High-precision measurement of the hypertriton lifetime and -separation energy exploiting ML algorithms with ALICE at the LHC.

Summary

At the CERN Large Hadron Collider (LHC), the energies reached in heavy-ion collisions are such that a state of the matter called Quark-Gluon Plasma (QGP) can form. The production of the QGP is characterised by the large number of charged particles emerging from the collision ($dN_{ch}/\,d\eta$ up to 2000 in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV), representing a major experimental challenge for the experiments operating in this high-multiplicity environment.

The A Large Ion Collider Experiment (ALICE) is designed precisely to operate in such conditions to study the properties of the QGP. Among the many particles produced in the collisions, (anti)hypernuclei are of particular interest. The lightest hypernucleus, the hypertriton, is a bound state of a neutron, a proton and a Λ baryon and is the subject of this thesis.

(Anti)hypernuclei provide the access door to study the hyperon-nucleon interaction, a crucial component of the nuclear force ruling the nuclear interactions. Therefore, the study of (anti)hypernuclei could provide significant clues for the comprehension of the nuclear force, with implications that go far beyond the High Energy Nuclear Physics. For example, determining the repulsive three-baryon interactions between nucleons and hyperons could explain the observation of two-solar-masses neutron stars.

New measurements of the (anti)hypertriton lifetime and Λ-separation energy (B_{Λ}), performed in recent years, have questioned the widespread belief – based on measurements from the late 60s and early 70s – that the (anti)hypertriton is a loosely bound object with a mean lifetime close to that of a free Λ baryon. The measurement of significantly higher B_{Λ} and lower lifetime suggested that the (anti)hypertriton is a much more bound and compact object than previously believed. However, the statistical and systematic uncertainties of the measurements did not allow for a conclusion on the (anti)hypertriton structure and lifetime.

The main goal of this thesis is to perform a new and more precise measurement of the (anti)hypertriton lifetime and B_{Λ}. Taking full advantage of the ALICE tracking and particle identification capabilities and a new dataset with an unprecedented number of detected collisions, the purpose was to obtain the most precise measurement ever achieved.

Thanks to state-of-the-art machine learning solutions for the signal/background discrimination and new approaches to the systematic uncertainty estimation designed

explicitly for this analysis, it was possible to outperform any other measurement obtained in modern experiments. This thesis's findings strongly support the loosely-bound nature of the hypertriton with a mean lifetime compatible with that of the Λ baryon.