Update on Development of ETEL/ADIT 11” HQE PMTs

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ET Enterprises electron tubes ADIT

ET Enterprises manufactures and supplies the Electron Tubes brand of photomultipliers that were previously made by EMI Electronics, **Thorn EMI** Electronics and Electron Tubes Ltd. ET Enterprises is now a subsidiary of Ludlam Measurements (Texas, USA), including their PMT production facility of ADIT in Sweetwater Texas.

Benefits:

Additional vendor in the marketplace
- price competition
- additional capacity

Purchase from U.S. will be viewed more favorably if a U.S. vendor participates

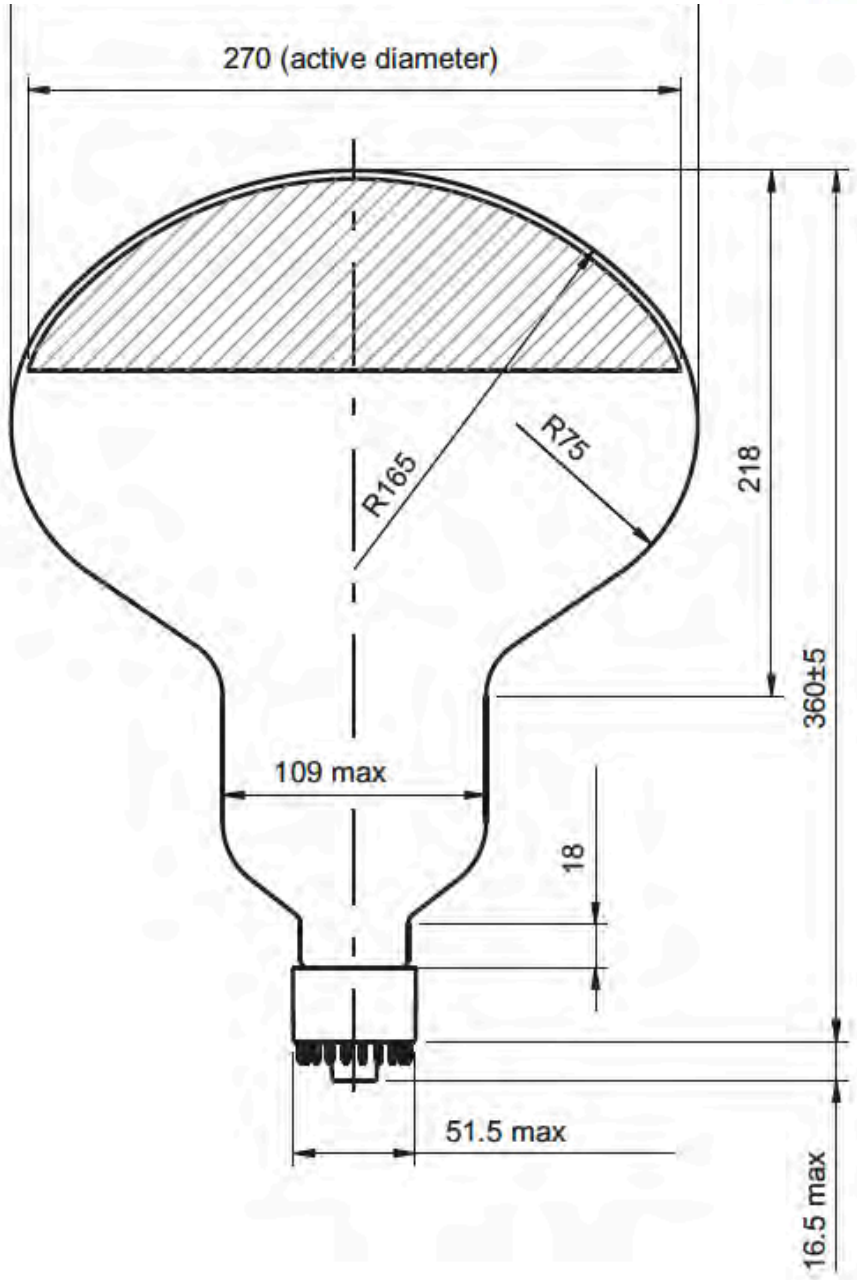
An NSF award under the S4 program was granted to develop PMTs for the WCD option of LBNE. This award funds production of 20 11-inch HQE PMTs.

