

# Introduction to GLG4sim

An introduction to GLG4sim features

2006/05/19

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# GLG4sim: what is it?

- GLG4sim stands for “GenericLAND Geant4 simulation”
- LAND stands for Liquid-scintillator Anti-Neutrino Detector (as in KamLAND)
- It's a “Generic” Geant4 simulation for LANDs.
- It can serve as a library or a starting point for specific liquid scintillator antineutrino detectors.

# GLG4sim: who wrote it?

Quoting from the ACKNOWLEDGEMENTS file:

GLG4sim is derived from the most general parts of KGL4sim, a Geant4-based Monte Carlo for KamLAND started in 1999 at Tohoku University by myself (Glenn Horton-Smith) and Haruo Ikeda.

Contributors to KLG4sim between 1999 and 2004 have included, in alphabetical order, S. Dazeley (Tohoku, LSU), J. Detwiler (Stanford), G. Horton-Smith (Tohoku, Caltech), L. Hsu (LBL), H. Ikeda (Tohoku), T. Iwamoto (Tohoku), K. McKinney (Alabama), D. Markoff (TUNL), D. Ray (LBL), R. Rohm (TUNL), O. Tajima (Tohoku), B. Tipton (Caltech), and Y. Uchida (Stanford). It is important to acknowledge their valuable contributions to KLG4sim.

(see ACKNOWLEDGEMENTS file for more.)

# GLG4sim features

- Completely functional simulation.
- Supports multiple detector options; cylindrical and spherical “generic examples” provided.
- GLG4DataInputReader class for reading in G4MaterialPropertyVector data from an external file:  
`materials.dat`
- GLG4param class implements trivial database of detector-defining numbers, read from file:  
`settings.dat`
- GLG4DebugMessenger adds some useful tools.

# GLG4sim features, continued

- GLG4Hit\* classes collect hit data efficiently.
- Support for multiple, easily customizable output formats.
- GLG4VertexGen classes provide a variety of event types, including external HEPEVT-like input.
- GLG4PosGen classes allow fixed point, surface paint, volume fill for event location, and more.
- GLG4PrimaryGenerator, GLG4DeferTrackPos work together to provide event mixing, correlation, separation.

# GLG4sim features, continued

- GLG4OpAttenuation includes scalar scattering.
- GLG4Scint class implements scintillation process with more options, “bulletproof” energy deposit catching, optical photon reemission.
- GLG4PMTOpticalModel implements complex semi-transparent thin cathodes.
- GLG4TorusStack special shape for PMTs, domes.
- GLG4\_PMT\_LogicalVolume implements construction of Hamamatsu 17/20-inch and 8-inch PMTs and ETI 5-inch PMTs; extendable.

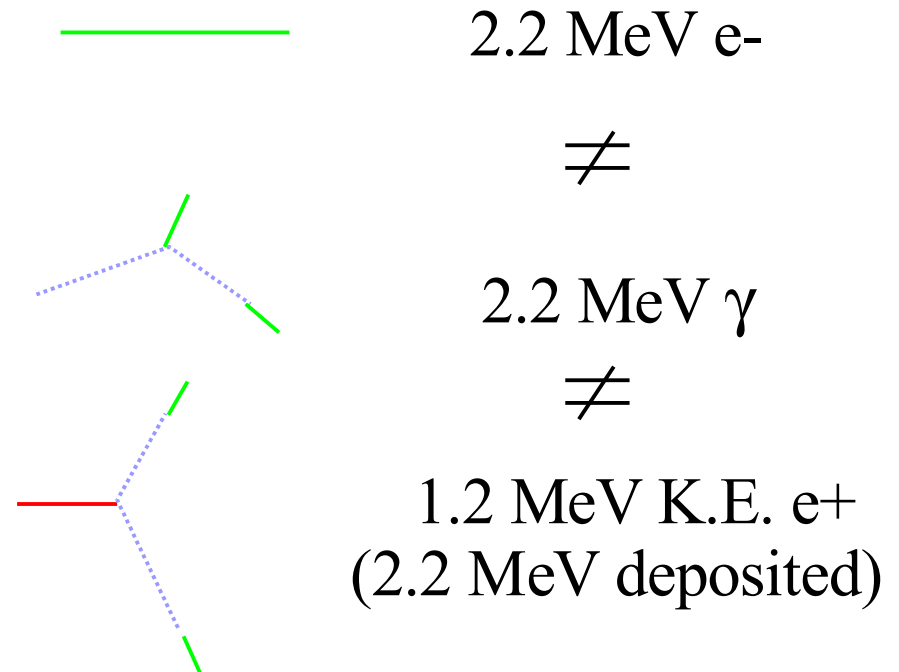
# Yield dependence on $dE/dx$ and particle type

Birks' law:

$$\frac{dS}{dx} = \frac{k dE/dx}{1 + kB dE/dx}$$

$kB \approx 0.015 \text{ cm/MeV}$  in KamLAND  
(see arXiv:physics/0404071)

Incident particle  
determines secondaries,  
changes calibration:



“ $S(2.2) \neq S(1.1)+S(1.1) \neq S(1.2)+S(0.5)+S(0.5)$ ”

# The slow and fast scintillation components †

## Fast component:

- Decays exponentially
- Time const. ~ few ns
- Has ionization quenching (Birks' law)
- Produced by fluorescence decay of excited singlet state:  ${}^1M^* \rightarrow {}^1M$
- Occurs only in the track of the ionizing particle.

## Slow component:

- Decays *non-exponentially*
- “Effective” time constants ~ hundreds of ns
- Little or no ionization quenching!
- Attributed to collisional interactions of pairs of molecules in an excited triplet state:  
$${}^3M^* + {}^3M^* \rightarrow {}^1M + {}^1M^*$$
- Occurs over entire volume available to  ${}^3M^*$ .

† See Birks' 1964 book, or his 1973 review in “Proc. of Intl. Symp. on Liq. Scint. Counting”, Sydney, Australia.



