

# Spin-exotic search in the $\rho\pi$ decay channel: **New results on $\pi^- \pi^0 \pi^0$ in comparison to $\pi^- \pi^+ \pi^-$ final states** (diffractively produced on proton)

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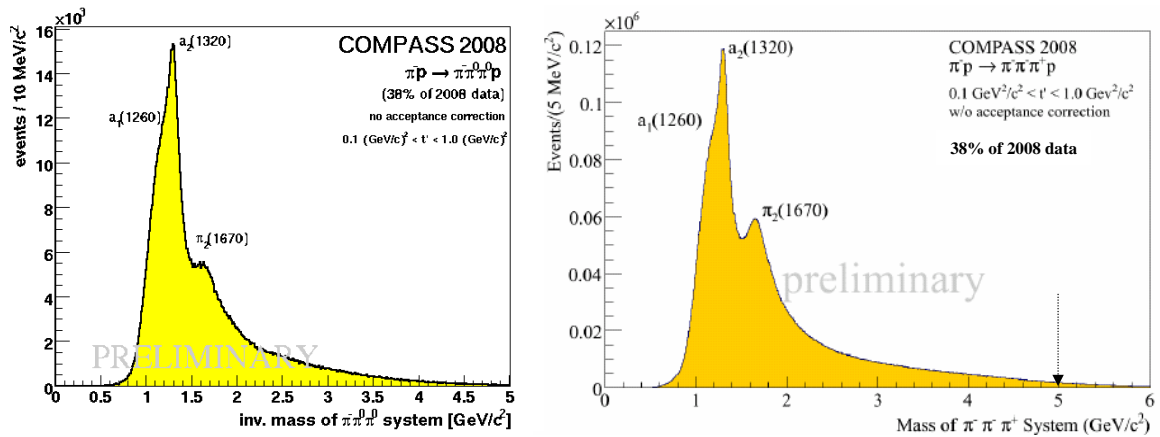
The COMPASS experiment at CERN SPS features charged particle tracking as well as good coverage by electromagnetic calorimetry, and our data provide an excellent opportunity for simultaneous observation of new states in different decay modes by the same experiment. The existence of the spin-exotic  $\pi_1(1600)$  resonance in the  $\rho\pi$  decay channel is studied for the first time at COMPASS in both decay modes of the diffractively produced  $(3\pi)^-$  system:  $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$  and  $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p$ . A preliminary partial-wave analysis performed on the 2008 proton target data allows for a first conclusive comparison of both  $(3\pi)^-$  decay modes not only for main waves but also for small ones. We find the neutral versus charged mode results in excellent agreement with expectations from isospin symmetry. Both, the intensities and the relative phases to well-known resonances, are consistent for the neutral and the charged decay modes of the  $(3\pi)^-$  system. The status on the search for the spin-exotic  $\pi_1(1600)$  resonance produced on a proton target is discussed.

## 1 Introduction

The existence of exotic states beyond the simple Constituent Quark Model (CQM) has been speculated about almost since the introduction of colour [1,2]. So-called hybrid mesons ( $q\bar{q}$  states with excited gluonic degree of freedom) and glueballs (purely gluonic states without valence quarks) are allowed within Quantum Chromodynamics due to the self-coupling of gluons via the colour-charge, while they are forbidden within the CQM. Even though glueball candidates have been reported by the Crystal Barrel and the WA102 experiments, the mixing with ordinary isoscalar mesons makes the interpretation difficult. Several light hybrids on the other hand are predicted to have exotic  $J^{PC}$  quantum numbers and are thus promising candidates in the search for resonances beyond the CQM. The hybrid candidate lowest in mass is predicted [3] to have a mass between 1.3 and 2.2 GeV/ $c^2$  and exotic quantum numbers  $J^{PC} = 1^{-+}$ , not attainable by ordinary  $q\bar{q}$  states. Several experimentally

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**Figure 1:** Total mass spectrum of the  $(3\pi)^-$  systems – neutral (*left*) versus charged decay mode (*right*). The spectra look similar as expected, showing both the most prominent, well-known resonances  $a_1(1260)$ ,  $a_2(1320)$  and  $\pi_2(1670)$ .