Initial production is in the U.K., a large future order would be produced in the U.S.

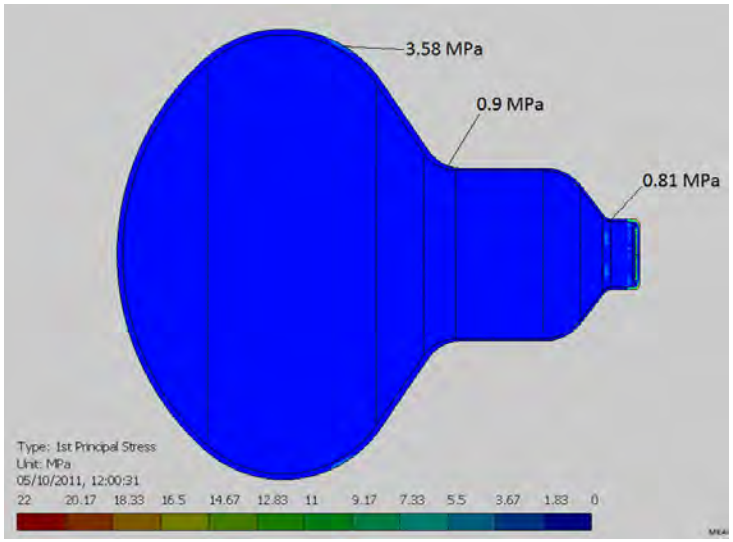
280 mm (11″) photomultiplier
D784KFLB provisional data sheet

ET Enterprises electron tubes

	unit	min	typ	max
photocathode: bialkali				
active diameter	mm		270	
active surface area	cm^2		800	
quantum efficiency at peak	%		30	
luminous sensitivity	µA/lm		70	
with CB filter		8	12	
with CR filter			1	
dynodes: 12LFSbCs				
anode sensitivity in divider A:				
nominal anode sensitivity	A/lm		500	
max. rated anode sensitivity	A/lm		2000	
overall V for nominal A/lm	V		1400	1800
overall V for max. rated A/lm	V		1550	
gain at nominal A/lm	$x\ 10^6$		7	
dark current at 20 °C:				
dc at nominal A/lm	nA		20	200
dc at max. rated A/lm	nA		80	
dark count rate	s^{-1}		20000	
pulsed linearity (-5% deviation):				
divider A	mA		30	
divider B	mA		100	
pulse height resolution:				
single electron peak to valley	ratio		2	
rate effect (I_a for $\Delta g/g$=1%):	µA		20	
temperature coefficient:	% $°C^{-1}$		± 0.5	
timing:				
single electron rise time	ns		5	
single electron fwhm	ns		6	
single electron jitter (fwhm)	ns		3	
transit time	ns		62	
weight:	g		2600	
maximum ratings:				
anode current	µA			100
cathode current	nA			2000
gain	$x\ 10^6$			30
sensitivity	A/lm			2000
temperature	°C	-30		60
V (k-a)[1]	V			2350
V (k-d1)	V			750
V (d-d)[2]	V			300
ambient pressure (absolute)	kPa			808



Strength against hydrostatic pressure:



Glass	8250 & 8246
Young's Modulus	70 GPa
Poisson's ratio	0.21
Pressure Difference Inside / Outside	**11 bar**

