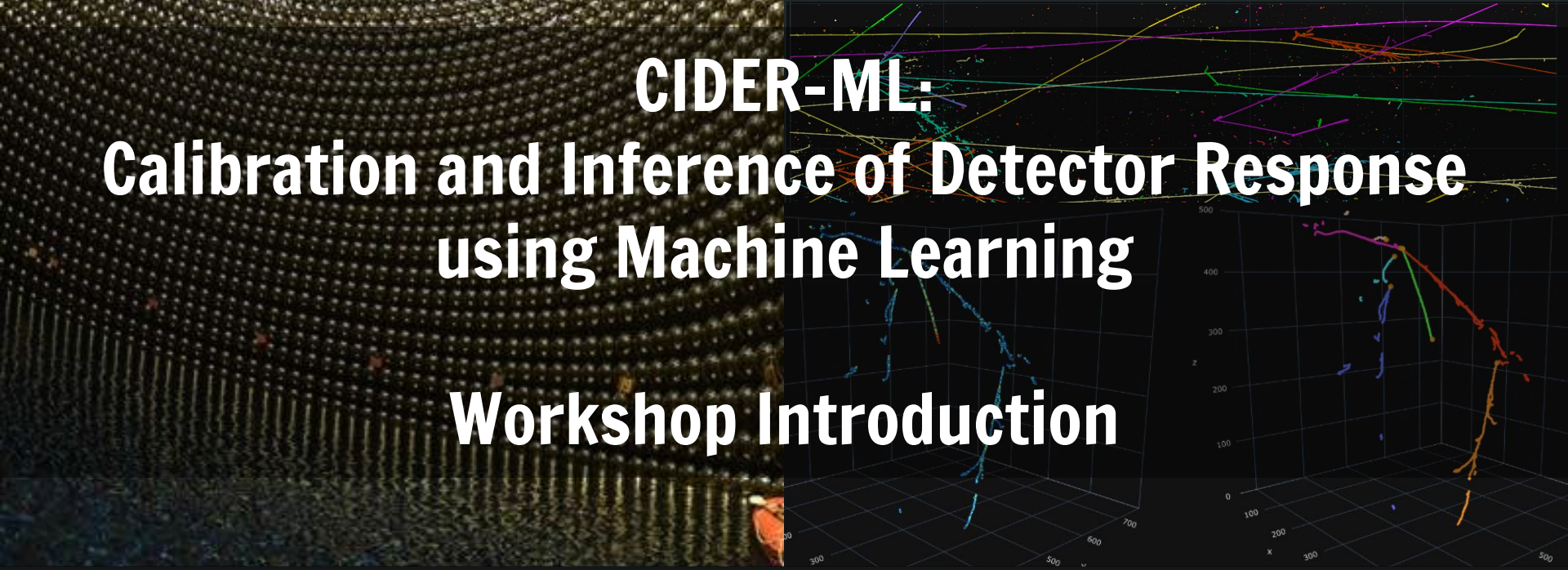


CIDER-ML:
Calibration and Inference of Detector Response using Machine Learning

Workshop Introduction

CIDER-ML SUMMER WORKSHOP @ SLAC
JULY 30, 2024

Patrick de Perio
KAVLI IPMU

Kazuhiro Terao
SLAC

Link to these slides

Ref: first proposal slides

Recall: Traditional Paradigm of Detector Physics Modeling

Geometry

Cherenkov physics

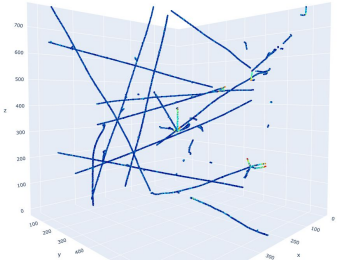
Water properties (light scattering, absorption)

