Exclusive nucleus-ν cross sections from quantum computers

Alessandro Roggero

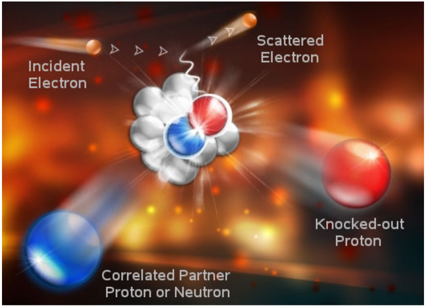


figure credit: JLAB collab.

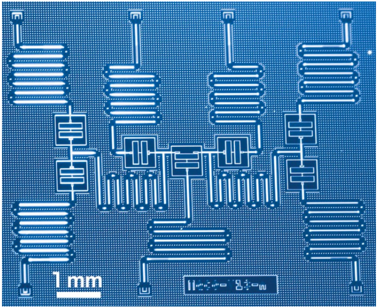
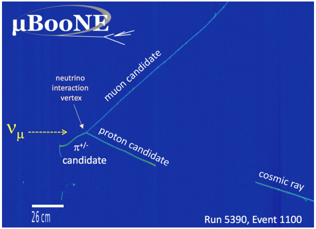


figure credit: IBM

FNAL – 09 May, 2019

Exclusive cross sections in neutrino oscillation experiments



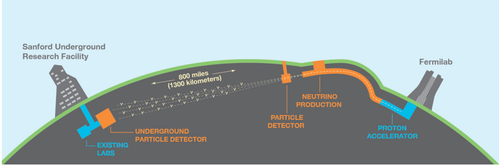
Goals for ν oscillation exp.

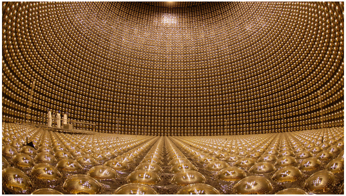
- neutrino masses
- accurate mixing angles
- CP violating phase

$$P(\nu_\alpha \to \nu_\alpha) = 1 - sin^2(2\theta)sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

- need to use measured reaction products to constrain E_ν of the event

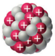
DUNE, MiniBooNE, T2K, Minerνa, NOνA,. . .





Idealized algorithm for exclusive processes at fixed q

- prepare the target ground state



Roggero & Carlson (2018)

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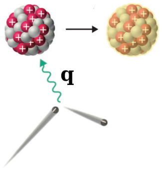

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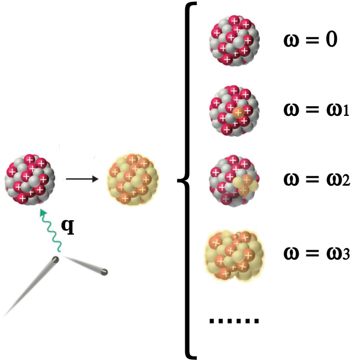

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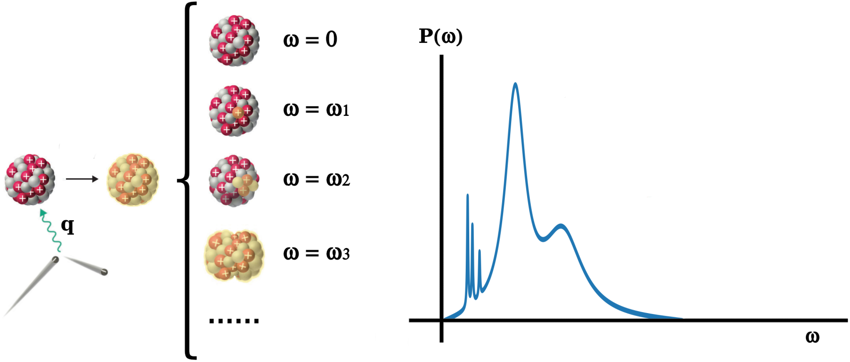

