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Multiple Detector Stage at the MID instrument of European XFEL

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Abstract. The Multiple Detector Stage is an ancillary detector setup for the Materials Imaging and Dynamics instrument at the European X-Ray Free-Electron Laser Facility. It is developed to improve the current capabilities concerning X-ray detection and make entirely new experiments possible. A unique feature of the MID instrument is the large flexibility in positioning of the AGIPD detector relative to the sample. This enables a large variety of instrument configurations ranging from small-angle to wide-angle X-ray scattering setups. A recurrent request from the users, which is currently not enabled, is the option of simultaneously recording both wide- and the small angle scattering by using two area detectors. The aim of developing MDS is to provide this missing capability at MID so that SAXS and WAXS experiments can be performed in parallel. The MDS will not be installed permanently at the instrument but only on request to provide as much flexibility as possible. In this article, the background and status of the MDS project is described in detail.

1. Introduction

The Multiple Detector Stage (MDS) was first presented at the MEDSI 2023 conference [1]. This paper provides recent developments and the result of the first small-angle X-ray scattering (SAXS) measurements of SiO_2 nanoparticles (NPs) dispersed in water collected by a Jungfrau detector in the new MDS vacuum chamber.

An important feature of MDS is that it can be positioned either on the existing arm of the instrumentation at MID [2], together with the AGIPD detector [3], or as a standalone device on a separate girder (Fig. 1 and Fig. 2). The girder stands on air pads, suitable for the floor in the MID experimental hutch. With this, the MDS can be positioned inside the hutch and operated in parallel with the well-established Adaptive Gain Integrating Pixel Detector (AGIPD). The AGIPD is a hybrid pixel detector developed by DESY, PSI, and the Universities of Bonn and Hamburg to cope with the very demanding pulse structure of the extreme brilliant free electron pulses of the European XFEL.

The basis for the MDS is a vacuum chamber that can host two small-area detectors simultaneously. The full chamber is assembled on a platform which includes a vertical motion. The platform also carries electronics required for the X-ray detectors, motors, and the vacuum system.

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Figure 1: Assembled MDS on separate girder. Including the vacuum chamber with the detectors inside and the tray for electronics

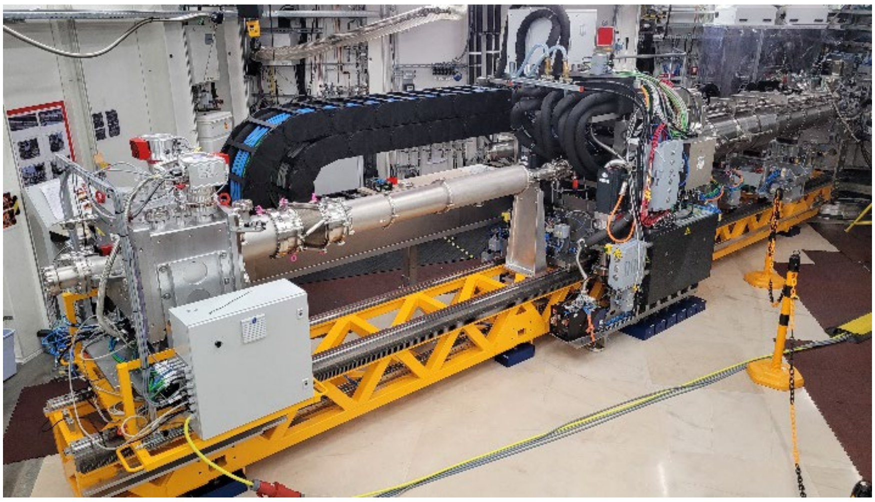

Figure 2: MDS assembled into the MID instrument at the back of the AGIPD. Fully vacuum integrated. Only for preparation moved into WAXS geometry.

2. Configurations

The recurrent request of the user community for simultaneous wide- and small-angle scattering capabilities is the motivation behind the MDS project.

Experiments, where information about the scattering sample is required in-situ on both atomic (nm and sub-nm) and micro scales (μm and sub- μm) would benefit enormously from such a setup. Another frequent request is to move a detector into the direct beam for beam characterization, X-ray holography, or other X-ray imaging applications.

By positioning the MDS on the detector arm behind AGIPD, such measurements are feasible (Fig. 3).

