Snowmass2021 - Letter of Interest

CHESS

NF Topical Groups: (check all that apply □/■) □ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
□ (NF4) Neutrinos from natural sources
□ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
□ (NF7) Applications
□ (TF11) Theory of neutrino physics
□ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
□ (Other) *[Please specify frontier/topical group(s)]*

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Abstract: We describe here the CHESS experimental setup, originally designed to perform measurements of Cherenkov and scintillation separation in liquid scintillator and water-based liquid scintillator (WbLS). Given the advanced DAQ system, well-understood setup, fully constructed analysis chain, and associated, detailed Monte Carlo, CHESS is an ideal experiment to continue to perform measurements of ultra-fast photosensors, new scintillating target materials (including WbLS and slow scintillators), and instruments that enhance photon detection, such as the dichroicon. These studies will allow characterization and optimization of crucial technologies for future neutrino experiments, such as THEIA and AIT-NEO.

Future large-scale scintillation-based neutrino detectors, such as THEIA [1], will utilize ultra-fast photosensors, state-of-the-art liquid scintillators, and other emerging technologies. The CHErenkov / Scintillation Separation (CHESS) setup is a multi-purpose experimental setup located at LBNL [2, 3], originally constructed to demonstrate the separation of Cherenkov and scintillation light emitted by various liquid scintillators. Going forward, CHESS can be utilized to perform measurements with several developing technologies, including WbLS [4, 5] and the dichroicon [6], to expand and improve Cherenkov and scintillation separation, as well as provide a small-scale test bed for a broad range of new technologies — complementary to related efforts, such as the FlatDot setup [7].

The CHESS setup, shown in the Figure 1 (left), is distinctly equipped for performing many of the important measurements necessary to demonstrate the capabilities of emerging technologies critical to the success of next-generation liquid scintillator-based experiments. The experimental setup has been successfully calibrated, and the results have been compared against a detailed Monte Carlo simulation built using the open-source RAT-PAC software [2]. Additionally, the CHESS DAQ is capable of providing synchronous, fast-digitization of more than 100 channels, the data from which is analyzed using an existing, verified analysis chain. This allows for easy deployment of multiple LAPPDs [8], or relatively large arrays of low-TTS photomultiplier tubes. Using the latter approach, various WbLS mixtures have been characterized [9], providing measurements of both the emission time profiles as well as the light yields, by direct comparison to microphysical simulation. The capability to perform measurements using both high energy cosmic rays [3] and low energy radioactive sources [9] has been demonstrated, which span the energy scales relevant for both long-baseline physics and neutrinoless double beta decay searches. Overall, CHESS-based measurements provide crucial input to sensitivity studies performed for next-generation detectors such as THEIA [1, 10].

