Large-Volume Scintillator Detectors for Nuclear Nonproliferation

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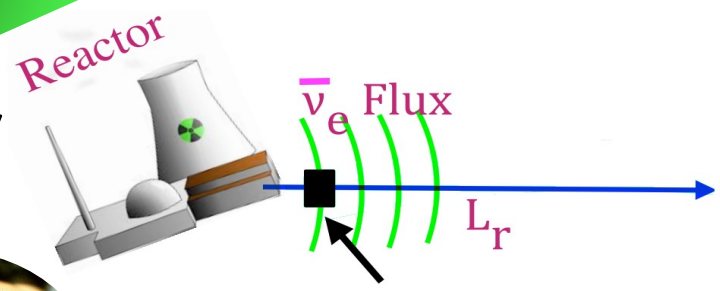
Consortium for Enabling Technologies & Innovation

Introduction

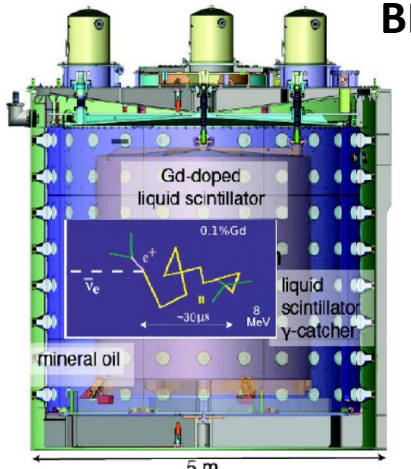
Nuclear nonproliferation

Fuel Cycle

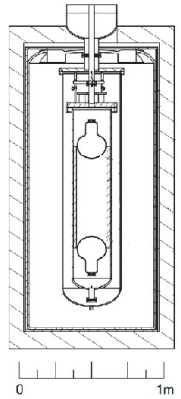


Remote Detection

BNL



WbLS



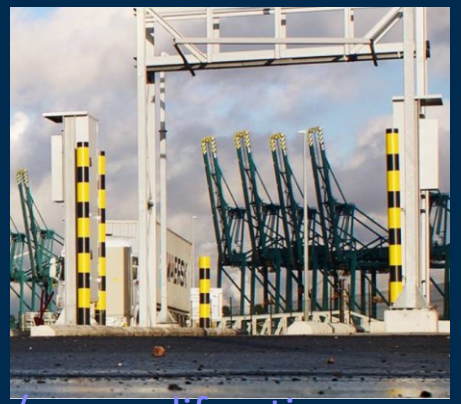
ArLS

High-energy physics

Policy

LLNL

γ Flux



Mid-Range Detection

https://www.energy.gov/nnsa/missions/nonproliferation

Collaborating Members

Plastic scintillator detectors

Georgia Tech

Oliver Moreno

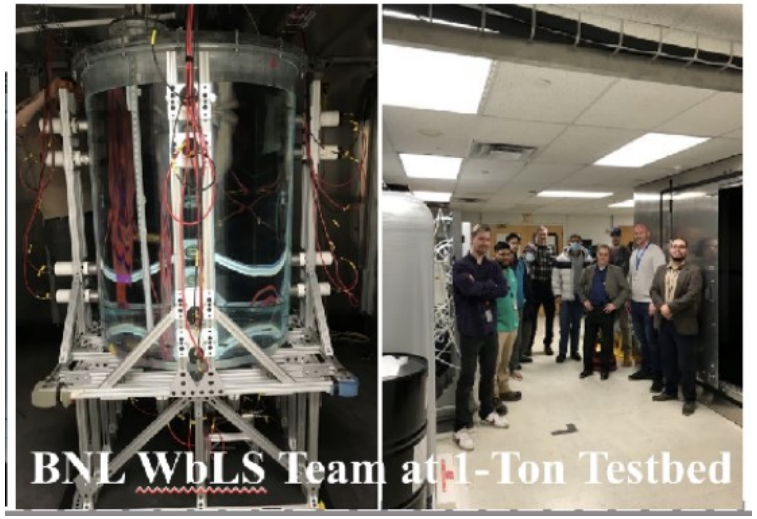
Dr. Bernard Kippelen

Large Volume WbLS

Brookhaven National Laboratory

Dr. Milind Diwan

Dr. Minfang Yeh



Plastic Scintillators for UxV Component

Project Summary

- 3D printable plastic scintillator with mechanical properties suitable for rugged UxV applications
- Need for higher detector surface area without adding payload weight
- Approach
  - Photo-crosslinked matrix
  - CMB loading for increasing capture cross-section
  - Green TADF emitters for increasing exciton harvest
- Metrics
  - Thermogravimetric: T_d 200-300 °C
  - DSC showed no glass transition
  - Microindentation: uniaxial yield strength ~66 Mpa for compositions with up to 40 wt.% of CMB

S. Abraham *et al.*, An approach towards plastic scintillators from thermally activated delayed fluorescent dyes and cross-linkable bismuth compounds. *Journal of Materials Chemistry C* **10**, 17481-17488 (2022).

