Photons: other considerations

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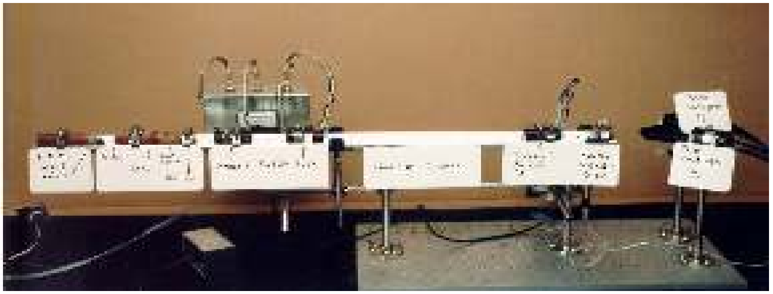
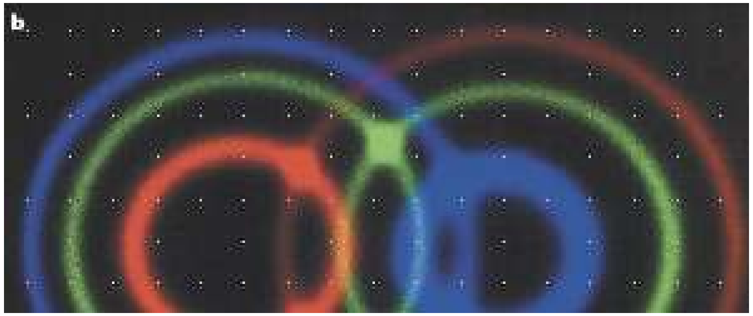
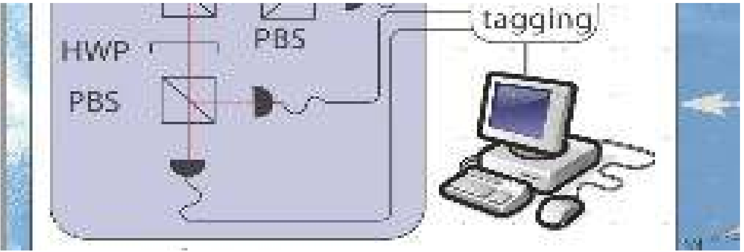
Q Comm / Crypto



Entanglement creation



Entanglement based protocols



Quantum computation

???

All-optical quantum computing

All-optical quantum computing

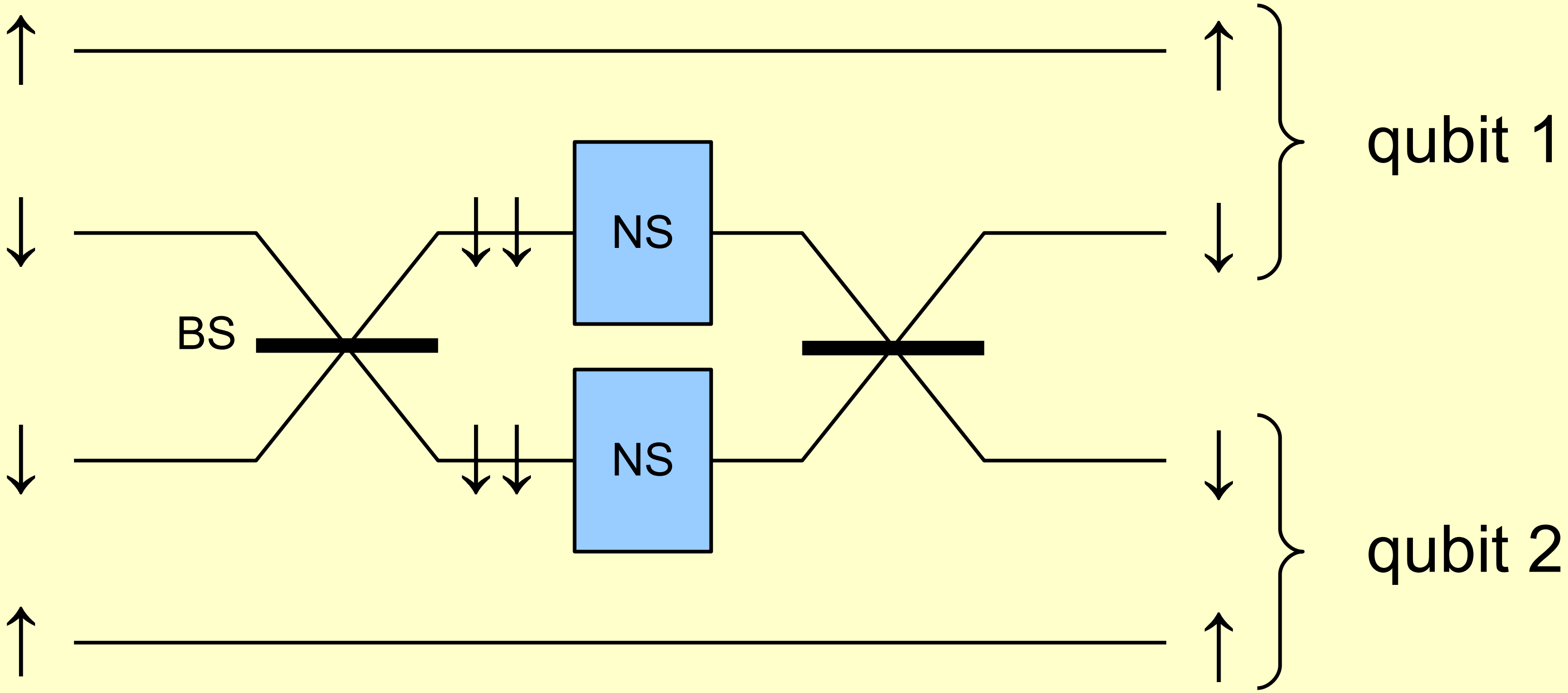
- QC requirements
- Qubit
- Register initialization
- Single-qubit operations
- Measurements

