Quantum Communication with a High-Rate Entangled Photon Source

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Georgia Institute of Technology Physics Senior Seminar I

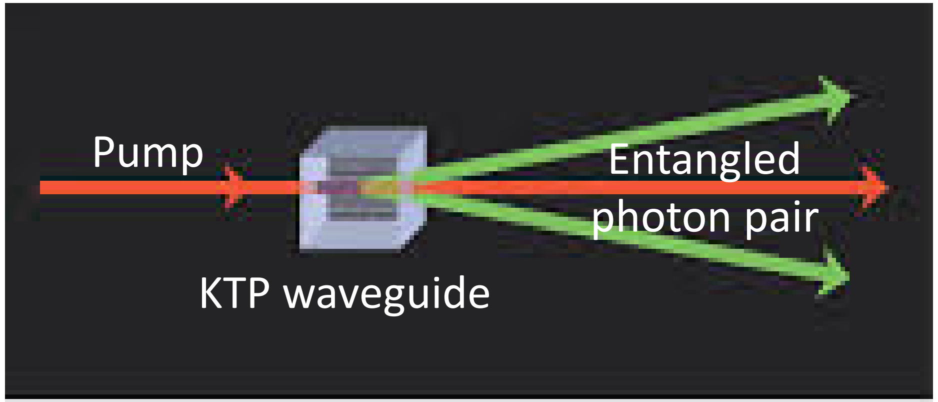
October 14, 2016

Introduction

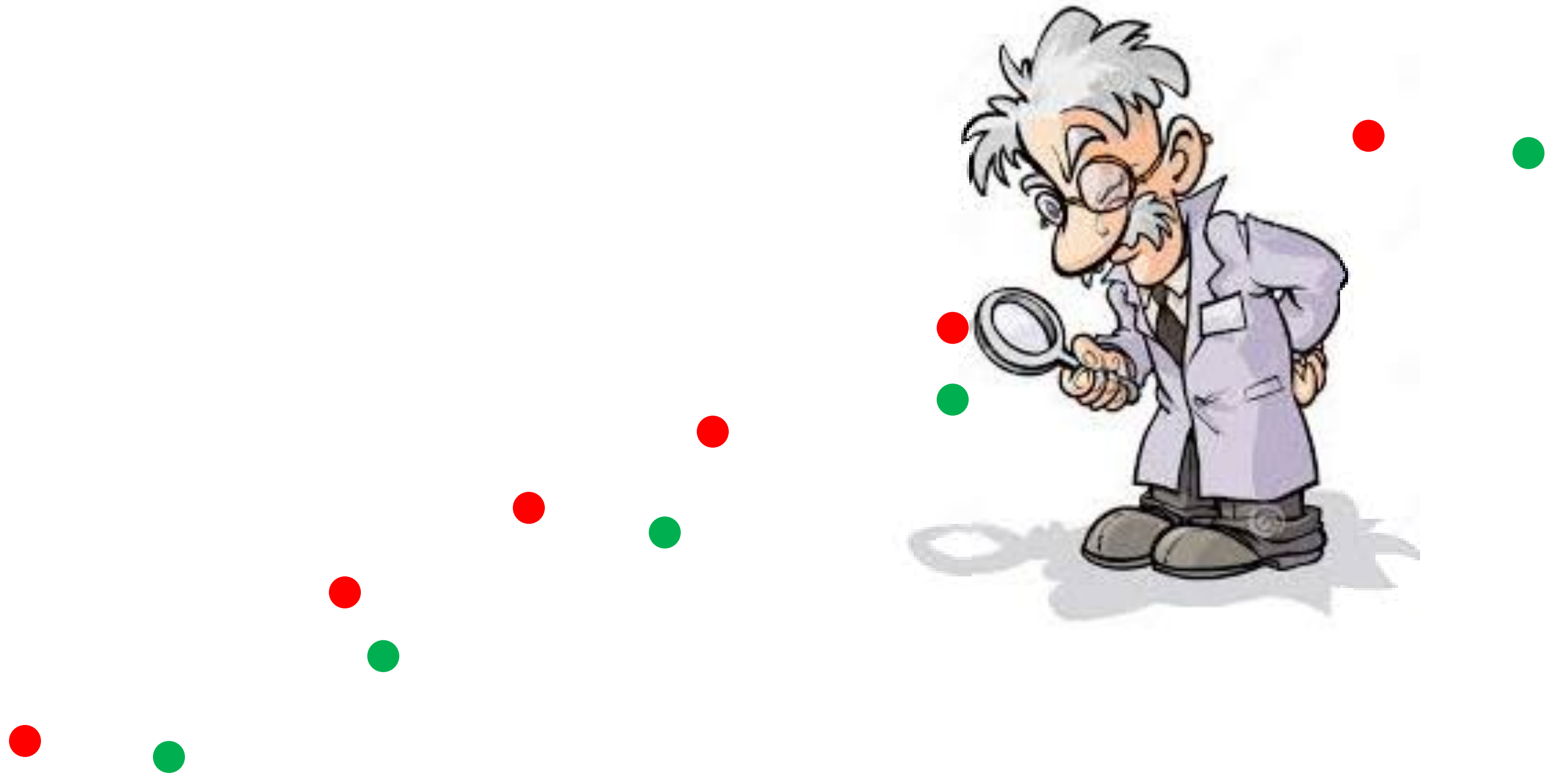
- Current encryption techniques use algorithms that rely on computational assumptions
- Quantum communications rely only on the laws of physics
- Quantum Key Distribution (QKD) protocols typically require the use of either single or entangled photon sources
- We characterize a high-rate entangled photon source and demonstrate free-space QKD

Entangled Photon Source

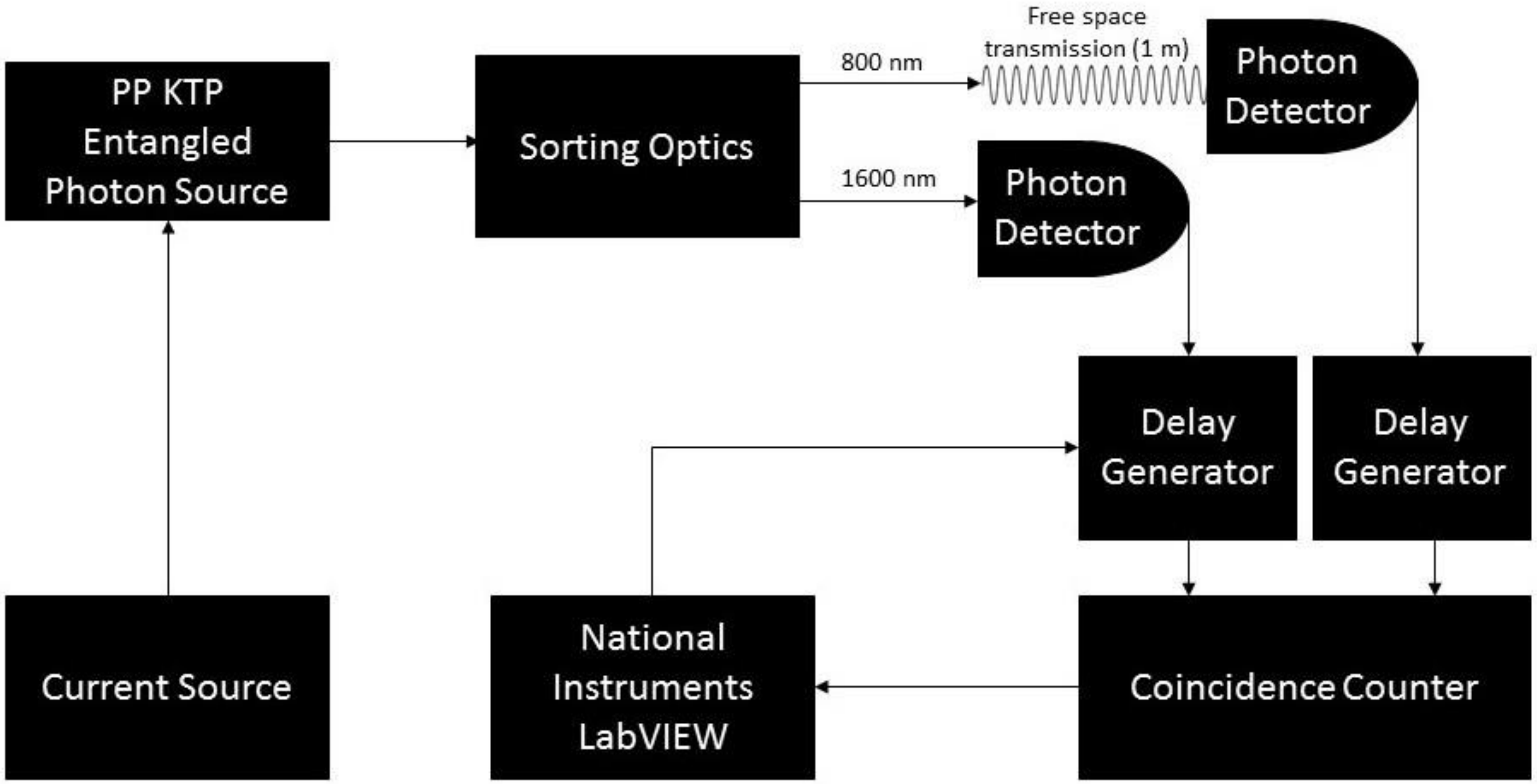
- Developed through Phase 3 SBIR with AdvR, Inc.
- Creates entangled photon pairs via spontaneous parametric down-conversion in a dual element periodically poled potassium titanyl phosphate (KTP) waveguide



