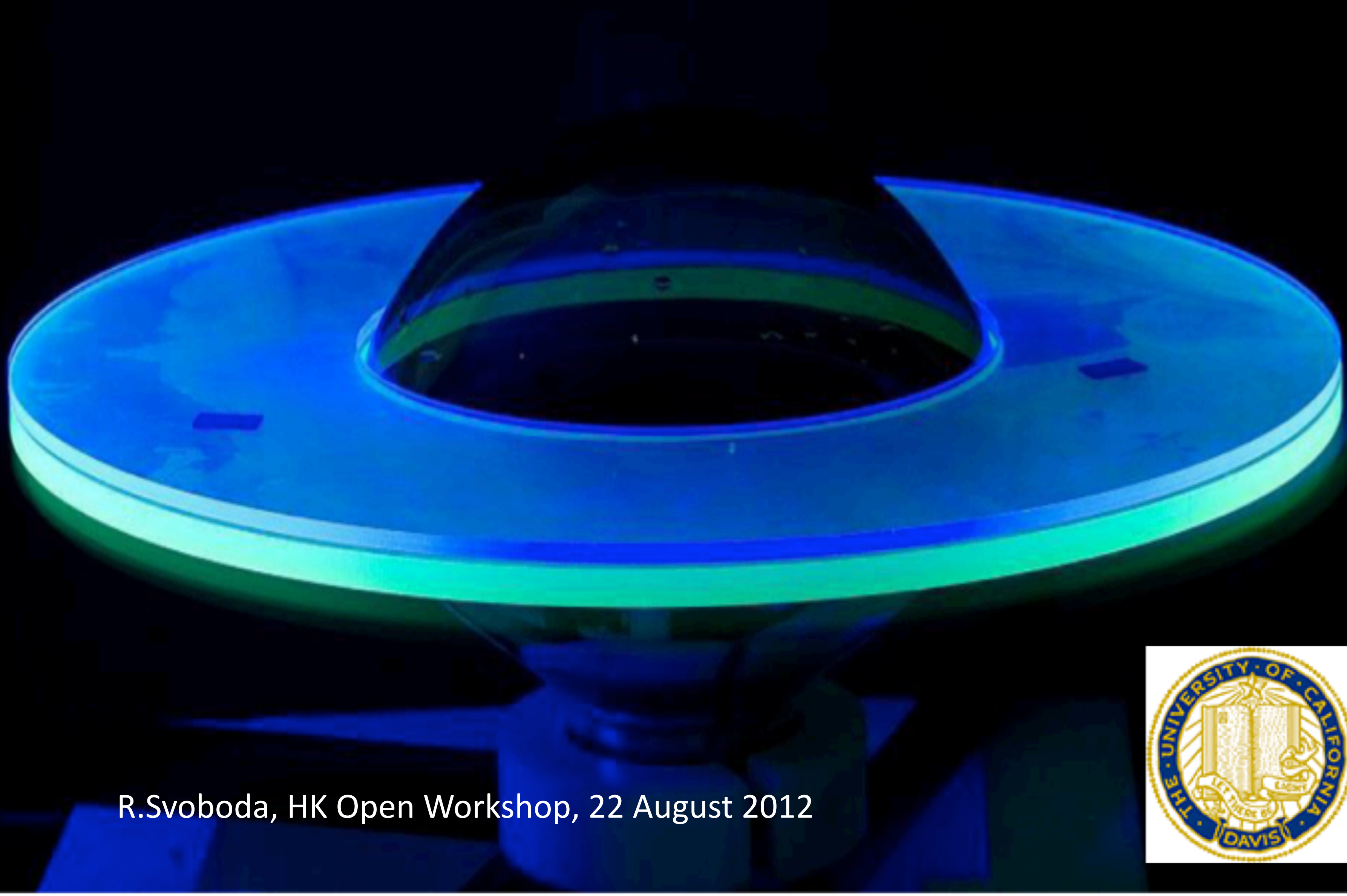
Work on Light Sensors in U.S.



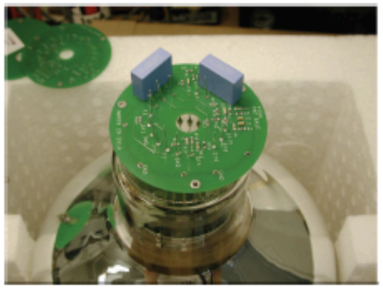
R.Svoboda, HK Open Workshop, 22 August 2012

Scope of work in U.S.

- Evaluation of Hamamatsu 10 and 12 inch High Quantum Efficiency (HQE) PMTs and ETL 8" 9354KB
- Measurement of magnetic field effects and compensation concepts
- Development and evaluation of three concepts for external light collectors
- Work with ADIT/ETL to develop an 11 inch HQE PMT
- Mechanical testing of PMTs
- Future plans

Institutions: Brookhaven, Caltech, Colorado State, UC Davis, Duke, Drexel, Fermilab, Penn, Wisconsin

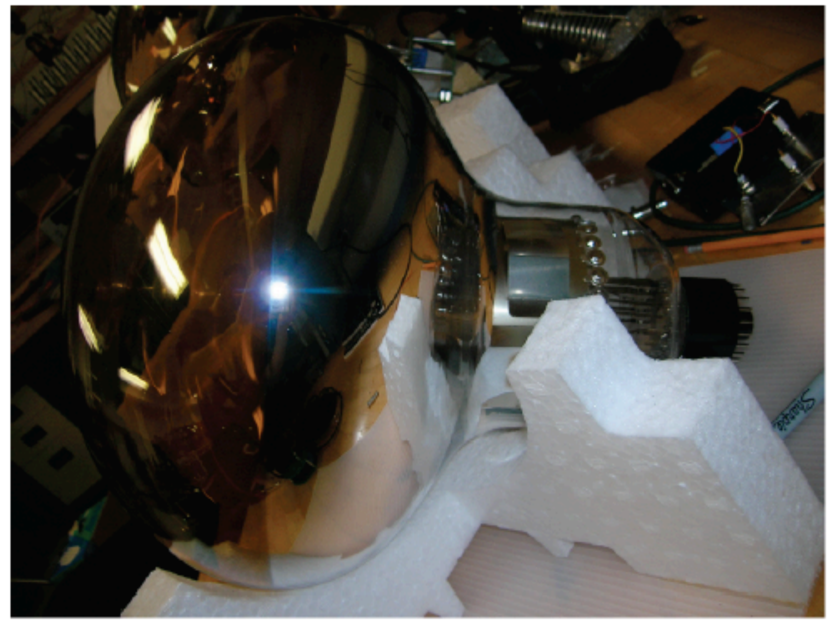
PMT's evaluated thus far



10" HQE (16+ total)

8" ETL (5 total)

12" Standard (10 total)



In this talk:

10" HQE evaluated against 20" SK PMT

Performance of Both standard And HQE 12" PMT

Results from HQE version now completed

Penn PMT testing lab

Rob Knapik (post-doc),
Tony Latorre, Kevin Shapiro (undergrads)

