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Nanometer Resolution on a Femtosecond Timescale – First Experiments with pnCCDs for High Speed X-ray Imaging and Spectroscopy at LCLS

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Fourth generation accelerator-based light sources, such as VUV and X-ray **F**ree **E**lectron **L**asers (FEL), deliver ultra-brilliant (~10^{12}-10^{13} photons per bunch) coherent radiation in femtosecond (~10 fs to 100 fs) pulses and, thus, require novel focal plane instrumentation in order to fully exploit their unique capabilities. As an additional challenge for detection devices, existing (FLASH, Hamburg) and future FELs (LCLS, Menlo Park; SCSS, Hyogo and XFEL, Hamburg) cover a broad range of photon energies from the EUV to the X-ray regime with significantly different bandwidths and pulse structures reaching up to MHz micro-bunch repetition rates. Moreover, hundreds up to trillions of fragment particles, ions, electrons or scattered photons can emerge when a single light flash impinges on matter with intensities up to 10^{22} W/cm^2.

In order to meet these challenges, the Max Planck Advanced Study Group (ASG) within the Center for Free Electron Science (CFEL) has designed the **C**FEL-**A**SG **M**ulti**P**urpose (CAMP) chamber. It is equipped with specially developed photon and charged particle detection devices dedicated to cover large solid-angles. A variety of different targets are supported, such as atomic, (aligned) molecular and cluster jets, particle injectors for bio-samples or fixed target arrangements. CAMP houses 4π solid-angle ion and electron momentum imaging spectrometers ("reaction microscope", REMI, or "velocity map imaging", VMI) in a unique combination with novel, large-area, broadband (50 eV to 25 keV), high-dynamic-range, single-photon-counting and imaging X-ray detectors based on the pnCCDs.

This instrumentation allows a new class of coherent diffraction experiments in which both electron and ion emission from the target may be simultaneously monitored. This permits the investigation of dynamic processes in this new regime of ultra-intense, high-energy radiation – matter interaction. After a brief introduction into the salient features of the CAMP chamber and the properties of the redesigned REMI/VMI spectrometers, the new 1024 x 1024 pixel format pnCCD imaging detector system will be described. The data obtained at LCLS illustrate the unprecedented performance of the X-ray detectors, which have a voxel size of 75 x 75 x 450 μm^3 and a typical read-out noise of 5 electrons (rms) at an operating temperature of -50^{o}C.

With CAMP we have performed the very first X-ray imaging experiments at the most brilliant X-ray Free Electron Laser, the Linac Coherent Light Source (LCLS) at SLAC in December 2009. Fig. 1 shows the experimental end station, Fig. 2 the arrangement of the two 1k x 1k pnCCDs and Fig. 3 first diffraction patterns from atomic clusters. The offline data analysis is still in progress. New results on fluorescence measurements of gas targets will be shown, more detailed results from atomics clusters, nanocrystals and biological samples. The focus of the talk will be on the performance of the pnCCDs during the first three sets of imaging experiments at the AMO beamline at LCLS with special emphasis on the achieved spatial and time resolution.

