EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report

	Experiment title: Demonstration of proof-of-concept experiment for x-ray quantum interferometers	**Experiment number**: MI-1422
Beamline: ID01	**Date of experiment**: from: 08/06/22 to:13/06/22	**Date of report**: 01/09/2022
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Report:

Quantum interferometers have much higher sensitivity than classical interferometers as has been demonstrated by experiments with visible light and predicted by theory, hence can lead to the development of phase contrast imaging methods for the measurements of samples with refractive index contrasts much smaller than the capabilities today. In our beamtime we demonstrated a proof-of-concept experiment, which demonstrates the ability to use x-ray quantum nonlinear interferometers for precise phase sensing.

The experiment is based on a simple setup that includes a monolithic crystal with two lamellas separated by air, with the possibility to add thin membranes (samples) between them to allow the control on the phases between the beams that propagate between the crystals, as is illustrated in Fig. 1. Each of the lamellas will be configured for the generation of entangled x-ray photon pairs utilizing the effect of x-ray parameter down conversion (PDC), which is a second order nonlinear optics process, in which a pump photon is converted, via a nonlinear interaction in the medium, into a pair of correlated photons at lower energies. This setup is also known as a SU(1,1) interferometer where the key idea is that the generation rate of the photon pairs in the second lamella depends on the relative phases between the pump, idler and signal photons.

As shown in Fig 1. We used a monolithic double Laue silicon crystal structure that serves as the interferometer and a detection kit that includes two silicon drift detectors (SDDs) with energy resolving and photon number resolving capabilities. The interferometer was mounted on a rotation stage to control its angle with respect to the input beam and the detection kit was mounted on the diffractometer arm. A monochromatic collimated beam at 27 keV with beam size of 1.2 x 0.3 mm^2 (HxV determined by the mirrors and slits) pumped the first lamella to generate photon pairs at 13.5 keV. For momentum conservation, we have used the reciprocal lattice vector normal to the silicon (220) atomic planes in transmission geometry and the interferometer and the detectors was aligned accordingly. The angle between the pump and the signal and idler was about 0.2 rad. The signal and idler photons that are generated in the first lamella and the pump will propagate in air and then in a second silicon lamella. As a phase object we used silicon membranes with different thicknesses that allowed us to control the phase differences systematically by changing the number and type of membranes. We first used the Maxipix camera to aligned the interferometer and the detectors to the Bragg angle of the Si(220). Then we tuned the SDD's detectors to the angles for the pair production (about ± 50 mrad from the elastic beam), and the interferometer to 0.75 mrad from the Bragg angle of the Si(220).

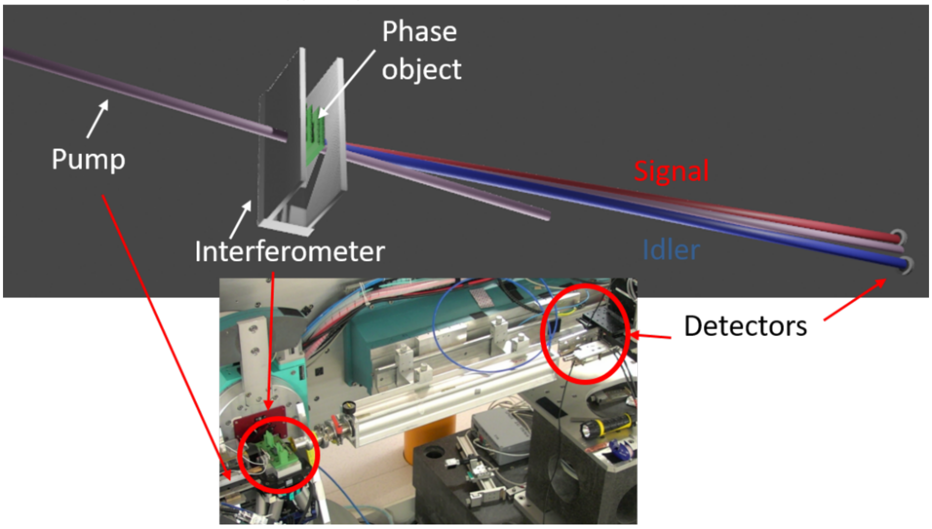

Figure 1- Experimental setup, drawing and reality

After we verified the observation of PDC and measure the spectral dependence of the effect with the SDDs we added the phase objects and measured the coincidence count rate dependence on the phase that the sample introduces for various thicknesses of the membranes. The average coincidence count rate was around 0.01 counts per second. In Fig 2 we present the measured dependence of the PDC count rate on the thickness of the membranes. To compare the results with the theoretical model we plot the results (green squares) with a fitting function (black dashed line). It is clear that the measured variation in the coincidence count rate for the various membranes is larger than the error of the experiment. However, as can be seen from fig. 2, further measurements are required to complete at least 2 periods. In parallel we should improve the theoretical model to consider all the parameters like as the overlap between the three beams.

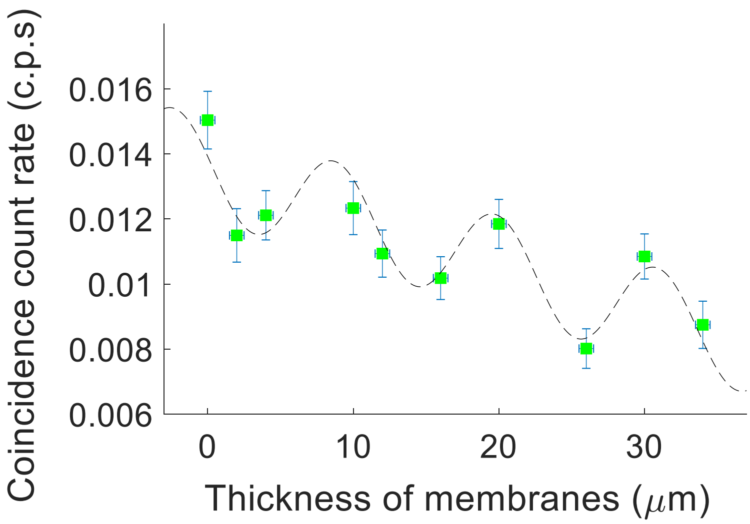

Figure 2 – Experimental results

In conclusion, we have successfully demonstrated a proof-of principle experiment showing the ability to use non-linear interferometer in the x-ray regime for phase measurements. We will propose a follow up experiment where will measure several more membranes with various thicknesses for better fitting and understanding.