Source is ^{90}Sr embedded in SNO acrylic, triggered on fast (250ps FWHM) PMT

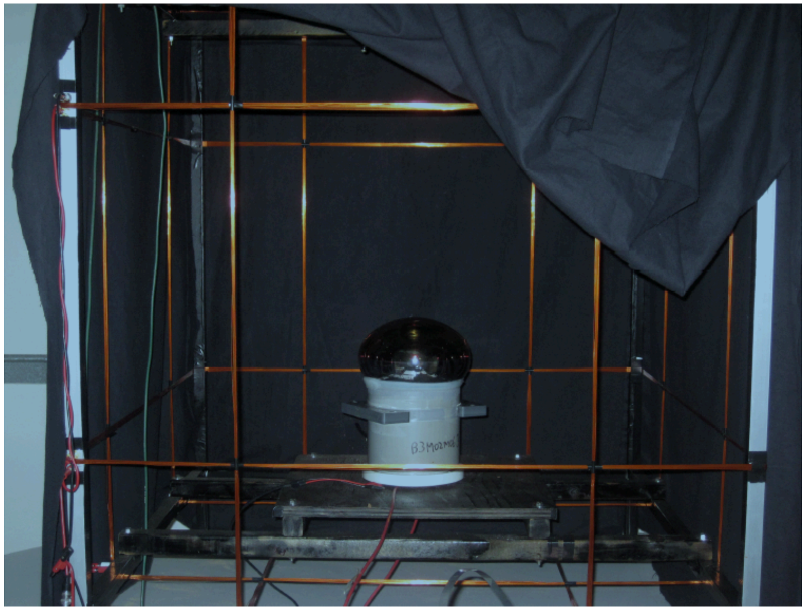
Two dark boxes:

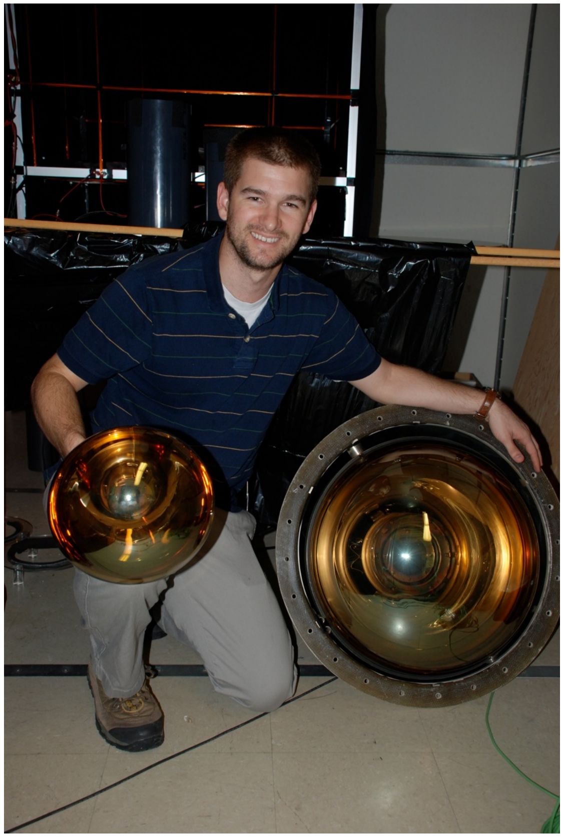
"small box"

"Tony's box"

UC Davis Test Lab

Tests on Magnetic Effects and relative Quantum Efficiency





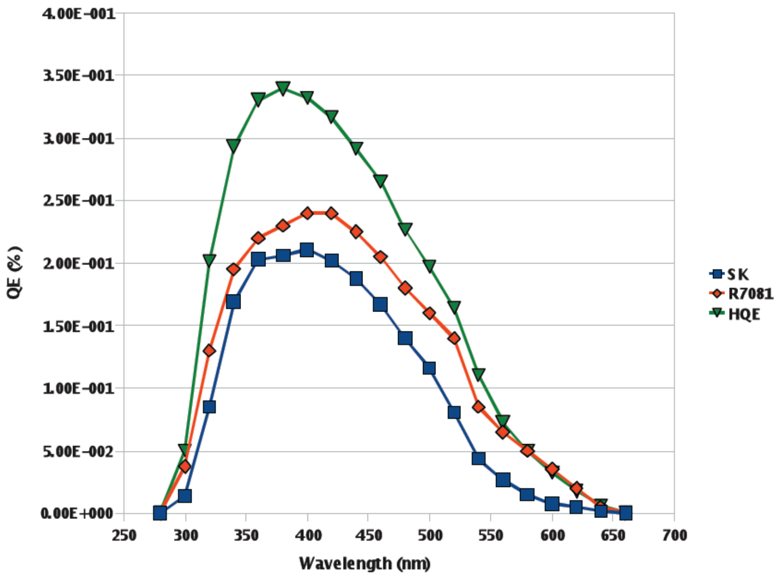
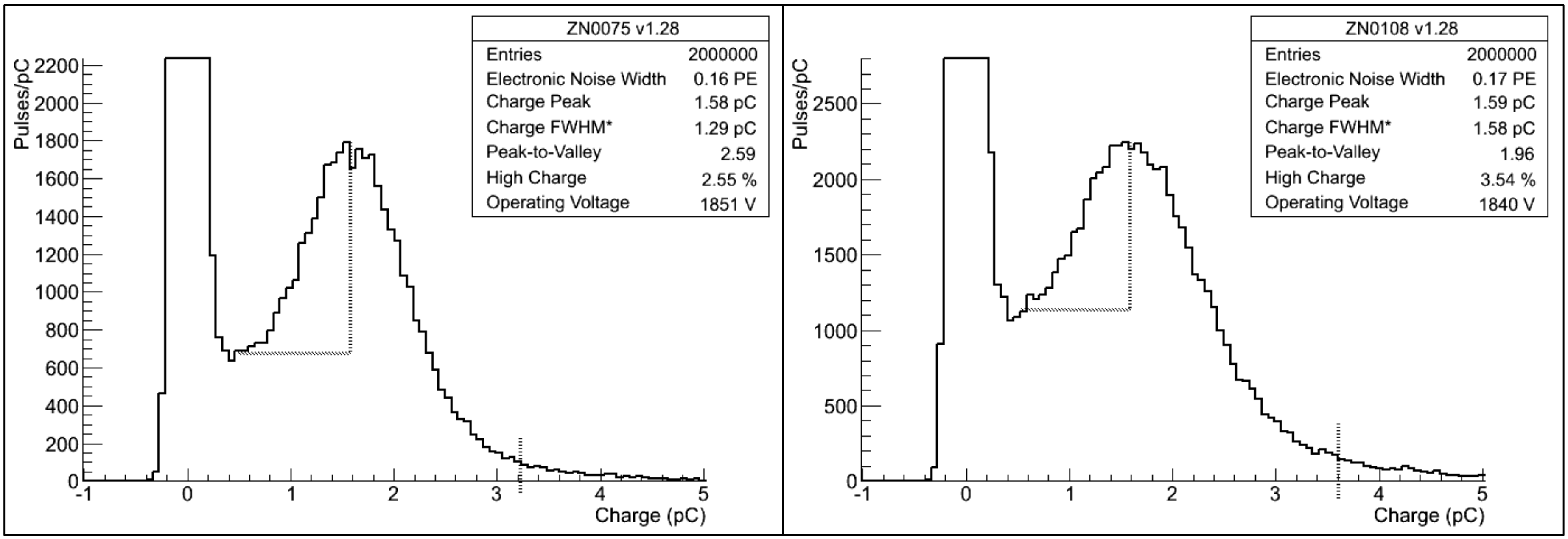


