Quantum pattern recognition with a few photons

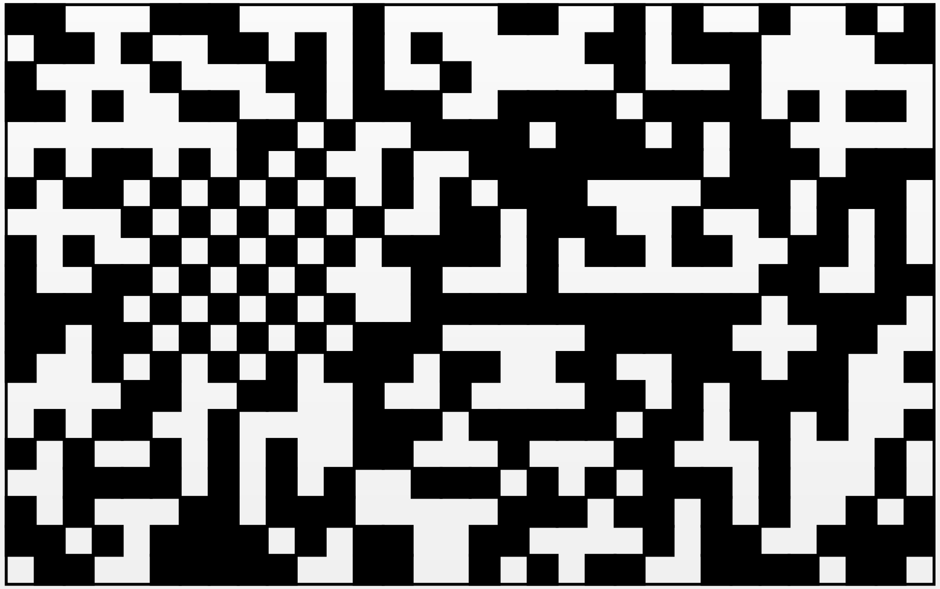
Ralf Schützhold

Fakultät für Physik

Universität Duisburg-Essen

Pattern Recognition

$N \gg 1$ pixels
-black: absorptive
-white: reflective

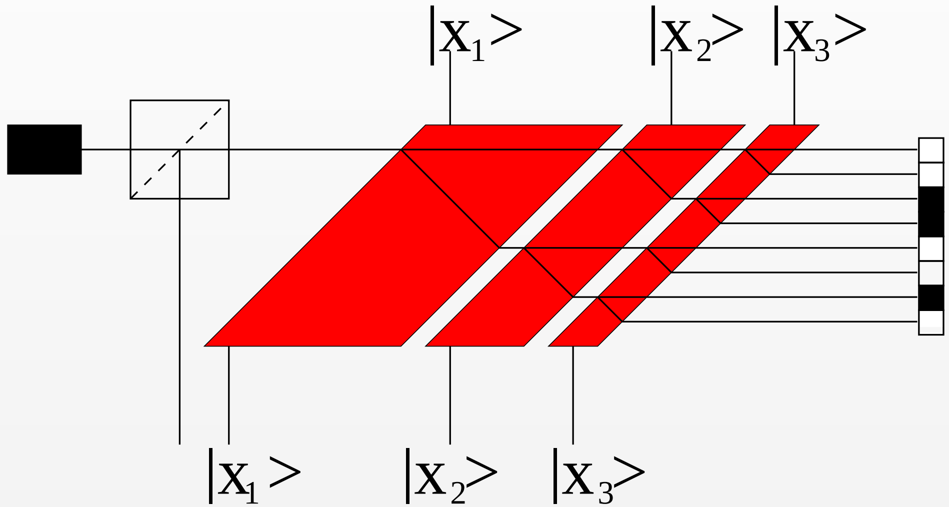


Pattern
(e.g., parallel lines)

Goal:
Detect and classify pattern with a few photons only!

