Neutrino Detection with Liquid Scintillator Detectors

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Neutrino and Nuclear Chemistry
Chemistry/Instrumentation

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

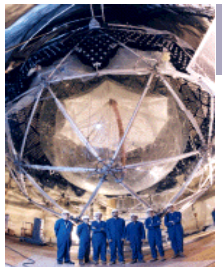
Office of Science
U.S. DEPARTMENT OF ENERGY

BNL VIRTUAL SYMPOSIUM FOR ETI/MTV CONSORTIA, 2021

Neutrino and Nuclear Chemistry

at BNL since 1960+

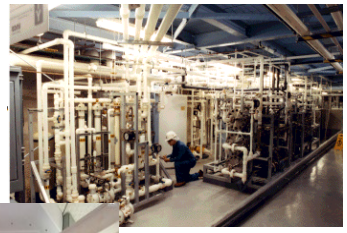
HOMESTAKE — 615t $^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$



Gallex — 30-t $^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$

780t D_2O CC/NC — SNO

200-kt H_2O or 37-kt LAr — LBNE (DUNE)

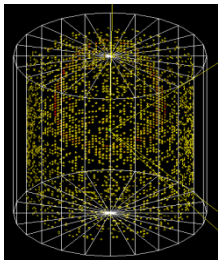


120-t 8% In-LS — LENS

200-t 0.1% Gd-LS — Daya Bay

780t 0.3% Nd/Te-LS — SNO+

^6Li, ^{10}B or Gd doped LS — PROSPECT/LZ



Metal-doped WbLS and plastic scintillator resins — 0νββ, dark-matter, AIT-NEO, medical

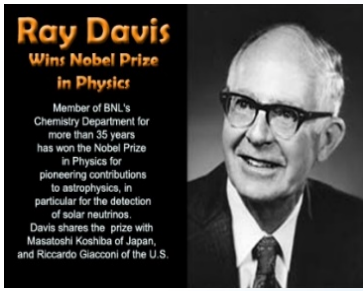
Water-based LS

Scintillator

Radiochemical

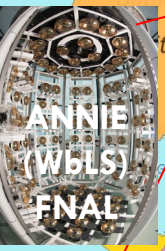
Cerenkov

1960 1970 1980 1990 2000 2010 2020



BNL-ν-Map

by liquid scintillator detectors



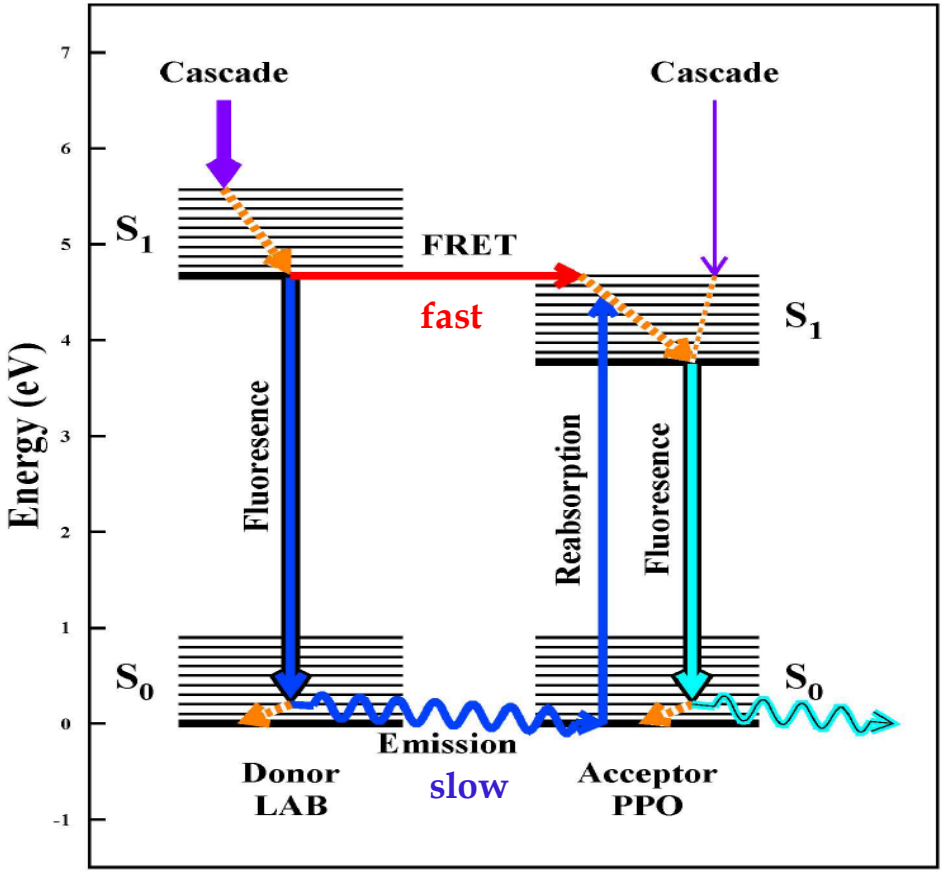
1. Burundi
2. Malawi
3. Rwanda
4. Armenia
5. Azerbaijan
6. Bahrain
7. Qatar
8. Liechtenstein
9. Andorra
10. Belgium
11. Bosnia and Herzegovina
12. Croatia
13. Czech Republic
14. Vatican City
15. Kosovo
16. Luxembourg
17. Montenegro
18. Moldova
19. Montenegro
20. North Macedonia
21. Netherlands
22. San Marino
23. Serbia
24. Slovenia
25. Switzerland
26. Saint Vincent and the Grenadines

