Creating Rabi Oscillations in a Quantum Computer

Exploring Quantum Theory with Qubits

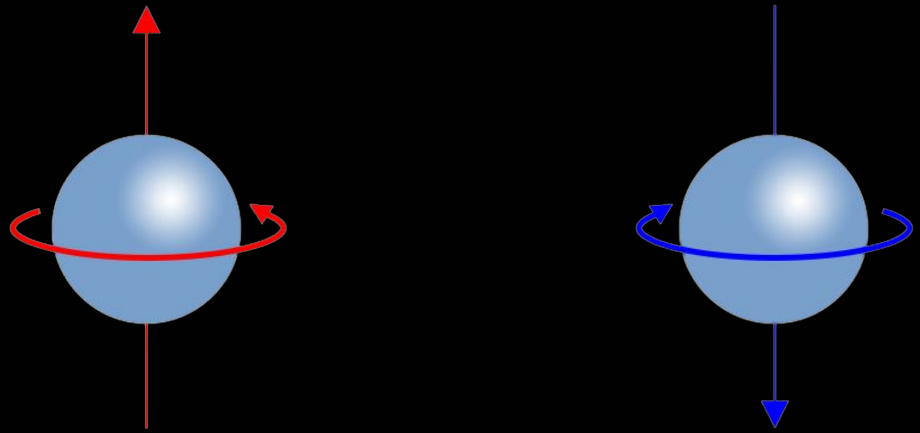
Kristina Prošková, Denisa Vítková, Berenika Zemanová

FZU Fyzikální ústav Akademie věd České republiky

OTEVŘENÁ VĚDA
AKADEMIE VĚD ČR

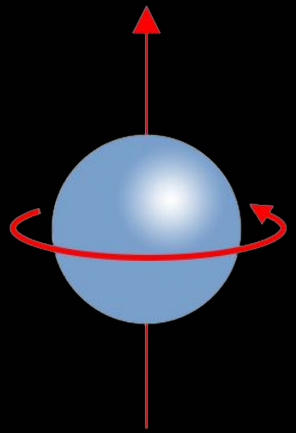
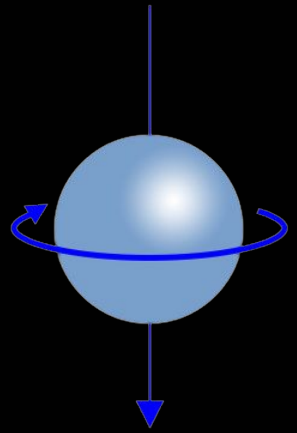
Introduction to Quantum Mechanics

- **Qubits** are the building blocks of quantum computers
- The simplest quantum systems



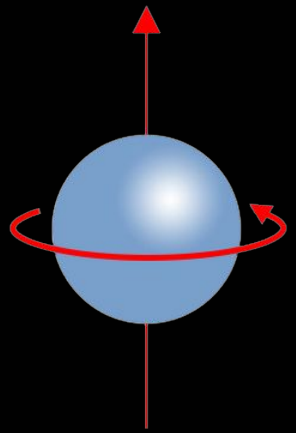
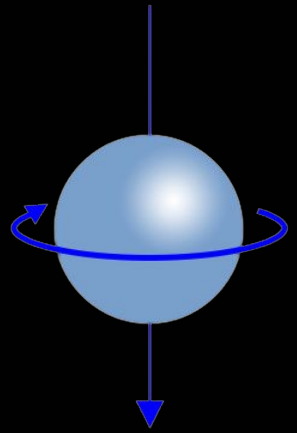
Introduction to Quantum Mechanics

- **Qubits** can be in two states at once = **superposition**

$$|\text{state}\rangle =$$  $+$ 

Introduction to Quantum Mechanics

- **Measurement** compels the system to land on a specific state

$$|\text{state}\rangle =$$  or 

- Which state? **Probability**

Introduction to Quantum Mechanics

- Quantum systems evolve in time following **Schrödinger's equation**:

$$|\text{state at time t}\rangle = e^{\frac{i}{\hbar}Ht}|\text{state at t=0}\rangle$$