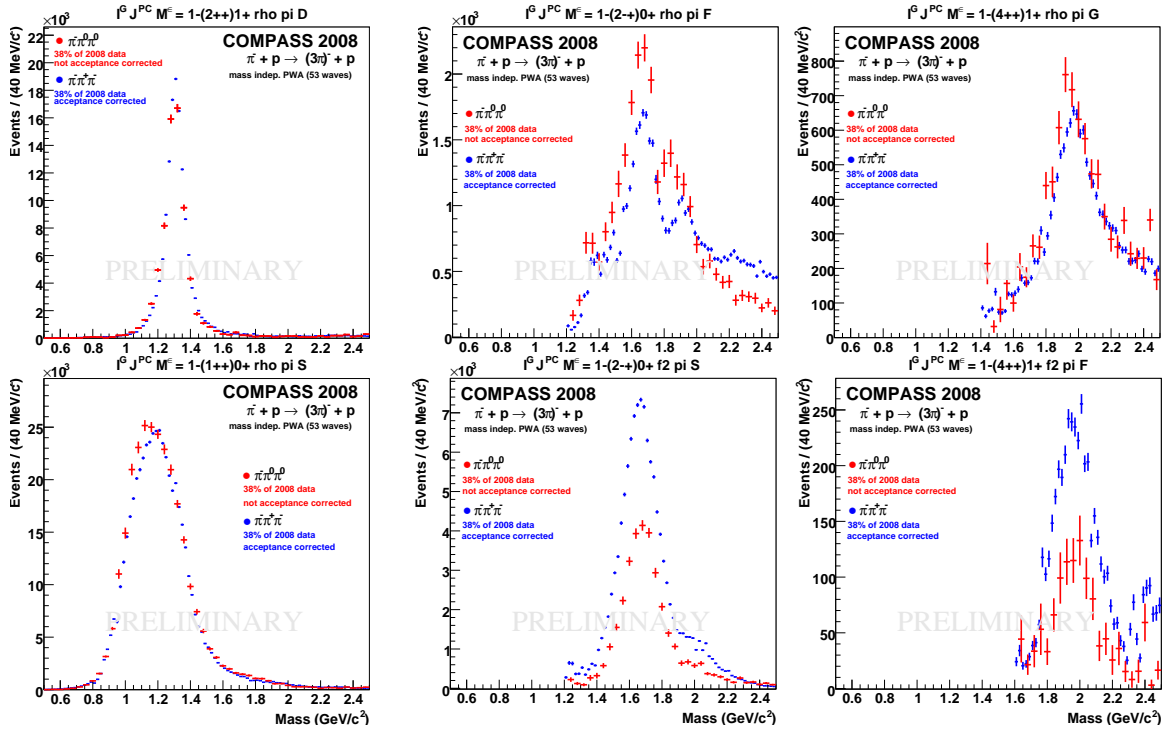
observed  $1^{-+}$  hybrid candidates in the light-quark sector have been reported in different decay channels in the past, however, they are all still controversially discussed in the community, see e.g. [4]. In particular, the resonant nature of the  $\pi_1(1600)$  observed by both E852 and VES in the  $\rho\pi$  decay channel [5, 6] in  $3\pi$  final states is questioned. In later publications, certain conclusions were withdrawn [7] and re-analyses of the  $(3\pi)^-$  system in two different final states within the same collaboration lead to opposite conclusions [8], respectively. One may get a hint at this controversy looking at [9].

After a short pilot run in 2004 (190 GeV/c  $\pi^-$  beam, Pb target), we recorded high statistics using a 190 GeV/c negative pion beam scattered off a liquid hydrogen (proton) target. A similar amount of data with 190 GeV/c positive hadron beams has been taken in 2009, as well as some data (negative beam) with nuclear targets. As a first input to the puzzle, COMPASS observed a significant  $J^{PC}$  spin-exotic signal in the 2004 data (in three charged pion final states) consistent with the disputed  $\pi_1(1600)$  that was accepted for publication last year [10]. The proton and nuclear target data taken in 2008/09 will enable COMPASS to further clarify the situation.

