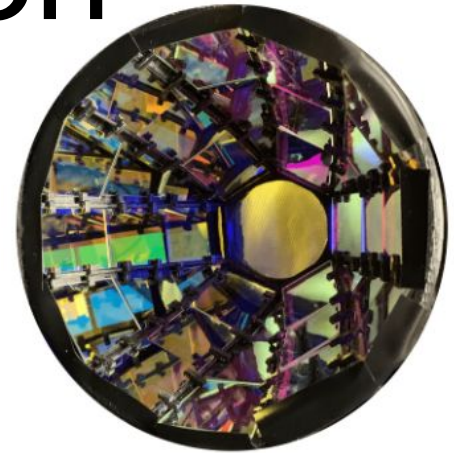
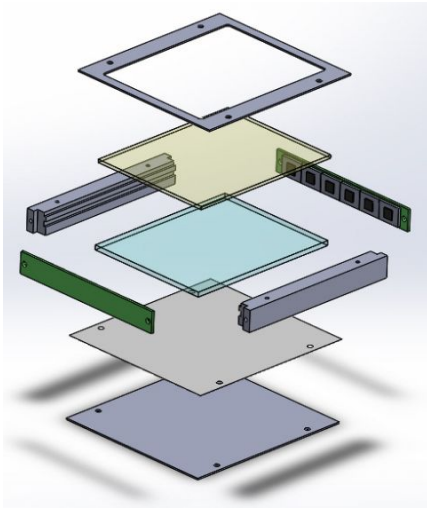


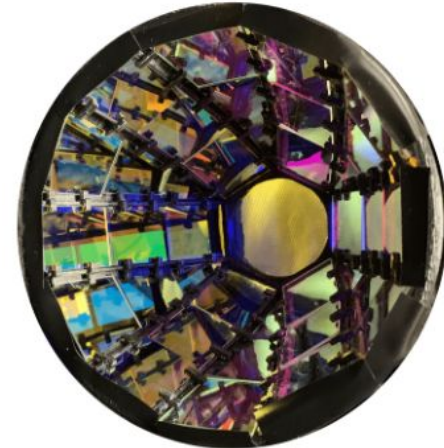
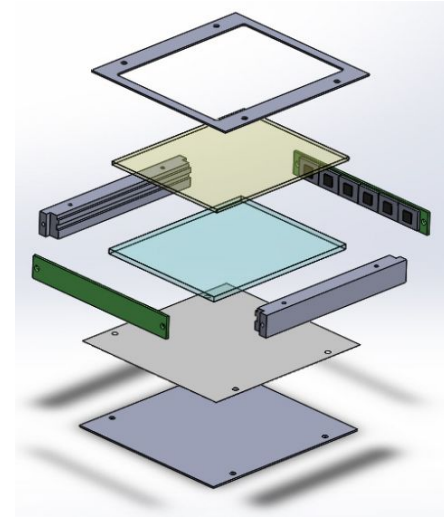
Dichroic Approaches to Photon Collection

Samuel Naugle



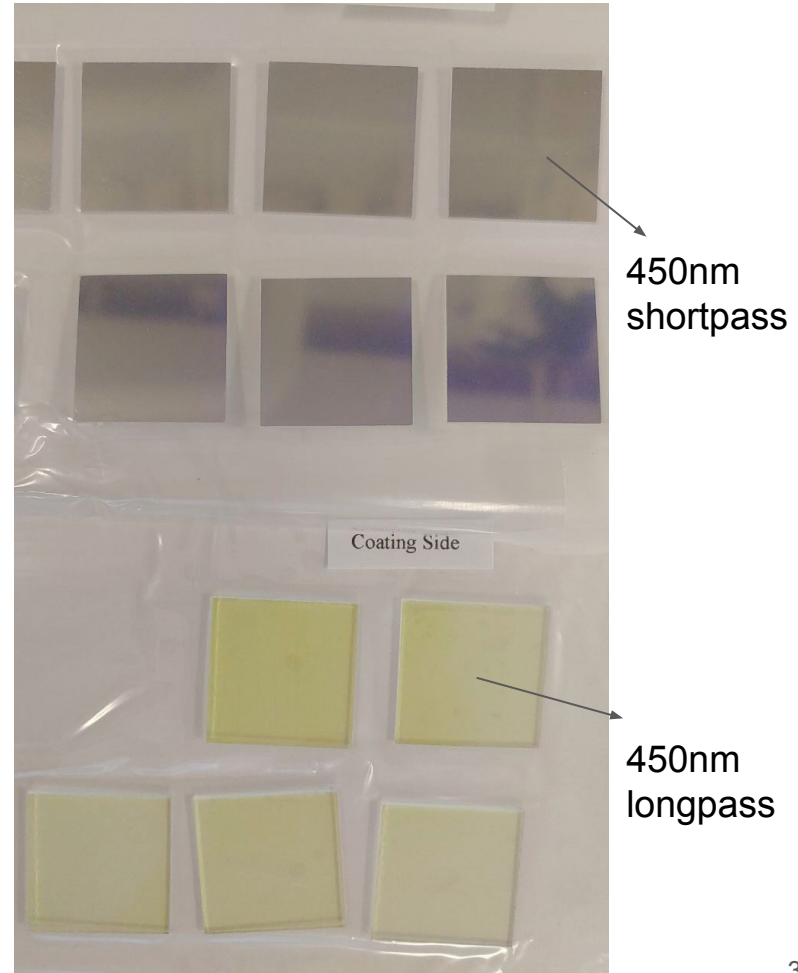
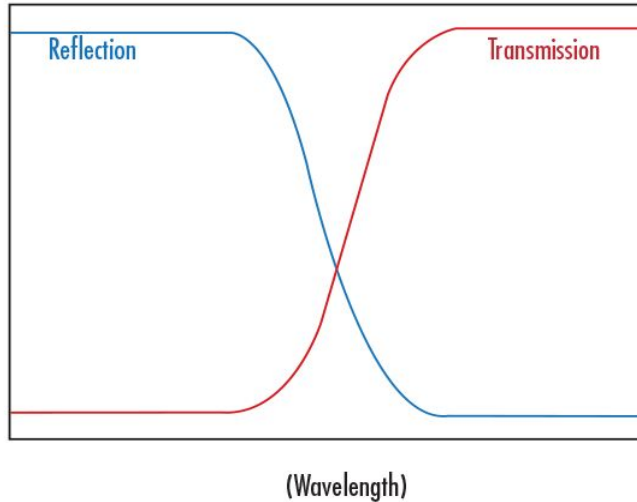
Outline

