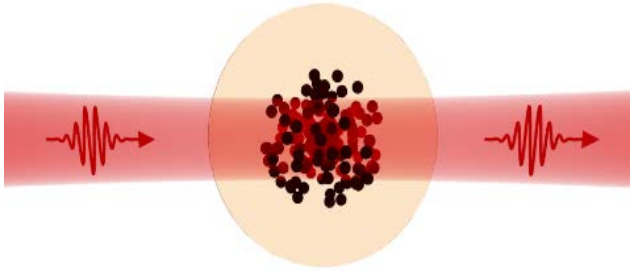
Collective dynamics of Rydberg superatoms

Nina Stiesdal, Jan Kumlin, Kevin Kleinbeck, Hannes Busche, Hanspeter Büchler, Sebastian Hofferberth



Nonlinear Quantum Optics group

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„Portable“ quantum technology

2020/2021

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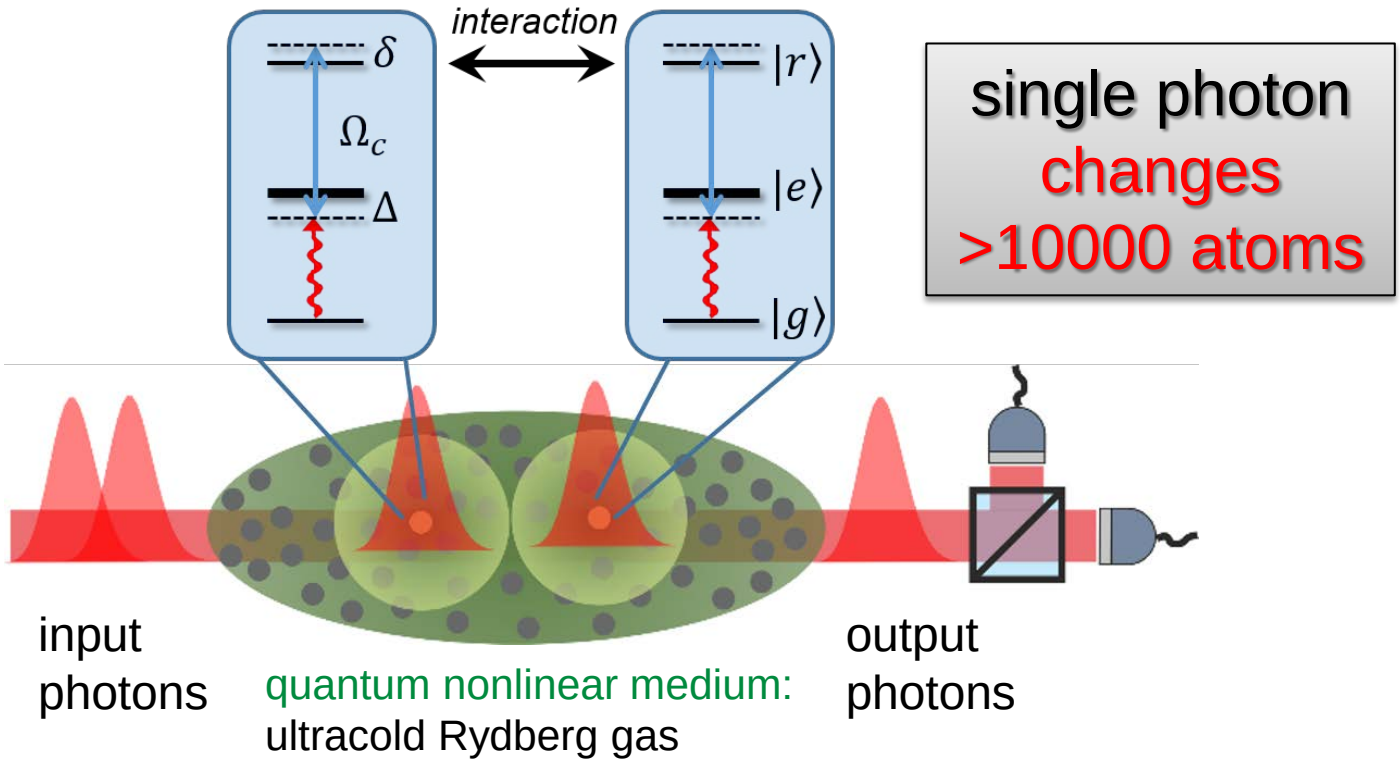
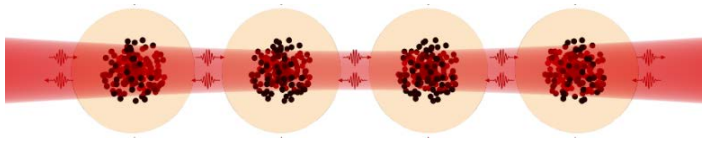
Rydberg Quantum Optics