# Pulse shape discrimination

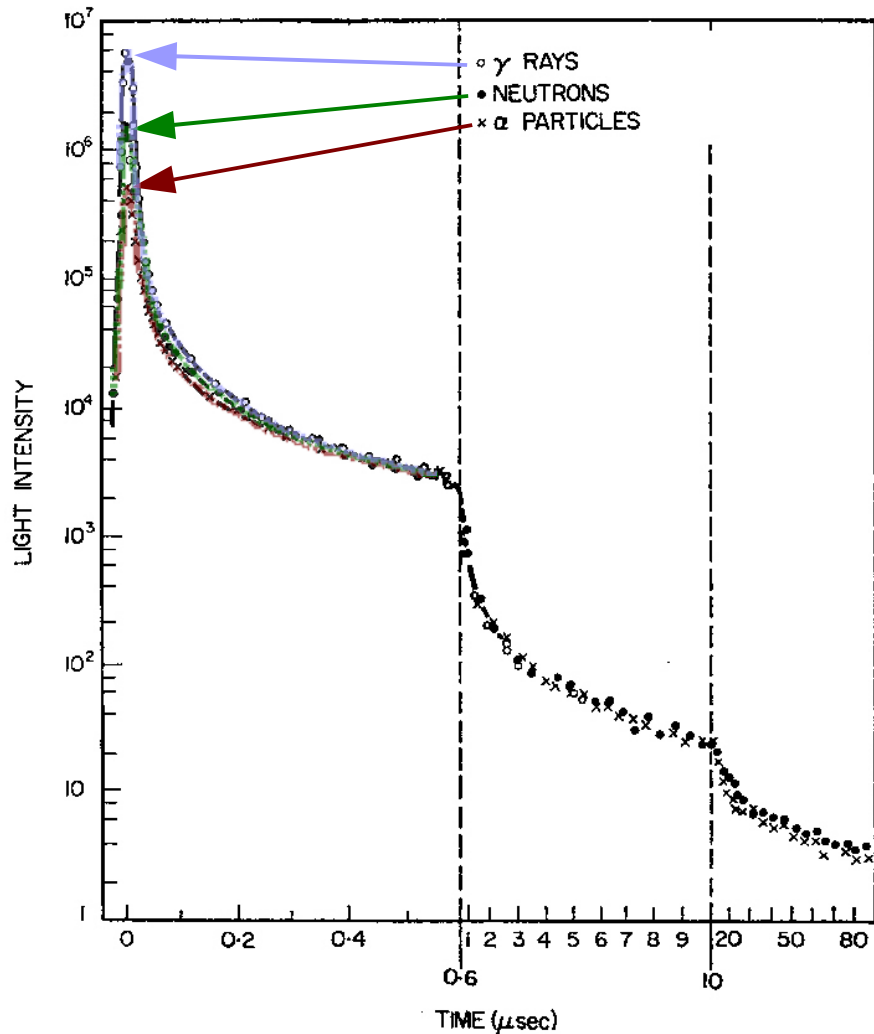


FIG. 6.19. *trans*-Stilbene crystal. Decay of scintillations excited by  $\gamma$ -rays, neutrons and  $\alpha$ -particles. The intensities are normalized at time  $t = 400$  nsec, to show the similar form of the slow decay component (Bollinger and Thomas, 1961).

Figures from Birks' classic book tell the story: because the fast part quenches and the slow part doesn't, the pulse shape can tell you something about  $\langle dE/dx \rangle$ .

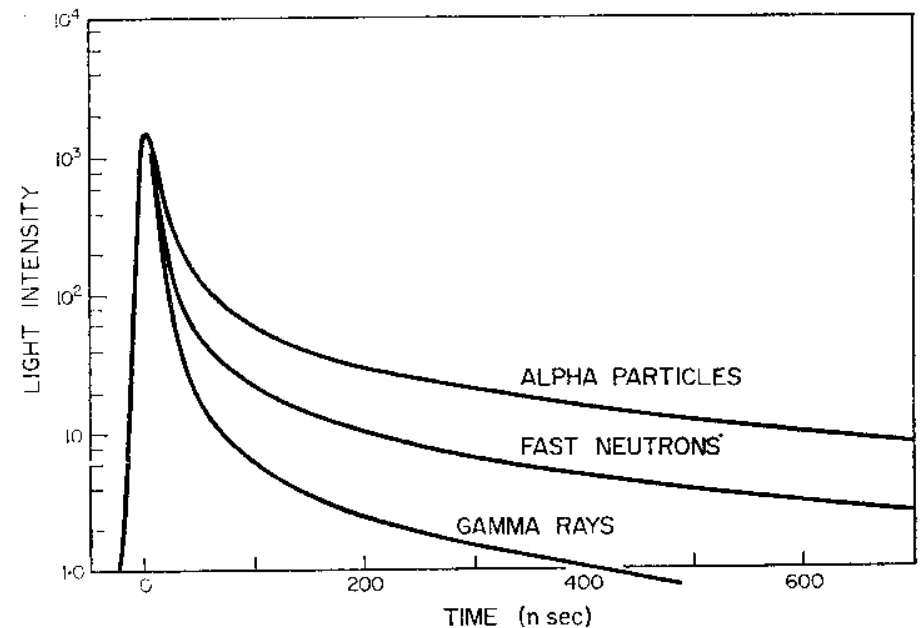


FIG. 6.20. *trans*-Stilbene crystal. Decay of scintillations excited by  $\gamma$ -rays, neutrons and  $\alpha$ -particles. The intensities are normalized at the peak (time  $t = 0$ ), to show the dependence of the scintillation pulse shape on the nature of the exciting radiation (Bollinger and Thomas, 1961).