1. Dichroic filters
2. Applications to photon collection
 - a. ARAPUCA
 - b. Dichroicon
3. Design considerations
4. Concluding remarks



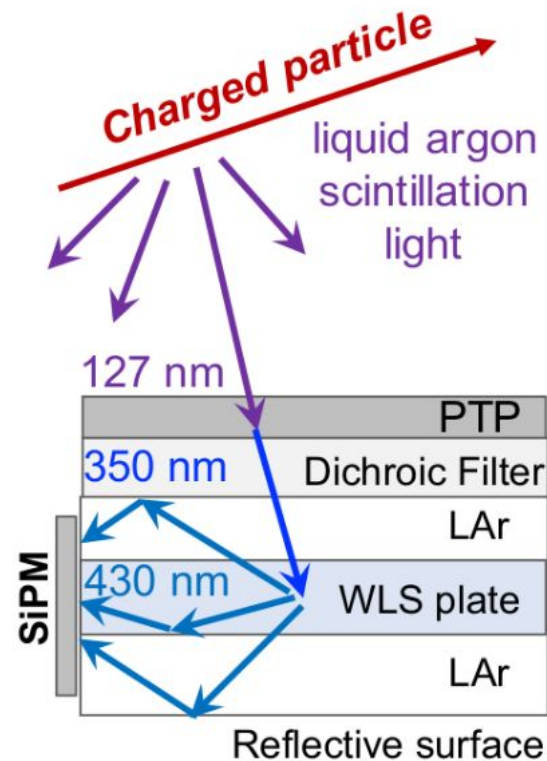
Dichroic Filters

- Reflect or transmit photons by wavelength
 - With minimal absorption
- Many films of differing indices of refraction
 - Strongly angularly dependent response
 - Surrounding medium affects filter response



Applications: ARAPUCA

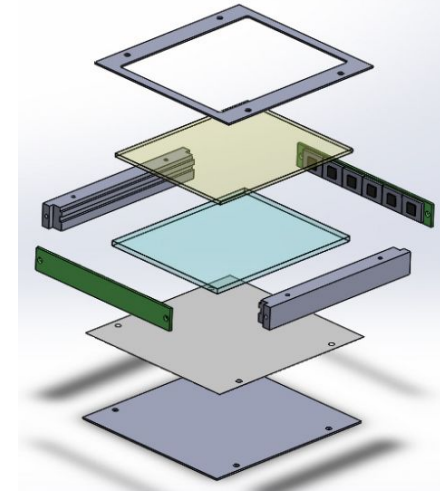
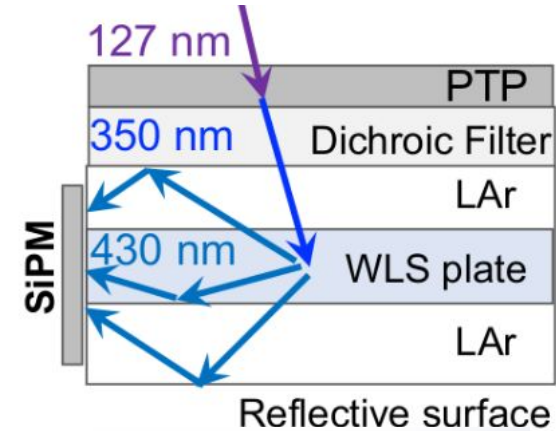
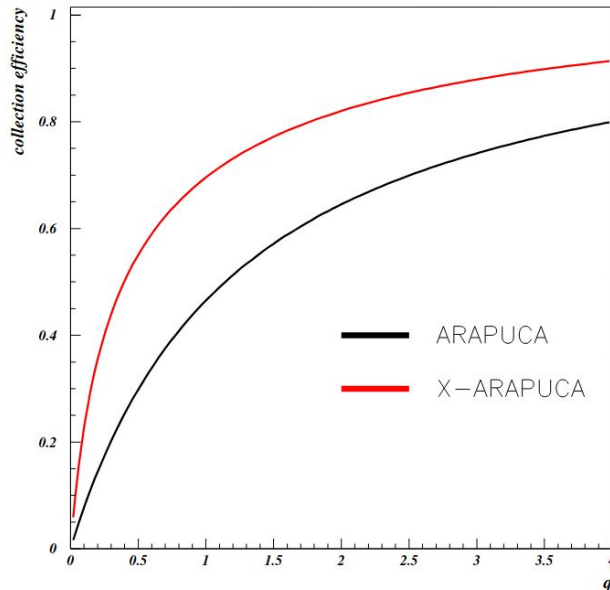
- Named after a hunting trap as it “traps” light
- Employs dichroic filters and wavelength shifting materials
- Trapped light then bounces around inside the “trap” until it is absorbed or detected



