Water-based Liquid Scintillator for Large-Scale Physics

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Metal-loaded liquid scintillators

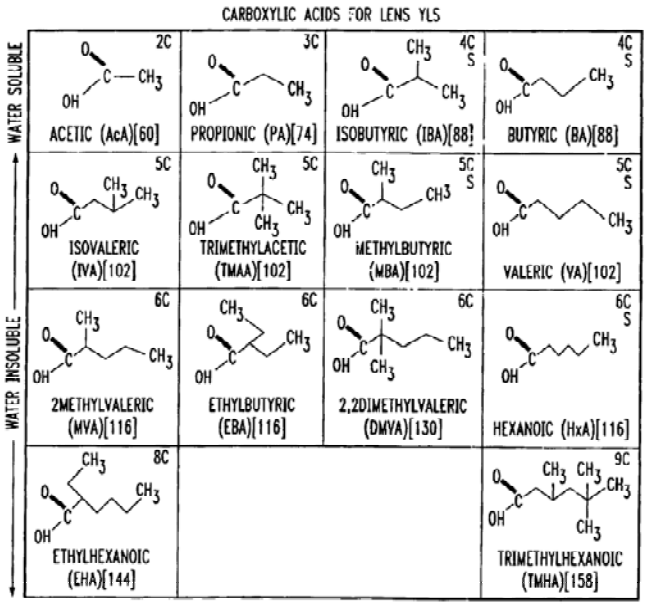
Development and production of Metal-loaded liquid scintillator (LS) for neutrino experiments

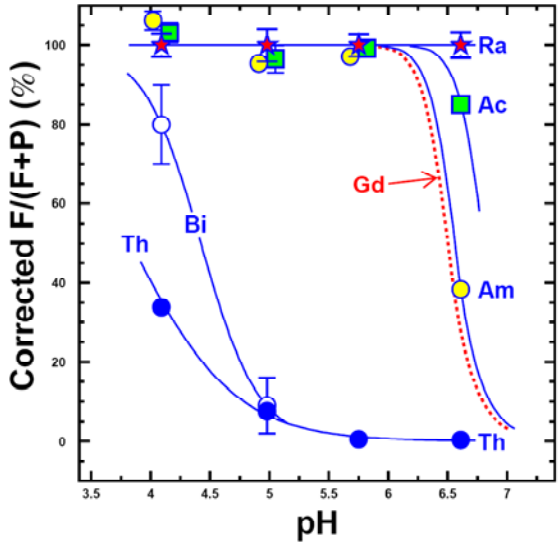
- SNO+ uses 1 kT of Nd-loaded LAB
- LENS uses 125 tons of In-loaded LAB or PC
- Daya-Bay uses 200 tons of Gd-loaded LAB

BNL M-LS R&D over 10 yrs

- M. Yeh et al. Gadolinium-Loaded Liquid Scintillator for High-Precision Measurements of Antineutrino Oscillations and the Mixing Angle, θ13, NIM A 578 (2007) 329-339

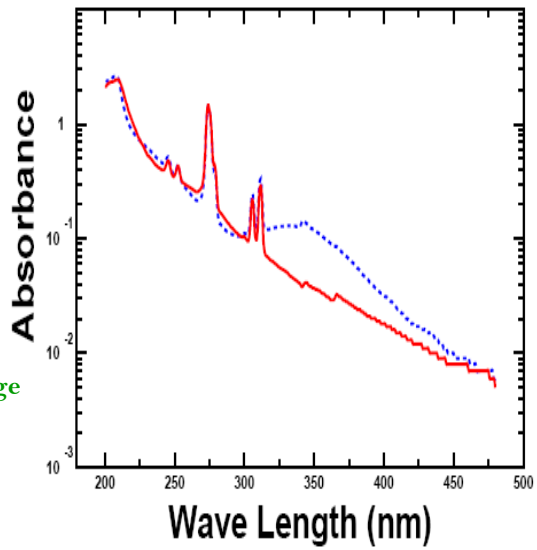
Study of M-LS properties as a function of purity levels and of metal concentration





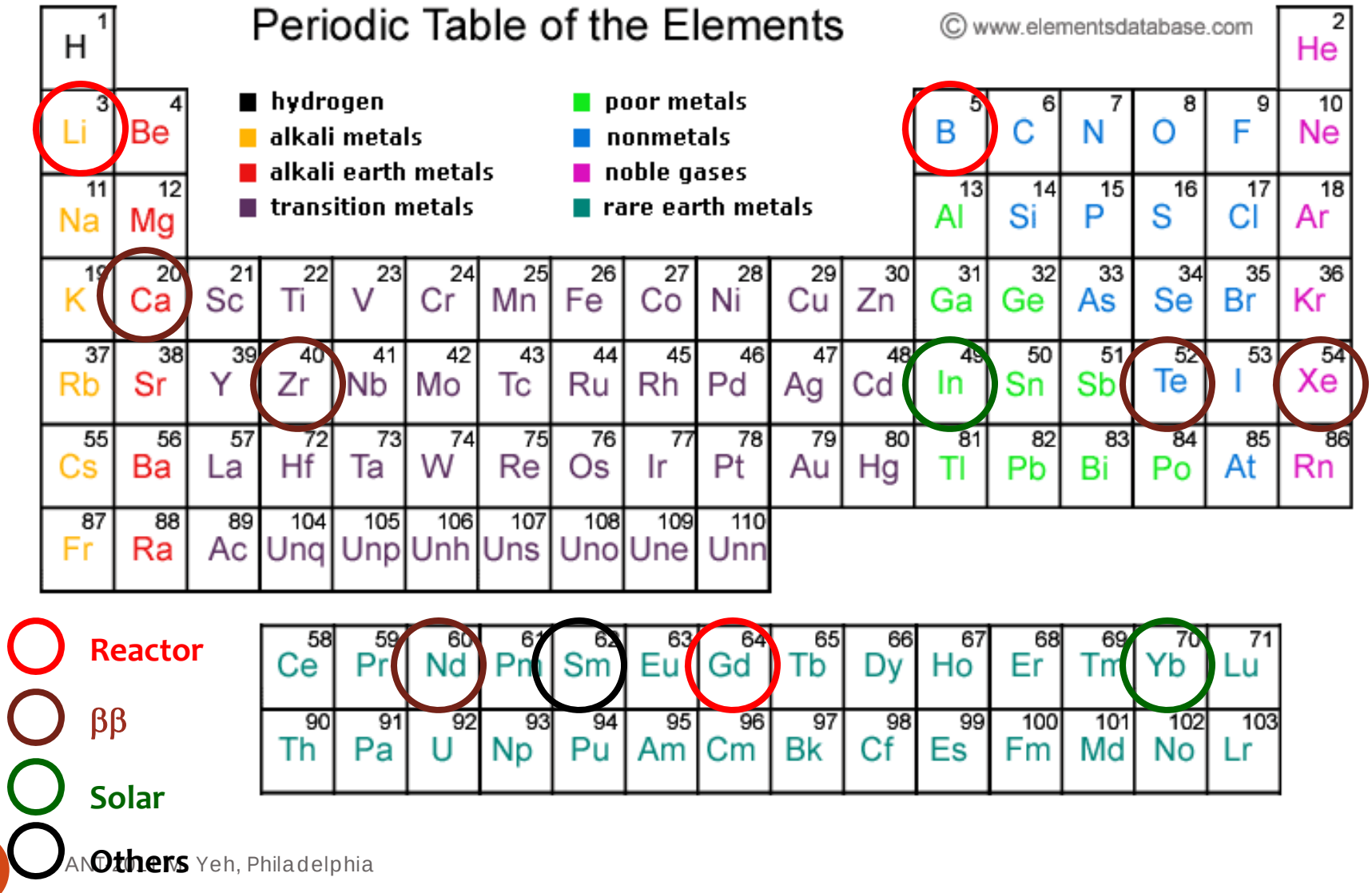
- M. Yeh et al. Purification of lanthanides for large neutrino detectors, NIM A 618 (2010) 124–130

