



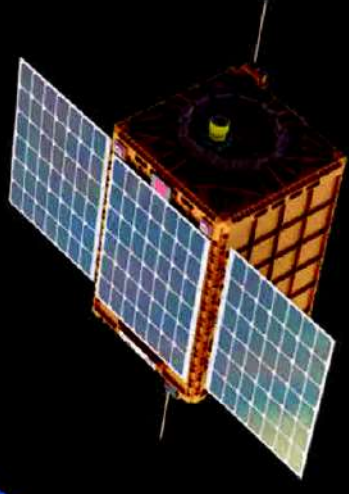
Disruptive Computing Networks & Sensors

Q4S Demonstration: Quantum Entanglement in Space

Jay Lowell

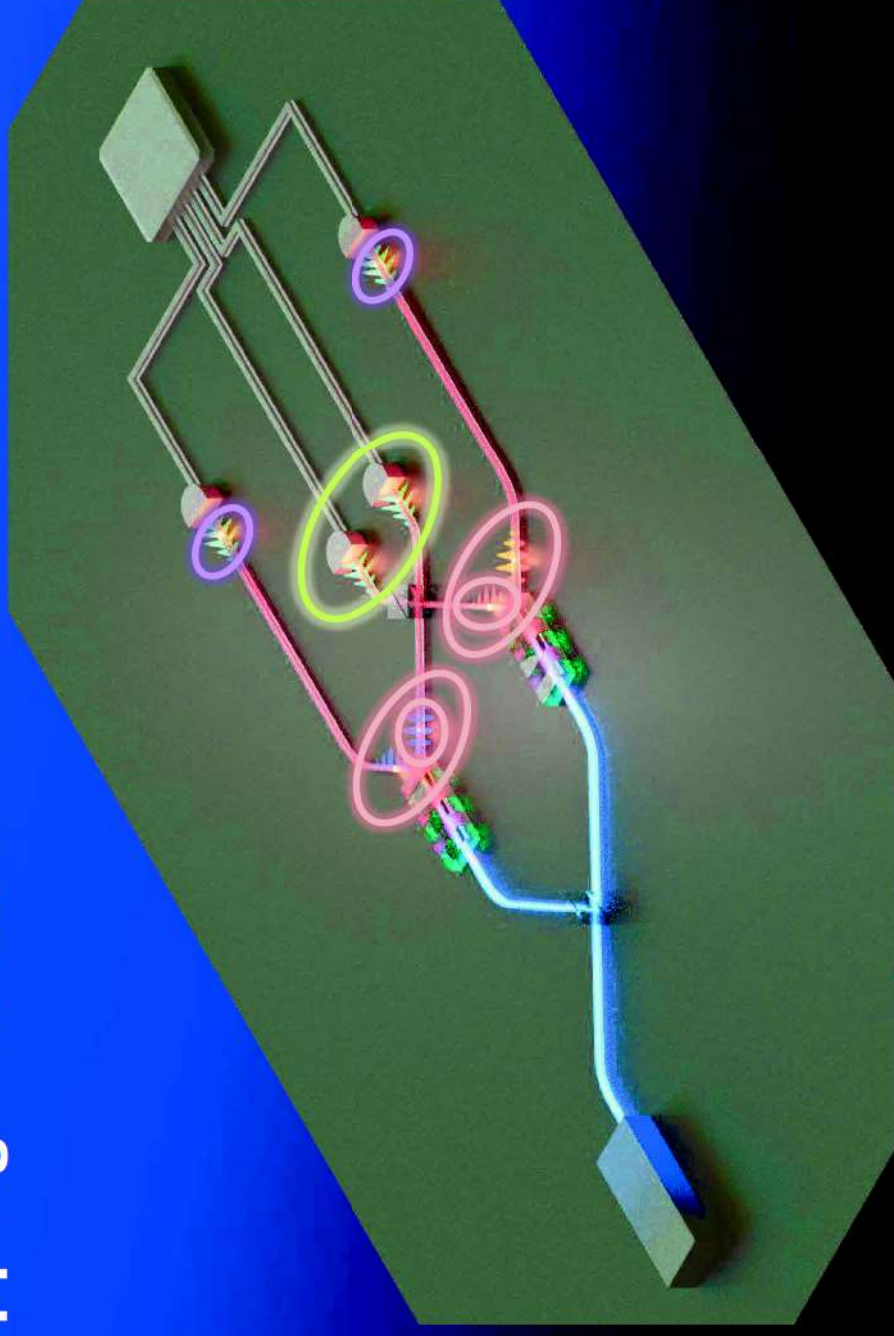
Q4S Mission

- Launching 2026
- One year mission life
- Sun-Synchronous Orbit
- Demonstrate quantum entanglement swapping
- Evaluate components



Entanglement Swapping Protocol

- Create two pairs of entangled photons
- Select one photon from each pair
- Entangle that pair with each other
- The remaining photons are entangled



The journey so far....

