Kevin Wood, for the ND-LAr Consortium
July 26, 2024
DUNE Collaboration Call

Status of the DUNE ND-LAr 2x2 Demonstrator

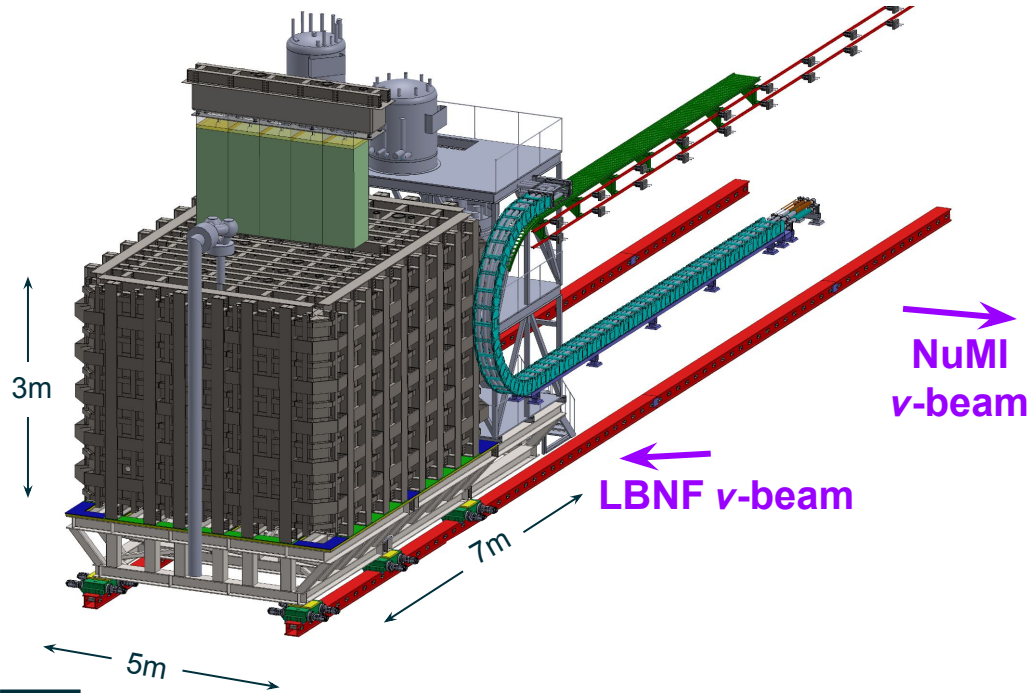
Front left:
Livio Calivers

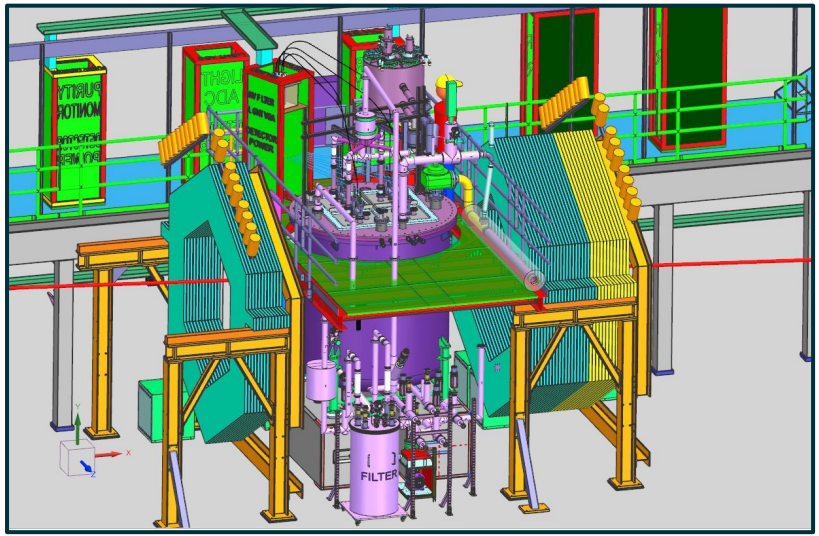
Front right:
Tom Murphy

2x2 Demonstrator for ND-LAr Design

ND-LAr: 7x5 array of 1x1x3 m^3 LArTPC modules

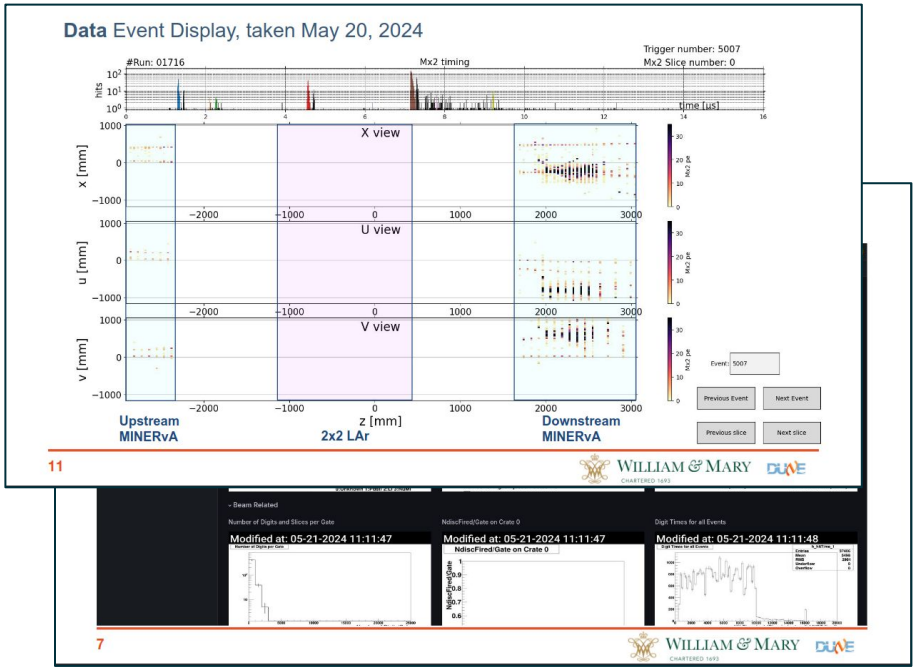
2x2: 2x2 array of 0.6 x 0.6 x 1.2 m^3 LArTPC modules