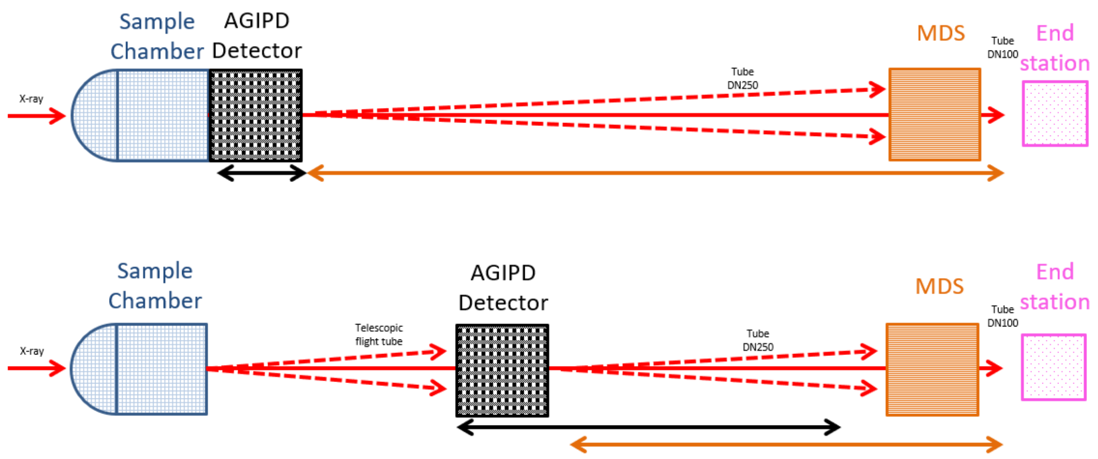

Figure 3: Sketch of the geometry with MDS positioned behind AGIPD on a common detector arm.

Another option provided by the MDS is its individual positioning independent of the AGIPD detector arm. For this purpose, a support girder was built where the MDS can reside on. The girder can be moved freely on the high-quality floor of MID by use of the high-pressure air pads underneath. Fig. 4 shows that when the AGIPD detector is moved to WAXS, the MDS can cover the SAXS configuration.

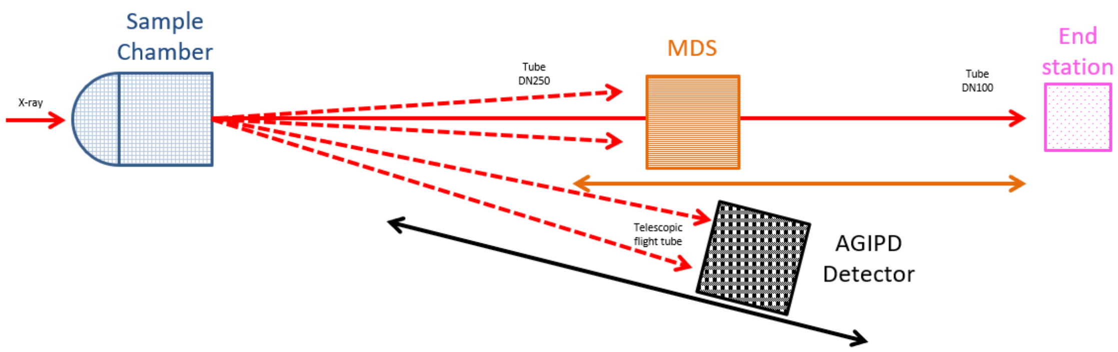

Figure 4: Sketch of the geometry with AGIPD in WAXS while MDS covers the SAXS region mounted on its own girder.

2.1. Detectors / Orientation

The MDS contains a high vacuum chamber with two detectors mounted on individual stages. The chamber can host versatile configurations and different types of small detectors. For instance, two ePix [4] or two Jungfrau [5] detectors can be operated in parallel. The individual horizontal and vertical stages allow positioning the detectors in “elongated” and “squared” arrangements (Fig. 5 (a) and 5 (b)).

