Towards DNN Analysis of ^{137}Xe decays to ^{137}Cs in EXO-200

Seth Thibado

DANCE-ML Workshop

August 6th 2020

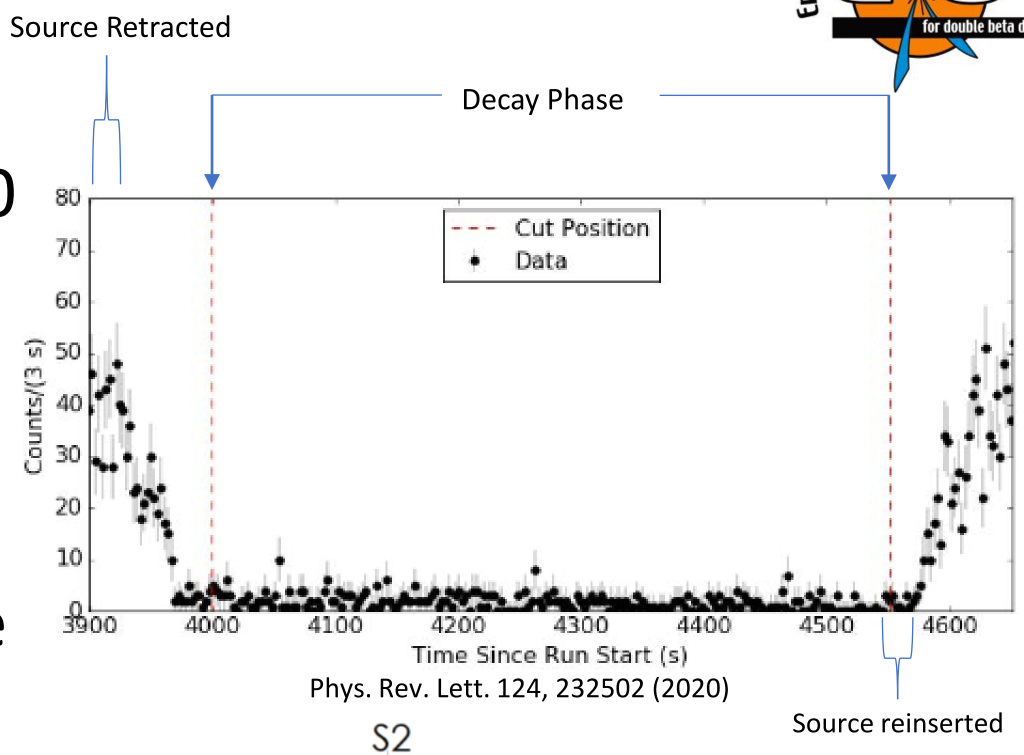
^{137}Xe in the EXO-200 TPC

- The EXO-200 TPC has a xenon isotopic ratio of 80.6% ^{136}Xe and 19.1% ^{134}Xe. The remaining 0.3% are isotopic impurities.
- ^{137}Xe is not one of the stable isotopes of Xenon, with a half-life of 3.813 minutes.
- ^{137}Xe can be bred in the cell from cosmic neutron flux, this occurs at a rate of ~400 events/yr[1]
- A more controlled number of ^{137}Xe decays are obtained through use of an AmBe neutron source.

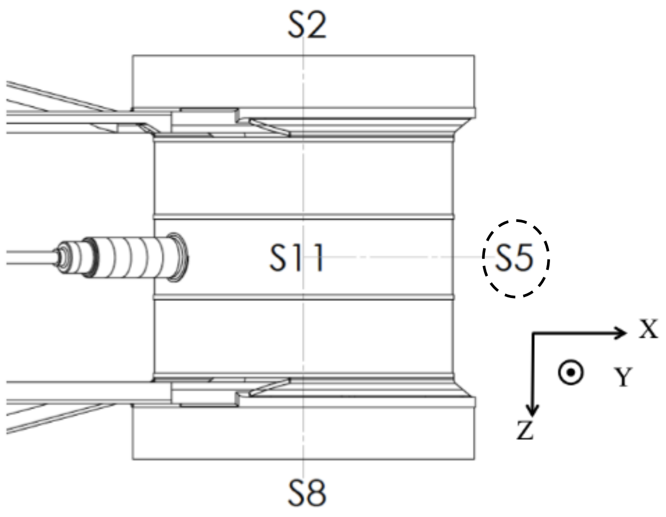
1. Collaboration, EXO-200, J. B. Albert, D. J. Auty, P. S. Barbeau, D. Beck, V. Belov, M. Breidenbach, et al. "Cosmogenic Backgrounds to 0{\nu}{\beta}{\beta} in EXO-200." *Journal of Cosmology and Astroparticle Physics* 2016, no. 04 (April 15, 2016): 029–029. https://doi.org/10.1088/1475-7516/2016/04/029.

