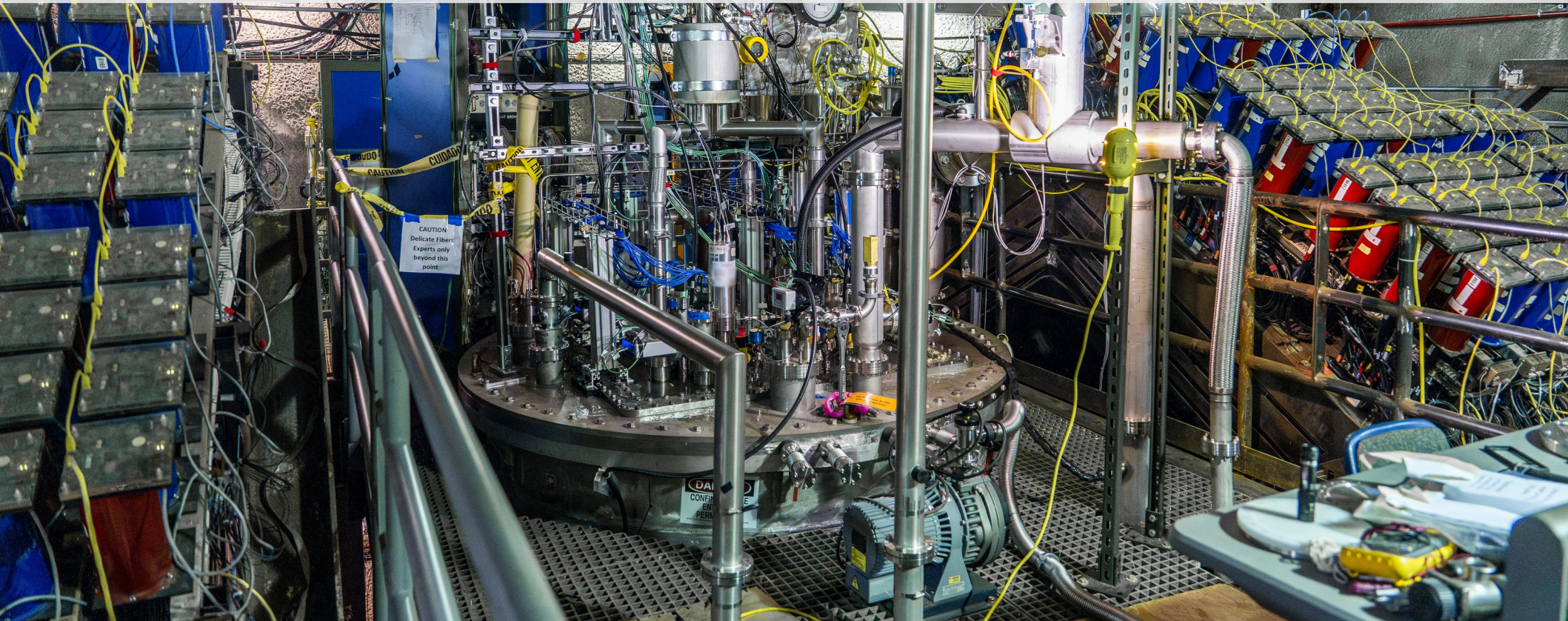
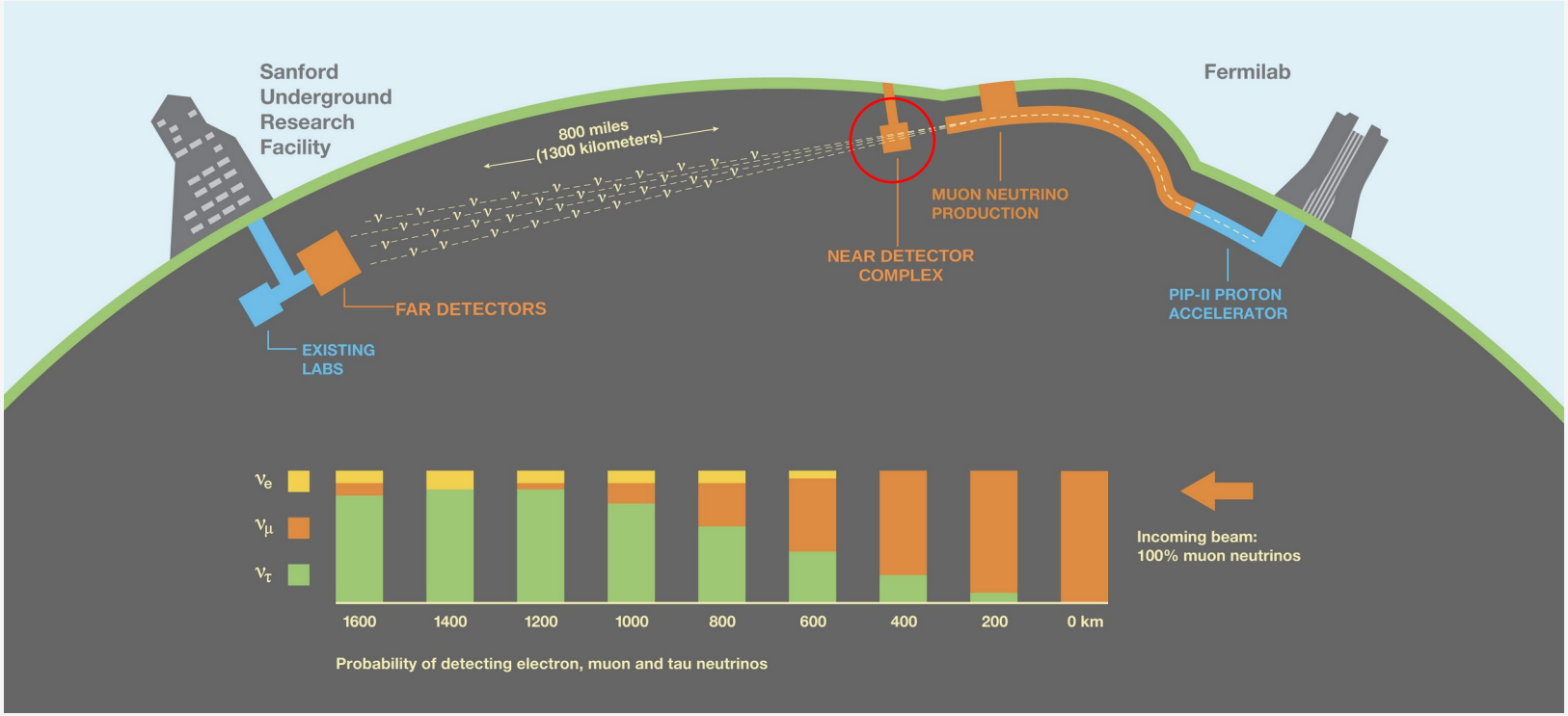
# DUNE ND-LAr 2x2: Design and Status

