Optimal Control for Robust Atomic Fountain Interferometers

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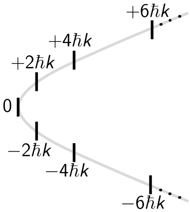
APS March Meeting

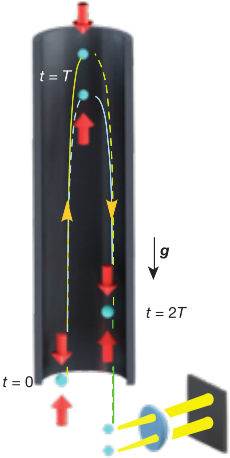
March 8, 2019

10 m atomic fountain at Stanford (Kasevich lab): ultracold ^{87}Rb atomic cloud



laser couples between electronic states: absorbs photon momentum

$$\Delta\phi = -2k_{\max} g T^2$$



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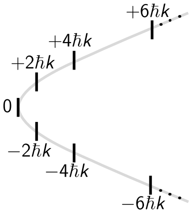

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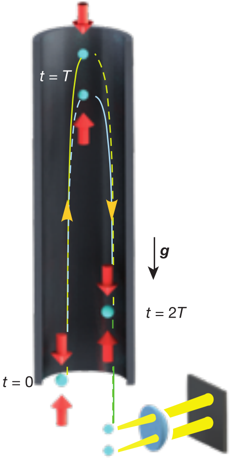

Applications:

- inertial navigation
- gravitational sensing
- test of equivalence principle

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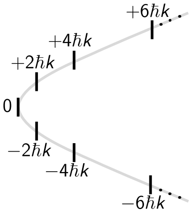

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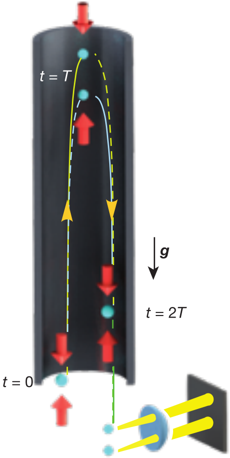
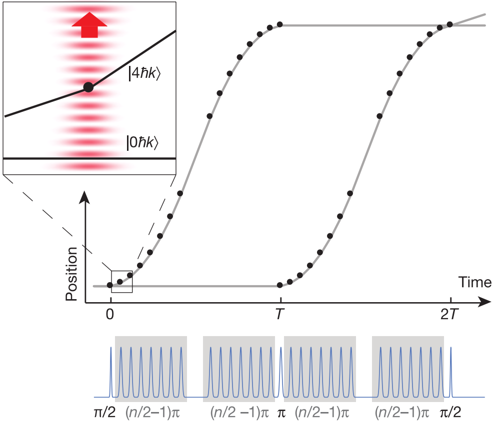


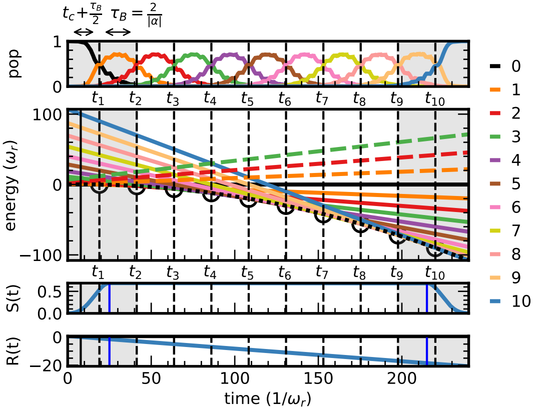


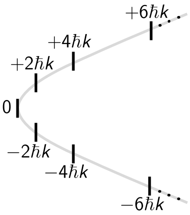
Kovachi et al. *Nature* **528**, 530 (2015)

rapid adiabatic passage

V. S. Malinovsky and P. R. Berman, Phys. Rev. A 68, 023610 (2003).

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





$|0\rangle \to |n\rangle$: $\alpha < 0$ ("mirror")
$|0\rangle \to |-n\rangle$: $\alpha > 0$
$|0\rangle \to |n\rangle + |-n\rangle$ ("beamsplitter"):
two pulses with opposite chirp

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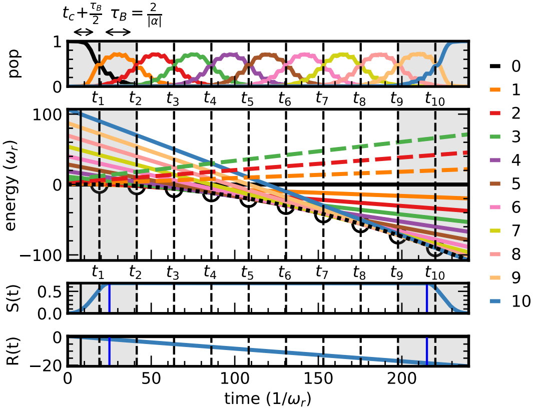


sources of error:

- laser amplitude (μ)
- initial velocity of atoms (δ_0)