On Orbit Demonstration

Satellite / Payload

Integrated System

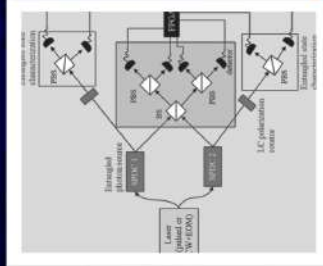
Environmental Testing

Sub-Assemblies

Benchtop

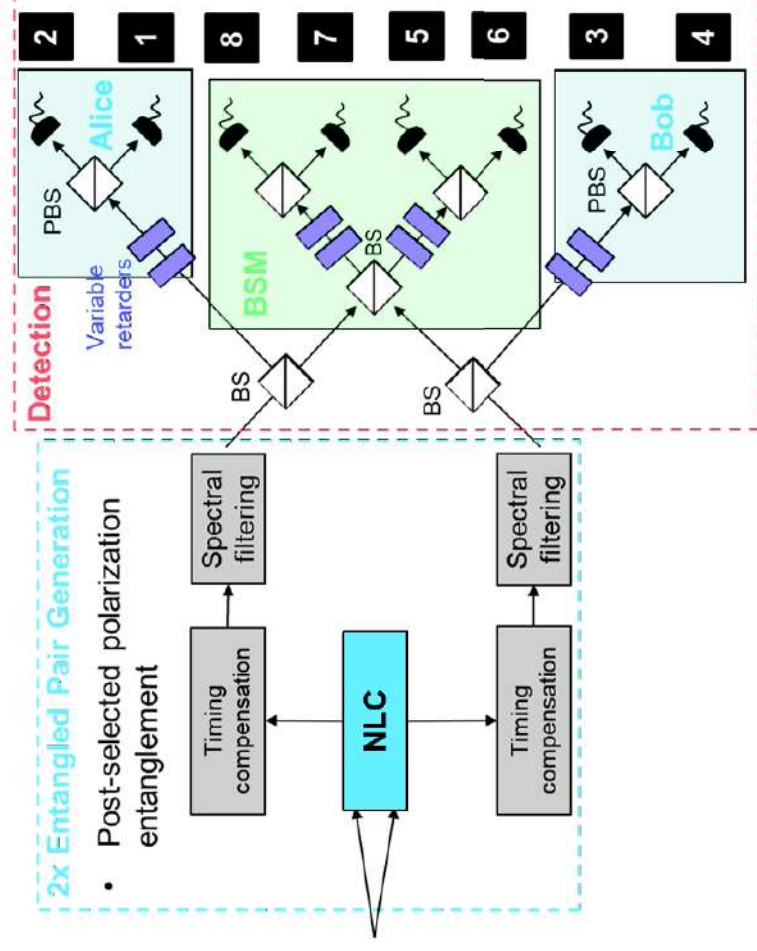
✓ Trade Study

✓ Concept





- Basic concept is relatively straightforward



2 detector combinations per Bell-state e.g. ψ^-

Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8

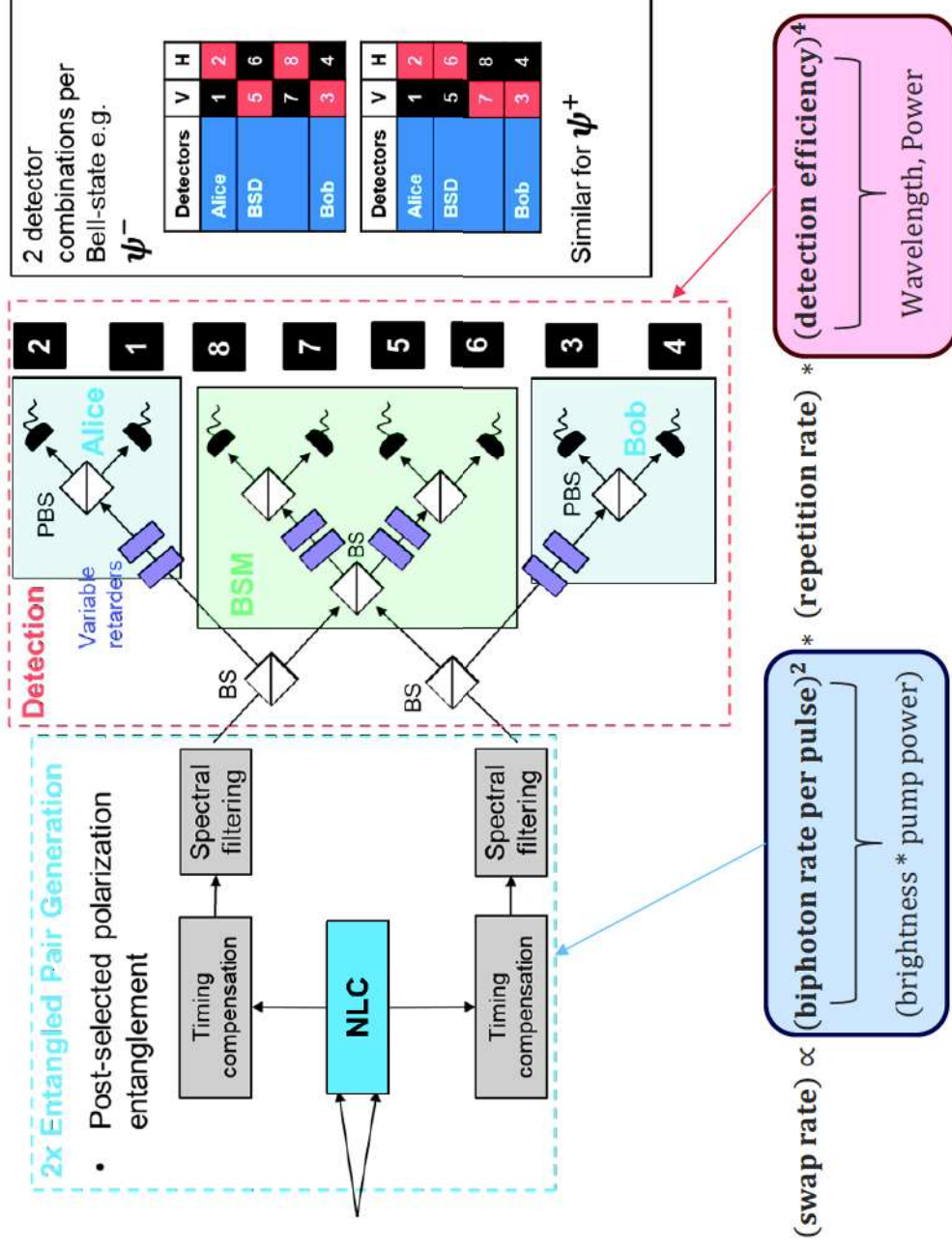
Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8

Similar for ψ^+



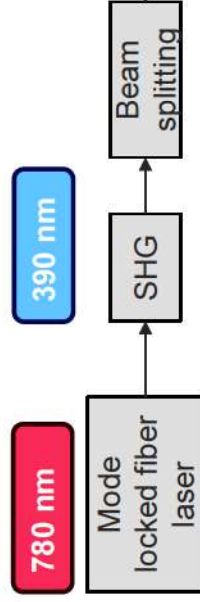
■ Engineering constraints force consideration of tradeoffs

- Laser selection
 - Power consumption
 - Brightness
 - Repetition rate
 - Wavelength
- Free space or fiber implementation
- Nonlinear crystal selection
- Detector selection
 - Operating wavelength
 - Power consumption

