

## MCP BASED DETECTORS OF EUROPEAN XFEL

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### Abstract

Radiation detectors based on microchannel plates (MCP) are used for measurements of the SASE process of the European XFEL. Detectors operate in a wide dynamic range from the level of spontaneous emission to the saturation level (between a few nJ and 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. Photon pulse energies are measured by the MCPs with an anode and by a photodiode. The MCP imager measures the photon beam image with a phosphor screen. Three MCP detectors are installed, one behind each SASE undulator (SASE1, SASE2, and SASE3). Calibration and first experiments with the MCP detectors are under discussion.

### MCP DETECTORS

An important task of the photon beam diagnostics at the European XFEL is providing reliable tools for measurements aimed at the search and fine-tuning of the FEL creating the SASE process (Self Amplified Spontaneous Emission). The problem of finding SASE amplification is crucial for the XFEL because of a large synchrotron radiation background. This requires a detector with a wide dynamic range, controllable tuning to the required wavelength range, and suppression of the unwanted radiation background. The JINR-XFEL collaboration manufactured MCP-based photon detectors as a primary tool for the search for and fine tuning of the SASE process. Three MCP devices [1,2] will be installed, one behind each SASE undulator of the European XFEL (SASE1, SASE2, and SASE3).

Three different tasks can be fulfilled with the XFEL MCP-based photon detectors [1,2]: study of the initial stage of the SASE regime, measurement of the photon pulse energy, and measurement of the photon beam image. The MCP detector will resolve each individual pulse at a repetition rate of 4.5 MHz. The following wavelength ranges are to be covered by three MCP stations: 0.05-0.4 nm for MCP1 and MCP2 and 0.4-4.43 nm for MCP3.

The MCP detectors for SASE1 and SASE2 are installed behind the deflecting mirrors [3-5]. The offset mirrors are used for two distinctive and separate purposes. Firstly, during early commissioning they cut off high harmonics of spontaneous radiation and improve the ratio of FEL/spontaneous intensity; secondly, they serve as additional attenuators of the radiation intensity. The diamond attenuator and the Ce:YAG screen are installed in front of the first carbon coated offset mirror. The attenuation ranges of the mirrors combined with the diamond plate attenuators are

about 103-104. The dynamic range of the MCP is 103-104.

The MCP detector for SASE1&SASE2 (Fig.1) consists of a silicon photodiode, three MCPs equipped with an anode as a pulse energy monitor and one MCP detector for imaging the photon beam. The first MCP detector port houses one silicon photodiode and two F4655 Hamamatsu MCPs 18 mm in diameter. The PM 100-250 3D vacuum manipulator displaces these MCPs in the horizontal direction within a range of 250 mm. The range of vertical displacement is  $\pm 2.5$  cm relative to the beam axis.

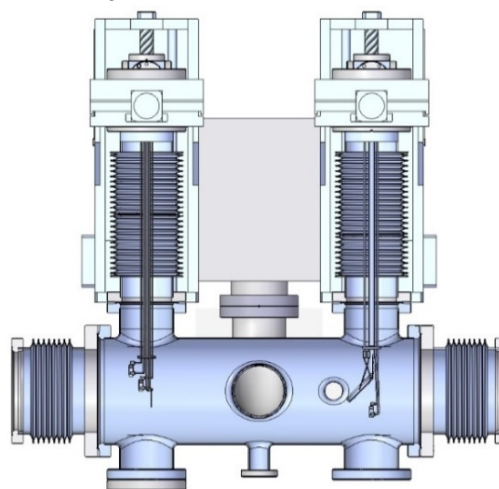


Figure 1: View of SASE1 MCP detector.

The second detector 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) 40 mm in diameter with a phosphor screen. The BOS MCP is set at an angle of 45° with respect to the photon beam and a viewport allows imaging onto a CCD.

The MCP detector for SASE3 will have an additional port with a movable semi-transparent mesh and wire targets to produce scattered FEL radiation similar to those used at FLASH [6-8].

To search for the SASE mode, the CCD camera (Basler avA1600-50gm) with a large field of view of about 90 mm in diameter (MCP diameter of 40 mm and vertical displacement of  $\pm 20$  mm) and a relatively small number of pixels per mm was installed in the second port of the MCP detector for recording the phosphor screen image.

