The DUNE ND 2x2 Prototype

Fermilab Users Meeting

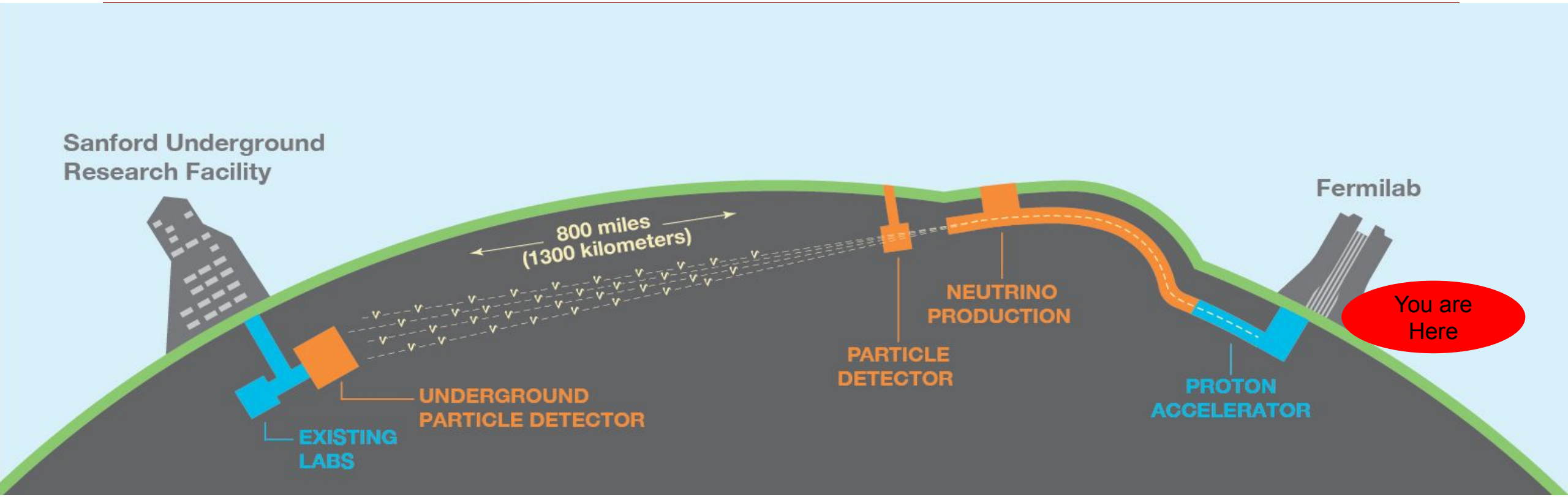
Zach Hulcher for the DUNE collaboration

June 30th, 2023

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

DUNE



- Neutrino beam from Fermilab to a Near Detector (ND) and Far Detector (FD)
- Looking for CP violation in neutrinos and to ascertain neutrino mass ordering
- Many analyses from proton decay to dark matter searches to identification of solar and astrophysical neutrinos
- Same experiment from Zoya's last talk!

The DUNE Near Detector (ND)

ND-LAr: LArTPC

- 130t of active Argon
- Collects scintillation light + charge (ionization electrons)
  - Two types of scintillation light
    - **Prompt Light**: **O(ns)**
    - **Slow Light**: **O(μs)**
- Hadronic shower contained, but muons not.

The Muon Spectrometer (TMS)