Coincidence Counting

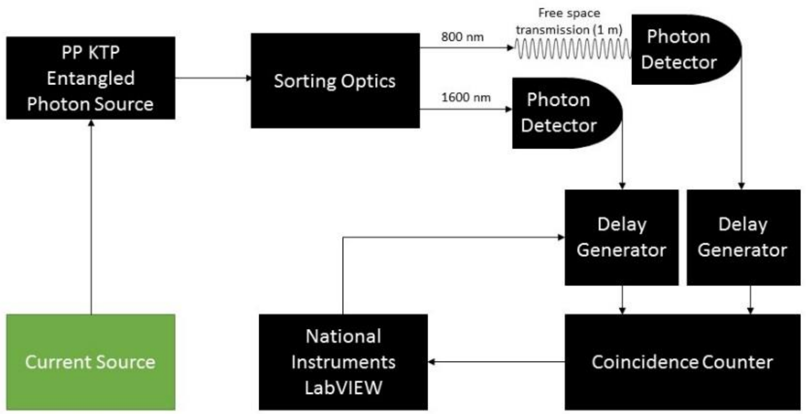


Coincidence Counting: Experimental Design



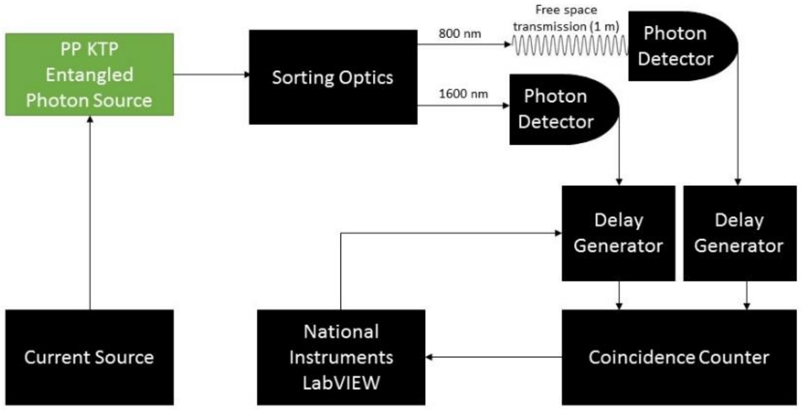
Coincidence Counting: Experimental Design

- **Laser pump current controls laser power entering entangled photon source**



Coincidence Counting: Experimental Design

- Laser pump current controls laser power entering entangled photon source
- **Source creates entangled 800-nm and 1600-nm photons**



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- Laser pump current controls laser power entering entangled photon source
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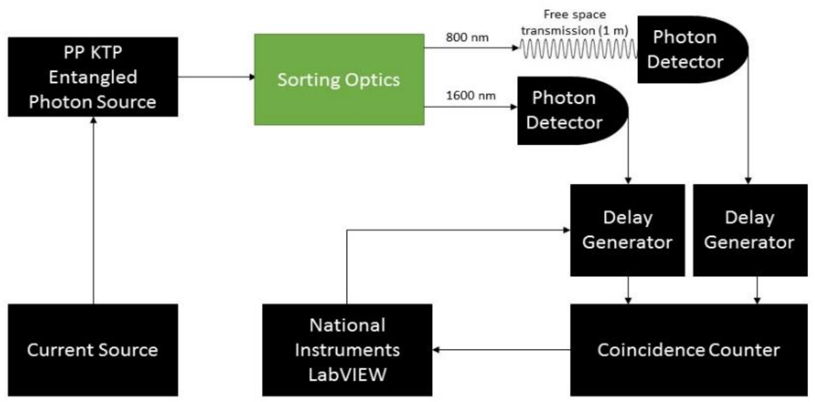
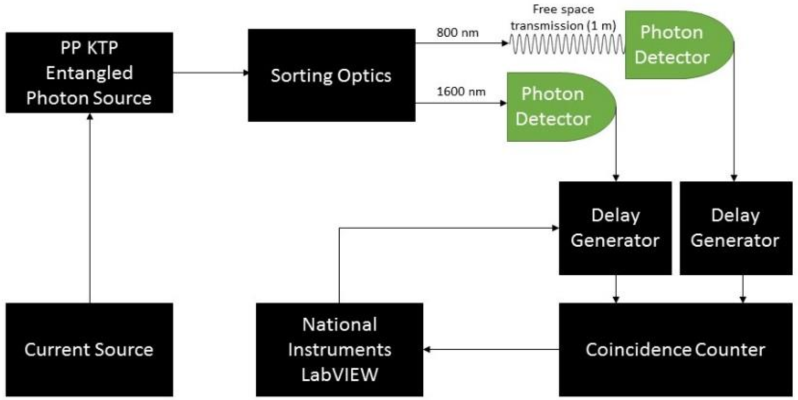
- **Sorting optics separate 800-nm from 1600-nm photons**



Coincidence Counting: Experimental Design

- Laser pump current controls laser power entering entangled photon source
- Source creates entangled 800-nm and 1600-nm photons
- Sorting optics separate the 800-nm from the 1600-nm photons
- **Photon detectors count rate of photons received**



Coincidence Counting: Experimental Design

- Laser pump current controls laser power entering entangled photon source
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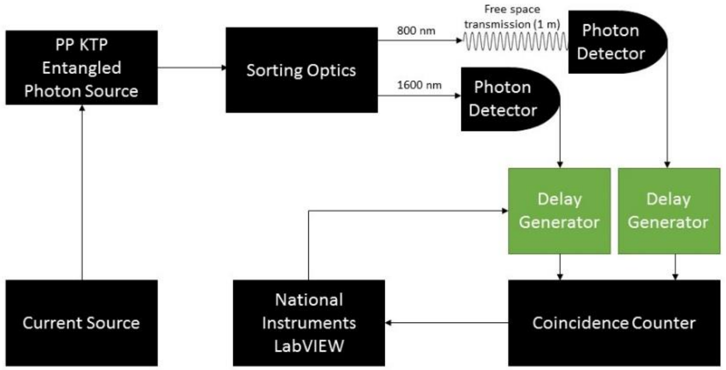
- **Delay generators account for differences in path length to each photon detector and one generator is swept around the coincidence peak**



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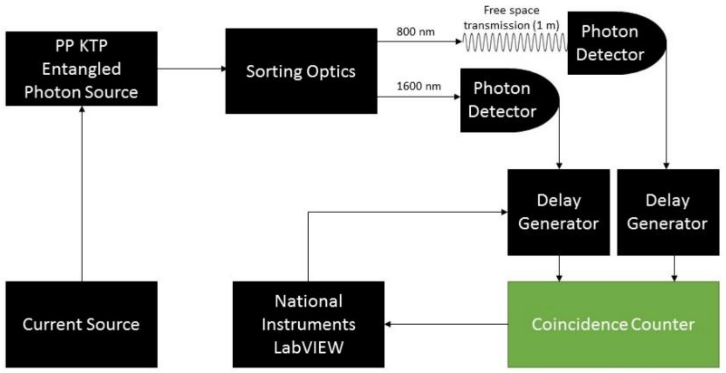
- **Coincidence Counter determines how many coinciding (+/- 243 picoseconds) 800-nm and 1600-nm photons were detected**



