Event Reconstruction in an Opaque Scintillator

Garrett Wendel† on behalf of the CLOUD Collaboration

CLOUD

Fig. 1: Diagram of the CLOUD Detector
35 m from the Chooz reactor, ~10000 fibers, 5–10-ton opaque target volume.
See poster by D. Navas

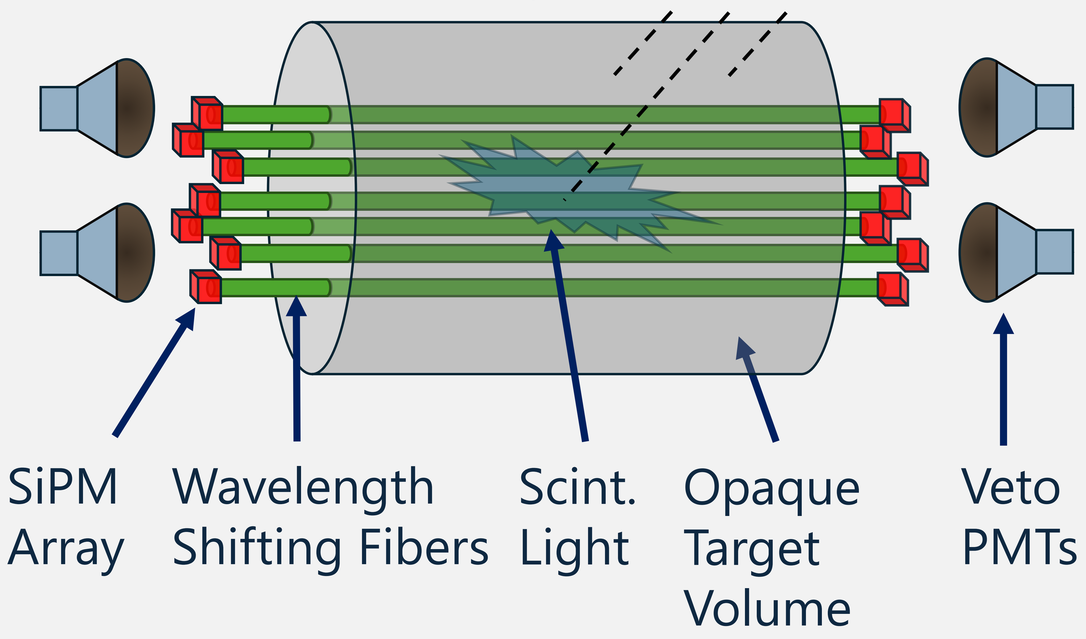
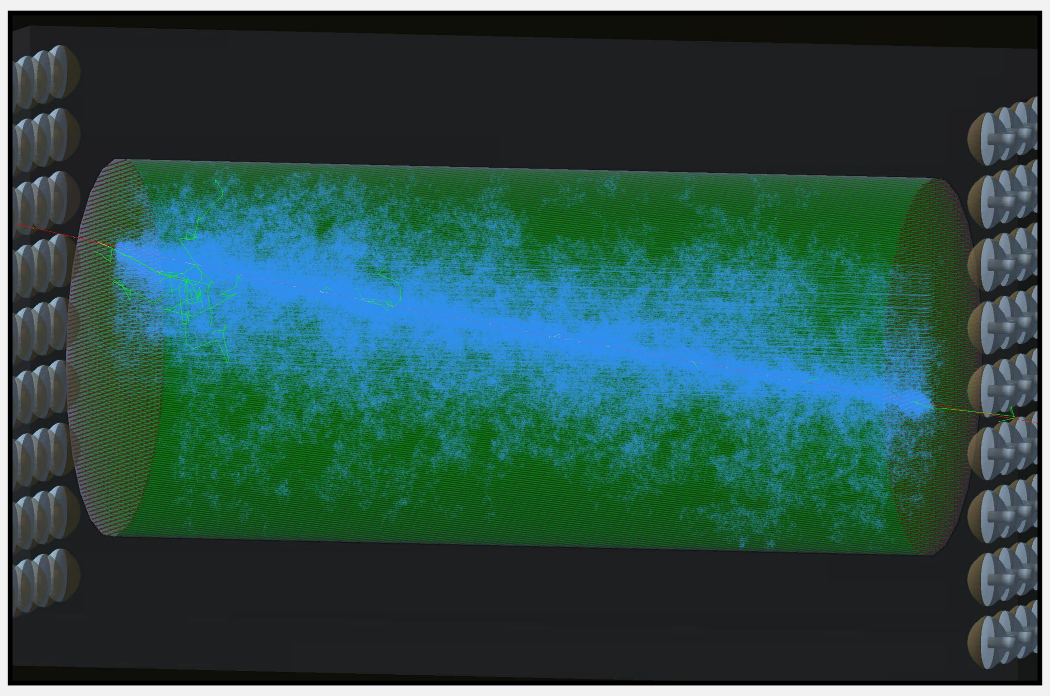


