# Low mass dimuon production in pp, p–Pb and Pb–Pb collisions with the ALICE muon spectrometer

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**Abstract.** We present results on the low mass dimuon analysis in pp, p–Pb and Pb–Pb collisions.
In pp collisions at $\sqrt{s} = 2.76$ TeV the $\phi$ differential cross section as a function of the transverse momentum has been measured, while the $\phi$ yield and the nuclear modification factor $R_{pPb}$ at forward and backward rapidity have been measured in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
The $\frac{BR\sigma_\phi}{BR\sigma_\rho + BR\sigma_\omega}$ ratio and the $\phi$ nuclear modification factor $R_{AA}$ have been measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the intermediate $p_{\mathrm{T}}$ region $2 < p_{\mathrm{T}} < 5$ GeV/$c$, as a function of the number of participating nucleons. Remarkable differences are observed in the comparison between these results and the ones measured in the same $p_{\mathrm{T}}$ range at midrapidity in the hadronic decay channel $\phi \to KK$.

## 1. Introduction

Low mass vector 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 the different probes, strangeness enhancement can be accessed through the measurement of $\phi$ meson production [1], while the measurement of the $\phi$ nuclear modification factor provides a powerful tool to probe the production dynamics and hadronization process in relativistic heavy-ion collisions.
Vector meson production in pp collisions provides the reference for these studies and is interesting by itself, since it can be used to tune particle production models in the LHC energy range. The analysis in p–A collisions can give an insight on soft particle production in cold nuclear matter, being p–A a system where a hot, dense medium is not expected to be formed in the final state, while its initial state is similar to that of A-A collisions.

Vector mesons are reconstructed with the ALICE muon spectrometer [2] in the rapidity range $2.5 < y < 4$ through their decay 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, an iron wall acting as a muon filter and two stations 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 minimum bias trigger, independent from the muon trigger, was based on a set of forward scintillators and on a silicon pixel detector placed

in the vertex region.

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

Data were collected in pp collisions in 2013 at $\sqrt{s}$ = 2.76 TeV. Muon tracks were selected requiring that the tracks reconstructed in the tracking stations matched the ones in the trigger chambers (single muon $p_{\mathrm{T}}$ trigger threshold $\sim 0.5$ GeV/$c$) and that their pseudorapidity was in the range $2.5 < \eta_\mu < 4$. Muon pairs were selected inside the dimuon rapidity interval $2.5 < y_{\mu\mu} < 4$.
The combinatorial background was evaluated through the event mixing technique. The invariant mass distribution after combinatorial background subtraction, shown in Fig. 1, left panel, for a dimuon $p_{\mathrm{T}} > 1$ GeV/$c$, 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 resonances 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 [5].
Figure 1, right panel, shows the comparison of the $\phi$ differential cross section as a function of $p_{\mathrm{T}}$ with PHOJET [4] and several tunes of PYTHIA (Perugia0 [6], Perugia11 [7], ATLAS-CSC [8] and D6T [9]): the PYTHIA tunes Perugia0 and Perugia11 strongly underestimate the measured cross section; PYTHIA ATLAS-CSC also underestimates the data (even if to a lesser degree than Perugia0 and Perugia11), while PYTHIA D6T and PHOJET are in fair agreement with the measured values.
The integrated cross section $\sigma_\phi$ $(2.5 < y < 4, 2 < p_{\mathrm{T}} < 5$ GeV/$c) = 0.108 \pm 0.010$ (stat.) $\pm\, 0.007$ (syst.) mb has been used as baseline for the Pb–Pb analysis, while the value $\sigma_\phi$ $(2.5 < y < 4$, $1 < p_{\mathrm{T}} < 5$ GeV/$c) = 0.542 \pm 0.052$ (stat.) $\pm\, 0.043$ (syst.) mb has been used as baseline for the interpolation of the $\phi$ cross section in the p–Pb analysis at 5.02 TeV.

