Abstract

Strangeness production is a key tool to understand the properties of the medium formed in heavy-ion collisions: an enhanced production of strange particles was early proposed as one of the signatures of the Quark-Gluon Plasma. The \( \phi \) meson, due to its \( s\bar{s} \) valence quark content, provides insight into strangeness production. The ALICE experiment has measured \( \phi \) meson production in the dimuon channel in the forward rapidity region \( 2.5 < y < 4 \) in Pb–Pb collisions at \( \sqrt{s_{\text{NN}}} = 5.02 \) TeV.

The preliminary \( \phi \) meson \( p_T \) spectra for different centrality classes and the yield as a function of the collision centrality in the transverse momentum range \( 2 < p_T < 7 \) GeV/c are presented. These results are also compared with the ones previously obtained in Pb–Pb collisions at \( \sqrt{s_{\text{NN}}} = 2.76 \) TeV.

Keywords:
Quark Gluon Plasma, heavy ions, dimuons, vector mesons, low mass region

1. Introduction

Quantum Chromodynamics predicts the occurrence of a phase transition from the hadronic matter to a plasma of deconfined quarks and gluons (Quark-Gluon Plasma) when extreme conditions of temperature and energy density are reached. These conditions can be recreated in laboratory through ultrarelativistic heavy-ion collisions.

Strangeness production provides key information on the hot and dense state of strongly interacting matter produced in high-energy heavy-ion collisions: in fact, an enhanced production of strange particles was early proposed as one of the signatures of the Quark-Gluon Plasma (QGP) [1]. The \( \phi \) meson, due to its \( s\bar{s} \) valence quark content, is an excellent probe of strangeness production in heavy-ion collisions. The observables considered in this analysis are the transverse momentum (\( p_T \)) spectra as a function of the collision centrality and the central-over Peripheral ratio \( R_{\text{CP}} \).

Vector mesons are reconstructed with the ALICE muon spectrometer [2] in the rapidity range \( 2.5 < y < 4 \) through their decay into muon pairs. Dileptons are not affected by strong final-state interactions in the QGP, differently from the products of the hadronic decay channels, which are unlikely to escape the medium without reacting further.

The ALICE muon spectrometer is composed of a front hadron absorber, a set of cathode pad chambers (five stations, each one composed of two chambers) for the track reconstruction in a dipole field, an iron wall...
acting as a muon filter and two stations, each one made of two resistive plate chambers (RPC) for the muon trigger. The analyzed data were collected requiring the coincidence of an unlike-sign dimuon trigger and a minimum bias trigger. The dimuon trigger requires two opposite sign tracklets in the muon trigger system. The single muon $p_T$ threshold was set at $\sim 1\text{ GeV}/c$. The minimum bias trigger, independent from the muon trigger, was based on a set of forward scintillators (V0) and on a silicon pixel detector (SPD) placed in the vertex region.

2. Analysis

The data from Pb–Pb collisions were collected in 2015 at $\sqrt{s_{\text{NN}}}=5.02\text{ TeV}$ and amount to an integrated luminosity of $\sim 225\mu\text{b}^{-1}$. Muon tracks were selected requiring that the tracks reconstructed in the tracking stations matched the ones in the trigger chambers and that their pseudorapidity was in the range $-4<\eta_\mu<-2.5$. Here and in the following, the sign of $\eta_\mu$ is determined by the choice of the LHC reference system. A cut on the single muon $p_T>0.85\text{ GeV}/c$ was also applied. Muon pairs were selected inside the dimuon rapidity interval $2.5<y_{\mu\mu}<4$. Due to the fact that the acceptance for low mass dimuons is close to zero for $p_T<2\text{ GeV}/c$, only dimuons with $p_T>2\text{ GeV}/c$ were selected.

The combinatorial background was evaluated through the event mixing technique; like-sign pairs were used to normalize the background. The ratio between the opposite-sign spectra and the combinatorial background, shown in Fig. 1 (left panel) for $2<p_T<7\text{ GeV}/c$, grows from central to peripheral collisions. In particular, at the $\phi$ peak, this ratio grows from $\sim 0.05$ in the most central bin (0-10%) to $\sim 5$ in the most peripheral one (80-90%).

An example of invariant mass distribution, after the combinatorial background subtraction, is shown in Fig. 1 (right) for $2<p_T<7\text{ GeV}/c$, for the most central bin (0-10%). The invariant mass distribution is described as a superposition of light meson decays into muon pairs, with an additional contribution coming from charm and beauty semi-muonic decays. Low-mass resonance shapes come from a Monte Carlo simulation with a parametric generator [3], while open charm and beauty have been generated using a parametrization of PYTHIA [4]. In order to extract the signal, the mass spectrum has been fitted with these contributions, leaving as free parameters the normalizations of $\eta\rightarrow \mu^+\mu^-\gamma$, $\omega\rightarrow \mu^+\mu^-\phi\rightarrow \mu^+\mu^-$ and open charm. The other processes were fixed according to the relative branching ratios or cross sections ($\sigma$), as done in [3]. In particular, the normalization of the $\rho$ relative to the $\omega$ meson was fixed requiring that $\sigma_\rho = \sigma_\omega$ [5, 6, 7].

