Characterization of the NEXT-White Detector with Calibration Data

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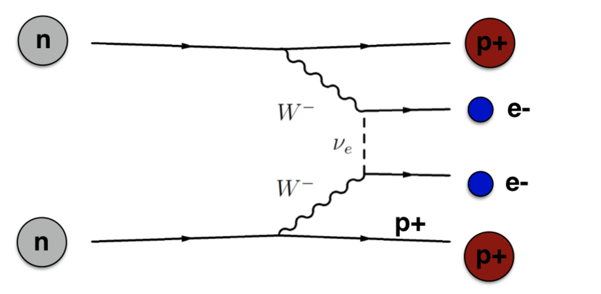
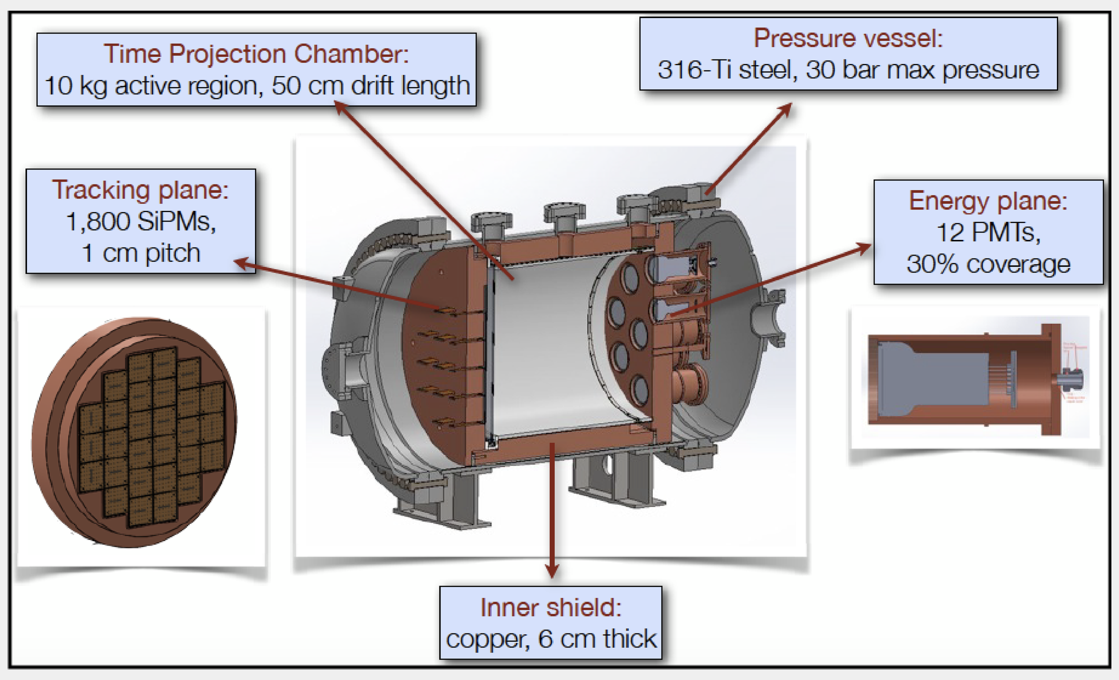


$0\nu\beta\beta$: $^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba}^{++} + 2e^{-}$