Pattern recognition on a quantum computer,
Ralf Schützhold, Phys. Rev. A **67**, 062311 (2003)

Quantum Algorithm



$n = \log_2 N$ qubits encoding position of photon

Quantum parallelism

Input $\sum_{x=0}^{N-1} |x\rangle / \sqrt{N}$

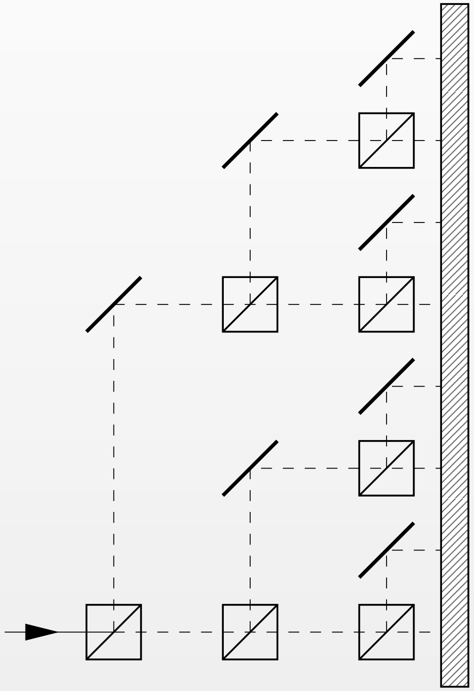
Detect photon – project to $\sum_{x=\text{white}} |x\rangle / \sqrt{N_{\text{white}}}$

Quantum Fourier Transform

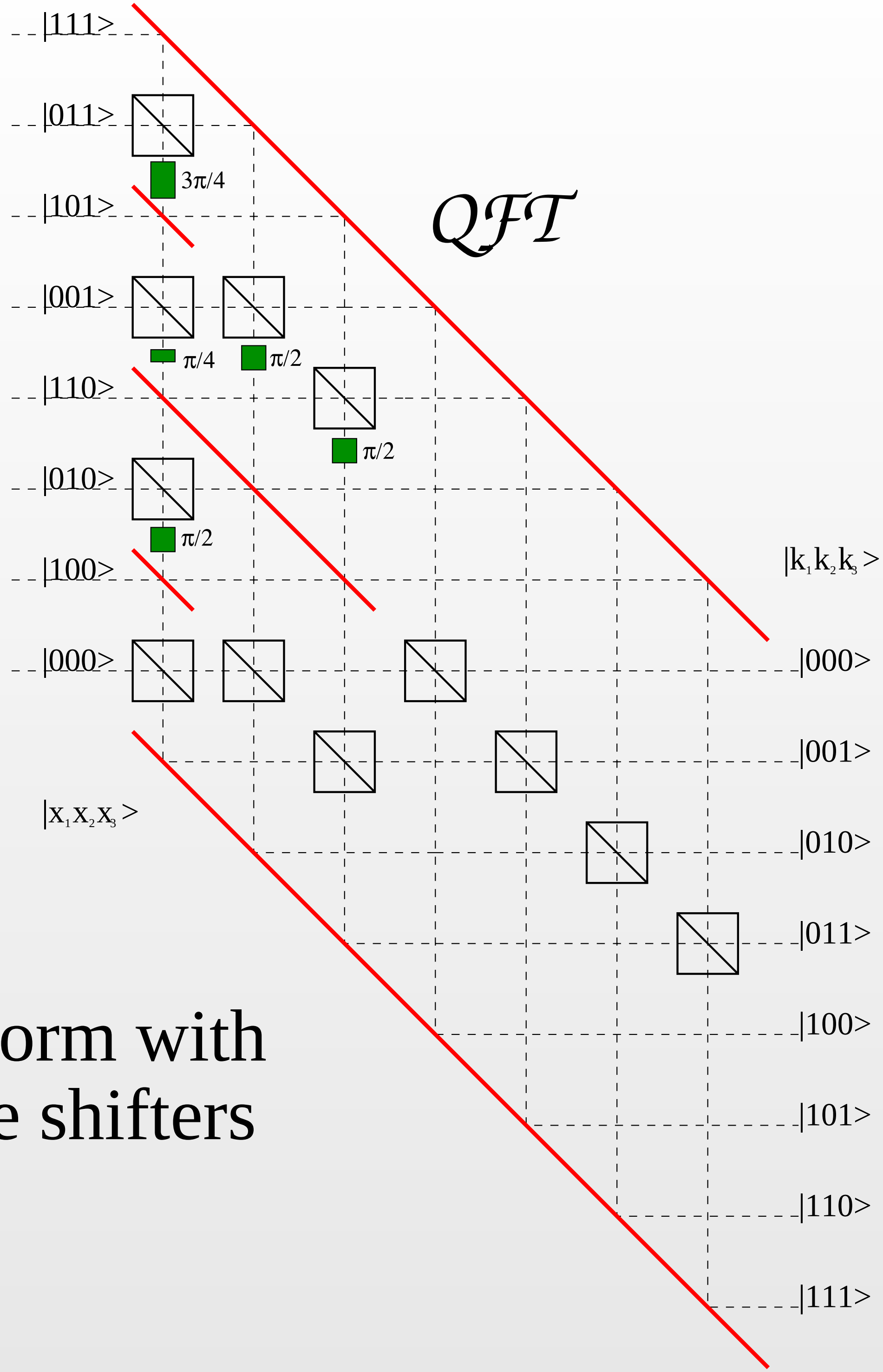
$$\mathcal{QFT} : |x\rangle \rightarrow \frac{1}{\sqrt{N}} \sum_{k=1}^{N} \exp\left(2\pi i \frac{xk}{N}\right) |k\rangle$$

