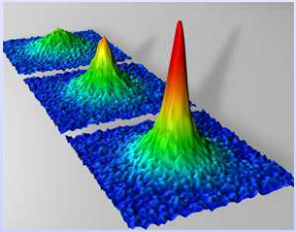
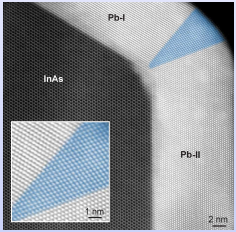
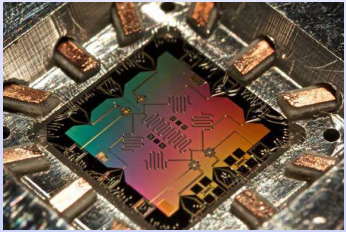
Condensed matter physics

Center for Quantum Devices





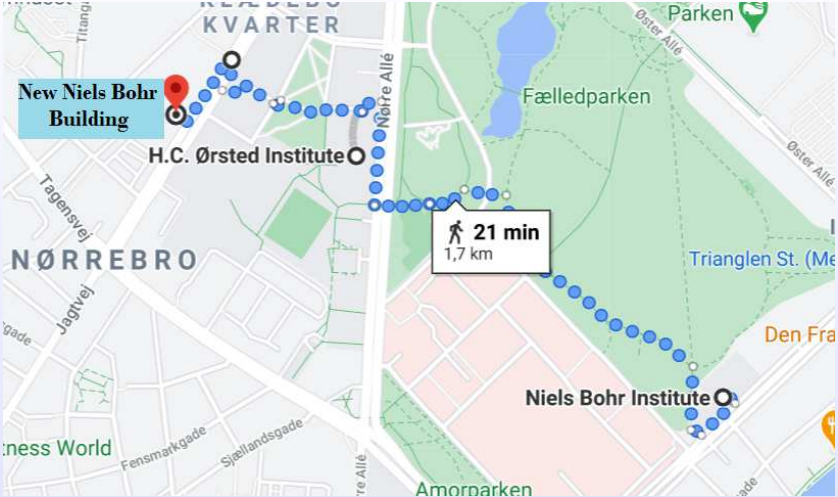


Michele Burrello
michele.burrello@nbi.ku.dk

Evert van Nieuwenburg
evert.vn@nbi.ku.dk

Condensed Matter Theory and QDEV

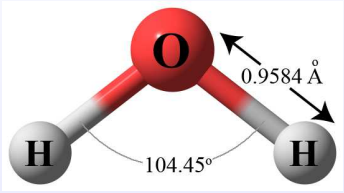
Where are we?



More is different!

P. Anderson

The challenge of many-body physics is to master the complexity of thermodynamic systems and describe their emergent properties.



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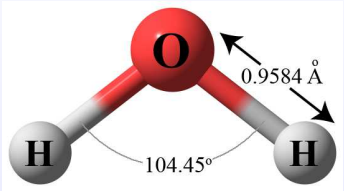

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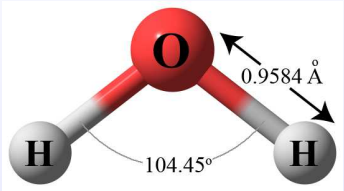

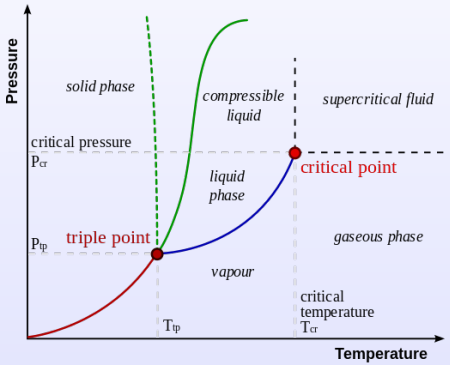

Let’s discuss about energies

From High Energy....

... to Low Temperatures

Let's discuss about energies

From High Energy....

