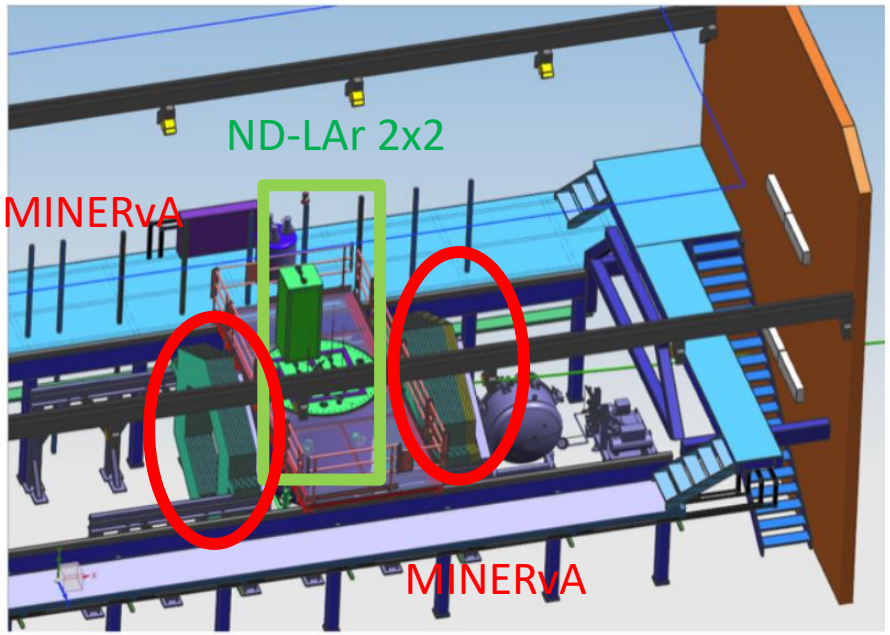
DEEP UNDERGROUND NEUTRINO EXPERIMENT

UNIVERSITÄT BERN



DUNE ND-LAr 2x2: Software Interface

Richie Diurba (Bern) for the DUNE Collaboration
WireCell Workshop II

For a dedicated physics talk on ND-LAr and 2x2, please see Brooke's talk this afternoon.
For reconstruction information at ND-LAr and 2x2, please see Jessie's talk.

DUNE Neutrino Flux at the Near Site

- Will use a 1.2 MW beam, upgradeable to 2.1 MW.
- Estimated for ND-LAr to collect millions of neutrino interactions **per year** (1.1*1E23 POT).

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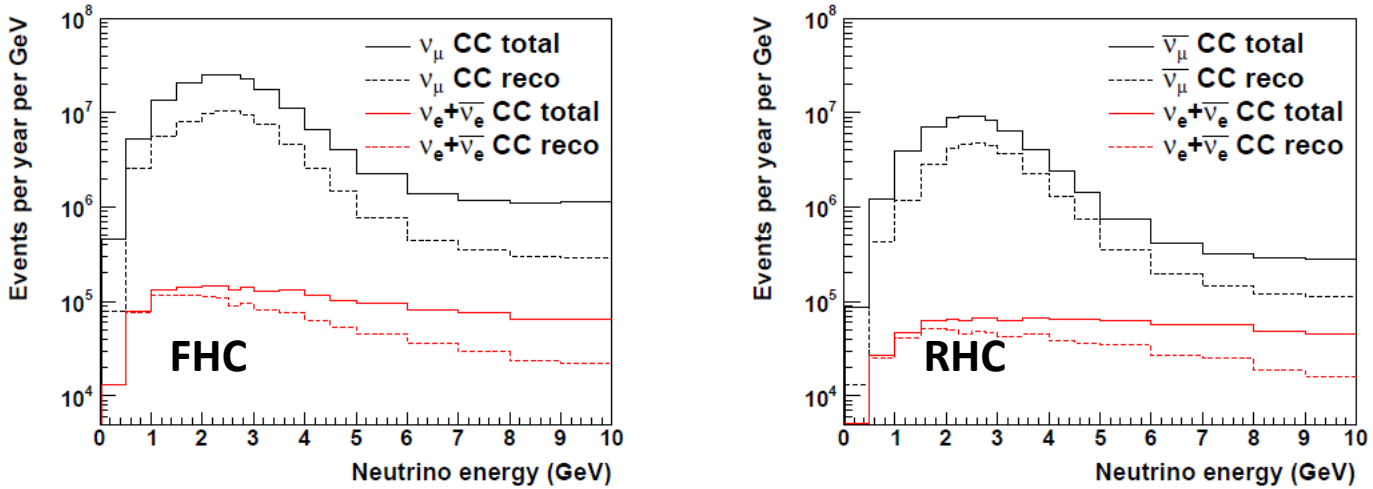
Event rate as a function of energy (top) and event rate as a function of interaction type (bottom) for ND-LAr with 50-ton fiducial volume of liquid argon.



