# Towards fast, deterministic preparation of few-fermion states

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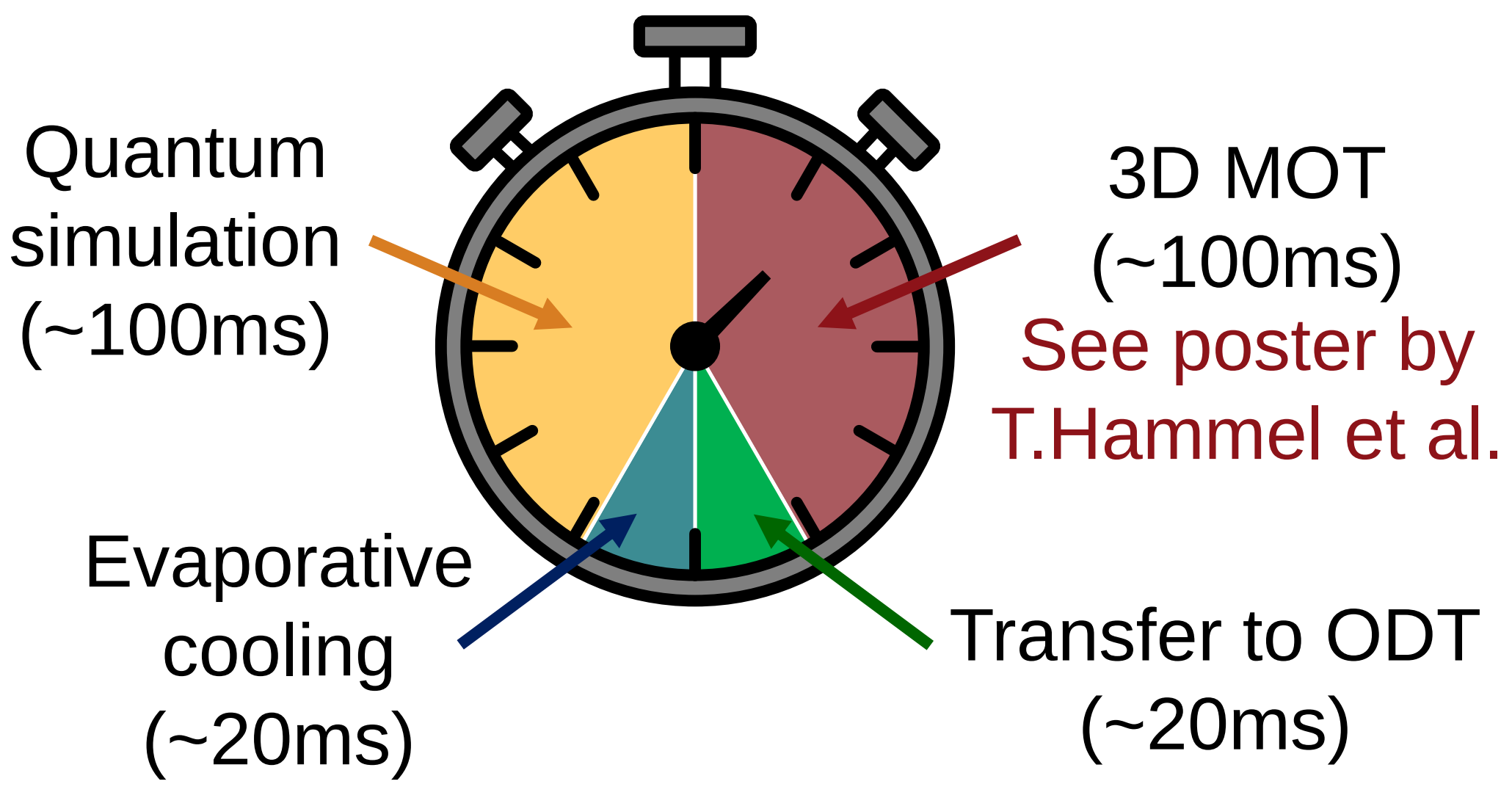
## Motivation and Goals

