Developing Detectors for Scintillation Light in Liquid Argon for DUNE

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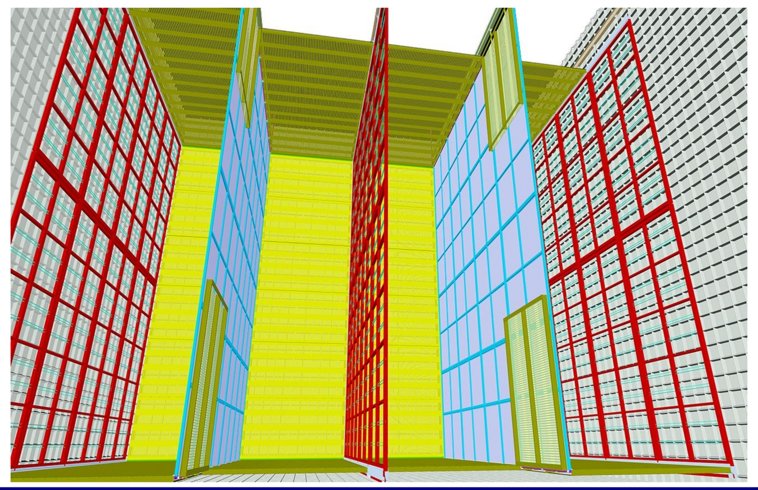
on behalf of the DUNE collaboration

INDIANA UNIVERSITY
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

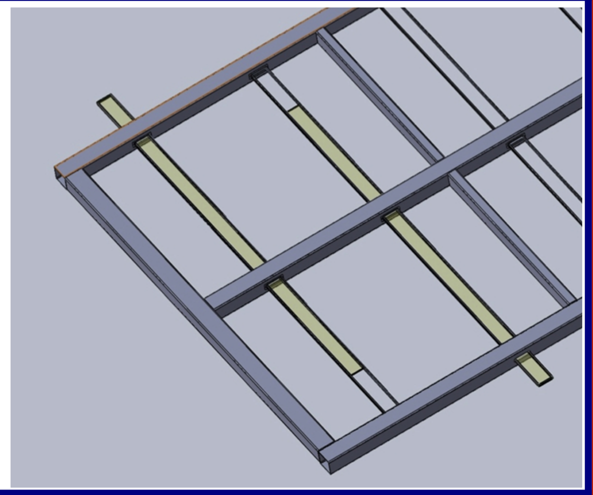
The Deep Underground Neutrino Experiment (DUNE) will measure the properties of neutrinos via a beam originating at Fermilab. Additionally, it will study non-beam physics events, including atmospheric neutrinos, neutrinos from supernovae, and nucleon decay. To perform these studies, a far detector consisting of four 10kt fiducial mass liquid argon (LAr) time-projection chambers (TPCs). The passage of charged particles through LAr will produce electrons which will drift in an applied field to a readout plane. Their propagation also induces scintillation light from LAr at 128nm. Detecting this light can be used to precisely determine event times within the TPC volumes, providing ~mm spatial resolution in the drift direction [1]. The baseline for the DUNE single-phase design consists of wavelength shifters which convert VUV light to visible wavelengths and light-guides to transmit converted photons to a readout system via total internal reflection [1].



Illustrations showing the layout of elements in the DUNE single-phase detector [1]:

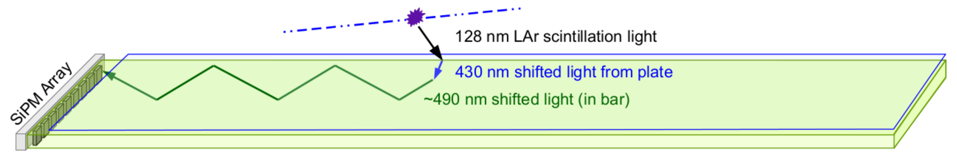
Left) Drift volumes showing anode plane assemblies (APAs) in red, cathode plane assemblies (CPAs) in blue, and a field cage

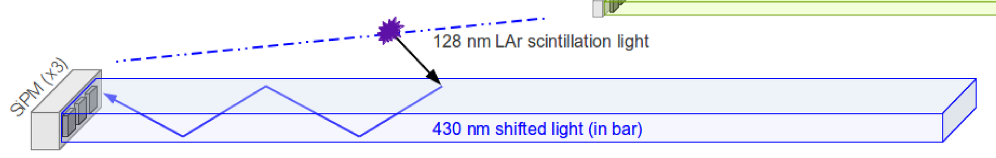
Right) The DUNE single-phase photon detection system slides into the APA.