Self-scavenging method to remove Th/U and improve UV



carboxylic acids are the preferred ligands

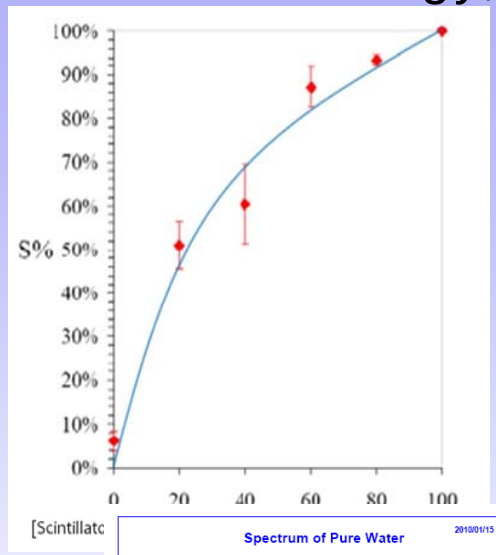
BNL Metal-loaded LS

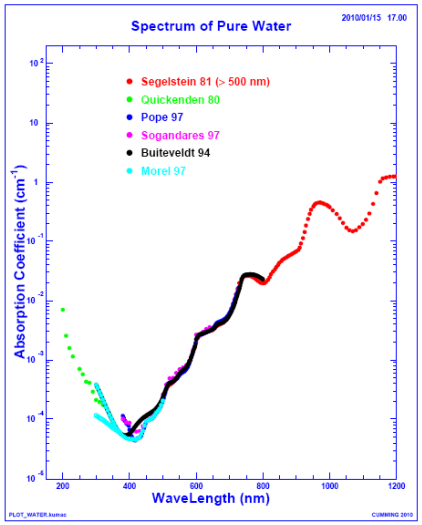


Water-based liquid scintillator

Develop a WbLS to be used as energy spectrometer in large-scale physics experiments and in veto-system, radionuclide-metrology, national-security applications

- Replace large unloaded or metal-loaded organic liquid scintillators:
  - simpler sensitive detection medium
  - enhance chemical safety
  - large cost savings
- Provide an environmental-friendly water-based scintillator



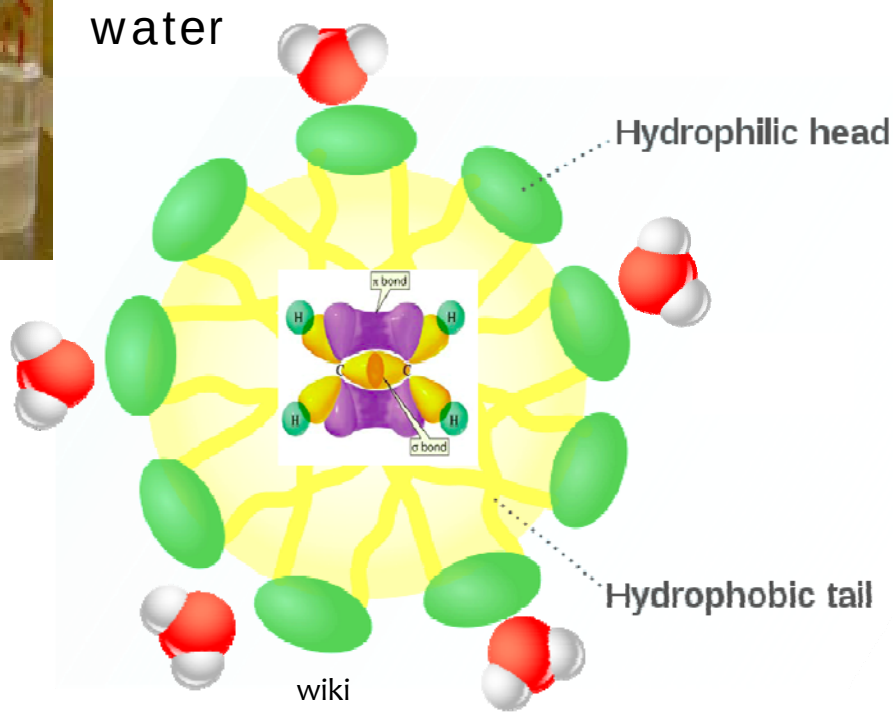


Non-linear photon production plus superior water attenuation length make a 100-kT WbLS detector possible to detect physics below Cherenkov threshold (PDK+)

Water-based liquid scintillator is different from dissolving fluor or shifter in water.

Principle: Surfactant reduces the polarity tension; thus balances the "like to like"

Conventional water-miscible cocktails for α/β counting or in medical imaging are not stable in water



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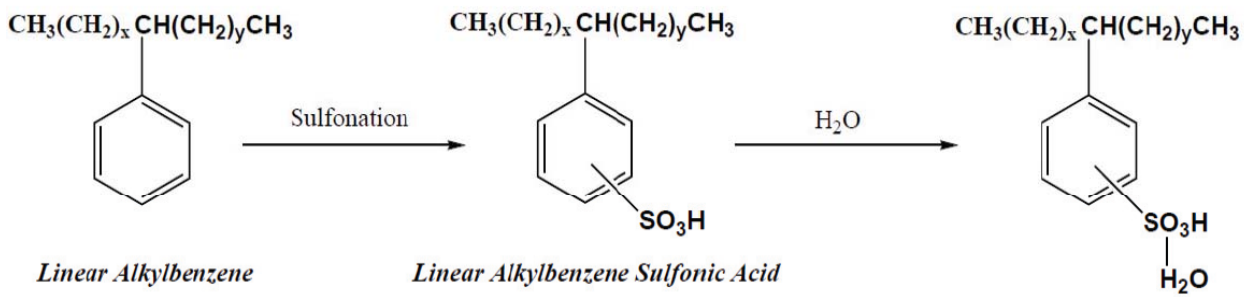
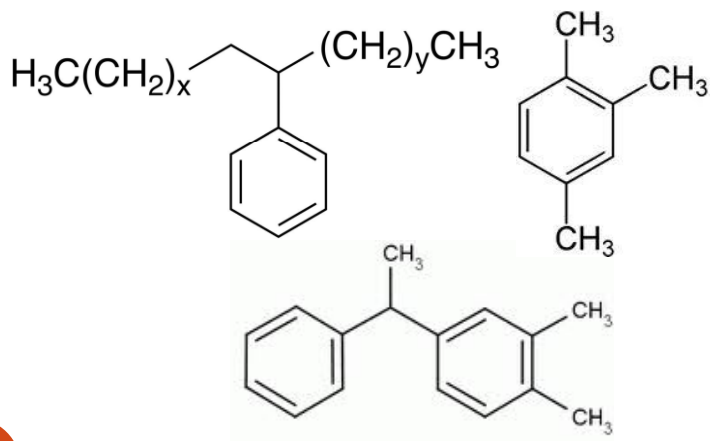
A stable WbLS with adequate $\lambda_{1/e}$ and scintillation light can be used as particle detector

Two Working Schemes

(A) The surfactant lights itself up!



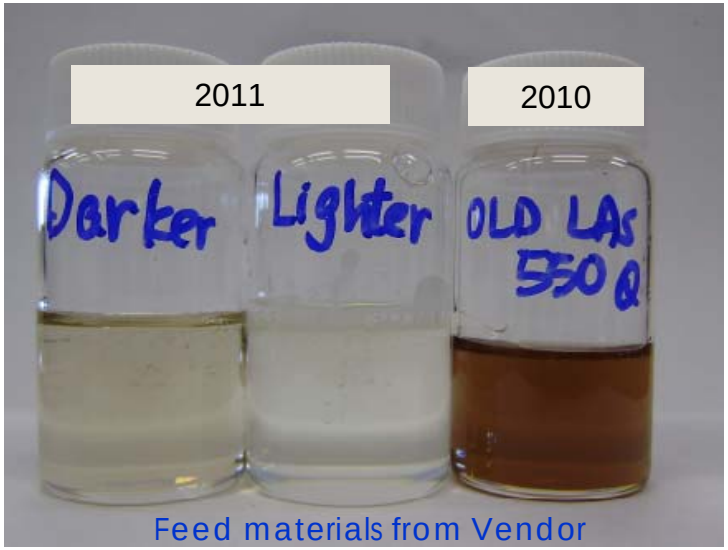
(B) The surfactant is just a surfactant!



