Past quantum state analysis of the photon number evolution in a cavity

I. Dotsenko, T. Rybarczyk, B. Peaudecerf, M. Penasa, S. Gerlich, B. Julsgaard, K. Mølmer, S. Gleyzes, M. Brune, JM. Raimond, S. Haroche

Introduction: Quantum Non-Demolition photon-number measurement

System
High-Q superconducting microwave cavity C, circular Rydberg atoms prepared one by one in B, and Ramsey interferometer R1-R2-D0

Dispersive interaction
Light-shift effect maps a cavity photon number n into the phase of the atomic coherence |φ⟩|n⟩

Ramsey interferometry
(1) 1st Ramsey zone: a π/2 pulse transfers the atom into |φ⟩|n⟩.
(2) Cavity: atom undergoes phase shift φn followed by state-sensitive detection of the atom.
(3) 2nd Ramsey zone: a π pulse with a tunable phase shifts q followed by state-sensitive detection of the atom.

One-atom measurement
Partial information on photon-number distribution Pn(n) repeating the measurement with many atoms on the same field realization progressively projects its initially broad P(n) into a random photon-number state

Solution
Partial information on photon-number distribution Pn(n) or

Resolution of quantum jumps
Initial field (coherent state with 7 photons on average) decays to vacuum state.

Final state Pn(n) = Pn(n, T) = 1/N

Improved resolution of the photon-number evolution

Decoherence

Measurement at time t1 (Bayes’ rule)
Pf(n, t1) = Tr[ρ(t1)O(n1)ρ(t1)]

Dephasing

Probabilities of result n based on the past of t

Probabilities of result n based on both the past and the future of t

Case of diagonal matrices in the measurement basis (e.g., photon-number distribution and QND measurement)
Pf(n, t) = \frac{1}{\sum_m Pf(m, t) P^m(n, t)}

Additional validation
Improved correlation between distributions reconstructed from two independent subsets of data measured on the same experimental realization

Photon-number lifetimes extracted from the statistics of individual resolved quantum jumps

Past quantum state

Idea
A quantum system can be monitored through repeated interactions with meter systems. The state of the system at time t is represented by the density matrix ρ(t), then becomes conditioned on the information obtained by the meters until that time.

More insight in the state of the system at any time t is provided, however, by taking into account the full detection of all meters interacting with the system both in the past and in the future of t.

Result

Probability of result n based on the past of t

Probability of result n based on both the past and the future of t

Reference
S. Gammelmark et al., PRL 111, 160401 (2013)