Plate and Light-Guide Based Photon Detection System Design for DUNE

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for the DUNE collaboration

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DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

New Technologies for Discovery II
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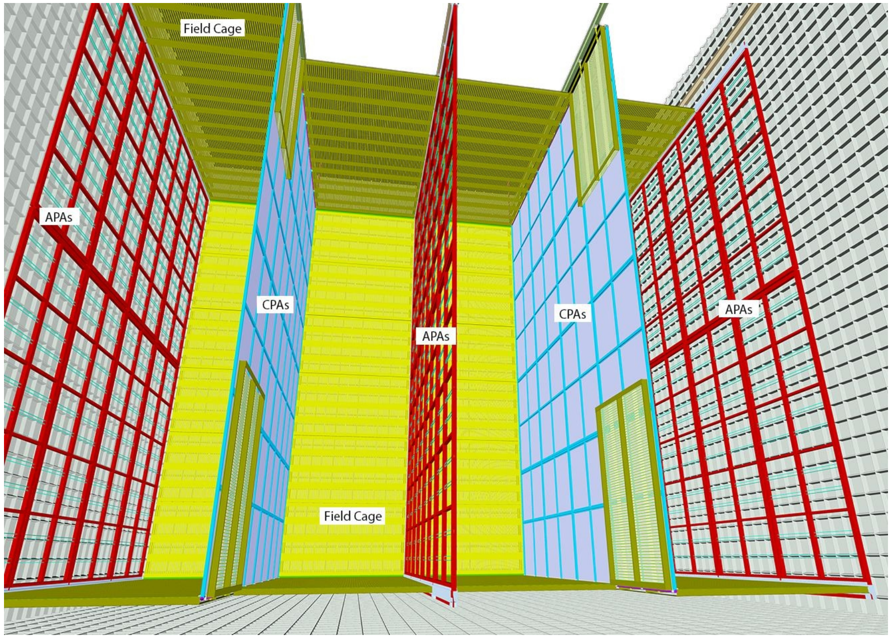
DUNE in a nutshell

- Deep Underground Neutrino Experiment
  - 40 kiloton liquid argon (LAr) time-projection chamber (TPC) far detector at Sanford Underground Research Facility in Lead, SD
  - Single- and dual-phase designs (*here focus on single-phase*)
  - High sensitivity to neutrino oscillation physics (CP-violating phase, mass hierarchy, etc.) via beam of neutrinos from Fermilab (1300 km baseline)
  - Also a large, sensitive detector for non-beam physics such as supernova neutrino studies and proton decay searches

DUNE Far Detector

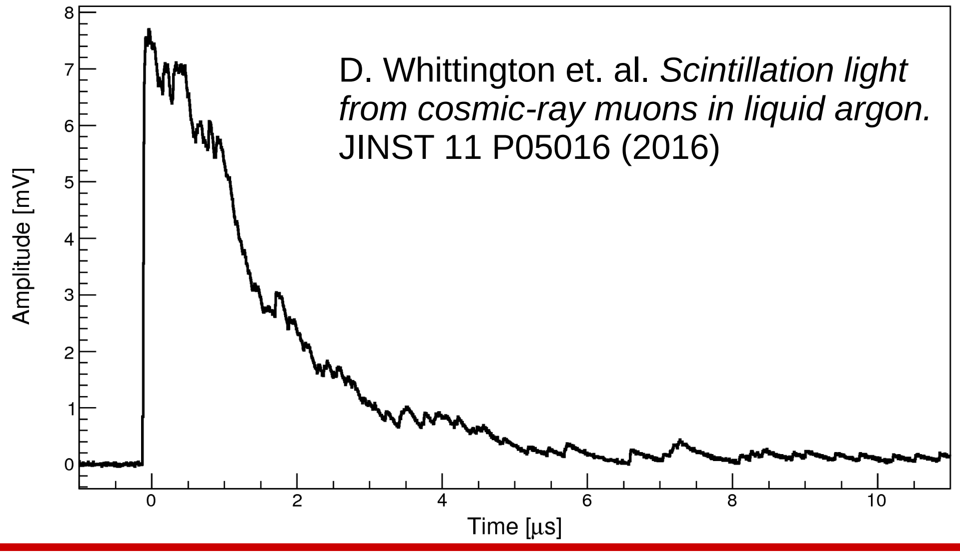
- 10kt single-phase far detector modules segmented into TPC volumes with anode and cathode planes
  - High-resolution tracking, dE/dx, calorimetry
- To precisely determine event time and correct for drift, a prompt signal comes in handy
  - Enter photon detectors (PDs)
    - provides prompt signal for t_0
  - Photon information essential for non-beam physics (e.g. supernova neutrinos and nucleon decay)