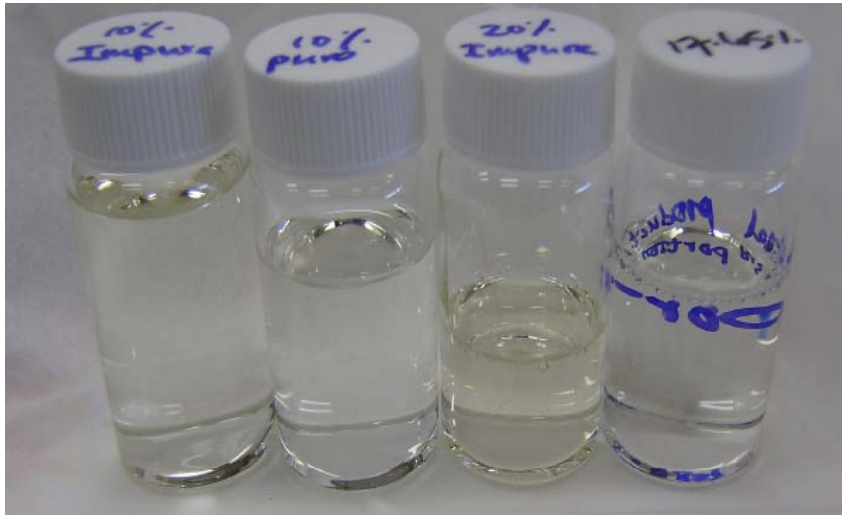
Bring PC, LAB, or PXE in water; an ability to tune light, τ, etc

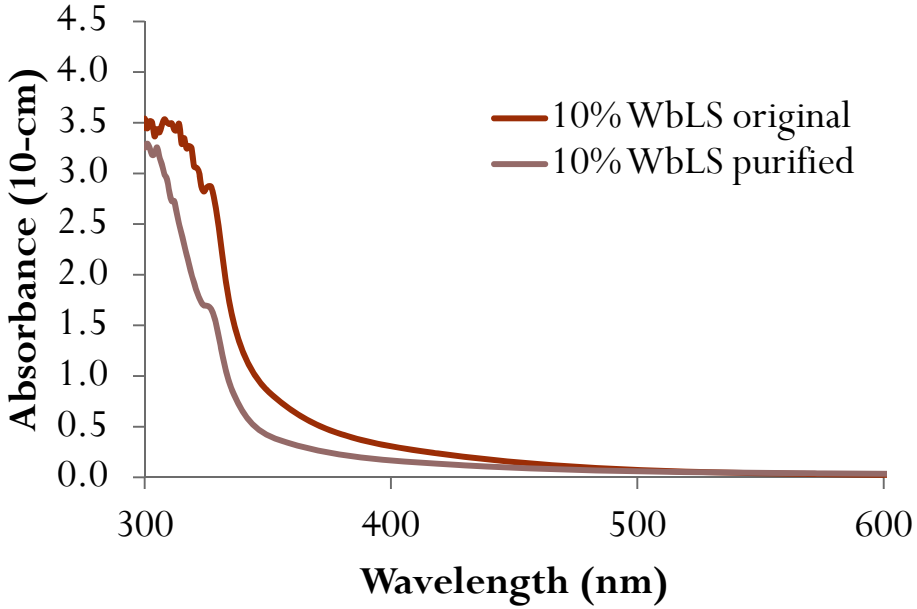
Optical Transmission: 10-cm cell and 2-m dual vertical system

- Improve the feedstock (collaborate with vendors)
- Develop purification strategy for synthesis and on-line once loading



