Neutron Event Detection Using Machine Learning

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Introduction

- Neutron scattering is a powerful technique to study the atomic structure and dynamics of materials in a broad range of applications.
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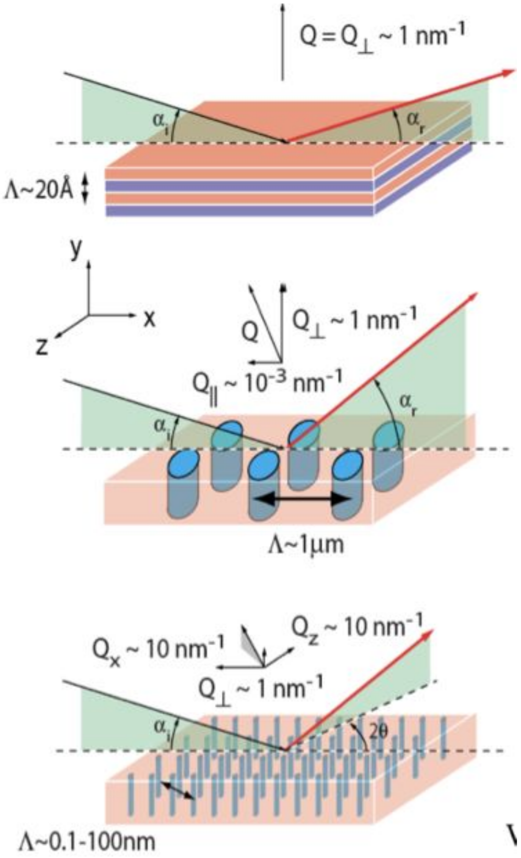
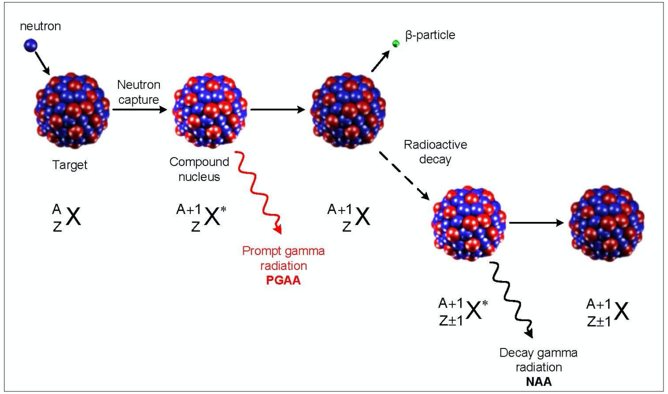
- Motivated by the scientific advancement in neutron scattering, more powerful neutron sources are being constructed.

- The advancement in neutron facilities calls for a concurrent improvement in neutron detection technologies.

