Hanbury-Brown-Twiss (HBT) Effect:

Correlation Between Photons in Two Coherent Beams of Light

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Advanced Lab Seminar Series
October 30, 2017

Agenda

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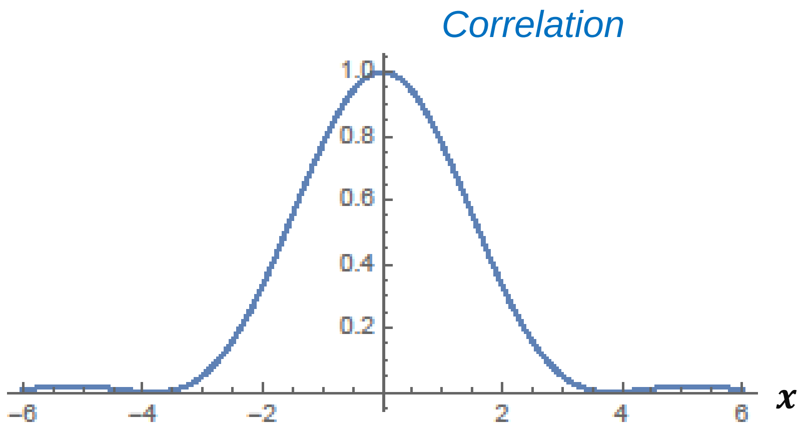
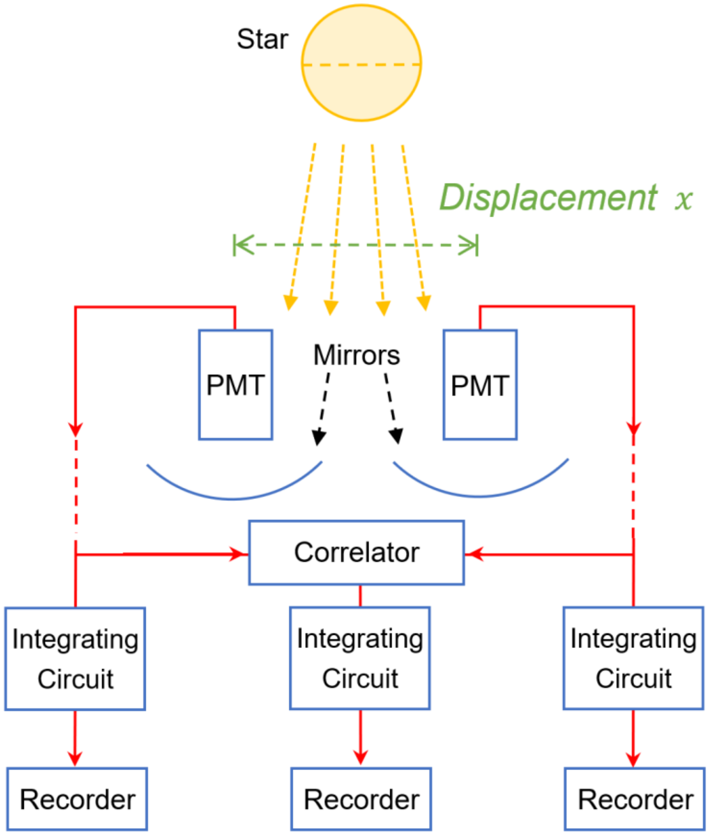
1. Background on HBT interferometer
2. Experimental setup
3. Results
4. Suggestions for successors