The DUNE Collaboration. *LBNF and DUNE Conceptual Design Report, volume 4 The DUNE Detectors at LBNF*. 2016. arXiv:1601.02984 [physics.ins-det]

Scintillation of liquid argon

- In addition to ionization signal, argon excites into singlet and triplet states which release photons
  - Singlet ~5ns, Triplet ~1500ns
  - High yield [e.g. T. Doke et. al. NIM A269 (1988) 291-296]
    - Yield depends on field strength [e.g. S. Kubota et. al. PhysRevB. Volume 17, number 6 (1978)], but still high
  - Challenge for PDs in LAr TPCs is to maximize spatial resolution without affecting functioning of TPC and sticking within budget/space requirements – improve photon yield (by increasing detection and cost efficiencies)
    - [B. Jones. *Scintillation Light Detection in Large Liquid Argon TPCs.* New Technologies for Discovery. CPAD. (2015)]



Motivation of photon detector design

- Doesn't affect TPC operation or take up active volume
  - Place detectors inside the anode plane, behind wires
  - Sensitivity to both sides of anode plane (each is a TPC volume). Large active area for detection.
- Use of light-guides to transport wavelength-shifted scintillation light to readout
  - Direct detection of VUV is difficult
  - Wavelength shifters (WLS) to convert VUV→VIS, which is easier to detect
    - e.g. tetraphenyl butadiene (TPB)
  - Silicon photo-multipliers (SiPMs) well-matched to light-guide dimensions, relatively low voltage, robust in cryogenic environment