Sindhujha Kumaran | University of California Irvine
for the DUNE collaboration

NuFact 2024 | September 19th, 2024



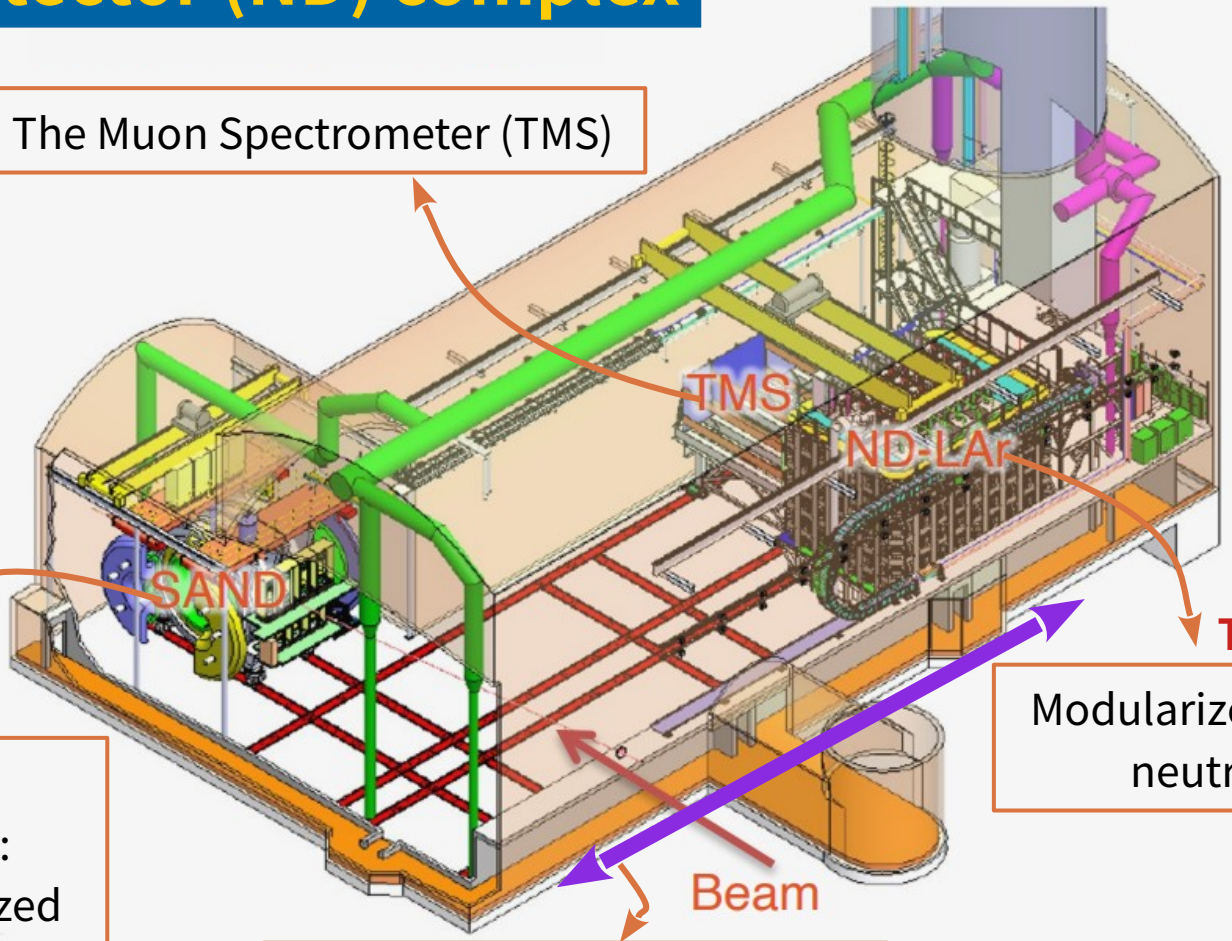
# DUNE experiment overview




- 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 $\Delta m^2_{32}$, $\delta_{CP}$, $\sin^2\theta_{23}$, $\sin^2\theta_{13}$

# DUNE Near Detector (ND) complex

The Muon Spectrometer (TMS)



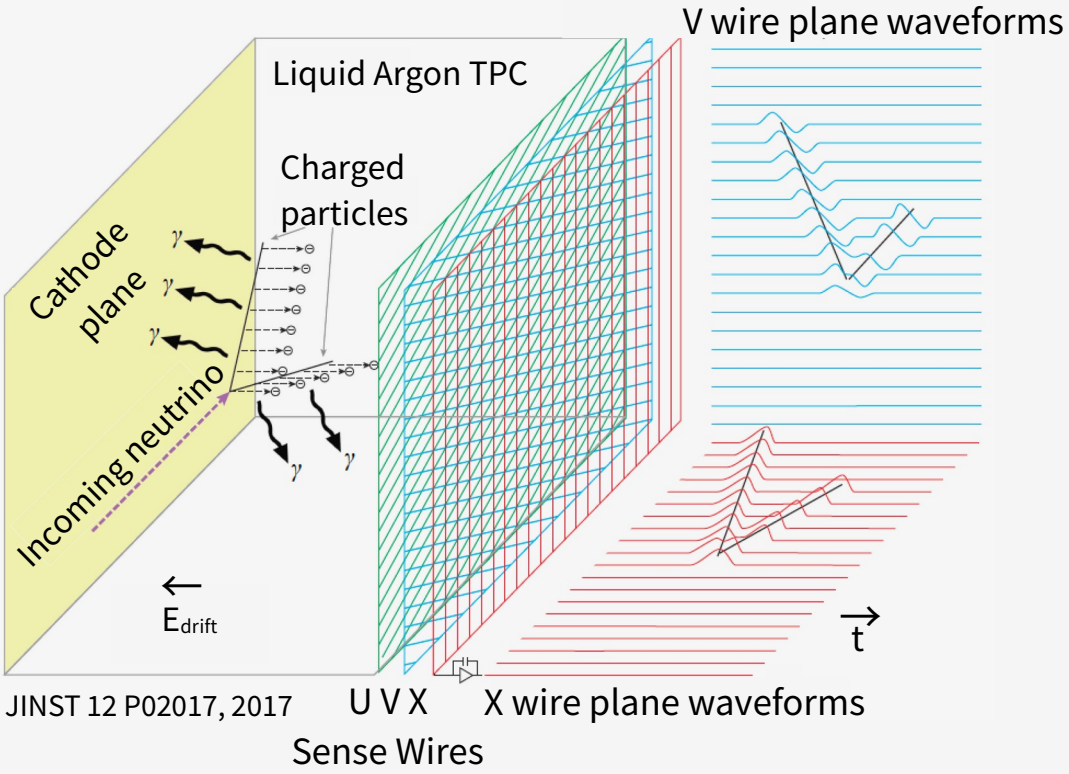

**This talk!**

Modularized Liquid Argon neutrino target

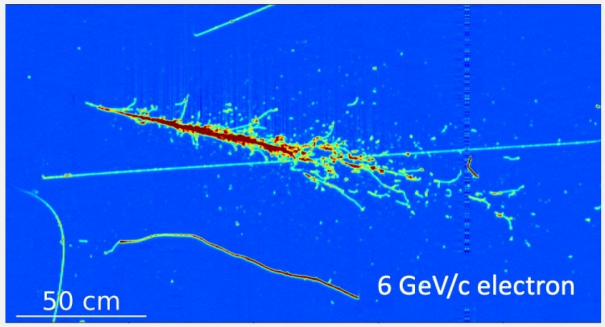
System for On-Axis Neutrino Detection: fixed on-axis magnetized beam spectrum monitor