OK, ☑

- Entanglement
  - natural sources
  - post-selection
- Scalability

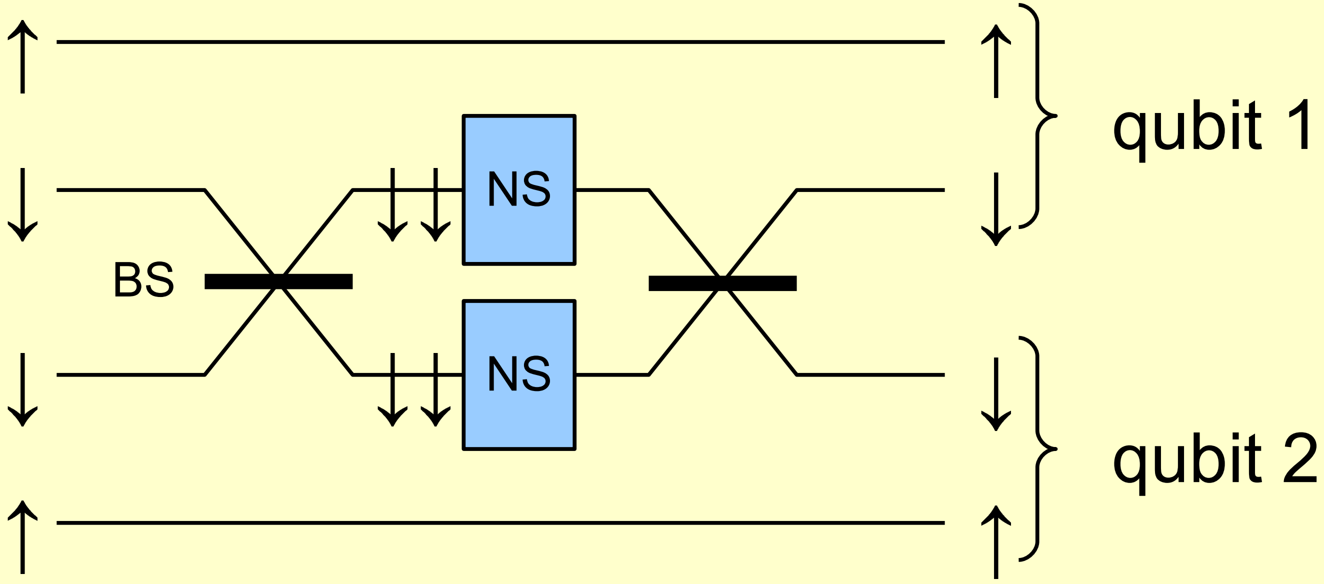
Too inefficient, ☒

Knill-Laflamme scheme



- This scheme for QC is based on a dual-rail encoding.
- Photons with same polarization are merged in the middle rails and suffer a nonlinear phase shift.

