BERKELEY LAB

DEEP UNDERGROUND NEUTRINO EXPERIMENT

The Deep Underground Neutrino Experiment (DUNE): ND-LAr and the 2x2 Demonstrator

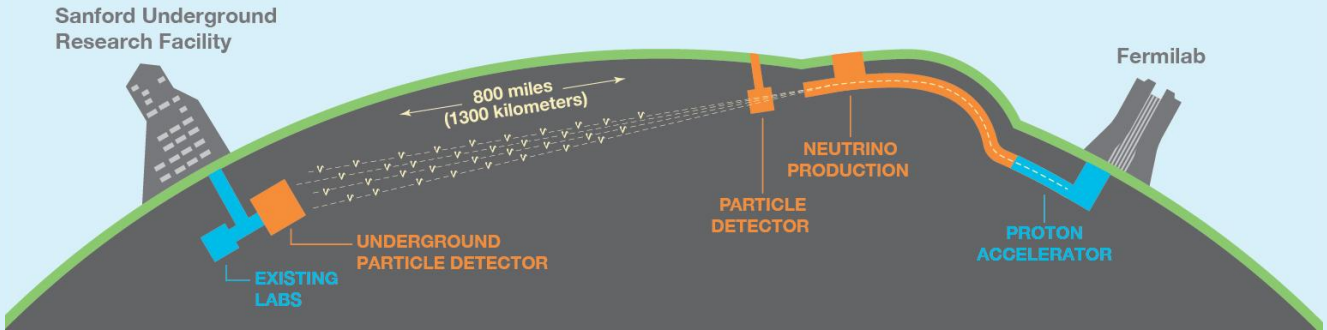
Kevin Wood, kwood@lbl.gov, on behalf of the DUNE Collaboration

CoSSURF 2024, Sanford Underground Research Facility

May 14, 2024

DUNE Overview

- Long-baseline accelerator-based neutrino oscillation experiment that will vastly improve the precision of neutrino oscillation parameter measurements
  - Mitigation of statistical uncertainties:
    - Unprecedented neutrino beam intensity: 1.8 MW → 2.1 MW
    - Massive far detector: up to 4 modules with 17 kton LAr / module
  - Mitigation of systematic uncertainties:
    - Highly performant near detector complex



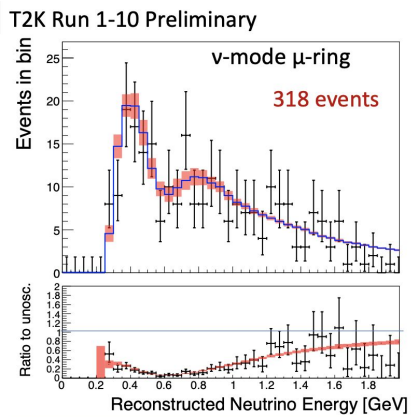
Example: T2K Systematic Uncertainty

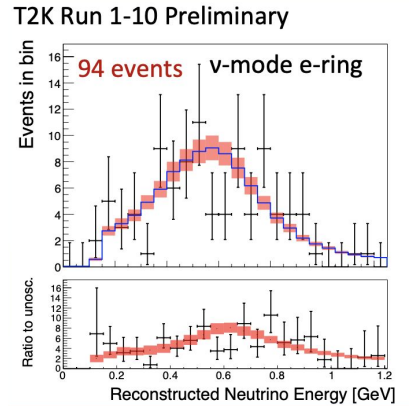
- Systematic errors are greatly constrained by near detectors
- Systematic errors on the shape of the distributions also have important impact on oscillation measurements
- Results limited by statistics
- Off-axis → sampling narrow energy band
  - DUNE's wide band beam will be more challenging

Eur. Phys. J. C (2023) 83:782

Sample		Uncertainty source (%) Flux	Interaction	FD + SI + PN	Flux⊗Interaction (%)	Total (%)
1Rμ	ν	2.9 (5.0)	3.1 (11.7)	2.1 (2.7)	2.2 (12.7)	3.0 (13.0)
	$\overline{\nu}$	2.8 (4.7)	3.0 (10.8)	1.9 (2.3)	3.4 (11.8)	4.0 (12.0)
1Re	ν	2.8 (4.8)	3.2 (12.6)	3.1 (3.2)	3.6 (13.5)	4.7 (13.8)
	$\overline{\nu}$	2.9 (4.7)	3.1 (11.1)	3.9 (4.2)	4.3 (12.1)	5.9 (12.7)
1Re1de	ν	2.8 (4.9)	4.2 (12.1)	13.4 (13.4)	5.0 (13.1)	14.3 (18.7)

Current T2K uncertainty on integrated event rates with (without) the near detector constraints

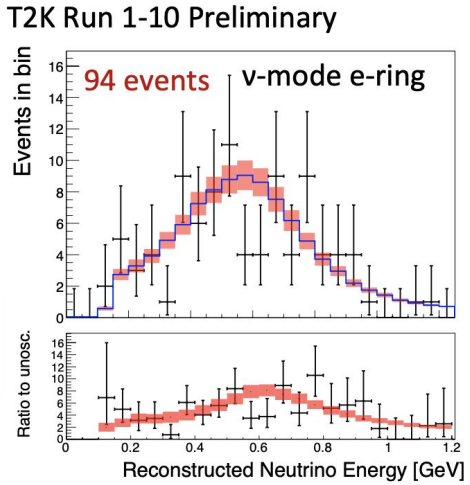


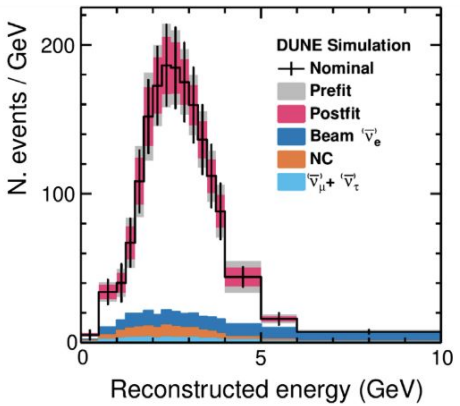


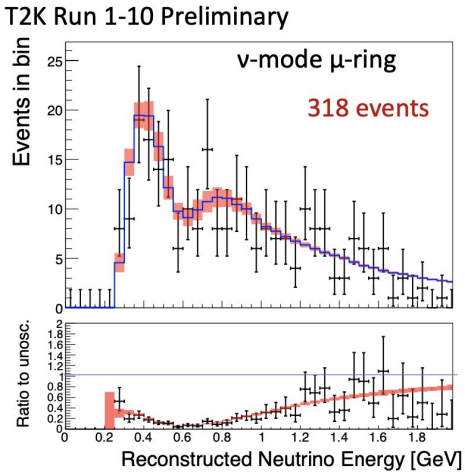
https://doi.org/10.5281/zenodo.3959558

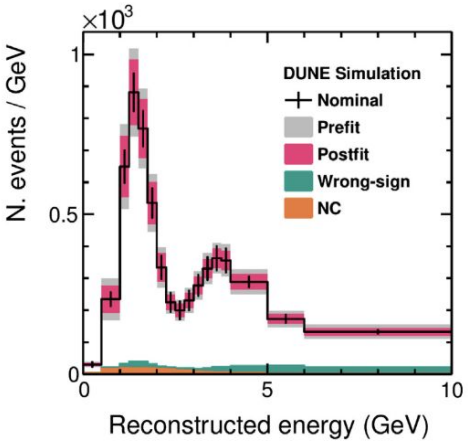
Enter DUNE

- Compare 10 years of T2K data to projection for the first few years of DUNE data
  - "Low exposure long-baseline neutrino oscillation sensitivity of the DUNE experiment" Phys.Rev.D 105 072006 (2022)
  - Projected spectra for 100 kt-MW-CY exposure
    - Few years of data assuming 57% uptime and NuFIT 4.0 best fit