PMT and wall reflectivity

Residual magnetic fields

PMT+electronics response

- **Limitations**
  - Lack of “end-to-end” optimization
  - Some models are not even optimizable (e.g. look-up tables)
  - Same physics, two separate software (i.e. simulation & calibration)
- **Goals** toward “detector systematics @ <1% level”
  - Automation + fast compute that can scale for HK/DUNE
  - Accurate model optimized directly to minimize data/MC disagreement



Simulation Input (true dE/dX)

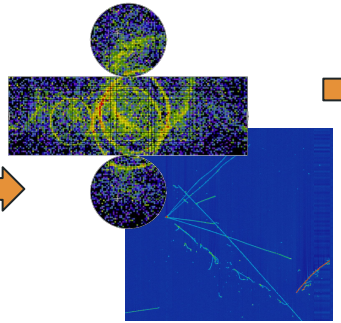
Detector Simulation

$$\mathcal{R}_{\text{ICARUS}} = \frac{A_B}{1 + k_B \cdot (dE/dx)/\mathcal{E}}$$

$$Q = Q_0 \exp(-v_{\text{drift}} t/\tau)$$

$$\sigma_t^2(t) \simeq \sigma_t^2(0) + \left(\frac{2D_L}{v_d^2}\right) t$$

...

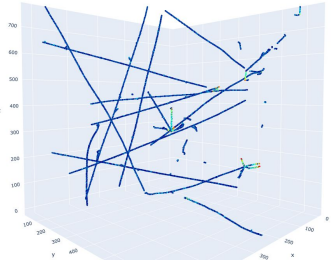


Detector Output (ADC)

Reconstruction

Detector physics model parameters

Calibration

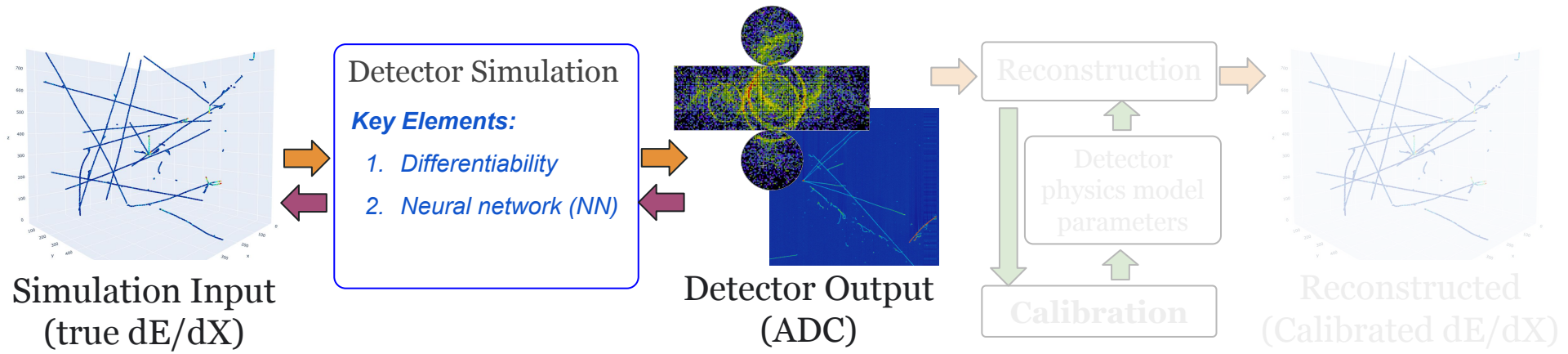


Reconstructed (Calibrated dE/dX)