Photon Detection System Design

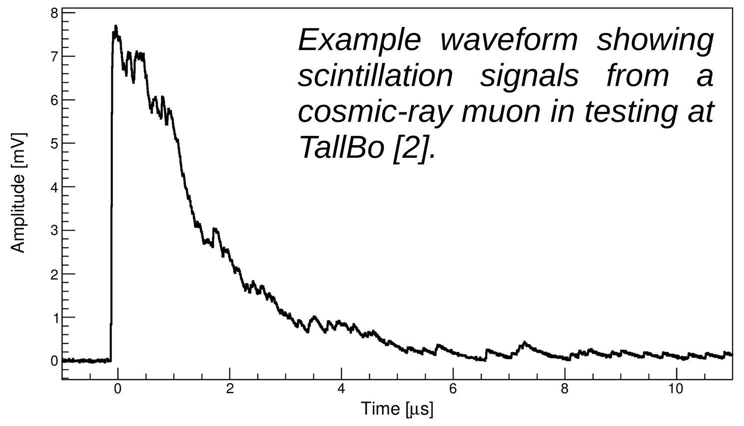
- Light-guides for single-phase design in anode plane, behind TPC wires
- Two main light-guide styles currently under active investigation:
  - Plates coated in wavelength shifter (such as tetraphenyl-butadiene [TPB]) sit in front of system to convert 128nm light, some of which is incident on light guides doped with a second wavelength shifter. Light converted there is then totally internally reflected to readout
  - Light-guides dipped in a solution containing TPB. Wavelength shift from 128nm happens in bar and converted light is totally internally reflected to readout





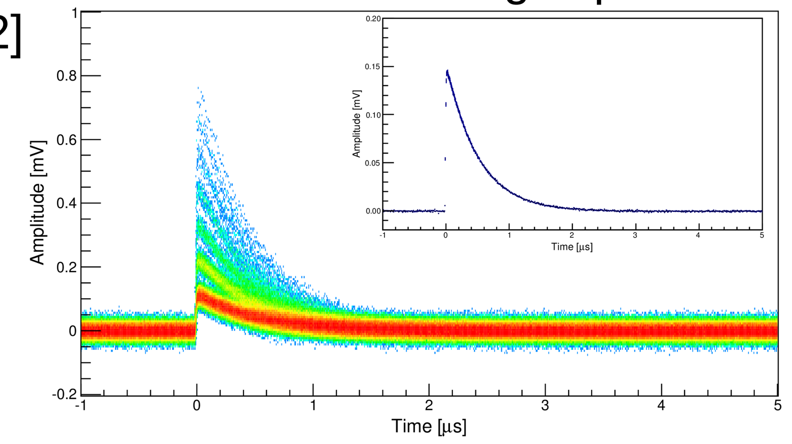
Above is a cartoon of design using wavelength-shifting plates (courtesy Denver Whittington). Left is a cartoon of the dipped design [2].

- Photons read out by silicon photo-multipliers (SiPMs). Array of SiPMs covers much of readout end.
- SiPM signals read out by custom digitizer. Record waveforms from events within LAr volumes.
- Waveforms collected show clear prompt and late light, as LAr scintillates with singlet and triplet components [2]



Example waveform showing scintillation signals from a cosmic-ray muon in testing at TallBo [2].

- Reading out dark noise pulses shows what raw waveforms from SiPM look like when there are only a few (and often only 1) photoelectrons (PE) digitized. This is useful in discerning aspects of the scintillation structure itself [2]

