Study of central production of charged pionic modes at COMPASS

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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 years 2008 and 2009 the collaboration focused on hadron spectroscopy: data with hadronic beams at a momentum of 190 GeV/c impinging on hydrogen, lead, nickel and tungsten targets were taken. In the preparation for this run-time, the apparatus was adapted to measure the formation of resonances by both diffractive scattering and central production. In the latter case, the study of charged pionic channels is well-suited to search for members of the f_0 particle family, including some of the glueball candidates. The analysis of the newly taken data has started, these proceedings are meant to give a status and overview of the current activities.

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INTRODUCTION

The spectroscopy of mesonic resonances is a long-standing and important method to gain insight into the nature of the strong interaction, especially in the non-perturbative regime. Resonances, where the leading $q\bar{q}$-term vanishes, have become particularly interesting. These states are per se not forbidden in the QCD framework, but cannot be expressed in the simple quark model ansatz. Having only a two-body system, one finds only a distinct way to couple both spins with an orbital angular momentum. This gives a set of allowed quantum numbers J^{PC} (0^{-+}, 0^{++}, 1^{--} etc.) in contrast to the forbidden, and thus so-called *exotic* quantum numbers. The quark model provides a good explanation for most of the observed particles, but only lets the quarks contribute to the resonance's quantum numbers. In general, gluonic degrees of freedom can be added as well. A resonance is for instance categorized as a *glueball*, if only gluons carry the quantum numbers, whereas a system of quarks and gluons is named *hybrid*.
To search for such states, one studies the t-channel exchange of reggeons and pomerons in a fixed target experiment. The main formation processes are known as diffractive scattering and central production (cf. Fig. 1). Diffractive scattering is understood to be basically a single pomeron exchange (SPE) between the beam and the target particles. As a result, the beam particle is excited. Central production is in general not well-defined within the common literature. With respect to COMPASS analyses, central production is understood in the original sense: Formation of resonances at central rapidities. Such a formation can occur via a double pomeron exchange (DPE) or more general as an exchange of reggeons between the beam and the target particles leaving both intact. At COMPASS kinematics, resonances with

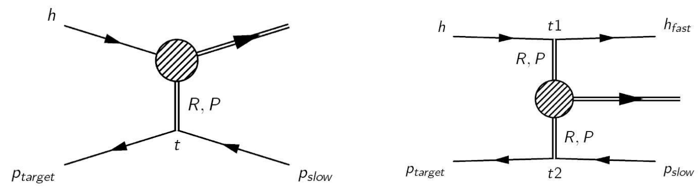

FIGURE 1. Diffractive Scattering (*left*) and Central Production via double Reggeon/Pomeron exchange (*right*) as typical formation mechanisms of resonances.

masses up to a few GeV/c^2 can easily be produced. Quenched lattice QCD calculations[1] shown in Fig. 2 predict several glueball candidates within the kinematic coverage of COMPASS.

The lightest scalar glueball with a predicted mass of about 1.5 GeV/c^2 has non-exotic quantum numbers 0^{++} and thus mixes with nearby states. This is why a study of the surrounding f_0 states at masses of 1500 and 1700 MeV/c^2

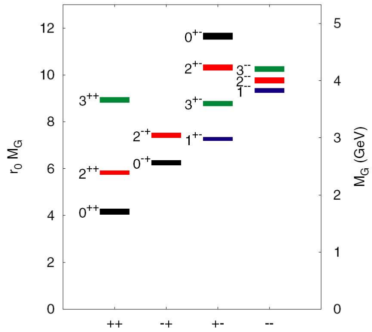

FIGURE 2. Quenched lattice QCD calculations for light glueball candidates, taken from [1]

is particularly interesting. The lightest tensor glueball seems to be measurable, too, keeping in mind that unquenched calculations respecting dynamic quark processes tend to shift the spectrum to smaller mass values.

Apart from the search for glueballs, the nature of many resonances seen in central production needs to be clarified. Even though the PDG lists the $f_0(1500)$ as a single state [2], in fact several distinct states are observed around 1500 MeV/c^2. The GAMS collaboration, specialized in neutral final states, was first pointing to this interesting mass region with their discovery [3] of the $f_0(1590)$. The Crystal Barrel Collaboration then found the $f_0(1500)$ with its unexpected decay modes [4] in several channels ($\pi^0\pi^0$, $\pi^+\pi^-$, 4π, $K\bar{K}$,$\eta\eta$,$\eta\eta'$). Later on, the WA91 Collaboration investigating the $4\pi^\pm$ final state found a comparable resonance at 1454 MeV/c^2 [5, 6]. It is still to be clarified whether these states around 1500 MeV/c^2 are the same, merely differing only by the production mechanism. There are moreover several disputed problematic isoscalar scalar mesons, such as the $f_0(1370)$ and the high-mass tensor mesons, which are broad and their parameters are not well known from previous experiments.

