Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU

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@HadNucAtUB

Quantum algorithms for the nuclear shell model

UNIVERSITAT DE BARCELONA

FUJITSU

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

UAB
Universitat Autònoma de Barcelona

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

B Juliá-Díaz, J Menéndez, E Costa, **K Gallego**, **J Ainaud**, **A Morón**, AM Romero, A García-Saez, S Masot-Llima, A Pérez-Obiol, M Carrasco-Codina

Digital: Scientific Reports **13**, 12291 (2023) + EPJA **59**, 240 (2023) + PRC **113** 024332 (2026) + arXiv:2409.04510

Annealing: SciPost Physics 19 062 (2025) + Phys Lett B **872** 140042 (2025)

Arnau Rios Huguet
Associate Professor
Institute of Cosmos Sciences
Universitat de Barcelona
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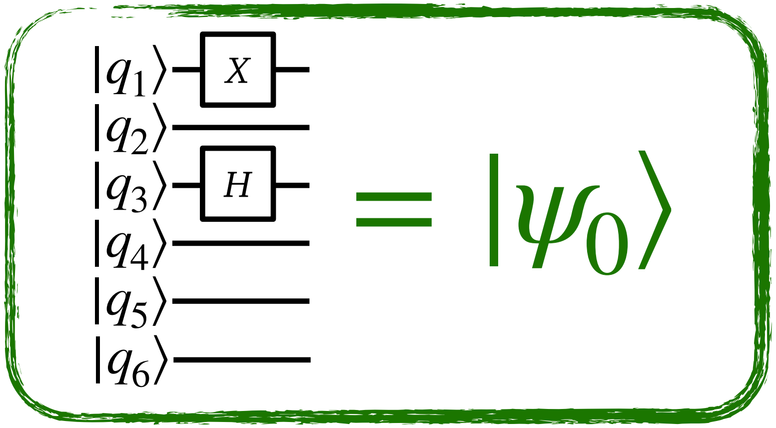
IoP Nuclear Physics Conference 2026
Brighton
14 April 2026

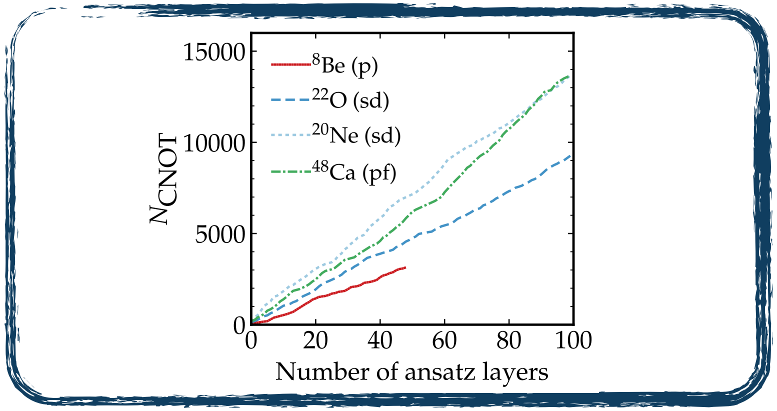
Outline

- **Quantum algorithms**



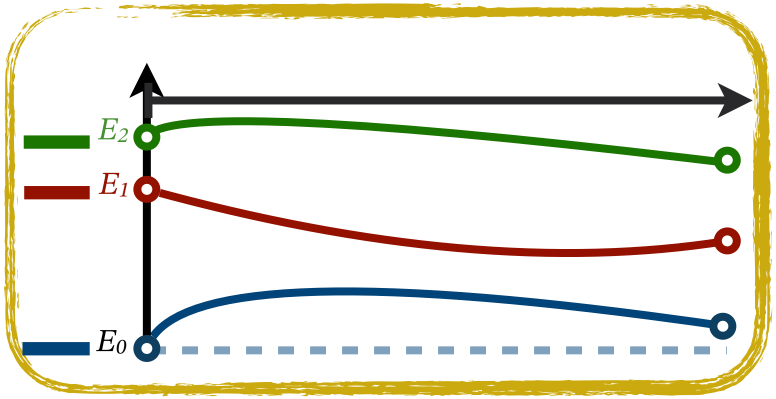
- Variational approach

Scientific Reports **13**, 12291 (2023)
EPJA **59**, 240 (2023)
+ arXiv:2409.04510 + PRC **113** 024332 (2026)



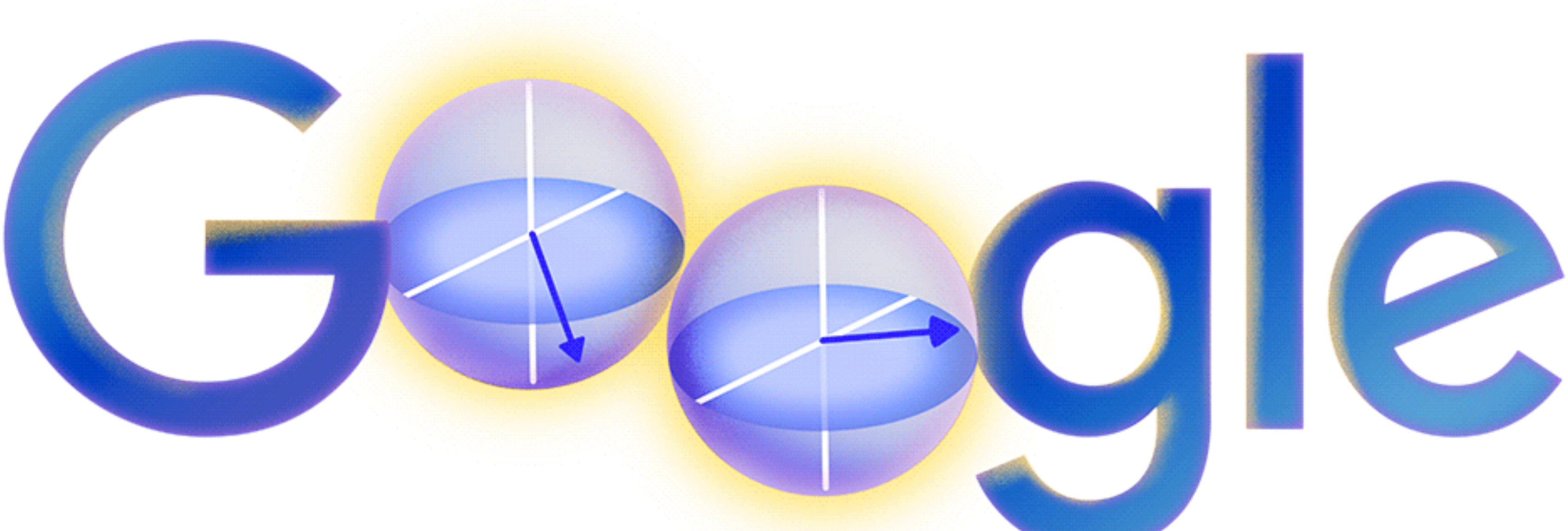
- Adiabatic approach

SciPost Physics 19 062 (2025)
+ Phys Lett B **872** 140042 (2025)



World Quantum Day

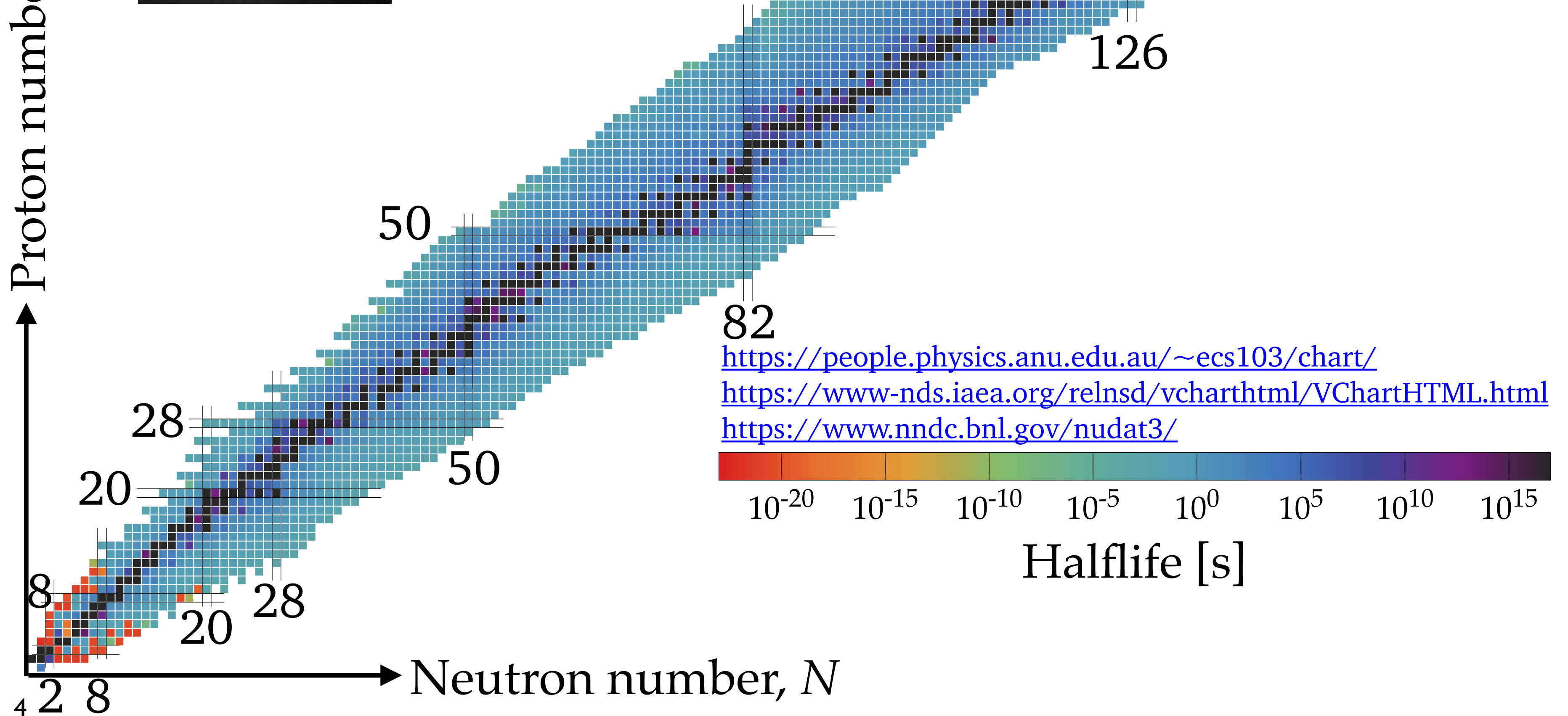
WORLD QUANTUM DAY
APRIL 14



https://worldquantumday.org/

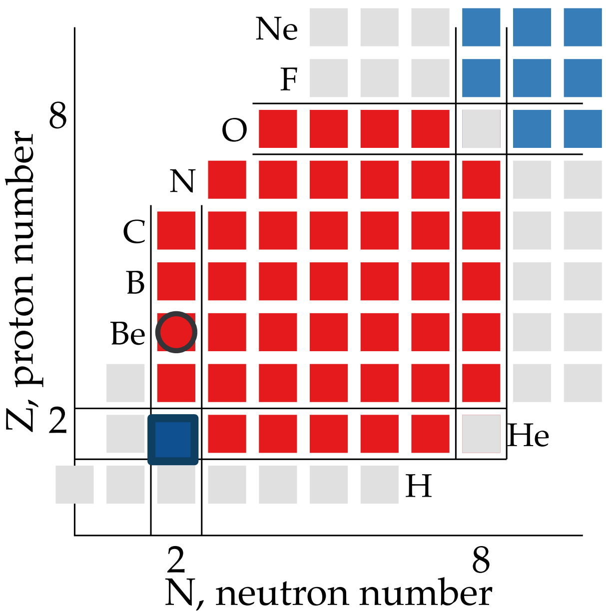
Isotope chart

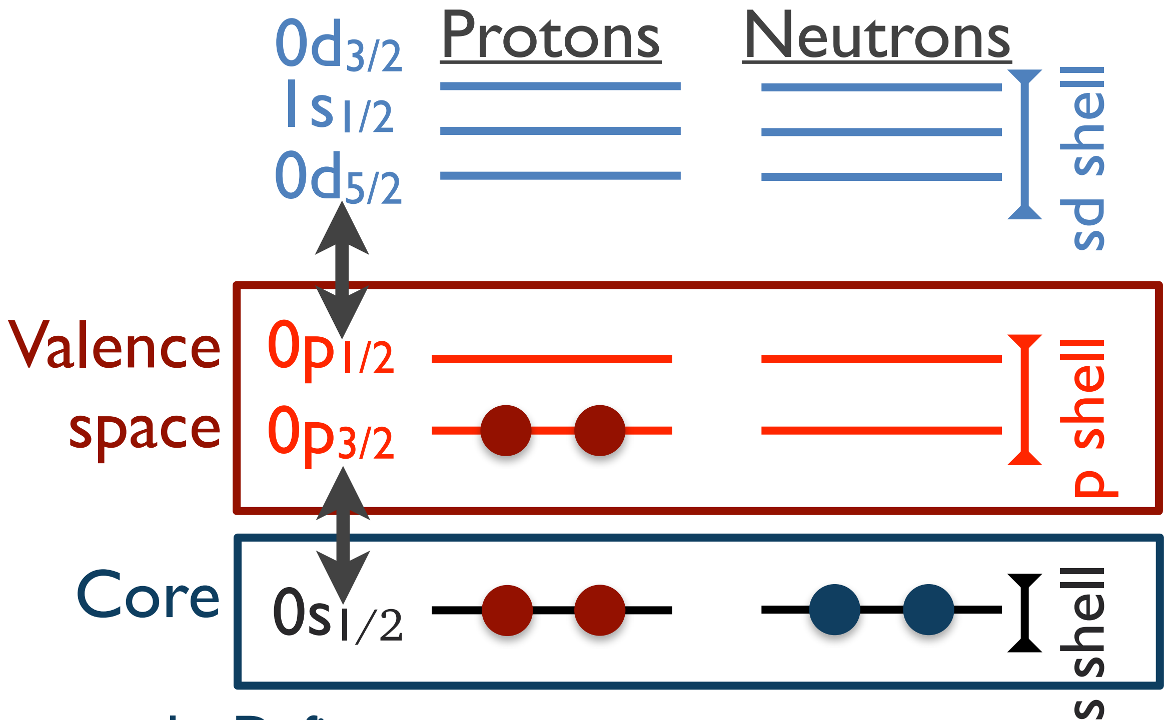
Maria Goeppert Mayer
Nobel Prize (1963)



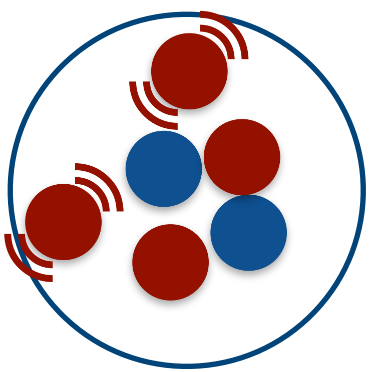
https://people.physics.anu.edu.au/~ecs103/chart/
https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html
https://www.nndc.bnl.gov/nudat3/

Shell model





^{6}Be

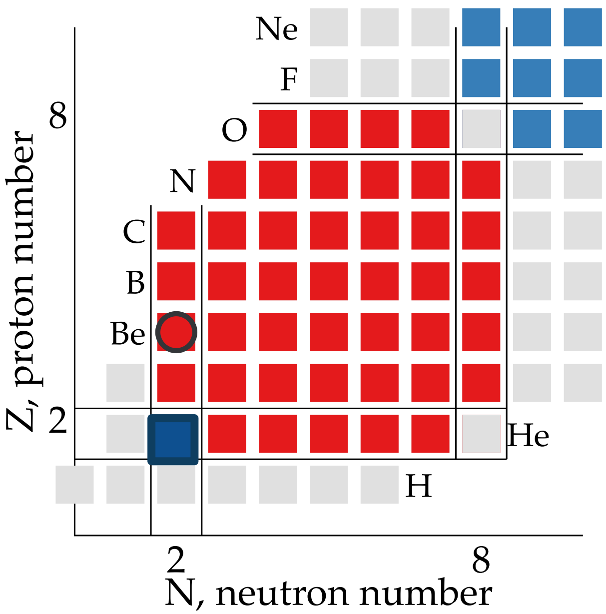


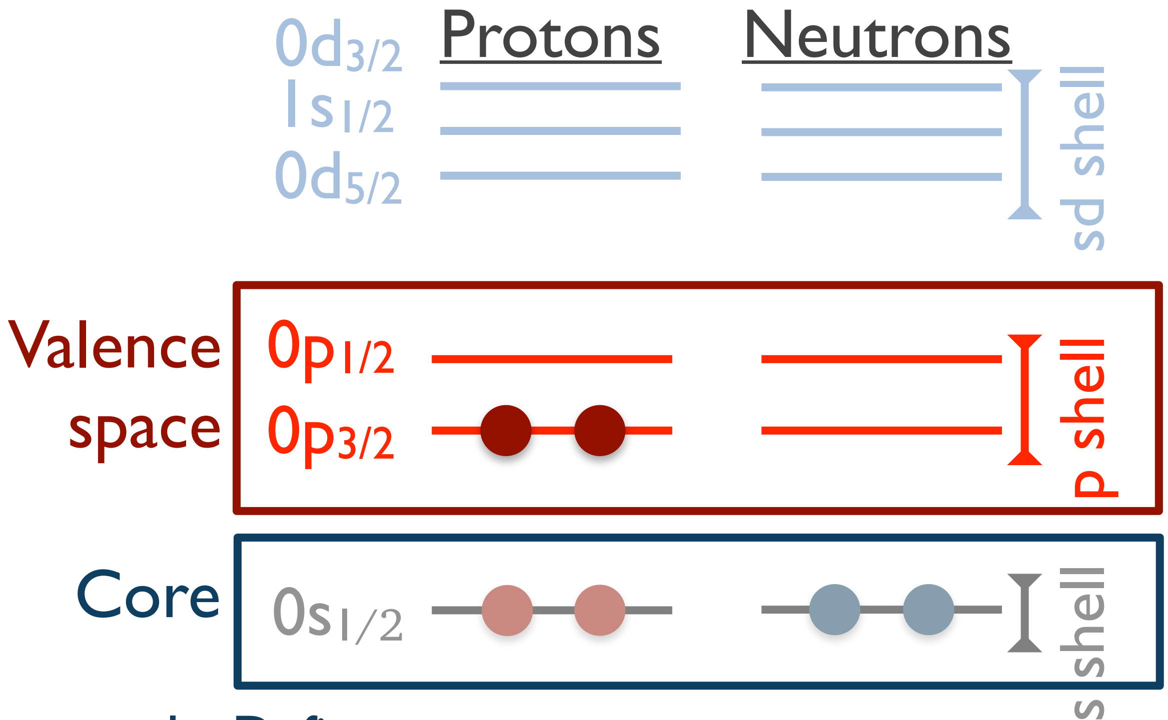
1. Define **core**
2. Define **valence space**
3. Use **effective Hamiltonian** in valence space
4. Generate **many-body basis** for system
5. Diagonalise **effective Hamiltonian matrix**

$$\hat{H} = \sum_{p} \epsilon_p a_p^\dagger a_p + \frac{1}{2} \sum_{pqrs} v_{pqrs} a_p^\dagger a_q^\dagger a_s a_p$$

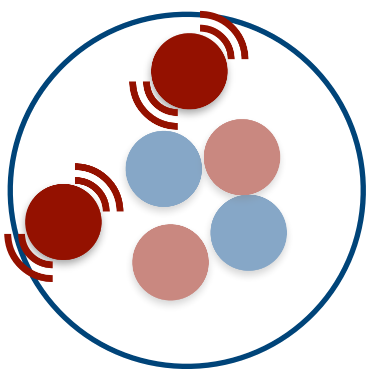
Caurier, **Martínez-Pinedo**, **Poves** et al
Rev. Mod. Phys. **77** 427 (2005)

Shell model





^{6}Be



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Caurier, **Martínez-Pinedo, Poves** et al
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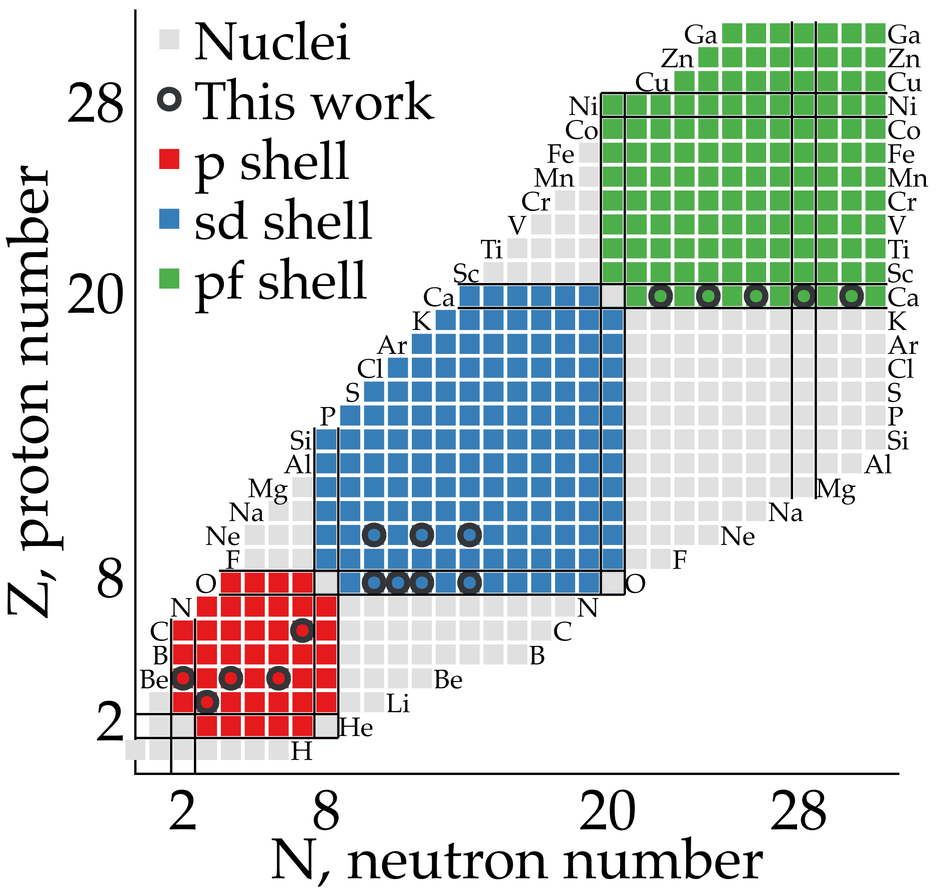
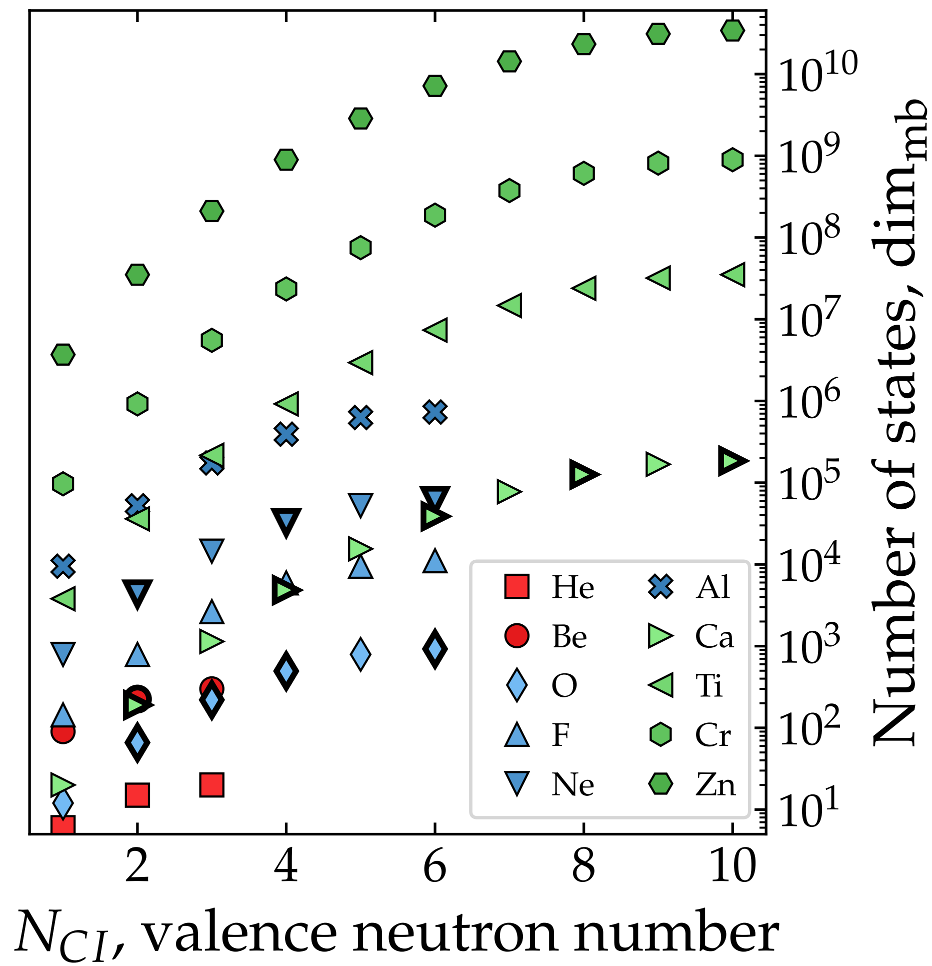
Shell model complexity

$$\hat{H} = \sum_{p} \epsilon_p a_p^\dagger a_p + \frac{1}{2} \sum_{pqrs} v_{pqrs} a_p^\dagger a_q^\dagger a_s a_p$$





Scientific Reports **13**, 12291 (2023)

What is quantum computing?

