ESRF	**Experiment title:** Converting resonant absorption into gain via time-domain control of nuclear dynamics	**Experiment number:** HC-1899
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Report:

In our proposal, we suggested a setup to convert nuclear x-ray absorption lines into gain lines. The method works by redistributing spectral power from regions off-resonant with the nuclei into the resonant modes. This way, effectively the brilliance for resonant nuclear coupling could be enhanced. For this, we proposed to mount a foil containing ^{57}Fe on a piezo drive (thin foil piezo, fast nanosecond response). We suggested to operate the piezo drive via an arbitrary waveform generator triggered using the bunch clock such that a controlled motion is applied immediately after the synchrotron pulse excites the target. Our theoretical calculations suggested that a suitable sudden displacement of the nuclear target can achieve the desired gain.

In the experiment, we realized this setup as suggested. We used two ~150nm thickness stainless steel targets enriched in ^{57}Fe. Both were sputtered onto piezos, in order to perturb the piezo motion as little as possible. As planned, we recorded spectra for different motional patterns of the piezo drive. We employed an event-based detection method to record not only the Mössbauer velocity and the photon arrival time, but also a reference signal to characterize the piezo motion for the later data evaluation.

The key step of the ongoing data evaluation is the reconstruction of the actual piezo movement. We have already achieved good agreement between theory and experiment for the part of the motion in which corresponding spectra were measured. A full reconstruction of the complete motion is not possible since only a limited number of spectra with different delays between synchrotron excitation and piezo movement could be measured. The main reason for this is a low count rate due to the thin targets employed. Still, from this analysis, we could determine the desired spectrum of the moving piezo alone, deconvoluted from the effects of the analyzer foil used for the detection of the spectrum. An example result is shown in figure 1. The emergence of the desired gain is clearly visible in the piezo spectrum in (b).

Next to the low count rate, our data analysis is further hindered by the fact that the sputtered stainless steel targets could not be tempered in order not to damage the piezo foils. Therefore, their spectral lines are inhomogeneously broadened, which complicates an exact characterization. This in turn renders the analysis of the piezo movement by fitting the theory to the experimental spectra complicated. However, at the end of the beam time, we performed an exploratory measurement with a ~µm thickness piece of an well-defined enriched alpha-^{57}Fe foil glued onto a piezo instead of thin sputtered targets. We observed significantly higher count rates, while apparently the piezo motion could still be controlled as desired. Our results further suggest that significant improvement in the gain is possible by using suitable amplifiers to achieve higher piezo voltages, and more advanced mechanical mounting of the piezo targets. Altogether, these new approaches have great prospect for significantly improved experimental results in future experiments.

In summary, we have demonstrated the possibility to induce gain by redistributing spectral power from regions off-resonant with the nuclei into the resonant modes. This successful experiment opens a number of promising research directions. Further optimization, e.g., using new piezo targets such as the glued thicker foils may lead to significant overall gain, which could form an important step towards non-linear interactions between x-rays and nuclei. Also, this new setup allows for other motional patterns. Our theoretical calculations suggest that this enables a number of fascinating applications, and is expected to have broad significance for x-ray quantum optics as a whole.

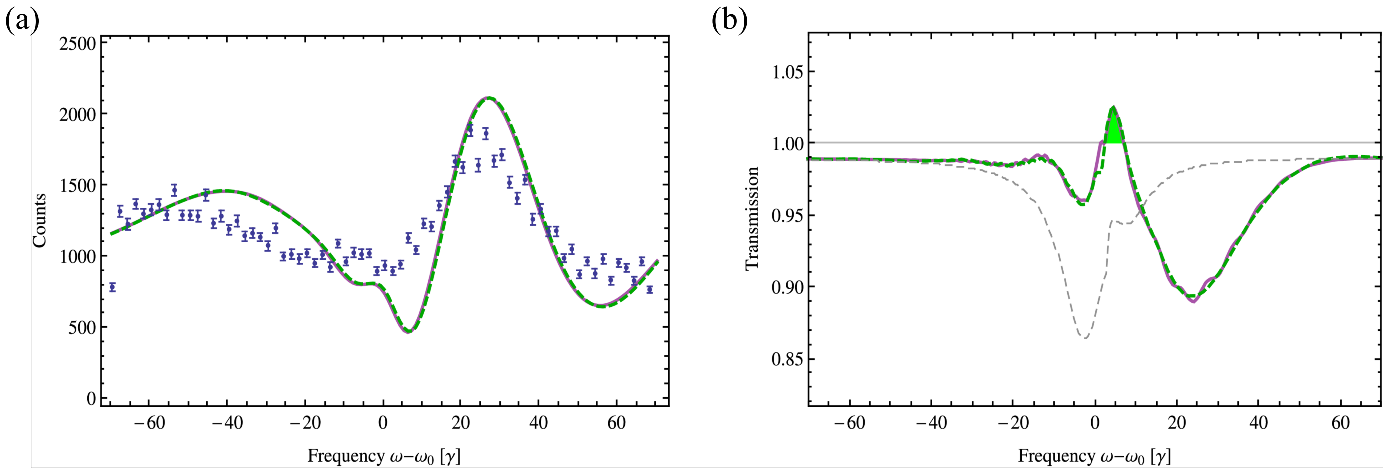

Fig. 1: Example results (preliminary data analysis). (a) shows a measured spectrum (blue dots) together with the theoretical predictions obtained from two independent methods to reconstruct the piezo movement (green dashed and purple solid). The two reconstructions coincide well. (b) shows the two corresponding theoretically reconstructed spectra of the piezo target alone, deconvoluted from the effect of the reference foil to measure the spectrum. The gray dashed curve shows the reference spectrum without motion. The solid purple and the green dashed curves show the reconstructed spectra with motion. The green shaded area indicates a spectral range in which the piezo spectrum exceeds the baseline, indicating gain. Clearly, this gain is induced by the piezo motion.