

# MCP – based Detectors, Calibration, Acceptance Tests, and First Photon Radiation Measurements

Alexander GREBENTSOV<sup>1\*</sup>, Evgeny SYRESIN<sup>1</sup>, Oleg BROVKO<sup>1</sup>, Mikhail YURKOV<sup>2</sup>,  
Wolfgang FREUND<sup>3</sup>, Jan GRÜNERT<sup>3</sup>

<sup>1</sup>Joint Institute for Nuclear Research (JINR), Joliot – Curie Str. 6, Dubna, Moscow Region, 141980,  
Russian Federation

<sup>2</sup>Deutsches Elektronen – Synchrotron (DESY), Notkestraße 85, Hamburg, 22603, Germany

<sup>3</sup>European XFEL, Holzkoppel 4, Schenefeld, 22869, Germany

\*Correspondence email: [grebentsov@jinr.ru](mailto:grebentsov@jinr.ru)

(Received March 4, 2019)

**Abstract:** Detectors based on micro channel plates (MCP) are used to detect the radiation of free electron lasers. Three MCP detectors were developed by JINR for the European XFEL (SASE1, SASE2, and SASE3 beamlines). These detectors were designed to operate in a wide dynamic range from the level of spontaneous emission to the SASE (Self-Amplified Spontaneous Emission) saturation level (between a few nJ and up to 25 mJ), and in a wide wavelength range from 0.05 nm to 0.4 nm for SASE1 and SASE2, and from 0.4 nm to 4.43 nm for SASE3. The photon pulse energies are measured by an MCP with an anode and with a photodiode. The photon beam image is observed by an MCP imager with a phosphor screen anode.

**KEYWORDS:** XFEL physics; photon beam diagnostics; micro channel plates detectors.

## 1. Introduction

The radiation detectors based on micro channel plates (MCP) were installed at the European XFEL [1]. An important task of the photon beam diagnostics at the EuXFEL is providing reliable tools for measurements aiming at the search for and fine-tuning of the FEL creating SASE process (Self-Amplified Spontaneous Emission). The problem of finding SASE amplification is crucial for the XFEL because of a large synchrotron radiation background. The detectors operate in a wide dynamic range from the level of spontaneous emission to the saturation level, and in a wide wavelength range. An essential feature of the detectors is high relative accuracy of measurements (below 1%), which is crucial for detection of a signature of amplification and characterization of statistical properties of the radiation. The photon pulse energies are measured with traditional MCPs with anodes and with a photodiode. The photon beam image is measured by an MCP imager with a phosphor screen anode. The visualization of a single bunch or average image over the full train will be performed [2].

Three different tasks can be performed with the EuXFEL MCP – based photon detectors:

- 1) study of the initial stage of the SASE regime;
- 2) measurement of the photon pulse energy;
- 3) measurement of the photon beam image.

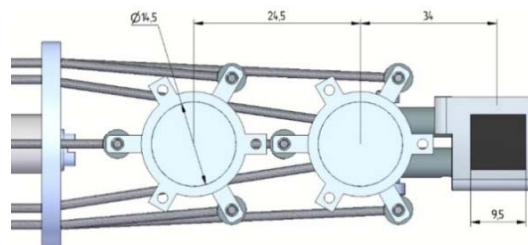
## 2. Construction of the detectors

MCP detectors are installed downstream of the horizontal offset mirrors. Those are used for two purposes: firstly, during early commissioning they cut off high harmonics of spontaneous radiation and improve the ratio of FEL/spontaneous intensity; secondly, they can be used as additional attenuators complementing the beamline attenuators.

