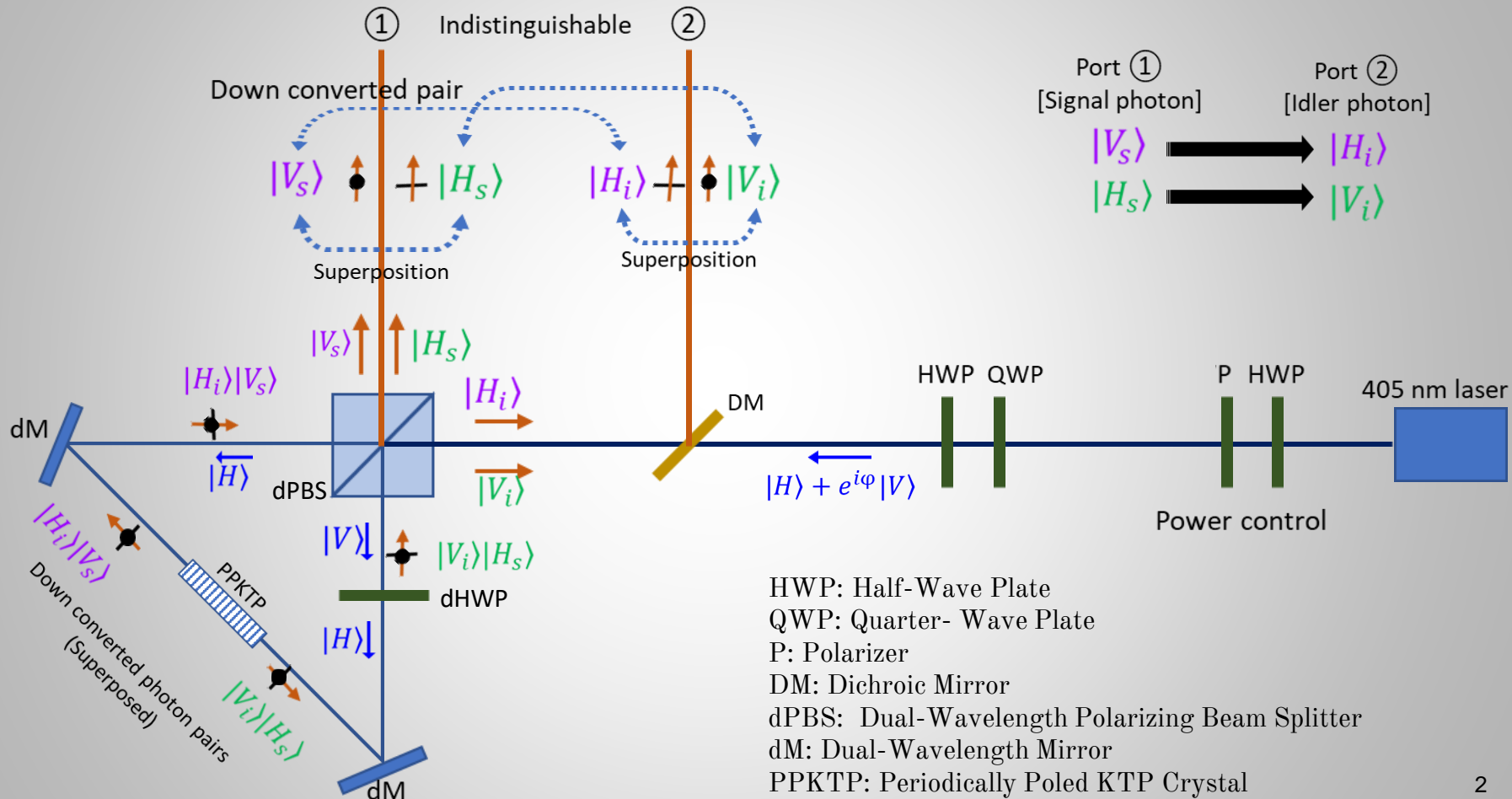


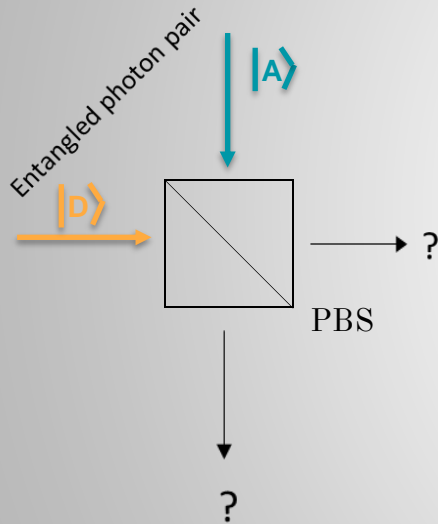
Verification of Polarization Quantum Entanglement Between Two Photons

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Advanced Electronics Group, NIST