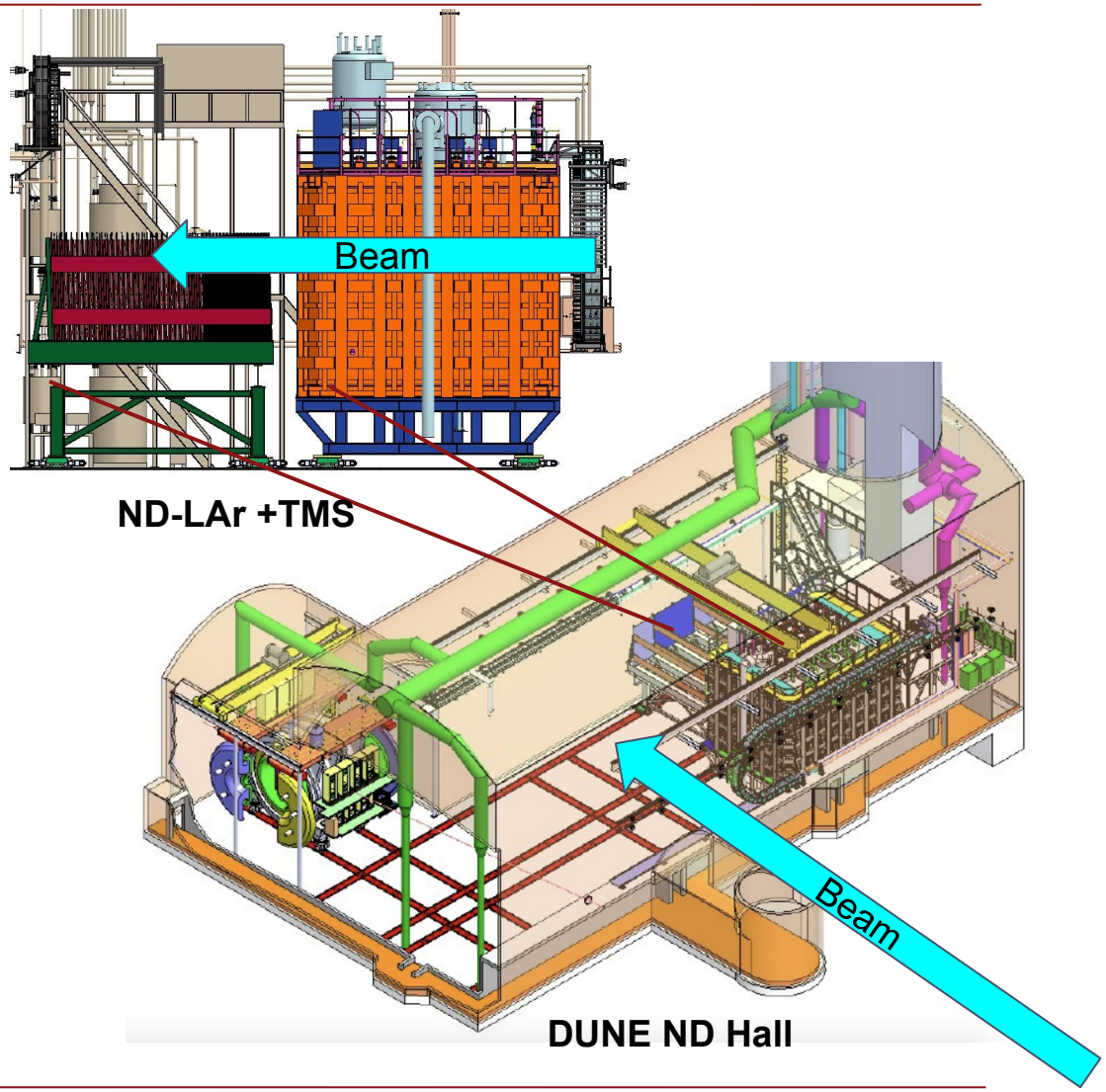
- Records the energy of those muons

PRISM

- System for ND-LAr +TMS to move off-axis and record flux at various angles relative to the beam

SAND

- On-axis neutrino detector

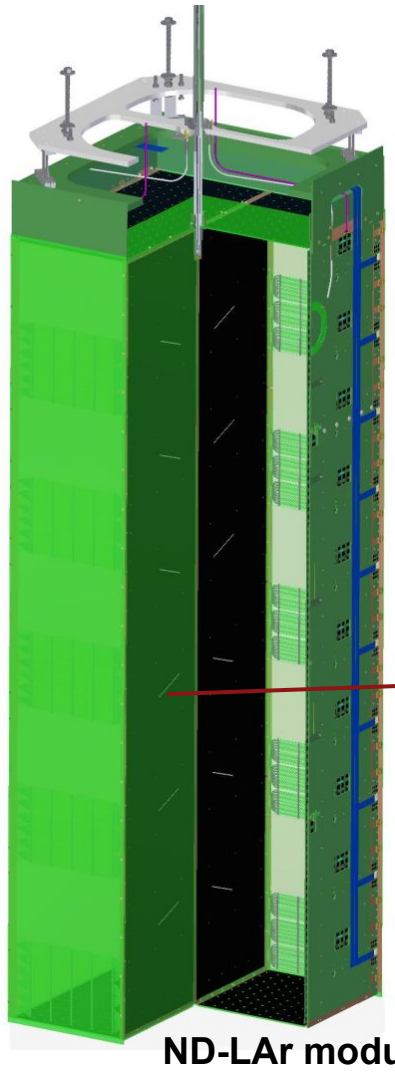


ND LAr-TPC

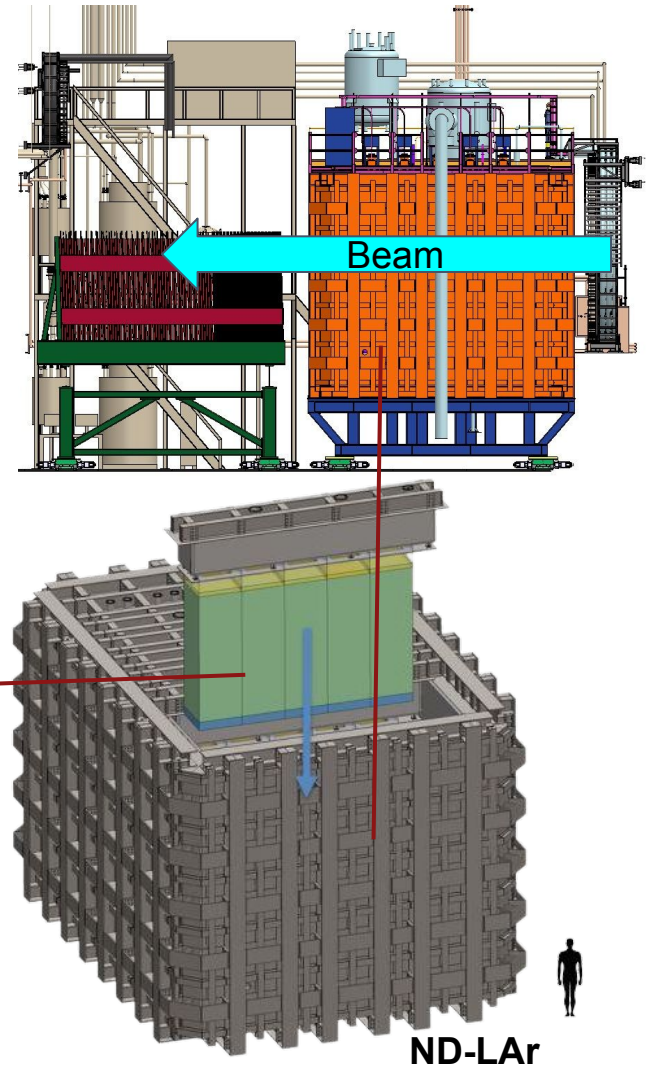
- 130t of active Argon
- ~20 **ν** events (energy from ~50 events)/ **10 μs spill** **(**with a 2 MW beam)
- (FD sees 3.4 **ν** events/**hr**)

Necessary to reduce pileup

1. Optical: the detector is sliced up into 7x5 modules to contain prompt scintillation light
2. Charge: pixelated charge readout

