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The Bell-CHSH inequality in 2D fermion theories: numerical and formal study via bumpified Haar wavelets, from free to interacting case

Monday 26 May 2025 12:00 (45 minutes)

We investigate the violation of the Bell-CHSH inequality in the vacuum state in the context of Quantum Field Theory. Summers and Werner showed in the eighties, using tools from algebraic quantum field theory and operator analysis, that test functions exist that lead to an asymptotic reaching of Tsirelson's upper bound violation of 2 \sqrt 2.

We propose a different strategy that allows to explicitly construct such test functions. We apply the method to massless spinor fields in (1+1)-dimensional Minkowski space-time. Alice's and Bob's test functions are numerically constructed, first by employing Haar wavelets which are then massaged into proper C^\infty bump functions via a smoothening procedure relying on the Planck-taper window function. Relativistic causality is implemented by requiring the support of Alice's and Bob's test functions to be located in the left and right Rindler wedges, respectively. Violations of the Bell-CHSH inequality as close as numerically desired to Tsirelson's bound of 2 \sqrt 2 are reported.

The bumpification procedure can be brought under rigorous mathematical control. For the asymptotic reaching of the Tsirelson's bound, we show how to match the issue onto a Toeplitz matrix problem and its spectral properties. This allows to already give a formal proof for reaching 99,3% of the upper bound.

We end by commenting on the extra portal, compared to earlier works, that our numerical procedure opens to scrutinize Bell-CHSH inequalities with generic, interacting Quantum Field Theories, a yet unexplored area of research. Here, the spectral representation in Minkowski space enters the game.

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