Cover a wide range of physics topics!

neutrinos, dark matter, 0νββ, nonproliferation, medical physics,…

Scintillation Mechanism

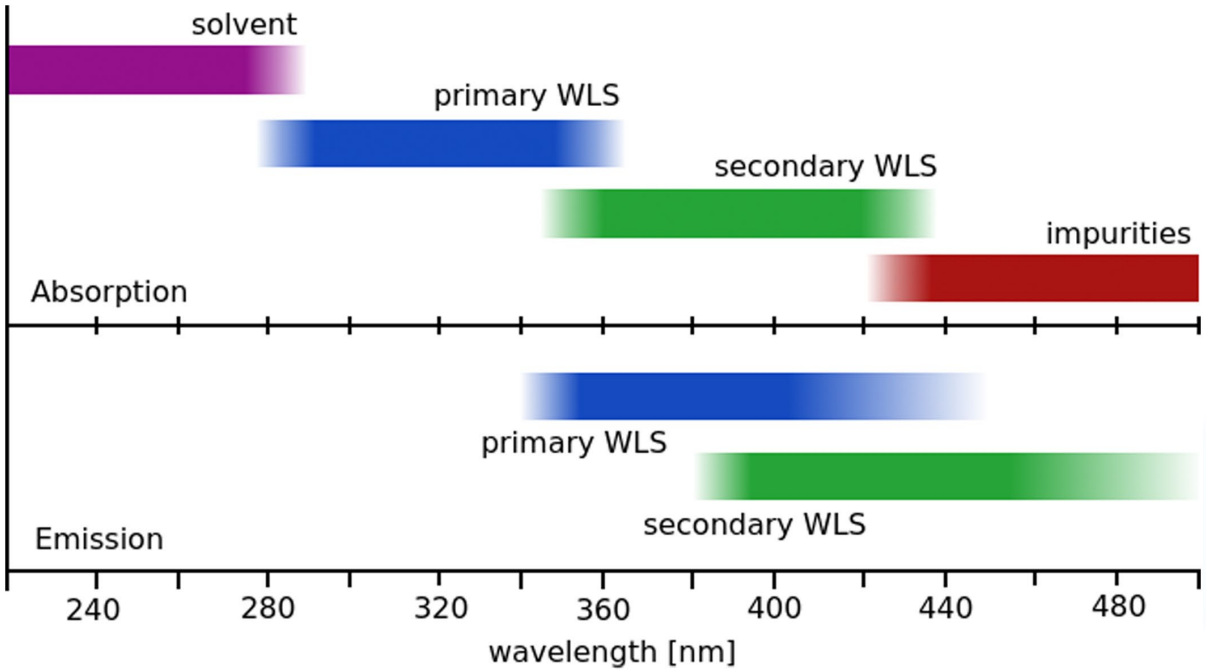
S. Hans, J. Cumming, R. Rosero, S. Gokhale, R. Diaz, C. Camilo, M. Yeh, Light-yield quenching and remediation in liquid scintillator detectors, 2020 *JINST* 15 P12020



Stokes shift, photon-yield, timing structure, and C/H density determine the detector responses