# Other nonlinear effects

- Cerenkov light adds another non-linear contribution to output:  $dN_c/dx = k_c(1-\beta^{-2}n^{-2})$

$$N_{phot}(E, primary) = \sum_{secondaries} \int_{track} \left[ \left( \frac{k_{fast}}{1 + kB dE/dx} + k_{slow} \right) \frac{dE}{dx} + k_c \left( 1 - \frac{1}{n^2(1 - m^2/E^2)} \right) \right] dx$$

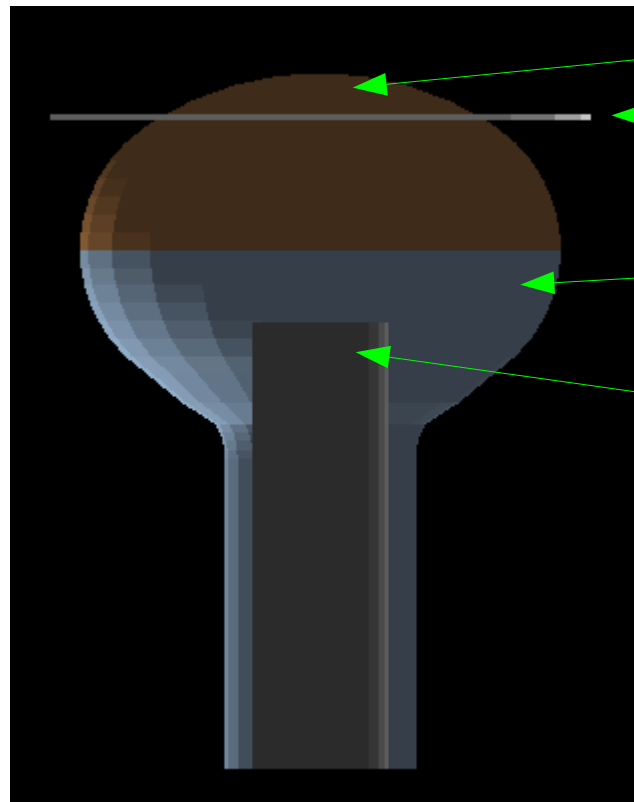
- Spatial dependence of emission and reemission cause a non-exponential dependence of light collected vs. distance from source.

$$N_{pe}(x_{PMT}, x_{source}, E) = N_{phot}(E) f(x_{PMT}, x_{source}),$$

where  $f(x_{PMT}, x_{source})$  is some nontrivial function,

$$f(x_{PMT}, x_{source}) \neq f(|x_{PMT} - x_{source}|).$$

# PMT shape

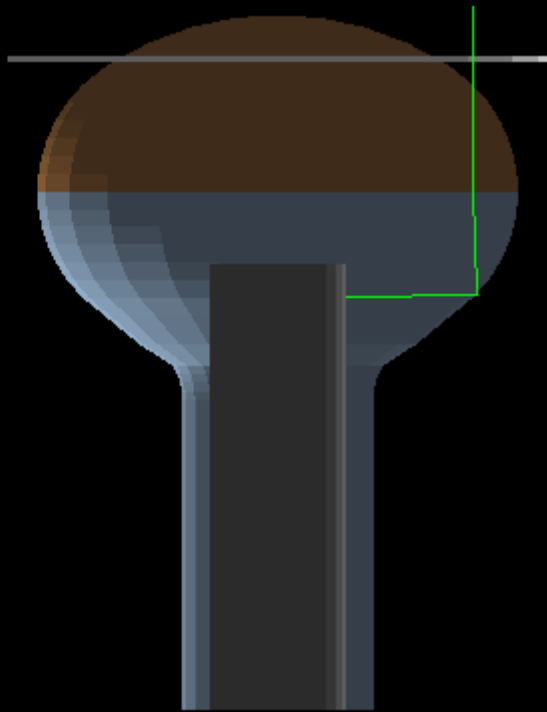


Cathode  
mask

silvered surface

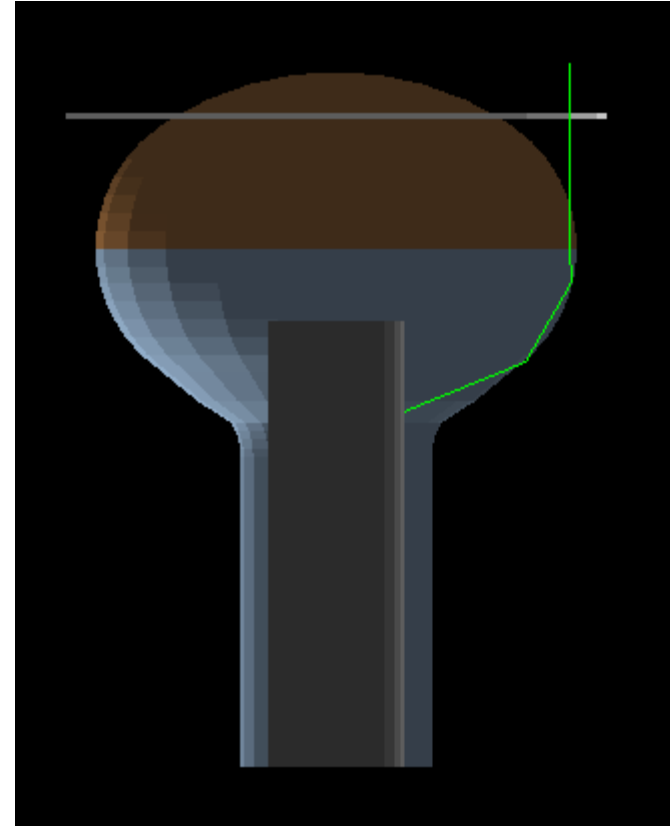
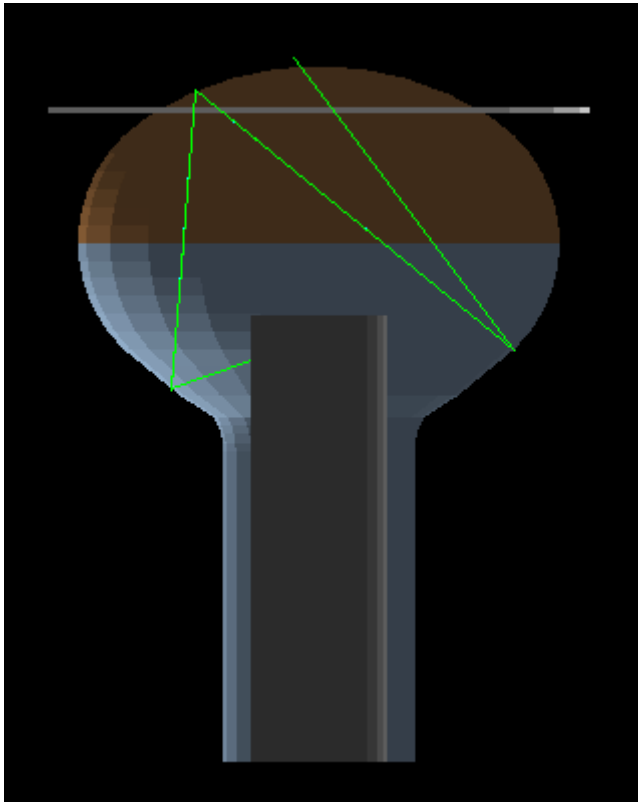
dynode crudely  
approximated as solid  
cylinder of low  
density metal

