UNIVERSITÀ DEGLI STUDI DI CATANIA

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Doctor of Philosphy
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$K^*(892)^\pm$resonance with ALICE detector at LHC

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In conclusion, it appears to me that nothing can be more improving to a young naturalist, than a journey in distant countries. It both sharpens, and partly allays that want and craving, which, as Sir J. Herschel remarks, a man experiences although every corporeal sense be fully satisfied. The excitement from the novelty of objects, and the chance of success, stimulate him to increased activity. Moreover, as a number of isolated facts soon become uninteresting, the habit of comparison leads to generalization. On the other hand, as the traveller stays but a short time in each place, his descriptions must generally consist of mere sketches, instead of detailed observations. Hence arises, as I have found to my cost, a constant tendency to fill up the wide gaps of knowledge, by inaccurate and superficial hypotheses.

But I have too deeply enjoyed the voyage, not to recommend any naturalist, although he must not expect to be so fortunate in his companions as I have been, to take all chances, and to start, on travels by land if possible, if otherwise, on a long voyage. He may feel assured, he will meet with no difficulties or dangers, excepting in rare cases, nearly so bad as he beforehand anticipates. In a moral point of view, the effect ought to be, to teach him good-humoured patience, freedom from selfishness, the habit of acting for himself, and of making the best of every occurrence. In short, he ought to partake of the characteristic qualities of most sailors. Travelling ought also to teach him distrust; but at the same time he will discover, how many truly kind-hearted people there are, with whom he never before had, or ever again will have any further communication, who yet are ready to offer him the most disinterested assistance.

The Voyage of the Beagle, Charles Darwin

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INTRODUCTION

The present thesis is the result of my Ph.D. research programme as member of the ALICE Collaboration at the CERN (European Organization for Nuclear Research) laboratories. The main interest of this high energy physics experiment is connected to the study *strong nuclear* force which is one of the four fundamental interaction forces. On the nuclear dimension scale (1-3 fm) this is the force that binds protons and neutrons (nucleons) together to form the nuclei of an atom; on a even smaller scale (less than about 0.8 fm, the radius of a nucleon), it is the force that holds quarks together to form protons, neutrons and other particles, all called hadrons.

ALICE experiment is designed to probe the characteristics of the nuclear matter phase diagram. **Quantum Chromodynamics** (QCD) predicts the existence of a state of matter called *Quark-Gluon Plasma* (QGP), which consists of asymptotically free strong-interacting quarks and gluons, which are ordinarily confined by colour confinement inside atomic nuclei or other hadrons at extremely high temperatures and densities. This is the state of matter that is believed to have existed in the early stages of the evolution of our universe. We can recreate QGP in high energy collisions involving ions and protons. *maybe an image of phase diagram*

In the analysis reported in this document the production rates of charged multi-strange baryons, Ξ and Ω and their antiparticles have been measured in Pb–Pb and pp collisions at the same energy in order to study the behaviour of one of the first proposed signatures for the QGP formation, the *strangeness enhancement*. The original prediction that the strange quark would be produced with a higher probability in a QGP scenario with respect to that expected in a pure hadron gas scenario (as the one thought to be created in pp collisions) was confirmed in measurements at lower energies. These studies can now be revisited at the much higher LHC energy, where results on strangeness enhancement and their comparisons with lower energy measurements can help to clarify the full picture.

In addition, the study of the so called nuclear modification factor as a function of transverse momentum (p_T) and the study of multi-strange baryon production in pp collisions can give insight into their production mechanism. In particular, the large transverse momentum range covered by the identification techniques adopted in the ALICE experiment provides the possibility of studying the competition between the hard mechanism (fragmentation) and soft mechanism (coalescence) in the different p_T regions.

This thesis is divided in seven chapters.

chapter 1 The general physics context, with an introduction to QCD and the connection with the idea of the QGP, obtained at high density and temperature, is given in this first chapter. In addition a general description of the fundamental characteristics of heavy-ion collision and the time evolution of the created system are presented.

chapter 2 This chapter is focused on the theoretical description of the strangeness production mechanisms (within the thermodynamical description) and the original idea of strangeness enhancement. Furthermore, results on the nuclear modification factor and the strangeness enhancement obtained in lower energy experiments are shown.

chapter 3 In this chapter the detection capabilities of the ALICE apparatus are given. Moreover, the details on the different steps necessary to convert the electronic signals from the detectors into data suitable for analysis are presented.

chapter 4 Here, the identification technique, based on the topological reconstruction of the weak decay of the multi-strange baryons, is described. Details on the difference between the two systems produced during the collision in Pb–Pb and pp are discussed.

chapters 5 and 6 In these two chapters all the needed steps to measure the production rates of multi-strange baryons, in Pb–Pb and pp collisions respectively, are detailed.

chapter 7 In this last chapter the physical results are presented. Transverse momentum spectra are first compared to model predictions. Then, results on the strangeness enhancement and the nuclear modification factors for the multi-strange baryons at the LHC energy are presented and discussed.