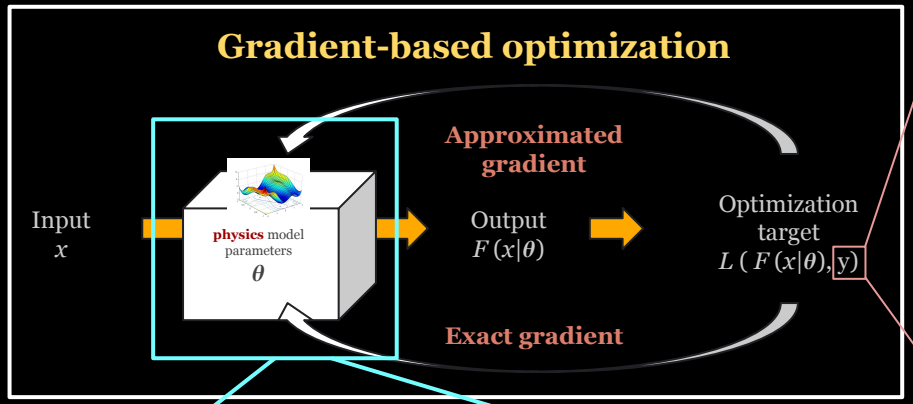
Recall: Automation of Physics Model Tuning

Research Proposal: differentiable detector physics simulator (DDSim)

- **"End-to-end"**: gradient-based optimization using control (calibration) dataset
- **Interpretable**: analytical physics models for well understood physics
- **Flexible**: neural representation to incorporate complex features in real data
- **Fast**: utilization of modern computing accelerators (e.g. GPUs)



Water Cherenkov Organization



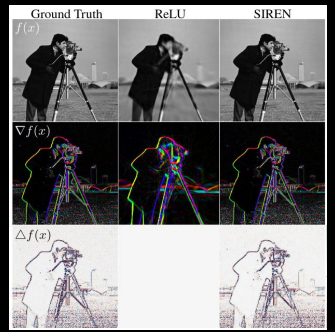
Simulation Packages

- SimpleSim (César)
- WCSim (Ka Ming, Patrick)
  - Computing (Zhe, Kazu)

Later: real calibration data

1) Implicit Neural Representation

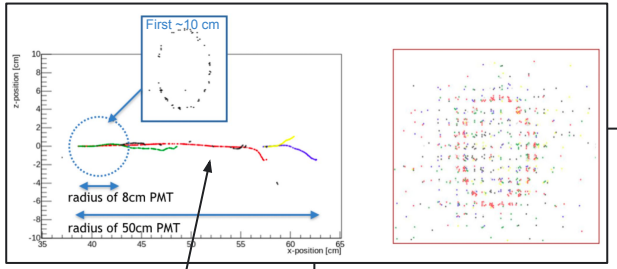
- SIREN
- Junjie, Ryo, Ryotaro



2) Explicit Physics Parameterization

- ~~Taichi Lang~~ → **JAX**
- Omar, César

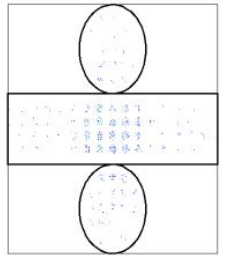
Overview of SIREN Method



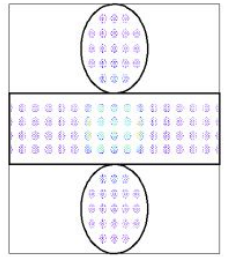
Goal:
Track reconstruction and classification

Particle Reconstruction

"Real" data

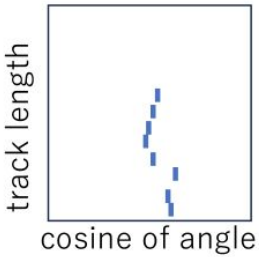


Optical SIREN:
PMT charge
(PMT hit time)



"Simulated" data

Get particle information

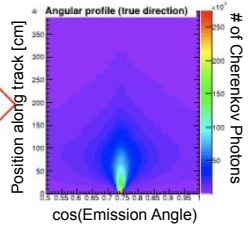


Get photon emission angle

Charged particle information:
- PID
- Momentum

Cherenkov profile SIREN:
- track position
- photon emission angle
- (photon emission time)

