Self-background Removal in $LaBr_3$ Using Machine Learning

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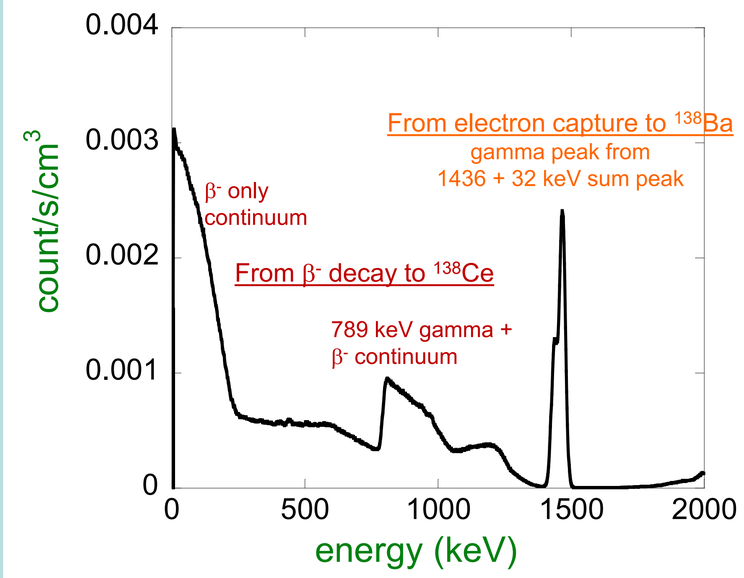
Introduction

A convolutional neural network (CNN) was developed to discriminate external radiation signals from the self-background events in the $LaBr_3$(Ce) crystal scintillator detector. The model is trained to identify the self-background pulses from ^{138}La decay with 1.46 MeV deposition energy, and the gamma-ray pulses from external ^{40}K and ^{228}Th sources with the same energy deposition.

$LaBr_3$(Ce) self count spectrum

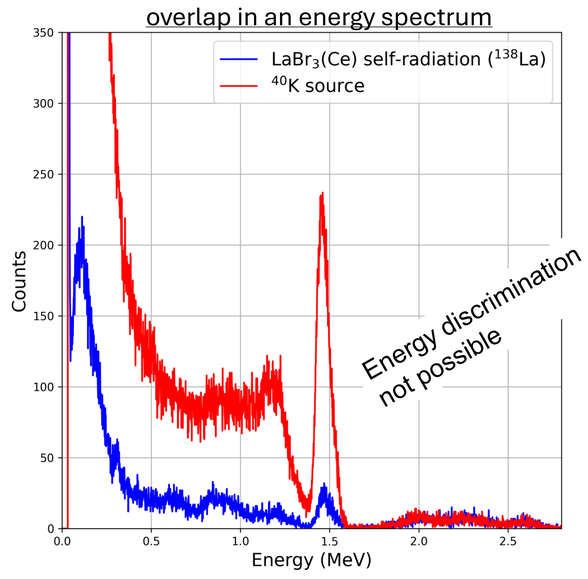


The Problem

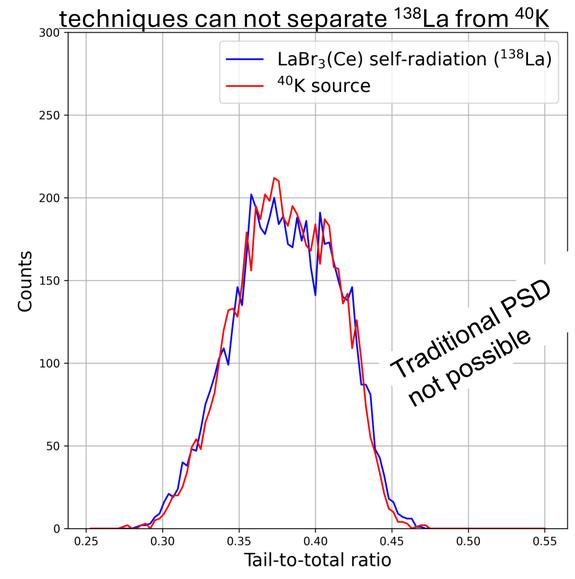
^{138}La decays mask ^{40}K gamma detection

