Spectral Sorting of Photons Using Dichroic Winston Cones

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Next Generation Nucleon Decay and Neutrino Detectors (NNN) 2018

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Overview

- Motivation
- Introduction to dichroic Winston cones
- Preliminary data
- Conclusion and future prospects

Motivation

- Next generation liquid scintillator neutrino detectors hope to have achieve both a high light yield and direction reconstruction
- Separation of scintillation and Cherenkov light would improve particle ID, background rejection, solar neutrino sensitivity
- Actively investigated for experiments like THEIA, SNO+, JUNO
- Techniques include water-based liquid scintillator, slow scintillator, fast PMTs, LAPPDs, Quantum Dots, Red Sensitive PMTs, etc. [1] [2] [3]
- *How to separate Cherenkov from scintillation light without losing photons?*

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[1] J Cavacara et al. (2017). arXiv:1610.02011 [physics.ins-det]
[2] M. Li et al. (2015). arXiv:1511.09339 [physics.ins-det]
[3] A. Elagin et al. (2016) arXiv:1609.09865 [physics.ins-det]

Introduction To Dichroic Winston Cone

- Take advantage of broad wavelength spectrum of Cherekov light and narrow spectrum for scintillation light
- Short wavelength Cherenkov light will be absorbed and re-emitted by the scintillator, but long wavelength light will reach the PMTs without ever being absorbed
- Use two or more types of PMTs each sensitive to different wavelength regimes
- Use a Winston cone made of dichroic filters to focus the light toward the PMTs with higher detection efficiency for the given wavelength
- Winston Cones used by SNO+ and Borexino to increase light collection by more than a factor of 2 for a fraction of the cost of more PMTs
- Dichroic filters studied for neutrino detectors: ARAPUCA design for DUNE, photon traps for Hyper-K [4] [5]
- *Use dichroic winston cones to sort photons by their wavelength and separate Cherenkov from scintillation light without losing photons!*

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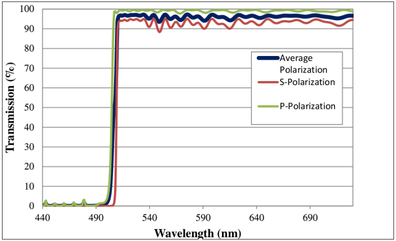
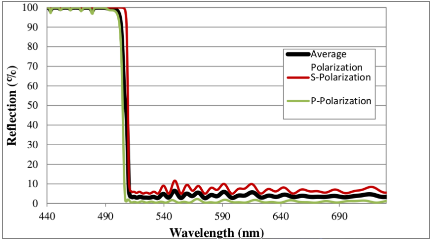
[4] G. Cancelo et al. (2018). arXiv:1802.09726 [physics.ins-det]

[5] C. Rott et al. (2017). arXiv:1708.01702 [astro-ph.IM]

Dichroic Filters

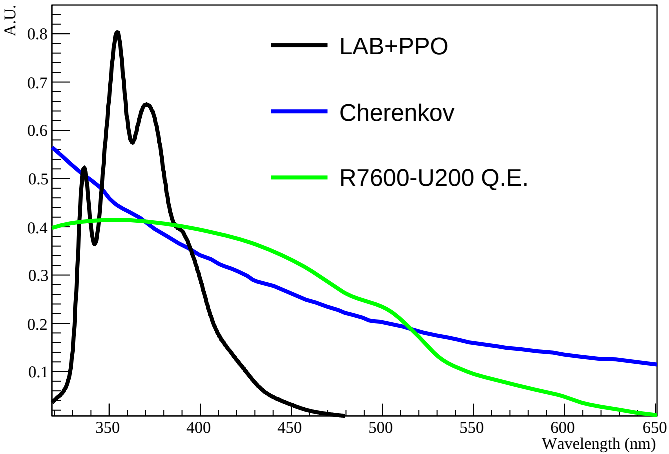
Transmit above ‘cut-on’ wavelength and reflect below. Minimal absorption.



