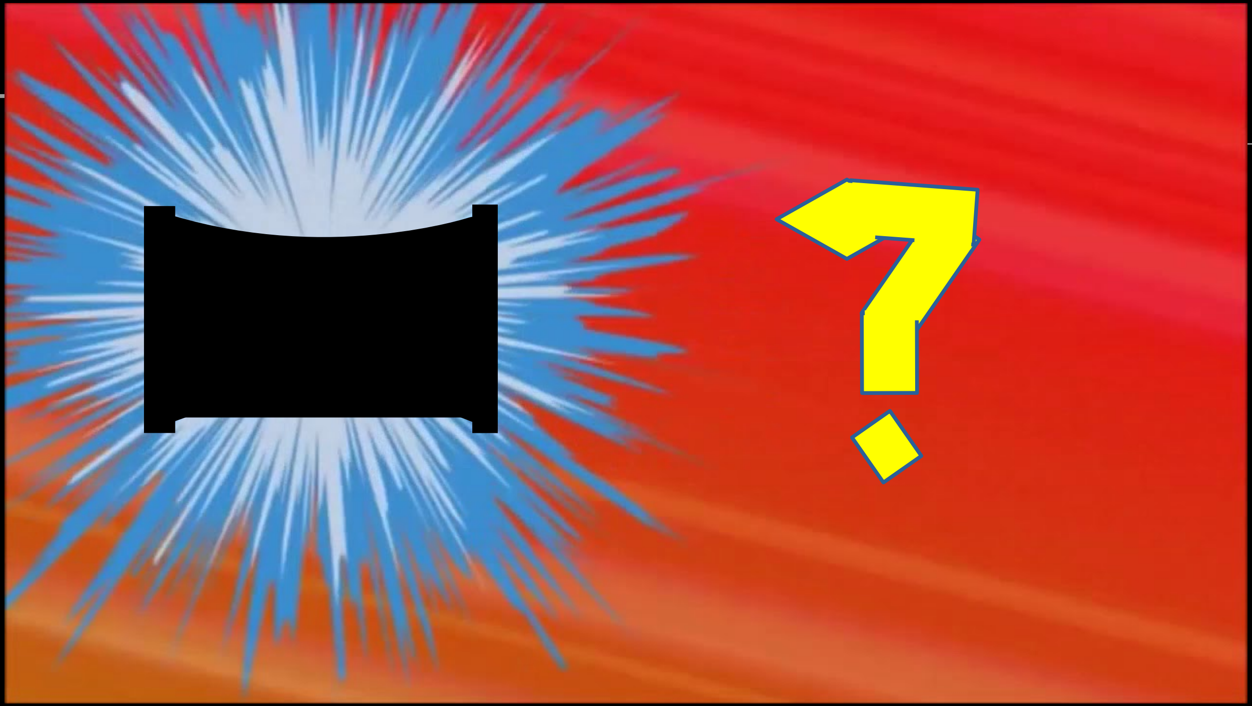
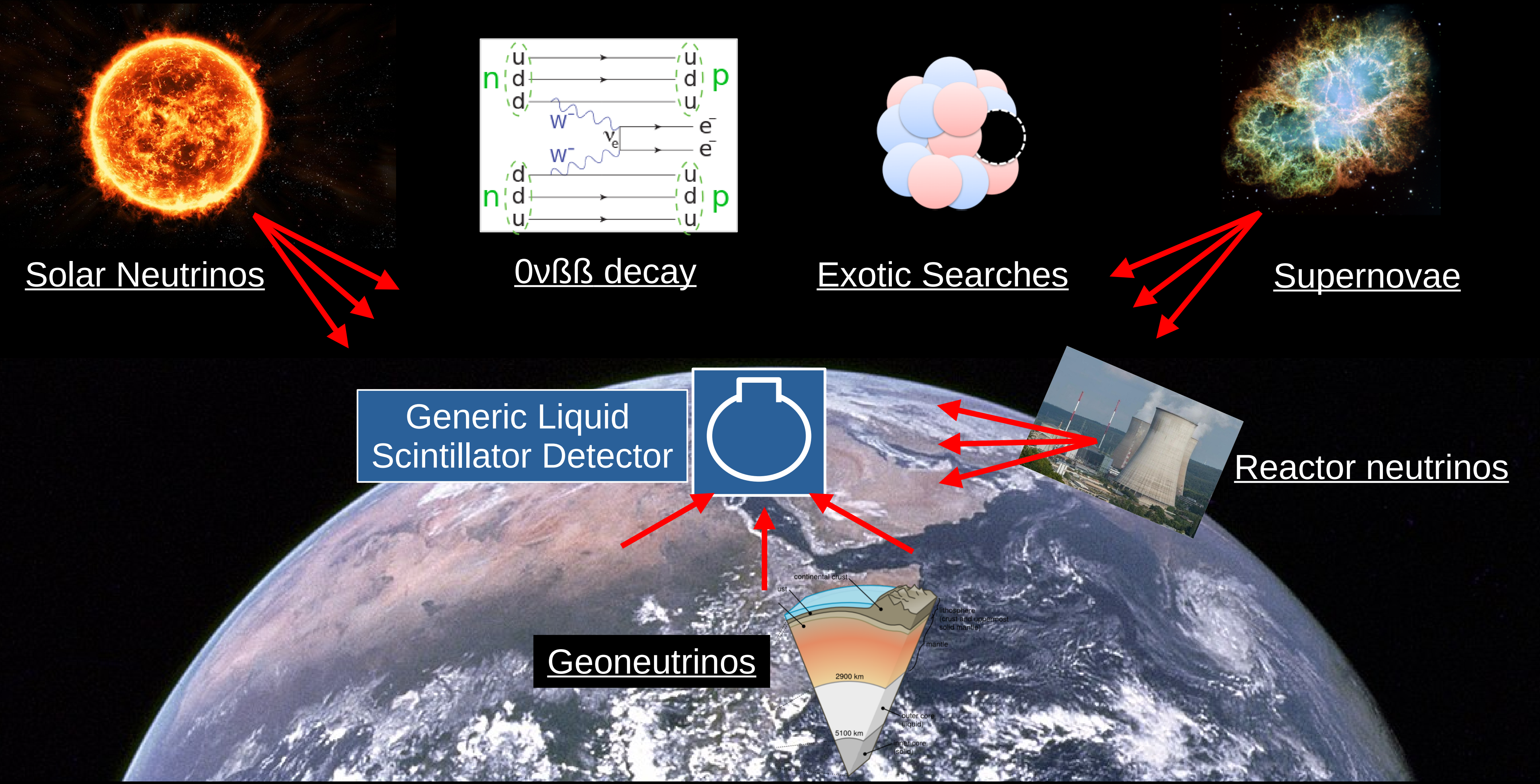
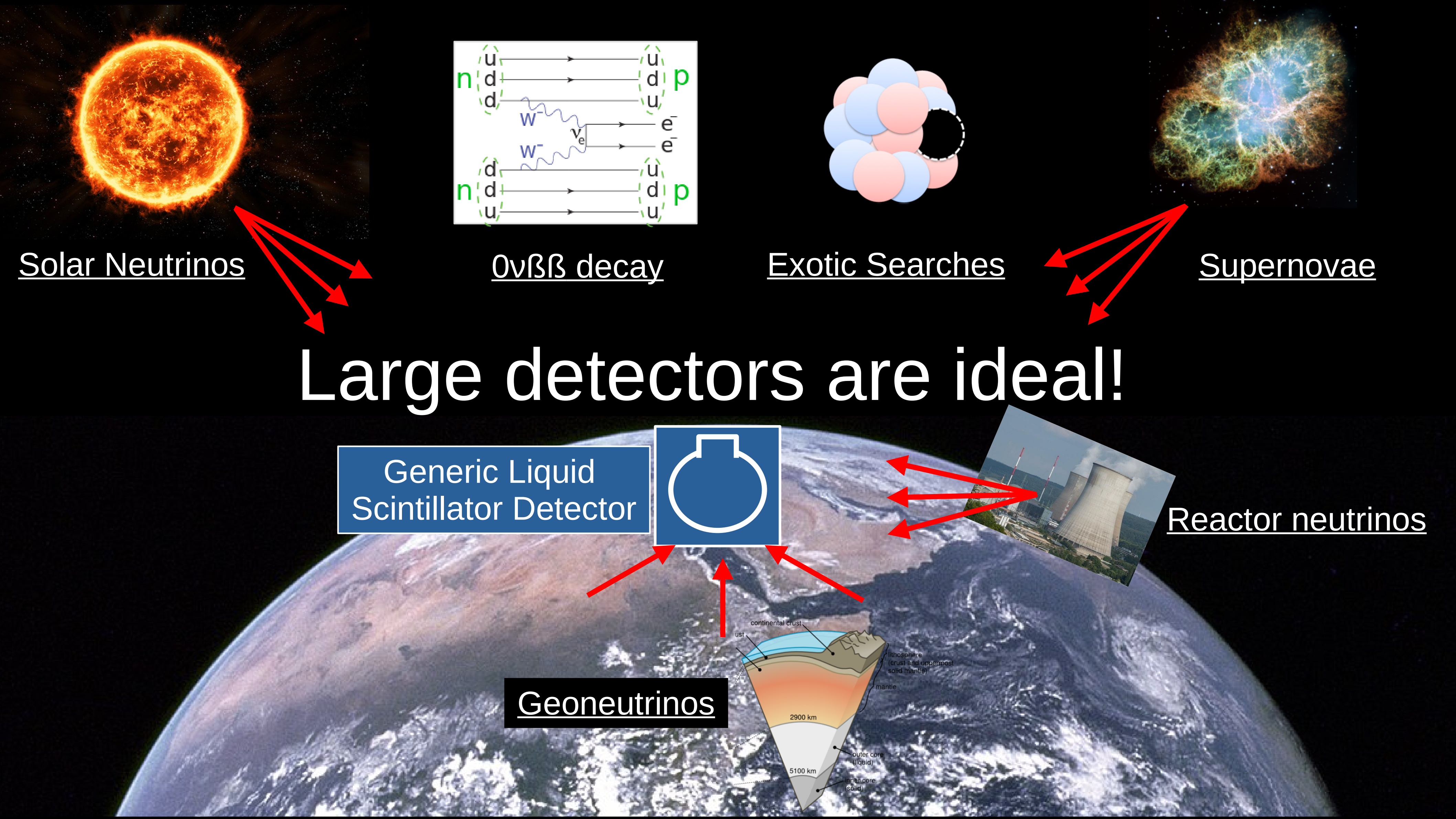


An Alternative Design for Large Scale Liquid Scintillator Detectors

Iwan Morton-Blake University of Oxford

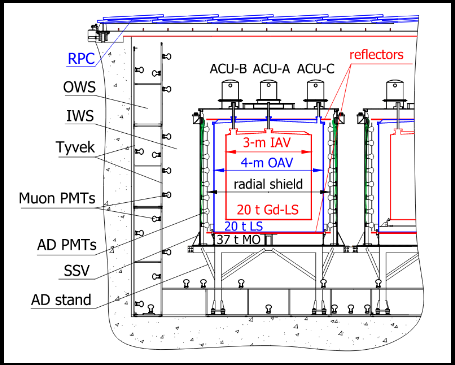
What have liquid scintillator detectors ever done for us?



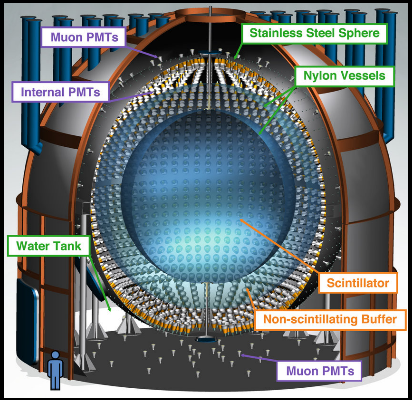


Solar Neutrinos
n
p
W⁻
ν_e
e^-
0νßß decay
Exotic Searches
Supernovae
Large detectors are ideal!
Generic Liquid Scintillator Detector
Reactor neutrinos
Geoneutrinos
continental crust
lithosphere (crust and uppermost solid mantle)
mantle
2900 km
outer core (liquid)
5100 km
inner core (solid)

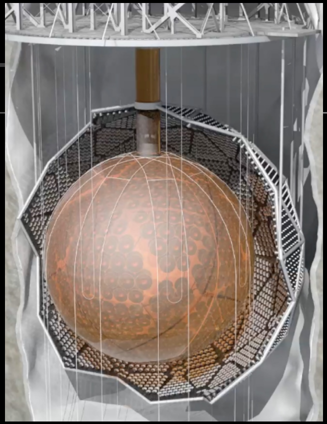
Liquid scintillator detectors are getting larger and larger...