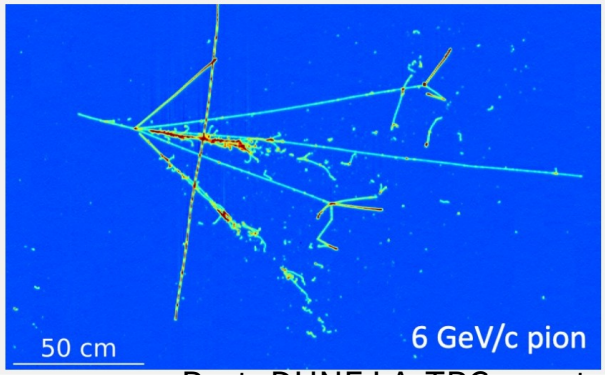
PRISM: system for moving ND-LAr + TMS

# Traditional Liquid Argon Time Projection Chamber




JINST 12 P02017, 2017



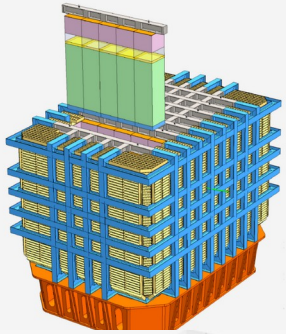



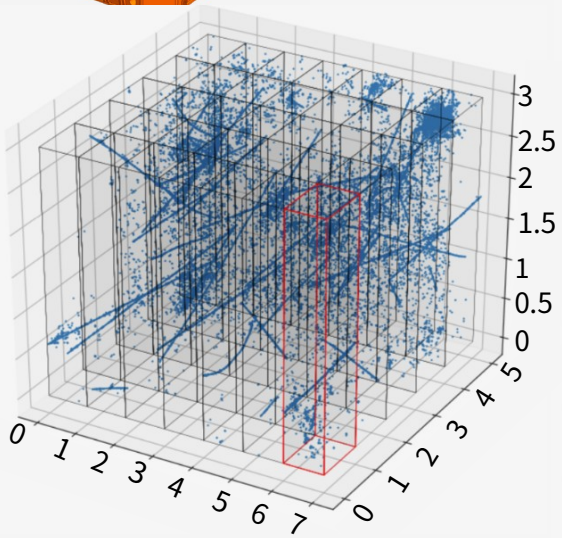

ProtoDUNE LArTPC events

B. Abi et al 2020 JINST 15 P12004

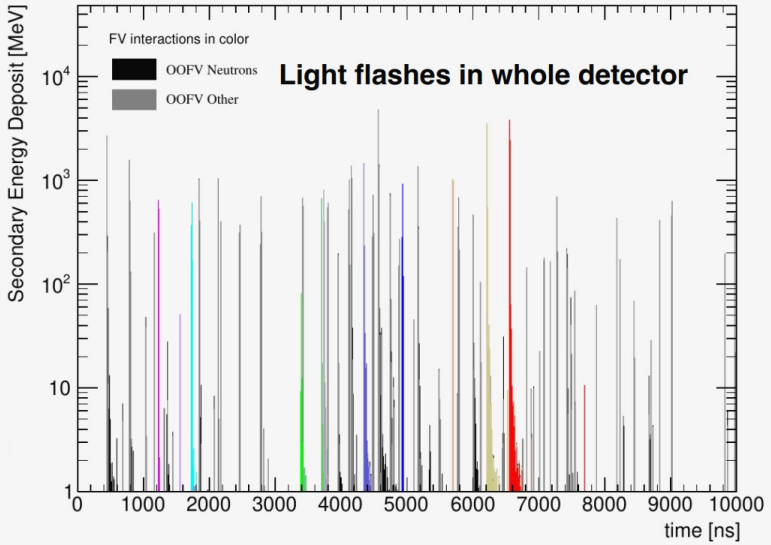
- Timing information from scintillation light collected by light detection systems
- Ionization electrons → drifted towards segmented wire planes
- Excellent spatial and calorimetric resolution
- 3D reconstruction by combining 2D views

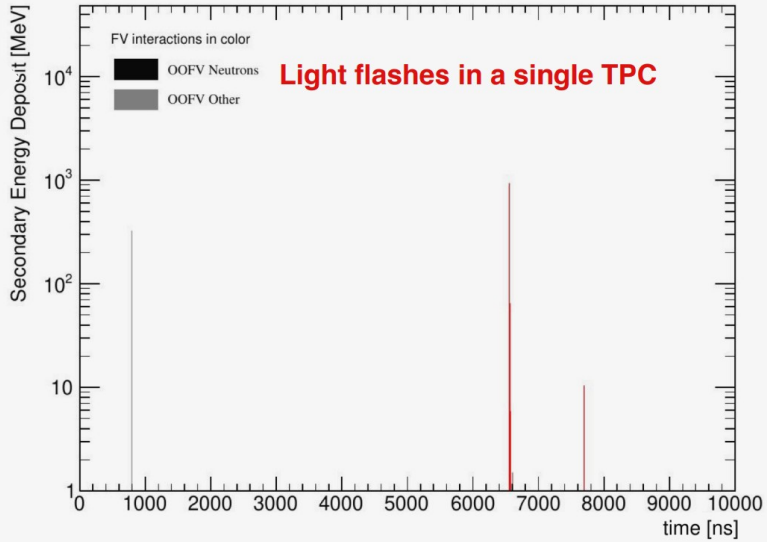
# The ND-LAr TPC: A modular TPC





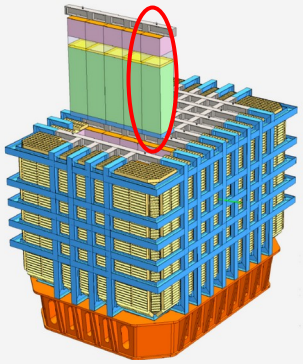
**One simulated beam spill in ND-LAr**

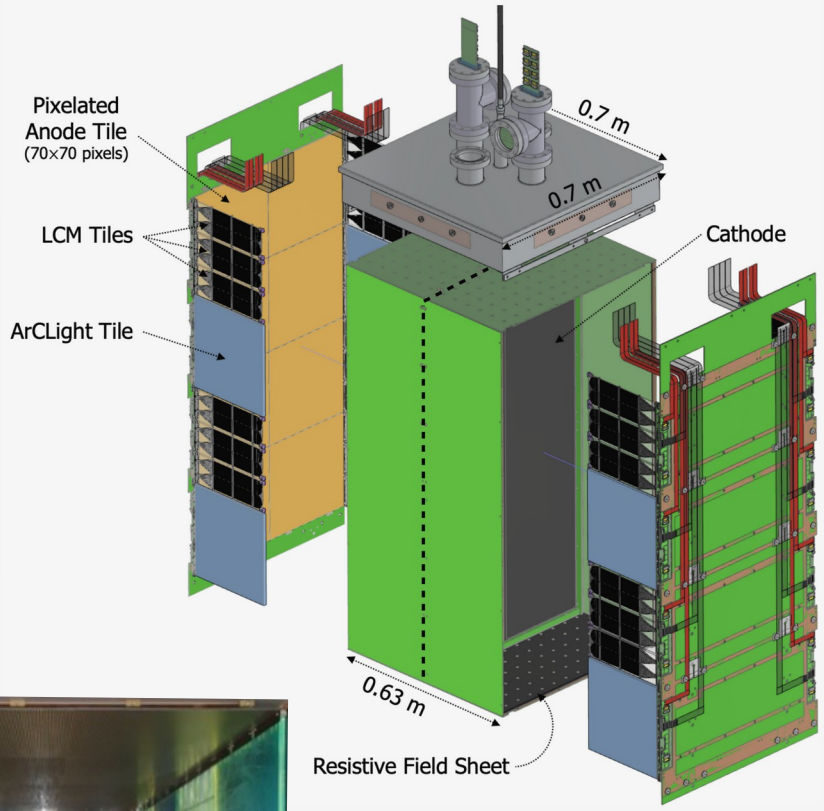


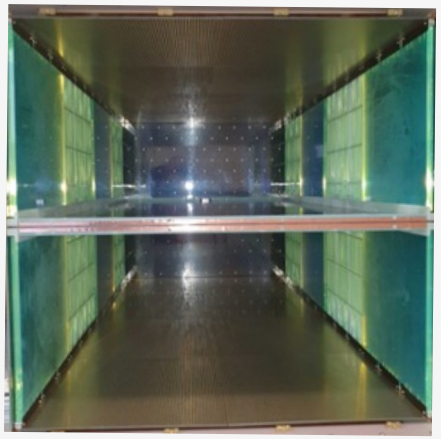




- ND-LAr will precisely measure the energy, cross-section and flux of the outgoing neutrino beam
- Drift time (300 μs) > spill width (10 μs)
- Event rate at ND: ~50 interactions per spill with a 1.2 MW beam
- 130 t of active Liquid Ar (same detector material as the far detector)
- 35 modules in a 7×5 array. Each module: 1×1×3 $m^3$
- Potential failures are isolated