- Free kick (vs ENG) by Damsgaard:
  $\sim 10^{21}$ eV $\sim 1.2 \times 10^{25}$K

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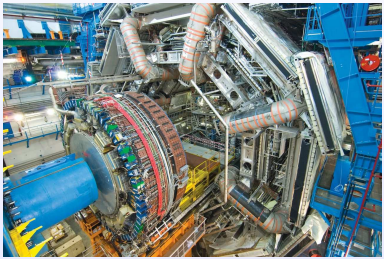

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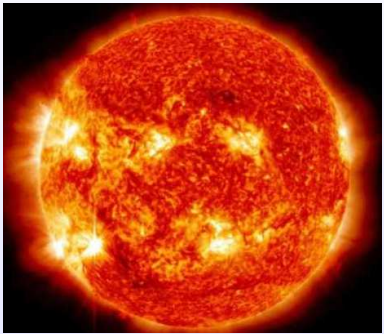

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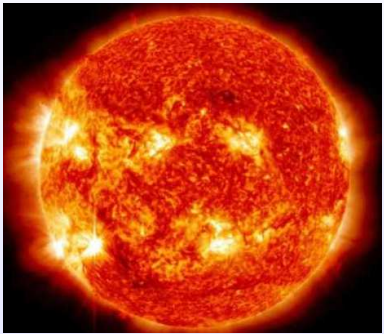

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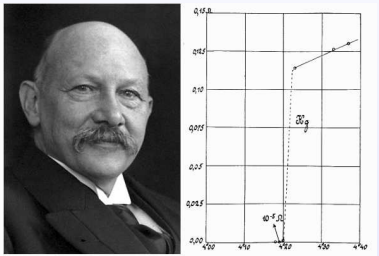

Kamerlingh Onnes 1911

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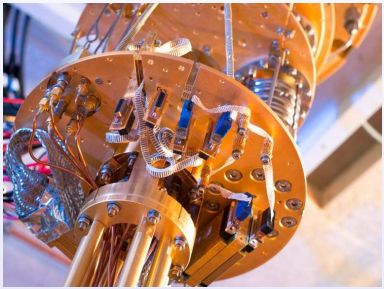

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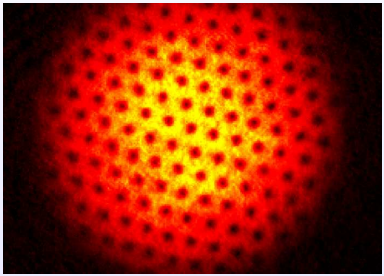
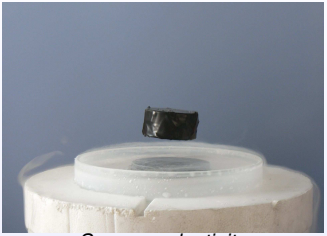
- QDEV dilution fridges: 2×10^{-2}K
- Ultracold atoms: 10^{-8}K

... to Low Temperatures

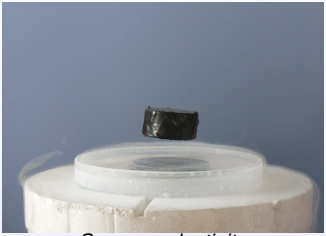


Quantum world at low temperature



Superconductivity

Quantum world at low temperature



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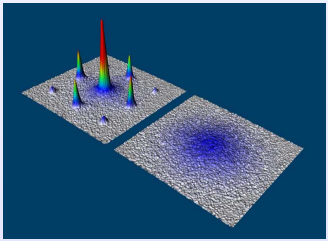
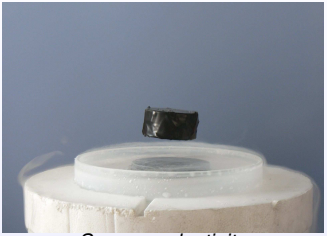


