SHORT-LIVED RESONANCES IN ALICE: RECONSTRUCTION OF $K^*(892)^0$ AND $\Lambda(1520)$ SIGNALS IN p–p AND Pb–Pb COLLISIONS*

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The ability of the ALICE detector to reconstruct the $K^*(892)^0$ and $\Lambda(1520)$ resonances in p–p and Pb–Pb collisions at LHC energies has been investigated. PYTHIA events for p–p collisions and HIJING events for Pb–Pb collisions have been generated and fully reconstructed. The $K^*(892)^0$ and $\Lambda(1520)$ were identified by their hadronic decay into πK and pK, respectively, through an invariant mass analysis. The combinatorial background has been evaluated by the event-mixing technique for p–p events and by the like-sign technique for the Pb–Pb events.

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1. Introduction

Ultra-relativistic heavy ion collisions allow the study of a hot and dense matter. In-medium modifications of meson resonances have been proposed as a possible signal of a phase transition from nuclear matter to a plasma of quarks and gluons [1]. However, even in absence of a phase transition, modification of the properties of meson resonances can arise due to the interaction of such particles and/or their daughters with the fireball medium [2,3]. Typical lifetimes of such resonances are a few fm/c, comparable to the expected lifetime of the hot and dense matter produced in such collisions. The study of short-lived resonances may also probe the role of the rescattering phase between chemical and kinetic freeze-out. Resonance measurements are affected by two competing effects. A fraction may not be reconstructed due

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to the rescattering of their daughter particles. This effect depends on the time between chemical and kinetic freeze-out, the source size, the resonance phase-space distribution and the hadronic interaction cross-section of the daughters of the resonances. On the other side, after chemical freeze-out, pseudo-elastic interactions among hadrons in the medium may increase the resonance population. This regeneration mechanism depends on the cross-section of hadrons in the medium. Thus, the study of resonances can probe the time evolution of the source from chemical to kinetic freeze-out and test different hadronization scenarios [4].

The observation of such resonances is critical in heavy ion experiments, because of the large background originating from the high multiplicity and from detector limitations. For a recent review of resonance measurements at SPS and RHIC energies, see [5].The $K^*(892)^0$ meson resonance and its antiparticle decay into $K\pi$, with a cτ around $4\,\mathrm{fm}/c$ [6]. The $\Lambda(1520)$ resonance decay into pK, with a $c\tau$ around 13 fm$/c$ [6]. Their decay products may therefore be considered as originating from the primary vertex of the collision as far as the tracking is concerned. Reconstruction of such resonances for Pb–Pb collision at LHC energies will be challenging due to the expected high-multiplicity environment. Here a simulation study of the $K^*(892)^0$ signal in pp and Pb–Pb collisions is discussed. Some results on this topic were already published in [7–9]. A preliminary study of the $\Lambda(1520)$ signal in pp collisions is also reported.

2. Proton–proton collisions

In order to study the $K^*(892)^0$ signal in pp collisions, a sample of 2×10^5 PYTHIA pp minimum bias events at $\sqrt{s}=14\,\mathrm{TeV}$ was generated and fully reconstructed. A magnetic field of 0.4 T was used for the L3 magnet. Particles were considered over the whole solid angle and in the full momentum range. All ALICE subdetectors [10], together with the beam pipe, were included in the simulation, and all physical processes were switched on in GEANT. About 6×10^4 PYTHIA events were analyzed for the $\Lambda(1520)$ study. The average $K^*(892)^0$ multiplicity, as generated by PYTHIA, is of the order of 1.7 per event (*i.e.* 3.4 for both $K^*(892)^0$ and its antiparticle). After the reconstruction process the number of findable candidates (*i.e.* $K^*(892)^0$ for which the pion and kaon tracks have been reconstructed) is about 0.02 per event. This strong decrease is due to several factors as: the geometrical acceptance of the TPC ($|\eta|\leq0.9$), the branching ratio of the $K^*(892)^0$ decay into charged $K\pi$ pairs (1/3 of $K^*(892)^0$ decays into neutral πK pairs) and the tracking efficiency (see [10] for further details), especially for low momentum particles and for charged kaons which decay inside the TPC volume. For similar reasons the number of findable $\Lambda(1520)$ is 0.007 per event whereas the average number of generated $\Lambda(1520)$ per event is 0.11.

We first assumed to have a 100% efficiency for particle identification (PID). Under such conditions, the true signal obtained from a proper correlation of the true πK pairs is shown in the left panel of Fig. 1. Both $K^*(892)^0$ and its antiparticle were included in the plot, by summing $K^+\pi^-$ and $K^-\pi^+$ pairs. Fitting this peak with a Breit–Wigner function gives a centroid at $M = (897.6 \pm 0.9)$ MeV/c^2, and a width $\Gamma = (52.8 \pm 2.1)$ MeV/c^2, which are compatible with the standard PDG values.

