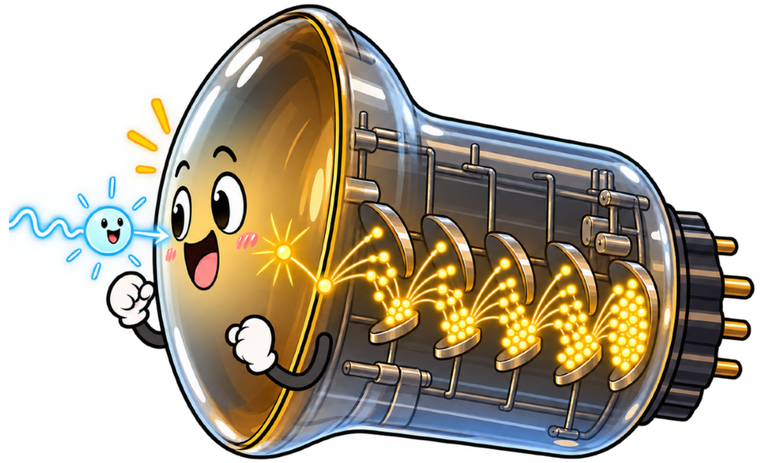


PMTs for a Future Detector

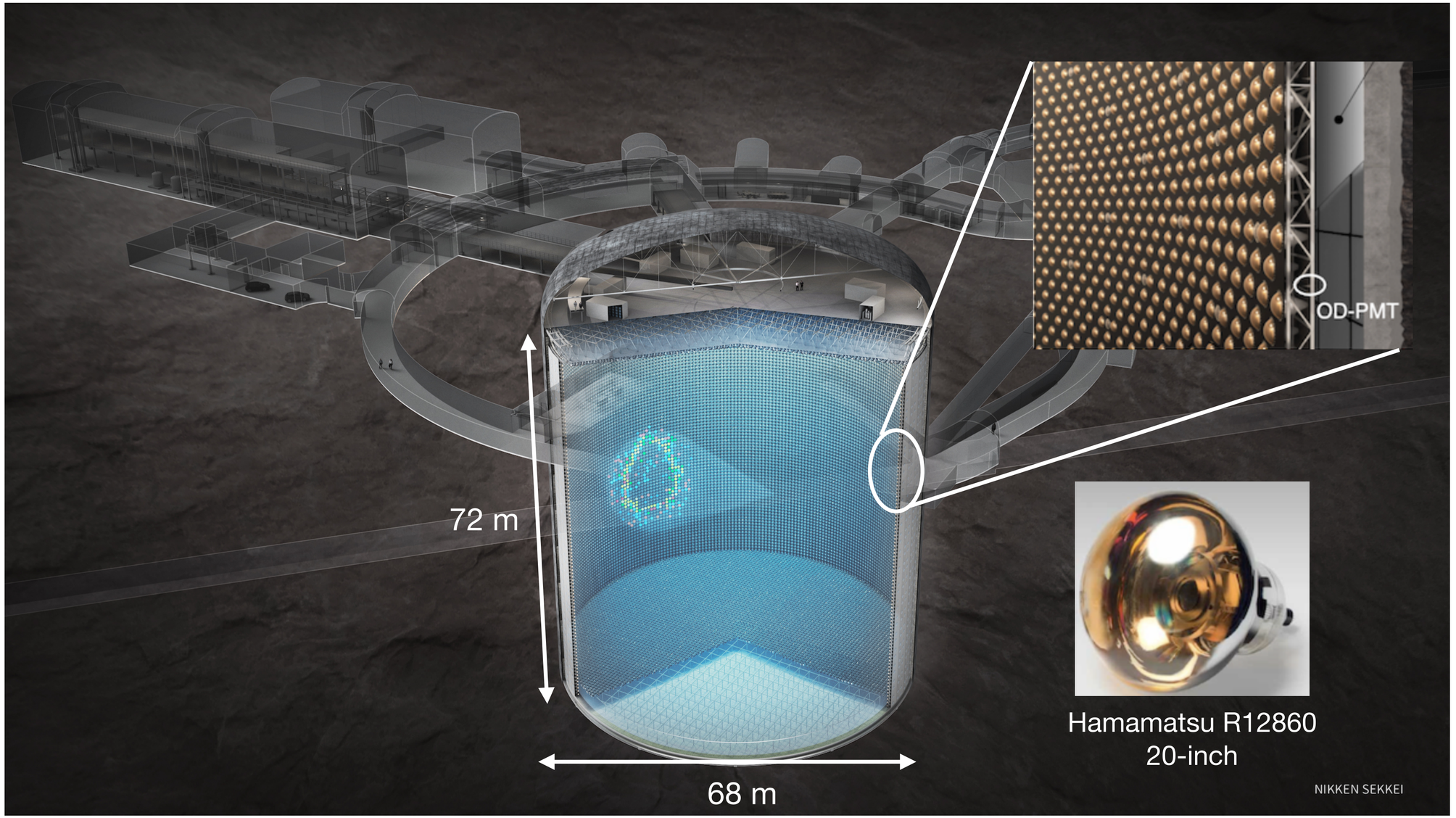
Physics Opportunities of Large Liquid Scintillator Detectors (II)