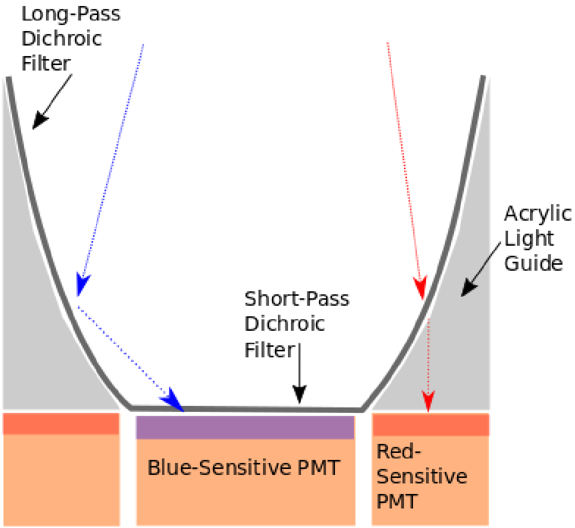


*Data from Edmund Optics

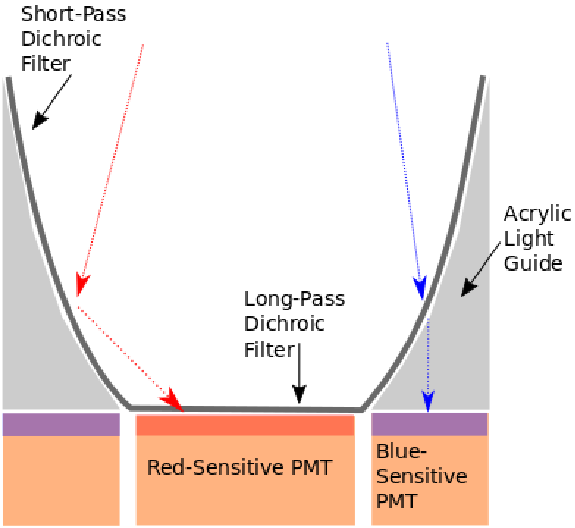
Emission Spectrum



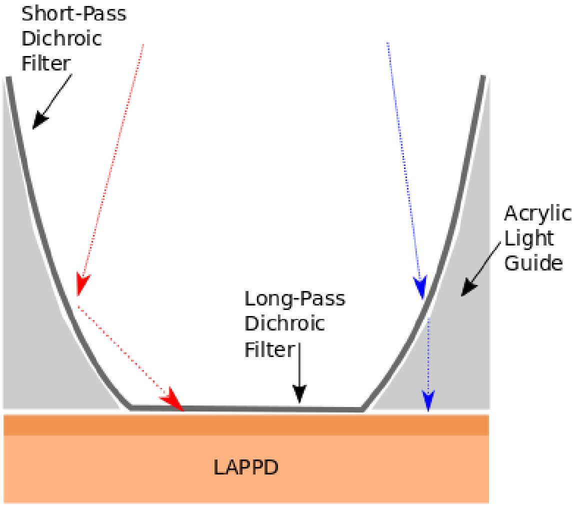
Basic Design



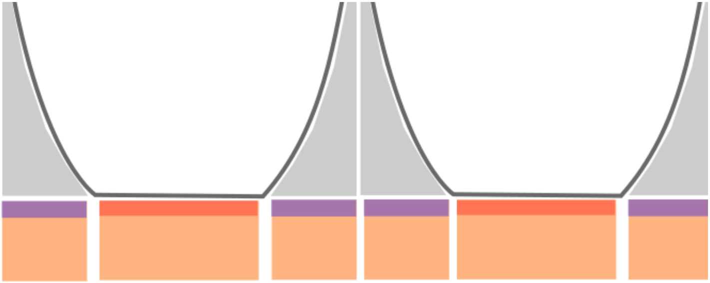
Basic Design



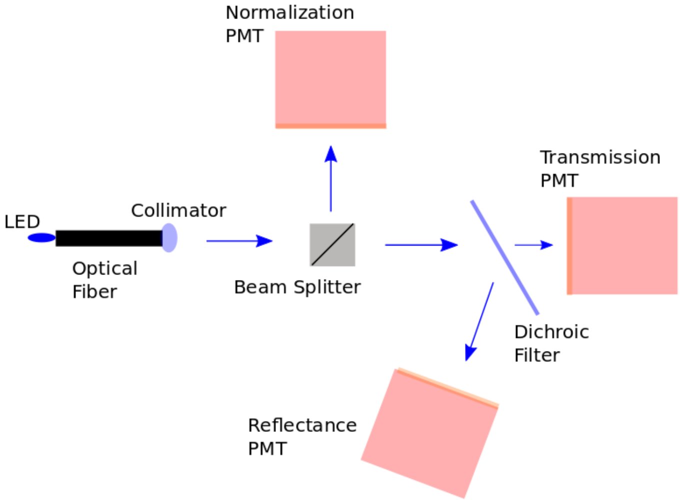
Basic Design



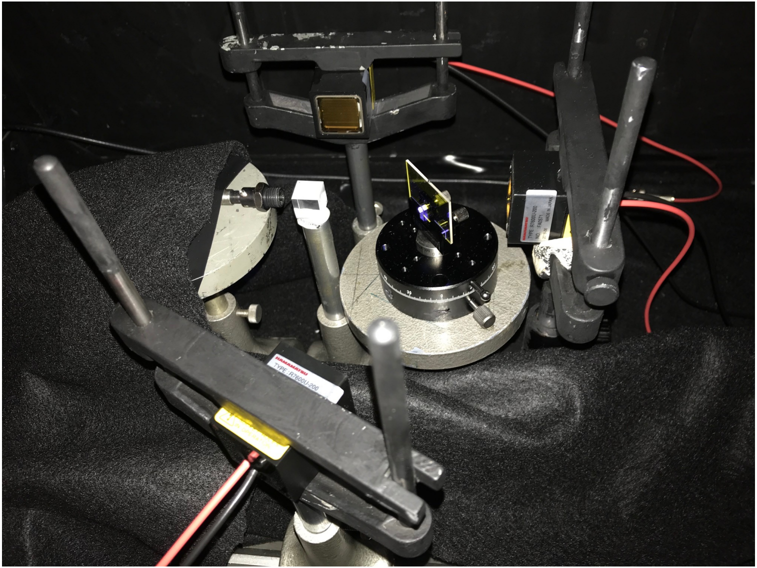
Basic Design



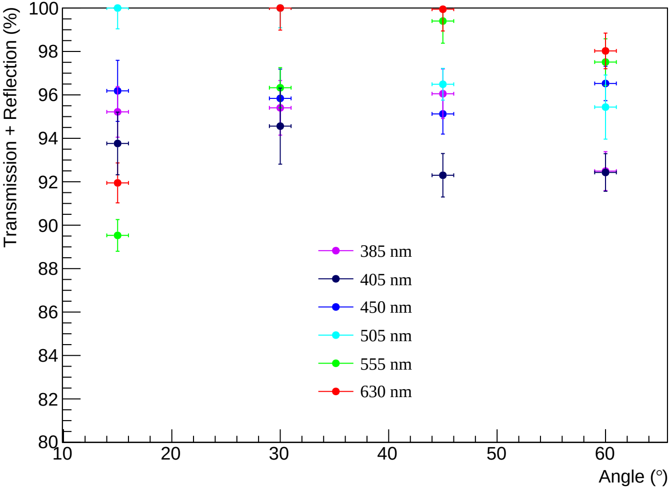
Testing Filters



