# Introduction to Quantum Networking

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NSF

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1st Global Research Platform Workshop.

# I. Quantum Communication Networks

**Bits**

- Fundamental building blocks of classical computers:
- STATE: 0 or 1
- Definitely 0 or 1

**Qubits**

- Fundamental building blocks of quantum computers:
- STATE: $|0\rangle$ or $|1\rangle$
- Superposition: $a\,|0\rangle + b\,|1\rangle$


**A single qubit can be forced into a *superposition* of the two states denoted by the addition of the state vectors:**

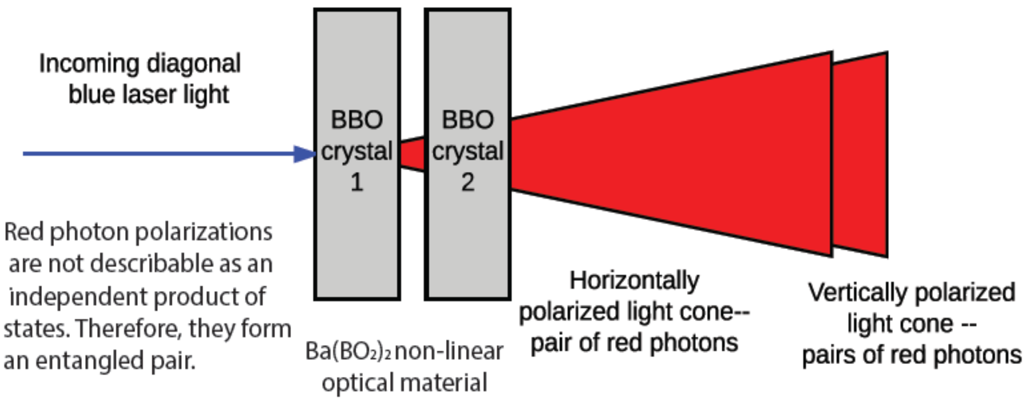
$$|\psi\rangle = \alpha\ |0\rangle + \alpha\ |1\rangle$$

- **Photon**: Vertical or Horizontal polarization
- **Electron**: Spin up or Spin down
- **Atom**: Discrete energy levels

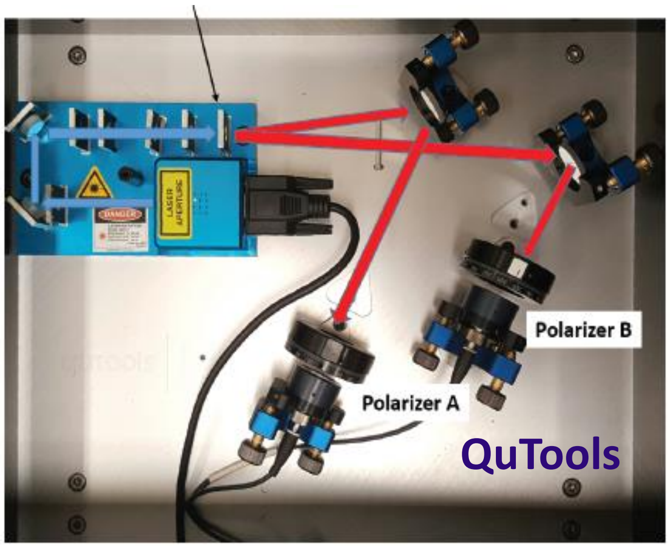
# Creating entanglement with light

Quantum entanglement: Is a quantum phenomenon in which the quantum states of two or more objects have to be described with reference to each other.

- *"Spooky action at a distance"* - A. Einstein
- *" The most fundamental issue in quantum mechanics"* –E. Schrödinger




– "Red" photons are always born in pairs



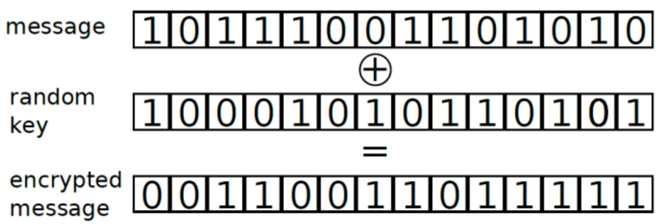

$$|\phi^+\rangle = \frac{1}{\sqrt{2}}\left(|HH\rangle + |VV\rangle\right)$$

$$|\phi^-\rangle = \frac{1}{\sqrt{2}}\left(|HH\rangle - |VV\rangle\right)$$

PRL 75, 4337 (1995)

# Connection to security: quantum cryptography

**The best method to encrypt a message is the <u>One-Time-Pad (OTO)</u> protocol: for a n-bit message, a n-bit secure key is needed.**




