

# Vector meson production in pp collision at $\sqrt{s} = 7$ TeV and at $\sqrt{s} = 2.76$ TeV measured with the ALICE detector

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**Abstract.** Strangeness enhancement is one of the possible signatures of the Quark Gluon Plasma formation and can be accessed through the measurement of  $\phi$  meson production with respect to  $\rho$  and  $\omega$  mesons. Vector mesons can be detected through their decays into muon pairs with the ALICE muon spectrometer.

We present transverse momentum spectra of  $\phi$  and  $\rho + \omega$  mesons in the rapidity range  $2.5 < y < 4$  in p-p collisions at  $\sqrt{s} = 7$  TeV, as well as the absolute production cross sections at  $\sqrt{s} = 7$  TeV and at  $\sqrt{s} = 2.76$  TeV. We also show the  $\phi/(\rho + \omega)$  ratio in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV.

## 1. Introduction

Low mass meson ( $\rho$ ,  $\omega$ ,  $\phi$ ) 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 [1]. Vector meson production in pp collisions provides a reference for these studies and it is interesting by itself, since it can be used to tune particle production models in the LHC energy range.

We analyzed the vector mesons [2] produced in the rapidity range  $2.5 < y < 4$  at the ALICE experiment [3] and detected through their decays into muon pairs.

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, two stations of two resistive plate chambers (RPC) for the muon trigger and an iron wall acting as a muon filter. The muon trigger is fired when at least three of the four RPC planes give a signal compatible with a tracklet in the muon trigger system. A minimum bias trigger, independent from the muon trigger and based on a set of forward scintillators and on a silicon pixel detector placed in the vertex region, was used to evaluate the integrated luminosity.

## 2. Analysis in pp collisions at $\sqrt{s} = 7$ TeV and at $\sqrt{s} = 2.76$ TeV

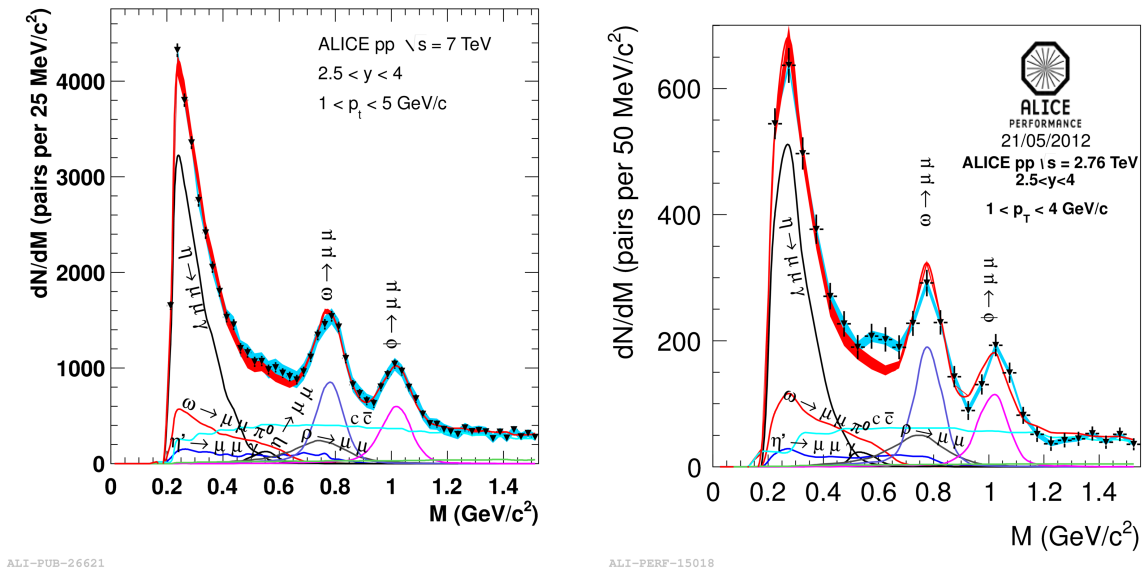
Data were collected in pp collisions in 2010 at  $\sqrt{s} = 7$  TeV and in 2011 at  $\sqrt{s} = 2.76$  TeV. Muon tracks were selected asking that the tracks reconstructed in the tracking stations matched



