THEIA – A Water Based Liquid Scintillator Detector

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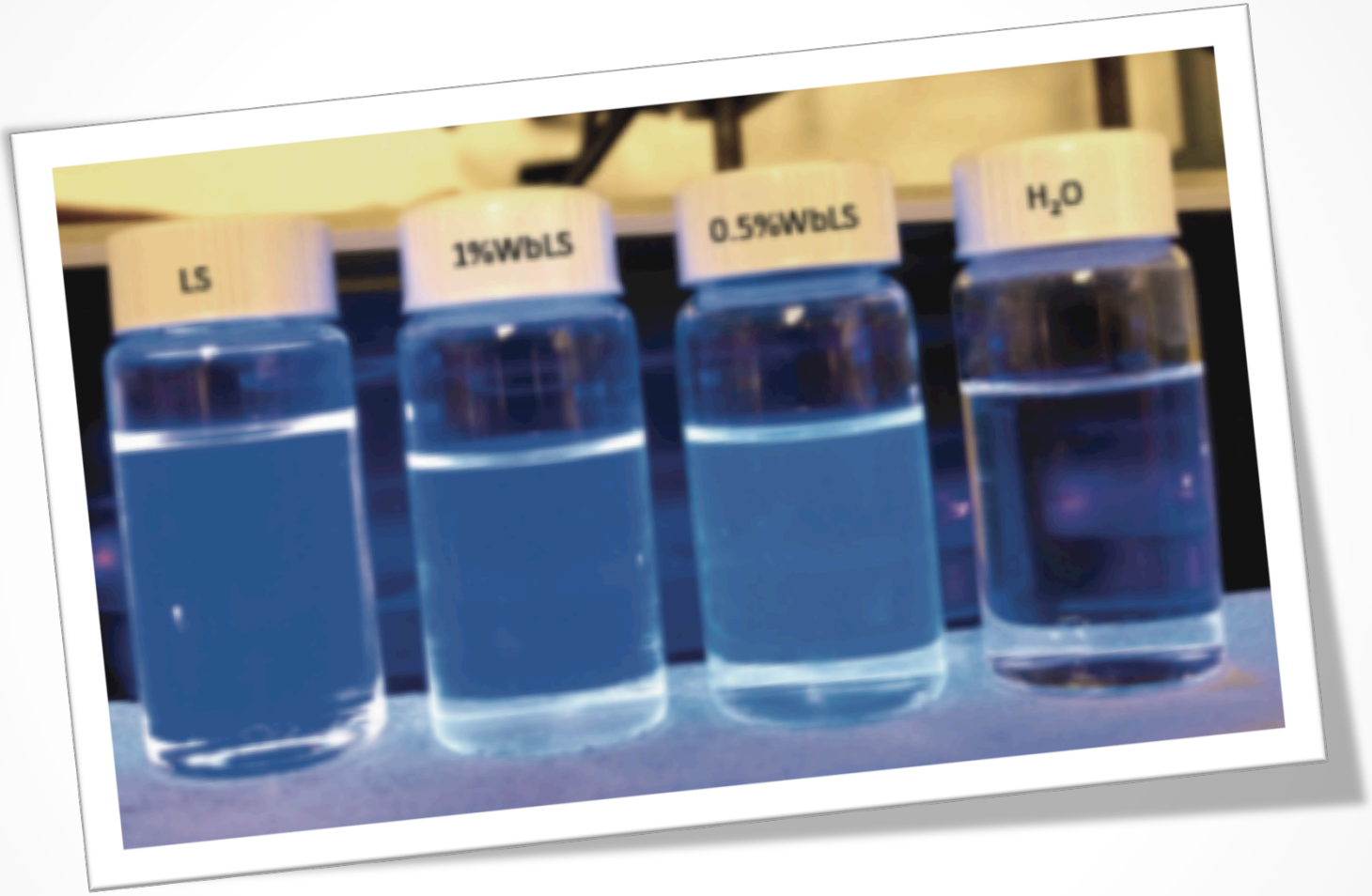
TAUP 2017

Content

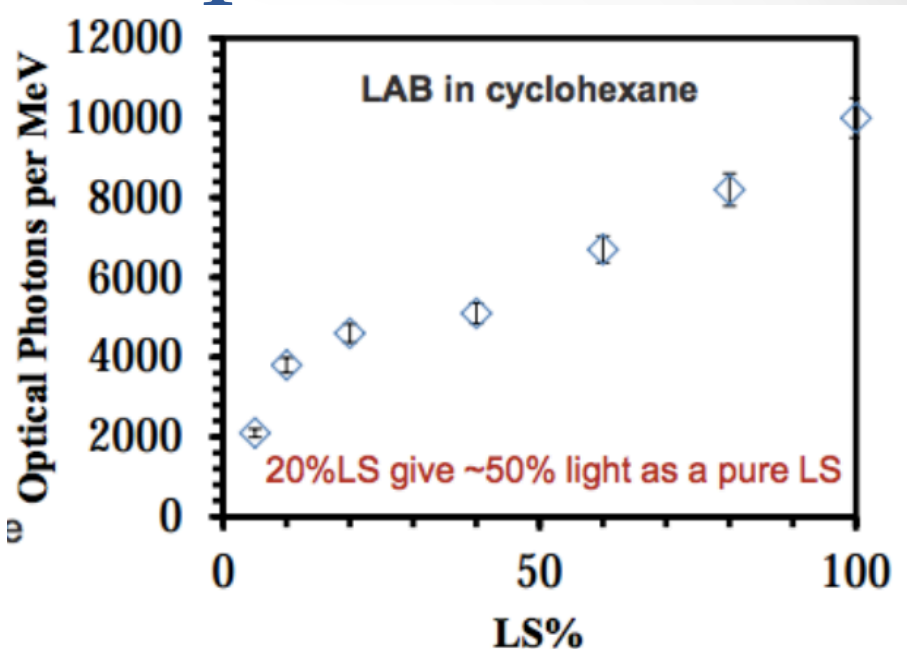
- Water based liquid scintillator (WbLS) concept.
  - What are the advantages of this novel medium?
- WbLS research and development.
  - Ongoing hardware and software development.
- Future physics potential.
  - What is THEIA and what can it do?

