Analyzing the Pointing Resolution of Supernova Neutrino in LArTPC

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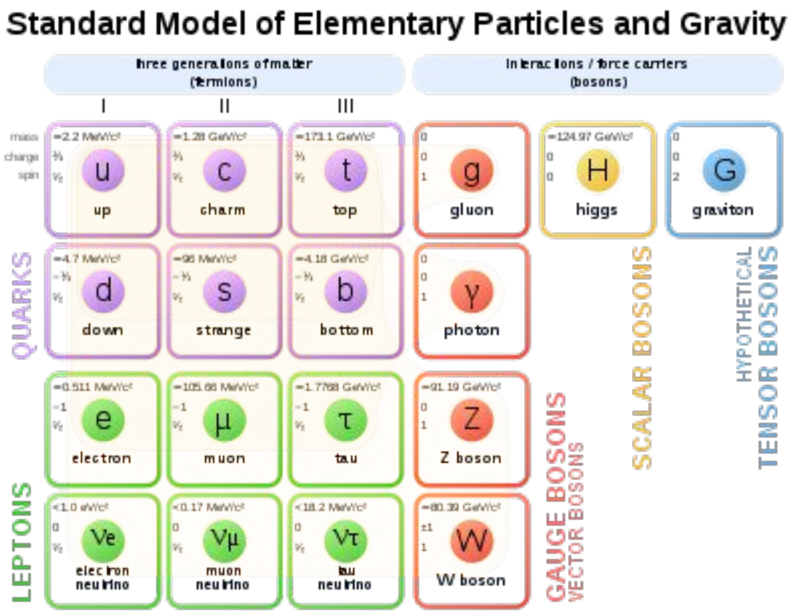
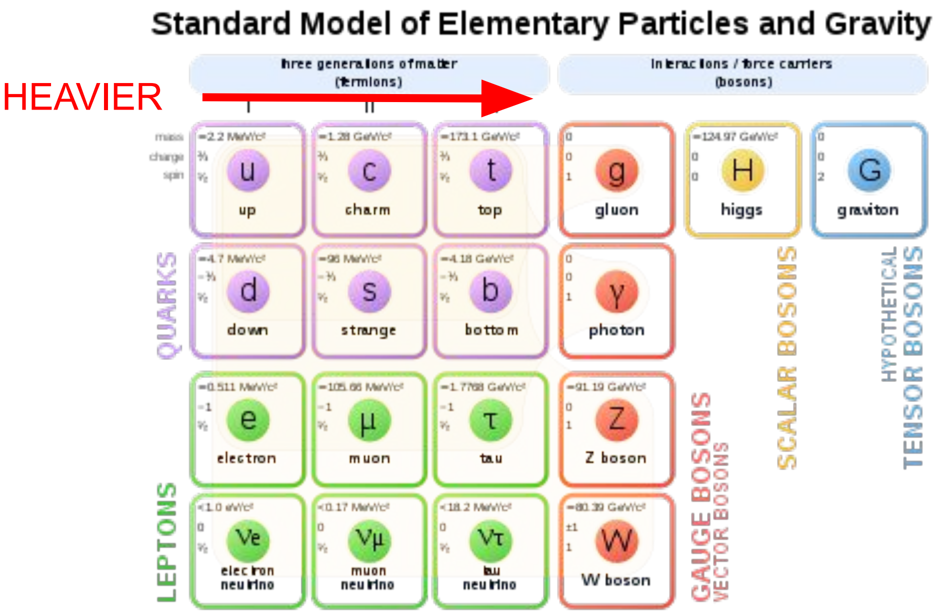
The standard model of particle physics

- Quarks (which make up protons and neutrons)
- Leptons
    - Electrons, and their heavier relatives
    - Neutrinos
- Interaction / force carriers