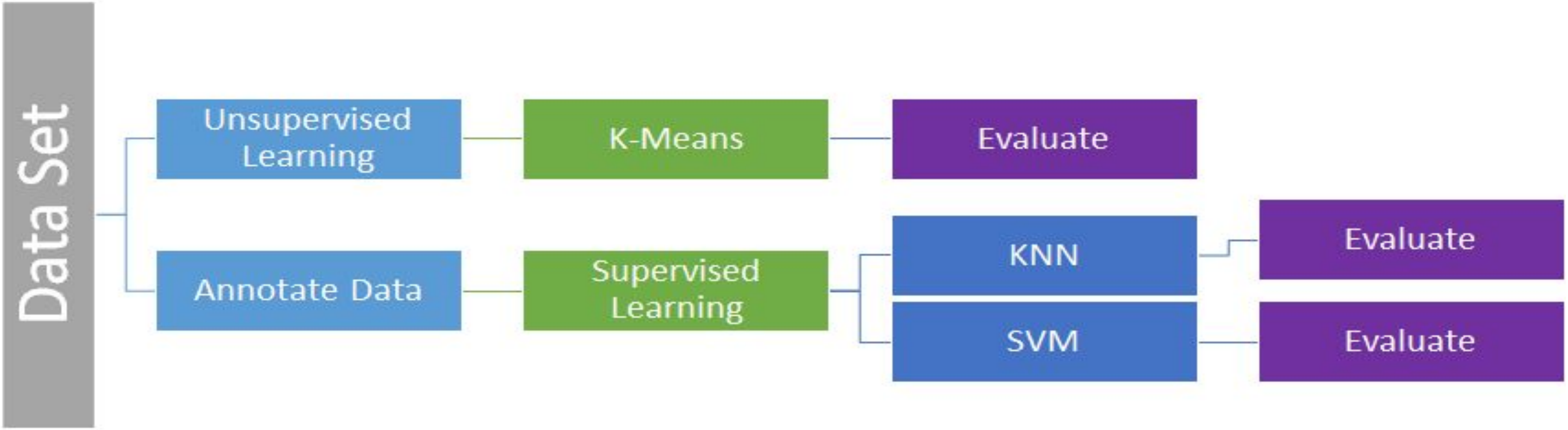


Motivation

- Detection of neutrons is often not straightforward because neutron events are usually accompanied by other events such as gamma events, noise and background radiation.
- We want to explore the potential of machine learning in neutron event detection to improve the performance of neutron detection technologies, especially in terms of classification of neutron events from other events.
- We also aim to find machine learning algorithms that can process high rates of neutron events in real time.