- Building a versatile, modular and fast experiment to deterministically prepare fermionic systems of $^6$Li
- Integrate „existing“ experimental toolbox (e.g. spin resolved read-out, „matter wave microscope“ [1,2]…) into experiment with simplified experimental interface
- Optimize control over the system to overcome limitations of existing machines
  - Larger objectives (0.66NA and 0.3NA)
  - Fast coils with additional, tuneable DOFs
  - More characterization possibilities (direct sensor access to atom position)
- Increase cycle rates to >1Hz for „real time“ programmable quantum simulation

## Towards high cycle rates

- Measurements of higher-order correlations in quantum systems (e.g. for tomography of complex quantum states) require large data sets
- Improve cycle rates to achieve sufficient statistics in reasonable time
  - Goal: Cycle <1s with experiment as a significant contribution

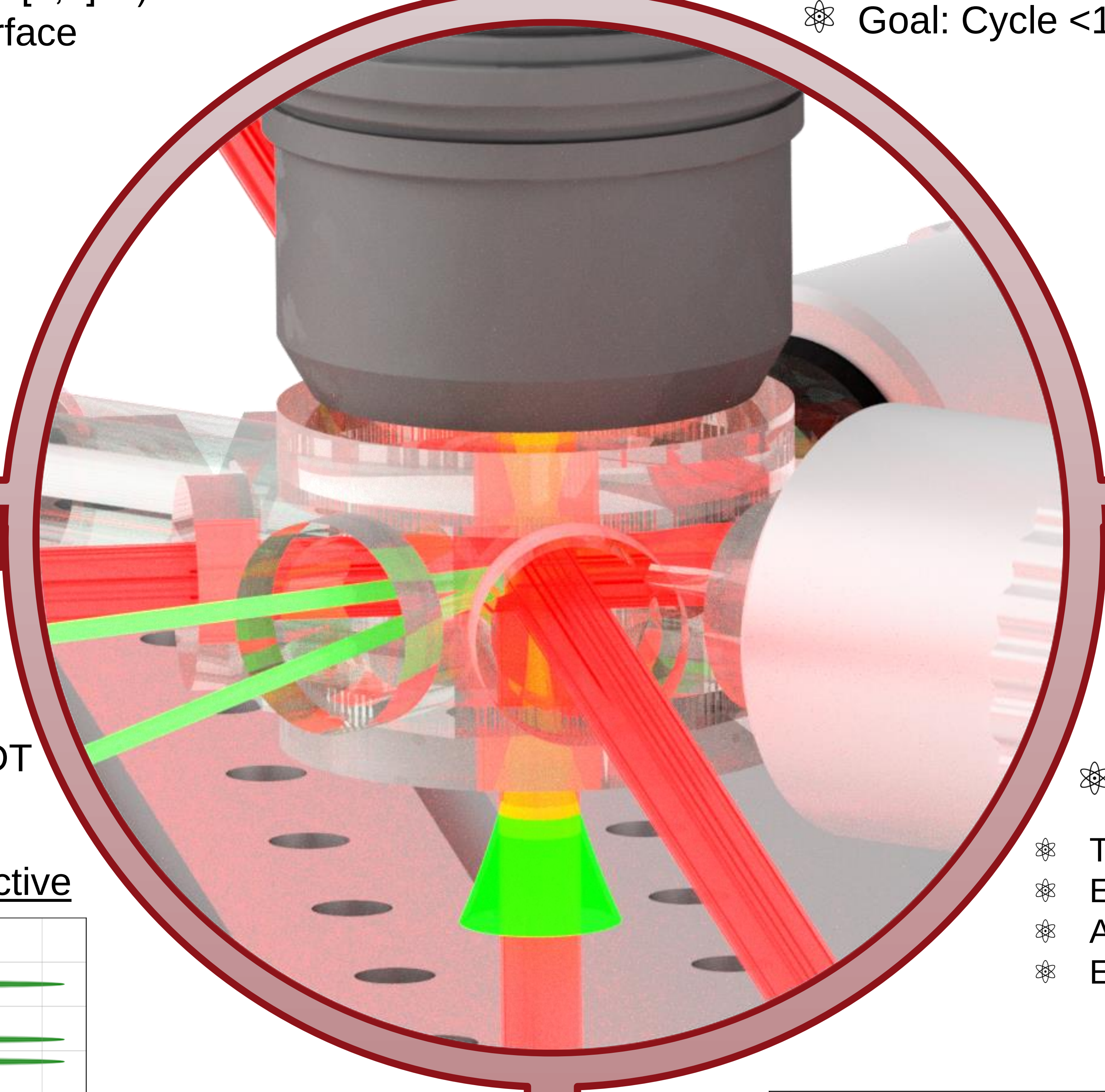


Quantum simulation (~100ms)