Knill-Laflamme scheme



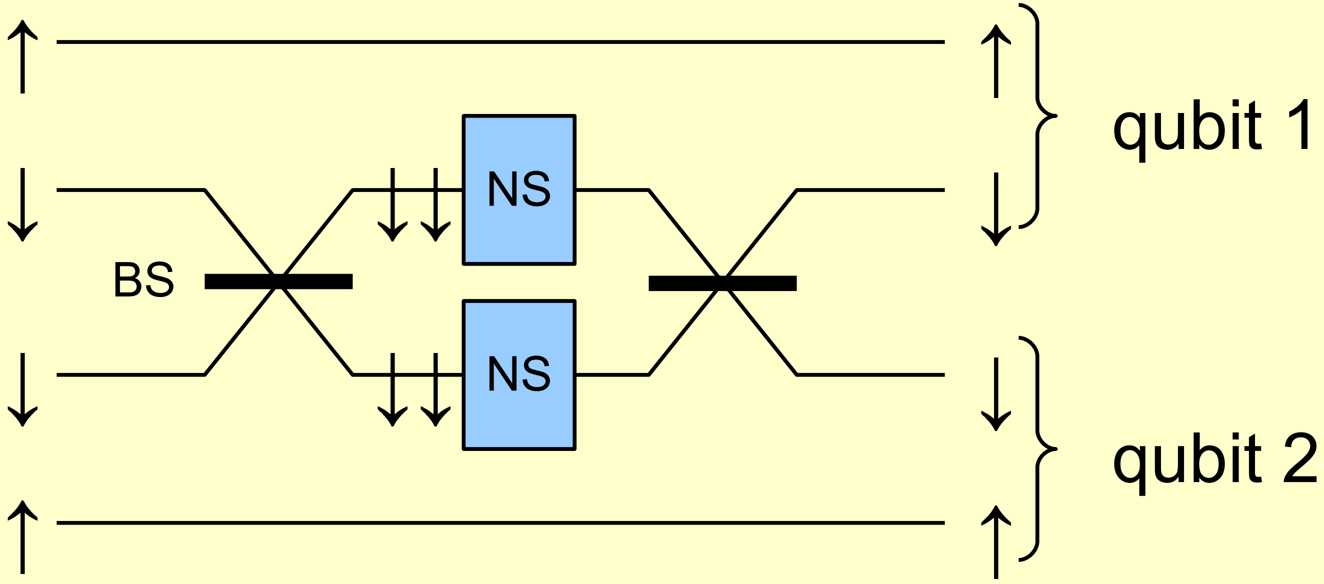
Inside NS

$$|vac\rangle \rightarrow |vac\rangle$$
$$a^{+}|vac\rangle \rightarrow a^{+}|vac\rangle$$
$$a^{+2}|vac\rangle \rightarrow (-1)\,a^{+2}|vac\rangle$$

At the qubit level

$$|\uparrow\uparrow\rangle \rightarrow |\uparrow\uparrow\rangle$$
$$|\downarrow\uparrow\rangle \rightarrow |\downarrow\uparrow\rangle$$
$$|\uparrow\downarrow\rangle \rightarrow |\uparrow\downarrow\rangle$$
$$|\downarrow\downarrow\rangle \rightarrow (-1)|\downarrow\downarrow\rangle$$