Background

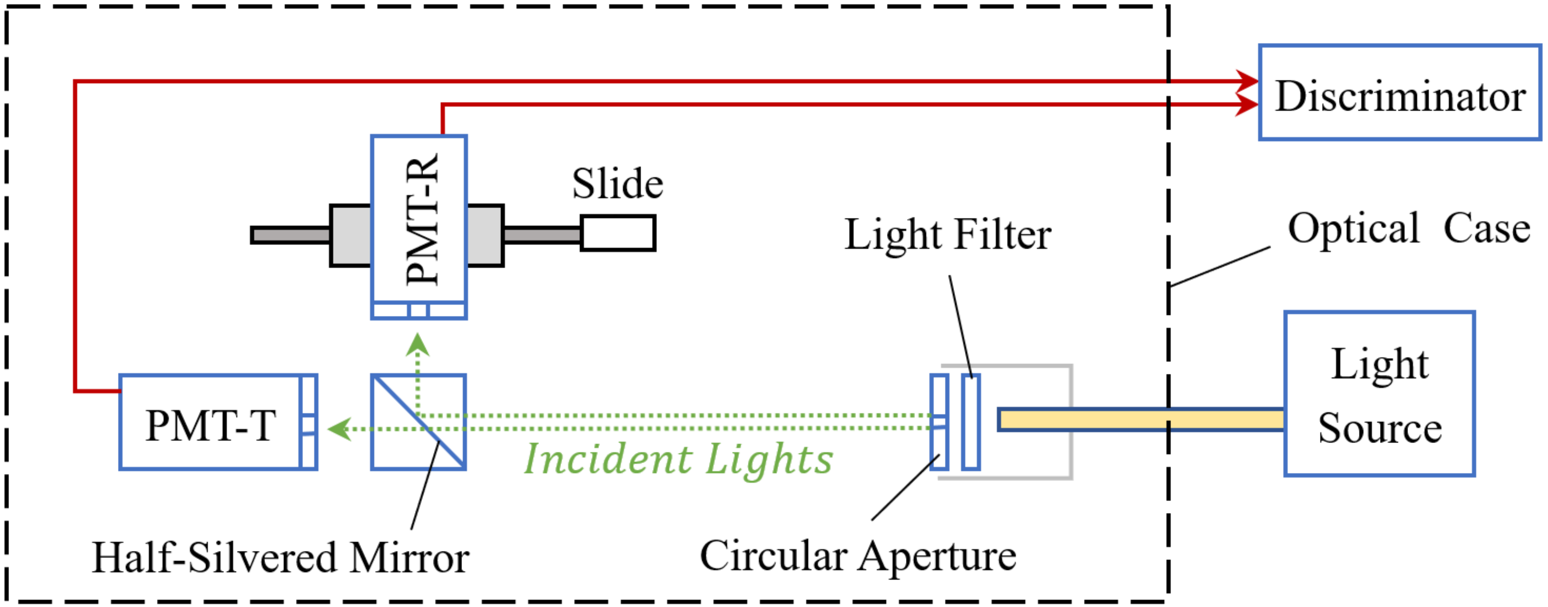
HBT interferometer

- Correlation of two photomultiplier tube (PMT) signals
- PMT displacement, x

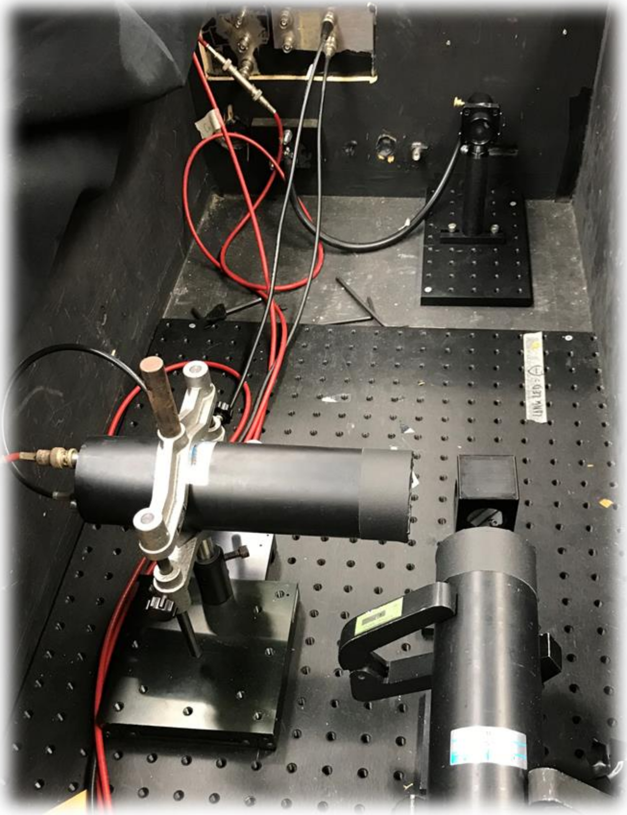


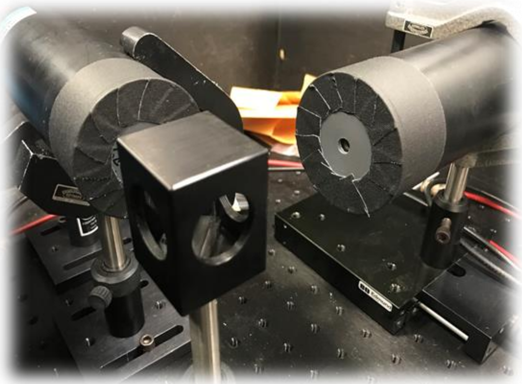


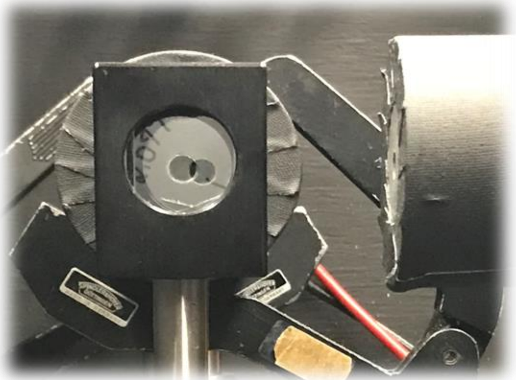
Experimental Setup



Experimental Setup







Experimental Setup

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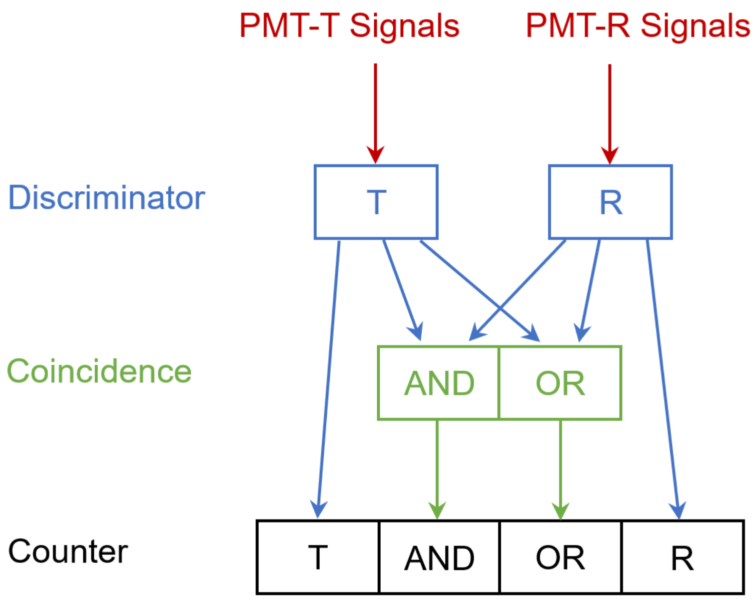

