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APEX Design and VD Technology for DUNE FD3

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DUNE needs 40 kilotons of LAr fiducial mass to achieve its core CPV physics goal specified in the 2014 P5 report. To complete the fiducial mass, the DUNE phase 2 program requires two more FD modules in addition to FD1 and FD2. The construction of phase II FD3 is endorsed in every budget scenario in the 2023 P5 report. DUNE envision its phase II FD3 with a much more capable photon detection system than its phase I FD. The most reliable path towards this vision is to optimize the existing technologies in FD2 (VD). In this talk, we present the APEX (Aluminum Profiles with Embedded X-arapucas) design where we will instrument the Phase II DUNE FD3 with large-area X-arapuca photodetectors on the entire LArTPC field cage. The photon detectors will cover four vertical walls of the LArTPC volume, with an optical area coverage up to 2000m^2. This offers DUNE improved event reconstruction, better timing and energy resolution, enhanced background rejection capability, and improved physics reach across GeV and MeV energy region. Furthermore, this light detection system can be combined with all proposed phase 2 charge readout concepts.
The PoF (power over fiber) and SoF (signal over fiber) technologies developed and successfully demonstrated in DUNE VD make detector and electronics deployment on high voltage field cage surface possible. Despite this, the scaling up of the photodetectors to thousands of square meters as well as integrating with the LArTPC field cage structure poses challenges to mechanics and electronics. One particular challenge is understanding how the instrumented PD modules interplay with the LArTPC E field. To address this, we performed a material charge-up test in a small TPC system at the surface environment. The PoF and SoF require multiple optical fibers to supply detector power and read out signals. The routing of hundreds-of-kilometers-long fibers throughout the entire field cage structure also requires new designs of the profile and field cage. The large area detector also puts higher requirements on detector production cost and efficiency, and prompt us to optimize detector design while maintaining comparable detection efficiency as phase I FD.

The scaling up of the photon detectors also drastically increases the number of readout channels. This brings challenges to the power consumption of cold electronics and signal readout bandwidth. In response to these challenges, we proposed a new PoF design that can supply the high SiPM bias for many PD modules sitting on equipotential FC profiles. This solution will mitigate both cold readout power consumption challenges and noise problems. A wavelength-division multiplexing solution in combination with a novel ring resonator modulation technology that offers hundreds of GB/s readout ability is proposed and being pursued to address the signal readout bandwidth problem. The signal amplification and digitization with in-house designed ASICs are also proposed to reduce the cost and power consumption. Staged prototype plans to address these development goals will be presented at the end of the talk.

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