The DARPA Quantum Network

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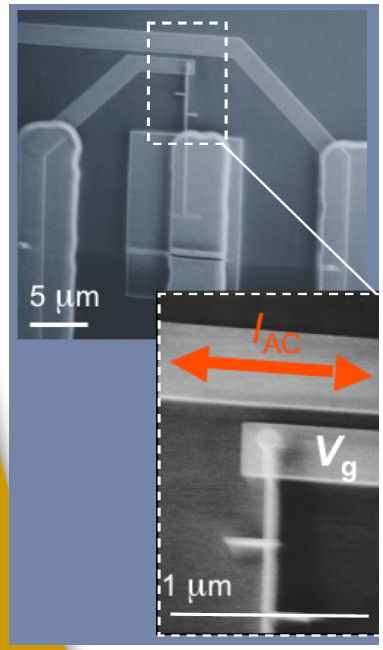
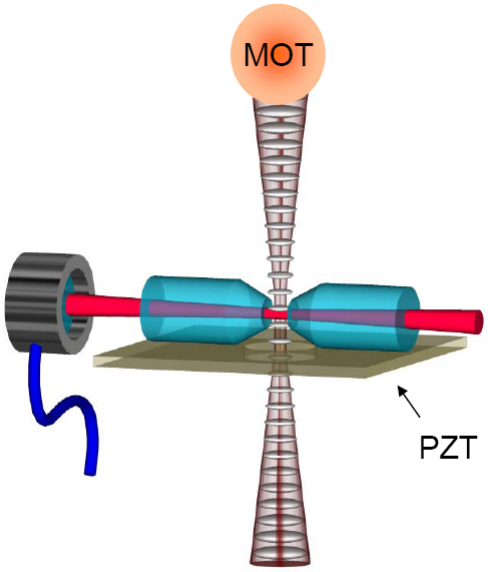
Physics Today

- Routine manipulation of single particles / waves
  - Photons, atoms, electron spins, . . .
- Now starting to engineer quantum states and quantum interactions (e.g. entanglement)

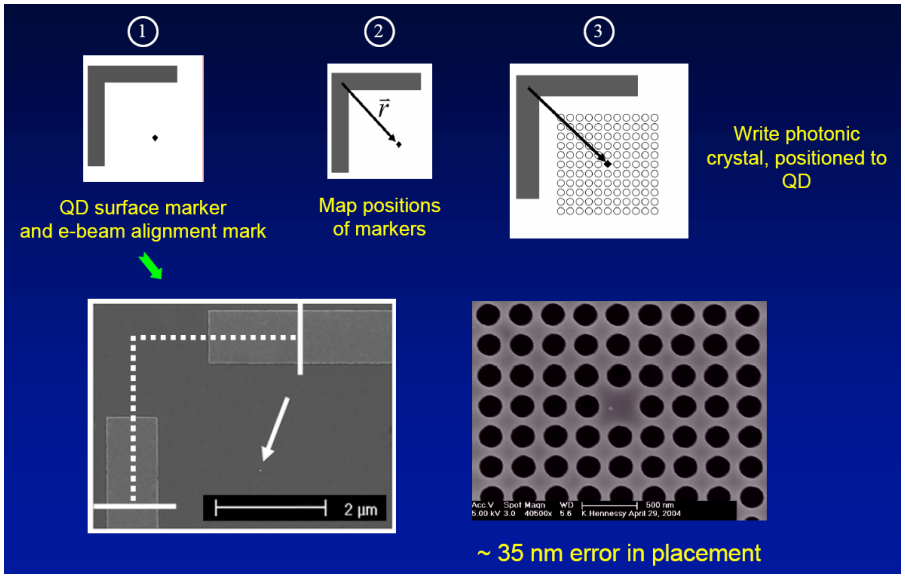


Electron Spins



Optical dipole trap

Rubidium Atom



Quantum Dot in Photonic Crystal

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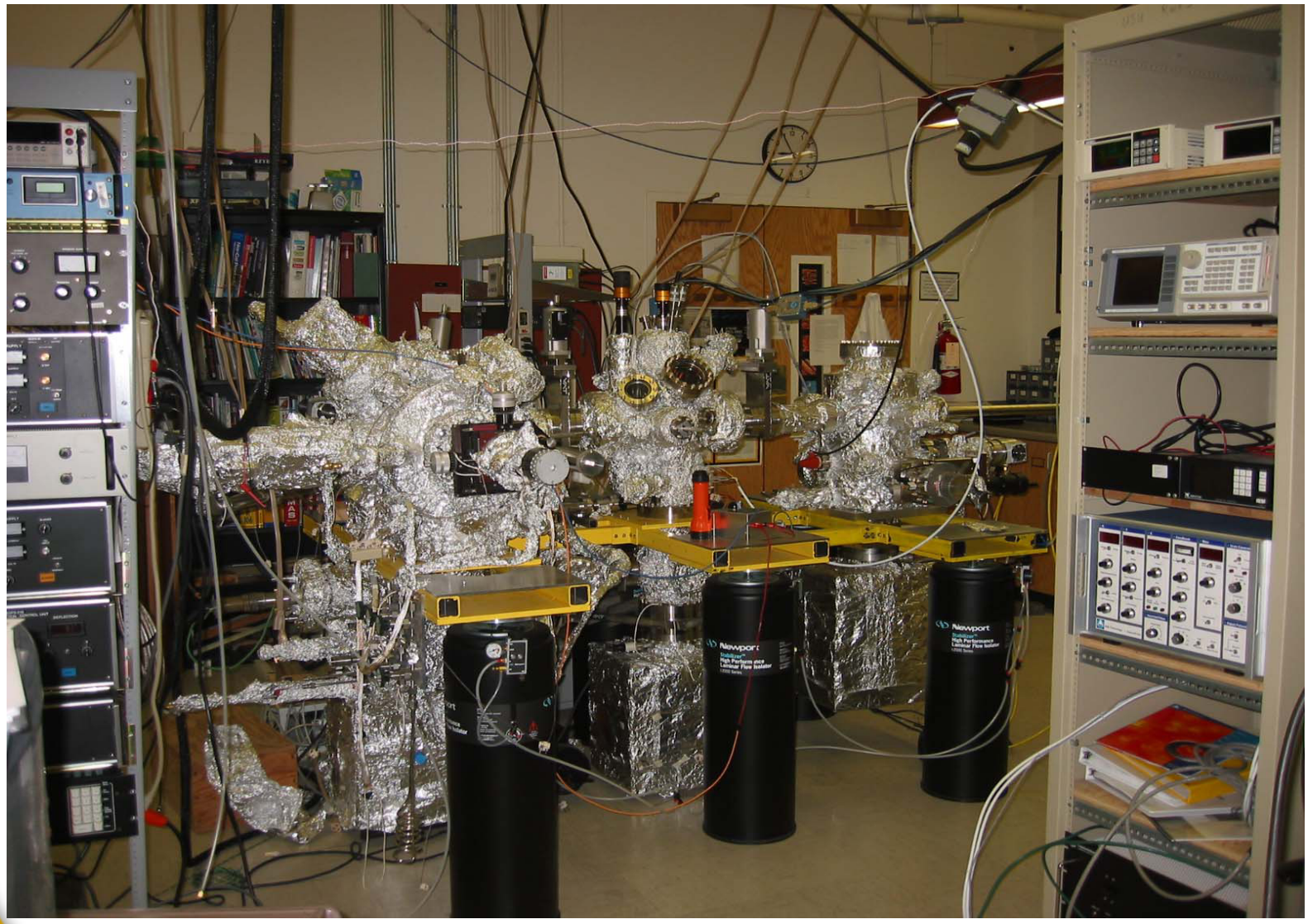
That Single Particle in Context