Get photon distribution for 1 particle



Get hit PMT distribution for 1 photon

Differentiable detector simulation

Overview of SIREN Method - Personnel

Ryotaro Tsuchii (TITech)

Junjie Xia (KIPMU)

Ryo Matsumoto (TITech)

Get particle information

track length

cosine of angle

Particle Reconstruction

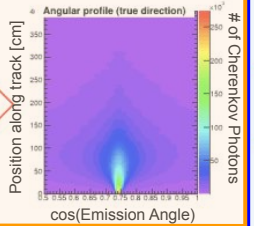
"Real" data

Get photon emission angle

Charged particle information:
- PID
- Momentum

Cherenkov profile SIREN:
- track position
- photon emission angle
- (photon emission time)

Get photon distribution for 1 particle



Get hit PMT distribution for 1 photon

Optical SIREN:
PMT charge
(PMT hit time)

"Simulated" data

Differentiable detector simulation

Overview of SIREN Method - Personnel

Ka Ming Tsui (KIPMU)

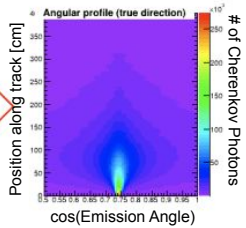
WCSim Integration

Charged particle information:
- PID
- Momentum

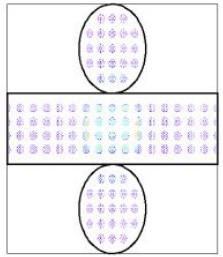
Cherenkov profile SIREN:
- track position
- photon emission angle
- (photon emission time)

Optical SIREN:
PMT charge
(PMT hit time)

