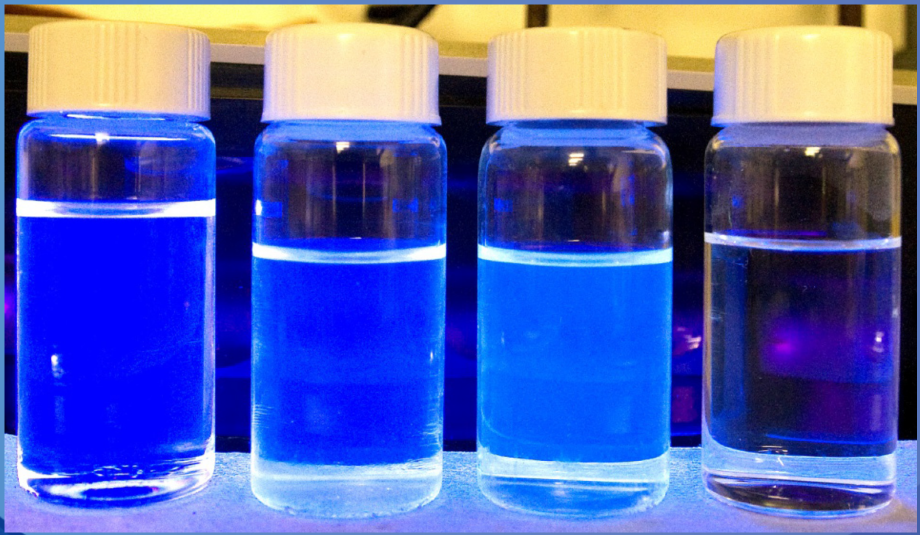
Water-based Liquid Scintillator Detector



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BROOKHAVEN NATIONAL LABORATORY

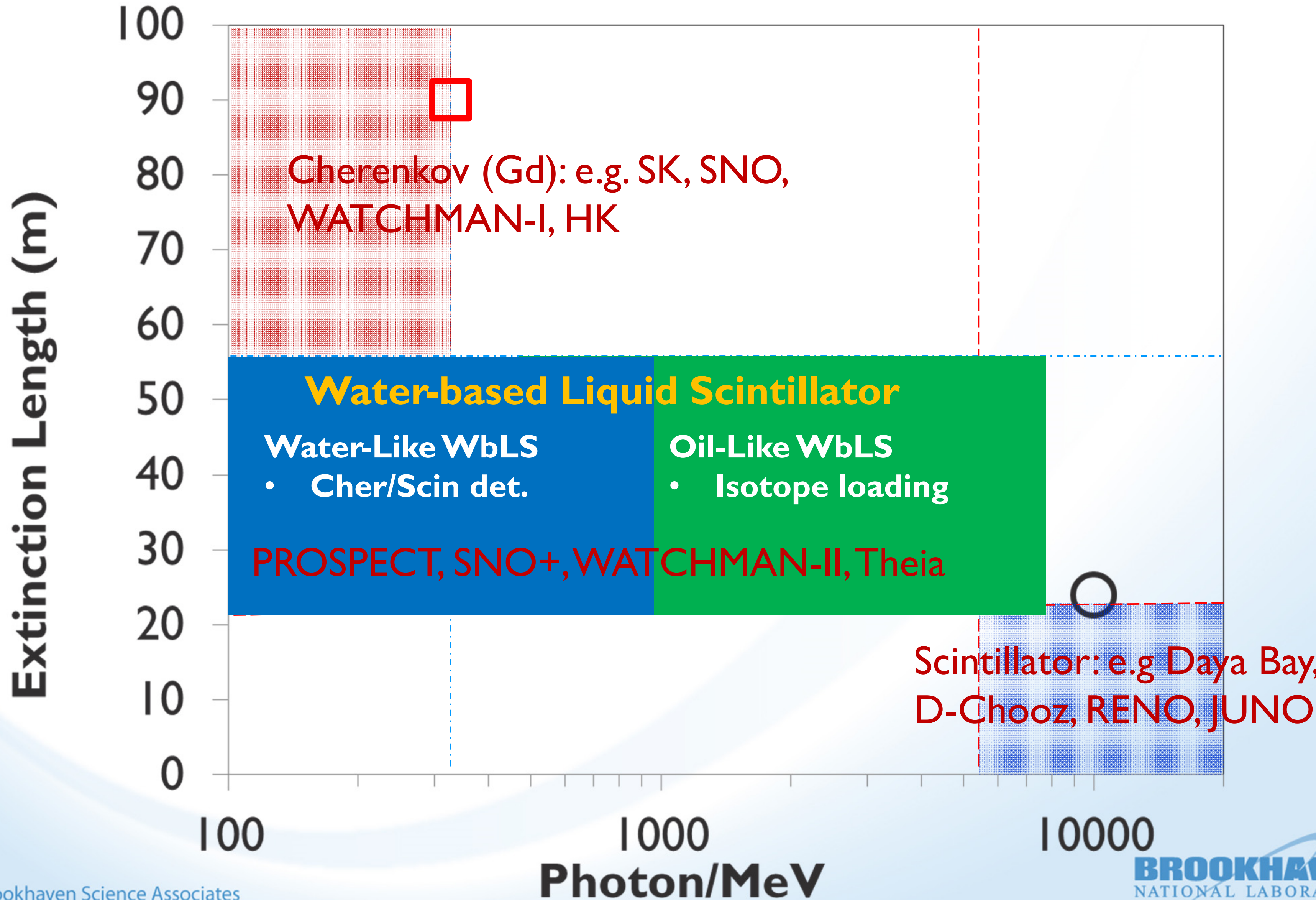
a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