Chris Grant
Helmholtz Institute Mainz, Oct 13 – 15, 2026

BOSTON UNIVERSITY

Hyper Kamiokande

Science: leptonic CP violation (δ_{CP}), proton decay, and astrophysical neutrinos in a ~260 kt water detector



Hyper Kamiokande

Science: leptonic CP violation (δ_{CP}), proton decay, and astrophysical neutrinos in a ~260 kt water detector



~800 × (19 × 3-inch) modules
Hamamatsu R14374

Hamamatsu R12860
20-inch

Hyper Kamiokande

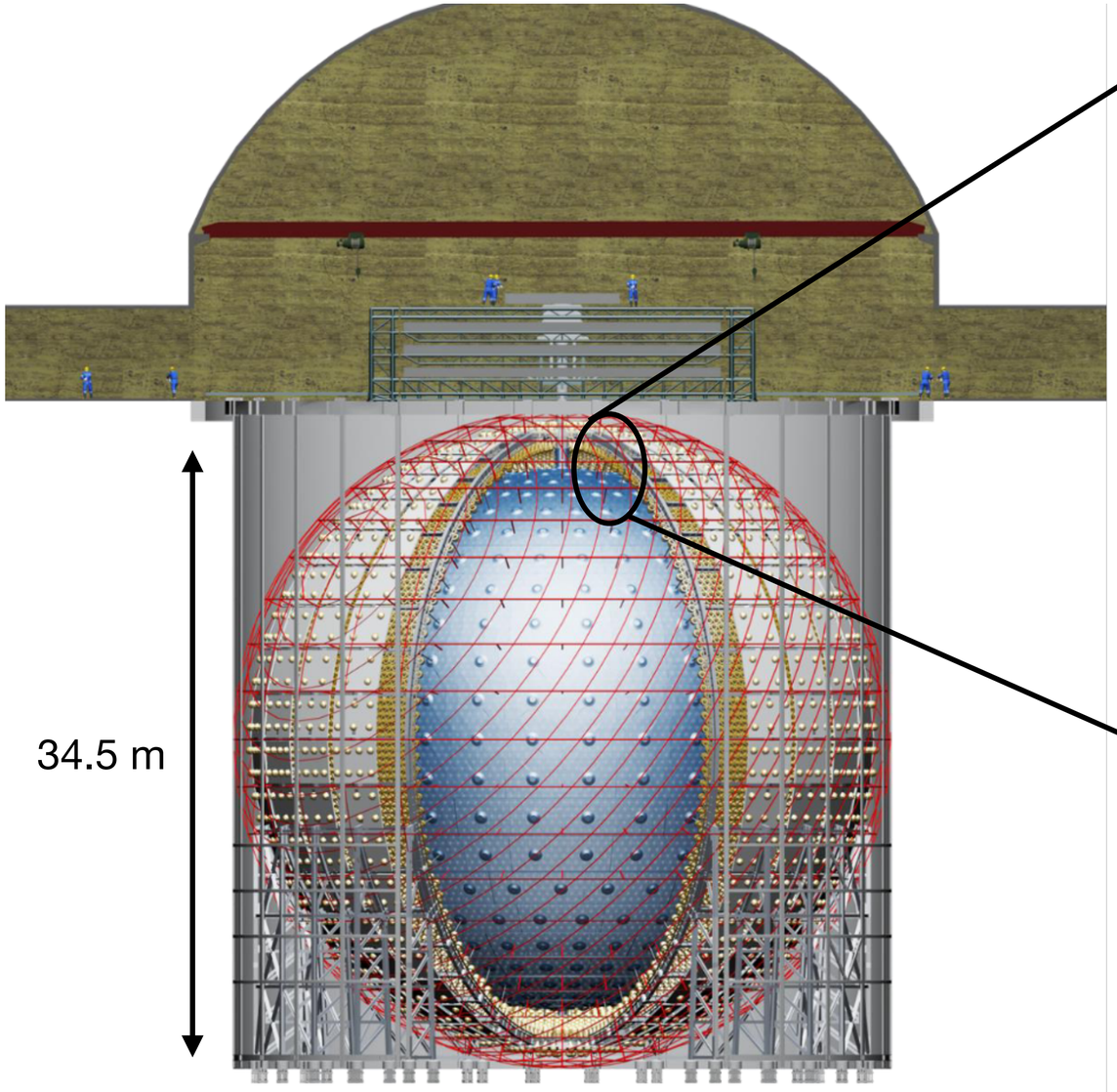
Science: leptonic CP violation (δ_{CP}), proton decay, and astrophysical neutrinos in a ~260 kt water detector

