# The Near Detector Liquid Argon (ND-LAr) 2×2 prototype of the Deep Underground Neutrino Experiment (DUNE)

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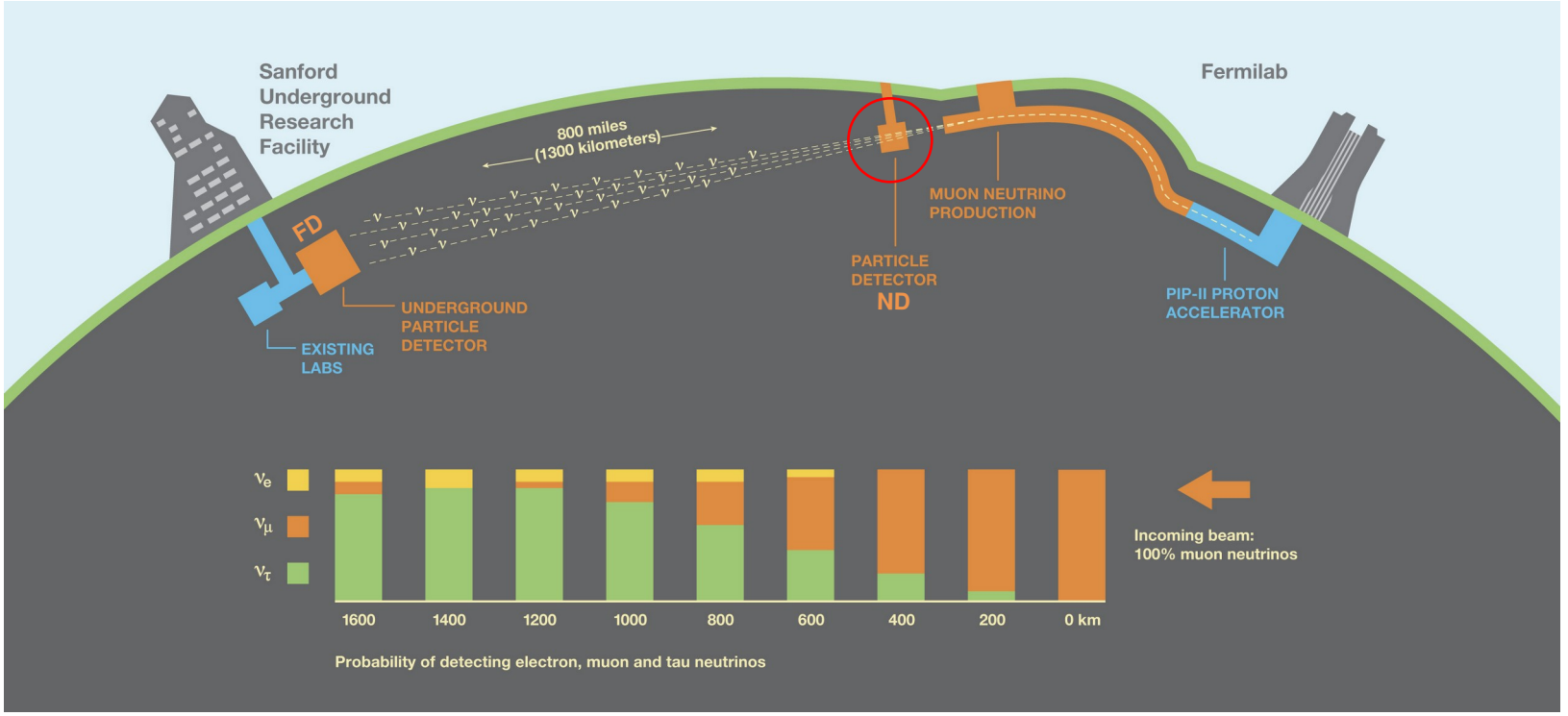
for the DUNE collaboration