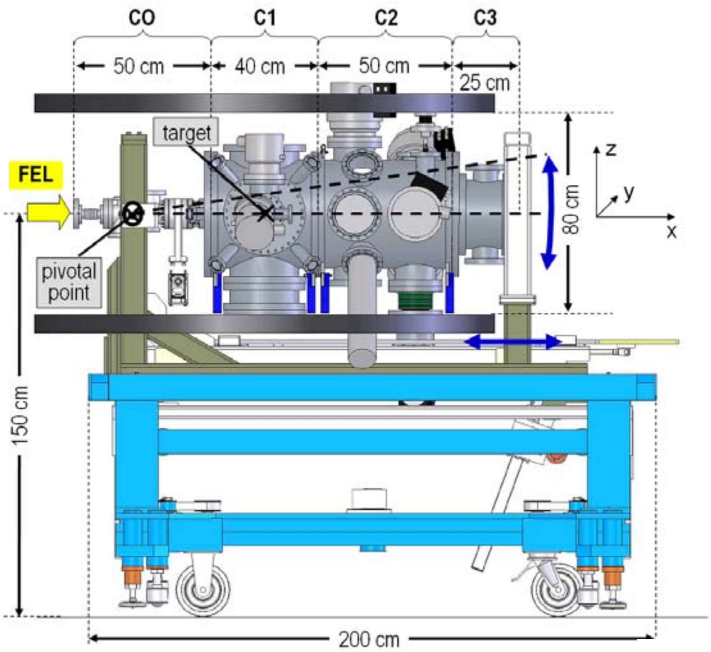

FIG.1. The CAMP chamber consists of four individual units: the X-ray beam transfer device C0, the injector chamber C1, the detector chamber C2 and the back detector chamber C3. In both chamber C2 and C3 two large format pnCCDs have been operated to detect the large angle scattering (up to 130 ^{o}) and the small angle scattering about 60 cm downstream of the interaction point. The detectors have a center hole to let the non-scattered photons (about 10^9) in 100 fs slices go through.

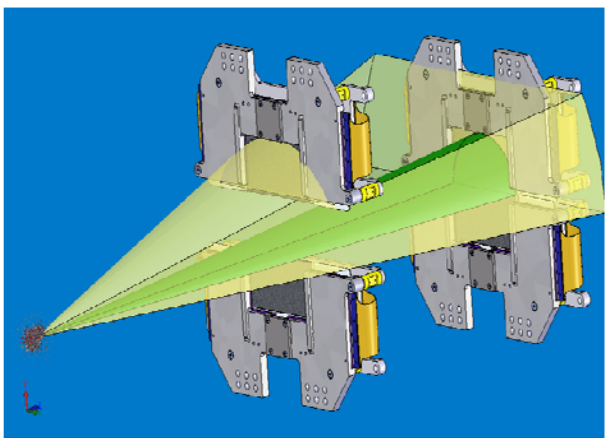

Fig.2: Artist's view of the two pnCCD mountings. The two halves of the pnCCD on the left side (closest to the interaction point), CCD1, can be opened vertically by up to 90 mm, 45 mm each. Photons scattered under large angles can hence be detected (C2), while the second (fixed) pnCCD2 records the X-rays under smaller angles (C3). The distance between the detectors can be changed by moving the CCD1 system up to 250 mm along the beam axis. Moreover, if needed, CCD2 can be placed at any distance larger than 550 mm away from the interaction zone by simply introducing fixed spacer tubes of the desired length.

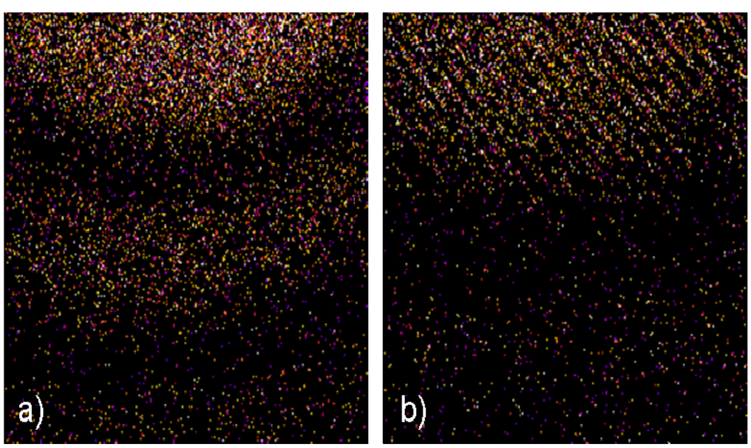

Fig.3: *Single shot diffraction images of clusters taken with a pnCCD camera. a) a single cluster was hit by the FEL pulse. b) one cluster in the shadow of another one leads to a fine interference pattern in the scattering signal. The LCLS photon energy was 1.6 keV. In addition to those measurements, nanocrystals and biological samples were analysed.*

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