Test of the OZI rule in vector meson production with the COMPASS experiment

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Abstract. The COMPASS experiment at CERN collected a large set of data with hadron beams (p, π, K) and different targets (H_2, Pb, Ni, W) in the years 2008 and 2009. The main goal is the search for exotic bound states of quarks and gluons (glueballs, hybrids) and several preliminary results from the ongoing analysis have already emerged.

The production of exotic states is known to be favoured in glue-rich environments, *e.g.* so-called OZI-forbidden processes. The Okubo-Zweig-Iizuka (OZI) rule states that processes with disconnected quark line diagrams are suppressed. As a consequence, states with an $s\bar{s}$ component should be suppressed with respect to states containing mainly u and d quarks. The numerous reported violations of the OZI rule show that the underlying physics is more complicated. By studying the degree of OZI violation a lot can learned about the production mechanism and possibly also about the nucleon structure itself. The uniquely large COMPASS data sample allows for detailed studies with respect to kinematic variables (*e.g.* x_F). Results from the ongoing analysis on the comparison of ω and ϕ vector mesons production in $p\,p \longrightarrow p\,p\,(\omega/\phi)$ are presented and an outlook on the prospect of spin alignment measurements with COMPASS is given.

1. Introduction

The Okubo-Zweig-Iizuka rule [1] asserts that processes with disconnected quark line diagrams are suppressed. Starting as a phenomenological interpretation of *e.g.* the large branching fraction of ϕ decays into $K\overline{K}$ final states, the OZI rule found its foundation in the QCD framework. The OZI rule has been helpful in understanding numerous other processes, such as the suppressed production of mesons with an $s\bar{s}$ component. For example, the production of ϕ mesons in reactions with exclusively non-strange hadrons in the initial state, is only OZI-allowed due to the deviation $\delta_V = 3.7^o$ from ideal mixing of ω and ϕ. As a consequence, the cross section ratio $R = \sigma(AB \to \phi X)/\sigma(AB \to \omega X)$ is predicted to be $4.2 \cdot 10^{-3}$ [2], where A, B and X are non-strange hadrons. Despite being based on a very simplistic picture, the OZI prediction is well fulfilled in most types of reactions [3]. Apparent violations have however been found in $p\overline{p}$ collisions at rest, NN collisions [3] and reactions near the kinematic threshold [4]. These OZI violations show that the underlying physics is more complicated and are often interpreted as intermediate gluonic states [5], a polarised strangeness component in the nucleon [6] or differences in the production mechanism and the nature of the meson-nucleon interaction for reactions near the kinematic threshold. The picture changes when studying the degree of OZI violation with respect to different beam energies of the production experiments, tending to a constant or slowly decreasing violation at higher energies [4]. In order to clarify the trend, details and results of the ongoing analysis at 190 GeV will be presented in the following.

2. Experimental set-up

COMPASS is a two-stage magnetic spectrometer [7] at the CERN SPS dedicated to structure studies and spectroscopy. In 2008 and 2009, secondary hadronic beams were used, impinging on different targets (liquid H_2, Pb, Ni, W). In this work, we present results from 2008 collected with a positive beam composed of about 74.6 % protons, 24.0 % pions and 1.4 % K^+ with the same energy of 190 GeV. Two differential Cherenkov counters with achromatic ring focus (CEDAR) were installed to distinguish between the two main beam components. Recoiling particles from the target were measured by the Recoil Proton Detector (RPD), a cylindric time-of-flight detector surrounding the target with two concentric rings of scintillator strips. The main trigger required a recoiling proton to enhance the aquisition of data from diffractive dissociation and central production. The spectrometer itself features large angular acceptance over a wide momentum range and is capable of particle identification with the means of a RICH detector. Neutral particles are detected with electromagnetic (ECAL1+2) and hadronic (HCAL1+2) calorimeters in both stages of the spectrometer which are defined by the two spectrometer magnets SM1 and SM2 (*cf.* Fig. 1).

