Vector meson production in pp collisions at $\sqrt{s} = 7$ TeV, measured with the ALICE detector

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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. A preliminary measurement of the $\phi$ and $\omega$ differential cross sections was performed by the ALICE experiment in pp collisions at $\sqrt{s} = 7$ TeV, through their decay in muon pairs. The $p_T$ and rapidity regions covered in this analysis are $p_T > 1$ GeV/c and $2.5 < y < 4$.

Low mass vector meson ($\rho^0, \omega, \phi$) production provides key information on the hot and dense state of strongly interacting matter produced in high-energy heavy ion collisions. Among them, strangeness enhancement can be accessed through the measurement of $\phi$ meson production, while the measurement of the $\rho$ spectral function can be used to reveal in-medium modifications of hadron properties close to the QCD phase boundary. Vector meson production in pp collisions provides a reference for these studies. Moreover, it is interesting by itself, since it can be used to tune particle production models in the unexplored LHC energy range.

The ALICE experiment at the LHC can access vector mesons produced at forward rapidity through their decays in muon pairs, and at central rapidity in the di-electron decay channel. The detector is fully described in [1]. In this paper, results from the analysis of the data collected during the 2010 pp run at $\sqrt{s} = 7$ TeV are reported.

The measurement in the dimuon channel was performed using the forward muon spectrometer, that consists of an absorber acting as muon filter, a set of cathod pad chambers (five stations, each one composed of two chambers) for the track reconstruction in a dipole field, two stations of two resistive plate chambers for the muon trigger, two absorbers and an iron wall acting as a muon filter.

The data sample used for the analysis in the dimuon channel amounts to an integrated luminosity of approximately 85 nb$^{-1}$. Since only a fraction of the data contained the full information relevant for the extraction of the integrated luminosity, a subsample corresponding to $L_{\text{INT}} = 55.7$ nb$^{-1}$ was used for the measurement of the $\phi$ cross section, while the full sample was used to extract the $p_T$ distribution. Muon pairs were selected asking that each muon track reconstructed in the tracking chambers matches the corresponding tracklet in the trigger stations in the position in the (x-y)
plane and in the slope in the (r-z) plane. A cut on the muon rapidity 2.5 < y_μ < 4 was applied in order to remove the tracks close to the acceptance borders. About 291,000 opposite sign (N_+-), 197,000 like-sign (N_++ , N_-- ) muon pairs survived these selections.

The combinatorial background was evaluated using the event mixing technique, and normalized to 2R√N_++N_-- , where R = A_+-/√A_+A_-- , and A_±± is the acceptance for a (±±) pair. The event mixing was checked by comparing the results obtained for like-sign mixed pairs with the real ones. The shapes of the background calculated with the two methods are identical, while the amount of like-sign pairs estimated with the event mixing differs from the one in the real data by 5%. We take this value as the uncertainty on the background normalization. The signal-to-background ratio for 2 |y| < 1 was limited to 1 at the φ and ω masses. Alternatively, the combinatorial background contribution to the opposite sign mass spectrum for a given ∆M mass bin can be evaluated from the like sign mass spectra using the formula: N^{comb}_+(∆M) = 2R√N_++(∆M)N_--(∆M).

The two techniques are in good agreement for p_T > 1 GeV/c, while for lower pair transverse momenta both methods fail in describing the background. The analysis is thus limited to p_T > 1 GeV/c.

After subtracting the combinatorial background from the opposite sign mass spectrum, we obtain the signal mass spectrum shown in Fig. 1 (left). The invariant mass spectrum is fitted with the contributions given by the light meson decays into muons and open charm/beauty contributions. The free parameters of the fit are the normalizations of the η → μμγ, ω → μμ, φ → μμ and open charm signals. The other processes (η → μμ, ρ → μμ, ω → μμπ^0 , η' → μμγ and open beauty) are fixed according to the relative branching ratios or cross sections. The main sources of systematic uncertainty are due to the uncertainty in the background normalization and on the relative normalization of the sources, mainly due to the error on the branching ratios for the ω and η' Dalitz decays. The raw number of φ and ρ + ω resonances obtained from the fit is \( N_φ = (3.20 \pm 0.15) \times 10^3 \) and \( N_{ρ+ω} = (6.83 \pm 0.15) \times 10^3 \).