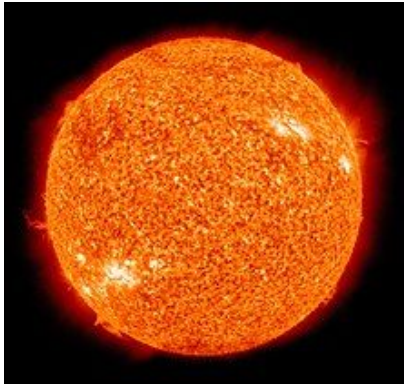


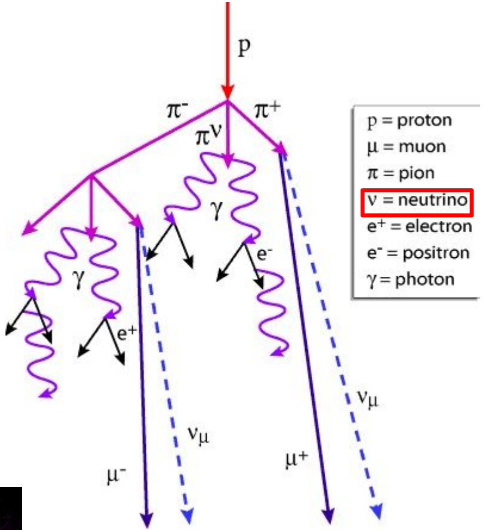
Quarks and Leptons come in families

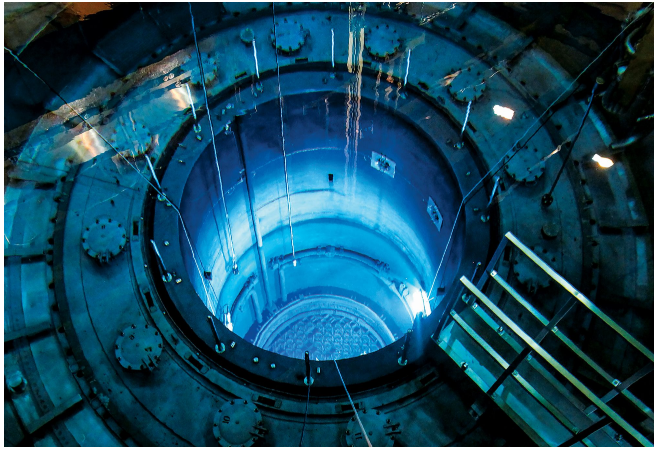
- Neutrinos come in (we think) three flavors, each flavor is associated with a lepton.
- Neutrinos only interact with the weak nuclear force, and only have very tiny mass

