



# DUNE and ProtoDUNE @ Liverpool

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# Overview

- Content
  - Overview of DUNE
    - Focus on the items with heavy Liverpool involvement
  - Status
  - ProtoDUNEs
- Apologies as none of us are in Liverpool, we are both at CERN

## Overview

- Intense (anti-)neutrino beam
  - From Fermilab to SURF about 1300 Km
  - Multiple physics goals:
    - CP violation in the lepton sector
    - Mass Ordering
    - Precision tests of the 3-neutrino paradigm
    - Proton decay, neutrinos from supernovae
    - BSM searches
- 4 caverns housing 10 Kt LAr TPCs
  - 3D imaging bubble chamber quality
  - energy measurements capability
  - two types of modules
    - horizontal drift (Liverpool involvement)
    - vertical drift
  - integrated scintillation photon readout
- The collaboration
  - 1,500 collaborators
    - about 200 institutes from 32 countries
  - UKRI 65 M Infrastructure Project:
    - APAs, DAQ, PIP-II cryomodules, proton target
- ProtoDUNE @ CERN Neutrino Platform
  - CERN NP: Test beam facility at CERN
  - ProtoDUNE-HD: 1:25 prototype of FD1-HD
  - Phase-I data taken 2018-2020
  - Phase-II data taken in 202<u>4</u> onward





# Physics programme

- Standard Oscillation framework
  - Enough to be able to resolve mass hierarchy and measure CP violation
    - Possibly with 5 sigma significance depending on the value

#### • BSM

- $\circ$  proton decay in the p  $\rightarrow$  K<sup>+</sup>
- neutrino anomalies
- $\circ$  direct searches in the ND and FD
- Supernova neutrinos

#### • ProtoDUNE

- Crucial to develop and demonstrate technology
  - Both software and hardware
- $\circ$  Learn how to assemble and work with these detectors
- First DUNE physics measurements published
  - More to come



# People

- Christos Touramanis: former APA consortium leader and ProtoDUNE HD run coordinator
- Dave Sim, Carlos Chavez, Krish Majumdar: APA production team
- Marco Roda: DAQ developer and protoDUNE operation
- Kostas Mavrokoridis: Technologies forDUNE Phase II (Ariadne), ProtoDUNE-III
- Costas Andreopoulos, John Plows: BSM program development
- Many thanks to Dave and Carlos who have moved on in 2025
  - Their dedication, skills, and ingenuity made a real difference in APA production

# Construction progress (Phase I: FD1,2)

- Underground excavation completed. AUP (Beneficial Occupancy) Q1/2026.
- Steel (warm structures, 2 x 2,000t) is in the USA.
- Insulation and cold structures in production.
- Cryostat installation from 2026; First DAQ server installation 2027.



#### Engineer (for scale)



# DAQ

- One of the UK deliverables ۲
  - New grant started in April 2025
  - Approved for 2 years
  - Includes the first phase of the
- Liverpool has a number of ۲ responsibilities:
  - Monitoring
  - Configuration management and development
  - DAQ training for the whole
  - DAQ Operation lead for the 2025 run of the ProtoDUNE
  - Interface with some other subsystems
    - PDS and trigger



#### DAQ recap

Readout

•

- constantly receiving data from hardware
  - Applications tailored for the data stream/hardware type
- **Optionally generating TPs**
- Storing data to provide data on the demand to dataflow
- Trigger •
  - elaborate the TPs generated by readout and HSI to create TA, TC and trigger decisions
  - Trigger decisions are sent to Dataflow
- Dataflow •
  - Takes the TD and gueries the readout buffers to construct an "event"
  - Write the event and TPs on disk



- **Run Control** 
  - synchronized commands to the distributed system
  - Defines the FSM of the system
- Configuration
  - All these applications are highly configurables
  - Flexibility comes with the price of detailed configurations

- It's a DAQ that is similar to a proton decay experiment ۲
  - Due to constraints from supernova detection
- We constantly read out all the data and buffer them for a O(10) seconds 0 1.5 TB/s from each module ۲