Payload limitations for power management

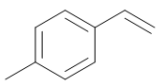
UxV Application

Mid-Range Detection

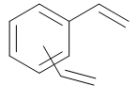
Need for body components that serve detector function

Approach

Matrix



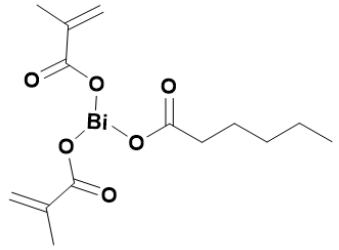
Vinyltoluene



Divinylbenzene

Co-polymer Cross-linking

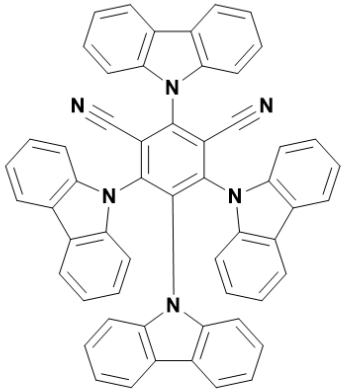
Improve Capture Cross-section



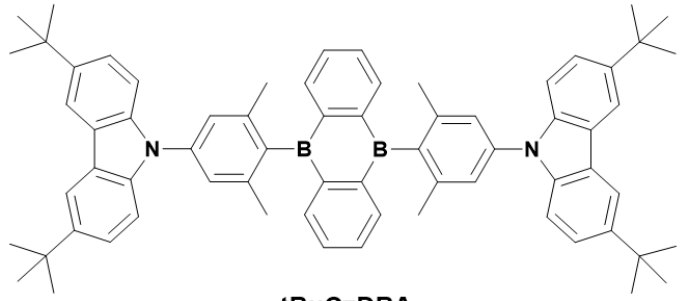
CMB

High Z Material

Exciton Harvest



4CzIPN



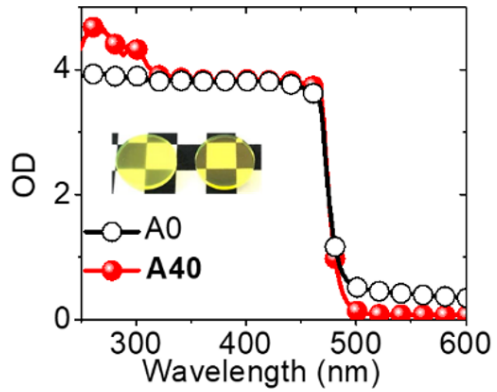
tBuCzDBA

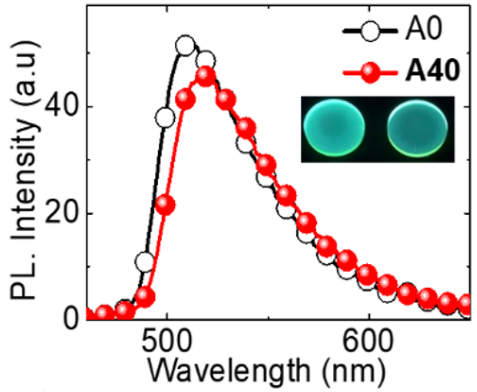
TADF Dyes

Optical Characterization

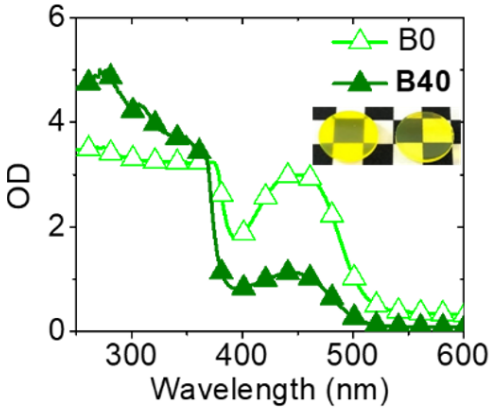
- Absorption measurements show tradeoff between transparency and CMB loading
- Green emission spectrum under 365 nm UV lamp suitable for some PMT choices
- Sample thicknesses of ~2.7 mm