Scintillator Components

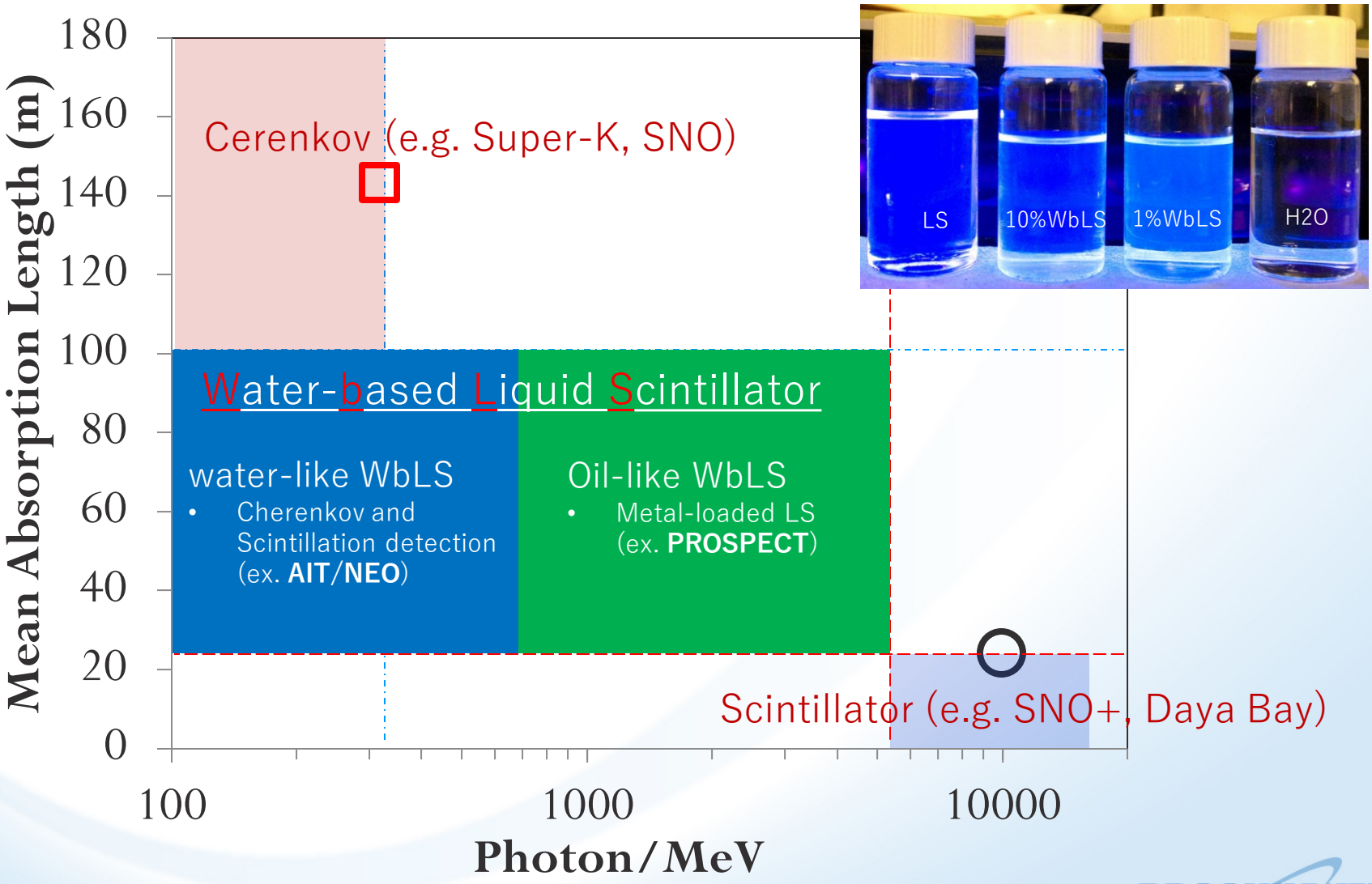
C. Buck and M. Yeh, J. Phys. G: Nucl. Part. Phys. 43 093001 (2016)



200tons of Daya Bay Gd-LS produced in 2010; stable since production. Transfer ~4 tons to JSNS^2 in 2020/21

- *Key requirements of scintillator detectors for neutrino research: high photon yield, long-term stability, long attenuation length, low toxicity, and high flash point*

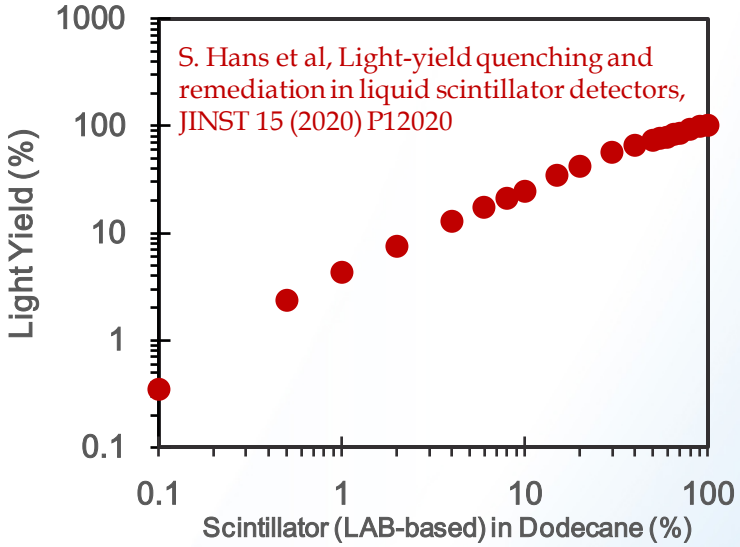
If you always do what you always did, you will always get what you always got. **-Albert Einstein**