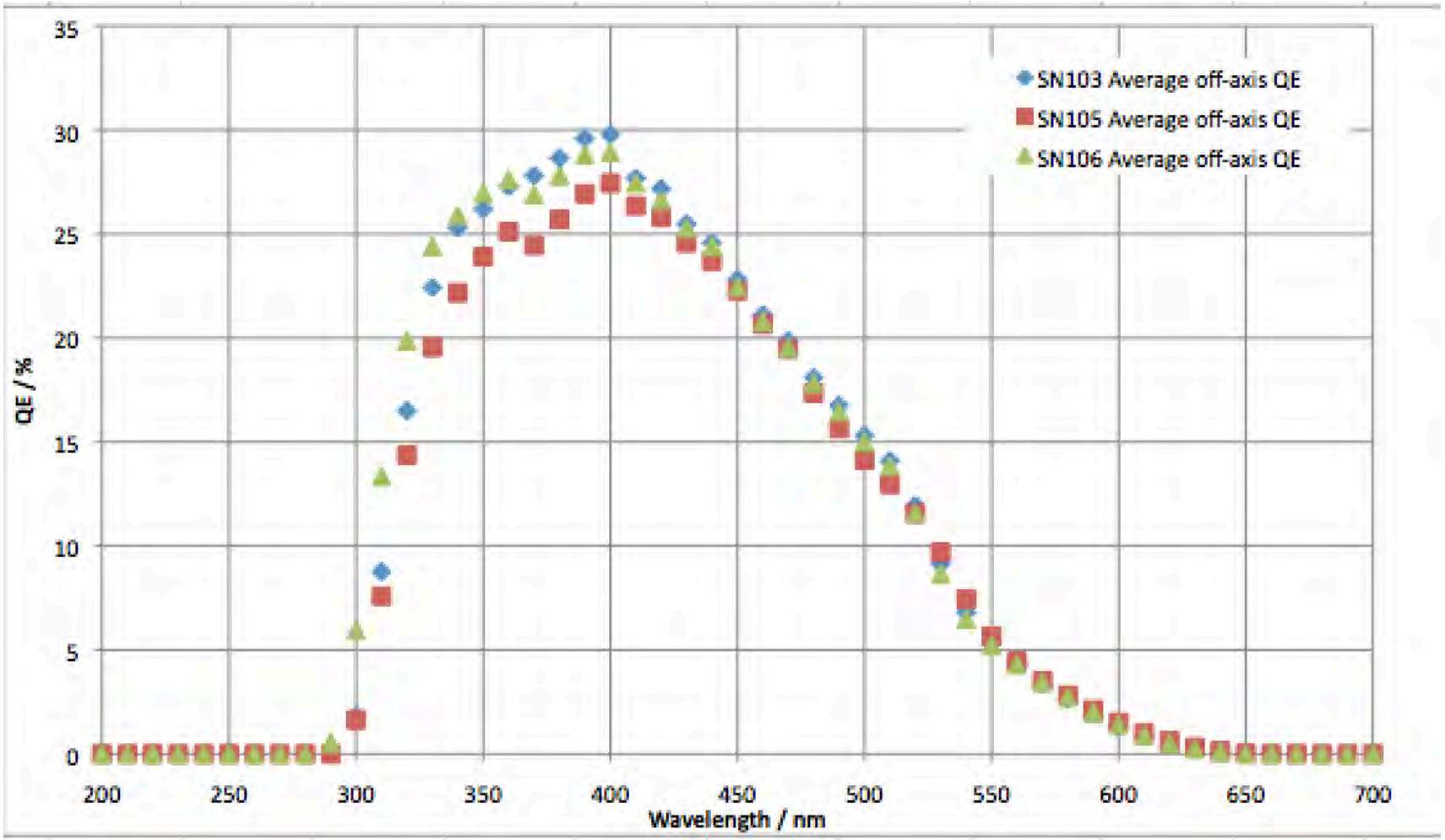
Radioactivity of the glass:

Schott 8246	Concentration
Natural potassium	60 ppm
Thorium	30 ppb
Uranium	30 ppb

Glass thickness	Expected mass (g)	Gamma rate (Bq)* (60ppm K, 30ppb Th, 30ppb U)
Maximum	2,218	3.2 ± 1.7
Minimum	1,482	2.2 ± 1.1

data from Electron Tubes

Preliminary results: QE of first 3 PMT's

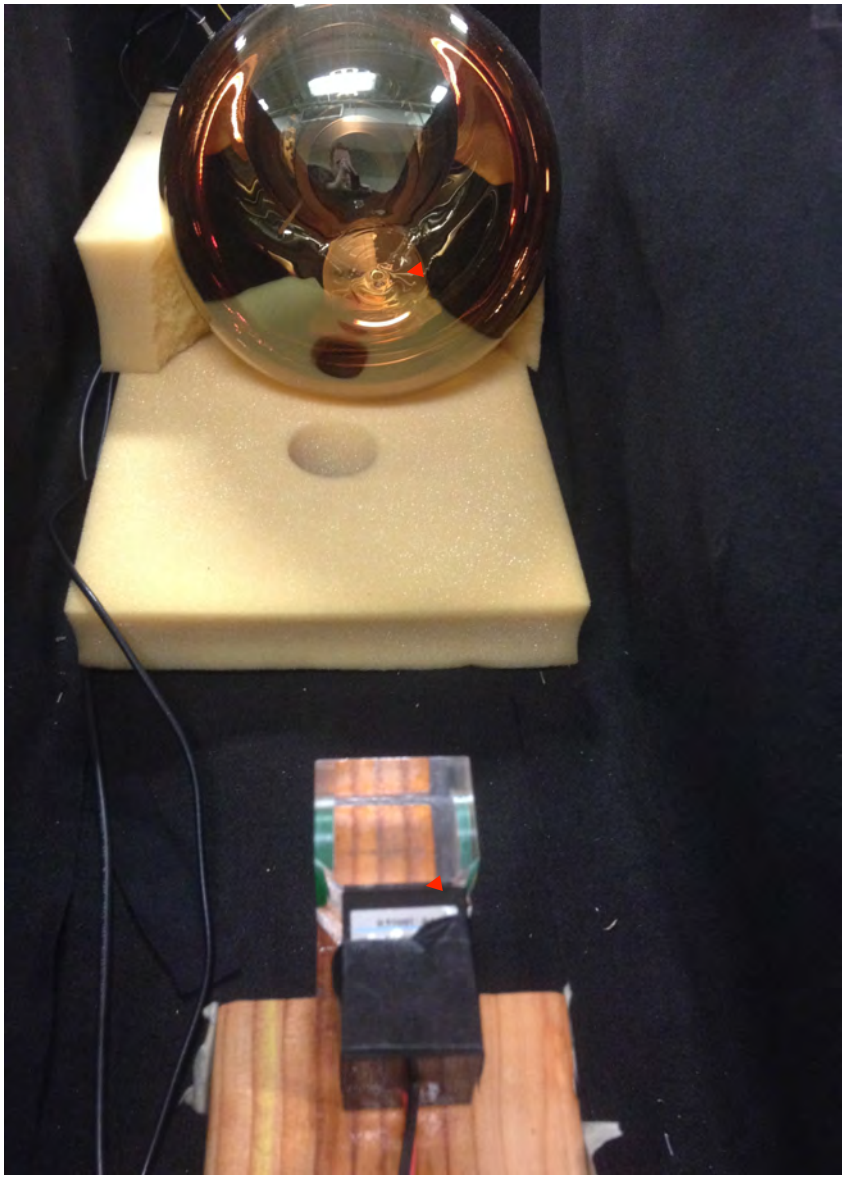


data from Electron Tubes

Testing at U. Pennsylvania – Tanner Kaptanoglu

Single Photoelectron Characterization Set-up

- Two Sr^{90} sources embedded into UVT acrylic
- Sr^{90} undergoes 0.546 MeV beta decay with a half life of 29.1 years
- Y^{90} daughter undergoes 2.28 MeV beta decay, creating Cherenkov light when it travels through the acrylic
- 1 inch R7600 Hamamatsu PMT is optically coupled to the acrylic and used as a fast (~250ps FWHM) trigger
- Source is placed in magnetic shielded dark box 50cm from the PMT for testing