Get photon distribution for 1 particle



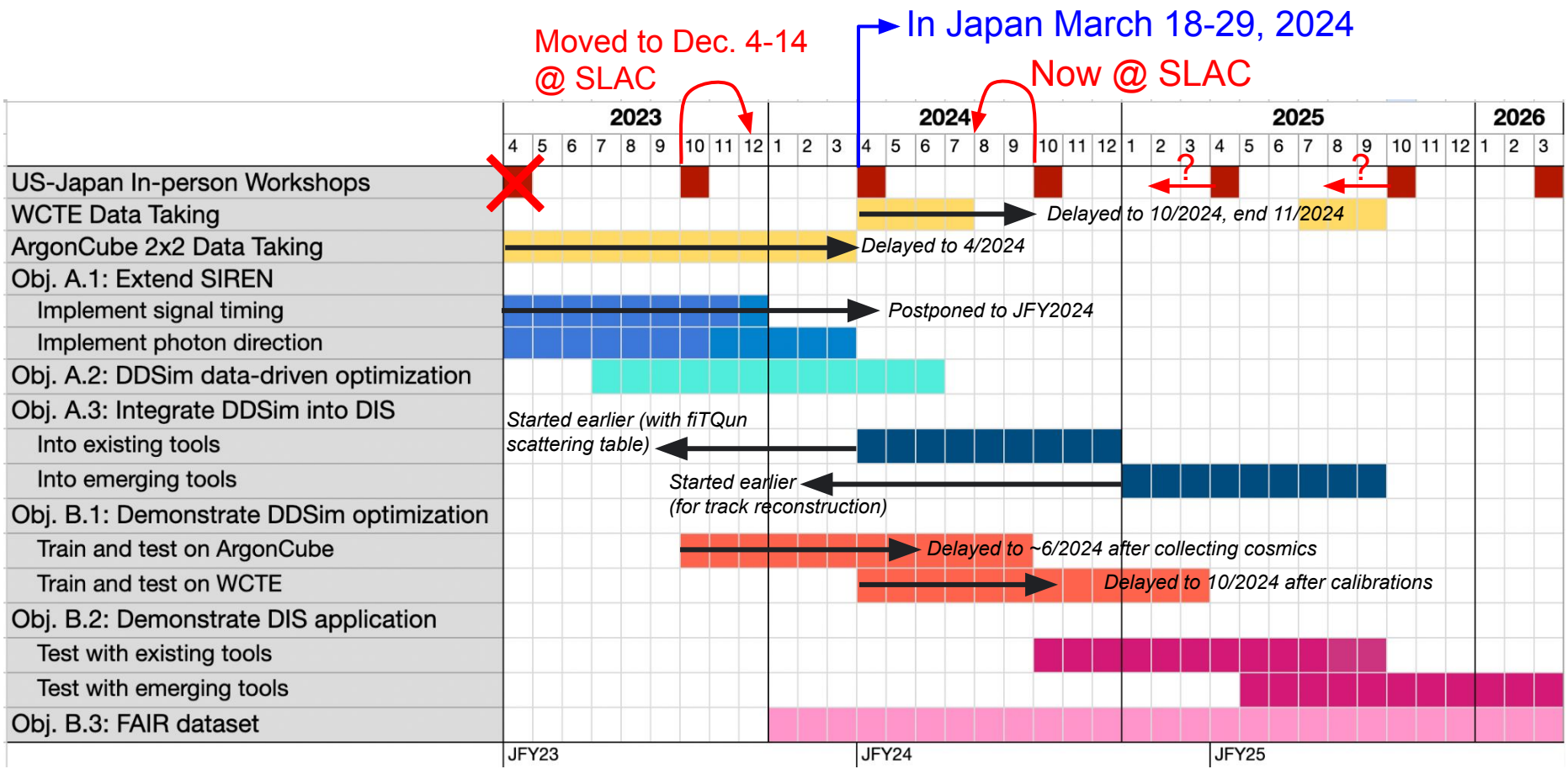
Get hit PMT distribution for 1 photon



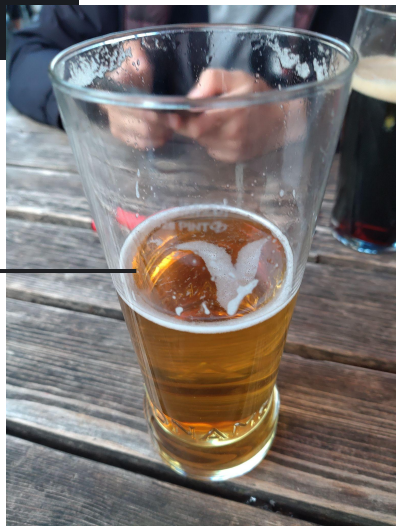
"Simulated" data

Differentiable detector simulation

Workshop Schedule



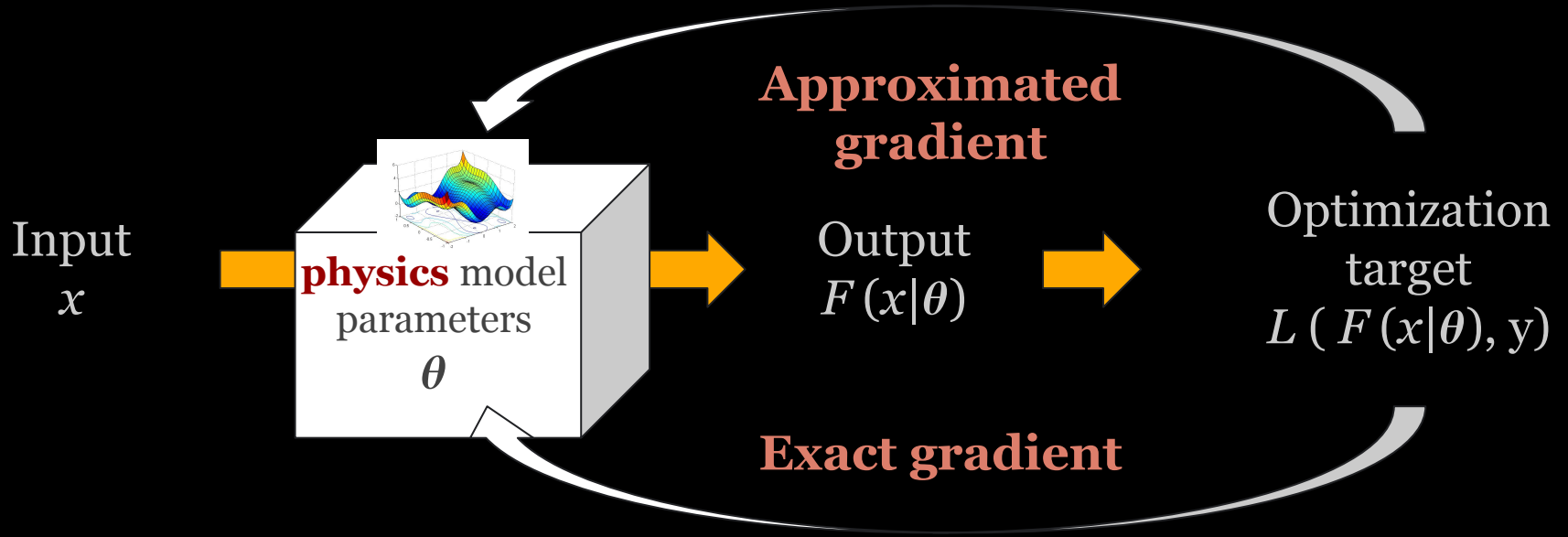
Logo



Appendix

Recall: Differentiable Detector Physics Simulator (DDSim)

Gradient-based optimization



Training an Optical SIREN

- Encapsulate all the detector physics modeled in WCSim (except Cherenkov, later) with an ideal calibration source:
  - Photon “shotgun” positioned and aimed uniformly throughout the detector
  - To be input to train a SIREN that learns the PMT response from a photon originating from a given position and direction

Geometry

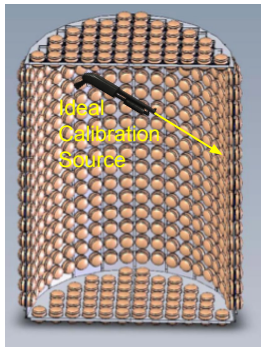
Cherenkov physics

Water properties (light scattering, absorption)

