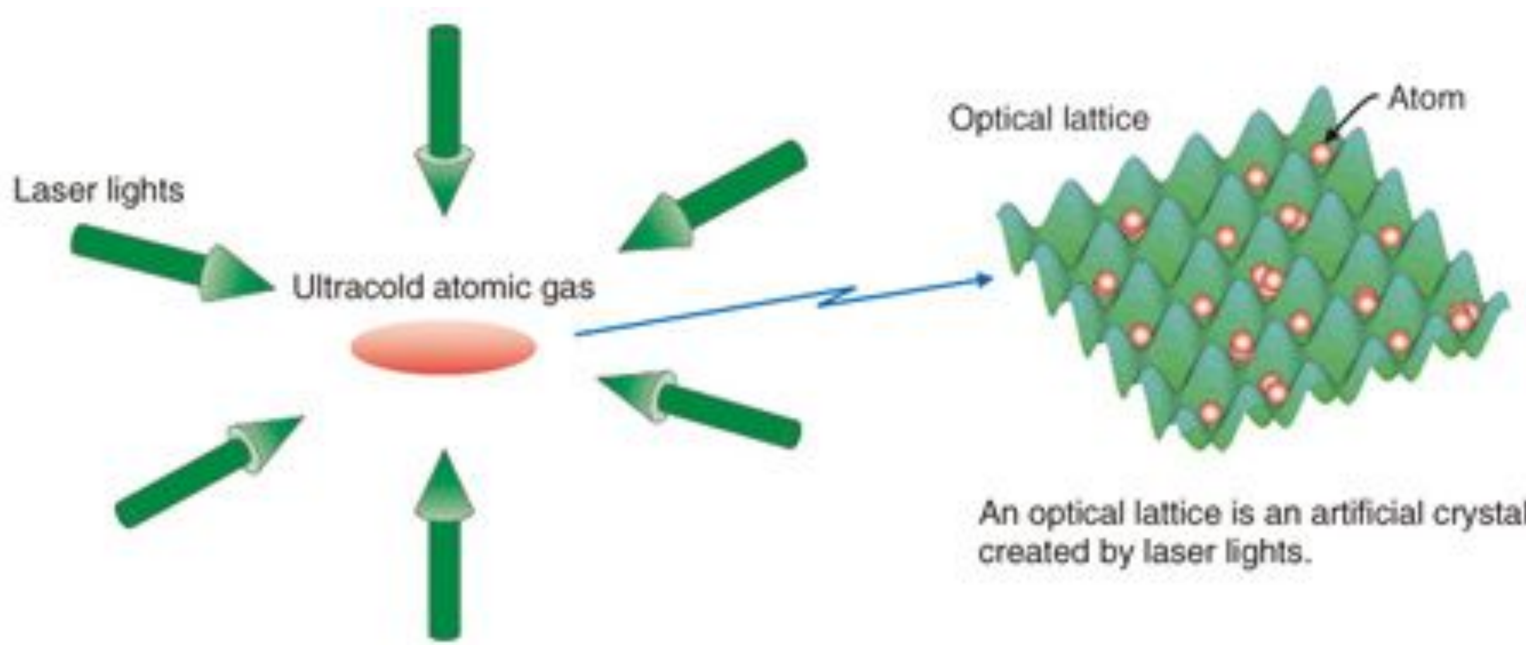
Classifying snapshots from experiment and theory

Contents

- Experiment: Quantum Gas Microscopy
- Motivation
- CNNs to classify snapshots
- Discussion of results
- Summary and Outlook