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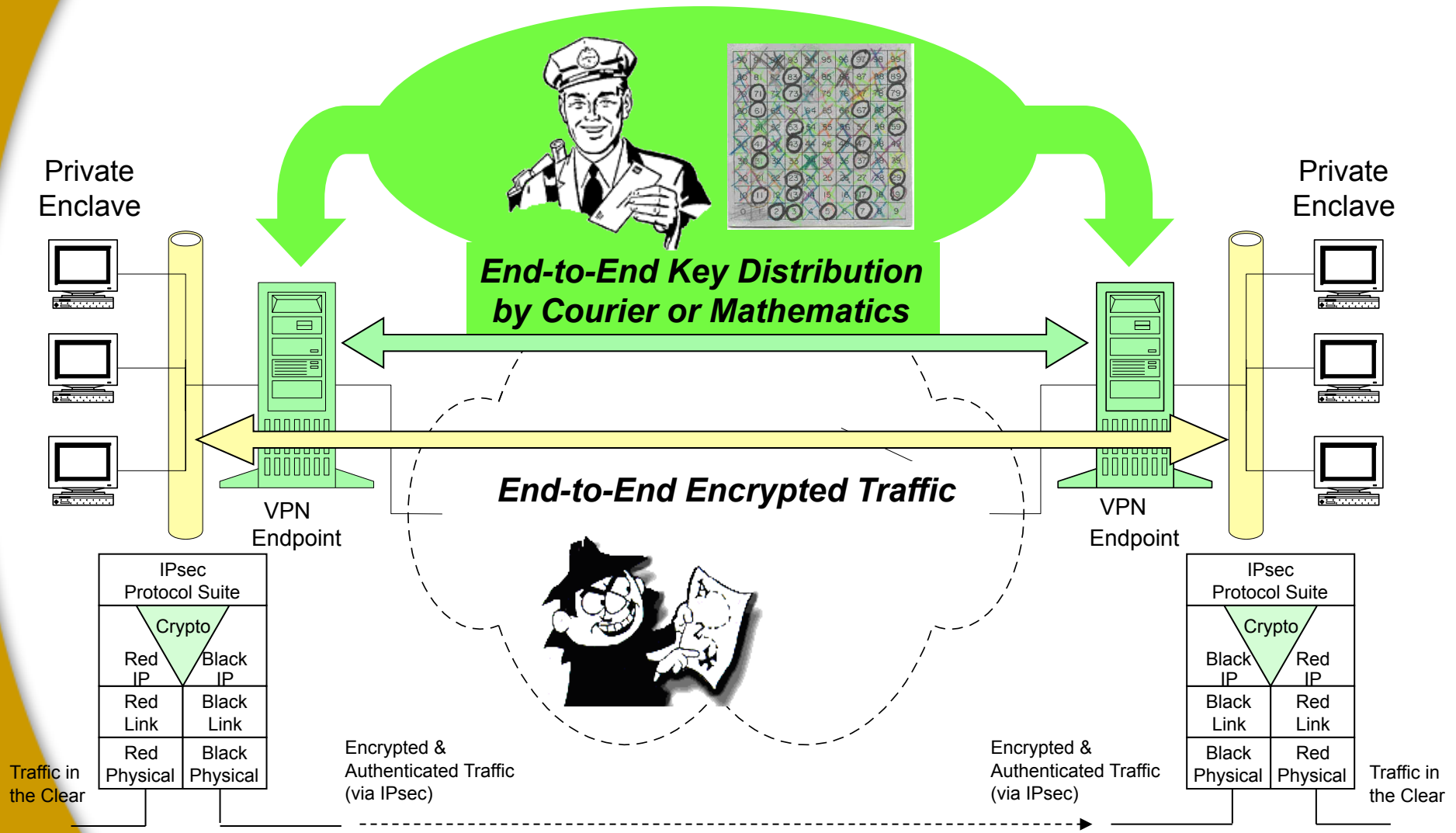
Today's Secure Networks



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Potential Weakness in Math-Based Key Distribution Techniques