PMT and wall reflectivity

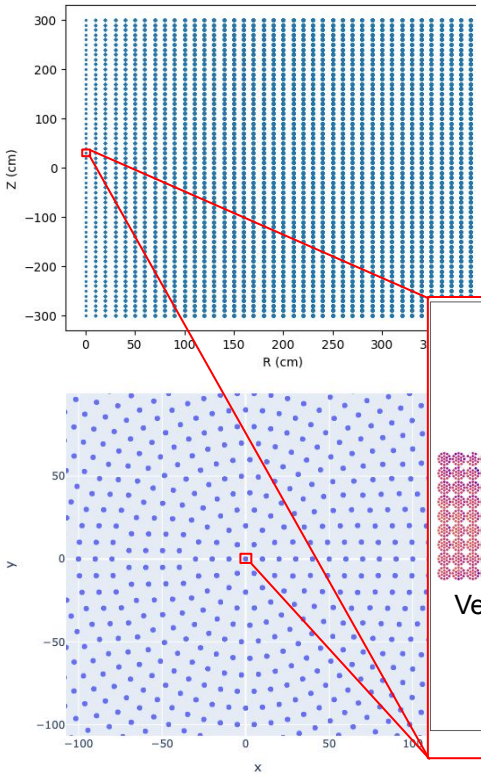
Residual magnetic fields

PMT+electronics response

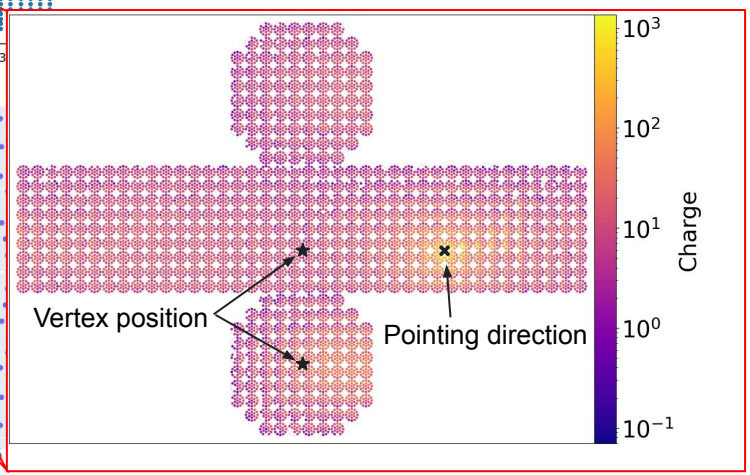


- Huge computational task, bookkeeping database and production framework has been developed
  - Started production on SLAC clusters

E.g. IWCD-like detector

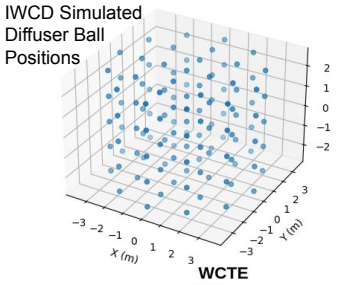


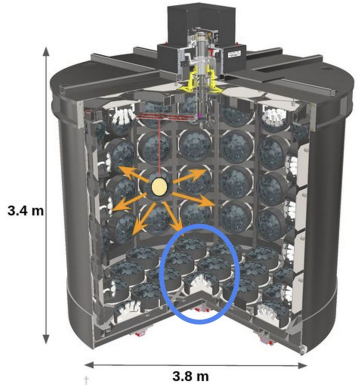
Position spacing (cm)	Direction spacing (°)	Number of configurations	Total Simulation Time (CPU-years)
10	10	215M	8144
20	15	12.7M	458

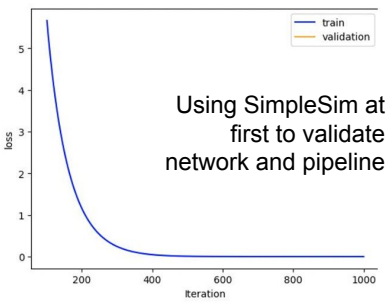


Optimizing Optical SIREN with Real Data

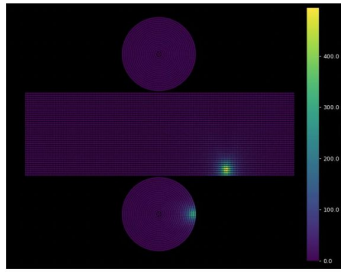
- Eventually want to train with real calibration data to mitigate data/MC discrepancies:
  - E.g. moveable laser diffuser ball
    - Or light injectors, radioactive sources, cosmics, decay-e, etc.
- Successfully trained a SIREN on one source position
  - Extending to all positions, then more realistic WCSim