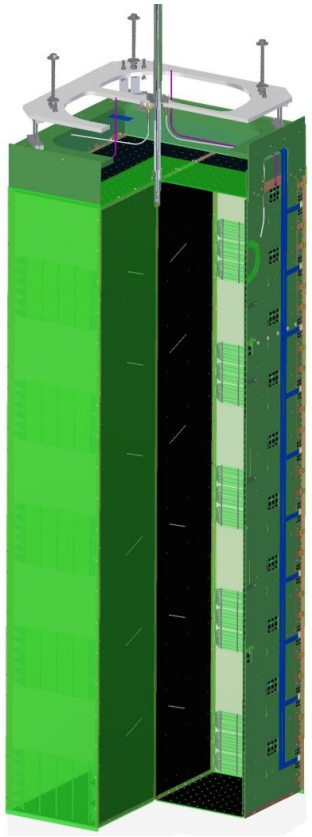


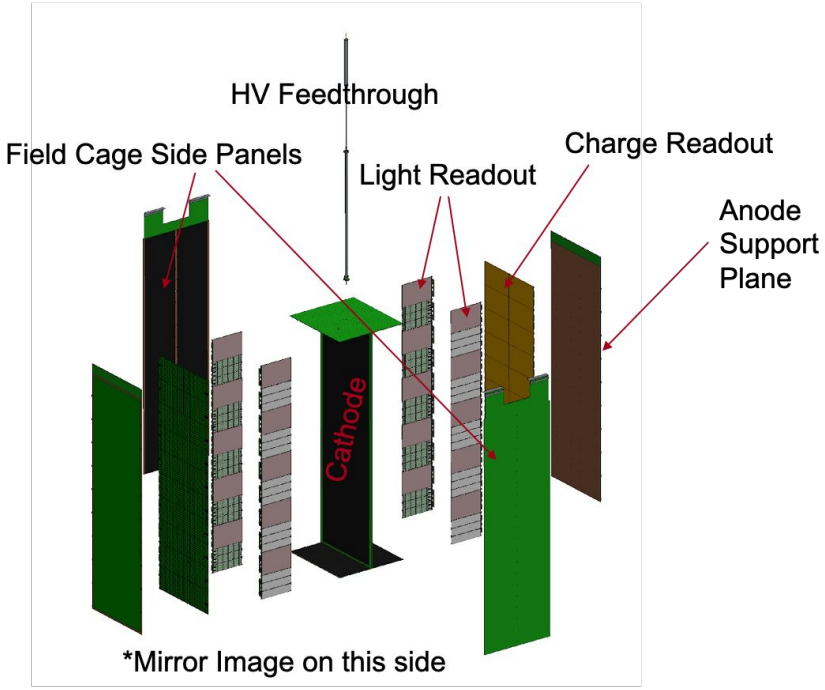
ND-LAr module



ND-LAr

Modules Reduce Optical Pileup





Advantages:

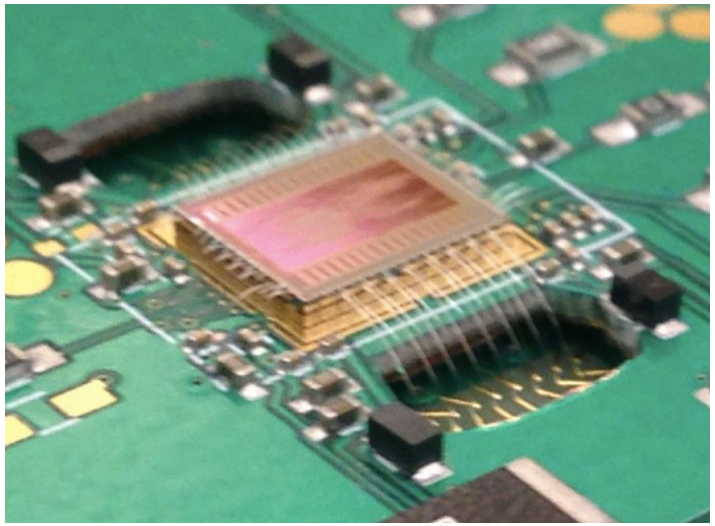
- Segmented scintillation light
  - If ND were monolithic:
    - heavy pileup builds slow scintillation light until prompt readout impossible
    - Prompt light in general far from nearest readout/ harder to see
  - prompt light localized
  - Associate spatially separated energy deposits to particular vertex
- Reduced HV requirements
  - Lower drift distance means lower voltage
  - E-field nonuniformities less important

Disadvantages:

- Inactive volume where deposited charge cannot be recorded (~5cm thick between active regions)

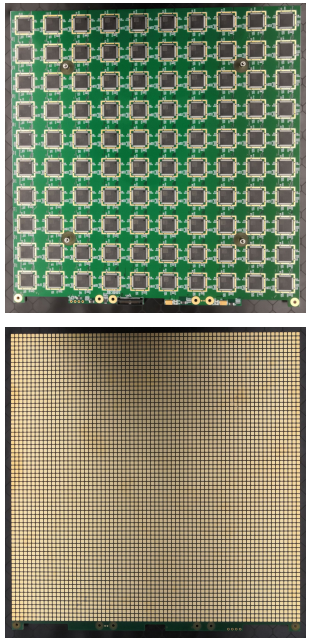
Pixelated Charge Readout

- **Readouts that excessively boil Argon are not ideal**
- Unambiguous pixel readout is new to LArTPCs… (Have been used in gas TPCs previously, like ND280)
- Low power amplifiers and digitizers enable pixel readout in cryo, enabled by LArPix-ASIC.
- Low power consumption (less than 100 μW/ pixel) to keep heat dissipation out of the Argon

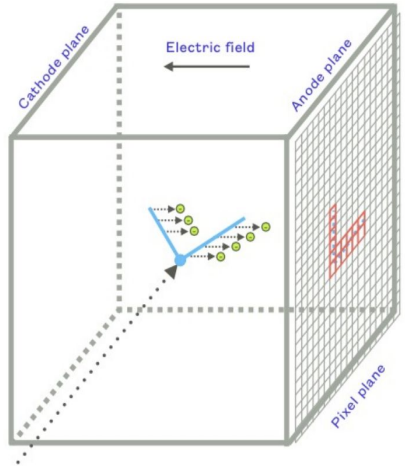


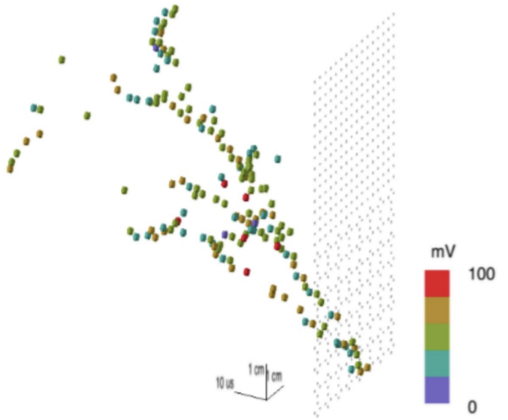
A LArPix-ASIC

[JINST 13 (2018) no.10, P10007]