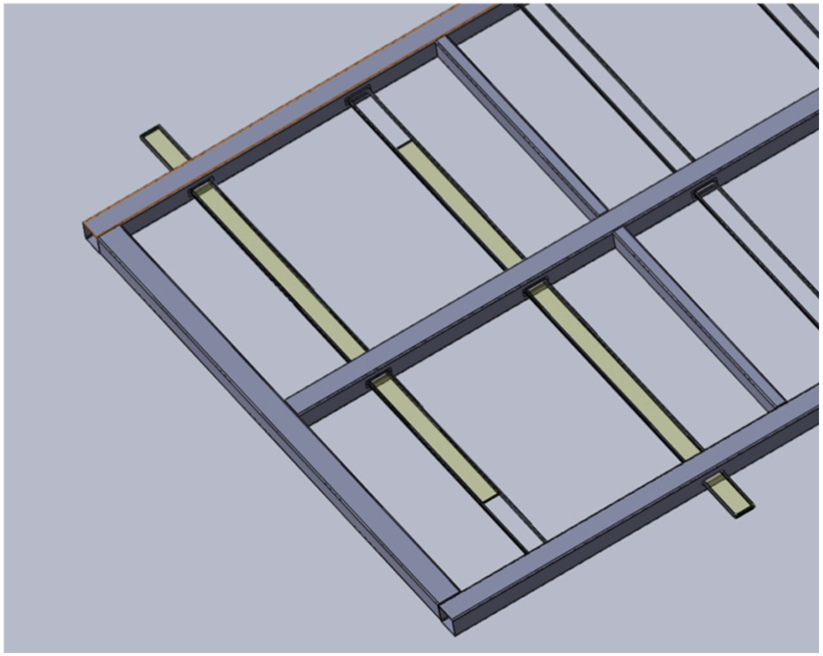


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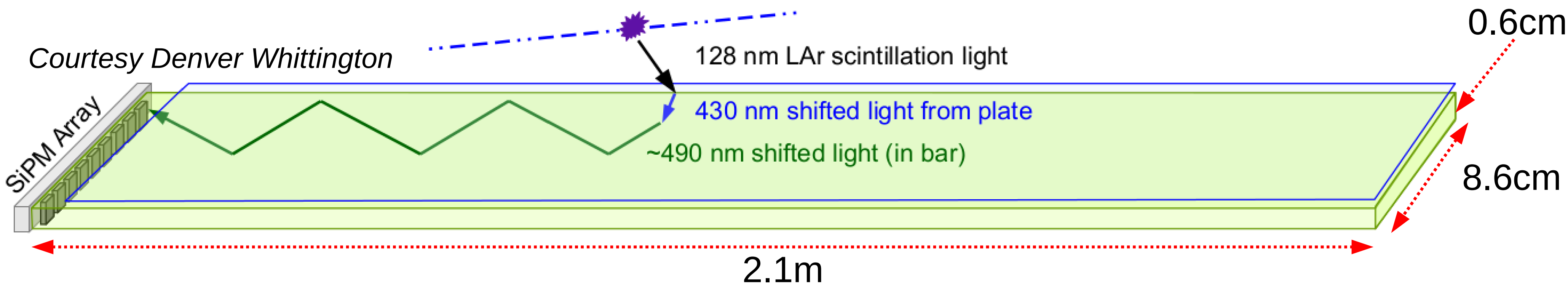
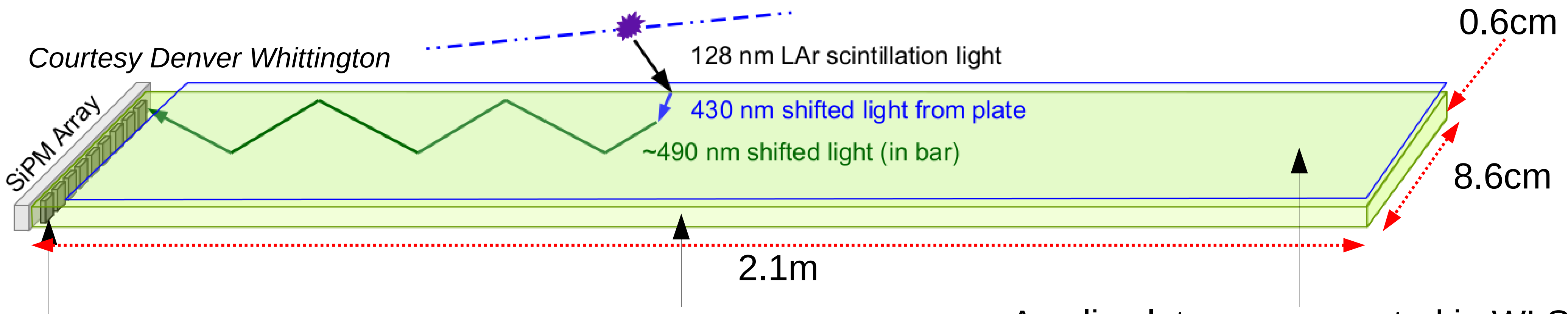
Plate and light-guide based design



- A promising design under development at Indiana University is to place a plate coated in WLS in front and in back of a wavelength-shifting light-guide
  - While it requires a second wavelength-shift, it decouples initial VUV→VIS process from the transport (attenuation length)
    - More free to optimize plate design without impacting transport to readout
  - Use commercially-produced light-guides from Eljen
    - Long attenuation length by design

