Scintillation Light Detection Performance for the DUNE ND-LAr 2x2 Modules

Anja Gauch for the DUNE Collaboration

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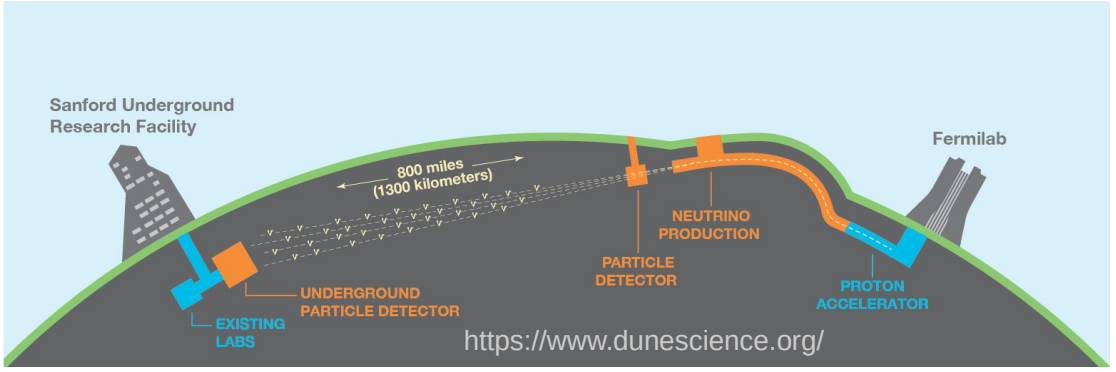
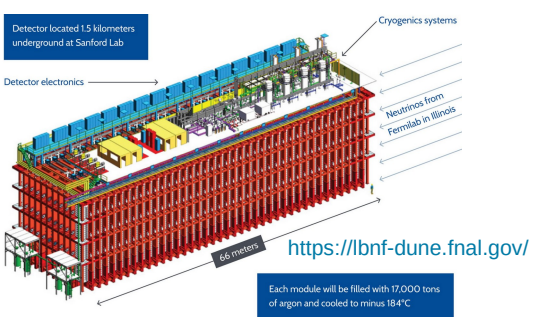
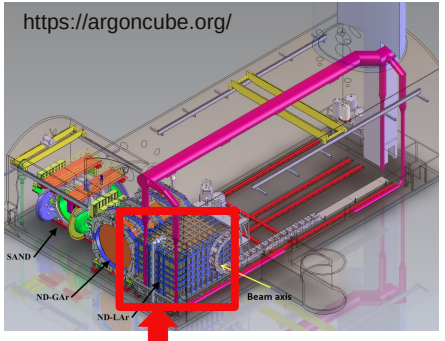
Deep Underground Neutrino Experiment - DUNE

- International experiment for **neutrino science**
- Intended to determine CP violating phase in leptonic sector and neutrino mass hierarchy
- Two neutrino detectors placed 1300 km apart in the world's most intense 1.2 MW neutrino beam
- Beam is upgradable to 2.4MW



