

Acceptance Tests for the PMTs of the Large-Angle TOF Scintillators

ELTON SMITH, MICHAEL TURNER,
CLAUDE MARCHAND AND LUC MURPHY
AUGUST 22, 1995

The large-angle scintillators for the CLAS Time-of-Flight (TOF) system requires 360 3" XP4312B photomultiplier tubes (PMTs) and 48 2" XP2262 PMTs, purchased according to CEBAF Specifications 66330-S-01110 and 66540-S-01113, respectively. The XP4312B PMTs are to be coupled on each side of 22 cm wide scintillators (BC-408) through curved light guides. Due to geometrical constraints, the design of the forward-angle scintillators was used in the last four scintillators of each sector with straight light guides and XP2262 PMTs. We have received, tested and accepted 377 XP4312B PMTs and 67 XP2262 PMTs. This document briefly describes the procedures used and the tabulated results for each tube.

1 Tests

Each of the PMTs was tested by Philips at the factory using divider C. The following quantities were measured and recorded on the test ticket that accompanied each tube:

CB Cathode Blue sensitivity ($\mu\text{A}/\text{lm}$). ¹

Voltage Voltage to attain a gain of 10^7 .

Dark Current Dark current (nA) at a gain of 10^7 (XP4312B) or

Dark Count Dark count (Hz) at a gain of 3×10^7 (XP2262).

¹ $10\mu\text{A}/\text{lm}$ corresponds to a QE of approximately 24.5% at 400 nm.

The following acceptance tests were performed at CEBAF using the procedure described below:

Pulse Pulse height for LED4 scaled from the manufacturer voltage to a gain of 6×10^6 , taking into account differences in voltage dividers. For XP2262s, the voltage was set to obtain a 3 V pulse.

Transit Time Relative transit time for three LED's along the diameter of the photocathode. The selected LEDs showed the largest transit time spread for one particular orientation.

Dark Current Dark current (nA).

Table 1 summarizes the number (3%) and reasons for rejection of a few tubes. All tubes were replaced by Philips with tubes which were later accepted.

2 Procedure

The procedure for CEBAF tests was based on the setup used for testing the effect of magnetic fields on the XP4312B PMTs [2]. The voltage divider was the UNH design including the housing [3]. Seven LED's were uniformly spaced along a line and placed on a disc with matching holes. The hole spacing was 10 mm and their diameter was 8 mm. LED number 4 was at the center of the PMT. The disc fit into the μ -metal shield and placed up against the face of the PMT. The row of LEDs thereby spanned a diameter of the PMT. By pulsing the LEDs one at a time, the transit time for photons striking the photocathode at the position of the LED was determined. Typical time

Table 1: Summary of rejected PMTs.

<i>PMT type</i>	<i>Reason</i>	<i>Number Rejected</i>
XP4312B/D03	No Insulating Sleeve	8
	High dark current	2
	Dead	1
XP2262/H03	High dark current	1
	Lost photocathode	1

spectra are shown in Figure 1 for each LED. Three times were measured for each PMT, LEDs 2, 4 and 5 for the XP4312B's and LEDs 3, 4 and 5 for XP2262's. This corresponded to the maximum transit time variations across the photocathode.² The results of the factory and CEBAF tests were tabulated (Table 2 and 3) and kept as ASCII files for reference.

3 Results and Conclusions

Figures 2 and 3 show the distribution of values for the parameters which were measured during acceptance tests for the 3" and 2" PMTs respectively. We review in detail the performance of the specifications for the 3" XP4312B PMT. The cathode blue sensitivity was required by the factory to exceed $10 \mu\text{A}/\text{LmF}$, which corresponds to a quantum efficiency of 24.5% and satisfies the specification. The dark current measurements were made soon after voltage was applied to the PMT and in all cases were less than 30 nA. The specification requires that the dark current be less than 20 nA after 30 minutes in darkness. In many instances when high "dark currents" were obtained, they were determined to be leakage currents which did not depend on the performance of the PMT, but rather on how the voltage divider housing, including μ -metal shield, was connected. Our final design for assembly, which requires that the μ -metal shield be connected to cathode potential through an $8 \text{ M}\Omega$ resistor, resulted in the smallest and most stable configuration for dark currents. The performance of the PMTs was measured at the factory for a gain of 1×10^7 , which exceeds our specification of 0.6×10^7 . The specification requires that the average transit time spread (FWHM) be less than 2.1 ns. We have measured the maximum transit time spread across one diameter and in all cases this time is less than 2.5 ns, which corresponds approximately to a FWHM of 1.9 ns.

We conclude that the XP4312B PMTs satisfy all our specifications with low dark current and little transit time variation across the face of the PMT. We therefore expect that these tube will perform well when integrated into our time-of-flight system.

²Figure 1 corresponds to a different orientation of the LEDs.

ACKNOWLEDGEMENTS

We wish to thank Drew Weisenberger from the CEBAF Detector Group for organizing the apparatus used for the tests and very helpful discussions. We would also like to thank Tony Day for assistance in producing and debugging a PC board used to fire the LED's.

A Cathode-Grid Voltage

A auxiliary test was conducted to determine the proper voltage between the cathode and the grid of the XP4312B PMTs. The maximum transit time between two LEDs was used to infer the average resolution due to transit time differences over the face of the PMT. Plotted in Figure 4 is the resolution as a function of resistor values tried as well as the resolution obtained using two 150 V zener diodes (components used for the 2" PMT divider networks.) An approximate value for the resistor of 500 k Ω was determined to be optimal.

References

- [1] "Conceptual Design Report — Basic Experimental Equipment," CEBAF April 13, 1990.
- [2] Jason Flint and Elton S. Smith, "Tests of Phillips XP4312B/D1 PMT in Magnetic Field," CLAS-NOTE 94-008, May 31, 1994.
- [3] K. MacArthur and J. Distelbrink, "CEBAF Large-Angle TOF Prototype Photomultiplier Circuits," CLAS-NOTE 94-021, October 27, 1994.

List of Figures

1	Time distribution measured for different LEDs.	14
2	Distribution of XP4312B characteristics.	15
3	Distribution of XP2262 characteristics.	16
4	PMT resolution vs cathode-grid voltage.	17

Table 2: XP4312B photomultiplier characteristics as measured by Philips Components and CEBAF. Each column is labeled by the PMT serial number (SN), voltage (Hi-V) used for measurements at CEBAF, dark current measured by Philips (DCman), dark current measured at CEBAF (DCEXP), corning blue sensitivity measured at the factory (CB), time of LED 4 (Delta1) and 5 (Delta2) relative to LED 2 in counts (23 counts/ns), and pulse height in volts.