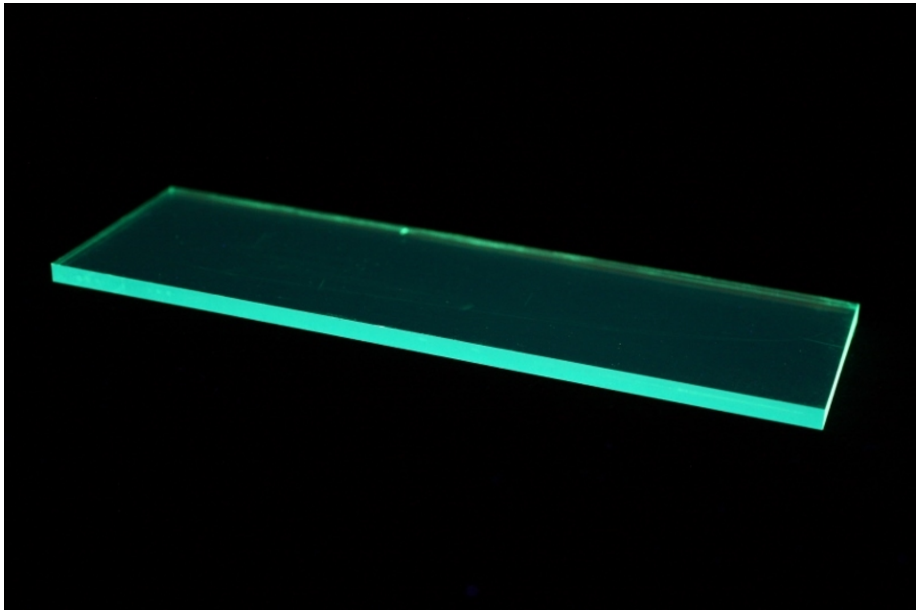
Plate and light-guide based design



SensL SiPMs (C-series)

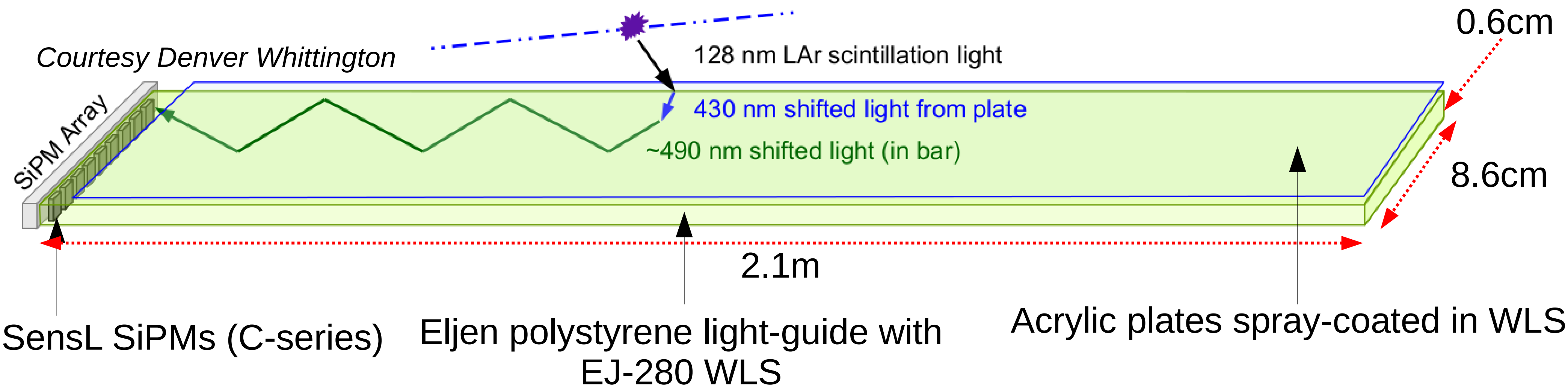
Eljen polystyrene light-guide with EJ-280 WLS