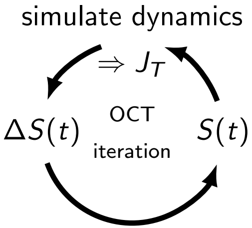
here: $\delta_0 = 0, \mu = 1$

Apply optimal control to atom optics pulses

$\Rightarrow$ increase fidelity

$\Rightarrow$ robustness against fluctuations

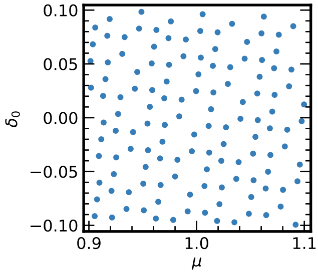
ensemble optimization for robustness



numerical optimal control: minimize functional

$$J_T = 1 - \langle \Psi(T) \,|\, \Psi^{\mathrm{tgt}} \rangle$$

start from guess pulse: improve J_T in every iteration
Krotov's method: guaranteed monotonic convergence

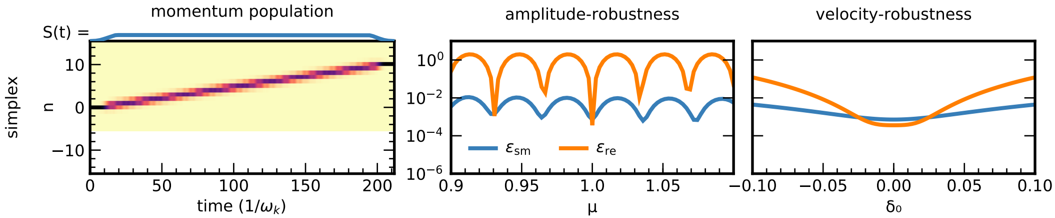


ensemble optimization:

- sample space of perturbed Hamiltonians
- optimize over average
- with a single control pulse!

M. H. Goerz et al., Phys. Rev. A 90, 032329 (2014).

mirror at quasi-adiabatic time scale



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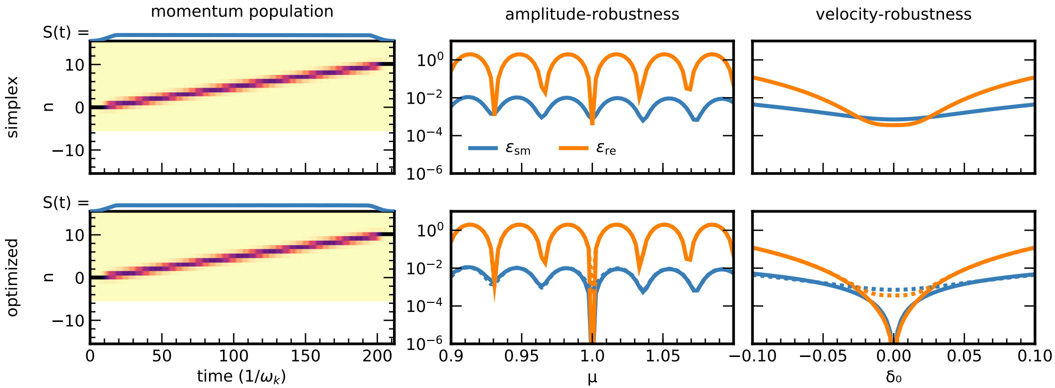

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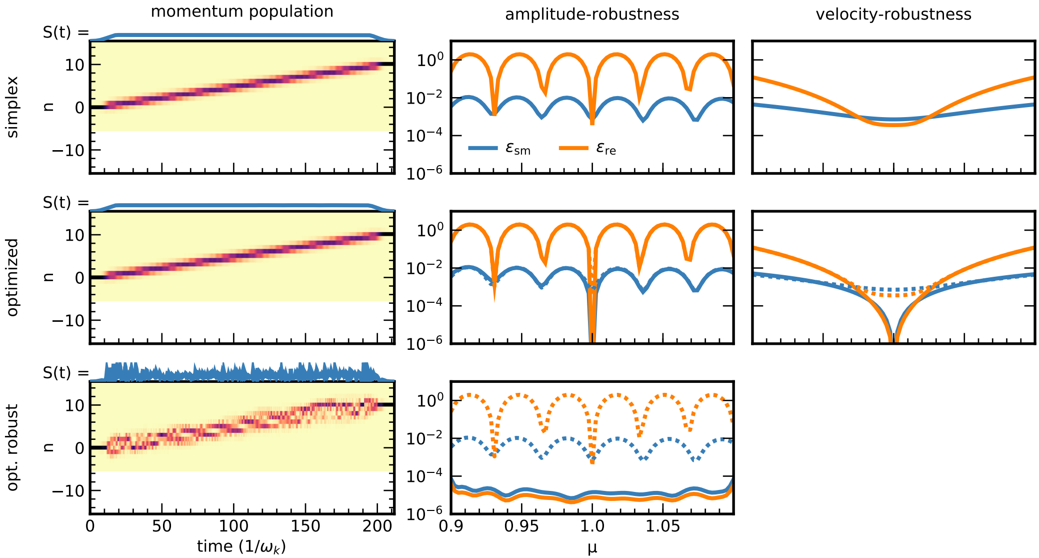