Peaks in k-space $\rightarrow$ pattern

Linear Optics



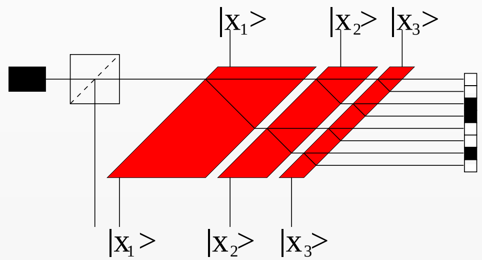
$\mathcal{H}^{(3)}_{|000>}$



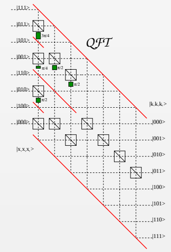
Quantum Fourier Transform with Beam splitters and Phase shifters (analogous to FFT)

Complexity Analysis

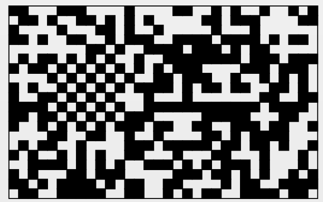
- quantum algorithm with qubits:
  $\mathcal{O}(n^0)$ photons and
  $\mathcal{O}(n)$ quantum gates (QFT)



- quantum algorithm with linear optics:
  $\mathcal{O}(n^0)$ photons and
  $\mathcal{O}(N \ln N) = \mathcal{O}(n2^n)$ quantum gates (FFT)