# The ND-LAr TPC: A modular TPC



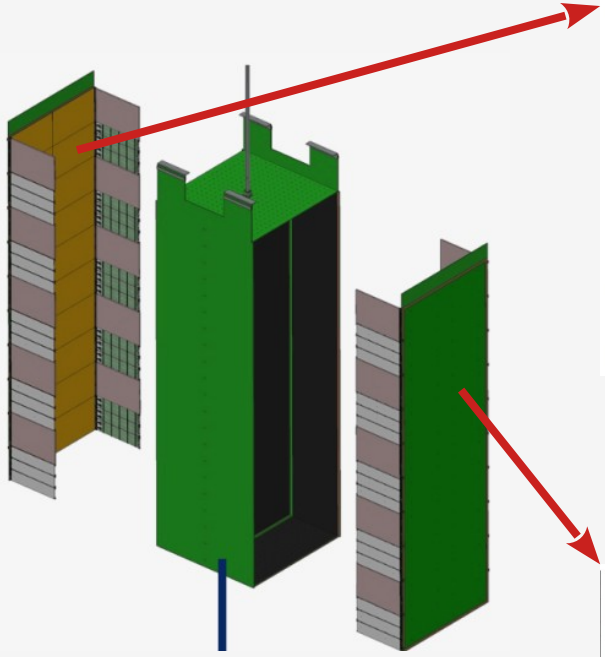


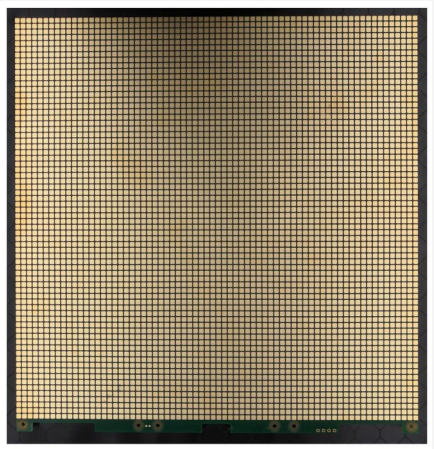



**Prototype module**
**0.7×0.7×1.4 m³**

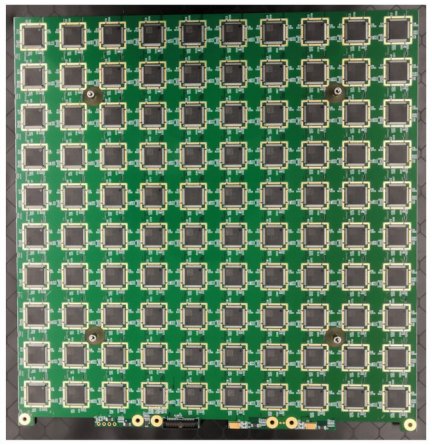
- 2 TPCs in each module
  - 50 cm–drift TPC volumes
  - ~25% optical detector coverage
- Pixelated charge readout system and modularized design to handle pile-up
- High performance, custom-made light readout system
- Prompt light will be well-localized
- Charge-light matching to further tackle pile-up
- Reduced HV requirements:
  - Lower drift distance (~50 cm) means lower voltage
  - E-field uniformity easier to achieve
- Inactive volume: ~5 cm between active regions

# Pixelated charge readout system





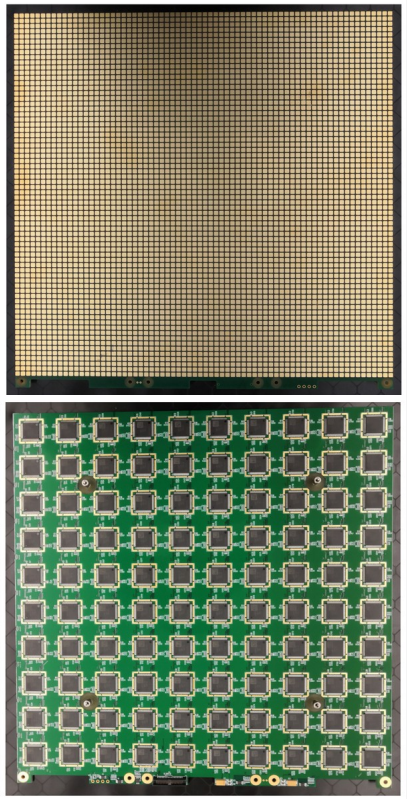
JINST 13 P10007

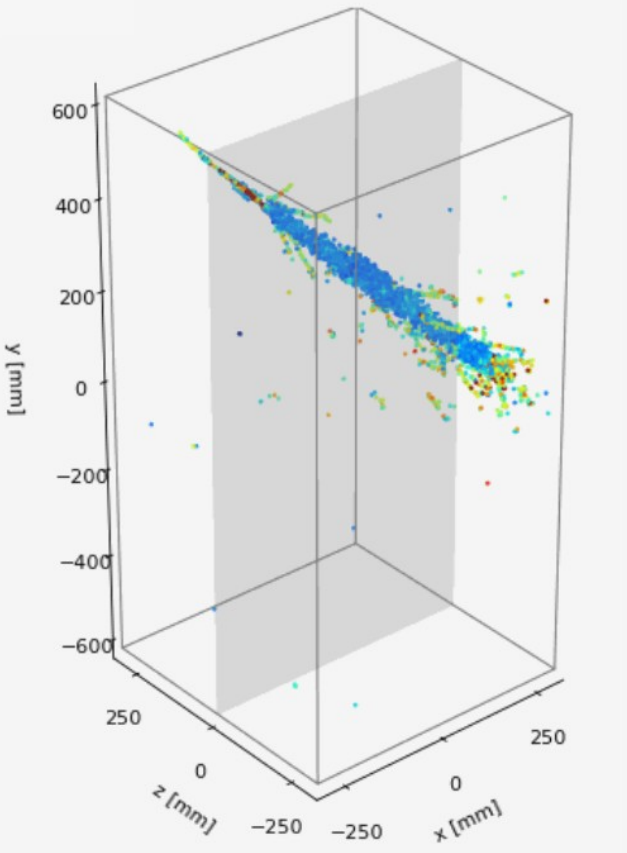


- Front (inside TPC) contains charge-sensitive pixels that face the cathode
- 32 × 32 $cm^2$ LArPix tile
- 8 LArPix tiles per TPC
- 4900 square pixels per tile
- 4.4 mm pixel pitch
- 300k channels

- Back (outside TPC) contains an array of custom-made LArPix ASICs
- 10×10 grid of ASICs
- O(100) keV pixel threshold

# Pixelated charge readout system

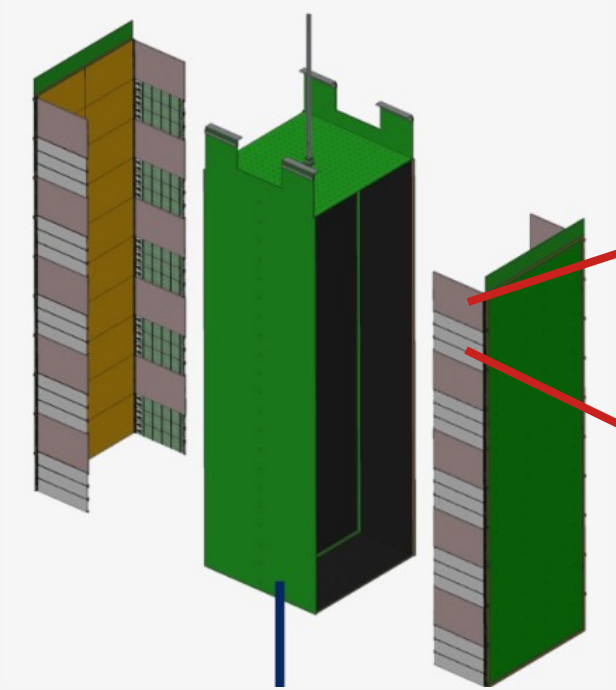





**Cosmic ray event in module-0**

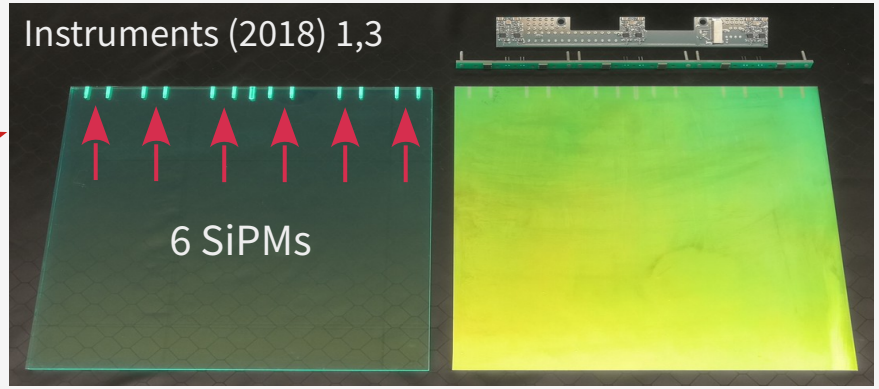
- Unambiguous true 3D tracking of particles crossing the LarTPC
- Each pixel tile is self-triggering → always active
- Pixel readout in cryo via LArPix-ASIC
- Low power amplifiers and digitizers → low power dissipation (less than 100 µW/ pixel)
  → avoid boiling of Ar