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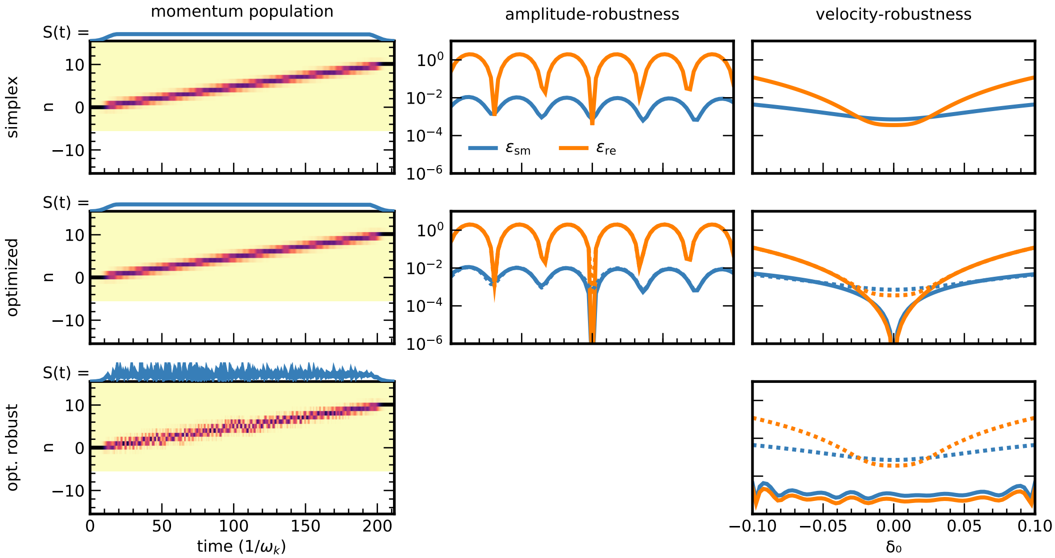

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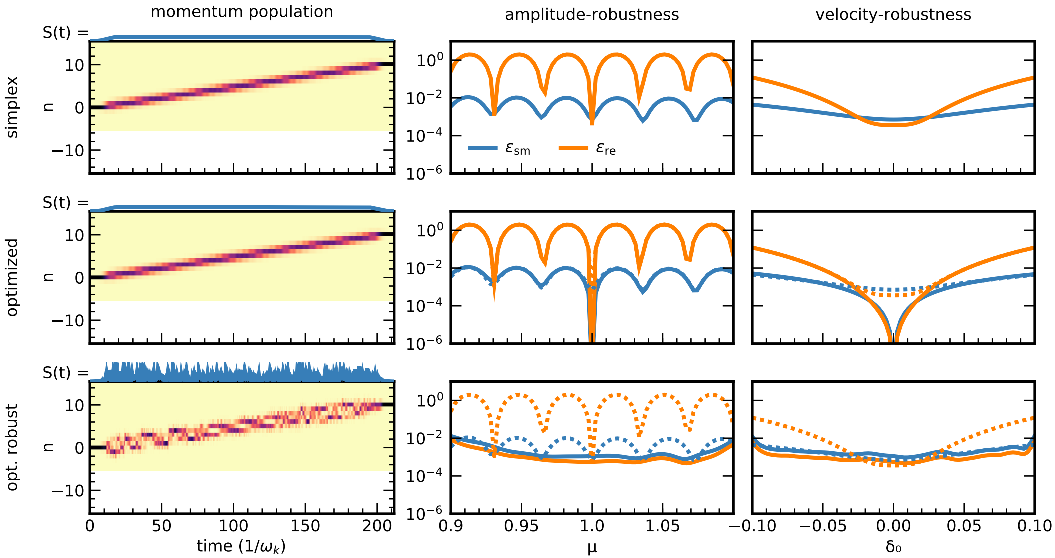
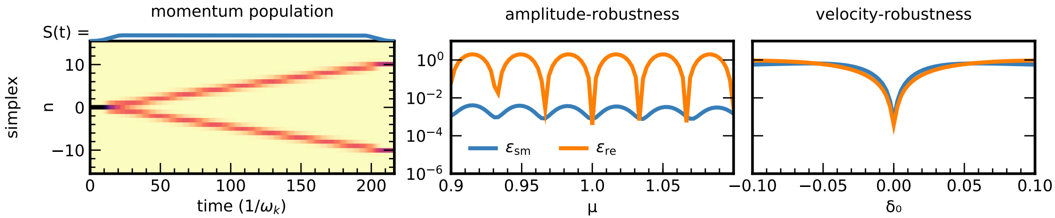