Fig. 2: A detailed optical Monte Carlo simulation of a muon in CLOUD.
See poster by C. Girard-Carillo



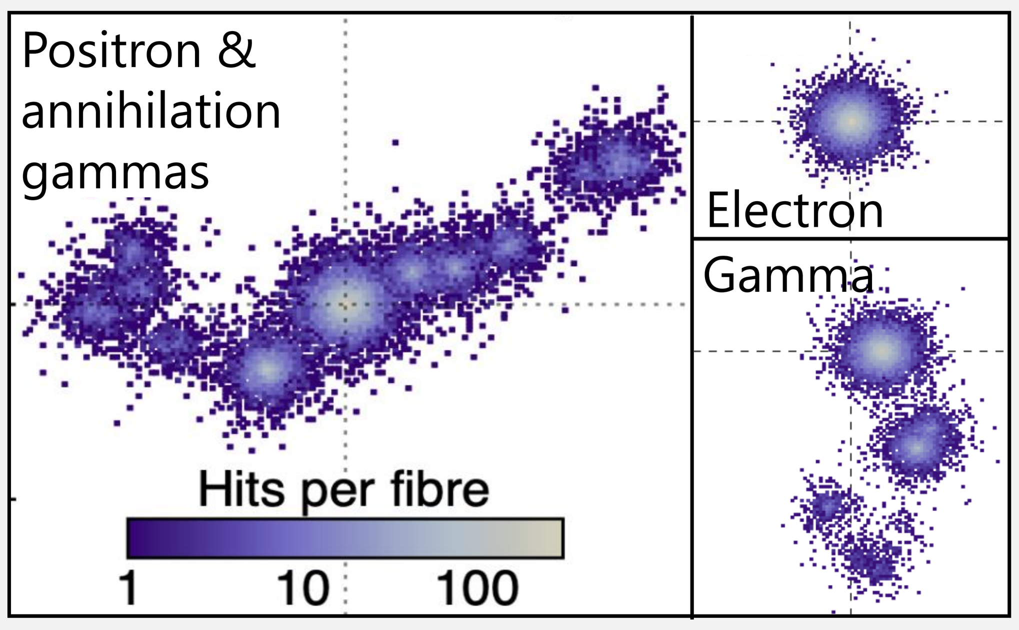
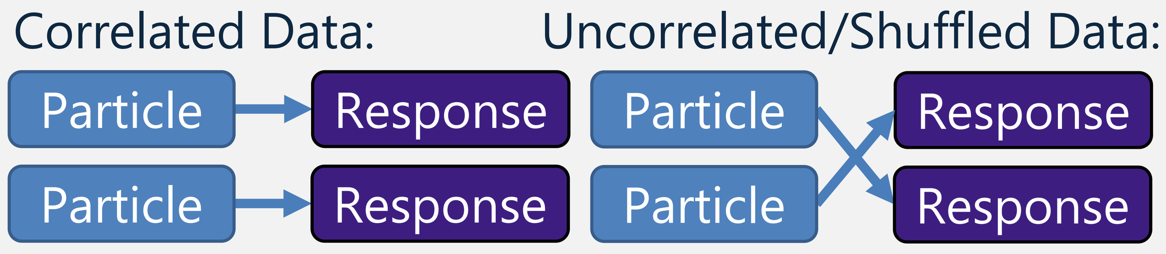


Fig. 3: Rich particle signatures[1], shaped by detector geometry, materials, and signal multiplexing, motivate deep learning techniques for event reconstruction.

