Superconducting qubits: circuit QED

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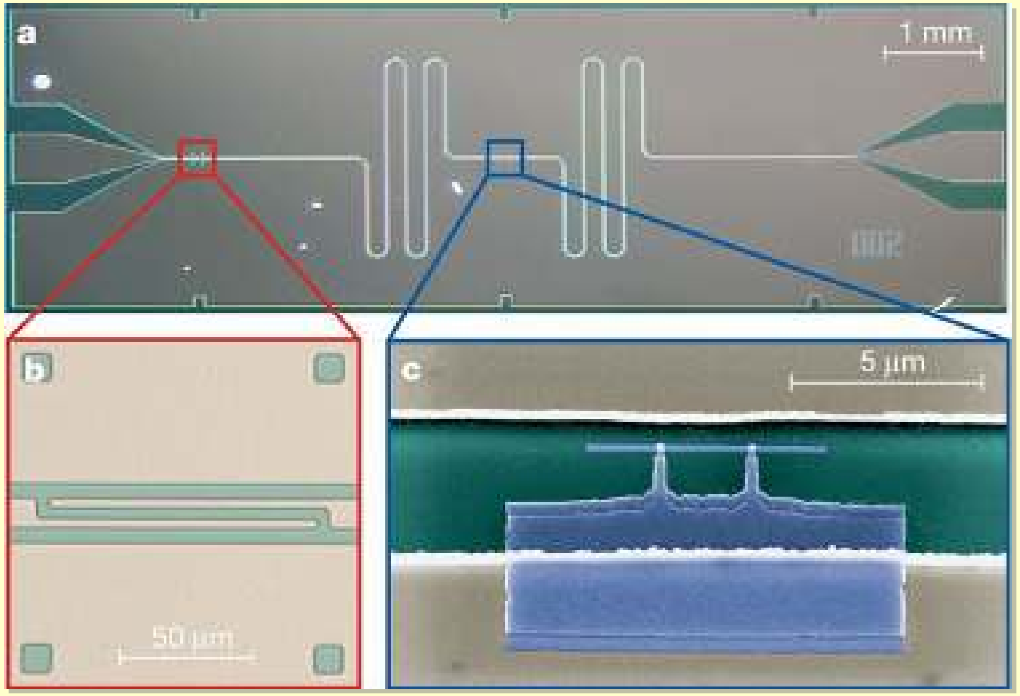
Interaction

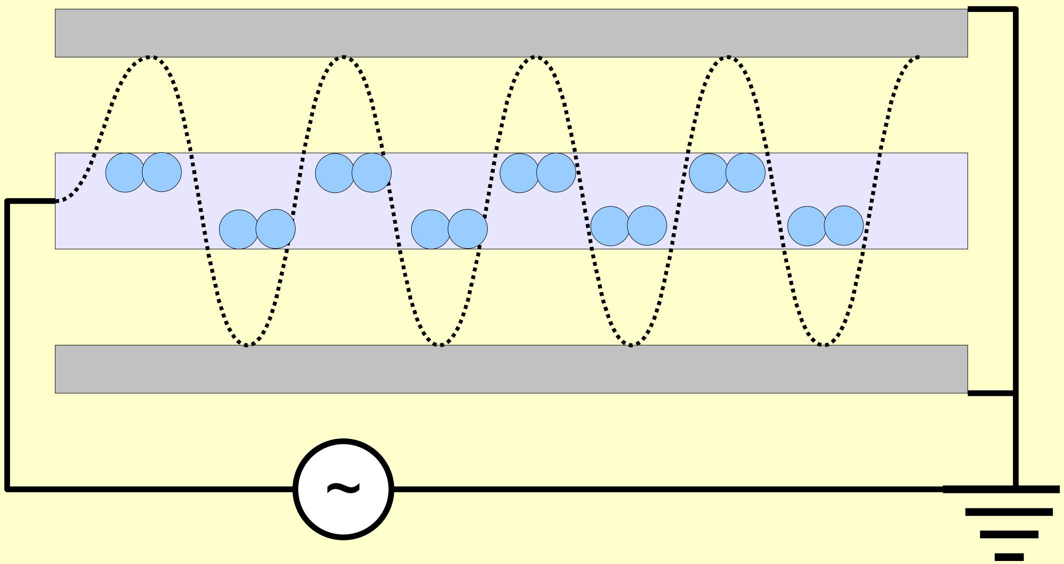
- To do QC we need some kind of interaction mechanism.
- For trapped ions we had the phonon bus: harmonic oscillator.
- For ultracold atoms, cavities have been suggested.
- Why not use our almost perfect resonators?



Microwave cavities

Field quantization: waveguides

- A coaxial waveguide: conductor plane among ground lines.
- EM field is associated to charge distributions on the conductors.



