

# Quantum Information Science

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MITRE Sponsored Research

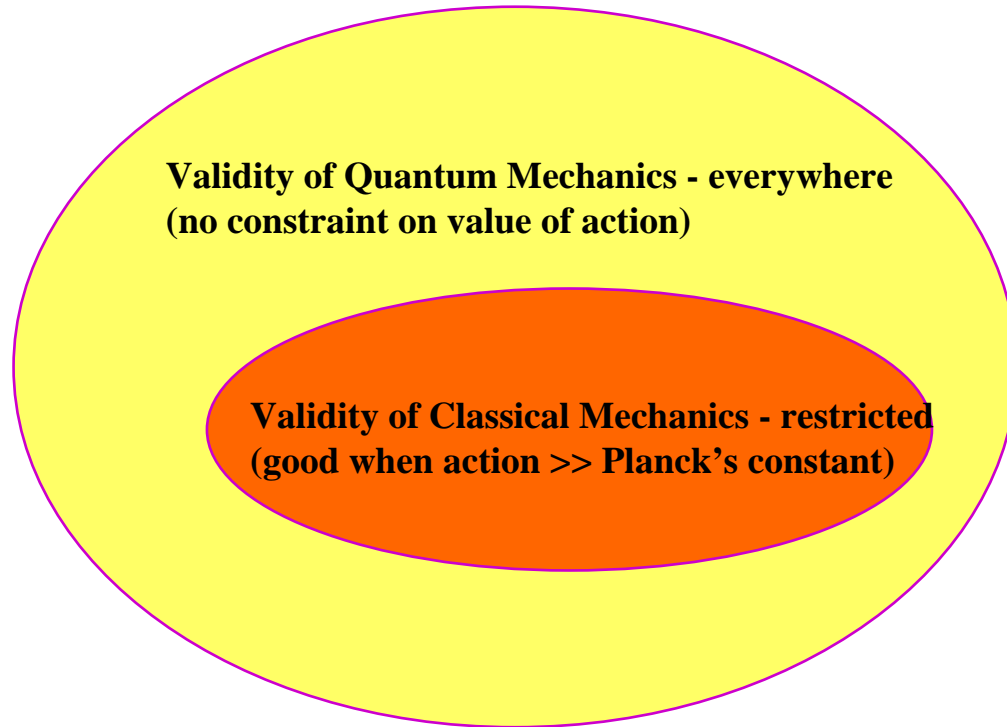
The logo consists of a cluster of 3D cubes in yellow, orange, and blue, arranged in a stepped pattern. To the right of the cubes, the text "MITRE Technology Program" is written in a bold, sans-serif font. "MITRE" is in yellow, "Technology" is in orange, and "Program" is in blue.

MITRE  
Technology  
Program

# Problem

- Quantum computers can solve problems that are effectively *impossible* to solve with classical computers.
- What is the best design for a practical quantum computer?
  - fault tolerance, scalability, efficiency
- Can we discover new quantum computing algorithms, and new applications?

# Background



This diagram (roughly) indicates the conditions for which one *must* use quantum mechanics (yellow), and those for which one *may* use classical mechanics (red)

Quantum information science exploits unique features of quantum mechanics to obtain results difficult or impossible to achieve with classical mechanical systems.

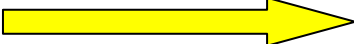
# Activities

- **Perform theoretical and systems engineering quantum computing analyses**
- **Develop quantum information processing components using the linear quantum optics or photonic cluster approach**
- **Design/demonstrate quantum memory device; prototype non-linear sign shift gate or cluster fusion operator**
- **Demonstrate quantum computing component(s)**

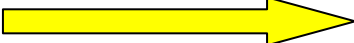
# Objective

- Develop the *world's first efficient, scalable quantum computer design*; prototype selected components of the design
- Obtain *fundamental theoretical results*: maintain MITRE's position as a world leader in the field of quantum information science
- Contribute to solving problems of national importance in the areas of code breaking, steganography analysis, real-time analysis of spread-spectrum communications, high-intensity computing, etc.