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5060	2197.0	6.0	35.0	10.0	9.0	18.0	2.0
5065	2175.0	18.0	27.0	12.3	.0	16.0	7.2
5066	2443.0	7.0	30.0	11.0	-8.0	10.0	6.1
5072	2353.0	10.0	6.0	11.0	4.0	17.0	5.0
5074	2265.0	7.0	16.0	10.9	6.0	15.0	4.0
5075	2316.0	13.0	12.0	10.9	4.0	23.0	5.6
5077	2330.0	9.0	7.0	11.1	6.0	17.0	4.8
5079	2238.0	18.0	6.0	10.0	12.0	30.0	4.0
5081	2272.0	11.0	17.0	11.0	10.0	27.0	4.6
5082	2338.0	9.0	10.0	10.9	15.0	45.0	6.0
5083	2218.0	29.0	11.0	10.8	15.0	36.0	4.4
5086	2292.0	10.0	9.0	10.0	8.0	23.0	5.3
5088	2327.0	9.0	5.0	11.2	13.0	44.0	5.5
5089	2280.0	12.0	12.0	10.9	11.0	32.0	4.5
5090	2400.0	27.0	18.0	10.7	7.0	25.0	2.7
5091	2339.0	15.0	6.0	10.7	12.0	33.0	4.8
5092	2326.0	17.0	6.0	10.4	7.0	25.0	4.4
5093	2367.0	10.0	9.0	10.7	9.0	21.0	3.9
5094	2321.0	23.0	13.0	11.0	13.0	33.0	4.8
5095	2329.0	10.0	8.0	11.0	7.0	14.0	3.1
5096	2361.0	7.0	10.0	10.6	7.0	20.0	3.7
5097	2347.0	16.0	16.0	10.9	6.0	19.0	4.9
5098	2337.0	11.0	8.0	10.7	10.0	34.0	4.5
5100	2226.0	24.0	9.0	11.8	11.0	39.0	5.8
5101	2298.0	16.6	40.0	10.0	13.0	33.0	4.0
5102	2347.0	24.0	8.0	11.1	13.0	32.0	4.8
5103	2308.0	9.0	3.0	11.0	10.0	22.0	3.0
5104	2214.0	33.0	14.0	12.1	1.0	26.0	6.0
5105	2309.0	33.0	20.0	11.1	10.0	21.0	4.5
5111	2174.0	10.0	7.0	10.7	15.0	31.0	4.1

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5116	2216.0	13.0	8.0	10.0	16.0	33.0	2.4
5117	2163.0	6.0	9.0	10.0	14.0	28.0	3.1
5118	2163.0	24.0	15.0	10.0	12.0	23.0	3.6
5119	2205.0	18.0	17.0	10.4	8.0	21.0	3.9
5120	2208.0	13.0	18.0	10.0	16.0	33.0	3.0
5121	2275.0	25.0	14.0	10.5	14.0	32.0	4.0
5122	2337.0	8.0	8.0	10.0	12.0	27.0	3.9
5123	2235.0	10.0	6.0	10.0	7.0	19.0	2.7
5124	2228.0	10.0	13.0	10.0	5.0	19.0	3.0
5125	2218.0	9.0	14.0	10.5	17.0	34.0	2.5
5127	2250.0	8.0	8.0	10.0	12.0	2.0	4.0
5129	2180.0	5.0	5.0	10.4	16.0	36.0	1.9
5132	2200.0	7.0	8.0	10.1	14.0	32.0	4.5
5136	1910.0	8.5	7.0	11.1	1.0	13.0	3.7
5137	2133.0	10.0	30.0	11.1	14.0	31.0	3.9
5139	2185.0	13.0	5.0	10.8	11.0	24.0	3.8
5140	2096.0	7.0	7.0	10.8	29.0	51.0	3.8
5146	2040.0	10.5	7.0	11.0	.0	8.0	4.8
5147	2130.0	15.0	8.0	10.9	2.0	10.0	5.8
5148	2210.0	12.0	6.0	10.9	-2.0	18.0	6.4
5149	2120.0	11.0	10.0	10.8	-10.0	6.0	5.4
5152	2130.0	30.0	6.0	11.2	-11.0	13.0	6.2
5153	2200.0	25.0	12.0	11.0	-11.0	13.0	6.3
5155	2050.0	22.0	10.0	10.1	-7.0	-6.0	3.0
5157	2380.0	19.0	12.0	10.8	17.0	34.0	3.0
5159	2470.0	17.0	7.0	10.7	18.0	37.0	3.2
5165	2410.0	13.0	10.0	10.3	12.0	29.0	3.3
5168	2350.0	16.0	15.0	10.1	14.0	28.0	2.9
5169	2330.0	20.0	6.0	10.5	9.0	24.0	2.7
5170	2350.0	10.0	4.0	10.3	9.0	24.0	2.5
5171	2300.0	13.0	5.0	10.3	18.0	38.0	2.8
5173	2300.0	10.0	25.0	11.0	14.0	36.0	2.7
5174	2100.0	30.0	27.0	10.9	22.0	33.0	2.3
5175	2250.0	23.0	10.0	11.3	17.0	35.0	2.8
5178	2320.0	6.0	15.0	10.8	12.0	25.0	3.0
5179	2210.0	24.0	6.0	10.3	15.0	33.0	1.9
5180	2300.0	17.0	10.0	10.8	39.0	43.0	2.7
5182	2330.0	23.0	10.0	10.8	19.0	36.0	3.0
5183	2370.0	6.0	10.0	11.0	18.0	39.0	2.9
5185	2440.0	24.0	19.0	10.8	13.0	28.0	3.3
5186	2450.0	20.0	15.0	10.3	13.0	36.0	3.1
5190	2530.0	24.0	17.0	11.0	9.0	22.0	3.6
5192	2440.0	30.0	12.0	10.6	14.0	34.0	3.5
5193	2500.0	18.0	11.0	11.1	21.0	48.0	3.9
5194	2270.0	8.0	5.0	10.0	15.0	37.0	3.0
5195	2380.0	30.0	13.0	10.0	15.0	33.0	3.3
5196	2420.0	27.0	10.0	10.8	15.0	35.0	3.5
5198	2440.0	10.0	13.0	10.0	17.0	39.0	3.0
5202	2400.0	8.0	6.0	10.7	15.0	32.0	4.3
5203	2380.0	15.0	7.0	11.6	11.0	31.0	3.5