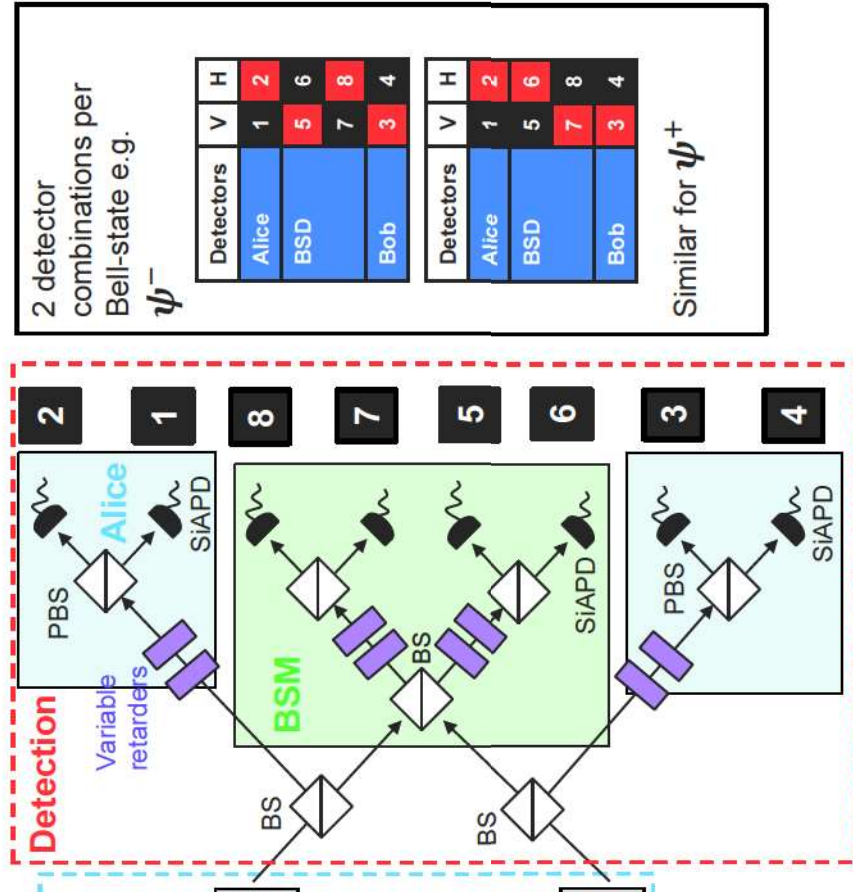
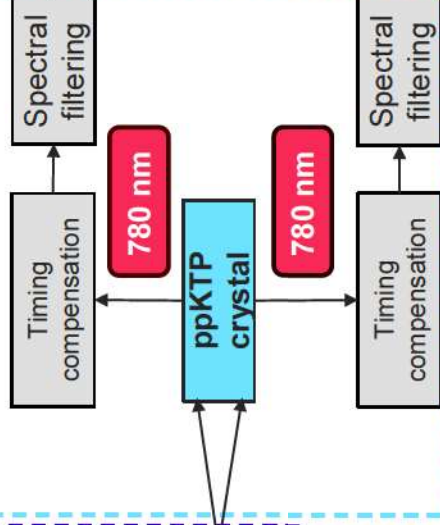


