

MCP detectors of the European XFEL

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The Radiation detectors based on micro channel plates (MCP) are planned for installation at the European XFEL. Main purpose of these detectors is searching a signature of lasing and further fine tuning of the FEL process. 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 5 nm for SASE3. 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. Photon pulse energies are measured with traditional MCP with anode, and photon beam image is measured by MCP imager with phosphor screen anode.

MCP detector for SASE1&SASE2 consists of photodiode and three MCPs equipped with the anode as a pulse energy monitor and one MCP detector for imaging the photon beam. The MCP detectors for SASE1&SASE2 were constructed and SR tests were performed. The SASE1 MCP detector was installed in XFEL tunnel in November 2015. MCP detector for SASE3 have an additional port with movable semitransparent mesh and wire targets for production of scattering FEL radiation similar to those used at FLASH. Acceptance tests of SASE2 and SASE3 MCP detector were performed and equipment is ready for installation in XFEL tunnel.

XFEL MCP PHOTON DETECTOR

An important task of photon beam diagnostics at the European FEL is reliable measurements for the search for and fine tuning of the FEL process.

The problem of finding SASE is crucial for the XFEL because of 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.

Three different tasks can be fulfilled with the XFEL MCP-based photon detectors:

study of the initial stage of the SASE regime;

measurement of the photon pulse energy;

measurement of the photon beam image.

The MCP will allow operation at the XFEL pulse repetition rate, thus resolving each individual radiation pulse.

The following first harmonic wavelength ranges are to be covered by three MCP stations:

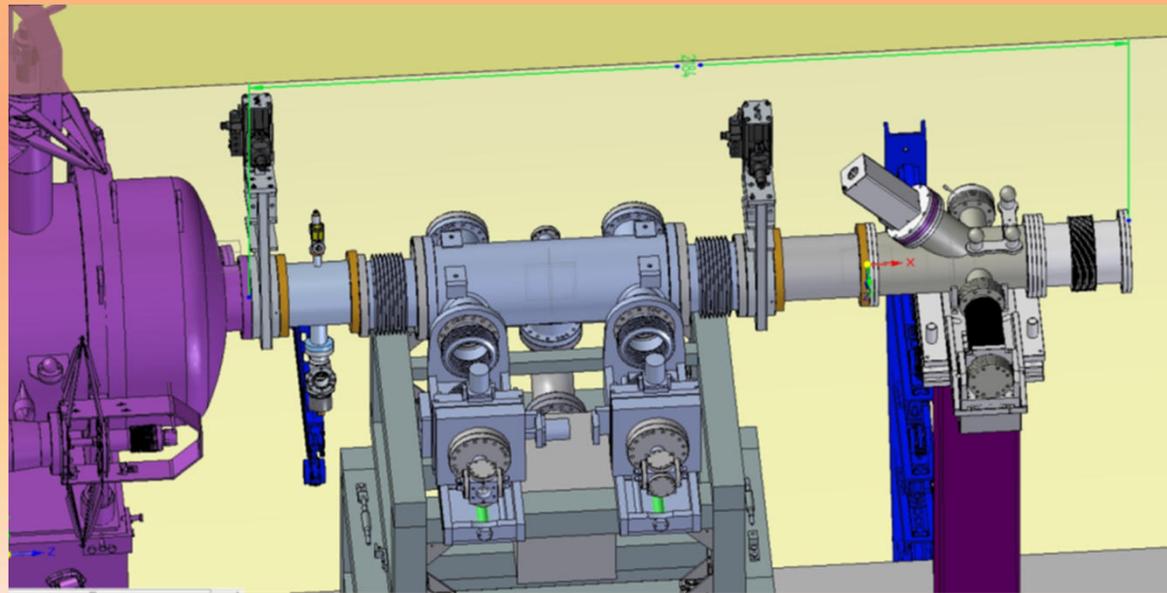
0.05-0.4 nm for MCP1 and MCP2,

0.4-4.43 nm for MCP3.

SASE1&SASE2 mirrors and attenuators applied for the MCP detectors

The SASE1&SASE2 systems associated with the MCP detectors consists of four main elements: the first XFEL C mirror 800 mm long with a variable incident angle of 1.1-3.6 mrad; the second XFEL C mirror placed at a distance of 10.4 m from the first one, which provides the large incident photon angles of 10-30 mrad; the diamond attenuator; the Ya screen installed in front of the first C mirror.

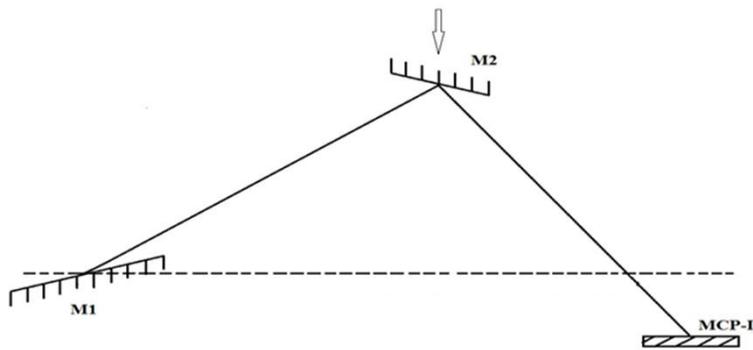
The C mirrors operate as an attenuator of the FEL radiation. The dynamic range of the C mirror attenuator and diamond plates is about 10^3 - 10^4 . The dynamic range of the MCP monitor is 10^3 - 10^4 . It detects XFEL radiation in the dynamic range of 10^7 .



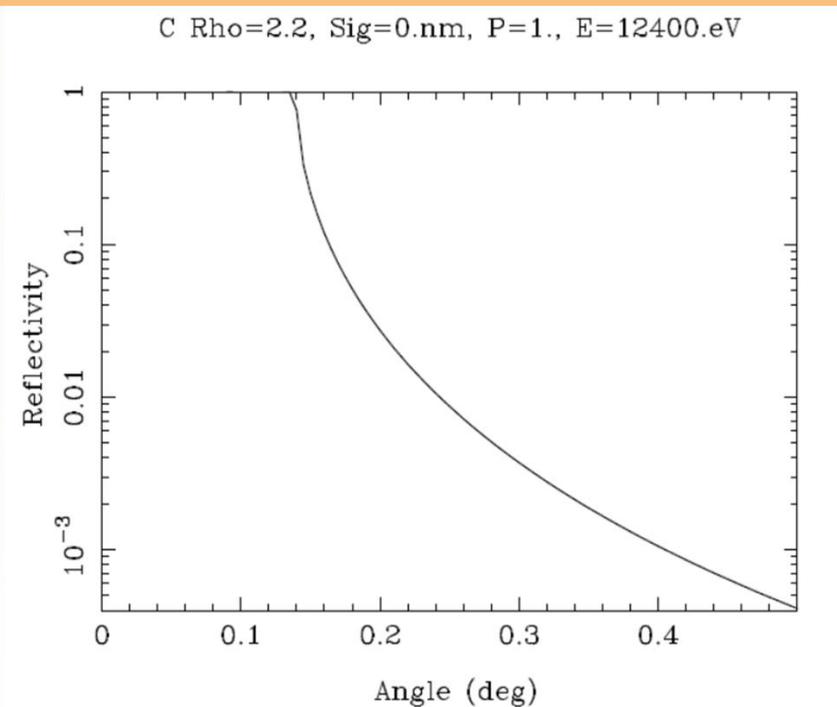
Sketch of installation of SASE-1 MCP detector in XFEL tunnel

Three MCP operation regimes

Finally, three MCP operation regimes are considered:
with both C mirrors removed at large horizontal acceptance to search for initial stages of SASE processes,
with only one C mirror installed to provide the attenuation factor $R=10^{-3} \cdot 10^{-2}$ and small horizontal acceptance,
with two C mirrors installed to produce the total attenuation factor $R=1-10^{-5}$.



