Snowmass2021 - Letter of Interest

SPECTRAL PHOTON SORTING WITH THE DICHROICON

IF Topical Groups: (check all that apply □/■)

□ (IF2) Photon Detection/(NF10) Neutrino Detectors

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Abstract: We describe here a new device, the “dichroicon,” capable of sorting photons by wavelength in large-scale detectors. The dichroicon is a Winston-style light concentrator built out of dichroic filters. The ability to sort photons by wavelength has a range of applications, including correction for photon dispersion in large-scale detectors, the discrimination of Cherenkov and scintillation light in liquid scintillator or water-based liquid scintillator detectors, and new handles on particle ID. We show here some of the excellent Cherenkov/scintillation discrimination between Cherenkov and scintillation photons achieved with a low-energy source on the benchtop, using high light-yield LAB-PPO scintillator.

There is a rich history of discovery for detectors that use photons as their primary detection method Typically such detectors use a target medium in which Cherenkov or scintillation light is produced, viewed by an array of photon sensors. Most often these photon-based detectors record no more than the number of detected photons and their arrival times. But photons may also carry information about physics events in their direction their polarization, and their wavelength.

We present here a device (the "dichroicon") that is capable of providing information on photon wavelength in a large-scale detector [1]. Spectrally sorting photons provides information about event position (via dispersion), and in a scintillation detector leads to the ability to distinguish broad-band Cherenkov and narrow-band scintillation light, thus providing good directional reconstruction while retaining the narrow energy resolution provided by scintillator. Discrimination between Cherenkov and scintillation light also provides a way of removing low-energy α and β-α backgrounds by looking for the absence of Cherenkov light.

As shown in Figure 1 below, the dichroicon follows the off-axis parabolic design of an ideal

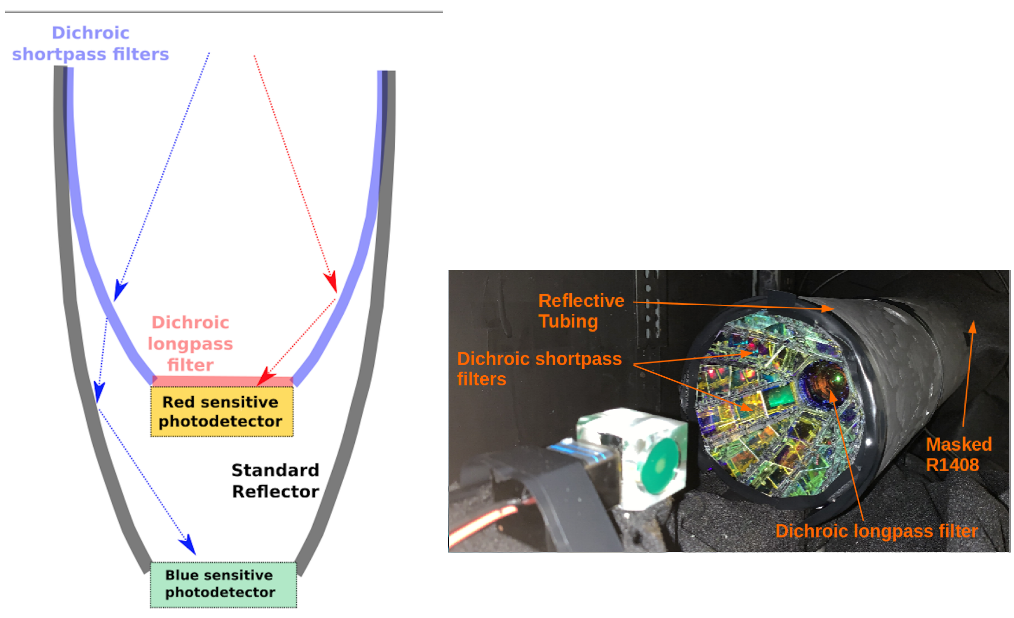

FIG. 1. Left: Schematic of a "nested" dichroicon configuration, with shortpass filters on the barrel and a longpass filter at the aperture. Right: Dichroicon in benchtop test setup, viewing ^{90}Sr source embedded in an acrylic block containing LAB-PPO.

Winston light concentrator but is built as a tiled set of dichroic filters. The filters are used to direct long-wavelength light towards a central red-sensitive PMT, while transmitting the shorter wavelength light through the "barrel" of the Winston cone to secondary photodetectors. This is possible because of the remarkable property of the dichroic reflectors, which reflect one passband of light (below or above a 'cut-on' wavelength) while transmitting its complement, with very little absorption. As shown schematically in one possible design in Figure 1, the barrel of the dichroicon is built from shortpass dichroic filters (cutoff wavelength near 480 nm) and a longpass dichroic filter is placed at the aperture of the dichroicon. The shortpass filter passes short-wavelength light while reflecting long-wavelength light; the longpass has the complementary response. In the "nested" design shown, the back PMT detects the short wavelength light.