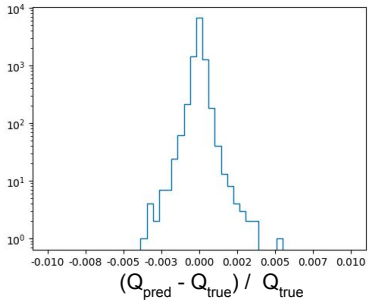


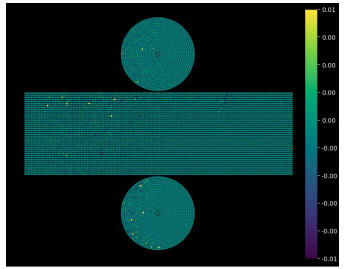


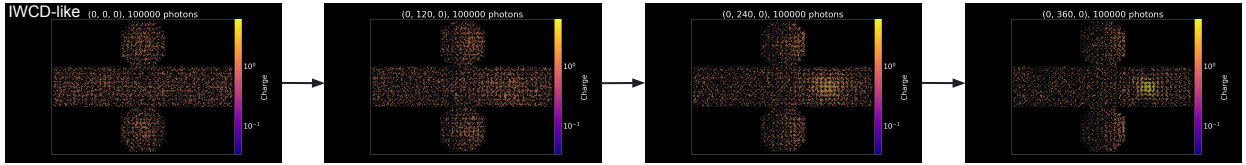


Using SimpleSim at first to validate network and pipeline





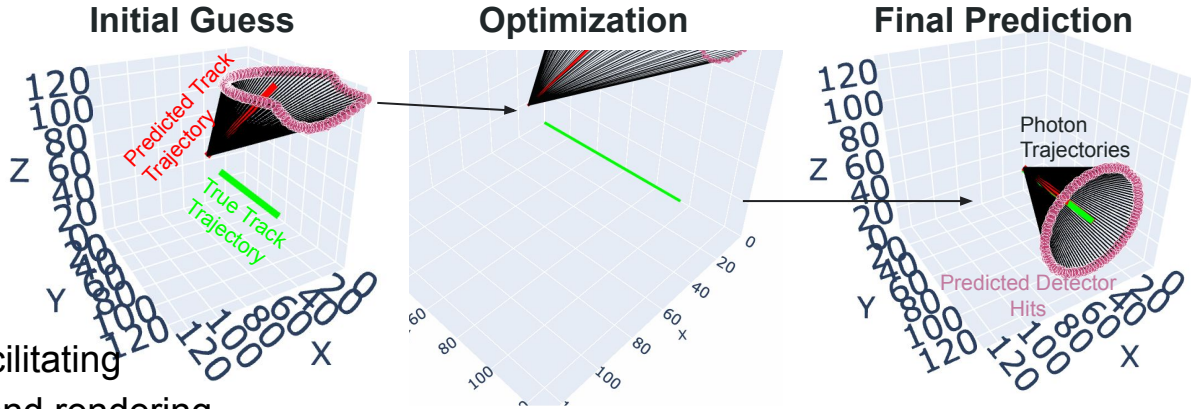


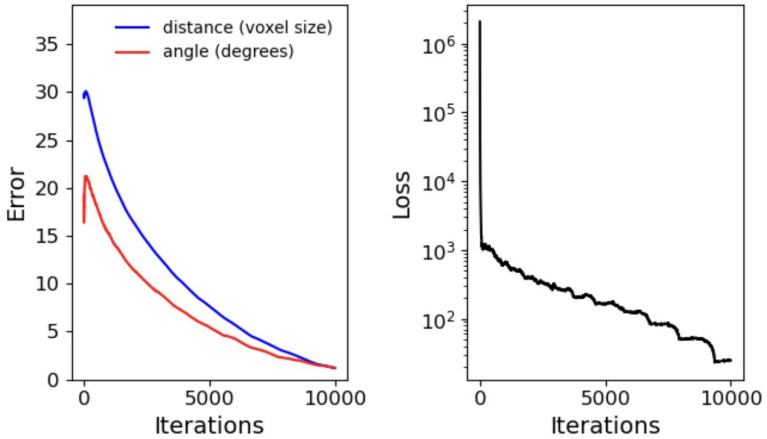


Simulated full set of isotropic light source with WCSim to be used with Optical SIREN

Status of 2) Taichi Method

- Very basic water Cherenkov detector (geometry of PMTs, ray tracing) implemented in Taichi Lang
  - A programming language facilitating differentiable programming and rendering of physical processes
- Demonstrated simple track reconstruction using the differentiability
- Start considering how to implement stochastic process such as light scattering





CIDeR-ML Collaboration Photos @ SLAC, Dec. 4-14, 2023