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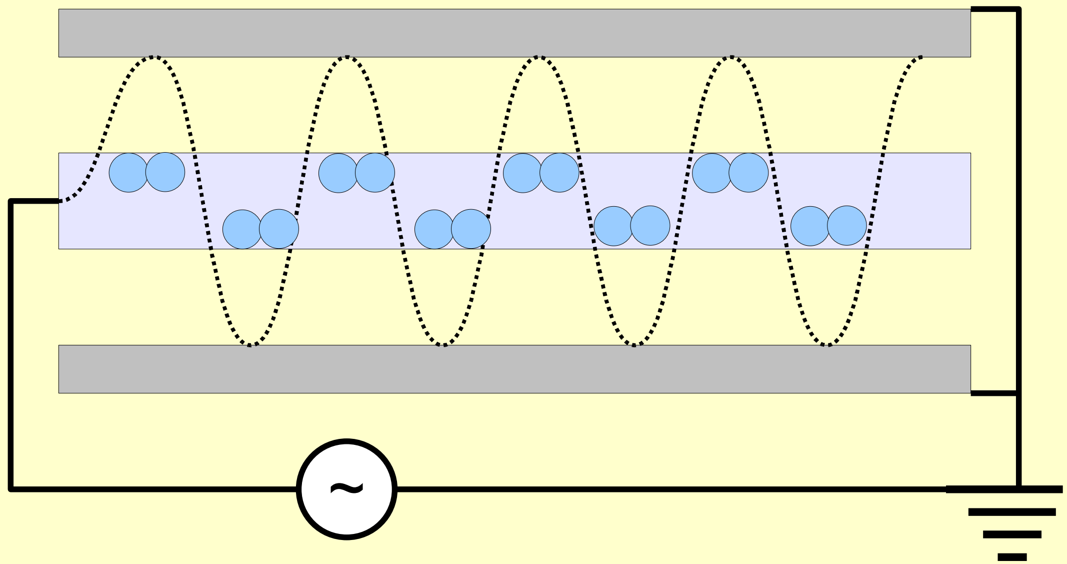
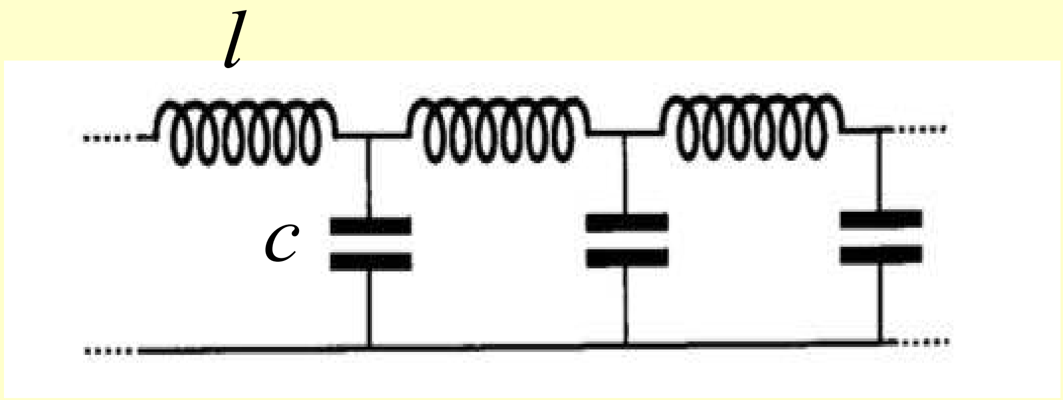
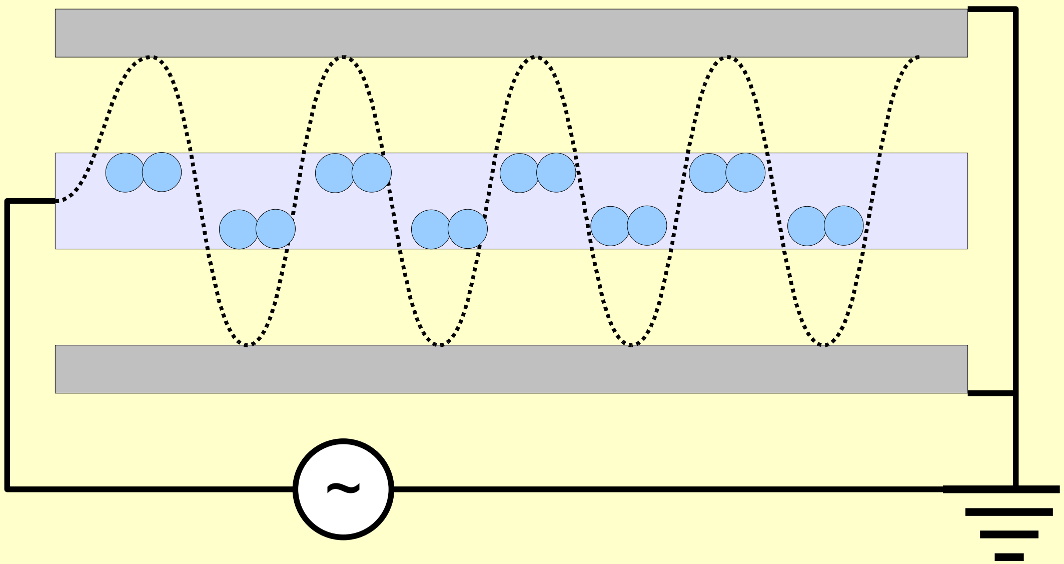
- Everything modeled with circuit theory.