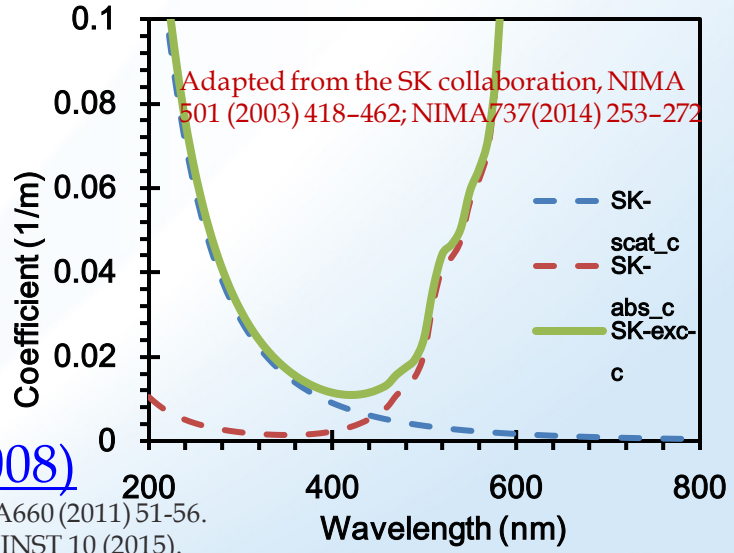


Water-based Liquid Scintillator

WbLS is

- a novel low-energy threshold detection medium, bridging scintillator and water.
- tunable scintillation light from ~pure water to ~organic
- a NEW hybrid scintillation Cherenkov particle detector ***(first proposed for proton decay)*** for varied neutrino programs with multiple applications in non-proliferation, beam-physics, veto, medical physics, LSC counting, etc.
- environmentally friendly with high flash point for underground physics.
- cost-effective in comparison with LS
- viable to load a variety of metallic isotopes for varied physics applications
- Cherenkov λ emits at >400nm still propagate through the detector (maintain directionality).



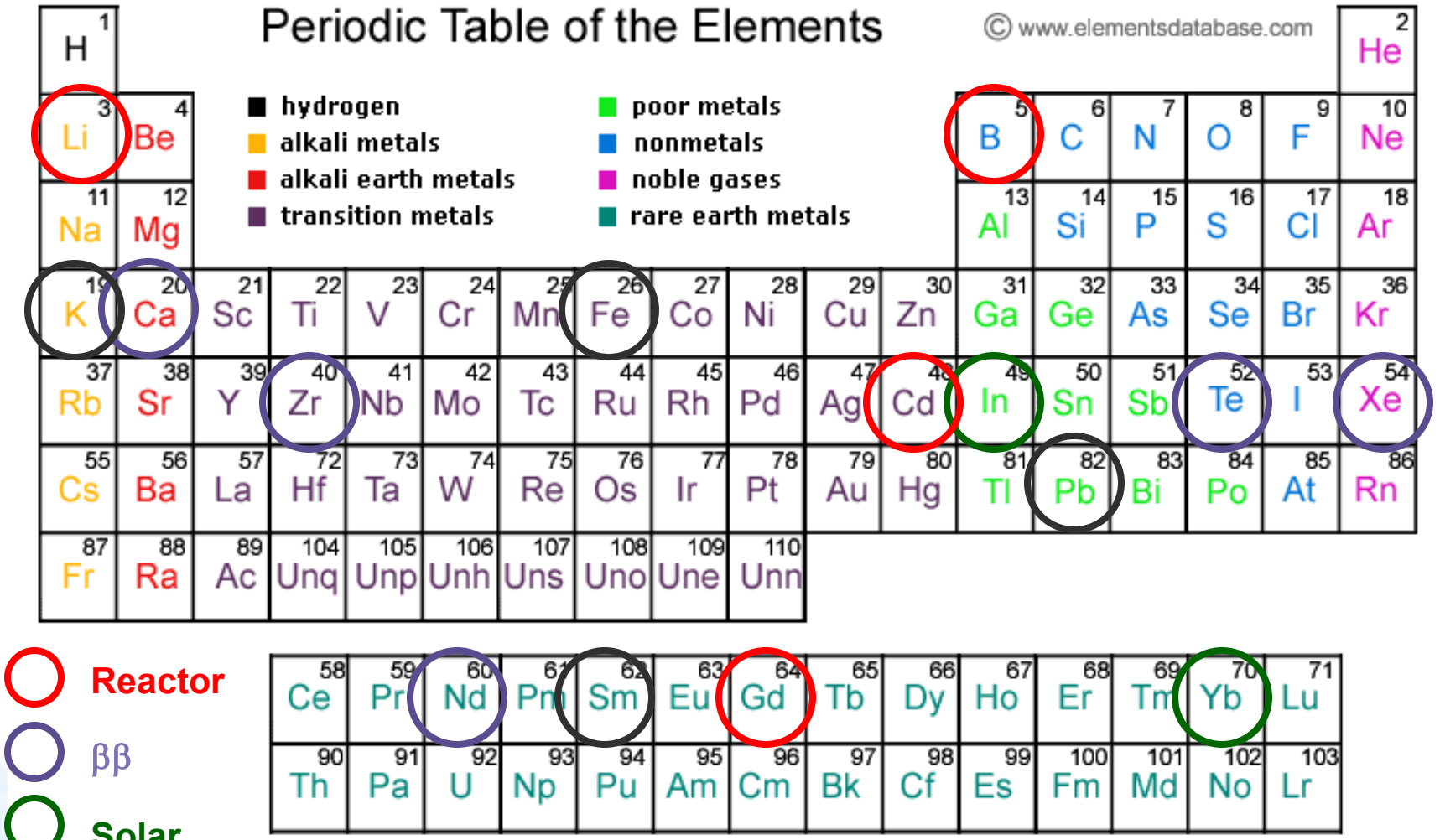


Principle proven in 2011 (first proposed in 2008)

- M. Yeh et al., A New Water-based Liquid Scintillator and Potential Applications, NIMA660 (2011) 51-56.
- L.J. Bignell et al., Characterization and Modeling of a Water-based Liquid Scintillator, JINST 10 (2015).
- L.J. Bignell et al., Measurement of Radiation Damage of Water-based Liquid Scintillator and Liquid Scintillator, JINST 10 (2015) P10027..

