

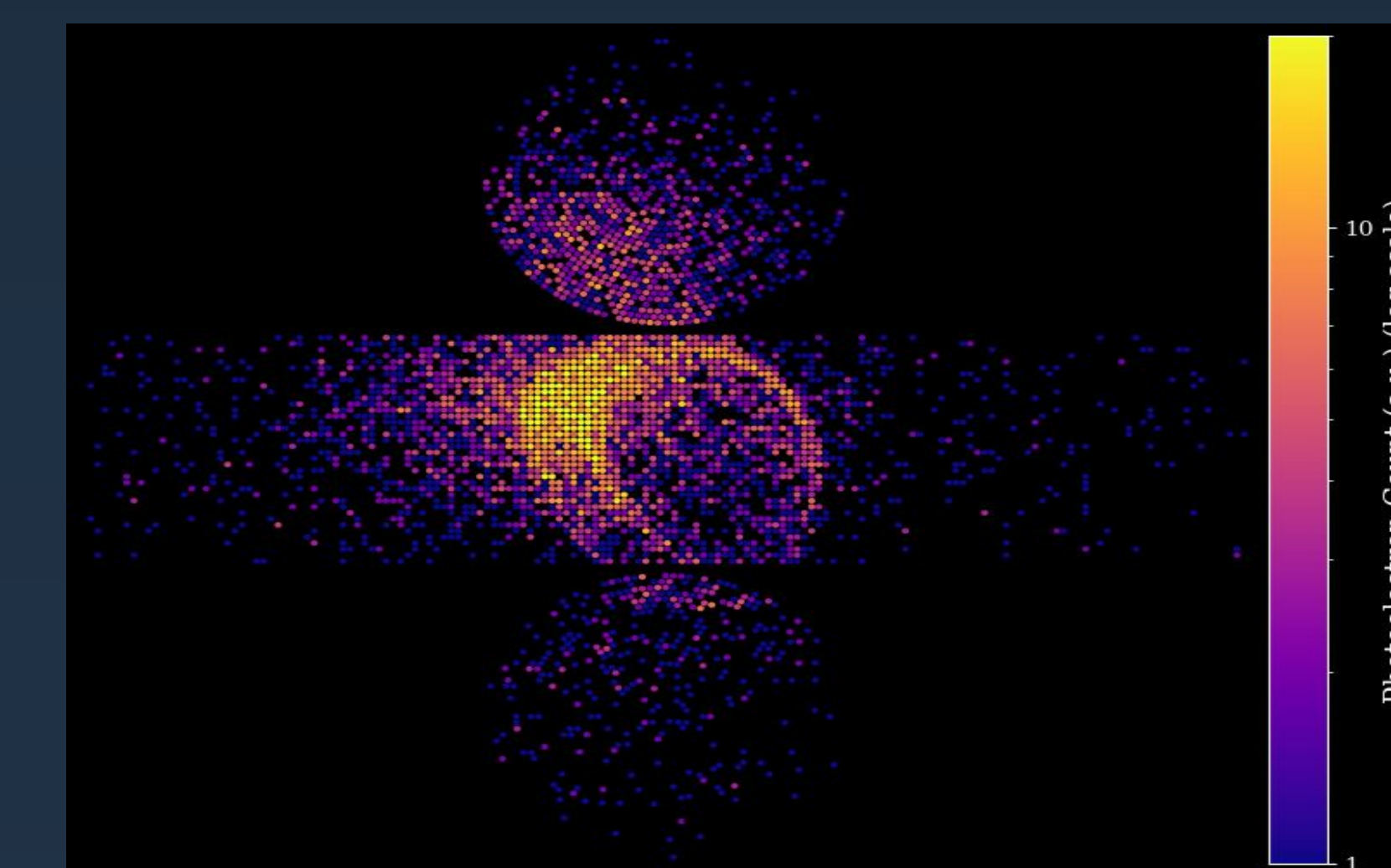
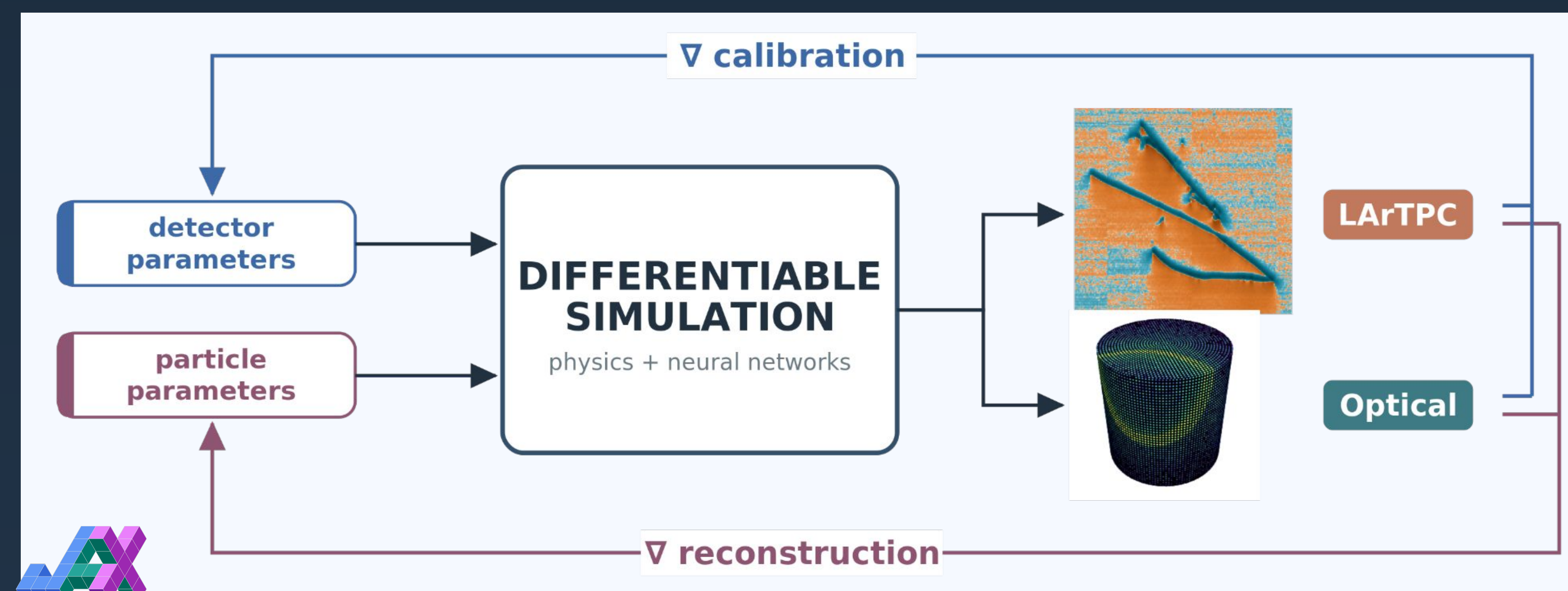
# Differentiable Programming for Neutrino Detector Simulation, Reconstruction, and Calibration