EXPERIMENTAL SETUP AND TRIGGER

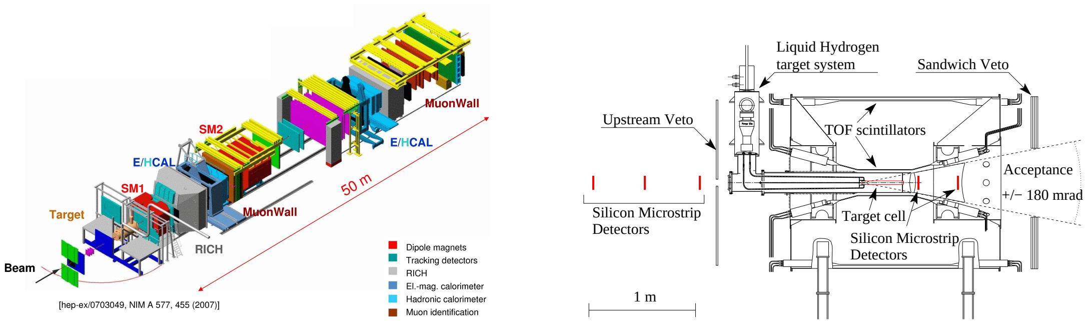

FIGURE 3. Left: Artistic view of the COMPASS spectrometer at CERN. Right: The newly built target region for the spectroscopy setup.

The COMPASS spectrometer is situated at the CERN SPS accelerator and has used secondary hadronic beams for the measurements taken in 2008 and 2009. The negative beam with an energy of 190 GeV is mainly composed of pions with a kaonic component of about 2.5%, leaving a very small background of anti-protons. For 2009, data were additionally taken with a positive beam composed of about 71.5% protons and 25.5% pions with the same energy as in 2008. CEDAR detectors were installed to distinguish between the two main beam components. Major changes had to be introduced in the target region, where contrary to the years before the polarized target was replaced by a 40 cm long liquid hydrogen target. On the right side of Fig. 3 an overview of the newly build target region is given. The beam is entering from the left side through the cold silicon strip detectors, which are used as a beam telescope. The Recoil Proton Detector (RPD, denoted in Fig. 3 as TOF scintillators) is surrounding the target in two concentric rings in order to perform a Time-Of-Flight measurement of the recoiling proton. This detector is a crucial part of the trigger system as well due to its fast response on selecting potentially interesting interactions inside the target volume. A high background can arise from secondary particles accompanying the beam, thus a hodoscope veto wall was used in front of the target region. To preserve the exclusivity of the measurements, the gap between the RPD and spectrometer acceptance was closed by a sandwich calorimeter veto. The non-interacting beam was vetoed by beam-killer hodoscopes. The information from RPD, Veto system and a beam hodoscope is combined to the main physics trigger DT0. The spectrometer itself consists of two stages defined by the two spectrometer magnets SM1 and SM2. This helps to guarantee a very high momentum resolution over a wide momentum range. A detailed description of the COMPASS spectrometer can be found in [7].

DATA SELECTION

Charged pionic decays of resonances include two main decay channels: The $2\pi^{\pm}$ and the $4\pi^{\pm}$ channel. In this study we will concentrate on the selection of $\pi^- p \rightarrow \pi^-_{fast}\pi^+\pi^-\pi^+\pi^- p_{recoil}$ based on a part (13%) of the 2008 data. The

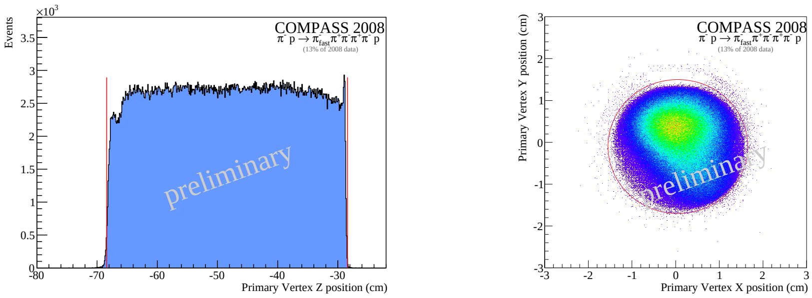

FIGURE 4. Distribution of primary vertices of the $\pi^- p \rightarrow \pi^-_{fast}\pi^+\pi^-\pi^+\pi^- p_{recoil}$ channel.

analysis comprises the selection of primary vertices inside the target volume. In Fig. 4 the distribution of primary vertices along the beam (denoted as z position) and in the transverse plane are shown. The applied cuts on the data are depicted with red lines. Only DT0 trigger data with 5 charged outgoing tracks were chosen. The CEDAR detectors were used to suppress the kaonic component of the beam. Besides charge conservation, there was also an exclusivity requirement for the event selection. During the data taking in 2008 and 2009, COMPASS was not equipped with a beam momentum determining detector. The beam momentum is known from Monte-Carlo simulations of the beam line and selected by the beam optics to be 190 GeV/$c \pm 1\%$. Hence, exclusivity is ensured by calculating the total momentum of the outgoing spectrometer tracks (cf. Fig. 5), which is to be 190 GeV/c $\pm$ 5 GeV/c. The resulting invariant mass distribution is depicted in Fig. 5 on the right side. Since central production lets the beam particle stay intact, finally only events were accepted, where the leading hadron had a negative charge.