Field quantization: waveguides

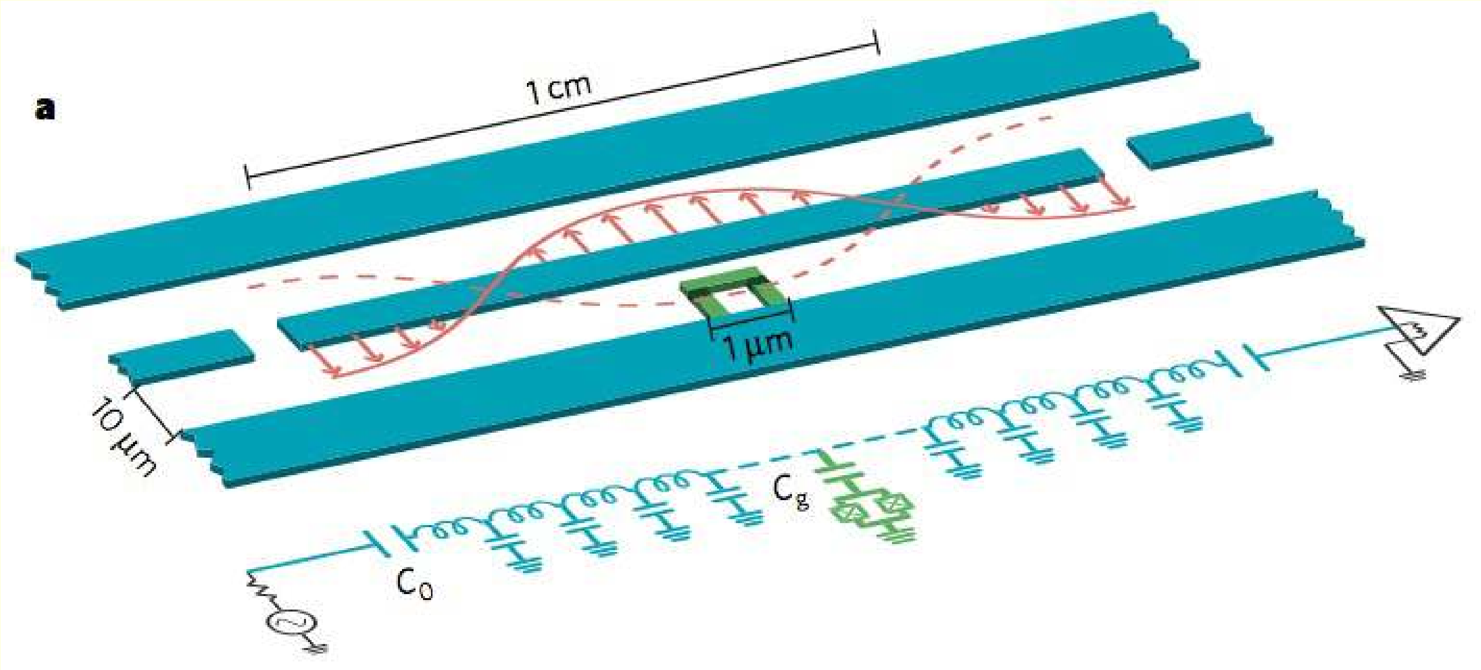
- A coaxial waveguide: conductor plane among ground lines.
- EM field is associated to charge distributions on the conductors.
- Everything modeled with circuit theory.
- Results are quantized microwave fields.
- Tunable speed of "light"
- One-dimensional



$$L = \int dx \left[\frac{l}{2} (\partial_t Q)^2 + \frac{1}{2c} (\partial_x Q)^2 \right]$$

$$\omega_k = v_g |k|$$

Circuit-QED



- The transmission line provides us with long lived microwave photons (Q = 10000, T_{ph} ~ 100 ns)
- Frequency of photons close to resonance of qubits (~ 10 Ghz)
- Simple interaction model: Jaynes – Cummings.
- Like cold atoms in cavities, but with stronger couplings.

Jaynes-Cummings

- Coupling Hamiltonian

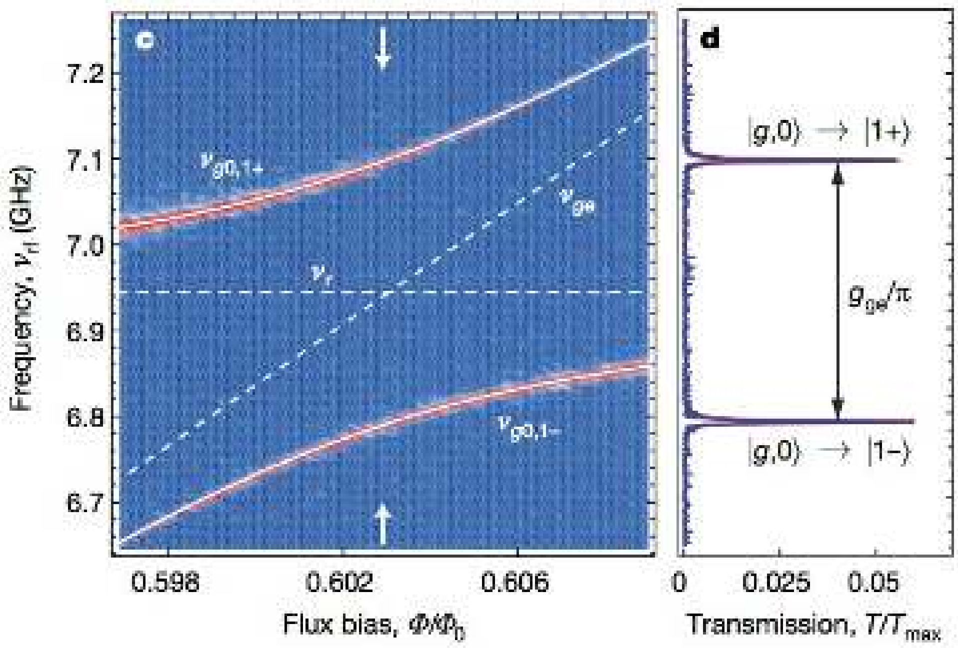
$$H = \frac{1}{2}\hbar\Omega\sigma_z + \sum_k \hbar\omega a_k^+ a_k + + \sum_k g_k \sigma^x (a_k + a_k^+)$$

- Jaynes – Cummings (RWA)

