A ^{6}Li-doped pulse-shape-sensitive plastic scintillator for reactor antineutrino detection

The largest-to-date application of the novel ^{6}Li-doped PSD plastic scintillator shows promise for Mobile Antineutrino Demonstration

neutrinos.llnl.gov

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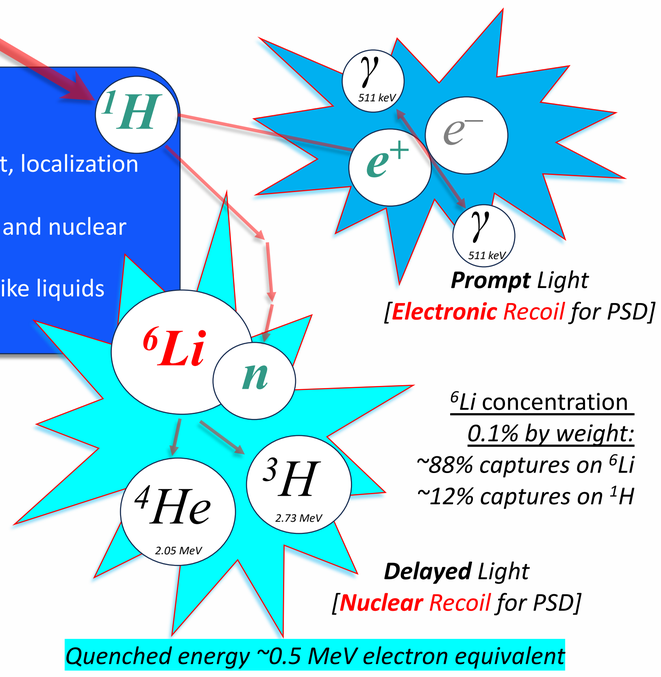
on behalf of the Mobile Antineutrino Demonstrator Project

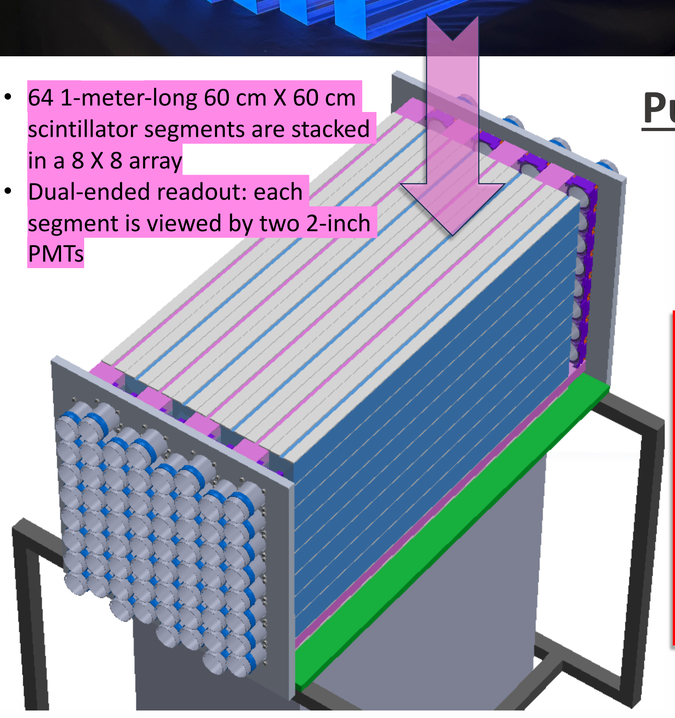
*Large-scale 6Li-doped pulse shape sensitive plastic scintillator is one of several technologies under development within the Mobile Antineutrino Demonstrator project. Liquid scintillator with similar capabilities was one of key aspects of the aboveground reactor antineutrino detection demonstration by the PROSPECT experiment. However, a plastic material is considered a requirement for truly mobile above-ground detection systems suited to **reactor monitoring for safeguards**. The new formulation of plastic scintillator is being developed in partnership with Eljen Technologies and can be obtained in multi-liter single volumes enabling the construction of segments at meter-scale lengths. We present a summary of measured performance criteria, which include attenuation length, stability, pulse shape sensitivity, and neutron efficiency measurements.*

Key Advantages of ^{6}Li PSD Plastic Scintillator:

- **^{6}Li(n, T)α reaction**: short-range reaction product, localization (scintillation from triton)
- **Pulse-Shape Discrimination** between electronic and nuclear recoils to suppress backgrounds (identify IBDs)
- **Plastic**: ease of handling and machineability unlike liquids allows to consider mobile detectors



