Effect of environment on the interferometry of clocks

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Abstract. Mach-Zehnder (MZ) interferometry involving spatial superposition of a massive particle with its internal degrees of freedom (DOF) modelled as clocks had been previously proposed as an experiment encapsulating genuine general relativistic effects on quantum systems. We have analysed a realistic model of the clocks in which they are subject to the effects of environment leading to noise during their transit through the arms of the interferometer. We have shown that interferometric visibility is affected by the type of noise and also the time scale and transition probabilities in the noise models representing the environmental effects.

Keywords: Mach-Zehnder, Visibility, Environment

The fundamental idea in the recent proposals [1, others] towards exploring the interplay between quantum mechanics and gravity is that of a quantum system acting as a clock effected by time dilation. In brief, the proposal consists of a clock prepared in a spatial superposition evolving through different proper times (due to gravity) in the arms of a MZ interferometer (Fig. 1). Through the evolution with proper time, the internal degree of freedom (DOF) of the clock (constituted by energy levels) get entangled with its external DOF (position of the centre of mass). As such, the clock acquires which path information and this leads to a drop in interferometric visibility on the account of a widely known complementarity principle. However, in such an experiment the DOF may be prone to environmental effects which raises the question that how is the interferometric visibility affected by noise.

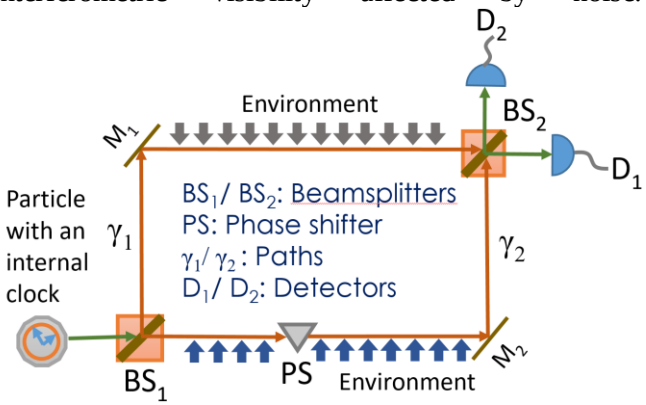

Fig. 1 MZ setup with the elements marked in the fig itself

While the answer is straightforward if the noise is acting on external DOF, contradicting inferences can be drawn in the scenario wherein noise affects the internal DOF. One may expect the visibility to decrease on the account of corruption of which path information but on the other hand, by modelling the environment as quantum DOF, which increase the dimensionality of the timekeeping system, one expects the visibility to increase – simply going by the complementarity principle.

In this work, we resolve the above contention by probing the effect of noise on internal DOF by modelling it effectively as the application of standard quantum channels on the clock DOF or by the Jaynes-Cummings (JC) model whereby the clock interacts with a bosonic bath.

We have compared the visibility offered by the different noise models in Fig. 2 for various noise strength parameters (λ). In general, we find that the effect of environment may also lead to higher visibility than that without the environment as seen for the depolarizing (DP) channel in Fig. 2, which is a very interesting result. Intuitively, it can be expected that the visibility shall fall for small difference in proper time in the low noise regime as the effect of extended Hilbert space of the clock system overwhelms the loss in which path information. We have explicitly shown this to be true for all types of noise models considered.

For details of the method used and individual analyses of noise models, please refer to the arxiv link.

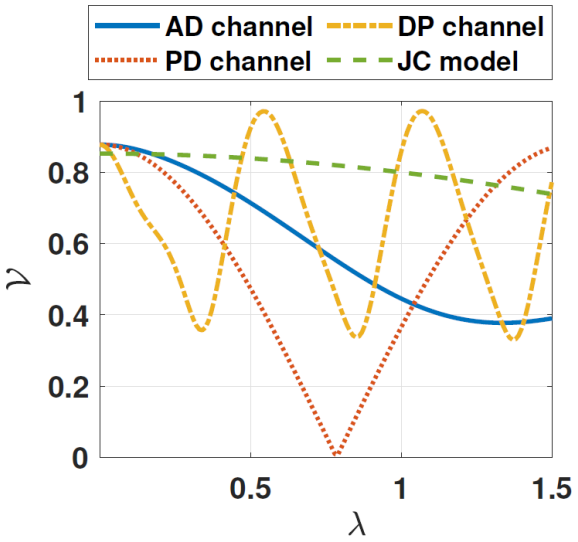

Fig. 2 Comparison of visibilities offered by different channels for different noise strength parmeter (λ)

References

[1] M. Zych et al., "Quantum interferometric visibility as a witness of general relativistic proper time". Nature Communications 2 (2011), p. 505.