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Making a Dark box Light Tight.

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Outside dimensions: ($68\frac{1}{4}$" x $23\frac{3}{4}$" x $11\frac{5}{16}$")

Inner dimensions: (60" x $16\frac{1}{4}$" x 6")

Figure 1.1 a Dark Box

We designed and built a dark box, and improved the dark box by making it impermeable to light. Our goal was to make the box completely light tight. To test its light tightness a Hamamatsu H2431-50 PMT was placed in the box and its dark rate recorded with the room lights on and then off. If the box is completely light tight then we expect that the PMT dark rate would be the same with the box completely covered with a black tarp and lights off, as when left uncovered and room light on. The PMT "dark rate" or "noise" is due to the PMT's cathode emitting thermionic electrons; the PMT powered up at a high voltage has a strong electric field between its dynodes creating a large gain in the number of electrons off the anode. By counting PMT dark rate under different room lighting condition we were able to test the dark box.

The original lid was made of plywood which splits easily with screws, it was not light tight and thus replaced. A new cover was designed and built using ¾" thick Particleboard Panel board. The new lid is an unhinged "cap" whereas the old lid was hinged on one side; the previous lid had three standard type hinges which were replaced by 8 compression loaded latches placed around the box perimeter (three on each side, and one on each end). The new latches pull down the cap cover equally on all 4 sides creating tension between the insulating gasket placed between the cap and body of the box. On both long sides of the box latches were placed ¾ the way out from the center to pull the cap down with more pressure on each corner of the box.

We screwed in additional "liners" made of particle panel board around the perimeter of the body of the box as shown in Fig. 1.6 as a second light seal. The original foam gasket that had been installed is porous having micro holes (Fig. 1.7), it was replaced by D-profile self-stick weather-seal rubber gasket material. The new gasket was placed around the top perimeter of the box's body where it meets the cap on the inside. More gasket was placed in a 2nd location between the wood cover liners and the lid (running along the body of the box on the sides).

After replacing the lid, hinges, gasket, and installing the additional wood liners and gasket, DYNAFLEX 230 black silicon was used to fill in all corners, gaps on the inside and outside of the box. The box was measured to be 92% light tight. The leaks were found to be through the bulkhead connector panel. DYNAFLEX 230 black silicon was used to fill around all SHV and BNC connector interfaces through the metal bulkhead panel, and the unused bulkhead connectors were covered after the box was measured to be 99.6% light tight.

List of improvements made:

1) Areas around screws filled with silicone.

2) Lid replaced with more solid wood, 3 hinges replaced with 8 compression loaded latches. Porous gasket replaced with non-porous foam rubber gasket.

3) Bulkhead panel connectors and metal plate interfaces sealed with black silicone inside and outside.

4) Unused bulkhead connectors covered.

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Lights on												
Voltage (V)	2011		2109		2207		2305		2403		2501	
Trial	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
1	2456	296	3780	455	4899	590	6437	776	10313	1243	16057	1935
2	2324	280	3718	448	4894	590	6644	800	10381	1251	15755	1898
3	2346	283	3627	437	5021	605	6722	810	10602	1277	15191	1830
4	2266	273	3731	450	4854	585	7093	855	10162	1224	15840	1908
5	2325	280	3725	449	5040	607	6799	819	10866	1309	15899	1916
6	2369	285	3784	456	5018	605	7156	862	10246	1234	16342	1969
Average	2348	283	3728	449	4954	597	6809	820	10428	1256	15847	1909

Lights off												
Voltage (V)	2011		2109		2207		2305		2403		2501	
Trial	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate	Count	Rate
1	2308	278	3853	464	5216	628	6741	812	10808	1302	15206	1832
2	2292	276	3777	455	5338	643	6749	813	10503	1265	16523	1991
3	2335	281	3703	446	5099	614	6439	776	10292	1240	16183	1950
4	2480	299	3832	462	4983	600	6557	790	10208	1230	16520	1990
5	2487	300	3822	460	4967	598	6764	815	10892	1312	16190	1951
6	2436	293	3742	451	4987	601	6700	807	10810	1302	15930	1919
Average	2390	288	3788	456	5098	614	6658	802	10586	1275	16092	1939

Figure 1.2 Final test Data Tables.

Figure 1.3 Data table Before improvement of the metal plate.

	uncovered lights off	uncovered lights on	covered lights on	covered lights off
Voltage =2207(V)	7328	7569	7126	6963
	7449	7640	7286	6927
	7356	7587	7043	7107
	7208	7516	7227	6975
	7195	7544	7031	6969
	7216	7686	7014	7182
Average counts	7292	7590	7121	7021

$$\%error = \left|\frac{(\#\textbf{uncovered}, lights\ on - \#\textbf{covered},\ lights\ off)}{\#\textbf{covered}, lights\ off}\right| * 100\% = 8\%$$

The bar chart below shows the results after improving the bulkhead panel; the number of counts with lights off is now higher than with lights on, a difference which is expected to be fluctuations in the photomultiplier tube dark rate.

