**Engineering Designer Neutrons for Fundamental Physics Experiments**

The structure of the neutron wavefunction is an important quality in neutron optics. It is well known that the coherence length of the wavepacket is a limiting factor for the resolution of most neutron scattering instruments. N(R)SE techniques use magnetic fields to split neutron wavefunctions into two spatially separated parts with opposite spin [1]. By using this simple structured wave, these techniques can exceed the resolution limits of their classical analogues (i.e. ToF or SANS). In recent years it has been demonstrated that wavefunctions exhibiting more complicated structures, specifically wavefunctions with orbital angular momentum (OAM), could be used to extract the real and imaginary parts of the scattering amplitude in neutron scattering experiments [2,3]. In this talk I will demonstrate how NRSE techniques can be employed to engineer structured waves exhibiting OAM by coherent averaging [4-6]. In addition, the new NRSE interferometer at the Vienna Atominstitut for generating and measuring structured wavefunctions will be presented. Finally, three fundamental applications of structured waves in NRSE interferometry will be discussed. Firstly the search for OAM dependent scattering cross sections, secondly the Sagnac effect, a coupling between neutron OAM and the rotation of the earth and finally Bell inequalities in time, also known as Legget-Garg inequalities.

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[4]: D. Sarenac et al., PRL **121** 183602 (2018).
[5]: D. Sarenac et al., PNAS 116 20328-20332 (2019).
[6]: N. Geerits et al., Comm. Phys. **6** 209 (2023).