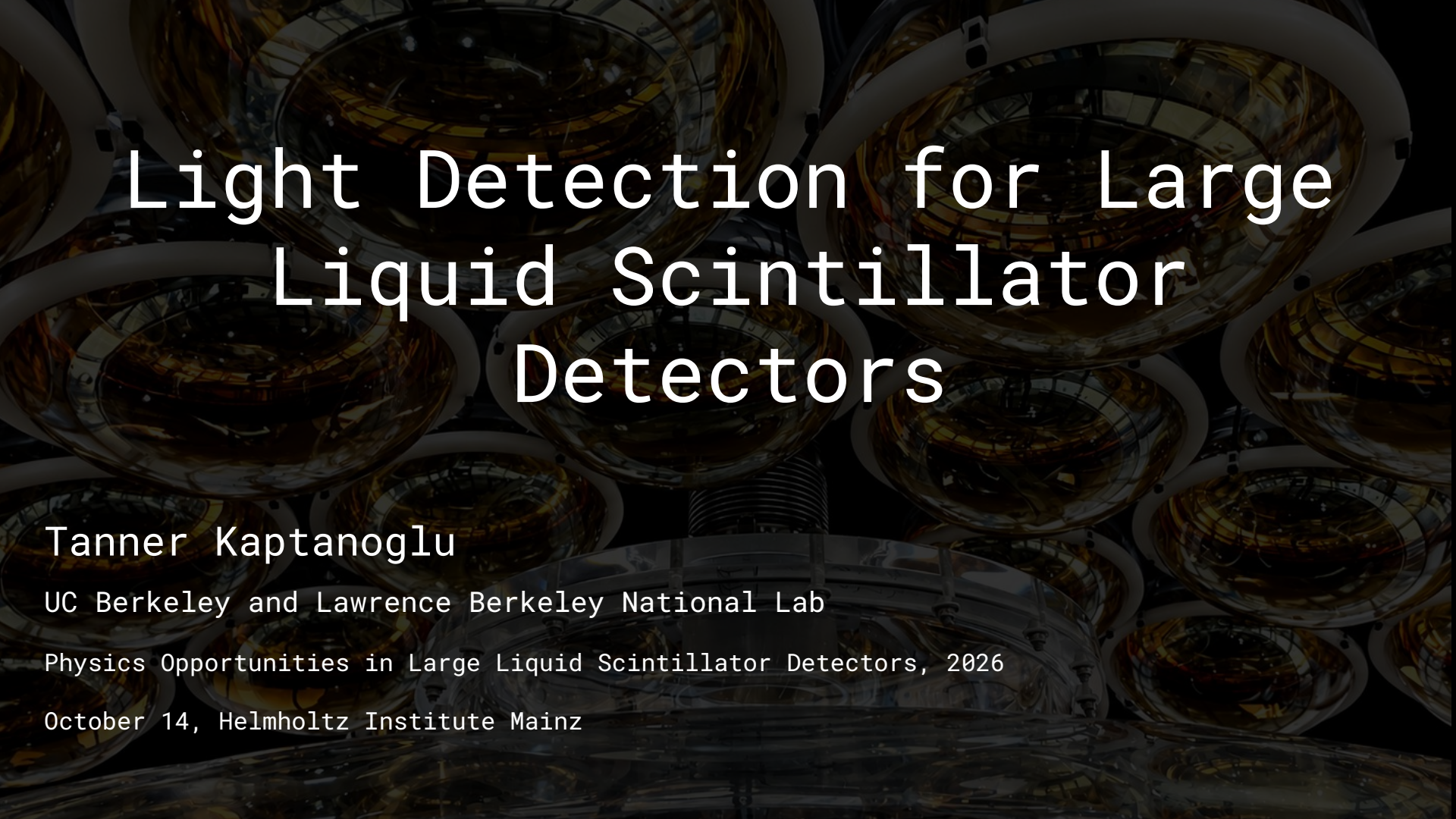




Light Detection for Large Liquid Scintillator Detectors

Tanner Kaptanoglu

UC Berkeley and Lawrence Berkeley National Lab

Physics Opportunities in Large Liquid Scintillator Detectors, 2026

October 14, Helmholtz Institute Mainz

Introduction

- PMTs: Chris Grant (Boston University)
- LAPPDs: Amanda Weinstein (Iowa State University)
- Dichroicons: Josh Klein (University of Pennsylvania)

