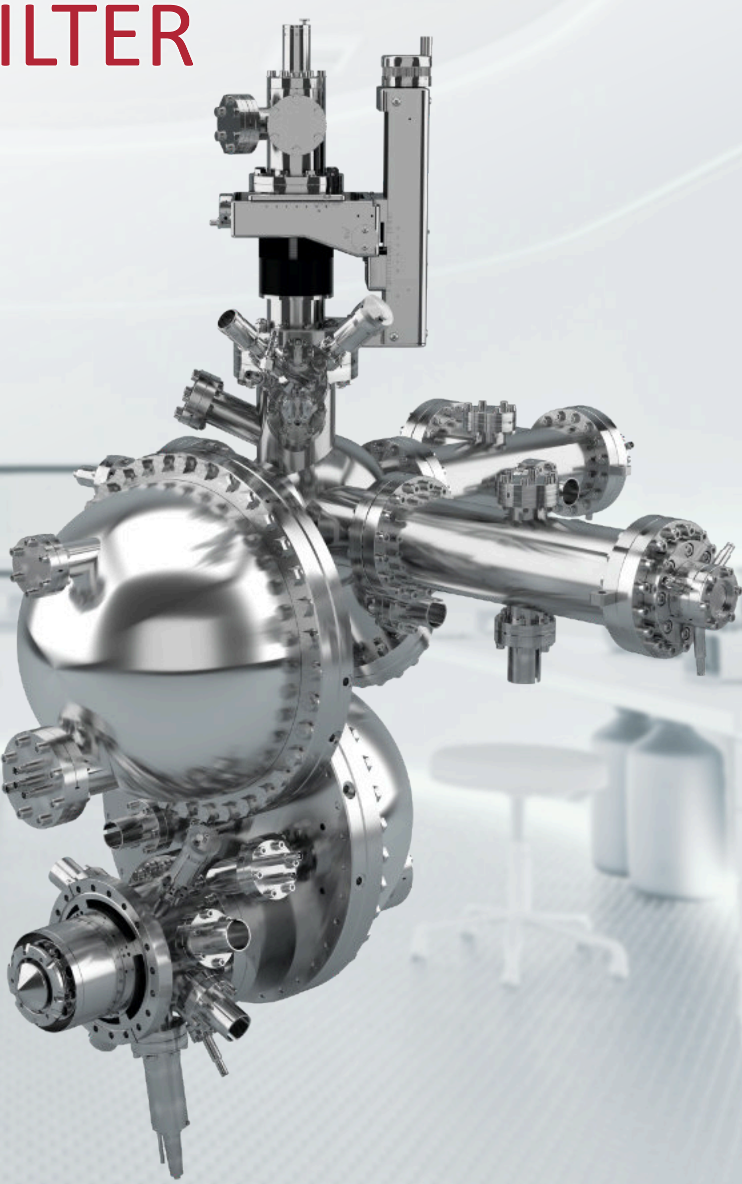
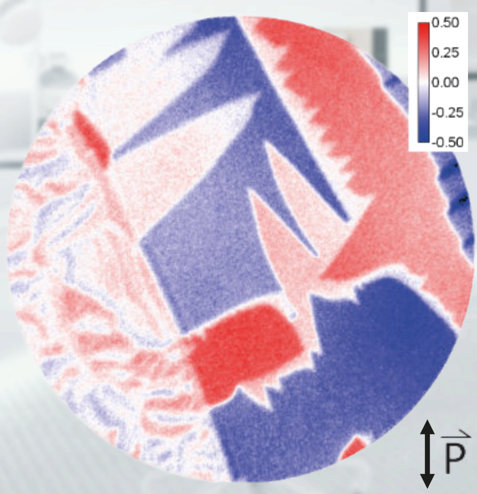
Highly Parallelized Spin Detection