Rencontres du Vietnam, 30th anniversary, Aug 6-12, 2023

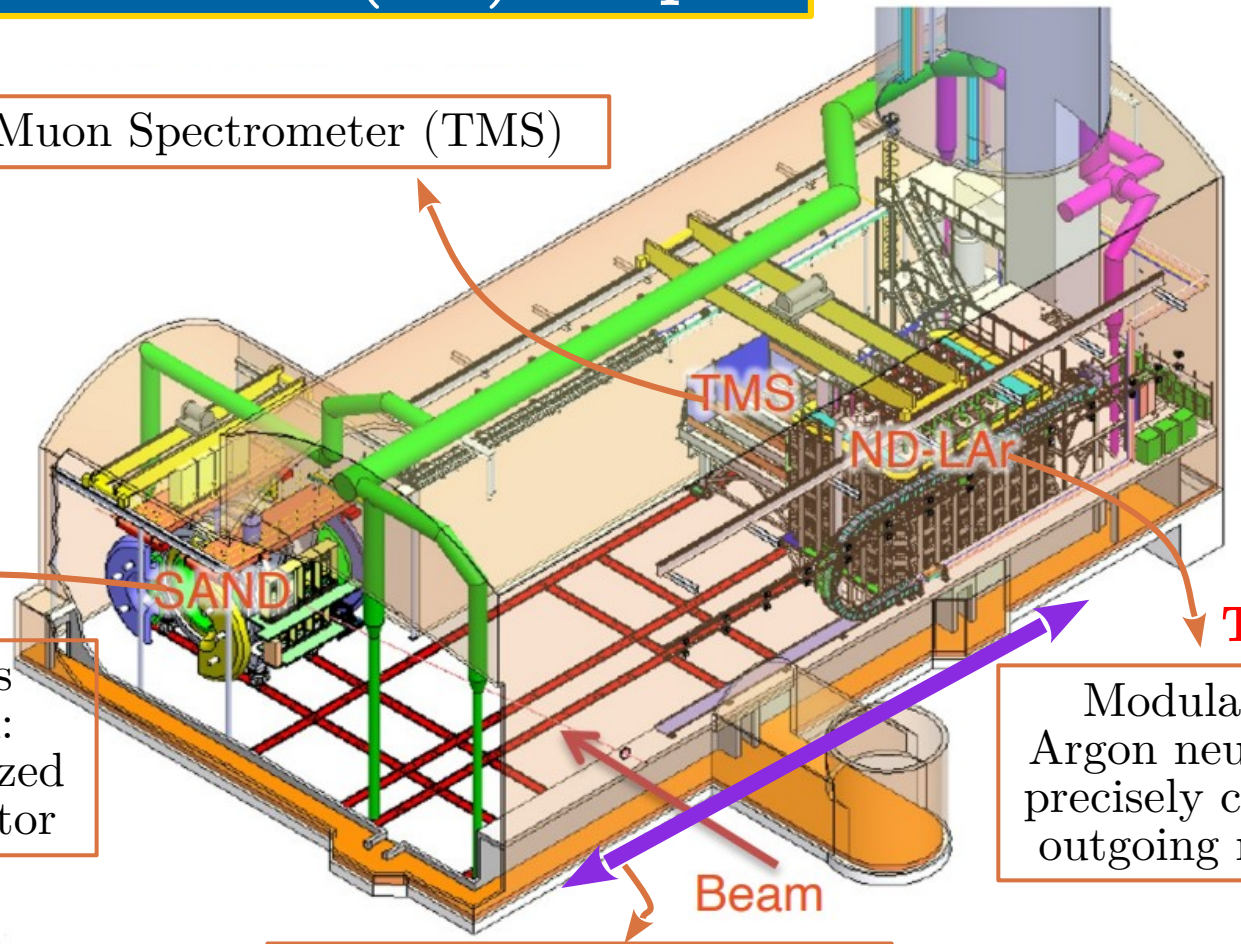
# The DUNE experiment: overview




- The Deep Underground Neutrino Experiment (DUNE) is designed to study neutrino oscillations
- Main oscillation physics goals:
  - Determination of neutrino mass ordering
  - Search for CP violation in the leptonic sector
  - Precision measurement of $\Delta m^2_{32}$, $\delta_{CP}$, $\sin^2\theta_{23}$, $\sin^2\theta_{13}$

# The DUNE Near Detector (ND) complex

Temporary Muon Spectrometer (TMS)



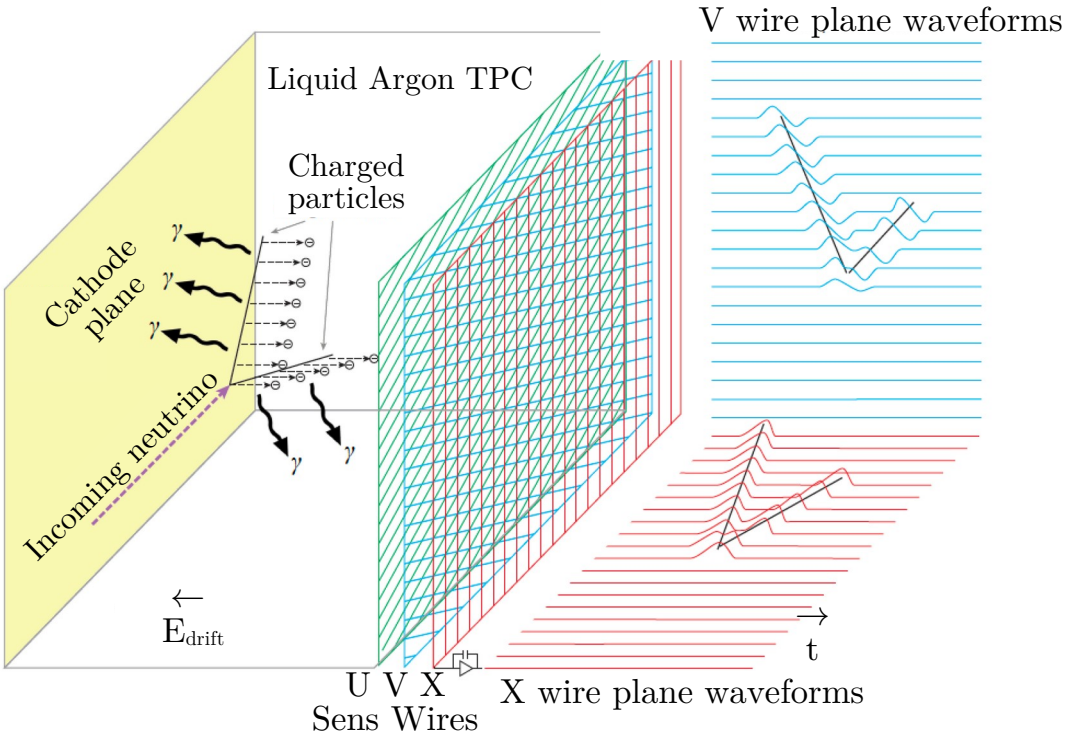

System for On-Axis Neutrino Detection: fixed on-axis magnetized beam spectrum monitor

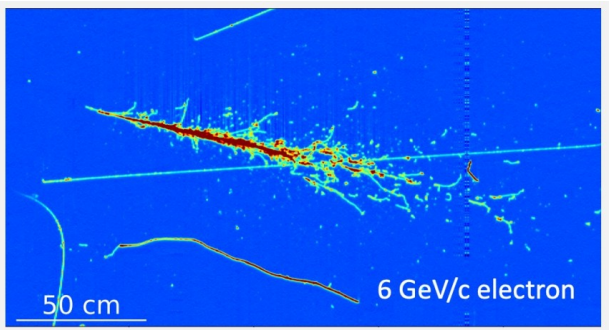
This talk!