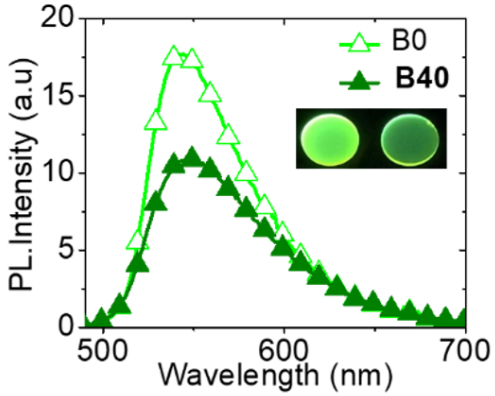
4CzIPN





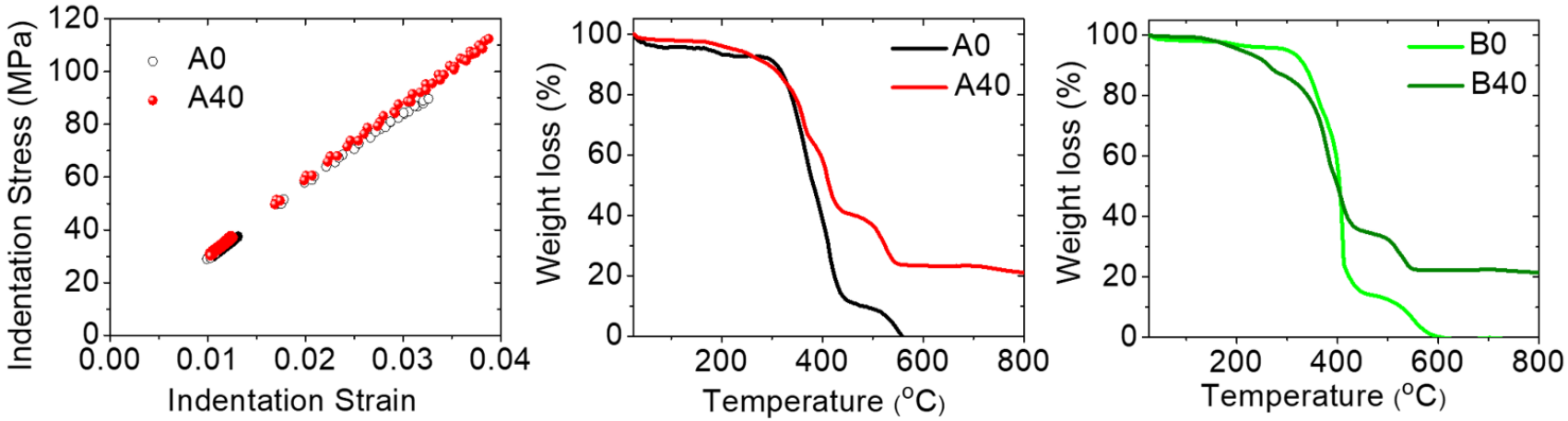
tBuCzDBA





PVT Scint. (wt.%)	Vinyl toluene (wt.%)	DVB (wt.%)	TADF Dye (wt.%)	CMB (wt.%)	Bi (wt.%)
A0	94.05	4.95	1	0	0
A40	59	0	1	40	16.91
B0	94.05	4.95	1	0	0
B40	59	0	1	40	16.91

