EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report

	Experiment title: First demonstration of interaction-free measurement protocol with x-rays	**Experiment number**: MI-1443
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Report:

Interaction-free measurements (IFM) accomplish a classically impossible task: detecting objects without any radiation ever hitting them. This is made possible when utilizing the quantum nature of electromagnetic fields and in particular the interference of a single photon in an interferometer. In our beamtime we tried to demonstrate a proof-of-concept experiment of the IFM effect with x-rays.

As shown in Fig 1, we used a Laue-Laue-Laue (LLL) monolithic crystal interferometer, which was provided by Roberto Verbeni with 780 µm silicon crystals cut in the <220> direction. The input beam was unfocused monochromatic beam at 46.7 keV to maintain the absorption of the interferometer sufficiently low to allow efficient detection. The detector was an Eiger CdTe 2D detector that we mounted at 200 mm from the interferometer. The detector detected all the output ports of the interferometer. The input monochromatic beam was split by the first crystal into 2 beams. The second crystal functions as mirrors. Then, the two beams were recombined by the third crystal. Due to interference occurring at the final beam splitter, and with no obstructions present along the optical pathways, the photons invariably arrive at just one of the output points, D2 or D5, resulting in a complete lack of coincidence between the two detectors. This can be used for IFM since when an object is placed in one arm, it reduces the probability of the photon to arrive at the output beam splitter from that arm. thus changes the interference. This leads to a non-zero probability to measure photons at both detectors. For the object, we used a small piece of lead, which absorbs the radiation.

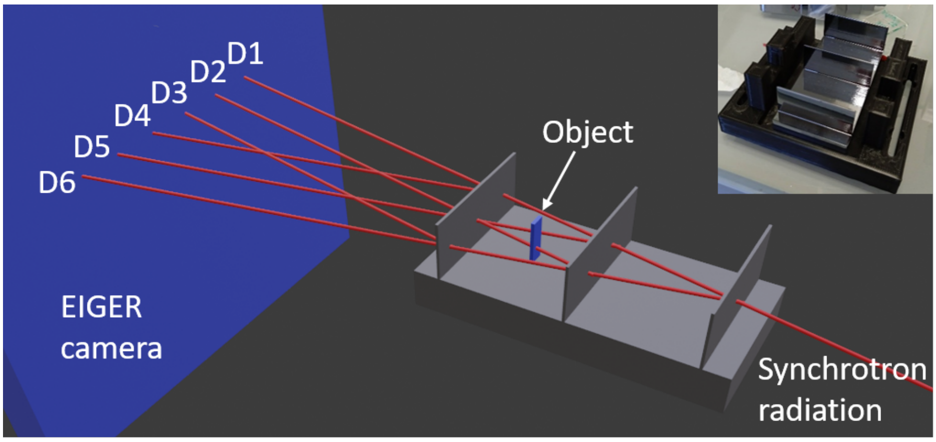

Figure 1- Experimental setup, drawing and reality

We used the reciprocal lattice vector normal to the silicon (440) atomic planes in transmission geometry and the interferometer was aligned accordingly. We started without the object and the result of the measurement is shown in Fig. 2. While port D2 seems to be darker than D5 the observation did not change when we mounted. After a few tests we realized that the intensity at the output port that corresponds to the arm without the sample is much higher than the one that propagates throw the sample. Thus, the difference in the intensity between the two ports is due to the difference in the reflection and transmission coefficients. While this ratio significantly reduces the modulation, in principle the interference still exists. However, we were not able to measure any interference effect.

Figure 2 – experimental measurement of the six outputs with the EIGER camera

We found several possible reasons for the invisible interference at the output of the interferometer. First, the beam was not sufficiently monochromatic. To improve the monochromaticity of the beam, we added a Si crystal tuned to anomalous transmission before the interferometer, but this addition did not solve the problem. We observed large fluctuations of the intensity occurring from variations in the angle of the interferometer. To address this issue, we strengthened the connections and extended the measurement time to improve the reliability and accuracy of the results. However, this improvement did not lead to the observation of interference.
We suspected that the low Signal-to-Noise Ratio (SNR) was caused by inadequate modulation, and thus, we attempted to rectify the situation by introducing a phase shift that would alternate between the dark port. Unfortunately, this approach failed to yield any noticeable improvement. We then proceeded to block half of the object to prevent any impact from disparate coefficients, but even this strategy proved to be unsuccessful in resolving the issue.
In conclusion, the experiment was unsuccessful as classical interference was not observed in the interferometer. We believe that the issue lies with the device itself, particularly with a small crack on the middle crystal that may have compromised the interferometer's stability. Moreover, typically, LLL interferometers operate at much lower photon energies, where absorption is higher, and the transmitted beam is both coherent and monochromatic. However, for IFM purposes, low absorption is necessary, and this trade-off poses a significant challenge to this experiment. Therefore, further theoretical analysis is needed to determine the optimal experimental conditions for this setup.