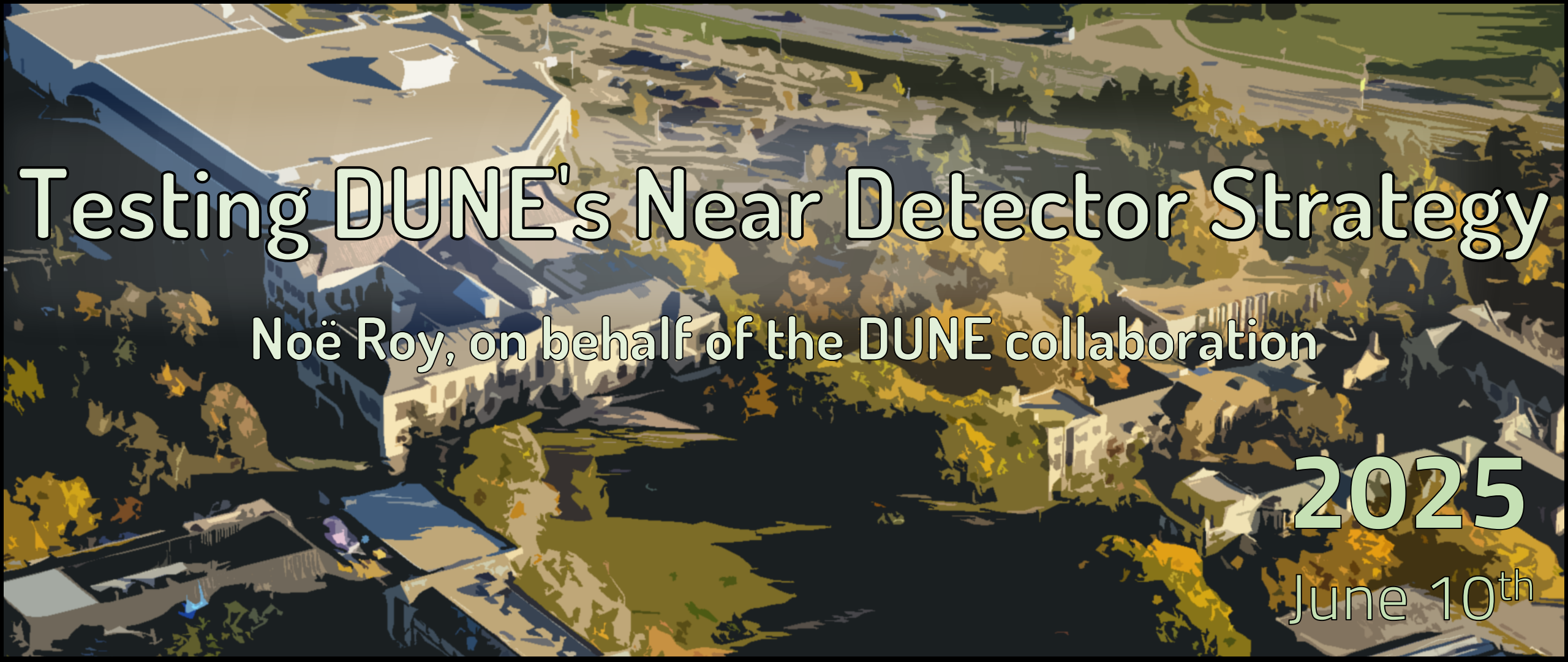


# Testing DUNE's Near Detector Strategy

Noë Roy, on behalf of the DUNE collaboration

2025

June 10th

YORK U

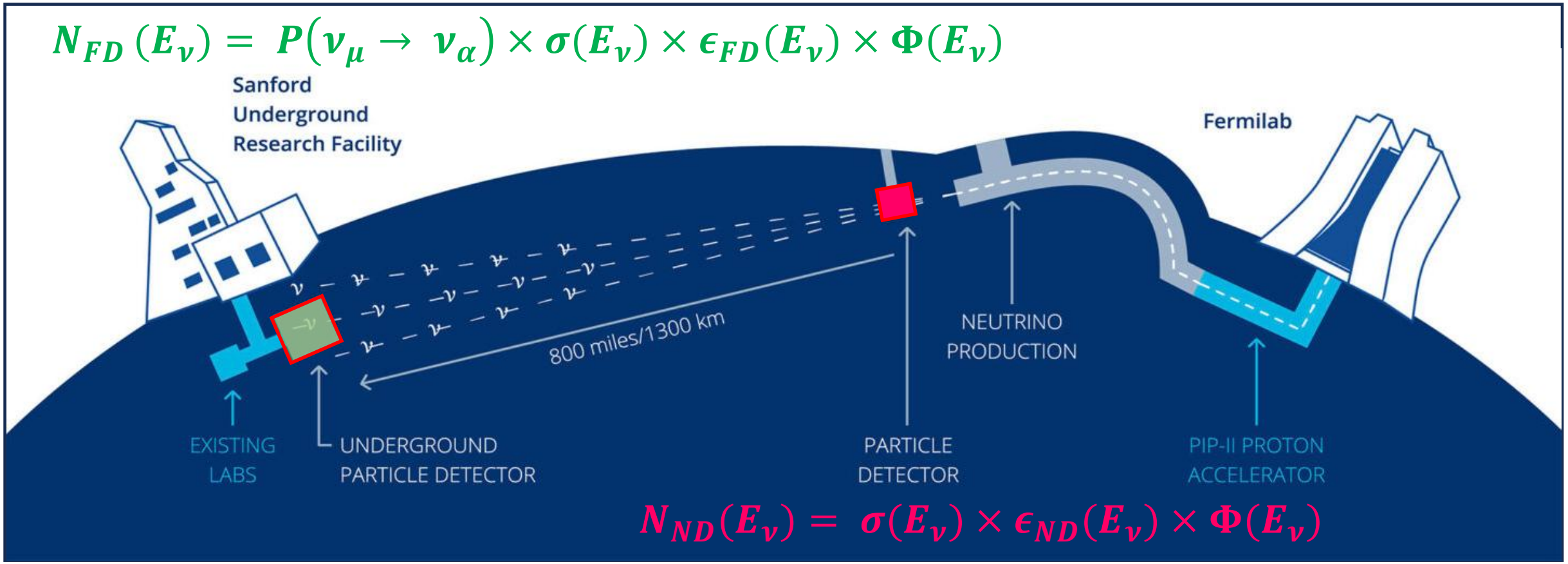
Canadian Association of Physicists

Association canadienne des physiciens et physiciennes

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

# DUNE neutrino detectors

$$N_{FD}(E_\nu) = P(\nu_\mu \rightarrow \nu_\alpha) \times \sigma(E_\nu) \times \epsilon_{FD}(E_\nu) \times \Phi(E_\nu)$$