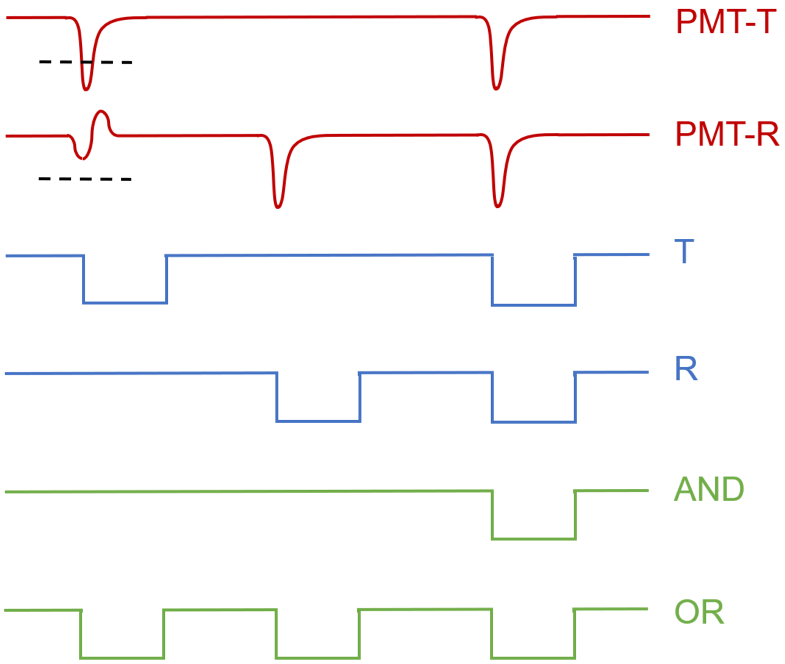

Waveforms

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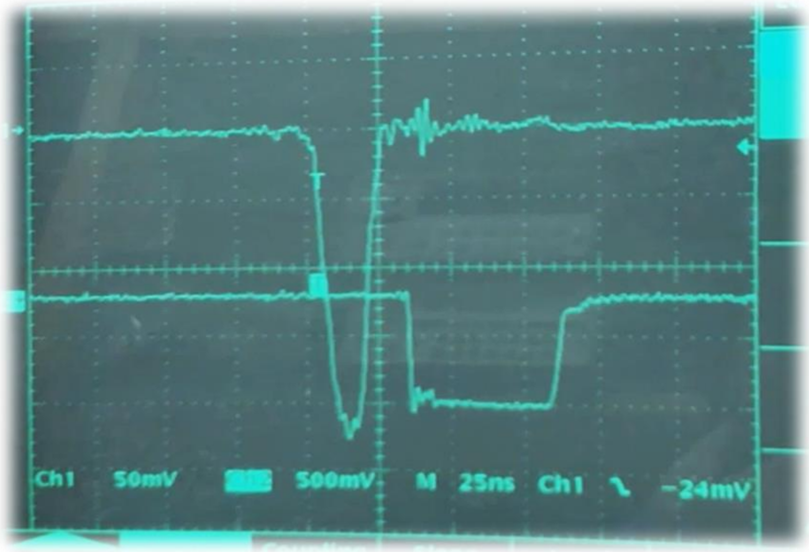
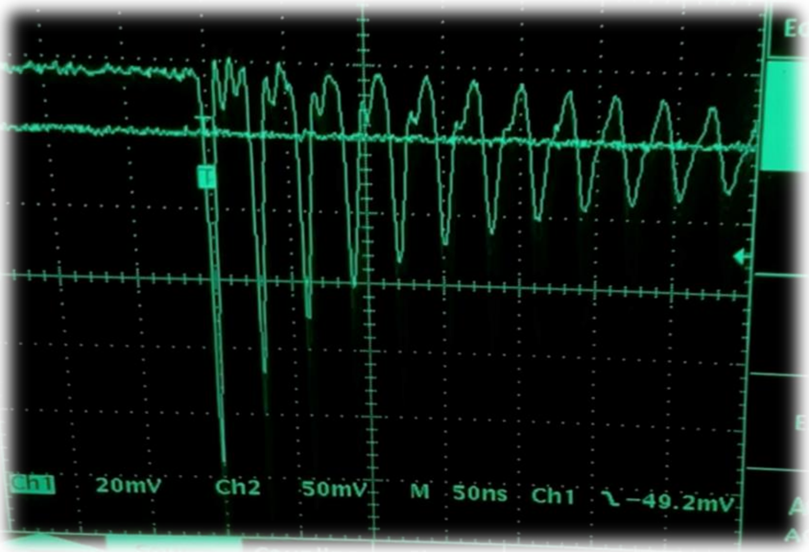


Photon

Nuclear Instrumentation Methods (NIM)



Unterminated Cable

Results and Suggestions

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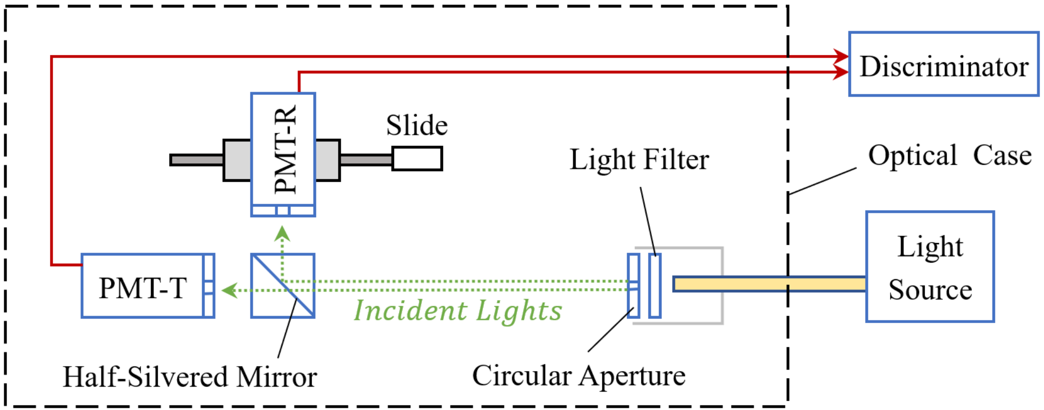
Results

- Need improvements

Suggestions

1. Focused light
2. PMT aperture
3. PMT-T on slider
4. Correlator
5. Results interpretation
6. Half-silvered mirror



Thank you!

Acknowledgement

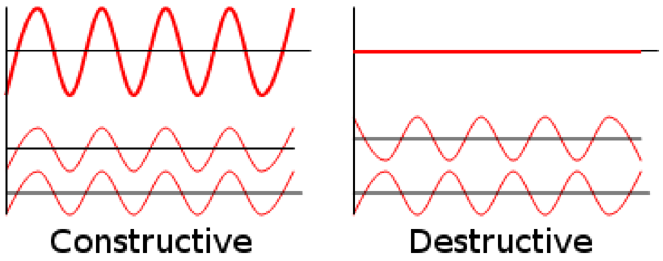
I express sincere appreciation to **Deepak Sathyan**, my collaborator, for contributing a great amount of efforts and talents in this experiment. I also express sincere appreciation to **Daniel Arcaro**, to **Lawrence R. Sulak**, and to **Yaokun Situ** of Boston University for sharing their valuable experience and guidance in setting up this experiment. We also thank **Steve Ahlen**, also of Boston University, for providing notes on theoretical background for this experiment.