$$H = \frac{1}{2}\hbar\delta\sigma_z + g\left(\sigma^+ a + a^+ \sigma^-\right.$$

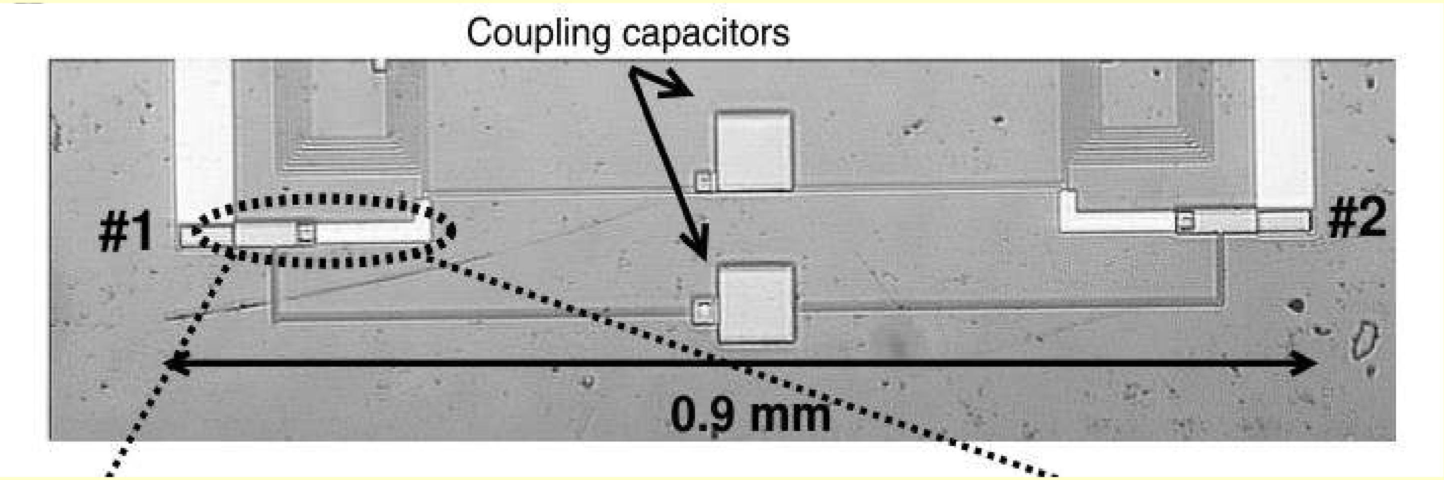
where δ is the detuning

- Absolutely equivalent to trapped ions' sidebands.
- Photon bus can mediate interactions.