Not to scale.

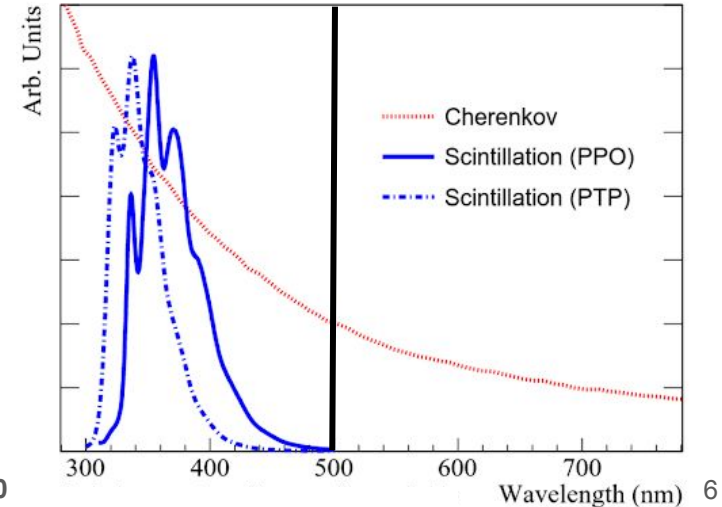
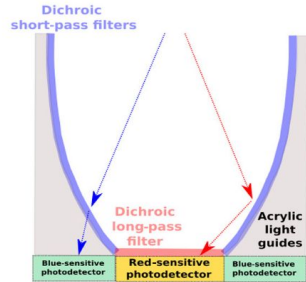
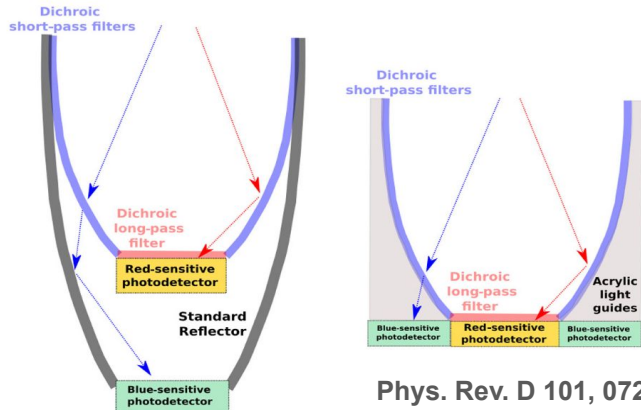
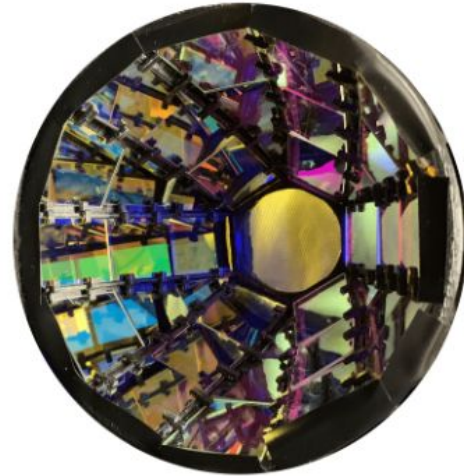
Applications: ARAPUCA

- Allows for a small active surface area to collect photons from a larger surface area
- Effectively functions like a concentrator