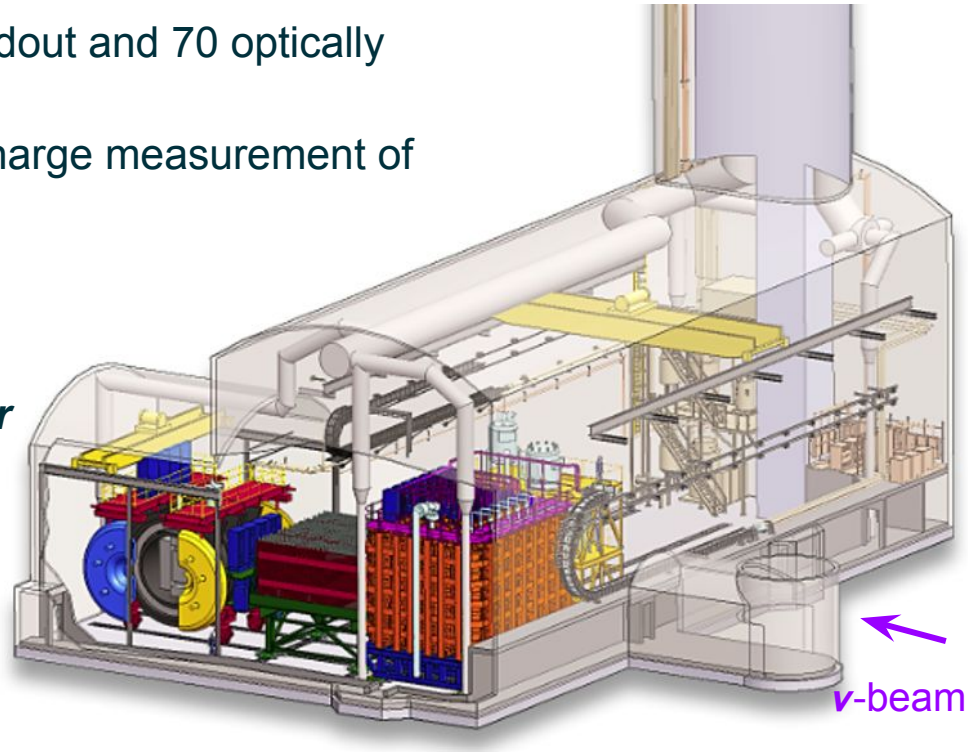




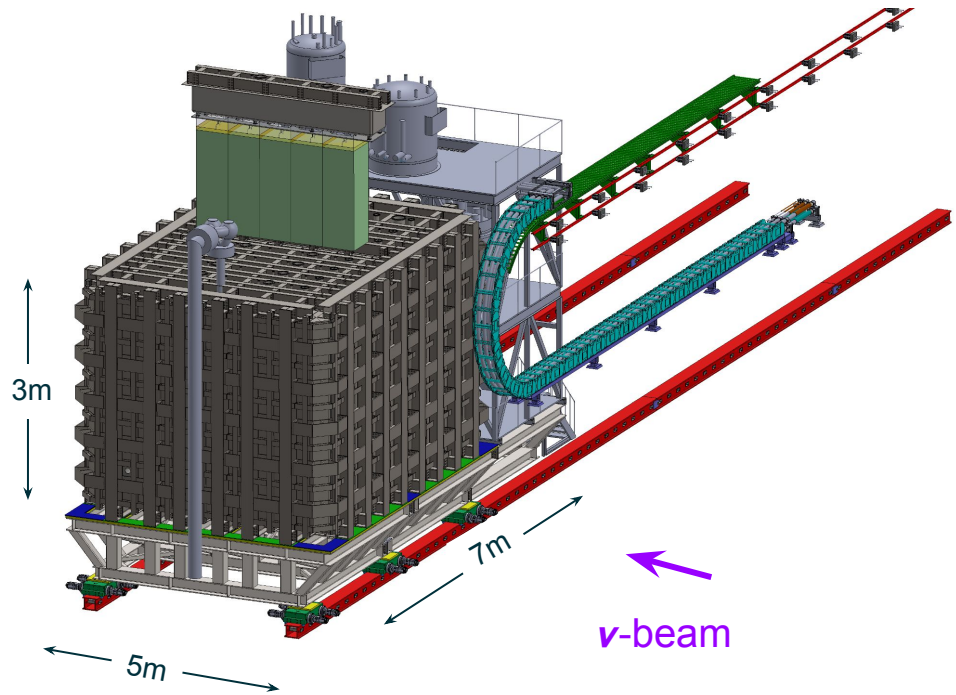


DUNE (Phase 1) Near Detector Complex

- ***Moveable LArTPC system***
  - ND-LAr: novel LArTPC with pixelated readout and 70 optically isolated TPC volumes
  - TMS: spectrometer for momentum and charge measurement of ν_μ-CC muons exiting ND-LAr
  - PRISM: ND-LAr + TMS system moves up to 28.5m (2.8°) off-axis
- ***Multi-purpose on-axis magnetized detector***
  - SAND: Straw tube tracker with Argon target inside KLOE superconducting solenoid

