



# Quantum noise eater for a single qubit

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We propose quantum noise eater for a single qubit and experimentally verify its performance for recovery of a superposition carried by a dual-rail photonic qubit. A coherent but randomly arriving photon penetrating into single rail of this system causes a change of its state, which results in an error in a subsequent quantum information processing. We theoretically prove and experimentally demonstrate a conditional full recovery of the superposition by the quantum noise eater.

## Motivation

### Qubit resource

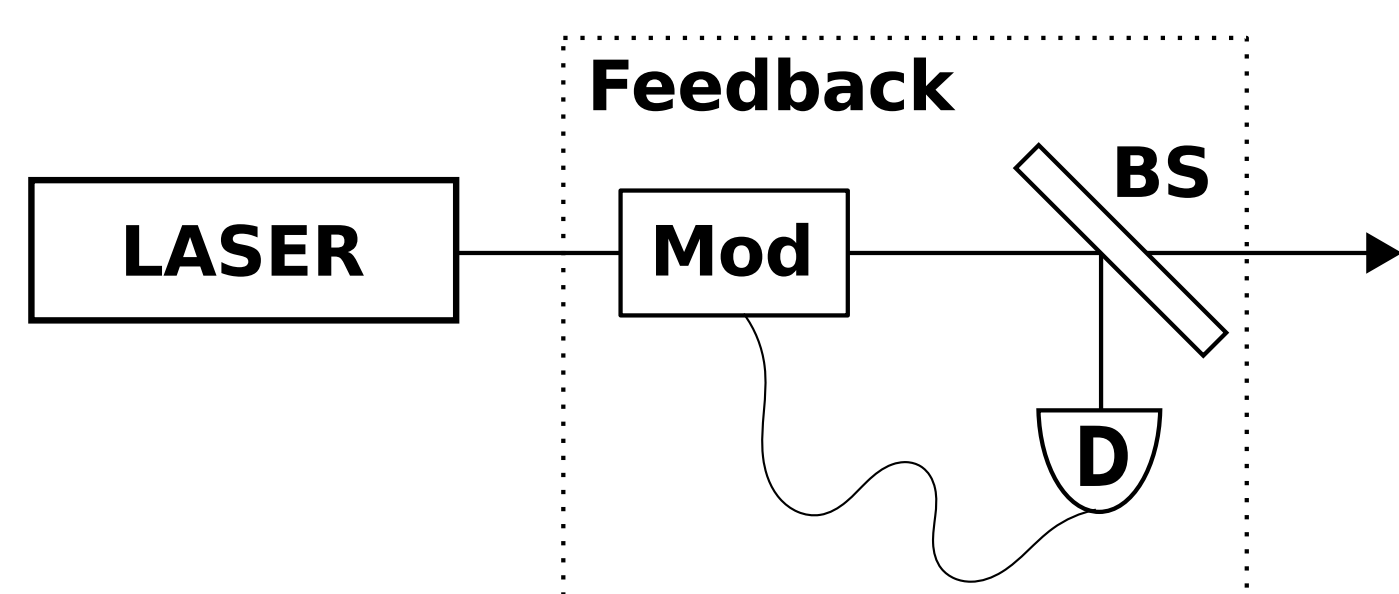
- $[|0\rangle + \exp(i\varphi)|1\rangle]/\sqrt{2}$
- dual-rail enc:  
 $|\Psi\rangle_{AB} = [|1,0\rangle_{AB} + \exp(i\varphi)|0,1\rangle_{AB}]/\sqrt{2}$
- Perfect resource for further quant inf processing
- Evaluation of the resource by visibility  $V$
- $V = 1$

### Trouble with coherent noise

- $a_B^\dagger |\Psi\rangle_{AB} = |\Psi'\rangle_{AB} = [|1,1\rangle_{AB} + \sqrt{2}\exp(i\varphi)|0,2\rangle_{AB}]/\sqrt{3}$
- state fully coherent
- may cause errors in further processing
- $V = \frac{2}{3}$