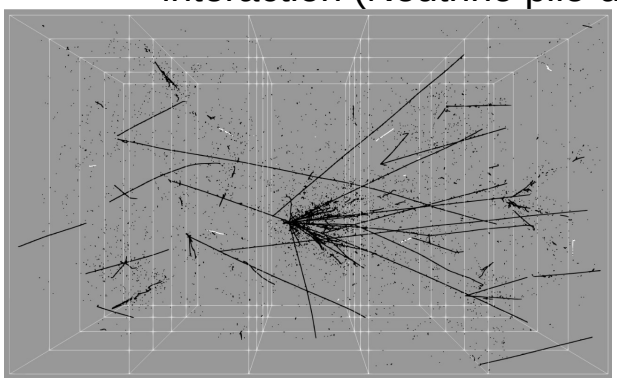




ND-LAr

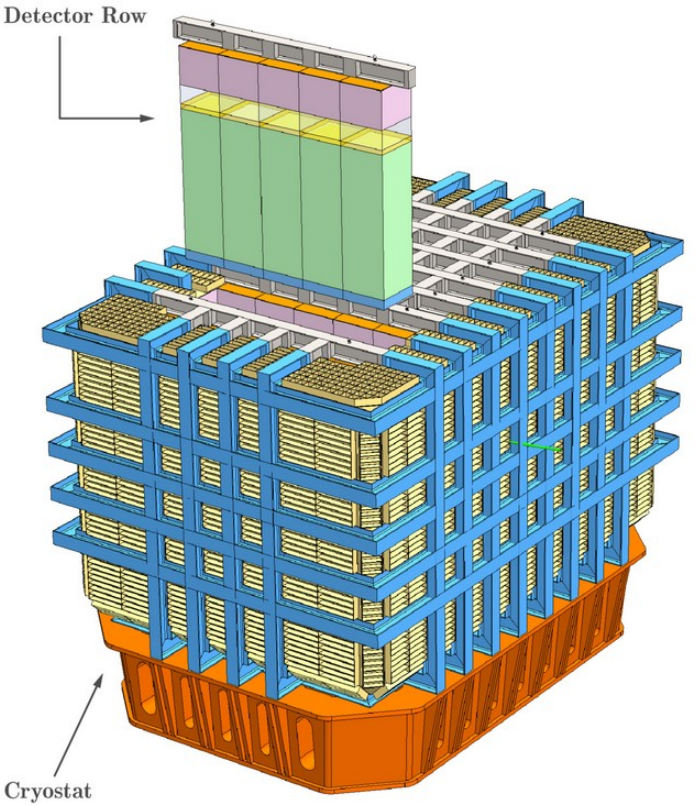
DUNE ND-LAr

- 5 by 7 optical separated modules
- Each 1x1x3 m^3
- Need modularity to increase:
  - Precision
  - Light spatial resolution
  - Associate unique charge attachment to each interaction (Neutrino pile-up)



A. Abed Abud et al. [DUNE], Instruments 5, no.4, 31 (2021) doi:10.3390/instruments5040031 [arXiv:2103.13910 [physics.ins-det]].

Beam spill in ND-LAr. Highlights the challenge of associating fast neutron induced energy deposits to a neutrino vertex



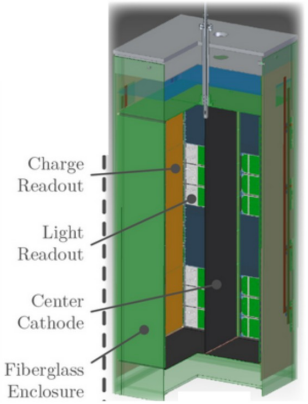
A. Abed Abud, 2021, Instruments 5, no.4, 31

Dune Near Detector Modules

- Currently, prototyping the DUNE ND-LAr Modules
- ProtoDUNE-ND is a 2x2 ND-LAr prototype
- Module-0 is the first of four modules in the 2x2 ND-LAr

Module 0

Module 1

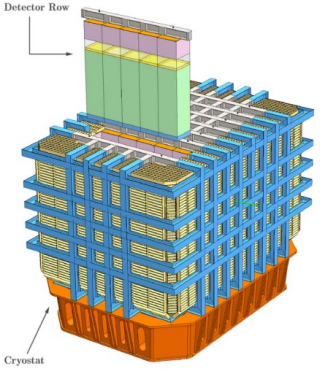


A. Abed Abud, 2021, Instruments 5, no.4, 31

Single Module
- 0.7x0.7x1.4 m^3

https://argoncube.org/

ProtoDUNE-ND
- 2 by 2 modules
- Each 0.7x0.7x1.4 m



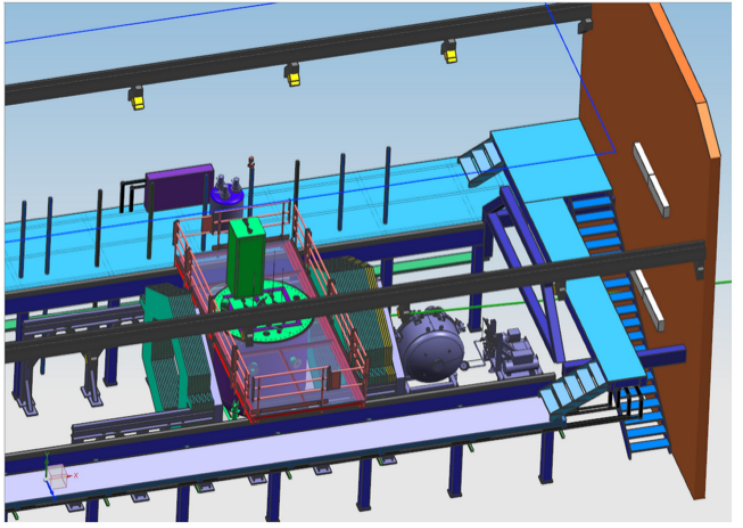
A. Abed Abud, 2021, Instruments 5, no.4, 31

Dune Near Detector
- 5 by 7 modules
- each 1x1x3 m^3

Role of ProtoDUNE-ND in DUNE

- Demonstrate modular TPC performance in Fermilab's NuMI neutrino beam.
- Test includes:
  - Charge and light system
  - Data acquisition system (DAQ)
  - Charge reconstruction with pixel-based readout
  - Combined charge and light reconstruction
  - Physics performance with neutrino interactions