Metal-doped (Water-based)LS

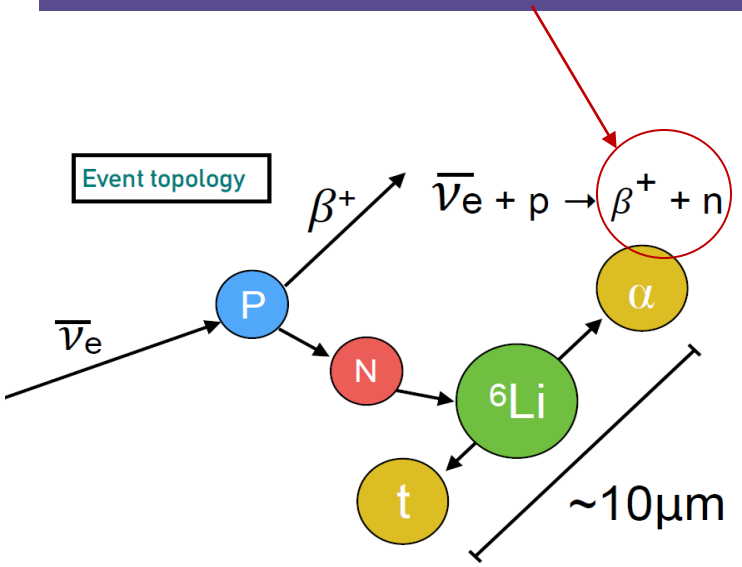
extended reaches for Neutrino Physics and Other Applications



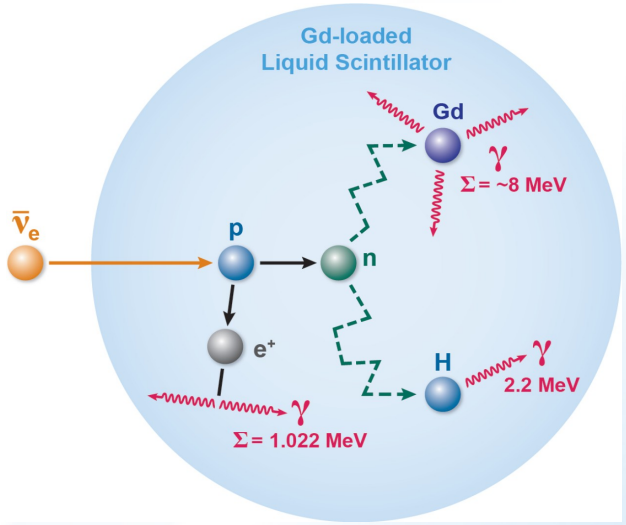
Li, K, and Fe are loaded with water-based Liquid scintillator

Reactor Antineutrino Detection (by Liquid Scintillator)

coincidence of two consecutive events (prompt and delayed) → **Enhance neutrino detection efficacy** / **Reduce accidental background)**



A segmented detector
Li loaded using Water-based Liquid Scintillator

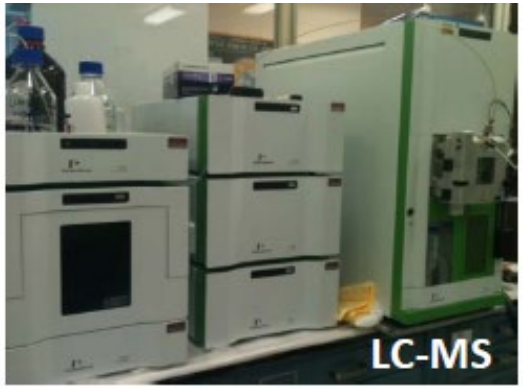


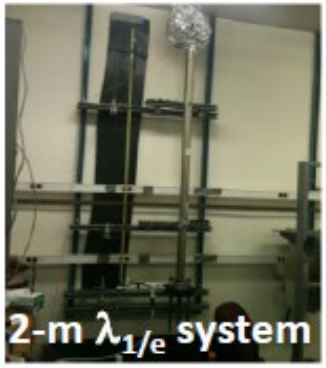
A monolithic detector
Gd loaded with organo-metallic complexation

What can BNL offer?

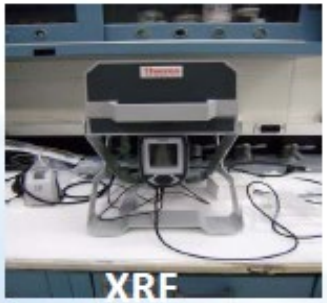
- A unique combination of scientific expertise in chemistry, physics and instrumentation, engineers, project management for varied scientific projects
- Hands-on experiences from benchtop R&D to scale-up production (in-house)
- Data-analysis and optical detector development

