Impacts of Spectral Photon Sorting in Large Neutrino Detectors

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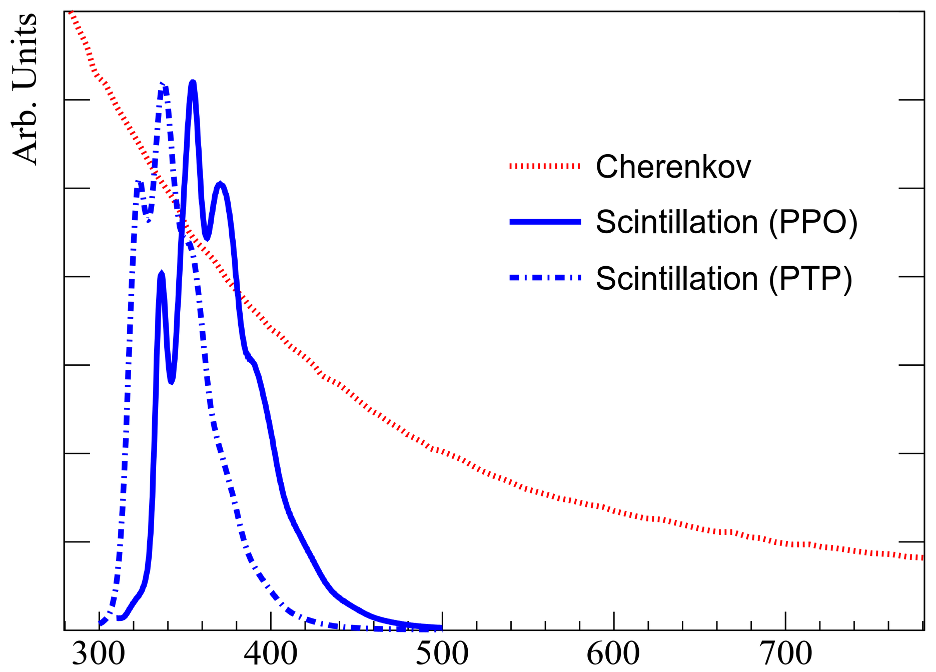
University of Pennsylvania / Neutrino 2020

Spectral Photon Sorting

Cherenkov and scintillation photons produced when charged particles interact in a sicntillating media carry complementary information and typically have dissimilar spectra.

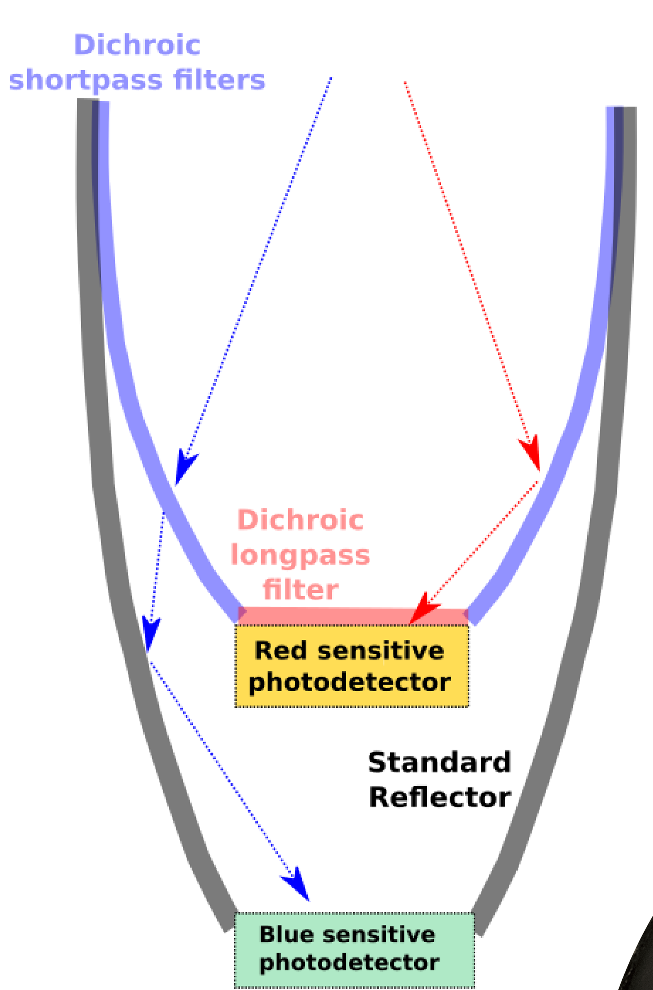


Emission spectra of two readily available scintillators, PPO and PTP, compared to Cherenkov light.