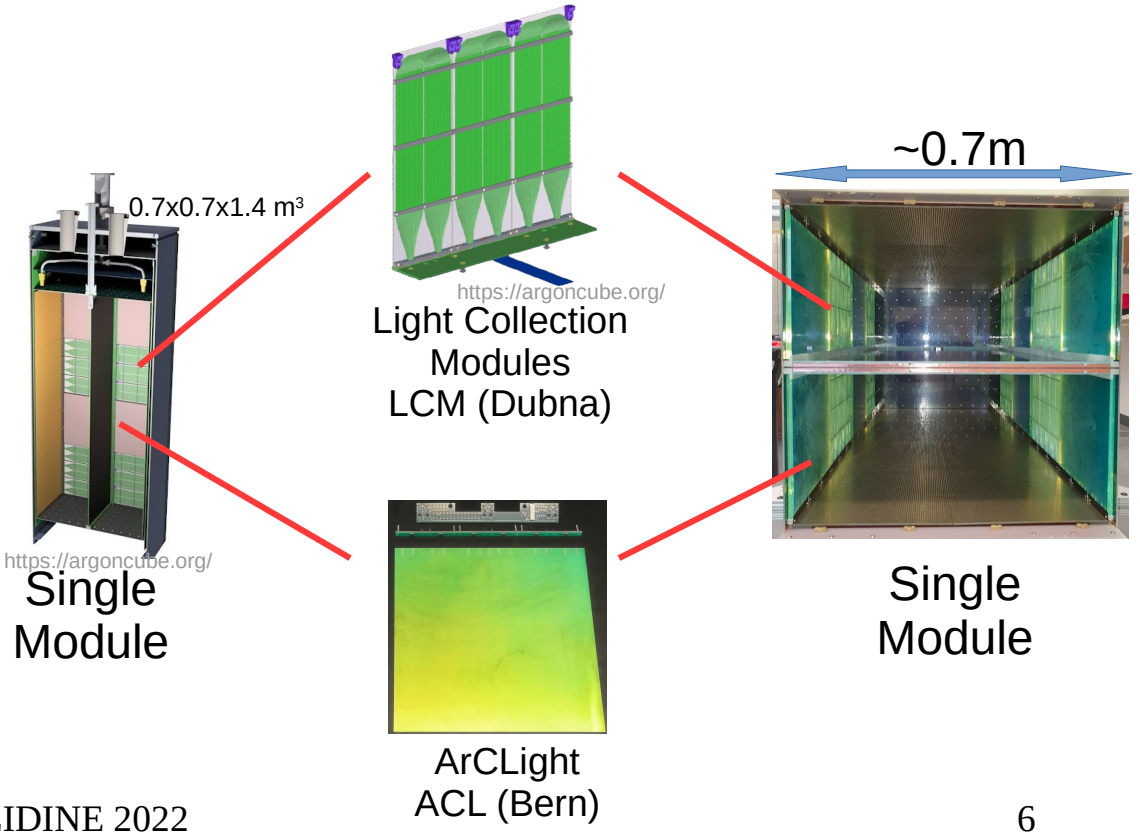
P. Adamson, K. Anderson, M. Andrews, R. Andrews, I. Anghel, D. Augustine, A. Aurisano, S. Avvakumov, D. S. Ayres and B. Baller, et al. Nucl. Instrum. Meth. A 806, 279-306 (2016) doi:10.1016/j.nima.2015.08.063 [arXiv:1507.06690 [physics.acc-ph]].



A. Abed Abud, 2021, Instruments 5, no.4, 31

Light Readout System (LRS) in ProtoDUNE-ND Modules

- 24 LCMs and 8 ACL per Module
- SiPM-based detectors for efficient collection of single UV photons with large surface coverage (6 SiPM per ACL 2 SiPM per LCM)
- Placed inside the field-shaping structure to increase light yield and decrease dead space
- LRS provides 30% optical detector coverage
- Photon detection efficiency of 0.6% for LCM, for ACL 0.2%
- Photomultiplier Tubes (PMT) are too big for modular TPCs like DUNE ND-Lar
- ACL has better spatial resolution, LCM has better timing resolution

