Maximal negation of macrorealism of a qubit under PT symmetric dynamics

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Abstract. We investigate the three-term Leggett-Garg inequality (LGI) for a two-level quantum system undergoing Parity-Time (PT) symmetric dynamics governed by a non-Hermitian Hamiltonian, when a sequence of dichotomic projective measurements are carried out at different time intervals. In contrast to the case of coherent unitary dynamics, violation of LGI is shown to increase beyond the temporal Tsirelson bound 3/2 and approach its algebraic maximum value 3, in the limit of the spontaneous PT symmetry breaking point.

Keywords: Quantum Correlations, Leggett-Garg inequality, PT symmetry, Quantum foundations

Quantum and classical descriptions of correlations between observables differ drastically. Correlations between observables of spatially separated quantum entangled systems do not adhere to Bell's local realism by violating the Bell-CHSH inequality [1,2]. Similarly, through the violation of Leggett-Garg inequalities (LGI), *temporal correlations* between observables in a single quantum system do not abide to the worldview of *macrorealism* [3,4].

Analogous to how the Tsirelson bound determines the highest violation of Bell-CHSH inequality [5], quantum Temporal Tsirelson Bound (TTB) has been evaluated for LGI. Violations beyond the Tsirelson bound of a Bell-CHSH inequality cannot be realized by spatial correlations in the quantum realm even though the inequality admits an algebraic maximum value. However, violation of LGI beyond the TTB up to its algebraic maximum has been shown to be realized within the quantum scenario for systems belonging to Hilbert space dimension N >2. It is reported that the algebraic maximum of LGI can only be attained when the dimension of the system approaches infinity [6]. This contrast between spatial and temporal correlations with respect to violations larger than the Tsirelson bound, prompts us to ask: "Can two-level systems (qubits), being genuinely quantum in nature, negate macrorealism to the algebraic limit?"

In this work, we answer the above question in the affirmative and report violation of LGI higher than the TTB in a qubit undergoing PT symmetric non-unitary dynamics. We have taken a deviation from the standard framework of unitary dynamics generated by a Hermitian Hamiltonian (for measuring temporal correlations); we consider non-unitary dynamics generated by a non-Hermitian PT symmetric Hamiltonian which has been attracting increasing attention due to its peculiar features around critical points [7,10]. Moreover, current experimental advances indicate that it is possible to engineer/simulate such PT symmetric evolution via Naimark extension into a larger unitary system [7-11].

Results:

Consider the three-term LGI: $-3 \leq K_3 \equiv C_{21}+C_{32}-C_{31} \leq 1$ where $C_{ji} = \langle Q(t_j)Q(t_i)\rangle$ denote temporal correlations of a dichotomic observable Q with outcomes ±1, measured at two different time intervals $t_j>t_i$. We evaluate the two time correlations of the observable σ_y on a qubit initially in a maximally mixed state under the PT symmetric evolution: $U(t) = e^{-iHt}$ $where\ H = s\begin{pmatrix} isin(\alpha) & 1 \\ 1 & -isin(\alpha)\end{pmatrix}$; $s,\alpha \in \mathbb{R}$, $\hbar=1$. The Hamiltonian H is Hermitian for α=0. For α>0, it is non-hermitian but possesses real eigenvalues ($E_\pm=\pm s\cos(\alpha)$). In this regime, violation beyond TTB is observed. At the critical point $\alpha=\pm\pi/2$, spontaneous breaking of the symmetry occurs and here we witness the algebraic maximum violation of LGI!(Fig.1)[12].

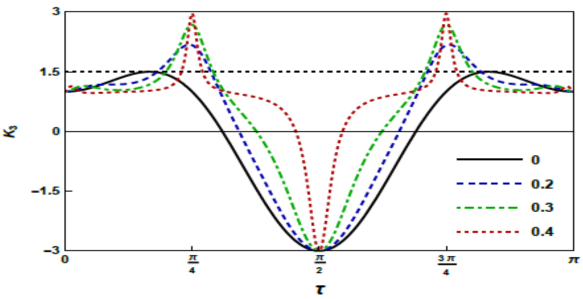

Figure 1 LGI parameter K_3 vs τ (scaled time step) On the side is α/π. At τ = π/4 and α/π→0.5, K_3→3.

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