beamsplitter at quasi-adiabatic time scale



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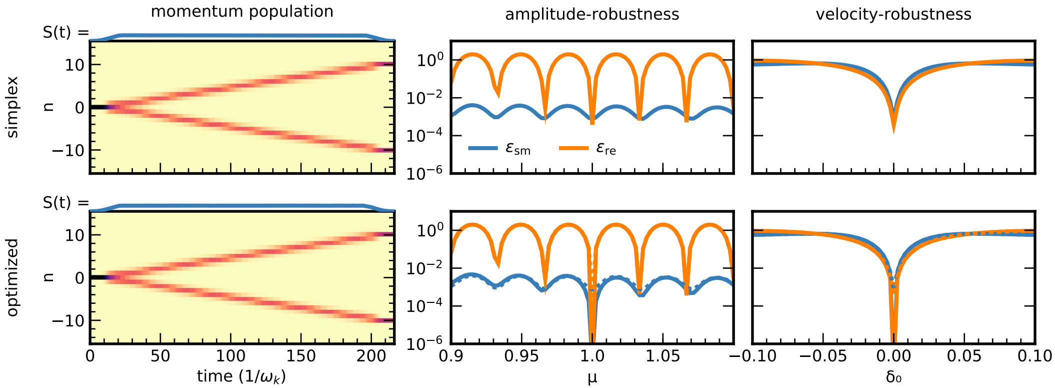

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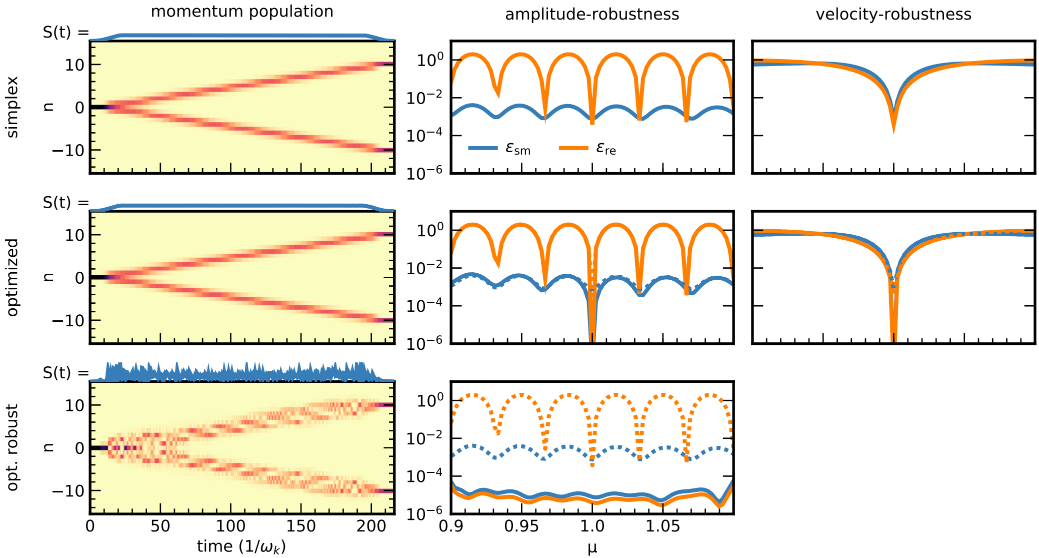

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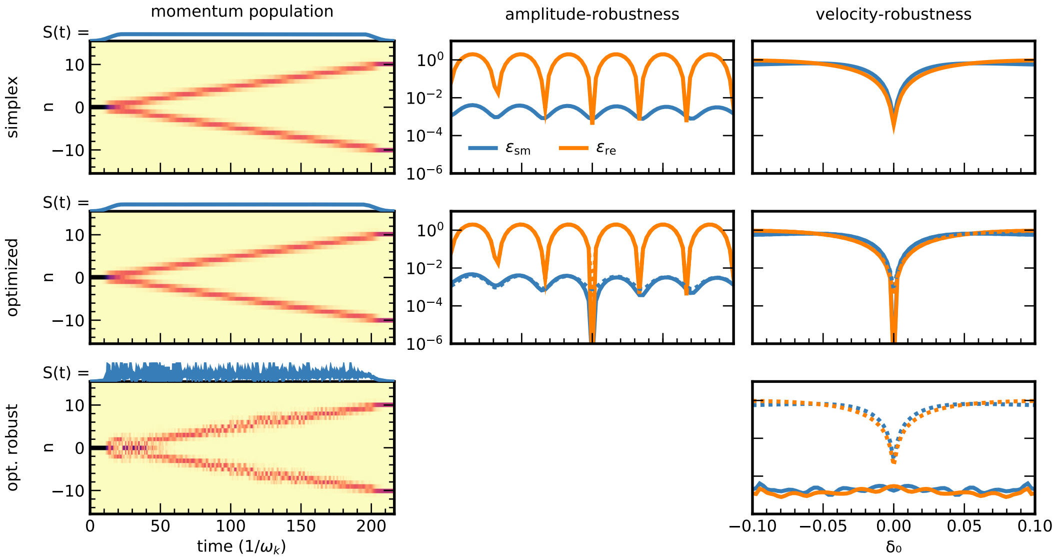