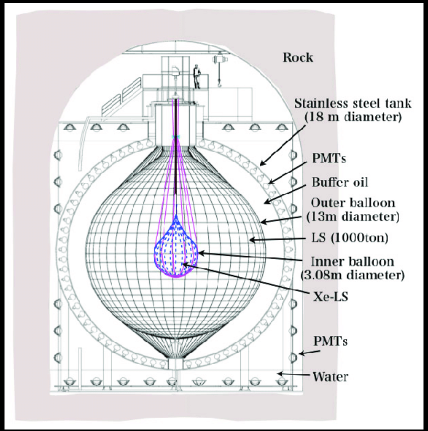
Daya Bay 8 x 20t



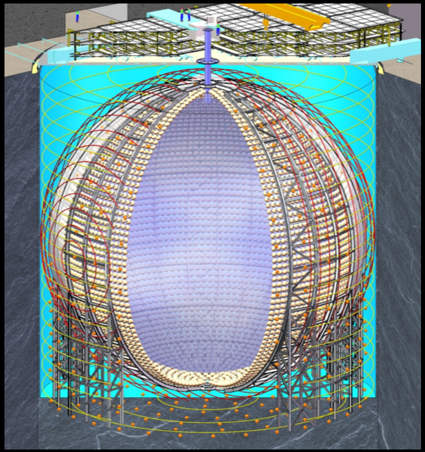
Borexino ~300t



SNO+ ~1000t

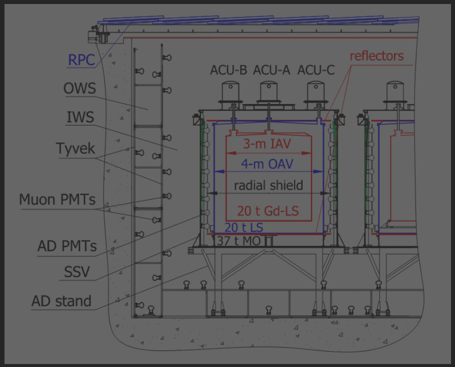


KamLAND ~1000t



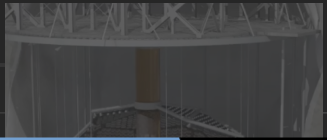
JUNO ~20,000t

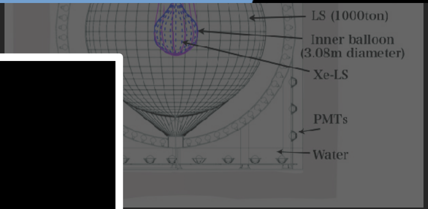
Liquid scintillator detectors are getting larger and larger



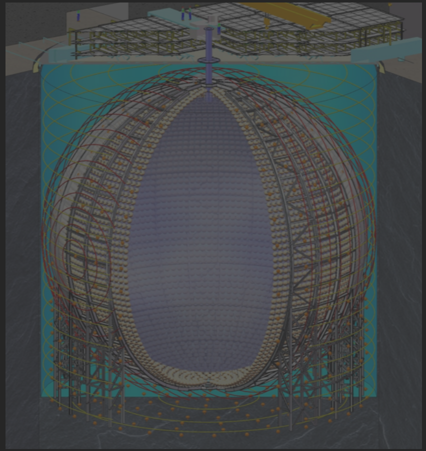
Daya Bay 8 x 20t

Borexino ~300t

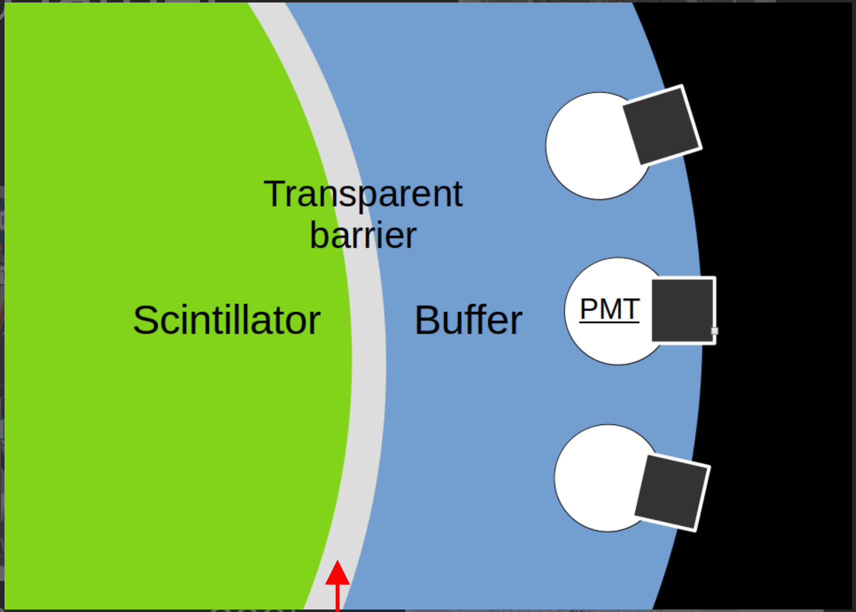




LAND ~1000t

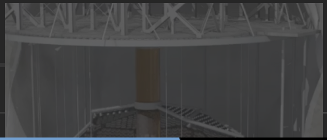


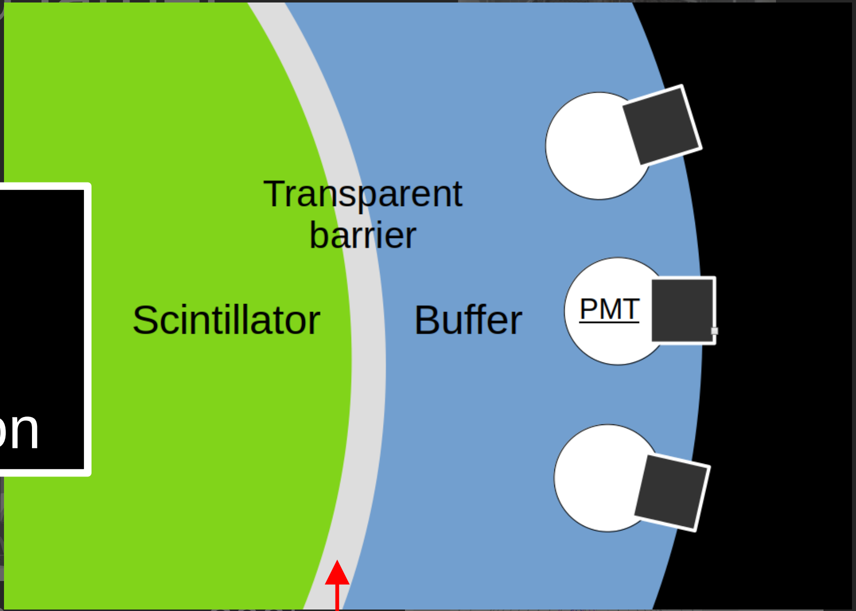
JUNO ~20,000t



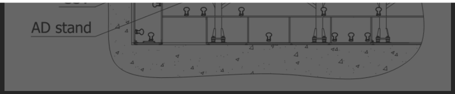
Common to all:
A barrier separating the scintillator from
The detector structure’s radiation + PMTs

Liquid scintillator detectors are getting larger and larger



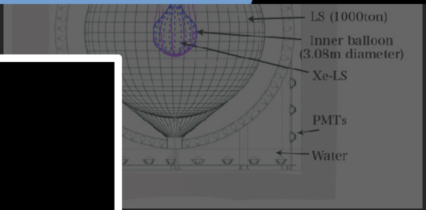


Transparent Barriers:
- Difficult to build
- Contributes Contamination

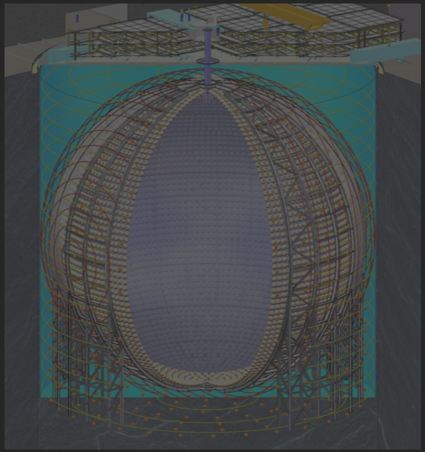


Daya Bay 8 x 20t

Borexino ~300t



KamLAND ~1000t



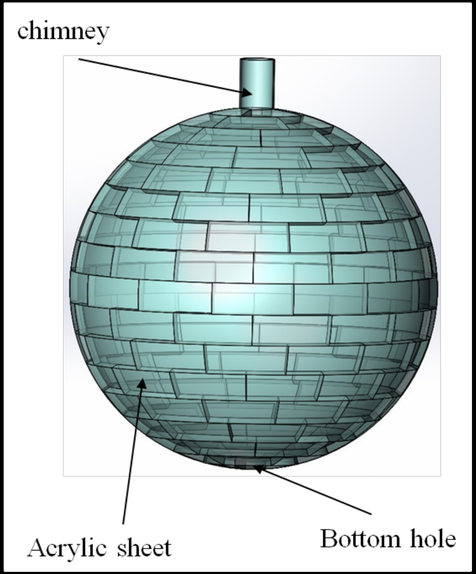
JUNO ~20,000t

Common to all:
A barrier separating the scintillator from
The detector structure's radiation + PMTs

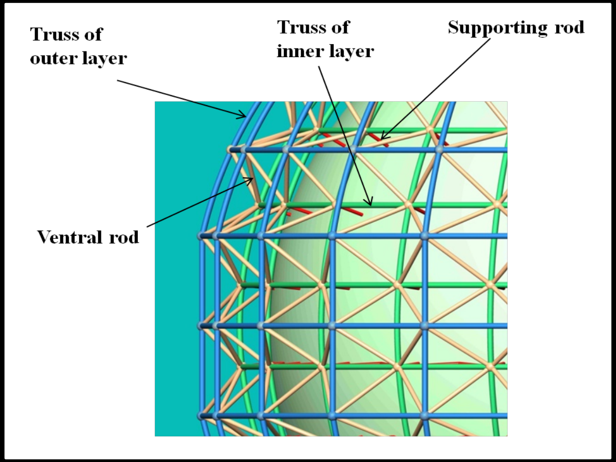
Increasing Size → Increasing Complexity

e.g. JUNO : 20kt

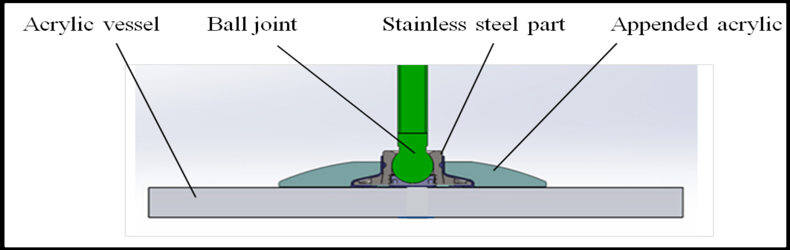
Construction of the Acrylic Vessel



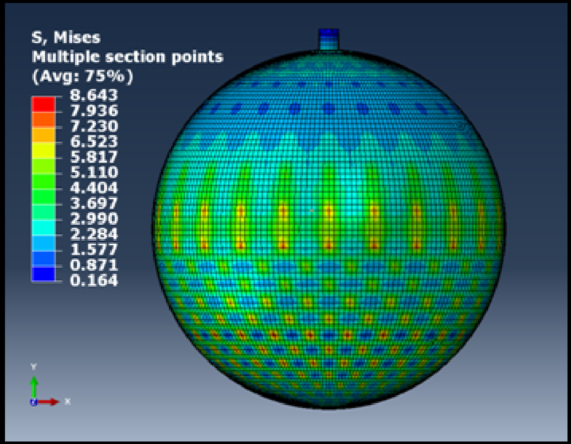
Stainless-steel Support Structure



Support Joints for the Acrylic Vessel



Acrylic Vessel Stress Distribution

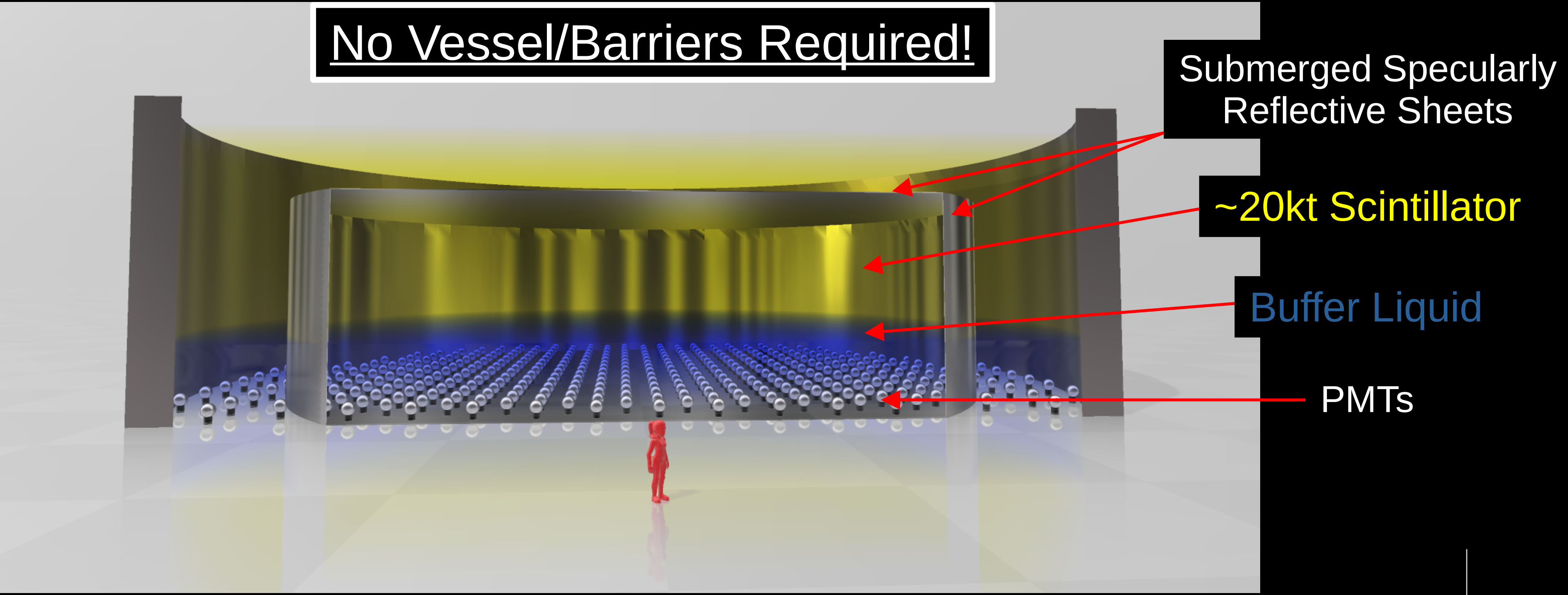


Images taken from the
JUNO Conceptual Design Report [1]

An Alternative Design?