Pump laser

- Pulsed laser source:
 - 100 fs @ 780 nm
 - SHG to convert to 390 nm

**2x Entangled Pair Generation**

- Post-selected polarization entanglement

**Detection**

2 detector combinations per Bell-state e.g. ψ^-

Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8
	3	4

Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8
	3	4

Similar for ψ^+

Trade Study Results:**Payload Requirements**

Average power draw < 65 W

Total payload weight < 20 kg

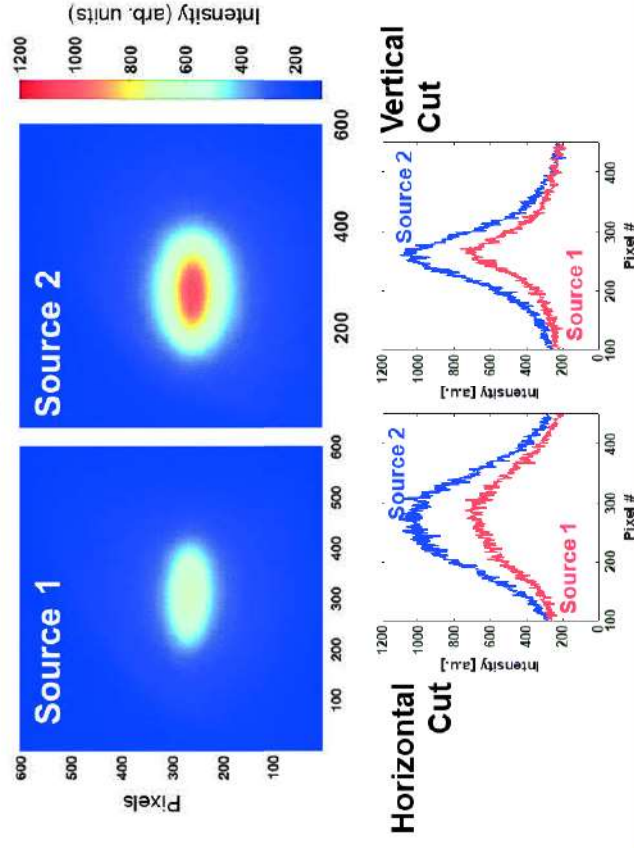
Performance Requirements

10-200 swaps / hour

0.7 < Fidelity < 0.9

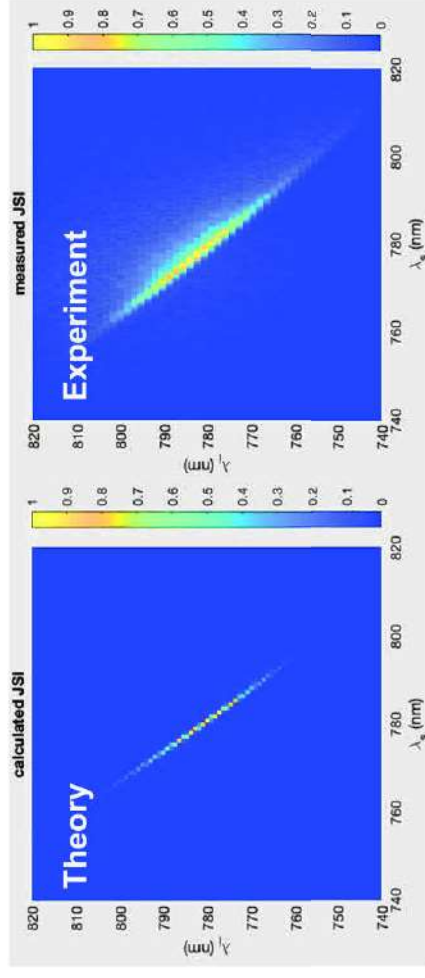
Need two sources of photons with no spatial which-path information

SPDC images recorded after the
Bell State beam splitter:



Both sources have the same intensity profile when
intensity normalized → Geometric overlap: 98%

Need two sources of photons with no spectral which-path information

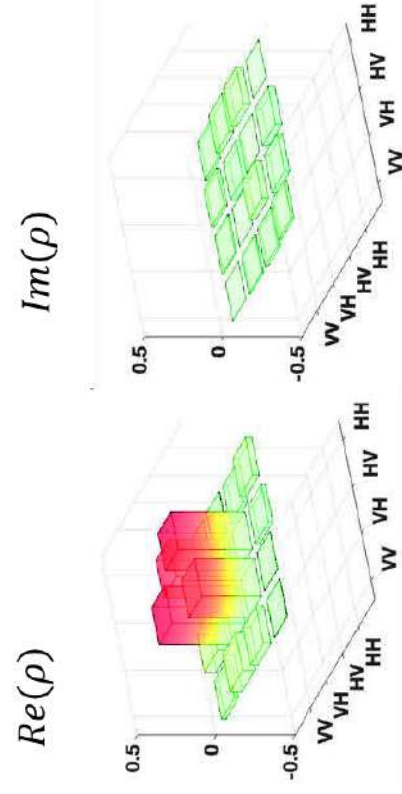


- Width of JSI along the antidiagonal is limited by phase matching in ppKTP down conversion crystal.
- Single-source entanglement visibility up to 0.978 predicted with appropriate bandwidth.

Post-selected polarization entanglement generated
between photon pairs from the same source

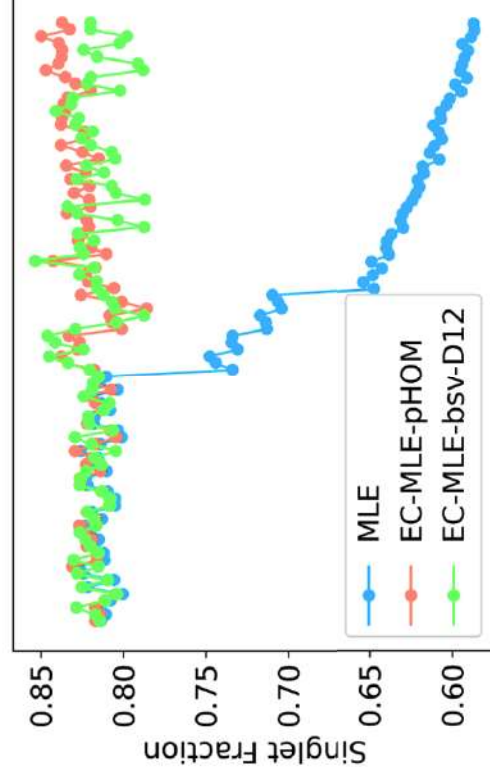
Single Source Tomography

Measured between Alice + BSD56



- Fidelity to Bell state (ψ^+): 0.87 +/- 0.005
- Polarization Hong-Ou-Mandel Visibility: 0.88 +/- 0.025
- Coincidence rate: up to 3000 cc/sec