# Highlight

**CNOT:**  $U_{CN} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$    $\begin{matrix} |00\rangle \rightarrow |00\rangle \\ |01\rangle \rightarrow |01\rangle \\ |10\rangle \rightarrow |11\rangle \\ |11\rangle \rightarrow |10\rangle \end{matrix}$

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**Hadamard:**  $H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$    $\begin{matrix} |0\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \\ |1\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle) \end{matrix}$

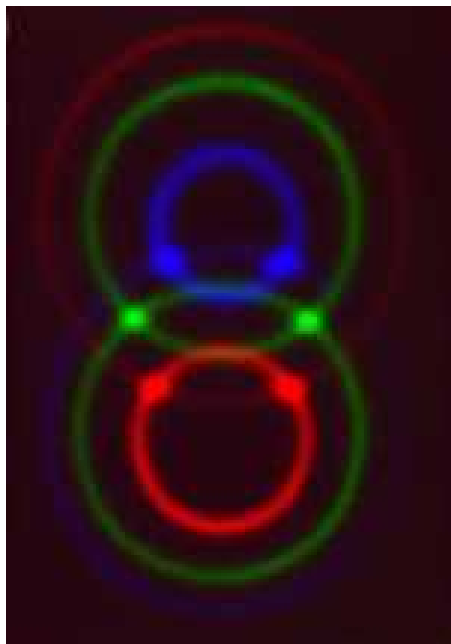
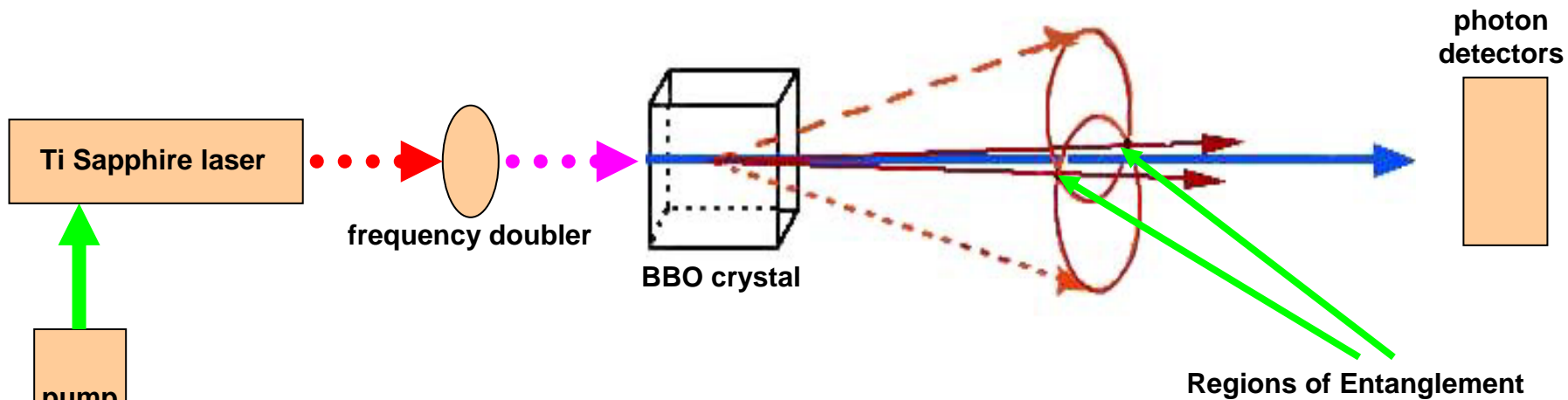
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$$U_{CN}H|00\rangle = U_{CN} \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle)|0\rangle$$
$$= \frac{1}{\sqrt{2}} (|00\rangle + |11\rangle)$$


**Hadamard followed by CNOT  
yields an entangled state**

such states provide computational capabilities  
that are not possible in classical computers

