HORIZON 2020

Infinite-dimensional quantum effects

Reporting

Project Information

InDiQE

Grant agreement ID: 845486

Project website

DOI
10.3030/845486

Project closed

EC signature date
11 April 2019

Start date
1 June 2019

End date
31 May 2021

Funded under
EXCELLENT SCIENCE - Marie Skłodowska-Curie Actions

Total cost
€ 174 167,04

EU contribution
€ 174 167,04

Coordinated by
OESTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN
Austria

Periodic Reporting for period 1 - InDiQE (Infinite-dimensional quantum effects)

Reporting period: 2019-06-01 to 2021-05-31

Summary of the context and overall objectives of the project

The fundamental understanding of quantum correlations, as well as their characterization and quantification, play a fundamental role for information processing and communication. The investigation of quantum correlations in high-dimensional, infinite dimensional or hybrid systems is of particular interest for the development of novel applications in quantum technologies. High-

dimensional states contain potentially a large amount of quantum correlations, which represents a vital resource for applications in quantum information processing. The goal of this proposal is to find an optimal strategy to exploit this resource. Crucial open problems to be solved are the continuation of the development of mathematical methods and observable conditions for a convenient description of general high-dimensional systems, and verifying as well as quantifying general quantum correlations in high-dimensional and multipartite systems. This project is placed at the border between quantum information theory and quantum optics, exploring the potential of high and infinite dimensional systems for quantum information tasks. We aimed at furthering these developments through the following main objectives:
The formulation of experimentally accessible criteria for certifying and quantifying genuine quantum correlations.
The investigation of efficient techniques to store, transmit, extract or quantify quantum information from highly dimensional states.
The characterization of discrete- and continuous-variables hybrid systems and the discretization problem.
The advance in the understanding of practical systems and realistic scenarios for quantum information tasks and quantum thermodynamics applications.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Our starting point was to research on possible formulations of experimentally accessible criteria for certifying and quantifying genuine quantum correlations. First, we proposed a method for the conditional generation of nonclassical states of light in a cavity [Phys. Rev. A 100, 043812 (2019)]. Nonclassical properties of the cavity mode, as quadrature squeezing, sub-Poissonian photon-number distributions, and negative Wigner function, are identified and characterized. Next, we derive a family of inequalities (based on Chebyshev's inequality) involving different phase-space distributions of a quantum state which have to be fulfilled by any classical state [Phys. Rev. Lett. 124, 133601 (2020)]. The violation of these inequalities is a clear signature of nonclassicality. Our approach combines the characterization of nonclassical effects via negativities in phase-space distributions with inequality conditions usually being formulated for moments of physical observables. Importantly, the obtained criteria certify nonclassicality even when the involved phase-space distributions are non-negative. Following this lead, we look for the possibilities of generalization of such phase space inequalities. Thus, we devise a method to certify nonclassical features via correlations of phase-space distributions by unifying the notions of quasiprobabilities and matrices of correlation functions [Quantum 4, 343 (2020)]. The method developed here correlates arbitrary phase-space functions at arbitrary points in phase space, including multimode scenarios and higher-order correlations. To demonstrate the power of our technique, the quantum characteristics of discrete- and continuous-variable, single- and multimode, as well as pure and mixed states are certified only employing second-order correlations and Husimi functions, which always resemble a classical probability distribution. Once our method was proposed and generalized, we team up with experimentalists to certify experimentally nonclassicality via phase-space inequalities [Phys. Rev. Lett. 126, 023605 (2021)]. In addition, we implement a robust kind of nonclassical photon-photon correlated state, with quantum correlations beyond entanglement and quantum discord, with useful applications in quantum information processing. For this contribution, we team up with experimental and theory groups in Germany to certify the presence of such quantum correlations via negativities in the regularized two-mode Glauber-Sudarshan function [Phys. Rev. Lett. 126, 170404 (2021)] and also show how multimode entanglement can be activated based on the generated, nonentangled state.

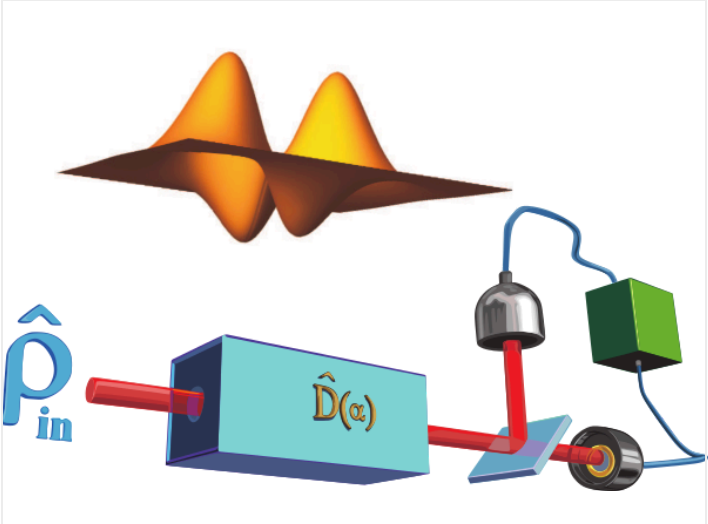
We worked on the investigation of efficient techniques to either certify, store, transmit, extract or quantify quantum information from highly dimensional states, independently if they are DV or CV systems. We explored different aspects of characterization and measurements of quantum states and parameters. Firstly, we considered three paradigmatic estimation schemes in continuous-variable quantum metrology and analysed them from the Bayesian perspective [Quantum Sci. Technol. 6 025018 (2021)]. We identify Bayesian estimation strategies that combine good performance with the potential for straightforward experimental realization in terms of Gaussian states and measurements. Besides precision, the fast and accessible verification of nonclassical resources is an indispensable step towards a broad utilization of continuous-variable quantum technologies. We use machine learning methods for the identification of nonclassicality of quantum states of light by processing experimental data obtained via homodyne detection [Phys. Rev. Research 3, 023229 (2021)]. For this purpose, we train an artificial neural network to classify classical and nonclassical states from their quadrature-measurement distributions.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

The implementation of high-capacity and ultra-secure quantum information networks rely on the possibility to generate and precisely manipulate multipartite, highly dimensional, and strongly correlated systems. Understanding the correlations and control of such physical systems is a research field in the making that boasts a steady increase in efforts. Most developments in this field thus go beyond the state of the art. The results of this project have contributed to strengthening both the conceptual and technical foundations of these general developments. Fundamentally, the present project has laid the basis for much follow-up research. In particular, the implementation of high-capacity and ultra-secure quantum information networks rely on the possibility to generate and precisely manipulate multipartite, highly dimensional, and strongly correlated systems.

As part of the effort for shaping Europe’s digital future it is necessary to unlock the transformative power of quantum, it is crucial to develop a solid industrial base that builds on its long tradition of excellence in quantum research. The Quantum Technologies Flagship, launched in 2018, is a large-scale, long-term research initiative funded by the EU that brings together research institutions, industry and public funders, consolidating and expanding European scientific leadership and excellence in this field. Quantum computing and quantum communications are at the centre of it. The EU Commission is now planning to build state-of-the-art pilot quantum computers by 2023 and since 2019 supports development of a quantum communication infrastructure covering the whole EU.

Hence, our area of research receives attention from the public and thus has a potential impact on society by also reshaping the public understanding of our technologies in the long run.



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Last update: 2 September 2021

Permalink: https://cordis.europa.eu/project/id/845486/reporting