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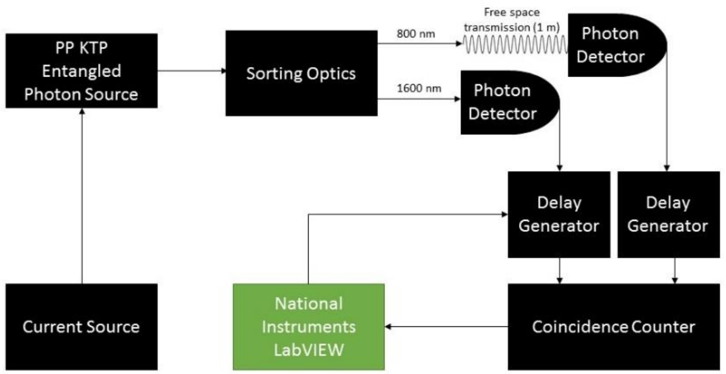
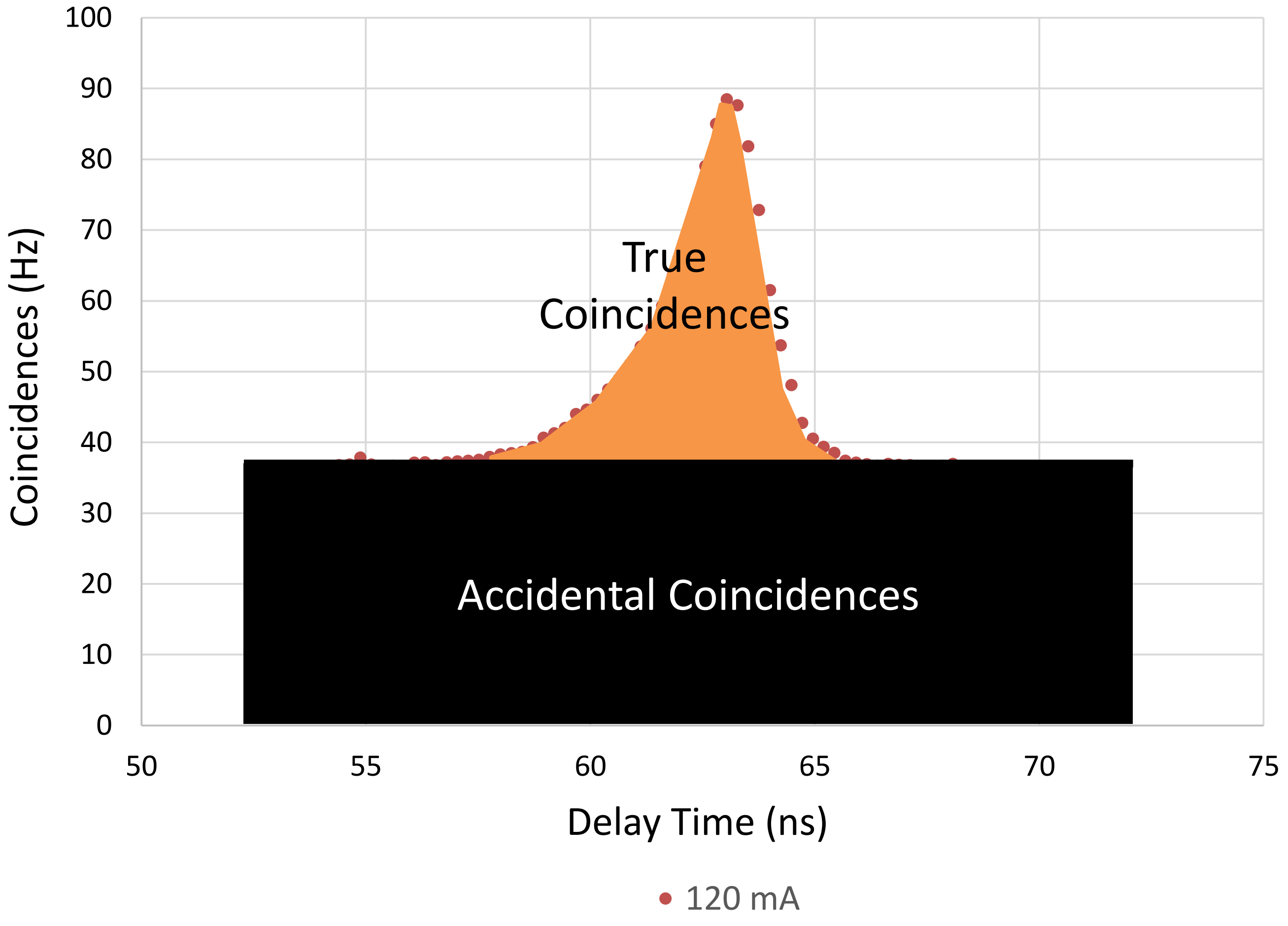
- Delay generators account for differences in path length to each photon detector and one is swept around coincidence peak
- Coincidence Counter determines how many coinciding (+/- 243 picoseconds) 800-nm and 1600-nm photons were detected
- **Delay sweep and data collection are automated via LabVIEW**



Coincidence Counting: Results



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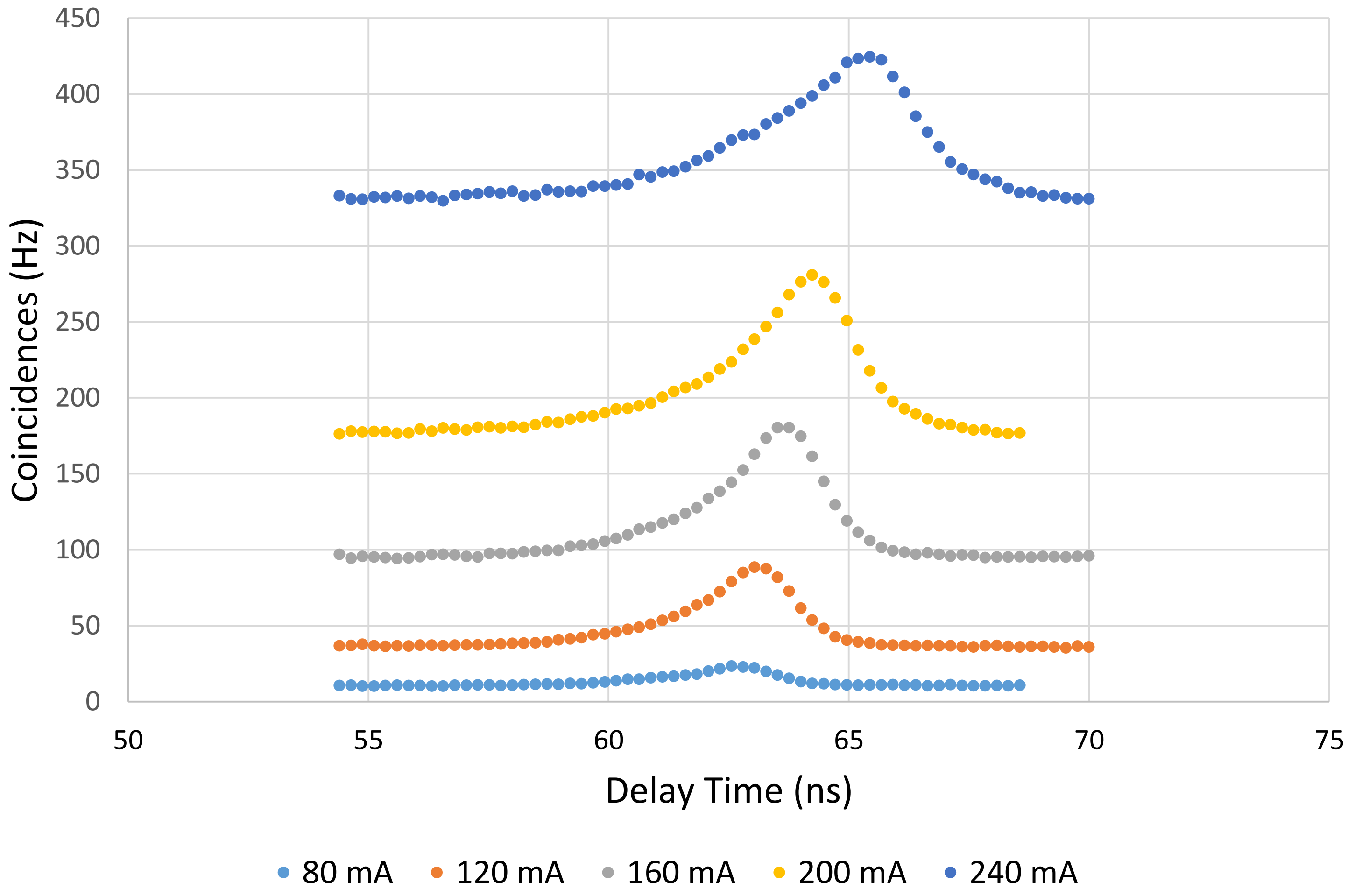

