Calibration and Inference of Detector Response with Machine Learning (CIDeR-ML): Water Cherenkov Goals

US-JAPAN SCIENCE AND TECHNOLOGY COOPERATION PROGRAM
CIDER-ML COLLABORATION MEETING, MARCH 18, 2024

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Link to these slides

Ref: first proposal slides

Recall: Traditional Paradigm of Detector Physics Modeling

Geometry

Cherenkov physics

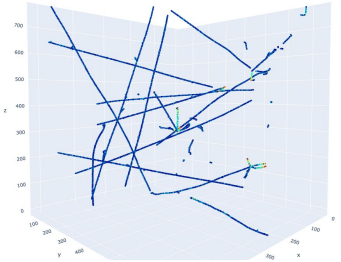
Water properties (light scattering, absorption)

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)

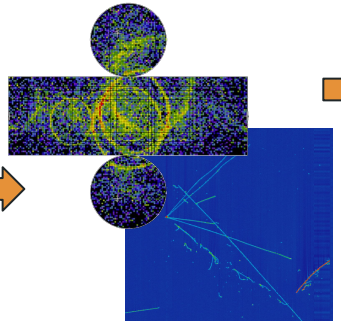
Detector Simulation

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

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

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

...

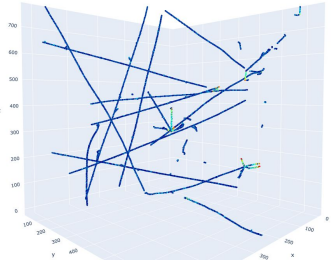


Detector Output (ADC)

Reconstruction

Detector physics model parameters

Calibration

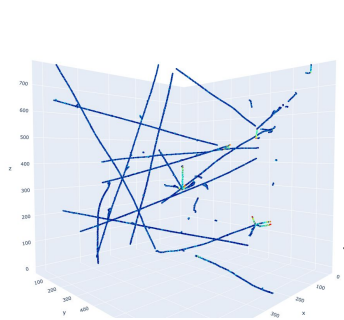


Reconstructed (Calibrated dE/dX)

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)

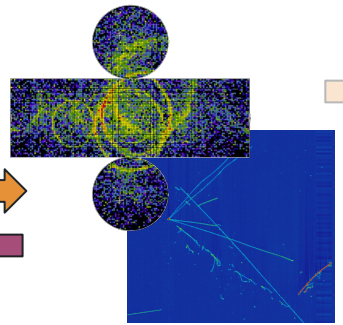


Simulation Input
(true dE/dX)

Detector Simulation

Key Elements:

1. *Differentiability*
2. *Neural network (NN)*



Detector Output
(ADC)

Reconstruction

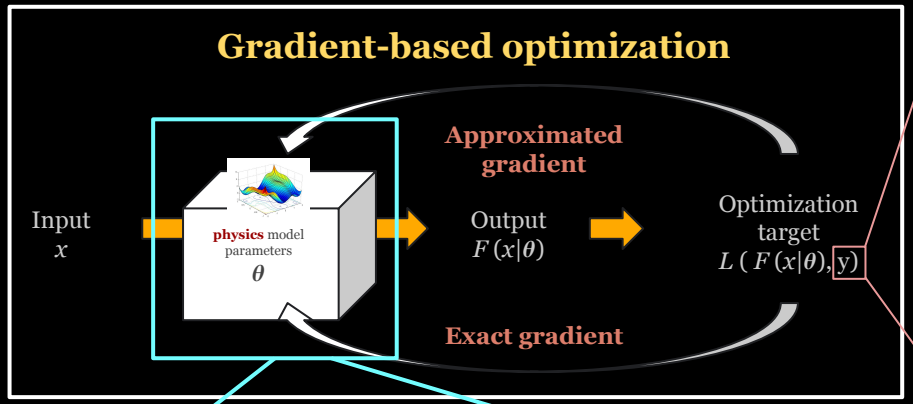
Detector physics model parameters

Calibration

Reconstructed
(Calibrated dE/dX)