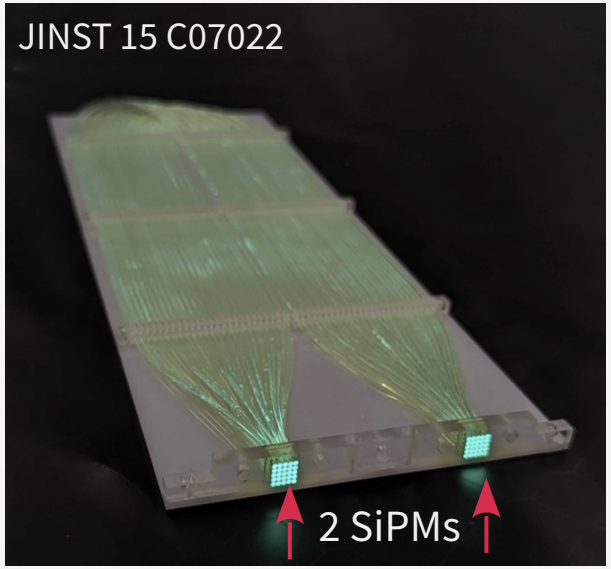
# Light readout system



- ~25% photo coverage
- Two novel dielectric SiPM-based light detection techniques: 3 LCM & ArCLight alternated along the anode walls
- ~384 SiPMs

**ArC light tile**

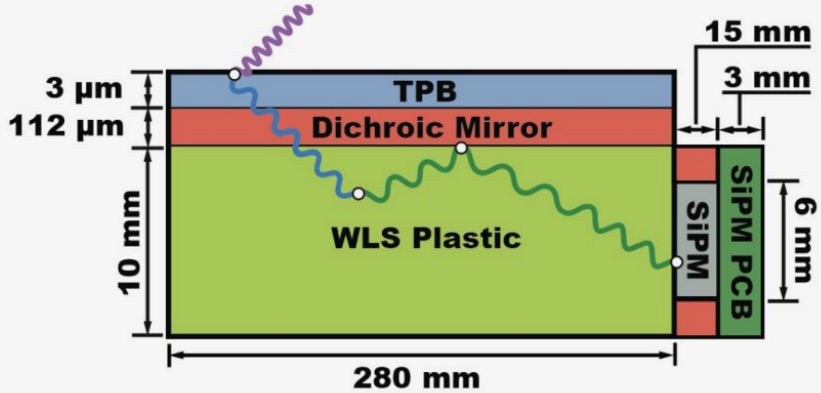


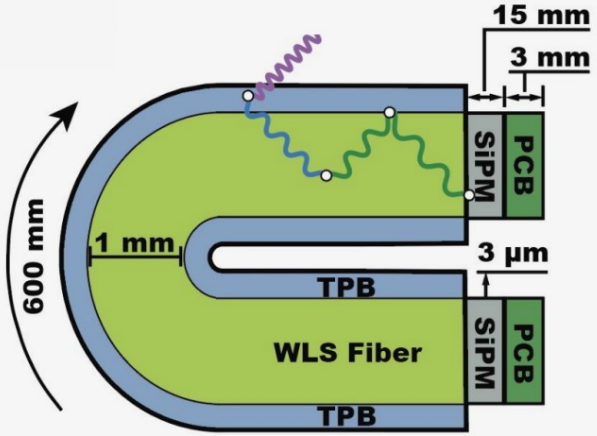




**Light Collection Module (LCM)s x3**

# Light readout system

- UV Ar scintillation light → blue light using Tetraphenyl butadiene (TBP) as a wavelength shifter → re-emitted as green within the WLS plastic/fiber
- Complementary to each other!




| | ArCLight | LCM |
|---|---|---|
| **Photon detection efficiency** | ~0.2% | ~0.6% |
| **Spatial resolution** | ~5 cm | ~10 cm |
| **Additional notes** | High dynamic range | O(ns) time resolution |

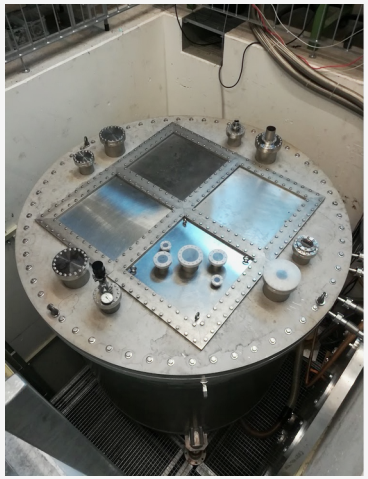
# ND-LAr 2x2 + MINERvA


**At MINOS underground cavern, Fermilab**

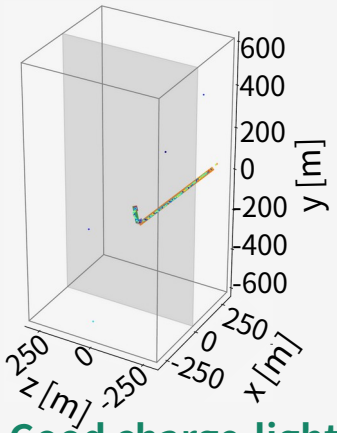
- ND-LAr prototype 2×2 array of modules + repurposed MINERvA detector trackers
- Placed in the NuMI beam at Fermilab
- Goals:
  - Demonstration of a modular LArTPC with a muon tracker in a high intensity neutrino beam
  - Development and testing of end-to-end infrastructure for DUNE
  - Physics analysis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

# ArgonCube 2x2

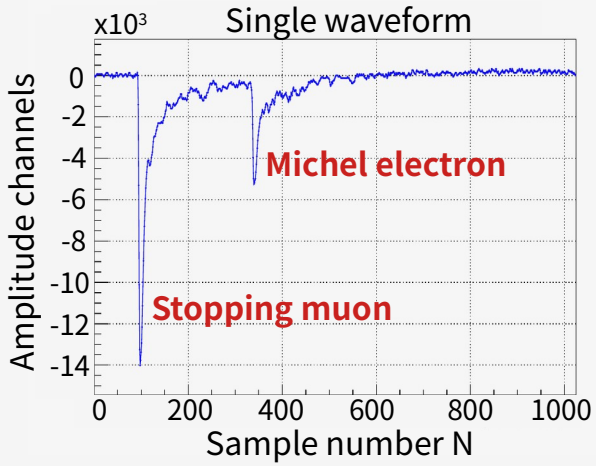
- 2.4 t active mass
- 2×2 array of modules
- Each module: 0.7×0.7×1.4 $m^3$
- Smaller but identical to ND-LAr
- Each module assembled and tested individually at University of Bern with millions of cosmic rays
- Smooth operation + validation of ND-LAr requirements

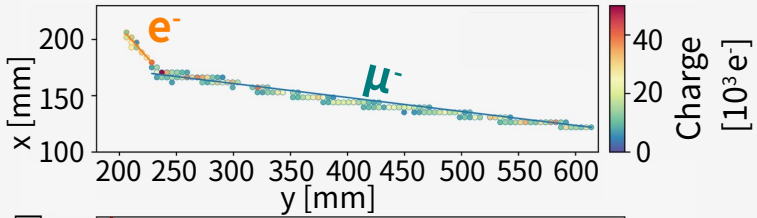
## Physics performance highlights of module-0

