Material Development and 30-ton WbLS Demonstrator at BNL

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CPAD Workshop, Nov 7-10, 2023

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY


Engineering, technical and project supports for 1T & 30T Prototypes


Ton-scale production and purification facilities

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Liquid Scintillator (LS) Detectors

- $\bar{\nu}_e + p \rightarrow n + e^+;\ n + p \rightarrow d + \gamma$
- $\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B \rightarrow {}^{12}C + e^- + \bar{\nu}_e$
- $\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N \rightarrow {}^{12}C + e^+ + \nu_e$
- $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^* \rightarrow {}^{12}C + \gamma$
- $\nu_x + e^- \rightarrow \nu_x + e^-$
- $\nu_x + p \rightarrow \nu_x + p$

Large Liquid Scintillation Detectors*

C. L. Cowan, Jr., F. Reines, F. B. Harrison, E. C. Anderson, and F. N. Hayes
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico
(Received February 24, 1953)

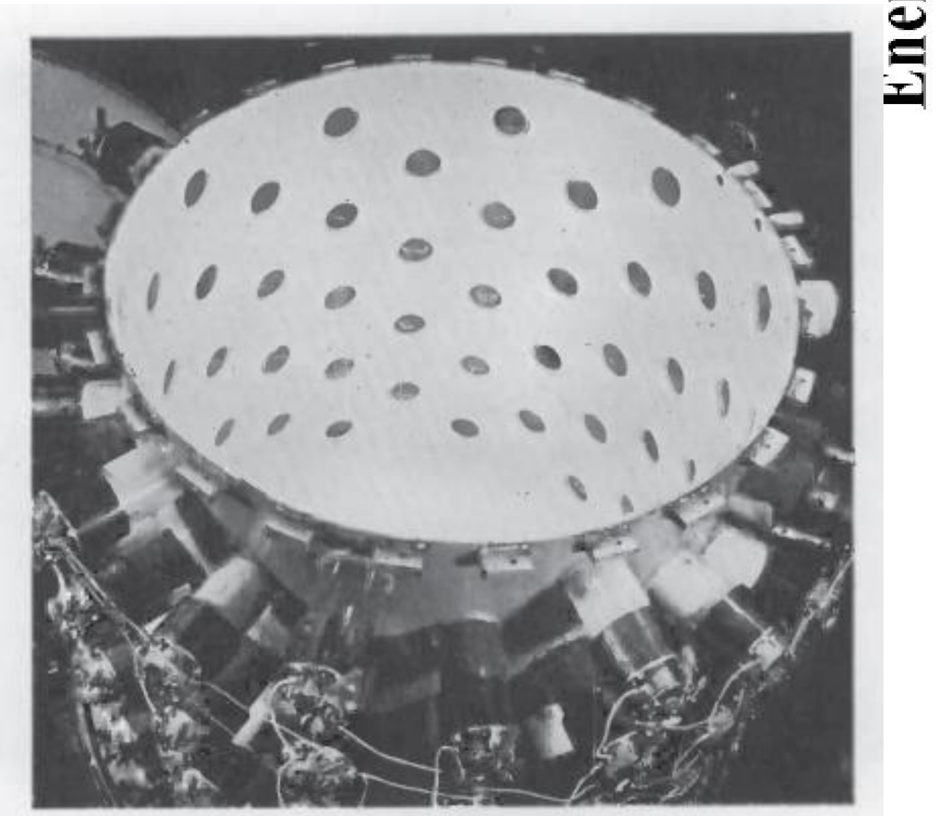
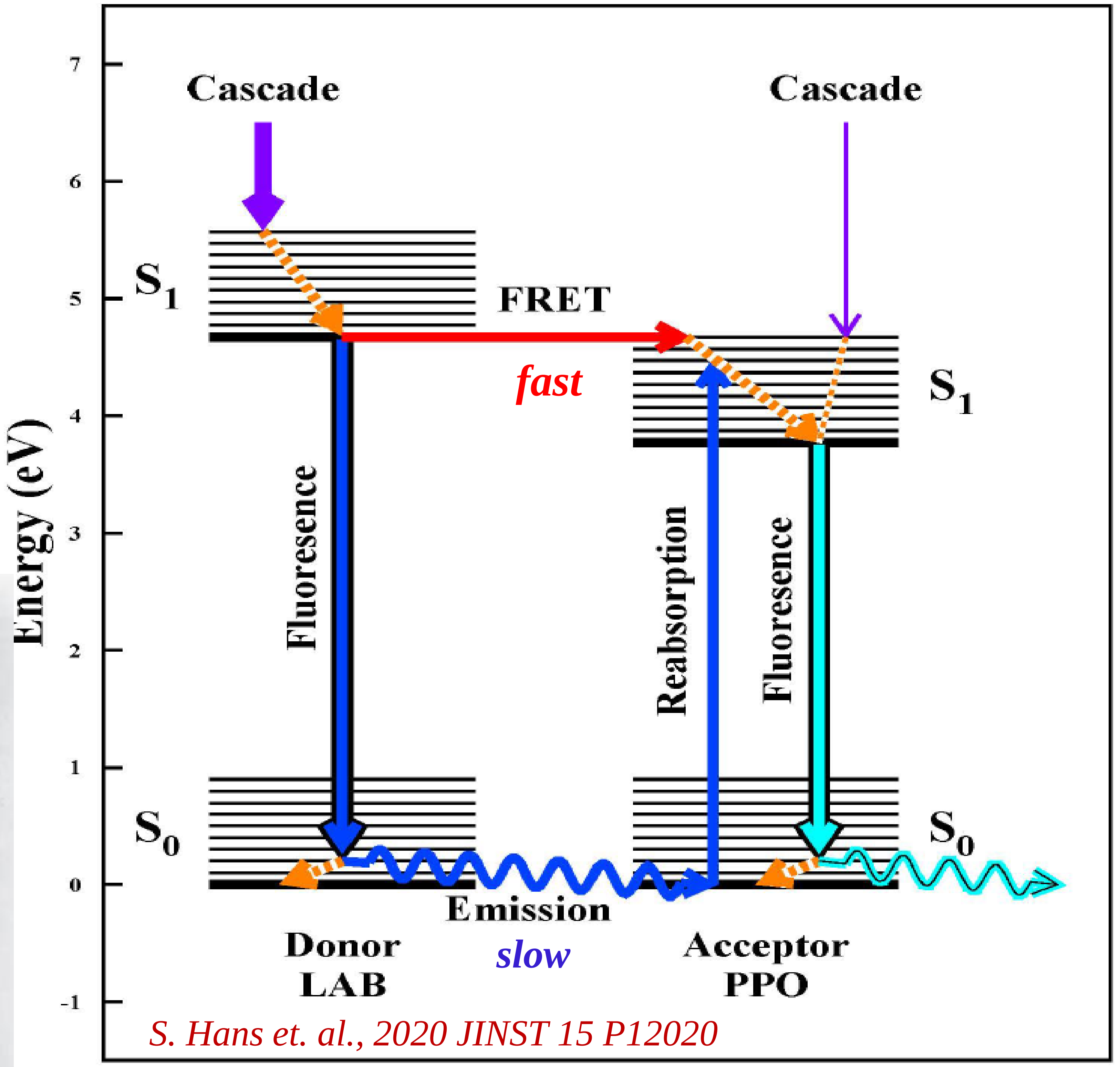
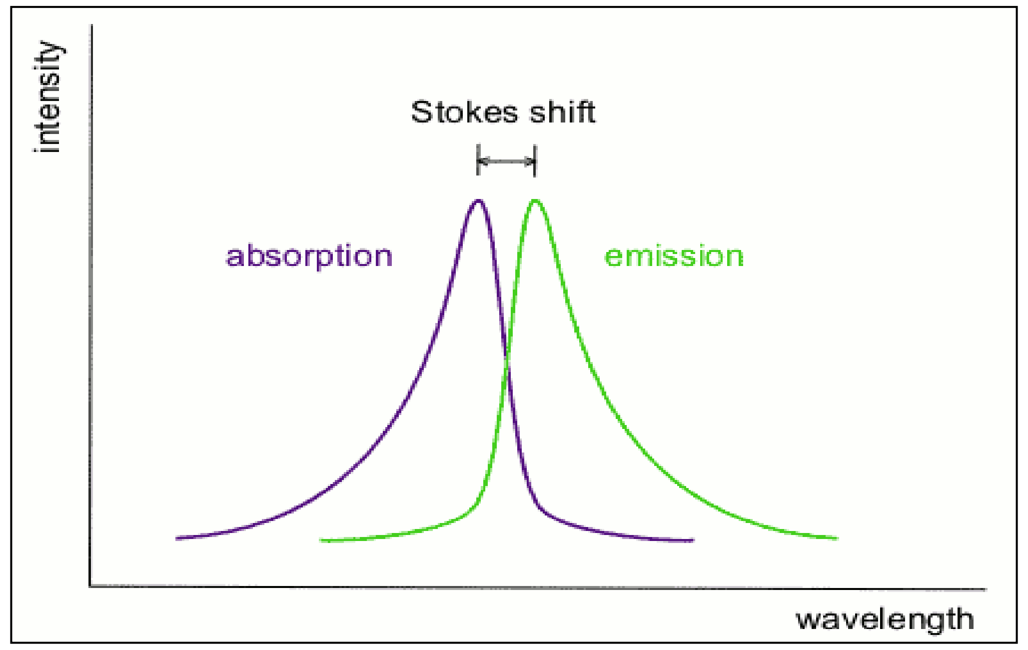
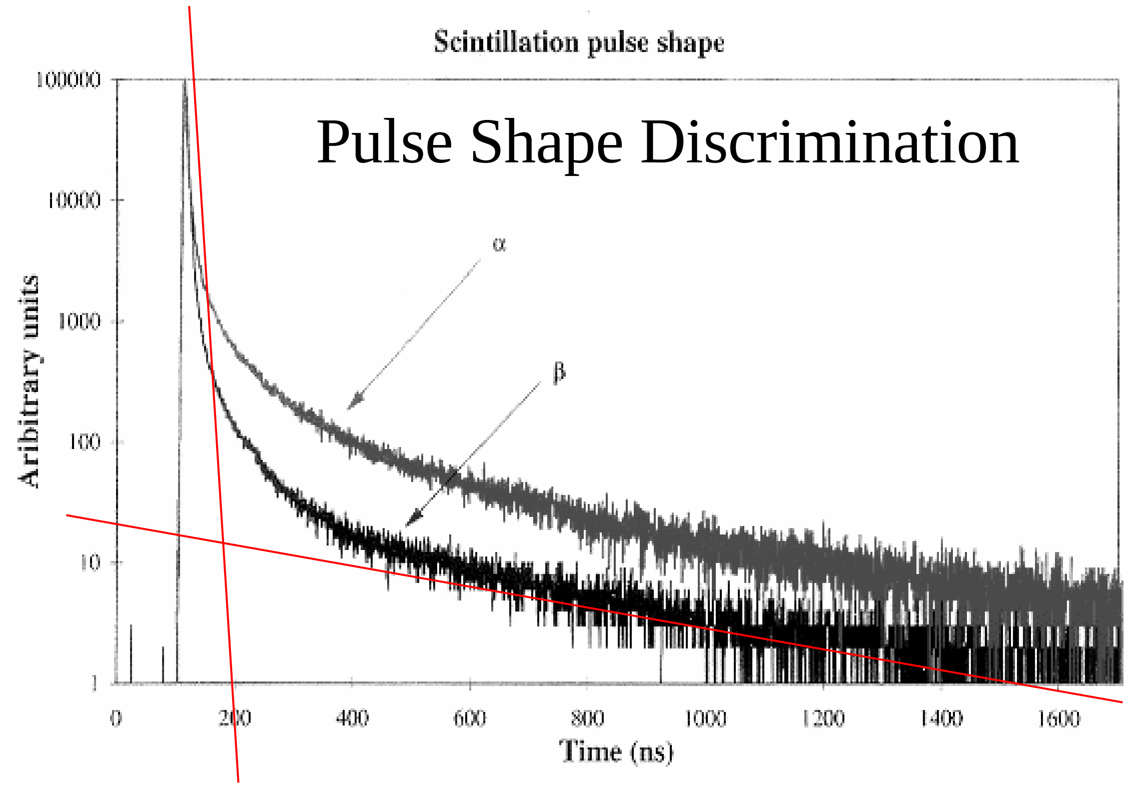


Fig. 2. The Hanford neutrino detector (1953).