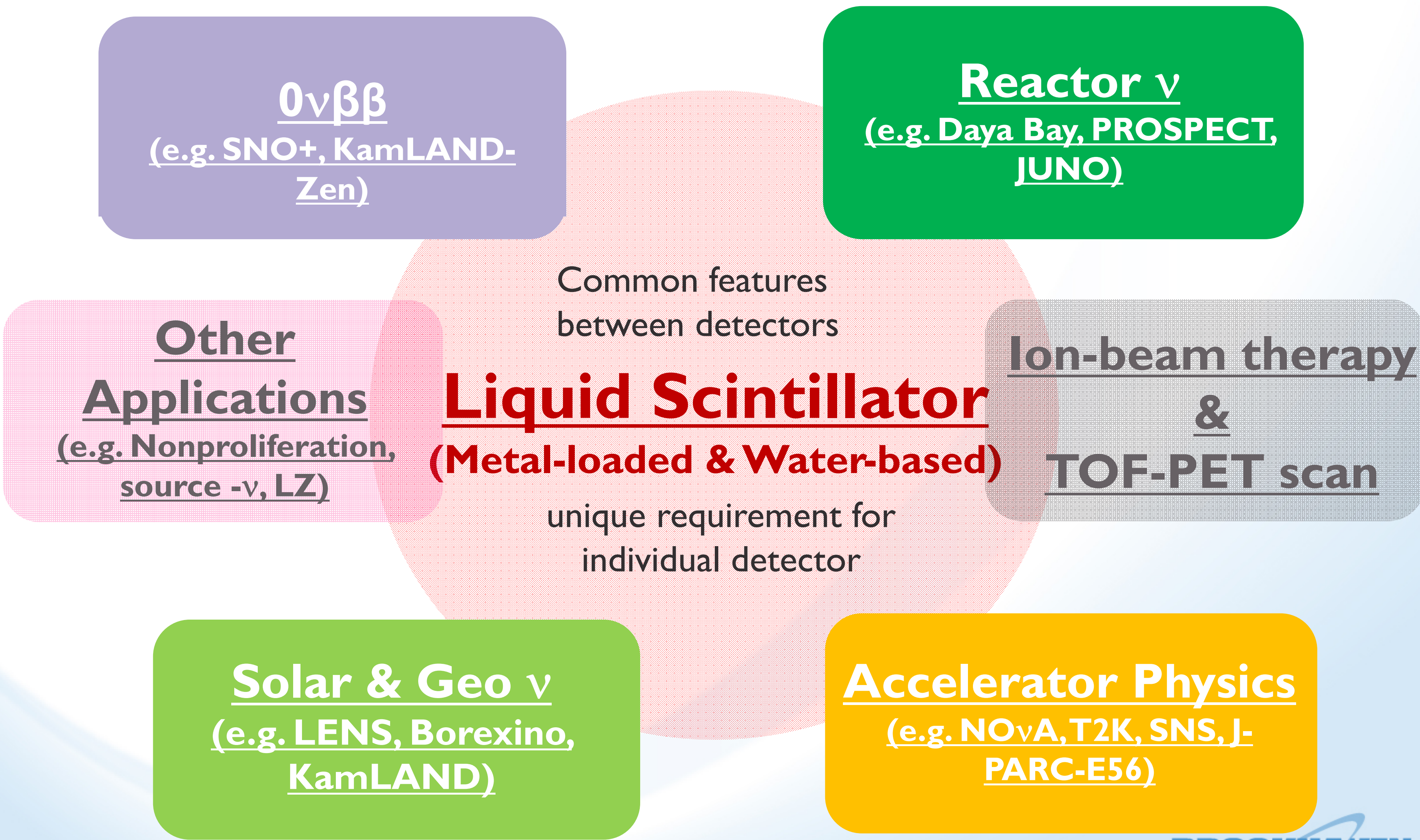
Water Detector Workshop, SBU

October 27, 2015

Cherenkov and Scintillator Detector

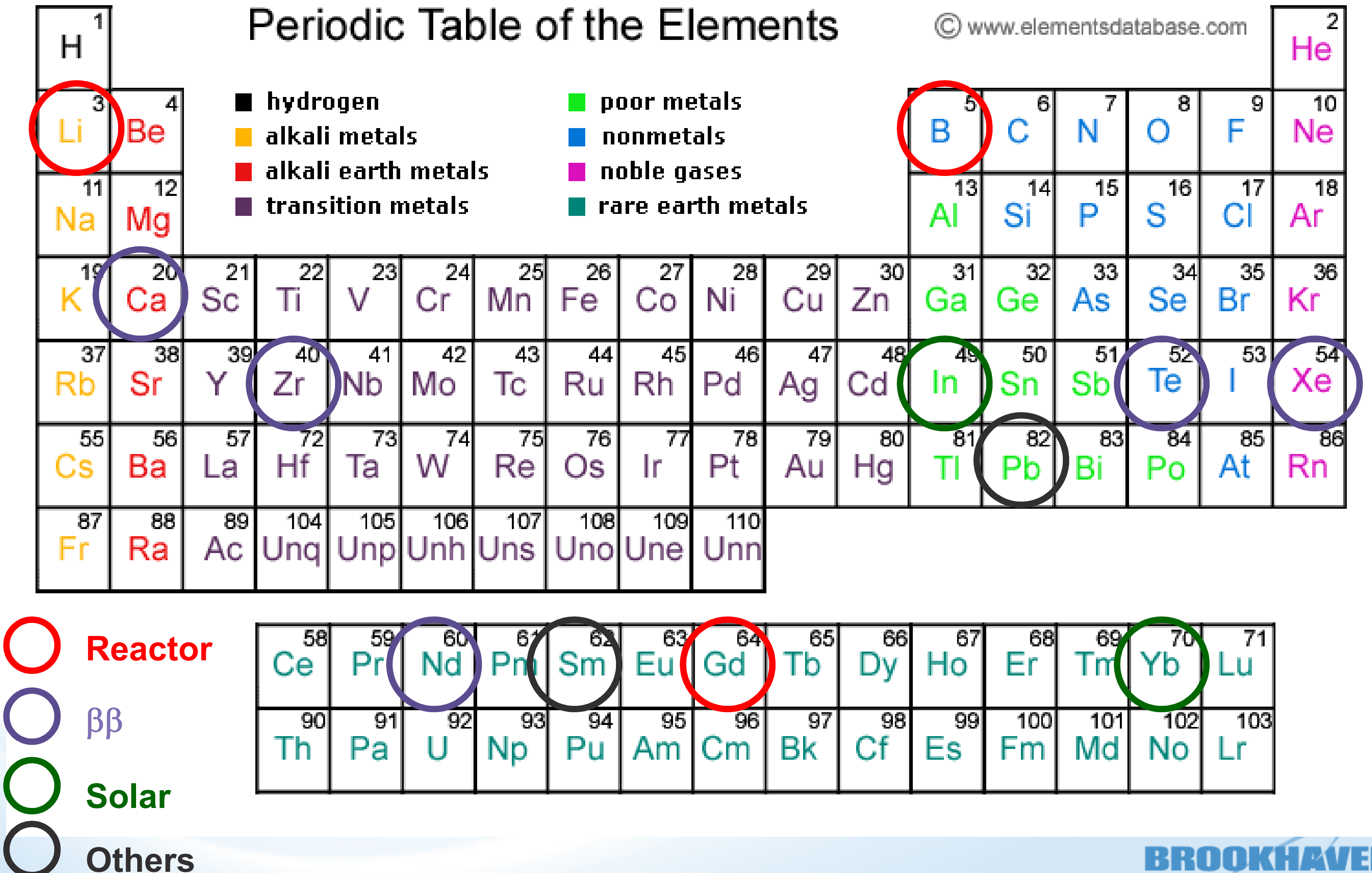


Liquid Scintillator Physics



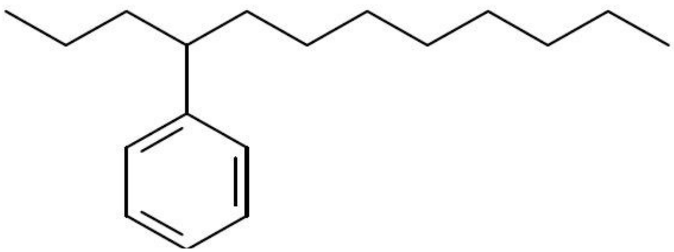
Isotope-doped Liquid Scintillator

An extension of Physics Reaches

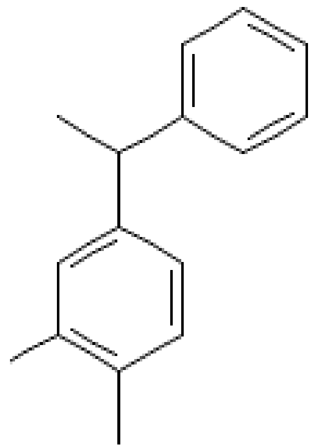


Liquid Scintillators

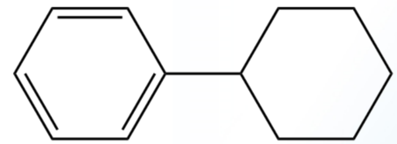
- Stability, light-yield and optical transparency
- High flashpoint (PXE>DIN>LAB>PCH>PC) and low toxicity
- New generation scintillation water (next)



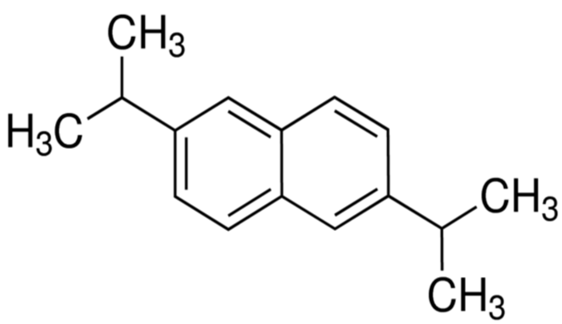
Linear alkylbenzene (LAB)



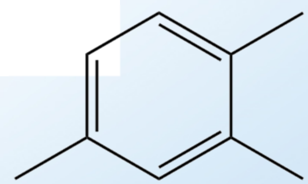
1-phenyl-1-xylyl-ethane (PXE)



Cyclohexylbenzene (PCH)



Di-isopropylnaphthalene (DIN)



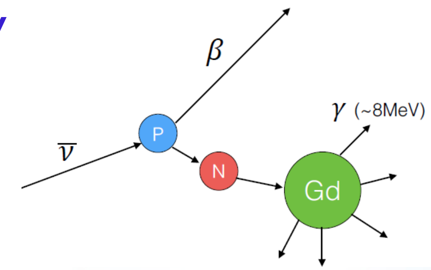
1,2,4-trimethylbenzene (PC)

Water-based Liquid Scintillator

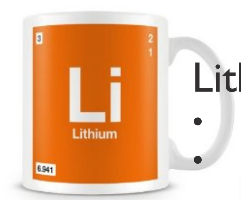
- A new detection medium, bridging scintillator and water, motivated by Nucleon Decay
- Tunable scintillation light (%) from ~pure water to ~organic:
  - **Water-like** WbLS: A long attenuation-length scintillation water with Cherenkov and Scintillation detections
  - **Oil-like** WbLS: A novel technology for loading various isotopes, particularly for hydrophilic elements, in scintillator
- Cherenkov transition
  - λ overlaps with scintillator energy-transfers will be absorbed and re-emitted to give isotropic light.
  - λ emits at >400nm will propagate through the detector (directionality)
- Environmental safer: higher flash point in comparison with any scintillators (confined or limited space)
- Low material cost (~$3k/t for LAB)

(Oil-like) WbLS Isotope Dopings

- Solubility, light-yield, optical transmission, and radiopurity (radiogenic and cosmogenic isotopes) are the keys

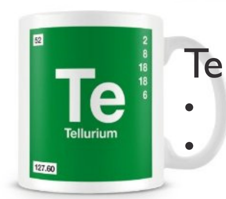


1. Oragnometallic-extraction in scintillator has been successfully applied to reactor $\bar{\nu}_e$ detection (e.g. Daya Bay)
   - *Require a mixing ligand to bring inorganic metallic ions into organic liquid scintillator*
   - *Additional discrimination for radioactive isotopes*
   - *difficult for hydrophilic isotopes*

