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Kaon-Production in Pion-Induced Reactions at 1.7 GeV/c

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The production and properties of open and hidden strange hadrons (K^+, K^- and ϕ) in cold nuclear matter generated in pion-nucleus reactions ($\pi^- + A$, $A = C, W$) at $p_{\pi^-} = 1.7$ GeV$/c$ have been studied with the HADES setup (SIS18/GSI). In total about 10×10^7 events were collected in $\pi^- + C$ collisions containing 104×10^3 K^+, 3.6×10^3 K^- and 522 ϕ, while in $\pi^- + W$ reactions with a compatible number of events 133×10^3 K^+, 1.9×10^3 K^- and 266 ϕ were measured. The strategy for the (anti-)kaon signal extraction is outlined including the identification and reconstruction techniques. Moreover the integrated phi yield reconstructed using the dominant charged kaon decay channel is presented.

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1. Introduction

The production of strange hadrons in pion-nucleus reactions allows for a quantitative study of in-medium effects such as the KN potential at a well defined nuclear density. Already at saturation density the modification of the (anti-)kaon spectral function is expected to be apparent [1]. While for the kaon (K^+, K^0) several hints for the existence of a repulsive KN potential with moderate strength of $20-40$ MeV exist [2, 3, 4], the available data on in-medium effects of the antikaon produced off nuclear targets are very scare [5]. Moreover, several underlying effects like the K^- absorption in nuclear matter via strangeness exchange processes on one ($K^-N \rightarrow Y\pi$) or more nucleons ($K^-NN \rightarrow YN$) have to be disentangled. Here, the K^+ can be exploited providing stringent constraints on the production mechanism of strange hadrons since it does not undergo strong absorption processes and can be treated as a quasi particle within nuclear matter. In this context also the ϕ production and absorption ($\phi \rightarrow K^+K^-$, $BR = 48.9 \pm 0.5\%$ [6]) off light (C) and heavy (W) nuclei is essential to draw any conclusion about in-medium effects on kaons, as ϕ decays may substantially affect the measured K^- yield and phase-space population. On the contrary, in-medium modifications of kaons and antikaons might also influence the properties of the ϕ meson. A mass drop of the antikaon could manifest itself in an increased phase space of the ϕ decay to K^+K^- pairs which would consequently decrease the ϕ lifetime [7]. Besides, also the absorption of the ϕ meson in cold nuclear matter could be interpreted as a proof of the widening of the ϕ natural width [8].

2. The HADES experiment

The **H**igh-**A**cceptance **D**i-**E**lectron **S**pectrometer (HADES) [9] is a fixed target experiment operated at the SIS18 accelerator at the Helmholtzzentrum für Schwerionenenforschung (GSI) in Darmstadt. It is divided into six identical sectors around the beam axis equipped with several detector types covering almost the full azimuthal angle range and polar angles from 18° to 85°. Particle tracking and identification via dE/dx is performed with two layers of six **M**ultiwire **D**rift **C**hambers (MDC), in front and behind a superconducting toroidal magnet, with a momentum resolution of $\Delta p/p \approx 3\%$. In the presented experiment the LVL1 trigger condition required a T_0 signal in the target detector and a minimum multiplicity of two charged particle hits (M2) in the **M**ultiplicity and **E**lectron **T**rigger **A**rray (META) wall consisting of the two time-of-flight detectors, RPC and TOF. In total, 10×10^7 and 13×10^7 events have been collected in $\pi^- + C$ and $\pi^- + W$, respectively.

3. Particle identification

The HADES detector offers the possibility to identify particles by means of time-of-flight or specific energy loss (dE/dx) measurements combined with the determination of the particle's momentum. The latter identification technique exploits the effect described by the Bethe-Bloch formula. Regarding the identification of charged kaons in terms of the specific energy loss, the huge abundance of pions and protons has to be decreased by a pre-selection of the K^+ within a distinct velocity range[1]. The such obtained MDC dE/dx distribution as a function of the momentum

[1] $p/\sqrt{p^2+m_K^2} \pm 0.05 \gtrless \beta_{(RPC/TOF)}$

is shown in Fig. 1 separately for the two different time-of-flight detectors (RPC/TOF) covering different regions in phase space. Even though the MDC energy loss is independently measured, it shows a dependence on the selected time-of-flight system (RPC/TOF) indicating a not perfectly calibrated dE/dx. Moreover, in the case of the RPC selection the theoretical Bethe-Bloch curves (dashed white lines) are in rather good agreement with the experimental distribution, whereas the distribution for the TOF deviates from the theoretical ones for all particle species.

