Optimal Control for Robust Atom Interferometry

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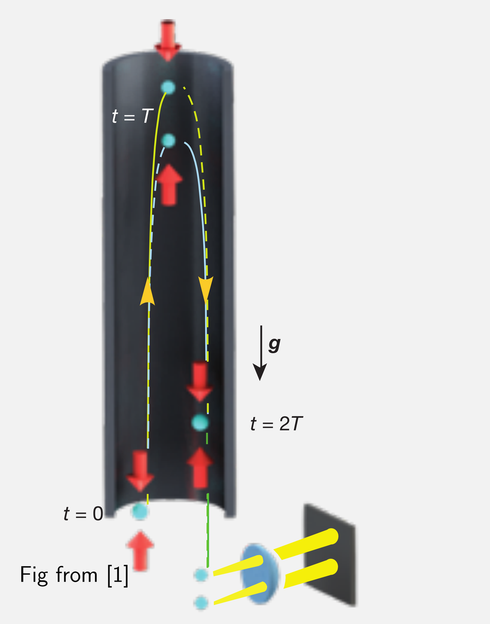
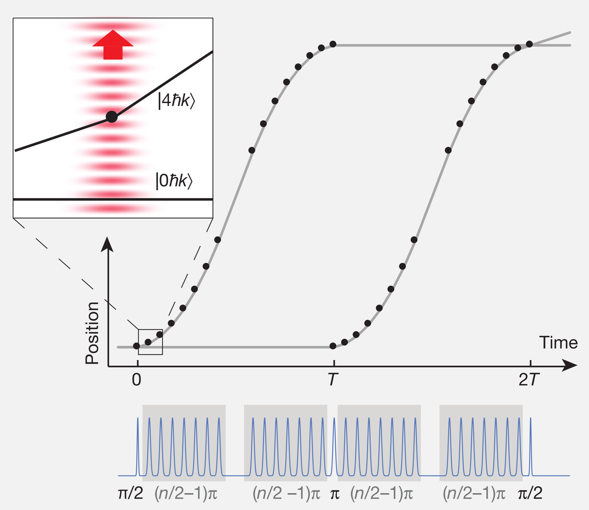
① Atomic Fountain Interferometer

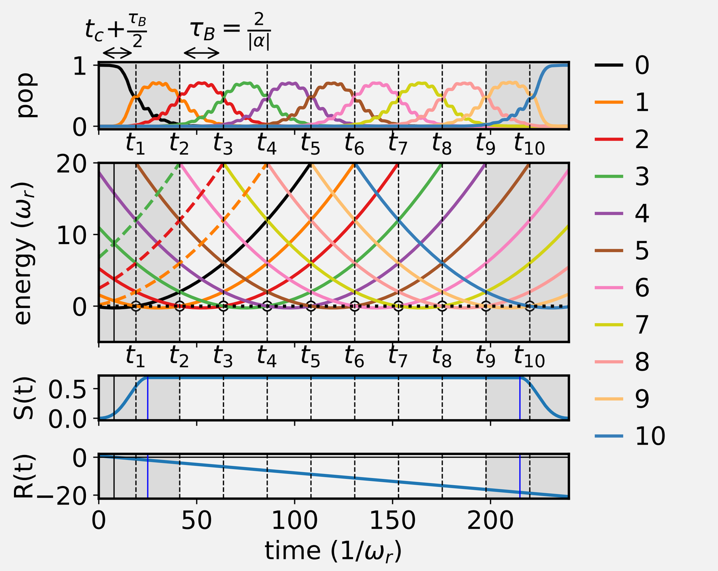




Laser pulses implement atomic beamsplitter and mirror.
Bragg pulses: internal states are adiabatically eliminated
⇒ **momentum transfer**

Applications: gravitational sensing, inertial navigation, test of equivalence principle

Analytic pulse schemes: Train of Rabi pulses, or rapid-adiabatic passage (RAP) [2]