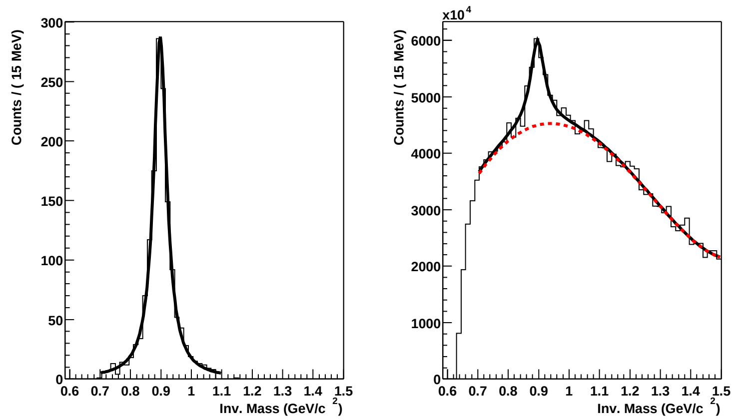

Fig. 1. Invariant mass distribution of the true pairs originating from the $K^*(892)^0$ and its antiparticle decay (left panel) and from all unlike-sign $K\pi$ pairs (right panel) in case of a perfect particle identification, for 2×10^5 PYTHIA pp collisions. The solid curves are the fit results.The dashed curve in the right part is the polynomial function representing the background.

The $K^*(892)^0$ signal is sitting on top of the combinatorial background resulting from fake πK associations, with a signal-to-background ratio $S/B = 0.1$, calculated within $\pm 2\sigma$ with respect to the nominal $K^*(892)^0$ invariant mass, and a significance $S/\sqrt{S+B}$ equal to 18.0 for the number of events used in the present analysis. A fit of the unlike-sign $K\pi$ invariant mass distribution (Fig. 1, right panel) carried out with the sum of a 5th order polynomial plus a Breit–Wigner function, gives a centroid at $M = (896.3 \pm 2.6)$ MeV/c^2 and a width $\Gamma = (57.2 \pm 8.6)$ MeV/c^2 for the $K^*(892)^0$ peak, values still compatible with the nominal ones, although with a large uncertainty in the width. These results show that with a perfect particle identification, the $K^*(892)^0$ signal may be extracted even with a limited number of events.

For the $\Lambda(1520)$ resonance, Fig. 2 shows the invariant mass spectrum obtained from a correlation of all pK pairs. The combinatorial background is here estimated by the event-mixing technique, considering only events with similar multiplicities and z-vertex positions. The spectrum obtained after the subtraction of the combinatorial background is fitted with a Breit–Wigner convoluted with a Gaussian. The fit gives a centroid at $M = (1521 \pm 1)$ MeV$/c^2$, and a width $\Gamma = (18 \pm 6)\,\mathrm{MeV}/c^2$, which are compatible with the standard PDG values. The signal-to-background ratio, calculated within $\pm 2\sigma$ with respect to the nominal $\Lambda(1520)$ invariant mass, is $S/B = 0.18$, with a significance $S/\sqrt{S+B} = 8.2$ for the number of events used in the present analysis.

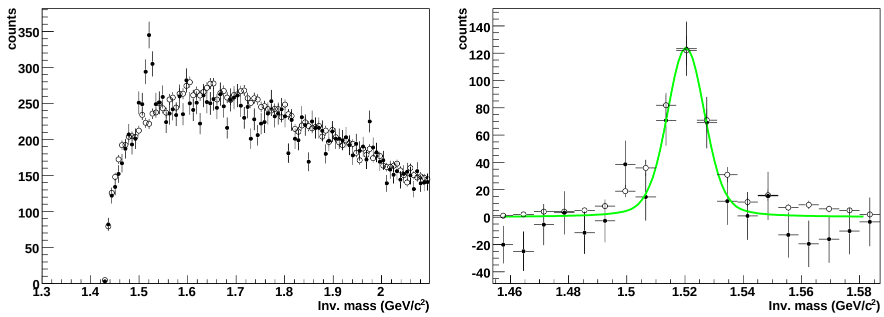

Fig. 2. Left: Invariant mass distribution of all charged pK pairs (black points) in the case of a perfect particle identification, for 6×10^4 PYTHIA pp collisions, and combinatorial background estimated by the event mixing tecnique (open points). Right: Invariant mass distribution of $\Lambda(1520)$ obtained after the background subtraction (black points). The open points represent the invariant mass distribution of the true pairs originating from the $\Lambda(1520)$ decay.