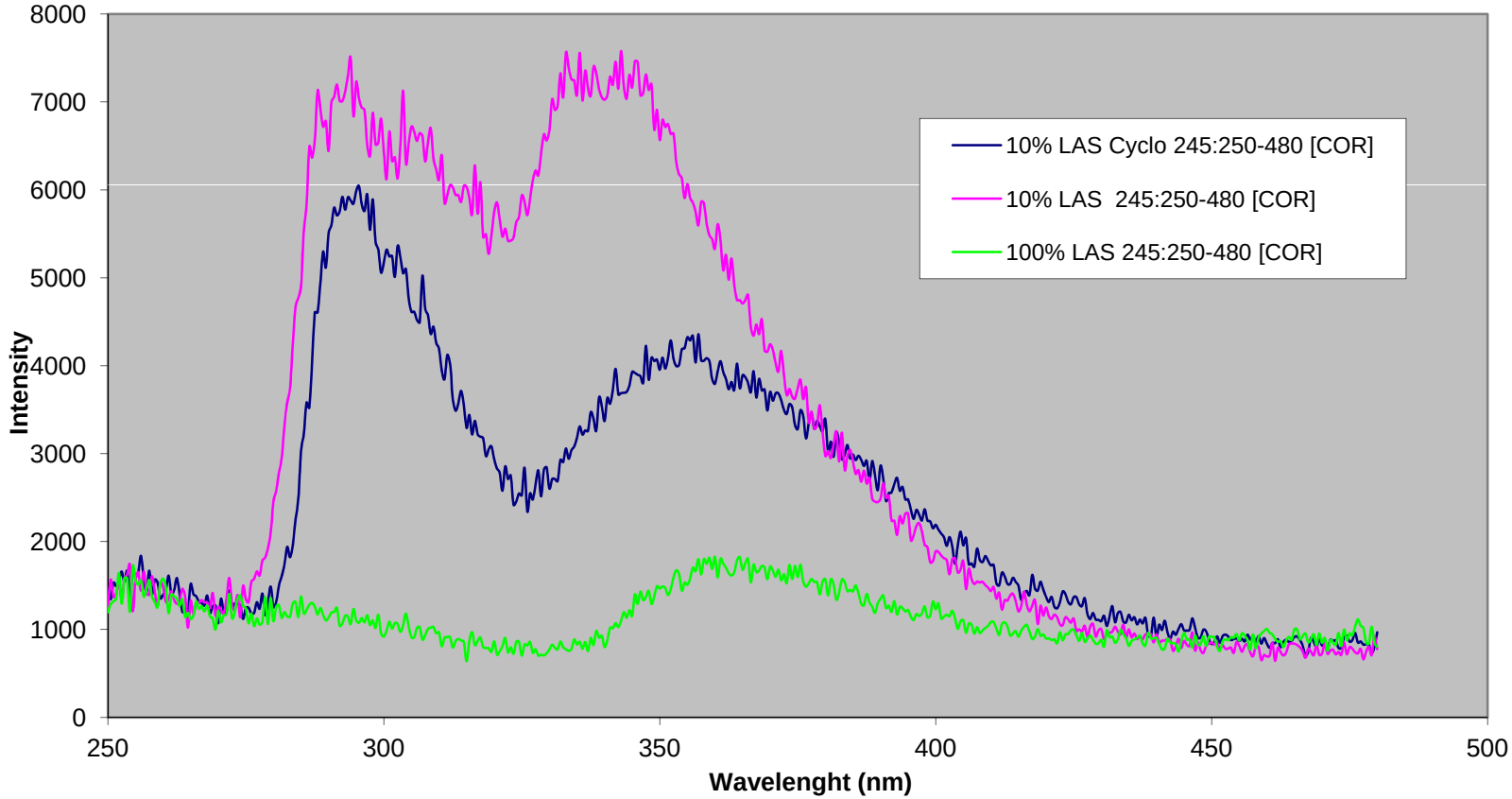
Feed materials from Vendor



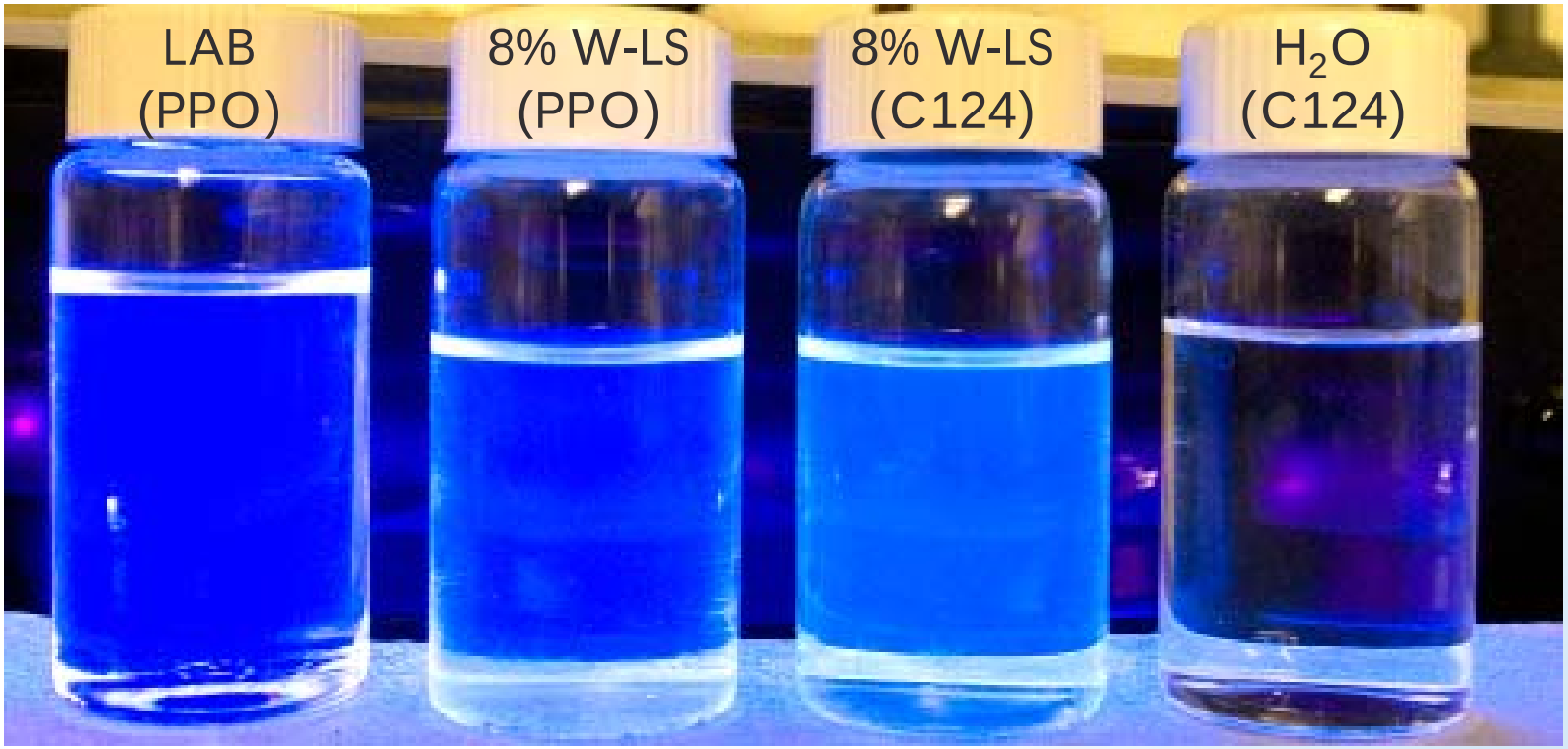


Color Quenching attenuates the light

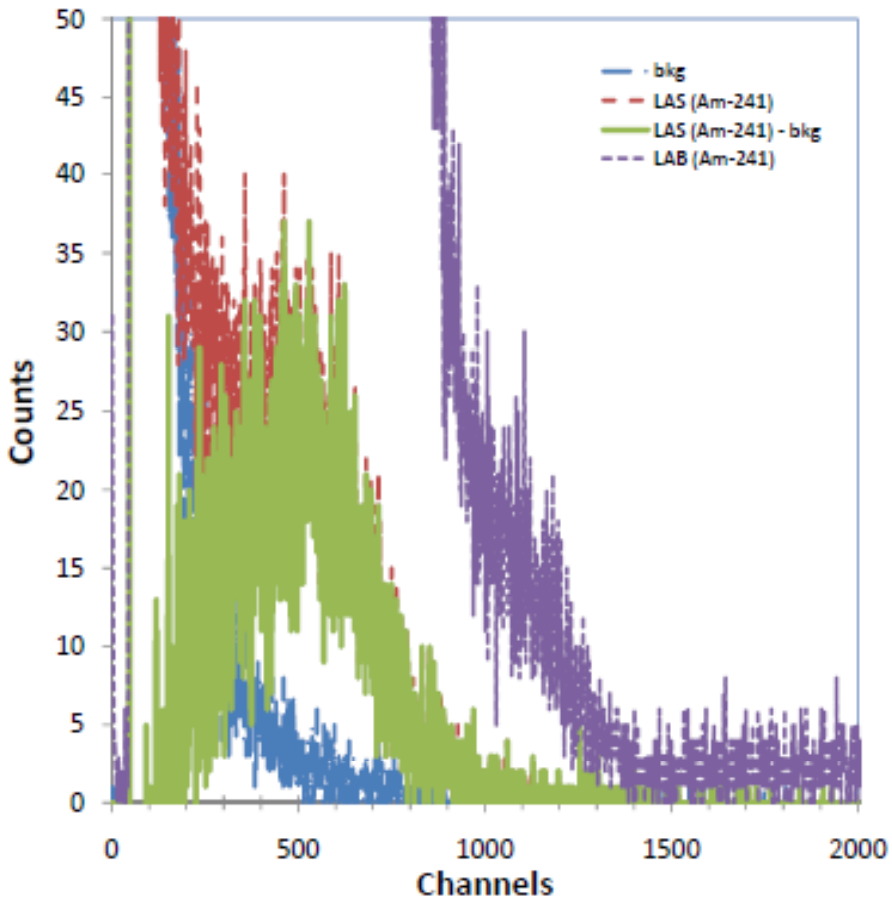
Emission at 245-nm

