Smoothly breaking unitarity

Studying spontaneous collapse using two entangled, tuneable coherent amplifiers

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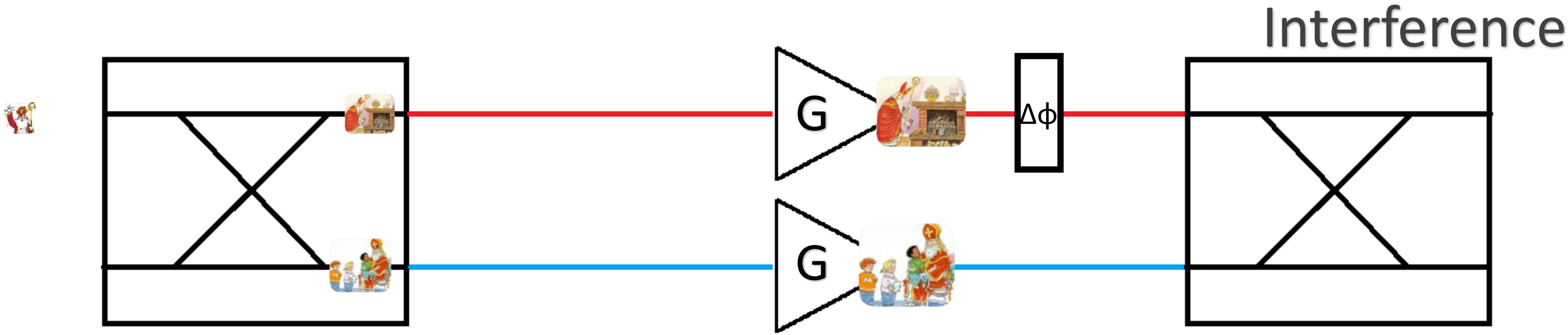
Macroscopic superpositions: why (not)?

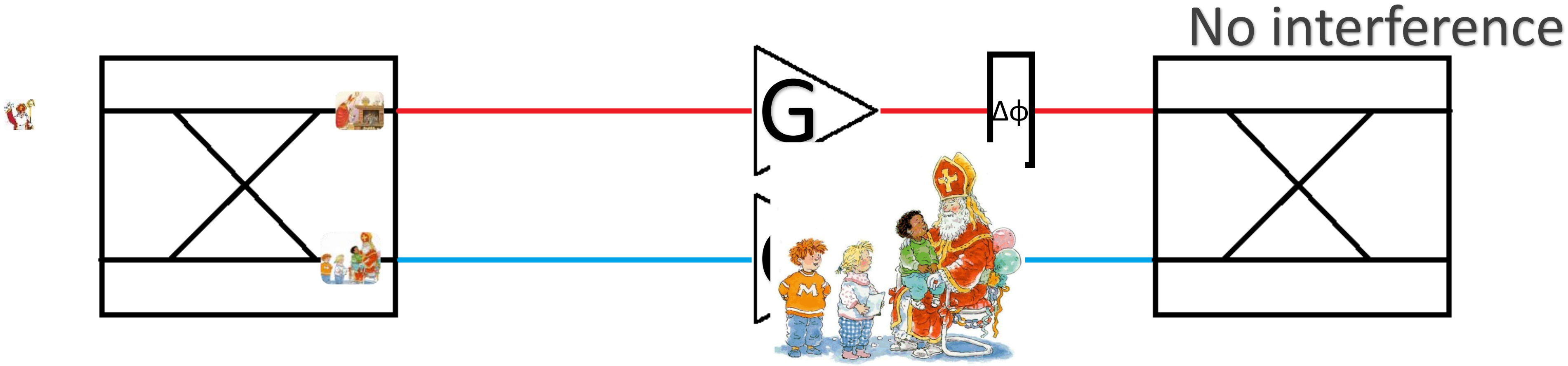
- Copenhagen: don’t ask
- Many worlds: not falsifiable
- Environmental decoherence: can’t explain collapse

- Spontaneous localisation
- Spacetime ill-defined: $\Delta E \Delta t \geq \hbar$
- …