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5204	2380.0	8.0	20.0	10.0	10.0	18.0	3.1
5205	2350.0	28.0	20.0	10.1	12.0	29.0	3.0
5207	2430.0	13.0	12.0	10.8	10.0	22.0	3.4
5208	2440.0	10.0	10.0	10.2	5.0	11.0	3.0
5211	2450.0	.0	7.0	.0	10.0	28.0	3.0
5212	2450.0	14.0	10.0	10.4	12.0	29.0	3.3
5216	2410.0	13.0	14.0	10.6	12.0	29.0	3.3
5217	2450.0	15.0	8.0	10.0	10.0	25.0	3.0
5226	2325.0	18.0	18.0	10.5	8.0	22.0	4.0
5227	2440.0	14.0	25.0	10.0	14.0	30.0	4.0
5228	2350.0	20.0	12.0	10.7	12.0	25.0	4.0
5231	2320.0	14.0	10.0	10.0	19.0	36.0	2.5
5234	2297.0	8.0	18.0	10.0	8.0	20.0	3.1
5236	2230.0	21.0	12.0	11.1	14.0	37.0	2.9
5237	2354.0	10.0	10.0	11.0	14.0	30.0	2.9
5238	2290.0	8.0	8.0	10.0	29.0	42.0	2.5
5239	2250.0	9.0	8.0	10.0	14.0	29.0	1.5
5240	2380.0	6.0	4.0	10.3	28.0	46.0	2.0
5241	2440.0	13.0	11.0	10.6	15.0	27.0	2.0
5249	2390.0	8.0	20.0	10.0	17.0	39.0	1.9
5253	2260.0	6.0	8.0	10.0	15.0	36.0	2.5
5256	2416.0	15.0	19.0	10.5	7.0	24.0	3.0
5257	2396.0	11.0	2.0	10.0	14.0	31.0	2.2
5259	2300.0	10.0	3.0	10.4	15.0	30.0	3.0
5260	2290.0	10.0	8.0	10.0	7.0	24.0	3.0
5262	2290.0	30.0	5.0	10.0	20.0	37.0	3.0
5266	2297.0	25.0	17.0	10.1	14.0	34.0	3.0
5268	2317.0	7.0	17.0	10.0	21.0	37.0	2.0
5271	2315.0	22.0	5.0	10.0	18.0	38.0	3.0
5272	2235.0	7.0	4.0	10.0	12.0	26.0	2.0
5273	2300.0	13.0	7.0	11.0	9.0	23.0	3.0
5275	2260.0	9.0	15.0	10.0	15.0	34.0	3.0
5276	2262.0	15.0	11.0	11.0	15.0	34.0	3.0
5278	2257.0	7.0	20.0	11.0	19.0	39.0	3.0
5279	2436.0	10.0	6.0	11.0	12.0	32.0	3.4
5282	2305.0	10.0	18.0	11.1	2.0	34.0	3.0
5283	2464.0	8.0	18.0	10.5	14.0	34.0	2.6
5289	2140.0	10.0	6.0	10.7	14.0	45.0	3.9
5291	2130.0	5.0	7.0	10.0	19.0	38.0	2.7
5292	2340.0	8.0	9.0	10.0	18.0	35.0	3.4
5293	2117.0	11.0	5.0	10.0	5.0	42.0	3.6
5294	2281.0	15.0	8.0	10.0	18.0	35.0	3.3
5295	2177.0	29.0	20.0	10.0	18.0	37.0	3.2
5296	2246.0	10.0	4.0	10.6	20.0	36.0	3.4
5299	2130.0	8.0	5.0	10.0	18.0	42.0	3.0
5300	2322.0	12.0	6.0	10.0	19.0	35.0	3.0
5301	2195.0	8.0	19.0	10.1	19.0	36.0	3.3
5305	2318.0	14.0	8.0	10.2	15.0	32.0	2.6
5309	2180.0	25.0	5.0	10.5	23.0	43.0	3.4
5312	2080.0	12.0	6.0	10.2	18.0	44.0	3.3

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5313	2050.0	13.0	5.0	10.6	11.0	29.0	4.2
5315	2235.0	28.0	8.0	10.9	15.0	32.0	3.7
5317	2345.0	24.8	15.0	10.7	20.0	40.0	3.4
5318	2150.0	10.8	4.0	11.0	12.0	46.0	4.8
5322	2230.0	20.0	7.0	10.9	6.0	32.0	4.1
5323	2160.0	8.0	4.0	10.0	13.0	41.0	3.5
5324	2200.0	22.0	6.0	10.4	10.0	37.0	4.0
5325	2170.0	10.0	5.0	10.0	9.0	37.0	3.9
5328	2190.0	9.0	5.0	10.2	9.0	38.0	5.1
5331	2170.0	11.5	4.0	10.0	10.0	41.0	4.0
5333	2210.0	10.0	6.0	11.3	3.0	35.0	5.2
5334	2190.0	10.5	4.0	10.6	14.0	47.0	4.6
5335	2362.0	12.5	6.0	10.1	9.0	27.0	3.5
5336	2200.0	12.5	6.0	10.6	-4.0	31.0	5.4
5337	2230.0	13.0	6.0	10.0	11.0	42.0	4.4
5339	2240.0	10.0	5.0	10.9	-4.0	31.0	5.2
5340	2200.0	30.0	10.0	11.0	4.0	51.0	5.6
5342	2130.0	14.0	5.0	10.5	1.0	21.0	3.2
5343	2050.0	9.0	4.0	10.2	20.0	49.0	3.5
5345	2010.0	10.0	4.0	10.2	9.0	34.0	2.7
5346	1970.0	25.0	8.0	10.6	12.0	42.0	2.9
5349	2000.0	10.0	6.0	10.2	14.0	39.0	3.7
5350	2130.0	14.0	12.0	10.6	10.0	37.0	3.9
5354	2180.0	17.0	5.0	10.4	12.0	36.0	4.0
5355	2030.0	9.5	8.0	10.6	15.0	43.0	3.1
5356	2040.0	12.8	5.0	10.3	13.0	39.0	3.8
5358	2090.0	12.0	5.0	10.3	10.0	31.0	3.3
5360	1951.0	9.5	5.0	10.7	19.0	47.0	2.8
5361	1850.0	16.0	3.0	10.4	19.0	43.0	2.3
5362	1898.0	10.0	8.0	10.3	-5.0	16.0	4.7
5363	2031.0	8.5	10.0	10.6	1.0	23.0	5.4
5365	2004.0	14.0	6.0	11.1	-5.0	27.0	5.7
5366	1922.0	8.9	9.0	10.6	-2.0	20.0	5.2
5367	2080.0	8.7	4.0	11.5	16.0	47.0	3.1
5370	1945.0	10.9	10.0	10.9	1.0	23.0	5.3
5371	2024.0	13.5	10.0	10.7	-9.0	25.0	5.9
5376	2190.0	8.5	8.0	10.8	12.0	51.0	4.3
5377	1993.0	8.5	9.0	10.3	6.0	32.0	5.4
5379	2210.0	13.0	8.0	10.6	13.0	38.0	3.9
5380	2280.0	15.0	7.0	10.7	10.0	31.0	4.8
5381	2160.0	15.0	6.0	10.5	11.0	38.0	3.5
5382	2245.0	10.5	8.0	10.0	10.0	34.0	3.8
5383	2170.0	15.0	10.0	10.6	-3.0	20.0	3.5
5384	2250.0	12.0	6.0	10.7	8.0	34.0	4.2
5385	2220.0	13.4	5.0	10.6	8.0	28.0	3.9
5386	2140.0	13.0	7.0	10.4	13.0	36.0	3.3
5387	2220.0	12.0	6.0	10.7	12.0	44.0	5.5
5388	2160.0	13.4	7.0	10.4	6.0	31.0	3.7
5389	2210.0	11.5	6.0	10.7	10.0	36.0	3.3
5390	2250.0	25.0	6.0	10.7	13.0	45.0	4.4