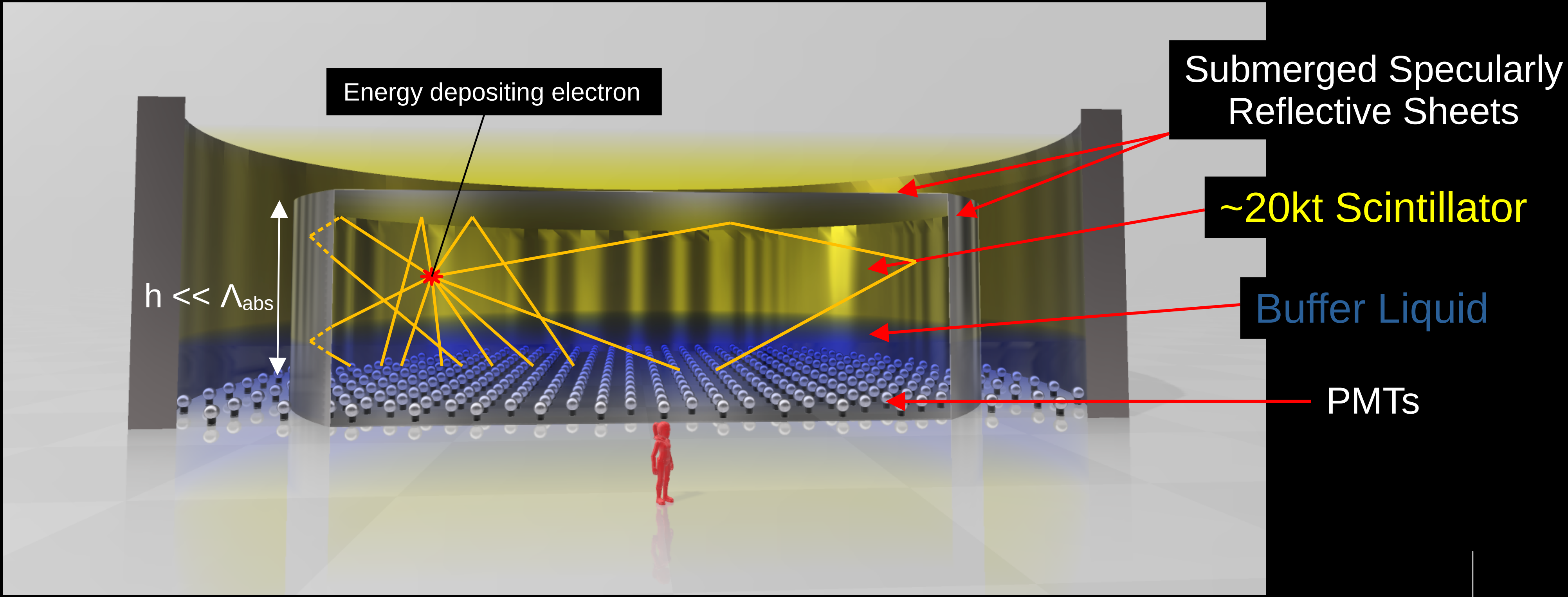
Stratified LIquid Plane Scintillator: SLIPs

Use Immiscible Liquids:
Float the less-dense scintillator on top of the buffer liquid

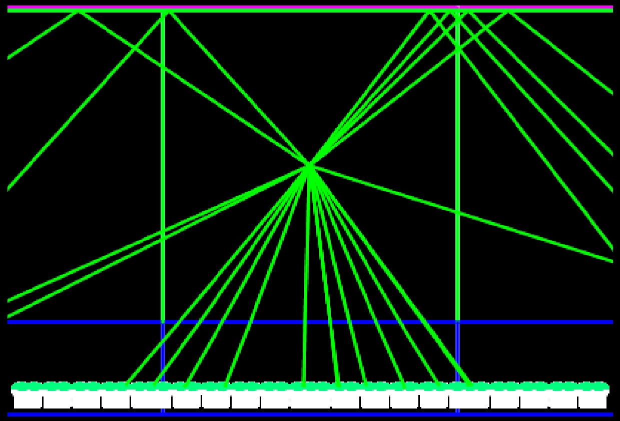


Stratified LIquid Plane Scintillator: SLIPS

Use Immiscible Liquids:
Float the less-dense scintillator on top of the buffer liquid

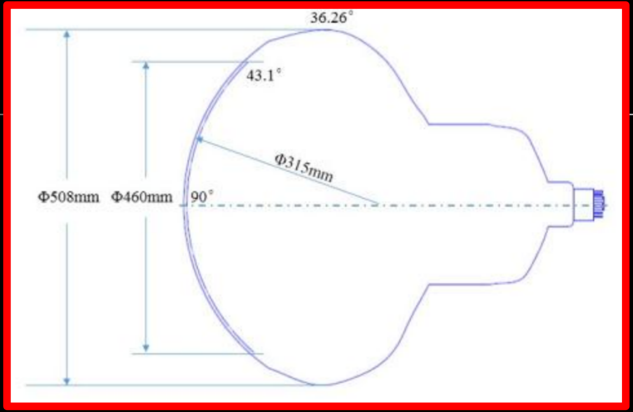


Performance Testing Simulation in GEANT4

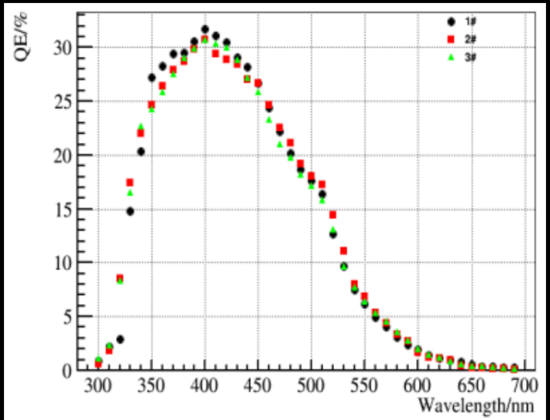


Photomultiplier Tubes

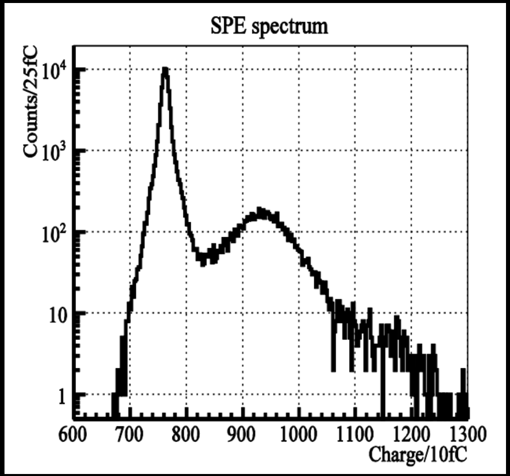
Plots taken from [2]



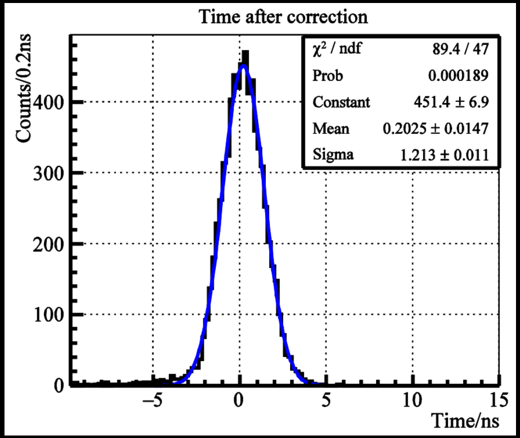
Chose 20” r12860 Hamamatsu PMTs
for testing in simulations



Quantum Efficiency
~30% @ 400nm



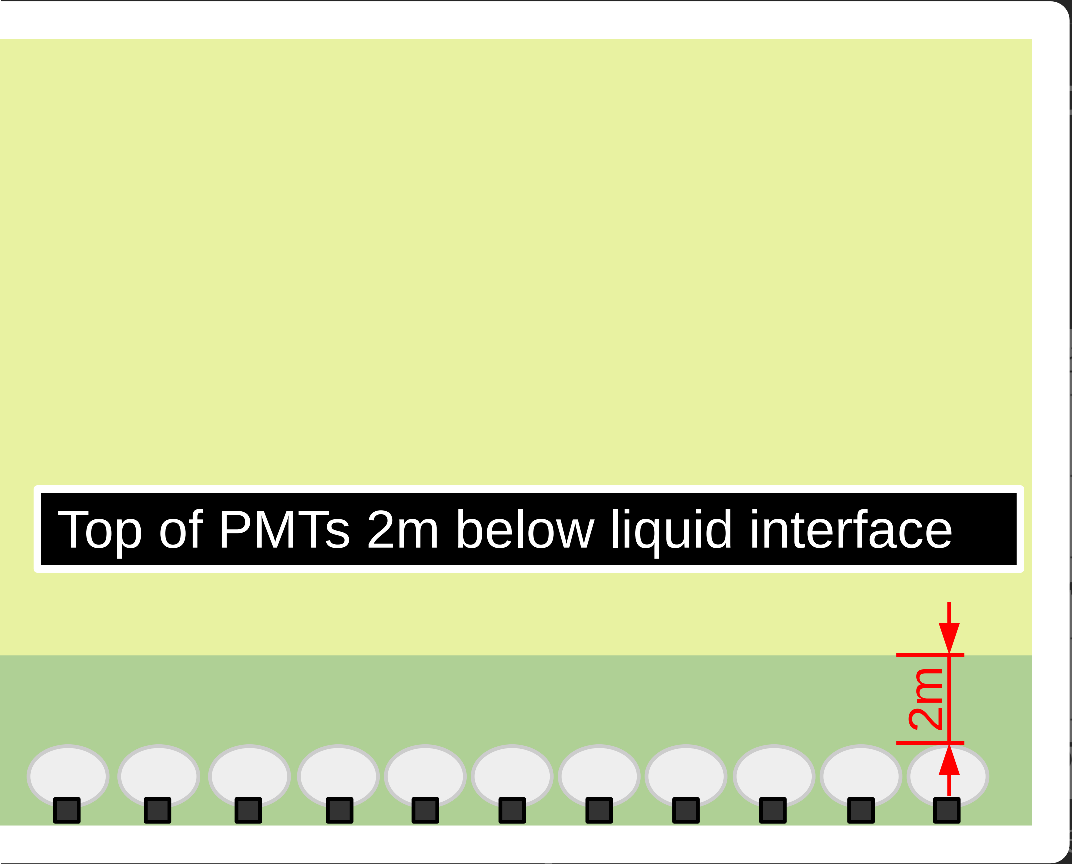
Single photoelectron
Peak/Valley ratio = 4.75



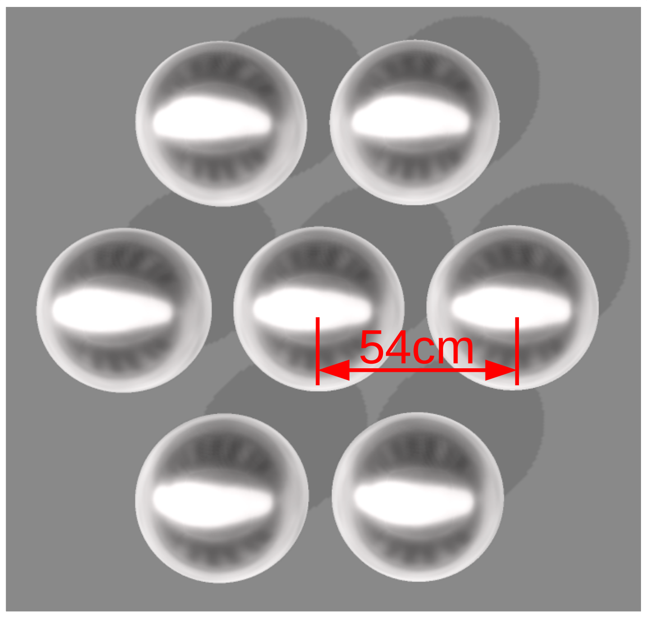
Transit Time Spread
(FWHM) = 2.86ns

Photomultiplier Tubes

Plots taken from [2]