- mapping interaction between Rydberg atoms onto propagating photons realizes effective interaction between individual photons



Superatom chain

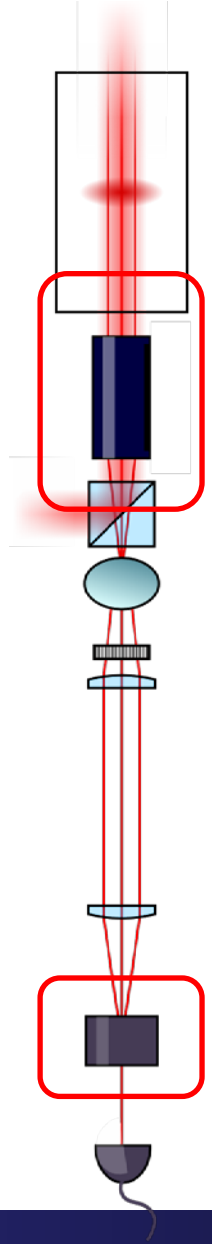


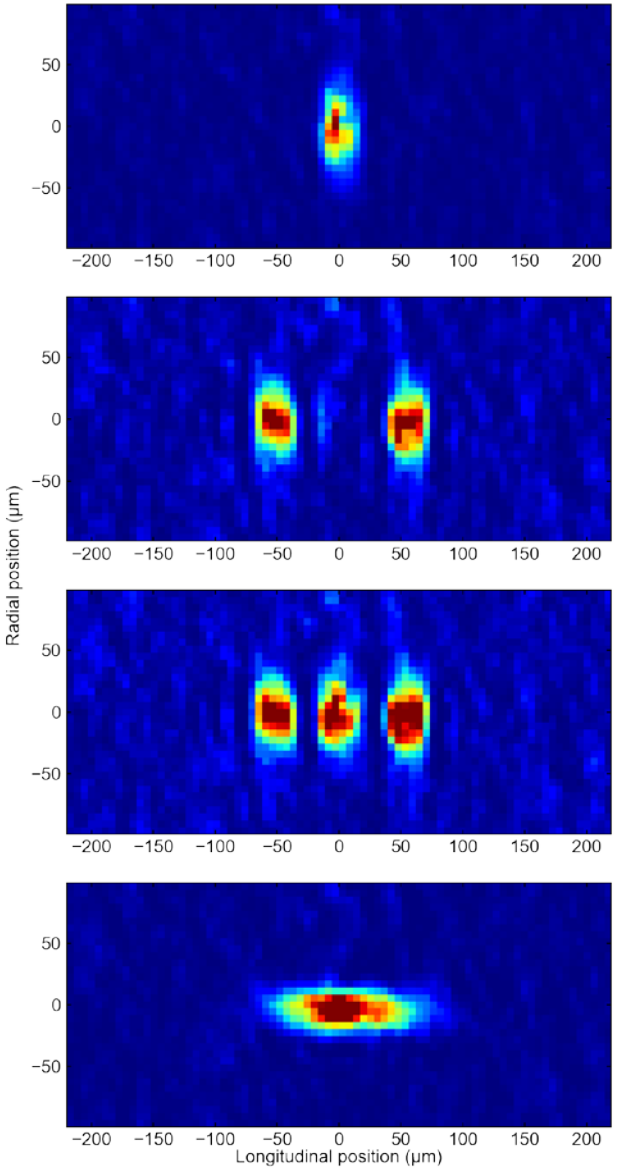
- Accousto-optical deflector with multiple RF components

under construction:

