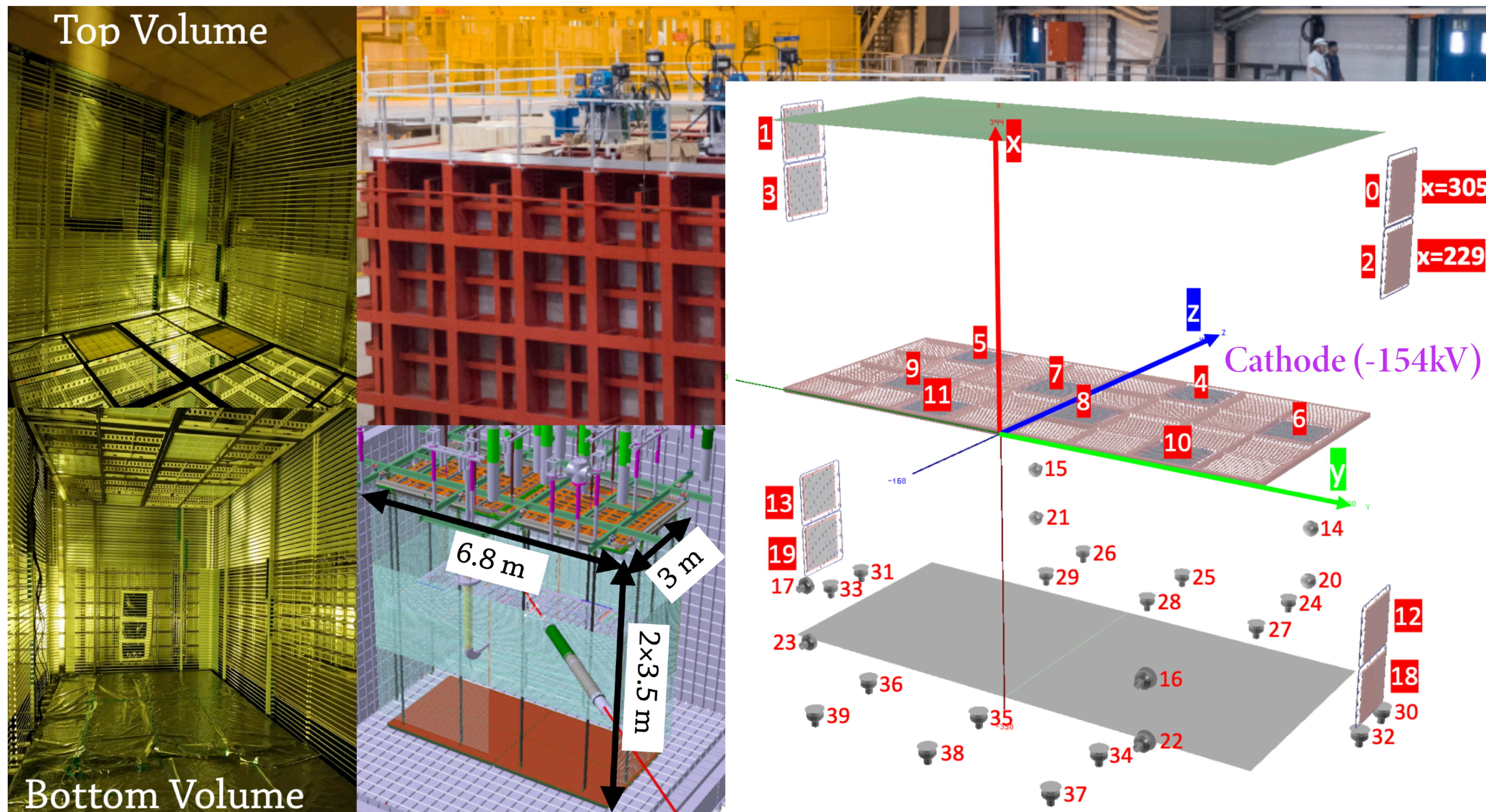


# ProtoDUNE-VD for BSM Searches: Initial Studies and Future Prospects

Biao Wang<sup>1</sup>, for the DUNE collaboration  
<sup>1</sup>University of Iowa, IA, USA • Neutrino 2026, Irvine, June 21-26, 2026

## 1. Overview of ProtoDUNE-VD

- Full-scale prototype of the first DUNE Far Detector module, validation of detector R&D, calibration, reconstruction, and analysis techniques before DUNE operations.
- Test-beam data provide precise detector-response measurements using known particle species: Electrons, Pions, Kaons and Protons at specific momenta (0.5-8 GeV/c) allow for direct measurement of track-length vs. deposited energy, charge recombination and  $dE/dx$  based PIDs.
- Unique opportunity to search for BSM physics, and previous studies have characterized both the underlying mechanism and the associated phenomenology [1, 2].



