Cherenkov/scintillation separation and performance of water-based liquid scintillator detectors

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Introduction

Goal

Characterize water-based liquid scintillators and estimate performance in large-scale detectors, between 1 and 100 kilotonnes.
By exploiting the separation of Cherenkov and scintillation, we seek to enable a novel hybrid optical detector with unprecedented sensitivities for measurements in neutrino physics and rare-events searches.

Analysis flow

Water-based liquid scintillator characterization
- Scintillation light yield
- Emission time profile with betas and X-rays
- Emission spectra

→ Construction of Monte Carlo model → Cherenkov/scintillation separation at small scale using muons → Prediction of impact in large-scale detectors

→ Validation of Monte Carlo model → Prediction of impact in large-scale detectors

Why separating Cherenkov and scintillation light?

Cherenkov

Provides particle direction and particle identification capabilities (mainly electrons vs muons) at the cost of a poor energy resolution (~15% at 5MeV) and an energy threshold of a few MeV.

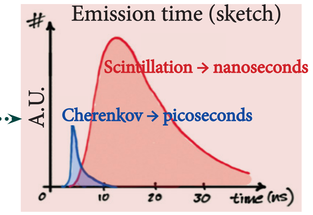
Scintillation

Provides good energy resolution (typically 5% at 1MeV), very low energy threshold (hundreds of keV), good position resolution and particle identification capabilities (mainly alphas vs betas).

Cherenkov&Scintillation

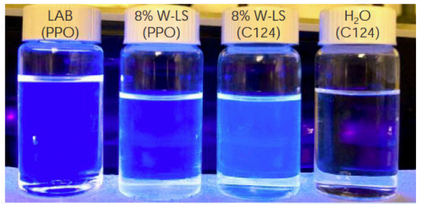
Good energy resolution, low energy threshold and direction reconstruction in the same detector, with an improved particle identification.

Cherenkov light yield is orders of magnitude smaller than scintillation light yield. A promising technique to separate them is exploiting the **different emission times**, (demonstrated in [1,2]) combined with the topology information.



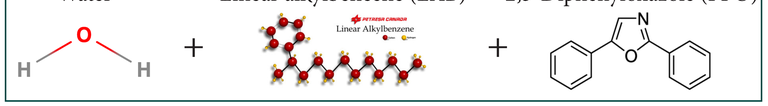
What are water-based liquid scintillators (WbLS)?

Mixtures of liquid scintillator in water, allowing for different scintillator cocktails and concentrations [3]:
- Almost water-like transparency, so allows construction of tens of kilotonnes detectors
- Tunable scintillation properties



This work uses a WbLS version with:

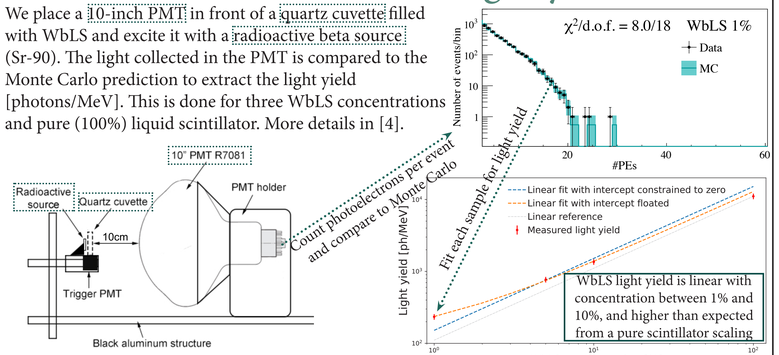
Water + Linear alkylbencene (LAB) + 2,5-Diphenyloxazole (PPO)



Measurements

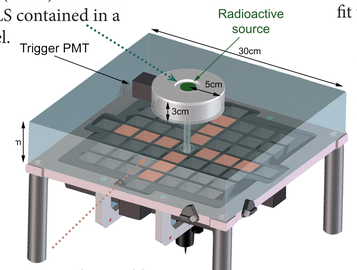
WbLS scintillation light yield

We place a 10-inch PMT in front of a quartz cuvette filled with WbLS and excite it with a radioactive beta source (Sr-90). The light collected in the PMT is compared to the Monte Carlo prediction to extract the light yield [photons/MeV]. This is done for three WbLS concentrations and pure (100%) liquid scintillator. More details in [4].



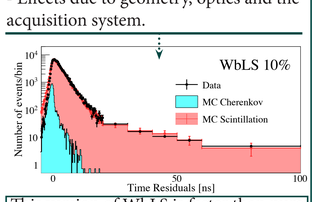
WbLS emission time profile

A beta emitter (Sr-90) is used to excite the WbLS contained in a cilindical vessel.