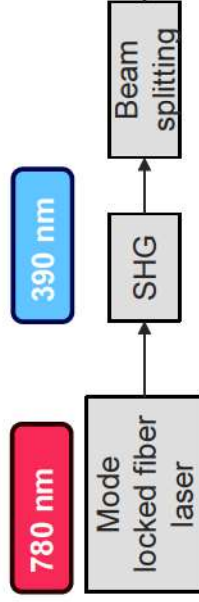
Extracting Quantum Information in a Changing Environment



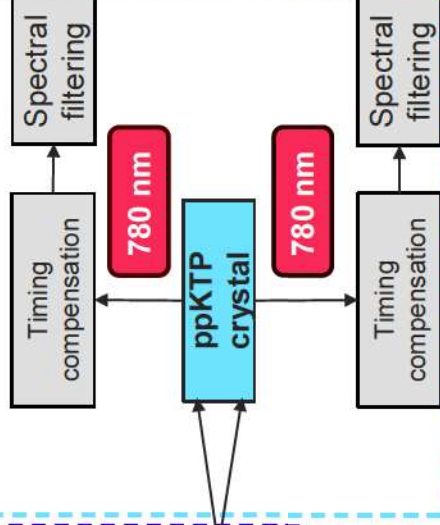
- New algorithms robustly extract quantum state under wide variety of environmental conditions
- Have demonstrated end-to-end automation of quantum state tomography
 - Newly developed algorithms have improved the robustness of state reconstruction
 - Hardware and software testing will continue through delivery for launch

Pump laser

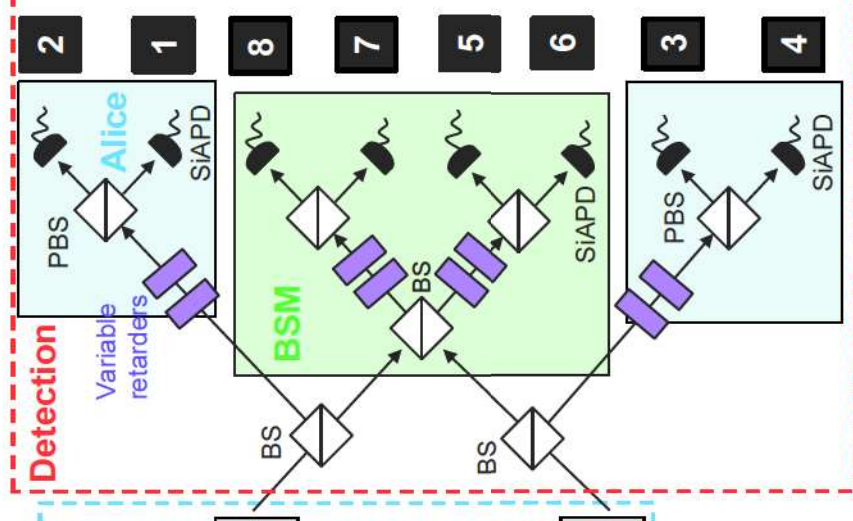
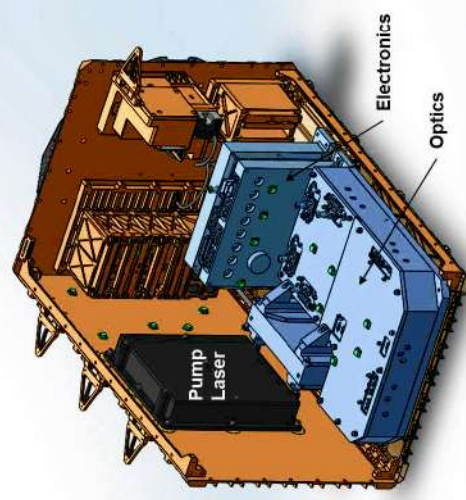
- Pulsed laser source:
 - 100 fs @ 780 nm
 - SHG to convert to 390 nm

**2x Entangled Pair Generation**

- Post-selected polarization entanglement

**Payload Design Concept**

- 4 sub-assemblies
- <10 L volume
- 19 kg design mass
- <45 W design power draw

**Detection**

2 detector combinations per Bell-state e.g. ψ^-

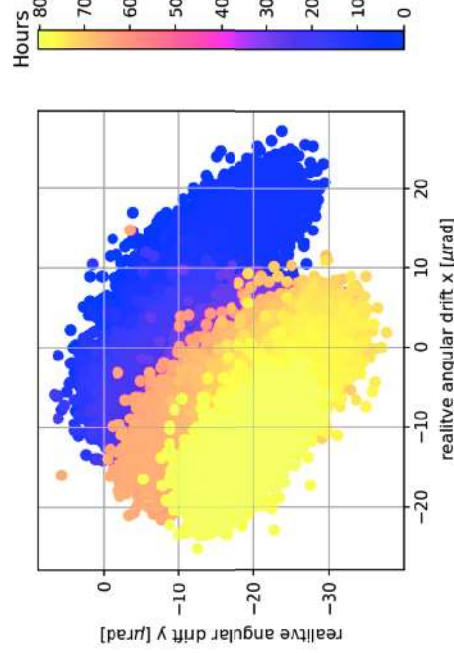
Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8