Fig. 1. Left: opposite-sign/combinatorial background ratio for $2<p_T<7\text{ GeV}/c$. Right: Invariant mass distribution for $2<p_T<7\text{ GeV}/c$, for the most central collisions (0-10%).
Fig. 2. Top, left: $p_T$ spectrum, integrated over centrality, in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76 $ TeV. Top, right: $p_T$ spectrum, integrated over centrality, in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02 $ TeV. Bottom: $p_T$ spectrum for several centrality classes in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02 $ TeV.

3. Results

Figure 2 (top, left and right panels) shows the comparison between the $p_T$ spectra, integrated over centrality, in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76 $ TeV and at $\sqrt{s_{NN}} = 5.02 $ TeV respectively. The $\sqrt{s_{NN}} = 2.76 $ TeV spectrum covers the $p_T$ range $2 < p_T < 5$ GeV/c and can be fitted with the exponential function of the form $dN/dp_T \propto p_T e^{-m_T/p_T}$.

For the spectrum measured at $\sqrt{s_{NN}} = 5.02 $ TeV, the $p_T$ range has been extended up to 7 GeV/c, and a power-law function $dN/dp_T \propto p_T \left[1 + (p_T/p_0)^2\right]^{n}$ is needed to include the high $p_T$ tail.

The comparison of the $\phi$ $p_T$ spectra for different centralities is shown in Fig. 2 (bottom), for 0-10%, 10-20%, 20-40%, 40-60% and 60-90% centrality classes. All centralities are well described by a power-law function. Peripheral collisions are characterized by a slightly harder $p_T$ tail than the central collisions.

The $\phi$ central-over-peripheral ratio $R_{CP}$ has been calculated, for each centrality bin, as

$$R_{CP} = \frac{\left(\frac{dN_{\phi}}{dy}\right)^{\text{central}}}{\langle T_{AA}\rangle^{\text{central}}} \frac{\left(\frac{dN_{\phi}}{dy}\right)^{\text{peripheral}}}{\langle T_{AA}\rangle^{\text{peripheral}}}$$

where $dN_{\phi}/dy$ is the $\phi$ yield and $\langle T_{AA}\rangle$ is the average nuclear overlap function [8] in that centrality bin.

The $\phi$ $R_{CP}$ as a function of $\langle N_{\text{part}}\rangle$, for $2 < p_T < 7$ GeV/c, is shown in Fig. 3 (left). The peripheral reference bin corresponds to 60-90% centrality. The $R_{CP}$ decreases from peripheral to central collisions, implying a suppressed $\phi$ production in central collisions with respect to peripheral.
Fig. 3. $\phi R_{CP}$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Left: $\phi R_{CP}$ as a function of $\langle N_{\text{part}} \rangle$, for $2 < p_T < 7$ GeV/c. Right: $\phi R_{CP}$ as a function of $p_T$, for central to peripheral and semi-peripheral to peripheral collisions.

The $R_{CP}$ as a function of $p_T$ was calculated similarly as the $R_{CP}$ as a function of $\langle N_{\text{part}} \rangle$. The $p_T$ dependence of the $R_{CP}$ for central to peripheral and semi-peripheral to peripheral collisions is shown in Fig. 3, right side. The $R_{CP}$ is significantly smaller than 1 for $p_T \gtrsim 4$ GeV/c in the case of central to peripheral collisions. In the semi-peripheral to peripheral case, the decrease is much less pronounced, meaning that the $\phi$ production in the intermediate/high $p_T$ region is more suppressed in central collisions.

4. Summary

The production of $\phi$ meson was measured via its dimuon decay channel in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at forward rapidity, in the $p_T$ region $2 < p_T < 7$ GeV/c.

The comparison between the $\phi$ $p_T$ spectrum integrated over centrality at $\sqrt{s_{NN}} = 2.76$ TeV and at $\sqrt{s_{NN}} = 5.02$ TeV shows that the former, which covers the $2 < p_T < 5$ GeV/c range, can be fitted with an exponential function, while for the latter a power-law function is needed to describe the higher $p_T$ tail up to 7 GeV/c. The $p_T$ spectra are well fitted with a power-law function also in the case of 0-10%, 10-20%, 20-40%, 40-60% and 60-90% centralities, although the peripheral collisions are characterized by a harder slope with respect to central collisions.

The $\phi R_{CP}$ as a function of $\langle N_{\text{part}} \rangle$ decreases from peripheral to central collisions, implying a suppressed $\phi$ production in central collisions. The $R_{CP}$ as a function of $p_T$ decreases for $p_T \gtrsim 4$ GeV/c, implying a suppressed $\phi$ production in the intermediate/high $p_T$ region in central collisions with respect to peripheral collisions.

References