Mechanical Characterization

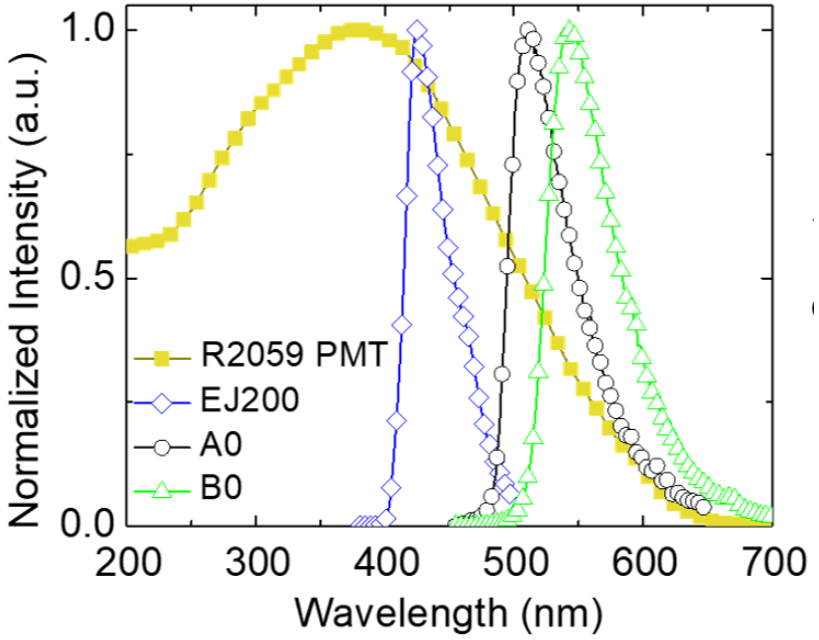


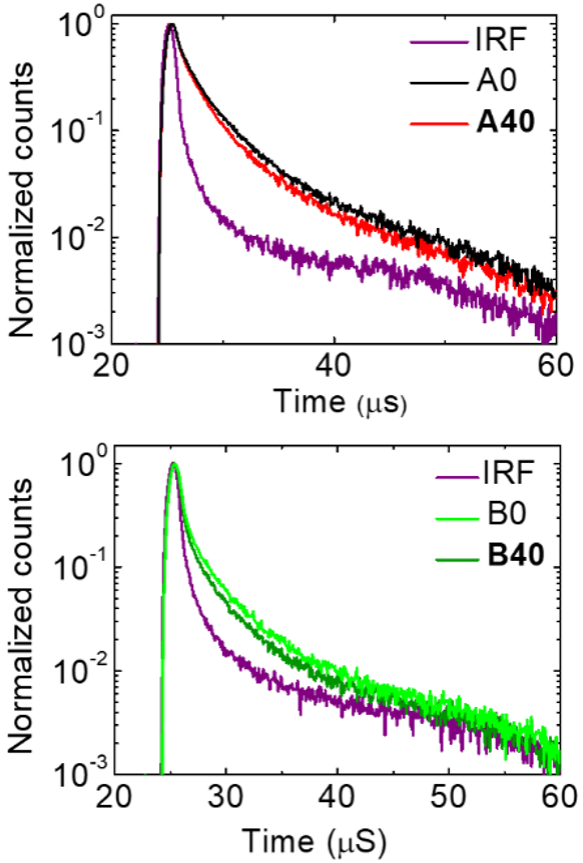
Uniaxial yield strength ~66 Mpa for compositions with up to 40 wt.% of CMB

T_d beyond 200 °C

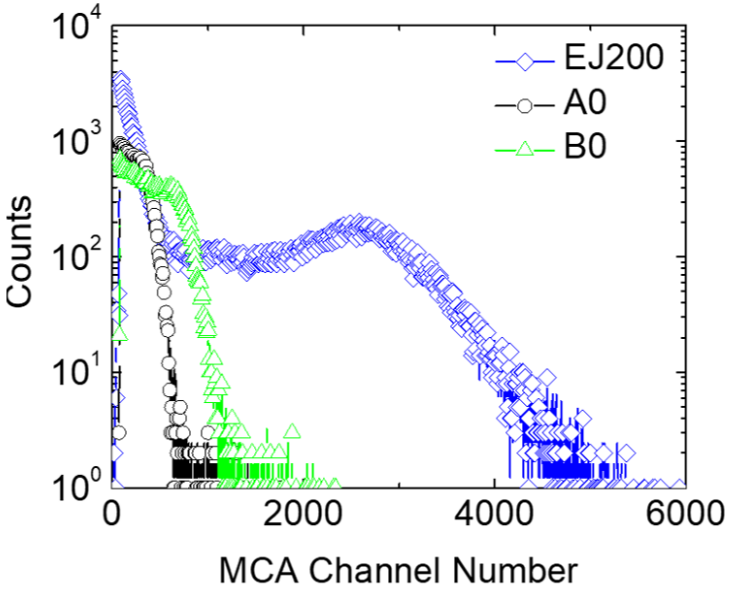
S. Abraham *et al.*, An approach towards plastic scintillators from thermally activated delayed fluorescent dyes and cross-linkable bismuth compounds. *Journal of Materials Chemistry C* **10**, 17481-17488 (2022).

Time-Resolved Measurements





Sample	Overlap Integral	Volume (cm^3)	Relative Light Yield
EJ-200	37.5	1.84	1
A0	24.3	1.71	0.11
B0	17.3	1.78	0.25



Cs-137 source
Comparison to EJ-200

S. Abraham *et al.*, An approach towards plastic scintillators from thermally activated delayed fluorescent dyes and cross-linkable bismuth compounds. *Journal of Materials Chemistry C* **10**, 17481-17488 (2022).