Experimental Realization

Trap fermionic ^{6}Li in optical Lattice

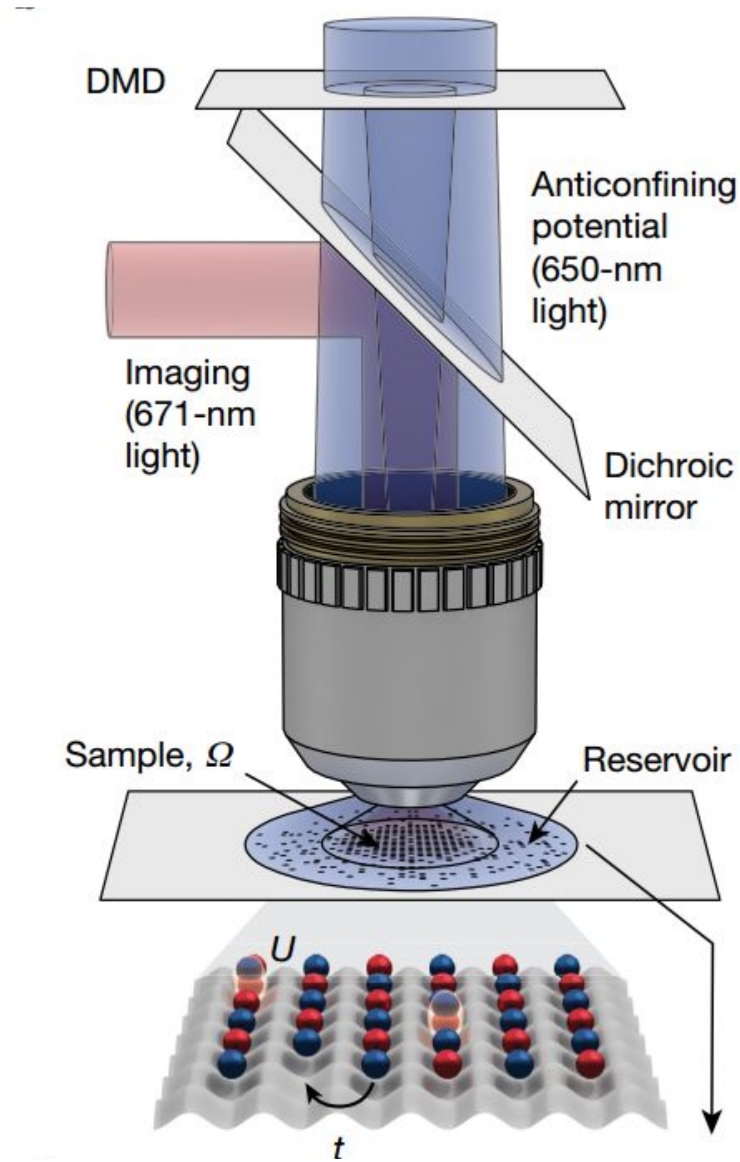


[1] M. Yamashita, K. Inaba, NTT Technical Review, Vol. 10 No. 9 Sep. 2012

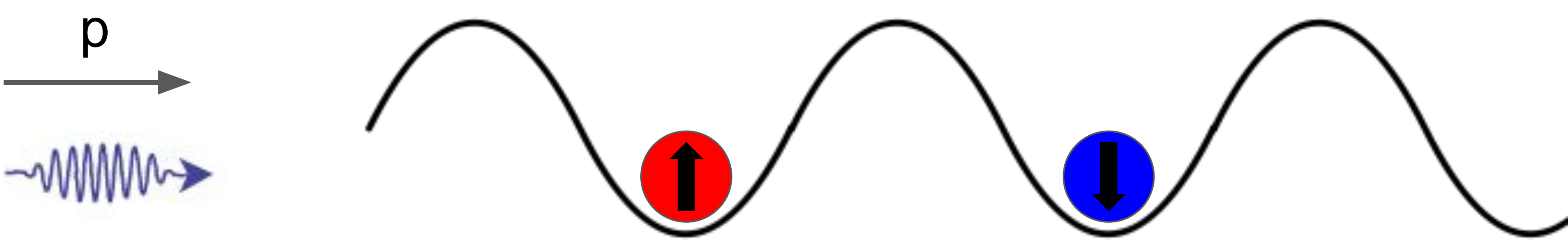
Quantum Gas Microscopy

Measure spin at each site

Prevent particle ejection while measuring



Spin removal technique



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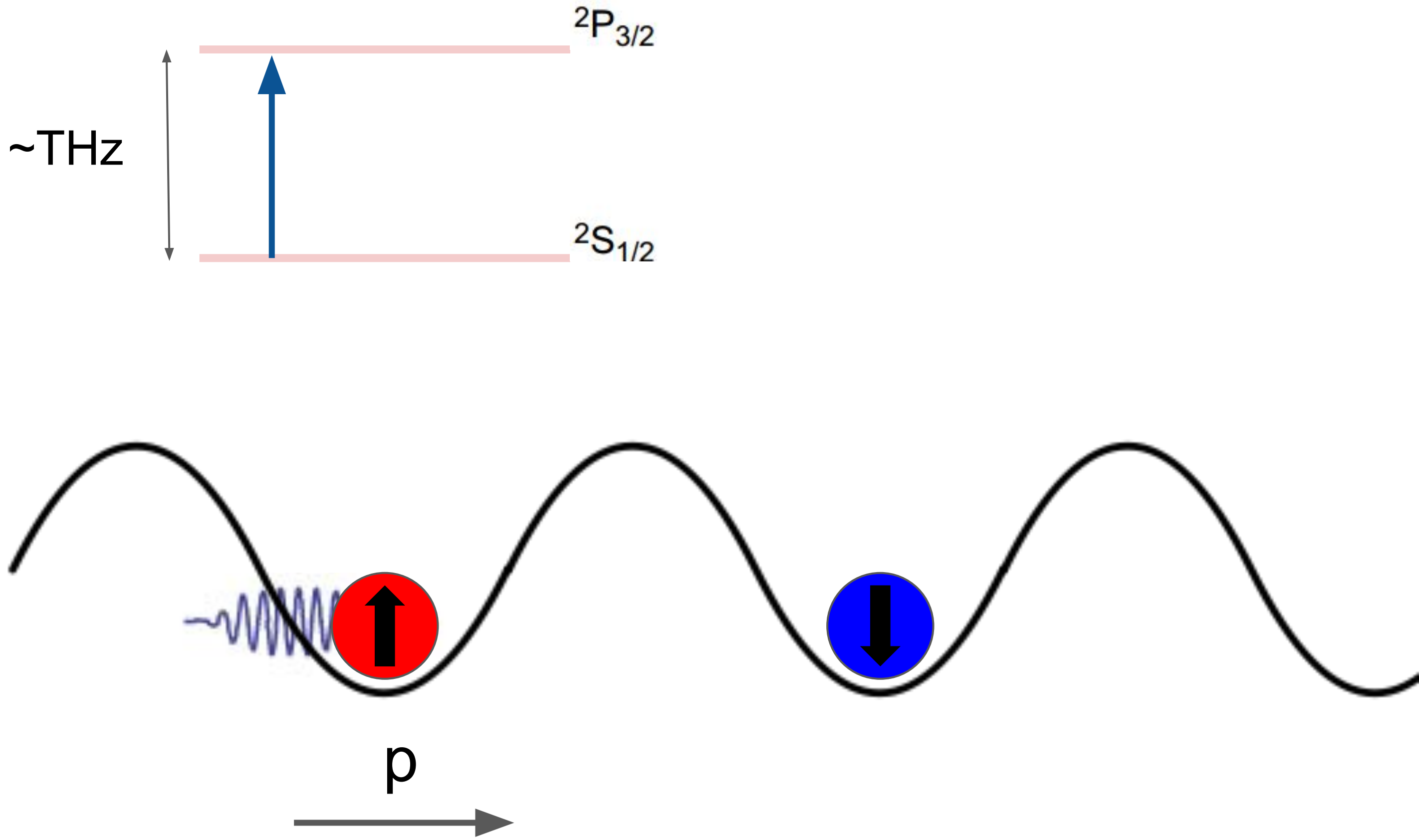

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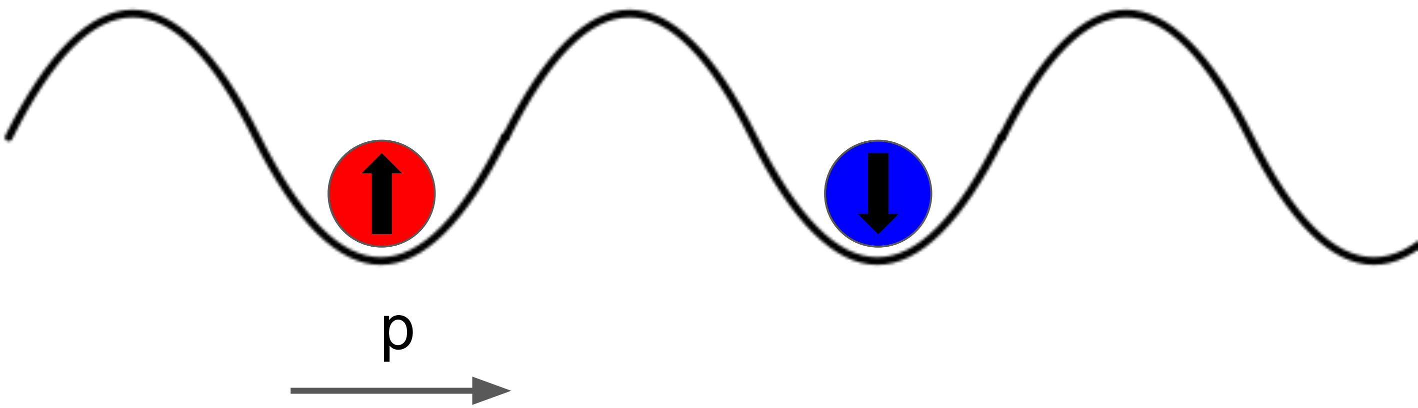

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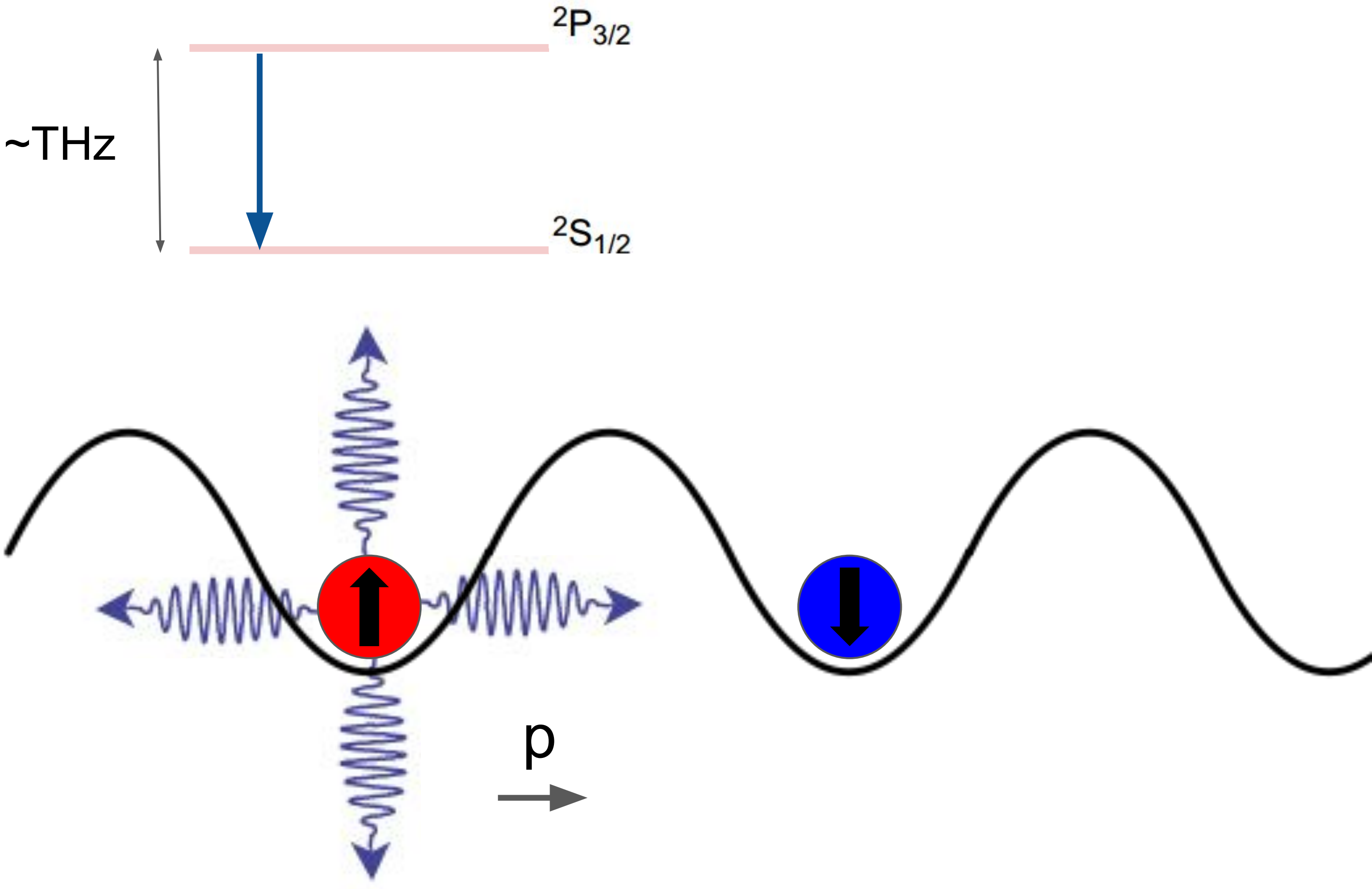