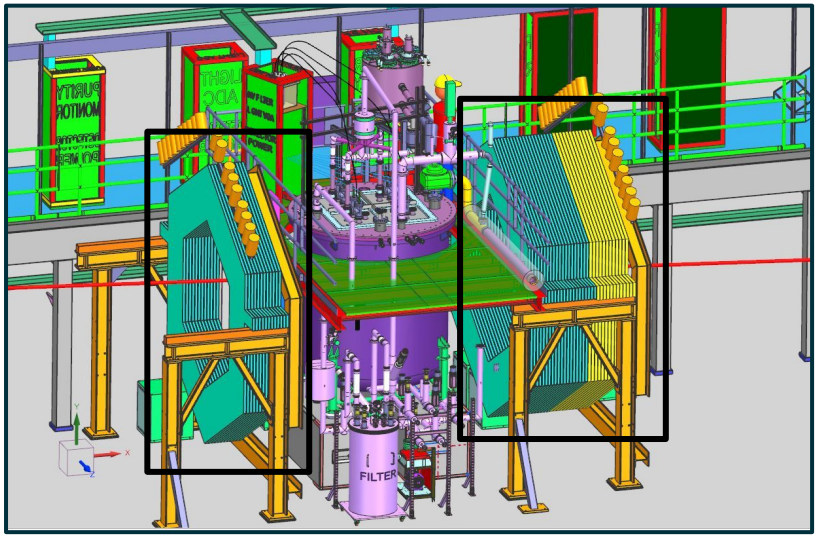




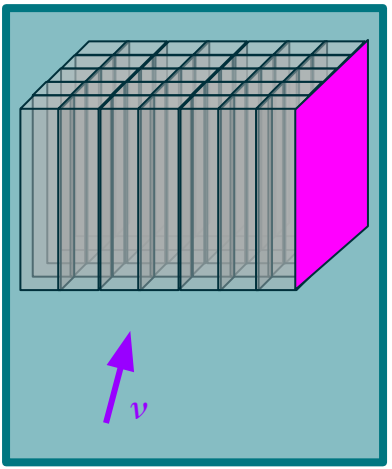
2x2 Demonstrator for ND-LAr Design

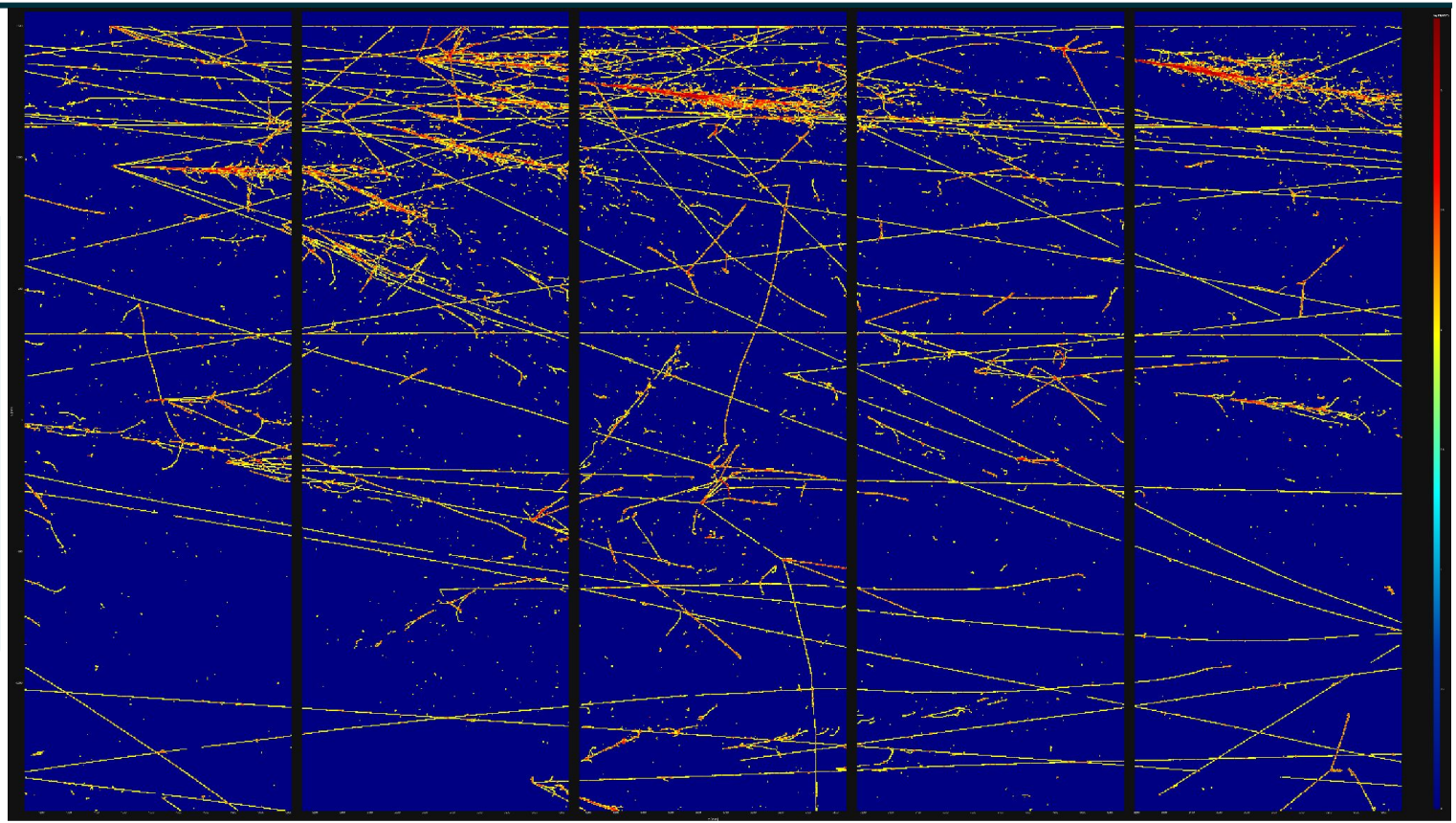
[Carlos Pernas, May 2024 DUNE CM Plenary, Minerva for 2x2 (Mx2): Operations and Commissioning]





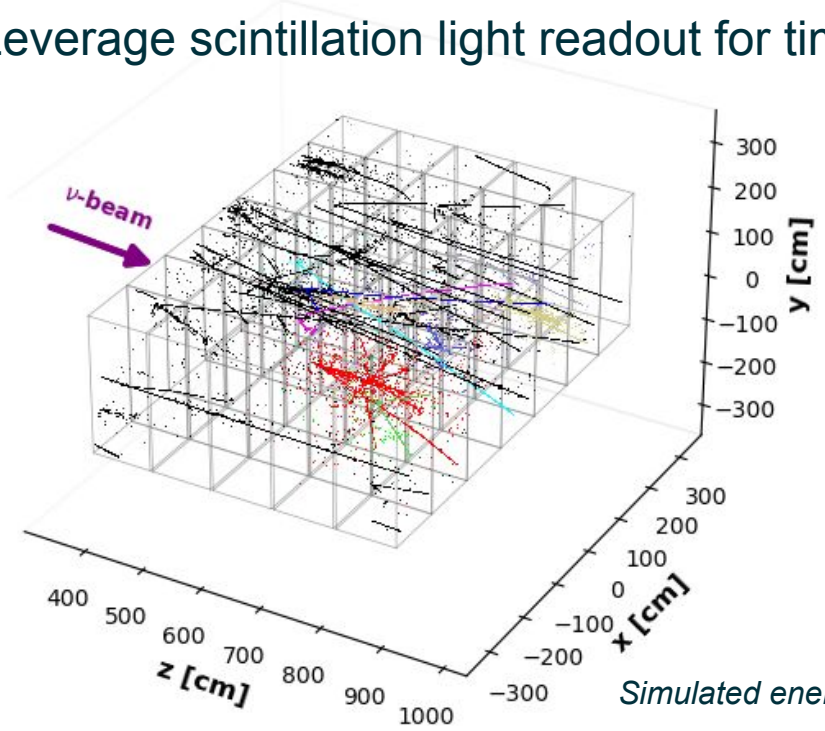
ND-LAr in a 1.2/1.8 MW LBNF Spill Simulation



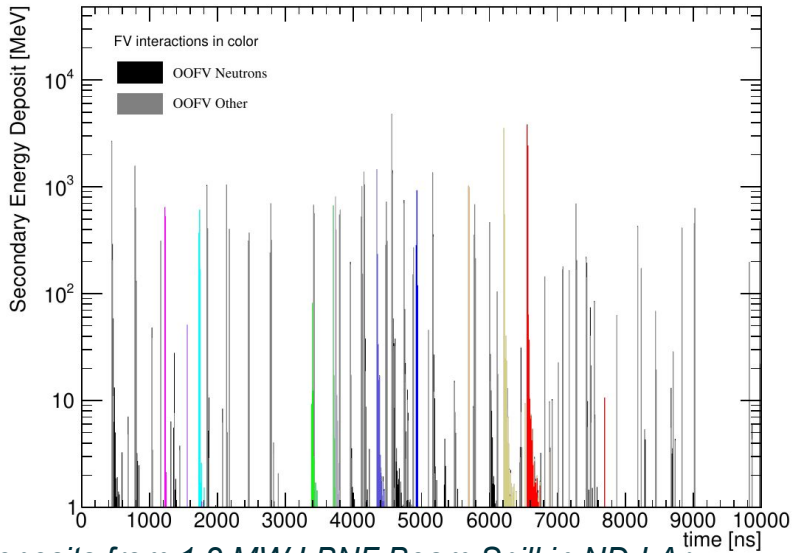


Coping with Pileup

- LArTPC charge readout very slow compared to beam microstructure
  - ~300us maximum drift, ~10us beam spill
- Leverage scintillation light readout for timing information: must match charge to light



Full Detector Volume (no smearing)

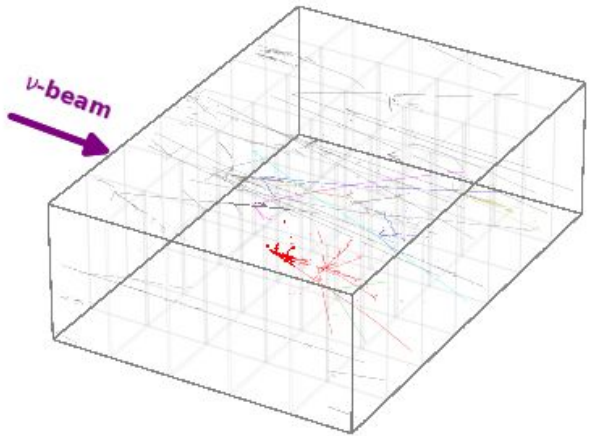


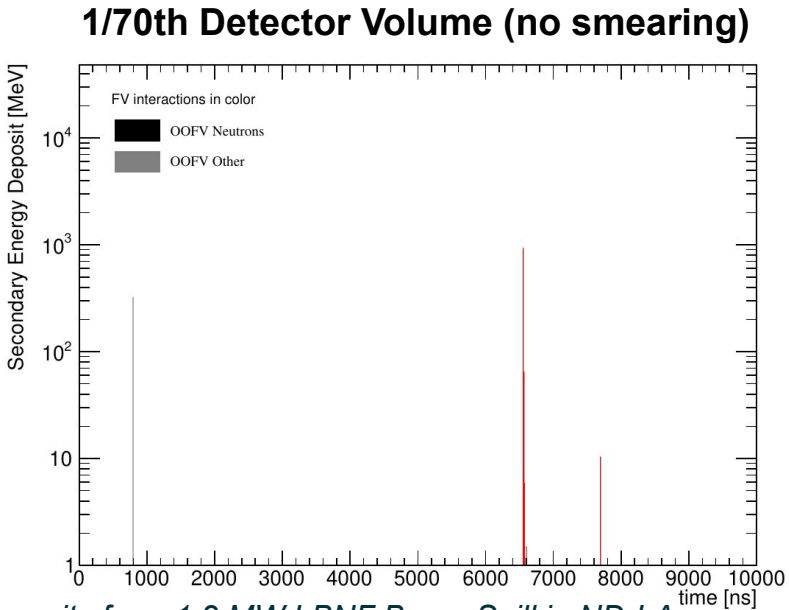
Simulated energy deposits from 1.2 MW LBNF Beam Spill in ND-LAr