the ones in the trigger chambers (single muon  $p_T$  trigger threshold  $\sim 0.5$  GeV/ $c$ ) and that their rapidity was in the range  $2.5 < y_\mu < 4$ . Muon pairs were selected requiring that the dimuon rapidity was inside 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  $\phi$  peak is  $\sim 1$  at 7 TeV and  $\sim 2$  at 2.76 TeV. The mass spectrum, shown in Fig. 1 for dimuon  $p_T > 1$  GeV/ $c$ , 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 resonances shapes come from a Monte Carlo simulation with a parametric generator [2], while open charm and beauty have been generated using a parametrization of PYTHIA. The cut on dimuon  $p_T$  is due to the fact that for  $p_T < 1$  GeV/ $c$  the background subtraction is not under sufficient control.

The numbers of  $\phi$  and  $\rho+\omega$  were extracted through the fit of the dimuon invariant mass spectrum with the aforementioned sources, using the full data sample corresponding to an integrated luminosity of  $\sim 85$  nb $^{-1}$ . We obtained  $N_\phi = (3.20 \pm 0.15) \cdot 10^3$  and  $N_{\rho+\omega} = (6.83 \pm 0.20) \cdot 10^3$  at 7 TeV, and  $N_\phi = 350 \pm 42$  and  $N_{\rho+\omega} = 801 \pm 40$  at 2.76 TeV. We used the full data sample to extract the  $\phi$  and  $\rho + \omega$   $p_T$  distributions as well.



**Figure 1.** Fit to the dimuon invariant mass spectrum for  $p_T > 1$  GeV/ $c$ , at  $\sqrt{s} = 7$  TeV (left) and at  $\sqrt{s} = 2.76$  TeV (right). Blue band: systematic uncertainty from background subtraction. Red band: uncertainty in the relative normalization of the sources.

At 7 TeV, part of the data was not collected with the minimum bias trigger in parallel with the muon trigger. For this fraction, the integrated luminosity could not be measured and the cross sections were determined with the remaining sub-sample, corresponding to an integrated luminosity  $L_{\text{INT}} = 55.7 \pm 2.8(\text{syst})$  nb $^{-1}$ , while the cross section at 2.76 TeV was determined from a sample with  $L_{\text{INT}} = 17.6 \pm 0.5(\text{syst})$  nb $^{-1}$ , in both cases through the formula  $\sigma_\phi = \frac{N_\phi^c}{BR(\phi \rightarrow \mu^+ \mu^-)} \frac{1}{L_{\text{INT}}}$ , where  $N_\phi^c$  is the measured number of  $\phi$  mesons corrected for efficiency and acceptance.

