Collaborations et financements
ANR, scala, DGA, IUF, JST

Laboratoire Kastler Brossel – Physique quantique et applications

Applications of QND measurement of the photon number : Quantum Zeno effect and Tomography of the relaxation process

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Aim of the experiment

• Demonstrate quantum Zeno effect in the cavity QED context (inhibition of the coherent growth of the field in a cavity coupled to a classical microwave source by repeatedly measuring the photon number).
• Use a statistical ensemble of quantum trajectories obtained by Quantum Non Demolition measurement of the photon number in a cavity to perform the tomography of the relaxation super operator.

Methods

• Quantum non-demolition (QND) measurement of the photon number : by inserting a high finesse cavity in an atomic interferometer, we detect the induced light shift on the atoms crossing the cavity field mode.

Results

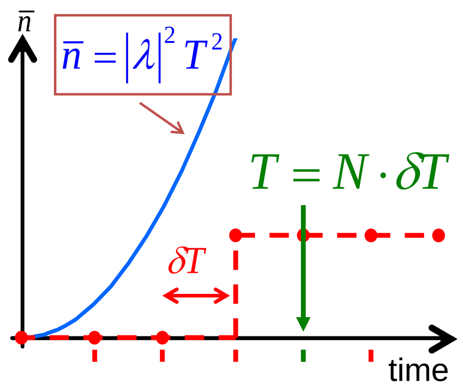
• First demonstration of Quantum Zeno effect on a runaway system [1]
• Experimental determination of all jump rates between Fock states [2]

References

[1] J. Bernu *et al.*, PRL **101**, 18402 (2008)
[2] M. Brune *et al.*, PRL **101**, 240402 (2008)

Quantum Zeno effect

“A watched kettle never boils”



Probability not to jump at first measurement :

$$\pi_0 \simeq \left(1 - |\lambda|^2 \delta T^2\right)$$

Probability to have no jump before Nth measurement :

$$\pi_0^N \simeq \left(1 - |\lambda|^2 \delta T^2\right)^N \simeq 1 - N|\lambda|^2 \delta T^2$$

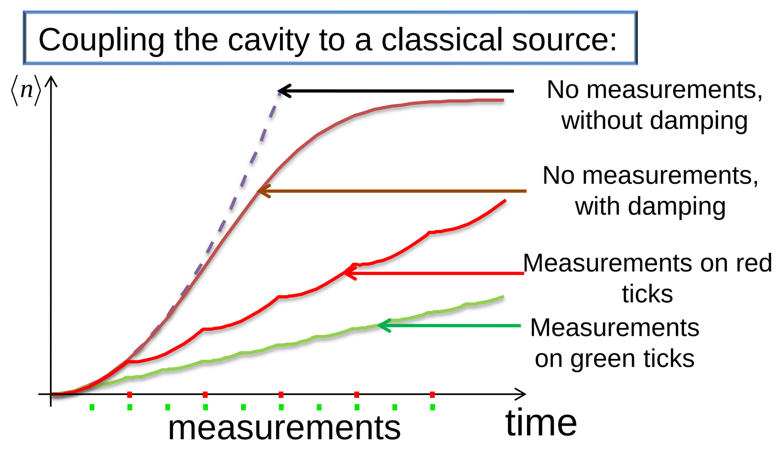
Mean photon number :

$$\bar{n}(T) \simeq N|\lambda|^2 \delta T^2 = T|\lambda|^2 \delta T$$

Linear increase ≠ quadratic

At the limit of infinitly frequent measurements the evolution is frozen

Coupling the cavity to a classical source:



Previous observations of Zeno effect

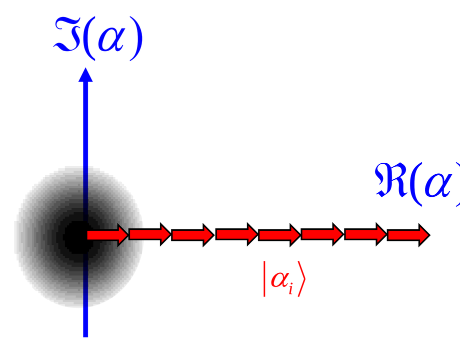
The first observation of Zeno effect was performed with trapped ions in 1990, Quantum Zeno effect was observed since then in several physical systems :

•Atoms
•Molecules
•Bose-Einstein condensates

So far, Zeno effect was only demonstrated on two-level systems. The repeated measurements inhibit a Rabi oscillation-like behaviour.

