Hadron spectroscopy in diffractive and central production processes at COMPASS

Prometeusz Kryspin Jasinski *for the COMPASS Collaboration*

Institut für Kernphysik, 55128 - Mainz University

Abstract. COMPASS is a fixed-target experiment using secondary high-energetic hadron beams provided by the CERN SPS. In 2008 and 2009, a large amount of data has been collected with a $190\,GeV/c$ pion beam for the investigation of the hadron spectrum in diffractive and central production processes. A big variety of observed final states, including $\pi^-\pi^+\pi^-$, $\pi^-\pi^0\pi^0$, $\pi^-\eta\eta$, $\pi^-K_sK_s$, $\pi^-K^+K^-$, $K^-\pi^+\pi^-$, and centrally produced 4π, is being analysed. The potential for systematic spectroscopic studies especially concerning the existence and nature of spin-exotic, hybrid and glueball states is discussed. In addition, we show the first results from the data set collected with a proton beam in 2008. These data indicate the chance of COMPASS to contribute to the field of baryon spectroscopy.

Keywords: diffraction, central production, fixed target, baryon/hadron spectroscopy, PWA, partial wave analysis, glueballs, exotic states
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INTRODUCTION

Since the introduction of the standard model, the interpretation of mesonic resonances in particle collisions as $q\bar{q}$-states was quite successful but by far does not explain all observed quantum states. This could be expected, because the theory of quantum chromodynamics (QCD) allows states beyond the simple constituent quark model (CQM). Objects such as hybrid mesons, which are $q\bar{q}$-states with excited glue, are as well predicted as states consisting of pure gluons only, so-called glueballs. Even multi-quark systems are allowed within this framework.

While glueballs in the lower mass region would mix with ordinary $q\bar{q}$-states of same quantum numbers, hybrid mesons can carry quantum numbers forbidden for simple CQM objects and should be distinguishable. Indeed objects as the $\pi_1(1400)$ and $\pi_1(1600)$, carrying the exotic quantum number $J^{PC} = 1^{-+}$, were reported from some experiments and are strongly disputed.

At high energies, diffractive (single Pomeron exchange) and central reactions (double Pomeron exchange) produce a rich spectrum of meson resonances. These processes are of special interest for the COMPASS collaboration. A hadron beam pilot run in 2004 led to very exciting results, which have recently been published [1] and are also summarised in [2]. As a consequence the hadron data taking in the years 2008 and 2009 were dedicated to hadron spectroscopy using a proton target. The analysis of many interesting channels is currently under investigation and a short overview is given here.

THE COMPASS SPECTROMETER

The COMPASS Spectrometer is located at the SPS north area at CERN and is supplied with high energetic secondary hadron beams or tertiary longitudinally polarized muons. Muon beams, impinging on a polarized target, were mainly used for the spin program (see this proceedings [3]). For the hadron-beam program some upgrades to the spectrometer, as described in [4], were necessary.

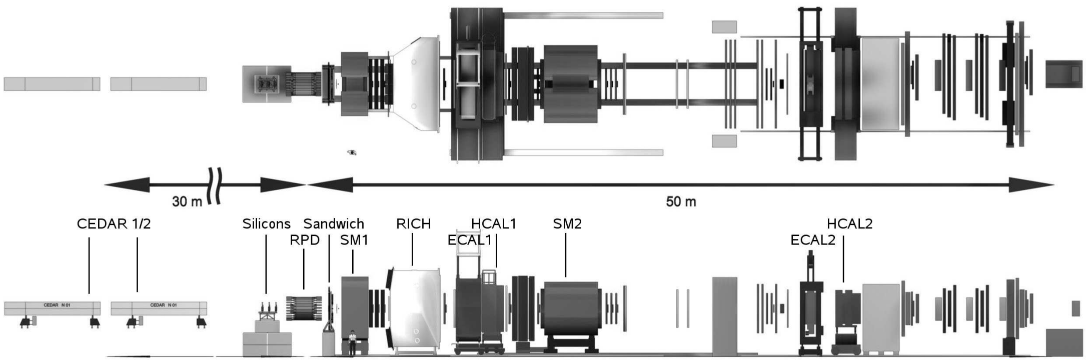

FIGURE 1. Illustration of the two-stage COMPASS Spectrometer (top/side view). For details see the text.

Figure 1 illustrates the COMPASS 2008/2009 Spectrometer. The positively charged beam, coming from left, consisted of approx. 75% protons, 24% pions and 1.4% kaons whereas a negatively charged beam contained 97% pions, 2.4% kaons and 1.4% antiprotons. The beam particles were identified using two Cerenkov Differential counters with Achromatic Ring Focus (CEDAR) [5] 30 m upstream the spectrometer. Using these devices kaons were tagged in the negative hadron beam and pions as well as protons in the positive hadron beam with a momentum of 190 GeV/c. The recoil proton from a liquid hydrogen target triggered a recoil proton detector (RPD). This typical signature of single diffractive processes enhanced significantly the triggered purity of events containing resonances decaying into charged and neutral final states.

Momenta of charged tracks are reconstructed by two stage spectrometer with two dipole magnets (SM1/SM2) containing many tracking detectors. Silicon strip detectors were placed upstream and downstream of the target to measure tracks in the beam region [6]. Also a new type of pixel Gas Electron Multiplier (GEM) detectors was used [7] as well as improved MicroMEsh GAseous Structure detectors (MicroMegas) [8]. Final state kaons and pions up to approx. 50 GeV/c are separated using the ring imaging Cerenkov detector (RICH) in the first stage.