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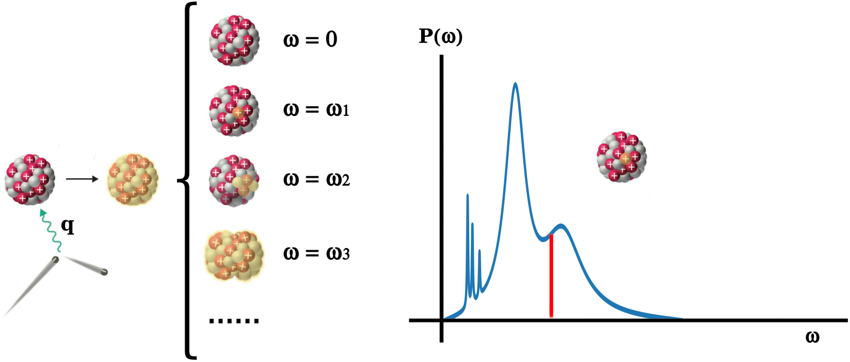

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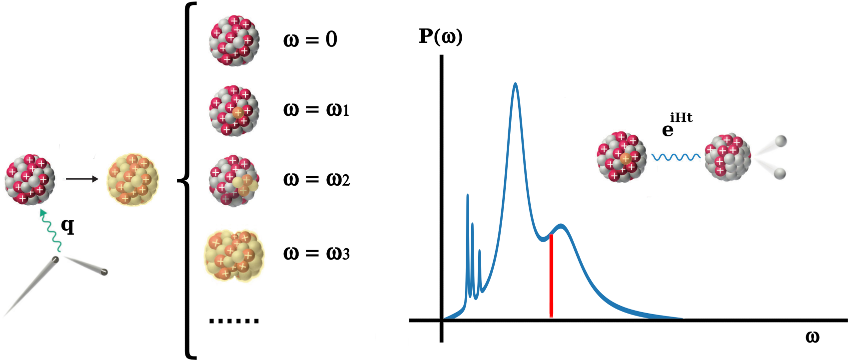

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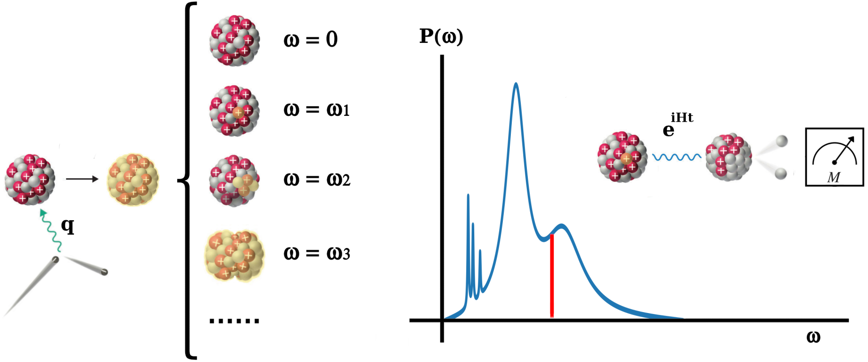

Roggero & Carlson (2018)

The nuclear many-body problem

A controllable theory for nuclear systems

$$H = \sum_i \frac{p^2}{2m} + \frac{1}{2}\sum_{i,j} V_{ij} + \frac{1}{6}\sum_{i,j,k} W_{ijk} + \cdots$$

- much easier to deal with than not the QCD lagragian
- being non-perturbative it is still extremely challenging
  - nuclear states live in huge Hilbert spaces: $dim\,(\mathcal{H}) > 4^A$

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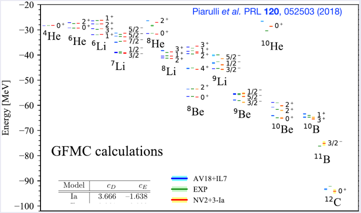
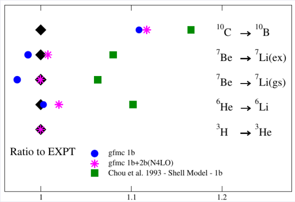
Great success for light systems with regular (super) computers