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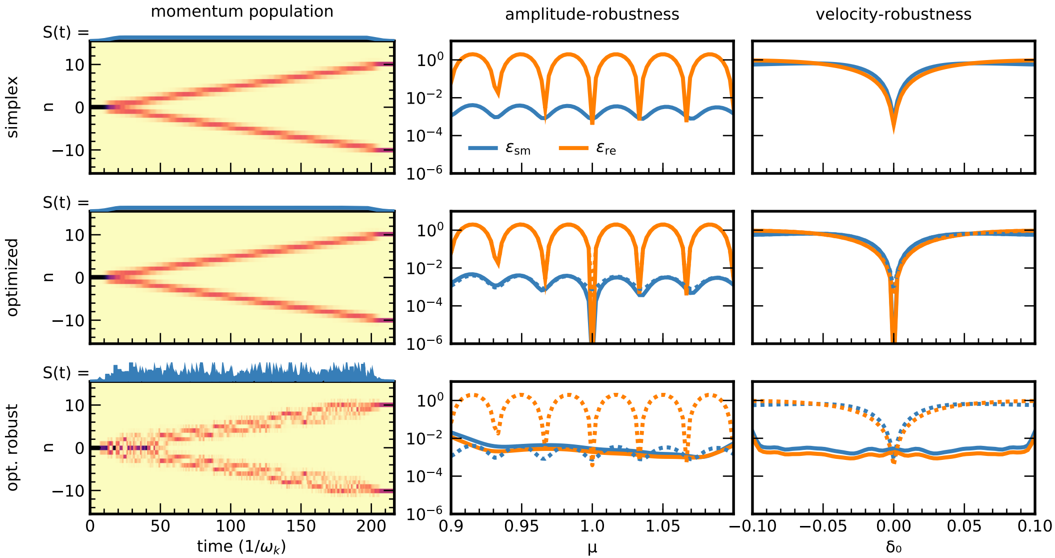
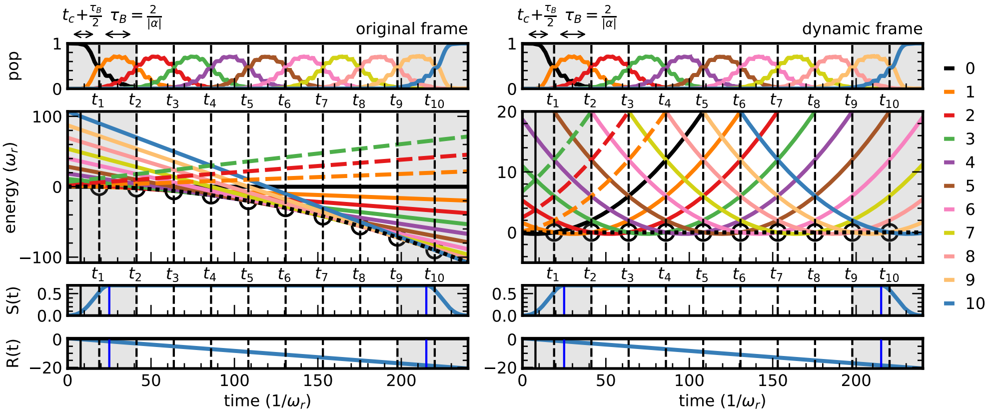


outlook: going to high momentum states

dynamic frame transformation:

$$\hat{U}(t) = e^{i\phi(t)}; \quad \phi(t) = -\frac{\alpha^2}{12}t^3 + \frac{t_c\alpha^2}{4}t^2 - \frac{t_c^2\alpha^2+1}{4}$$



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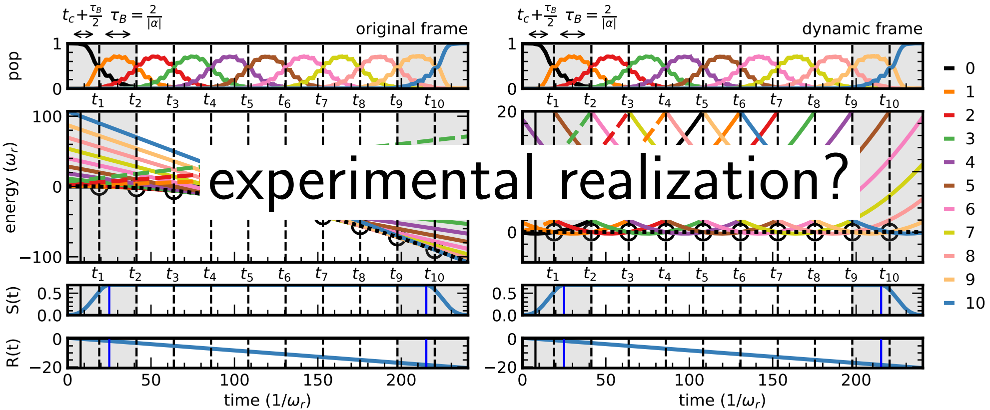
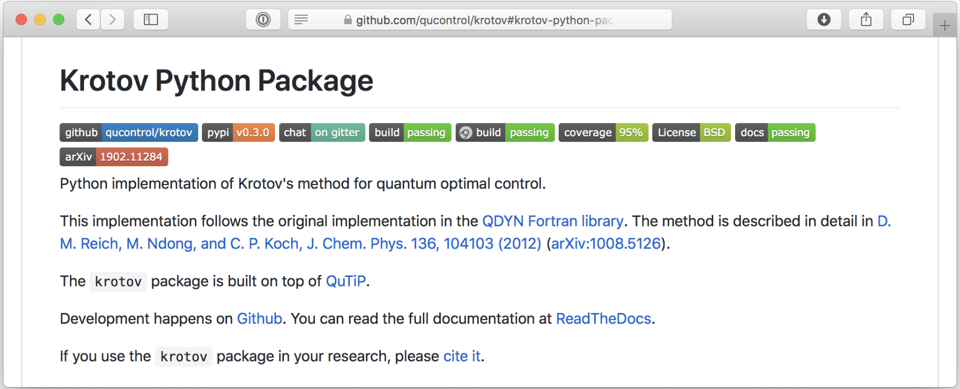


experimental realization?