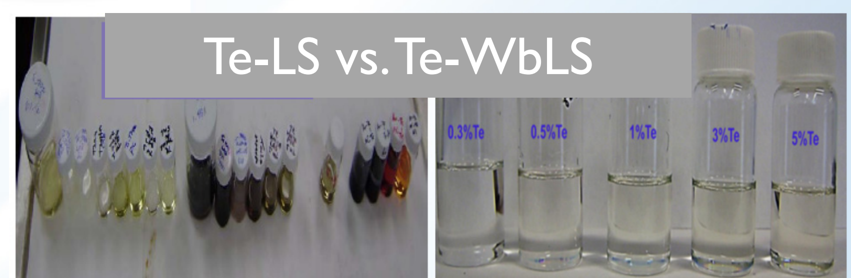


Lithium-doped scintillator detector
- Solar neutrino (^{7}Li, 92.5% abundance)
- Reactor antineutrino (^{6}Li, 7.6% abundance)

2. A New metal-doped technology using water-base Liquid Scintillator principal (e.g. PROSPECT, SNO+, etc.)
   - *Suitable for ~most metallic ions*
   - *less-selective isotope loading→ Require extensive purification for radiopurity*

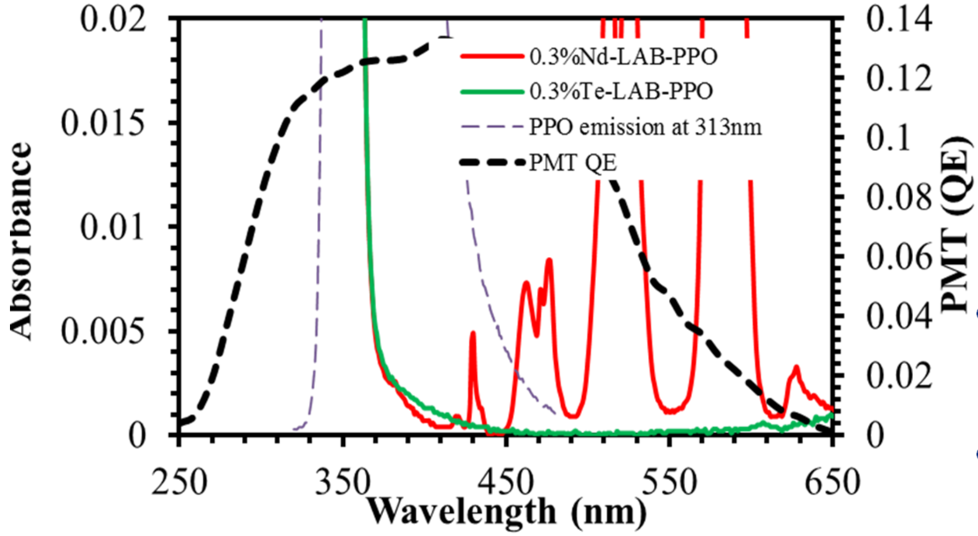


Tellurium-doped scintillator detector
- Double-beta decay isotope (^{130}Te, 34% abundance)
- Future ton-scale 0νββ

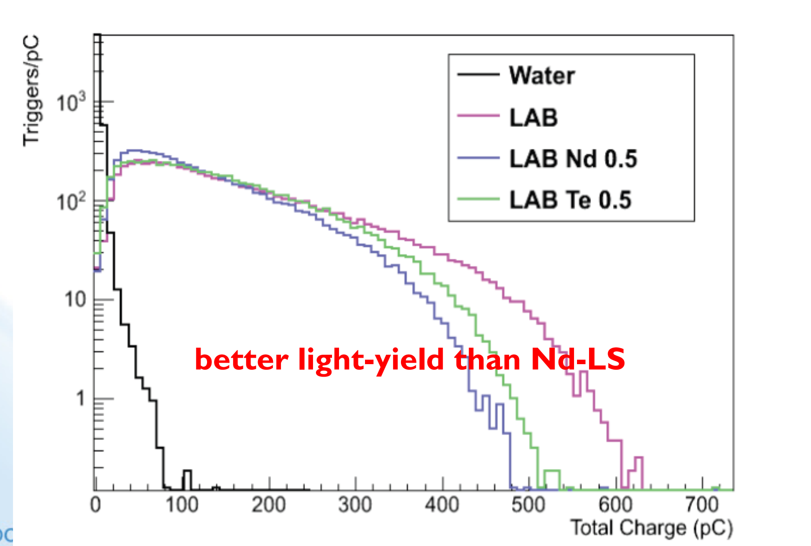


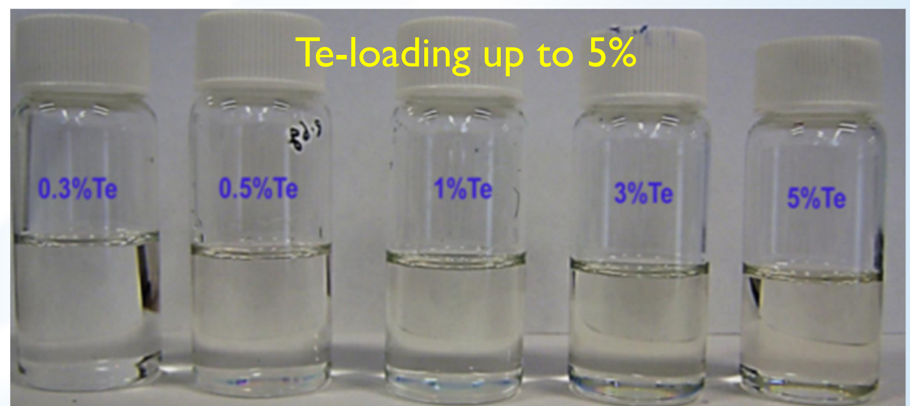
Lead-doped scintillator calorimeter
- Solar neutrino
- Total-absorption radiation detector (Medical)

Te-WbLS (SNO+)

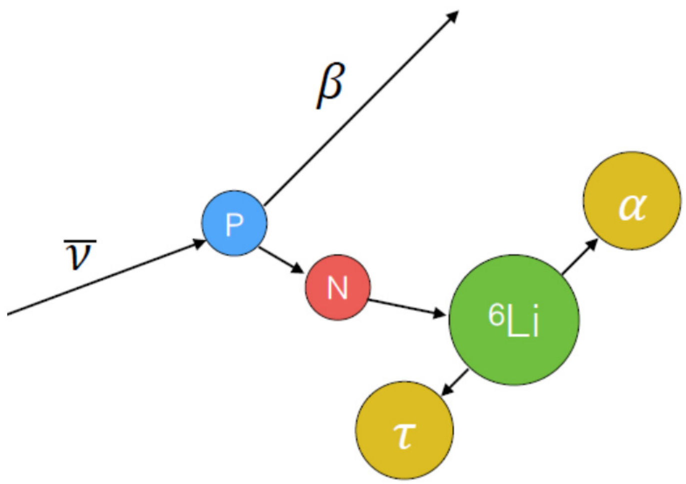


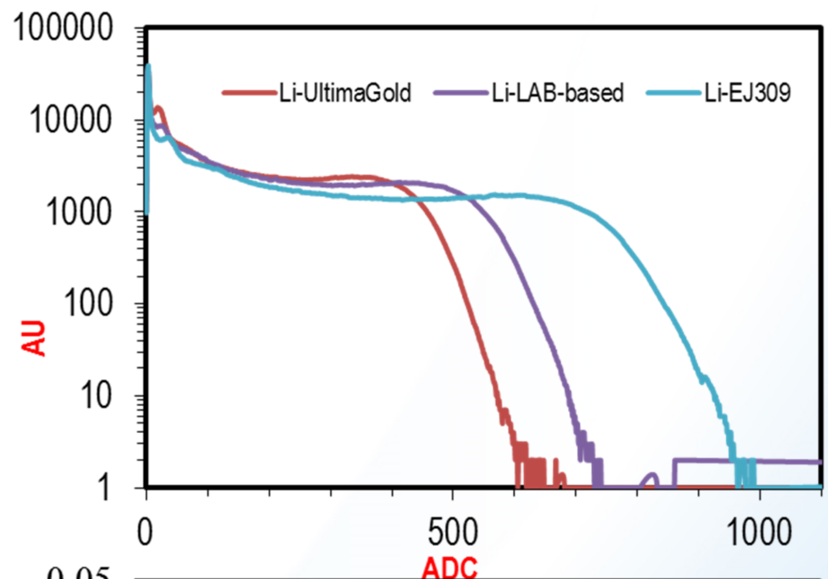
- New water-based LS loading Te in scintillator
  - Better UV (PMT region clear)
  - Higher light-yield
  - Stable for 1.5+yrs
- 0.3% Te is the baseline (phase-I); up to 5%Te stable is achieve
- Improve the optical and photon-yield at higher loading (>3%) toward a future ton-scale 0νββ experiment (phase-II)