Figure 2 Quantum efficiency curves used in WCSim. Shown are the curves for the 20" SK R3600 (blue), 10" Double Chooz and ICECUBE R7081 (red), and 10"

Single p.e. tests of Hamamatsu 12" Standard and HQE PMT (gain = 1×10^7)

Example of Pulse Height Distributions



"Normal" Quantum Efficiency

"High" Quantum Efficiency

7 normal QE PMT's

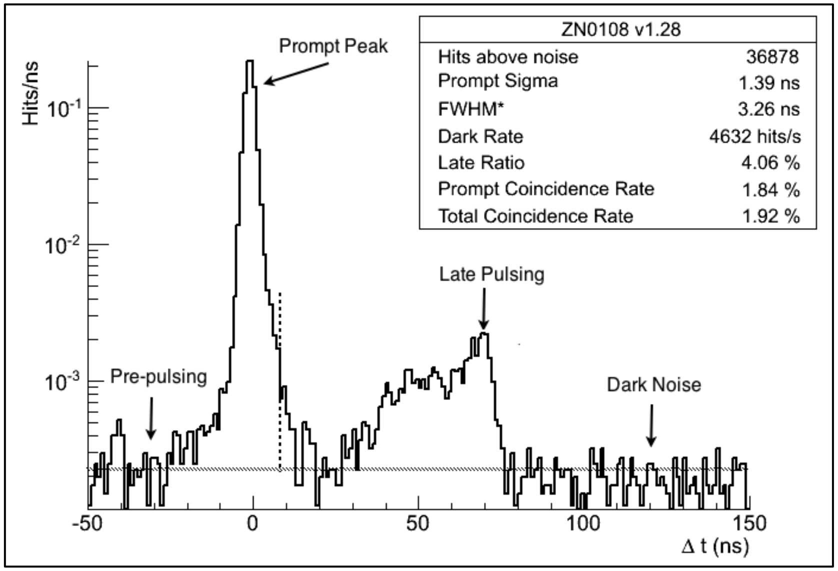
	Average	Standard Deviation	Minimum	Maximum
Charge FWHM (pC)	1.42	0.4	1.18	2.32
Peak/Valley	2.8	0.28	2.3	3.0
High Charge tail (%)	2.86%	0.84%	2.5%	4.94%
Operating Voltage (V)	1848	75	1920	1740

10 high QE PMT's

	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%
Operating Voltage (V)	1950	221	1750	2500

Conclusions: Performance is comparable, with perhaps a systematically low Peak/Valley ratio

Timing Response (gain = 1 x 10^7)



Look at time distributions using triggered Cherenkov source at the single p.e. level (~94% 1 pe expected) .

Conclusions: The performance of the Standard and HQE PMTs is very similar

	Average	Standard Deviation	Minimum	Maximum
Transit Time Spread (σ_{prompt})	1.37	0.15	1.20	1.6
Late Pulses (fraction)	4.48%	0.32%	3.93%	4.92%
Noise Rate	3669 Hz	5110	1962	16807
Operating Voltage (V)	1848	75	1920	1740

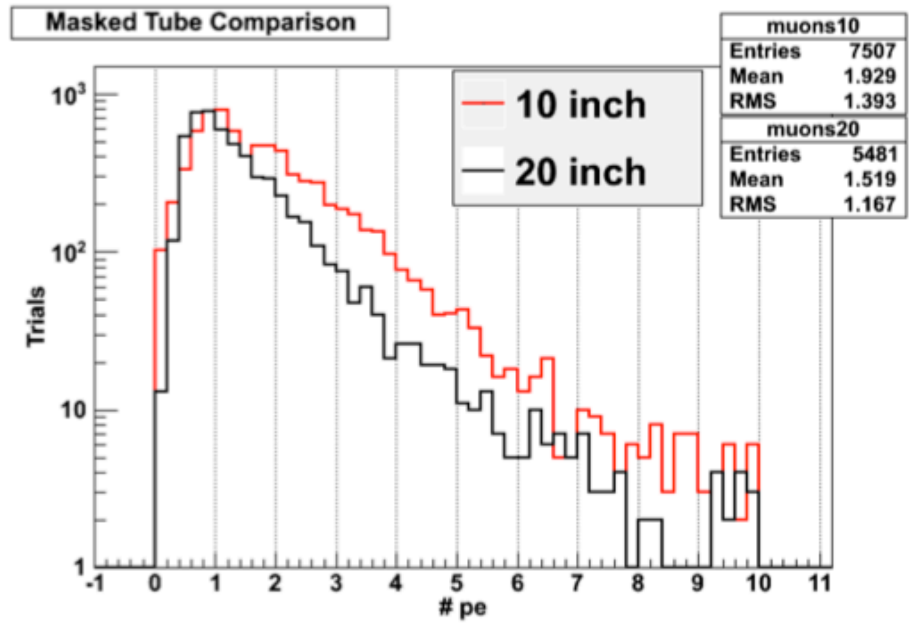
7 normal QE

	Average	Standard Deviation	Minimum	Maximum
Transit Time Spread (σ_{prompt})	1.29	0.14	1.16	1.52
Late Pulses (fraction)	4.3%	0.35%	3.6%	4.8%
Noise Rate	4428 Hz	1897	2398	8217
Operating Voltage	1950	221	1750	2500

10 high QE

HQE gain verified by lab tests

Comparison of ONE 10" HQE with ONE 20" SK PMT (with face masked to same area)



$$\frac{< q_{10} >}{< q_{20} >} = \frac{1.93}{1.52} \Rightarrow \frac{\mu_{10}}{\mu_{20}} = \frac{1.50}{0.90} = \boxed{1.67 \pm 0.1}$$

$$< q > = \frac{G\mu}{1 - e^{-\mu}}$$

Where G is the gain of the PMT which we measure before the test. And <q> is measured in number of photoelectrons.

