Mediciones cuánticas no destructivas

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Principales papers de la charla

Detecting an Itinerant Optical Photon Twice without Destroying It

Emanuele Distante, Severin Daiss, Stefan Langenfeld, Lukas Hartung, Philip Thomas, Olivier Morin, Gerhard Rempe, Stephan Welte

Nondestructive quantum measurements are central for quantum physics applications ranging from quantum sensing to quantum computing and quantum communication. Employing the toolbox of cavity quantum electrodynamics, we here concatenate two identical nondestructive photon detectors to repeatedly detect and track a single photon propagating through a $60\,\mathrm{m}$ long optical fiber. By demonstrating that the combined signal-to-noise ratio of the two detectors surpasses each single one by about two orders of magnitude, we experimentally verify a key practical benefit of cascaded non-demolition detectors compared to conventional absorbing devices.

Quantum Nondemolition Measurements

Vladimir B. Braginsky[1], Yuri I. Vorontsov[2], Kip S. Thorne[3]

Mediciones en cuántica

- $|\psi\rangle \longrightarrow |1\rangle$

  ¿En el laboratorio hacemos mediciones proyectivas?

  $$|\psi\rangle \longrightarrow |\quad\rangle$$

- Una forma simple de medir proyectivamente:

  $$|\psi\rangle = \underbrace{(\alpha|0\rangle + \beta|1\rangle)}_{\text{Sistema a medir}} \otimes \underbrace{|0\rangle}_{\text{Sistema acoplado}}$$

  $$H_{Cnot}|\psi\rangle = \alpha|00\rangle + \beta|11\rangle$$

$$H_{Cnot}|00\rangle = |00\rangle$$
$$H_{Cnot}|01\rangle = |01\rangle$$
$$H_{Cnot}|10\rangle = |11\rangle$$
$$H_{Cnot}|11\rangle = |10\rangle$$

Partícula libre

Motivación: **medición de ondas gravitacionales**

$$\Delta x \Delta p_x \geq \frac{\hbar}{2}$$

- Midiendo $\hat{x}$:

$$|\psi\rangle \longrightarrow |x\rangle$$

$\hat{p}$ está "destruido" y genera la evolución en $\hat{x}$
El estado $|x\rangle$ se contamina

- Midiendo $\hat{p}$:

$$|\psi\rangle \longrightarrow |p_x\rangle$$

Mientras la particula siga libre, volveremos a obtener p

Mediciones no demoledoras (QND)

- Una serie de mediciones de un observable $\hat{A}$ cuyo resultado está determinado por la primera medición
- La primera medición destruye a todo observable que no conmute con $\hat{A}$
- $\left[\hat{A}(t_i), \hat{A}(t_j)\right] = 0 \Rightarrow \hat{A}$ es un observable QND

$\downarrow \forall t_{i,j}$ $\qquad$ $\searrow t_{i,j}$ discretos

$\hat{A}$ QND continua $\qquad$ $\hat{A}$ QND estroboscopica

Para la partícula libre $[\hat{x}(t), \hat{x}(t+\tau)] = \frac{i\hbar\tau}{m}$

Oscilador armónico

$$[\hat{x}(t), \hat{x}(t+\tau)] = \frac{i\hbar}{m\omega} \sin \omega\tau$$
$$[\hat{p}(t), \hat{p}(t+\tau)] = i\hbar m\omega \sin \omega\tau$$

- Hay dos magnitudes continuas QND

$$\hat{X}_1 = \hat{x}(t) \cos \omega t - \frac{\hat{p}(t)}{m\omega} \sin \omega t$$
$$\hat{X}_2 = \hat{x}(t) \sin \omega t + \frac{\hat{p}(t)}{m\omega} \cos \omega t$$
$$\Delta X_1 \Delta X_2 \geq \frac{\hbar}{2m\omega}$$

Acoplamiento con sistemas externos

- Puede aparecer una fuerza F (onda gravitacional)

$$H_f = \mu F \hat{x}$$

$$\left[\hat{A}(t), H_f(t)\right] = 0$$

Podemos medir la fuerza F mediante el observable $\hat{A}$

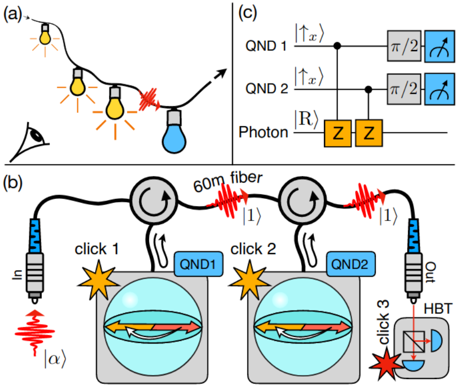
- Dispositivos de medición:

Las últimas etapas de la medición son siempre clásicas

$$H_1 = K\hat{A}\hat{M}$$

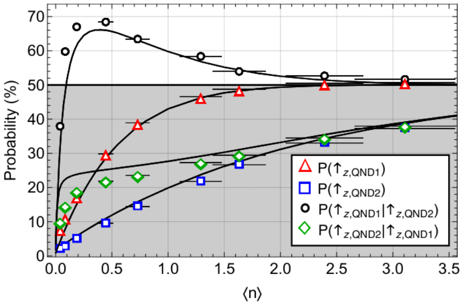
$$\left[\hat{A}(t), H_1(t)\right] = 0$$

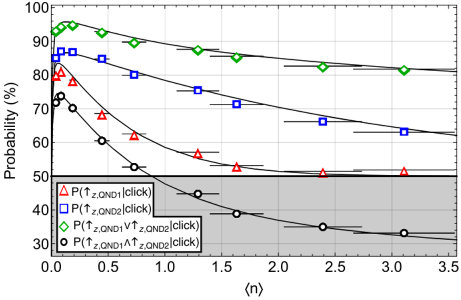
Detección múltiple de fotones



$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Detección múltiple de fotones





Gracias!

[Submitted on 3 Jun 2021]

Photon-number entanglement generated by sequential excitation of a two-level atom

S. C. Wein, J. C. Loredo, M. Maffei, P. Hilaire, A. Harouri, N. Somaschi, A. Lemaître, I. Sagnes, L. Lanco, O. Krebs, A. Auffèves, C. Simon, P. Senellart, C. Antón-Solanas

Entanglement and spontaneous emission are fundamental quantum phenomena that drive many applications of quantum physics. During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field. Here, we show that this natural process can be used to produce photon-number entangled states of light distributed in time. By exciting a quantum dot -- an artificial two-level atom -- with two sequential pi pulses, we generate a photon-number Bell state. We characterise this state using time-resolved intensity and phase correlation measurements. Furthermore, we theoretically show that applying longer sequences of pulses to a two-level atom can produce a series of multi-temporal mode entangled states with properties intrinsically related to the Fibonacci sequence. Our work demonstrates that spontaneous emission is a powerful entanglement resource and it can be further exploited to generate new states of quantum light with potential applications in quantum technologies.

[Submitted on 4 Jun 2021]

Curving the space by non-Hermiticity

Chenwei Lv, Ren Zhang, Qi Zhou

Quantum systems are often characterized into two distinct categories, Hermitian and non-Hermitian ones. Extraordinary properties of non-Hermitian systems, ranging from the non-Hermitian skin effect to the supersensitivity to boundary conditions and perturbations, have been widely explored. Whereas these intriguing phenomena have been considered peculiar to non-Hermitian systems, we show that many of them originate from a duality between non-Hermitian models in flat spaces and their counterparts, which could be Hermitian, in curved spaces. For instance, one-dimensional models with chiral tunnelings are equivalent to their duals in two-dimensional hyperbolic spaces. The dictionary translating between non-Hermiticity and curved spaces delivers an unprecedented routine connecting Hermitian and non-Hermitian physics, unfolds deep geometric roots of non-Hermitian phenomena, and establishes non-Hermiticity as a powerful protocol to engineer exotic curved spaces.

Quantum Heat Engines with Carnot Efficiency at Maximum Power

Mohit Lal Bera, Sergi Julià-Farré, Maciej Lewenstein, Manabendra Nath Bera

Conventional heat engines, be these classical or quantum, with higher power yield lesser efficiency and vice versa and respect various power-efficiency trade-off relations. Here we show that these relations are not fundamental. We introduce quantum heat engines that deliver maximum power with Carnot efficiency in the one-shot finite-size regime. These engines are composed of working systems with a finite number of quantum particles and are restricted to one-shot measurements. The engines operate in a one-step cycle by letting the working system simultaneously interact with hot and cold baths via semi-local thermal operations. By allowing quantum entanglement between its constituents and, thereby, a coherent transfer of heat from hot to cold baths, the engine implements the fastest possible reversible state transformation in each cycle, resulting in maximum power and Carnot efficiency. We propose a physically realizable engine using quantum optical systems.

