The 2x2 Demonstrator: A DUNE ND-LAr Prototype Update

Elise Hinkle for the DUNE Collaboration

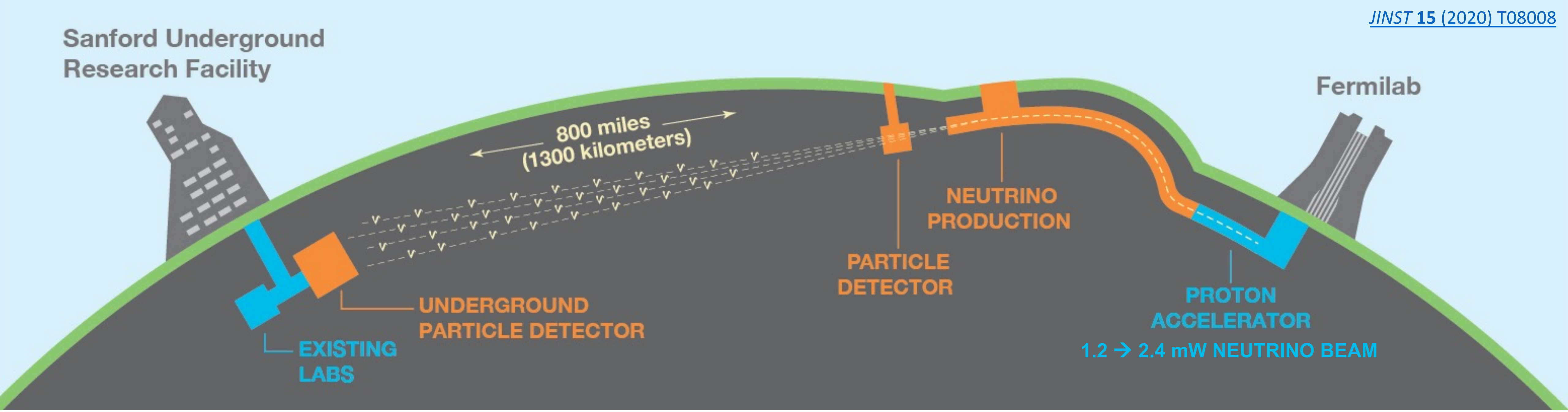
April 6, 2024

See L. Convery's April 5th Talk Session L08,
C. Marshall's April 5th Talk Session L11

What is DUNE?

- The **D**eep **U**nderground **N**eutrino **E**xperiment (**DUNE**) is an upcoming long baseline neutrino oscillation experiment with an expansive physics program including determining the **neutrino mass hierarchy** and quantifying **CP violation** in the lepton sector

JINST **15** (2020) T08008



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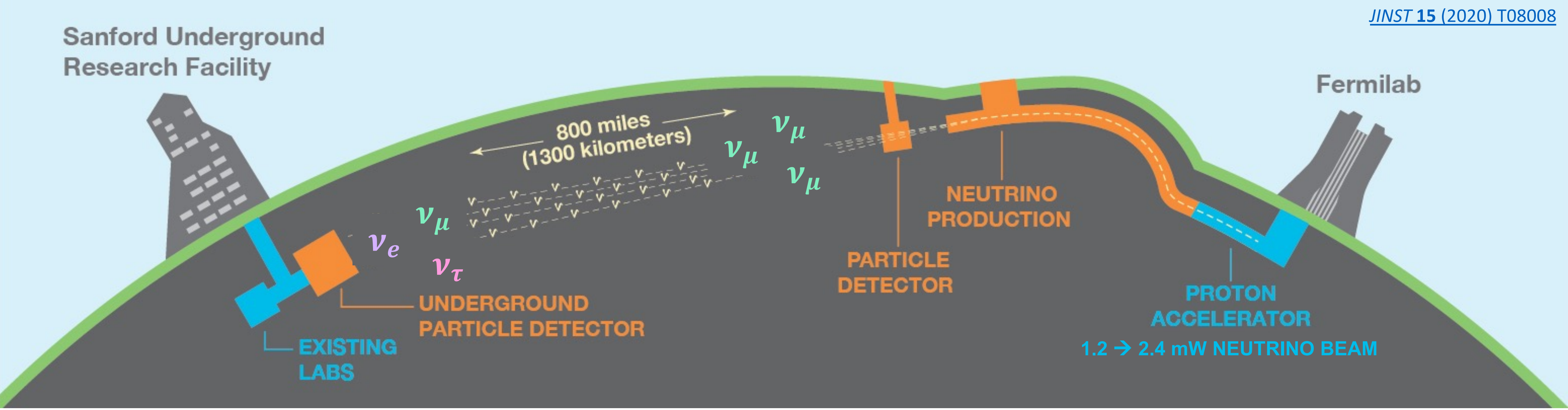

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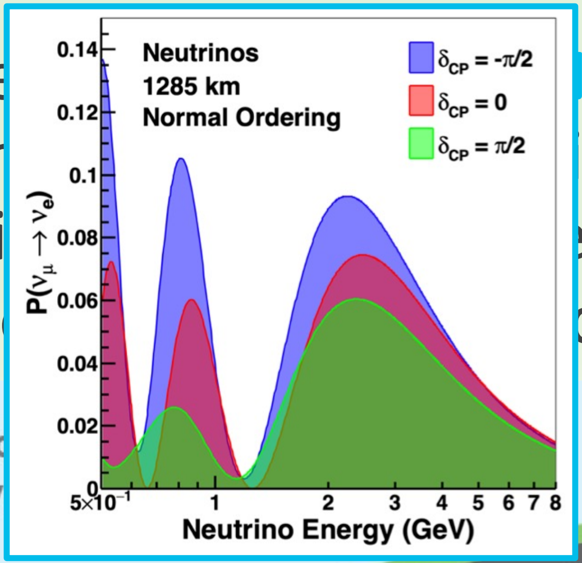
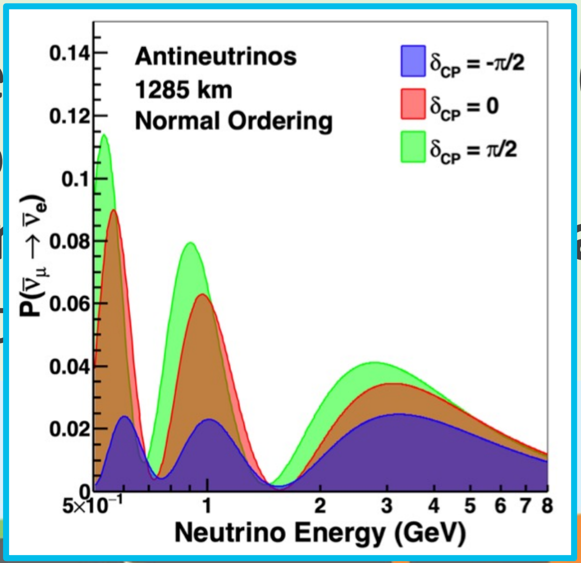
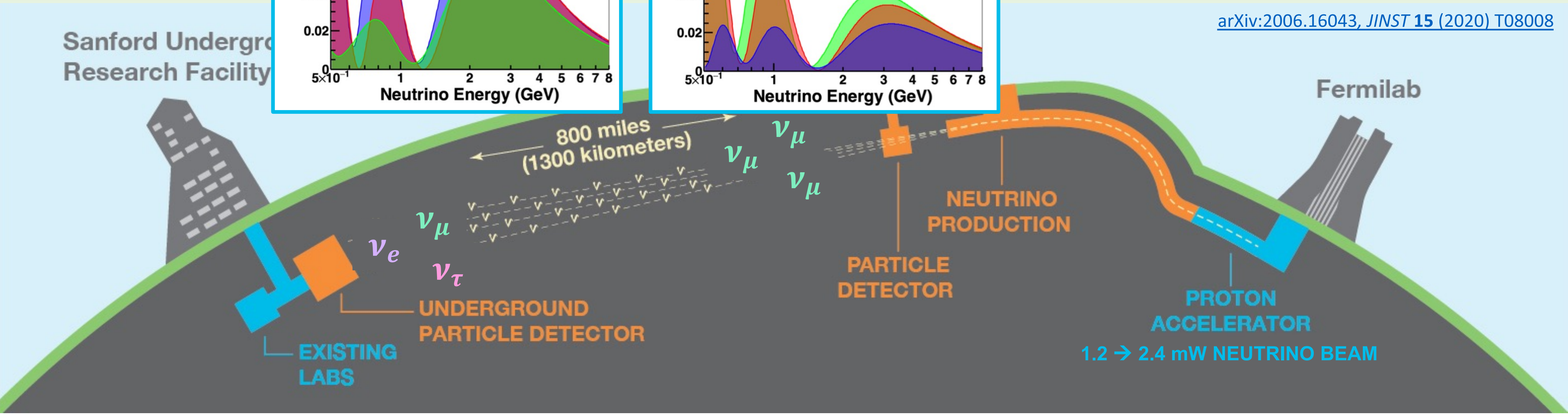




arXiv:2006.16043, *JINST* **15** (2020) T08008



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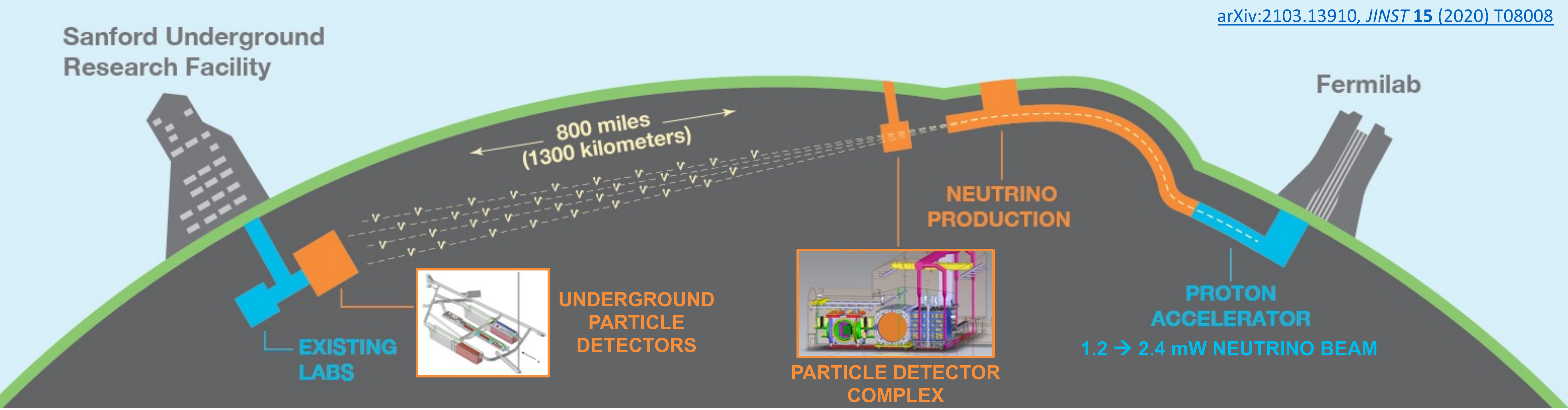
arXiv:2103.13910, *JINST* **15** (2020) T08008



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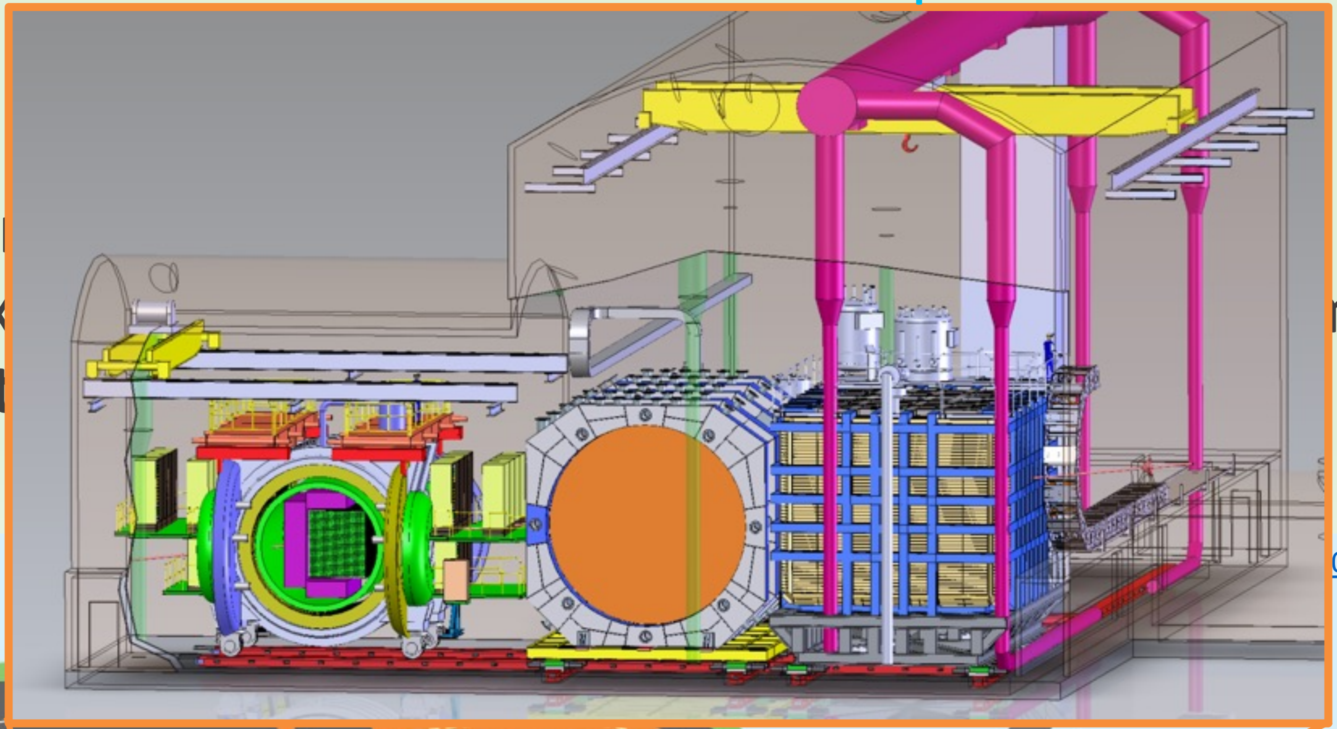
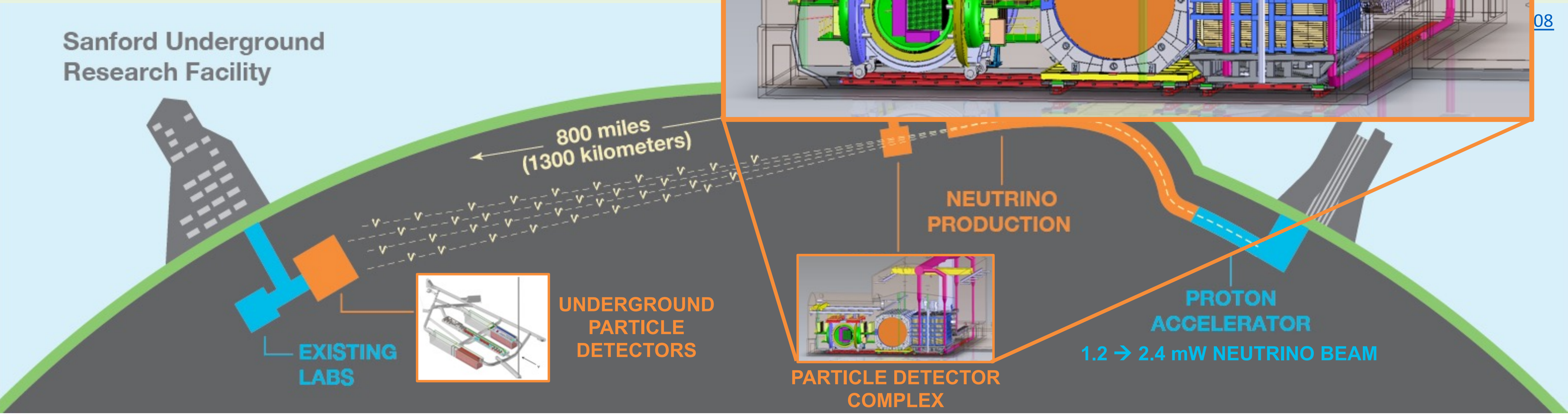
08