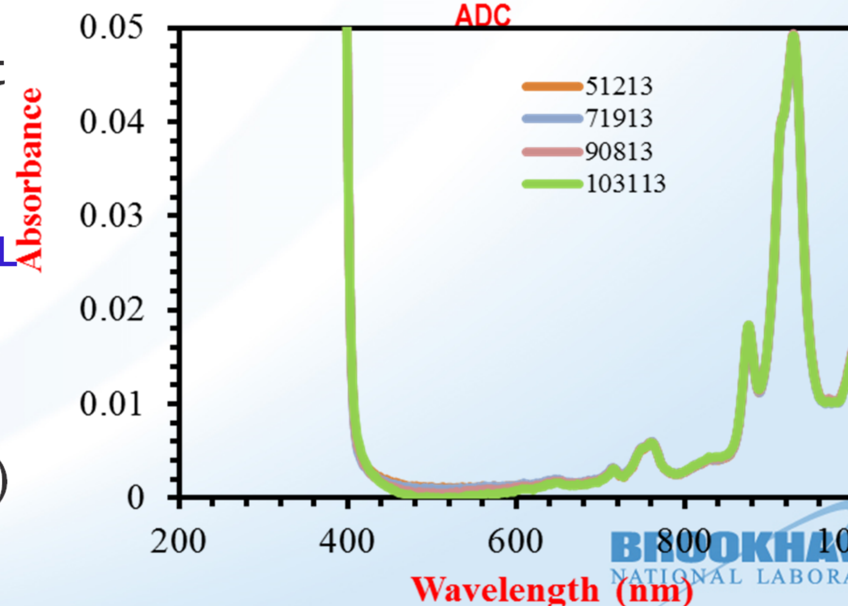


^{6}Li-WbLS (PROSPECT)

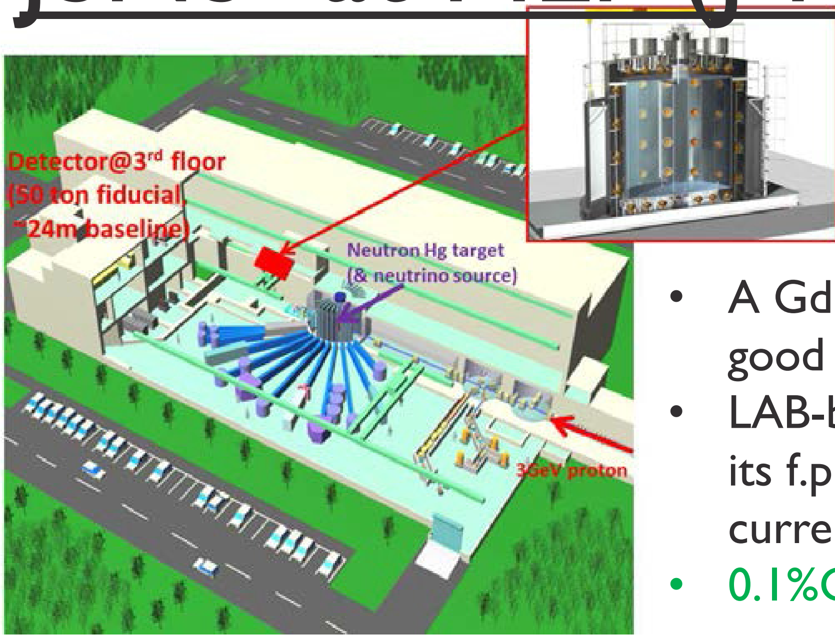




- New Li-doped WbLS with enhanced light-yield, optical better and PSD that has been stable over 1.5 years for PROSPECT
  - Background investigations (20-L) at ORNL reactor site
  - Plan to start full-scale 2-ton ND in 2015
- Continue R&D for higher loading at ~0.15% (Geometry, capture time, etc.)

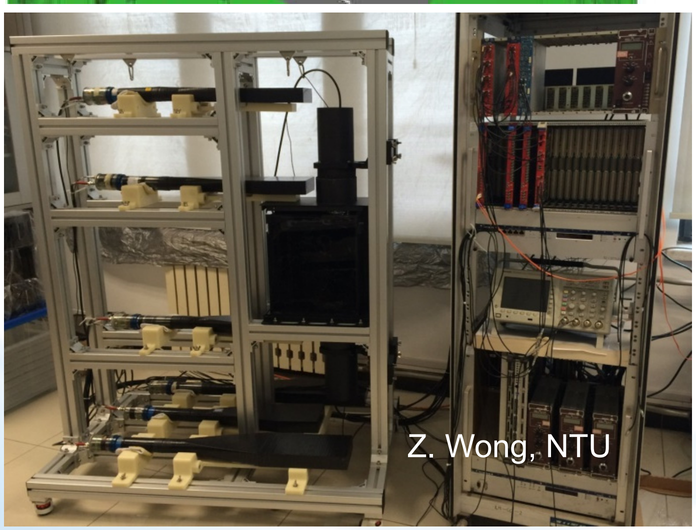


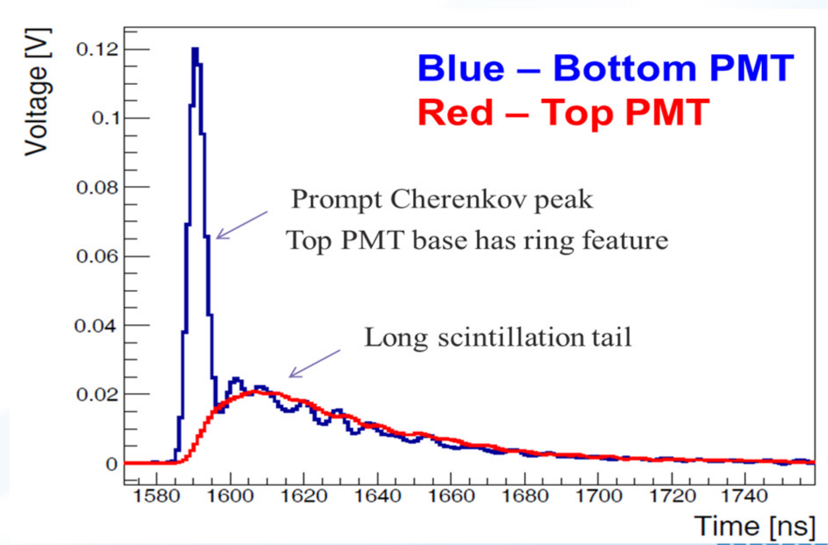
JSNS^2 at MLF (J-PARC E56)



- Search for sterile neutrino with pure neutrinos from stopping μ+

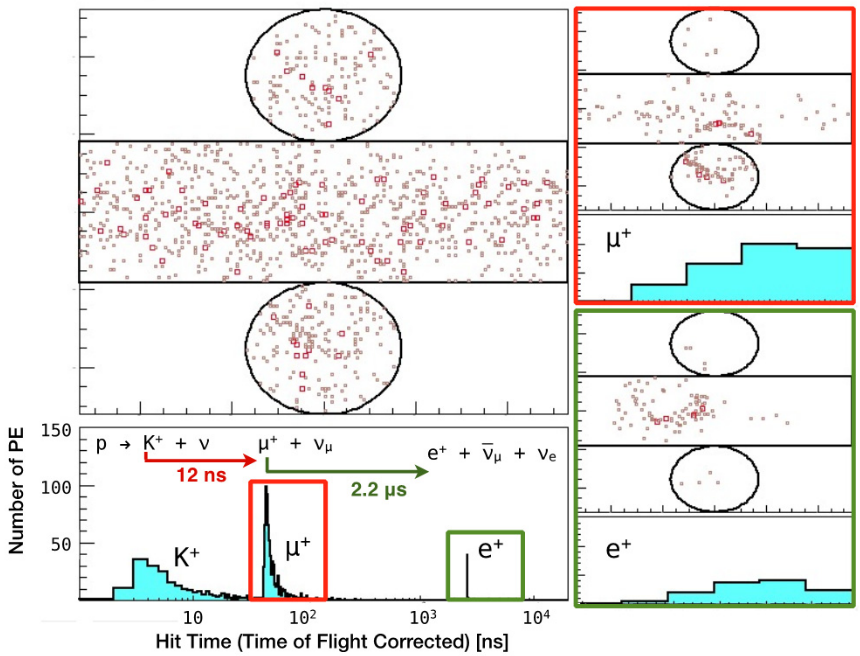
- A Gd-LS that can do Chev/Scin Separation with good PSD
- LAB-based achieves good Chev/Scin separation, but its f.p might still be too high for deployment cat the current location
- 0.1%Gd-doped WbLS is under investigation