Pixel board

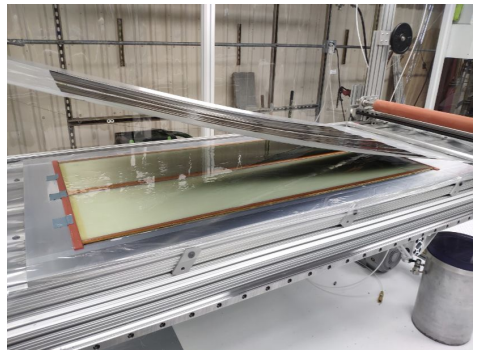




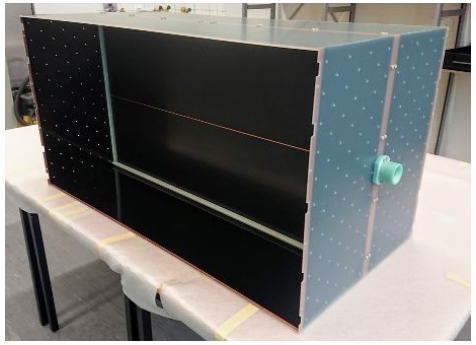
Electric Field Shaping and Dielectric Light Readout

2x2 panels are **G10 laminated w/ carbon-loaded Kapton**

- Continuous resistive plane with uniform heat dissipation
- Performs well in cryo
- No single point of failure
- G10 similar radiation length to LAr (16.8 vs 14 cm)
- O(1 GΩ/sq.) at the nominal electric field (0.5 kV/cm)



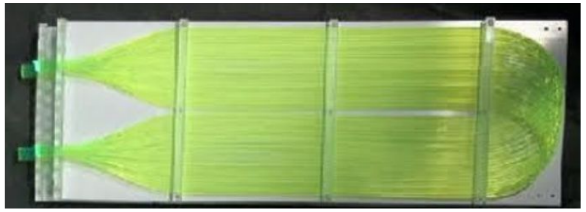
Kapton laminator



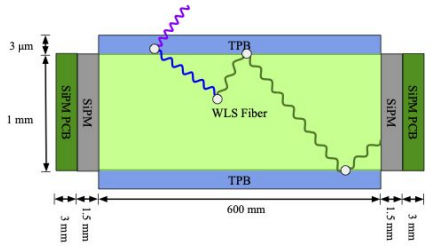
Field cage interior

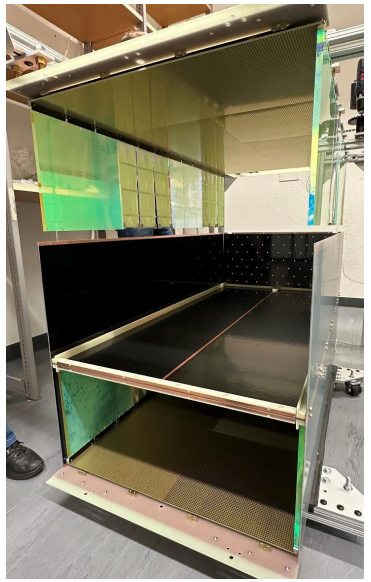
Two complimentary light readouts: **ArCLight** and **LCM**

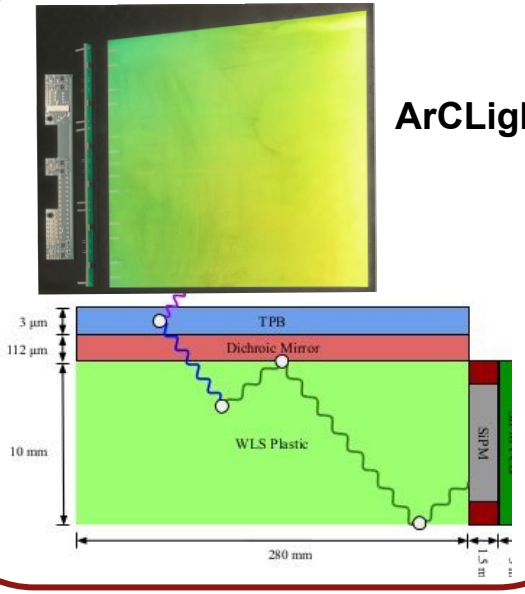
- Both fundamentally layered wavelength shifter light traps
- ArCLight better positional sensitivity
- LCM better detection efficiency
- Light shifted from VUV to blue in TPB then to green in WLS