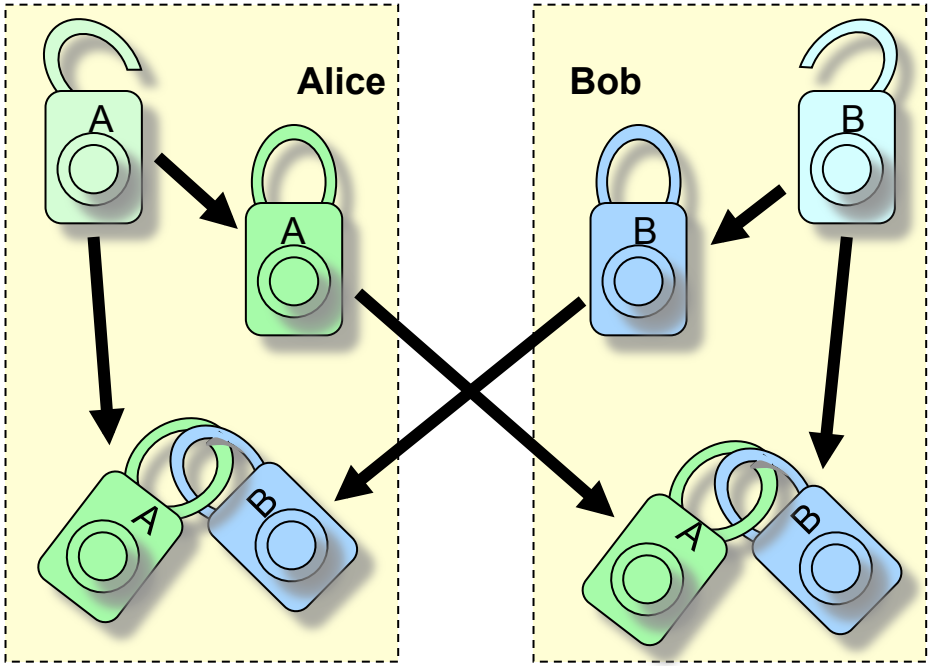
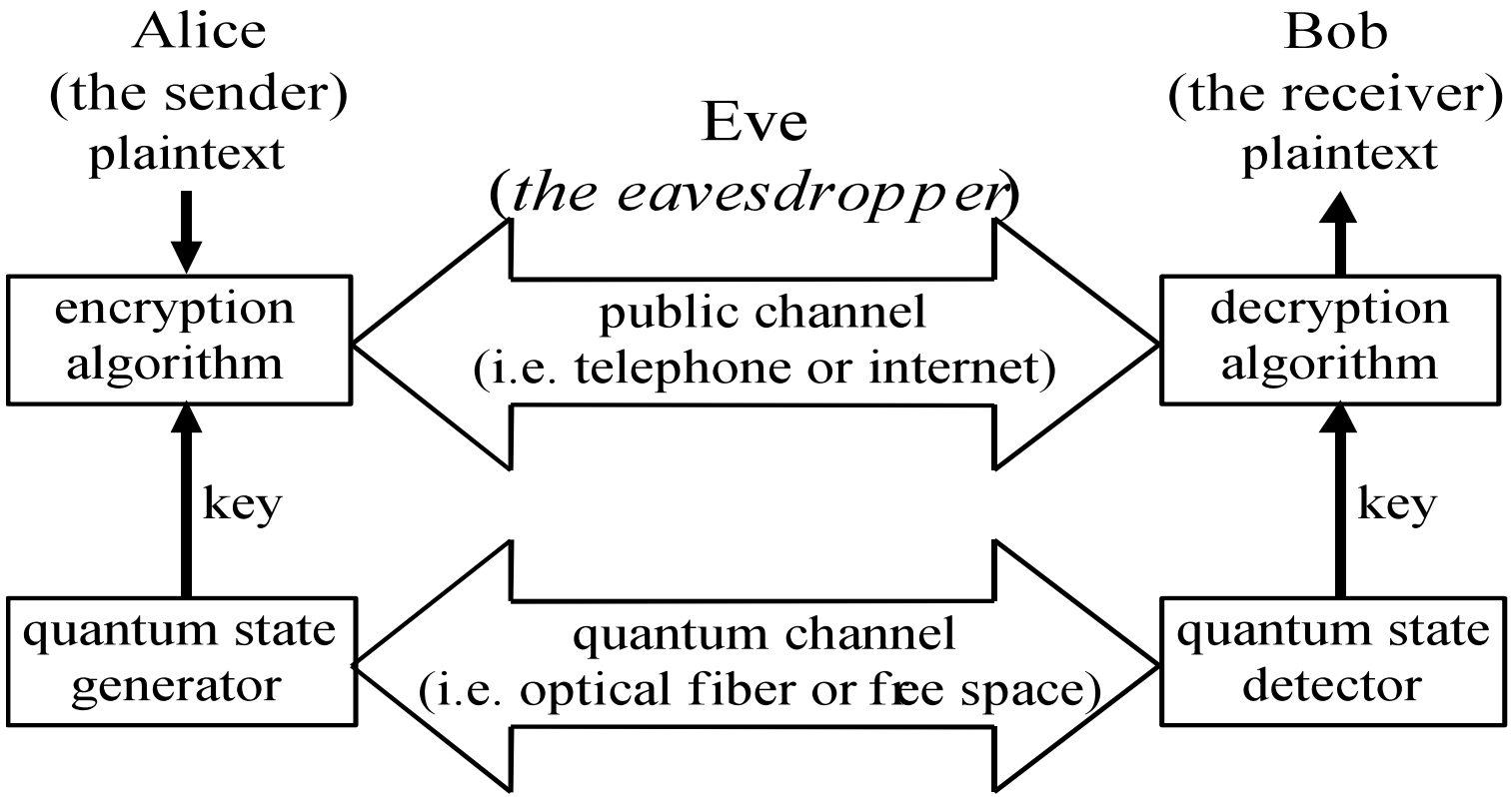


Diagram from Ueli Maurer

- Basic Idea
  - 2 Keys: Public, Private
  - Encrypt with Public Key
  - Decrypt with Private Key
- Variants
  - RSA (Large Prime #s)
  - Elliptic Curve
- Enabling Technology
  - Some math function that is easy to do but hard to undo

But . . . No Known Proofs of "One-Way" Property

A New Kind of Key Distribution - Quantum Key Distribution



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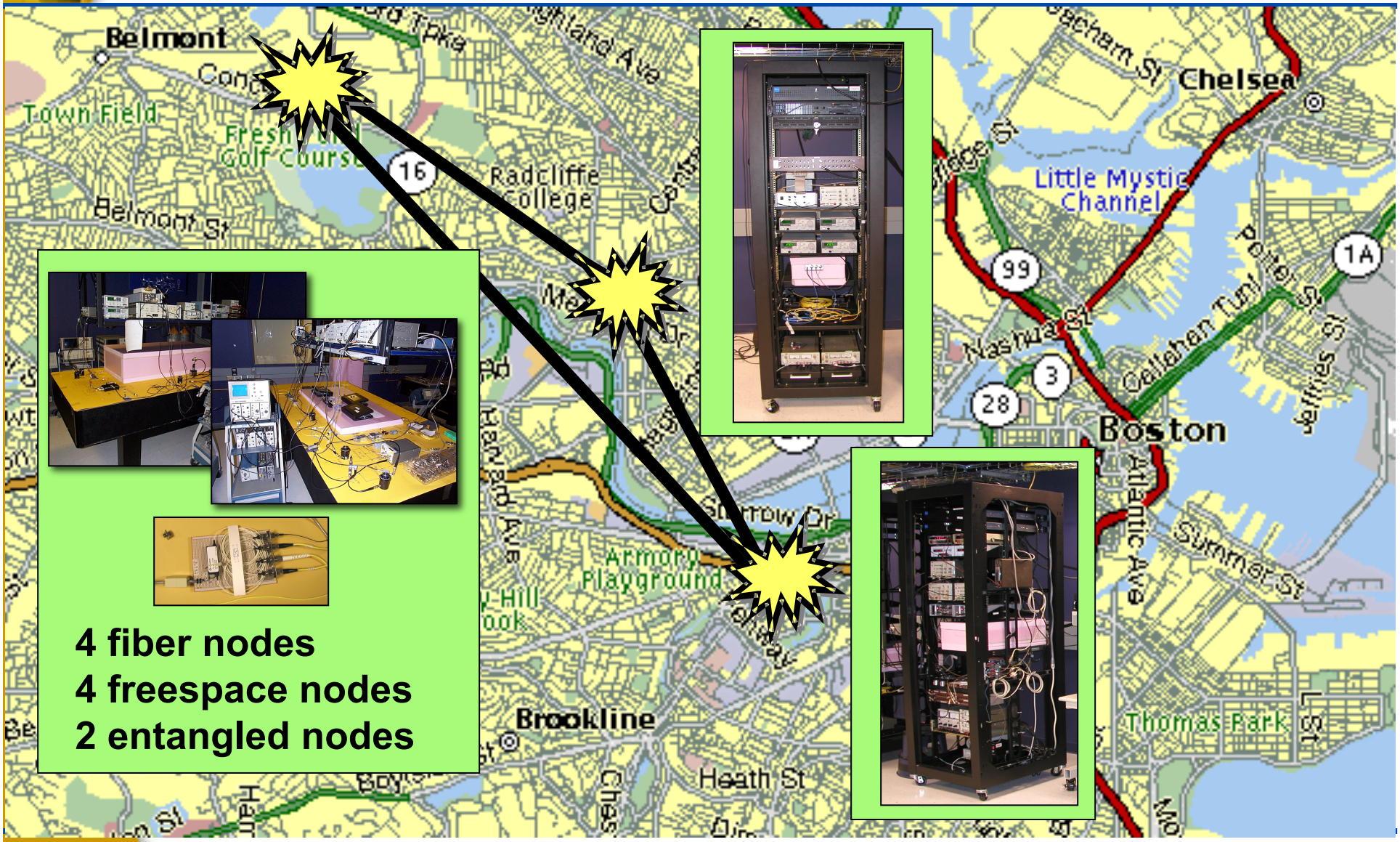
The DARPA Quantum Network