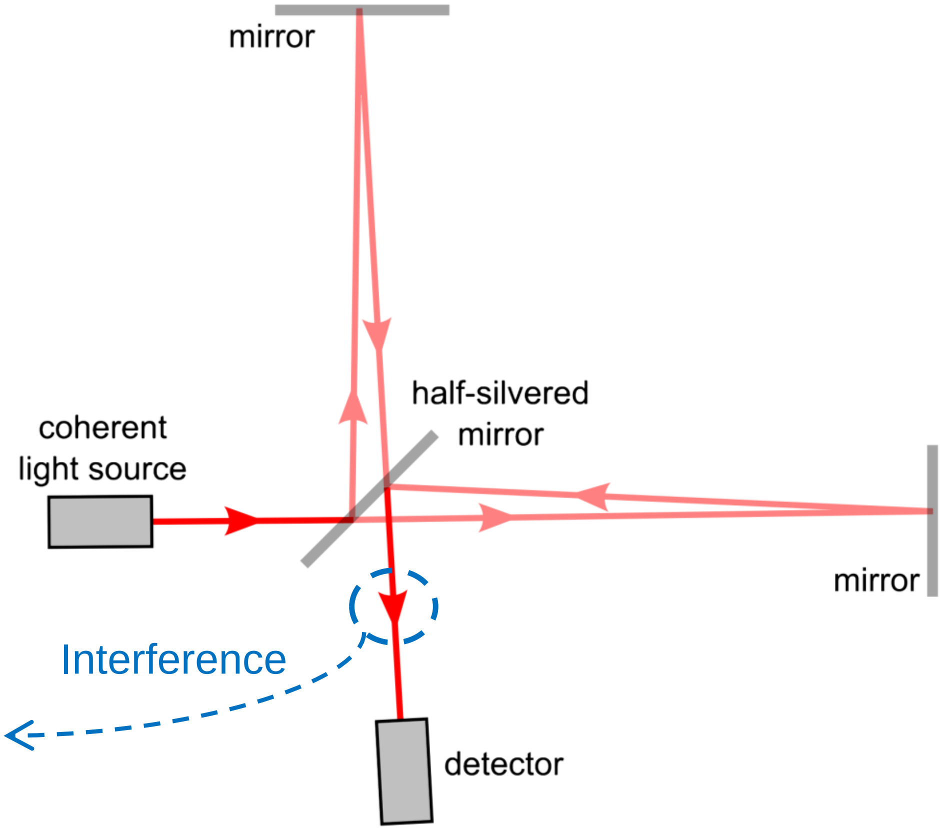
Extra Slides

Background

Interferometer

- Interference pattern
- Ex: Michelson interferometer





Significance of HBT effect

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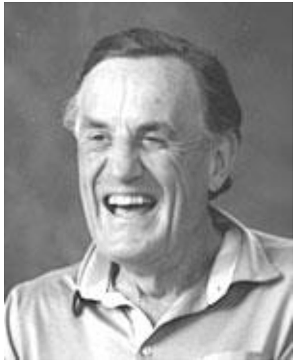
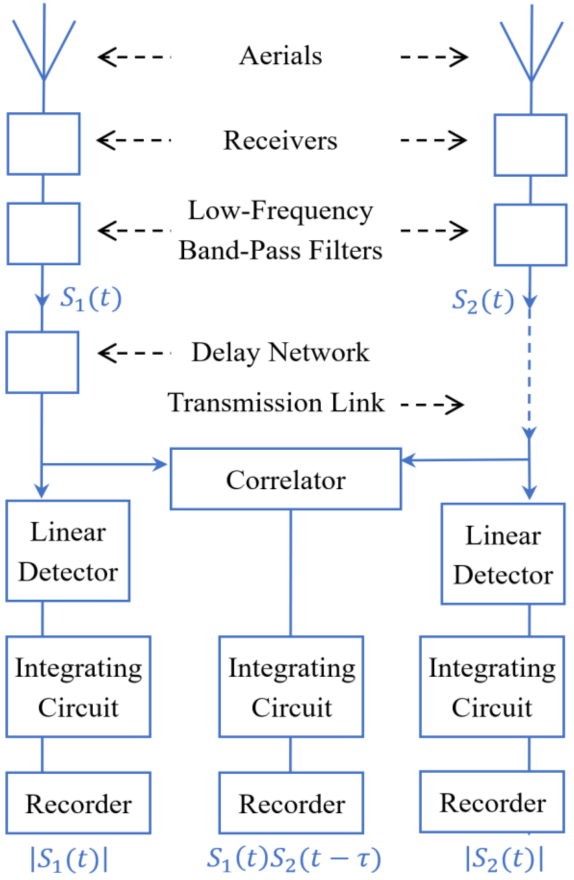
- Measured **angular diameter of a star**.
- Showed that it applies not only to radio waves but also to lights in **optical range**.
- Provoked a heated debate about the concept of **photon**.
- Solved by Glauber (recipient of 2005 Nobel Prize) through the theoretical development of **coherent states** (Glauber states).
- Opened the door to **quantum optics** and a much more comprehensive understanding of **coherence**.

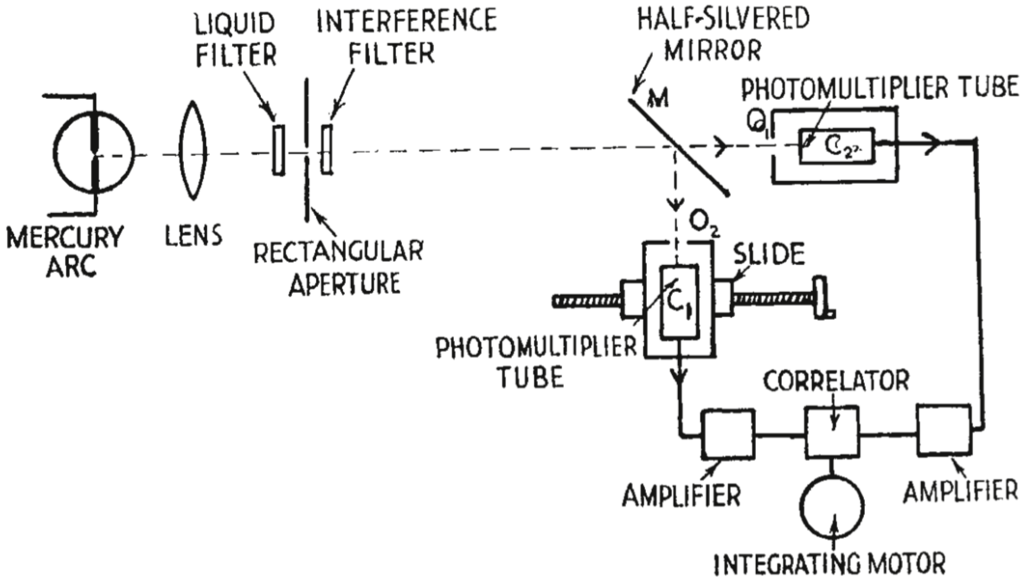


R. Hanbury Brown
(1916 – 2002)

R. Q. Twiss
(1920 – 2005)

Details of the original HBT interferometer

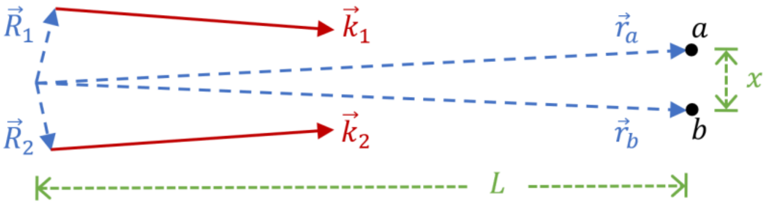




Theory

For a two-point light source, the correlation between the intensity of signals at a and b is:

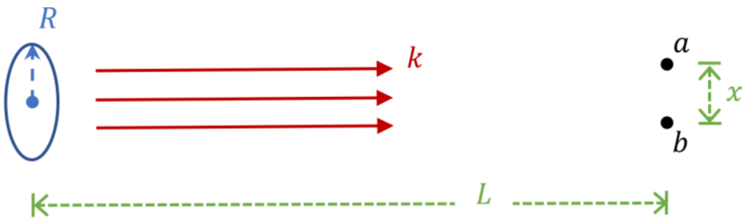
$$\frac{\langle I_a I_b \rangle}{\langle I_a \rangle \langle I_a \rangle} = 1 + \frac{2\, {A_1}^2 {A_2}^2}{(A_1^2 + A_2^2)^2} \cos((\vec{k}_1 - \vec{k}_2) \cdot (\vec{r}_a - \vec{r}_b))$$



where $\vec{k}_1$ and $\vec{k}_2$ are wave number of the incident light, and A_1 and A_2 are amplitudes.

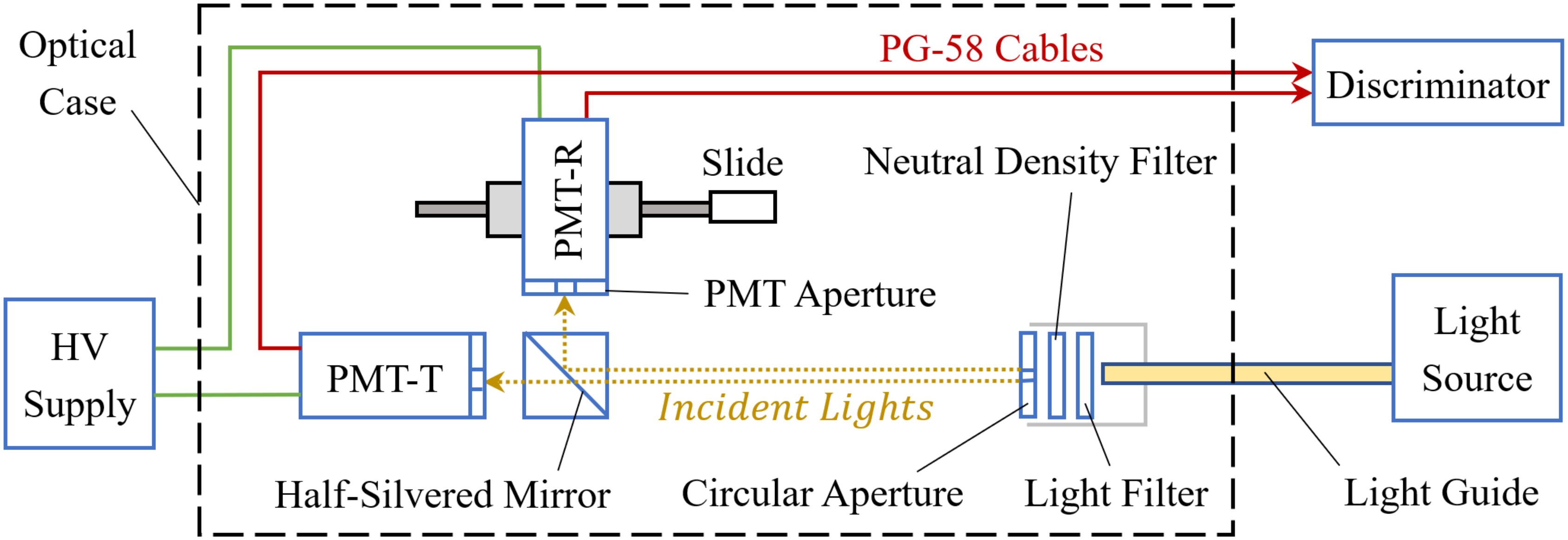
For a circular light source, the correlation between the intensity of signals at a and b is:

$$\frac{\langle I_a I_b \rangle}{\langle I_a \rangle \langle I_a \rangle} = 1 + \left(\frac{2\, J_1\left(\frac{kRx}{L}\right)}{\frac{kRx}{L}} \right)^2$$



where k is the wave number of the incident light, and $J_1(y)$ is the first order Bessel function.

Experimental Setup (Detailed)