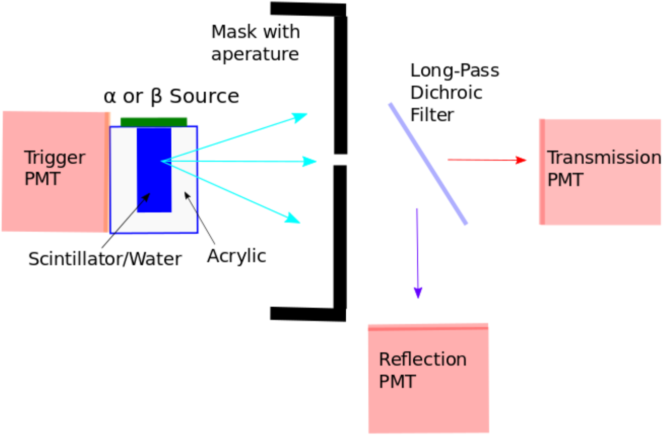
Testing Filters



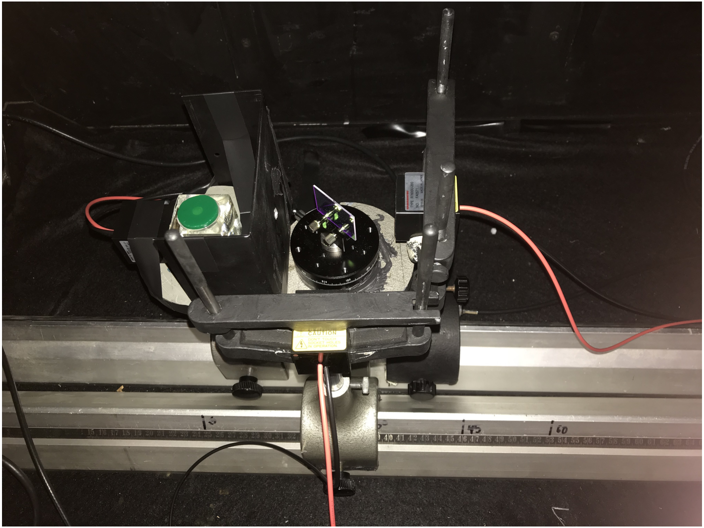
Sum: 506 nm Short-Pass



Cherenkov/Scintillation Separation Setup

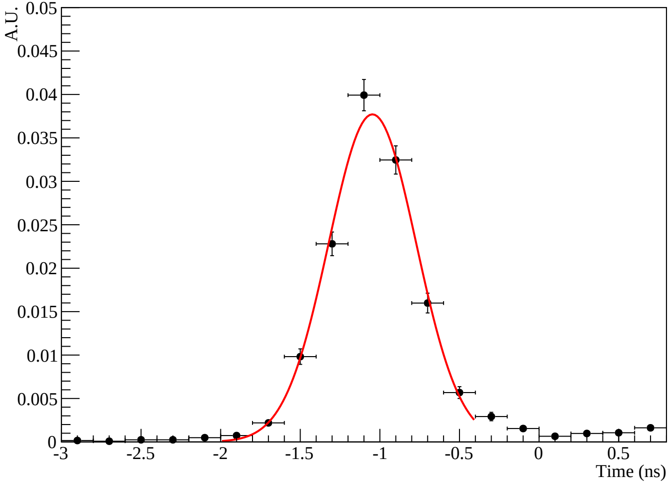


Cherenkov/Scintillation Separation Setup



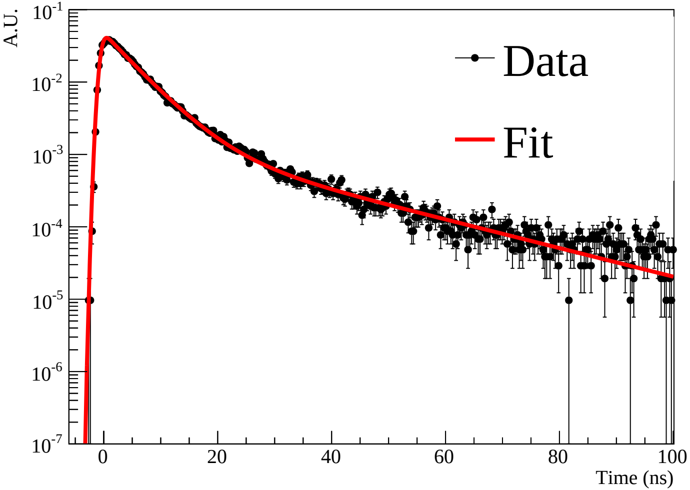
506 nm Long-Pass: Transmitted Light

β source, water target, transmitted light shows clear Cherenkov peak