# PMT optical model



Light reflects or transmits at most dielectric boundaries as per Geant4 process; reflects, transmits, or absorbs at photocathode based on complex index of refraction and thickness. (See Motta and Schoenert, NIM A 539 (2005), <http://arxiv.org/abs/physics/0408075>; see also NIM A 383 (1996) 485, 495.)

# PMT optical model



Can have internal reflections in glass, etc.  
(And yes, mask is placed too high here.)

# GLG4sim speed

- With full optical photon tracking, can simulate 10000 1-MeV events in 80 cpu-min on 3.2 GHz P4/Xeon.
- CPU-time proportional to number of photons tracked, works out to 0.5 cpu-sec/MeV.
- Can run with optical photon tracking disabled, in which case it just tracks total energy deposit in scintillator (with and without quenching) and “centroid” -- orders of magnitude faster.

# User support

- User supported.
- Website at <http://neutrino.phys.ksu.edu/~GLG4sim/>
- Current user base:
  - Daya Bay (used as library and/or spare parts yard)
  - Braidwood (used as library, tightly coupled to RAT)
  - Double Chooz (used as library, loosely in DOGS)
  - KamLAND (“organ donations” to parent)
- Bugs are being found, fixed!

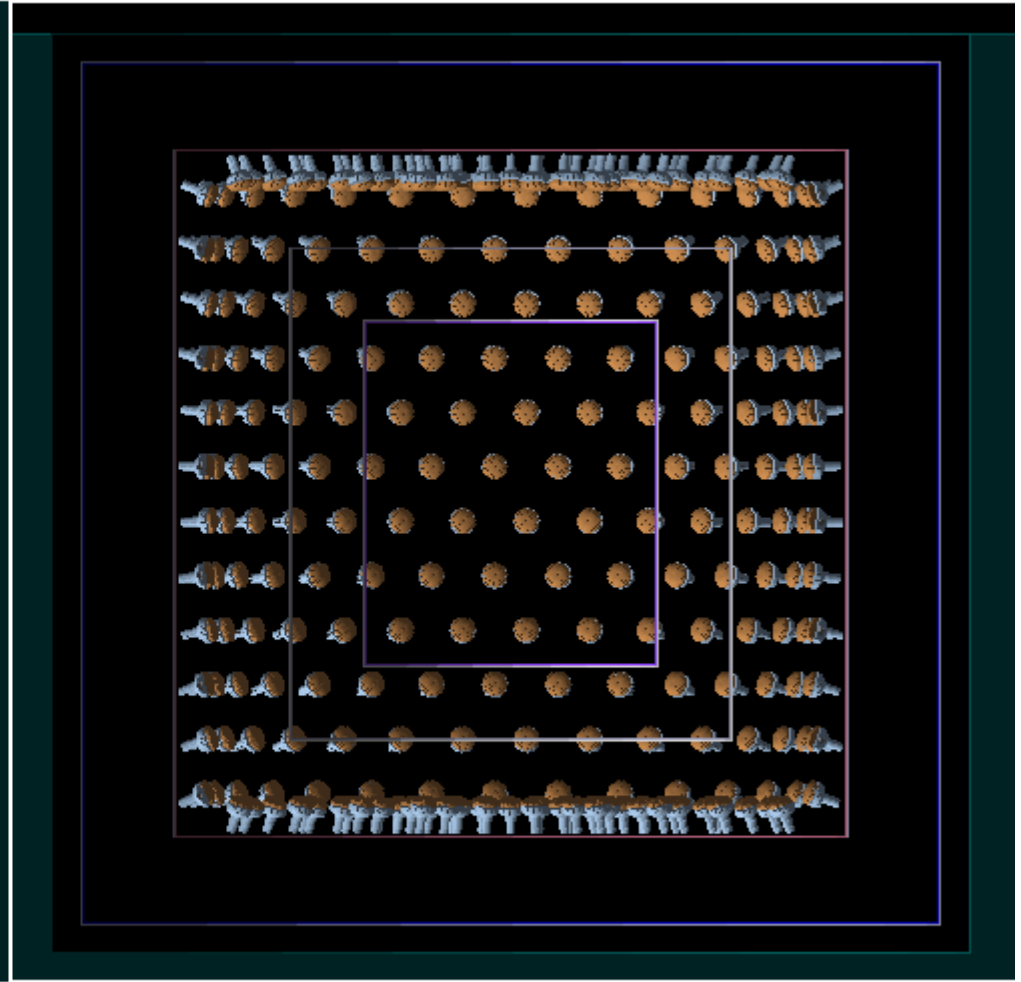
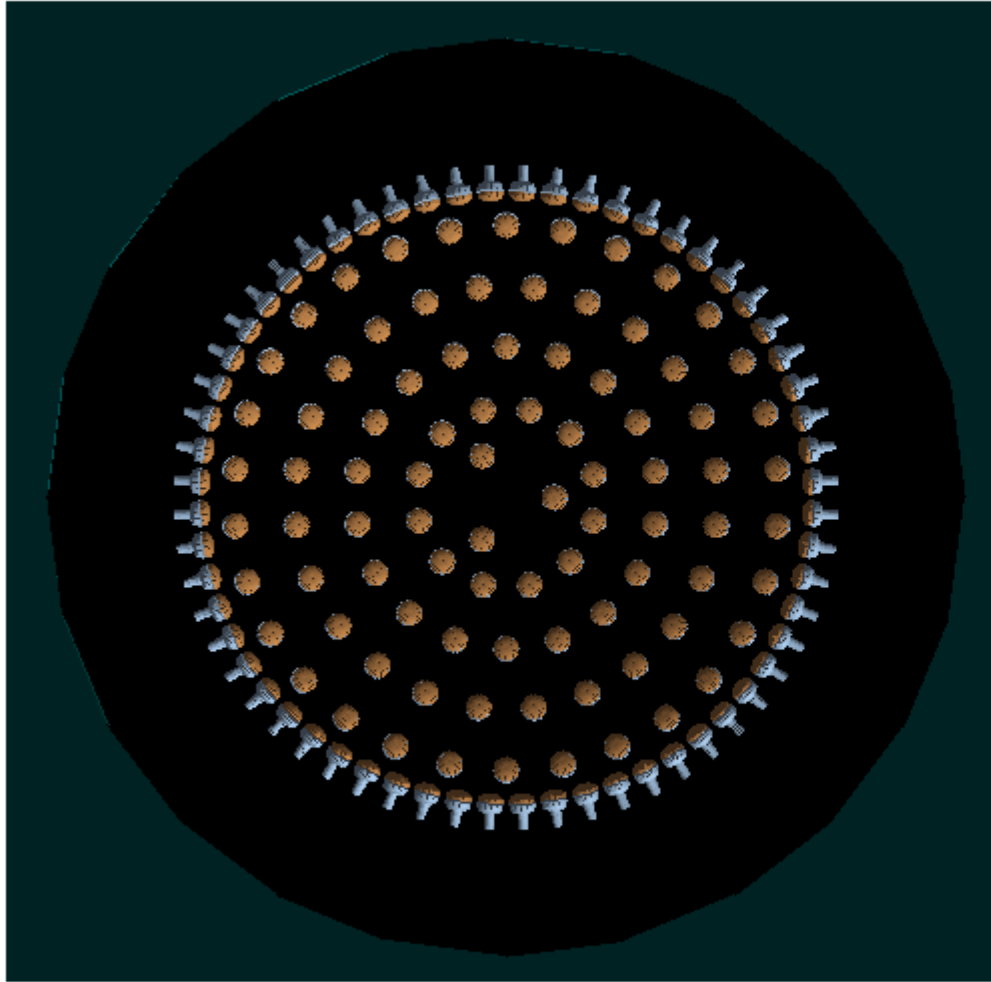
# Status