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5391	2280.0	14.0	7.0	10.2	14.0	49.0	5.8
5392	2240.0	13.0	8.0	10.0	-3.0	28.0	4.8
5393	2180.0	13.0	7.0	10.5	10.0	31.0	3.7
5395	2140.0	20.0	6.0	10.7	13.0	40.0	3.7
5396	2230.0	10.0	5.0	10.2	9.0	40.0	4.8
5397	2230.0	30.0	20.0	10.6	11.0	32.0	4.4
5399	2170.0	12.5	6.0	10.2	13.0	39.0	4.3
5400	2150.0	14.0	6.0	14.0	11.0	36.0	3.8
5402	2240.0	20.0	8.0	11.0	-8.0	43.0	5.8
5404	2240.0	11.0	6.0	10.9	1.0	26.0	4.8
5405	2210.0	14.0	6.0	10.8	10.0	40.0	4.3
5406	2180.0	18.5	7.0	11.0	-1.0	26.0	4.6
5408	2250.0	28.0	20.0	10.3	8.0	29.0	4.8
5409	2200.0	16.5	6.0	10.4	-7.0	23.0	4.8
5411	2180.0	15.5	8.0	11.0	15.0	49.0	4.4
5412	2220.0	15.0	7.0	10.0	11.0	49.0	4.9
5413	2270.0	28.0	22.0	10.7	10.0	44.0	5.5
5414	2280.0	22.0	11.0	10.5	11.0	46.0	5.7
5417	2150.0	30.0	10.0	10.6	11.0	41.0	4.7
5418	2030.0	17.0	9.0	10.9	14.0	31.0	3.5
5419	2220.0	13.0	6.0	10.8	3.0	29.0	4.1
5420	2300.0	10.0	7.0	10.2	-3.0	34.0	5.2
5421	2277.0	11.5	6.0	10.7	5.0	37.0	4.6
5422	2300.0	10.0	5.0	10.5	10.0	49.0	5.9
5423	2150.0	12.5	4.0	10.6	14.0	44.0	3.4
5424	2280.0	12.5	6.0	10.7	3.0	39.0	5.5
5425	2250.0	17.0	5.0	11.0	5.0	32.0	4.3
5426	2140.0	18.0	8.0	10.8	3.0	36.0	5.1
5427	2083.0	20.0	12.0	10.6	-3.0	18.0	5.5
5429	2270.0	15.4	8.0	11.0	3.0	46.0	6.4
5430	2240.0	10.8	6.0	10.8	3.0	36.0	5.0
5431	2270.0	18.0	5.0	11.6	6.0	44.0	5.4
5432	2220.0	10.7	5.0	10.9	11.0	44.0	3.9
5433	2260.0	10.5	8.0	10.1	-6.0	18.0	4.6
5434	2260.0	10.0	4.0	10.0	1.0	38.0	4.9
5437	2260.0	17.0	6.0	10.8	6.0	52.0	5.8
5438	2280.0	13.0	12.0	10.2	14.0	38.0	4.6
5439	2330.0	26.0	6.0	10.7	6.0	42.0	5.4
5442	2250.0	12.5	5.0	10.5	12.0	40.0	5.2
5443	2190.0	28.0	12.0	10.4	5.0	29.0	3.8
5444	2150.0	10.5	10.0	10.9	-10.0	14.0	5.6
5446	2290.0	10.5	5.0	10.6	6.0	54.0	5.4
5449	2210.0	12.0	7.0	10.5	6.0	31.0	4.5
5450	1930.0	14.0	7.0	11.0	19.0	49.0	1.8
5451	2150.0	12.0	5.0	10.3	7.0	39.0	4.6
5455	2360.0	10.0	6.0	10.6	-4.0	28.0	5.5
5456	2210.0	9.5	7.0	10.6	3.0	27.0	4.5
5457	2270.0	8.5	8.0	10.6	4.0	37.0	4.4
5459	2140.0	9.0	4.0	10.5	10.0	35.0	4.0
5462	2140.0	11.5	4.0	10.0	13.0	46.0	4.0

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5463	2230.0	9.3	4.0	10.8	7.0	38.0	4.5
5466	2130.0	10.0	4.0	11.0	6.0	33.0	4.3
5469	2190.0	14.5	9.0	10.2	4.0	25.0	5.0
5470	2220.0	20.0	8.0	10.0	3.0	36.0	4.0
5471	2250.0	13.5	8.0	11.1	-3.0	24.0	4.3
5477	2150.0	14.0	12.0	10.8	7.0	32.0	4.0
5478	2120.0	11.0	3.0	10.4	8.0	33.0	3.2
5479	2280.0	10.0	4.0	10.5	4.0	29.0	4.3
5490	2260.0	10.5	4.0	10.0	7.0	30.0	3.2
5491	2210.0	14.0	9.0	10.4	15.0	41.0	4.1
5493	2240.0	10.0	4.0	10.0	10.0	39.0	4.6
5495	2130.0	7.7	5.0	10.4	7.0	28.0	3.3
5496	2180.0	12.0	4.0	10.8	1.0	24.0	4.0
5497	2330.0	11.0	4.0	10.8	2.0	41.0	5.7
5499	2210.0	19.0	5.0	10.8	5.0	33.0	4.0
5501	2100.0	10.9	9.0	11.0	12.0	38.0	3.9
5502	2200.0	13.5	6.0	10.8	8.0	33.0	4.2
5504	2100.0	14.0	5.0	11.1	8.0	43.0	4.8
5505	2050.0	20.0	5.0	10.6	10.0	36.0	3.8
5506	2080.0	18.0	6.0	10.9	10.0	40.0	4.3
5508	2200.0	13.0	5.0	10.6	11.0	45.0	4.6
5509	2140.0	11.0	5.0	11.2	2.0	32.0	4.0
5511	2240.0	20.0	4.0	11.0	4.0	42.0	5.2
5512	2220.0	9.5	8.0	10.9	3.0	33.0	4.8
5513	2120.0	10.0	7.0	11.1	9.0	39.0	4.8
5514	2210.0	10.5	4.0	11.0	7.0	43.0	4.8
5515	2200.0	13.5	5.0	10.5	1.0	23.0	3.8
5516	2160.0	12.2	4.0	10.0	12.0	42.0	4.0
5517	2290.0	12.5	7.0	10.5	.0	32.0	4.8
5518	2210.0	13.0	7.0	10.7	5.0	39.0	4.3
5519	2180.0	10.0	7.0	10.6	14.0	44.0	4.8
5521	2190.0	7.0	5.0	10.6	7.0	31.0	3.8
5522	2260.0	15.0	7.0	10.4	5.0	33.0	5.3
5523	2100.0	8.5	6.0	10.2	21.0	51.0	3.6
5524	2120.0	16.0	7.0	10.6	17.0	42.0	4.2
5527	2180.0	18.5	10.0	11.2	11.0	40.0	4.6
5530	2220.0	11.5	7.0	10.8	15.0	46.0	4.4
5531	2290.0	12.0	7.0	11.0	14.0	56.0	5.8
5532	2210.0	7.5	5.0	11.1	13.0	44.0	4.8
5533	2130.0	13.0	5.0	10.7	13.0	40.0	3.2
5535	2130.0	9.6	5.0	11.2	11.0	42.0	4.0
5536	2190.0	8.8	5.0	10.8	12.0	42.0	3.4
5539	2220.0	10.9	9.0	11.0	-2.0	27.0	5.0
5540	2150.0	10.0	7.0	10.8	11.0	36.0	4.0
5541	2130.0	8.0	8.0	10.2	6.0	25.0	3.1
5543	2210.0	11.0	6.0	10.9	7.0	32.0	4.2
5544	2180.0	10.5	5.0	10.4	.0	19.0	3.5
5545	1920.0	18.0	4.0	10.8	17.0	46.0	2.8
5546	1990.0	18.5	3.0	10.5	17.0	46.0	2.1
5548	2030.0	8.0	4.0	10.9	18.0	45.0	3.7