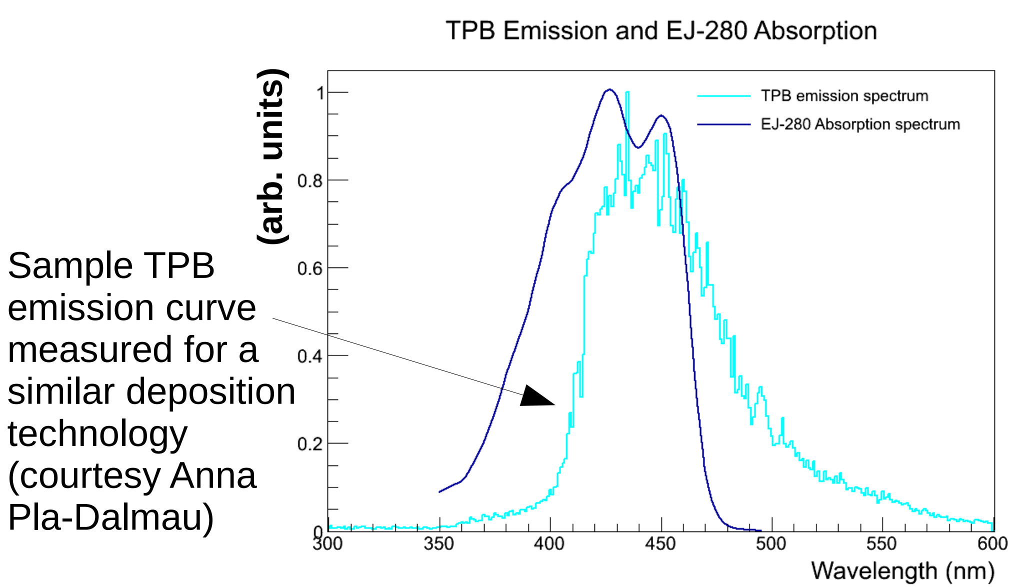
Acrylic plates spray-coated in WLS

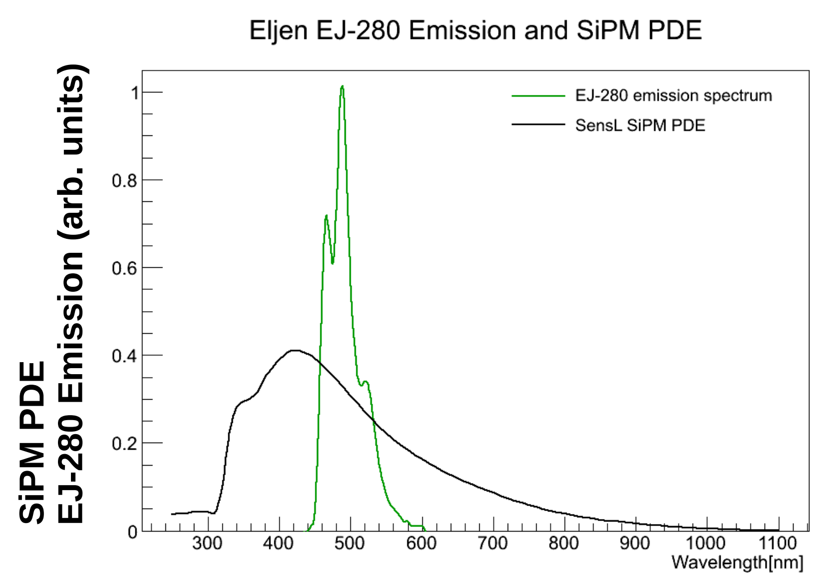


Picture from Eljen Technology: eljentechnology.com

Plate and light-guide based design



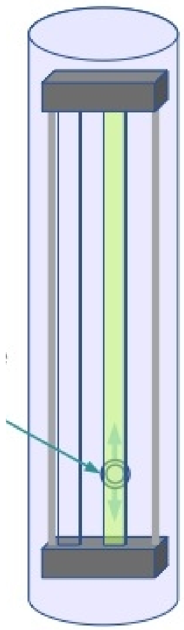


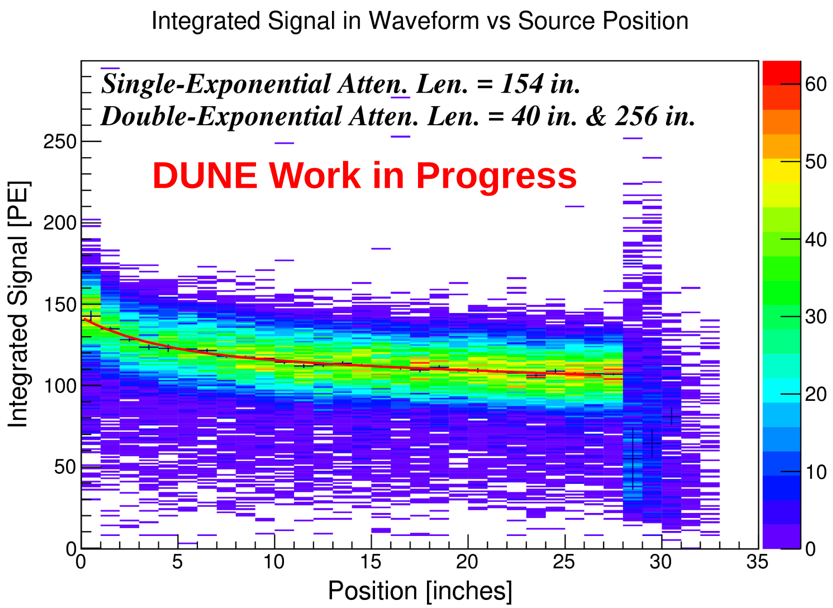


SiPM PDE curve drawn thanks to data provided by SensL and EJ-280 absorption and emission curves drawn thanks to data provided by Eljen Technology.