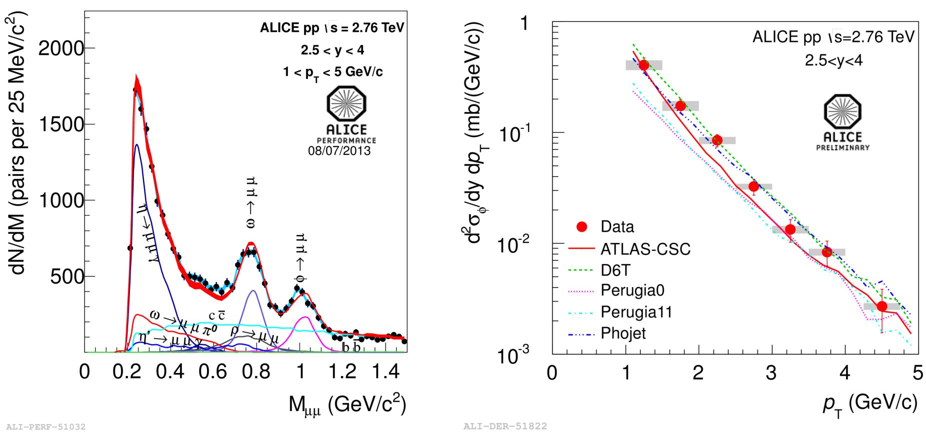


**Figure 1.** Left: Fit to the dimuon invariant mass spectrum for $p_{\mathrm{T}} > 1$ GeV/$c$ in pp collisions at $\sqrt{s}$ = 2.76 TeV; blue band: systematic uncertainty from background subtraction; red band: uncertainty in the relative normalization of the sources. Right: $\phi$ differential cross section as a function of $p_{\mathrm{T}}$ in pp collisions compared with PHOJET and several tunes of PYTHIA.

## 3. Analysis in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

The data for the p–Pb analysis were collected in 2013 at $\sqrt{s_{NN}}$ = 5.02 TeV, at forward rapidity, with the proton beam directed towards the muon spectrometer (p–Pb) and at backward rapidity, with the lead beam directed towards the muon spectrometer (Pb–p). Due to the different

energy of the proton (4 TeV) and of a nucleon in the lead nucleus (1.58 TeV), the rapidity of the nucleon-nucleon center of mass and the one of the laboratory do not coincide anymore: in p–Pb collisions, the rapidity of the center of mass is shifted by +0.465, and therefore the rapidity acceptance of the muon spectrometer is $2.03 < y_{cm} < 3.53$ (forward rapidity). In Pb–p collisions the rapidity of the center of mass is shifted by -0.465 and the rapidity acceptance of the muon spectrometer results to be $-4.46 < y_{cm} < -2.96$ (backward rapidity). A direct comparison between forward and backward is possible only in the rapidity window $2.96 < |y_{cm}| < 3.53$.
The criteria applied to the p–Pb analysis were the same as the ones applied in the pp analysis. The $\phi$ nuclear modification factor $R_{pPb}$ has been calculated as $R_{pPb} = \frac{Y}{\sigma_{pp} < T_{pPb} >}$, where Y is the $\phi$ yield in p–Pb, $\sigma_{pp}$ is the $\phi$ cross section at $\sqrt{s_{NN}} = 5.02$ TeV, calculated through an interpolation between the measurements at $\sqrt{s} = 2.76$ and 7 TeV [3], and $< T_{pPb} >$ is the nuclear overlap function in p–Pb collisions, calculated on the basis of the Glauber model [10].

The $\phi$ $R_{pPb}$ at forward and backward rapidity as a function of $p_{\rm T}$ is shown in Fig. 2. The nuclear modification factor is compatible with unity for $p_{\rm T} > 3$ GeV/$c$ at forward rapidity and is larger than 1 with a Cronin-like peak at backward rapidity. This effect is due to the asymmetry in the particle production present between forward and backward rapidities in pA collisions.