$LaBr_3$(Ce) scintillator is one of the most frequently-used detectors in gamma-ray spectroscopy applications, due to its excellent energy resolution, high detection efficiency and large light yield. However, $LaBr_3$ contains 0.09% natural abundance of the unstable ^{138}La, producing 1.5 Bq/cc. This isotope can decay to ^{138}Ba by electron capture and emits a 1.436 MeV gamma ray coincident with a Ba x-ray which total to about 1.46 MeV. The 1.46 MeV gamma ray signal often causes misidentification of external radioactive isotopes. Therefore, the self-background of $LaBr_3$ prevents its usage to identify isotopes that emit gamma rays with similar energies, such as ^{40}K (1.461 MeV). ^{40}K is the most abundant natural gamma emitter.

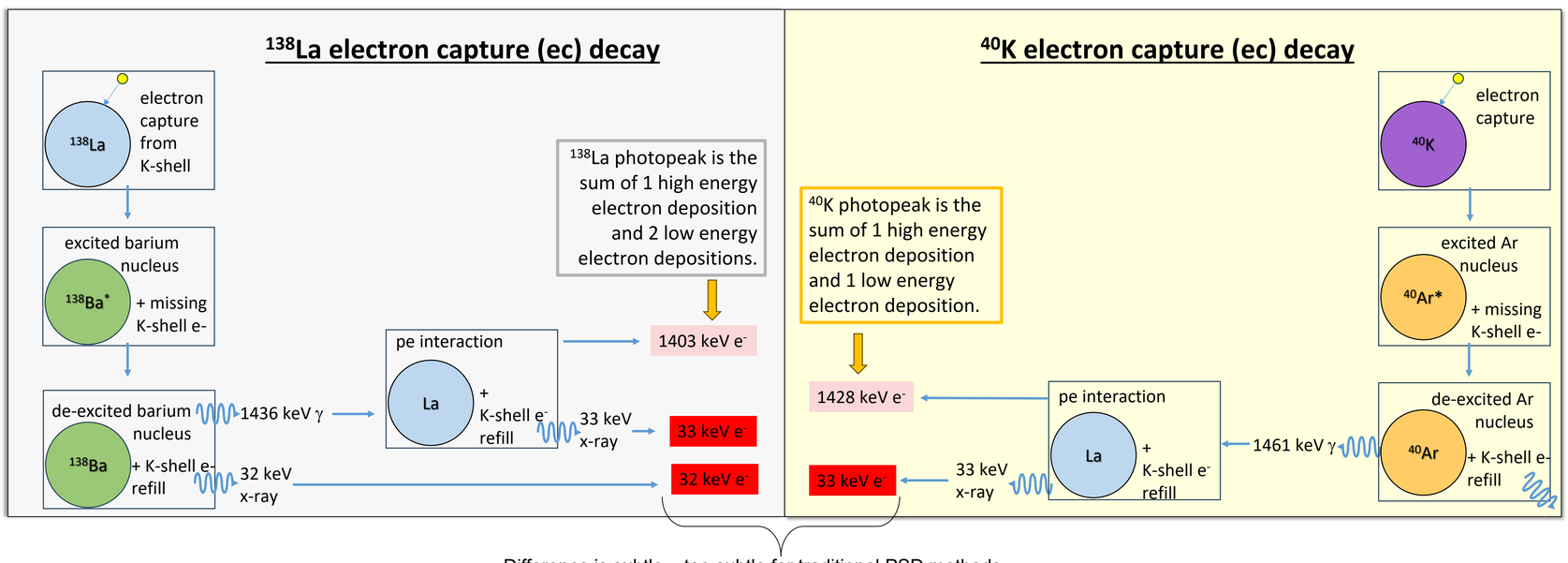
^{138}La and ^{40}K photopeaks almost completely overlap in an energy spectrum