<u>Quantum cryptography</u>

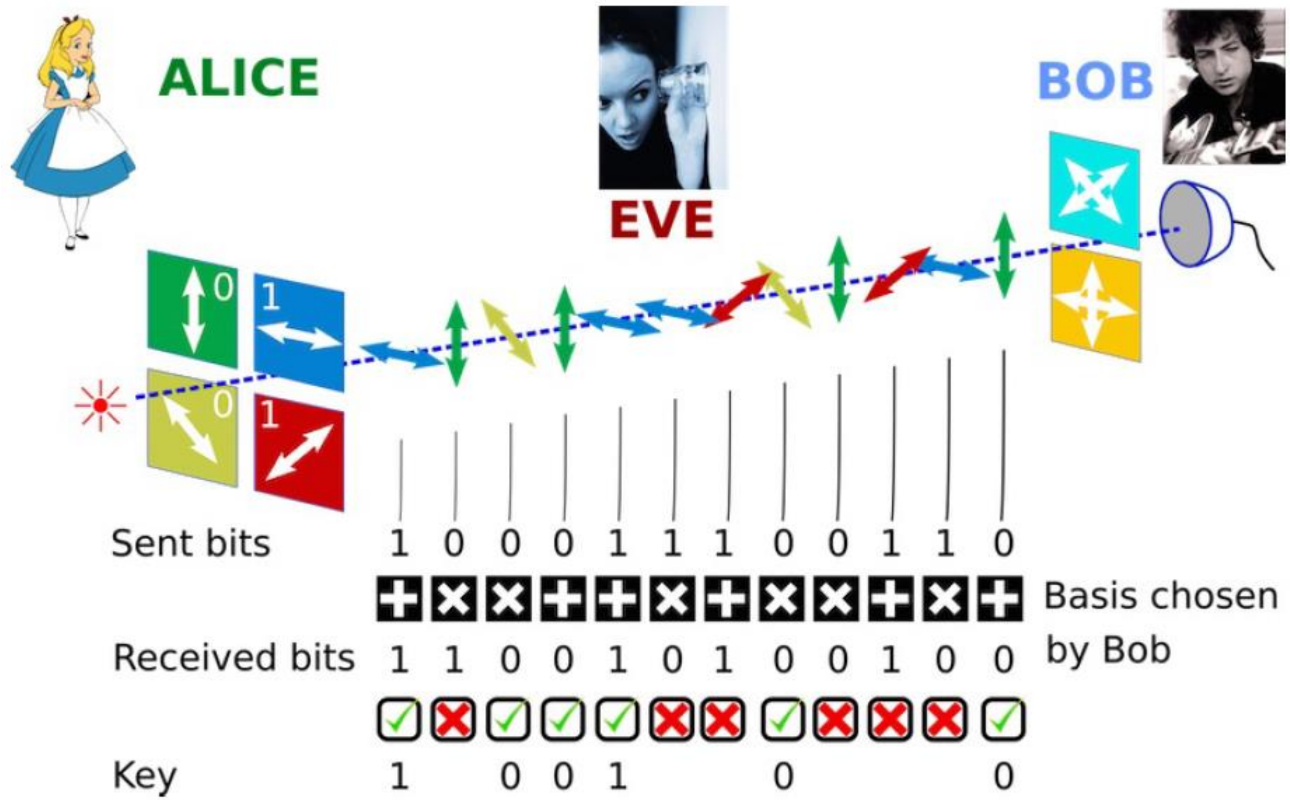
Basic tools:

- two non-commuting basis

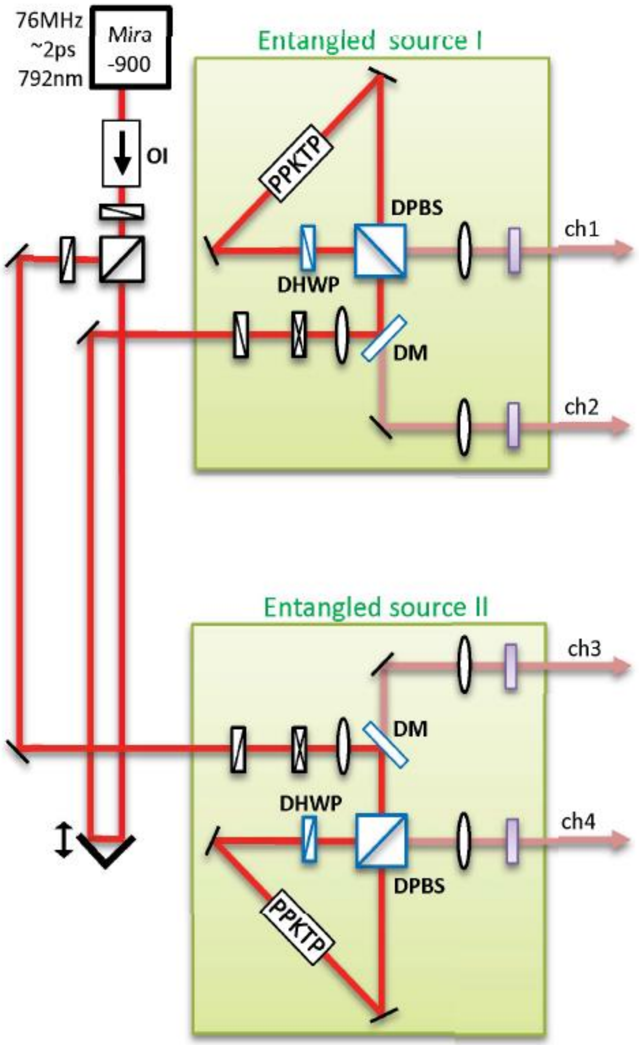
- no-cloning theorem

- any measurement perturbs the systems

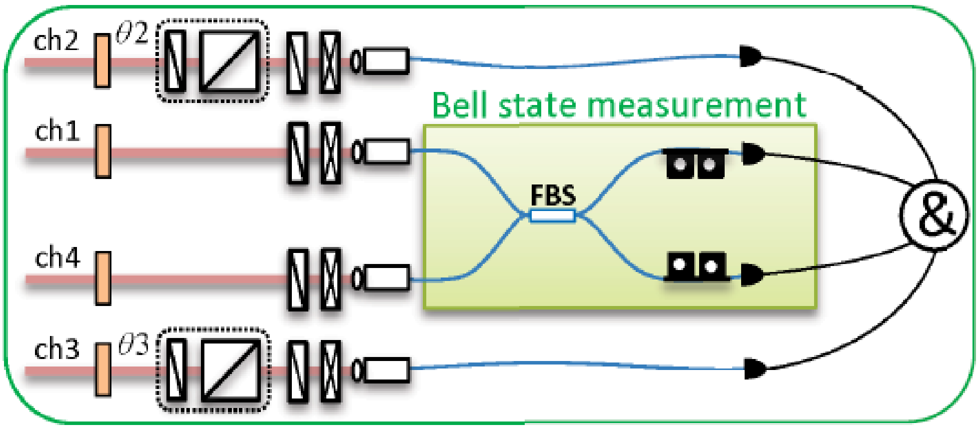
- Eve detection!