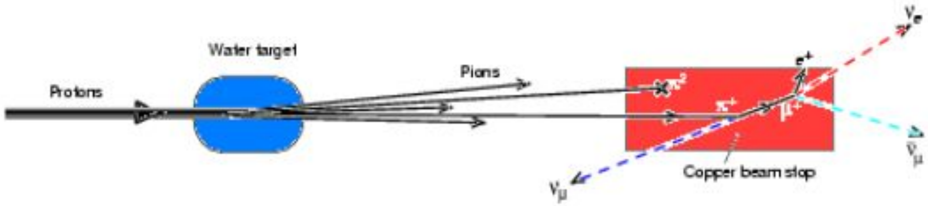


Sources of Neutrinos





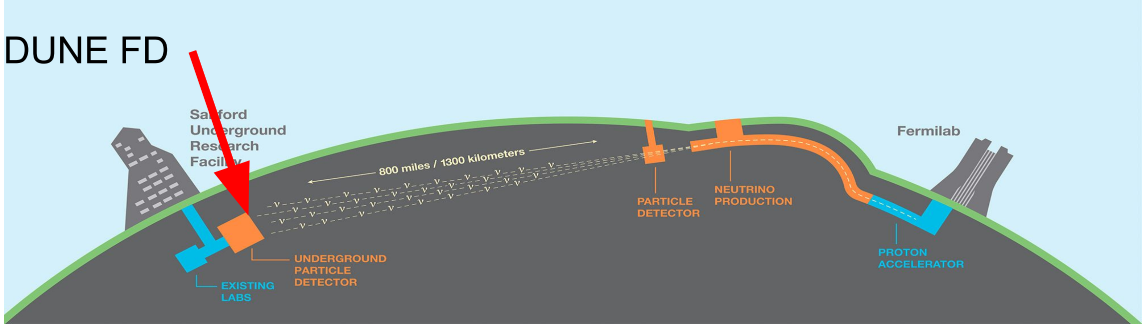




Supernova Neutrino & SNEWS

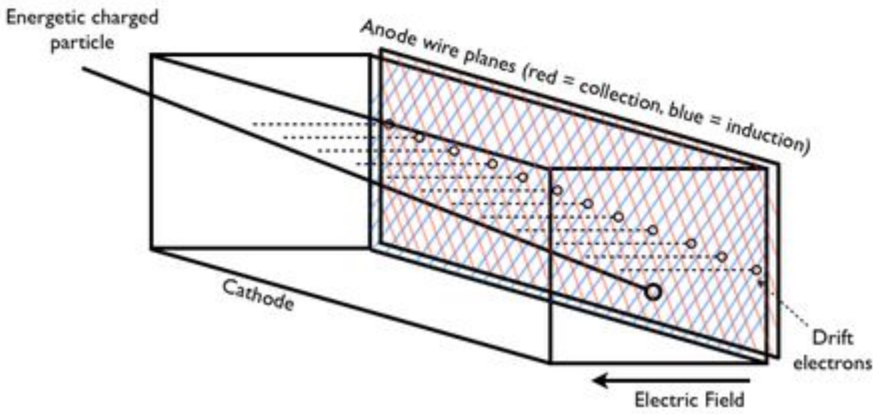
- Because neutrinos rarely interacts with matter, and travels at near-lightspeed, it can provide useful information about its source, even when it is far away.
- SuperNova Early Warning System (SNEWS) attempts to gather information from neutrino detectors around the world to provide information about an impending supernova explosion.
- Includes many components, **this study focuses on determining the direction of the supernova in the sky.**

DUNE FD



Deep Underground Neutrino Experiment (DUNE)

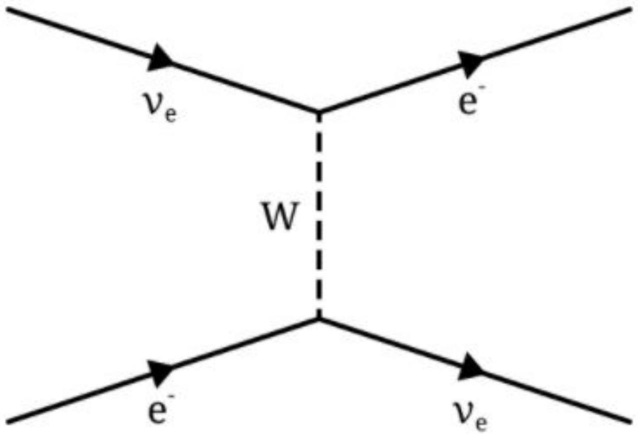
- Uses Fermi proton accelerator as a beam source
- Long baseline
- Liquid Argon Time Projection Chamber (LArTPC)
    - Voltage Across the volume, drift electrons are collected by the Anode Plane Assembly (APA)



Elastic Scattering Interaction

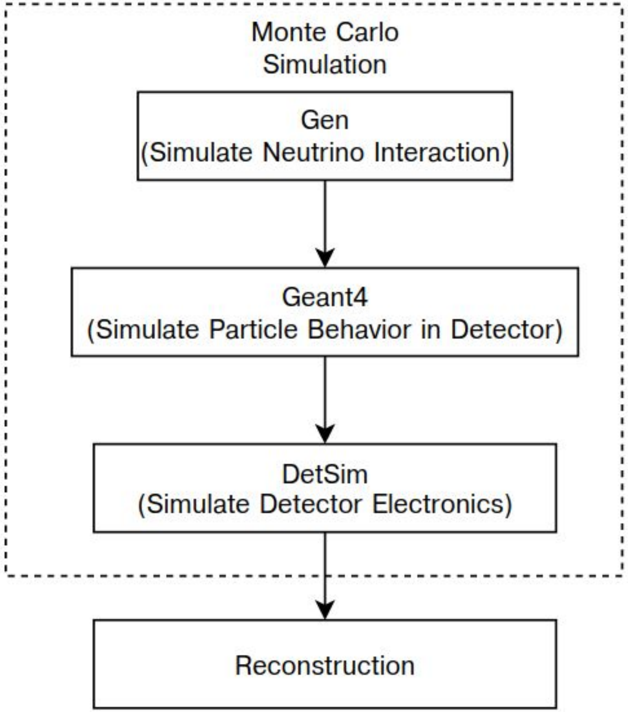
$$\frac{d\sigma(\nu e^- \to \nu e^-)}{dy} = \frac{G_F^2 s}{\pi}\left[C_{LL}^2 + C_{LR}^2(1-y)^2\right].$$