Testing Program

- In addition to testing of readout components, extensive R&D work is underway incorporating tests at local and national labs to demonstrate PD technology and continue to improve performance
- IU laboratory - test-benches for inspecting individual components
- Attenuation length tests: scan along EJ-280 light-guide in LAr with an alpha source behind small sample plate (travels along with the source). Consistently see attenuation lengths of order meters

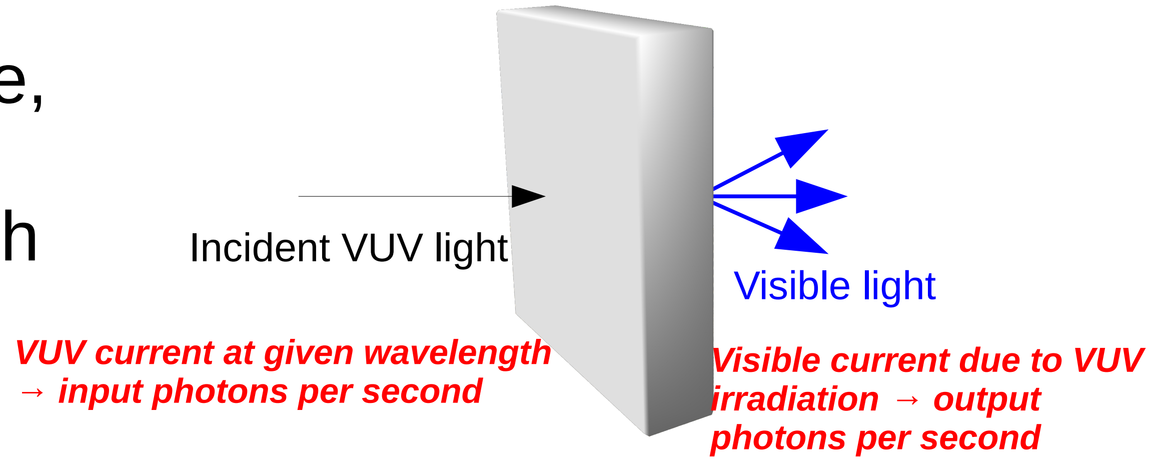


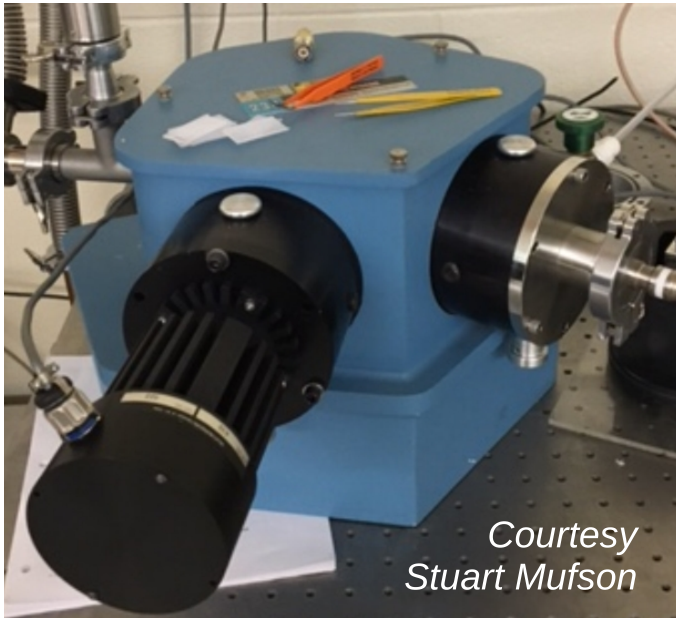


Figures Courtesy Denver Whittington

Testing Program

- VUV monochromator measurements
  - Procedure:
    1. Using VUV photodiode, measure light incident at selected VUV wavelength
    2. Measure output light with SiPM when WLS-coated plate is placed in front of output VUV
  - Ratio (2)/(1) provides plate’s relative efficiency (with corrections, provides absolute efficiency)
  - Compare WLS application methods and plate performance