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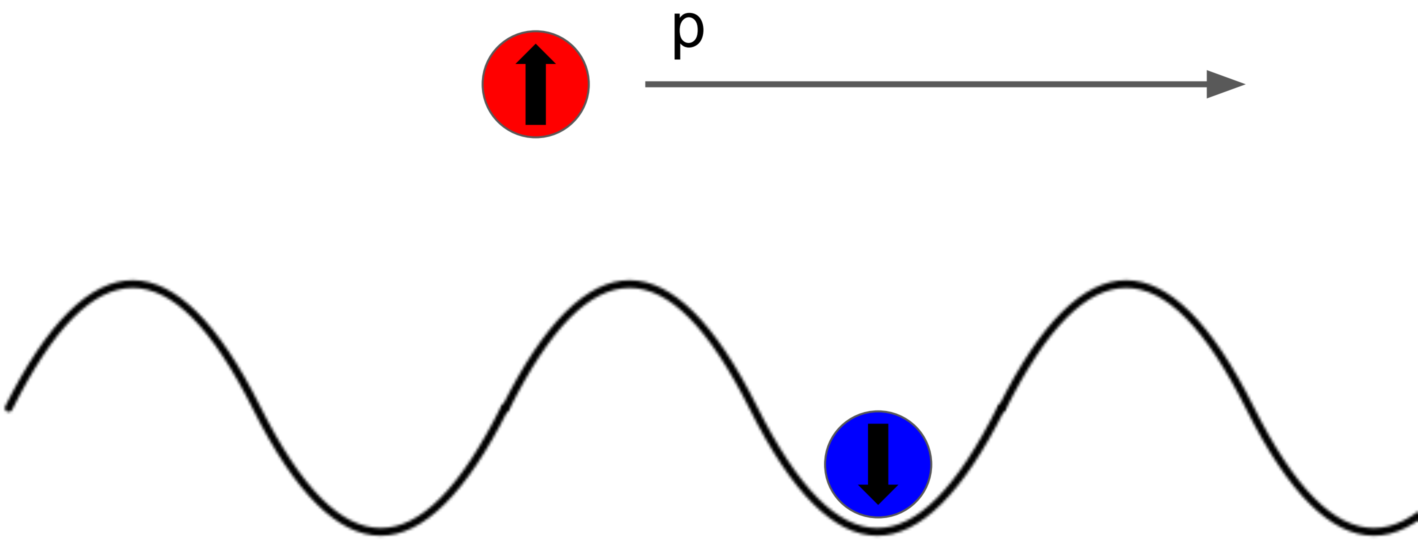
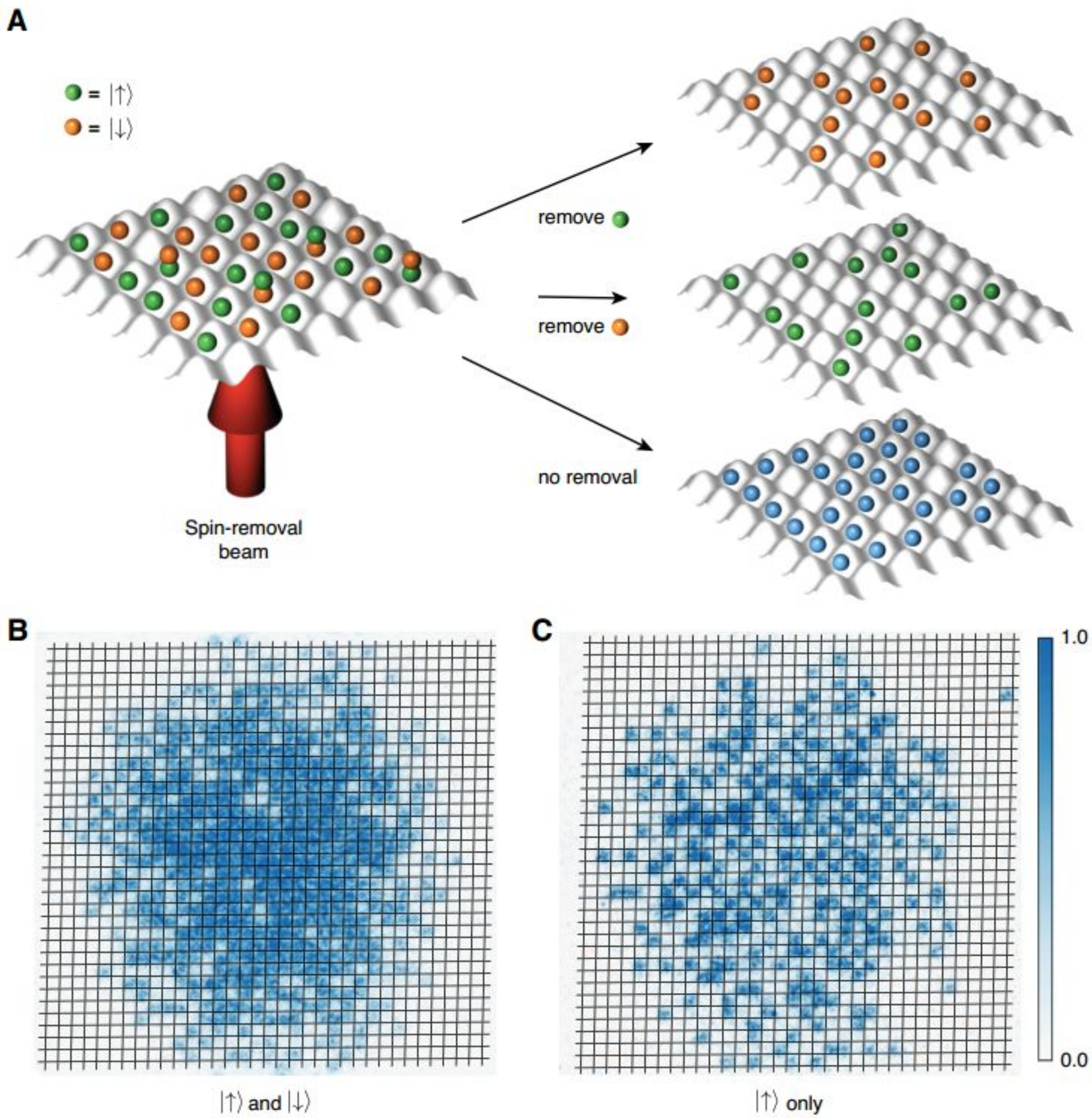