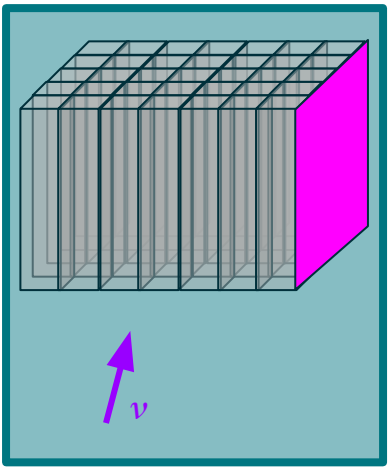


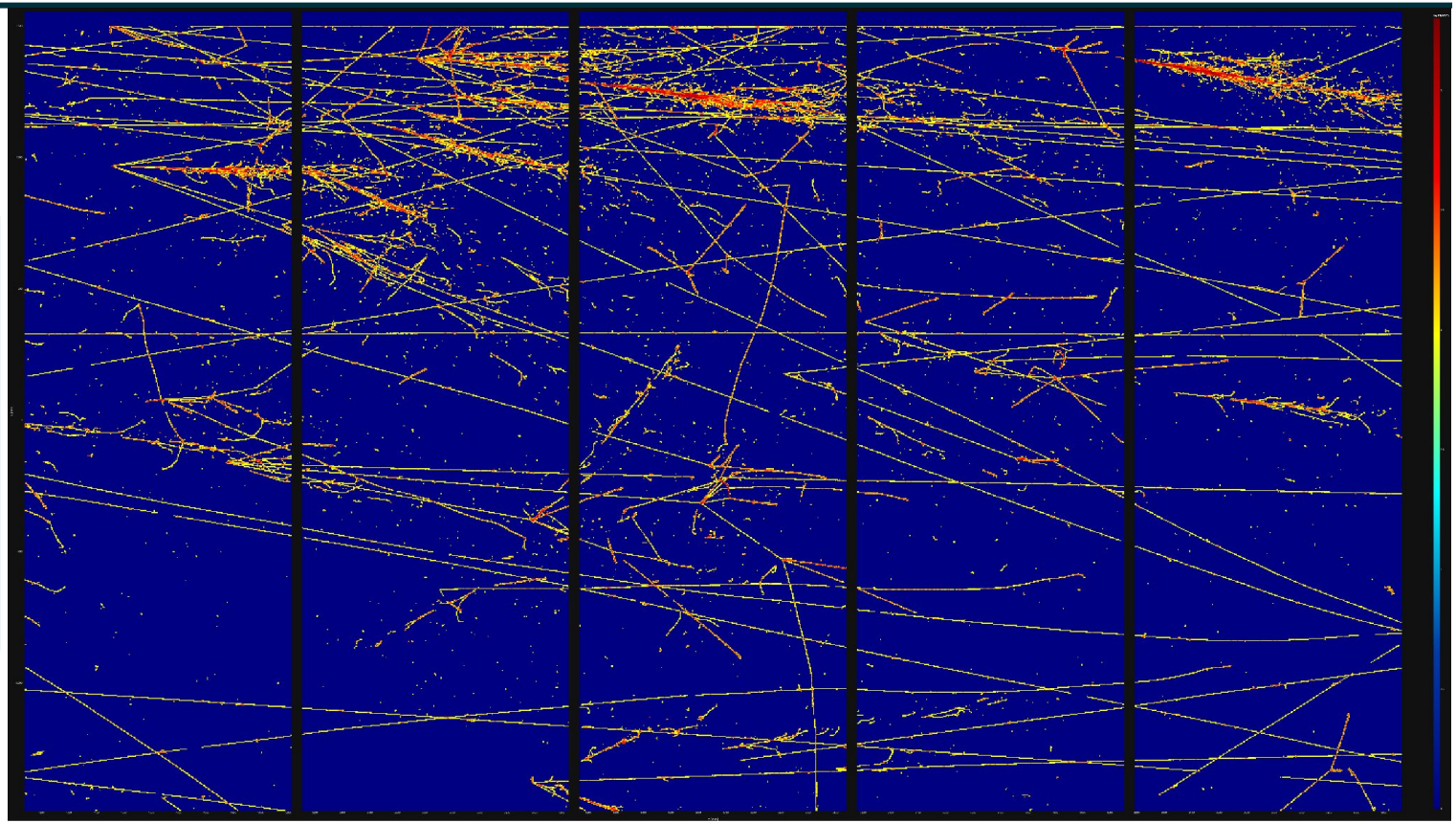
ND-LAr Detector



- 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!

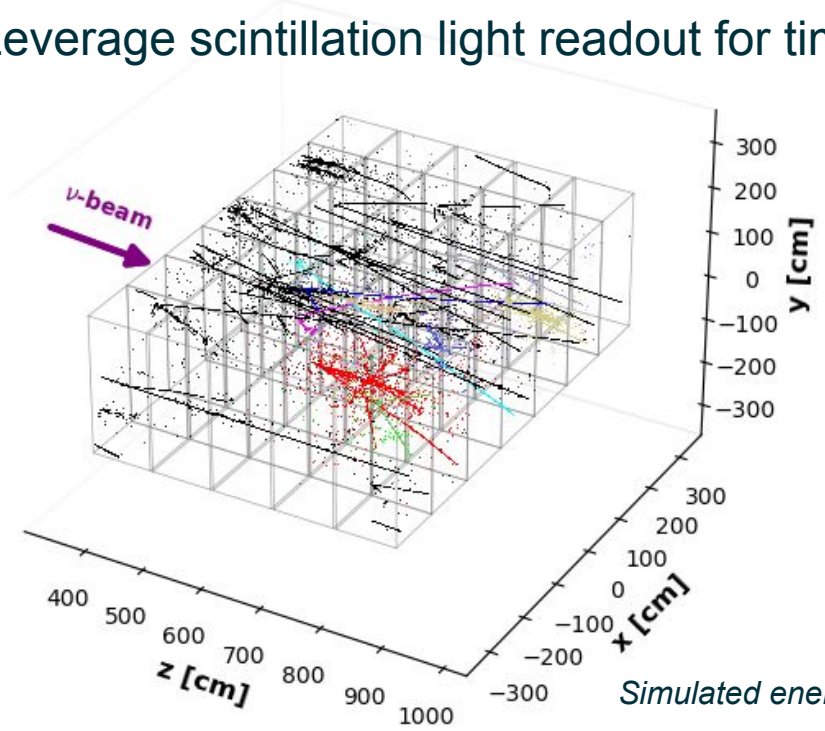
1.2 MW LBNF Spill Simulation

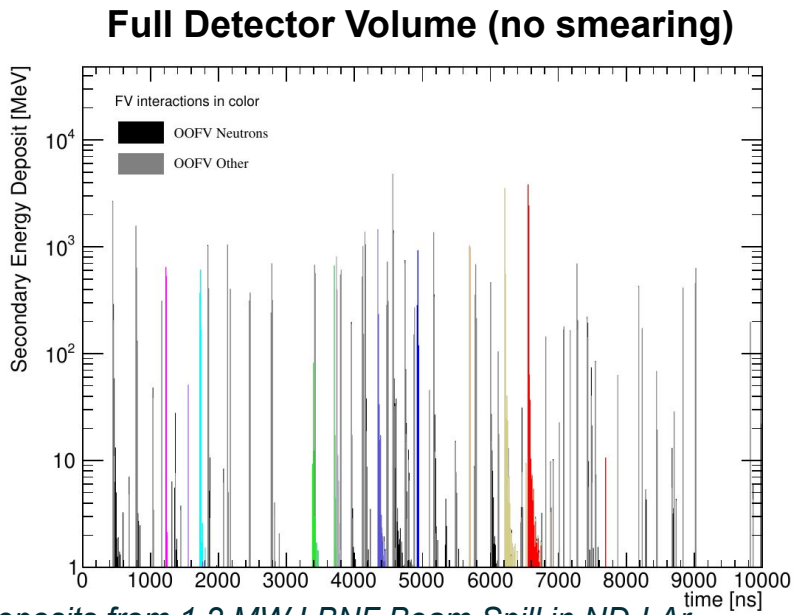




Coping with Pileup

- 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



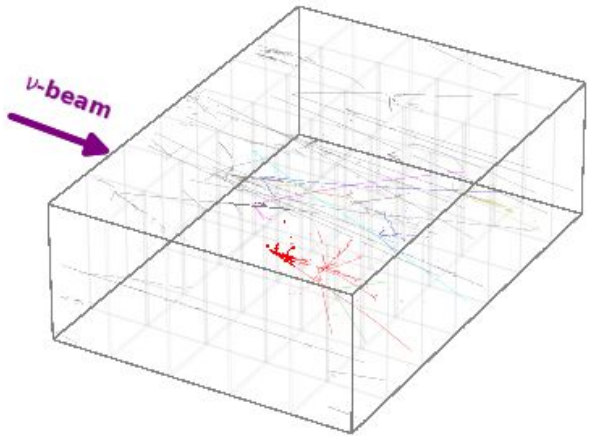


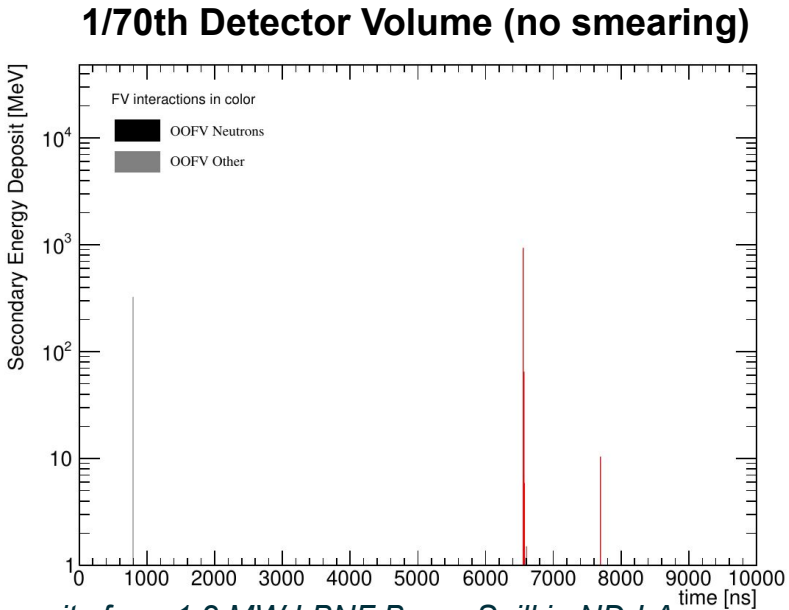
Simulated energy deposits from 1.2 MW LBNF Beam Spill in ND-LAr