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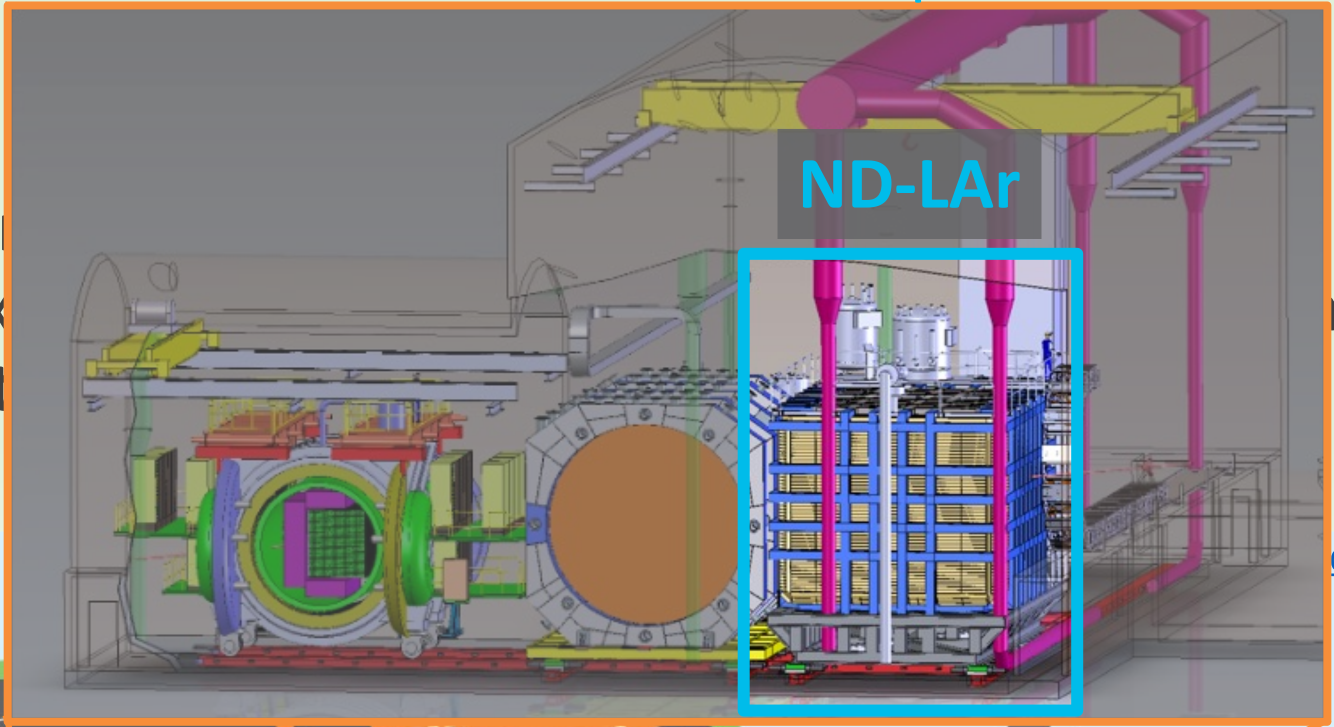

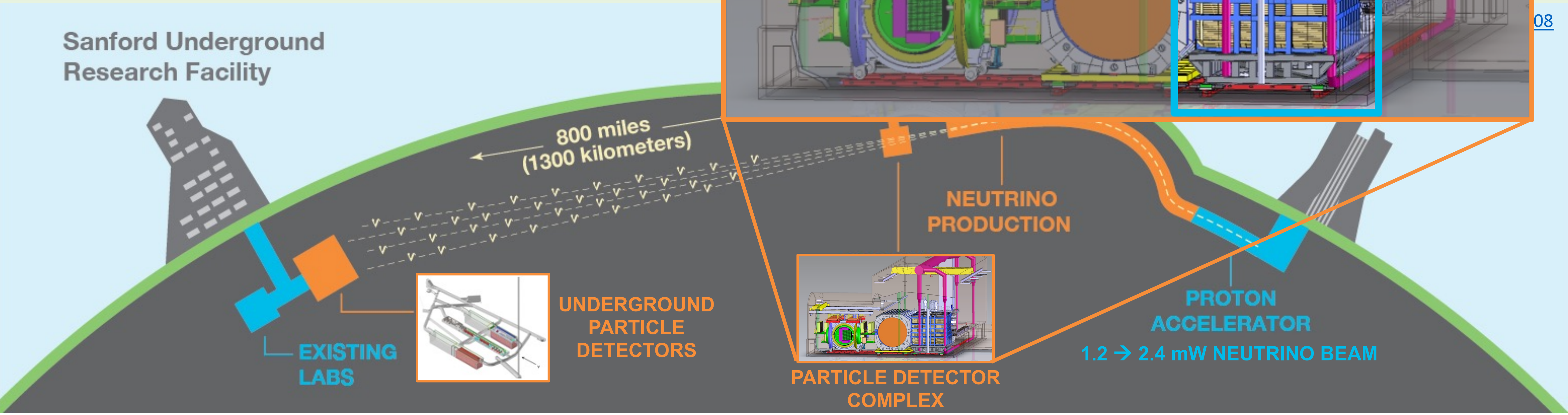

What is ND-LAr?

- **ND-LAr** is DUNE's **L**iquid **Ar**gon **N**ear **D**etector
- Based on **liquid argon time projection chamber (LArTPC) technology**
  - DUNE far detectors also using LArTPC technology
  - Will help to **constrain neutrino flux uncertainties and neutrino-nucleus interaction uncertainties**

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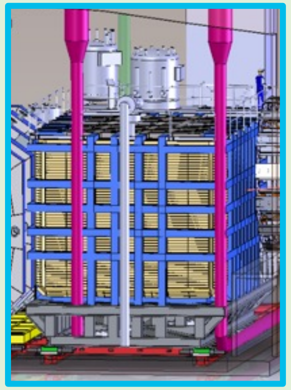

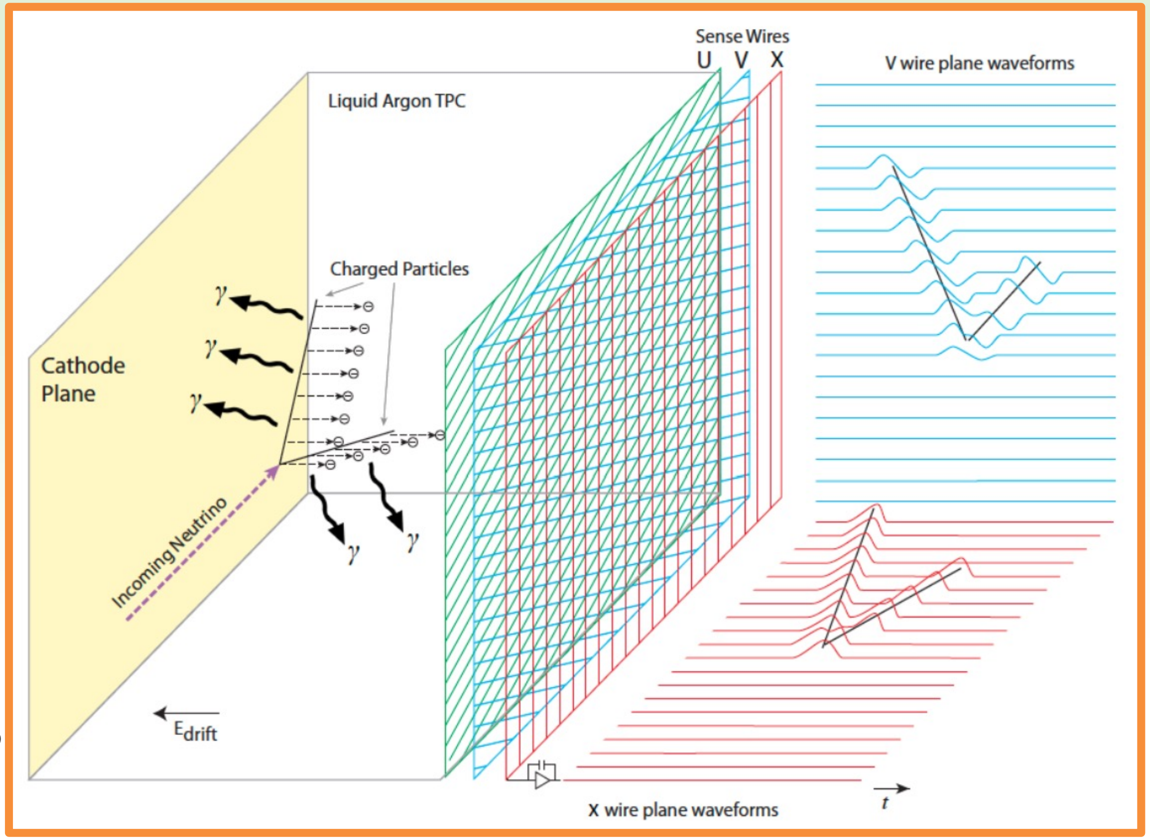

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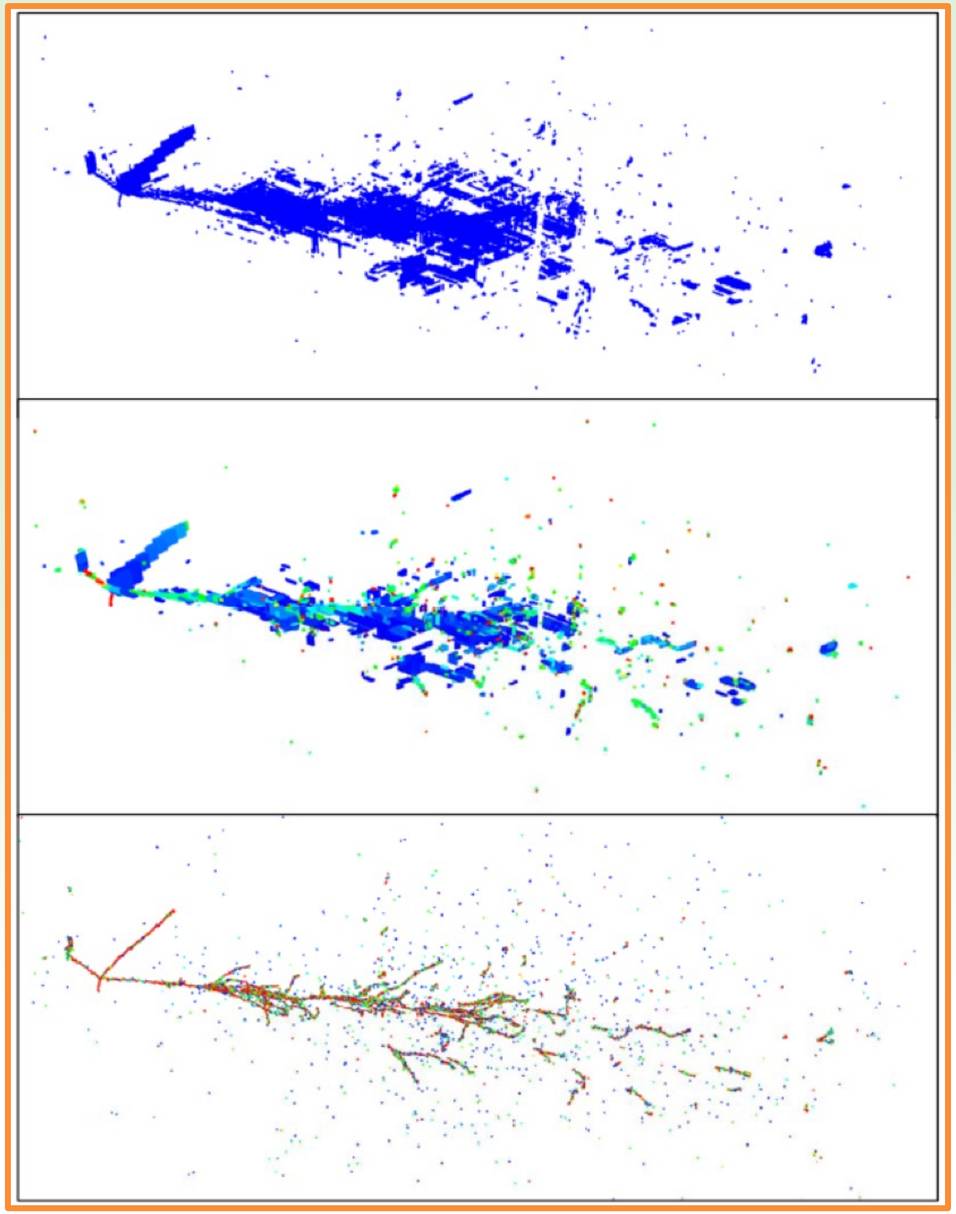
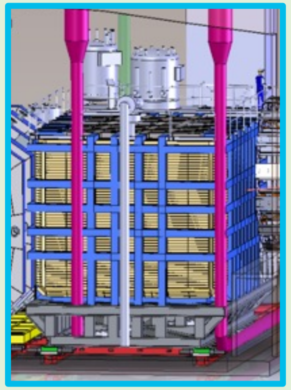


JINST **13** (2018) P05032

arXiv:2103.13910



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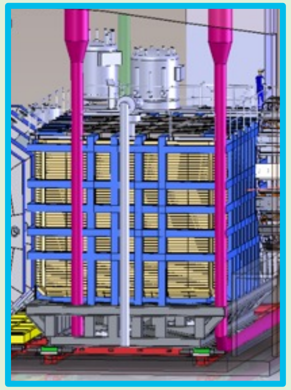

