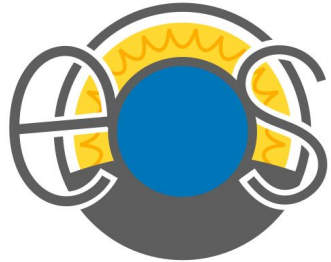


Spectral Photon Sorting Using Dichroicons in Large Optical Neutrino Detectors

James Shen
Department of Physics and Astronomy
University of Pennsylvania

Coordinating Panel for Advanced Detectors Workshop (2024), UTK



Particle Detectors using Light

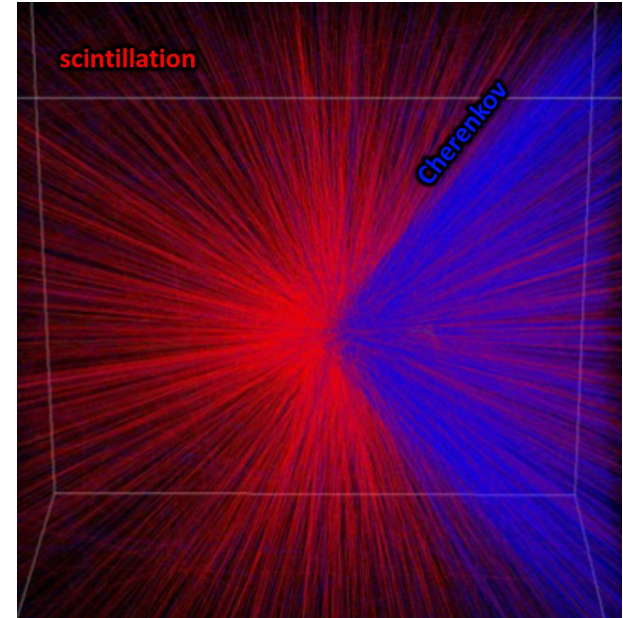
Optical Detectors have a long history of important discoveries

- SNO, Super-K, etc..

Generally utilize one type of light:

- Water Cherenkov Detectors:
 - Cherenkov light point in the particle direction
 - Good direction resolution
 - Poor position and energy resolution due to low light yield ($\sim O(10)/\text{MeV}$)
- Liquid Scintillator Detectors:
 - Isotropic emission, but much higher light yield ($\sim 12\text{k photons/MeV}$ for 2g/L LAB+PPO)
 - Good resolution in energy, position
 - Lower energy threshold
 - No directional information.

The ideal particle detector combines both types of light...



B. Land

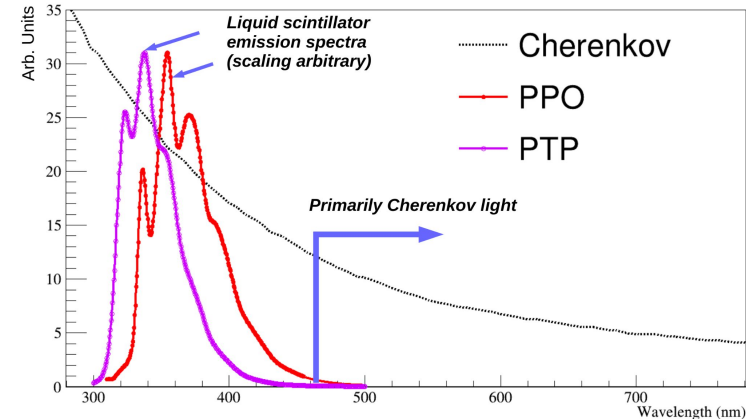
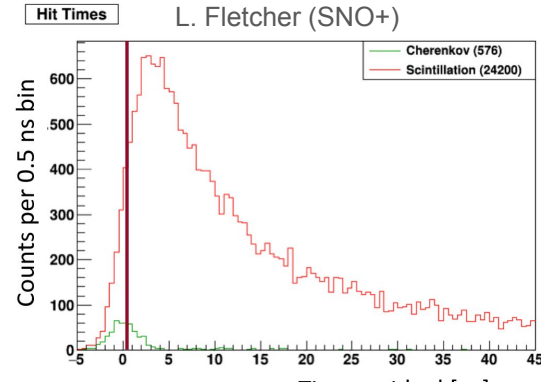
Separate Cherenkov and Scintillation Light

Goal: Maintain high cherenkov purity while losing as few photons as possible

Using Timing:

- Hard to implement in large optical detectors
- Scintillation light is orders of magnitude more intense
- Heavily depends on having photodetectors with fast timing response – expensive!