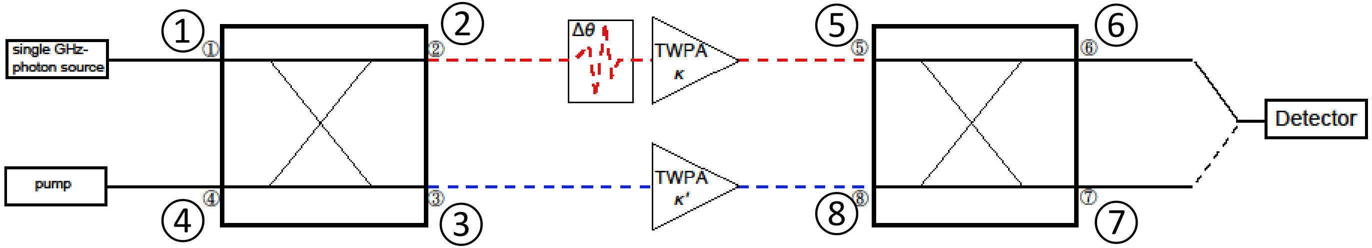
Experimental proposal



Experimental proposal



Let’s get more quantitative…

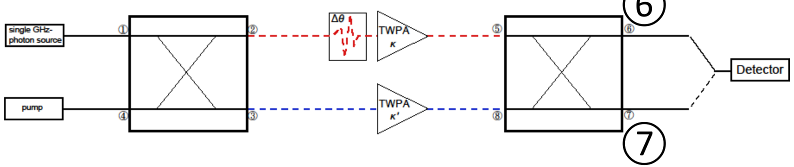


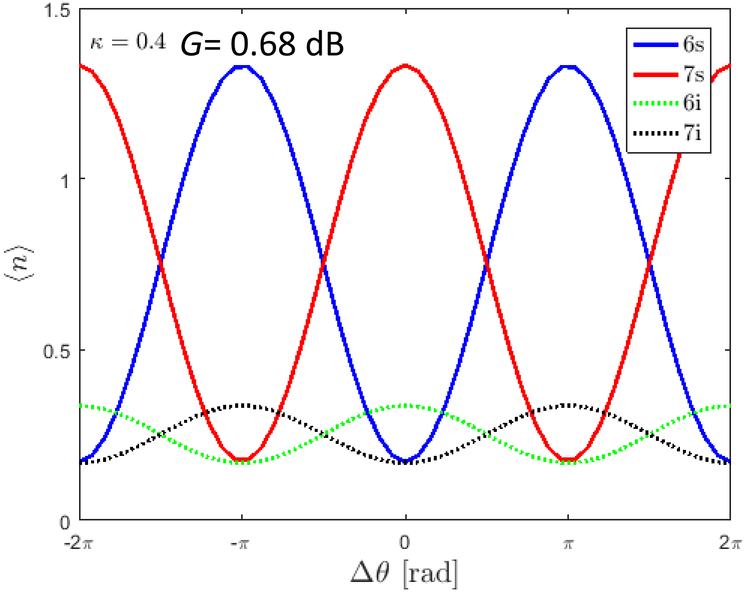
- Schrödinger evolution: $\psi(t+\Delta t)=\exp(i\hat{H}\Delta t)\,\psi(t)$
- Hybrid: $\hat{U}_h = \exp[i\,\pi/4\,(\hat{a}_U^{\dagger}\hat{a}_L + \text{H.c.})] \rightarrow \hat{H}_h = \pi/(4\Delta t_h)\,(\hat{a}_U^{\dagger}\hat{a}_L + \text{H.c.})$
- Phase shifter: $\hat{H}_{ps} = \Delta\theta/\Delta t_{ps}\,(\hat{a}_U^{\dagger}\hat{a}_U)$
- TWPA: $\hat{H}_{TWPA} = \kappa/\Delta t_{TWPA}\,(\hat{a}_{Us}^{\dagger}\hat{a}_{Ui}^{\dagger} + \text{H.c.})$ $(G_{dB} = 20\,{}^{10}\log(\cosh\kappa))$

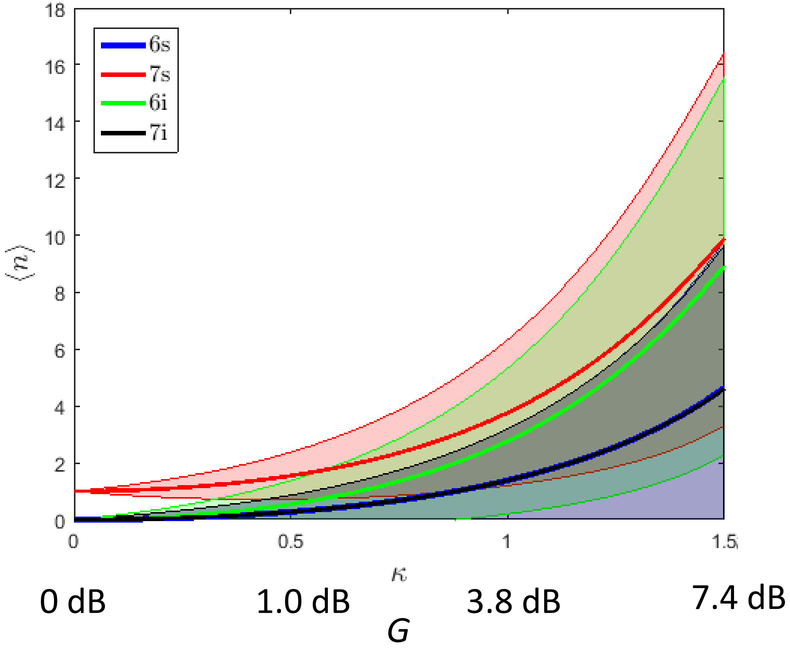
- Use Qutip[1] and let the magic happen…☺