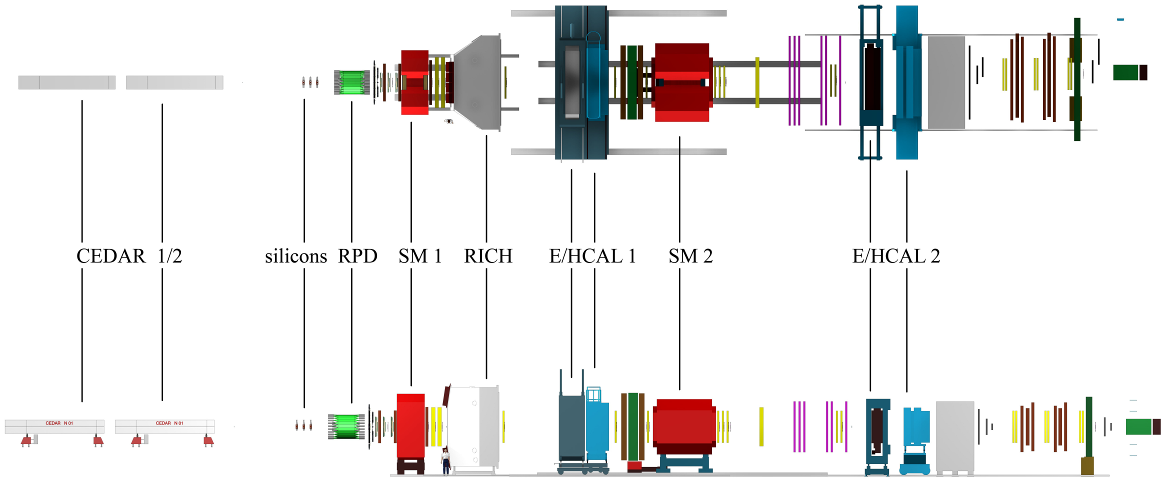

Figure 1. The COMPASS set-up for the 2008 and 2009 data taking.

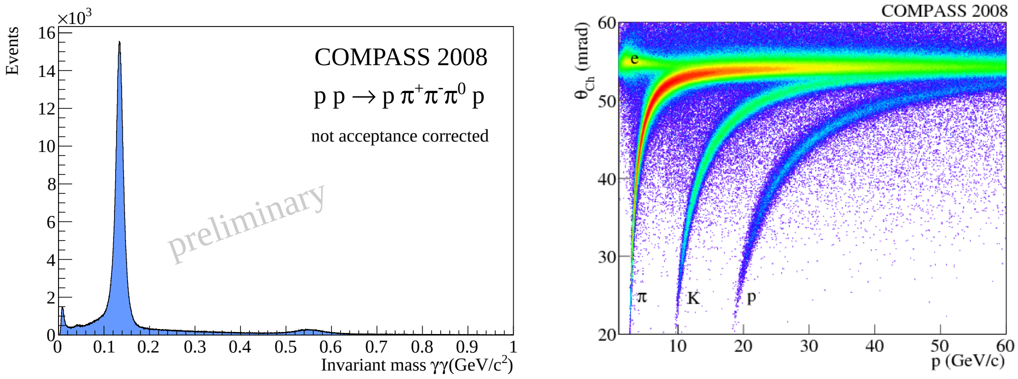

Figure 2. Left: Invariant mass distribution of reconstructed $\gamma\gamma$ before cuts in the $pp \rightarrow p\pi^0\pi^+\pi^- p$ channel. Right: Cherenkov angle (RICH detector) vs. momentum of charged particles.

3. Analysis

In this study, we compare the two channels $p\,p \rightarrow p_{fast}\,\omega\,p_{recoil}, \omega \rightarrow \pi^+\pi^-\pi^0$ and $p\,p \rightarrow p_{fast}\,\phi\,p_{recoil}, \phi \rightarrow K^+K^-$. In both cases, events were selected with one identified beam proton, one recoil proton in the RPD and three outgoing charged tracks from the primary vertex.