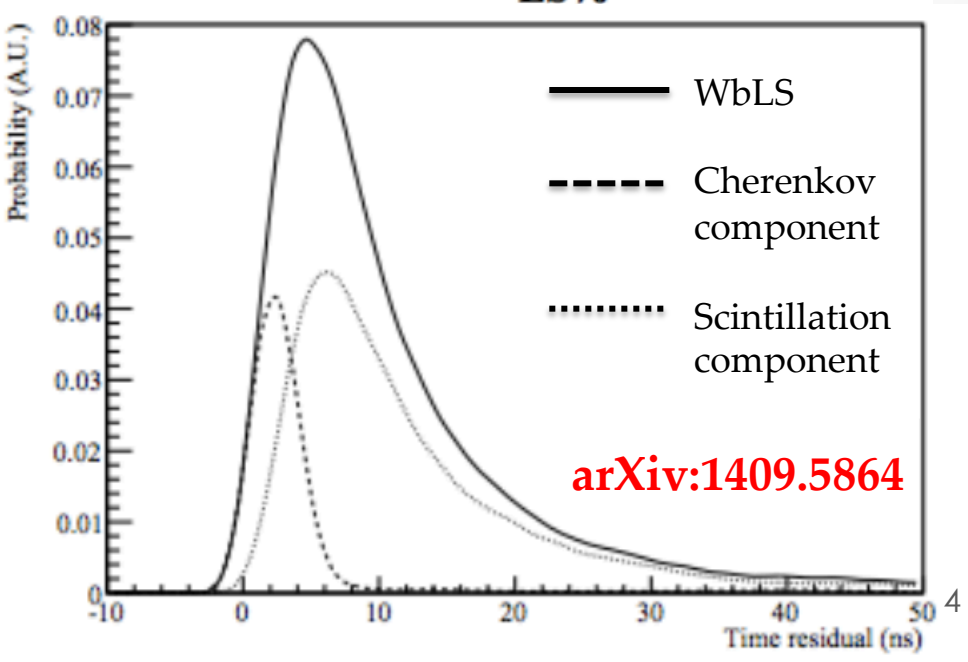
1. WbLS



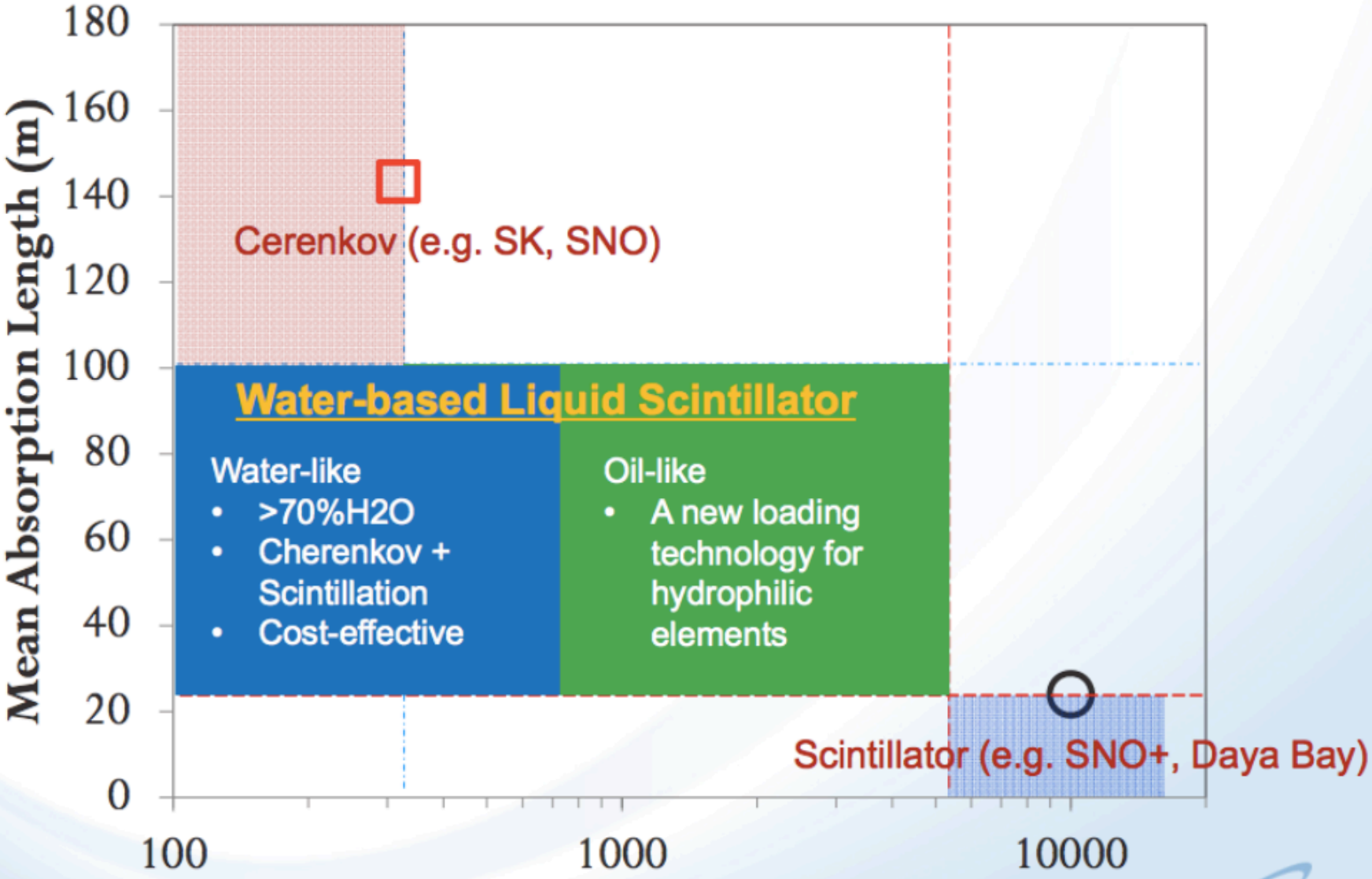
WbLS - Properties

- Simple mixture of oil and water
- Cost effective
- Environmentally friendly
- Non-linear light yield as function of scintillator percentage
- Benefits from characteristics of both scintillator and water:
  - Gives low energy threshold
  - Good energy resolution
  - Low absorption
  - Directional information
- Tunable timing profile to separate Cherenkov (fast and directional) and scintillation (slow and isotropic) light
- Loading of metallic ions possible