- Full-streaming: 2 top CRPs + 2 bottom CRPs. Cathode in the middle hanging from the top CRPs.
- 8 full-streaming Photon Detection modules on the cathode and 8 self-triggering modules on the walls.
- Future Xenon doping calibration by bottom PMTs.

## 2. Opportunities for New Physics

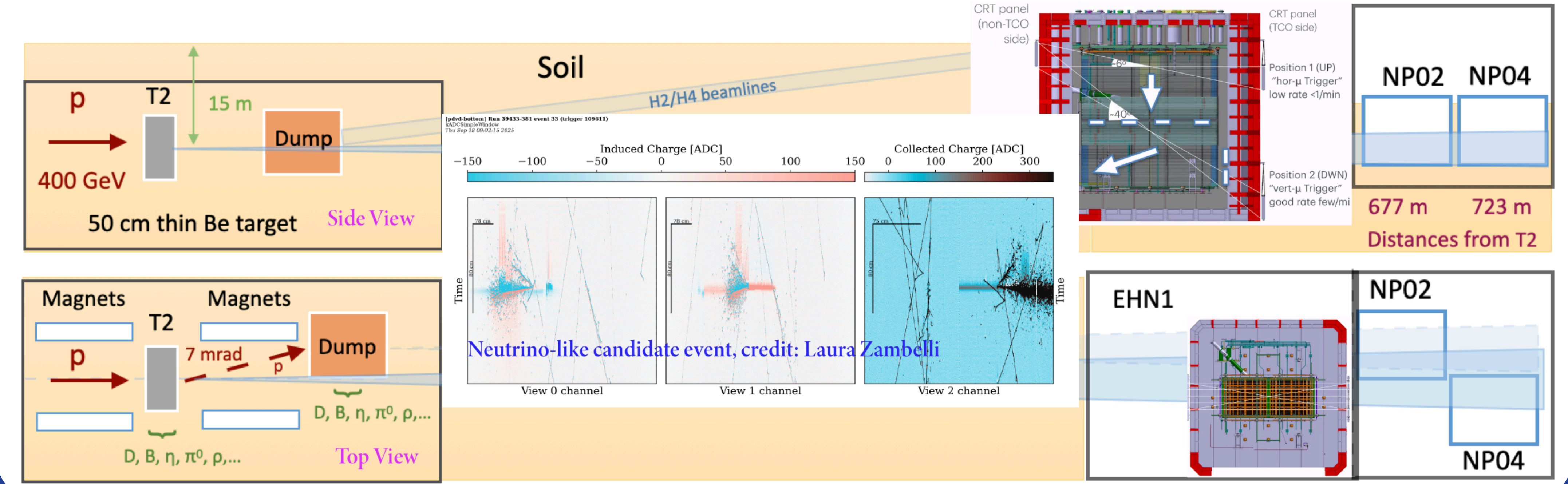
- A Heavy Neutral Fermion (HNF) can be produced either via meson decays (e.g.,  $K^+ \rightarrow \ell^+ N$ ) [1], via the Drell-Yan process (e.g.,  $Z' \rightarrow N\bar{N}$ ), or through muon bremsstrahlung where a high-energy muon radiates a dark boson that subsequently decays into a fermion pair ( $\mu \rightarrow \mu\phi, \phi \rightarrow N\bar{N}$ ) [3].

### Key Decay Channels of HNFs:

- $N \rightarrow \ell^- K^+ / \pi^+$  Determine the lifetime of HNFs.
- $N \rightarrow \nu X$  Angular distributions of the boson  $X$  (e.g.,  $\gamma, \pi^0$ ) probe anisotropy.
- $N \rightarrow \nu \ell^+ \ell^-$  Provide rich kinematic final state analysis.

