Simulation Methods for Transverse Beam Size Measurement Using Heterodyne Near Field Speckles of Hard X-rays (THPP33)

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Heterodyne near field speckles

The Heterodyne Near Field Speckles (HNFS) is a special type of **interferometry** technique where radiation is scattered by nanoparticles suspended in a medium.
The scattered waves and the transmitted radiation form an interference pattern, which is modulated by the **spatial coherence** of the radiation and by the **scattering** properties of the **nanoparticles**. The superposition of many such interference patterns results in a granular pattern, the so-called heterodyne near field speckles.

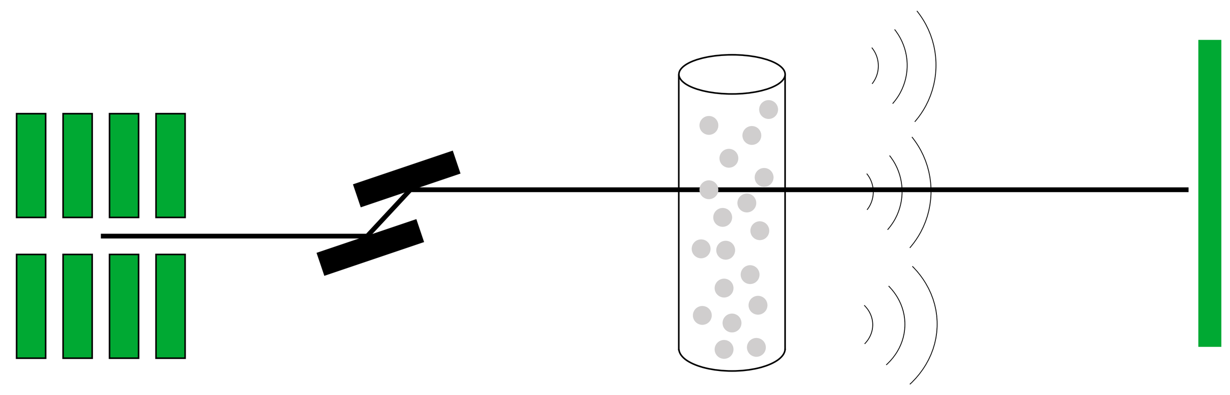


Figure 1: The **setup** from left to right: an undulator generating synchrotron radiation, a monochromator selecting a certain wavelength, a holder of nanoparticles which scatter the incoming radiation, an optical setup which detects the interference image

Application

The two-dimensional Fourier transformation of the speckle pattern shows **fringes** (the Talbot oscillations) which **decay** due to **several different effects**. Those are the

- $C_s(q)$, the **spatial coherence** of the beam (thus its size – linked via the Van Cittert and Zernike theorem)
- $C_t(q)$, the temporal coherence (thus its bandwidth – linked via Wiener and Chinchin Theorem)
- $S(q)$, the particle form factor, as a result of the scattering amplitude function
- $H(q)$, the optical transfer function
- $P(q)$, a noise pedestal

- $I(q)=C_s(q)\, C_t(q)\, S(q)\, H(q) + P(q)$

The simulation techniques and the proposed measurements focus on finding the spatial coherence and as a consequence the **transverse beam size**.