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

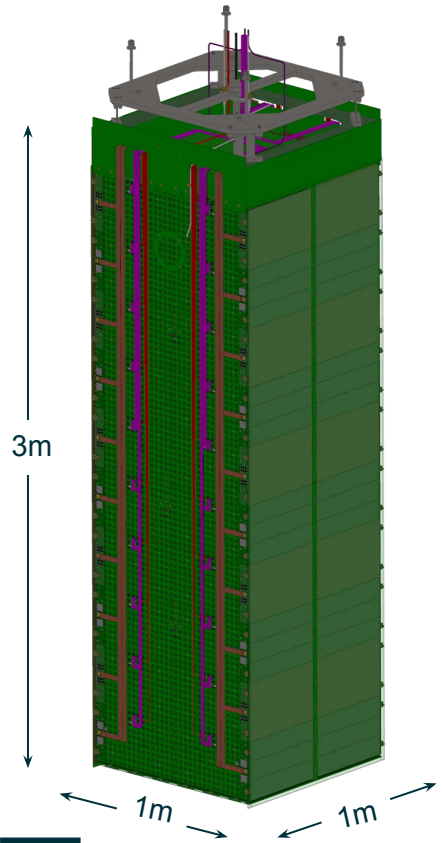
→ enabled through optical segmentation



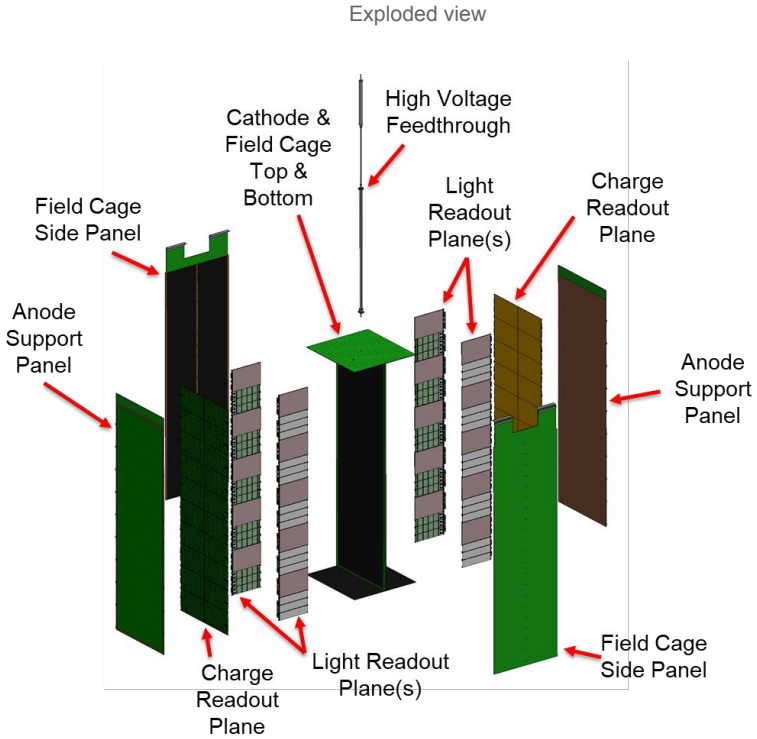


Simulated energy deposits from 1.2 MW LBNF Beam Spill in ND-LAr

ND-LAr Module



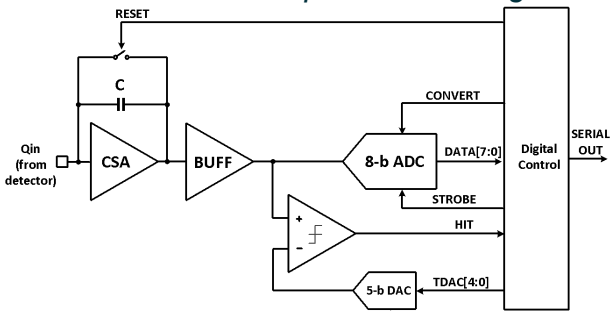
- 2 optically isolated TPCs per module
  - 50 cm drifts → 25 kV for 500 V/cm
- Pixelated charge readout with O(4mm) granularity
- Light readout with modules on the vertical field cage panels



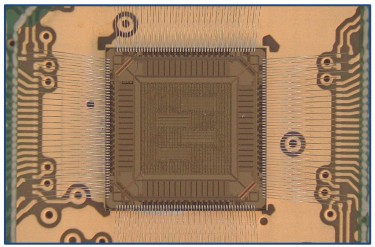
LArPix Charge Readout System

- Pixel tile PCB containing 1000's of pixels/ft^2 and minimal active components
- LArPix ASIC loaded onto backside of pixel tiles
- Scalable system for instrumental large areas:
  - **Data rates**: made manageable by channel-by-channel self-triggering
  - **Cryogenic compatibility**: < 100μW / channel
  - **Affordable**: Full system cost approaching ~$0.10/channel or ~$10k/m2
  - **Practical**: All components produced by commercially available vendors
  - **Robust**: Hydra I/O Networking provides protection against single ASIC failures

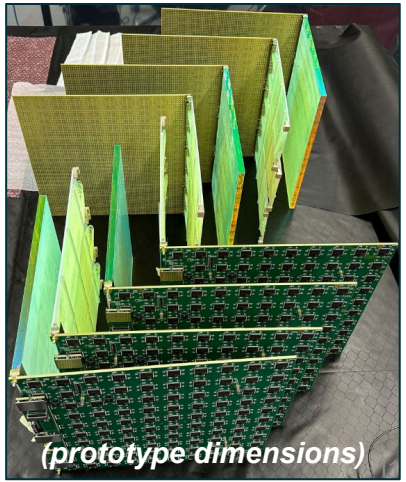
LArPix v2 conceptual block diagram



LArPix v2b bare die



pixel tiles (+light traps)



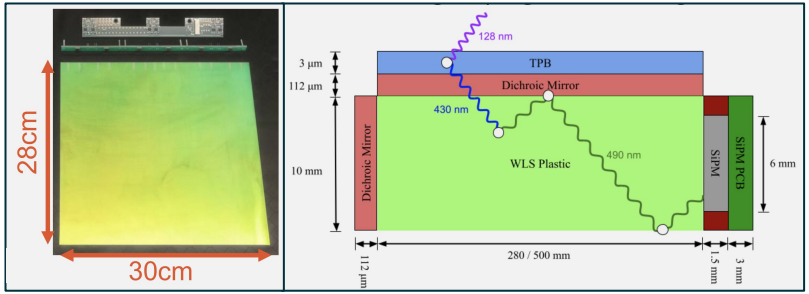
Light Readout System

- Two complementary designs for light traps
  - Increase coverage with fixed channel count

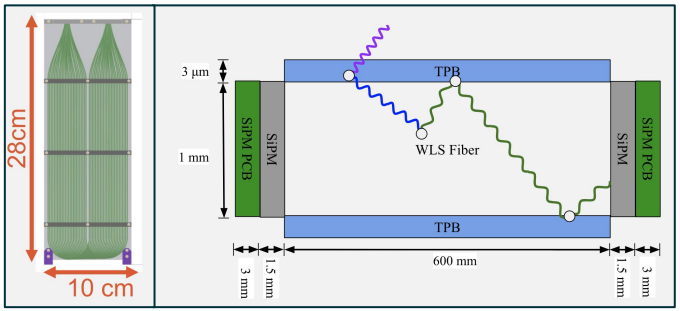
	ArcLight	LCM
Efficiency	~0.2%	~0.6%
Spatial resolution	~5cm	~10cm
Notes	– Large sense area – High dynamic range	– Scalable design – Mechanically robust