PMTs

Current state of the art, Hamamatsu large-area PMTs

8-inch



R5912

MiniBooNE
Daya Bay
SuperK (outer tank)



R14688

EOS

10-inch



R7081

IceCube
DoubleChoz
BUTTON

20-inch



R12860

HyperK
JUNO
KamLAND2-Zen

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Clearly the recent
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Can we justify the
extra cost of these
PMTs (and electronics
channels, cables,
etc)?

20-inch



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PMTs

Interesting large-area MCP-PMTs from NNVT in China

8-inch

GDB-6082

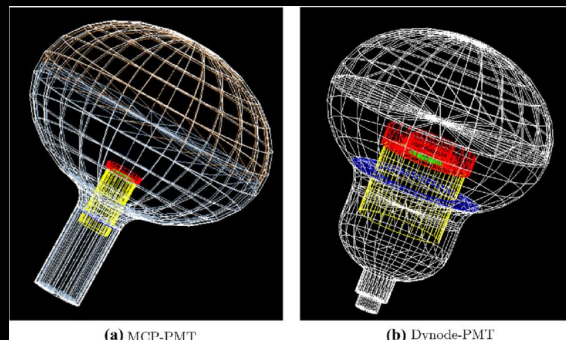
- Used by Jinping
- Characterization paper:
Nucl. Instrum. Methods Phys.
Res. A 1055 (2023)
... but very few details otherwise



20-inch

GDB-6201

- Used by JUNO
- Similar photon detection efficiency as HK PMTs
- Very poor TTS ~ 7 ns



Y. Wang et al., *EPJC* 82 (4) 2022

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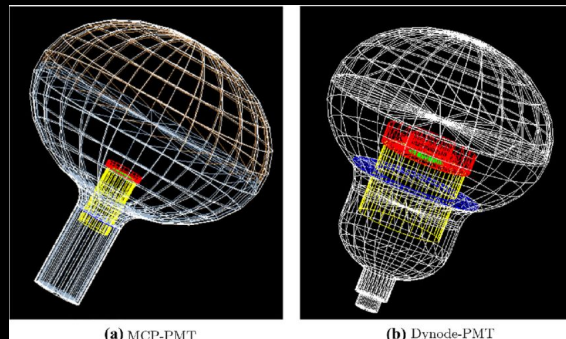


Is there a role
for cheaper PMTs
with similar
efficiency but
worse timing?

20-inch

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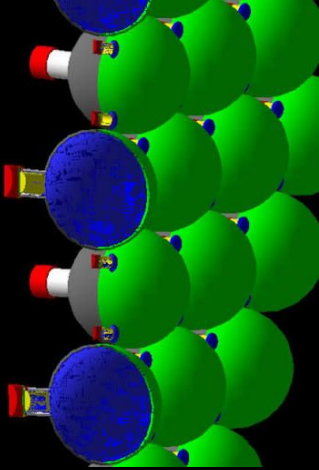
(a) MCP-PMT
Y. Wang et al., *EPJC* 82 (4) 2022

(b) Dynode-PMT

PMTs

A current trend...

JUNO: 3-inch PMTs between the 20-inch



Hyper-K: DOMs with 3-inch PMTs

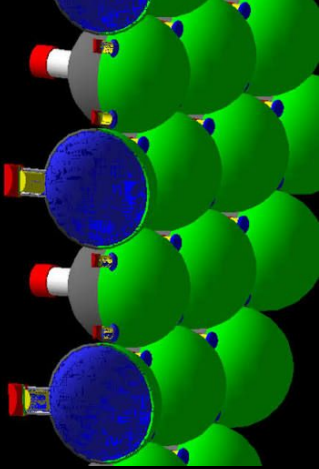


Interspersing small PMTs provides better timing, light collection, a natural method for extending dynamic range; different physics topics require optimizing different sensor aspects.