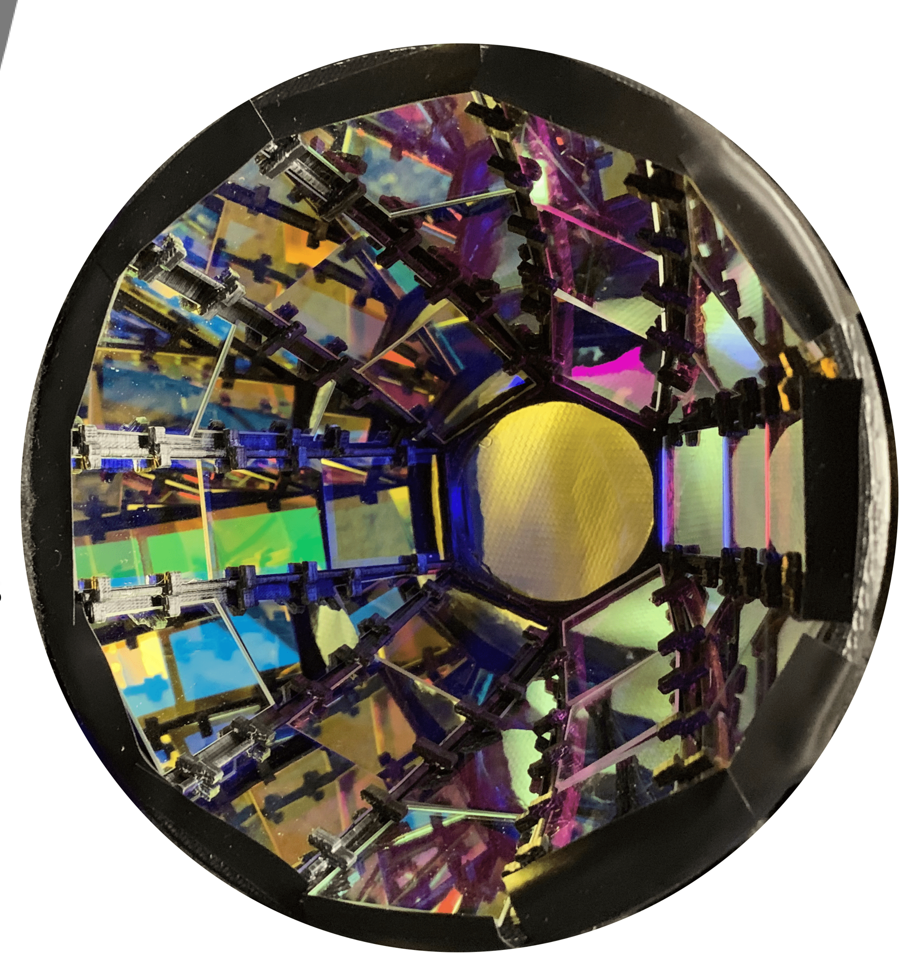
The relatively abundant scintillation photons provide a good measure of position and energy of an interaction while the geometry of less numerous Cherenkov photons provide a measure of direction. A combination of both allows for rudimentary particle identification.

Positively identifying a dim Cherenkov photons present in a bright scintillation signal could be done by selectively detecting long wavelength photons. A scheme is presented below for doing this with minimal loss of photons.

The Dichroicon



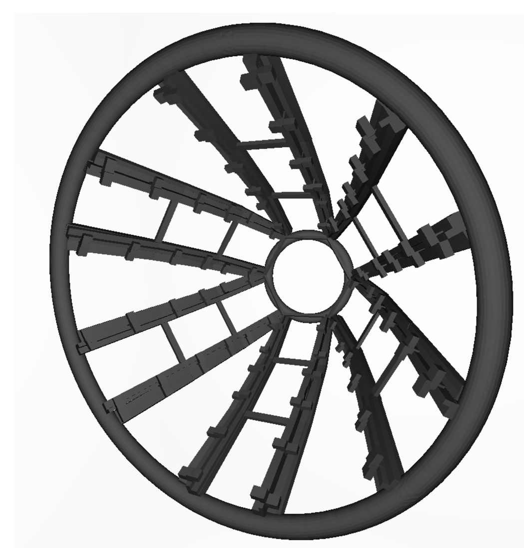
- Winston cone made of dichroic filters to concentrate Cherenkov light (left)
- Long wavelengths (Cherenkov) reflect to red sensitive PMT
- Short wavelength passes to blue sensitive PMT