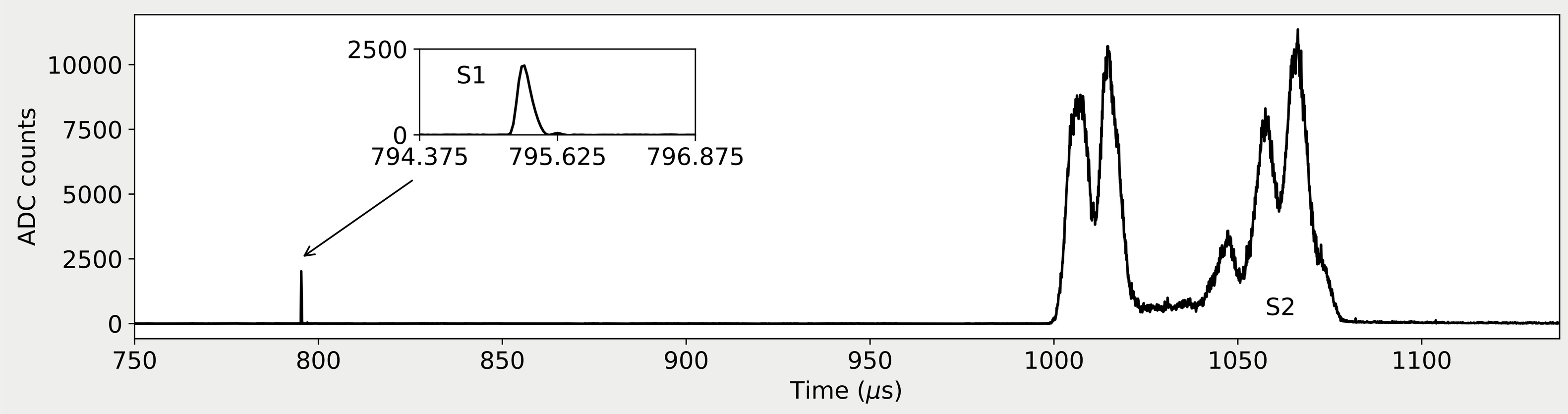
The NEXT (Neutrino Experiment with a Xenon TPC) experiment will search for neutrinoless double-beta ($0\nu\beta\beta$) decay in ^{136}Xe with a high pressure xenon gas time projection chamber (TPC). Two principle advantages of the NEXT approach are excellent energy resolution and topology-based event classification. We describe initial results from the first phase of the experiment, the detector NEXT-White deployed in the Laboratorio Subterráneo de Canfranc (LSC) in the Spanish Pyrenees, demonstrating recent progress towards sub-1% energy resolution at the double-beta Q-value. We also present the results of a topological analysis, using electron-positron pair events in place of the two-electron events expected from $0\nu\beta\beta$, which demonstrates how such events can be distinguished from background (single-electron) events of the same energy through the use of deep neural networks (DNNs).

The NEXT-White Detector

NEXT-White is the present phase of the NEXT experiment. It is a high pressure xenon electroluminescent (EL) TPC currently being calibrated in the LSC that will serve to measure the two neutrino double-beta decay mode ($2\nu\beta\beta$). It contains an *energy plane* of 12 PMTs, which detect the primary scintillation light (S1) produced upon creation of the ionization track and the secondary EL light (S2) produced by accelerating the ionization electrons through a narrow region of high electric field. A *tracking plane* of 1792 SiPMs is positioned just behind the EL region to provide information on the (x, y) location of the detected ionization electrons, which when combined with the drift time (measured between S1 and S2), gives a 3D reconstruction of the ionization track.