Coping with Pileup

- LArTPC charge readout very slow compared to beam microstructure
  - ~300us maximum drift, ~10us beam spill
- Leverage scintillation light readout for timing information: must match charge to light

→ enabled through optical segmentation





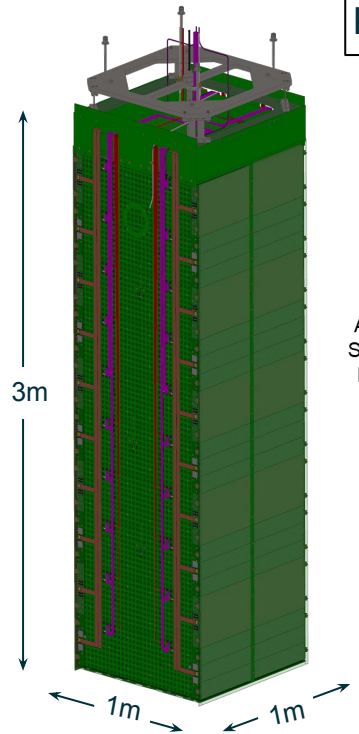
Simulated energy deposits from 1.2 MW LBNF Beam Spill in ND-LAr

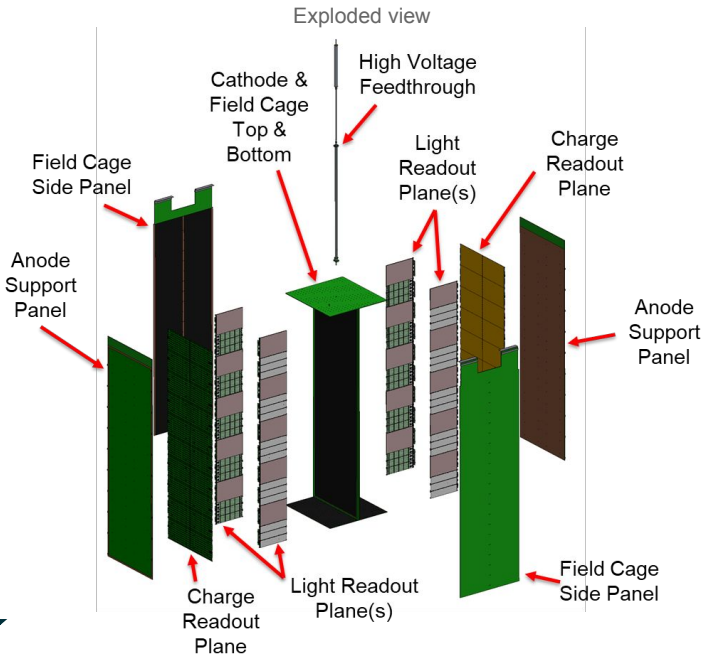
2x2 Demonstrator for ND-LAr Design

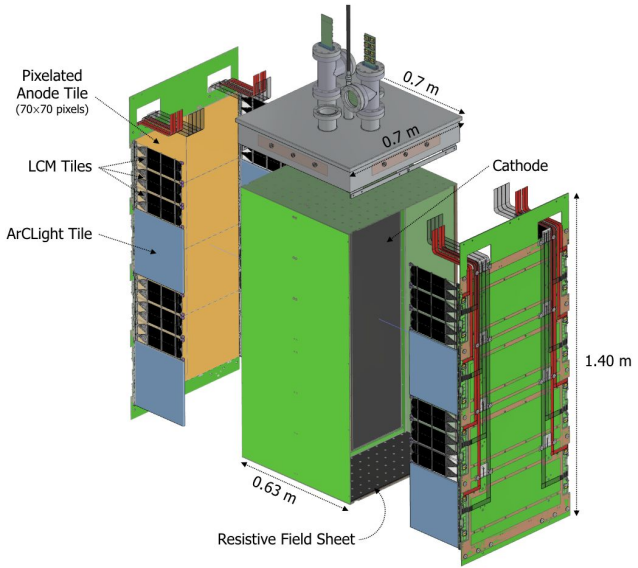
ND-LAr: 7x5 array of 1x1x3 m^3 LArTPC modules

2x2: 2x2 array of 0.6 x 0.6 x 1.2 m^3 LArTPC modules

Key design feature: Each module contains 2 optically optically isolated TPC volumes.







arXiv:2403.03212

2x2 Demonstrator Signal Detection

Charge readout:

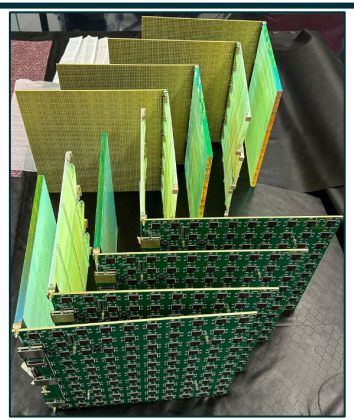
- >330,000 pixel channels across 8 TPCs
- 4mm pixel pitch
- Self-triggering readout for every pixel
  - Configurable thresholds, ~100% uptime
- Scalable: commercially fabricated, fast and affordable

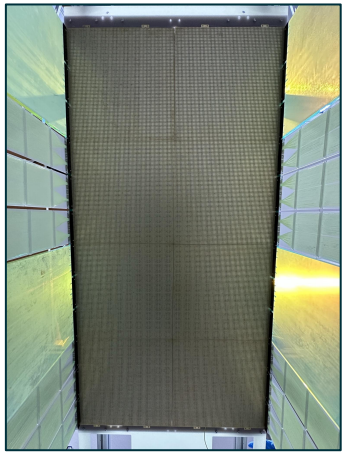
Light readout:

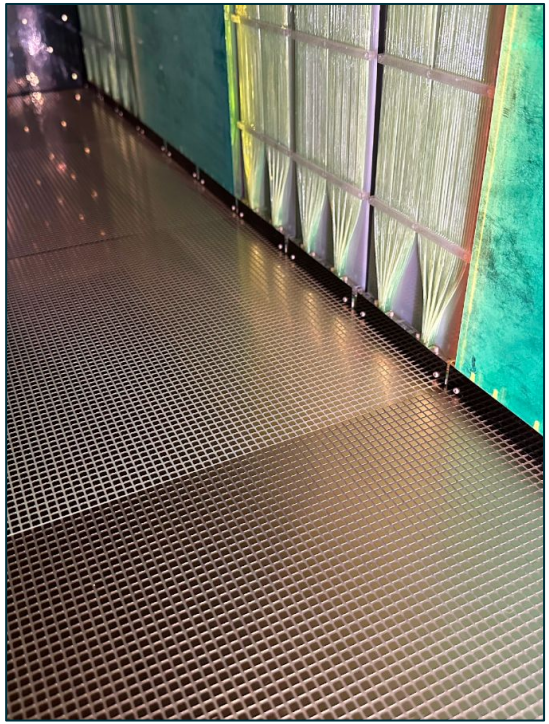
- 2 light collection technologies, common SiPM-based readout

	ArcLight	LCM
Efficiency	~0.2%	~0.6%
Spatial resolution	~5cm	~10cm
Notes	– Large sense area – High dynamic range	– Scalable design – Mechanically robust

- <10 ns single hit timing resolution





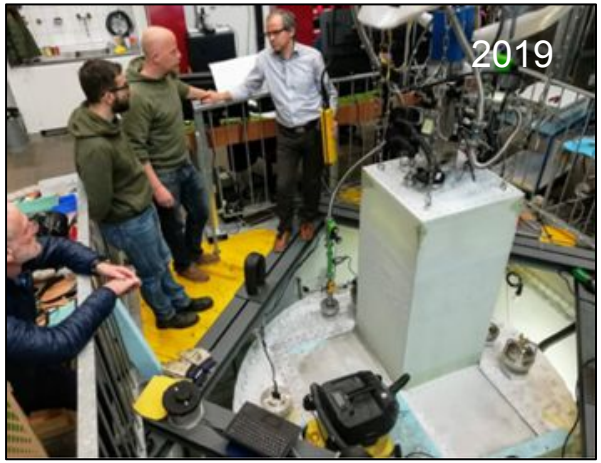


Laying the Groundwork

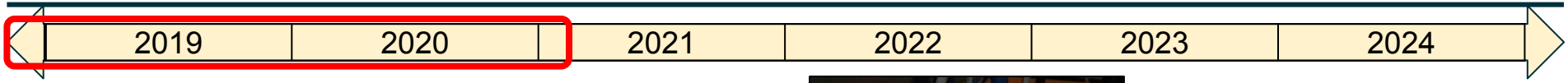
DEEP UNDERGROUND NEUTRINO EXPERIMENT

2019	2020	2021	2022	2023	2024

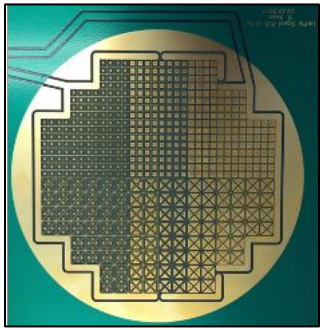
- 2014: idea for modular LArTPC was born and need for modular setup test with cosmic rays or neutrino beam identified
- 2016-2018: Preparations for the 2x2 cryostat and modules at University of Bern
- 2019: Agreements with FNAL/DOE, LoI, proposals, funding (Bern/FNAL/SLAC/LBNL)



