Reconstruction of Track-like Event in TRIDENT Based on Graph Neural Network

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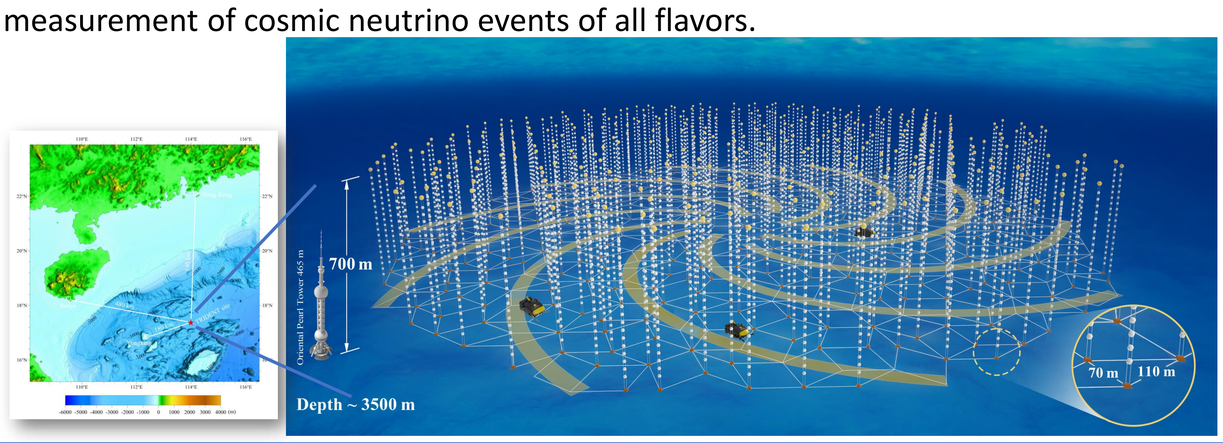
for the TRIDENT Collaboration

TRIDENT

TRopIcal DEep-sea Neutrino Telescope (TRIDENT) [1]: a next-generation neutrino detector to be located in the South China Sea. Its primary objectives include the discovery of high-energy astrophysical neutrino sources and enhancing the measurement of cosmic neutrino events of all flavors.

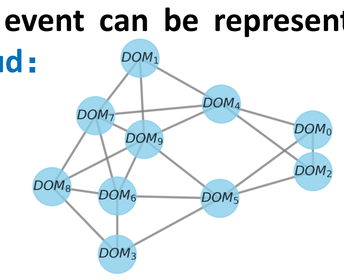


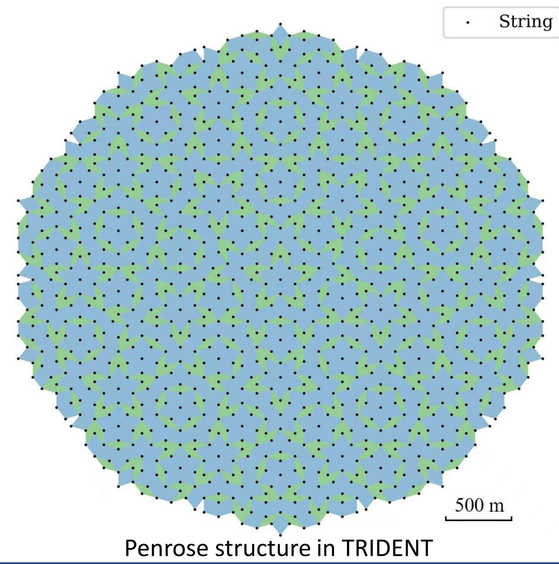
Reconstruction method

Events in TRIDENT:
- Irregular geometry.
- Sparse signal.

Graph Neural Network (GNN) outperforms Convolutional Neural Network (CNN) in terms of angular resolution.