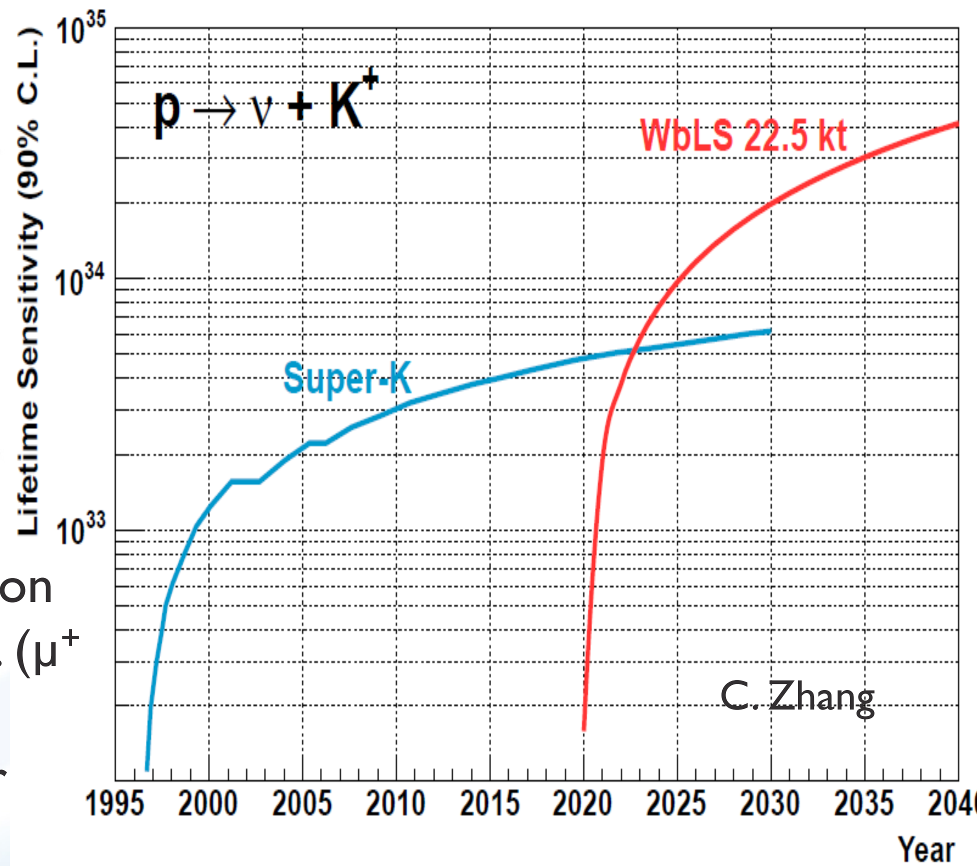
Water-like WbLS for proton-decay

$k^+ \rightarrow \mu^+ + \nu_\mu$ (63.47%)



A 50-m WbLS SK-like detector (90ph/MeV)

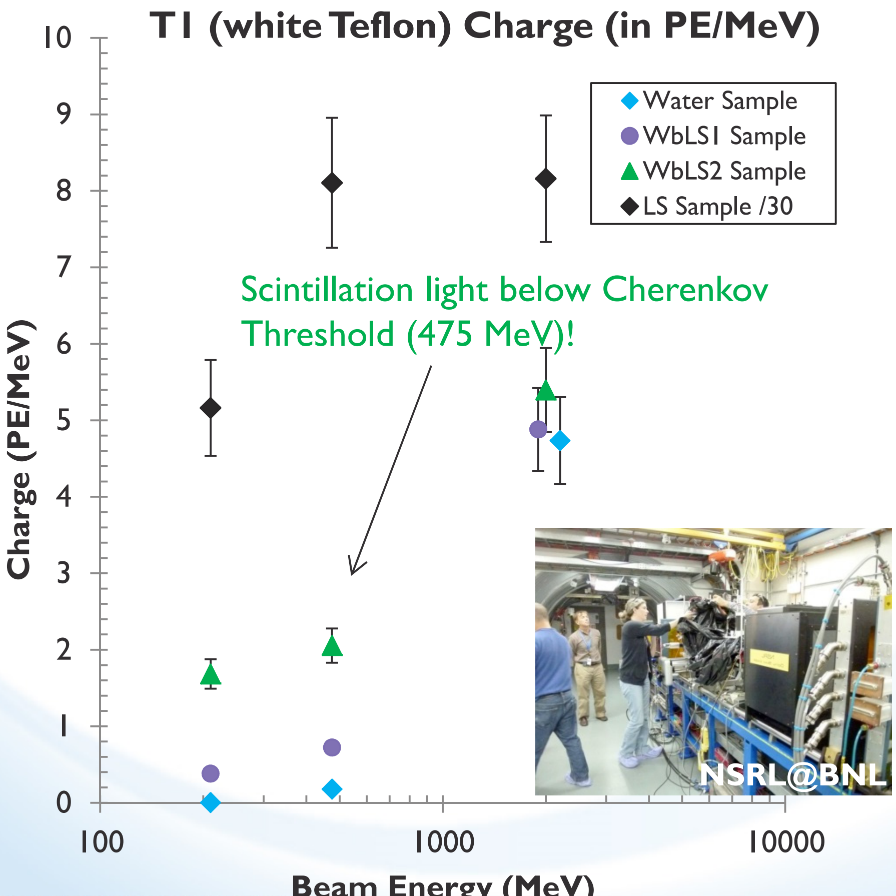
- T_{k+}= 90MeV
- 20% coverage with 25% QE photocathode
- Deep underground >3000 m.w.e.
- Fast decay at 12ns

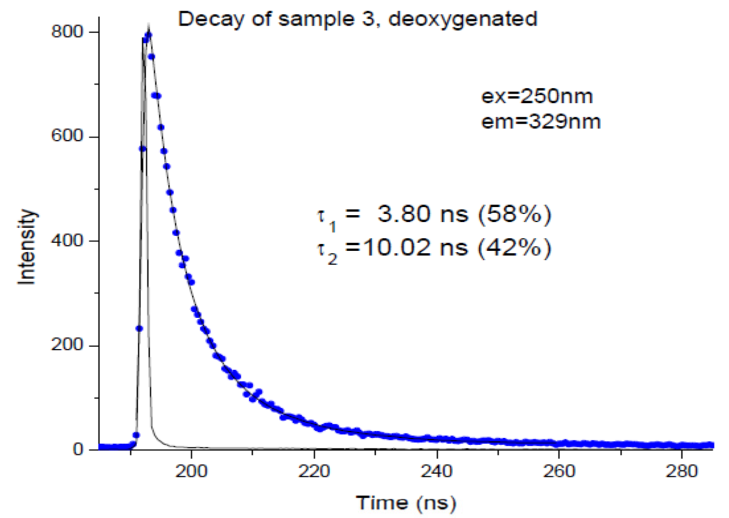


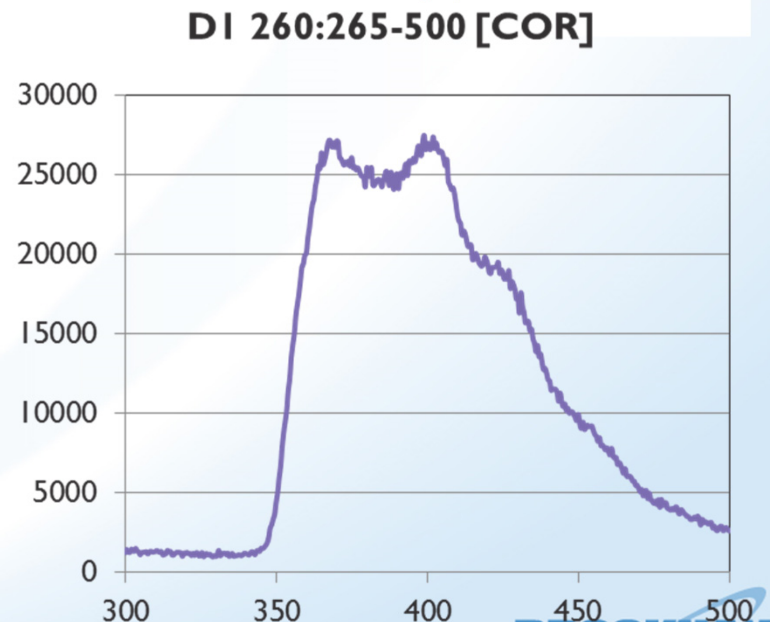
Time and energy cuts give a bkg. rejection efficiency of >99.975%; single-pulse bkg. (μ^+ from ν_μ) can be differentiated from the double-pulse signal (K^+ and its daughter μ^+).

Water-like WbLS Characterizations

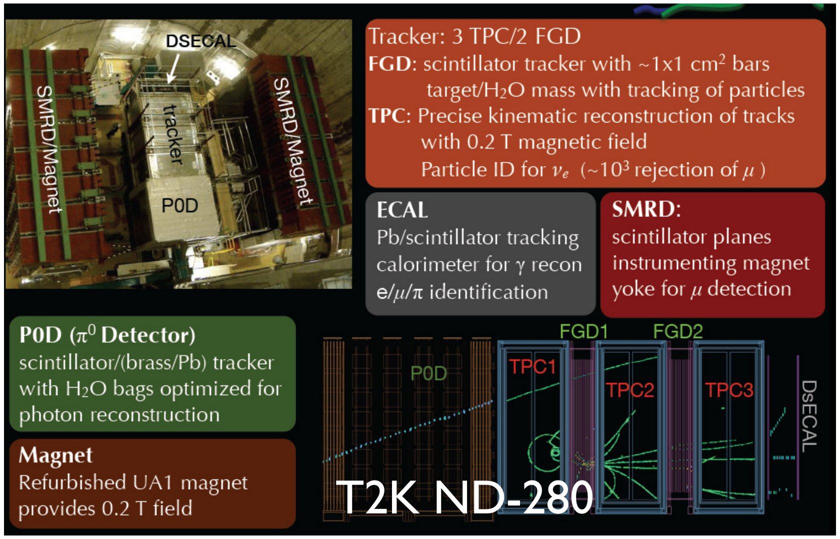
A scintillation water with fast and optical transparent light that can explore both scintillation and Cherenkov channels.