	Size	**Gain**	**Peak Quantum Eff. @ ~400 nm**	**Single PE TTS**
Hamamatsu R12860	20-inch	~10^7	~30%	2.6 ns
Hamamatsu R14374	3-inch multi-PMT modules	~10^7	~28%	1.3 ns

- Together, Hyper-K has ~20% photocathode coverage with large PMTs.
- Multi-PMT modules provide improved granularity, improved timing, and improved directional and spatial resolution, but with lower dark rate and less sensitivity to Earth's magnetic field.

JUNO

Science: reactor neutrino mass-ordering and precision oscillations in a ~20 kt liquid scintillator detector





17,596 × 20-inch PMTs of two varieties
(4,939 R12860 + 12,657 MCP from NNVT)

25,587 × 3-inch PMTs interspersed

JUNO

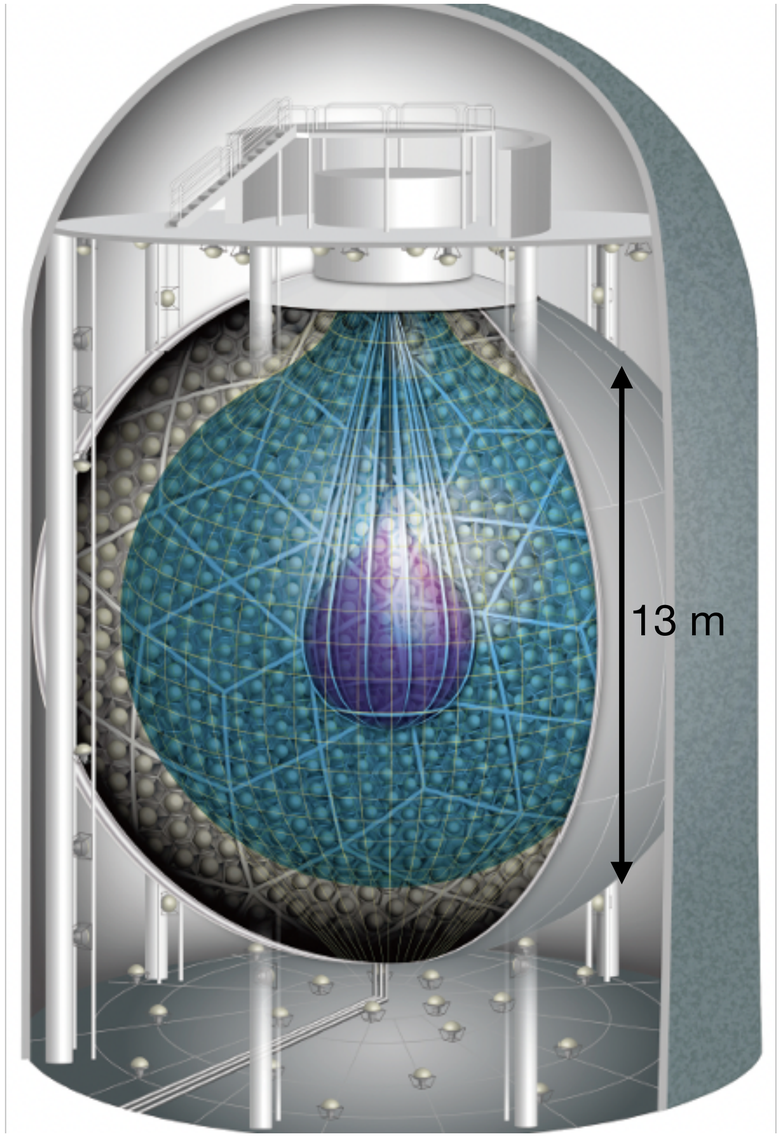
Science: reactor neutrino mass-ordering and precision oscillations in a ~20 kt liquid scintillator detector