- <10ns single hit timing resolution
- Common SiPM readout system
  - Analog signals feedout from cryo
  - VGA and ADC cards in VME crates on the warm side
- Common control and DAQ software

ArcLight module [prototype dimensions]

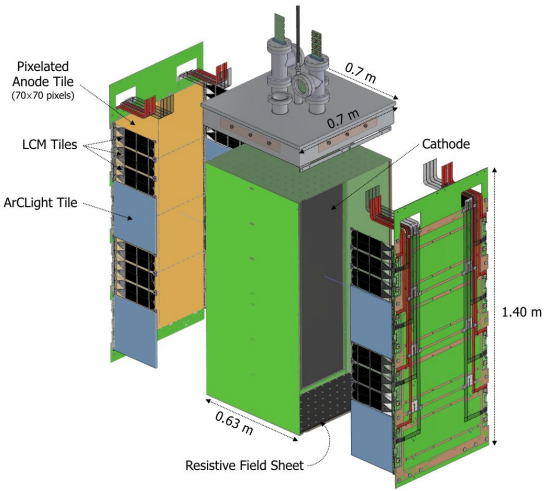


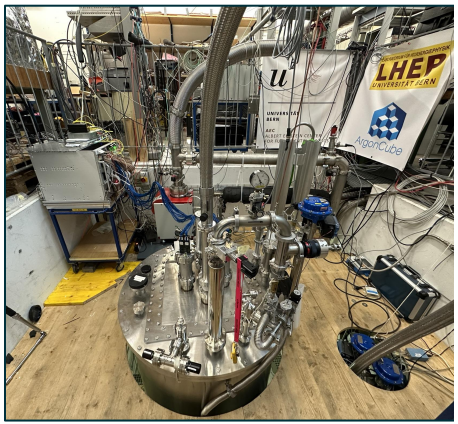
LCM [prototype dimensions]



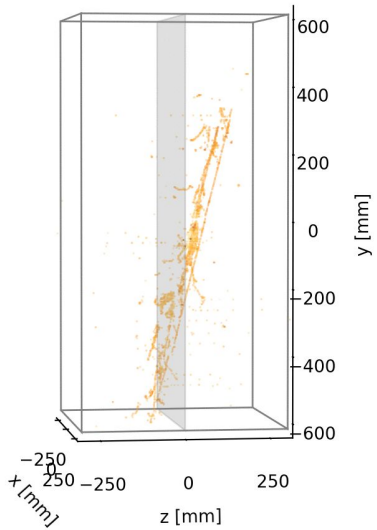
2x2 Demonstrator

- Demonstration of ND-LAr design in reconstructing neutrino interactions
- 2x2 array of 1.2 x 0.6 x 0.6 m^3 modules containing >300K pixel channels
- 4 modules operated individually at University of Bern
  - O(10^9) cosmic events





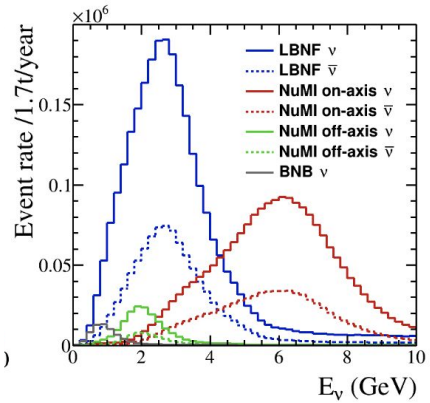
raw data!

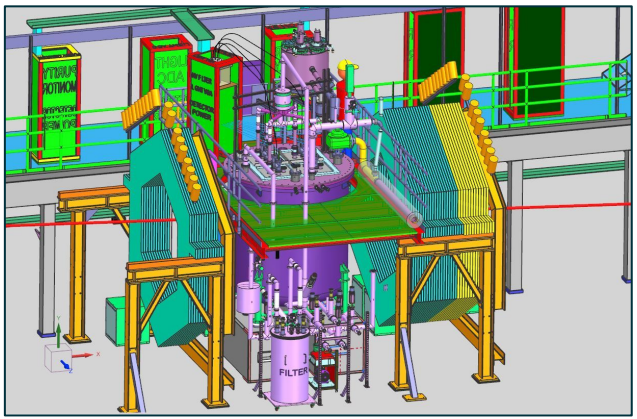


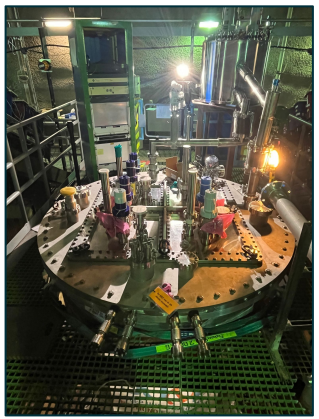
arXiv:2403.03212

2x2 Demonstrator

- Demonstration of ND-LAr design in reconstructing neutrino interactions
- 2x2 array of 1.2 x 0.6 x 0.6 m^3 modules containing >300K pixel channels
- 4 modules operated individually at Bern
  - O(10^9) cosmic events
- @ Fermilab underground facility (MINOS hall) between repurposed Minerva planes
- Will measure neutrino interactions in the GeV-energy regime from the NuMI beam