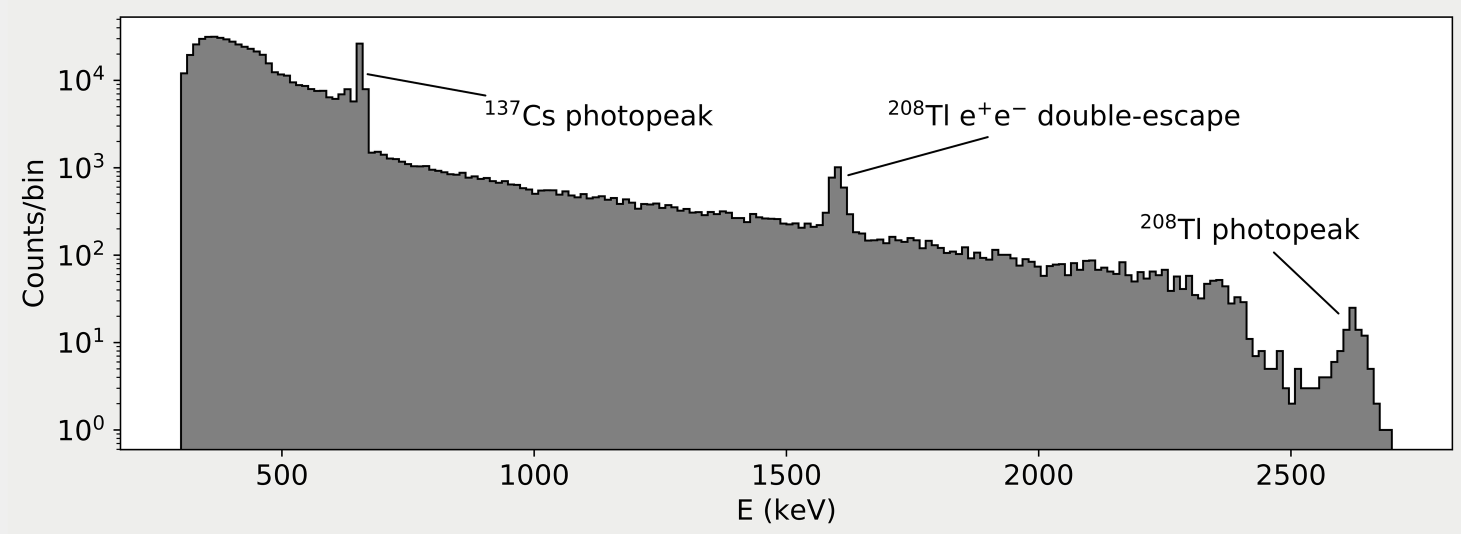


Schematic of the NEXT-White EL TPC

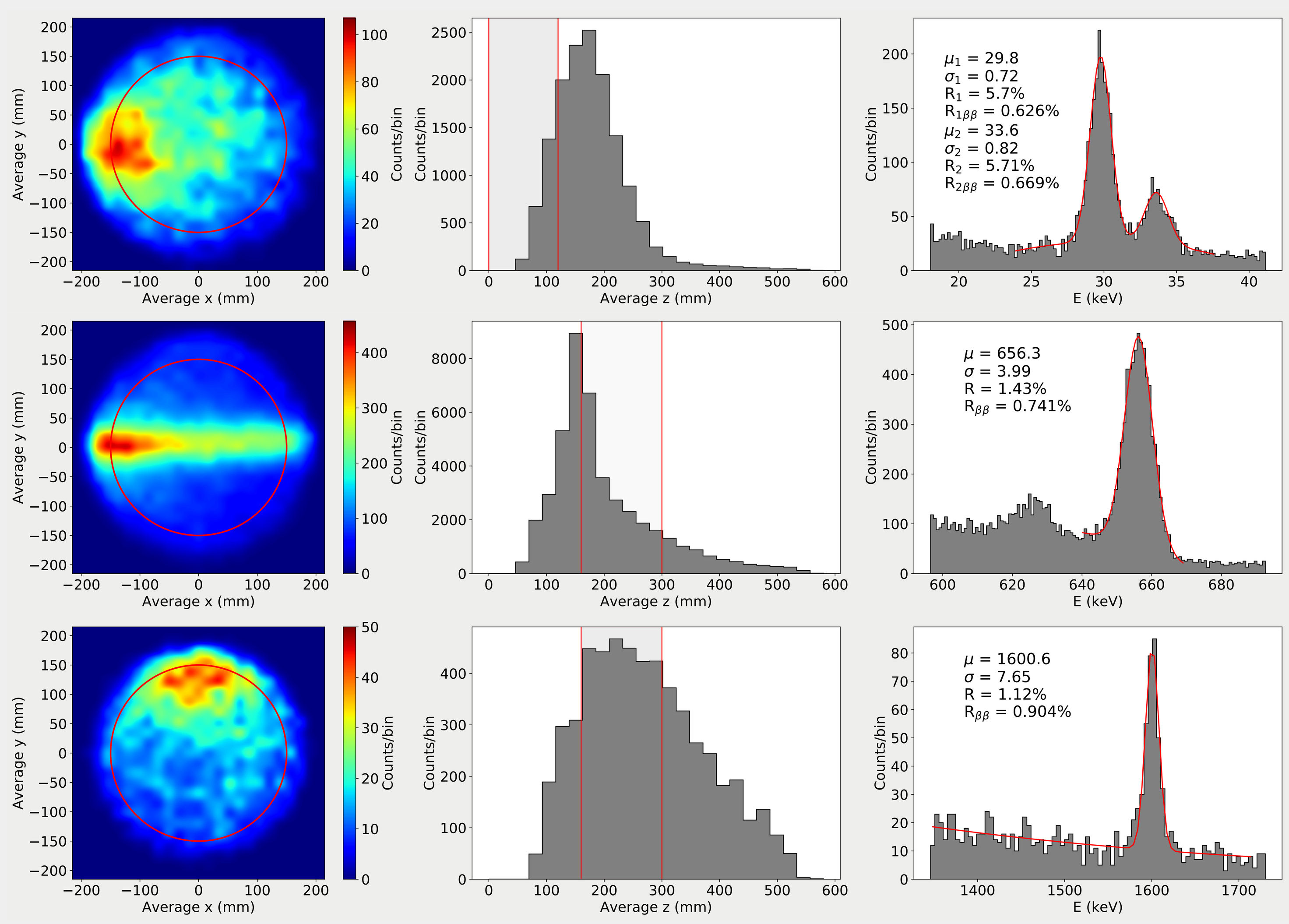


An example waveform showing primary (S1) and secondary (S2) scintillation

Energy Resolution



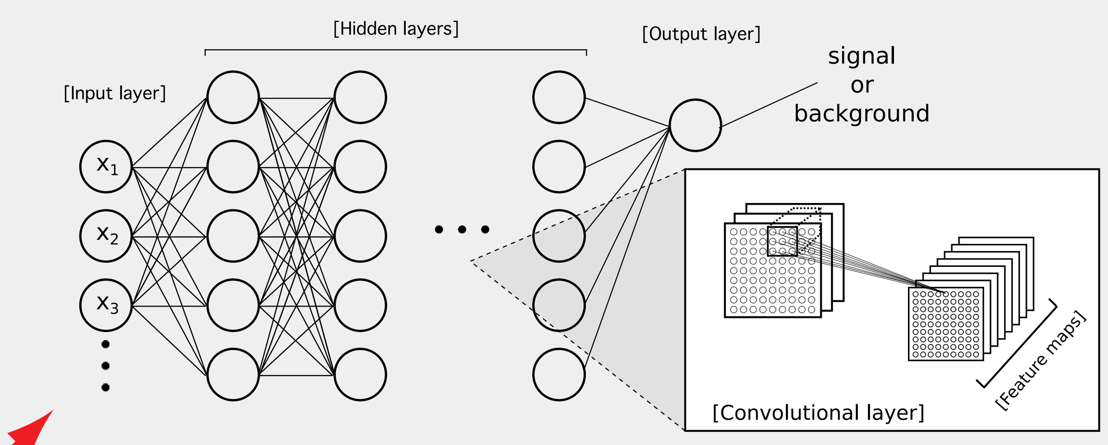
A full energy spectrum is shown above, with minimal fiducial cuts, as acquired with two calibration sources: a ^{137}Cs source placed on the side of the TPC and a ^{228}Th source placed on top. Corrections were applied to remove geometric variations in light collection and reduction in measured energy due to electron attachment.