- classical algorithm:
  between $\mathcal{O}(n)$ and $\mathcal{O}(N)$ photons…

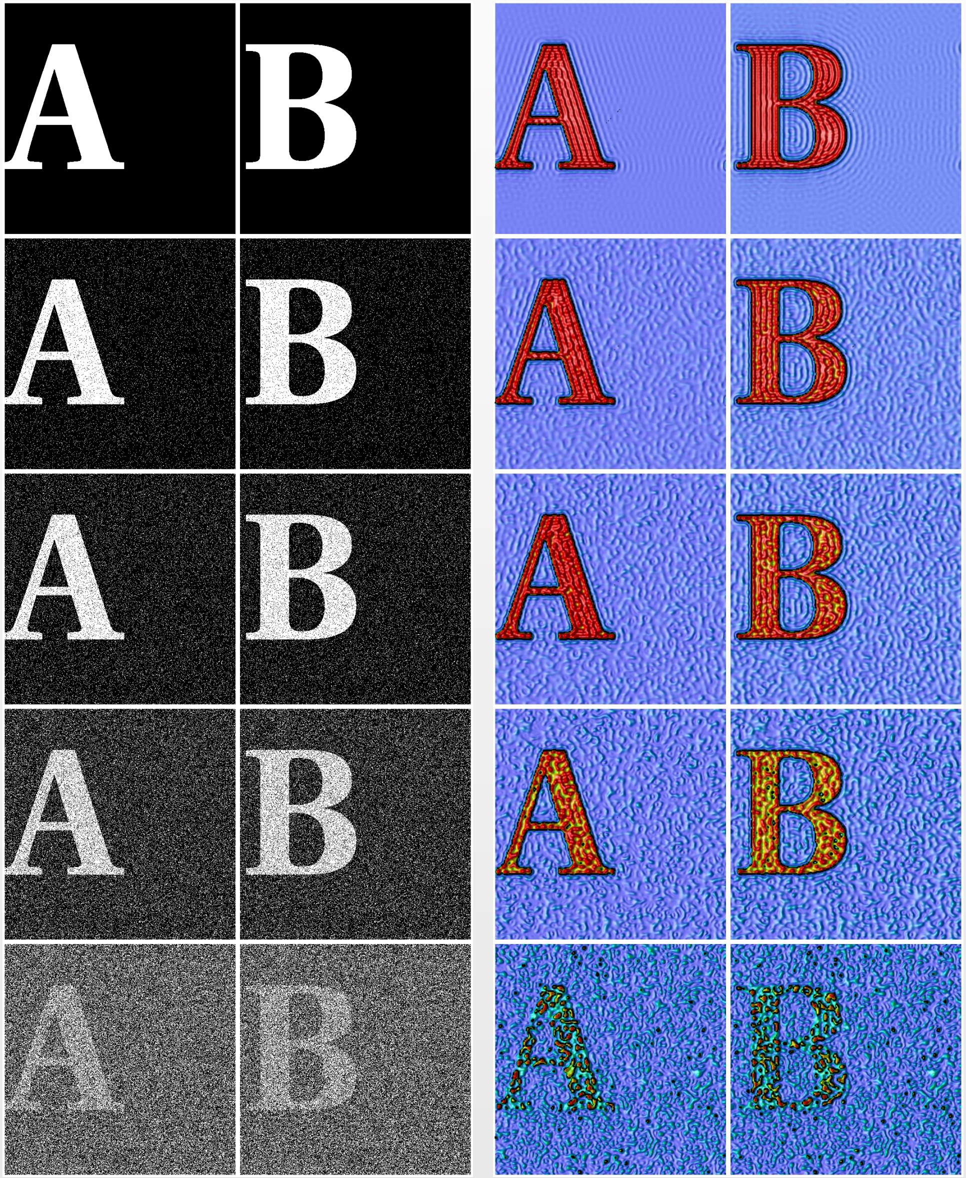


Take-home message:
A photon is much more than a qubit!

Pattern recognition on a quantum computer,
Ralf Schützhold, Phys. Rev. A **67**, 062311 (2003)

Template Matching with Noise

Quantum Parallelism
$\mathcal{QFT}$
Remove $k > k_{\rm max}$
$\mathcal{QFT}^\dagger$
Grover iteration
(w.r.t. **A**)
Hadamard gate
Measurement
Hadamard gate
Grover iteration
(w.r.t. **B**)
Hadamard gate
Measurement
etc.