PMTs arranged hexagonally - 54cm centre-centre



~30% @ 400nm

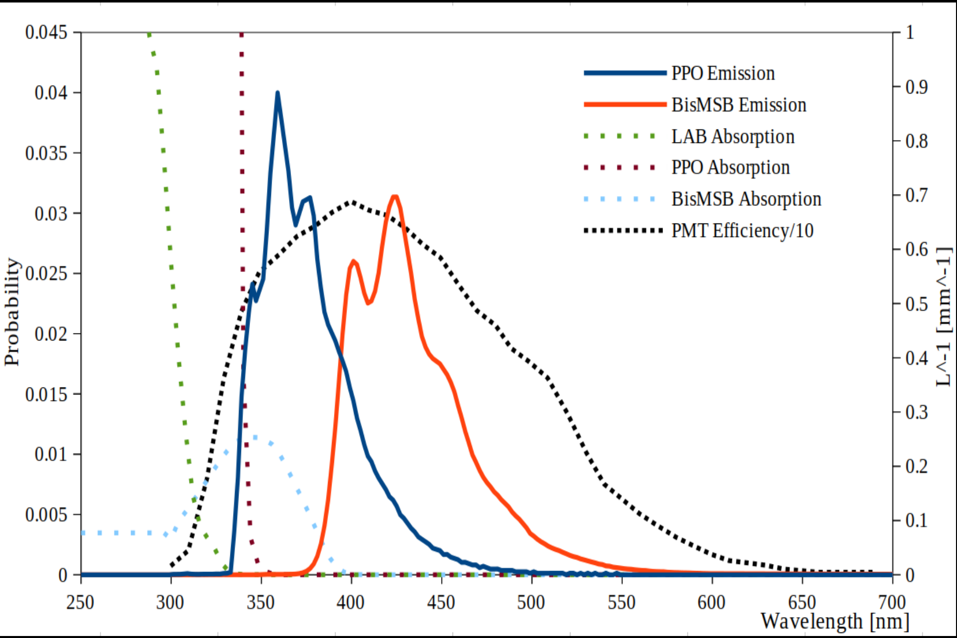
electron
Peak/Valley ratio = 4.75

Transit Time Spread (FWHM) = 2.86ns

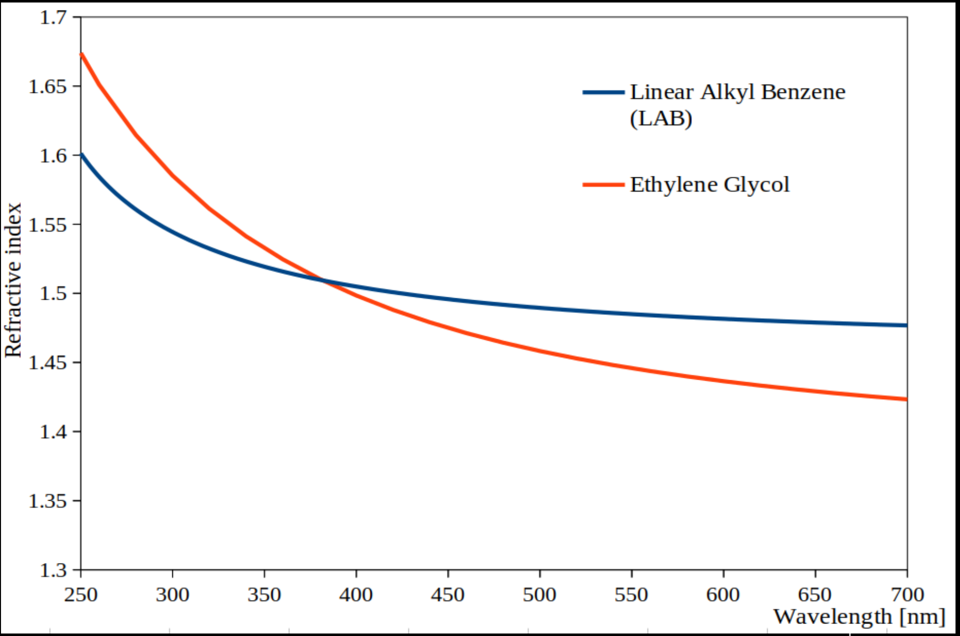
Scintillator + Glycol Buffer

Tested using SNO+ cocktail: LAB + 2g/L PPO + 15mg/L bisMSB

Scintillation Light Emission Spectra & PMT Collection Efficiency



Scintillator + Glycol Refractive Index



Scintillator + Glycol Buffer

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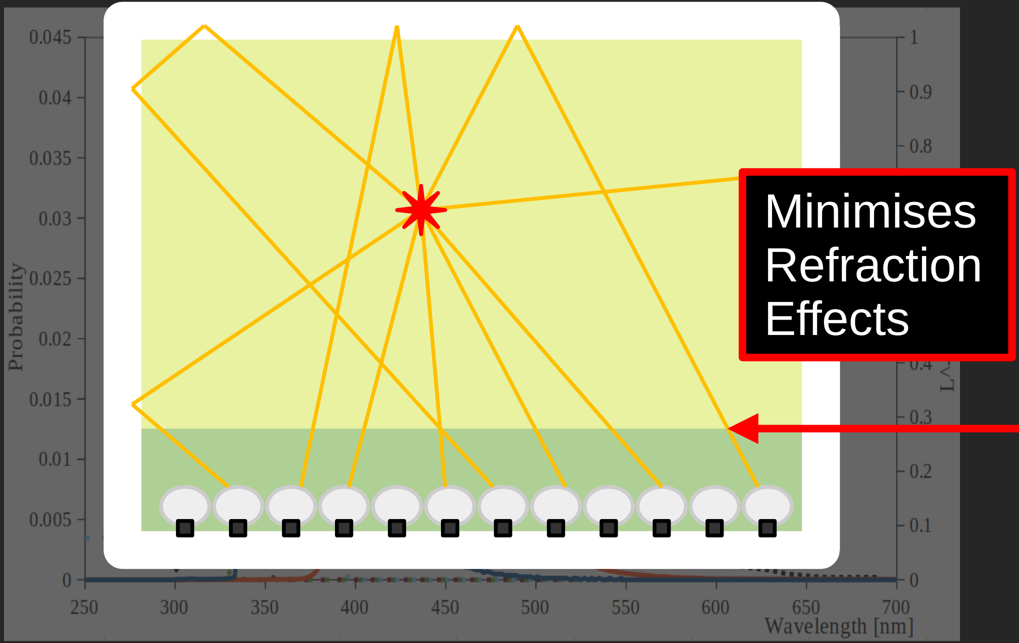
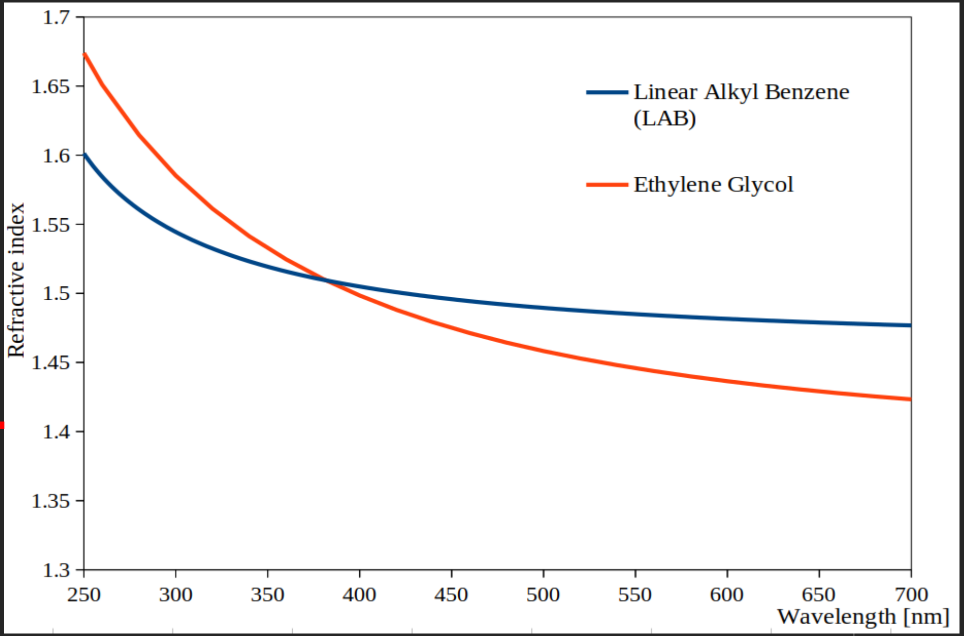
Scintillation Light Emission Spectra & PMT Collection Efficiency

Scintillator + Glycol Refractive Index

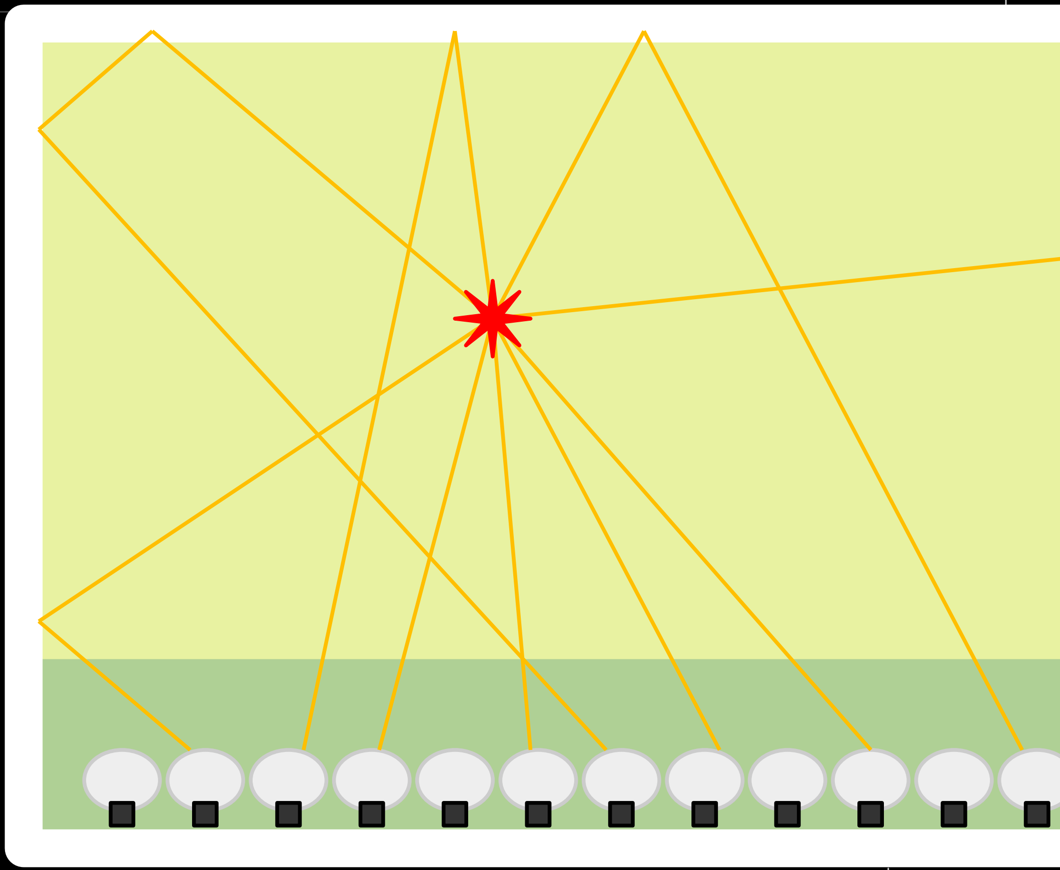




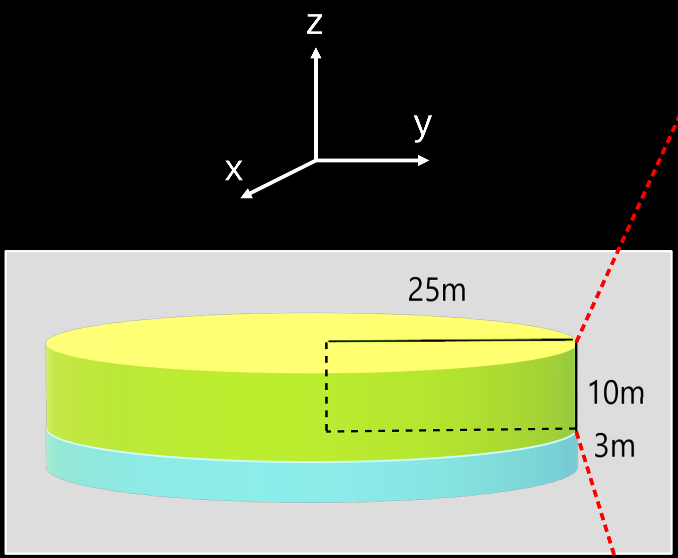
Light Yield

↓

(Energy/Position Resolution)

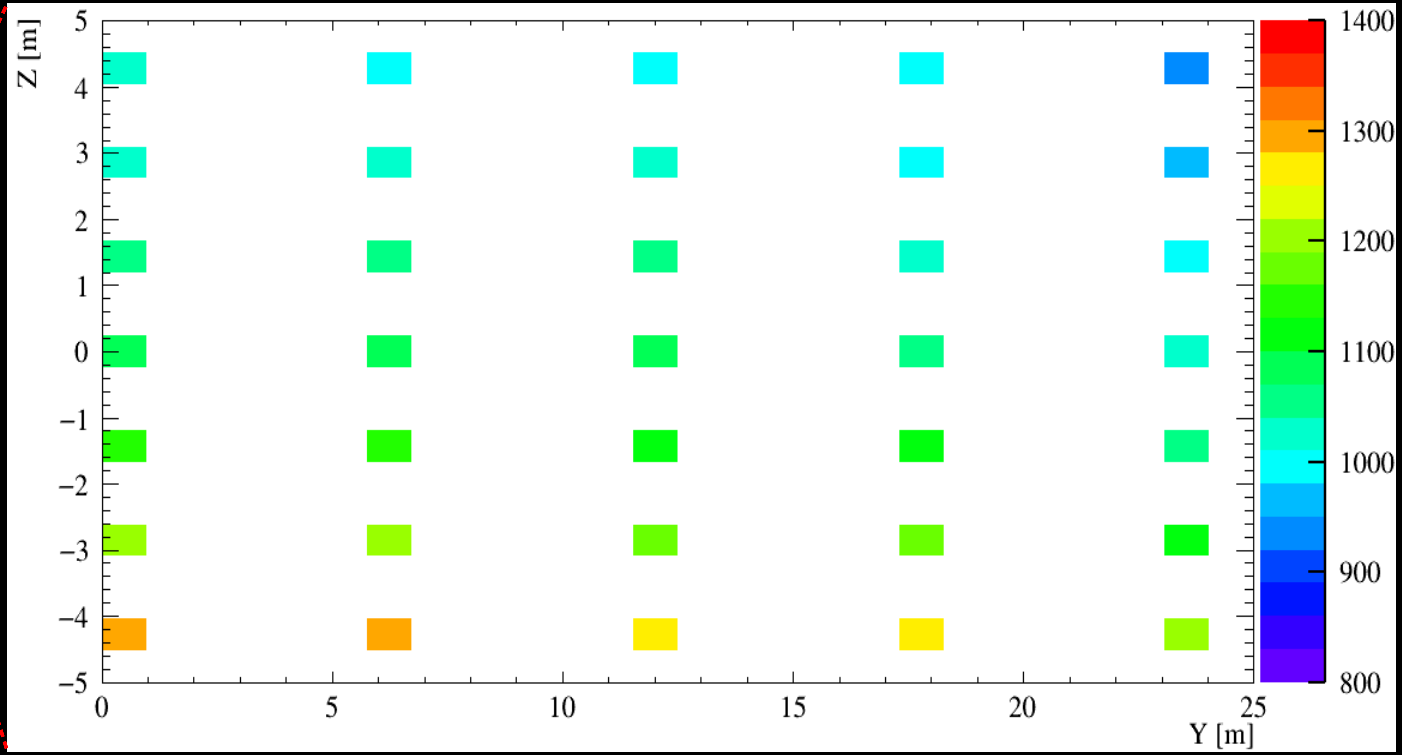


Light Yield

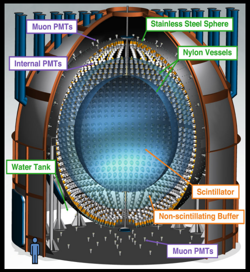


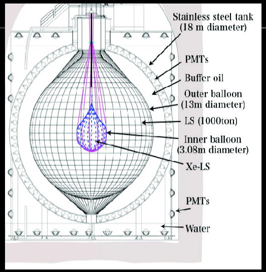
Total photoelectrons produced on PMTs by 1MeV electrons vs position