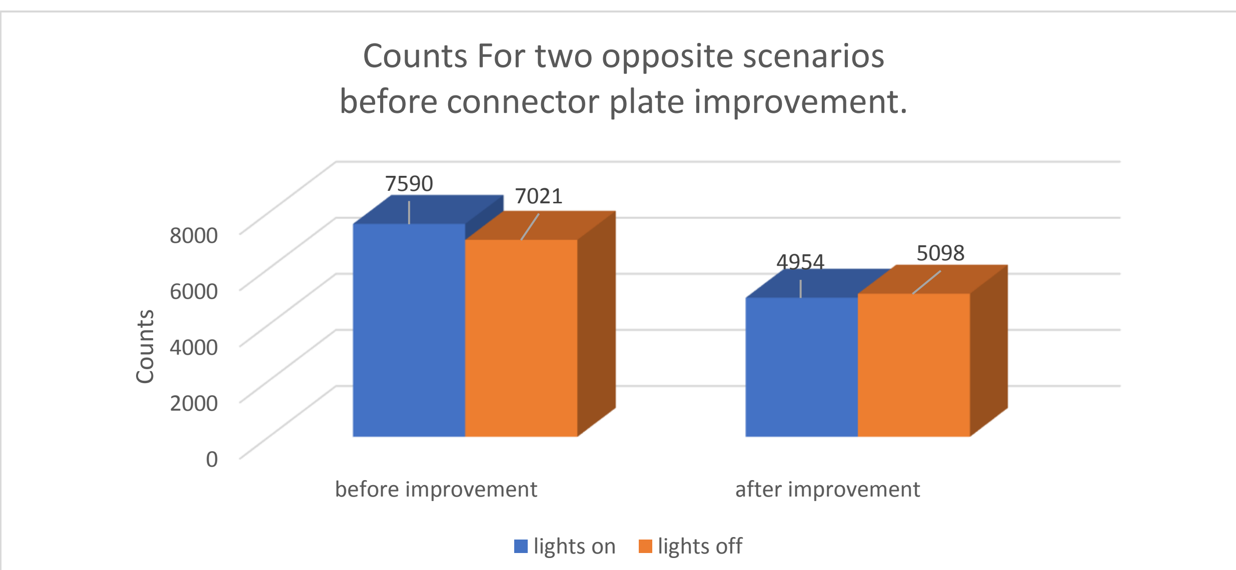

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Figure 1.4 Counts “before and after” graph.

NIM bin setup used:

Power supply (BNL 106900)

Visual scaler (BNL-52935)

Sixteen channel amplifier (model 776) – (BNL 13175) - *Set to 10x amplification.*

Six channel discriminator (model 711) – (BNL 5052) – *Set to 30(mV) threshold.*

Quad gate/delay generator (model 794) – (BNL 20992) *– Set to 8.3(s) delay.*

Multimeter: Fluke 8022B (QCC- PHY 4713)