Aromatic solvent at $3-4k per ton







From understanding of our Universe to applications in nonproliferation, medical physics, nuclear material detection, LSC, etc.

Stokes-shift, photon-yield, timing structure, and C/H density determine scintillator responses (modern LS is high fp and low toxicity; compatible with detector vessel)

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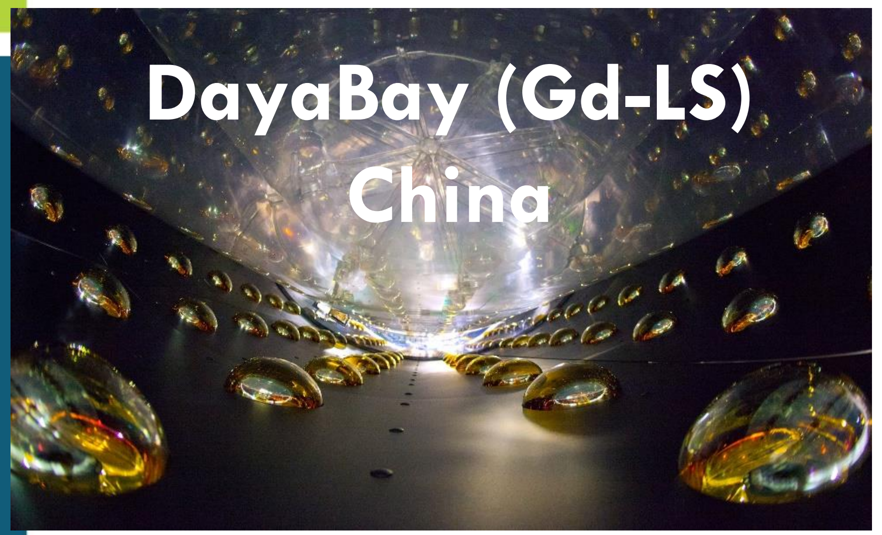
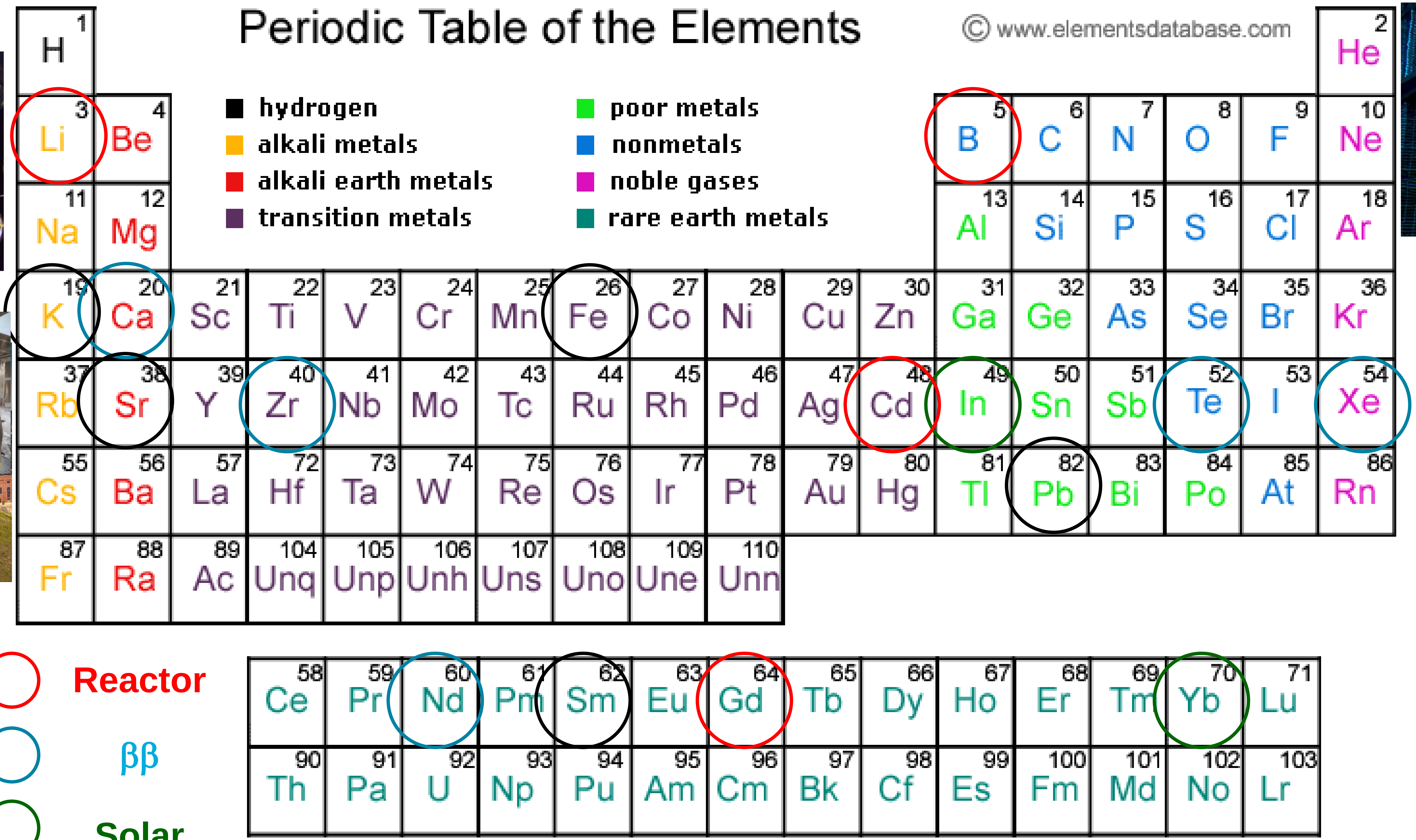
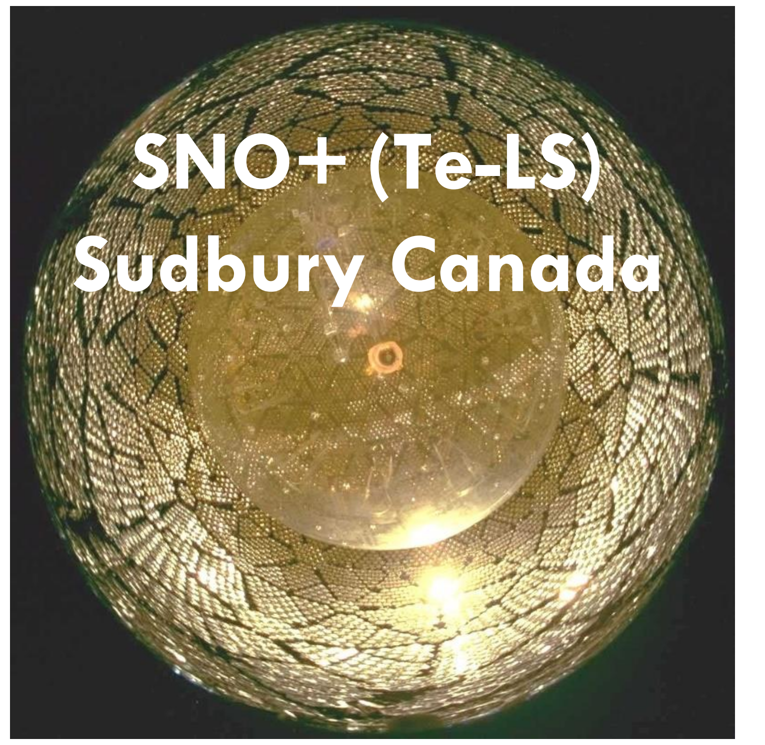
Metal-doped Liquid Scintillators

for neutrino physics and other frontiers since 2000







Reactor

ββ

Solar

Medical, calibration, LSC, etc

Started from LENS R&D

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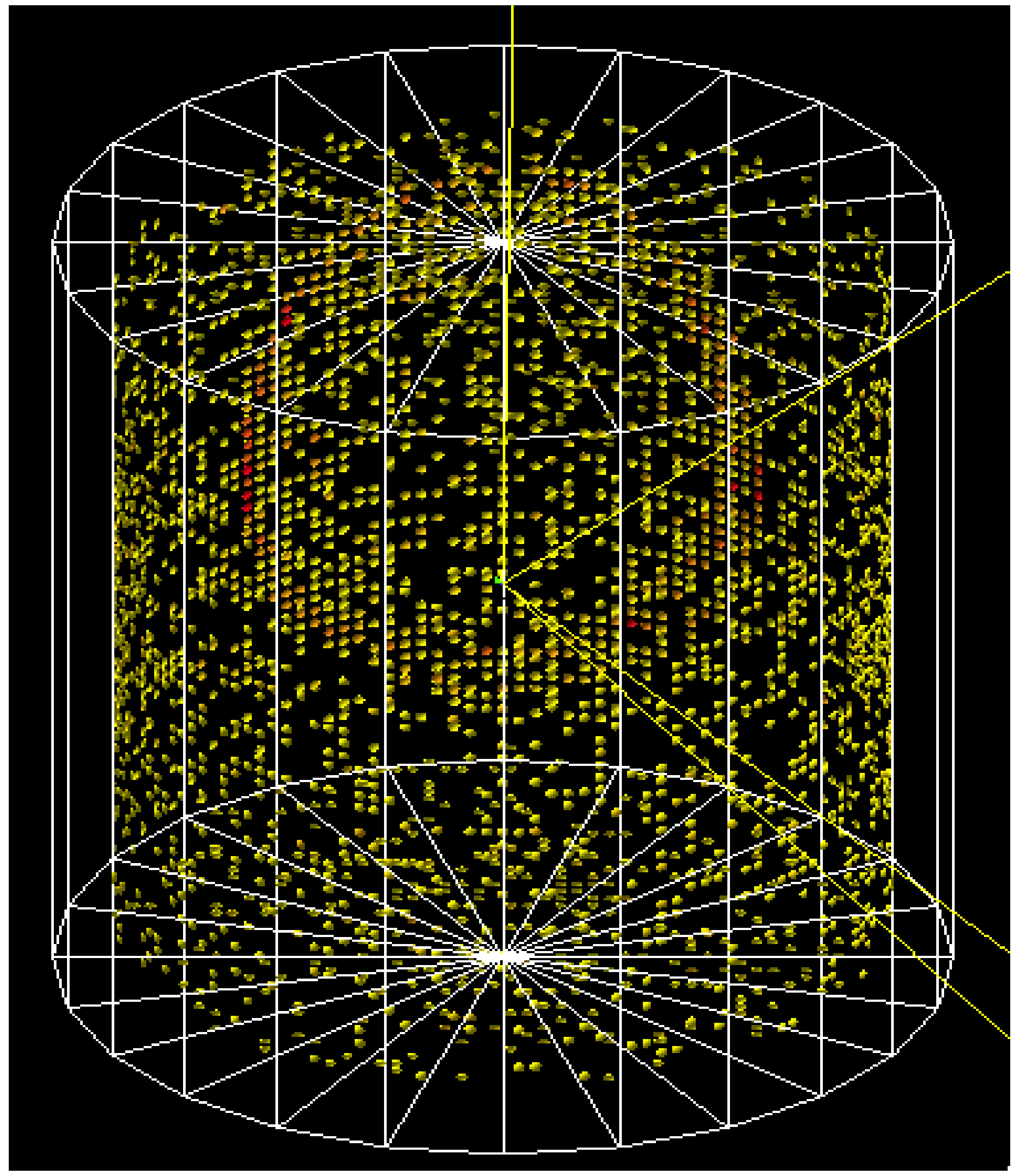
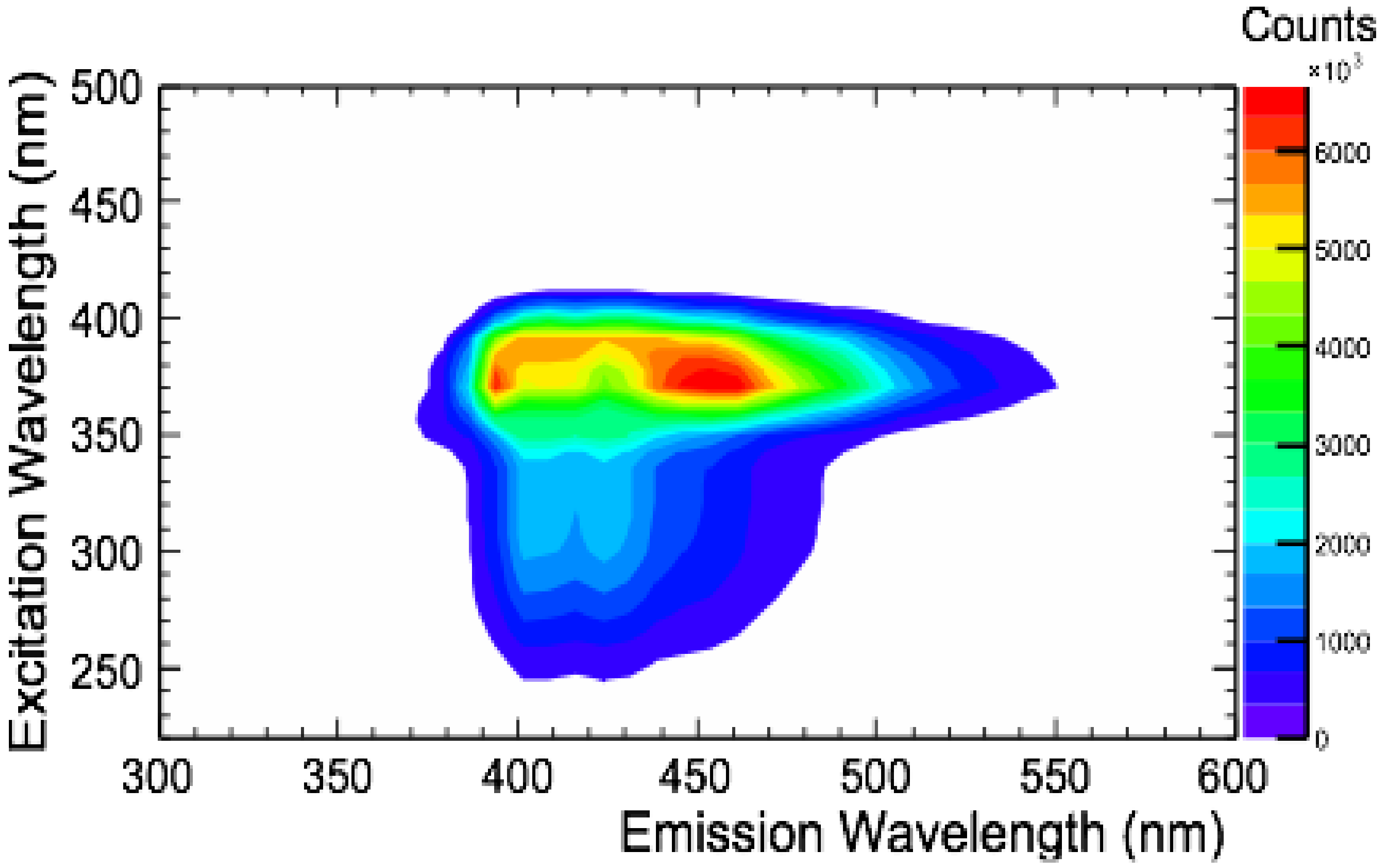
Water-based Liquid Scintillator