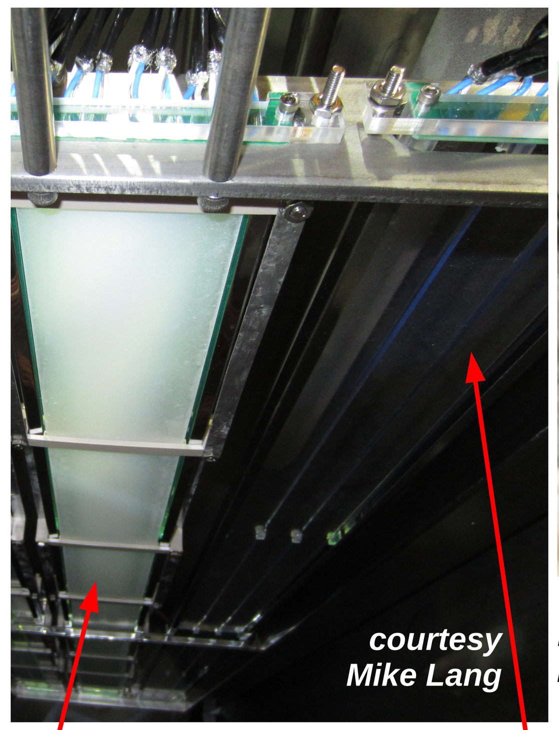


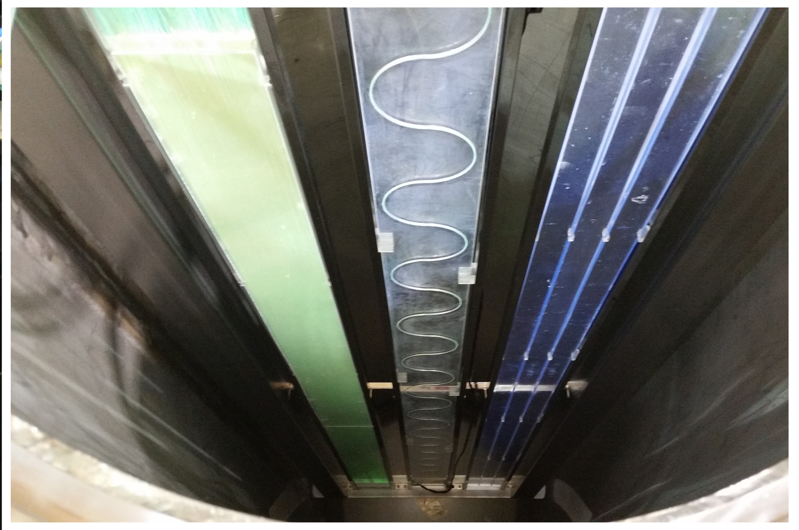
Example of dark noise pulses from an SiPM submerged in liquid nitrogen, showing the shape of SiPM signals and the ability to distinguish between photoelectron count [2].

TallBo Prototype Test Stand

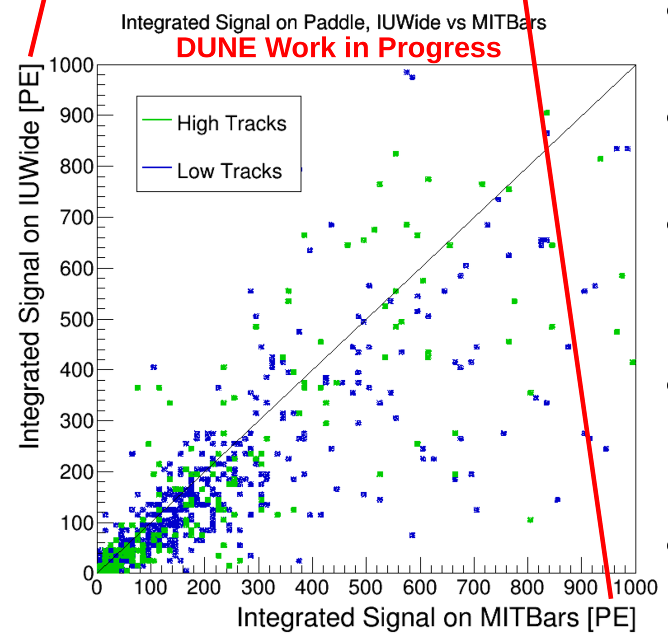
- Small-scale prototype tests necessary to evaluate performance and improve design
- Fermilab's liquid argon facility contains filtered input lines, purity monitors, and condensers to maintain consistent, low-contamination LAr volumes, such as the 84" TallBo dewar.
- PMTs on a hodoscope provide track info for through-going cosmic ray muons
- Varying hodoscope heights changes track positions and lengths through LAr volume
- Prototype light-guide based detectors produced at a number of institutions.

TallBo dewar





The picture above [3] shows several prototypes which were tested in LAr at TallBo. The two in the left picture are versions of the cartoons in the leftmost panel on this poster and were also tested in TallBo.