Split Effort into Two Methods: CIDeR-ML

Calibration and
Inference of
Detector
Response with
Machine
Learning



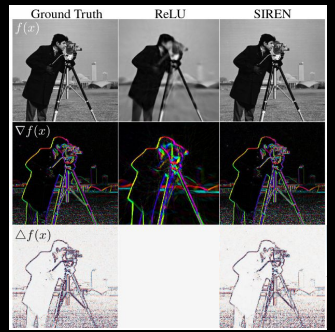
Simulation Packages

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

Later: real calibration data

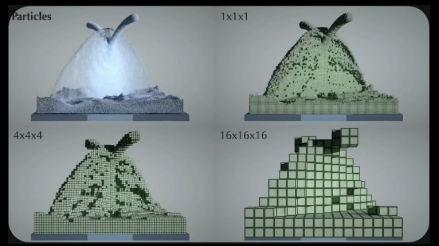
1) Surrogate Model

- SIREN
- Junjie, Ryo, Ryotaro
- Can treat sim mis-modeling

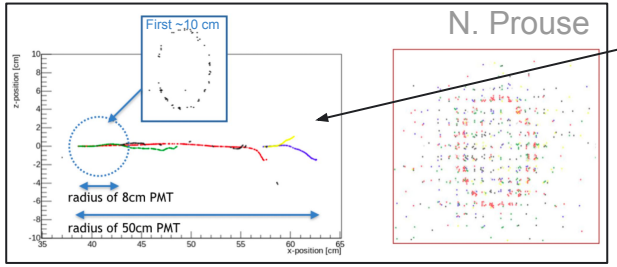


2) Analytical Differentiable Simulator

- Taichi Lang
- Omar, César
- First-principles description

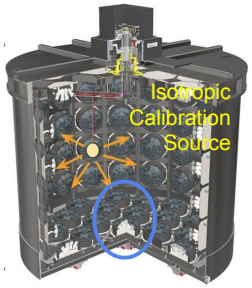


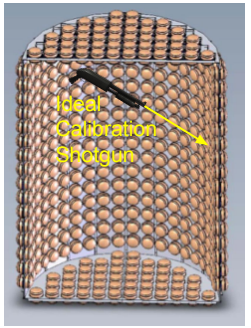