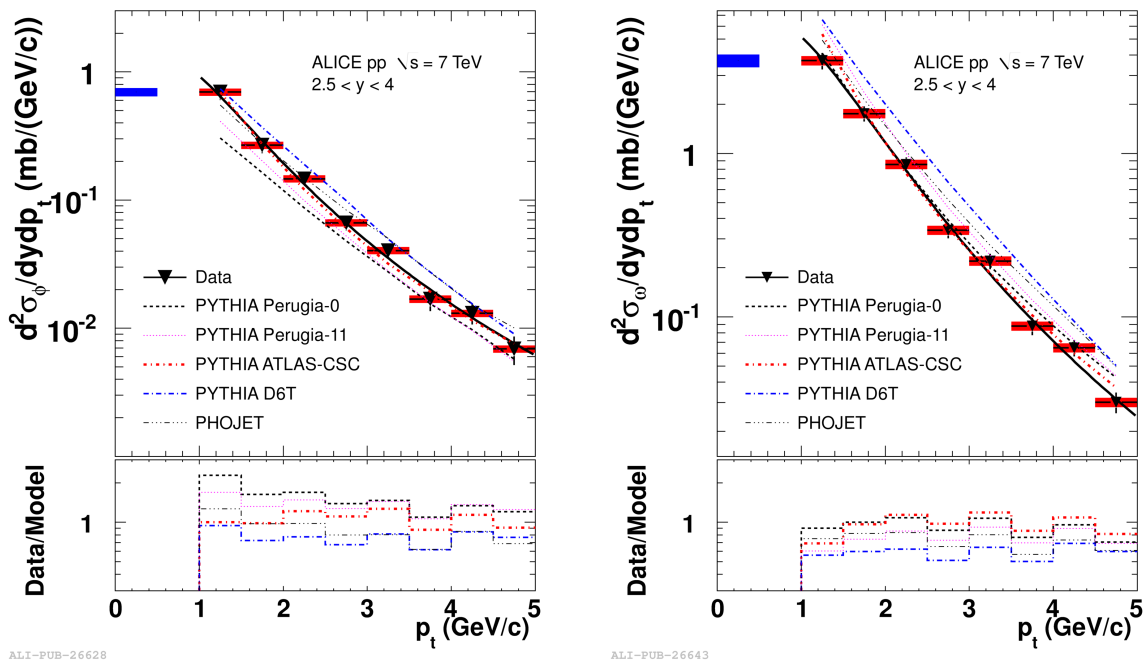
We obtained  $\sigma_\phi(2.5 < y < 4, 1 < p_T < 5 \text{ GeV}/c) = 0.940 \pm 0.084(\text{stat}) \pm 0.078(\text{syst})$  mb at 7 TeV [2], and  $\sigma_\phi(2.5 < y < 4, 1 < p_T < 4 \text{ GeV}/c) = 0.587 \pm 0.070(\text{stat}) \pm 0.045(\text{syst})$  at 2.76 TeV. The main sources of systematic uncertainty are those on the luminosity (5% at 7 TeV and 3% at 2.76 TeV), the tracking efficiency (3% and 4% respectively) and the muon trigger efficiency

(4% and 5% respectively). We have also taken into account the uncertainty on the background subtraction (2% at 7 TeV and 1 % at 2.76 TeV) and the one on the  $\phi$  branching ratio into dileptons (1%).

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 for  $1 < p_T < 5$  GeV/c gives  $\sigma_\rho/\sigma_\omega = 1.15 \pm 0.20(\text{stat}) \pm 0.12(\text{syst})$ . The  $\omega$  production cross section, calculated from this ratio, is  $\sigma_\omega(2.5 < y < 4, 1 < p_T < 5 \text{ GeV}/c) = 5.28 \pm 0.54(\text{stat}) \pm 0.49(\text{syst})$  mb.

In Fig. 2, left side, the  $p_T$ -differential cross section  $d^2\sigma_\phi/dp_T dy$  at 7 TeV is shown (black triangles). Data are here compared with some commonly used models as PHOJET [5] and PYTHIA [6] (Perugia-0 [7], Perugia-11 [8], ATLAS-CSC [9] and D6T [10] tunes): PYTHIA Perugia-0 and PYTHIA Perugia-11 underestimate the data, while the other models reproduce the data.

In Fig. 2, right side, the  $p_T$ -differential cross section  $d^2\sigma_\omega/dp_T dy$  at 7 TeV is shown (black triangles). Comparison with the models shows that all the PYTHIA tunes reproduce the  $p_T$  slope, even if D6T overestimate the data, while PHOJET gives a slightly harder spectrum.



**Figure 2.**  $\phi$  (left) and  $\omega$  (right) differential cross sections compared with PHOJET and several tunes of PYTHIA

### 3. Analysis in Pb-Pb collisions at $\sqrt{s} = 2.76$ TeV

Data in Pb-Pb collisions were collected in 2011 at  $\sqrt{s}_{NN} = 2.76$  TeV. 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 to reduce the background. The number of opposite sign muon pairs was  $\sim 2 \cdot 10^6$ .