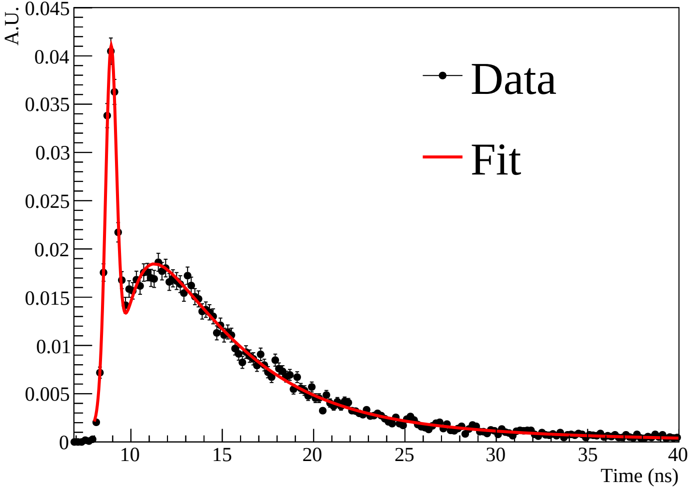
506 nm Long-Pass: Reflected Light

β source, LAB+PPO target, reflected light shows clear scintillation spectrum



506 nm Long-Pass: LAB+PPO Transmitted Light

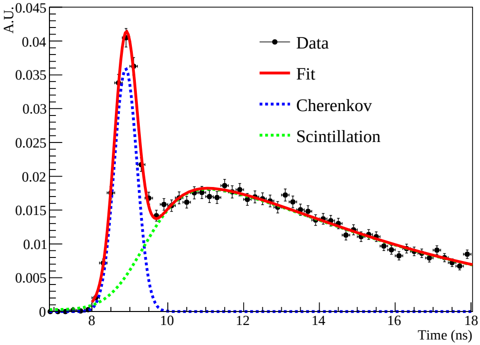
β source, LAB+PPO target, transmitted light shows clearly separated Cherenkov peak!



506 nm Long-Pass: LAB+PPO Transmitted Light

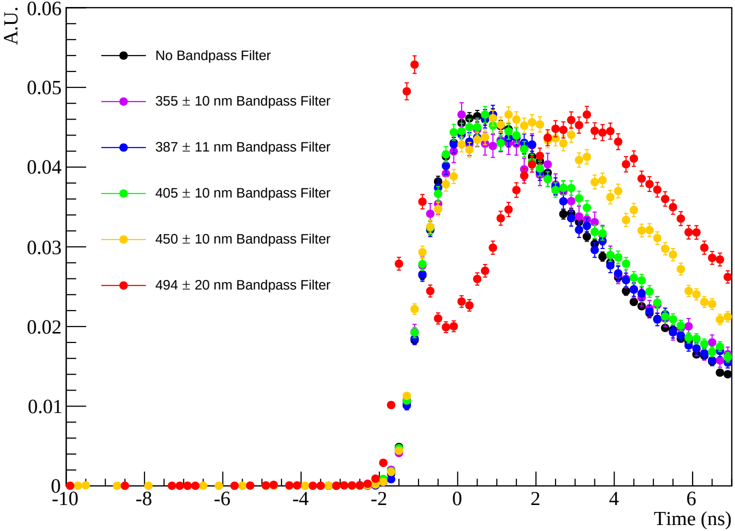