AmBe Source Runs

- An ^{241}Am-^{9}Be source was used in EXO-200 as a calibration campaign in December 2018.
- This calibration run consisted of inserting the AmBe source for a time on the order of the half-life allowing for $^{136}Xe(n,\gamma)^{137}Xe$ to reach steady state.
- This is done in cycles to allow for data collection in "decay phase" shown by cut on right.



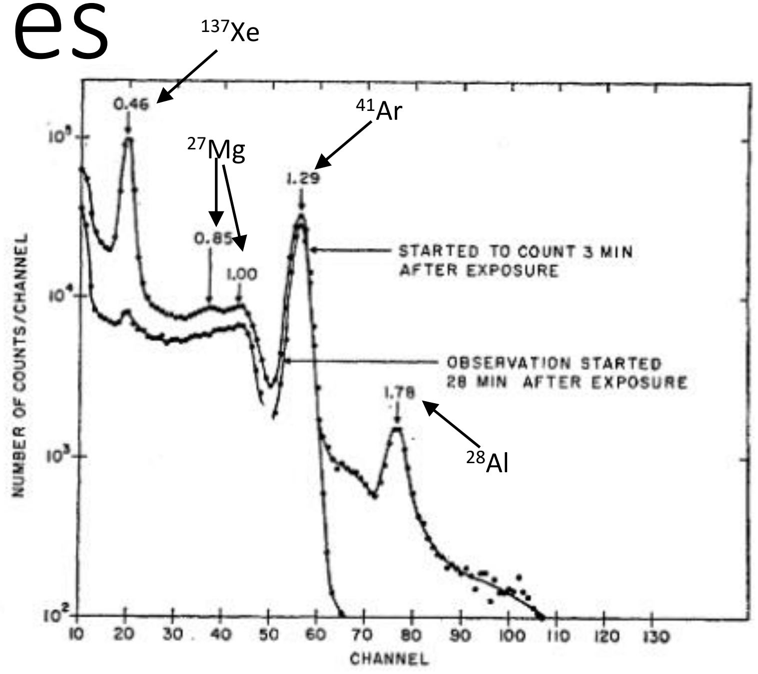
Phys. Rev. Lett. 124, 232502 (2020)



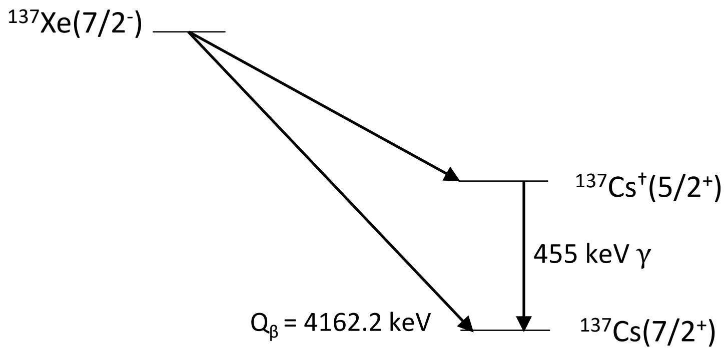
Phys. Rev. C 89, 015502

Differentiation of Decay Modes

- When ^{137}Xe decays, it will decay into the ground state(GS) of ^{137}Cs 67% of the time, and into the first excited state(ES) 31% of the time.
- The decay to the first excited state is always accompanied by a 455 keV gamma ray, emitted on average ~0.1 ns after the initial decay.
- The production of the gamma ray makes the decay to the excited state dominated by Multi-Site events while the GS is primarily Single-Site.