Superfluid-Mott phase transition in cold atoms

Quantum world at low temperature



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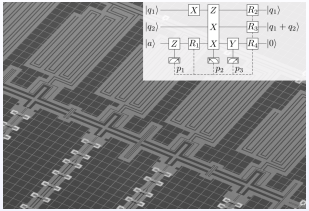
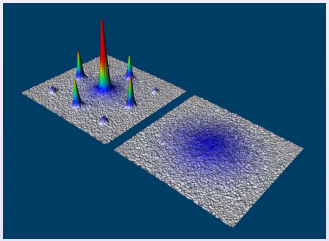


Quantum simulations



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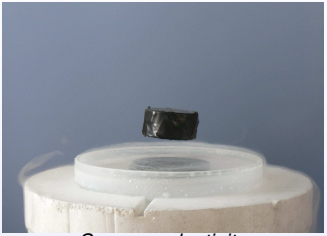

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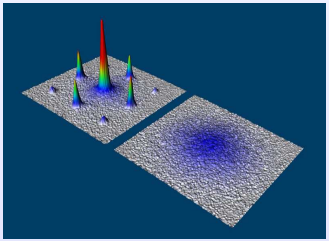

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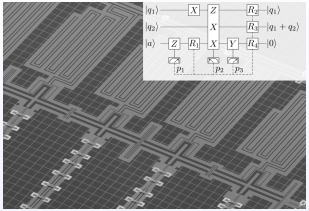

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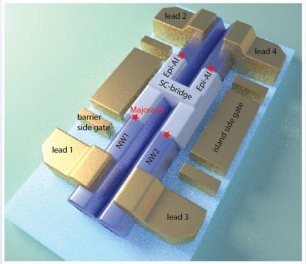
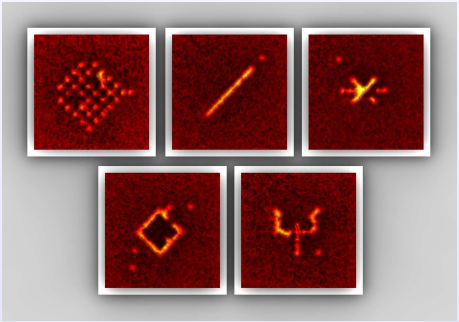


Topological Phases of Matter

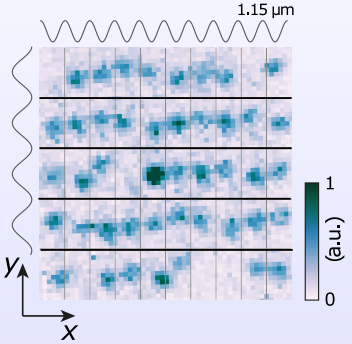
Majorana devices @ QDEV

Ultracold atoms in optical lattices

- Lasers define time-dependent optical potentials
- Quantum engineering of effective Hamiltonians
- Unprecedented possibility of studying quantum dynamics



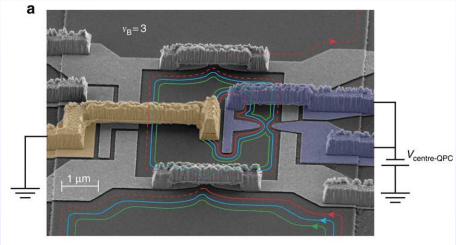
Potential design



Atomic microscope

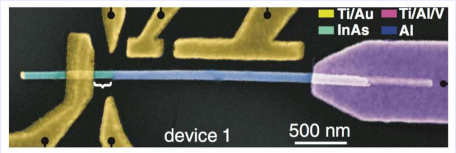
Topological phases of matter

Fractional quantum Hall:



Robustness against local perturbations

Majorana nanowires (@ QDEV):



Topologically protected quasiparticles

Topological phases of matter

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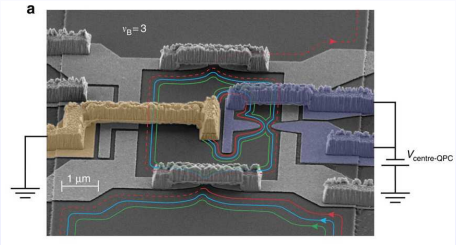