Classical Computer

0100011010
1010100100

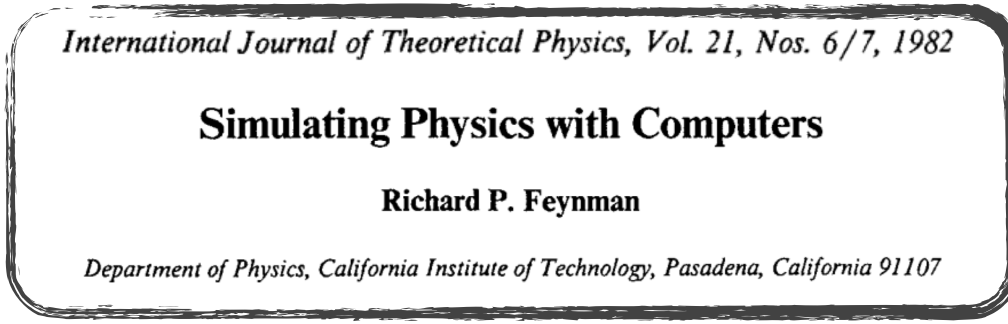
- Works with **bits**
- Bits are either 1 or 0

Quantum Computer

$$|0\rangle, |1\rangle,$$
$$c_0|0\rangle + c_1|1\rangle$$

- Works with **qubits**
- A **qubit** can be **superposition** of 1 or 0
- Many-qubits: **entanglement**, **interference**, etc

Quantum simulators



International Journal of Theoretical Physics, Vol. 21, Nos. 6/7, 1982

Simulating Physics with Computers

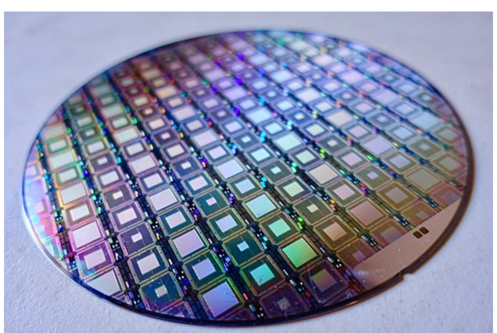
Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

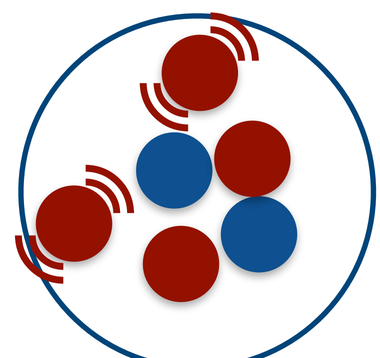
Idea

Use a **quantum computer** (controllable quantum device) to simulate the behaviour of another quantum system

Controllable quantum device

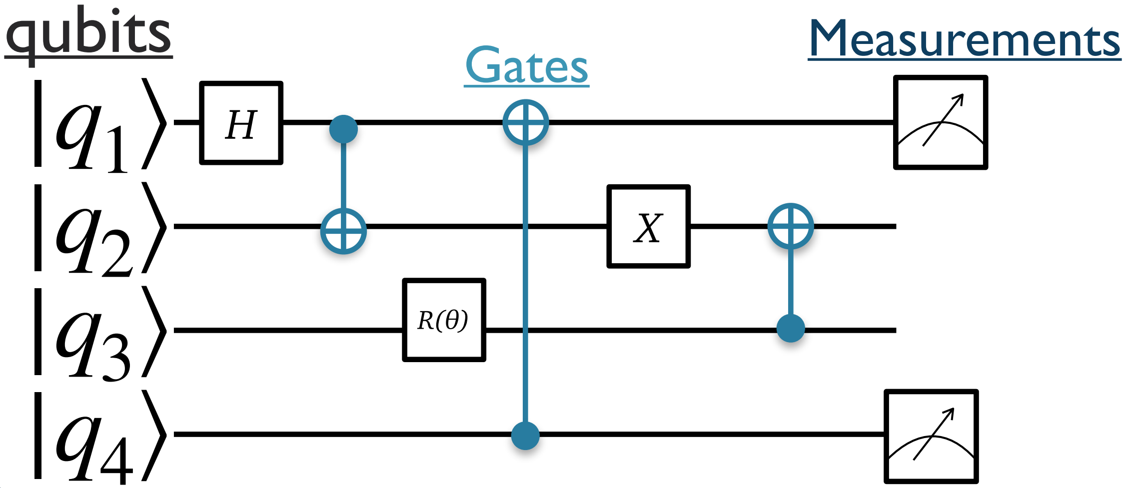


Quantum system



Quantum paradigms

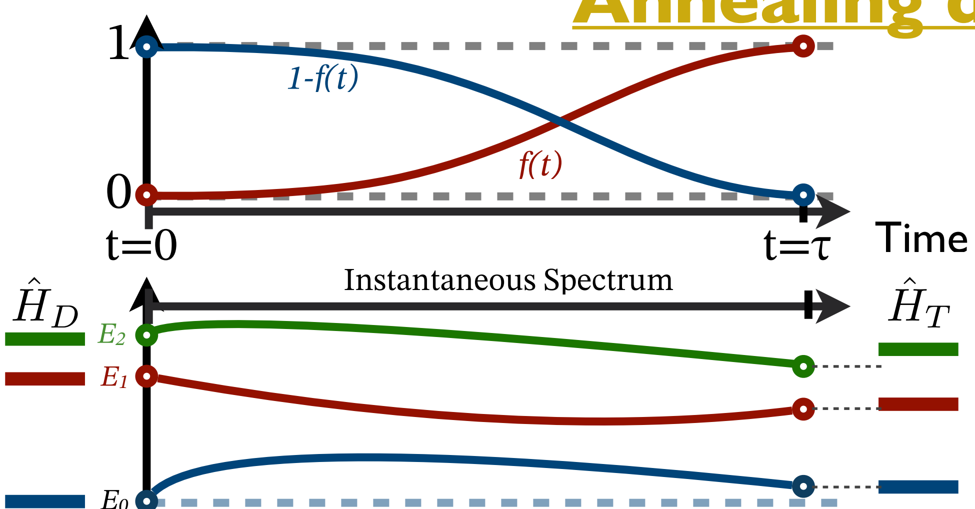
Digital quantum computers



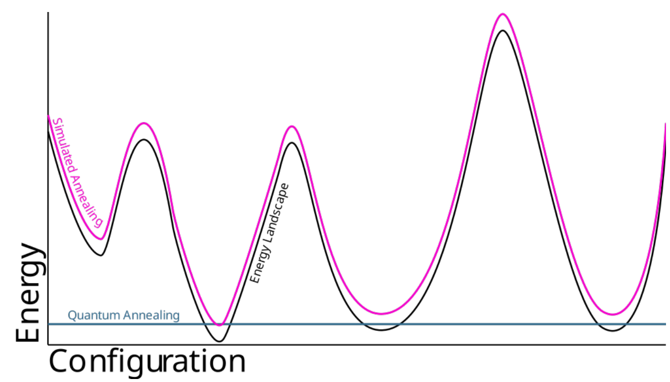
Lacroix *et al*, EPJA **59** 227 (2023)

Scientific Reports **13**, 12291 (2023)

Annealing devices



D:wave

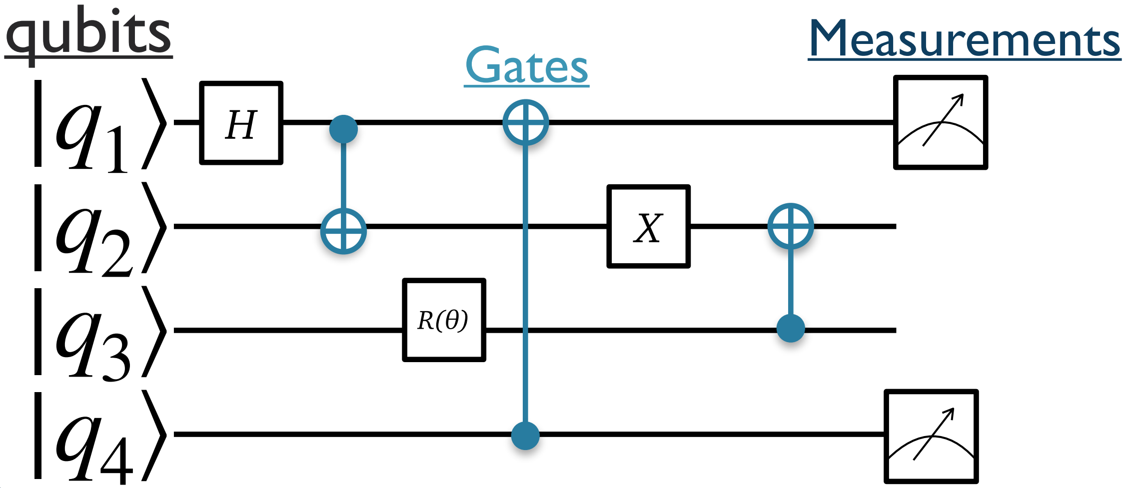


SciPost Physics 19 062 (2025)

Phys Lett B **872** 140042 (2025)

Quantum paradigms

Digital quantum computers



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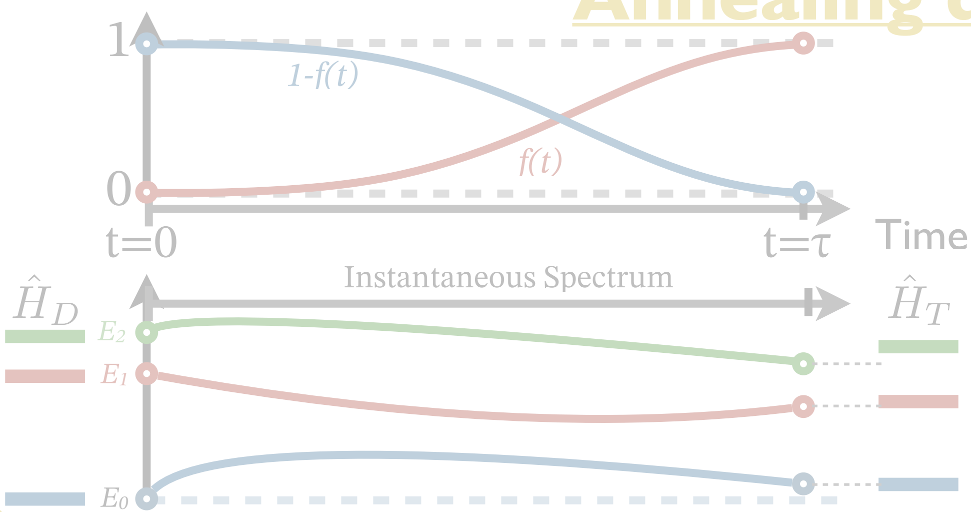

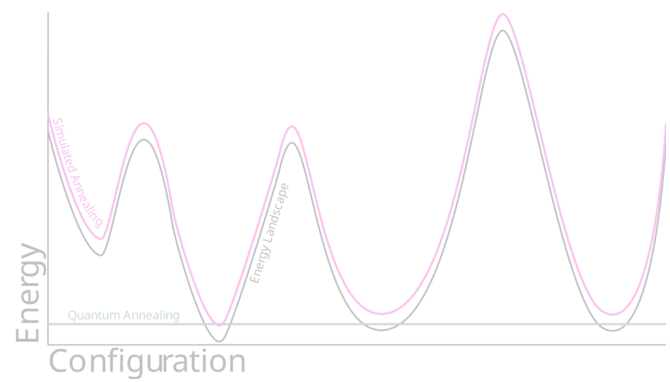

SciPost Physics 19 062 (2025)

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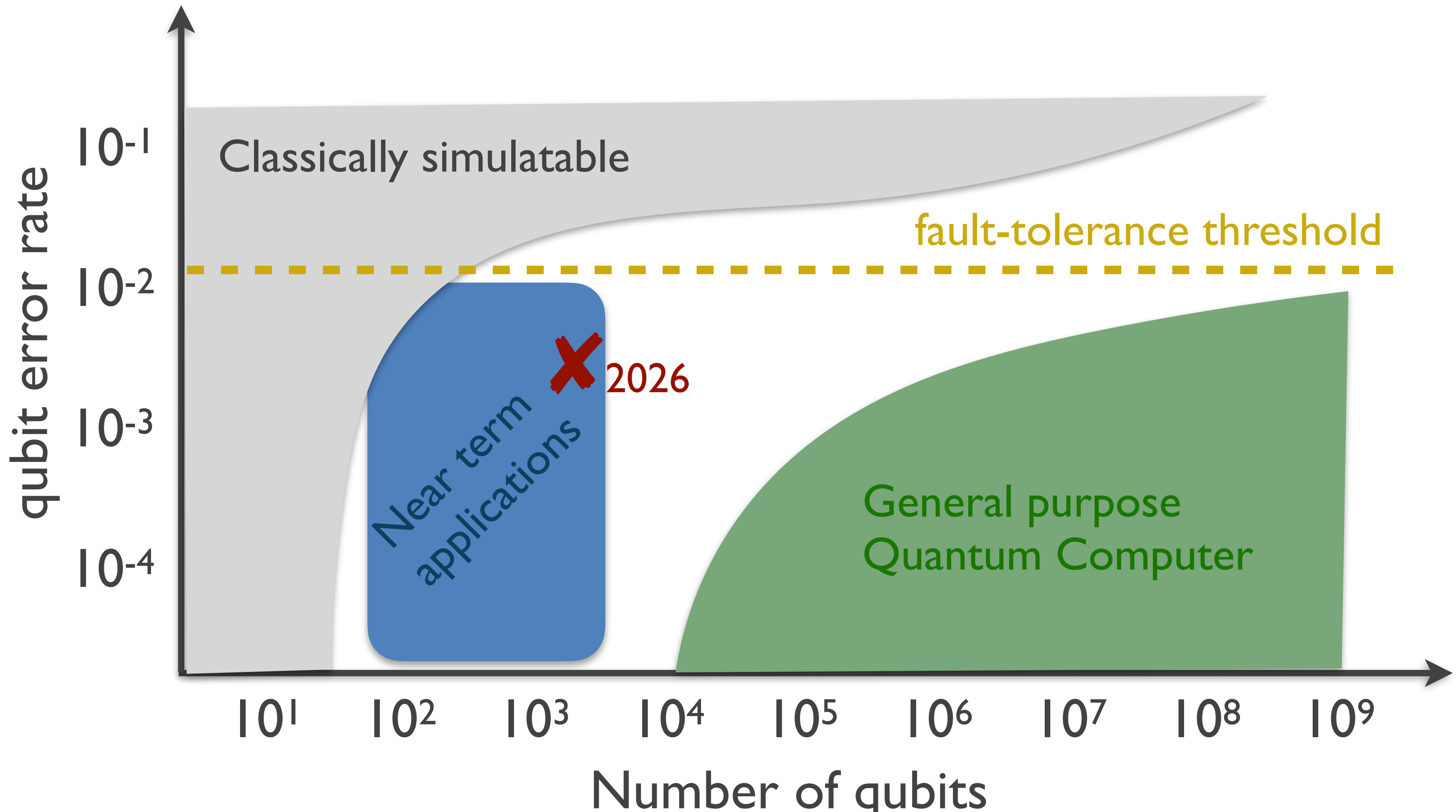
Near-Intermediate Scale Quantum Tech

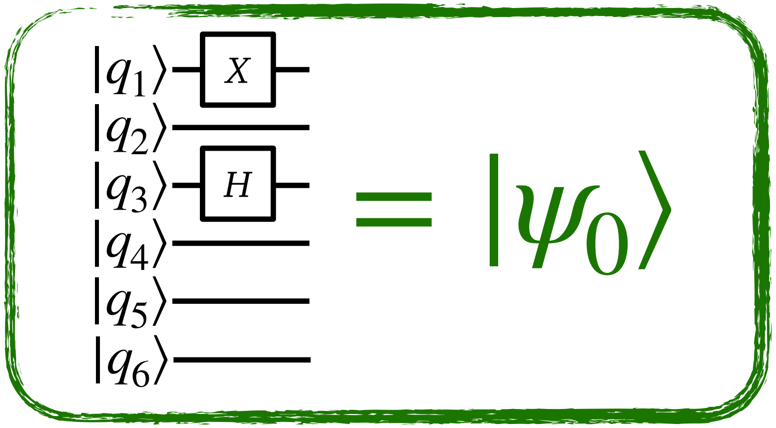


IBM Condor: 1100 qubits (2023)

Preskill, Quantum **2** 79 (2018)

Outline

- Quantum algorithms



- **Variational approach**

Scientific Reports **13**, 12291 (2023)
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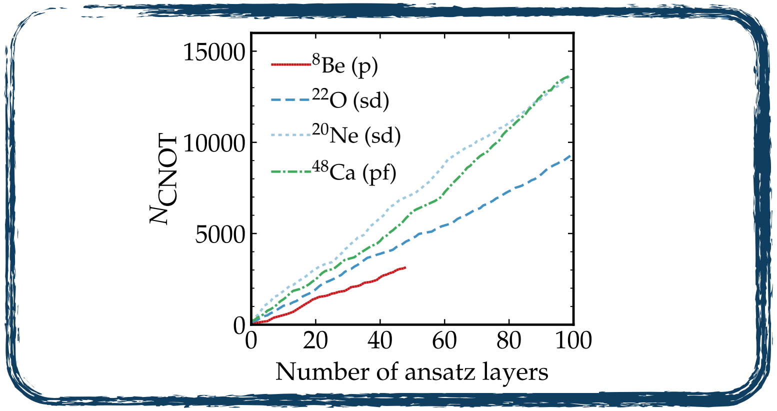

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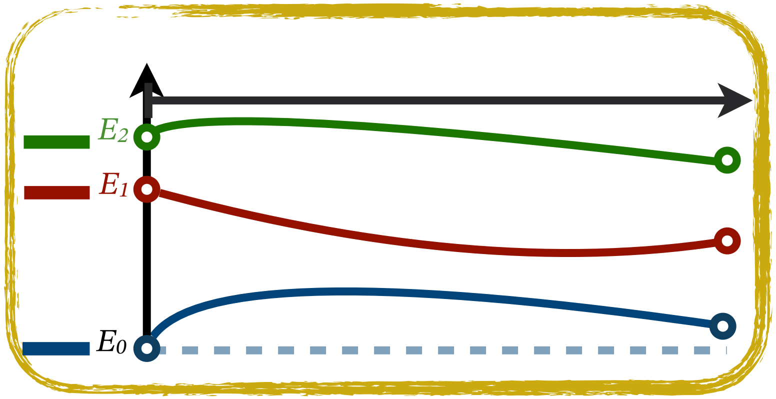
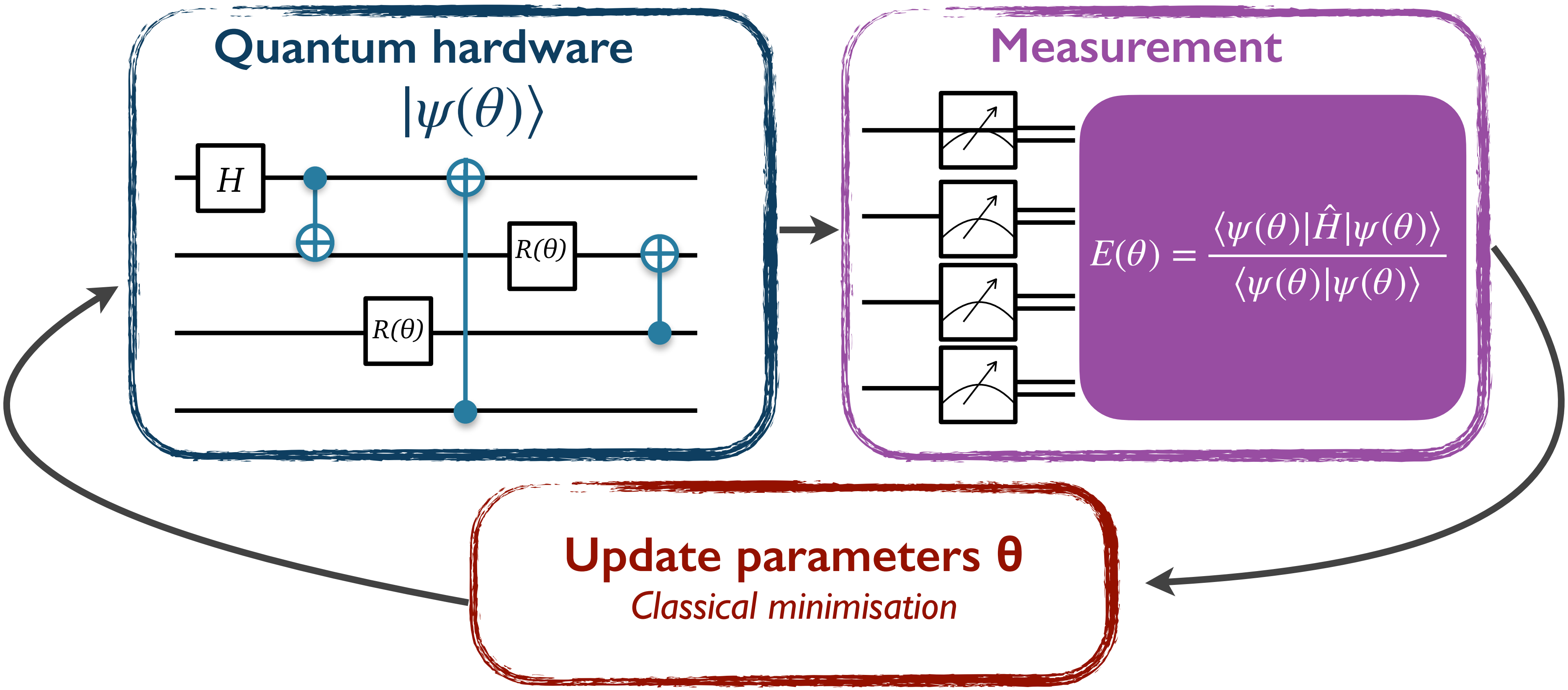
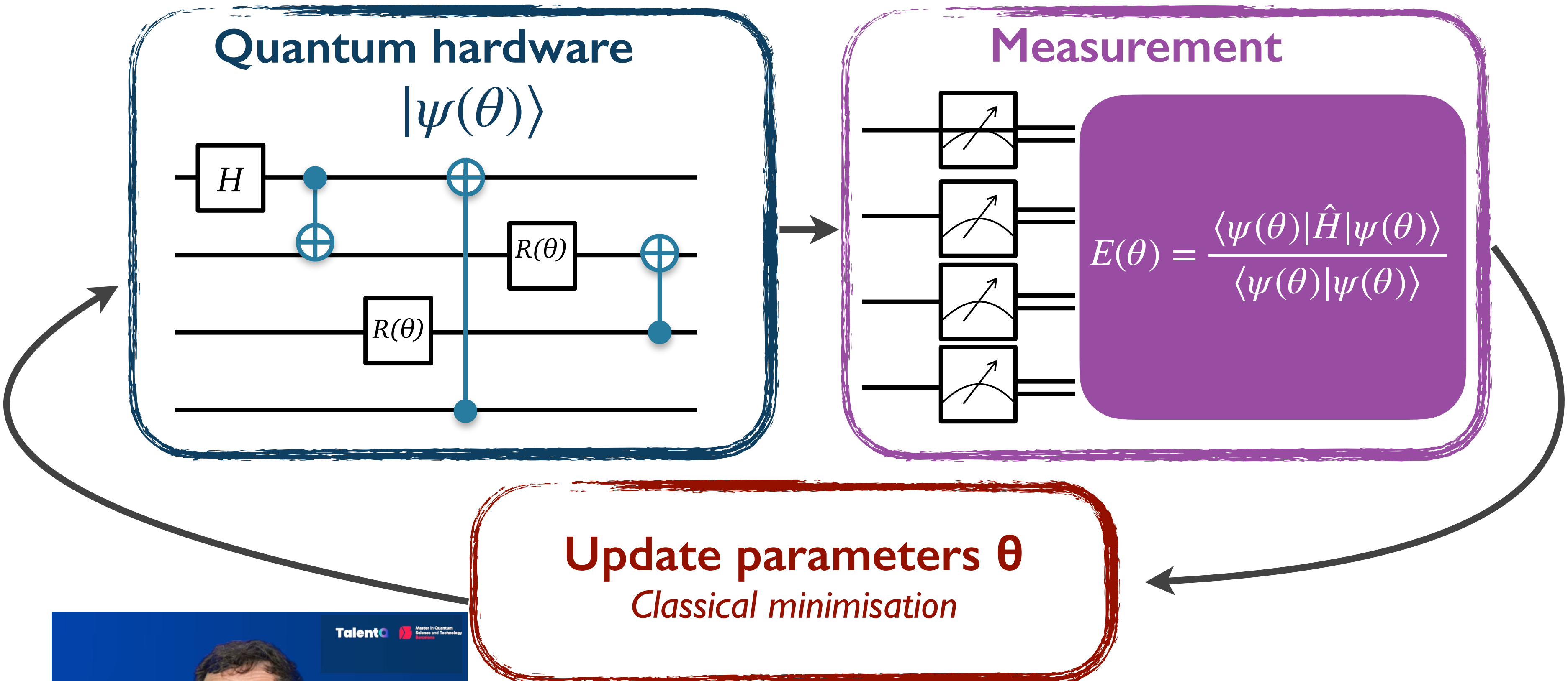


Variational Quantum Eigensolver

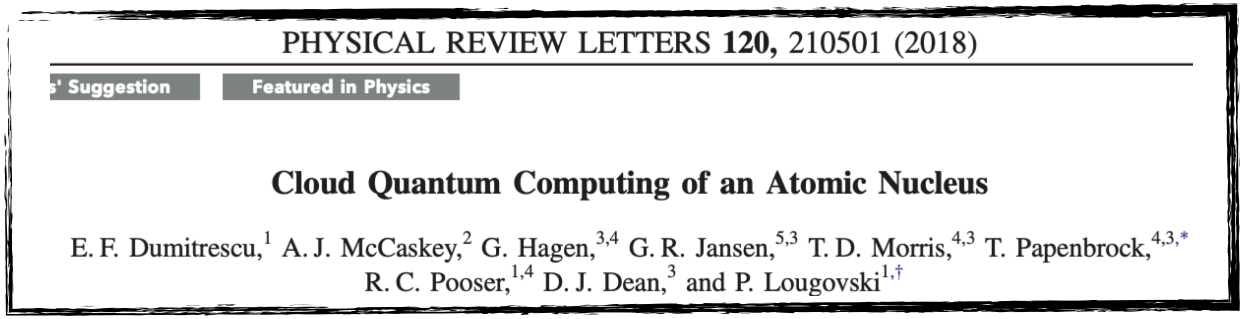


Variational Quantum Eigensolver



VQE: Variational Quantum Eigensolver, Arnau Rios@Quantum Spain
https://www.youtube.com/watch?v=lgqiDfpGg90

VQEs in nuclear structure

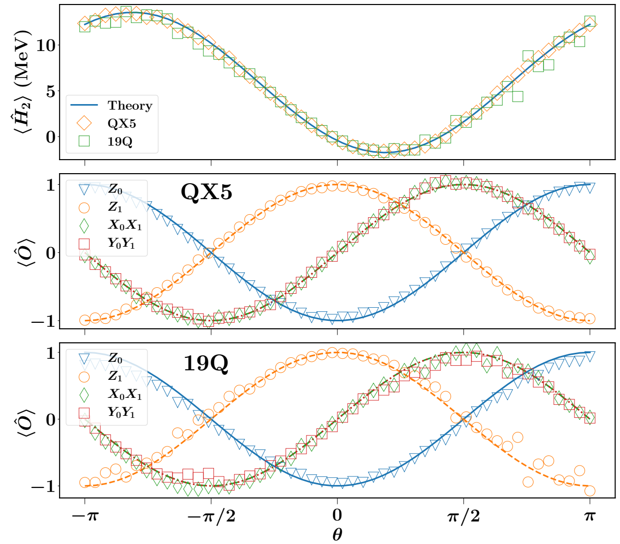

PHYSICAL REVIEW LETTERS **120,** 210501 (2018)

s' Suggestion | Featured in Physics

Cloud Quantum Computing of an Atomic Nucleus

E. F. Dumitrescu,[1] A. J. McCaskey,[2] G. Hagen,[3,4] G. R. Jansen,[5,3] T. D. Morris,[4,3] T. Papenbrock,[4,3,*] R. C. Pooser,[1,4] D. J. Dean,[3] and P. Lougovski[1,†]