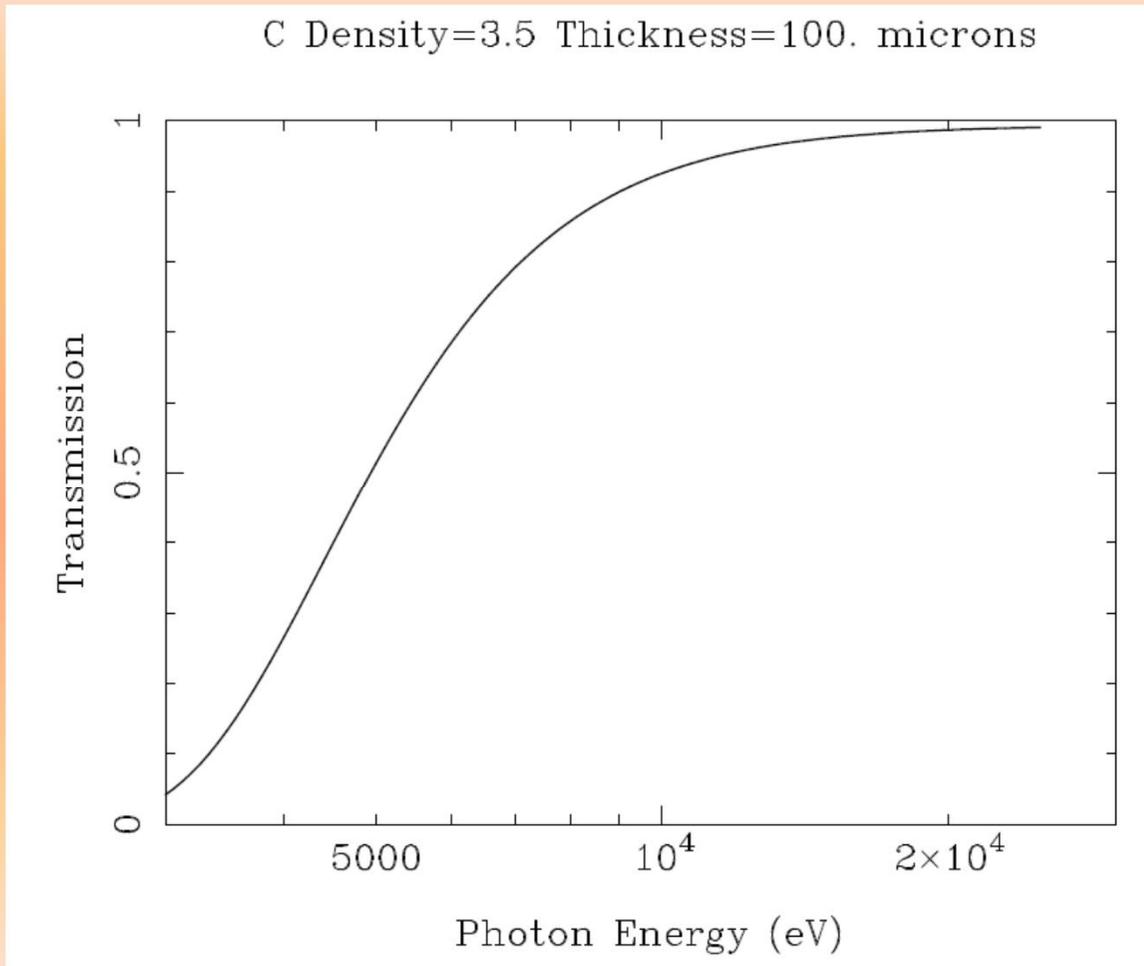
Sketch of SASE1 & SASE2 MCP and two reflection mirrors



Dependence of the C mirror reflectivity on the incident photon angle.

Diamond plate attenuation

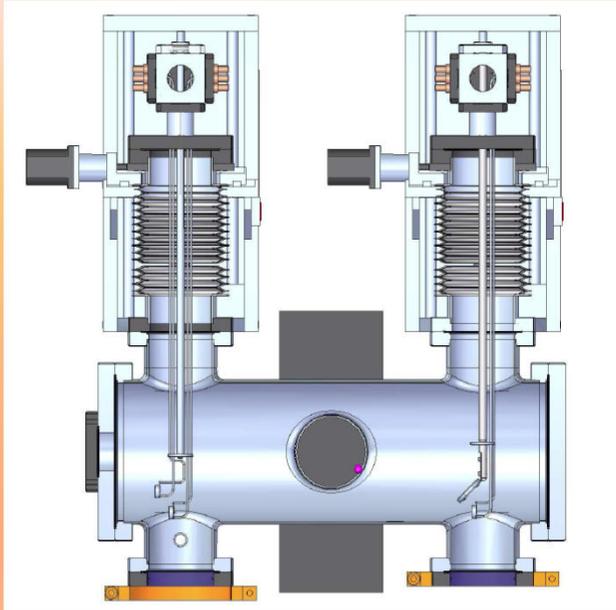
Diamond plates are used as the solid attenuator of FEL radiation. The attenuation coefficients at $\lambda=0.4$ nm are $T=0.1$ at $81 \mu\text{m}$, $T=10^{-2}$ at $162 \mu\text{m}$, and $T=10^{-3}$ at $243 \mu\text{m}$.



Dependence of the photon transmission through a diamond plate 0.1 mm thick on the photon energy.

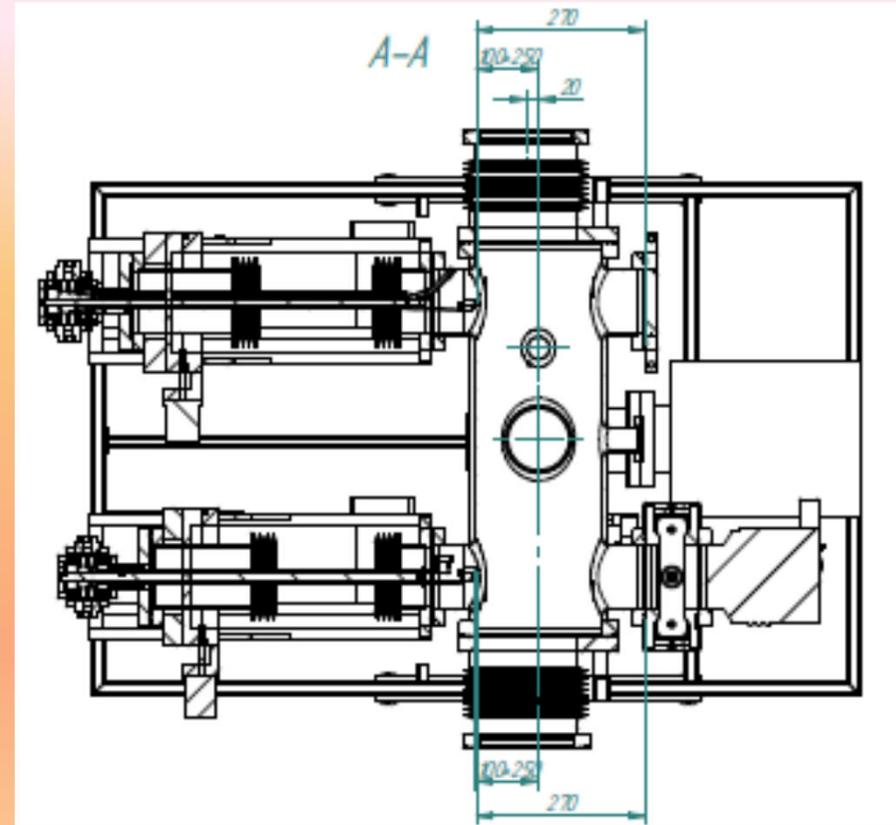
Design of of the SASE-1&SASE-2 MCP detector

An SASE1&SASE2 MCP detector consists of photodiode, three MCPs equipped with anode as a pulse energy monitor, photodiode and one MCP detector for imaging the photon beam.



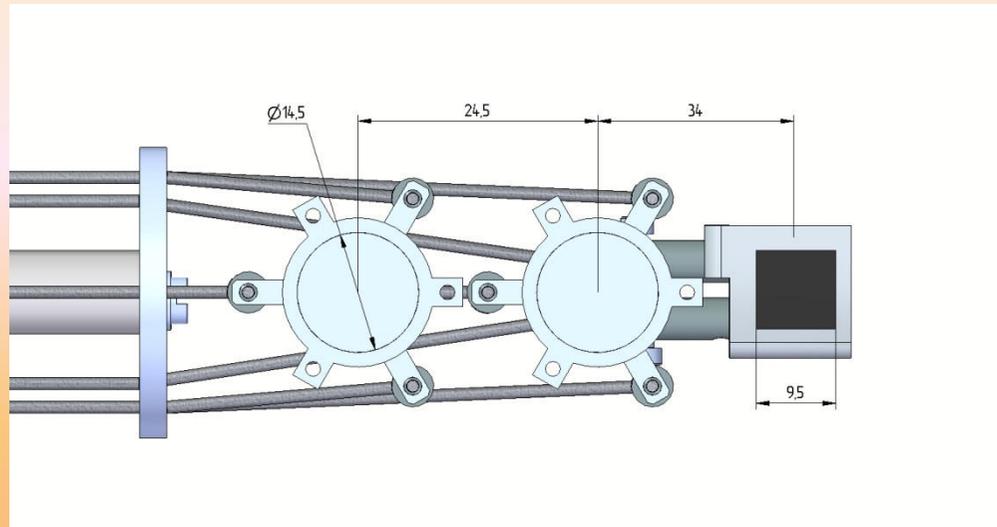
View of the SASE-1&SASE-2 MCP detector.

The MCP imager and three MCP pulse energy monitors are removed in horizontal direction, so it provides completely empty aperture of MCP vacuum chamber at diameter of 201 mm.