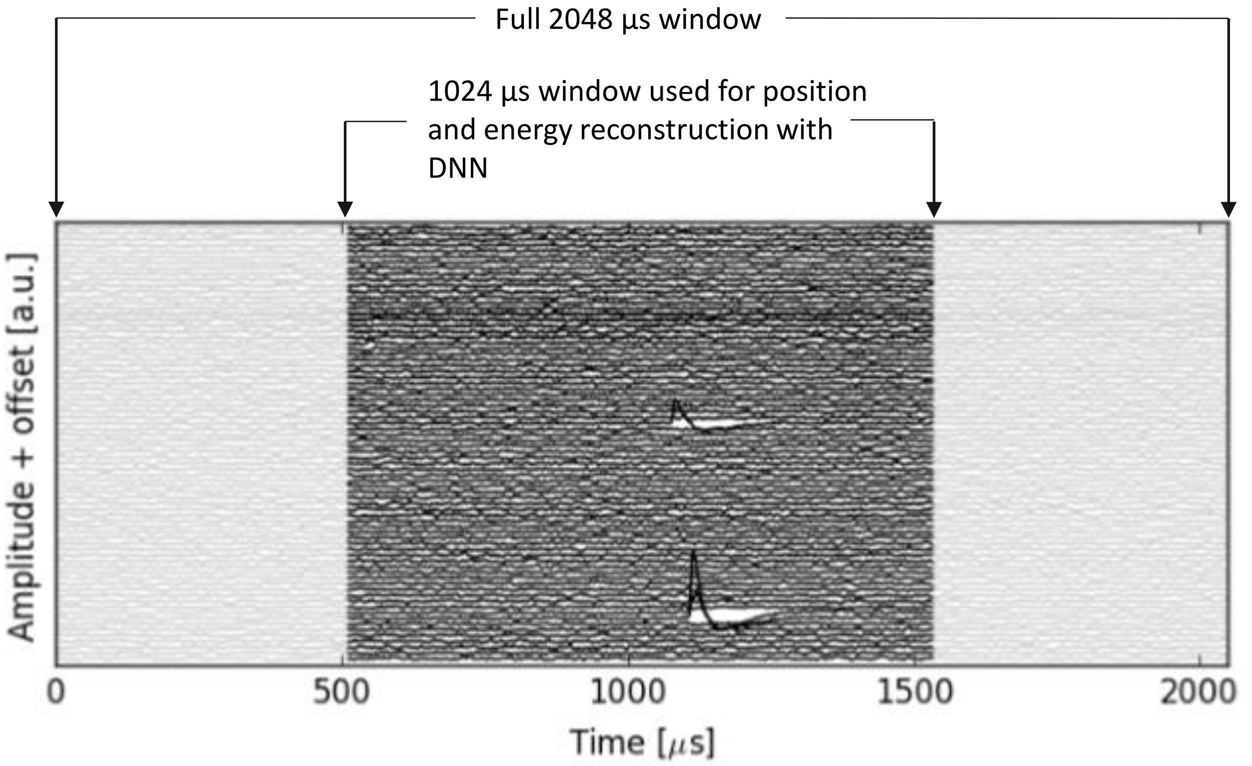


Physical Review 136, no. 2B (October 26, 1964): B365–70



Imaging of Waveforms

- Whenever an event happens, charge data is recorded on 152 channels, corresponding to all of the wires in both planes.
- This information is captured as a 2048 µs window, and when all the wire channels are put together, it becomes an image of the event.