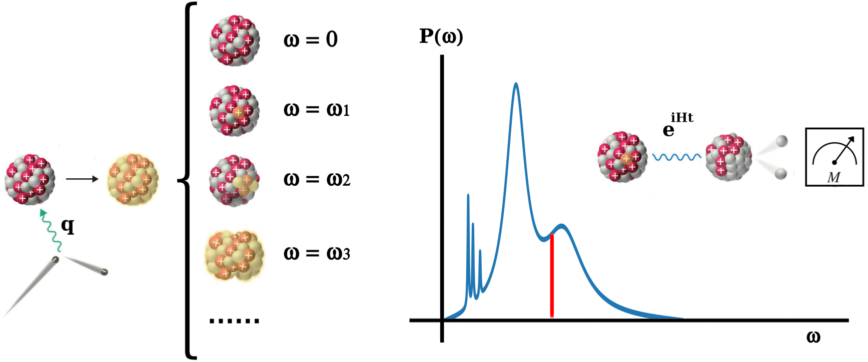




Pastore, Baroni et al. (2018)

Classical algorithm for exclusive processes at fixed q

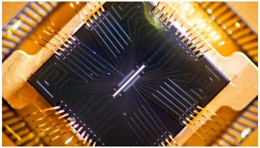
- prepare the target ground state (closed-shell and/or small)
- right after scattering vertex the target is left in excited state
- energy measurement selects subset of final nuclear states (Lovato's talk)
- further time evolution to let system decay
- measure asymptotic state in detector



Roggero & Carlson (2018)

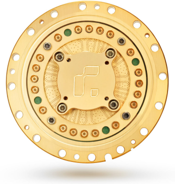
What is a Quantum computer?

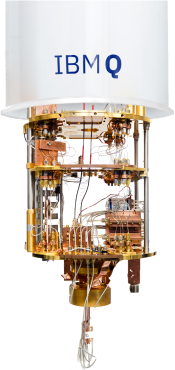
JQI@Univ. of MD



Google

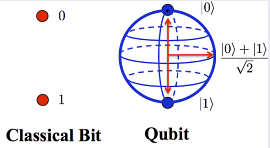
Righetti





- Microsoft?

Bits vs Qubits



- N bits: an integer number $< 2^N$
- N qubits: a vector $|\psi\rangle$ in 2^N-dim Hilbert-space

$\Longrightarrow$ exponentially more information available

Quantum Simulations with qubits

> *"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical."*
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> — R.Feynman (1982)

- in 1996 S.Lloyd shows the conjecture is correct for local interactions

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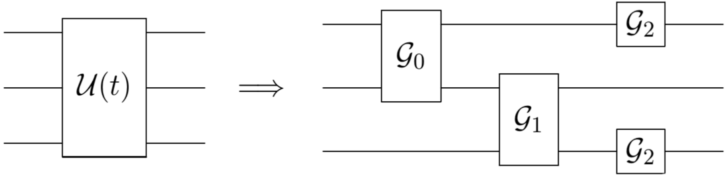
- choose a finite basis to discretize system $\longrightarrow dim(\mathcal{H}) = \Omega \propto e^A$
- physical states can be mapped in states of $\sim log_2(\Omega)$ qubits

$$|\Psi(t)\rangle = U(t)\,|\Psi(0)\rangle$$



Quantum algorithm for exclusive processes at fixed q

- prepare the target ground state on a finite qubit basis
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- energy measurements selects subset of final nuclear states
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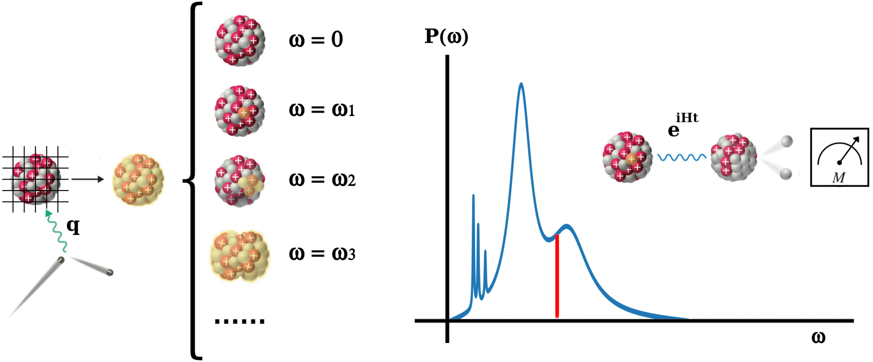
- measure asymptotic state in detector