$$(1-F) \times \sum_{i=1}^{2} \frac{A_i \times (e^{-t/\tau_i} - e^{-t/\tau_r})}{(\tau_i - \tau_r)} \circledast f_{PMT}(t-t') + F \times f_{PMT}(t-t'') \qquad (1)$$

- Acceptance (A): Fraction of cherenkov light in prompt window
- Leakage (L): Fraction of scintillation light in prompt window



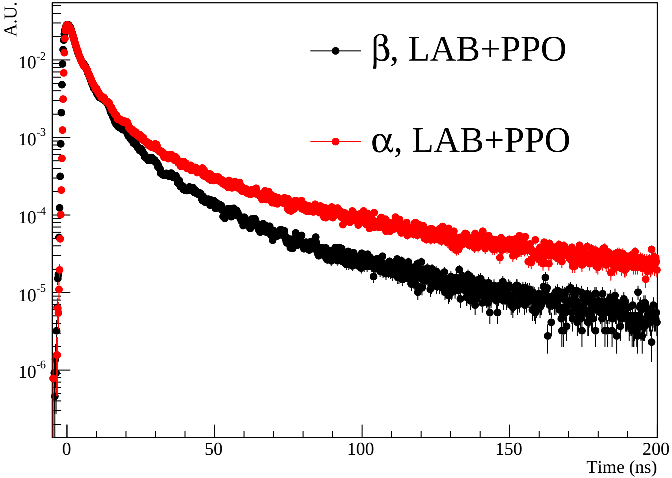
A_1	67 %
A_2	33 %
τ_1	3.8 ns
τ_2	11.6 ns
τ_R	2.1 ns
F	14.3 %
A	85.8 %
L	14.2 %