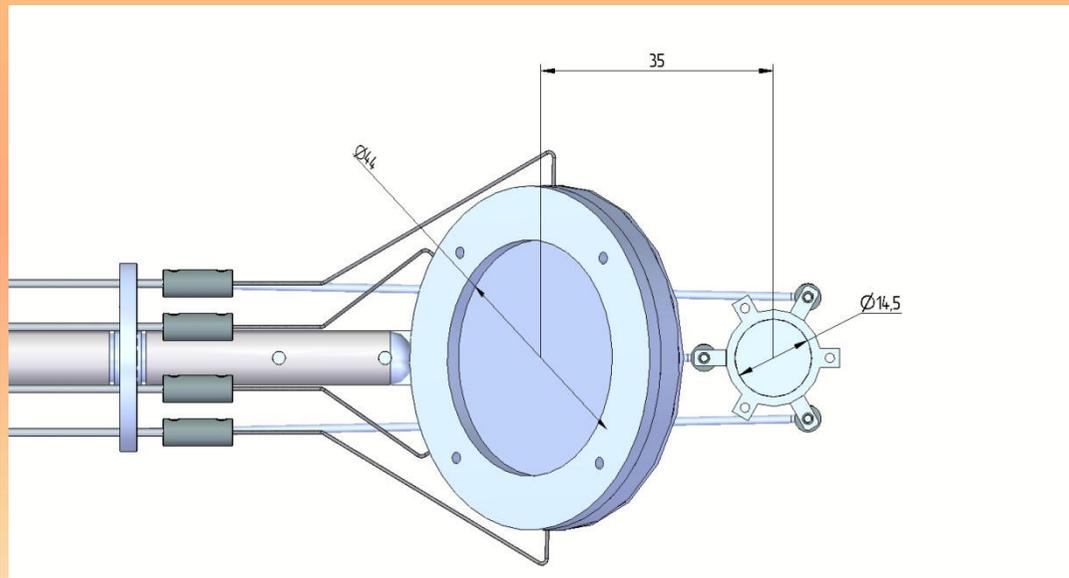


SASE-1&SASE-2 MCP detector with bellow sections for connection with mirror chamber and XFEL chamber.

Equipment of MCP detector



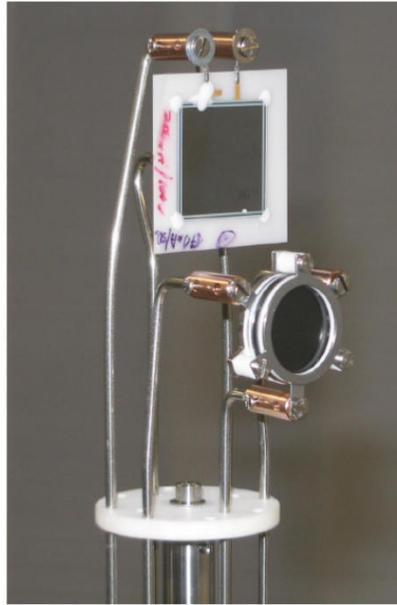
The first MCP detector port houses two F4655 Hamamatsu MCPs 14.5 mm in diameter and photodiode, which are used for measuring the pulse energy and used searching for the initial stage of the SASE regime.



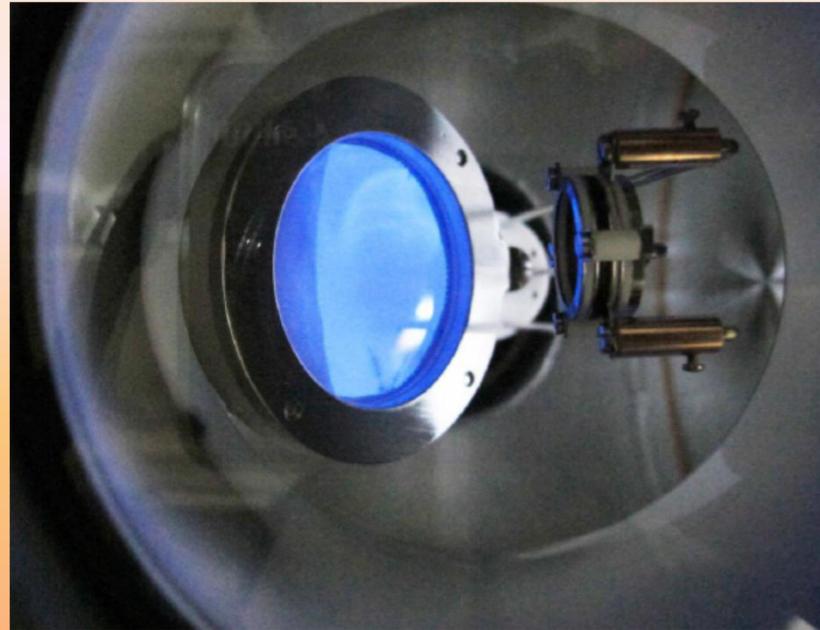
F4655 MCP and imaging MCP (model BOS-40-IDA-CH/P-47)

The special imaging MCP (model BOS-40-IDA-CH/P-47) 44 mm in diameter with a phosphorus screen and energy measurement (MCP F4655), installed in the second detector port inside the vacuum chamber. These MCPs are also displaced in the horizontal direction at a distance of 203 mm and in the vertical direction at a distance of ± 2.5 cm relative to photon beam axis. To provide imaging through the glass window in the CCD, the incident photon angle to MCP surface is about 45° .