Operating Continuously Across Cambridge Since 6/2004



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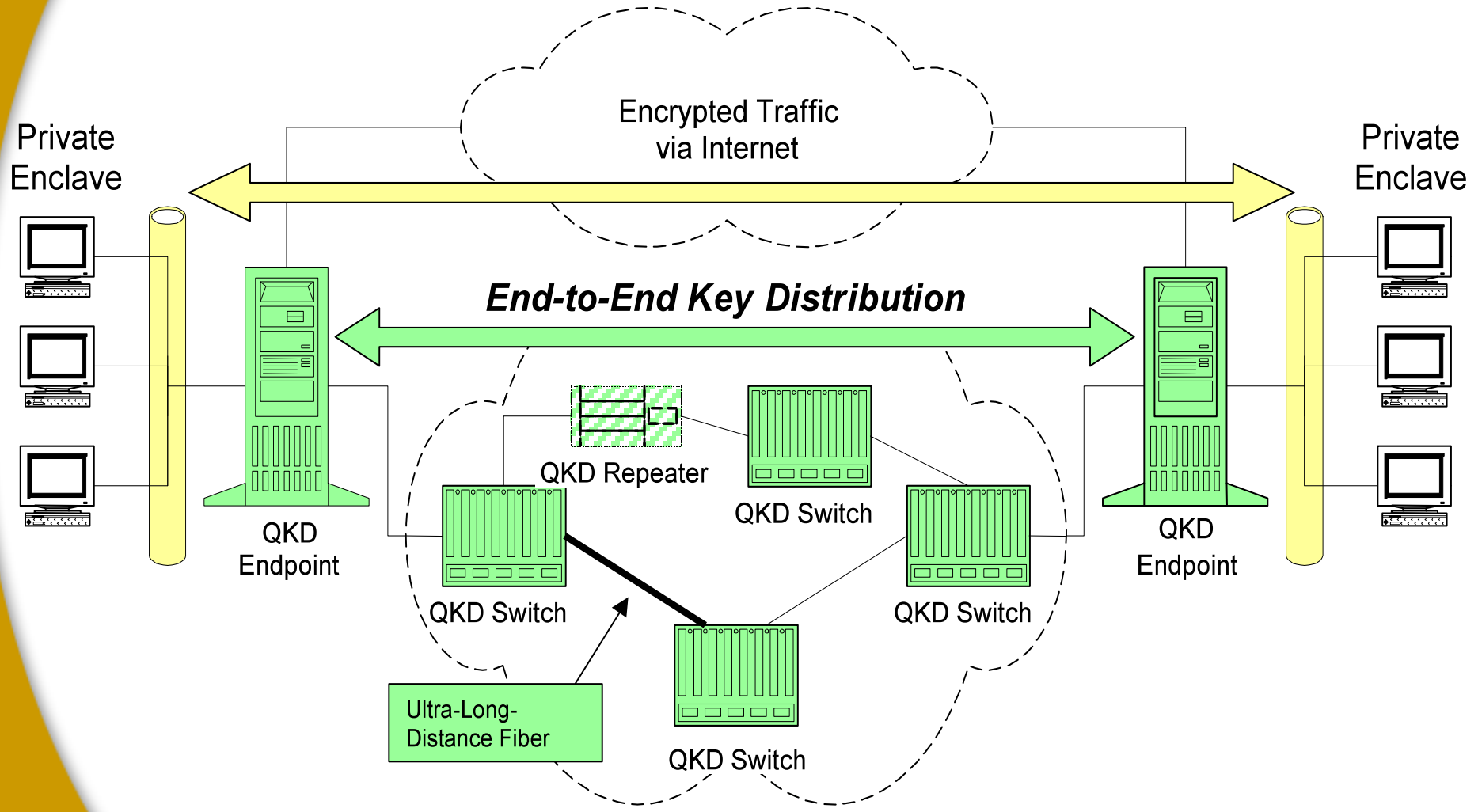
Project Goals

We are designing and building the world's first Quantum Network, delivering end-to-end network security via high-speed Quantum Key Distribution, and testing that Network against sophisticated eavesdropping attacks.

We have fielded this ultra-high-security network into commercial fiber across the metro Boston area and are now operating it 24x7 between BU, Harvard, and BBN.

The DARPA Quantum Network



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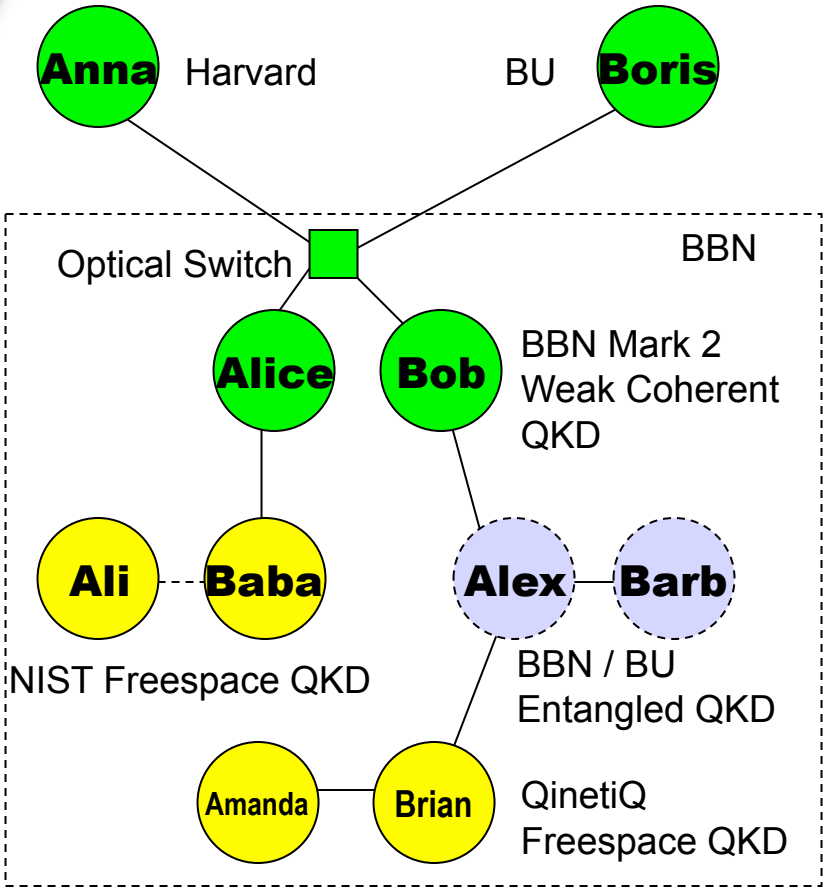
Building the DARPA Quantum Network

