4π-decays of scalar and vector mesons

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Abstract. Two different πn annihilation modes, πn → π−4π0 and πn → 2π−2π0π+ and 4π−, are used to study the 4π-decays of scalar and vector mesons. The data are dominated by 4π scalar isoscalar interactions. At least two states are needed, the f0(1370) and the f0(1500). The 4π-decay width of the f0(1370) is more than 6 times larger than the sum of all observed partial decay widths to two pseudoscalar mesons. The state has important couplings to (ππ)s(ππ)s and to pp. The 4π-decays of the f0(1500) represent about half of its total width. The ρ(1450) and the ρ(1700) are observed in several 4π decay modes. The ratio of the 4π relative to the 2π decay of the ρ(1450) is in contradiction to its proposed interpretation as a pure hybrid state but it suggests that it is not a pure 2S1− state either. Our results favour the assignment of the ρ(1700) as 1D1 state, its interpretation as 3S1 state is less plausible.

1 Introduction

The possibility that gluonic excitations of hadronic matter or of the QCD vacuum may exist is perhaps the most fascinating topic in hadron spectroscopy. In the absence of mixing with quarkonia, glueballs are bound states of only gluons. In lattice gauge theories the lightest glueball is predicted to have scalar quantum numbers and a mass of about 1.73 GeV/c² [1]. The existence of more scalar isoscalar mesons than the quark model can host has led to speculations that a glueball has intruded into the spectrum of scalar quarkonia and mixes with them, thus producing the states observed in the mass range below 2 GeV/c² [2,3]. Different mixing schemes e.g. [2,3] allow an explanation of the observed decays of the f0(1500) into two pseudoscalar mesons even though the glueball content of the f0(1370), f0(1500) and f0(1710) are quite
different in these models. Experimental information on decay modes for these states may be helpful for deciding which of these models is correct. Indeed, calculations exist which show that the determination of the different 4π decay modes might be crucial to shed light on this mixing scheme [4,5].

The situation is similar in the case of vector mesons. The question of interest is the existence of hybrids, or mesons in which the string mediating the interaction between quarks and antiquarks is excited. An isovector meson with exotic quantum numbers, \( J^{PC} = 1^{-+} \), (the \( \rho \) (1400) or \( \pi_{1}(1400) \)), has been observed recently by E852 at BNL [6,7] and at CERN by Crystal Barrel [8,9]. If this state is a member of a nonet, it should be accompanied by its 4\( ^\pi \) decays is presented in a re–

Data and data reduction

The Crystal Barrel is a detector with a close-to-4\( \pi \) acceptance for both charged particles and photons. A 200\,MeV/c \( \bar{p} \) beam stops in a liquid deuterium target at the center of the detector. The target is surrounded by a silicon strip vertex detector used for triggering (SVX) and a 23–layer cylindrical drift chamber (JDC). The momentum resolution for charged particles varies from \( \delta p/p = 2.0\% \) at 0.2\,GeV/c to up to \( \delta p/p = 6.5\% \) at 1\,GeV/c. The JDC is in turn surrounded by a 1380 crystal CsI(Tl) barrel calorimeter. The calorimeter covers polar angles between 12\(^{\circ}\) and 168\(^{\circ}\) degrees and 2\( \pi \) in azimuth. The useful acceptance for shower detection is 95\% of 4\( \pi \). Typical resolutions are \( \sigma_{E}/E = 2.5\% \) at 1\,GeV, and \( \sigma_{\rho,\phi} = 1.2\% \) with a minimum usable photon energy of 15\,MeV. Further details can be found elsewhere [17].

The data selection for the 30\,016 \( \pi^{-}4\pi^{0} \) events of reaction (2) has been discussed in a preceding paper [18]. This analysis adds data from the \( \pi^{-}2\pi^{-}4\pi^{0} \) final state from reaction (1) and describes a fit to the latter data set which is consistent with that of the former. These data stem from \( \sim 6.5 \times 10^{9} \) triggered events which have been collected using a three–prong trigger. The trigger selects events with three hits in the SVX and one or two hits per track in the outer layer of the JDC. In addition to the triggered data, \( \sim 1.3 \times 10^{9} \) minimum bias events are used to determine the branching fraction into this final state, and \( \sim 1.1 \times 10^{6} \) Monte Carlo events were generated for normalization and acceptance corrections. The data are required to satisfy the following criteria:

- Exactly one positive and two negative charged tracks.
- Exactly four photons with energy above 20\,MeV.
- For each electromagnetic shower due to a photon, the energy deposited in the central crystal should exceed 13\,MeV. This cut removes spurious photons due to shower fluctuations.
- Events containing photons centered in the crystals adjacent to the beam pipe are rejected due to possible shower leakage.

Data surviving these cuts are submitted to a 1–constraint kinematic fit to the hypothesis \( pd \rightarrow \pi^{-}2\pi^{-}4\pi^{0}p_{\text{spectator}} \) plus an unseen proton. In a second step, a series of higher-constraint kinematic fits is performed in which the \( \gamma\gamma \) pairs are constrained to be either \( \pi^{0} \) or \( \eta \). We then require the best hypothesis to be \( \pi^{-}2\pi^{-}2\pi^{0}p_{\text{spectator}} \). Events are rejected if the confidence level of this fit is less than 10\%. Additionally, all events with a spectator proton momentum larger than 100\,MeV/c are rejected to select events which are consistent with \( \bar{p} \) annihilation on a quasi–free neutron. From the 6.5 million triggered events, 46\,629 survive all the cuts. For these events, we form the four \( \pi^{-}\pi^{-}\eta \) invariant mass combinations and remove those events with at least one mass combination within \( \pm 60\,\text{MeV}/c^{2} \) of the \( \omega(782) \) mass or within \( \pm 30\,\text{MeV}/c^{2} \) of the \( \eta(548) \) mass, (see Fig. 1b). This yields 19\,419 events from the three \( \text{prong} \) data set.

The branching fraction for reaction (1) is determined using minimum–bias data. The number of reconstructed events excluding \( pd \rightarrow \pi^{-}\pi^{0}p_{\text{spec}} \) and \( pd \rightarrow \pi^{-}\pi^{0}\omega \), is \( N_{5\pi} = 742 \) from a sample of \( N_{mb} = 1 \times 10^{5} \) minimum bias events. The reconstruction efficiency, \( \varepsilon_{\text{rec}} = (1.9 \pm 0.1\%) \) includes the decay of \( \pi^{0} \), (\( \varepsilon_{\text{rec}}(\pi^{0} \rightarrow \gamma \gamma) = 0.98798 \pm 0.00032 \)). In addition, there is a correction for antiprotons which do not annihilate in the target, \( \varepsilon_{1} = 0.956 \pm 0.025 \). Excluding the contributions from \( pd \rightarrow \pi^{-}\pi^{0}p_{\text{spec}} \) and \( pd \rightarrow \pi^{-}\pi^{0}\omega_{\text{spec}} \), we find the rate as given in (3). In [18], it has been found that the rate for reaction (2) is as given in (4).

\[
\text{BR}(pd \rightarrow \pi^{-}2\pi^{-}2\pi^{0}p) = \frac{N_{5\pi}}{\varepsilon_{\text{rec}} \cdot \varepsilon_{1} \cdot N_{mb}}
\]