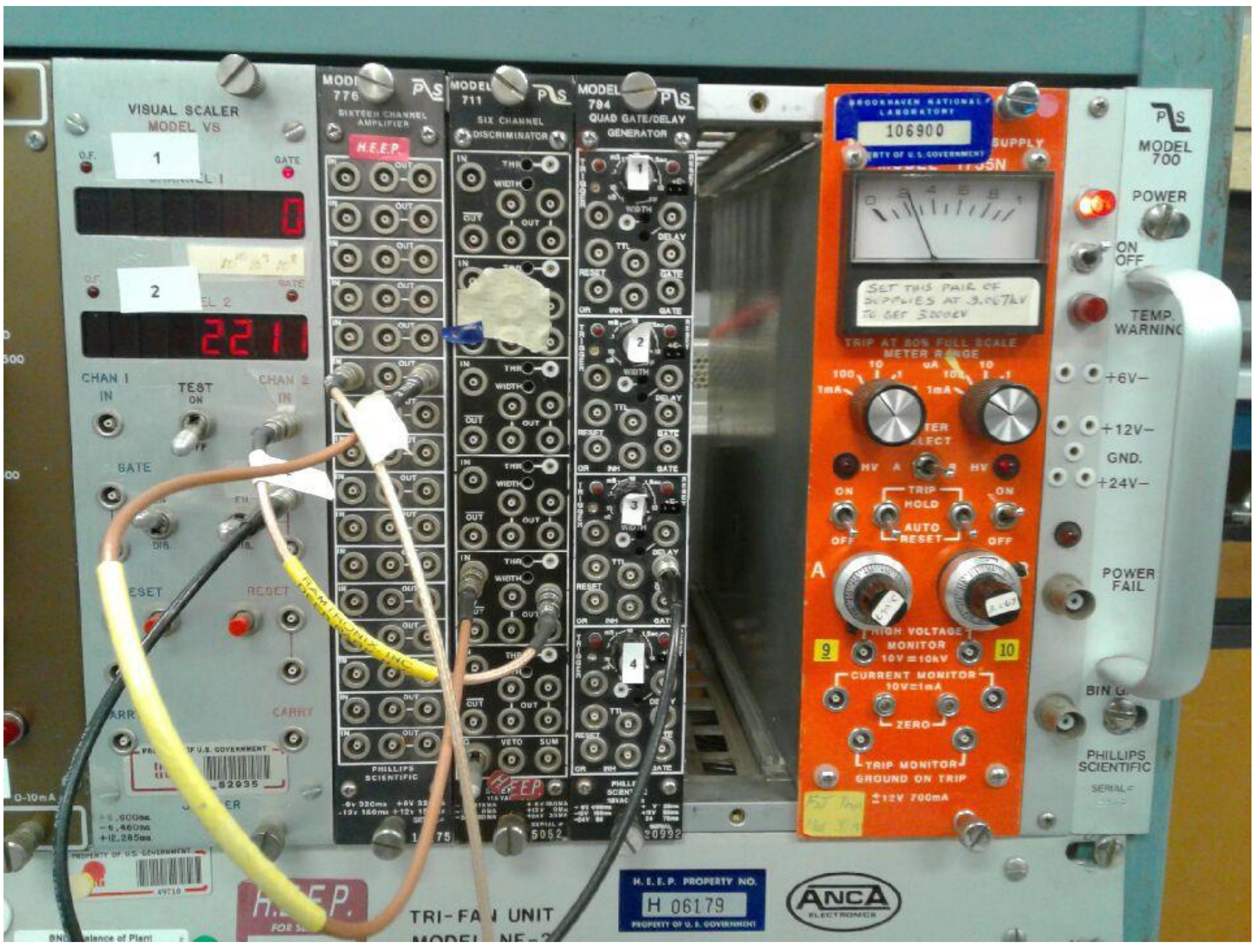

Figure 1.5 NIM bin setup.

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Figure 1.6 Power supply testing.

Tested Values			Expected values					
Rotation	Voltage(V)	Error(V)	Rotation	Voltage(V)	Error(V)	Rotation	Voltage(V)	Error(V)
0.1	50	1	2.1	1031	4	4.1	2011	6
0.2	100	1	2.2	1080	4	4.2	2060	6
0.3	149	1	2.3	1129	4	4.3	2109	6
0.4	199	1	2.4	1178	4	4.4	2158	6
0.5	248	2	2.5	1227	4	4.5	2207	7
0.6	297	2	2.6	1276	4	4.6	2256	7
0.7	346	2	2.7	1325	4	4.7	2305	7
0.8	392	2	2.8	1374	4	4.8	2354	7
0.9	443	2	2.9	1423	5	4.9	2403	7
1.0	491	2	3.0	1472	5	5.0	2452	7
1.1	540	2	3.1	1521	5	5.1	2501	7
1.2	588	2	3.2	1570	5	5.2	2550	7
1.3	640	3	3.3	1619	5	5.3	2599	7
1.4	690	3	3.4	1668	5	5.4	2648	8
1.5	738	3	3.5	1717	5	5.5	2697	8
1.6	788	3	3.6	1766	5	5.6	2746	8
1.7	835	3	3.7	1815	6	5.7	2795	8
1.8	883	3	3.8	1864	6	5.8	2844	8
1.9	932	3	3.9	1913	6	5.9	2893	8
2.0	982	3	4.0	1962	6	6.0	2942	8

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Voltage output vs Rotation graph for (BNL 106900) Power supply.