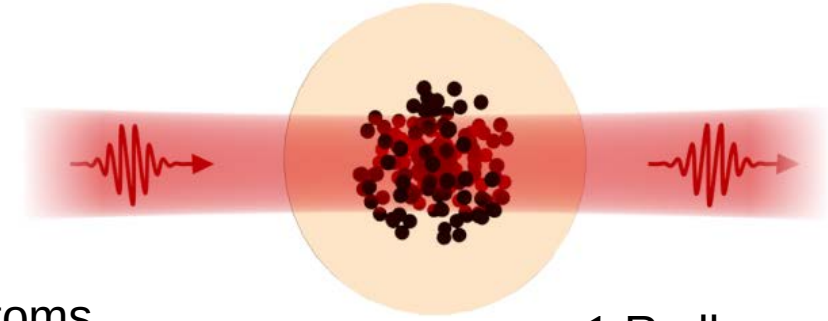
- single beam 1015nm „magic wavelength“ main trap

current implementation: up to 4 superatoms

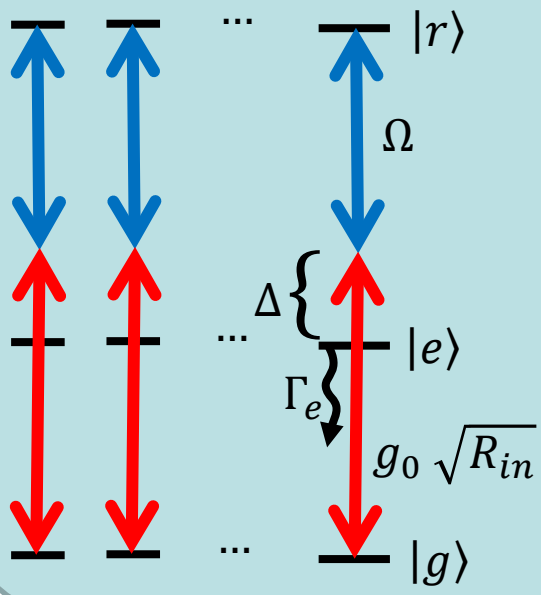




Rydberg superatom

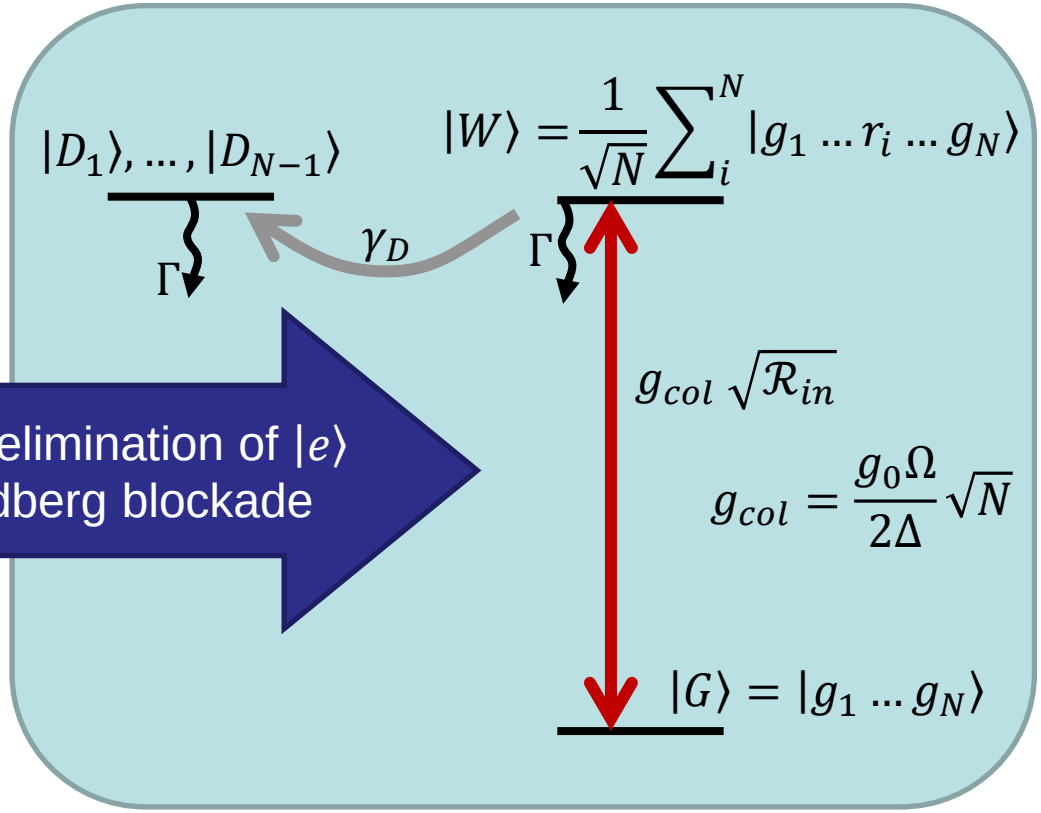


N 3-level atoms



Adiabatic elimination of $|e\rangle$ and Rydberg blockade

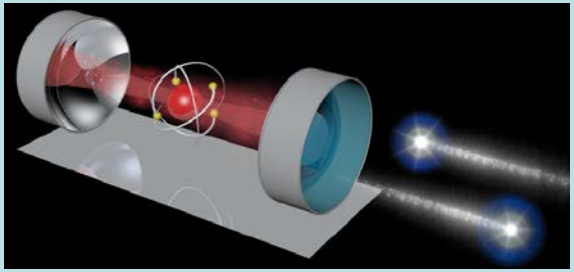
1 Rydberg superatom: 2+1 levels



The QED Zoo

Cavity QED / circuit QED:

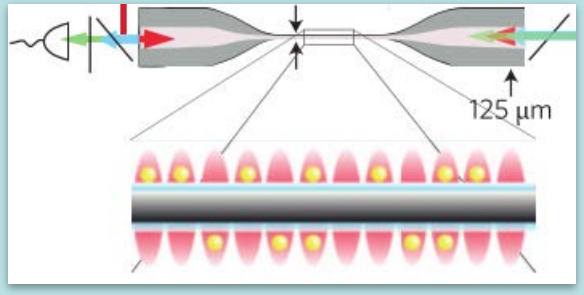