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5549	1930.0	18.6	5.0	11.2	17.0	43.0	2.9
5550	2180.0	25.0	16.0	10.7	2.0	34.0	4.4
5551	1960.0	8.3	6.0	11.0	10.0	31.0	2.7
5553	1960.0	8.0	6.0	10.7	17.0	44.0	3.0
5554	1950.0	23.0	7.0	11.6	21.0	48.0	3.7
5556	2020.0	5.5	4.0	10.7	25.0	52.0	3.1
5557	1950.0	5.5	2.0	10.8	19.0	42.0	2.9
5558	1960.0	5.6	3.0	10.7	13.0	38.0	2.7
5561	1892.0	7.8	12.0	10.6	.0	20.0	4.6
5562	1830.0	12.5	17.0	10.6	10.0	32.0	4.4
5564	1820.0	7.0	12.0	10.6	1.0	19.0	4.1
5565	1942.0	10.0	7.0	10.6	3.0	20.0	4.6
5566	1854.0	8.0	14.0	10.5	4.0	21.0	4.0
5567	1860.0	10.0	12.0	10.9	3.0	17.0	4.6
5568	1724.0	10.0	10.0	10.9	8.0	24.0	3.2
5570	1900.0	15.0	10.0	10.8	-1.0	21.0	4.7
5571	1948.0	10.0	10.0	10.5	4.0	19.0	3.9
5572	1895.0	18.5	8.0	10.7	-2.0	16.0	4.7
5573	1846.0	8.5	15.0	10.9	1.0	23.0	4.6
5574	1945.0	7.0	10.0	10.4	1.0	24.0	4.3
5575	1900.0	10.5	13.0	10.7	3.0	17.0	5.0
5576	1935.0	18.0	10.0	10.0	-2.0	12.0	4.0
5577	1800.0	10.0	10.0	10.6	5.0	17.0	3.4
5579	1974.0	12.0	9.0	10.6	-7.0	12.0	4.5
5580	1852.0	17.0	12.0	11.0	-2.0	18.0	5.3
5581	1822.0	12.5	12.0	10.9	1.0	15.0	4.7
5582	1900.0	10.0	8.0	10.2	6.0	27.0	4.7
5583	1840.0	8.6	11.0	10.3	.0	20.0	4.3
5584	1943.0	10.0	10.0	10.4	3.0	21.0	4.2
5585	1880.0	20.0	12.0	10.4	5.0	28.0	5.1
5586	1736.0	10.0	14.0	10.7	1.0	15.0	4.1
5587	1748.0	10.0	10.0	10.8	7.0	19.0	3.9
5588	1790.0	10.2	10.0	10.5	-7.0	7.0	4.1
5589	1753.0	8.0	10.0	11.3	-5.0	15.0	4.4
5590	1860.0	10.0	9.0	11.0	2.0	20.0	4.7
5593	1791.0	11.0	13.0	11.1	3.0	23.0	4.4
5594	1850.0	7.7	8.0	10.5	2.0	18.0	4.1
5601	2175.0	8.7	15.0	11.3	-11.0	22.0	7.2
5615	1850.0	8.5	10.0	11.0	5.0	25.0	3.8
5616	2042.0	6.0	7.0	10.6	-2.0	19.0	4.4
5619	2050.0	6.0	10.0	10.2	2.0	18.0	3.8
5621	2119.0	6.5	8.0	10.0	4.0	24.0	3.8
5622	2136.0	12.0	12.0	11.5	-14.0	9.0	4.5
5623	2156.0	6.0	10.0	10.8	1.0	16.0	4.2
5624	1930.0	8.0	6.0	10.1	1.0	13.0	4.2
5627	1989.0	17.0	10.0	10.8	3.0	23.0	4.8
5630	1913.0	10.0	18.0	10.8	1.0	16.0	4.5
5631	1770.0	10.0	7.0	11.2	-1.0	16.0	3.8
5635	2125.0	16.0	8.0	10.1	-2.0	24.0	5.2
5640	2086.0	13.0	9.0	10.8	-4.0	19.0	4.8

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
5642	2098.0	9.5	8.0	10.7	-2.0	30.0	5.6
5643	1974.0	10.0	8.0	10.6	-5.0	16.0	4.5
5645	2167.0	10.0	9.0	10.2	.0	39.0	7.0
5646	2094.0	17.0	8.0	10.4	5.0	28.0	5.6
5648	1964.0	12.5	8.0	10.8	.0	18.0	4.5
5649	2096.0	18.5	6.0	11.2	4.0	30.0	5.0
5650	2032.0	12.8	8.0	10.5	-1.0	26.0	4.9
5651	1989.0	15.0	8.0	11.0	-2.0	17.0	4.7
5654	2110.0	8.5	7.0	10.9	-11.0	18.0	5.6
5655	1785.0	10.0	9.0	10.2	2.0	19.0	3.8
5656	1750.0	10.5	6.0	11.0	-12.0	-21.0	3.0
5657	1805.0	6.0	10.0	10.0	6.0	26.0	3.2
5658	1760.0	10.0	8.0	10.1	7.0	27.0	4.4
5659	1870.0	18.0	10.0	11.2	4.0	29.0	5.1
5660	1720.0	16.5	6.0	11.1	2.0	22.0	4.2
5661	1730.0	16.7	9.0	10.6	-12.0	-16.0	3.0
5662	1712.0	8.5	9.0	10.3	1.0	17.0	3.2
5663	1810.0	13.5	13.0	10.7	-8.0	-14.0	3.0
5664	1779.0	14.0	9.0	10.9	-2.0	18.0	4.1
5665	1660.0	16.5	10.0	10.9	-20.0	-21.0	3.0
5666	1700.0	18.0	5.0	10.2	-9.0	-17.0	3.0
5667	1680.0	18.0	14.0	10.4	1.0	22.0	3.5
5671	1790.0	17.5	7.0	10.7	9.0	34.0	4.9
5673	1820.0	11.0	8.0	10.8	-12.0	-24.0	3.0
5674	1810.0	14.0	6.0	10.6	-1.0	19.0	3.7
5679	1850.0	8.5	4.0	10.2	-11.0	-1.0	2.3
5682	1900.0	13.4	5.0	11.0	-6.0	10.0	4.2
5686	1750.0	15.0	5.0	11.1	11.0	32.0	3.9
5690	1720.0	17.0	6.0	11.0	.0	18.0	3.4
5695	1720.0	10.5	6.0	10.1	4.0	19.0	2.9
5696	1850.0	10.0	4.0	10.8	9.0	32.0	4.0
5698	1810.0	14.5	6.0	10.1	-1.0	22.0	4.7
5702	1750.0	10.0	8.0	10.1	-15.0	-22.0	3.0
5703	1750.0	15.0	4.0	10.6	-2.0	14.0	2.9
5705	1800.0	17.0	5.0	10.6	.0	13.0	3.2
5710	1880.0	10.0	4.0	10.0	6.0	22.0	3.3
5712	1760.0	22.0	6.0	10.0	.0	19.0	4.2
5713	1910.0	10.0	3.0	10.0	2.0	27.0	3.2
5719	1990.0	10.0	5.0	11.5	-16.0	.0	3.7
5721	2000.0	7.4	4.0	11.0	-11.0	8.0	4.5
5723	2000.0	10.5	5.0	10.8	-13.0	5.0	4.5
5724	1910.0	10.5	4.0	11.1	1.0	24.0	4.6
5728	1950.0	11.5	5.0	11.4	-3.0	12.0	4.5
5729	1970.0	9.5	6.0	11.2	-1.0	14.0	4.3
5731	2120.0	7.2	7.0	10.7	-4.0	15.0	4.2
5732	1990.0	7.0	5.0	11.1	4.0	27.0	4.7
5733	2060.0	9.5	6.0	11.0	-3.0	15.0	5.0

Table 3: XP2262 photomultiplier characteristics as measured by Philips Components and CEBAF. Each column is labeled by the PMT serial number (SN), voltage (Hi-V) used for measurements at CEBAF, dark current measured by Philips (DCman), dark current measured at CEBAF (DCExp), corning blue sensitivity measured at the factory (CB), time of LED 4 (Delta1) and 5 (Delta2) relative to LED 3 in counts (23 counts/ns), and pulse height in volts.