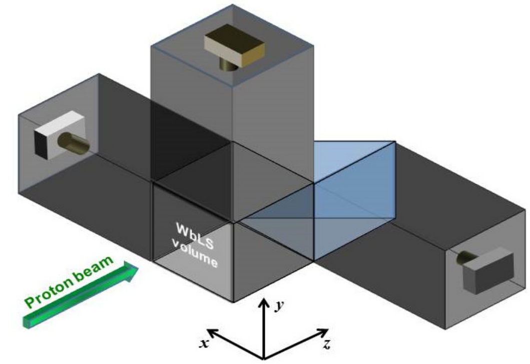




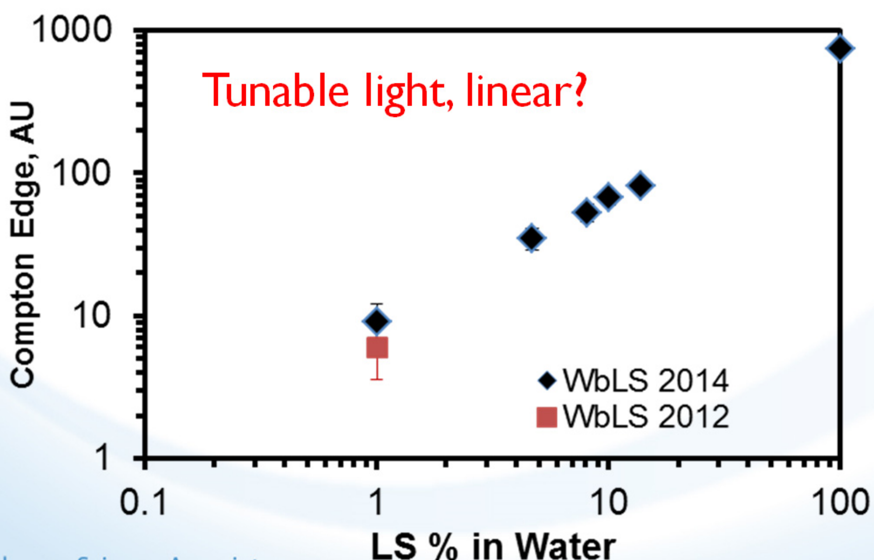


Tunable LY for various Physics

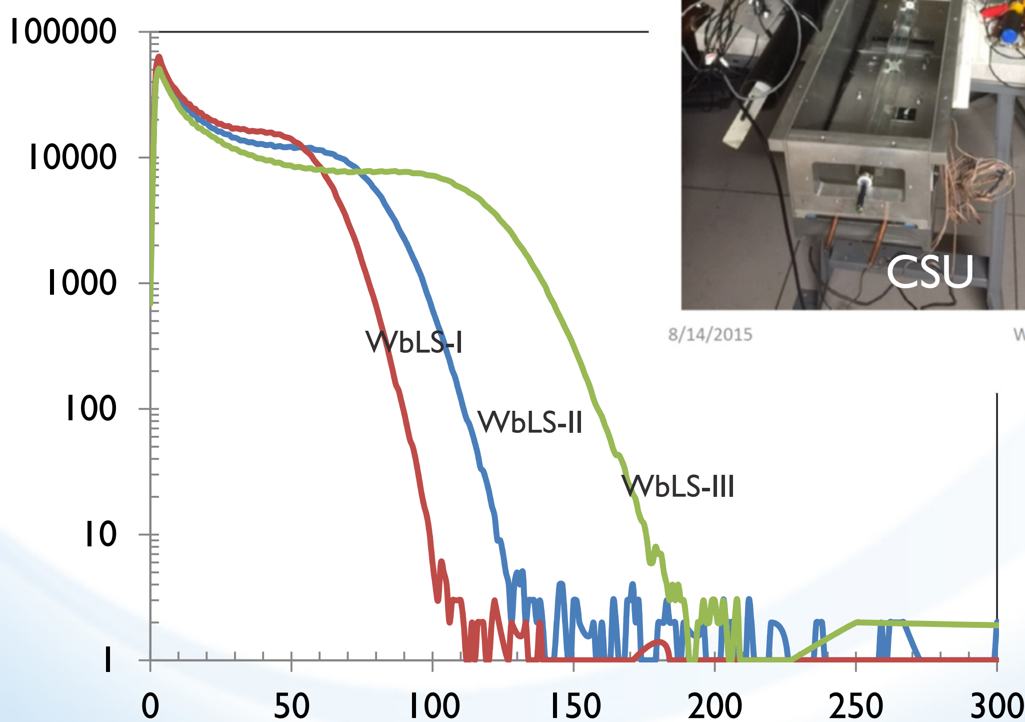


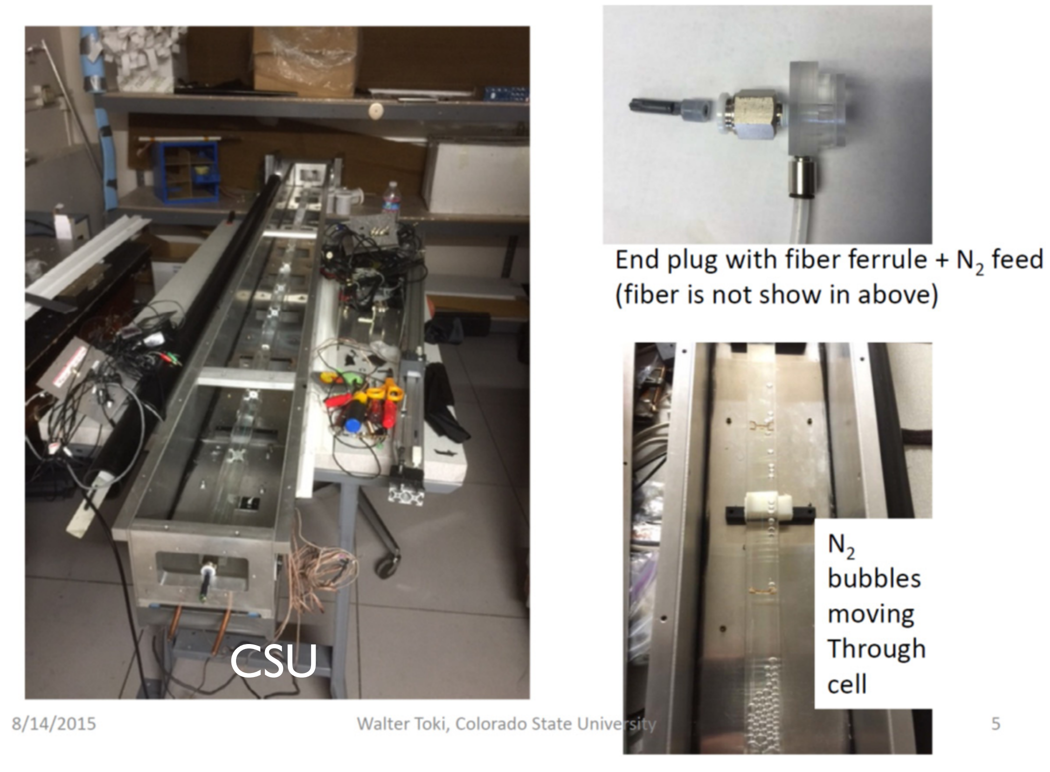


- 3-D medical Imaging for ion-beam therapy (5-10%WbLS) and TOF-PET (10%Pb-WbLS)



T2K-ND (15% WbLS)





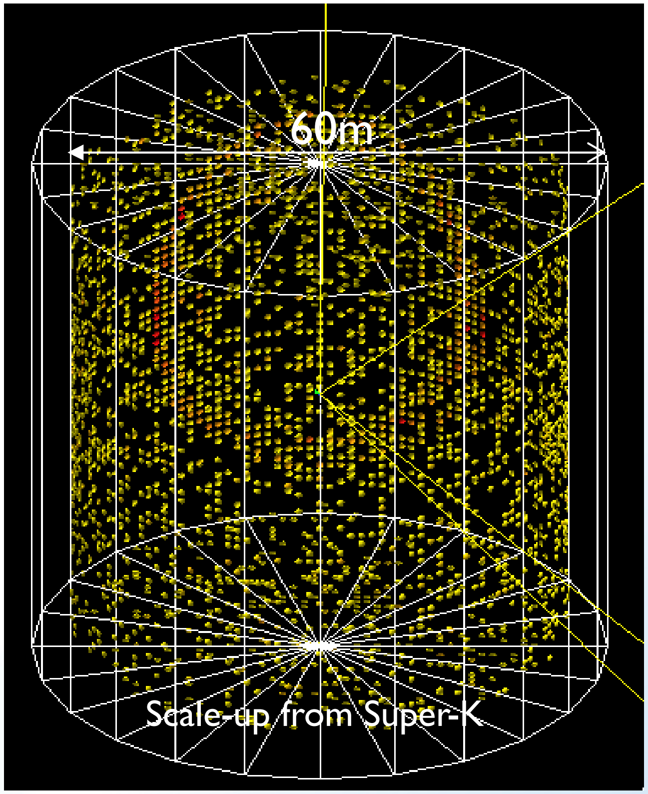
- WbLS with 70% H2O target
- WbLS-I & -II → not enough light
- WbLS-III is reasonable; testing ongoing