new: Python package for optimal control


github.com/qucontrol/krotov#krotov-python-pac

Krotov Python Package

github qucontrol/krotov | pypi v0.3.0 | chat on gitter | build passing | build passing | coverage 95% | License BSD | docs passing | arXiv 1902.11284

Python implementation of Krotov's method for quantum optimal control.

This implementation follows the original implementation in the QDYN Fortran library. The method is described in detail in D. M. Reich, M. Ndong, and C. P. Koch, J. Chem. Phys. 136, 104103 (2012) (arXiv:1008.5126).

The `krotov` package is built on top of QuTiP.

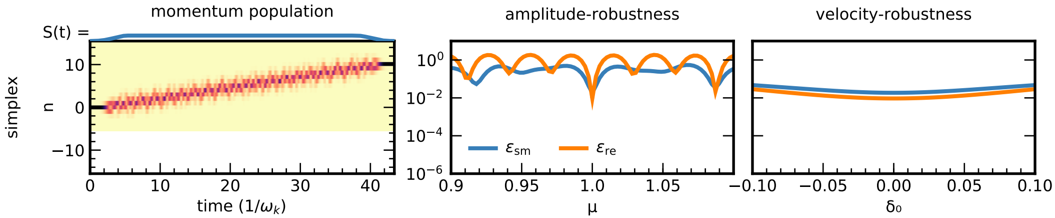
Development happens on Github. You can read the full documentation at ReadTheDocs.

If you use the `krotov` package in your research, please cite it.

Github: `https://github.com/qucontrol/krotov`

arXiv: 1902.11284

mirror at compressed time scale



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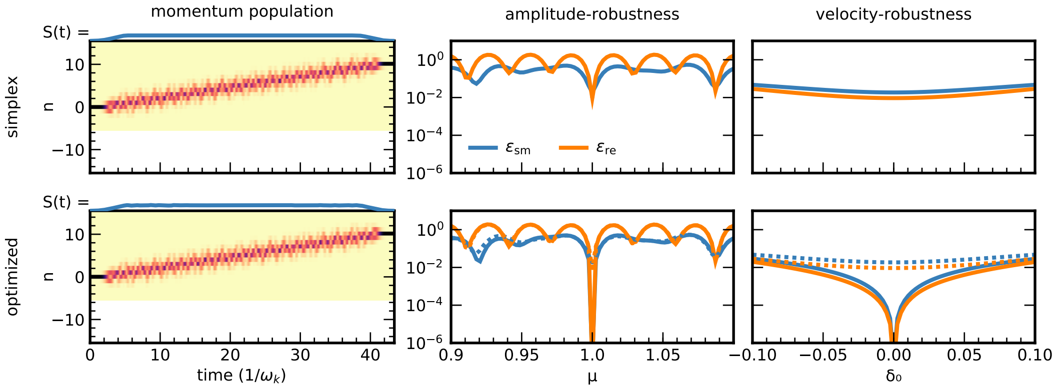

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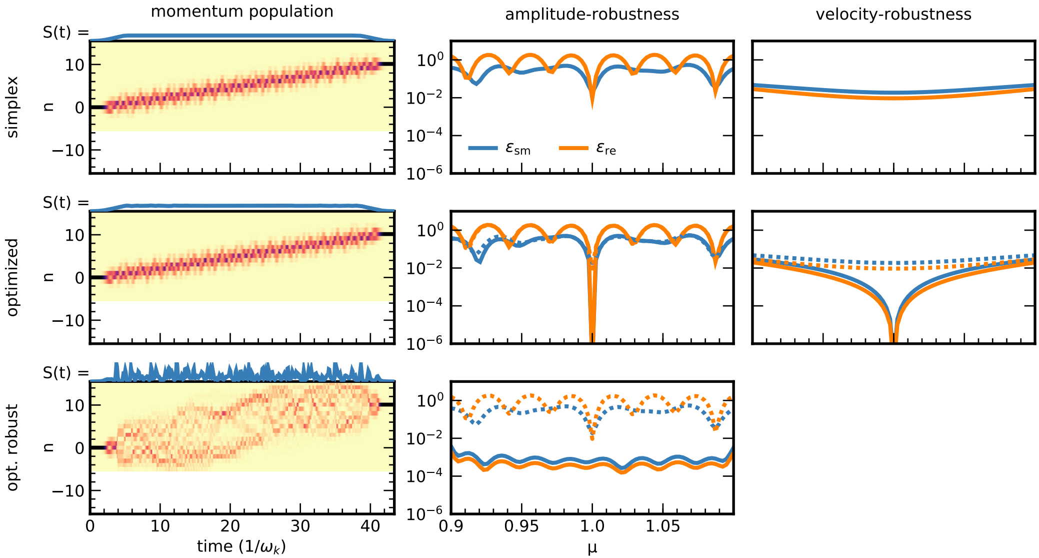