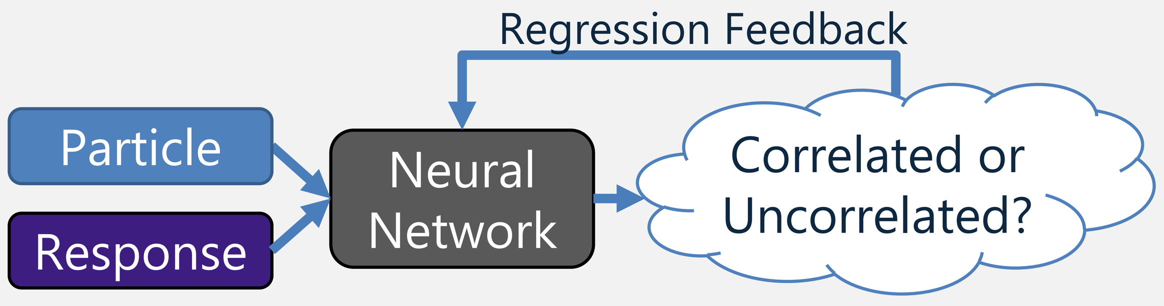
Reconstruction

Density Estimation using Likelihood-Free Inference[2]:

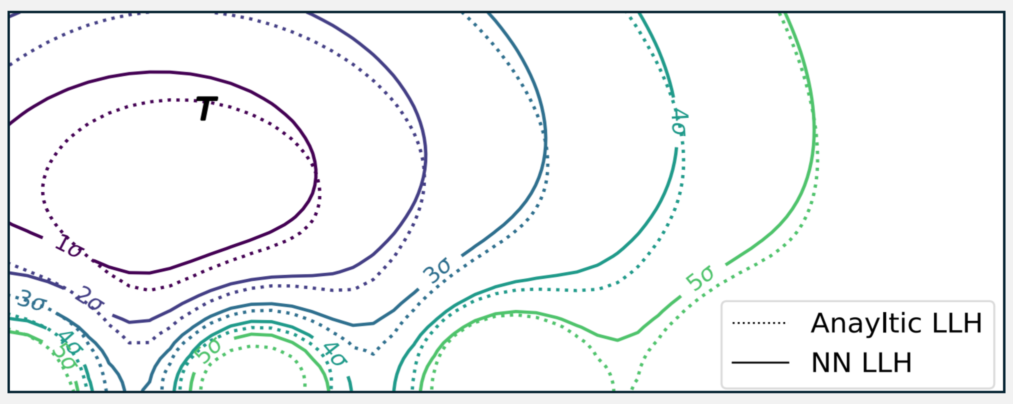
1. Generate two datasets from simulation:



2. Train a neural network to classify data:



3. Resulting network is a pseudo-likelihood space:



Enhancing Performance via Extended Maximum Likelihood[3]:

Generate likelihood by using individual photon measurement information.

- **Geometry:** Remove dependence of event data structure from detector geometry.
- **Symmetry:** Enable explicit symmetry enforcement e.g., time translation invariance of detector response.
- **Efficiency:** Reduce required training dataset size for accurate predictions.
- **Scalability:** Handle numerous channels and varying photon counts, ensuring flexibility across detectors.