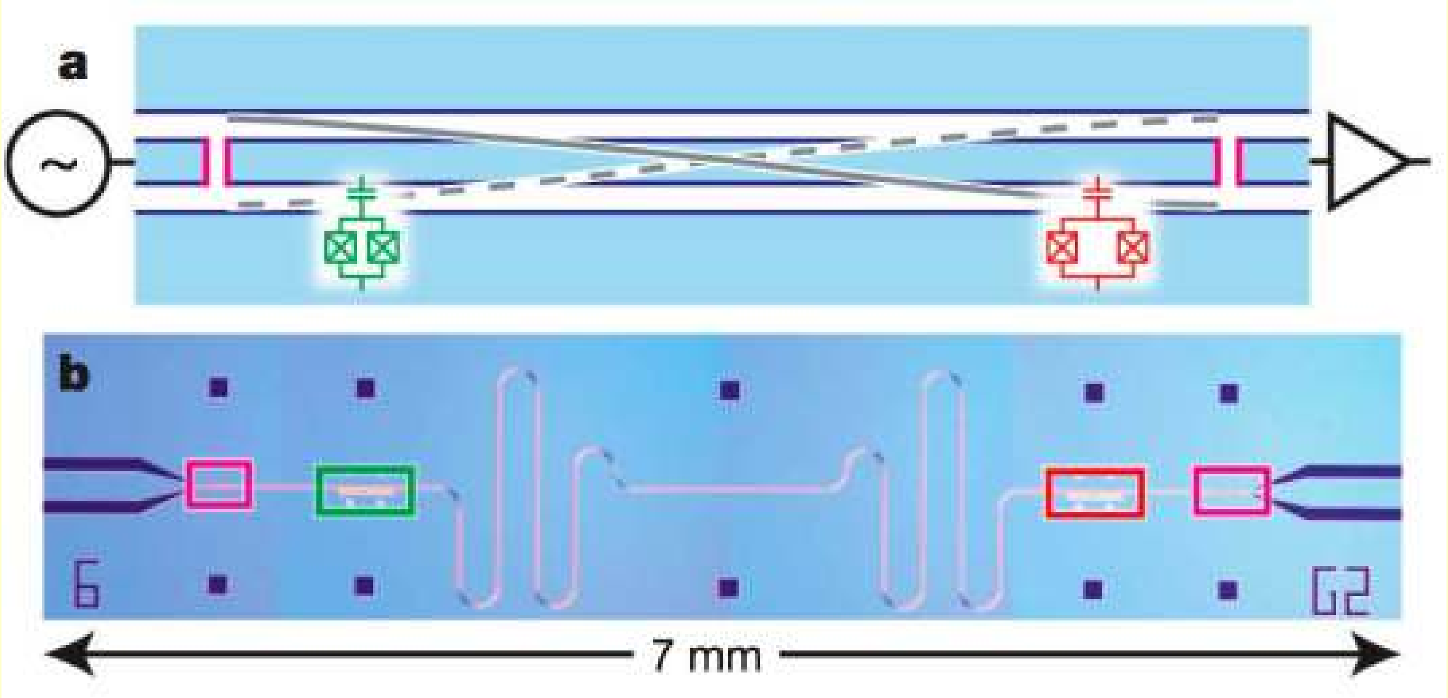


Interaction mechanisms

Direct



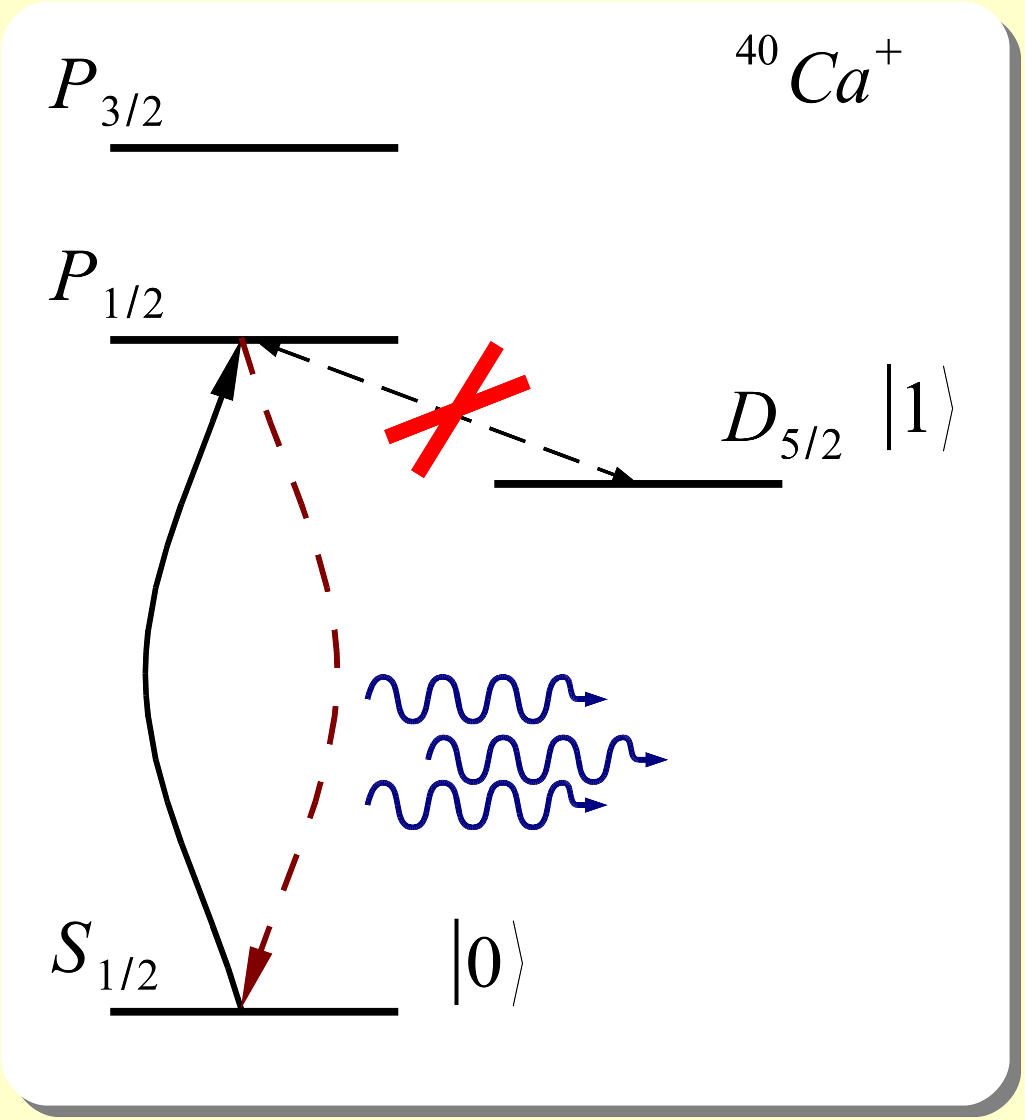
Indirect



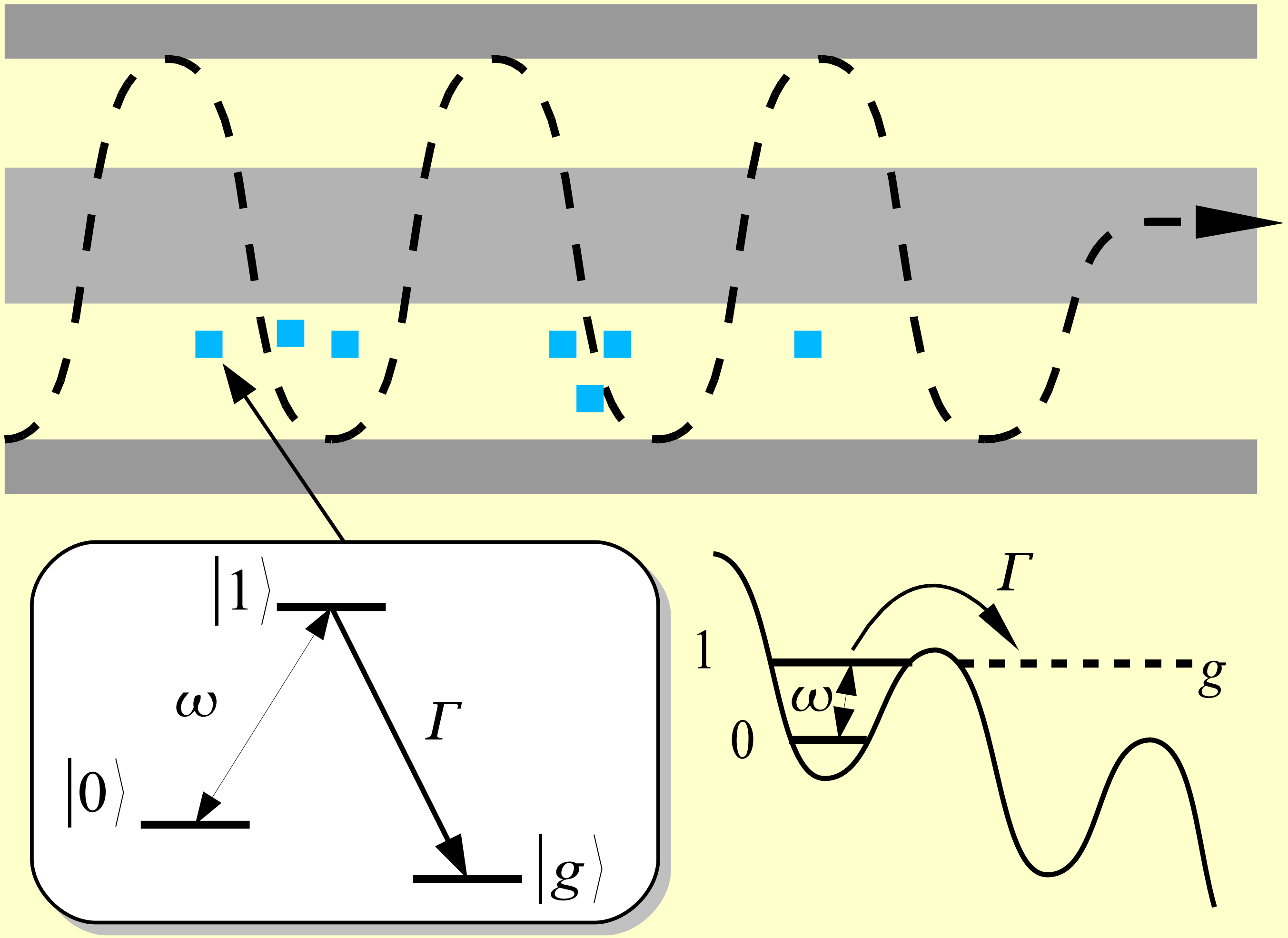
Outlook

Efficient qubit measurements

- Implementation of "electron shelving" with superconducting qubits.
- Lifts problems of inefficient microwave detection.
- Efficiency approaches 100% for long enough times.