Detectors	V	H
Alice	1	2
BSD	5	6
Bob	7	8

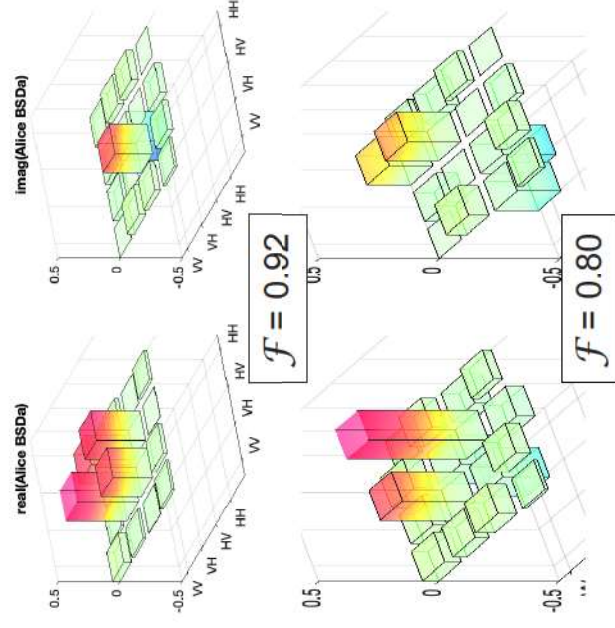
Similar for ψ^+

**Q-220: Sub-assembly integrated pointing stability**

Validate opto-mechanical and electrical pointing control sub-assembly performance

**Q-102a: Single-source entanglement visibility**

Validate single-photon source sub-assembly performance

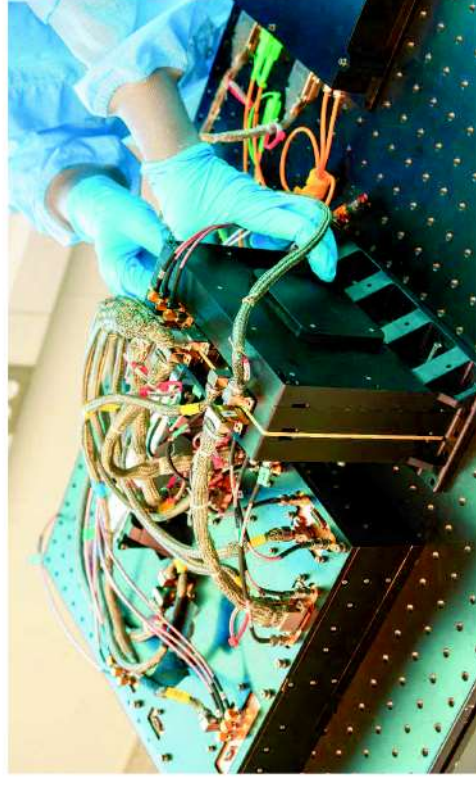


Both sources have the same intensity profile when intensity normalized → Geometric overlap: 98%

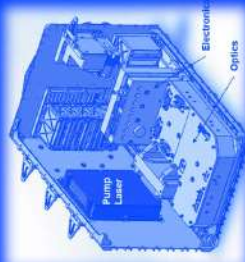
Post-selected polarization entanglement generated between photon pairs from the same source



- Integrated assemblies just completed thermal, vacuum and vibration testing including evaluation of performance under controlled environmental changes



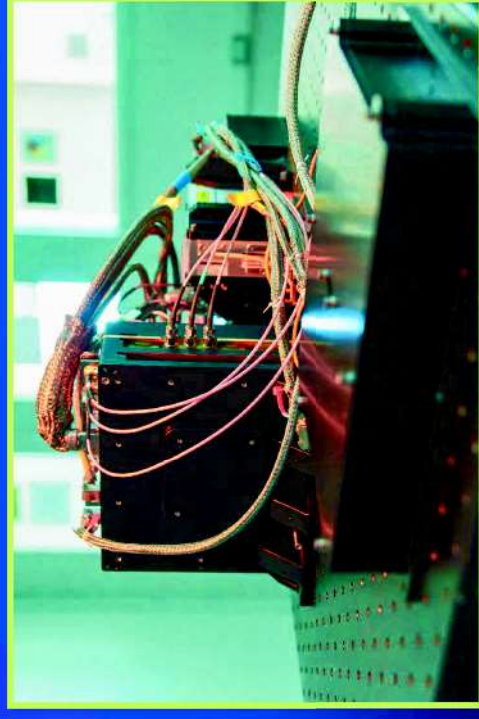
The journey so far...