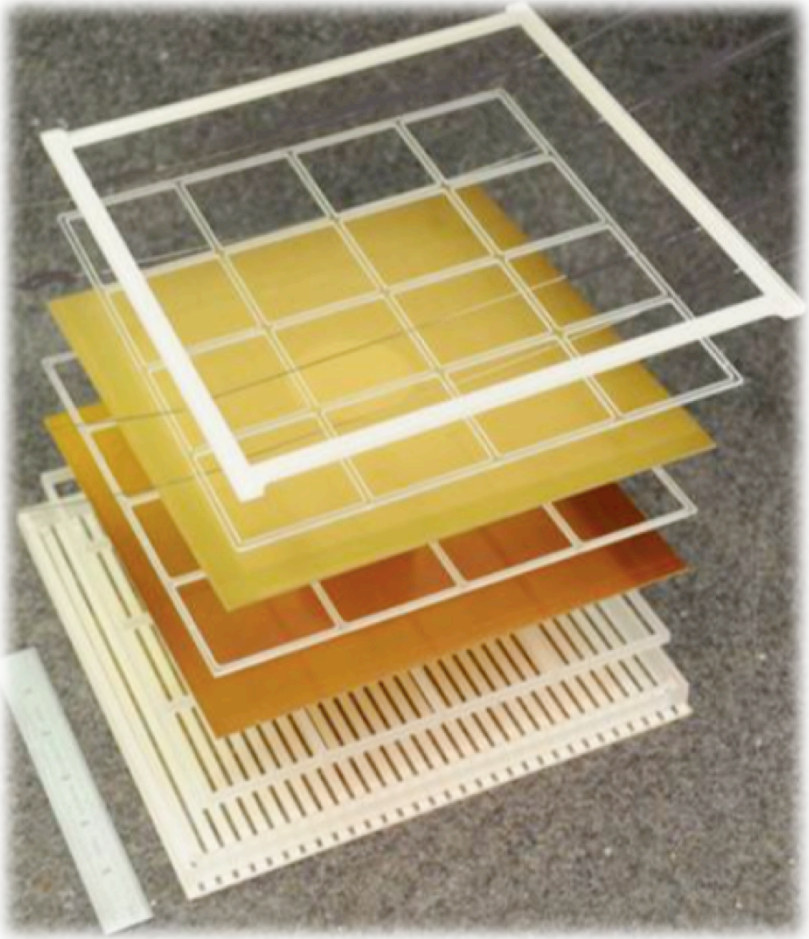




WbLS - Tunability



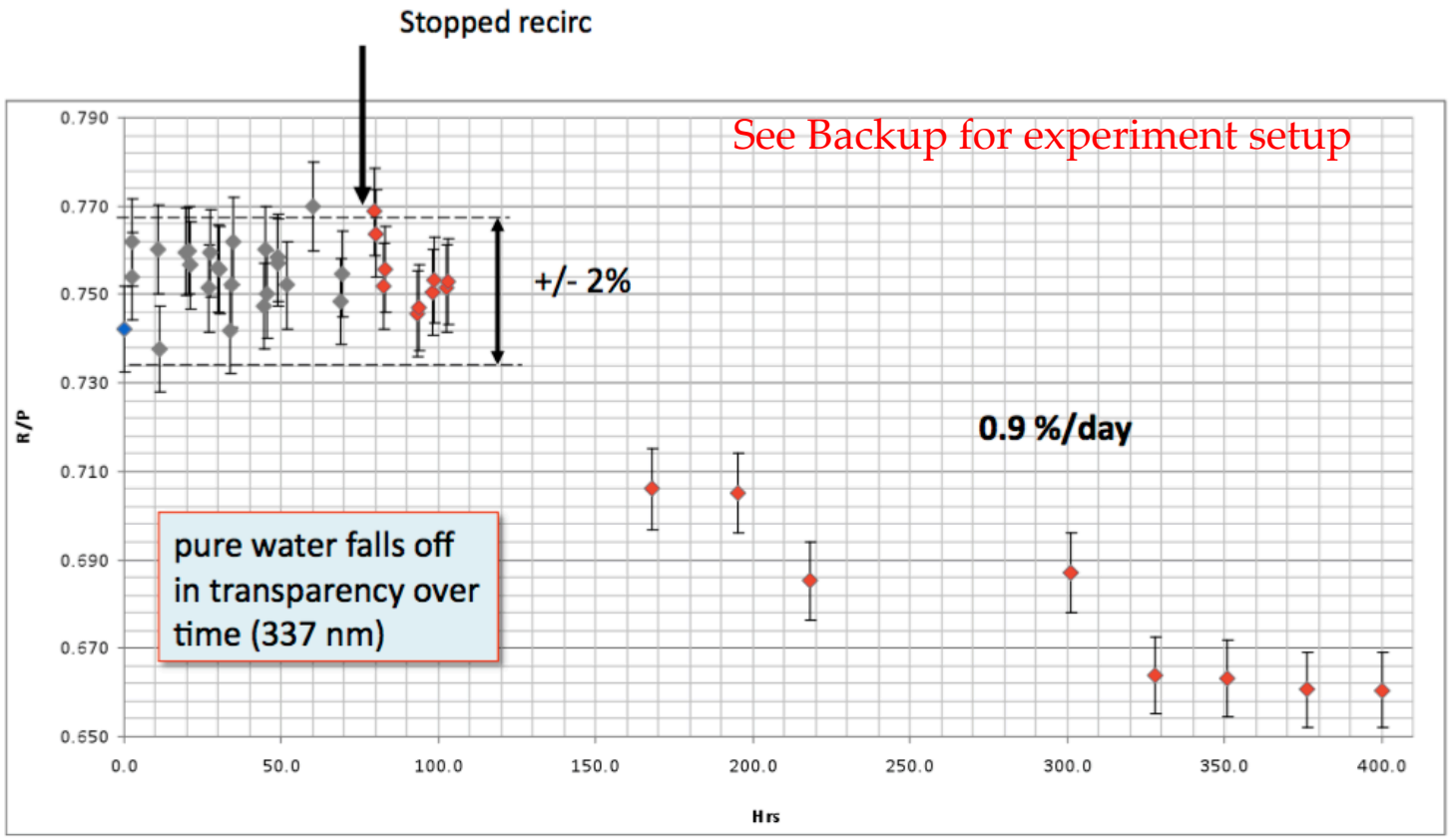
2. Ongoing research and development



Filtration

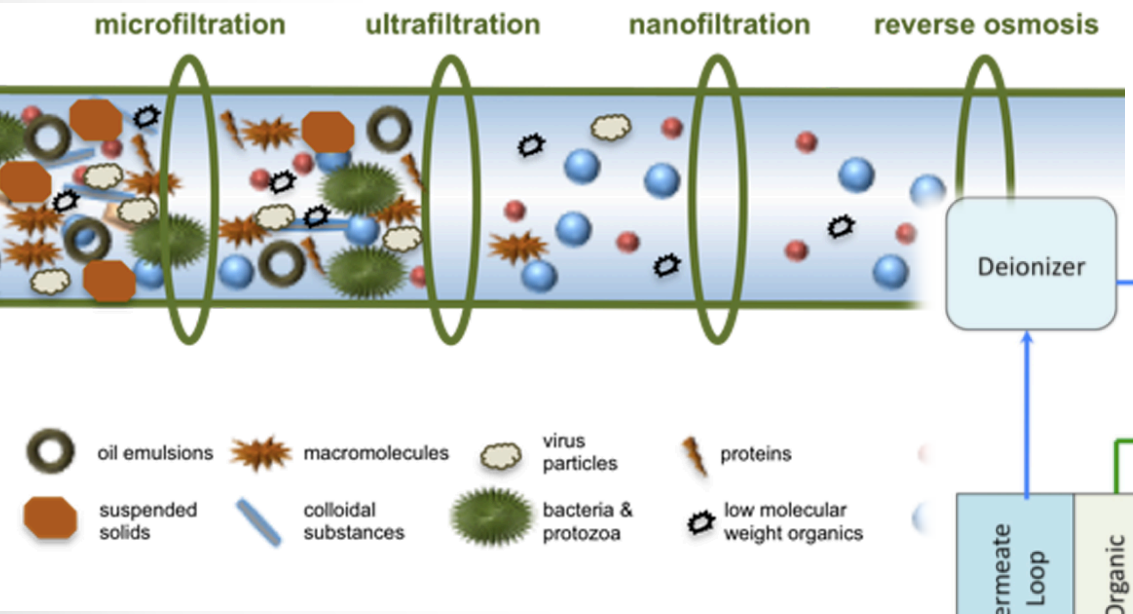
- A detector using WbLS will need to undergo purification.
- Why?

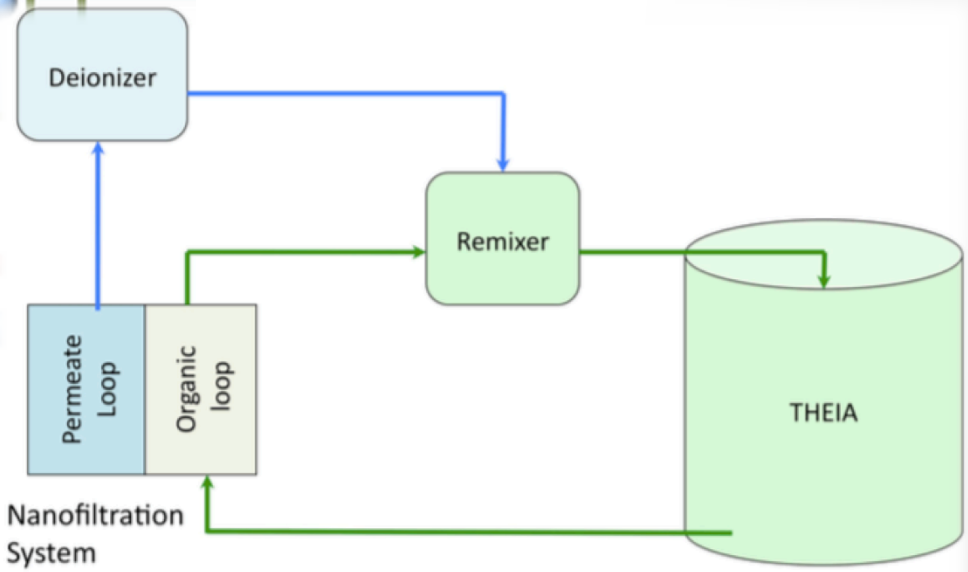
  Over time water loses its optical transparency due to interaction with stainless steel.



Nanofiltration

- To purify the water we must first separate it from the scintillator.
- The method needs to be scalable.
- The method must not damage the WbLS.
- Nanofiltration is a potential method.
  - This is used in the food industry to remove oils from water in order to decrease pollution.
  - Different nanofilter pore size can be used in order to optimise filtration.