Water-based Liquid Scintillator for Large Volume Detector

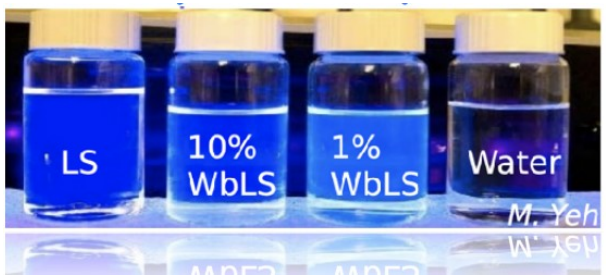
Large Volume WbLS

Simulations

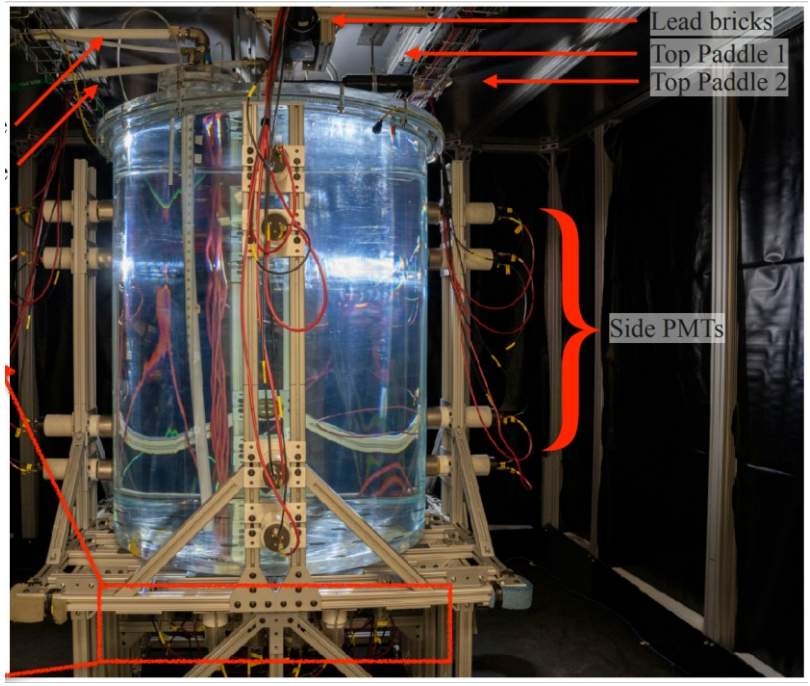
1-ton Detector

30-ton Detector
Deployment Q1-2024

