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Study of hadronic resonances in ALICE in a first physics scenario

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Abstract. ALICE [1] is the LHC experiment mainly devoted to heavy-ion physics and to quark-gluon plasma study. However, it has also excellent properties for pp physics at the unexplored energy regime available at LHC ($\sqrt{s} = 14$ TeV). Hadronic resonances play a fundamental role in the characterization of the strong interacting medium created in the collisions and can be sensitive to some expected QGP signatures like the chiral symmetry restoration and the strangeness enhancement. In this respect, a particularly important role is played by the $\phi(1020)$ resonance. The ability of ALICE to measure $\phi(1020)$ resonances by their K^+K^- decay has been investigated using simulated minimum bias PYTHIA events reconstructed with an implementation of the detector configuration (alignment, calibration, etc.) which will be available for the first data. Its transverse momentum spectrum and its yield as a function of the charged event multiplicity have been evaluated with a statistics of some million of events. This shows how physics with resonances can be done right after the first high energy collisions at the LHC.

1. Introduction

Ultrarelativistic heavy-ion collision experiments mainly aim at studying nuclear matter at high temperature and energy density, where it is expected to undergo a phase transition to a quark-gluon plasma state (QGP). In this wide topic, a fundamental role is played by hadronic resonances, already extensively studied at the RHIC energies [2]. Since their lifetime is comparable to that of the collision fireball, the interaction of their daughters with the surrounding medium allows one to probe its collective properties and evolution in time [3]. Moreover, resonances are sensitive to chiral symmetry restoration, which is expected to take place along with QGP formation and should cause a variation in their mass and/or width [4].

Resonances containing at least one strange quark can also contribute to the now classical topic of strangeness enhancement [5]. In this respect, the ϕ meson is particularly interesting due to its hidden strangeness ($\phi = s\bar{s}$), which should prevent it from being canonically suppressed in pp collisions [6]. Then, its study is interesting in the aim of testing the statistical models [6] at the LHC energy.

The CERN Large Hadron Collider (LHC), which has had its first collisions at $\sqrt{s} = 900$ GeV on 23 November 2009, will soon begin operating with pp collisions at $\sqrt{s} = 2.2$ TeV, which will then be raised to 7 TeV, and finally to 14 TeV after some

intermediate tuning phases. This will give the possibility to investigate such collisions in a completely new energy regime.

ALICE [1] is the LHC experiment specifically devoted to the heavy-ion collisions for QGP search and study. Anyway, it will have a detailed pp physics program, whose results are necessary as a baseline for a thorough understanding of heavy-ion collisions results. Moreover, pp collisions turn out to be quite interesting in themselves, since the LHC capabilities will allow to test QCD in a new energy domain. Then, it will also be important to well understand the properties of short-lived resonances in pp collisions, due to their importance as fireball probes.

Since several years activity the ALICE Collaboration has carried out an activity to evaluate the experiment's performance in resonance (ϕ , K^* , Λ^* , ρ) detection [8]. However, a careful study is now performed in order to maximize the information which could be extracted from the initial phase of data taking. A detailed analysis of $\phi(1020)$ resonance decaying into KK pairs has then been made on a small quantity (few millions) of minimum bias pp simulated events at 10 TeV, reconstructed in realistic conditions. Results of this study show that ϕ transverse momentum distribution as well as its yield as a function of charged event multiplicity can be rapidly extracted from first LHC data.

Section 2 will present a brief description of the ALICE experiment, Section 3 will show the analysis method, and Section 4 will present the results obtained. Finally, some conclusions will be drawn in Section 5.

2. The ALICE experiment at LHC

ALICE has been designed to guarantee optimal tracking and particle identification (PID) capabilities in a wide range of transverse momentum (from ~ 100 MeV to ~ 100 GeV) in the central rapidity region ($|\eta| \leq 0.9$). The principal tracking device is a Time Projection Chamber (TPC), which is able to collect up to 160 points per track, covering distances from interaction between $r \sim 0.85$ m to $r \sim 2.5$ m, and can also give a dE/dx information for particle identification. Primary vertex is identified by the Inner Tracking System (ITS), a vertex silicon detector which is able to collect up to 6 points per tracks starting at 4 cm from the interaction vertex.