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## Motivation

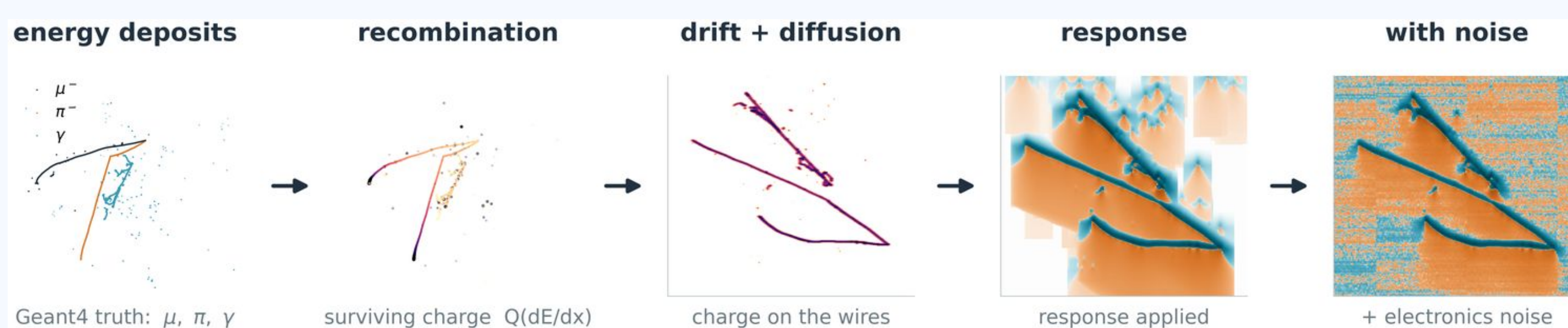
- Next-gen experiments (DUNE, HyperK) probe new physics at **unprecedented scale**, over many correlated detector parameters.
- A differentiable simulation returns the **gradient for all parameters** at once via **automatic differentiation (AD)**.
- **Simulation, reconstruction, and calibration**, all from one model.
- Built in **JAX**: a NumPy-like interface, JIT-compiled and parallelized across **GPU** or CPU.