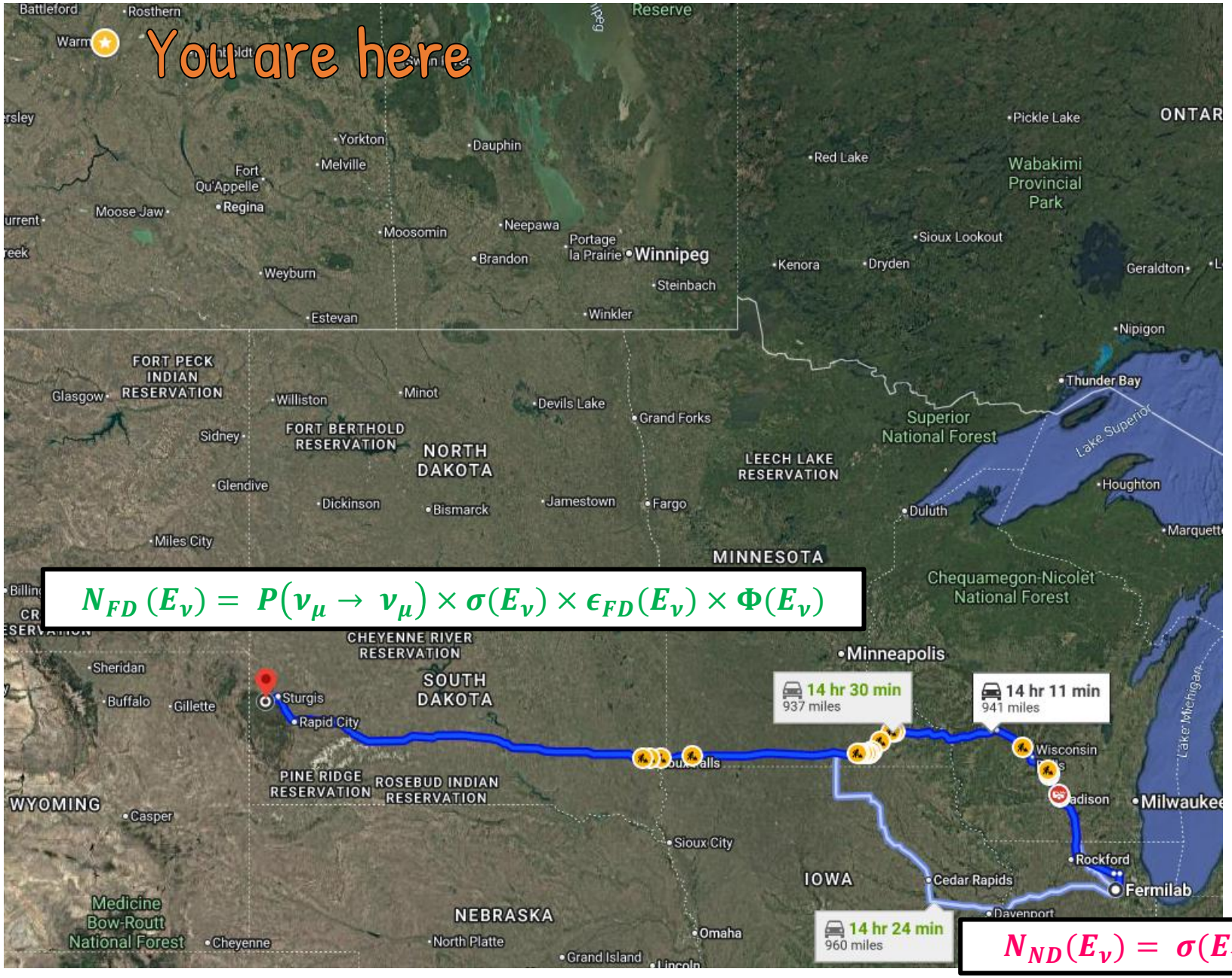



$$N_{ND}(E_\nu) = \sigma(E_\nu) \times \epsilon_{ND}(E_\nu) \times \Phi(E_\nu)$$

Rate of events for a given neutrino flavor depends on

- Oscillation for the Far detector (FD) $P(\nu_\mu \rightarrow \nu_\alpha)$
- Neutrino energy $E_\nu$
- Flux $\Phi$
- Cross section $\sigma$
- Detector acceptance $\epsilon$

# On a MAP!



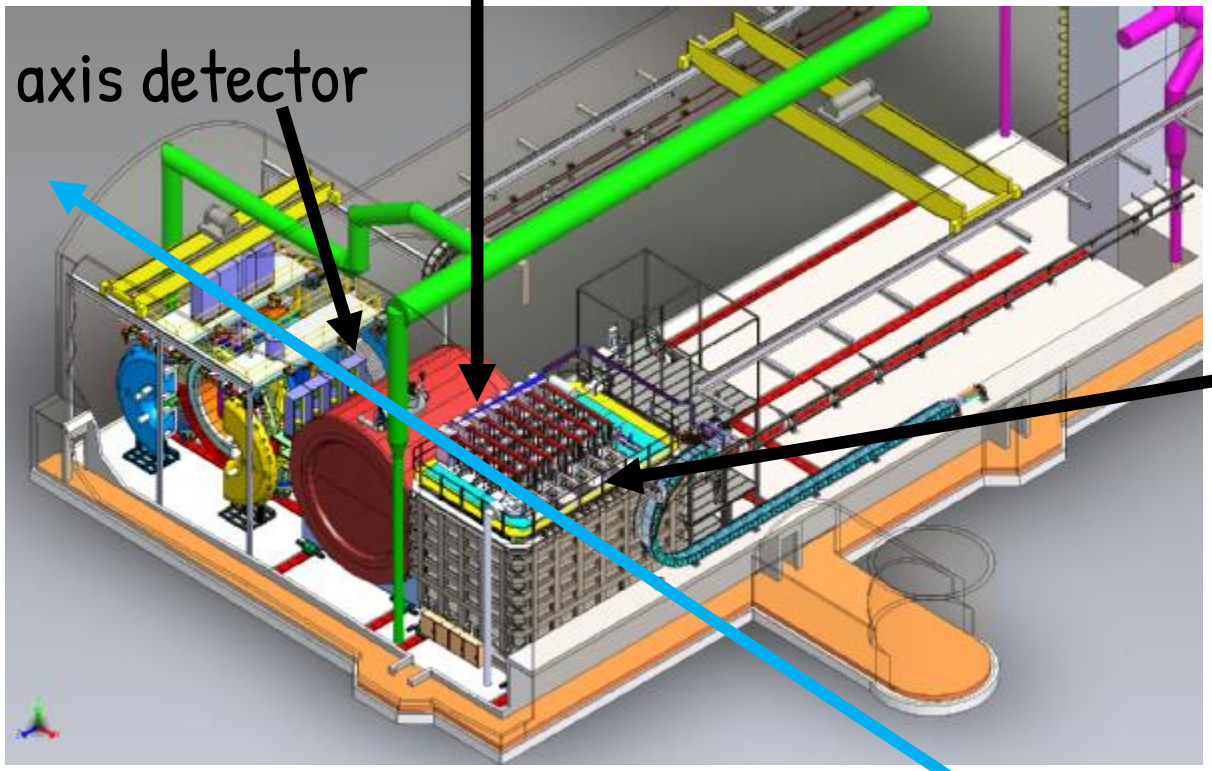

**Driving distance: 14h30**

Neutrino travelled distance:

- **1300 km** in a straight line underground
- ~ 4.3 ms travel time

$$N_{ND}(E_\nu) = \sigma(E_\nu) \times \epsilon_{ND}(E_\nu) \times \Phi(E_\nu)$$

# The Dune ND Complex




Argon detector like the Far Detector

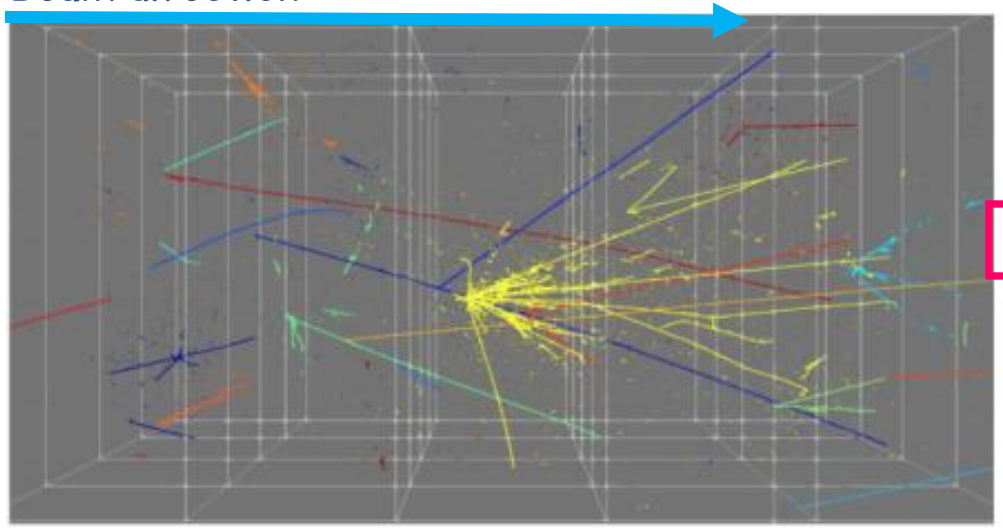
NDLAr (Liquid Argon Time Projection Chamber - TPC)

Suite of various detectors placed in the near detector site (~O(100m) from the beam target)

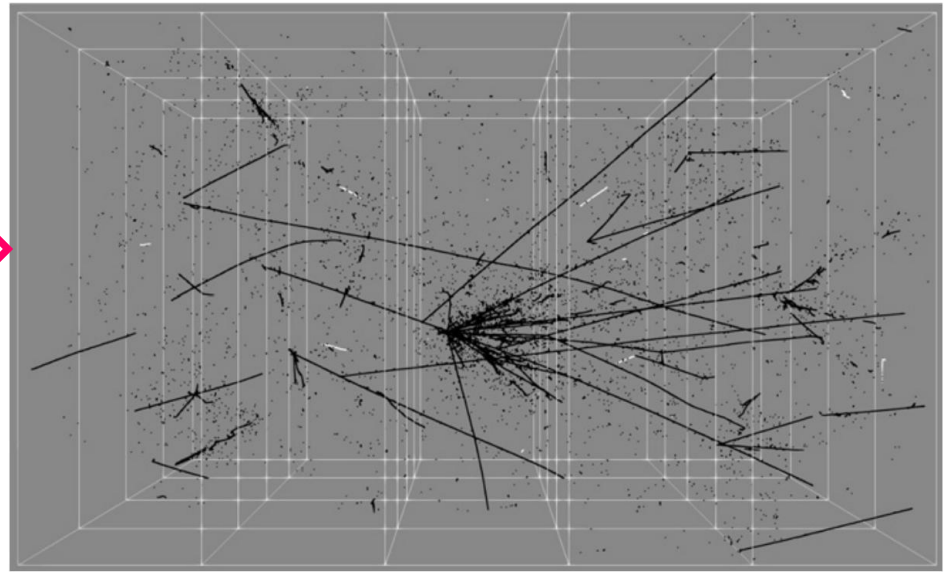
Aim is to constrain the neutrino flux and the neutrino interaction cross sections.

# NDLar expected pile up

Beam direction



Slow charge drift from TPC



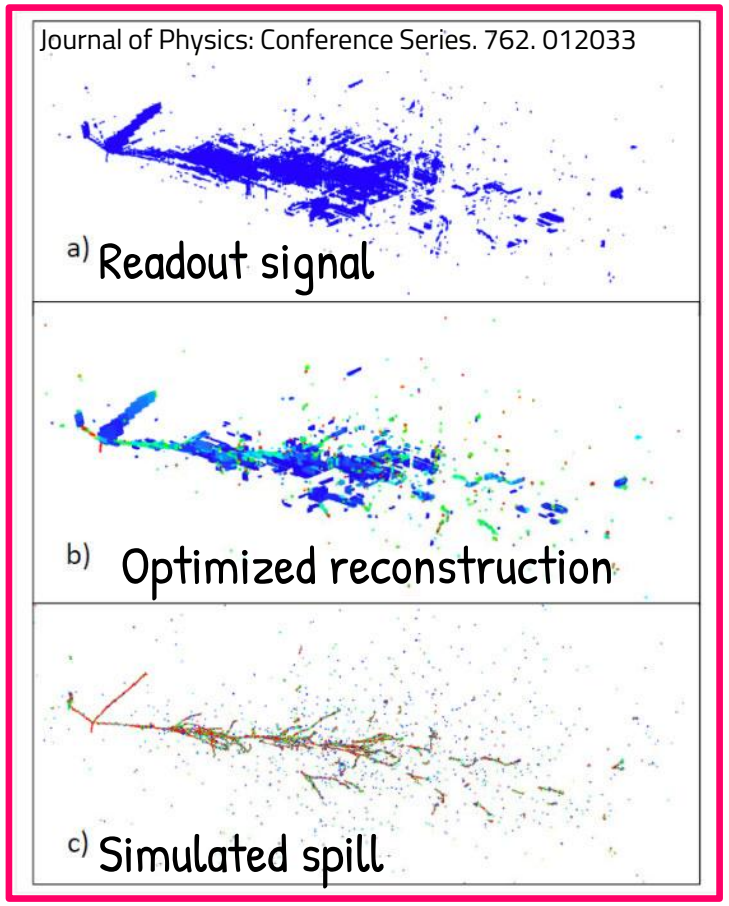
We expect 100 -150 neutrino interactions per spills.
Both inside and outside the fiducial volumes.

Charge readout is slow → Hard to use timing to remove pile up!

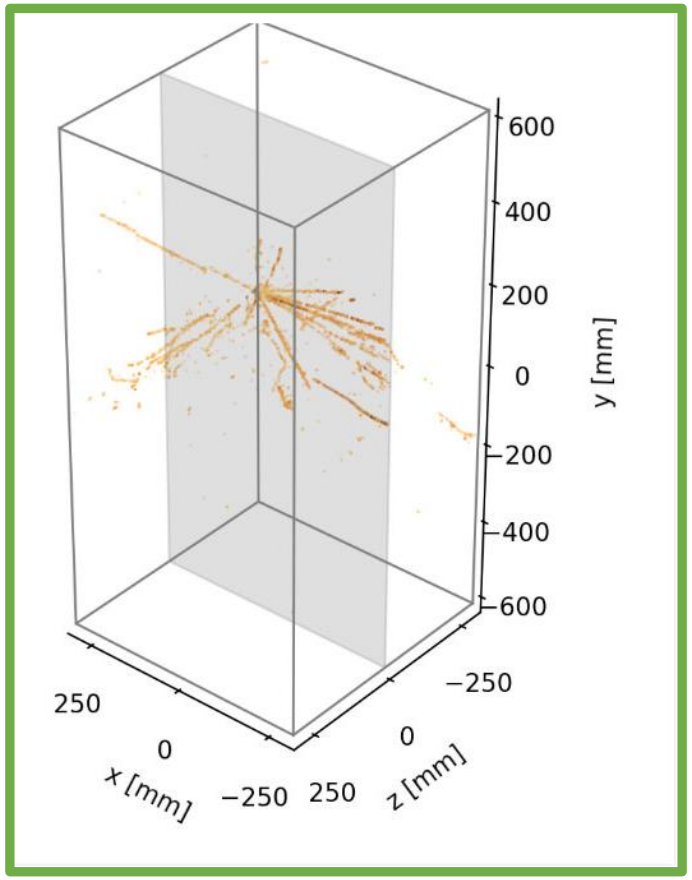
- DUNE will reach an era of **neutrino pile up** in its near detector.
- **Spill duration (10 μs)** < **Drift window (250 μs)**
- TPC signal is based on slow charge drift: makes it harder to disentangle different signals