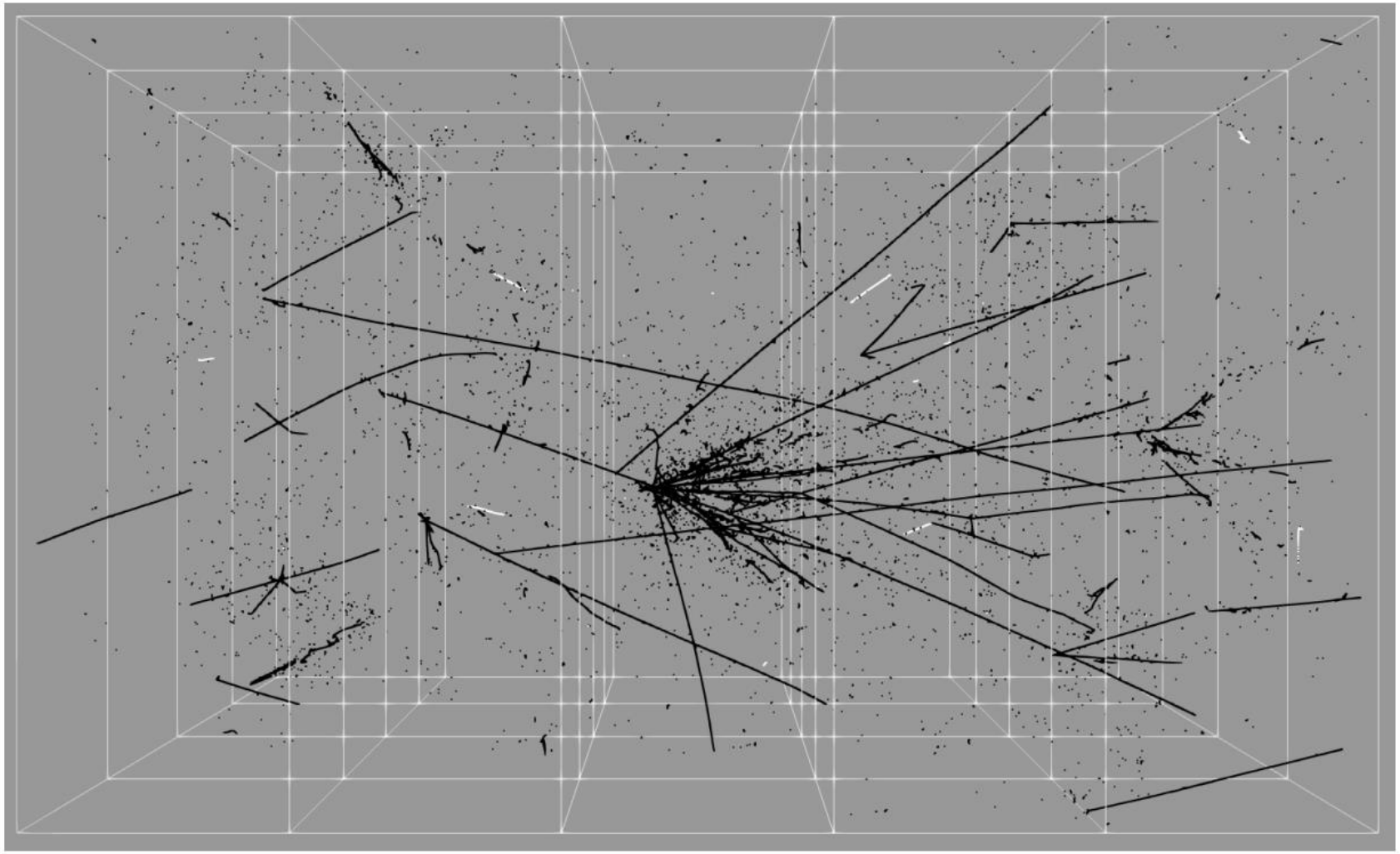
FHC

FHC mode	total	accepted	0.5 GeV to 4.0 GeV	accepted
ν_μ CC	8.2×10^7	3.0×10^7	5.9×10^7	2.4×10^7
$\bar{\nu}_\mu$ CC	3.6×10^6	1.4×10^6	1.1×10^6	4.6×10^5
NC total	2.8×10^7	1.6×10^7	1.9×10^7	1.3×10^7
ν_μ CC0π	2.9×10^7	1.6×10^7	2.6×10^7	1.3×10^7
ν_μ CC1$\pi^\pm$	2.0×10^7	7.5×10^6	1.7×10^7	6.0×10^6
ν_μ CC1π^0	8.0×10^6	2.9×10^6	6.5×10^6	2.2×10^6
ν_μ CC3π	4.6×10^6	7.2×10^5	1.7×10^6	3.8×10^5
ν_μ CC other	9.2×10^6	7.4×10^5	1.5×10^6	3.1×10^5
$\nu_e + \bar{\nu}_e$ CC	1.4×10^6	6.6×10^5	4.5×10^5	3.3×10^5
$\nu + e$ elastic	8.4×10^3	7.2×10^3	5.3×10^3	4.2×10^3

ND-LAr Simulated Event

- Tens of neutrino interactions per spill.
- Difficult to disentangle individual interactions and overlapping signals.

- Requires 70 optically segmented TPCs with pixel-based readout.
  - ND-LAr will have 200 m^2 of channels.
    - 14.3 million channels!
- 2x2 uses 4 60%-scale modules under NuMI.



Simulated neutrino spill in a ND-LAr environment with charged particles from the neutrino interaction (black) and secondary protons from primary neutrons scattering off the argon (white).