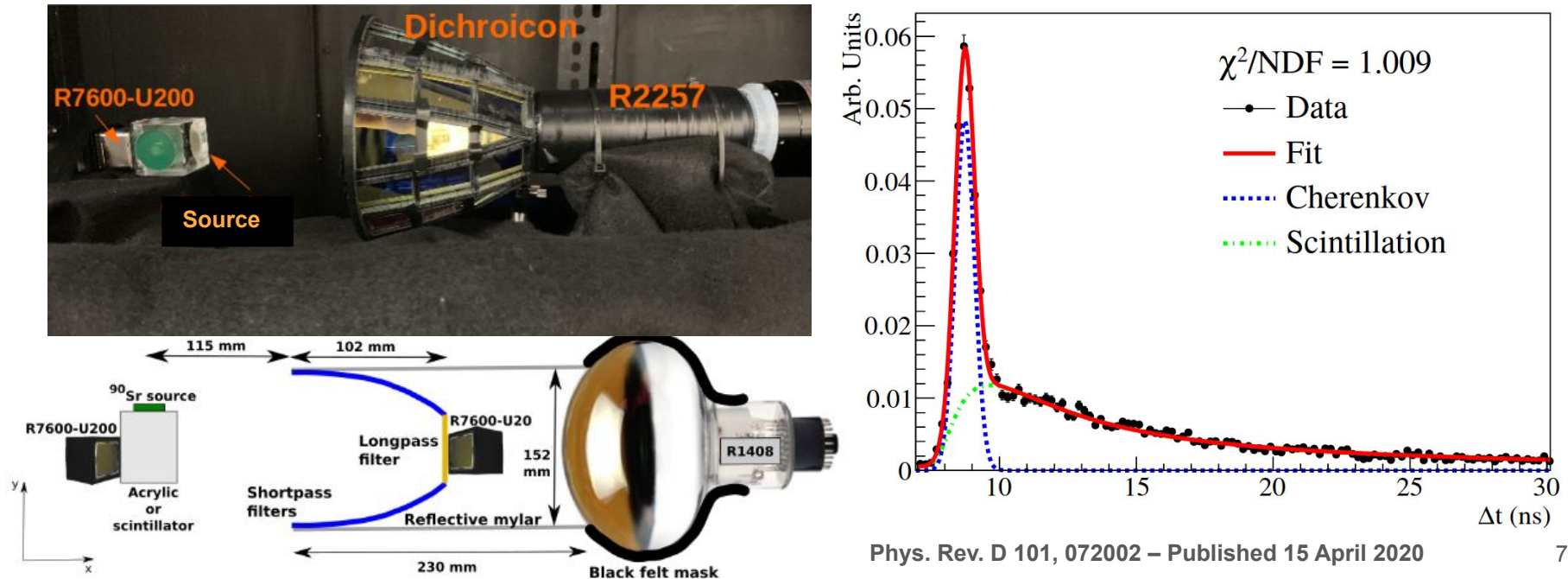
Applications: Dichroicon

- The “dichroicon” separates photons using dichroic filters
 - Many applications including Cherenkov/scintillation separation, correcting for dispersion, ...
- Allows for a hybrid Cherenkov scintillation detector with a broad physics program



Applications: Dichroicon

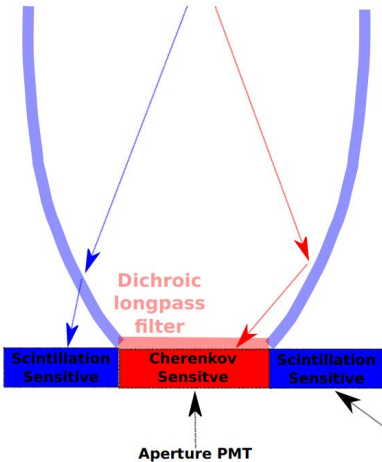
- Benchtop measurements show 93% of photons in early time window are Cherenkov



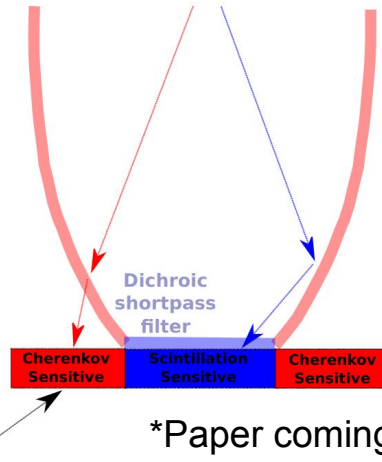
Applications: Dichroicon

- The performance of the dichroicon was also measured using the CHESSE experiment
 - Sources: **Cosmic-ray muons** and radioactive sources
 - Targets: Water, **10% WbLS**, LAB with 2 g/L PPO
 - Dichroicon layouts: **Standard and Complementary**

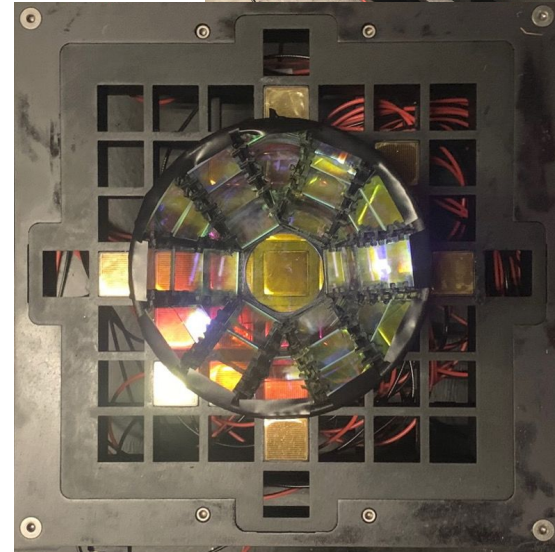
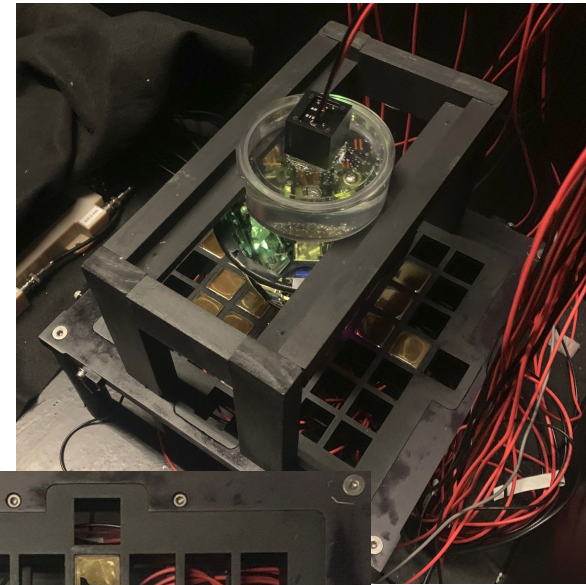
Standard