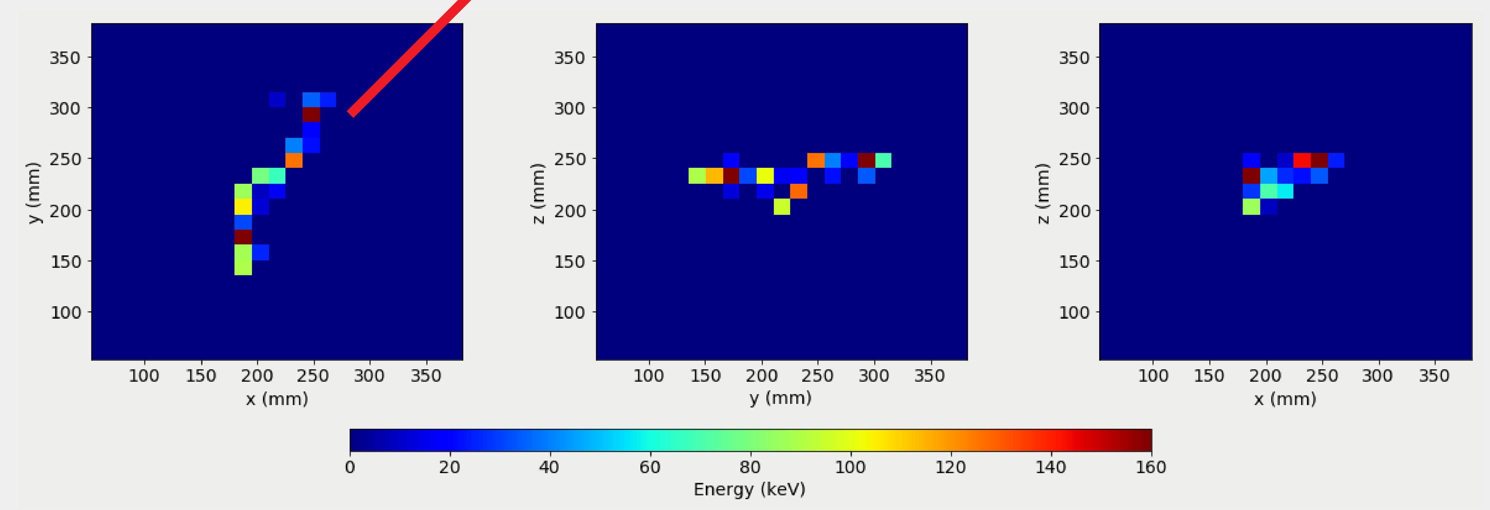


Fits were made to key components of the spectrum in selected fiducial regions to determine the optimal energy resolution at various energies ($\sim$30 keV xenon x-rays, $\sim$662 keV ^{137}Cs γ-ray, and $\sim$1592 keV e^+e^- pair-production double-escape events from the ^{208}Tl 2615 keV γ-ray). The resolution degrades at higher energies due to the increasing difficulty to correct consistently for geometrical variations over long tracks. Despite this, a sub-1% resolution (FWHM) was obtained when extrapolated to $Q_{\beta\beta}$ (assuming a $\sim 1/\sqrt{E}$ dependence).

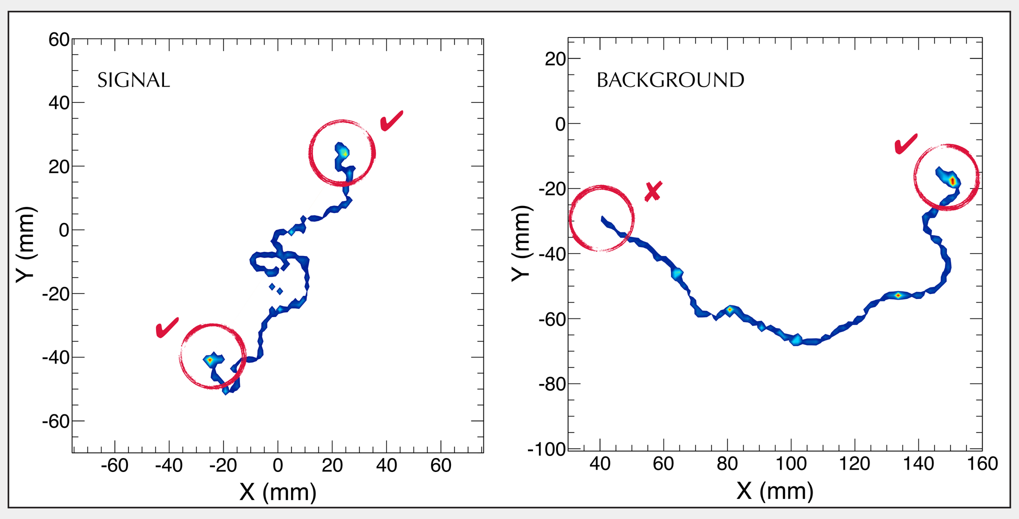
Deep Neural Networks

Recent developments in machine learning techniques have given rise to the ability to train networks of interconnected neurons with many layers, or *deep neural networks*, to solve complex problems with accuracies previously unattainable by computers.





Event Classification

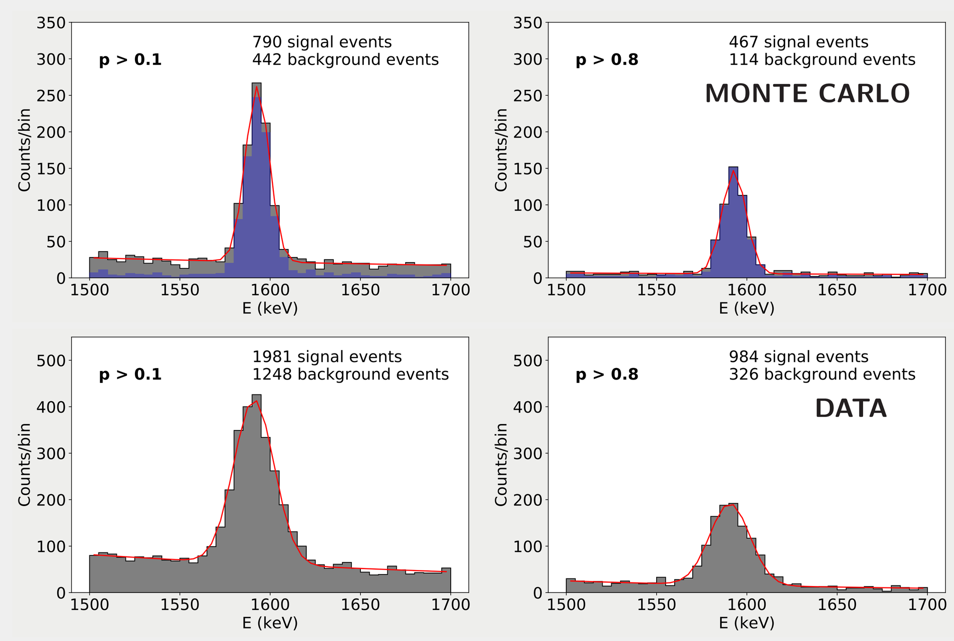


The NEXT topological signature [1]

