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Utilizing Artificial Intelligence Technologies for the Enhancement of X-ray Spectroscopy with Metallic-Magnetic Calorimeters

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With metallic-magnetic calorimeters (MMCs) - like the maXs-detector series developed within this collaboration - promising new tools for high precision x-ray spectroscopy application have become available. Because of their unique working principles, MMCs combine several advantages over conventional energy- and wavelength-dispersive photon detectors. They can reach spectral resolving powers of up to $E/\Delta E \approx 6000$ (at 60 keV) [1] - comparable to crystal spectrometers. At the same time, they cover a broad spectral range of typically $1 - 100$ keV similar to semiconductor detectors. Combined with their excellent linearity [2] and a sufficiently fast rise time - e.g., for coincidence measurement schemes as shown in [3] - they are particularly well suited for fundamental physics research in atomic physics. However, because of their high sensitivity, external sources of noise like fluctuating magnetic fields or physical vibrations lead to measurement artifacts like temperature dependant sensitivity drifts or the occurrence of satellite peaks (see for example [5]). Thus a shift from traditional analog to a digital signal processing is necessary to exploit the detector's full potential. During several successful benchmark experiments [3-6] a comprehensive signal analysis software framework was developed. Though, setting up the detectors and analyzing their complex behavior involves a multitude of numerical values and hardware settings to be optimized in the process. This also requires several manual steps which becomes increasingly more difficult to manage with a growing number of pixels per detector. Therefore, the usage of artificial intelligence to help with the simplification of the process and a possible improvement of the results is planned for future investigation. Starting with a simple peak characterization for a more precise identification of false-positive trigger events, up to more demanding tasks like an auto-tuning procedure to optimize the various setting of the SQUID read-out per pixel, MMC operation gives rise to a plentitude of opportunities to utilize novel AI technologies. In this work we will present our first steps and future plans regarding potential synergies between our quantum sensor technologies and AI-based algorithms for fundamental atomic physics research.

[1] J. Geist, Ph.D. Thesis, Ruprecht-Karls-Universität Heidelberg, Germany (2020)
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[3] P. Pfäfflein et al., Physica Scripta **97** (2022) 0114005
[4] M.O. Herdrich et al., X-Ray Spectrometry **49** (2020) 184–187
[5] M.O. Herdrich et al., Atoms **11** (2023) 13
[6] M.O. Herdrich et al., Eur. Phys. J. D **77** (2023) 125

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