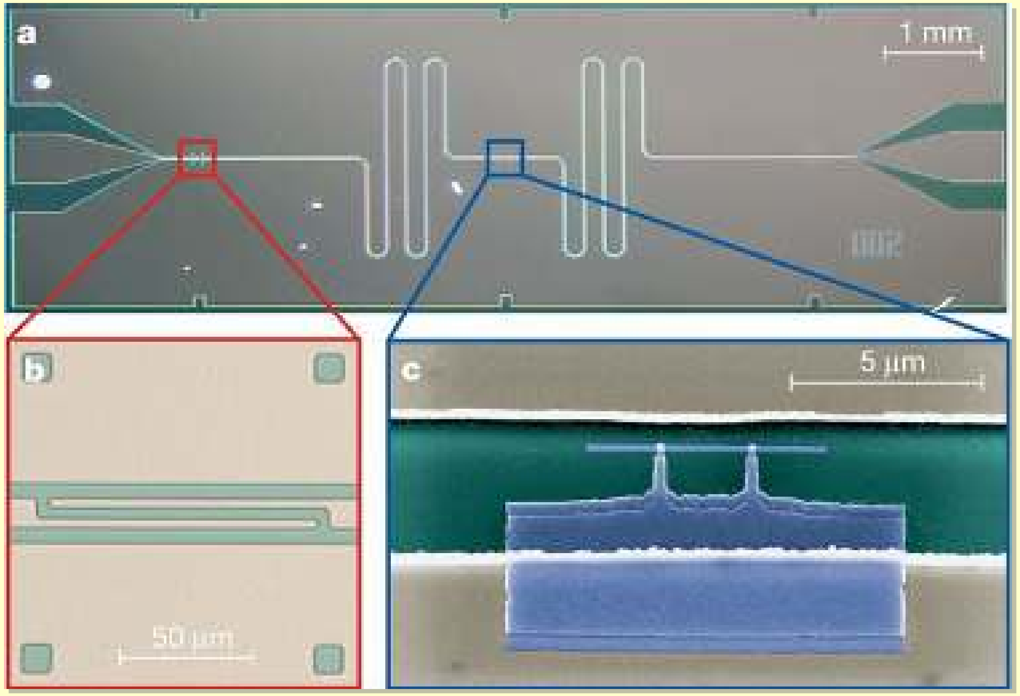
Efficient photodetection



- Treat light-qubit interaction as a atom-light scattering events.
- Engineer “optical” properties of the material for efficient absorpt.

Microwave Quantum Optics

- Study light-matter interaction.
- Engineer nonclassical states of light.
- Microwave photons as qubits for long distance communication.
- Instead of “atomic ensembles”, superqubits ensembles.
- Sophisticated many-body simulations
- ....