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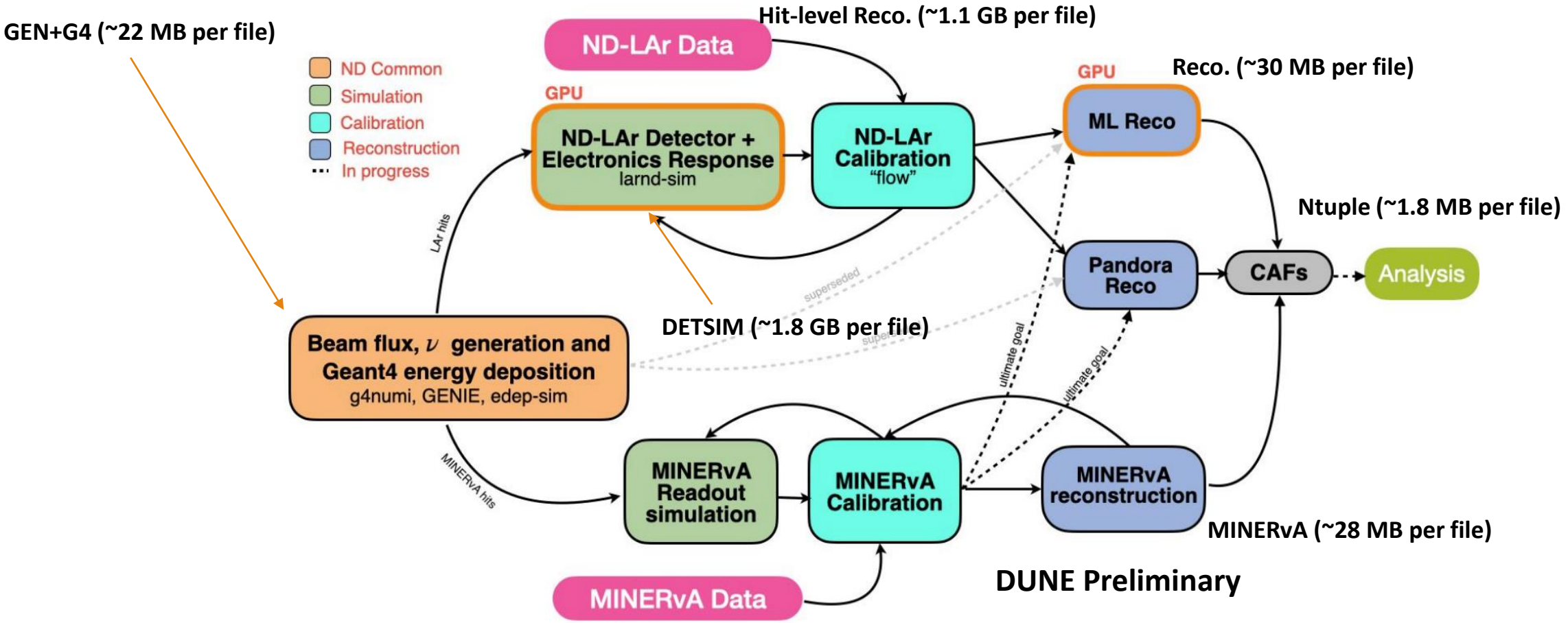
2x2 Simulation Chain

- Needs unique solutions to handle pile-up, more channels, more optical volumes.
- Fully exercised at NERSC Perlmutter with NuMI for ~1E19 POT (~200,000 spills).



Simulation Chain: Gen+G4

Neutrino Event Generation

- Uses GENIE event generator with pre-built function for gen. with flux+geometry.
  - Named gevgen_fnal (can be used with standalone genie).
  - Requires a flux file (dk2nu), a GENIE spline, a geometry file, and a beam config.

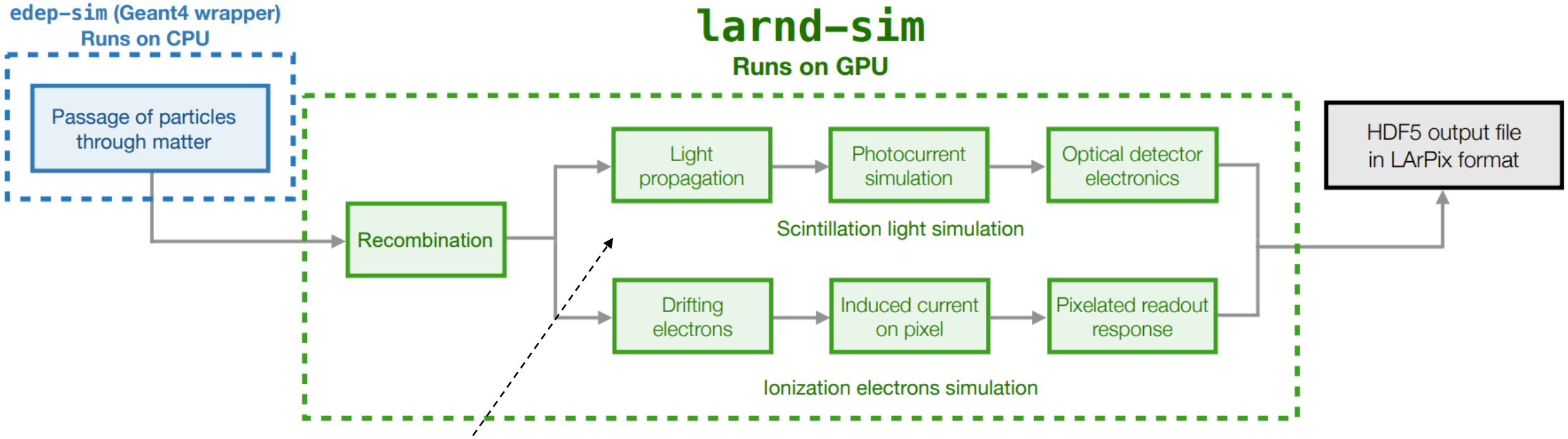
G4 with edep-sim:

- A wrapper for Geant4 (like larg4) designed primarily by Clark McGrew (Stony Brook).
- Input:
  - rootracker files from GENIE.
- Output:
  - ROOT file that then gets converted to h5.

- Link to flux file: https://portal.nersc.gov/project/dune/data/misc/NuMI_dk2nu/
- Link to geometry: https://github.com/DUNE/2x2_sim/tree/develop/geometry/
- Link to beam config.: https://github.com/DUNE/2x2_sim/tree/develop/run-genie/flux
- Link to gen. example: https://github.com/DUNE/2x2_sim/blob/develop/run-genie/run_genie.sh
- Link to g4 example: https://github.com/DUNE/2x2_sim/blob/develop/run-edep-sim/run_edep_sim.sh

Simulation Chain: Detector Simulation

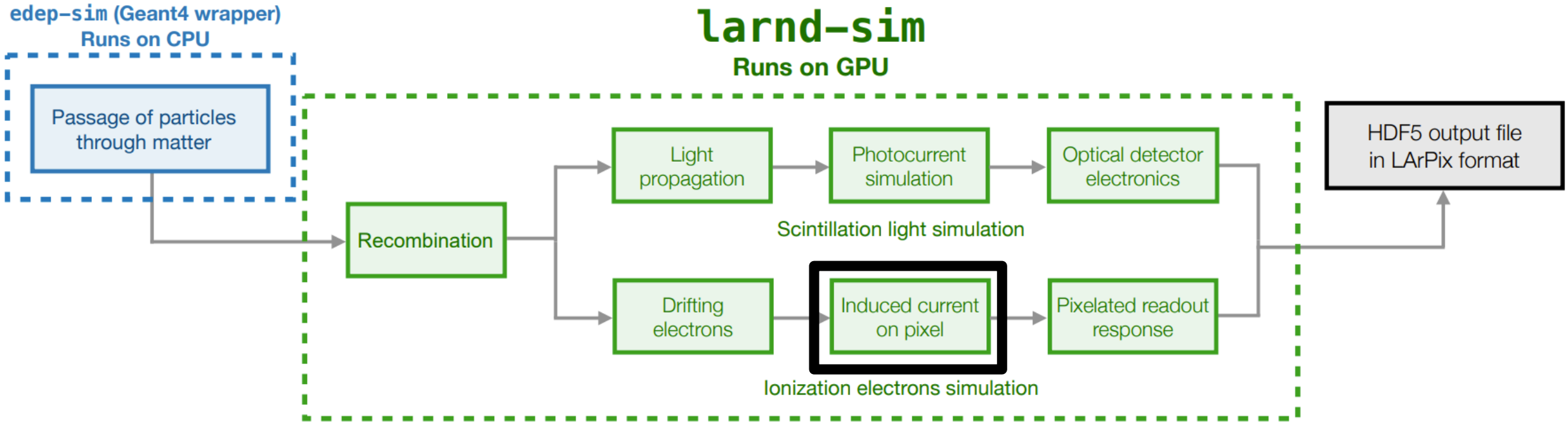
- Edep-sim provides the electrons and photons
  - larnd-sim (*JINST* **18** P04034) takes those inputs for the detector response.



Currently uses lookup table.

Simulation Chain: larnd-sim

- Parallelized simulation using NIVIDIA CUDA with Numba (Python with numpy)
- Induced charge simulation responsible for around 70% of the full computing time.