A random walk in phase space

Without measurements

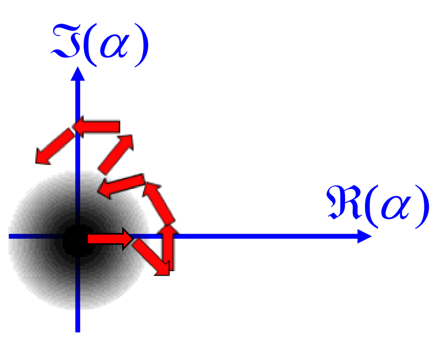


number of pulses, amplitude, amplitude injected in each pulse

$$A = p \cdot \alpha_i$$

$$n = A^2 = p^2 |\alpha_i|^2$$

With measurements



$$A = \sqrt{p}\alpha_i$$

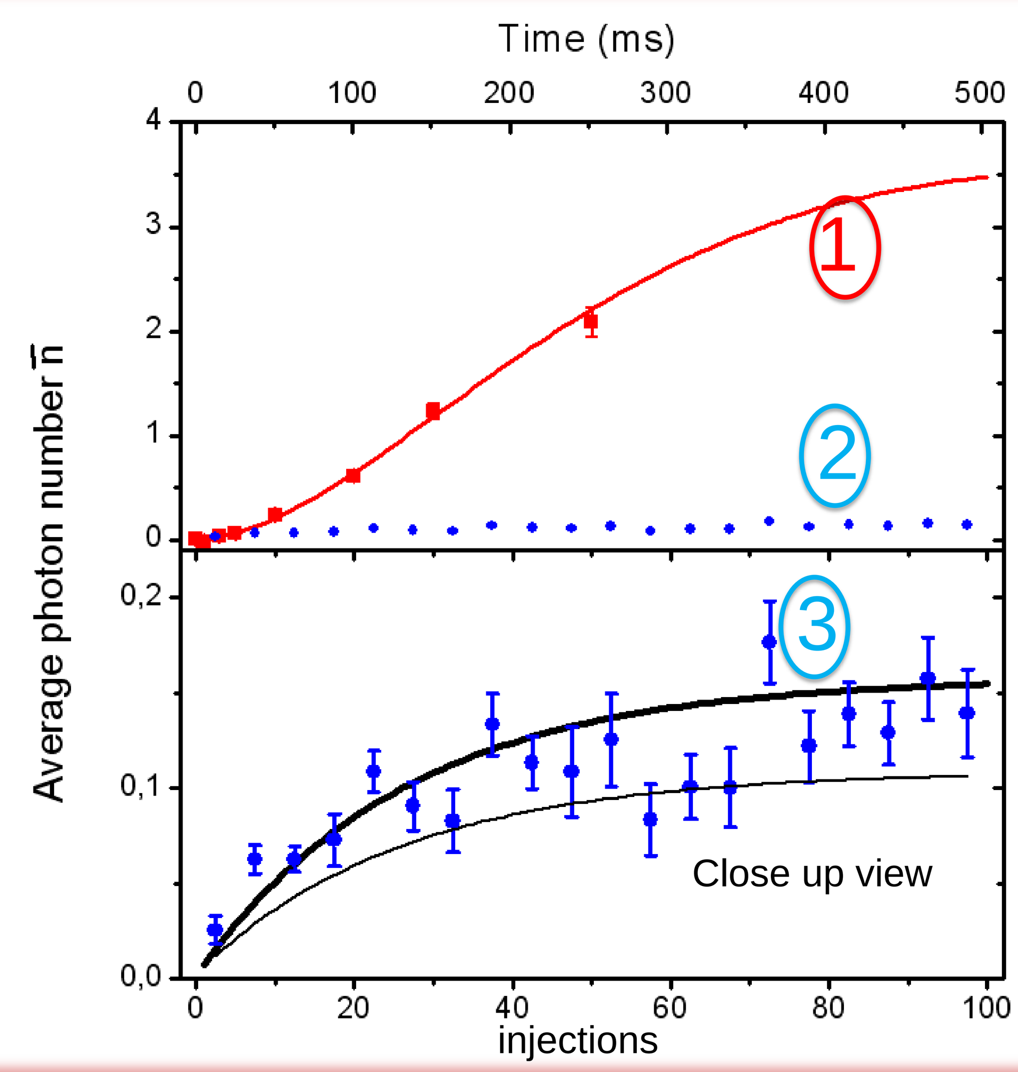
$$n = p|\alpha_i|^2$$

Experimental results

Cavity is prepared in the vacuum state
A series of injection pulses inject a field in the cavity.

$$|\alpha_i \approx 0.047\rangle \quad (n = \alpha_i^2 = 2.2\times10^{-3}\text{photons})$$