Knill-Laflamme scheme



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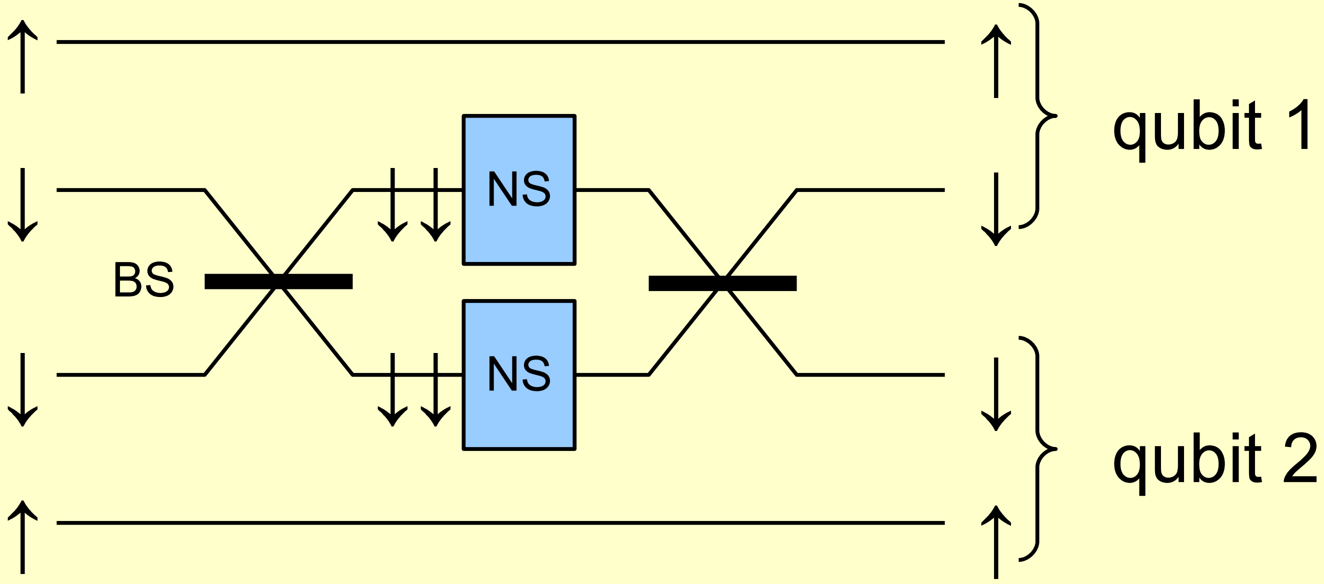
At the qubit level

$$(-1)|\downarrow\downarrow\rangle$$

Universal gate

Knill-Laflamme scheme



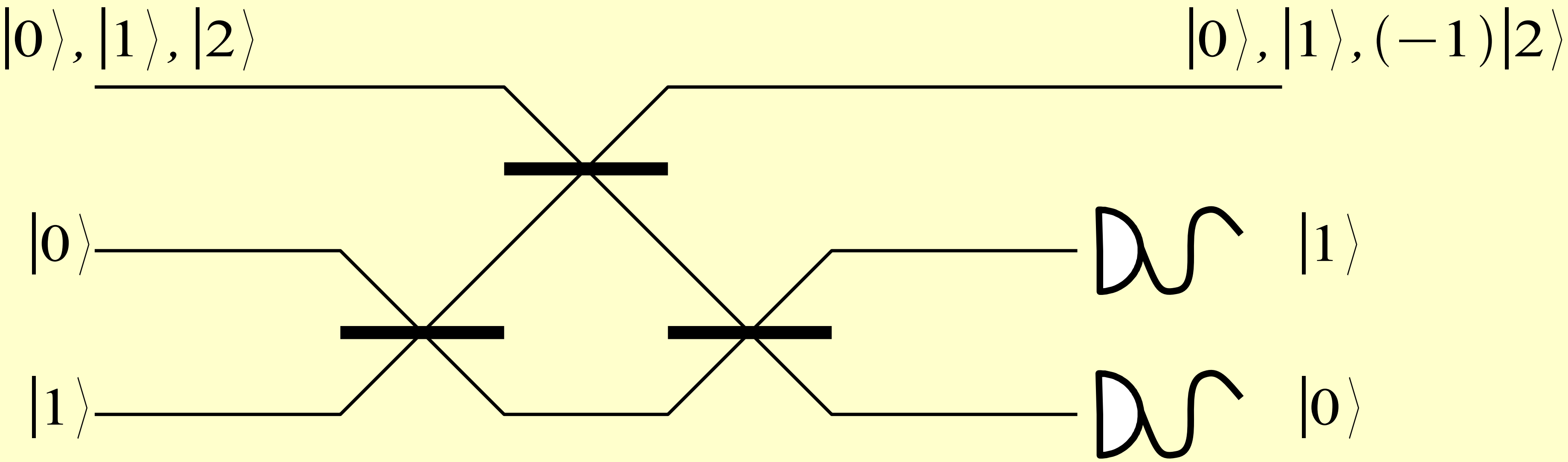
Exercise:

Proof that this gate can create a maximally entangled state

At the qubit level

$$
\begin{aligned}
|\uparrow\uparrow\rangle &\rightarrow |\uparrow\uparrow\rangle \\
|\downarrow\uparrow\rangle &\rightarrow |\downarrow\uparrow\rangle \\
|\uparrow\downarrow\rangle &\rightarrow |\uparrow\downarrow\rangle \\
|\downarrow\downarrow\rangle &\rightarrow (-1)|\downarrow\downarrow\rangle
\end{aligned}
$$