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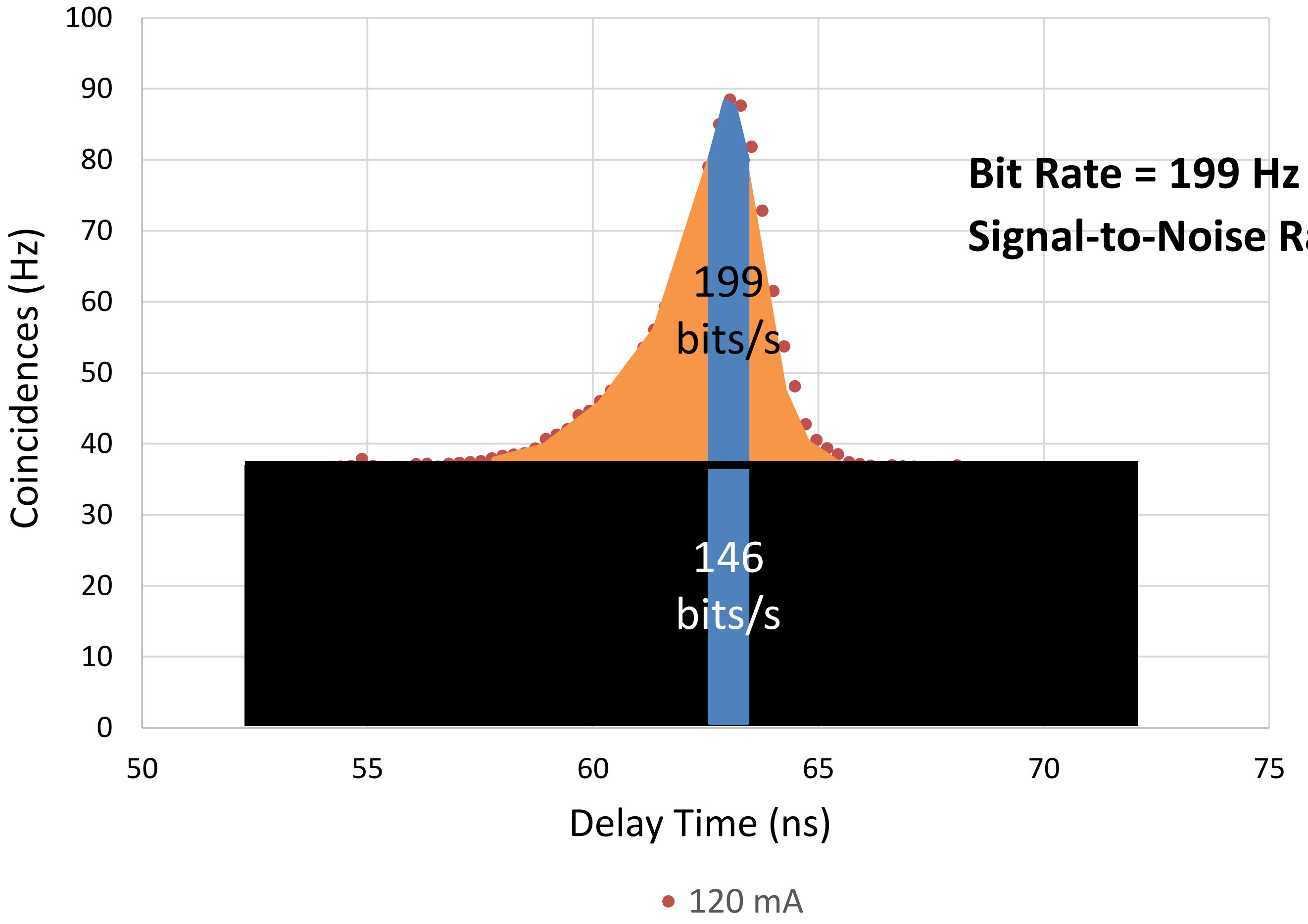
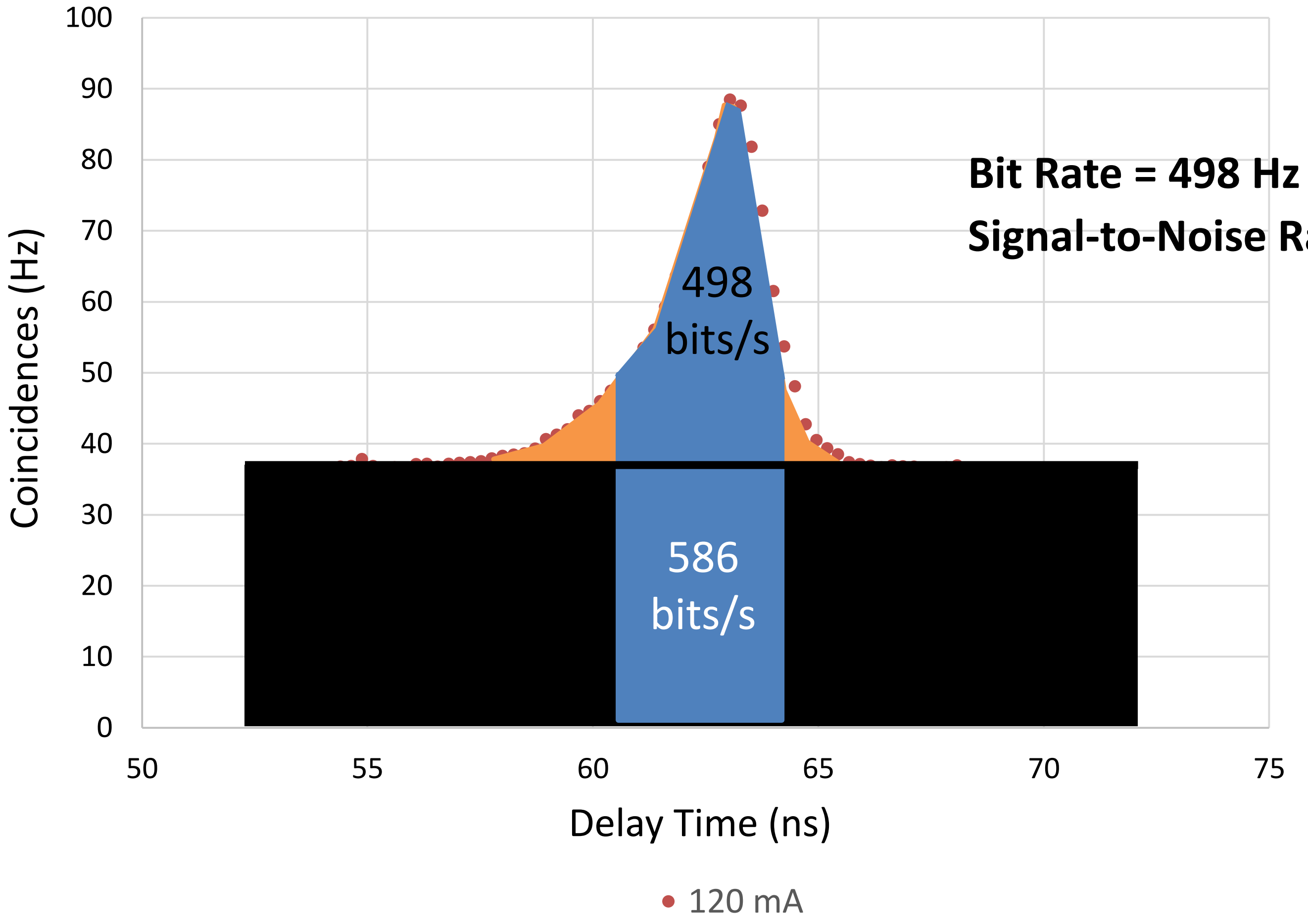


Bit Rate = 199 Hz

Signal-to-Noise Ratio (SNR) = 199/146 = 1.35

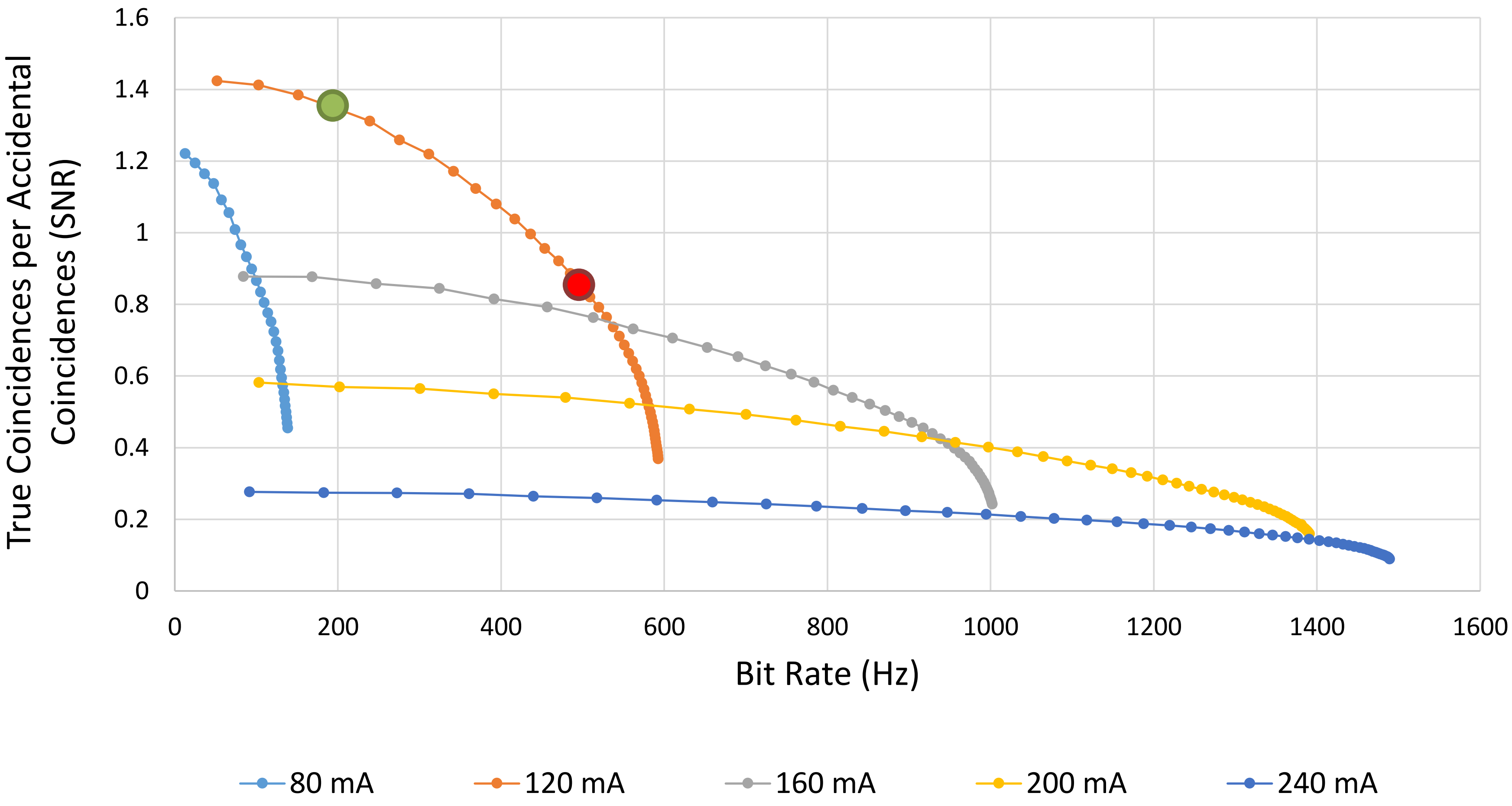
Coincidence Counting: Results



Bit Rate = 498 Hz

Signal-to-Noise Ratio (SNR) = 498/586 = 0.85

Coincidence Counting: Results



Coincidence Counting: Total Pairs Generated

1. $PhotonsDetected_{800} = PhotonsGenerated_{800} * PathEfficiency_{800}$
2. $PhotonsDetected_{1600} = PhotonsGenerated_{1600} * PathEfficiency_{1600}$
3. $PhotonsGenerated_{800} = PhotonsGenerated_{1600} = PairsGenerated$