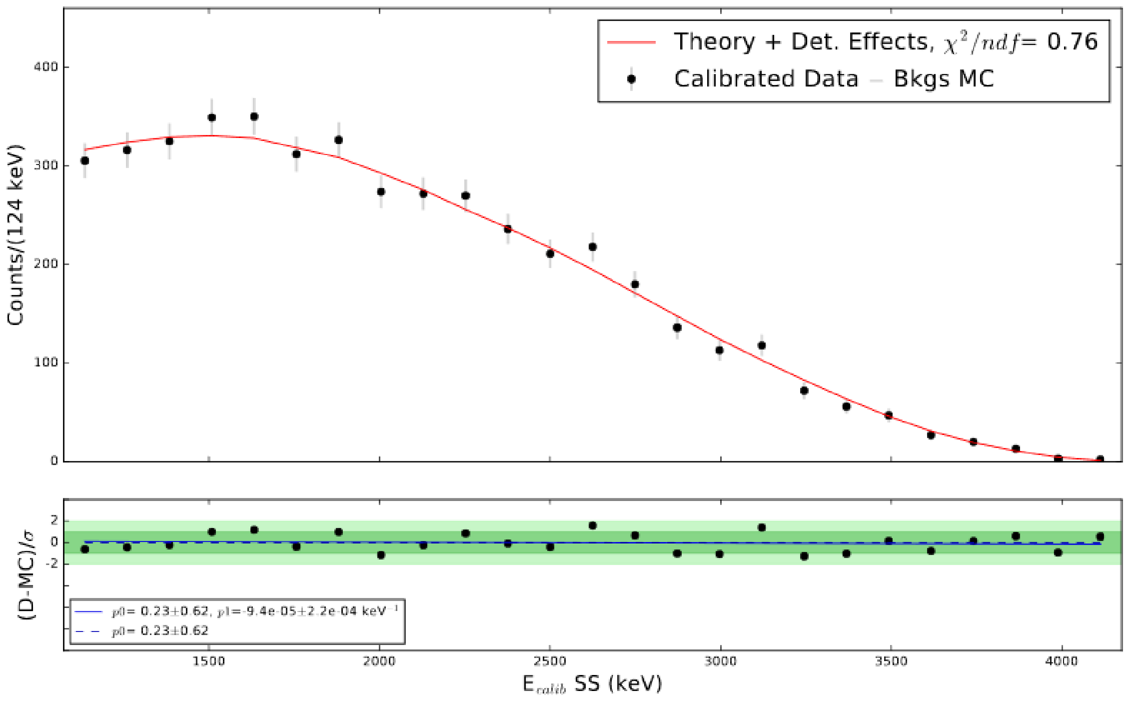


Journal of Instrumentation 13, no. 08 (August 29, 2018): P08023–P08023.

Goal of This Study

- An analysis of the decay to the ground state of ^{137}Cs has already been done in EXO-200.
- This study seeks to compliment the former by measuring the spectral shape of the ES decay.
- The GS decay shape is independent of the axial-vector coupling while the ES does have dependence.
- A measurement of both spectra can lead to a measurement of any quenching effects present in ^{137}Xe.

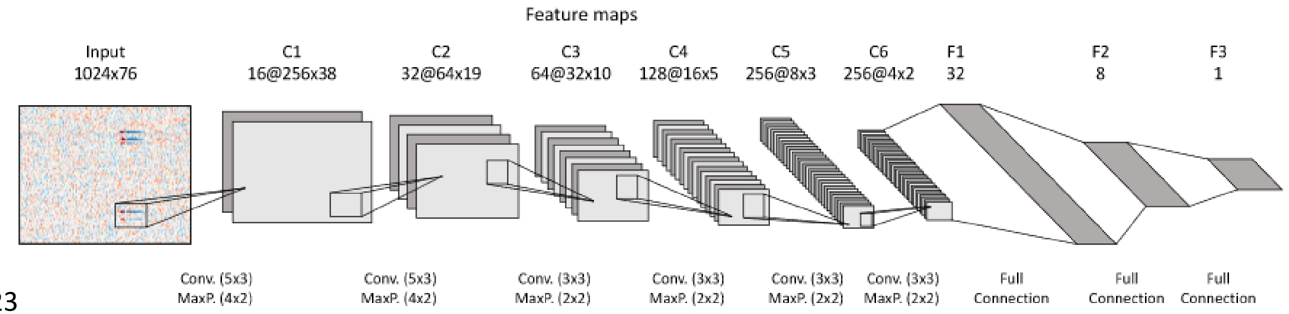
Ground State β⁻ spectrum



Phys. Rev. Lett. 124, 232502 (2020)