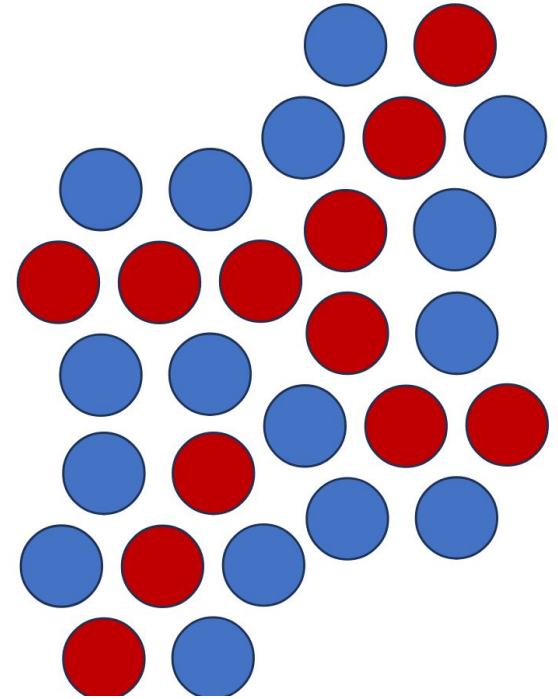
Spectral Sorting: Using photon difference in wavelength



Spectral Sorting – The Naive Approach

Cover half of the PMTs using red filters,
or with red-sensitive PMTs

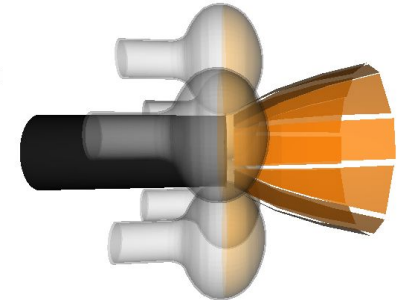
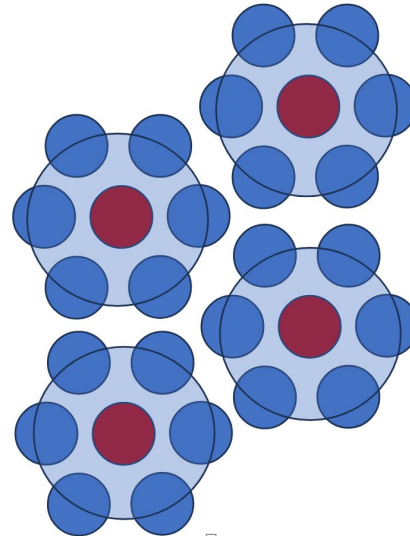
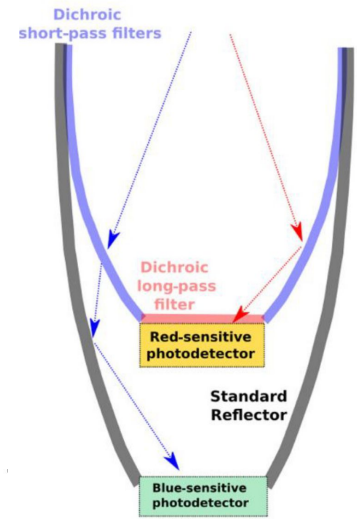
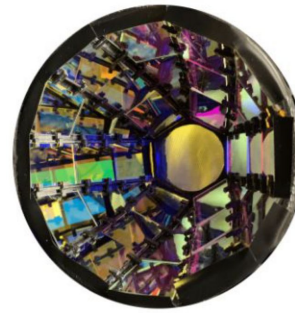
But now we lose half of the scintillation
light!