- light is longitudinally trapped
- Resonator enhances coupling



B. Hacker et. al. *Nature* 536, 193 (2016)

Waveguide QED:

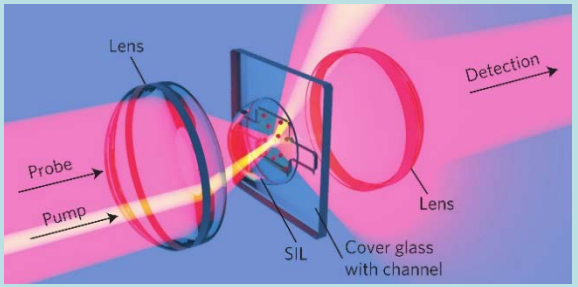
- light is transversally trapped
- single-pass interaction



E. Vetsch et. al. PRL 104 203603 (2016)

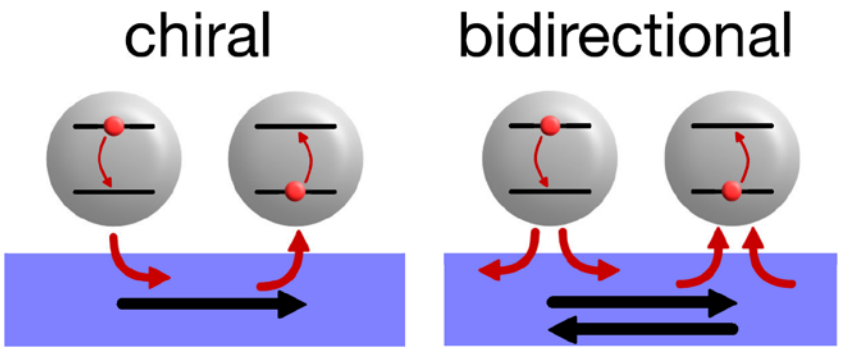
Free-space QED:

- light-matter interaction for single emitter fundamentally limited



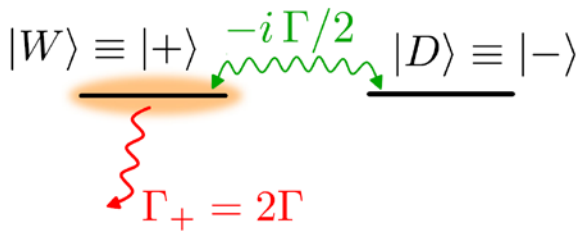
A. Maser et. al. *Nat. Photon.*, 10, 450 (2016)