- 64 1-meter-long 60 cm X 60 cm scintillator segments are stacked in a 8 X 8 array
- Dual-ended readout: each segment is viewed by two 2-inch PMTs



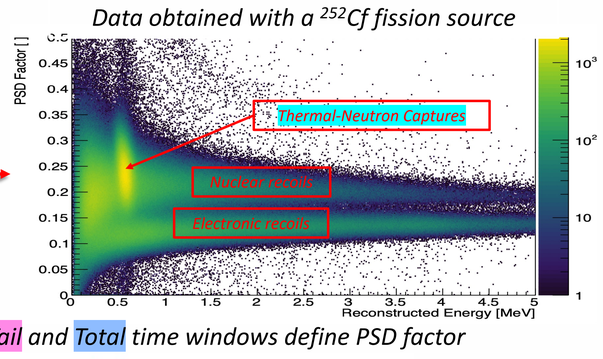
A specular reflector film is "air-coupled" to the scintillator bars:

1. Increases light collection
2. Air gap between the reflector and scintillator allows Total Internal Reflection

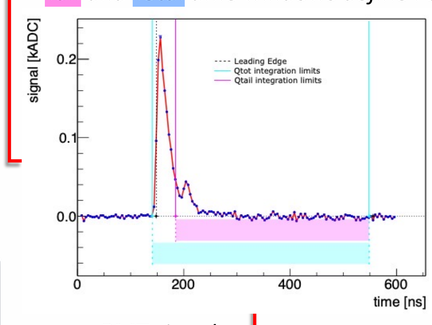
3M DF2000MA

Pulse-Shape Discrimination

Data obtained with a ^{252}Cf fission source



Tail and *Total* time windows define PSD factor

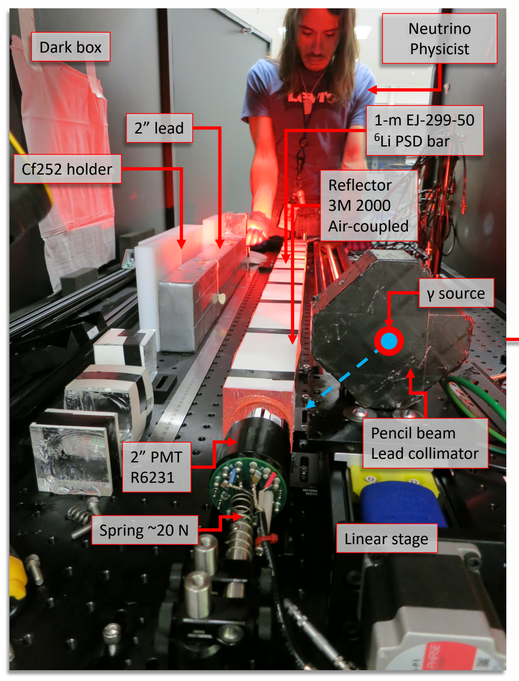


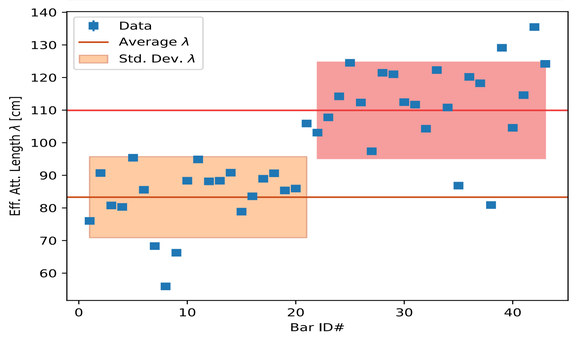
PMT signal