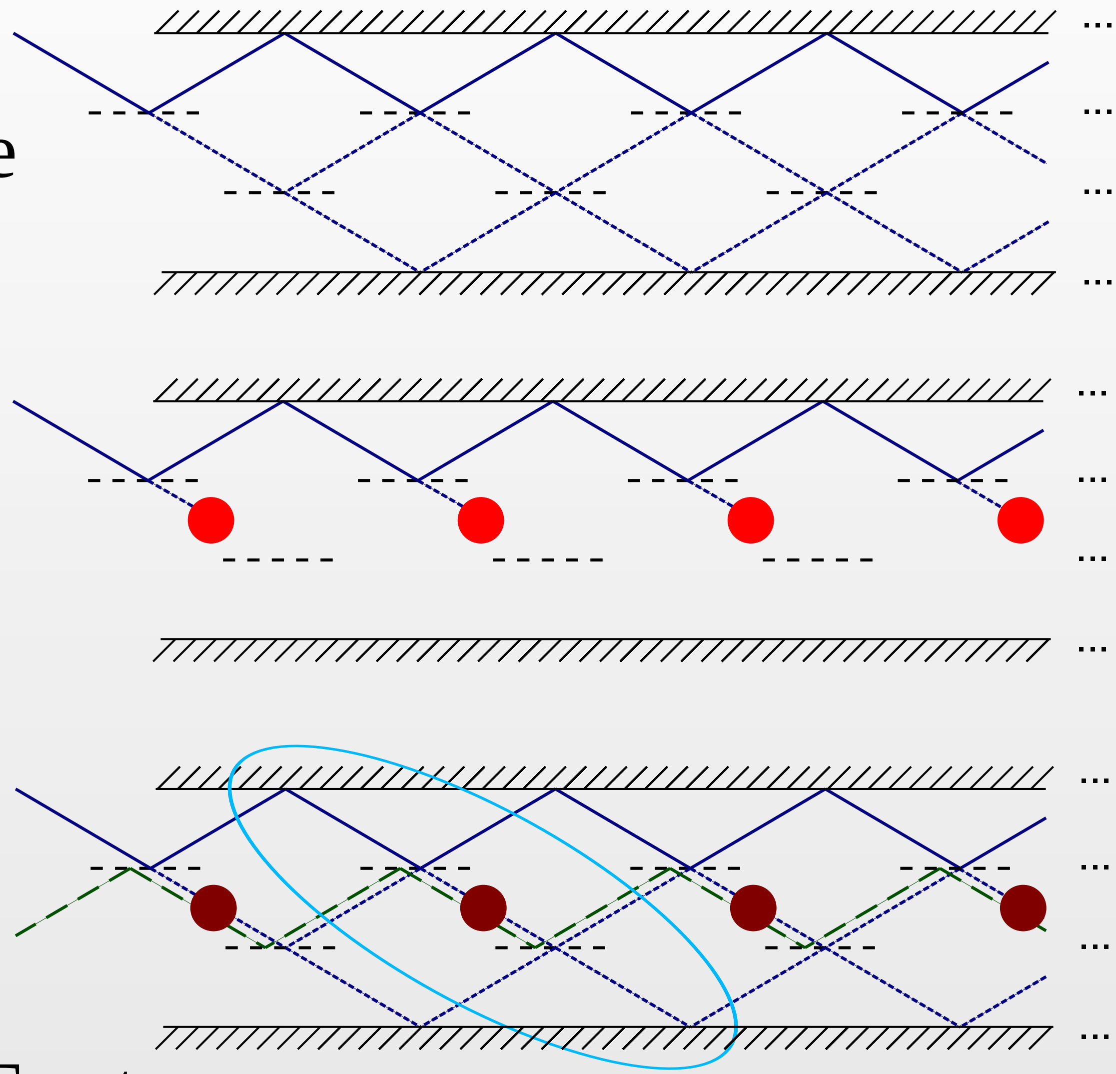
Gernot Schaller and Ralf Schützhold, Phys. Rev. A **74**, 012303 (2006)