- $y = T_e/E_v$
- **G_F**: Fermi Weak Coupling Constant
- **s**: the square of the total
- energy in the center-of-mass frame
- $C_{LL/LR}$ are constants depending on the neutrino flavor
- Essentially allows us determine the probability distribution of electron energy given a neutrino energy.
- More interactions can be considered (e.g. CC events), less directionality but more events per SNB



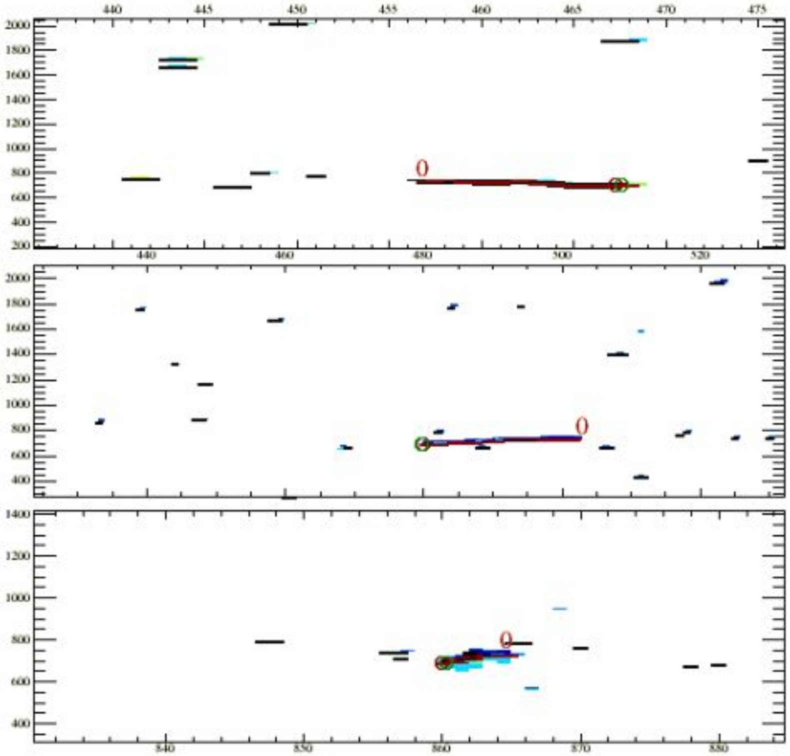
LArSoft Monte Carlo Simulation / Reconstruction Framework

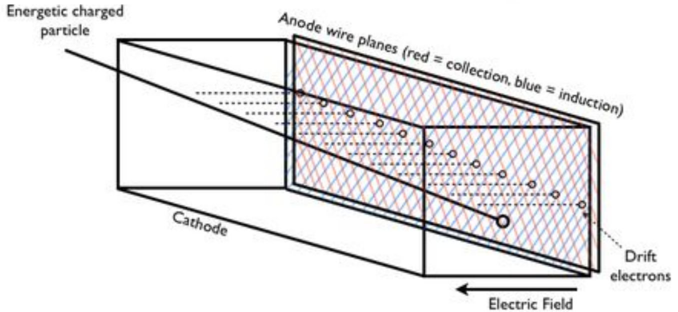
- Built by Fermilab, designed to simulate events in large LAr detectors like DUNE FD.
- Written in C/C++, uses ROOT as the primary data management framework
- Output of the components are organized into products. Components can also establish associations between products.
    - Example: HitFinder produces recob::Hits, TrackFinder produces recob::Tracks, associate hits with tracks.