## Liquid Argon TPCs (JAXTPC)

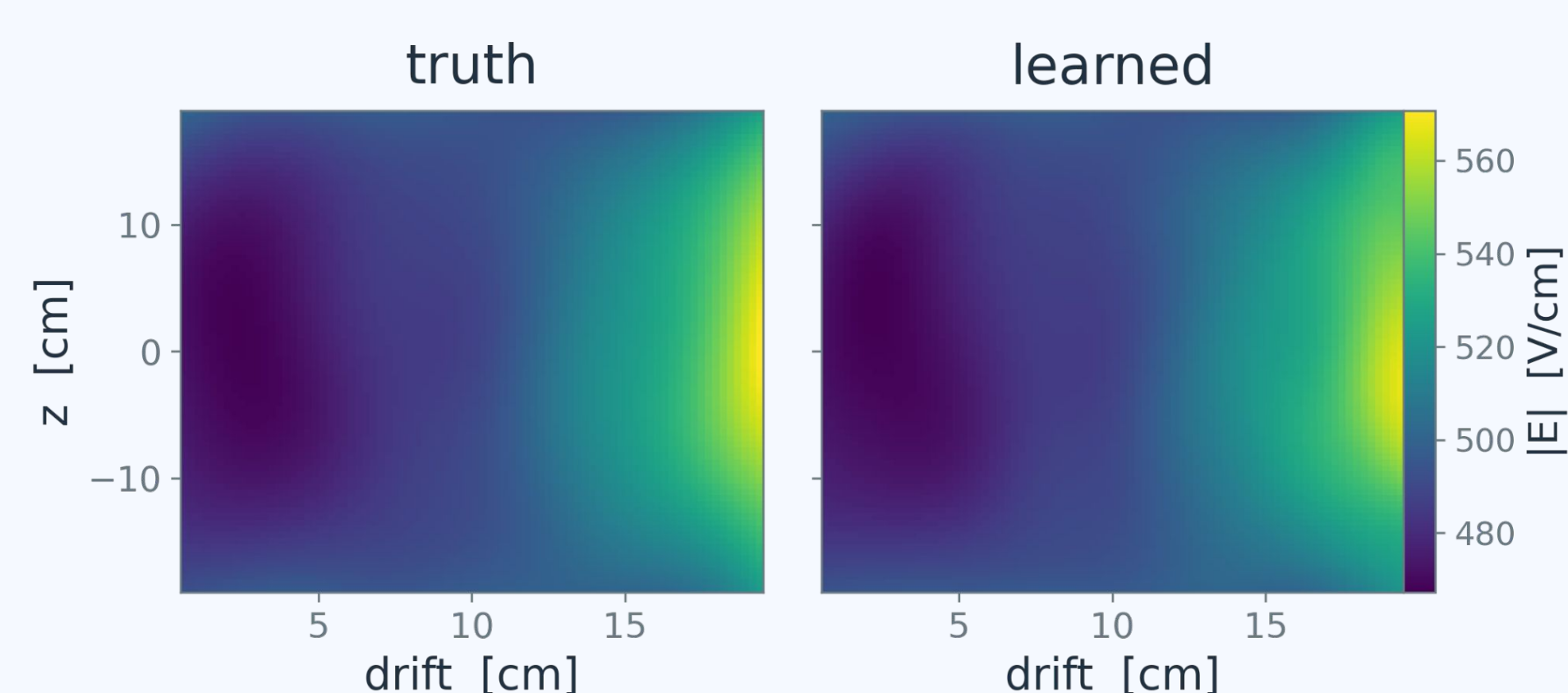
### ① THE SIMULATION

- First-principles physics and **empirical neural-network surrogates**.
- Multi-volume geometries (SBN, DUNE); **wire and pixel readout**.
- **≈0.4 s/event** on A100 and 2080 Ti GPUs, **>100× faster** than classic simulations.