1 PHYSICS OF THE QUARK-GLUON PLASMA

2 STRANGENESS PRODUCTION IN A QUARK-GLUON PLASMA

3 | THE ALICE EXPERIMENT

4 CASCADE IDENTIFICATION USING TOPOLOGICAL RECONSTRUCTION

5 MULTI-STRANGE BARYON ANALYSIS IN PB–PB COLLISIONS

6 MULTI-STRANGE BARYON ANALYSIS IN PP COLLISIONS

7 FURTHER RESULTS AND DISCUSSION

CONCLUSIONS

In this thesis the measurement of the multi-strange baryon production in Pb–Pb and pp collisions at the centre-of-mass energy of 2.76 TeV using the ALICE apparatus have been presented. The cascade identification technique, based on the topological reconstruction of weak decays into charged particles, has been described. Such a technique is very effective thanks to the excellent particle identification and tracking capability of the ALICE central barrel detectors.

The measurements of the strangeness enhancement for the Ξ and Ω at the LHC energy have been presented and compared with the lower energies measurements obtained by the NA57 and STAR Collaborations. The enhancements are larger than unity for all the particles. They increase with the strangeness content of the particle, showing the hierarchy already observed at lower energies and is also consistent with the picture of enhanced $s\bar{s}$ pair production in a hot and dense partonic (deconfined) medium. The centrality dependence shows that the multi-strange particle yields grow faster than linearly with $\langle N_{part} \rangle$, at least up to the three most central classes ($N_{part} > 100 - 150$), where there are indications of a possible saturation of the enhancements. Compared to measurements at lower energies, the enhancements are found to decrease as the centre-of-mass energy of the collision increases, continuing the trend established at SPS and between SPS and RHIC. The historical role of the strangeness enhancement measurement within the context of the QGP study has been emphasized, focusing on a possible explanation of the energy dependence of this observable as being due to the gradual reduction of the canonical suppression mechanism in the proton-proton system.

The hyperon-to-pion ratios as a function of $\langle N_{part} \rangle$, both in A–A and pp collisions, from the ALICE and STAR measurements, have been proposed as an alternative way to look at the strangeness enhancement. They indicate that different factors contribute to the evolution of the enhancements with centrality. Indeed the relative production of strangeness in pp collisions is larger than at lower energies. In addition, the enhancements are seen to be in part the result of a general relative increase of multiplicity at mid-rapidity, not entirely related to strangeness.

The increase in the hyperon-to-pion ratios in A–A relative to pp is indeed about half that of the usual enhancement ratio as defined by the participant-scaled yields.

The transverse momentum spectra for the Ξ^-, $\overline{\Xi}^+$, Ω^- and $\overline{\Omega}^+$ in Pb–Pb collisions have been compared with hydrodynamic model predictions finding that the best agreement is obtained with the Krakòw and EPOS models, with the latter covering a wider p_T range. In addition, the p_T spectra in pp collisions for Ξ^-, $\overline{\Xi}^+$ and Ω^-+$\overline{\Omega}^+$ have been compared with predictions by recent PYTHIA tunes; both the Perugia 2011 and Perugia 2012 tunes underestimate the yields for the cascades.

The nuclear modification factors for the Ξ and Ω have been calculated in five centrality classes and compared with the corresponding factors for $\pi^{\pm}$, $K^{\pm}$, p and ϕ also measured by the ALICE Collaboration. The Ξ seems to follow the same behaviour of the protons at high p_T to indicate that progenitor partons of the two baryons show similar energy loss, while the Ω seems to be strongly affected by the strangeness enhancement, showing an R_{AA} larger than unity. At mid-p_T, indications of mass-ordering between the different baryons (and mesons) are present. The higher p_T reach for all the particles compared to the spectra at RHIC and the nuclear modification factor for the Ω, not even measured at lower energies, make these preliminary results uniquely interesting: the observed features provide crucial constraints for the various energy loss models. The analysis is expected to be finalized in the next months and will bring the corresponding results to publication.