Using boosted decision trees to identify supernova neutrino interactions in DUNE

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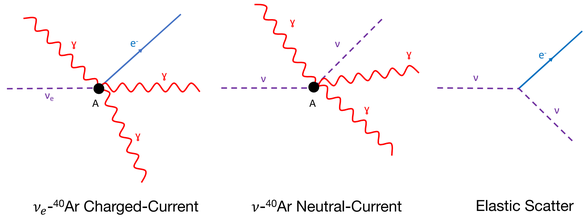
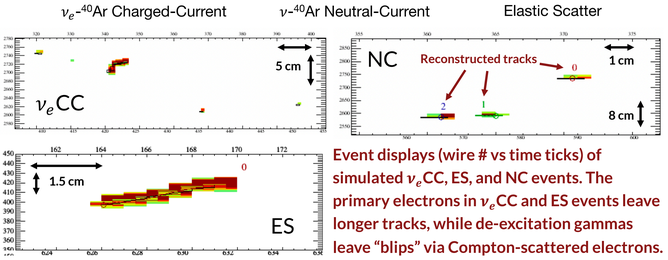
A core-collapse supernova (SN) releases 99% of its potential energy in the form of neutrinos each carrying <100 MeV in energy. The Deep Underground Neutrino Experiment (DUNE) will employ a 40 kton liquid argon time-projection chamber to observe these neutrinos via several interaction channels.





Event displays (wire # vs time ticks) of simulated ν_eCC, ES, and NC events. The primary electrons in ν_eCC and ES events leave longer tracks, while de-excitation gammas leave "blips" via Compton-scattered electrons.

In order to distinguish the interaction channels, we trained boosted decision trees (BDTs) in scikit-learn using simulated events in the proposed DUNE detector.

STUDY

1. Simulated ν_eCC, ES, and NC events (ν_eCC and NC simulated using MARLEY [1]); prepared samples for classification using "pinched-thermal" SN flux model [2]
2. Calculated a reconstructed energy cut optimized for the NC channel to separate the samples into "low" and "high" energy
3. Formed training variables with reconstruction information to be used in decision rule-making
4. Trained and tested boosted decision trees for the two sets of samples

Future work includes improving ES classification, studying effects from uncertainty in NC model

Analysis of a supernova burst can be improved by separating different interaction channels

Events in 40 kton LAr, 10 kpc SN	Classified as ν_eCC	Classified as ES	Classified as NC
True ν_eCC	4297	183	108
True ES	22	268	21
True NC	32	17	731

Combined classified event rates from two boosted decision trees trained on simulated events above and below an optimized cut in reconstructed energy. The simulated SN signal contained 4591 ν_eCC, 314 ES, and 783 NC events. Due to rounding, the total simulated signal is not entirely accounted for in the table.

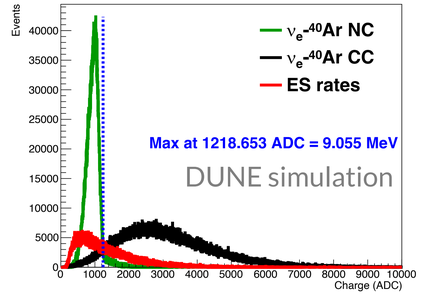
Interaction channel	Contamination in classified BDT signal	Misclassified true events
ν_eCC	1.24%	6.3%
ES	42.7%	13.8%
NC	15%	6.3%

- NC well separated from ν_eCC and ES
- Need to improve separation between ES and ν_eCC

The interaction channels in this study contain different information about neutrino properties and SN, for example:

- ν_eCC: mass ordering [2]
- ES: SN pointing information
- NC: total SN flux

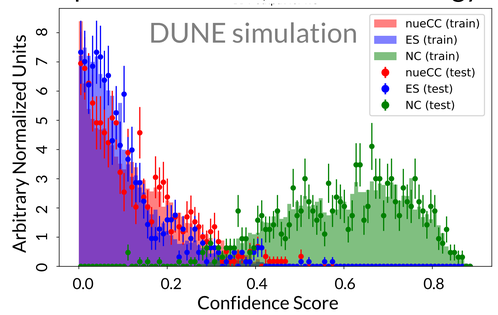
Energy cut: 9.055 MeV



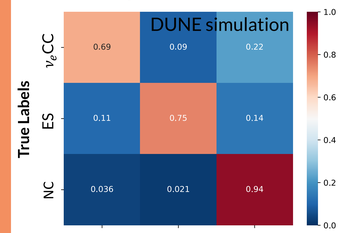
Optimizing the energy cut for $S/\sqrt{S+B}$:
S = NC events
B = ν_eCC and ES events

Additional information on boosted decision trees:

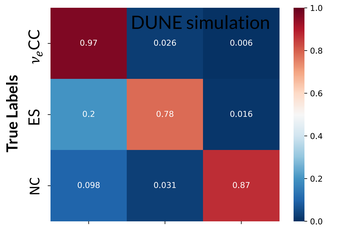
- 9 variables used for BDT training; variables include number of reconstructed 2D hits, total charge, average track length, etc.
- BDT outputs a confidence score for each channel; high confidence score = likely to originate from that channel according to BDT
  - Compare distributions from training and testing samples to check for over-fitting
  - Example: NC channel, above the energy cut



- Confusion matrices can be used to identify areas of improvement for misclassification



Below the cut; "low energy"



Above the cut; "high energy"

References
[1] S. Gardiner, "Nuclear effects in neutrino detection," Ph.D. dissertation, University of California, Davis, 2018.
[2] arXiv:1512.06148v2

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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