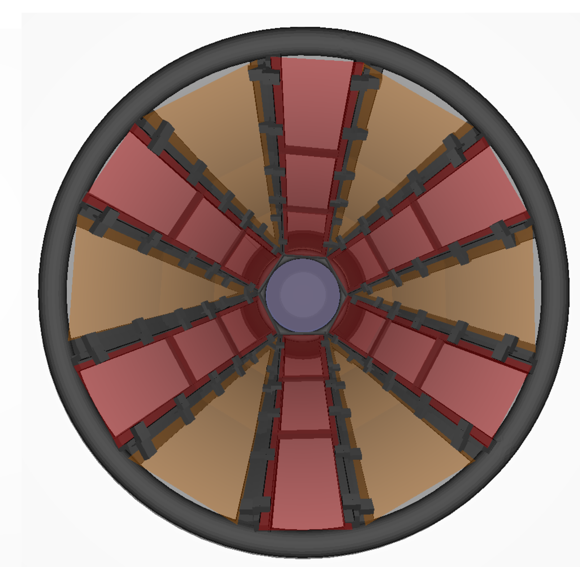
- Prototype (right) developed at University of Pennsylvania
- Benchtop measurements have demonstrated Cherenkov detection from liquid scintillators
- See [1] for more information on these measurements.

Fast Monte-Carlo with Chroma

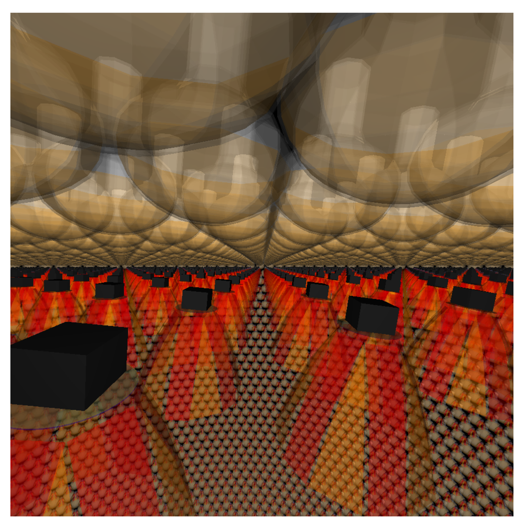
- Chroma [2,3] is a Python package for tracking photons on a GPU.
- Provides a full optical simulation for triangular mesh geometries
- Uses Geant4 to generate optical photons from physical interactions.
- Can directly import CAD drawings, defining optical properties on the mesh.



The 3D printed dichroicon holder CAD drawing rendered as a Chroma geometry.