Neutrino event can be represented by point cloud:





Penrose structure in TRIDENT

Event Topology

Neutrino Event Generator

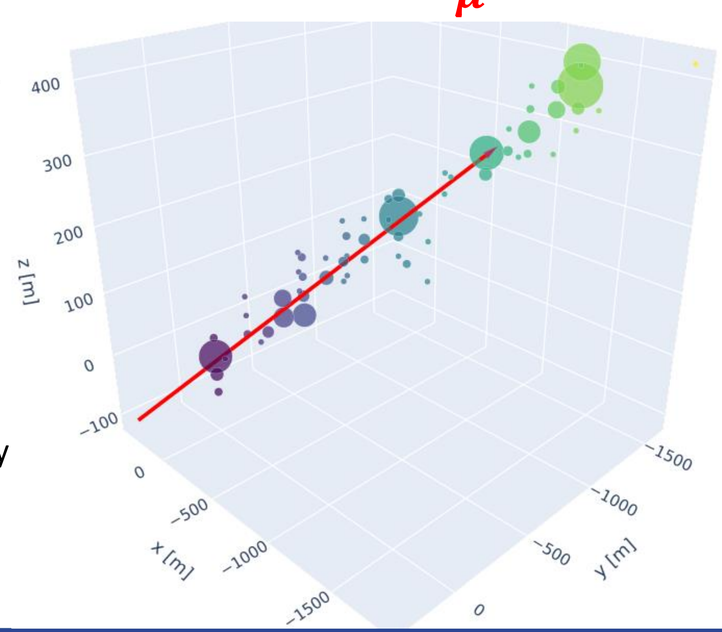
Based on CORSIKA8 [2]:
- ☐ Preliminary earth model with detector.
- ☐ Sampling over $\vec{P}_\nu$ and DIS vertex.

Hybrid DOM [6] (hDOM)

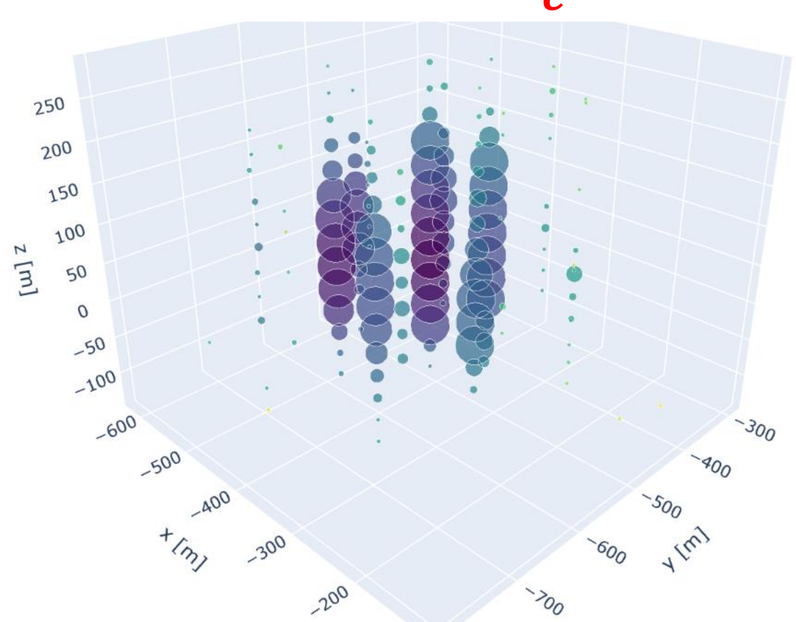
Detector Response Simulator

Based on Geant4 [3,4]:
- ☐ Cascade parametrization for high energy electrons.
- ☐ OptiX [5] for propagation of Cherenkov photons in water.