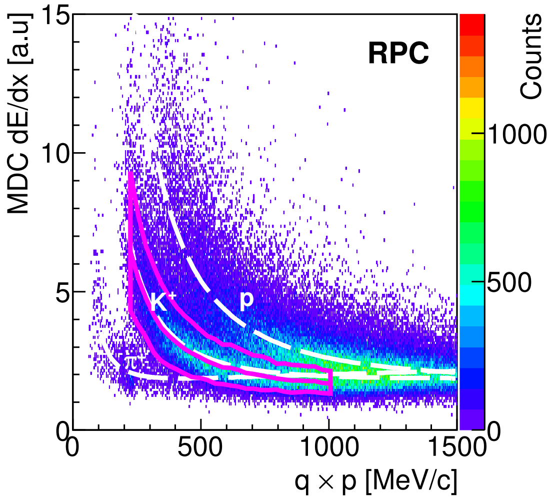

Figure 1: (Color online) Energy loss dE/dx in the MDCs as a function of the momentum times charge of reconstructed kaon candidates, separately for the two time-of-flight detectors RPC (left) and TOF (right). The contamination from other particle species has been reduced (see text). The white dashed line corresponds to the specific energy loss according to the Bethe-Bloch curve. The magenta line indicates the applied graphical cuts for the kaon selection.

In general, the energy loss distribution of all particle species (e.g. π^+, K^+, p) can be described by a Landau(μ_L, σ_L) convoluted with a Gaussian(σ_G) distribution. While the Landau function corresponds to the specific energy loss in the MDC chambers, the Gaussian takes into account the finite detector resolution. As follows, the energy loss spectrum was divided into momentum slices of 30 MeV$/c$ and projected onto the energy loss axis, to obtain two-dimensional cuts for the identification of charged kaons on the basis of the extracted mean and sigmas of Landau-Gauss function.

Due to the not negligible contamination from remaining pions and protons in the pre-selected and projected dE/dx spectra, two dedicated background samples have been produced using a particle identification cut based on beta[2] and fitted with a Landau-Gauss function to derive start values for the later on performed simultaneous fit of all three particle species. In such way, the mean ($\mu_{\mathrm{dE/dx},K^+} = \mu_{L,K^+}$) and sigma $\left(\sigma_{\mathrm{dE/dx},K^+} = \sqrt{\sigma^2_{L,K^+} + \sigma^2_{G,K^+}}\right)$ of the energy loss deposited only by the kaons was extracted for each momentum slices individually. The energy loss cut for the kaons indicated by the magenta lines in Fig. 1 was constructed around the mean $\mu_{\mathrm{dE/dx},K^+}$ with

[2] $p/\sqrt{p^2 + m^2_{\pi,p}} \pm 0.05 \gtrless \beta_{(RPC/TOF)}$

$\left(4 \times \sigma_{\mathrm{dE/dx},K^+}\right)$ on the upper and $\left(3 \times \sigma_{\mathrm{dE/dx},K^+}\right)$ on the lower side to account for the asymmetry of the distribution.
For the efficiency correction it is mandatory to analyse the simulated data in the same manner as the experimental data. Therefore, the selection efficiency of the graphical cuts needs to be equal for simulation and experimental data. The same energy loss cuts could not be applied to the simulation, as the energy loss resolution as a function of the momentum is not reproduced by the simulations. Thus, the same technique of extracting the two-dimensional energy loss cuts was applied to the simulation guaranteeing that the same kaon fraction is selected in both simulation and experiment, respectively.

4. Charged kaon reconstruction

After applying the energy loss cuts (see Sec. 3), the charged kaons have been reconstructed employing the determined mass, separately for the two detector systems, RPC and TOF. High statistics allow for double differential analysis of both charged kaon yields in the phase space (p_T, y). The mass spectrum of a single phase space cell in the RPC for the K^+ and K^- is shown in Fig. 2. Only events with atleast two fully tracked particles that originate from the target region[3] were considered. The signal can be described by a Gaussian distribution on top of the background composed of a second-order polynomial combined with a exponential function for each background particle species. The width of the Gaussian was allowed to vary around the width within the errors extracted from pure kaons based on simulation ($\sigma_{EXP} = \sigma_{SIM} \pm 0.5 \times \sigma_{err,SIM}$). The total amount of reconstructed (anti-)kaons is summarized in Tab. 1.