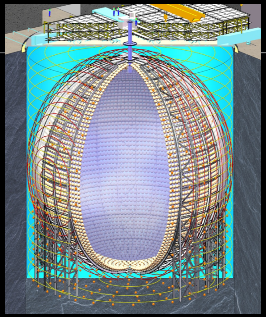
~1100 p.e./MeV

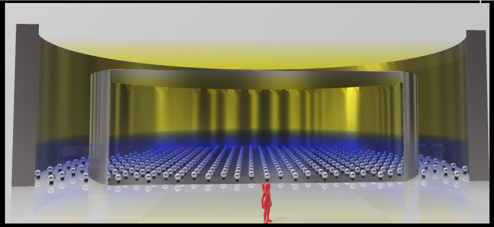


Light Yield



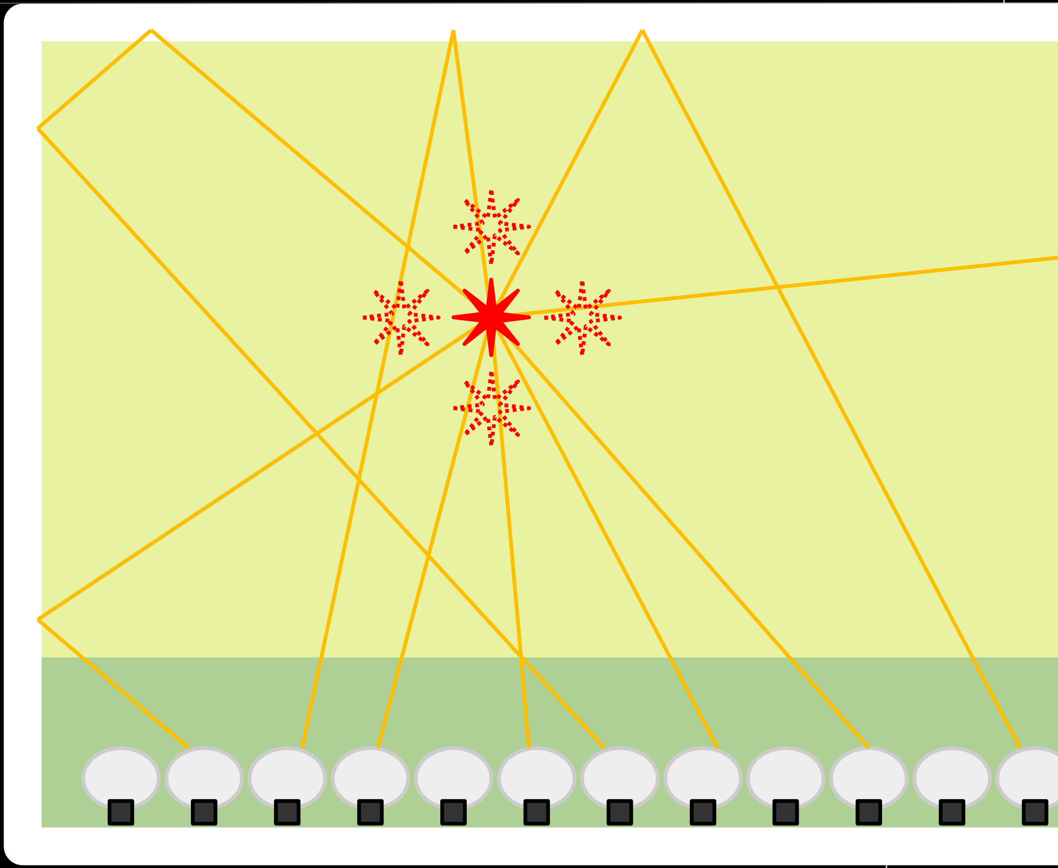




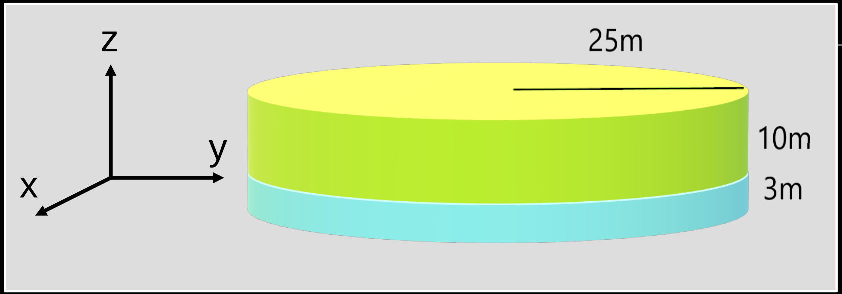


	Borexino [3] [4]	**KamLAND** [5]	**JUNO** [6]	**SLIPS**
Target Mass	300t	1kt	20kt	20kt
Num. PMTs	~2200	~1900	~20,000	~8000
Light Yield (photoelectrons/MeV)	~450	~200	>1200	~1100

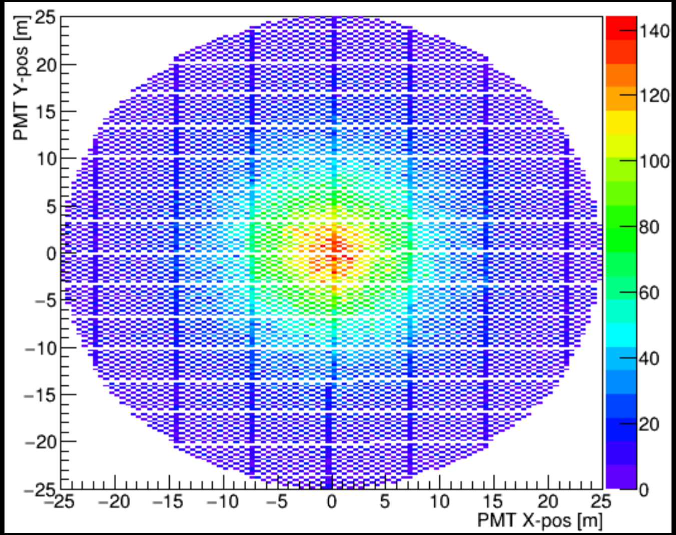
Position Reconstruction



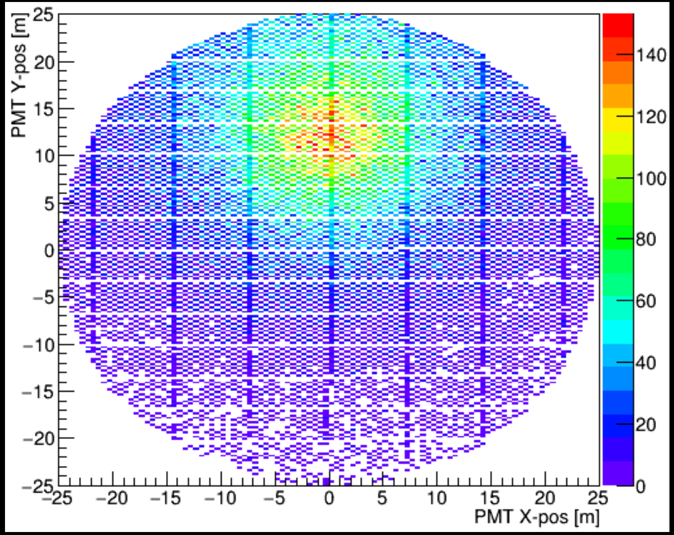
XY - Position Reconstruction



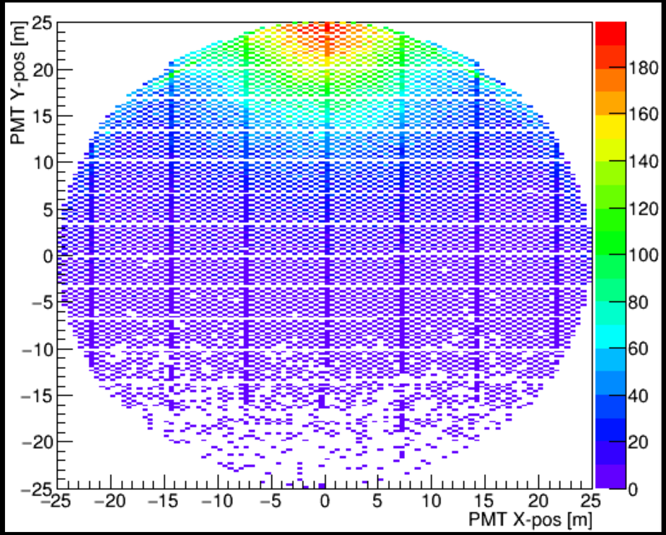
PMT Hit Density: e^- @ (x,y)=(0,0)