The Dichroicon

Combines the technologies of Dichroic filters and Winston cone concentrators

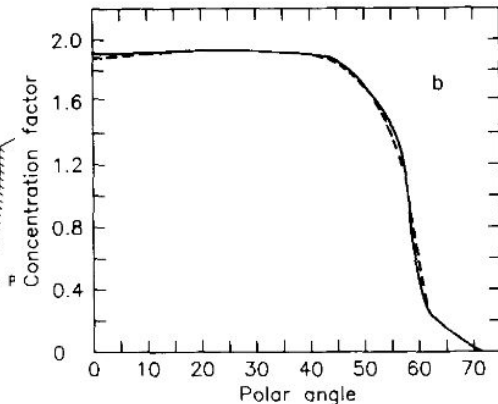
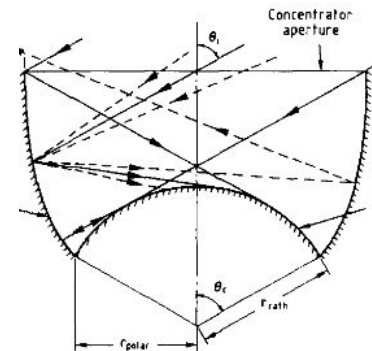
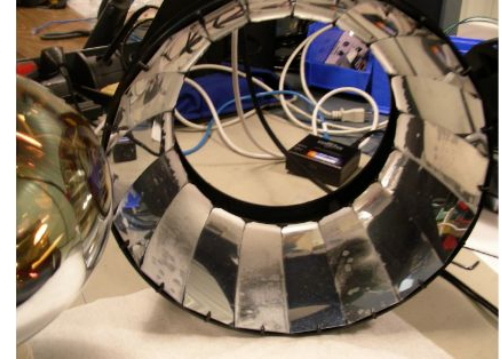
- One detector sits at the barrel of the dichroic concentrator – detects long-wavelength Cherenkov light
- Other detectors behind the barrel, collecting scintillation light
- Concentrator remains “transparent” to Scintillation light



Dichroicon Design Concerns

Concentrator Shape:

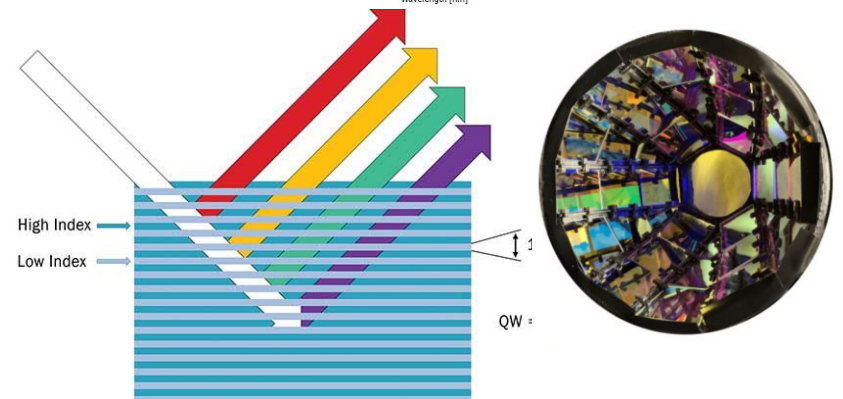
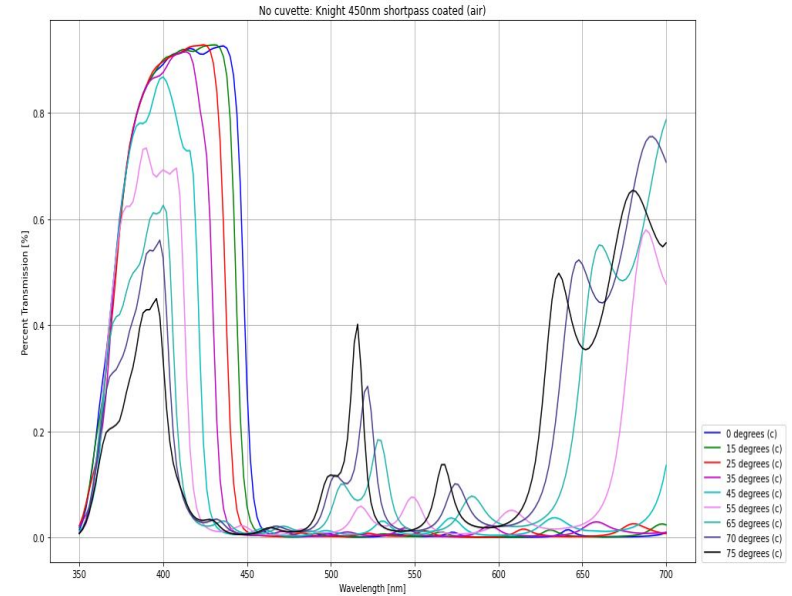
- “Winston Cone” – optimal non-imaging light collector developed by R. Winston in the 70s for solar energy applications
- Further optimization for large optical detectors for SNO
 - Optimization for spherical collector (PMTs)
 - Truncated cone for wider angle
 - “Pixelate” to use flat dichroic panels