### Noise eater technique

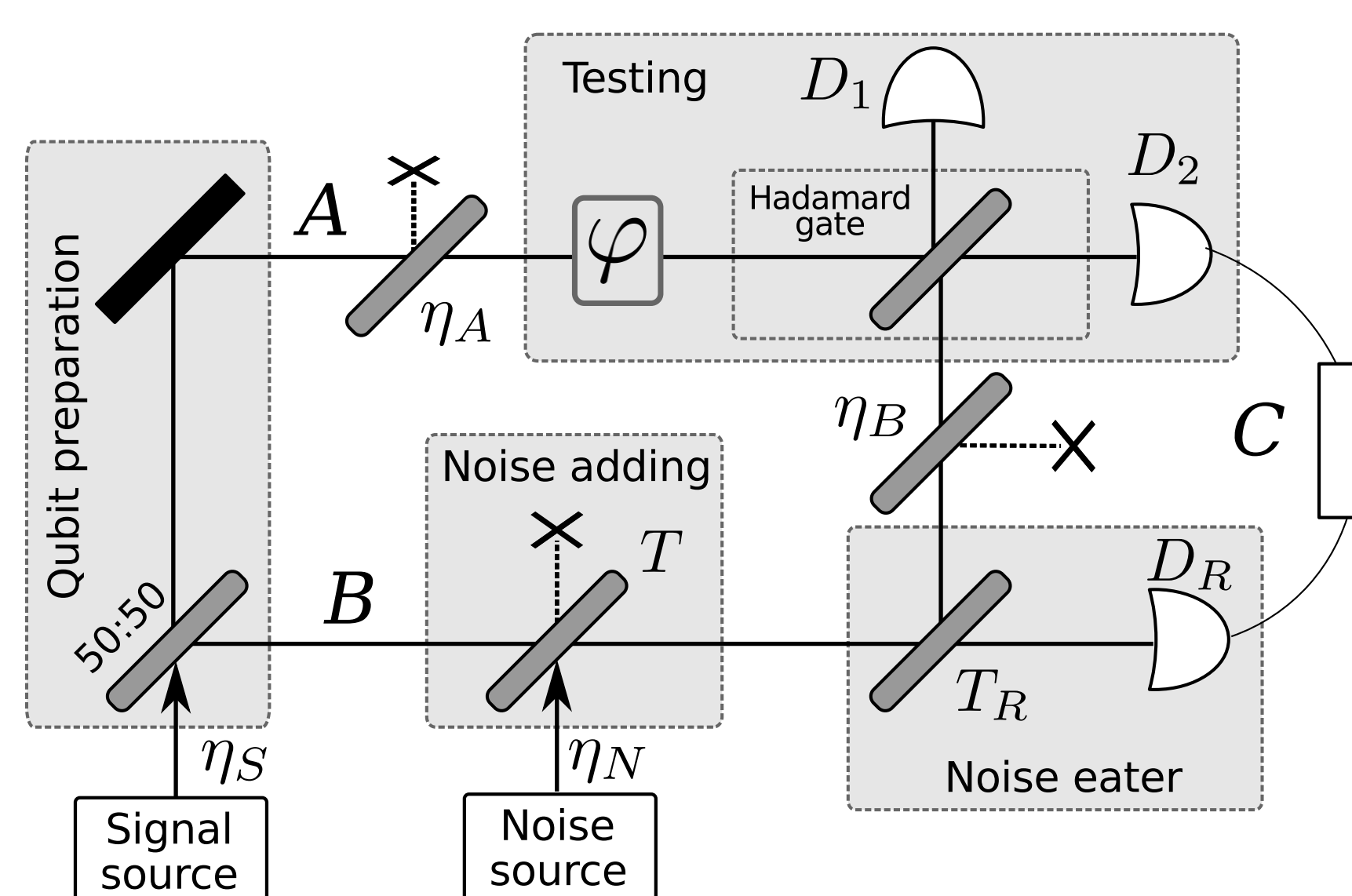
- Partial measurement of laser light
- Feedback controller with modulation



### Qubit noise eater

- photon subtraction
- $a_B |\Psi'\rangle_{AB}$  ending up with state
- $|\Psi''\rangle_{AB} = [|1,0\rangle_{AB} + 2\exp(i\varphi)|0,1\rangle_{AB}]/\sqrt{5}$
- If mode "B" properly attenuated  $V = 1$