4. $\boldsymbol{TrueCoincidences = PairsGenerated * PathEfficiency_{800} * PathEfficiency_{1600}}$

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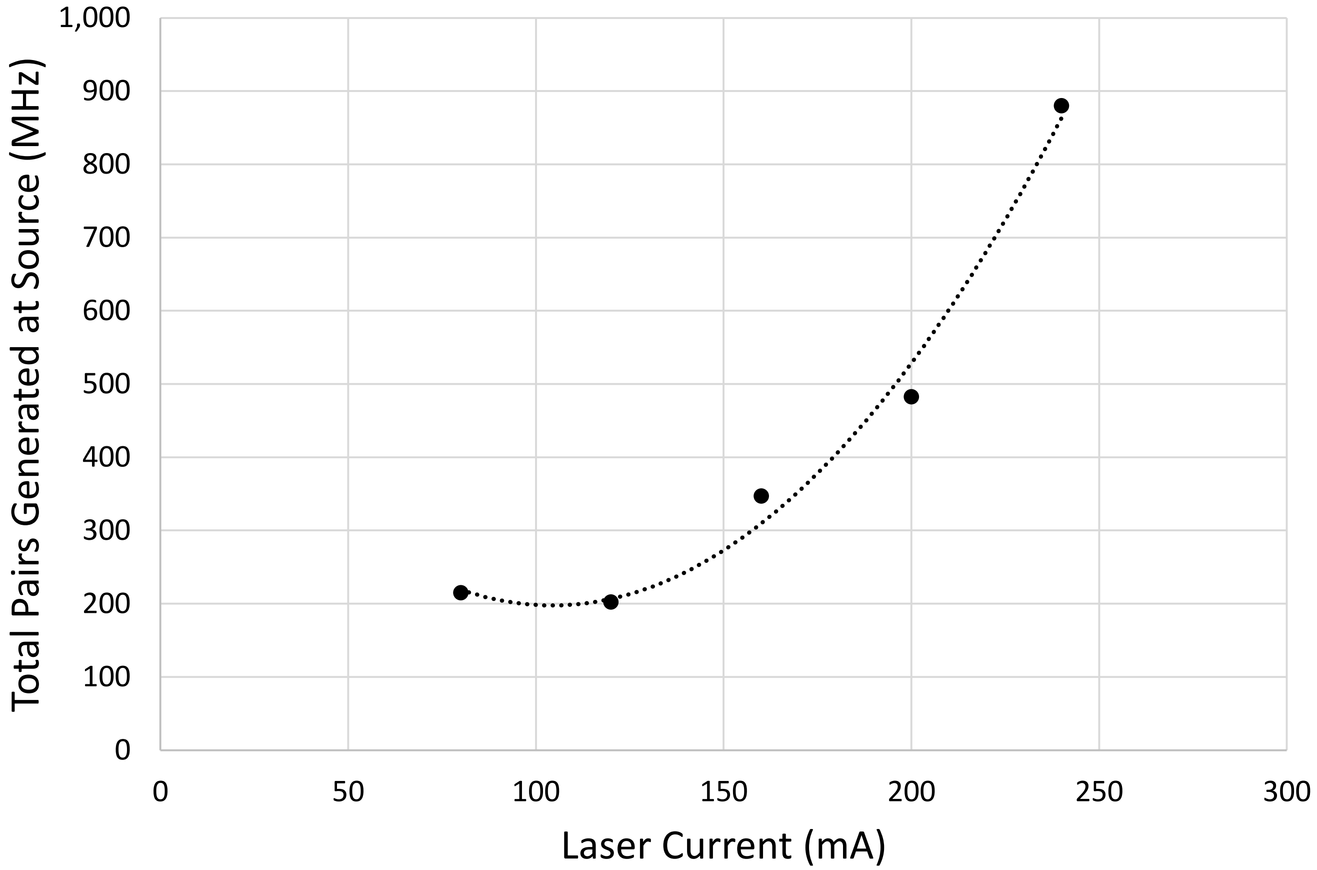
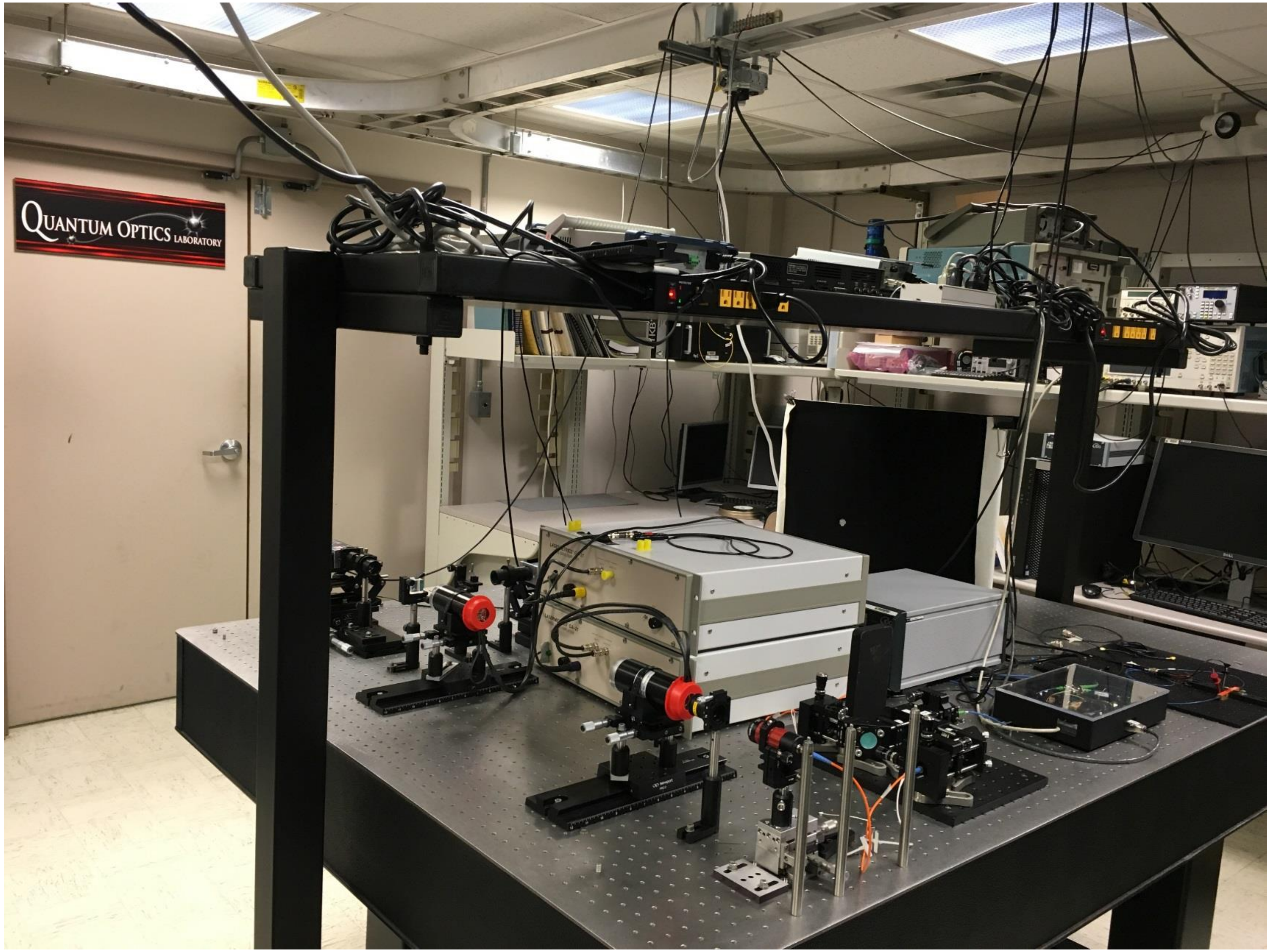
5. $$\boldsymbol{PairsGenerated = \frac{PhotonsDetected_{800} * PhotonsDetected_{1600}}{TrueCoincidences}}$$