# Connection to data transmission: quantum teleportation




$$|\psi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|HV\rangle \pm |VH\rangle) \text{ and } |\phi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|HH\rangle \pm |VV\rangle)$$




$$|\psi^{-}\rangle_{34} \otimes |i\rangle_1 = \frac{1}{\sqrt{2}}(|HV\rangle - |VH\rangle)_{34}(\alpha|H\rangle + \beta|V\rangle)_1$$

$$= \frac{1}{2}\left[\begin{array}{l} |\psi^{+}\rangle_{41}(-\alpha|H\rangle + \beta|V\rangle)_3 + |\psi^{-}\rangle_{41}(\alpha|H\rangle + \beta|V\rangle)_3 \\ + |\phi^{+}\rangle_{41}(\alpha|V\rangle - \beta|H\rangle)_3 + |\phi^{-}\rangle_{41}(\alpha|V\rangle + \beta|H\rangle)_3 \end{array}\right]$$

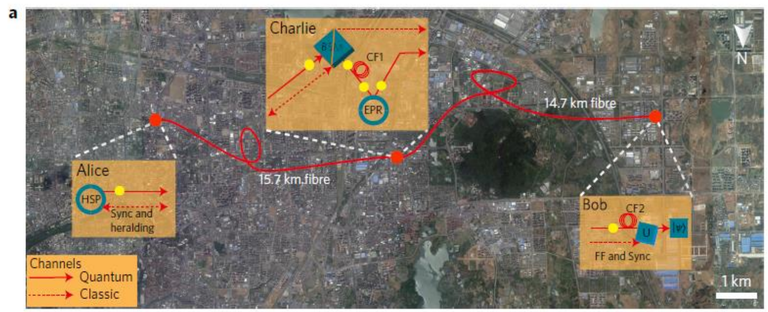
$$|\psi^{-}\rangle_{34} \otimes |i\rangle_1 \rightarrow |\psi^{-}\rangle_{41} \otimes |f\rangle_3$$

$$|f\rangle_3 = (\alpha|H\rangle + \beta|V\rangle)_3$$

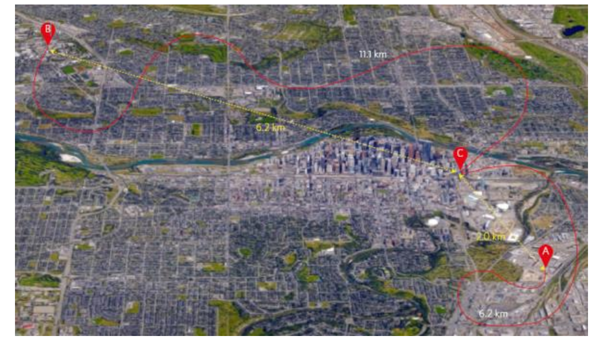
Nature 390, 575 (1997).
Scientific Reports 5, 9333 (2014)