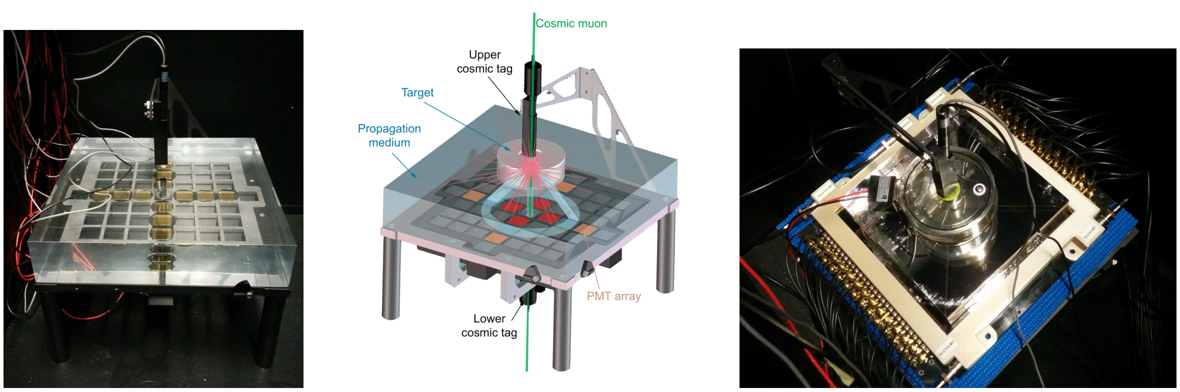

FIG. 1. (Left and center) The CHESS setup to demonstrate Cherenkov and scintillation separation using a variable target material and cosmic muons as source. The target volume is filled with water, WbLS, or liquid scintillator. (Right) A similar setup, where the PMT holder, designed to accomodate 53 1-inch square PMTs, is exchanged for an LAPPD.

With the rising availability of ultra-fast large-area photodetectors, such as LAPPDs, the characterization of these devices is a critical step to their eventual deployment. The CHESS PMT array can be easily replaced with an LAPPD, as shown in Figure 1 (right). Using CHESS, the roughly 50 ps timing of LAPPDs [11–13] enables a precision testbed for measuring the time profile of liquid scintillators. The spatial pixelization inherent to the LAPPD design allows for attempts to image Cherenkov rings simultaneous with the detection of scintillation light. In addition to LAPPDs, future large-area PMTs can be deployed in existing support structures, to view the target from above. This provides an opporunity for testing the performance of next-generation fast, large-area PMTs [14, 15] in combination with different target materials.

Additionally, because the target material in CHESS can be easily changed, the fast-timing response and well-calibrated setup provides an ideal method for both emission time profile and light yield measurements of future scintillators. WbLSs are being considered for use in THEIA, AIT-NEO [16], and ANNIE [17], and can be quickly and effectively characterized using the CHESS setup. Other classes of scintillator, such as slow scintillators [18–20] or metal-loaded scintillators [21, 22], potentially useful in neutrinoless double beta decay experiments, can also be studied.

A particularly novel use for CHESS is to perform measurements with the dichroicon [6, 23], a device designed to spectrally sort photons towards different photosensors. The dichroicon separates Cherenkov and scintillation light by taking advantage of the broad-band nature of the Cherenkov light. The CHESS setup provides an ideal sensor geometry for detecting the photons sorted by the dichroicon. With the dichroicon placed above the PMT array, the central PMTs can be used to detect the long-wavelength Cherenkov light, while the outer PMTs can be used to detect the short-wavelength scintillation light. With the inverted dichroicon design (central shortpass dichroic filter) the outer PMTs can be used to ring-image a pure sample of the transmitted Cherenkov light. Thus, CHESS provides a method for optimizing the dichroicon geometry, optical filter type, and filter orientation. Simulation efforts for the dichroicon in CHESS will develop in parallel, to be tuned against the data and used to understand the dichroicon's impact for future large-scale detectors.

Lastly, the CHESS experiment can also the study particle identification (PID) capabilities of various scintillators, and across a variety of experimental geometries. Such a characterization would investigate the common β^- / α separation expected from quenching of the scintillation time profile, but also the ability to discriminate β^+ against β^-, which would enhance inverse beta-decay-based detection of reactor neutrinos, and n / γ discrimination, of interest to the nuclear engineering community. To do so, CHESS will utilize state-of-the-art timing, provided either by a fast PMT array or an LAPPD, to detect small differences between the time profiles of single- and multi-site depositions [24], or electrons and annihilation γ-rays. Additionally, differences in the total amount of Cherenkov light produced can be used as an additional discriminant, which can be further exploited by the deployment of the dichroicon. Ultimately, the PID measurements, which are to be performed across different target materials, will utilize all of the various technologies available for use in CHESS, and will require further Monte Carlo validation.

In summary, the CHESS setup provides a proven facility to test fast photodetectors, characterize future scintillator mixtures, and, generally, provides a flexible test-bed for emerging technologies. The measurements described above are critical for the construction of future detectors, such as THEIA, that will leverage new technologies to perform important physics measurements. We encourage and welcome future collaboration with those interested in the capabilities provided by CHESS.

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