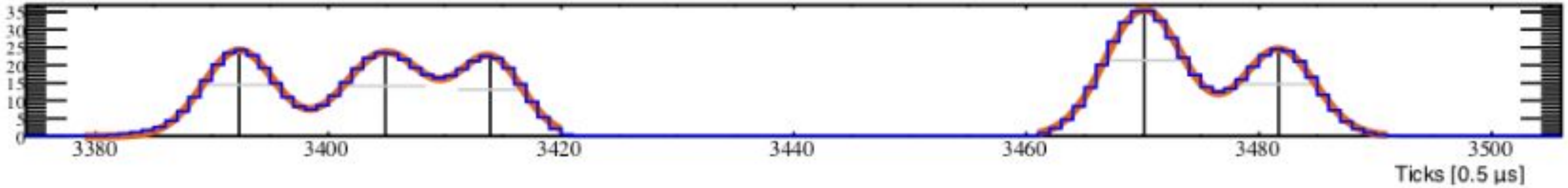
Challenges in reconstruction

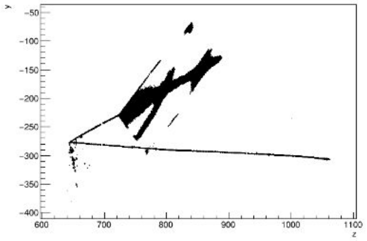
- Hits are ambiguous: some wires wrap around both sides of the APA.
- Tracks are temporally ambiguous: the timing of the charges are used to reconstruct one spatial coordinate.
- Combine information from three planes to resolve these ambiguities.