as known as of 2006/05/19

- Current release (0.9.5b) is functional
- Works with Geant4 v6.2-p02 through 7.1
- Does not work with Geant4 v8.
  - The changes needed to make it compile are easy, but I'm suspicious of the effect; also, they break compatibility with G4.7.1 and earlier.
- Documentation is a slow work in progress.
  - Getting it working and understanding it still requires way too many e-mails to me. I am motivated to fix that. Please help improve the documentation if you can!
- “Dusty corners” in code unimportant to KL...

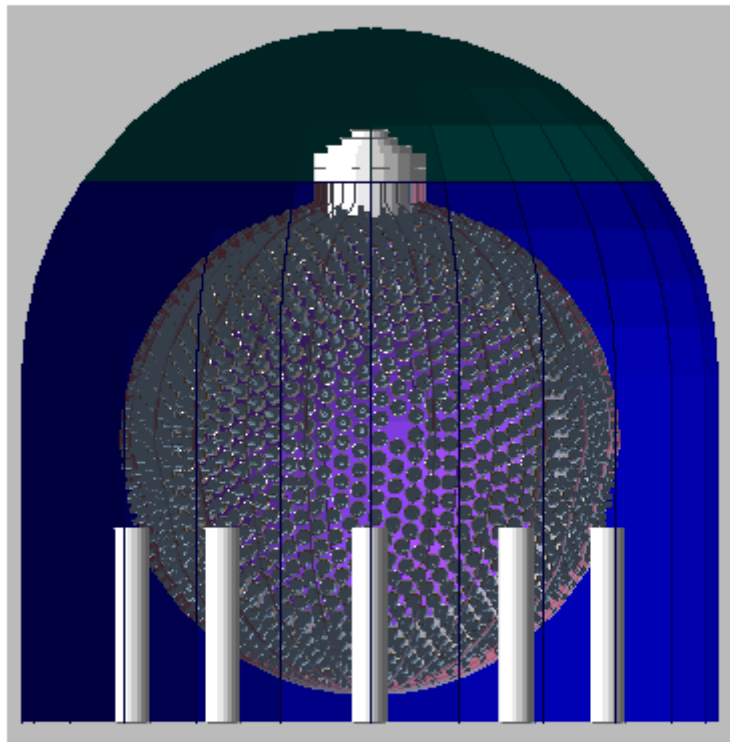


# Section views (cylindrical reference detector)



# Section views (spherical reference detector)

Spherical GenericLAND starter geometry:  
this needs to be modified to match your specific design.



**~1800 8-inch PMTs inside  $r \sim 3.6$  m tank**

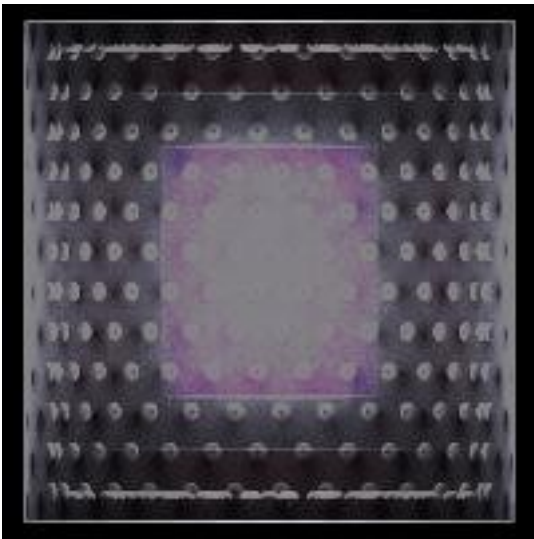
Main tank and cavern walls are made transparent here for clarity. Cavern walls and outer surface of tank and its supports actually have white optical surfaces, and interior of tank has black optical surface in simulation.