Using Convolutional Neural Networks for Event Identification

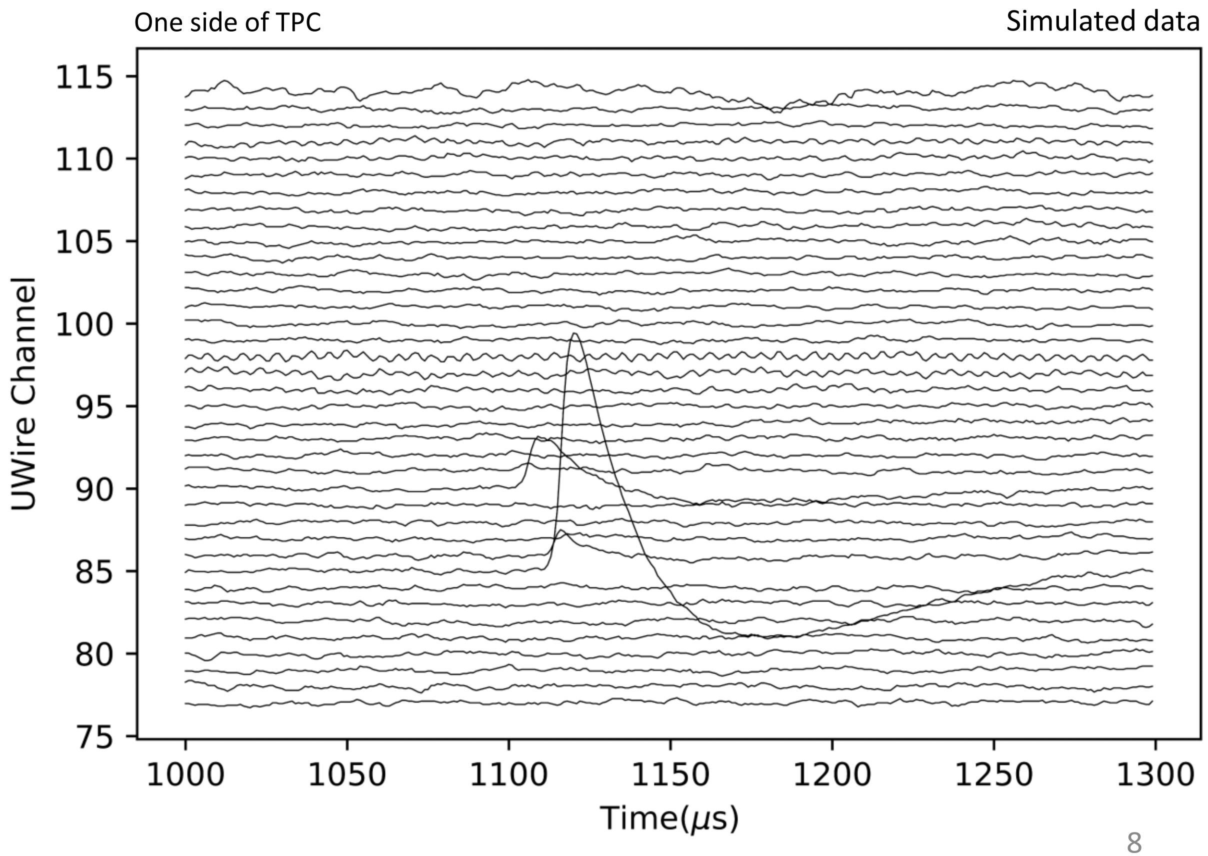
- Using this idea of a waveform image, use of a convolutional neural network(CNN) can be explored.
- Because CNNs are very good at recognizing features within an image, one can likely be trained to discriminate between the topology of a GS and ES state decay.
- It has also been demonstrated that Neural Networks can learn from waveforms and be competitive with traditional analysis methods.[2]