The journey so far



On Orbit Demonstration



Satellite / Payload



Integrated System

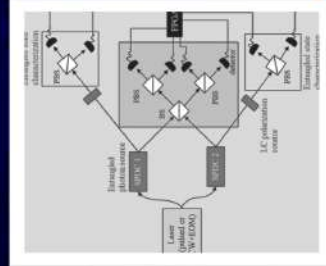
Environmental Testing

Sub-Assemblies

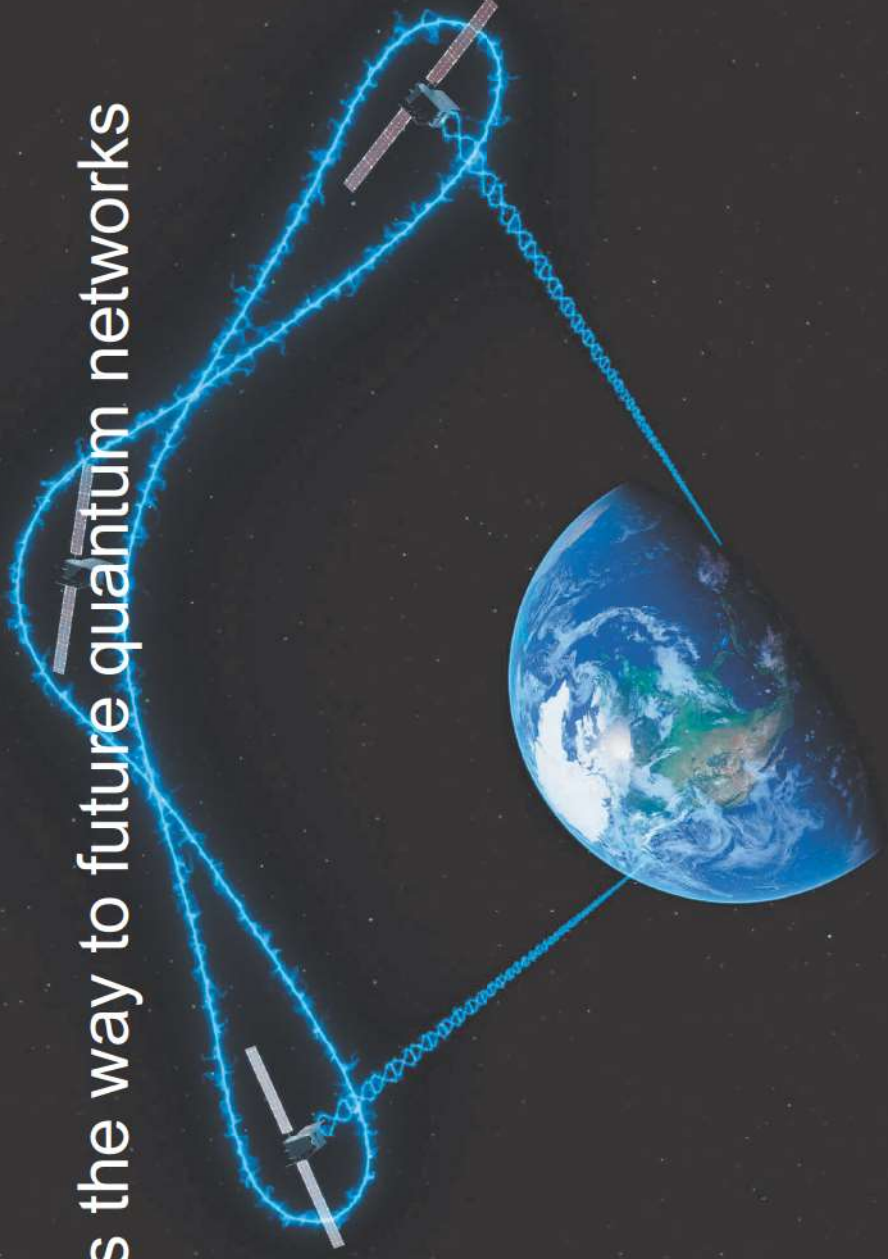
Benchtop

Trade Study

Concept



Q4S points the way to future quantum networks





boeing.com/quantum