Hong-Ou-Mandel Interference

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Hong-Ou-Mandel interference is an effect that results from the bosonic attraction of photons. In this experiment, we measured the coincidence defined as the arrival of two photons at two detectors at the same time by varying the amplitude and pulse period of our light source. From our results, we found that longer pulse period of 0.1ms has a lower photon count for coincidence while a shorter pulse period of 2µs has a higher photon count in the order of millions for coincidence.

The Hong-Ou-Mandel experiment is named after the three researchers Chung Ki Hong, Zhe Yu Ou and Leonard Mandel who provided experimental evidence for two photon interference in a paper published in 1987. [1] They showed that two indistinguishable photons meeting on a 1:1 beamsplitter always exit together, through the same but random output port because of bosonic attraction. As a result, it is impossible to detect one photon in each output port of the beam splitter simultaneously which means there is zero coincidence between photon detection events in the two outputs of the beam splitter. [2] This gives us the well known Hong-Ou-Mandel dip reported in the paper and shown in FIG 2. The coincidence is defined as the arrival of two photons at two detectors at the same time if we put detectors at the two outputs of the beam splitter.

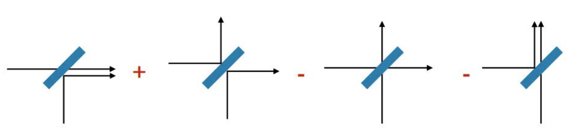

FIG 1: Four possibilities of two photon interaction when passing through a 1:1 beam splitter

Typical experiments done in undergraduate labs use a nonlinear crystal to create a two photon source with the same frequency. For instance, the nonlinear crystal will split a blue light source into two infrared sources. This requires two infrared detectors to detect the photons that come out the other side of the beamsplitter. However, in our lab, we had PMTs that detected blue light which allowed us to build an optical setup shown in FIG 3 to observe the Hong-Ou-Mandel effect. As shown in the setup, we didn't use a nonlinear crystal in our experiment.

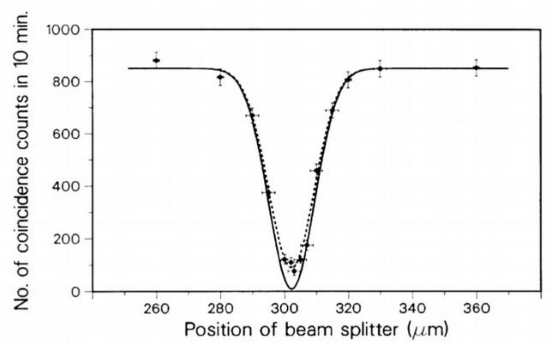

FIG 2: The measured number of coincidences as a function of beam-splitter displacement [1]

Instead, we used a pulsed blue LED diode (456nm) which is a single photon source that emits bunched and unbunched photons with the probability for the number of photons represented as a poisson distribution.

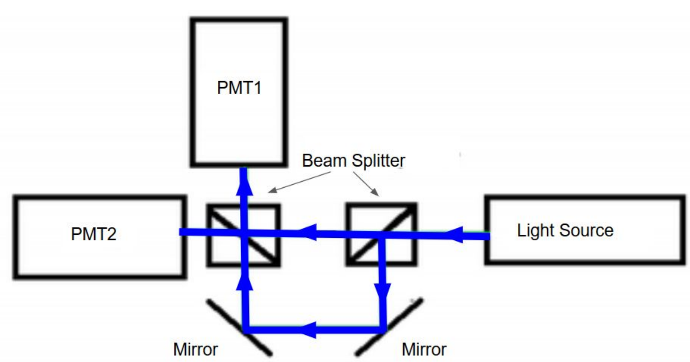

FIG 3: Optical Setup for Hong-Ou-Mandel interference experiment

As shown in FIG 3, two photodetectors are set up viewing opposite sides of the second beam splitter. In order to detect the Hong-Ou-Mandel effect, we needed two photons to enter the second 1:1 beam splitter, one in each input port. When the photons are indistinguishable, they will go to a single detector together. In this case, the probability for coincidence is zero. If they are distinguishable, the probability of coincidence will be 0.5. We created a path difference in the setup to introduce a phase shift between the two photons to make them distinguishable.

We used a discriminator to set a threshold of 300mv to make sure we're measuring single photons. In addition, we used a logic gate with AND and OR, and a counter to determine the coincidence in terms of photon counts. The counter measured the final counts of both PMTs, OR and AND over a 10 second interval.