[2]*Journal of Instrumentation* 13, no. 08 (August 29, 2018): P08023–P08023

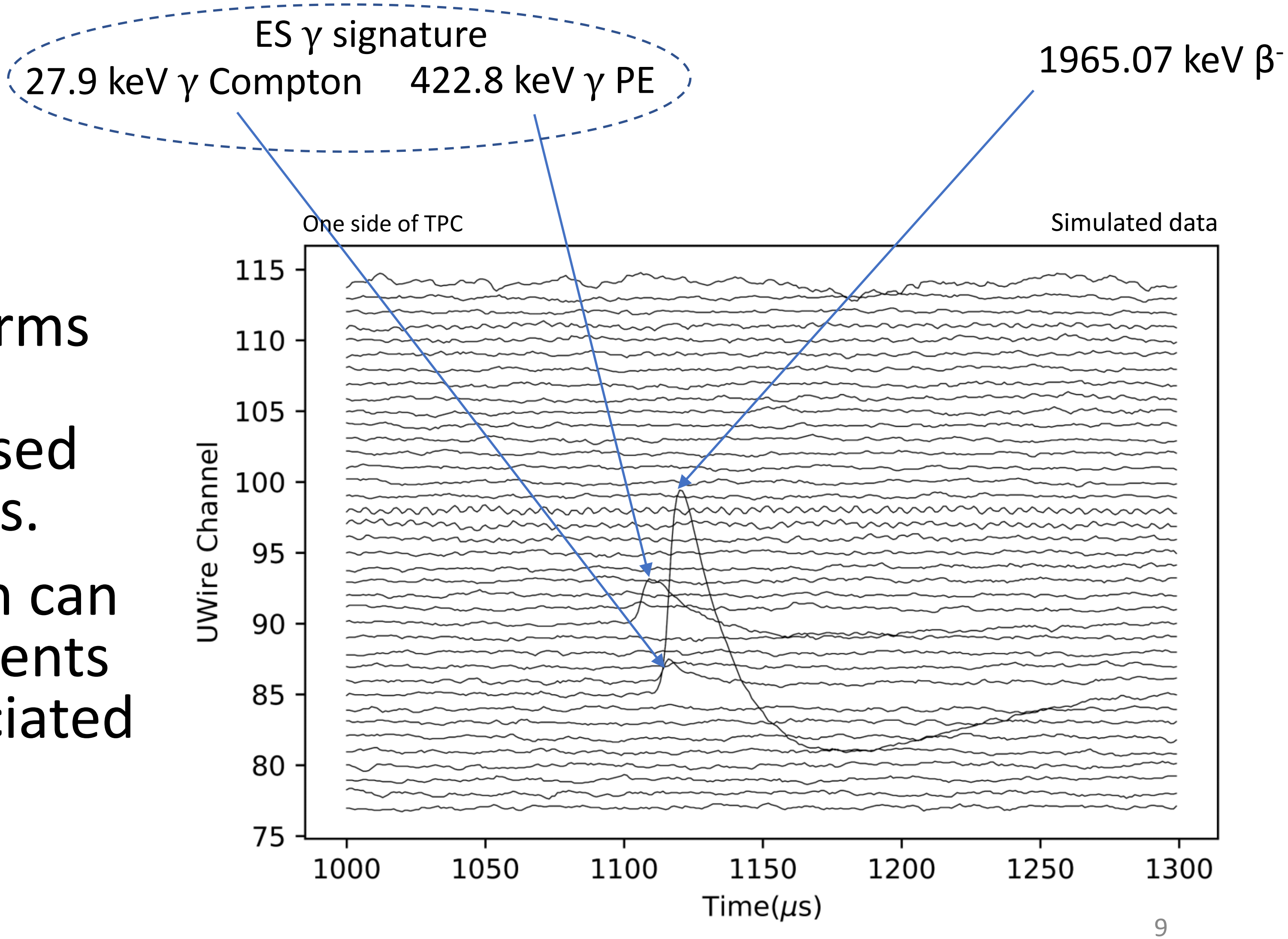
Monte Carlo Simulation of Data

- Training data is generated using a MC simulation which generates waveforms along with truth values which can be trained on.
- These events are then prepared into an hdf5 file format and tagged with labels indicating the truth that we want the DNN to learn from the waveforms.
- This allows for more controlled studies on how certain types of signals impact DNN performance.



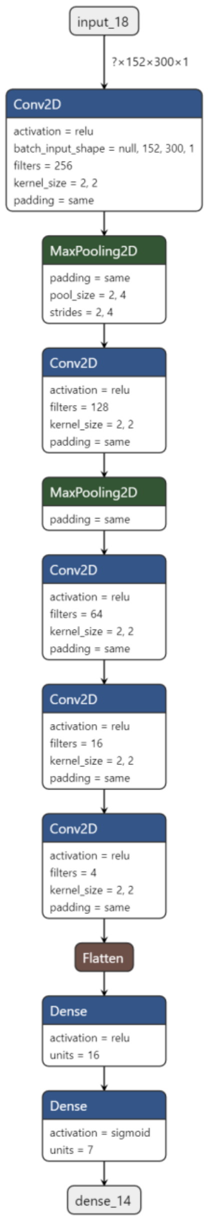
Deep Look at Waveforms

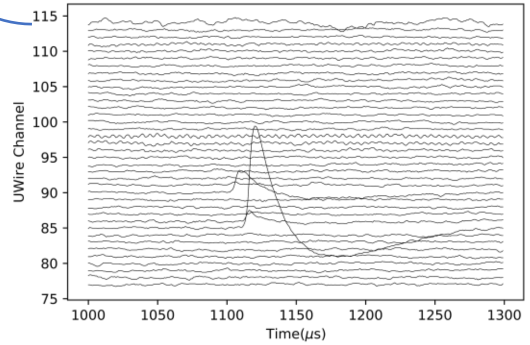
- When simulated, waveforms come with an array of information on what caused the signal, or its ancestors.
- This ancestor information can allow a deeper look at events and the waveforms associated with them.



Current Network

- The current network architecture is shown on the right.
- The network currently uses l2 regularization of 1E-2
- The network is trained at SLAC on GPU clusters.
- Programmed in python and uses Tensorflow and Keras.

