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Precision Low-Energy X-Ray Spectroscopy With an Asymmetric von Hamos Spectrometer at CRYRING@ESR

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We present recent advancements in the development and simulation studies of a high-resolution asymmetric von Hamos (AvH) spectrometer designed for low-energy X-ray spectroscopy (5–10 keV) at the CRYRING@ESR electron cooler [1]. The spectrometer exploits the unique features of a long linear X-ray source formed by the overlap of cold electron and highly charged ion beams, combined with an electron temperature in the meV range, enabling high energy resolution.

The experimental setup will consist of two identical AvH spectrometers installed symmetrically at 0° and 180° with respect to the ion beam direction. This configuration enables simultaneous detection of red- and blue-shifted radiative recombination (RR) photons, ensuring full cancellation of Doppler-induced energy shifts. Each spectrometer uses a 100 × 100 mm² cylindrically bent Si(111) crystal with a 1 m radius and a position-sensitive Timepix3-based detector featuring 25 × 25 μm² pixels and 1.6 ns time resolution. The system is optimized for operation in photon-ion coincidence mode, allowing effective background suppression and high-purity spectroscopy.

Comprehensive Monte Carlo simulations of X-ray diffraction predict an energy resolution ranging from approximately 160 meV at 5 keV to a few eV at 10 keV, with expected sub-meV precision in measuring X-ray transition energies [2]. The long, narrow photon source and asymmetric geometry enable high sensitivity to small energy shifts and allow flexible spectrometer alignment using Bragg angle tuning.

The Technical Design Report has been formally approved, and all technical specifications have been finalized. Project execution documentation is nearing completion, and major procurement and installation steps are scheduled between 2026 and 2028. Once operational, the AvH spectrometer will enable precision measurements of X-rays from radiative recombination and cascade transitions in mid-Z H- and He-like ions. These measurements will provide access to subtle quantum electrodynamics (QED) effects, including two-loop corrections and nuclear size contributions, with unprecedented experimental accuracy.

References:

[1] M. Lestinsky et al., *Eur. Phys. J. Special Topics* **225**, 797 (2016).
[2] P. Jagodziński et al., *J. Instrum.* **18**, 11002 (2023).

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