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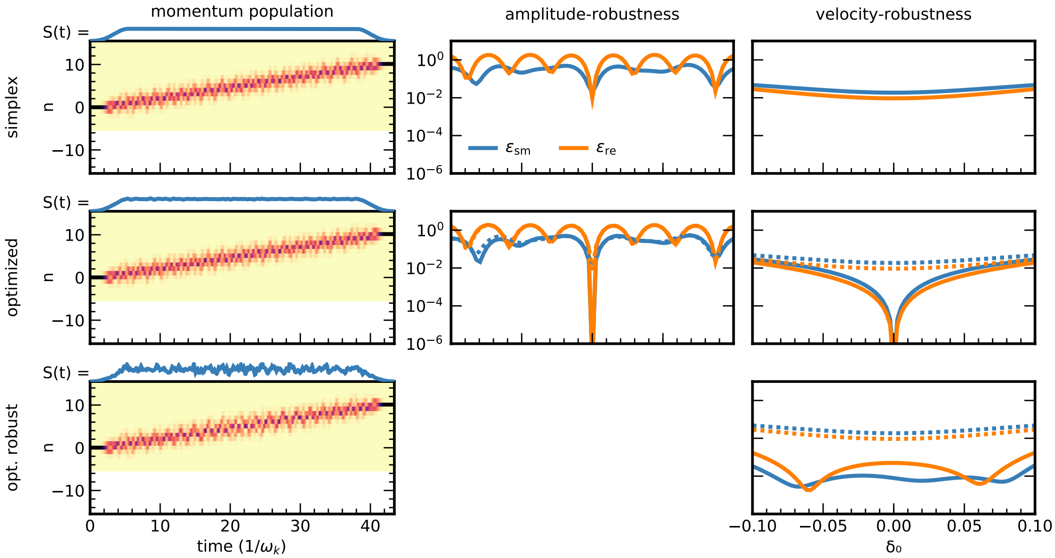

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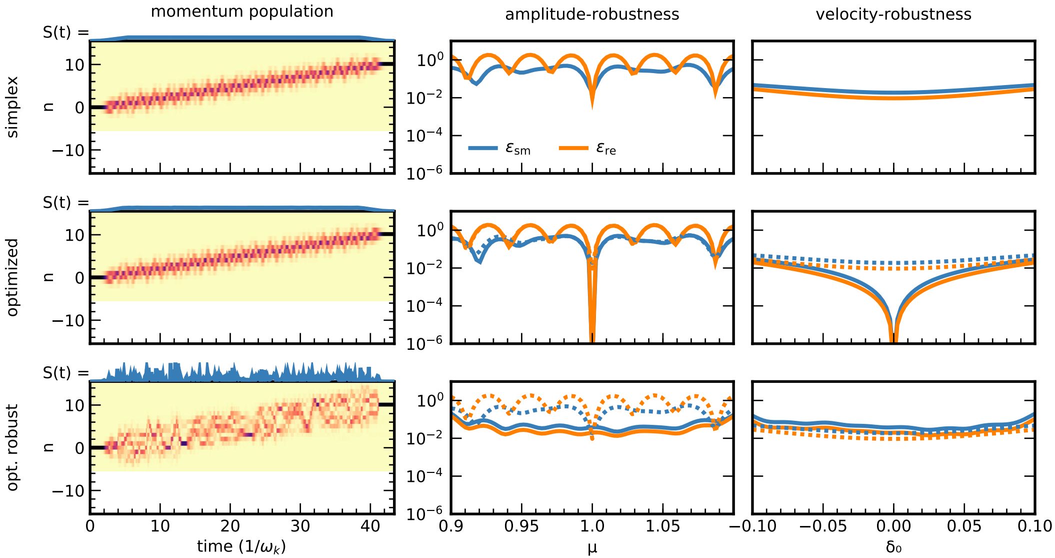
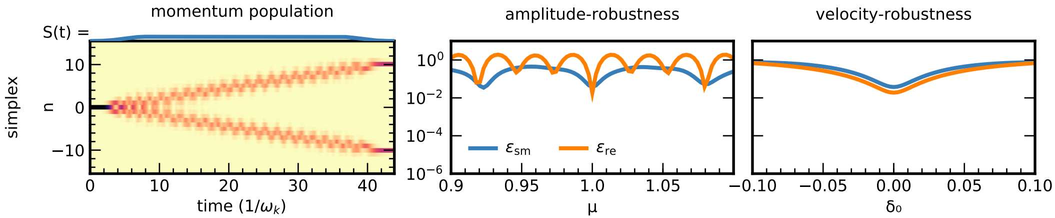