$0\nu\beta\beta$ events have a distinct topological signature - two electrons emanating from a common vertex. As an electron slows down and stops in the xenon gas, it leaves a region of high ionization density at the end of its track. Background events due to γ-rays will give a track indicative of a single electron.

A multi-layer convolutional neural network (CNN) can be trained on Monte Carlo events to distinguish between signal and background events based on their topology (see [2]). In the present results we use the Resnet [3] architecture.

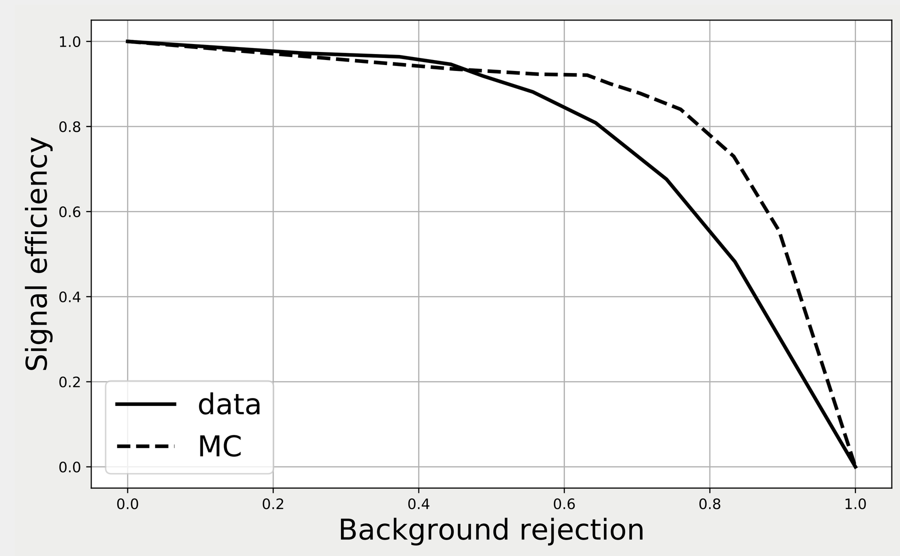
e^+e^- events from the double-escape peak of ^{208}Tl, which exhibit a similar track signature to $0\nu\beta\beta$ decay events, were used to evaluate the effectiveness of the neural network on calibration data from NEXT-White. The obtained background rejection for a given signal efficiency was quantified by varying the threshold of acceptance of the DNN, fitting the remaining events to the sum of a gaussian and an exponential, and integrating each function over the energy region of interest. A correction was made to account for the fact that some e^+e^- events (shaded blue in the MC spectra at right) fell outside the peak due to loss or capture of additional energy. The results shown are expected to improve at higher energies ($Q_{\beta\beta}$).



Signal (s) and background (b) events (before correction):

$$s = \int_{\mu-\Delta E}^{\mu+\Delta E} \frac{A_s}{\sqrt{2\pi}\sigma} e^{\frac{-(E-\mu)^2}{2\sigma^2}} dE = A_s \cdot \mathrm{erf}\left(\frac{\Delta E}{\sqrt{2}\sigma}\right)$$

$$b = \int_{\mu-\Delta E}^{\mu+\Delta E} A_b e^{\frac{-(x-E_0)}{\lambda}} dE = 2A_b\lambda e^{\frac{(E_0-\mu)}{\lambda}} \cdot \sinh\left(\frac{\Delta E}{2}\right)$$



References

[1] P. Ferrario *et al.*, "First proof of topological signature in the high pressure xenon gas TPC with electroluminescence amplification for the NEXT experiment," *JHEP*, vol. 2016, p. 104, 2016.

[2] J. Renner *et al.*, "Background rejection in NEXT using deep neural networks," *JINST*, vol. 12, p. T01004, 2017.

[3] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," 2015. [arXiv:1512.03385].

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