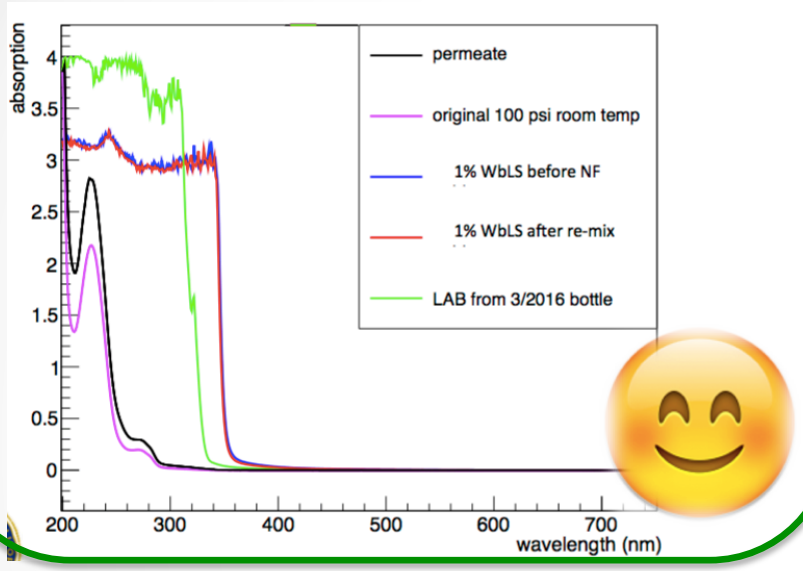




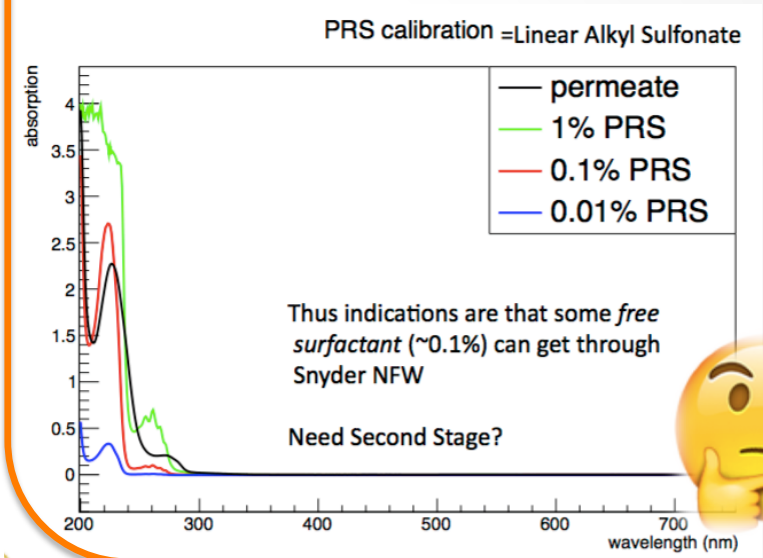
THEIA recirculation concept

Nanofiltration – effective, but with a potential issue?

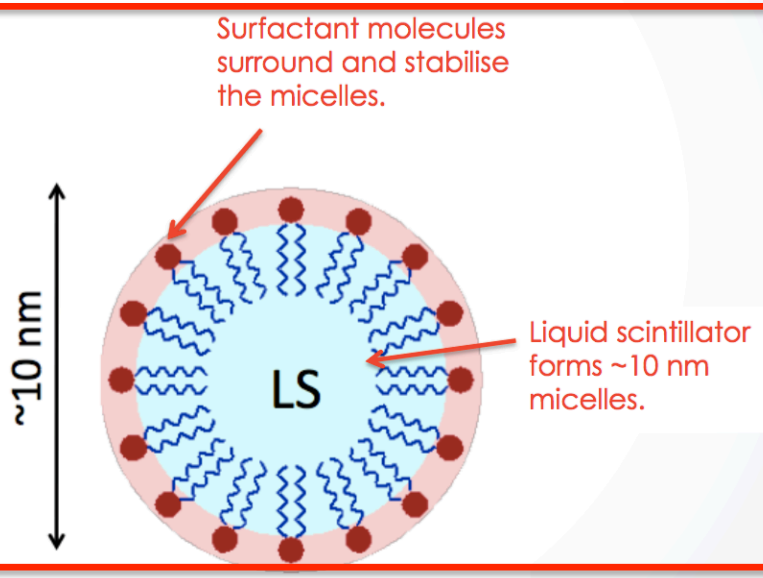
- Pre- and post-filtered WbLS show identical absorption spectra.



- Perhaps 0.1% surfactant passes through.

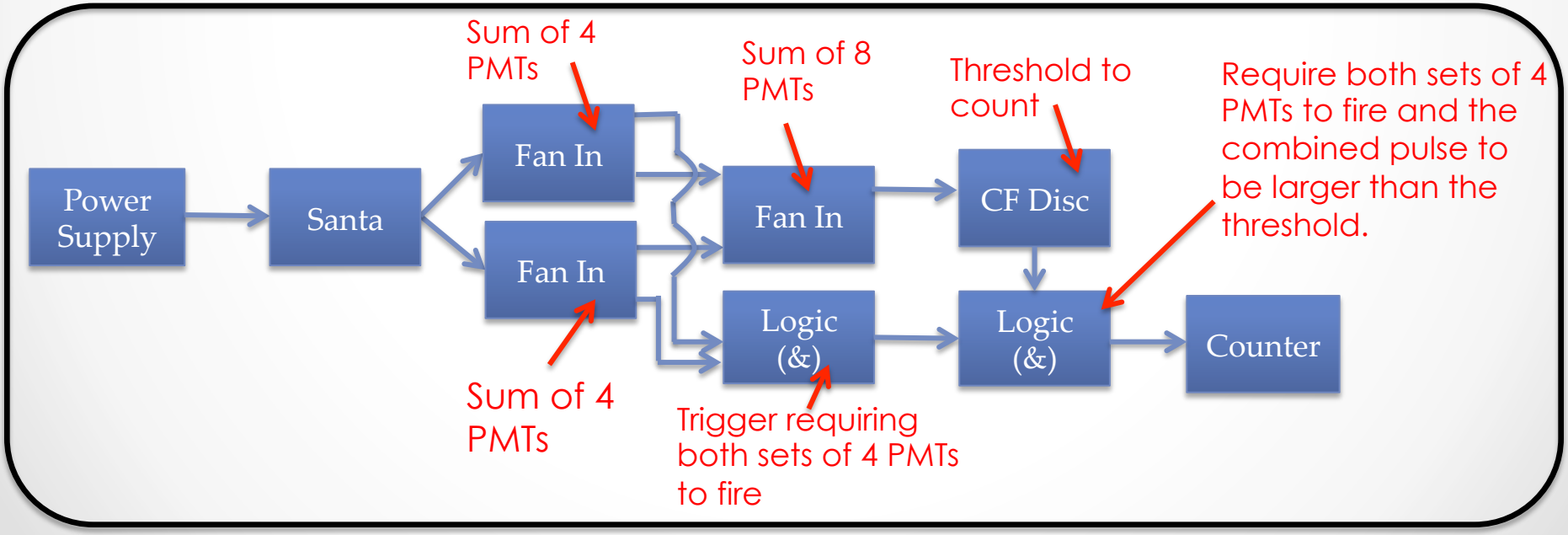


- Does nanofiltration damage the scintillator micelles?
- If so, the light yield will decrease.



