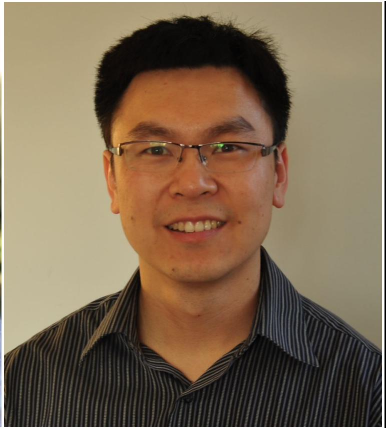
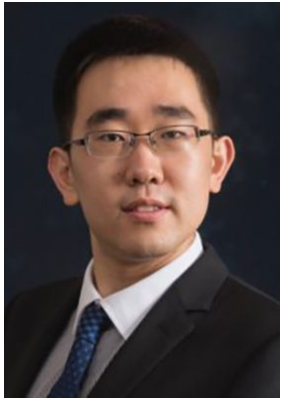
A-QNET Fermilab Group









Facilities

- Fully Equipped QNode Labs at **FQNET-FCC** and **FQNET-DAB**

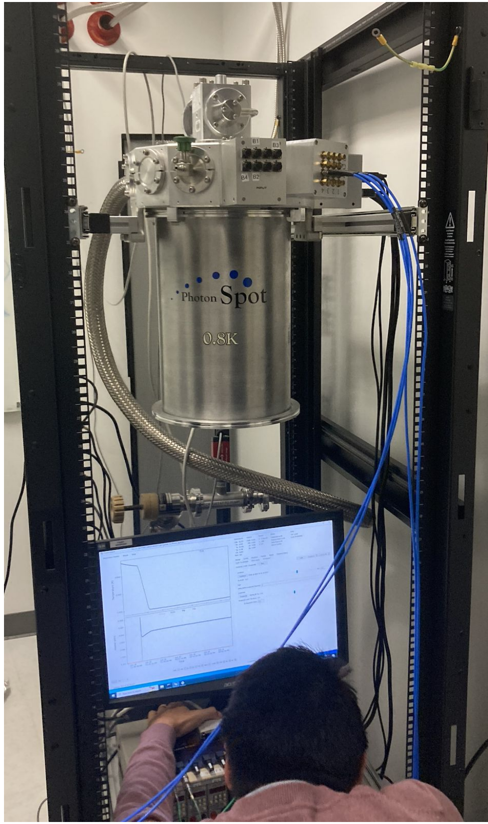
- 3rd QNode **FQNET-IERC** under construction at Helen Edwards Center (IERC)

- Commissioned connectivity with ANL via on-site transparent optical switch

QNode Infrastructure

- Single Photon Transmission and Receiving Capability

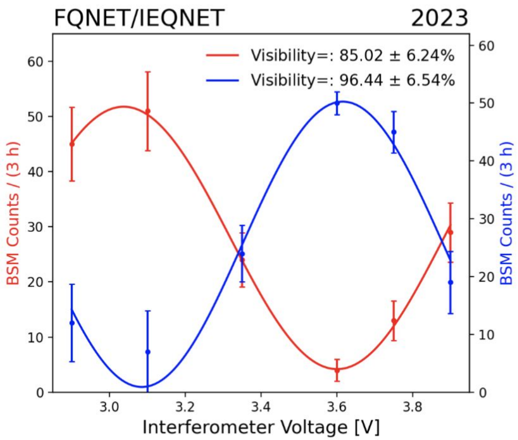
  - Time-bin photonic Entangled-Pair Sources with 200MHz rep-rate capability
  - Suite of SNSPD detectors (6+) with 50ps resolution with rack-mountable assembly



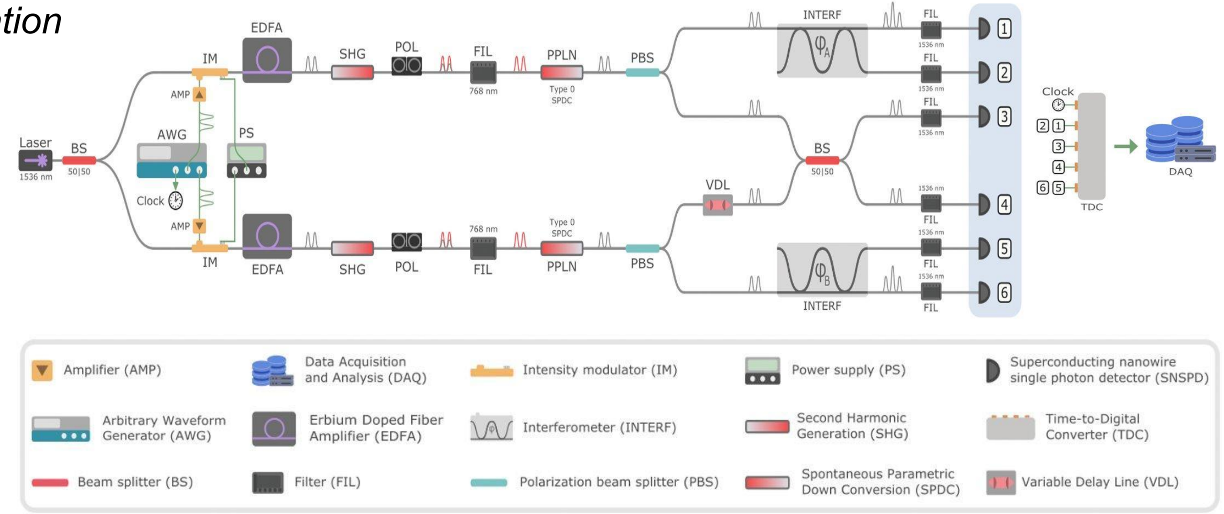
- Picosecond level time sync between QNodes
- Time-taggers with customized GUI software
- Precision Bell State Measurement capability