If you always do what you always did, you will always get what you always got. -Albert Einstein

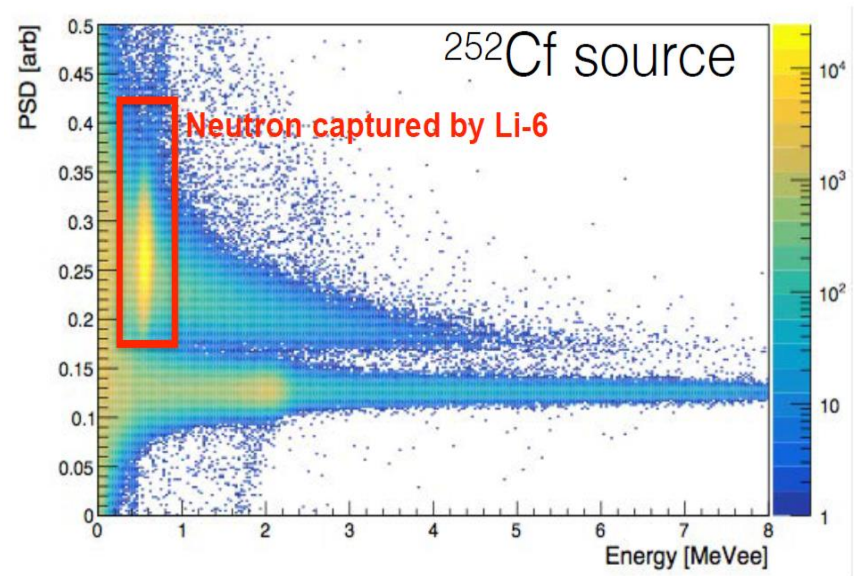
National Nuclear Security Administration

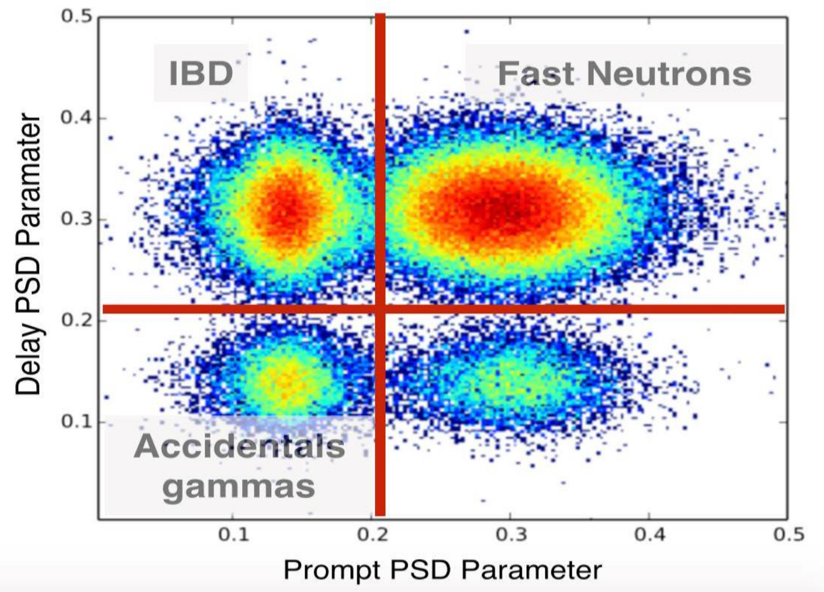
- A novel low-energy threshold detection medium, bridging scintillator and water.
- Tunable scintillation light from ~pure water to ~organic.
- Environment-friendly, noncombustible, and excellent material compatibility; feasible for **field study**.
- A particle detector capable of <u>Cherenkov and Scintillation detections</u>
- Viable to load a variety of metallic isotopes for varied particle detections (**neutron-enhanced**)