Tests using a low-energy (^{90}Sr) radioactive source in high light-yield LAB-PPO scintillator show extremely good "purity" (over 90%) for the dichroicon's ability to identify Cherenkov light as distinct from scintillation light. The left panel of Fig. 2 shows the prompt Cherenkov peak seen in

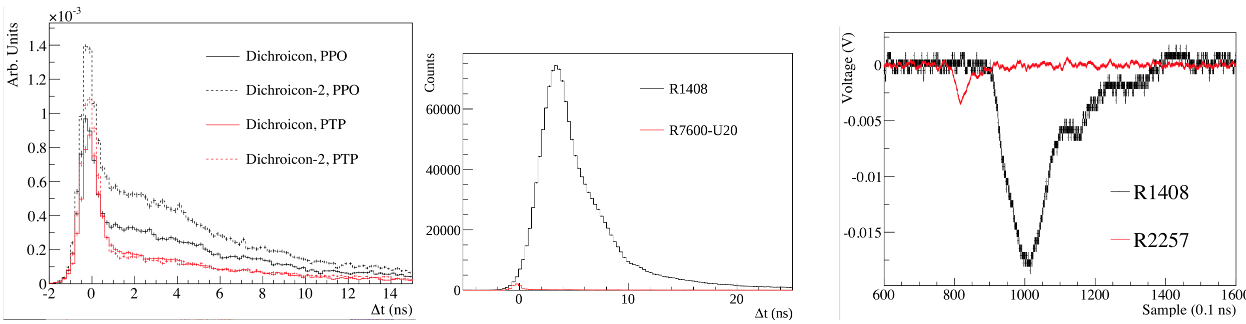

FIG. 2. Left: Time profile of light that is reflected by dichroicon through aperture, dominated by Cherenkov light. The plot shows two different dichroicon models, for two different secondary fluors (PPO and PTP) in LAB. The prompt Cherenkov peak can be seen, with some leakage of slower scintillation light. Middle: Timing profile for scintillation light (black curve) compared to Cherenkov light (red curve), normalized by the total number of events. Right: Coincidence between a Cherenkov photon (red trace) measured by aperture PMT (R2257), with multiple scintillation photons detected by back (shortpass) PMT (R1408).

the long-wavelength (aperture) dichroicon peak, and the middle panel compares the timing of the photons observed in the back ("scintillation") PMT (R1408) to the timing of photons in the aperture ("Cherenkov") PMT, normalized by the number of events and thus representing the observed ratio of short-wavelength scintillation light to long-wavelength Cherenkov light. The right panel shows a single coincidence between a Cherenkov photon in the long-wavelength PMT and the multi-photons in the scintillation PMT.

There are many possible configurations of the dichroicon; the ones built to date are not necessarily optimal, and different detectors may have different needs. The nested photon sensor configuration of the design above requires more than one photon sensor and is thus most useful when the available detection area is limited (for example, when the desired coverage is $> 50\%$, or in a segmented detector where each segment is viewed by a single sensor). Simpler designs could simply offset the dichroicon and its aperture PMT, collecting the low-yield Cherenkov photons while allowing the scintillation light to be detected by the rest of the PMT array. Using a pixelated photon sensor, such as an LAPPD or an array of SiPMs, would also work, with the pixels then mapping to different wavelength bands. A complementary design——with Cherenkov light passing through the barrel and scintillation light reflected toward the aperture——might be most useful when ring imaging is a high priority. To achieve more than two passbands, the "nested" design could be extended using mutliple dichroicons.

In addition to the applications already mentioned, we encourage researchers to look for new places where spectral sorting provides additional handles on the physics reach of particle physics detectors. It is clear that with the dichroicon, a truly hybrid Cherenkov/scintillation detector can be built without the kind of compromises on scintillation light yield that come with "thin" scintillators, or the loss of timing that are associated with slow fluors.

[1] T. Kaptanoglu, M. Luo, B. Land, A. Bacon and J. Klein, "Spectral Photon Sorting For Large-Scale Cherenkov and Scintillation Detectors," Phys. Rev. D **101**, no.7, 072002 (2020) doi:10.1103/PhysRevD.101.072002 [arXiv:1912.10333 [physics.ins-det]].