## Theory



### Without noise eater

$$P = \frac{\eta_D}{4} (W_1 + W_2 \cos \varphi),$$

$$W_1 = 2\eta_N\eta_B + \eta_S\eta_A + \eta_S\eta_N\eta_B T\eta_D\eta_A - 2\eta_N\eta_B T - \eta_S\eta_N\eta_B^2\eta_D T + \eta_S\eta_B T - \eta_S\eta_N\eta_B\eta_D\eta_A + \eta_S\eta_N\eta_B^2 T^2\eta_D$$

$$W_2 = \frac{2\eta_S\eta_N\eta_B^{3/2}\eta_D\sqrt{T}\sqrt{\eta_A} - 2\eta_S\eta_N\eta_B^{3/2}T^{3/2}\eta_D\sqrt{\eta_A} - 2\eta_S\sqrt{T}\sqrt{\eta_A}\sqrt{\eta_B}}{2\eta_S\eta_N\eta_B^{3/2}T^{3/2}\eta_D\sqrt{\eta_A} - 2\eta_S\sqrt{T}\sqrt{\eta_A}\sqrt{\eta_B}}$$

$$V = \frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}}$$

$$V = \frac{\eta_S T (\eta_B \eta_N T \eta_D - \eta_B \eta_N \eta_D + 1)}{\eta_B \eta_S \eta_N \eta_D T (T-1) + \eta_S T + \eta_N (1-T)}$$

$$\text{if } \eta_A = \eta_B T$$

$$V = \frac{2T + \eta_B \eta_S T (T-1)}{2 + \eta_B \eta_S T (T-1)}$$

$$\text{if } \eta_N \ll 1 \text{ and } \eta_S \ll 1$$

$$V = T$$

### With noise eater

$$P_c(\varphi) = \frac{1}{4} \eta_S \eta_N T_R \eta_D \eta_R (1-T) (\eta_A + 4\eta_B T (1-T_R) - 4 \cos(\varphi) \sqrt{\eta_A \eta_B T (1-T_R)}).$$