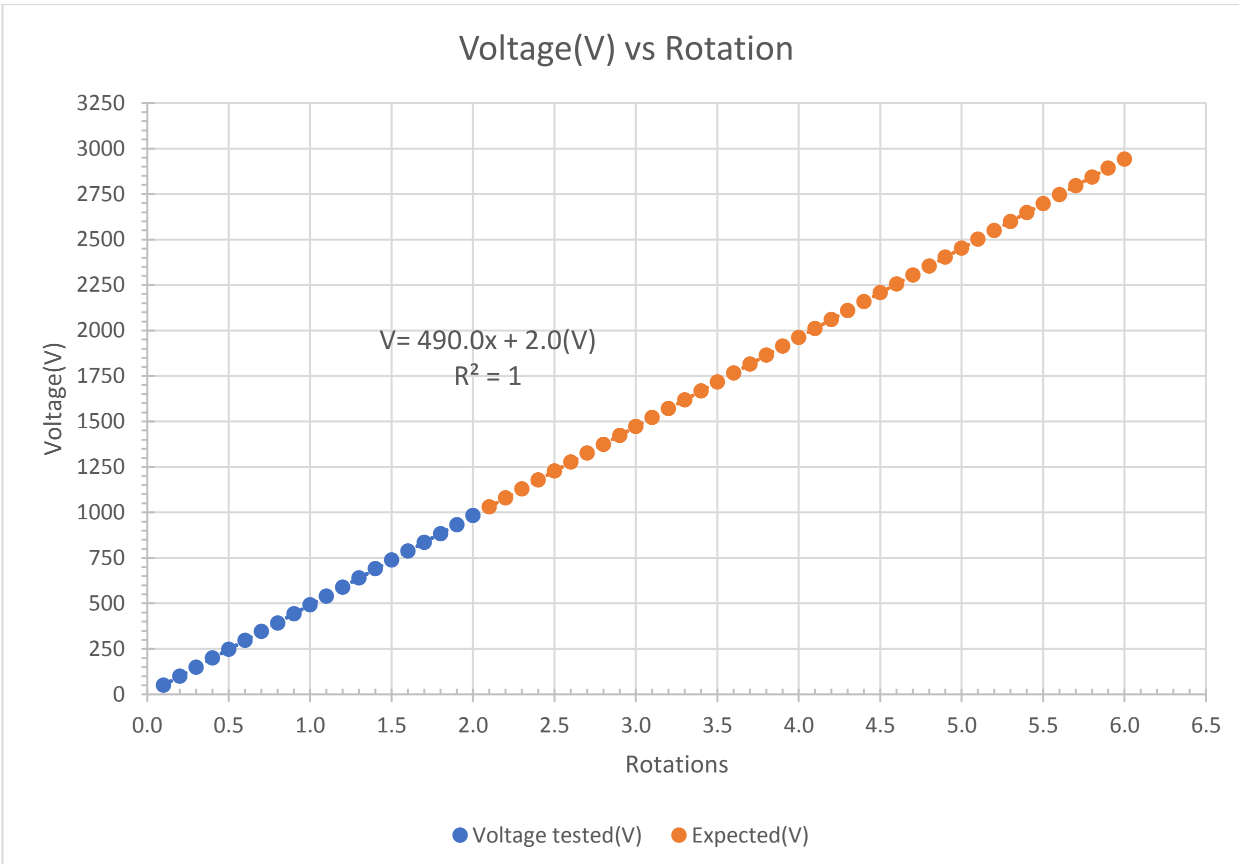

Table 1-2. 8022B Specifications

The following specifications assume a 2-year calibration cycle and an operating temperature of 18° C to 28° C (64° F to 82° F) at a relative humidity up to 90%, unless otherwise noted.

FUNCTIONS .... DC Volts, AC Volts, DC Current, Resistance

DC VOLTS

RANGE	RESOLUTION	ACCURACY FOR 2 YEARS
±200 mV	100 μV	±(.25% of reading + 1 digit)
±2V	1 mV	
±20V	10 mV	
±200V	100 mV	
±1000V	1V	

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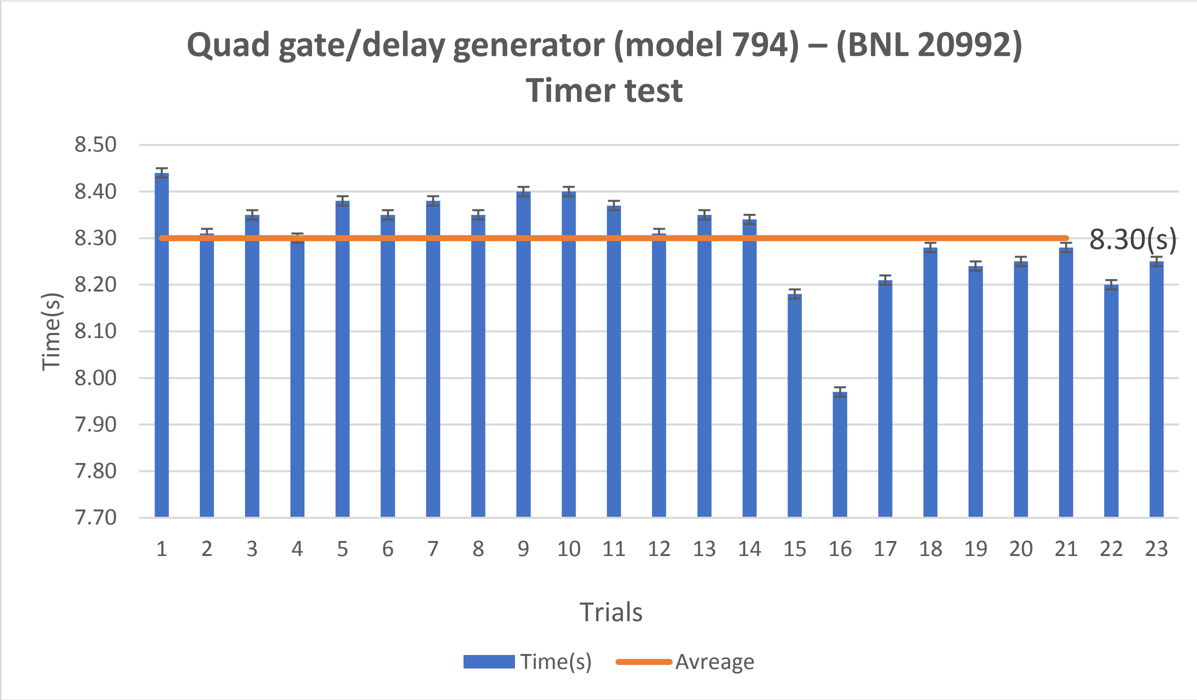
Figure 1.7 Gate time testing.



Time(s)	
8.44	8.34
8.31	8.18
8.35	7.97
8.30	8.21
8.38	8.28
8.35	8.24
8.38	8.25
8.35	8.28
8.40	8.20
8.40	8.25
8.37	8.30
8.31	8.35
±0.21(s)	
T=8.3±0.21(s)	