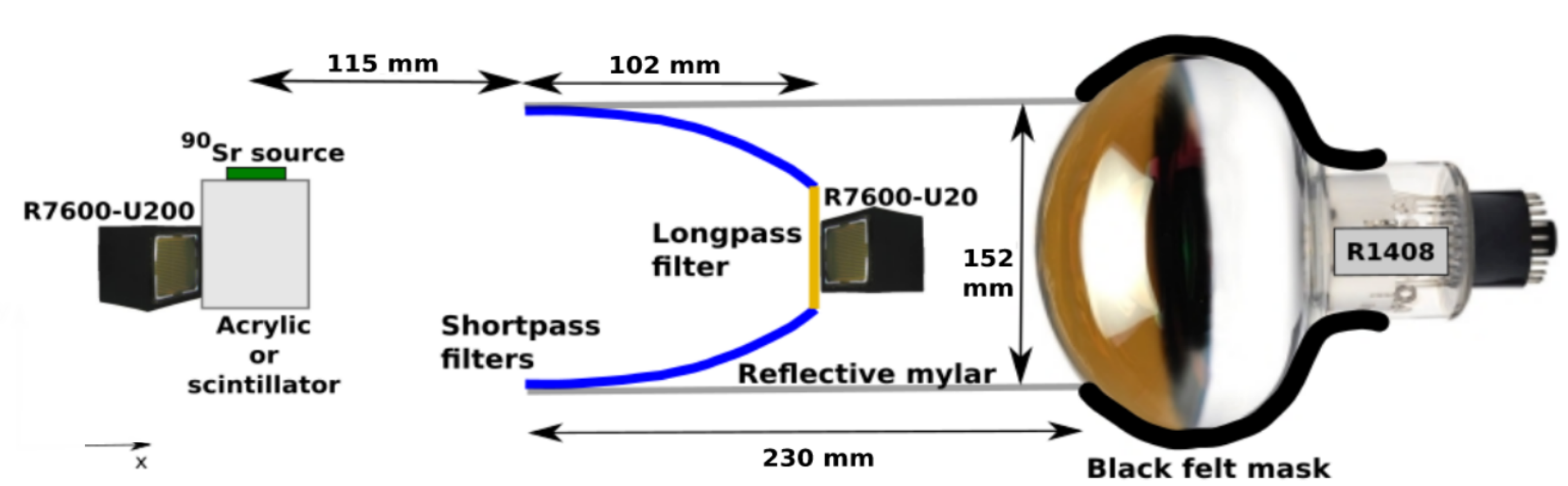


A custom dichroic filter model was developed for Chroma to capture the measured behavior of the filters [1].

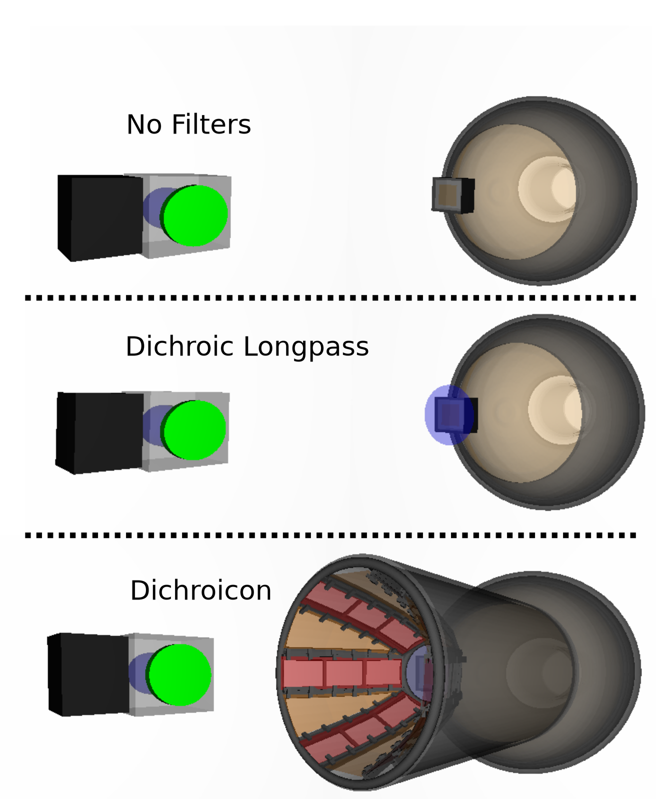


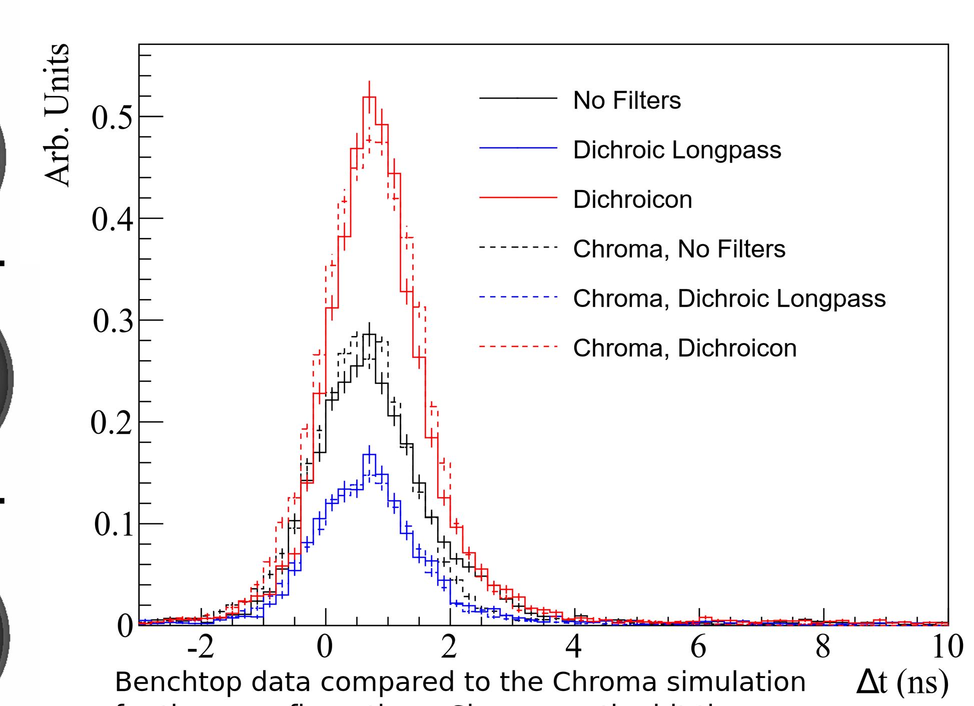
Example of a more complicated detector design based on Dichroicon-like detectors.