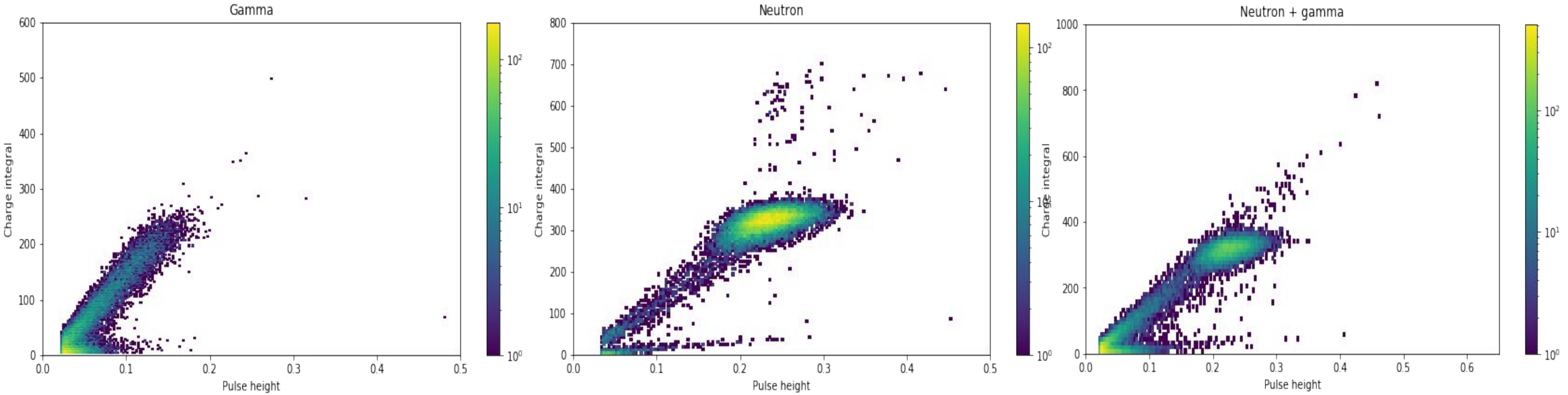


Methodology Flow Chart



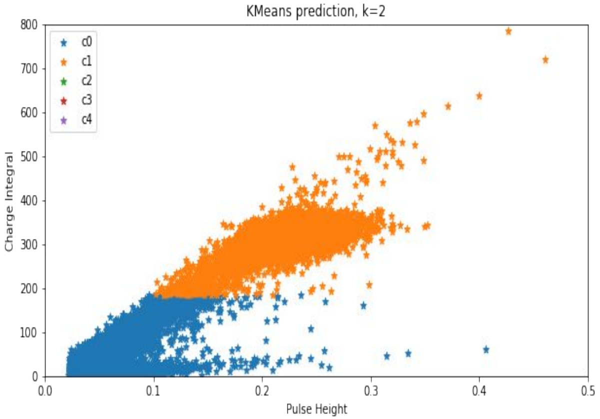
Original Unlabeled Dataset

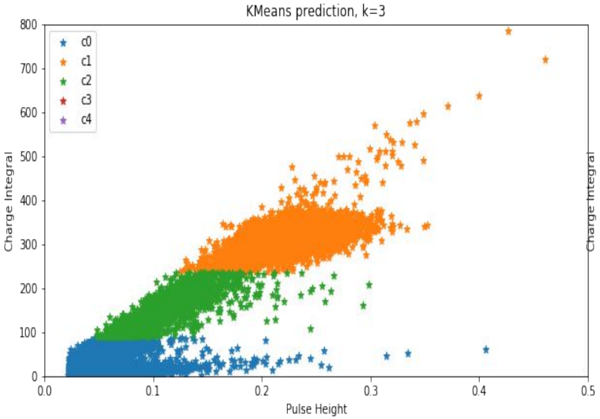
- Number of Features : 2
- Number of Samples : 60,000
- Missing values : None
- Data preprocessing : Conversion from binary to decimal

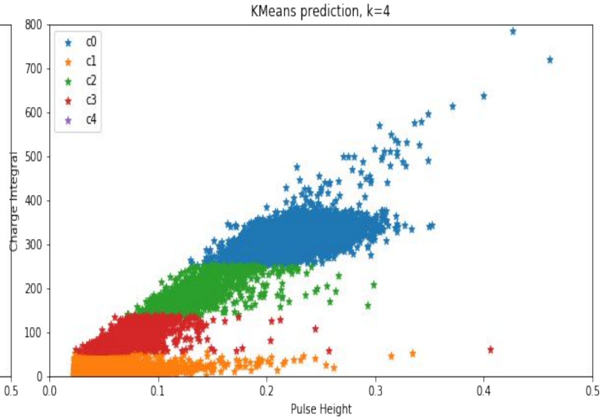


Unsupervised Learning: K-Means Clustering

- We attempted several iterations of this algorithm, however, none of them very successfully separated neutron events from the rest..