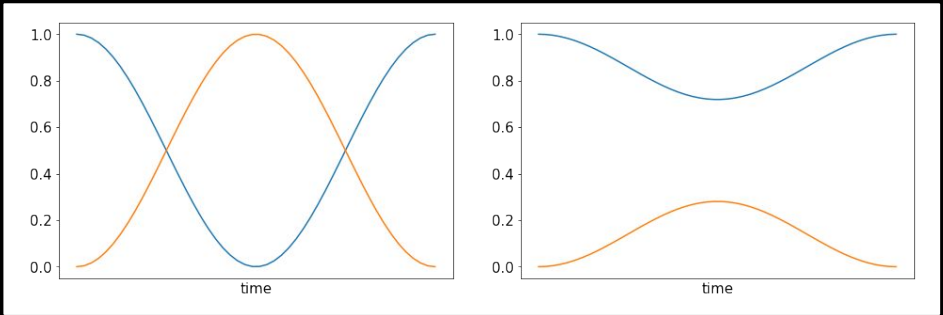
'H' is called a **Hamiltonian** (total energy)

- For a single qubit, 'H' is a 2 x 2 matrix

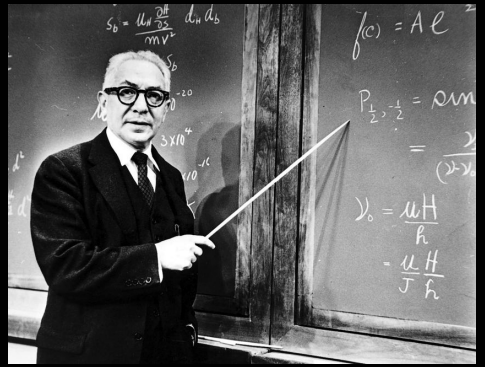
$$\begin{pmatrix} h_1 & h_2 \\ h_3 & h_4 \end{pmatrix}$$

Rabi Oscillations

- The probability of a qubit being in state 0 and 1 will oscillate with time
- Universal behaviour called Rabi oscillations – qualitatively of two types: **level crossing** and **no level crossing**



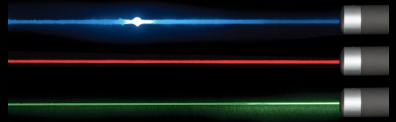
- Discovered by **Isidor Isaac Rabi**
- Nobel Prize in Physics in 1944



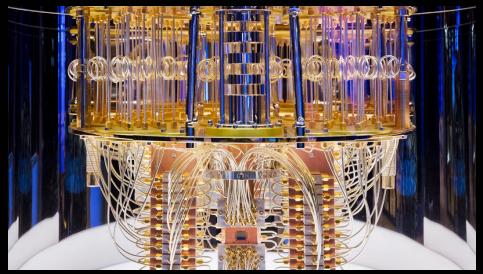
Isidor Isaac Rabi

Applications

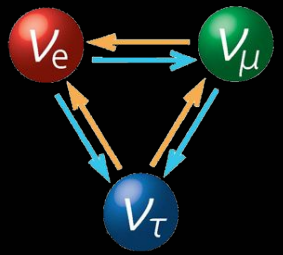
- Photonics and LASER



- Gate operations in quantum computers



- Neutrino oscillations



- Magnetic resonance imaging (MRI)

Methodology

How to Create Rabi Oscillation?

- Find a single qubit Quantum Computer

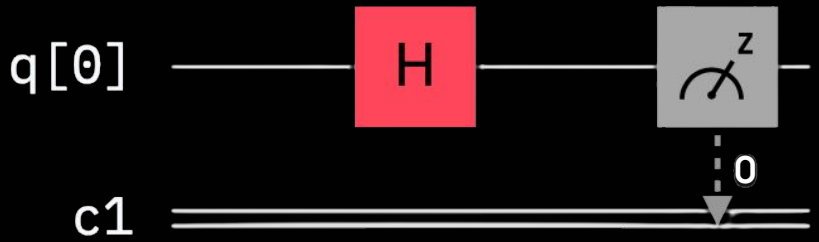
IBM Q System One

How to Create Rabi Oscillation?