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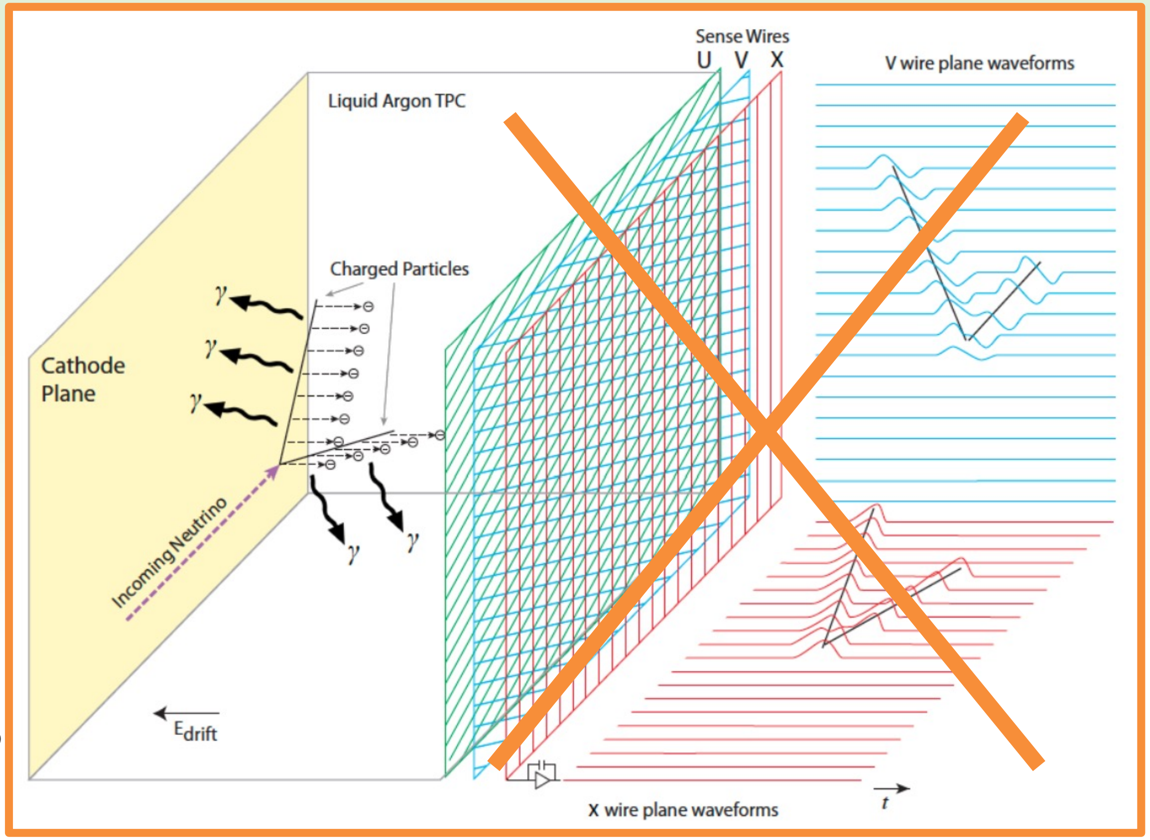
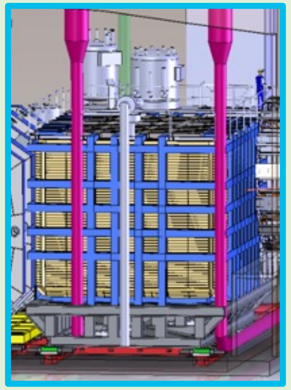


JINST **15** (2020) T08008

What is ND-LAr?

Expect ***O*(50) neutrino interactions** per beam spill



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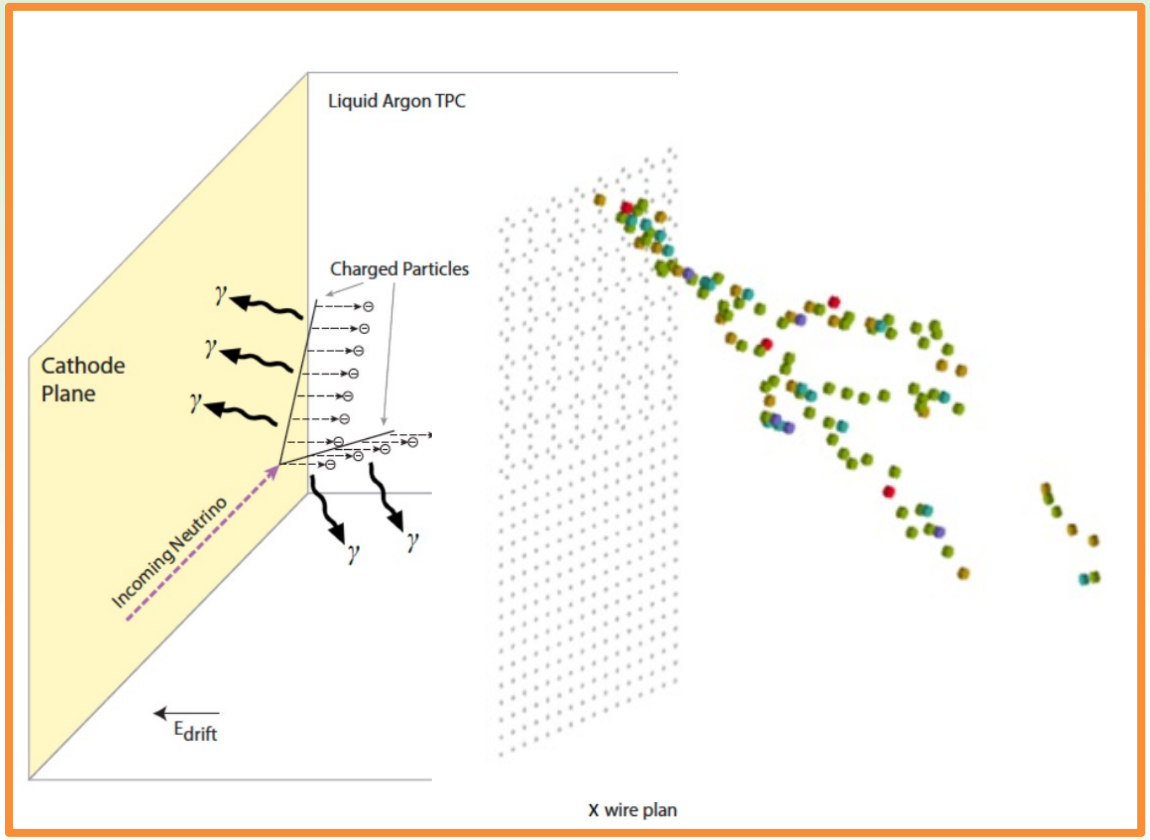
- **ND-LAr** is DUNE's **L**iquid **Ar**gon **N**ear **D**etector
- Based on **liquid argon time projection chamber (LArTPC) technology**
- **Pixel-based** charge readout
  - Pixels are self-triggering with ***O*(100) keV charge thresholds**
  - Allows for **native 3D reconstruction**



JINST **15** (2020) T08008, *JINST* **13** (2018) P10007

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- **Modular** design
  - 2 TPCs per module

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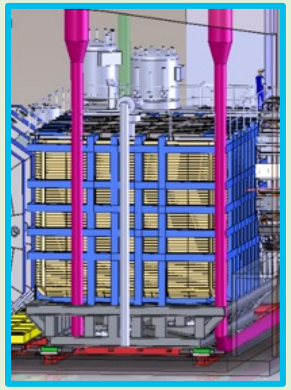

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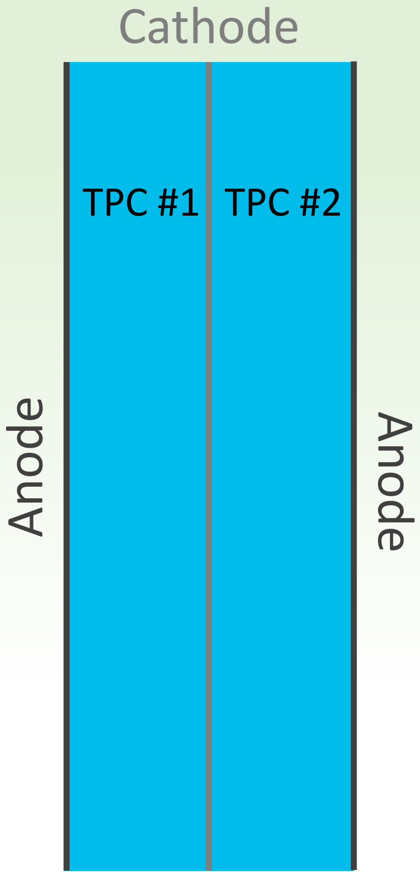

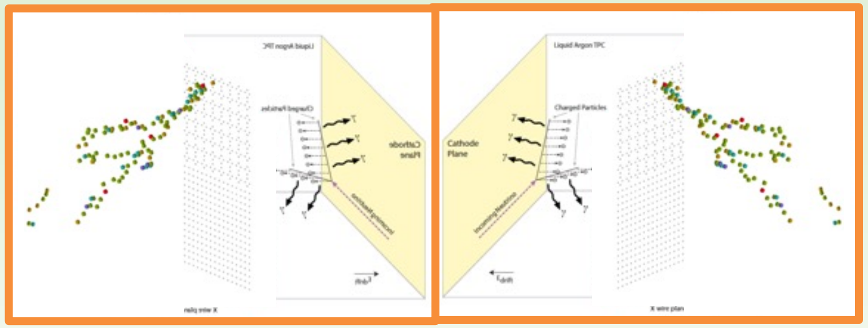

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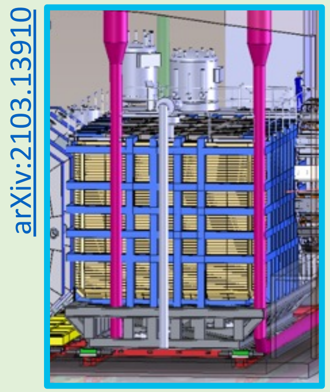

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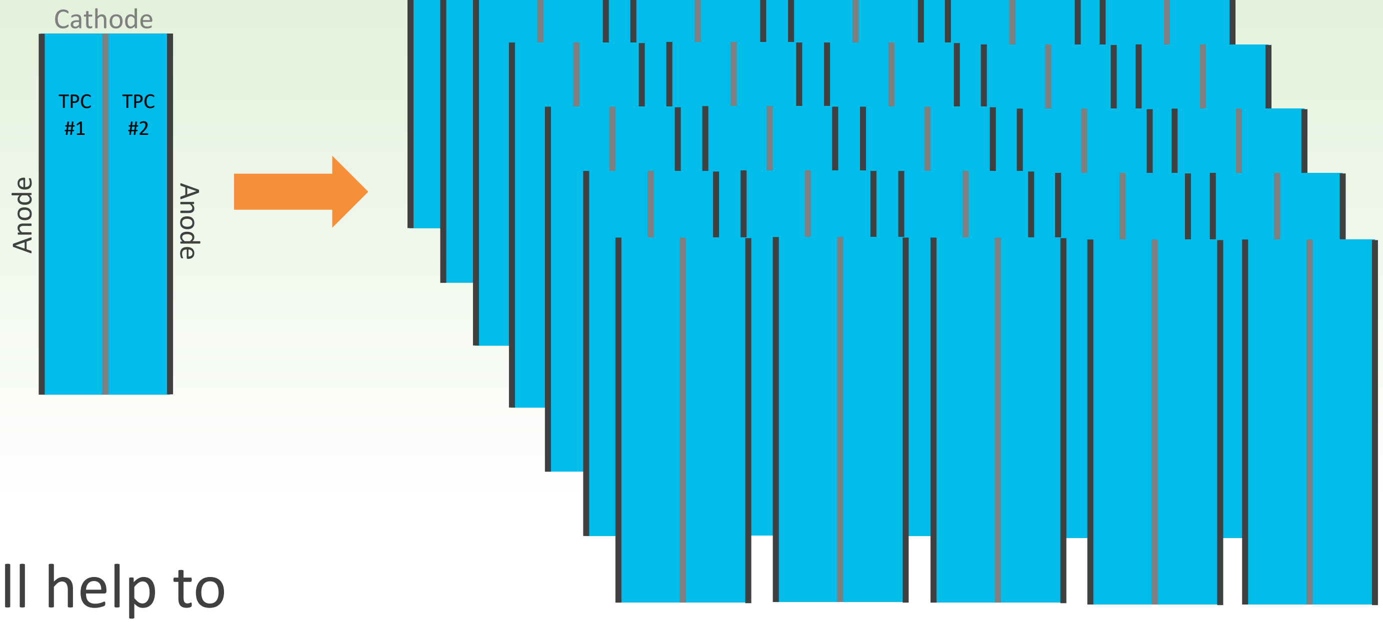
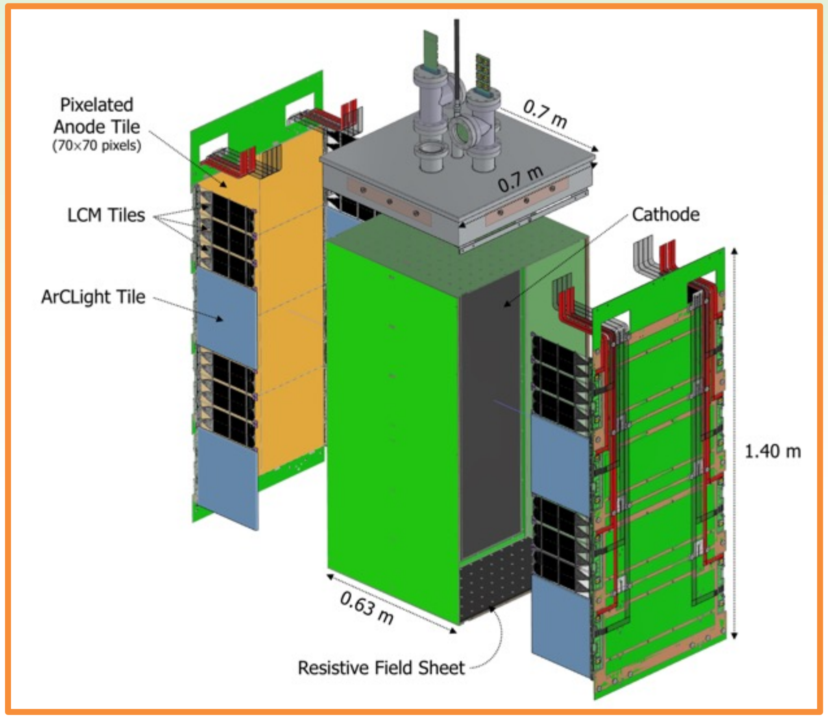
- Based on **liquid argon time projection chamber (LArTPC) technology**
- **Pixel-based** charge readout
- **Modular** design
  - 2 TPCs per module
  - 7x5 array of 35 modules
  - Optical isolation of modules will help to **mitigate uncertainties related to high interaction rate (pile-up)**



What is the 2x2 Demonstrator?