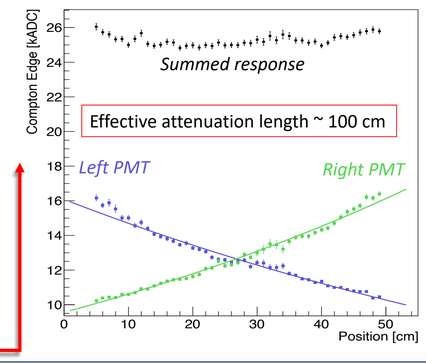
ROADSTR DAQ:
72 PMTs
250 MSa/s

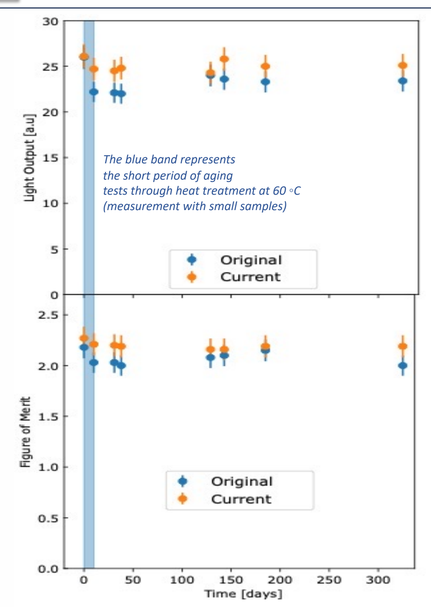
Performance Characterization: arxiv:2405.19573

Test stand to characterize the scintillator bar:



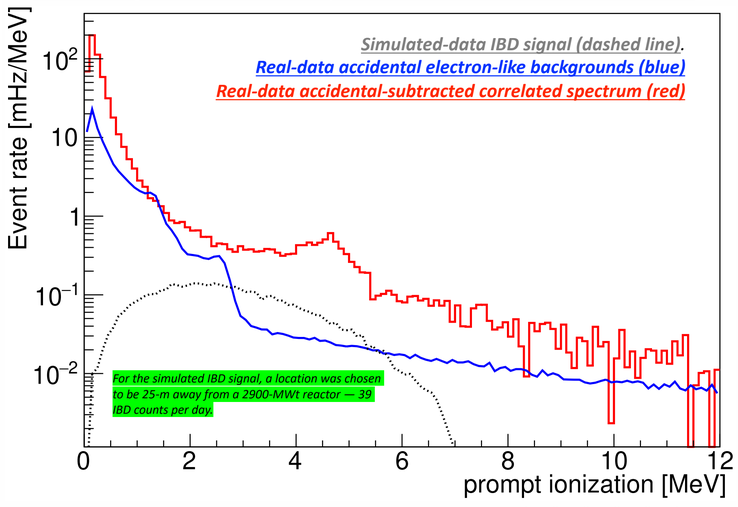


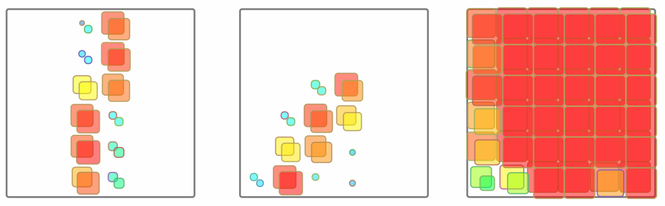




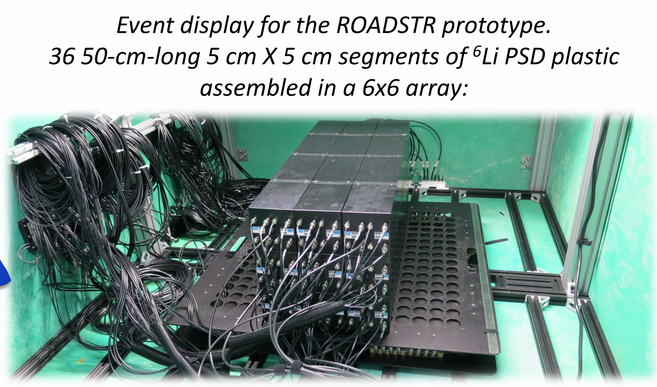
Light Output and PSD "quality" observed for both EJ-299-50 variants during almost one year of continuous measurements in an air environment.

Background Rejection [ROADSTR]



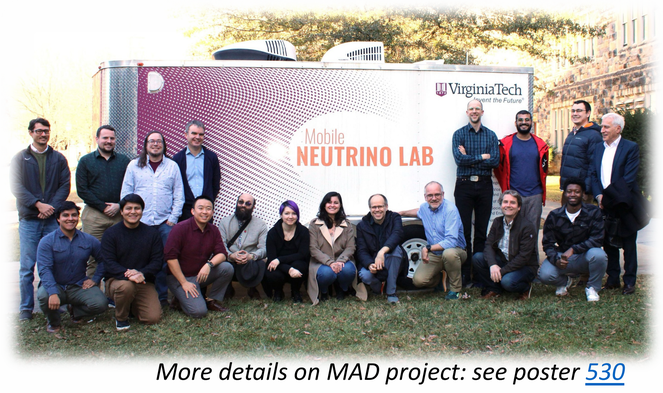


Event display for the ROADSTR prototype.
36 50-cm-long 5 cm X 5 cm segments of ^{6}Li PSD plastic assembled in a 6x6 array:



Summary and Integration with MAD

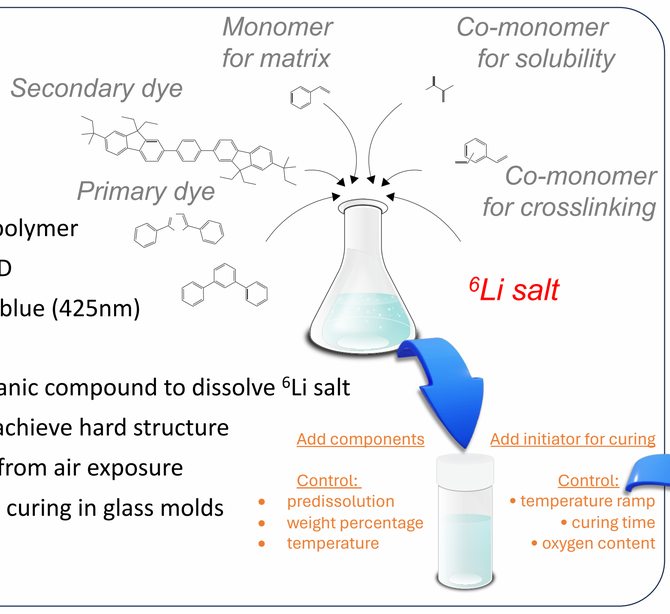
- New material (EJ-299-50) for IBD and neutron detection developed and characterized by Eljen and LLNL.
- ROADSTR prototype has been operational for ~2 years collecting background data.
- Will be the basis technology for the MAD 2D detector subsystem.



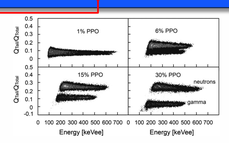
More details on MAD project: see poster 530

Scintillator Formulation

- Monomer – styrene or vinyl toluene
  - Building block for a scintillating polymer
- PPO – primary dye, also provides PSD
- Secondary dye – shifts light to deep blue (425nm)
- ^{6}Li salt – provides ^{6}Li
- Co-monomer – methacrylic acid organic compound to dissolve ^{6}Li salt
- Cross-linker – helps polymerization achieve hard structure
- Antioxidant – prevents degradation from air exposure
- Exacting temperature control during curing in glass molds

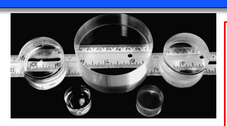


2012



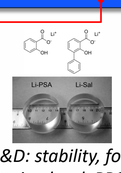
Plastic scintillators with efficient neutron/gamma pulse shape discrimination. Zaitseva et al. NIM A668.

2013



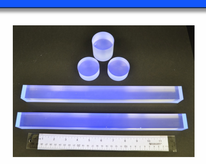
First stable ^{6}Li-doped PSD scintillators developed at LLNL. Zaitseva et al. NIM A729.

2014–2016

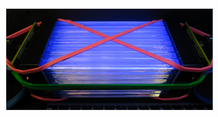


R&D: stability, formulation, doping level, PPO level, etc. Mabe et al. NIM A806.

2017–2019

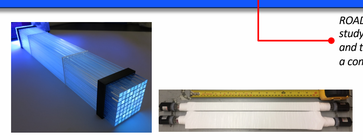


1st successful casting of ^{6}Li PSD at ~1-liter scale. Mabe et al. AAP 2018.



SANDD: SiPM-array readout and PSD Li et al. NIM A942.

2020–2023



SANDD: LLNL Exploratory Research to study feasibility of 10-liter detector and PSD with SiPM-array readout Sutanto et al. NIM A1006.

ROADSTR: LDRD Strategic Initiative to study IBD-like backgrounds and transfer formulation to a commercial partner

Ford et al. NIM A1050.

2024–2025

Material scaling at Eljen: EJ-299-50. Roca et al. arxiv:2405.19573.

Arrival of new material for MAD 2D

** The photographs, on which the scintillator appears blue, were taken under a UV-light exposure.*

PARTICIAPTING INSTITUTIONS in the Mobile Antineutrino Demonstrator (MAD) project:

Georgia Tech · Illinois Institute of Technology · Lawrence Livermore National Laboratory · NIST · Oak Ridge National Laboratory · USNA United States Naval Academy · Virginia Tech · Yale

The Mobile Antineutrino Demonstrator Project is constructing a 2D subsystem based on EJ-299-50

LLNL-POST-865288

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