Simulation method A

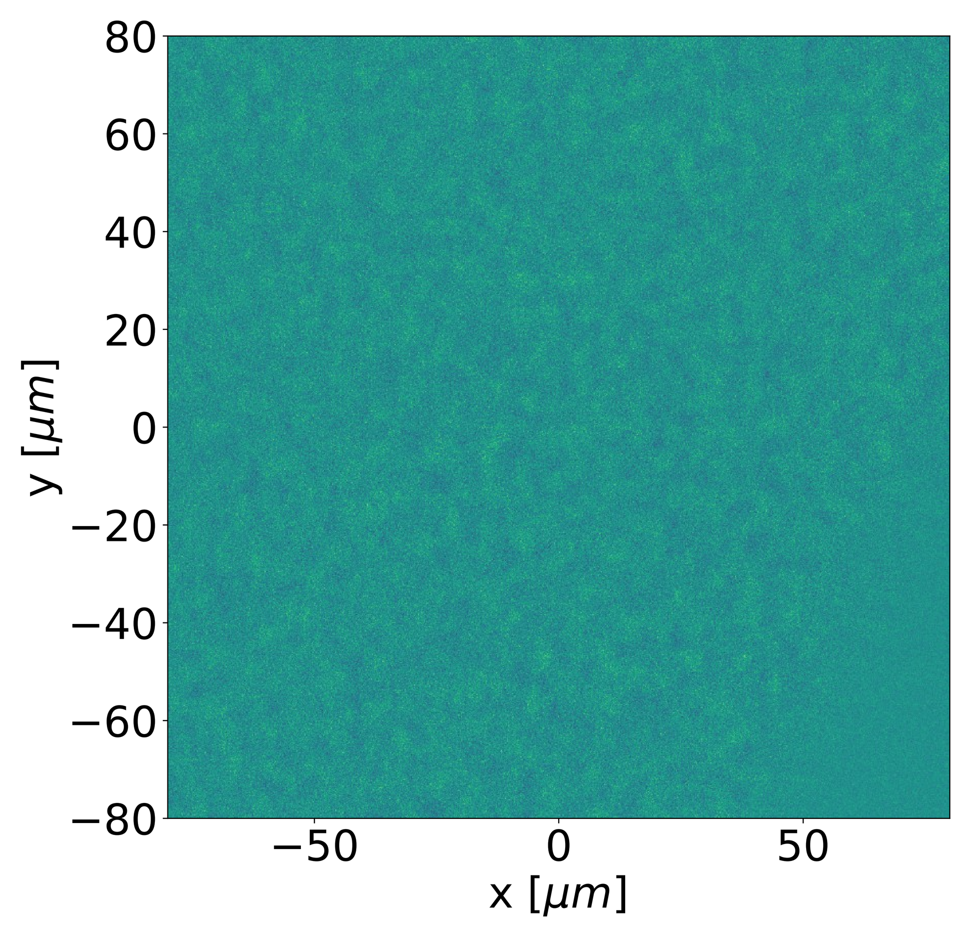
This method is based on the library "**Synchrotron Radiation Workshop**" (SRW), which is able to numerically evaluate synchrotron radiation of arbitrarily formed magnetic structures and propagate this radiation through any given attenuating or phase shifting structure.

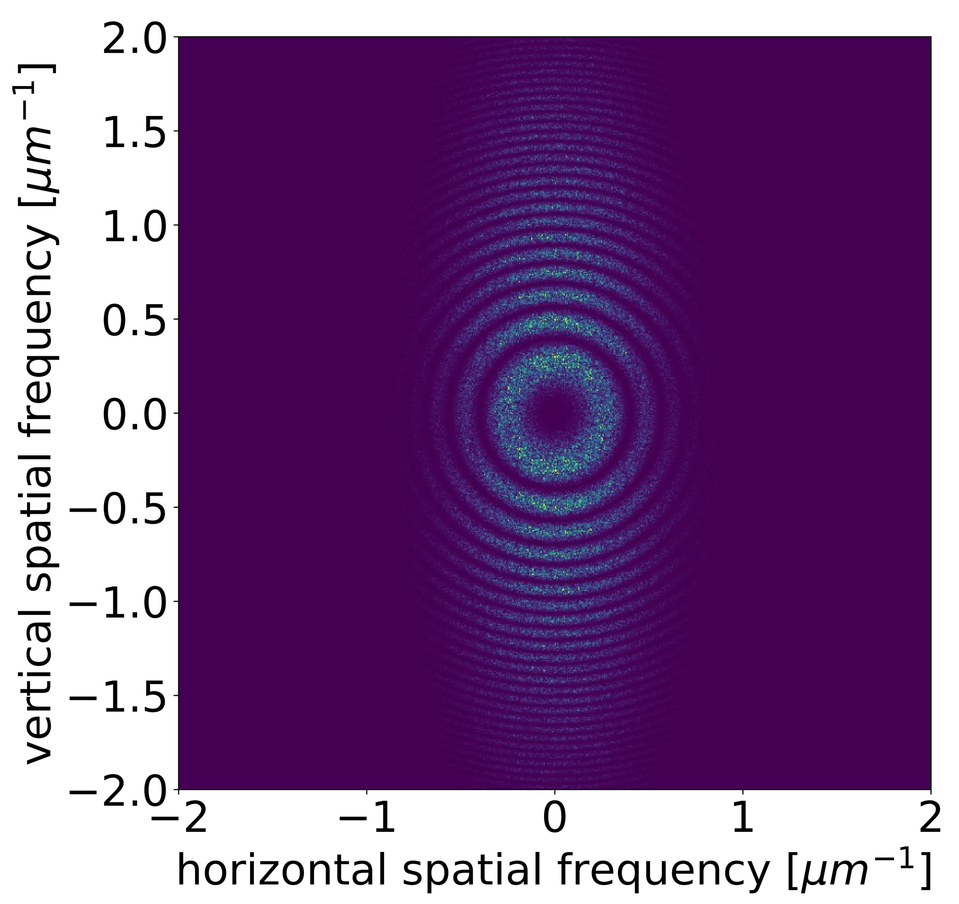
In order to model the scattering at the nanoparticles, the synchrotron radiation of a radiating electron is **propagated through a mask** of many phase shifting disks. For representing the finite size of the electron beam – thus its spatial coherence – a statistical ensemble of radiating electrons is simulated, whose propagated wavefronts are summed up resulting in the final speckles pattern.