# Demonstration



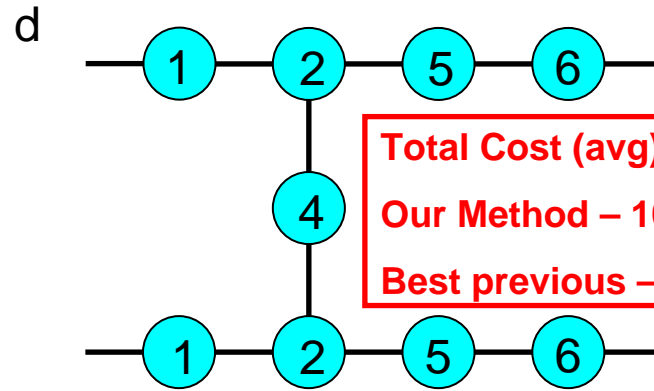
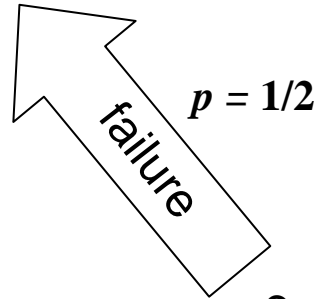
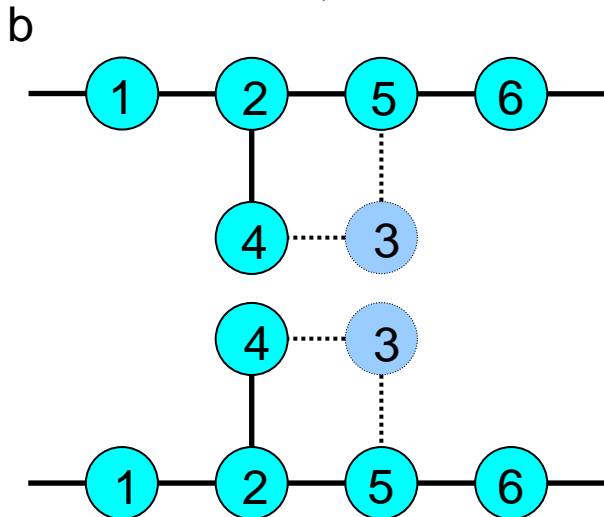
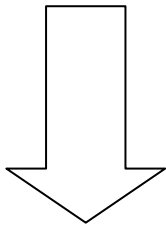
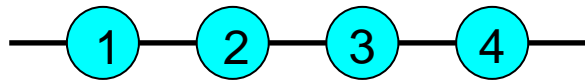
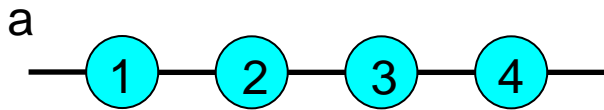
front-end view (actual experimental photograph)

**MITRE**

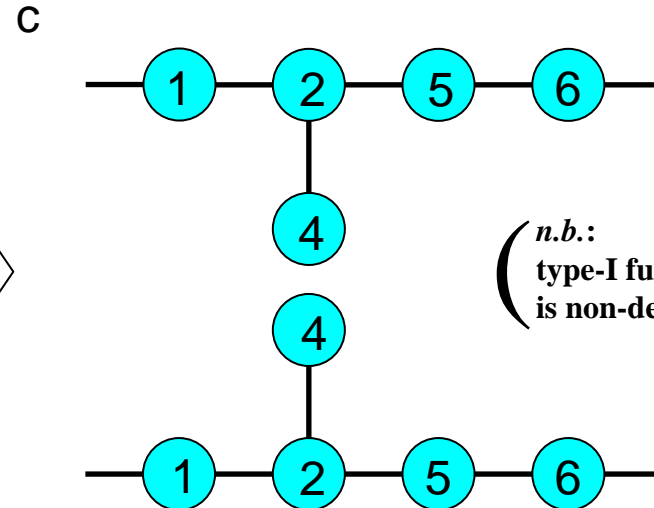
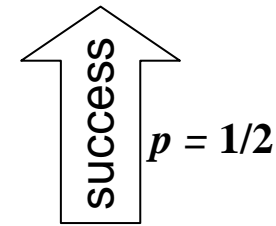
# Impacts

- **This work places MITRE at the very frontier of research worldwide: we are now recognized as a leading player in this high-visibility research area**
- **Continue to develop a unique resource to assist government to manage development and deployment of this new technology**
- **Will make basic advances in technology that will be crucial in addressing problems of national importance**

# Future Plans



**Total Cost (avg):**  
**Our Method – 10 bonds**  
**Best previous – 34 bonds**



(*n.b.:*  
 type-I fusion  
 is non-deterministic)

**PHOTONIC CLUSTER BUILDING PROCESS**

**MITRE**