J.Felde, UC Davis

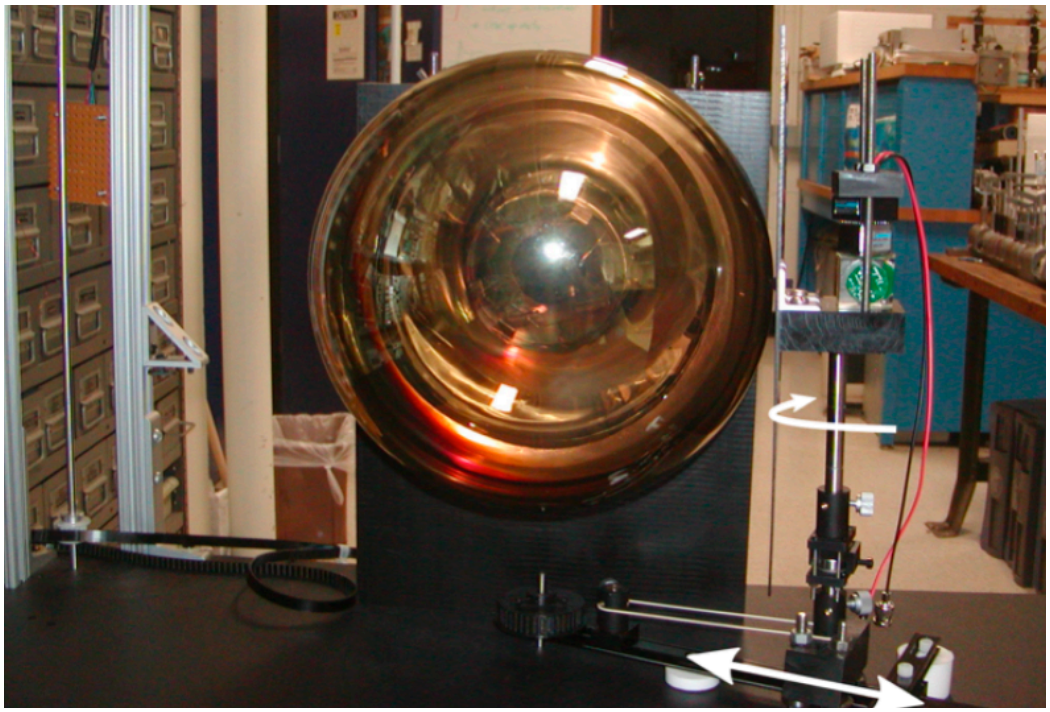
New!: comparison of Normal and High QE 12" PMT's

	Relative Efficiency
Tested Pair 1	1.56
Tested Pair 2	1.49
Tested Pair 3	1.66
Tested Pair 4	1.64
Tested Pair 5	1.32
Tested Pair 6	1.32
Average	1.50
Standard Deviation	0.15

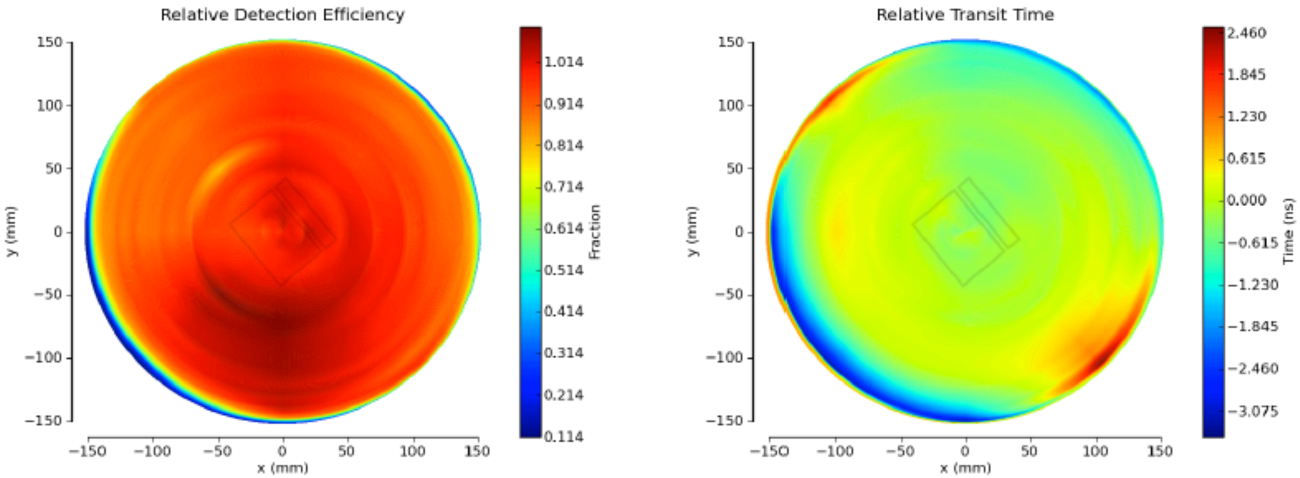
Test performed using triggered Cherenkov source

Conclusion: There is some significant tube-to-tube variation, but average is 50% improvement over standard photocathode

Variation in charge collection and timing

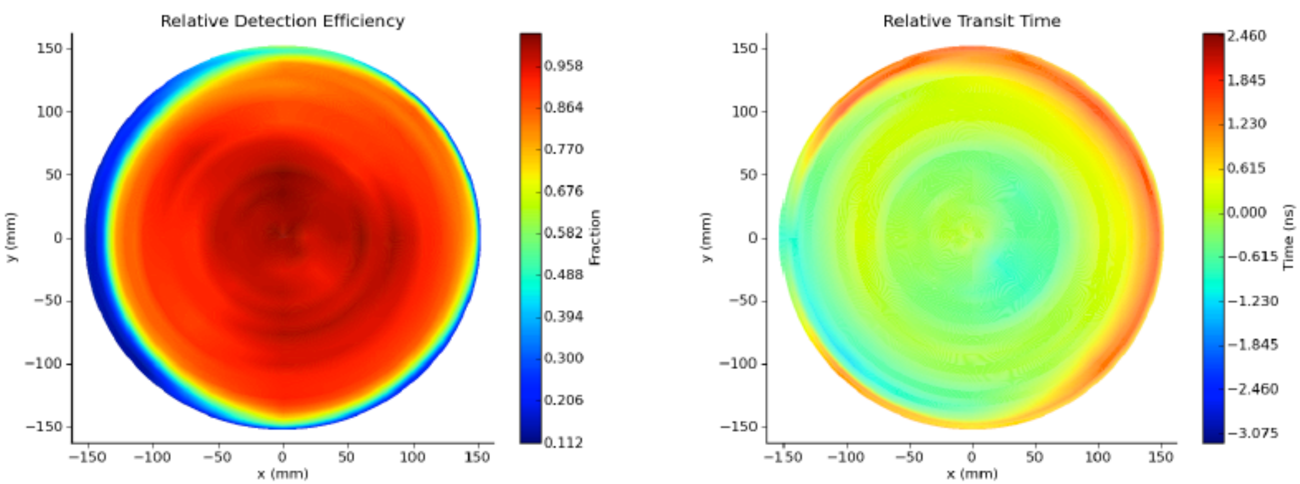


Automated scanning system using triggered Cherenkov source with pinhole



Example of 12" PMT with standard QE

Figure 13: The position-dependent photon detection efficiency is shown on the left, while position dependent shifts in the median transit time is shown on the right for a Hamamatsu 12-inch R11780 PMT with standard quantum efficiency. The color indexes are relative to measurements made at the center of the PMT.