Experimental Setup

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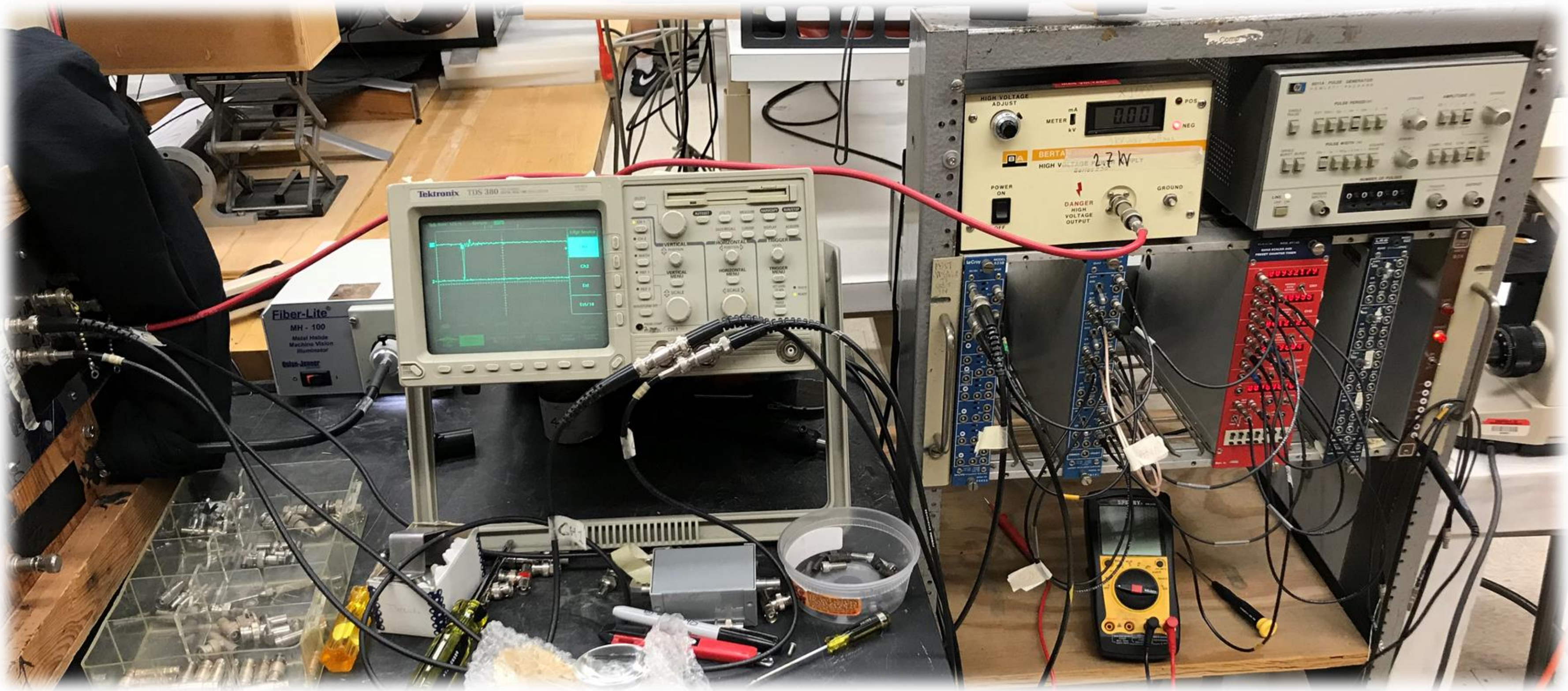
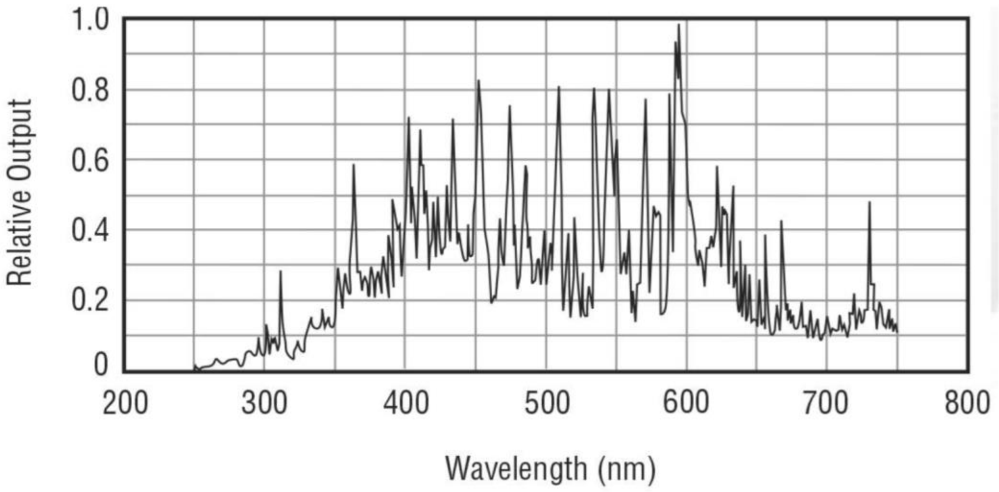


Light source information

Performance Data	
Lamp Output	Up to 3000 Lumens at fiber optic insertion plane
Electrical Data	
Input Voltage	115V AC 50/60 Hz, 230V AC 50/60Hz



PMT specifications

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Parameter		Description / Value	Unit
Spectral response		300 to 650	nm
Wavelength of maximum response		420	nm
Photocathode	Material	Bialkali	—
	Minimum effective area	ϕ46	mm
Window material		Borosilicate glass	—
Dynode	Structure	Linear focused	—
	Number of stages	12	—
Operating ambient temperature		-30 to +50	°C
Storage temperature		-30 to +50	°C
Base		21-pin glass base	—
Suitable socket		E678-21C (supplied)	—

PMT spectral response and gain

Figure 1: Typical spectral response

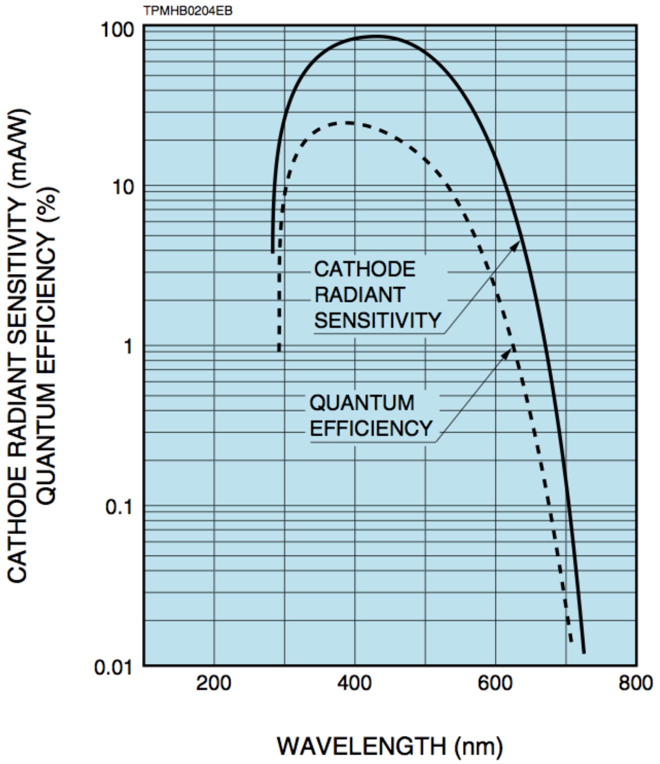
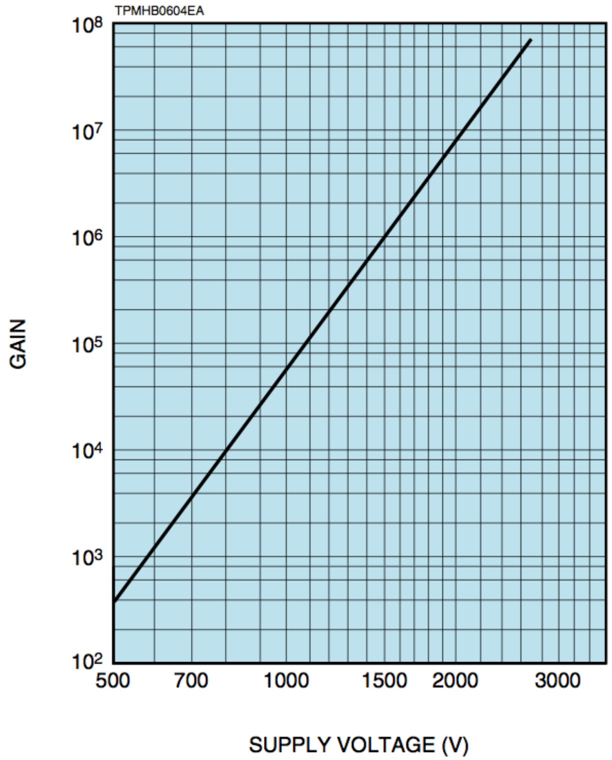


