Hadron Spectroscopy with COMPASS

Johannes Bernhard

Institut für Kernphysik der Johannes-Gutenberg-Universität zu Mainz, Johann-Joachim-Becher-Weg 45,

D-55099 Mainz, Germany

for the COMPASS collaboration

Abstract

The **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy is a fixed target experiment at the CERN SPS accelerator. In the past two years hadron spectroscopy was brought into focus. A huge amount of data was taken, using hadronic beams at a momentum of 190 GeV/c impinging on hydrogen, lead, nickel and tungsten targets. The primary goal for the hadron programme is the study of resonance production by diffractive scattering, central production and photon exchange. To bring clarity in the intriguing question about the existence of exotic states, such as glueballs and hybrids, the analysis of several channels have been started. We present here a selective overview of the current status.

Keywords:
hadron spectroscopy, glueballs, spin-exotic mesons, hybrids

1. Introduction

QCD, the theory of the strong interaction, describes successfully physics at perturbative scales. However, it is difficult to make predictions in the the non-perturbative regime where one needs to rely on specific models, such as chiral perturbation theory(ChPT) or quark models. The simple quark model ansatz describes the majority of observed particles and resonances, but unlike QCD, does not allow for states beyond the qqq or $q\bar{q}$ description, respectively [1]. In general, more complicated colour-neutral states might be observable, which are usually categorised as hybrids ($q\bar{q}$), glueballs (gg,ggg) and multi-quark states ($q\bar{q}q\bar{q}$). Processes with gluon or gluon-like exchanges are suited to provoke their production or formation. To search for hybrids, diffractive scattering is one adequate way of choice. It is described at medium and high energies with a single pomeron exchange (SPE) between the beam and the target particle. As a result, the beam particle is excited and hybrids might be produced. Model calculations (*e.g.* [2]) predict the lowest hybrid state between a mass of 1.3 GeV/c^2 and 2.2 GeV/c^2. To search for glueball candidates, central production can be used. However, the term is in general not well-defined. Central production is understood to be the production of resonances at central rapidities. This may either occur via a double pomeron exchange (DPE) or as an exchange of reggeons between the beam and the target particles leaving both intact. Members of the f_0 family of resonances are believed to be glueball candidates, as the observed number of resonances is not fitting the mesonic octet. Typically, for diffractive dissociation and central production, medium and high momentum transfer ranges ($t > 0.1$ GeV$^2/c^2$) are defining the interesting kinematic region, whereas at low and very low t photon exchange (Primakoff-like) reactions are probed, which is the area of ChPT. Therefore, the structure of mesons can be studied also in another way, namely by measuring form factors *e.g.* for pions.

2. The COMPASS spectrometer

The COMPASS spectrometer is situated at the M2 beam line of the CERN SPS accelerator and used secondary hadronic beams with an energy of 190 GeV for the hadron campaign in 2008 and 2009. The spectrometer consists of two stages defined by the two spec-

Email address: Johannes.Bernhard@cern.ch (Johannes Bernhard)

trometer magnets SM1 and SM2 (Fig. 2), equipped with a large number of tracking detectors, particle identification with a RICH and both electromagnetic and hadronic calorimetry, respectively. This results in a very high momentum resolution over a wide momentum range, [3] reviews the full details. Following the muon beam programme, the spectrometer was upgraded and the target region completely refurbished in 2008 for the hadron programme. CEDAR detectors are used to distinguish between the two main beam components, which are pions (≈97%) and kaons (≈2.5%) for the negative and protons (≈75%) and pions (≈23%) for the positive beam. A new 40 cm long liquid hydrogen target

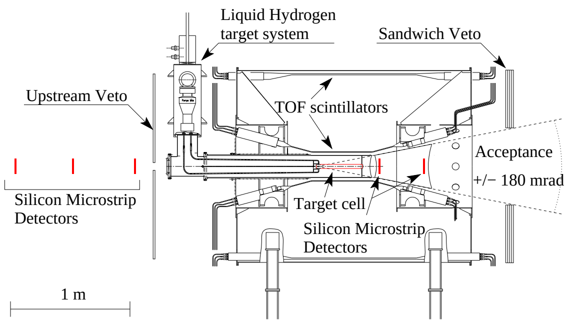

Figure 1: Target region for the hadron campaign 2008 and 2009.