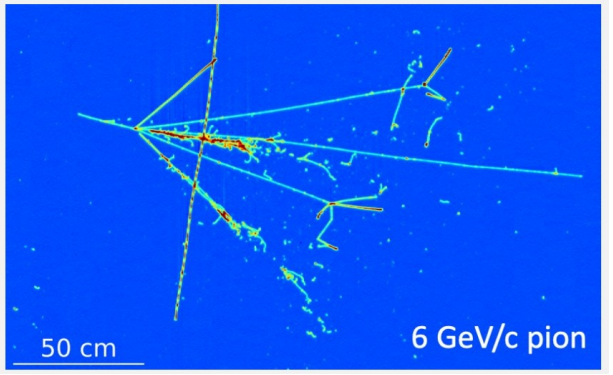
Modularized Liquid Argon neutrino target to precisely characterize the outgoing neutrino beam

PRISM: system for moving ND-LAr + muon tracker

# Traditional Liquid Argon Time Projection Chamber



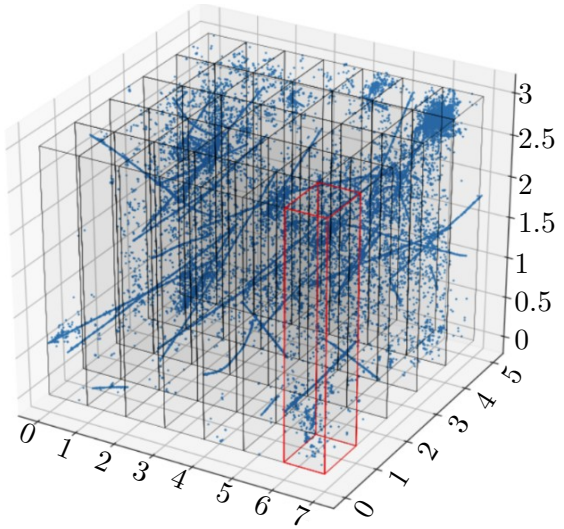



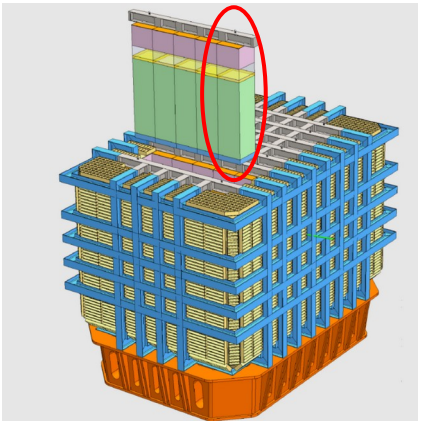

ProtoDUNE LArTPC events
B. Abi et al 2020 JINST 15 P12004

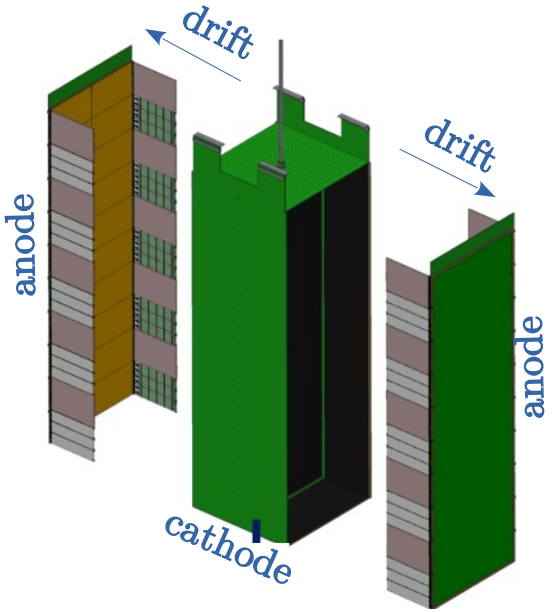
- Timing information from scintillation light collected by light detection systems
- Ionization electrons → drifted towards segmented wire planes
- Excellent spatial and calorimetric resolution
- 3D reconstruction by combining 2D views

# The ND-LAr TPC: a modular TPC



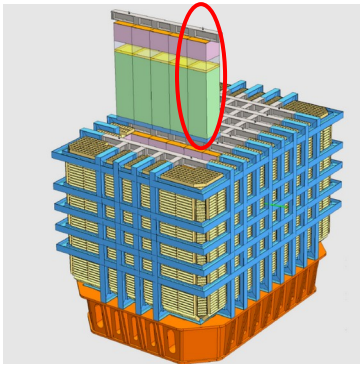
One simulated beam spill in ND-LAr






- Drift time (300 μs) > spill width (10 μs)
- Event rate at ND: ~50 interactions per spill with a 1.2 MW beam
- 130 t of active Liquid Ar (same detector material as the FD)
- 35 modules in a 7×5 array.
  Each module: 1×1×3 $m^3$
- 2 TPCs in each module
  - 50 cm–drift TPC volumes
  - ~30% optical detector coverage