LCM



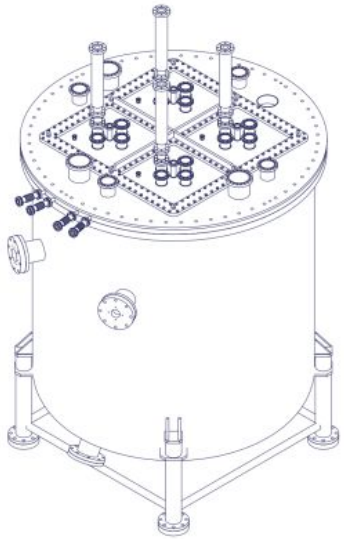




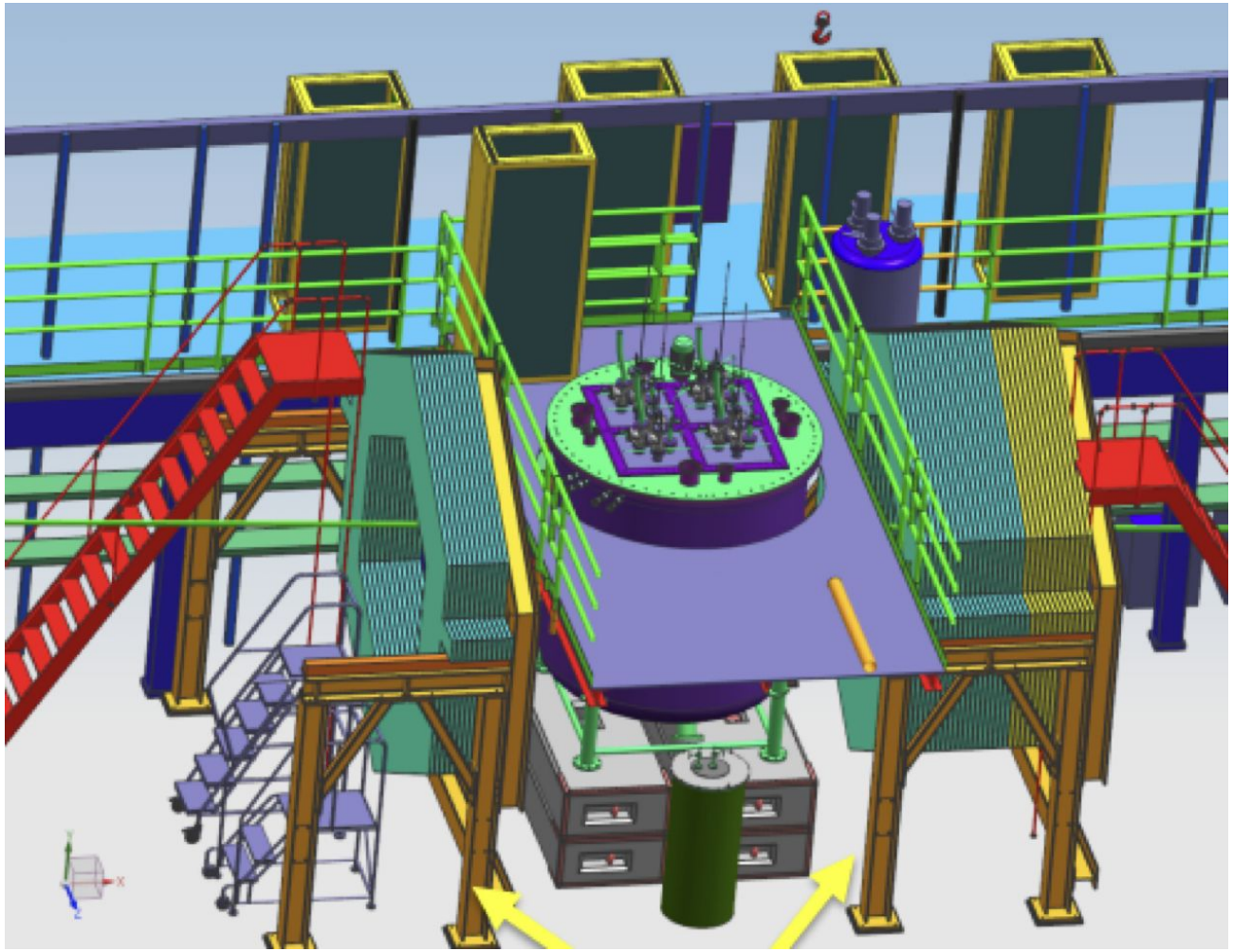
ArCLight

2x2 + MINERvA Technology Demonstrator

- Ingredients:
  - ND Prototype “Argoncube 2x2”
  - Sections of MINERvA detector
- Placed together in the NuMI neutrino beam