### Electric field distortions

recovered from 1024 cosmic muons |E| MAE = 1.09 V/cm

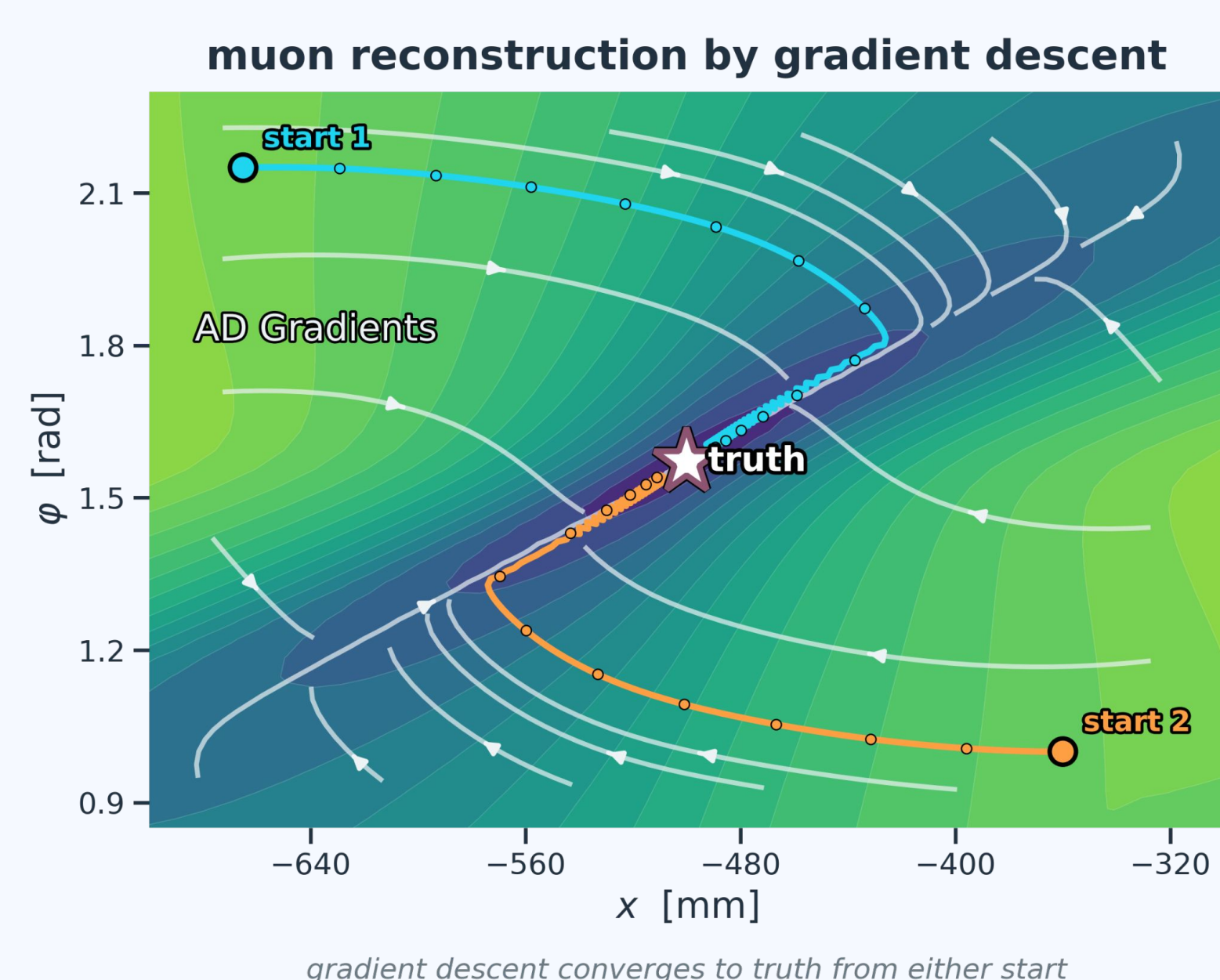


### ② CALIBRATION

- Seven correlated parameters (recombination  $\alpha/\beta$ , lifetime, drift velocity, diffusion) **fit jointly ~1% accuracy**;
- A surrogate network recovers the full 3D electric-field distortion from cosmic-muon tracks.

### ③ RECONSTRUCTION

- A muon is fit by gradient descent; the multi-scale mismatch is a smooth basin that reaches truth from far, where MSE difference gives none.
- **Full 3D segment reconstruction**, no track model: charge <1%, geometry sub-mm.