# IMAGING SPIN FILTER





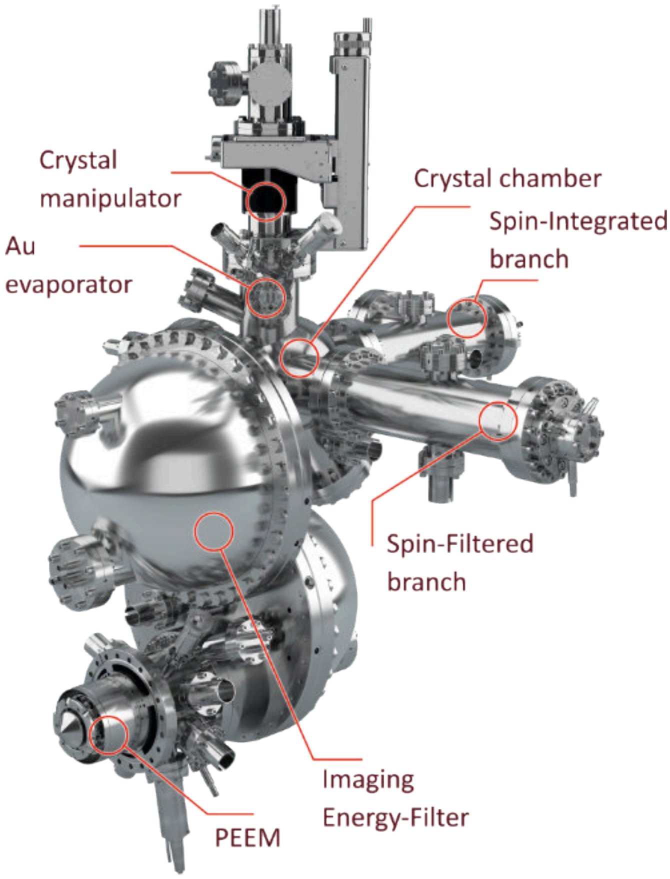

The spin filtered PEEM image of a poly-crystalline iron sample shows a strong spin contrast for different magnetic domains.

- The High-Tech Extension for the NanoESCA
- Spin resolved images in real and momentum space
- Stable working conditions for weeks
- Sherman function > 60%
- Reflectivity > 1%
- Ultimate efficiency due to > $10^4$ parallel detection channels

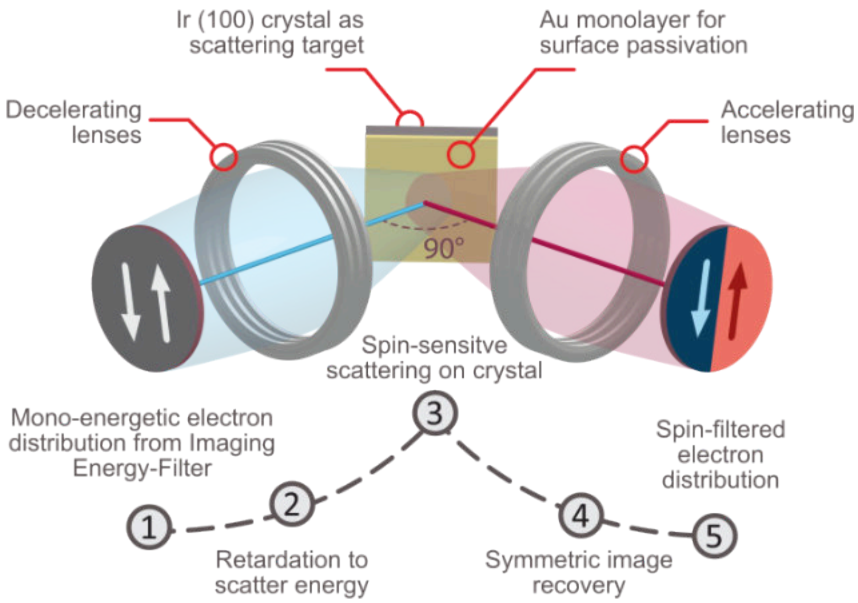
# A NEW APPROACH TO SPIN FILTERING

The instant spin filtering of a microscopy image takes the efficiency of spin related research to a new level. In combination with a NanoESCA analyzer, spin structures in real space (e.g. magnetic domains) as well as in momentum space (e.g. electronic band structure) can be examined.