Spin removal technique

Drive Atomic Transition of one spin state

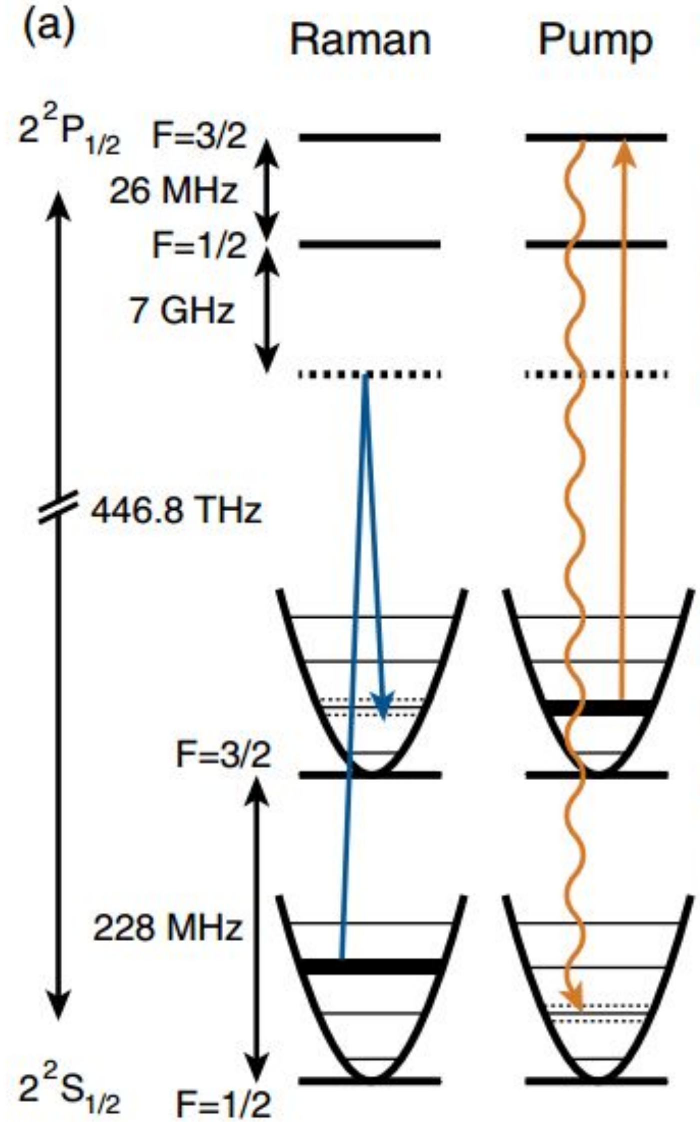
Ejection due to heating



[3] M. F. Parsons, et al. Science 353, 1253–1256 (2016)

Raman Side Band Cooling

- Raman
  - 2 detuned beams
  - Decrease vibr. excitation
  - Increase atomic excitation
- Pump
  - 1 beam
  - Deexcite Atom
  - Keep vibr. state



[2] M. F. Parsons, *et al.* Phys. Rev. Lett. 114, 213002 (2015)

Limitations of the Measurement

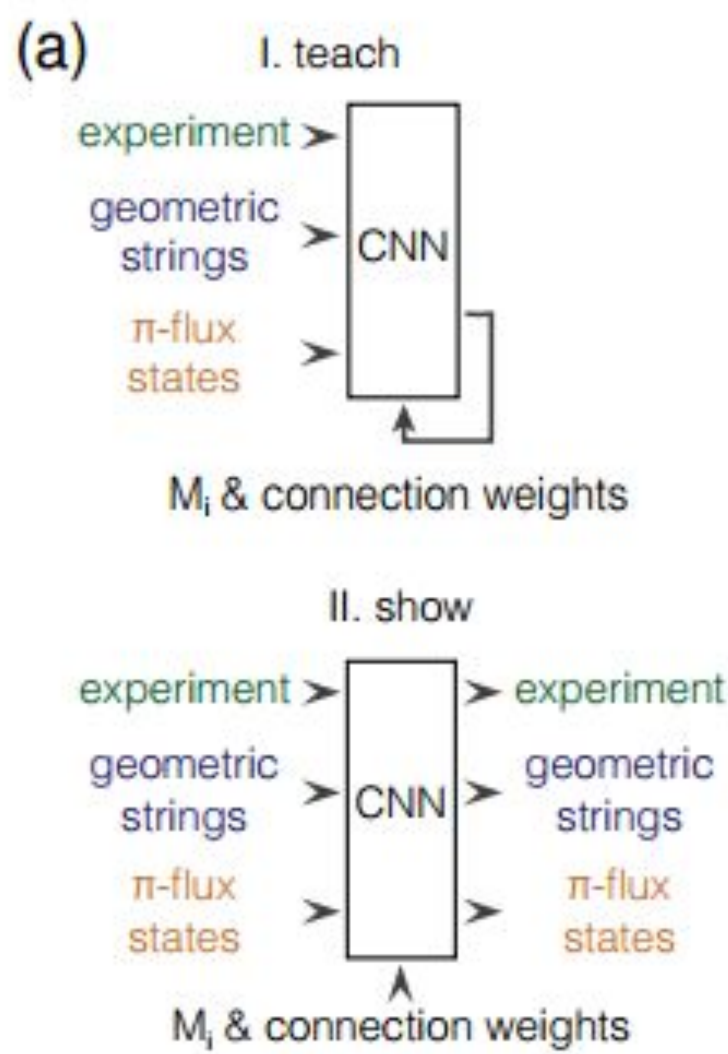
- Doublons appear as holes
- Only one spin species
    - Not full set of observables
- Finite boundaries
    - Additional effects not covered in Theory

Machine Learning

What?	Classify snapshots into Theory
Why?	Conventional Observables do not suffice
	Choice of observables introduces bias
How?	Train CNN with data generated from theory and experiment

