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# Identified particle production in p–Pb collisions with ALICE at the LHC

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The study of identified particle production in p–Pb and pp collisions provides a baseline measurement to be compared with Pb–Pb results. The excellent tracking and particle identification capabilities of the ALICE detector allow the study of identified particle production up to a very high transverse momentum ($p_{\mathrm{T}}$). We report recent results on $\phi$ and $\mathrm{K}^{*0}$ in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV along with measurements of $\pi$, K, p, $\Xi$, $\Lambda$ and $\Omega$ in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Integrated yields, mean transverse momenta, and particle ratios as a function of the charged particle multiplicity are studied to understand the particle production mechanism. The nuclear modification factor ($R_{\mathrm{pPb}}$) as a function of $p_{\mathrm{T}}$ is studied to understand the parton energy loss mechanism and the Cronin effect.

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†A footnote may follow.





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## 1. Introduction

Measurements of identified particle production as a function of the charged particle multiplicity in pp and p–Pb collisions are important tools for understanding the similarities and differences between small and large interacting systems. Because of their short lifetimes, resonances are good candidates to understand the mechanism of particle production and properties of the hadronic phase. The yields of resonances might be modified by in-medium effects such as re-scattering and regeneration [1]. The multiplicity dependent studies in pp and p–Pb collisions can be used to search for the onset of collectivity similar to what is observed in heavy ion collisions. The nuclear modification factors ($R_{\mathrm{pPb}}$) can be used to study the parton energy loss mechanism, cold nuclear matter effects such as the Cronin enhancement at intermediate $p_{\mathrm{T}}$ and shadowing effects [2]. The p–Pb collision system allows a study of the particle productions mechanisms in the multiplicity range intermediate between elementary pp and peripheral Pb–Pb collisions.
We present measurements of integrated particle yields, mean transverse momenta and $p_{\mathrm{T}}$ integrated yield ratios of $\phi(1020)$, K*$(892)^0$, $\pi$, K, p, $\Lambda$, $\Omega$ and $\Xi$ in p–Pb collisions at LHC energies. In addition, nuclear modification factors ($R_{\mathrm{pPb}}$) of $\pi$, K, p, $\Omega$ and $\Xi$ in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV are discussed.

## 2. Analysis

The detailed description of the ALICE detector can be found in Ref. [3]. The measurements of $\pi$, K, p, $\phi$ and K$^{*0}$ production are performed in p–Pb collision as a function of the charged particle multiplicity at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV in the rapidity range -0.5 $< y_{\mathrm{cm}} <$ 0. Resonances ($\phi$, K$^{*0}$) and multi-strange baryons ($\Omega$, $\Xi$) are reconstructed by using an invariant mass technique [1]. The $\phi$ and K$^{*0}$ are reconstructed in the following decay channels $\phi \rightarrow$ K$^+$ K$^-$ (BR = 48.2%) and K$^{*0}$($\bar{K}^{*0}$) $\rightarrow$ K$^+\pi^-$(K$^-\pi^+$)(66.6 %) while $\Omega$ and $\Xi$ are reconstructed in the decay channel $\Omega^-(\bar{\Omega}^+)$ $\rightarrow \Lambda$ K$^-$($\bar{\Lambda}$ K$^+$)(67.8%) , $\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda\ \pi^-(\bar{\Lambda}\ \pi^+)$ (99.9%) with a subsequent $\Lambda \rightarrow$ p$\pi^-$(63.9%) decay [4]. Long-lived particles like $\pi$, K, p and $\bar{\mathrm{p}}$ are identified with the help of various ALICE sub-detectors: the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the Time-Of-Flight (TOF), by using different PID techniques [5]. The centrality classes are defined based on the signal amplitude measured in the V0A scintillator. The resonance peaks reconstructed by the invariant-mass method sit on top of a large combinatorial background, which is estimated by using like-sign and event-mixing techniques. In the mixed-event method the shape of the uncorrelated background is estimated from the invariant-mass distribution of $h^+h^-$ combinations from five different events having similar characteristics like multiplicity, collision vertex position etc. In the like-sign technique, the background is evaluated by using invariant mass distribution of like-charge pairs from the same event [1]. After background subtraction the raw yield is extracted from the invariant-mass distribution and is then corrected for detector acceptance, tracking efficiency and branching ratio. The first two corrections are determined from Monte Carlo simulations of the ALICE detector response [6].