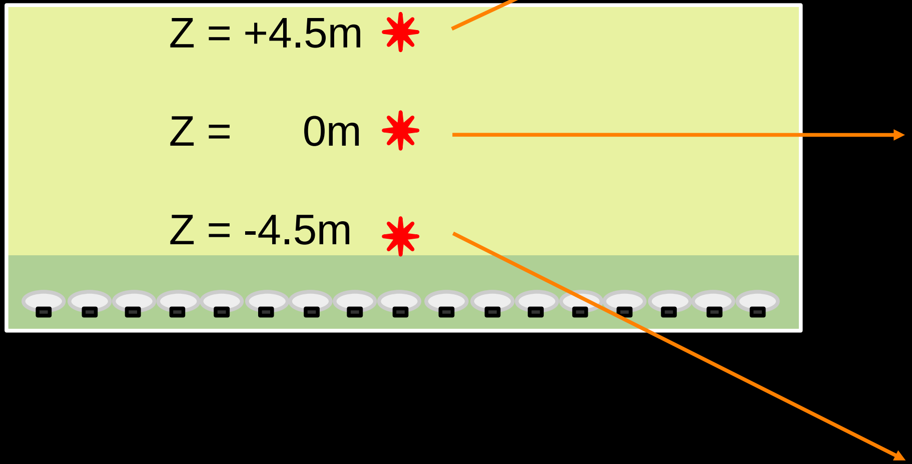
e^- @ (0,12)m



e^- @ (0,24.5)m

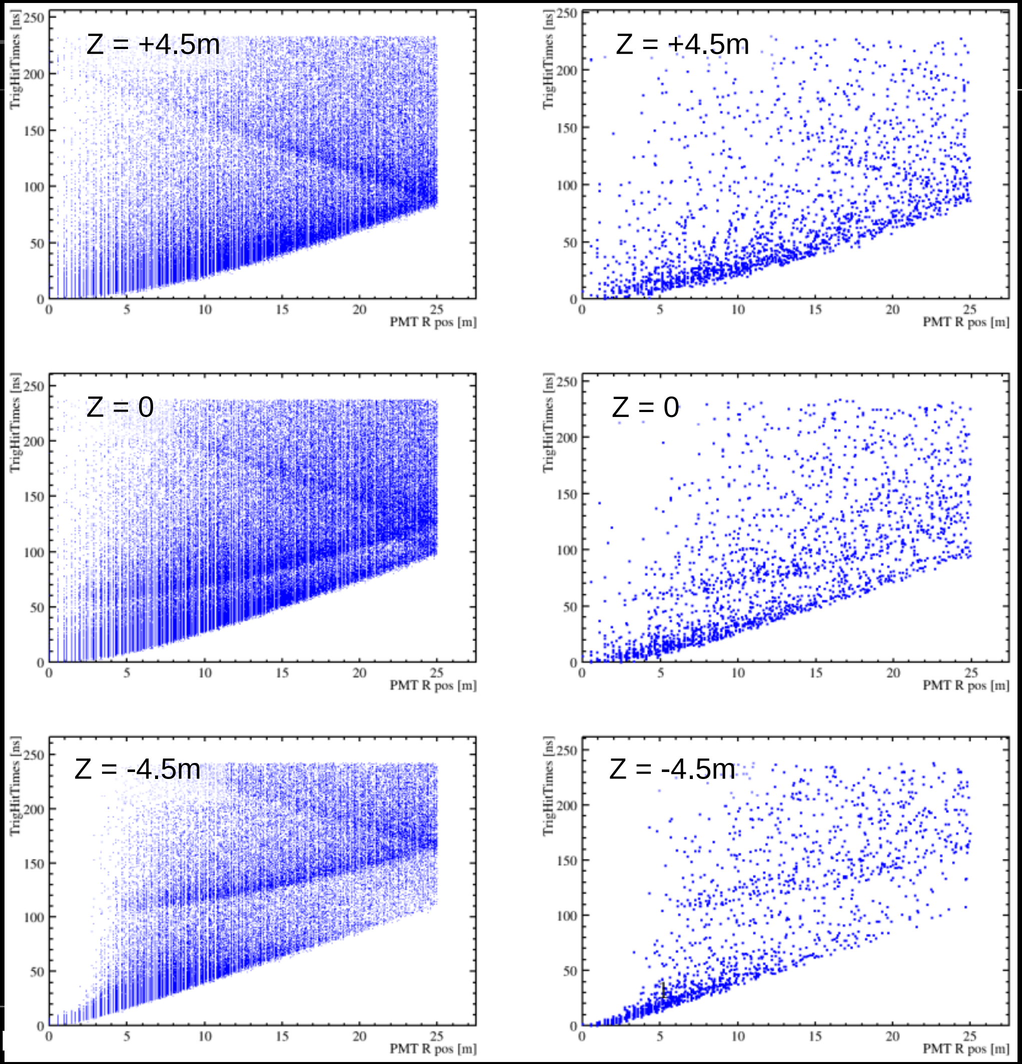


PMT hit times vs PMT Radius



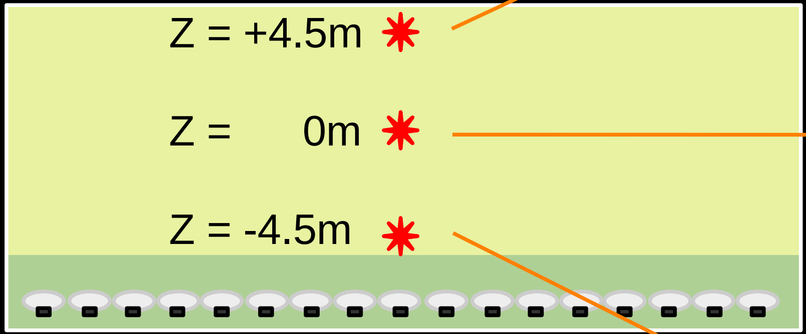
Many e⁻ events

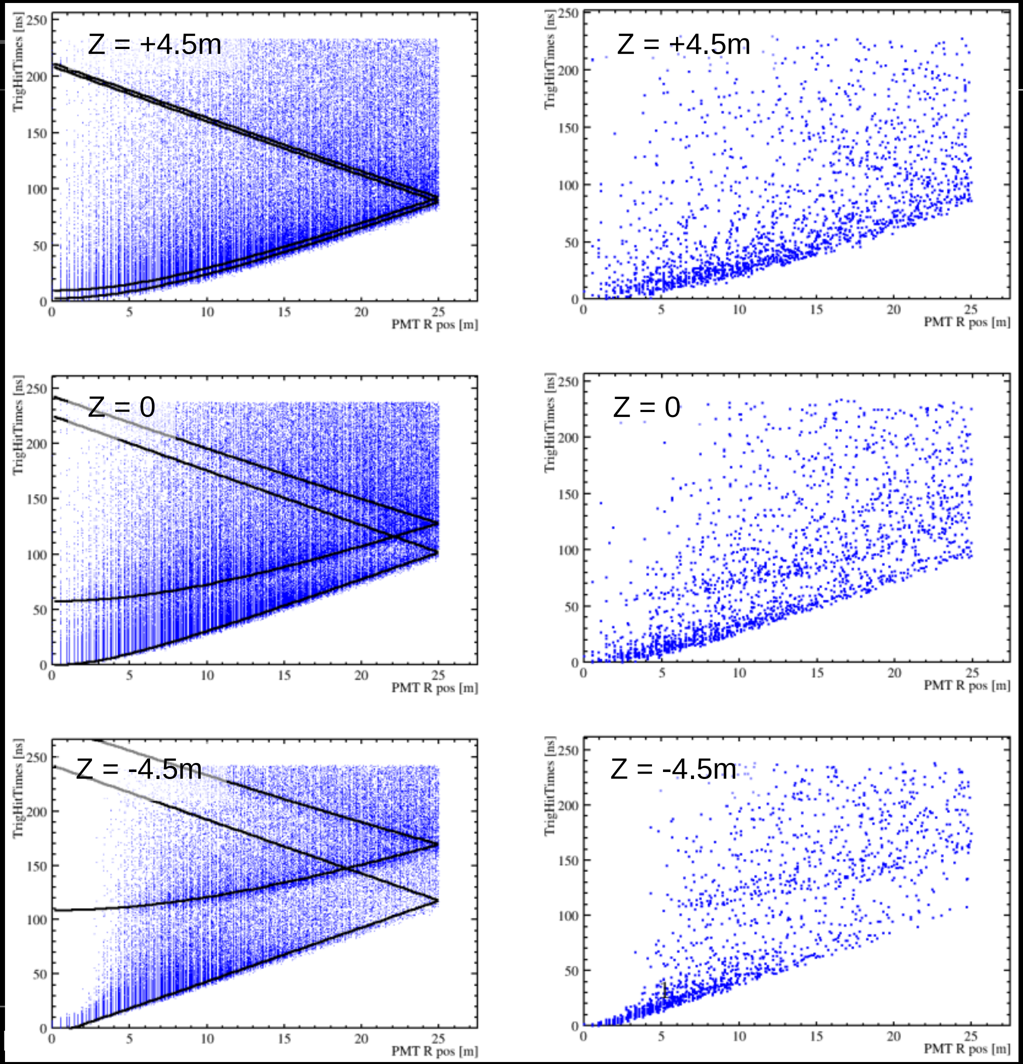
Single 3MeV event



Analytically Calculating Wavefront Times

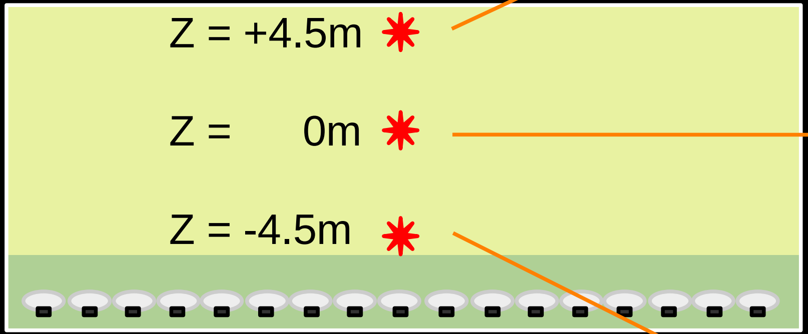
PMT hit times vs PMT Radius

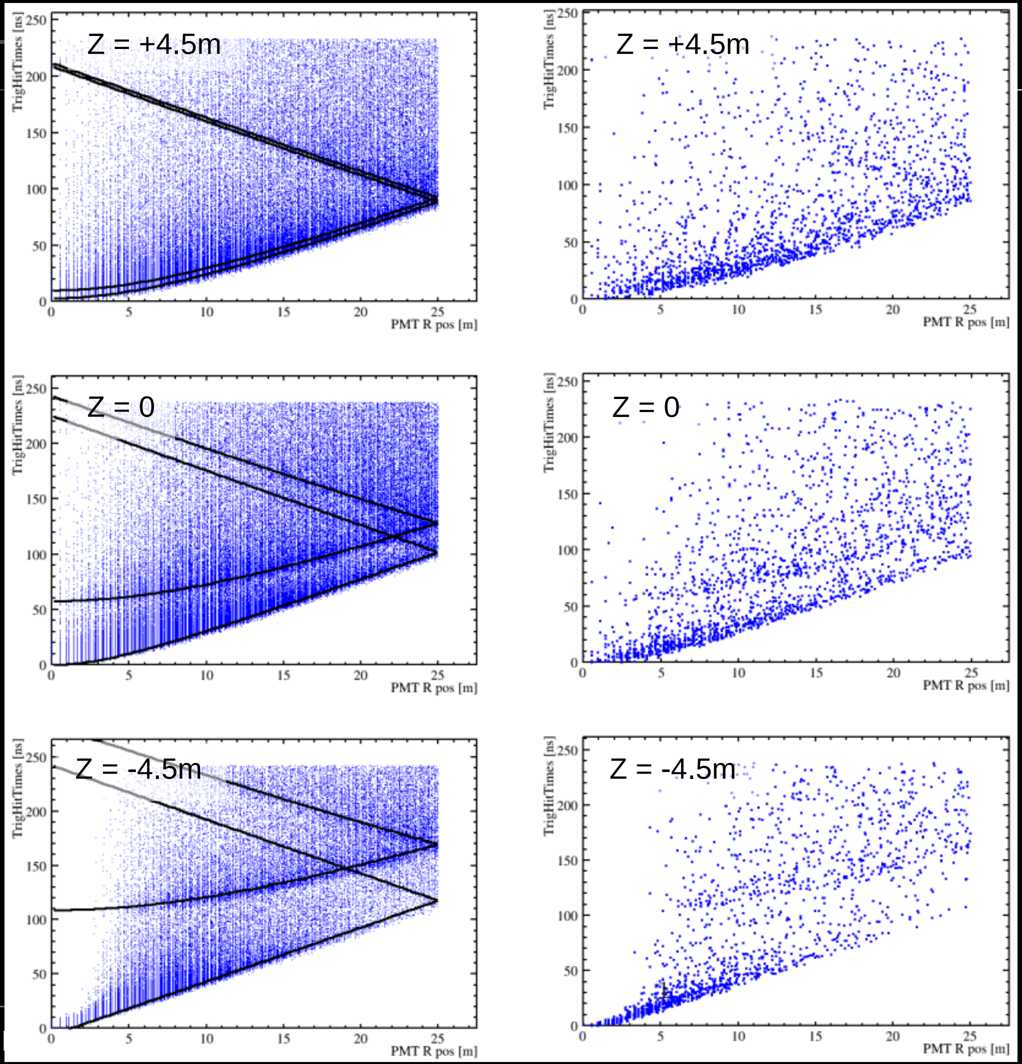




Analytically Calculating Wavefront Times

PMT hit times vs PMT Radius

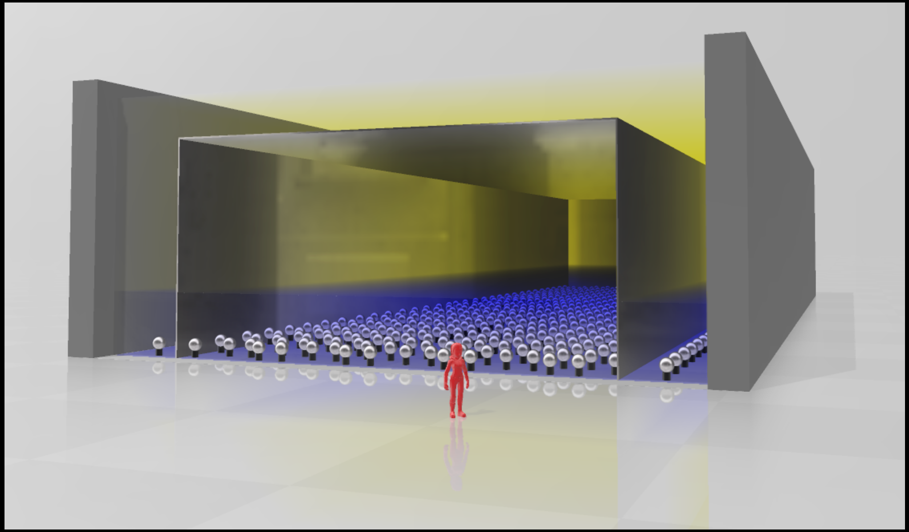




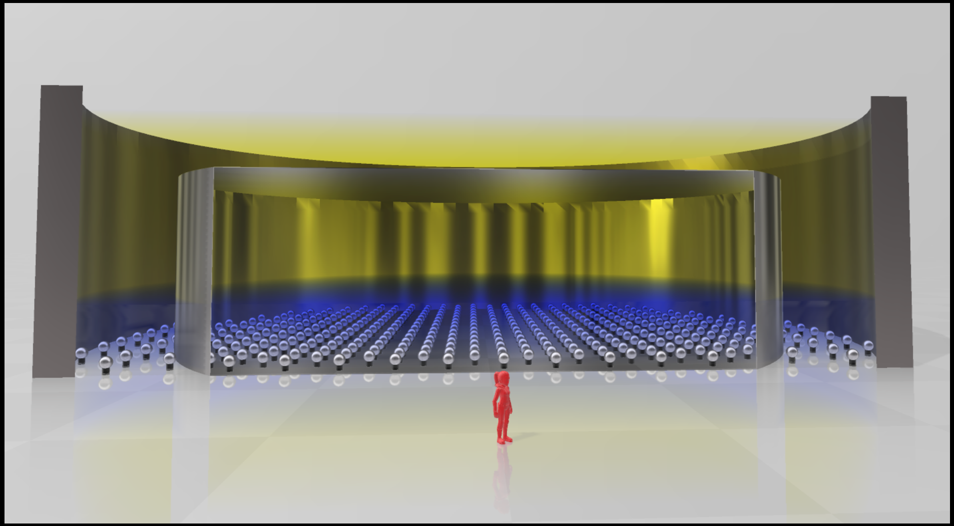
Likelihood fits of PMT hit time distributions
z-position resolution:
$\sigma_z \sim$ 8cm

Even Simpler Designs

“Cuboid”



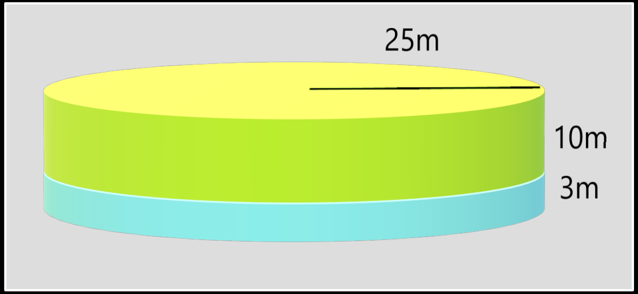
“Pancake”

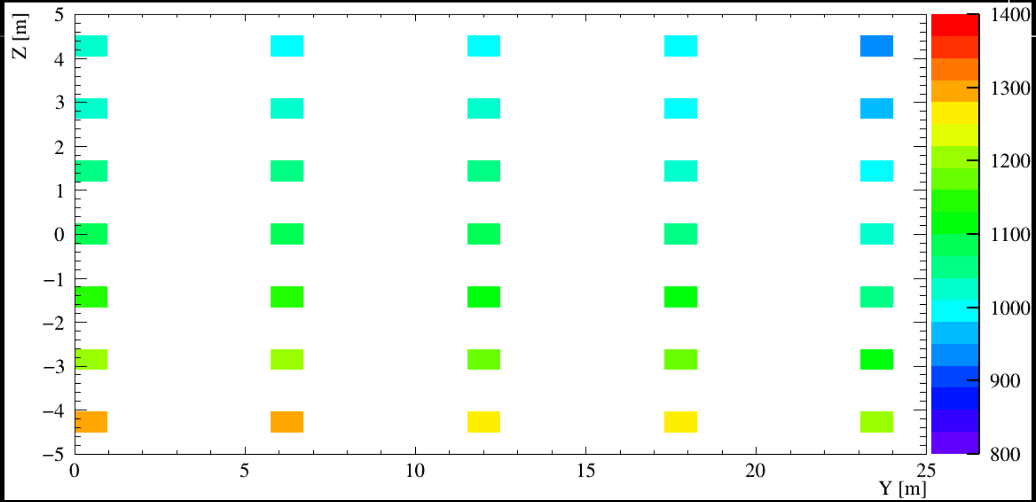


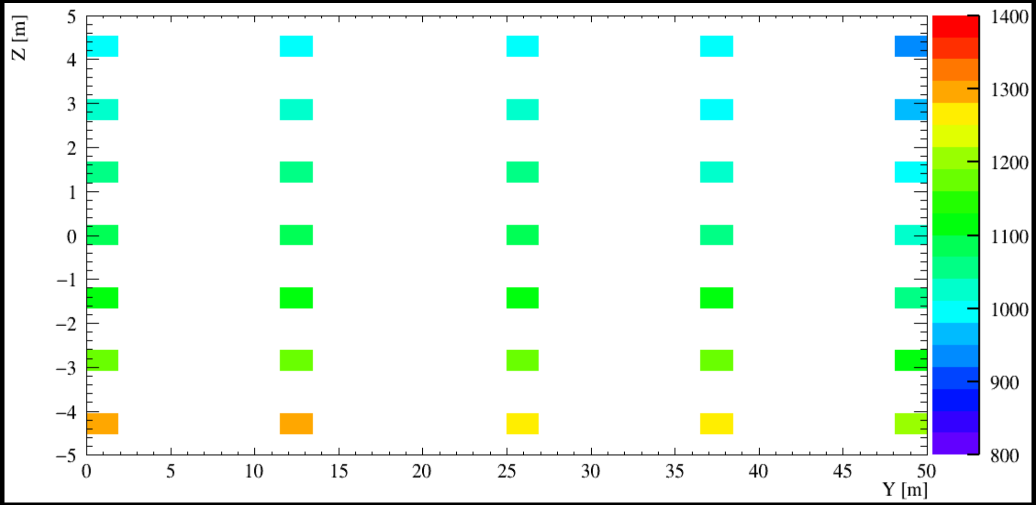
+ Simpler Construction
+ Easier Narrow Cavern Excavation
- Worse Position Reconstruction (more reflections in a narrow detector)