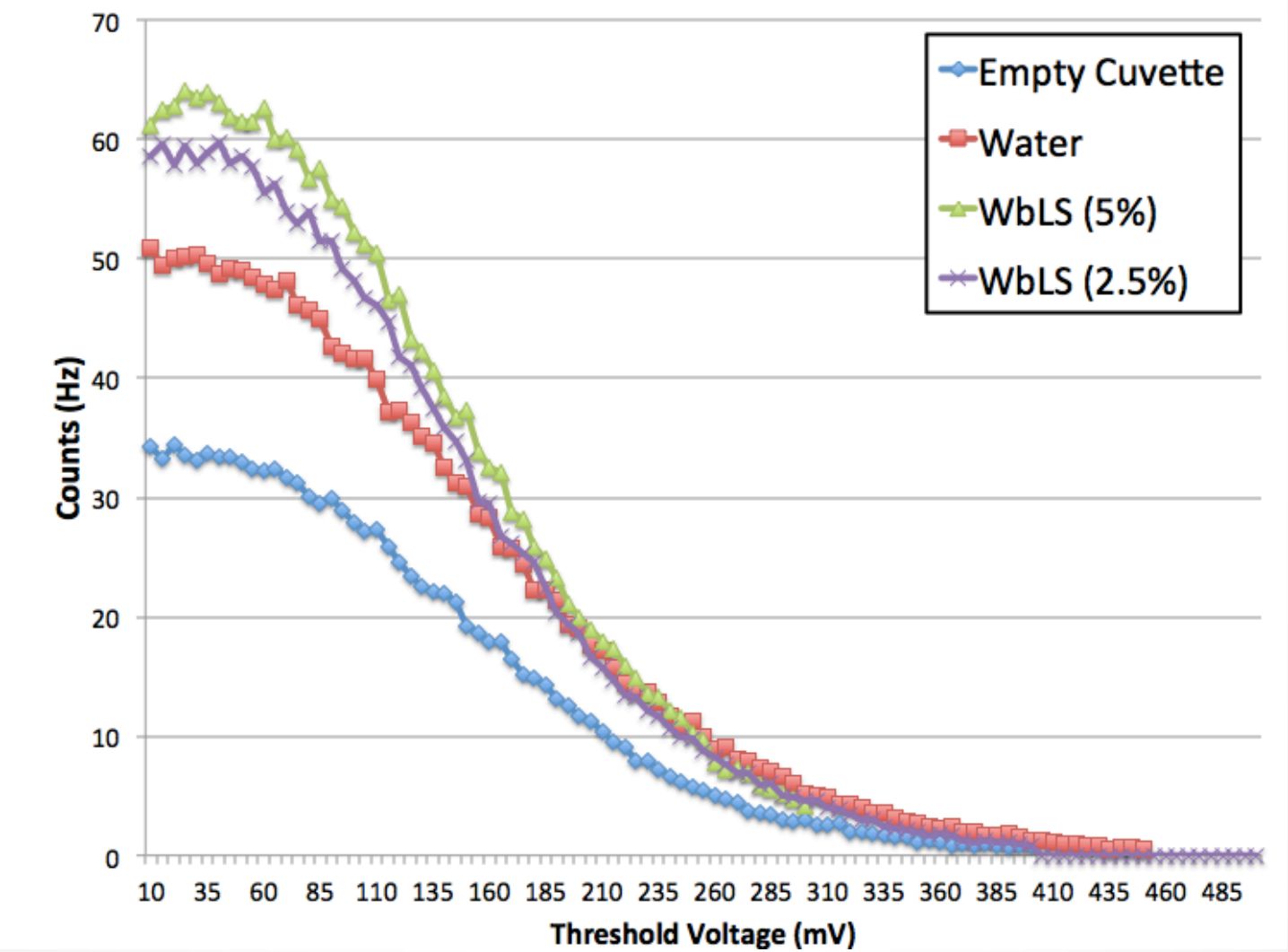
Light Yield Device - Santa

- Cylindrical Light Analyser Using Strontium (CLAUS, a.k.a. Santa).
- A light tight box lined with mylar.
- Sample is placed in the centre and is surrounded by 8 R928 side-facing Hamamatsu PMTs.
- Above the sample is a ^{90}Sr source; a β-emitter, with a maximum electron energy of 0.546 MeV.
- The emitted electron is then absorbed by the sample and the light yield can be determined.



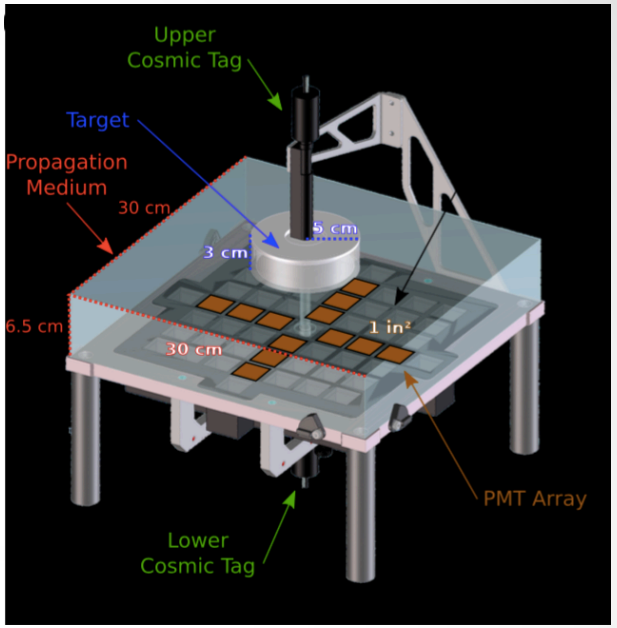
Santa setup and data acquisition

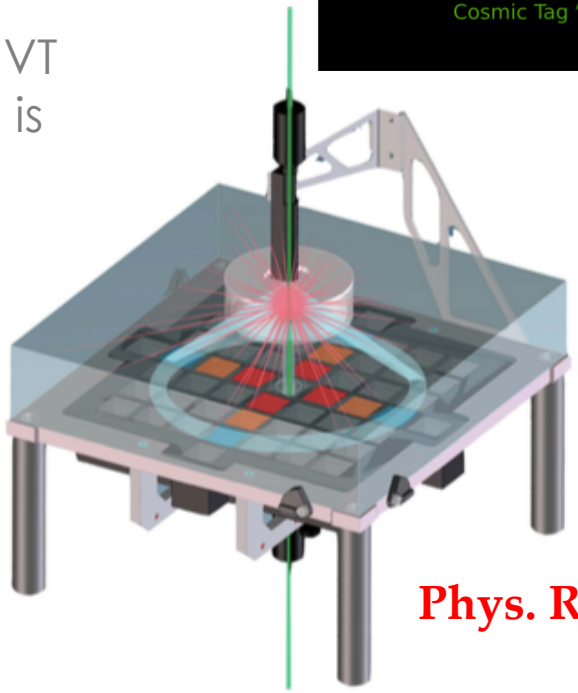
Santa - Results



CHESS – CHErenkov/Scintillation Separation

- Study of Cherenkov/Scintillation separation will provide invaluable information for THEIA:
  - WbLS target cocktail.
  - Photosensor requirements.
  - Detector scale.
- 12 ultra fast timing photosensors (Hamamtsu H11934-200 PMTs).
- Target vessel is a 5cm radius and 3cm high UVT acrylic cylinder.
- Target vessel optically coupled to UVT acrylic propagation medium which is itself optically coupled to the PMT array.
- Two cylindrical scintillator tags are positioned above and below the target vessel to trigger on vertical cosmic ray muons.
  - Known orientation of events.
  - Expect ~4 muons per day.

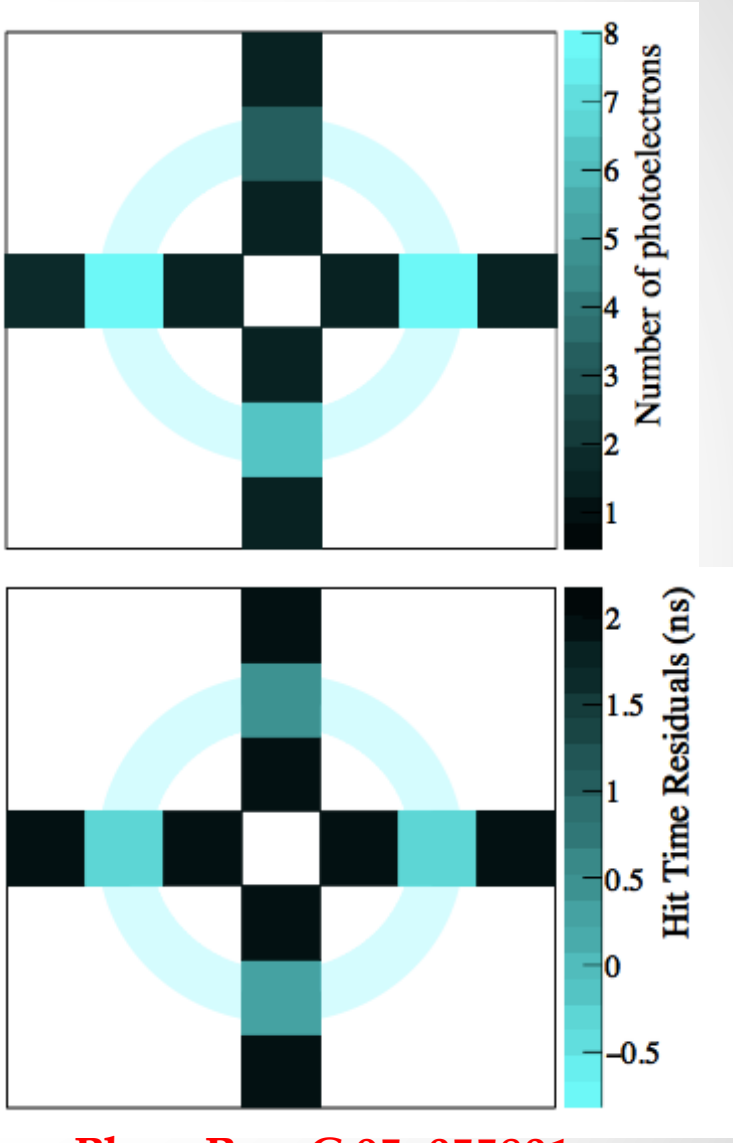




Phys. Rev. C 95, 055801

CHESS – Capabilities and Future Work

- Clear Cherenkov rings seen on an event by event basis.
- Time resolution demonstrated to the sub-ns precision required for Cherenkov/ scintillation separation (338±12 ps).
- With this time-resolution, impressive separation of Cherenkov light from scintillation light (with low scintillation contamination).
  - LAB
    - Time based separation - 83±3% separation with 11±1% contamination.
    - Charged based separation – 96±2% separation with 6±3% contamination.
  - LAB/PPO
    - Time based separation - 70±3% separation with 36±5% contamination.
    - Charged based separation – 63±8% separation with 38±4% contamination.