Coincidence Counting: Total Pairs Generated

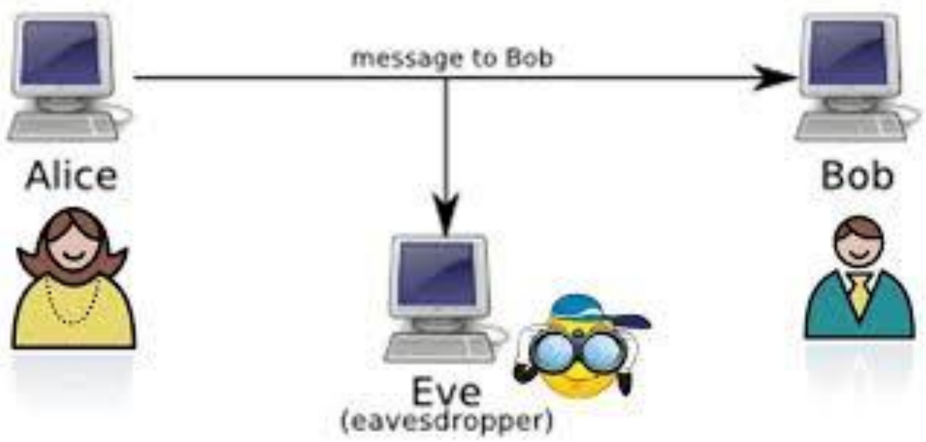


QKD: Demonstration



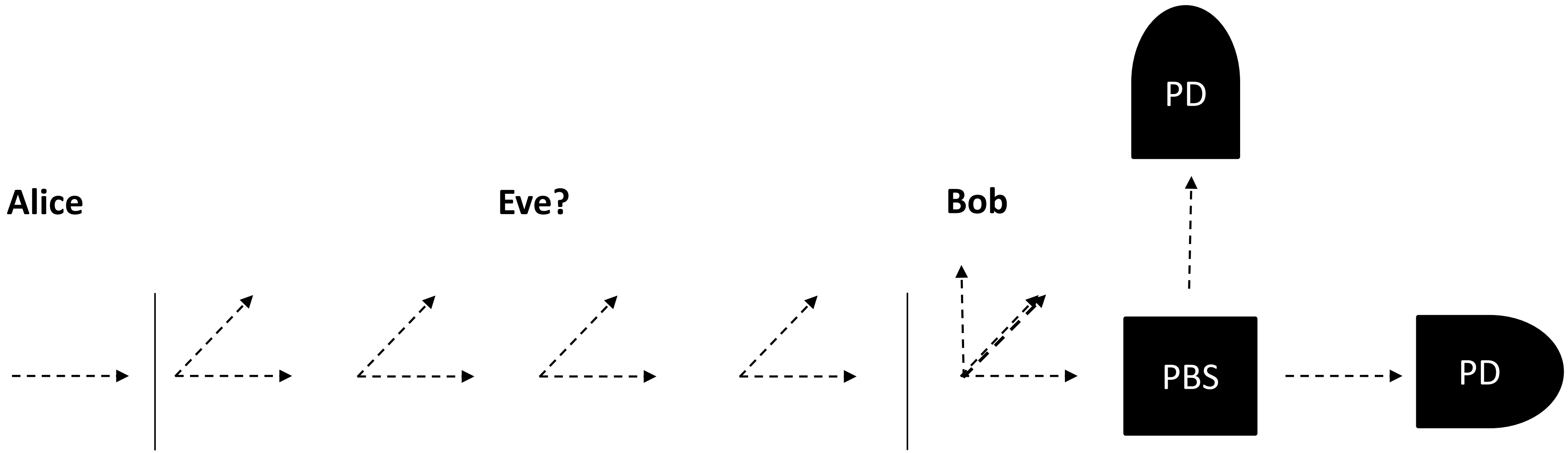
QKD: Overview

- Provably secure method of encryption
- A random key is distributed, then communication can be sent classically with this key
- Different QKD protocols exist
- We demonstrate one such protocol (B92)

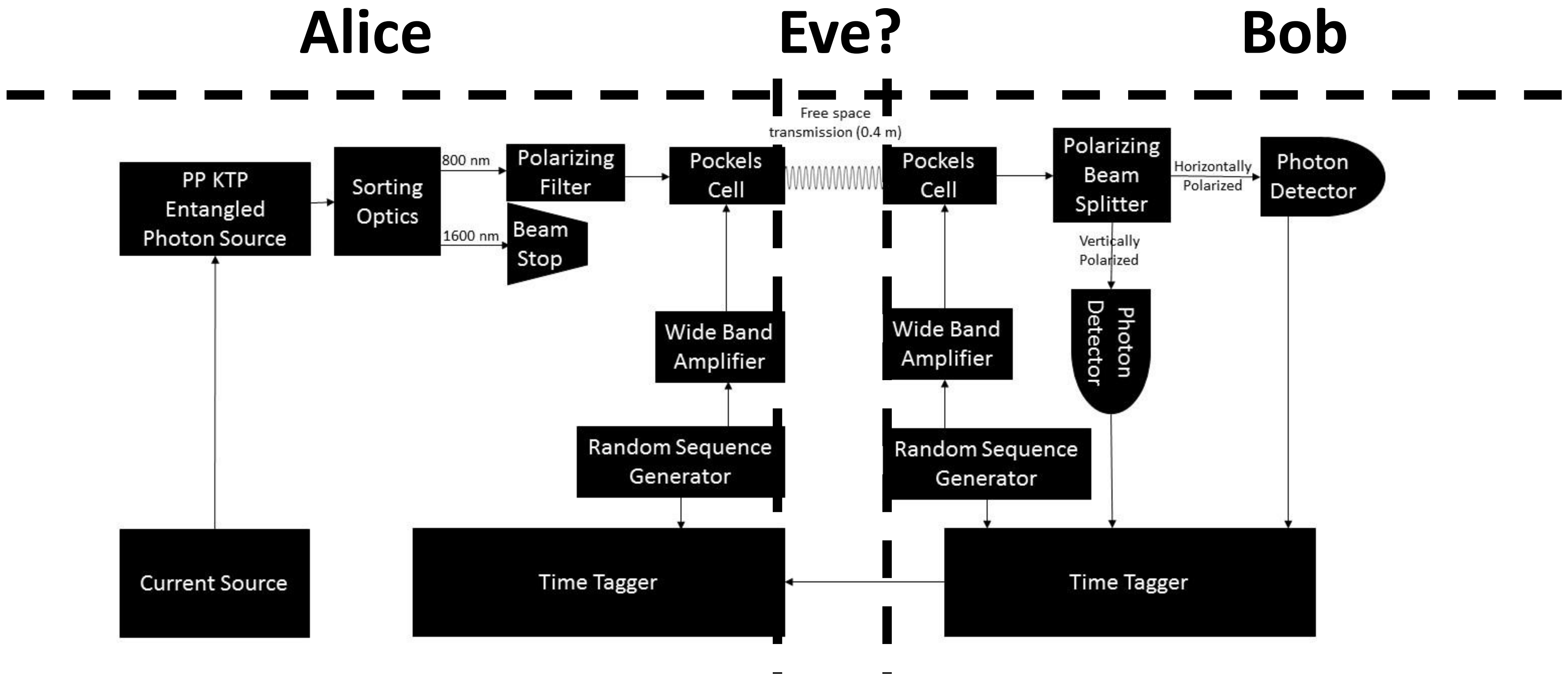


QKD: B92 Protocol

- Alice sends photons in one of two polarizations to Bob
- Bob measures the polarization of these photons in one of two bases
- If Eve eavesdrops, it will cause errors in the key
- Afterwards, Bob sends time tags of determined bits to Alice via classical channel
- Alice and Bob share a portion of the key classically to check for errors