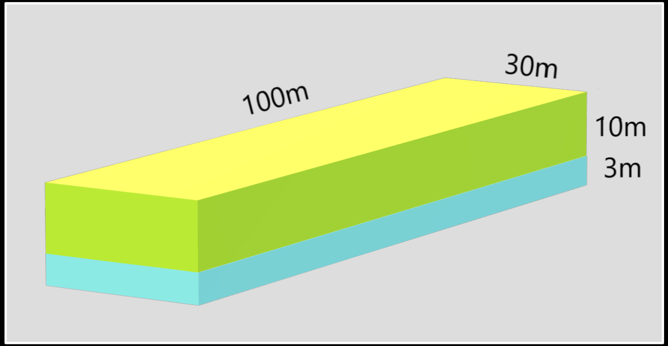
Light Yield

Total photoelectrons produced on PMTs by 1MeV electrons around the detector



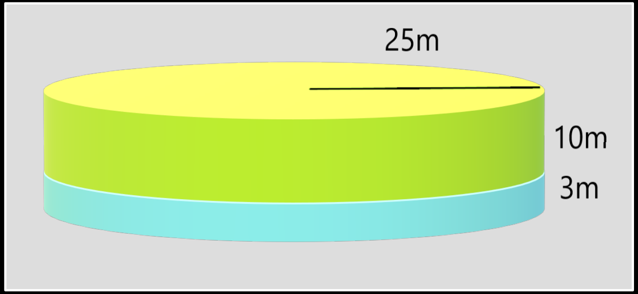


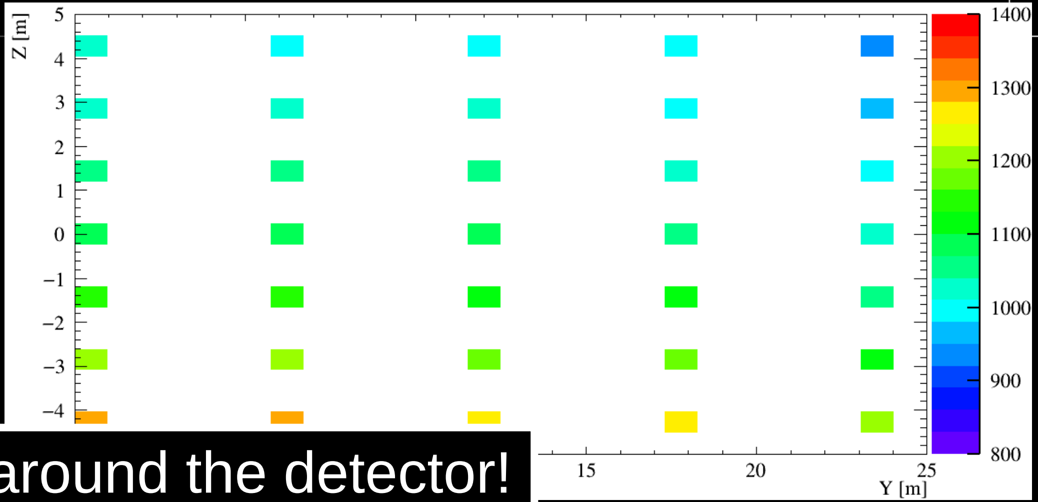




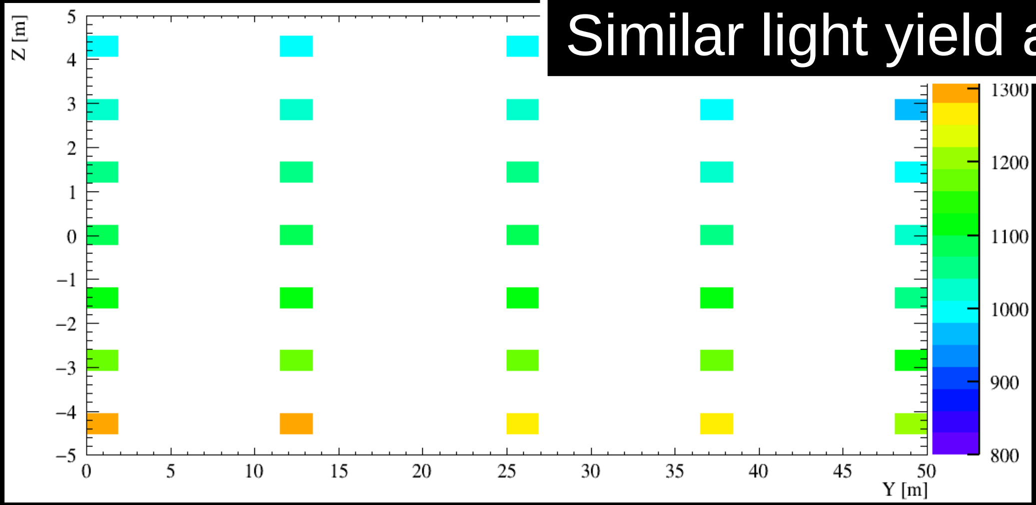
Light Yield

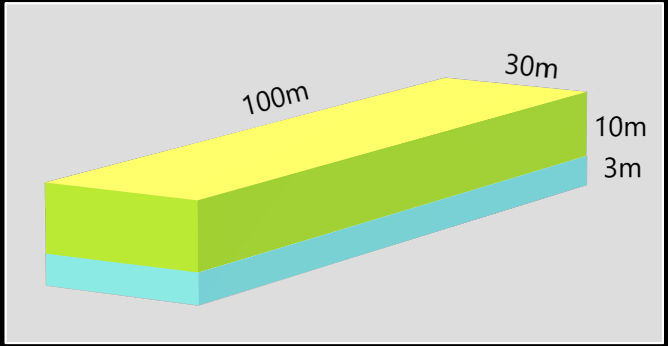
Total photoelectrons produced on PMTs by 1MeV electrons around the detector



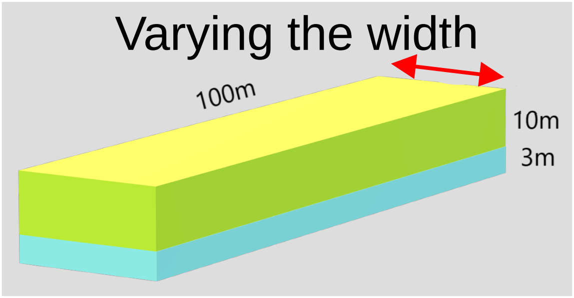


Similar light yield around the detector!

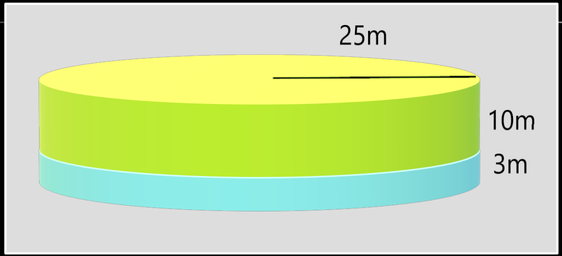




Cuboid: Minimum Detector Width

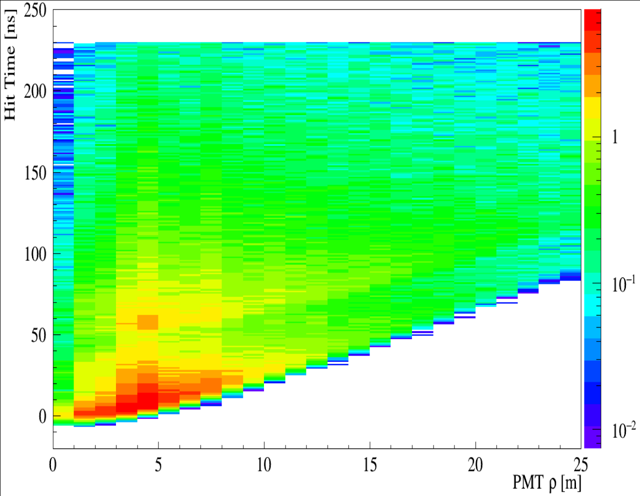


VS

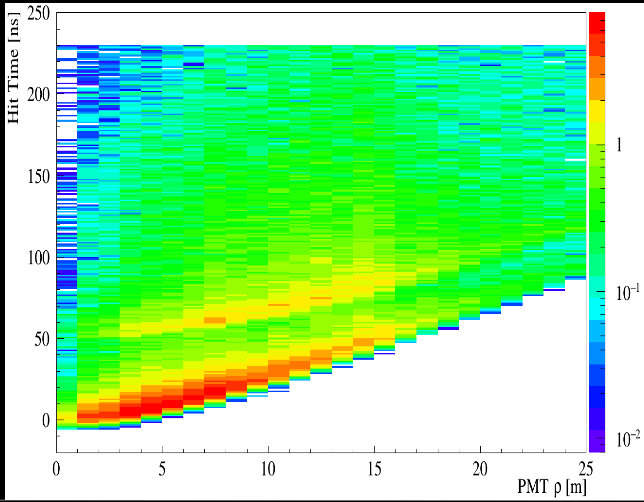


PMT Hit Time Distributions:

Width: 10m Length: 100m



Width: 30m Length: 100m



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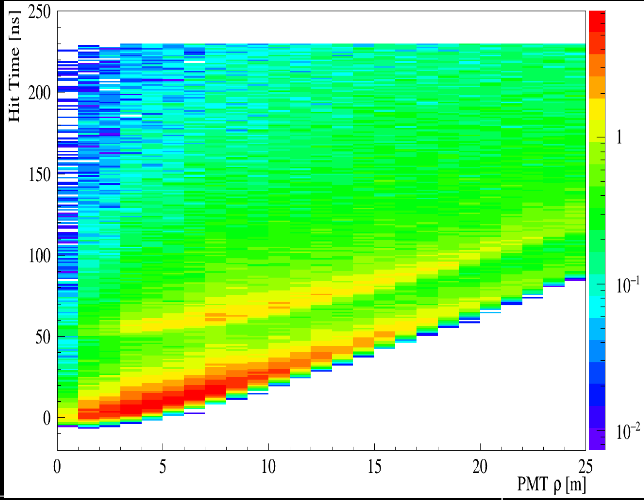
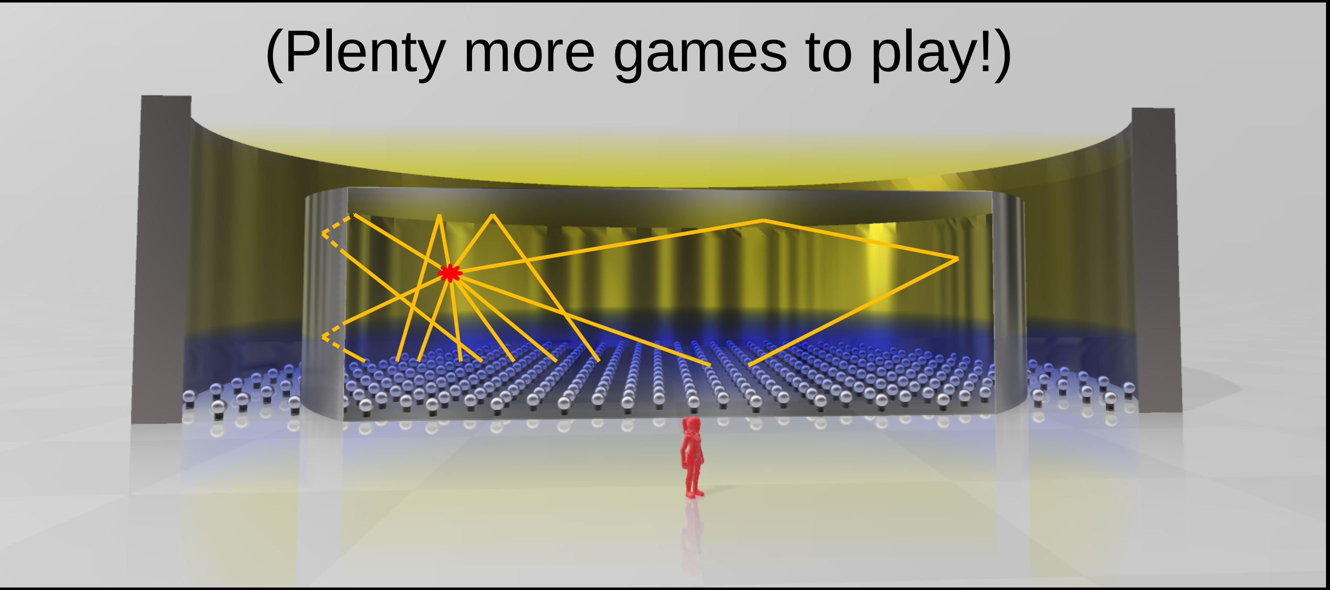


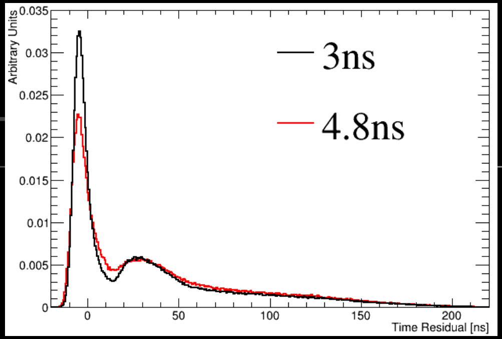
SLIPS

- Simple Design: Cheap and easy to construct
- High Light Yield with fewer PMTs
- Good position resolution