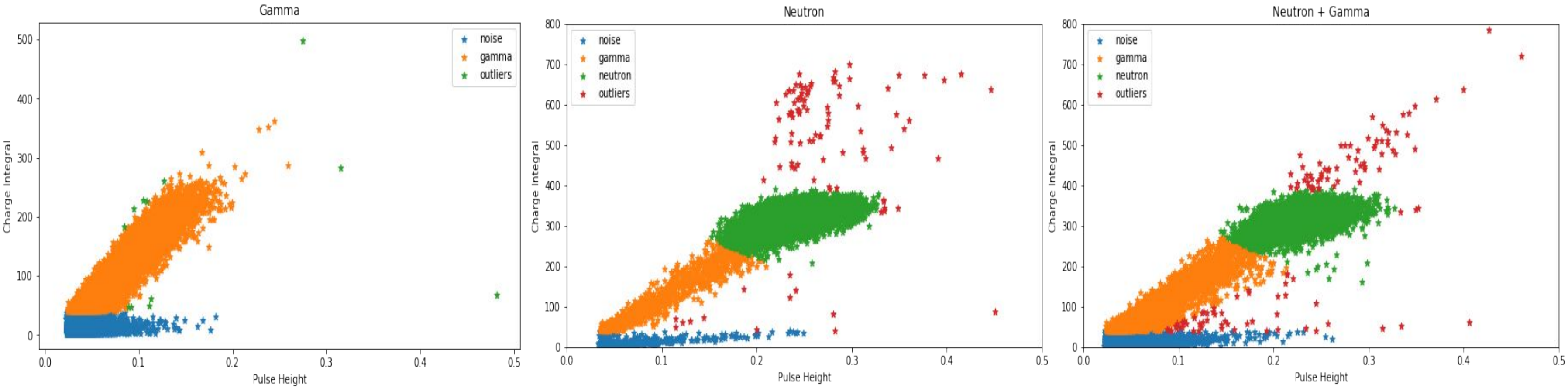






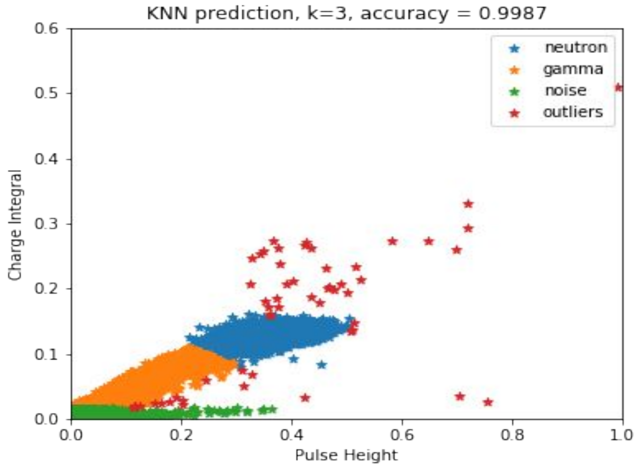
Modified Annotated Dataset

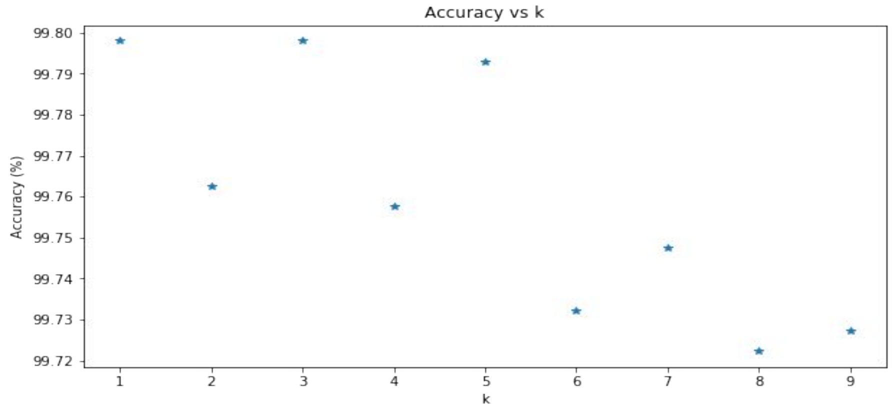
- We annotated our dataset based on domain knowledge and prior experience
- We only used straight lines to set our boundaries. A better way of annotating the data will require incorporating the physics behind the different distribution of various events.



Supervised Learning: K-Nearest Neighbors (KNN)

- We can see from the graph below that this method successfully separates the different events based on the annotated boundaries.
- We performed KNN with different values of k and chose the optimal k based on accuracy



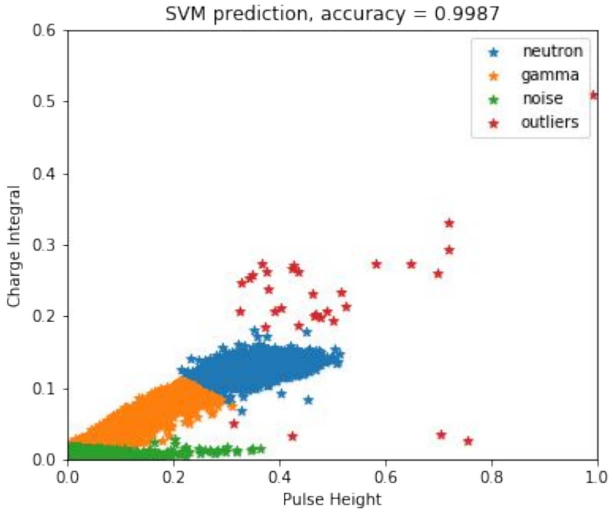


Supervised Learning: Support Vector Machine (SVM)

- We can see from the graph below that this method successfully separates the different events as we annotated..