CENTRALLY PRODUCED $4\pi^{\pm}$ FINAL STATES

The above described data selection is too general to select a production mechanism. Both centrally and diffractively produced final states contribute to the invariant mass spectrum shown in Fig. 5. Central production can be isolated by studying the rapidity y and the x_F distribution of the final state, respectively. These kinematic variables are defined in

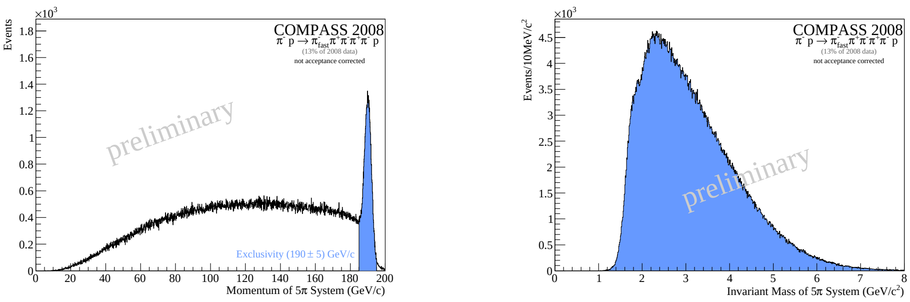

FIGURE 5. Left: Calculated momentum balance of the outgoing $\pi^-_{fast}\pi^+\pi^-\pi^+\pi^-$ system. Right: Invariant mass distribution of the same system.

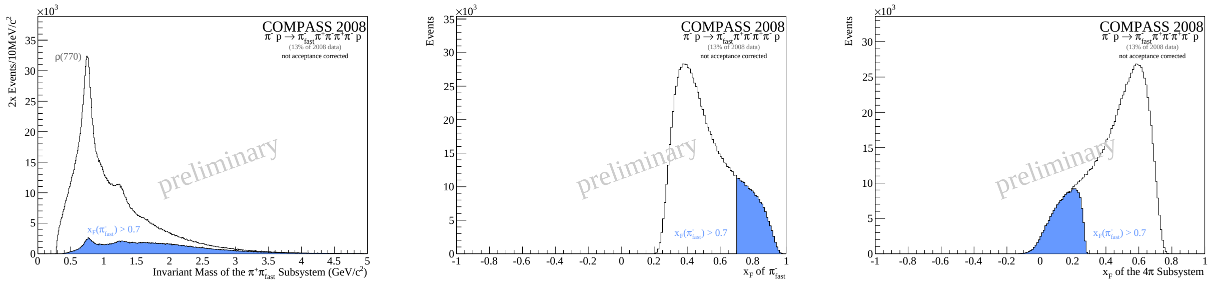

FIGURE 6. Left: Invariant Mass of the $\pi^-_{fast}\pi^+$ system. Middle and right: x_F distribution of the leading hadron and the central $4\pi^\pm$ system, respectively. In all plots the result of a cut on $x_F^{fast} > 0.7$ is depicted by the shaded histograms.

the following way:

$$y = \frac{1}{2}\ln\left(\frac{E+|\vec{p}_l|}{E-|\vec{p}_l|}\right) \qquad\qquad x_F = \frac{|\vec{p}_l|}{|\vec{p}_l{}^{max}|} = \frac{2|\vec{p}_l|}{\sqrt{s}},$$

where $|\vec{p}_l|$ denotes the longitudinal momentum of the particle, $\sqrt{s}$ the total center-of-mass energy of the interaction and $|\vec{p}_l{}^{max}|$ the maximum allowed longitudinal momentum.