Phys. Rev. Lett. **120** 210501 (2018)



- **Initial work on nuclear structure (<2023)**
  - Limited to **one minimisation strategy** (UCC)
  - Only a handful of isotopes (^{2}H, ^{6}Li, ^{8}Be, $^{20-20}$O, ^{20}Ne)

Stetcu, Baroni, Carlson, Phys. Rev. C **105** 064308 (2022)
Kiss, Papenbrock *et al* Phys. Rev. C **106** 034325 (2022)
Lacroix *et al*, *Quantum computing with and for many-body physics*, EPJA **59** 227 (2023)

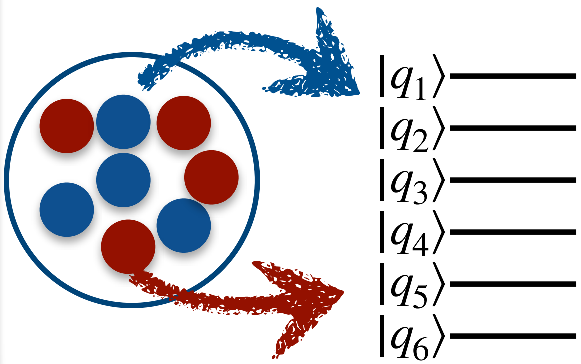
- **Consolidation phase (>2023)**
  - Methods: physics or hardware-inspired, UCC, ADAPT, GCM-like
  - Isotope reach extended: Ca, ^{58}Ni / ^{142}Ce@Surrey

Pérez-Obiol *et al.*, Scientific Reports **13** 12291 (2023)
Sarma, di Matteo et al, Phys Rev C **108** 064305 (2023)
Bhoy & Stevenson, New J Phys **26** 075001 (2024)

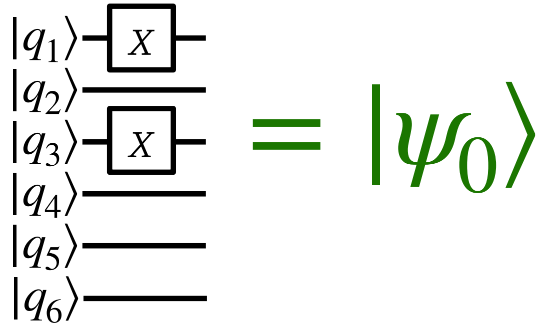
S. Yoshida *et al.*, Phys Rev C **109** 064305 (2024)
Singh, Siwach & Arumugan, Phys Rev C **112** 034320 (2025)
Gibbs, Stevenson *et al.*, arxiv:2603.11156

Variational Quantum Eigensolver

1.Mapping

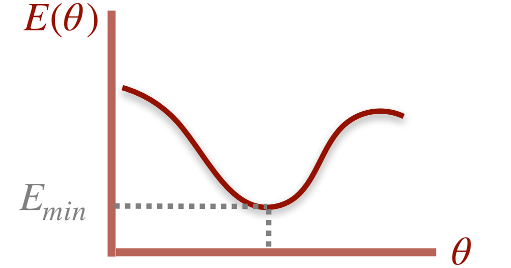


2.Reference state



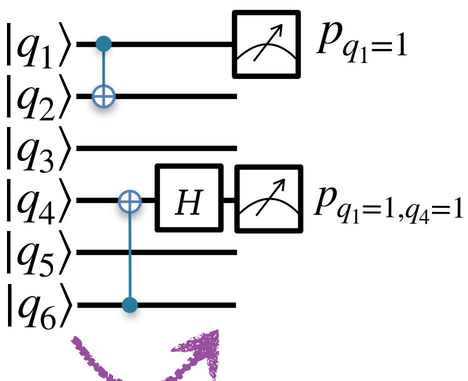
3.Minimisation

$$\min_{\theta} E(\theta) = \frac{\langle\psi_0|\hat{O}(\theta)^\dagger \hat{H}\hat{O}(\theta)|\psi_0\rangle}{\langle\psi_0|\hat{O}(\theta)^\dagger\hat{O}(\theta)|\psi_0\rangle}$$



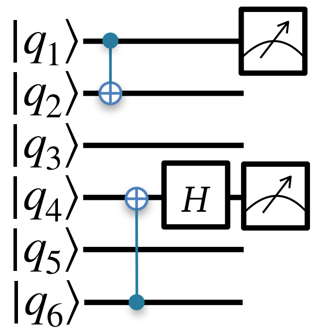
4.Measurement

$$\frac{\langle\psi_0|\hat{O}(\theta)^\dagger \hat{H}\hat{O}(\theta)|\psi_0\rangle}{\langle\psi_0|\hat{O}(\theta)^\dagger\hat{O}(\theta)|\psi_0\rangle} =$$



Repeat N_s shots

5.Error mitigation



J Tilly *et al.* Phys. Reports **986** 1 (2022)

Variational Quantum Eigensolver

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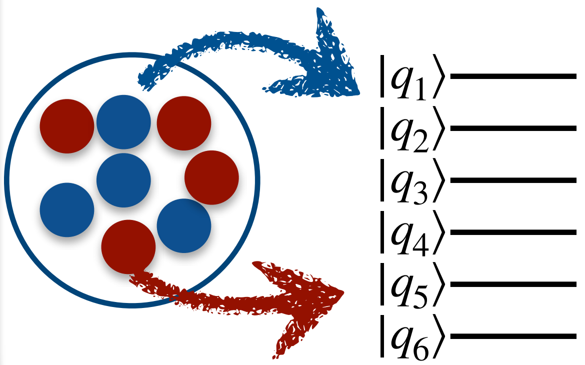

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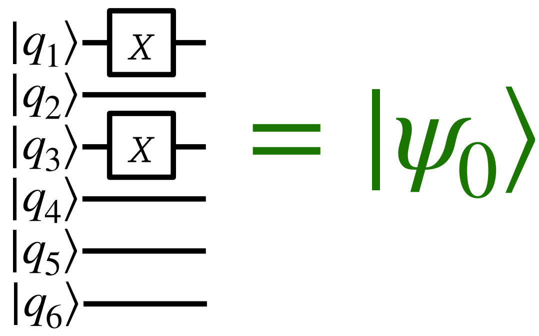

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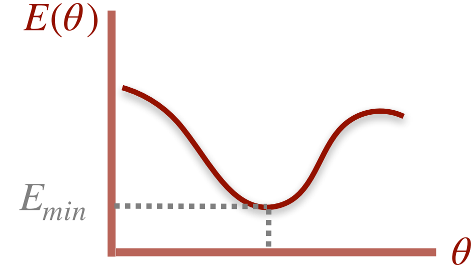

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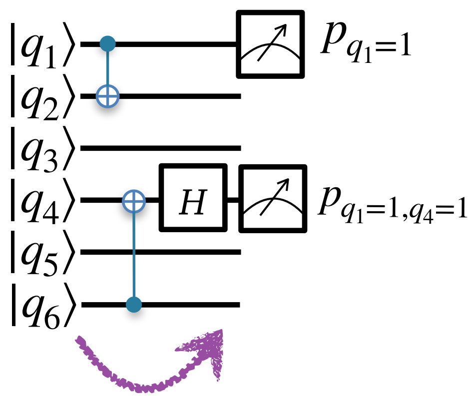

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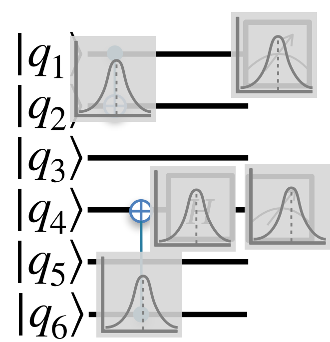
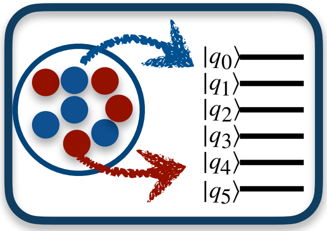
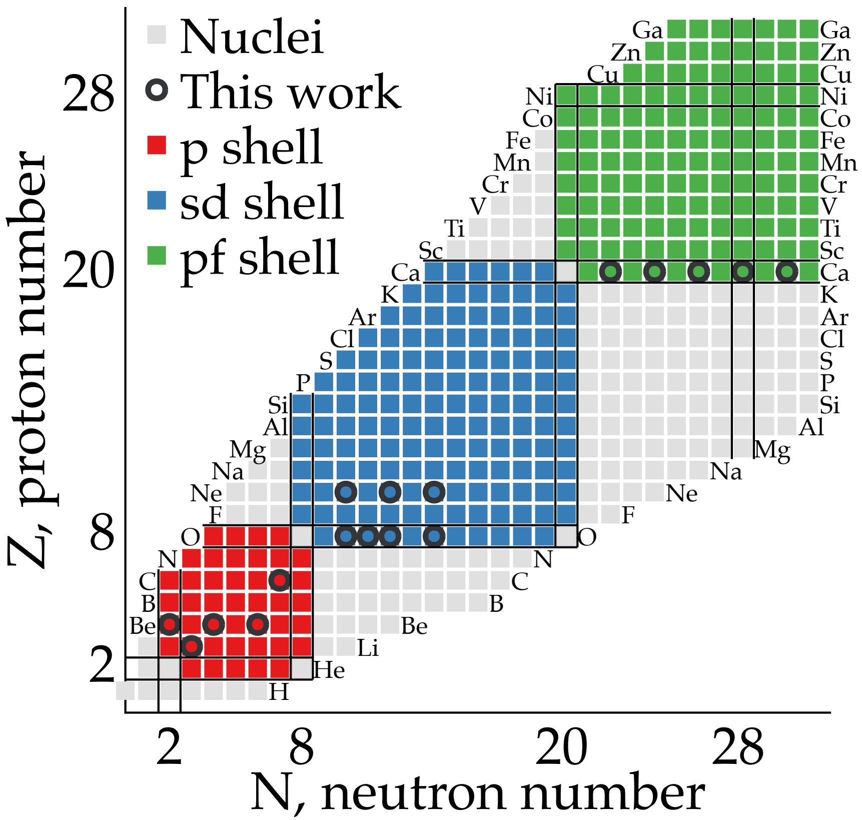


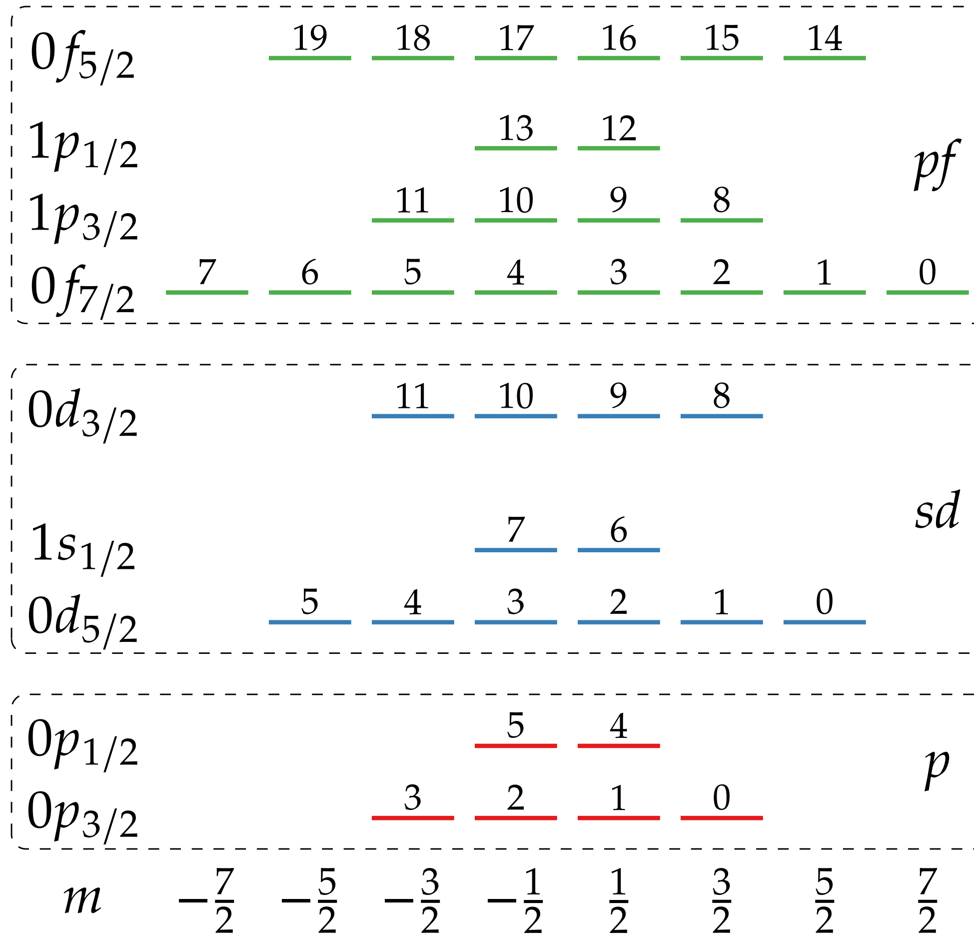
J Tilly *et al.* Phys. Reports **986** 1 (2022)

Jordan-Wigner mapping



$$|0_\alpha\rangle \mapsto n_\alpha = 0 \qquad |1_\alpha\rangle \mapsto n_\alpha = 1$$





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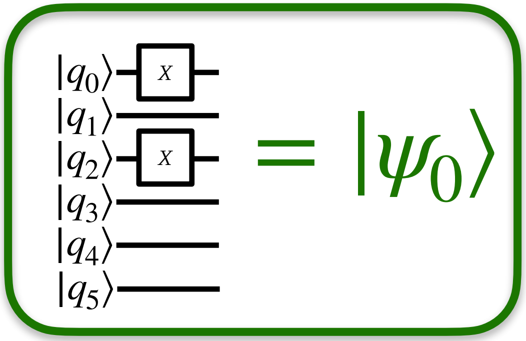
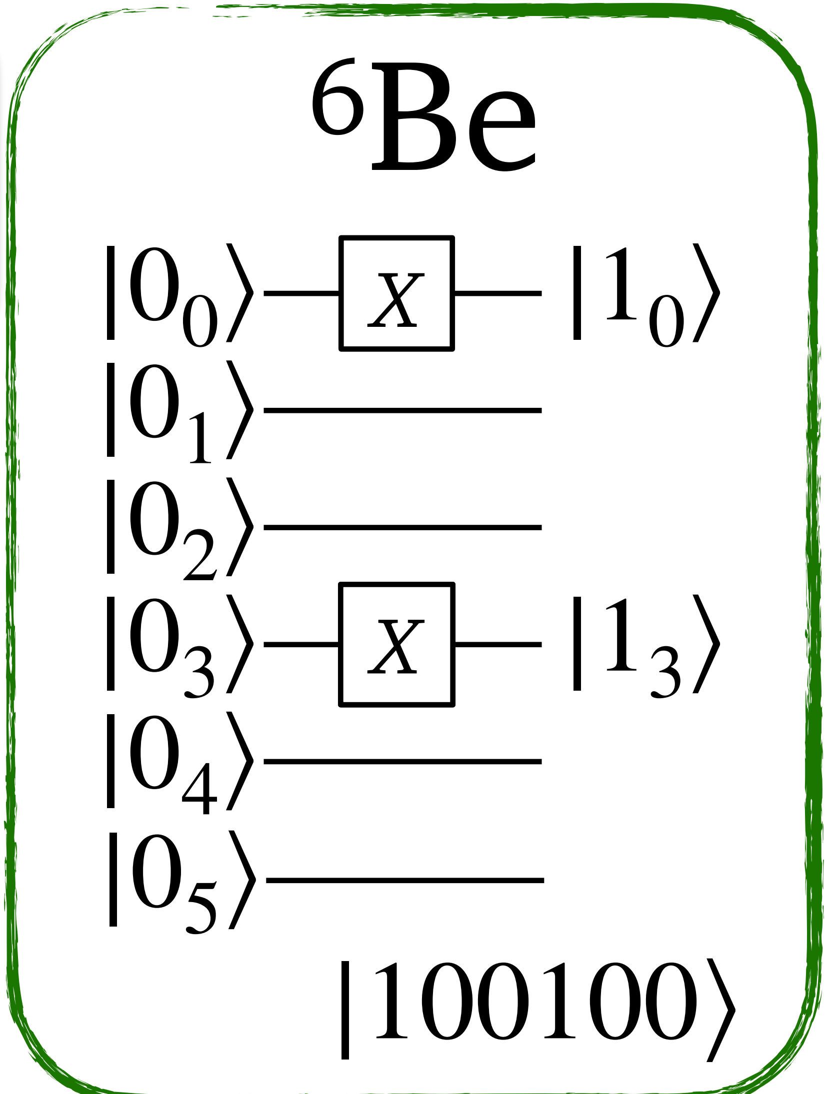
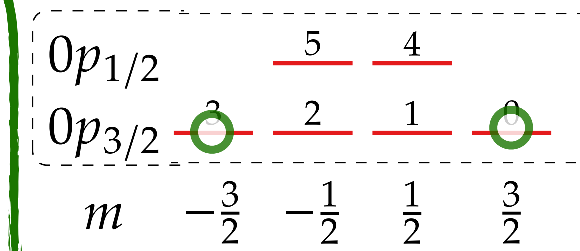
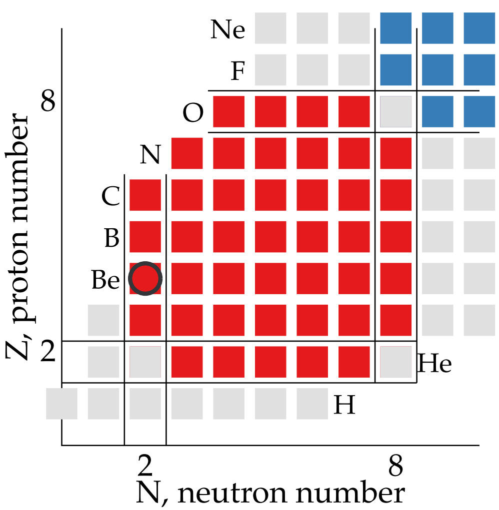


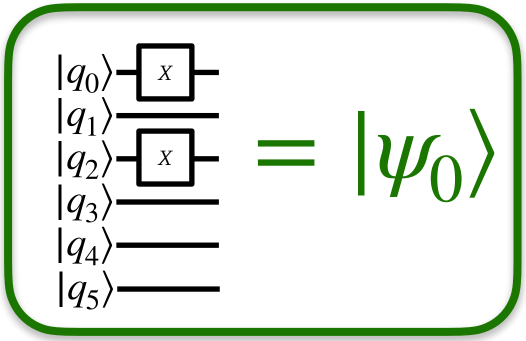


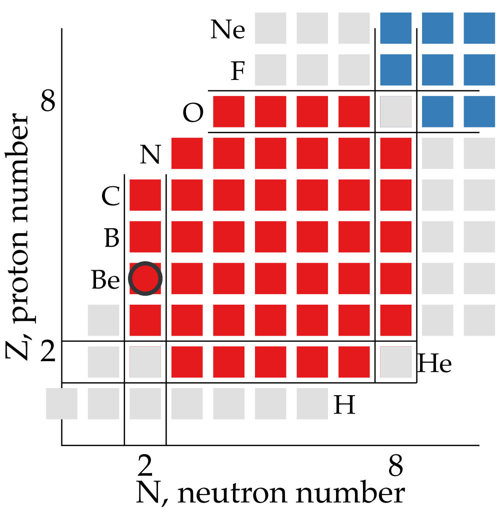


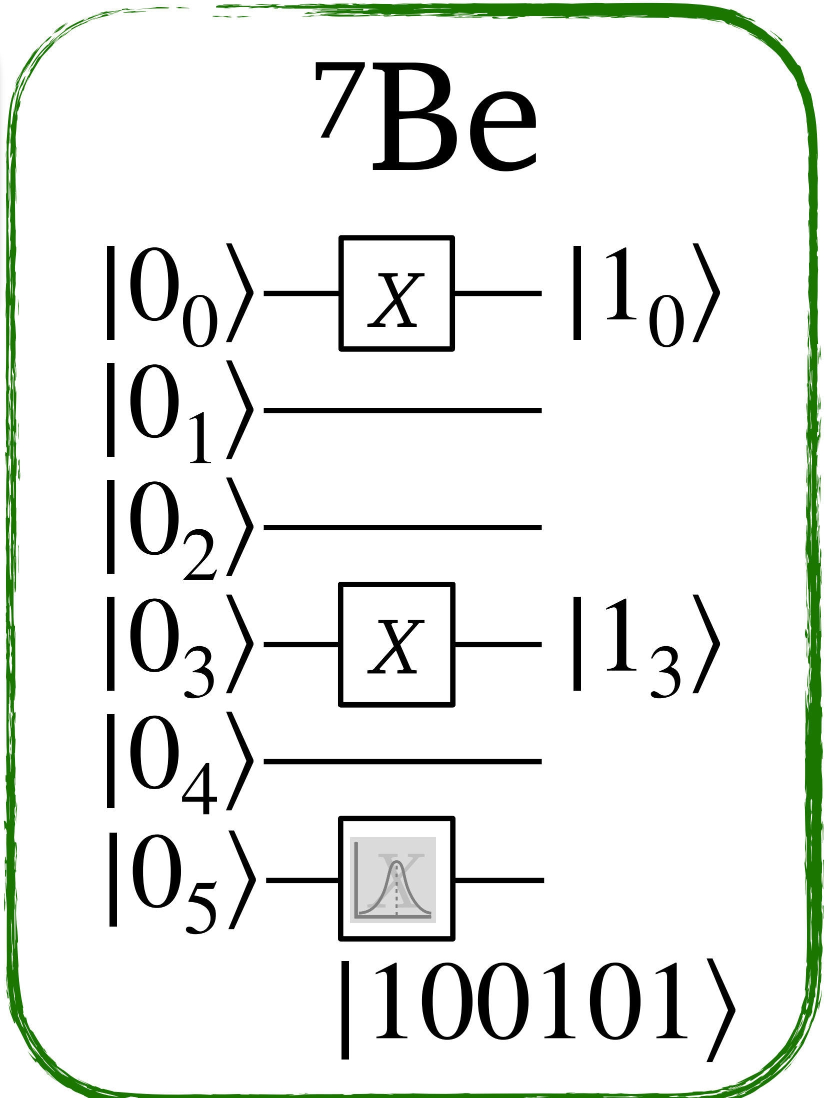


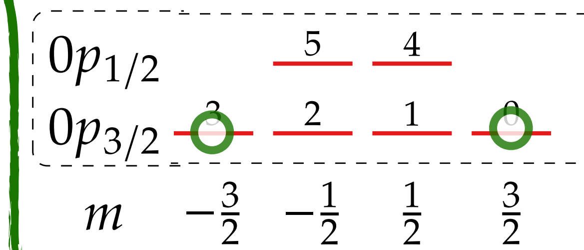
- **Minimum energy** Slater determinant
- Other options: Hartree-Fock state or random (see later)

Reference state









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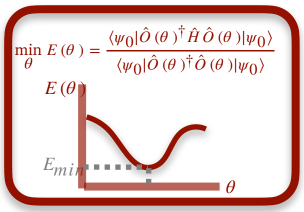


Layer 1

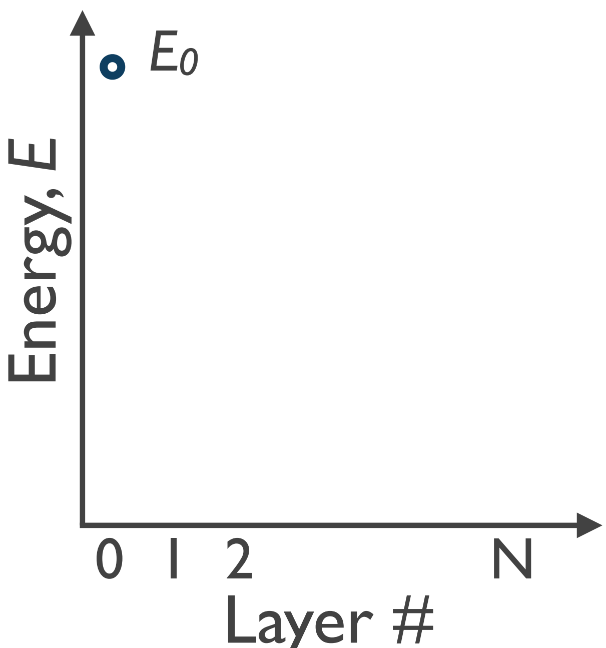
1. Ansatz

$$|\psi_1(\theta_1)\rangle = e^{i\theta_1 \hat{A}_k}|\psi_0\rangle$$

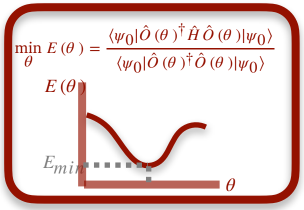
Operator pool

$$\hat{A}_m : i(a_p^\dagger a_q^\dagger a_r a_s - a_r^\dagger a_s^\dagger a_p a_q)$$

Δ operators (respecting symmetry)



Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)



Layer 1

1. Ansatz

$$|\psi_1(\theta_1)\rangle = e^{i\theta_1 \hat{A}_k}|\psi_0\rangle$$

2. Compute gradients

```
for k=1,Δ :
```

$$\left.\frac{\partial E}{\partial \theta_k}\right|_{\theta_k=0} = i\langle\psi(\theta)|[\hat{H}_{\text{eff}}, \hat{A}_k]|\psi(\theta)\rangle\Big|_{\theta_k=0}$$

Operator pool

$$\hat{A}_m : i(a_p^\dagger a_q^\dagger a_r a_s - a_r^\dagger a_s^\dagger a_p a_q)$$