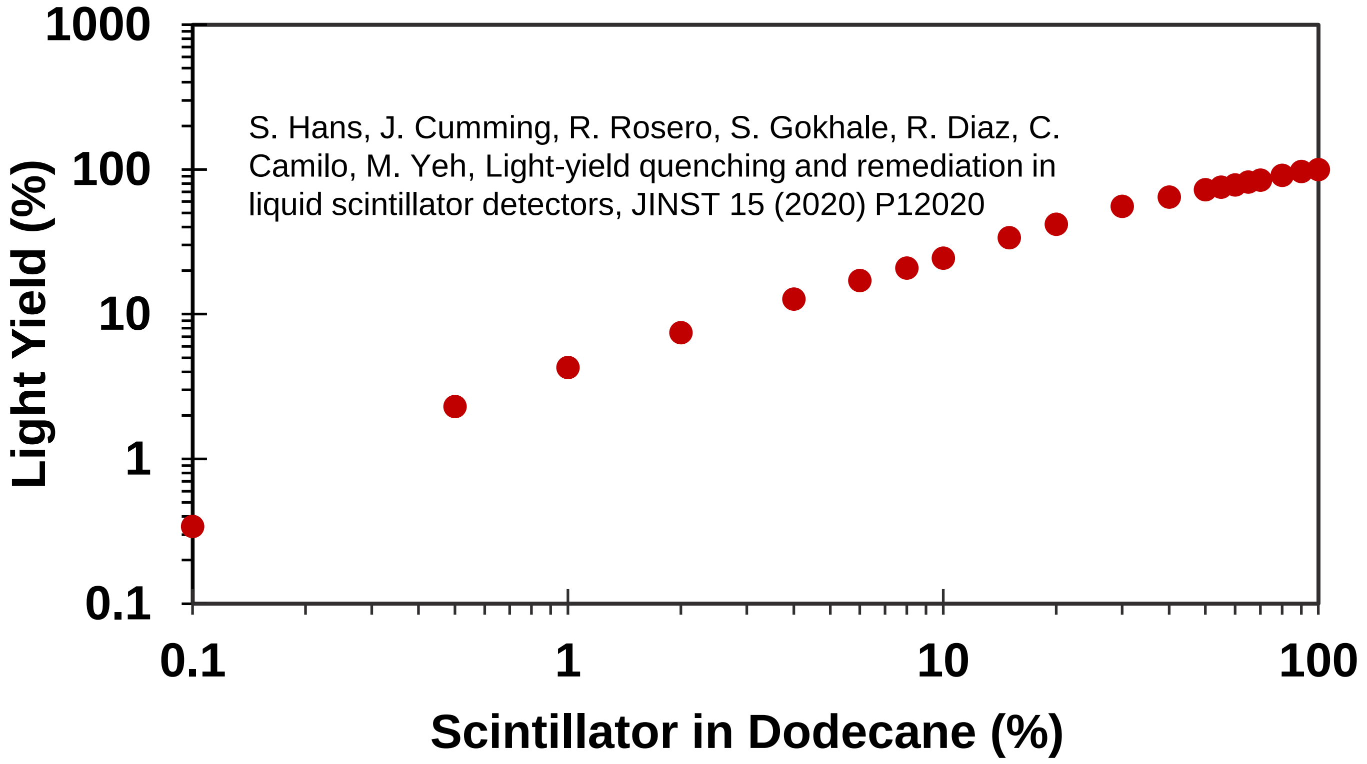


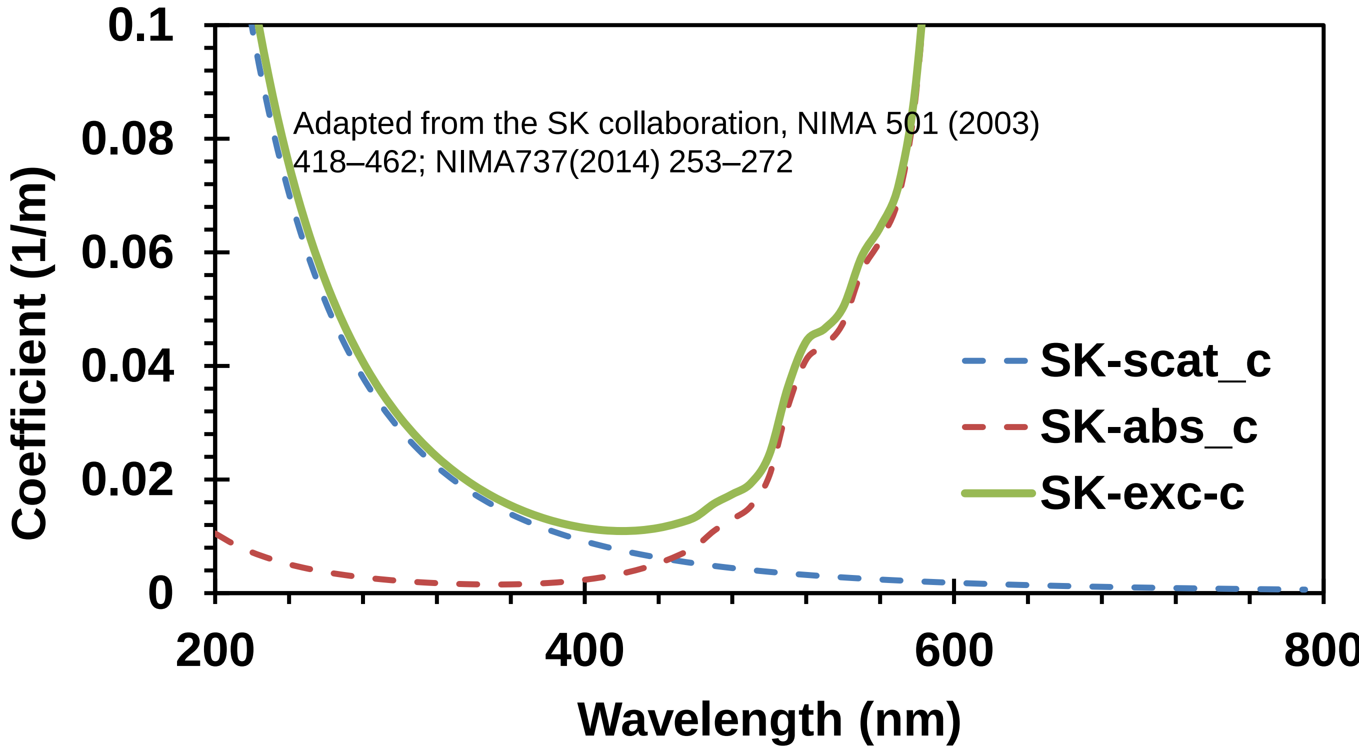


Tunable LS%, timing and emission









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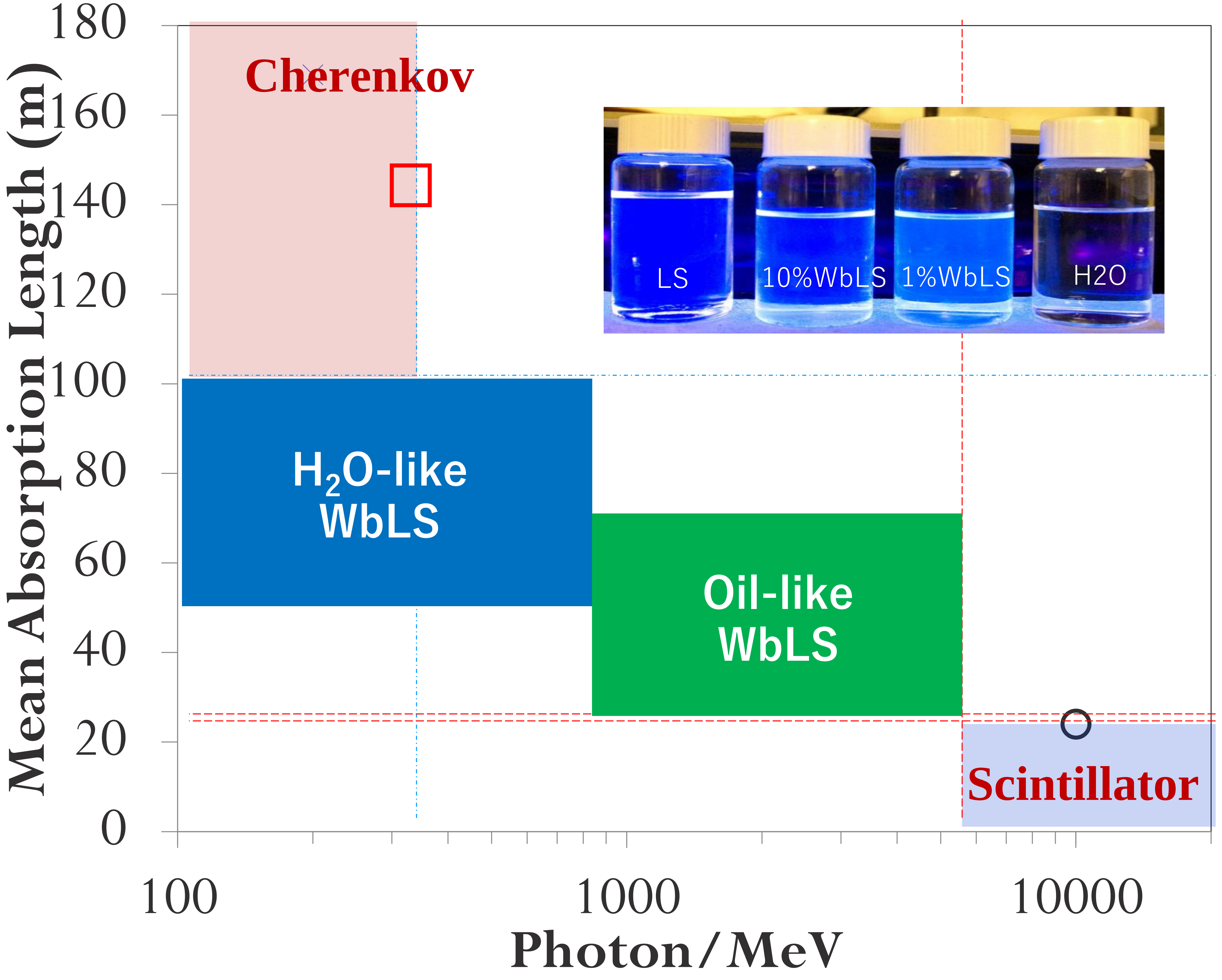
4 tons of (PROSPECT) ^{6}Li-doped LS production for at BNL in 2019

Oil vs H_2O

Water-like WbLS

- **1000s ton-scale detectors**
- **Long scattering length (>25m at 450nm)**
- **In-situ circulation feasible**
- **1-10% LS loading in water (100-1200 phs/MeV)**
- **Metal-dope (~all elements)**
- **30TBNL, Eos, ANNIE, BUTTON, THEIA**



Oil-like WbLS

- **1-10s ton-scale detectors**
- **High light-yield**
- **PSD capability**
- **Not necessary for in-situ circulation**
- **>90% LS with water (>10,000 phs/MeV)**
- **Metal-doped (~all elements)**
- **PROSPECT, (G3)DM, LiquidO**

First WbLS concept introduced in 2010ANT (Santa Fe) and A new water-based liquid scintillator and potential applications, NIMA, 2011

Yeh at AAP2023

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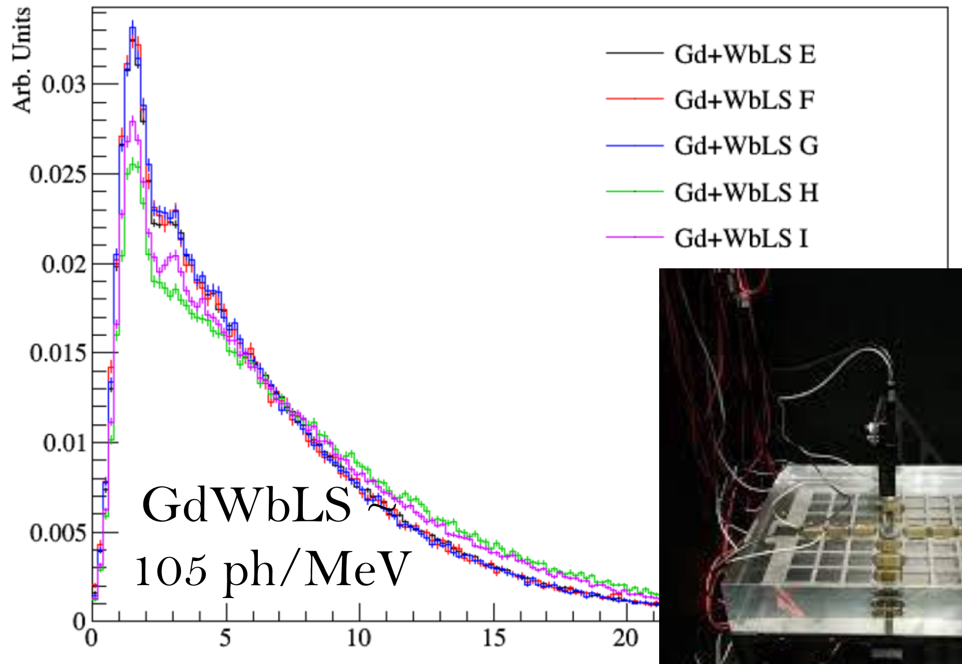
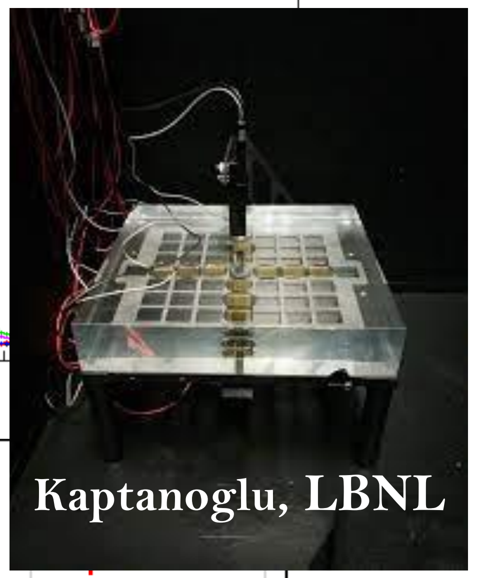
A water-like WbLS for kiloton-scale optical detector: GdWbLS vs (1~5%)WbLS

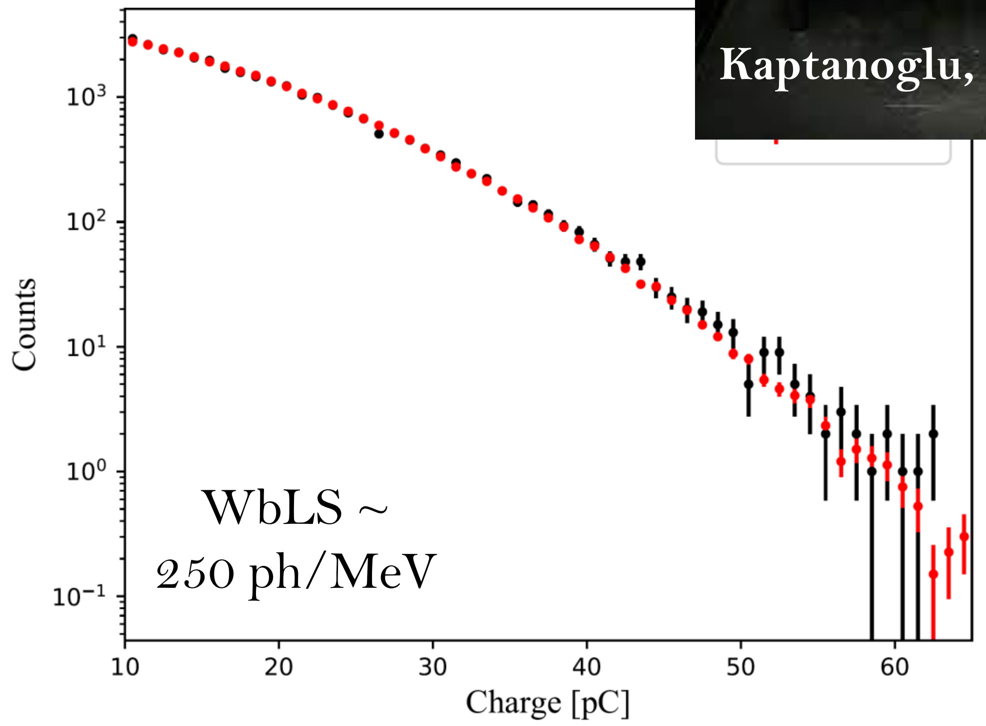
- Benchtop and Prototype developments
- Ton-scale production facility