Figure 2: Typical gain characteristics



Experimental setup measurements

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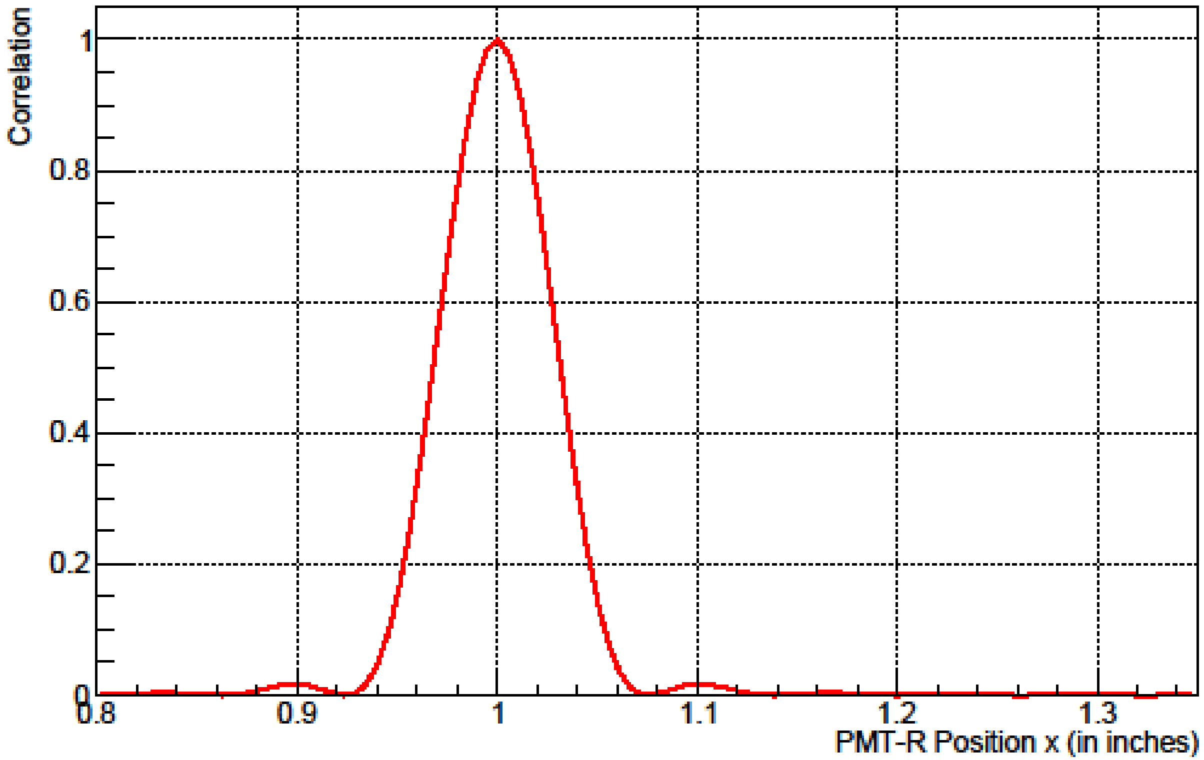
Length:

- Radius of light source aperture, $R = 100\ \mu\text{m}$
- Wavelength of light color filter, $\lambda = 2\pi/k = 546\ \text{nm}$
- Distance between light source and PMT, $L = 575.5 \pm 0.5\ \text{mm}$
- Central position of PMT-R, $x_0 = 1.00 \pm 0.01\ \text{inch}$
- Diameter of PMT aperture, $l = 6.57 \pm 0.05\ \text{mm}$

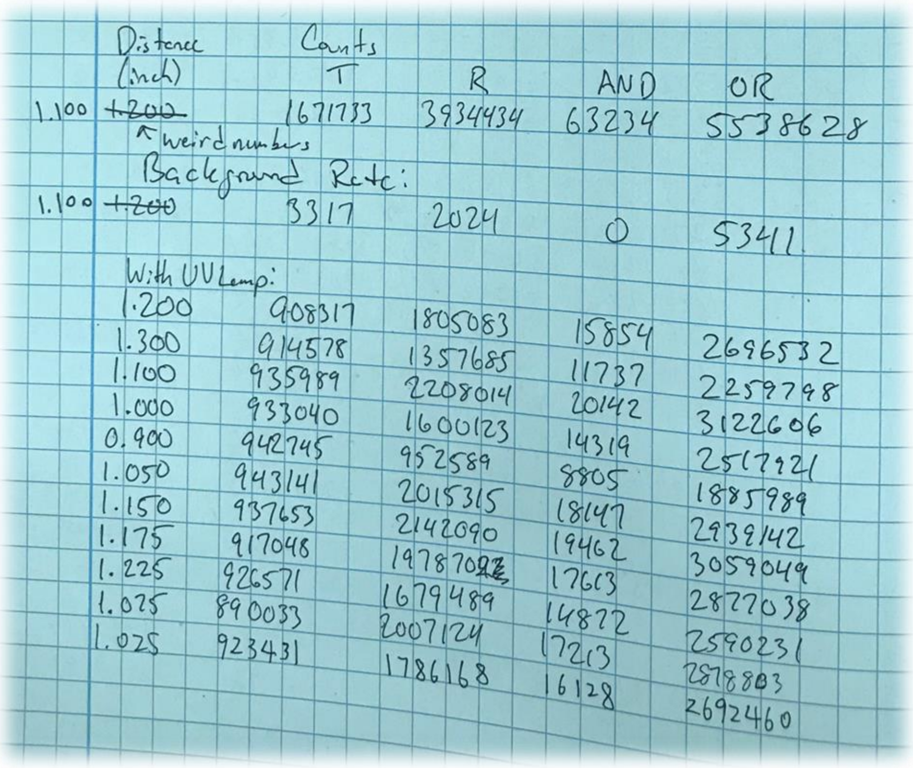
Voltage:

- Voltage of High Voltage (HV) Supply, $V = -2.7\ \text{kV}$

Expected Value



Data and analysis



Distance (inch)	Counts T	R	AND	OR
1.100 ~~1.200~~	1671733	3934434	63234	5538628

↑ weird numbers

Background Rate:

Distance (inch)	T	R	AND	OR
1.100 ~~1.200~~	3317	2024	0	53411

With UV Lamp:

Distance (inch)	T	R	AND	OR
1.200	908317	1805083	15854	2696532
1.300	914578	1357685	11737	2259798
1.100	935989	2208014	20142	3122606
1.000	933040	1600123	14319	2517921
0.900	942745	952589	8805	1885989
1.050	943141	2015315	18147	2939142
1.150	937653	2142090	19462	3059049
1.175	917048	197870[illegible]	17613	2877038
1.225	926571	1679489	14822	2590231
1.075	890033	2007124	17213	2878803
1.025	923431	1786168	16128	2692460

Data and Analysis

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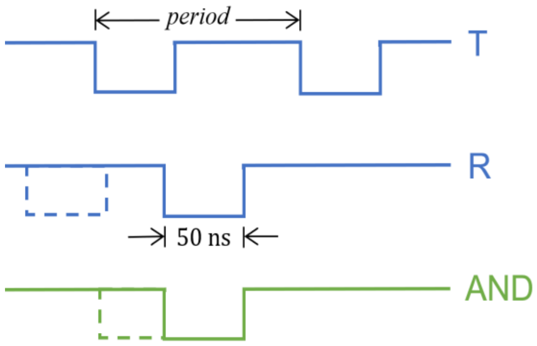
Scenarios		T	R	AND	Prob
Light source off **(background rate)**	*frequency*	350 Hz	720 Hz	0.09 Hz	0.0001
	period	2.9 ms	1.4 ms	11 s	
Light source on with **high** intensity	*frequency*	6.3 MHz	6.2 MHz	3.3 MHz	0.63
	period	160 ns	160 ns	300 ns	
Light source on with **low** intensity	*frequency*	90 kHz	220 kHz	2 kHz	0.02
	period	11 ms	4 ms	500 ms	

Probability of **random coincidence** =

$$\frac{2 \times 50\ \text{ns}}{\text{Min}\,(\,period_{\text{T}}\,,\,period_{\text{R}}\,)}$$



$\frac{\text{AND}}{\text{T}}$ and $\frac{\text{AND}}{\text{R}}$ ratios are low (< 5%), indicating a **low correlation.**

Too high!

Data and analysis

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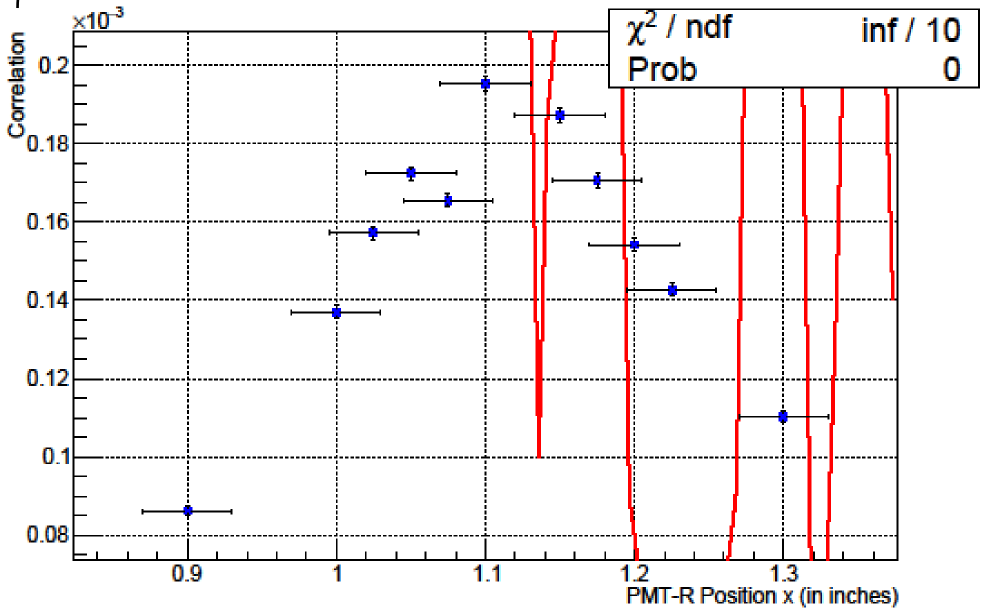
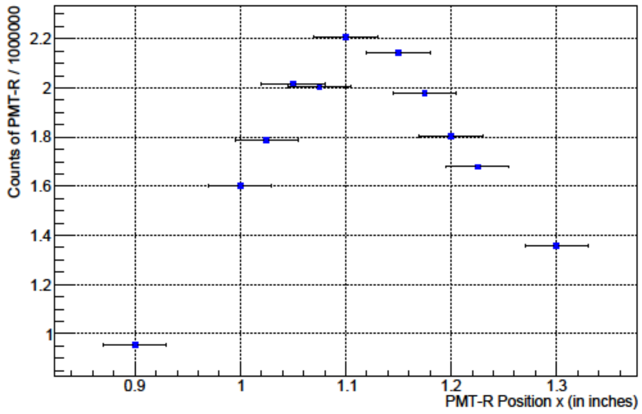
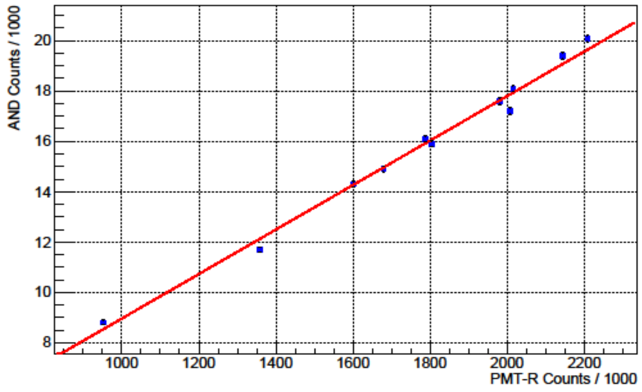
$$\text{Correlation} = \frac{{Counts_{\mathrm{AND}}}^2}{Counts_{\mathrm{R}} \cdot Counts_{\mathrm{T}}}$$







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- See product specifications at https://www.dolan-jenner.com/hubfs/products/illuminators/mh-100-data-sheet.pdf.
- See product specifications at https://www.dolan-jenner.com/hubfs/products/glass-fiber-optics/flexible-glass/single-fiber-optic-cables-data-sheet.pdf.
- See operation manual at https://www.hamamatsu.com/resources/pdf/etd/R329-02_TPMH1254E.pdf.
- Image downloaded from https://en.wikipedia.org/wiki/Interferometry.