). During experimental run of 2004-2007 years MCP detector demonstrated excellent performance and served as the main tool for SASE search, tuning, intensity characterization and statistical measurements in the wavelength range from 45 to 13 nm (see Fig. 4 from [5]).

We should note that the target of MCP detector (mesh or wire) always produces diffraction pattern resulting in an inhomogeneous intensity distribution at the sample position. Thus, MCP-detector can not be used for online monitoring of the intensity while operating with specific user experiments requiring undisturbed radiation pulse. Gas detector is used in this case [11].

MCP-DETECTOR WITH EXTENDED WAVELENGTH RANGE (MCP07)

For the planned upgrade of the FLASH for operation at 6 nm we also designed and manufactured a new MCP detector. The reason for a new installation is obvious from analysis of reflectivity curve versus the wavelength (see Fig.2). While gold target is perfect for use in the wavelength range above 10 nm, its reflectivity falls dramatically for shorter FEL Technology I

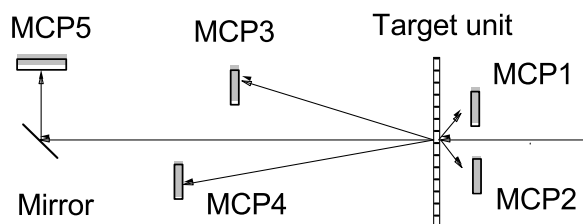


Figure 5: Layout of MCP detector with extended wavelength range installed at FLASH in 2007 (MCP07). Detection of backward reflected radiation is performed with stationary mounted MCP1 and MCP2. MCP3 and MCP4 are movable. When positioned off-axis they measure small angle reflected radiation. Measurements of direct photon beam is also possible when positioning MCPs on axis. MCP5 detects radiation reflected by Fe mirror. Target unit contains four grids of different materials (Au, Cu, Fe), and light attenuator.

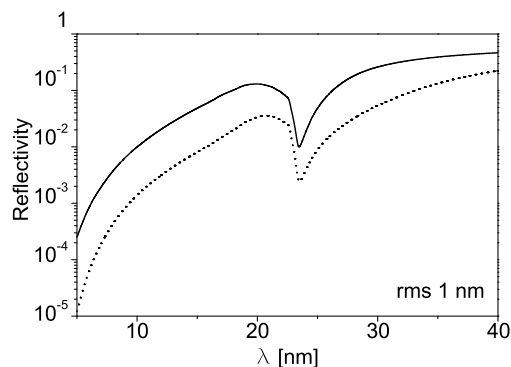


Figure 6: Reflectivities of Fe versus wavelength for angles of 30 and 45 degrees. Surface roughness is 1 nm [13].

wavelengths, and different targets and geometry of the detector should be used. General layout of the new detector (MCP07) is shown in Fig. 5. We conserved small/large angle reflection geometry of MCPs which demonstrated to be reliable solution for detection of the radiation above 10 nm.

Keeping gold mesh, we added three more targets: two iron meshes (88% and 79% open area), and one copper mesh (60% open area). This will help to operate the detector in some range below 10 nm. For tuning SASE at very short wavelengths we assume to use movable MCPs directly facing photon beam. Reduction of the light intensity (if required) will be provided with mechanical attenuator of light (perforated Ni foil located in the target unit, 2% open area). To have full control on light intensity in the wide range we installed side MCP which detects radiation reflected by iron mirror. Mirror serves for two purposes. The first one is to deflect the photon beam off-axis which allows to place MCP in better background conditions. The second function of the mirror is calibrated attenuation of the light (see Fig. 6). With two fixed angles of the mirror (30 and 45 degrees) and with mechanical attenuator we can change the light intensity on MCP in the range of several orders of magnitude. This will allow us to overlap all the range of radiation intensities, from the level of spontaneous emission to the saturation level.

REFERENCES

- [1] J. Andruszkow et al., Phys. Rev. Lett. **85**(2000)3825.
- [2] V. Ayvazyan et al., Phys. Rev. Lett. **88**(2002)104802.
- [3] V. Ayvazyan et al., Eur. Phys. J. D **20**(2002)149.
- [4] V. Ayvazyan et al., Eur. Phys. J. D **37**(2006)297.
- [5] W. Ackermann et al., Nature Photonics, 1 (2007)336.
- [6] R. Treusch, HASYLAB Annual Report, DESY, Hamburg, 2005, p.159-164 (see also http://www-hasyllab.desy.de/science/annual_reports/2005_report/index.html).
- [7] K. Tiedtke et al., AIP Conf. Proc. **705** (2004)588.
- [8] B. Faatz et al., Nucl. Instr. and Meth. A **483**(2002)412.
- [9] A. Bytchkov et al., Nucl. Instrum. and Methods A **528**(2004)254.
- [10] M. Richter et al., Verfahren und Monitor-detektor zur Bestimmung der Intensitat von gepulster VUV- oder EUV-Strahlung sowie Verwendung eines derartigen Monitor-detektors (Deutsches Patent- und Markenamt, No. 102 44 303.3, Munchen)(2002).
- [11] M. Richter et al., Appl. Phys. Lett. **83** (2003)2970.
- [12] V. Ayvazyan et al., Nucl. Instrum. and Methods **A507**(2003)368.
- [13] Data taken from LBL database
http://henke.lbl.gov/optical_constants
- [14] E.L. Saldin, E.A. Schneidmiller, and M.V. Yurkov, Nucl. Instrum. and Methods **A 429**(1999)233.