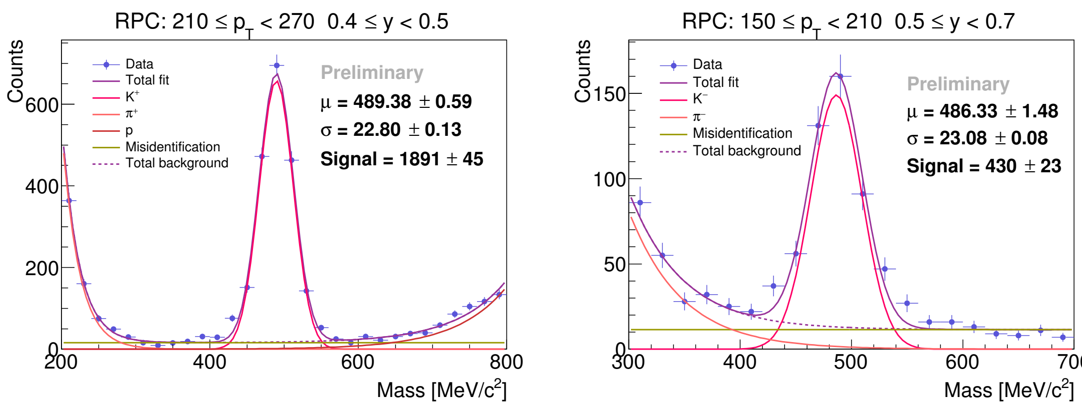

Figure 2: (Color online) Mass spectrum of K^+ (left) and K^- (right) in a specific $p_T - y$ cell (see legend) for the RPC in $\pi^- + C$ reactions. The K^+ signal is represented by a Gaussian (magenta line). The background is shown in pink (pions), red (protons) and green (misidentified particles), see text. The K^- mass spectra is fitted with a composed function of a Gaussian for the signal (magenta line) and exponential function for the pions (pink line) combined with second-order polynomial (green line).

[3] $r(x_{\mathrm{PV}}, y_{\mathrm{PV}}) \leq 20$ mm, -80 mm $< z_{\mathrm{PV}} < 5$ mm

5. Integrated phi yield

The neutral ϕ was reconstructed employing its decay into K^+K^- pairs ($BR = 48.9 \pm 0.5\%$ [6]) that originate from events inside the target region[4]. Both, K^+ and K^-, were identified on an event-by-event basis utilizing velocity and momentum determinations[5] for the sake of higher statistics. By selecting a reconstructed (anti-)kaon mass window of 400 MeV$/c^2 < m <$ 600 MeV$/c^2$, the contamination from other particle species was further reduced. The nominal mass value m_K = 493.677 MeV/c^2 [6] was then attributed to the identified particle candidates. The resulting K^+K^- invariant mass spectra for both nuclear systems (C,W) are presented in Fig. 3. In both cases a clear ϕ peak arises with an underlying background of non-resonant K^+K^- pairs together with misidentified particles. Both integrated mass spectra were fitted with a double Gaussian accounting for finite resolution effects as well as the collisional broadening due to the scattering of the K^+ and K^- inside the targets, while the background is described by a third-order polynomial together with a Gaussian representing the mass threshold ($2 \times m_K$).