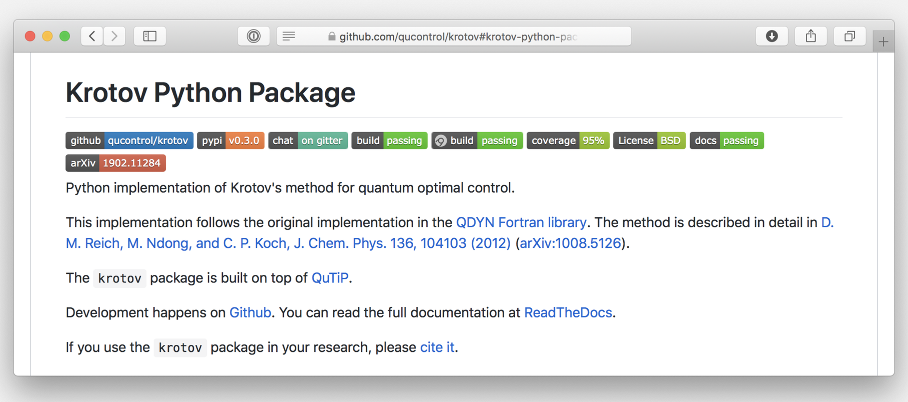


- RAP Hamiltonian; linear chirp rate α:

$$\hat{\mathrm{H}} = \sum_n \omega_r \Big(n^2 + \underbrace{\alpha(t - t_c)}_{R(t)} n - \delta_0 n\Big) \left|n\right\rangle\left\langle n\right| - \mu S(t) \sum_n \Big(\left|n\right\rangle\left\langle n+1\right| + \mathrm{H.c.}\Big)$$

- dynamic frame transformation: $\hat{\mathrm{U}}(t) = e^{i\phi(t)}$; $\phi(t) = -\frac{\alpha^2}{12}t^3 + \frac{t_c\alpha^2}{4}t^2 - \frac{t_c^2\alpha^2+1}{4}$
  $\Rightarrow$ $\hat{\mathrm{H}}$ independent of initial momentum state.
- Error sources: pulse amplitude ($\mu \neq 1$); initial velocity ($\delta_0 \neq 0$)

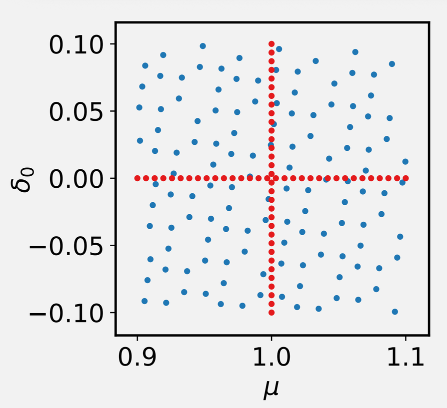
② Optimal Control for Robust Pulses



Krotov's method [3]
in order to minimize:

$$J_{T,\mathrm{sm}} = \varepsilon_{\mathrm{sm}} = 1 - \left|\left\langle \Psi^{\mathrm{tgt}} \,\middle|\, \Psi(T)\right\rangle\right|^2$$
$$J_{T,\mathrm{re}} = \varepsilon_{\mathrm{re}} = 1 - \mathrm{Re}\left\langle \Psi^{\mathrm{tgt}} \,\middle|\, \Psi(T)\right\rangle$$

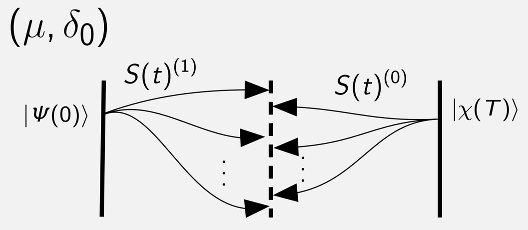
$$\left|0\right\rangle \to \left|\Psi^{\mathrm{tgt}}\right\rangle = \left|\pm 10\right\rangle$$



Ensemble optimization [4]

Optimize over average of ensemble of variations of the Hamiltonian (μ, δ_0)