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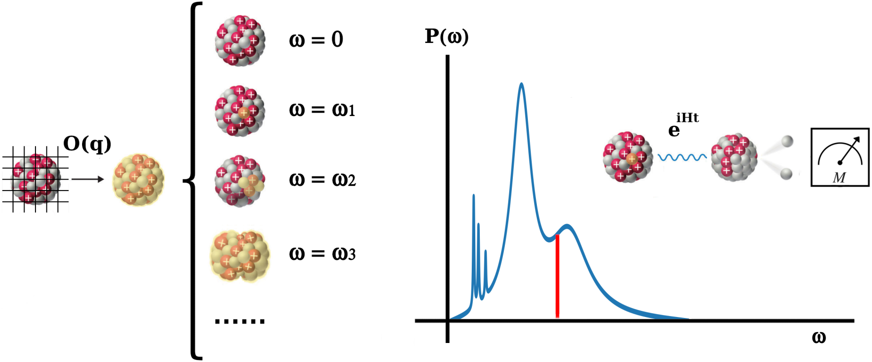

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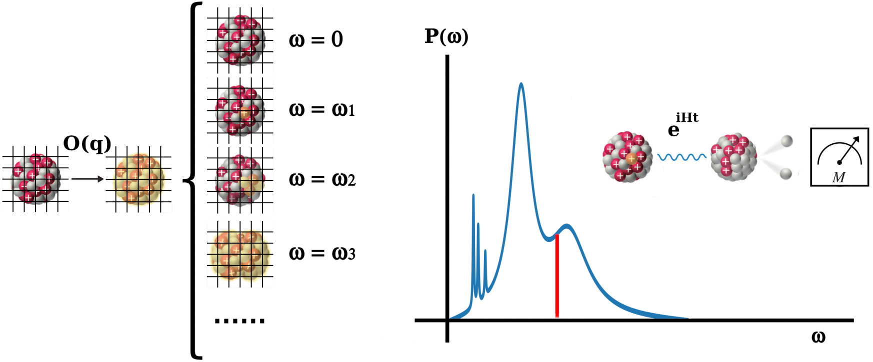

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Quantum algorithm for exclusive processes at fixed q

- prepare the target ground state on a finite qubit basis
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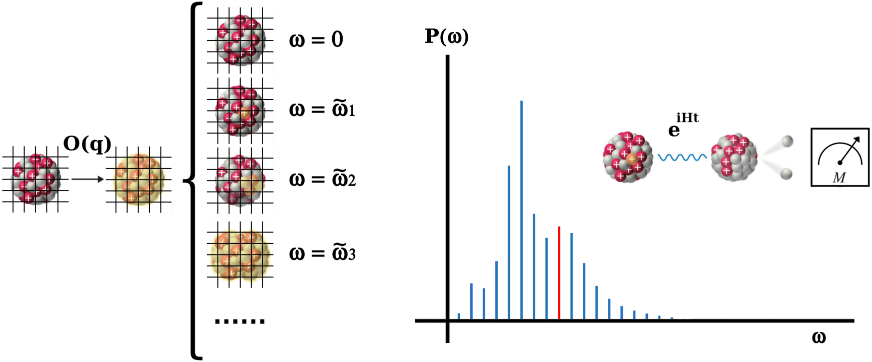