The monochromatic image delivered by the NanoESCA is a prerequisite for the defined kinetic electron energy needed for the spin-sensitive scattering process at the Au/Ir crystal.




# SPIN FILTER WORKING PRINCIPAL




The monochromatic image delivered by the Imaging Energy-Filter of the NanoESCA is projected onto a Au/Ir crystal.
For specific kinetic electron energies (see Fig. 1, a), one spin polarization is strongly preferred in the scattering process due to spin-orbit coupling. The reflected image is spin-filtered. The Au passivated surface of the Ir crystal keeps the scattering conditions stable for weeks.

Pre-characterizations of the Au/Ir crystal were done with LEED and a Ferrum-Detector setup [1] to find optimal preparation conditions and scattering energies for a high single-point figure-of-merit (with Spin-sensitivity >60% and Reflectivity >1%) [2]. The I-V-curve in (Fig. 1, a) was measured with the Ferrum setup and shows, at which scattering energy the highest spin-sensitivity can be reached. Images (Fig. 1, b,c) are then acquired at these two energetically sharp working points with the NanoESCA and are used to calculate the spin-polarization of the complete field-of-view (Fig. 2).


*[1] Escher, et al., e-J. Surf. Sci. Nanotech. Vol. 9, 340-343 (2011)*
*[2] C.Tusche et al., Ultramicroscopy 159, 520–529 (2015)*

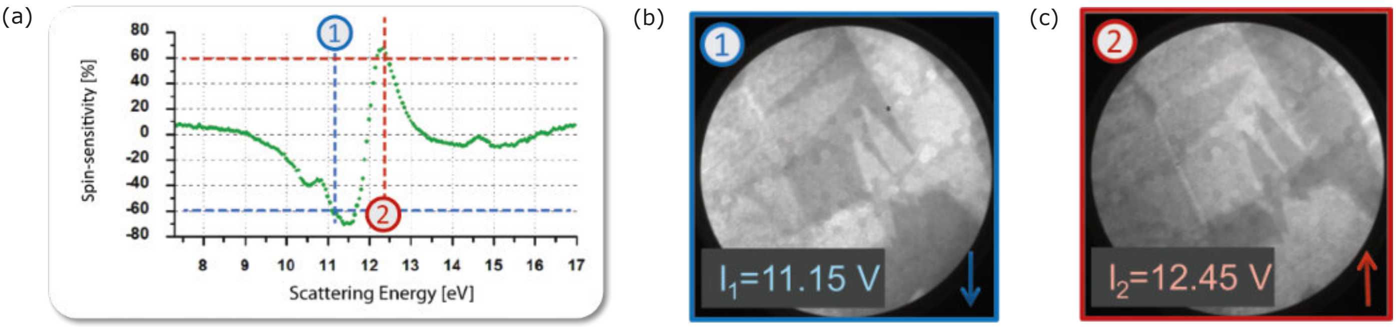



**Figure 1:** Precharacterization and spin-filtered raw images. (a) I-V-curve showing the spin sensitivity as a function of the scattering energy at the Au/Ir crystal. The raw images (b,c) were acquired at the working points with the highest spin polarization (1,2). The two working points are sensitive to opposite spin directions which results in the contrast inversion of the two images.

# PARALLEL DETECTION OF SPIN-CHANNELS

The already high single-point figure-of-merit for the Au/Ir crystal (Sherman function > 60% and Reflectivity > 1%) is multiplied by the amount of parallel detection channels given in the Imaging Spin Filter to define an effective 2D figure-of-merit. It is four orders of magnitude larger than the figure-of-merit of single-point detectors [3].