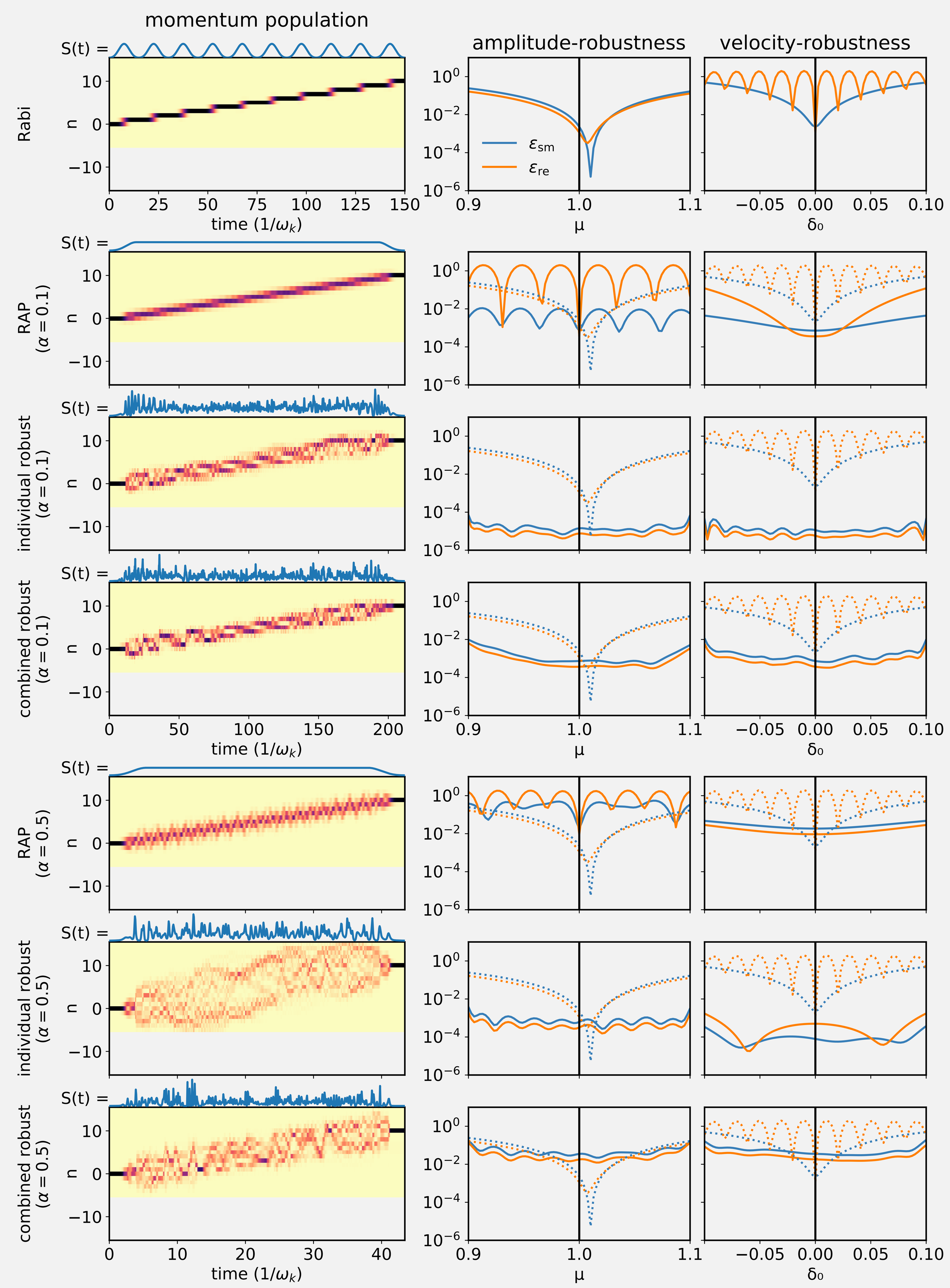
quasi-random sampling (128 points)
or 32 points "individual"