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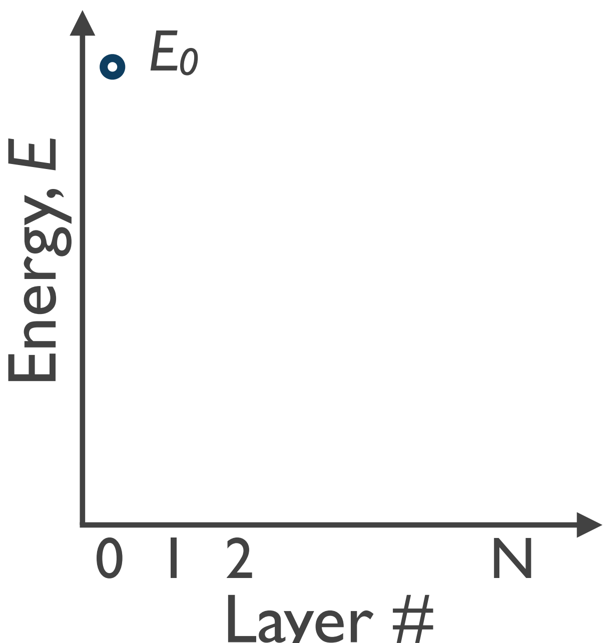
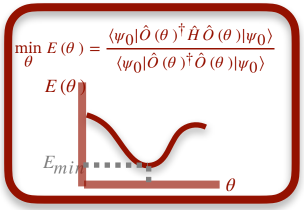


Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)



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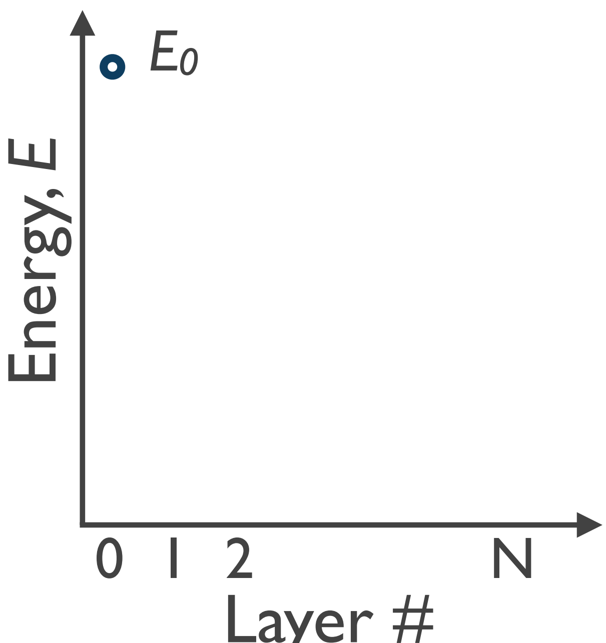

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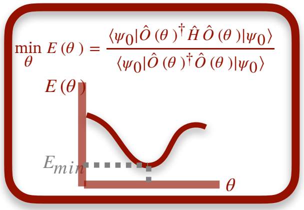
Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)



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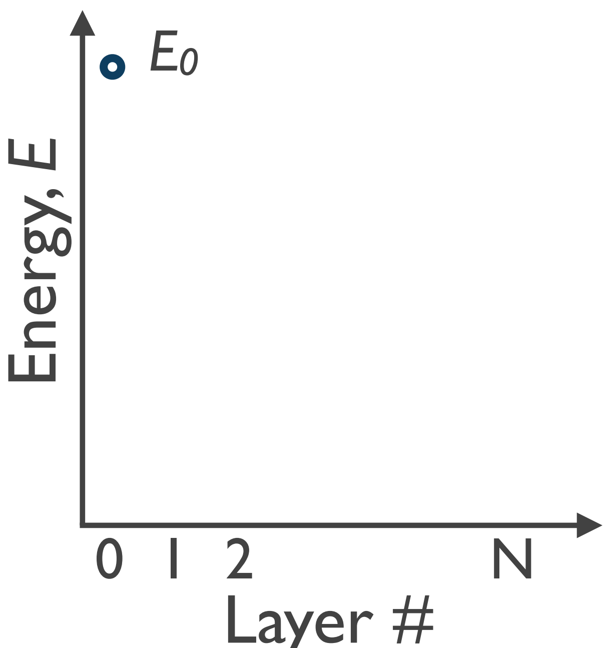

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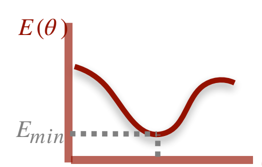
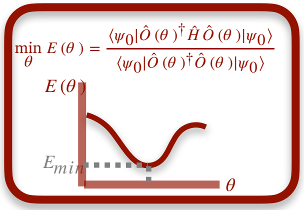


Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)



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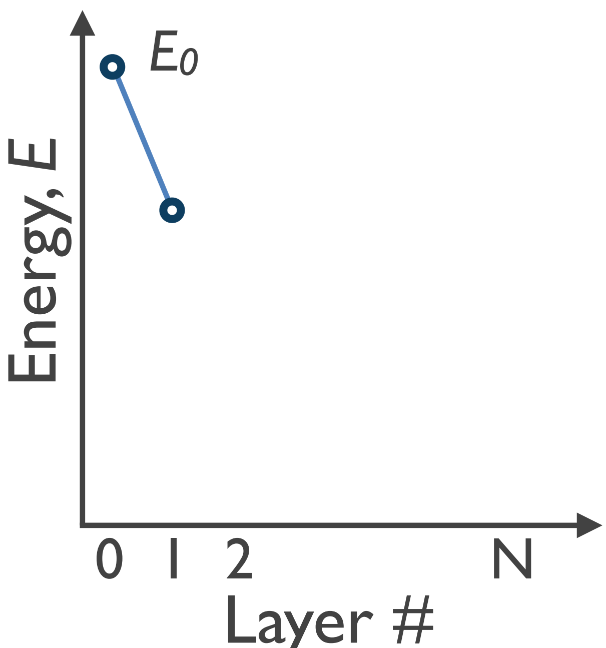

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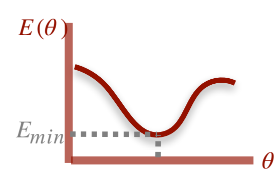
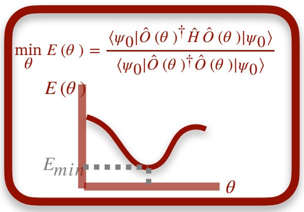


Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)

ADAPT



Layer 2

Operator pool

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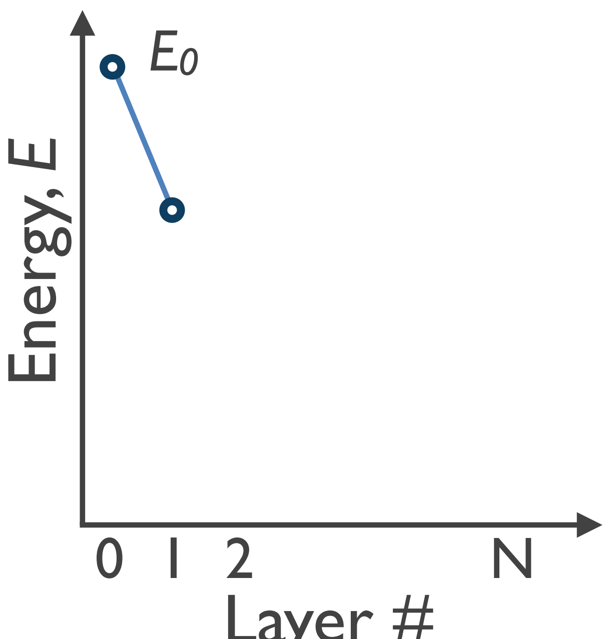
Δ operators (respecting symmetry)



1. Ansatz

$$|\psi_2(\theta_1,\theta_2)\rangle = e^{i\theta_2 \hat{A}_k} e^{i\theta_1 \hat{A}_{k_1}} |\psi_0\rangle$$

2. Compute gradients

```
for k=1,Δ :
```

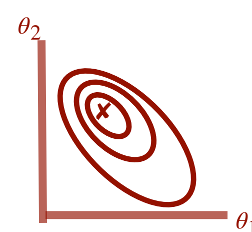
$$\left.\frac{\partial E}{\partial \theta_k}\right|_{\theta_k=0} = i\langle\psi(\theta)|[\hat{H}_{\text{eff}},\hat{A}_k]|\psi(\theta)\rangle\Big|_{\theta_k=0}$$

3. Keep the operator with largest gradient

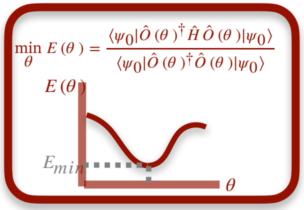
$$|\psi_2(\theta_1,\theta_2)\rangle = e^{i\theta_2 \hat{A}_{k_2}} e^{i\theta_1 \hat{A}_{k_1}} |\psi_0\rangle$$

4. Minimise the energy (classically)

$$\min_{\theta_1,\theta_2} E(\theta_1,\theta_2) = \langle\psi_0|e^{-i\theta_1 \hat{A}_{k_1}} e^{-i\theta_2 \hat{A}_{k_2}} \hat{H} e^{\theta_2 \hat{A}_{k_2}} e^{\theta_2 \hat{A}_{k_2}}|\psi_0\rangle$$



Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)



Layer 2

Operator pool

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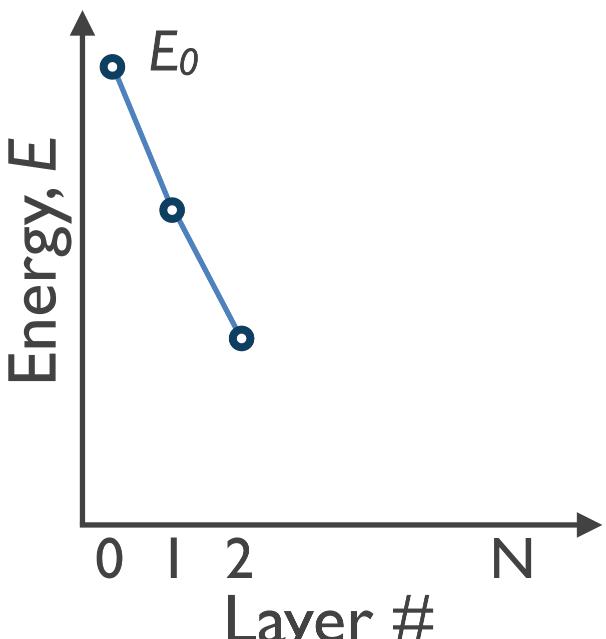

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```
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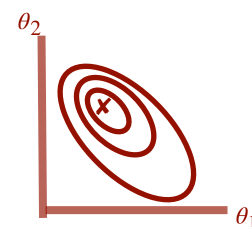
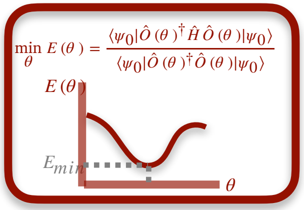


Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)

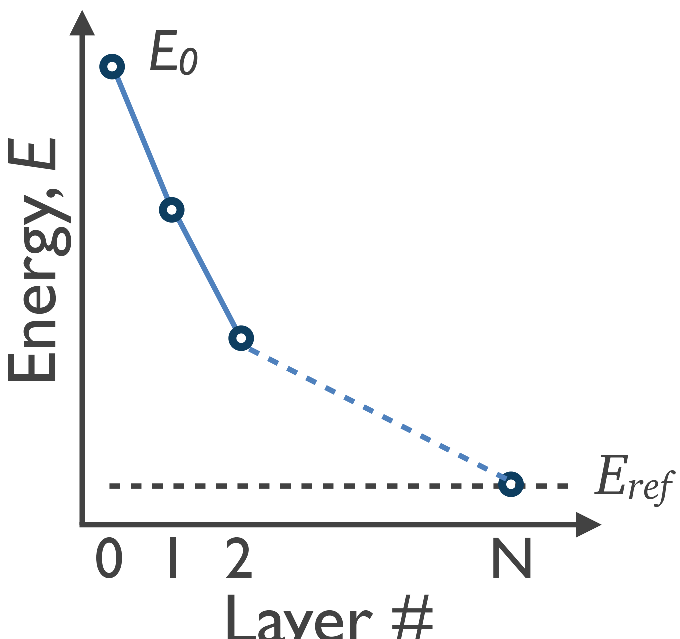


Layer N

Operator pool

$\hat{A}_m : i(a_p^\dagger a_q^\dagger a_r a_s - a_r^\dagger a_s^\dagger a_p a_q)$

Δ operators (respecting symmetry)



1. Ansatz

$$|\psi_N(\vec{\theta})\rangle = \Pi_{l=1}^{N} e^{i\theta_l \hat{A}_l} |\psi_0\rangle$$

2. Compute gradients

```
for k=1,M:
```

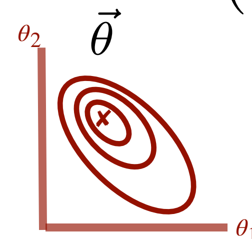
$$\left.\frac{\partial E}{\partial \theta_k}\right|_{\theta_k=0} = i\langle\psi(\theta)|[\hat{H}_{\text{eff}}, \hat{A}_k]|\psi(\theta)\rangle\Big|_{\theta_k=0}$$

3. Keep the operator with largest gradient

$$|\psi_N(\vec{\theta})\rangle = e^{i\theta_M \hat{A}_{k_N}} |\psi_{N-1}(\vec{\theta})\rangle$$

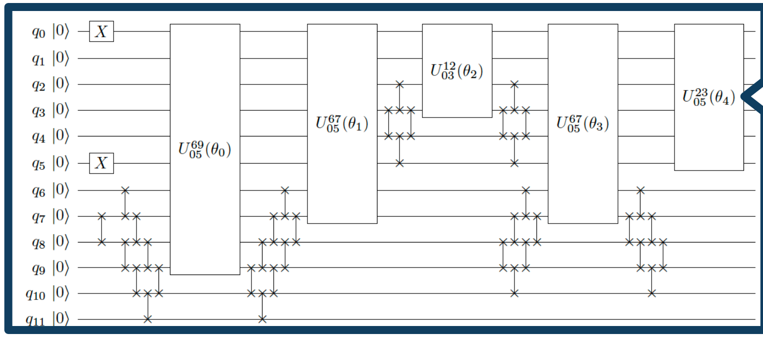
4. Minimise the energy (classically)

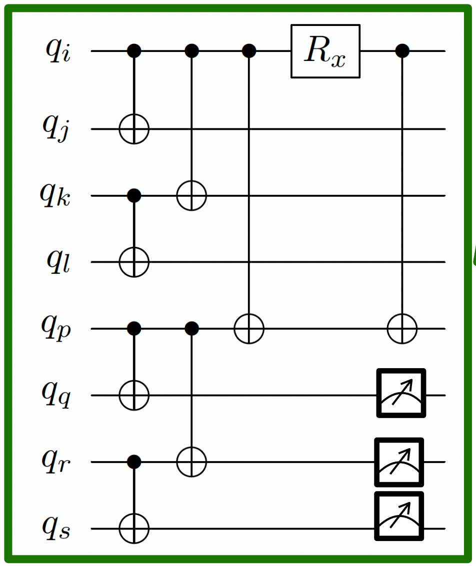
$$\min_{\vec{\theta}} E(\vec{\theta})$$



Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)

ADAPT





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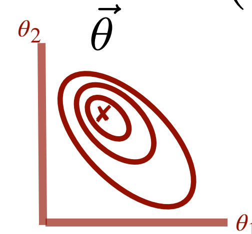
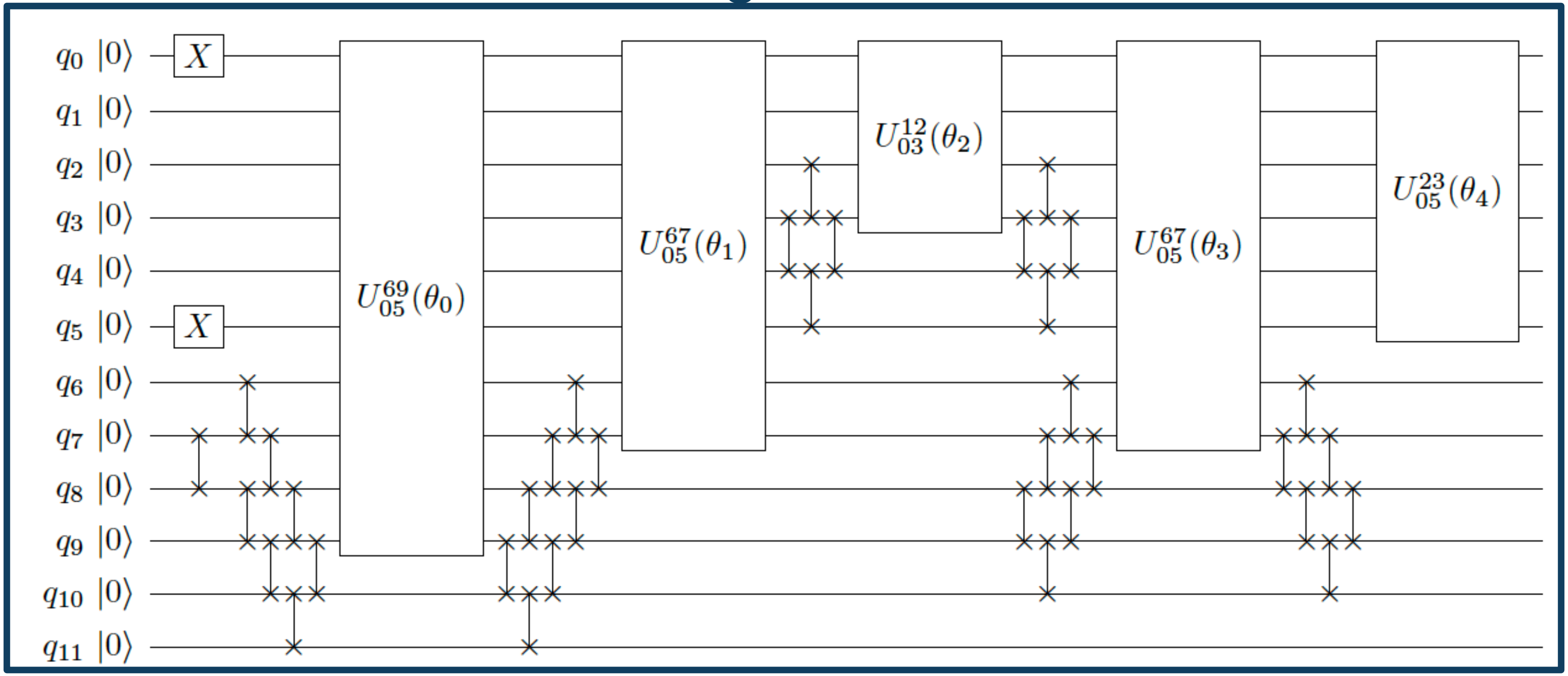



```
scipy.optimize.
minimize
```

Grimsley, Economou, Barnes & Mayhall, Nat Comms **10** 3007 (2019)

ADAPT state circuits

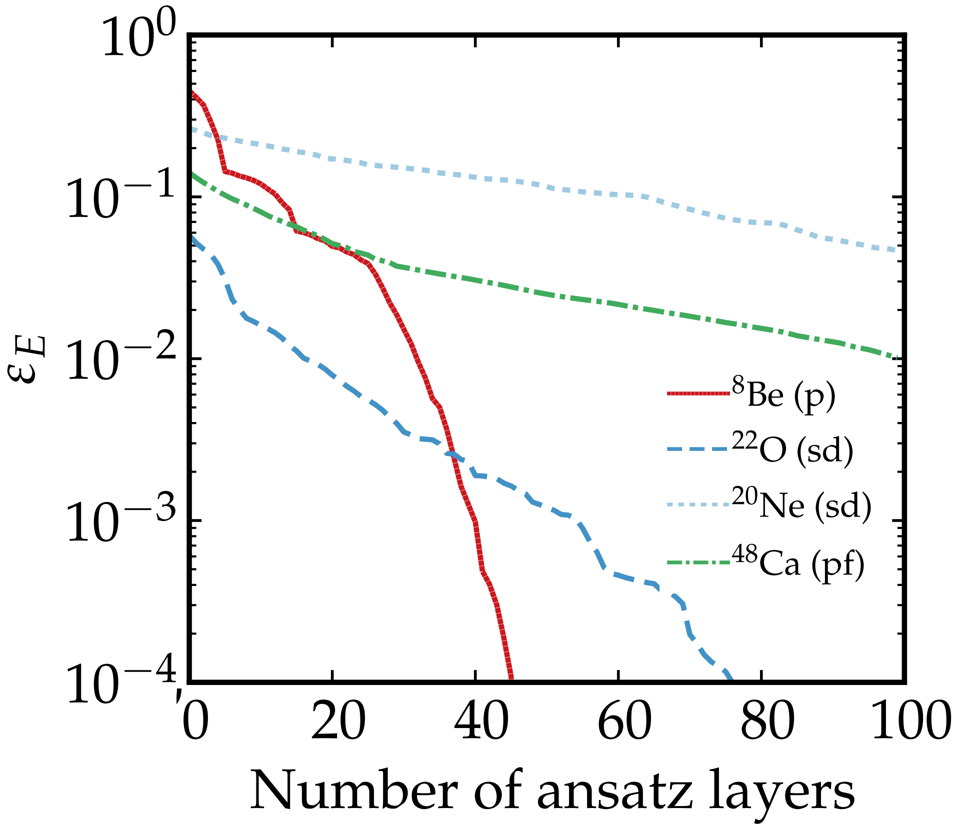
Circuit for the ground state of [18]O

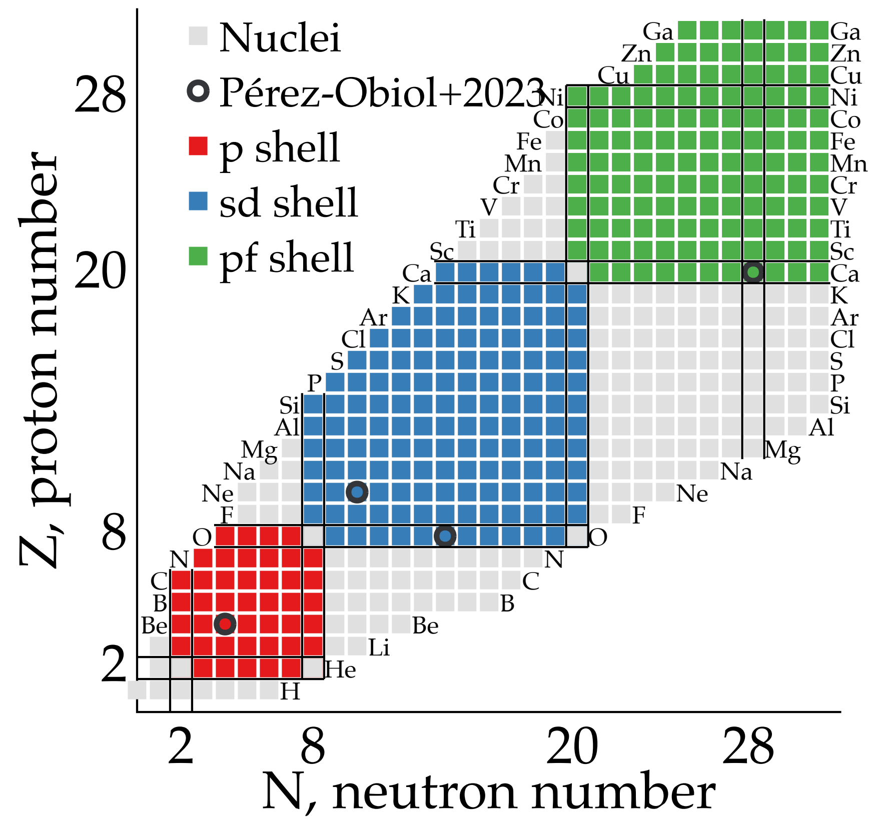


- 10^{-6} in energy with around 100 CNOTS/layer
- FSWAPS so operators act on adjacent qubits

Pérez-Obiol, Romero et al Scientific Reports **13**, 12291 (2023)

Results: resources



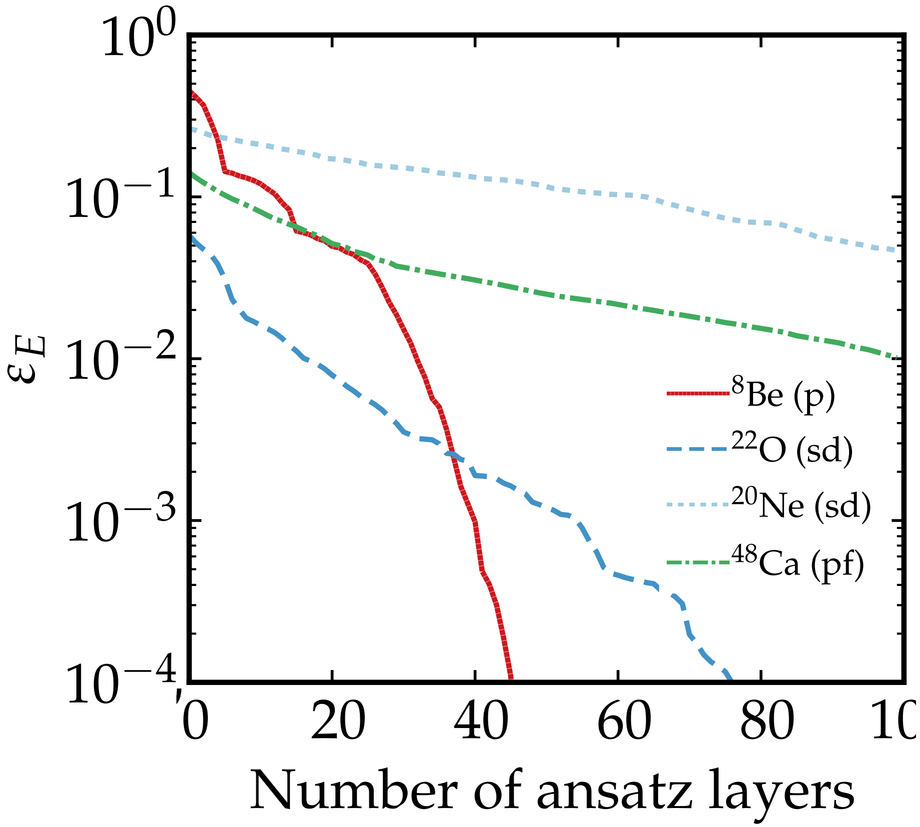


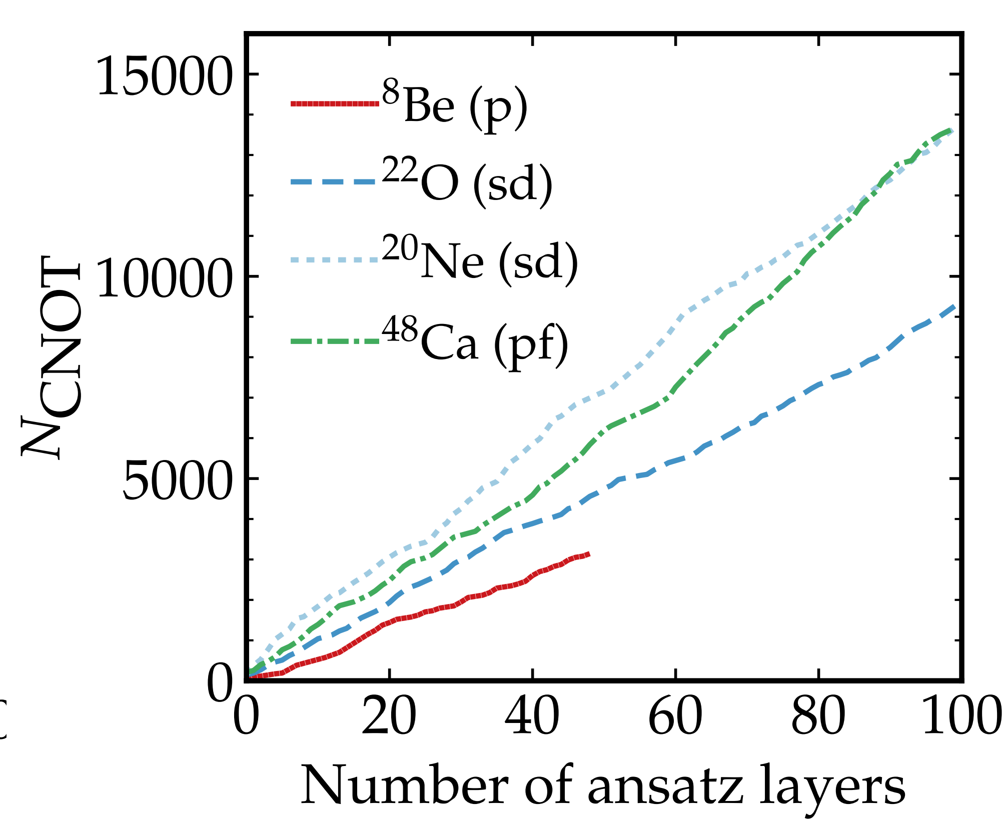
Relative Energy

$$\epsilon_E = \frac{E_{ADAPT} - E_{SM}}{E_{SM}}$$

Pérez-Obiol, Romero et al Scientific Reports **13**, 12291 (2023)