was installed, surrounded by a new recoil proton detector (RPD). An overview of this region is depicted in Fig. 1. Also major upgrades on tracking detectors were undertaken (cryogenic silicon micro-strip detectors, pixelised GEMs) as well as on electromagnetic calorimetry. Interactions from diffractive dissociation and central production can be tagged by detecting the mutual recoil proton. A trigger based on the information from the RPD combined with beam defining elements and veto detectors was set up. This physics trigger comprises high purity and introduces basically no bias on the forward particles.

3. Diffractive dissociation at COMPASS

Following promising results from the 2004 pilot hadron run, where the $\pi_1(1600)$ was observed [4] in only a few days of data taking, the analysis of 2008 and 2009 data is ongoing. Having the possibility to use calorimetric and RICH particle identification in these data sets, resonances can be observed in different decay modes. An important consistency check of the first analysis has been carried out by a simple check of isospin symmetry. As an example, we show the comparison between the neutral and charged modes of resonances decaying into 3π. A first mass-independent partial wave

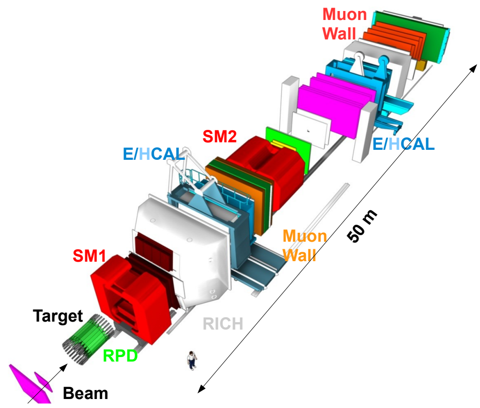

Figure 2: Experimental setup of the COMPASS spectrometer.

analysis (PWA) without acceptance corrections was performed [5], where the isobar model was applied. The kinematic range was confined to $0.1\ \text{GeV}^2/c^2 < t < 1\ \text{GeV}^2/c^2$. To account for the different statistics in both decay modes, a plain normalisation on the well-known $a_2(1320) \rightarrow \rho\pi$ decay in the $J^{PC} = 2^{++}\rho\pi D$ wave was done, cf. Fig. 3. Naïvely, just taking into account Clebsch-Gordan-coefficients, one expects the same intensities in all $\rho\pi$ modes, whereas decays via $f_2\pi$ should show differences for neutral and charged channels in the order of a factor of 2. For the examples discussed, effects due to Bose-symmetrisation with the bachelor-pion were checked and found to be negligible. Fig. 4 compares the $1^{++}\rho\pi S$ wave containing the $a_1(1260)$ and the $2^{-+} f_2(1270)\pi S$ wave containing the $\pi_2(1670)$. One sees clearly the expected behaviour. As a next step, Monte-Carlo acceptance corrections are currently being obtained and will be applied to the full data set. Only then smaller intensities in an extended partial wave set will be studied, such as the spin-exotic 1^{-+} wave containing the $\pi_1(1600)$.

4. Central production

In central production two intermediate, glue-rich particles produce a resonance at central rapidities and hence should favour glue-rich states, such as glueballs. Glueball candidates mix with states with the same quantum numbers in the same mass regions, but might show a characteristic flavour-neutral decay in various modes. COMPASS plans to analyse therefore $\pi\pi, K\bar{K}, \eta\eta$ and $\eta\eta'$ modes in negatively charged (mainly π^-) and positively charged (mainly p) beams. The major challenge of this analysis is the overlap of central and diffractive production mechanism at COMPASS energies. As an