THEIA

Advanced Scintillation Detector Concept (ASDC)

- A large water Chev and Scint detector
- 50-100 kton WbLS target
- High coverage with ultra-fast, high efficiency photon sensors
- Deep underground (e.g. 4800 mwe Homestake)
- Complementary program to proposed LAr detector at LBNF (P5, Scenario-C) with comprehensive low-energy program
  - Long-baseline physics (mass hierarchy, CP violation)
  - Neutrinoless double beta decay
  - Solar neutrinos (solar metallicity, luminosity)
  - Supernova burst neutrinos & DSNB
  - Geo-neutrinos
  - Nucleon decay
  - Source-based sterile searches

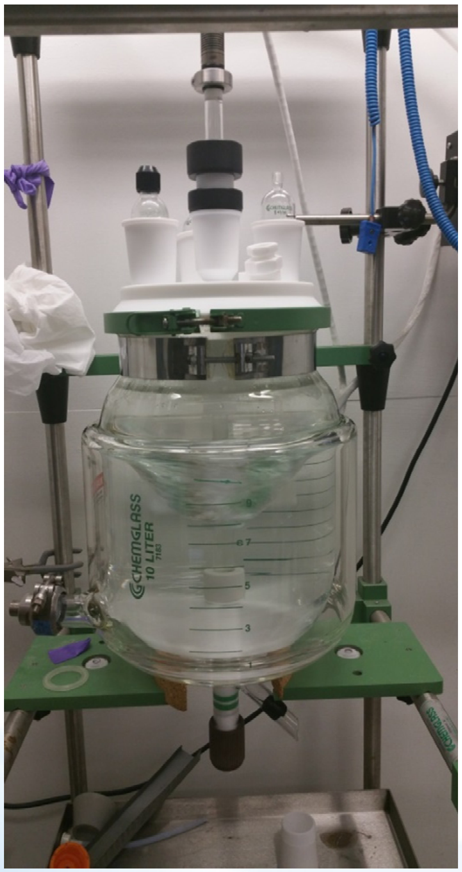
J. Klein talk

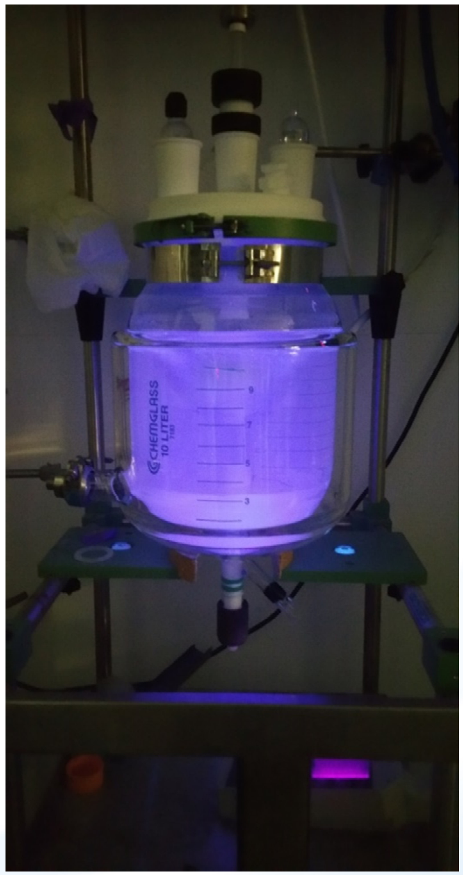


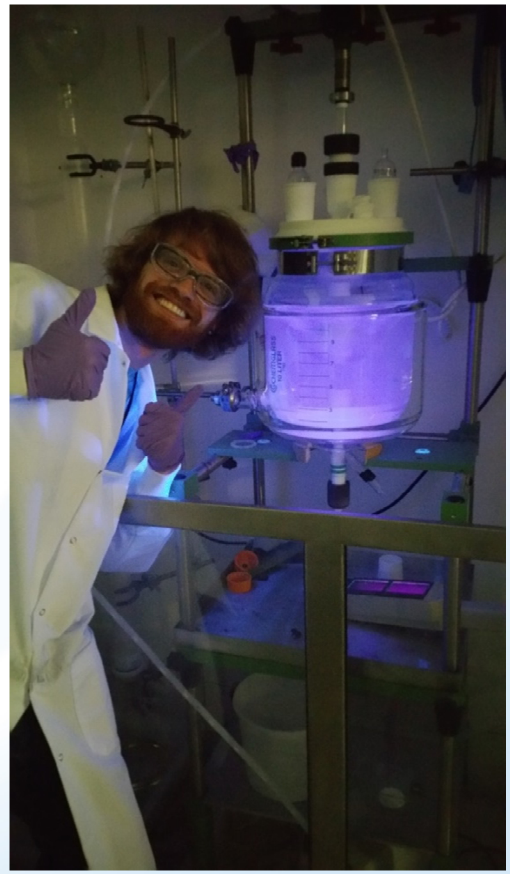
- arXiv:1409.5864: 50
- WATCHMAN could be the next large (kton) water Cherenkov detector

WATCHMAN R&D

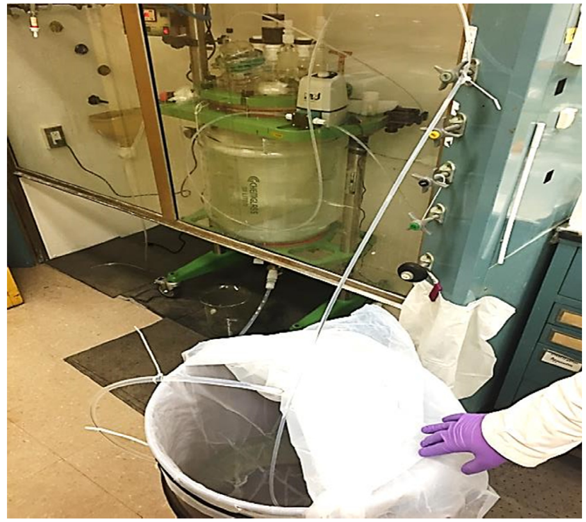
- 10L production for on-line (nanofiltration) circulation study → a purification by differentiating molecular sizes (BNL/UC Davis)