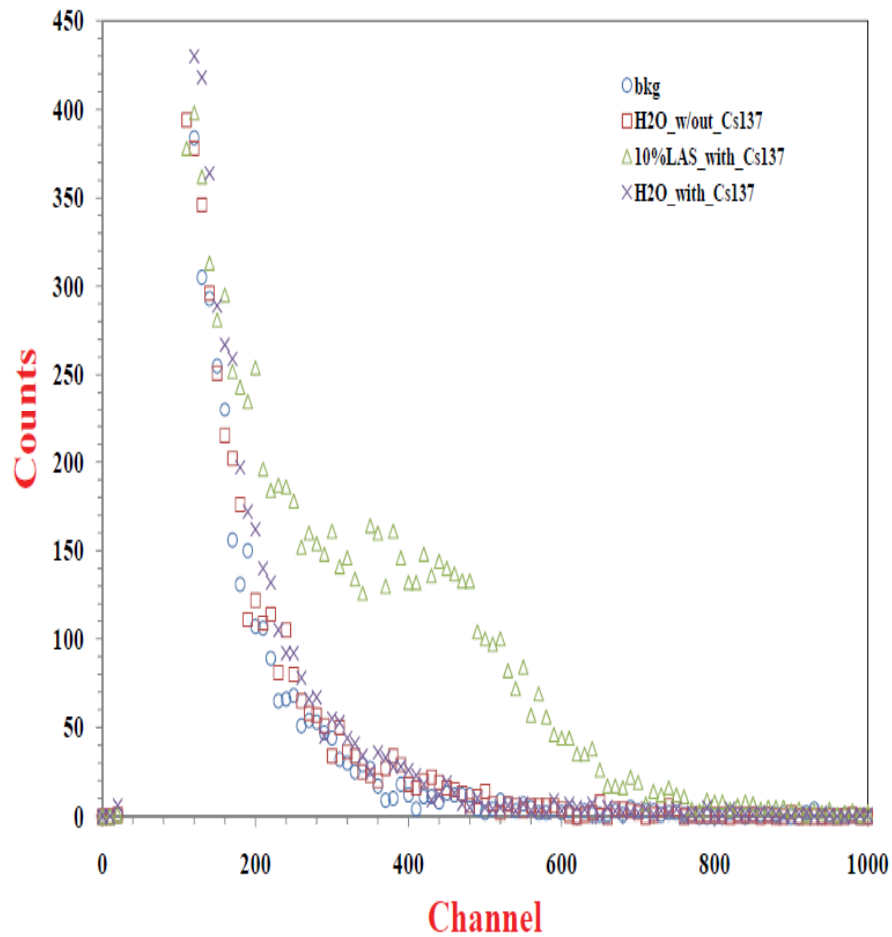


Scintillation Lights: Liquids under 260nm

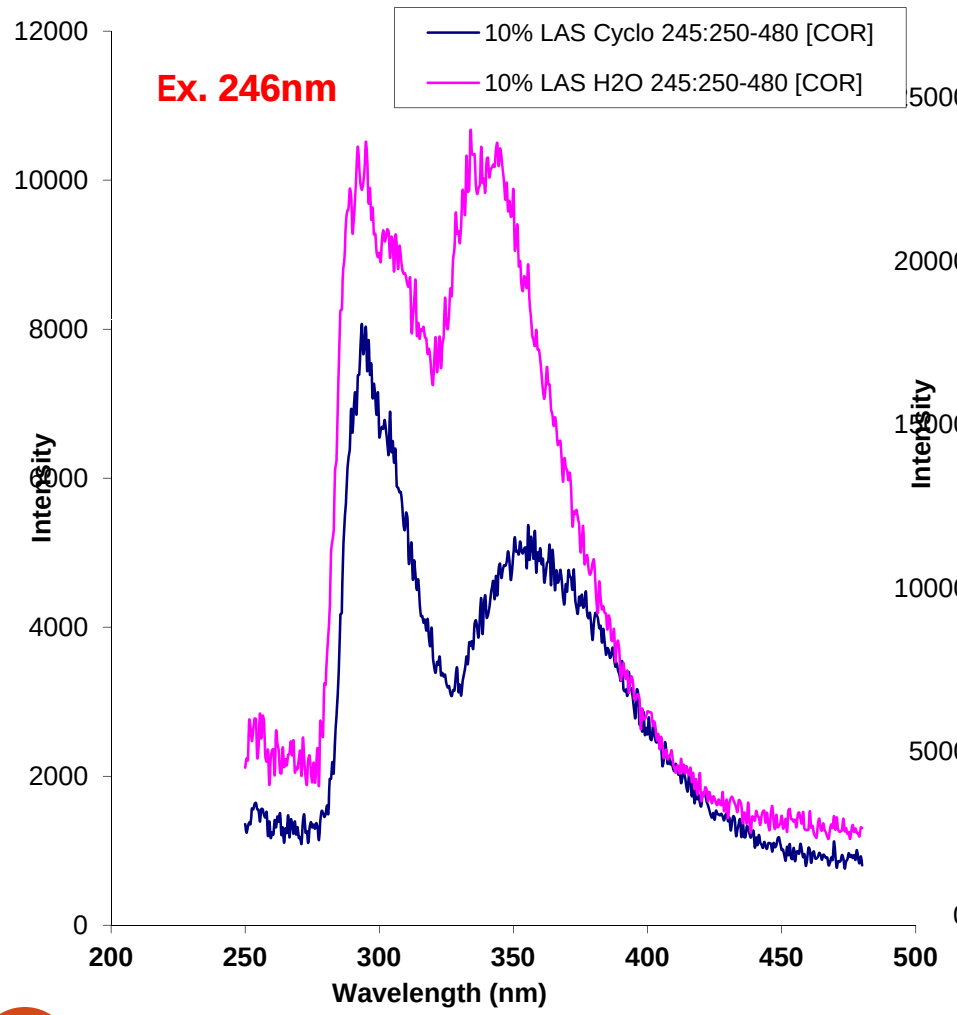


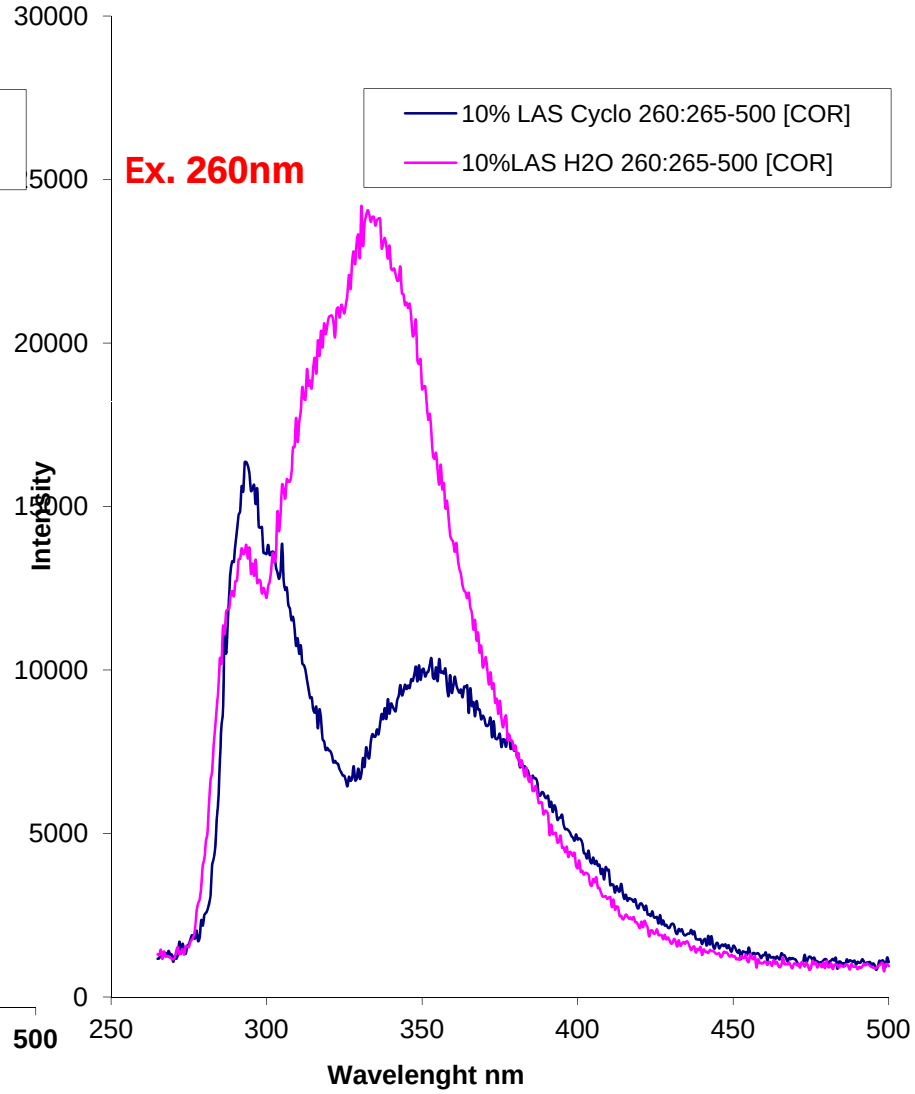
Counts with α (Am-241) & γ (Cs-137)