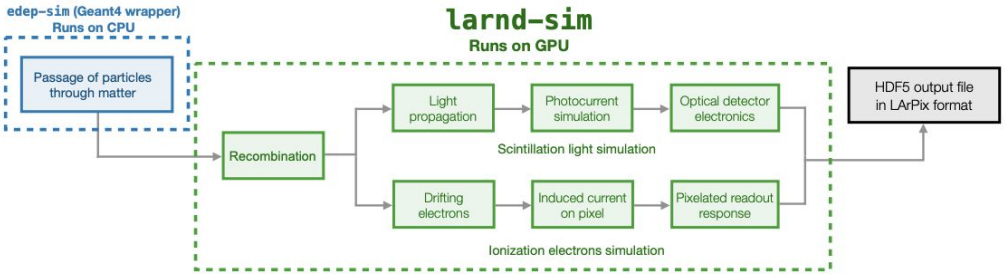


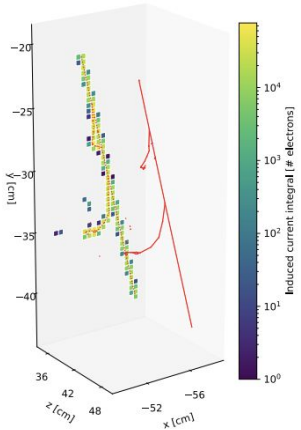


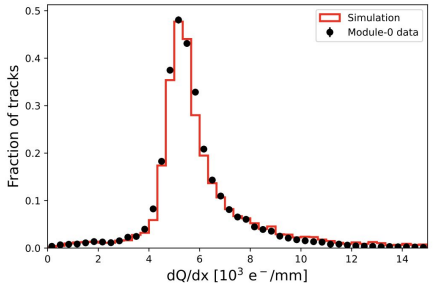


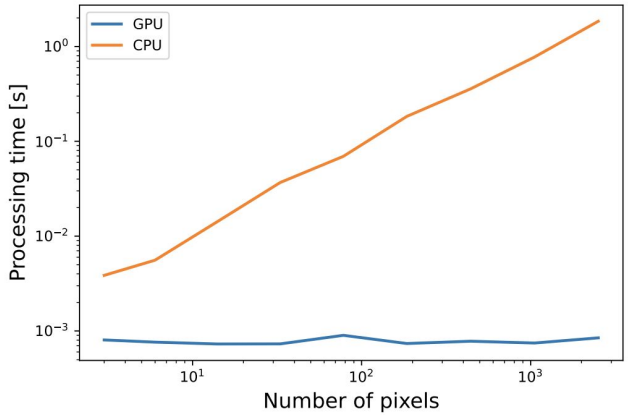
ND-LAr / 2x2 Detector Simulation

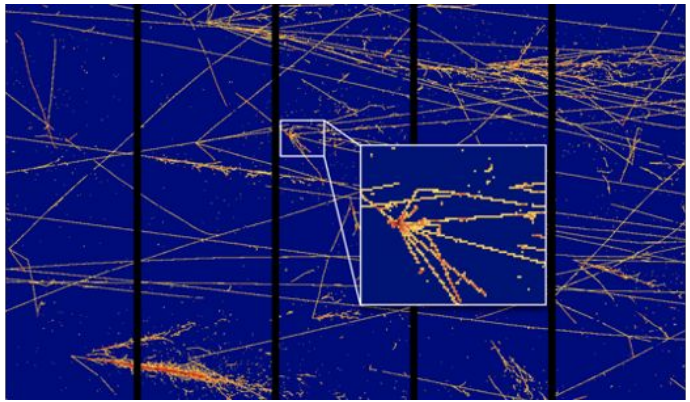
JINST 18 P04034 (2023)











Summary

- DUNE's near detector is critical to achieving its physics goals
- ND-LAr is at the heart of the DUNE near detector
  - On track to begin build in 2026-2027, operations in 2030-2031
- The 2x2 Demonstrator is coming online imminently and will measure DUNE's very first neutrinos! (*not for DUNE's main physics measurements, but still…)

April 2024 2x2 Analysis Workshop @ Fermilab

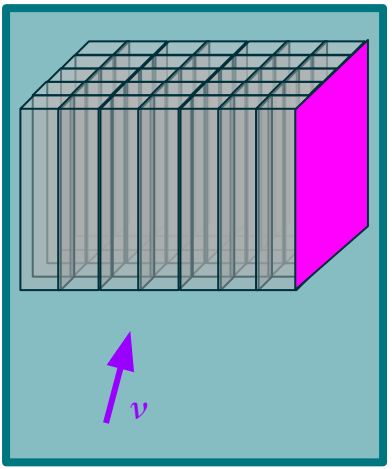
Thank you!

