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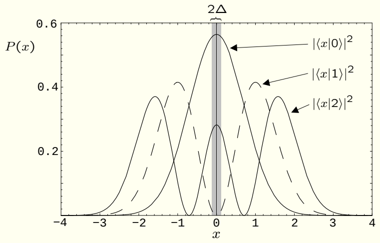
Photon Added Detection

A.M. Brańczyk, Alexei Gilchrist, Tobias J. Osborne and T.C. Ralph

The production of conditional quantum states and quantum operations based on the result of measurement is now seen as a key tool in quantum information and metrology. We propose a new type of photon number detector. It functions non-deterministically, but when successful, it has high fidelity. The detector, which makes use of an n-photon auxiliary Fock state and high efficiency Homodyne detection, allows a tunable tradeoff between fidelity and probability. By sacrificing probability of operation, an excellent approximation to a photon number detector is achieved.

Introduction

- We introduce the idea of a non-deterministic detector based on *photon added detection* (PAD).
- We make use of high efficiency homodyne detection and mix the input state with an $|n\rangle$ Fock state prior to detection.
- The essence of the detecting scheme is based on the observation that if we use homodyne detection and post-select within a narrow band of 2Δ around $x = 0$ then the detection will only be sensitive to even photon numbers, see figure.

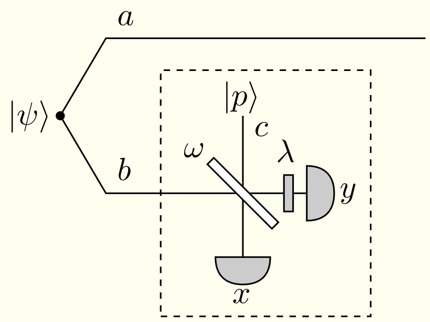


Our Scheme

- Consider an entangled state

$$|\psi\rangle = \frac{1}{\sqrt{2w+1}} \sum_{n=p-w}^{p+w} |a_n\rangle_a |n\rangle_b \qquad w = \text{window of states}$$

- The state $|\psi\rangle$ is input into the quantum circuit below.
- $|p\rangle$ is a p-photon Fock state, the beam splitter has reflectivity $\cos^2(\omega)$, the phase-shift is λ and x and y are homodyne detectors.

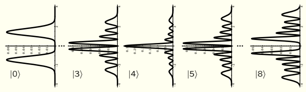


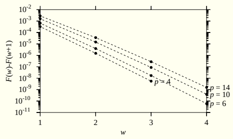
What can PAD be used for?

- PAD is non-deterministic in nature
- Main applications envisioned are in state preparation
- A good approximation to an $|n\rangle$ photon state can be prepared using parametric down conversion and a detector cascade in one arm. The PAD could possibly be employed in the proposal by Dakna *et al.* [1] where a good approximation to an optical Schrodinger Cat is generated by mixing a single mode sqeezed state on a beam splitter with the vacuum and conditioning on detecting a certain number of photons in one of the exit ports.
- Possible extention is to use other parameter choices and post-selection choices to directly project out certain distributions of photon number terms.

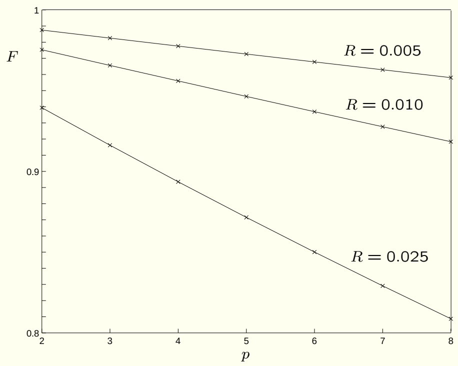
Nondeterministic Detection

- for $x = y = 0$ in the homodyne detectors, the detector only picks out the $|a_p\rangle$ component.
- Practically, we need to consider a small region around $x = y = 0$. We integrate over a range of values to evaluate success and failure probabilities.
- The PAD scheme is only sensitive to a band of number states near the target state. This can be seen intuitively from the figure on the left and is clearly demonstrated in the figure on the right.





- As we increase Δ, the probability we get a result we will accept also increaces, but due to the overlap with states near the target state, the fidelity of the detector will drop.
- The trade off between fidelity and probability is quantified in the figure below, where $R = P_\Delta / P_{\text{ideal}}$.

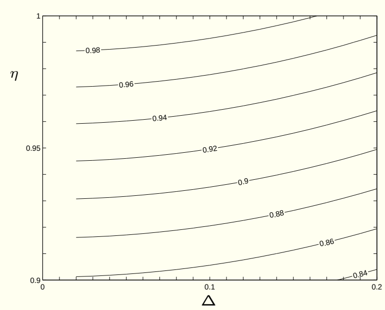


Inefficient Detection

- Detection efficiency for homodyne detection is very high (in the region of 98%) [2], especially compared with available photon counters.
- An ideal but inefficient photon detector can be modelled by the POVM elements $\Pi_p : p = 0, 1, \ldots$, where p is the number of detected photons, with

$$\Pi_p = \sum_{m=p}^{\infty} \binom{m}{p} \eta^p (1-\eta)^{m-p} |m\rangle\langle m| \qquad (1)$$

- PAD inefficiencies can be modelled simply by considering a beamsplitter of transistivity η in front of both homodyne detectors [3].
- For high efficiency, the ideal detector obtains a higher fidelity.
- The trend with higher photon numbers is similar for both detectors.
- The comparison between the fidelity of both detectors is shown in the figure below.



References

[1] M. Dakna *et al.*, Phys. Rev. A **55**, 3184 (1997).

[2] E. S. Polzik, J. Carri, and H. J. Kimble, Phys. Rev. Lett. **68**, 3020 (1992).

[3] U. Leonhardt and H. Paul, Phys. Rev. A **48**, 4598 (1993).