## X-RAY CALIBRATION TESTS OF SASE1 MCP DETECTOR

Prior to their installation at EuXFEL, the MCP SASE1 detectors were calibrated using radiation with wavelengths lying in the ultraviolet and X-ray ranges. A lamp generating ultraviolet radiation was used for calibration in this wavelength range. The linear dependence of the MCP gain on the applied high voltage was indicated at high voltage variation from 1.5 to 2.1 kV. The gain is increased by four orders of magnitude. Note that the spatial charge effects play a significant role in MCP channels at voltages below 1.4 kV. This voltage value is a minimum one for the F4655 MCP.

The SASE1 MCP detector was calibrated in the X-ray wavelength range at the DORIS BW1 beamline before installation of this detector in the EuXFEL tunnel [9-10].

The absolute measurements of photon pulse energy of 0.03 nJ and higher for hard X-ray radiation were performed with the MCP and photodiode detectors.

The photon flux was in a range of  $2 \times 10^{11}$  ph/s to  $2 \times 10^8$  ph/s. The SR measurements were performed at photon energies of 8.5 to 12.4 keV. Vacuum pressure in the MCP-detector UHV chamber was  $5 \times 10^{-9}$  mbar.

The ratio of the MCP2 signal to the SR pulse energy corresponds to 0.11-0.16 V/nJ at the photon energy of 8.5-12.4 keV and MCP voltage of 1.8 kV.

The SR photon flux was measured by a silicon photodiode. The linear dependence of the photodiode signal in the pulsed mode was demonstrated.

Both the MCP and the silicon photodiode measured time structure of SR pulses at a frequency of about 10 MHz.

The X-ray beam image was measured by the MCP detector at the intensity 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 was effectively used for the search of the SR photon beam position.

However, at the SR tests the measured X-ray beam size at small slits of 0.2-0.4 mm was about 1.8 -2 mm caused due to a contrast resolution of the phosphor screen and image spot spreading. The MCP imager can be used to search for the SASE photon beam spot; however, it cannot be used for detailed measurements of the spot shape and substructure.

## FIRST EUXFEL EXPERIMENTS WITH PHOTON BEAM

The SASE1 MCP was installed in the EuXFEL tunnel in November 2015 after calibration and acceptance tests. The final tests of the SASE1 MCP detector were performed in the EuXFEL tunnel in January 2017. The SASE3 MCP was delivered to the EuXFEL tunnel at the end of 2016 after calibration and acceptance tests. The SASE 2 MCP detector (Fig.2) was assembled in the EuXFEL tunnel in 2018 [11].

The SASE1 and SASE3 MCP detectors were commissioned in the single and multibunch modes. The minimum pulse separation inside an X-ray pulse train of the EuXFEL can be as short as 220 ns. The temporal resolution of the

MCP detectors was verified for this case of the 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 the 125 MHz sampling.

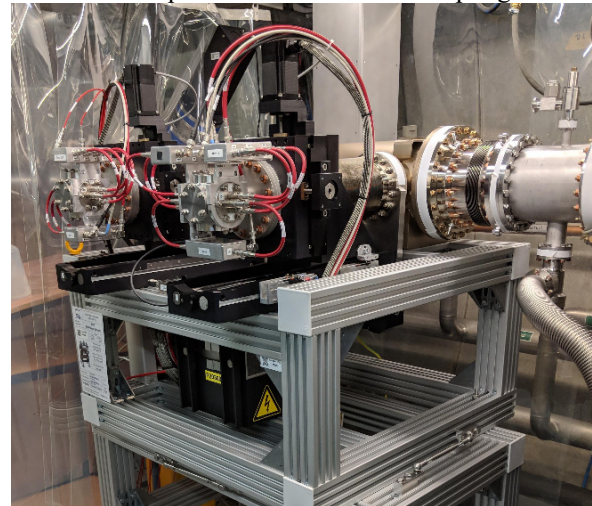


Figure 2: SASE2 MCP detector installed in the EuXFEL tunnel.

The first experience of the SASE3 commissioning in the multibunch mode is shown in Fig.3.