**Quantum communication:** Is the ability to transmit qubits or entanglement between two distant location.

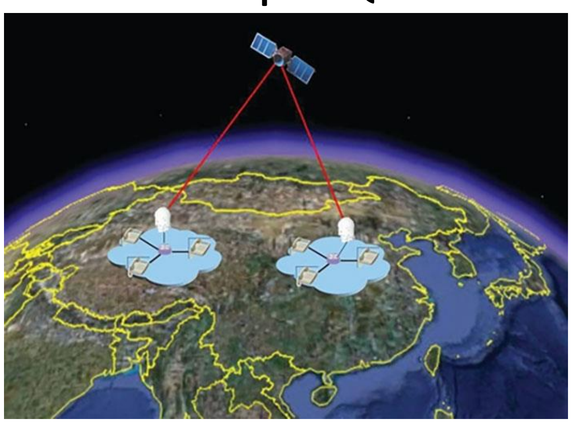
### Hefei-QN



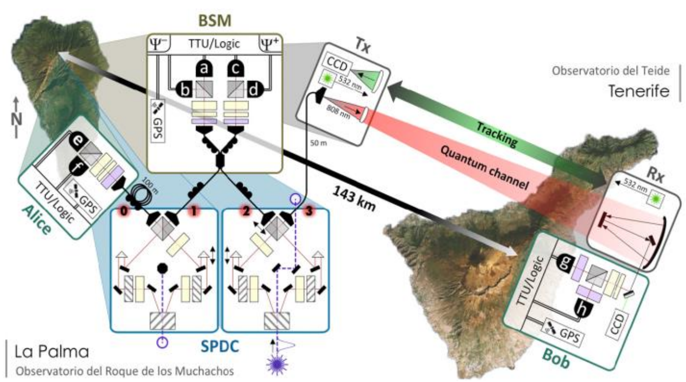

### Calgary QN



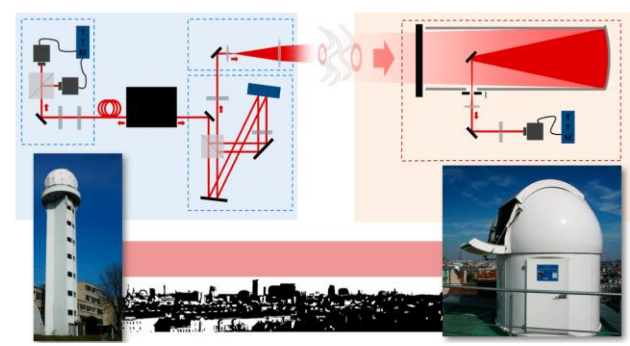
### Chinese Space QN



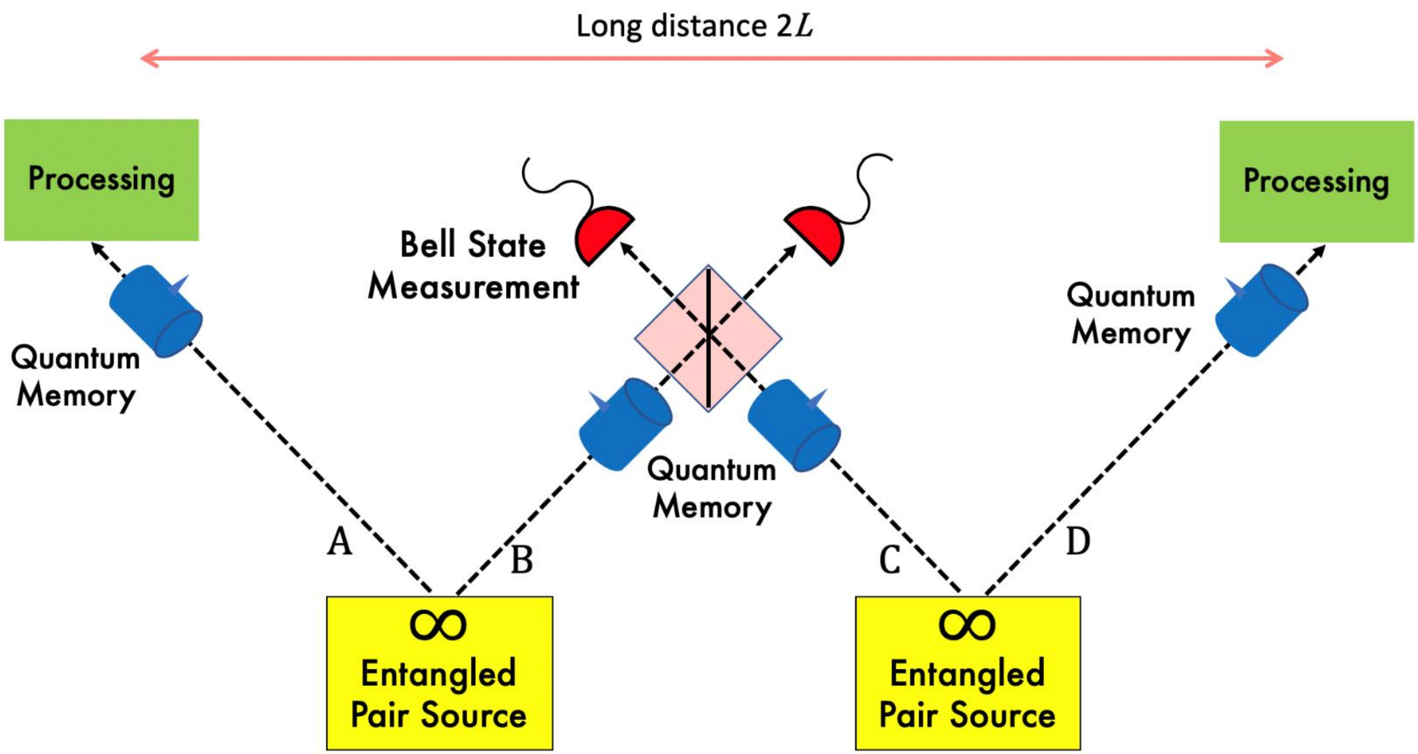
### Tenerife QN




### Vienna QN



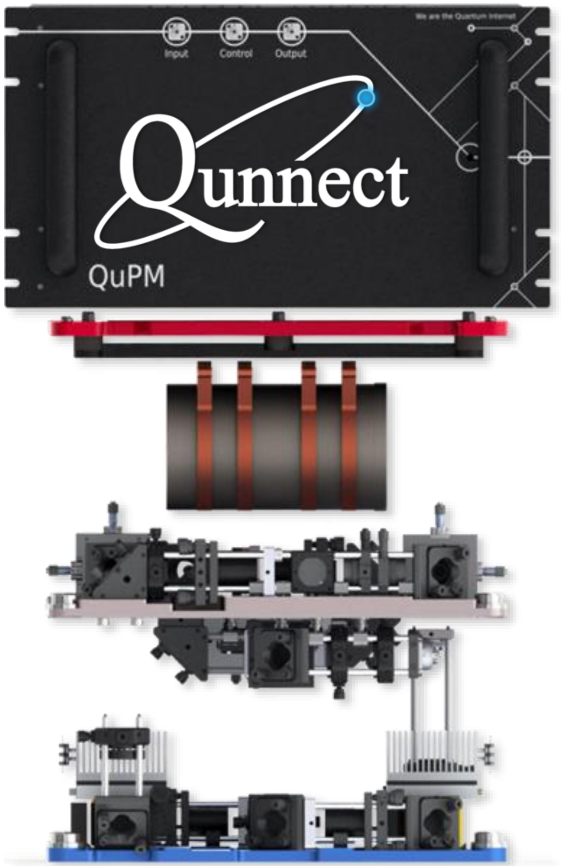
- Good entanglement sources compatible with QMs.
- Quantum Memories with good efficiency, fidelity and storage time.
- Entanglement distribution using optical fibers.