Water quenching is complicated…

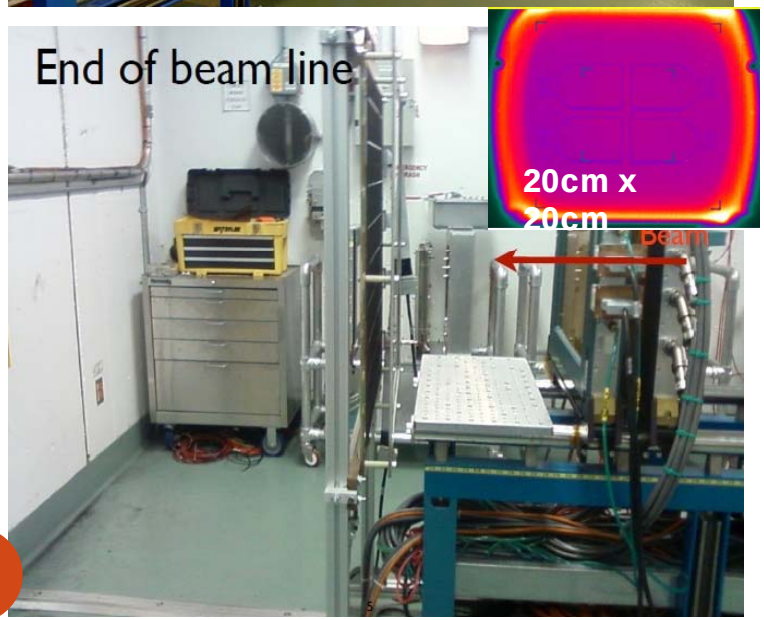


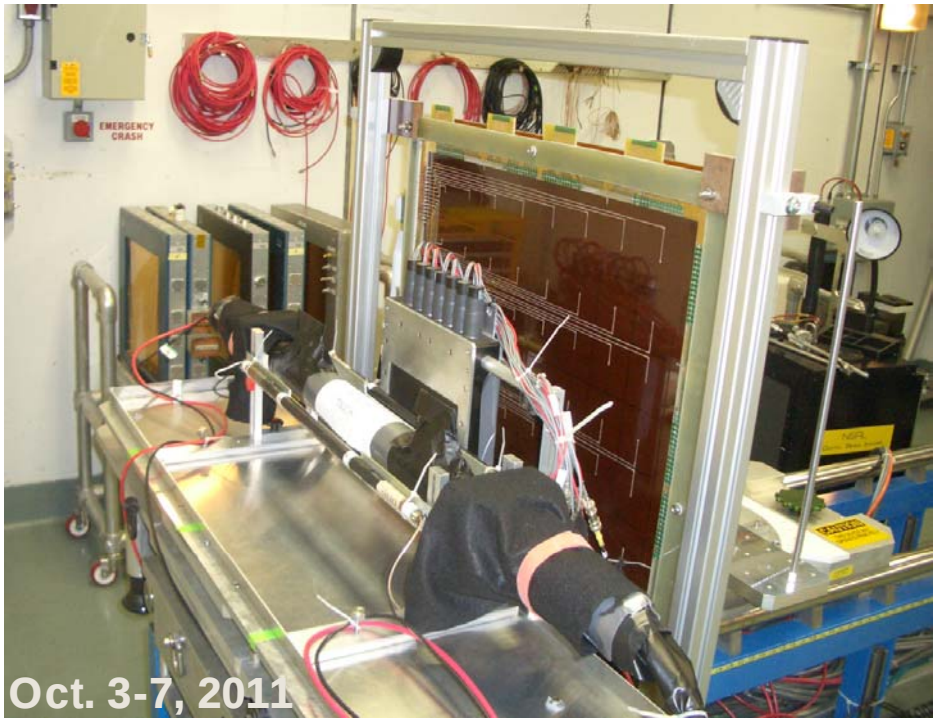


Light propagation

kg-scale Muon and Proton-beam runs

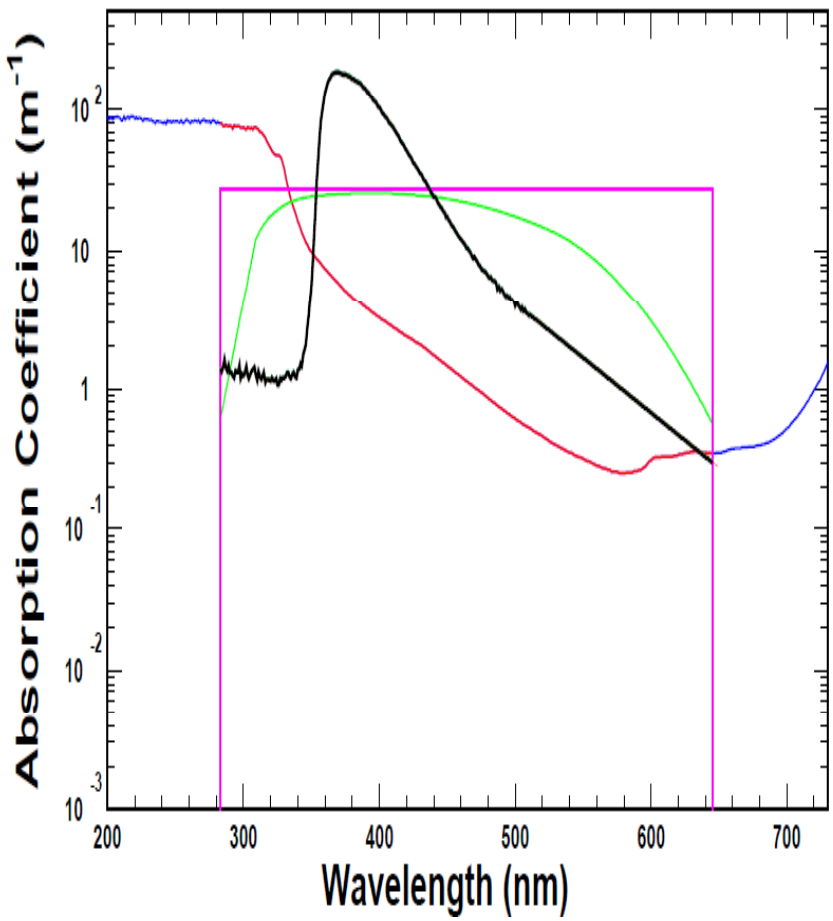
- Proton beam from 50 -1000 MeV (*dE/dx*~12.5 to 2.2 MeV/cm) per nucleon
- 10^{11} ions per spill
- 34”x 4” Lucite cylinder with 2” PMT on each site
- Hodoscopes before and after