- **2x2** array of 0.7 m x 0.7 m x 1.4 m tall modules
  - All modules previously tested at the University of Bern

arXiv:2403.03212



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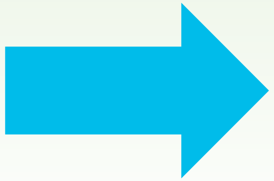
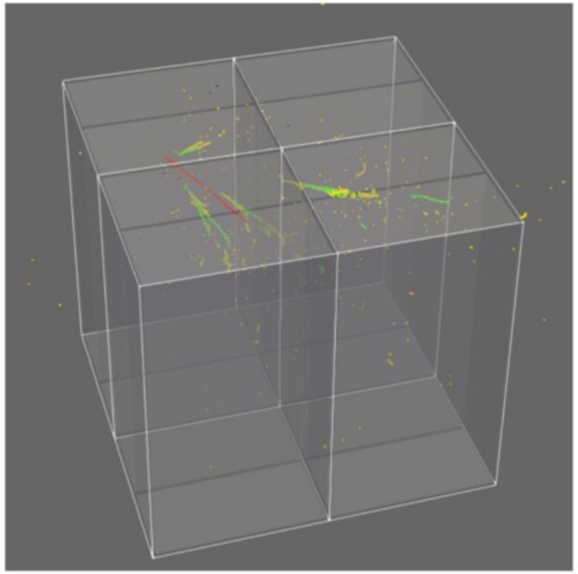


arXiv:2006.16043



(b) E_ν = 3.36 GeV

What is the 2x2 Demonstrator?

- **2x2** array of 0.7m x 0.7m x 1.4m tall modules
- Positioned in the Neutrinos at the Main Injector **(NuMI) beam at Fermilab**
    - Able to access **higher beam energies** than other Fermilab-based LArTPC neutrino experiments

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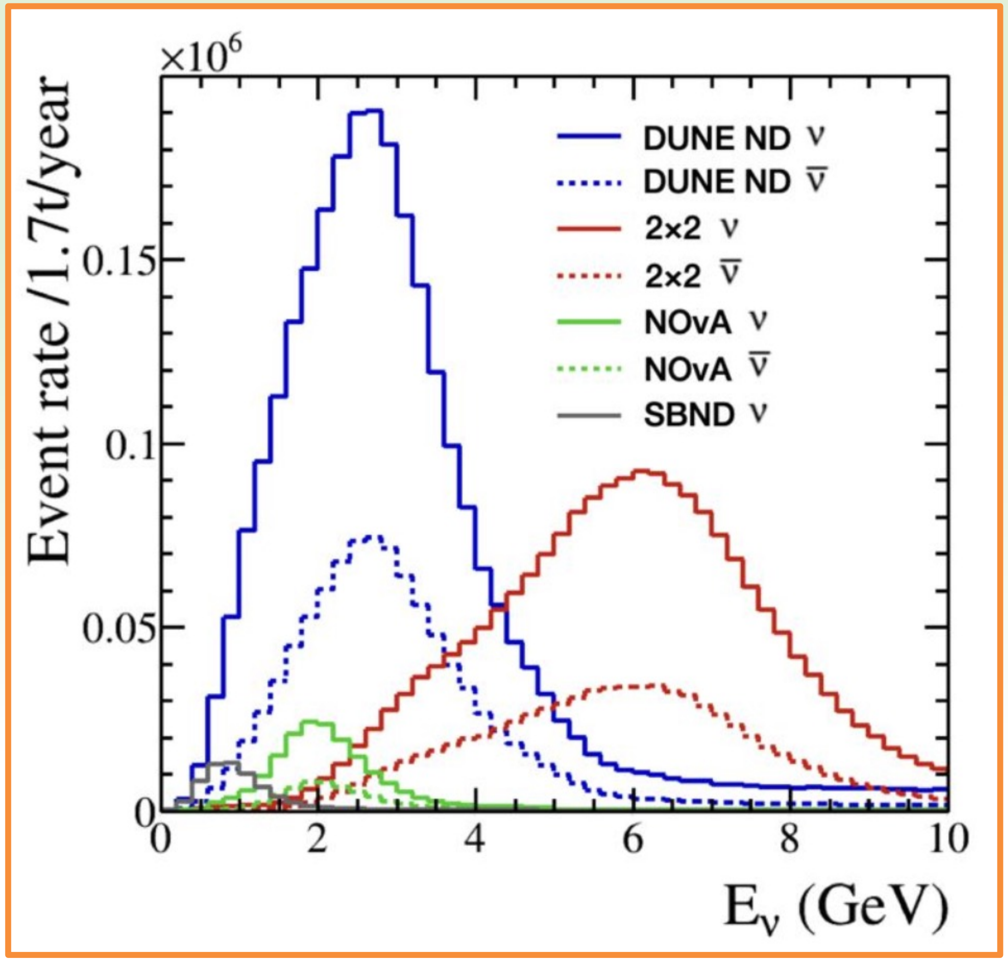

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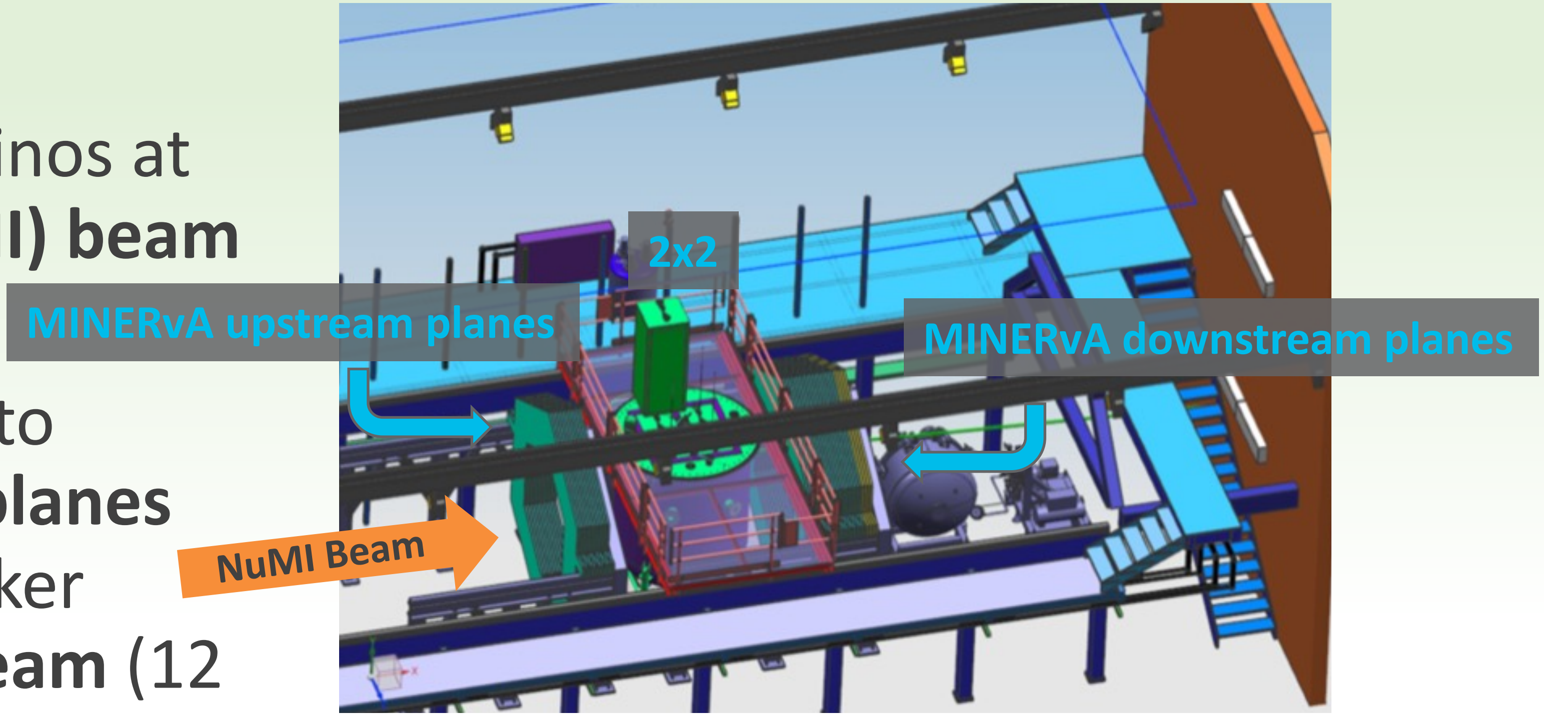
- Enhanced tracking due to **repurposed MINERvA planes** both **upstream** (12 tracker modules) and **downstream** (12 HCAL and 20 tracker + ECAL modules) of the 2x2

See C. Pernas's April 5th Talk Session P07



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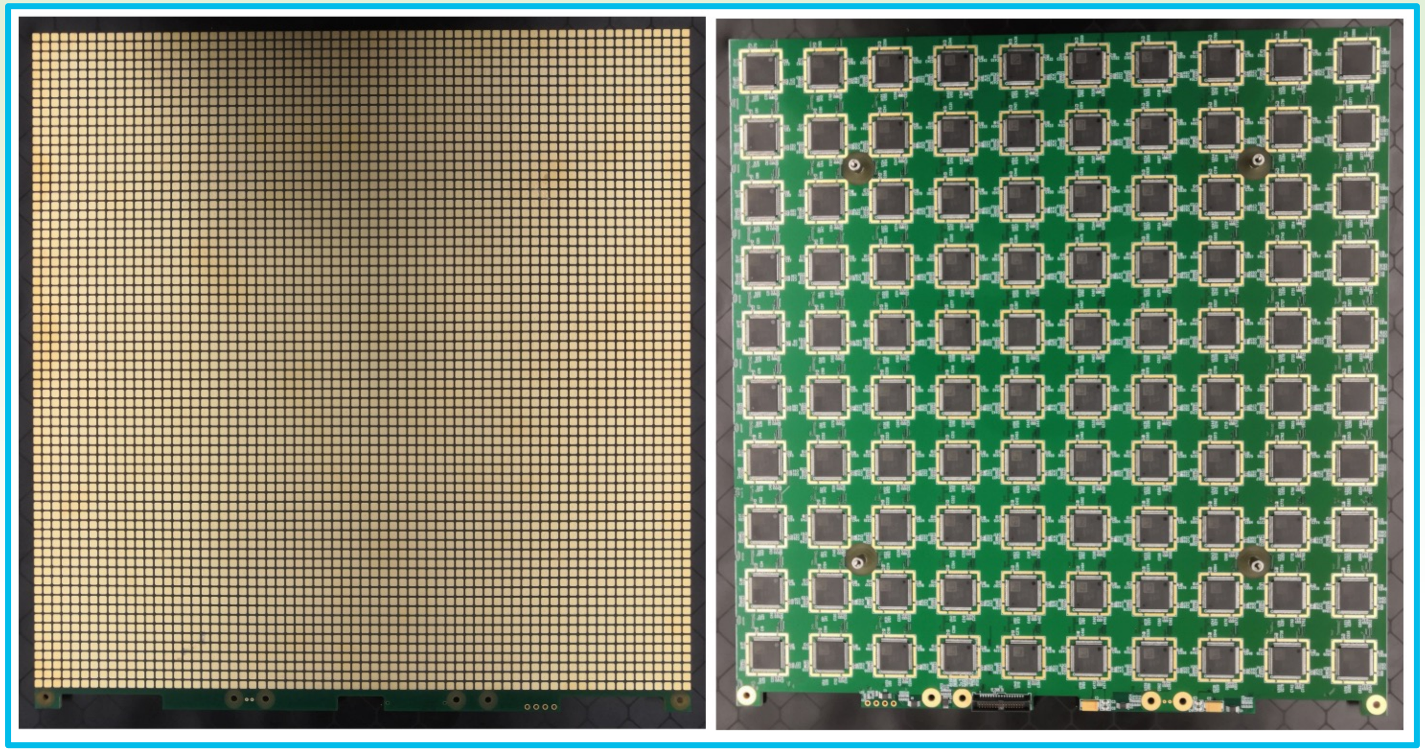
- Positioned in the Neutrinos at the Main Injector **(NuMI) beam at Fermilab**
- Enhanced tracking due to **repurposed MINERvA scintillation planes** both upstream and downstream of the 2x2
- Opportunity to **demonstrate ND-LAr design capabilities** and **perform physics studies relevant for DUNE**

Demonstrating Native 3D Reconstruction

- 2x2 has ~**337k LArPix pixels** total at ~4mm pitch



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LArPix pixels (L) and ASICs (R)

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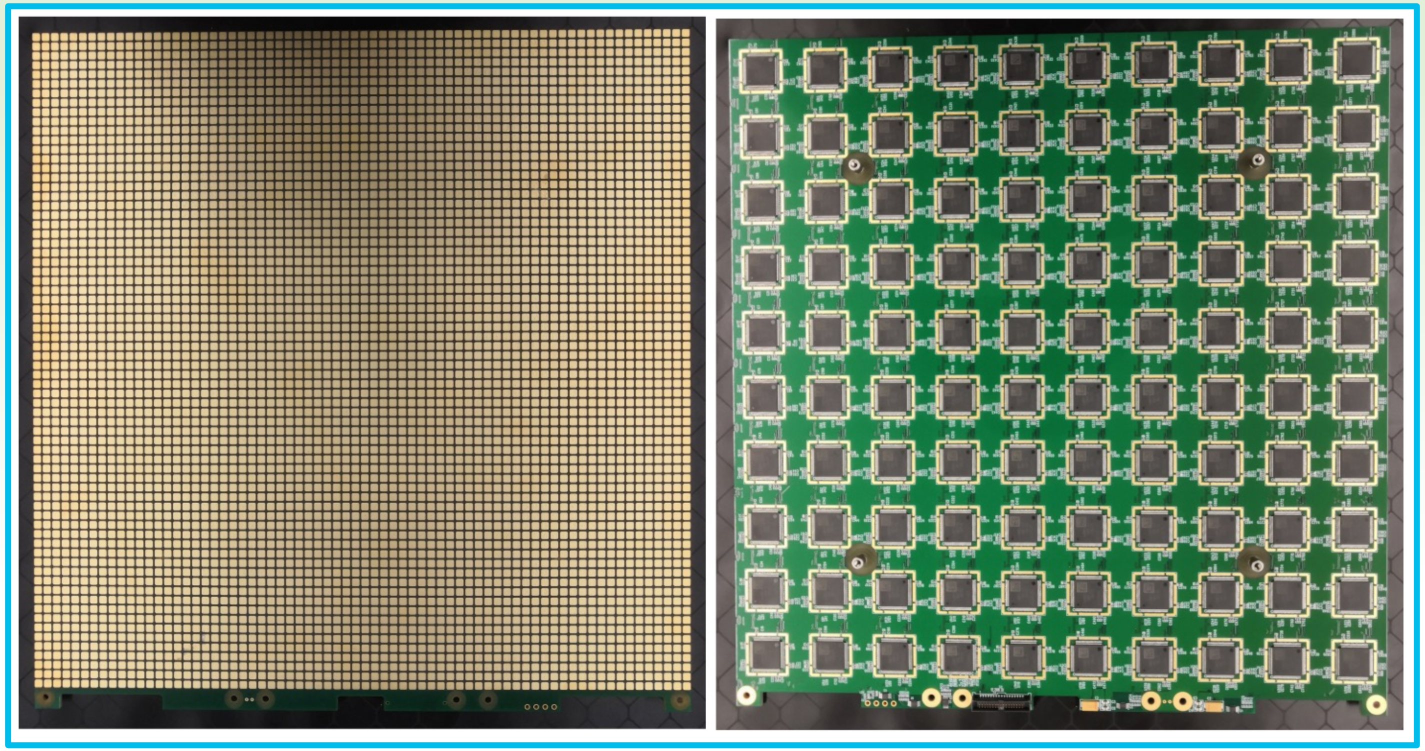