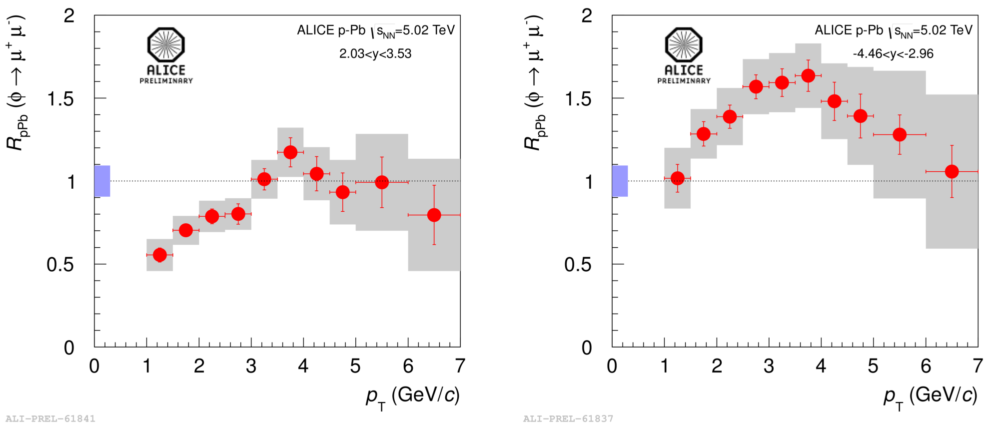


**Figure 2.** $\phi$ $R_{pPb}$ at forward (left) and backward rapidity (right) as a function of $p_T$. Grey boxes: uncorrelated systematic uncertainties; lilac box at 1: correlated ones.

## 4. Analysis in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 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 the pp and p–Pb analyses, with an additional cut on the single muon $p_{\rm T}$ at 0.85 GeV/$c$ to reduce the background. The combinatorial background was also evaluated with the event mixing technique; a cut on the dimuon $p_{\rm T}$ at 2 GeV/$c$ was applied, because for dimuon $p_{\rm T} < 2$ GeV/$c$ the acceptance for $\phi$, $\rho$ and $\omega$ is close to 0, since the single muon $p_{\rm T}$ trigger threshold in Pb–Pb collisions was set to 1 GeV/$c$.
In Fig. 3, left, the $\frac{BR\sigma_\phi}{BR\sigma_\rho + BR\sigma_\omega}$ ratio is shown as a function of the average number of participating nucleons $< N_{part} >$ in the intermediate $p_{\rm T}$ region $2 < p_{\rm T} < 5$ GeV/$c$. The Pb–Pb values obtained in four different centrality classes are compared to the value obtained in the pp analysis at 2.76 TeV.
The $\frac{BR\sigma_\phi}{BR\sigma_\rho + BR\sigma_\omega}$ ratio in Pb–Pb increases with respect to the value in pp by a factor of about 2, and tends to saturate from peripheral towards central events, indicating an enhancement of the $\phi$ meson production with respect to $\rho$ and $\omega$ mesons in central Pb–Pb collisions.

The $\phi$ $R_{AA}$ as a function of $< N_{part} >$ in the intermediate $p_{\mathrm{T}}$ region is shown in Fig. 3, right. The $R_{AA}$ is compatible with unity, within the uncertainties, in peripheral collisions and it is suppressed going towards central collisions.

The comparison with the results obtained at central rapidity in the KK decay channel shows a point-by-point agreement within the uncertainties. However, the most peripheral points of the $R_{AA}$ at forward rapidity are higher than the ones at midrapidity, while the semicentral and the central points are lower, hinting thus two different behaviors: this issue is currently under investigation and may be due to a different hydrodynamic push that the particles are subjected to at forward and at midrapidity in the intermediate $p_{\mathrm{T}}$ region.