3D MOT (~100ms) See poster by T.Hammel et al.

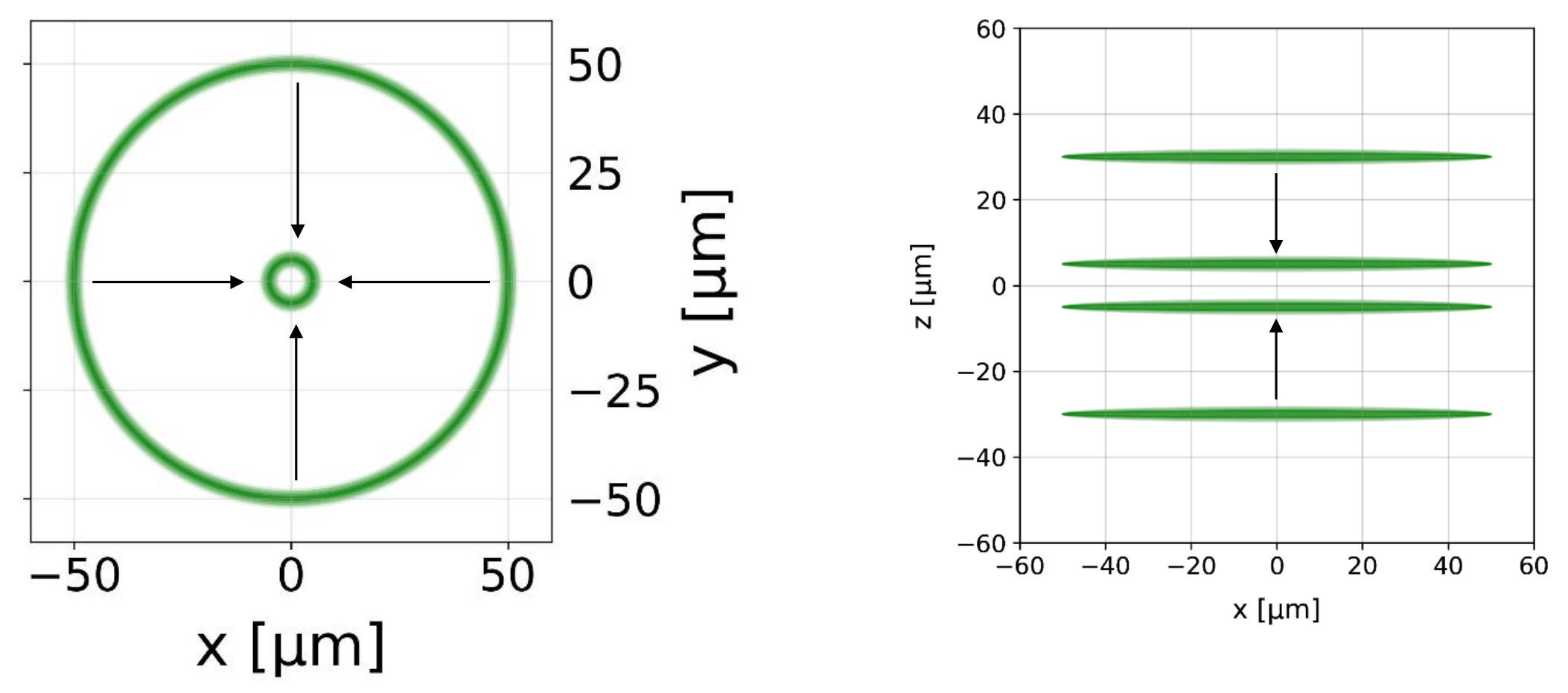
Evaporative cooling (~20ms)