PMTs

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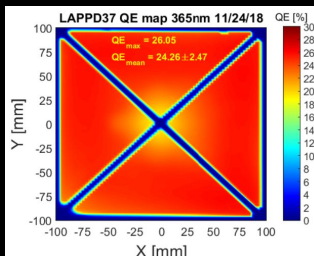
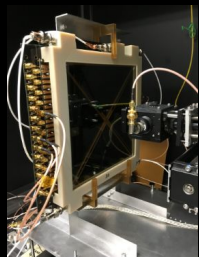
Interspersing small PMTs provides better timing, light collection, a natural method for extending dynamic range; different physics topics require optimizing different sensor aspects.

Have we seen if its “worth it” yet?

LAPPDs

“Gen 1”

- Manufactured by Incom
- MCP-based, stripline anode
- 8x8 inch sensitive area (~30% more than 8-inch PMT)
- ~20%+ Q.E.
- ~1 mm spatial resolution
- < 100 ps TTS

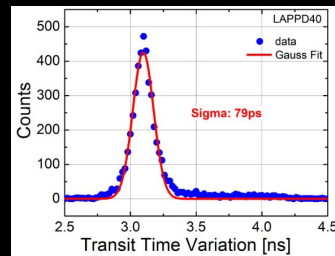


A.V. Lyashenko, *Nucl.Instrum.Meth.A* 958 (2020)

Status of LAPPDs

Challenges

- Cross-talk
- Multi-PE
- Channel density
- Readout



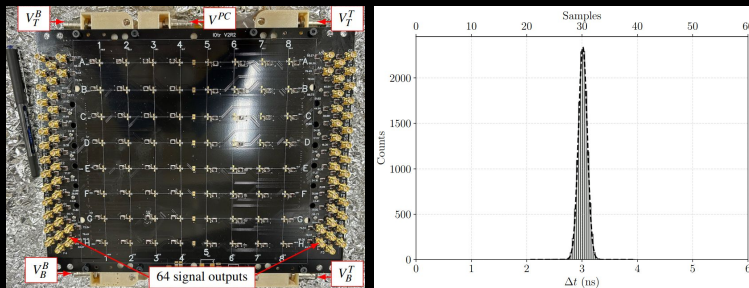
Status of LAPPDs

Challenges

-
- Figure 1 consists of three panels. Panel (a) is a photograph of the LAPPD40 detector assembly, showing a large, rectangular, metallic structure with various cables and components. Panel (b) is a color map of the LAPPD37 Quantum Efficiency (QE) map, showing a cross-shaped pattern with QE values ranging from 0 to 30%. The map is titled 'LAPPD37 QE map 365nm 11/24/18' and includes the text 'QE_{avg} = 26.05' and 'QE_{cross} = 24.26 ± 2.47'. The axes are labeled 'X [mm]' and 'Y [mm]'. Panel (c) is a histogram of the transit time variation for LAPPD40, showing a peak at approximately 3.2 ns with a sigma of 79 ps. The y-axis is labeled 'Counts' and the x-axis is labeled 'Transit Time Variation [ns]'. The legend indicates 'LAPPD40' with 'data' points (blue circles) and a 'Gauss Fit' (red line).

- Cross-talk
- Multi-PE
- Channel density
- Readout

- Thin-film anode
- Removed cross pattern spacers
- Capacitively coupled to pixelated readout board
- Similar performance across important metrics