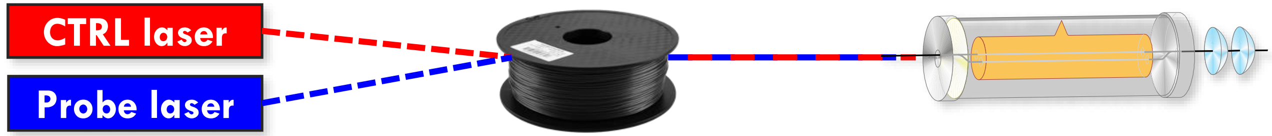


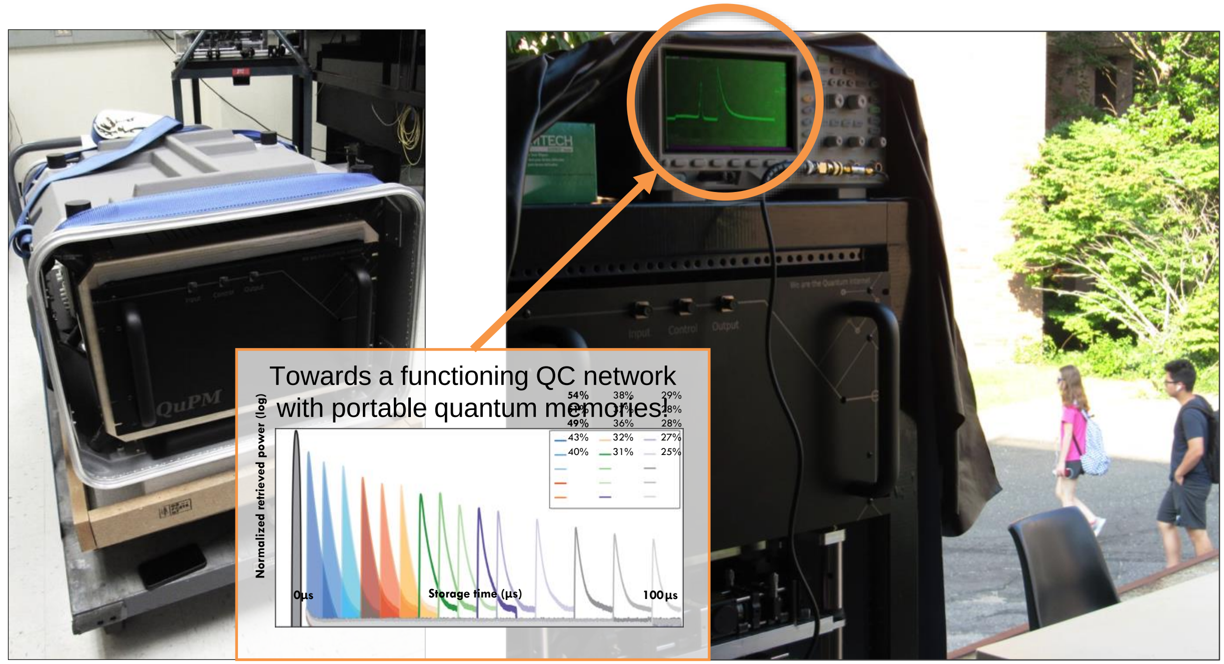

- All connections must preserve entanglement with high fidelity.
- Devices should be easy to operate, preserving high fidelity.
- Devices must be economically achievable for mass production.

# II. Long Island Quantum Information Distribution Network (LIQuIDNet)

# SBU Fully portable room temperature quantum memories




- **High-Fidelity (~99%)**
- **Storage efficiency (~50%)**
- **Storage time (~100us)**
- **Room-Temperature**