**Closup view of outer buffer, middle, and central volume, with PMTs omitted for clarity. Note 3-layer design. Acrylic separates outer from mid., thin balloon contains center. Please modify to suit.**

# “Self-illuminated” views

To create, compile with G4DEBUG option, and use /glg4debug/dump\_illumination\_map command after simulating some events. Output in map?.ppm.



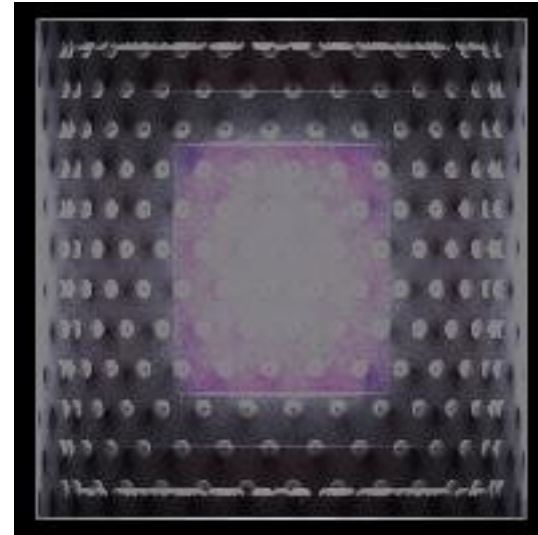
Side view, positrons uniformly filling central volume



Top half, muon\_test\_short.mac

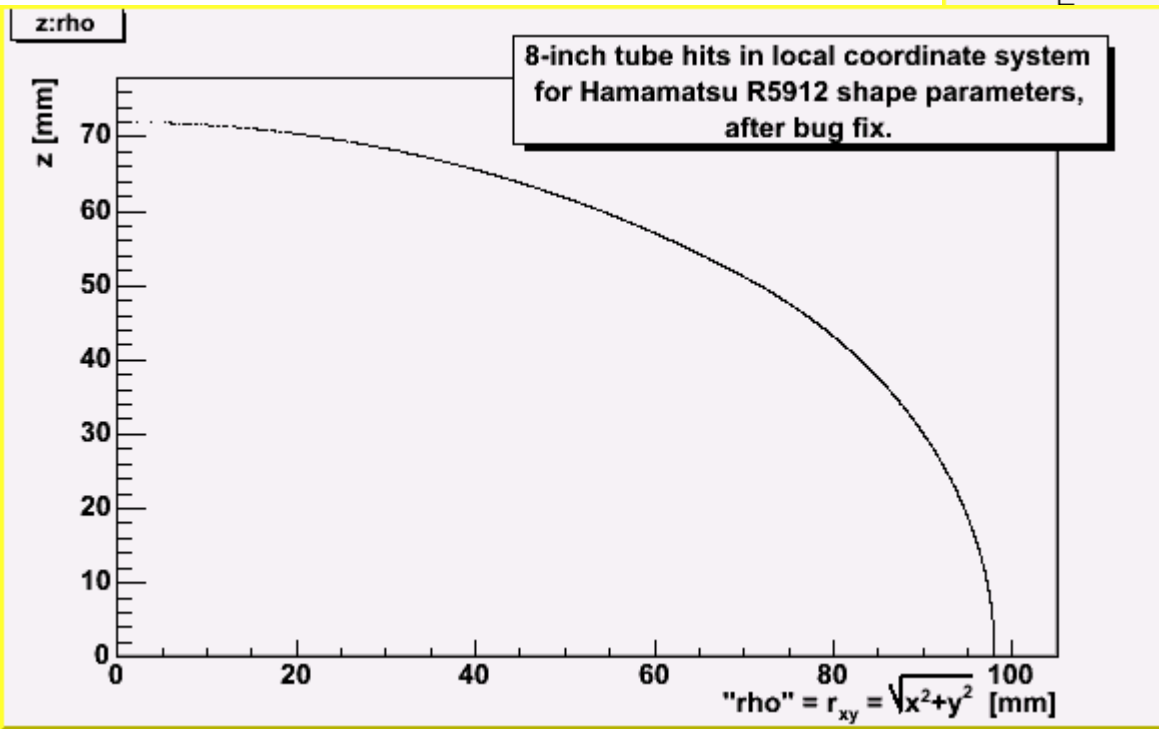
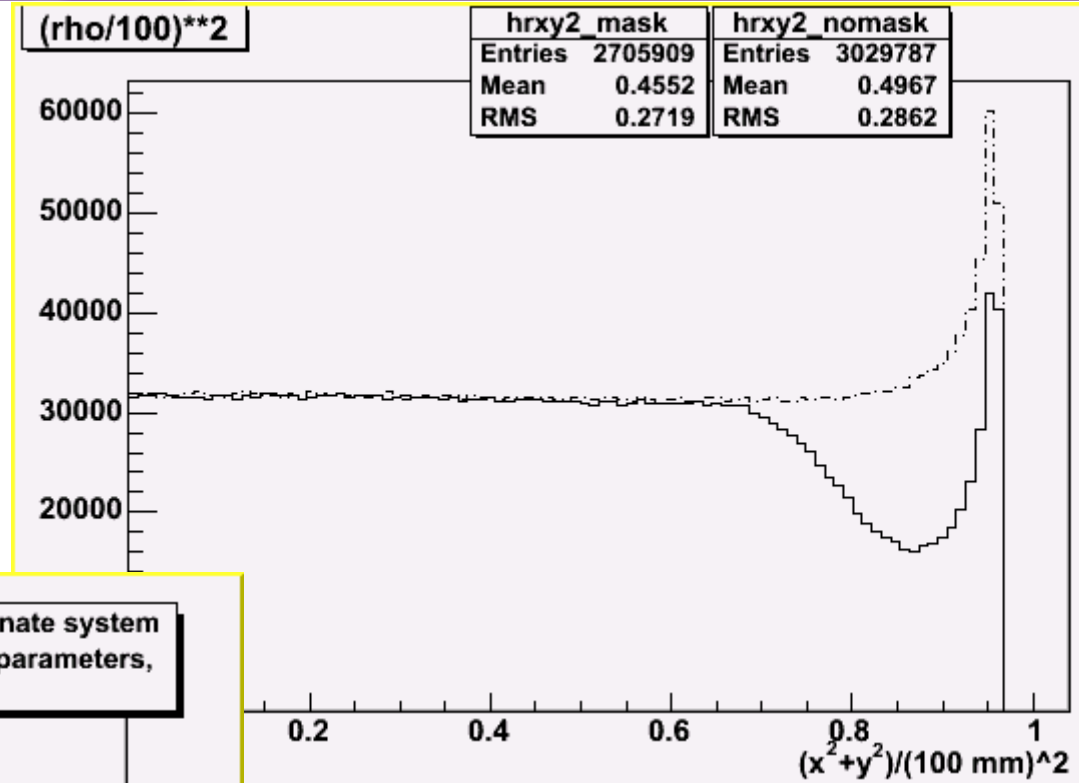
# Effect of PMT tilt on uniformity and yield

