A Quantum-Classical Coprocessing Protocol for the First Step of Simulating Nuclear Reactions

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Introduction

We want to simulate the nuclear scattering reactions. But, we have that:

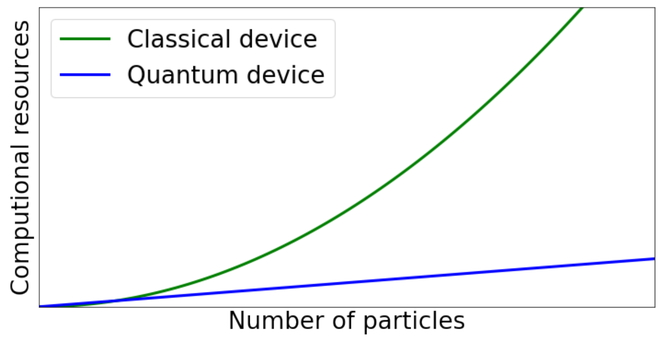
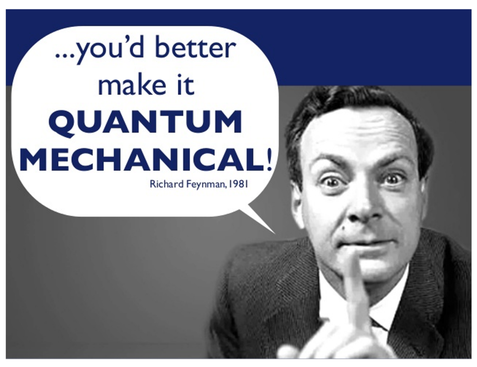


Figure 1: Classical vs Quantum computational resources for simulating a quantum system

A possible solution is to simulate a quantum system using a quantum computer because they should be more efficient than a classical device.



"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy".

Richard P. Feynman

Quantum computing in a nutshell

Essentially a quantum computer is a quantum system with well-characterized states where we can perform controlled operations.

	Classical	Quantum
Units	Bit $\{0, 1\}$	Qubits: $\|\psi\rangle = \alpha\|0\rangle + \beta\|1\rangle$
Operations	Logical Gates (AND,OR,NOT)	Quantum Gates = Unitary Operators

Real time evolution

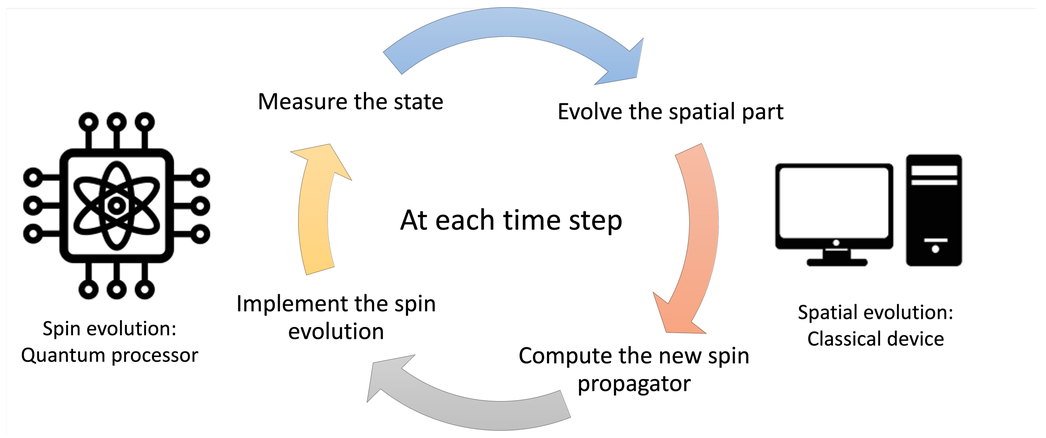
For simulating a nuclear scattering experiment, it is very easy to evolve it in real time through the quantum computer.
We can employ two approaches in a quantum simulation:

- Expanding the Hamiltonian in some basis set and map the elements of the basis set in a state of the quantum processor *Problem:* Up to now this approach is out of reach due to the requested huge number of clean quantum states into the quantum processors.
- with a **hybrid quantum-classical method**. At each time step, we simulate the spin and isospin dynamics through the quantum computer and, in a classical device the spatial evolution. We call this

COPROCESSING

- Work is based on the future paper: Turro, Chistolini, Roggero, Hashim, Kim, Livingston, Luchi, Amitrano, Wendt, Dubois, Quaglioni, Pederiva, *A Quantum-Classical Coprocessing Protocol for the First Step of Simulating Nuclear Reactions on NISQ Hardware*
- Connected to P. Luchi talk on "*Nuclear Quantum Simulations on Quantum Computers in the Optimal Control Context*"

Coprocessing scheme



First step of 2 neutron scattering

We implemented the coprocessing method for describing the 2 neutron scattering. The used Hamiltonian is derived from the Chiral EFT at Leading Order. For the first simulation, we computed the spatial evolution just by solving the Newton equation (saddle point approximation).
The results are obtained running the quantum circuits on the Advanced Quantum Testbed presented in the Berkeley Laboratory.