Transfer to ODT (~20ms)

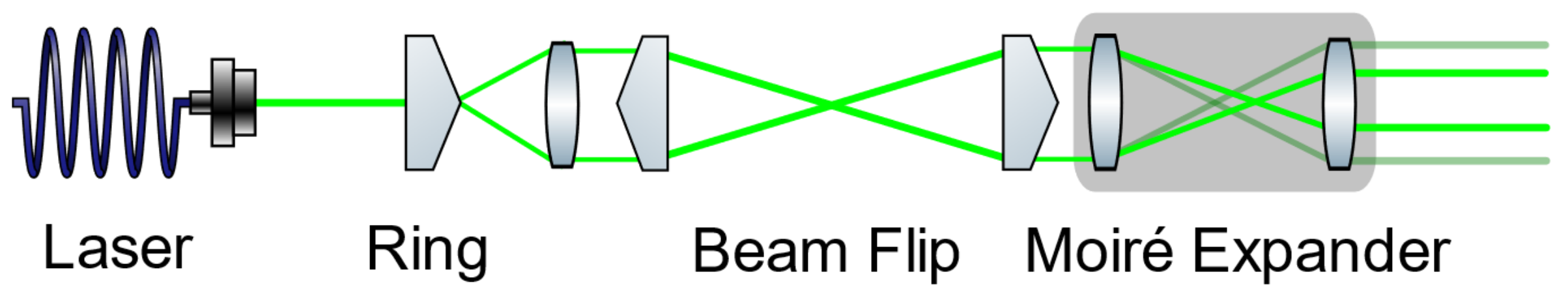


## “Pushbroom” compression

- Accelerate thermalization into optical tweezer by fast non-adiabatic compression
- Spatial compression with a blue-detuned ODT (cylinder-box-compression)



- Option for ring-potential creation: Moiré lenses
  - Each Moiré lens features two rotating phase plates
  - Electrically tuneable beam expander or axicons

