11” and 12” PMT R&D

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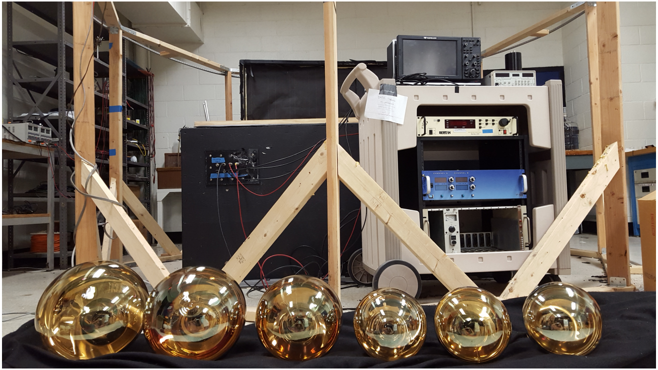
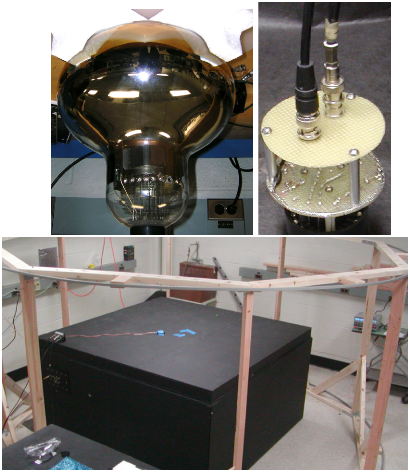
Introduction



- Large area, high efficiency photomultiplier tubes are excellent candidates for future optical detectors
- Two types of 12” Hamamatsu PMTs (R11780) characterized
- New 11” PMTs from ET Enterprises characterized

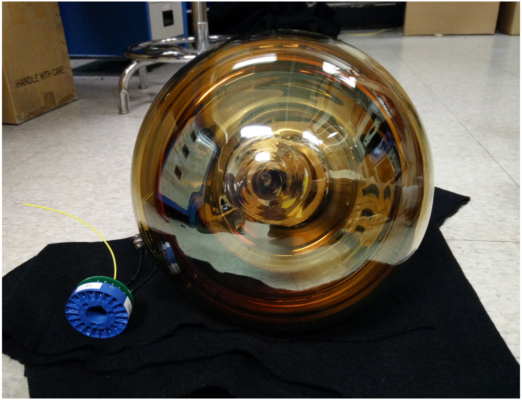
Hamamtasu R11780 12” PMT

- 12” diameter photocathode and 10 linear focused dynode stages
- Two sets of PMTs: ‘enhanced quantum efficiency’ (EQE) and ‘high quantum efficiency’ (HQE)
- EQE (HQE) PMTs expected QE peak of 21% (32%) at 390nm
- Grullon, et al. http://arxiv.org/abs/1210.2765



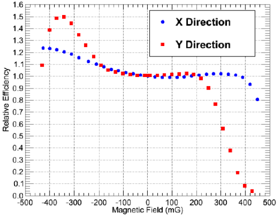
ET 11” PMT

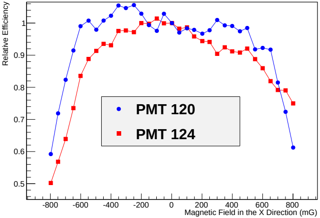
- ET Enterprises is now a subsidiary of Ludlam Measurements (USA) including their PMT production facility of ADIT in Sweetwater Texas
- Benefits: Price competition, additional capacity, purchase from the USA will be viewed more favorably if a US vendor participates
- Noticeable ‘swirly’ spot on the front face of the PMT, suspected to effect the efficiency
- 11” diameter photocathode and 12 linear focused dynode stages
- Expected peak QE of $\sim$30% at 390nm



Magnetic Field Testing

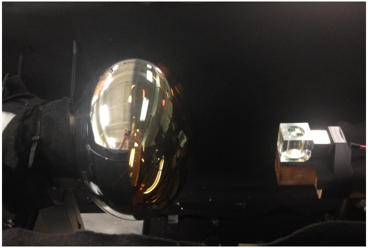
- Electron focusing capabilities are affected by magnetic fields
- Three pairs of 1 m^2 copper Helmholtz coils separated by 1m, capable of producing uniform fields up to 800 mG
- Entire PMT face illuminated by green LED
- Relative charge compared to to zero field measurement
- Measurements performed at UC Davis by Bob Svoboda, et al.