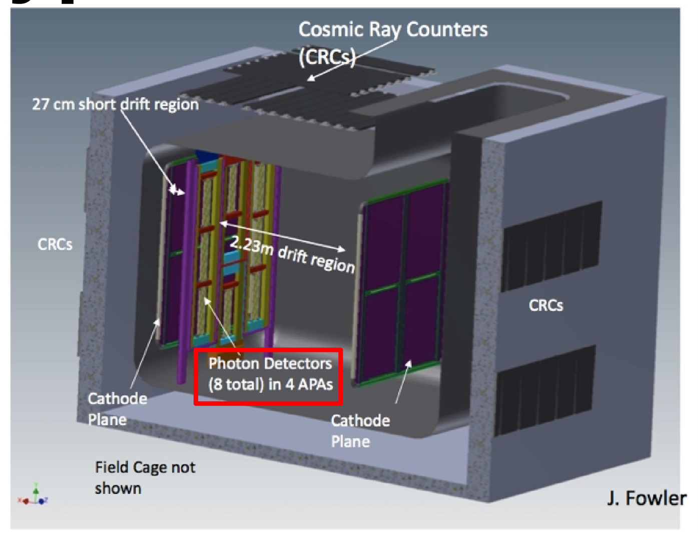


Courtesy Denver Whittington

- Testing multiple prototypes side-by-side determines relative performance
- Important in selecting best-performing technologies.
- Determine integrated photoelectrons (PE) from waveforms recorded for through-going cosmic-ray muons
- Can estimate detector efficiencies using integrated signals from tracks and expected signals in toy MC simulations.
- Recent testing at TallBo suggests that the two designs pictured above at the left perform similarly

35-ton Prototype Test

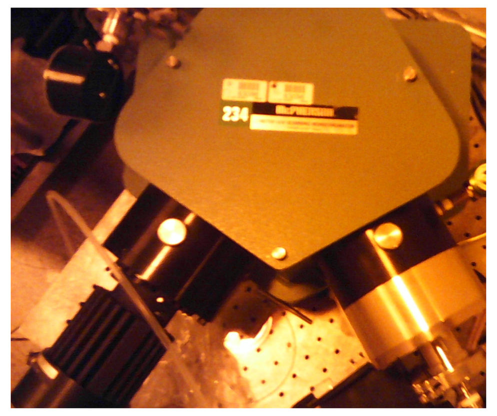
- Tested prototype single-phase photon detection technologies along with TPC elements in an LAr environment exposed to cosmic rays at Fermilab
- Two drift volumes sharing an anode
- Light-guide based technologies inside anode, w/ TPC wires wrapped around
- *Poster 413: The Design Goals of the 35-ton Liquid-argon Prototype and First Lessons Learned*



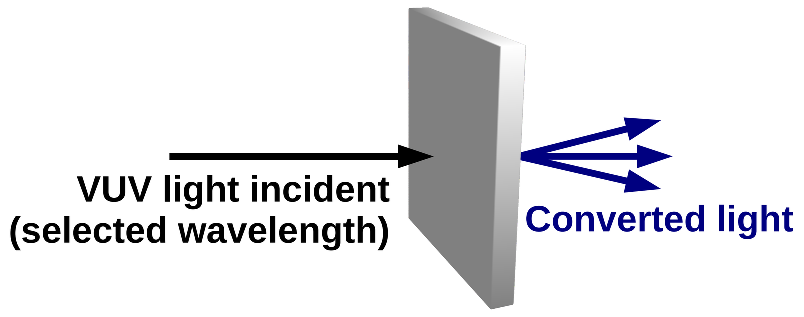
Depiction of the 35-ton prototype test conducted at Fermilab [1].

Prototype Quality Control

- Improved quality control measures aim to ensure that the most efficient prototypes are selected for constructing modules to test in LAr.
- For the design using wavelength-shifting plates to convert VUV light, compare measurements of 128nm light from a VUV monochromator incident on a sample to measurements of the resulting visible light.
- Provides quality control and efficiency measurements of wavelength-shifting plates, ensuring most efficient plates are chosen
- This will lead to an increase in performance in the photon detector design using plates



VUV monochromator used to expose samples of wavelength-shifting plates to 128nm light. A lamp produces VUV light, and selected wavelengths are then propagated to samples and detectors.



Cartoon of plate testing in a VUV monochromator. Selected wavelengths of VUV light are measured without a plate. Samples of plates are exposed to VUV light and converted light is measured.

Towards Realizing DUNE

- The continuing R&D and prototype testing aims to improve designs and explore designs that work in similar framework.
- protoDUNE single-phase prototype test at CERN will provide important feedback on the light-guide based photon detection system designs

Thanks to everyone who has been involved in developing the DUNE photon detection system!

Remember to see the other DUNE-related posters and talks at ICHEP 2016.

References:
[1] The DUNE Collaboration. *Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report.* Volume 4. (2016). arXiv: 1601.02984
[2] D. Whittington et al. *Scintillation light from cosmic-ray muons in liquid argon.* JINST 11 P05016 (2016)
[3] D. Whittington. *Photon detection system designs for the Deep Underground Neutrino Experiment.* JINST 11 C05019 (2016)