Supernova pointing with DUNE

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Overview

- DUNE detector and interaction channels
- Interaction channels for supernova (SN) pointing
- SN direction reconstruction (methods developed by AJ Roeth and James Shen)
- SN pointing visualization

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DUNE – The Far Detector

- 40 kt fiducial volume LArTPC
- Events create charge carriers that drift to read out wires, resulting in charge waveforms
- Far detector will be located 1 mile underground to reduce cosmological backgrounds
- LArSoft particle event simulation software → simulates neutrino events in the LArTPC to generates readout waveforms & perform event reconstruction/analysis

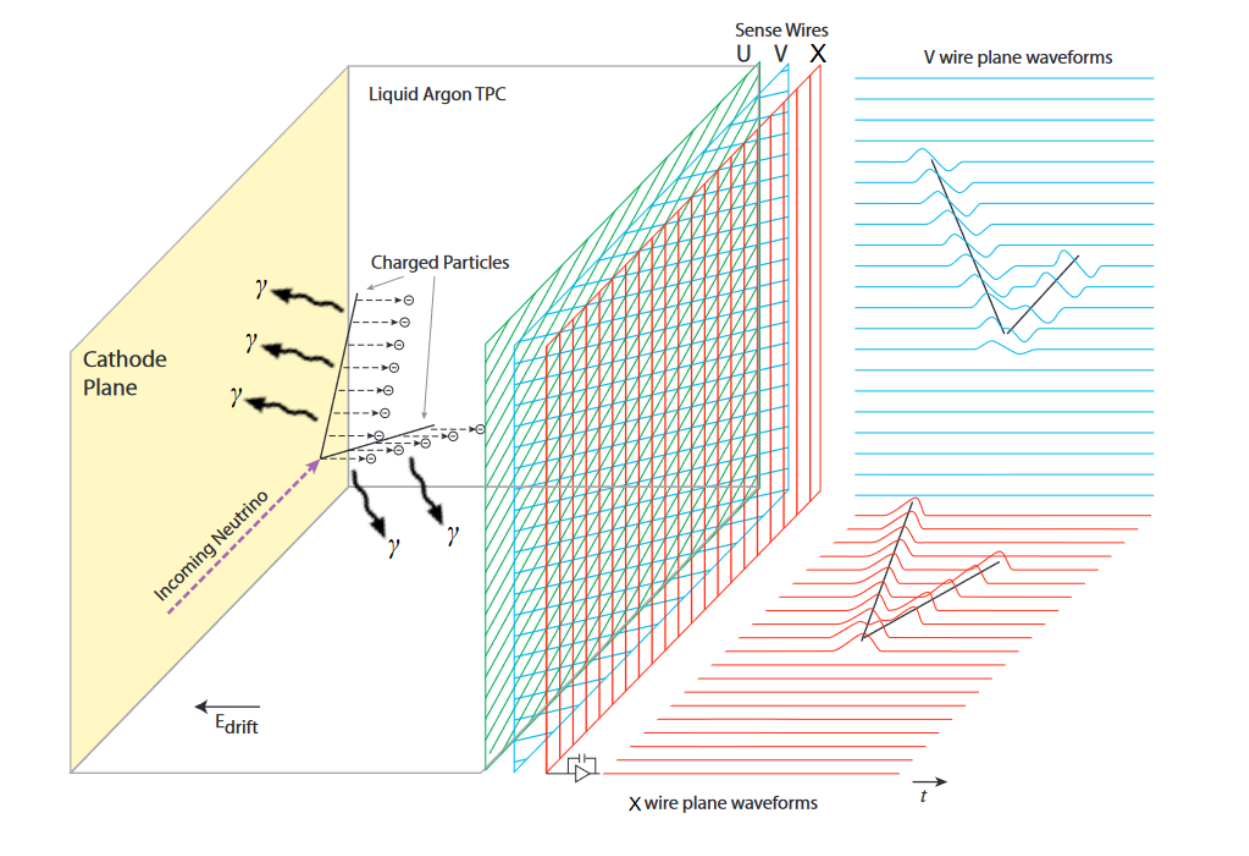