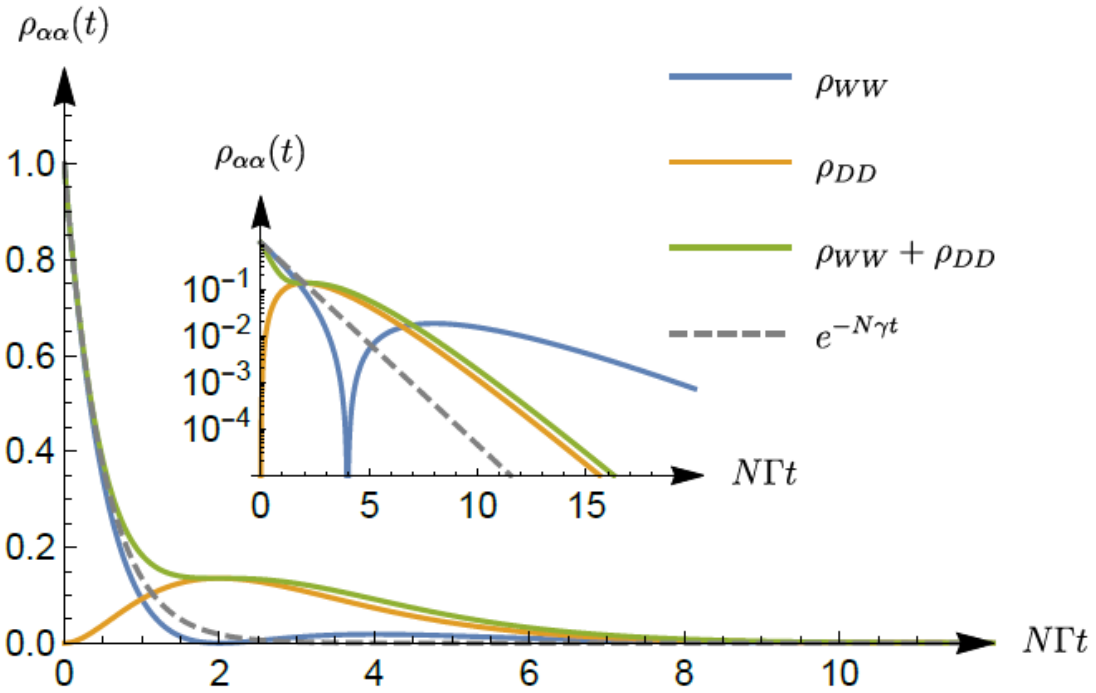
Decay of two cascaded emitters



$$|\mathrm{W}\rangle = \frac{1}{\sqrt{2}}\left[e^{ikx_1}|\uparrow\downarrow\rangle + e^{ikx_2}|\downarrow\uparrow\rangle\right]$$