Knill-Laflamme scheme



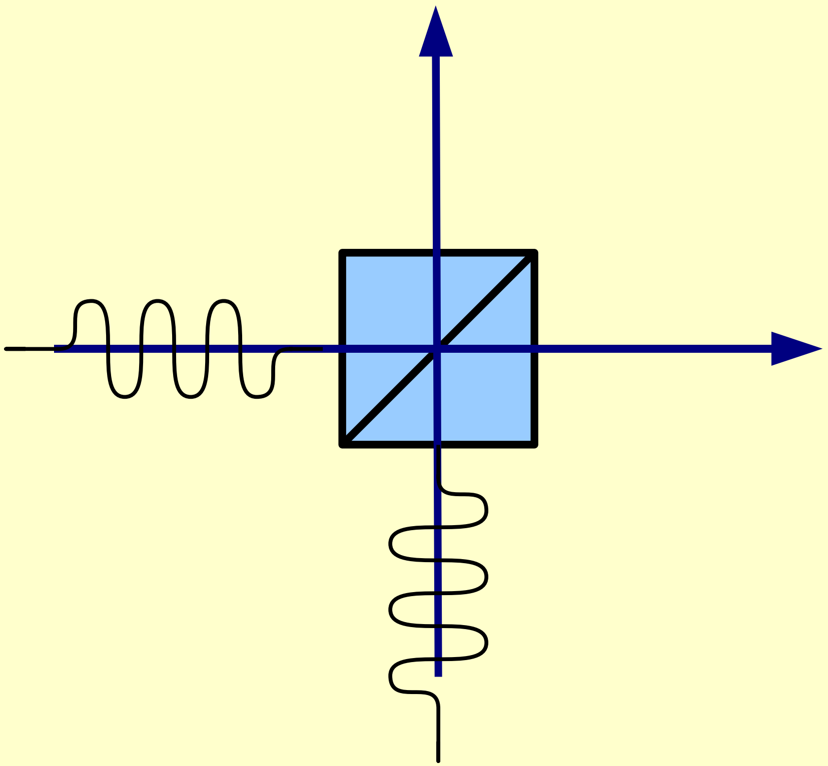
- Again a probabilistic protocol, p_ok = 1/4
- We introduce two ancilla rails, with 0 and 1 photon, respectively. We ask the detectors to click with 1 and 0 photons, respectively.
- If succeeds, a minus phase in the two photon state.

Imperfections

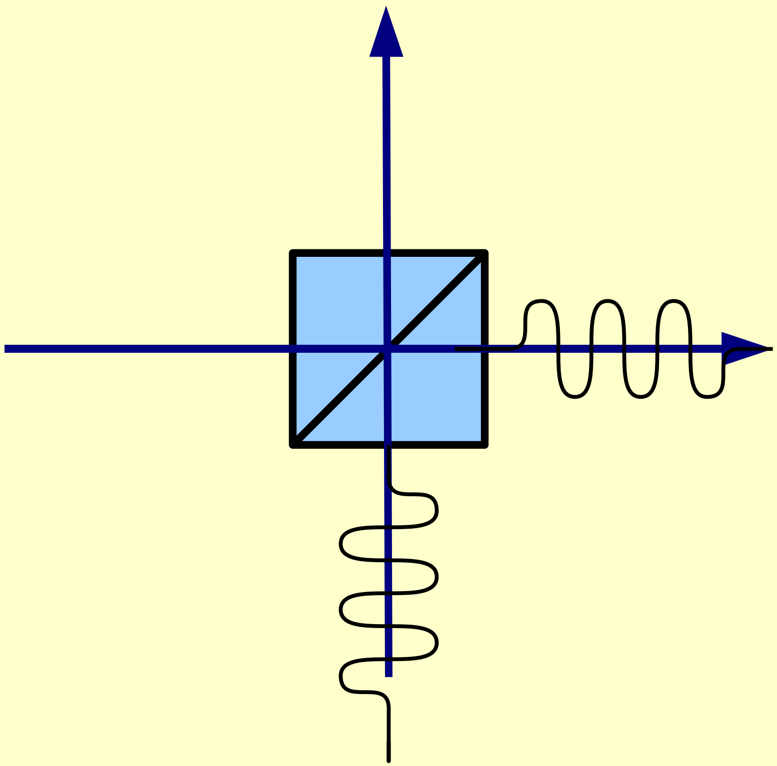
Imperfections

Light source	• Imperfect single photon sources
Detection	• Dark counts • Missed photons
Decoherence	• Polarization rotation and dephasing by materials – heating and systematic errors • Photon losses / absorption
Setup	• Synchronization • Low efficiency in probabilistic protocols.