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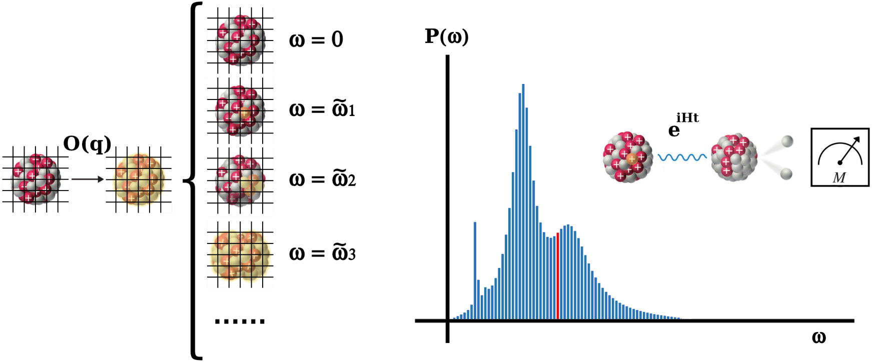

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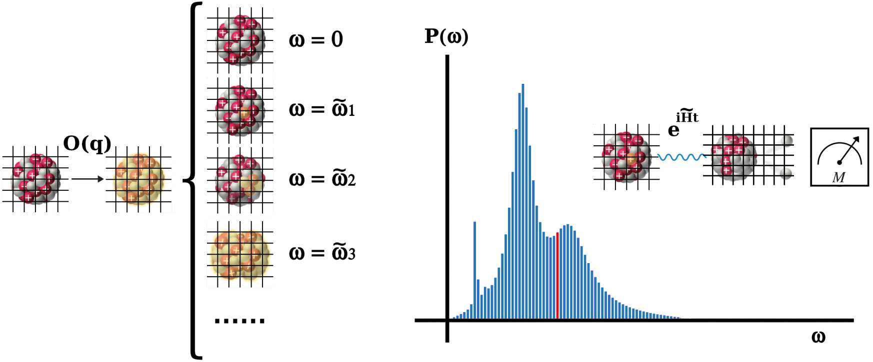

Roggero & Carlson (2018)

How practical is all this?

- pionless EFT on a 10^3 lattice of size 20 fm [$a = 2.0$ fm]
- 10x faster gates and negligible error correction cost (very optimistic)
- want $R(q, \omega)$ with 20 MeV energy resolution

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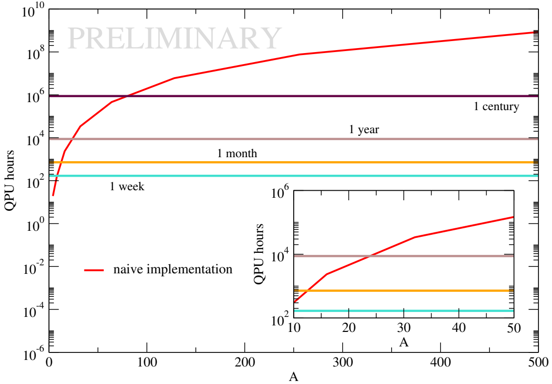

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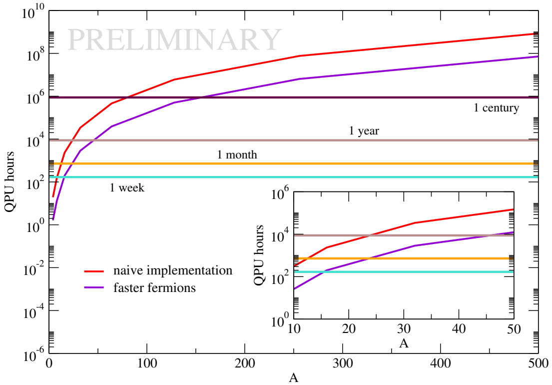

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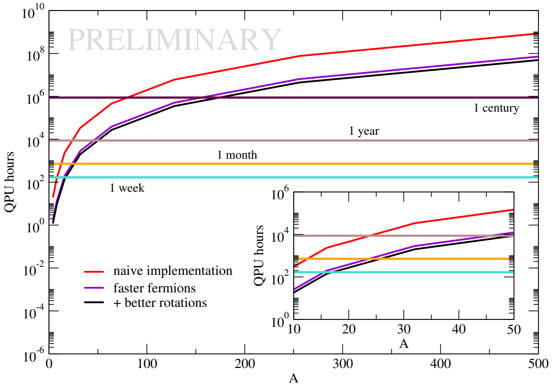