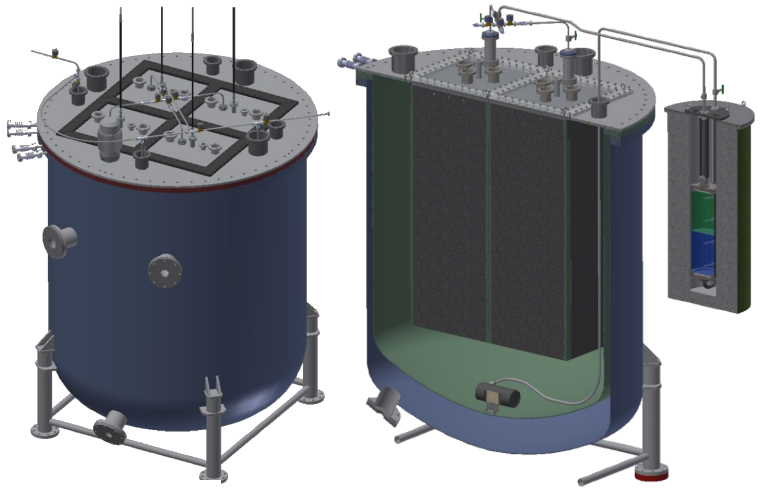
The 2x2 cryostat

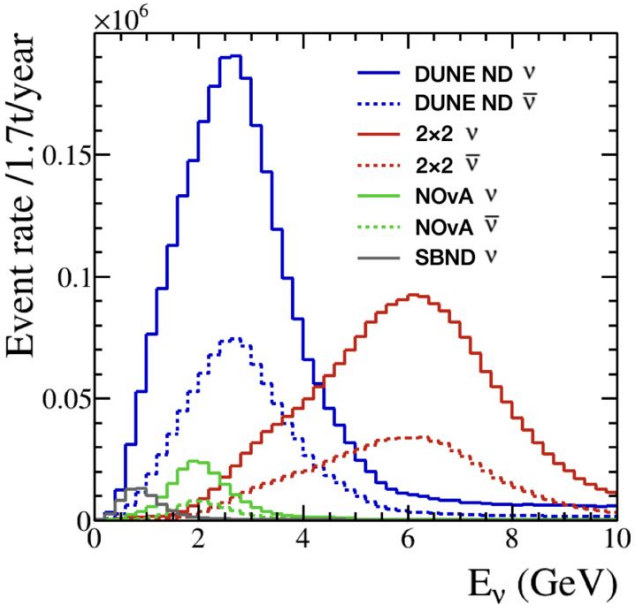


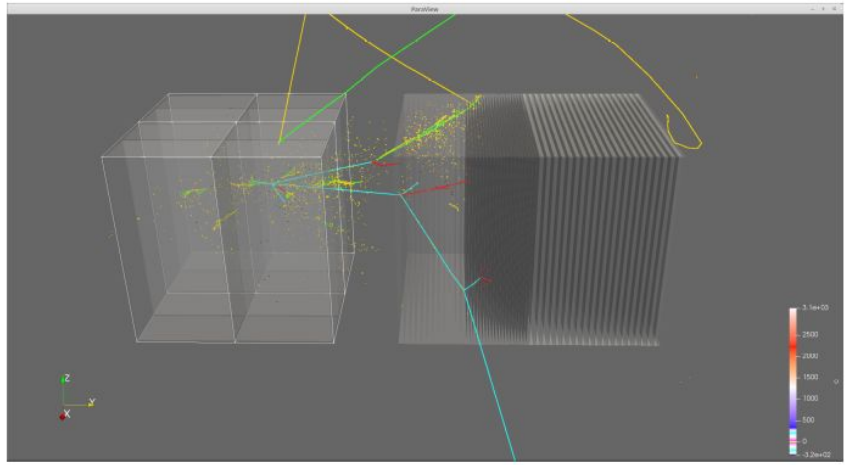
The Demonstrator fully assembled

Argoncube 2x2

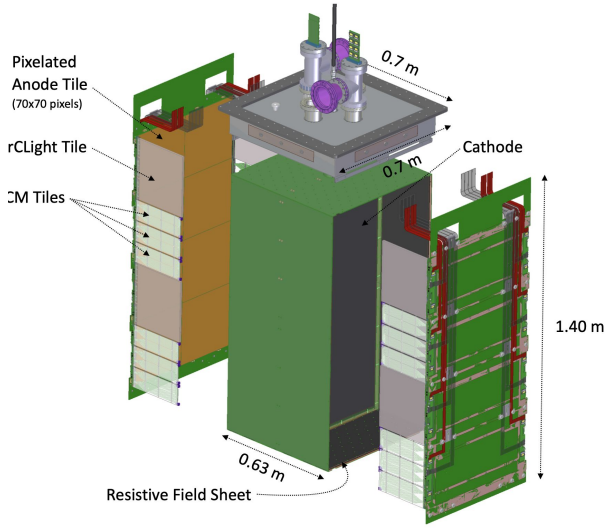
- Technology demonstrator for ND
  - Modular ND-LAr prototype with 2.4t active mass
- Placed in cryostat provided by CERN (size threshold)
- About 1/4 as long, with a lower event rate than DUNE-ND, but mean on-axis energy ~2-3 times more energetic







Containment is a challenge that MINERvA can help with!



Testing the 2x2 Modules

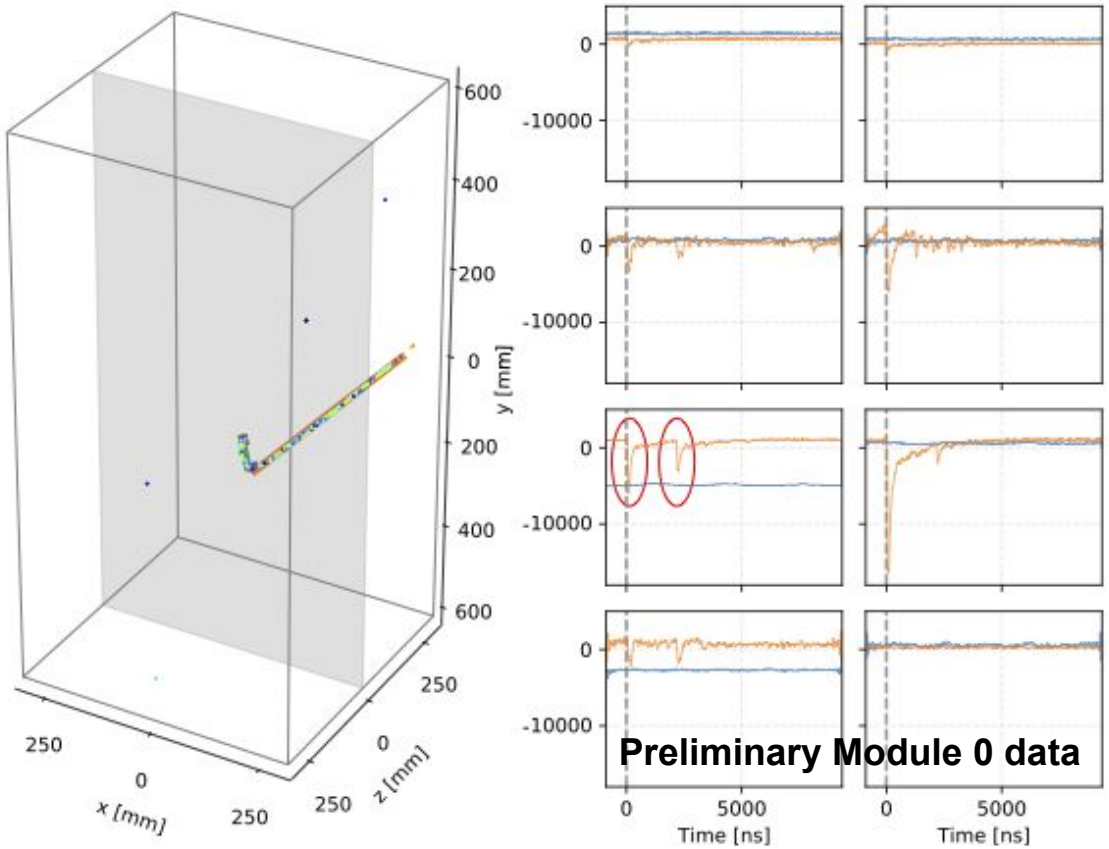
- Each module assembled and tested individually at University of Bern with cosmic data
- Analyzed noise levels, measured dQ/dx, searched for Michels (decay electrons from muon decay) to match charge and light, etc.

