Applications of Machine Learning in Nuclear Physics (PHN-300)

Dasari Abhijith Reddy, 20122014, Engineering Physics

Introduction:

In this project, we have used machine learning techniques to predict whether a nucleus is a halo or not. For this, first, we try to find out the FWHM (full width at half maxima) of the parallel momentum distributions obtained on a breakup reaction of a nucleus with the 'C' nucleus (used for this study) and then later use this FWHM to predict whether a nucleus is a halo or not using logistic regression.

About Halo Nuclei:

The halo is a threshold effect that arises from the weak binding of the last few valence nucleons (usually neutrons) and hence decouples from its inert core containing other nucleons. The neutron(s) can tunnel out into a volume considerably beyond the nuclear core and into the 'classically forbidden' region due to poor binding and short-range nuclear force (because the core is relatively compact). The Uncertainty Principle assures that such bound states have a brief lifetime of a few milliseconds to a few seconds, which is sufficient for producing such nuclei and using them in nuclear processes to explore their peculiar properties.

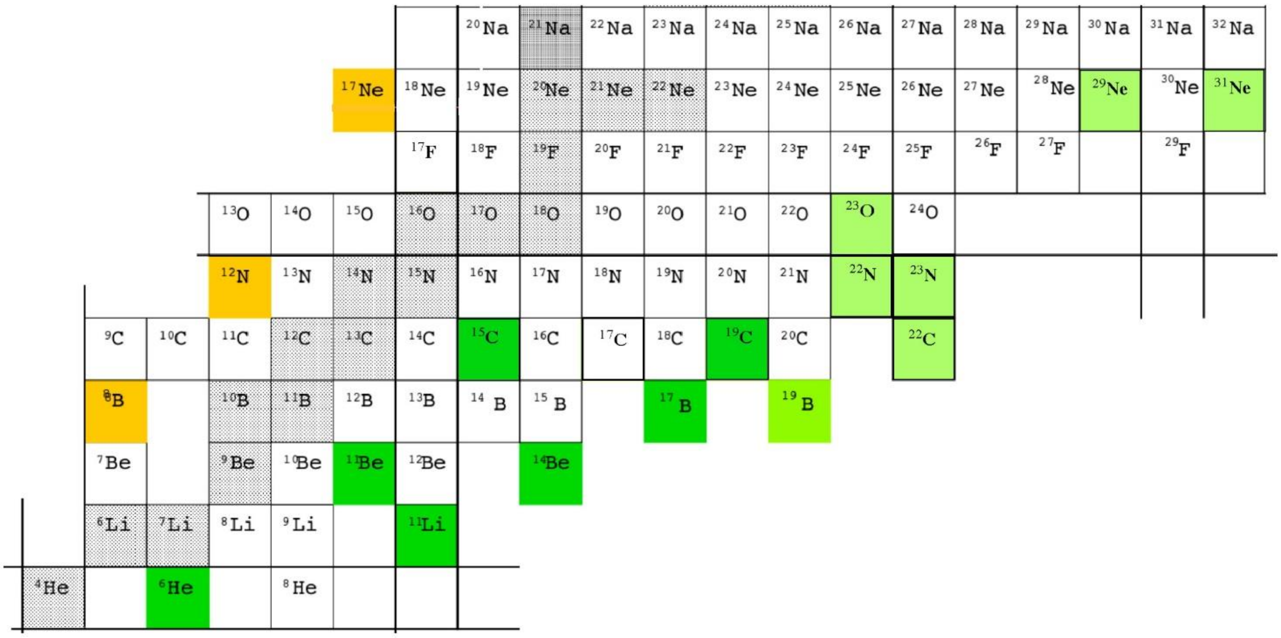

Figure 1: A small section of the Segre chart showing halo nuclei (- Neutron halo, - Proton halo)

The narrow width of the parallel momentum distribution (PMD) of charged breakup fragments emitted in breakup reactions induced by some neutron drip line nuclei reflects a neutron halo structure in the nucleus. This is because the PMD provides information about the relative momentum between the two fragments resulting from the breakup reaction, which is mainly determined by the internal structure of the nucleus. Since the PMD is least affected by the reaction mechanism, a narrow PMD can be related to a long tail in the matter distribution in the coordinate space using Heisenberg's uncertainty principle. In the case of a nucleus with a neutron halo structure, the spatial distribution of the neutron density can extend far beyond the core region of the nucleus, leading to a long tail in the matter distribution. This can result in a narrow PMD for the charged fragments produced in the breakup reaction.