Image from DUNE Technical Design Report. arXiv: 2002.03005

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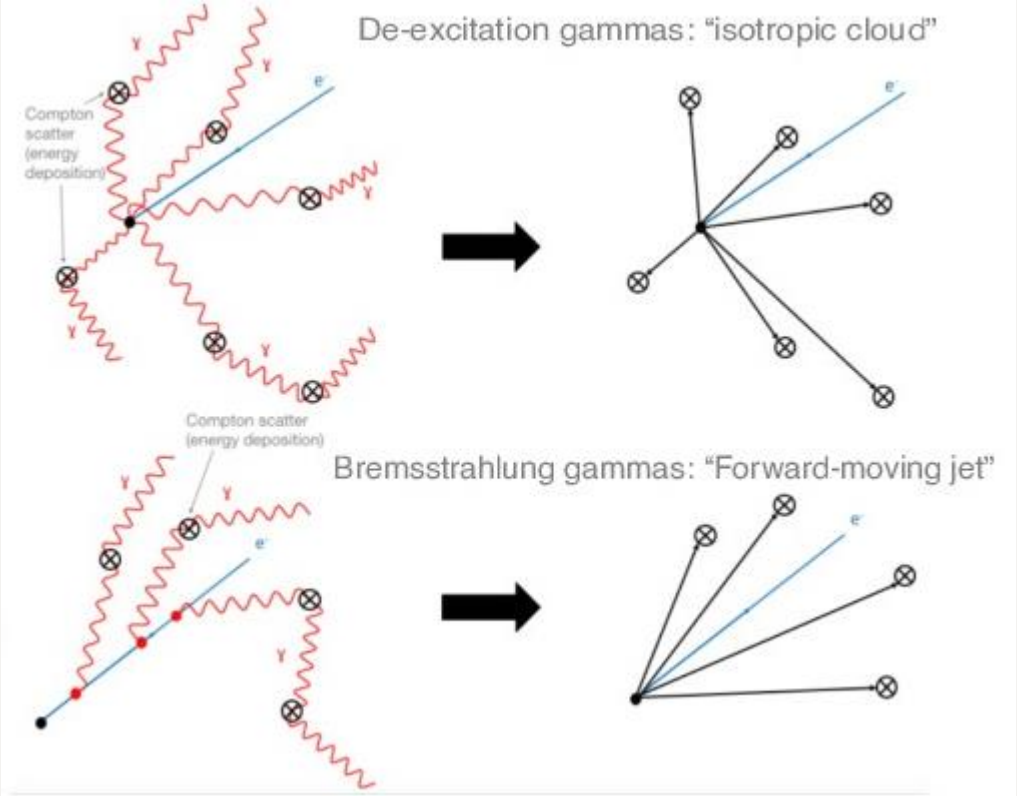
DUNE – Interaction channels

- DUNE will look for SN activity through **two channels:** charged current interactions and elastic scattering interactions.
- **Charged current:** electron neutrinos interact with Ar-40 to create an electron and excited K-40, which deexcites through emission of photons
- **Elastic scattering:** neutrinos of all flavors scatter off electrons, leaving an ionization path in the LAr as the electron loses energy.
- Other Channels: **neutral current** channel is ignored



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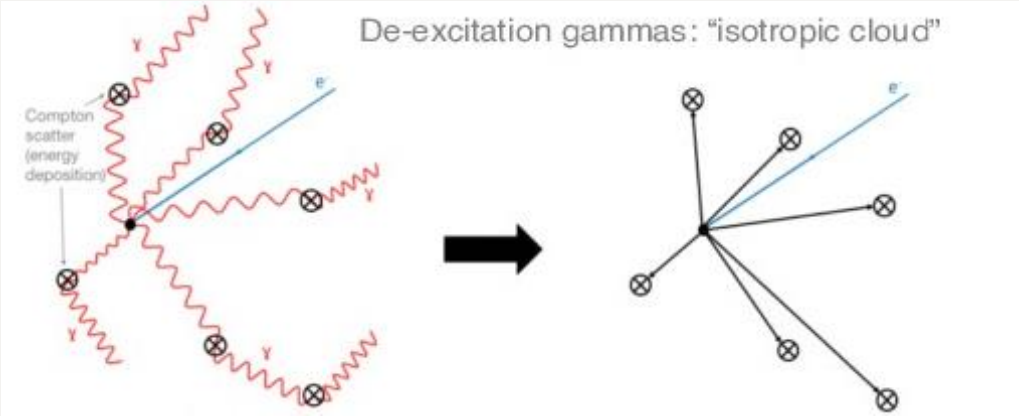
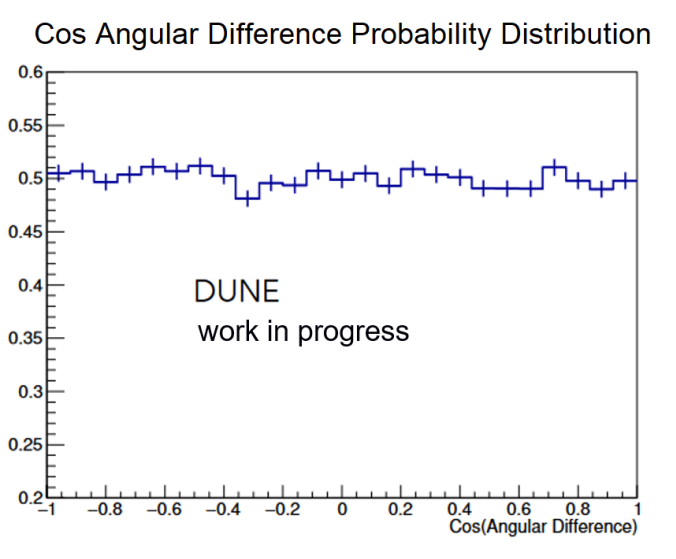
Charged Current (CC) Interactions