QKD: Experimental Design

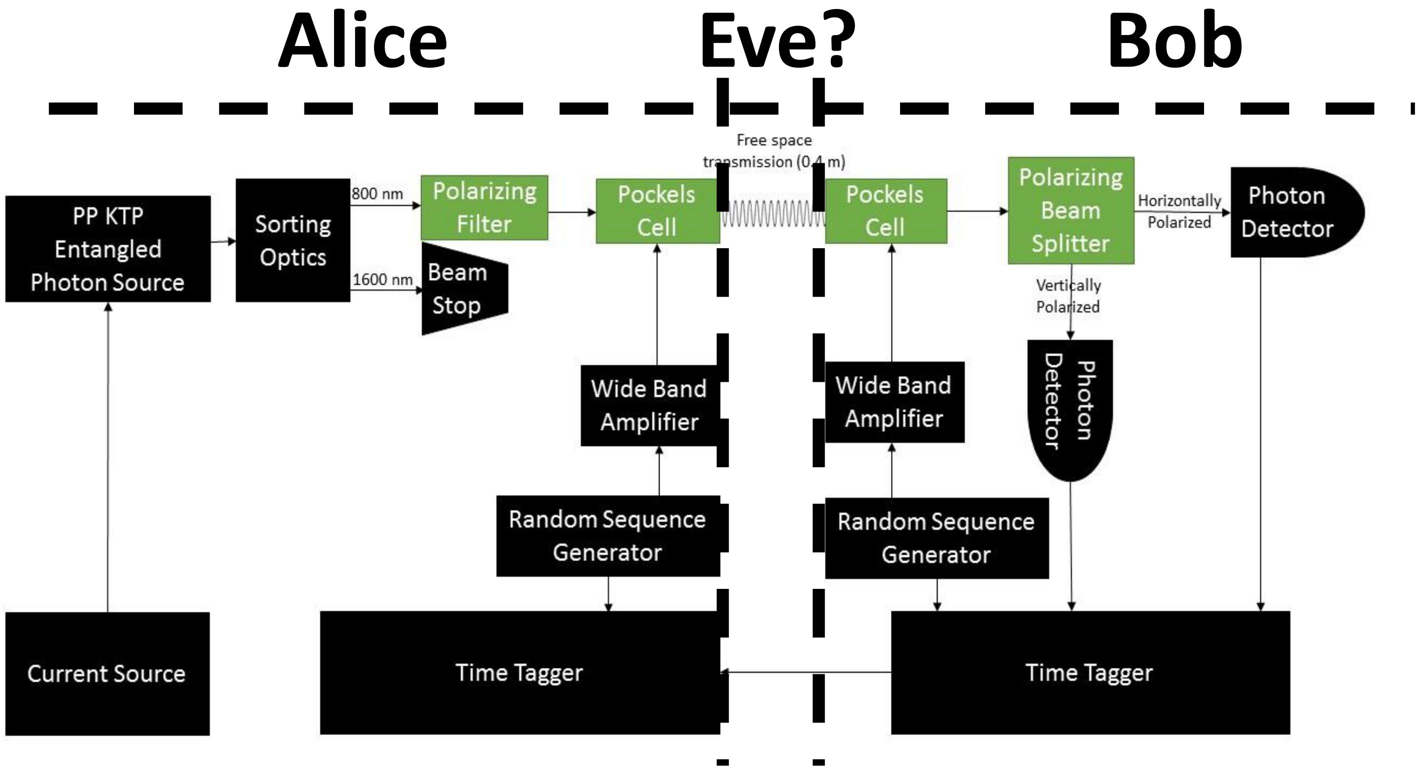


Time Tags of Determined Bits Are Sent to Alice via Classical Channel

QKD: Experimental Design

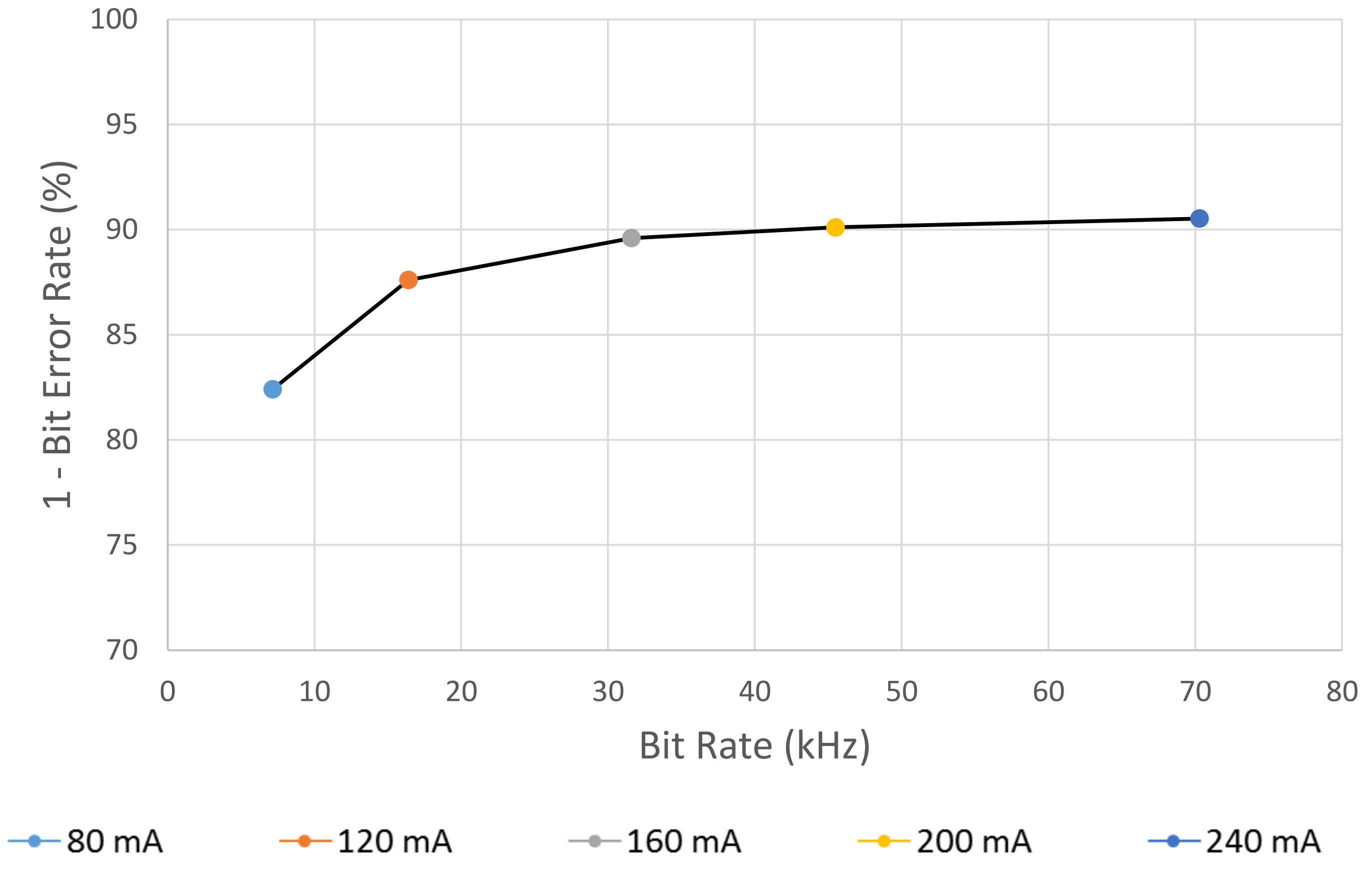
- *Pockels* cells provide voltage-controlled polarization rotation for basis choice

- Polarizing beam splitter distinguishes Bob's measurements



Time tags of determined bits are sent to Alice via classical channel

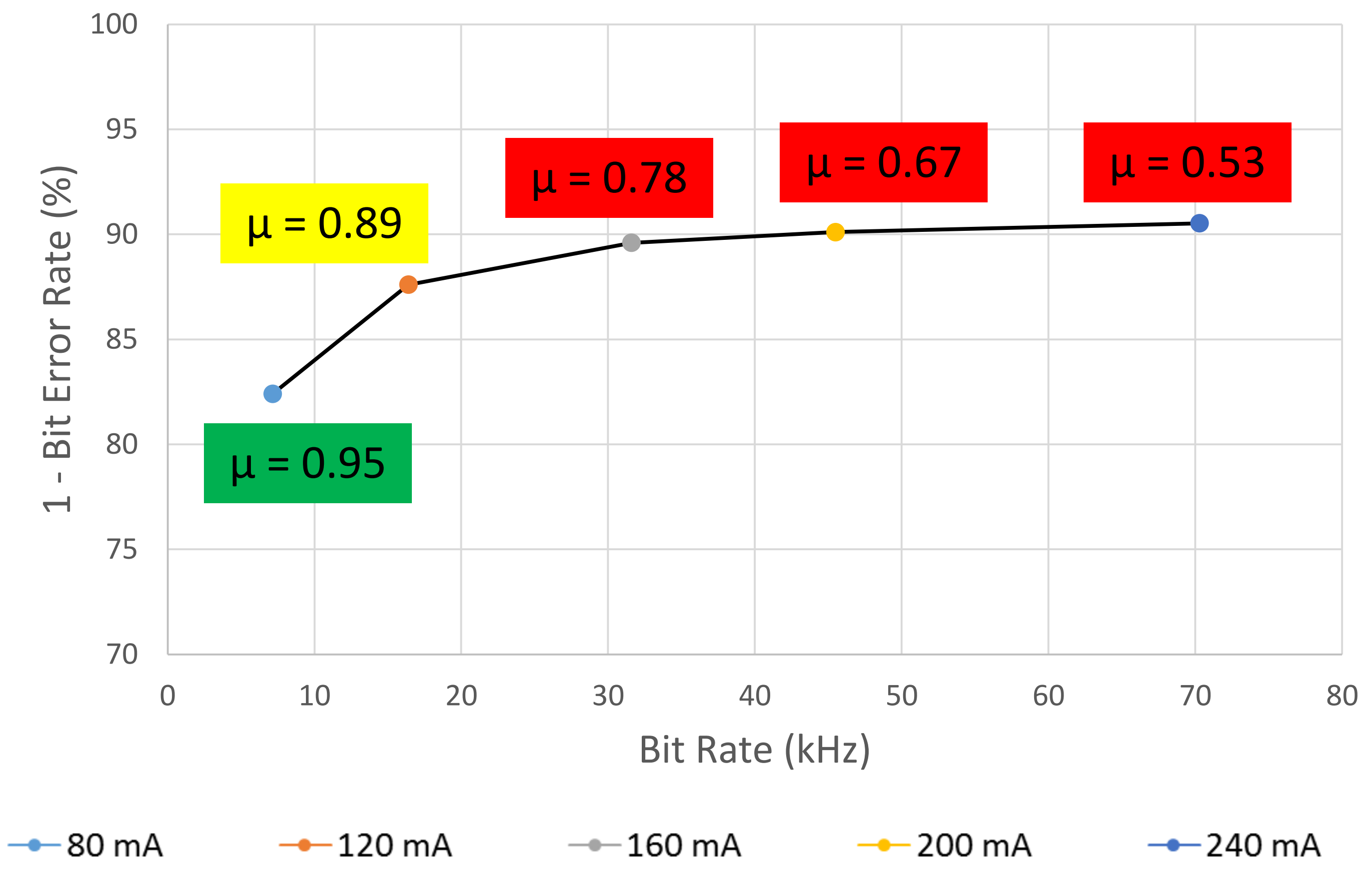
QKD: Results


100
95
90
85
80
75
70
1 - Bit Error Rate (%)
0
10
20
30
40
50
60
70
80
Bit Rate (kHz)
80 mA
120 mA
160 mA
200 mA
240 mA

QKD: Results

- *Pockels* cells operate at 2 MHz
- If Alice sends more than a photon per period, security is compromised
- $\mu = \dfrac{Periods\ with\ exactly\ one\ photon}{Periods\ with\ one\ or\ more\ photons}$
- Can be calculated assuming source exemplifies *Poisson* emission