[1] J. R. Johansson, P. D. Nation, and F. Nori, *Comp. Phys. Comm.* **184**, 1234 (2013)

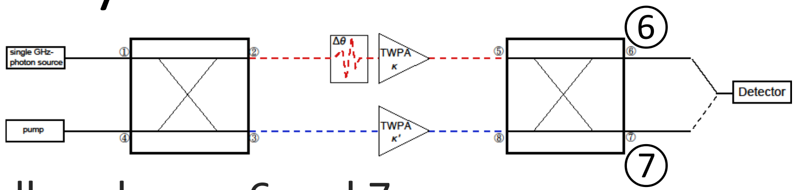
Results - verification





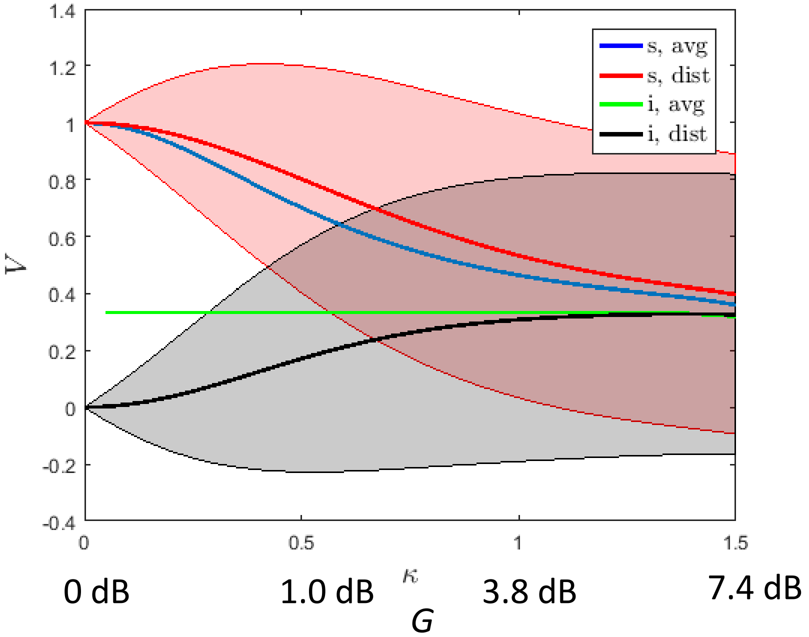


Results – interference visibility

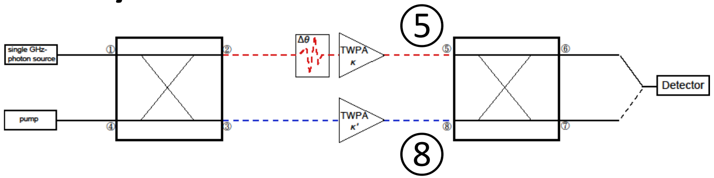


- Define visibility in two different ways
  - $V_{s,avg} = (\langle n_{7s}\rangle - \langle n_{6s}\rangle)/(\langle n_{7s}\rangle + \langle n_{6s}\rangle)$ for idler, change 6 and 7
  - $V_{s,dist} = \langle (n_{7s} - n_{6s})/(n_{7s} + n_{6s}) \rangle$