## 2 New results of $\pi^-\pi^0\pi^0$ in comparison to $\pi^-\pi^+\pi^-$ final states

The invariant mass of the  $(3\pi)^-$  system is shown for the neutral and the charged  $\rho\pi$  decay modes in Fig. 1. About half of the 2008 data with negative pion beam of 190 GeV/c have been analysed so far in the high momentum transfer  $t'$  region of  $0.1 \text{ GeV}^2/c^2 < t' < 1.0 \text{ GeV}^2/c^2$ . Due to the different detection efficiencies obtained for neutral and charged particles, this translates to  $\sim 1$  M events (neutral mode) and  $\sim 24$  M event (charged mode), respectively, being roughly in the range as expected in general.

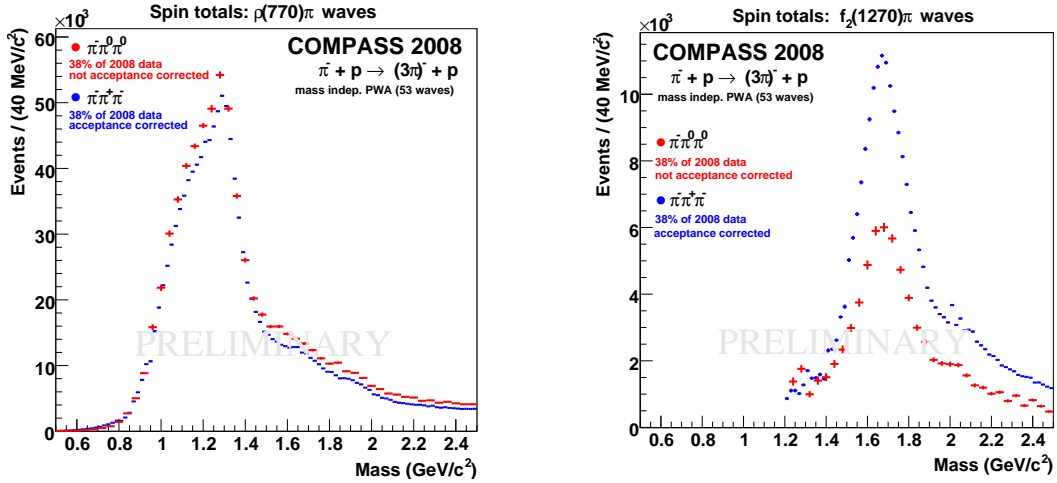
The new mass-independent PWA results for neutral and charged mode data presented in



**Figure 2:** Comparison of PWA mass-independent fit result for neutral versus charged mode – exemplary main and small waves: (Top, left)  $a_2(1320)$  used for normalisation, (top & bottom, centre)  $\pi_2(1670)$ , (top & bottom, right)  $a_4(2040)$ , and (bottom, left)  $a_1(1260)$ , respectively (red = neutral, blue = charged). For discussion see text.

this paper, are normalised using the  $a_2(1320)$  as a standard candle as shown in Fig. 2 (top, left) in order to compensate for the different detection efficiencies. This makes the fitted intensities for individual partial waves comparable between neutral and charged modes. With respect to [11], the wave-set has been extended from 42 to 53 waves, cf. also [12] giving further details on the analysis of the  $\pi^- \pi^+ \pi^-$  final states likewise, and the data analysed for the neutral mode has been increased by about a factor of five, allowing for a first conclusive comparison also for small waves. A detailed description of the applied PWA method can be found in [11, 12] and references therein.