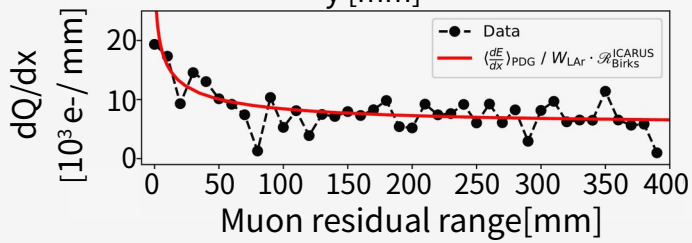



Good charge-light matching




Clear signals recorded by LCM

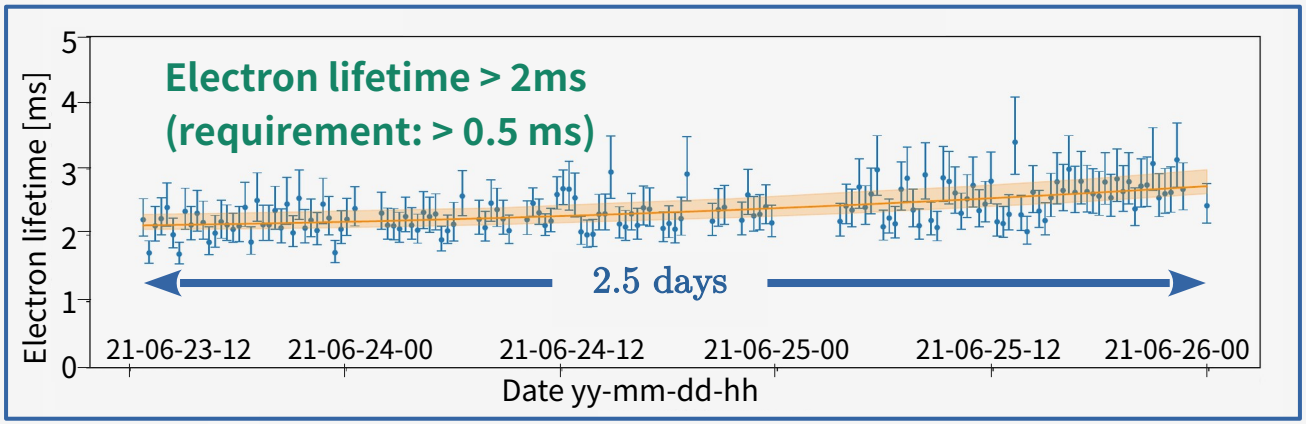


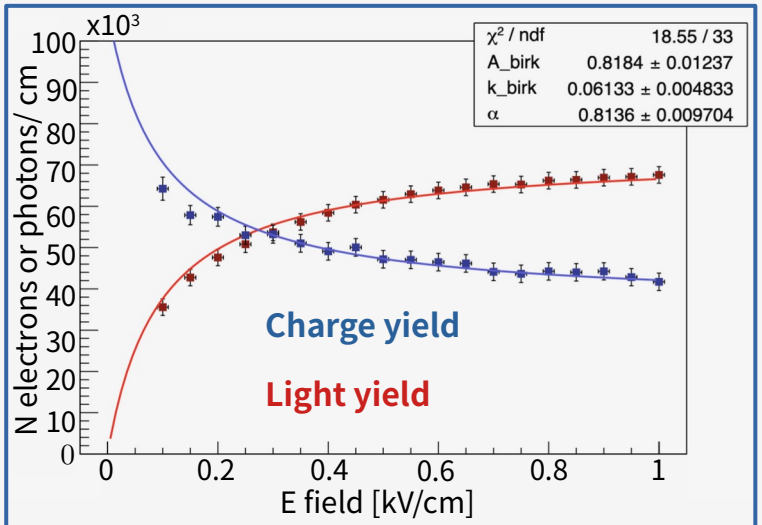




dQ/dx measurement agrees with model

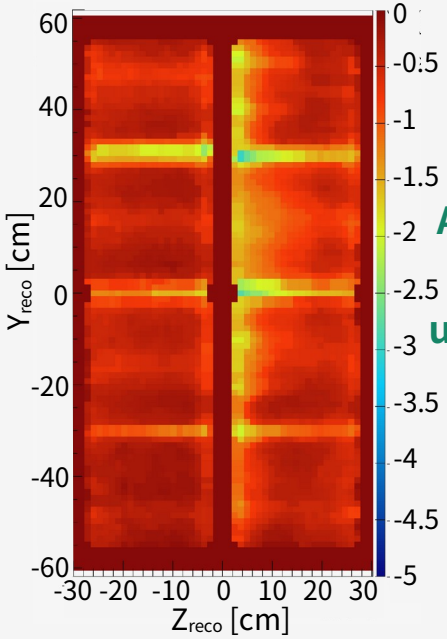
arXiv:2403.03212

# Physics performance of module-0



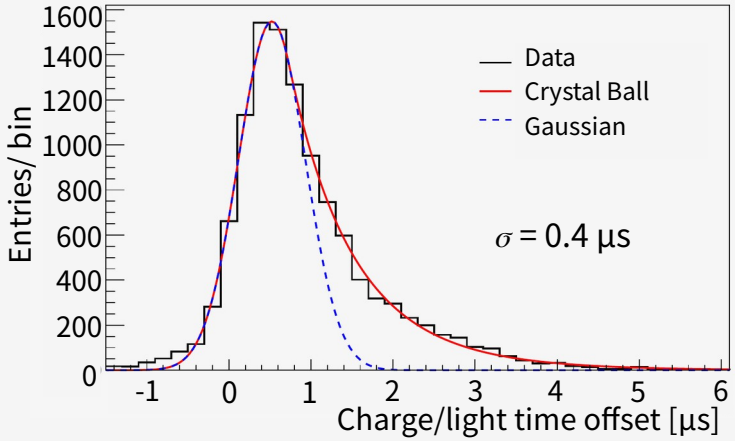




**Measurement of Birks parameters: consistent with other experiments**




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

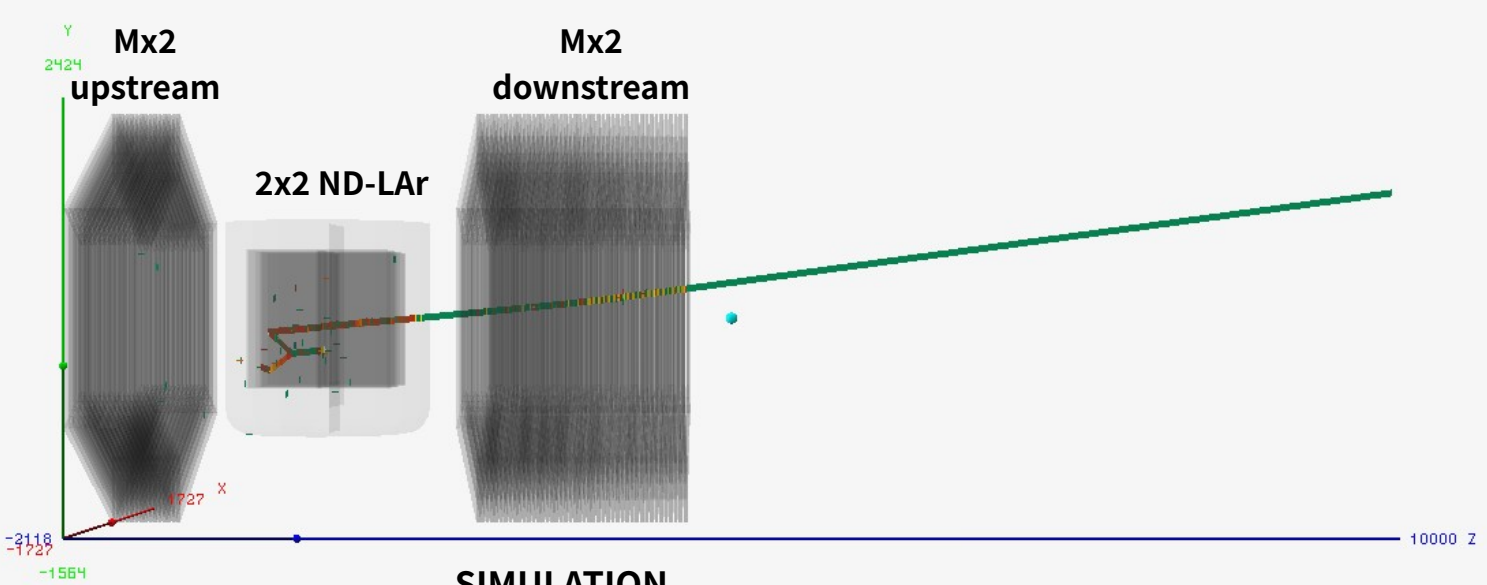
arXiv:2403.03212




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

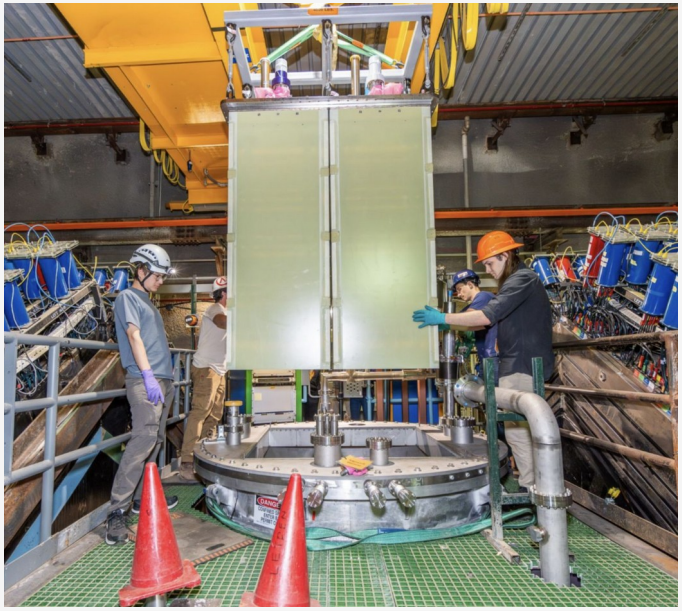
# MINERvA for 2x2 (Mx2)

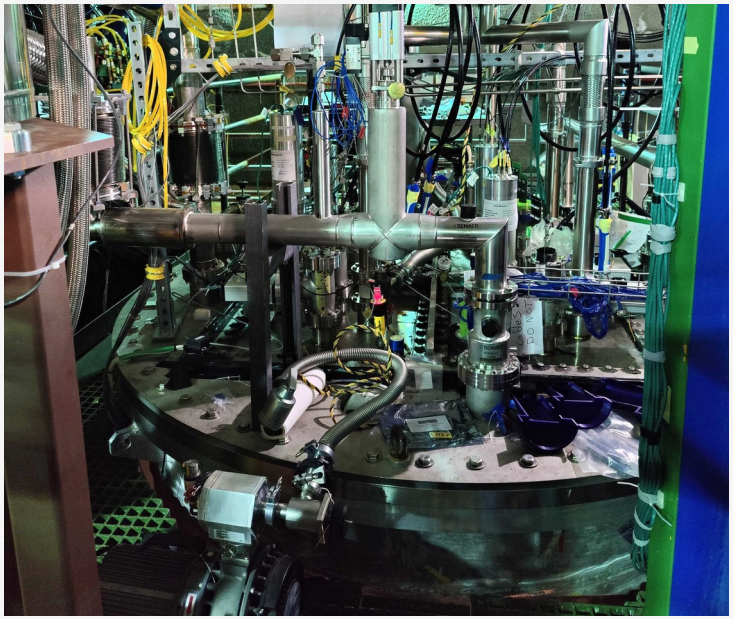
- MINERvA (Main Injector Neutrino ExpeRiment to study v-A interactions)
- Repurposed to act as muon taggers for ND-LAr 2×2
- 12 upstream tracker modules→ tag rock muons
- 32 downstream modules → 20 trackers + electromagnetic calorimeters and 12 hadronic calorimeters
  - to separate μ/π and analyze events not contained inside 2×2
- Combined 2x2 MINERvA track matching to boost reconstruction and analysis




SIMULATION

# ND-LAr 2x2 + Mx2: installation





# ND-LAr 2x2 + Mx2: current status

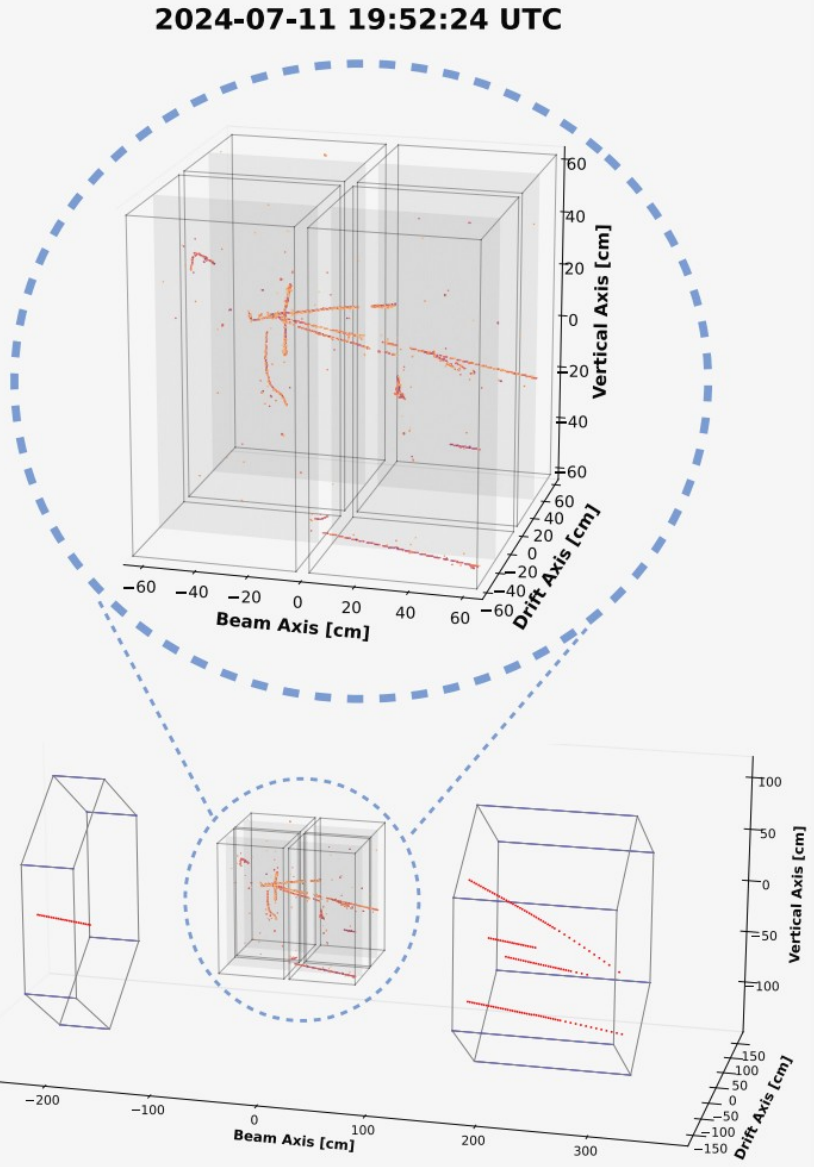
symmetry
dimensions of particle physics

**DUNE scientists observe first neutrinos with prototype detector at Fermilab**

physicsworld

DUNE prototype detector records its first accelerator-produced neutrinos

- Operations commenced on 8th of July, 2024
- Collected ~ 5 days of physics quality data
- ~10,000 neutrino interactions per day
- Recorded data also contains off-beam cosmic events and low-energy radioactivity
- Preparing for another beam run in 2024/25



# Summary and Conclusions

- DUNE is a next-generation long-baseline neutrino experiment with discovery potential for neutrino mass ordering and leptonic CP violation
- ND-LAr is crucial as it will precisely measure the energy, flux, and cross-section of the outgoing neutrino beam
- A modularized and pixelated LArTPC is necessary to handle the high event rate
  - Pixelated charge readout system that enables unambiguous 3D tracking of particles
  - Two novel dielectric light systems complementary to each other
- The design of ND-LAr is being tested using a 2×2 array of modules along with muon tracker planes from the MINERvA detector in the NuMI beamline at Fermilab
- Operations commenced this summer! More neutrinos to come!
- ND-LAr operation will begin by 2030!