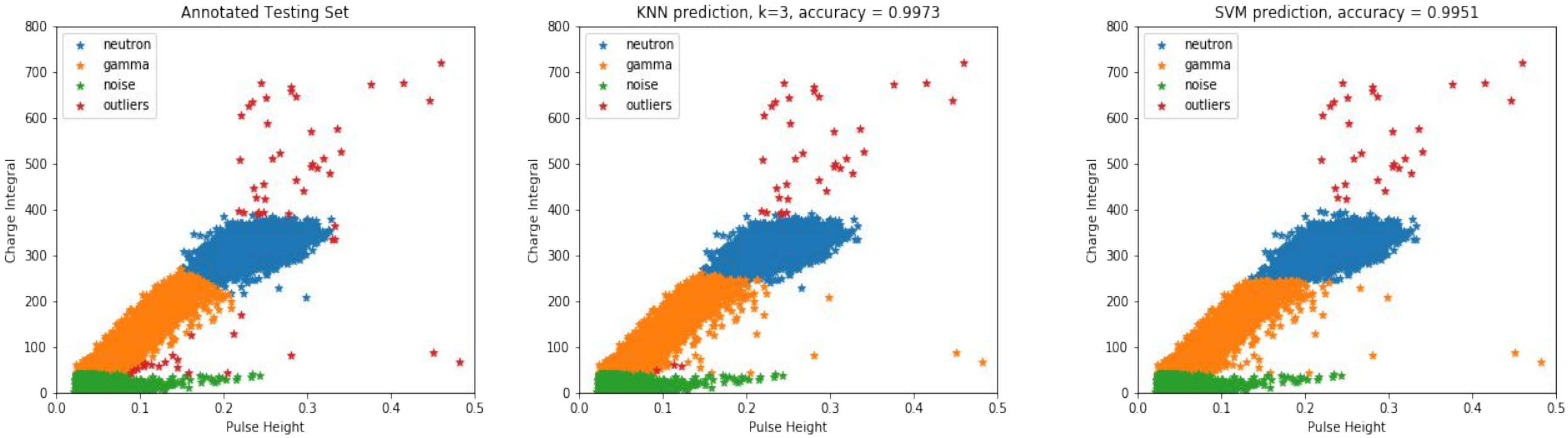
- The hyperparameters for SVM is chosen by brute force. Most of the hyperparameters are default setting:

    - Kernel = ‘rbf’
    - Gamma = ‘scale’
    - C = 1.0
    - Max_iter = -1 (no limits)



Results: Comparison between KNN and SVM

- Both methods are able to learn the boundaries that we set when we annotated our data and performs well in classifying neutron events, gamma events and noise but not so well on outliers.



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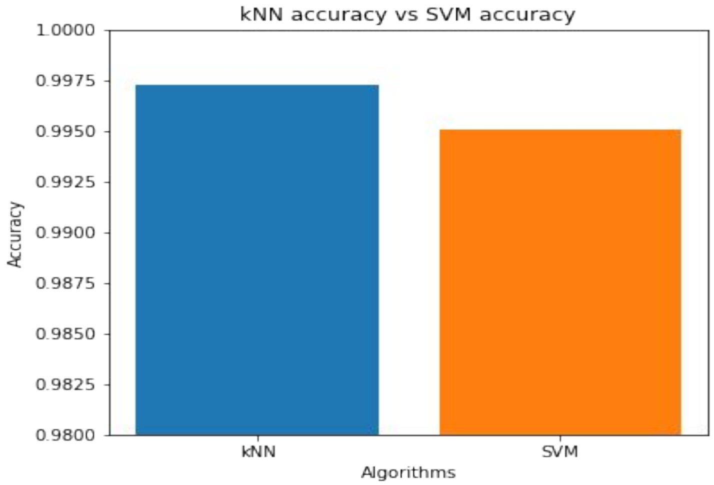
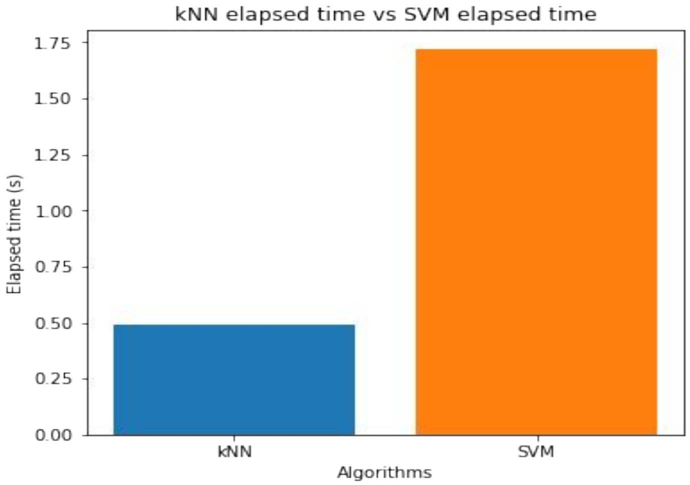
Evaluation: Accuracy and Computational Cost