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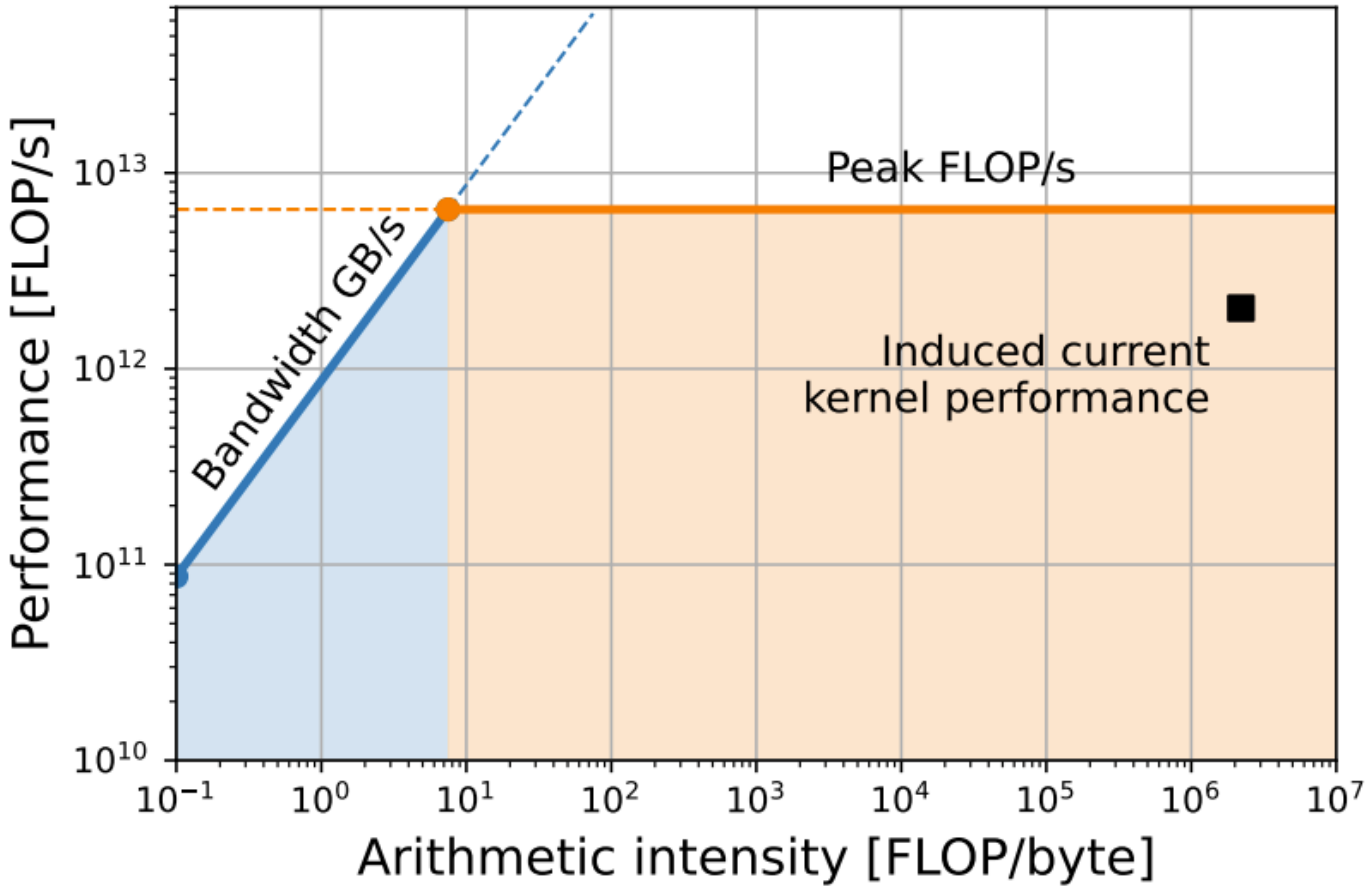
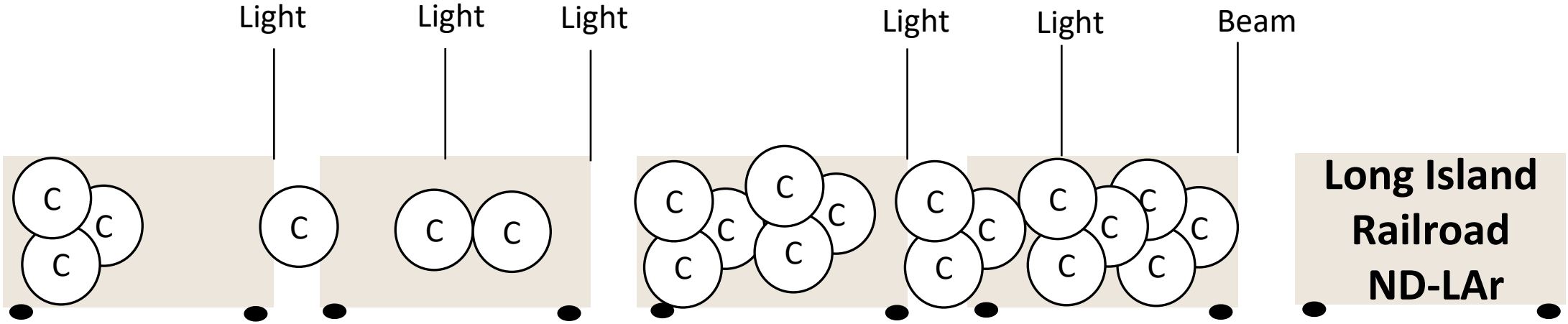


Performance of the induced charge performance compared to the limitations for 8 NVIDIA TESLA GPUs at NERSC.