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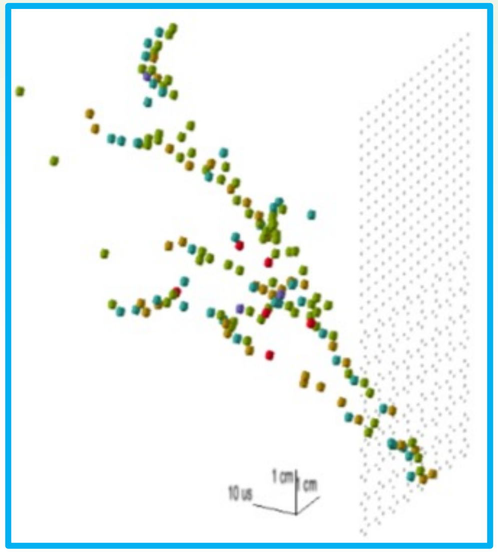

JINST **13** (2018) P10007

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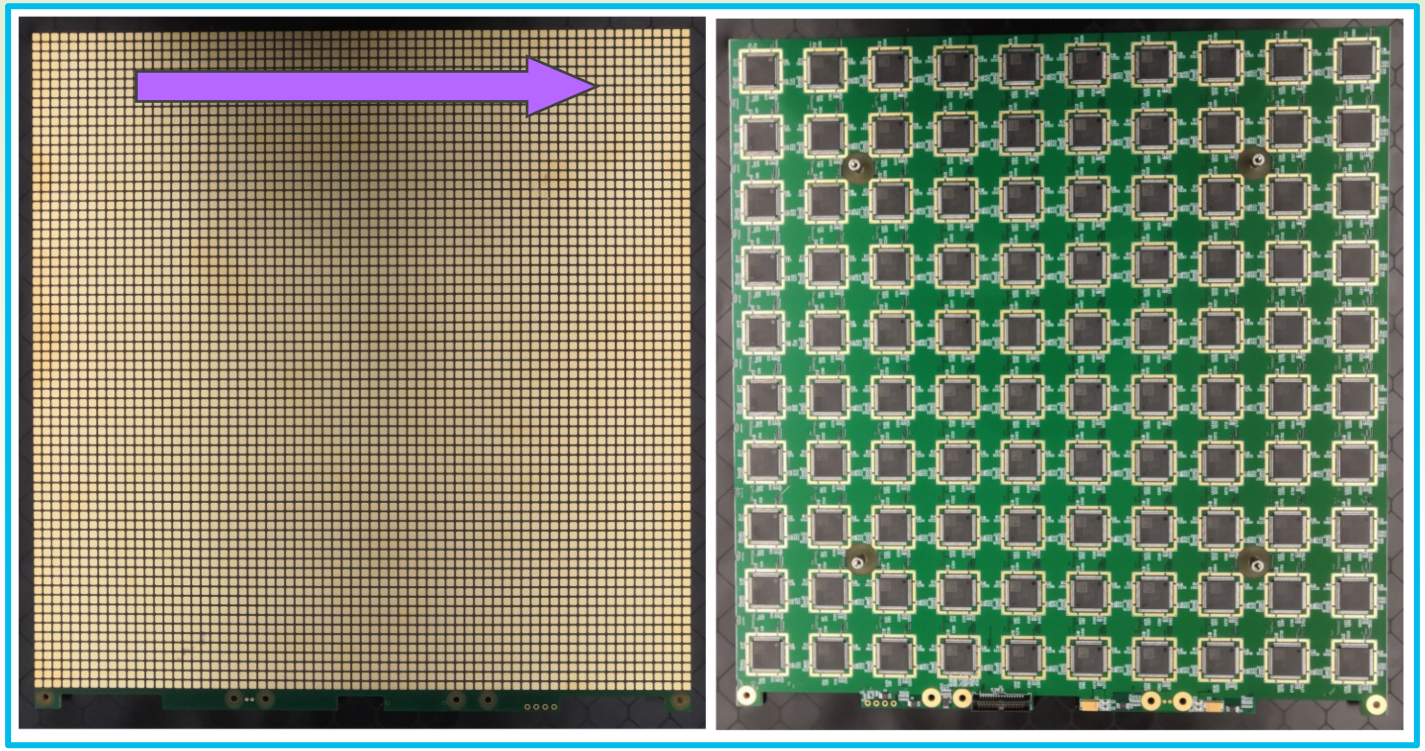

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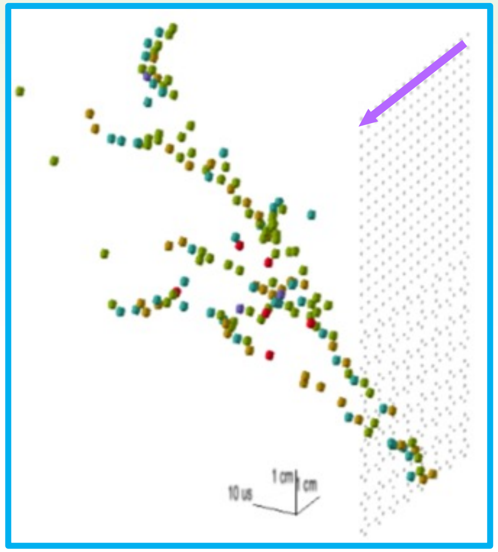
LArPix pixels (L) and ASICs (R)

1D: Pixel pitch horizontal



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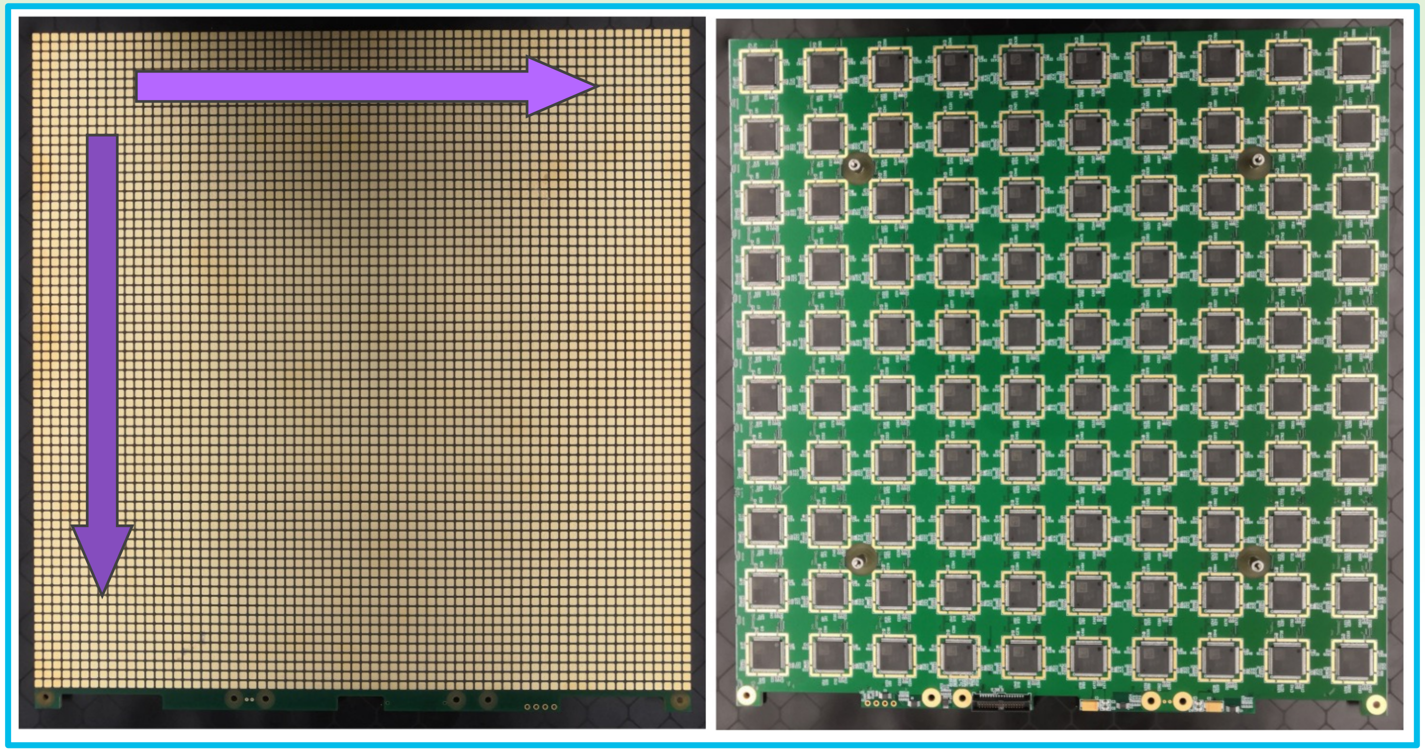

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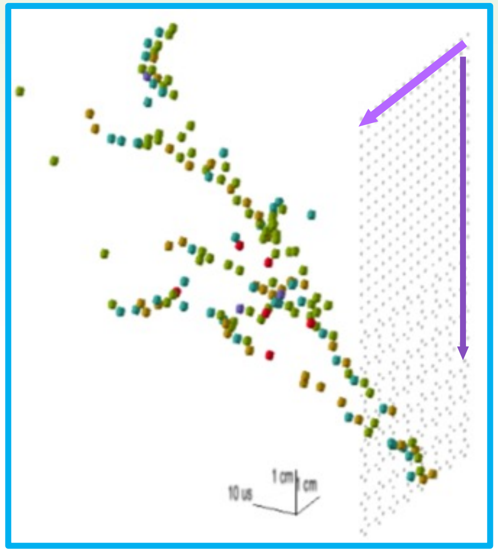
LArPix pixels (L) and ASICs (R)

1D: Pixel pitch horizontal

2D: Pixel pitch vertical



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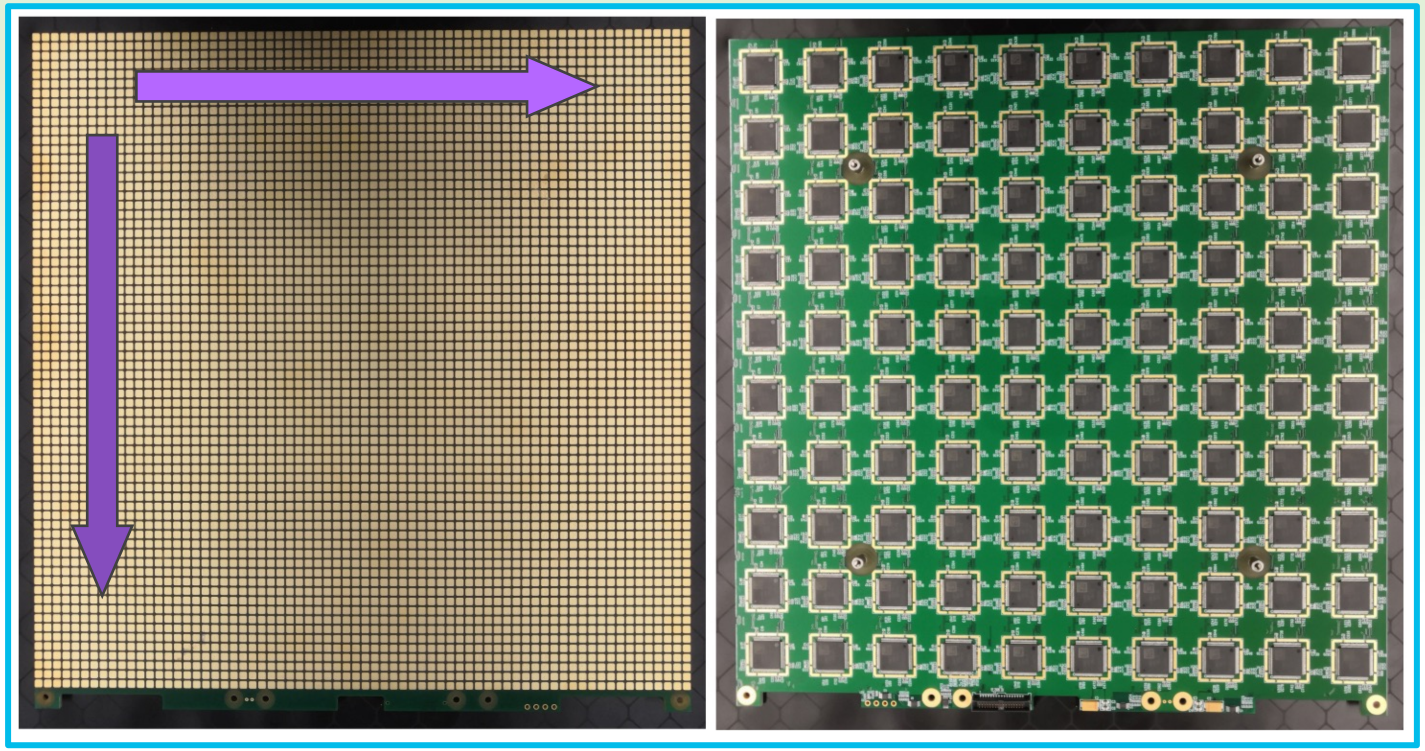

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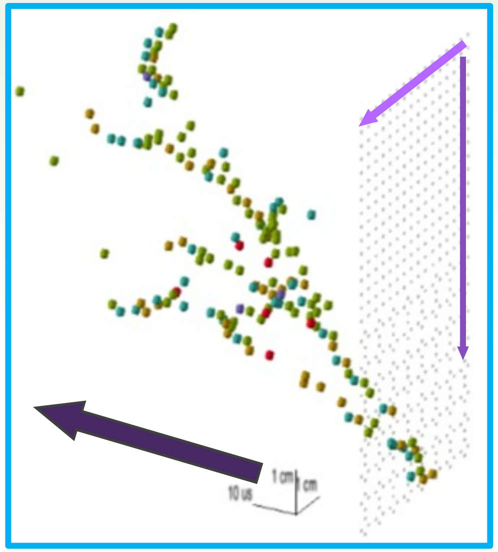
LArPix pixels (L) and ASICs (R)