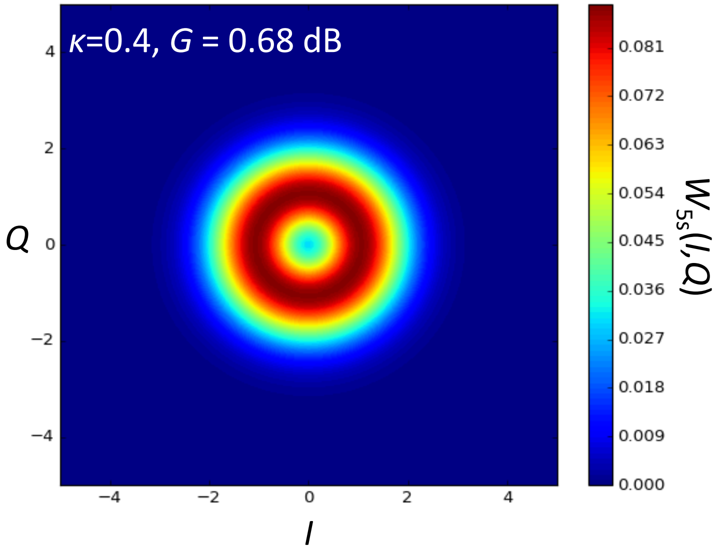
- Connected to measuring spectrum with long integration time or time trace (lock-in).

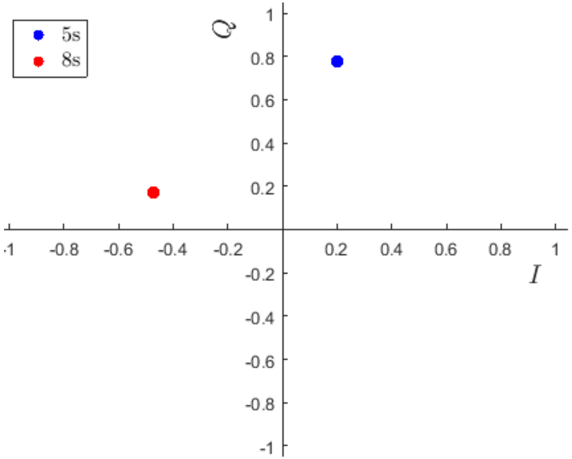


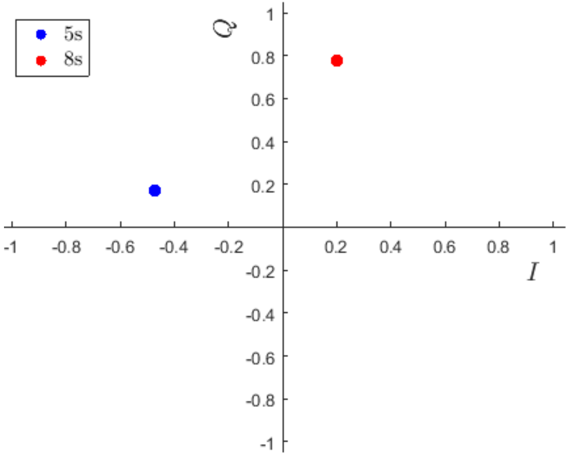
Observing collapse - intuitively



- Assume collapse at end of TWPA into (classical) coherent state
- Average visibility V_{avg} = 0!

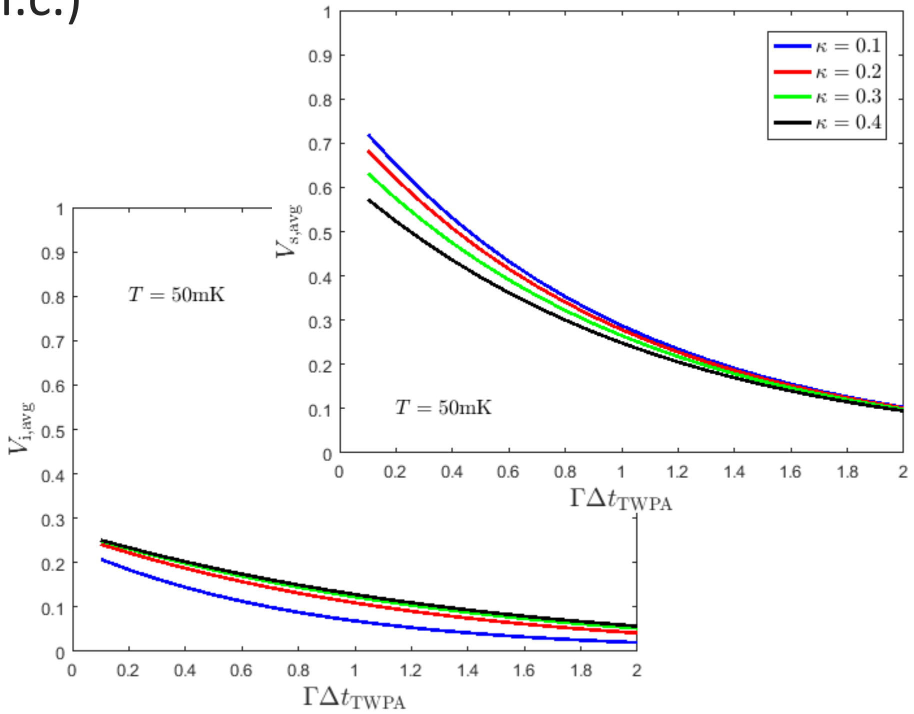






What about losses in the transmission line?