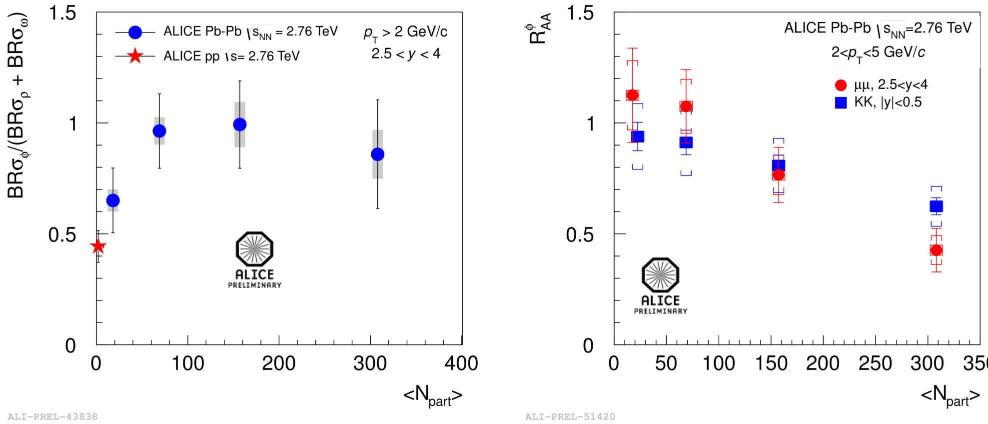


**Figure 3.** Left: $\frac{BR\sigma_\phi}{BR\sigma_\rho+BR\sigma_\omega}$ ratio as a function of the number of participating nucleons $< N_{part} >$. Right: Comparison of $\phi$ $R_{AA}$ as a function of $< N_{part} >$ for $|y| < 0.5$ (KK channel) and for $2.5 < y < 4$ ($\mu\mu$ channel) in the intermediate $p_{\mathrm{T}}$ region $2 < p_{\mathrm{T}} < 5$ GeV/$c$.

In conclusion, we measured both integrated and $p_{\mathrm{T}}$-differential cross sections of $\phi$ in pp collisions at $\sqrt{s} = 2.76$ TeV. The integrated values were used as baseline for the Pb–Pb and for the p–Pb measurement. In the p–Pb analysis, we measured the $\phi$ $R_{pPb}$ as a function of $p_{\mathrm{T}}$: $R_{pPb}$ is compatible with unity for $p_{\mathrm{T}} > 3$ GeV/$c$ at forward rapidity and larger than unity with a Cronin-like peak at backward rapidity. In the Pb–Pb analysis the $\frac{BR\sigma_\phi}{BR\sigma_\rho+BR\sigma_\omega}$ ratio and the $\phi$ nuclear modification factor $R_{AA}$ as a function of $< N_{part} >$ have been measured in the intermediate $p_{\mathrm{T}}$ region. The $\frac{BR\sigma_\phi}{BR\sigma_\rho+BR\sigma_\omega}$ ratio increases from pp to Pb–Pb and tends to saturate towards central events. The comparison between the $\phi$ $R_{AA}$ measured in the dimuon decay channel at forward rapidity and in the KK decay channel at midrapidity seems to indicate a different behavior, probably due to a different hydrodynamic push in the two rapidity domains in the intermediate $p_{\mathrm{T}}$ region $2 < p_{\mathrm{T}} < 5$ GeV/$c$.

## References

[1] J. Rafelski, B. Müller *Phys. Rev. Lett. 48* (1982) 1066.
[2] K. Aamodt et al. (ALICE Collaboration), *JINST* 3 (2008) S08002.
[3] B. Abelev et al. (ALICE Collaboration), *Phys. Lett. B* 710 (2012) 557.
[4] R. Engel, *Z. Phys. C* 66 (1995) 203; R. Engel, J. Ranft, *Phys. Rev. D* 54 (1996) 4244.
[5] T. Sjöstrand et al., *J. High Energy Phys.* 0605 (2006) 026.
[6] P.Z. Skands, *arXiv:0905.3418* (2009).
[7] P.Z. Skands, *Phys. Rev. D* 82 (2010) 074018.
[8] C. Buttar et al., *Acta Phys. Pol. B* 35 (2004) 433.
[9] R. Field, *Acta Phys. Pol. B* 39 (2008) 2611.
[10] K. Aamodt et al. (ALICE Collaboration), *Phys. Rev. Lett.* 106 (2011) 032301.