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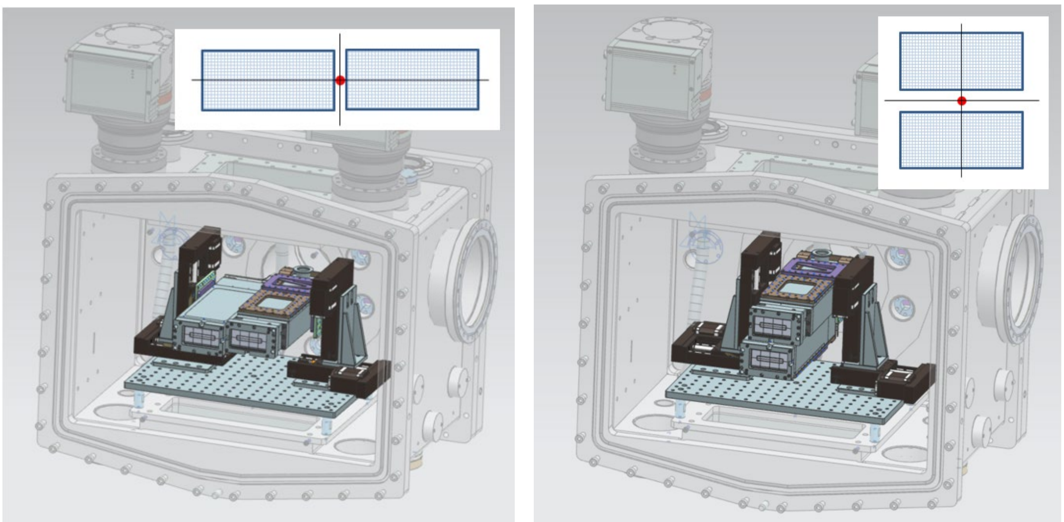

Figure 5 (a) and 5 (b): Elongated setup of two Jungfrau detectors (left) and a squared configuration (right), with the x-ray beam passing in-between the two detectors.

3. Initial commissioning

For the initial commissioning of the MDS one Jungfrau and one ePix module were installed in the vacuum chamber on individual stages (Fig. 6). The two detector types have different pixel sizes, active area, dark noise and dynamic range and can be selected according to the experimental requests (Table 1).

Table 1. Comparison of the ePix and Jungfrau Detector, established at MID.

Detector	Pixle size (µm)	No. of Pixels (adim.)	Detection area (mm^2)	Noise (eV)	Frame rate (Hz)	Dynamic range (photons per Pixel)
ePix100	50	704x768	35 x 38	< 280	120	10^2 8keV
Jungfrau	75	512x1024	38.55 x 77.25	< 450	2400	104 12keV

The MDS itself has been mounted at the back of the AGIPD on the long detector arm. The vacuum chamber is connected with tubes to the AGIPD chamber at the front side and connected to the Diagnostic end station (DES) [6] at the back side. Hence the x-ray beam can pass the instrument fully in vacuum without any distortion of windows [7].

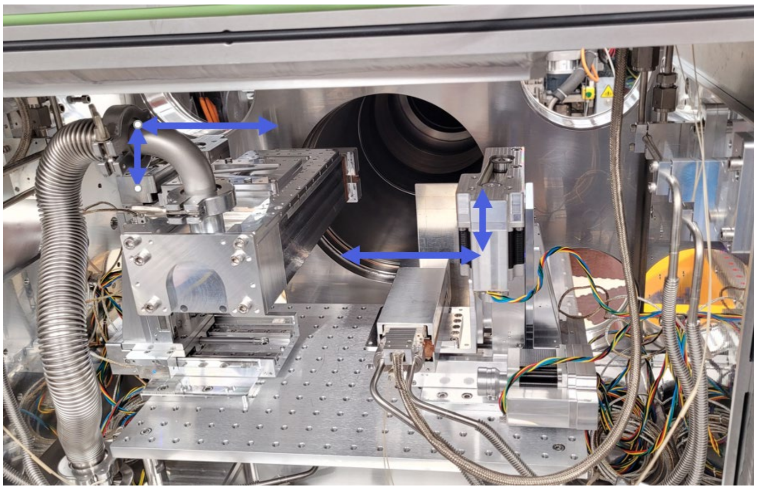

Figure 6: Configuration for the commissioning with one Jungfrau and its air box in the upper left corner and one ePix in the lower right corner, looking from the back side of the MDS.

3.1. First SAXS measurement of SiO_2 NPs with Jungfrau

The Jungfrau detector in the chamber collected SAXS patterns of colloidal NPs dispersed in water. The X-ray beam (9 keV photon energy) hit a capillary with the colloidal suspension sample and the detector-to-sample distance was 9.1 m. Figure 7 shows the azimuthally integrated intensity distributions for different radii of NPs (R = 50, 100, and 250 nm). Each I(q) is arbitrarily shifted vertically for better visualization. The black-dashed lines are the result of form-factor fitting, showing good agreement with the experimental data with radius estimates close to the expected values.