A purely centrally produced $4\pi^\pm$ system should be observed completely isolated with respect to the leading π^-_{fast}. However, at COMPASS energies this separation is not clearly seen. This is demonstrated in the left of Fig. 6 by probing possible resonances in the system of π^-_{fast} and a corresponding π^+ taken out of the central system. Especially the $\rho(770)$ is clearly visible and thus indicates a contamination with diffractive events. Following suggestions of WA91 and WA102 [8], a cut on $x_F^{fast} > 0.7$ on the leading hadron was applied to introduce an artificial rapidity gap. The resulting decrease of the $\rho(770)$ contamination is seen in Fig. 6. This leads to the conclusion, that the diffractive background could be largely reduced. On the middle and right part of Fig. 6 the x_F distribution of both the leading hadron and the central $4\pi^\pm$ system are depicted. Without the cut on $x_F^{fast} > 0.7$, two distinct structures are visible. Most of the events are located around $x_F^{fast} = 0.4$, which is believed to be a contribution from diffractive scattering. The shoulder structure at large x_F^{fast} corresponds to central production, which is reflected in the right part where $x_F^{central}$ is peaking at central $x_F \approx 0$. The invariant mass distribution of the central $4\pi^\pm$ system is shown in Fig. 7, left. The well known and narrow $f_1(1285)$ can be observed without applying any further selections. The particularly interesting region around 1500 MeV/c^2 is enhanced after selecting only high x_F^{fast} events, which reflects the contribution of centrally produced resonances. Another kinematic possibility to filter central production is the selection of high invariant masses in the $5\pi^\pm$ system. In the right part of Fig. 7 the effect of such cuts becomes visible: whereas the x_F^{fast} tends to pronounce structures at lower mass regions, the cut on the mass $m(5\pi^\pm)$ enhances structures around 2-3 GeV/c^2. The latter is of particular interest for a tensor glueball search. In the WA102 analysis a new selection

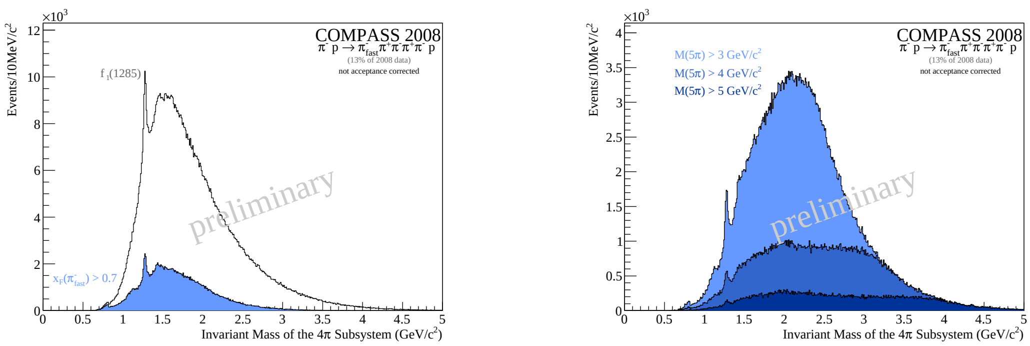

FIGURE 7. Left: Invariant mass distribution of the central $4\pi^\pm$ system. The shaded region corresponds to a cut on $x_F^{fast} > 0.7$. Right: Invariant mass distribution of the central $4\pi^\pm$ system after selecting $m(5\pi^\pm)$ mass regions (>3,4,5 GeV/c^2)

method was used, which is known as the Close-Kirk Glueball Filter. It was observed, that glue-rich resonances seem

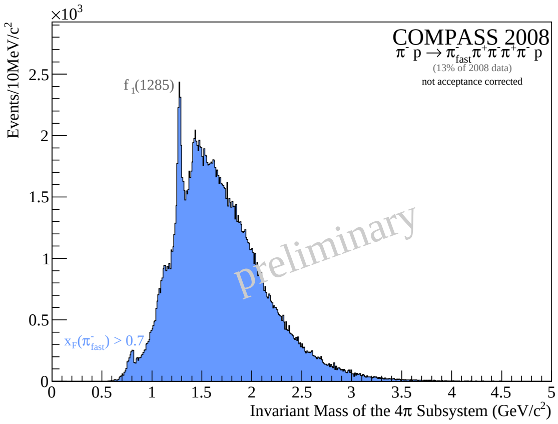

FIGURE 8. Invariant mass distribution of the central $4\pi^{\pm}$ system after the selection of $x_F^{fast} > 0.7$ events from this analysis.

to be predominately produced at symmetric p_T of the final-state protons. The difference betweens those p_T is referred to as dP_T in the literature [9]. WA102 binned their data with respect to dP_T in three bins. The similarity between the COMPASS and WA102 data is clearly visible, when comparing Fig. 8 to WA102 data (cf. [8]). This leaves the opportunity to refine the study of the glueball filter with large statistics.

OUTLOOK

Having the possibility to directly compare πp data with pp data, COMPASS has collected at least ten times more data compared to preceeding experiments. Hence, a search for minor waves in a dedicated Partial Wave Analysis (PWA) is feasible. The analysis of the $4\pi^{\pm}$ channel has just started, and a full PWA of this final state is under preparation. One potential choice for a PWA is the usage of the isobar model like it was done for several other COMPASS analyses [10, 11, 12, 13, 14, 15]. An interesting ansatz for the definition of a reference frame is given in [16] and its implementation in the current analysis is beeing investigated.

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