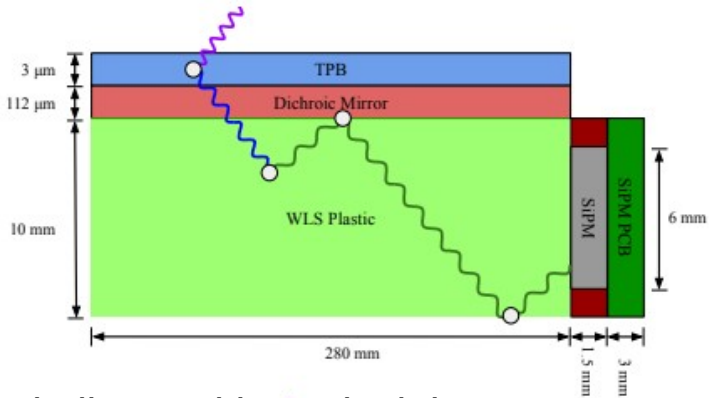


Light Detector for DUNE ND-LAr LRS

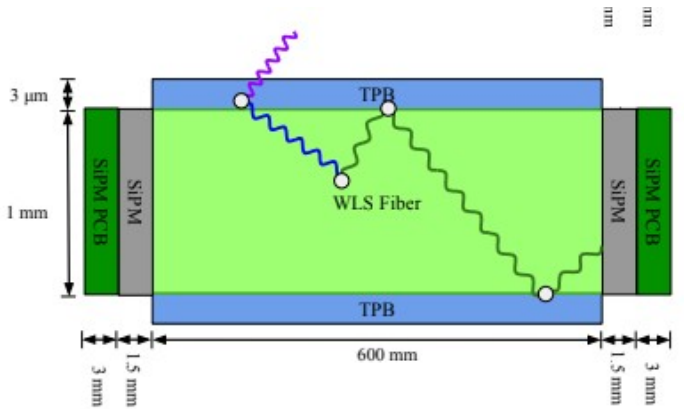
M. Auger et. al., Instruments 2, no.1, 3 (2018)
doi:10.3390/instruments2010003 [arXiv:1711.11409 [physics.ins-det]].

- **ArCLight** is based on the ARAPUCA principle of light trapping

Machado, A.; Segreto, E. ARAPUCA a new device for liquid argon scintillation light detec tion. Journal of Instrumentation 2016, 11, C02004–C02004. doi:10.1088/1748-0221/11/0 2/c02004.)



- **Light Collection Modules** have WLS fibers as bulk structure



Similar working principles:

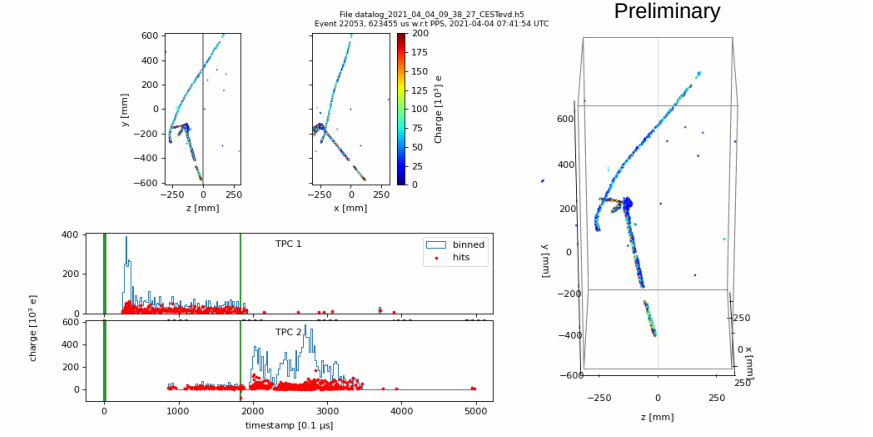
- Vacuum ultraviolet (VUV) scintillation light transitions when traveling through TPB coated surfaces
- Light enters bulk structure which acts as light trap
- In the bulk structure the photons are measured by SiPMs

For more informations about the ArCLight see Jan Kunzmann's talk

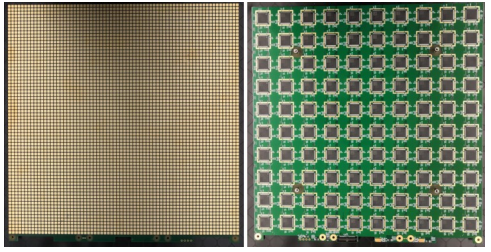
*Tetraphenyl butadiene

2 ProtoDUNE-ND Modules Tested at Bern

- Module 0:
  - 8 days
  - 60 million self-triggered cosmic ray-induced events
- Module 1:
  - 3 days
  - 20 million self-triggered cosmic ray-induced events
- Trigger:
  - **Charge**: self-trigger mode, tile triggers when channel-level charge threshold is exceeded (~100keV)
  - **Light**: LCM provide external trigger to charge readout system (~ 30 photoelectrons (p.e.))
- To merge data, LRS trigger signal is written to the charge readout data stream