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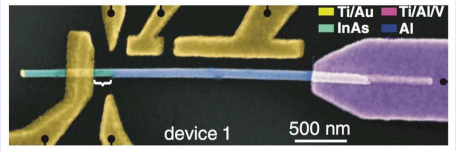

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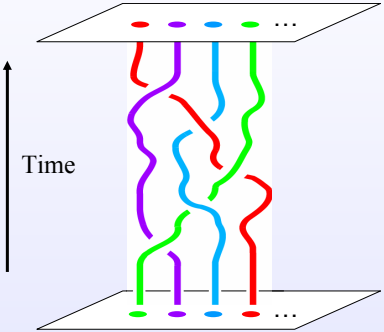


Quasiparticles with fractional charges and anyonic statistics

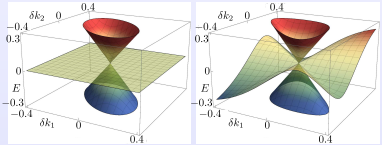
Methods and techniques

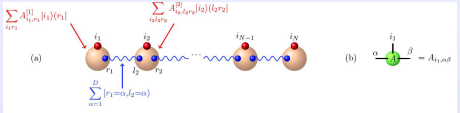
Analytical methods:

- Advanced quantum mechanics
- Quantum field theories
- Feynman path integral
- Gauge theories
- ...

Numerical methods:

- Exact diagonalization
- DMRG and tensor networks
- Machine learning
- ...





Condensed matter courses

IV year

- **Block 2:**
  - Condensed matter physics 2 (Course, 7.5 ECTS)
    Karsten Flensberg
  - Condensed matter theory 1 (Course, 7.5 ECTS)
    Brian Andersen
- **Block 3:**
  Condensed matter theory 2 (Course, 7.5 ECTS)
  Jens Paaske
- **Block 4:**
  Advanced condensed matter theory (**PUK: Study Project**, 7.5 ECTS)
  Michele Burrello
  Visit: https://absalon.instructure.com/courses/56023
  Enroll: https://absalon.instructure.com/enroll/BLA9W8