Example of 12" PMT with high QE

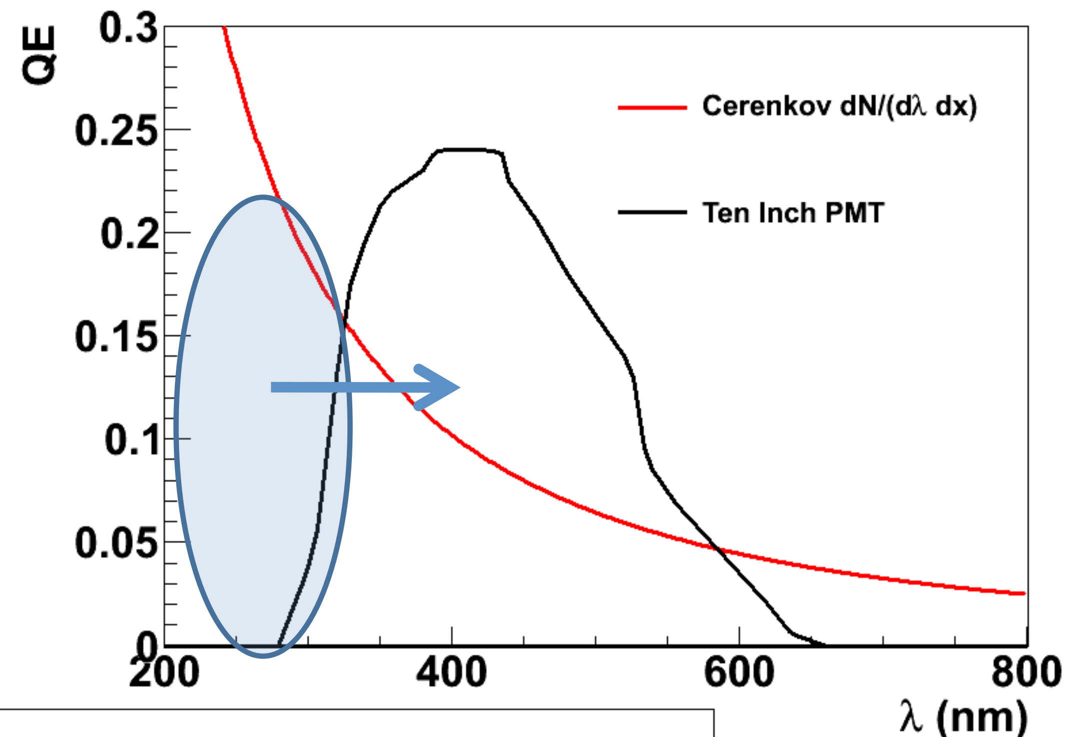
Figure 14: The position-dependent photon detection efficiency is shown on the left, while position dependent shifts in the median transit time is shown on the right for the high quantum efficiency configuration of the Hamamatsu 12-inch R11780 PMT. The scanned high quantum efficiency PMT has an alternative dynode structure designed by Hamamatsu to mitigate the large shifts in the mean transit time observed in the standard configuration shown in Figure 13. The color indexes are relative to measurements made at the center of the PMT.

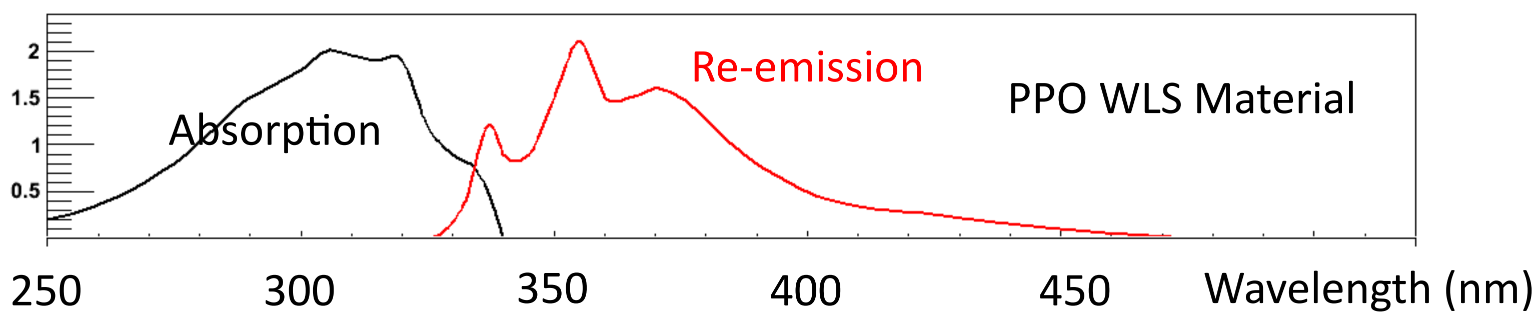
Light collector options studied

- Three different light concentrator option are subject to R&D
  - Wavelength shifting film: coat thin layer of wavelength shifting material on the PMT glass surface - ~10-15% light collection improvement
  - Wavelength shifting plates: flat panels put around PMT above the equator doped with WLS: large light collection improvement, will discuss in simulation talk
  - Winston cones: elliptically shaped, reflective, non imaging cones – interface with PMT close to equator: large light collection improvement, will discuss in simulation talk

Wavelength shifting

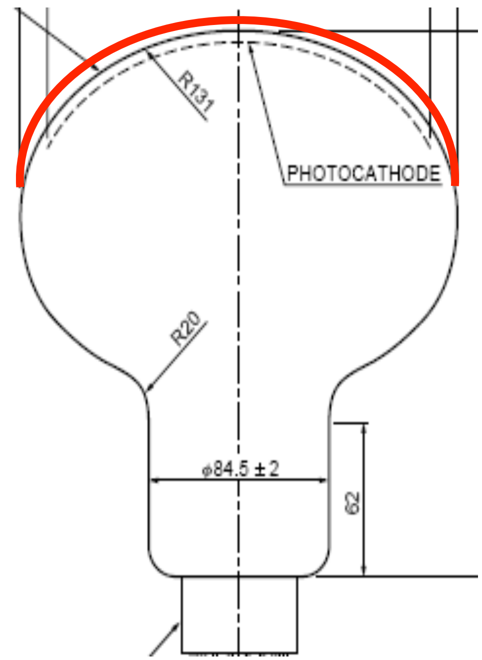
- Quantum Efficiency of PMT is low @ shorter wavelength
  - Properties of glass, dominated by photo-electric effect
- Cerenkov Spectrum roughly follows $1/\lambda^2$
- Use WLS to shift light at shorter WL to longer WL to increase light collection.