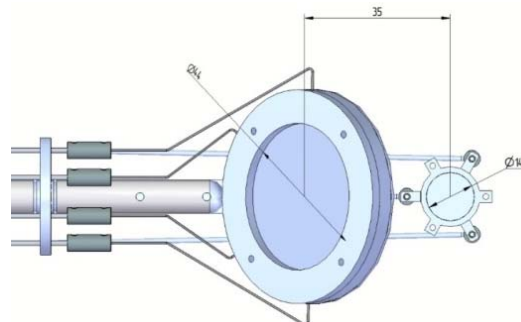
The radiation detector for SASE1 and SASE2 consists of two ports. The first port houses one silicon photodiode (Hamamatsu S3590) and two units of the MCP detector equipped with an anode for monitoring pulse energy (Hamamatsu F4655), as shown in Fig. 1. The second port houses two MCPs: F4655 for measurement of the pulse energies, and the beam observation system (BOS) MCP (model BOS-40-IDA-CH/P-47) with a phosphor screen, as shown in Fig. 2.

The MCP detector for SASE3 is constructed similarly, but additionally features a port with an insertable semi-transparent mesh and wire targets to produce scattered FEL radiation. The MCP detector for SASE3 is shown in the Fig. 3.

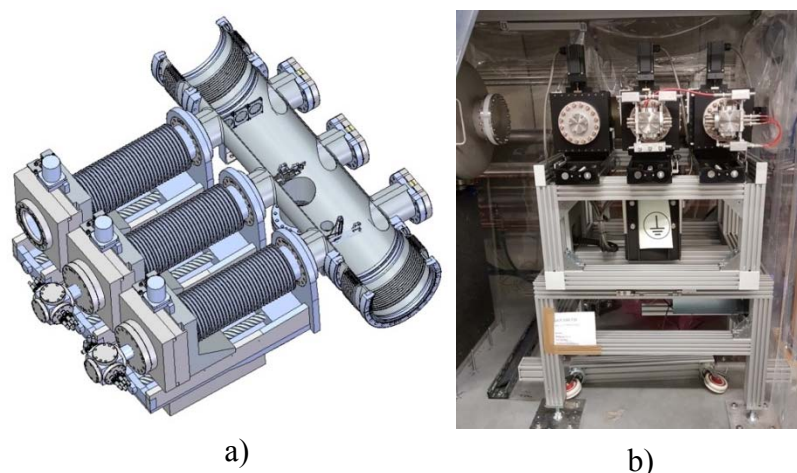
The 3D vacuum manipulator displaces these MCPs in the horizontal direction in a range of 200 mm. The range of vertical displacement is  $\pm 15$  mm relative to the beam axis.



**Fig.1** Scheme of the first manipulator (SASE1) with two MCP detectors (Hamamatsu F4655) and one photodiode (Hamamatsu S3590).



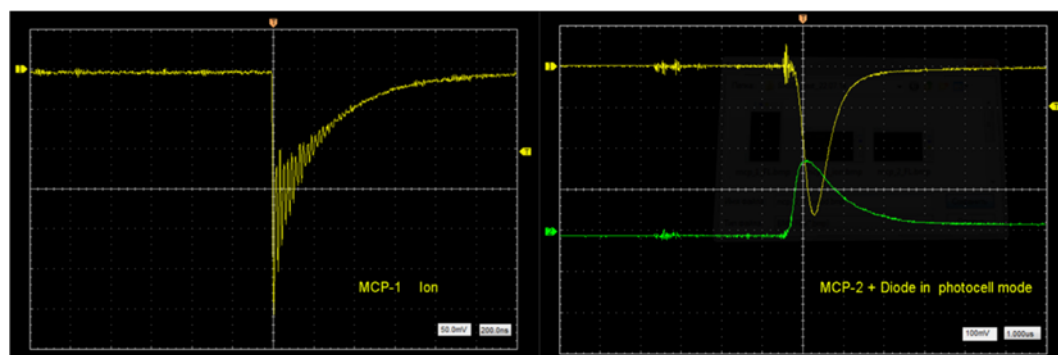
**Fig.2** Scheme of the second manipulator (SASE1) with an MCP detector (Hamamatsu F4655) and an Imager based on the MCP detector with a phosphor screen (Beam Imaging Solutions BOS-40)



**Fig. 3** a) Sketch of SASE3 MCP detector, b) SASE3 MCP detector in tunnel XTD10

### 3. Tests of MCP detectors in the lab

The operability of the small integrating MCP detectors was verified with signals from the direct and reflected radiation from a UV lamp (Fig.4) using the operation parameters of the power supplies, preamplifiers, and voltage dividers. The operability of the photodiode was checked using the photovoltaic effect without any bias voltage.