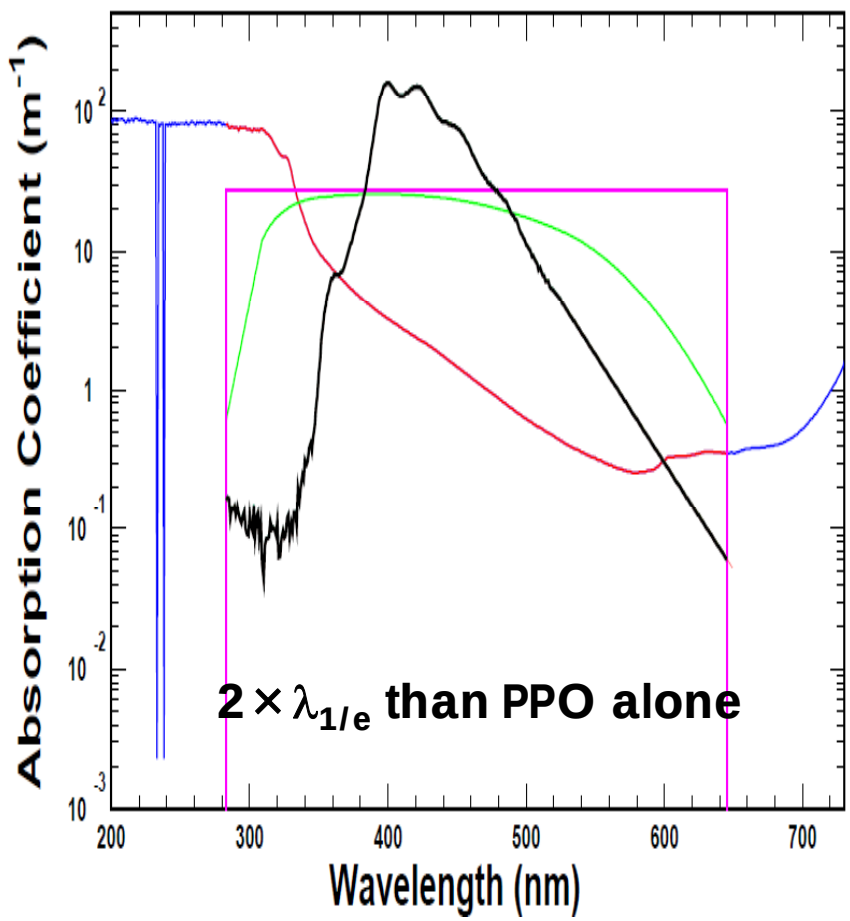


Fluor and Shifter: critical

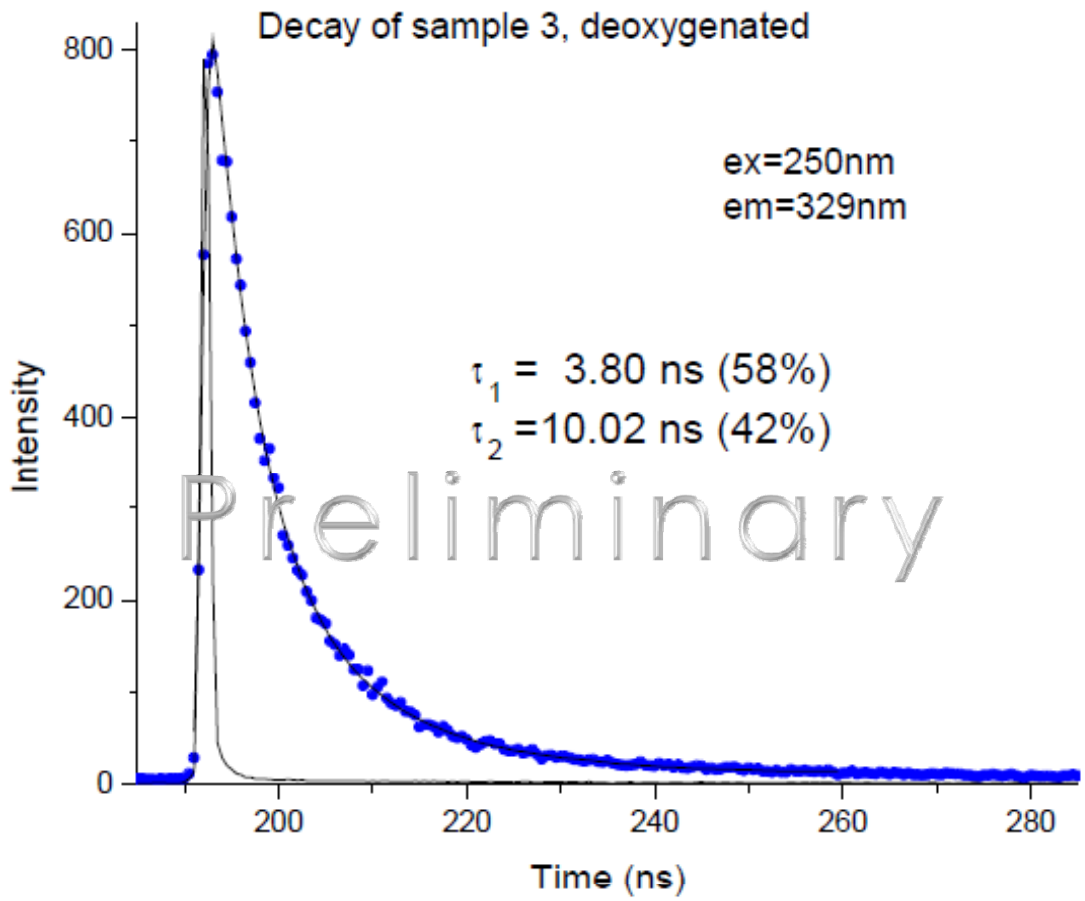
PPO



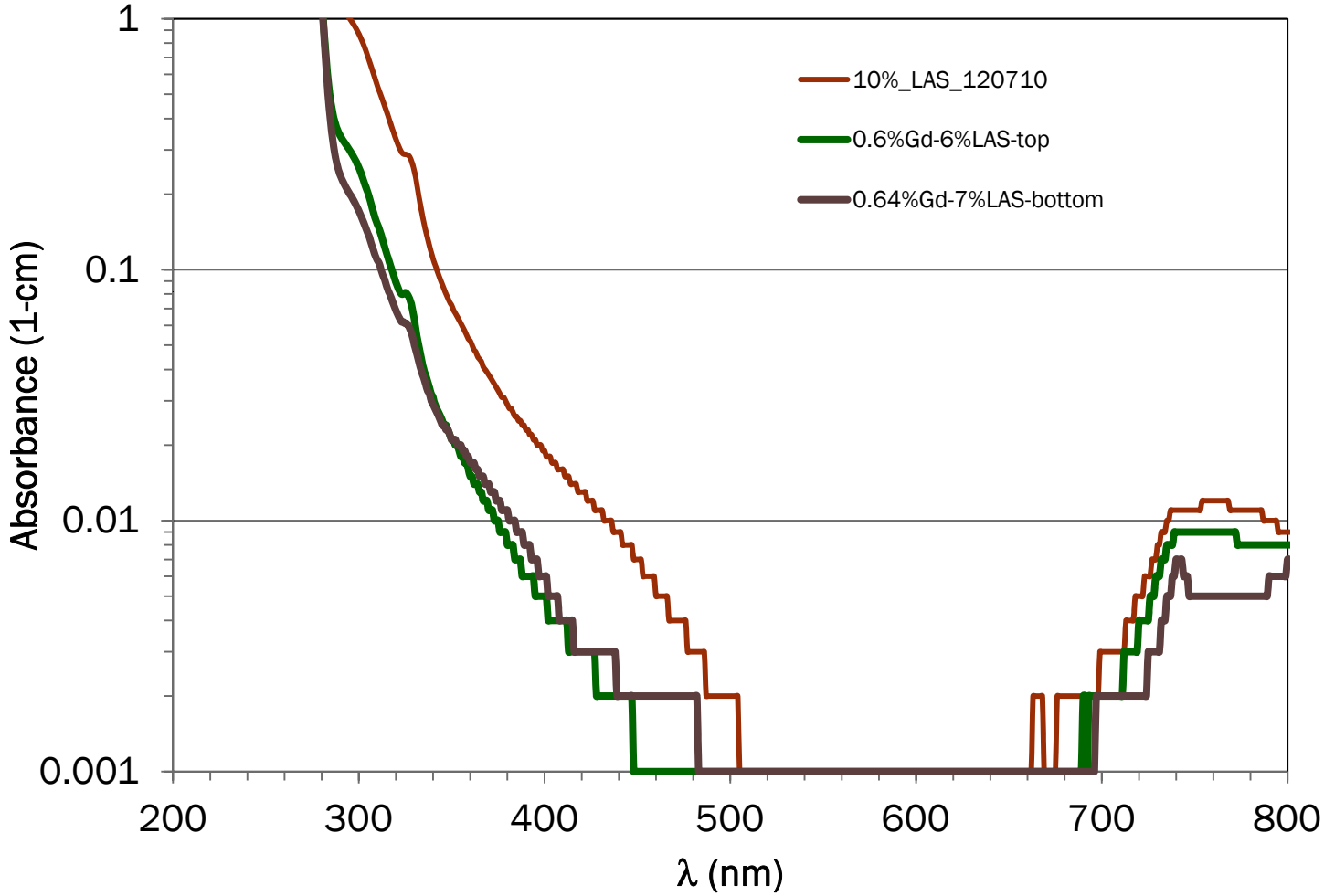
PPO + bis-MSB



decay time is in the region of interest

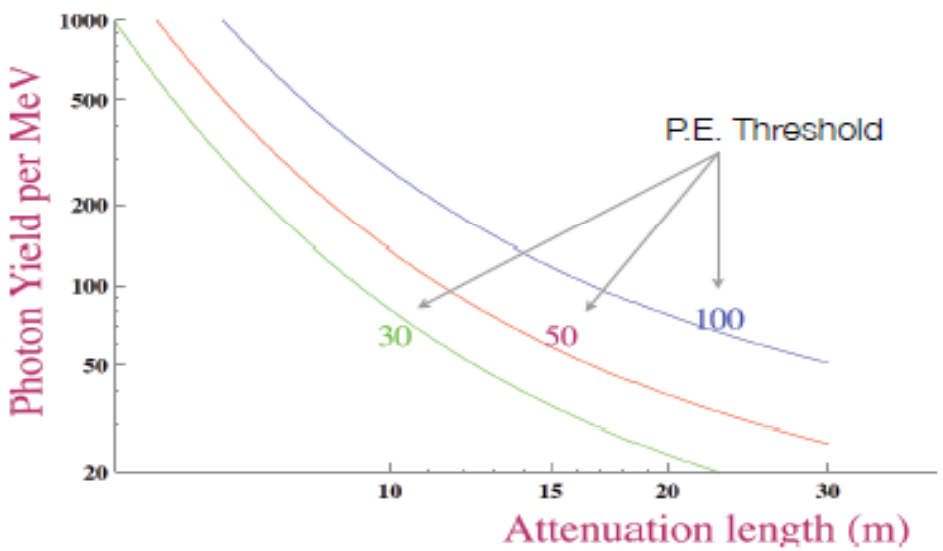


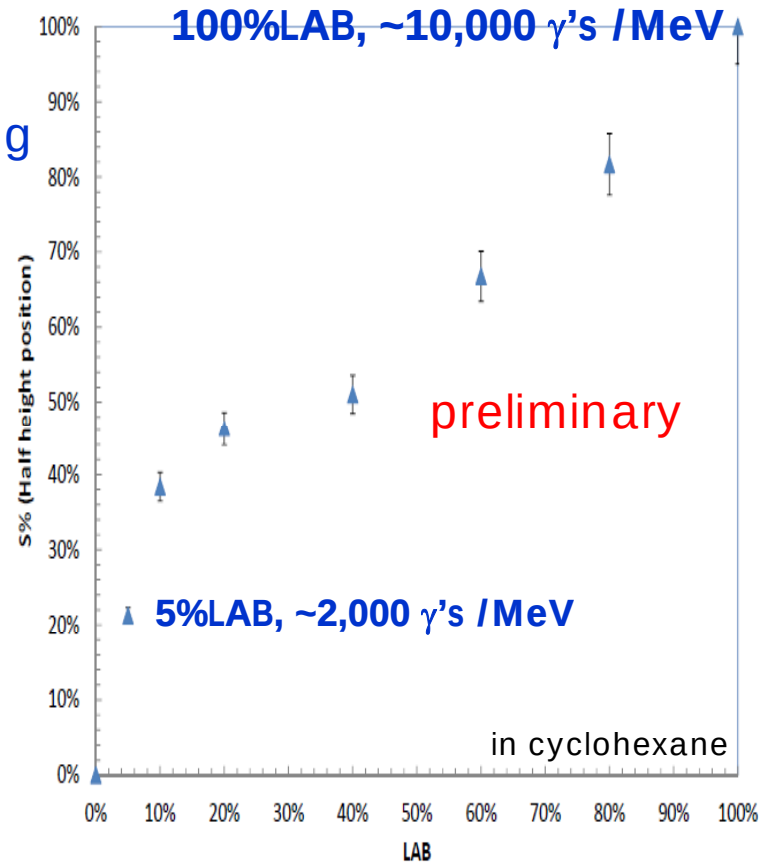
Loading Gd in WbLS
to enhance neutron-tagging