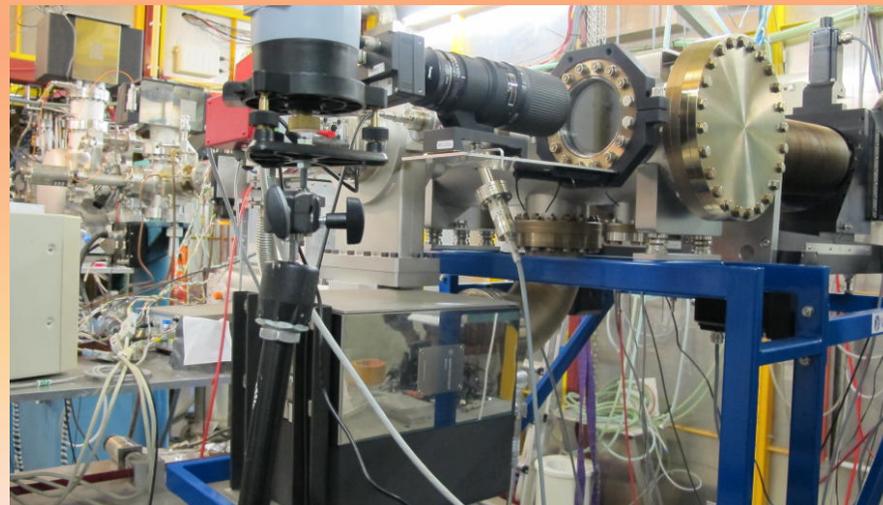
European XFEL MCP-based detector



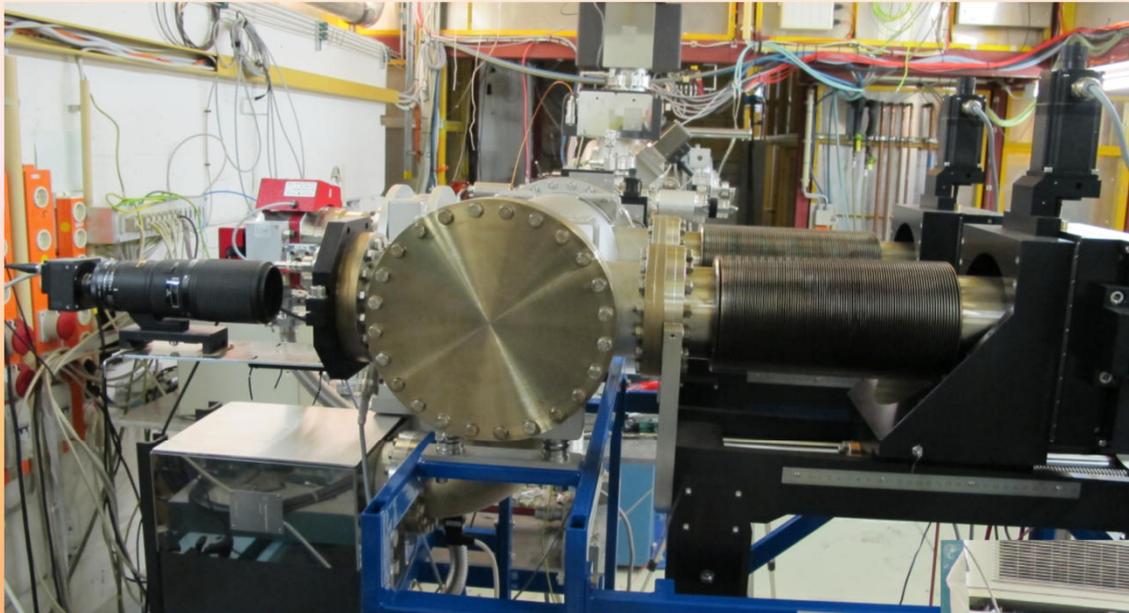
**F4655 Hamamatsu MCP2
and photodiode**



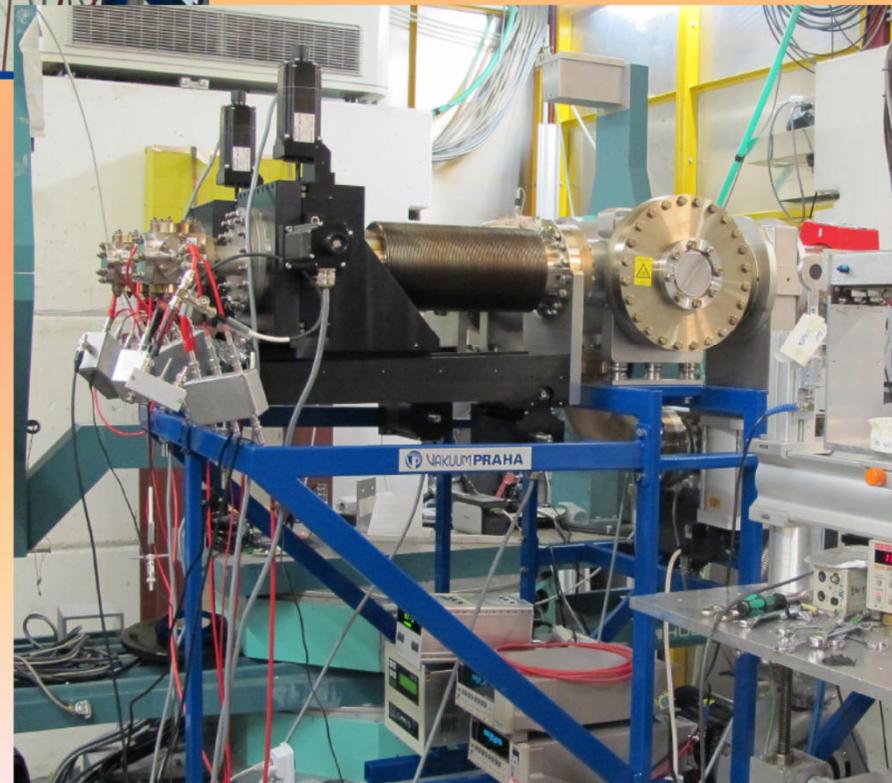
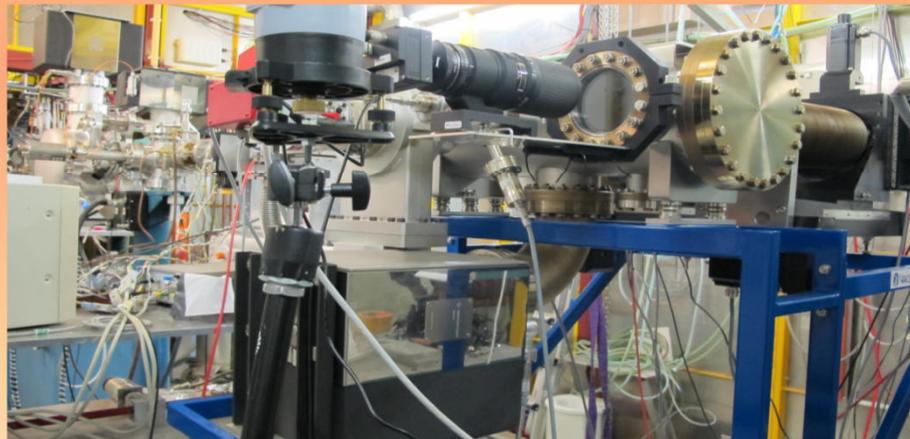
MCP BOS-40-IDA-CH/P-47



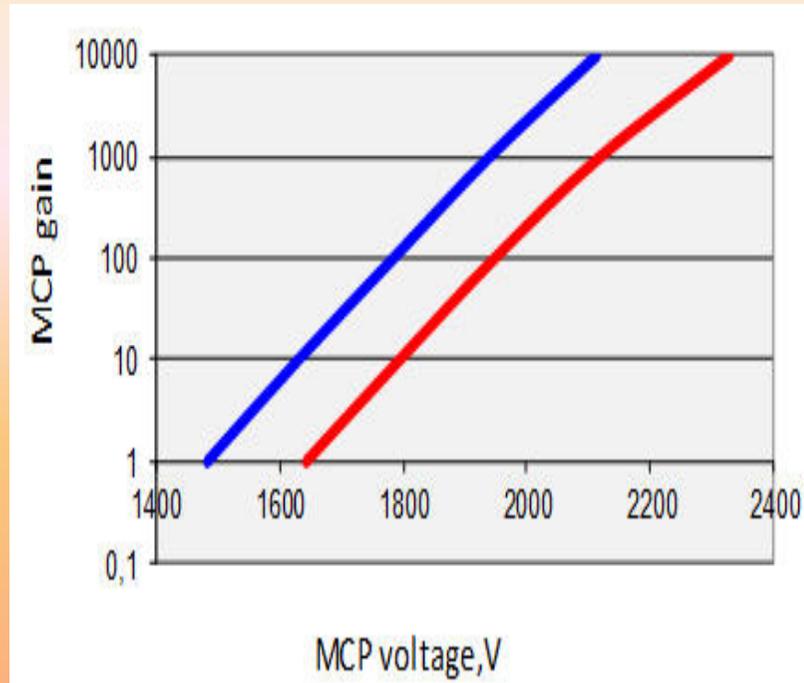
SASE1&SASE2 MCP Detector Construction and Tests



SASE1&SASE2 MCP



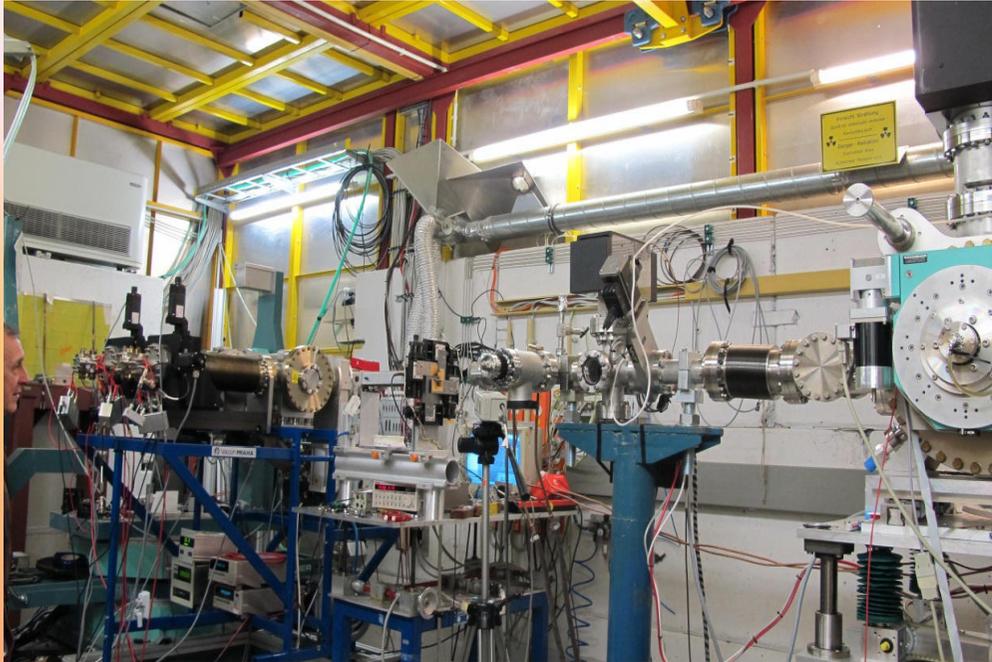
MCP UV test calibration



Dependence of MCP1 (blue line) and MCP 2 (red line) gains on MCP voltage.

The practical operating range of MCP gain is about 3 orders of magnitude that is less than the dynamic range of the SASE mode.

SR test validation of the European XFEL MCP-based detector performed at the DORIS beamline BW1



bunch repetition time was 192 ns and 96 ns,
the positron beam current was 140-100 mA,
the positron beam energy was 4.5 GeV.
the photon flux was in range of $2 \cdot 10^{11}$ to $2 \cdot 10^8$ ph/s,
photon energies of 8.5 to 12.4 keV,
variation of photon energy was done with the BW1 undulator gap.