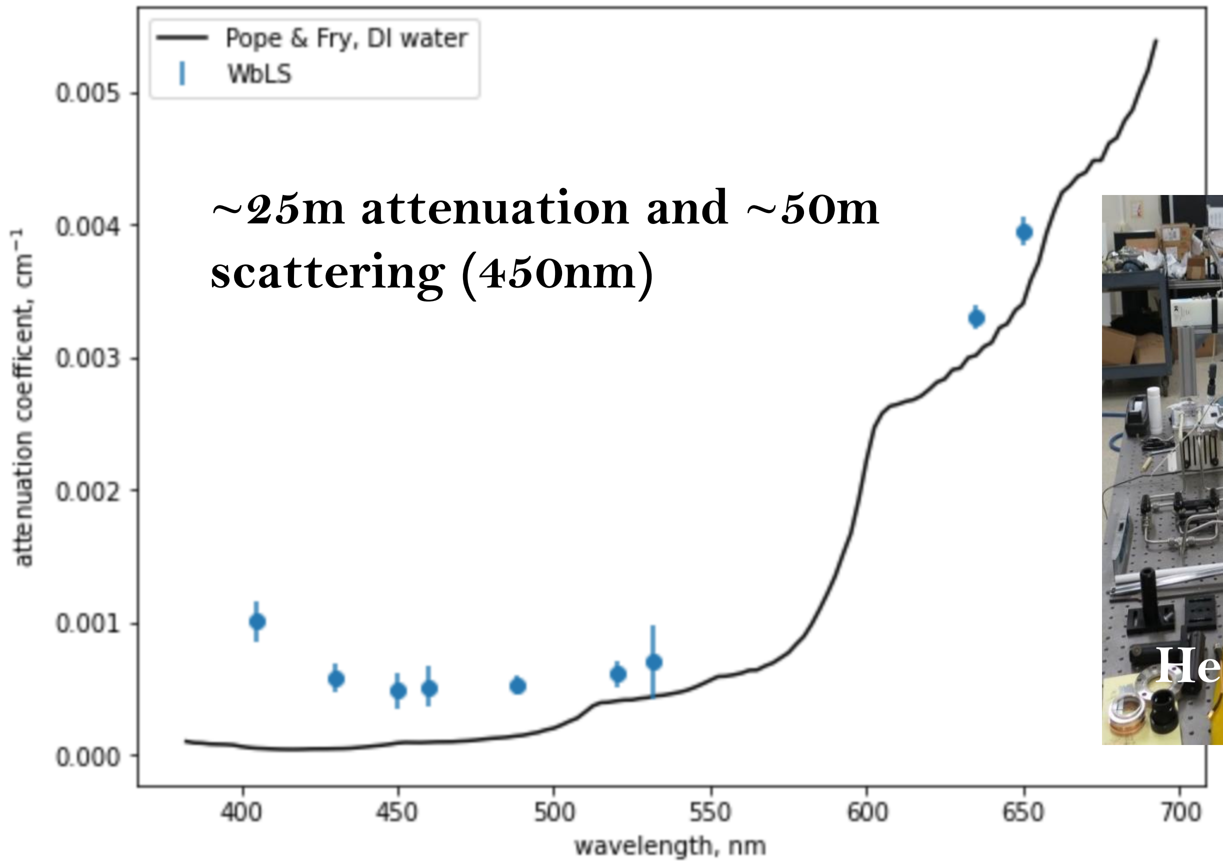
Benchtop Development

- Developed and characterized a variety of WbLS formulas for multiple frontiers; all liquids stable since production (~years).
- Demonstrated Gd-, Li-, and B-doped WbLS with projected performances.
- Established material compatibility program to qualify detector construction.

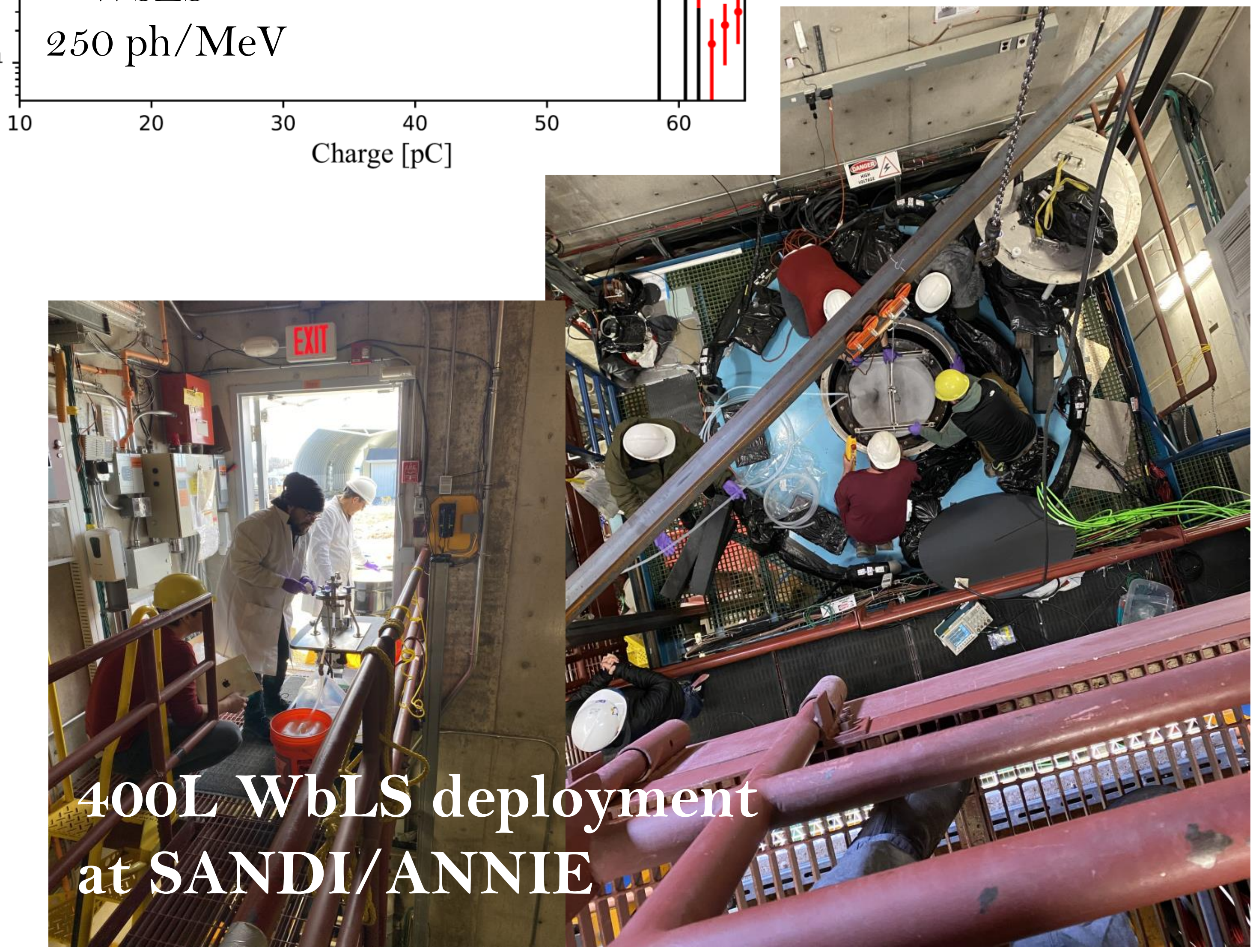


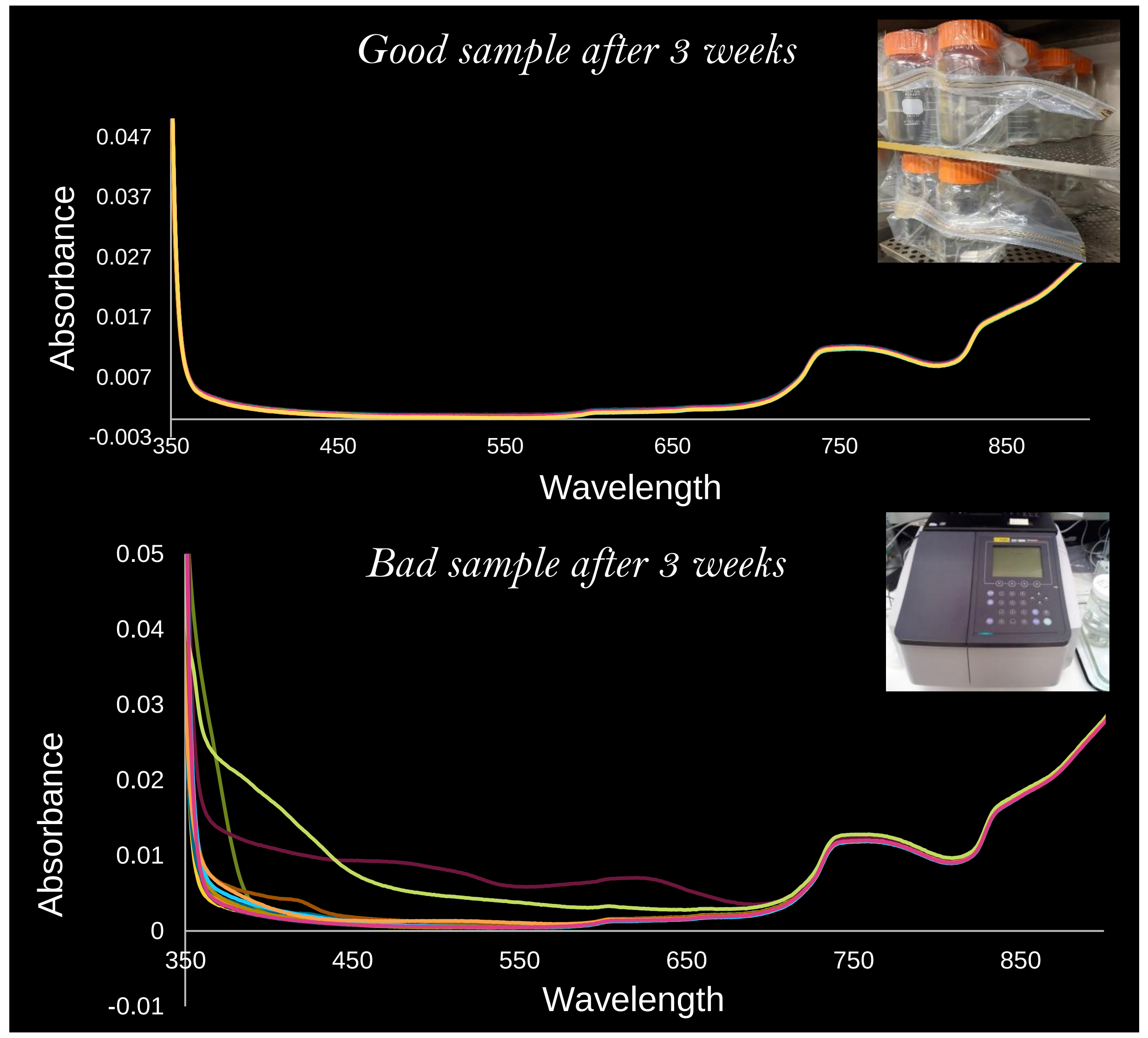






orcid.org/0000-0003-2244-0499





Scale-up Development: 1-ton Testbed (1TBNL)

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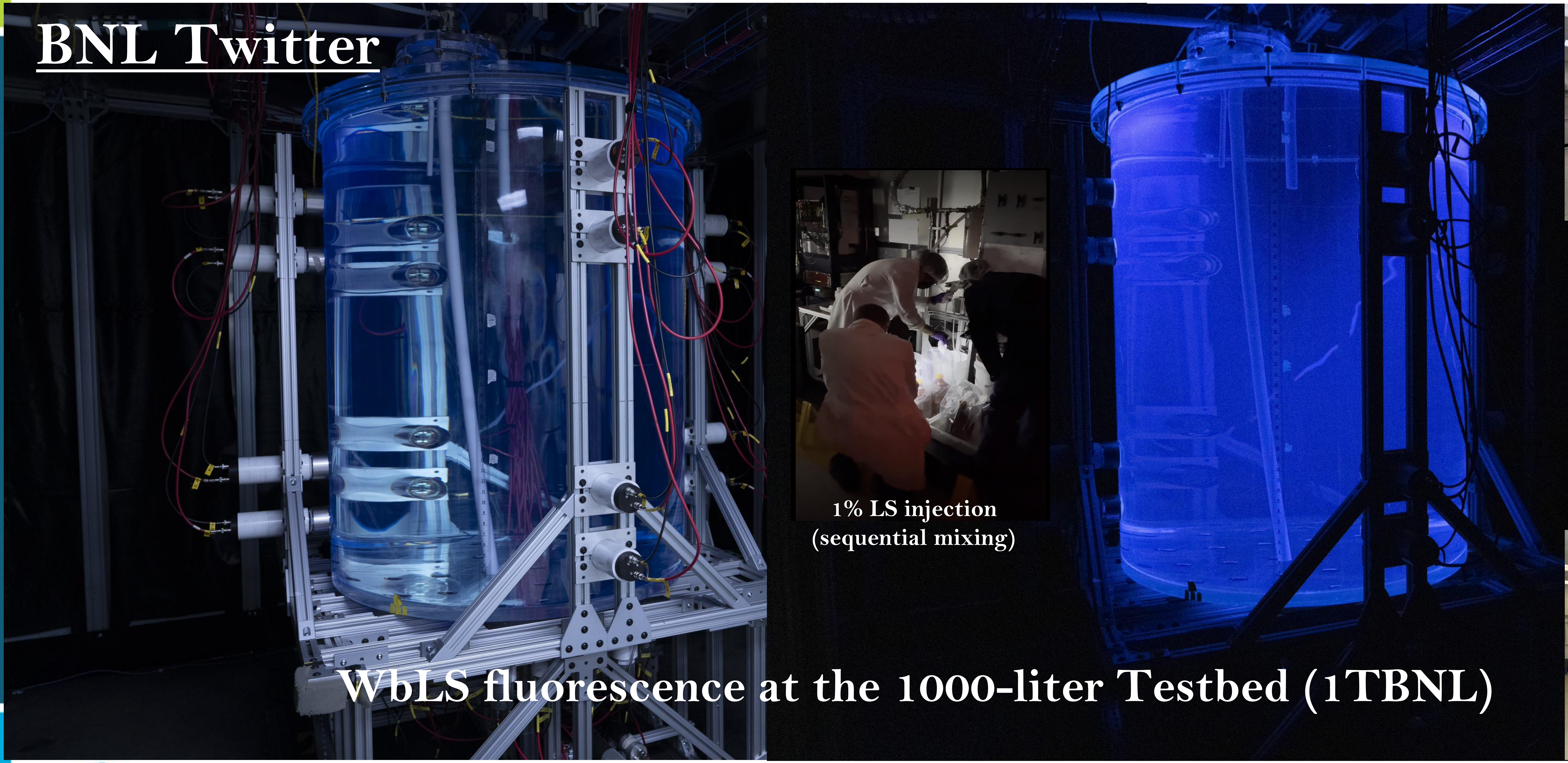