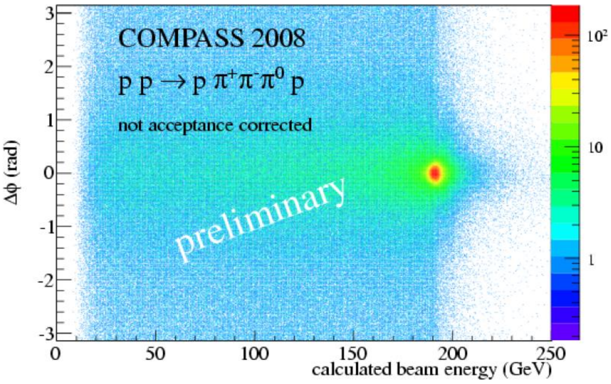

Figure 3. Coplanarity criterion (see text) vs. total energy of the $p\,\pi^0\,\pi^+\,\pi^-\,p$ final state before cuts.

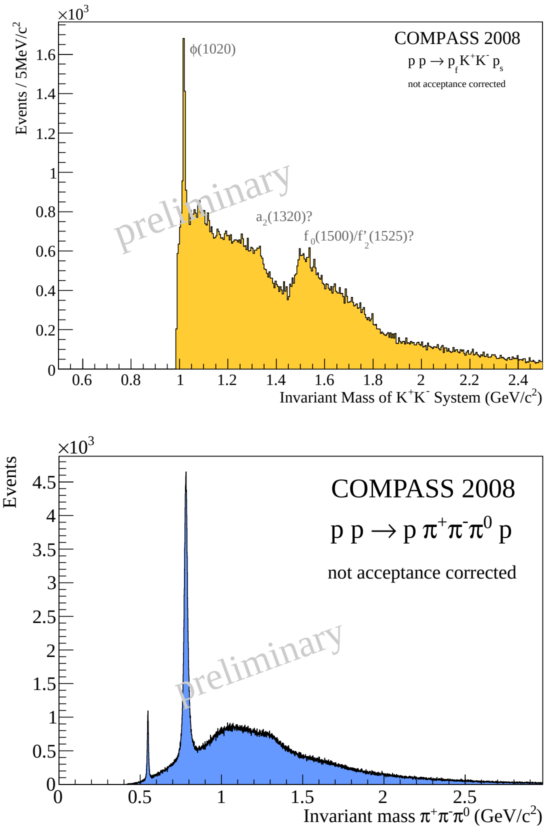

Figure 4. Invariant mass distributions of the $K^+\,K^-$ (top) and $\pi^0\,\pi^+\,\pi^-$ subsystems (bottom).

In the ω case, a π^0 candidate reconstructed from two photons (see Fig. 2, left) and a positive RICH identification of the π^+ were required. In the ϕ case, positive RICH identification of the K^+ was required. In the right panel of Fig. 2), the separation power of the RICH detector is shown in terms of the Cherenkov angle with respect to the momentum of the particle.

In the ω case as well as in the ϕ case, the total momentum of the final state was required to be within $\pm\,6\,\mathrm{GeV}/c$ of the beam momentum. In addition, a coplanarity criterion was applied between the recoil proton and the forward $p_{fast}\,\phi/p_{fast}\,\omega$ system ($\pm\,2\,\sigma$ of the RPD's angular resolution, *i.e.* 0.28 rad). The distribution of both the total momentum and the degree of coplanarity before application of the afore mentioned cuts is depicted in Fig. 3 and shows already a concentration of exclusive and coplanar events thanks to the trigger system.

In Fig. 4, the invariant mass distributions of the $K^+\,K^-$ and $\pi^0\,\pi^+\,\pi^-$ systems are presented. In the $M(\pi^0\,\pi^+\,\pi^-)$ distribution, the ω signal is dominating, but other well-known resonances like η and a possible contribution from $a_2(1320)$ can also be seen. In the $K^+\,K^-$ subsystem, the ϕ signal appears strongly. In addition, an excess of events is observed around 1500 MeV which could possibly be identified with f_0 and f_2 contributions.