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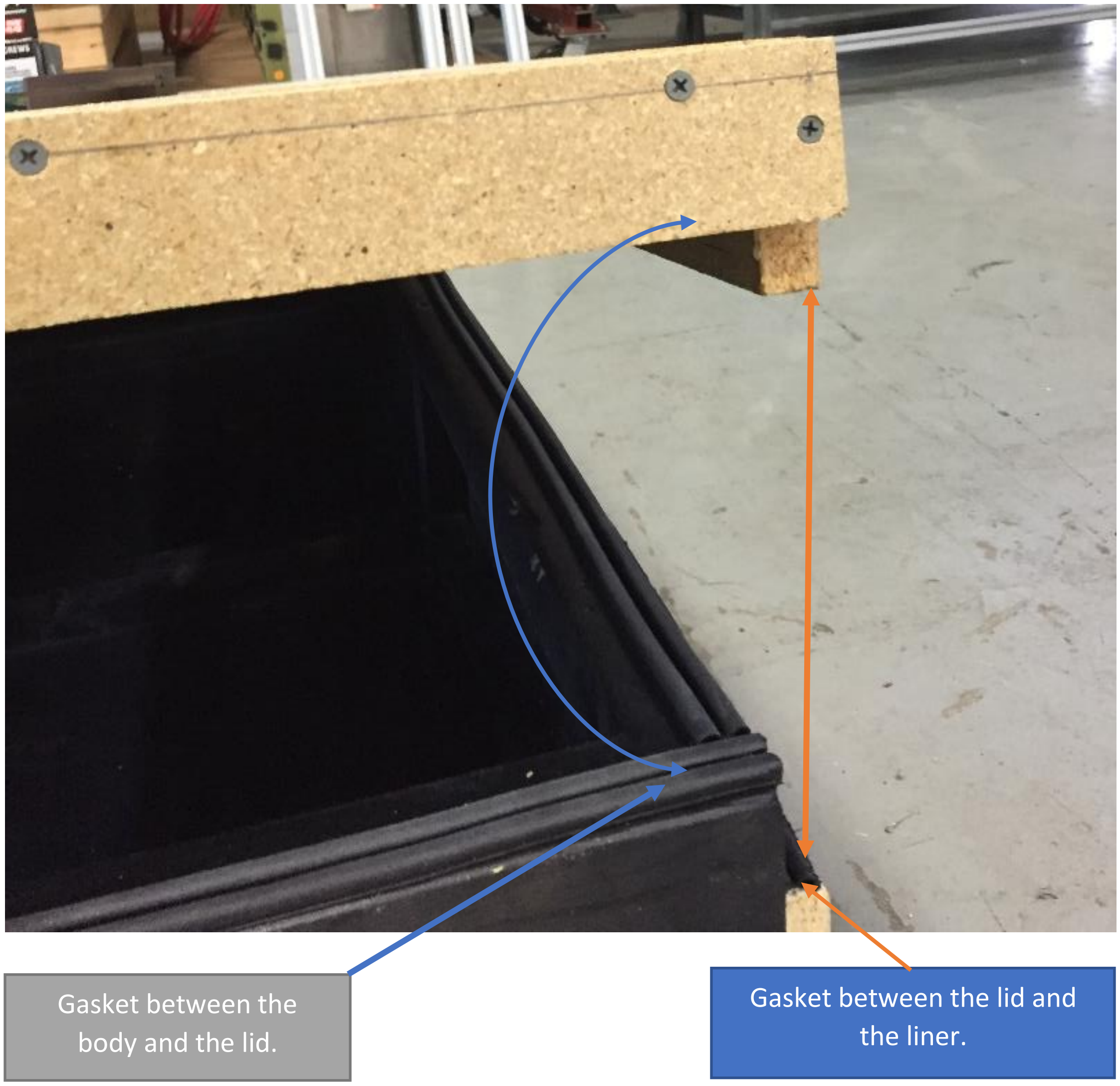

Figure 1.8 Types of Gaskets.

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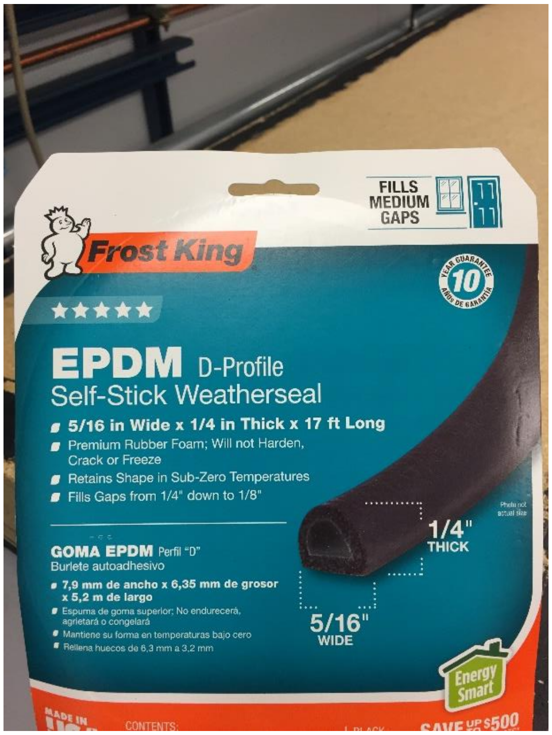
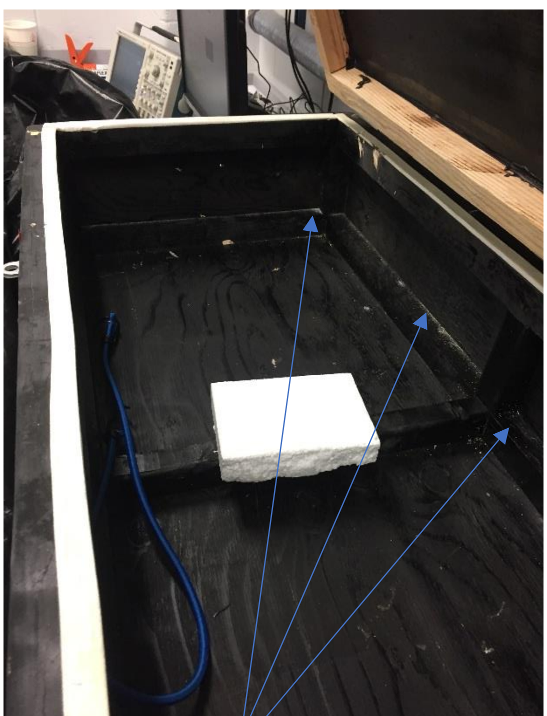