Polarization-Entanglement: The Principle



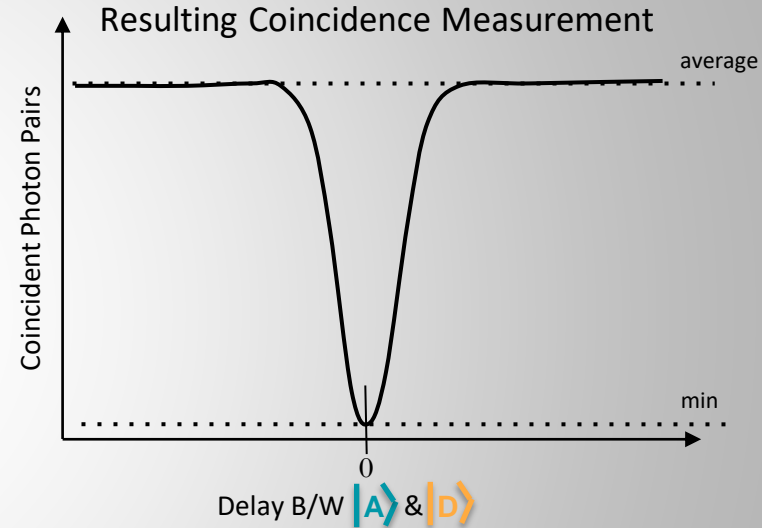
HOM Effect: Quantum Interference



Possibility

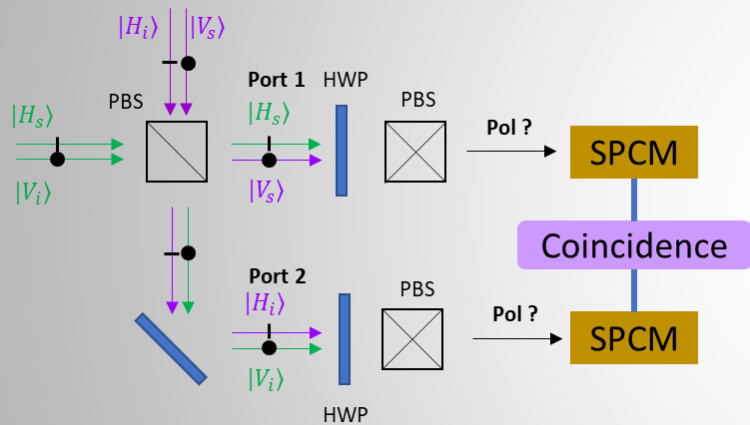