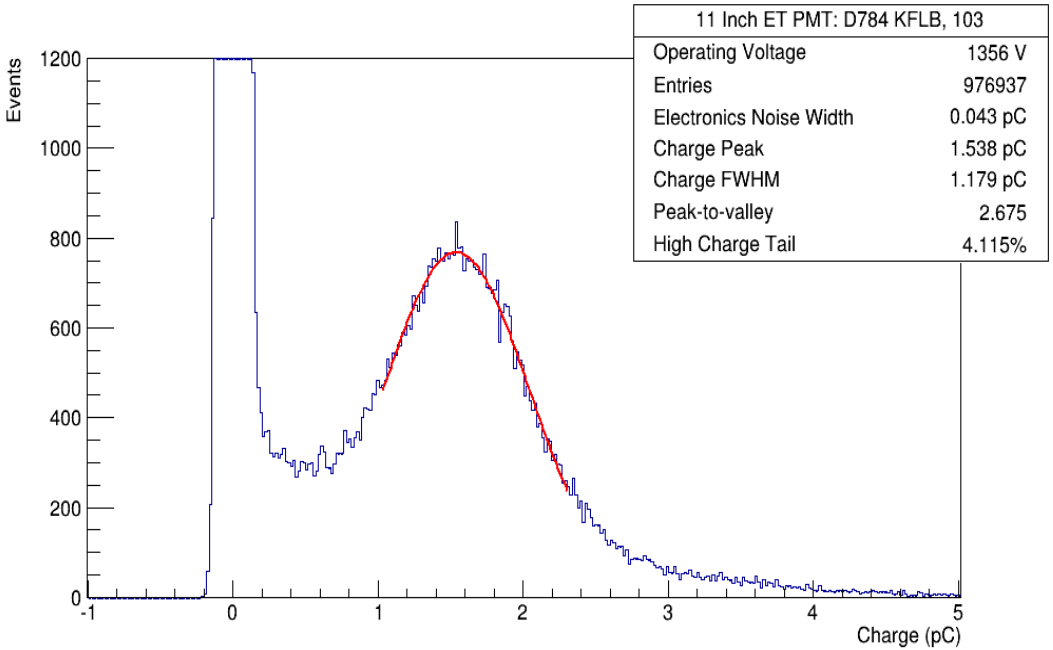


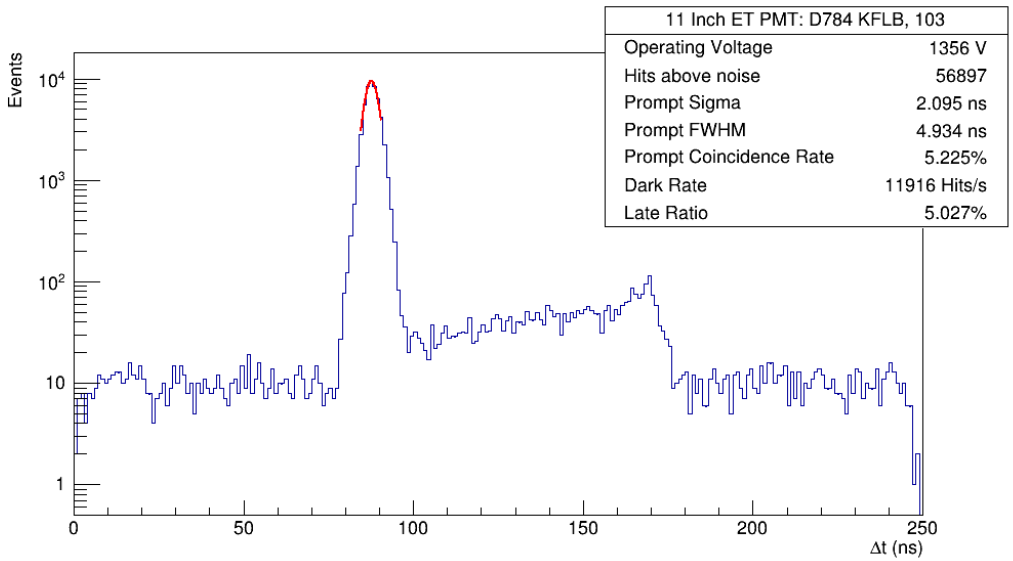
Brown swirl spot on front face of the ET PMT