Module 0

Module 1

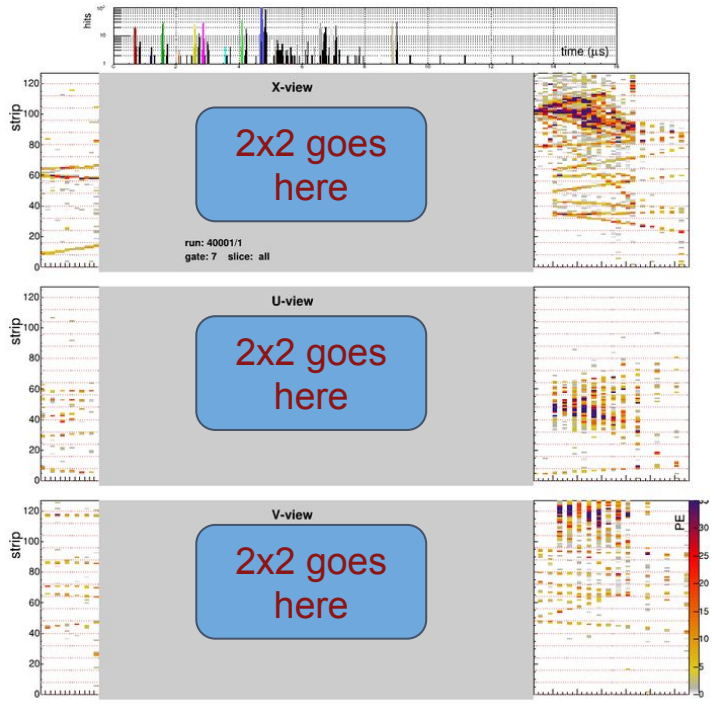
Module 2

Module 3

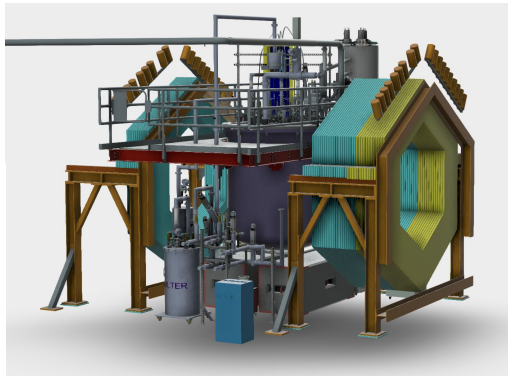


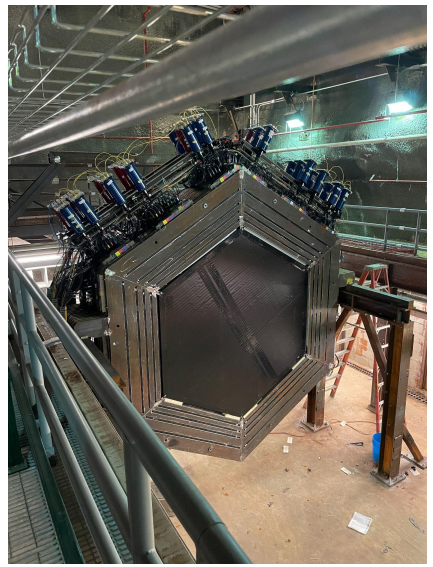
Minerva: The Reborn 2x2 Muon Tagger

- Same hexagonal Minerva panels from Laura's talk this morning! (but we are using 44 total)
- 12 upstream tracker modules
  - Tag rock muons
- 32 downstream modules:
  - 20 tracker + ECAL
  - 12 HCAL
  - Separate μ/π and analyze 2x2's uncontained energy
- Utilize straight crossing tracks to calibrate 2x2's E-field
- Simultaneous operation of MINERvA spectrometers/trackers and 2x2 a test for ND-LAr/TMS



Preliminary
DUNE ND-LAr 2x2 MINERvA data





Downstream MINERvA being installed

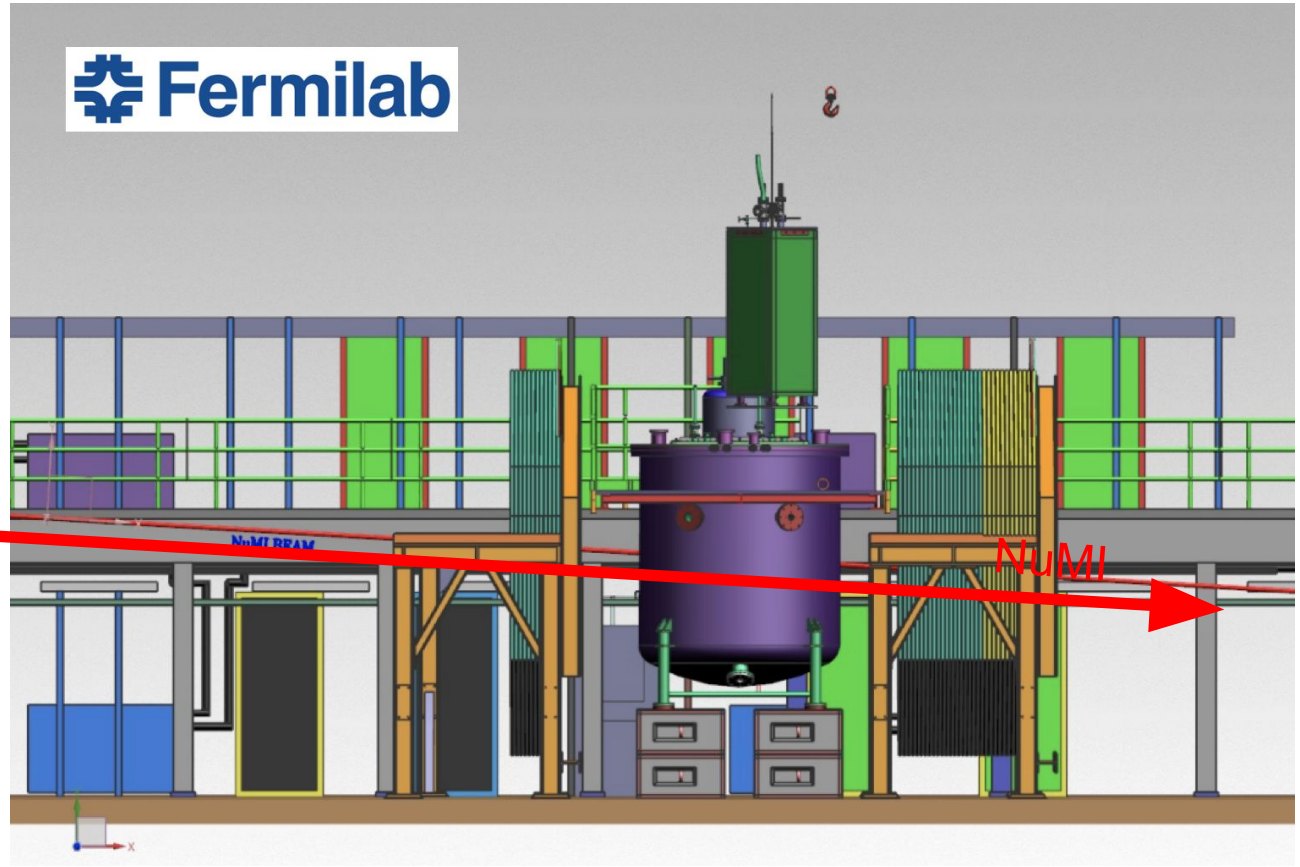
Status of 2x2+MINERvA

- Final 2x2 module (3) shipped to FNAL earlier this year
- Final assembly/ prepping the MINOS Hall ongoing
- Working with many different teams at Fermilab to make sure the detector is ready by the time the beam comes back in the Fall 2023
- Many efforts in parallel to develop analysis + software tools

Hard at work preparing the modules!