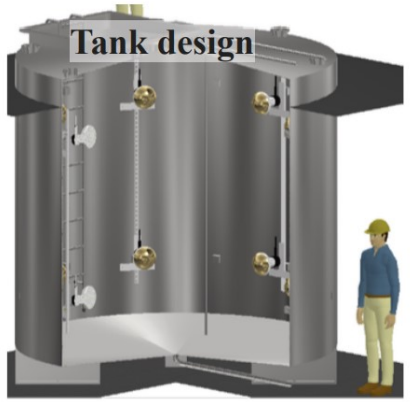
WbLS



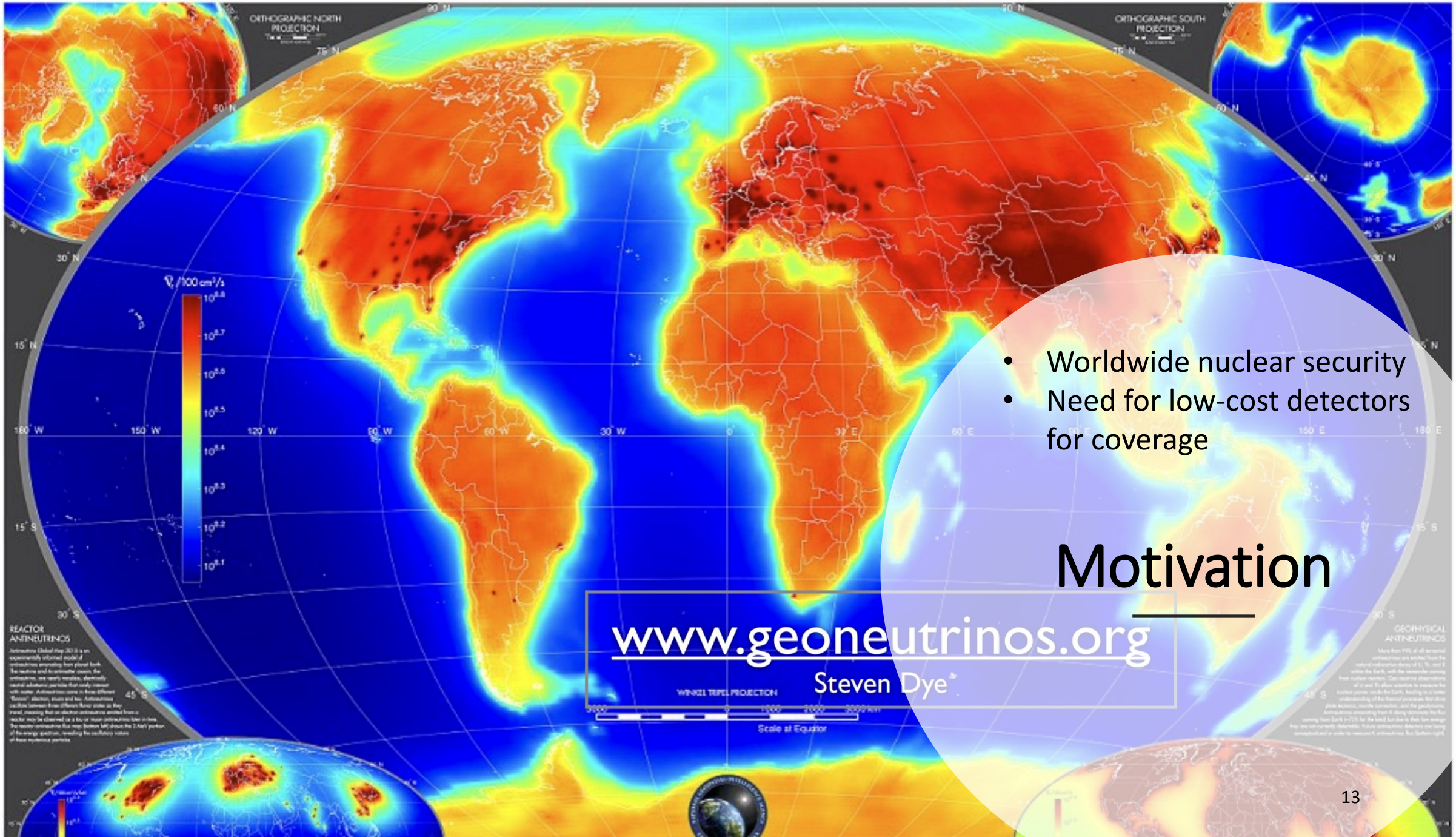
Water
Purification



Bottom PMT



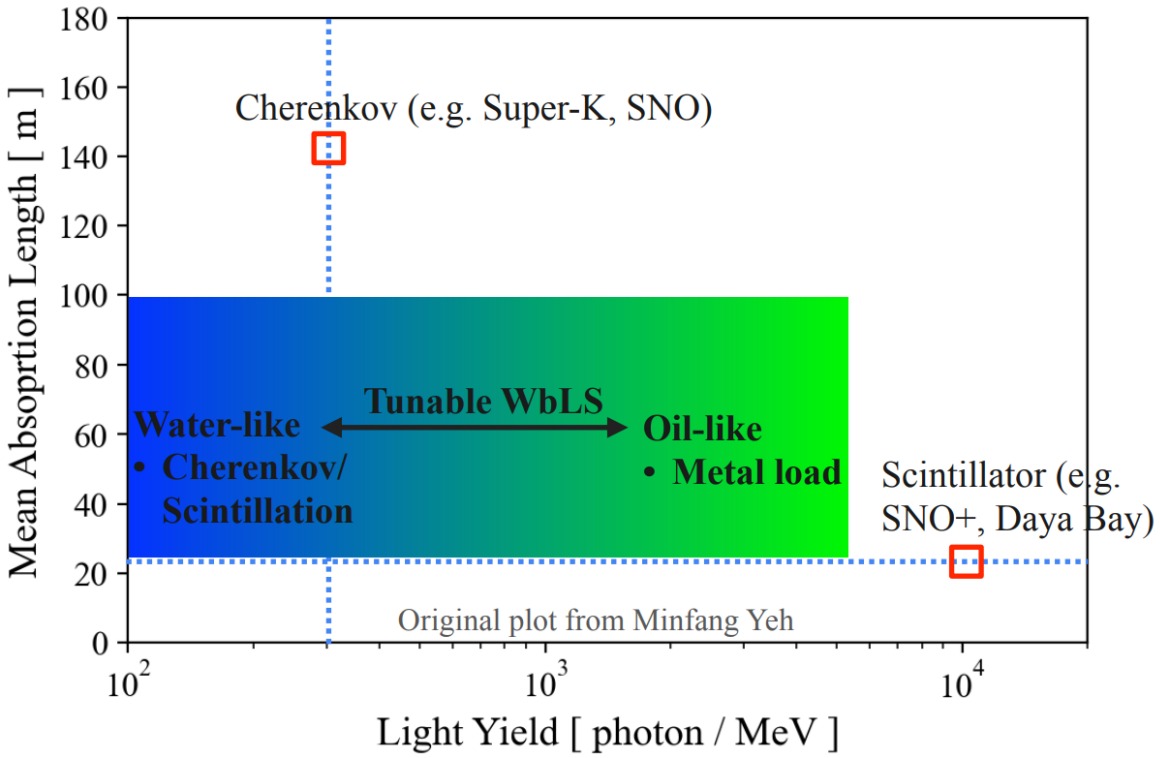
X. Xiang, CPAD, Stony Brook University (2022).