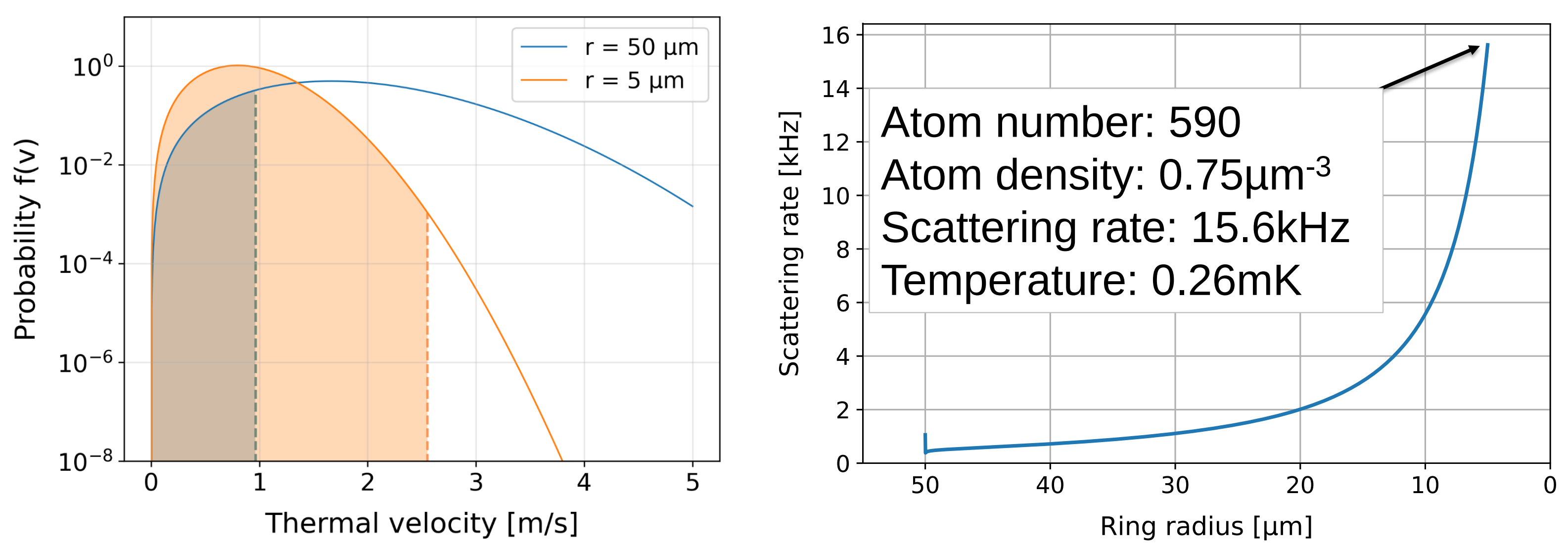


- Option(s) for sheet-potential creation: Optical accordion, AOM etc.

## “Pushbroom” simulation

**Adiabatic simulation of 2D ring compression**

- Fast collection of atoms from MOT
- Iterative calculation steps in simulation:
  - Truncated Boltzmann distribution due to potential
  - Evaporation and re-thermalization
  - Assume adiabatic compression of an ideal gas
  - Evaporation and re-thermalization of compressed gas

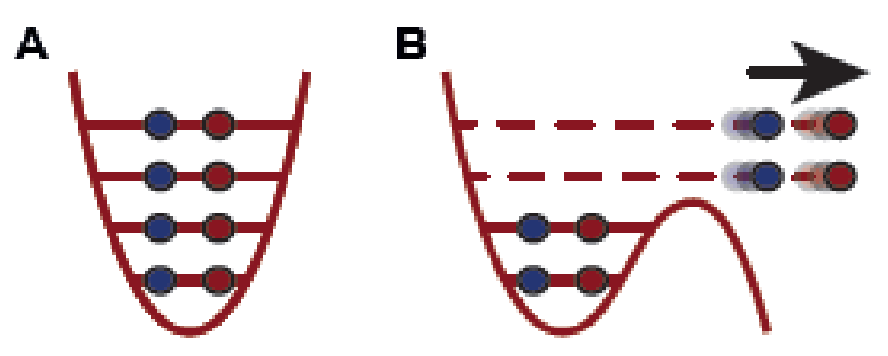


Atom number: 590
Atom density: 0.75µm$^{-3}$
Scattering rate: 15.6kHz
Temperature: 0.26mK

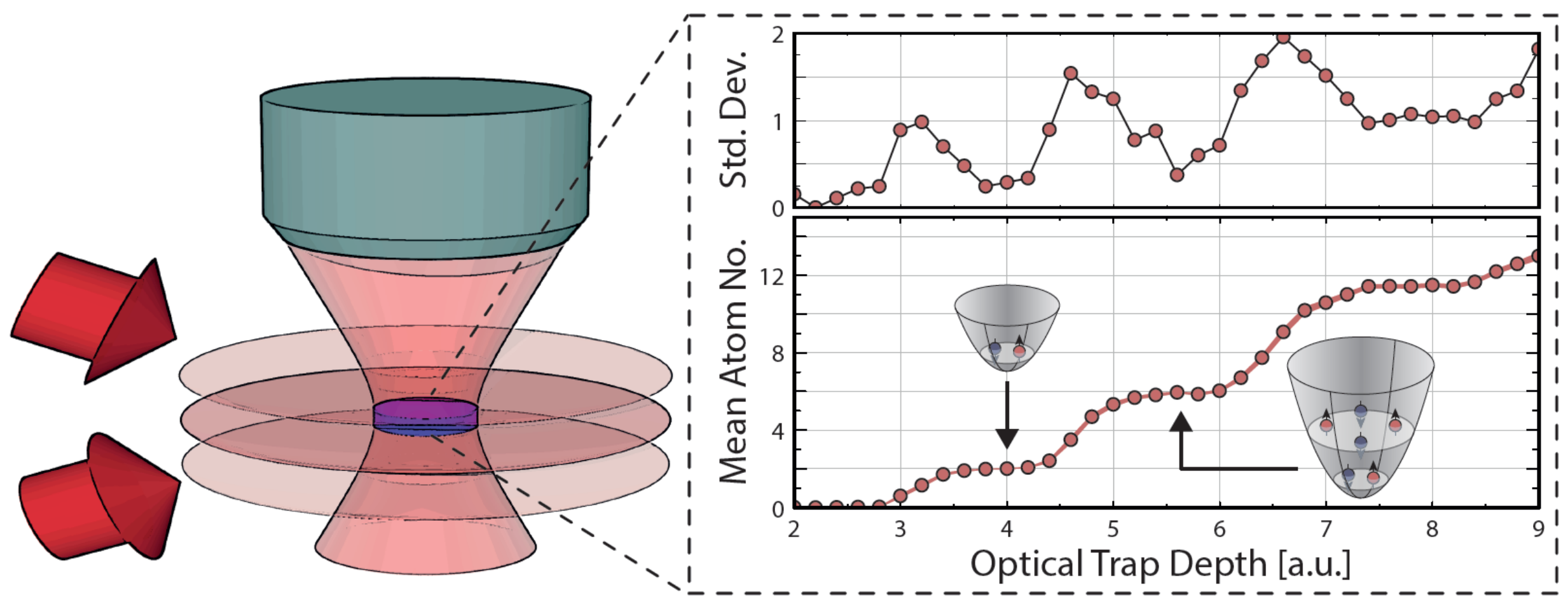
- Increased final density and scattering rate accelerate thermalization into tightly focussed trap and reduce experiment cycle times
- Transfer into tweezer in 20ms appears to be feasible