Results: resources





Relative Energy

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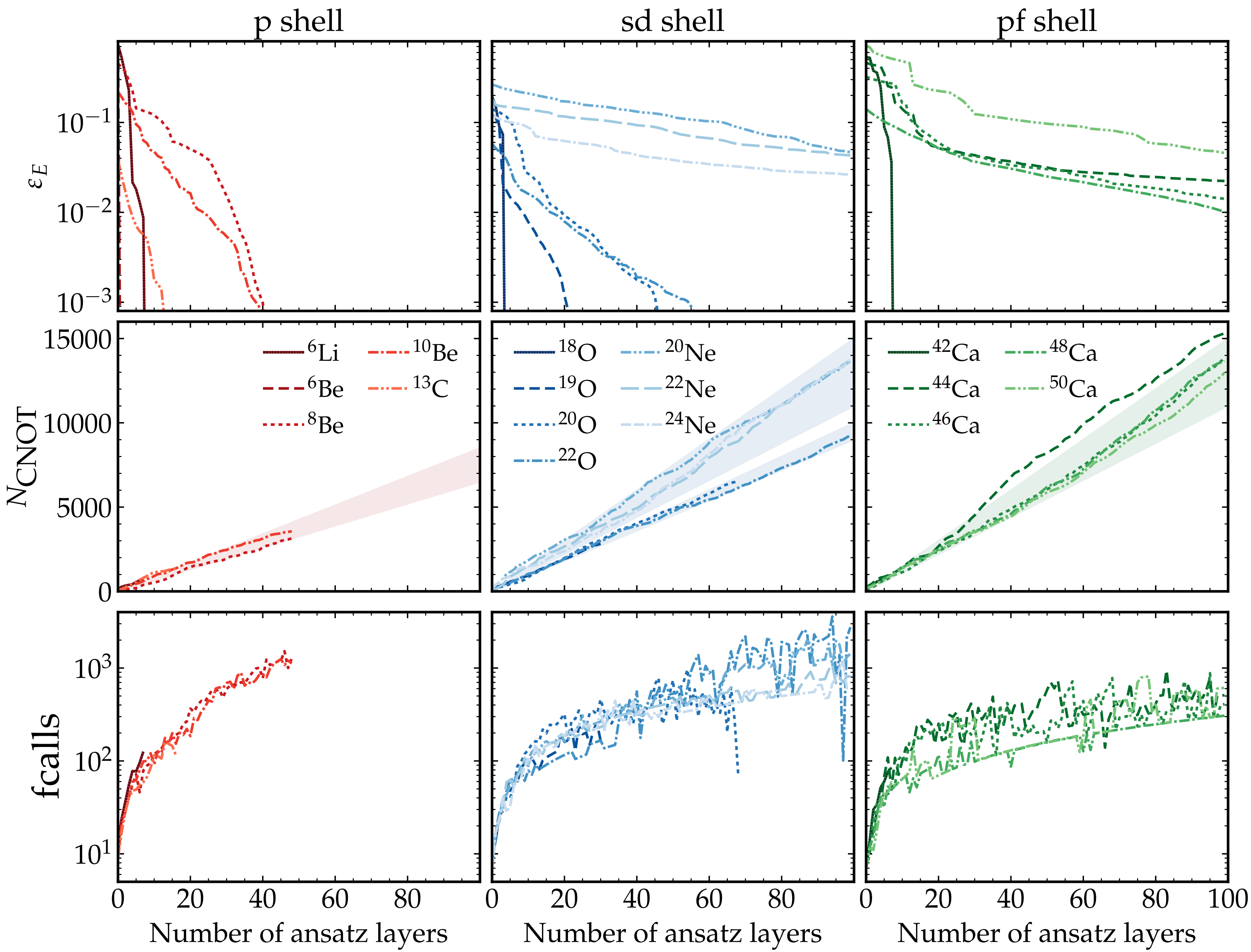
N_{CNOT} is **proxy** for **circuit depth**

But also **quantum complexity**

Pérez-Obiol, Romero et al Scientific Reports **13**, 12291 (2023)

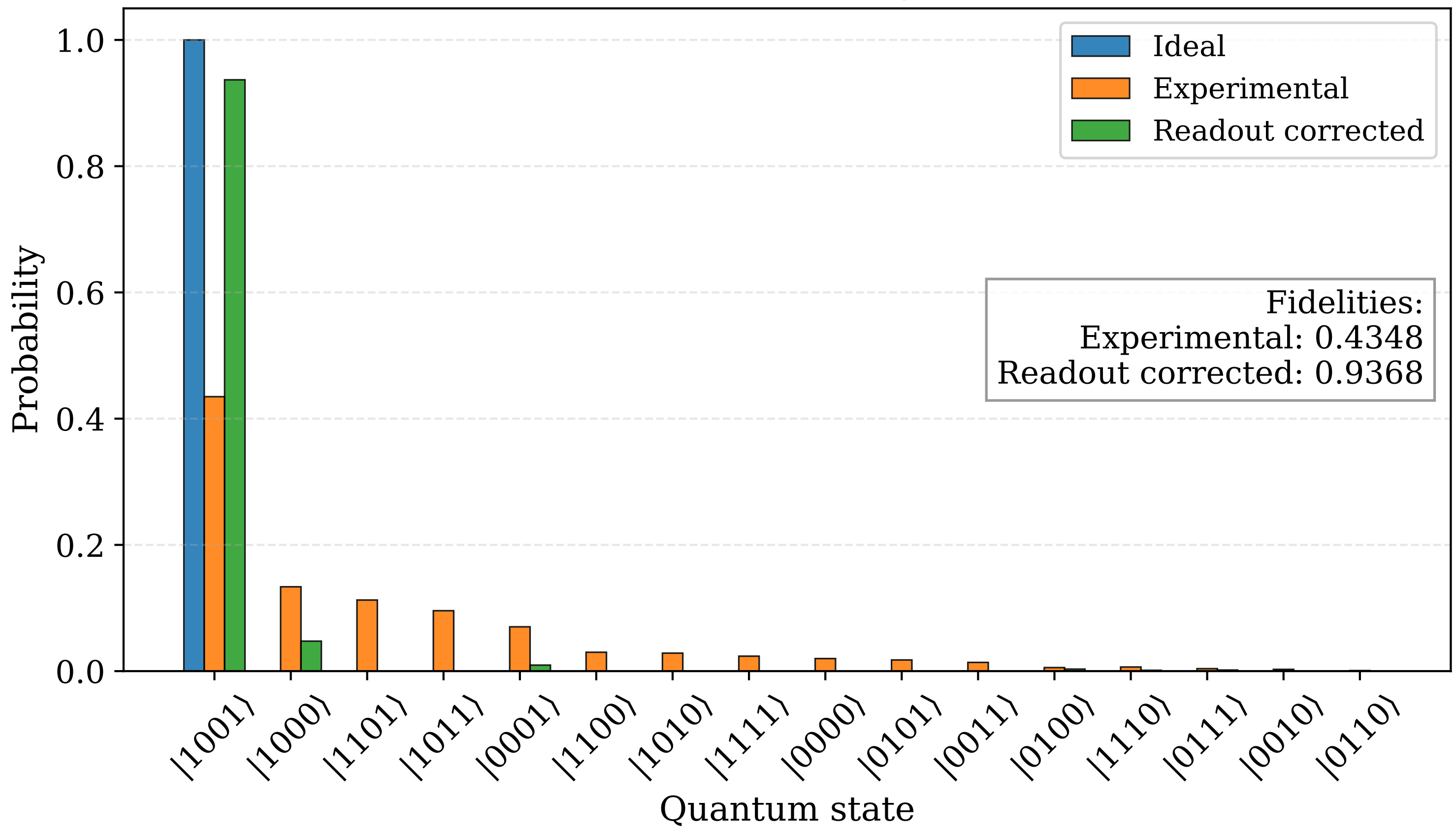
Results: resources across shells



Pérez-Obiol, Romero et al Scientific Reports **13**, 12291 (2023)

Hardware runs

Reference state ^{6}Be reduced system ($1p_{3/2}$) (BSC Quantum Blue data)



Master's thesis, Arnau Morón (ongoing)

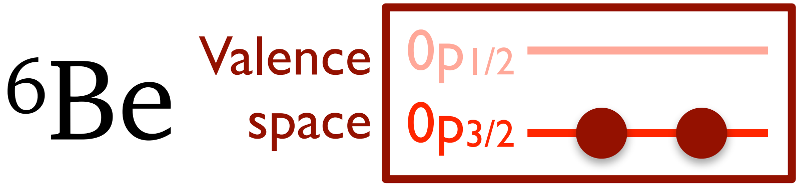
MareNostrum Ona@BSC

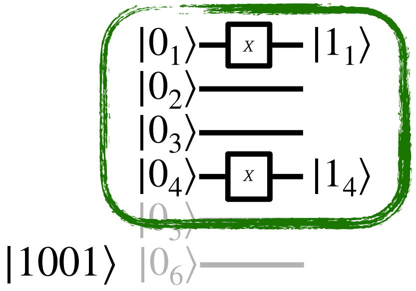
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

A. Morón

J. Ainaud

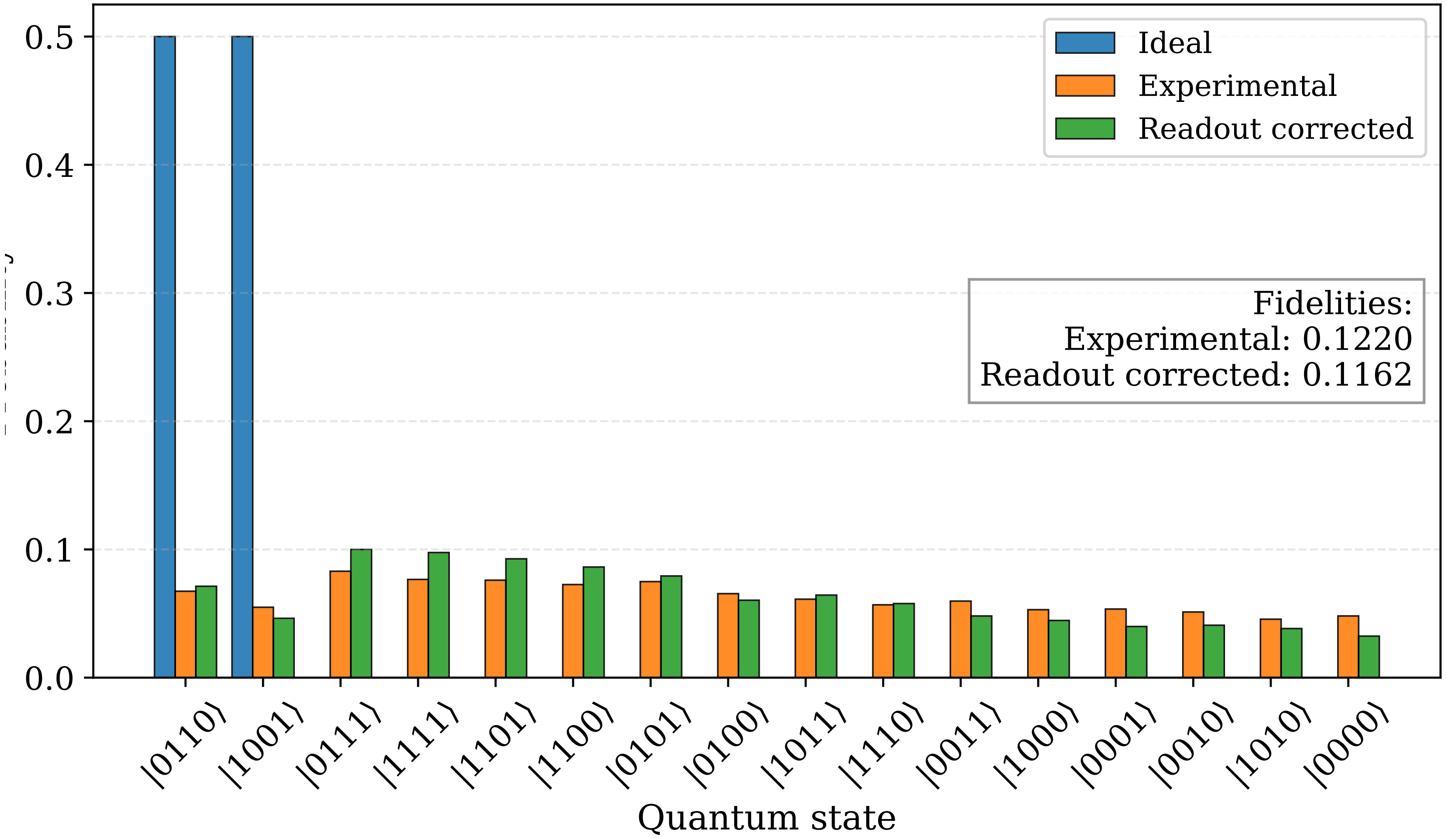
K. Gallego





Hardware runs

1 Layer ADAPT ^{6}Be reduced system ($1p_{3/2}$) opt. circuit (BSC Quantum Blue data



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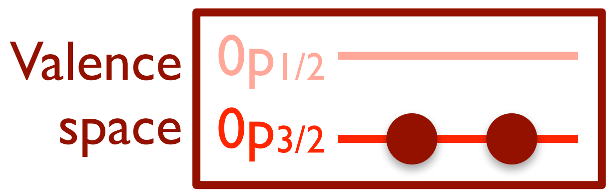
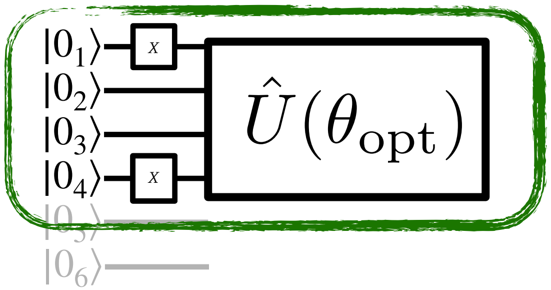
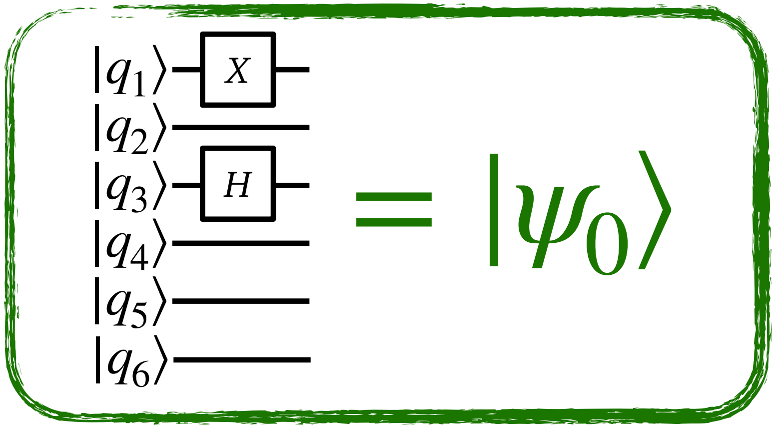
^{6}Be





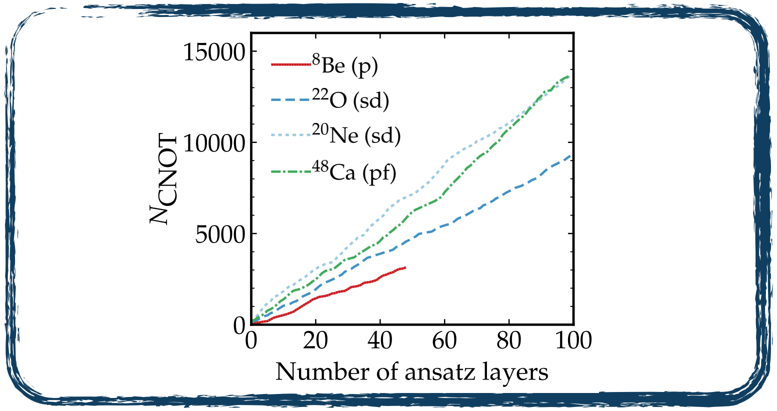
Outline

- Quantum algorithms



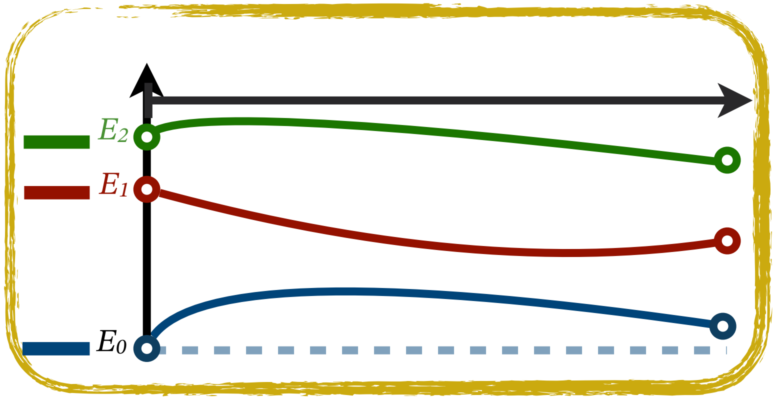
- Variational approach

Scientific Reports **13**, 12291 (2023)
EPJA **59**, 240 (2023)
+ arXiv:2409.04510 + PRC **113** 024332 (2026)



- Adiabatic approach

SciPost Physics 19 062 (2025)
+ Phys Lett B **872** 140042 (2025)



Adiabatic quantum computing

$$i\frac{d}{dt}|\psi(t)\rangle = \hat{H}(t)|\psi(t)\rangle$$

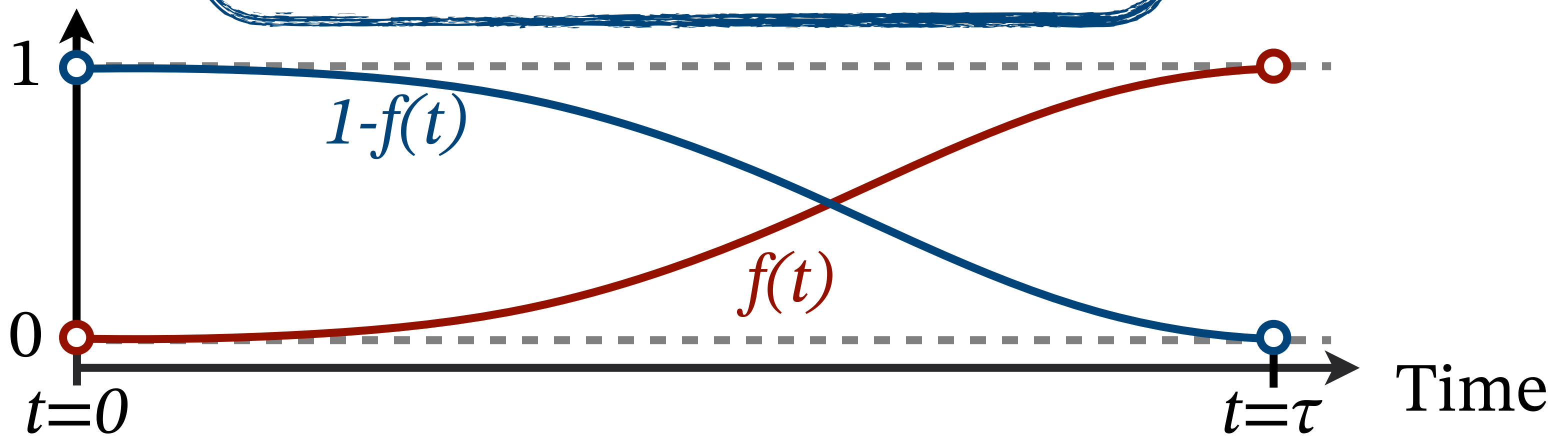
$$\hat{H}(t) = [1 - f(t)]\hat{H}_D + f(t)\hat{H}_T$$

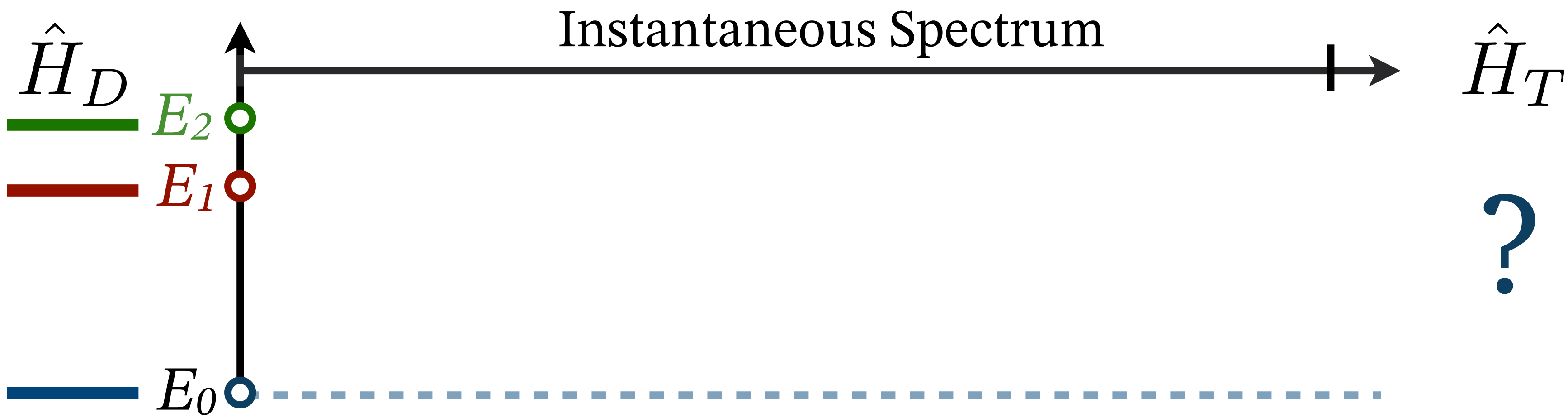
Known

(Driver) $\hat{H}_D$

Unknown

$\hat{H}_T$ (Target)





Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

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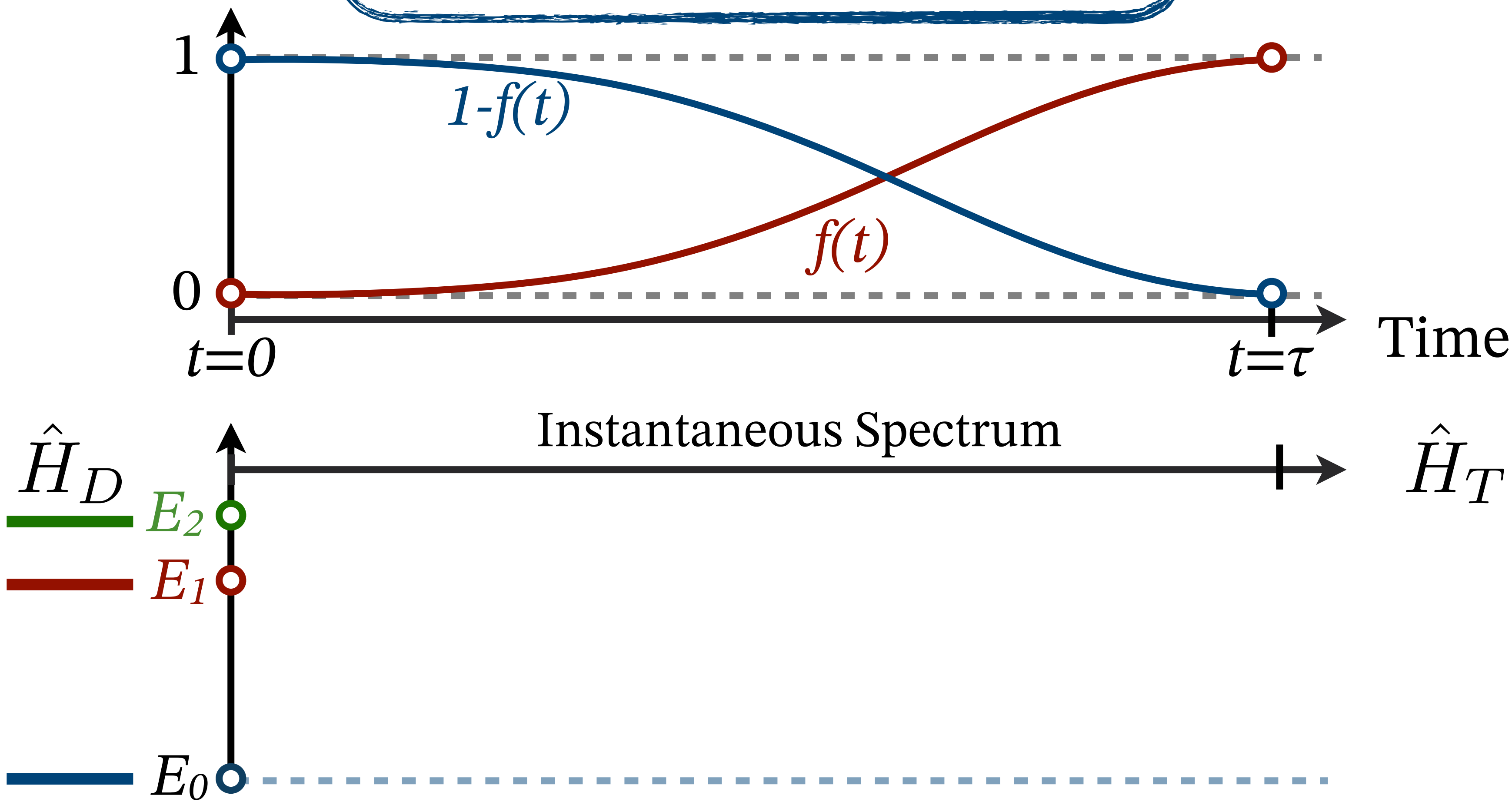

Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

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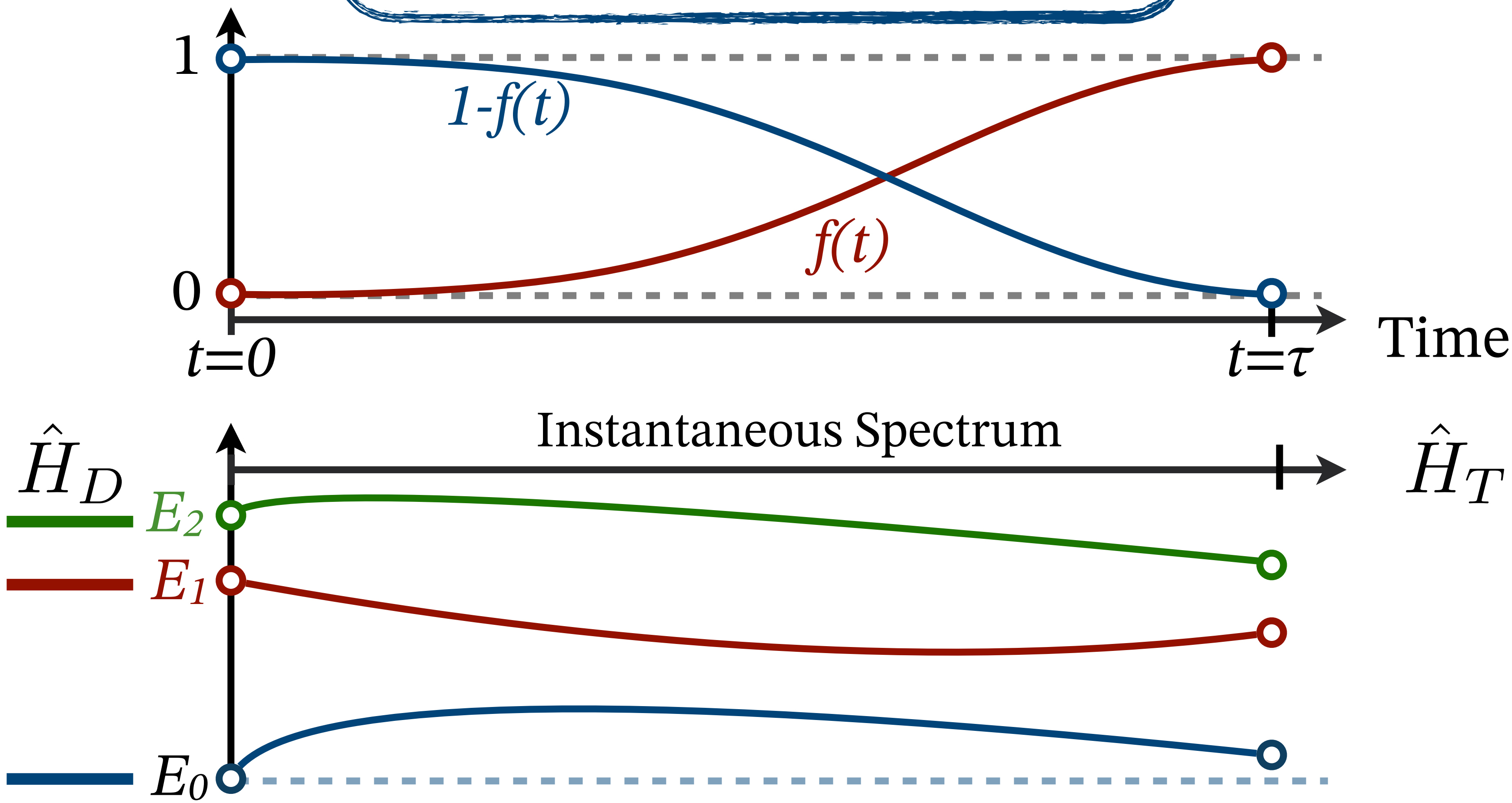

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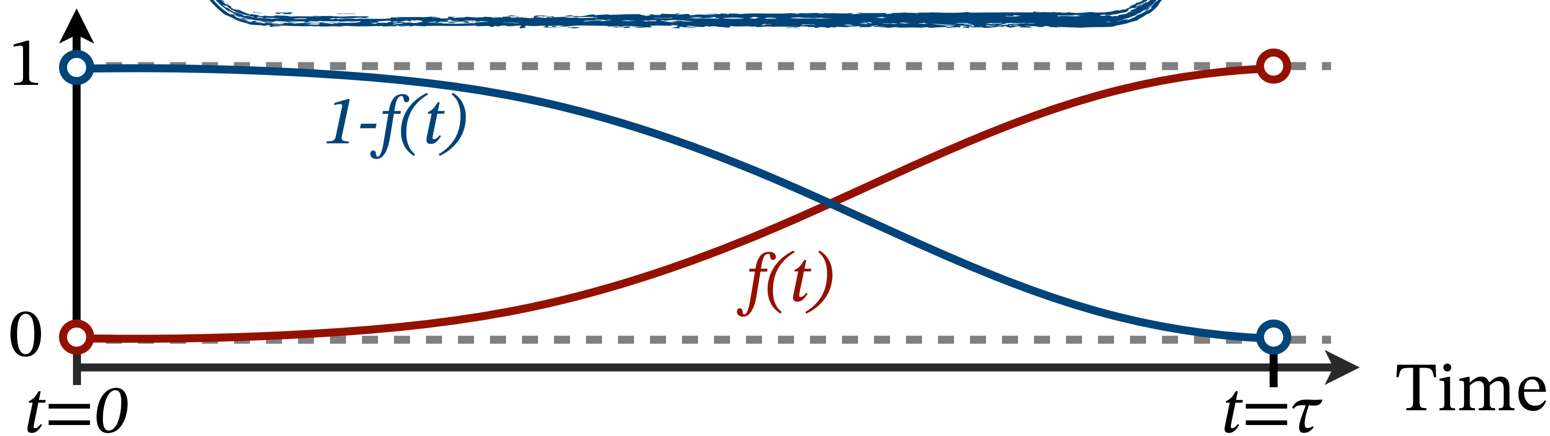
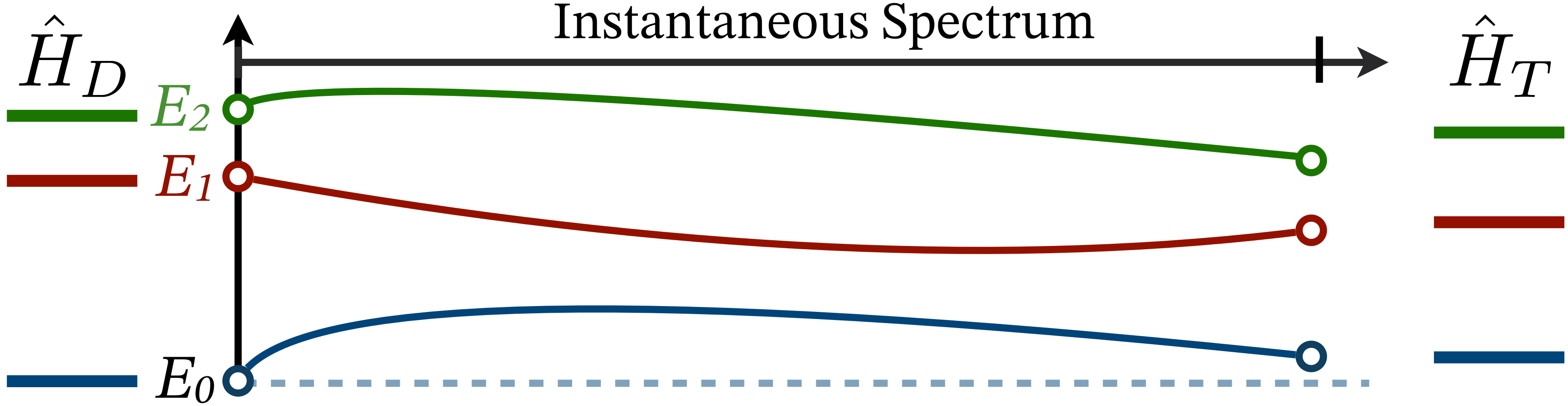




Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

Adiabatic quantum computing

$$i\frac{d}{dt}|\psi(t)\rangle = \hat{H}(t)|\psi(t)\rangle$$

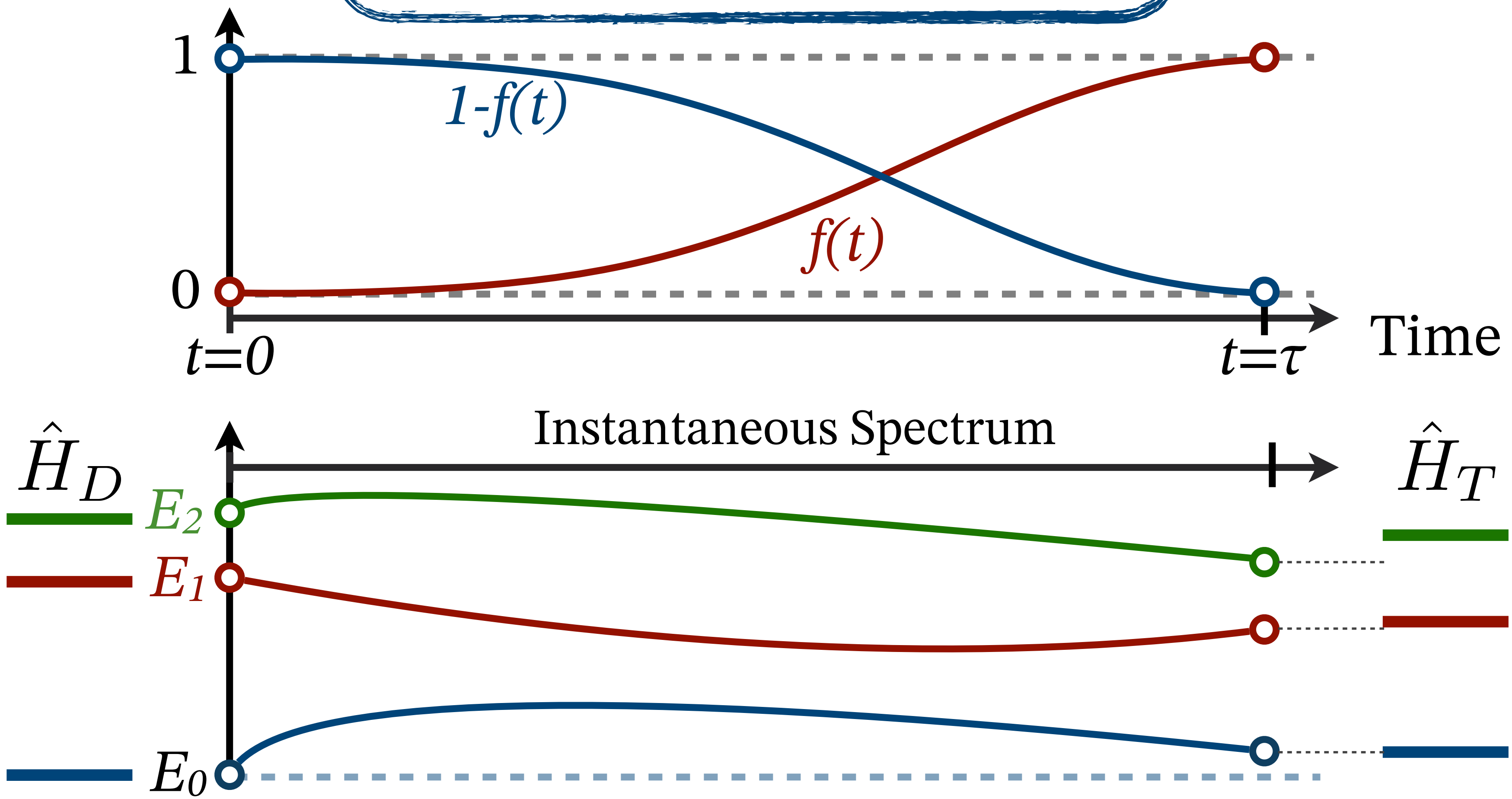
$$\hat{H}(t) = [1 - f(t)]\hat{H}_D + f(t)\hat{H}_T$$

Known

(Driver) $\hat{H}_D$

Unknown

$\hat{H}_T$ (Target)



Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

Adiabatic quantum computing

$$i\frac{d}{dt}\left|\psi(t)\right\rangle = \hat{H}(t)\left|\psi(t)\right\rangle$$

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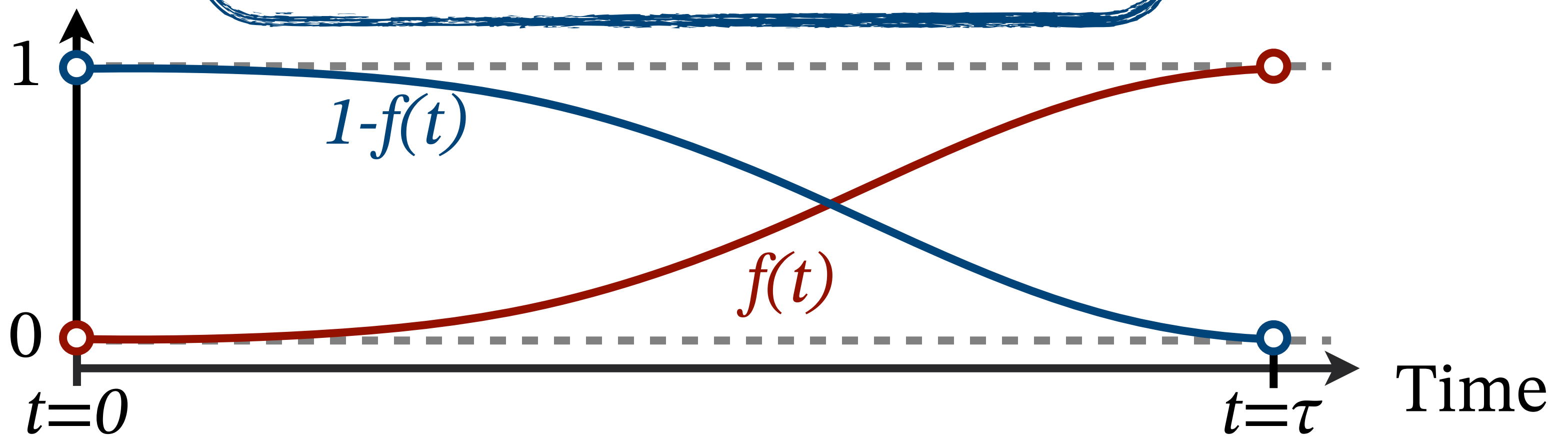

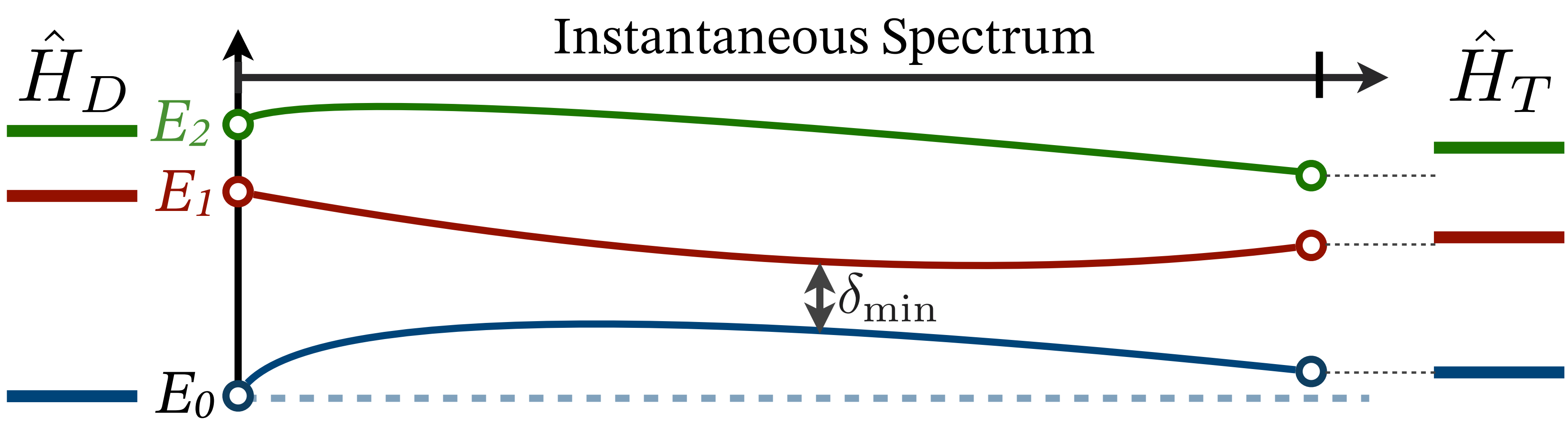

Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

Adiabatic quantum computing

$$i\frac{d}{dt}|\psi(t)\rangle = \hat{H}(t)\,|\psi(t)\rangle$$

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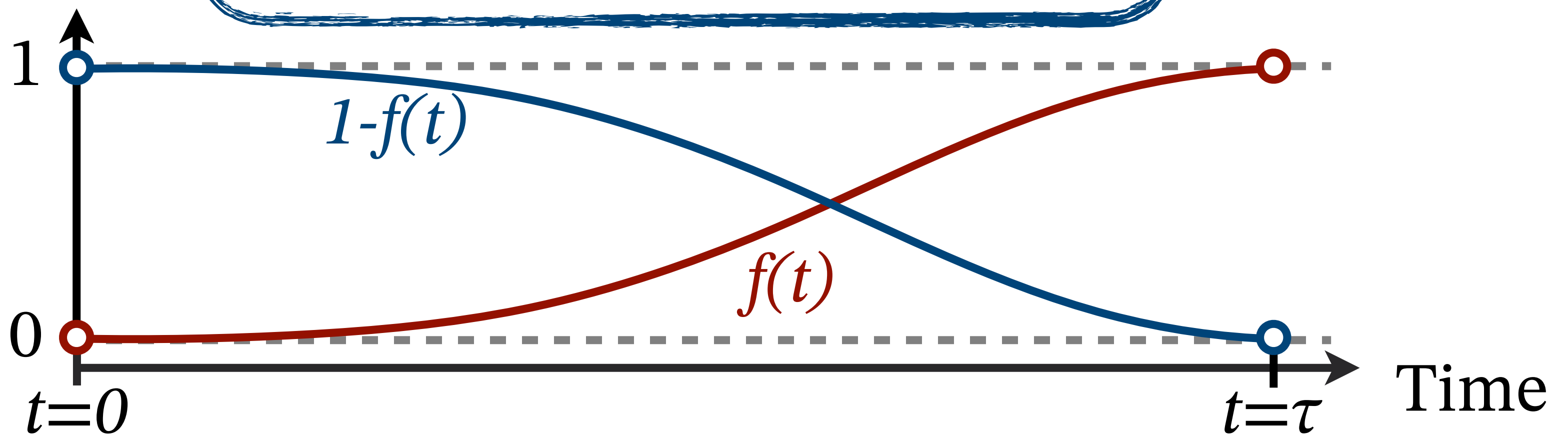
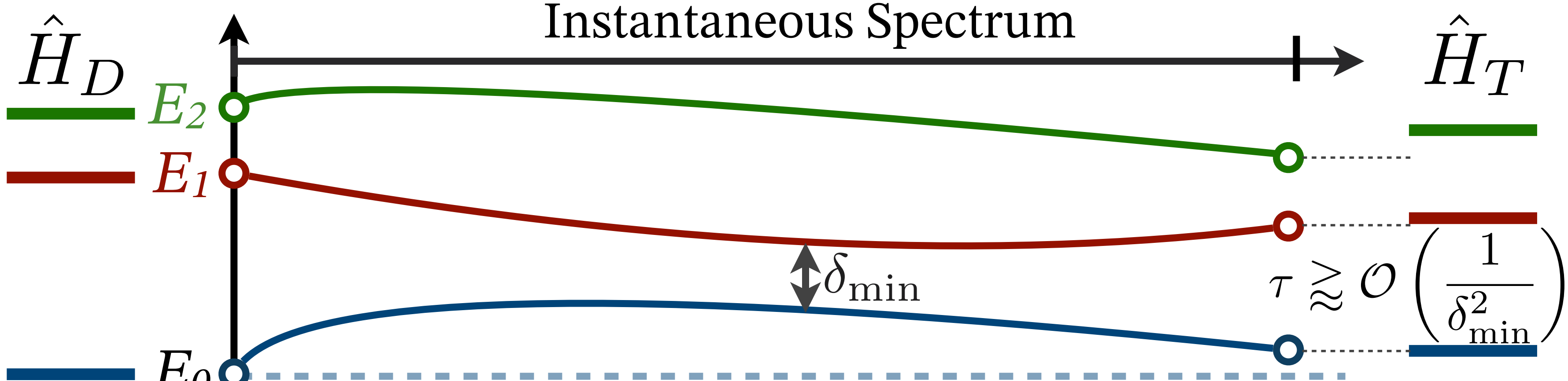
Known (Driver) $\hat{H}_D$

Unknown $\hat{H}_T$ (Target)





$$\left[\hat{H}_D, \hat{H}_T\right] \neq 0$$

Albash & Lidar, Rev. Mod. Phys. **90** 015002 (2018)

Shell Model annealing algorithm

SciPost Physics — Submission

A Quantum Annealing Protocol to Solve the Nuclear Shell Model

Emanuele Costa[1,2], Axel Pérez-Obiol[3], Javier Menéndez[1,2], Arnau Rios[1,2], Artur García-Sáez[4,5] and Bruno Juliá-Díaz[1,2]

E Costa

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

Questions

- What **driver hamiltonian** H_D?
- What **initial** state?
- What is the gap?
- Can it be implemented?