Track-like ν_μ Event



Shower-like ν_e Event

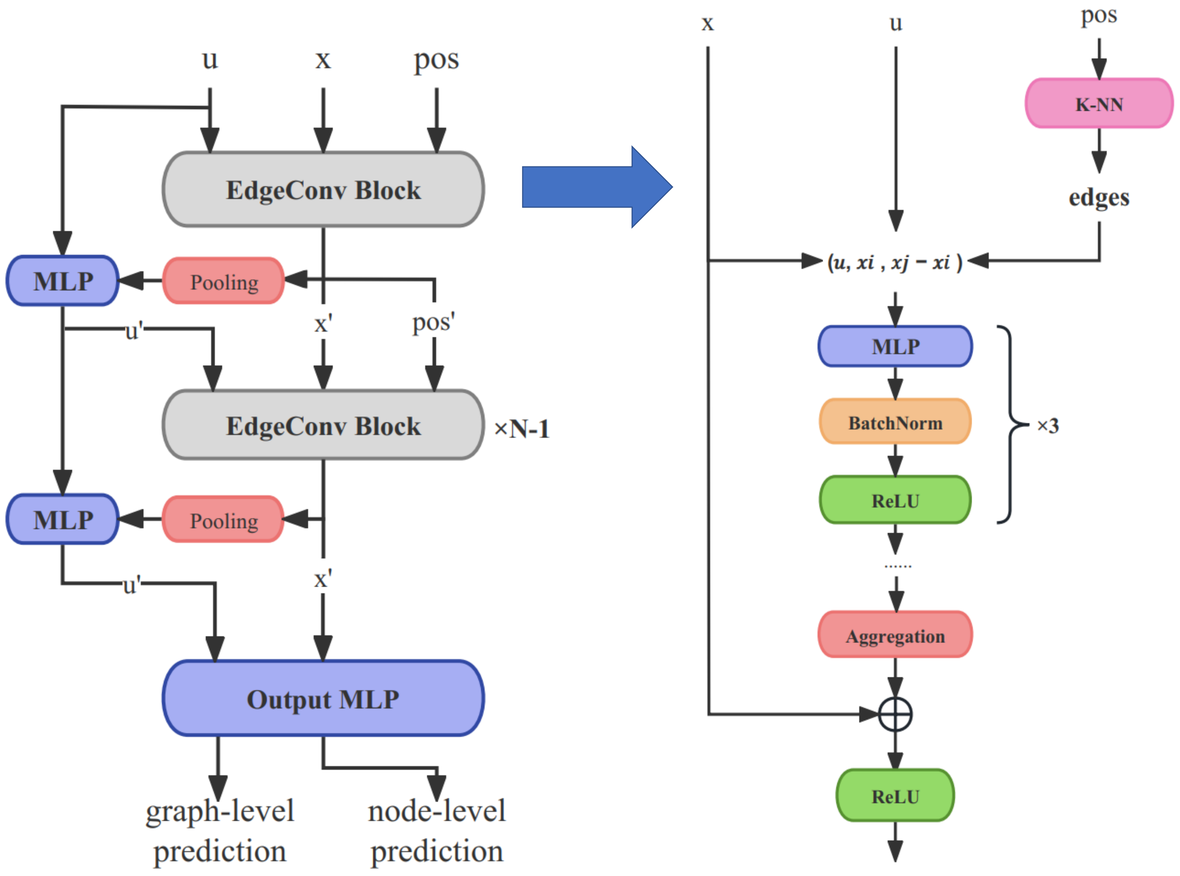


Network Architecture

GNN designed to handle data with a graph structure:

$$Graph := \{V, u, P\}$$

- $V = \{x_i\}$: attributes (measured time and charge) of the i–th node (hDOM).
- u: graph-level attributes, i.e. Event description or $Mean(x_i)$.
- $P = \{pos_i\}$: location of the i-th node (hDOM).