- Large cross section – event counts will be useful in triggering real time SN detection
- Gammas and electron are not correlated with the incident neutrino direction, so there is no directional information.
- Define $\cos(\theta) = \hat{d}_{SN} \cdot \hat{d}_{event}$





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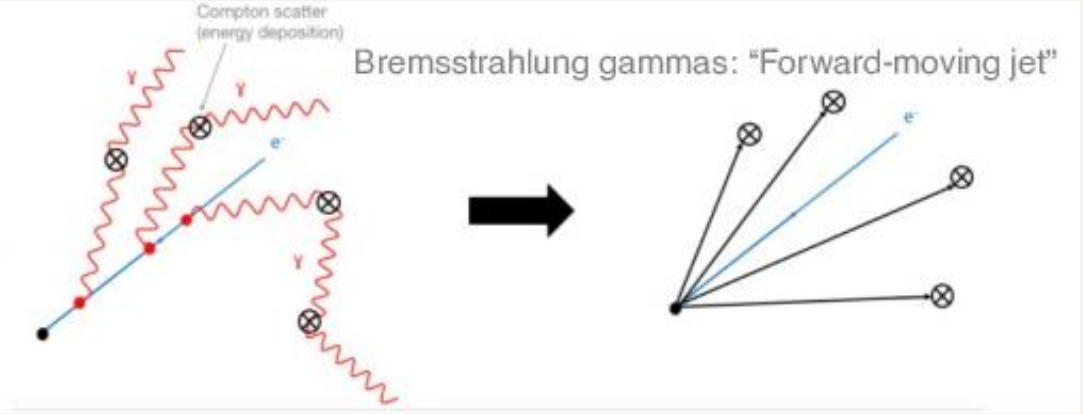
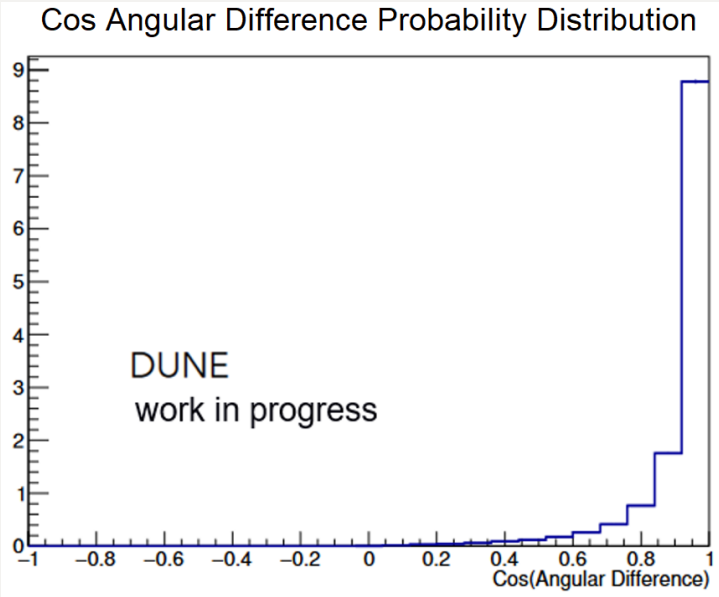
Elastic Scattering (ES) Interactions