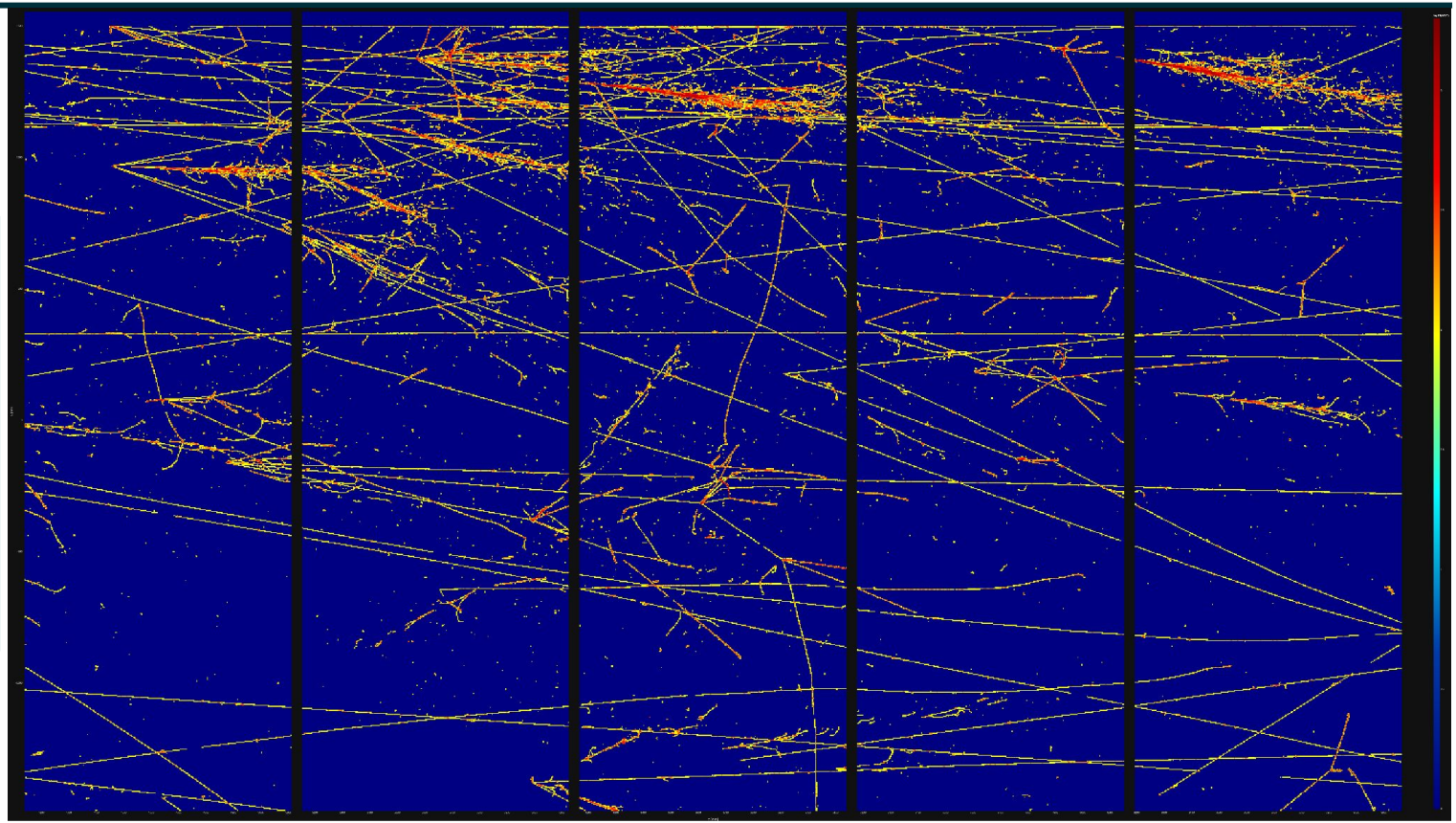
DEEP UNDERGROUND NEUTRINO EXPERIMENT

January 2024 DUNE Collaboration Meeting @ CERN

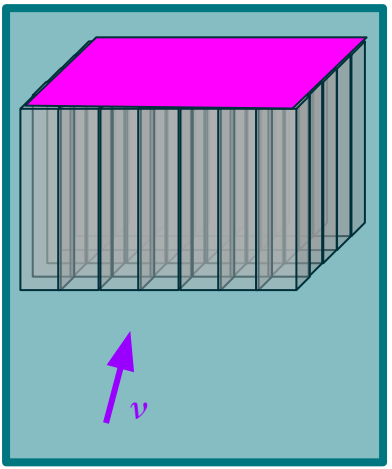
Backups

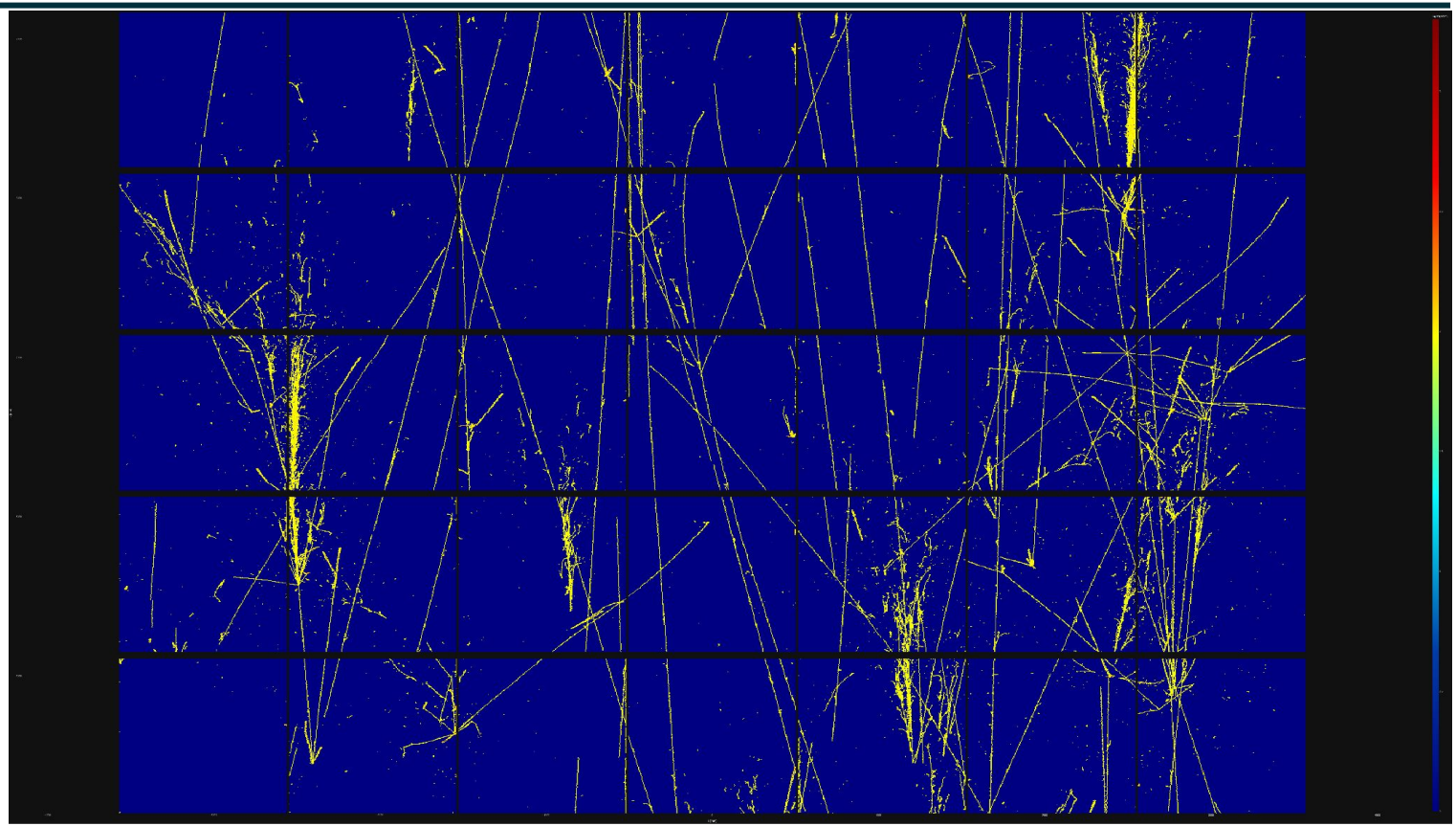
1.2 MW LBNF Spill Simulation





1.2 MW LBNF Spill Simulation (inc. det. sim.)





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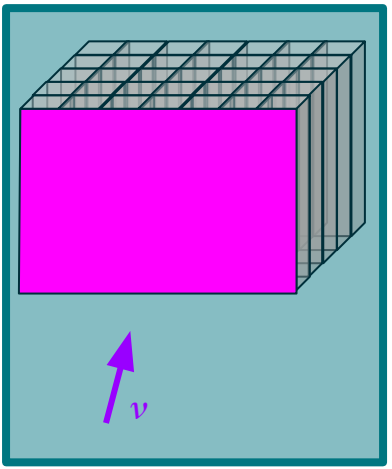
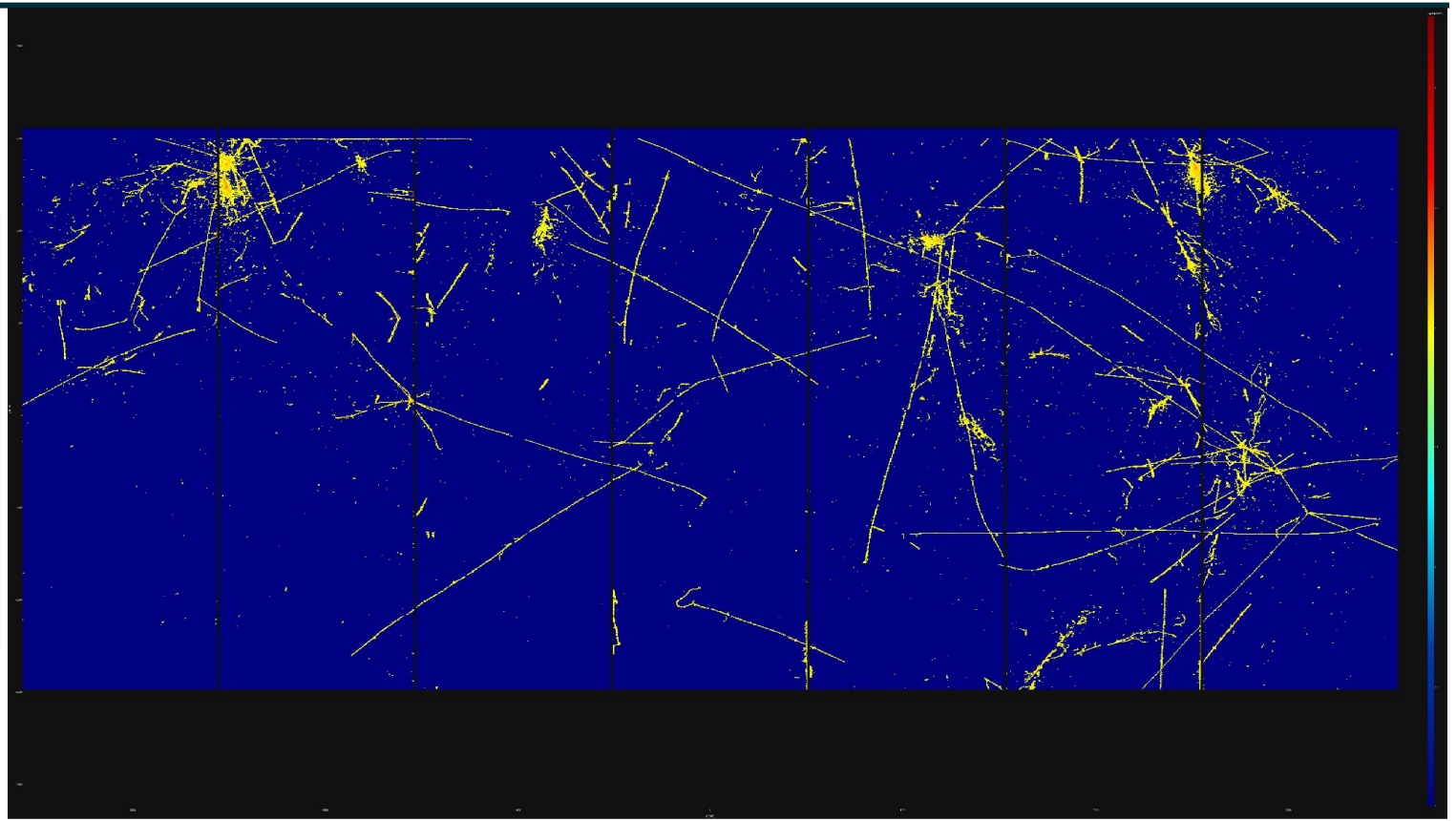
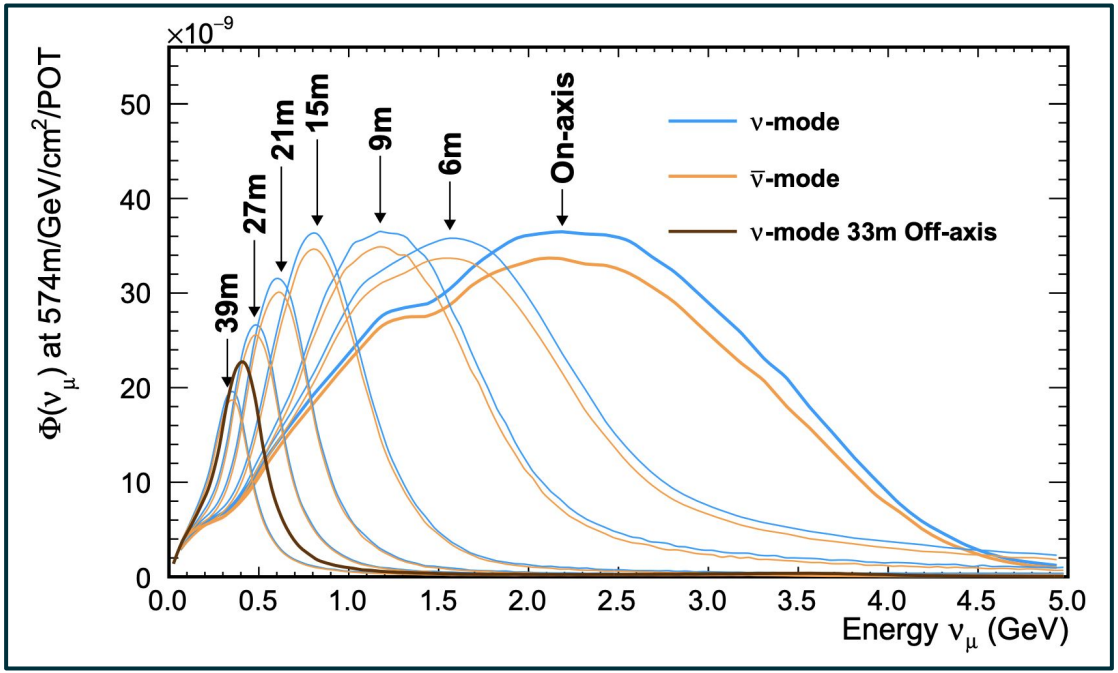