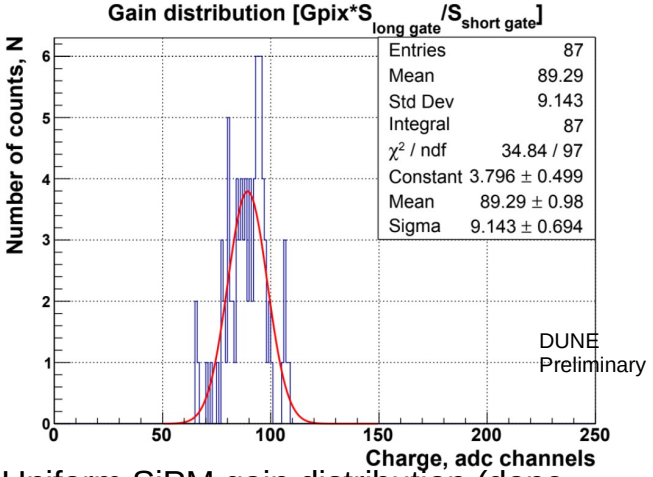


Neutrino like interaction in Module-0


TPC anode tile, front (left) contains 4900 charge pixels, back (right) LArPix ASICs

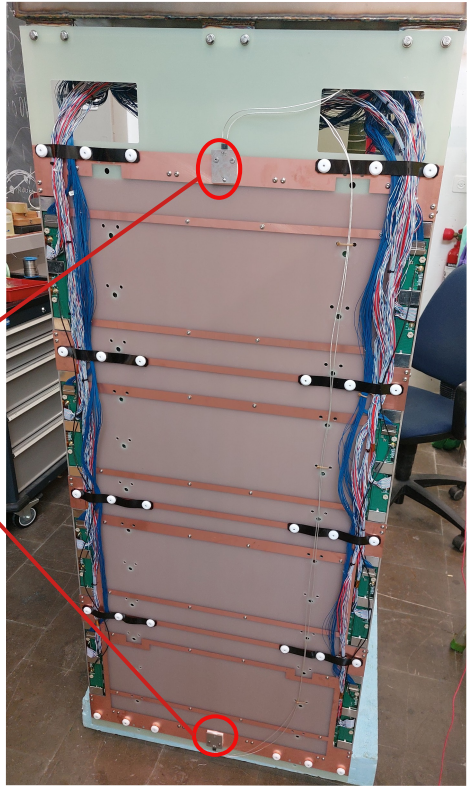
SiPM gain calibration

- Hamamatsu S13360-6050CS SiPMs
- Calibration with LED before taking cosmic data
- Bias voltage of SiPM channel adjusted to obtain uniform gain distribution across the channels



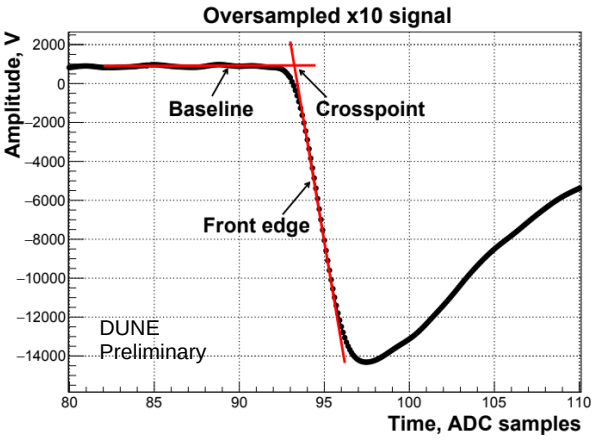
Uniform SiPM gain distribution (done for each SiPM)