New rubber gasket.

New rubbery to old foamy gasket comparison.



Unsealed joints.

Poor gasket choice has micro holes in it.

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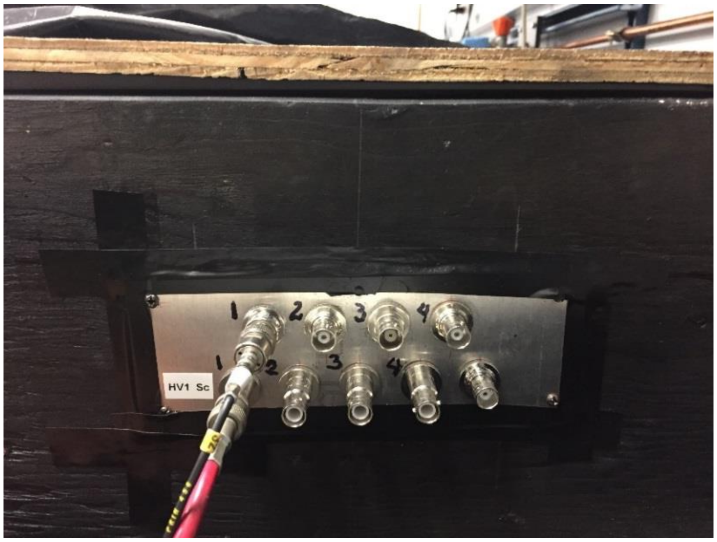
Figure 1.9 A Box before improvement.



Open connectors and unsealed connector plate.

Covered connecters and sealed connector plate.

Before.

After.

Figure 2.0 Before and after examples.