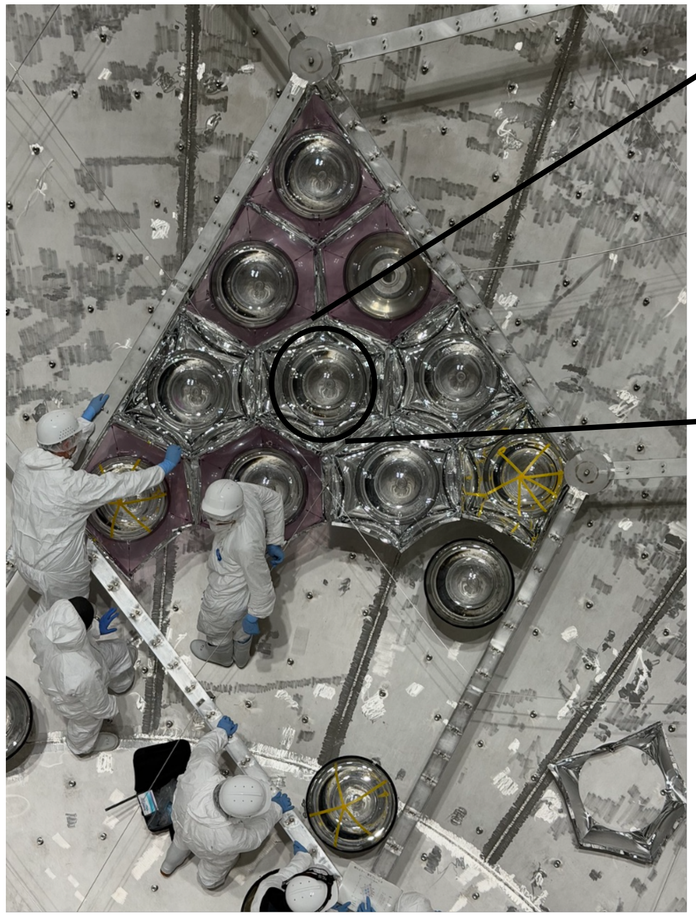
	Size	**Gain**	**Peak Quantum Eff. @ ~400 nm**	**Single PE TTS**
Hamamatsu R12860	20-inch	~10^7	~30%	2.6 ns
NNVT	20-inch	~10^7	~32%	7.0 ns
Hainan Zhanchuang Photonics Tech.	3-inch multi-PMT modules	~3×10^6	~27%	1.3 ns

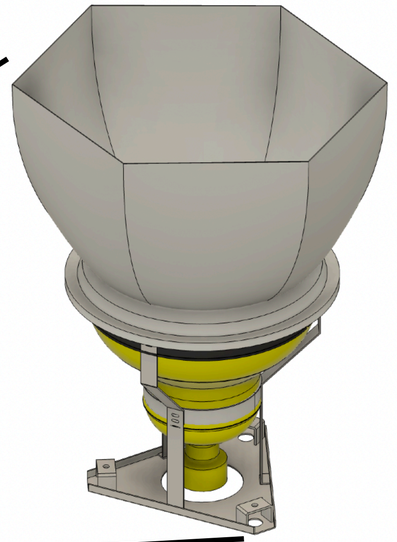
- Together, JUNO has ~78% photocathode coverage with all PMTs. Achieves ~3% energy res.
- Smaller PMTs provide independent energy calibration (for non-linearities in 20-inch PMTs).