1. Without intermediate measurements : varying number of injection pulses is applied. The field is then measured by atoms.
2. A series of 100 injection pulses is performed. The field is measured by ≈10 atoms crossing the cavity between successive pulses.
3. A zoom on the last curve shows a linear initial increase of *n*, followed by saturation due to cavity damping

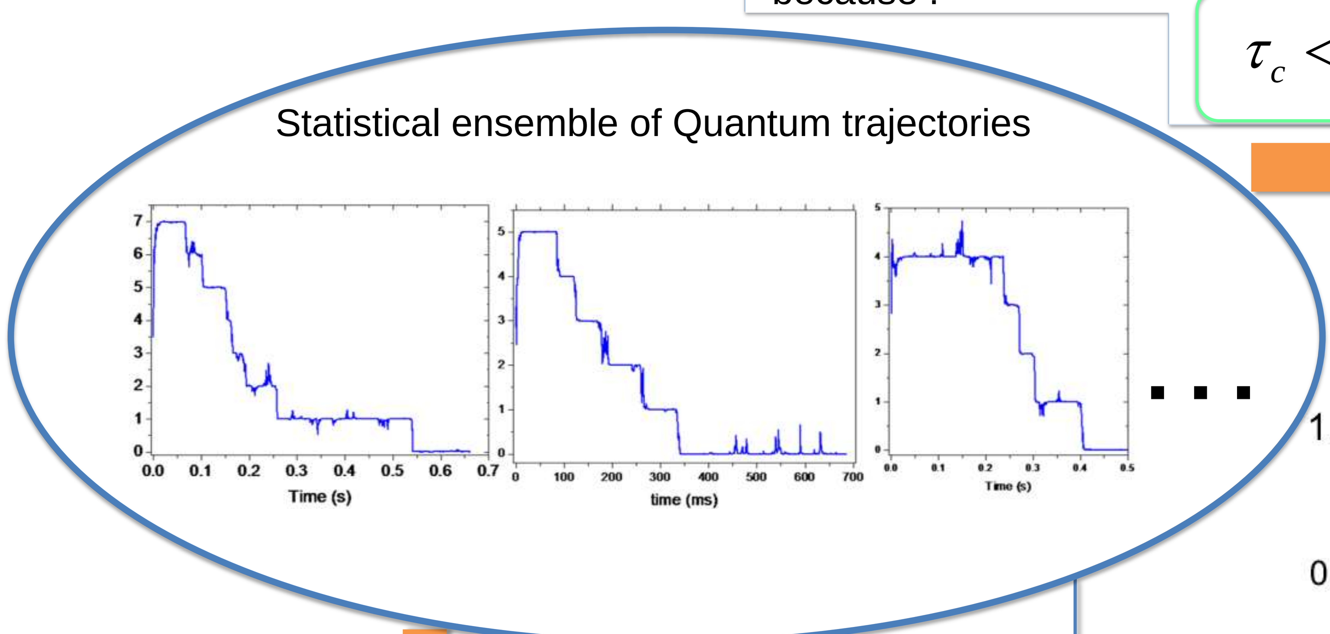


Tomography of decoherence of pure photon number states

1. Prepare vacuum state
2. Inject a coherent field (≈3 photons)
3. Measure continuously the photon number with probe atoms for 700 ms