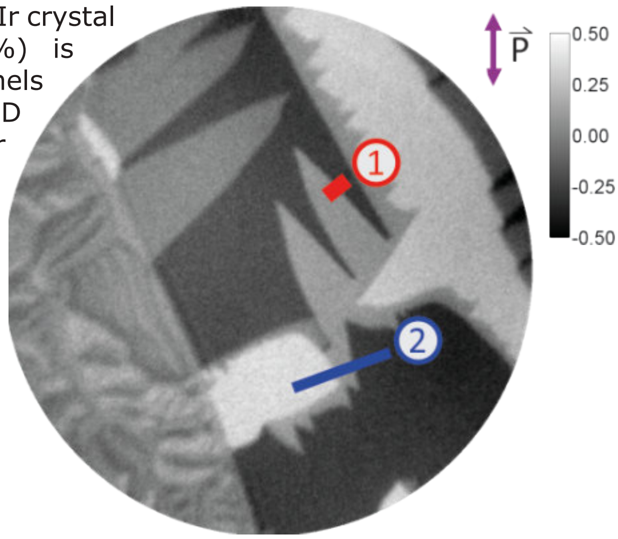



**Figure 2:** The spin filtered PEEM image of a poly-crystalline iron sample shows a strong spin contrast for different magnetic domains. The indicated line profiles are shown in Fig. 3.

### Estimation of parallel detection channels

- Field of View = 996 pixel along the diameter
- Resolution of domain boundary = 7 pixel (Fig. 3,a)
- 142 resolvable image points (along diameter)
- $\pi \cdot (142/2)^2$ = 15900 parallel detection channels

*[3] M. Escher, et al., Ultramicroscopy 253 (2023) 113814*

Measured with: NanoESCA, ELI-ALPS, Hg-discharge lamp excitation, 100 meV instrumental energy resolution, Room temperature, 200 s exposure time, 66 µm lateral FoV

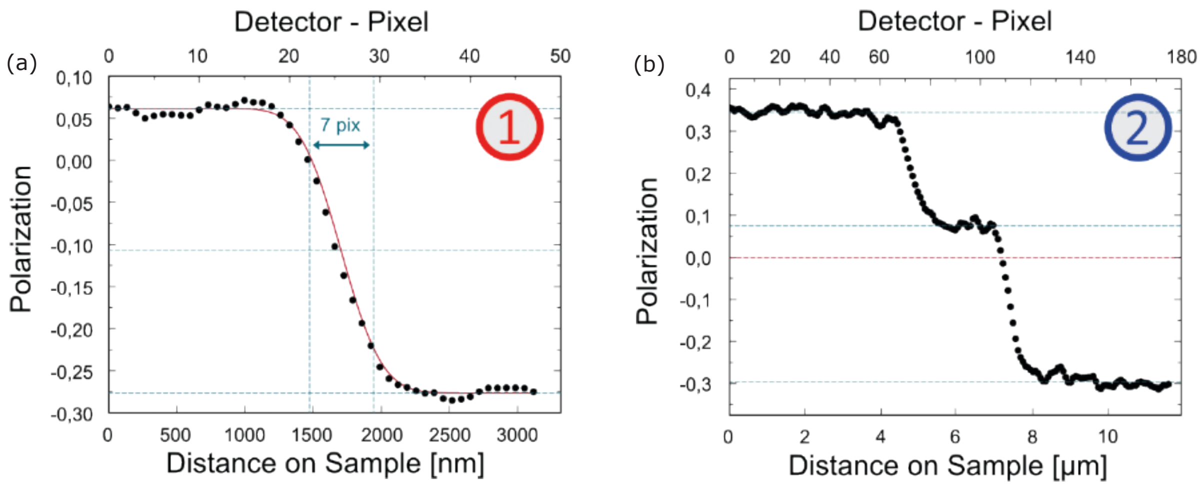
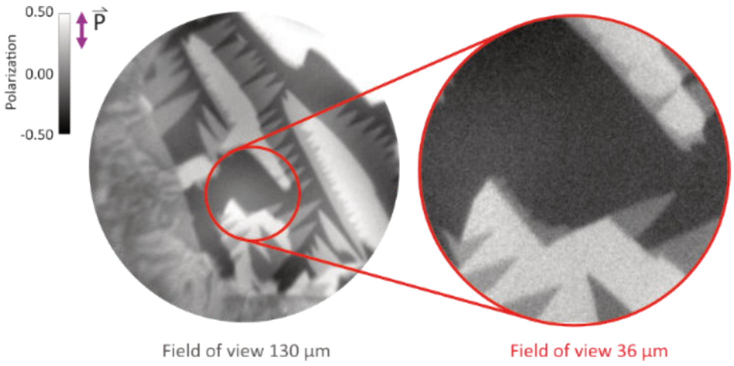