## Few fermion state preparation

- Final few fermion state preparation envisioned via a scheme based upon [3]
- Confinement in a “pancake”-like trap + optical tweezer



**A**: Trapping in optical tweezer
**B**: Spilling/evaporative cooling
**C**: Prepared system



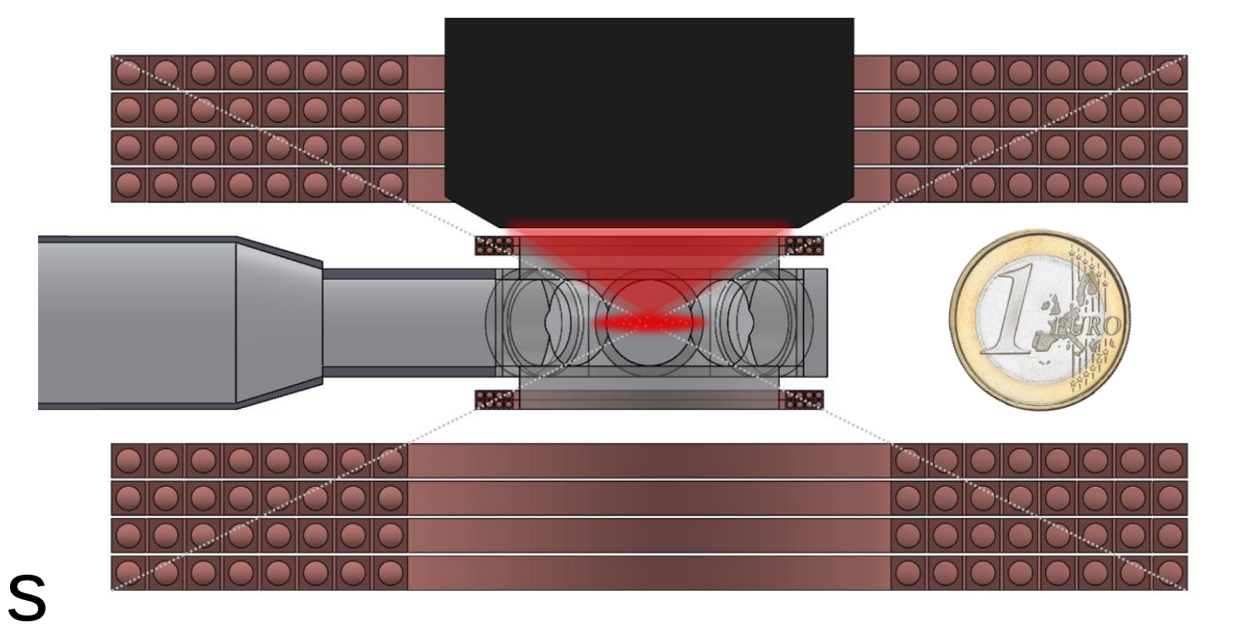
- Spilling procedure: Deterministic preparation of ground states with given atom number
- Shell wise spilling/evaporation of atoms out of trap confinement
- Potential either formed by a separate red-detuned ODT as in [1] alternatively directly via cylinder-shaped, blue-detuned “pushbroom” ODT
- In both cases: Tuneable aspect ratio for tuneable dimensionality