Progress at 1TBNL

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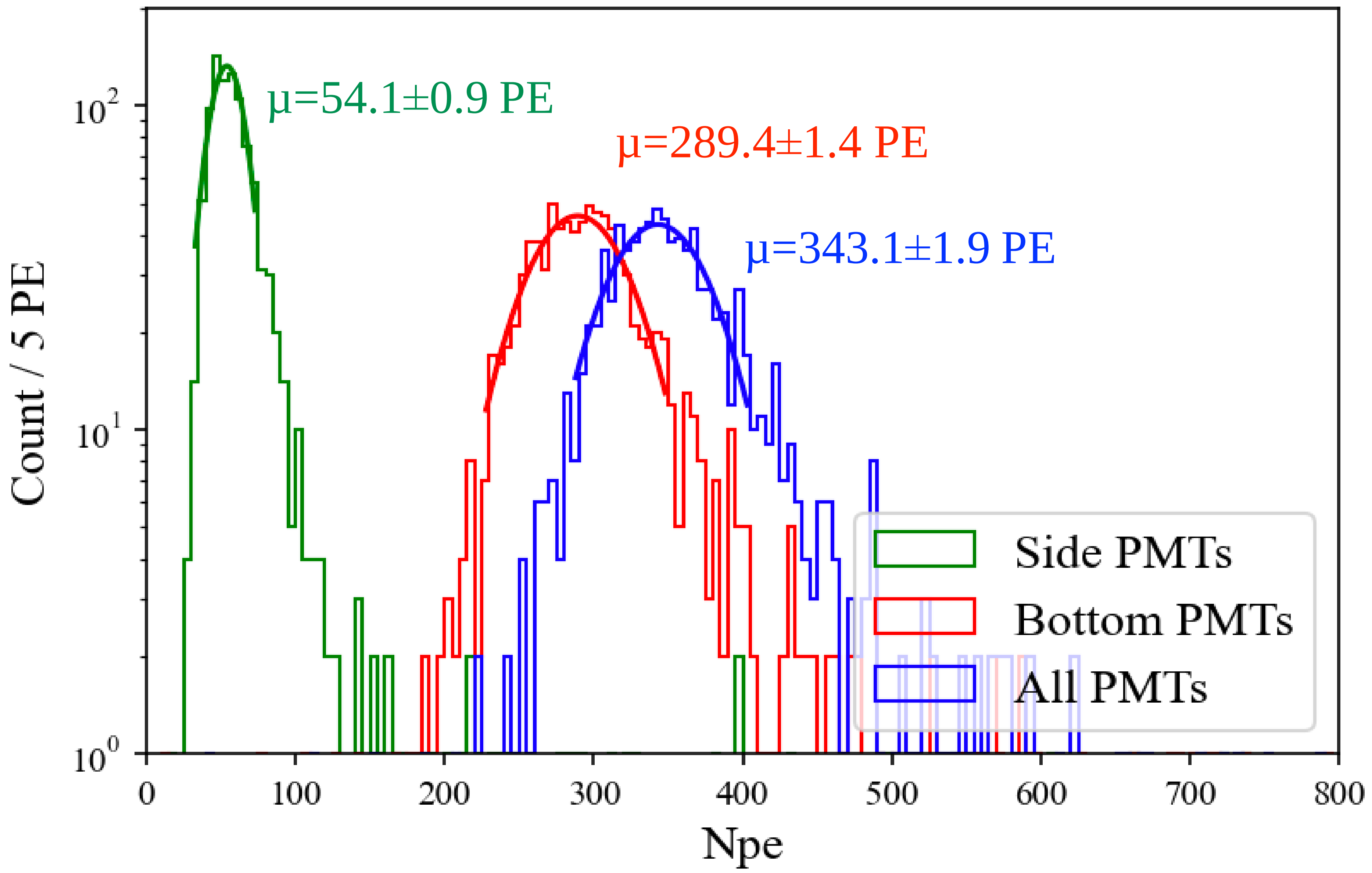
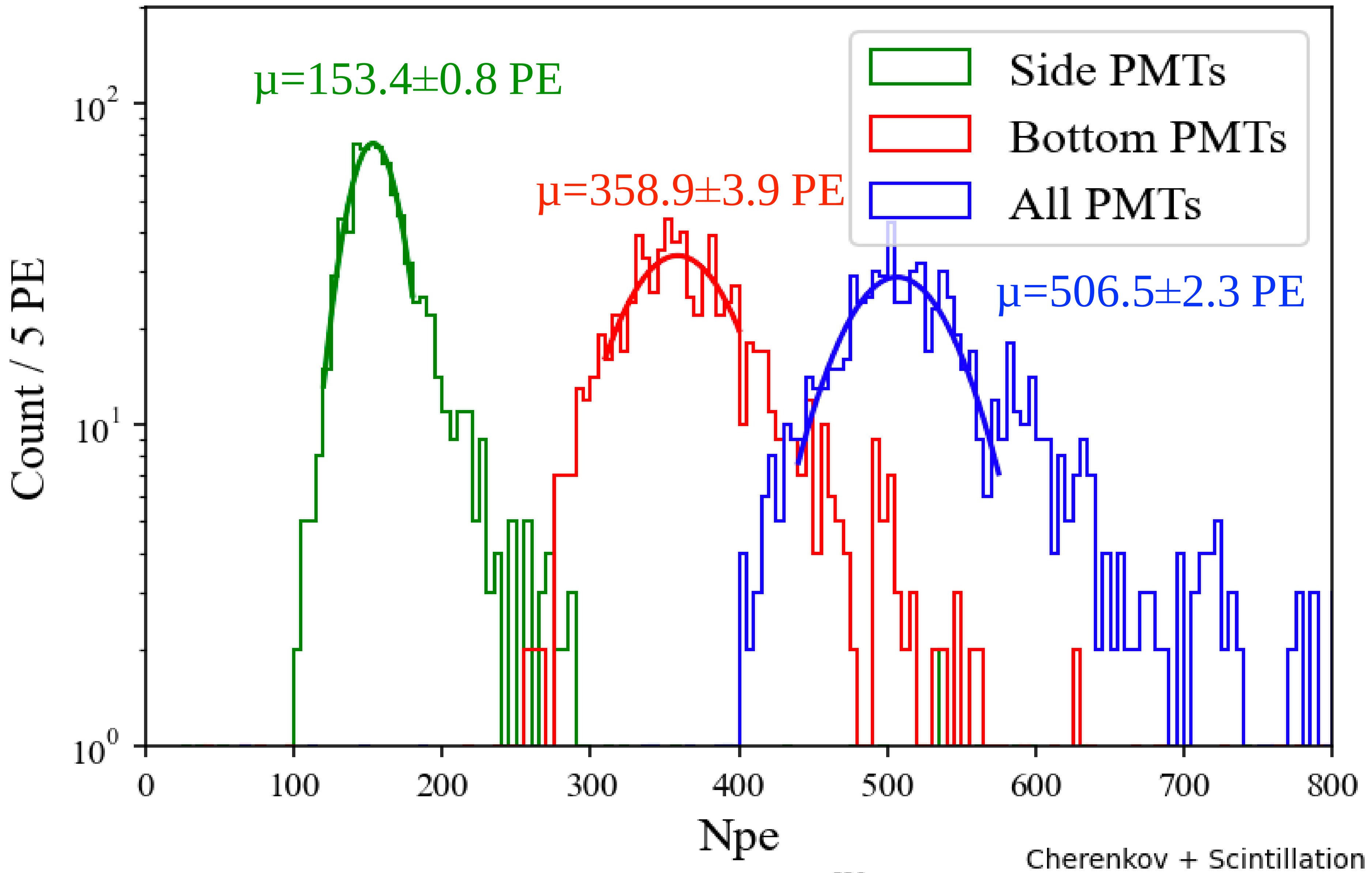
Tagged crossing muons in **water**