- Worldwide nuclear security
- Need for low-cost detectors for coverage

Motivation

Motivation

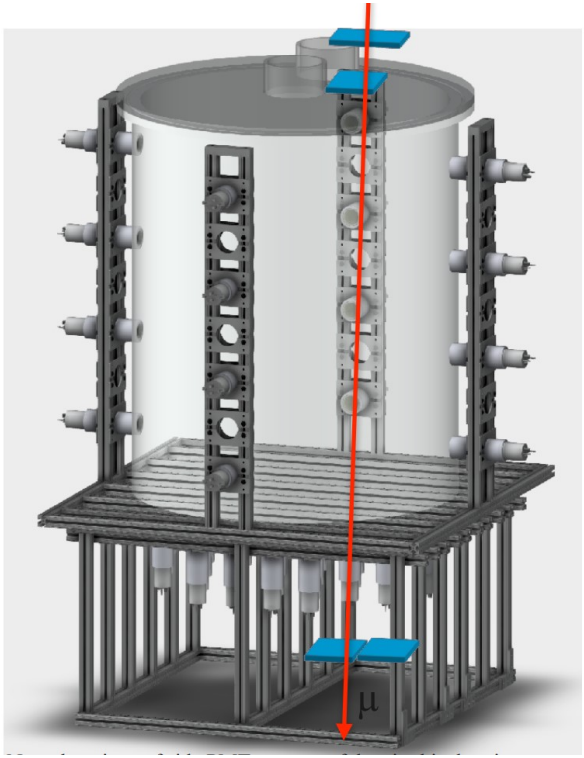


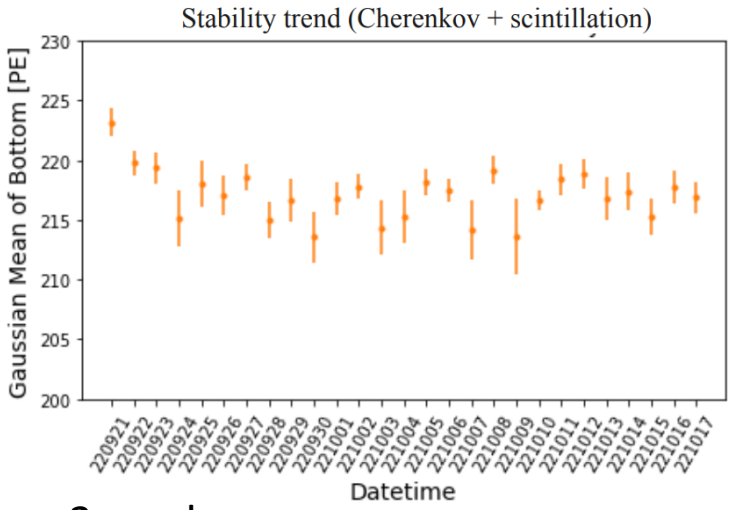
- Directional reconstruction of Cherenkov radiation and scintillation
- Adjustable light yield
- Vary attenuation length
- Low toxicity

X. Xiang, CPAD, Stony Brook University (2022).

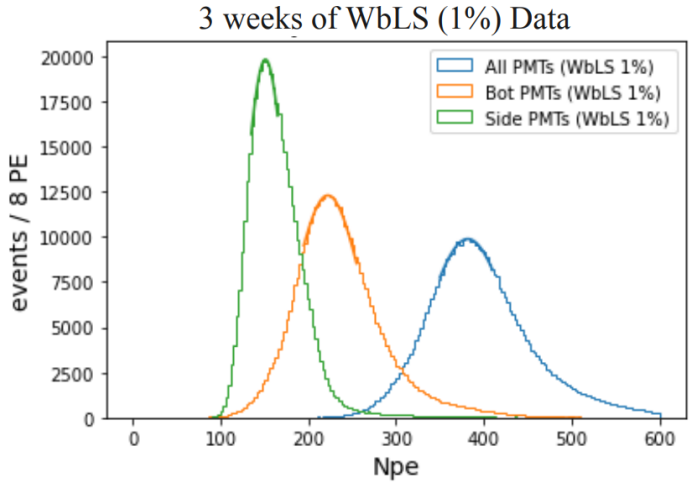
Ongoing work: 1-ton detector

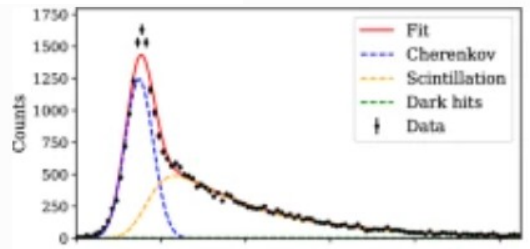
- Signal analysis of downward muon and Cherenkov radiation emitted
- Understanding distribution for trajectory reconstruction





3 weeks



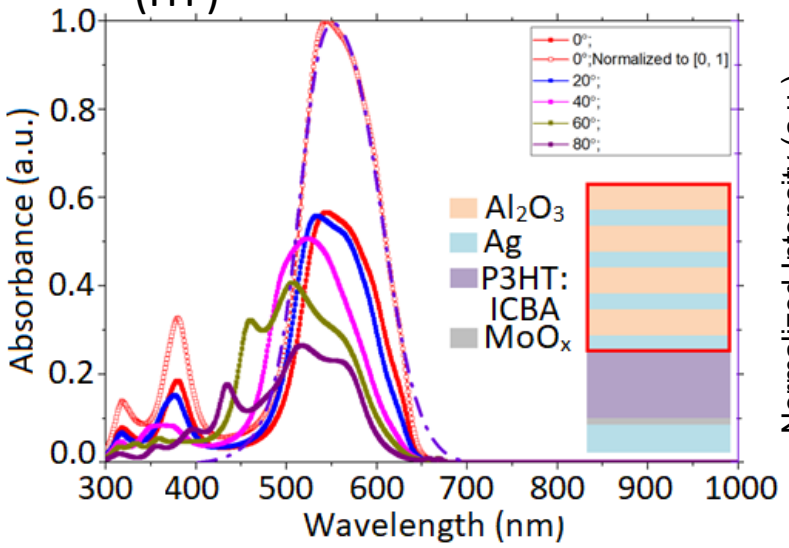


X. Xiang, CPAD, Stony Brook University (2022).

T. Kaptanoglu, E. J. Callaghan, M. Yeh, G. D. Orebi Gann, Cherenkov and scintillation separation in water-based liquid scintillator using an LAPPDTM. *The European Physical Journal C* **82**, 169 (2022).