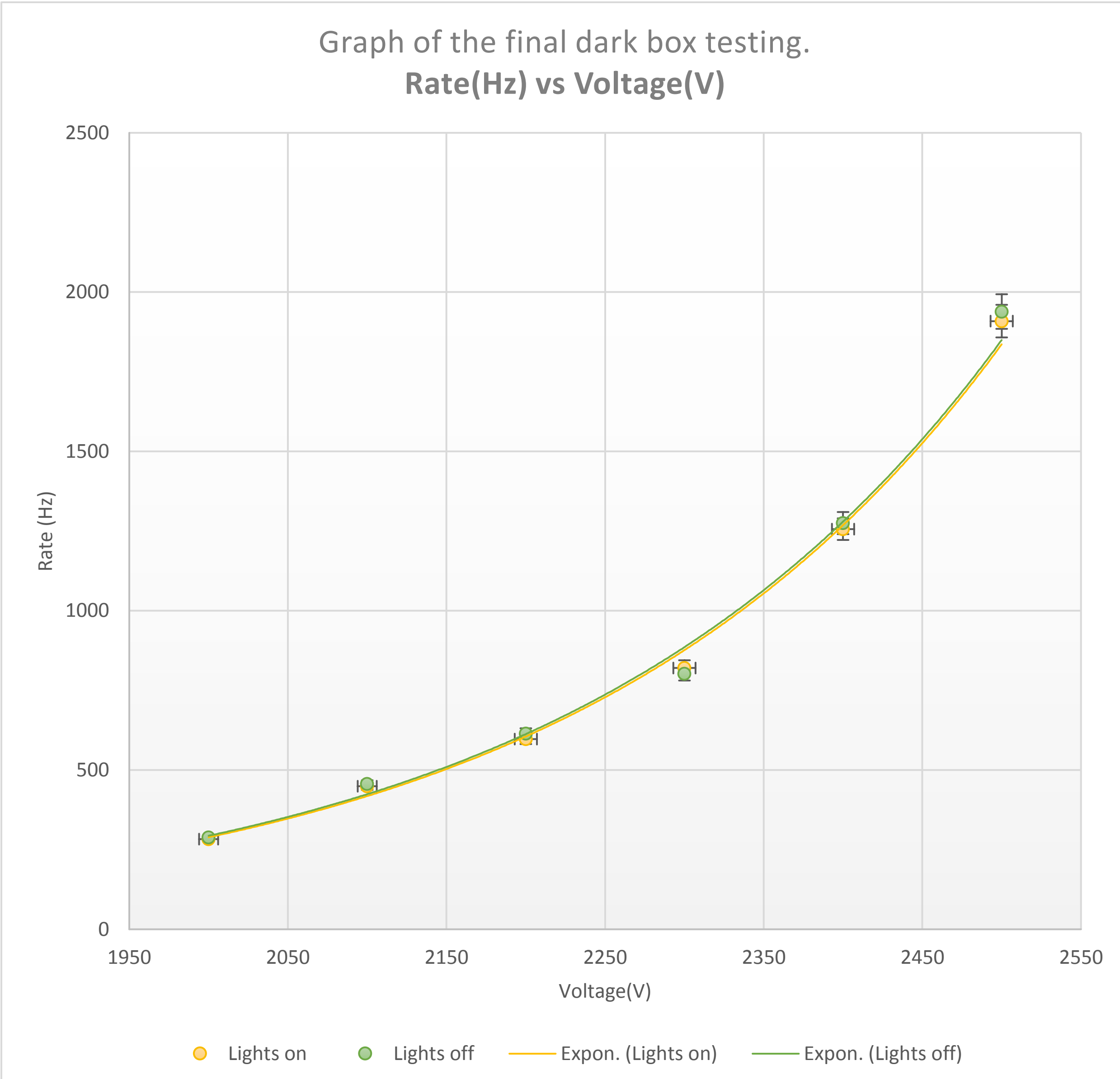


Figure 2.1 Final test graph.

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Errors: The standard deviation estimates the uncertainty in our measurements of Counts, caused by random errors such as inconsistency of "dark rate" of PMT, uncertainty of scalar and equipment). According to Mechanics lab manual of the SCCC physics department edited by Robert L. Warasila the measurement uncertainties have a 68% probability of being within σ of the average value. Calculating uncertainty of time for Quad gate/delay generator we sum uncertainty based on the measuring instrument division ±0.01(s). The average reaction time for humans according to google search is 0.25 seconds to a visual stimulus, 0.17 for an audio stimulus, and 0.20 seconds for a touch stimulus. So, total uncertainty of time is equal to ±0.21(s). To examine the propagation of error for Rate we must use propagation formula to take into count time and count errors.

The standard deviation formula:

$$\sigma = \sqrt{\frac{1}{N}\sum(x_i - X_{ave})^2}$$

average or mean $\sigma_{ave} = \frac{\sigma}{\sqrt{N}}$

Rate Error propagation:

$$R = \frac{C}{T} = \frac{Counts}{Time}$$

,Where (T=t ± ðt and C= c ± σ.)

$$ðR = R\sqrt{(\frac{ðt}{T})^2 + (\frac{\sigma}{C})^2}$$

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Figure 2.2 Error and uncertainty tables.

Error table (lights on)							
Voltage (V)	Counts	Counts error	Time(s)	Time error(s)	Rate(Hz)	Rate error(Hz)	Rate error Percentage
2011 ± 6	2456 2324 2346 2266 2325 2369	24	8.3	0.21	283.0	7.7	2.7%
Average:	2348						
2109 ±6	3780 3718 3627 3731 3725 3784	21	8.3	0.21	449.1	11.6	2.6%
Average:	3728						
2207 ±7	4899 4894 5021 4854 5040 5018	30	8.3	0.21	596.9	15.5	2.6%
Average:	4954						
2305 ±7	6437 6644 6722 7093 6799 7156	102	8.3	0.21	820.3	24.5	3.0%
Average:	6809						
2403 ±7	10313 10381 10602 10162 10866 10246	97	8.3	0.21	1256.4	33.9	2.7%
Average:	10428						
2501 ±7	16057 15755 15191 15840 15899 16342	142	8.3	0.21	1909.3	51.2	2.7%
Average:	15847						

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Error table (lights off)							
Voltage(V)	Counts	Counts error	Time(s)	Time error(s)	Rate(Hz)	Rate error(Hz)	error Percentage
2011 ± 6	2308	33	8.3	0.21	288.0	8.4	2.9%
	2292						
	2335						
	2480						
	2487						
	2436						
Average:	2390						
2109 ±6	3853	22	8.3	0.21	456.4	11.8	2.6%
	3777						
	3703						
	3832						
	3822						
	3742						
Average:	3788						
2207 ±7	5216	56	8.3	0.21	614.3	16.9	2.8%
	5338						
	5099						
	4983						
	4967						
	4987						
Average:	5098						
2305 ±7	6741	49	8.3	0.21	802.2	21.1	2.6%
	6749						
	6439						
	6557						
	6764						
	6700						
Average:	6658						
2403 ±7	10808	109	8.3	0.21	1275.4	34.7	2.7%
	10503						
	10292						
	10208						
	10892						
	10810						
Average:	10586						
2501 ±7	15206	182	8.3	0.21	1938.8	54.3	2.8%
	16523						
	16183						
	16520						
	16190						
	15930						
Average:	16092						

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Figure 2.3 Testing set up. Schematic drawing.