Component Development



- 2016 - 2019 ArgonCube R&D Collaboration carried out a successful program developing, prototyping, and demonstrating LArTPC technology demonstrations:
  - LCM and ArCLight dielectric light traps enabling high coverage scintillation light detection
  - LArPix ASIC, integrated pixel PCB tile, PACMAN controller enabling pixelated charge readout
  - High resistivity film as continuous resistive field cage enabling low-profile field cage
  - Modular TPC design enabling optical segmentation
- Operated SingleCube LArTPC in October 2020

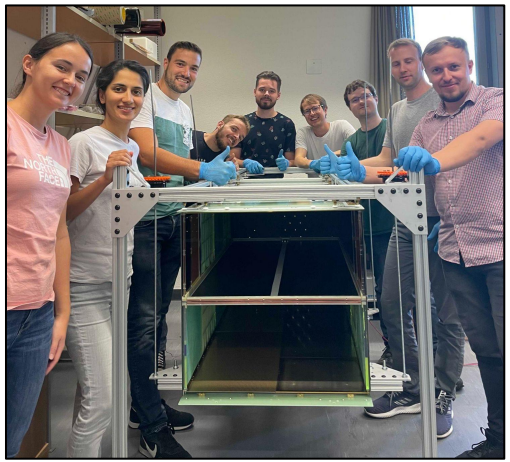


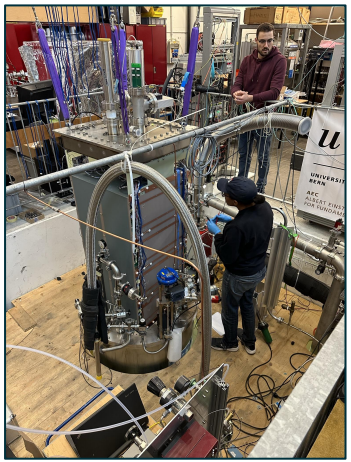
Module Production

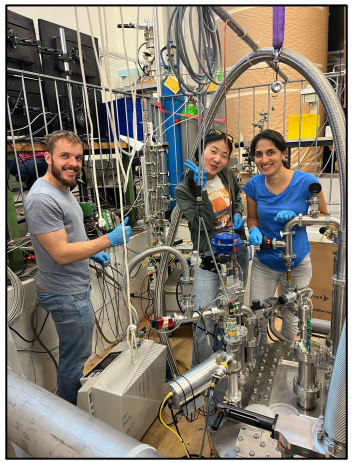
DEEP UNDERGROUND NEUTRINO EXPERIMENT

2019	2020	2021	2022	2023	2024

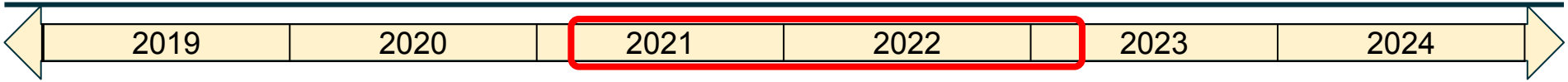
- 2x2 module production and operations at University of Bern; gathered O(10^8) cosmic events





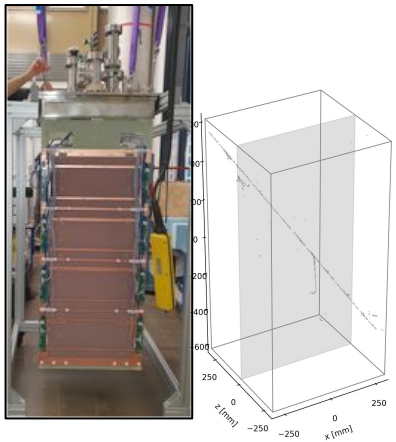


Module Production



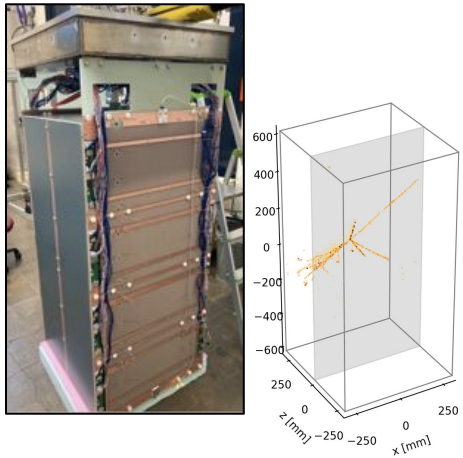
- 2x2 module production and operations at University of Bern; gathered O(10^8) cosmic events

Module 0



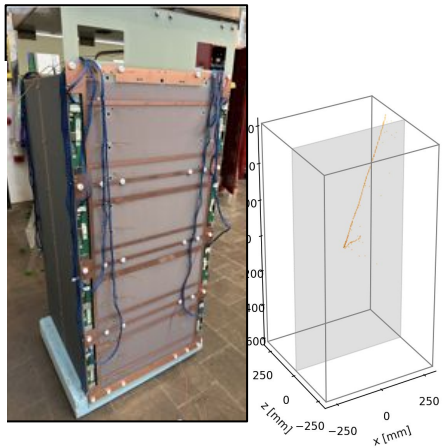
Operations:
Apr. 1-10, 2021
Jun. 21-26, 2021

Module 1



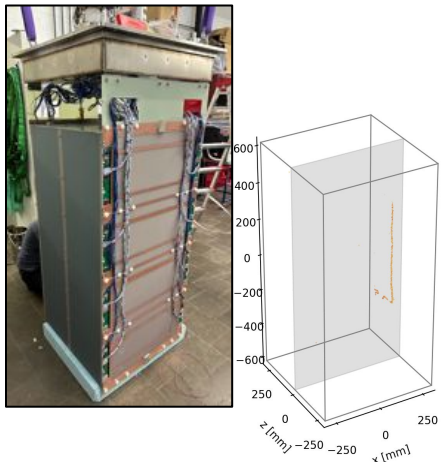
Operations:
Feb. 5-13, 2022

Module 2



Operations:
Nov. 14-22, 2022
Nov. 29-Dec. 6, 2022

Module 3



Operations:
Jan. 27-Feb. 5, 2023
Feb. 21-23, 2023
Mar. 13-16, 2023

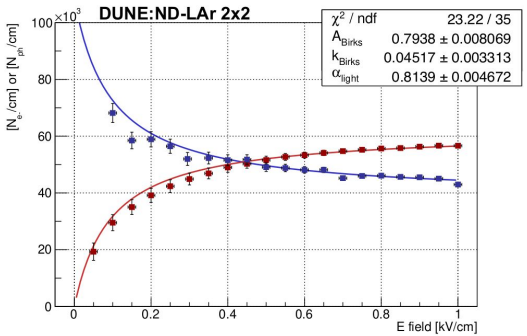
~~Module~~ Paper Production

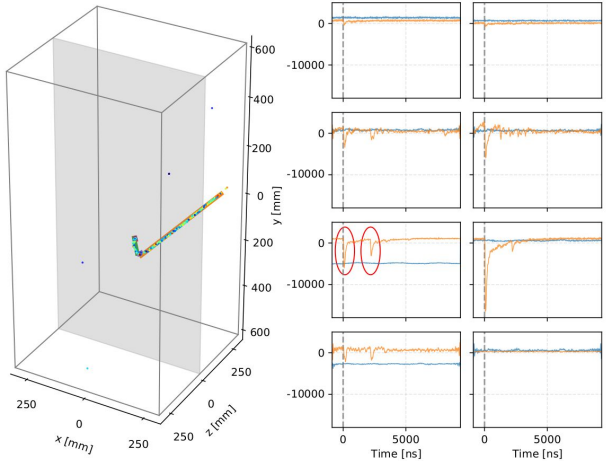
DEEP UNDERGROUND NEUTRINO EXPERIMENT

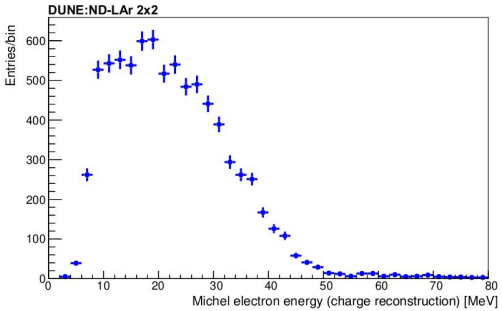
2019	2020	2021	2022	2023	2024

- 2x2 module production and operations at University of Bern; gathered O(10^8) cosmic events
  - "Performance of a modular ton-scale pixel-readout liquid argon time projection chamber" (A.K.A. "The Module 0 Paper") 2403.03212