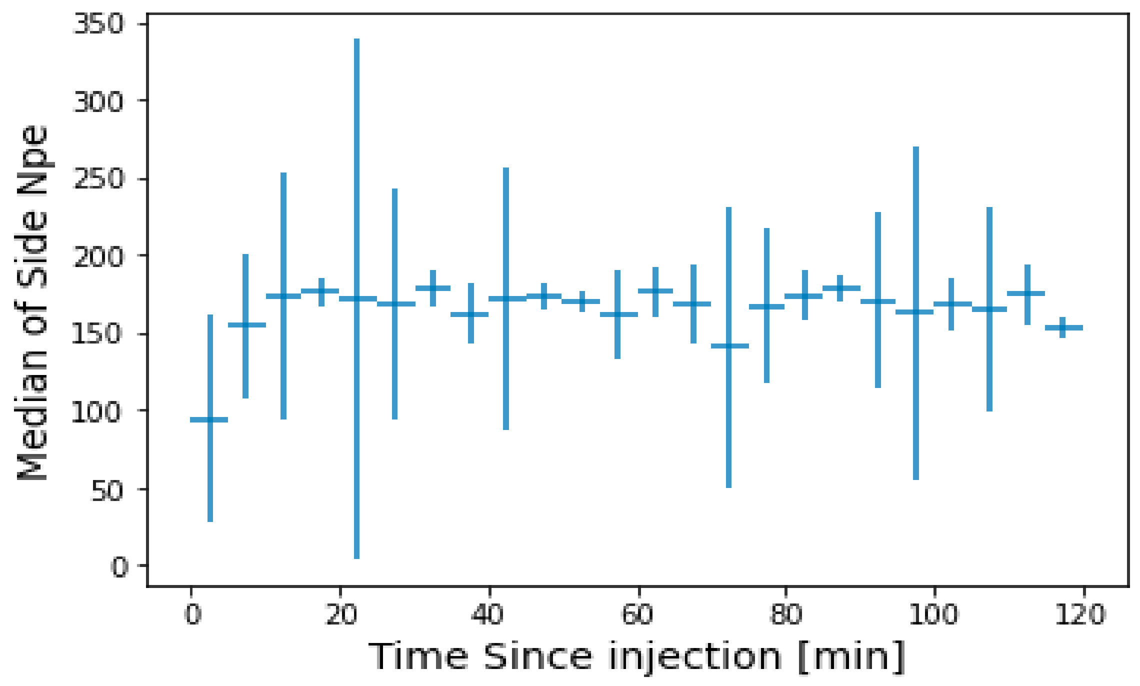


1% LS injection

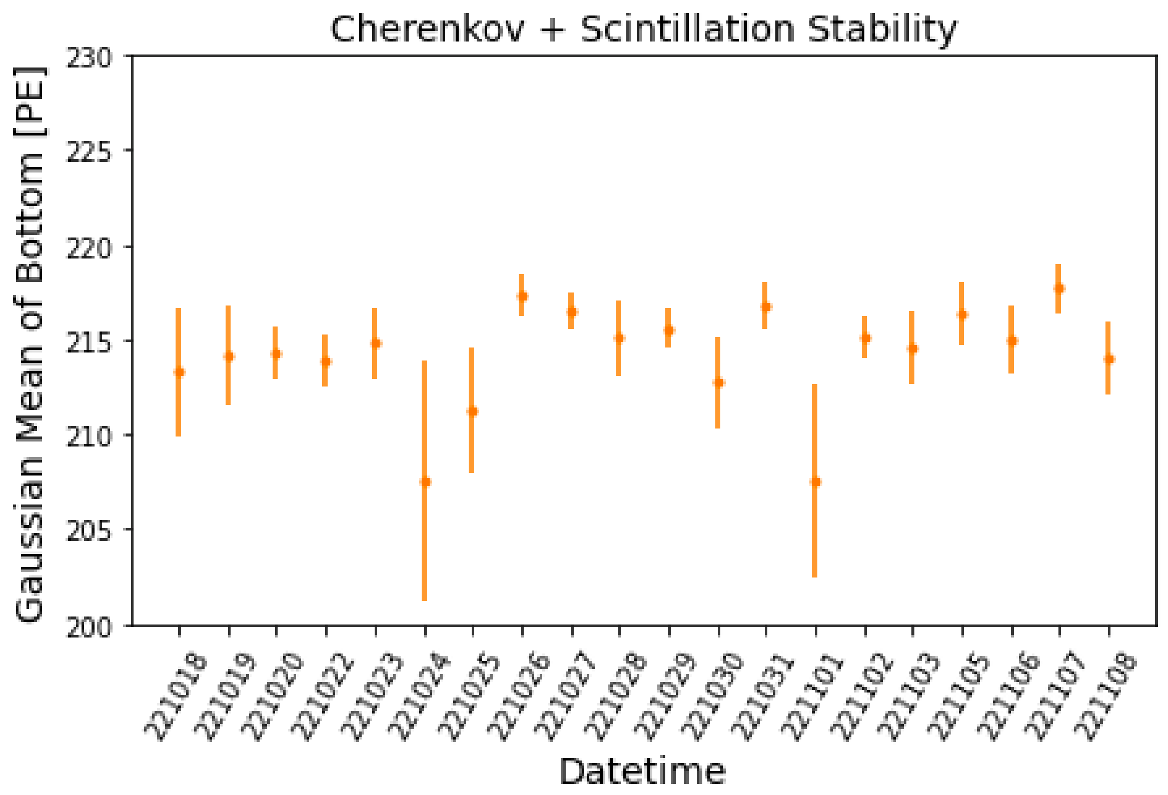
Tagged crossing muons in **WbLS (1%)**



- Light enhancement (scintillation) from the tagged crossing muons with only 1% LS in water
- Successful demonstration of transforming a water Cherenkov detector to a WbLS detector by **sequential mixing technology** (cost-effective with minimum labor)
- WbLS stability observed over months of operation (cont.)



Homogeneity observed 20mins after injection



Stability of 1%WbLS observed

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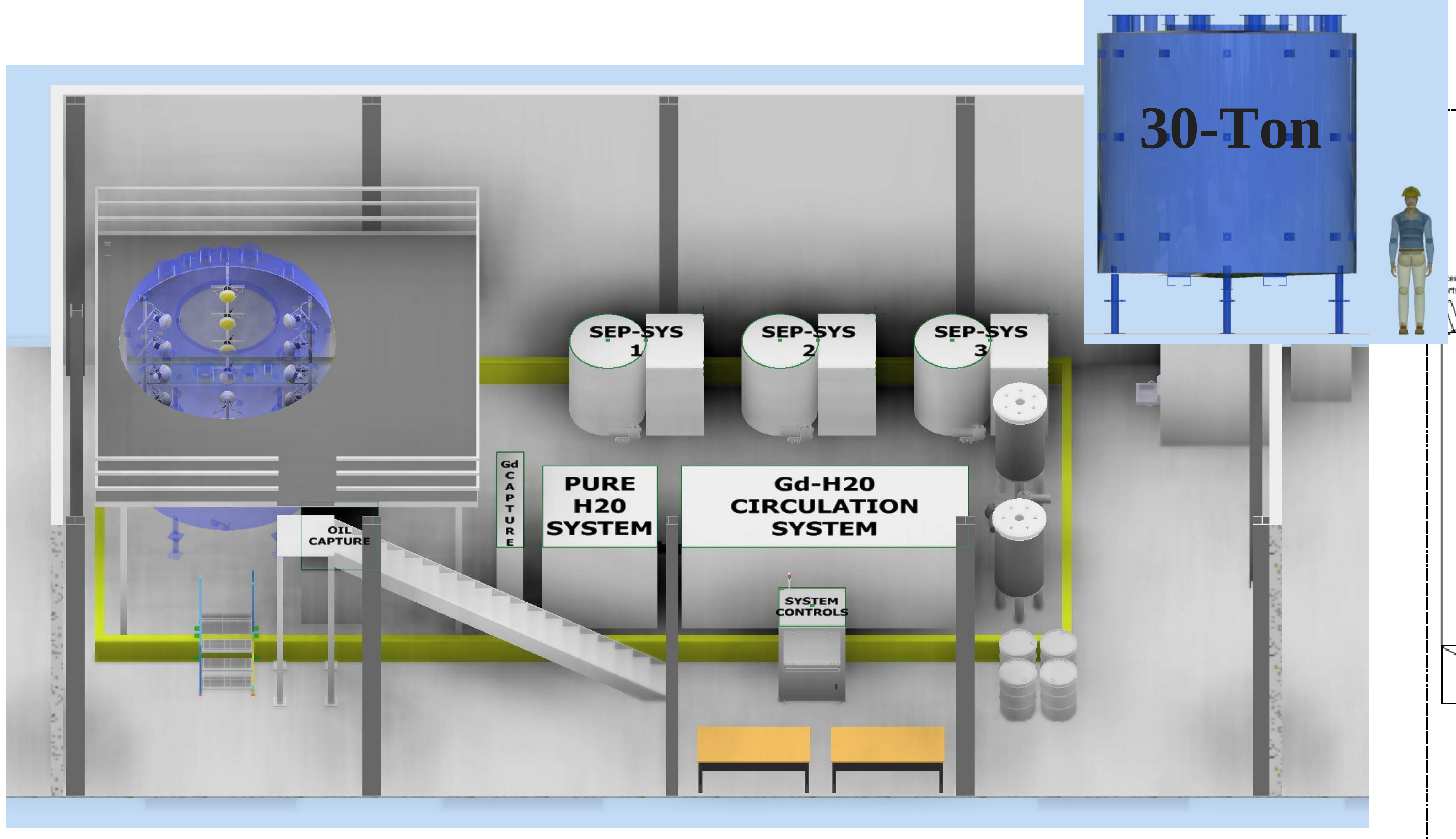
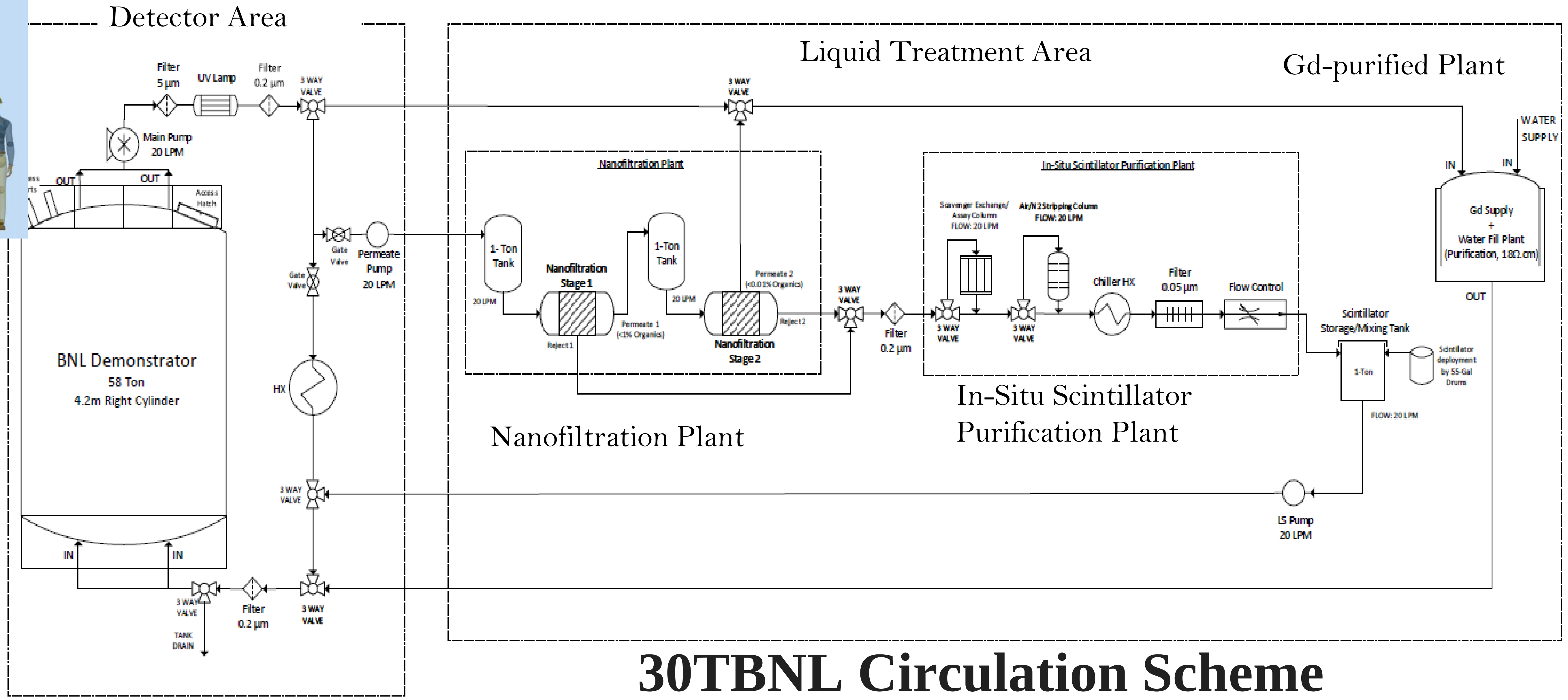
30-ton Demonstrator (30TBNL)

- **A fully-equipped 30-ton optical detector with in-situ circulation system to demonstrate large-scale WbLS deployment**
- engineering and integration studies with Gd-water system and nanofiltration system (in-situ purification)
- Performance stability, interface, and slow-control
- Capable of adding an Inner Vessel (IV)