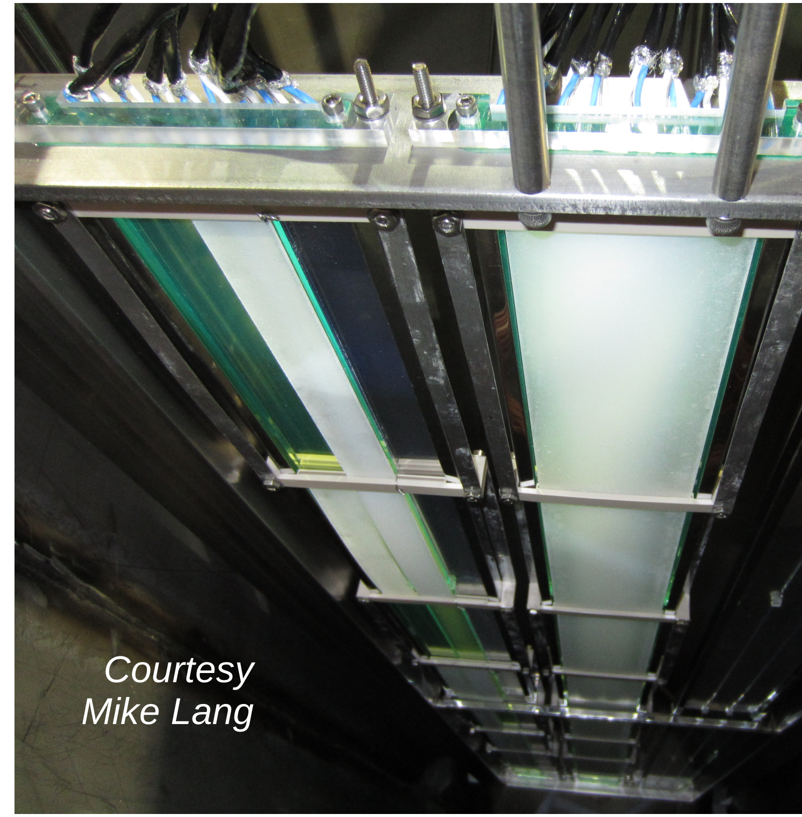
Testing Program

- Liquid argon test facilities at Fermilab
  - Have used the TallBo dewar to test scintillation detectors several times over past few years
    - Approximately 450 liters of LAr
    - Condenser to maintain level of LAr
    - Filtered input and purity monitors
  - Hodoscopes trigger readout on through-going cosmic-ray muons.
    - Four-fold coincidence between PMT arrays and scintillator paddles
    - Arrays of PMTs gives track info

Courtesy Denver Whittington

Testing Program

- Have already tested one full-width, 60” long (~1.5m) prototype at TallBo
- Tests ongoing in Blanche dewar at Fermilab
  - Blanche shorter/wider, but same infrastructure as TallBo
  - Testing full-width, 30” light-guides with improved plates selected using monochromator
    - Since we decouple attenuation length from conversion, we can test shorter prototypes
  - Further demonstrate integrated system prototypes