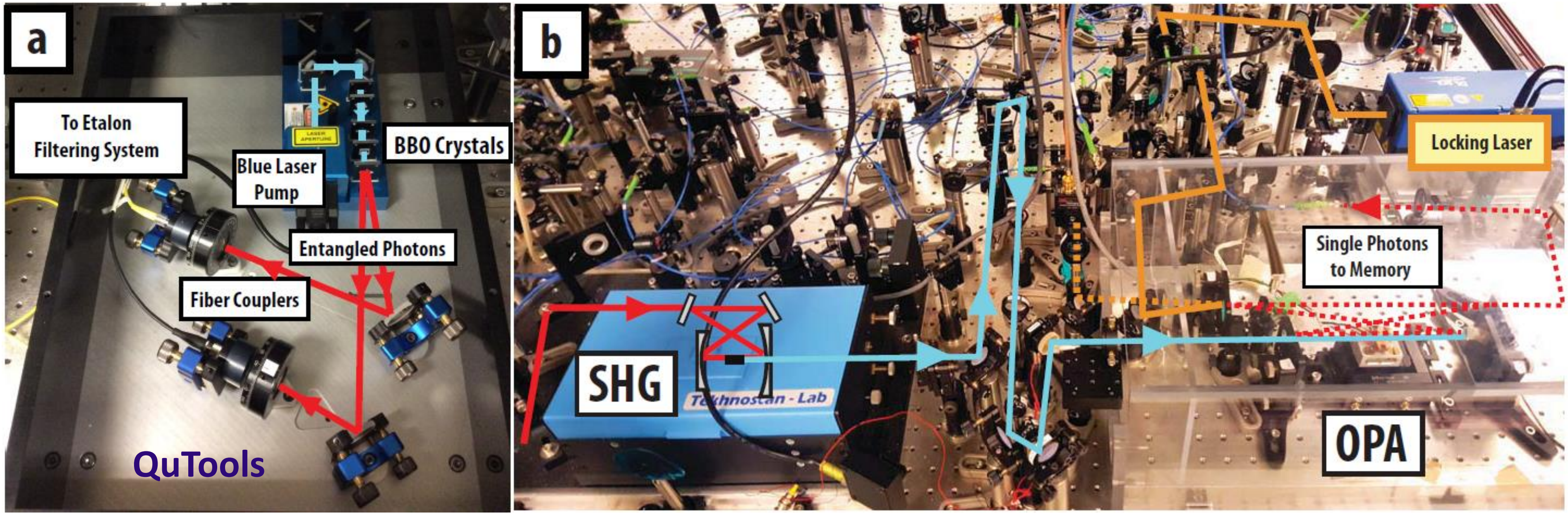
**Scientific Reports 5, 7658 (2015).**

**Phys. Rev. Applied 8, 034023 (2017).**

**Phys. Rev. Applied 8, 064013 (2017).**

**Patent pending: PCT/US19/24601**

# SBU Entanglement sources tuned for quantum memory operation

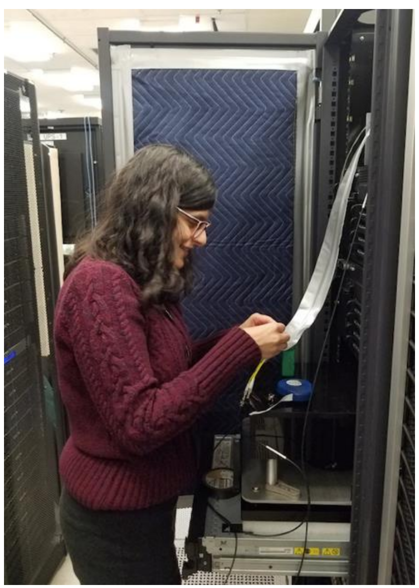


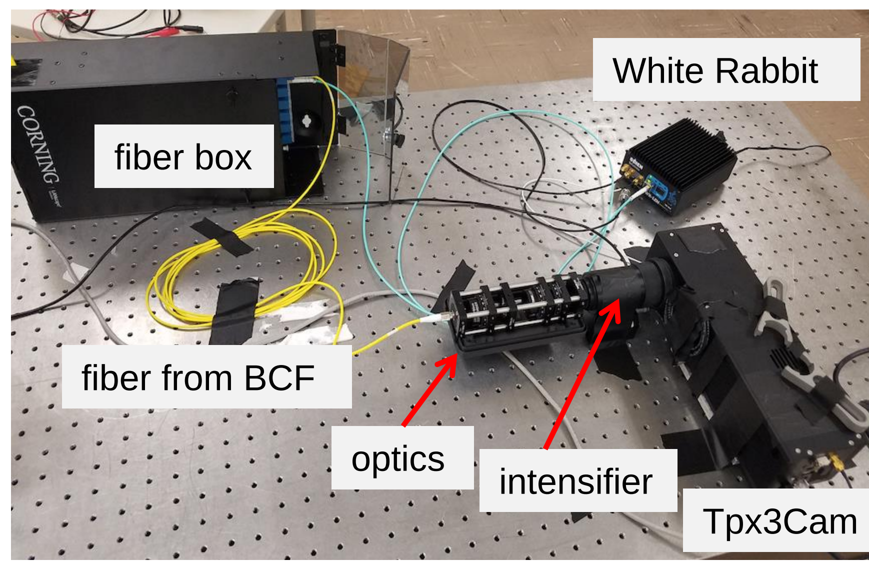

Portable Entangled source

Quantum memory tuned entangled source

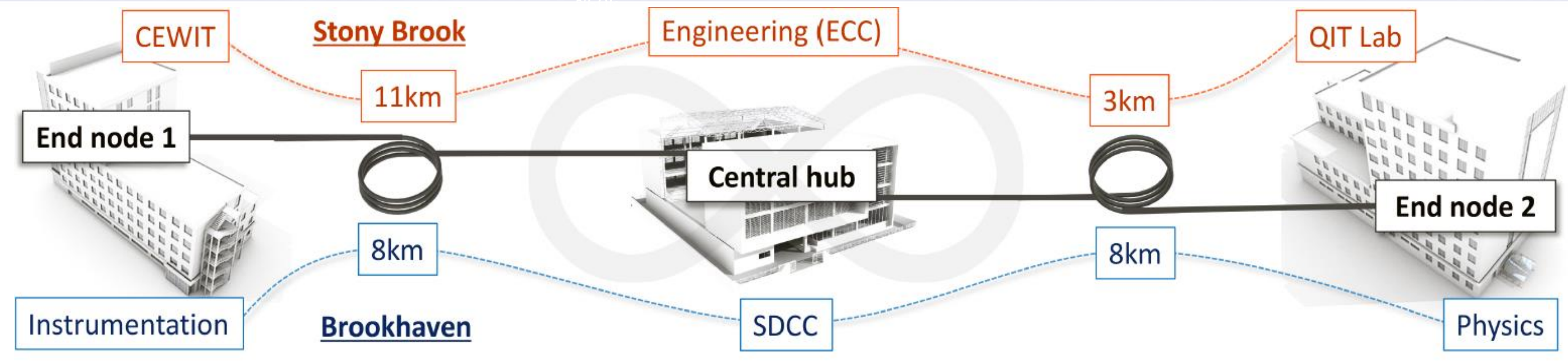
- Resonant to $^{87}$Rb absorption line
- Already producing single photons with a 2 MHz bandwidth
- Entanglement production at MHz ratios.