1D ($\omega_z \ll \omega_r$) to 2D ($\omega_z \gg \omega_r$) to 3D ($\omega_z \approx \omega_r$)

## (Future) Experimental toolbox

**Highly controllable magnetic fields**

- Stable offset fields of ≥1500G and gradients of ≥100G/cm
- Tuneable field curvature of up to 80Hz for „matter wave optics“ [4]
- Fast jumps (~100G in ~1µs) via jump coils

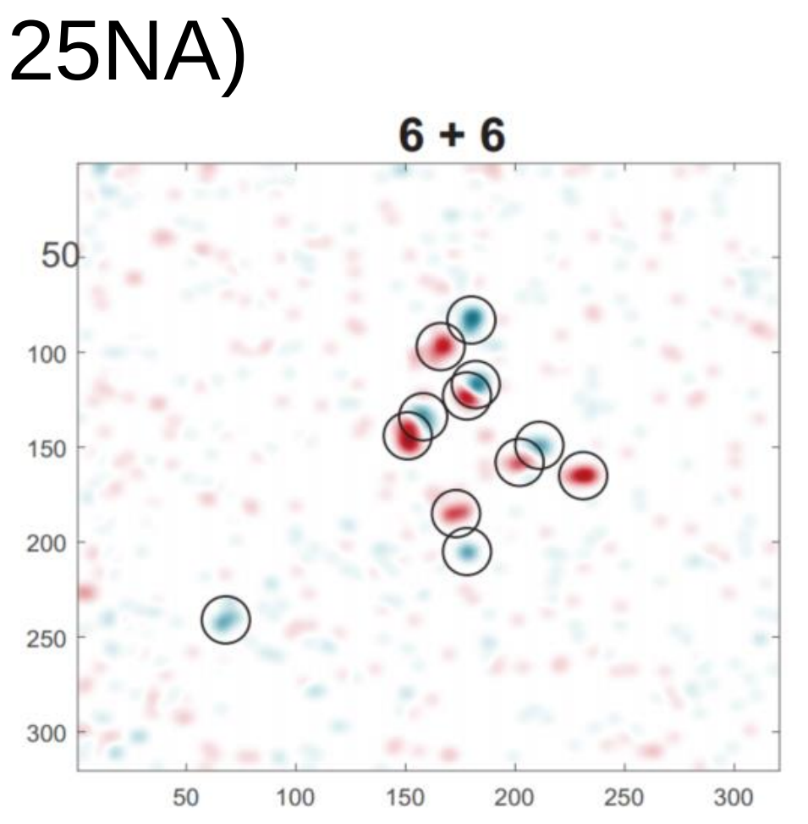


**Optical confinements and tuneable dimensionality**

- Tuneable “pushbroom” traps enable full control over dimensionality
- Final tweezer with adjustable aspect ratio via SLM
- Small glass cell with nanostructured windows allows high NA-objectives from all sides (side objectives with 0.25NA)

**Spin resolved single atom imaging**

- Compact glass cell allows RF- and microwave coils close to the atom position (large Rabi frequencies achievable)
- Spin resolved single atom imaging



*In-situ imaging of Feshbach molecules*

## References

[1] Weitenberg et al. Nature 599, 571-575 (2021) [3] F.Serwane *et al.* Science 15, 6027 (2011)
[2] Holten et al. Arxiv Preprint 2109.11511 (2021) [4] Murthy et al. Phys. Rev. A 90, 043611 (2014)