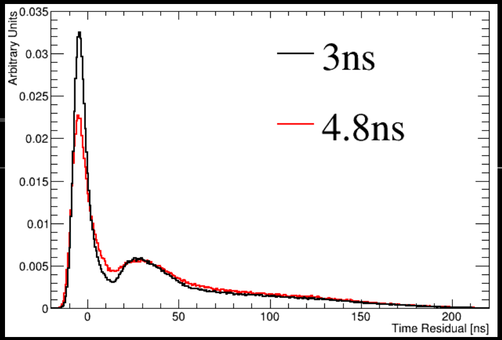
Onward

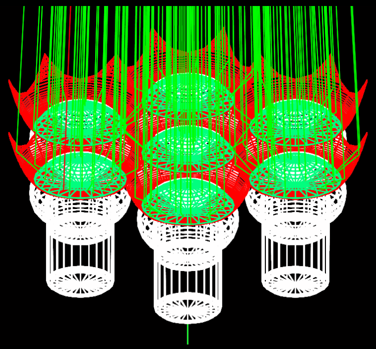
- Faster Scintillator



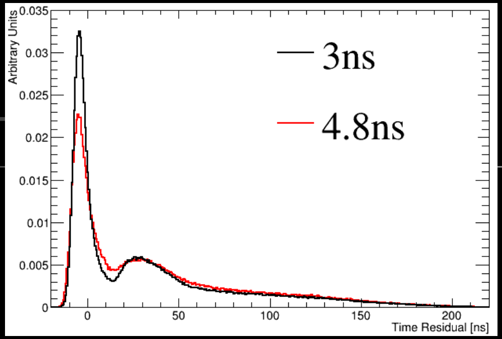
Onward

- Faster Scintillator
- Light Collecting Concentrators



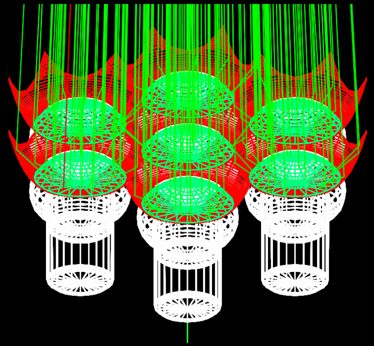


Onward



- Faster Scintillator
- Light Collecting Concentrators
- Double PMT Layer

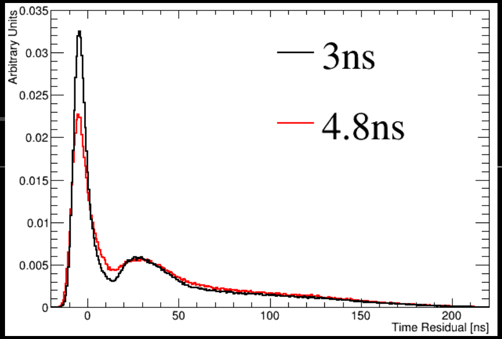
  (3 liq. System)

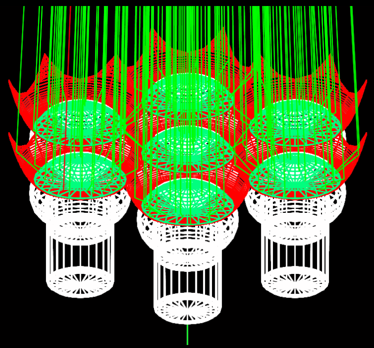


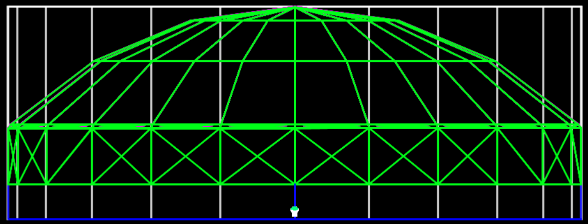
Onward

- Faster Scintillator
- Light Collecting Concentrators
- Double PMT Layer

  (3 liq. System)
- Concave Reflective Lid



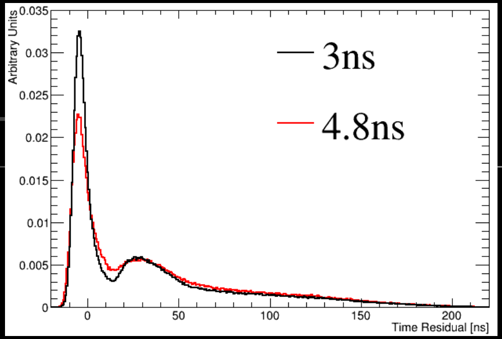


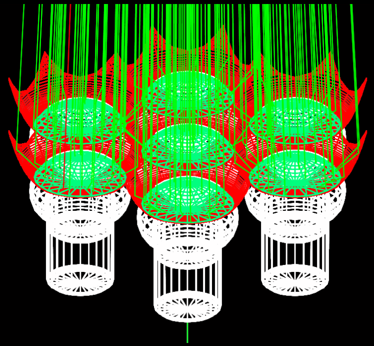


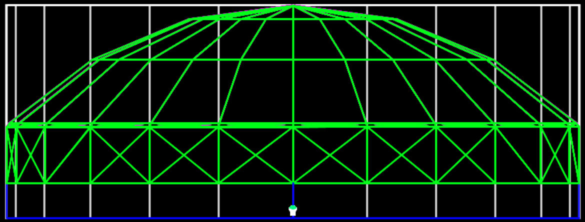
Onward

- Faster Scintillator
- Light Collecting Concentrators
- Double PMT Layer
  (3 liq. System)
- Concave Reflective Lid

(Paper coming soon)







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[2] X.-C. Lei, Y.-K. Heng, S. Qian, J.-K. Xia, S.-L. Liu, Z. Wu, B.-J. Yan, M.-H.Xu, Z. Wang, X.-N. Li et al. Evaluation of new large area pmt with highquantum efficiency. Chinese Physics C, 40(2):026002, 2016

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[4] Smirnov, O. Yu., M. Agostini, S. Appel, G. Bellini, J. Benziger, D. Bick, G. Bonfini, et al. "Measurement of Neutrino Flux from the Primary Proton–Proton Fusion Process in the Sun with Borexino Detector." Physics of Particles and Nuclei 47, no. 6 (2016): 995–1002.

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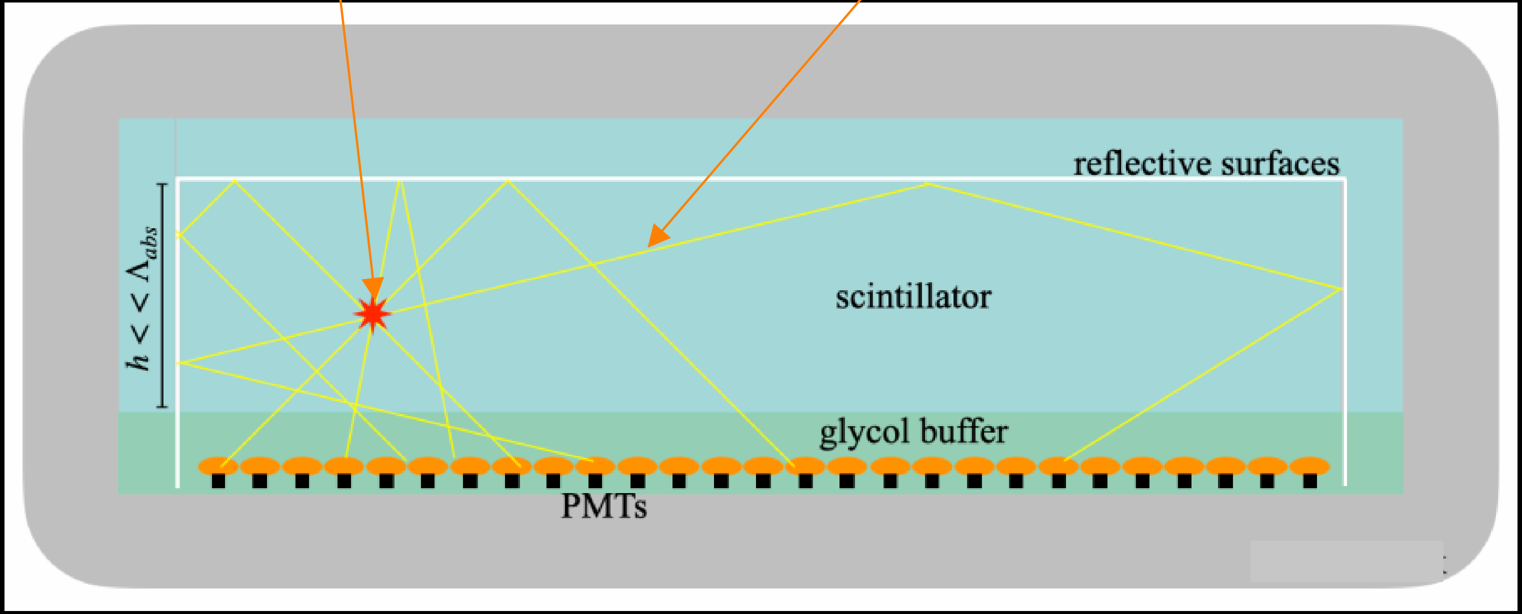
Backup

Efficient Light Collection

Energy depositing radiation

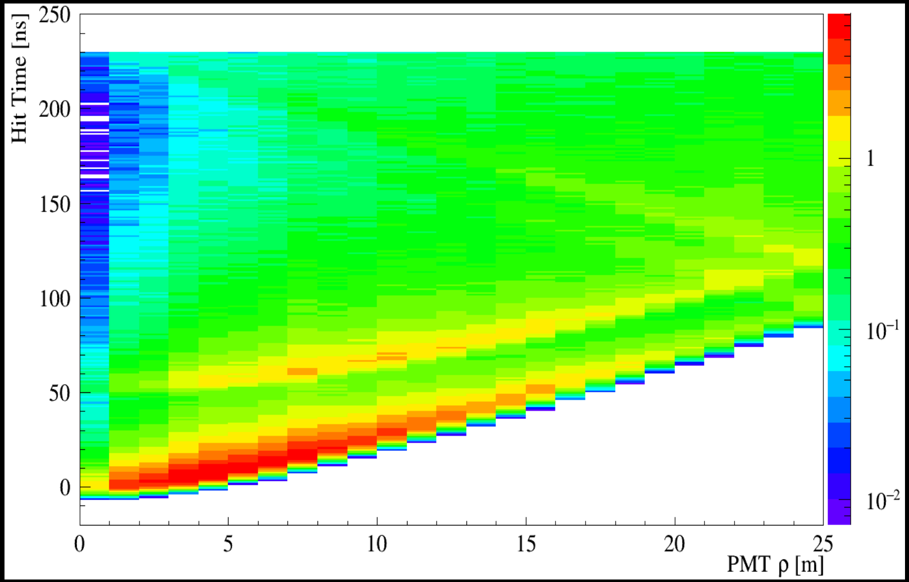
Scintillation light

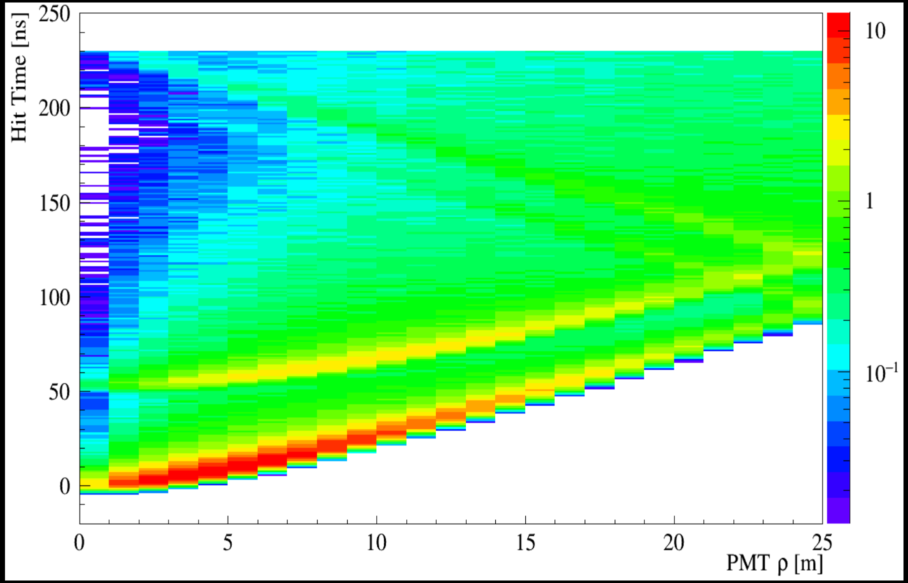


Side-on view of SLIPs

Faster Scintillator & PMTs

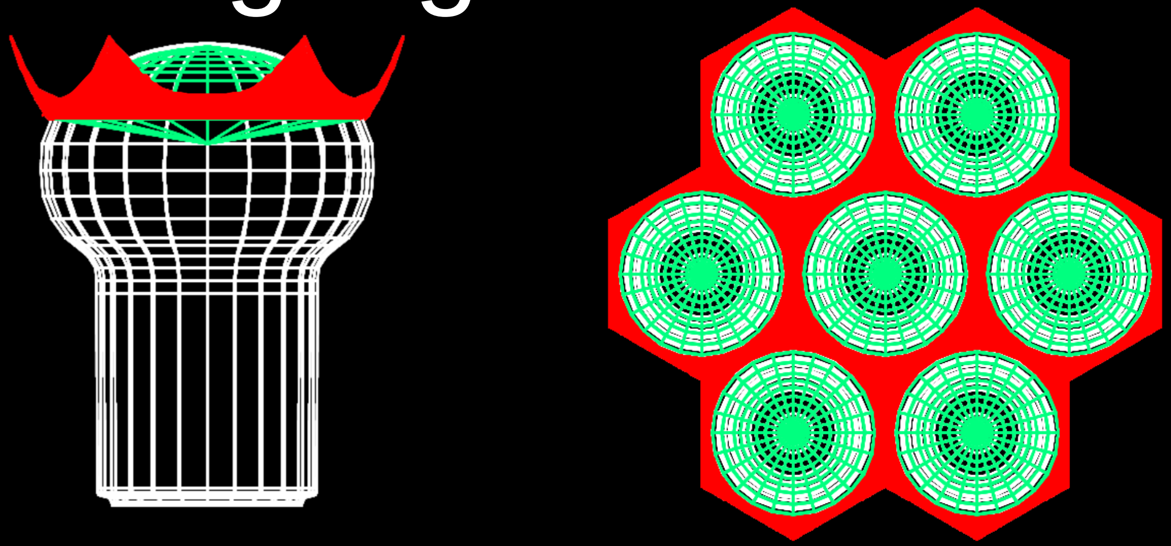
20” PMTs → Faster 8” PMTs (2.86→2.05ns FWHM TTS)
7.2ns scintillator → 3ns scintillator (4.9→3ns scintillation time)





Improved Wavefront Separation,
Improved z-position resolution:
$\sigma_z \sim 5\text{cm}$

Light Reflecting Concentrators: Improving Light Yield



Side-on and top-down views of PMTs with concentrators
glass (white), photocathode (green) and concentrator (red)

Simulations show a ~10% improvement in light collection
(compared to densely packed PMTs without concentrators)

Working "Prototype" : Immiscible Liquids

Picture from inside the SNO+ detector during the scintillator fill phase