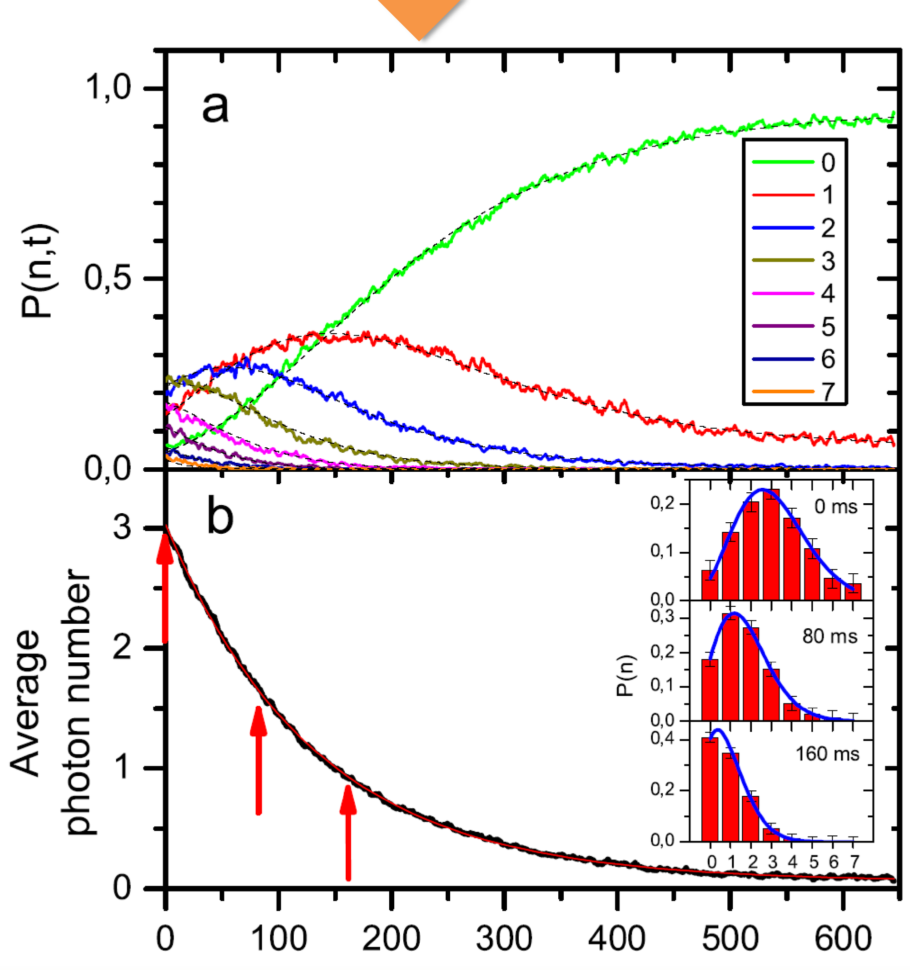
• QND measurement projects an initial coherent field into a random Fock state, decay of which appears as a cascade-like succession of quantum jumps.
• By averaging many individual trajectories, we find the mean photon number evolution of the initial coherent state.
• In contrast to Quantum Zeno Effect, decay rate is unaffected by the measurement because :