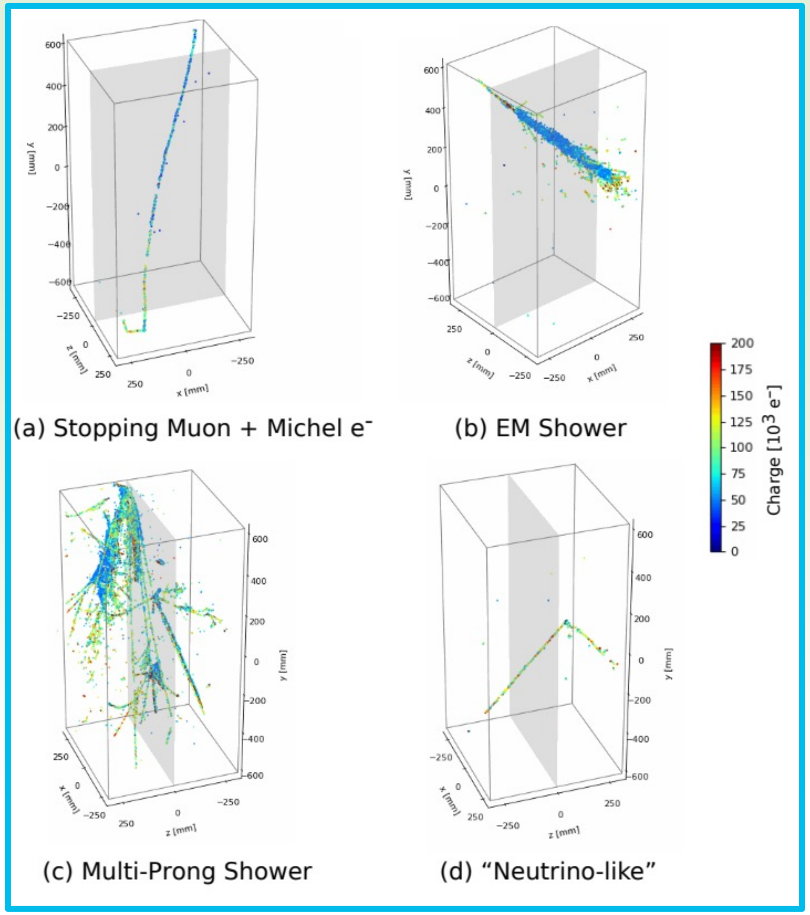
1D: Pixel pitch horizontal

2D: Pixel pitch vertical

3D: Time



Demonstrating Native 3D Reconstruction



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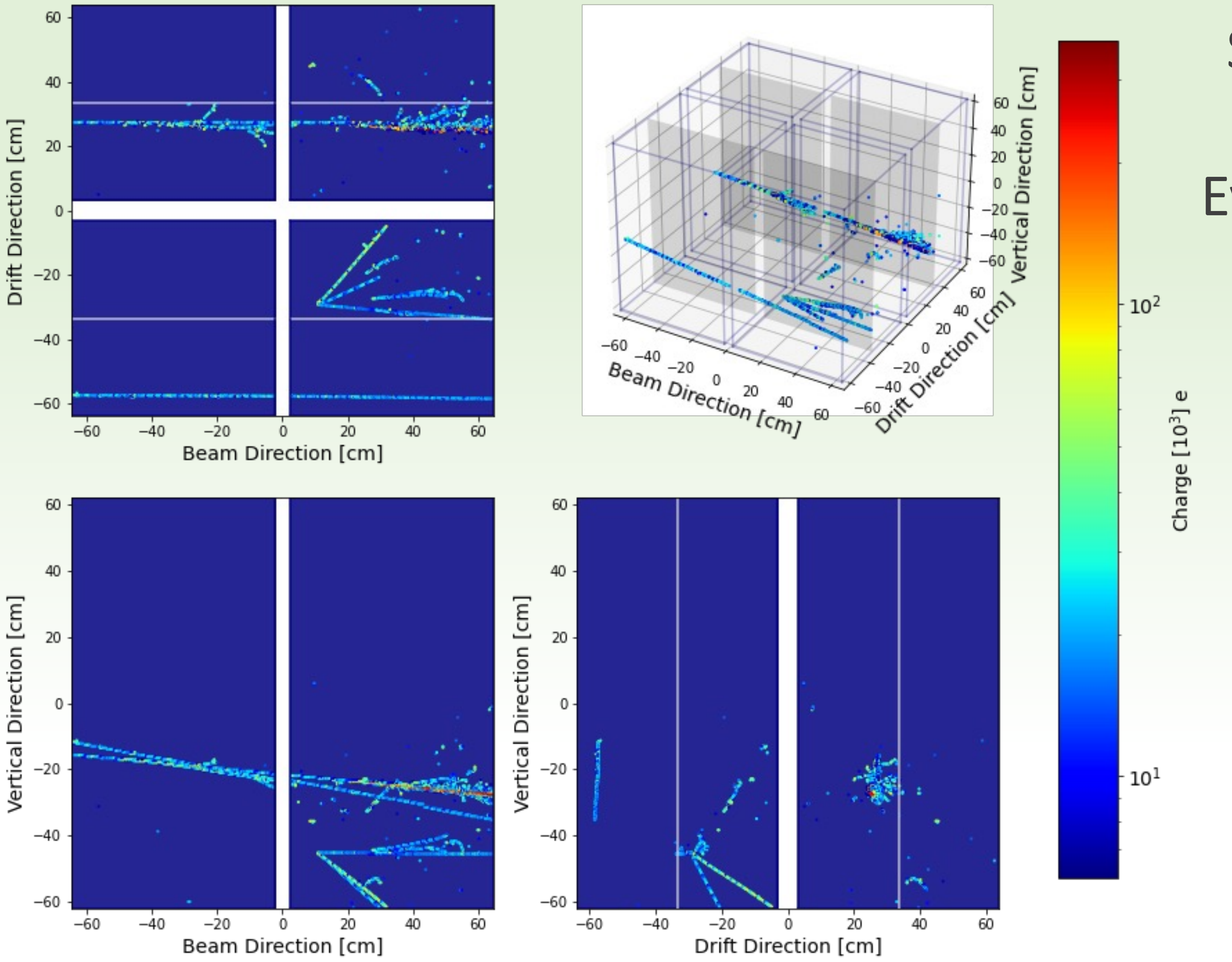
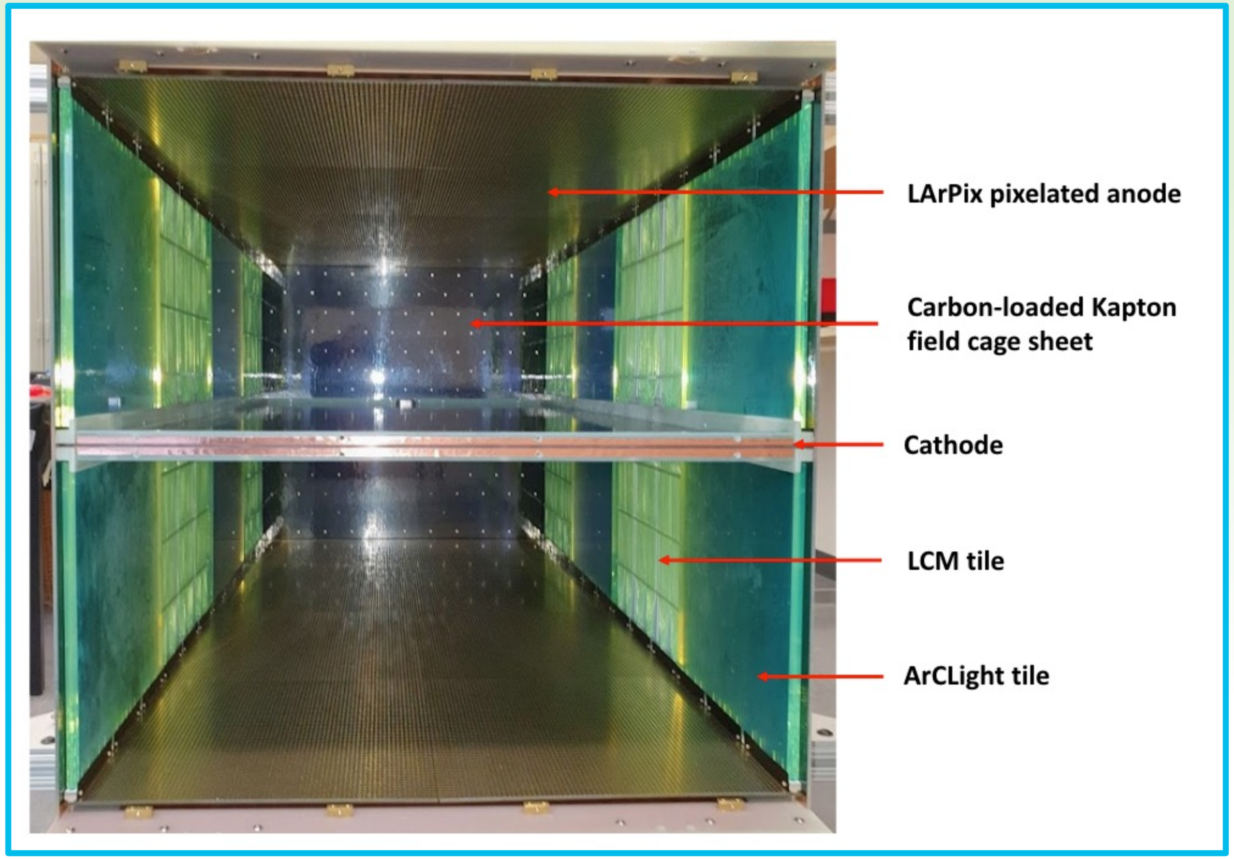
Module 0 Data from University of Bern runs



Simulated Neutrino Event in 2x2

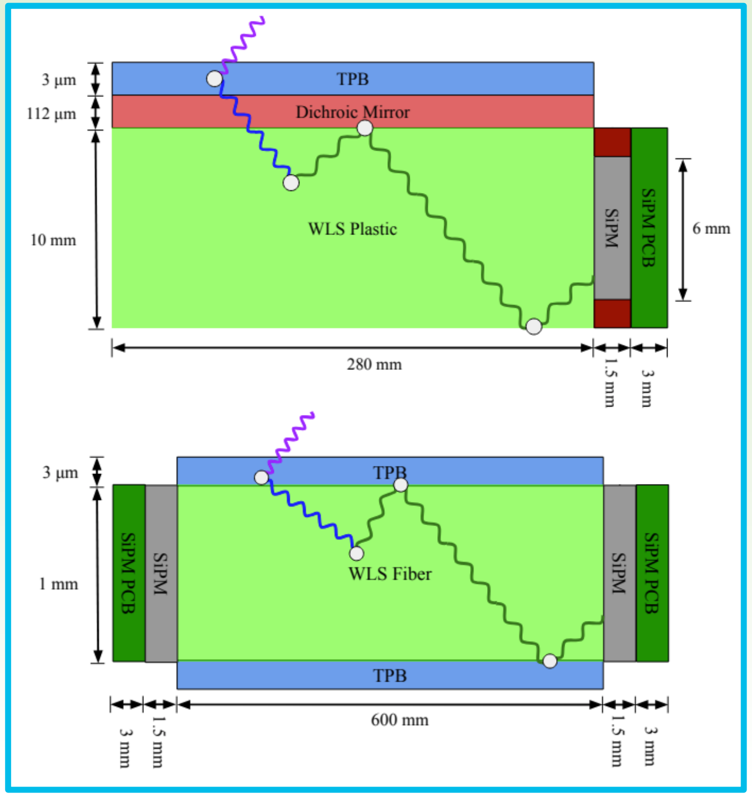
Demonstrating Pileup Uncertainty Mitigation



arXiv:2403.03212

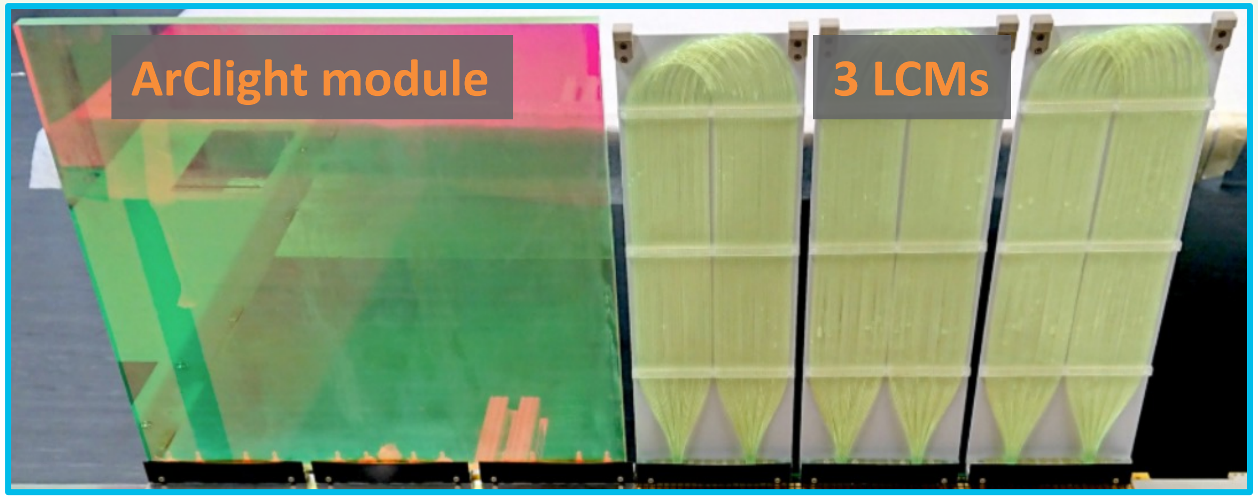
- Timing resolution in high pileup environments possible due to **optically isolated modules**
  - Light signals from distinct modules allow for **improved event localization**
- In 2x2, use two different silicon photomultiplier (SiPM)-based light readout modules to achieve **25% optical coverage**

Demonstrating Pileup Uncertainty Mitigation



arXiv:2403.03212

- **ArCLight** modules use ARAPUCA light trapping technique
- **Light Collection Modules (LCMs)** uses wavelength-shifting fibers
- ArCLight modules allow for **higher spatial resolution** while LCMs have **higher detection efficiency**



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Demonstrating Tracking Across Modules

- In ND-LAr, it will be necessary to **match tracks and showers across modules**
- 2x2 gives us an opportunity to **tune event reconstruction algorithms** to make sure we can match effectively