The data were divided into bins with respect to the fraction of the longitudinal momentum, x_F, of the p_{fast}. The $K^+\,K^-$ and $\pi^0\,\pi^+\,\pi^-$ invariant mass distributions were extracted in each bin, as shown in Fig. 5. A Breit-Wigner curve, convoluted with a Gaussian on top of a polynomial background, was fitted to the data. The resulting background was then subtracted in order to obtain the yields of ω and ϕ. These yields were corrected for the branching ratio (89.2% for $\omega \rightarrow \pi^+\,\pi^-\,\pi^0$ and 48.9% for $\phi \rightarrow K^+\,K^-$) and the spectrometer acceptance, obtained by Monte-Carlo simulations. The overall systematic uncertainty in the photon reconstruction efficiency was estimated to be 10%, obtained by comparing the acceptance corrected yields of $\omega \to \pi^+\pi^-\pi^0$ and $\omega \to \gamma\pi^0$. The error of the Breit-Wigner fit was smaller than 1.5%. Additional systematics from *e.g.* the RICH identification and the model-dependence of the acceptance are not fully calculated yet and therefore not included in the error bars of our preliminary data points. In Fig. 6, the cross section ratio R with respect to x_F of p_{fast} is presented. The COMPASS data show an OZI violation of approximately a factor of three, slightly tending to a lower degree of violation for high x_F.

4. Outlook

The presented result is based on one week of data taking with positive hadron beam in 2008. The 2009 data set, which is 10 larger than the 2008 set with about a factor of 10, has recently been processed and the analysis has started. The increase in statistics will allow a finer binning in x_F and multidimensional analysis in x_F and four momentum transfer $t = (p_{beam} - p_{fast})$.

In addition, a comparative study of the *spin alignment* of the vector mesons is planned. The spin alignment, or the polarisation, can give deeper insight in the underlying physics, and is quantified in terms of the spin density matrix element ρ_{00}. The ρ_{00} of a spin 1 meson produced with an unpolarized beam impinging on an unpolarized target is obtained from the angular distribution where the angle is defined between the normal of the vector meson decay plane and some quantization axis [8]. The relation between the production mechanism and the ρ_{00} is outlined in Ref. [9]. Very few comparisons of ρ_{00} for ω and ϕ exist so far. A comparative study of the polarisation of ω and ϕ produced with a photon beam was carried out at SAPHIR [10] but in hadron induced reactions, very few simultaneous measurements of ω and ϕ polarisation have been published. The MOMO collaboration measured the ρ_{00} of the ϕ in $pd \to ^3\mathrm{He}\ \phi$ near the kinematic threshold and the result was consistent with a complete polarisation of the ϕ meson [11]. This is in sharp contrast to the ω meson, which is produced unplorarised at the same excess energy and the same reaction according to a measurement by the WASA collaboration [12]. The results were explained in terms of meson-nucleon interactions rather than quark structure, but it cannot be excluded that a polarised hidden strangeness content in the nucleon could play a role. Therefore, it will be interesting to see whether there are differences in polarisation also at high energies.

A simultaneous measurement of the spin density matrix element ρ_{00} of ω and ϕ using the same experimental setup will also be more reliable than the comparison between WASA and MOMO, which have very different designs and thus different systematics. The vector meson spin is expected to be very differently sensitive to different reference axes depending on the production mechanism and by extracting ρ_{00} from several different axes, we expect to get a deeper insight into diffractive and central processes which are both present at COMPASS energies. Studies of central systems need in particular more detail on mixing of production processes [13], and also the search for exotic states in diffractively produced multi-particle final states will profit from a better understanding of backgrounds, *e.g.* in $\pi^- p \to K_s K^\pm \pi^\mp \pi^- p$ [14].

The evolvement of ρ_{00} with respect to x_F may also give clues about the nucleon structure, as outlined in [15].