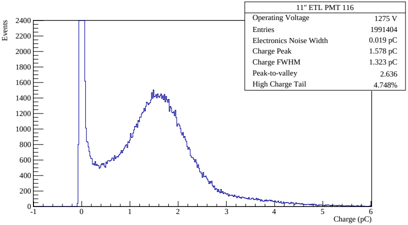




Single PE Characterization: Charge

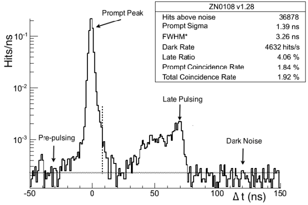
- PMTs in large scale water or scintillator detectors often detect no more than a couple of photons per event
- Fast ($\sim$250ps FWHM) ‘trigger’ PMT optically coupled to acrylic cube embedded with a Sr90 beta source
- Coincidence rate between the trigger and ‘measurement’ PMT kept below 5% in order to reduce multi-PE contamination
- High voltage set so that the gain is 10^7 corresponding to charge peak of 1.6pC
- Measurements taken in darkbox with magnetic shielding

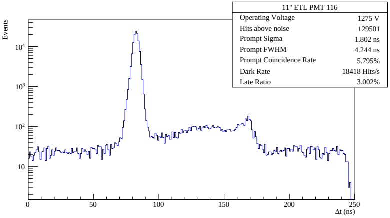




Single PE Characterization: Timing

- Timing spectrum characterized by:
  - spread in the transit time
  - late pulsing
  - double pulsing
  - pre-pulsing
  - dark noise
- Transit time spread found by fitting a Gaussian to the peak
- Late pulsing, caused by scattering of photoelectron of the first dynode, characterized as percent of the coincidence pulses
- Dark noise rate for R11780 is $\sim$4 kHz, yet to carefully characterize ET PMT dark noise rate





SPE Comparison

11-Inch ET	Average	Standard Deviation	Minimum	Maximum
Charge FWHM (pC)	1.44	0.40	1.11	2.73
Peak/Valley	2.32	0.67	1.15	3.68
High Charge Tail (%)	3.86	1.28	0.921	5.71
TTS (ns)	1.98	0.17	1.79	2.47
Late Ratio	4.51	0.74	3.0	5.76
Operating Voltage (V)	1330	117	1183	1575

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
TTS (ns)	1.37	0.15	1.20	1.6
Late Ratio (%)	4.48	0.32	3.93	4.92
Operating Voltage (V)	1840	75	1740	1920

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
TTS (ns)	1.29	0.14	1.16	1.52
Late Ratio (%)	4.3	0.35	3.6	4.8
Operating Voltage (V)	1950	221	1750	2500

2D Scan

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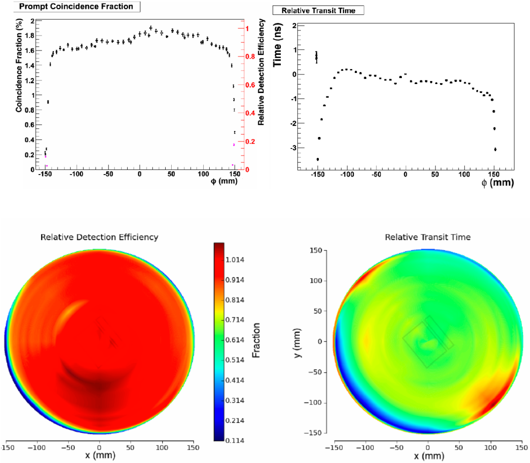
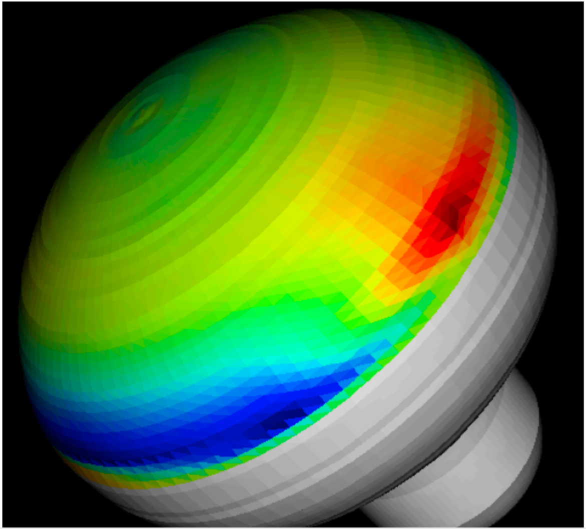
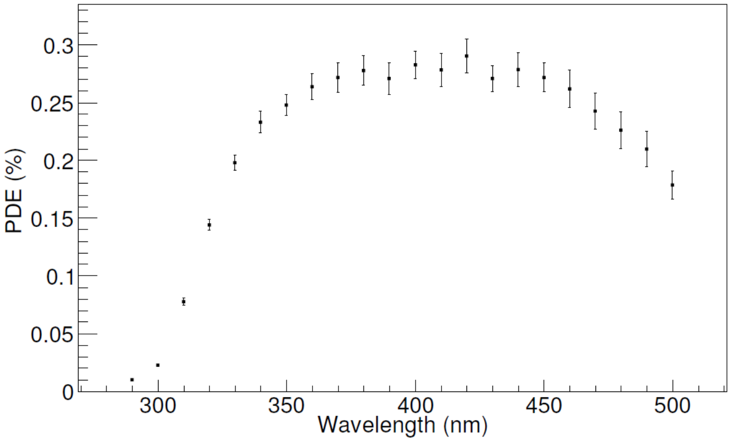
- Angular and position dependence in the detection efficiency and transit time are caused by:
  - optics of the glass
  - transmission and absorption of the photocathode
  - different electron optics between the photocathode and first dynode
- A collimated Cherenkov source on a scanning arm was used to probe these effects
- Hamamatsu produced five prototype R11780s with alternative dynode structure that mitigated the transit time shift along the edge of the PMT