Trigger PMT coupled to Cherenkov source

11 inch ET PMTs: Single Photoelectron Charge and Timing

- Charge and timing data taken for eight 11 inch ET PMTs
- High voltage set for gain of 10^7 → SPE charge peak ~1.6pC
- Time found between peak of the trigger pulse and 20% the height the the peak of the ET pulse
- Transit time spread found by fitting Gaussian to peak corresponding to coincidence events
- Late Pulsing caused by scattering of the photoelectron off the first dynode





Tanner Kaptanoglu

Data for eight 11 inch ET PMTs

Serial #	Charge FWHM (pC)	Peak/ Valley	High Charge Tail (%)	Transit Time Spread (ns)	Late Pulse (%)	Operating Voltage (V)
102	1.144	2.955	3.335	2.471	5.005	1203
103	1.179	2.675	4.115	2.095	5.027	1356
105	1.292	2.295	3.354	2.002	5.442	1224
118	1.107	2.841	5.307	2.023	4.814	1255
120	1.264	2.170	4.017	2.068	4.049	1470
124	1.215	3.683	5.112	2.122	5.763	1280
128	1.327	2.841	5.129	2.028	5.116	1245
129	1.159	1.414	2.915	1.814	5.338	1244

11 inch ET PMTs: Single Photoelectron Charge and Timing

Table shows results for the 8 ET tubes against the results found for 12 inch Hamamatsu high (HQE) and standard (EQE) quantum efficiency tubes (Hamamatsu tube measurements done by Sean Grullon*)

*Grullon et al., http://arxiv.org/abs/1210.2765 (2013)

12-Inch EQE	Average	Standard Deviation	Minimum	Maximum
Charge FWHM (pC)	1.42	0.4	1.18	2.32
Peak/Valley	2.8	0.28	2.3	3.0
High Charge Tail (%)	2.86	0.84	2.5	4.94
Transit Time Spread (ns)	1.37	0.15	1.2	1.6
Late Pulses (%)	4.48	0.32	3.93	4.92
Operating Voltage (V)	1848	75	1740	1920

ETL 11" is 12 stage Hamamatsu 12" is 10 stage

12-Inch HQE	Average	Standard Deviation	Minimum	Maximum
Charge FWHM (pC)	1.64	0.62	1.19	3.36
Peak/Valley	2.24	0.27	1.78	2.76
High Charge Tail (%)	3.75	0.66	2.73	5.2
Transit Time Spread (ns)	1.29	0.14	1.16	1.52
Late Pulses (%)	4.3	0.35	3.6	4.8
Operating Voltage (V)	1950	221	1750	1920

Peak to valley looks good

11-Inch ET	Average	Standard Deviation	Minimum	Maximum
Charge FWHM (pC)	1.21	0.07	1.11	1.33
Peak/Valley	2.61	0.62	1.41	3.68
High Charge Tail (%)	4.16	0.87	2.92	5.31
Transit Time Spread (ns)	2.08	0.17	1.81	2.47
Late Pulses (%)	5.07	0.48	4.05	5.76
Operating Voltage (V)	1285	82	1203	1576

Transit time spread 60% larger than HQE Hamamatsu PMTs

Low operating voltage

Future Plans

- Receive second and final batch of 10 more 11”-PMTs from Electron Tubes (March 2015)
- Improve timing resolution by altering HV divider on PMT base
- Relative efficiency tests comparing ET-PMTs to Hamamatsu PMTs
- 2D scan across face of PMT - correct for “swirl” in glass bulb
- Magnetic field sensitivity (U.C. Davis)

After full testing and characterization of 20 PMTs, they will be available for long-term deployment. We would like to propose operating 2-4 11”-PMTs in the EGADs tank along side the other Hyper-K prototype PMTs.