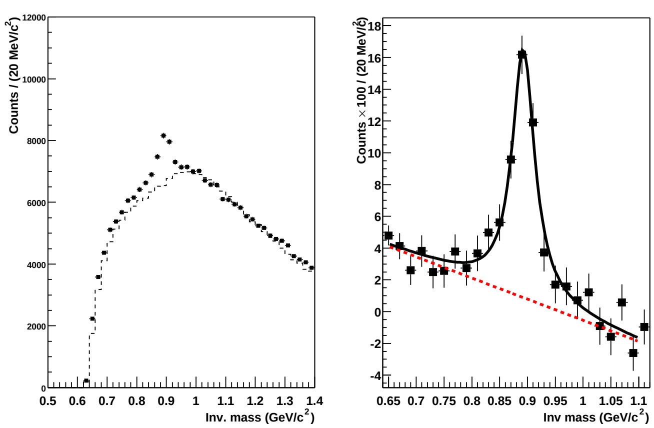

Fig. 3. Left: invariant mass distribution of the $K^+\pi^-$ and $K^-\pi^+$ pairs in the case of a realistic PID; the dashed line represents the combinatorial background obtained from the event-mixing technique. Right: signal spectrum obtained after the background subtraction. The solid curve is a Breit–Wigner fit to the spectrum whereas the dashed curve is the linear function representing the residual background.

ALICE uses a Bayesian combination of the PID weights for each individual detector. To maximize the number of the tracks, the PID information was req uired from at least one of the three detectors ITS, TPC and TOF [10]. The invariant mass distributions of πK in case of realistic PID are shown in Fig. 3.

3. Pb-Pb collisions

To study the ability of ALICE to detect the $K^*(892)^0$ signal in Pb-Pb collisions, two sets of events have been considered. The first is a sample of 3840 central HIJING events ($b \leq 5\,\mathrm{fm}$), for which a perfect particle identification was assumed. The second is a sample of 15440 central HIJING events ($b \leq 5$ fm), for which only a realistic particle identification, based on the weights calculated by a Bayesian approach during the tracking procedure, was available.

Here the combinatorial background was calculated by sampling the like-sign pairs ($K_i^+\pi_i^+$ and $K_i^-\pi_i^-$) taken in the same event. In this way possible problems related to the event structure (as multiplicity, flow, primary vertex position) are avoided. The like-sign $K\pi$ invariant mass (m) distribution is calculated as suggested by the STAR Collaboration [11]:

$$N_{\mathrm{like-sign}}(m) = 2 \times \sqrt{N_{K_i^+\pi_i^+}(m) \times N_{K_i^-\pi_i^-}(m)}\,. \tag{1}$$

More details about the background estimation in our study can be found in [9]. Fig. 4 (left) shows the $K^*(892)^0$ peak obtained after background subtraction from the distribution of unlike-sign $K\pi$ pairs, with the method described in [9], when limiting the study to total transverse momenta smaller than $1\,\mathrm{GeV}/c$. A fit of the $K\pi$ effective mass spectrum using a Breit–Wigner function plus a linear background gives reasonable results for the centroid and the width of the resonance peak. In this sample of events $\sim$ 2100 $K^*(892)^0$ are generated per event. The number of findable $K^*(892)^0$ drops down to ~ 67/event after reconstruction. The global signal to background ratio is S/B $(\pm 2\sigma)) \simeq 10^{-4}$.

In order to evaluate the visibility of the peak in a more realistic PID scenario, another sample of 15440 central fully reconstructed HIJING events was used. The $K^*(892)^0$ resonance peak was extracted in the same way as before, by creating the unlike-sign pairs invariant mass distribution, and subtracting from it the like-sign pairs invariant mass distribution. Fig. 4 (right) shows the result. Also in this case, the peak is clearly visible and a fit by a Breit–Wigner distribution plus a linear background gives reasonable results for the centroid and the width of the resonance peak.

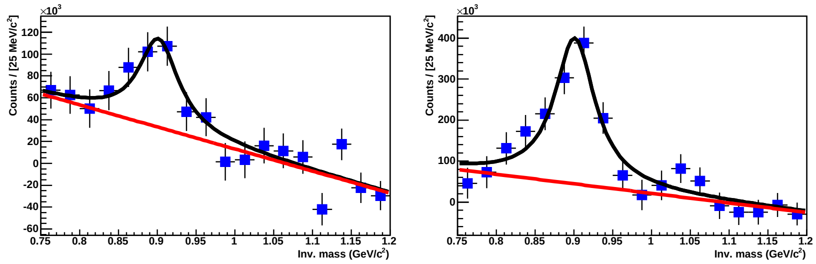

Fig. 4. $K^*(892)^0$ resonance peak obtained after subtraction of like-sign background, with a perfect PID (left, 3840 HIJING events) and realistic ID (right, 15000 HIJING events). The curves represent a fit by a Breit–Wigner plus a linear background.

4. Conclusions

A study of $K^*(892)^0$ and $\Lambda(1520)$ resonances in *pp* and Pb–Pb collisions at LHC has been described with a realistic simulation and reconstruction of minimum-bias PYTHIA *pp* and central HIJING Pb–Pb events. Studies of the extraction of these signals have been done in the case of a perfect PID efficiency and in the case of a realistic one for the $K^*(892)^0$. In both cases, results show that the resonance peaks are detectable with a small number of events. Great care has been devoted to the estimation of the combinatorial background, evaluated by the event-mixing technique for the *pp* events and by the like-sign technique for the Pb–Pb events.

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