**MODULAR DESIGN !**

# Pixelated readout: Towards a true 3D reconstruction



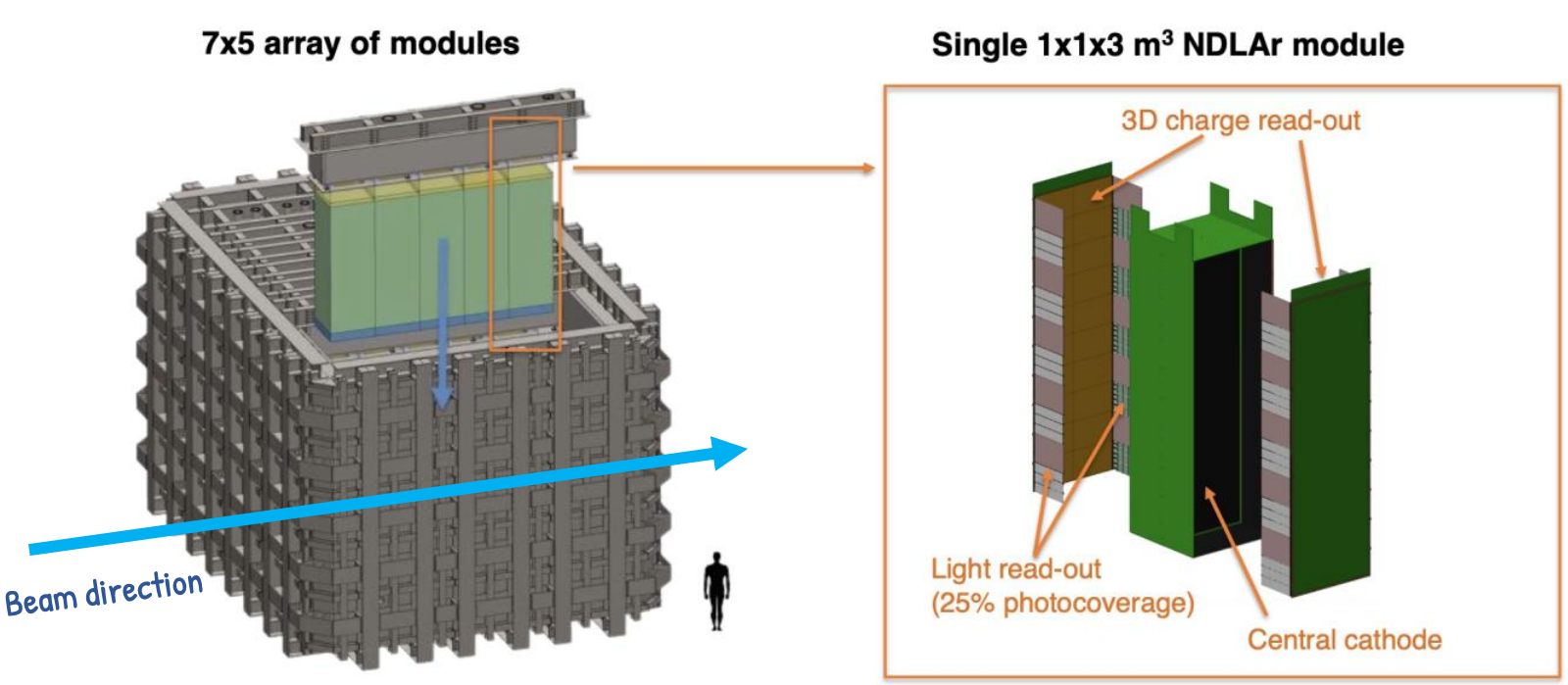

*2D reconstruction with wire based TPC*

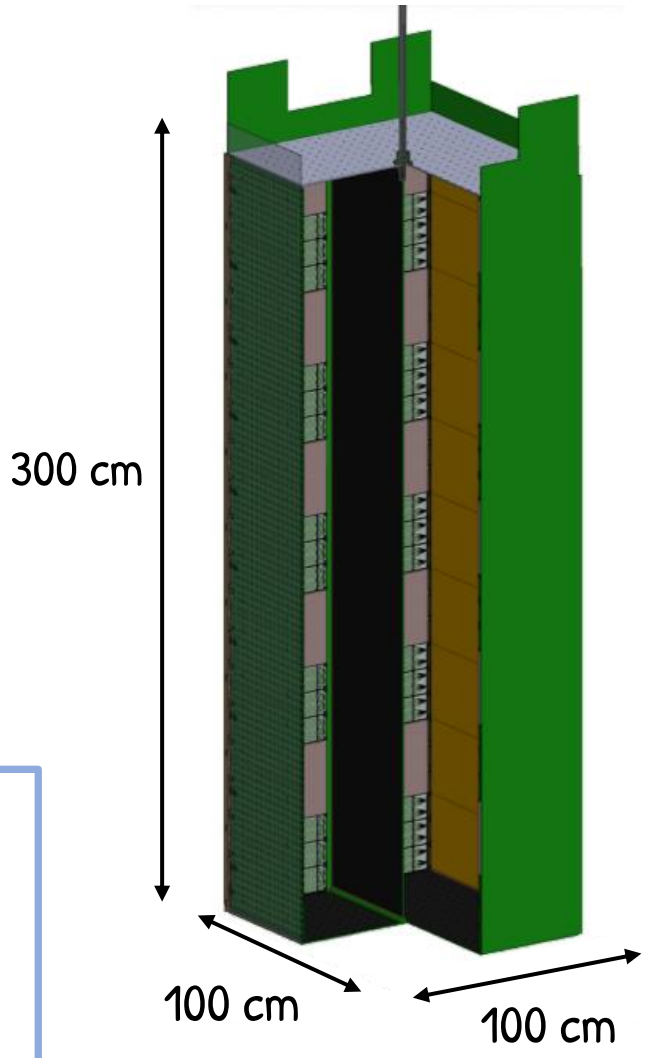



*3D reconstruction with Pixelated readout (actual data)*

- Current 2D reconstructions for busy events can get fuzzy compared to the true initial deposits
- Use of pixelated tiles allow a true 3D reconstruction of the event with a much better granularity