1) SIREN Surrogate Model Method

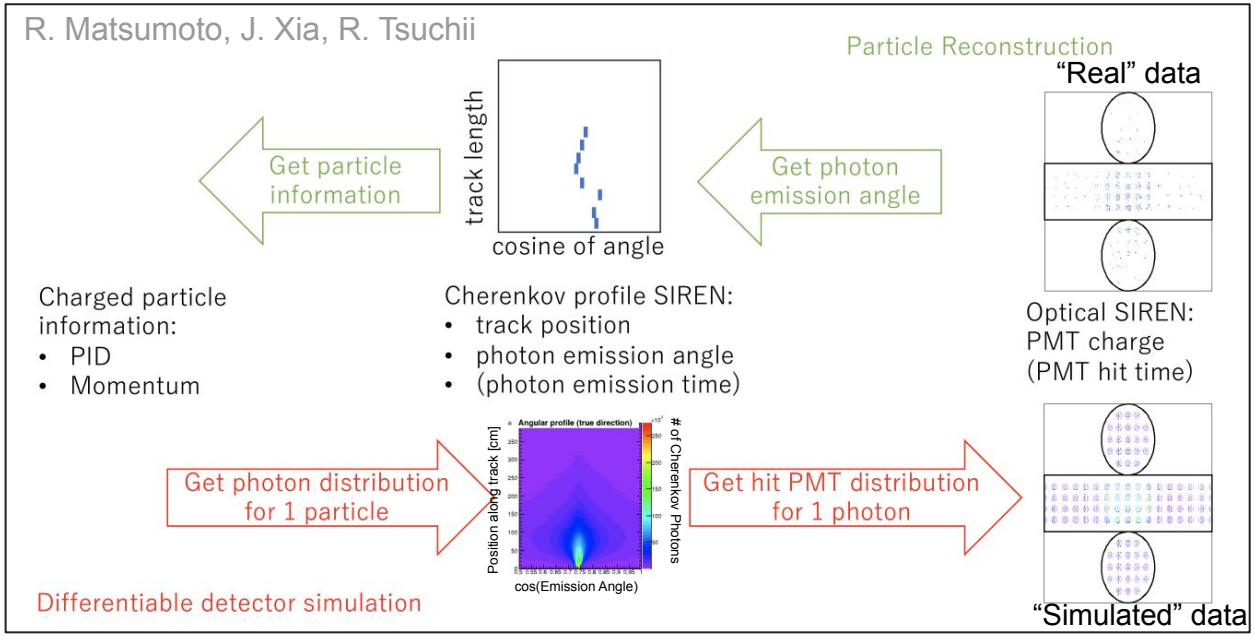


Track reconstruction and classification (Detector Inverse Solver, DIS)

- Status: training with isotropic source MC and simulated Cherenkov profiles
- Japan FY goal: “the first successful optimizations of SIREN and demonstration of the track reconstruction were completed”



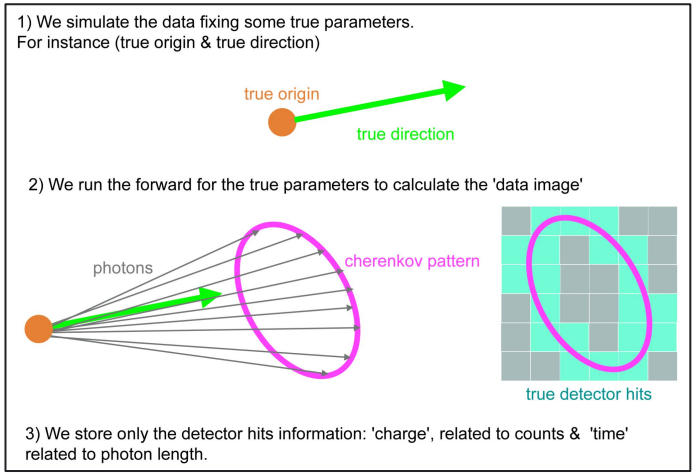




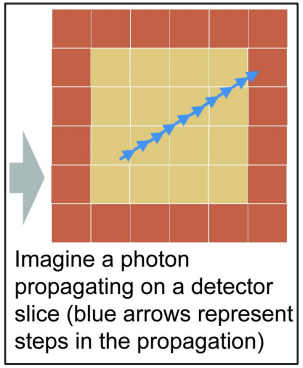
- *This meeting’s goals:*
  - *Train OptSIREN on “shotgun” MC*
  - *Demonstrate track reconstruction with either:*
    - *OptSIREN trained on isotropic or shotgun MC*
    - *Fake data from ChSIREN*