Calibration with Benchtop Model



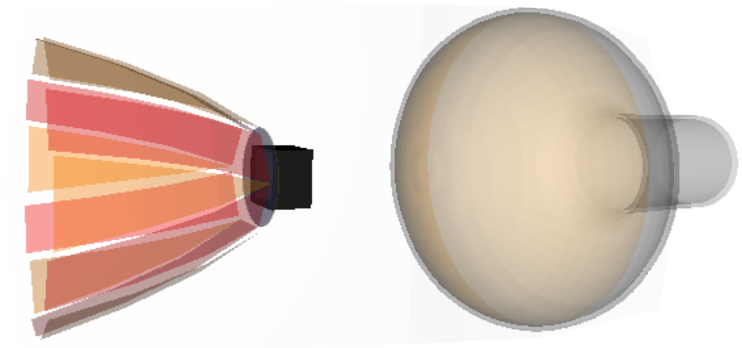
- Cherenkov collection efficiency in Chroma model calibrated to match experimental measurements with setup above.
- Calibrated simulation reproduces timing distributions and relative intensities of all three configurations below.
- Using this model, we can create larger detectors in simulation.

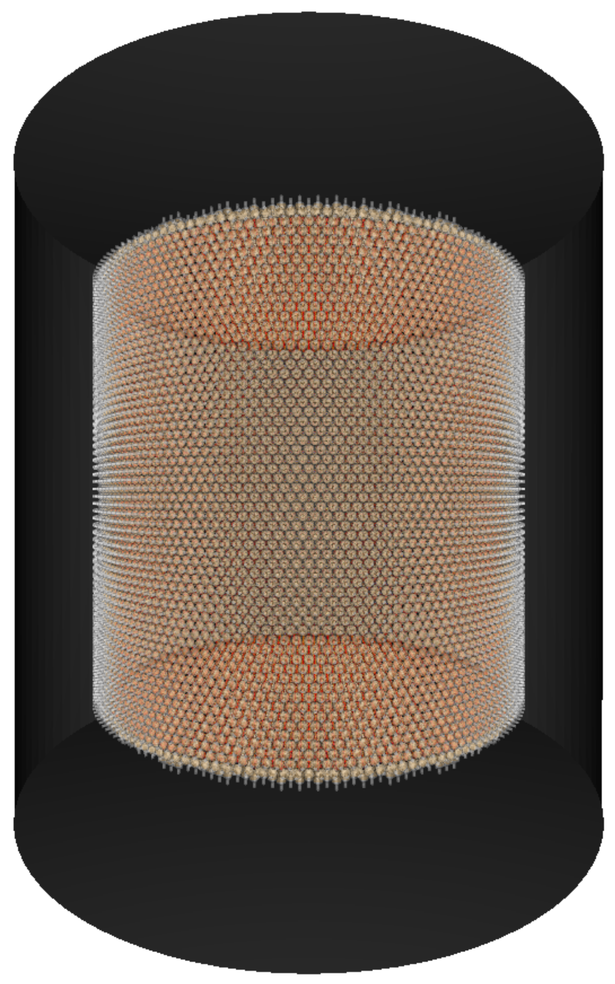




Benchtop data compared to the Chroma simulation for three configurations. Shown are the hit time residuals of the long-wavelength PMT.