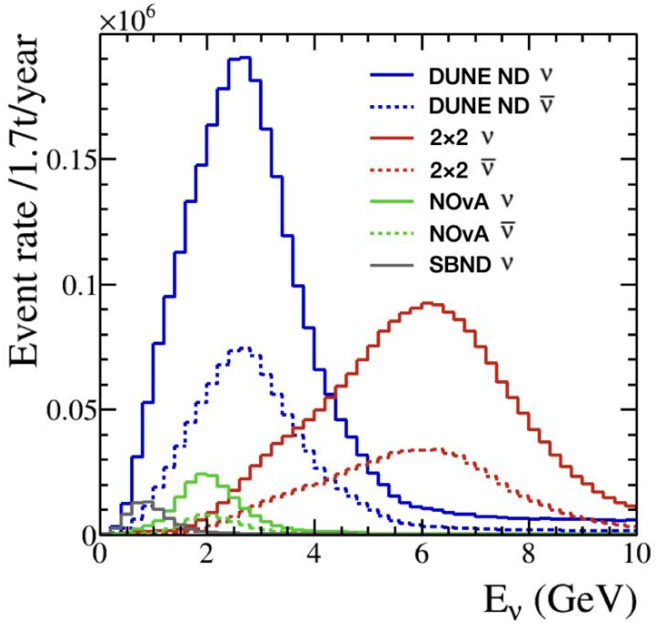
2x2 + MINERvA installed and awaiting supporting infrastructure!

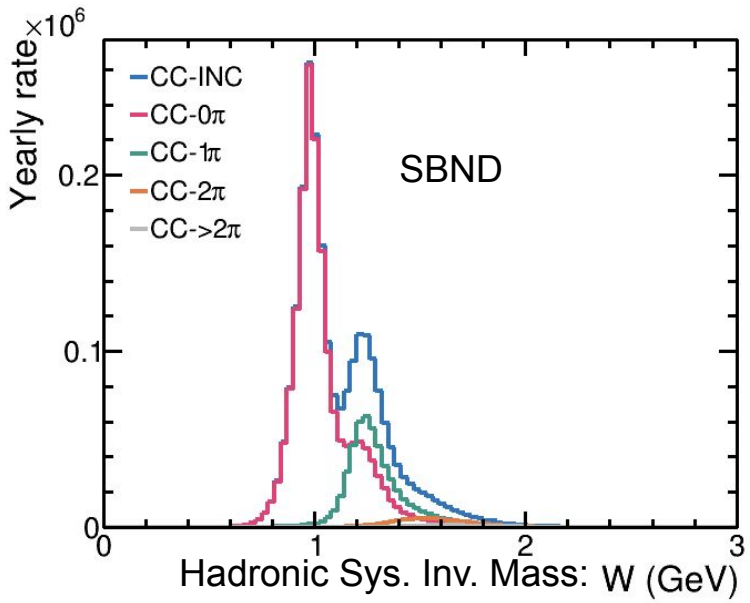
2x2 + MINERvA goals

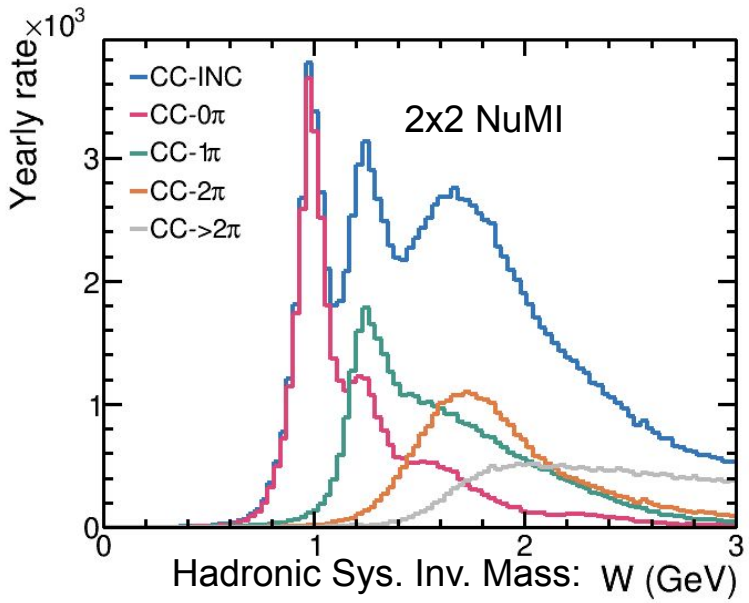


- Demonstrate a modularized LArTPC in an intense neutrino and antineutrino beams
- Develop end-to-end analysis infrastructure in preparation for DUNE
- Provide neutrino cross-section measurements at DUNE-relevant energies/ improve neutrino interaction models for future accelerator neutrino experiments/ generally do physics at the DUNE energy scale before DUNE

2x2 Analysis Prospects







- **SBN and 2x2 are complementary!**
  - The energy regime of SBND overlaps with the low energy regime of the DUNE
  - The energy regime of the 2x2 demonstrator overlaps with the higher energy regime of DUNE
  - 2x2's higher energy will yield significant π (also kaon) production, vs QE interactions from BNB
- Initial beam operation in RHC mode means initial analyses will be antineutrino focused!
- Analysis workshop at FNAL last month!

Summary

The use of a LArTPC at the DUNE near detector necessitates a modularized design to cope with the high-multiplicity environment.

In order to test the DUNE ND-LAr design, the DUNE 2x2 ND Prototype is a smaller scale demonstrator incorporating the new technology which will be implemented in DUNE ND-LAr.

The DUNE 2x2 ND Prototype brings together the excellent tracker planes of MINERvA with the already-individually-operated 2x2 modules, assembles them all together in the NUMI beam, and enables neutrino physics analysis at DUNE ND energies well before DUNE ND arrives.

The 2x2 will be the first component of DUNE to see neutrinos!

This is an exciting year for DUNE ND!

Thank You!

DUNE Collaboration, May 2023, Fermilab

Liquid Argon Time Projection Chambers

“Liquid Argon, E-field, Various Readouts”

1. Neutrino interacts with Argon nuclei and charged particles from interactions ionize their paths
2. An E-field drifts charge to the periphery to be recorded by charge readout
3. 3D image reconstructed from 2D location that charge drifted to and drift time
4. the flash of light from each interaction can be recorded by photo-detector light readout