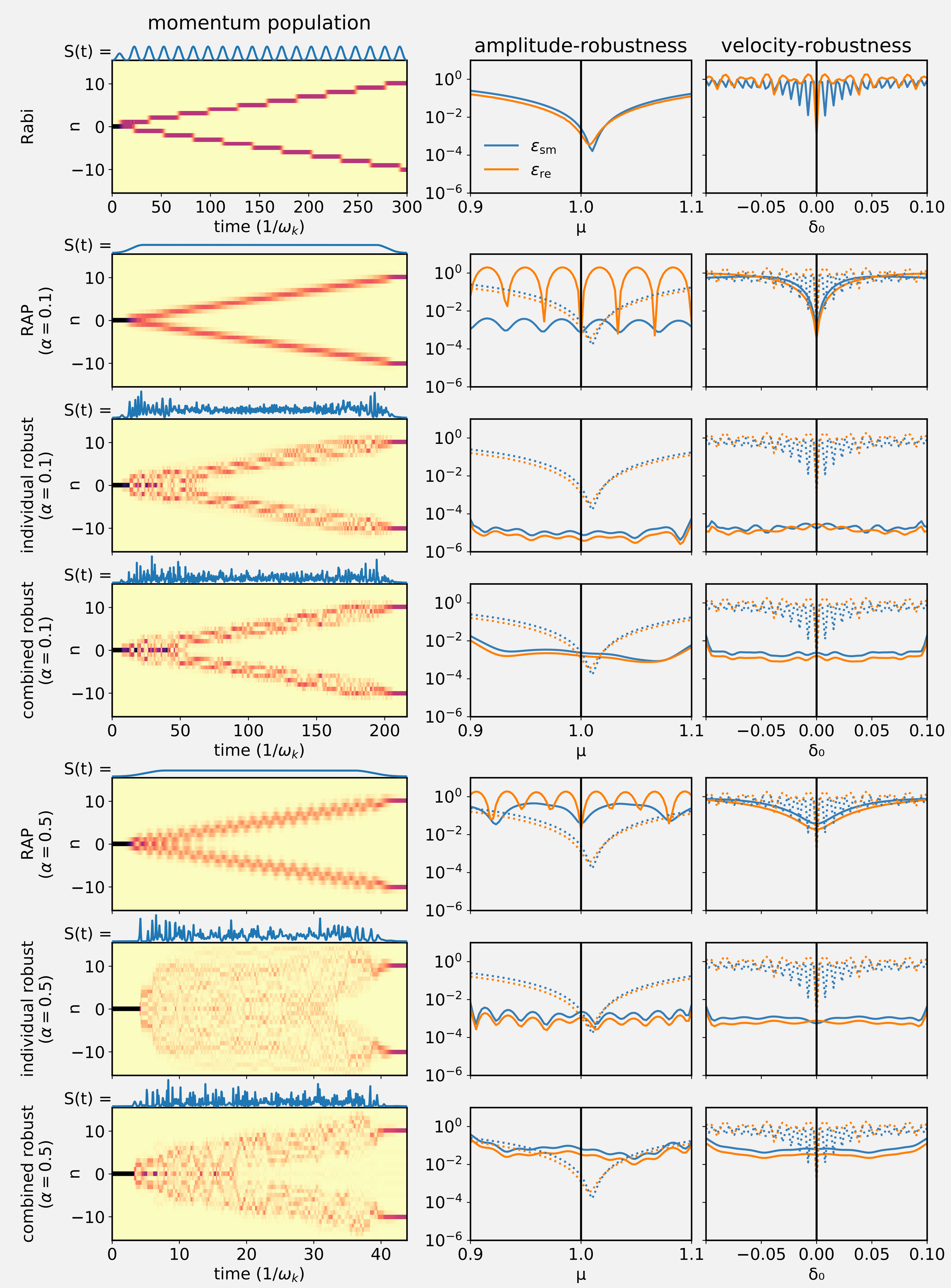
References

[1] Kovachi et al. *Nature* **528**, 530 (2015)
[2] Malinovky, Berman, *Phys. Rev. A* **68**, 023610 (2003)
[3] Reich et al. *J. Chem. Phys.* **136**, 104103 (2012)
[4] Goerz et al. *Phys. Rev. A* **90**, 032329 (2014)