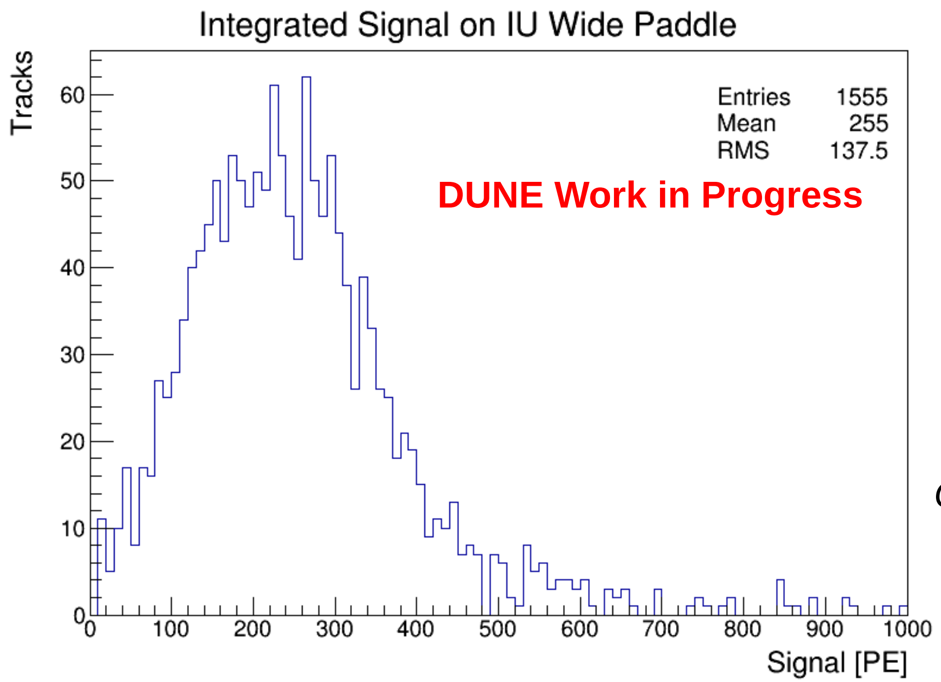


Courtesy Mike Lang

Courtesy Stuart Mufson

Testing Program

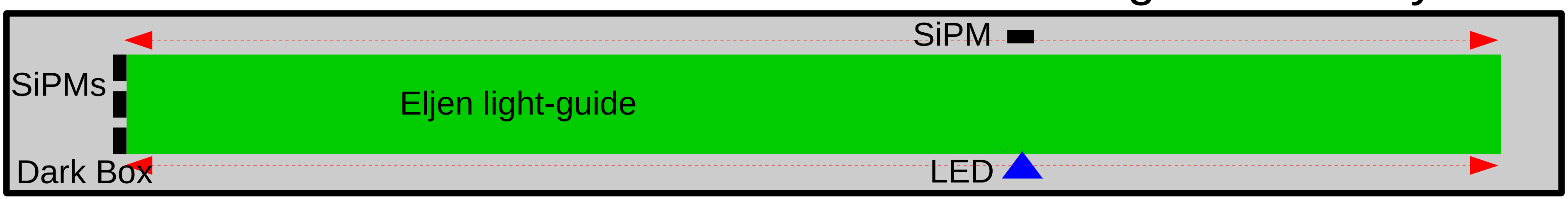
- Measure photoelectrons from cosmic-ray muons triggered by hodoscope
  - Relative efficiency in comparing technologies
    - Directly looking at photo-electron output
  - Estimate absolute efficiency using toy MC w/ track info to determine how many/where photons hit along the PD



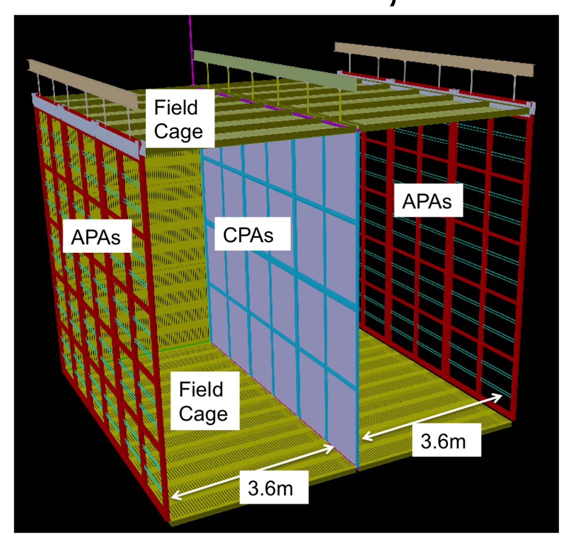
Courtesy Denver Whittington

The Path Forward

- Continue working on value engineering
  - Make most efficient plates possible
  - Pick best matching components
- Ensure quality control. For example:
  - Check in a dark box with LED for attenuation length/uniformity



  - Test samples in VUV monochromator: efficiencies, uniformity
- ProtoDUNE-SP
  - Prototype LAr TPC installed at CERN. Put full-scale plate and light-guide PDs in single-phase module.



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Conclusions

- Detecting LAr scintillation signal in coincidence with the ionization signal in TPCs gives t_0 to locate event within detector
  - Especially valuable for non-beam physics analyses (e.g. supernova neutrinos and proton decay)
- The plate and light-guide design undergoing research and development at IU provides a decoupled approach to converting and transporting signal
  - Commercial light-guides offer long attenuation lengths
  - Improving plate design improves brightness without harming attenuation
- Liquid argon testing at Indiana and Fermilab provide test benches
  - VUV monochromator and smaller local dewar allow component testing
  - Fermilab facilities have well-understood LAr environment for integrated testing
- Plan for future includes value engineering, enhanced QC, prototype testing in protoDUNE-SP