Traditional Pulse Shape Discrimination (PSD) techniques can not separate ^{138}La from ^{40}K



Physical reason why pulse shape discrimination could be possible with Machine Learning



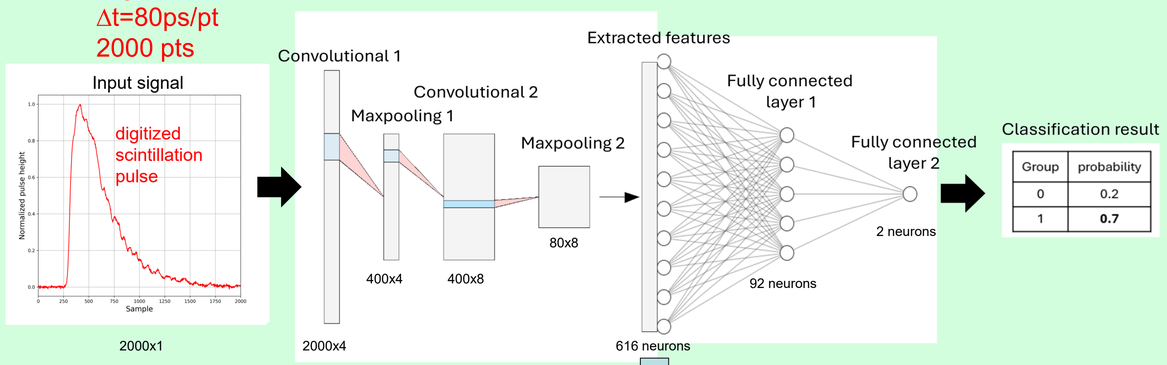
Difference is subtle – too subtle for traditional PSD methods
However, neural networks are good at finding subtle differences
^{138}La depositions will have slightly higher ionization densities
and larger fraction of its total from low energy x-rays

DAQ set up

Ø25 x 150mm $LaBr_3$(Ce) crystal coupled to H10828 PMT

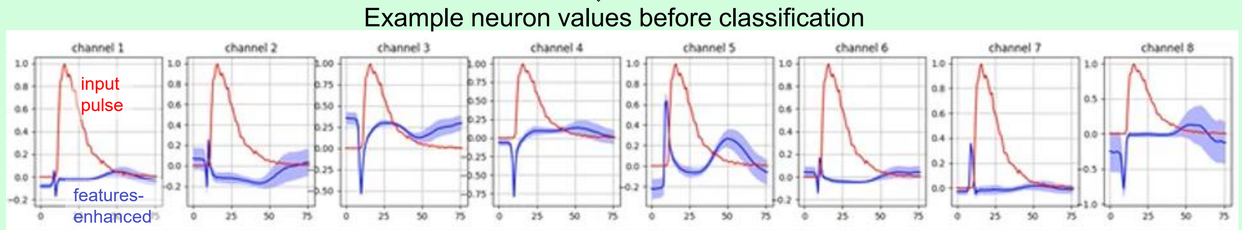
Convolutional Neural Network can separate ^{138}La background