Dichroicon Design Concerns

Dichroic filters

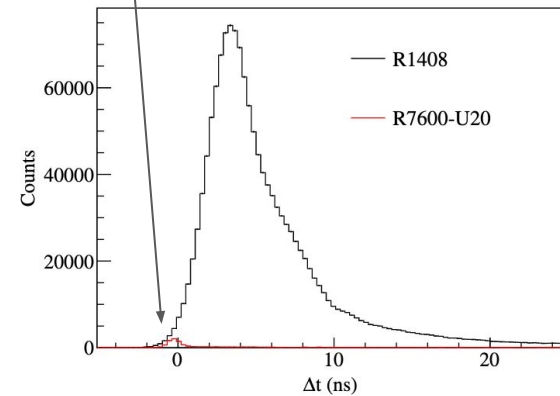
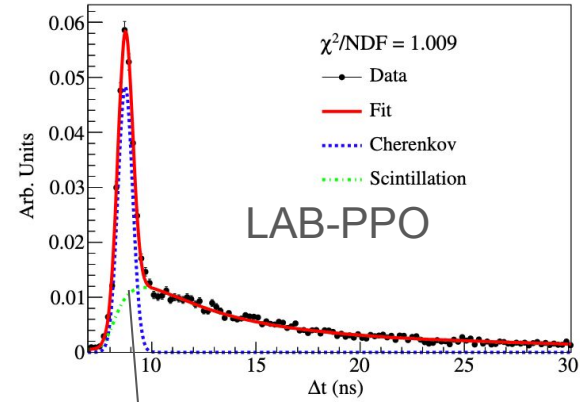
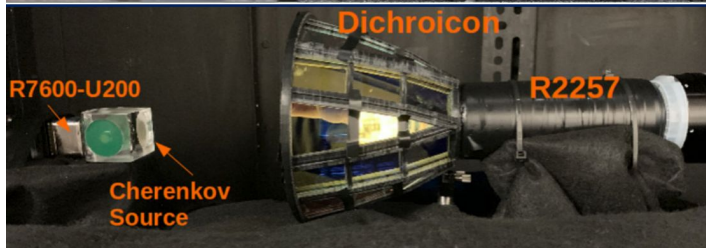
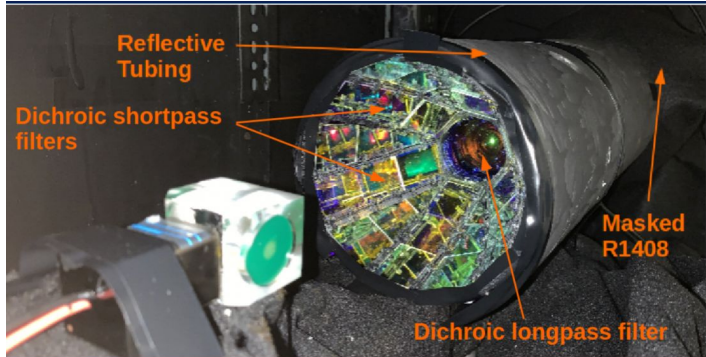
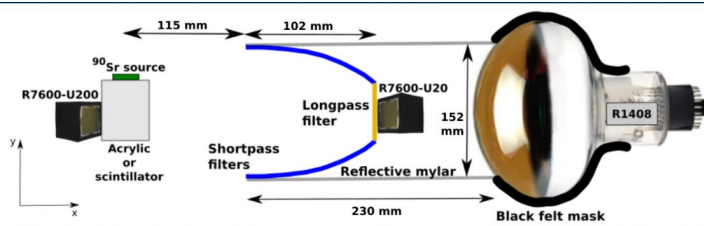
- Combination of many thin-film interference layers
- Wavelength response depends strongly on angle of incidence -> significantly more complex to model in simulation and design
- Ongoing effort to optimize angular response
 - See talk by [Y. Li yesterday](#)