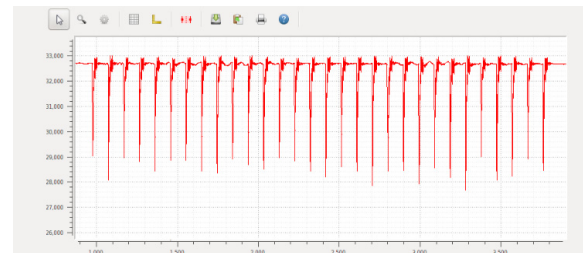


Figure 3: SASE3 MCP detector operation in the multibunch mode with 30 bunches per train.

Thirty bunches per train were formed in the multibunch regime at the minimal number of undulator segments (12) closed for lasing, low-intensity SASE (X-ray gas monitor shows 10 uJ in linear regime), SRA 2x2 mm, photon energy of 930 eV, and electron energy of 14 GeV. The MCP2 (SASE3) can detect radiation scattered from the offset mirrors and thus operates parasitically.

The peculiarity of the SASE XFEL MCP measurement is large synchrotron radiation background at the electron energy of 14 GeV. The MCP image of the SASE signal (spot of red round shape) and the image of background synchrotron radiation (spot of rectangular shape) are shown in Fig.4.

Absolute intensity values of SASE radiation can be obtained through the cross-calibration with X-ray Gas Monitors (XGM) [12], which can be operated simultaneously with the MCP-based detectors (Fig.5). There are six XGMs in the EuXFEL, which provide online beam position and intensity radiation monitoring. The XGM consists of four vacuum chambers placed on a common girder, and it can record the fast shot-to-shot beam position and intensity, as well as absolutely calibrated intensity.



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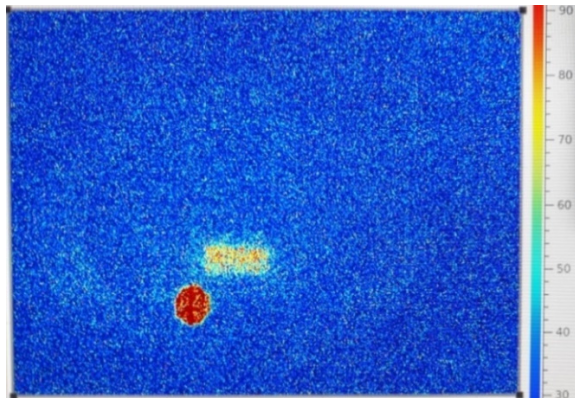


Figure 4: SASE3 MCP detector operation.

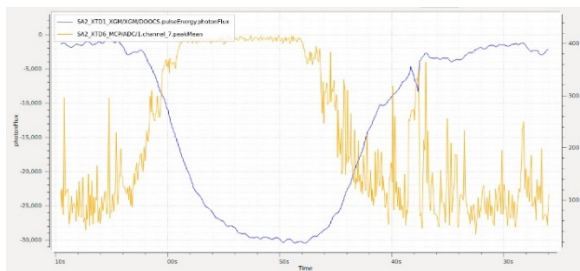


Figure 5: SASE3 MCP (yellow) and XGM signals (blue) at EuXFEL operation.

## CONCLUSION

Successful operation of FEL strongly depends on the quality of the radiation detectors. The EuXFEL MCP detectors operate in a wide dynamic range from a few nJ up to 25 mJ and in a wide wavelength range from 0.05 to 0.4 nm for SASE1 and SASE2 and from 0.4 to 4.43 nm for SASE3. The MCP detectors with these unique characteristics will be used as key instrumentation for tuning the EuXFEL accelerator and searching for SASE regimes.

During validation tests at the DORIS BW1 channel, the detector calibration was done in the X-ray range at the photon energies of 8.5 to 12.4 keV. The ratio of the MCP signal to the radiation energy in a micropulse is 0.16 V/nJ at a voltage of 1.8 kV and a photon energy of 9.66 keV.

In 2015-2018, the SASE1, SASE2, and SASE3 MCP detectors were installed in the EuXFEL tunnels. The first beam time structure was measured by the MCP the detectors. The peculiarity of the SASE XFEL MCP measurement is large synchrotron radiation background at the electron energy of 14 GeV. The first SASE radiation intensity measurements were done by the MCPs and XGMs.

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