Quantum Information Science at BNL

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Quantum Sensors Workshop, Argonne
12 December 2017

BNL overview

- RHIC, US ATLAS with Tier I computing, neutrino experiments, LSST
- Instrumentation Division: LAr; cold, low noise electronics; ASIC design; silicon sensor R&D; metrology
- NSLS-II & CFN
- Computing Science Initiative

BNL Magnetic Monopole Searches

- Search for cosmic monopoles in 80-90's, proposals for bigger experiments
- Based on gradiometer coils and SQUID magnetometer

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New Limit Set on Cosmic-Ray Monopole Flux by a Large-Area Superconducting Magnetic-Induction Detector

S. Bermon, C. C. Chi, C. C. Tsuei, J. R. Rozen, P. Chaudhari, and M. W. McElfresh
IBM Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598

A. Prodell
Brookhaven National Laboratory, Upton, Long Island, New York 11973
(Received 25 October 1989)

A search for cosmic-ray magnetic monopoles has been conducted using a fully coincident superconducting induction detector consisting of six independent high-order gradiometer coils forming the surfaces of a rectangular parallelepiped. The detector had an effective area for isotropic flux averaged over 4π sr of 1.0 m^2. Data have been collected from October 1986 to January 1989 with an accumulated live time of 13410 h. No monopole candidate events were seen, setting a new lower monopole-flux limit for induction detectors of 3.8×10^{-13} $cm^{-2}s^{-1}sr^{-1}$ at the 90% confidence level.

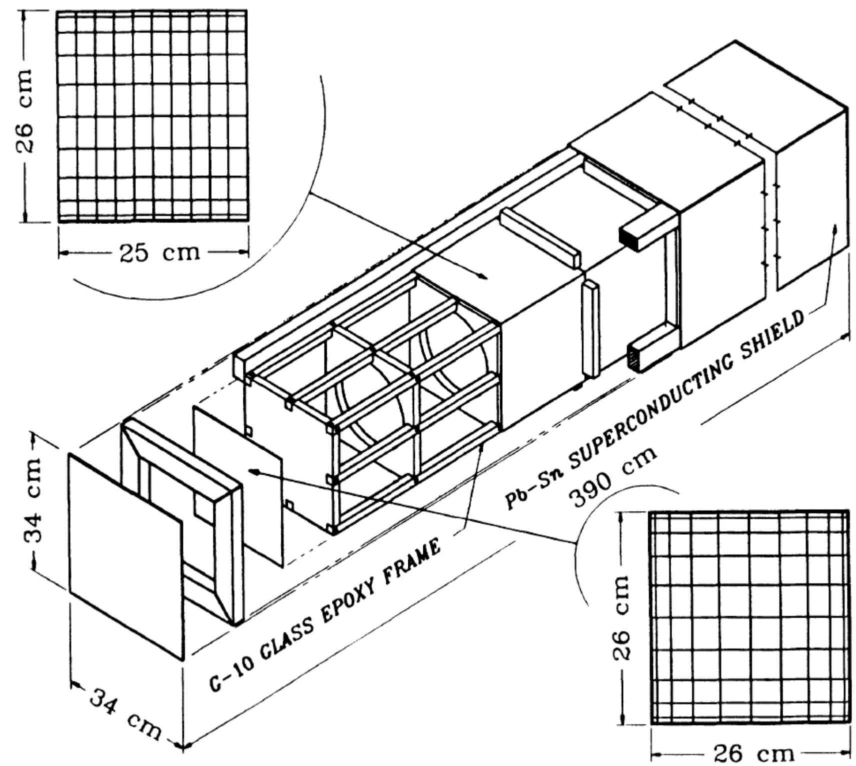


FIG. 1: A schematic drawing of the IBM-BNL totally coincident 1.0-m superconducting shown are the high-order gradiometer designs for the end and side boards.