Brief Aside: Wavelength Dependence of Time Profile



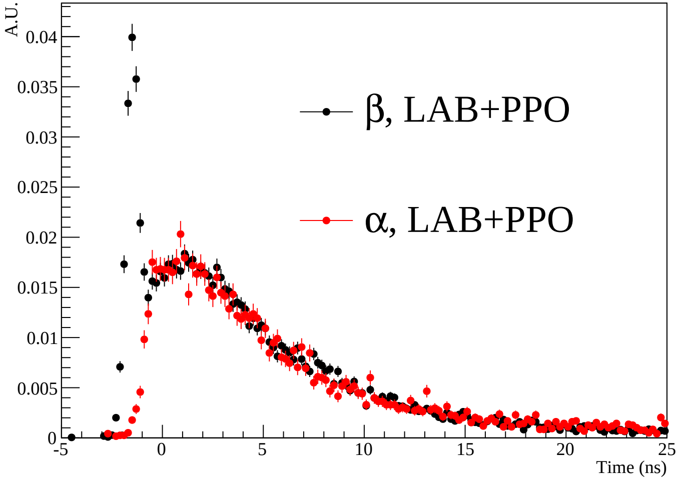
Reflected Light, 506 nm Long-Pass Filter

Tail from triplet light used to distinguish α from β particles



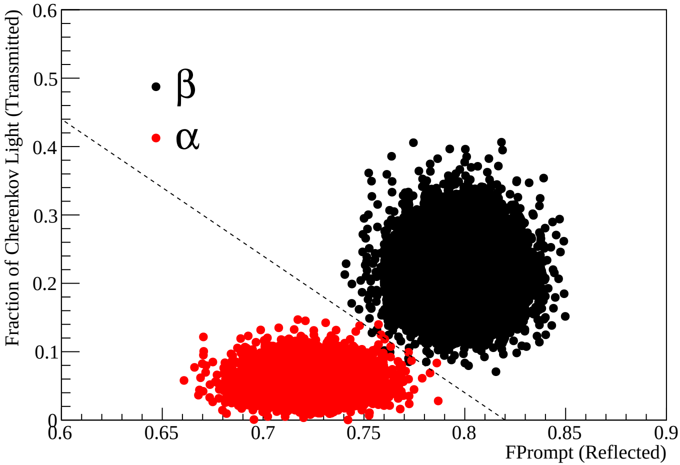
Transmitted Light, 506 nm Long-Pass Filter

Cherenkov light can be used as an additional handle!



α/β Separation

- Critical for background rejection in large scintillator detectors
- $> 99.99\%$ Separation