Complementary



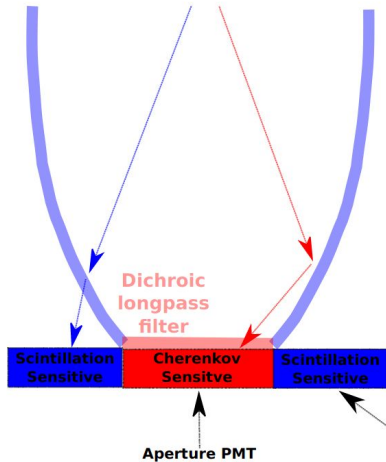
*Paper coming soon!



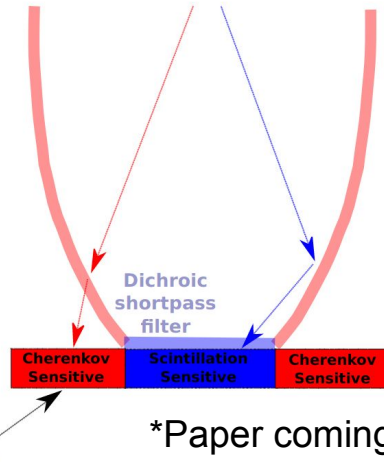
Applications: Dichroicon

- Probes much higher energy regime with a pixelated array of fast PMTs
- Includes measurements taken with 10% WbLS
- Introduces complementary dichroicon design

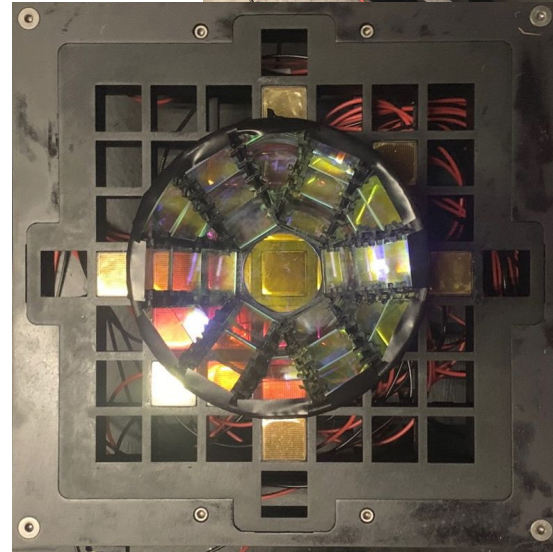
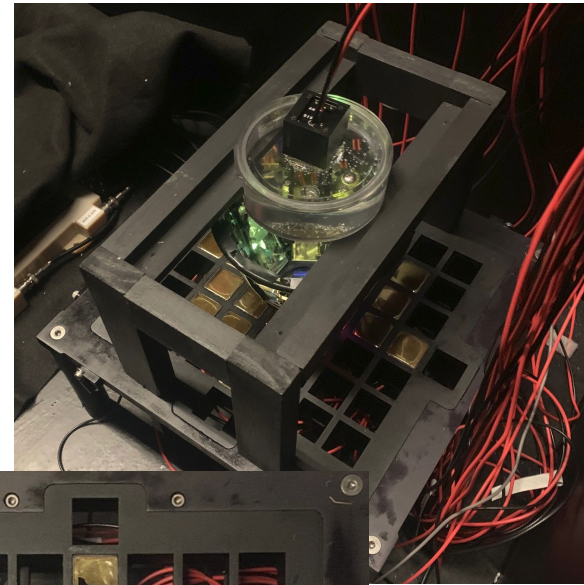
Standard



Complementary



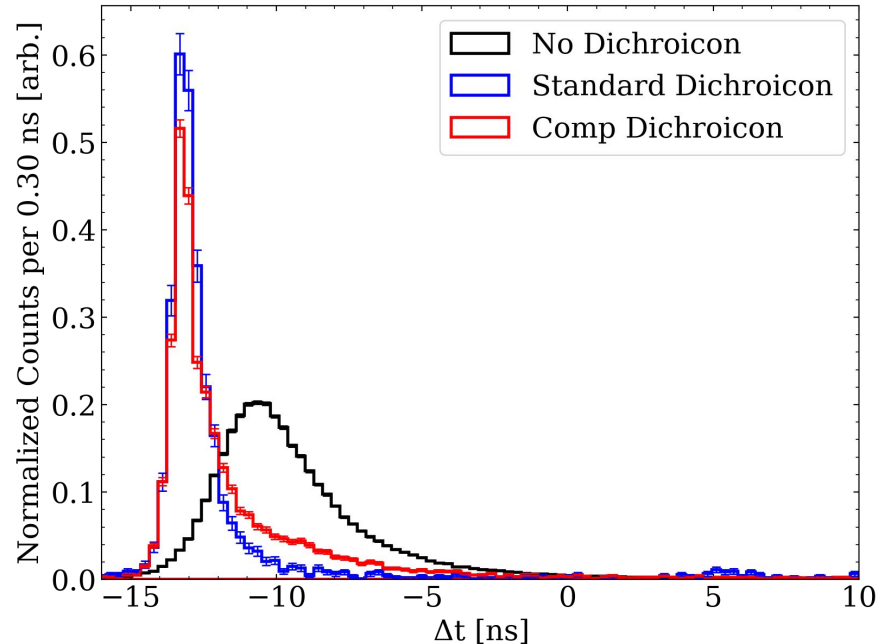
*Paper coming soon!