Indistinguishable -> Visibility: 100 %

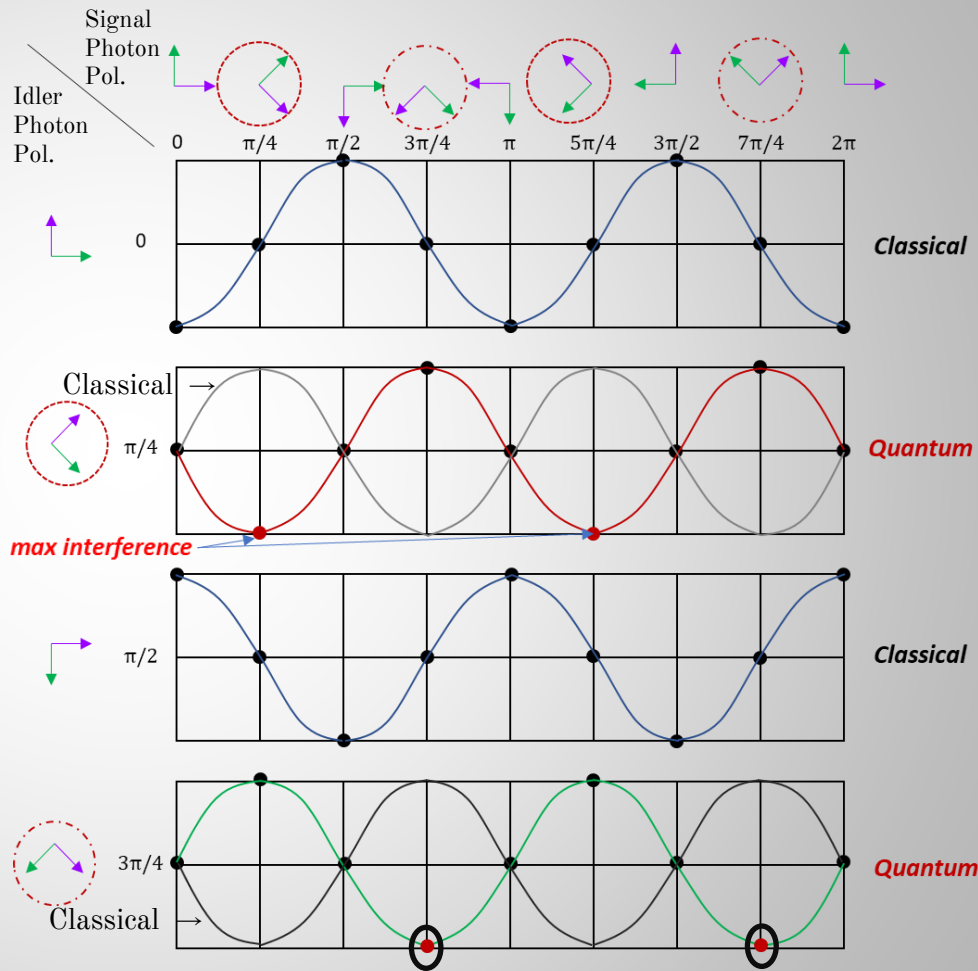


Shows Quantum Correlation

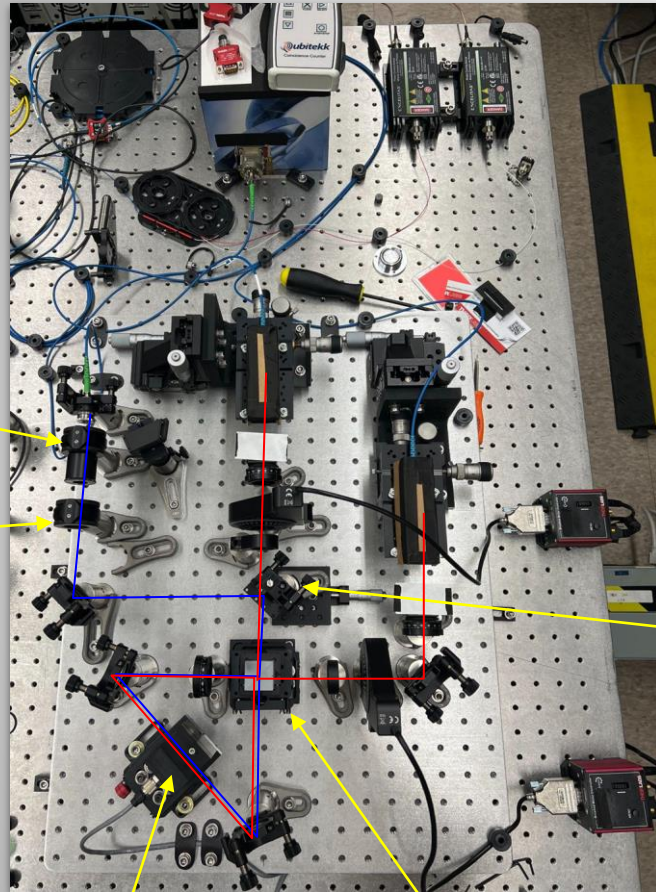
Quantum Interference by Quantum Entanglement/Correlation