Classifying Snapshots

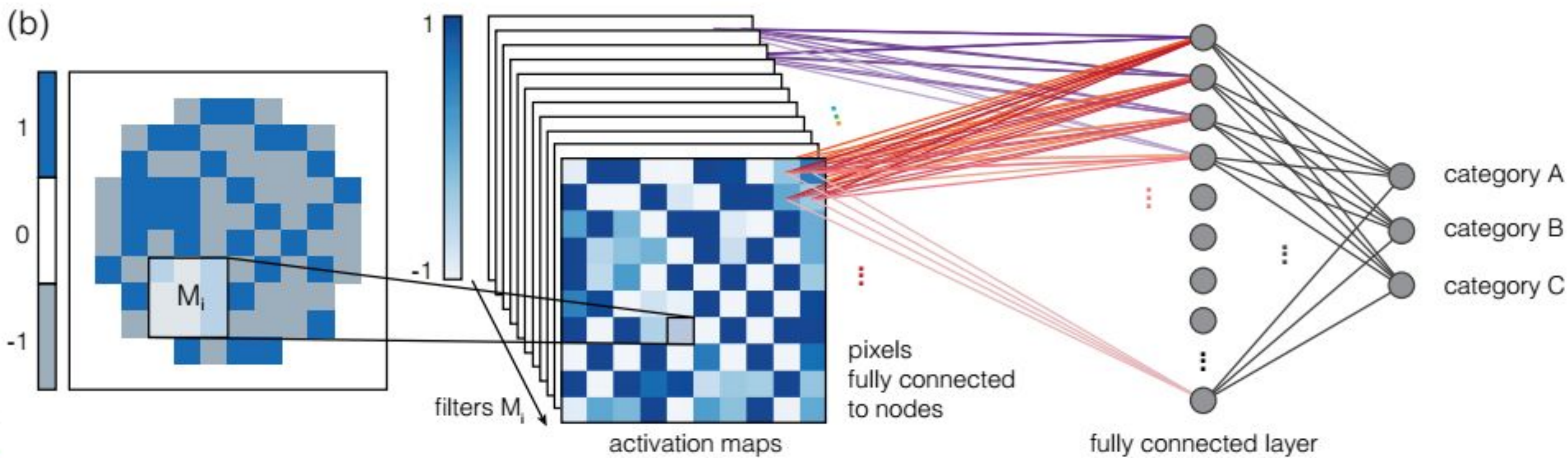
1st Machine Learning Task



[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

Classifying Snapshots

Network Architecture



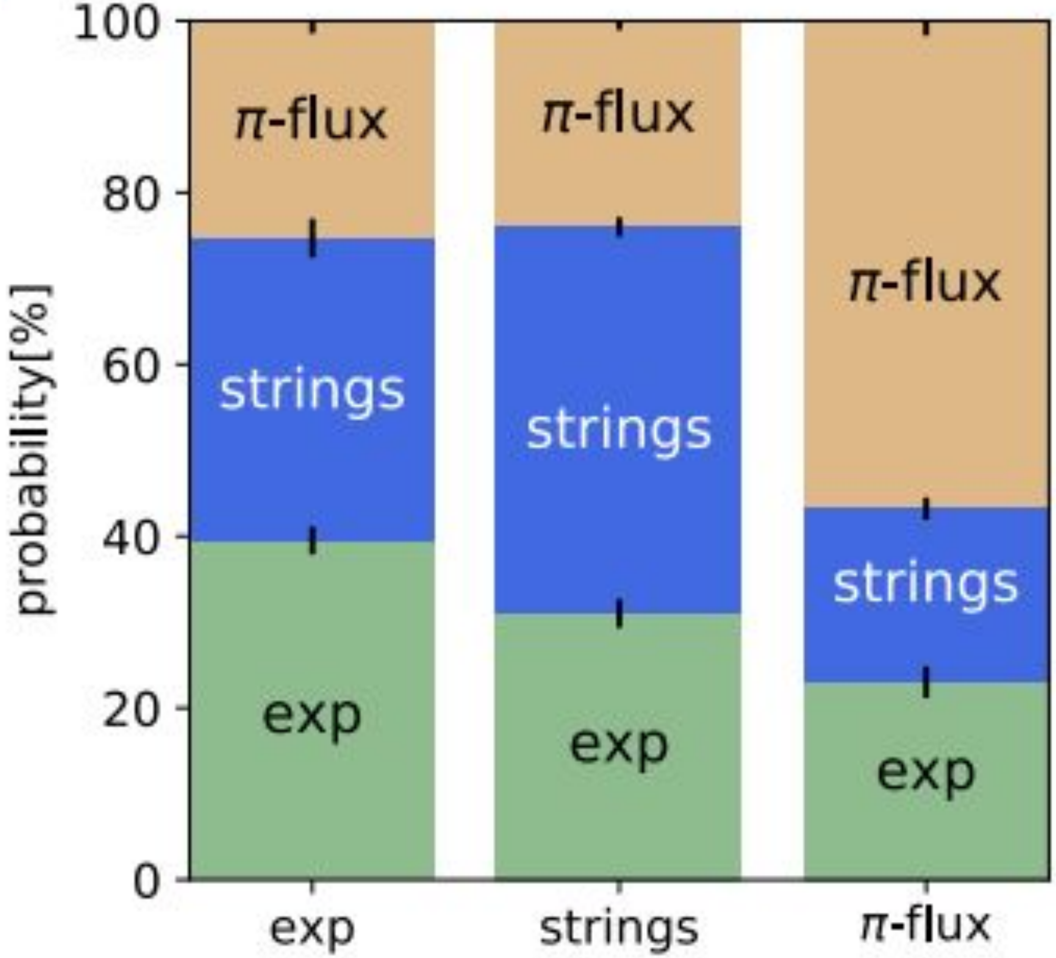
[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

Classifying Snapshots

Result (9% doping)

Accuracy: 47.1%

If strings and exp combined: 69.2%

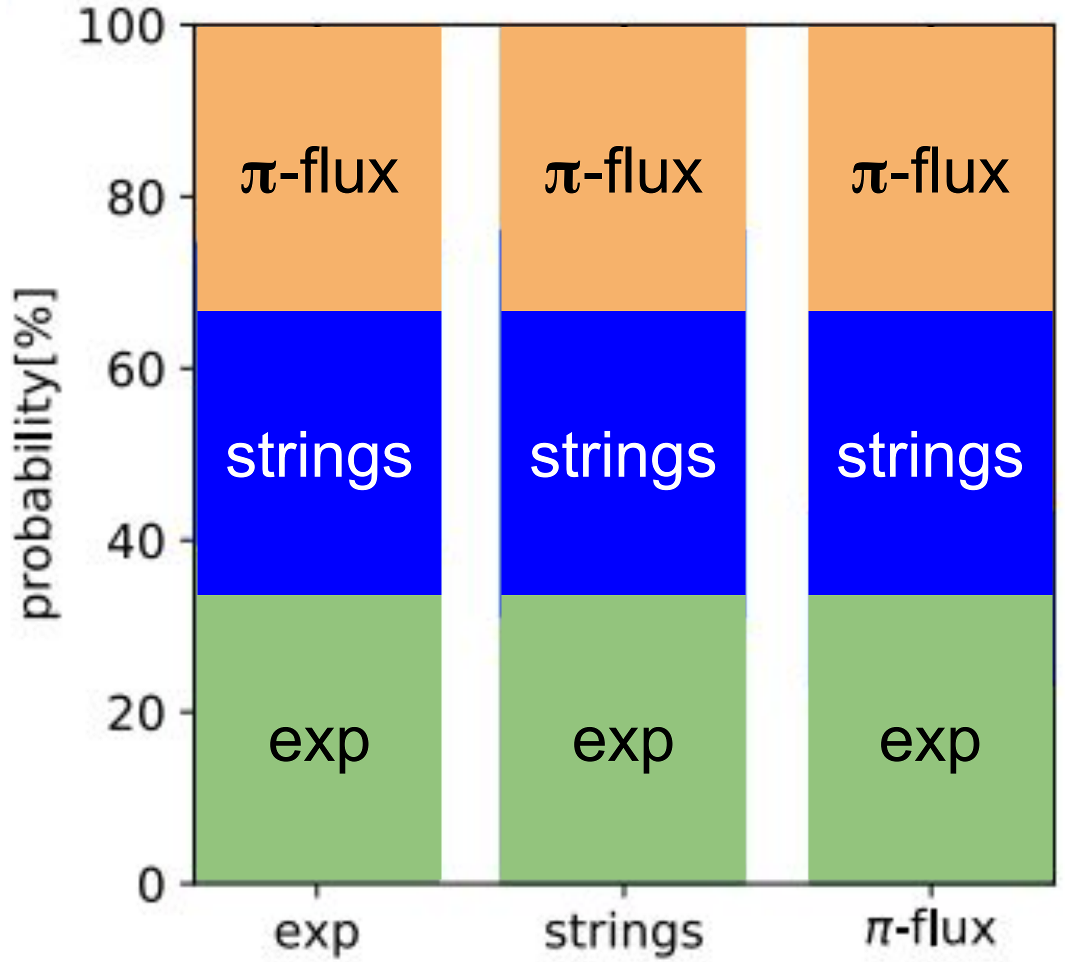


[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

Classifying Snapshots

Extreme Cases:

Both theories perfect

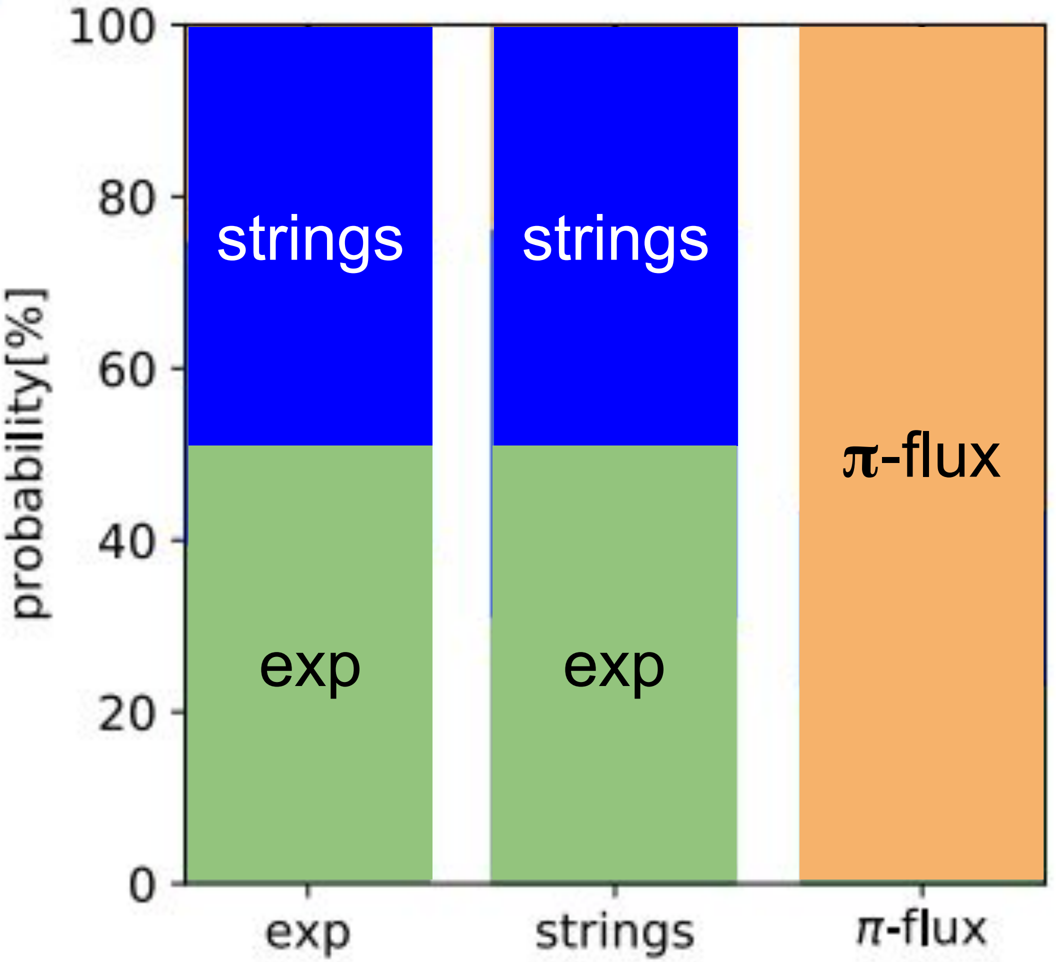


Classifying Snapshots

Extreme Cases:

Strings perfect

π-flux completely wrong



Classifying Snapshots

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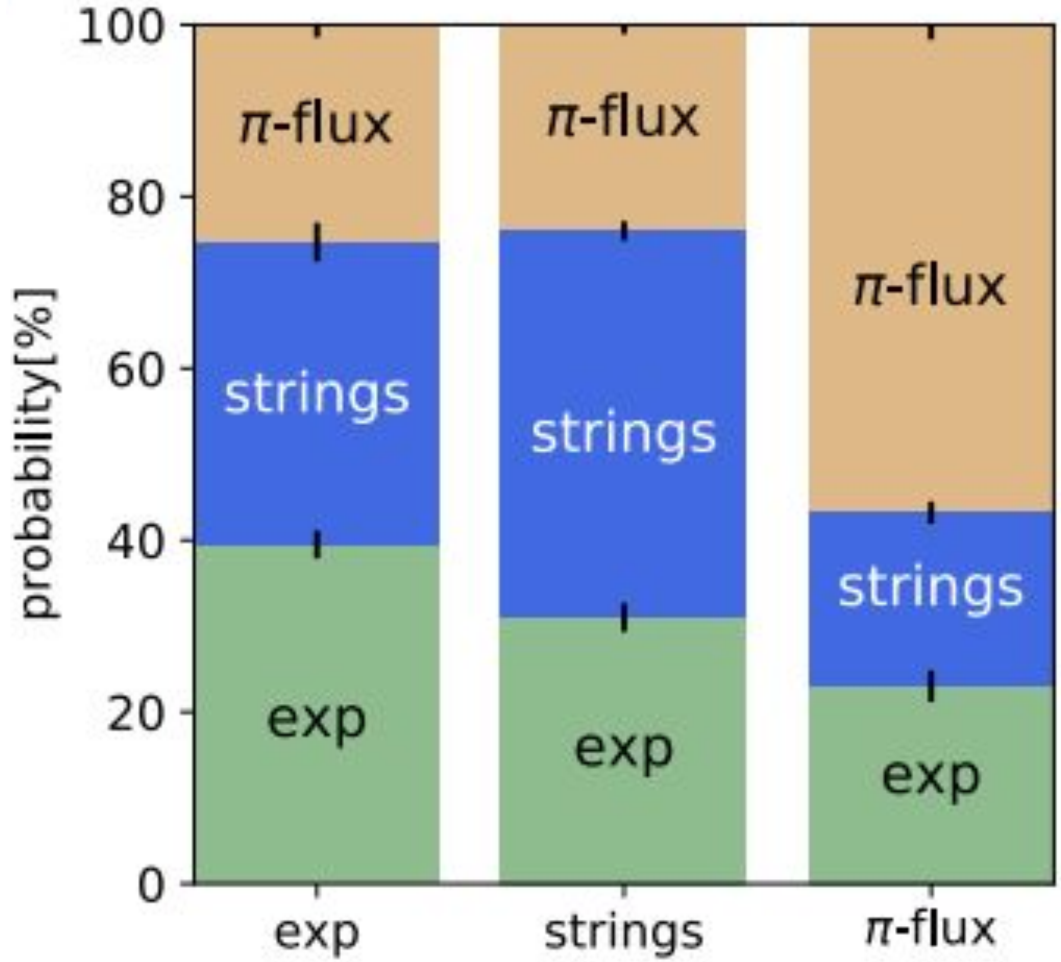