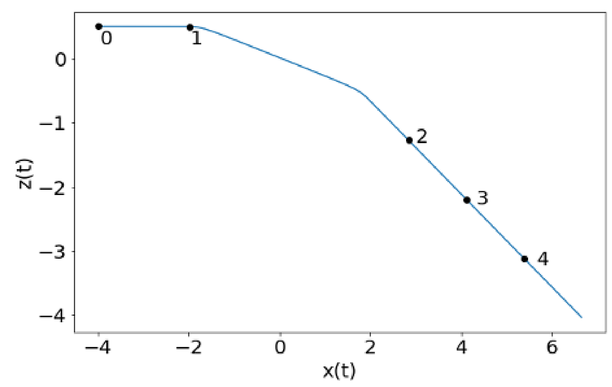


Figure 2: Spatial Trajectory. The enumerated points represent the positions of the two neutrons at time t=0,1,2,3,4 MeV^{-1}

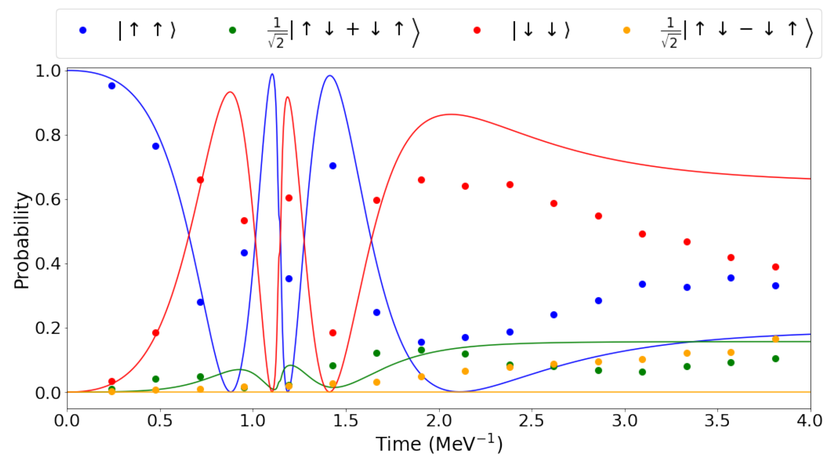


Figure 3: AQT results. Lines indicate the analytical evolution

We are interested in obtaining the asymptotically probability. We cannot get their correct values due to the noise of the machine.
Employing **an algorithm to reduce the noise contribution**

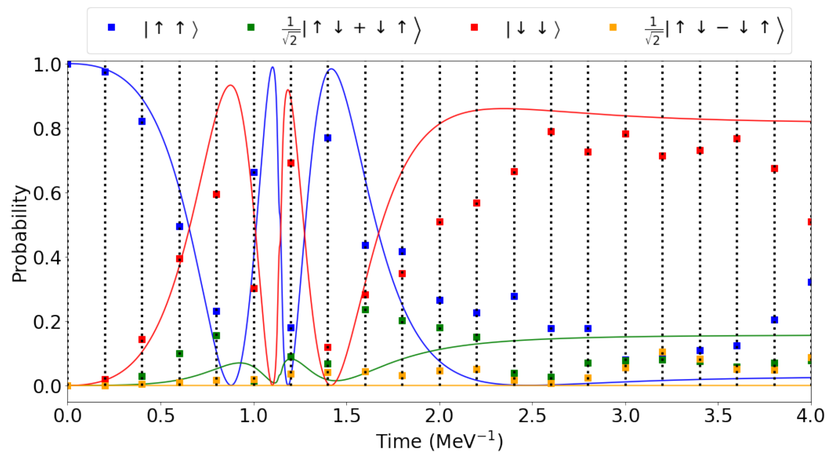


Figure 4: AQT results. Lines indicate the analytical evolution

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