CMT @ NBIA

see also `cmt.nbi.ku.dk`

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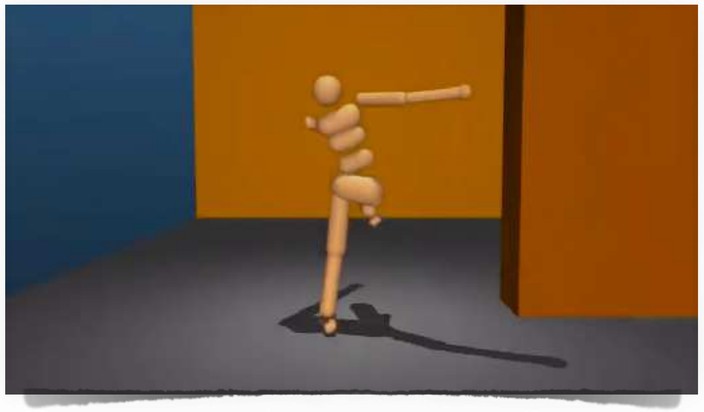
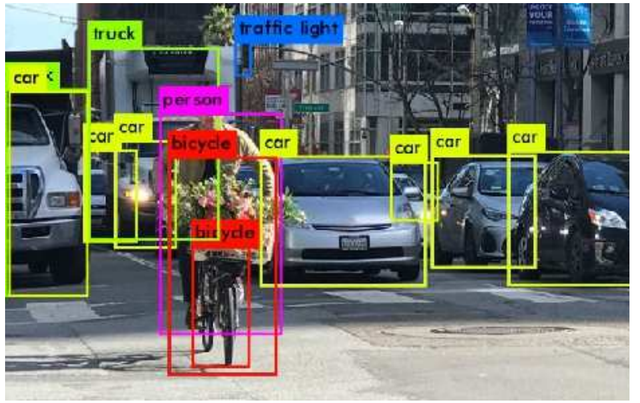
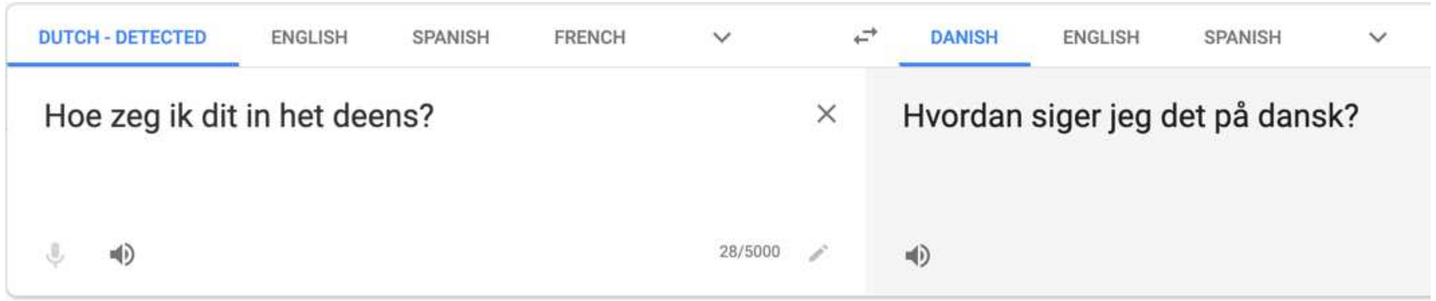
evert.vn@nbi.ku.dk

Other CMT professors:
Jens Paaske
Karsten Flensberg
Brian Andersen
Per Hedegård
Constantin Schrade

Machine Learning is everywhere







Natural Language Processing
https://talktotransformer.com/

Generative Modelling
https://thispersondoesnotexist.com/

Speech Synthesis
"Deep-Fakes"
...

There are roughly three types of ML

Each of these types has a use in physics

Supervised Learning
Learning from examples

Material -> superconductor?

Is there a phase transition in this dataset?

Which quantum error occurred?

Unsupervised Learning
Learning about examples

Optimised quantum readout

Optimise quantum experiments

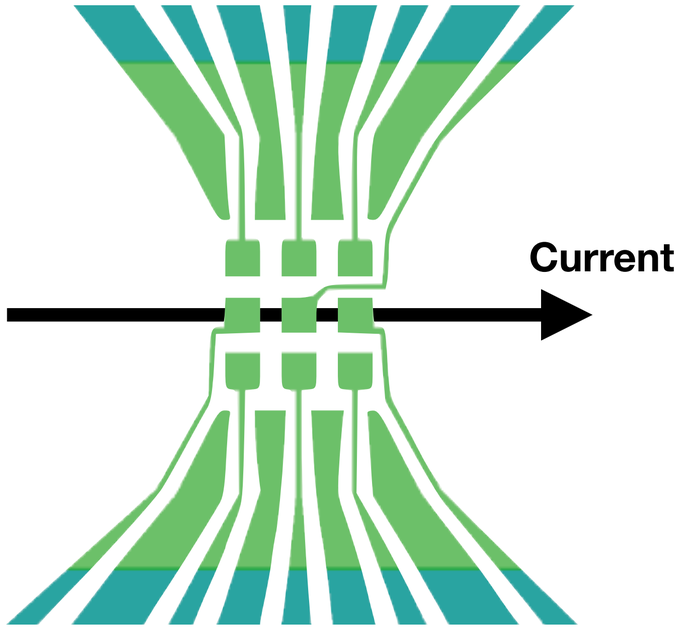
Reinforcement Learning
Learning from feedback