Micro pulse radiation energy was 0.03 nJ
It was 50 times smaller than FLASH spontaneous emission level

The MCP measurements:

1. Calibration experiments at hard X-ray radiation

1.1 MCP gain versus MCP voltage at different photon energies

1.2 Measurements of MCP photon conversion efficiency

2. Absolute measurement of photon pulse energy

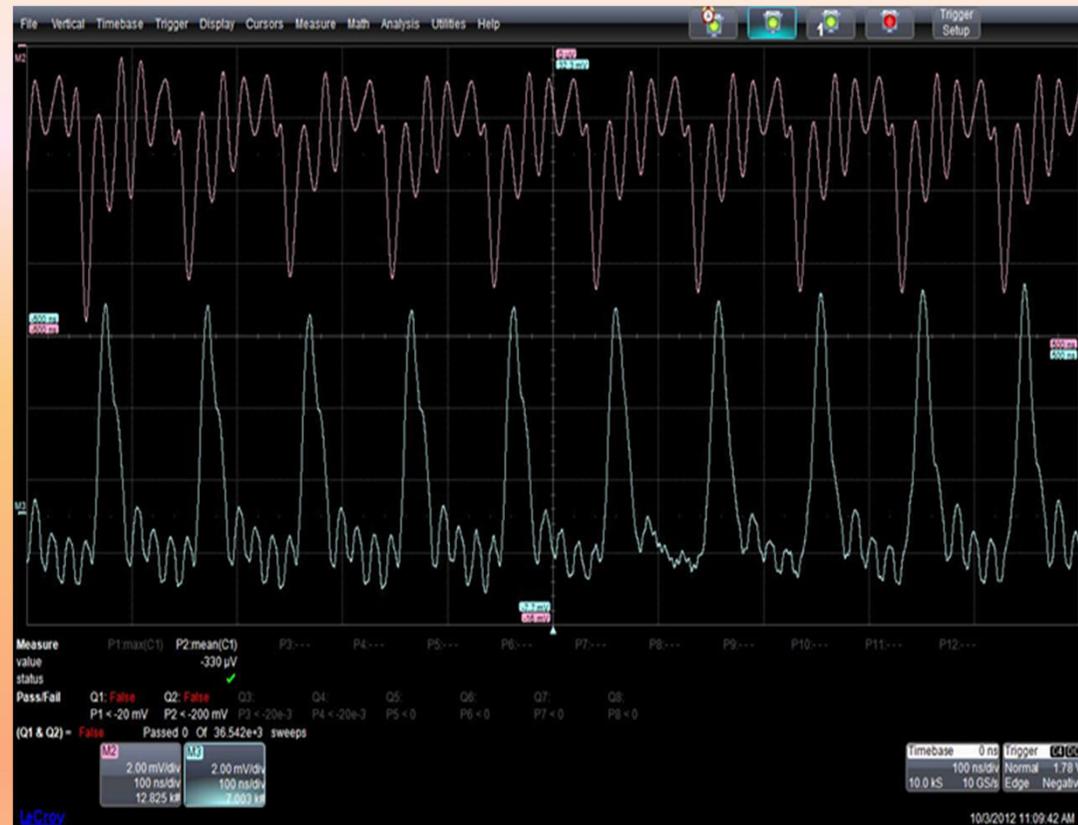
2.1 Absolute measurements of photon pulse energies.

2.2 Pulse to pulse photon energy measurements with 192 ns and 96 ns repetition intervals

3. Image measurements

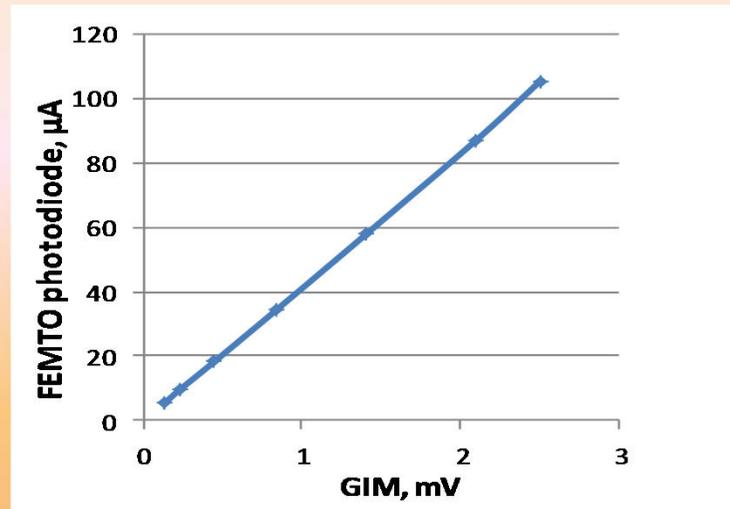
3.1 Visualization, with the MCP imager of SR beam size

MCP and Photodiode measurements of SR time structure



The time structure of MCP 1 signals with fast amplifier and photodiode at bunch repetition time 96 ns.

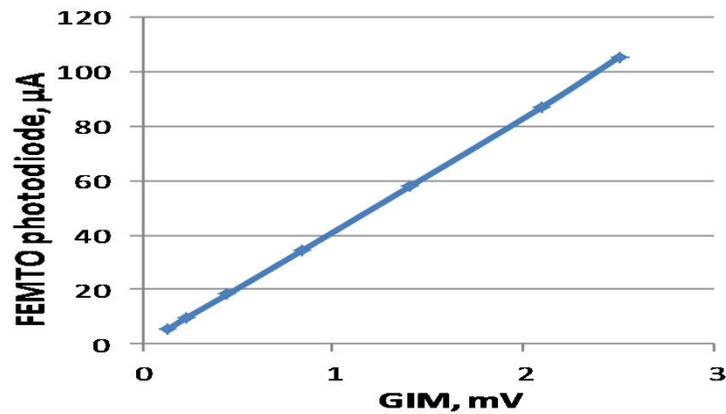
SR parameters measured by Photodiode



Dependence of photodiode currents on gas ionization monitor signal at $E_\gamma=9.66$ keV

Ratio of JINR photodiode signal to SR pulse energy is equal to 0.52 V/nJ
at photon energy - 9.66 keV,
SR pulse energy - 0.03 nJ, SR flux - 2.1×10^{11} ph/s.

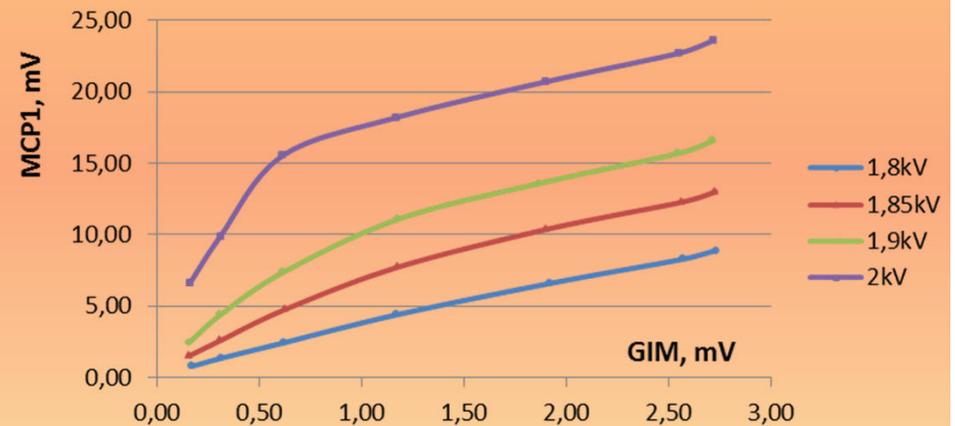
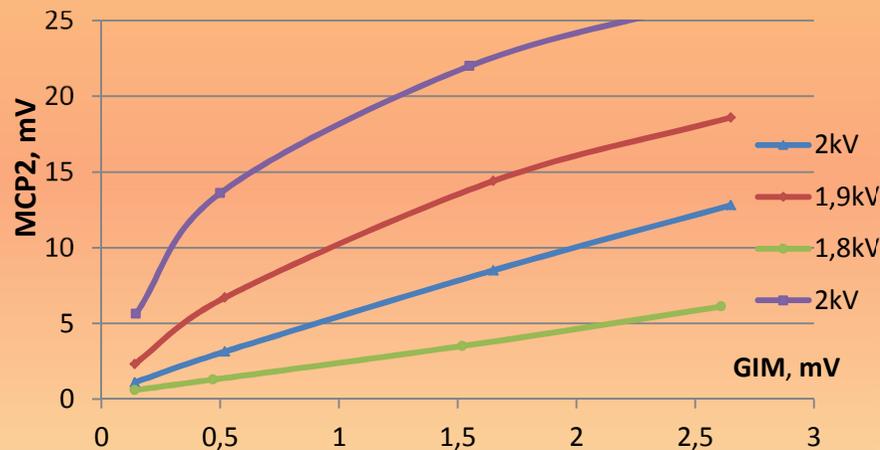
SR pulse energy measured by MCPs



Ratio of MCP 2 signal to SR pulse energy is equal to **0.16 V/nJ** at photon energy **9.66 keV**
SR pulse energy **0.032 nJ**,
SR flux - 2×10^{11} ph/s.