Exploiting potentials of satellite applications for establishing a global quantum communication network without fibre-based relays

Xingyu Wang, Chen Dong, Shanghong Zhao, Tianyi Wu, Lei Shi, Boyu Deng, Haonan Zhu, Yijun Zhang

Recent the large-scale quantum network that connects metropolitan area quantum networks between the cities is realized by integrating the free-space and fibre QKD links, yet the fiber-based trusted nodes in such network could be subject to constant surveillance and probes. To remove these fiber-channel risks, we consider a network where a space-based relay, Micius satellite, executes a sequence of keys delivery missions, allowing thus any two cities to have a shared key. In this work, we develop a comprehensive framework integrated with the precise orbital modeling and the cloud statistics model to enable a pre-assessment on the satellite-based QKD applications. Using this framework, we consider three different scheduling strategies and estimate the keys possible to deliver to the cities, respectively. Results show that the strategy of pursing the total final keys maximized significantly embodies space-based QKD advantage, while the strategy of considering different levels of missions achieves more keys delivered to a higher priority mission. Most importantly, the targeted strategy of pursuing the distribution of final keys delivered being coincident with network traffic distribution, guarantees the individual needs, further promoting the utilization of delivered keys in practice. We also provide a comparison between the total number of delivered keys by the satellite with different altitude orbits. It is demonstrated that the plans for constructing a low earth orbit (LEO) satellite constellation, are more effective than that for employing an expensive high-orbit satellite, for a realization of the potential applications. Our works not only provides a practical method in the near term but also gives the aforehand exploration to establish satellite-based quantum communication network.

A kinetic theory for quantum information transport

F. Anza

In this work we develop a theoretical framework for the transport of information in quantum systems This is a framework to describe, using an approach from transport theories, how open and closed quantum systems move information around their state space.

Chaotic Einstein-Podolsky-Rosen pairs, measurements and time reversal

Klaus M. Frahm, Dima L. Shepelyansky

We consider a situation when evolution of an entangled Einstein-Podolsky-Rosen (EPR) pair takes place in a regime of quantum chaos being chaotic in the classical limit. This situation is studied on an example of chaotic pair dynamics described by the quantum Chirikov standard map. The time evolution is reversible even if a presence of small errors breaks time reversal of classical dynamics due to exponential growth of errors induced by exponential chaos instability. However, the quantum evolution remains reversible since a quantum dynamics instability exists only on a logarithmically short Ehrenfest time scale. We show that due to EPR pair entanglement a measurement of one particle at the moment of time reversal breaks exact time reversal of another particle which demonstrates only an approximate time reversibility. This result is interpreted in the framework of the Schmidt decomposition and Feynman path integral formulation of quantum mechanics. The time reversal in this system has already been realized with cold atoms in kicked optical lattices in absence of entanglement and measurements. On the basis of the obtained results we argue that the experimental investigations of time reversal of chaotic EPR pairs is within reach of present cold atom capabilities.

Simulating a measurement-induced phase transition for trapped ion circuits

Stefanie Czischek, Giacomo Torlai, Sayonee Ray, Rajibul Islam, Roger G. Melko

The rise of programmable quantum devices has motivated the exploration of circuit models which could realize novel physics. A promising candidate is a class of hybrid circuits, where entangling unitary dynamics compete with disentangling measurements. Novel phase transitions between different entanglement regimes have been identified in their dynamical states, with universal properties hinting at unexplored critical phenomena. Trapped ion hardware is a leading contender for the experimental realization of such physics, which requires not only traditional two-qubit entangling gates, but a constant rate of local measurements accurately addressed throughout the circuit. Recent progress in engineering high-precision optical addressing of individual ions makes preparing a constant rate of measurements throughout a unitary circuit feasible. Using tensor network simulations, we show that the resulting class of hybrid circuits, prepared with native gates, exhibits a volume-law to area-law transition in the entanglement entropy. This displays universal hallmarks of a measurement-induced phase transition. Our simulations are able to characterize the critical exponents using circuit sizes with tens of qubits and thousands of gates. We argue that this transition should be robust against additional sources of experimental noise expected in modern trapped ion hardware, and will rather be limited by statistical requirements on post selection. Our work highlights the powerful role that tensor network simulations can play in advancing the theoretical and experimental frontiers of critical phenomena.

Genuinely quantum SudoQ and its cardinality

Jerzy Paczos, Marcin Wierzbiński, Grzegorz Rajchel-Mieldzioć, Adam Burhardt, Karol Życzkowski

We expand the quantum variant of the popular game Sudoku by introducing the notion of cardinality of a quantum Sudoku (SudoQ), equal to the number of distinct vectors appearing in the pattern. Our considerations are focused on the genuinely quantum solutions, which are the solutions of size N^2 that have cardinality greater than N^2, and therefore cannot be reduced to classical counterparts by a unitary transformation. We find the complete parameterization of the genuinely quantum solutions of 4×4 SudoQ game and establish that in this case the admissible cardinalities are 4, 6, 8 and 16. In particular, a solution with the maximal cardinality equal to 16 is presented. Furthermore, the parametrization enabled us to prove a recent conjecture of Nechita and Pillet for this special dimension. In general, we proved that for any N it is possible to find an $N^2 \times N^2$ SudoQ solution of cardinality N^4, which for a prime N is related to a set of N mutually unbiased bases of size N^2. Such a construction of N^4 different vectors of size N yields a set of N^3 orthogonal measurements.