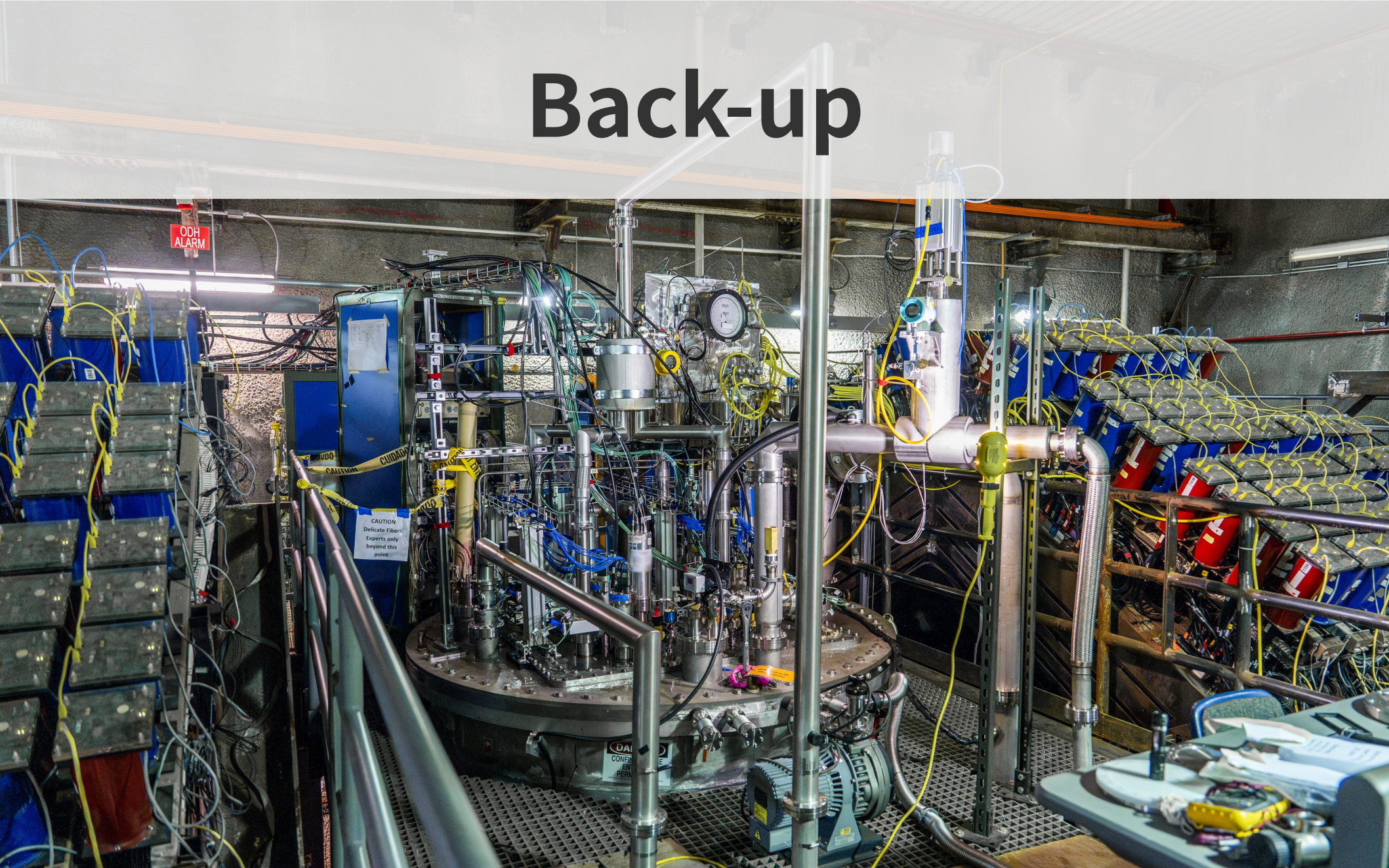
28. The DUNE 2x2 Demonstrator physics prospects and plans with neutrino data
Andrew Cudd (University of Colora...
19/09/2024, 17:35
WG2: Neutrino Scatterin... | Talk: in-person | Parallel: WG2

77. Machine Learning Reconstruction for DUNE's Near Detector Prototype: Handling Multi-Detector Input to Identify 3D Particle Signatures
Dr Jessie Micallef (Tufts University and...
18/09/2024, 11:00
WG6: Detectors | Talk: in-person | Parallel: WG 1x6

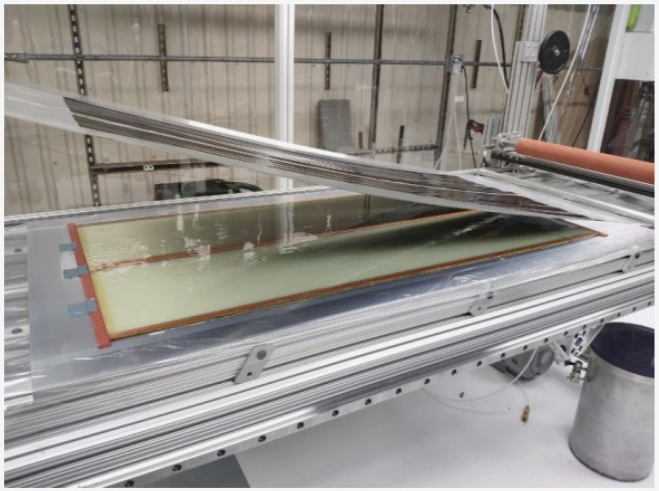
# Thank you!

DUNE near detector protoypes analysis workshop, Chicago, September 2023

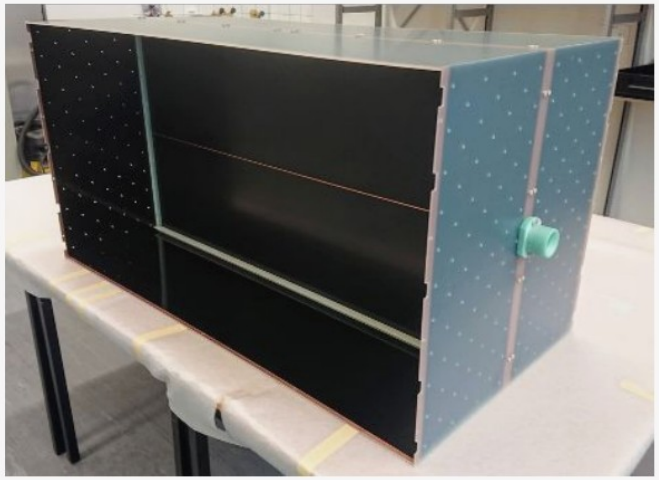
# Back-up


ODH
ALARM
CAUTION
Delicate Fibers
Experts only
beyond this
point

# Electric field shaping



Kapton laminator



Field cage interior

- Alternative to traditional field cage
- TPC drift region is surrounded by a low-profile resistive field shell made of C-loaded Kapton films
- Electric field shaping→ uniform electric field throughout the TPC volumes
- Fewer points of failure than resistor chains