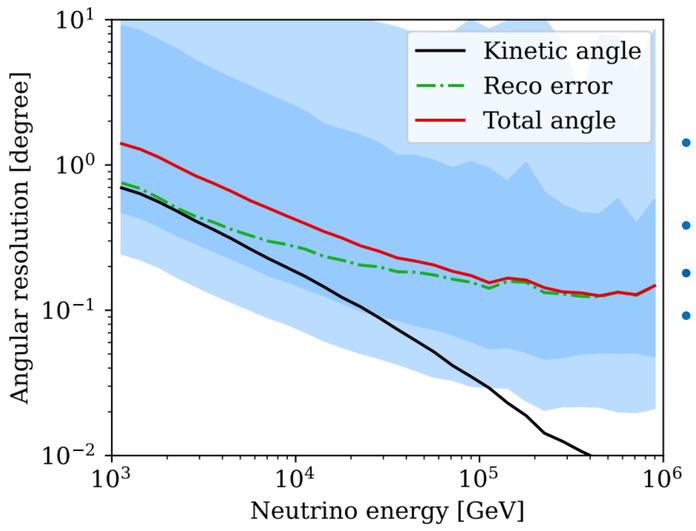


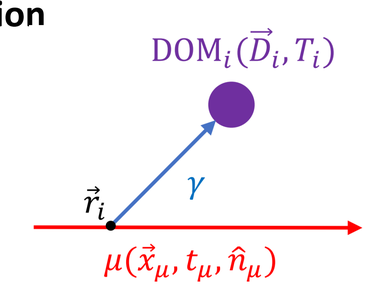
Track-like Event Reconstruction

GNN models are trained to reconstruct the direction and energy of track-like ν_μ events.

ν_μ Direction Reconstruction

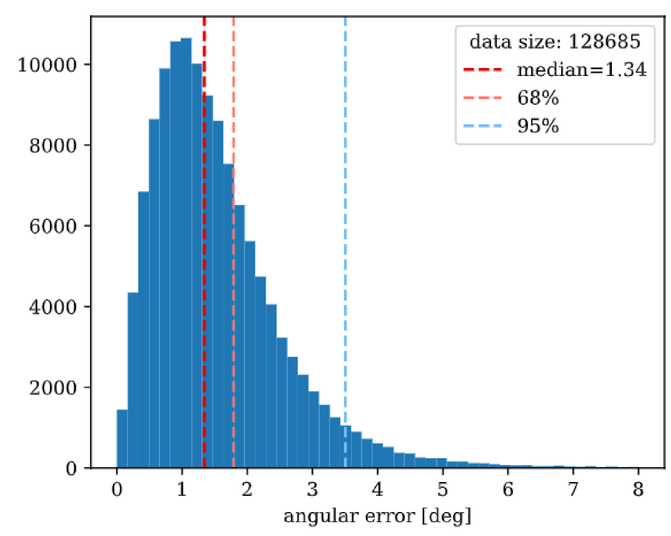
- **Kinetic angle** = $<\vec{n}_\mu, \vec{n}_\nu>$
- **Reco error** = $<\vec{n}_\mu, \vec{n}_{recon}>$
- **Total angle** = $<\vec{n}_\nu, \vec{n}_{recon}>$





- Input features: $\vec{D}_i$, T_i and number of hits n_i
- Object of interest: $\vec{r}_i$
- $Loss = \Sigma_i n_i \times \left|\overrightarrow{output_i} - \vec{r}_i\right|^2 / \Sigma_i n_i$
- Linear fit on $\vec{r}_i \longmapsto \hat{n}_\mu$

100TeV ν_e Direction Reconstruction



- Input features: $\vec{D}_i, Histogram\{T_i\}$
- Object of interest: $\hat{n}_{\nu_e}$
- $Loss = \left(output - \hat{n}_{\nu_e}\right)^2$

Outlook

- ➢ Improve the GNN architecture to enhance the accuracy of reconstruction.
- ➢ The GNN architecture to be used to distinguish neutrino signals from atmospheric muon background.
- ➢ Reconstruction of ν_e and ν_τ to be further investigated with GNN method.

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[3] A. et al. (GEANT4 Collaboration) IEEE Transactions on Nuclear Science, vol. 53, no. 1,pp. 270–278, 2006
[4] S. A. et al. (GEANT4 Collaboration) Nucl. Instrum. Meth. A, vol. 506, no. 3, pp. 250–303,2003.
[5] S. Blyth, "Opticks : GPU Optical Photon Simulation for Particle Physics using NVIDIA®OptiXTM," EPJ Web Conf., vol. 214, p. 02027, 2019
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