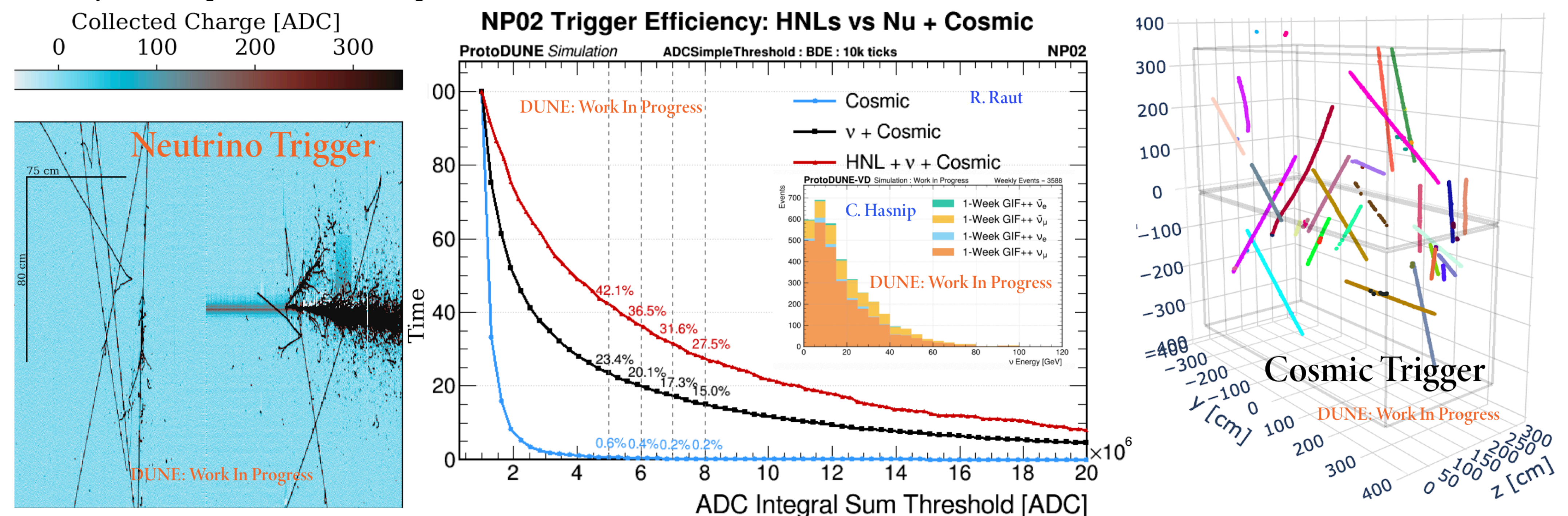
## 3. CERN SPS T2 Beamline

- The T2 primary target/wobbling station receives the 400 GeV/c proton beam from the CERN Super Proton Synchrotron (SPS) and uses target, magnet, and collimation elements to produce and select secondary beams.
- Generates an intense flux of mesons and muons in a beam-dump environment that can enable studies of Heavy Neutral Fermions (HNFs) and other hidden-sector particles [2], alongside the ProtoDUNE-VD test-beam program.



## 4. Trigger Development and Analysis Progress

- ADCSimple trigger selects events with large deposited charge in a short (about 0.2 ms) time window.
- Optimize the ADC threshold to maximize HNF ( $N \rightarrow \mu^- \pi^+$ ) and neutrino signal efficiency while suppressing cosmic backgrounds.



- Automated reconstruction and event-selection frameworks under development for future DUNE analyses aim to classify high-energy neutrino interactions and potential HNF/BSM signatures, with current iterations showing adaptable performance capabilities [4].

## 5. Reference

- [1] André de Gouvêa, Patrick J. Fox, Boris J. Kayser, and Kevin J. Kelly. Characterizing heavy neutral fermions via their decays. Phys. Rev. D, 105(1):015019, January 2022.
- [2] Pilar Coloma, Jacobo López-Pavón, Laura Molina-Bueno, and Salvador Urrea. New physics searches using ProtoDUNE and the CERN SPS accelerator. JHEP, 01:134, 2024.
- [3] Yu. M. Andreev et al. Shedding light on dark sectors with high-energy muons at the NA64 experiment at the CERN SPS. Phys. Rev. D, 110(11):112015, 2024.
- [4] Francois Drielsma, Kazuhiro Terao, Laura Dominé, and Dae Heun Koh. Scalable, End-to-End, Deep-Learning-Based Data Reconstruction Chain for Particle Imaging Detectors. In 34th Conference on Neural Information Processing Systems, 2 2021.