Quantum Zeno Effect

Zeno(n) of Elea:
Achilles vs Tortoise
Arrow paradox

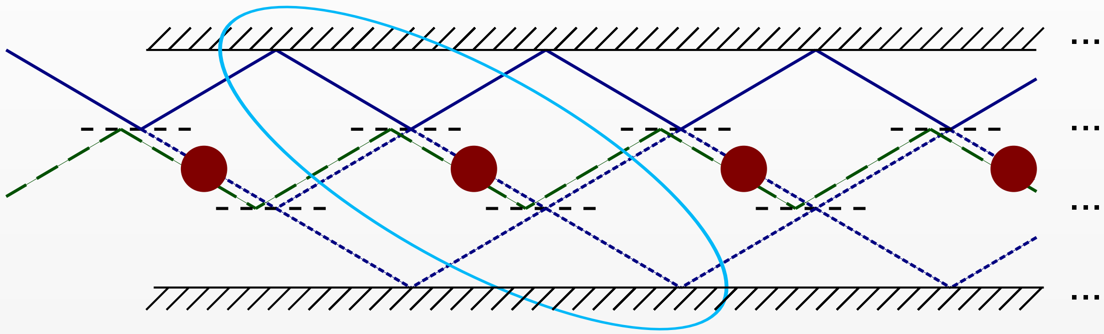
Quantum Zeno effect: Slow-down or inhibition of quantum evolution by frequent measurements

Two-photon absorbers → CNOT gate
→ talks by J. Dowling, A. White



Requirement

One-photon loss rate ξ_1
Two-photon absorption rate ξ_2



Entangling photons via the double quantum Zeno effect,

N. ten Brinke, A. Osterloh, R. Schützhold, Phys. Rev. A **84**, 022317 (2011)

Given error probability $P_{\rm error}$

$$\frac{\xi_2}{\xi_1} = \frac{\pi^2}{2P^2_{\rm error}} \gg 1$$

Factor of 64 better than previous proposals, e.g.

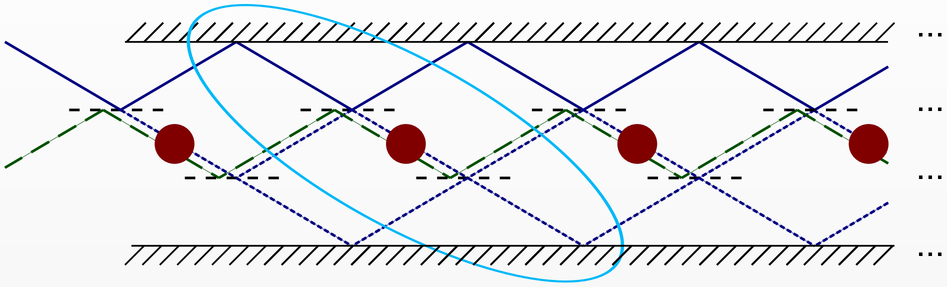
J.D. Franson, B.C. Jacobs, and T.B. Pittman, Phys. Rev. A **70**, 062302 (2004)

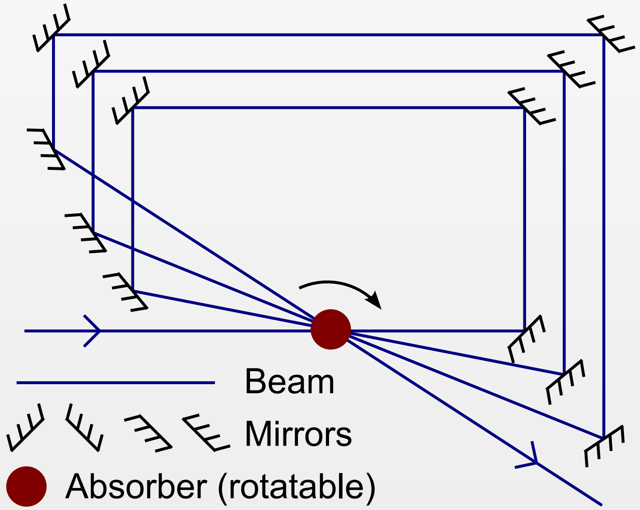
Problem: typically $\xi_1 \gg \xi_2$, e.g., three-level system

