Enhancing Phase Estimation by Harnessing Negative Quasiprobabilities

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Operator noncommutation, a hallmark of quantum theory, limits measurement precision, according to uncertainty principles. Wielded correctly, though, noncommutation can boost precision. A recent foundational result relates a metrological advantage with negative quasiprobabilities-quantum extensions of probabilities-engendered by noncommuting operators. We crystallize the relationship in an equation that we prove theoretically and observe experimentally. Our proof-of-principle optical experiment features a filtering technique that we term partially postselected amplification (PPA). Using PPA, we measure a waveplate's birefringent phase. PPA amplifies, by over two orders of magnitude, the information obtained about the phase per detected photon. In principle, PPA can boost the information obtained from the average filtered photon by an arbitrarily large factor. The filter's amplification of systematic errors, we find, bounds the theoretically unlimited advantage in practice. PPA can facilitate any phase measurement and mitigates challenges that scale with trial number, such as proportional noise and detector saturation. By quantifying PPA's metrological advantage with quasiprobabilities, we reveal deep connections between quantum foundations and precision measurement.