QKD: Results



1 - Bit Error Rate (%)
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Bit Rate (kHz)
μ = 0.89
μ = 0.78
μ = 0.67
μ = 0.53
μ = 0.95
80 mA
120 mA
160 mA
200 mA
240 mA

Conclusions & Future Work

Conclusions

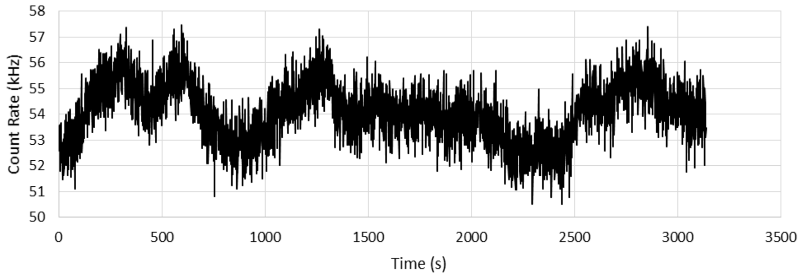
- Pair generation rate of 880 MHz is 3500 times better than previously used (bulky, expensive) conventional entangled photon source

- Preliminary free-space QKD results show secure communications with bit rate ≈ 10 kHz, bit error rate ≈ 10%

Conclusions: Coincidence Counting Limitations

- Path efficiencies are low, severely limiting coincidence rates
- Much of this loss is unexplained: may occur within source
- Much of the explained loss, as well as 54 kHz of dark counts, comes from the 1600 nm detector
- Better (more expensive) detectors do exist

1600 nm Detector Dark Counts



Path efficiency breakdown at 120 mA

Signal Chains	Filters in Sorting Optics	Detection Efficiency	Dead Time Effect	Total Known Effects	Total Unknown Effects	Path Efficiency
800 nm	0.484	0.620	0.954	28.6%	1.6%	0.460%
1600 nm	0.689	0.035	0.817	2.0%	3.2%	0.064%

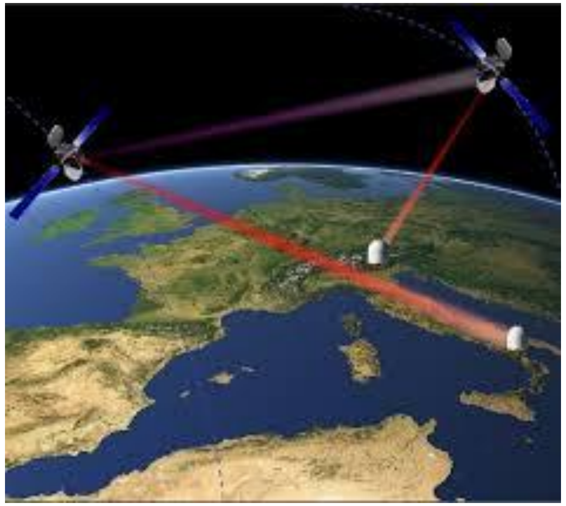
Conclusions: QKD Limitations

- Wide-band amplifier speed and output voltage are the two biggest limiting factors

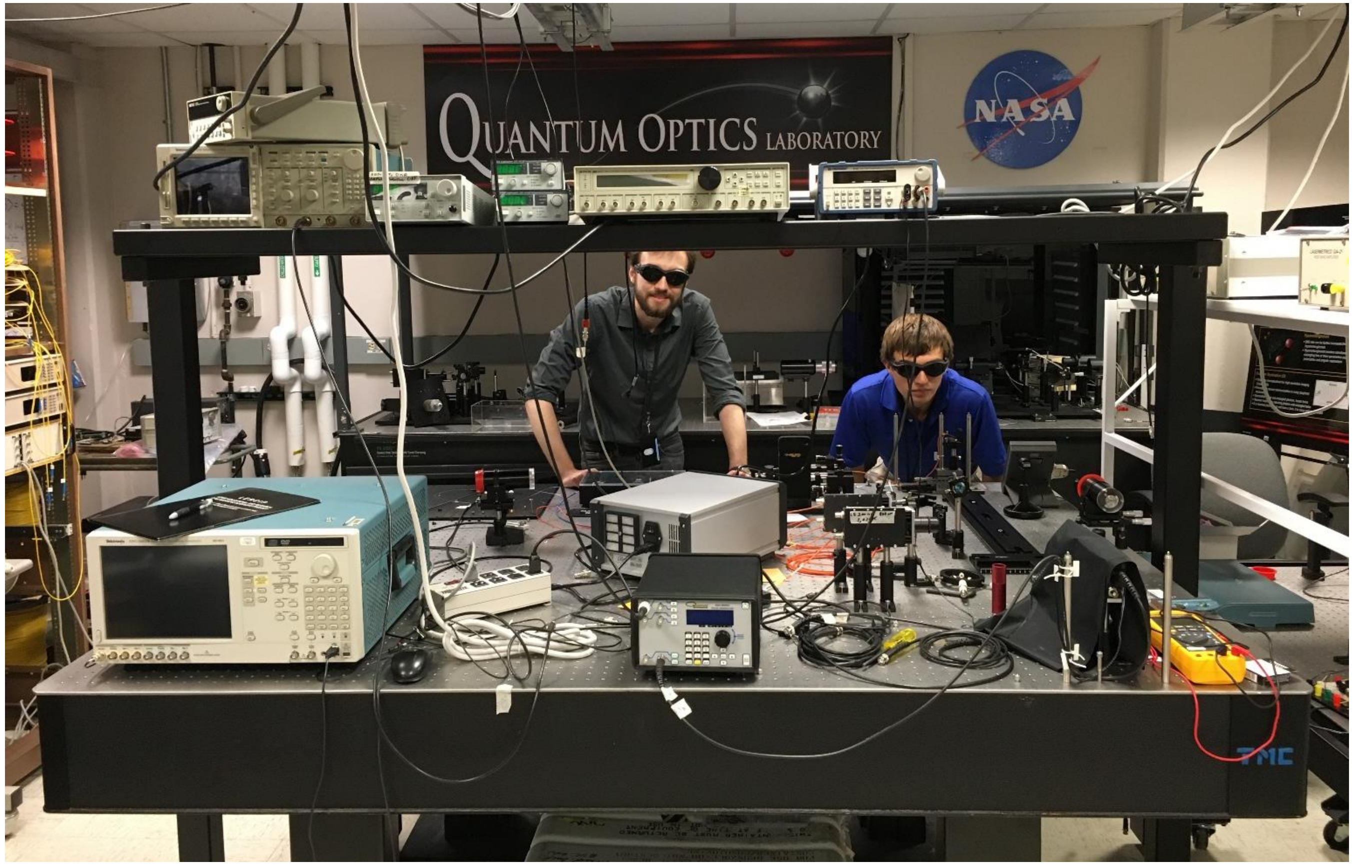
- Current protocol (B92) is not noise-resistant

Future Work

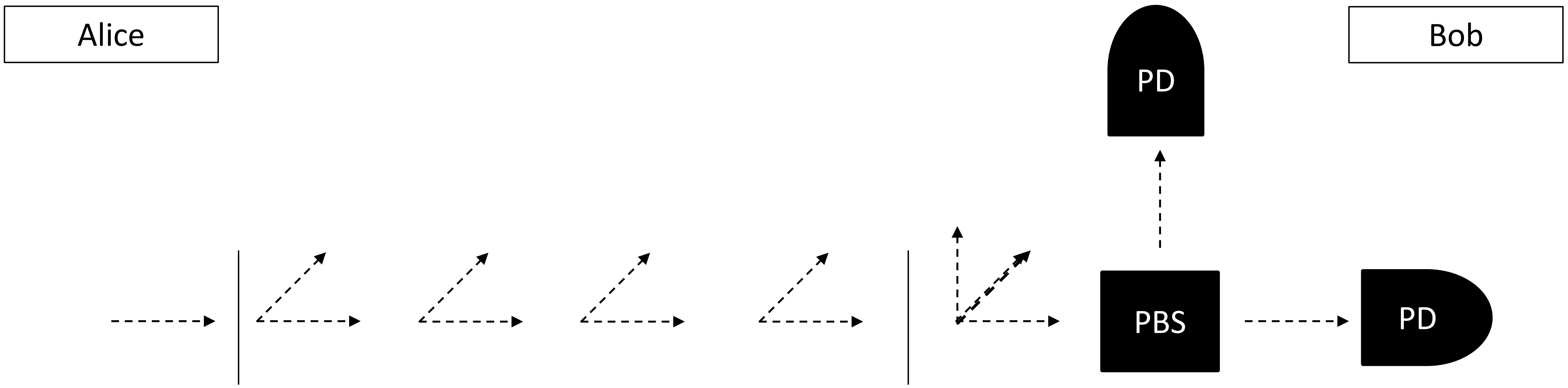
2016	Isolate and improve lossy components
2016-2017	Design QKD protocol to use time correlation of entangled photons to reduce noise
2017	Demonstrate QKD across 550 m link between buildings
2020?	Demonstrate QKD between ground and low-earth orbit in daylight



Questions?



QKD: B92 (Back up)



Alice Bit/Basis	Bob Basis	Bob Measurement	Bob Bit
0 (0° polarization)	0°	0°	?
1 (45° polarization)	0°	0°/90°	?/**1**
1	45°	90°	?
0	45°	0°/90°	**0**/?