The φ production cross section was evaluated in the range 2.5 < y < 4, 1 < p_T < 5 GeV/c through the formula \( \sigma_φ = \frac{N_φ}{BR(φ→l^+l^-)N_{MB}N_μ^{-MB}} \), where \( N_φ \) is the measured number of φ mesons corrected for the efficiency and the acceptance, \( BR(φ→l^+l^-) = (2.95 ± 0.03) \times 10^{-4} \) is the branching ratio in lepton pairs, obtained as a weighted average of the branching ratios in e^+e^- and μ^+μ^- pairs [2], \( N_{MB} \) is the number of minimum bias collisions, \( σ_{MB} \) is the ALICE minimum bias cross section in pp collisions at \( \sqrt{s} = 7 \) TeV and \( N_μ^{MB}/N_μ^{-MB} \) is the ratio between the number of single muons in the region 2.5 < y_μ < 4, p_T,μ > 1 GeV/c collected with the minimum bias trigger and with the muon trigger. The minimum bias cross section was measured in a Van der Meer scan [3]. Its value is \( σ_{MB} = 62.3 ± 0.4rible (stat) ± 4.3(\text{syst}) \) mb. The number of minimum bias collisions was corrected, run by run, for the probability of having multiple interactions in a single bunch crossing. The ratio \( N_μ^{MB}/N_μ^{-MB} \) strongly depends on the data taking conditions and was evaluated run by run. We obtain \( σ_φ(1 < p_T < 5 \text{ GeV/c}, 2.5 < y < 4) = 0.940 ± 0.084(\text{stat}) ± 0.095(\text{syst}) \) mb. The systematic error comes from the uncertainty on the background subtraction (2%).
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Figure 1. Left: dimuon invariant mass spectrum for $p_T > 1$ GeV/c. Yellow band: systematic uncertainty from background subtraction. Red band: uncertainty in the relative normalization of the sources. Right: $d^2\sigma_\phi/dp_Tdy$ in dimuons compared to the LHCb [4] and ALICE [5] measurements in kaons.

The measurements in kaon pairs performed by LHCb in a similar rapidity range ($2 < y < 4$, open circles) [4] and by ALICE at midrapidity ($|y| < 0.5$, full circles) [5] are also plotted, showing that the shapes are similar. The rescaling of the LHCb cross section to $p_T > 1$ GeV/c and to $2.5 < y < 4$ leads to $\sigma_\phi = 1.07 \pm 0.15$ (full error) mb. There is a 14% difference between the ALICE and LHCb measurements. Considering the ALICE statistical error and the part of the systematic uncertainty which are certainly not correlated among the two experiments, the two measurements are in agreement.

The ratio $N_{\phi}/(N_\rho + N_\omega)$ was measured as a function of the transverse momentum, showing a flat trend with an average value of 0.42 ± 0.02. In order to extract the $\omega$ cross section, the $\rho$ and $\omega$ contributions must be disentangled, leaving the $\rho$ normalization as an additional free parameter in the fit to the dimuon mass spectrum. The result of the fit gives $\sigma_\rho/\sigma_\omega = 1.15 \pm 0.20$ (stat) ± 0.12 (syst). The systematic uncertainty was evaluated changing the normalizations of the $\eta' \to \mu\mu\gamma$ and $\omega \to \mu\mu\pi^0$ according to
Figure 2. Left: Ratio $\sigma_\phi/\sigma_\omega$ as a function of $p_T$. Right: $d^2\sigma_\omega/dp_Tdy$ for $2.5 < y < 4$.

the uncertainties in their branching ratios, and the background level by $\pm 10\%$, twice the uncertainty in the normalization. From these results, it was possible to extract the ratio $\sigma_\phi/\sigma_\omega = 0.178 \pm 0.015$ (stat) $\pm 0.008$ (syst). This ratio is plotted as a function of $p_T$ in Fig. 2 (left). The $\omega$ production cross section, calculated from this ratio, is $\sigma_\omega(1 < p_T < 5 \text{ GeV/c}, 2.5 < y < 4) = 5.28 \pm 0.46$ (stat) $\pm 0.58$ (syst) mb. In Fig. 2 (right) the $\omega$ differential cross section is shown. Data are fitted with the power law function, obtaining $p_0 = 1.44 \pm 0.09$ GeV/c and $n = 3.2 \pm 0.1$.

In conclusion, the $\phi$ and $\omega$ $p_T$ differential cross sections were measured in pp collisions at $\sqrt{s} = 7$ TeV. The ratio between the $\phi$ and the $\omega$ cross sections is flat as a function of $p_T$. In Pb-Pb collisions work is in progress to measure $\phi$ production as a function of centrality.

References

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