SR pulse energy is 50 times smaller than XFEL spontaneous emission level

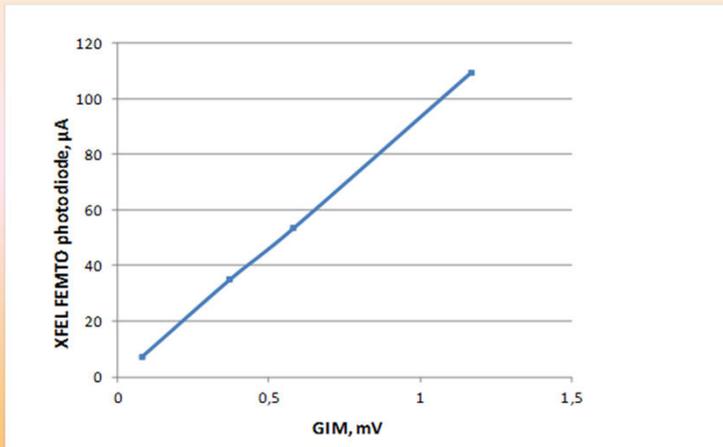
Dependence of XFEL photodiode current on gas ionization monitor signal at $E_\gamma = 9.66$ keV



Dependence of MCP2 and MCP1 signals on gas ionization chamber signal.

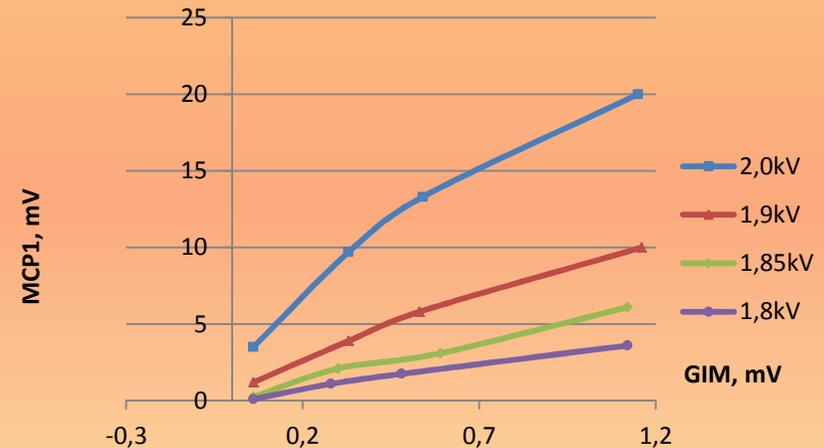
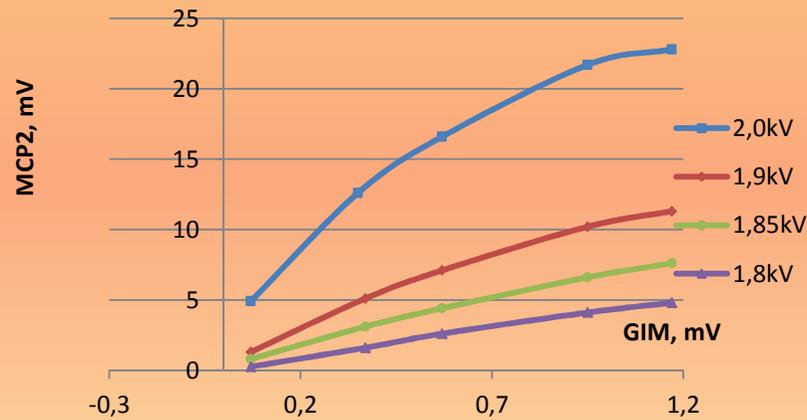
An essential influence of secondary ions was observed during MCP operation in DORIS BW1 at MCP voltage higher 1.85 kV.

SR parameters measured by MCPs



Ratio of MCP 2 signal to SR pulse energy is equal to **0.116 V/nJ** at photon energy **12.4 keV**
SR pulse energy **0.04 nJ**,
SR flux - 2×10^{11} ph/s.

Dependence of XFEL photodiode current on gas ionization monitor signal at $E_\gamma = 12.4$ keV



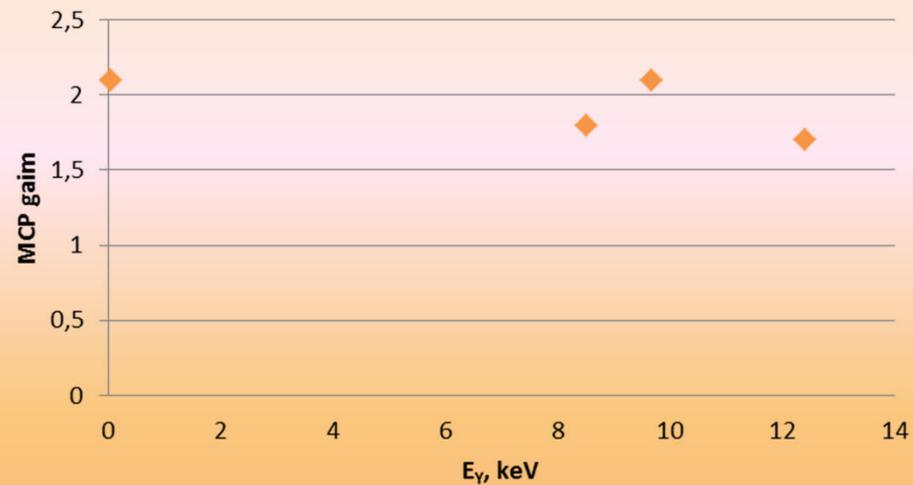
Dependence of MCP2 signals on gas ionization chamber signal

ion pump is switched on

ion pump is switched off.

Influence of secondary ions produced by X-rays in the MCP chamber at a pressure of 5×10^{-9} mbar was observed during MCP operation in DORIS BW1.

SR parameters measured by MCPs

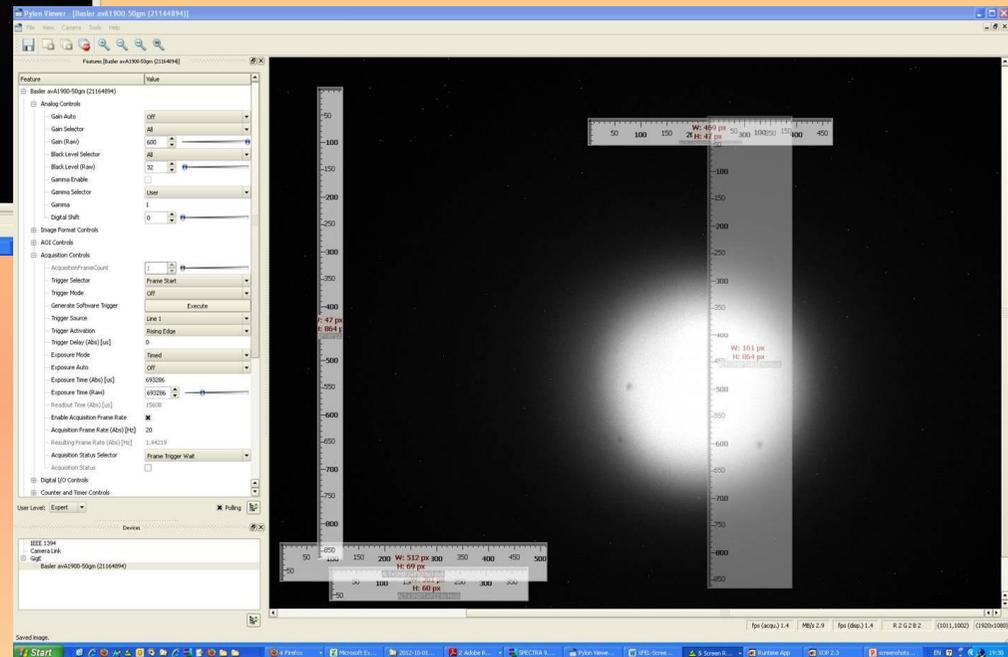
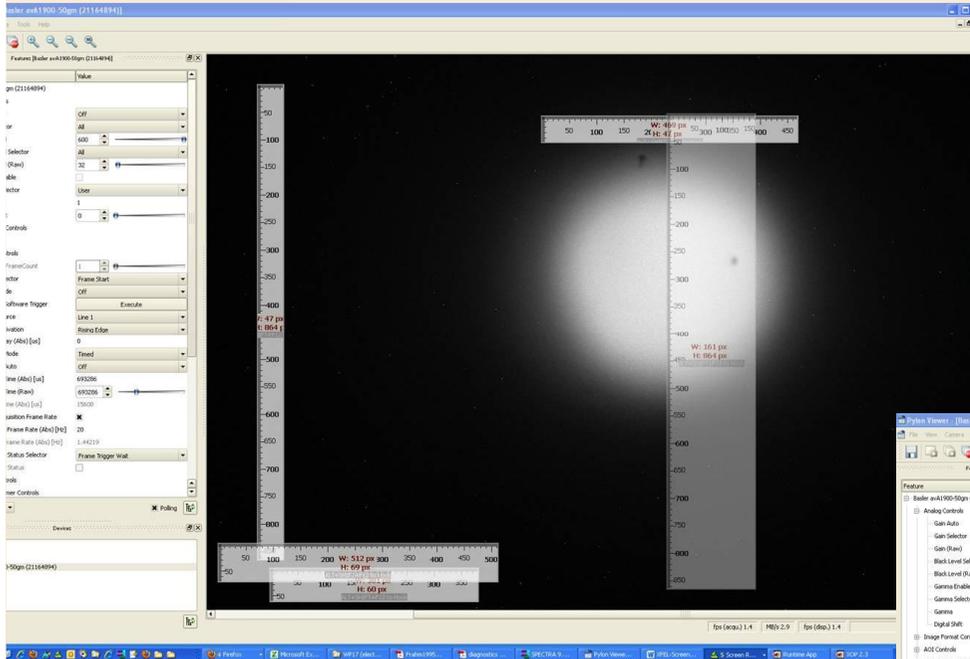


MCP2 gain at voltage increase from 1.8 kv to 1.85 kV for UV lamp and X-ray radiations

The XFEL micro pulse energy of 1 mJ should produce the MCP signal at amplitude 1.2 V for MCP voltage of 1.5 kV (at MCP gain reduction of 10^{-2} in comparison with MCP voltage 1.8 kV) and attenuation factor of XFEL radiation $R=10^{-3}$ in accordance with SR test measurements of the calibration ratio 0.12 V/nJ at MCP voltage 1.8 kV.