### ④ OPEN DATASET · DORAEMON

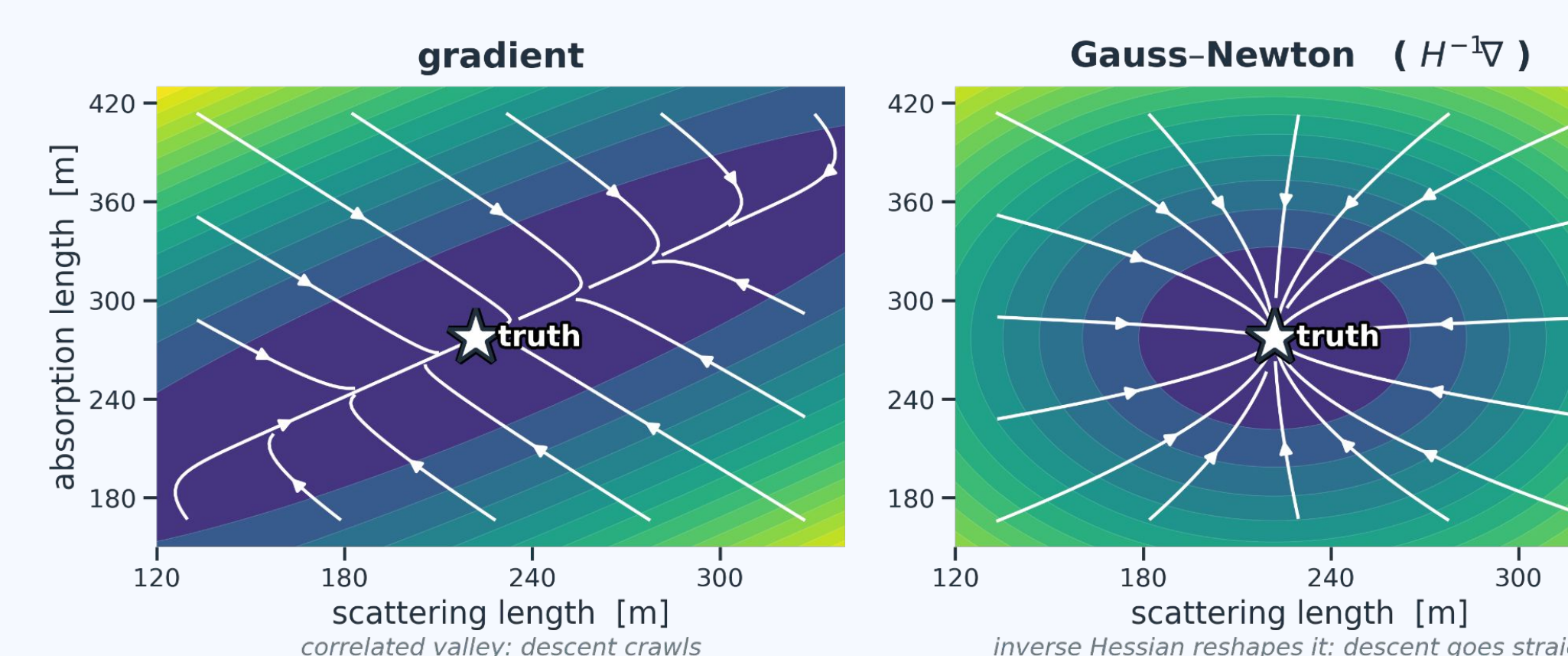
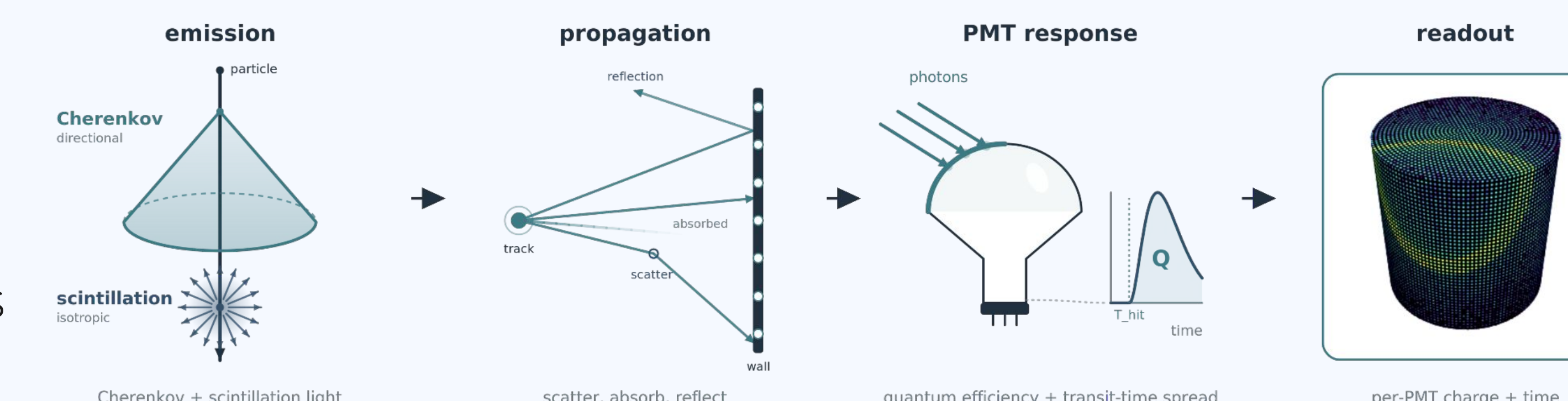
A **10M+ event**, fully labeled liquid-argon dataset, multi-modal (3D, wire pre/post-response, optical), including a particle-bomb set.