**Fig. 4** MCP1 and MCP2 detectors (SASE1) during the tests with a UV lamp and ions produced by the ion pump.

The in-vacuum particle contamination in the SASE3 MCP detector was checked under a clean room tent with a Trotec particle counter PC200. It was operated in the differential mode with a measurement time of 1 min.

The movement tests were done with a control crate, which included Beckhoff and Technosoft controllers for the X and Y axis motors and camera motor.

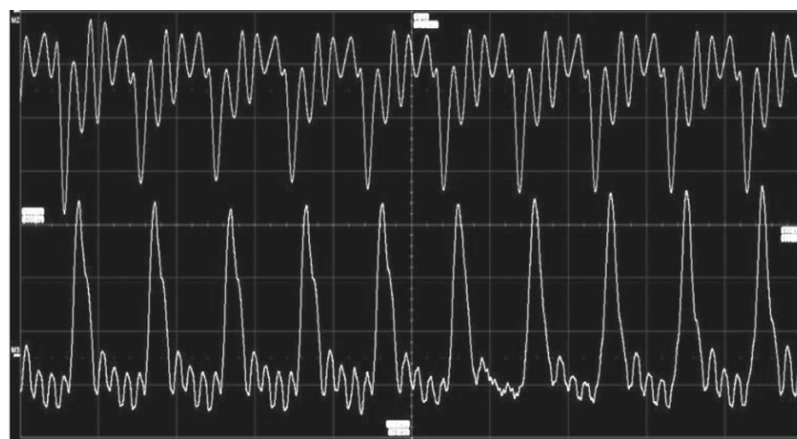
### 4. DORIS BW1 SR test validations of the EuXFEL MCP based detectors

The SR tests validation of the MCP – based detector applied for the EuXFEL undulator lines SASE1 and SASE2 were performed at the DORIS beamline BW1 at SR with a photon energy of 8.5 – 12.4 keV. The absolute measurements of a photon pulse energy of 0.03 nJ and higher for

hard X-ray radiation were performed with application of MCP and photodiode detectors. Pulse-to-pulse photon energy measurements with MCPs and a JINR silicon photo detector were done with 192 ns and 96 ns repetition intervals (Fig. 5). Secondly, the SR beam imaging measurement at X-ray irradiation was performed in test validation experiments [3].

The X-ray beam image was measured by the MCP detector at intensities higher than  $4 \times 10^7$  ph/s at a photon energy of 9.66 keV. The MCP beam observation system with a phosphor screen can be effectively used for search of the SASE mode starting from spontaneous emission.

The ratio of MCP2 signal to SR pulse energy corresponds to 0.11 – 0.16 V/nJ at a photon energy of 8.5 – 12.4 keV and MCP voltage 1.8 kV. MCP2 signal is linear to the X-ray beam intensity at an MCP voltage below 1.85 kV. The MCP gain for UV and X-ray radiation at a photon energy of 8.5 – 12.4 keV corresponds to 1.7 – 2.1 at an increase in MCP voltage from 1.8 kV to 1.85 kV.



**Fig.5** The signals from the MCP and the photodiode at a radiation pulse repetition time of 96 ns.

## 5. MCP acceptance tests

The acceptance tests for precise positioning and movements of the detectors inside the vacuum chamber were performed with a laser positioner for the SASE1 unit. The optical laser beam was directed onto the MCP BOS system at different angles and, correspondingly, in different positions. This procedure was fully analogous to recording XFEL radiation under variation of the incidence angle of the horizontal offset mirrors, which are located just upstream of the MCP – based detector [4]. At each laser irradiation angle the MCP BOS system was moved to the position, where the laser spot was observed in the center of the phosphor screen. The x and y coordinates of the center of the phosphor screen were measured. The information about these coordinates was stored in the control software system for later correct positioning of the MCP1-MCP3 pulse energy monitors relative to the x-ray beam. The simulated coordinates in the position of MCP1-MCP3 detectors were determined. The manipulator shifts one of the MCP pulse energy monitors to the required coordinate X1 and Y1. The procedure of searching XFEL irradiation was successfully tested with application of the laser positioner.