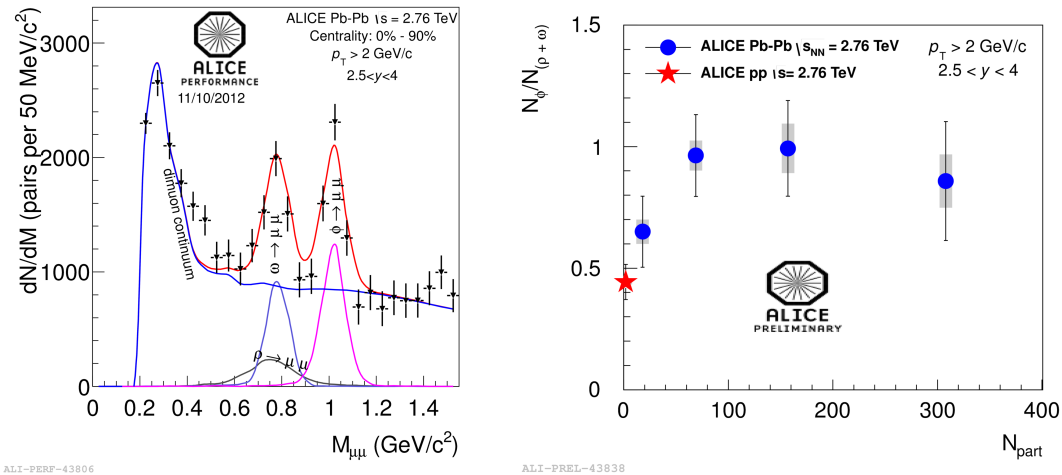
Combinatorial background was evaluated with the event mixing technique also in Pb-Pb analysis; a cut on dimuon  $p_T$  at 2 GeV/c was applied too, because for dimuon  $p_T < 2$  GeV/c the acceptance for  $\phi$ ,  $\rho$  and  $\omega$  was close to 0, a consequence of the fact that the single muon  $p_T$  trigger threshold in Pb-Pb collisions was set at  $\sim 1$  GeV/c. S/B ratio at the  $\phi$  peak is  $\sim 0.1$  for

most central collisions, increasing up to  $\sim 3$  for peripheral collisions.

In Fig. 3, left side, the dimuon invariant mass spectrum for dimuon  $p_T > 2$  GeV/c is shown. The other processes are here described as an empirical continuum that describes the sources of the low mass resonances as well as other characteristic sources which may be present in heavy-ion collisions, such as thermal dileptons.

In Fig. 3, right side, the  $N_\phi/N_{\rho+\omega}$  ratio, corrected for the acceptance, is shown as a function of the number of participating nucleons  $N_{part}$ . The Pb-Pb values obtained in four different centrality classes are compared to the value obtained in pp analysis at 2.76 TeV.

$N_\phi/N_{\rho+\omega}$  increases from pp to Pb-Pb; within the uncertainty, no centrality dependence is observed. Systematic uncertainties are due to the uncertainty in the branching ratio of  $\phi$  into dileptons, to the variations related to  $p_T$  cut on single muons (we have tried three different cuts at 0.7, 0.85 and 1 GeV/c), to the description of the correlated background (we have also used Crystal Ball functions to describe  $\phi$  and  $\rho+\omega$  peaks, with an exponential plus a constant, or an exponential plus a Landau to describe the other processes) and to the uncertainty on the mass resolution, which is a fixed parameter in the fit.



**Figure 3.** Dimuon invariant mass spectrum integrated in centrality for Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV (left) and  $N_\phi/N_{\rho+\omega}$  ratio as a function of the number of participating nucleons  $N_{part}$  (right)

In conclusion, we measured both integrated and  $p_T$ -differential cross sections of  $\phi$  and  $\omega$  in pp collisions at  $\sqrt{s} = 7$  TeV and integrated and  $p_T$ -differential cross sections of  $\phi$  at  $\sqrt{s} = 2.76$  TeV. In Pb-Pb collisions work is in progress to measure nuclear modification factor of  $\phi$  mesons.

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