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How Entanglement Uncovers Entanglement

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Can quantum entangled probes uncover the inherent entanglement of the target matter? We have recently developed a fundamentally new quantum probe, an entangled neutron beam, where individual neutrons can be entangled in spin, trajectory and energy. To demonstrate entanglement in these beams we crafted neutron interferometric measurements of contextuality inequalities whose violation provided an indication of the breakdown of Einstein's local realism. In turn, the tunable entanglement length of the neutron beam from nanometers to microns and energy differences from peV to neV opens a pathway to a future era of entangled neutron scattering in matter. What kind of information can be extracted with this novel entangled probe? A recent general quantum entangled-probe scattering theory provides a framework to respond to this question. Interestingly, by carefully tuning the probe's entanglement and inherent coherence properties, one can directly access the intrinsic entanglement of the target material. This theoretical framework supports the view that our entangled beam can be used as a multipurpose scientific tool. We are currently pursuing several ideas for future experiments in candidate quantum spin liquids, unconventional superconductors, and topological quantum materials.