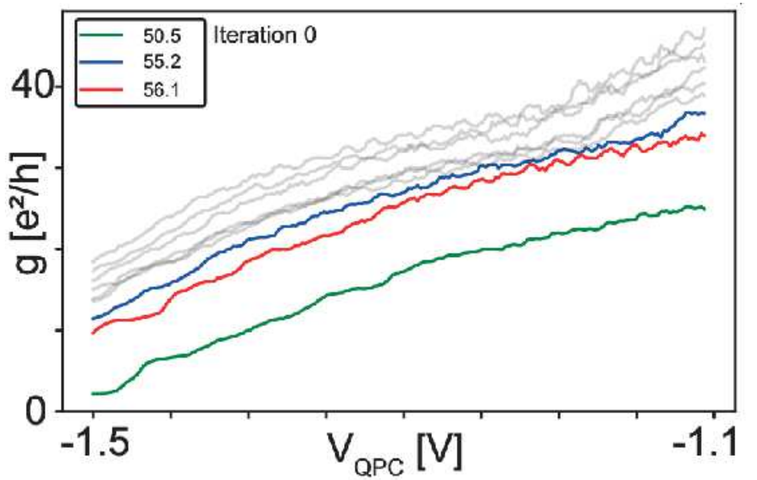
Correct quantum errors

Control and optimise experiments

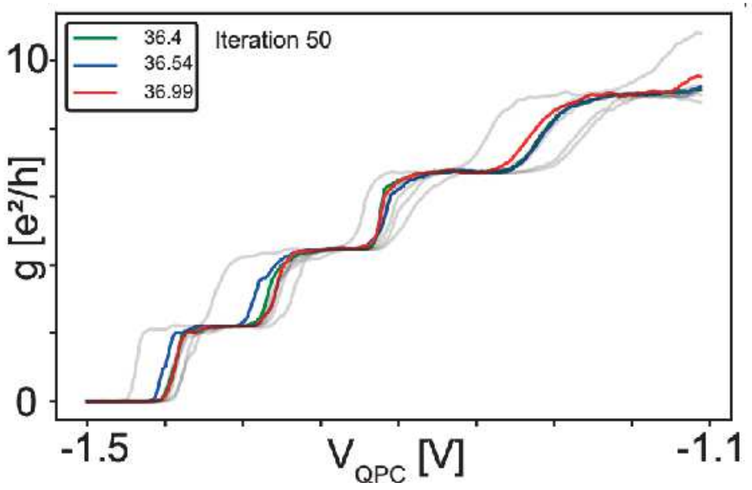
Design quantum circuits/experiments

Optimizing Quantum Experiments