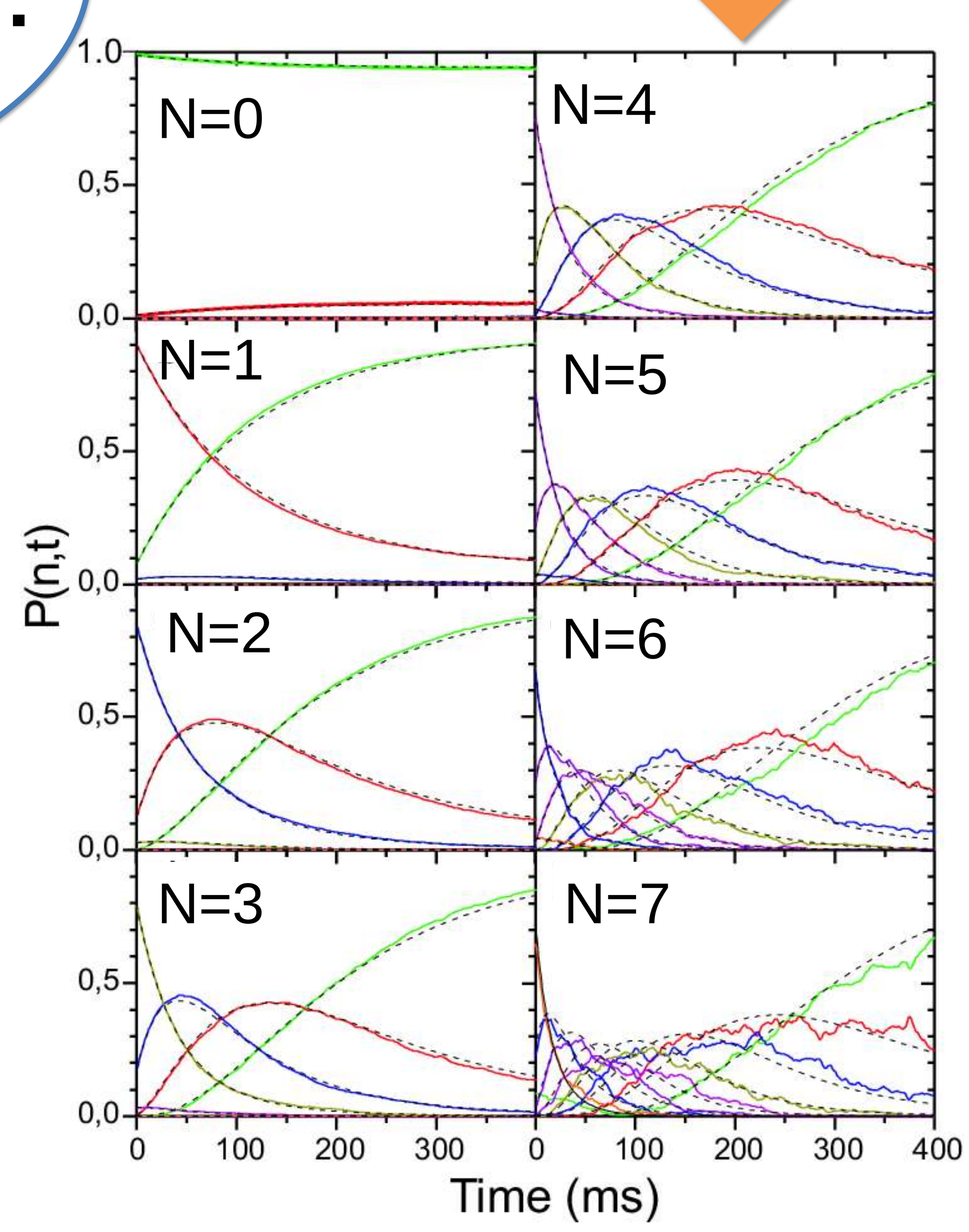
$\tau_c << T_{meas}$ — τ_c : memory time of the environment; T_{meas} : time to perform a measurement



Whenever P(n) > 0.7, the subsequent evolution is averaged in the corresponding graph

