Testing the Supernova Pointing Resolution of DUNE with ICEBERG

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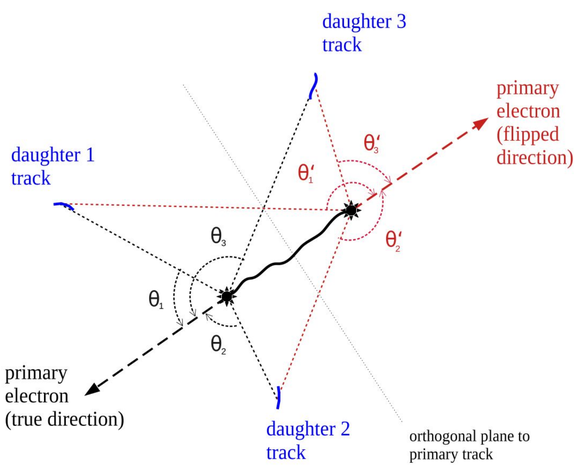
Motivation

- The **next galactic supernova (SN)** will provide a wealth of data to the multi-messenger astronomy (MMA) community through in depth measurement of the electromagnetic and neutrino components of the SN signal
- The **Deep Underground Neutrino Experiment** (DUNE) will be a **unique neutrino detector** due to its ability to measure the electron neutrino spectrum
- To make the best MMA observation, SN neutrino detectors can provide **early warnings of the burst and point to its location** in the sky, as neutrinos will proceed the photons from the burst
- A key challenge for SN pointing in liquid argon time projection chambers (LArTPCs) like DUNE is **understanding the directionality of the neutrino interactions**

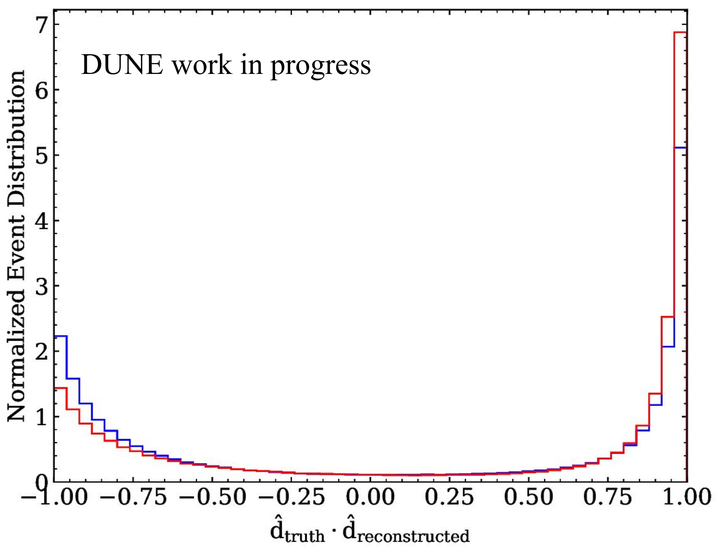
Daughter Flipping



- Neutrino interactions in LArTPCs relevant to SN detection come in two basic types
  - **Charged Current (CC):** neutrinos interact with argon-40 and produce an electron, K-40, and de-excitation gammas. The emitted particle **directions have little correlation** with the incident neutrino direction
  - **Elastic scattering (ES):** neutrinos "bounce" off of electrons in the argon atoms, ionizing them in a **direction correlated** with the neutrino direction
- ES interactions used for SN pointing, however **their directionality is ambiguous** in LArTPCs
- Daughter flipping uses the location of particles generated by the primary electron to **infer the head/tail orientation** of the track
- The starting vertex is selected as the vertex with largest

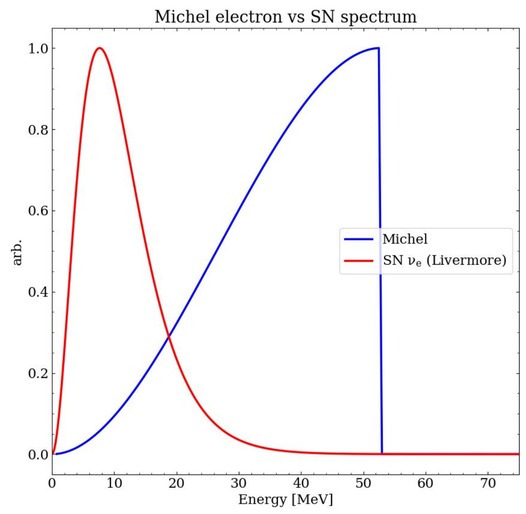
$$\sum_i cos(\theta_i)$$

- SN pointing **resolution is a function of daughter flipping** efficiency



The dot product of the reconstructed electron track direction and the truth direction. The blue line shows no daughter flipping while the red shows using daughter flipping. [2]