Synchronization



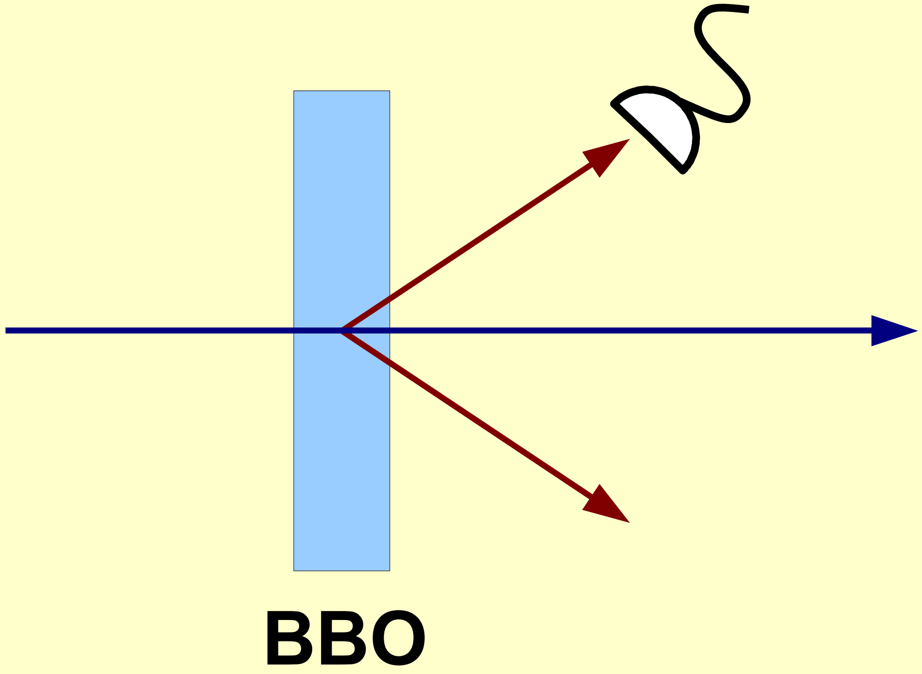
Interference:



Distinguishable

- The time of arrival of photons matters for any interference or entangling setup.
- Frequency, phase and polarization matter as well.

Heralded photon sources



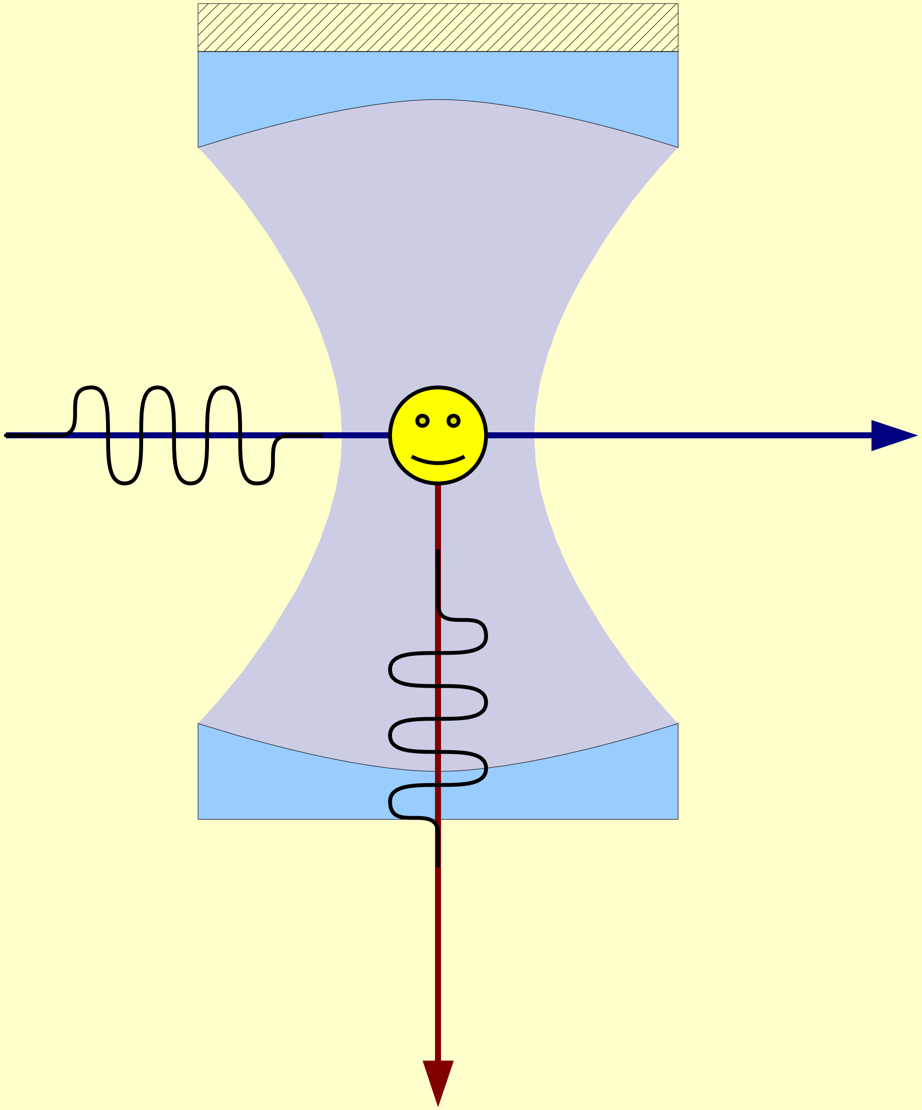
We rely on a material generating pairs of photons.