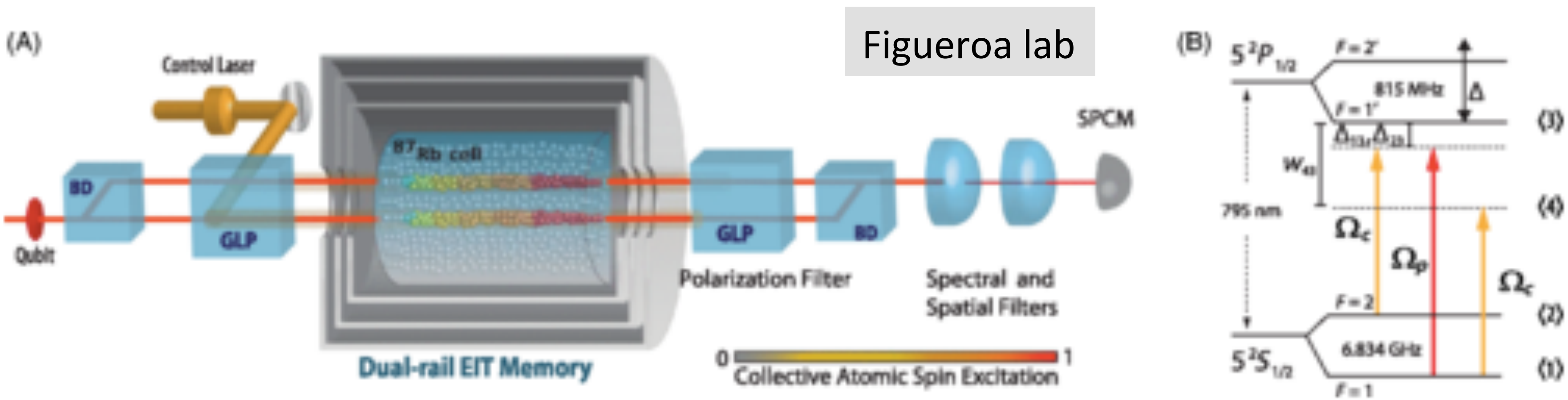
Current interest in QIS

– Implementation of quantum repeater and long distance network
  - Local collaboration with Stony Brook U

– Quantum simulations and quantum algorithms applicable to QFT calculations
  - Computer science Initiative (BNL), UMD, MIT, SBU, Tufts, Syracuse, UCSB

SBU (Eden Figueroa group) expertise in:

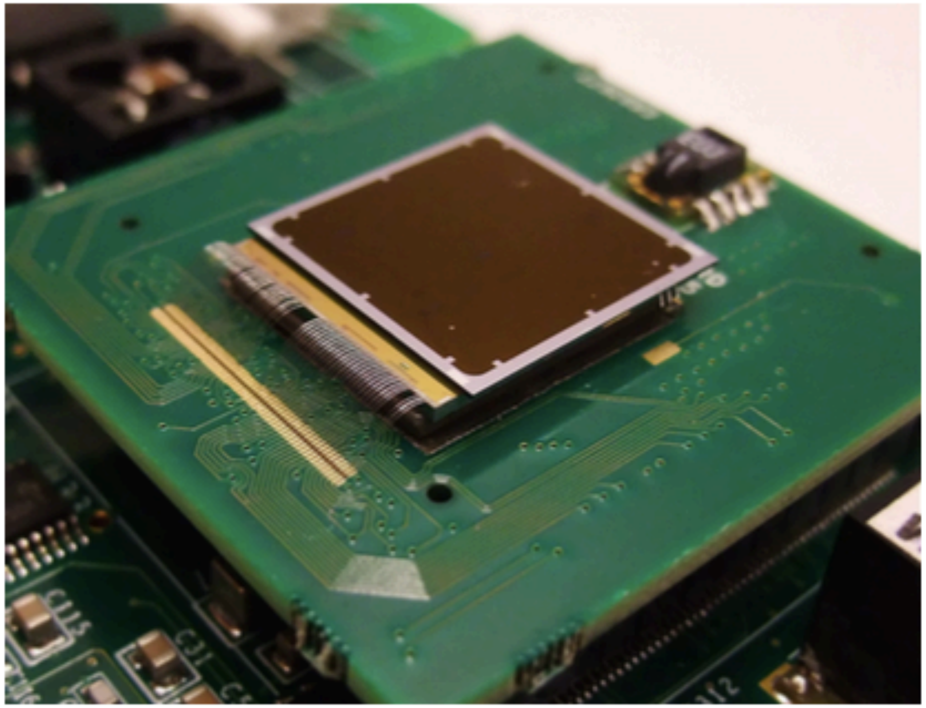
- Room temperature, portable quantum memories based on ^{87}Rb
- MHz sources of entangled photons