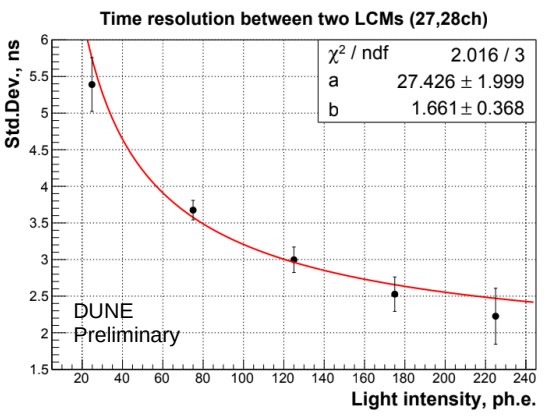
Positions of LEDs on Module



Time resolution of LCM

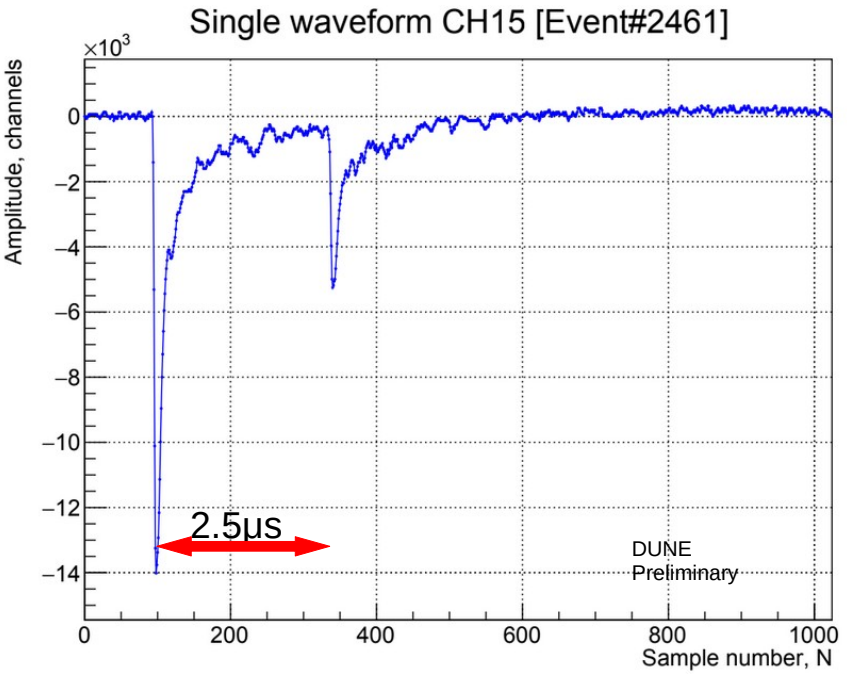
- Cosmic muons traversing the TPC were used to extract the time resolution
  - Waveforms are processed with a Fourier transform to increase ability to measure the front edge.
  - Linear fit to baseline and front edge
  - Crossing point provides a robust single-channel event time
- For large signals, timing resolution approaches ~2 ns





Time resolution of LCM

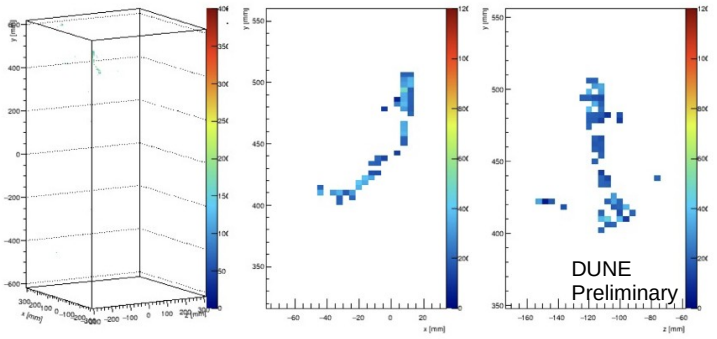
- Timing resolution of ~2 ns
- DUNE must be capable with its timing resolution to:
  - identify Michel electrons
  - Study event pile-up in neutrino interactions
- Example of stopping muon and delayed Michel electron

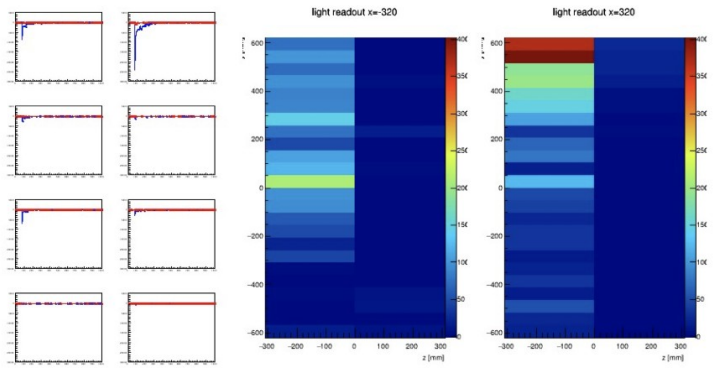


Wave form with sample number of 10ns (Module 0)

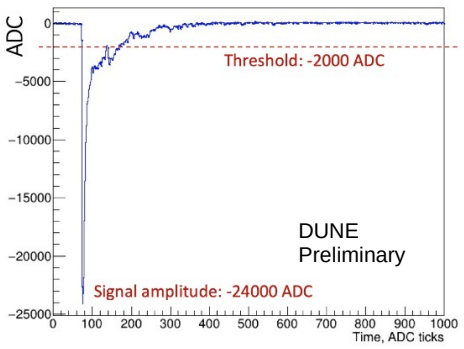
Module 1 - Trigger threshold in terms of energy