# The ND-LAr TPC: a modular TPC

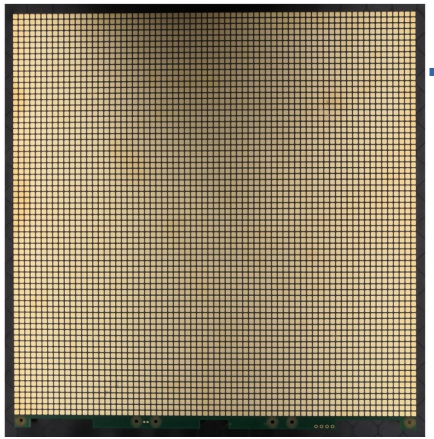




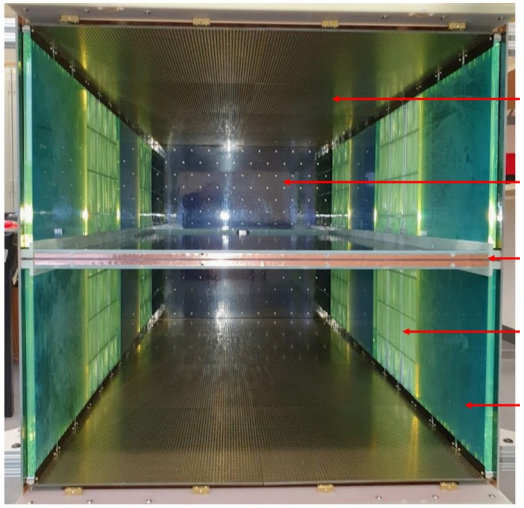

Prototype module: 0.7×0.7×1.4 $m^3$

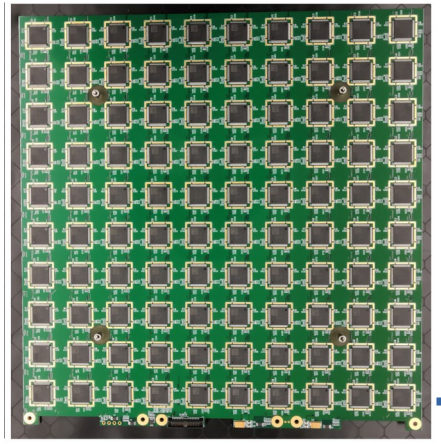
- Pixelated charge readout system and modularized design to handle pile-up
- High performance, custom-made light readout system
- Prompt light will be well-localized
- Charge-light matching to further tackle pile-up
- Potential failures are isolated
- Reduced HV requirements:
  - Lower drift distance (~50 cm) means lower voltage
  - E-field non-uniformities not as important
- Inactive volume: ~5 cm between active regions

# The ND-LAr TPC: pixelated charge readout system



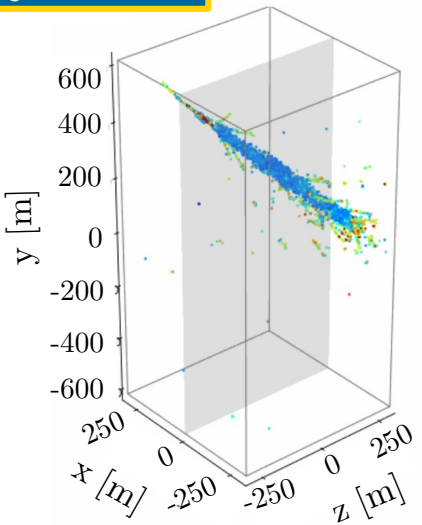
front contains charge-sensitive pixels that face the cathode



back contains an array of custom-made LArPix ASICs

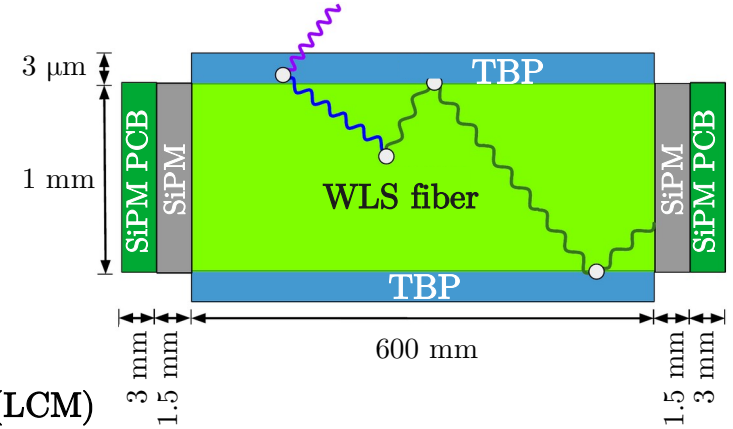
D.A. Dwyer et al. JINST 13 P10007 (2018)

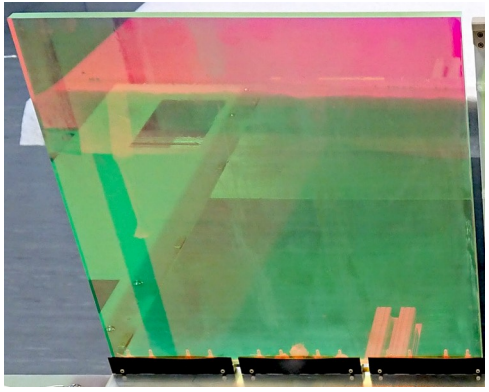



- Unambiguous true 3D tracking of particles crossing the LarTPC
- Each pixel tile is self-triggering → always active
- Pixel readout in cryo via LArPix-ASIC
- Low power amplifiers and digitizers → low stored energy and power dissipation (less than 100 μW/ pixel) → keeps heat out of Ar