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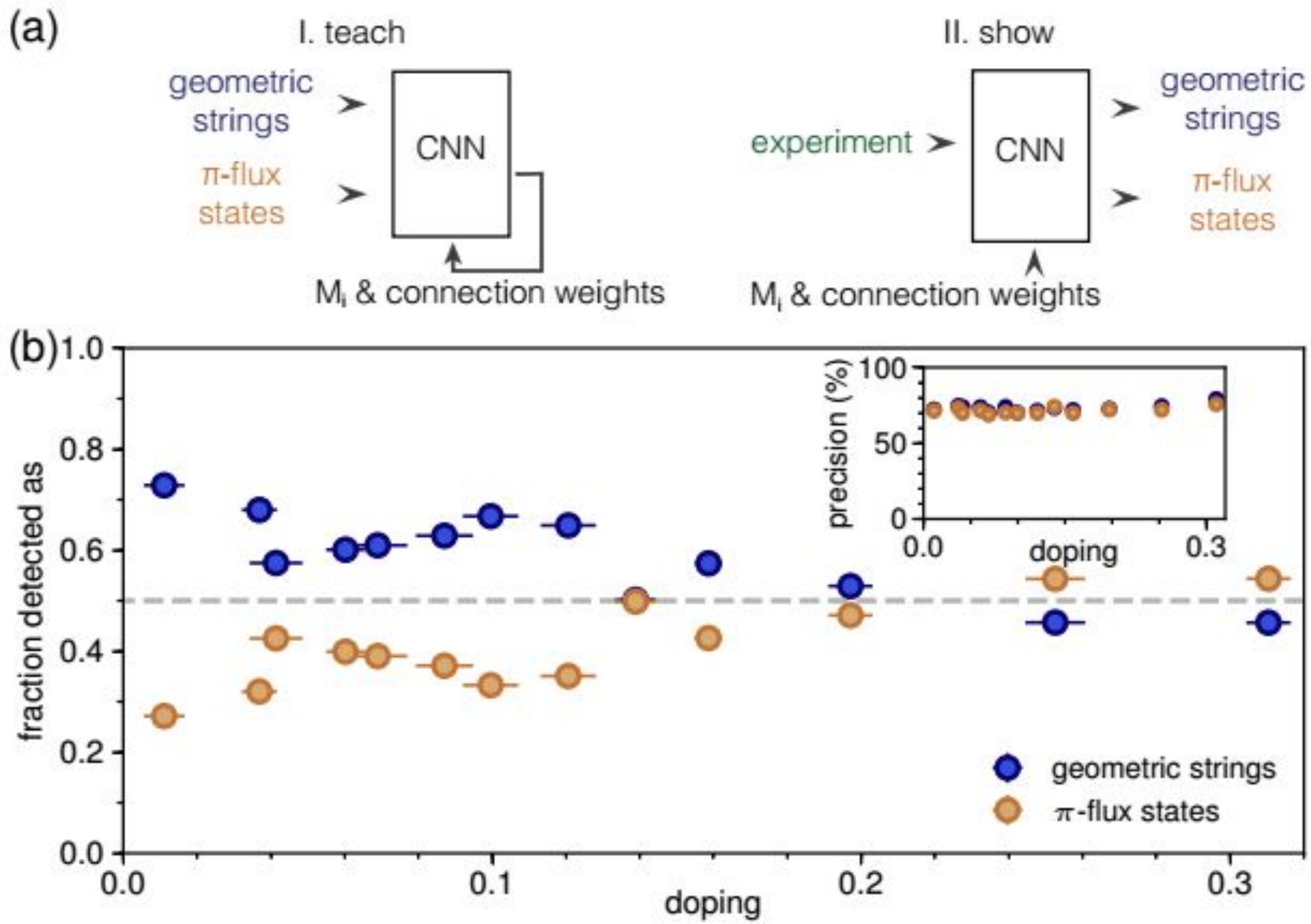
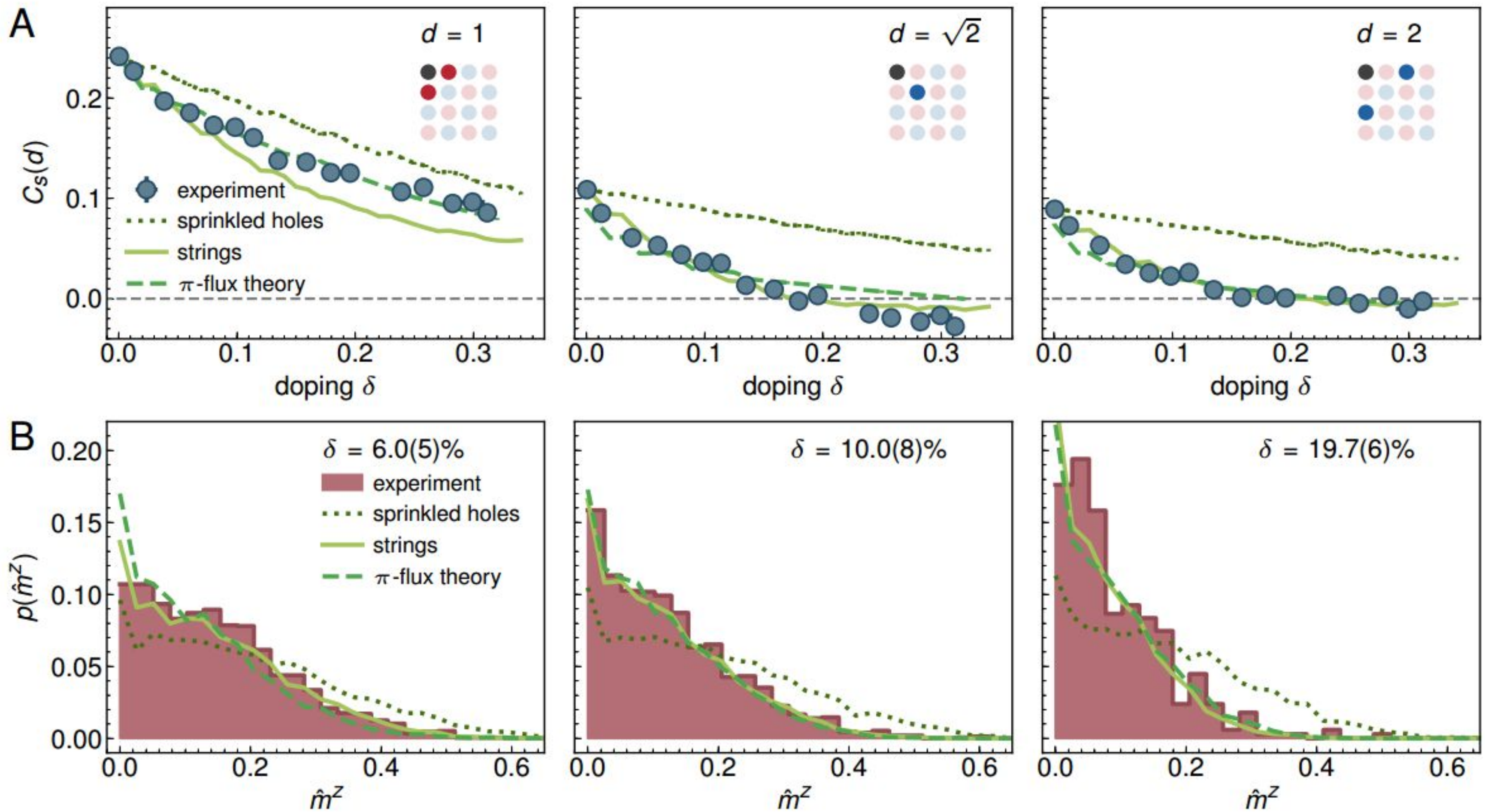
Sort experiment into theory



[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

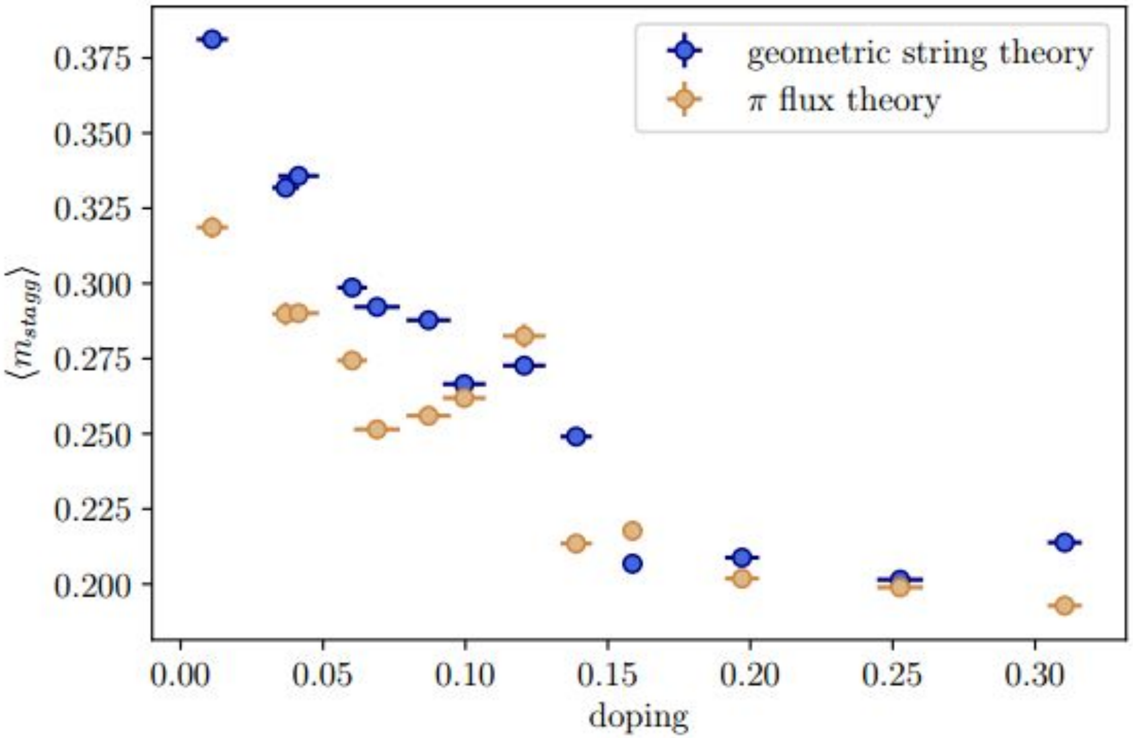
Conventional Analysis



[6] C. S. Chiu, et al. ArXiv e-prints (2018), arXiv:1810.03584 [cond-mat.quant-gas].

