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Machine-learning analysis of cosmic-ray nuclei data from the AMS-02 experiment

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The Alpha Magnetic Spectrometer-02 (AMS-02) experiment is a magnetic spectrometer on the International Space Station (ISS) that can measure the flux of particles from cosmic sources in a rigidity window ranging from GVs to a few TVs and up to at least Nickel (charge Z=28). High-precision measurements of fluxes of rare nuclei, such as Sc, Ti, and Mn, provide unique constraints to models of cosmic-ray propagation in the galaxy. These measurements are challenging because of the low abundances of such high-mass nuclei compared to their neighbors.
Manually optimized standard selection criteria have been shown to work well for low-mass nuclei but they are static and variables often have non-linear correlations. Also, they only include a very few variables. Machine learning (ML) algorithms learn from data by analyzing examples and the selection applied through them is non-linear. Various ML algorithms such as MLPs, CNNs, transformers, and XGBoost were tried and XGBoost shows better performance in terms of accuracy and speed. To build an ML model that analyzes nuclei from Li (charge Z=3) to Ni (charge Z=28), Monte Carlo (MC) simulations are used for training the ML algorithm. The data contains every nuclei species in equal abundance. After training and checking the ML model performance for overfitting and underfitting, it is applied to an MC sample with natural abundances. Tests have been performed on the rare medium-mass F nuclei. The ML model shows better purity than the standard selection for F at the same signal efficiency. The ML algorithm can suppress the background much better than the standard selections of the AMS-02 experiment. ML algorithms are often termed black boxes, therefore, to understand the approximate behavior of the model the Shapley method is used. The method shows that the algorithm makes decisions according to the underlying physics.

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