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Φ-meson nuclear modification factors at the lead nuclei collisions in the ALICE experiment at the LHC

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Abstract

Hadron spectra measurements in proton–proton and nucleus–nucleus collisions at the LHC provide the means to study the mechanisms of particle production and properties of the medium formed in relativistic heavy ion collisions. The φ-meson is a very rich probe since it is sensitive to several aspects of the collision such as strangeness enhancement, chiral symmetry restoration, and parton energy loss. Due to its small inelastic cross-section, the φ-meson is not strongly affected by the late hadronic rescattering and is sensitive to the initial evolution of the system. With a mass similar to that of the proton, it is interesting to see how the φ-meson fits within the meson/baryon pattern of observables. Being a pure $s\bar{s}$ state, it further constrains the energy loss and recombination pictures. This article presents recent results on φ-meson invariant yields and nuclear modification factors measured in a wide range of transverse momentum up to 21 GeV/c^2 in $(p + p)$ and (Pb + Pb) collisions at different centralities. The proton-to-(φ-meson) yield (p/φ) ratio as a function of transverse momentum in (Pb + Pb) collisions at an energy of $\sqrt{S_{NN}} = 2.76$ TeV is also presented.

Keywords: Nuclear modification factor; Quark-gluon plazma; Meson; Heavy nucleus; Proton; ALICE; LHC.

Introduction

One of the main goals of high-energy nuclear physics is studying the phase diagram of the strongly interacting nuclear matter. It is assumed that nuclear matter undergoes a phase transition from hadronic to partonic degrees of freedom at high temperature and/or baryonic density [1,2]. Phase transition studies can help to better understand different phenomena of quantum chromodynamics (QCD) such as confinement and chiral symmetry violation which do not have a clear theoretical explanation at the moment.

In laboratory conditions, high temperatures and baryonic densities can be achieved in central collisions of relativistic heavy nuclei. In such collisions the kinetic energy of colliding particles disperses inside a large volume of nuclear matter involved in the reaction. Simultaneous heating and squeezing of nuclear matter can lead to a phase transition of matter from colorless hadrons to

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a state of free quarks and gluons called the quark-gluon plasma (QGP) [3].

In 2005 all collaborations at the Relativistic Heavy Ion Collider (RHIC) [4] in the Brookhaven National Laboratory (BNL, USA) announced the experimental observation of a new state of matter that is the strongly interacting QGP [1,2]. The observed substance had properties of a nearly perfect liquid with partonic degrees of freedom, high energy and color charge density.

The conclusion that a new state of nuclear matter is formed in central heavy nuclei collisions at RHIC energies was based on the body of experimental observations and their interpretation within the QCD. One of the main results in favor of QGP formation at RHIC was the observation of hadron suppression at high transverse momentum called the jet-quenching effect [5,6]. This suppression occurs as a result of energy losses of high-energy partons traversing the color-charged medium formed in the relativistic nuclei collisions [7,8]. Measuring the suppression level allows to estimate the energy losses of the in-medium partons and so to study the properties of that medium. It should be noted that an intermediate medium is not expected to form in the collisions of light and heavy nuclei and the jet-quenching effect should not occur.

Measurements of light hadrons produced in heavy ion collisions at RHIC energies indeed indicated the suppression of hadron production by over a factor of five in central Au+Au collisions [6]. Meanwhile, no suppression was observed for the same hadrons and high-energy direct photons in case of d+Au collisions [9,10]. It was the first experimental confirmation of jet-quenching and it allowed to estimate the energy and color charge density in the formed medium associated with QGP. In spite of the fact that there are many theoretical models successfully describing the suppression of light hadrons in central heavy ion collisions, these models cannot explain a similar suppression of hadrons containing light quarks (u, d) and hadrons containing heavy quarks (c, b). It is clear that such a problem demands a deeper study of the jet-quenching effect, as well as systematical measurements of production and suppression of a wider sample of identified hadrons with different masses and quark content.

Another important observation made at RHIC was the enhancement of baryon production with respect to mesons at intermediate transverse momentum in central heavy ion collisions [11]. The p/π ratio measured in central collisions of heavy ions in the transverse momentum range of 2–5 GeV/c was observed to be several times larger than the same ratio measured in p+p collisions at the same energy. For an explanation of this experimentally observed effect, called the baryon anomaly [12], hadron production mechanisms other than fragmentation need to be taken into account. Some existing models [13,14] try to explain this enhancement of baryon production through the recombination of structural quarks. In this scenario, three-quark baryons get a larger increase in transverse momentum than two-quark mesons. Recombination models assume a thermal source of partons is formed that can be associated with QGP. It should be noted that other alternative models explaining this effect also exist, including models based on hydrodynamic effects and radial flow evolution [15–17]. In such models, the difference between baryon and meson production is driven by the difference in particle masses. It is obvious that for a better understanding of dominating hadron production mechanisms, a systematic study of the production of different hadrons at intermediate transverse momentum is necessary, focusing on the production of baryons and mesons with similar masses.

The experimental program of relativistic heavy ion collisions started at the Large Hadron Collider (LHC) at CERN (Switzerland) in 2010 [18]. All discoveries made at RHIC were confirmed by experiments at the LHC.

In this work φ-mesons are considered the key instrument for studying the hot and dense matter produced in central heavy nuclei collision at the LHC. By mass and quark content this particle sits in between light (u, d) and heavy (c, b) hadrons. Measurements of φ-meson production in central heavy ion collisions will contribute to the systematic studies of the jet-quenching effect. Moreover, the mass of the φ-meson is similar to that of the proton, making it an ideal candidate for baryon anomaly studies.

In this article measurements of φ-meson invariant production spectra in p+p collisions at $\sqrt{s} = 2.76$ TeV and in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are presented. These results are used for calculating the nuclear modification factors for φ-mesons in Pb+Pb collisions at different centralities. The implications of the obtained results for the determination of the properties of the hot and dense medium and the dominating mechanisms of hadron production at different transverse momenta are discussed.

Measurement of the invariant production spectra of φ-mesons

All results presented in this article were obtained by analyzing the data of the ALICE experiment at the LHC. A detailed description of the detector subsystems along with the discussion of the ALICE experimental program can be found in Ref. [19].