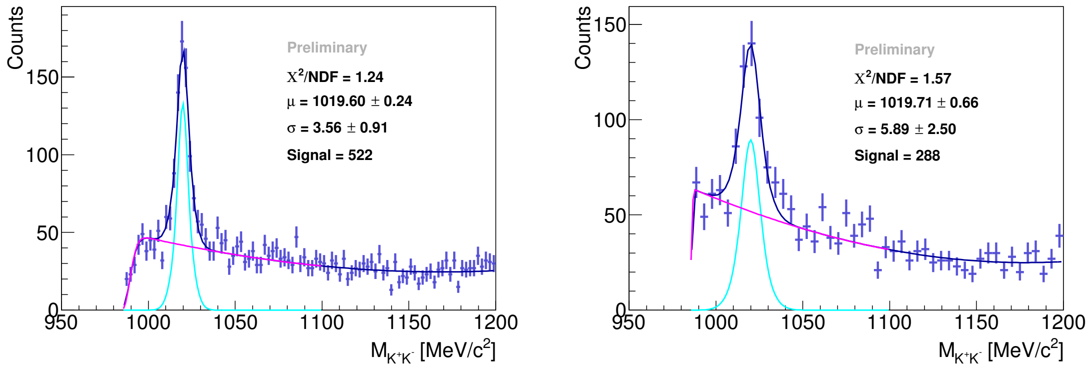

Figure 3: (Color online) Invariant mass distribution of K^+K^- pairs in $\pi^- + C$ (left) and $\pi^- + W$ (right) reactions. The fit consists of two Gaussian for the ϕ signal (light blue line) together with the background described by a polynomial and Gaussian function (pink line).

The total yields of the ϕ meson are listed in Tab. 1. The mass of the ϕ was determined to be $m_\phi = 1019.60 \pm 0.24$ MeV/c^2 with a width of $\sigma_\phi = 3.56 \pm 0.9$ MeV$/c^2$ $(\pi^- + C)$ and $m_\phi = 1019.71 \pm 0.66$ MeV/c^2 with a width of $\sigma_\phi = 5.89 \pm 2.5$ MeV$/c^2$ $(\pi^- + W)$. While the reconstructed mass of the ϕ is consistent within errors in both nuclear systems, an increase of the width in $\pi^- + W$ reactions compared to $\pi^- + C$ is observed. Even though not significant, it hints to multiple scattering effects of the K^+ and K^- inside the heavier nuclear target (W).

6. Summary and outlook

In this contribution, we presented the on-going analysis of K^+, K^- and ϕ production in $\pi^- + C$ and $\pi^- + W$ reactions at 1.7 GeV$/c$ beam momentum measured with the HADES detector. We

[4] -10 mm $< x_{\mathrm{PV}}, y_{\mathrm{PV}} <$ 10 mm, -65 mm $< z_{\mathrm{PV}} < -5$ mm

[5] $p/\sqrt{p^2 + m_K^2} \pm 0.5 \gtrless \beta$

Table 1: Extracted total yield of strange hadrons (K^+, K^- and ϕ) produced off light (C) and heavy (W) nuclei.

	K^+	K^-	ϕ
$\pi^- + C$	104×10^3	3.6×10^3	522
$\pi^- + W$	133×10^3	1.9×10^3	288

were able to extract the double differential phase space population of the charged kaons, which were reconstructed by means of the time-of-flight and momentum measurements combined in the mass observable, after they have been identification using energy loss cuts. The integrated neutral ϕ yield was reconstructed employing the invariant mass of charged kaon candidates ($M_{K^+K^-}$). Overall, 522 and 288 ϕ mesons candidates have been identified in $\pi^- + C$ and $\pi^- + W$ collisions, respectively. In the next step we plan to disentangle different in-medium effects of the antikaon. A first evidence of the K^- absorption will be obtained on the basis of K^-/K^+ ratios in both nuclear environments (C, W) as a function of four different kinematic observables (p, θ, p_T, y). Moreover, the contribution from the ϕ feed-down to the total K^- yield will be studied in terms of ϕ/K^- ratios.

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References

[1] J. Schaffner, J. Bondorf and I. N. Mishustin, *Nucl. Phys. A* **625** (1997) 325–346.

[2] M. L. Benabderrahmane et al. [FOPI Collaboration], *Phys. Rev. Lett.* **102** (2009) 182501.

[3] G. Agakishiev et al. [HADES Collaboration], *Phys. Rev. C* **82** (2010) 044907.

[4] G. Agakishiev et al. [HADES Collaboration], *Phys. Rev. C* **90** (2014) 054906.

[5] W. Scheinast et al. [KAOS Collaboration], *Phys. Rev. Lett.* **96** (2006) 072301.

[6] C. Patrignani et al. [PARTICLE DATA GROUP collaboration], *Review of Particle Physics*, *Chin. Phys. C* **40** (2016) 100001.

[7] G.-Q. Li and C. M. Ko, *Nucl. Phys. A* **582** (1995) 731–748.

[8] D. Cabrera, L. Roca, E. Oset, H. Toki and M. J. Vicente Vacas, *Nucl. Phys. A* **733** (2004) 130–141.

[9] G. Agakishiev et al. [HADES Collaboration], *Eur. Phys. J. A* **41** (2009) 243–277.