Instrumentation at Liquid Scintillator Research Center

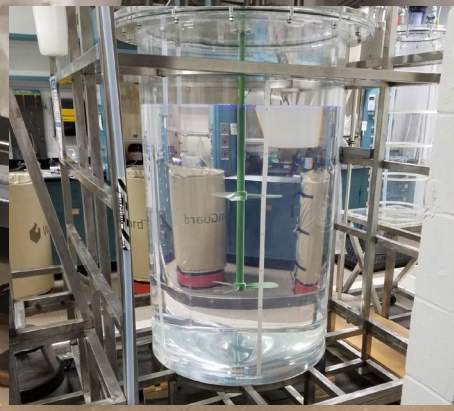




- An existing facility for water-based and metal-doped liquid scintillator Detector R&D for particle physics applications.
- *Covering a variety of particle physics experiments*
- Instrumentation including XRF, LC-MS, GC-MS, TFVD, FTIR, UV, Fluorescence emission, LS6500, 2m dual-attenuation system, low bkg.,Compton-suppressing system, etc. (access to ICP-MS at other facilities)
- Provide an educational platform for students (hand-on instrumentation training for next-generation scientists in academic/private sectors)



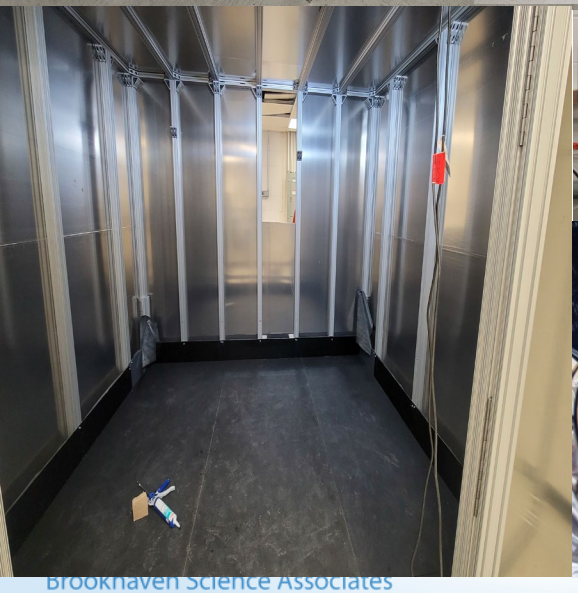
Scale-up production at Liquid Scintillator Production Facility

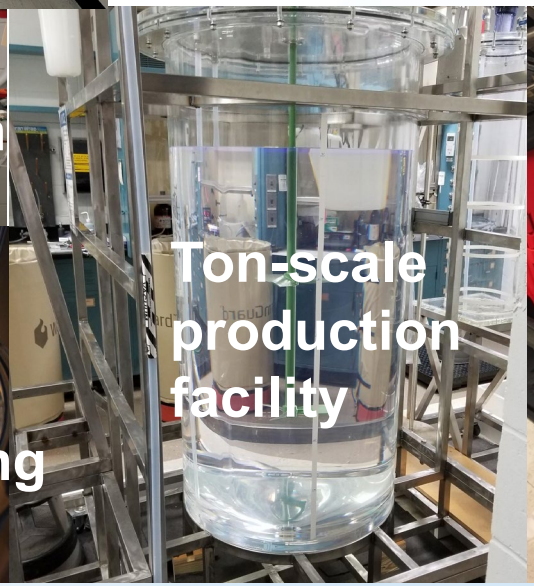


Only ton-scale production facility in U.S. academic institutes

1000L Testbed Facility
(students/postdocs recruiting…)

- prototyping liquid performance (UVT-tank compatible with GdH_2O, WbLS, or LS)
- exercising in-situ filtration/purification and deployment schemes and ESH training (and potentially testing for other subsystems, i.e. photosensors)
- fast turn-around operation using in-house resources in liquid production, QA/QC equipment, and existing mixing facility (partially supported by BNL)





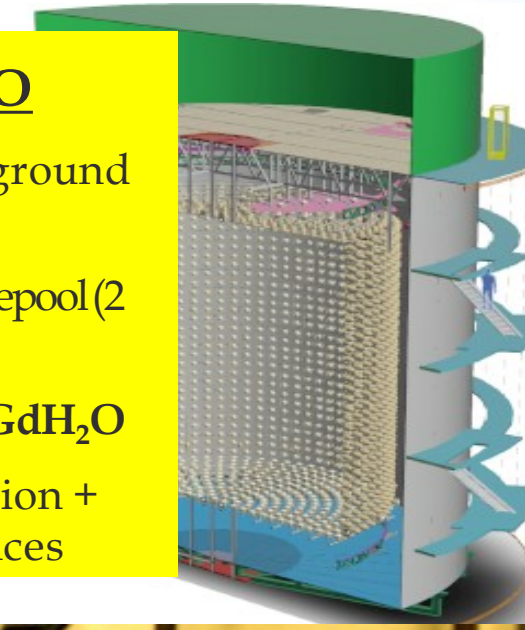
AIT/NEO (DNN-NA22)