## Optical Detectors (LUCiD)

### ① THE SIMULATION

- **End-to-end** Cherenkov and scintillation transport
- **Implicit capture**: every photon survives with a continuous weight onto every PMT it can reach. Scintillation's large yields give the **expected light** at low variance.
- Grid-based acceleration, **~10 ms / 10<sup>6</sup> photons** (A100, 2080 Ti): **10<sup>3</sup> to 10<sup>4</sup>× faster** than classic CPU simulations.

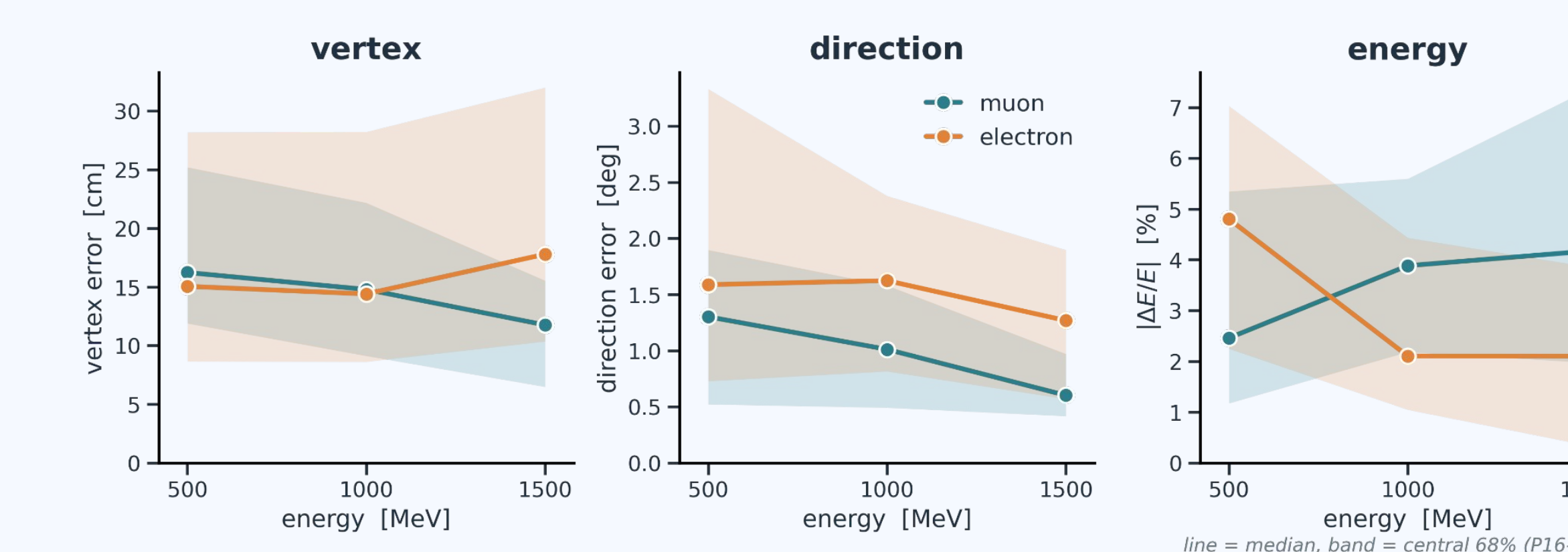


### ② CALIBRATION

- Many correlated optical parameters fit to **<1% simultaneously** with enough statistics
- The **inverse Hessian** (Gauss-Newton) reshapes the correlated valley into an isotropic bowl, so descent reaches truth directly.

### ③ RECONSTRUCTION

- Recovers vertex, direction, and energy, beating fitQun out of the box: **~1° direction, ~15 cm vertex, 3% energy** (SK-like detector, real Geant4 photons).



### ④ OPEN DATASET · DORAEMON-WAND

**10M event**, fully labeled water-Cherenkov dataset (3D, per-PMT multi ring contribution) We are launching an open US-Japan AI/ML R&D ecosystem for neutrino physics, with **open datasets and benchmarks before the end of 2026**.