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Towards a new generation split-crystal interferometer

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Neutron Interferometry was introduced by H. Rauch and U. Bonse in 1974. It opened the path to matter wave interferometry, allowing many direct precision tests of quantum mechanics and fundamental physics and the precise measurement of scattering lengths. A thermal neutron interferometer uses perfect crystals as optical elements (beam splitters, mirrors, and recombiner), where all acting diffraction planes are machined out of a single silicon ingot. This technology allows splitting the neutron wave paths by several centimeters and achieving interference contrast up to 90%. However, it also imposes limitations on the size (given by the available size of perfect silicon ingots) and systematic errors (mainly due to intrinsic crystal imperfections).
To overcome these limitations, the concept of neutron interferometry was extended to the use of diffracting gratings. So far, grating interferometers have not yet allowed for achieving comparable contrast and/or path separation. Other, more recent efforts are based on using multilayer optics. While these devices achieve excellent contrast, their beam-path splitting remains very small, typically in the range of a few hundred micrometers.
To overcome the size limitations of crystal interferometers, we have recently demonstrated that it is possible to construct an interferometer using two separated crystals. We are currently developing a dedicated setup for crystal separation up to one meter, enabling the introduction of massive samples into one of the beam paths for the first time. The main idea consists of setting up a combined optical, X-ray, and neutron interferometer. The optical interferometer allows for the control of the position of all crystals in space on a subnanoradian and subnanometer level with kHz readout. The Xray interferometer informs about the lattice constant properties in time. A neutron interferometry measurement consists of a spatial- and time-resolved neutron detection, where to every detection event a phase value from the optical and X-ray interferences is associated. This allows the reconstruction of the neutron quantum phase induced by interactions in the interferometer, despite time- and space-dependent instability and imperfection of the interferometer.
We present several proof-of-principle reconstructions of the interference, which allowed us to work out the new interferometer concept. Each of them was carried out using a conventional single-crystal interferometer, applying the perturbations that are expected to occur in the split-crystal version. We further present the first proof of principle of a split-crystal prototype as well as the full design of a next-generation split-crystal interferometer and its status of implementation, which is foreseen to happen until spring 2026.

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