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
22671	1600.0	5440.0	3.0	11.3	-3.0	6.0	3.0
22770	1610.0	4719.0	4.0	11.5	-5.0	1.0	3.0
22775	1630.0	4089.0	4.0	11.5	-3.0	8.0	3.0
22776	1690.0	4722.0	5.0	11.2	.0	7.0	3.0
22778	1660.0	2186.0	4.0	11.5	-3.0	6.0	3.0
22786	1640.0	3846.0	3.0	11.0	-1.0	6.0	3.0
22787	1630.0	2805.0	4.0	11.6	1.0	10.0	3.0
22790	1650.0	1989.0	3.0	11.1	1.0	8.0	3.0
22791	1630.0	3848.0	3.0	11.5	-4.0	4.0	3.0
22792	1560.0	4004.0	5.0	11.1	-1.0	1.0	3.0
22793	1570.0	3632.0	5.0	11.6	-3.0	5.0	3.0
22795	1590.0	3525.0	3.0	11.4	-1.0	9.0	3.0
22796	1650.0	2370.0	2.0	11.5	-1.0	5.0	3.0
22799	1560.0	3812.0	2.0	11.6	-5.0	2.0	3.0
22803	1630.0	2135.0	3.0	11.1	-1.0	4.0	3.0
22804	1610.0	2826.0	3.0	11.3	-6.0	.0	3.0
22810	1610.0	1835.0	3.0	11.5	-4.0	4.0	3.0
22811	1610.0	5425.0	4.0	11.5	-2.0	4.0	3.0
22812	1560.0	2370.0	4.0	11.7	-2.0	6.0	3.0
22819	1640.0	3415.0	3.0	11.6	-1.0	1.0	3.0
22823	1610.0	5416.0	3.0	11.3	-1.0	5.0	3.0
22824	1620.0	4076.0	4.0	11.6	-3.0	4.0	3.0
22825	1630.0	2168.0	4.0	11.3	-4.0	3.0	3.0
22826	1630.0	2702.0	2.0	11.0	-1.0	6.0	3.0
22828	1700.0	4507.0	4.0	12.0	-2.0	9.0	3.0
22832	1650.0	2509.0	2.0	11.8	-4.0	3.0	3.0
22838	1670.0	4567.0	2.0	11.6	-4.0	7.0	3.0
22850	1650.0	2141.0	4.0	11.3	.0	10.0	3.0
22860	1680.0	5762.0	2.0	11.0	-3.0	.0	3.0
22868	1610.0	5975.0	3.0	11.7	-4.0	5.0	3.0

SN	Hi-V	DCMan	DCExp	CB	Delta1	Delta2	Pulse
22878	1640.0	2209.0	4.0	11.5	-4.0	6.0	3.0
22888	1580.0	2044.0	4.0	12.0	-1.0	11.0	3.0
22931	1640.0	4171.0	3.0	12.6	-3.0	3.0	3.0
22937	1640.0	3818.0	3.0	12.6	-4.0	.0	3.0
22938	1620.0	2039.0	4.0	12.8	-2.0	5.0	3.0
22939	1640.0	4728.0	4.0	12.6	-3.0	5.0	3.0
22941	1640.0	1662.0	4.0	12.4	-3.0	-1.0	3.0
22942	1680.0	5529.0	3.0	12.4	-1.0	7.0	3.0
22944	1630.0	5413.0	1.0	12.4	-4.0	4.0	3.0
22946	.0	5182.0	5.0	12.8	-3.0	5.0	3.0
22947	1600.0	3360.0	2.0	12.5	-3.0	3.0	3.0
22948	1580.0	4574.0	4.0	12.5	-4.0	3.0	3.0
22949	1600.0	3395.0	2.0	12.7	-2.0	5.0	3.0
22951	1660.0	2189.0	4.0	12.3	-4.0	3.0	3.0
22954	1630.0	5671.0	6.0	13.0	-5.0	3.0	3.0
22955	1600.0	4775.0	3.0	13.1	-2.0	6.0	3.0
22956	1660.0	4045.0	3.0	12.1	-4.0	3.0	3.0
22957	1660.0	5980.0	2.0	12.5	-4.0	3.0	3.0
22959	1660.0	1956.0	1.0	12.0	-4.0	3.0	3.0
22961	1710.0	3635.0	3.0	11.8	-1.0	7.0	3.0
22964	1650.0	4659.0	1.0	12.1	-5.0	1.0	3.0
22965	1640.0	4123.0	2.0	12.1	.0	6.0	3.0
22968	1660.0	1828.0	5.0	11.6	1.0	7.0	3.0
22970	1610.0	5225.0	3.0	12.9	-2.0	7.0	3.0
23840	1610.0	5430.0	4.0	11.8	-1.0	6.0	3.0
23848	1670.0	.0	4.0	.0	-4.0	2.0	3.0
23858	1680.0	3572.0	4.0	12.5	-3.0	7.0	3.0
23860	1680.0	4921.0	5.0	11.0	-7.0	3.0	2.4
23891	1570.0	5359.0	4.0	12.9	-2.0	6.0	3.0
23892	1640.0	2497.0	3.0	12.7	-1.0	7.0	3.0
23902	1670.0	2958.0	3.0	12.6	-2.0	6.0	3.0
23904	1600.0	.0	2.0	.0	-3.0	7.0	2.8
23905	1620.0	1425.0	3.0	12.1	-1.0	7.0	3.0
23906	1630.0	2295.0	12.0	12.3	.0	9.0	3.0
24600	1650.0	4590.0	4.0	11.0	-4.0	6.0	3.0
24624	1600.0	2313.0	4.0	11.2	-4.0	6.0	3.0
24636	1640.0	1496.0	2.0	12.4	-1.0	9.0	3.0