Neutral channels are identified by electromagnetic calorimeters (ECAL1/ECAL2) in both stages where the second one was significantly improved by using a laser monitoring system and by the installation of radiation hard shashlik modules in the central region [9].

OVERVIEW OF ANALYSIS CHANNELS

One important advantage of the COMPASS spectrometer is the simultaneous measurement of charged and neutral channels that allows direct comparison of isospin symmetric decay chains giving the opportunity to control systematic influences.

One example is the direct comparison of $\pi^- p \rightarrow \pi^-\pi^+\pi^- p_{recoil}$ and $\pi^- p \rightarrow \pi^-\pi^0\pi^0 p_{recoil}$. First partial-wave analysis, not yet acceptance corrected, is shown in figure 2. One can see that partial waves, normalized to the well established $a_1(1260)$, give a very good agreement in the $\rho(770)$ decay branches while a decay into $f_2(1270)$ gives an amplitude in the charged channel twice as strong as in the neutral one, which is expected from isospin symmetry. For more details we refer to [10].

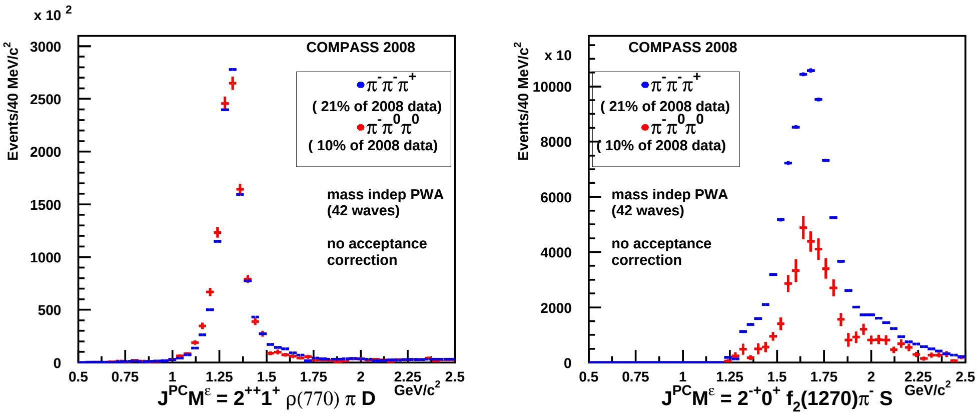

FIGURE 2. Direct comparison of partial waves of diffractively produced three-pion final states in the neutral and charged case. (see text for details)

The same systematic studies can be performed when comparing the decays into $\pi^- K^+ K^-$ and $\pi^- K_s K_s$ [11]. While charged channels have to be identified by the RICH detector, K_s are accessible by reconstruction of secondary decay vertices into charged pions. The detection of photons allows not only the reconstruction of pionic final channels but also η decay channels [12]. Final states as $\pi^-\eta$ and $\pi^-\eta\eta$ are currently being analysed. Centrally produced $\pi^+\pi^-\pi^+\pi^-$ systems give access to resonances around the $f_0(1500)$. Several glueball candidates in that region were reported by different collaborations.

Thanks to the tagging of kaons in the negative hadron beam, COMPASS is able to analyse strangeness in the incoming channel as well. Of major interest is the diffractive production of $K^- p \rightarrow K^-\pi^+\pi^- p_{recoil}$ where many higher mass states still need to be confirmed. We present here the preliminary invariant mass distributions (fig. 3). The double peak structure of the K_1 is clearly visible as already reported for example in [13].

The proton dominance in the positive hadron beam will be used for analysis of centrally produced systems as well as for baryon spectroscopy [14]. Hadroproduced baryon resonances show a rich spectrum of broad resonances. Specially the charged final states $pp \rightarrow p\pi^+\pi^- p_{recoil}$ and $pp \rightarrow pK^+K^- p_{recoil}$ are currently in the process of analysis and are expected to contribute to the field of baryon resonances.

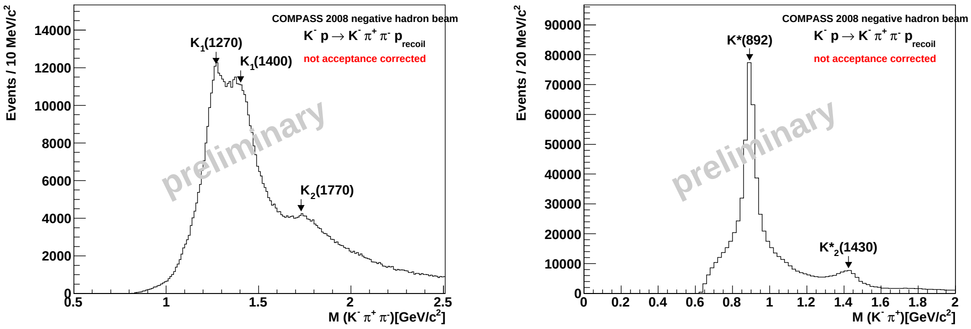

FIGURE 3. left: Invariant mass distribution of diffractively produced $K^-\pi^+\pi^-$. right: Invariant mass distribution of $K^-\pi^+$ subsystem.

CONCLUSION AND OUTLOOK

COMPASS successfully took data with hadron beams in the years 2008 and 2009. For some channels the amount of recorded statistics exceeds the existing data from previous experiments by nearly two orders of magnitude. The data are currently being analysed applying partial-wave analysis techniques to a number of final states. This high precision measurement will contribute significantly to the clarification of many questions in the domain of QCD.

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