Simulation method B

The second method is a **semi-analytic approach**. Here, the coherence area is directly calculated by means of the Van Cittert and Zernike theorem and for the scattering, the Mie theory is used for an exact solution of the refraction of X-rays at spherical nanoparticles. Following the conditions of the HNFS, only the heterodyne terms are considered. Those term are the mixing terms in the interference of the transmitted and the scattered waves.

Following those prerequisites the problem can be reduced to the solution of an **convolution integral** over the spatial coherence, the scattering amplitude function and an oscillation term, which originates from the interference of the plane transmitted and the spherical scattered waves.





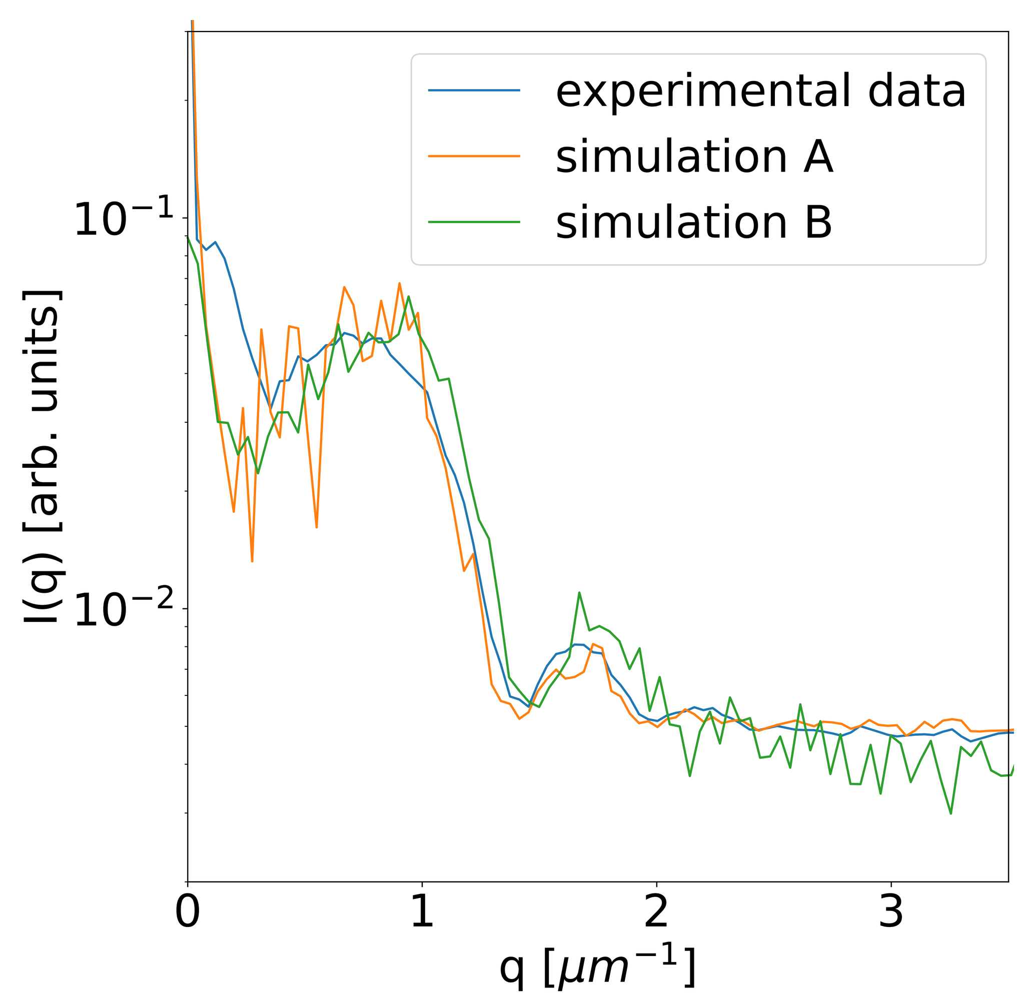


Figure 2/3/4: The measured speckle pattern (left), the Fourier transformation of the simulated speckle pattern (middle) and the comparison of the horizontal cut of the measured and the simulated power spectrum for the setup as currently studied at the ALBA-CELLS NCD-SWEET undulator. Agreement is found between simulations and the measured curve. Remarkably, simulation A and simulation B yield the same results, in spite of the fundamentally different approaches adopted.