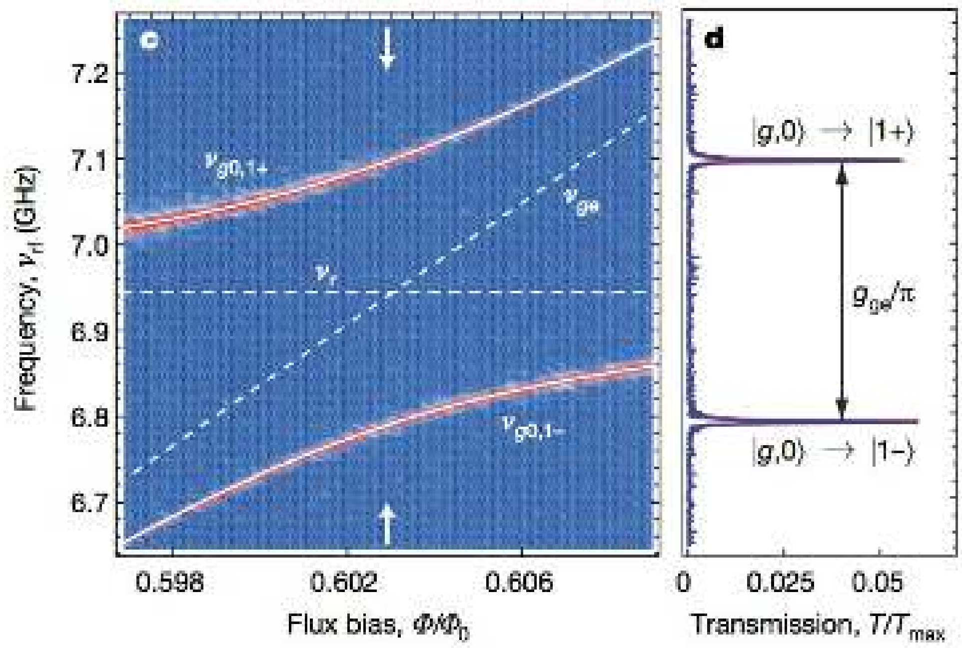
Cavity state tomography

Jaynes-Cummings

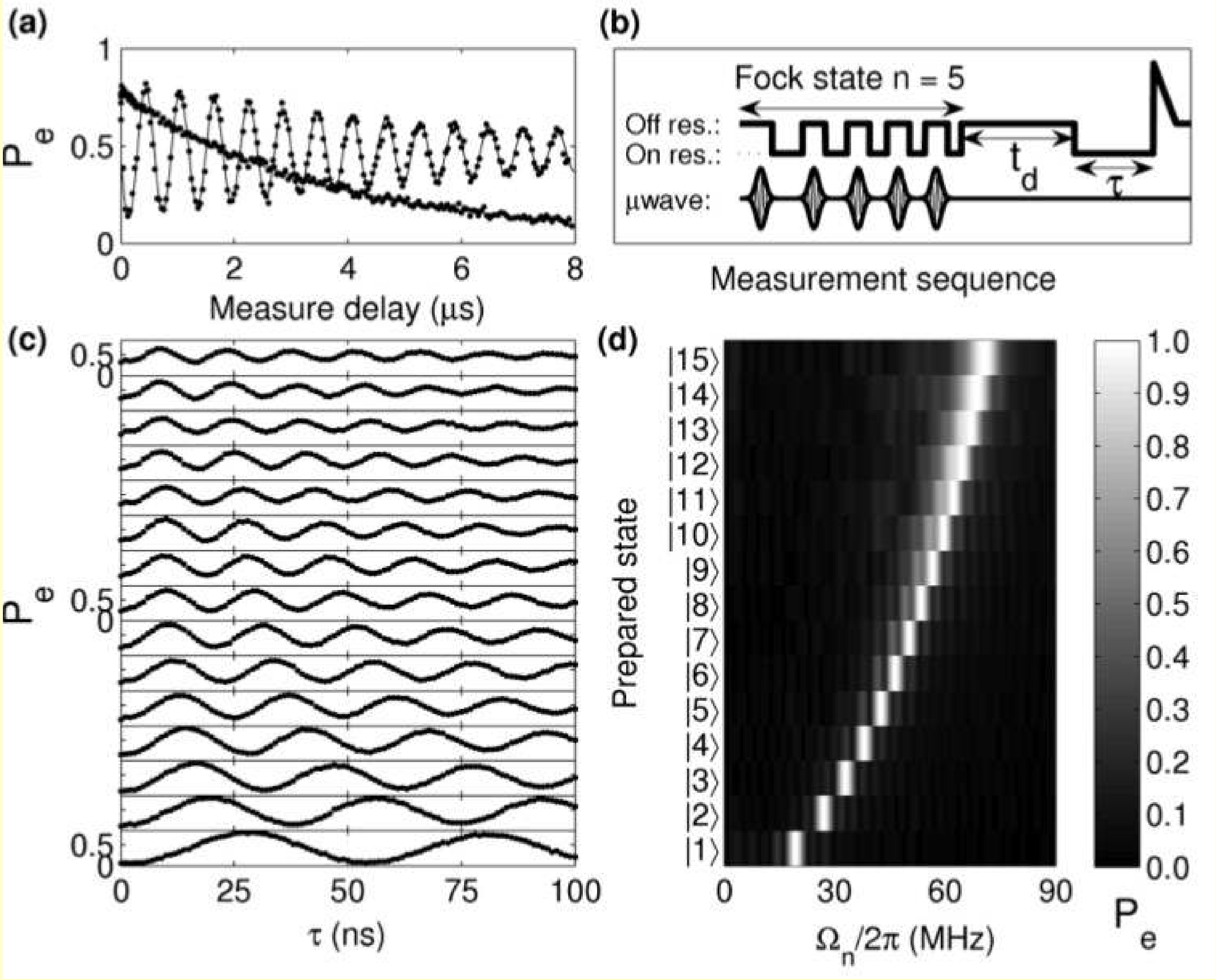
- Coupling Hamiltonian

$$H=\frac{1}{2}\hbar\Omega\sigma_z+\sum_k \hbar\omega a_k^+ a_k+$$
$$+\sum_k g_k\sigma^x(a_k+a_k^+)$$

- The dynamics of the qubit is influenced by the photon population of the cavity.
- In the RWA, integrable problem.
- We can obtain <n> and other observables from the expected value of 0 and 1.