BW 1 SR MCP image tests

The MCP phosphor screen can be effectively used for search of X-ray beam position in XFEL starting in spontaneous mode at low intensity of 1.5×10^8 ph/s.



X-ray beam size at diaphragm size
 0.4×0.4 mm at zero and 1 mm slit
displacement

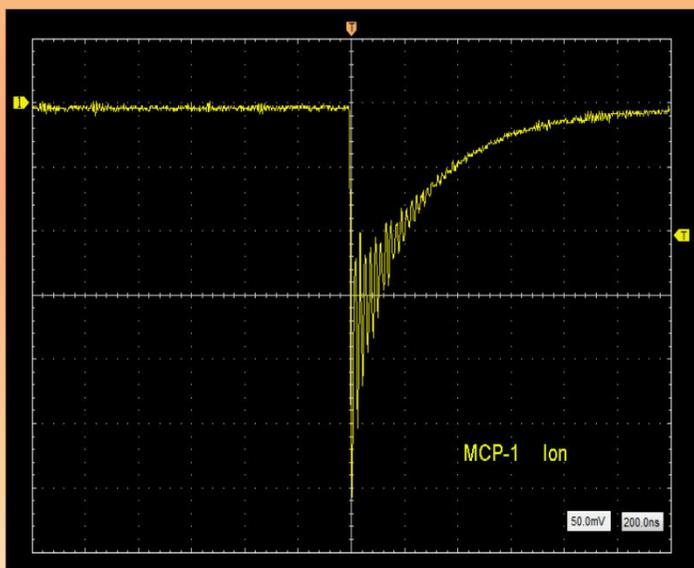
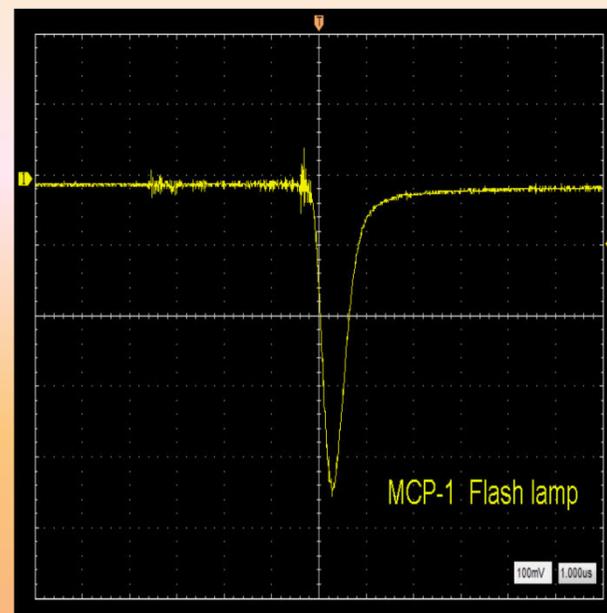
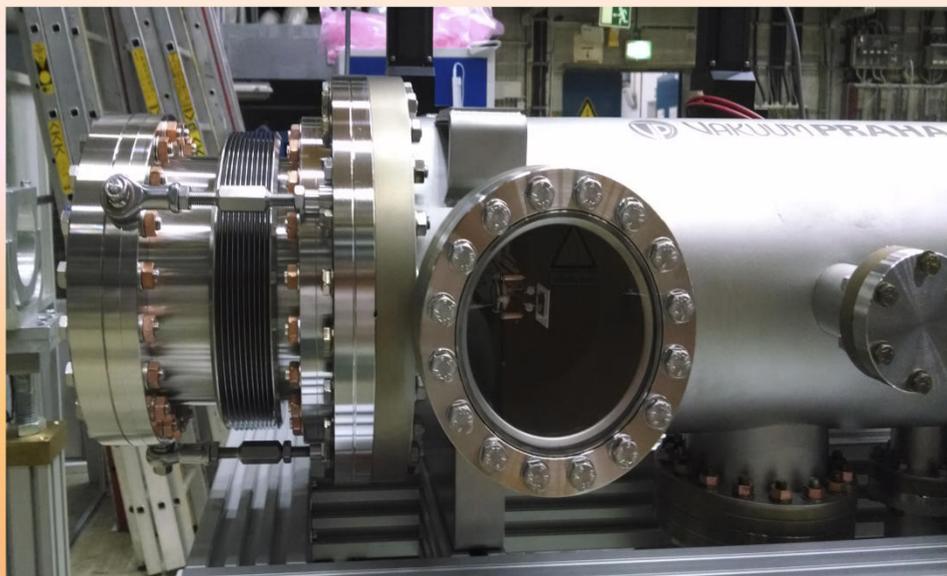
Large X-ray spot size of 2 mm at
small aperture of 0.4 mm.

The photon flux scattered in air gap may be a reason of
same spreading of X-ray beam spot for MCP phosphor
screen at its relatively small contrast resolution.

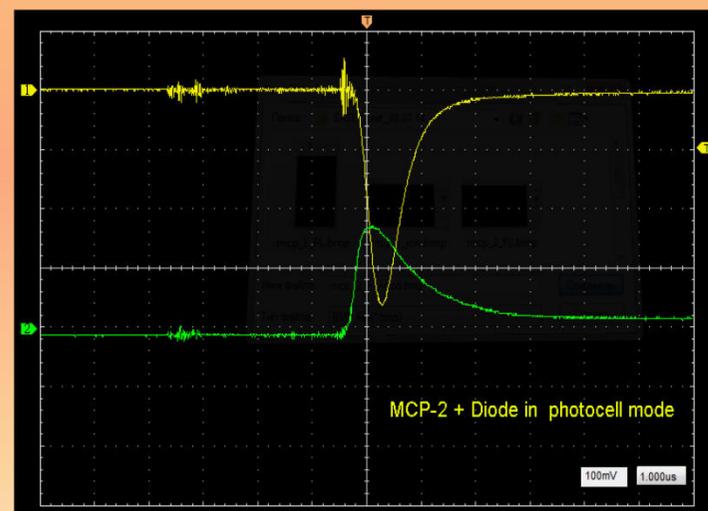
SR pulse measurements with MCPs

1. The SR micropulse energy of 0.03-0.04 nJ at X-ray photon energy of 8.5-12.4 keV was measured by MCP and photodiode in DORIS BW1 line. It is smaller 25-50 times than micropulse energy 1-2 nJ at XFEL spontaneous emission.
2. The ratio of MCP2 signal to SR pulse energy corresponds to 0.11-0.16 V/nJ at photon energy of 8.5-12.4 keV and MCP voltage 1.8 kV. MCP signal is linear to X-ray beam intensity at MCP voltage below 1.85 kV. The MCP gain for UV lamp radiation and X-ray radiation at photon energy of 8.5-12.4 keV corresponds to 1.7-2.1 at increase of MCP voltage from 1.8 kV to 1.85 kV.
3. SR pulse time structures with bunch repetition time of 192 ns and 96 ns were measured by MCP detector and photodiode with FEMTO amplifier.
4. The ratio of photodiode signal to SR pulse energy corresponds to 0.55 V/nJ at 9.66 keV.
5. The XFEL micro pulse energy of 1 mJ should produce the MCP signal at amplitude 1.2 V for MCP voltage of 1.5 kV (at MCP gain reduction of 10^{-2} in comparison with MCP voltage 1.8 kV) and attenuation factor of XFEL radiation $R=10^{-3}$ in accordance with SR test measurements of the calibration ratio 0.12 V/nJ at MCP voltage 1.8 kV.
6. The X-ray beam image was measured by MCP detector at intensity higher than 4×10^7 ph/s at photon energy of 9.66 keV. The MCP beam observation system with a phosphor screen can be effectively used for search of SASE mode starting from spontaneous emission.