Flow Event Building

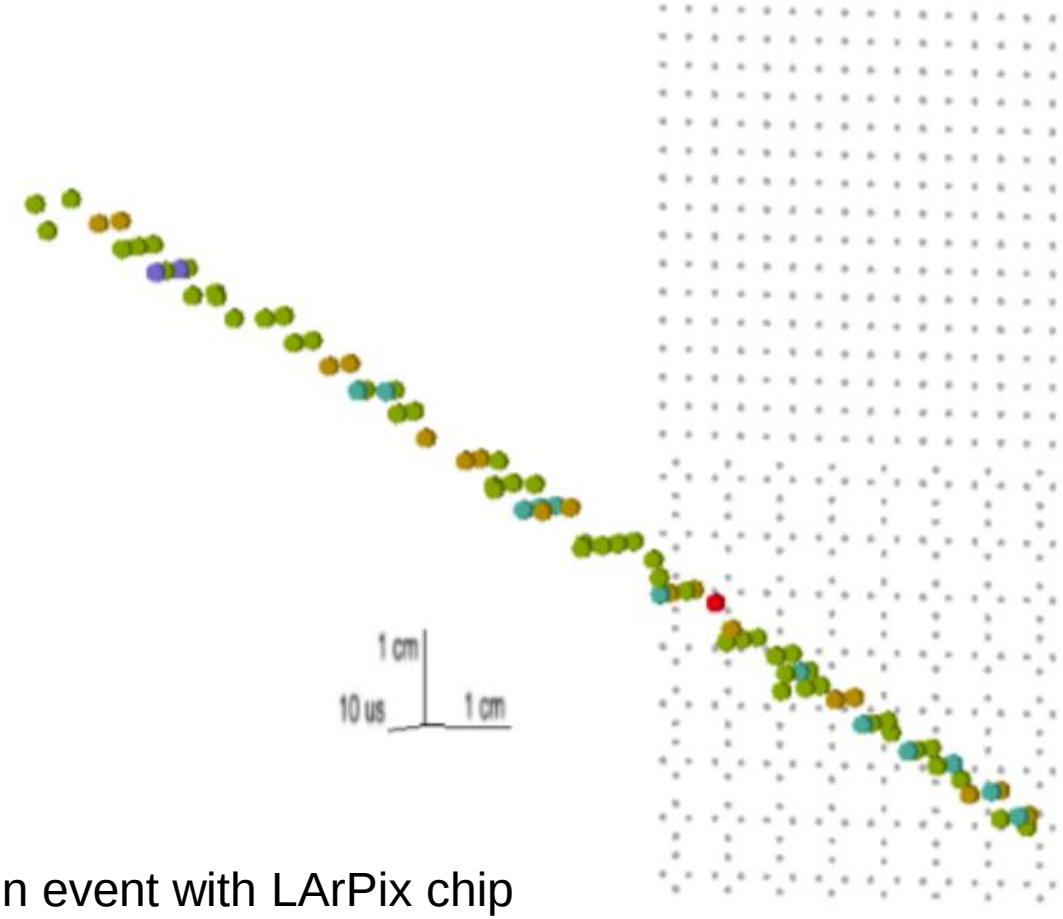
- Run ndlar-flow to translate the simulation into hits and events.
- What is an event?
  - Charge readout runs continuously so event is defined by a “flag.”
  - Max drift time of charge is 180 μs.
  - Variable event length and time between events.
- **Multiple interactions inside each event**
- Example: A train with passengers (charge signals) and conductors (triggers)



- 2x2 will use a trigger linked to NuMI for neutrino beam data-taking.

Flow Hit-Level Reconstruction

- Fully native 3D reconstruction with pixel readout.
- Flow does:
  - channel mapping
  - translates packets (hardware designation) to hits (software designation)



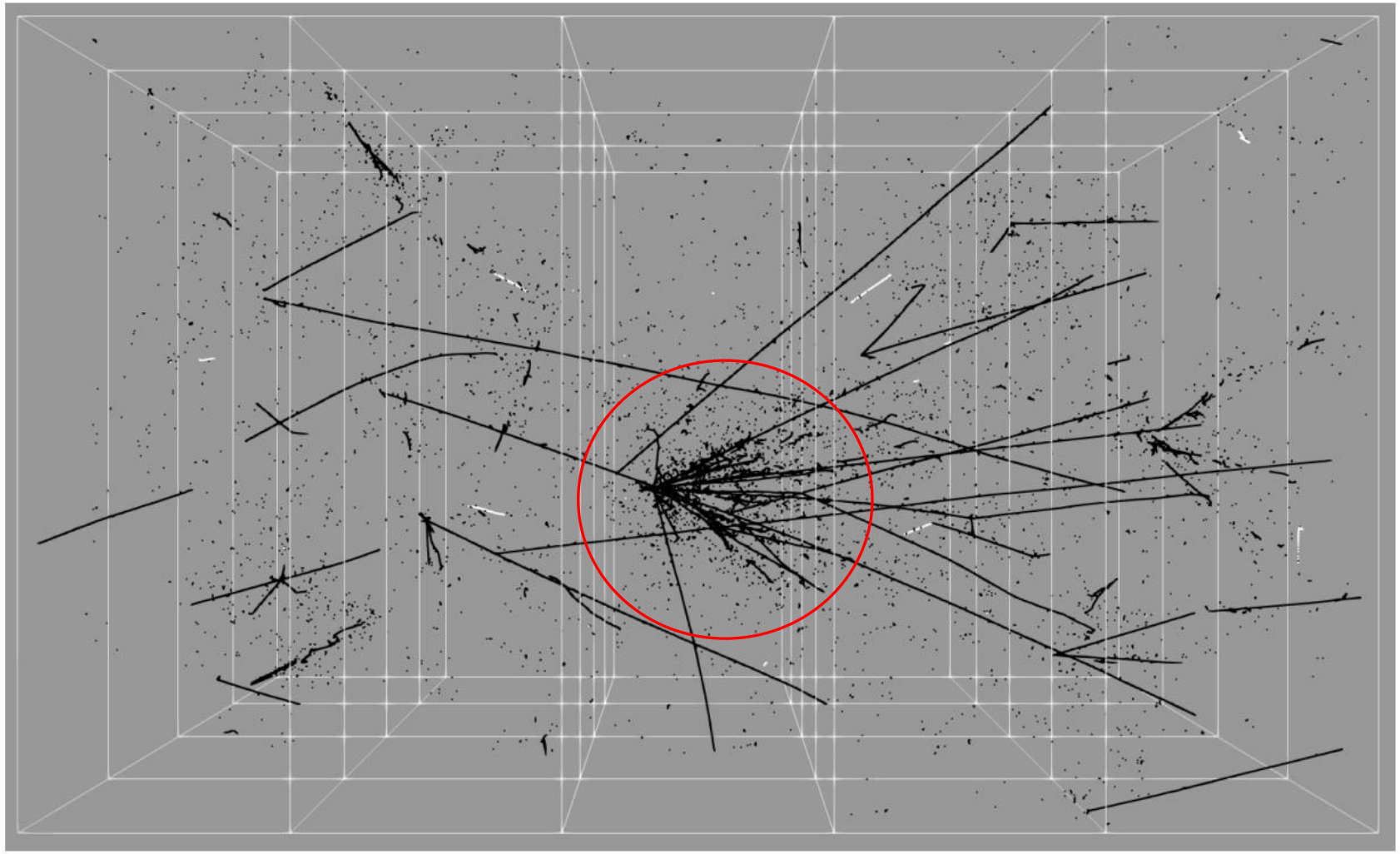
Cosmic-ray muon event with LArPix chip with a 60 cm LArTPC (*JINST* **13** P10007)