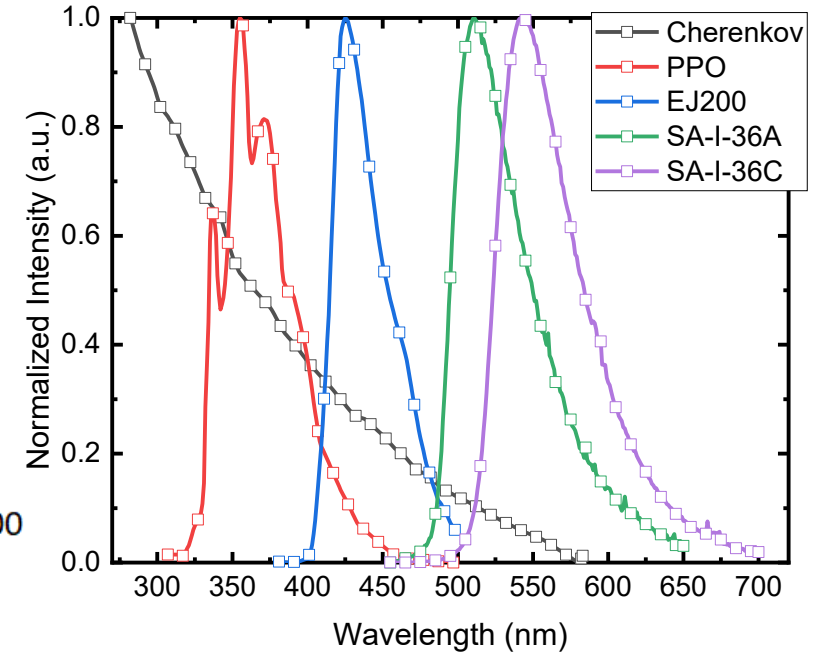
Concurrent Exploration

Induced Transmission Filter (ITF)

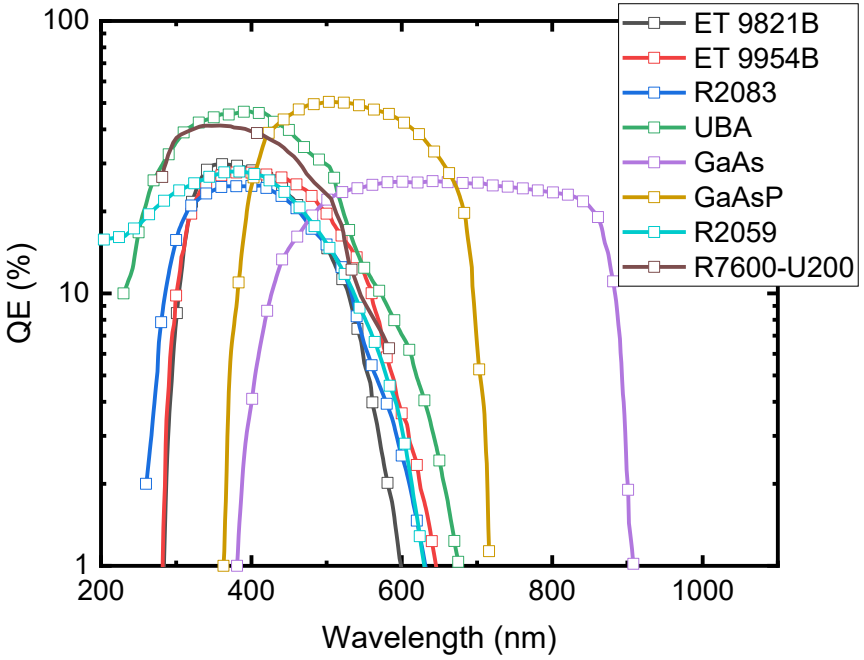


Data credit: Jingwei Yang

Emission Spectra of Interest



PMT QE



$$\text{Spectral } irradiance\ [W * m^{-2} * sr^{-1}] = \int SPD(\lambda) * QE_{det}(\lambda) * d\lambda$$

$$N_{e^-} = G \sum N_{photons} * QE_{det}(\lambda)$$

Status: fabrication of ITF

Summary

- 3D-printable plastic scintillators with favorable mechanical properties
- Ongoing work to design and prototype large-volume detectors with BNL for high-energy physics
  - Developing method for consistent distribution characterization
- Assisting BNL team with signal processing for separation of Cherenkov and scintillation light

ACKNOWLEDGEMENTS

This material is based upon work supported by the Department of Energy / National Nuclear Security Administration under Award Number(s) DE-NA0003921.