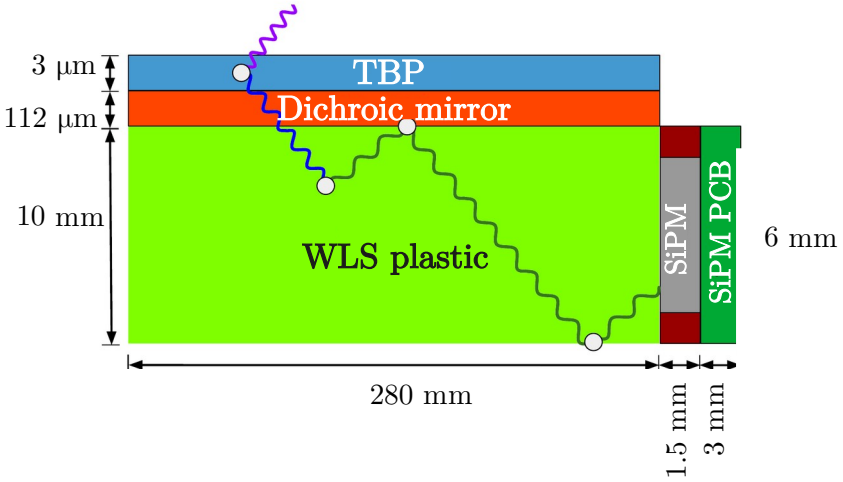
# The ND-LAr TPC: light readout system

Light Collection Module (LCM)



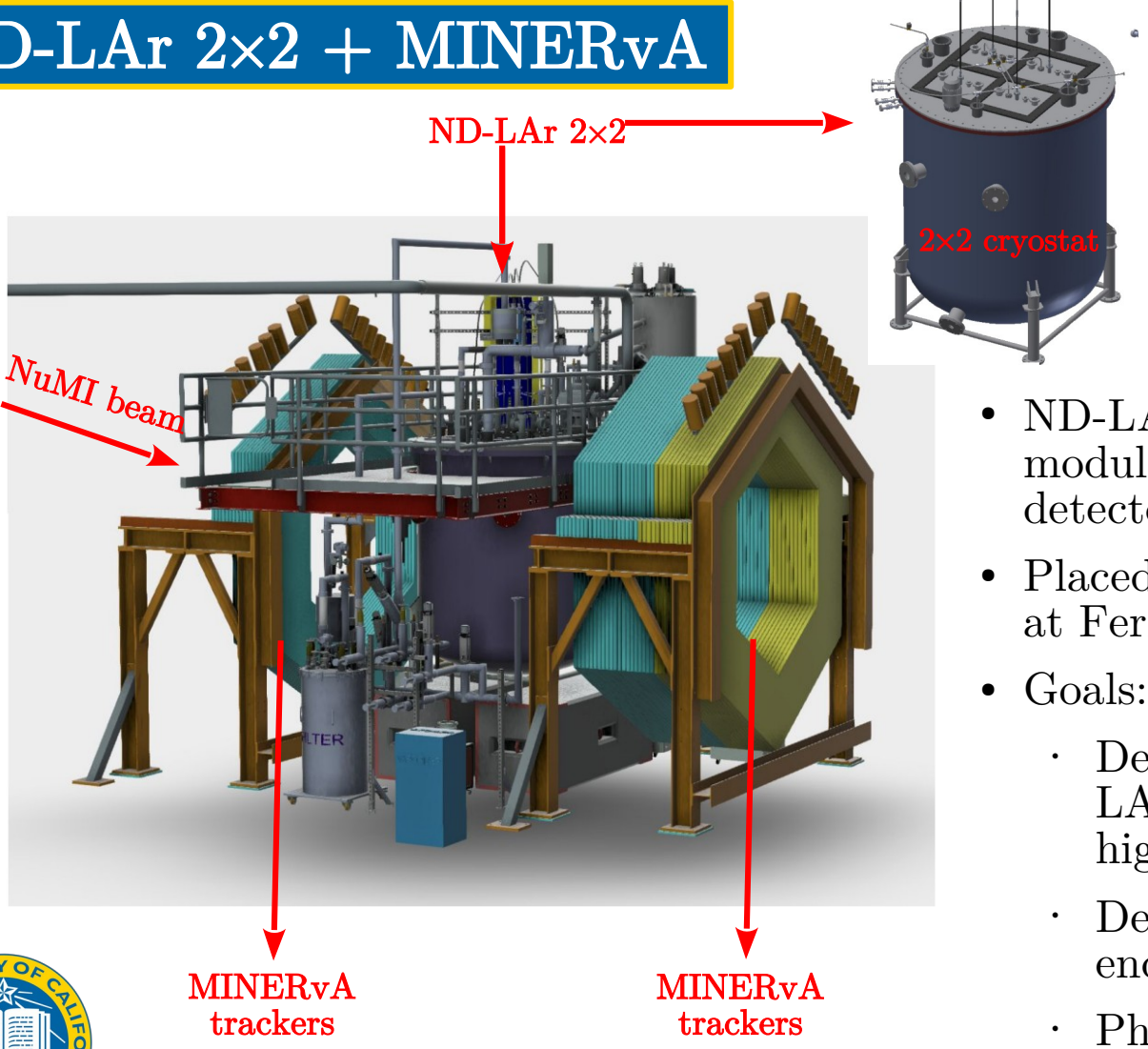
ArC light tiles




- Two novel dielectric light detection techniques:

  LCM + ArCLight tiles
- Alternated in the detector
- SiPM-based detectors
- UV Ar scintillation light → blue light using Tetraphenyl butadiene (TBP) as a wavelength shifter → re-emitted as green
- Complementarity between two systems:
  - ArCLight tiles→ better position sensitivity
  - LCM → better detection efficiency

# ND-LAr 2×2 + MINERvA

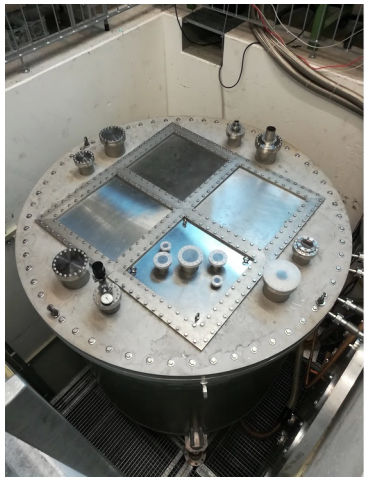



At MINOS underground cavern, Fermilab

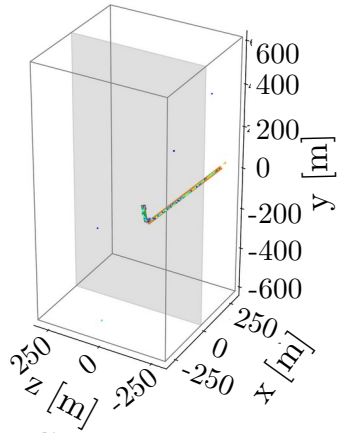
- ND-LAr prototype 2×2 array of modules + repurposed MINERvA detector trackers
- Placed together in the NuMI beam at Fermilab
- Goals:
  - Demonstration of a modular LArTPC with a muon tracker in a high intensity neutrino beam
  - Development and testing of end-to-end infrastructure for DUNE
  - Physics analysis at DUNE energy scale

# Argon Cube 2×2

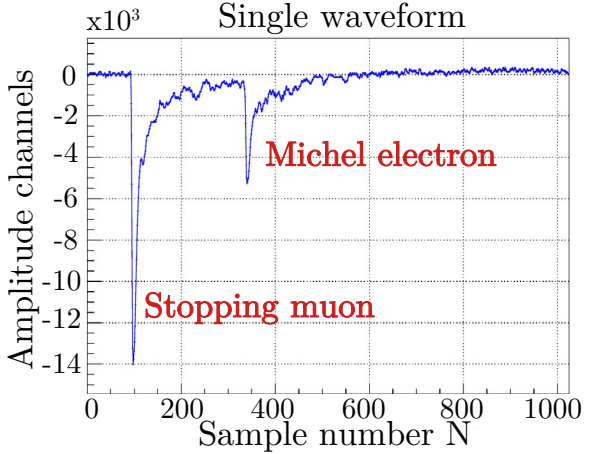
- 2.4 t active mass
- 2×2 array of modules
- Each module: 0.7×0.7×1.4 $m^3$
- Smaller but identical to ND-LAr
- Each module assembled and tested individually at University of Bern with millions of cosmic rays
- Smooth operation + validation of ND-LAr requirements

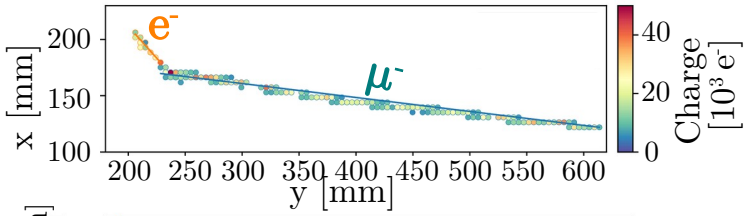
## Physics performance highlights of module-0