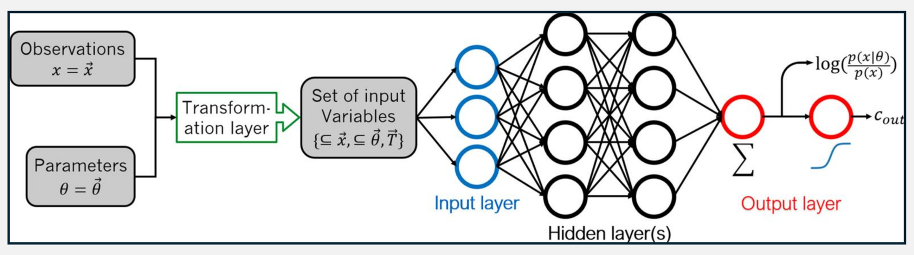


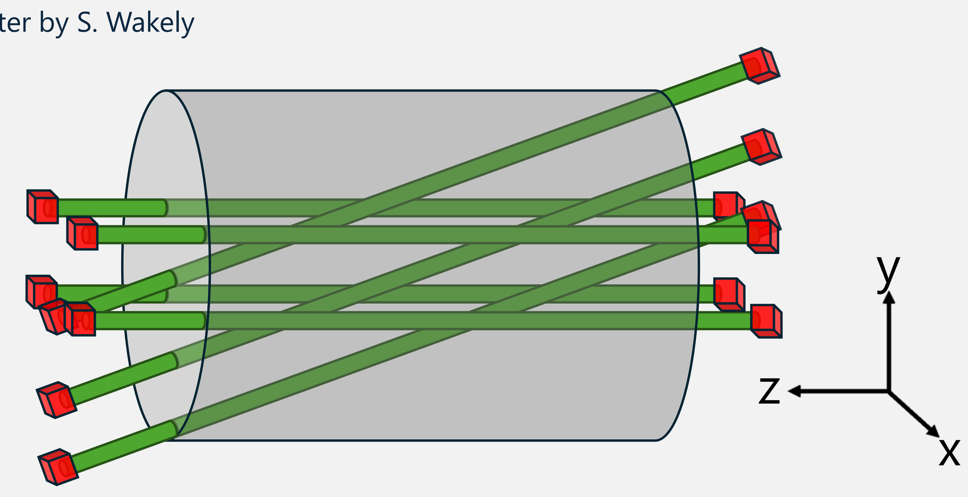
Diagram of network structure.

Reconstruction Study Stereo Layers:

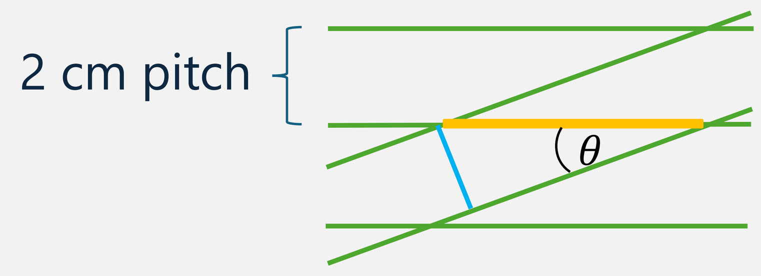
Reconstruct MeV scale electron events using outlined technique on two CLOUD configurations:

1. Non-stereo layers (Fig. 1), only timing information along fiber axis
2. Alternating stereo layers (20° tilt), timing and geometric information for all three dimensions

See poster by S. Wakely



Expectation for stereo z resolution: $\sim \frac{\sigma_{x\,stereo}}{\sin(\theta_{tilt})}$