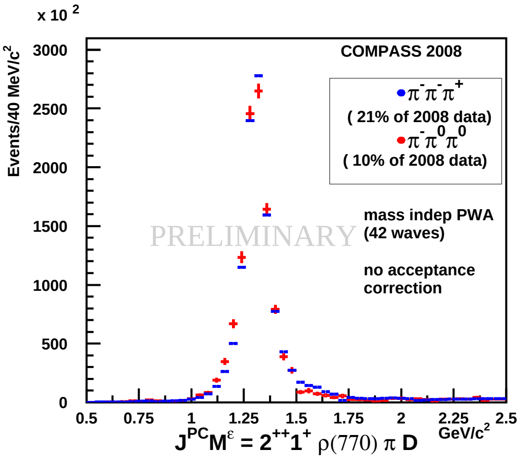

Figure 3: $J^{PC} = 2^{++}\rho\pi D$ wave for neutral and charged channels used to normalise intensities in other waves within the same PWA.

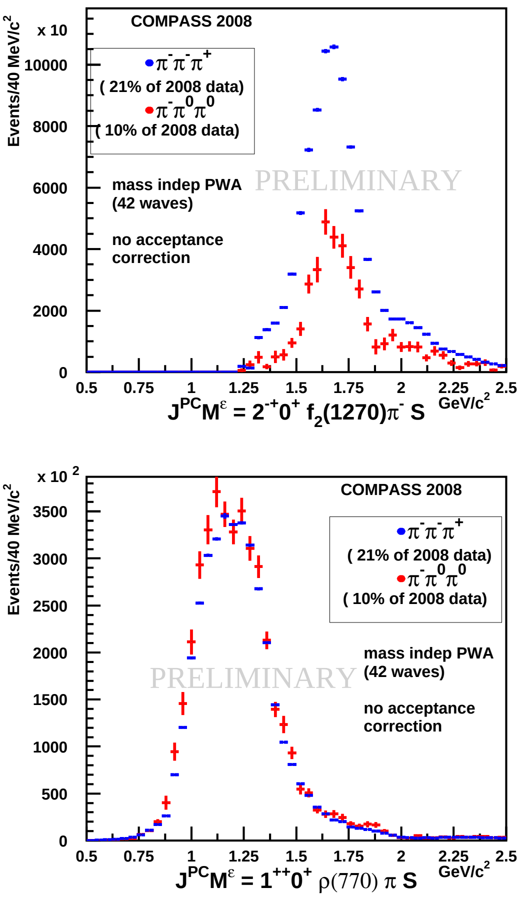

Figure 4: Comparison of the $1^{++}\rho\pi S$ and $2^{-+}f_2(1270)\pi S$ waves in the $\pi^-\pi^0\pi^0$ and $\pi^-\pi^+\pi^-$ channels.

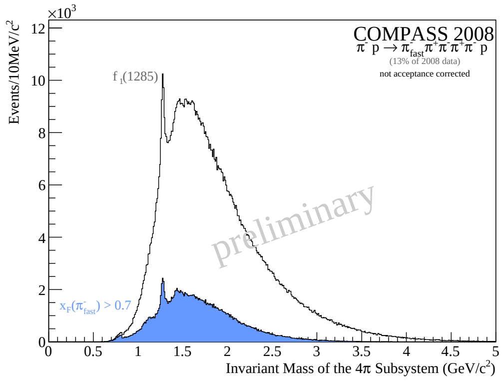

Figure 5: Invariant mass of the 4π sub-system. The distinct $f_1(1285)$ contribution is evident.