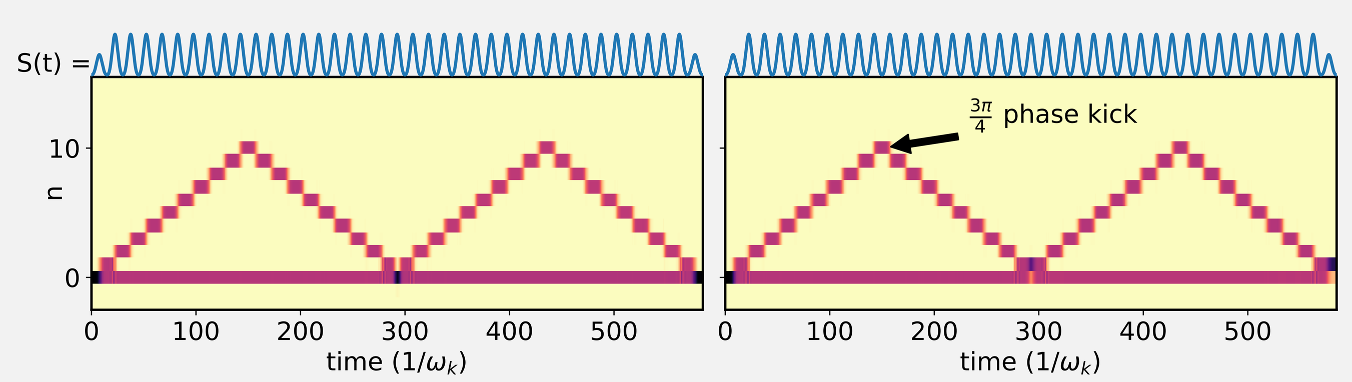
③ Atomic Mirror



④ Atomic Beamsplitter

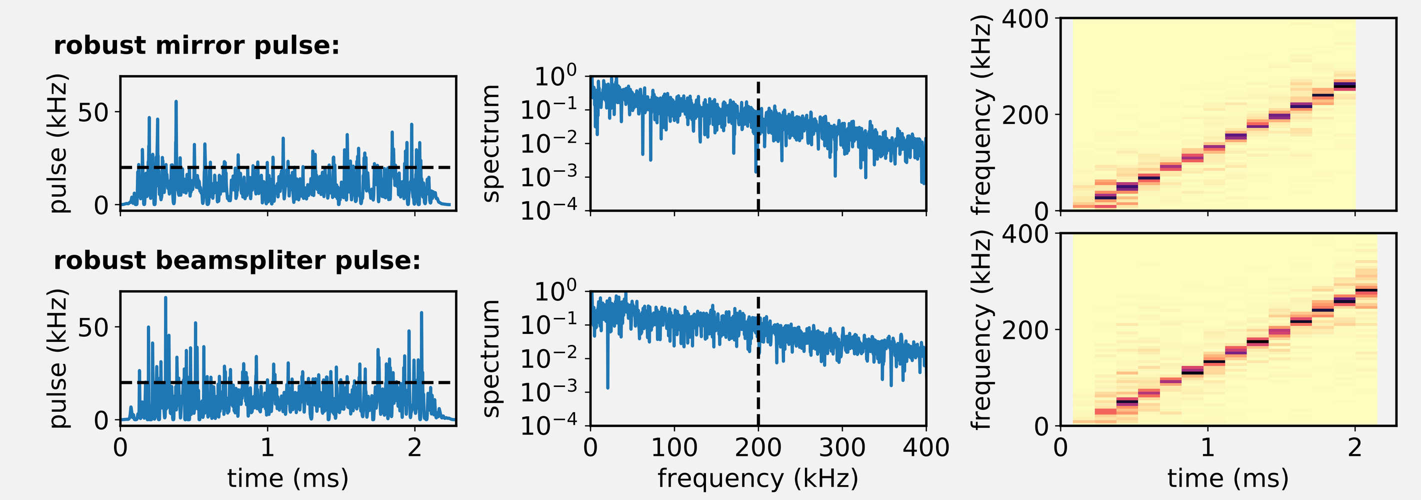


⑤ Outlook: Full Interferometer Scheme



- Full interferometer: beamsplitter – mirror – beamsplitter
- Phase errors lead to superposition of $|0\rangle$, $|1\rangle$
- Cancellation of errors due to symmetry?

⑥ Outlook: Experimental Constraints



Experimentally available max pulse amplitude: 20 kHz; max spectral width: 200 kHz