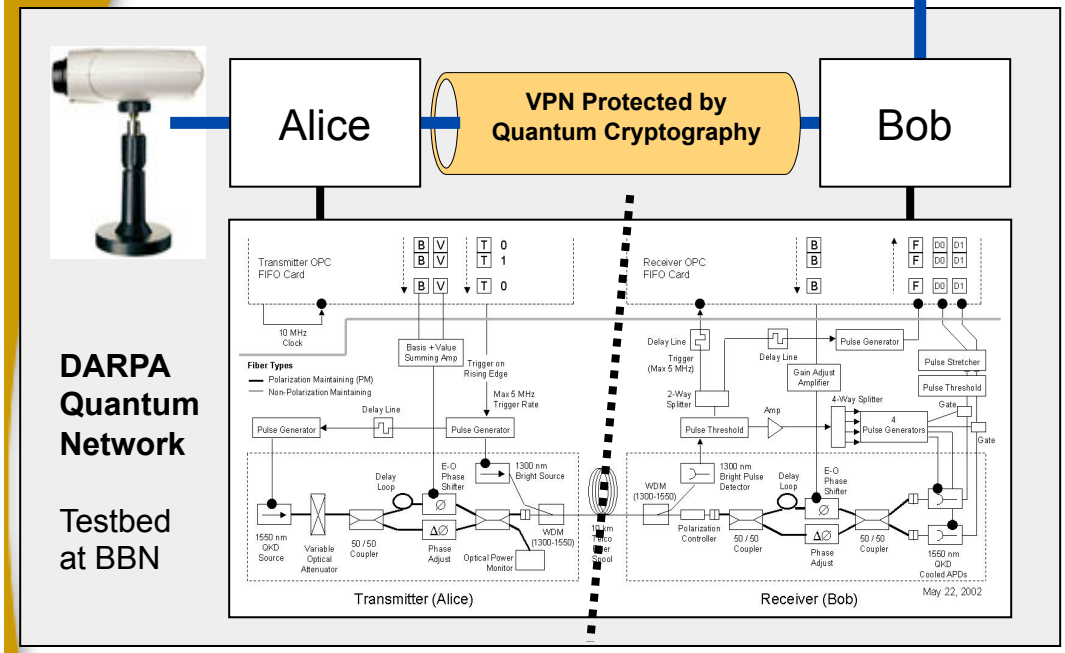


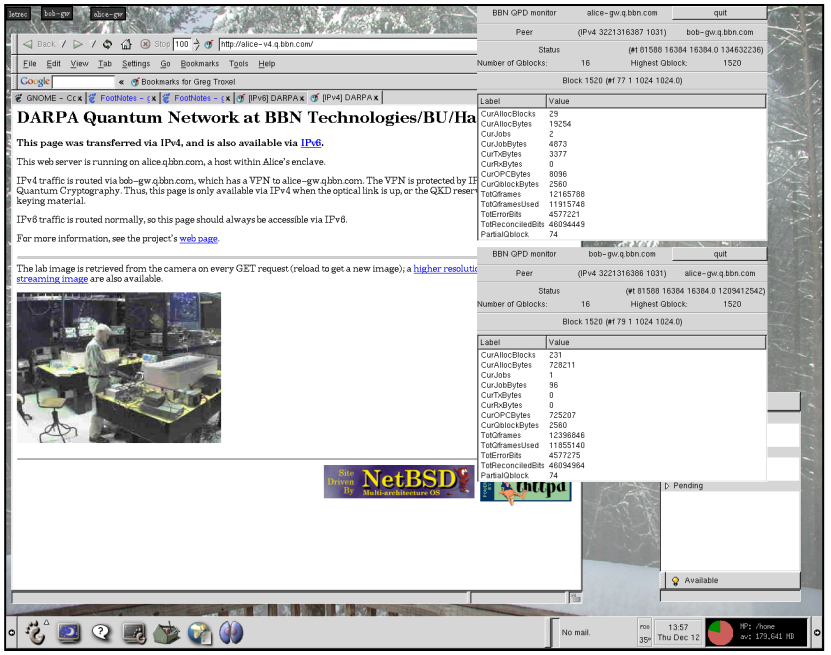
- End-to-End Architecture
  - Multiple QKD technologies
  - Shared software protocol stack
  - Allows graceful evolution
- QKD Networking
  - Key Relay via trusted intermediaries for distance & bridging incompatible technologies
  - Passive optical switches for compatible endpoints

8 Nodes Running 24x7 in DARPA Quantum Network
And 2 More Running in Hardware Emulation

Secure Network Protected by Quantum Cryptography

Full system continuously operational since Dec 2002





- 5 MHz pulse rate, 0.1 photons / pulse, 1550 nm
- TEC cooled APDs
- Full system measured long term QBER approx. 3% in 10 km Cambridge network
- Full suite of QKD Protocols operational

- Privacy-amplified “secret bits” output approx 700 bits / sec.
- Fully integrated with Internet Protocols for both rapid rekeying (AES, 3DES) and one-time pad