Applications: Dichroicon

- Compare between set ups and target using the purity, P

Atmospheric Muons Incident on WbLS Target
Cherenkov PMT

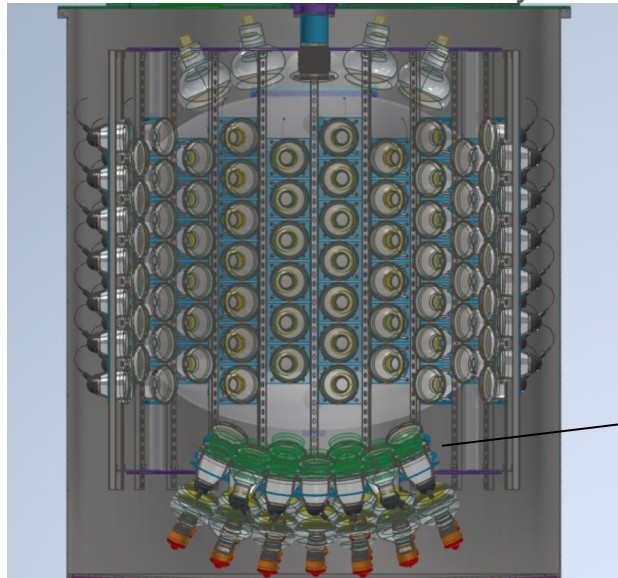


$$P = \int_{\mu-3.5\sigma}^{\mu+1.5\sigma} \frac{N_{Ch}(t)}{N_{Ch}(t) + N_{Sc}(t)} dt$$

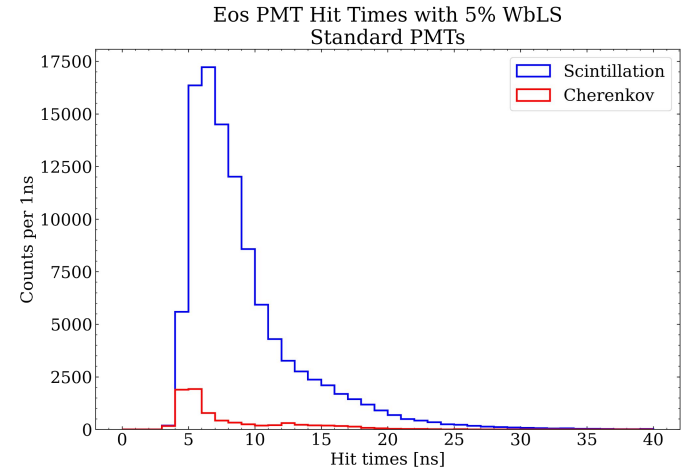
Purities	Standard	Complementary
10% WbLS	0.98	0.87
LABPPO	0.98	0.63

Applications: Dichroicon

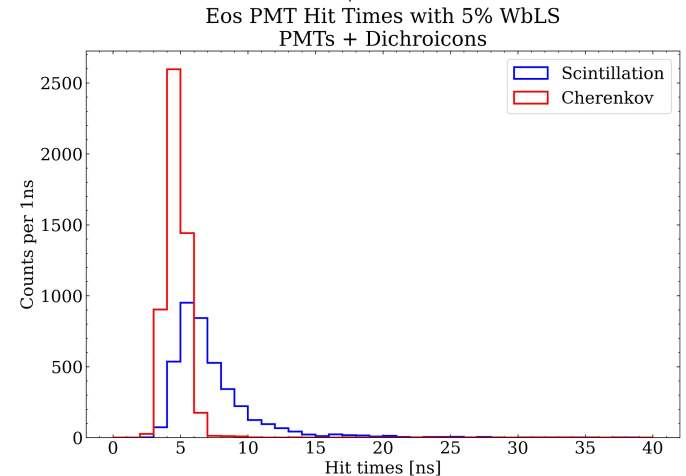
- Planned future deployment of dichroicons in Eos
 - Eos is a ~4 ton demonstrator planned to be constructed in the next year