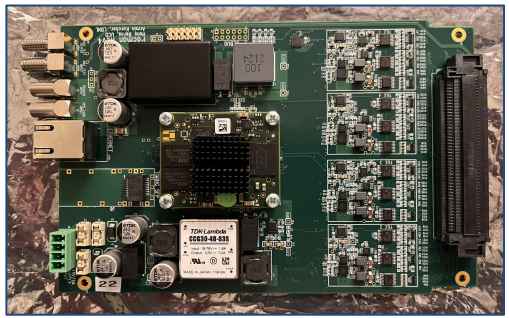
DUNE/LBNF Off-axis Fluxes (PRISM)

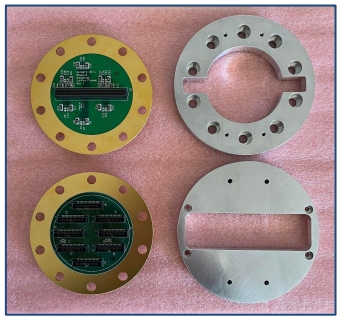


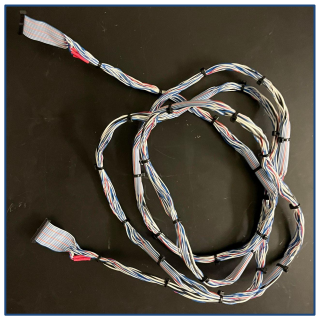
Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics. arXiv:2002.03005

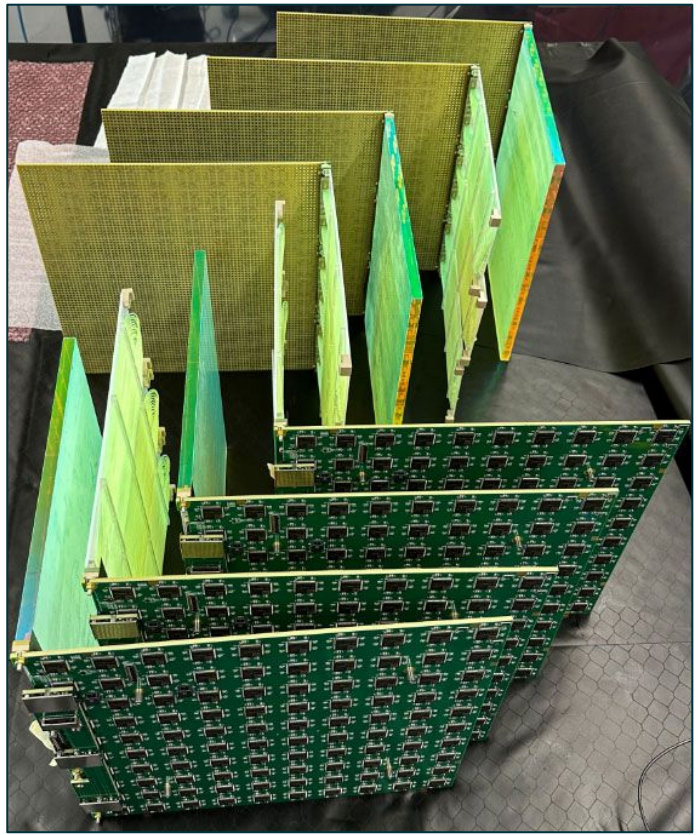
LArPix Charge Readout System

- Pixel tile PCB containing 1000's of pixels/ft^2 and minimal active components
- LArPix ASIC loaded onto backside of pixel tiles
- Single 34-pin ribbon cable per tile
- PACMAN controller
  - Delivers clean power to 100's of ASICs
  - Establishes I/O with ASICs
  - Handles DAQ and configuration for up to 8 tiles

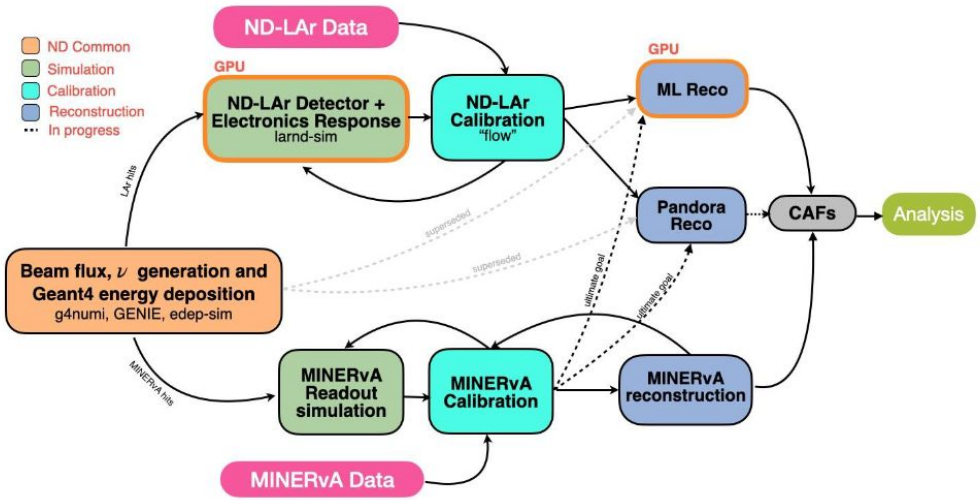








ND-LAr / 2x2 Analysis Pipeline

- Analysis pipeline being prepared to promptly analyze 2x2 data
  - End-to-end simulation
  - Data processing
  - Calibrations
  - Event reconstruction
  - High level analysis

- Directly portable to ND-LAr (MINERvA stand in for downstream muon spectrometer)