Michel Electrons



- Muons, created in the upper atmosphere from cosmic ray collisions, decay at rest in a characteristic 3-body decay

$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$

- The Michel electrons are emitted in a **similar energy range as SN neutrino** induced electrons
- **Rate of Michel electrons is small** compared to other interactions, thus selection criteria for candidate events must be developed

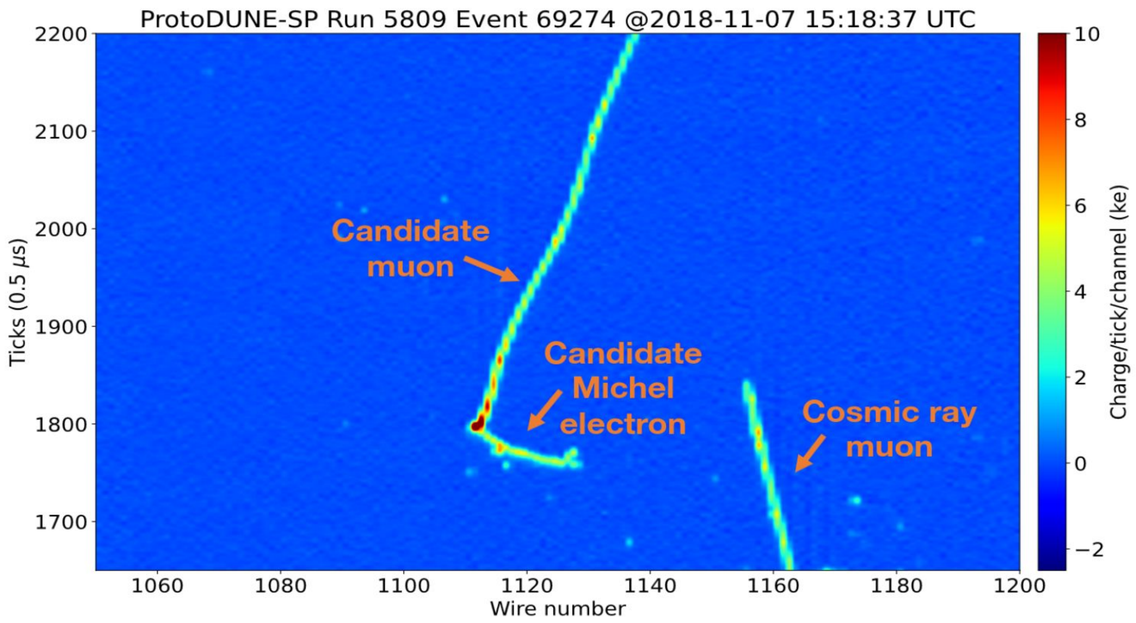


Figure 2 from [1]. Data taken from the ProtoDUNE LArTPC, this is what a typical Michel electron event looks like in a LArTPC.

Using ICEBERG to test track reconstruction

- **ICEBERG is a ~1 ton LArTPC** equipped with the DUNE DAQ electronics, allowing for testing of online reconstruction algorithms
- **Michels will be used as a proxy** for SN interactions
- **Daughter flipping will be tested on Michels** to quantify the efficiency of the algorithm
- In depth profile of noise in the ICEBERG detector will allow for testing **daughter flipping as a function of prevalent noise**
- **Training sets will be generated** using a GEANT4 based physics software LArSoft that will simulate the detector response to events
- **ML models** will be trained on simulated data to aid in **event identification**

A picture of the inside of the ICEBERG detector, showing the surrounding field cage and photon detector slots. [3]

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References

[1] A. Abed Abud et al. (DUNE), Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector, Phys. Rev. D 107, 092012 (2023), arXiv:2211.01166 [hep-ex].
[2] J. Shen, A. Roeth, J. Hakenmueller, J. Queen, D. Pershey, K. Scholberg, "Supernova Pointing Resolution of DUNE", DUNE doc 27538, DUNE, 2023
[3] S. Mishra, T. Junk, D. Adams, I. C. Terrazas, R. Fitzpatrick, Y. Liu, "ICEBERG at Fermilab", EDMS id 2620749/1, DUNE, 2021, *https://edms.cern.ch/document/2620749/1*