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On a rigorous Framework for a Quantum N-Body Theory on curved Spacetime

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The construction of a mathematically rigorous relativistic quantum theory has so far remained elusive. Within the 'axiomatic quantum field theory in curved spacetime' research program it has been acknowledged that such a theory needs to be compatible with the general-relativistic conception of a spacetime. That is, one may not rely on the symmetries of Minkowski spacetime in formulating the axioms of such a theory, even if one is merely interested in the special-relativistic case. In the aforementioned approach mathematical physicists thus attempted to generalize the Wightman axioms to the general-relativistic setting.
In this work, we pursue a more direct and arguably more physical ansatz by generalizing the N-body Born rule from non-relativistic quantum mechanics to curved spacetime. We first review the one-body case, closely tied to the mathematical theory of the relativistic continuity equation, and then generalize the general-relativistic spacetime concept to the case of N-bodies (with 'fixed background'). We show how the conservation of probability therein is mathematically tied to the validity of a scalar many-body continuity equation—as one would a priori expect. If it holds, the integrand for calculating the respective detection probability turns out to be an absolute invariant in the sense of Poincaré-Cartan, so that a 'preferred spacetime splitting' is not required.
The general-relativistic N-body Born rule presented here allows one to infer important, structural aspects of a rigorous relativistic quantum theory, and it provides an essential step towards the more general case in which N is allowed to vary. The formalism overcomes some problems of related approaches in the literature, including the use of non-canonical geometric structures and overly restrictive causal/topological conditions (see Reddiger & Poirier, arXiv:2012.05212 [Math-Ph] (2020)).

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