

Low mass vector meson production in pp and Pb-Pb collisions measured with ALICE at the LHC

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Abstract. Vector mesons are key probes of the hot and dense state of strongly interacting matter produced in heavy ion collisions. Their dileptonic decay channel is particularly suitable for these studies, since dileptons have negligible final state interactions in hadronic matter. In particular, strangeness production can be studied through the measurement of muon pairs coming from the decay of ϕ mesons. The ALICE apparatus at the LHC can access vector mesons produced at forward rapidity ($2.5 < y < 4$) through their decays in muon pairs. We present results on vector meson production in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The ϕ meson production cross section is measured in pp collisions. In Pb-Pb collisions, a measurement of the $\phi/(\rho + \omega)$ ratio and of the ϕ nuclear modification factor as a function of the collision centrality is obtained.

Low mass vector meson (ρ, ω, ϕ) production provides key information on the hot and dense state of strongly interacting matter produced in high-energy heavy ion collisions. In particular, strangeness production can be accessed through the measurement of ϕ meson production. The nuclear modification factor provides information about hadron production [1]. At low transverse momenta, $p_T < 2$ GeV/ c , hadron production is governed by soft processes which can be described in terms of hydrodynamical and thermal models [2, 3], while at high p_T ($p_T > 5$ GeV/ c) hard processes dominate. In the latter region, yields are suppressed due to the parton energy loss caused by gluon bremsstrahlung [4]. At intermediate p_T ($2 < p_T < 5$ GeV/ c), light mesons are suppressed with respect to binary scaling, differently from protons and antiprotons. In this context, it is interesting to compare their suppression pattern with the one of the ϕ , which is a meson having a mass similar to the proton one.

The detection of the ϕ meson through its decay in lepton pairs has the advantage that, differently from the K^+K^- channel, dileptons are not influenced by final state interactions, like rescattering and absorption [5]. Previous results at the SPS [6, 7] showed a discrepancy between results in the two channels, while most recent measurements [8, 9] showed an agreement between the measurements in dileptons and kaons in Pb-Pb and In-In.

Vector meson production in pp collisions provides a reference for the determination of the nuclear modification factor. Moreover, it is interesting by itself, since it can be used to tune particle production models in the LHC energy range.

The ALICE experiment at the LHC can access vector mesons produced at forward rapidity through their decays in muon pairs. The detector is described in [10]. The measurement in the dimuon channel was performed using the forward muon spectrometer, that covers the pseudorapidity range $-4 < \eta < -2.5$ (although in the ALICE reference frame the muon spectrometer covers a negative η range, we chose to present our results with a positive y

notation). It consists of an hadron absorber, a set of cathode pad chambers (five stations, each one composed of two chambers) for the track reconstruction in a dipole magnetic field, two stations of two resistive plate chambers for the muon trigger and an iron wall acting as a muon filter. The centrality is determined with the VZERO detector, that consists of two arrays of plastic scintillators placed at 3.4 m and -0.9 m from the IP.

Data were taken in both pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The data sample in pp collisions was collected in 2013 and amounts to an integrated luminosity $L_{\text{int}} = 81.1 \text{ nb}^{-1}$. Data relevant for this analysis were acquired with a dimuon trigger, that is provided by the coincidence of two single-muon trigger signals. The trigger selects tracks with a low p_T threshold of roughly 0.5 GeV/c. Offline selections were applied in order to remove beam-gas background. Muon tracks were selected asking that the tracks reconstructed in the tracking stations matched the ones in the trigger chambers and that their pseudorapidity was in the range $-4 < \eta_\mu < -2.5$. Muon pairs were selected requiring that the dimuon rapidity was within the interval $2.5 < y_{\mu\mu} < 4$.

The combinatorial background in the opposite sign dimuon mass spectrum was subtracted using the event mixing technique. The S/B ratio at the ϕ peak is ~ 2 .