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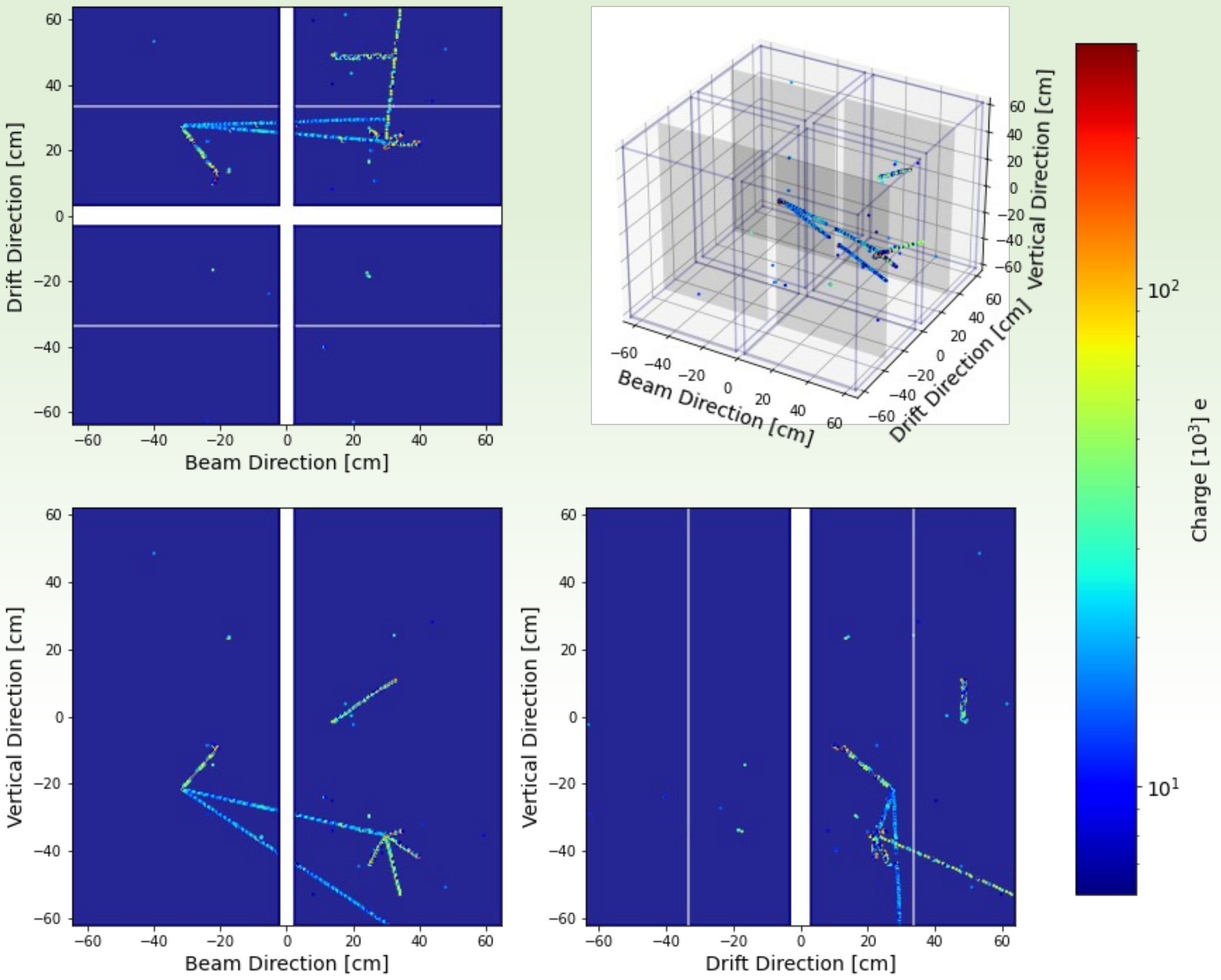

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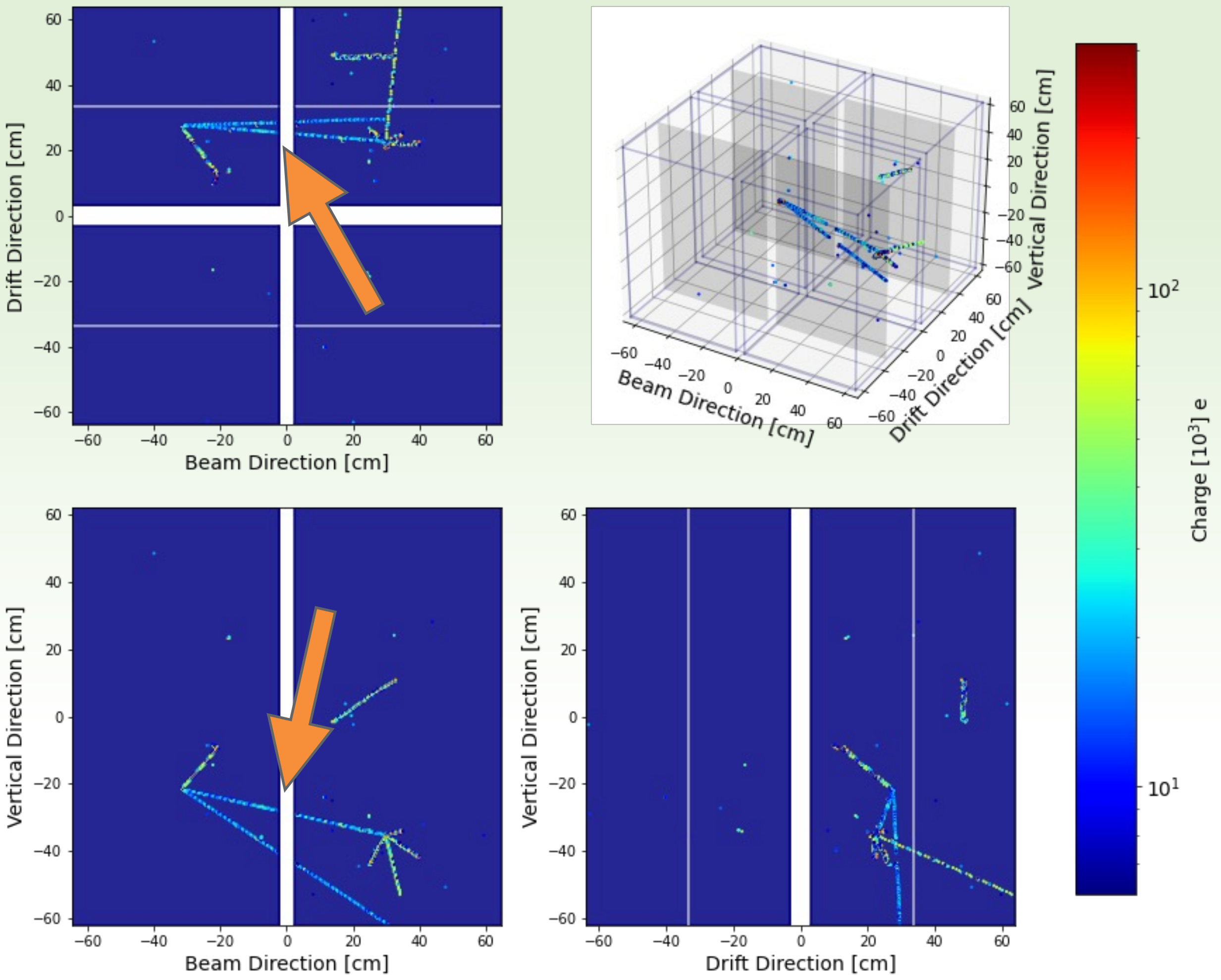
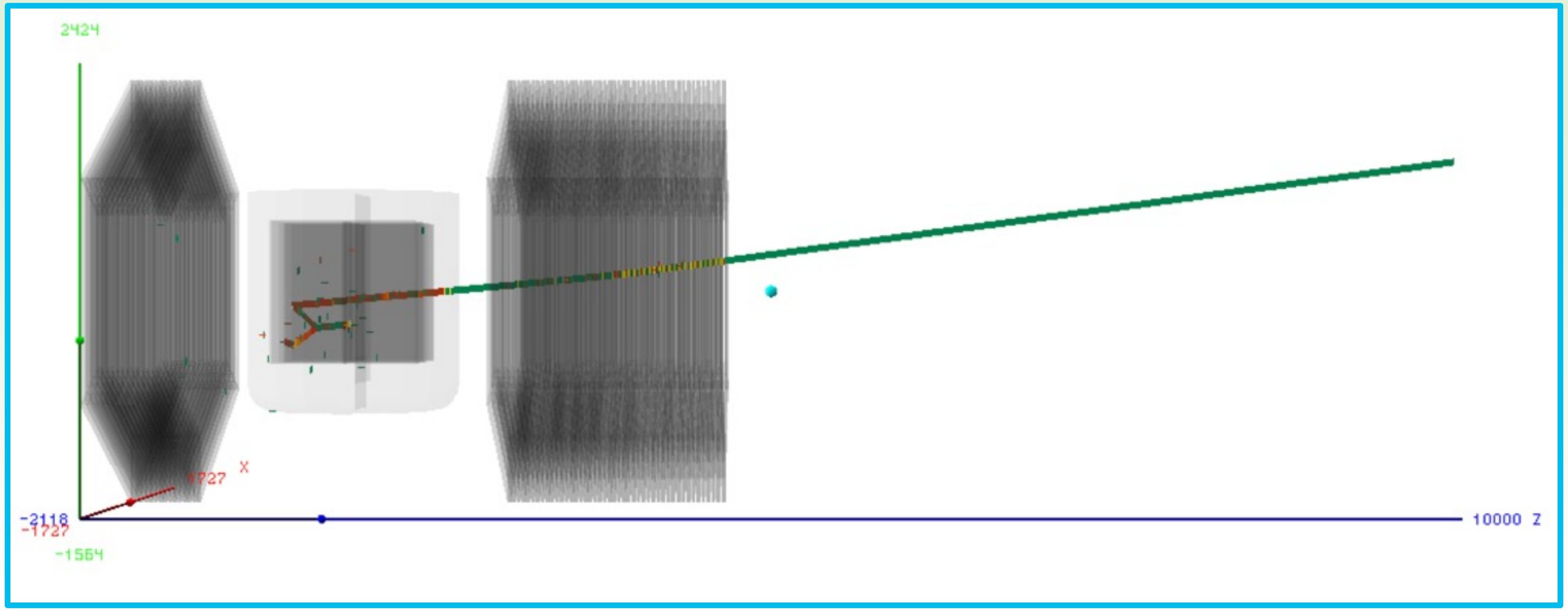


Demonstrating Tracking Across Detectors



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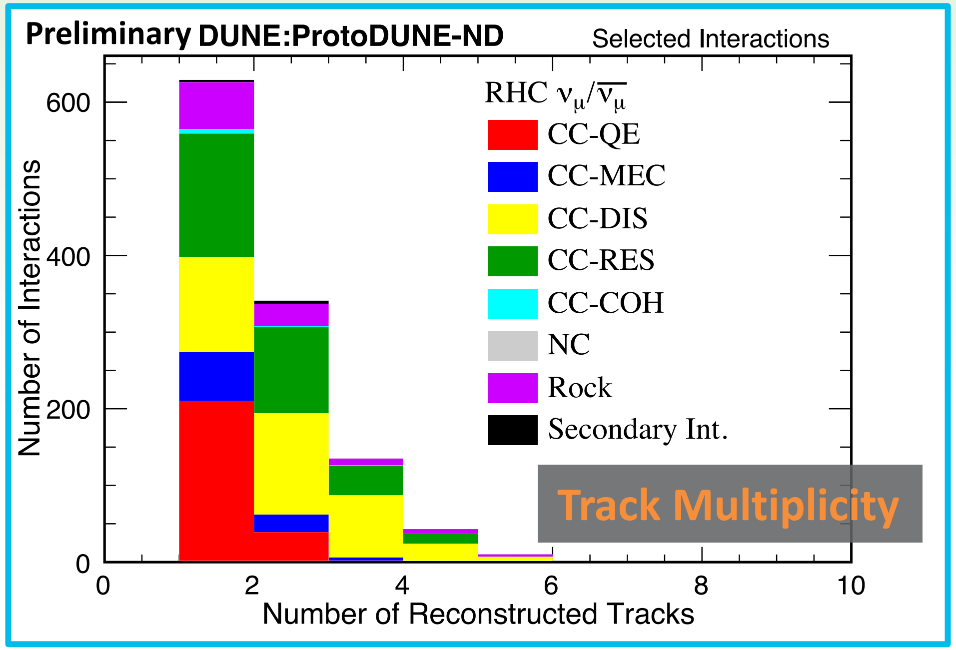
- As ND-LAr is part of a suite of near detectors in DUNE, it is important to be able to **match events across detectors**
- In 2x2, we have an opportunity to **match events across detectors using MINERvA**

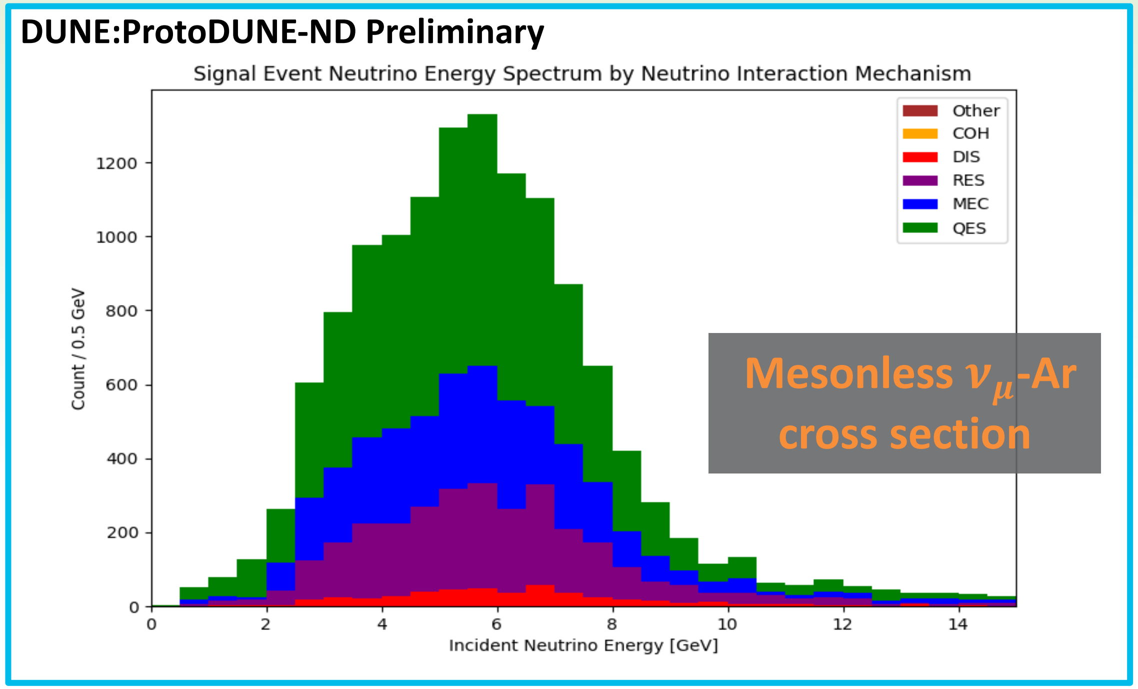
See C. Pernas's April 5th Talk Session P07

See M.B. Azam's April 5th Talk Session P07

Demonstrating Physics Studies

- Also positioned to make physics measurements which can help constrain systematic uncertainties in DUNE
- First physics studies include **track multiplicity** and **mesonless ν_μ-Ar cross section** measurements





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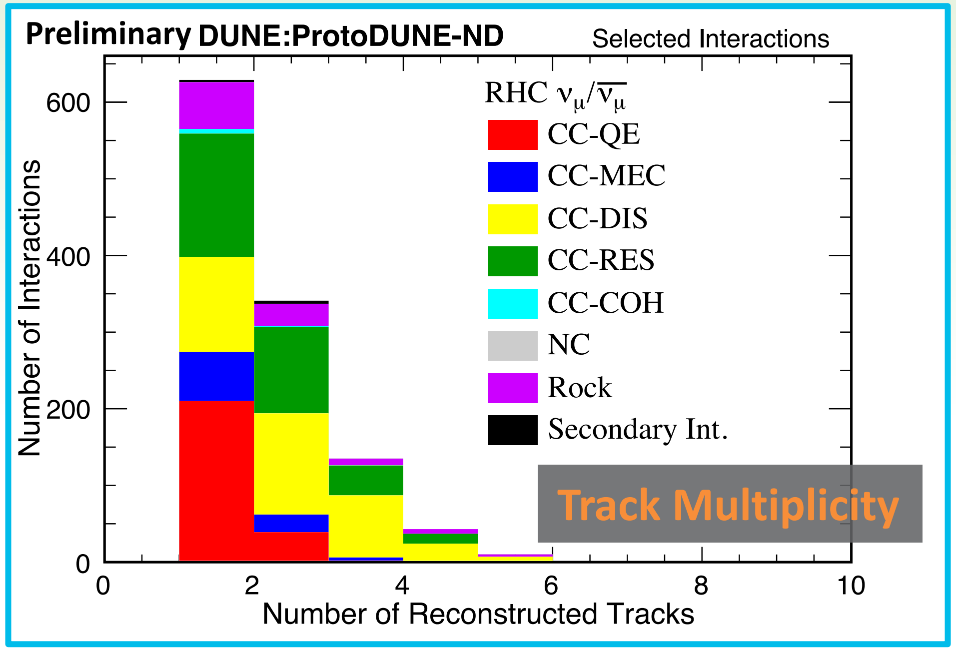