Even though the neutral mode data have not yet been corrected for acceptance (which is rather flat for the charged mode), our data is in good agreement with expectations from isospin coupling considerations. If an isospin 1 resonance decays into  $\rho\pi$ , similar intensities are expected for neutral and charged mode, whereas decays into  $f_2\pi$  should show a suppression factor of two for the neutral w.r.t. to the charged mode data, simply due to the Clebsch-Gordan coefficients determining the different isospin coupling for the different underlying isobar structure, i.e. decays into an isovector versus an isoscalar. This is shown for some exemplary main and small waves in Fig. 2. The  $a_1(1260)$  decaying into  $\rho\pi$  is observed with same width and intensity for both modes, similarly for the  $\pi_1(1670)$



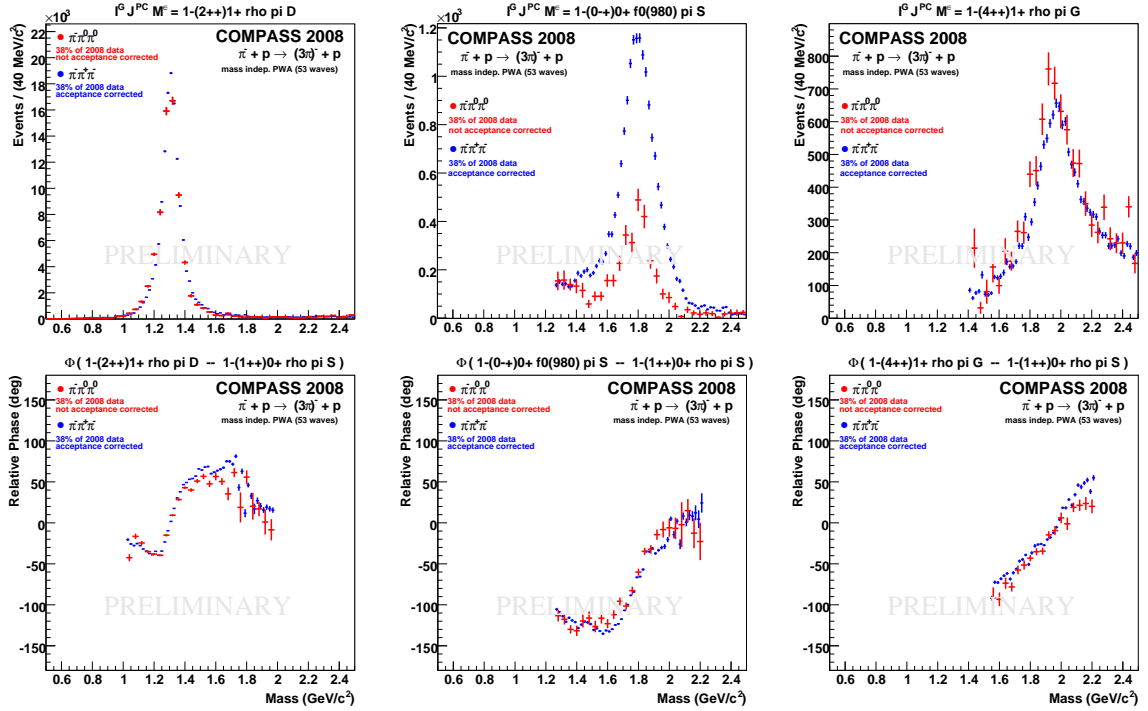
**Figure 3:** Intensity sums of all partial waves decaying into  $\rho\pi$  (left) and  $f_2\pi$  (right) intermediate states included in the fit are in good agreement with expectations from isospin symmetry. For discussion see text.

and  $a_4(2040)$  decays into  $\rho\pi$ , whereas a suppression factor of about two is observed for the neutral mode intensities as compared to the charged mode data for the resonances decaying into  $f_2\pi$  — as expected. That our data follows the expectation from isospin symmetry to a large extent throughout the whole wave-set is shown by Fig. 3, depicting the intensity sums of all  $\rho\pi$  and  $f_2\pi$  partial waves, respectively.