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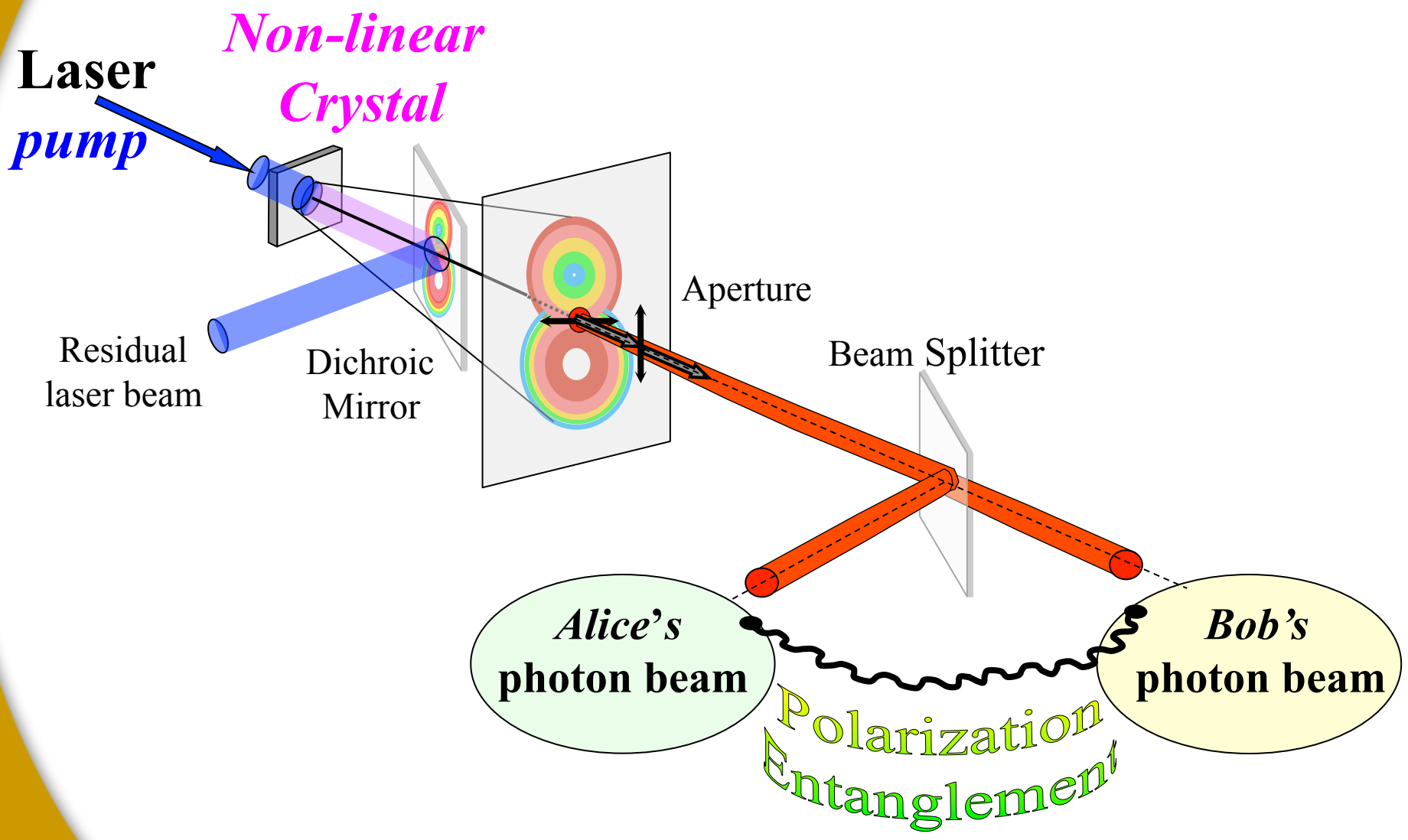
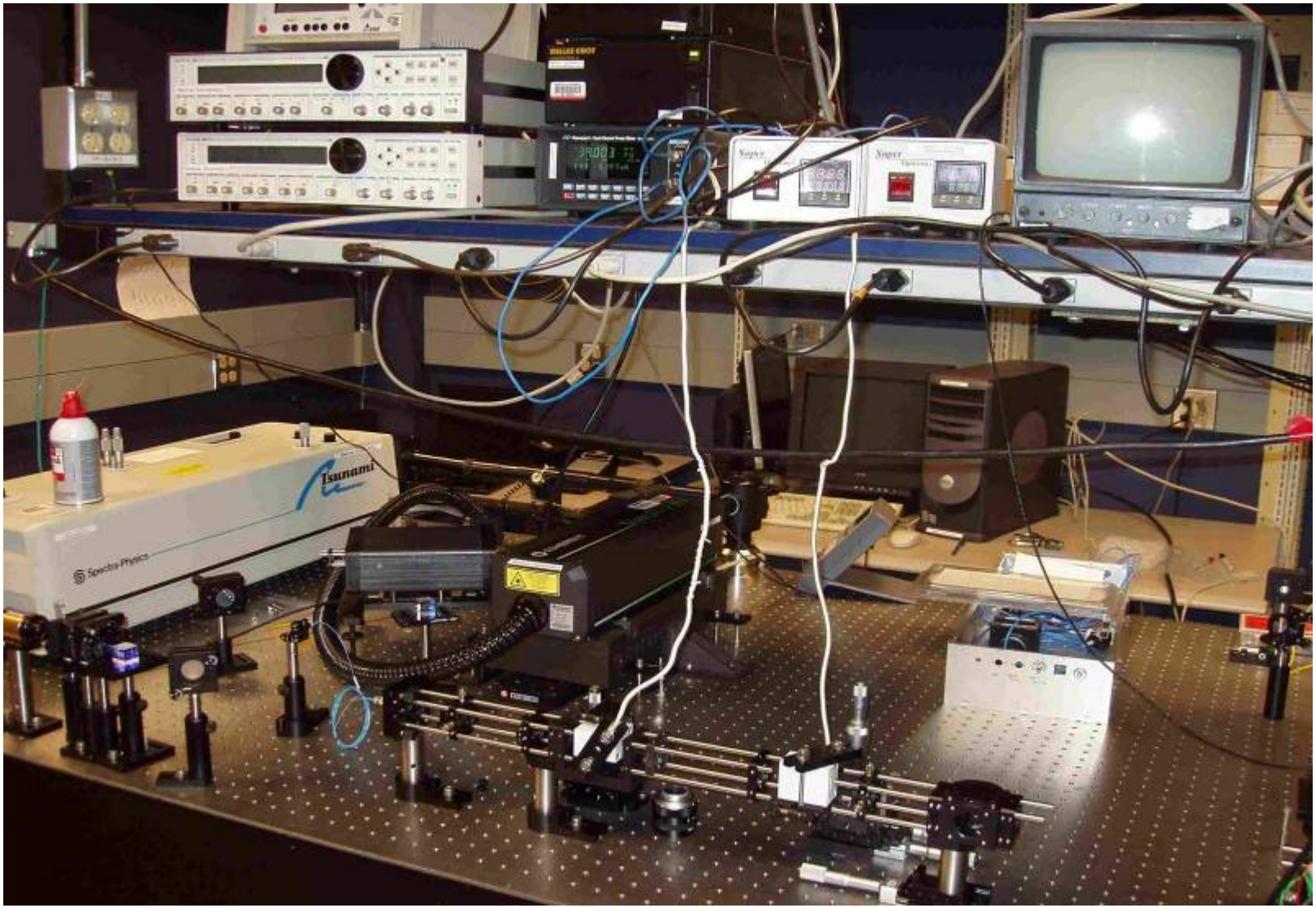
Telecom-Ready Source of Entangled Photons