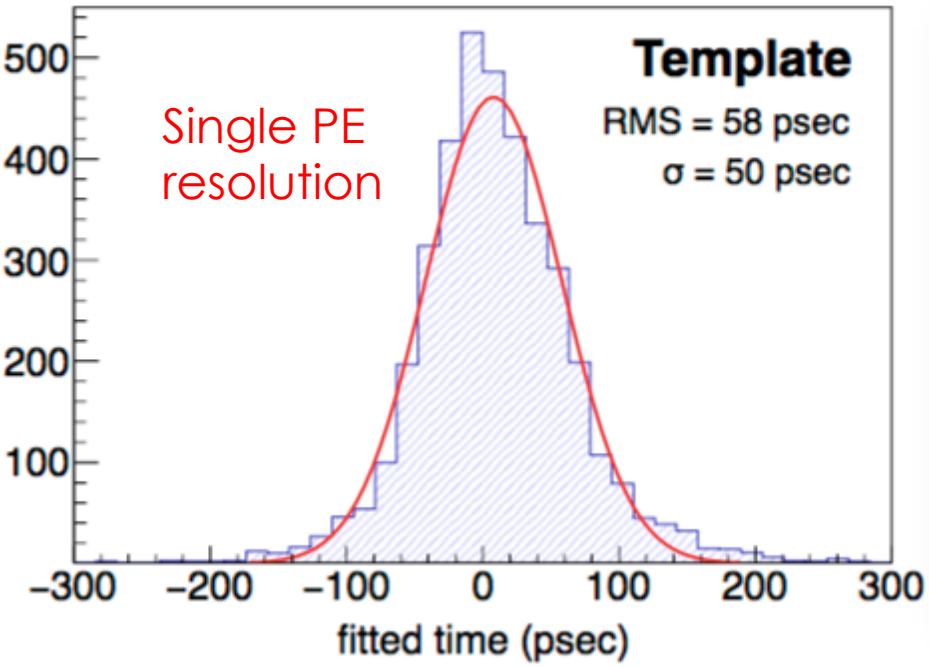


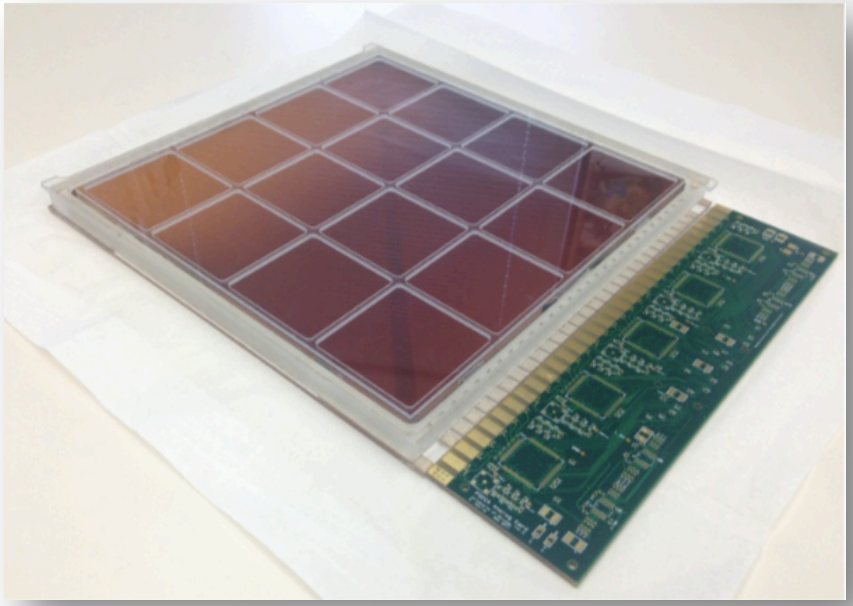
Phys. Rev. C 95, 055801

arXiv:1610.02011v1

LAPPDs

- Large Area Picosecond Photodetector
- Gain – $>10^7$
- Exceptional single PE timing resolution – 50ps.
- Excellent spacial resolution – 1mm.
- Currently commercialised by Incom Inc.



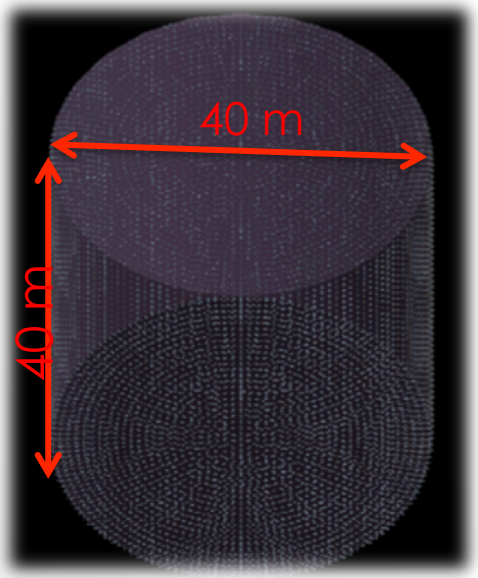


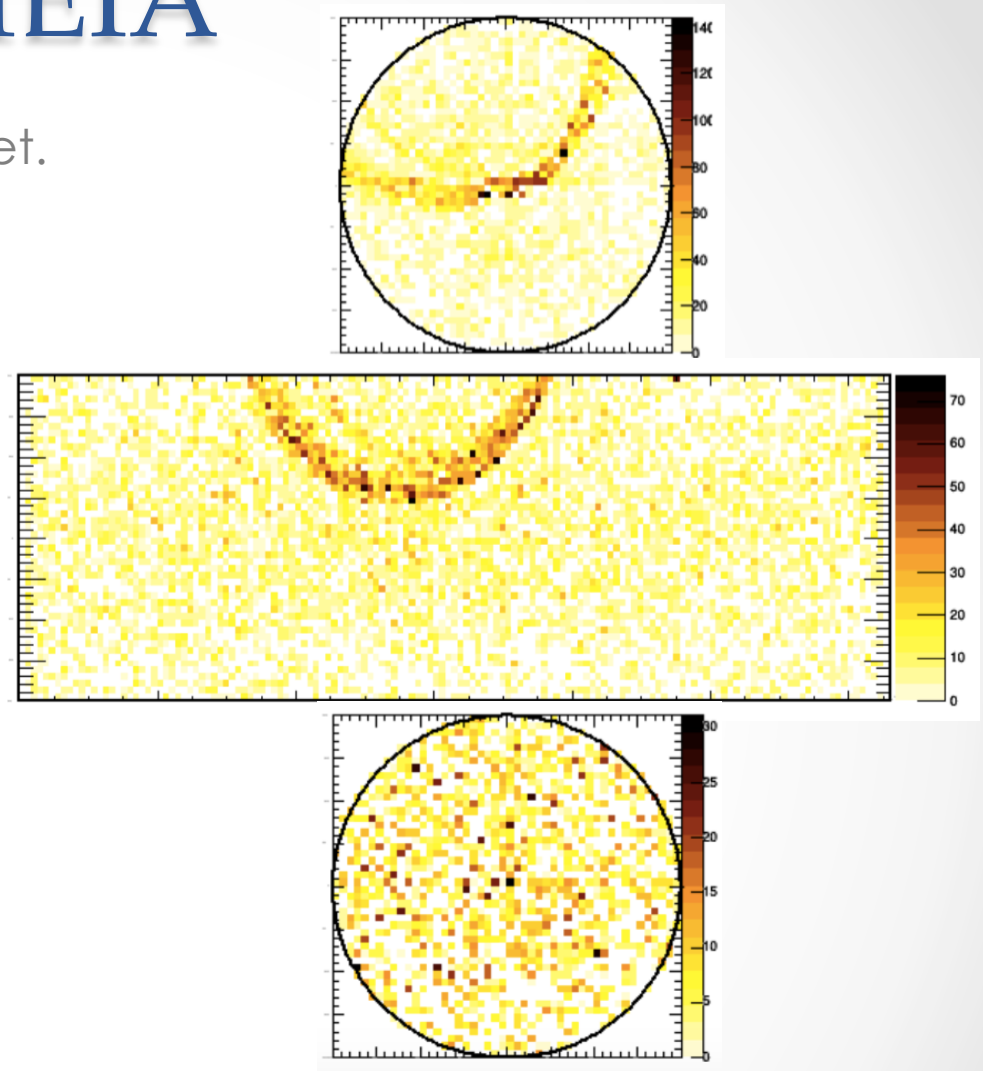
- **Nucl. Instrum. Methods A. 795 (2015)**