# BNL QIST Instrumentation Laboratory.





# Quantum entanglement distribution in BNL




**The Register** — Biting the hand that feeds IT

Data Centre ▸ Networks

**US boffins tangle with quantum entanglement in spooky rack-mounted networking hardware**

BROOKHAVEN NATIONAL LABORATORY — *Features* — *Media & Communications Office*

By Charity Plata — share:

Quantum Goes the Distance

U.S. research team expands quantum network with successful long-distance entanglement experiment

April 8, 2019

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**Research team expands quantum network with successful long-distance entanglement experiment**

by Brookhaven National Laboratory


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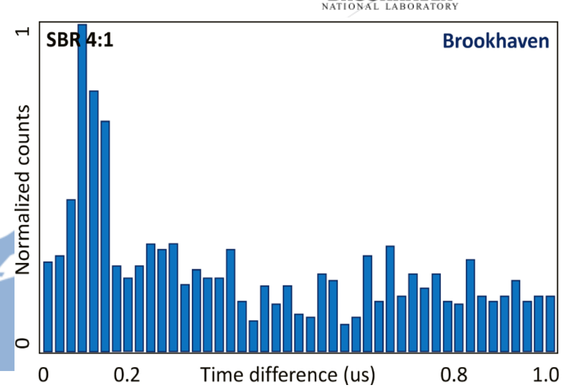
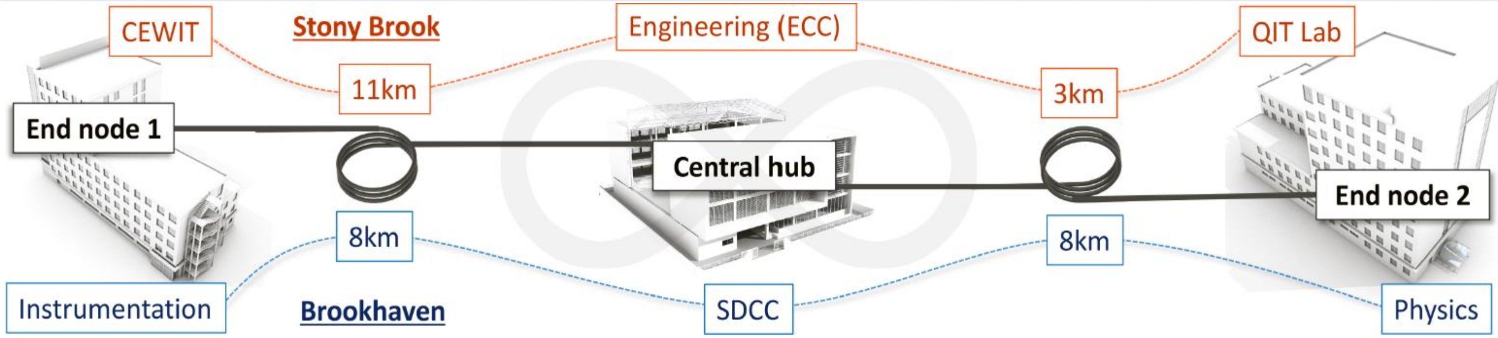
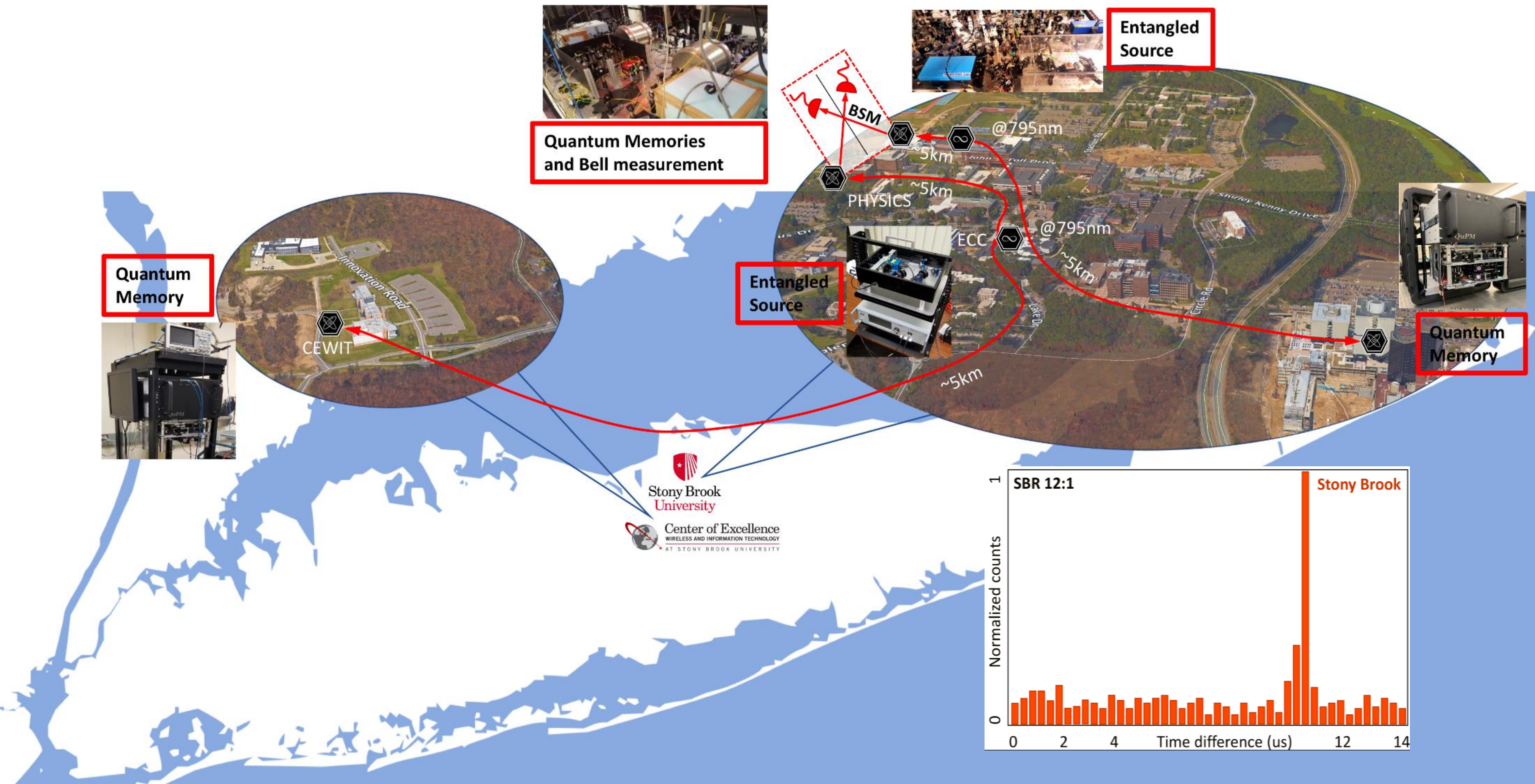