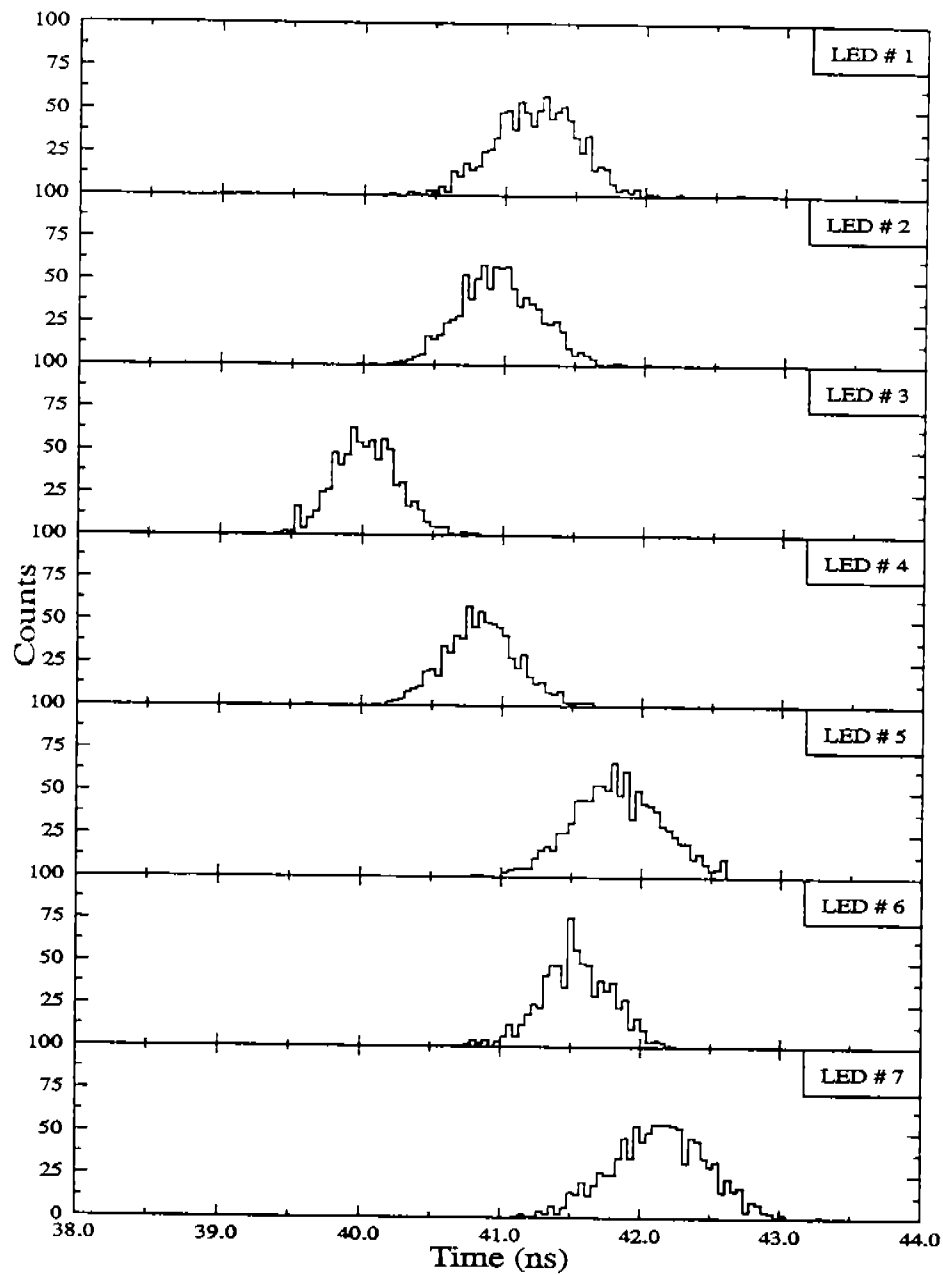


Figure 1: The measured time distribution is plotted for each LED corresponding to a fixed position along the face of the PMT. The width of the distributions is due to the jitter of the firing of the LED relative to the trigger pulse. The shift in the centroid reflects the transit time differences across the face of the XP4312B PMT.

TOF Large-Angle PMT XP4312B

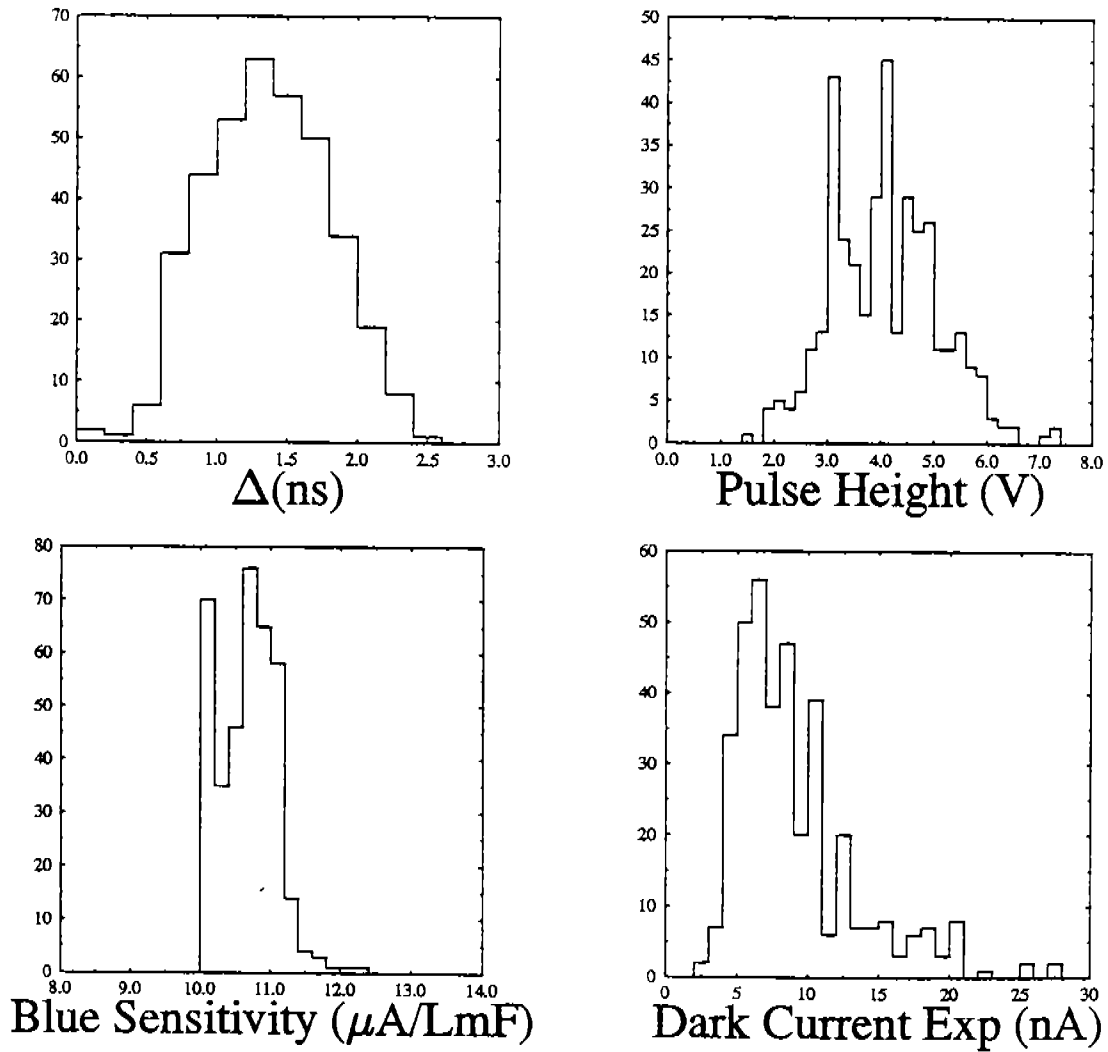


Figure 2: Distribution of XP4312B characteristics. The transit time variation Δ , dark current and range of pulse heights for the CEBAF measurements. The corning blue sensitivity is from the PMT test ticket.