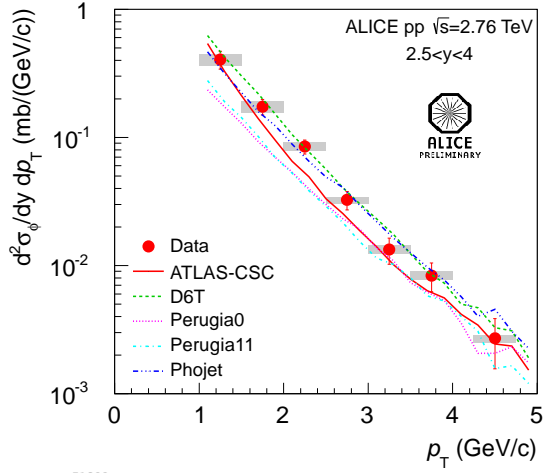
The mass spectrum after background subtraction was described as a superposition of light meson decays into muon pairs, with an additional contribution coming from charm and beauty semi-muonic decays. Low-mass resonance shapes, as well as the acceptance and efficiency for each process, were obtained through a Monte Carlo simulation with a parametric generator [11], while open charm and beauty were generated using a parametrization of PYTHIA. Alternative fits to the mass spectrum were performed replacing this hadronic cocktail with empirical functions. In order to extract the p_T -differential cross section, the measured number of ϕ mesons $N_\phi^{\text{meas}}(\Delta p_T)$ was measured in several p_T intervals. The differential cross section in Δp_T was calculated as $d\sigma_\phi/dydp_T = N_\phi^{\text{meas}}(\Delta p_T)/(A\varepsilon(\Delta p_T)BR_{\phi \rightarrow l+l-}L_{\text{int}})$, where $BR_{\phi \rightarrow l+l-}$ is the branching ratio for the ϕ decay into lepton pairs (assuming lepton universality, the more precise measurement in e^+e^- is used), A is the acceptance and ε is the efficiency for the $\phi \rightarrow \mu^+\mu^-$ process. The sources of systematic uncertainty are those on the evaluation of the branching ratio (1%), on the integrated luminosity (1.8%), on the number of ϕ determined by the fit (ranging from 8.7% at low p_T to 4.6% at high p_T), on the tracking and trigger efficiency (4.5% and 3%, respectively). The differential cross section is reported in Fig. 1. In the same figure, the predictions based on the PYTHIA tunes ATLAS-CSC, D6T, Perugia-0 and Perugia-11 and on PHOJET are shown [12, 13, 14, 15, 16]. It can be observed that, while the Perugia-0 and Perugia-11 tunes underestimate the cross section by about a factor of two, the other calculations agree with the measurement within 15%. Consistent results have been obtained in a previous measurement at $\sqrt{s} = 7$ TeV [11].

Data in Pb-Pb collisions were collected in 2011 at $\sqrt{s_{NN}} = 2.76$ TeV. For this data set, a higher p_T selection, with a threshold at about 1 GeV/c, was applied on the single muons at the trigger level. The selections applied were the same as in pp analysis, with an additional cut on the single muon p_T at 0.85 GeV/c that removes muons that, due to the fact that the trigger threshold is not sharp, have been accepted at the trigger level. Due to the limited acceptance at low p_T caused by the high p_T threshold imposed by the trigger, an additional cut on the dimuon p_T at 2 GeV/c was applied. The number of opposite sign muon pairs was $\sim 2 \cdot 10^6$.

The combinatorial background was evaluated with the event mixing technique also in Pb-Pb analysis. S/B ratio at the ϕ peak is ~ 0.1 for most central collisions, increasing up to ~ 3 for peripheral collisions.

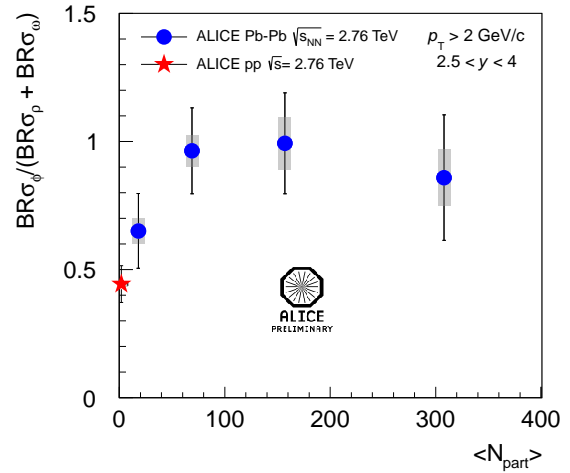
The detector acceptance and efficiency was estimated by means of an embedding Monte Carlo technique, that consists in simulating signal particles and embedding the generated hits on the detector to those of real events. This technique allows one to account for the variation of the reconstruction efficiency with the detector occupancy and, thus, the collision centrality.

In Fig. 2, the ratio $BR_\phi\sigma_\phi/(BR_\rho\sigma_\rho + BR_\omega\sigma_\omega)$, is shown as a function of the number



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Figure 1. ϕ differential cross section vs p_T in pp collisions at $\sqrt{s} = 2.76$ TeV compared with the predictions based on several PYTHIA tunes and PHOJET.



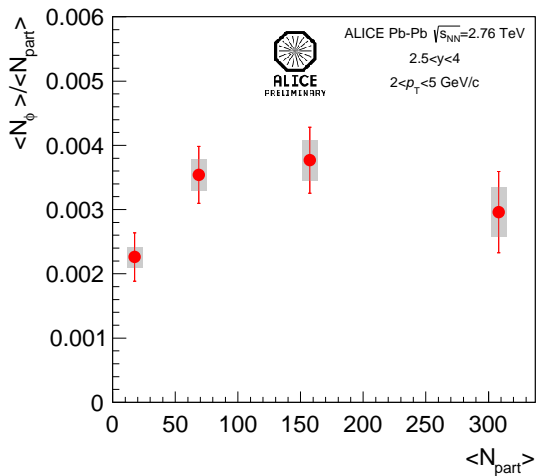
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Figure 2. Ratio $BR_\phi\sigma_\phi/(BR_\rho\sigma_\rho + BR_\omega\sigma_\omega)$ as a function of the number of participating nucleons N_{part} .