Out of a pair, we only keep one of the photons.

The other one is used to detect the production of the single photon.

No control over time.

On-demand photon sources



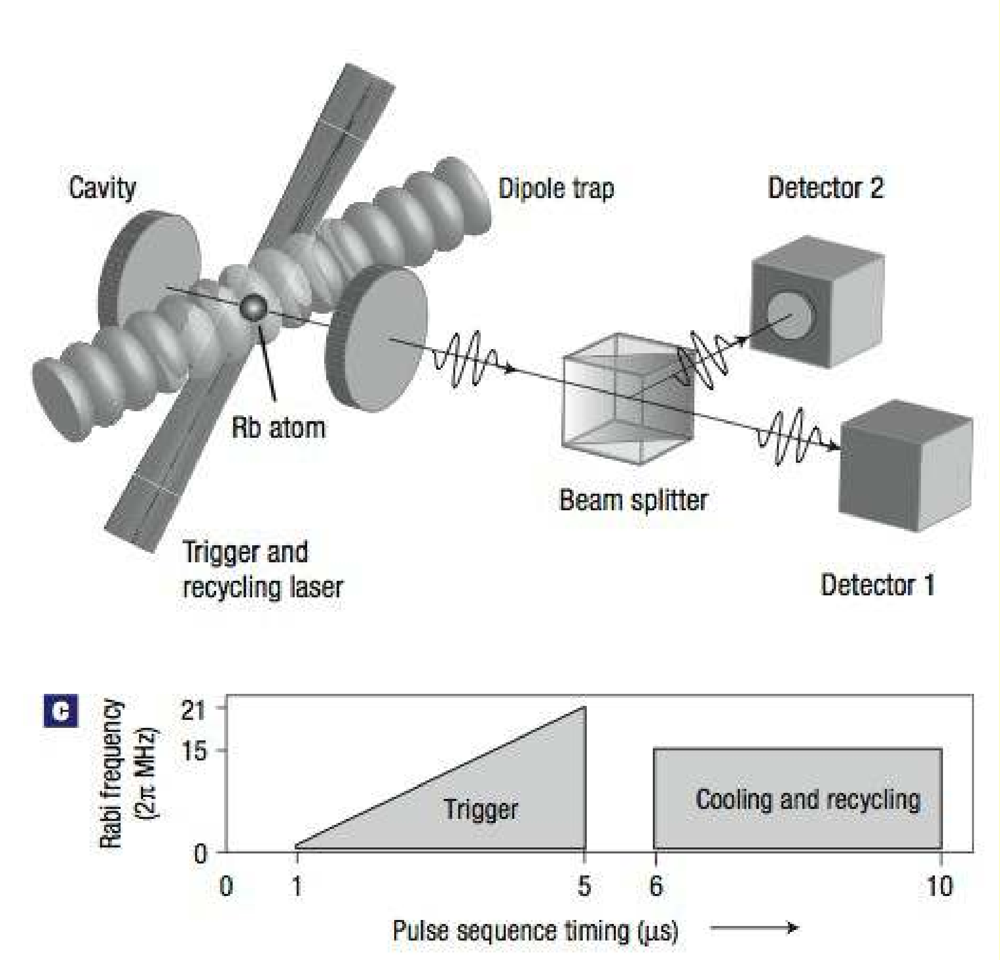
A two-level system inside a cavity.