Large Neutrino Detector Simulation





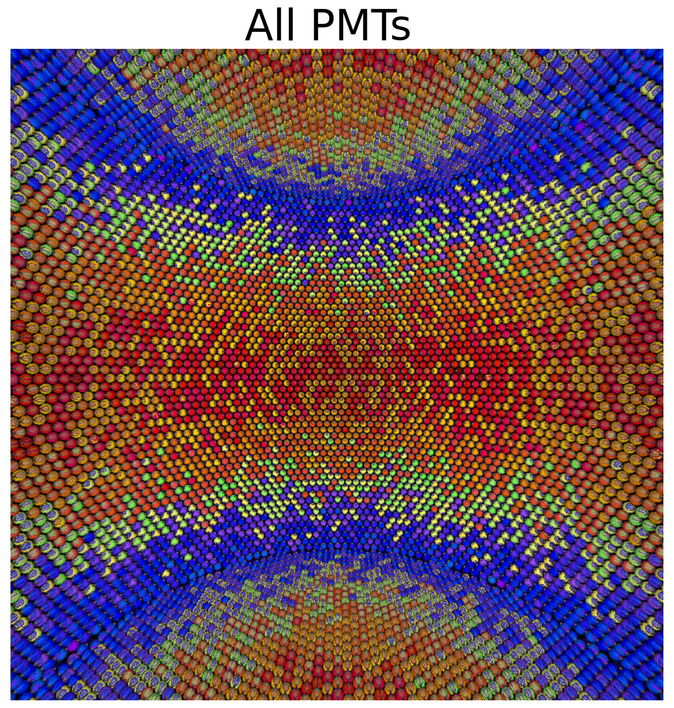
- 25 kT right cylinder detector modeled with Chroma (right)
- 90% (concentrate area) coverage of simplified Dichroicon model (above)
- Liquid scintillator targets like LAB with 2 g/L of PPO being explored.

10-MeV Event Visualization

- A single 10-MeV electron simulated at center towards far side.
- Event viewer below shows PMTs colored by hit time on far side.

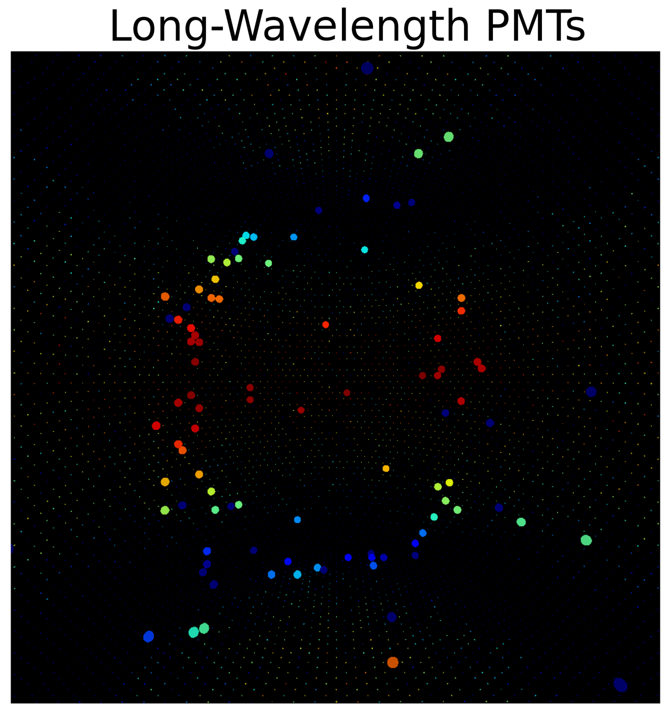
Prompt Photons — Late Photons

All PMTs



A view showing all PMTs, which is dominated by scintillation light. The observed time distribution is primarily due to the cylindrical geometry.

Long-Wavelength PMTs



A view where the long-wavelength PMTs are shown much larger than short-wavelength PMTs. Here the Cherenkov ring is clearly visible, despite the much higher sicntillation intensity.

Conclusions

- A fast Chroma simulation of a Dichroicon has been developed and calibrated against a bench-top setup.
- This model can be used to build and evaluate 25+ kT detectors with liquid scintillator targets like LAB with 2g/L PPO.
- Simulations indicate excellent identification of Cherenkov photons, which could enhance event reconstruction and background rejection in future detectors.

[1] "Spectral photon sorting for large-scale Cherenkov and scintillation detectors" Phys. Rev. D 101, 072002
[2] Chroma whitepaper https://chroma.bitbucket.io/_downloads/chroma.pdf
[3] Chroma updated for Python3 and modern systems https://github.com/BenLand100/chroma