SPCM – Single Photon Counting Module



Experimental Setup



Components:

- Polarizers
- Half-Wave Plates
- Polarizing Beam Splitter (PBS)
- Periodically Poled KTP Crystals (PPKTP)
- Filters
- Single Mode Fibers (SMF)
- Single Photon Counting Module (SPCM)
- Coincidence Counter

Power Control

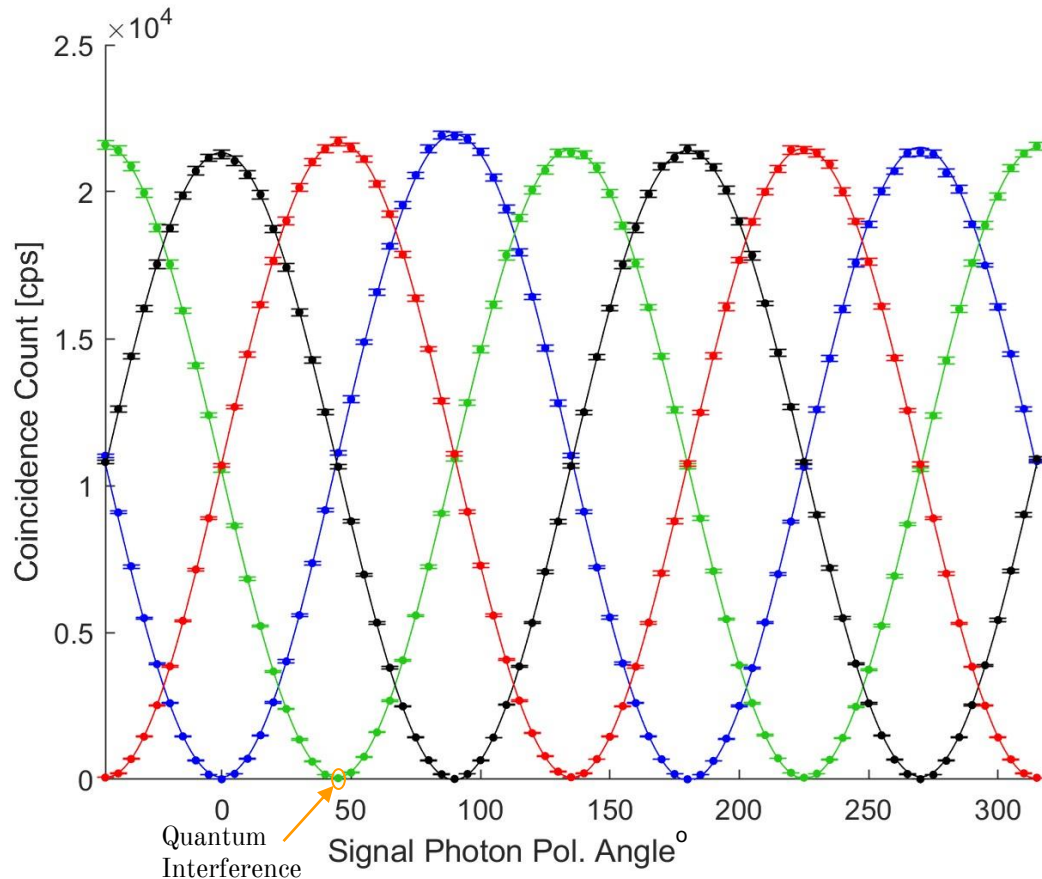
QWP/
HWP

DM

PPKTP

PBS

Graphical Verification



Idler HWP Angle:

- Idler: 0 degrees
- Idler: 45 degrees
- Idler: 90 degrees
- Idler: 135 degrees

$$V = \frac{C_{\max} - C_{\min}}{C_{\max} + C_{\min}}$$

Visibilities:

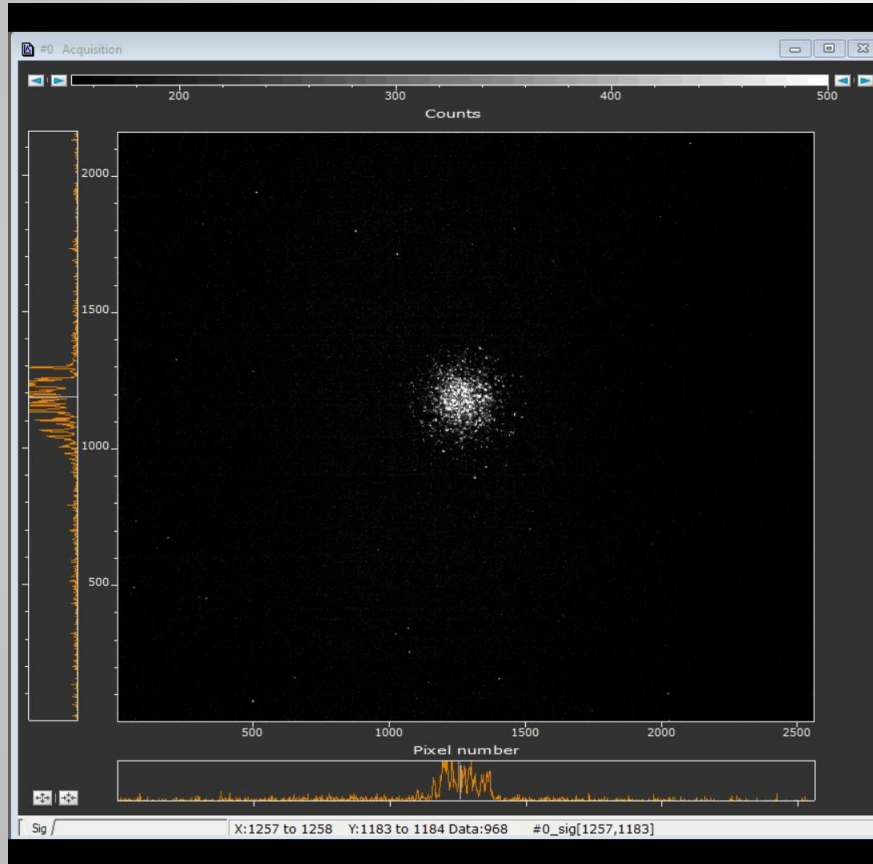
0 degrees: $99.974\% \pm 1.3e-04\%$

45 degrees: $99.974\% \pm 2.8e-04\%$

90 degrees: $99.974\% \pm 1.2e-04\%$

135 degrees: $99.974\% \pm 3.1e-04\%$

Visual Verification



The HWP_idle window displays the status of the motor controller. The status bar at the top right shows: SN: 27601470: V3.0.6(2.2.6). The main display shows the current position as 0.0000 and the travel distance as 360.0. A dialog box titled "Enter Position [Ch 1]" is open, prompting for a position value. The status bar at the bottom shows: THORLABS Ident Active Error Setting. The status bar at the bottom of the window shows: X:1257 to 1258 Y:1183 to 1184 Data:968 #0_sig[1257,1183]

Mathematical Verification

- John Stewart(J.S.) Bell
 - Contradicts Hidden Variable Theorem by EPR
 - Mathematically contradicts the hidden variables theory (Bell's Inequality)

$$P(\vec{a}, \vec{b}) = \int d\lambda \rho(\lambda) A(\vec{a}, \lambda) B(\vec{b}, \lambda)$$

$$4(\epsilon + \delta) \geq \sqrt{2} - 1$$

For small finite δ ,
 ϵ cannot be arbitrarily small

- CHSH Inequality
 - A way to test Bell's inequality
 - If $S \leq 2 \rightarrow$ Classical
 - Theoretical Maximum
 - $2\sqrt{2}$ or 2.828
 - 2.8177 ± 0.0032 } Very Close

$$S = E(a,b) - E(a,b') + E(a',b) + E(a',b')$$

$$E(a,b) = \frac{N(a,b) + N(a_{\perp}, b_{\perp}) - N(a, b_{\perp}) - N(a_{\perp}, b)}{N(a,b) + N(a_{\perp}, b_{\perp}) + N(a, b_{\perp}) + N(a_{\perp}, b)}$$

Therefore we have shown three separate methods to verify polarization QE.

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