4. THEIA

THEIA

- THEIA is a proposed large scale detector (50 kton) with a WbLS target.
- Aims to use fast, high-efficiency photodetectors, with high photocoverage.
  - Either fast timing PMTs, LAPPDs or a combination of both.
- Would ideally be placed deep underground.
- Isotope loading is possible.

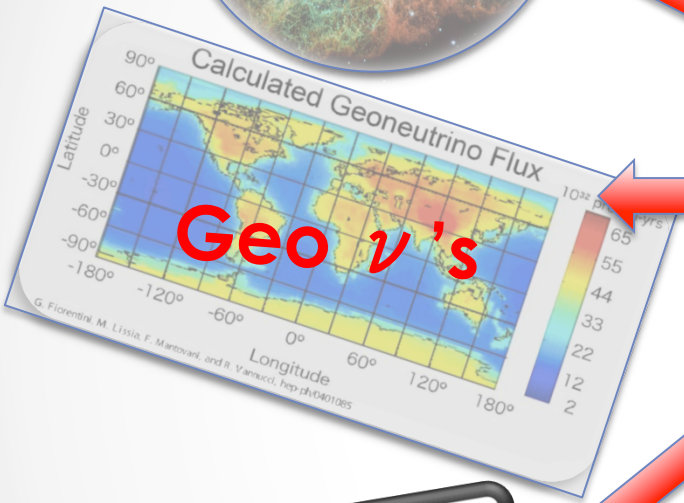




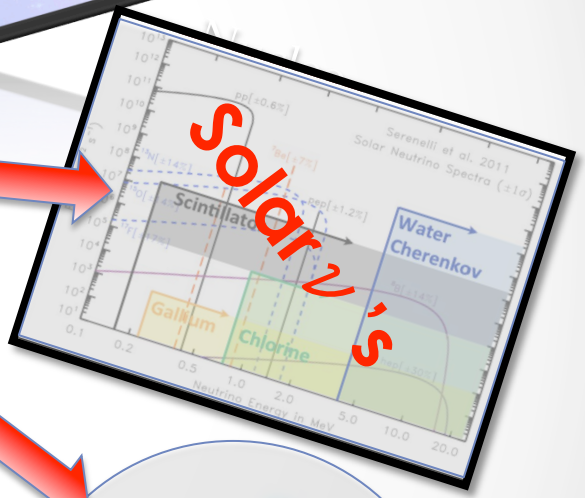
Simulated Numu CC Quasi-Elastic interaction. The Cherenkov ring can be seen clearly over the homogenous scintillation light.

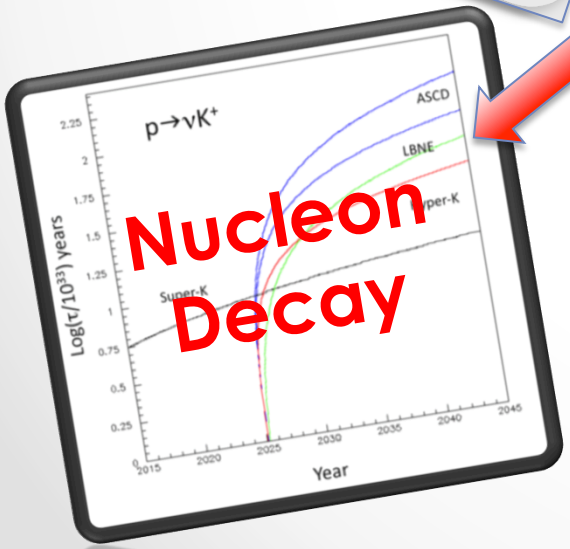
THEIA – Physics Reach

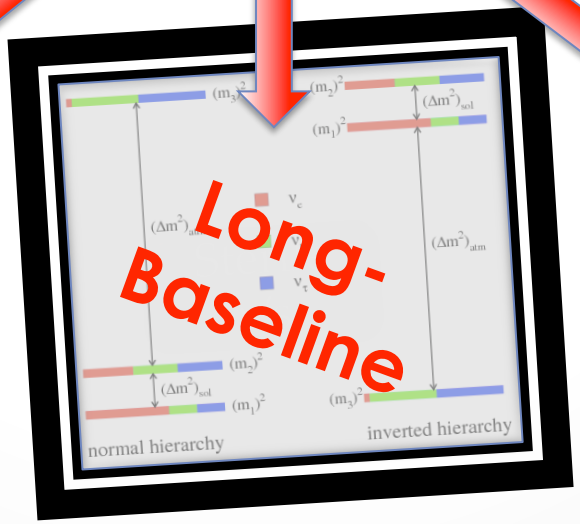
For an in depth review of all: arXiv:1409.5864