From Xin

Wavelength Shifting Film



- Anticipate 10-15% increase with optimal material (the same level achieved in similar studies performed for Ice Cube)
- WLS material and coating thickness can be varied.

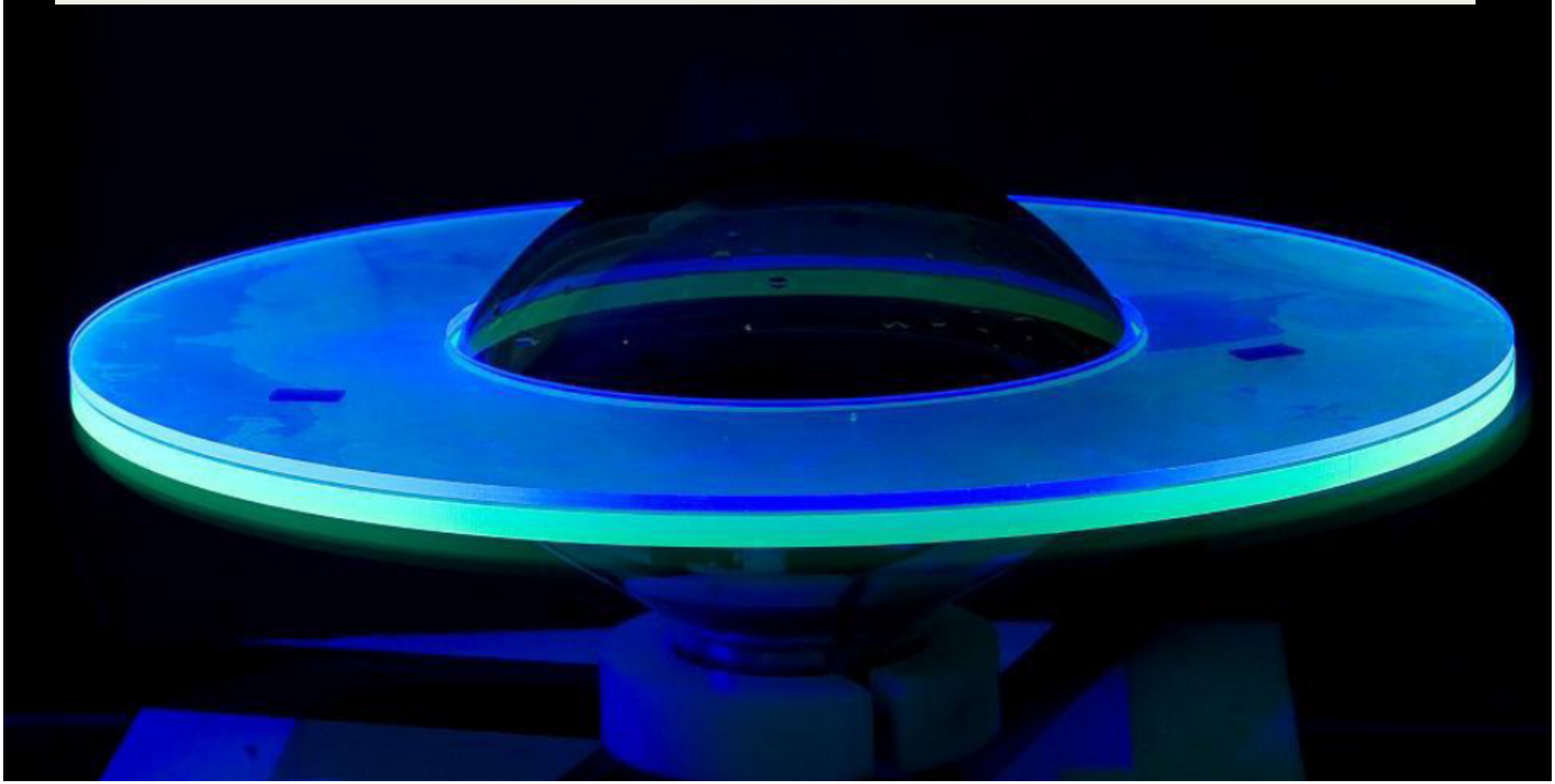
- Modest cost, but also modest light increase
- Easy to implement: no mechanical changes in the design needed

PA

- May be added to the baseline at the later time

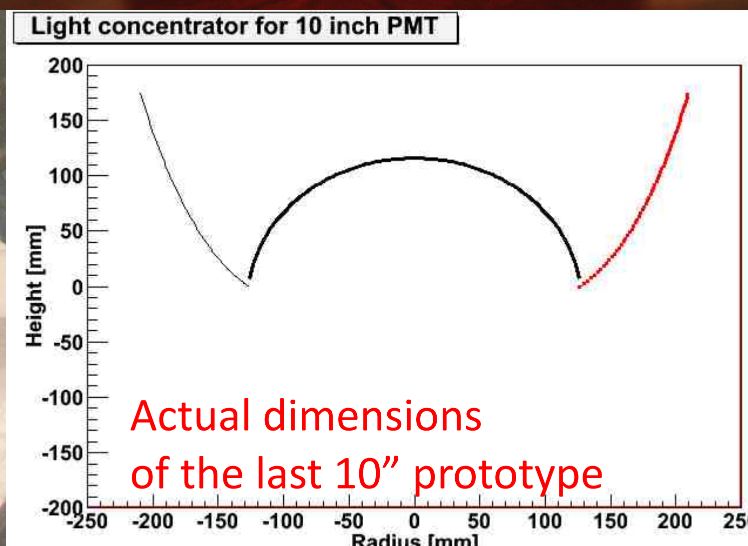
WLS Plates

Stand alone simulations showed light collection increase of 50% or more depending on the size of the plate, interface with PMT, fluor, decay time.
The effect of timing degradation on vertex resolution is under study in WCSim. More to come in separate talk on WLS plates and simulation.



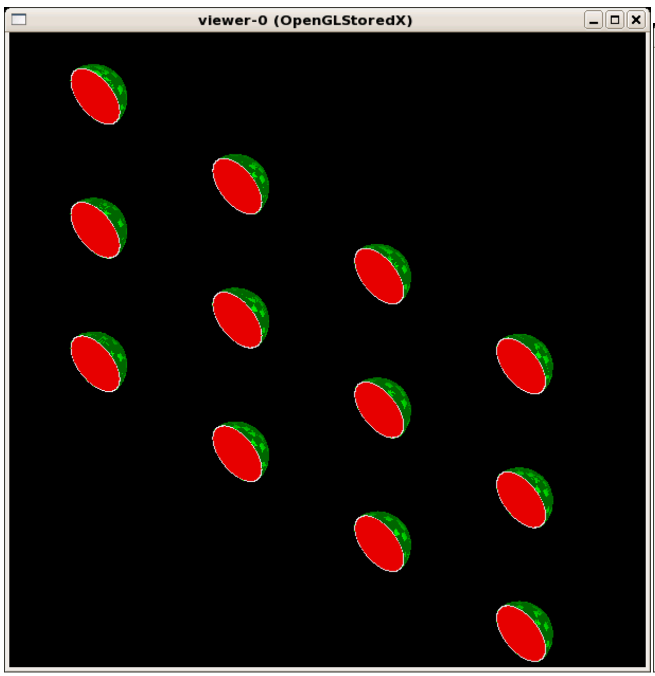
Winston cones (LCs)