11

LAPPDs

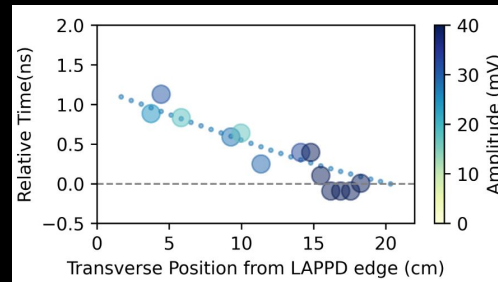
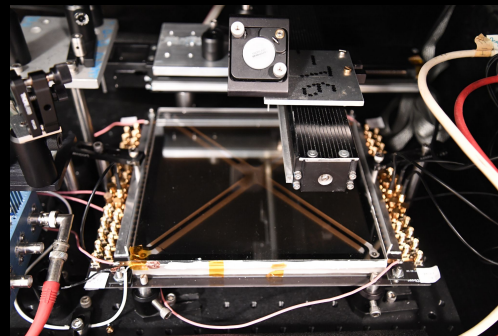
First LAPPDs deployed in a neutrino detector

Beam neutrinos detected in the ANNIE detector using one Gen-1 LAPPD

Marks the first use of LAPPDs in an active neutrino detector

Understanding the impact of LAPPDs on reconstruction will be very interesting.

ANNIE Collaboration, *JINST* 21 02002 (2026)



LAPPDs

First LAPPDs deployed in a neutrino detector

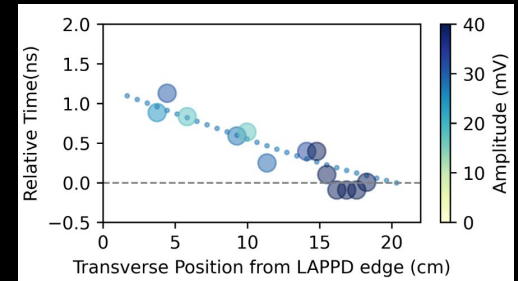
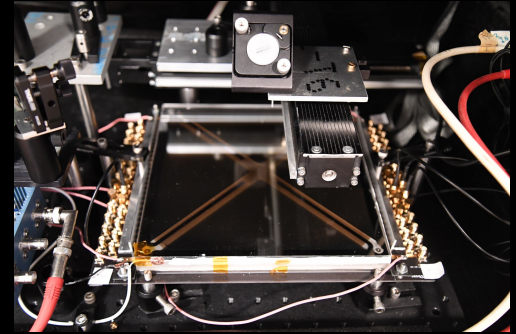
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ANNIE Collaboration, *JINST* 21 02002 (2026)

How do the inclusion of LAPPDs impact the reconstruction performance (and ultimately physics sensitivities) at low energy (e.g., 1-5 MeV)?

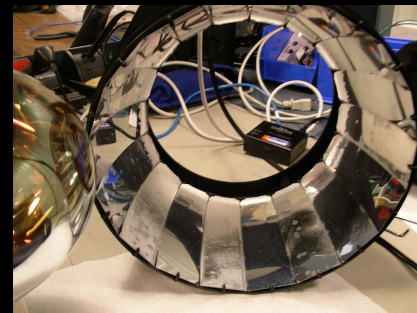


See: B. Land et al.,
PRD 103 (2021) 5, 0520040

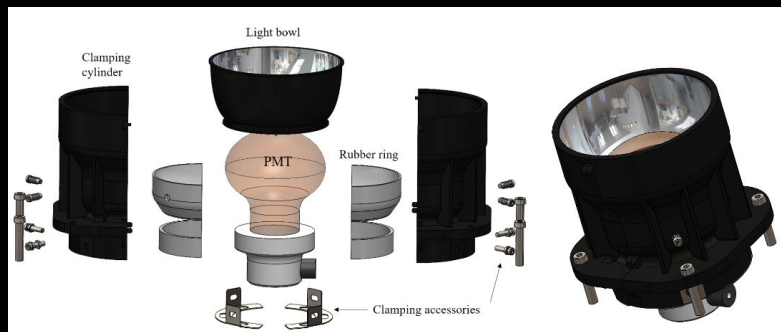
Beyond the sensor

Aiding in light collection: what are the options?