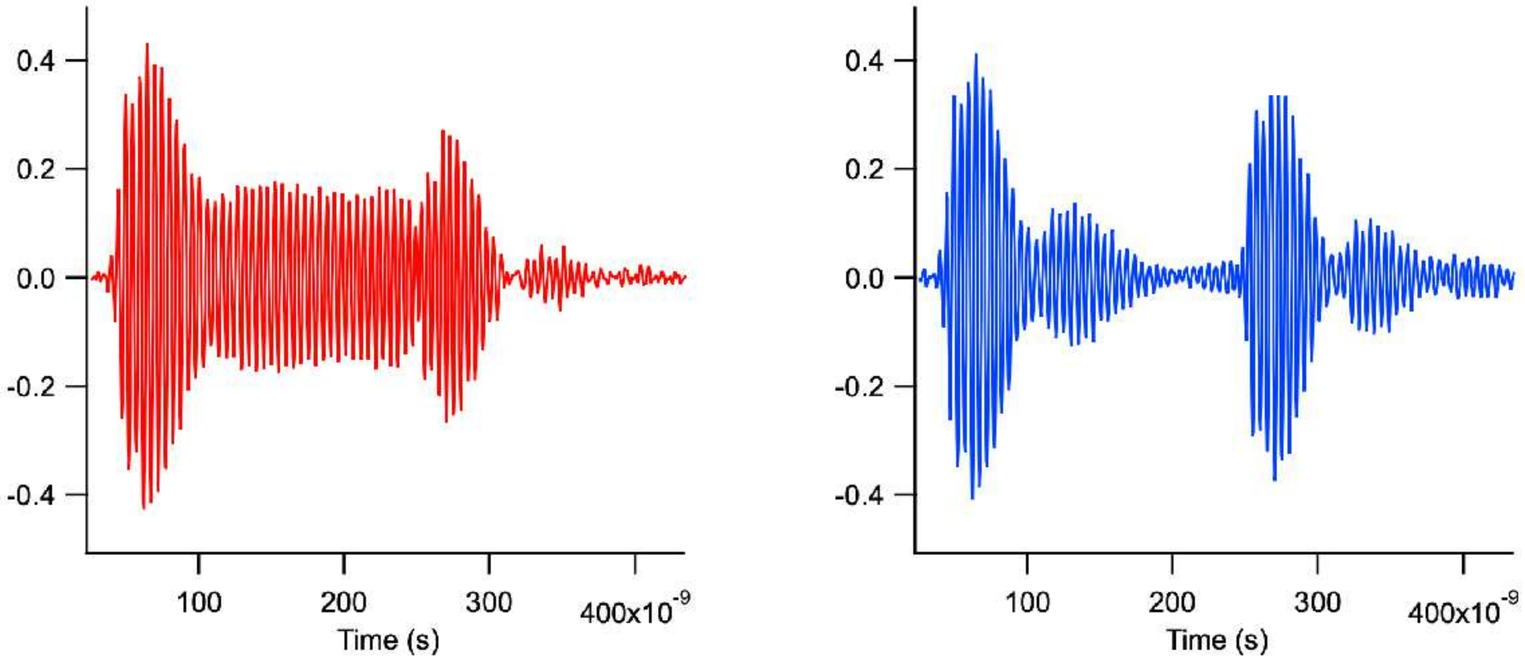




Optimize



Optimizing Quantum Experiments



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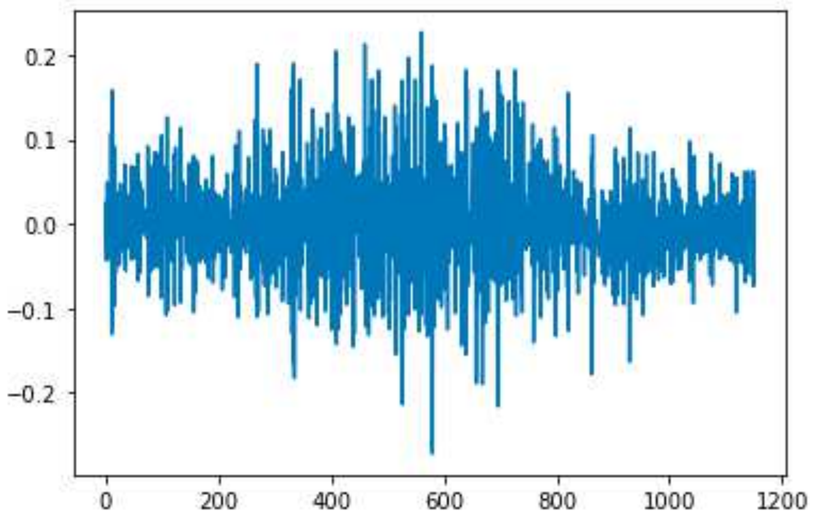
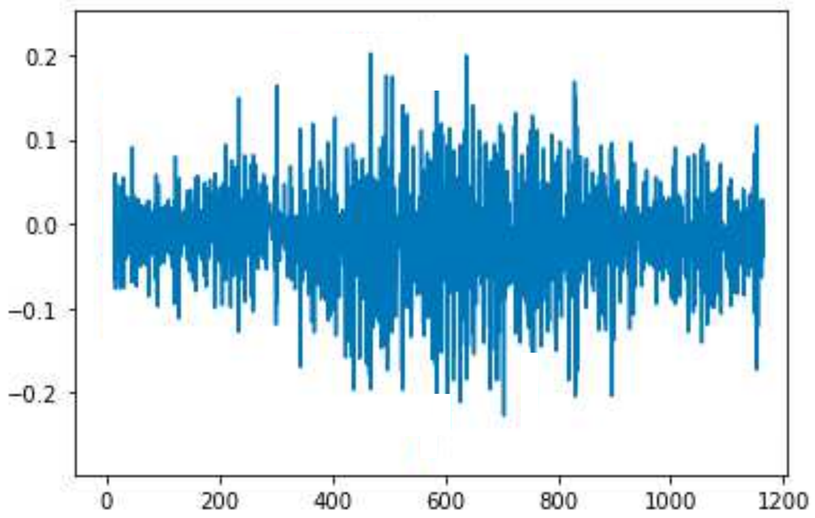
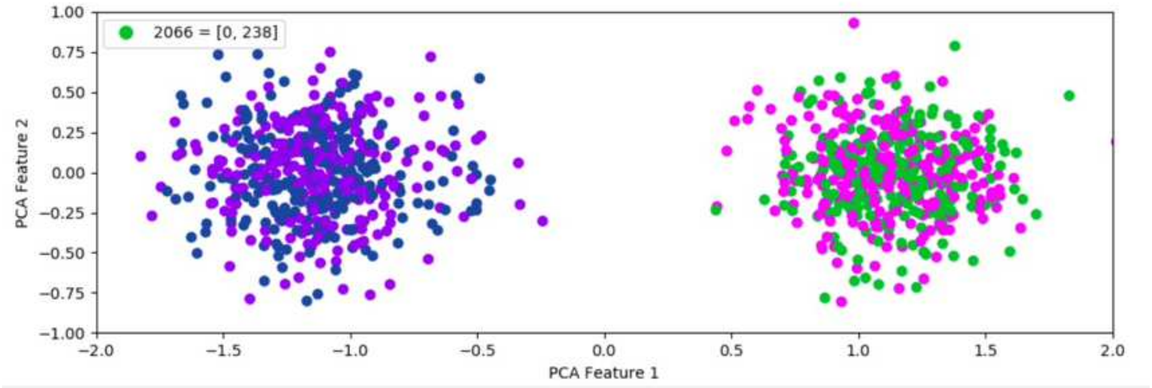