The emitted photons are detected by an array of 1-inch PMTs and the single photoelectron times with respect to the trigger time are computed.

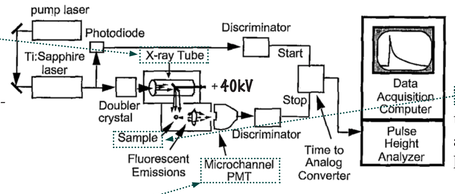
Single photoelectron time distributions are fit to the Monte Carlo, which includes:
- Scintillation time profile: double exponential decay plus a rise time
- Effects due to geometry, optics and the acquisition system.



This version of WbLS is faster than pure liquid scintillator.
Our model fits the data well and we refer to [4] for the fit results.

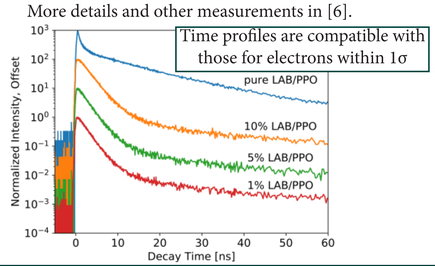
X-ray characterization of WbLS

We produce a beam of ~40keV XRays with a pulse width of 100ps FWHM. This provides a complementary source different from the betas.

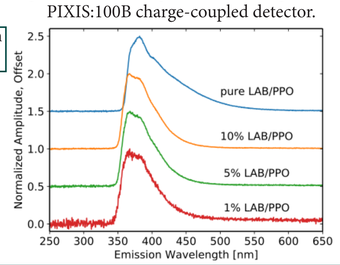


WbLS samples contained in quartz vials are excited and scintillation light produced.

Single photoelectron time distributions are recorded using an MCP-PMT for further analyis. More details and other measurements in [6].



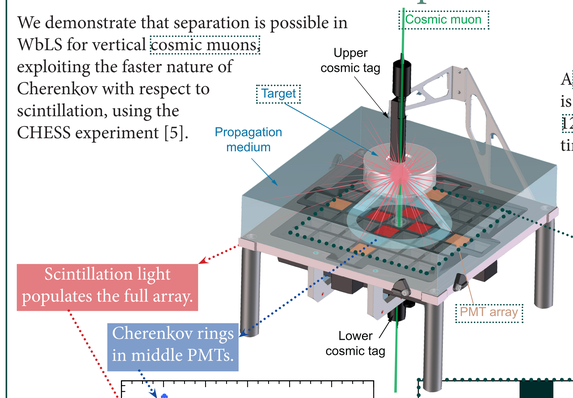
Emission spectra were obtained using a SpectraPro-2150i spectrometer coupled to a PIXIS:100B charge-coupled detector.



Performance

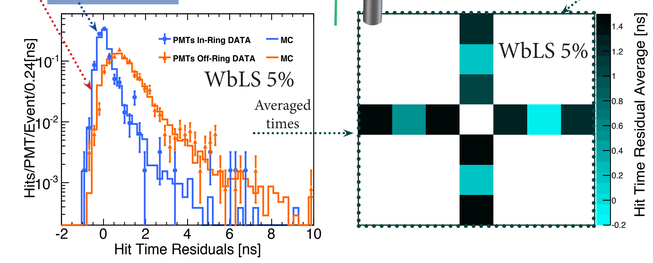
Cherenkov/scintillation separation at small scales

We demonstrate that separation is possible in WbLS for vertical cosmic muons, exploiting the faster nature of Cherenkov with respect to scintillation, using the CHESS experiment [5].



A target filled with WbLS is observed by an array of 12 1-inch PMTs with a time resolution of 130ps at 1σ

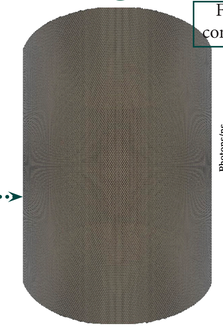
We image Cherenkov rings in WbLS using the PMT time information. More details in [4].



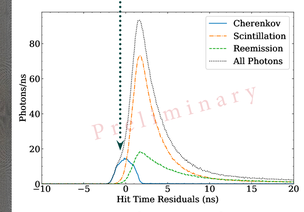
Prospects for large scale detectors

We predict performance of large scale detectors like THEIA [7] using our WbLS model.

We explore a number of different configurations varying detector size, photosensor time resolution and WbLS cocktail. This is a specific example simulated with the RAT-PAC toolkit [8]:
- 50 kilotonnes (38m height)
- 90% optical coverage
- 60ps time resolution and ~30% quantum efficiency [9]
- WbLS 5%



For 2.6MeV electrons, the Cherenkov component is clearly visible at early times



A paper with a comprehensive analysis including impact on detector capabilities is under preparation.

Acknowledgments

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