- Look at light collected from stopped  $e^+$  annihilation at points uniformly random in target volume.
- Absolute light yield high. Only relative effects of interest.



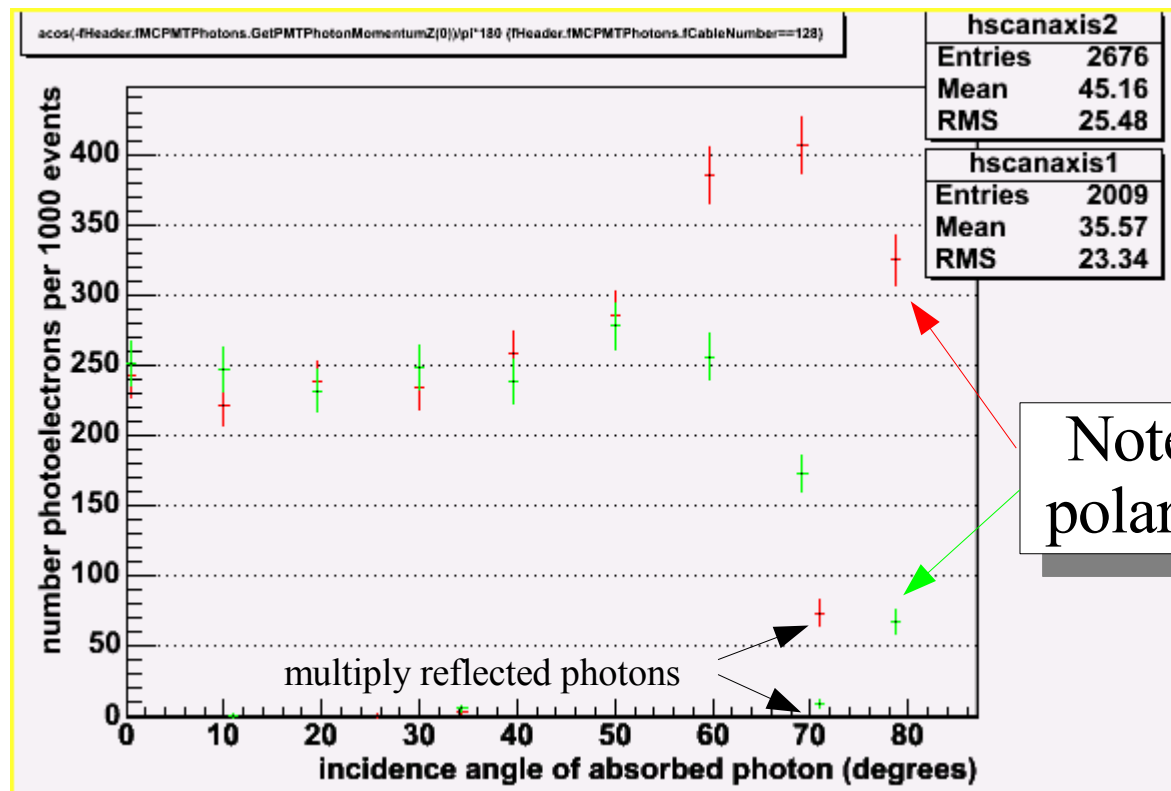
# PMT response vs. photon hit position

Uniformity of hits across tube consistent with geometry (but not actual measurements, needs new code feature to implement)



Position of hits consistent with desired shape.