Dichroicons

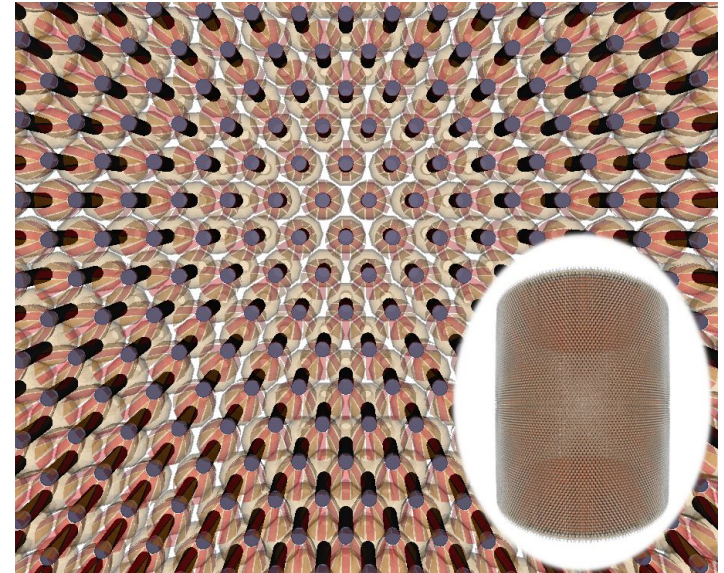
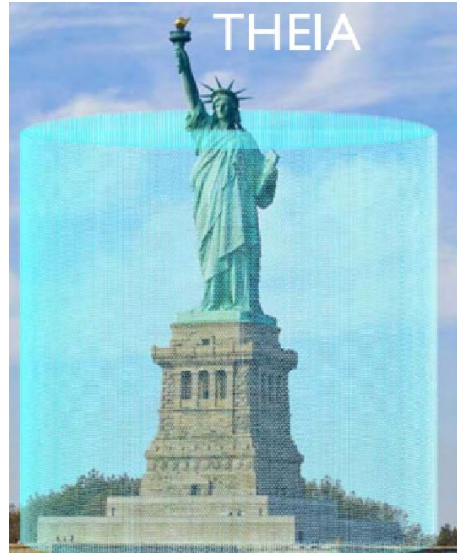
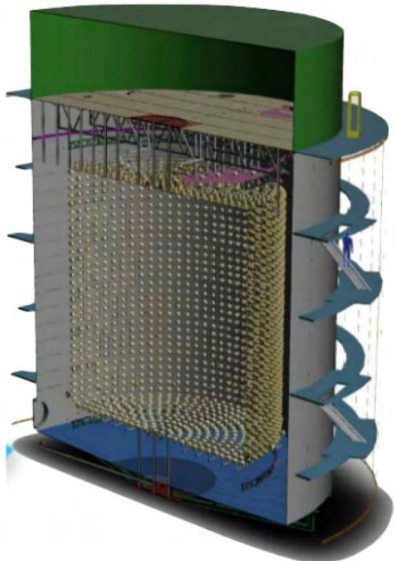


+Dichroicons



Applications: Dichroicon

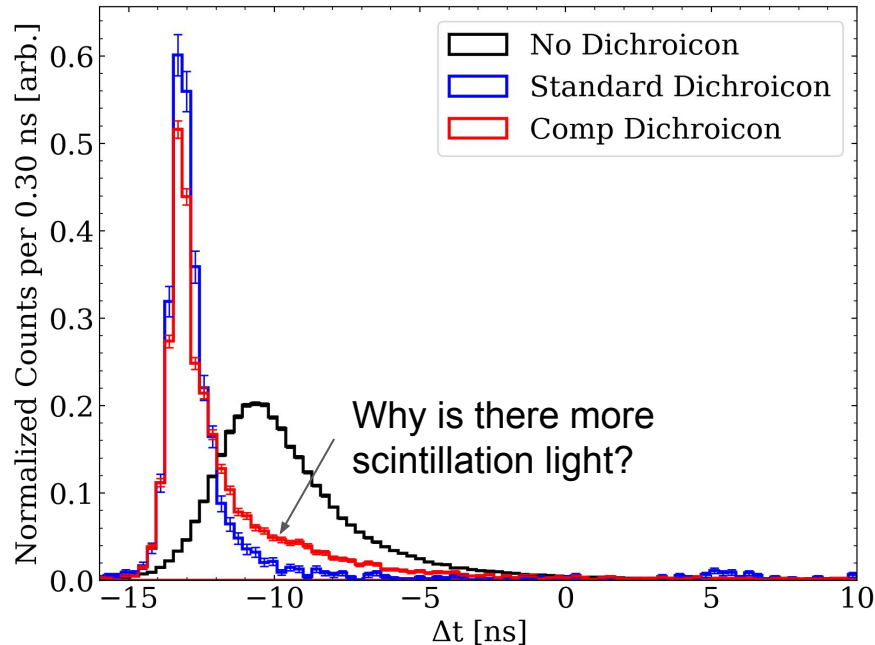
- Far future goal for dichroicons is Theia
 - Monolithic kiloton-scale hybrid Cherenkov/scintillation detector
 - Could be equipped with large number of dichroicons