Module 0

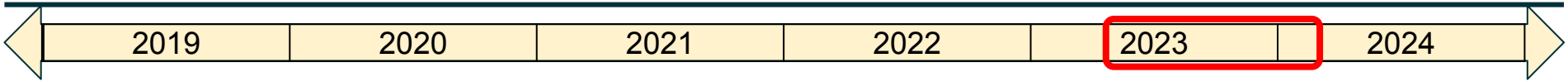




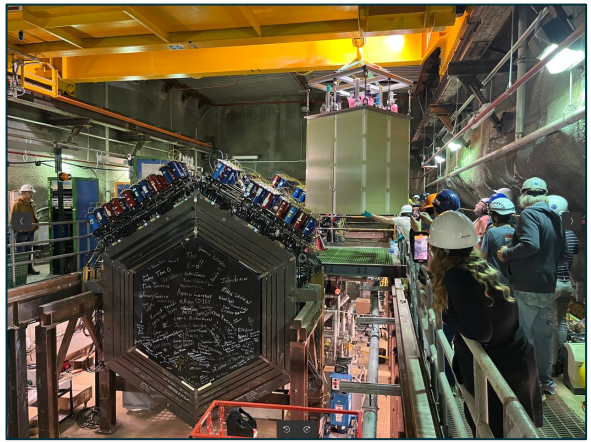


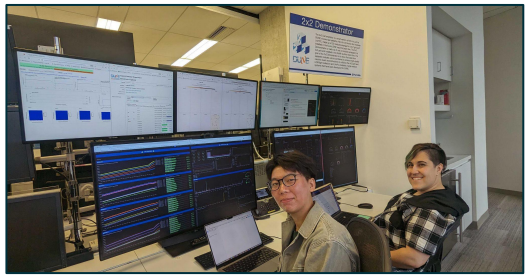
Operations:
Apr. 1-10, 2021
Jun. 21-26, 2021

Facility Preparation



- 2x2 modules shipped from Bern to Fermilab and underwent acceptance testing, which concluded by Spring 2023
- MINOS underground area prepared in 2023
  - Electrical services, ventilation for ODH mitigation, computing infrastructure, etc.
- October 2023: detectors installed into cryostat
- Installation of cryogenics, connecting readout electronics wrapping up when we lost access to the hall from March 19 - May 10 ‘24
  - Made some progress with control software, monitoring systems, DAQ development, operating procedures, control station, etc.





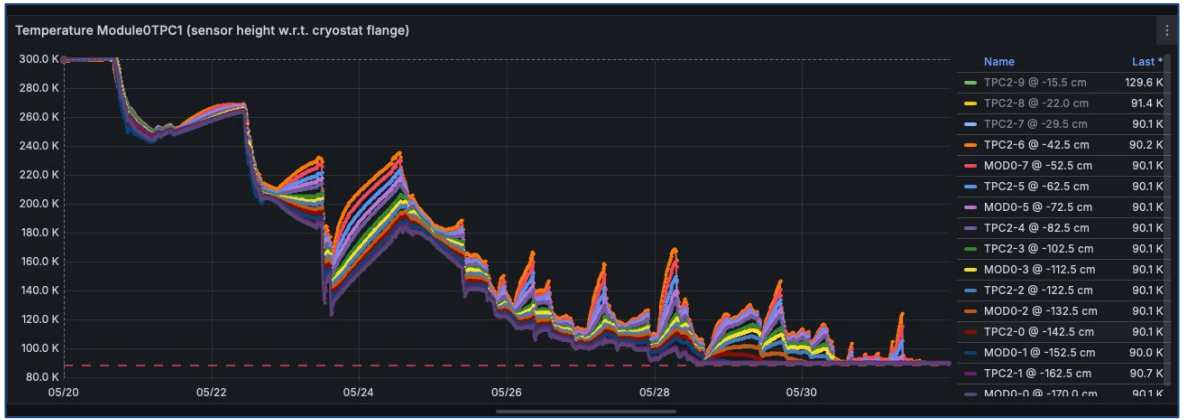
Cryogenic Commissioning

DEEP UNDERGROUND NEUTRINO EXPERIMENT

2019 | 2020 | 2021 | 2022 | 2023 | 2024

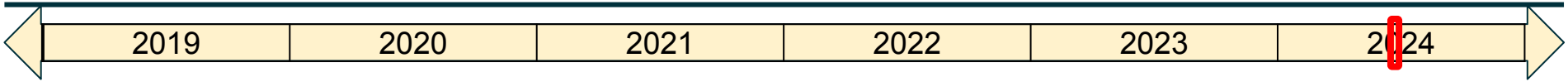
- Cryogenic commissioning
- May 20-31 cool down and LAr fill completed. 10 days instead of anticipated 4 weeks due to support from partners in LAr procurement
  - Bern, MIT, U-Chicago, LBNL

- Challenges:
  - Leaks → maintain LAr level
  - Purity → single pass LAr top offs degrade LAr purity
  - Malfunctioning cold head (1/3) → limited cooling power

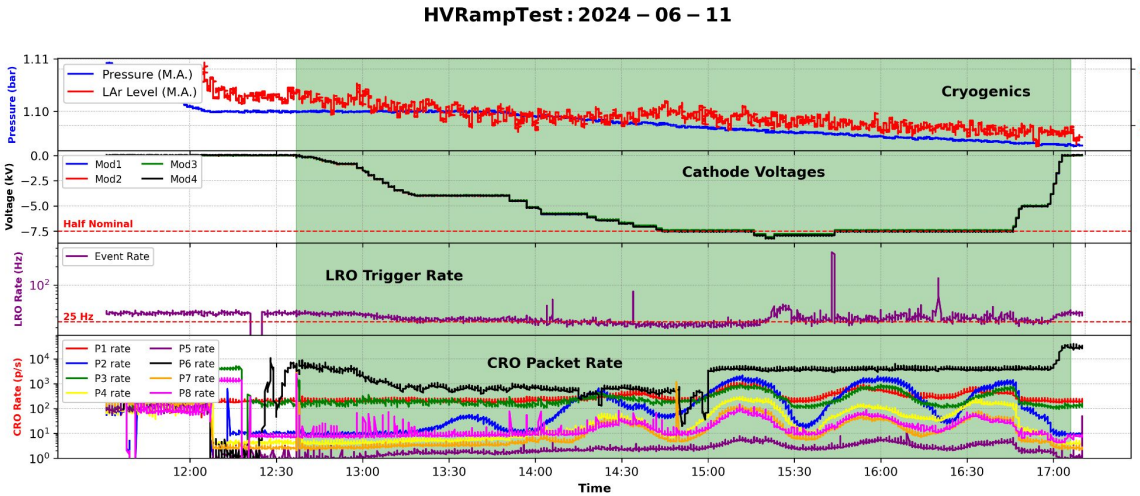


  - Gas makeup system → degrading pump performance
  - Inlet tube from ullage to condenser located low → tight level requirements
  - Capacitive level meter inoperable while recirculation pump powered

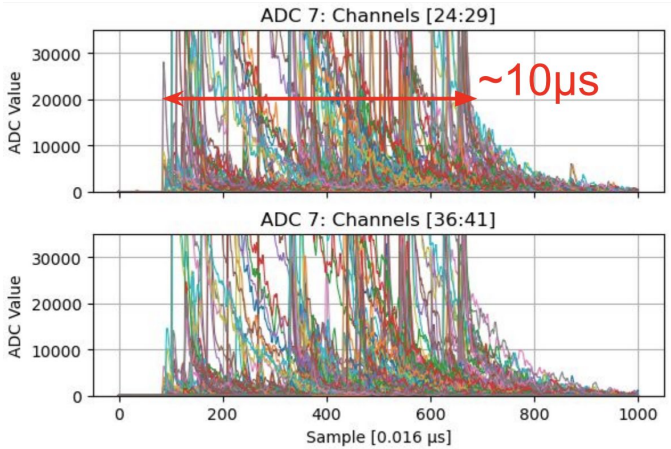
High Voltage Ramp #1



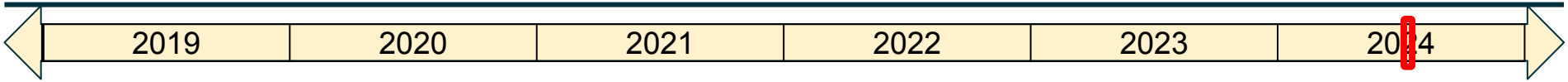
- Ramped up cathode voltage to half nominal on June 11, 2024 for a 1-day HV commissioning test
- LAr purity was very poor (~O(10) μs e^- lifetime) and LAr level was not being maintained (intentionally)
  - Started seeing some sign of micro-discharge in light system around half-nominal (250 V/cm)
  - Ramped down, analyze data, and spent ~3 weeks working on cryo