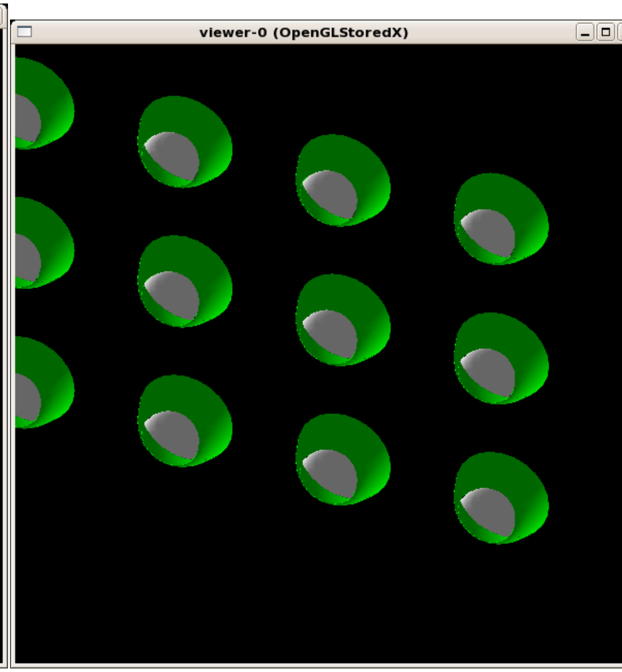
- Non imaging light collectors – ellipsoidal in shape that operate as reflective mirrors(Al and Ag investigated so far).

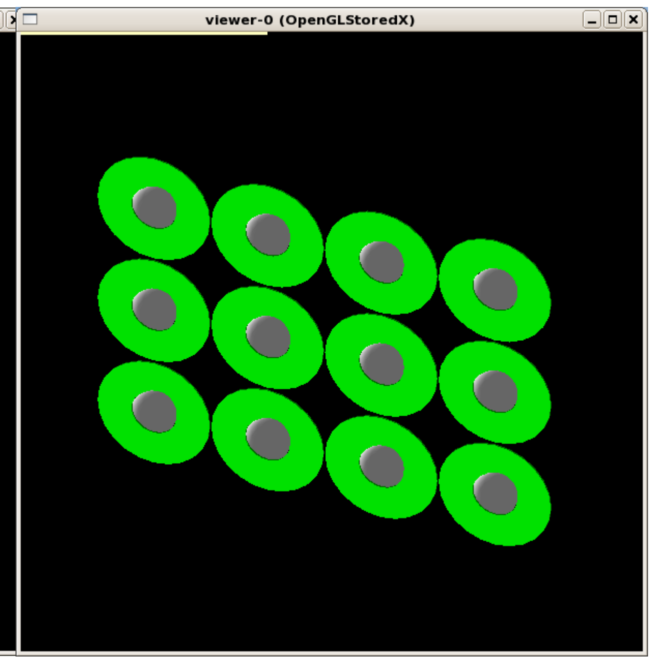


Light Collectors in WCSim

- All three LCs are implemented in WCSim
- Analysis Team: X. Qian (Caltech), W. Johnston (CSU), S. Perasso and R. Wasson (Drexel)







Very Preliminary Results

- Light Collectors can improve the performance of WC when the PMT coverage is small.
- 2 m fiducial volume cut @ LBNE is conservative.
- More PMT coverage would lead to a high electron PID efficiency and high muon PID rejection factor.

	LC	WLS	WLSP
NPE Gain	~50%	~10%	~30%
Reconstruction	Large Spread	Small Spread	Small Spread
Intrinsic resolution	Large loss	N/A	Small loss
Fiducial volume	~10% reduction	No loss	No loss
Vertex Resolution	Small effect	5% increment	15% increment
Electron/Muon	Small loss	No clear effect	No clear effect
Neutral Pion	N/A	N/A	Small effect

N/A means no dedicated studies were performed.