beamsplitter at compressed time scale



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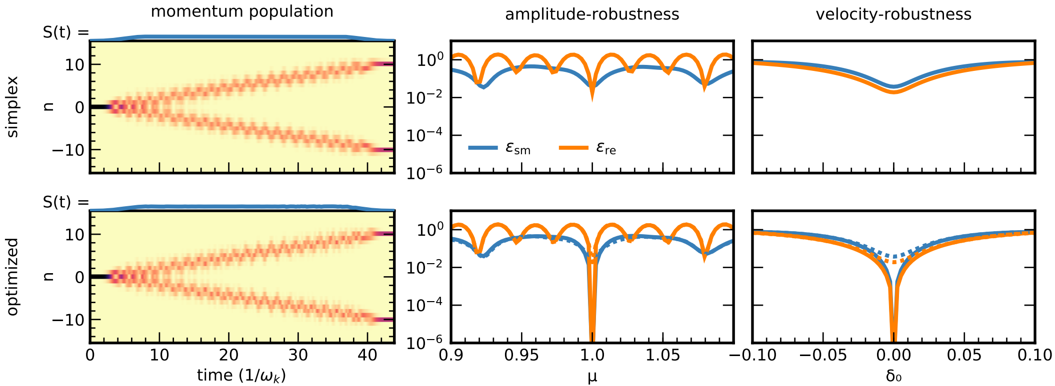

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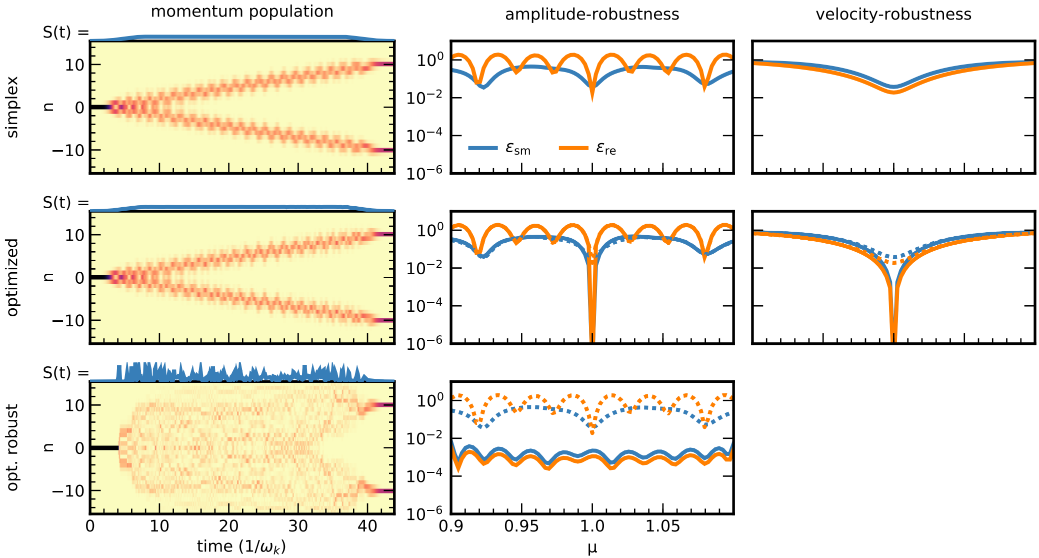

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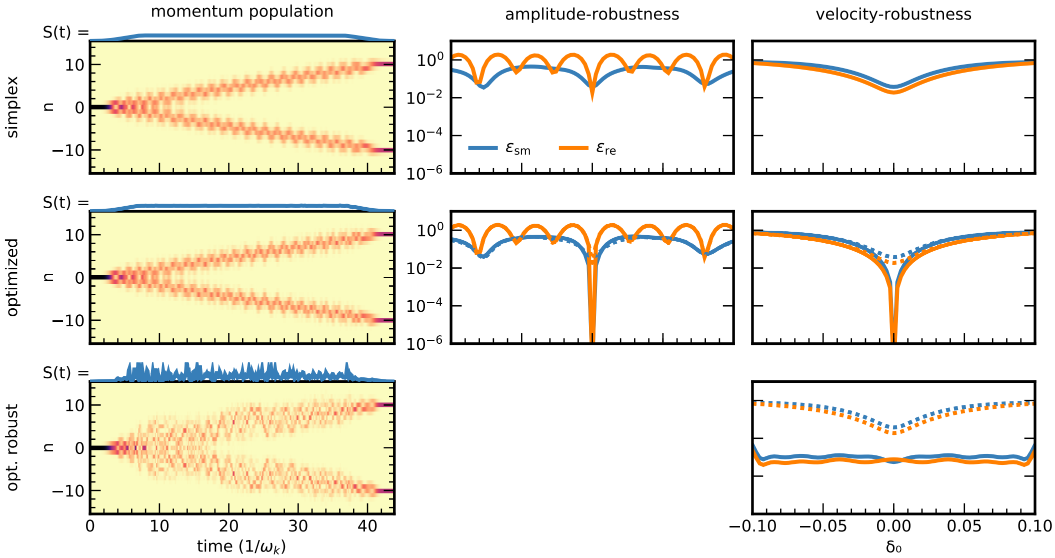

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