Besides TPC and ITS, which provide dE/dx information, there are several detectors which contribute to Particle IDentification (PID): a Time Of Flight detector (TOF), a high-momentum particle identification detector (HMPID) and a Transition Radiation Detector (TRD) which will allow electron identification. Moreover, a Photon Spectrometer (PHOS) and an Electromagnetic Calorimeter (EMCAL) identify neutral particles, allowing π^0 and photons measurements. EMCAL also contributes to high energy electron identification and jet reconstruction. PID information coming from all detectors is put together by means of a Bayesian algorithm [9] which also takes into account the “a priori” probability to have a particle of a given species in the sample of tracks used for analysis.

3. Analysis in a “first physics” scenario

ALICE has already undergone a raw data calibration phase in 2008-2009 using cosmic runs. This has allowed to tune TPC dE/dx resolution to a value $\sigma_{TPC} \sim 6\%$. On the other hand, most of ALICE detectors still need a further tuning phase with first beam data. Then, a “first physics” resonance study can be performed without any

Figure 1. Computed S/B (left) and statistical significance (right) of $\phi(1020)$ resonances as a function of p_T , with different PID strategies. Plots are in semilog scale. Open circles are the results without any PID; triangles correspond to TPC PID with the compatibility cut at 3σ . For comparison, filled circles show the values obtained with a realistic PID done with the standard Bayesian method.

PID, or using a limited PID information; for example, one could think to exploit the TPC PID capabilities in their current state.

A study had been carried out to evaluate the ALICE capability to extract the $\phi \rightarrow K^+ K^-$ resonance in such conditions in both cases: without any PID, and with the TPC PID information only. This has been done using a sample of 5 millions of pp minimum bias events at $\sqrt{s} = 10$ TeV, simulated with the PYTHIA generator and transported by GEANT3 through a realistic and detailed simulation of the ALICE detector and response. The chosen energy was the initially expected value of $\sqrt{s}$ at the LHC start-up, and the number of events is a reasonable estimate of the amount of data which will be collected in the first days of ALICE data taking.

In both studies, some cuts are applied to tracks and events. To improve momentum resolution, cuts are applied on the track quality parameters (track parameter covariance values, chi square) and on the number of TPC clusters required ($ncluster_{TPC} > 50$).

Due to the very small lifetime (44 fm/c) of the ϕ resonance, its daughters are essentially indistinguishable from primary particles. Then, to be sure to have events with a good enough reconstructed primary vertex, only events with at least 3 reconstructed tracks were analyzed. In the selected events primary tracks were then selected by a cut on their impact parameter.

The TPC PID has been used in the form of a “compatibility cut”. Taking into account the reconstructed momentum of each track, and using a Kaon mass hypothesis, one can estimate its energy loss in the TPC using a Bethe-Bloch (BB) formula which takes into account the TPC characteristics. One can then compare the measured TPC signal with this BB estimation, and accept or reject the track depending on the relative difference of these quantities. For the present analysis the cut on this difference has been set to $3\sigma_{TPC}$.

The TPC information is of great help for ϕ identification, especially at small momenta, as in this range the separation between the dE/dx curves for the different particles is quite large. This can be easily observed from the ϕ signal to background ratio (S/B) and its statistical significance ($S/\sqrt{S+B}$), which are reported in Figure 1 as a function of transverse momentum for both strategies. At large transverse

Figure 2. Efficiency · acceptance as a function of p_T , integrated over η (left) and as a function of η , integrated over p_T (right) for the different PID strategies adopted in the study. Open circles are the results without any PID; triangles correspond to TPC PID with the compatibility cut at 3σ . For comparison, filled circles show the values obtained with realistic PID done with the standard Bayesian method.

momenta ($p_T > 5$ GeV), S/B and significance shows similar values in both cases, since here all tracks reach the Minimum Ionizing Particle status (MIP) and then the TPC compatibility cut becomes almost ineffective.