H5 and Translating Flow for Reconstruction

- Reconstructions (Pandora, MLReco) process h5 files.
- At this step:
  - Truth information dumped
  - Charge signals mapped to true particle/deposits (Example from Pandora)
  - Vertices and particle hierarchies are created
- H5flow in DUNE's ndlarflow can be used in Python to accelerate backtracking.
  - Documentation on how it works.
- Results need to be readable by CAF maker.

- Physics Choices:
  - **Multiple interactions need to be allowed per event**
  - Reco-truth overlap required (majority or largest overlap)

ND-LAr Challenge: Disentangling Overlap



How do we define the hit information within this DIS event?

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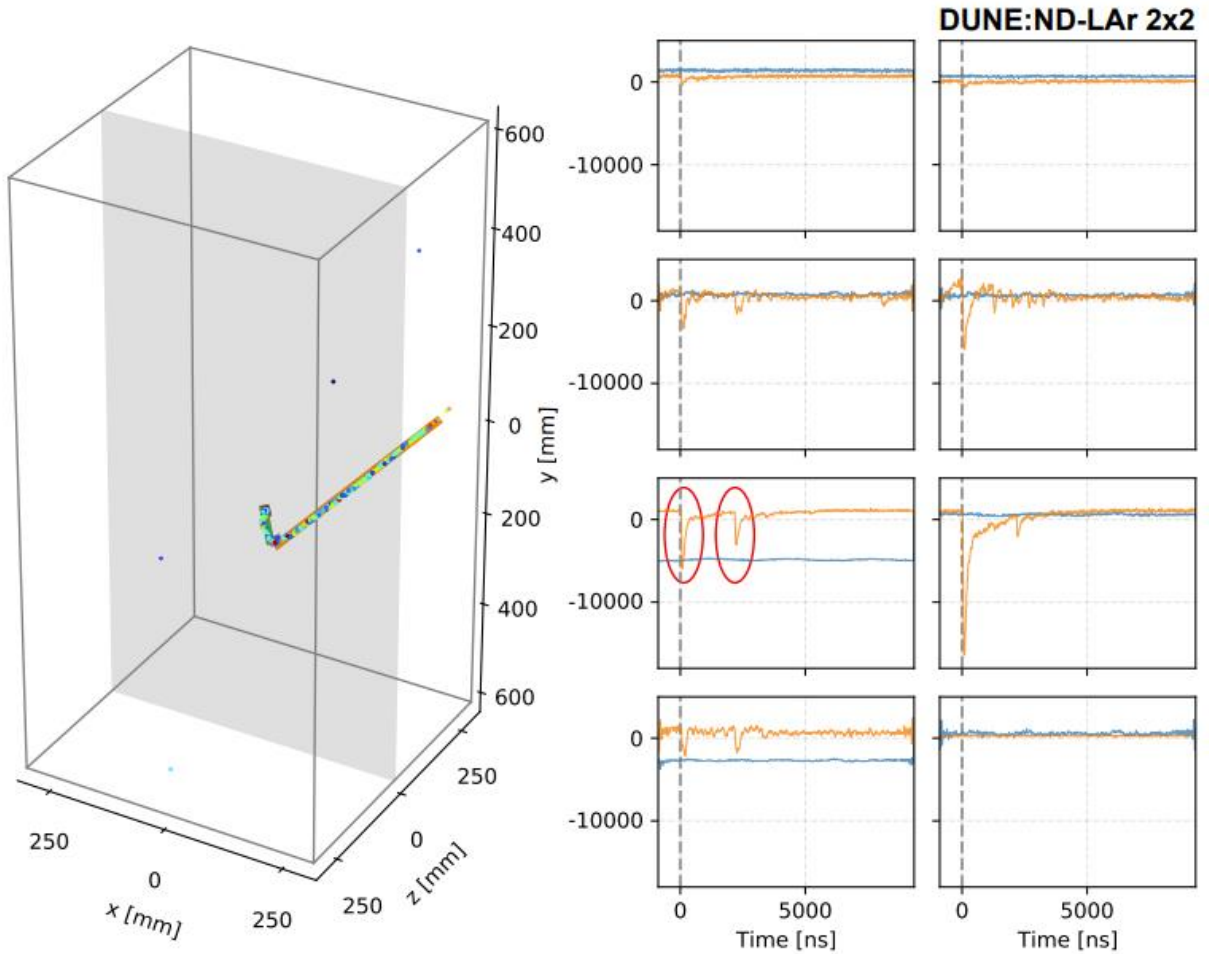
Light and Charge Matching