- Smaller cross section than CC
- Emitted electron has strong correlation with the incident neutrino direction – useful for SN pointing
- In reconstruction, starting direction of electron is ambiguous – daughter particles can infer correct direction





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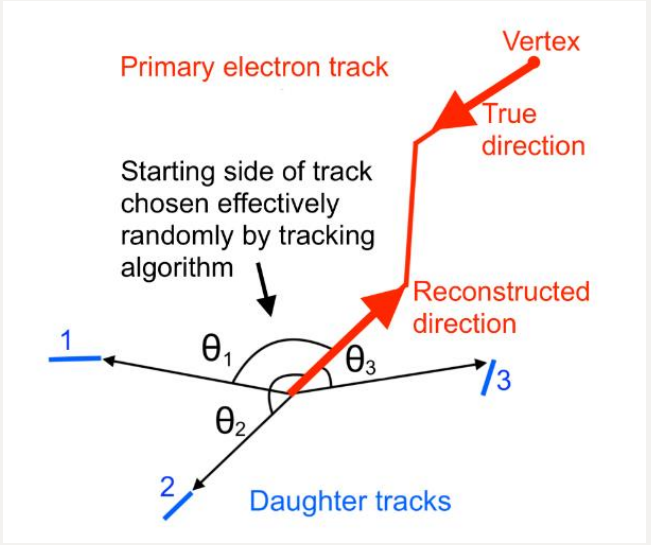
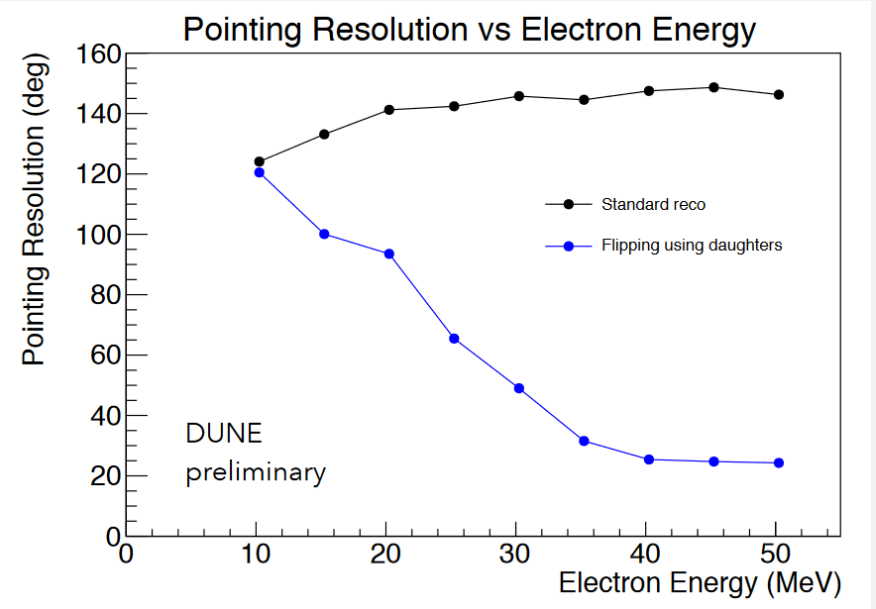
Daughter Flipping

- ES event daughter particles are distributed in the direction of the primary electron
- Higher energy events → more daughter particles and better disambiguation of primary electron direction