## 3. Results

Figure 1 (left panel) shows the integrated yields of $\phi$ as a function of the charged particle multiplicity in pp collisions at $\sqrt{s}$ = 7 and 13 TeV and in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV. The integrated yield increases with increasing $\langle \mathrm{dN_{ch}}/\mathrm{d}\eta \rangle$. The right panel of Fig. 1 shows the mean transverse momentum ($\langle p_{\mathrm{T}} \rangle$) of $\phi$ as a function of $\langle \mathrm{dN_{ch}}/\mathrm{d}\eta \rangle$ in pp collisions at $\sqrt{s}$ = 7 and 13 TeV and in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV. The $\langle p_{\mathrm{T}} \rangle$ increases as a function of the charged particle multiplicity and seems to saturate at high multiplicity in p–Pb collisions. A similar trend of $\langle p_{\mathrm{T}} \rangle$ dependence on multiplicity is also observed for other resonances [7]. In the most central p–Pb collisions, $\langle \mathrm{dN_{ch}}/\mathrm{d}\eta \rangle$ has the same order of magnitude as in peripheral heavy ion collisions. The new results for $\langle p_{\mathrm{T}} \rangle$ may lead to a better understanding of the mass ordering (particles with similar masses have similar $\langle p_{\mathrm{T}} \rangle$) observed in central and semi-central Pb–Pb collisions, which is consistent with expectations from the hydrodynamic expansion of the system [1]. The mass ordering is not observed in small collisions systems [6].

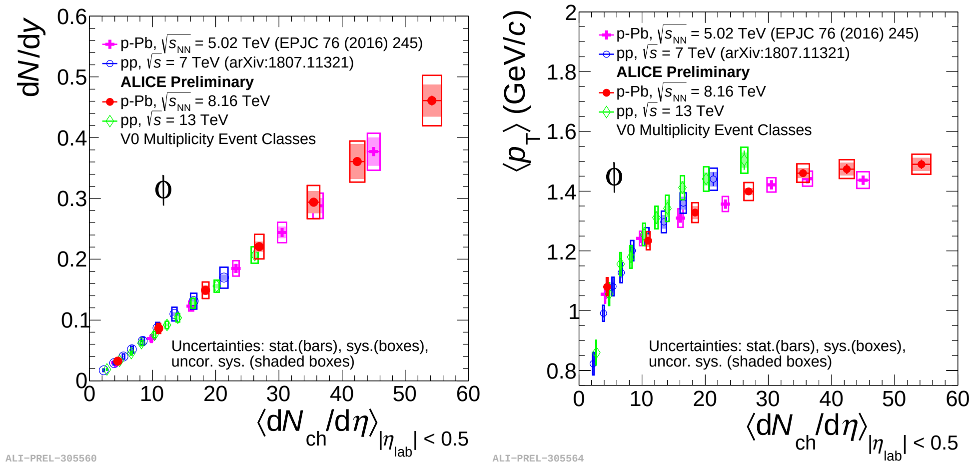


**Figure 1:** (Left) The integrated yield (d$N$/d$y$) and (right) the mean transverse momentum ($\langle p_{\mathrm{T}} \rangle$) of $\phi$ meson as a function of charged particle multiplicity ($\langle \mathrm{dN_{ch}}/\mathrm{d}\eta \rangle$) in pp collisions at $\sqrt{s}$ = 7 and 13 TeV and in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV.

Figure 2 (left panel) shows the ratios of the yields of p, $\mathrm{K}^0_s$, $\Lambda$, $\phi$, $\Xi$, and $\Omega$ to pions as a function of charged particle multiplicity in various systems at different energies. A significant enhancement of strange to non-strange hadron production is observed with increasing charged particle multiplicity in pp and p–Pb collisions [8]. No significant energy dependance is observed. The larger the strangeness content of the particle, the stronger the observed enhancement. This effect is due to strangeness and not due to baryon number or mass. At high multiplicity in pp and p–Pb collisions the yield ratios have similar values as observed in Pb–Pb collisions. The $\Xi/\phi$ ratio as a function of charged particle multiplicity for three different collision systems and energies is shown in Fig. 2 (right panel). The net strangeness of $\phi$ is 0 (the $\phi$, as an $\mathrm{s\bar{s}}$ state, has hidden strangeness) while net strangeness of $\Xi$ is 2. From the figure we can see that $\Xi/\phi$ ratio slightly increases in pp and p–Pb as a function of the charged particle multiplicity, but is fairly constant over a wide range of multiplicities. This indicates that $\phi$ behaves as if it had an effective strangeness $\mathrm{S}_{\phi} \leq 2$. From $\phi$/K ratio (not shown here), the effective strangeness of $\phi$ is $\mathrm{S}_{\phi} \geq 1$.