Design Considerations

- To discuss design considerations we can revisit the CHESSE deployment

Atmospheric Muons Incident on WbLS Target
Cherenkov PMT



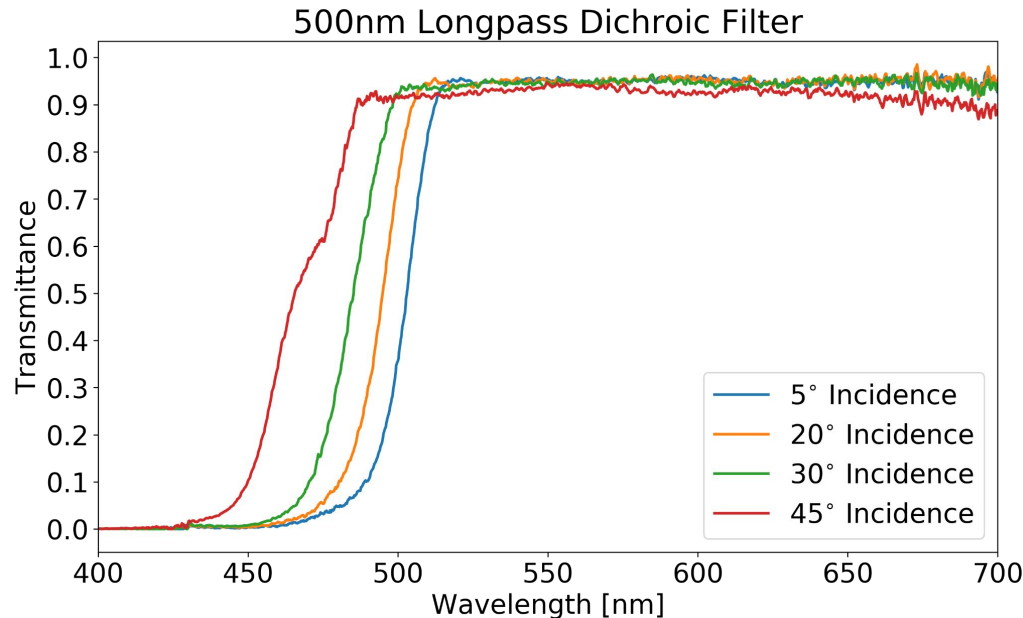
$$P = \int_{\mu-3.5\sigma}^{\mu+1.5\sigma} \frac{N_{Ch}(t)}{N_{Ch}(t) + N_{Sc}(t)} dt$$

Purities	Standard	Complementary
10% WbLS	0.98	0.87
LABPPO	0.98	0.63

Why is the purity lower?

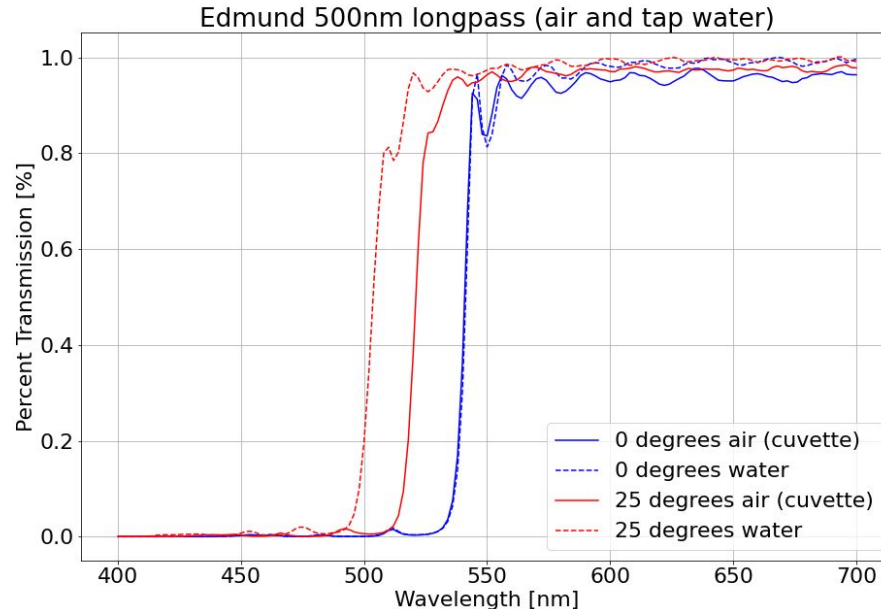
Design Considerations: Angular Dependence

- Dichroic filters have a strongly angular dependent response
 - Due to the thin film interference that transmits and reflects photons
- This must be considered in device design



Design Considerations: Media Dependence

- The behavior of the dichroic filters also depends on the index of refraction of the surrounding media



Concluding Remarks

- Dichroic filters have many new and exciting applications to a wide range of particle physics
 - ARAPUCAS, dichroicons
 - A variety of new analysis and reconstruction techniques
- Demonstrations of their utility have already been confirmed
- Still in early stages of R&D, many new and exciting possibilities still haven't been explored

Acknowledgements

ARAPUCA information:

A.A. Machado et al 2018 JINST 13 C04026

H.V. Souza, arXiv:2112.02967

Previous dichroicon paper:

Phys. Rev. D 101, 072002 – Published 15 April 2020

More information on Eos can be found in “Future Advances in Photon-Based Neutrino Detectors: A SNOWMASS White Paper”:

<https://arxiv.org/abs/2203.07479>

Theia: an advanced optical neutrino detector:

Eur. Phys. J. C 80, 416 (2020)

Funding for dichroicon deployment on CHESSE through the U.S. Department of Energy, National Nuclear Security Administration, Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D).

Feel free to email me with any additional questions at smnaugle@sas.upenn.edu and thanks for listening!