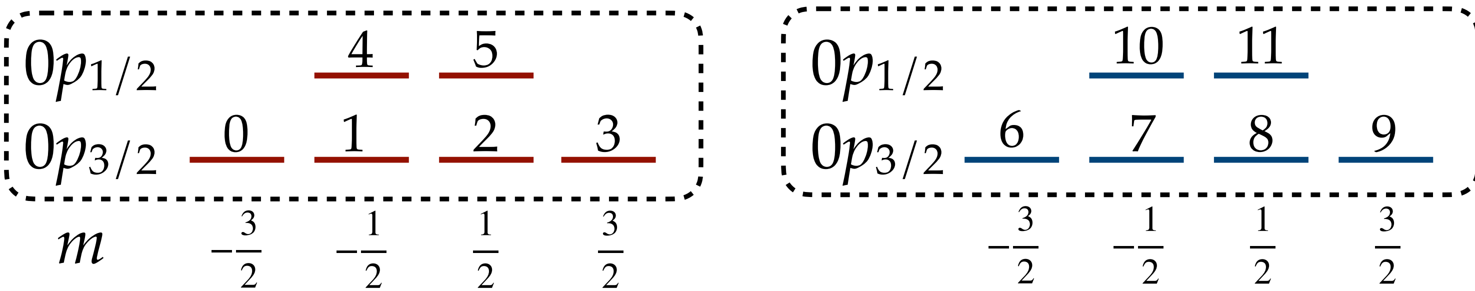
Driver hamiltonian

Naive SM filling + $|m|$ protocol

Lowest sp energies with decreasing $|m|$ values

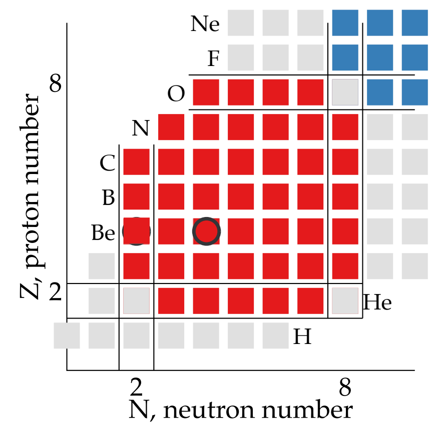
***p* shell**

^{8}Be



1.Slater determinant reference state

$$|\mathbf{s}\rangle = |1,0,0,1,0,0,1,0,0,1,0,0\rangle$$



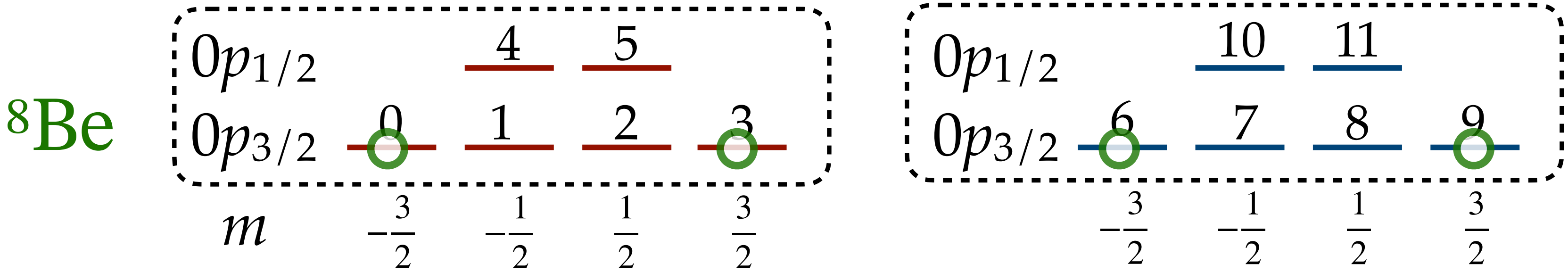
Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

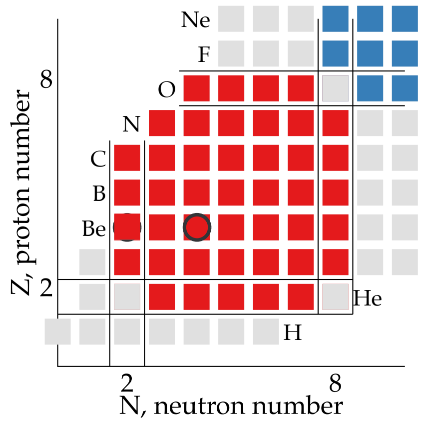
Driver hamiltonian

Naive SM filling + $|m|$ protocol

Lowest sp energies with decreasing $|m|$ values

***p* shell**





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Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

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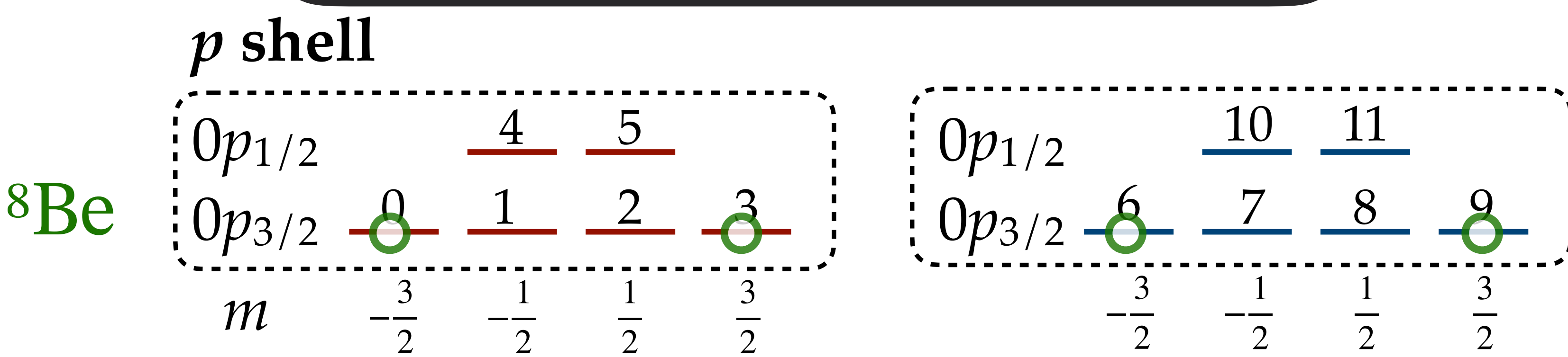
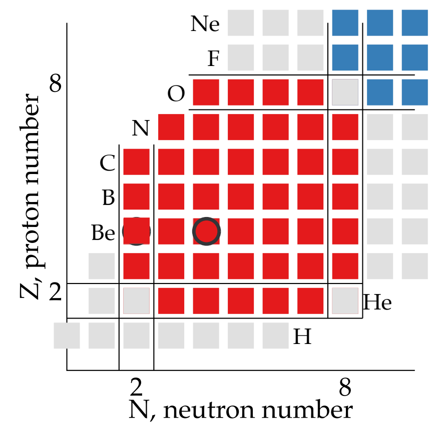


1. Slater determinant reference state

$$|\mathbf{s}\rangle = |1,0,0,1,0,0,1,0,0,1,0,0\rangle$$

2. Reference energy $\quad E_0 = \langle \mathbf{s}| \hat{H}_T |\mathbf{s}\rangle$



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Driver hamiltonian

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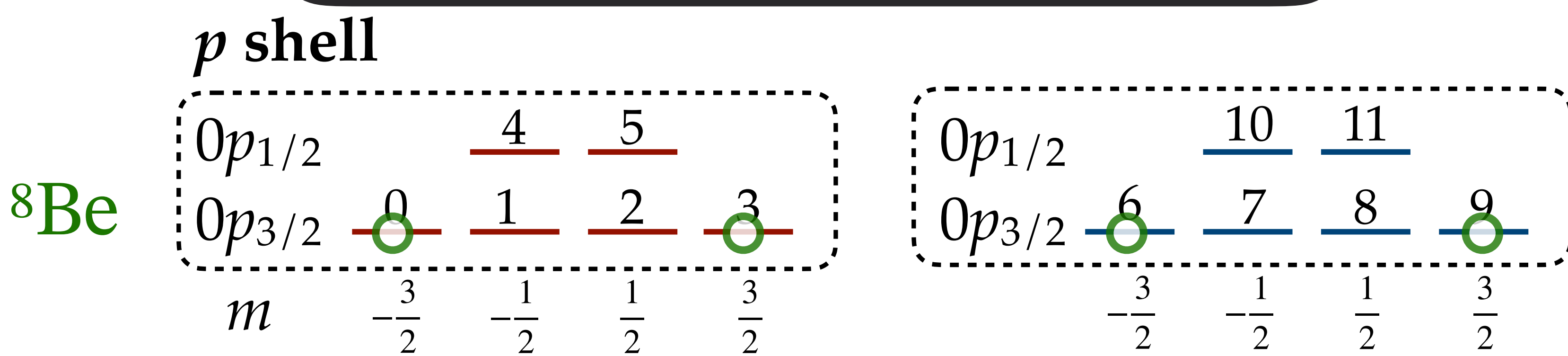

1. Slater determinant reference state

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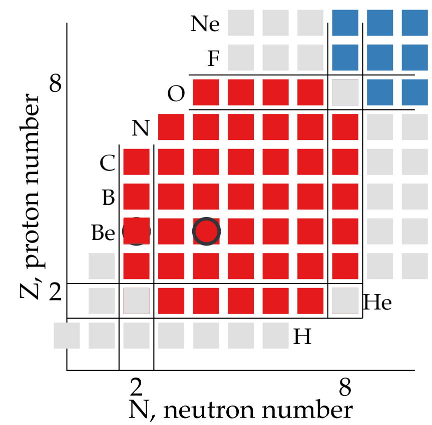
3. Valence particle numbers $Z_p = 2 \quad N_n = 2$



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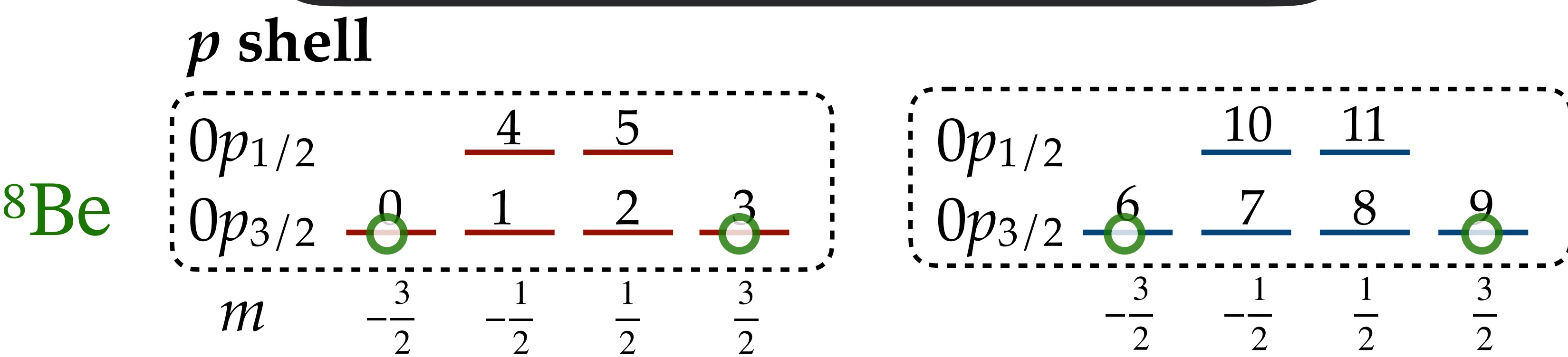

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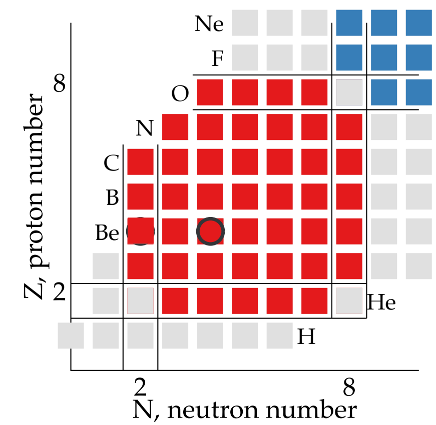


4. Driving Hamiltonian

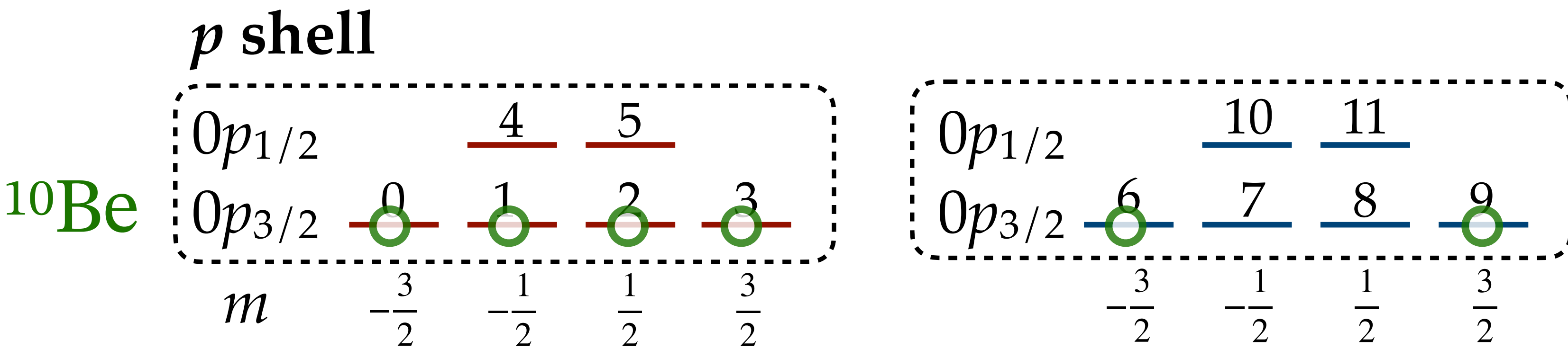
$$\hat{H}_D = \frac{E_0}{(N_n + Z_p)} \sum_\alpha s[\alpha]\hat{n}_\alpha$$

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

Driver hamiltonian

Naive SM filling + $|m|$ protocol

Lowest sp energies with decreasing $|m|$ values

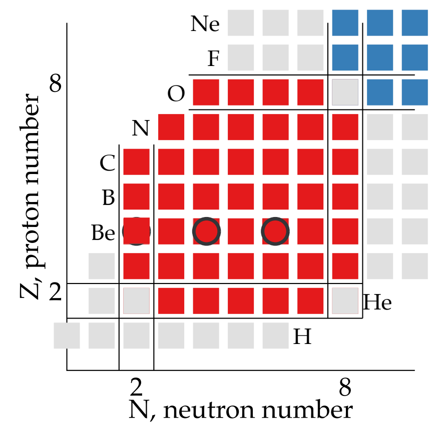


1. Slater determinant reference state

$$|\mathbf{s}\rangle = |1,1,1,1,0,0,1,0,0,1,0,0\rangle$$

2. Reference energy $E_0 = \langle \mathbf{s}| \hat{H}_T |\mathbf{s}\rangle$

3. Valence particle numbers $Z_p = 2 \;\; N_n = 4$



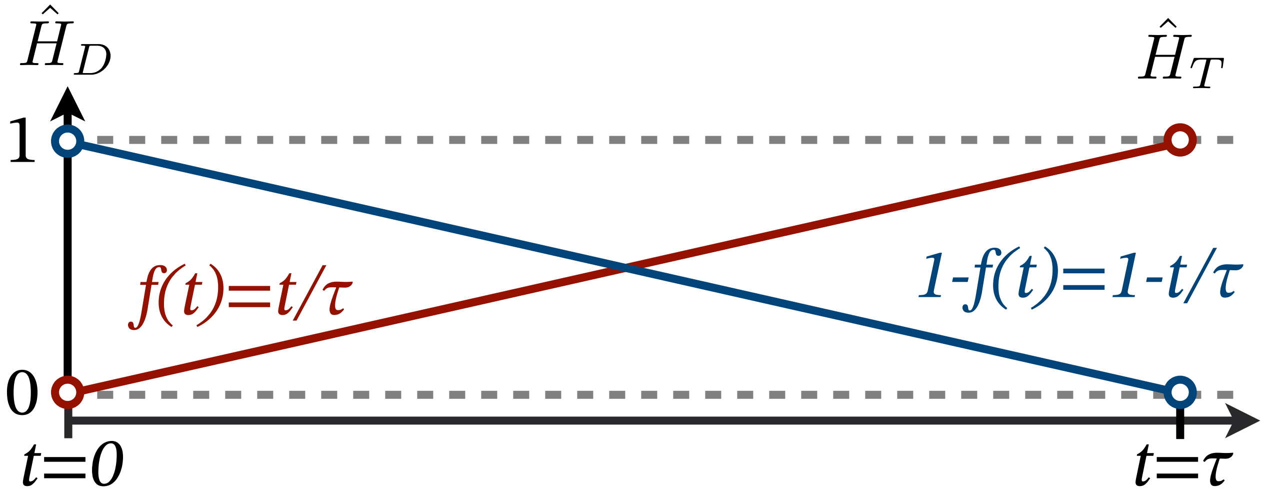
4. Driving Hamiltonian

$$\hat{H}_D = \frac{E_0}{(N_n + Z_p)} \sum_\alpha s[\alpha]\hat{n}_\alpha$$

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

Implementation

- Linear annealing protocol $\hat{H}(t) = [1 - f(t)]\hat{H}_D + f(t)\hat{H}_T$



- Driver & target hamiltonians

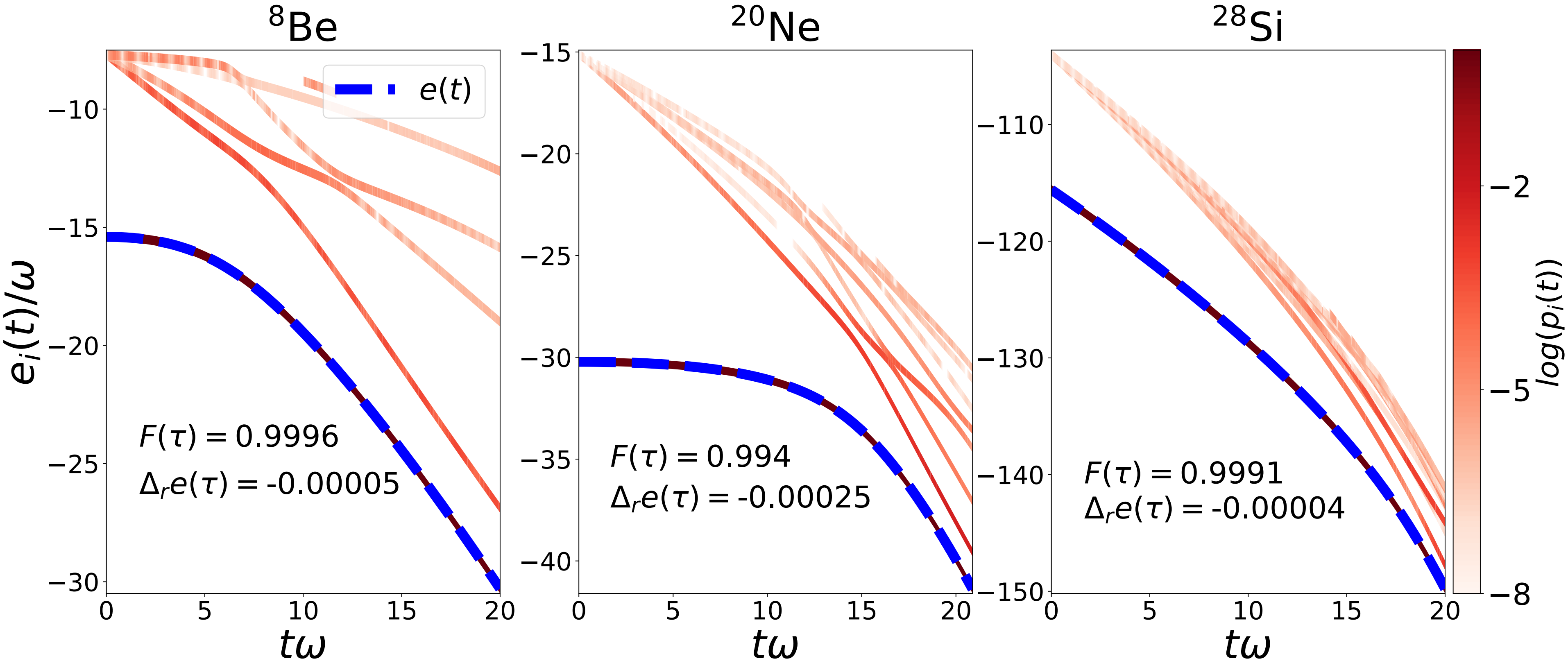
$$\hat{H}_D = \frac{E_0}{(N_n + Z_p)} \sum_\alpha s[\alpha] \hat{c}^\dagger_\alpha \hat{c}_\alpha \quad \xrightarrow{\hat{U}(\tau,0)} \quad \hat{H}_T = \sum_\alpha \varepsilon_\alpha c^\dagger_\alpha c_\alpha + \frac{1}{4} \sum_{\alpha\beta\gamma\delta} \bar{v}_{\alpha\beta\gamma\delta} c^\dagger_\alpha c^\dagger_\beta c_\delta c_\gamma$$

- Time evolution $\hat{U}(\tau, 0) = \prod_{k=0}^{N_t} \hat{U}_k = \prod_{k=0}^{N_t} \exp\left[-ik\Delta t \hat{H}(t_k)\right]$

- Parameters $\omega = 1 \text{ MeV}, \ \Delta t = 0.1, \ \tau\omega = \{10, 20, 30\}$

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

Results

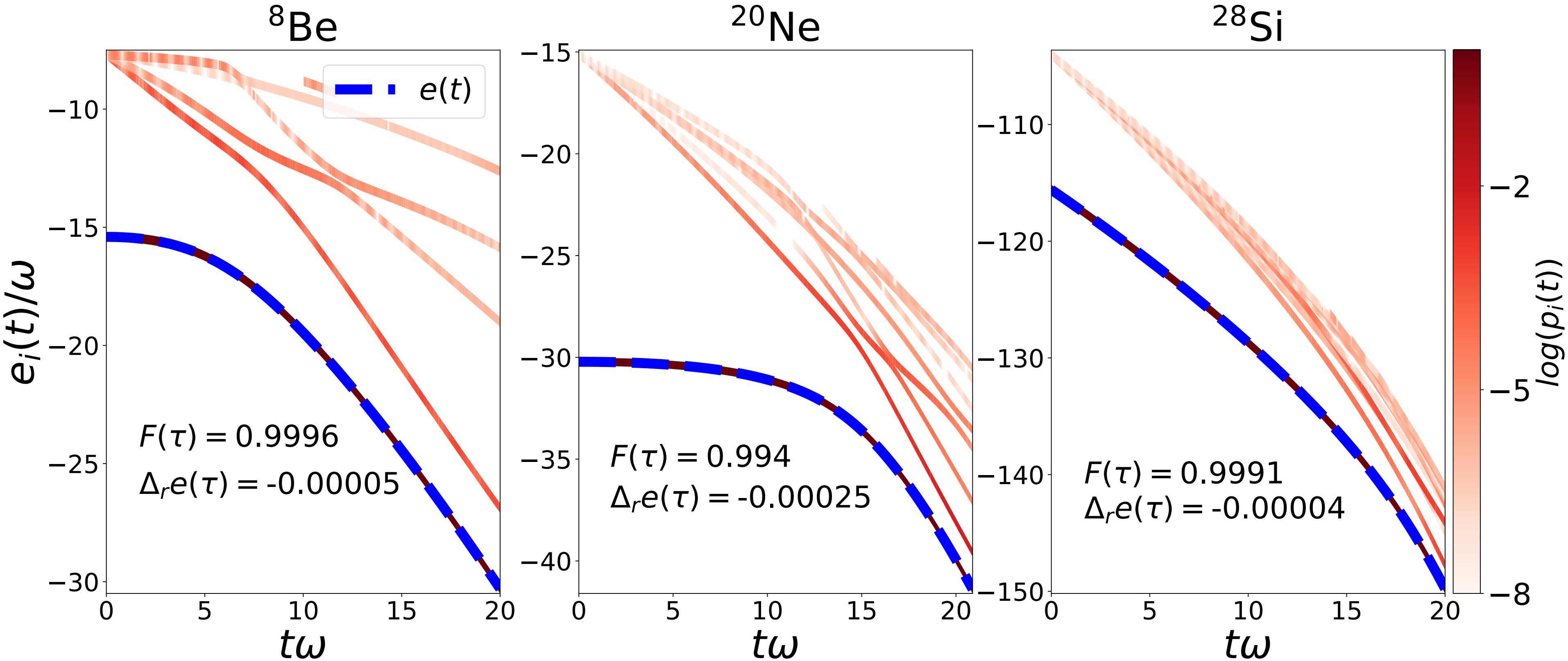


- **Final state:** $\Delta_r e(\tau) = \frac{\langle \Psi(\tau) | \hat{H}_T | \Psi(\tau) \rangle - E_T}{|E_T|}$ $\quad F(\tau) = |\langle \Psi(\tau) | \Psi_T \rangle|^2$
- **Instantaneous:** $\hat{H}(t) |e_i(t)\rangle = e_i(t) |e_i(t)\rangle$ $\quad p_i(t) = |\langle \Psi(t) | e_i(t) \rangle|^2$

$$e(t) = \langle \Psi(t) | \hat{H}(t) | \Psi(t) \rangle$$

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

Results



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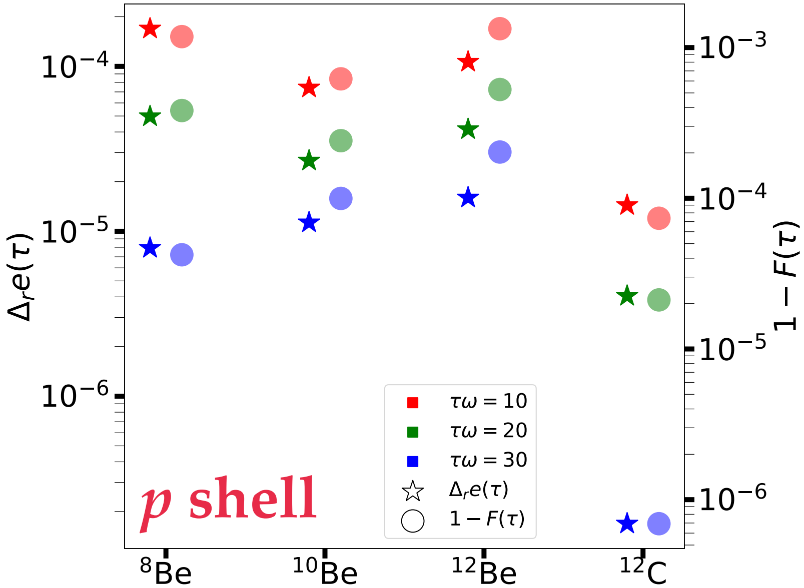
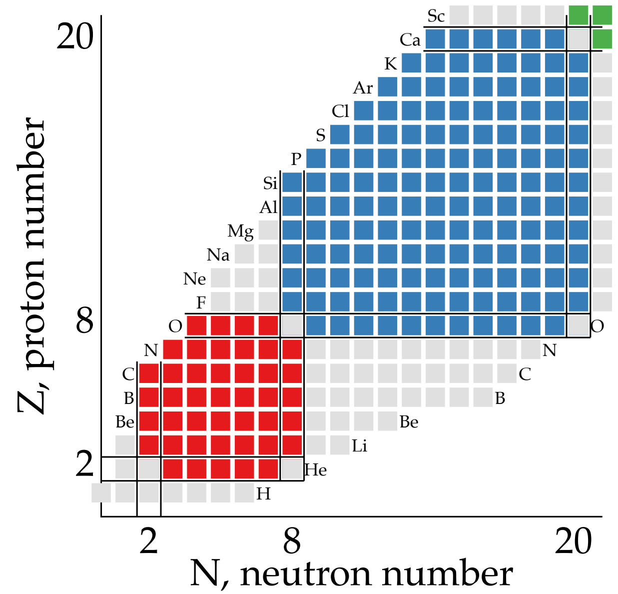
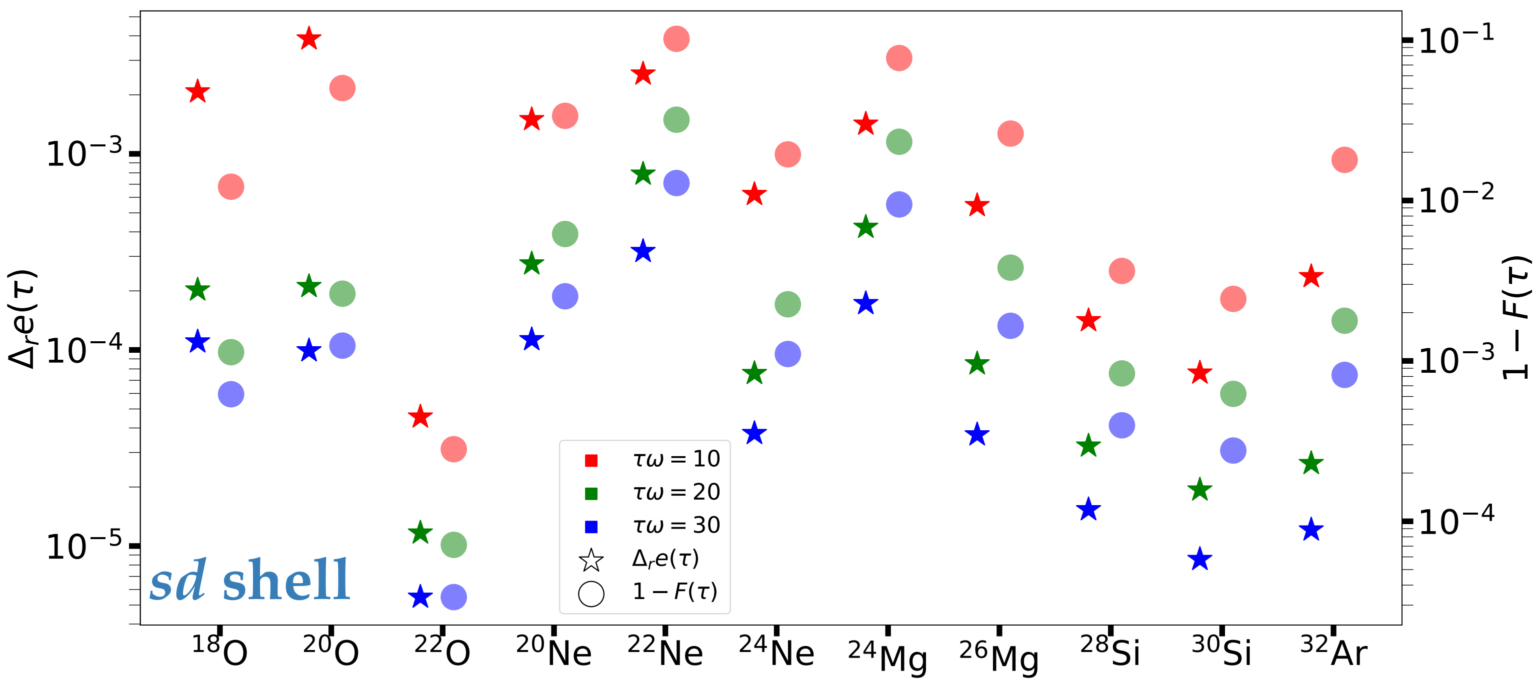
$$e(t) = \langle \Psi(t) | \hat{H}(t) | \Psi(t) \rangle \approx e_0(t)$$