  - This comes in combinations of fixed/variable rates and formats

# **ProtoDUNE Horizontal Drift (2024)**

Christos Tourmanis: Run Coordinator Marco Roda: DAQ expert on site

# ProtoDUNE HD

- Substantially overhauled from previous run (2018)
  - New Cold Electronics; Photon Detectors; DAQ; Ionisation Laser; APAs
  - All components are Far Detector (pre)production units
- Design to demonstrate hardware/software of the Far Detector (Module-0)
  - ProtoDUNE I proved that a kton-scale TPC of the chosen technologies can meet DUNE requirements
- Total beam run of 10 weeks ended 16 Sep
  - Beam scans of 1-7 GeV (both polarities)
    - Negative polarity was never used in 2018
  - Large datasets at 1 GeV (pion xsec) and 5 GeV (kaons/protons)
    - Fundamental physics for our reconstruction
- 99.7% channels active during entirety of NP04 run
- DAQ performed stably and well over the ProtoDUNE-HD run -
  - Over beam run, could collect 'typical' readout windows (3 ms TPC data, 5.5 ms others) at ~35-40 Hz instantaneous rate
  - $\sim$  ~15 Hz averaged rate, utilizing time between spills to push data over network



## Main milestones

- Successful integration of all readout components:
  - APA (charge readout), PDS (light readout),  $\hat{C}RT$ , Laser calibration
  - External trigger for the beam
  - This is the integration level of an experiment, not of a test beam!
  - Exceptional stability; often run for 3 days without shifter intervention
- Self triggering capability has been proved using charge information
  - Critical milestone to validate the readout of the Far Detector
  - It confirmed the specification for the readout procurements
  - Proved sensitivity to Sub-MeV events from calibration sources





### .... and more!

- BSM search background tests with special TPC trigger configurations
  - parasitic running, no charged beam in the detector
- Christos, Costas A. & John Plows participating
- We saw neutrinos!!
  - Produced mainly from the interaction of the 400 GeV/c SPS
    protons on the primary target 700m upstream
- Tens of events, deposited energy > 10 GeV



# **ProtoDUNE Vertical Drift (2025)**

Marco Roda: DAQ run coordinator

# The vertical drift

• Cathode (middle) and anode planes horizontal

- Electrons drift vertically over up to 6m
- First full-size demonstration
- PDS on cathode (300 kV), power & readout over fiber
- DAQ integration is extremely challenging:
  - Two different charge readout systems (top/bottom)
    - They even have different clock systems!
  - PDS read out over fiber and over copper
- Commissioning looks promising although still very early stages
  - We can successfully readout part of the detectors





# First commissioning results and plans for the summer



- Seen tracks already in the bottom drift volume
  - Early stage (November 2024) with only the first bottom half of the detector filled
- Progress in self-triggering using light information as well as charge
  - This is something new WRT the horizontal drift
- DAQ Operating using the same configuration system and run control to be used in the far detector
- Keep running regularly the detector
  - Monitoring noise
  - Developing the calibration procedures
  - While development continues for the beam

- Unfortunately we are delayed due to an accident that happened in December in another building related to Neutrino platform
  - No access to EHN1 building except with dedicated authorisation for critical actions
  - Things might go back to normal in 2 weeks hopefully
- Beam planned for 6 non-continuous weeks starting from early July
  - Shifting some beam time later is under consideration
- Over the summer we plan to also integrating remaining subsystem:
  - Cosmic Ray Taggers
    - again that come in 2 different types
  - Re-commission self trigger capabilities
- If we succeed, the level of capability of the detector will even surpass the HD run in terms of integration

# Summary

- DUNE is in construction: first physics (one FD): 2029
  - beam & ND & FD1,2: 2032
- ProtoDUNEs second phase at the CERN NP ongoing:
  - "our" HD did very well
  - $\circ$  VD is starting
  - $\circ$   $\;$  Liverpool provides leadership in:
    - Overall coordination
    - DAQ integration and operations
    - BSM searches with ProtoDUNEs (before SHiP program starts)
- Huge Liverpool contribution especially from such a small group
  - Compared to other DUNE UK groups