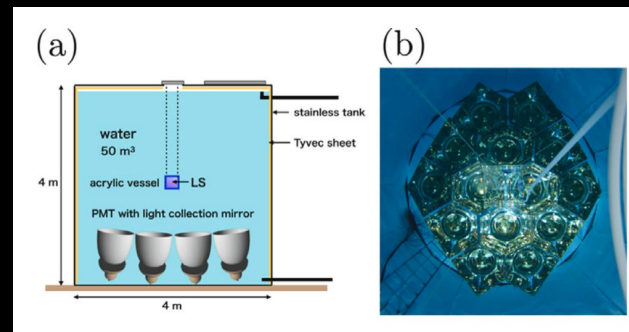
- Light concentrators; SNO & Borexino pioneered, KamLAND2-Zen and Jinping are updating



SNO concentrator



Jinping concentrator design, NIMA 1080 (2025)

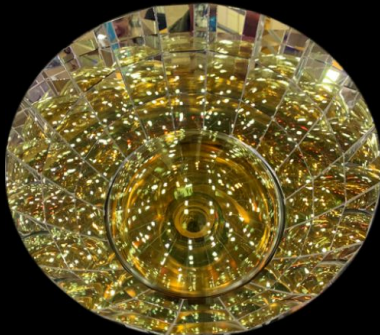


KZ2 prototype: J. Nakane, NIM A 1081 (2026)

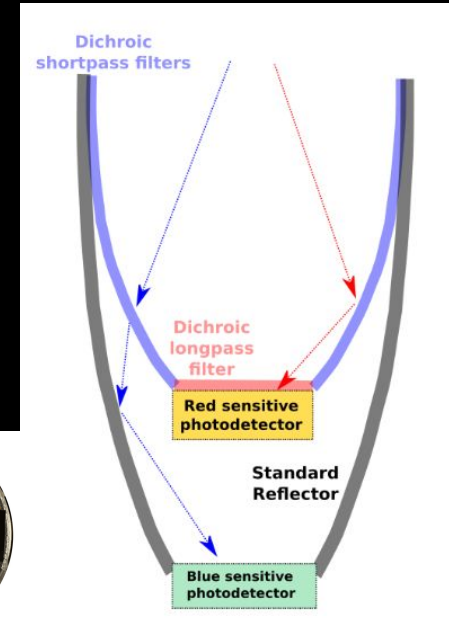
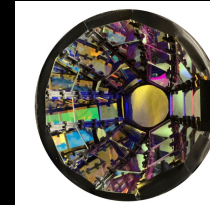
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- Light concentrators; SNO & Borexino pioneered, KamLAND2-Zen and Jinping are updating
- Dichroicons for spectral sorting, used in EOS



Dichroicon in EOS

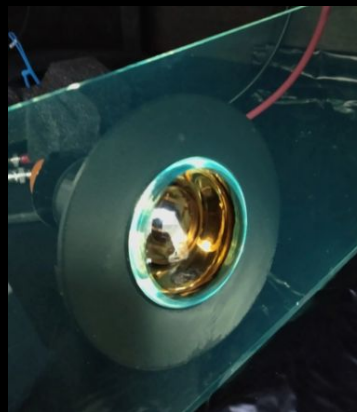
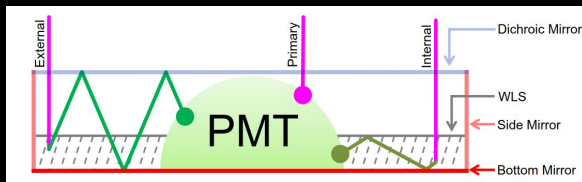


Phys.Rev.D 101 (2020) 7, 072002

Beyond the sensor

Aiding in light collection: what are the options?

- Light concentrators; SNO & Borexino pioneered, KamLAND2-Zen and Jinping are updating
- Dichroicons for spectral sorting, used in EOS
- Other ideas: DOMs, wavelength shifting plates (HK outer detector), photon traps, etc.



How to decide?

We will hear from three speakers about interesting options for light detection in future scintillator detectors.

Ultimately, the decision will be driven by the physics goals & will have to be coordinated with the scintillator development.

What studies need to be performed such that this community can make decisions about which light sensors to pursue?