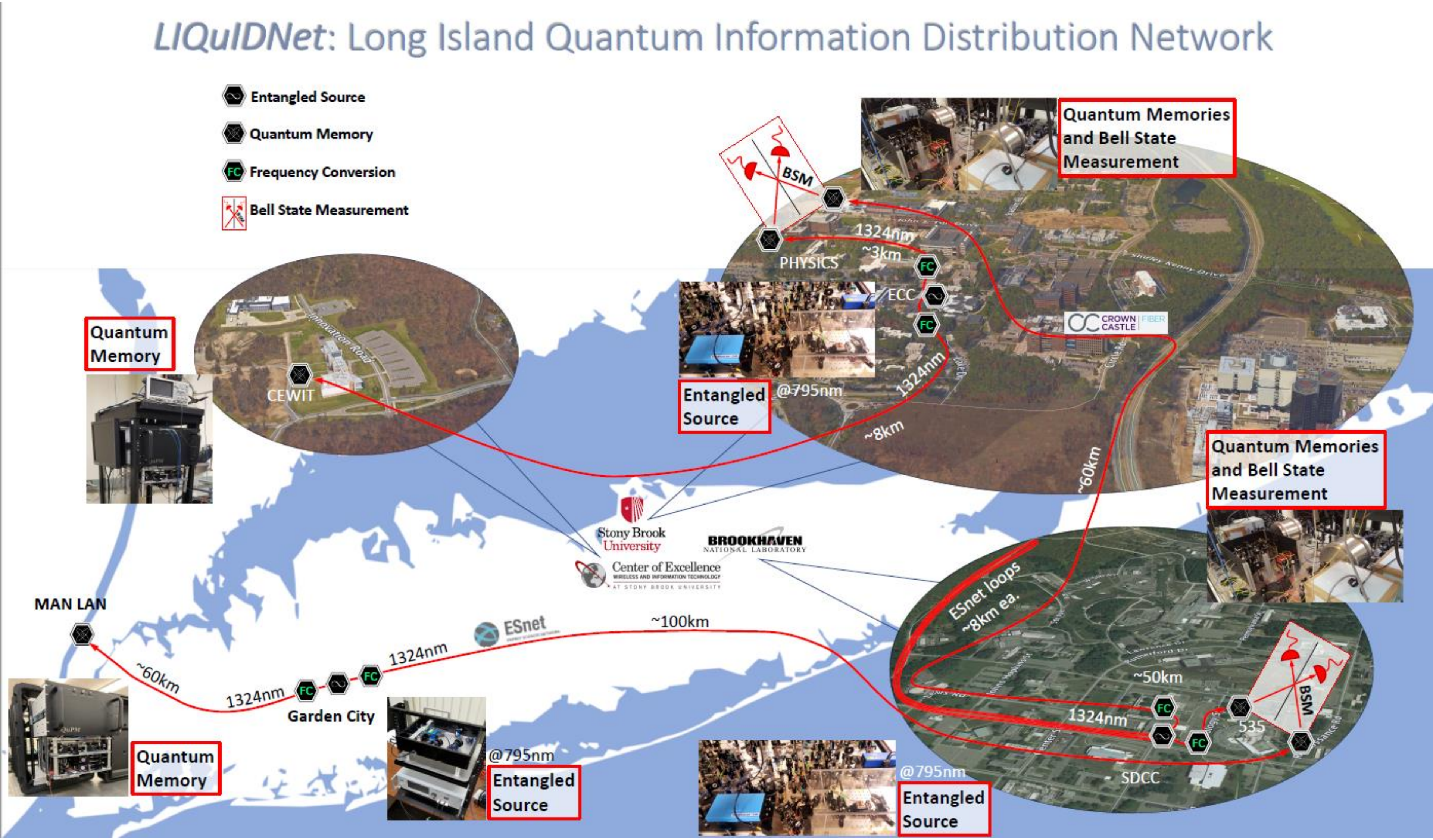

Entangled Source

# Quantum entanglement distribution in SBU



# SBU-BNL Quantum repeater test bed




**- Three new DOE Awards granted to the SBU-BNL Quantum Communication Testbed project.**