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True Limits to Precision via Unique Quantum Probe

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Quantum instruments derived from composite systems allow greater measurement precision than their classical counterparts due to coherences maintained between N components; spins, atoms or photons. Decoherence that plagues real-world devices can be particle loss, or thermal excitation and relaxation, or dephasing due to external noise sources (and also due to prior parameter uncertainty). All these adversely affect precision estimation of time, phase or frequency. We develop a novel technique uncovering the uniquely optimal probe states of the N "qubits" alongside new tight bounds on precision under local and collective mechanisms of these noise types above. For large quantum ensembles where numerical techniques fail, the problem reduces by analogy to finding the ground state of a 1-D particle in a potential well; the shape of the well is dictated by the type and strength of decoherence. The formalism is applied to prototypical Mach-Zehnder and Ramsey interferometers to discover the ultimate performance of real-world instruments.

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