Gamma conversion event, charge pixel view





Gamma conversion event view from SiPMs



Gamma conversion event, triggering wave form from SiPM sum channel

- Charge is self triggering, therefore the triggering threshold of the LRS determines which charge events can be matched to light events
- Trigger signal is based on sum channels of the LCM light readout
- Gamma conversion with total energy deposit of about 20MeV
- LCM sum signal peaks at -24000 ADC counts which means that the effective threshold was 1.6MeV
- Given signal clarity (compared to Module 0), operation below threshold of 1MeV possible

Photon detection efficiency (PDE)

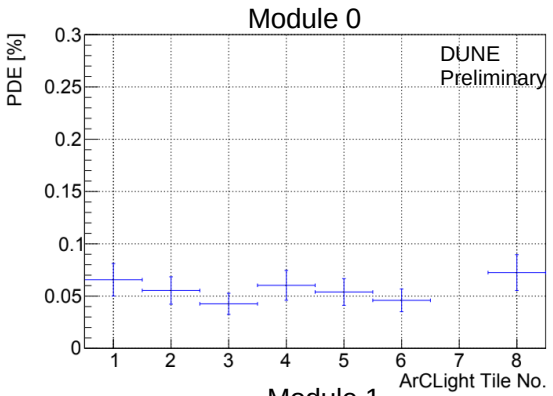
- Expected PDE is dependend on the efficiency of:
  - TPB
  - WLS
  - Average spectral acceptance
  - Reflecting surfaces to deliver photons to the SiPM openings
  - SiPMs

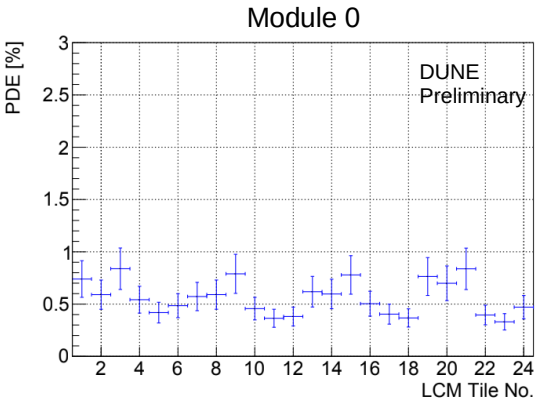
$$Q_{PDE} = \frac{1}{2}\,\varepsilon_{TPB}\,T_{425}\,\varepsilon_{WLS}\,\varepsilon_{SA}\,\varepsilon_{coll}\,\varepsilon_{SiPM}$$

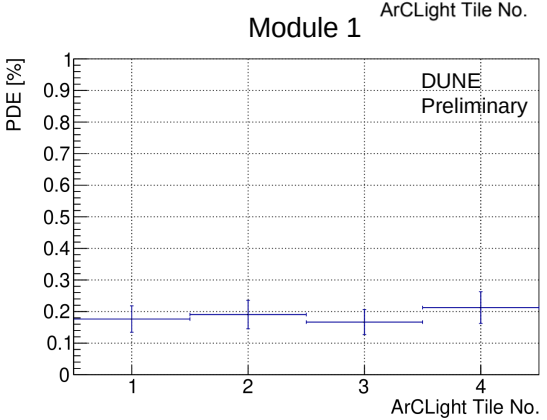
M. Auger, 2018, Instruments 2, no.1, 3

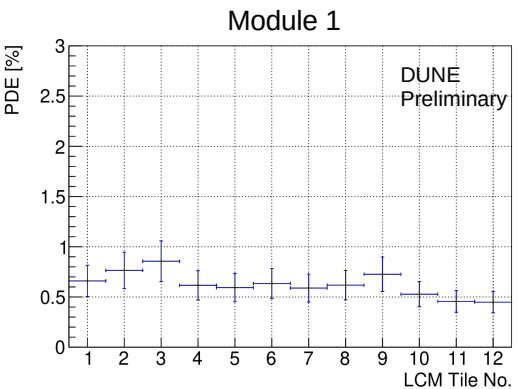
- PDE is estimated by comparing the data and Geant4 simulation.

Photon detection efficiency (PDE)









Module 0:

- PDE for data across both TPCs of the module
- ACL 7 missing because of turned of charge tile

Module 1:

- PDE for data across one TPC of the module
- Improvement for the ArCLights when compared to Module 0 due to addition of mirrors on bordering edges.