M. Namazi, C. Kupchak, B. Jordaan, R. Shahrokhshahi, E. Figueroa, Phys. Rev. Applied **8**, 034023 (2017)

BNL: Intensified fast cameras, by-product of HEP experiments

- 256x256 pixels, 1.5 ns time resolution
- single photon sensitivity, 10 Mphoton/sec throughput

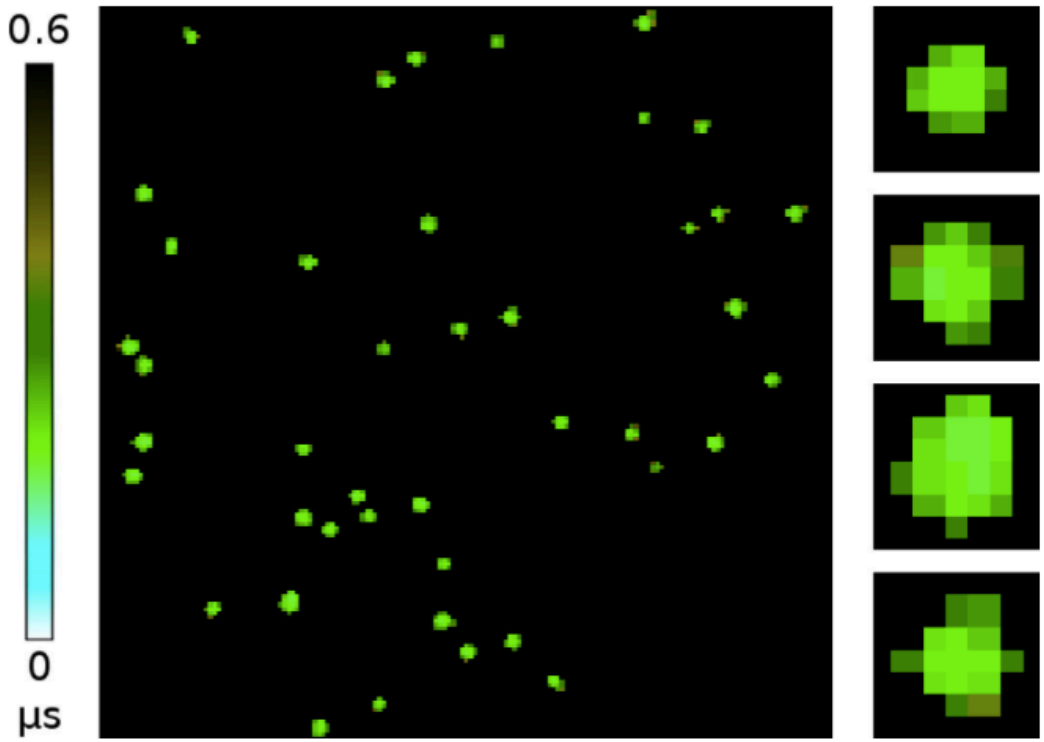


(a) The new sensor in TimepixCam.

Characterization of TimepixCam, a fast imager for the time-stamping of optical photons
A Nomerotski, I Chakaberia, M Fisher-Levine, Z Janoska, P Takacs, ...
Journal of Instrumentation 12 (01), C01017

TimepixCam: a fast optical imager with time-stamping
M Fisher-Levine, A Nomerotski
Journal of Instrumentation 11 (03), C03016

single photon time stamping (nsec)