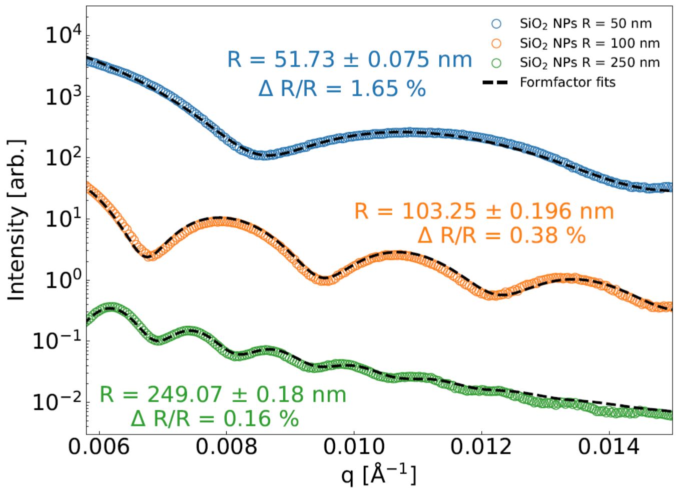

Figure 7: Azimuthally integrated intensity distributions I(q) of SiO2 nanoparticles at 9keV photon energy.

The implementation of a full in-vacuum scattering geometry provides the great advantage of minimizing air scattering that provides an unwanted background signal, particularly penalizing single-shot experiments and low photon count rate measurements. The single-shot X-ray scattering images were collected by the Jungfrau detector in a burst mode, resolving the X-ray pulse patterns of EuXFEL at 112.5 kHz repetition rate. Figure 8 shows the single-shot scattering image (lower right) and averaged over 13000 images (upper left).

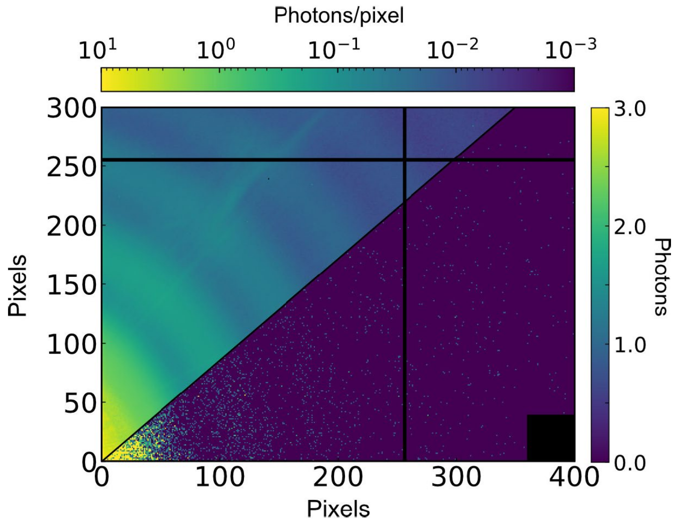

Figure 8: Collected X-ray image of SiO_2 NPs (R = 100 nm) dispersed in water. Upper left: Averaged over 13000 images and an upper colour-bar of the photon/pixel level. Lower right: Single image with up to 3 photons registered per pixel (right colour-bar)

4. Status and outlook

The initial commissioning of the MDS setup was successful. The MDS chamber was assembled into the MID instrument and fully integrated in the vacuum environment. The Jungfrau detector was integrated into the MDS and operated in burst-mode. Scattering patterns of SiO2 nanoparticles with different radii could be successfully recorded. The obtained azimuthally integrated intensity distributions and the form-factor fitting results show good agreement with expectations. The full vacuum scattering path helps to resolve single photon events on the Jungfrau detector in the burst mode at an X-ray pulse repetition rate of 112.5 kHz. The development of the MDS chamber will provide a novel capability for conducting experiments in SAXS and WAXS geometries, particularly for single-shot based data collection like in X-ray photon correlation spectroscopy and X-ray speckle visibility spectroscopy. It is expected that the MDS setup will be available for user experiments soon.

Space constraints and cable routing are currently the limiting factors for the positioning of the MDS. Therefore, only measurements in small-angle X-ray scattering (SAXS) are archived. We are working on upgrades to bring the MDS in wide-angle X-ray scattering (WAXS) configuration.

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