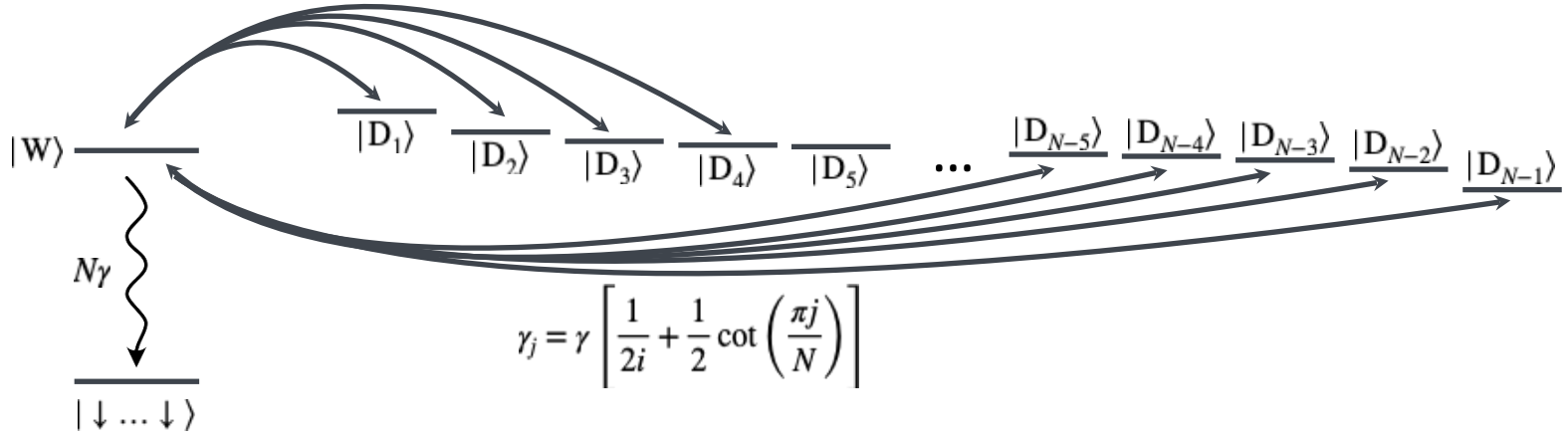
(b) chiral



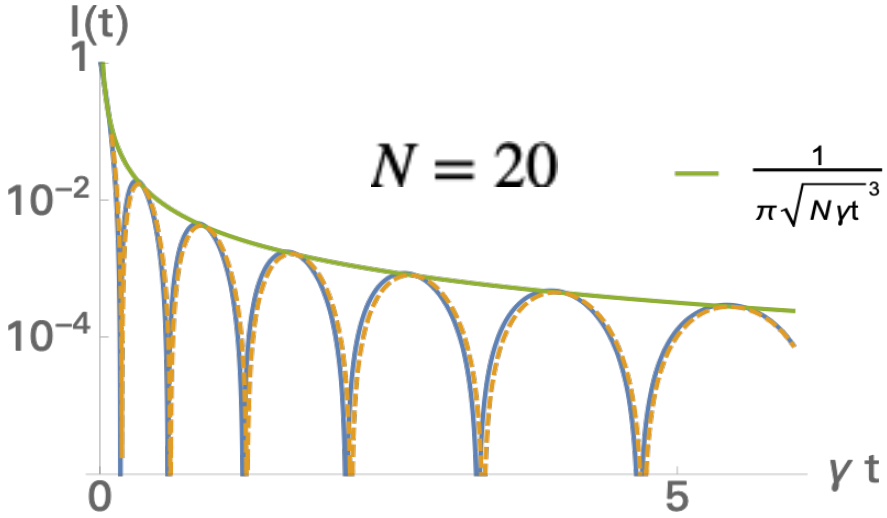


J. Kumlin, K. Kleinbeck, N. Stiesdal, H. Busche, S. Hofferberth, H.P. Buechler, arXiv:2006.14977

N emitters



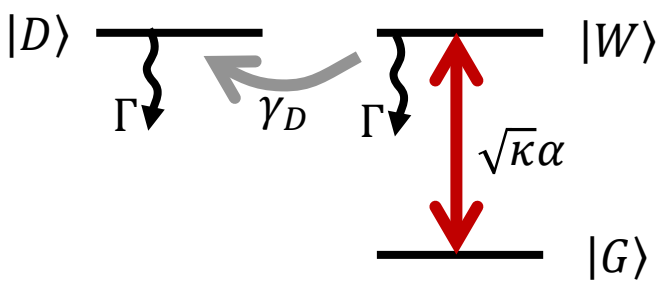
J. Kumlin, K. Kleinbeck, N. Stiesdal, H. Busche, S. Hofferberth, H.P. Buechler, arXiv:2006.14977



$$I(t) = \frac{1}{N^2}\left[L_{N-1}^{(1)}(\gamma t)\right]^2 e^{-\gamma t}$$
$$= 1 - N\gamma t + \mathcal{O}(\gamma^2 t^2) \approx e^{-N\gamma t}$$

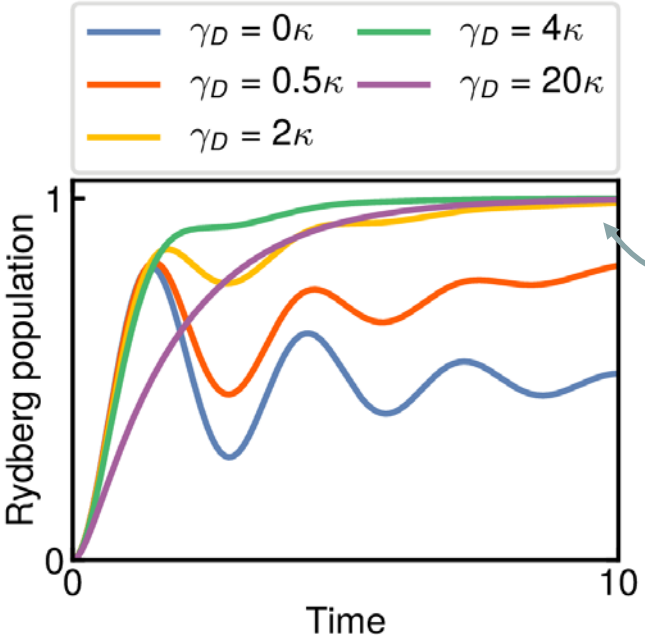
Reason: Rabi Oscillations and dephasing in Dark state manifold