example, we show first results [6] of the $\pi^-\pi^+\pi^-\pi^+\pi^-$ final state. Fig. 5 depicts the invariant mass spectrum of the centrally produced 4π system, where also the diffractively produced $f_1(1285)$ is observed. Thus we conclude, that at the incident beam energy of 190 GeV, diffractive and central production processes can not be easily separated. Kinematic cuts were applied to select events with the characteristic rapidity gap between the centrally produced 4π system and the fast outgoing particle; in Fig. 5 the blue spectrum is the invariant mass of the central system after a cut on the fast particle's $x_F > 0.7$. The $f_1(1285)$ peak is clearly diminished. Fig. 6 shows the corresponding x_F distributions for the central system. Small acceptance effects on the left slope due to the forward setup of the spectrometer are seen, but more importantly, two distinct contributions which we interpret as central production and diffractive scattering. In Fig. 5 the region around 1.5 GeV is also better pronounced after the cut on x_F, this region yields e.g the $f_0(1500)$ as one major candidate for a glueball. As the spectrum is well populated and resonances cannot be cleanly separated, the next step is the application of a partial wave analysis technique, suited for a combined analysis of both production mechanism due to their overlap, as well. An interesting start can be deduced *e.g.* from [7], where a reference system for the process is defined. The Close-Kirk glueball filter [8] as another technique is being studied for the COMPASS case, as well. It was formerly used *e.g.* in WA102 analyses [9]. Afterwards, the method will be generalised to allow for the simultaneous treatment of multiple decay modes, like the $K\bar{K}$ channel. Fig. 7 shows exemplary the invariant mass spectrum of this channel as an outlook on forthcoming studies [10], where a contribution from the $f_0(1500)$ becomes visible.

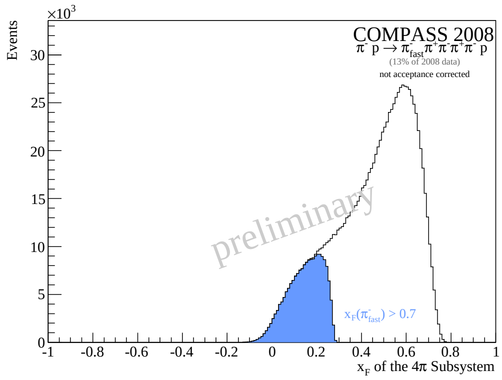

Figure 6: x_F distribution for the 4π sub-system.

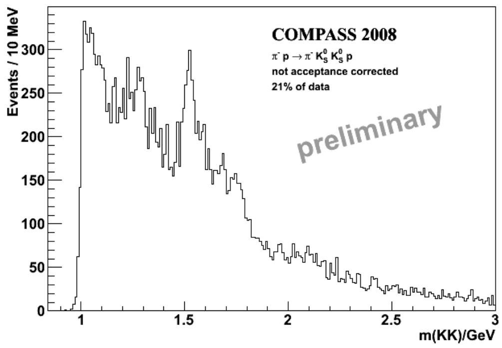

Figure 7: Invariant mass of the $K_s K_s$ system.

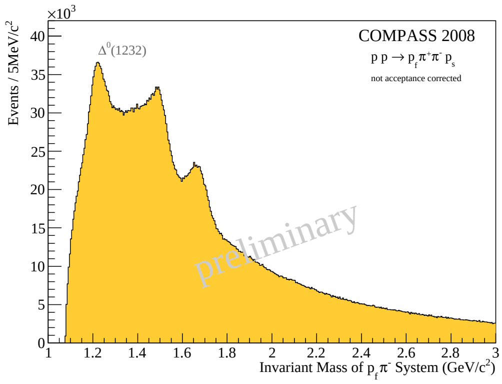

Figure 8: Invariant mass of the $p\pi^-$ system with proton beam.

5. Outlook

COMPASS took data for hadron spectroscopy exceeding the existing world data by one to two orders of magnitude. We started to analyse various decay modes comprising kaonic channels, neutral and charged particles making use of various formation processes, such as diffractive dissociation and central production. After the observation of the spin-exotic $\pi_1(1600)$ in the 2004 data, new results of partial wave analyses are coming up; first checks look promising.

Besides the multiple meson spectroscopy activities, baryon spectroscopy and studies with the kaonic beam component have become a part of the repertoire, as well. Fig. 8 shows the invariant mass spectrum of the $p\pi^-$ system in the $pp \rightarrow p\pi^+\pi^-p$ channel from 2008 proton beam data [11]. The various Δ and N^* resonances will also be subject to a dedicated PWA. Using 2009 data on different target materials with a new multiplicity trigger, processes at low and very-low t' are studied [12] in addition.

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