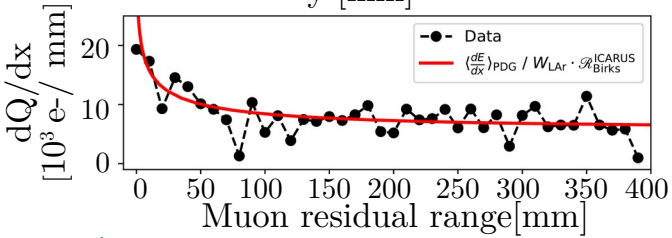



Good charge-light matching



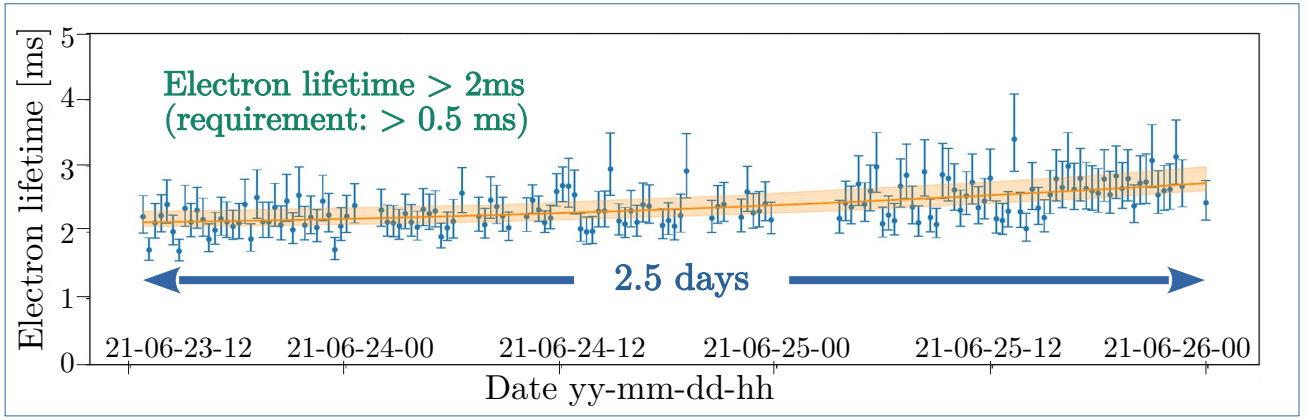

Clear signals recorded by LCM

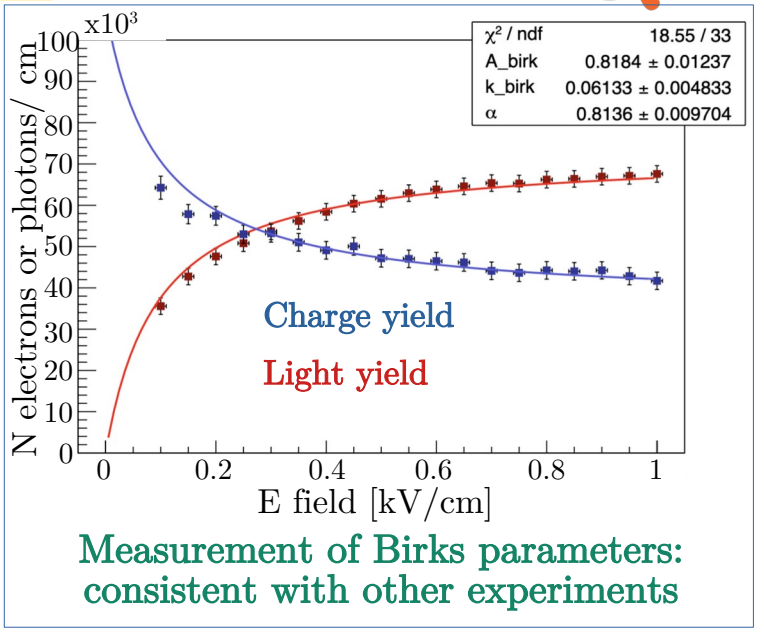


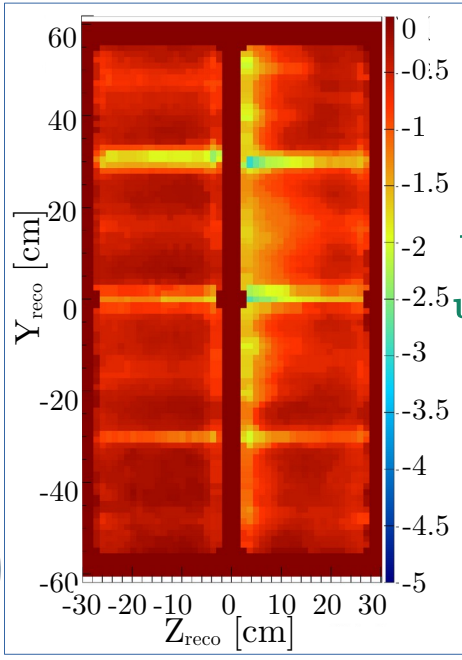

dQ/dx measurement agrees with theory

# Physics performance highlights of module-0

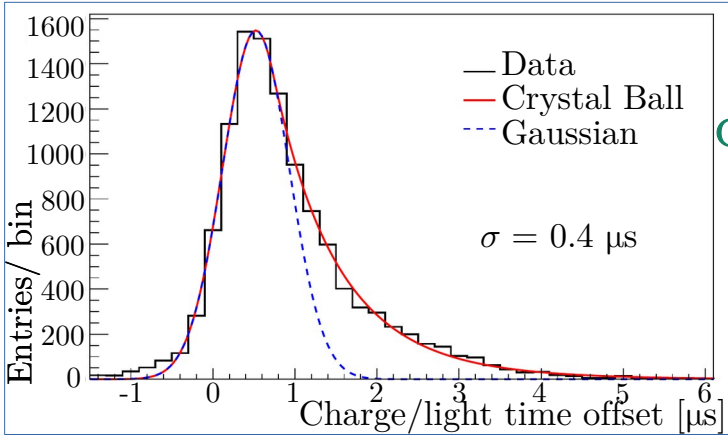



Measurement of Birks parameters: consistent with other experiments

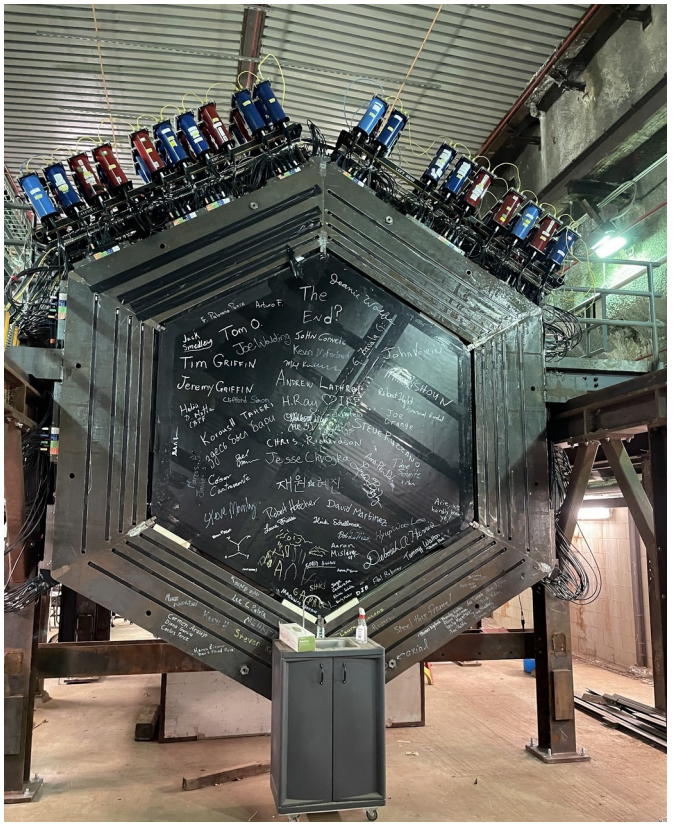



Average electric field non-uniformity: 0.2% (requirement: ≤ 1%)



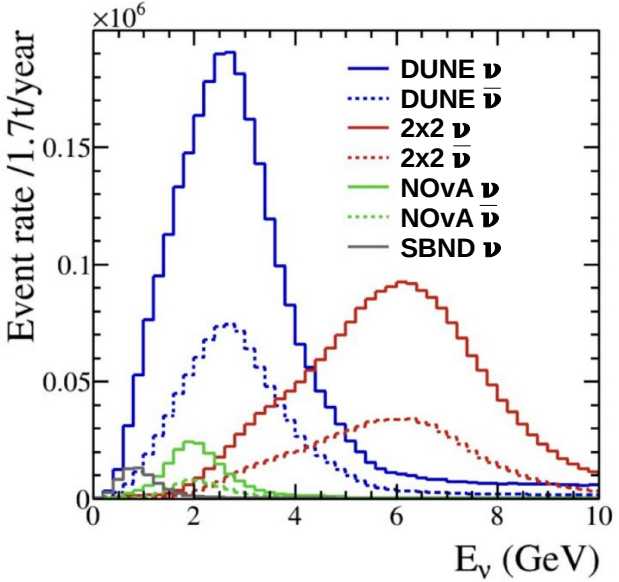

Charge readout resolution: 0.6 mm @ 500 V/cm (requirement < 1.3 mm)

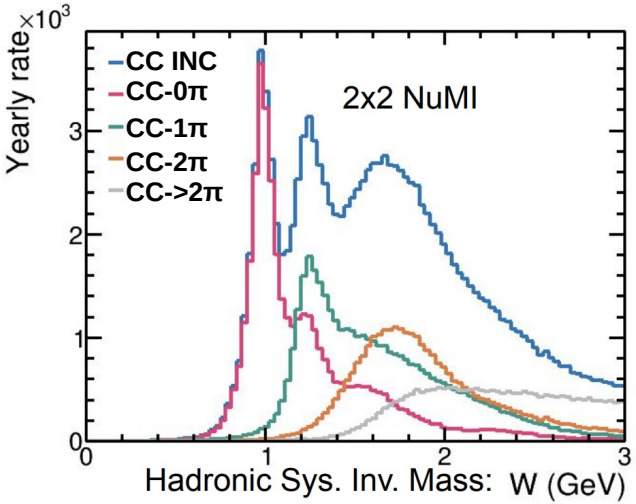
# MINERvA as a muon tagger




- MINERvA (Main Injector Neutrino ExpeRiment to study v-A interactions)
- Repurposed to act as muon taggers for ND-LAr 2×2
- 12 upstream tracker modules→ tag rock muons
- 32 downstream modules → 20 trackers + ECAL and 12 HCAL
  - to separate μ/π and analyze events not contained inside 2×2

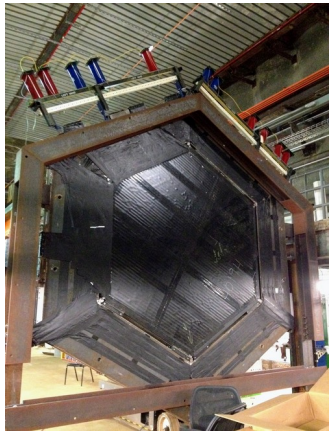
# ND-LAr 2×2 + MINERvA: prospects




- 2×2 will record antineutrino beam data from NuMI in fall 2023
- Energy region → high energy region of DUNE
- Significant kaon and pion production
- Possibilities: Measurement of neutrino cross-sections in Ar, neutrino interaction studies, searches for BSM physics, and demonstration of detector performance among others

# ND-LAr 2×2 + MINERvA: status



- Installation almost complete in Fermilab!
- Prototype will record reactor antineutrinos from the NuMI beam starting fall 2023

# Summary

- DUNE is a next-generation long-baseline neutrino experiment with discovery potential for neutrino mass ordering and leptonic CP violation
- The liquid Ar near detector (ND-LAr) is crucial as it will precisely characterize the outgoing neutrino beam
- A modularized and pixelated LArTPC is necessary to handle the high event rate
- The design of ND-LAr will be tested in a high-intensity neutrino beam using a 2×2 array of modules along with muon tracker planes from the MINERvA detector
- Installation of ND-LAr 2×2 + MINERvA at Fermilab in progress and will record antineutrino beam data from NuMI in fall 2023
- This will be the first DUNE prototype that will detect neutrinos!