First application: N-photon absorber



each superatom
removes exactly one photon
from an arbitrary input

$|n\rangle$ → - 1 → $|n-1\rangle$

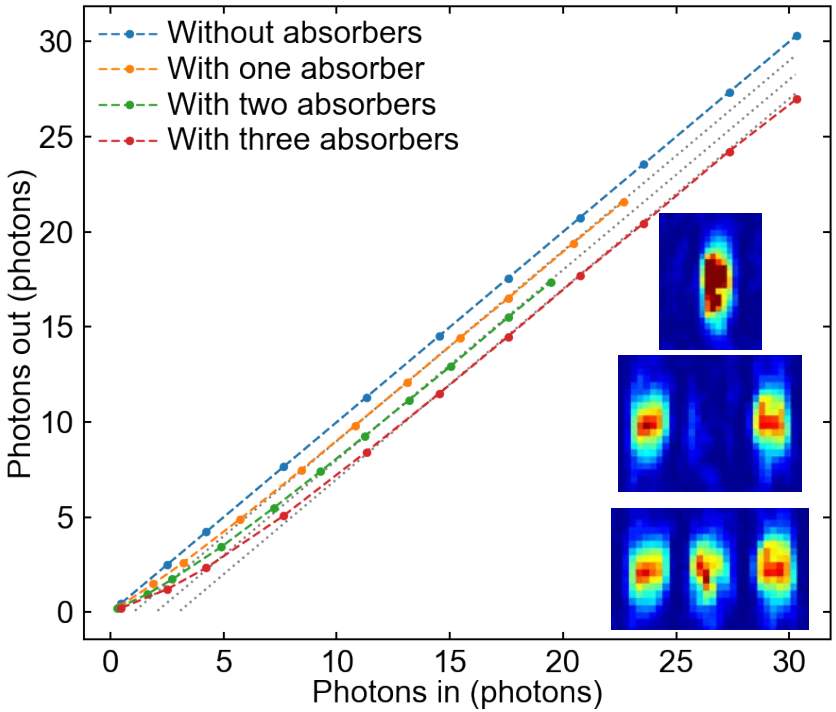


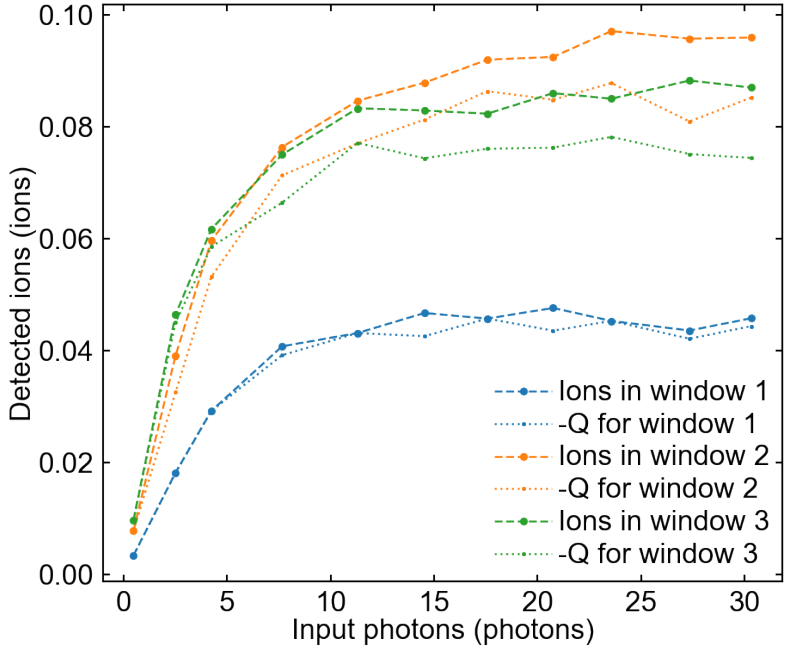
Rydberg population =

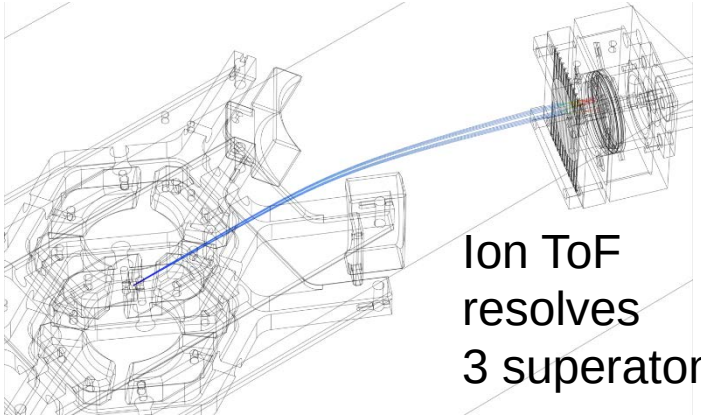
$$P_W + \sum_{k=1}^{N-1} P_{D_k} \leq 1$$

J. Honer, R. Löw, H. Weimer, T. Pfau, H.P. Büchler, PRL **107**, 093601 (2011)