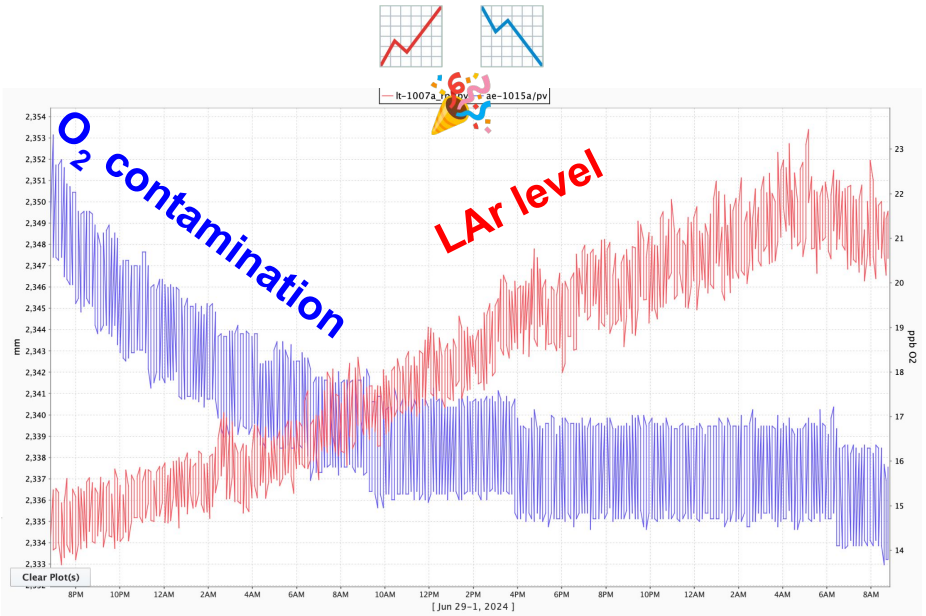
Evidence of NuMI signals from the light detection system:



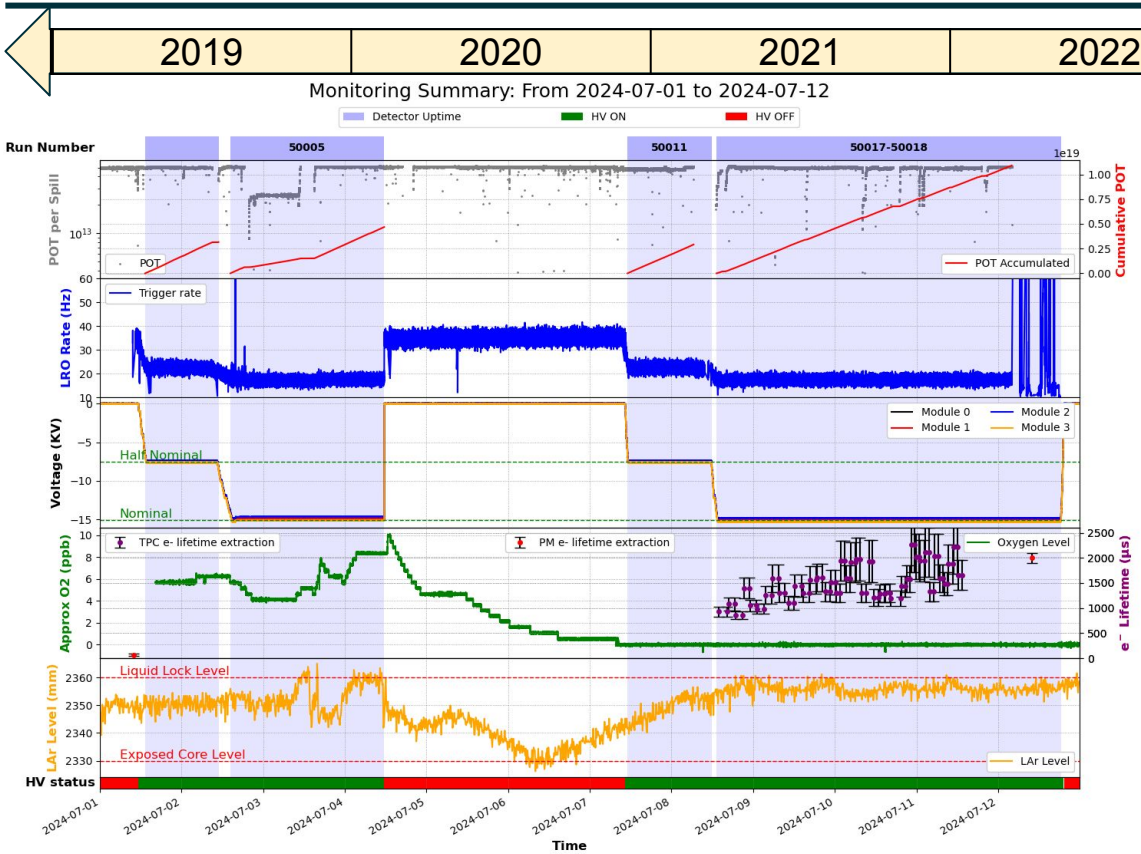
Cryogenic System Fixes



- June 12 - June 29: address cryogenic challenges to maintain LAr level and purity
  - Regenerate LAr purifier
  - Fix leak in LAr purifier vessel
  - Install additional cold head
  - Implement alternative readout of level meter
  - Install O2 getters inline with the gas makeup
  - …
- Huge thanks to Mike Zuckerbrot and Brandon Howe!



Achieving Target Operating Conditions

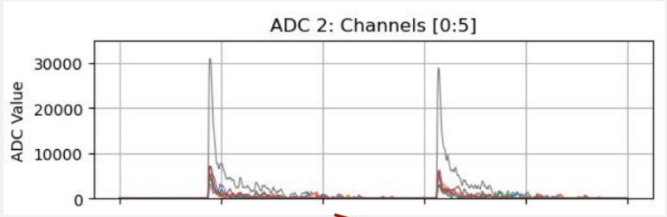


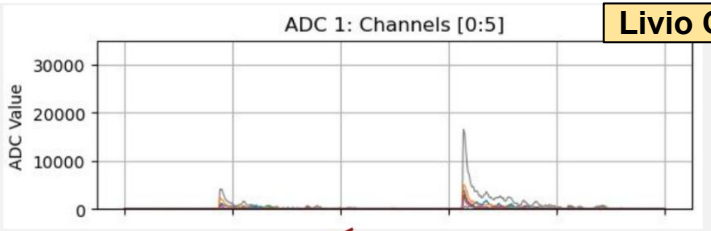
- July 1: Started 2-day HV ramp to 500 V/cm
- Maintain LAr level to keep HV on ✅
- LAr purity plateaued around O(100) μs e^- lifetime
- Observed a degradation in the recirculation pump performance, suspected due to gas makeup
- → replaced getters in gas makeup system
- Understood the pump performance and developed an operating procedure
- July 7: Started 2-day HV ramp to 500 V/cm
  - No signs of any instability!

