Macroscopic Locality and same-biasness condition almost reproduces quantum-distribution achieving Tsirelson's bound

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Abstract. It has been proved that the quantum mechanical probability distribution can not be reproduced under consideration of Information Causality (IC) or Macroscopic Locality (ML), alone. Thus it becomes interesting whether separate consideration of these two principles along with some further plausible physically motivated constraints can reproduce quantum distribution. In this article we show that under ML, along with constraint of *equal biasness* for local measurement results, a general no signaling probability distribution, with Bell violation equal to optimal quantum value, becomes identical to quantum distribution. The necessary condition of IC remains unsatisfactory to reproduce the desired results.

Keywords: Macroscopic Locality, Tsirelson's bound, quantum-distribution

Quantum mechanics is the most accurate theory to explain the physical phenomenon of microscopic world. But, till date, its foundation lags physical explanation and starts with some abstract mathematical axioms. Along with various non-classical concepts, like Heisenberg's uncertainty principle and Bohr's complementarity principle, one of the most counter intuitive non-classical feature of quantum mechanics is that it exhibits correlation that can not have local causal description. Correlations with this surprising property are commonly known as nonlocal correlations, which have been certified by violation of celebrated Bell inequality. However, Tsirelson first proved that amount of Bell-Clauser-Horne-Shimony-Holt (B-CHSH) violation in quantum mechanics is upper bounded by $2\sqrt{2}$. Interestingly, in 1994 Popescu and Rohrlich pointed out existence of correlation, compatible with relativistic causality or no-signalig (NS) condition, that violates B-CHSH inequality up to its maximum algebraic value equal to 4. Then they asked the following question: why quantum correlations cannot violate B-CHSH inequality more than the Tsirelson's bound? This question motivates researchers in constructing quantum mechanics with generalized nonlocal theory (GNLT) respecting the no-signaling condition.

In the recent past, some physically motivated principles like, Information Causality (IC) and Macroscopic Locality (ML), have been introduced with the aim to separate quantum mechanics from the other GNLTs as the only theory of physical world. Though these principles explain some elegant features of quantum mechanics, it may not be possible to derive all features of quantum mechanics from these principles, alone. On the other hand it has been proved that the optimal B-CHSH violation in quantum mechanics can be explained as manifestation of different non classical features of quantum mechanics like uncertainty principle as well as complementarity principle. So it becomes interesting to study whether ML or IC along with some further plausible constraints, motivated from quantum mechanics itself, can reproduce quantum probability distribution or some important features of quantum mechanics. This approach also allow us to compare the relative strength of different principles in reproducing that particular feature of quantum mechanics with respect to that constraints.

It is well known that B-CHSH violation in quantum mechanics is restricted to Tsirelson bound and this bound is uniquely achieved from maximally entangled state (e.g. singlet) by performing two suitably chosen dichotomic spin measurements on each part of the entangled pair. According to Born's rule, in maximally entangled state the marginal probability distribution for all the four observables, two at each end of the singlet, are equal and uniform i.e. completely random ; however, in GNLT this is not the only solution, i.e., for $2\sqrt{2}$ B-CHSH violation, complete randomness of local outcomes is not a necessity. Therefore correlations achieving Tsirelson's value in quantum mechanics have some stringent features namely- (a) *equal biasness* for local outcomes and (b) *complete randomness*: all the marginals are completely random. It has been shown that under separate consideration of IC and ML, Tsirelson bound can be derived. But neither IC nor ML can reproduce any of the above features, namely *equal biasness* and *complete randomness*.

In this paper we pose the following question;

We consider a general (no-signaling) bipartite correlation with violation of B-CHSH by $2\sqrt{2}$. Then we impose the condition of *equal biasness* as a constraint. Now we want to see whether feature of *complete randomness* is reproduced under separate consideration of IC principle and ML principle. Under necessary condition of IC we find that it allows correlations which assigns 65% randomness of measurement results to all the four observables, which is far apart from quantum *complete random-*

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ness. Interestingly under ML, we find that all the four obsevables becomes completely random like quantum correlation. More importantly, not only the marginal distribution but also the joint probability distribution allowed by ML is almost identical to quantum joint distribution, whereas the joint distribution under IC is much different from that of quantum one. It remains an interesting open question whether the aforementioned quantum feature is reproduced under the same constrains along with the condition of IC, which is both necessary and sufficient. Of course such condition remains unknown till date.