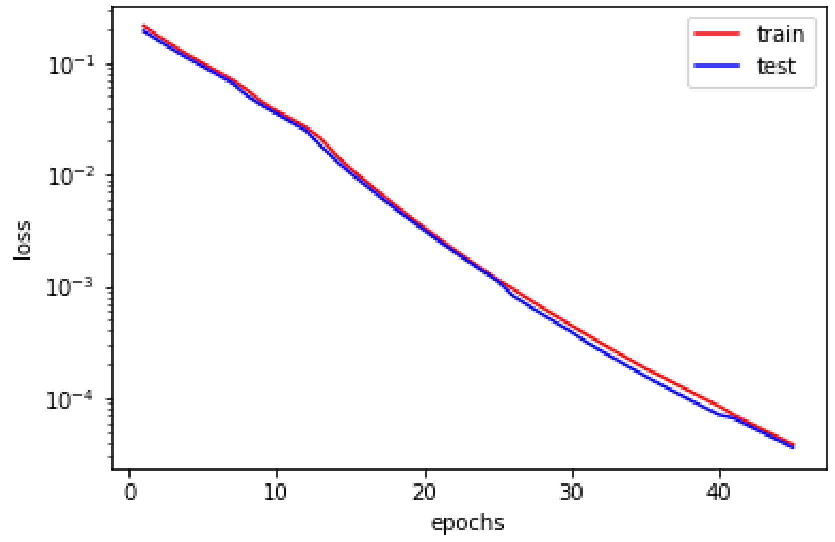




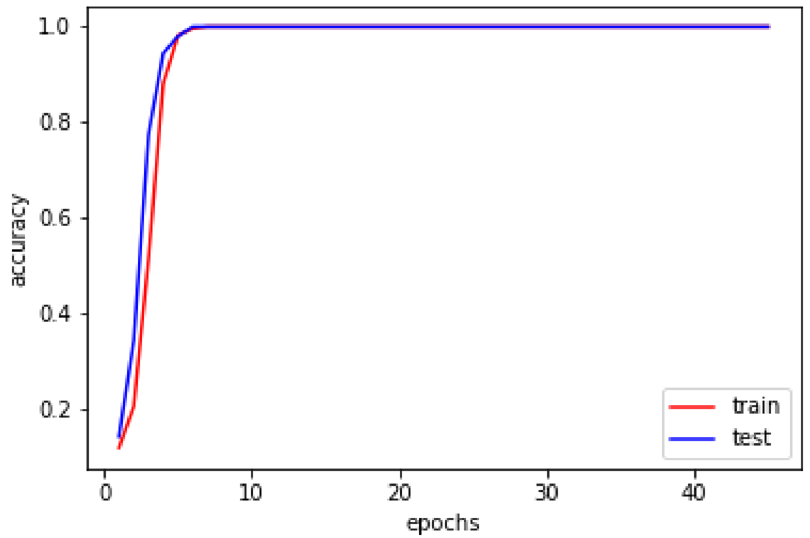
First Excited state!!
(we hope)

DNN performance on “Clean” Events

- As a performance benchmark, feed the network very clean events that meet criteria:
- Inside a Fiducial Volume Cut
- For ES Events: >93% Gamma ray energy captured in simulated wire signal. (Arbitrary Choice)
- The Network was trained on 12000 events that met this criteria.
- Over 45 epochs, categorical accuracy quickly rose to 1.0.
- Loss continued to decrease throughout training, showing it was still learning on training data.