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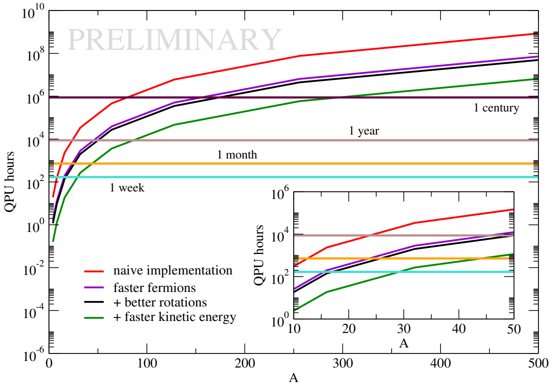

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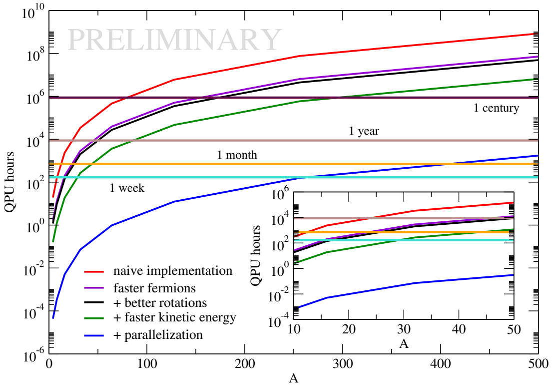

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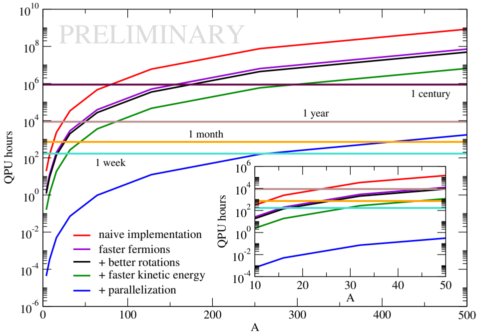
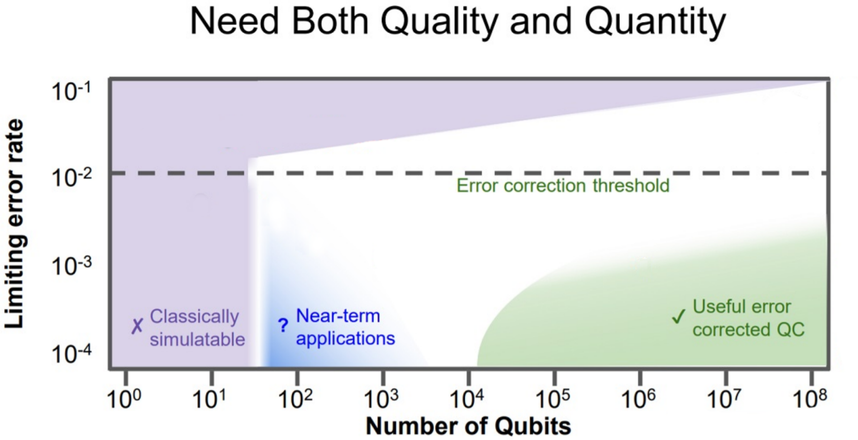


coherence time for ^{40}Ar	
naive	≈ 9 years
optimized	≈ 3 minutes

- algorithm efficiency is critical
- there is still a long way to go
- find new algorithms and/or approximations for near term

Where are we right now?