Benchttop measurements

T. Kaptanoglu (2020)

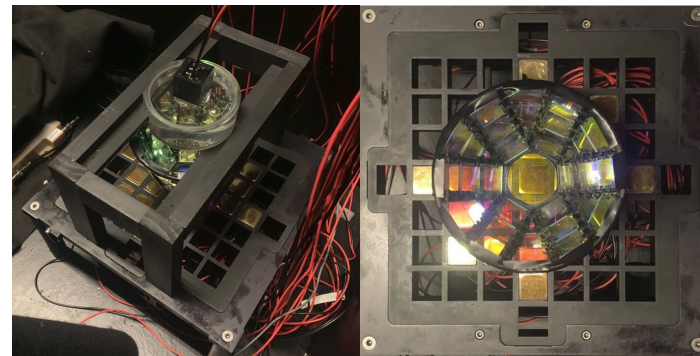
Phys. Rev. D 101, 072002



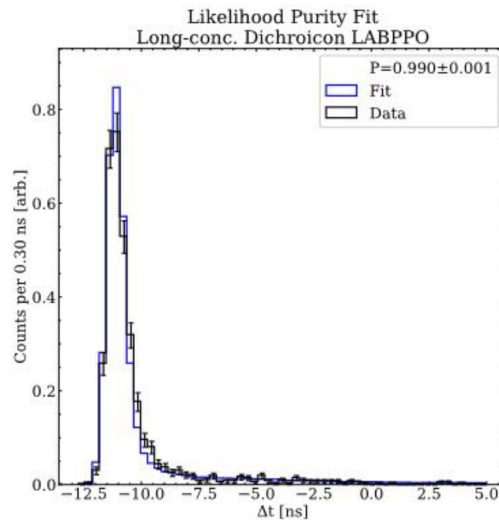
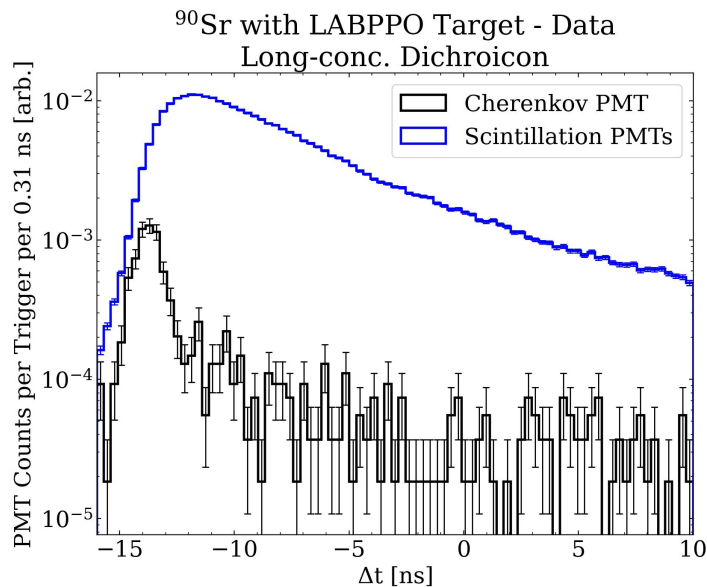
Benchtop Measurements (CHESS)