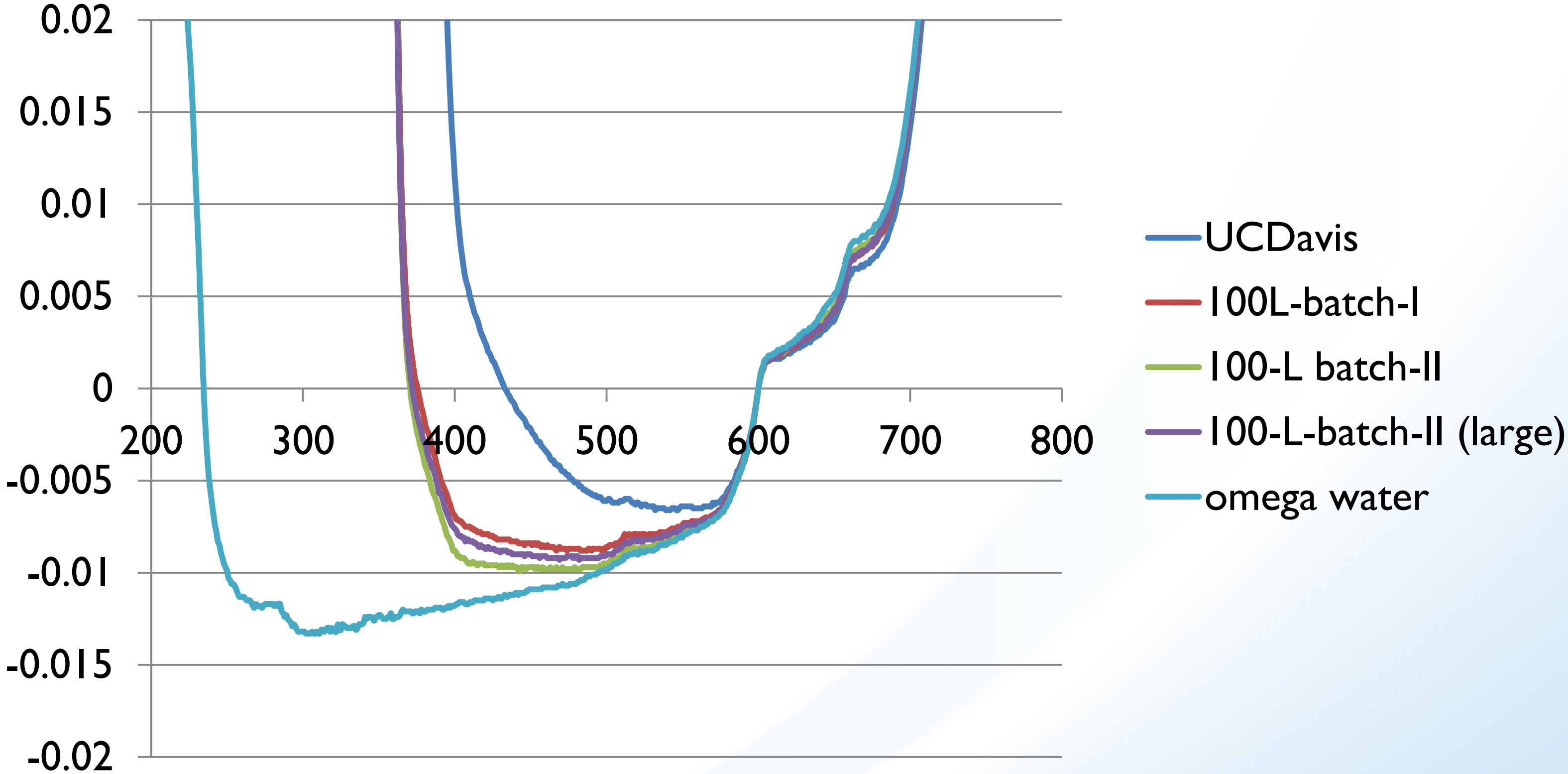
WATCHMAN R&D cont'd



- 100-L production for long-arm attenuation measurement (LBL and UCI)
- Large scale feasibility and purification (BNL)

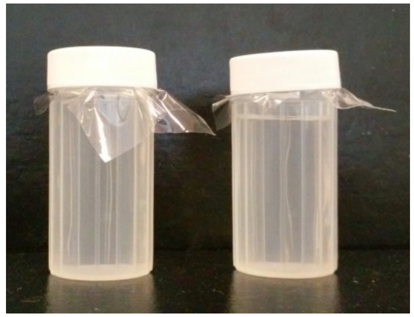
Optical Transmisson of WbLS (100 ph/MeV)

- Scattering reduction is the key
- Material compatibility needs to be demonstrated



Ongoing Compatibility Testing

PP cap


PP vial


PTFE bag


PFA bag


Epoxy drum

S.S. 316


PP drum liner

PEEK screws


SNO acrylic

Medical Application of WbLS

1. Intensity-modulated pencil proton beam therapy (IMPT) in which a tumor can be targeted for radiation while sparing the surrounding healthy tissue.

2. Uses the Bragg peak of stopping protons to localize dose

3. WbLS-based "phantom" would serve as a real-time quality assurance device

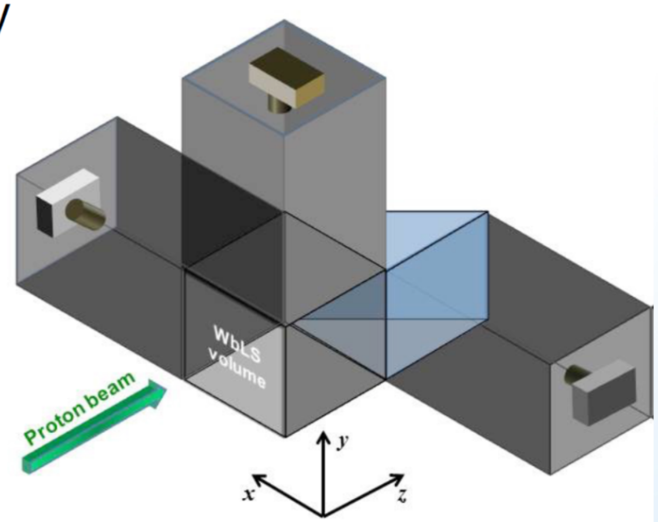
4. Requirements on WbLS:

    1. Able to withstand ~600Gy yearly facility dose

    2. Understanding of light yield and collection to ~1-2%.

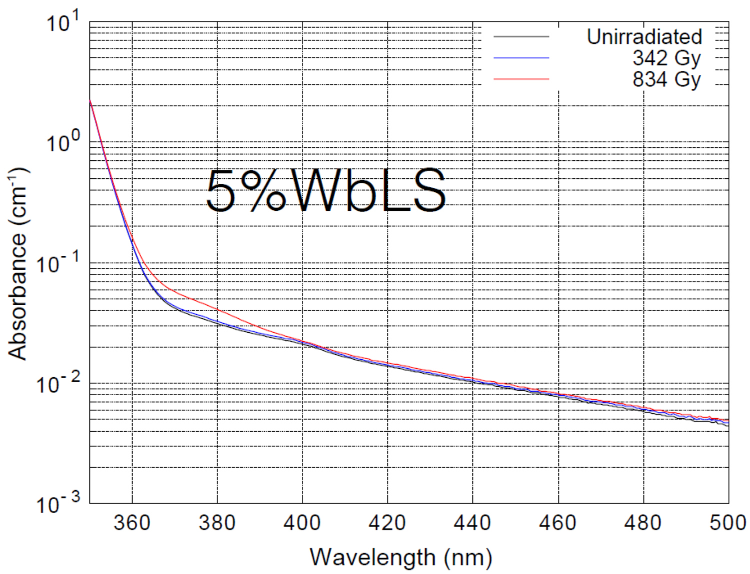
    3. Millimeter scale position resolution

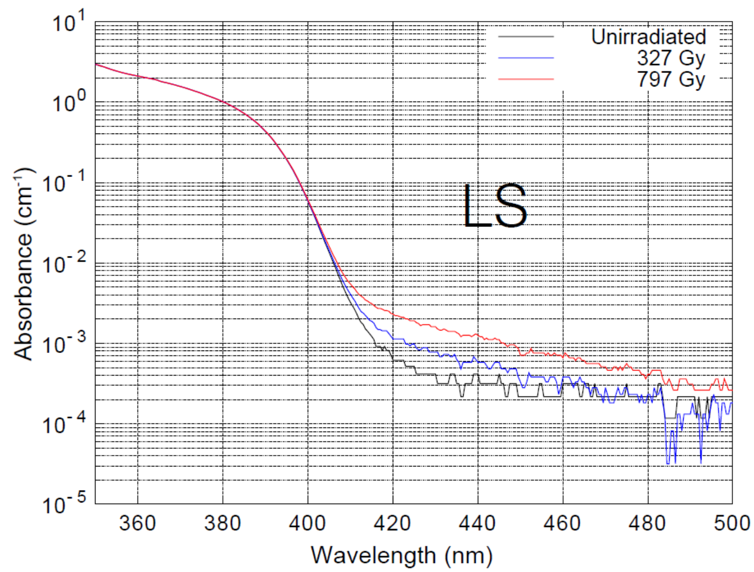
    4. ~5% concentration of LS in water ("5%WbLS")

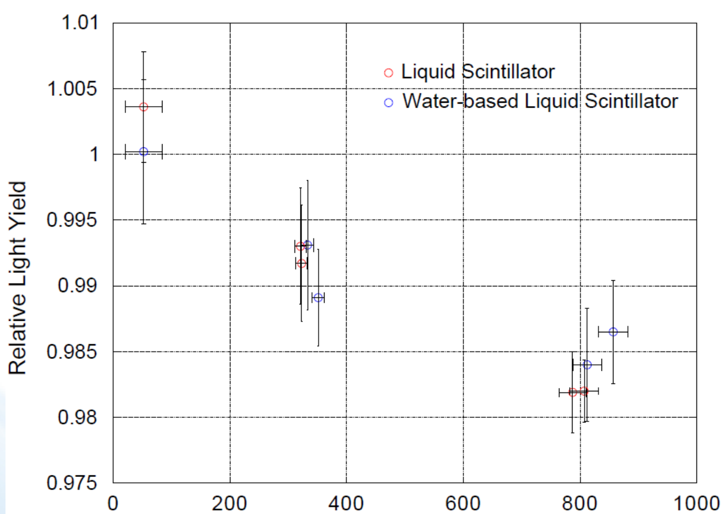


Patent filed (2014) and received (2015)

Radiation Hardness







1. LY reduced 1.74±0.55% and 1.31±0.59% for LS,5%WbLS resp. after ~800Gy dose at NSRL
2. Implies ~0.1% LY reduction in one year of operation of a proton therapy QA device

Summary

1. Water-based liquid scintillator is a new detection medium invented at BNL with numerous possible applications
2. We have shown that the light yield is adjustable and begun developing a detailed simulation to account for all light production and absorption mechanisms
3. Further investigation underway to understand why WbLS properties differ from bulk LS
4. We are currently commissioning a 1000 liter acrylic vessel to study WbLS performance and characteristics in a modest scale detector
5. We also plan a suite of measurements of light yield, absorbance and emission for various WbLS concentrations to incorporate in simulation