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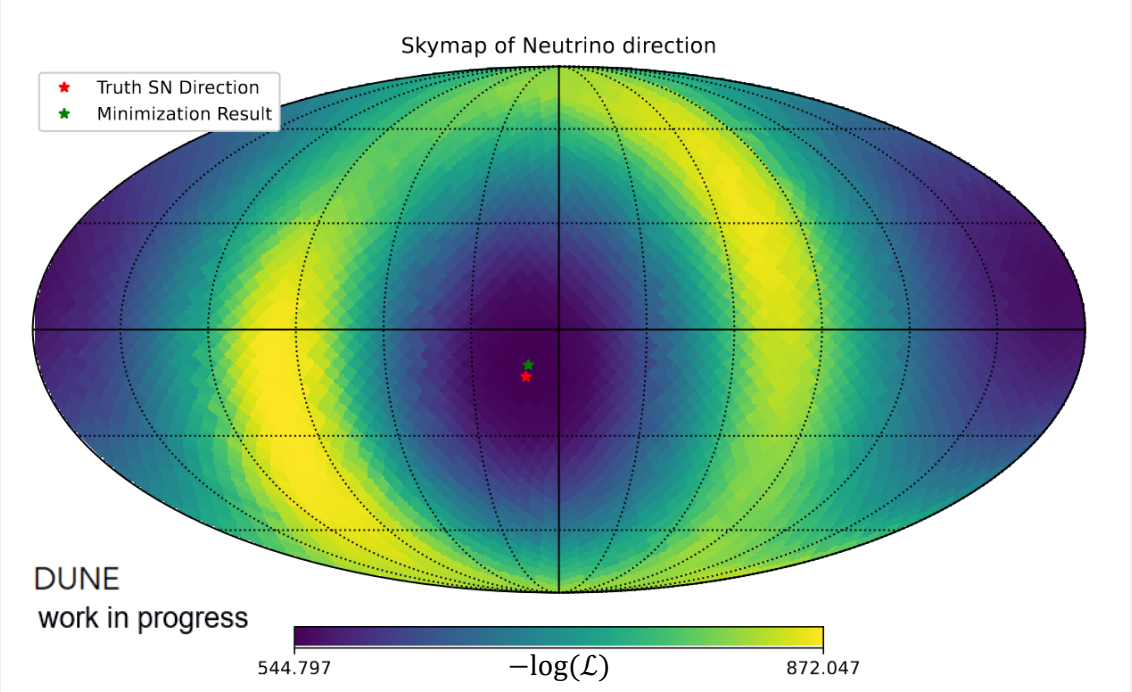
Determining SN direction

- Use maximum likelihood estimation (MLE) on the collected events

$$max(\mathcal{L})$$
$$= max \prod_i p_i(\cos(\theta)) = min \sum_i -\log(p_i(\cos(\theta)))$$

- Minimizing the negative log likelihood will give the predicted SN direction

- Example skymap: ~300 ES events



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Classification

- In order to get the best SN pointing information, we want to only look at the ES events when doing pointing analysis

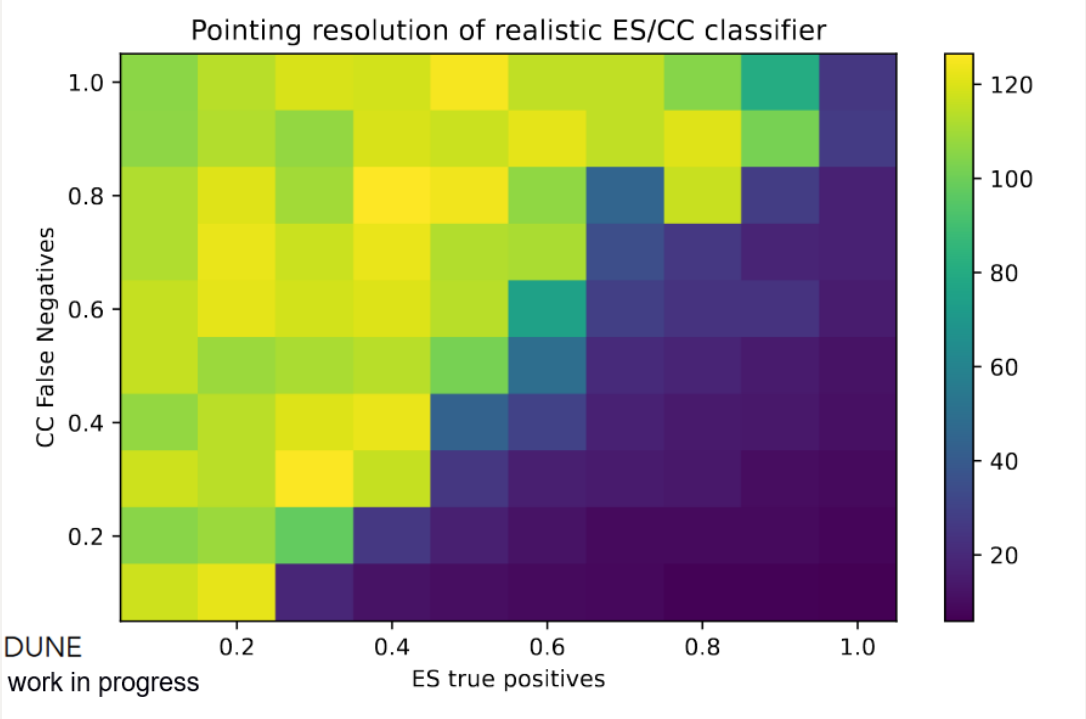
- Confusion matrix:

$$C = \begin{pmatrix} C_{ES} \to C_{ES} & C_{CC} \to C_{ES} \\ C_{ES} \to C_{CC} & C_{CC} \to C_{CC} \end{pmatrix}$$

- Optimistic BDT classification result:

$C_{ES} \to C_{ES} = 0.86\,, C_{CC} \to C_{ES} = 0.04$

Pointing resolution: 5.3 degrees [2]



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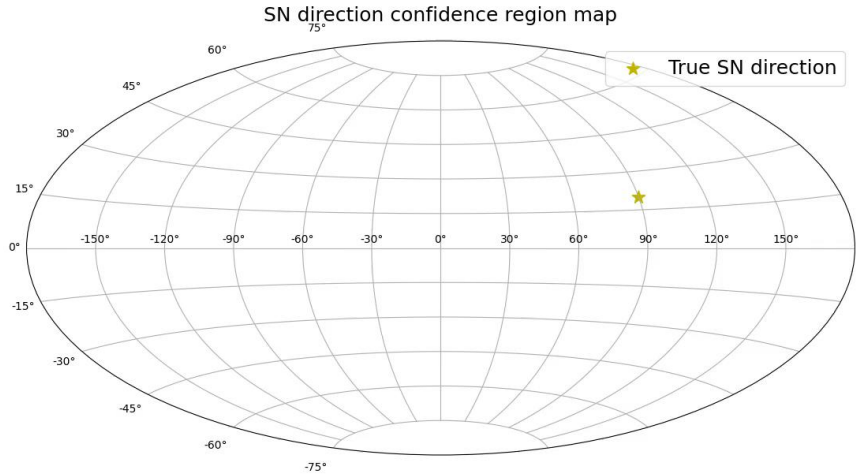
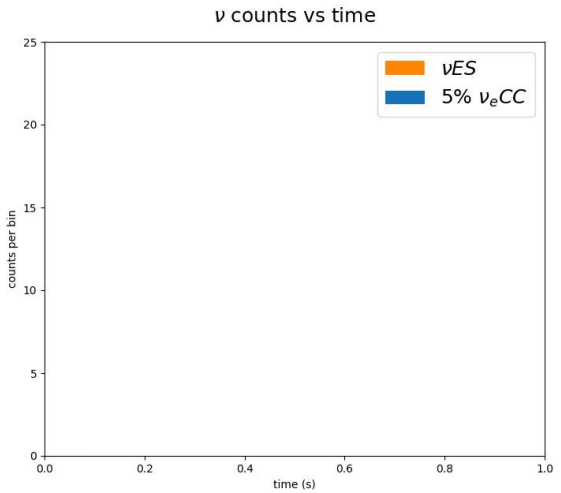
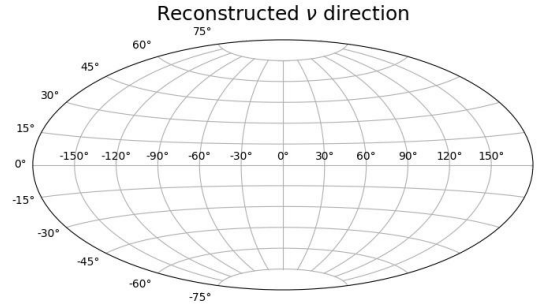
Visualization

- A visualization tool for real time SN neutrino pointing
- Implemented here with a toy model based on previous works ([1] & [2])
- Demonstrates pointing of a 10 kpc SN, with only 5% CC events misclassified as ES







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References

[1] AJ Roeth. Supernova Pointing Resolution of DUNE. *Bulletin of the American Physical society*, 64, 2019.

[2] James Shen. Supernova Pointing Resolution of DUNE. April 2022.

[3] Erin Conley. Using boosted decision trees to identify supernova neutrino interactions in DUNE, June 2020.

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