FQNET Status

- Demonstrated high fidelity teleportation (2020) *PRX Quantum **1**, 020317*
- Achieved picosecond time synchronization to ANL (2022) *JQE V59, no. 4, 1-7*
- Progress towards QN operations using RFSoC FPGA (2023) JQE V59, no. 5, 1-7
- Demonstrated high fidelity entanglement swapping in-the-lab (2023) *Pub under preparation*



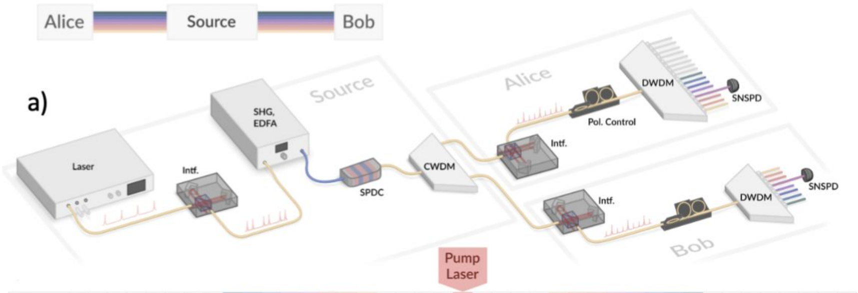
Entanglement Swapping Experiment Setup



Long Range Entanglement Swapping

Current Focus: Extending Ent. Swapping to Long Range (FNAL-to-ANL)

- Upgrade to Low Jitter SNSPD
- Upgrade to High-Rate EPS

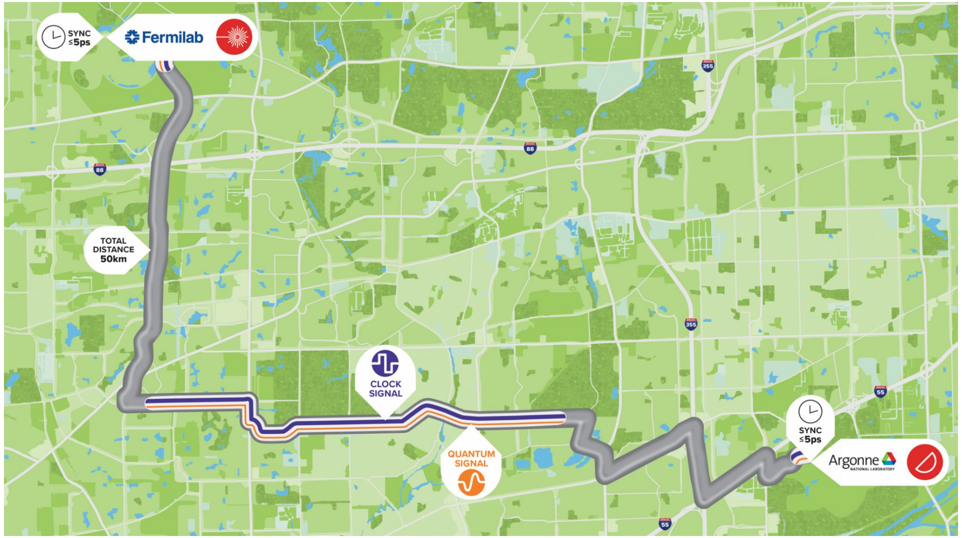


ITU Channel	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Wavelength (nm)	1555.75	1554.94	1554.13	1553.33	1552.52	1551.72	1550.92	1550.12	1549.32	1548.51	1547.72	1546.92	15546.12	15545.32	1544.53	1543.73	1542.94	1542.14	1541.35	1540.56	1539.77

ITU Channel	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
Wavelength (nm)	1538.98	1538.19	1537.40	1536.61	1535.82	1535.04	1534.25	1533.47	1532.68	1531.90	1531.12	1530.33	1529.55	1528.77	1527.99	1527.22	1526.44	1525.66	1524.89	1524.11

