# Quantum Optics Lab

## Part 1: Introduction to Quantum Optics (Quantum Flytrap)

### 1) Quantum Gates

**Objectives**: Test high level quantum gates within optical platform.

**Elements**: Single photon source (1), Detector (1), Single Qubit Gates

**Description**: Try out the basic single qubit gate (X, Y, Z, H). Observe the changes in the Quantum State panel.

### 2) Classical and Quantum Wave split

**Objectives**: Get introduced to the Beam Splitter element. Observe the difference between classical and quantum behavior leading to superposition.

**Elements**: Single photon source (1), Beam splitter (1), Detector (2)

**Classical**: Continuous wave input splits into 50:50 power at each detector.

**Quantum**: Input $|1\rangle$ into one port. The output becomes $(|10\rangle + |01\rangle)/\sqrt{2}$, showing quantum superposition.

**Note**: Beam splitter matrix is $U_{BS} = \begin{pmatrix} \cos\theta & e^{i\phi}\sin\theta \\ e^{i\phi}\sin\theta & \cos\theta \end{pmatrix}$, reflectance $\theta$, reflection phase $\phi$.

### 3) Mach–Zehnder Interferometer (MZI)

**Objectives**: Observe quantum interference phenomena and its results dependance on relative phase. Experience superposition collapse due to which-path information detection.

**Elements**: Single photon source (1) – Beam splitter (2) – Mirror (2) – Detectors (2) – QND (1) – Phase shifter (1)

**Behavior**: Interference results in constructive or destructive output at one detector depending on the relative phase between the two arms. The superposition state collapses into single state when which-path information is exposed.

$$U_{MZI} = U_{BS}\, U_{phase} U_{BS}$$

## 4) Quantum Entanglement Creation

**Objectives**: Creation of Bell states (entanglement). Understand the impact of basis measurement choice on the entangled pair.

**Elements**: Single photon source (2) – Polarizer (2) – Detectors (2) – CNOT (1) – Hadamard (1)

**Description**: Generate Bell state $|\phi^{+}\rangle = (|VV\rangle + |HH\rangle)/\sqrt{2}$. Filter horizontal polarization in one path and vertical in the other. The filtration will demolish the superposition and keep the state in one of the polarizations. If the measurement is done in another basis (other than vertical and horizontal polarization) the result will be also equal probability because the entanglement is created within all of the possible basis in space.

## 5) Quantum Entanglement Measurement

**Objectives**: Effect of the early measurement done on one photon on the other.

**Elements**: Bell state generator (1) – Mirror (2) – Polarizer (1) – Polarizing beam splitter (1) – Detector (3)

**Description**: Generate the state $|\phi^{+}\rangle = (|VV\rangle + |HH\rangle)/\sqrt{2}$ using the Bell state generator. In one path put the polarizer to filter one of the polarizations (e.g. $|V\rangle$) before the detector. In the other path use the polarizing beam splitter to split $|V\rangle$ and $|H\rangle$ into two different detectors.

**Behavior:** Entanglement forces the unpolarized photon to follow the result of the measurement done on the polarized photon, so they match one of the states in the superposition of $|\phi^+\rangle$.

## 6) Hong–Ou–Mandel effect:

**Objectives**: Observe HOM effect and verify its results.

**Elements**: Two single-photon sources (1 per input port), Beam splitter (1), Detectors (2)

**Behavior**: One photon in each port results in two photons in either port and never one photon in each port.