Costa et al., SciPost Physics 19 062 (2025), arXiv:2411.06954

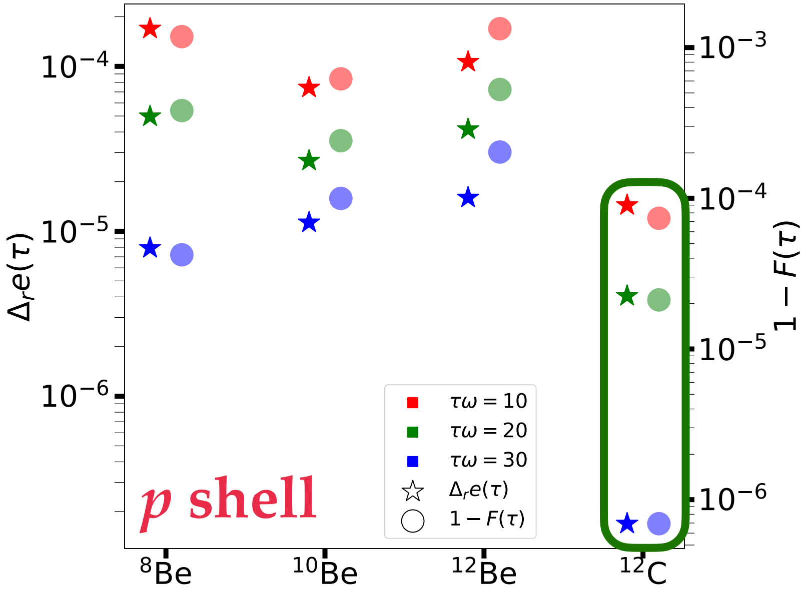
Different isotopes & schedules

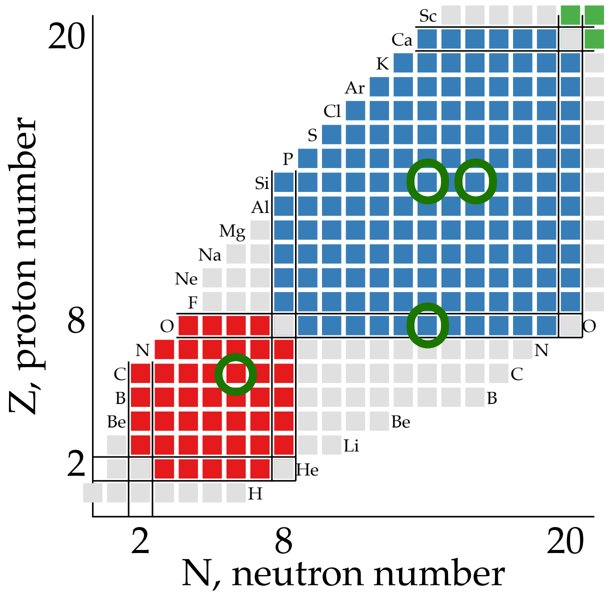


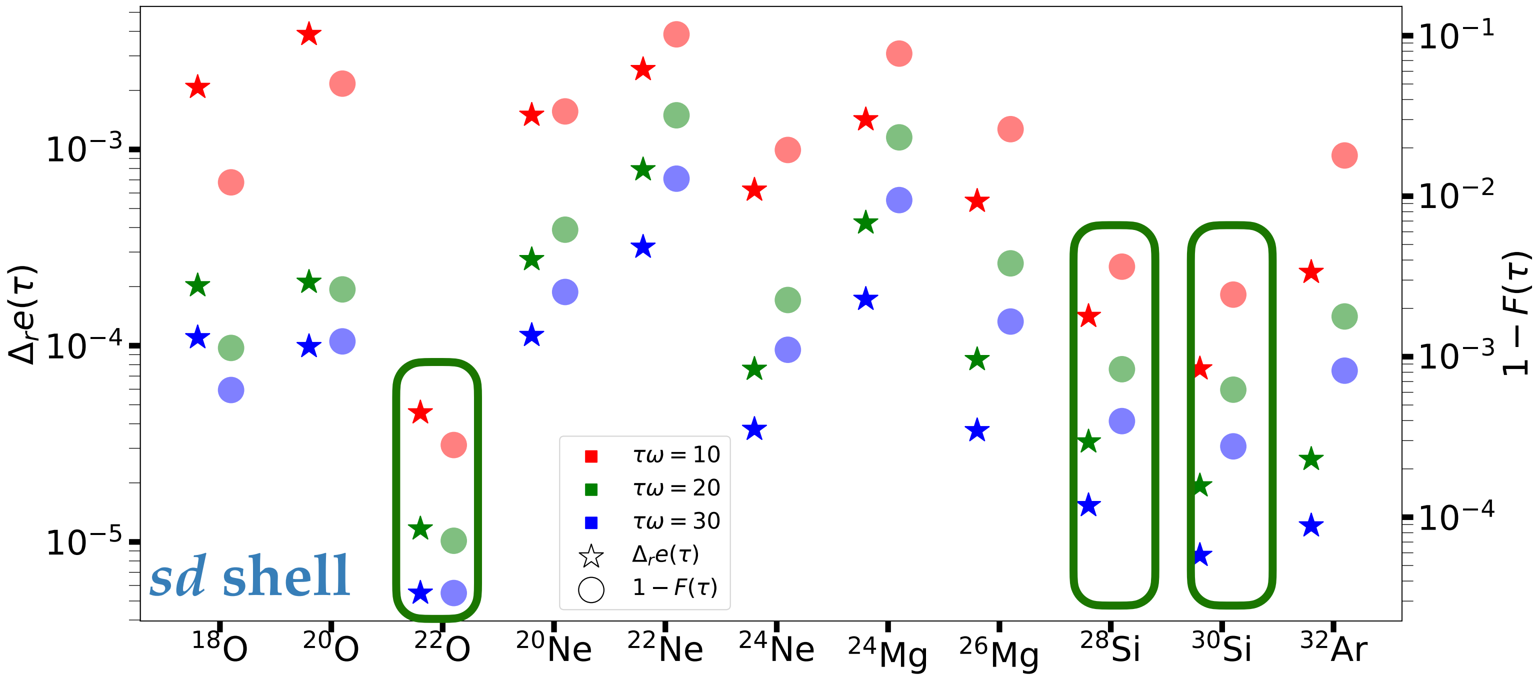




Different isotopes & schedules





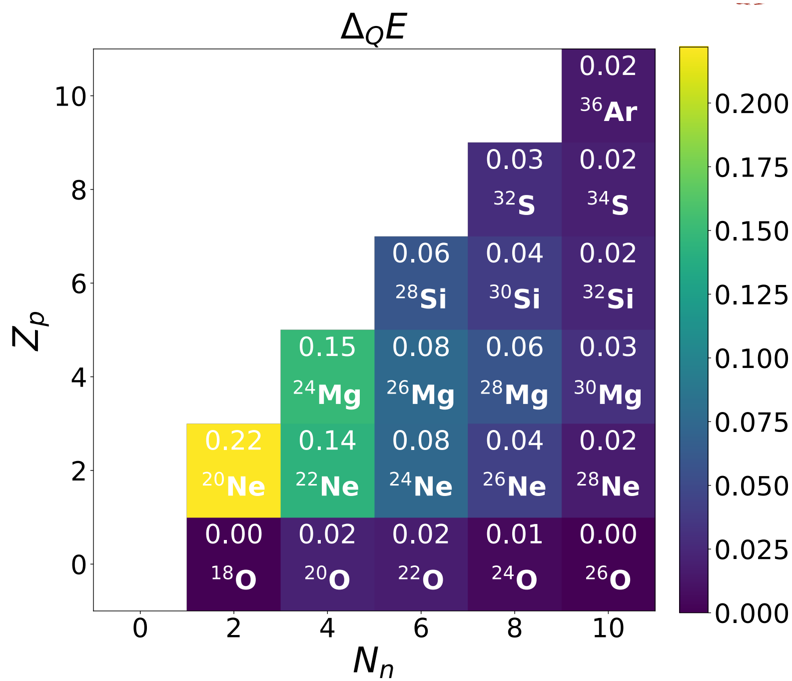


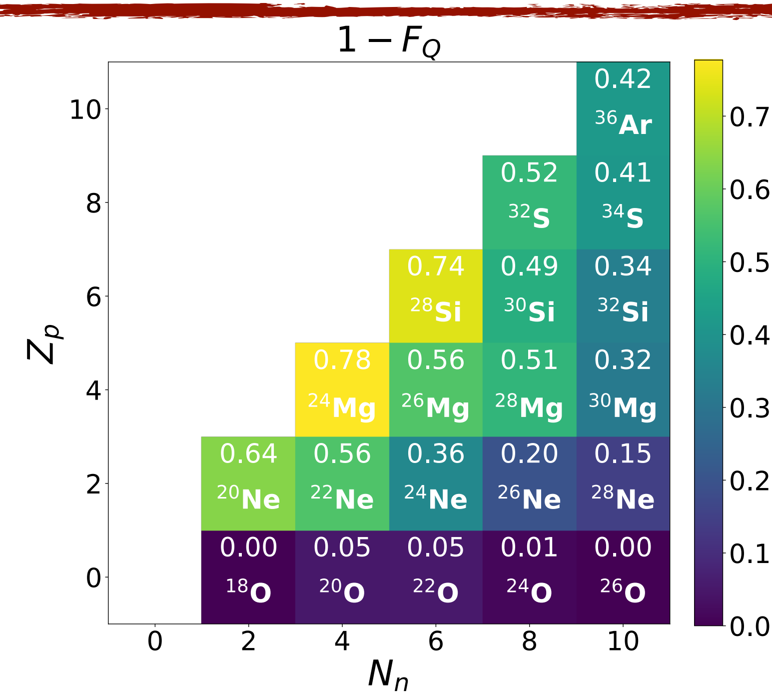
Quasi-boson mapping

Quasi-boson (~Cooper pairs): $Q_A^\dagger = \hat{a}_\alpha^\dagger \hat{a}_{\tilde{\alpha}}^\dagger$ $\quad [Q_A, Q_B^\dagger] = \delta_{A,B}(1 - n_\alpha - n_{\tilde{\alpha}})$

Boson-to-qubit map: $Q_A^\dagger = S_A^+; \;\; Q_B = S_B^-; \;\; \hat{N}_A = Q_A^\dagger Q_A = (1 + Z_A)/2,$

Projected hamiltonian: $$H_Q = \frac{1}{2}\sum_{AB} g_{AB} S_A^+ S_B^- + \frac{1}{4}\sum_{ABCD} g_{AB}^{CD} S_A^+ S_B^+ S_C^- S_D^-$$





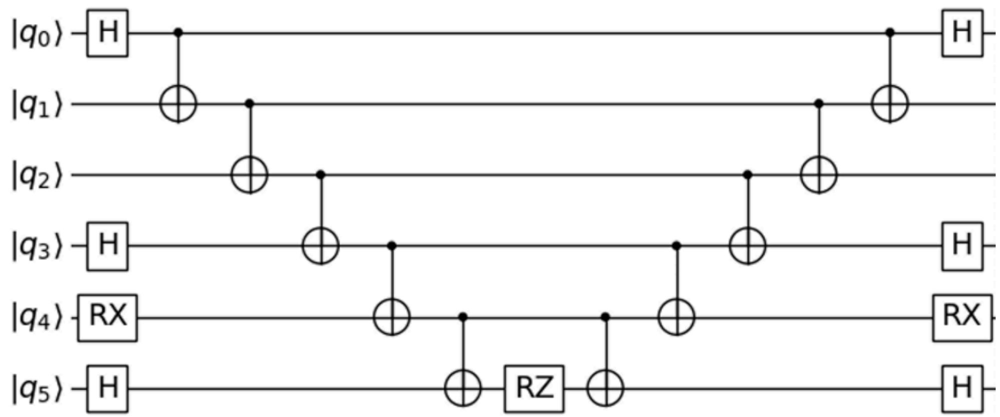
E Costa

- Tailored to quantum circuit execution
- Pairing correlations only

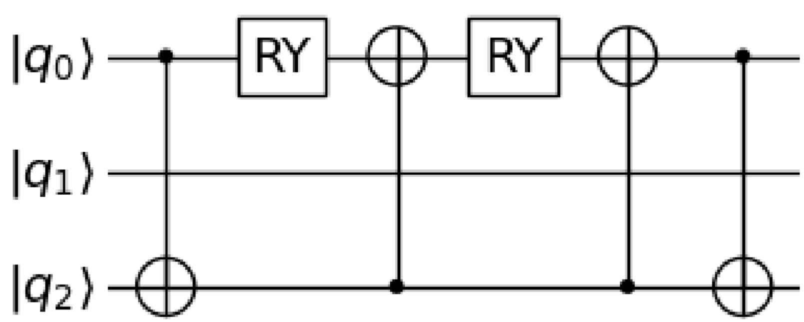
Costa *et al.*, PLB **872** 140042 (2025)

See also: Yoshida et al PRC 109 064305 (2024)

Quasi-boson encoding



Circuit depth = 105
Total number of gates = 158
Number of qubits = 6
Most common gates:
cx: 80
rx: 32
h: 32
rz: 8

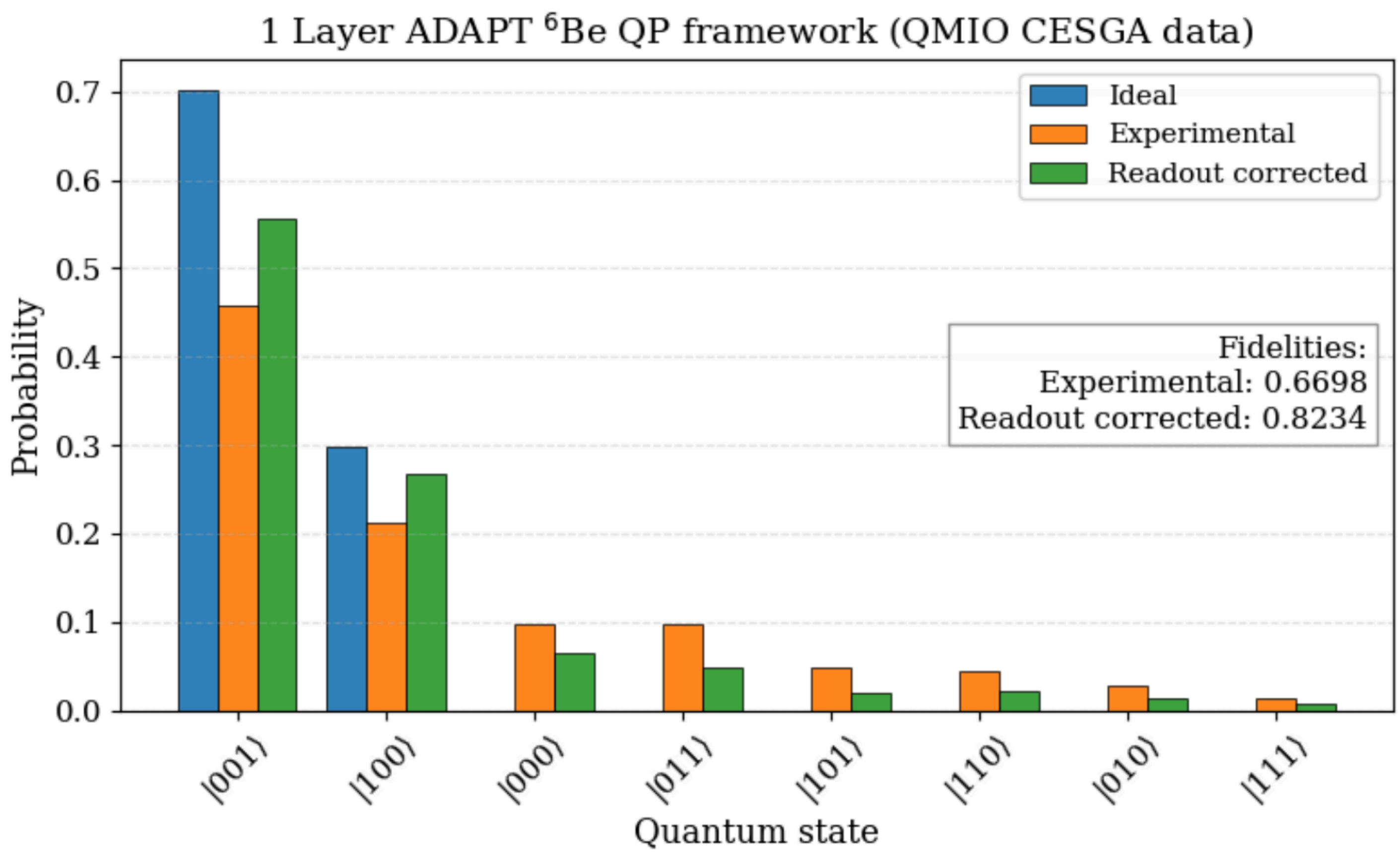


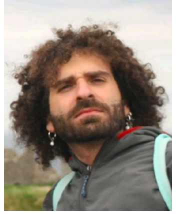
Circuit depth = 6
Total number of gates = 6
Number of qubits = 3
Most common gates:
cx: 4
ry: 2

A Morón

Hardware runs: quasiparticles

QMIO@CESGA





E Costa

A. Morón

J. Ainaud

K. Gallego

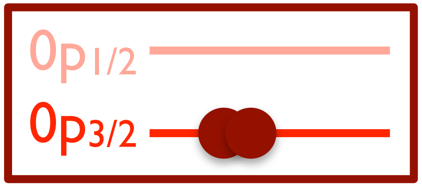
Master's thesis, Arnau Morón (ongoing)

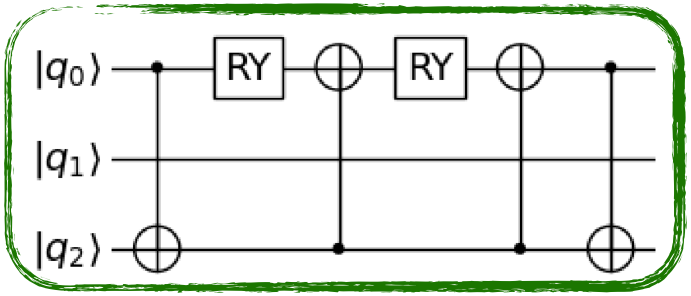
Phys Lett B **872** 140042 (2025)

Hard-core boson mapping

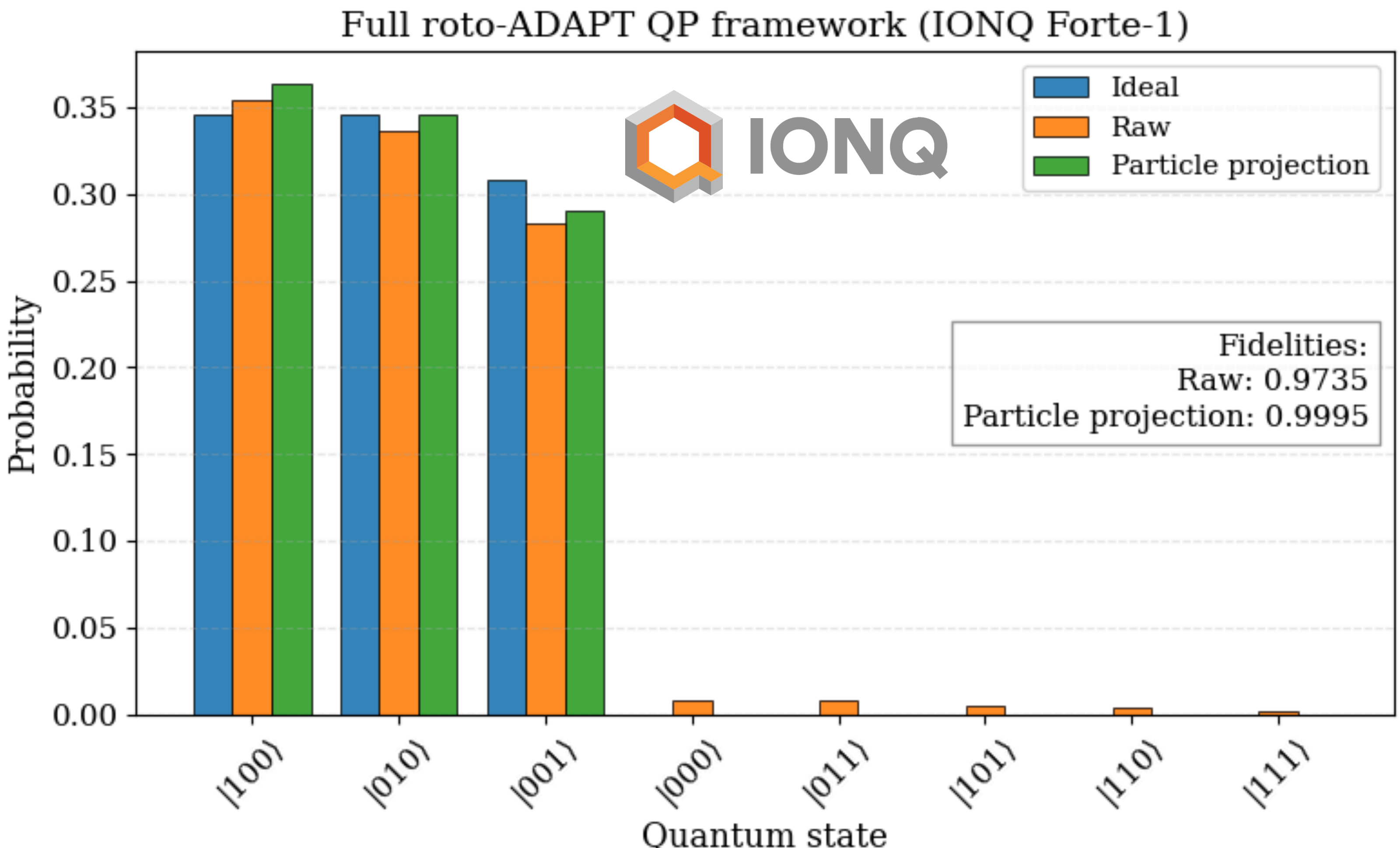
^{6}Be

Valence space

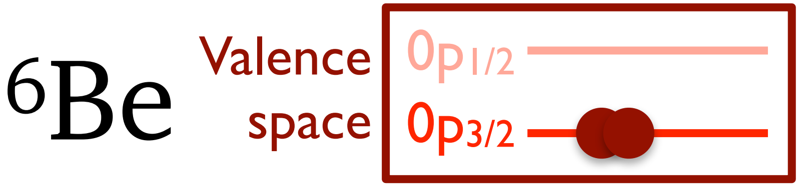


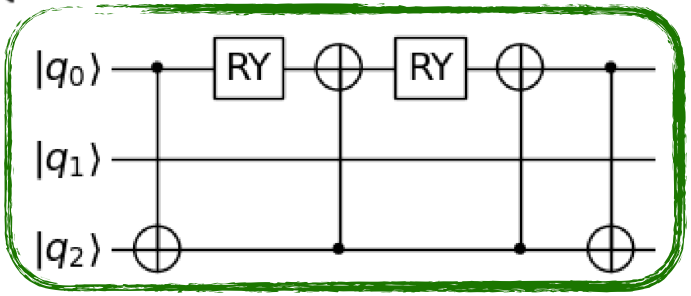


Quasi-boson ADAPT



Hard-core boson mapping

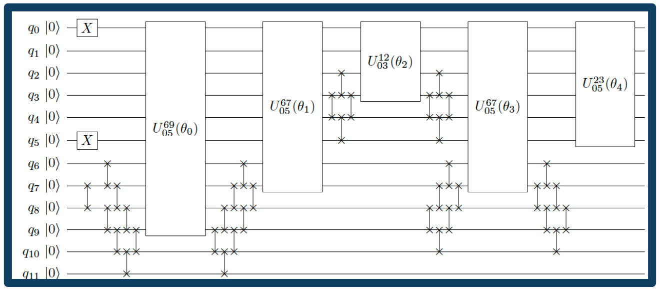


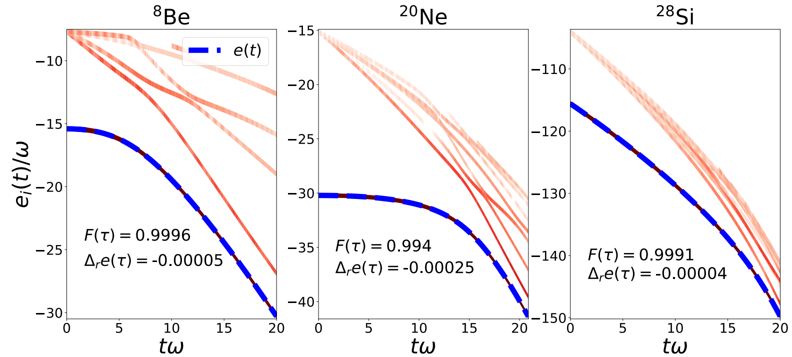


A Morón

Outlook & Perspectives

- VQEs can reproduce **shell model** wavefunctions
  - **Number of qubits** not an issue
  - Depth of circuit **is** an issue
  - Algorithm development
  - Entanglement forging





To-Do List:

- Error mitigation

J Ainaud

A Morón

- Quantum complexity

K Gallego

- Excited states

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EXCELENCIA MARÍA DE MAEZTU

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Thank you!

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https://sites.google.com/view/arnaurios/

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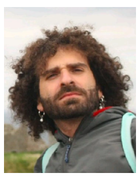

E Costa


J Menéndez


B Juliá-Díaz


K Gallego


J Ainaud


A Morón

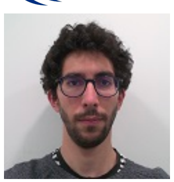
FUJITSU

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

UAB Universitat Autònoma de Barcelona

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH


AM Romero


S Masot-Llima


A García-Saez


A Pérez-Obiol


M Carrasco-Codina

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Funding from

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Financiado por la Unión Europea
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