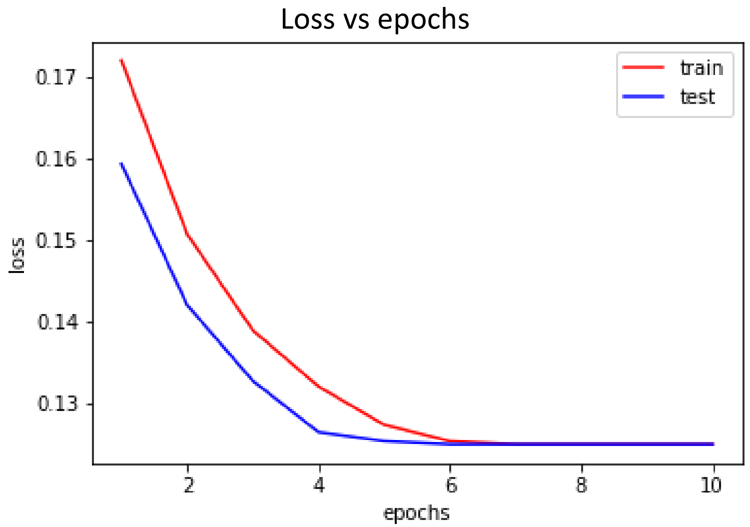


Simulated data

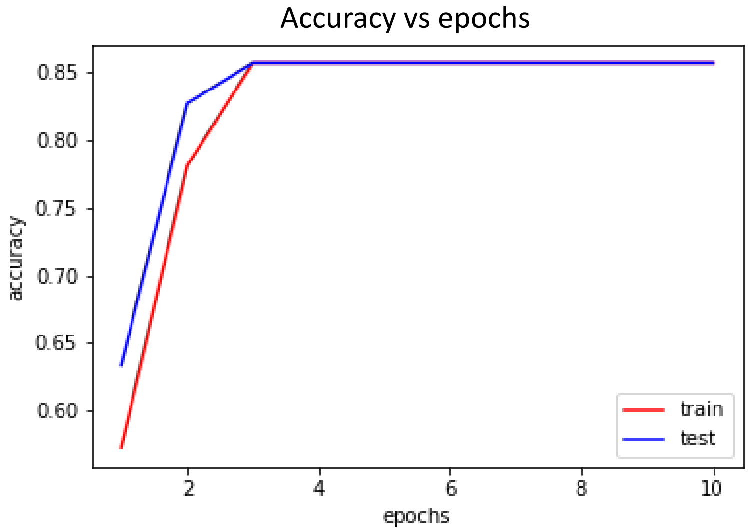


Preliminary Results on unfiltered data

- While still in early stages and progressing, early work on unfiltered datasets showed promise.
- Data does not include any restrictions on gamma rays, only requires fiducial event.
- The DNN was able to quickly train up an accuracy of 0.8571.
- While there are improvements that can be made, it is a glimpse at the potential of the DNN approach.
- Hopefully studying cleaner events can give insight into why the curves saturate this way.



Simulated data



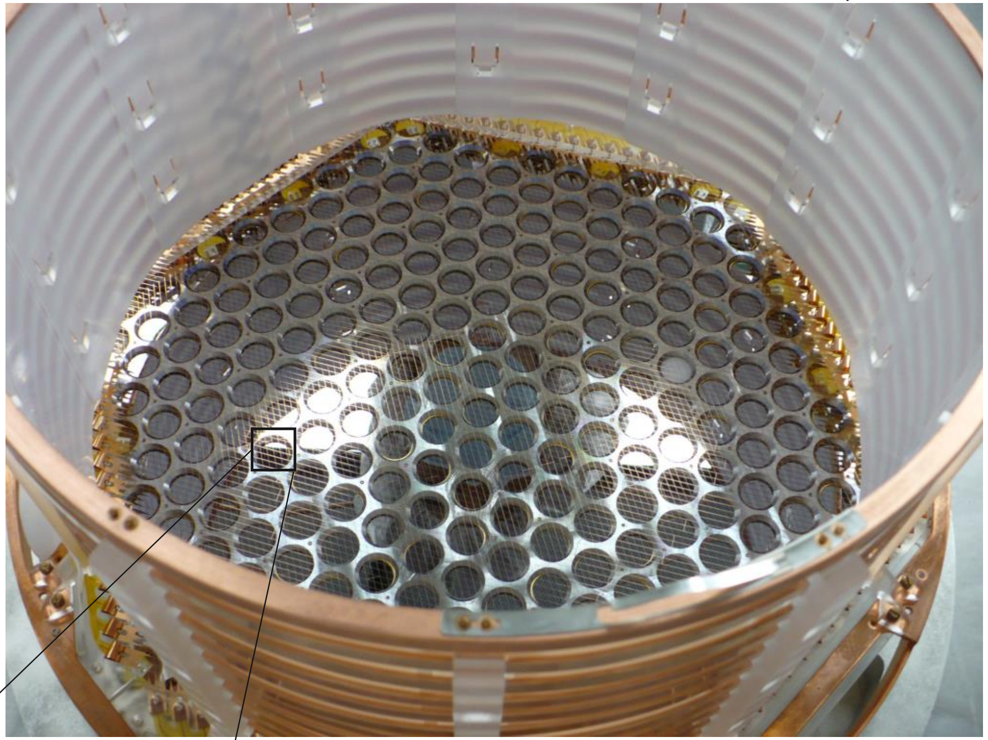
Conclusions & Future Work

- The name of the game is more data, simulations take time, and so I am constantly simulating more and more data to be used for training.
- The gamma ray >93% energy is an arbitrary choice and needs to be relaxed to include more gamma escape events in training data.
- Backgrounds, while small, are still present in the dataset and needed to be introduced to the training set so the network can learn to differentiate them from signal.
- With all of this, the CNN shows promise for identification of decay modes in EXO-200!

Backup Slides

Signals in EXO-200

- In EXO-200, position and energy measurements are made by combining the charge and scintillation energy that are created by high energy ions in LXe.
- Scintillation light is collected by LAAPDs mounted behind wire planes which measure charge energy.
- The wire planes consist of two planes of wires crossed at 60^{o} which measure an induction signal and charge signal as a set of 152 waveforms.



One end of the EXO-200 TPC

Closeup of the EXO-200 Wire readout planes