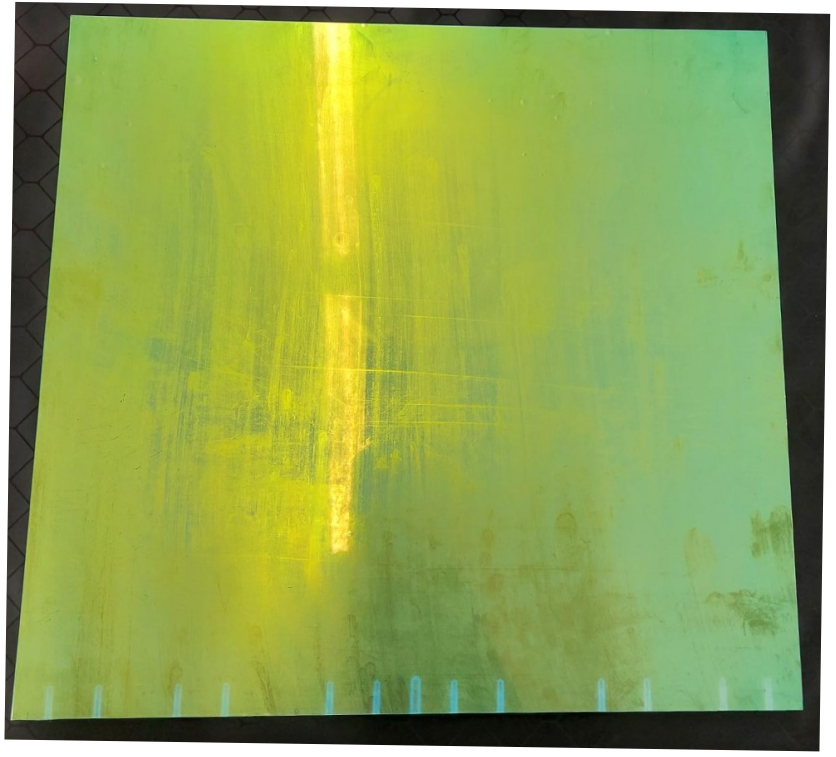
Summary

- DUNE ND-LAr is a modular detector using compact light detectors borrowing principles from ARAPUCA.
- Prototype experiment named ProtoDUNE-ND is in construction and will test LRS under cosmics (Bern) and neutrino interactions (Fermilab)
- LRS has a timing resolution of ~2ns for LCM
- LRS has PDE of 0.6% and 0.2% for LCM and ArCLights, respectively.
- Publication in progress on analyzing LRS data under cosmic at Bern for a single module.

Back up

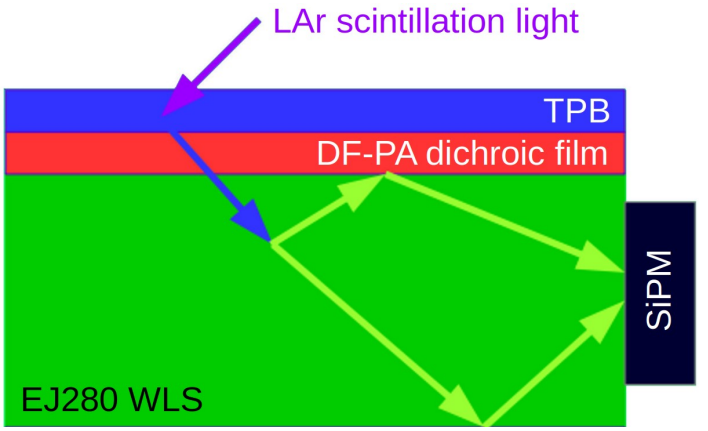
ArCLight

- Low-volume large-area light detector
- Development, production and testing in Bern
- Fully dielectric to be placed in drift field along drift direction
- ArCLight achieves spatial resolution requirement (aim for 5cm)
  - associate a recoil proton with the corresponding neutrino event



ArCLight

- VUV photons 128 nm
- shift to blue 430 nm
- shift to green 490 nm

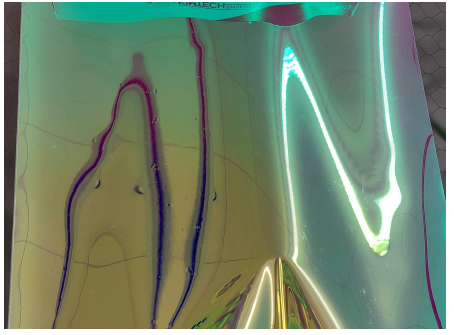


https://cds.cern.ch/

- Blue photons can penetrate through the dichroic mirror
- green photons can not

- Size: 30 cm x 28 cm x 1cm

TPB
1,1,4,4-Tetraphenyl-1,3-butadiene


Dichroic


Wave length shifter

TPC Anode Tile

- Front (left) contains 4900 charge-sensitive pixels with 4.43mm pitch, facing the cathode
- Back (right) contains a 10x10 array of LArPix ASICs
- The tile dimensions are 31cm x 32cm
- 8 anode tiles per TPC in ND-LAr 2x2 modules
- Module-0 comprises 78400 instrumented LArTPC pixels