Advanced laboratory course consists of four experiments:

1. **Entanglement and Bell’s inequalities**

   In quantum mechanics, particles are called **entangled** if their state cannot be factored into single-particle states. Any measurements performed on first particle would change the state of second particle, no matter how far apart they may be.

   \[
   |\psi\rangle = |V\rangle\psi + e^{i\phi} |H\rangle H
   \]

2. **Single-photon interference (Young’s double-slit and Mach-Zehnder interferometer).**

   Mach-Zehnder interferometer (Fig. 2.2) is used for the demonstration of a single-photon interference after removing “which-way” information (identification of the path).

   For single photons, the second order correlation function of an optical field

   \[
   g^{(2)}(\tau) = \frac{\langle I(0)I(\tau)\rangle}{\langle I(0)\rangle^2}
   \]

   that characterizes the difference between a single-photon source and an ordinary laser source should have a minimum at time \(\tau = 0\) (in an ideal case \(g^{(2)}(0) = 0\)), indicating the absence of photon pairs, i.e., antibunching.

3. **Confocal microscope imaging of single-emitter fluorescence**

   Single Dil dye-molecule fluorescence imaging with ~ 6 ps pulse duration, 76 MHz pulse repetition rate excitation at 532-nm (20 μm x 20 μm scan). Maximum fluorescence wavelength of Dil dye is ~580 nm.

4. **Hanbury Brown and Twiss setup. Photon antibunching**

   (a) A typical confocal fluorescence microscope image of a single CdSe quantum dot in a 1-D photonic bandgap chiral liquid crystal host.

   (b) Histogram of coincidence counts of a single CdSe quantum dot fluorescence in a 1-D photonic bandgap chiral liquid crystal host, showing fluorescence antibunching.