KamLAND2-Zen

Science: 0νββ decay, oscillations, geoneutrinos and astrophysical neutrinos in a ~1 kt liquid scintillator detector









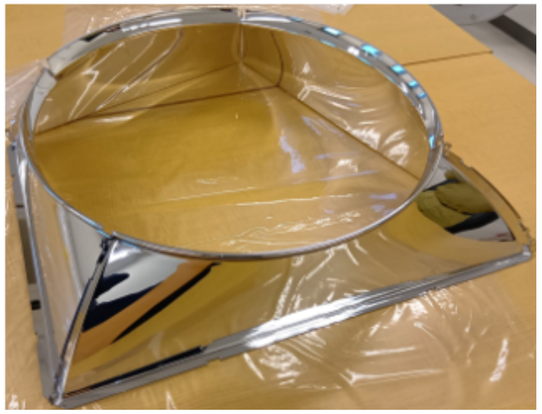
Hamamatsu R12860
20-inch

KamLAND2-Zen

Science: 0νββ decay, oscillations, geoneutrinos and astrophysical neutrinos in a ~1 kt liquid scintillator detector

	Size	**Gain**	**Peak Quantum Eff. @ ~400 nm**	**Single PE TTS**
Hamamatsu R12860	20-inch	~10^7	~30%	2.6 ns

PET (Polyethylene Terephthalate) coated with vapor-deposited aluminum

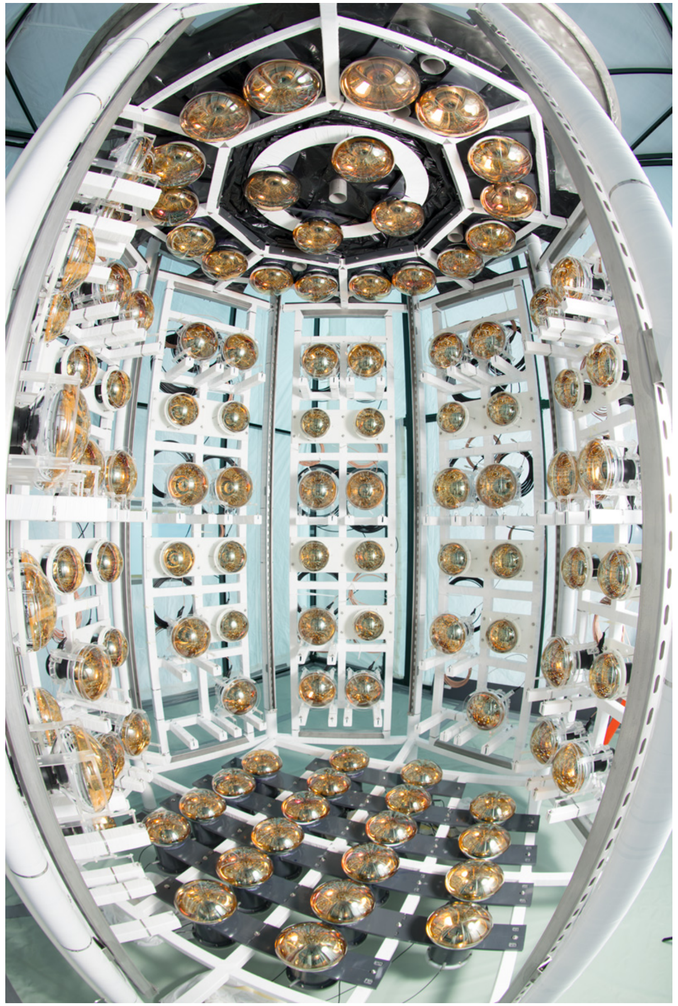




- We'll have 1,892 20-inch R12860 PMTs in the inner detector.
- Use light concentrating mirrors to try and achieve close to 100% effective photocathode coverage.
- Just collect as much light as we can.