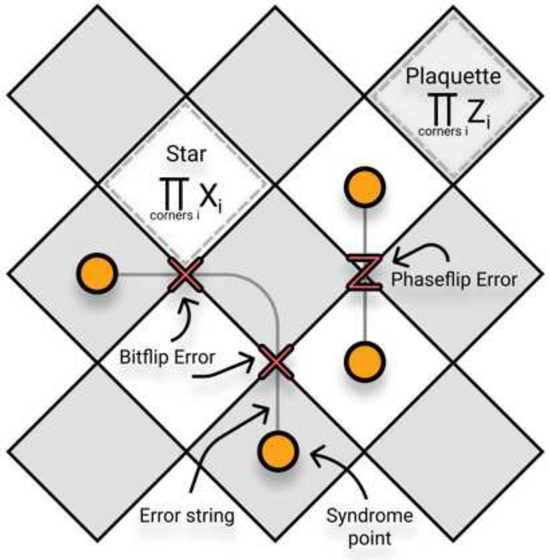


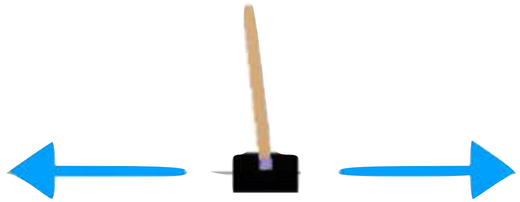


Quantum Information Processing

Using Reinforcement Learning

Quantum Error Correction





The “Cartpole”

Quantum Circuit Design