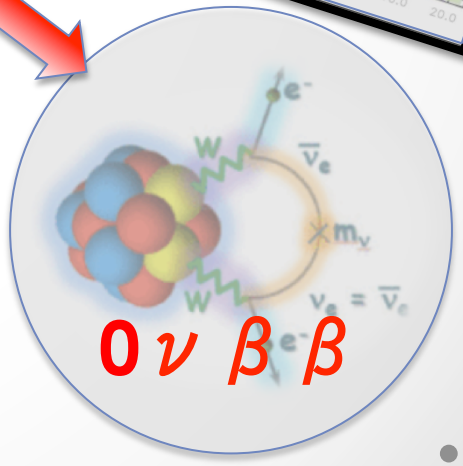


THEIA



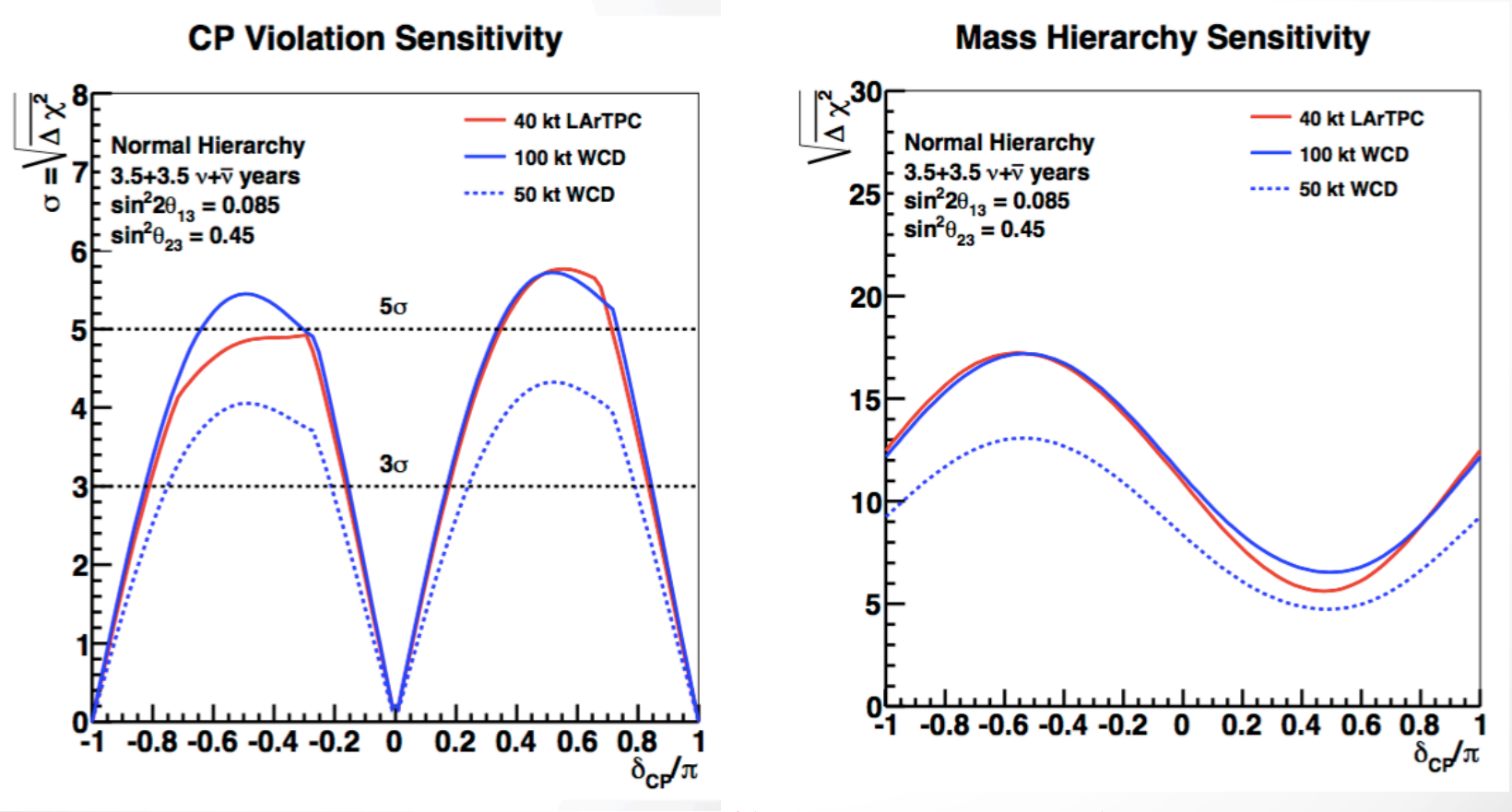






THEIA – Long-Baseline Reach

- Large detector in the LBNF beam, complementary to the LArTPC programme.
- Below shows the complementarity of a water Cherenkov detector alongside LAr. However, THEIA, using WbLS, will be even more effective.
  - Improved background reduction due to improved photodetector timing and utilisation of below Cherenkov threshold scintillation light.



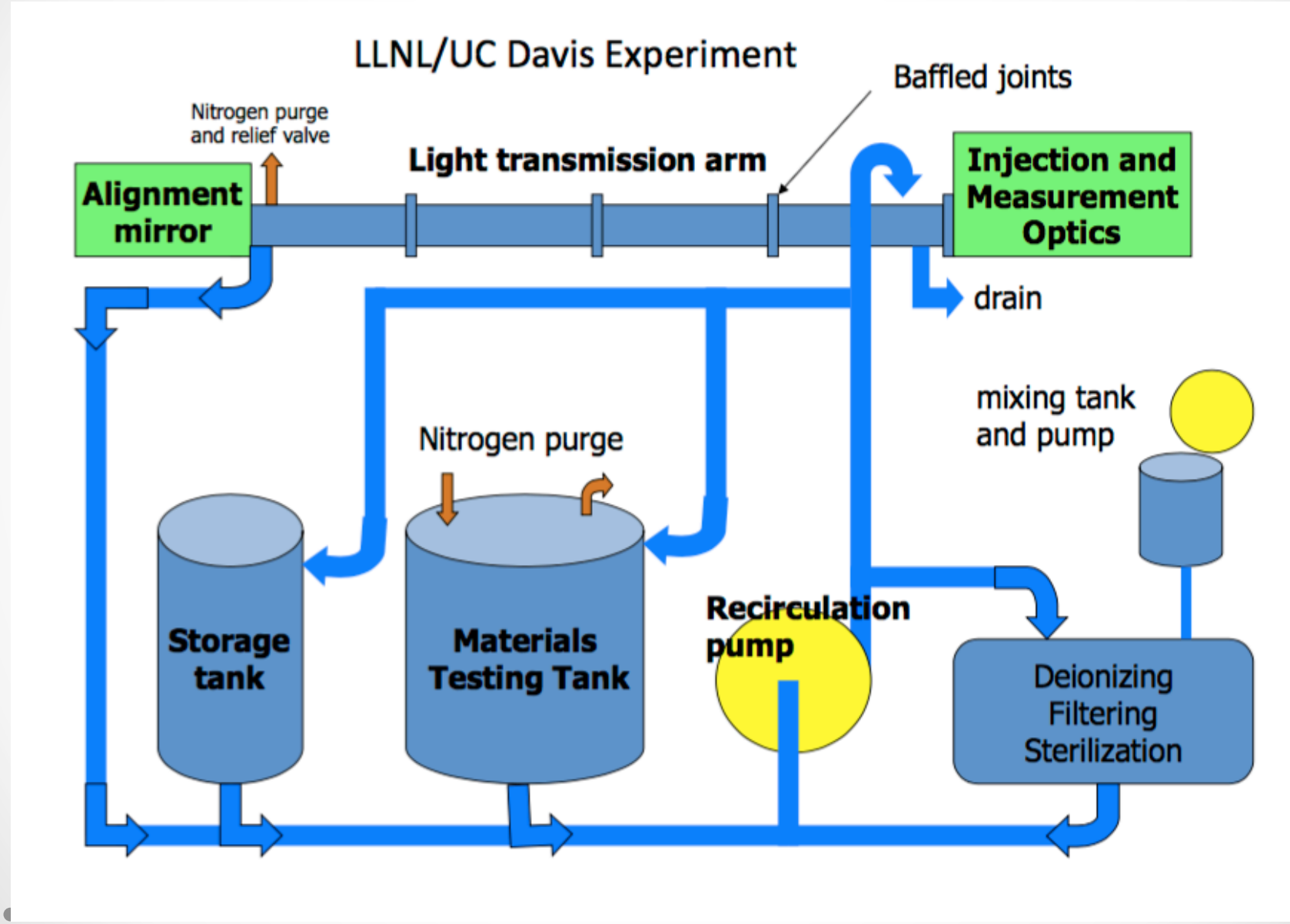
E. Worcester – "WCD-Like" Detectors and DUNE Long-Baseline Neutrino Oscillation Physics

Conclusions

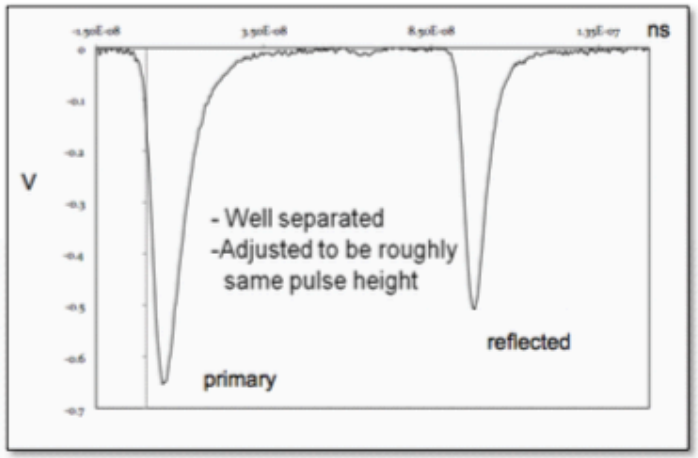
- WbLS is a cost effective, highly tunable, novel medium benefitting from the characteristics of both scintillator and water:
  - Gives low energy threshold
  - Good energy resolution
  - Low absorption
  - Directional information
- Much research is ongoing into the potential of WbLS and how it can be implemented into THEIA.
- The physics reach of THEIA is extrordinary; offering world leading measurements in a wide range of fields:
  - Supernova neutrinos
  - Sterile neutrinos
  - Solar neutrinos
  - Geo neutrinos
  - Nucleon decay
  - Long baseline measurements
  - Neutrinoless double beta decay

Backups

Optical Transparency Measurement - Setup



Optical Transparency Measurement - Setup



The ratio of outgoing and return pulse (ρ) changes linearly with transparency