Source: Atmospheric muons, ^{60}Co , ^{90}Sr , ^{210}Po

Target: Water-based liquid scintillator (WbLS),
LAB+PPO, Water



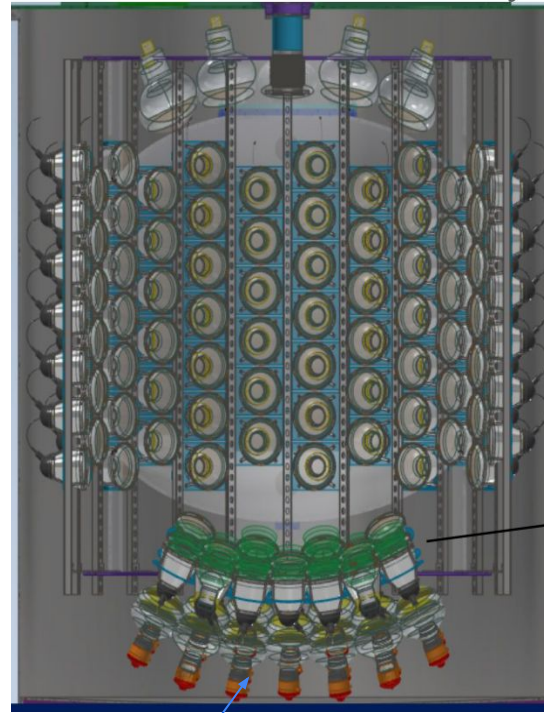
S. Naugle



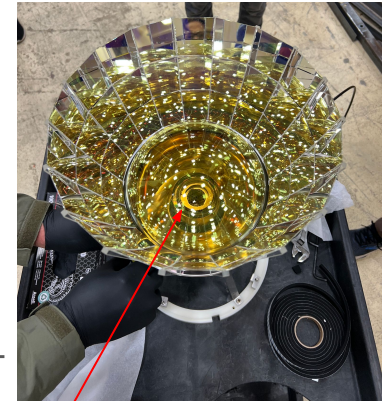
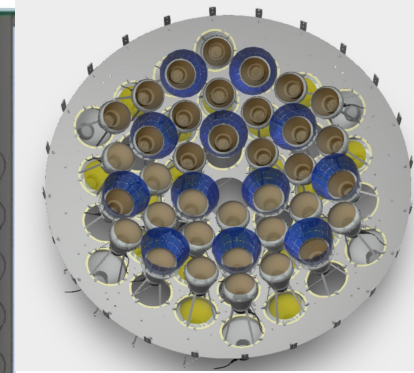
Purities	
10% WbLS	0.978 ± 0.004
LABPPO	0.990 ± 0.001

Eos @ LBNL

- Eos is a 20-ton experiment that demonstrates hybrid Cherenkov/Scintillation technologies
- 12 Dichroicons installed at the space-constrained bottom of the detector
 - Equipped with curved, acrylic, longpass absorbing filters – increasing lightyield by ~50% compared to paneled design.
 - Shortpass dichroic filters as concentrator
 - Cut-on frequency of 450nm.
- Commissioned and installed early 2024
- Started taking water data May 2024.



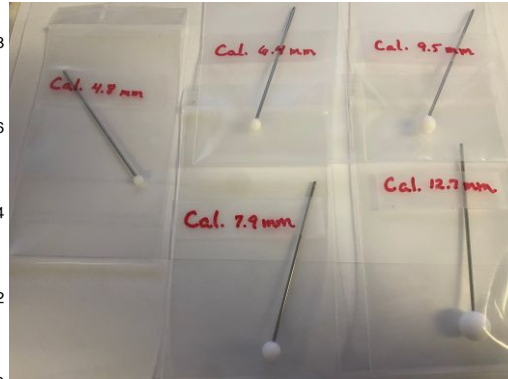
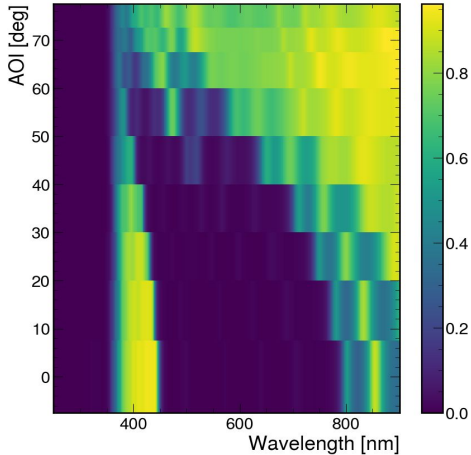
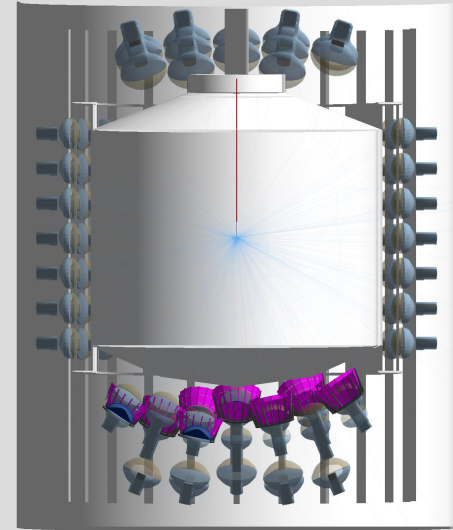
Short wavelength sensitive 10in PMT