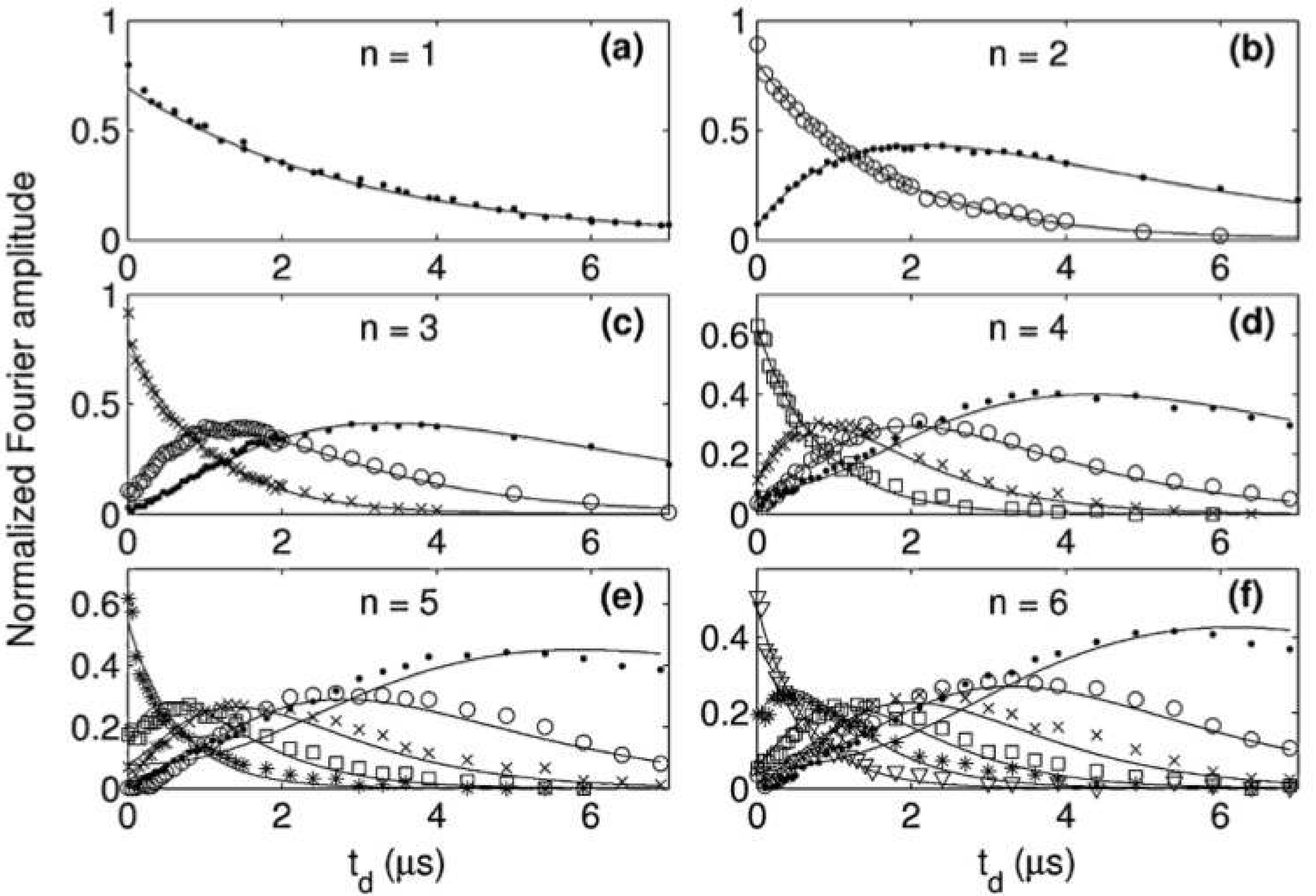


Arbitrary state preparation



Wang et al, PRL 101, 240401 (2008)

Fock state decay



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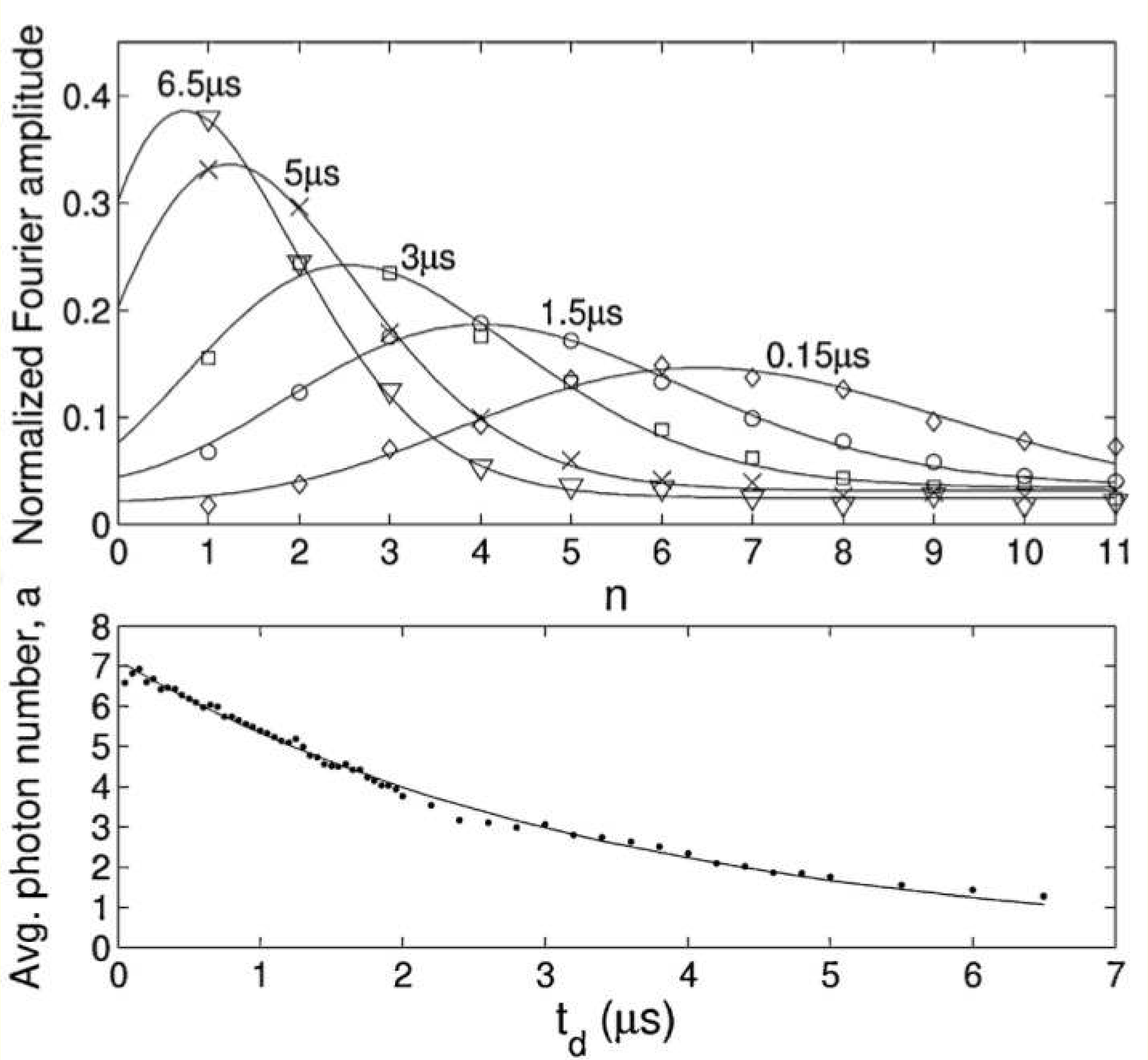

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