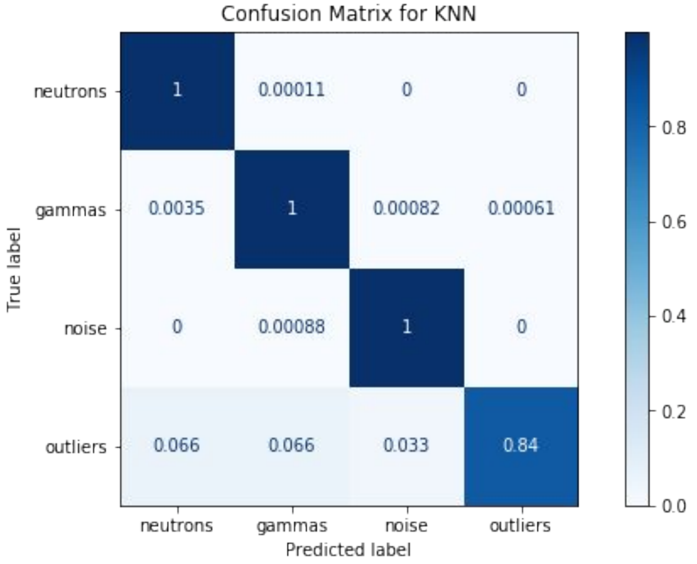
- Both methods perform really well in terms of accuracy: kNN (99.75%) and SVM (99.5%).
- KNN is less computationally expensive, The computational time of KNN is at least 3 times faster than that of SVM