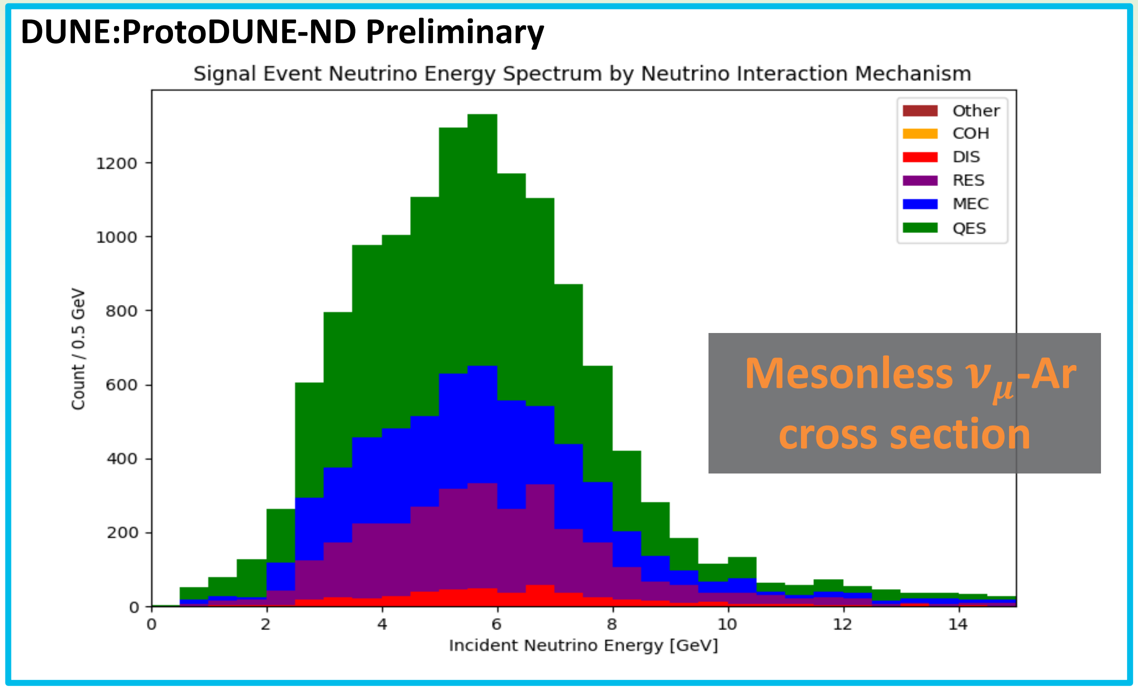

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Performing Physics Studies

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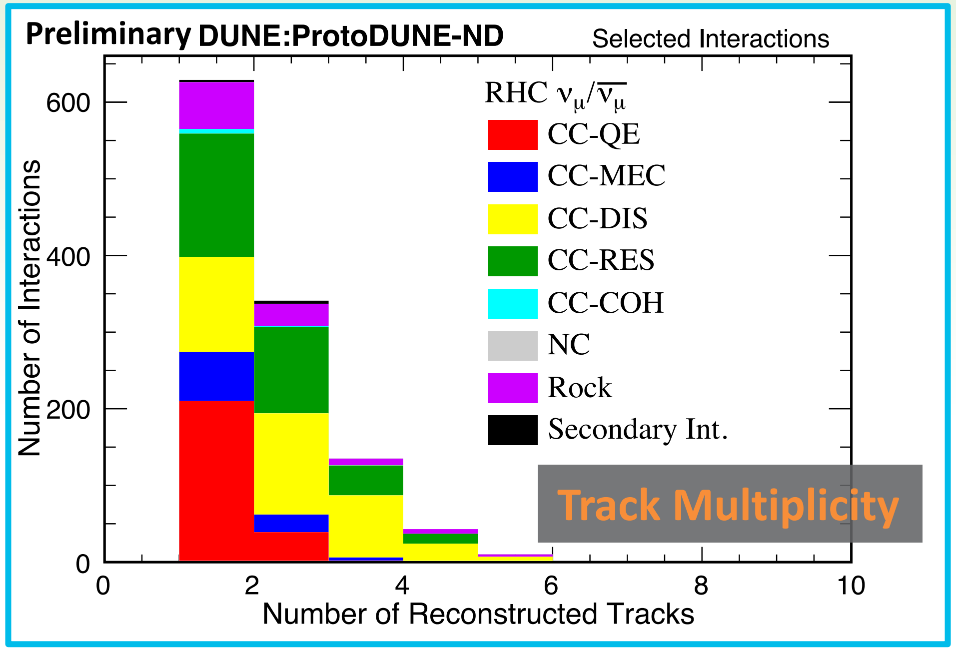
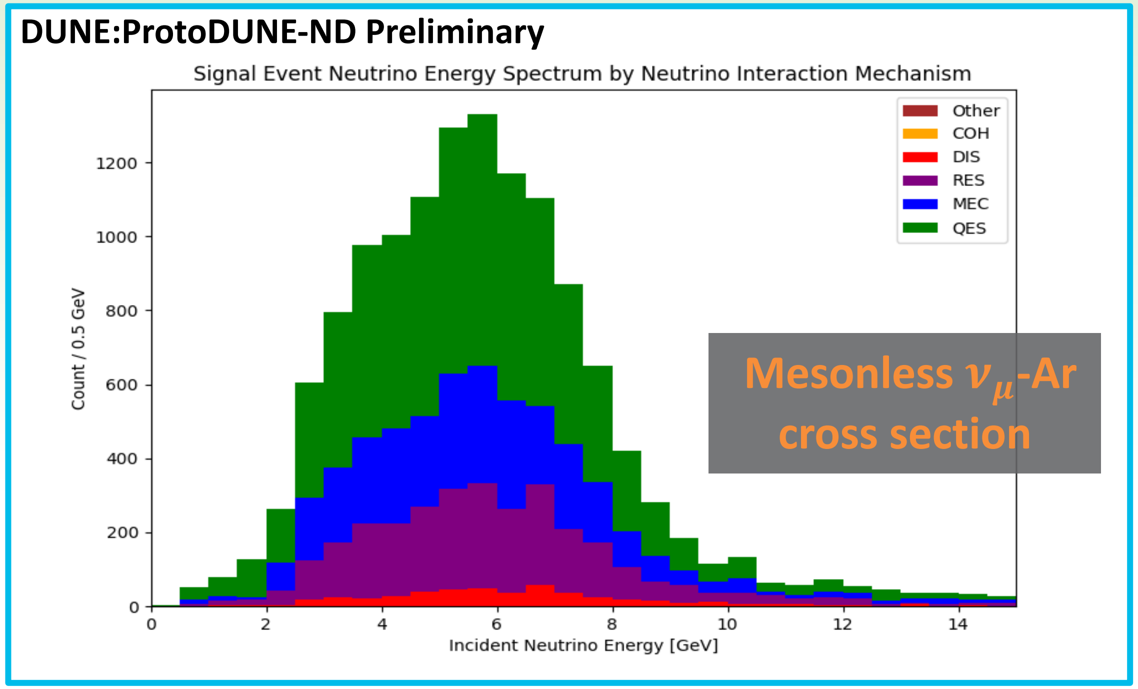
- First physics studies include **track multiplicity** and **mesonless ν_μ-Ar cross section** measurements



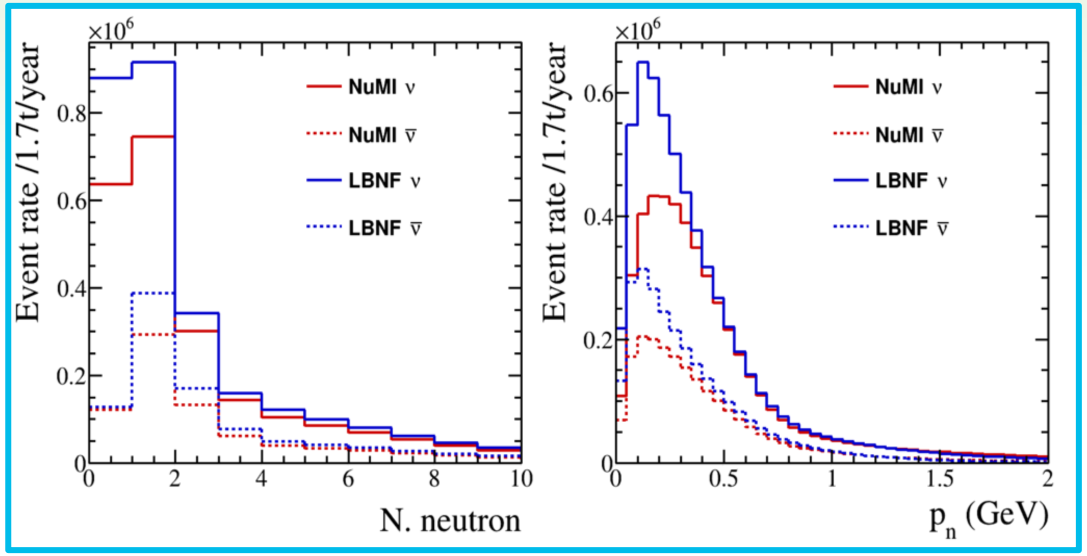


See M.B. Azam's April 5th Talk Session P07

Performing Physics Studies

- Also positioned to make physics measurements which can help constrain systematic uncertainties in DUNE
- First physics studies include **track multiplicity** and **mesonless ν-Ar cross section** measurements
- Future physics studies include **neutron tagging**

arXiv:2006.16043

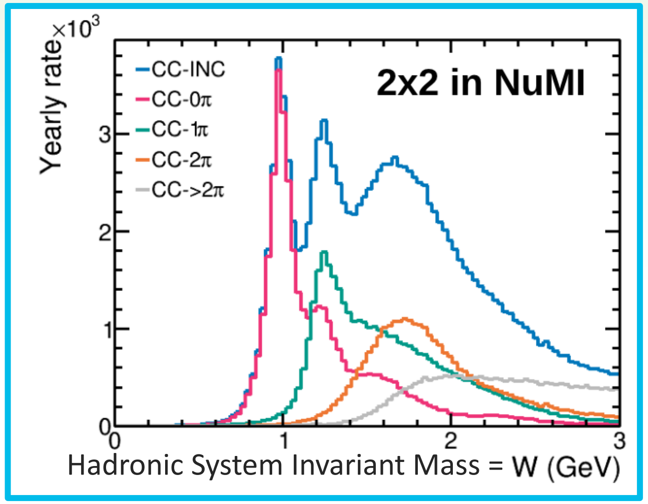


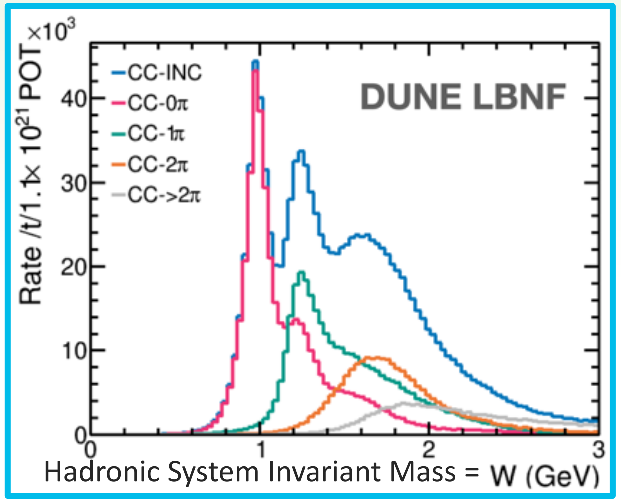
See M.B. Azam's April 5th Talk Session P07

Performing Physics Studies

- Also positioned to make physics measurements which can help constrain systematic uncertainties in DUNE
- First physics studies include **track multiplicity** and **mesonless ν-Ar cross section** measurements
- Future physics studies include **neutron tagging** and **ν-Ar cross sections with pions in the final state**

Y. Chen for DUNE, NuINT 2022





Current Status

- Performing final installation tasks
- Preparing to fill cryostat with liquid argon and **start data-taking this spring**

Top of 2x2 cryostat

Modules being lowered into cryostat

MINERvA downstream planes

Summary

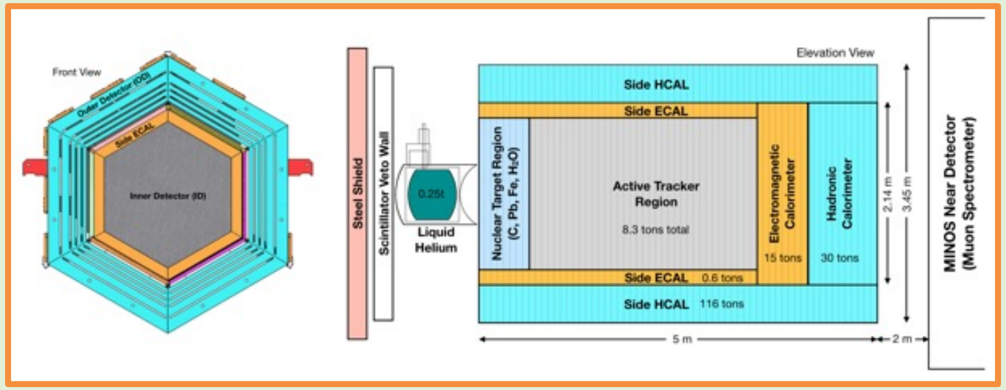
- DUNE ND-LAr is prototyped in the **2x2 Demonstrator**
- The 2x2 will use ND-LAr features such as **pixel-based charge readout** and a **modular design** to demonstrate key ND-LAr design capabilities including **native 3D event reconstruction**, **event pileup uncertainty mitigation**, and **tracking across modules and detectors**
- Installation in the **NuMI beamline** allows for a **rich physics program** initially including track multiplicity and ν-Ar cross section measurements
- The 2x2 is set to **begin data-taking this spring** and is set to see **DUNE's first accelerator beam neutrinos** … stay tuned!

Thank you!

Backup Slides

MINERvA

- **MINERvA** is the **M**ain **I**njector **N**eutrino **E**xpe**R**iment to study **ν-A** interactions and took data from 2009 to 2019 while in the NuMI beamline at Fermilab
- Studied **neutrino-nucleus interactions** with multiple target nuclei
- MINERvA tracking, hadronic calorimetry (HCAL) and electromagnetic calorimetry (ECAL) modules all include plastic scintillator for tracking, while ECAL modules also include lead absorbers and HCAL modules include steel



arXiv:1305.5199