16 ch. DWDM

8 ch. DWDM

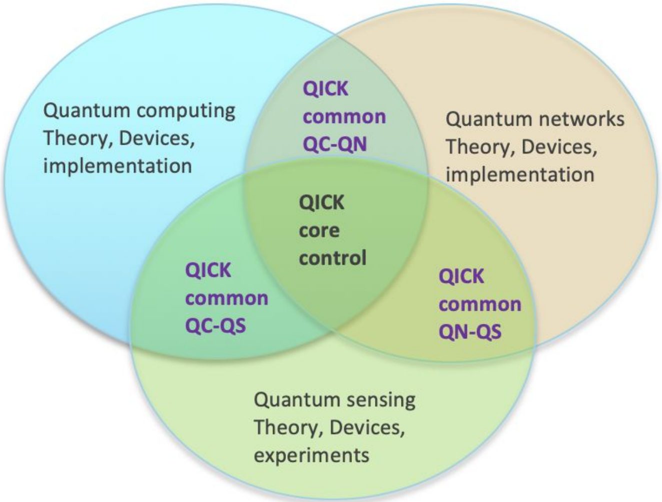


FPGA Controls

A comprehensive, control and readout system for QIS

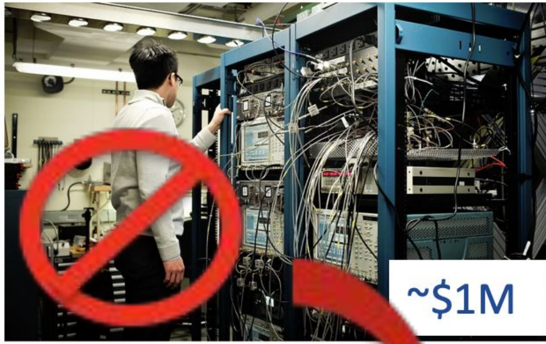
– **Open source**: including hardware schematics/layouts, firmware, software. See https://github.com/openquantumhardware https://qick-docs.readthedocs.io/en/latest/

– Easy to use, Cost effective, Collaborative, Supported by a growing international community



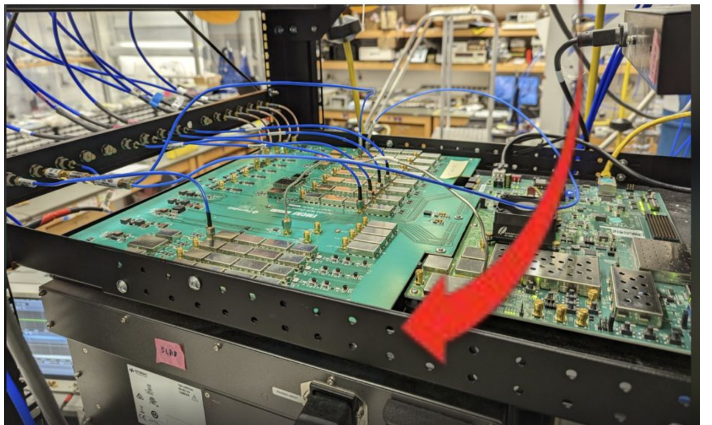
QICK: Quantum Instrumentation Control Kit

QIS before QICK w/off the shelf control

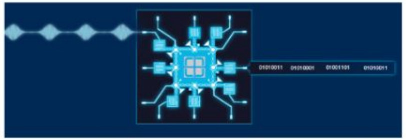


No Missed Connections
Jerry M. Chow, PhD, manager of theory of quantum computing and information at IBM Rese... inspects the cables connecting a vast array of microwave equipment powering quantum computing processors in ... lab.

Control with QICK



Transduction



Superconducting qubits

Optical communication

Microwave ⟷ Microwave-optical transducers ⟷ Optical

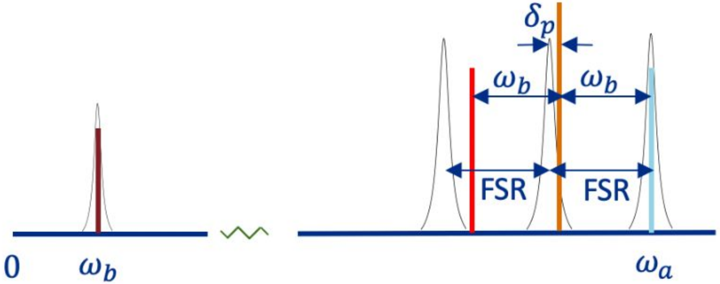
~GHz ~200 THz

Cryogenic temperature Room temperature

Electro-optic material: Lithium Niobate ($LiNbO_3$)

Three-wave mixing:

$$H_{int} = g_{eo}\,(a_p a^\dagger b + a_p^\dagger a b^\dagger)$$



- Cooperativity: $C = \frac{4|g_{eo}|^2 n_p}{\Gamma_a \Gamma_b}$
- Efficiency: $\eta = \frac{4C}{(1+C)^2}\eta_a \eta_b$
- Requirement:

1) Single-photon microwave-optic coupling rate (g_{eo}).
2) Q factor of the microwave and optical cavities.
3) Pump power.

Han, Xu, et al. *Optica* 8, 1050-1064 (2021).
Hease, William, et al. PRX Quantum 1, 020315 (2020):.
https://sqms.fnal.gov
https://www.antaira.com/Blog-Four-Advantages-of-Fiber-Optic-Communications

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