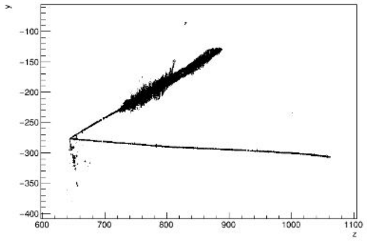


Hit finding and Disambiguation

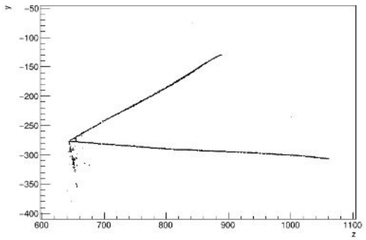




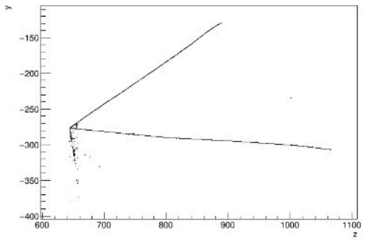
(a) All coincidences



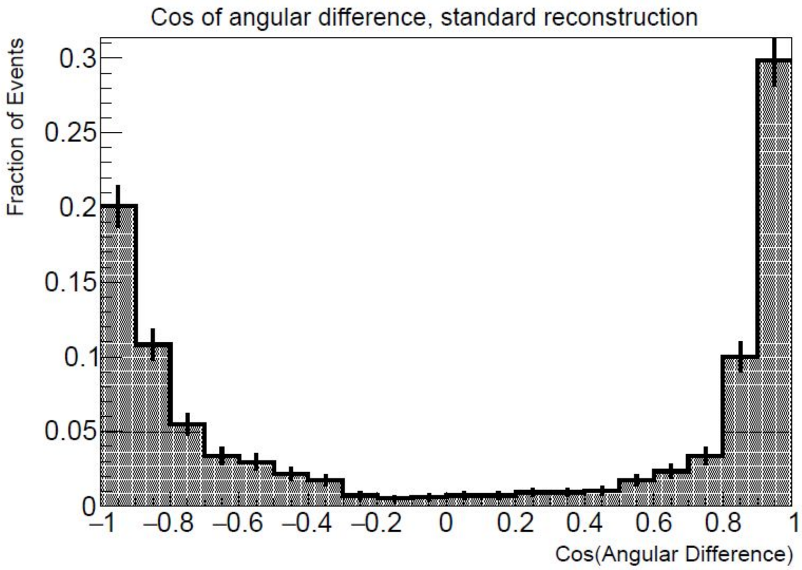
(b) Without regularization



(c) With regularization



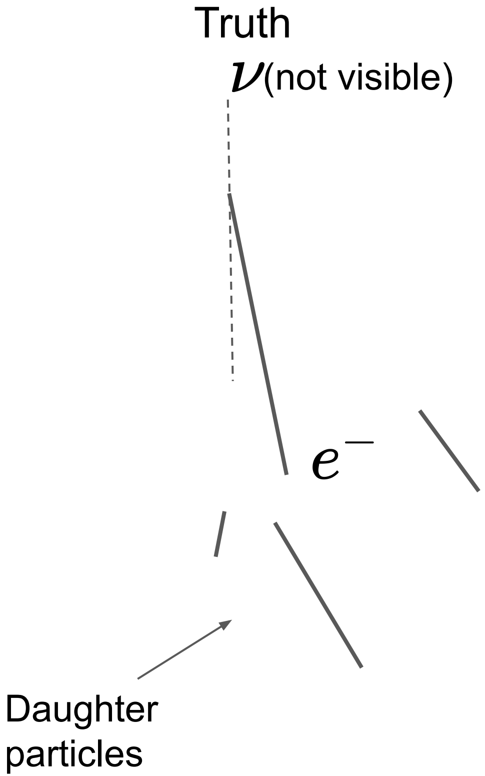
(d) True charge distribution



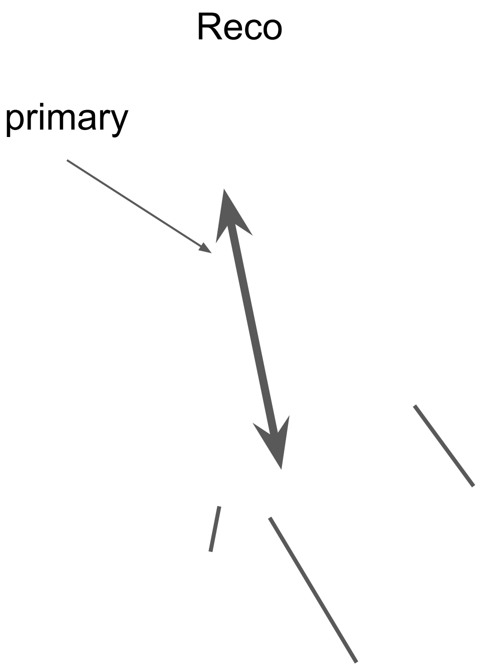
Cos of angular difference, standard reconstruction
Fraction of Events
0.3
0.25
0.2
0.15
0.1
0.05
0
–1
–0.8
–0.6
–0.4
–0.2
0
0.2
0.4
0.6
0.8
1
Cos(Angular Difference)

Resolve track directional ambiguity: Daughter Flipping

- The primary electron subsequently bumps into other particles in the detector, emitting daughter particles through Bremsstrahlung radiation, Compton scattering, ionization, etc.