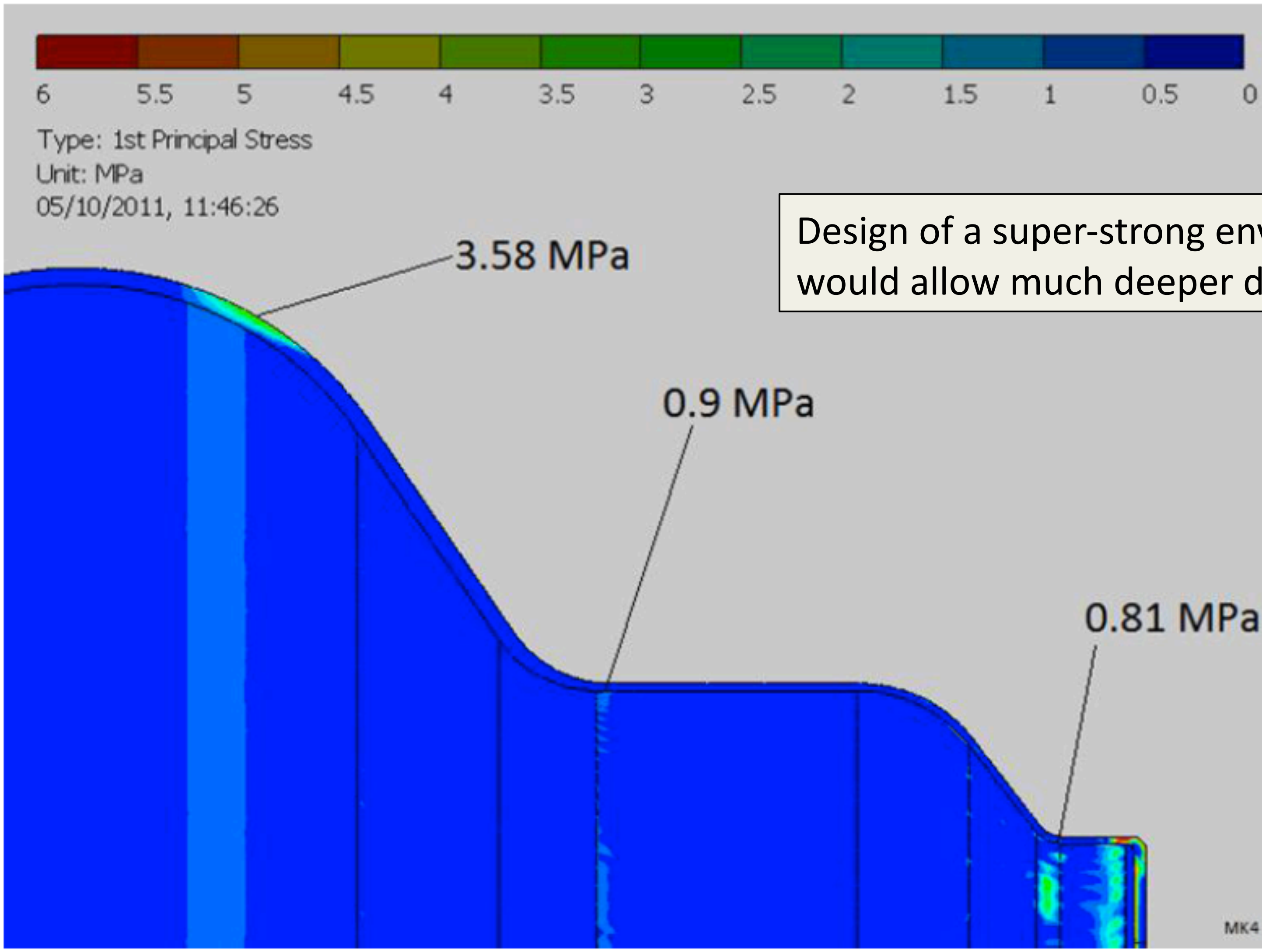
ADIT
Electron Tubes

Design of 11" PMT Envelope for LBNE

Specifications:

- External water pressure of 11 bar
- Long life in pure water
- Glass with low content of radioactive isotopes
- Shape for good photoelectron collection
- Shape for good timing (TTJ)

11 inch diameter envelope Mk4



Design of a super-strong envelope would allow much deeper detectors

Future Plans

- Will continue work on WLSP characterization over the next year
- Will complete and publish results for 12" PMT characterization
- We have asked NSF to spend some existing R&D funds to complete production of at least 10 11" ETL PMT's. This would take ~15 months. We will evaluate these for performance in similar fashion to 12" Hamamatsu

Backup

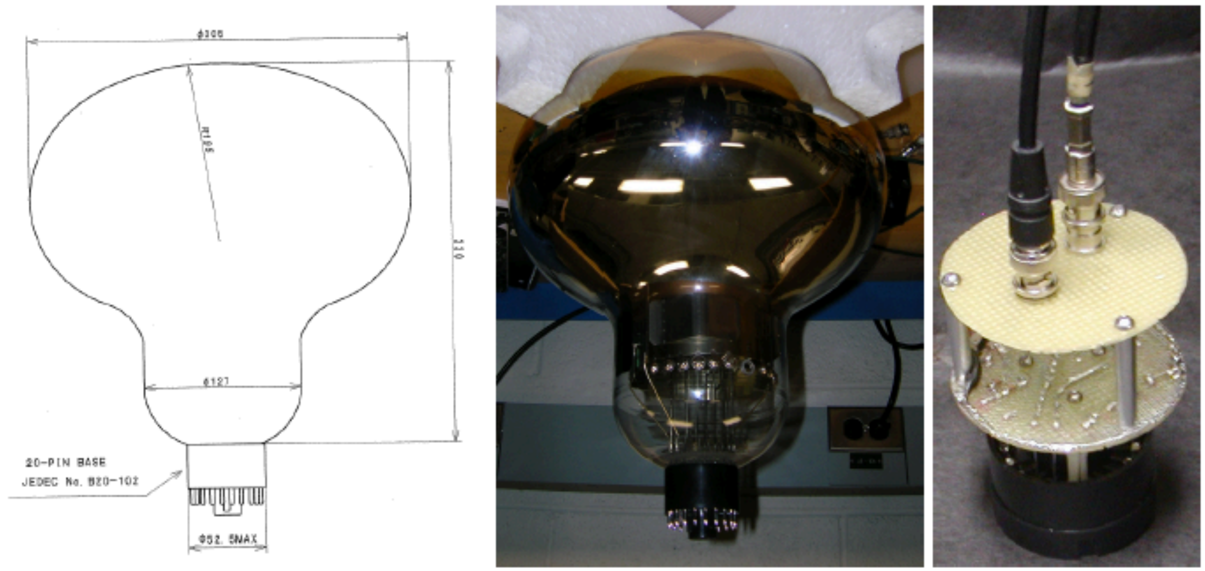


Figure 3: The R11780 12 inch Hamamatsu PMT and the two-cable voltage divider used.

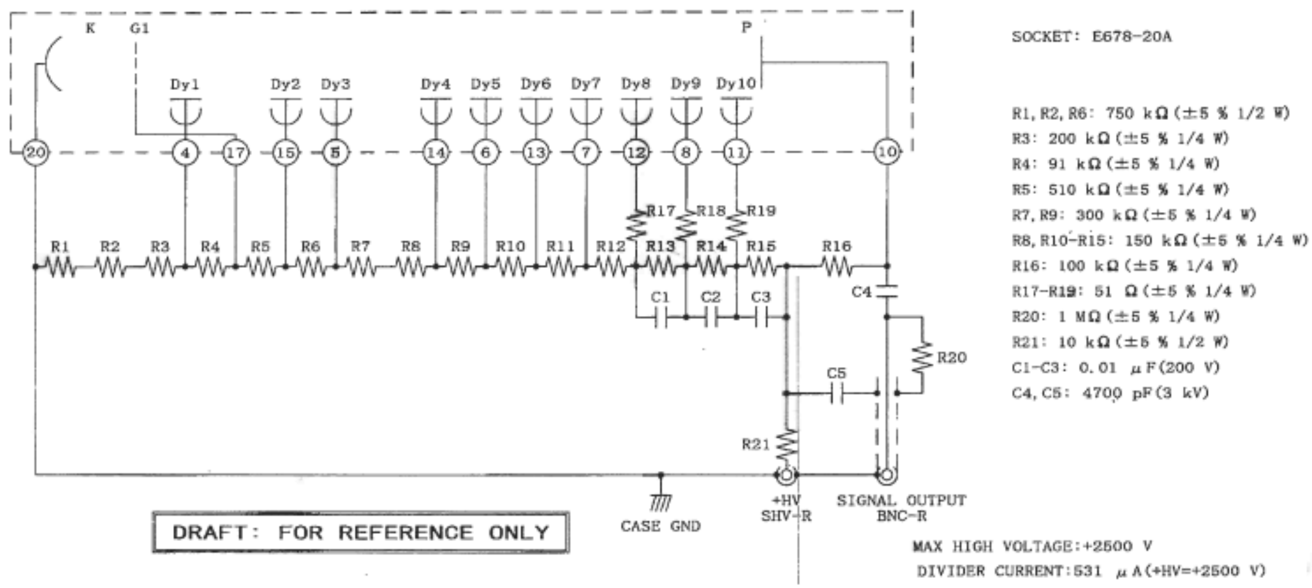


Figure 4: Schematic of the voltage divider circuit for the Hamamatsu 12 inch R11780 PMT. Provided by Hamamatsu Photonics.