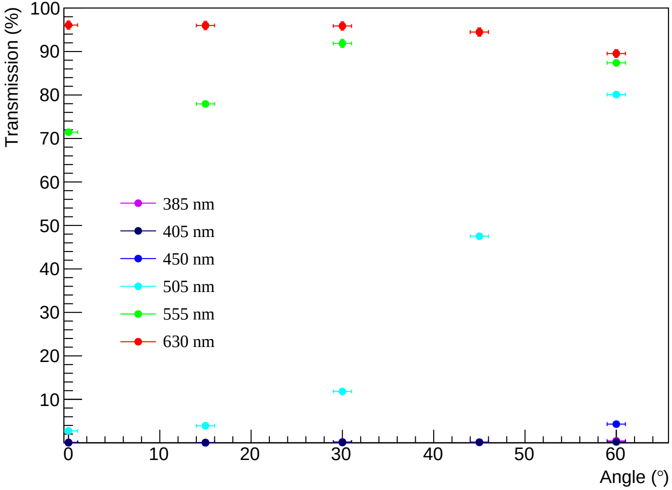


Conclusion and Outlook

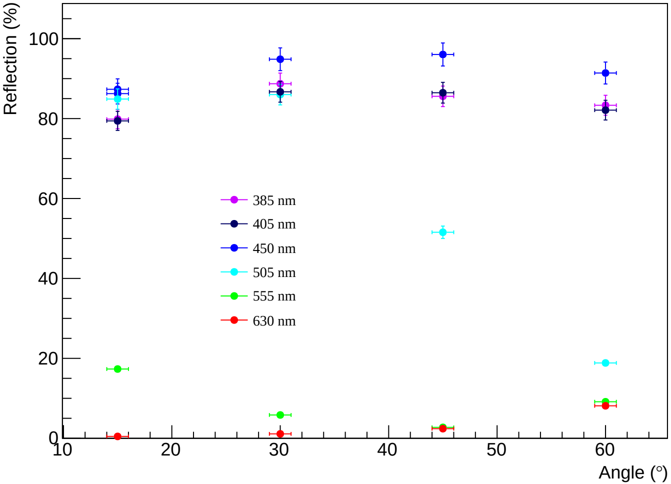
- Many possible detector designs using dichroic Winston cones
- Developing simulation studies using rat-pac, which will shed light on optimal design options
- This technology would be used *in addition* to WBLS, better PMTs, LAPPDs, etc. to improve the Cherenkov/Scintillation separation
- Initial bench-top measurements of dichroic filters are promising and on-going

Backup

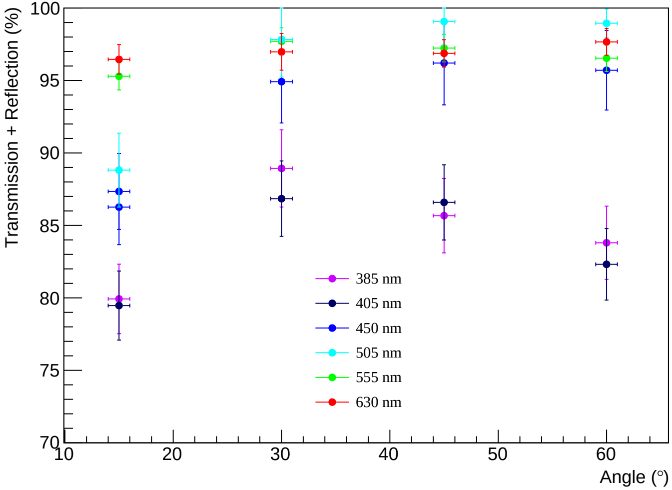
Transmission: 506 nm Long-Pass



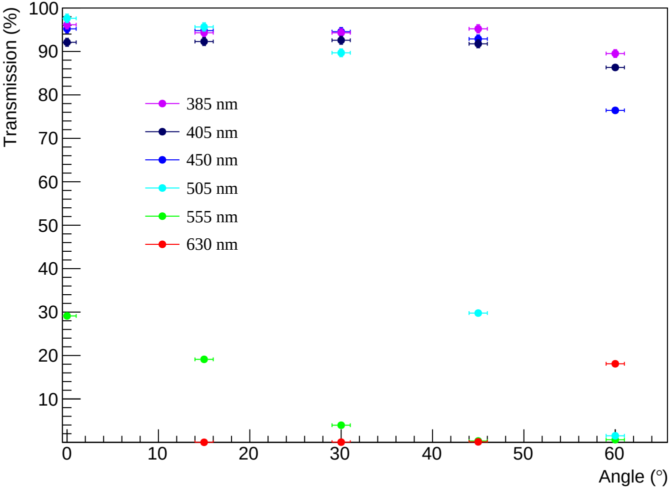
Reflection: 506 nm Long-Pass



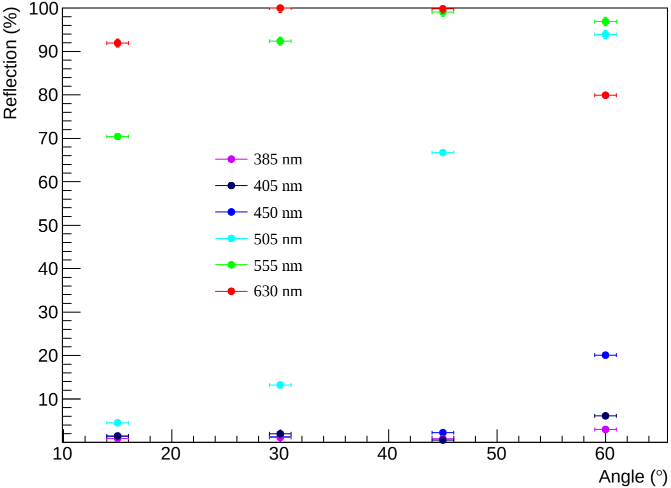
Total: 506 nm Long-Pass



Transmission: 506 nm Short-Pass



Reflection: 506 nm Short-Pass



506 nm Long-Pass: LAB+PPO