# What do we actually do?

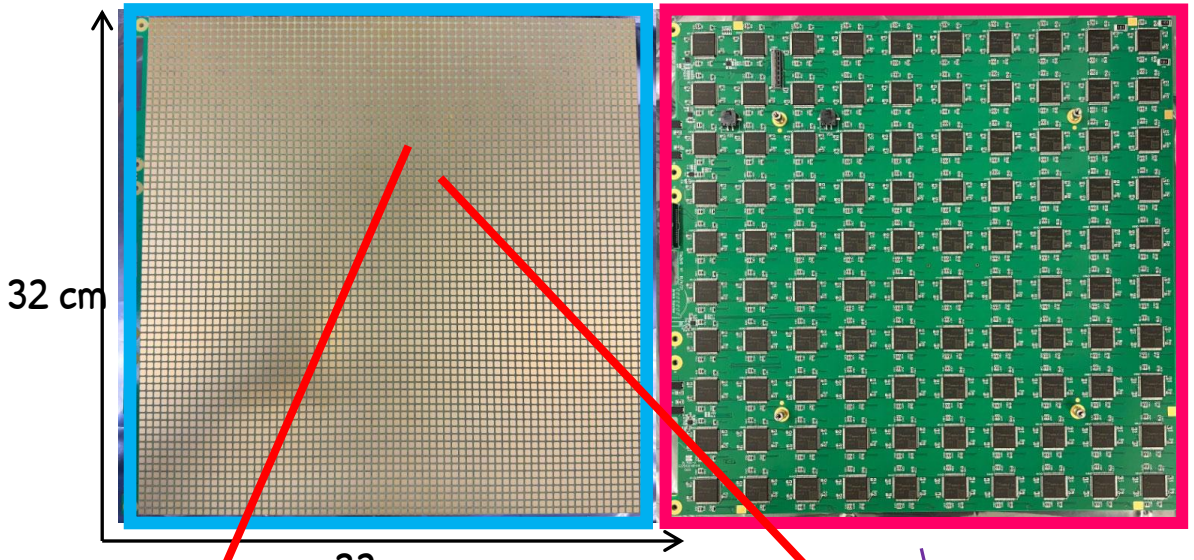



NDLar main design concept:

- Pixelated charge readout → True 3D reconstruction and granularity
- Modularization → Pile Up reduction
- 1x1x3 m3 modules
- 130 tons of LAr Each module consists of 2 TPCs
- High-performance light readout 35 modules in 7x5 array

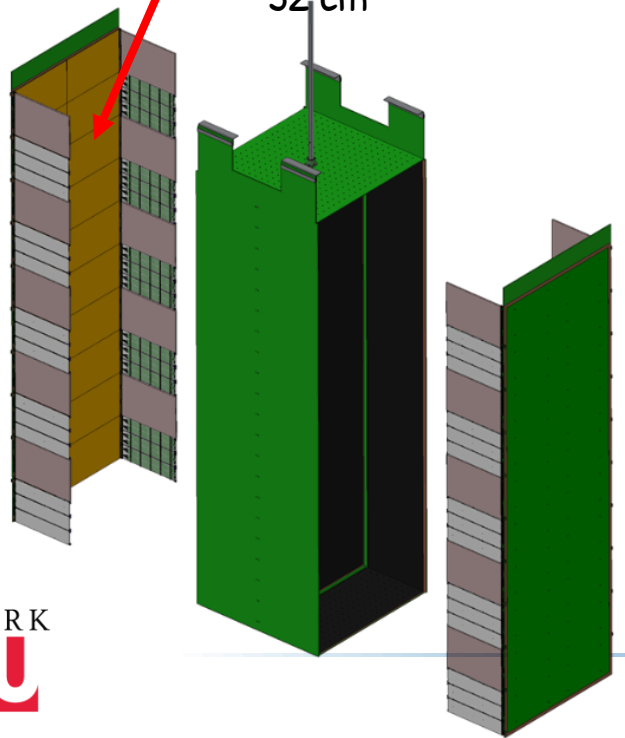
# Charge readout




Front (inside TPC) charge sensitive pixels

- Self triggering pixels
- ~**4mm pixel pitch**: High coverage
- ~**14 millions pixels** for the full detector
- Pixel readout in Cryo (to preserve argon quality)

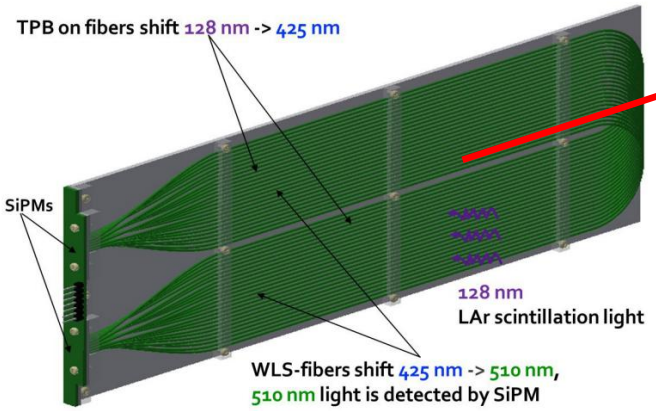
Back (outside TPC) with a grid of 10 x 10 LArPIx ASICs

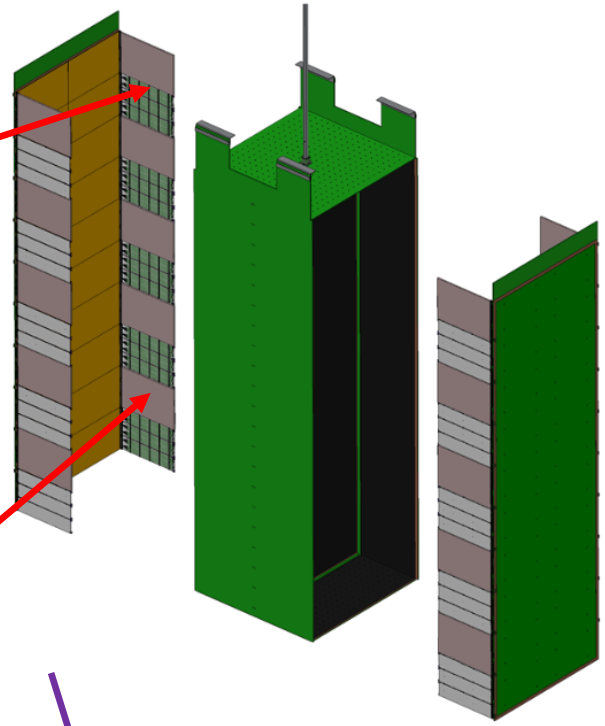



- Charged particle ionizes the LAr.
- Charges drift towards the readout planes in a slow signal **O(10-100µs).**
- 2D charge position from the readout + 3rd dimension with the drift time

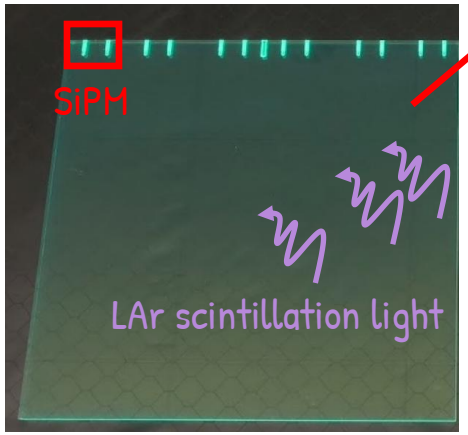
# Light readout

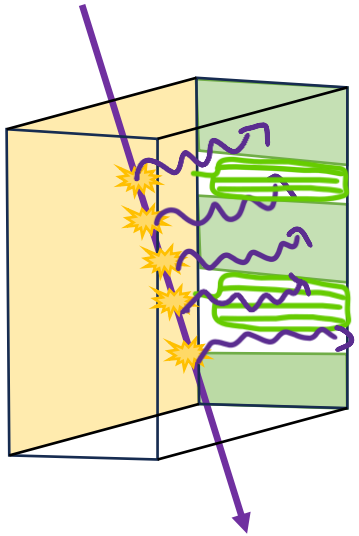
**LCM optical fibre detector**



**ArCLight scintillation tile**



Complementary light readout system alongside the charge readout:

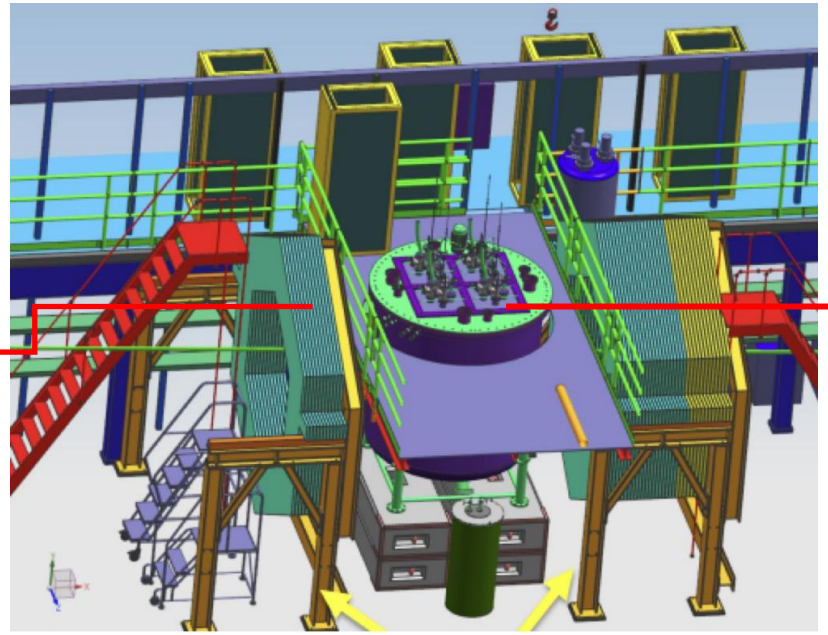
- **LCM** for **detection efficiency**
- **ArCLight** for **position sensitivity**

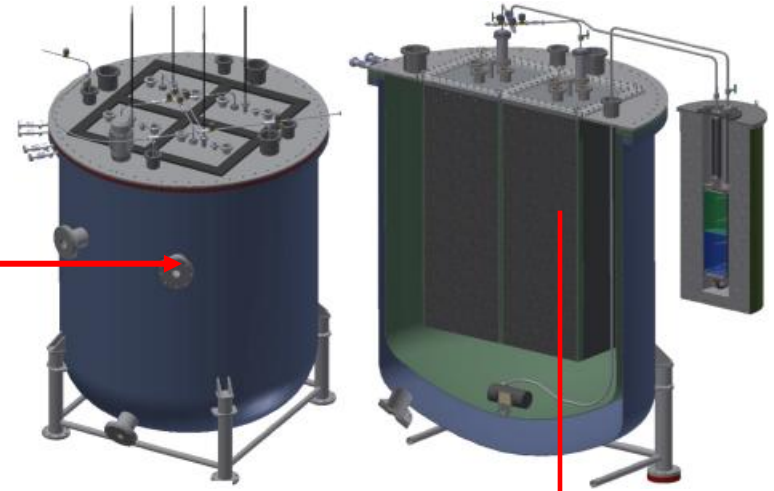
Optimized for UV Ar scintillation light

Allow to give the t0 of « an event » to get a 3D positioning and help reducing the pile up.

Charged particle excite Ar.
Fast scintillation light signal **O(1 µs)** is recorded by two different light readout system.

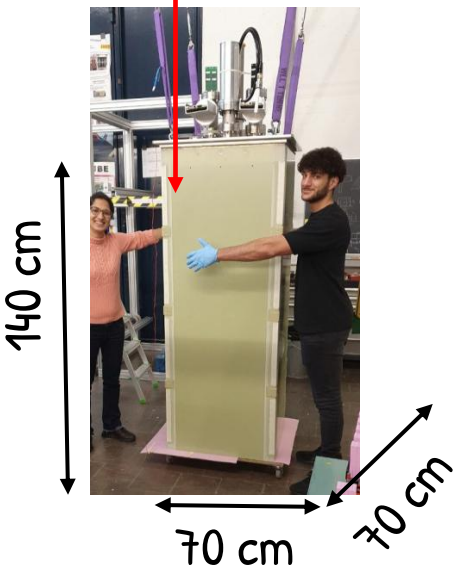
# 2x2 Prototype – Curently underground at Fermilab





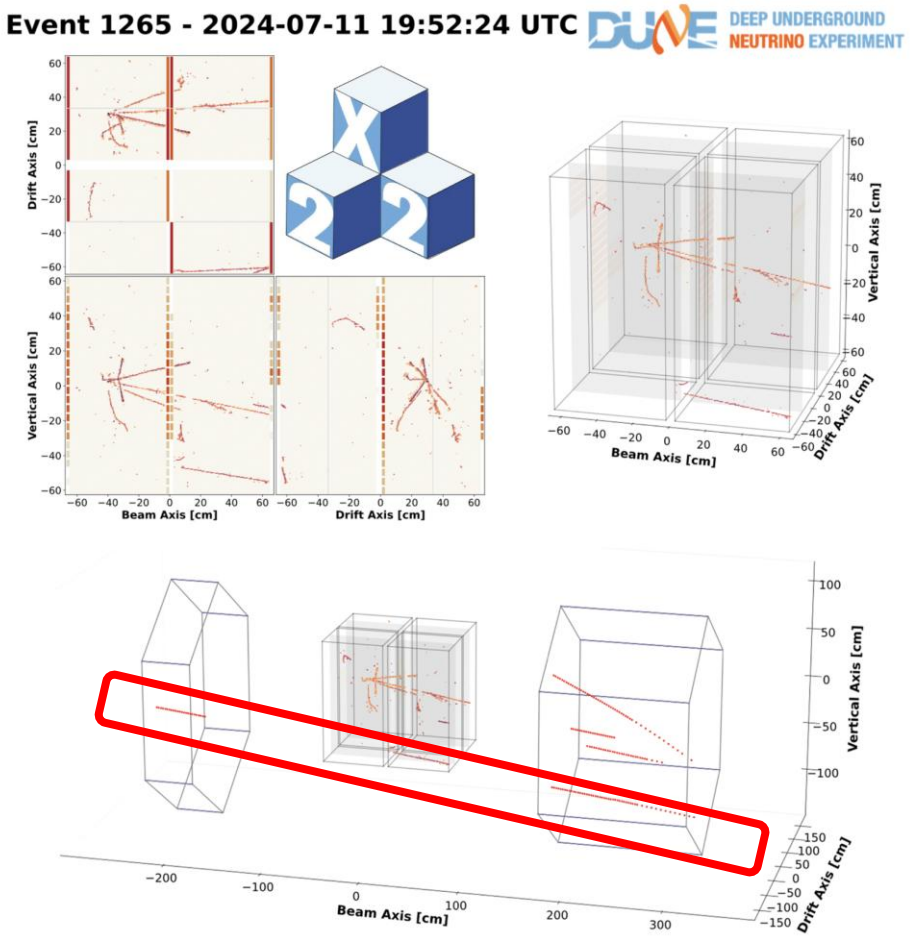
- Demonstrator for NDLar:
  - **4 modules** of each **0.7 tons** of active liquid argon
  - About 1/4 less long than future ND detector placed in NuMI beam with high event rate
  - Smaller scale than actual NDLar module and various pixel configuration
  - **~330k charge pixels**

- Addition of repurposed plastic scintillator planes from the **MINERvA** detector used as muon tagger.