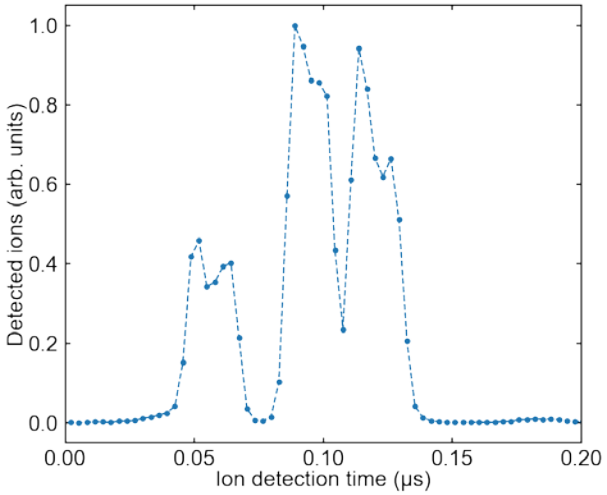
One-, two-, three-photon absorption



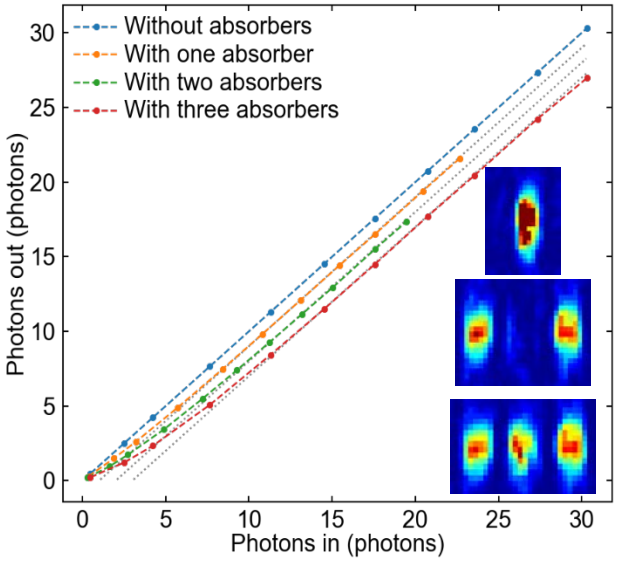


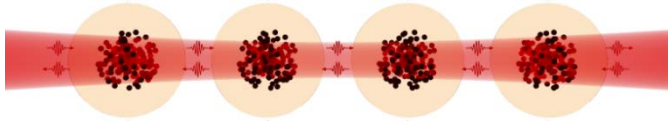


Ion ToF
resolves
3 superatoms



Summary & Outlook





- superatom chain:
  - N-photon absorber
  - cascaded/chiral system of superatoms
  - new trap geometry / tweezer hardware
    - 10-20 (smaller) superatoms in „1d-waveguide“