Renzo Vizarreta, Alicia Vázquez Ramos
BERKELEY LAB

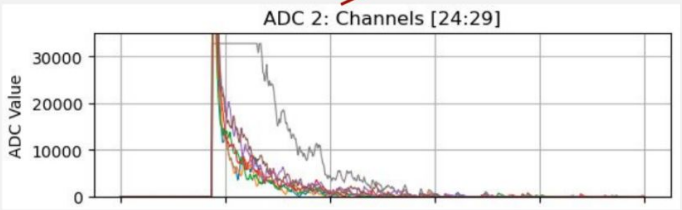
Low Purity (Anti)Neutrino Data

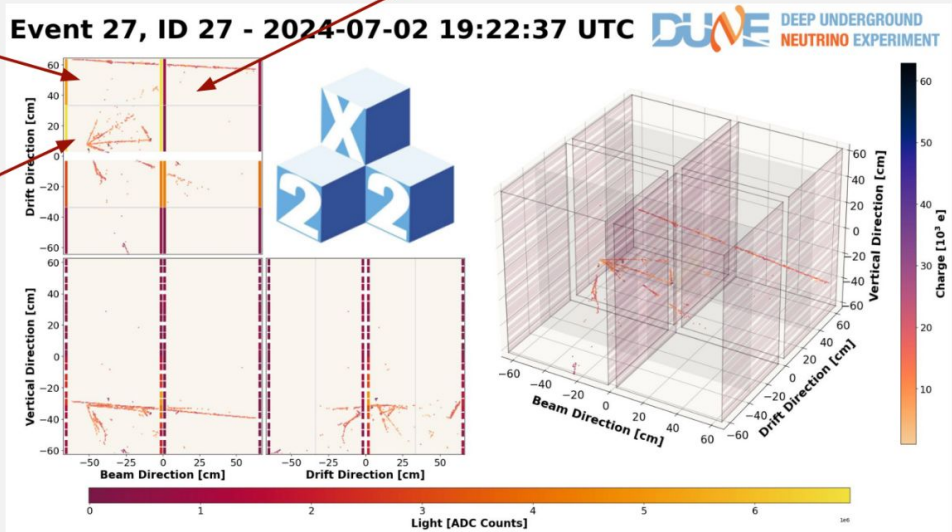
Livio Calivers



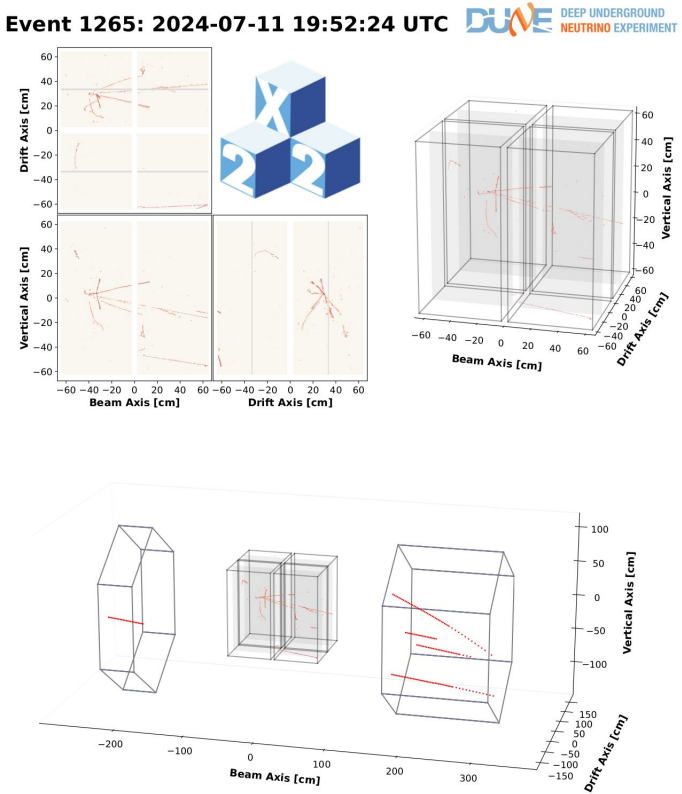


Attention: Bad purity example
→ charge close to anode missing

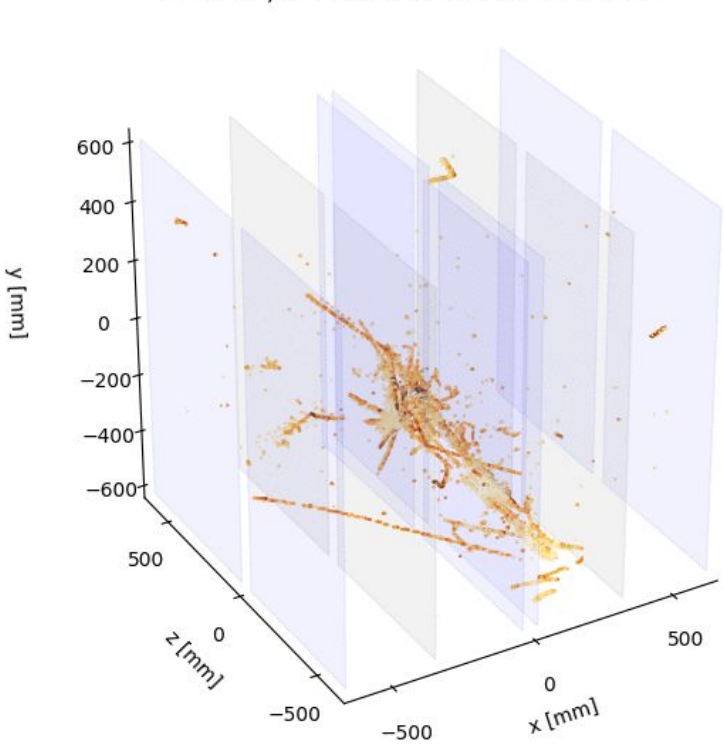




High Purity (Anti)Neutrino Data!



~ 10K interactions in active LAr volume per day



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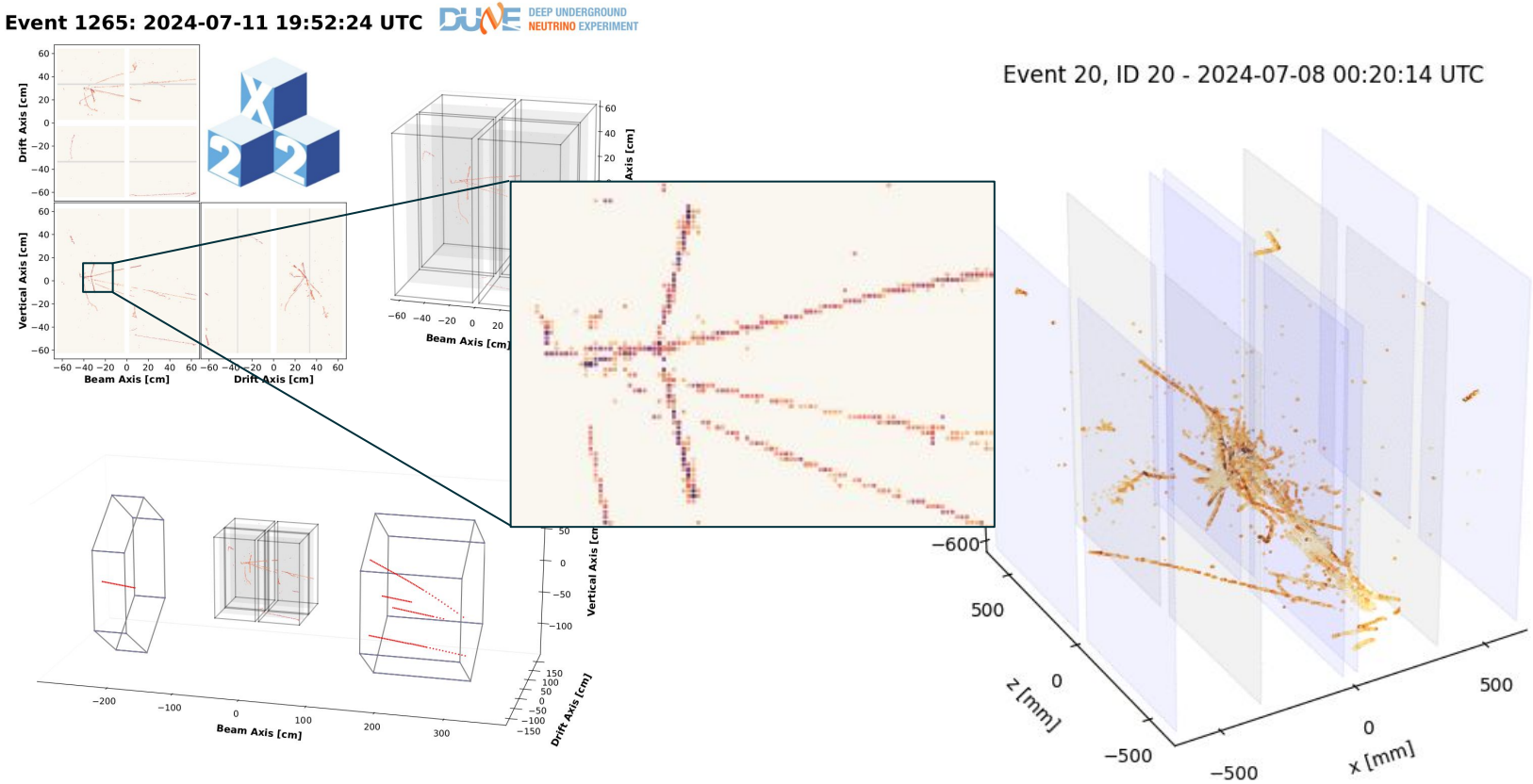
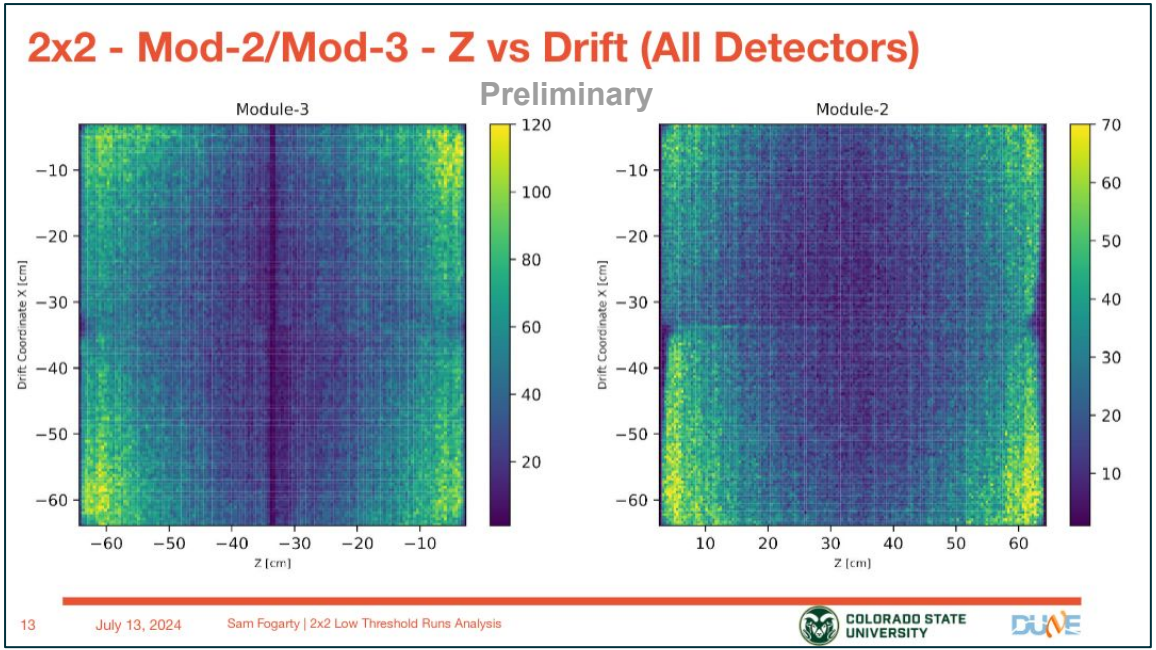


And more!