# 2x2 collected data

- During summer 2025, about 5 days of physics data.
- ~1E19 protons of targets (POT) → **10k neutrinos/day**

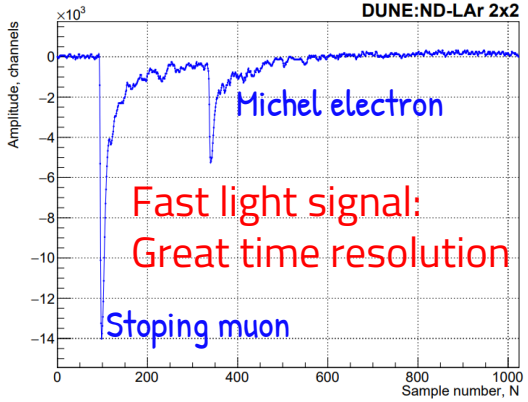



*Operation room during the start-up of the detector*

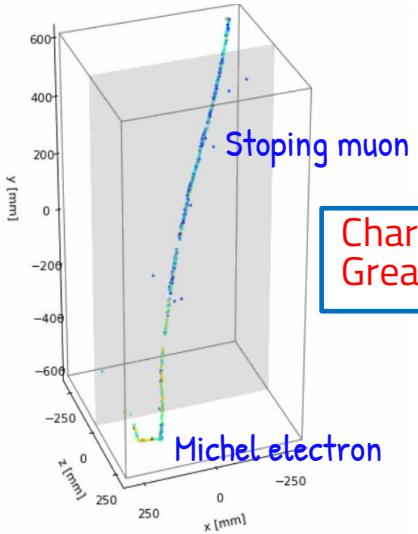
- Actual neutrino interaction inside the liquid Argon.
- Pile up with 1 « rock muon » coming from a coincident neutrino interaction outside the sensitive volume.
- MINERvA detector will help the individual track reconstruction

# First performance of the 2x2 – Module 0 at Bern

**Michel electrons**

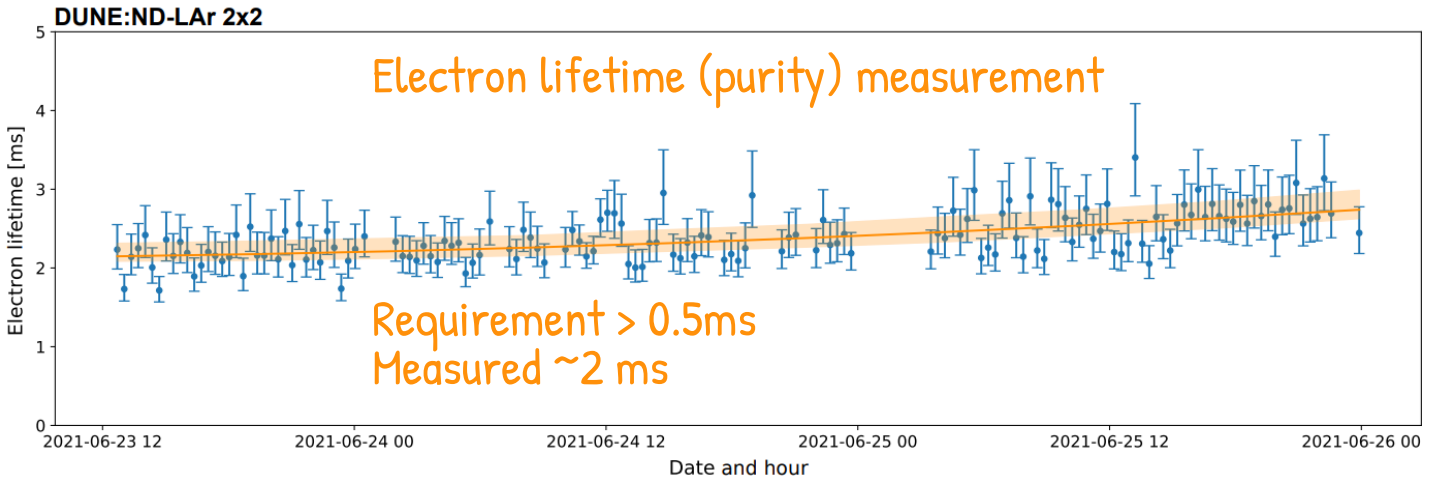


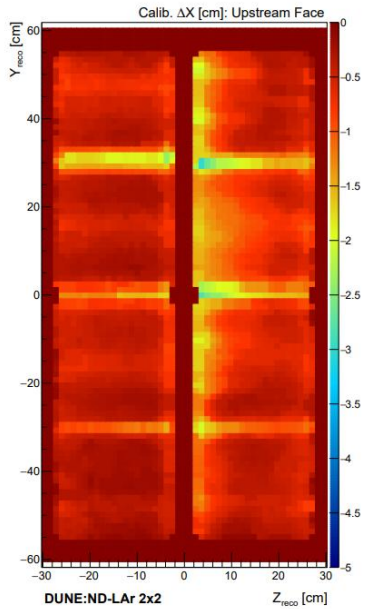

$\mu^- \rightarrow e^- (\sim 1.6\ \mu s)$




Charge signal:
Great spatial resolution

- Thorough calibration of a module has been performed at Bern with cosmic data.
- Similar measurements are ongoing for the 4 module prototype using neutrino beam data.