We send pulses of light with a given temporal profile.

With some probability, these pulses excite the “atom”, which emits in the cavity.

The generated photon leaves the cavity.

On-demand photon sources



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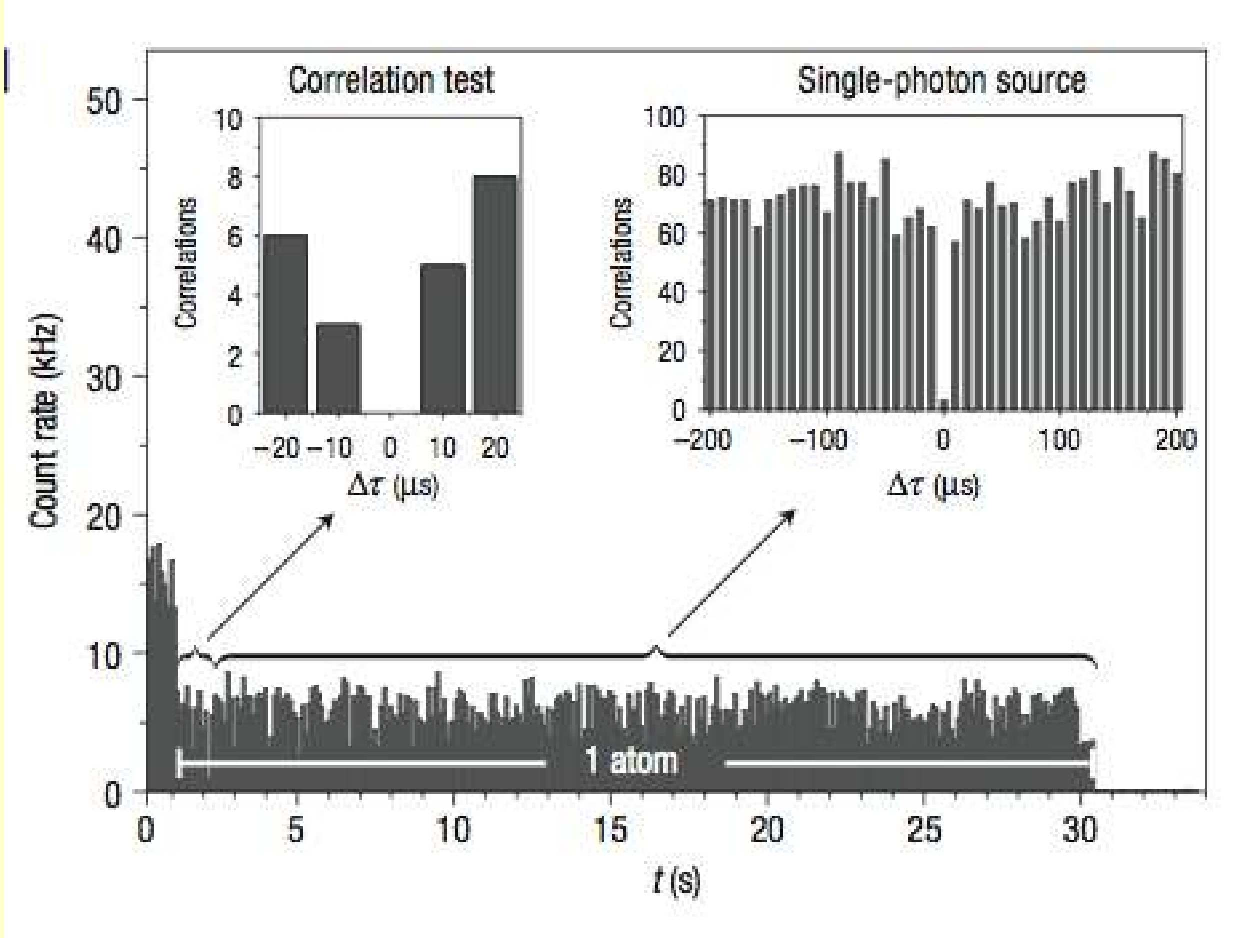

Right now, single-photon sources, but not too good control over the emission profile

Outlook

- Better synchronization and single photon sources
  - Atomic sources, quantum dots, impurities in diamonds, etc.
- Light matter interface:
  - Photon storage
  - Atomic ensembles, BECs, trapped ions,...
- Better cryptographic protocols
  - Security proofs
  - Use of entanglement
  - Black-box cryptography