Single-Photon Gyroscope: Quantum Metrology for Relativistic Physics

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Recent advances in quantum-interference–based metrology [1] and single photon detection technologies (as for example superconductive nanowires) have enabled unprecedented sensitivities, opening new opportunities to probe the interplay between quantum mechanics and special or general relativity [2]. Building on these developments, and as detailed in [3], we present the first thermal-state single-photon fiber-optic gyroscope (spFOG). We demonstrate that this device reaches zeptosecond-level delay sensitivity, providing a proof of concept for extremely precise phase detection. Its performance is sufficient to resolve special-relativistic effects—such as the Sagnac phase shift from Earth's rotation—using intrinsically quantum probes. The proposed spFOG reaches 93–95% of the Cramér–Rao bound in direct measurements, while the differential detection scheme ($\Delta\tau$), immune to pump instabilities and drifts, attains a saturation exceeding $S(\Delta\tau) > 99.5\%$. This configuration therefore maximizes the information extracted from each detected photon. Moreover, with a total enclosed area of 125 m², the drift-free sensitivity at $t = 10^4$ s corresponds to a detection limit per unit area of 1.2×10^{-16} s/km^2. This performance lies well within the range required to observe special-relativistic effects associated with Earth's rotation, whose upper sensitivity bound has been estimated by Brady et al. [2] to be on the order of 10^{-15} s/km^2.

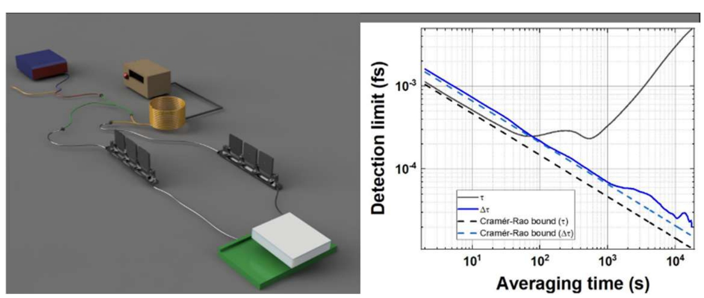

Fig. 1: *Right: 3D sketch of the optical setup. Left: Detection limit as a function of averaging time*

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References

[1] Lyons, Ashley, et al. "Attosecond-resolution hong-ou-mandel interferometry." *Science advances* 4.5 (2018): eaap9416.

[2] Brady, Anthony J., and Stav Haldar. "Frame dragging and the Hong-Ou-Mandel dip: Gravitational effects in multiphoton interference." *Physical Review Research* 3.2 (2021): 023024.

[3] Sgobba, Fabrizio, et al. "Zeptosecond-Scale Single-Photon Gyroscope." *Advanced Quantum Technologies* 7.9 (2024): 2400166.