1st Build of Entangled Source



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Alex and Barb

Transmitter and Receiver for the Entangled Link

Alex

Barb

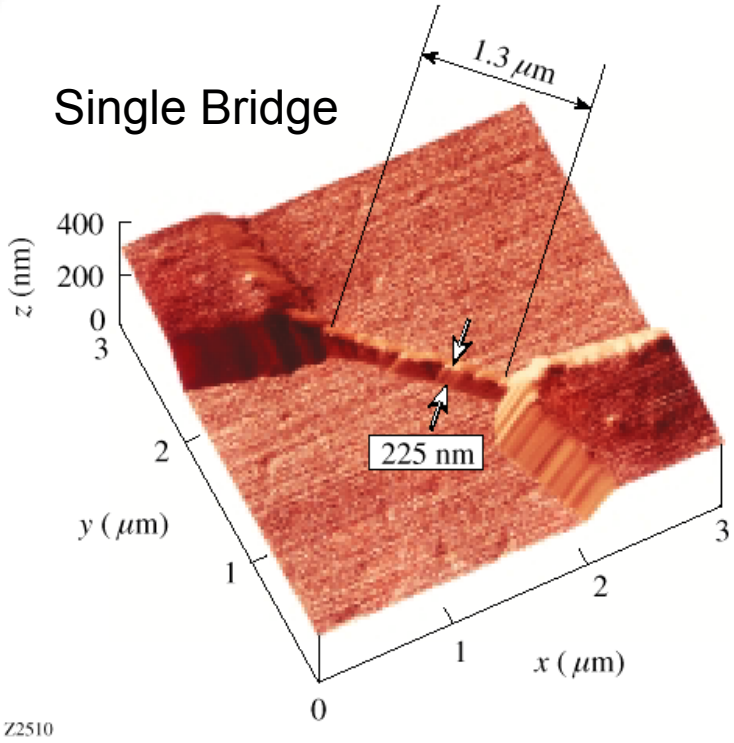
- Opto-Electronics
  - External polarization-entangled 1550 nm source for use in (dark) telecom fiber
  - Uses 4 IBM Almaden detector pairs!
  - 1 MHz pulse rate, InGaAs detector limited
  - Asynchronous link operation based on Alice's detects
- System Design
  - Interfaces with BBN's protocol stack
  - Currently employs BB84 protocol
  - Eventual upgrade to Ekert
- Current Status
  - Testing with Emulated SPDC Source
  - Running 24x7 in shakedown
  - Connected via PM fiber in lab, will introduce polarization control once full system is operating well

BBN / U. Rochester / NIST Detector Collaboration

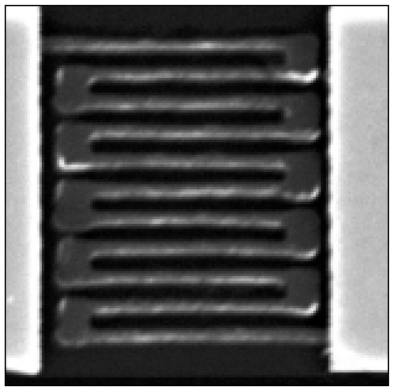
From University Demonstration to the Telecom Closet

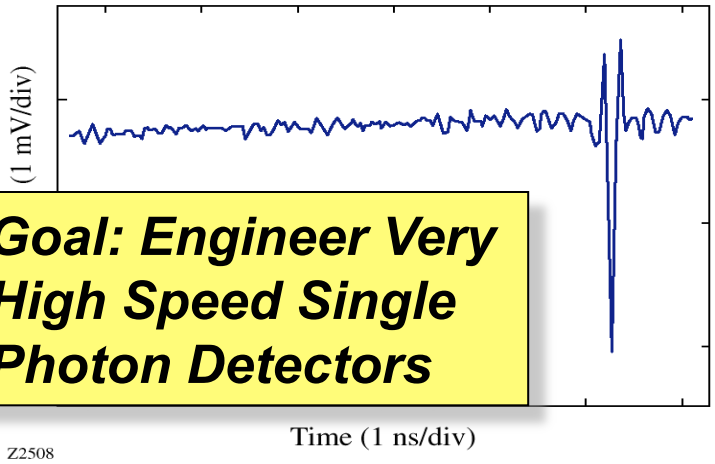
Fabrication and Properties of an Ultrafast NbN Hot-Electron Single-Photon Detector," R. Sobolewski, LLE Review, Volume 85, p. 34.

Single Bridge



Meander Structure





Superconducting (4.2 K) NbN hot-electron photodetector (HEP) with picosecond response time, high intrinsic quantum efficiency, negligible dark counts, and the capability to detect single photons from the ultraviolet to the infrared wavelength range.

Goal: Engineer Very High Speed Single Photon Detectors

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NbN Detector Packaging for Network Operation

Closed-Cycle Cryocooler with 10,000 hr maintenance

Successful QKD trials at BBN in June 2005, Experimentation and continuous operations since.

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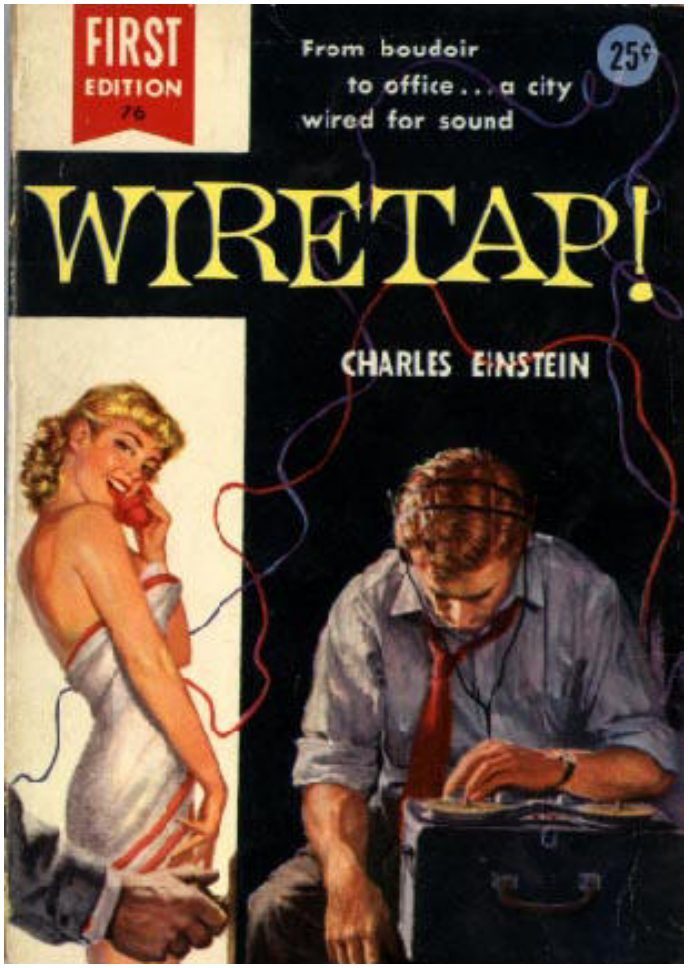
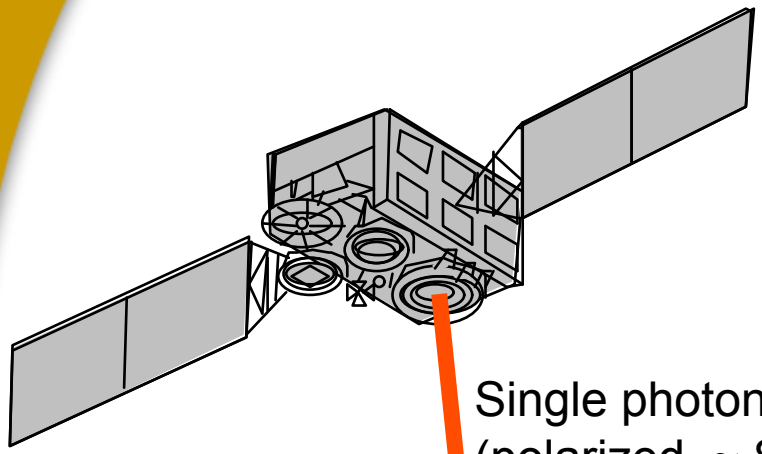
‘Eve’ Collaboration with MIT