Photon counting phosphorescence lifetime imaging with TimepixCam

Liisa M. Hirvonen, Merlin Fisher-Levine, Klaus Suhling, and Andrei Nomerotski

Citation: Rev. Sci. Instrum. **88**, 013104 (2017); doi: 10.1063/1.4973717

SBU: Bright sources of entangled photons with MHz rate

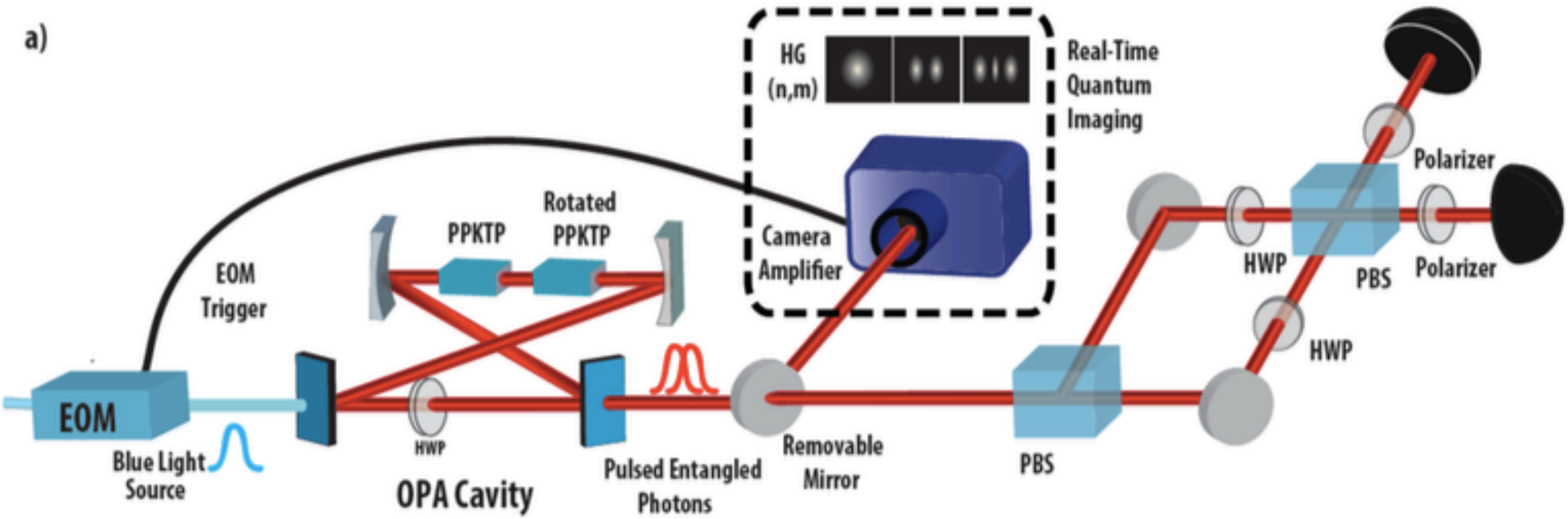
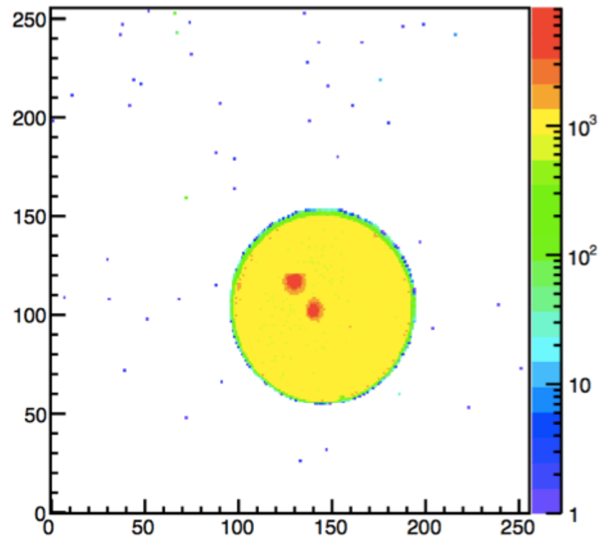
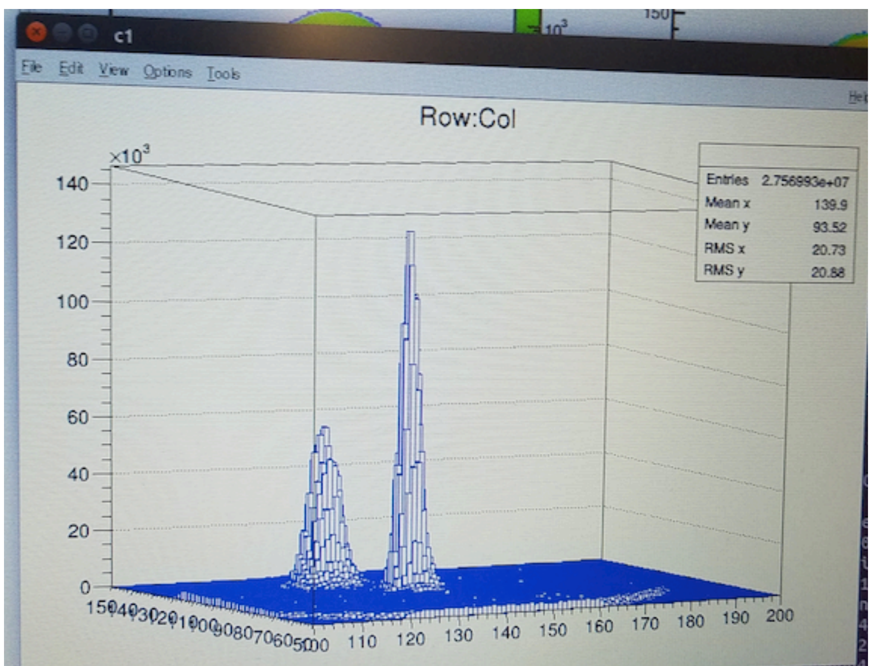