Long wavelength sensitive 8in PMT

Dichroicon Efficiency Characterization

- Laser is injected via an optical fiber down the center of the detector at various heights, diffused by a PTFE sphere
- More details in [L. Lebanowski's talk yesterday](#).
- Data / MC Comparison:
 - Both longpass/shortpass filters modeled based on off-site spectrophotometer measurements done at Penn.

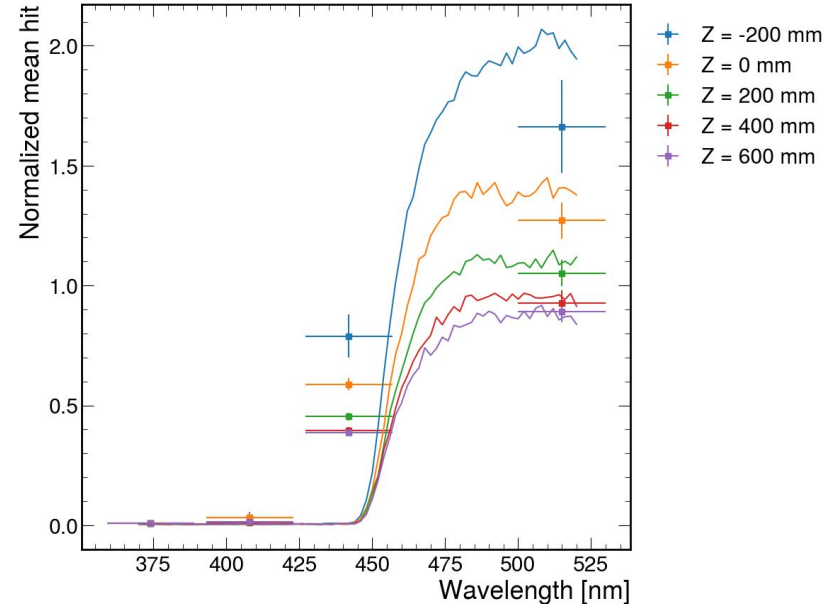


Dichroicon Laserball Calibration

Comparison between data (points) and MC wavelength scan (lines).

Comparing average light yield of dichroicon PMTs vs. other PMTs in the detector

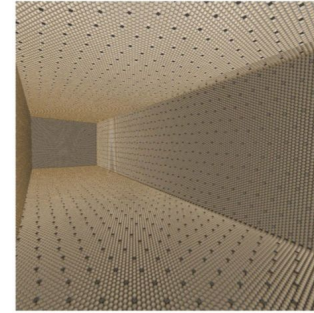
- Light yield below 450 nm is heavily suppressed, and light yield above 450 nm is higher than other adjacent PMTs
 - *Improved effective coverage compared to filtered PMTs.*
- Working on a more quantitative description.