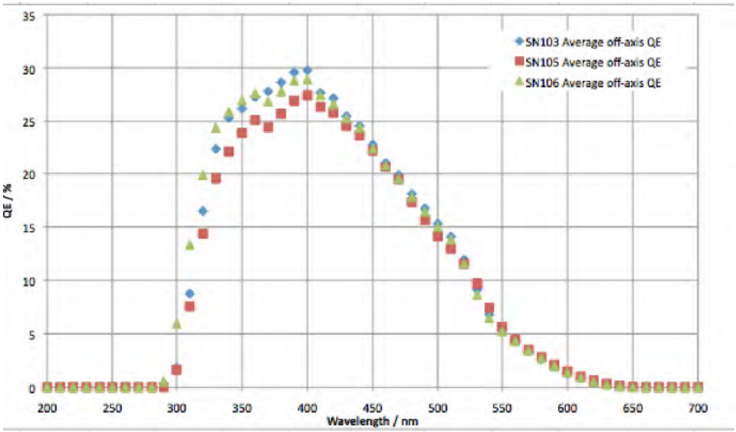
2D Scan



Particle Detection Efficiency: R11780

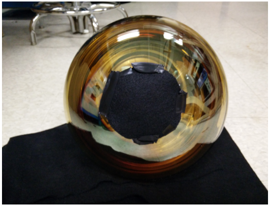


Quantum Efficiency: ET PMT



Relative Detection Efficiency

- Directly compare the detection efficiency of the ET PMT, the EQE R11780, and HQE R11780 by placing them in the same setup and comparing coincidence rates
- Detection efficiency of HQE R11780 was found to be on average 32% higher than the EQE PMTs
- Coincidence rates scaled for the size of the PMT, swirly spot of the ET PMT felted
- Coincidence rate of three ET PMTs similar to 12 and 10 inch HQE PMTs



PMT Type	Coincidence Rate
12" Hamamatsu HQE PMT	3.42%
10" Hamamatsu HQE PMT	3.46%
11" ET PMT (134)	3.01%
11" ET PMT (105)	3.31%
11" ET PMT (142)	3.63%
8" SNO PMT	1.83%

Conclusions

- Introduction of the ET PMTs brings new USA vendor to the market
- Magnetic field effects on the PMTs have been characterized
- Single photoelectron charge and timing characterized
- R11780 PMTs most notably have a narrower transit time spread. Additional improvements are possible
- 2D scan of R11780 PMT showed noticeable timing shifts along the edge of the PMT, which Hamamatsu resolved by using an alternative dynode structure
- Efficiency of the ET Tube and HQE R11780 are similar up to ‘swirly’ spot on ET PMT, which they are working on fixing
- These large area PMTs are excellent candidates for large scale water Cherenkov or liquid scintillator detectors