Acknowledgments

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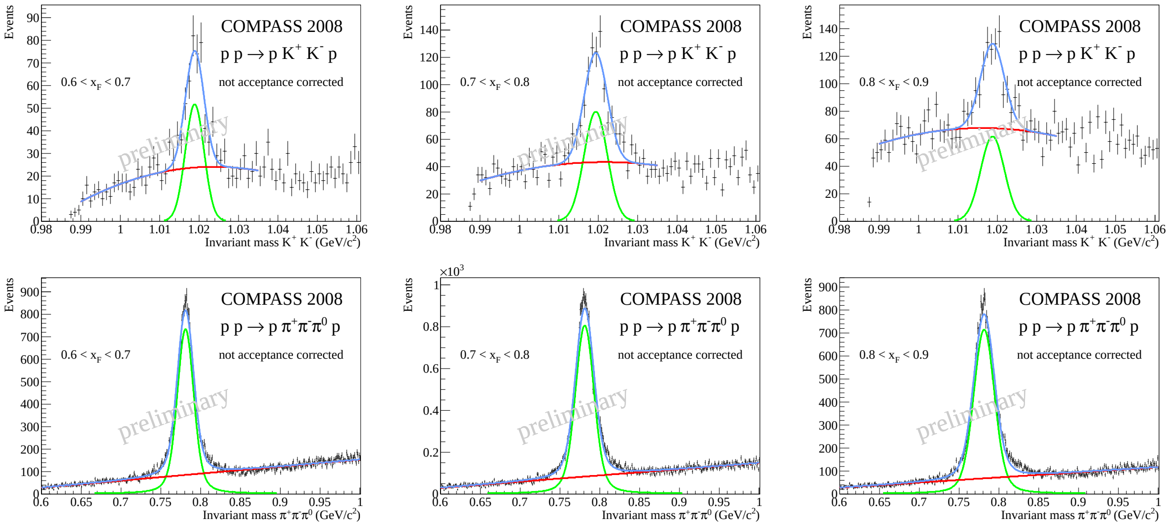

Figure 5. x_F of forward proton in the three measured bins ($0.6 < x_F < 0.9$), with fitted curves as explained in the text.

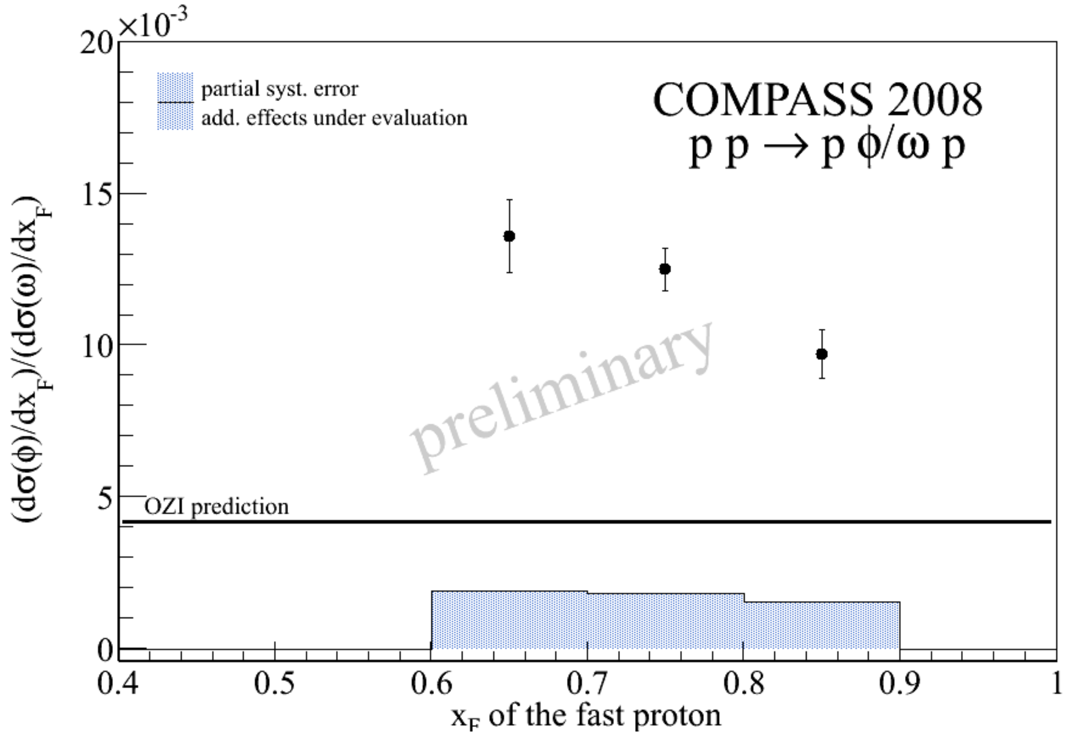

Figure 6. Acceptance corrected ratio R of ϕ and ω yields as a function of x_F of the forward proton.

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