This simple isospin-symmetry holds only presumed the branchings are entirely determined by the isospin Clebsch-Gordan coefficients, which is not true in general for  $f_{0,2}\pi$  decays, as Bose-Symmetrisation with the other  $\pi^-$  and  $\pi^0$ , respectively, is required and might change the observed ratio of intensities due to interference effects. There is no such effect, however, for  $\rho\pi$  decays since whatever the effect might be, it is the same for both decay modes, and therefore cancels out. We checked by calculation using the wave function, that there is no such effect for  $\pi_2(1670)$  decaying into  $f_2\pi$ , for which the pure suppression factor of two is indeed expected, as given in Table 1. Depending on the overlap of the isobars on the Dalitz plot, interference effects might change the factor of two, as for example in case of the  $\pi(1800)$  decay into  $f_0(980)\pi$ , for which we expect to find an enlarged suppression factor (Tab. 1) in good agreement with our data, see Fig. 4 (top, centre). Apart of the fitted

$\text{BR} = \text{N}(\pi^- \pi^0 \pi^0) / \text{N}(\pi^- \pi^- \pi^+) - \text{calculated from isobar model amplitudes}$
$\text{BR}(0^-+ f_0(980)\pi S) = 0.44$ (at 1.8 GeV)
$\text{BR}(1^{++}(\pi\pi)_s \pi P) = 0.80$ (at 1.3 GeV)
$\text{BR}(2^-+ f_2(1270)\pi S) = 0.50$ (at 1.67 GeV)

**Table 1:** Isospin symmetry and final state Bose-Symmetrisation: Calculation of the relative branching ratios (BR) of neutral to charged mode for decays via different isobars. The isospin Clebsch-Gordan coefficients have been applied inside the PWA normalisation integral calculator to calculate the BR for the different partial waves.



**Figure 4:** Relative phase difference  $\Phi$  for main and small waves with respect to the prominent  $a_1(1260)$  (see Fig.2, left, bottom): (Left)  $a_2(1320) \rightarrow \rho\pi$ , (centre)  $\pi(1800) \rightarrow f_0(980)\pi$ , and (right)  $a_4(2040) \rightarrow \rho\pi$ , respectively (red = neutral, blue = charged). The well-known  $a_2(1320)$  resonance as well as the smaller, less prominent ones show a clean, rapid phase motion relatively to the  $a_1(1260)$ . Not only the intensities but also the phases are consistent for both, neutral and charged mode, for discussion see text.

intensities it is conclusive to look at the phase difference of a possible resonance with respect to a well-know one. If the candidate is indeed a resonance, connected with the reference one (but not phase-locked), it should manifest in a clean phase motion between them, as it is shown for main and small waves in Fig.4, using the prominent  $a_1(1260)$  as reference. For the  $a_2(1320)$ , we find a rapid phase motion just in the range between the maxima of both objects, consistently coinciding for the neutral and the charged mode data. For the  $\pi_2(1670)$  and the  $a_4(2040)$ , we observe a clean, rapid phase motion as well, again consistently coinciding for both modes. As they are more separated in mass from the reference, they are resonating against the tail of the  $a_1(1260)$  resulting in observed phase motions limited to the mass range (about 1.7-1.9 and 1.7-2.0  $\text{GeV}/c^2$ , respectively) of the given resonance under study.

### 3 Conclusions & summary

The hadron data taken in 2008/09 will allow COMPASS to contribute solving the puzzle of light spin-exotic mesons. The high statistics and the possibility of detecting final states involving neutral particles allows for simultaneous observation and confirmation of new states in different final states by the same experiment. The new results presented on the  $\rho\pi$  decay channel in both, neutral and charged decay modes of the  $(3\pi)^-$  system, appear very consistent and solid not only for main but also for small waves. There is presently no contradiction between both analysis results. In particular the coinciding relative phases of various resonances confirm already now the excellent potential to conclude on the existence of the spin-exotic  $\pi_1(1600)$  resonance in the  $\rho\pi$  decay channel, simultaneously observed in two different final states with the same experiment.

### Acknowledgements

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