rle AT MIT RESEARCH LABORATORY OF ELECTRONICS AT MIT

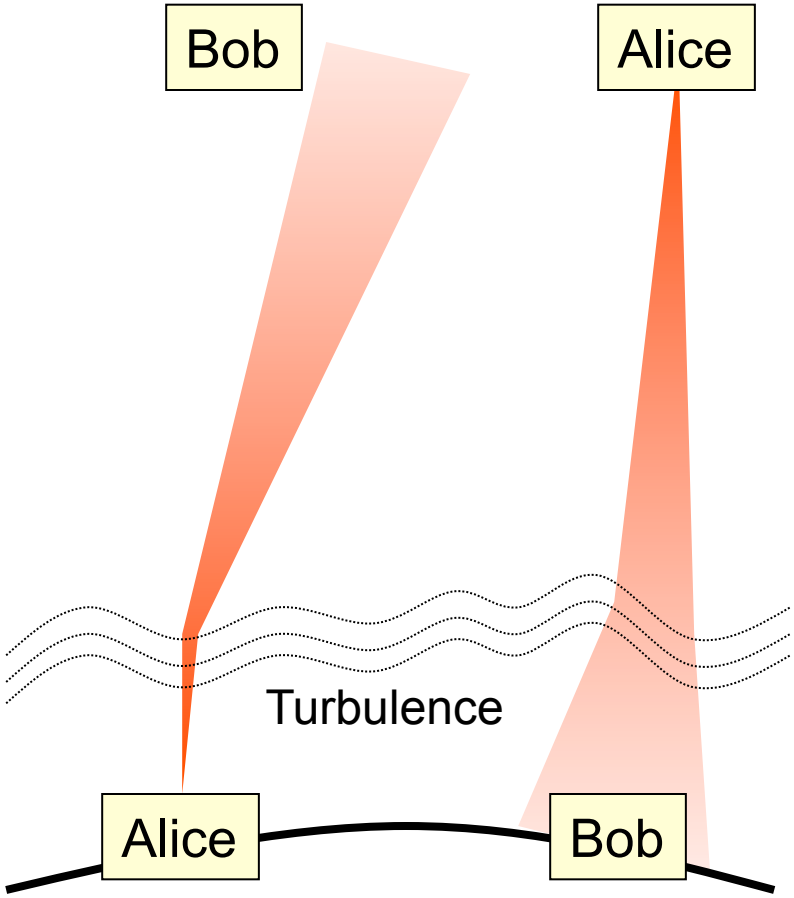
- Goal
  - Demonstrate Fuchs-Peres (Brandt) optimal entangling probe on polarization-based BB84 protocol
- Investigators
  - Prof. Jeffrey Shapiro, Dr. Franco Wong
- Planned Approach
  - Proof of principle, not actual eavesdropping system
  - MIT builds combined Alice-Bob-Eve to eliminate all extraneous problems (such as synchronization)
  - MIT perform experiments varying degree of entanglement
  - BBN post-processes with BB84 protocol engine, reports QBER, etc.

Quantum Cryptography for Space Systems



Single photons
(polarized, ~ 800 nm)

Alice in space is probably preferable for various reasons.



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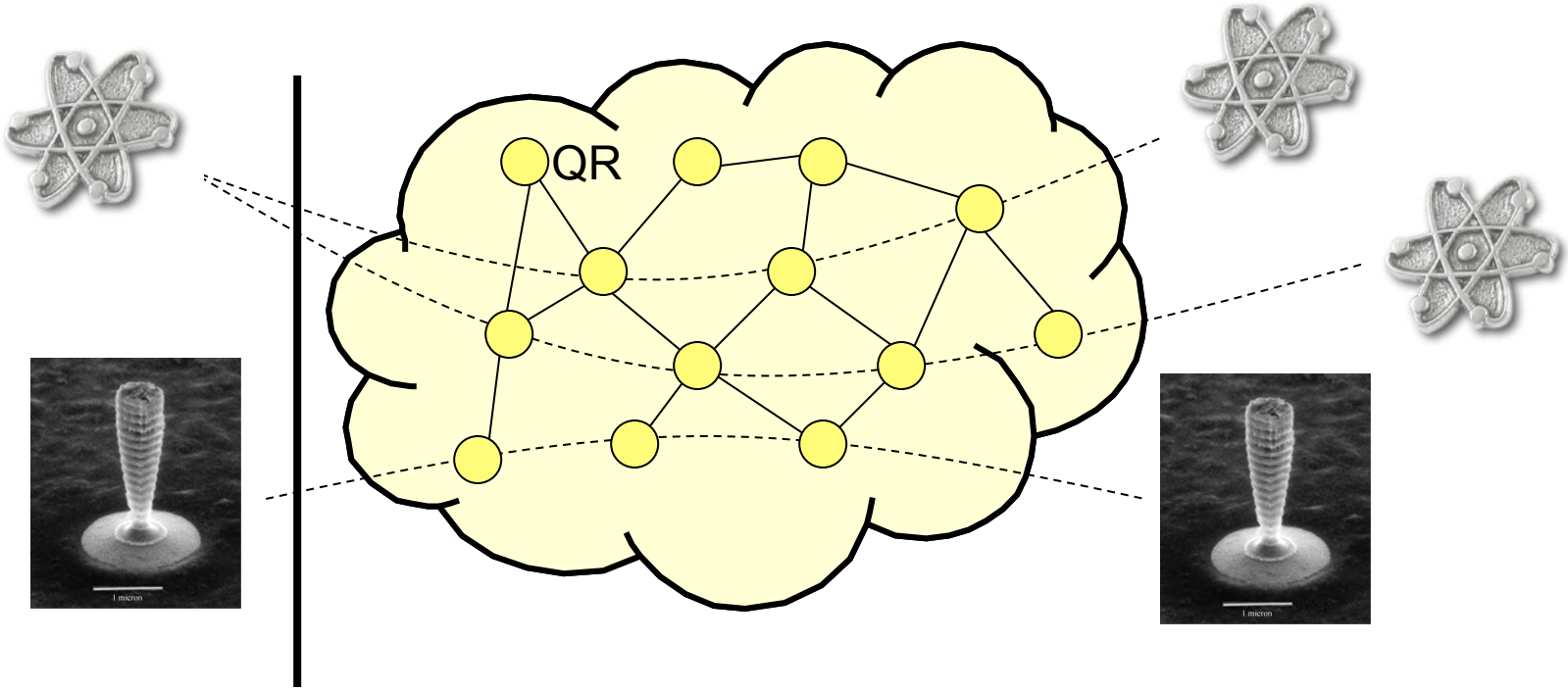
Building the Quantum Internet



"Edge" interface is polarized photon

Transport is via end-to-end teleportation

Transport is fundamentally analog, not digital (fidelity guarantees)

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Thank You !

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