Estimating FHWM:

We have obtained data from the physical review paper on "One-neutron removal reactions on light neutron-rich nuclei" (given under the references section). It has several plots of parallel momentum (P_z) distributions, and transverse momentum (P_x) distributions of core fragments obtained using a carbon target. These plots consist of both experimental data and Glauber model calculations. For extracting data from these graphs, we used ‘plotdigitizer' - an online data extraction tool to extract numerical data from images. The required plot was uploaded here, and then the axis and scale of the graph were set by placing the reference points on respective axes at the points where values on each axis are marked. Next, each experimental data point was carefully extracted in a CSV file which was used for further analysis.

Now, the task was to fit a function (Gaussian or Lorentzian) through the data extracted. For this, we have used the 'curve_fit' function from the 'scipy.optimize' module, which takes the required function, data along the x-axis, data along the y-axis & initial guess parameters (optional). The 'curve_fit' function is based on non-linear least squares regression, and it estimates the required parameters of the input function. For example, let us take the input function to be a Gaussian. The general form of a Gaussian function:

$$G(x) = Ae^{-\frac{(x-b)^2}{2c^2}}$$

Using the curve_fit function, we estimate the amplitude/peak value of the function (A), the position of the peak value (b), and the standard deviation (c).

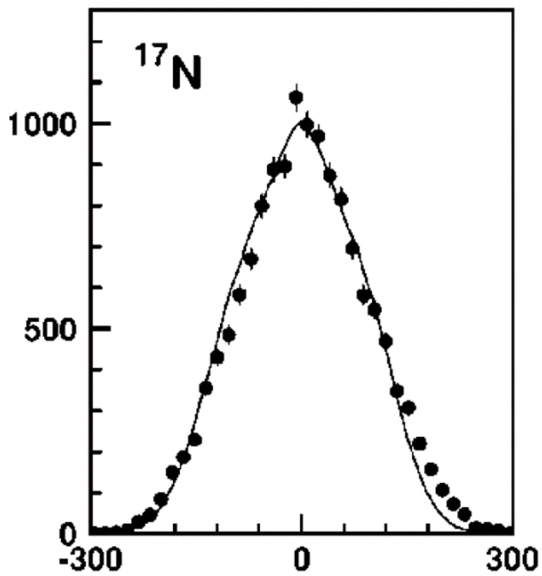

Figure 2(a)

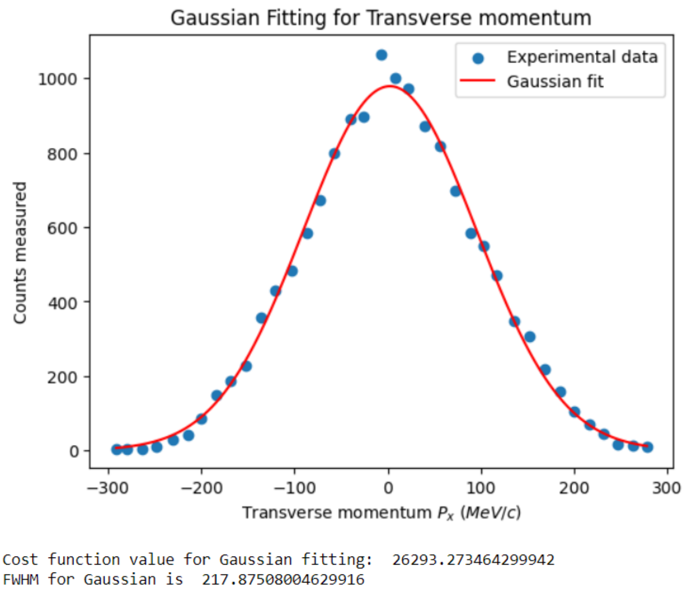

Figure 2(b)

Figure 2: The figure 2a has the experimental data (solid dots) (Counts vs P_x (MeV/c)) with the Glauber model calculations (solid line). The figure 2b is the Gaussian function fit for the same experimental data.