Digitization
Δt=80ps/pt
2000 pts



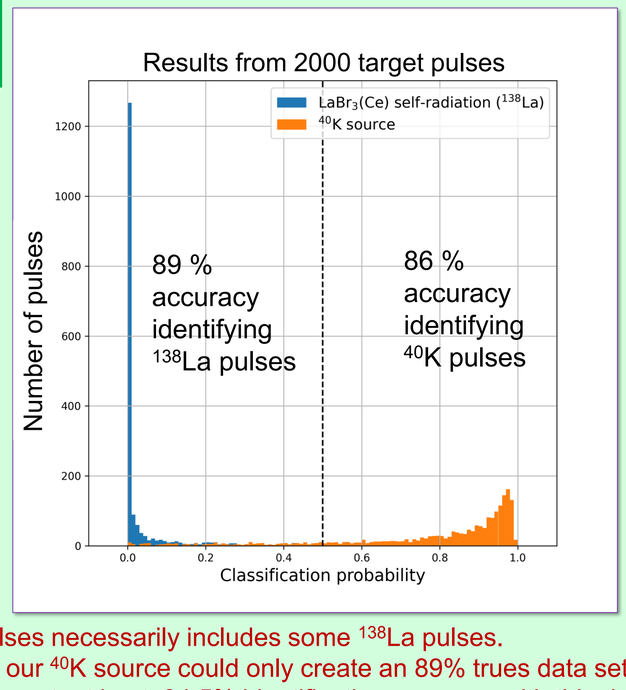
3000 training pulses of each type
1500 validation pulses of each type
2000 target pulses of each type

Example neuron values before classification



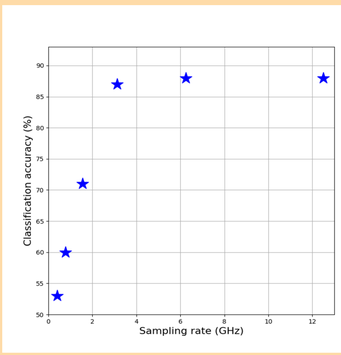
Neural Network seems to be sorting on the late parts of the pulse
- low E electrons thermalize and recombine faster
- high E electrons have longer transport times

result



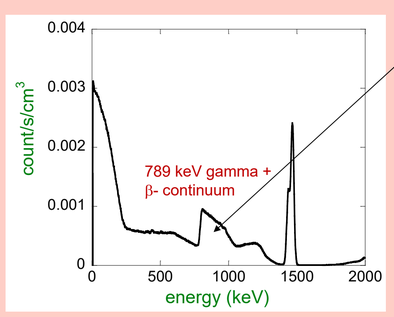
- Training data for ^{40}K pulses necessarily includes some ^{138}La pulses.
- The fairly low activity of our ^{40}K source could only create an 89% trues data set.
- Therefore, we should expect, at best, 94.5% identification accuracy with this data set.
- **Training with a strong enough ^{40}K source should produce nearly 100% separation accuracy.**

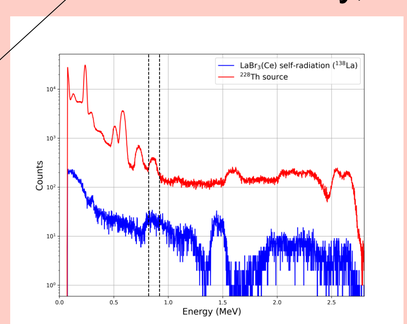
Optimum digitization rate



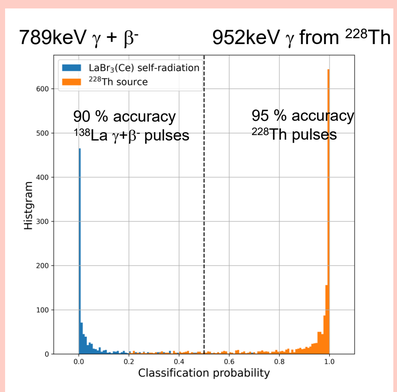
Digitization rate needs to be at least 3GHz for optimal separation of ^{40}K and ^{138}La photopeaks

CNN technique works for ^{138}La beta decay, too





result



Takeaways

- A machine learning neural network process can very accurately separate ^{138}La electron capture and ^{40}K photopeaks (1468 vs 1461 keV) in $LaBr_3$(Ce).
  - 88% accuracy is demonstrated
  - Nearly 100% accuracy should be possible with better training set
- A similar process can remove ^{138}La beta decay background
- ***This technique enables large $LaBr_3$(Ce) detectors in low count rate RIID applications.***

2025 IEEE Nuclear Science Symposium & Medical Imaging Conference 1 – 8 November 2025, Yokohama, Japan