Discussion

Does the Network use unconventional observables?

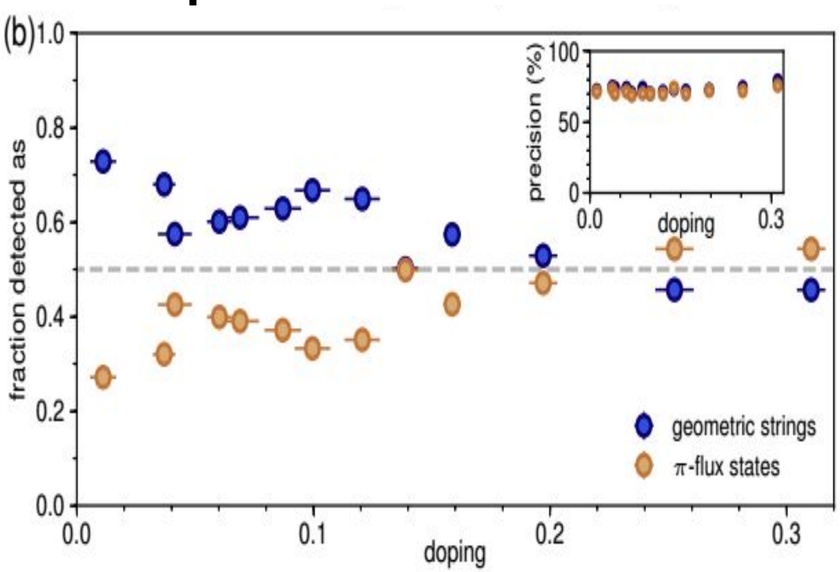


[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

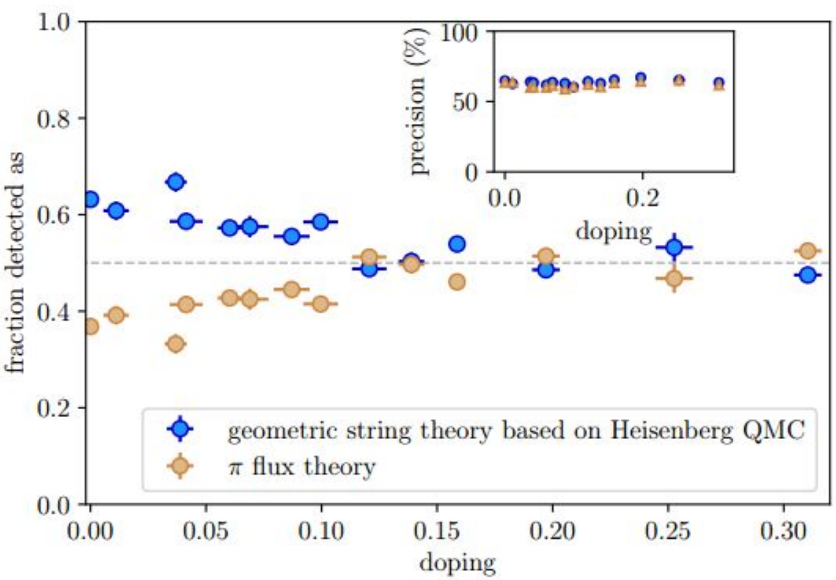
Discussion

Potential bias: string theory uses experimental ground state, test again with MC generated GS

Experimental GS



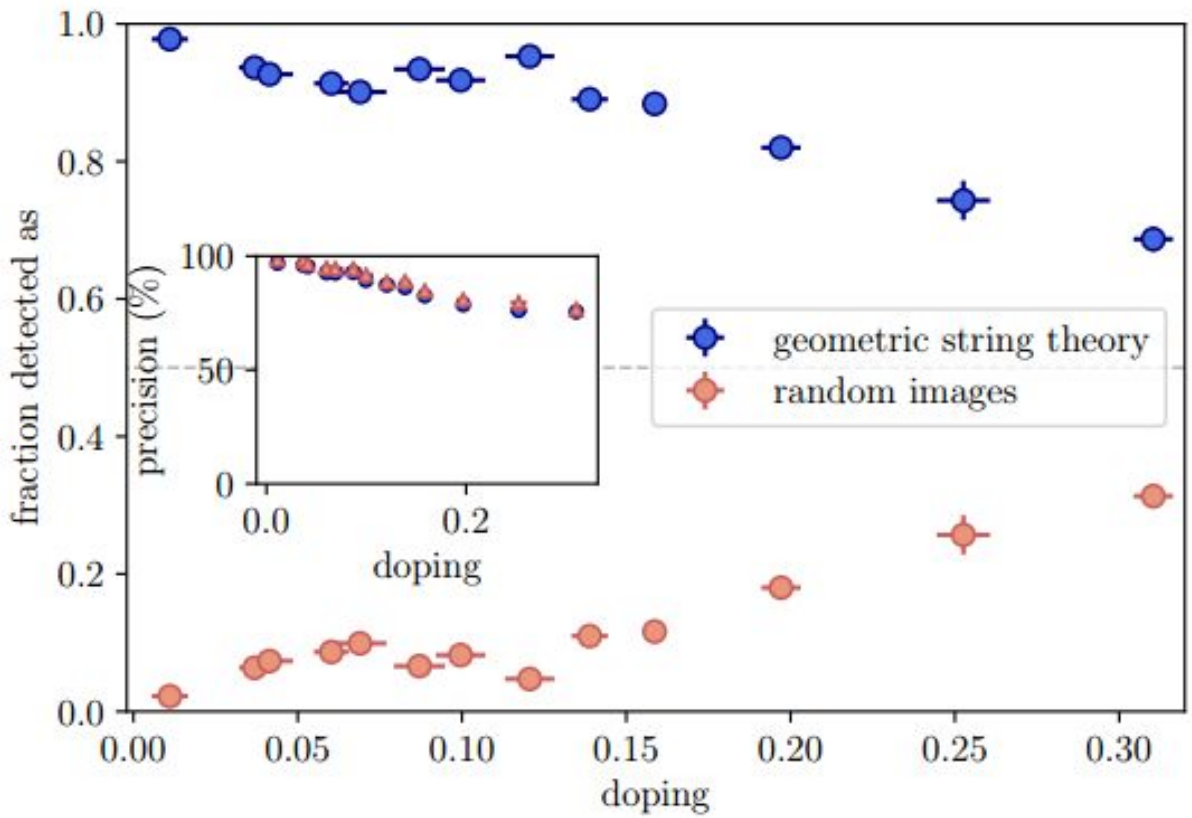
Simulated GS



[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

Discussion

String Theory vs. Random data



[4] A. Bohrdt, *et al.* arXiv:1811.12425 [cond-mat.quant-gas]

Summary & Outlook

- Experimental Realization of Fermi-Hubbard
- Quantum Gas Microscopy
  - Other regions of phase diagram
- NN to analyze experimental data
  - Analyze Network how it does so
  - Investigate use of unconventional observables further
  - Compare also other theories
  - Broader parameter space
- Investigate also other models

References

[1] M. Yamashita, K. Inaba, **Quantum Simulation with Ultracold Atomic Gases in an Optical Lattice.** NTT Technical Review, Vol. 10 No. 9 Sep. 2012

[2] M. F. Parsons, *et al*. **Site-Resolved Imaging of Fermionic ^{6}Li in an Optical Lattice.** Phys. Rev. Lett. 114, 213002 (2015)

[3] M. F. Parsons, *et al.* **Site-resolved measurement of the spin-correlation function in the Fermi-Hubbard model.** Science 353, 1253–1256 (2016)

[4] A. Bohrdt, *et al.* **Classifying Snapshots of the Doped Hubbard Model with Machine Learning.** arXiv:1811.12425 [cond-mat.quant-gas]

[5] A. Mazurenko, *et al.* **A cold-atom Fermi–Hubbard antiferromagnet.** Nature 545, 462 (2017)

[6] C. S. Chiu, *et al.* **String patterns in the doped Hubbard model.** ArXiv e-prints (2018), arXiv:1810.03584 [cond-mat.quant-gas].