Figure 2 shows the correction factors for ϕ yields due to efficiency and geometrical acceptance as a function of the transverse momentum p_T and pseudo-rapidity η , separately, for the two adopted kaon selection strategies. For comparison purposes, the same figure reports also the factors computed in case of a standard PID procedure carried on using all ALICE detectors.

This figures shows that the efficiency with no PID and with the TPC compatibility cut are roughly equal, while Figure 1 clearly shows a substantial difference in their S/B and significance: this results in a quite large increase of signal purity (even if it does not reach the level obtained with realistic full PID), with the $3\sigma_{TPC}$ compatibility cut, at the cost of a very small loss in efficiency.

4. Results

The number of reconstructed resonances was estimated by a Breit-Wigner fit of the unlike-sign K^+K^- invariant mass distribution obtained after the subtraction of the background estimated by the like-sign pairs (both K^+K^+ and K^-K^-) in the same event. The number of generated ϕ is then estimated by correcting for the branching ratio of the K^+K^- channel, and for acceptance and efficiency.

Figure 3 shows the estimated transverse momentum distribution, in the two different analysis strategies, and shows the initial Monte Carlo distribution for comparison. One can observe that both results reproduce well the MC yields for $p_T > 2$ GeV. Instead, at small transverse momenta the no-PID analysis fails, as

Figure 3. Corrected reconstructed yields (full circles) as a function of transverse momentum (full circles). For comparison, Monte-Carlo yields are shown (open circles) in open circles for the same data sample. Plot on the left (a) shows the results in case of a no PID analysis. Plot on the right (b) shows the results in case of use of a TPC compatibility cut with a 3σ interval.

one could expect due to the extremely small significance in this range, while the TPC compatibility cut seems to work better. At larger transverse momenta, instead, both methods reproduce the Monte-Carlo quite well; one can then conclude that the obtained values of S/B and significance in this range are large enough to allow the extraction of the ϕ signal in these conditions.

Estimating the yield as a function of charged particle multiplicity can be of interest in the aim of detecting alterations in the ϕ production mechanisms with respect to multiplicity, since it could be a signal of new processes taking place in the fireball, as already checked by E735 Collaborations at FNAL [10]. Then, in the case where the TPC compatibility is applied, the whole event sample has also been analyzed in bins of charged multiplicity, and in each one the integrated yield has been computed. The result of this computation is shown in Figure 4. Charged multiplicity has been estimated using the number of tracklets reconstructed from correlated clusters in the two ITS silicon pixel detector layers [9], without any correction for efficiency and acceptance. The trend of this plot is almost linear, which is what one expects in absence of additional and unexpected ϕ production processes.

5. Conclusions

In this paper a study has been presented for the extraction of $\phi(1020)$ transverse momentum spectrum and its yield as a function of multiplicity in the initial ALICE experimental scenario. While waiting for a proper tuning of all PID devices, a track selection has been done using the TPC in its current state-of-the-art, by defining a

Figure 4. Corrected reconstructed integrated yields (full circles) for different bins SPD tracklet multiplicity (uncorrected), obtained in the analysis done using the TPC dE/dx compatibility in 3σ . For comparison, Monte-Carlo yields are shown (open circles) for the same data sample.

selection criterion based on the compatibility of the TPC signal of each track with the expected Bethe-Bloch energy loss of a Kaon inside this detector. Yields reconstructed using this method reproduce the Monte-Carlo data quite well. A ϕ analysis can also be carried on without any PID information, but this works only for $p_T \geq 2$ GeV, while it fails in reproducing correctly the MC yields below this threshold.

The software for this analysis is fully integrated in the ALICE computing framework and deals perfectly with any format of input data, both coming from simulation or real data taking. ALICE is then ready for resonance study, especially for what concerns the $\phi(1020)$ since the very beginning of data taking.

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