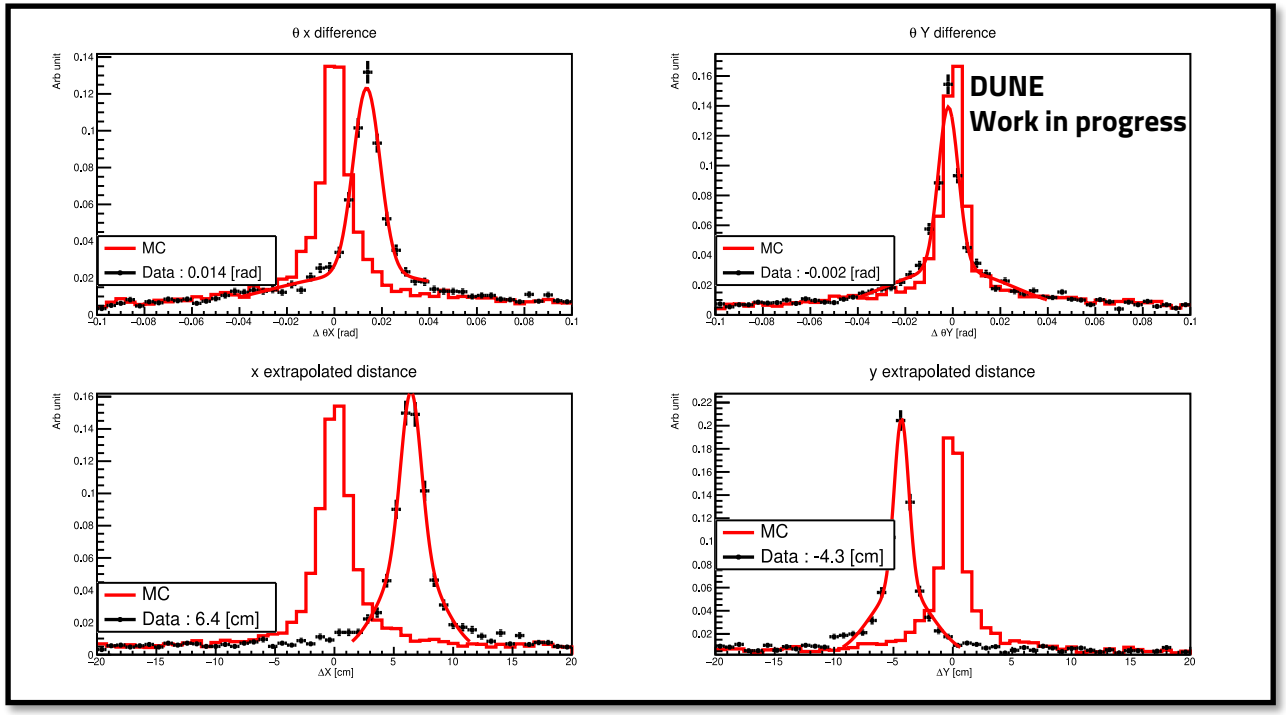


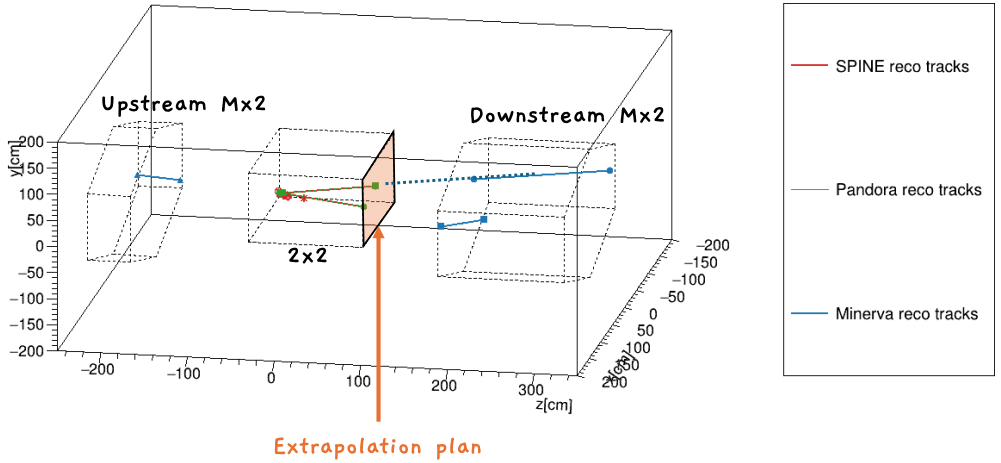




Electric field non uniformity measured at .2% level for a requirement of <1%

*Instruments* **2024**, *8*, 41

# First measurement of alignments & Matching



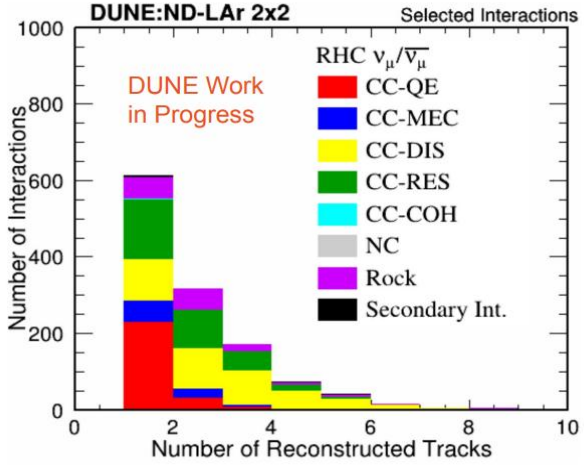

First measurement of the alignment between the two detectors:

- Very good matching efficiency for muon crossing both detectors

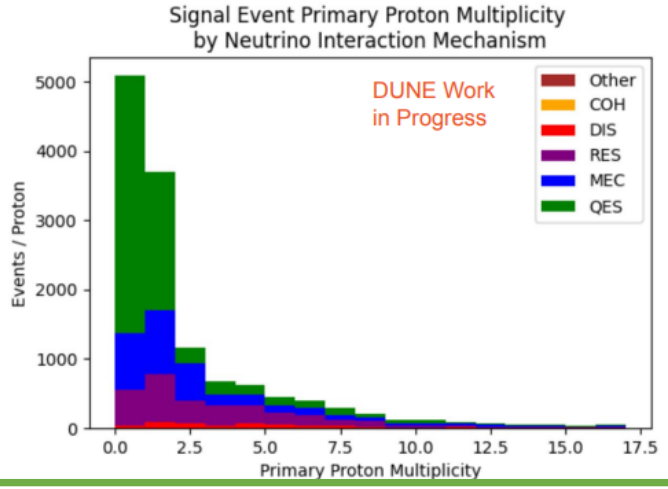
- Sensitive to **O(cm)** displacement between the two detectors
- Sensitive to **<1°** rotations
- Alignment offsets later confirmed with on-site measurements

# Lots of analyses on their way

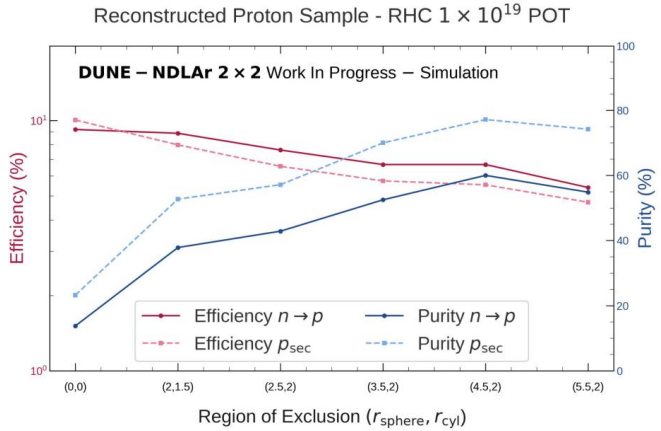
## Track multiplicity




## 0 pion events




## Neutron Tagging




Liquid argon detector in a neutrino beam allows us to study lots of various physics processes that will be essential for Dune:

- Charge particle production multiplicity can give precious information on Final state interactions
- 0 pions events are the most common neutrino interaction and more straightforward to reconstruct
- Neutron detection will be crucial to model the non-visible energy from neutrino interactions
- And many more…

# Conclusion

- DUNE's Near/Far Measurement
  - Precision oscillation physics needs robust near/far correlations and high-quality modelling, provided by the complementary detectors of the ND complex
- High pile up expected in the near detector-> Novel pixelated and modular design!
- 2x2 detector taking data on antineutrino beam
  - Good first test of the reconstruction strategies in a high yield environment
  - Operation with 2 detectors show good performance in matching
  - First physics analyses on their way.
- Full scale detector module taking cosmic data at Bern