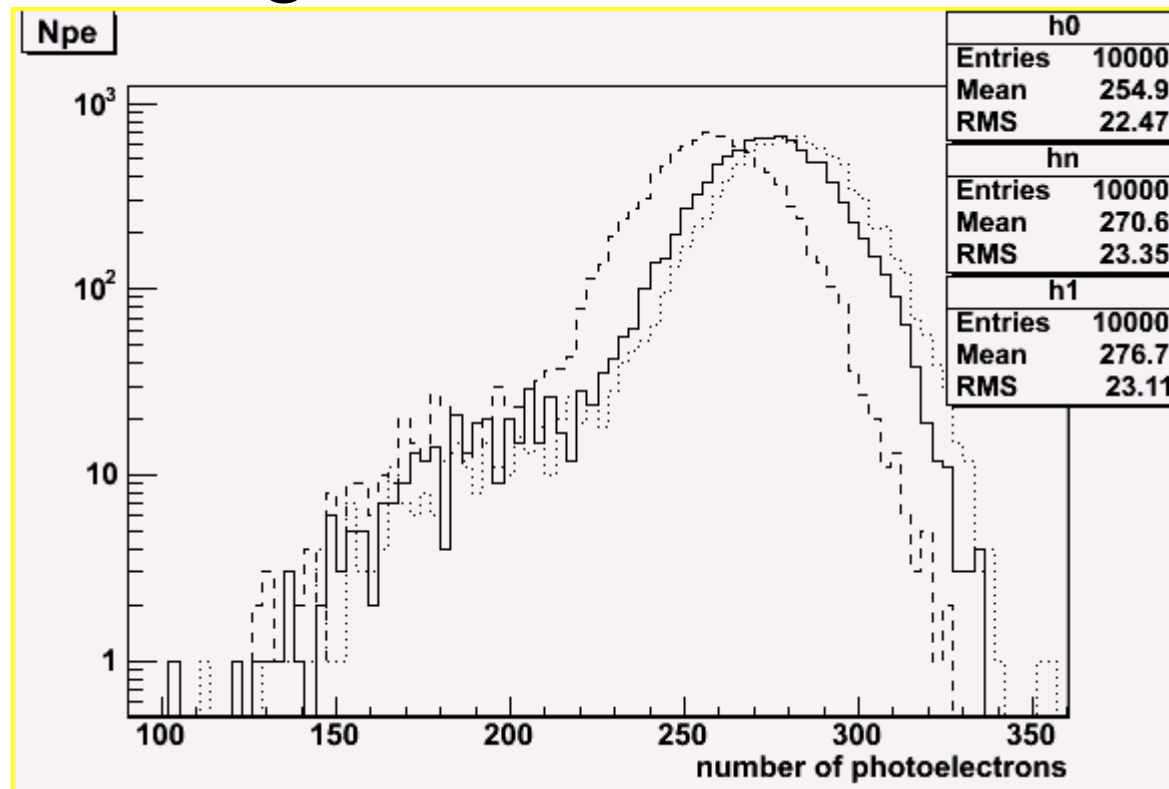
# PMT response vs. photon angle of incidence (here all photons incident on same point of PMT)



Above study done with PMT in oil and full “luxury level” requested for PMTOpticalModel. Behavior is consistent with figures in Motta and Schoenert, NIM A 539 (2005).

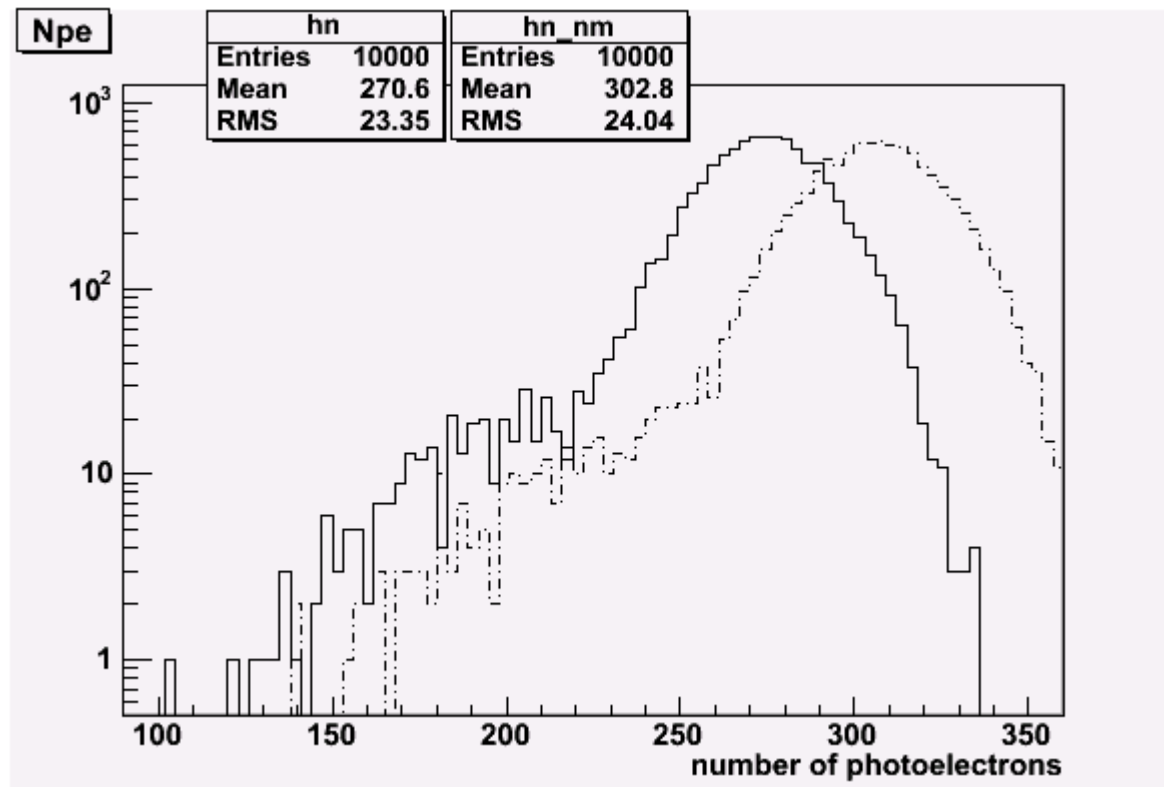
# Masked case

- All configurations have 98.0% efficiency when threshold set to 75% of mean light level.
- Untilted configuration collects 8% less light.



# Unmasked vs. masked

- 192-mm mask takes away 11% of photoelectrons.
- $(192/202)^2 = 0.90$ , so that actually makes sense.





# On the “To Do” list...

(subset of desired new features, in no guaranteed order)

- GLG4Scint upgrade to use better Birk's model for shape-dE/dX dependence
- PMT photocathode response vs. position as explicit table (photoelectron collection efficiency)
  - implemented in KL and DC versions, coming soon to v0.96
- Easily vary optical properties “on the fly”
  - incompatibly implemented in KL and DC versions
- improve the generators interface
  - implemented in Braidwood/RAT version
- Improve code structure and documentation!