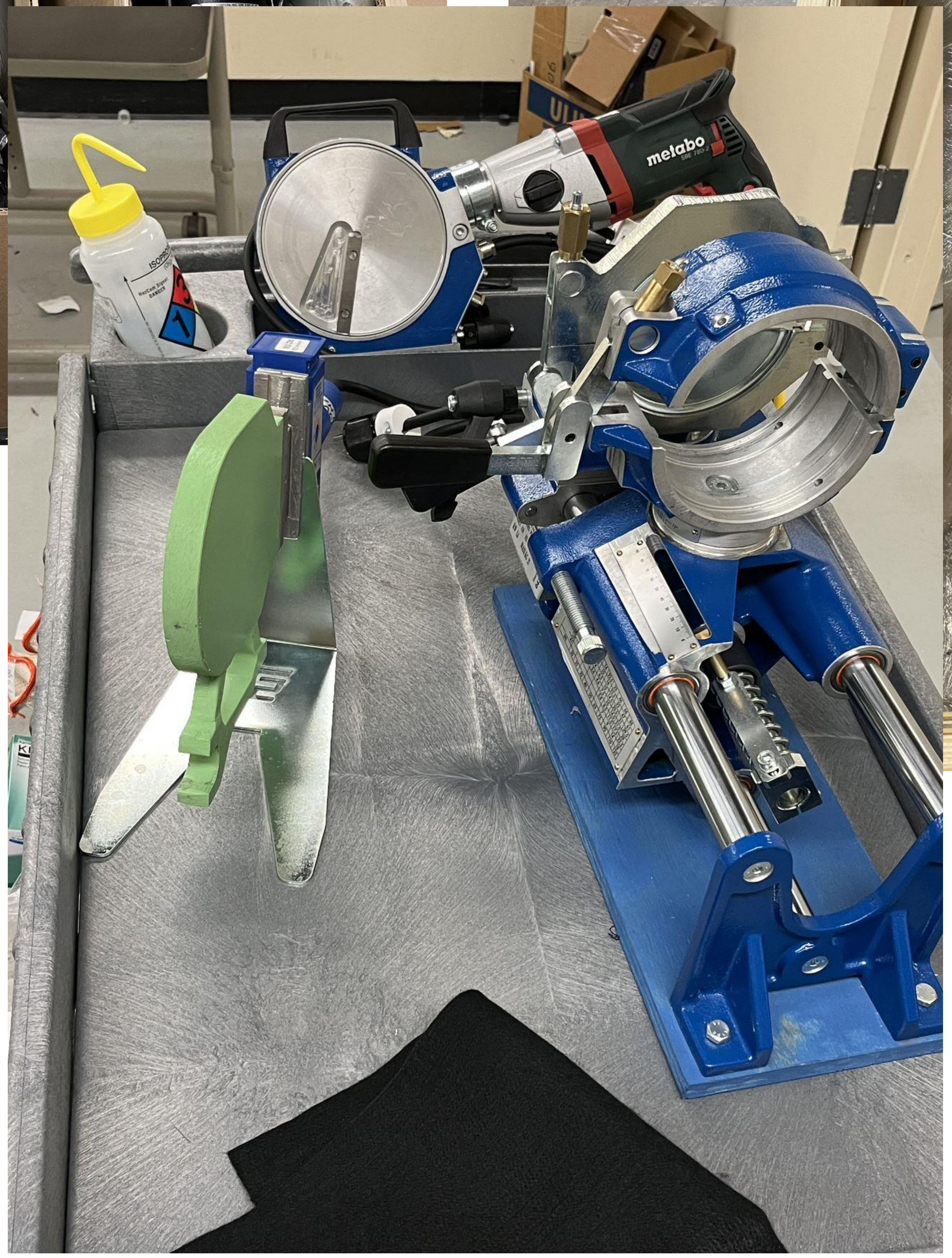
30TBNL Circulation Scheme

Parts and Equipment arrived at BNL



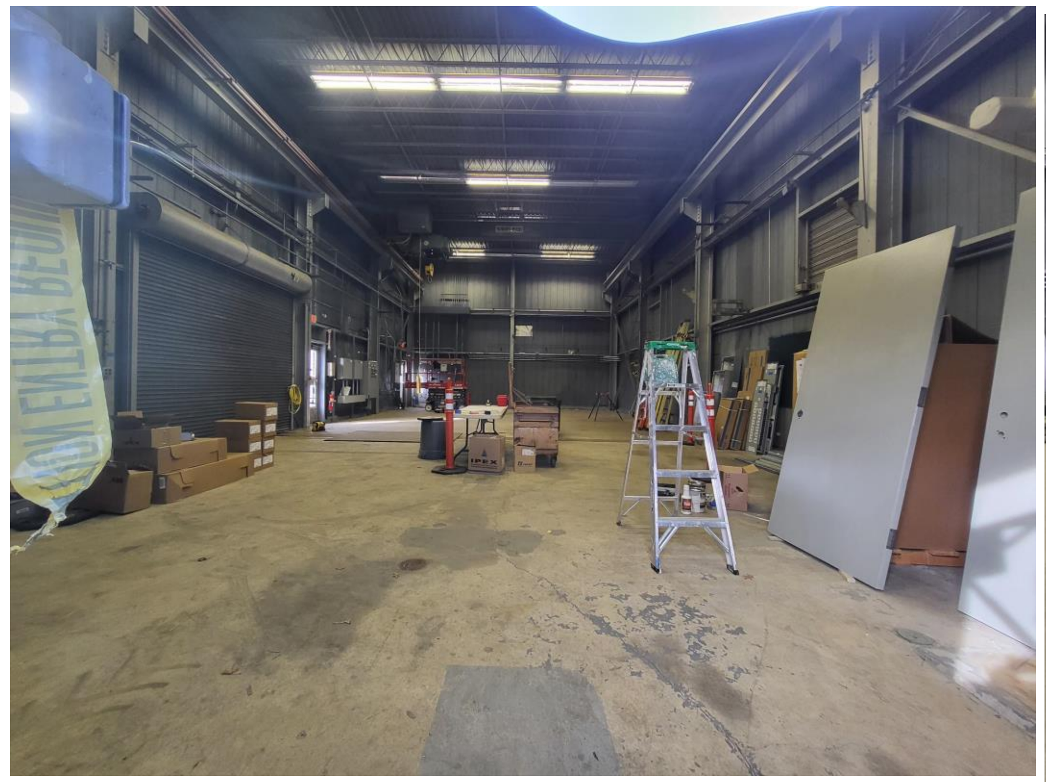






30TBNL Installation

Started in FY22

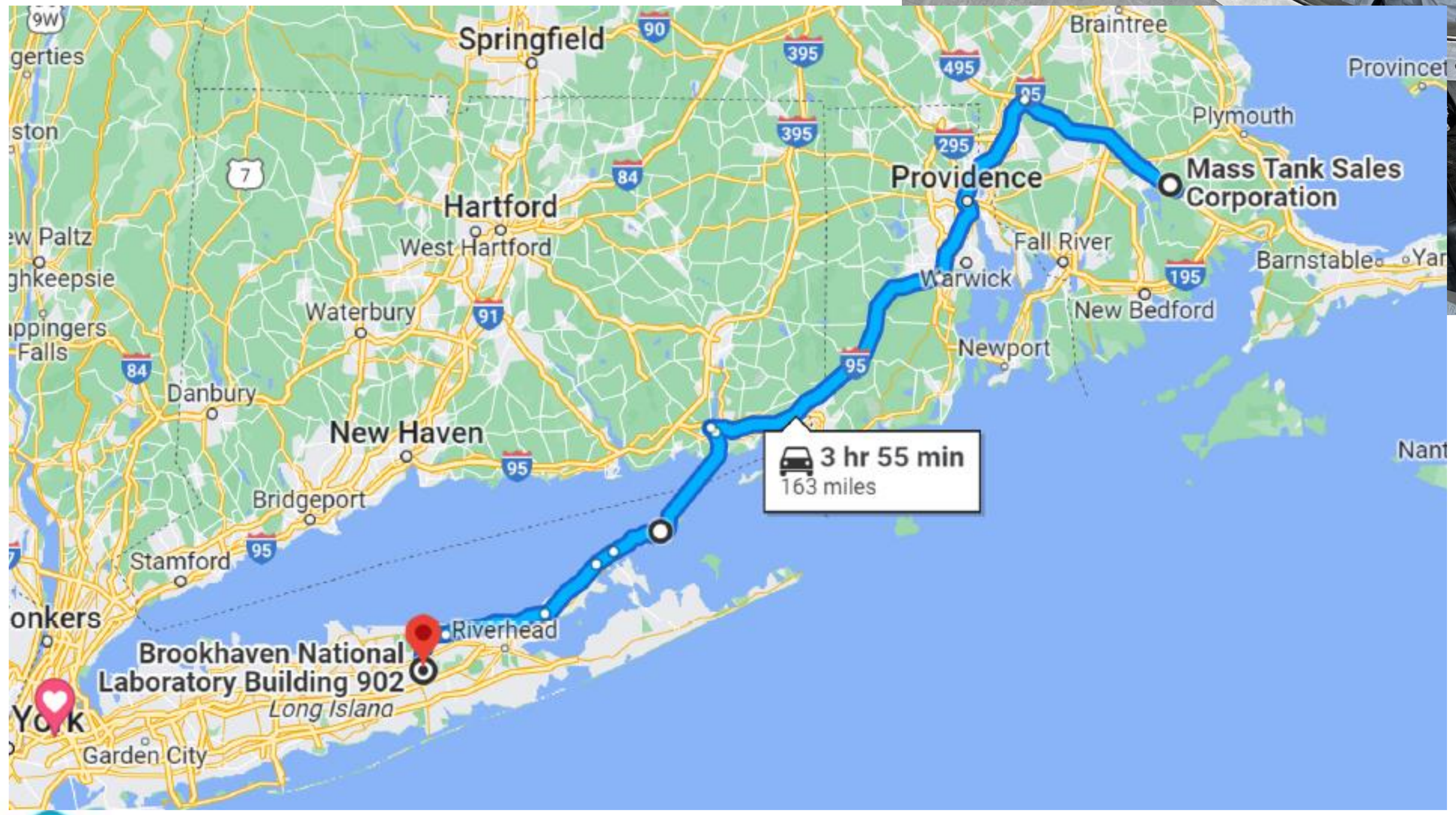


A collaborative effort between multiple universities and other labs

30-ton Tank

National Nuclear Security Administration

Delivered to BNL on July 21, and moved into Facility on July 25, 2023



Milestone!

Preparing for cleaning and water fill

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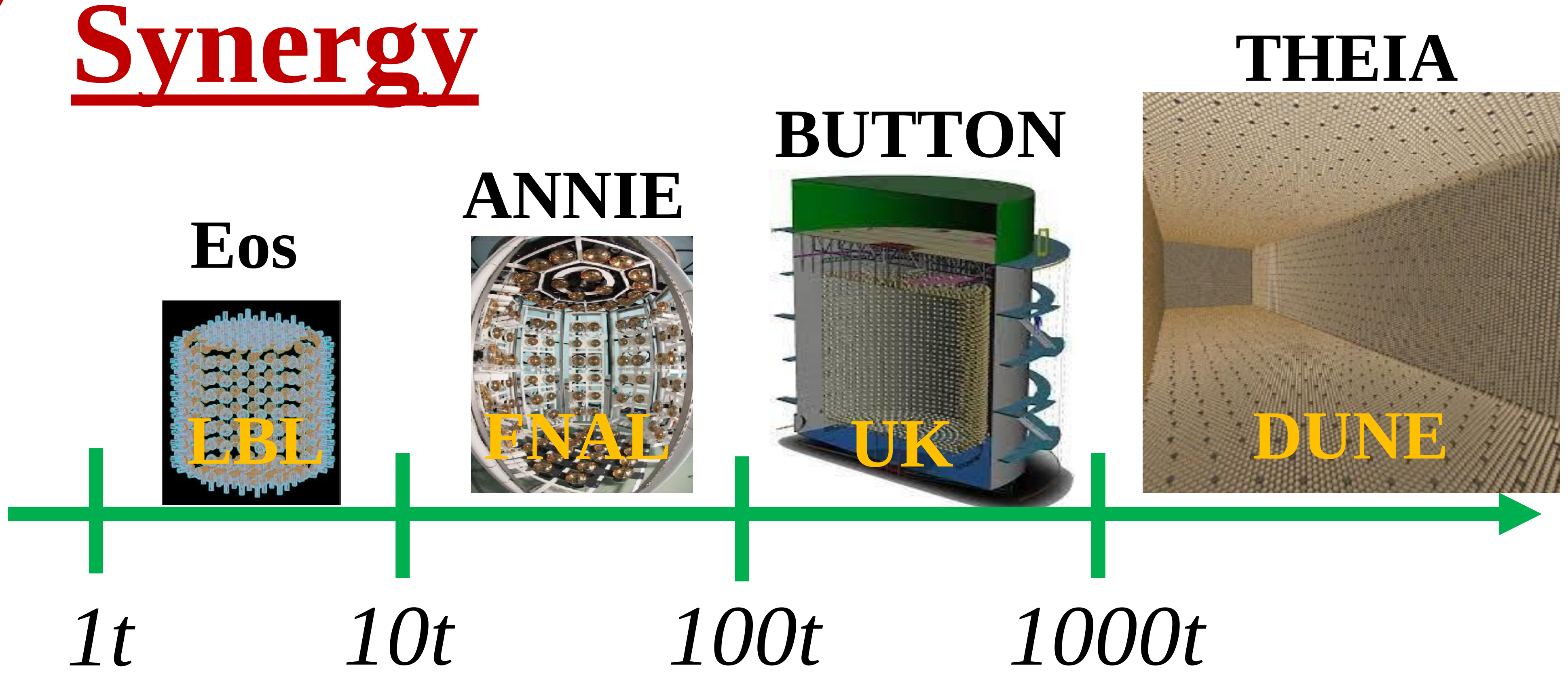
Summary

Sampling | Tabletop R&D | Early prototype | **Current 1-ton detector** | 30-ton demonstrator

2011 | 2014 | 2016 | 2022 | 2023 | 2024

Synergy



Continue research in new detector mediums and technologies

- Modern LS are safe to use and compatible with most vessel materials.
- Good progress towards technical developments on WbLS; usage can be applied to other frontiers (i.e. Calorimetry).
- Ton-scale production facility ready in Q1/2024 that any experiments can use.
- A different approach using highly scattering WbLS for a self-segmented imaging detector. Such a detector using highly pixelated SiPM arrays capable of particle ID and bkg reduction.