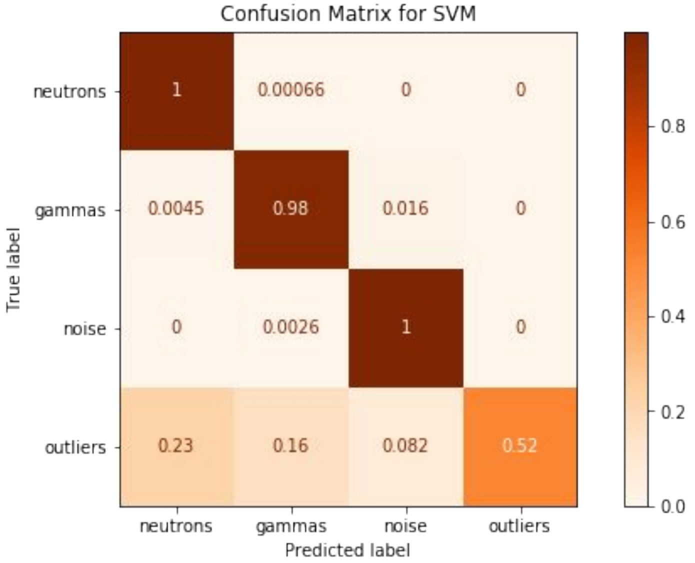




Evaluation: Confusion Matrix

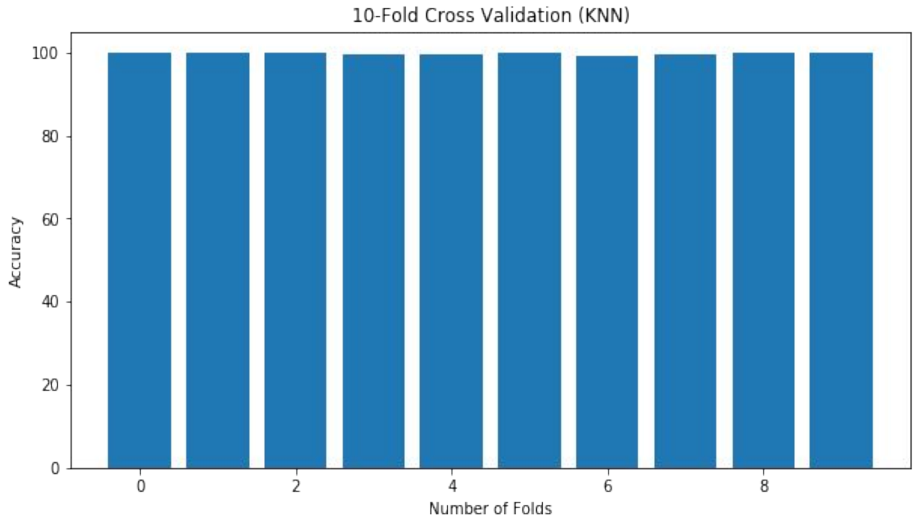
- Both methods exhibit an overall very strong correlation between the true labels and the predicted labels especially for neutrons, gamma and noise events.

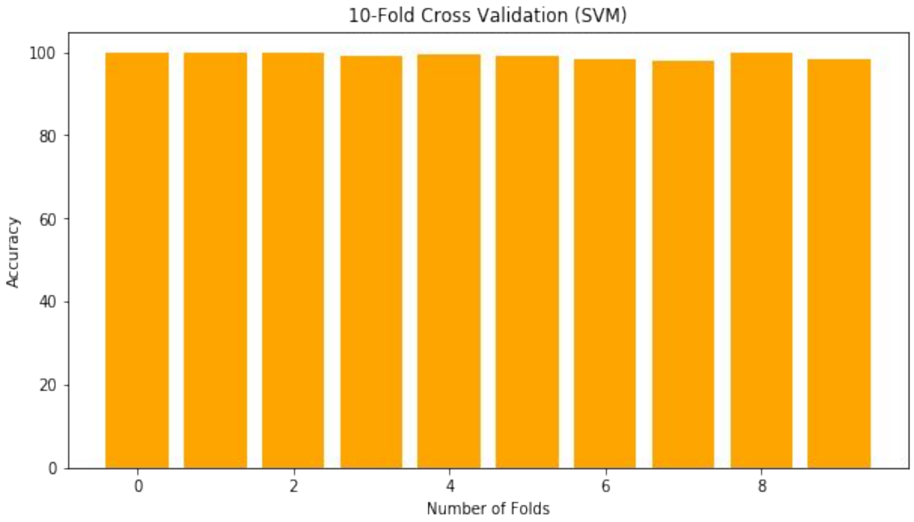




Evaluation: K-Fold Cross-Validation

- Below are two graphs that show the accuracy for left: K-Nearest Neighbors and right: SVM.
- The accuracy had little variation depending on number of folds used in validation.





Summary

- Unsupervised learning on unlabeled dataset:
  - K-Means modeling on unsupervised data did not perform well.

- Data annotation on unlabeled dataset

- Supervised learning on labeled dataset:
  - KNN and SVM both performed well in terms of accuracy
  - The performance of both classifiers are pretty consistent using 10-fold cross validation
  - However, KNN has a significantly lower computational cost than SVM

Future Work

- The physics behind the distribution of different events can be incorporated to have better annotated data that reflects the reality.

- KNN seems to be powerful in terms of accuracy, computational cost and performance consistency, making it attractive for an accurate and high-speed neutron detection system.

- Other computationally inexpensive algorithms can also be explored such as Bayes probability using Maximum Likelihood Estimates.