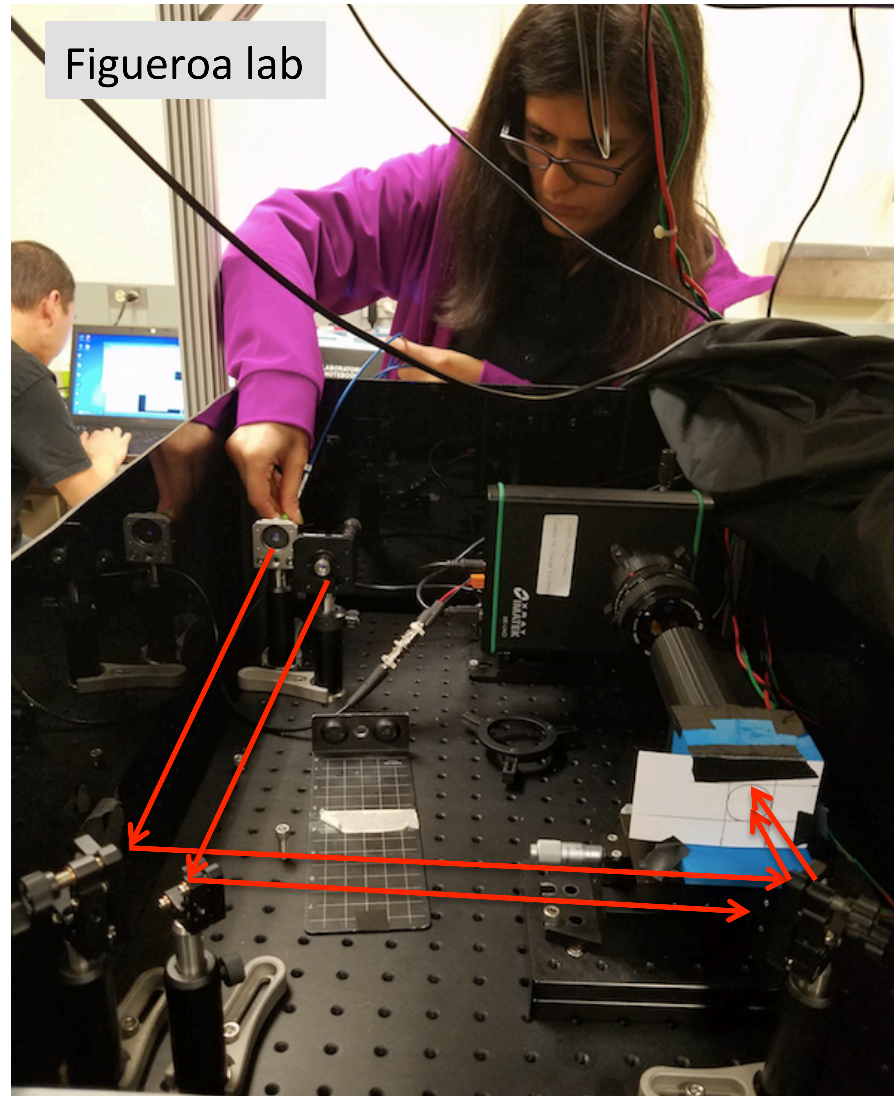
Figure 3. Proposed table-top set-up for the optimization of entanglement generation rates using fast photon imaging. Photon generation will be improved using real-time monitoring of the single photons' mode out of the OPA cavity enable by using our single-photon-sensitive TimepixCam with an intensifier. HWP = half wave plate, PBS = polarizing beam splitter, EOM = electro-optical modulator.