Results

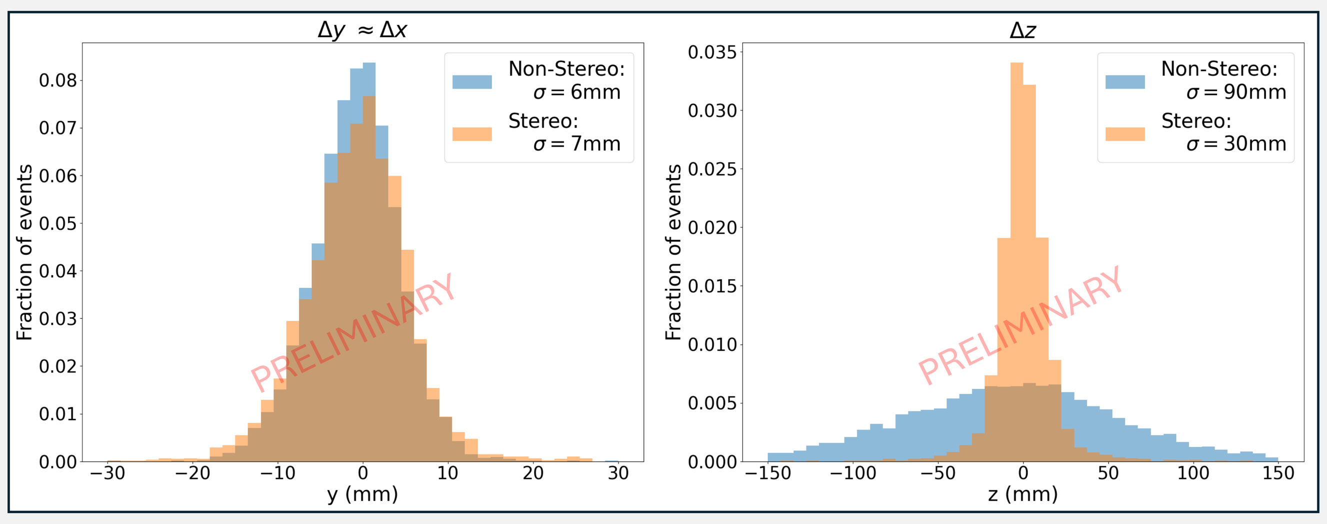


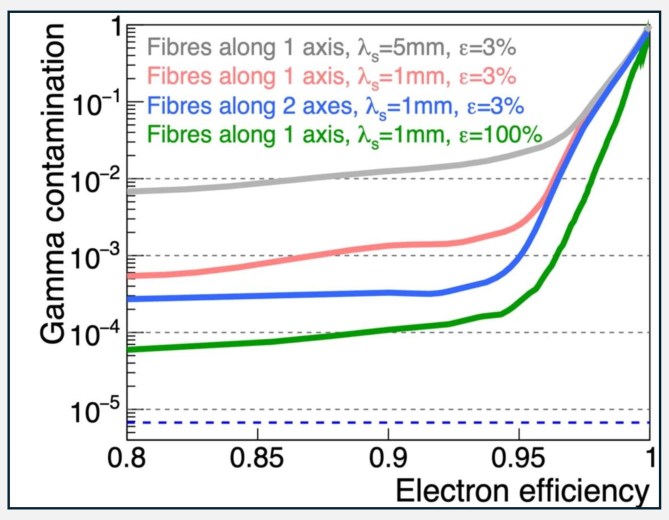
Fig. 4: The histograms compare vertex resolution, $\sigma \equiv$ MSE, for non-stereo (blue) and stereo (orange) setups using conservative estimates when simulating detector performance. The left shows xy-plane resolution, and the right shows z-axis resolution.

Noteworthy Features:

1. Vertex resolution in the xy-plane is smaller than fiber pitch.
2. Z vertex is significantly enhanced by stereo layers.
3. Stereo layers suggest improvement in event reconstruction, fiducialization efficiency, and particle identification performance.

Future Work:

Implement and compare reconstruction performance with GraphNeT architecture[4]



Perform detailed background rejection studies using both network architecture types and compare with previous results[1]

References:
[1] A. Cabrera et al., Neutrino physics with an opaque detector, Communications Physics 4, 1 (2021).
[2] J. Hermans et al., Likelihood-Free MCMC with Amortized Approximate Ratio Estimators (2019).
[3] P. Eller et al., A Flexible Event Reconstruction based on Machine Learning and Likelihood Principles, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1048, 168011 (2023).
[4] R. Abbasi et al., Graph Neural Networks for Low-Energy Event Classification & Reconstruction, Journal of Instrumentation 17 (11), P11003

†gmw5164@psu.edu

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