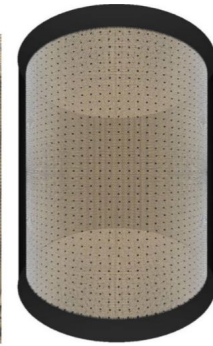
Looking ahead – THEIA

Working towards THEIA: 10kton+ hybrid cherenkov-scintillation detector

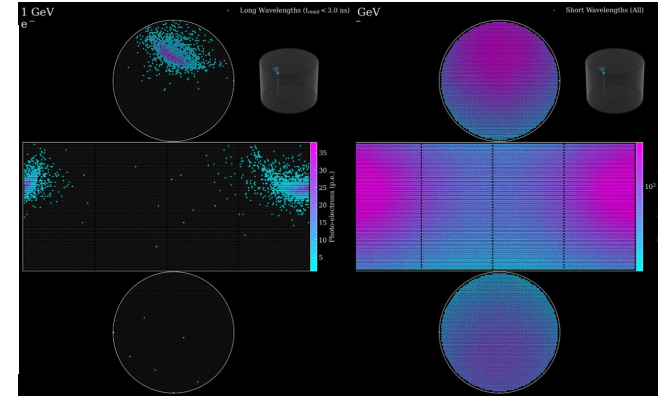
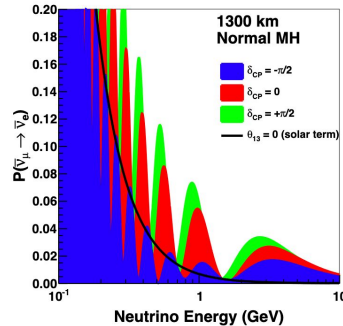
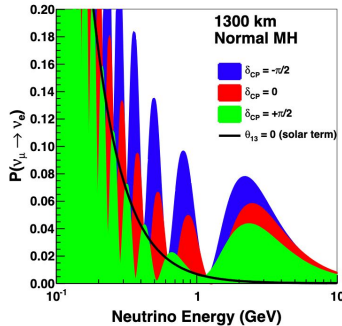
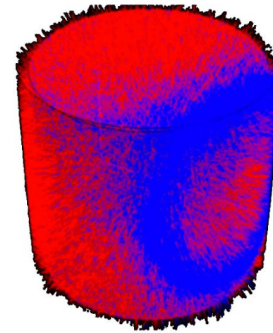
- 4 detector caverns for DUNE
- 2-3 will be liquid argon detectors
- 4th Cavity could house Theia
- Scan for anti-electron neutrino appearance, complementary to electron neutrino in LAr
- Address FSI uncertainties for LAr
- See [S. Linden's talk yesterday](#)



THEIA 25kt



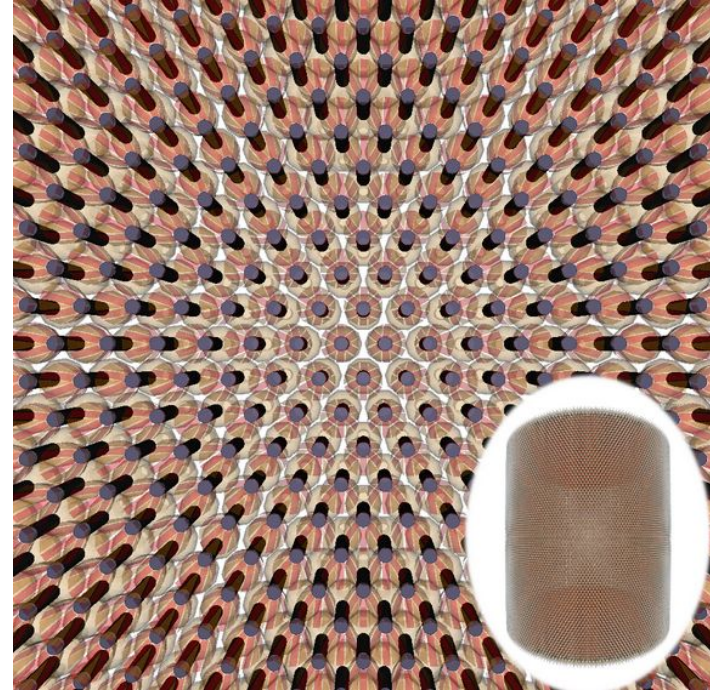
THEIA 100kt



1 GeV muon in Theia

Conclusion

- The dichroicon is a good candidate for achieving cherenkov / scintillation separation in future hybrid optical detectors via spectral sorting.
- Mature design process, benchtop measurements that demonstrate C/S separation
- Successful deployment in Eos, with preliminary calibration results showing an increase in effective coverage compared to absorber designs
- Future applications in kiloton-scale hybrid optical detectors such as THEIA



Thanks for your attention!

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Backup

Cherenkov/scintillation separation