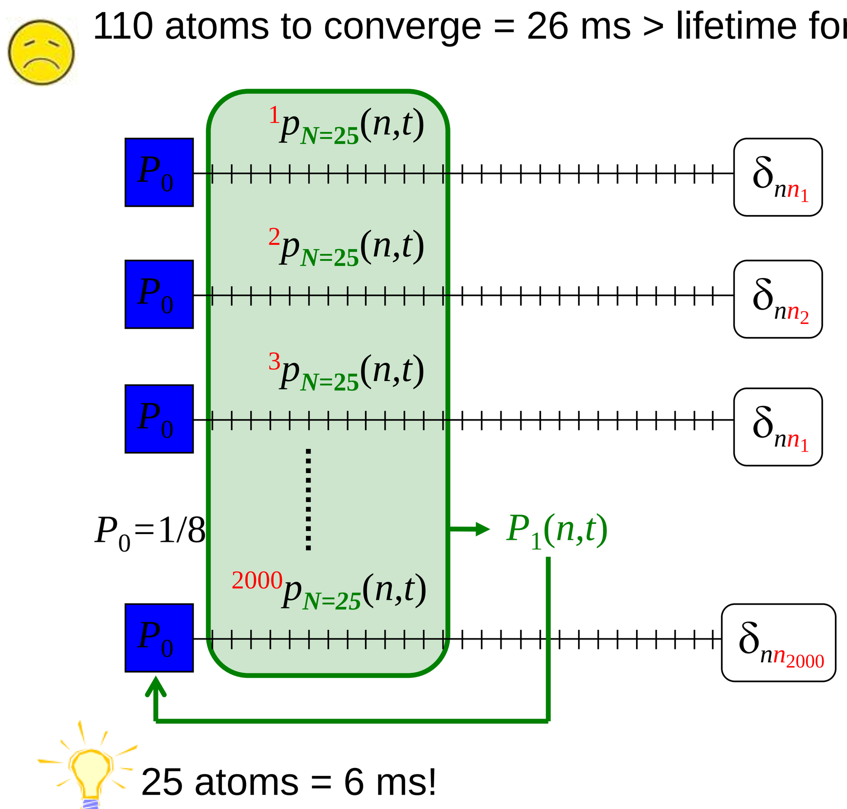
Average over 2000 realizations





Improving the time resolution

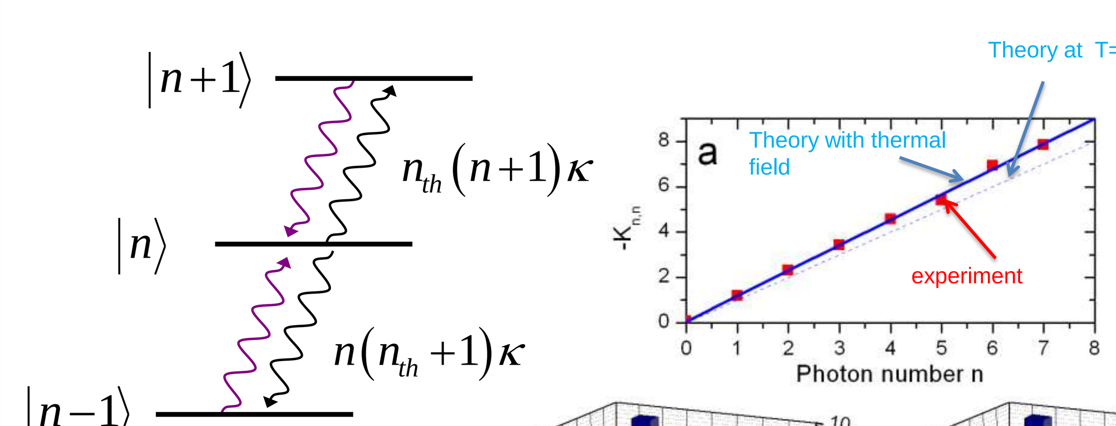
110 atoms to converge = 26 ms > lifetime for n=7 (18 ms)



By iterating this process, we refine our initial guess $P_1(n)$ untill it reaches the fix point of the procedure $P(n)$.

$P(n)$ is the population distribution at the middle time of the window

Reconstructed jump rates



$$\frac{dP(n,t)}{dt} = \sum_{n'} K_{n,n'} P(n',t)$$

Decoherence superoperator