ANNIE

Science: beam neutrino-nucleus interactions in a ~26 ton loaded water/WbLS detector + technology demonstrator



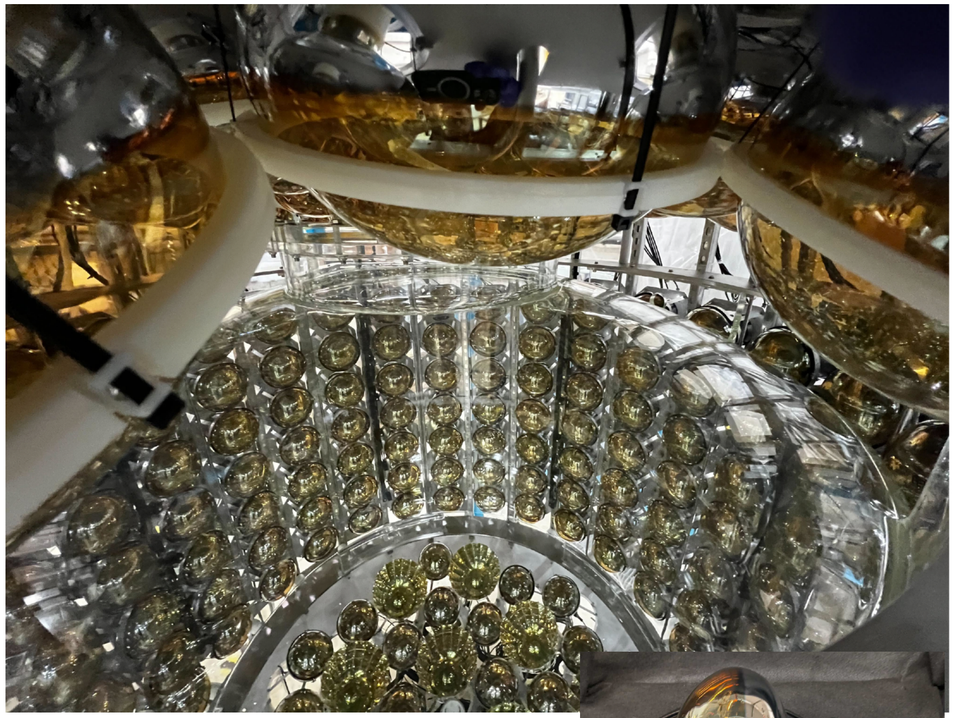


Hamamatsu
10-inch R7081

+11-inch ETEL D784UKFLB
+ 8-inch R5912-100

Eos

Science: hybrid reconstruction technology demonstrator + SNS neutrino-oxygen interactions in ~4 ton WbLS detector





Hamamatsu
8-inch R14688-100

ANNIE

Science: beam neutrino-nucleus interactions in a ~26 t loaded water/WbLS detector + technology demonstrator

Eos

Science: hybrid reconstruction technology demonstrator + SNS neutrino-oxygen interactions in 4 t WbLS detector

	Size	**Gain**	**Peak Quantum Eff. @ ~400 nm**	**Single PE TTS**
Hamamatsu R7081	10-inch	~10^7	~25%	3.4 ns
Hamamatsu R14688-100	8-inch	~10^7	~35%	1.0 ns

- Would anything be gained by using mid-sized PMTs?
- Fast, high-QE eight-inch PMTs support precise photon timing for vertex reconstruction and Cherenkov/scintillation separation. Does this scale to, and benefit, a large detector?

Summary Discussion

Starting point: Large, high-QE PMTs with high optical coverage, using light collectors where beneficial.

Starting Metric:

$$\text{Cost effectiveness} = \frac{\text{Detected Light Yield (PE/MeV)}}{\text{Total installed photosensor-system cost}}$$

- Compare the same detector geometry and isotope-loaded scintillator, while meeting the required energy resolution at $Q_{\beta\beta}$
- What improvement in background rejection or energy reconstruction would justify paying more for faster timing, finer segmentation, or spectral information?
- Choose the system that delivers the required 0νββ sensitivity at the lowest cost.
- **PE/MeV per dollar is just a starting comparison.** For example, a system that collects slightly less light could still be preferable if it improves background rejection enough.