However, there were several challenges to do the experiment: first, we needed a coherent light source such as a laser with a nanosecond pulse width. This will allow for making sure we have a source that would create two photons which will allow us to detect the Hong-Ou-Mandel effect. Second, in order to observe the Hong-Ou-Mandel dip, we had to vary the path length in the order of micrometers; however, in addition to being limited by space in the black box where we had our setup, a precision in the order of micrometers is a difficult task on its own. We also needed to make a distinction between a stream of doubly-bunched photons that split at the beam splitter and arrive at the same detector from a stream of unbunched photons that go to the same detector. This makes sure that we're detecting only the Hong-Ou-Mandel effect and not any other classical effect.

Even if we didn't detect the Hong-Ou-Mandel effect in our experiment, we measured the photon counts for the two PMTs for different voltage amounts and pulse width of the light source as shown in FIG 4 and 5. From the plots, Parallel PMT is referring to PMT2 and Perpendicular PMT is referring to PMT1 from the optical setup as shown in FIG 3. We can see that PMT2 had higher number of photon counts which might be due to the fact that it's more sensitive to light.

For both pulse widths, we can see that there is an exponential relation between photon count and voltage which shows the transition from quantum regime of detecting single photons to classical regime. This is also illustrated by the exponential increase in coincidence as photons arrive at both detectors at the same time.

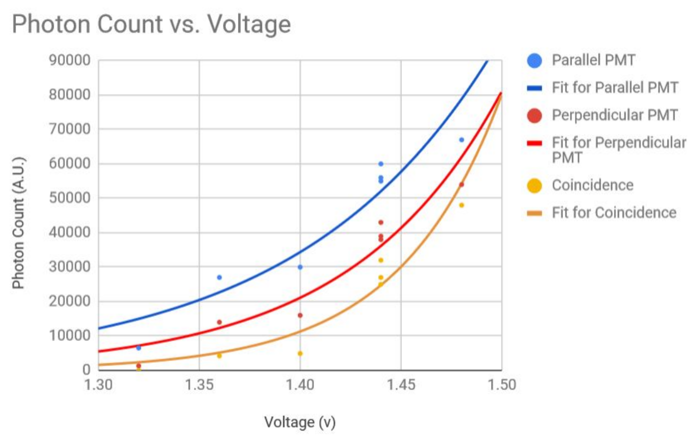

FIG 4: Exponential fit and data for pulse period of 0.1ms showing Photon count for each PMT and coincidence versus Voltage

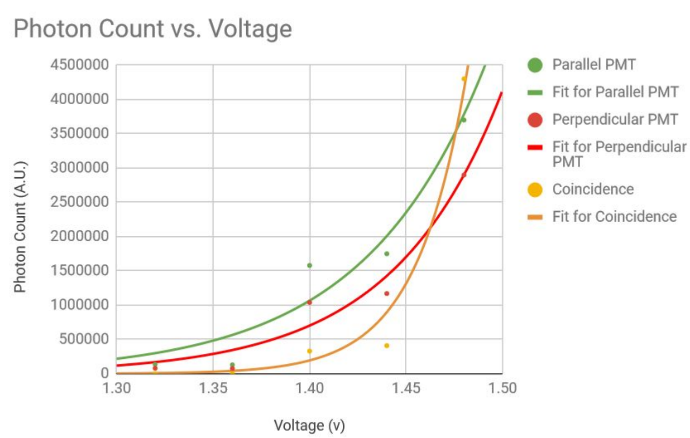

FIG 5:Exponential fit and data for pulse period of 2µs showing Photon count for each PMT and coincidence versus Voltage

The two plots indicate that longer pulse period results in lower photon counts and lower coincidence compared to smaller pulse period of 2µs which resulted in a large amount our coincidence counts even exceeding the PMT1 and PMT2 counts. Possible source of errors for this experiment are systematic errors from the oscilloscope where we read the voltage measurements, the sensitivity of the PMTs and the photon counter.

In this study, we built an experimental setup to observe the Hong-Ou-Mandel effect without using a nonlinear crystal. However, due to experimental constraints, we couldn't detect the effect. Instead, we compared the effect of pulse period and amplitude of the light source on the coincidence. From our results, we found that longer pulse period of 0.1ms gives lower photon count which is in the single photon quantum regime while a shorter pulse period of 2μs transitions to the classical regime as shown by the high number of counts in the order of millions.

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[1] C. K. Hong; Z. Y. Ou and L. Mandel (1987). "Measurement of subpicosecond time intervals between two photons by interference". Phys. Rev. Lett. 59 (18): 20442046.

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