SASE1 MCP tests before installation in XFEL tunnel



MCP1 signal from an residual gas ion produced in the ion pump



MCP and photo diode signals produced by flash lamp.

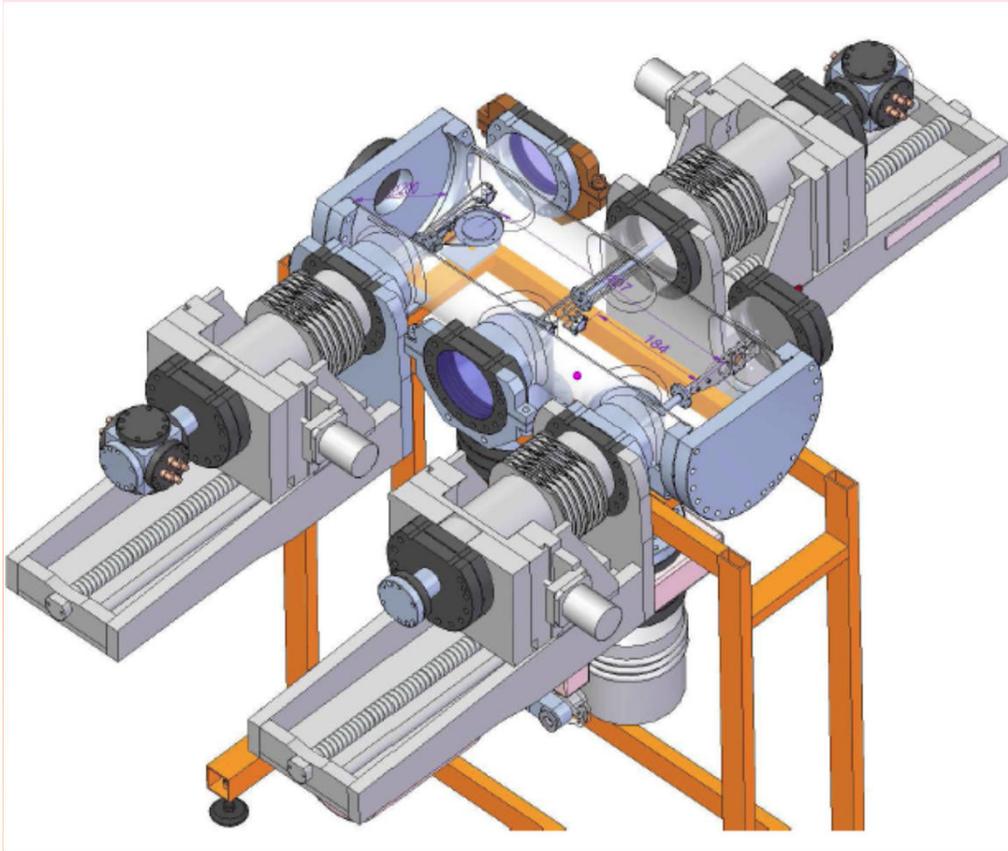
SASE1 MCP Detector in XFEL Tunnel



November 2015

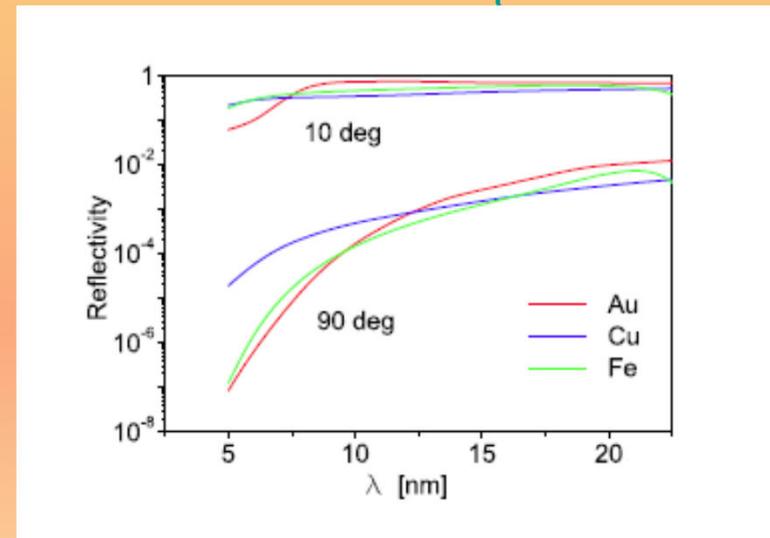
Design of of the SASE-3 MCP detector

The MCP detector for SASE3 has an additional port with movable semitransparent mesh and wire targets for production of scattering FEL radiation similar to those used at FLASH.



View of the SASE-3 MCP detector.

The SASE3 MCP is placed at the distance $L_2 = 1.5$ m from the middle of the second mirror. The distance between the middle points of the first and second mirrors is $L_1 = 3.89$ m.



The special movable Fe and Ni targets are installed in SASE 3 MCP vacuum chamber before MCP detector, to provide large variation of SASE 3 signals at different observation angles of scattered radiation.

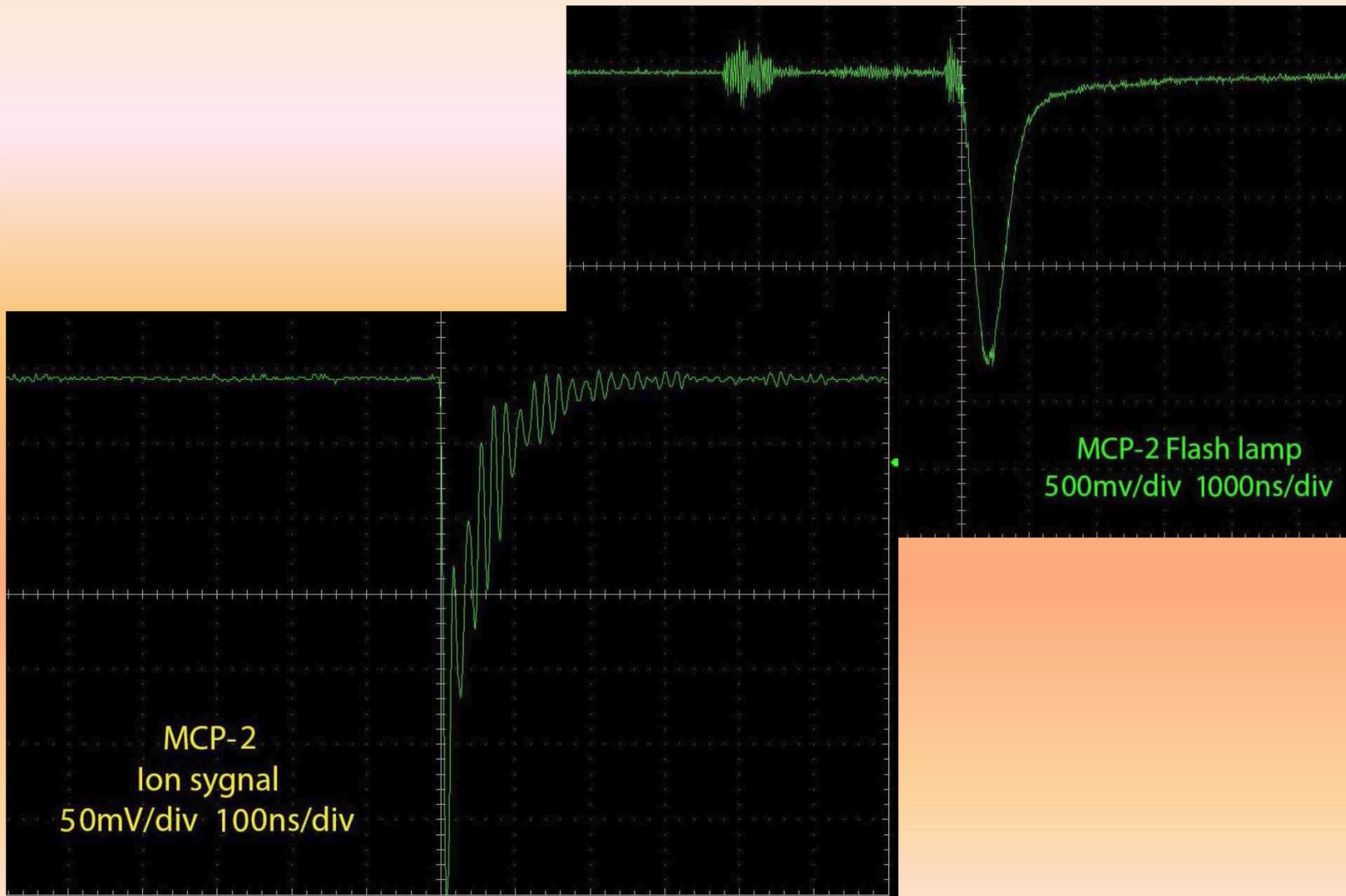
SASE3 MCP Detector



SASE3 MCP detector after assembling in XFEL.



SASE3 MCP Detector Acceptance Test Measurements



Thanks for Attention