Similarly, for a Lorentzian function having the general form:

$$L(x) = \frac{A}{1 + \frac{(x - x_0)^2}{\gamma^2}}$$

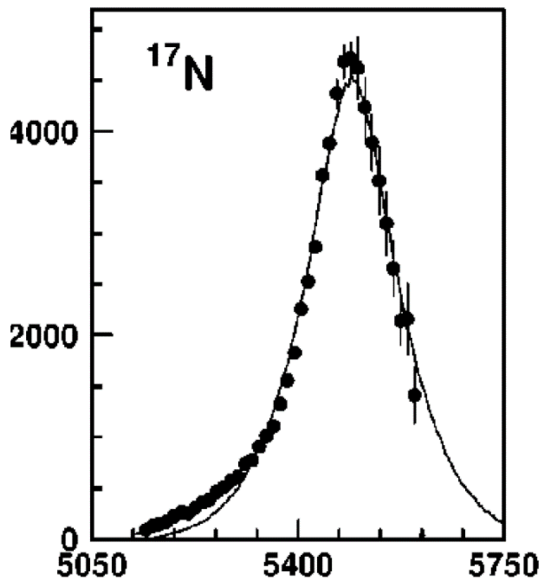

Figure 3(a)

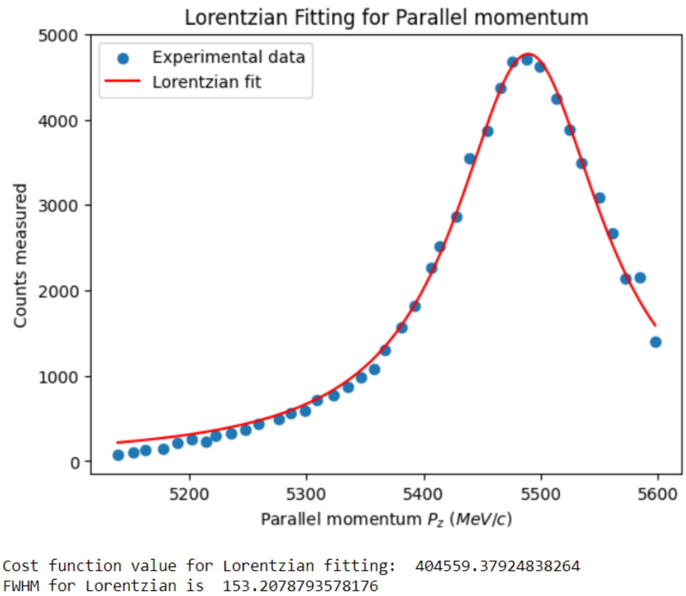

Figure 3(b)

Figure 3: The figure 3a has the experimental data (solid dots) (Counts vs P_z (MeV/c)) with the Glauber model calculations (solid line). The figure 3b is the Lorentzian function fit for the same experimental data.

We estimate the peak value of the function (A), the location of the peak (x_0), and the FWHM, which is 2γ. The guess parameters are given for required plots as the curve_fit function uses numerical optimization algorithms to find the best-fit parameters.

Now, we obtain the Gaussian and Lorentzian fits for the experimental data, plotted using Matplotlib. To choose which curve fit is better, we define a cost function that calculates the error involved in the regression. This cost function is the sum of the squared residuals, which measures the difference between the fitted curve and the actual data points. The lower the cost function, the better the fit, hence used for fitting the data points and calculating FWHM.

Prediction:

By logistic regression, we have predicted whether a nucleus is a halo or not using the FWHM obtained in the previous step. The dataset is divided into training and test sets based on the ratio we input. The accuracy we obtained was 83.33333333333334%. Given our data set is small, the accuracy we obtained is good!

We have also done another mini project on star prediction using parameters like temperature, luminosity, star radius & absolute magnitude and predict which type of star it is: red dwarfs, white dwarfs, main sequence stars, supergiants, etc.

References:

1. https://journals.aps.org/prc/pdf/10.1103/PhysRevC.69.044603

2. https://www.sciencedirect.com/science/article/pii/S014664101830053X

3. https://www.euroschoolonexoticbeams.be/files/nlp/LNP651_contrib3.pdf

4. https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.curve_fit.html

5. Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 2nd Edition, by Aurélien Géron

Link to the github repository of this project:

https://github.com/Abhijithreddydasari/ML-applications-in-nuclear-physics

Your Name: Dasari Abhijith Reddy   Name of your Supervisor : Mr. Rajdeep Chatterjee