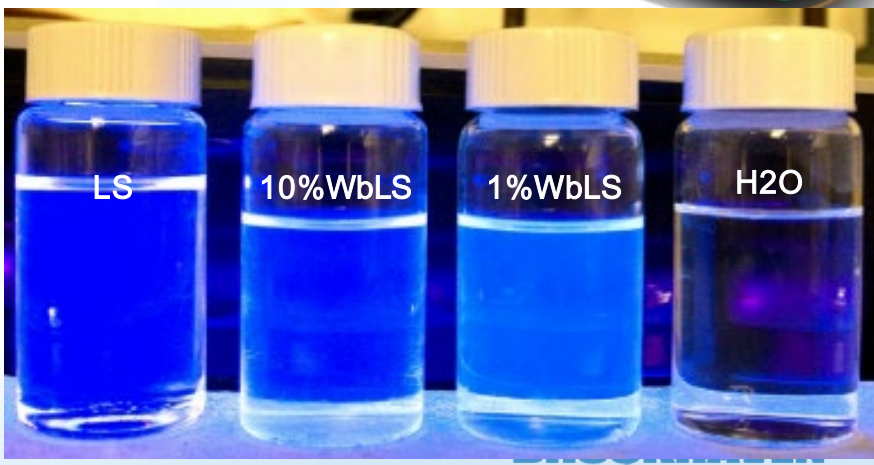
Advanced Instrumentation Testbed, Neutrino Experiment One

- Two matrices: M-WbLS (**ex**. Gd for AIT/NEO) and WbLS (high loading); dependent on physics of interest
- Optical property, absorption + scattering, feasible to the detector geometry of choice (size)
- Stability over experimental lifetime
- Scalability of commercially available and cost-effective
- Compatible to commercial detector materials
- Capability of Mixing (circulation) in a practical time-scale deployment
- Purification (before mixing) and In-situ circulation (nanofiltration)