2) Taichi Analytical Differentiable Simulator

- 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

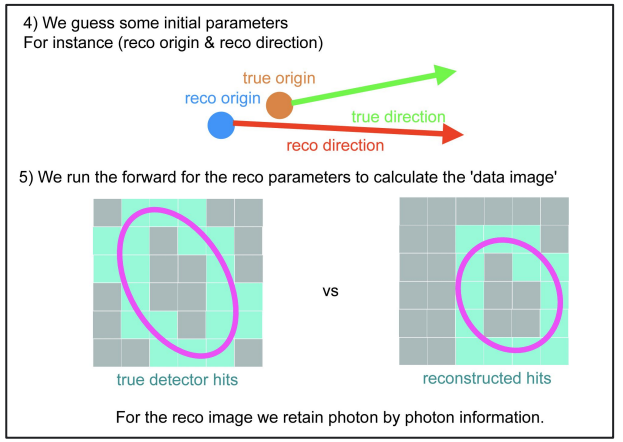


C. Jesus-Valls, O. Alterkait



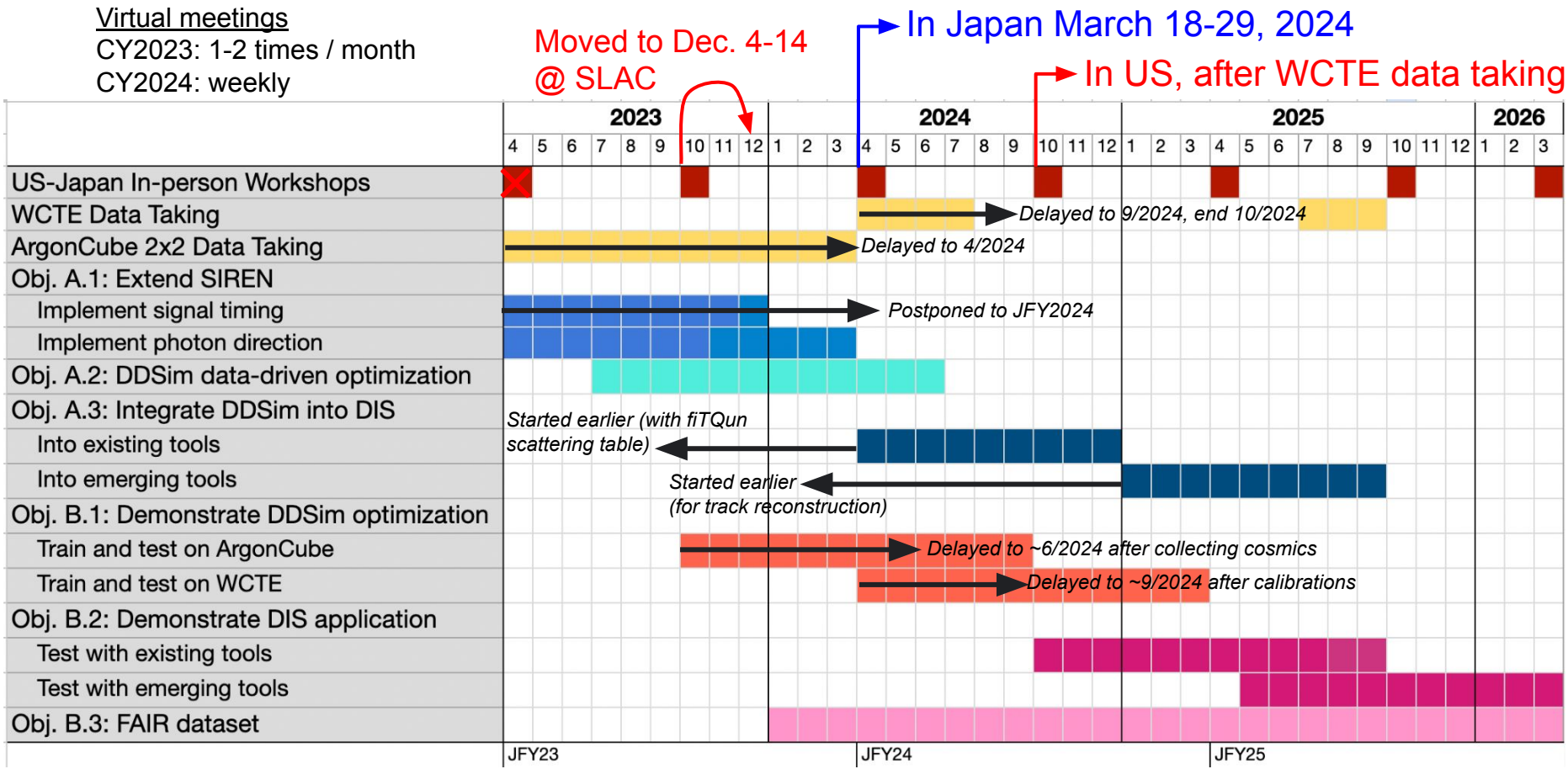
- Japan FY goal: “SimpleSim was used to generate a photon bomb sample, which Taichi Lang successfully inferred the positions of.” ✔

- *This meeting’s goal: Determine a method for stochastic processes such as light scattering*



Project Schedule

Virtual meetings
CY2023: 1-2 times / month
CY2024: weekly



Workshop Structure

- Morning huddle:
  - Focus presentation
  - Everyone involved in brainstorming daily goals and plans for each project group (WC and LAr)
- Working time:
  - Breakout into project groups, hack, and discuss
- Daily summary:
  - Short reports of daily progress from each project group
- Friday weekly summary:
  - Usual CIDeR virtual meeting
- Special events:
  - Thursday, March 28: Yifan's seminar (Hongo)
  - (Tentative) Tuesday, March 26: Omar's seminar (IPMU)

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

Let's have fun!