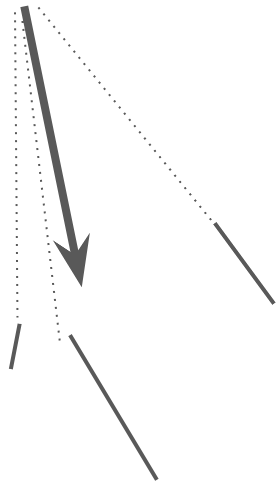


Pick the longest track as the primary electron

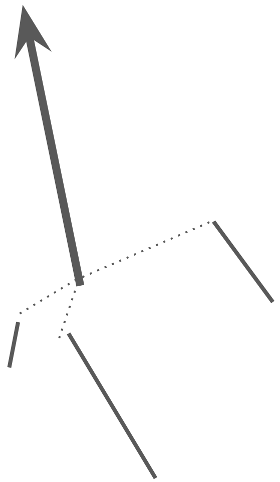


Calculate spread of the daughter tracks

Forward Direction

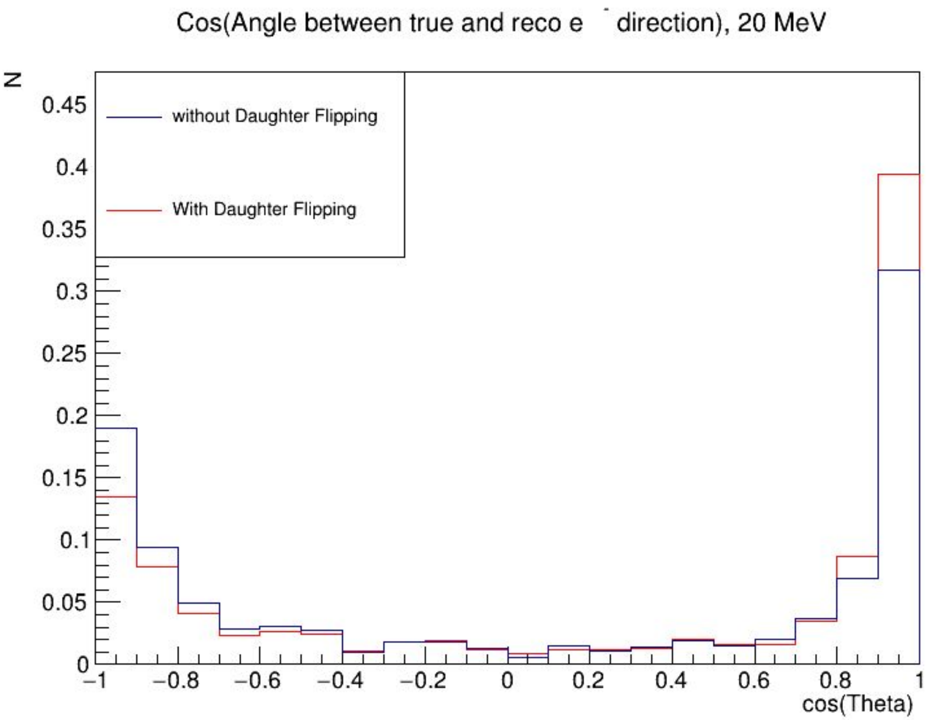


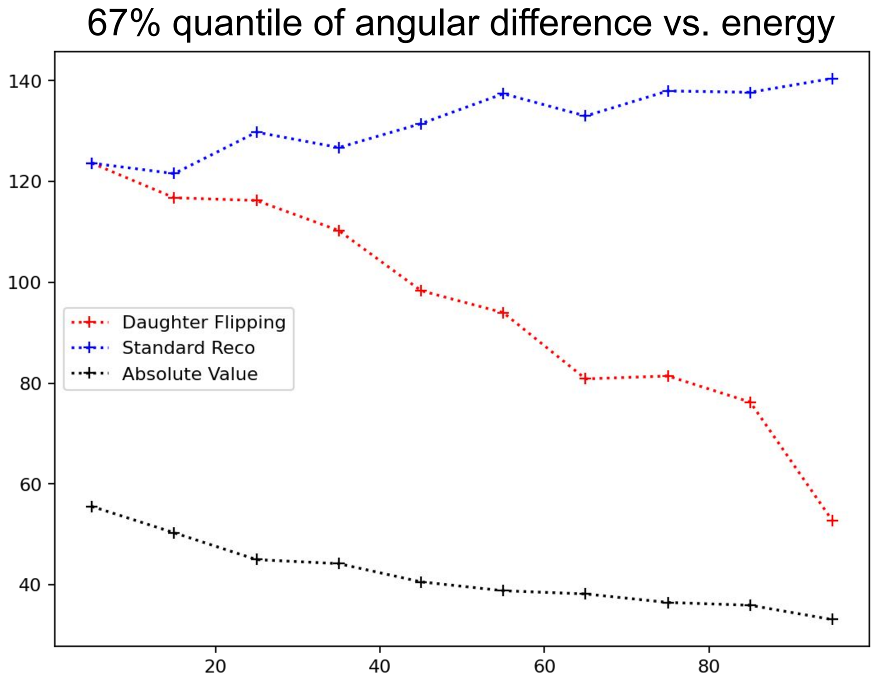
Backward Direction



Daughter Flipping: Summary

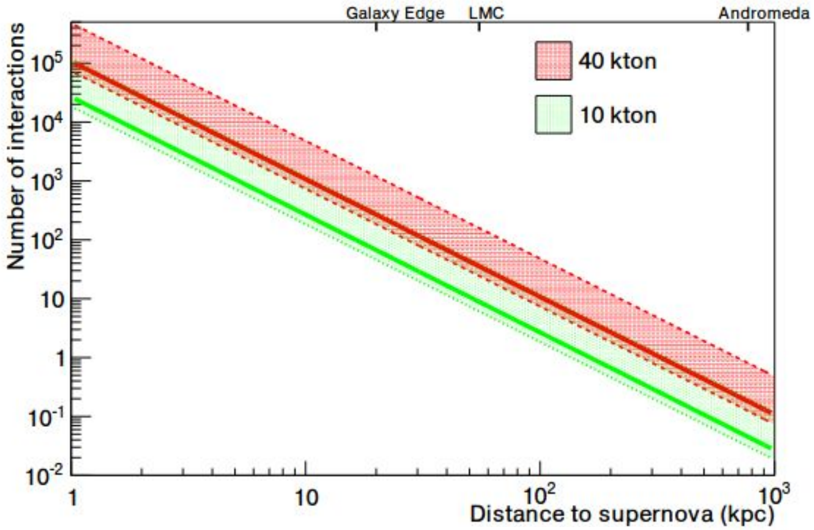
1. Find the longest reconstructed track, assume that this is the track of the primary electron.
2. Pick one side of the primary track, calculate the average cosine of the angle formed by the primary track direction and the daughter track positions. Do this for both sides of the track.
3. Pick the side with the bigger average cosine value (therefore the smaller spread).

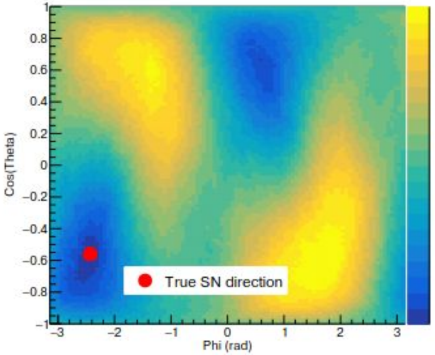

Cos(Angle between true and reco e⁻ direction), 20 MeV
N
without Daughter Flipping
With Daughter Flipping
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
cos(Theta)


67% quantile of angular difference vs. energy
Daughter Flipping
Standard Reco
Absolute Value
140
120
100
80
60
40
20
40
60
80

Subsequent Steps

- Use the simulated events to generate a Probability Density Function (PDF) of the angular offset vs. electron energy.
- When a supernova comes, we receive many of these events.
- Plug the events into the PDF, determine the SN direction by minimizing the cost.





Challenges

- Vertex identification can be challenging, particularly when radiological decays are simulated in the detector.
- Daughter flipping can potentially be improved by looking at the charge deposition along different parts of the track.
- Dealing with a high degree-of-freedom pattern recognition / image processing problem. Machine learning and other general pattern recognition algorithms may provide better results by a holistic view of the entire event.

Summary

- Using Monte Carlo simulations, elastic scattering events were generated in a LArTPC detector.
- By applying pre-existing hit finding and tracking algorithms, we are able to capture the SNB particles in the detector.
- Track pointing ambiguity is resolved by applying daughter flipping.
- Results can likely be improved with adoptions of more advanced pattern recognition algorithms.

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