of participating nucleons N_{part} . The pp result is also reported for comparison. Systematic uncertainties are mainly due to the variations related to p_T cut on single muon and to the description of the correlated background due to non-resonant components. Other components, like the uncertainty on the tracking and trigger efficiency and on the acceptance, mainly cancel out in the ratio and are thus neglected. The ratio increases from pp to Pb-Pb and tends to saturate when moving from semiperipheral to central collisions. The value for most central Pb-Pb collisions is about two times the one measured in pp collisions. A similar behaviour is observed in the ϕ multiplicity per participant, displayed in Fig. 3: the multiplicity increases faster than N_{part} from peripheral to semiperipheral collisions, and tends to saturate for higher N_{part} values.

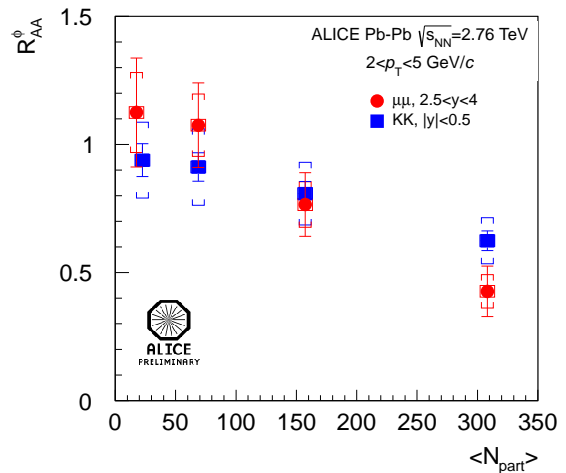
The nuclear modification factor for a given centrality, p_T and y range is obtained as $R_{AA} = \langle\phi\rangle/(\sigma_{pp}\langle T_{AA}\rangle)$, where $\langle\phi\rangle$ is the ϕ multiplicity, σ_{pp} is the cross section in pp collisions in the same p_T and rapidity range and $\langle T_{AA}\rangle$ is the average nuclear overlap function of the considered centrality class [17, 18]. Deviations of R_{AA} from unity quantify the departure of the multiplicity in Pb-Pb from a superposition of incoherent nucleon-nucleon collisions. R_{AA} measured as a function of the number of participants is shown in Fig. 4. In addition to the sources of systematic uncertainties already discussed for the $BR_\phi\sigma_\phi/(BR_\rho\sigma_\rho + BR_\omega\sigma_\omega)$ ratio, also the uncertainty on tracking and trigger efficiency, on the acceptance, on σ_{pp} and T_{AA} give a sizeable contribution to the systematic uncertainty on R_{AA} . In peripheral collisions, the nuclear modification factor is compatible, within uncertainty, with unity, indicating that these collisions behave as a superposition of incoherent pp collisions. In most central collisions, R_{AA} is reduced to about 0.5, showing a clear suppression of the ϕ multiplicity with respect to the pp reference in the intermediate p_T region. In the same figure, a comparison with the ALICE measurement in the KK channel at midrapidity [19] is shown. Within uncertainties, each point measured in the dimuon channel is compatible to the corresponding one in the hadronic channel. On the other side, the decrease of R_{AA} vs N_{part} appears steeper than the one in the kaon channel, such that differences in the two channels, or rapidity ranges, cannot be excluded within the precision of the measurement.

In 2013, data were taken also in p-Pb collisions. Results are currently under analysis. Thanks



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Figure 3. ϕ multiplicity per participant as a function of the number of participating nucleons.



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Figure 4. ϕ R_{AA} as a function of N_{part} measured in the dimuon channel for $2.5 < y < 4$, compared to the ALICE measurement in the K^+K^- channel for $|y| < 0.5$.

to the large statistics, cold nuclear matter effects will be investigated with good accuracy.

In conclusion, the ϕ production cross section was measured in pp collisions at $\sqrt{s} = 2.76$ TeV. The comparison with some commonly used PYTHIA tunes and PHOJET shows the ATLAS-CSC and D6T tunes, as well as PHOJET, reproduce the measured cross section within $\sim 15\%$, while Perugia-0 and Perugia-11 underestimate the cross section by about a factor of two. In Pb-Pb collisions, the ϕ multiplicity per participant increases from peripheral to semiperipheral collisions and tends to saturate in semicentral and central collisions. The nuclear modification factor is compatible with unity for peripheral collisions and decreases down to ~ 0.5 for most central collisions. Each point measured in the dimuon channel is compatible to the corresponding one in the hadronic channel, although the decrease of R_{AA} vs N_{part} in the dimuon channel at forward rapidity appears steeper than the one in the kaon channel at midrapidity.

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