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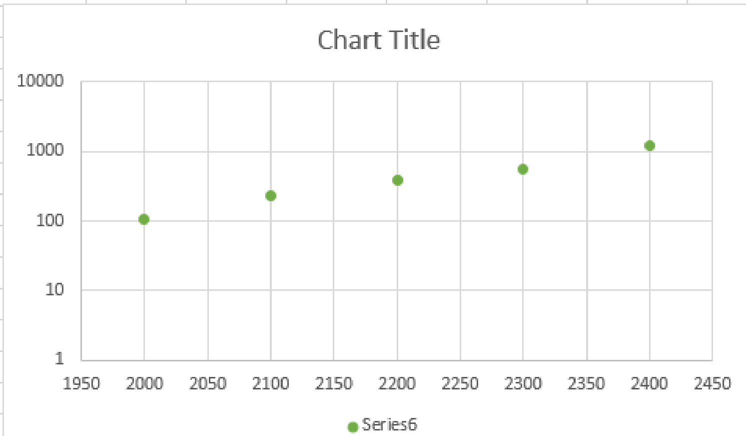
Figure 2.4 Test of the same Photomultiplier tube in different dark box.

Data recorded by group in summer 2017.

PMT58 AA720 CH2						
Dark count in 8 sec, 10* amplification, -30 mV threshold discrimination						
HV set = 2000V for > 8 hours						
Voltage	count 1	count 2	count 3	count 4	count 5	rate (Hz)
2000	827	828	825	879	846	105.125
2100	1779	1832	1920	1862	1890	232.075
2200	3012	3074	2986	3164	2878	377.85
2300	4647	4593	4504	4353	4657	568.85
2400	9504	9668	10057	9814	9927	1224.25



Data recorded in fall 2017.

PMT58 AA720 Dark count in 8.3±0.21(s), 10x amplification,-30mV discrimination,			
Voltage(V)	Rate(Hz)	Error(Hz)	Error(percent)
2011 ± 6	288	8	2.9%
2109 ±6	456	12	2.6%
2207 ±7	614	17	2.8%
2305 ±7	802	21	2.6%
2403 ±7	1275	35	2.7%
2501 ±7	1939	54	2.8%

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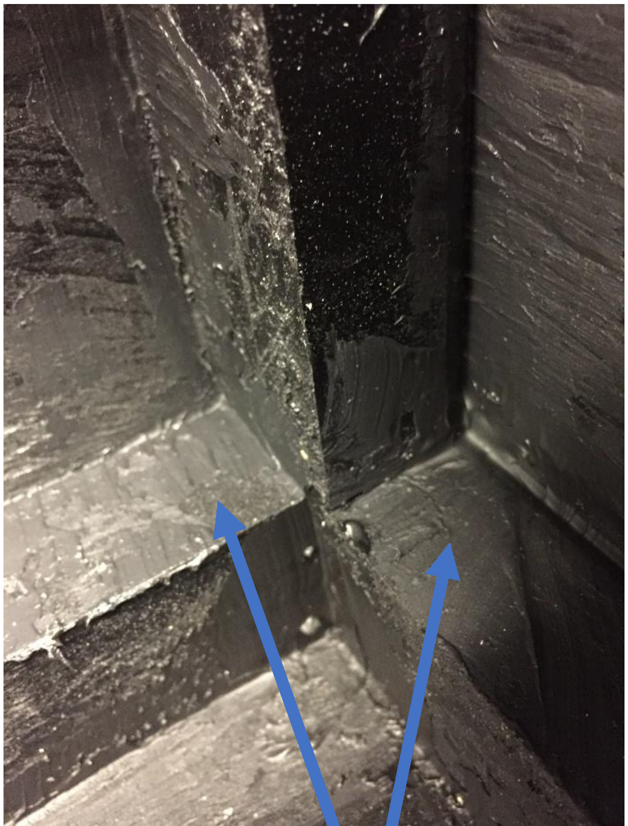

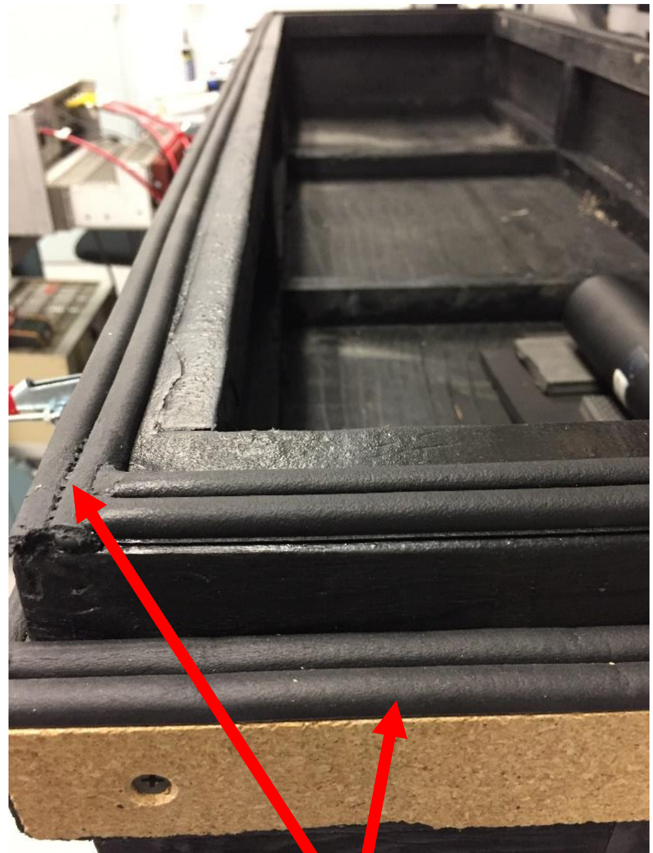

Figure 2.5 A Dark box Inside.