Use fast camera for real-time quantum imaging and tuning of single photons sources

First experiments with fast camera





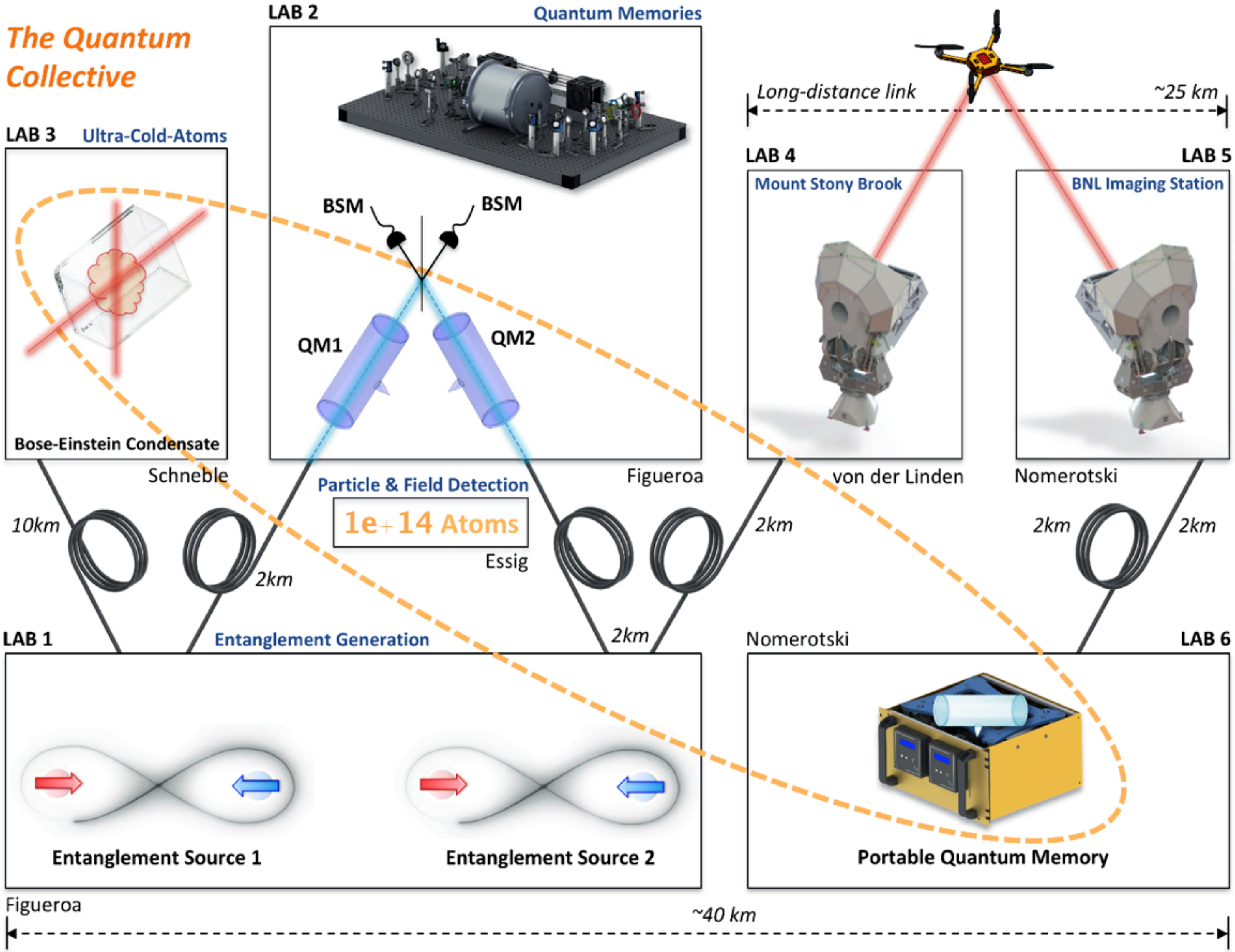


applications related to quantum communication

- Demonstration of quantum repeater operation over long distances and creation of a free space quantum cryptographic link between SBU and BNL

- Quantum cryptography with orbital angular momentum modes and quantum memories → spatial modes & hyper-dense encoding

SBU-BNL quantum network




20 miles

Quantum simulation of Dirac equation for fermions

Realizing topological relativistic dynamics with slow light polaritons at room temperature

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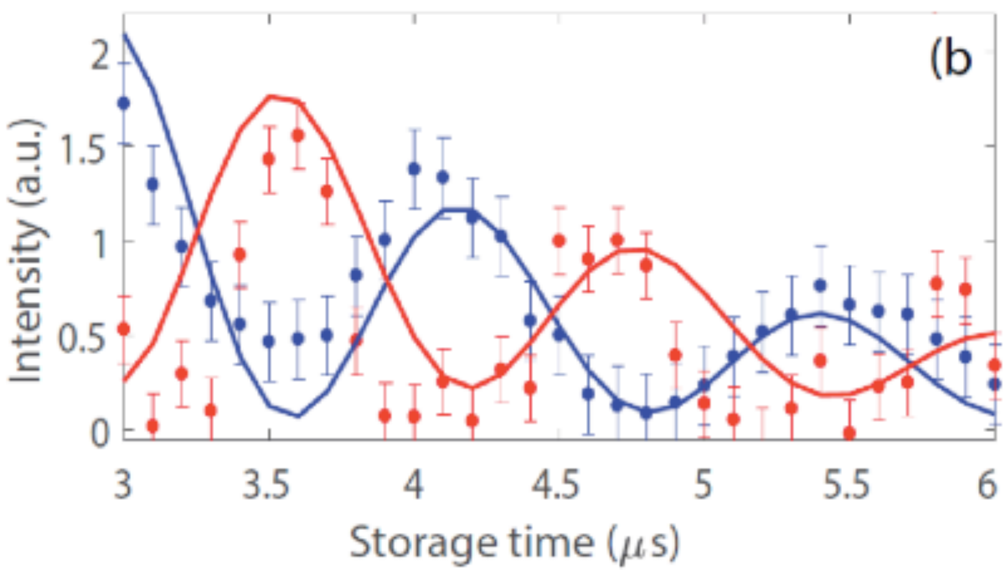

Figure. 2 Spinor tensor Dirac dynamics using light and atoms. *Out of phase oscillation between the forward (blue) and backward (red) components of the spinor tensor. The dynamics is shown versus the storage time for a two-photon detuning of 700 kHz. The solid lines are the result of a full numerical simulation of the spinor Dirac equation.*

Quantum Simulations

- Add bosons & interaction terms
- Considerable scope for HEP theoretical work:

  Gauge invariant Lagrangians → Hamiltonians

  Interpretation of atomic interactions in terms of bosonic and fermionic interactions

- Develop quantum algorithms for QFT

  – 2014. Quantum Algorithms for Fermionic Quantum Field Theories, Stephen P. Jordan, Keith S. M. Lee, John Preskill

- Quantum algorithms could be generalized to Abelian and Non-Abelian lattice gauge and scalar theories