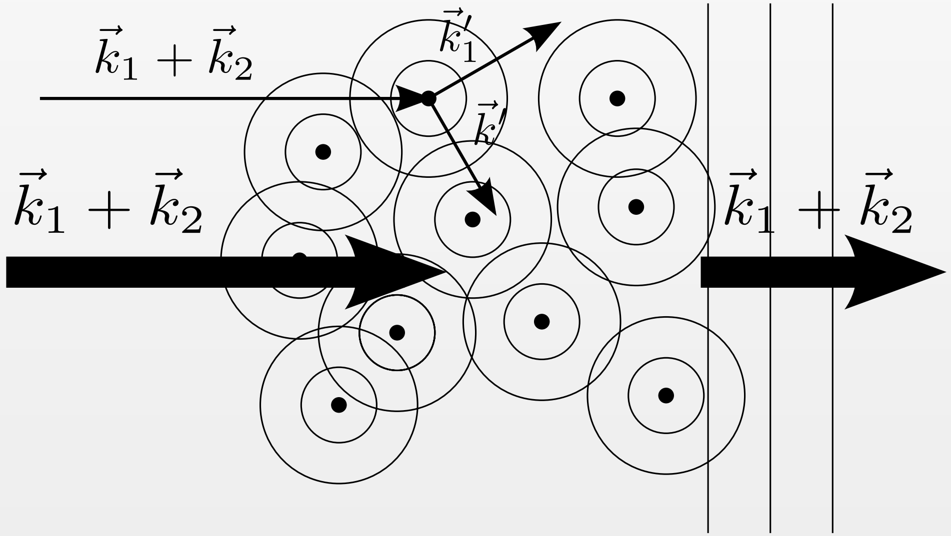
$$\frac{\xi_1}{\xi_2} = \mathcal{O}(\omega^2 A) \gg 1$$

Feasibility

$$\frac{\xi_2}{\xi_1} = \frac{\pi^2}{2P_{\text{error}}^2} \gg 1$$



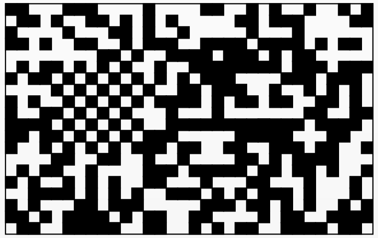


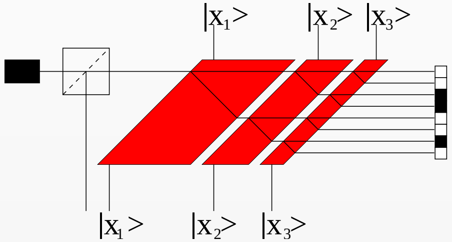


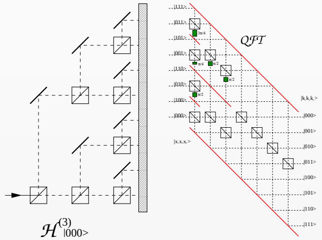
$$\frac{\xi_2^{\text{total}}}{\xi_1^{\text{total}}} = \frac{\xi_2^{\text{single}}}{\xi_1^{\text{single}}} \times \#\text{repetitions} \times \#\text{excited atoms}$$