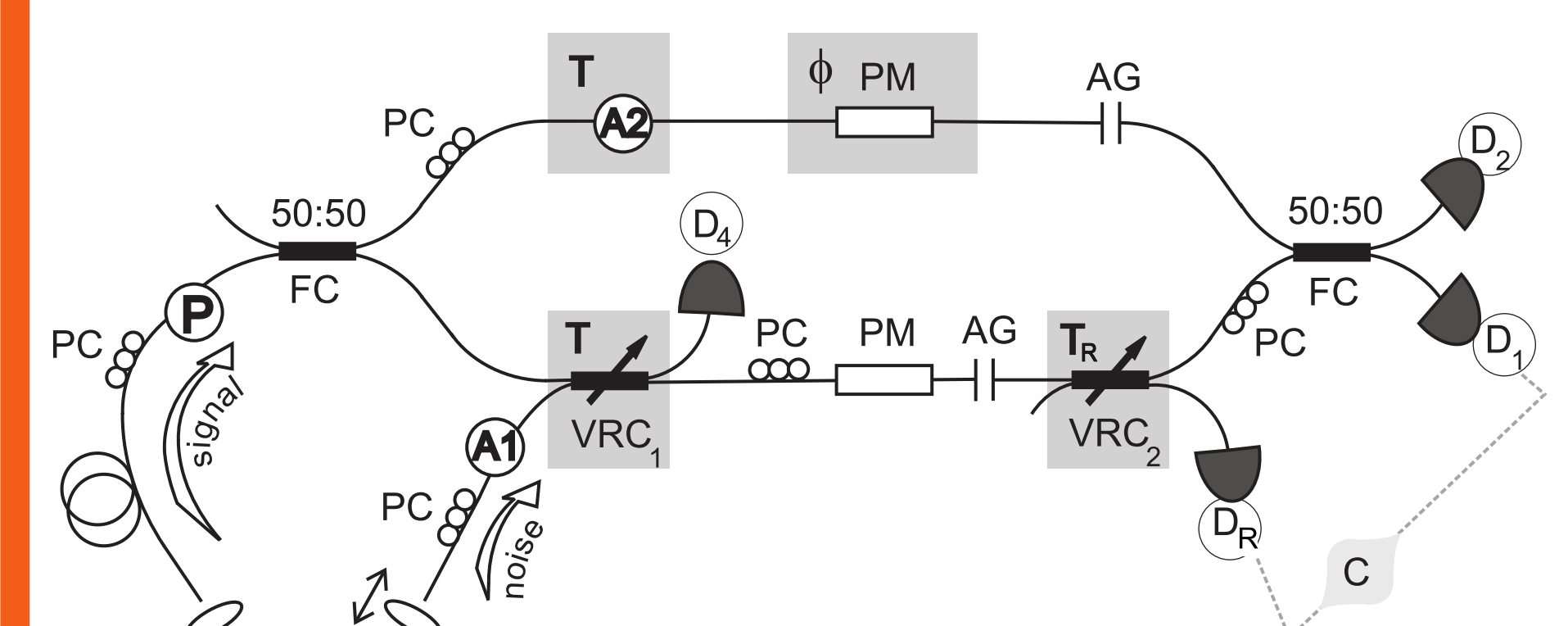
$$\text{if } \eta_A = \eta_B T$$

$$V = \frac{4\sqrt{1-T_R}}{5-4T_R}$$

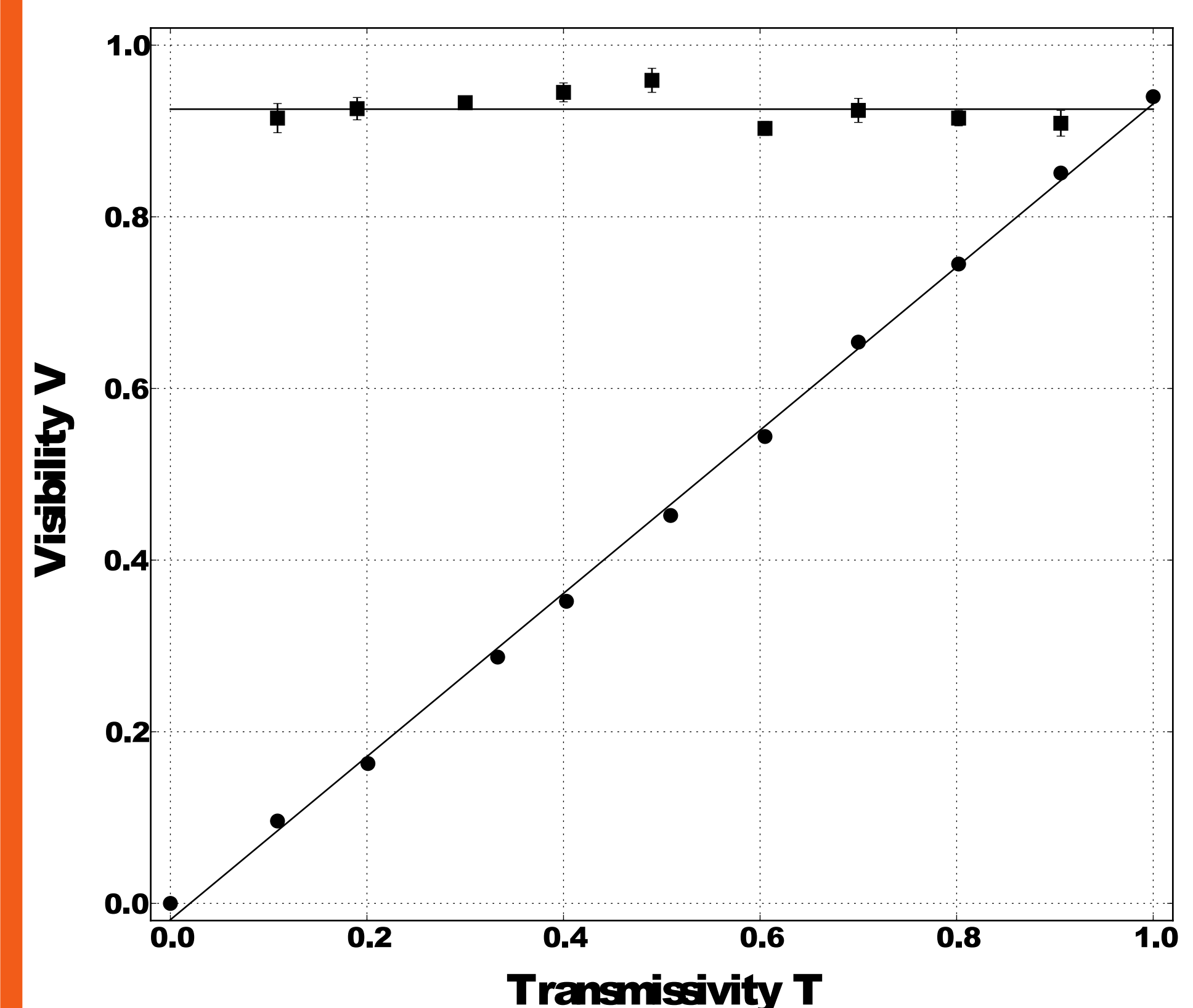
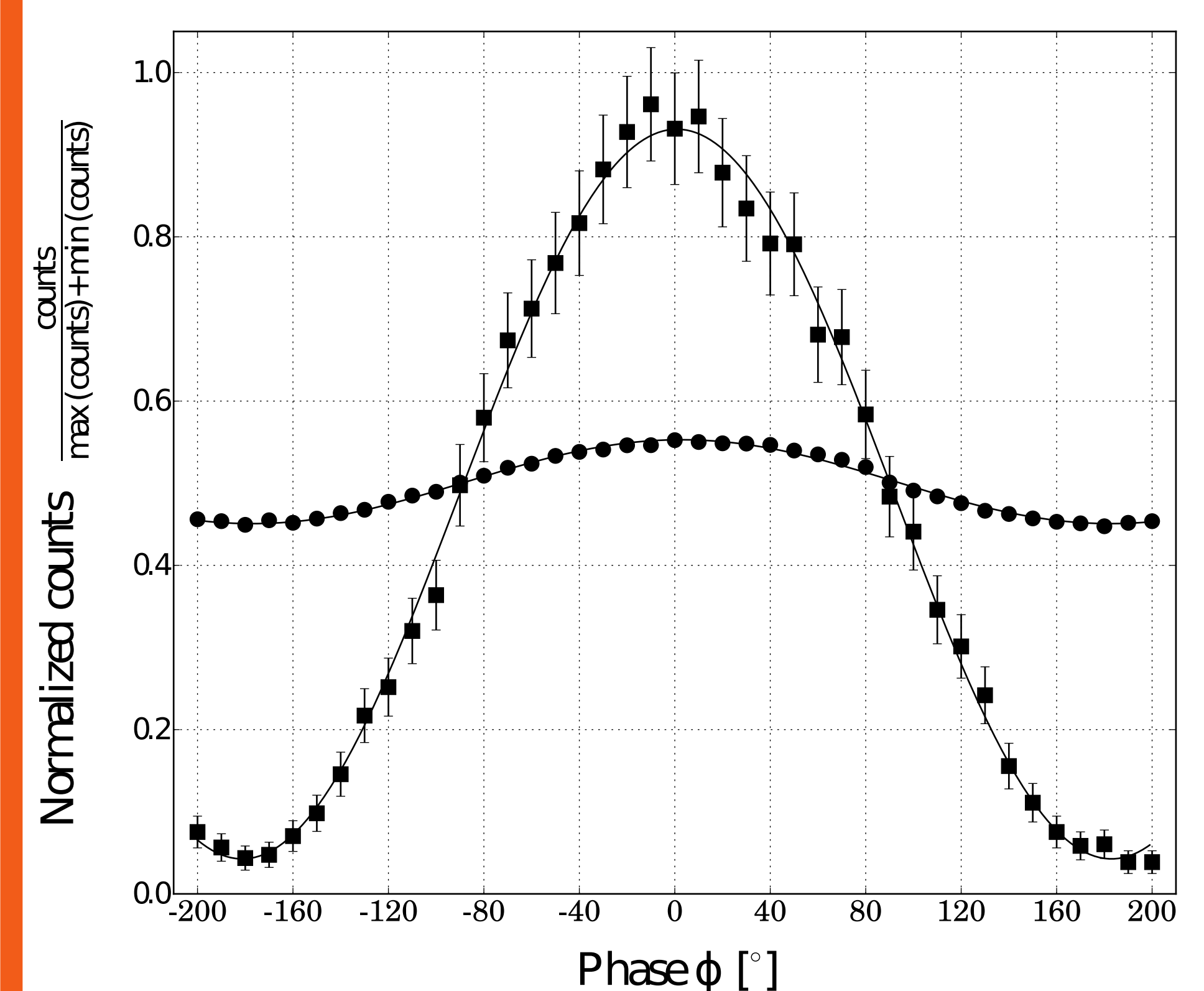
$$\text{If } T_R = \frac{3}{4}$$

$$V = 1$$

## Experiment



- Photons in fibre-optics two-photon Mach-Zehnder interferometer
- Signal and noise photon generated in SPDC process type I, pumping at 413 nm, LiIO3 crystal
- Noise photon coherently added to the signal photon



### Summary & outlook

1. Coherent noise can be harmful for qubit superposition.
2. We have proposed and experimentally demonstrated an elementary quantum noise eater that recovers the resource



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