The SASE1, SASE2, SASE3 MCP detectors were installed in the EuXFEL tunnels after calibration and acceptance tests.

## 6. First experiments with the photon beam

The SASE1 and SASE3 MCP detectors were commissioned in the single and multi-bunch mode (Fig.6). The minimum pulse separation inside an X-ray pulse train of EuXFEL can be as short as 220ns. The temporal resolution of the MCP detectors was verified for this case of 4.5 MHz repetition rate by demonstrating clear pulse separation. The intensity in each pulse can be provided by fast digitizer electronics that operate at 125 MHz sampling. Absolute intensity values can be obtained through cross-calibration to gas-based online intensity monitors which can be operated simultaneously with the MCP – based detectors.

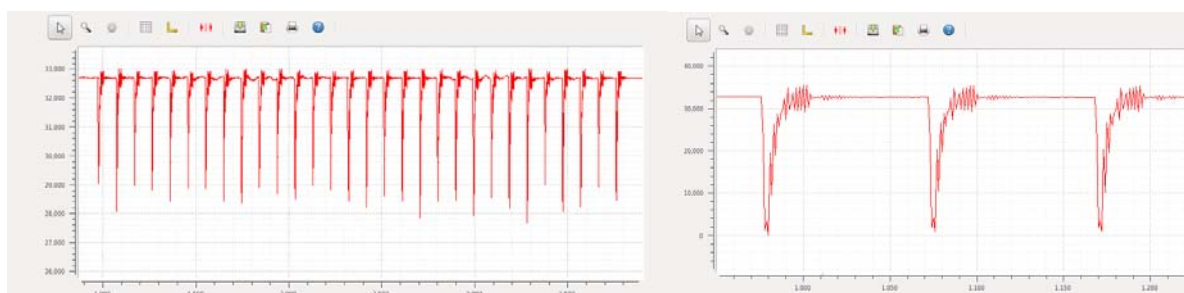


Fig.6 First experience of the SASE3 commissioning in multi-bunch mode: 30 bunches per train

## 7. Conclusion

The MCP detectors allowed studying the FEL radiation generation in a wide dynamic range from the spontaneous emission to the saturation regime. Three MCP detector systems operating in the X-ray range from 0.05 to 4.3 nm were constructed for the EuXFEL. The detectors could be effectively used in multi-bunch mode.

**Acknowledgements** All authors acknowledge for the outstanding contributions Support European XFEL groups: X-Ray Optics (XRO) led by Harald Sinn, Vacuum (VAC) led by Martin Dommach, advanced Electronics (AE) led by Patrick Gessler, Information Technology and Data Management (ITDM) led by Krzysztof Wrona, and Control and Analysis Software (CAS) led by Sandor Brockhauser.

## References

- [1] M. Altarelli et al., “XFEL Technical Design Report”, DESY 2006-097  
<https://bib-pubdb1.desy.de/record/77248/files/european-xfel-tdr.pdf>
- [2] E. Syresin, O.Brovko, M. Kapishin, Shabunov, A., Yurkov, M., Freund, W., Gruenert, J & Sinn, H.(2011). “Development of MCP Based Photon Detectors for the European XFEL”, Proceedings of the IPAC2011, San Sebastian, Spain, September 2011.
- [3] E. Syresin et al., “Synchrotron Radiation Test Validations of European XFEL MCP – based Detectors at DORIS Beamline BW1”, in Proc. 5th Int. Particle Accelerator Conf. (IPAC'14), Dresden, Germany, June 2014, pp. 2180-2182, doi:10.18429/JACoW-IPAC2014-WEPRO094.
- [4] E. Syresin, O.I. Brovko, W. Freund, A.Yu. Grebentsov, J. Grünert, and M.V. Yurkov, “MCP Based Detectors Installation in European XFEL”, in Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, paper THPAB132, pp. 4031-4033, ISBN: 978-3-95450-182-3, <https://doi.org/10.18429/JACoW-IPAC2017-THPAB132>.