TOF Large-Angle PMT XP2262

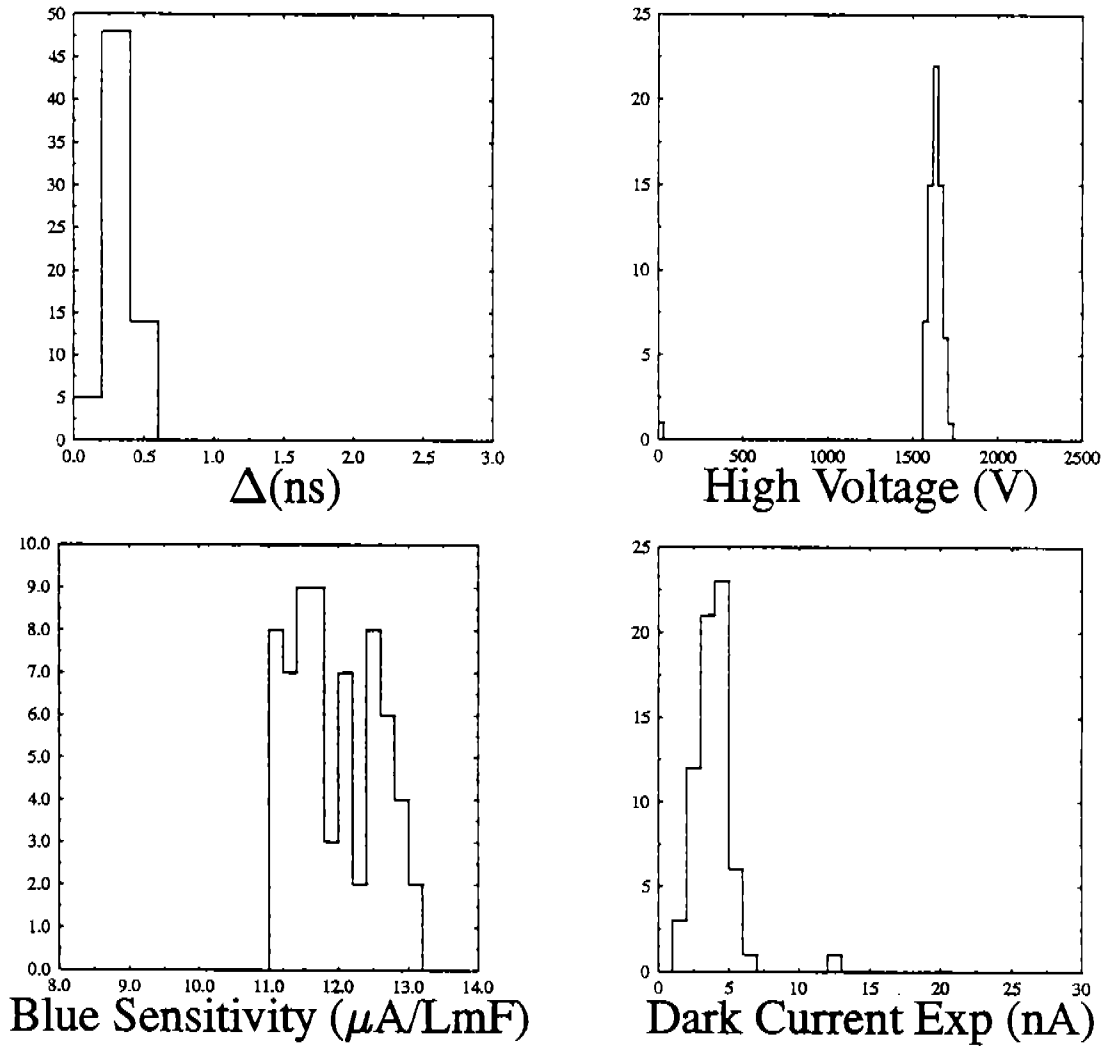


Figure 3: Distribution of XP2262 characteristics. The transit time variation Δ , dark current and range of pulse heights for the CEBAF measurements. The corning blue sensitivity is from the PMT test ticket.

Cathode-Grid Voltage for XP4312B

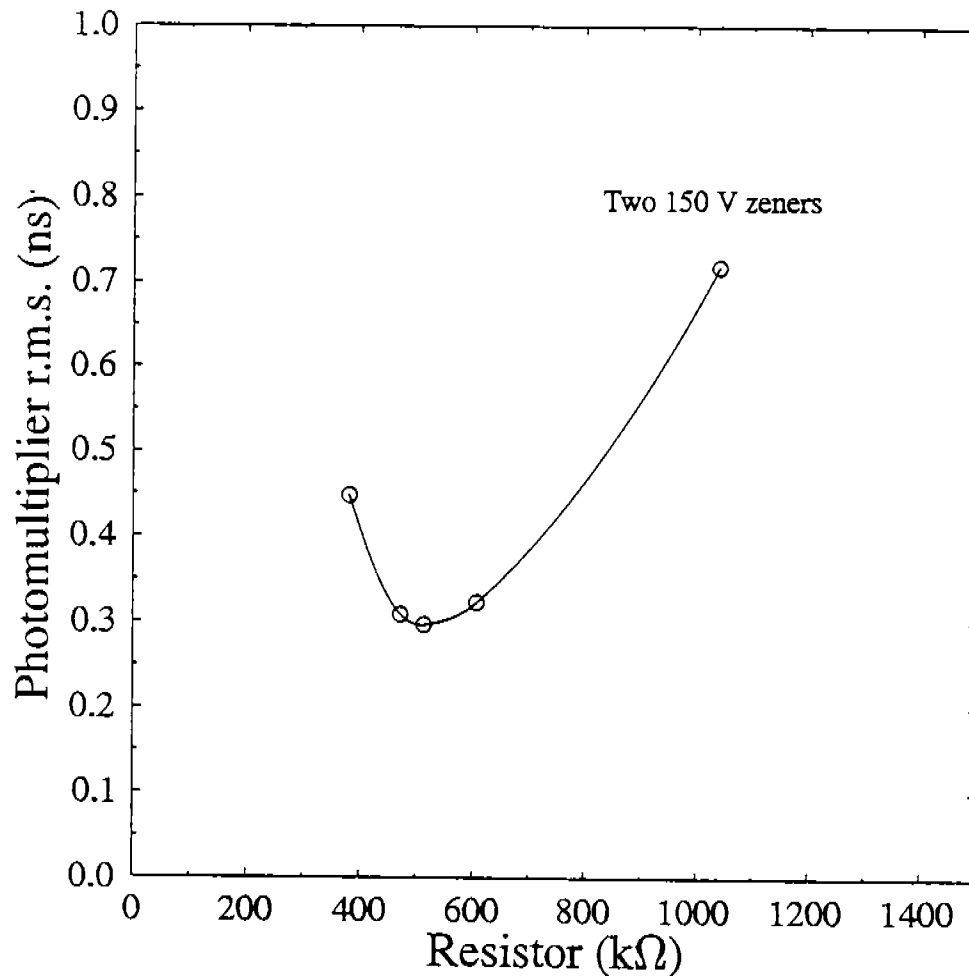


Figure 4: The inferred time dispersion averaged of the entire PMT face is plotted against the resistor value between the cathode and the grid. Two 150 V zener diodes are plotted at the corresponding resistor value to produce 300 volts between the cathode and the grid. The optimum resolution is obtained for a resistor value of 500 $k\Omega$.