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New developments in the analysis of the hypernuclear experiment WASA-FRS with machine learning

The WASA-FRS HypHI Experiment focuses on the study of light hypernuclei by means of heavy-ion induced reactions in 6Li collisions with 12C at 1.96GeV/u. It is part of the WASA-FRS experimental campaign, and so is the eta-prime experiment [1]. The distinctive combination of the high-resolution spectrometer FRagment Separator (FRS) [2] and the high-acceptance detector system WASA [3] is used. The experiment was successfully conducted at GSI-FAIR in Germany in March 2022 as a component of the FAIR Phase-0 Physics Program, within the Super-FRS Experiment Collaboration. The primary objectives of this experiment are twofold: to shed light on the hypertriton puzzle [4] and to investigate the existence of the previously proposed $nn\Lambda$ bound state [5]. Currently, the data from the experiment is under analysis.

Part of the data analysis is to provide a precise ion-optics of the measurement of the fragment originated from the mesonic weak decay of the hypernuclei of interest. The reconstruction the ion-optics of fragments is based on the calibration run of FRS optics. We have proposed to implement machine learning models and neural networks to represent the ion-optics of FRS: While the current state of the problem involves solving equations of motion of particles in non-ideal magnetic fields - which leads to the application of approximations in the calculations - the implementation of data-driven models allows us to obtain accurate results with possible better momentum and angular resolution.
Another important contribution to the analysis would be the correct identification of signal versus background in the experimental data. For this purpose, we present an analysis using ML techniques as opposed to typical selection conditions methods. The interest of this new approach comes from the fact that the models interpret the physics behind the data by making more accurate cuts and more consistent with the experiment.

In this presentation, we will show two different results of the current status of the R&D in machine learning model of the ion-optics and the prospect of the inference of the track parameters of the fragments based on the calibration data recorded during the WASA-FRS experimental campaign of 2022 and the signal to background ratio enhancement with ML. For the ion optics part: our model selection optimization follows this approach: we utilize AutoML environments [6], to determine the best pipeline for our data. Once identified, this optimized pipeline is implemented in a PyTorch model. Regarding the signal to background ratio enhancement, we will make use of autoML libraries such as autogluon [7] to identify the $H3\Lambda$ hypernuclei present in the experimental datafile.

The results of this study demonstrate a robust reconstruction of the track angles in the FRS mid-focal plane, achieving an improvement of up to a ~40%. A resolution of 0.65 mrad and 0.46 mrad was achieved for the horizontal and vertical angular track plane, respectively. Additionally, the reconstruction of the magnetic rigidity in the final focal plane attained a resolution $\Delta p/p$ of 5 10^{-4}. From these results, we demonstrated that a data-driven model of non-linear ion optics is feasible. We also observed that training the full model can be achieved very quickly, paving the way for online training during data collection at the FRS. This capability will enable more accurate real-time analysis of fragment identification and improve the quality of the exotic beam obtained from the fragment separator.
Also, a correct identification of signal events in the experimental data has also been carried out, which allows a precise analysis of the properties of the $H3\Lambda$ from the experimental data, such as the lifetime of the hypernuclei.

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