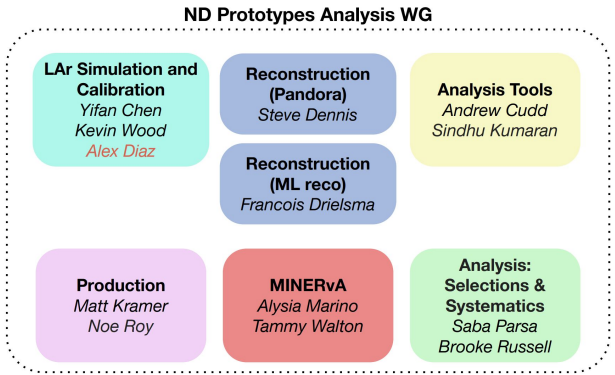
- Continuously taking data from cosmic and low energy events in addition to beam
  - Particularly useful for calibrations
  - Cosmic rates comparable to beam spill rate
  - Low energy depends on thresholds, but ~10-100x higher rates
- Example: low energy event selection, Sam Fogarty (CSU)



Next Steps

Analyze the beautiful data we have gathered!

- Reach out to Zoya Vallari and Pedro Ochoa-Ricoux to get plugged into analyzing DUNE's first neutrinos!
  - ND Prototypes Analysis WG
  - dune-physics-nd-proto-analysis@fnal.gov
  - #nd_prototype_analysis on Slack



Prepare to gather more!

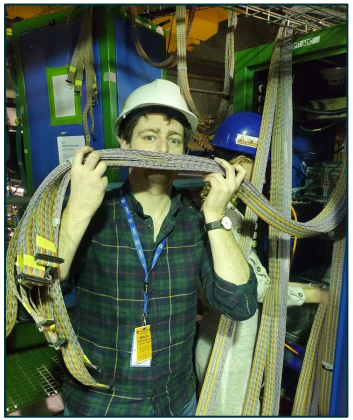
- Task force assembled to plan hardware upgrades during the summer shutdown
- Off-beam runs to gather additional cosmics, low energy decays, etc.
- Learn more about future NuMI runs in the coming weeks

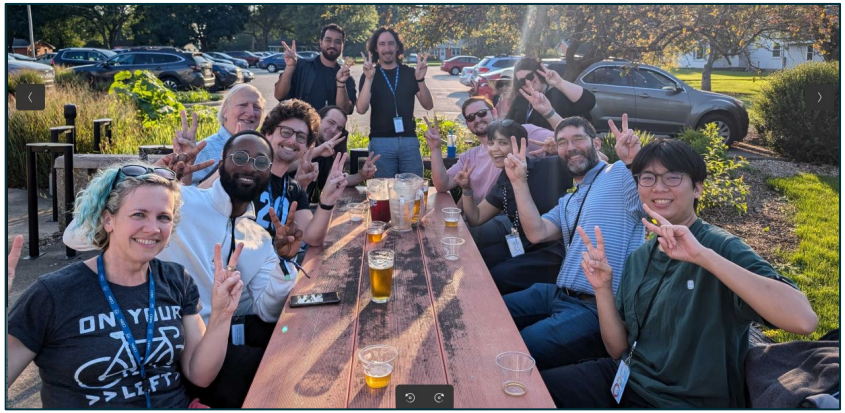
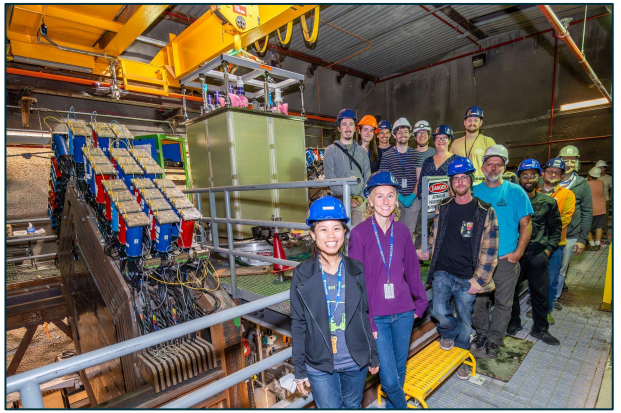
FY25 + FY26		16+16 weeks	24+24 weeks	40+40 weeks
$0\pi^0$	$1\pi^\pm$	26320	39760	66080
	$2\pi^\pm$	6683	10096	16780
	$3\pi^\pm$	1457	2201	3658
$1\pi^0$	$1\pi^\pm$	1673	2528	4201
	$2\pi^\pm$	458	692	1149
	$3\pi^\pm$	100	151	250

Predicted exclusive event rates for various NuMI running scenarios

Thanks!

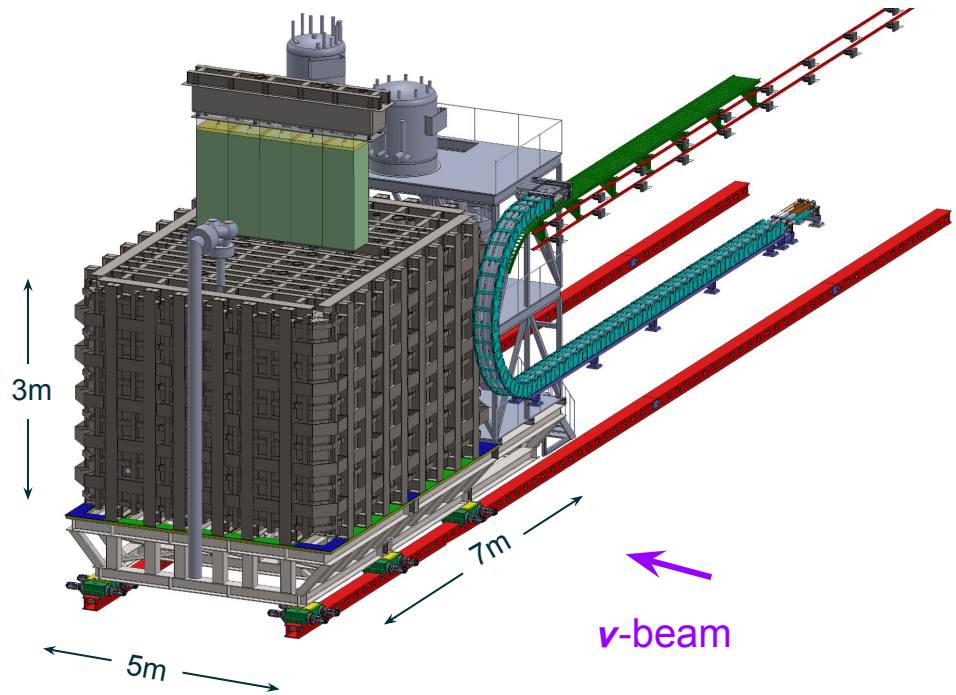


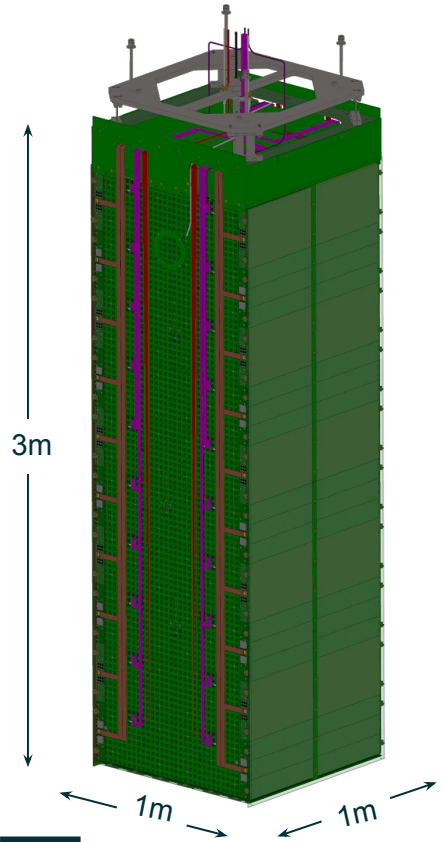
Back Ups

ND-LAr Detector



- 7x5 grid of 1x1x3 m^3 LArTPC modules
  - 7x5x3 m^3 active volume
- Moveable transverse to neutrino beam
  - Sample off-axis flux
- Designed to cope with high-pileup environment
  - ~60 interactions / 1.2 MW spill
- Optical segmentation provides interaction-level timing information
- Native 3D readout from pixelated charge readout mitigates hit ambiguity
  - $\lesssim$ 4mm pixel pitch (granularity)
  - > 14M pixel channels!

ND-LAr Module



- 2 optically isolated TPCs per module
  - 50 cm drifts → 25 kV for 500 V/cm
- Pixelated charge readout with O(4mm) granularity
- Light readout with modules on the vertical field cage panels