figure adapted from Google AI



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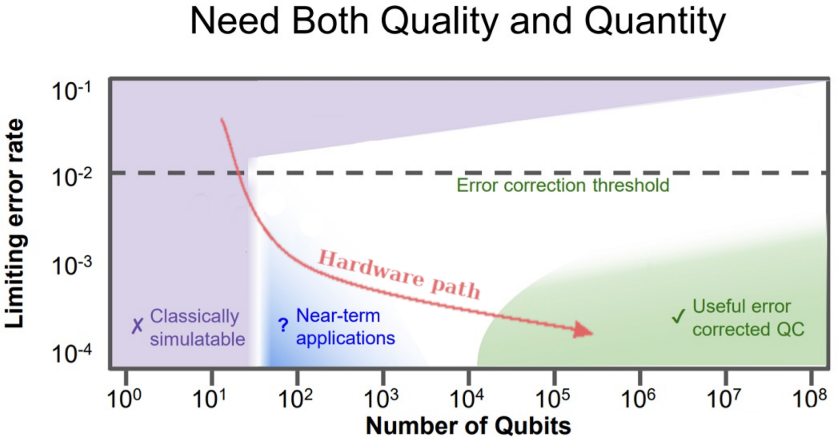

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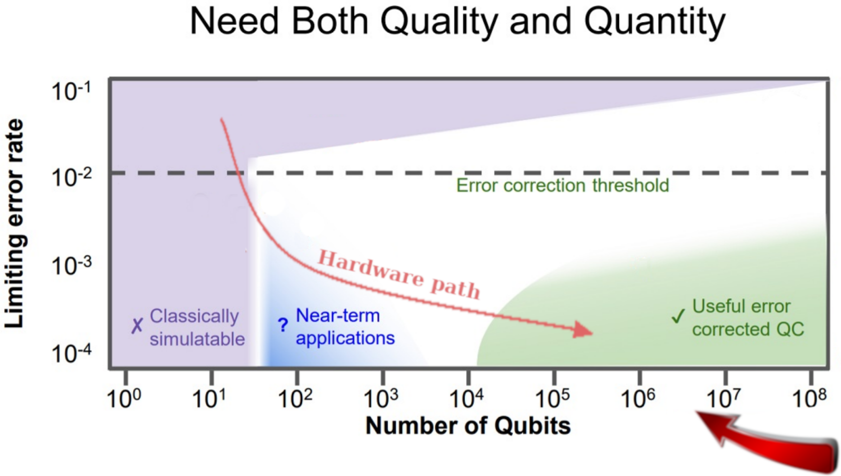

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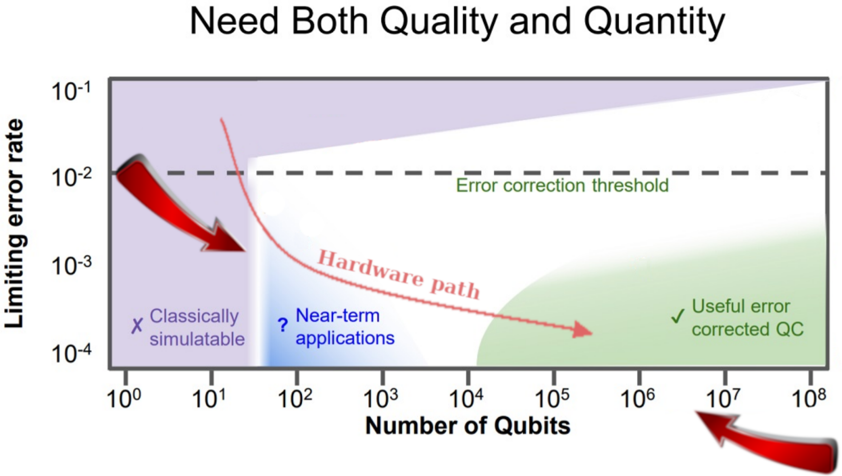

FNAL - INT - LANL effort

A.R. (INT), J. Carlson & R. Gupta (LANL), G. Perdue, A. Li & A. Macridin (FNAL)

Summary

- understanding low-energy dynamics of nuclear many-body systems is important for current and planned neutrino oscillation experiments
- remarkable progress for inclusive x-sec of light nuclei (See Lovato's talk)
  - still not enough for exclusive scattering off ^{40}Ar, need new ideas: short time approximation(See Carlson's talk)? quantum computing?

- QC is an emerging technology with the potential of revolutionarize the way theory calculations are done
- we already know how to simulate efficiently the time-evolution of non relativistic systems and how to study exclusive scattering
- more work has to be done to make all this viable in the near term

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Collaborators:

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