The nuclear modification factor for $\pi$, K, p, $\Omega$ and $\Xi$ as a function of $p_{\mathrm{T}}$ in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV is shown in Fig. 3. At intermediate $p_{\mathrm{T}}$ ($3.0 < p_{\mathrm{T}} < 6$ GeV/$c$) a Cronin peak

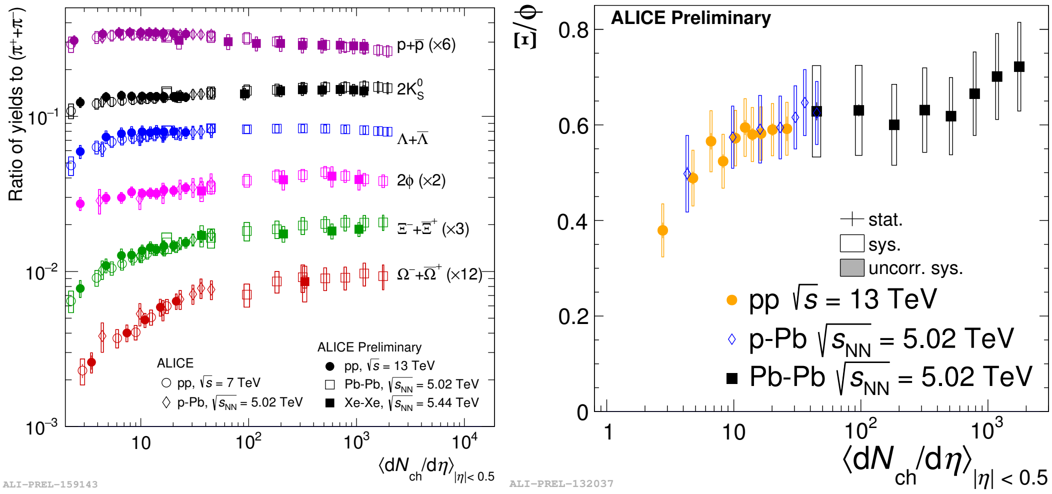


**Figure 2:** (Left) The ratio of yields of hadrons (p, $K^0_s$, $\Lambda$, $\phi$, $\Omega$, $\Xi$) to pions as a function of charged particle multiplicity ($\langle dN_{ch}/d\eta \rangle$) in pp collisions at $\sqrt{s}$ = 7, 13 TeV, in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 [9], in Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 and in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. (Right) $\Xi/\phi$ ratio as a function of $\langle dN_{ch}/d\eta \rangle$ in pp collisions at $\sqrt{s}$ = 13 TeV, in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

is observed in $R_{pPb}$ for p, $\Xi$ and $\Omega$. At intermediate $p_T$ baryons and mesons show different $R_{pPb}$ and the enhancement for p, $\Xi$ and $\Omega$ is stronger. $R_{pPb}$ at high $p_T$ ( $p_T > 8$ GeV/$c$) is consistent with unity within uncertainty, suggesting that final state effects do not play a role. The $R_{pPb}$ for the proton has a peak at $p_T \sim 4$ GeV/$c$. A similar enhancement of protons was observed in Pb–Pb collisions and similar pattern was observed at RHIC [10].

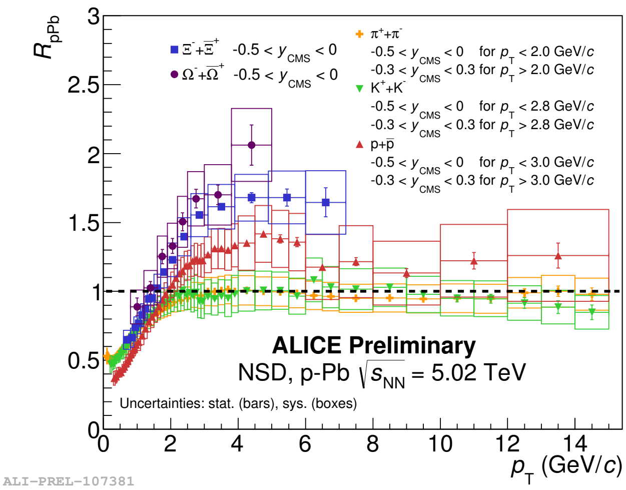


**Figure 3:** The nuclear modification factor ($R_{pPb}$) of $\pi$, K, p, $\Omega$ and $\Xi$ as a function of $p_T$ in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

## 4. Conclusions

We have reported the measurements of identified particle production as a function of the charged particle multiplicity in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 and 8.16 TeV. The integrated yields (d$N$/d$y$) of $\phi$ and K$^{*0}$ mesons are independent of collision system and energy, indicating that particle production is driven by multiplicity. The $\langle p_{\rm T} \rangle$ of the $\phi$ meson saturates at high multiplicity in p–Pb collisions. In the ratios of p, K$^0_s$, $\Lambda$, $\phi$, $\Omega$, $\Xi$ yields to that of pions, a significant enhancement of strange to non-strange hadron production is observed with increasing charged particle multiplicity in pp and p–Pb collisions. The yield ratios are independent of the energies. While the net strangeness of $\phi$ is zero, it behaves as a particle with an effective strangeness of 1-2. The $R_{\rm pPb}$ is independent of particle species at high momentum, it is consistent with unity within uncertainty. The enhancement at intermediate $p_{\rm T}$ is stronger in case of p, $\Xi$ and $\Omega$. In the future, new results for $R_{\rm pPb}$ from p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV may help to study the energy dependence of $R_{\rm pPb}$.

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