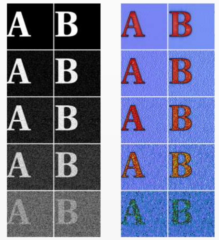
N. ten Brinke, A. Osterloh, R. Schützhold, Phys. Rev. A **84**, 022317 (2011)

Summary

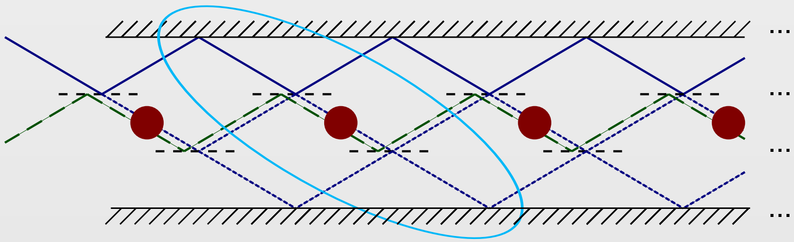


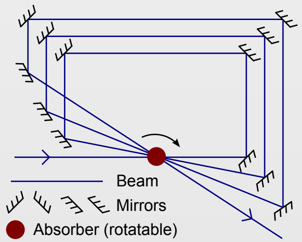


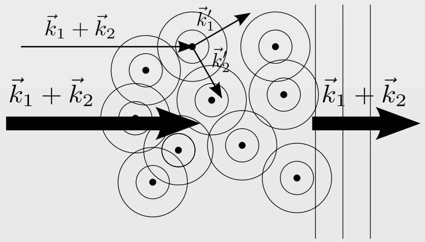




- pattern recognition with a few photons
  full quantum algorithm – linear optics set-up
- template matching with a few photons
- quantum Zeno CNOT gate
  $P_{\mathrm{error}} = 50\%$ with 10 segments and $\xi_2/\xi_1 = 12$
  $\rightarrow$ required amplification: 100-1000



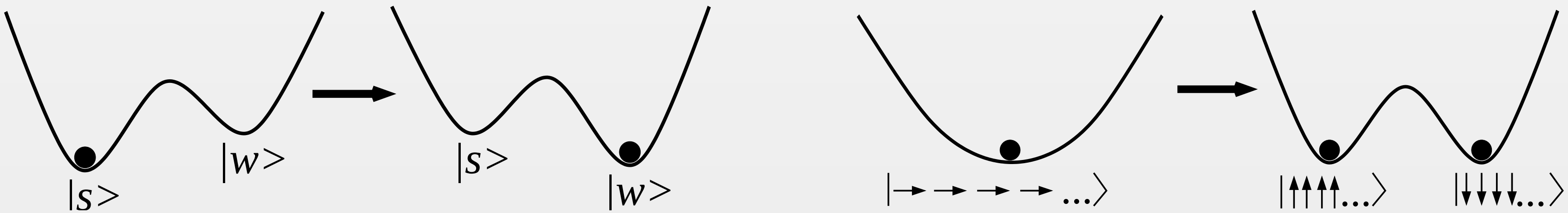




Adiabatic Quantum Computing

→ session on Friday, talks by Amin, Farhi, Lidar,Young, etc.

- *General error estimate for adiabatic quantum computing* G.Schaller, S.Mostame, R.S., Phys. Rev. A **73**, 062307 (2006) $T_{\mathrm{Landau-Zener}} \propto 1/\Delta E_{\mathrm{min}}^2$ and $T_{\mathrm{min}} \propto 1/\Delta E_{\mathrm{min}}$
- *Adiabatic quantum algorithms as quantum phase transitions: First versus second order*, R. S., G. Schaller, Phys. Rev. A **74**, 060304 (2006)



- decoherence: S. Mostame, G. Schaller, and R. S., Phys. Rev. A **81**, 032305 (2010); Phys. Rev. A **76**, 030304 (2007) M. Tiersch and R. S., Phys. Rev. A **75**, 062313 (2007)

Quantum simulators/simulations. . .