- Recall: $H_{TWPA} = \kappa / \Delta t_{TWPA} (\hat{a}_{Us}^{\dagger} \hat{a}_{Ui}^{\dagger} + H.c.)$
- Apply Lindblad formalism
- Jump operators $\sqrt{(\Gamma(1+n_{th}))}\hat{a}$ and $\sqrt{(\Gamma n_{th})}\hat{a}^{\dagger}$
- Vary Δt_{TWPA} to vary loss in TWPA.
  → $\Gamma\Delta t$ is relevant only!
- For other components $\Gamma\Delta t=0.1$



Caveats

- What if the two amplifiers are different, i.e. $\kappa \neq \kappa'$?
- Cryogenic phase shifter?

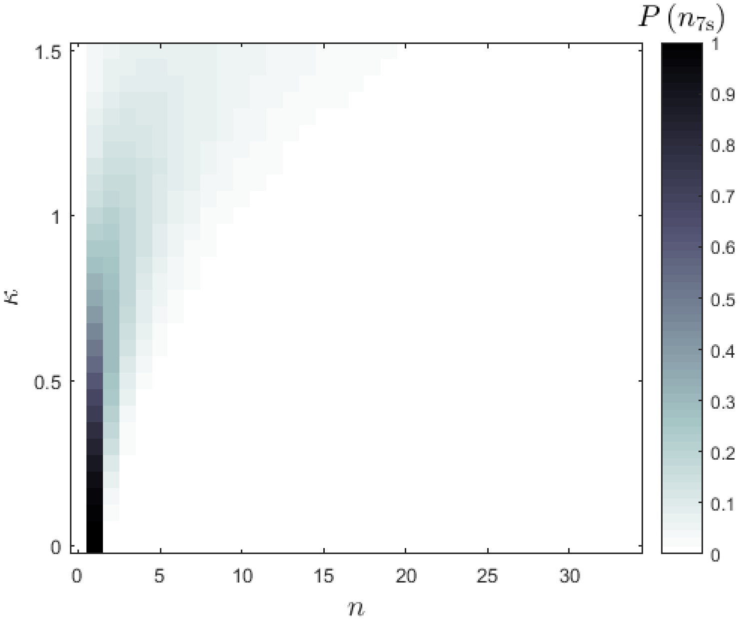
Acknowledgements

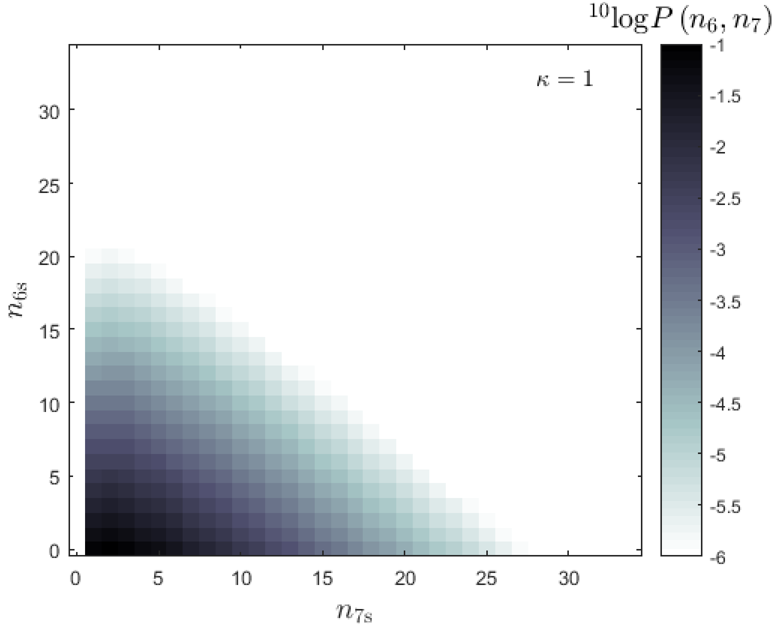
- Louk Rademaker
- Michiel de Dood
- The Oosterkamp group

NanoFront

Appendices

Results – photon number distribution





Results – photon number distribution (II)