- Choose any Hamiltonian you like

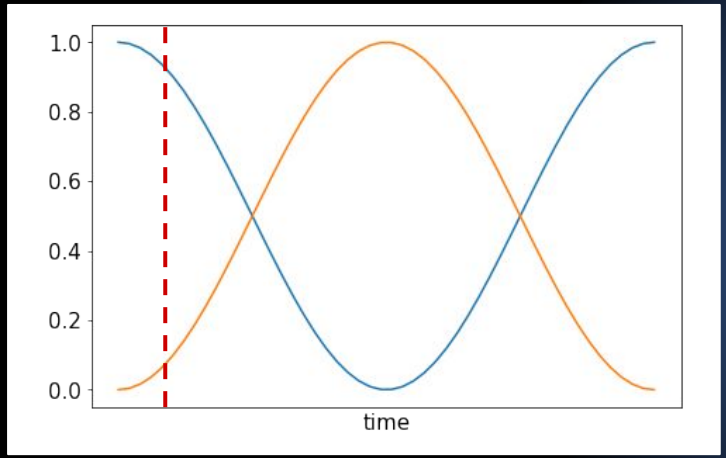
$$\begin{pmatrix} h_1 & h_2 \\ h_3 & h_4 \end{pmatrix}$$

- Use Qiskit to implement the following circuit in the Quantum Computer:



How to Create Rabi Oscillation?

- Repeat this experiment for a specific time instance
- The relative proportion of getting 0 or 1 gives us the respective probabilities
- Repeat this set up for a number of time instances to get the oscillatory behaviour



Aim of the Project

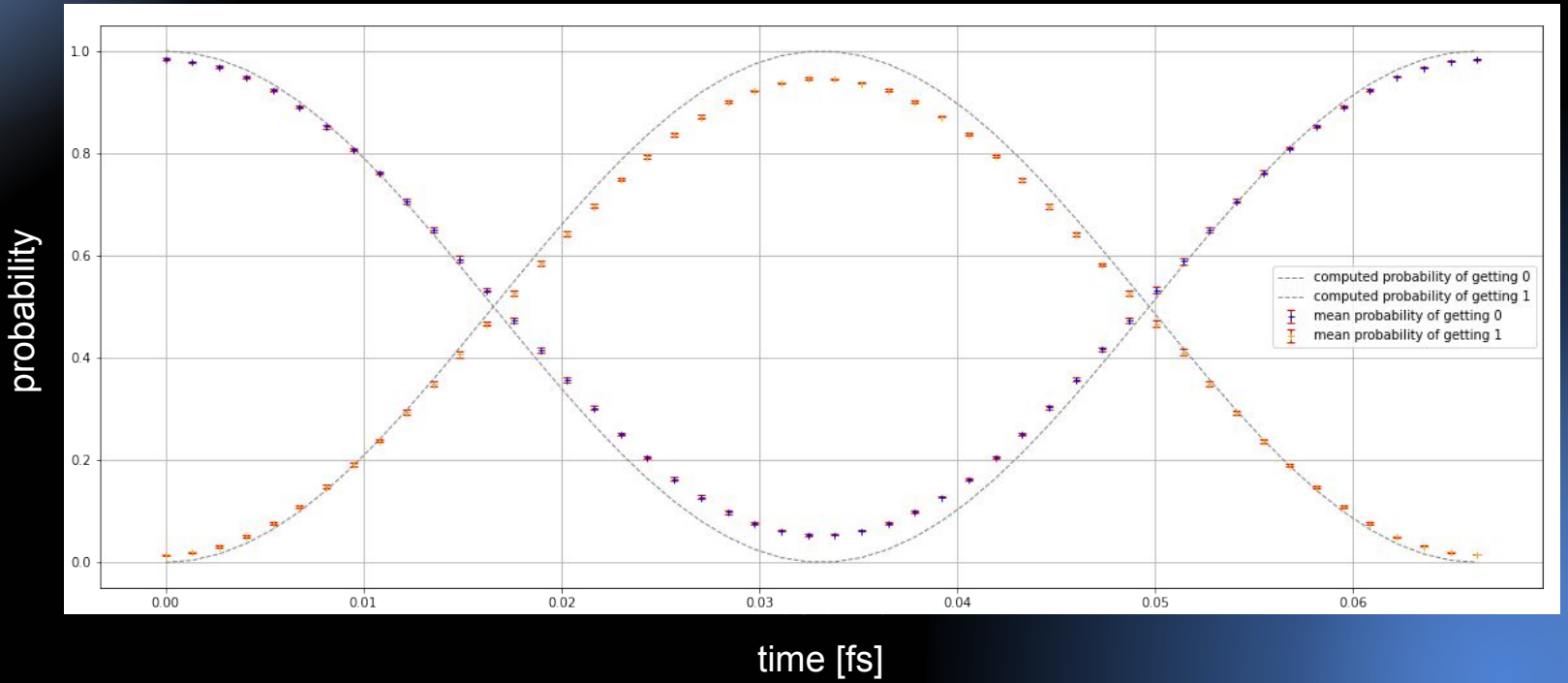
- Reproduce Rabi oscillation in an **IBM quantum computer**
- Capture how a qubit evolves under different Hamiltonians
- Analyse the effects of error and how to mitigate it
- We will work with these three Hamiltonians:

$$H_1 = \begin{pmatrix} 71 & 50i \\ -50i & 71 \end{pmatrix} \qquad H_2 = \begin{pmatrix} 3.2 & 0.3 \\ 0.3 & 4.16 \end{pmatrix} \qquad H_3 = \begin{pmatrix} 5 & 3+2i \\ 3-2i & 5 \end{pmatrix}$$

Results

Results: Before Error Mitigation H_1

Mean error: 6.244%

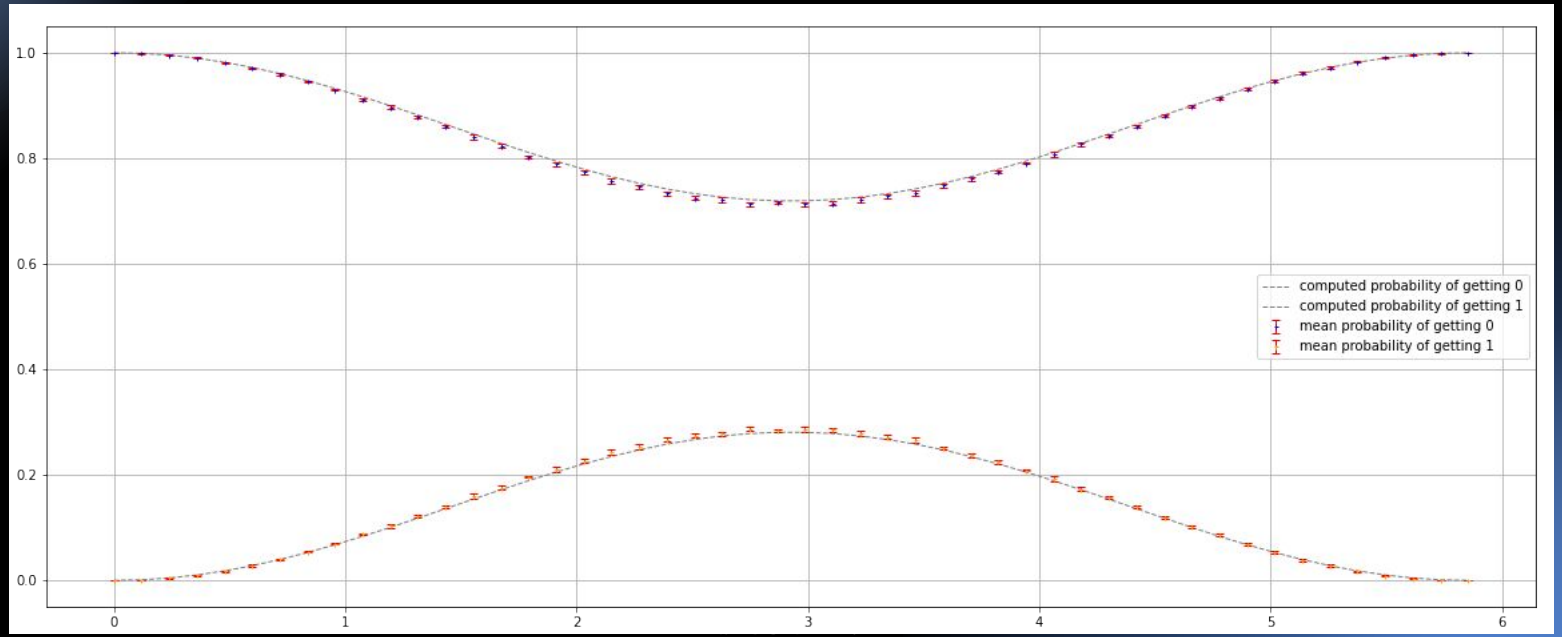


Results: After Error Mitigation H_1

Mean error: 1.061%

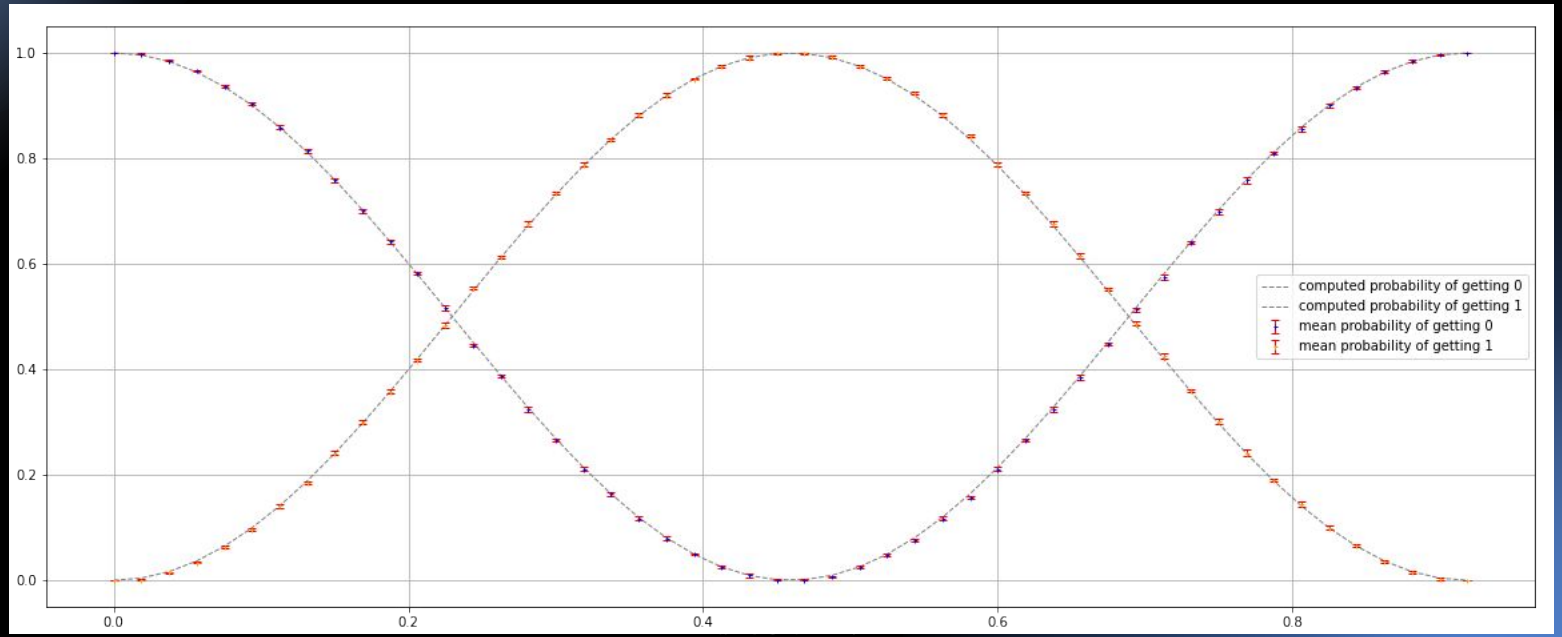
Results: H_2

Mean error: 0.417%



Results: H_3

Mean error: 0.519%



Conclusion

Conclusion

- We successfully reproduced Rabi oscillations in IBM-Q
- It shows good agreement with theoretical predictions prior to error mitigation
- After error mitigation the agreement is excellent

System	Mean Error
H_1 Before Error Mitigation	6.244%
H_1 After Error Mitigation	1.061%
H_2 After Error Mitigation	0.417%
H_3 After Error Mitigation	0.519%

An Invitation

- The quantum world is rich – entanglement, quantum cryptography, quantum teleportation, etc.
- We firmly believe high school students can understand basics of quantum computing
- You can find more details, including the relevant maths and physics background, on our webpage:

Thank you for your attention!

Link to our webpage

https://t.ly/_2j0