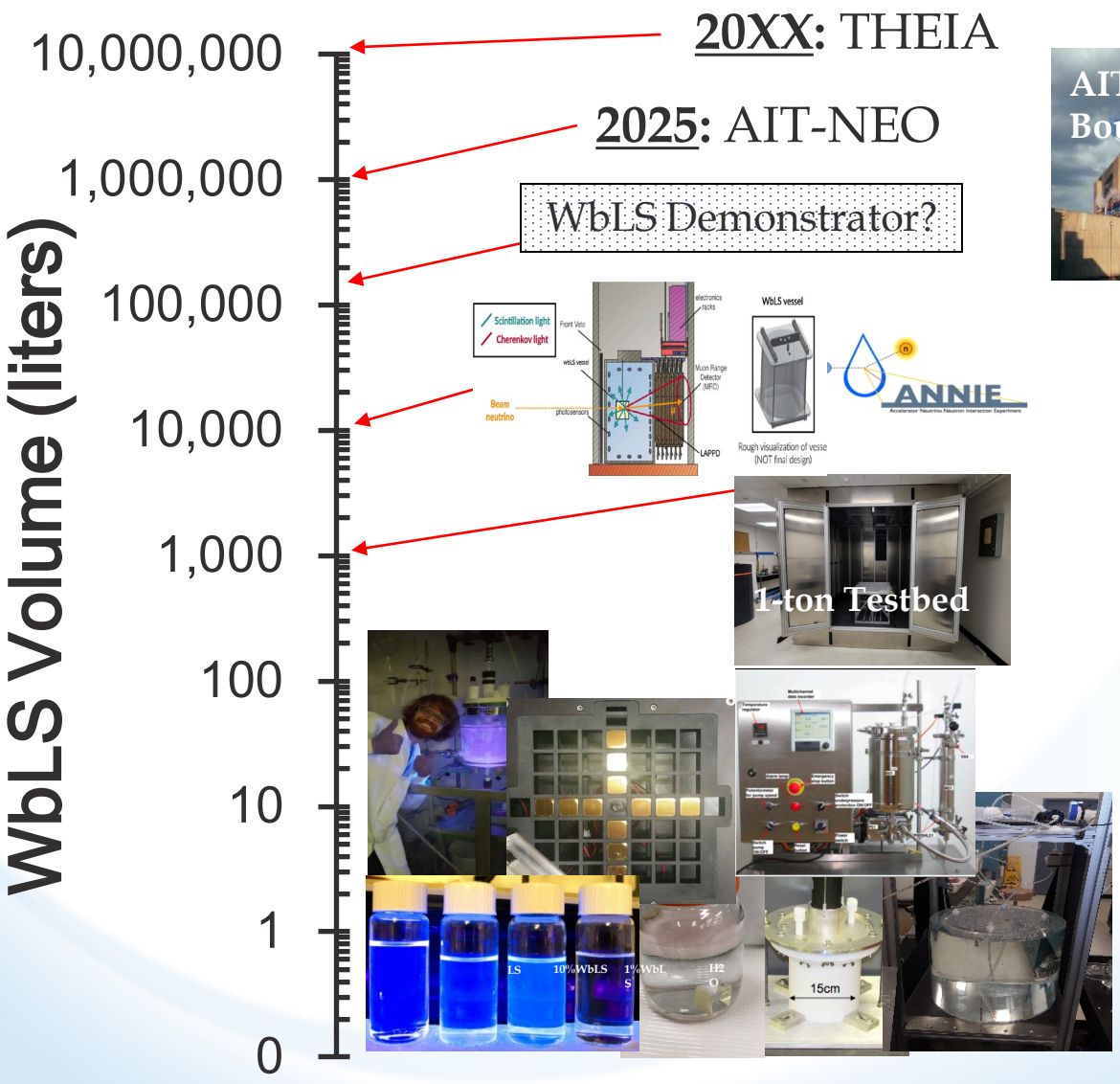
AIT/NEO

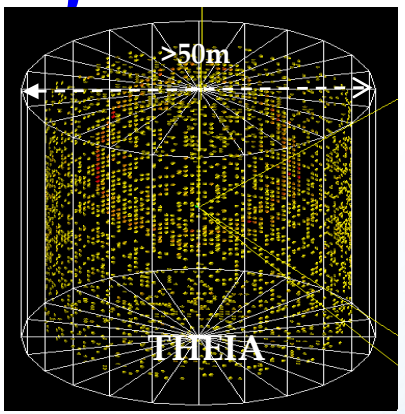
- Boulby Underground Lab (UK)
- 3GW with Hartllepool (2 cores) at 25km
- **(Gd)WbLS vs GdH_2O**
- Non-proliferation + stretched sciences





(Near-term) Scientific Projection





2023-2024:

- Readiness of WbLS scale Production

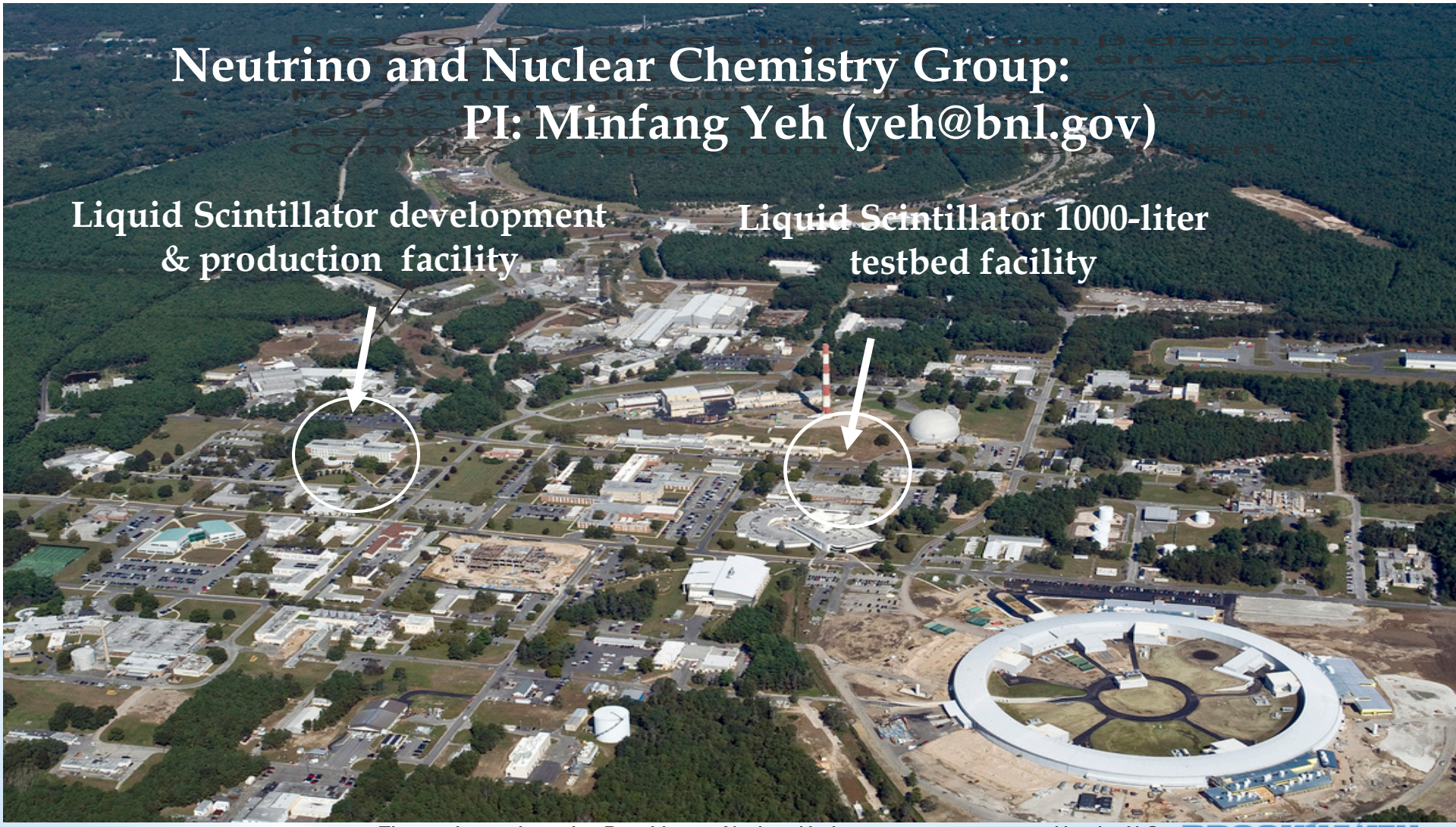
2022-2023:

- Prototyping exercise and Scalability designs

2020-2021 : (multi-institutes)

- Formulation, Purification, Filtration and Characterization
- Material compatibility

Brookhaven National Laboratory



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