- Matching charge and light requires backtracking with truth, charge, and light.
- First tests for light-charge matching in a neutrino bema environment in 2x2 happening soon!

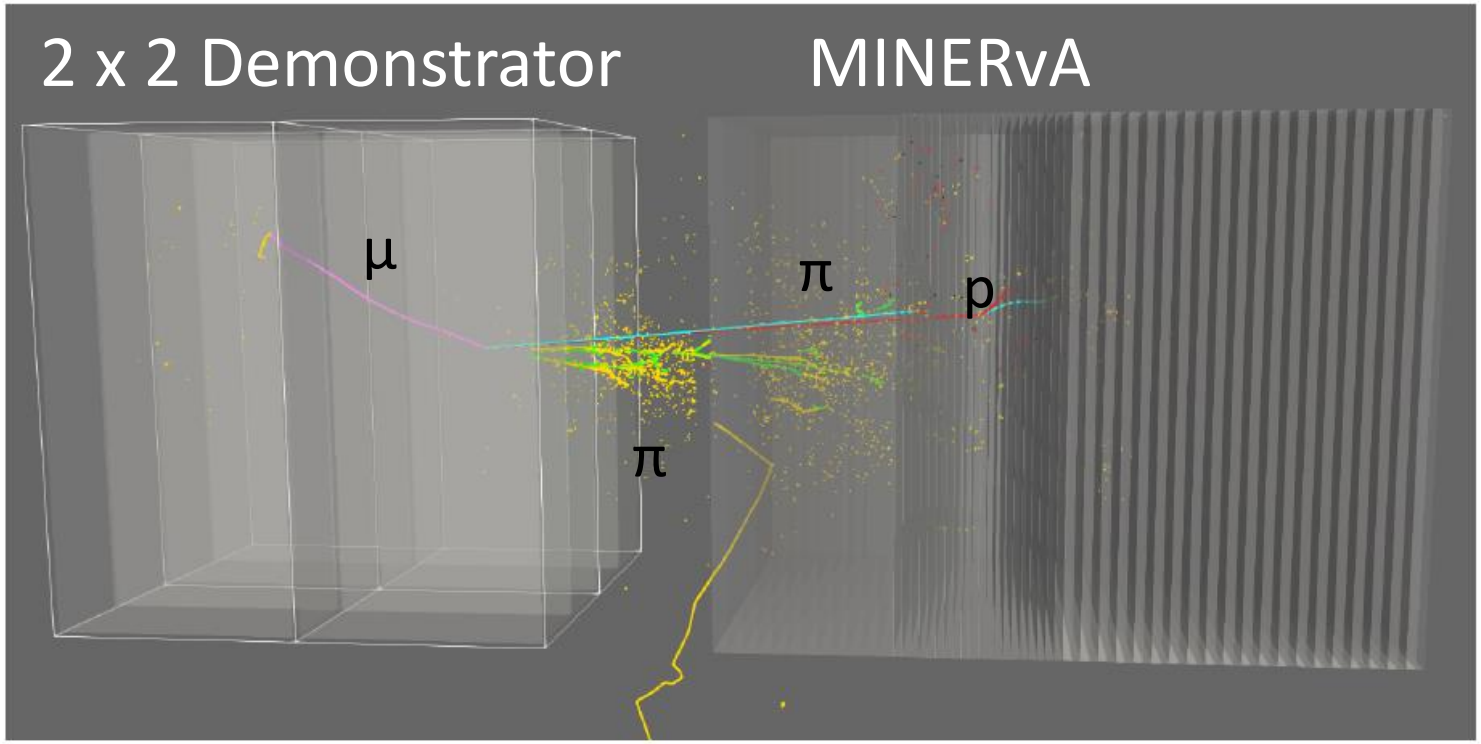


Candidate Michel event from Module 0 analysis

arXiv:2403.03212

Multi-Detector Event Matching

- Need to integrate MINERvA in reconstruction to collect all particle information.



Example neutrino event with a 7 GeV/c muon neutrino in the 2 x 2 Demonstrator with containment aided by MINERvA.s

- Precursor to ND-LAr+TMS matching.

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Conclusion

- 2x2 uses a robust simulation chain fully operation at NERSC using h5 and ROOT files.
- Requires fast simulations to be able to handle future ND-LAr spills.
- Current focus on reconstruction and analysis of light and charge signals with 2x2.