**Figure 3:** The line profiles (taken from Fig. 2) show the level of spin polarization of different domains. The edge resolution reveals 142 resolvable image points along the diameter which corresponds to more than $10^4$ parallel detection channels for the detector.

# FLEXIBLE ZOOM RANGE

The NanoESCA microscope allows to adjust the field-of-view over a wide range (6 - 800 µm). Spin structures can thus be imaged in various levels of detail.

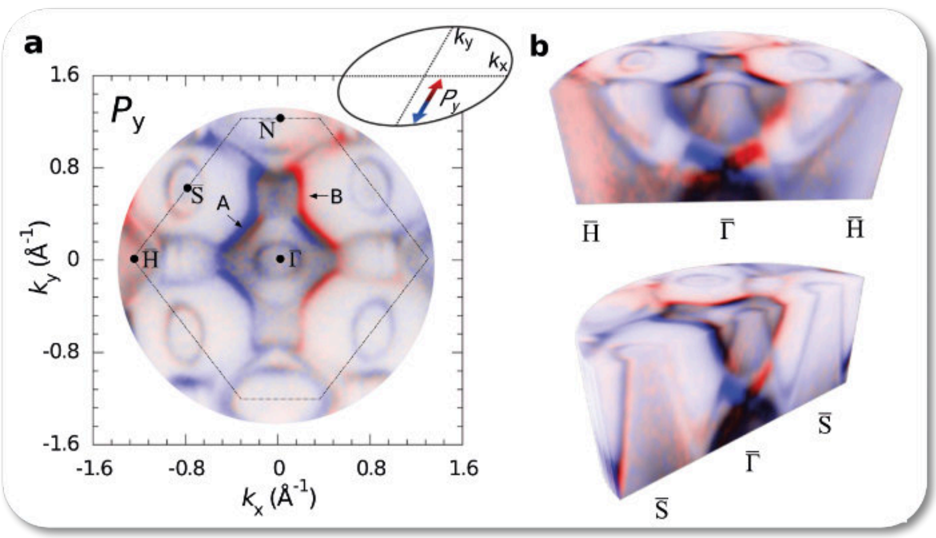


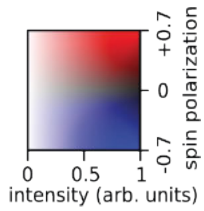

## WHY ARE THE NANOESCA AND THE IMAGING SPIN FILTER THE PERFECT MATCH?

The spin filter process utilizes a spin-dependent back-scattering of low energetic electrons from the Au/Ir target. The spin-sensitivity of the scattering process is a function of the scattering energy with very sharp features (Fig. 1, a). It is important, that the electrons have a precise kinetic energy which is homogenous across the whole microscopy image. The double-hemispherical energy filter of the NanoESCA is the best choice for providing a narrow energy bandwidth electron image with high transmission, which can be used for the Imaging Spin Filter. A perfect match!

# SPIN FILTERED BAND STRUCTURE MAPPING

The Imaging Spin Filter works in the momentum space microscopy mode in the same way as in the real space microscopy mode. The graphic shows the spin-resolved Fermi surface of W(110) (a) as well as full 3D spin-resolved momentum maps (momentum vs. binding energy) (b). This experiment was performed with a W(100) crystal as scattering target. The new Au/Ir target is more efficient and also suitable for the use with laboratory light sources.




Measured with:
NanoESCA, Elettra (Trieste, Italy), Synchrotron radiation, hv=50 eV, p-polarized, T=130 K

*Adapted from: Ying-Jiun Chen, Christian Tusche et al., Comm. Phys. (2021) 4:179 (CC-by 4.0 License)*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