Scintillation + Cherenkov

- Can we preserve the Cherenkov feature while scintillating?
- Excellent detector for nucleon decay
  - Water is an excellent proton provider
  - Cherenkov hit pattern helps in suppressing the Atm. ν induced bkg.
  - We might not need much scintillator

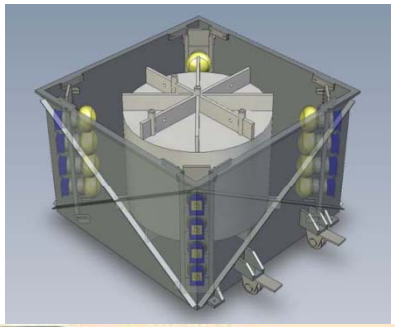


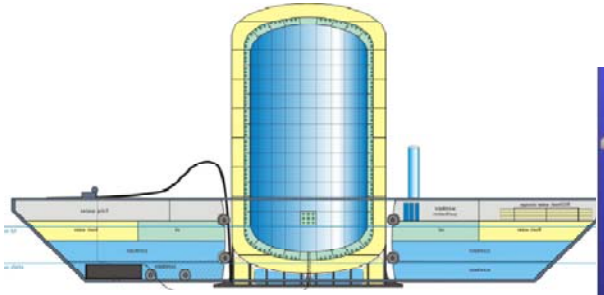


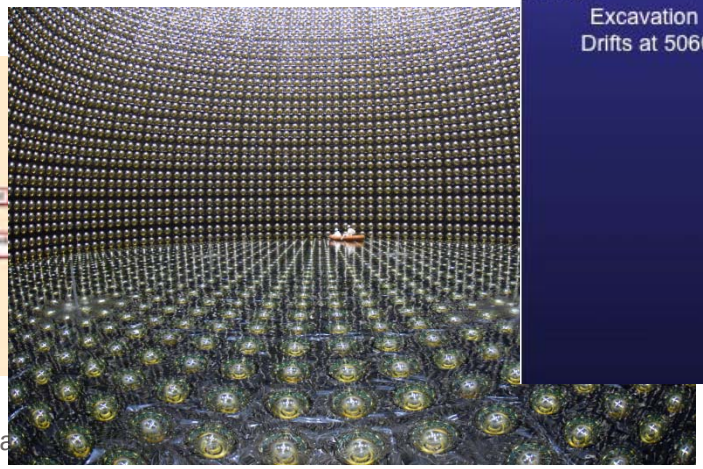
WbLS-to-be

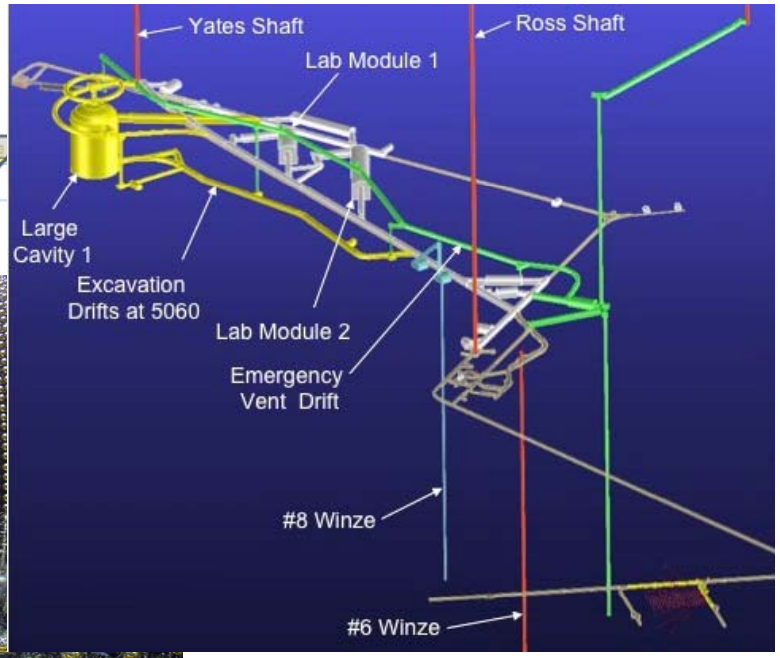
Say we have a cost-effective; e.g. $12.5M vs. $125M (50-kT) or $25M vs. $250M (100-kT); and environmental friendly water-based detector in 1~2 years

- A multiple-physics detector with safeguard and nonproliferation applications
- 100-kT WbLS could reach the pDK^+ sensitivity in 10-yr run
- DUSEL could be the ideal location.









Summary

- First milestone of developing a new WbLS detection medium as energy spectrometer
  - Stability is demonstrated
    - Samples of W-LS have been stable (~2 yrs) since preparation
  - It's lighting
    - but need to understand its light-transfer mechanism
  - decay is fast
    - few ~ns at region of interest for PDK+
  - optical-transmission is tough
    - feedstock improved; in-lab scale achieved

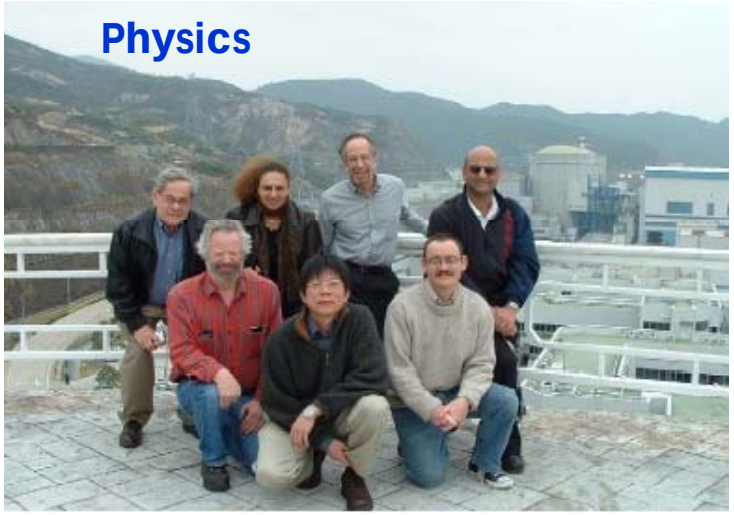
- Many applications with Large Physics (50 – 100 kT) feasibility
  - S% and $\lambda_{1/e}$ can be adjusted; depending on the physics

Next

- large-scale and on-line purification
  - develop techniques and possibly transfer to contractor
    - Got a better starting Material
  - can we run it at lower temperature to minimize the microorganisms?
- flours and shifters (organic and aqueous) optimization
- Light production and quenching effect (*dE/dx*)
  - cosmic muon run in Oct. 2011
  - proton beam at NSRL in Nov. 2011
- can we preserve the Cerenkov while scintillating?
  - Little scintillation not to overcome Cerenkov (5 p.e./MeV at 30%)
  - how scintillation affects the PID
- Neutron-tagging by adding metal (e.g. Gd) into the WbLS
  - IBD followed by Gd-capture sum of 8-MeV
- Material Compatibility Test
- A working group to focus on the physics of interests
  - distinguish k+ track with its subsequent decay
  - K's background by cosmic muon or atm. ν
  - absorption/re-emission
- Build a ton-scale WbLS demonstrator (reactor run)

Working forces...

- Minfang Yeh (PI)
- James Cumming (consultant)
  - Sunej Hans
  - Liangming Hu
  - Pankaj Sinha
  - Wanda Beriguete
  - Richard Rosero
  - Wai Ting Chan



Physics
- Milind Diwan
- David Jaffe
- Hide Tanaka
- Dana Beavis
- Lisa Whitehead
- Chao Zhang

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